Les 5èmes Rencontres de l'Observatoire de Paris

# VISIONS FOR INFRARED ASTRONOMY

# VISIONS EN ASTRONOMIE INFRAROUGE

*A tribute to Pierre Léna* — *En l'honneur de Pierre Léna*

20-22 March 2006 - PARIS -

## Program and Abstracts for the Conference

## *Programme et Résumés de la Conférence*

- Carré des Sciences - Observatoire de Paris -

URL : http://www.lesia.obspm.fr/VIRA

Abstract book editorial staff/*Comité éditorial* :

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Notes: The content of this abstract book was fixed on March 7th, 2006. As usual, (minor) changes in the program may still occur. Abstracts and list of participants inputs have been imported "raw" from the web and are thus given under the sole responsability of their autors.

*Remarques: Le contenu de ce recueil de résumés a été arrêté au 7 Mars 2006. Comme il se doit, des changements (mineurs) peuvent avoir lieu. Les résumés et les coordonnées des participants sont directement issus de la Toile et sont donc donnés sous la seule responsabilité de leurs auteurs.*

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## SCIENTIFIC ORGANIZING COMMITTEE

# CONFERENCE OVERVIEW

| | | |
|---|---|---|
| Monday, March 20th | 8:30 - 8:45 am | Welcome address |
| | 8:45 - 11:00 am | 1-GROUND BASED AND SPACE INFRARED ASTRONOMY |
| | Coffee break… | and poster viewing (session 1) |
| | 11:30 am - 1:10 pm | 1-GROUND BASED AND SPACE INFRARED ASTRONOMY |
| | Lunch | ... then poster viewing (session 1) |
| | 3:00 - 3:30 pm | 1-GROUND BASED AND SPACE INFRARED ASTRONOMY |
| | 3:35 - 5:10 pm | 2-ADAPTIVE OPTICS<br>... then poster viewing (session 1) |
| Tuesday, March 21st | 8:30 - 10:15 am | 2-ADAPTIVE OPTICS |
| | 10:15 - 10:50 am | 3-INFRARED INTERFEROMETRY |
| | Coffee break… | and poster viewing (session 2 & 3) |
| | 11:20 am - 1:00 pm | 3-INFRARED INTERFEROMETRY |
| | Lunch | ... then poster viewing (session 2 & 3) |
| | 3:00 - 5:15 pm | 3-INFRARED INTERFEROMETRY<br>... then poster viewing (session 2 & 3) |
| | 6:00 pm | Departure for dinner |
| | 8:00 pm | Conference dinner at the *Musée de l'Aviation du Bourget* |
| Wednesday, March 22nd | 9:00 - 11:00 am | 4-ASTROPHYSICS, SCIENCE, DEVELOPMENT AND EDUCATION |
| | Coffee break | |
| | 11:30 - 12:50 am | 4-ASTROPHYSICS, SCIENCE, DEVELOPMENT AND EDUCATION |
| | Lunch | |
| | 2 :15- 4:00 pm | 4-ASTROPHYSICS, SCIENCE, DEVELOPMENT AND EDUCATION |
| | 4:00 pm | Conclusion of the Conference by Pr. Reinhard Genzel |
| | 4:20 pm | *Champagne !* |

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Monday & Tuesday at *Carré des Sciences, Amphithéatre Poincaré*

Wednesday at *Observatoire de Paris, Salle Cassini*

Posters of the session 1 will be displayed on Monday, posters of sessions 2 & 3 will be displayed on Tuesday.

# *DÉROULEMENT DE LA CONFÉRENCE*

| | | |
|---|---|---|
| *Lundi 20 Mars* | *8:30 - 8:45* | *Allocution de Bienvenue* |
| | *8:45 - 11:00* | *1-ASTRONOMIE INFRAROUGE AU SOL ET DANS L'ESPACE* |
| | *Pause café…* | *et séance poster (session 1)* |
| | *11:30 - 13:10* | *1-ASTRONOMIE INFRAROUGE AU SOL ET DANS L'ESPACE* |
| | *Déjeuner* | *... puis séance poster (session 1)* |
| | *15:00 - 15:30* | *1-ASTRONOMIE INFRAROUGE AU SOL ET DANS L'ESPACE* |
| | *15:35 - 17:10* | *2-OPTIQUE ADAPTATIVE* |
| | | *... puis séance poster (session 1)* |
| *Mardi 21 Mars* | *8:30 - 10:15* | *2-OPTIQUE ADAPTATIVE* |
| | *10:15 - 10:50* | *3-INTERFÉROMÉTRIE INFRAROUGE* |
| | *Pause café…* | *et séance poster (session 2 & 3)* |
| | *11:20 - 13:00* | *3-INTERFÉROMÉTRIE INFRAROUGE* |
| | *Déjeuner* | *... puis séance poster (session 2 & 3)* |
| | *15:00 - 17:15* | *3-INTERFÉROMÉTRIE INFRAROUGE* |
| | | *... puis séance poster (session 2 & 3)* |
| | *18:00* | *Départ pour le dîner* |
| | *20:00* | *Dîner de la Conférence au Musée de l'Aviation du Bourget* |
| *Mercredi 22 Mars* | *9:00 - 11:00* | *4-ASTROPHYSIQUE, SCIENCE, DÉVELOPPEMENT ET ÉDUCATION* |
| | *Pause café* | |
| | *11:30 - 12:50* | *4-ASTROPHYSIQUE, SCIENCE, DÉVELOPPEMENT ET ÉDUCATION* |
| | *Déjeuner* | |
| | *14:15 - 16:00* | *4-ASTROPHYSIQUE, SCIENCE, DÉVELOPPEMENT ET ÉDUCATION* |
| | *16:00* | *Conclusion de la Conférence par le Pr. Reinhard Genzel* |
| | *16:20* | *Champagne !* |

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*Les sessions des lundi et mardi se dérouleront à l'amphithéâtre Poincaré du Carré des Sciences.*

*La session du mercredi aura lieu à l'Observatoire de Paris, salle Cassini.*

*Les posters de la session 1 seront affichés la journée du lundi, les posters des sessions 2 & 3 la journée du mardi.*

# Program & Contents

*Programme & Sommaire*

**Session 1:**
**Ground based and space infrared astronomy /** *Astronomie infrarouge au sol et dans l'espace*
**[ Monday, March 20, 8:30 am to 3:30 pm /** *Lundi 20 Mars, 8h30 à 15h30*] **3**

## Session 2:
## Adaptive Optics / *Optique adaptative*

## Session 3:
## Infrared Interferometry / *Interférométrie infrarouge*

**[ Tuesday, March 21, 10:15 am to 5:30 pm /** *Mardi 21 Mars, 10h15 à 17h30*] **89**

# Session 1:
# Ground based and space infrared astronomy

*Astronomie infrarouge au sol et dans l'espace*

## INFRARED ASTRONOMY: WHERE DO WE STAND TODAY? HOW DID WE GET HERE?

**Martin Harwit**
*Cornell University, USA*

Until the early 1960s, infrared astronomy was largely restricted to the near infrared. Sensitivities, even there, were very low. Around that time a gradual change came about, largely triggered by powerful detectors, initially developed for military purposes, that became available to astronomers. In the early years, traditional astronomers did not expect any remarkable results; but the discovery of stars luminous in the near infrared and virtually unobservable at optical wavelengths, as well as investigations of the Galactic Center and dust-shrouded star-forming regions gradually changed that perception. Telescopes taken above the atmosphere aboard airplanes, balloons, and rockets further opened the accessible wavelength range, and brought powerful far-infrared sources into view. By the time the mid-1970s had arrived, interest in infrared astronomy had grown to the point where significant investments were undertaken in a large airborne observatory and small satellite observatories. Many of these became affordable because detector development and space facilities for surveys conducted by the U.S. Air Force had already paved the way. At each step, increased sensitivity, imaging capabilities and spectral resolution, as well as access to previously unexplored wavelength ranges, translated into unanticipated discoveries that heightened interest, attracting ever greater numbers of young astronomers to the field. From perhaps half a dozen dedicated infrared astronomers world-wide, in the early 1960s, we have grown to a large international community today. Multi-nationally constructed satellite observatories like IRAS, ISO, SWAS and ODIN, internationally accessible space facilities like Spitzer, and large dedicated ground-based facilities, have accelerated the pace of discovery and heightened expectations for evermore sophisticated facilities under construction today. These developments, and highlights of some of the most striking discoveries that infrared astronomy has provided, will be presented to outline where we stand today, and how we arrived here.

Notes

# SPITZER OBSERVATIONS OF DEBRIS DISKS AND IMPLICATIONS FOR PLANET FINDING

**Charles Beichman and Geoff Bryden**
*Michelson Science Center, Caltech/JPL*
*JPL*

A number of projects with the Spitzer Space Telescope have focused on the finding debris disks around nearby main sequence stars. We will summarize the results of these projects and discuss their importance for the detection of planets. These observations reveal the limitations of a single small telesocpe for finding debris disks at the level of our own solar system. Interferometers will be required to reach levels below about 50 times that of our own zodiacal cloud.

Notes

# HIGH RESOLUTION IMAGING OF DUST DISKS STRUCTURES AROUND HERBIG AE STARS WITH VISIR

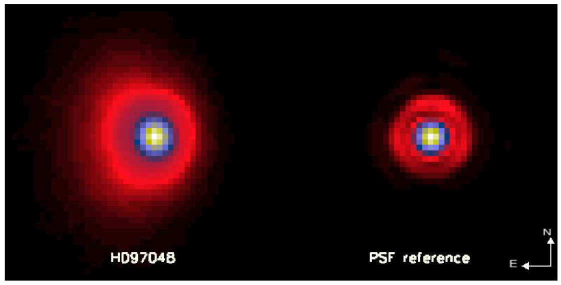
**Doucet, C. (1), Habart, E. (2), Lagage, P. O. (1), Pantin, E. (1), Pinte, C. (3), Duchêne, G. (3), and Ménard F. (3)**
*(1)CEA/Saclay DSM/DAPNIA/SAp, F-91191 Gif sur Yvette, France*
*(2)Institut d'Astrophysique Spatial (IAS), 91405 Orsay cedex, France*
*(3)Laboratoire d'Astrophysique - Observatoire de Grenoble BP53, F38041 Grenoble cedex 9, France*

Circumstellar (CS) disks are ubiquitous around stars with intermediate ages around a few million years. They are a natural outcome of the star formation process, because of the need of angular momentum conservation during the collapse of the initial molecular core (Shu, F. H., & Adams, F. C., 1987, IAUS, 115, 417.). We consider normally that disks contain gas and dust. As the star evolved, the disk changes: the gas is dissipated and a variety of processes (collisions...) leads to the growth of dust grains and the formation of planets. In order to characterise planets'formation, it is interesting to understand the physics of the medium where they were born. Herbig Ae (HAe) stars represent a particularly interesting laboratory for studying disks evolution and planet formation since the planets are still in the building process or eventually just formed. HAe stars are believed to be the more massive analogues of T Tauri stars ($\sim$ 2-10 $M_{\odot}$). Although great progress had been made in modelling the disk struture with radiative transfer models able to reproduce the SEDs (Chiang, E. I., & Goldreich, P. 1997, ApJ, 490, 368; Natta, A., Prusti, T., Neri, R., et al. 2001, A&A, 371, 186; Dullemond, C.P., & Dominik, C., & Natta, A. 2001, ApJ, 560, 957), the structure of the disks is not uniquely constrained. Spatially resolved observations are also needed to constrain more the geometry of the disks.

The observations were performed using the ESO mid-infrared instrument VISIR installed on the Very Large Telescope (Paranal, Chili), a mid-IR (around 10 and 20 $\mu$m) camera and spectrometer. With a 8 m telescope, the Full Width Half Maximum due to diffraction gives a spatial resolution of 0.3" at 10 $\mu$m. As a result, we are able to resolve disks with a typical size of 100 AU around Herbig stars at a distance of 100 pc. Around 10 $\mu$m, the emission may be produced by non-equilibrium reprocessing of ultraviolet radiation by very large organic molecules (like PAH: polycyclic aromatic hydrocarbons particle). Such particles undergo transient heating : they do not reach thermal equilibrium with the radiation field, but absorb individual photons, experiencing a rapid increase in temperature, and slowly cool, re-radiating the absorbed energy at longer wavelengths. This radiation allows us to see much further since this grains could reach high temperature far away from the star.

Under the assumption of good seeing (0.5 arc second in the visible), the diffraction is the limitation at 10 $\mu$m on a 8 m telescope. Unfortunatly, during our exposures, we observe a seeing of 0.8 arc second wich restricts our resolution. Indeed, the source is moving on the detector of about 5 pixels (pfov = 0.075"/pixel). In order to get the best spatial resolution, we experiment a new imaging mode on the bright objects, the 'BURST' mode. The principe is to take rapid images (exposure time = 50 ms) shifted and added to correct from seeing effect and 'possible' bad positions of the chopper in order to reach the *best spatial resolution*.

So, we present high angular imaging and spectroscopic observations of a sample of Herbig stars, extracted from the lists of Thé et al.(1994, A&AS, 104, 315) and Malfait et al.(1998, A&AL, 332, 25). We have **spatially resolved** most of them and an example, HD97048, is shown in Fig.1. With both imagery and spectroscopy, the object is spatially resolved and is quite extended (around 1.5") at 11.3 $\mu$m (feature of PAH). We can also resolve an asymmetry in the direction east/west due probably to a geometric effect of the flared disk. We will discuss the comparison of the observed spatial distribution of the 11.3 $\mu$m feature and the adjacent continuum emission with the predictions of a disk model that includes transiently heated small grains PAHs in addition to large grains in thermal equilibrium (Habart, E., Natta, A., Krugel, E., 2004, A&A, 427, 179).



# GALACTIC (OMC1) AND EXTRAGALACTIC (MCS) STAR FORMING REGIONS OBSERVED IN THE INFRARED WITH ADAPTIVE OPTICS

**Jean Louis Lemaire(1), Gérard Testor(2), David Field(3), and Daniel Rouan(4)**
*(1) LERMA, Observatoire de Paris et Université de Cergy-Pontoise*
*(2) LUTH, Observatoire de Paris*
*(3) IFA, Aarhus University (Dk)*
*(4) LESIA, Observatoire de Paris*

They are many cases where adaptive optics (AO) improvements in ground-based infrared astronomy are paramount. First of all AO allows competition with space borne instruments, without the expenses and with the ease of access. This will be illustrated with the recent advances and discoveries obtained in two examples of star forming regions. The first one is the Orion Molecular Cloud (OMC1), a very crowded and complex region in our neighbourhood (450 pc). The second ones are extragalactic objects in the Magellanic clouds(MCs) located at 50 to 70 kpc.

In OMC1, where two main excitation mechanisms are coexisting, namely i) the strong UV field emanating from nearby OB stars creating the so called photon dominated regions (PDRs) and the different kind of shocks associated with the star formation process itself, the actions of multiple sources have to be disentangled. This is obtained, among many others means, through detailed studies of the morphology, the preferred scale sizes of the turbulent interstellar medium, the analysis of the velocity field and of the ratio of ortho- to para-lines of molecular hydrogen. Use is made of spectral imaging and slit spectroscopy at high spatial and spectral resolutions in the numerous emission lines of $H_2$ available in several infrared bands.

The use of IR wavefront sensors has opened the access to new regions as it is the case for the MCs. Due to their distances, extragalactic objects equivalent to OMC1 in the MCs require the full power of the AO. We present observations of HEBs (High-Excitation Blobs) in the MCs. HEBs are compact HII regions that constitute a rare class of ionized nebulae in the MCs. They are considered to be the final stage of ultra compact (UC) HII regions. Their main characteristics are: high excitation, small size ($\sim$ 2 pc), high density, and large extinction compared to typical MCs HII regions. These objects are tightly linked to the early stages of massive star formation, when the stars disrupt their natal molecular clouds. Such studies yield important informations for a better understanding of massive stars formation. We are now able to resolve clumps of stars inside highly obscured UC and UHC HII regions and detect the excitation sources.

Soon the Laser Guide star (LGA) will open the whole sky to the power of the AO.

Notes

## MIR PROBES OF THE ISM AND STELLAR POPULATIONS AT THE GALACTIC CENTER

**Jihane Moultaka(1), Thomas Viehmann(1), Rainer Schödel(1), and Andreas Eckart(1)**
*(1) I. Physikalisches Institut - University of Cologne*

We will present the results of our last NIR-MIR observations of the central parsec of our Galaxy. These investigations benefit from the high quality of the ESO instrumentation and would have been impossible to conduct without the use of NIR adaptive optics.
NACO photometry results in the NIR combined with N- and Q-band photometry from images obtained with the MIR camera VISIR at the ESO VLT enabled us to construct Spectral Energy Distributions of over 60 compact sources. We identified four typical classes of sources, each of which show characteristic features that may enable us to understand the nature of previously unclassified objects in the region. They cover sources in the northern arm, high and low luminosity bow-shock sources as well as the hot and cool stars.
On the other hand, spectroscopic observations with ISAAC at the VLT enabled us to build the first L-band data-cube of the central region corrected for the foreground extinction. This led to the discovery of 3 Wolf-Rayet stars all of which show, for the first time, prominent HeII emission lines in their MIR spectra providing an indication of their early evolutionary phase. One of the newly found stars seems not to belong to the two disk systems of young stars.
The data-cube also enabled us to study the distribution of water ice and hydrocarbon absorption features in the central parsec. The show of correlation that comes out between the distribution of these features suggests that the ISM presents itself as a (probably clumpy) mixture between the dense dusty and the diffuse ionized ISM.
Finally, very recent ISAAC M-band observations of a number of bright sources in the central parsec will be presented and the study of the CO gas/solid phase distributions will be discussed.

Notes

## NIR/X-RAY VARIABILITY AND POLARIZED NIR EMISSION OF SGRA*

**Eckart A. (1), Schoedel R. (1), Meyer L. (1), Trippe S. (2), Ott T. (2), and Genzel R. (2)**
*(1) University of Cologne*
*(2) Max Planck Institute for extraterrestrial physics*

I will report new simultaneous near-infrared/sub-millimeter/X-ray observations of the SgrA* counterpart associated with the massive 3-4 million solar masses black hole at the Galactic Center. The observations have been carried out using the NACO adaptive optics (AO) instrument at the European Southern Observatory's Very Large Telescope and the ACIS-I instrument aboard the Chandra X-ray Observatory as well as the Submillimeter Array on Mauna Kea, Hawaii, and the Very Large Array in New Mexico. In addition the most recent results from a VLT NACO observations of polarized NIR flare emission of SgrA* is presented and interpreted using a model in which spots are on relativistic orbits around SgrA*.

Notes

# PROBING THE PROPERTIES OF ULIRGS WITH THE INFRARED SPECTROGRAPH ON SPITZER

**V. Charmandaris(1,2,3), L. Armus(4), H. W. W. Spoon(2), J. Marshall(2),V. Desai(4), B. T. Soifer(4), and J. R. Houck(2)**
*(1) University of Crete, Greece*
*(2) Cornell University, USA*
*(3) Obs. de Paris, LERMA, France*
*(4) Spitzer Science Center, Caltech, USA*

Ultraluminous Infrared Galaxies (ULIRGs) have power outputs rivalling quasars, yet they emit nearly all of their energy in the mid and far-infrared. Both starbursts and dust-enshrouded AGN have been implicated as the power sources in ULIRGs. While rare in the local Universe, ULIRGs may play a dominant role in producing the far-infrared background as well as the star formation energy density at high redshifts. A large spectroscopic survey of 100 ULIRG with redshifts of $0.02 < z < 0.9$ has been performed with the Infrared Spectrograph on Spizter over the 5-35micron range. We will present highlights on the major results from this survey, and discuss their implications on models of cosmological galaxy evolution based on the interpretation of recent mid-IR surveys.

Notes

## FAR-INFRARED EMISSION OF SOLAR FLARES

**Karl-Ludwig Klein, Gérard Trottet, Guillaume Molodij, and Alain Sémery**
*Observatoire de Paris, LESIA - CNRS UMR 8109, 92195 Meudon*

Observations of the Sun at near-infrared wavelengths brought major advances in our knowledge of magnetic fields in the solar atmosphere, and of magnetic structures in the corona. The infrared spectrum also holds promise for a better understanding of solar flares. However, at present there is a gap of two orders of magnitude between solar flare observations at submillimetre and near-infrared wavelengths. We propose a pioneering experiment, called DESIR, dedicated to the first ever measurements of solar flares at far infrared wavelengths, where we expect basically two emission processes to provide crucial information on particle acceleration and energy transport in flares : the synchrotron emission of relativistic electrons and positrons and the transient thermal emission of the low chromosphere in response to energy transport from coronal flaring regions. Observing continuum emission in this range with a typical time resolution of a second will bring us the most stringent test of particle acceleration at the Sun, as well as a new powerful means to probe the thermal response of low atmospheric layers. The scientific rationale of DESIR will be discussed along with very recent first observations of flares at submillimetre wavelengths, which show us some glimpses of the processes we may deal with in the far infrared range. The DESIR instrument is presently under study. It is part of the payload proposed for the project of a French-Chinese microsatellite, SMESE, which entered phase A studies in January 2006 and which should be launched around the next solar maximum..

Notes

## AN OVERVIEW OF DEVELOPMENTS IN IR INSTRUMENTATION AT ESO

**Mark M. Casali**
*European Southern Observatory*

The European Southern Observatory will continue development and delivery of state-of-the-art infrared instrumentation for the VLT, through its first and second generation instrument programmes, to supplement the existing IR instrument complement (ISAAC, VISIR, SINFONI and NACO).

Two major new instruments will be delivered within the next year to complete the suite of first-generation instruments. CRIRES, the 100,000 resolution 1-5 micron AO-corrected spectrometer is currently in the integration and test phase, with first-light anticipated in a few months. HAWK-I, a 1 to 2.5 micron imager which uses mirrors and is equipped with a mosaic of four Hawaii 2RG detectors to achieve high throughput and a wide 7.5 arcminute square field is expected to achieve first light in early 2007.

Beyond 2007, other major new projects have been funded and are under development by external consortia as part of the second generation instrument programme. X-shooter is a simultaneous UV-to-K band intermediate resolution spectrometer, using high-efficiency dichroics to split the wavelength ranges. KMOS, due to be delivered in 2010, will combine 24 independently deployable IFUs with three spectrographs to gain a major multiplex advantage in IR spectroscopy. Planet-finder will be developed to use extreme-AO and coronagraphs to isolate planets around nearby stars and study them with spectroscopy and polarimetry.

In addition, the Adaptive Optics Facility project has been approved. This is a major project to develop a multiple laser-based system with a deformable secondary mirror for one unit telescope. By reducing the number of mirror surfaces required to only two, the facility will be ideal for thermal infrared work. At first light, the AOF will be used with HAWK-I for GLAO correction of the full field.

Notes

**WHAT A BIG ANTARCTIC TELESCOPE COULD ACHIEVE**

**John W. V. Storey, M. C. B. Ashley, M. G. Burton and J. L. Lawrence**
*School of Physics, University of New South Wales, Sydney NSW 2052, Australia*

Despite its diminutive size, the 60 cm SPIREX telescope at the South Pole has produced a wealth of important publications from just two seasons of operation. What could a 2 m, 8 m, or even 25 m telescope achieve? With infrared sky backgrounds up to two orders of magnitude below those of the best temperate sites, plus cleaner, wider and more stable atmospheric windows, the Antarctic plateau provides a remarkable opportunity for the deployment of the next generation of ground-based telescopes. In addition to the obvious sensitivity gains, the atmospheric turbulence profile above Dome C has now been measured by two groups using independent techniques. The results are in excellent agreement and promise unrivalled spatial resolution across wide fields of view, and unbeatable levels of speckle supression over small fields. Will the first direct detection of an earth-like exoplanet be achieved by an Antarctic telescope? If so, how big does this telescope need to be?

Notes

## SCIENCE WITH THE JAMES WEBB SPACE TELESCOPE

**Jonathan P. Gardner**
*NASA's GSFC*

The scientific capabilities of the James Webb Space Telescope (JWST) fall into four themes. The End of the Dark Ages: First Light and Reionization theme seeks to identify the first luminous sources to form and to determine the ionization history of the universe. The Assembly of Galaxies theme seeks to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, and active nuclei within them evolved from the epoch of reionization to the present. The Birth of Stars and Protoplanetary Systems theme seeks to unravel the birth and early evolution of stars, from infall onto dust-enshrouded protostars, to the genesis of planetary systems. The Planetary Systems and the Origins of Life theme seeks to determine the physical and chemical properties of planetary systems around nearby stars and of our own, and investigate the potential for life in those systems. To enable these for science themes, JWST will be a large (6.5m) cold (50K) telescope launched to the second Earth-Sun Lagrange point early in the next decade. It is the successor to the Hubble Space Telescope, and is a partnership of NASA, ESA and CSA. JWST will have three instruments: The Near-Infrared Camera, and the Near-Infrared multi-object Spectrograph will cover the wavelength range 0.6 to 5 microns, while the Mid-Infrared Instrument will do both imaging and spectroscopy from 5 to 27 microns. I review the status and capabilities of the observatory and instruments in the context of the major scientific goals.

Notes

# INSTRUMENTAL PROSPECTS IN INFRARED AND SUBMILLIMETER ASTRONOMY

**Jean-Loup Puget**
*Institut d'Astrophysique Spatiale, Université Paris Sud, Orsay*

L'astronomie infrarouge et submillimétrique est devenue une des sources essentielles des informations astronomiques grâce aux progrès spectaculaires des 30 dernières années en particulier sur les détecteurs mais aussi sur la cryogénie dans l'espace et les électroniques de lecture.

On discutera de deux des frontières actuelles de ce domaine: les mesures de polarisation et la confusion liée à la résolution angulaire. Dans le domaine de l'infrarouge thermique et lointain, gagner en sensibilité impose de refroidir les télescopes mais cela limite la taille des télescopes. On bute alors sur une autre difficulté: la limite de confusion. Des méthodes permettant de dépasser cette limite en combinant les données de plusieurs télescopes seront discutées.

Pour ce qui est des mesures de polarisation, les contraintes sur la stabilité du dispositif de mesure demandent de nouvelles conceptions de la mesure. De plus les sensibilités requises exigent que le pas vers les grandes matrices de détecteurs franchi tout d'abord dans l'optique puis dans l'infrarouge thermique le soit maintenant dans l'infrarouge lointain. Les nouvelles générations de matrices de bolomètres devraient permettre dans les prochaines décennies de contraindre simultanément la physique à très haute énergie et donc celle de l'univers primordial.

Notes

## 3D SPECTROSCOPY WITH A MICHELSON INTERFEROMETER

**Jean-Pierre Maillard**
*Institut d'Astrophysique de Paris*

An Imaging Fourier transform spectrometer (IFTS) being based on a Michelson Interferometer offers among the various solutions for integral field spectroscopy the unique capability of making possible to combine wide-field coverage, high spectral resolution and high spatial resolution. The spectral resolution can be much higher than with a F-P, with in addition a more flexible choice of resolution and spectral range. Illustration will be given with by results obtained with BEAR, a prototype instrument on various astronomical targets (PNs, Galactic Center, Jupiter). A review of astronomical IFTS in operation or in project will be presented with conclusions for future possible instruments at Dome C and for ELTs.

Notes

# INFRARED VARIABILITY AS A NEW POSSIBILITY TO EXPLORE CIRCUMSTELLAR DISK STRUCTURE

**Péter Ábrahám(1), Timea Csengeri(2), Attila Juhász(2), and Ágnes Kóspál(1)**
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Young pre-main sequence stars typically show variability at optical wavelengths, which is mainly due to stellar spots or variable extinction along the line of sight. At longer wavelengths these effects become less important, and in the mid- and far-infrared regimes – where the bulk of emission is originated from the circumstellar matter – young stellar objects (YSOs) are usually assumed to exhibit constant brightness.

With the availability of a growing number of ground-based and space-born infrared observations, however, infrared variability among YSOs can be reconsidered. We selected several intermediate-mass Herbig Ae/Be stars as well as FU Orionis and EX Lupi type objects, and looked for temporal changes in their 1–100$\mu$m infrared spectral energy distributions (SEDs). For each objects we collected infrared photometric data from the literature (IRAS, MSX, ISO, Spitzer, as well as MNQ-band ground-based observations), and constructed SEDs for different epochs. Measurements performed by ISOPHOT, the photometer on-board the Infrared Space Observatory, were re-evaluated using methods developed in our group. Special care was taken when data from different instrument were combined (colour correction, beam differences). For several objects variability at infrared wavelengths was found in the data, and in these cases we analysed also the wavelength-dependence of the variations.

In the literature there exist models of YSOs, which assume a certain circumstellar geometry (disk, envelope) and produce an infrared SED. We show that – with some assumptions – these models can also be used to predict how the star+disk system would react, as a function of time, on variations of the emission from the central illuminating source. In those cases when the luminosity of a YSO changes with time (e.g. due to variable accretion rate) one can compare the synthetic time-dependent SEDs with multiepoch infrared observations. This comparison may place strong constrains on some basic assumptions of the model, and can serve as an efficient diagnostic tool of the circumstellar structure. In the contribution we show several examples to illustrate the application of the method.

Notes

## COMMON PROPER MOTION SEARCH FOR FAINT COMPANIONS AROUND EARLY-TYPE FIELD STARS

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The derived binary fraction of early-type stars is different for individual star forming regions, suggesting a connection with the age and the environment conditions. The few studies that have investigated this connection do not provide conclusive results. To fill in this gap, we started a detailed adaptive-optic-assisted imaging survey of early-type field stars to derive their multiplicity in a homogeneous way. The sample has been extracted from the Hipparcos Catalog and consists of 341 BA-type stars within $\sim$300 pc from the Sun. We report the current status of the survey and describe a Monte-Carlo simulation that estimates the completeness of our companion detection. Finally, the first results from our second epoch observations of stars with companion candidates are discussed.

Notes

## OO SERPENTIS: AN INTERMEDIATE-TYPE OBJECT BETWEEN FUORS AND EXORS?

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OO Serpentis is a deeply embedded young star which brightened by 5 mag in the K band between 1994 and 1995, and gradually faded afterwards. In many respects the star and its outburst is very similar to the well-known young eruptive stars (FUors and EXors). These outbursts are closely connected to the circumstellar material, thus infrared observations are essential in understanding the physics of these objects. Since very few outbursts have ever been documented at infrared wavelengths, we monitored OO Ser for 20 months with the Infrared Space Observatory in the $3.6 - 100$ $\mu$m wavelength range. We complemented this dataset with new (ground-based and spaceborn) infrared observations from $2004 - 2005$, and constructed the light curve of the outburst at 10 different wavelengths as well as pre-outburst, outburst, and post-outburst spectral energy distributions. Our results show that by 2004 OO Ser had already returned to the pre-outburst state at 12 um and below, suggesing a significantly shorter outburst timescale than that of classical FUors, but longer than that of the EXors. This may indicate, that OO Ser – together with the recently erupted star V1647 Ori – is the first example of an intermediate object between FUors and EXors.

Notes

# MODELLING OF STELLAR HYDROGEN AND HELIUM LINE SPECTRA IN THE IR

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The quantitative interpretation of the hydrogen and helium line spectra is one of the foundations of modern astrophysics. The modelling of the spectral features in the visual has been brought close to perfection in the last few decades, allowing astrophysical plasma parameters to be determined with high accuracy. Despite fewer applications so far, quantitative IR-spectroscopy offers great potential in view of upcoming instrumentation and diffraction-limited observations with large telescopes using adaptive optics. However, we have to ask ourselves whether the status of the modelling in the IR is as good as in the visual.

We report on results obtained in an ongoing project to develop reference model atoms for NLTE computations in early-type stars that are able to reproduce observed spectra in the optical and in the $I$ to $L$-bands simultaneously. Our approach takes advantage of the amplification of NLTE effects on the line source function in the Rayleigh-Jeans limit. This makes IR lines in hot stars very susceptible to small changes in the atomic data, allowing us to discriminate between different model atoms empirically.

In the case of hydrogen [1] it is found that even for a standard star like Vega neither the classical LTE approach nor traditional NLTE recipes allow for highly accurate modelling of the IR line spectrum. The discrepancies become more pronounced for OB-stars and for supergiants. Equivalent widths $W_\lambda$ of the IR lines computed under the assumption of LTE or with standard NLTE model atoms may differ from observation by factors up to $>3$. Our improved reference model atom on the other hand succeeds in reproducing the optical and IR line spectra over the whole parameter space. For helium, our efforts have concentrated on the He I $\lambda 10\ 830$ Å transition so far. Our modelling reproduces the observed trend of $W_\lambda$ with $T_{\rm eff}$ for early-A to late-O main sequence stars – including the transition from absorption to emission characteristics – for the first time [2]. Modelling deficiencies in extreme helium stars could also be resolved [3]. Again, changes in the computed $W_\lambda$ for the IR line by factors up to $>3$ are found relative to LTE or NLTE computations with older model atoms, while classical results in the optical are retained.

Besides the immediate relevance for quantitative analyses of early-type stars there is a further impact. The reference model atoms are also of interest beyond stellar astrophysics because of the universality of atomic data. Finally, telluric line removal from IR spectra involving A-type dwarfs as telluric standards may benefit from the improved spectrum synthesis.

[1] Przybilla, N., & Butler, K. 2004, ApJ, 609, 1181
[2] Przybilla, N. 2005, A&A, 443, 293
[3] Przybilla, N., Butler, K., Heber, U., & Jeffery, C.S. 2005, A&A, 443, L25

Notes

# M DWARFS DOPPLER IMAGING AND THE INFRARED

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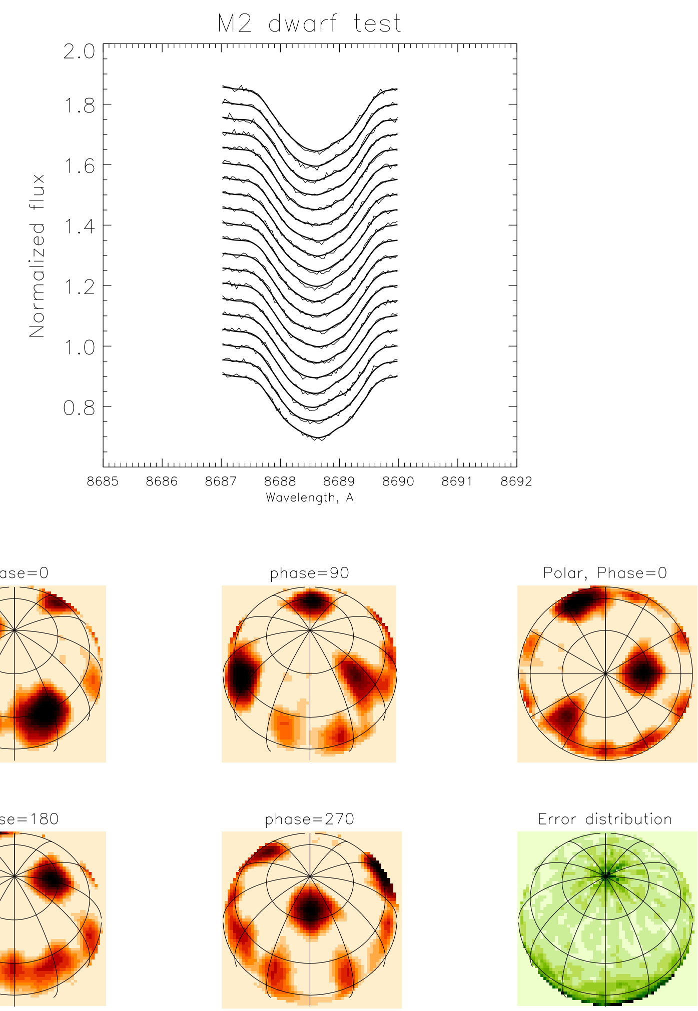
High-resolution spectroscopy at near and mid-infrared wavelengths can provide unique information about the surface inhomogeneities of the rapidly rotating cool (and faint) dwarf late-type stars. In particular, Doppler imaging technique (which solves the integral equation that relates the stellar surface parameters to the observed line profile variations) is a powerful tool for the reconstruction of an 'image' of the stellar surface.

We breifly discuss available now temperature 'images' of the late-type stars and present the numerical experiments with our new line-profile inversion code based on the mathematical approach of quasi-optimal Kolmogorov-Wiener filtering applied to the objects' principal components of the Doppler imaging problem. Stars cooler than M2 could be only mapped by considering numerous molecular bands.

*The M2-star test: Forward and inverse computations are done with molecular lines. The thin lines in the top panels show the artificial data with $T_{Phot}$=3500 K, $T_{Spot}$=3000 K, log g=5.0, v sini=24 km $s^{-1}$, i=60 degrees and S/N of 200:1 and the thick lines are the fits with our inversion. The lower panels show the reconstructed images and the error distribution for the restoration.*



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## SPATIALLY RESOLVED DIRECT MID-INFRARED IMAGING OF FU ORIONIS STARS

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The small group of YSOs know as FU Orionis stars provide striking evidence for the importance and irregularity of disk accretion during early stellar evolution. FU Orionis star were originally identified as a class of young stars with large ($>$ 4 magnitudes) outbursts in optical light. All are surrounded by reflection nebulae. More recently it has been realized that the physical reason for such an FU Orionis outburst is that the accretion rate onto the central star changes, within a period less than a month, from those commonly found around T Tauri stars into values of $10^{-3}$–$10^{-4}$ $M_\odot$ $yr^{-1}$. Intriguingly, meteoritic evidence suggests that chondritic material has formed when our own proto-solar nebula went through an episode of enhanced temperatures. FU Orionis objects may therefore not only constitute a crucial phase in the evolution of proto-planetary disks, but may also be directly relevant for the condensation of the protoplanetary disk into solids.

Here we present diffraction-limited images in the 9.0–18.7 $\mu$m range of a sample of FU Orionis and related objects obtained with the new mid-infrared imager/spectrometer VISIR on the VLT. Apart from the wide-scale morphology due to material heated in the stars natal cloud, evident in most sources in our sample, we clearly resolve two sources into a compact structure with an elliptical shape. This morphology of the region in the mid-infrared is quite distinct from near-IR images which are dominated by scattered light in the dusty envelope.

We interpret the new mid-infrared data as direct evidence for the presence of a disk surrounding these two objects. In both, the drop-off in brightness with radius in the Par 21 disk can be described as a broken power-law, with a sharp edge. These observation represent the first direct imaging of disks around FU Orionis stars at mid-infrared wavelength, vividly illustrating the scientific pay-back of the gain in spatial resolution and sensitivity that can be obtained by a dedicated mid-IR instrument on a 8m class telescope. Although they confirm the existence of disks, the observations presented here are not in agreement with predictions for the extent of these disks based on models for simple gaseous accretion disks, illustrating the importance of re-processing of accretion energy by dust.

Notes

# INFRARED IMAGES OF STAR FORMING REGIONS IN M101

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We have analysed near infrared narrow-band images of two giant HII regions in M 101 obtained with NIRI at Gemini North Telescope. After performing astrometric and flux calibration using archive Hubble Space Telescope images as templates, we have identified several new emission-line knots, undetected in optical narrowband images from HST. These knots are associated to star forming events taking place within the molecular cloud in an area very close to the one where the strong starbursts are taking place. A total number of about 100 regions have been detected above $5\,\sigma$ from background level and each of these could harbour stellar clusters formed by tens of bright O-type stars. The analysis of the HII luminosity function in the surroundings of NGC 5461 already shows a continuous distribution of HII regions up to H$\alpha$ luminosities as bright as $3\times10^{40}$ ergs s$^{-1}$.

## HYPERFINE SPLITTING OF [AL VI]3.66UM AND THE AL ISOTOPIC RATIO IN NGC6302

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The core of planetary nebula NGC 6302 is filled with high-excitation photoionised gas at low expansion velocities. It represents a unique astrophysical situation in which to search for hyperfine structure (HFS) in coronal emission lines from highly ionised species. HFS is otherwise blended by thermal or velocity broadening. Spectra containing [Al VI] 3.66$\mu$m $^3\mathrm{P}_2 \leftarrow ^3\mathrm{P}_1$, obtained with Phoenix on Gemini-South at resolving powers of up to 75000, resolve the line into five hyperfine components separated by 20 to 60 km $\mathrm{s}^{-1}$ due to the coupling of the $I = 5/2$ nuclear spin of $^{27}$Al with the total electronic angular momentum $J$. $^{26}$Al has a different nuclear spin of $I = 5$, and a different HFS, which allows us to place a 3 $\sigma$ upper limit on the $^{26}$Al/$^{27}$Al abundance ratio of 1/33. We measure the HFS magnetic-dipole coupling constants for [Al VI], and provide the first estimates of the electric-quadrupole HFS coupling constants obtained through astronomical observations of an atomic transition.

**THE HERSCHEL-PACS GUARANTEED TIME KEY PROGRAM ON EVOLVED STARS**

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Is this contribution the current status of a Herschel-PACS Guaranteed Time Key Program on evolved stars in presented. The Key Program consists of an imaging part of about 80 objects with the main aim to study the time-evolution of mass loss and the (a)-sphericity of the dust shells, and a spectroscopic part of about 25 objects in order to study mainly dust features.

The sample consists of a representative number of low-and intermediate mass stars (AGB, post-AGB, PNe objects, both C- and O-rich, from low- to extreme mass loss rates) and massive stars (WR, LBV).

The Program will be carried out in Belgian and Austrian PACS Guaranteed Time and involves several institutes in Belgium and the University of Vienna.

In addition, the link with very similar programs on evolved stars by the SPIRE and HIFI teams will also be briefly presented.

## INFRARED MULTI-SPECTRAL LUNAR OCCULTATION OBSERVATIONS - RESOLVING THE DUST SHELL AROUND OH06.86-1.5

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We present observations obtained from 1-4 microns simultaneously (resolving power of order 100) of a lunar occultation of the AGB star OH06.86-1.5 using a high speed spectrophotometer, pMIRAS, developed at the University of Texas McDonald Observatory. The broad wavelength coverage extends from the 1 micron region where the flux is dominated by the central star to the 4 micron region where it is dominated by emission from the dust shell produced by mass loss from the central star. This broad and inclusive wavelength coverage allows us to produce models for the dust shell that constrain the location and density of the shell. We fit both the overall energy distribution as well as the roughly 50 independent Fresnel fringe light curves as a function of wavelength. Although lunar occultation observations have a number of practical limitations, the high angular resolution afforded by this technique is a valuable complement to separated-aperture interferometry in the infrared.

## THE MANY FACES OF RED GIANTS

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Research on the astrophysics of red giants started in Vienna in the mid 1980s. Infrared astronomy of course played a crucial role in these efforts. Equally important were the development and continuous improvement of dynamic model atmospheres yielding synthetic spectra and visibilities. In this poster we summarize highlights of the past work and present some of the latest results.

Systematic comparisons of ISO-SWS spectra with hydrostatic and dynamic models have shown that stars with small variability can be rather well reproduced with static models while dynamic models are needed for stars with larger amplitudes. For C-stars there is rather good agreement between models and observations out to about $7\mu$m but there is a remarkable discrepancy in the N-band in the sense that a very deep $C_2H_2$ absorption predicted by the models is basically never observed.

Analysing an extensive set of ground based high-resolution IR-spectra the common characteristics of the atmospheric motions in Miras and the differences to Semiregular variables could be well established.

Using ISO-SWS data of O-rich AGB-stars in combination with laboratory measurements of various dust species the possible carriers of features at $13\mu$m and $19.5\mu$m were identified. In view of future far-IR observations of circumstellar shells with HERSCHEL, we are currently investigating the optical properties of astrophysically relevant solids at wavelengths longer than $57\mu$m.

Recent results presented in the poster concern the atmospheric dynamics, elemental abundances and dust mineralogy of AGB-stars in galactic and extragalactic globular clusters using ground based IR-spectrometers and the Spitzer-IRS.

We also discuss the atmospheric motions and the atmospheric structure of nearby carbon-rich giants investigated with FTS-spectra and MIDI at the VLTI.

## CONSTRAINTS ON THE NATURE OF DUST PARTICLES BY INFRARED OBSERVATIONS

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The far-infrared emissivity ($\epsilon$) of the large interstellar grains can be obtained for many molecular and moderate density regions thanks to the availability of more far-infrared and submillimetre observations and on-line star count (optical extinction) data. Several papers reported on the detection of an enhancement of the far-infrared dust emissivity in various sky regions, which was interpreted as an increase in grain size. However, the observed emissivities show a large scatter and due to the relatively low number of observations the trend was not well determined.

We compiled a list of interstellar coulds observed with ISOPHOT (the photometer onboard ISO) at least at two infrared wavelengths ($\sim$100$\mu$m and $\sim$200$\mu$m), constructed FIR emission maps, calculated dust temperatures, created extinction maps using 2MASS and USNO data, and calculated far-infrared emissivity for each cloud. This is the largest homogeneously reduced database constructed so far. During the data analysis special care on was taken on possible systematic errors and we conclude that these do not affect the final $\epsilon$ values significantly. Our far-infrared emissivity values have a clear temperature dependence, and show a general $\epsilon$ increase of a factor of 2 prior to the diffuse ISM in the low temperature (12K$\leq$T$\leq$14K) regime. This suggests the presence of grain growth, however, the limited emissivity excess resticts the possible grain growth processes to ice-mantle formation and coagulation of silicate grains, and excludes the coagulation of carbonaceous particles. The latter procedures might be important in some specific clouds (e.g. LDN1251), but are not efficient enough in most regions.

# DETERMINATION OF DUST EMISSIVITY COMBINING ISO AND IRAS OBSERVATIONS

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We investigated the dust emissivity at far-infrared wavelengths using a method which reproduces ISOPHOT temperature and optical depth values combining ISOPHOT and IRAS far-infrared data. A sample of clouds was analysed formerly (Kiss et al., 2004) and the method was found to be reliably applicable, allowing us to extend the sample of clouds appropriate for such investigations. We examined a new sample of clouds for which ISOPHOT measurements were made at only one wavelength, to make use of these data in completing our knowledge on dust emissivity properties.

## FAR-INFRARED STUDY OF SNIA HOST GALAXIES

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Recent observations of distant type Ia supernovae suggested the existance of a non-zero $\Lambda$ cosmological constant and lead to the concordance model of $\Omega_\Lambda \simeq 0.7$ and $\Omega_M \simeq 0.3$. However, spiral and irregular host galaxis may contain a significant amount of dust, and therefore the internal extinction in these galaxies may be systematically underestimated. This would mean that supernovae are apparently brighter and their Hubble–diagram did not show deviance from $\Lambda$=0 cosmological models.

We observed 50 high-z (0.1≤z≤1) SNIa host galaxies with the MIPS camera on board the Spitzer Space Telescope at the three protometric bands (24, 70 and 160 $\mu$m). The galaxies were selected to be detectable up to z≈1. Their 24, 70 and 160$\mu$m Hubble-diagrams (redshift versus apparent brihtness) provide information about the dust content of the galaxies, and show whether the visible-light observations should be corrected for the unexpected dust content.

## THE ASTEROID MODEL OF THE FAR-INFRARED SKY

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Asteroids contribute siginificantly to the general look of the infrared sky, much more than at visible wavelengths. As infrared space mission are more and more sensitive, it is important to test the impact of asteroids on these observations.

We used the Statistical Asteroid Model-I (Tedesco et al. 2005) and a simple thermal model (Lang, 1992) to calculate the brightness of $\sim$1.9 million asteroids from mid-infrared to submillimetre wavelengths, at various dates/solar elongations. Using this model, we calculated expected number densities and confusion noise values, which are crucial parameters for the detectors of present and future space missions (e.g. PACS and SPIRE aborad Herschel, Planck).

## THE SMALL-SCALE STRUCTURE OF FAR-INFRARED AND VISIBLE SCATTERED LIGHT IN INTERSTELLAR CIRRUS CLOUDS

**Cs. Kiss(1)**
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The small-scale structure of the interstellar cirrus is important since (1) it contains information about the physical processes forming the structure itself and (2) it is a foreground for the cosmic infrared background, and should be separable from that. The investigation of the small-scale structure in the (far-)infrared is difficult, due to the limited available spatial resolution. However, is some well-selected cirrus clouds the visible scattered light and the far-inrared emission is strongly correlated, making it possible to study the structure at a resolution higher than infrared instruments can reach. Here we demonstrate the usability of this method for a sample of northern cirrus clouds and derive parameters describing the small-scale structure.

## CARBON STARS IN THE IRTS SURVEY

**Thibaut Le Bertre (1), Masahiro Tanaka (2), Issei Yamamura (2), Hiroshi Murakami (2), Jack MacConnell (3), and Alexandre Guertin (1&4)**
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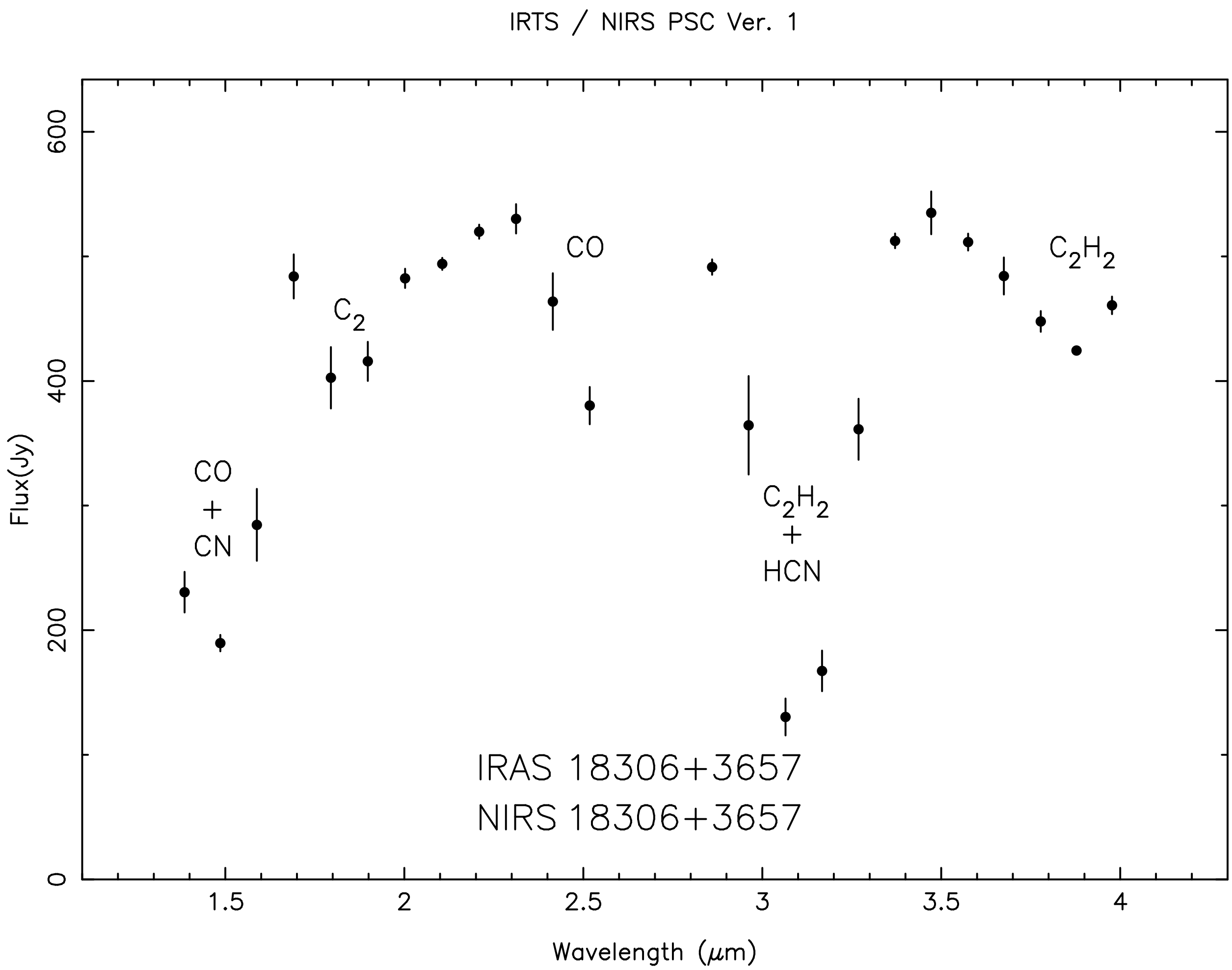
*(2) Institute of Space and Astronautical Sciences, JAXA, Japan*
*(3) Science Programs, Computer Sciences Corporation, Space Telescope Science Institute, U.S.A.*
*(4) University of Montréal, Canada*

In this poster we illustrate the potential of infrared spectro-photometry to identify and characterize late-type stars. Carbon star spectra from the Near-Infrared Spectrometer of the Infrared Telescope in Space (IRTS) are taken as examples (T Lyr ≡ CGCS 4038, in the figure).



## SPITZER OBSERVATIONS OF EXTRAPLANAR PAH EMISSION FROM SPIRAL GALAXIES

**Nicolas Lehner and J. Christopher Howk**
*University of Notre Dame*

We present new Spitzer/IRAC observations of polycylic aromatic hydrocarbon (PAH) emission from interstellar material in the thick disks of normal spiral galaxies. These data show PAHs to be a common constituent of extraplanar material in spirals, implying that the processes that eject material from the thin interstellar disks of these systems do not destroy these very small grains. This knowledge is crucial for understanding the thermal physics of the interstellar thick disks. We discuss the distribution of extraplanar PAH emission in these systems, both on small scales (e.g., the observed filamentary and cloud-like morphology of the emission) and on large scales (e.g., the overall scale lengths and scale heights of the emission) in several galaxies. We also discuss how the new observations fit into our overall understanding of interstellar thick disks and halos in galaxies.

# SEMIEMPIRICAL HYPOTHESES OF THE TURBULENCE THEORY IN THE ATMOSPHERIC ANISOTROPIC BOUNDARY LAYER (FOR MOUNTAIN REGION)

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With the use of semiempirical hypotheses of the turbulence theory it was shown theoretically and experimentally that an arbitrary anisotropic boundary layer can be considered to be locally weakly anisotropic. For example, it is experimentally established that the turbulence behavior in the mountain boundary layer has significant anisotropy. As well known, the turbulence theory originates from the description of liquid and gas flows based on equations of hydrodynamics. The complete statistical description of random hydrodynamic fields is given by a characteristic functional. The characteristic functional contains information on endless ensemble of the field moments and satisfies the dynamic equation with functional derivatives. At present the acceptable methods of solutions are not found. At same time, for many practical problems it is enough to define only statistical moments of lower orders. Therefore the investigations in the turbulence theory are based traditionally on the set of Reynolds equations, which is the result of averaging of equations of hydrodynamics. However, in the set of Reynolds equations the number unknown values exceeds the number of equations. Closure of this set of equations is usually made by setting some relations between moments of hydrodynamic fields. The indicated relations found from the experiments or obtained from the physical considerations (for example, from considerations of dimensionality) are said to be semiempirical hypotheses of the turbulence theory. The main semiempirical hypotheses are usually reduced to setting the relationship between second moments of pulsations (deviations from the mean) of the velocity and the temperature and the averaged fields of the velocity and the temperature . These hypotheses are based, as a rule, on the analogy between turbulent and molecular motions. Therefore the terms can be considered as components of turbulent momentum fluxes and heat fluxes. A concept of the isotropic boundary layer (for plane-parallel flows) is not connected with the isotropy of hydrodynamic fields. In the isotropic layer there is a defined direction (the distance from the boundary plane), therefore the fields will not be isotropic. As is well-known, the outer scale of turbulence can be defined in different ways. For example, Tatarskii defines the vertical outer scale of turbulence L0T from the condition that the mean-square difference of random temperature values at two points is equal to its systematic difference. The outer scale of turbulence can be also defined from the deviation of the structure function of temperature fluctuations from the "2/3" law. In the Fourier-transform space, this scale corresponds to the scale L0V defined from the deviation of the one-dimensional spatial or temporal frequency spectra from the "5/3" law. There are also scales, which are the parameters in various theoretical models of the energy interval of the three-dimensional spectrum of fluctuations (for example, the Karman outer scale).

## INVESTIGATION OF THE VEGA PHENOMENON AMONG F-TYPE STARS

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We observed a sample of 78 Vega candidate stars with the IRS and MIPS instruments on-board the Spitzer Space Telescope. All stars were in the spectral range of F0-F9, resulting in a rather homogeneous sample in terms of stellar mass and luminosity. Our investigation focused on the following issues:

1. the temporal evolution of debris disks;
2. individual systems with very high fractional luminosity;
3. old stars with warm debris disks;
4. debris disks in young moving groups.

In this contribution we present our first results especially related to the existence of debris disks in young nearby stellar kinematic groups.

## DUST PROCESSING IN YOUNG CIRCUMSTELLAR DISKS

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We address the problem of crystallization, melting and evaporation of dust particles in disks around YSOs. This problem has attracted much interest in recent years since it is one important feature which gives considerable insight into evolutionary processes in such disks that is accesible to observations with the new generation of large telescopes. Shock waves seems to be the mechanism able to explain the formation of crystalline silicates found in chondrites, long-period comets, and disks around YSOs (Jones et al. 2000, Protostars and Planets IV, 927; Scott and Krot 2004, ApJ in press). We propose a new energy source of gas dynamics shocks based on gravitational perturbations excited by a companion object, i.e., a giant planet or a companion star. We carry out a parameterization of the wave dynamics and of the dust heating in the shock front that predicts the melting and/or evaporation of silicates in bound orbital ranges determined by the companion parameters. We obtain that the gravitational perturbations of the companion would generate shock waves able to process dust particles at  1-5 AU depending on the central star and disk physical parameters as well as on the companion parameters (Parisi and Sterzik 2005 submitted to $A\&A$). We especulate that the precense and abundance of crystalline and amorphus silicate grains in young binary systems (young brown dwarfs, T-Tauri stars, and Herbig AeBe stars) are determined by this process. Current infrared observations are just approaching the necessary precision to test this hypothesis.

Notes

# NUCLEAR ACTIVITY IN A SAMPLE OF THE MOST ISOLATED GALAXIES: FAR INFRARED AND RADIOCONTINUUM SELECTION.

**José Sabater(1) and the AMIGA team**
*(1) Instituto de Astrofísica de Andalucía*

The project AMIGA (Analysis of the interstellar medium of isolated galaxies) will provide a statistically significant sample of the most isolated galaxies in the northern sky. Such a control sample is necessary to understand the role of the environment in evolution and galaxy properties like the interestelar medium (ISM), start formation and nuclear activity. The sample is based on the CIG catalog (Karachentseva 1973) and the data base includes blue luminosity, near-infrared luminosity, far-infrared (FIR) emission, atomic gas (HI) emission, radio continuum, and, for a red-shift limited subsample of 200 galaxies, CO and Ha emission. The data is being released and periodically updated at http://www.iaa.csic.es/AMIGA.html. One of our main goals is the study of the triggering of nuclear activity in non-interacting galaxies using diferent methods. We will focus on the well known radiocontinuum-FIR correlation in order to find radio-excess galaxies which are candidates to host an active galactic nucleus (AGN) and FIR colors to find obscured AGN candidates. We have looked for the existing information on nuclear activity in the Véron-Cetty catalogue and in the NASA Extragalactic Database (NED). Finally we have produce a final catalogue of AGN candidate galaxies which will provide a baseline for the study of the nuclear activity depending on the galaxy-galaxy interaction.

## DENIS: A SOUTHERN HEMISPHERE INFRARED SURVEY

**Jean Borsenberger, Bertrand DeBatz, Sebastien Derriere, Nicolas Epchtein, Gary Mamon, Alain Omont, Guy Simon and the DENIS Consortium**
*GEPI, Observatoire de Paris*
*GEPI, Observatoire de Paris*
*Observatoire de Strasbourg*
*LUAN, Universite de Nice*
*Institut d'Astrophysique deParis*
*Institut d'Astrophysique de Paris*
*GEPI, Observatoire de Paris*

The DENIS survey has mapped the southern sky in three wavebands: I (0.8 microns), J (1.2 microns) and Ks (2.1 microns). The main catalog, now available through ALADIN and VIZIER at CDS, and in ds9 (v4.0), covers 80 % of the southern sky and contains 350 million objects.

The main science includes the discovery of new populations (isolated brown dwarfs, a new class of L dwarfs), M dwarfs in the solar neighbourhood, galaxies behind the Milky Way, AGB/RGB and YSOs in the Galactic Plane (in association with the ISOGAL survey), the Galactic structure, extinction in the molecular clouds and the Galactic Plane and stellar populations in the Magellanic Clouds.

In 2006 we plan a release with a larger sky coverage, a global photometric calibration and a blind extended source database.

# SN1987A AFTER 18 YEARS: MID-INFRARED GEMINI AND SPITZER OBSERVATIONS OF THE REMNANT

**Patrice Bouchet(1), Eli Dwek(2), I. John Danziger(3), Richard G. Arendt(4), I. James M. De Buizer(5), Sangwook Park(6), Nicholas B. Suntzfeff(7), Robert P. Kirshner(8), and Peter Challis(8)**

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We present high resolution 11.7 and 18.3 um mid-IR images of SN 1987A obtained on day 6526 since the explosion with the Thermal-Region Camera and Spectrograph (T-ReCS) attached to the Gemini South 8m telescope. The images show that all the emission arises from the equatorial ring (ER). Near contemporaneous spectra obtained on day 6184 with the MIPS, IRAC and IRS instruments on board the Spitzer Space Telescope show that the emission consists of thermal emission from silicate dust that condensed out in the red giant wind of the progenitor star. The dust temperature is 166(+18, -12) K, and the emitting dust mass is 2.6(+2;0, -1.4) 10-6 Solar Mass. Comparison of the mid-IR Gemini images with X-ray images obtained by Chandra, UV-Optical images obtained by HST, and radio synchrotron images obtained by the ATCA show generally good correlation of the images across all wavelengths. Because of the limited resolution of the mid-IR images the location or heating mechanism of the dust giving rise to the emission cannot be uniquely determined. The dust could be collisionally heated by the X-ray emitting plasma, providing a unique diagnostic of plasma conditions. Alternatively, the dust could be radiatively heated in the dense UV-optical knots that are overrun by the advancing supernova blast wave. In either case the dust-to-gas mass ratio in the circumstellar medium around the supernova is significantly lower than that in the general interstellar medium of the LMC, suggesting either a low condensation efficiency in the wind of the progenitor star, or the efficient destruction of the dust by the SN blast wave. Overall, we are witnessing the interaction of the SN blast wave with its surrounding medium, creating an environment that is rapidly evolving at all wavelengths. Continuous multi wavelengths observations of SN 1987A such as these provide unique snapshots of the very early evolution of supernova remnant, and shed some light on the role of supernovae in the dust production in the universe.

# Session 2:
# Adaptive Optics
*Optique adaptative*

## CURRENT RESULTS AND INSTRUMENTS (TITLE TBC)

**François Rigaut**

n/a

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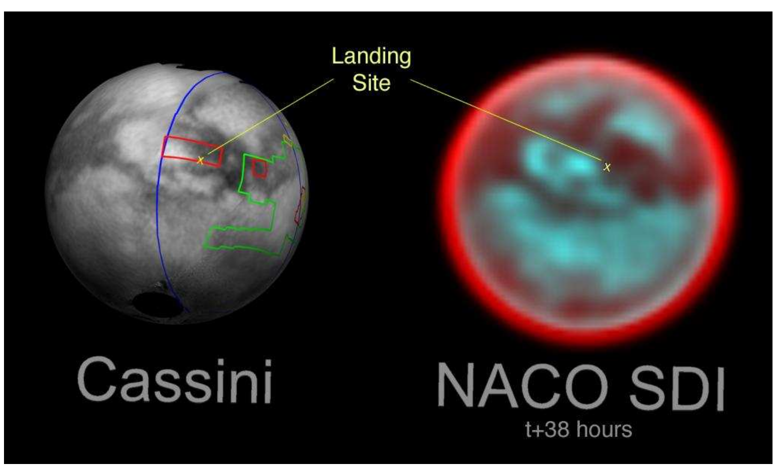
# STUDYING SMALL SOLAR SYSTEM OBJECTS WITH ADAPTIVE OPTICS IN CONTEXT WITH SPACE MISSIONS

**M. Hartung(1), A. Coustenis(2), C. Dumas(1), M. Hirtzig(2), T. M. Herbst(3), E. Gendron(2), L. M. Close(4), R. Lenzen(3), M. Combes(2), and P. Drossart(2)**
*(1) European Southern Observatory, Santiago de Chile, Chile*
*(2) Observatoire Paris-Meudon, Meudon, France*
*(3) Max-Planck Institut für Astronomie, Heidelberg, Germany*
*(4) Steward Observatory, University of Arizona, Tucson, USA*

Adaptive optics (AO) has left its infancy and experimental phase. The major telescopes are equipped with mature AO facility instruments. AO has become indispensable for high-resolution astrophysics since a couple of years. Still, data reduction techniques are in the process of evolution (e.g. convolution, PSF reconstruction, photometry), and the reliability of these data (AO artefacts) under discussion. For most astronomical targets, AO generated image data cannot be directly verified. Only space missions to solar-system objects make a direct comparison possible.

In the context of the Cassini/Huygens mission within the ESA coordinated ground-based observation campaign, stunning VLT/NACO data of Titan have been obtained uniquely demonstrating the potential and reliability of modern AO technology. Re-projecting the Cassini/ISS map to the same viewing angle prevailing at the time of NACO AO observations allows us to compare directly the surface details (see figure).

At small angular-size objects as Titan, Pluto, Charon, and the asteroid Vesta, we demonstrate how AO supported ground-based observations combined with sophisticated instrumentation such as Simultaneous Differential Imaging, Fabry-Perot, 3-D spectroscopy have become inalienable to support space missions and to complement their scientific achievements.



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# PARSAMIAN 21: HIGH-CONTRAST INFRARED MAPPING OF AN EDGE-ON FU ORI DISC

**Ágnes Kóspál(1) and Dániel Apai(2,3)**

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*(2) Steward Observatory, The University of Arizona, 933 N. Cherry Avenue, Tucson, AZ 85721, USA*

*(3) NASA Astobiology Institute*

FU Ori-type objects (FUors) are low-mass pre-main sequence stars that have undergone outbursts in optical light of 4 mag or more. FUors are usually modelled by a flared accretion disc and an extended envelope. Outburst are thought to be caused by enhanced accretion from the disc to the star, triggered by an external event, probably the passing of a close companion.

Parsamian 21 is a unique object among FUors, as it is surrounded by an edge-on disc, which makes it an ideal case for studying disc/envelope structure. We present high-resolution, high-contrast imaging of Parsamian 21 obtained with VLT/NACO using the "differential polarimetric imaging" technique in the H band as well as direct images in the H, $K_S$ and $L'$ bands. We could detect scattered light as close as $0.1''$ from the star, and measure the polarization structure of the innermost part of the system with unprecedented contrast and resolution. Using this dataset, we searched for close companions and tested the basic assumptions of FUor disc models.

Notes

# THE GALACTIC CENTRE : THE LESSONS FROM AO

**Yann Clénet(1), Daniel Rouan(1), Eric Gendron(1), and François Lacombe(2)**
*1 : Observatoire de Paris, LESIA, France*
*2 : Mauna Kea Technologies, France*

At the beginning of the 90th, many studies were tending towards the presence of a supermassive compact source at the gravitationnal centre of the Galaxy. Adaptive optics was the instrumental breakthrough that cleared up the uncertainties on the nature of the central compact source, revealing its black hole nature and its properties.

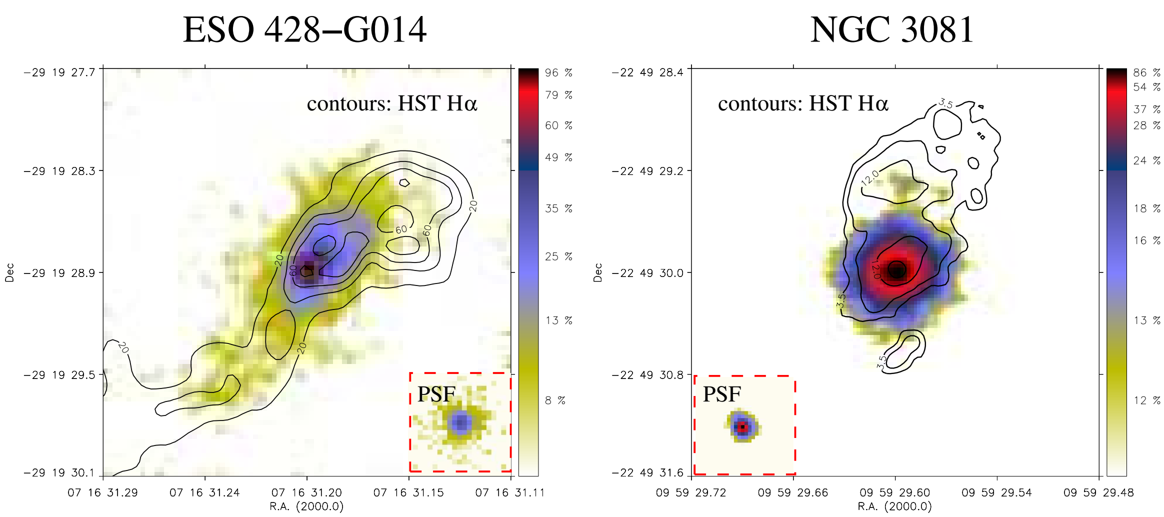
In this presentation, I will review first what Adaptive Optics have brought in our knowledge of the Galactic Centre and its supermassive black hole but also the questions still pending on the black hole emission mechanism and the central star formation history.

Notes

# MORPHOLOGY OF THE CORONAL-LINE REGION IN A SAMPLE OF AGN USING NACO, THE VLT AO SYSTEM

**Olivier M. Marco**
*ESO Paranal*

We present our new work on the coronal emission in a sample of AGN. We used the adaptive optics system NACO on the VLT to obtain high angular resolution images (~0.15") of the coronal emission in the vicinity of the central engine. In each of these galaxies, the coronal-line emission, as traced by [Si vii] 2.48 ?m, comprises a bright, compact central source and extended emission showing broad alignment along a particular direction, usually coinciding with that defined by the radio emission or the extended narrow-line region. The full extent of the coronal-line emission ranges from a few tens of parsecs to 150 pc radius from the nucleus and is a factor of 10 smaller than that seen in the extended, lower ionization gas. With a spatial resolution of 10 pc or better, the coronal region shows diffuse and filamentary structure in all cases, and it is difficult to see whether it breaks down into discrete blobs such as those seen in lower ionization lines or radio images of comparable resolution. The extent of the coronal-line emission is larger than would be predicted by photoionization models, which argues for additional in situ gas excitation, the most plausible energy source being shock excitation.



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**FROM THE VLT NAOS TO THE FUTURE PLANET FINDER EXTREME AO SYSTEMS**

**Thierry Fusco(1), Gérard Rousset(2), David Mouillet(3), Jean-Luc Beuzit(4), Anne-Marie Lagrange(4) and Pascal Puget(2)**
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After more than 15 years of developments for astronomy, adaptive optics [AO] has become a powerful tools for ground based instrumentation at optical wavelengths. Installed in 2001 on one of the four 8-m telescopes of the ESO-VLT, NAOS is the paradigm of astronomical AO. This fully integrated and multi-purpose system coupled with the CONICA camera provides diffraction limited images in a large range of conditions (atmospheric turbulence and guide star flux) and applications. In the past five years, the system has generated numerous new and exciting astrophysical results among which the first direct image of an extrasolar planet. Despite of its first discovery, NAOS ultimate performance does not allow to properly cover this challenging area of current astronomy. Hence, new extremely high performance adaptive optics (XAO) system have to be designed to achieve the direct detection of extro-solar planets from the ground. Such systems will be coupled with coronographic and smart imaging technics. In the framework of the second generation instrumentation for the VLT, the "VLT-planet finder" [VLT-PF] instrument is currently designed and will be built within the next 4 years. The goal of this system is the direct imaging of hot Jupiter planets. Using a general framework, we propose here to depict the evolution of the AO systems from NAOS to VLT-PF. The performance and limitations of NAOS will be presented and discussed. Using the lesson learned on NAOS, new ideas and concepts are proposed for VLT-PF in order to overcome these limitations. The global philosophy of VLT-PF design will be presented and each new concept will be described. Using the same kind of approaches, we give some basic considerations on planet finder systems for the next generation of extremely large telescope (ELT).

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# MULTI-CONJUGATE ADAPTIVE OPTICS FROM VLTS TO ELTS

**J.-M. Conan(1), B. Neichel(1,2), Th. Fusco(1), E. Gendron(2), G. Rousset(3,2,1), C. Petit(1), M. Nicolle(1), P. Jagourel(1), and F. Hammer(1)**

*(1) ONERA*

*(2) Observatoire de Paris-Meudon*

*(3) Université Paris 7*

The resolution of ground based astronomical telescopes is limited by the presence of atmospheric turbulence. The current Very Large Telescopes [VLTs] (10 meter-class) are now equipped with Adaptive Optics [AO] that provides a real time correction of turbulence. These systems are however limited in performance and sky coverage by anisoplanatism effects. Various ideas have emerged in the last few years to partially overcome such a limitation and to answer new astronomical challenges: Multi-Conjugate AO, per se, for diffraction limited imaging in a wide field of view [FoV], Ground-Layer AO [GLAO] for resolution enhancement in large FoV, Multi-Object AO [MOAO] for the simultaneous observation of several faint galaxies with 3D spectroscopy. These variations around the theme of Multi-Conjugate AO [MCAO] are based on two main concepts: the use of multi-guide-star wavefront sensing, and the potential use of several deformable mirrors.

The first MCAO demonstrators and systems are now under development. The interest of such techniques for VLTs is discussed and the associated key issues and design choices are presented. Besides, a new era of astronomical telescopes is about to start with diameters reaching 30 to 60 meters. The respective advantage of the various MCAO techniques is shown to evolve with the diameter size. The influence of the change in diameter on MCAO design rules is also studied: evolution of the deformable mirror characteristics (number, stroke, pitch...), of the temporal sampling frequency, choice of natural versus laser guide stars... Of course the effect of atmospheric parameters (outer-scale, distribution in altitude) will be discussed.

Notes

## ON INSTRUMENTAL PROSPECTS VS BIG QUESTIONS IN ASTRONOMY (TITLE TBC)

**Anne-Marie Lagrange**

n/a

Notes

# INCOHERENT BEAM PHASE RECONSTRUCTION USING PHOTOREFRACTIVE MATERIALS.

**Jean-Paul Gaffard**

Photorefractive materials are extremely non linear and exhibit time constants down to the millisecond. They are mainly used for recording of dynamic holograms, two wave mixing, beam amplification ...

We demonstrate that photorefraction may apply to natural non coherent light beams, for instance light emitted by thermal sources, and can be used to modify or restore the beam phase. We suppose that the phase distribution of the incoming incoherent beam can be measured by a wave-front analyser, and therefore is known. The demonstration is based on the Kukhtarev set of equations and uses the Fresnel ellipsoïd method.

The task is to monitor the photorefractive index and restore the desired optical path distribution in order to correct the phase map. This is done using an auxilliary laser beam used as a writing source. The two beams must have strictly the same path in the cristal. We first demonstrate, using the Kukhtarev set of equations, that it is possible to record the desired phase field within the crystal by properly controlling the intensity of the laser beam. The second condition is due to the propagation in the crystal. It is well known that light can propagate in a cristal for only two orthogonally polarised modes. On the other hand, a natural non polarised light beam can be projected on any couple of orthogonal polarisations. Using the Fresnel ellipsoïd method, we demonstrate that there exists a crystal orientation that allows the same optical path distribution for the two polarised modes.

Instrumentation draft: Due to the nature of photorefraction itself, the diameter of the beams in the photorefactive crystal must be as small as possible. A high aperture number optical system must be used to obtain the desired aperture diameters. The result is an extremly compact optical system. The writing beam intensity is monitored by a spatial attenuation modulator. The Kukhtarev equations show that a writing beam with a strong mean intensity is needed for optimal effect: ie intensity modulation must be small. The result is that very simple intensity modulator as a liquid crystal display can be used.

Applications: A photorefractive phase reconstructor can replace conventionnal Adaptive Optics using deformable mirrors. The gains expected from the photorefractive effect, compared to the discrete actuators of conventional adaptive mirrors, are: system simplification, compactness of the optical system, and costs reduction.

Moreover the use of LCD modulators greatly simplifies the control system, compared to the high voltage amplifiers needed by conventionnal adaptive mirrors. This allows a huge number of sampling points to be controlled (we can imagine up to 1 million samples in the aperture).

Domains of application can be: replacement of conventionnal adaptive optics, especially in applications for astronomy, residual aberrations correction for multiple lens optical systems: application in microlithography.

Keywords Photorefraction, adaptive optics, multiconjugate mirrors, beam control, real time image restoration.

## A DEEP NEAR INFRARED SURVEY FOR BROWN DWARFS TOWARDS TAURUS

**Bertrand Goldman, Sascha Quanz, Wolfgang Brandner, and Thomas Henning**
*MPIA*

We used the Omega2000 wide-camera on the 3.5m at Calar Alto, to perform a deep J, H, and Ks survey of the Taurus star formation region. Our deep imaging allows us to detect brown dwarfs down to $\sim$ ten Jupiter masses, over 2 square degrees (assuming evolutionary models). We conduct an ongoing campaign to confirm candidates using the multi-slit spectrograph MOSCA, on the same telescope. This program will allow the preliminary determination of the initial mass function (IMF) down to the end of the brown dwarf regime and planetary masses in the Taurus region. The determination of the IMF in various star forming regions and its variations with respect to the location within the regions will shed light on the brown dwarf formation mechanisms and evolution of stellar clusters.

In this paper we will report on our preliminary brown dwarf candidate sample.

# TITAN IN INFRARED WITH ADAPTIVE OPTICS : AN OVERVIEW

**Mathieu Hirtzig (1,2), Athéna Coustenis(1), Eric Gendron(1), Pierre Drossart(1), Alebrto Negrão(1,3), Michel Combes(1), Olivier Lai(4), Pascal Rannou(3), and Markus Hartung(5)**
*(1) LESIA, Observatoire de Paris-Meudon, France, (2) LPG, Université de Nantes, France, (3) Service d'Aéronomie, Univ. de Versailles, France, (4) CFHT, Hawaii, USA, (5) ESO, Garching, Germany*

Since 1994, our team at the LESIA has explored Titan's atmosphere, gathering information before and during the arrival of the Cassini-Huygens mission. The data presented here rely on adaptive optics, harvesting infrared images of Titan between 0.8 and 2 micron with either PUEO at the CFHT or NAOS/CONICA (NACO) at the VLT. The imaging modes we used vary from one observing run to another : (a) narrow-band filter imaging, around each methane window at 1.3, 1.6 and 2.0 micron [Combes et al (1997), Coustenis et al (2001), Gendron et al (2004)], (b) NACO spectroscopy around 2 micron with a 1400 resolving power (Negrao et al., 2006), (c) SDI imaging, probing the core and wings of the 1.6 micron methane window [Hirtzig et al (2006a)], and (d) Fabry-Pérot Imaging (FPI), used as a collection of 2-nm wide filters to scan the 2.0 micron window. We also used (e) Integral Field Spectrometry to probe the 0.8-1 micron range [Hirtzig et al (2006b)].

We will describe here the latest conclusions drawn from these runs, focusing both on the features detected on Titan's surface [Coustenis et al (2005)] and the diagnostic of the atmosphere [Hirtzig et al (2006)] : the latter it displays at the present era variations or new apparitions of atmospheric phenomena, such as seasonal and diurnal effects, or some very interesting features in the Southern polar region. The North-South Asymmetry (NSA) is shown to have changed since 2000 in the near-IR and to be currently organized in a brighter northern than southern pole. We report here on this evolution. From our data, we also have significant statistical evidence for diurnal effects in Titan's stratosphere, with a brighter (by as much as 19%) morning limb appearing in our images in many cases, when the phase effect is on the evening side. The southern bright revolving feature detected by many authors since 2000 cannot be seen any more since January 2005. It was a meteorological (and possibly seasonal) phenomenon, revolving around the Southern pole (confined in its motion within the 80th S parallel) and located somewhere in the upper troposphere (20-40 km of altitude). We will discuss some of its aspects.

Our knowledge of the nature of Titan's surface is based on the accumulation of many images acquired systematically at given wavelengths in the aforementioned "methane absorption windows". First we will show the latest surface maps, before giving new hints regarding the chemical composition of the surface components. Two ways we can consider in this study: direct spectroscopy of Titan's surface albedo spectrum, as returned by our radiative transfer model [Rannou et al (2005), Negrão et al (2005)]; or differential spectroscopy, so as to eliminate as many model-dependent artefacts as possible.

All theses studies can illustrate, if needed, that the remote observation from Earth, in the infrared, is utterly complementary to the *in situ* measurements by the state-of-the-art Cassini/Huygens mission.

## MORPHOLOGICAL EVOLUTION OF HIGH REDSHIFT GALAXIES SEEN IN THEIR OPTICAL REST-FRAME WITH ADAPTIVE OPTICS

**Marc HUERTAS-COMPANY(1), Daniel ROUAN(1), and Geneviève SOUCAIL(2)**
*(1) Observatoire de Paris*
*(2) Observartoire Midi-Pyrénées*

We present the first results of a program of observations of a sample of far galaxies ($z_{median} = 0.8$) at high spatial resolution aiming to study their morphological evolution with redshift. We observed 8 fields of $1 \times 1$ with the NAOS/CONICA AO system in Ks ($2.2 \mu m$) band with typical $m_v = 14$ guide stars. The observed fields are selected within the COSMOS-ACS and VVDS treasury survey area, in which multi-wavelength photometric and spectroscopic observations are ongoing. We analyzed the morphologies by means of B/D (Bulb/Disk) decomposition using GIM2D (Simard et.al) for a number of 30 galaxies with magnitudes between $Ks = 17 - 20$. Simulations and comparisons with CFHT and HST data have been carried out: preliminary results are shown.

# ADAPTIVE SYSTEM OF TIP-TILT CORRECTION OF IMAGE WITH MODIFIED CORRELATION TRACKER FOR BSVT

**Vladimir P. Lukin, Leonid V. Antoshkin, Nina N. Botygina, Oleg N. Emaleev, Pavel G. Kovadlo, and Peter A. Konyaev**
*Institute of Atmospheric Optics SB RAS,*
*Av. Academicheski, 1, 634055, Tomsk, Russia*

The possibility of applying adaptive correction to ground-based solar astronomy is considered. Different ways of development of an adaptive correction to be used in the BSVT of the Baikal Astrophysical Observatory are discussed. The correlation technique for measuring the displacement of an image fragment consists in the following: a reference frame is stored and then the correlation function of irradiance distribution in the reference frame and any pre-selected current frame is calculated. The position of the maximum of the correlation function determines the coordinates of displacement of the current frame with respect to the reference one. The correlation tracker failed to track the image, because, as turned out, the CCD array of the DALSTAR camera featured four equidistant horizontal linear arrays with the sensitivity 0.4-1.2% lower than that of the other elements, which led to the appearance of four lines in the recorded image. With the uniform irradiance of the array, the contrast of these lines was 0.2-0.6%. When low-contrast objects were observed, the static local maximum could appear higher than the moving one associated with the image displacement. In this case, the tracker failed to detect the image motion. During the tests of the adaptive optical system at the BSVT in August 2003 and August 2004, the contrast of the granulation pattern in different areas of the solar disk (at the center, at an edge, near sunspots) averaged from 1 to 4%. To calculate the mutual correlation function of the irradiance distribution in the reference and current frames, out algorithm employs the mixed-radix Fast Fourier Transform (FFT). The algorithm operates in the 16-bit floating point arithmetic. When recording displacements of the granulation pattern, we noticed that the mutual correlation function of the reference and current frames had several extremes, in particular, static ones, attributed to the detector features. To separate the maximum of the correlation function, whose coordinates determine the displacement of the granulation pattern, the following algorithm is proposed. In the spatial spectrum of the image of the reference and current frames, the characteristic frequencies associated with the granule size are amplified. The amplification contour is a gaussian, whose parameters are defined for every detected fragment of the granulation pattern. Thus, with the properly chosen parameters, low frequencies are suppressed in the spatial spectrum, which leads to smoothing of the irradiance over the detector field of view, and high frequencies associated, in particular, with defects of the detector array are suppressed as well. Once these spectra are multiplied and the inverse Fourier transform is calculated, the maximum of the correlation function, attributed to the shift of the solar granulation pattern intensifies. The use of the movies allowed us to find certain criteria for selection of the parameters of the optimal amplification contour. The correctness of measurement of the image displacement by the modified correlation tracker (MCT) was checked by comparison with the displacement measured by the traditional correlation tracker (TCT). For this check, the image fragments, which are successfully processed by the traditional correlation tracker, were taken.The contrast of the spot was 21%. The rms deviations of the tracking signals measured by TCT are 0.723 arc sec (along the axis X) and 5.121 arc sec (along the axis Y), for MCT they are 0.720 arc sec and 5.119 arc sec, respectively. The movie was recoded on August 3 of 2004 at the strong wind. In the image jitter spectrum, a maximum at the frequency of 7.6 Hz, associated with the oscillations of the siderostat mirror about the fixation axis, was observed. During the realization, the contrast of the granulation pattern varied from 1.80 to 2.49% with the average value of 2.12%. For the traditional correlation tracker, the maxima of the mutual correlation function, associated with the static structure of the image and the moving one, have close values. The tracker either indicates “0” or tries to track the image motion. The mutual correlation function of MCT has a pronounced maximum, which shifts together with the image.The rms deviations of the tracking signals measured by MCT amount to 1.345 arc sec (along the axis X) and 4.495 arc sec (along the axis Y). The values obtained are in a good agreement with the corresponding values for the previous realization. The time interval between the realizations compared was 9 minutes. Hence of the modified correlation tracker algorithm permits the detection of displacements of low-contrast image fragments.

## THE LYOT PROJECT: CURRENT STATUS AND FIRST RESULTS

**Rémi Soummer et al.**
*American Museum of Natural History*

The Lyot project is a near-infrared coronagraph used at the Advanced Electro-Optical System at the Maui Space Surveilance System. The project consists of a survey of nearby stars for faint companions and disks. The coronagraph was designed and optimized to take advantage of the world's highest order astronomical adaptive optics system with 941 actuators, enabling near-IR observations at very high Strehl Ratios. Since first light in March 2004, a polarimetry mode was added in 2005. I will discuss the performance of the AO system and coronagraph, the dynamic range limitations, and present some results.

# Session 3:
# Infrared Interferometry
*Interférométrie infrarouge*

# GROUND-BASED OPTICAL INTERFEROMETRY: WHERE WE ARE TODAY

**Stephen T. Ridgway**
*NOAO*

More than three decades ago, the modern era of optical interferometric astronomy began with the first prototype arrays. Today, our communities are enjoying the fruits of sophisticated facility-class arrays incorporating, among other things, most of the worldźs largest telescopes, wavefront control systems, multi-beam combination, moveable telescopes and achieving direct resolutions of 1 milliarcsecond. Along the way, most or all of the essential technical problems of optical interferometry have been solved in at least one way and more elegant solutions continue to arrive. Interferometry stands poised to rewrite the text books of stellar astronomy and astrophysics. Let's reflect on the progress and enjoy the moment.

Notes

# PROTOPLANETARY WORLDS AT THE ASTRONOMICAL UNIT SCALE

**Jean-Philippe Berger**
*Laboratoire d'Astrophysique de Grenoble*

Optical interferometry has started to play a crucial role in the field of star formation. In particular, it offers a unique opportunity to observe protoplanetary disks at a spatial scale where planest may be forming. I will present a status of the most recent discoveries in this field putting the emphasis on the progress towards direct imaging of proto-planetary worlds at the astronomical unit scale.

Notes

# HOT CIRCUMSTELLAR MATERIAL IN VEGA'S INNER PLANETARY SYSTEM

**Olivier Absil(1), Emmanuel di Folco(2), Antoine Mérand(3), Vincent Coudé du Foresto(3), Jean-Charles Augereau(4), Jason P. Aufdenberg(5), Pierre Kervella(3), Stephen T. Ridgway(5), David H. Berger(6), Theo A. ten Brummelaar(7), Harold A. McAlister(8), Judit Sturmann(7), Lazslo Sturmann(7), and Nils H. Turner(7)**

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Using the FLUOR beam-combiner installed at the CHARA Array (Mt Wilson, CA), we have obtained high-precision visibility measurements of Vega, one of the prototypic debris-disk stars, known to be surrounded by large amounts of cold dust in a ring-like structure at 80-100 AU. The combination of short and long baselines has allowed us to separately resolve the stellar photosphere and the close environment of the star ($< 8$ AU). Our observations show a significant deficit in square visibility at short baselines with respect to the expected visibility of a simple uniform disk stellar model ($\Delta V^2 \simeq 2\%$), suggesting the presence of an extended source of emission around Vega. The sparse $(u, v)$ plane coverage does not allow for discriminating between a point source and an extended circumstellar emission as the origin of the extended emission. However, we show that the presence of a point-like source within the FLUOR field-of-view (1 arcsec in radius = 7.7 AU at the distance of Vega) is highly unlikely, and propose that the excess emission is most likely due to the presence of hot circumstellar dust in the inner part of Vega's debris disk, with a flux ratio of $1.29 \pm 0.19\%$ between the integrated dust emission and the stellar photosphere. Using this information together with archival photometric measurements in the near- and mid-infrared, we derive the expected physical properties of the circumstellar dust by modelling its infrared Spectral Energy Distribution. The inferred properties suggest that the Vega system could be currently undergoing major dynamical perturbations.

Notes

# LOOKING INTO THE HEART OF THE OUTBURSTING STAR V1647 ORI: FIRST AU-SCALE OBSERVATIONS WITH VLTI/MIDI

**Péter Ábrahám(1), László Mosoni(1), Thomas Henning(2), Ágnes Kóspál(1), Christoph Leinert(2), Attila Moór(1), Sascha P. Quanz(2), and Thorsten Ratzka(2)**
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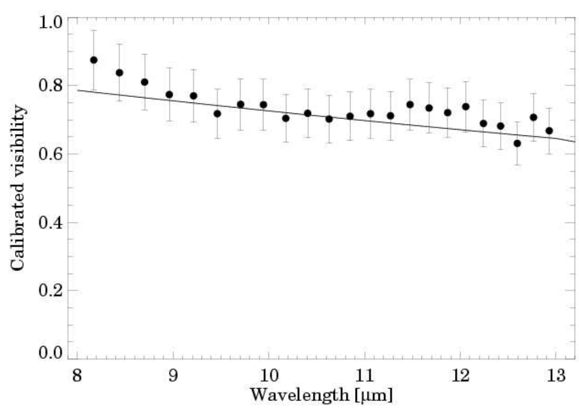
The young eruptive star V1647 Ori was observed with MIDI, the mid-infrared interferometric instrument at the Very Large Telescope Interferometer, on March 2, 2005. We present the first spectrally resolved interferometric visibility points for this object. Our results are summarised in the following.

1. The calibrated visibilities (see figure) show that the source is resolved by MIDI on the UT3-UT4 baseline. The visibility curve suggests a non-uniform temperature distribution of the emitting material. The size of the mid-infrared emitting region is ≈7 AU at 10 $\mu$m.

2. The $8 - 13\,\mu$m spectrum *i*) exhibit no obvious spectral features thus cannot support models consisting of optically thin components; *ii*) the source faded in the N-band significantly (compared to Andrews et al. 2004 ApJ 610, 45); *iii*) the correlated flux density, i.e. the emission of the innermost part of the circumstellar structure, contains $\approx$ 70% of the total mid-infrared flux density.

3. There are proposals in the literature that the FU Ori phenomenon is triggered by a close companion (e.g. Reipurth & Aspin 2004, ApJ 608, 65). A companion would cause sinusoidal variations in the spectrally resolved visibilities with appropriate baseline position angles. The shape of our visibility curve suggests that no companion is present at the measured position angle whose separation is less than 100 AU and brightness ratio is greater than 10%. Nor do the acquisition images show any companion. However, we can exclude the companion only along the measured baseline further observations will be needed to clarify the existence of a companion.

4. A simple disk model is able to fit both the spectral energy distribution and the observed visibility values simultaneously (solid line in figure). Model parameters for the disk were the following: $T(1\,\mathrm{AU}) = 680\,\mathrm{K}$ and $T{\sim}r^{-0.53}$, inner and outer disk radii $7R_{\odot}$ and $100\,\mathrm{AU}$, respectively, surface density $\Sigma{\sim}r^{-1.5}$, disk mass $M_d = 0.05\,\mathrm{M}_{\odot}$, inclination angle 60°.



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# THE GALACTIC CENTRE: FROM SINFONI TO GRAVITY

**Thibaut Paumard(1), Frank Eisenhauer(1), Reinhard Genzel(1,2), Sebastian Rabien(1), Stefan Gillessen(1), Fabrice Martins(1), Thomas Müller(3), Guy Perrin(4), Andreas Eckart(5), and Wolfgang Brandner(6)**
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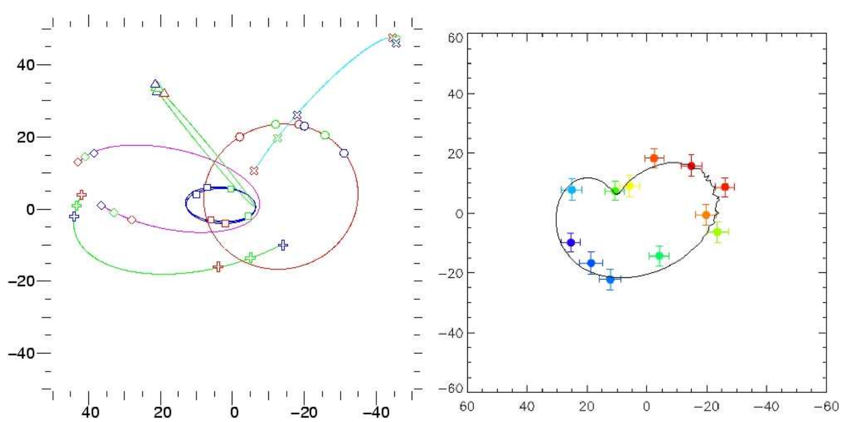
*(5) University of Cologne (Germany)*
*(6) MPIA (Heidelberg, Germany)*

The new infrared integral field spectrometer on the VLT, SINFONI, has allowed several breakthroughs in the Galactic Centre research. Among other results, it has enabled us to (1) detect for the first time OB main sequence stars that reside in two disks orbiting the supermassive Black Hole Sgr A* at the centre of the Milky Way galaxy; (2) obtain unambiguous Keplerian orbits for the S-stars, which orbit the black hole in the central arcsecond, reaching velocities of thousands of kilometres per second; and (3) determine the spectral energy distribution of the energetic outbursts (flares) of Sgr A*.

We want to thank Pierre Léna for his early involvement in the instrumental project that is the natural follow-up to SINFONI and will undoubtedly bring the next lot of breakthroughs: GRAVITY. The imaging capabilities of this second generation instrument for the Very Large Telescope Interferometer will give us the opportunity to trace the orbits of stars even closer to the black hole, for which relativistic precession will be detectable within a couple of orbital periods (of the order of one year!). Furthermore, this instrument will have an astrometric accuracy of 10 $\mu$as (microarcseconds), equivalent to the angular length of one Schwarzschild radius of the central black hole. By resolving the path of the centroid of Sgr A*'s flares, we will be able to probe the space-time close to the event horizon of the supermassive black hole.

*Left panel below:* simulation of 15 months of GRAVITY observations of the central 100 mas of the Galaxy. Several of the stars have completed at least one orbit and show detectable relativistic precession (axes are in milliarseconds). *Right panel:* we have modeled flares in Sgr A* as a hot spot on the innermost stable orbit of a Schwarzschild black hole, and simulated astrometric observations of the object. The complex structure of the apparent path of the centroid reveals relativistic effects (strong lensing, beaming...). Axes are in microarcseconds. Ten simulated flares co-added.



Notes

## INTERFEROMETRY WITH THE LARGE BINOCULAR TELESCOPE

**T. M. Herbst**
*Max Planck institute for Astronomy*

The Large Binocular Telescope will be a unique interferometric facility when it begins dual-beam operation in late 2007. The combination of two, 8.4 meter mirrors in a compact array provides enhanced sensitivity, spatial resolution, and the ability to perform true interferometric imaging. I will give an update on LBT progress and place it in the context of existing and planned interferometers. Two interferometric instruments are planned for the Large Binocular Telescope. A group based at the University of Arizona is building LBTI, a thermal infrared beam combiner. LBTI will initially concentrate on nulling observations of exo-zodiacal dust in candidate stellar systems for the Terrestrial Planet Finder Mission. The instrument is flexible, and will likely later incorporate imaging instruments. A second group, based in Germany and Italy, is building LINC-NIRVANA, a near-infrared, Fizeau-mode beam combiner with multi-conjugated adaptive optics (MCAO). Fizeau interferometry preserves phase information and allows true imagery over a large field of view, limited ultimately by the delivered field of the adaptive optics system. The combination of MCAO and state-of-the-art detector arrays will allow LINC-NIRVANA to deliver the ultimate in sensitivity, field of view, and spatial resolution.

Notes

## MATISSE - INTERFEROMETRIC IMAGING IN THE MID-INFRARED

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MATISSE, the Multi AperTure mid-Infrared SpectroScopic Experiment, is foreseen as a mid-infrared imaging spectro-interferometer combining up to four UT/AT beams at the VLTI. It will measure closure phase relations and thus offer an efficient capability for image reconstruction with the VLTI.

MATISSE will be the first instrument to allow imaging in the 8 - 13 micron wavelength range with a spatial resolution of up to 10 mas. This imaging capability will permit to extend the astrophysical potential of the VLTI by overcoming the ambiguities often existing in the interpretation of pure visibility measurements. We will present science programs for different classes of objects for which a qualitatively new level of understanding is predicted, based on previous indirect observational and theoretical constraints.

Notes

# 'OHANA

**G. Perrin**
*Observatoire de Paris / LESIA*

The 'OHANA project aims at combining the large telescopes of the Mauna Kea site into a large interferometer with a maximum baseline of 800 m. Infrared single-mode filbers are used to transport light from the telescope focus to the beamcombiner in the J, H and K bands. The astrophysical targets of 'OHANA are compact sources among which the central core of active galactic nuclei or the inner astronomical unit of young stellar objects. The purpose of 'OHANA is also to demonstrate the use of single-mode fibers to build large interferometers as a preliminary step towards post-VLTI interferometers. First fringes have been obtained using the two Keck telescopes with the 'OHANA system in 2005. This first result demonstrates that single-mode fibers can be used to propagate light from a telescope focus to a beam combiner in an astronomical environment. We discuss the lessons we have learned from this first experience and present the next steps for 'OHANA. We also discuss the prospects of using single-mode fibers in future kilometric baseline interferometers.

Notes

# PROSPECTS FOR AN EXTREMELY LARGE SYNTHESIS ARRAY

**Andreas Quirrenbach**
*Sterrewacht Leiden*

An Extremely Large Synthesis Array (ELSA) with 27 ten-meter telescopes and baseline lengths up to 10 km, operating in the visible and near-infrared, would provide completely new insight into many astrophysics phenomena. It could be used to obtain resolved images of nearby brown dwarfs which would reveal weather phenomena in their atmospheres, to give detailed pictures of stellar surfaces and interacting binaries, to study general-relativistic effects on the orbits of stars near the center of our Galaxy, to obtain "movies" of expanding supernovae, to image the broad-line regions of active galaxies, and to measure the geometry of the fireballs producing the afterglow of gamma-ray bursts.

Observations of faint objects will be possible by using an external reference star to co-phase the array. Telescopes with large diameters are essential to provide good sky coverage in this observing mode. The use of optical fibers for beam transport and delay compensation is highly desirable, as this eliminates the need for an expensive beam train with meter-sized optical elements, and a very large vacuum system.

Advances in telescope technology and fiber optics expected for the next decade may bring the cost of ELSA into a range that would be affordable for an international project. Key to reducing the cost of the telescopes will be the adaptation of mass-production techniques similar to those envisaged for extremely large monolithic telescopes.

Notes

## WILL EXOBIOLOGY OUT OF THE SOLAR SYSTEM STOP AFTER THE DARWIN MISSION?

**Marc Ollivier (1), Alain Léger (1), Pascal Bordé (2), and Bruno Chazelas (1)**
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*(2) Michelson Science Center, Pasadena, USA*

The DARWIN space mission aims at detecting the (possible) 1-10 Earth-mass planets around 200 to 300 nearby stars, and perform their thermal infrared spectroscopy. The goal is to determine their atmospheric composition. With a spectral resolution of the instrument ($\lambda/\Delta\lambda$) of about 50 and a signal to noise ratio varying from 5 to 20, the mission has 2 major objectives:
(1) Exoplanetology, with an attractive possibility of comparing the properties of these objets to those of the Solar System planets;
(2) Exobiology by the search for biosignatures that can reveal the presence of life similar to ours.

Even if one of the first objectives is to have the mission flying promptly, it makes sense thinking to the "After DARWIN", although the latter will probably be strongly determined by the (unexpected) discoveries of DARWIN. We will discuss the merits and technical requirements of the different possibilities , including:
(1) imaging these planets (e.g. mission such as "Exo Earth Imager";
(2) performing visible-Near IR spectroscopy;
(3) spectroscopy in the thermal IR at higher resolution, S/N and on a larger stellar sample ("Super DARWIN").

The ultimate goal of searching for indices of technological life will also be discussed.

Notes

## SPACE INTERFEROMETRY AND EXOPLANETS

**Malcolm Fridlund**
*Research and Scientific Support Department, European Space Agency*

One of the most promising technologies for discovering and studying nearby (< 30pc) Terrestrial exoplanets is nulling interferometry in the mid-infrared. This has been proposed by a number of researchers, dating back to the 1980;ties, and have now been studied technologically and scientifically since several years by the European Space Agency in the context of the Darwin mission study. Significant technology developments have been initiated in a number of critical techniques. Nevertheless, several problems remain to be overcome, relating mainly to the strict requirements on path compensation, thermal aspects due to the requirement that one need to operate in the mid-infrared in order to detect characteristic signatures of terrestrial type planets, and the significant level of complexity required by the mission as a whole. In this paper we discuss the current results in relation to the set of scientific goals that have been formulated in Europe for the topic of understanding the formation and evolution of planets like our own. Being one of the most ambitious undertakings of any space agency ever, one has to ask if there exist the possibility of dividing up the mission in steps, allowing significant simplifications and lowering of cost for each such step, while retaining for each one a compelling scientific case. Here we describe current investigations into this problem and outline the current level of understanding in this context and present possible scientific objectives for such a stepwise approach.

Notes

# TOMORROW OPTICAL INTERFEROMETRY: INSTRUMENTAL PROSPECTS AND ASTROPHYSICAL ISSUES

**Fabien Malbet**
*Laboratoire d'Astrophysique de Grenoble*

Interferometry has brought many new constraints in optical astronomy in the recent years. A major leap in this field is the opening of large interferometric facilities like the Very Large Telescope Interferometer and the Keck Interferometer to the astronomical community. By analysing the steps which led us to the current situation, we will present a view of what could be the future of interferometry in the short term and in the far future.

Notes

# INFRARED INTERFEROMETRIC GRAVITY DARKENING OBSERVATIONS OF VEGA WITH CHARA/FLUOR

**Jason P. Aufdenberg(1), Antoine Mérand(2), Vincent du Foresto(2), Olivier Absil (3), Emmanuel Di Folco(2), Pierre Kervella (2), Stephen T. Ridgway(1), David H. Berger(4), Theo A. ten Brummelaar(5), Hal A. McAlister(6), Judit Sturmann(5), Lazslo Sturmann(5), and Nils H. Turner(5)**

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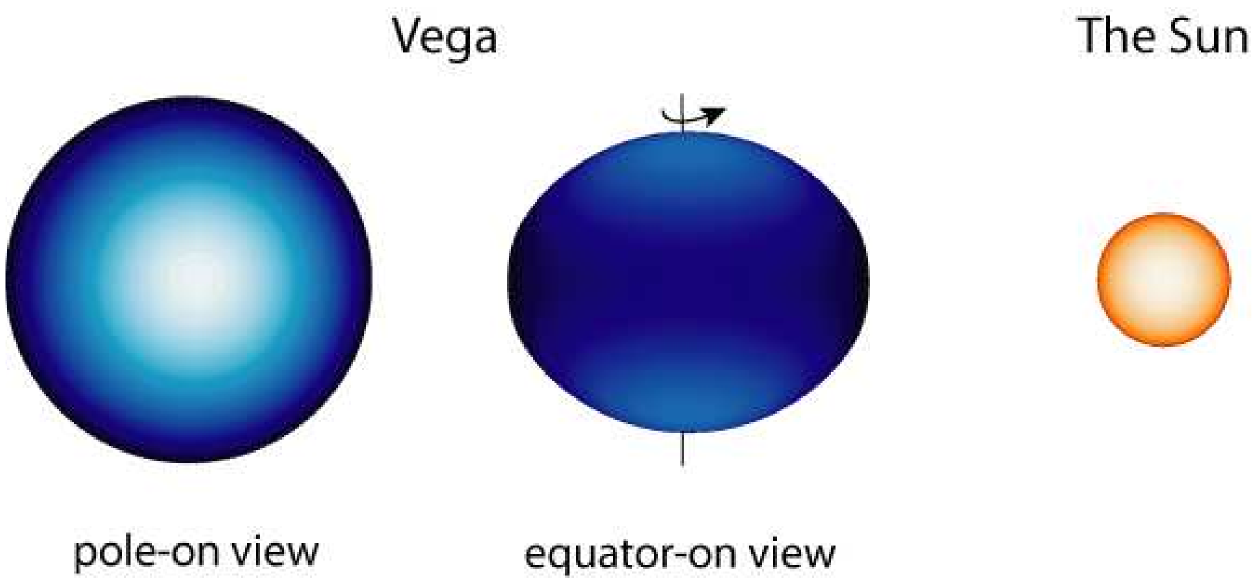
*(5)CHARA Array, Mt. Wilson Observatory*
*(6)CHARA, Georgia State University*

We have obtained high-precision interferometric measurements of the A0 V standard star Vega with the Center for High Angular Resolution Astronomy (CHARA) Array and the Fiber Linked Unit for Optical Recombination (FLUOR) beam combiner in the K' band at projected baselines between 103 m and 273 m. The measured squared visibility amplitudes beyond the first lobe are significantly weaker than expected for a slowly rotating star and provide strong evidence for the model of Vega as a rapidly rotating star viewed very nearly pole on. We have constructed a Roche-von Zeipel gravity-darkened model atmosphere which is in generally good agreement with both our interferometric data and archival spectrophotometry. Our model indicates Vega is rotating at ∼91% of its angular break-up rate with an equatorial velocity of ∼275 km s$^{-1}$. We find a polar effective temperature of ∼10150 K and a pole-to-equator effective temperature difference of ∼2300 K. Our model suggests that Vega's cool equatorial atmosphere may have significant convective flux and predicts a significantly cooler spectral energy distribution for Vega as seen by its surrounding debris disk.



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# NEW INTERFEROMETRIC RESULTS OBTAINED WITH MULTI-BEAM INTEGRATED OPTICS COMBINERS

**Myriam Benisty(1), Jean-Philippe Berger(1), Laurent Jocou(1), and Pierre Labeye(2)**
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Designing a performant second generation spectro-imaging instrument for the VLTI is challenging and several concepts have been proposed. During the past 10 years, the potential of integrated optics (IO) technology has been tested to replace the heart of an interferometric beam combiner. Studies of optimized IO optical schemes and complete characterizations of IO combiners have been made. It has been proved that it improves the quality of the interferometric measurements, by providing high stability and spatial filtering and that it highly simplifies a multi beam combination instrument. We report new interferometric measurements obtained with four-telescope IO combiners in the near infrared H band. We describe the combiners and their complete characterization through the analysis of polarisation properties, instrumental visibilities and sources of losses. These results demonstrate one more time that the IO technology is particularly well suited for interferometric combination of multiple beams.

Notes

# BRISE: A MULTI-PURPOSE BENCH FOR COPHASING SENSORS

**Frédéric Cassaing(1), Béatrice Sorrente(1), Laurent Mugnier(1), Gérard Rousset(1), Vincent Michau(1), Isabelle Mocoeur(1), and Fabien Baron(2)**
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The cophasing sensor (CS), which measures the disturbances between the sub-apertures of multiple-aperture telescopes, is a key component. As multiple-aperture telescopes become more ambitious, requirements for the CS become more demanding: low flux (for stellar interferometers), sub-nanometric accuracy (for interferometric nullers), image with very small contrast (for wide-field telescopes, such as spaceborne Earth imagers), larger number of beams (for all applications).

Focal-plane sensing is a solution to cope with all these requirements, with a very simple opto-mechanical setup. Two implementations have been investigated at ONERA: phase retrieval, using the sole focal-plane image, and phase diversity, based on the joint analysis of a focal and an extra-focal images. Phase diversity can measure any mode on any source, while phase retrieval is more suited to real-time piston/tip/tilt measurements on an unresolved (or partially resolved) source.

To evaluate accurately the performance of CS or other high-resolution devices, ONERA has built a multipurpose bench called BRISE (Banc Reconfigurable d'Imagerie sur Sources Etendues). BRISE mainly includes: a source module delivering an extended scene and a reference point source; the detection module recording the focal-plane image of each object and implementing a phase diversity sensor; the perturbation module focusing the source on the detector, defining the aperture configuration and introducing calibrated aberrations. Afocal input/output ports are used to interface with our Zygo interferometer or a visitor instrument. The MASTIC software (Multiple-Aperture Software for Telescope Imaging and Cophasing) is used to process or simulate BRISE data.

BRISE has already been (or will be) used for several applications:

- validation of a phase diversity sensor from the image of Earth scenes (French Defense);
- validation of a phase retrieval/diversity sensor for nulling, for ESA/Kayser-Threde (cf companion paper "DARWIN fringe sensor: experimental results on the BRISE bench") or PEGASE (CNES);
- generation of distorded wavefronts for a fiber-coupling demonstrator (ESA/KONGSBERG)

This talk describes the bench, the main experiments carried out on BRISE, and reports main results such as nanometric accuracy. This shows that simple solutions based on focal-plane devices can cophase multiple-aperture optical telescope with challenging requirements.

Notes

# OPTICAL VERY LONG BASELINE INTERFEROMETRY: THE QUEST FOR NANO-ARCSEC RESOLUTION IN ASTRONOMY

**Hans Ulrich Käufl and Andreas Glindemann**
*European Southern Observatory D-85748 Garching b. München, Germany*

A new generation of frequency standards based on the principle of the "*Frequency Comb*" will soon be readily available for field-use. With such a frequency standard $CO_2$ or $NH_3$-lasers operating in the astronomical N-band ($8\mu m \leq \lambda \leq 13\mu m$) can be frequency and phase stabilized with unprecendented precision. Heterodyne receivers based on such lasers as local oscillators have been used for more than 2 decades in astronomy.

We describe at the conceptual design level a Very-Long-Baseline Interferometer working at $\lambda \approx 10\mu m$. Data reduction (correlation, phase-closure and image reconstruction) could be based either on micro-wave links or on the European VLBI Network (EVN) and the Joint Institute for VLBI in Europe (JIVE) in Dwingeloo. Extrapolating the demonstrated performance of the *ISI*-interferometer (e.g. Hale et al. APJ **537** p. 998, 2000) to 8m-class telescopes we discuss the realisation and sensitivity of a VLBI network. Basically such a system could have a sensitivity of few Jansky per resolution element. The spatial resolution could approach 100 nano-arcsec, if a link between telescopes in Chile and Hawaii is considered. Science cases for such a system, ranging from AGB-star imaging to AGN-research will be elaborated. In a similar sense propagation effects limiting the spatial resolution in radio-VLBI will be discussed and scaled for infrared VLBI.

Notes

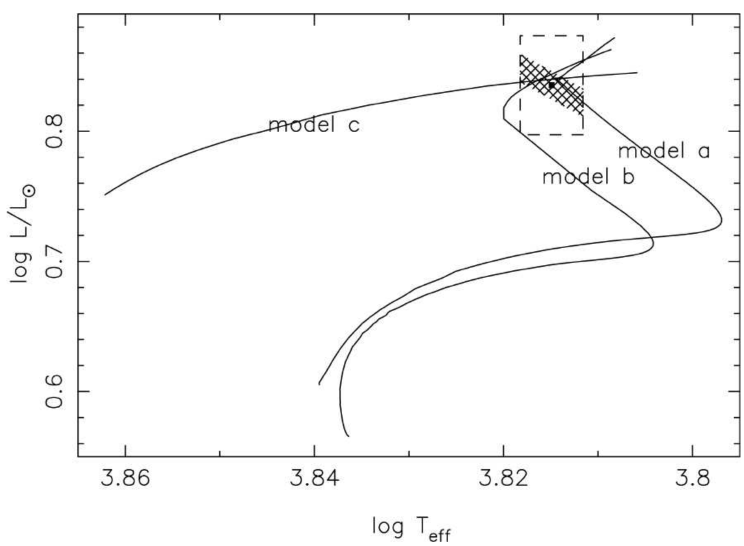
# INTERFEROMETRY AND ASTEROSEISMOLOGY OF MAIN SEQUENCE STARS

**Pierre Kervella**
*LESIA, Observatoire de Paris*

The interferometric measurement of the angular diameter of a number of nearby main sequence (MS) stars with the VLTI Test Instrument VINCI has allowed to retrieve their linear radii within 1-2% or better, thanks to their accurate Hipparcos parallaxes.

For several stars ($\alpha$ Cen A & B, Procyon A, $\delta$ Eri, $\xi$ Hya, $\eta$ Boo), asteroseismic oscillation frequencies are also available, in addition to the classical photometric and spectrographic observations. The combination of these data allows to constrain precisely the evolutionary status of each star (mass, internal structure and age). The figure below shows a comparison of different evolutionary tracks for Procyon A in the HR diagram. The interferometric measurement reduces significantly the classical error domain (rectangular box) to the shaded parallelogram. Model $a$ fits the observed large frequency spacing the best. It corresponds to a mass of $1.42\,M_\odot$ and an age of 2.3 Gyr.

High accuracy interferometric measurements from the VLTI combined with SIM or GAIA parallaxes will enable a great improvement of our understanding of the internal structure and evolution of MS stars. I will give a panorama of the nearby MS stars whose diameter is already within reach of such measurements with the VLTI.



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# INTEGRATED OPTICS FOR MID-INFRARED NULLING INTERFEROMETRY: STATUS AND PERSPECTIVES

**Lucas Labadie (1,2), Pierre Kern(1), Laetitia Abel-Tiberini(1), Brahim Arezki(1), Marc Barillot(5), Jean-Emmanuel Broquin(4), Alain Delboulbe(1), Pierre Labeye(3), Annie Pradel(6), Cyril Ruilier(5), Pierre Saguet(4), Caroline Vigreux(6), and Volker Kirschner(7)**

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*(2) Max-Planck Institut fur Astronomie*
*(3) Commissariat a l'Energie Atomique*
*(4) Institut de Microelectronique et Photonique de Grenoble*
*(5) Alcatel Alenia Space*
*(6) Laboratoire de Physico-Chimie des Materiaux de Montpellier*
*(7) Agence Spatiale Europeenne*

This paper presents the results obtained for the extension to the thermal infrared of the Integrated Optics (IO) concept in preparation of ESA's space interferometer Darwin. This mission is devoted to the detection and characterization in the spectral range 6 - 20 ţm of earth-like planets orbiting solar-type stars. Since high dynamic range is required - typically 1:1e5 rejection ratio - wavefront modal filtering is mandatory. This cuold be achieved in the future with currently developed mid-infrared integrated optics. An IO component could also support various optical functions, and is thus likely to relax instrumental constraints. This paper addresses the manufacturing process and the characterization test results of newly developed IO device based on dielectric chalcogenide glasses and hollow metallic waveguides (HMW). In a first phase, the pre-selected technologies were validated and modal behaviour of the manufactured devices was demonstrated through polarization analysis. Preliminary nulling ratios higher than 1000 have been obtained with an IO modal filter at 10 microns. The methods used to validate the waveguide modal behaviour as well as implemented improvements are also discussed. After achieving 1:1e5 polychromatic extinctions with similar solutions in the near IR, the presented results further underline the credibility of a mid-infrared IO concept for Darwin.

Notes

# IMAGING MIRA STARS

**S. Lacour(1), G. Perrin(1), X. Haubois(1), S. Meimon(2), J. Woillez (3), P. A. Schuller(4), and S. T. Ridgway(5)**

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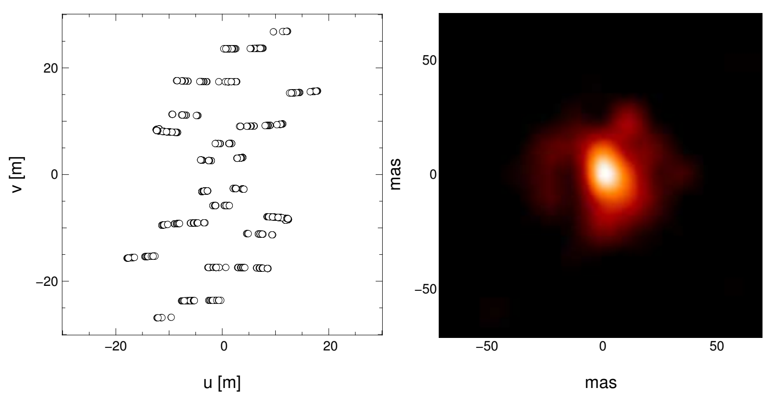
Interferometric data of Mira type stars in the near-infrared have already produce radial visibility curves with a shape far from the simple limb darkening profile. The measured visibilities as a function of wavelength revealed the presence in K band of a close ( at a $\sim$ 1 stellar radius distance above the photosphere ) molecular layer. However, thanks to the phase closure and telescope mobility of the *IOTA* interferometer, we have now access to the two dimensional complex visibility profile. We will present the u-v plane of two Mira stars (including Mira), and we will discuss the problems and advantages of analyzing complex objects either in the Fourier domain or in the reconstructed image.

The following figure shows the u-v coverage and the reconstructed image of Mira. These H band data required ten nights of observation at the *IOTA* interferometer in October 2005.



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# DARWIN FRINGE SENSOR: EXPERIMENTAL RESULTS ON THE BRISE BENCH

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Nulling interferometers require a very accurate control of the optical paths. For DARWIN, requirements are real-time piston/tip/tilt sub-nanometric correction and measurement of higher order modes with a 10 nm accuracy.

A study was performed to identify the best cophasing sensor for DARWIN, taking into account the large number of beams (6 initially) and Zernike modes (1 to 11). The selected solution is based on focal-plane sensing, allowing the combination of all the beams and the measurement of all the modes of interest in a single frame with a simple opto-mechanical device. For piston/tip/tilt, wave-front estimation is based on "Phase Retrieval", using the sole focal-plane image, whereas "Phase Diversity", based on the joint analysis of a focal and an extra-focal images, allows the measurement of higer order modes. A breadboard "DWARF" (DarWin AstRonomical Fringe sensor) was manufactured by Kayser-Threde and used at ONERA to validate experimentally this concept with three beams, using the ONERA laboratory test bench BRISE (cf companion paper: BRISE: a multipupose bench for cophasing sensors). New algorithms were also developped and gathered in the stand-alone tool MASTIC (Multiple-Aperture Software for Telescope Imaging and Cophasing).

We present here the selected concept and algorithms. Experimental results, which confirm the correct behaviour of the algorithms, are reported. Sub-nanometric repeatability is demonstrated for piston/tip/tilt up to magnitude 12 and a 10 nanometer error is obtained for high-order modes. These results confirms the validity of focal-plane sensors for the cophasing of multiple-aperture telescopes.

Notes

# MID-INFRARED INTERFEROMETRIC OBSERVATIONS OF THE NUCLEUS OF NGC 1068

**Anne Poncelet(1,2), Guy Perrin(2), Helene Sol(1), Coralie Doucet(3), and Pierre-Olivier Lagage(3)**

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NGC 1068 is one of the brightest and nearest Seyfert 2 galaxy, therefore it is unique for the study of the active galactic nucleus (AGN) it harbors. The MIR contribution of the AGN is thought to originate from the reradiation by dust of the UV emission coming from the central engine.

Here we present a new analysis of the first mid-infrared (MIR) $N$-band high-resolution interferometric observations of this AGN, obtained with MIDI (Mid-InfraReD Interferometer) of the VLTI. The resolution of 10 mas, never achieved in this band with an other technique, should allow from now on the MIR observations of the distribution of dust in the inner part of bright AGNs.

Both visibility measurements and MIDI spectrum obtained on NGC 1068 are well reproduced with a simple radiative transfer model with two concentric spherical components. A detailed $\chi^2$ analysis led to angular sizes and temperatures of respectively $\sim$ 35 and 83 mas, and $\sim$ 361 K and 226 K for the two components. Some other evidences strongly support such low temperatures. This modeling also provides the variation of optical depth as a function of wavelength for the extended component across the $N$-band pointing towards the presence of amorphous silicate grains. This provides the confirmation that MIDI actually carried out the first direct observations of the distribution of dust around the compact core of an AGN.

Besides, configurations of telescopes at VLTI do not allow to reach low spatial frequency. These points are however of first importance in order to put strong additional constrains on the modeling. Therefore, we used VISIR (the VLT Imager Spectrometer in the Infra-Red) images of the core of NGC 1068 obtained in january 2005 at 12.8 $\mu$m to derived visibility points from 0 to 8.2 m of baseline. Visibilities then derived show interesting features that will have to be taken into account in the modeling of interferometric data obtained with MIDI. These images are also important to make the link between the dust distribution around the nucleus and larger scales, a further step that is mandatory to get a global understanding of the sources of MIR emission in AGNs.

Notes

# MULTI-AXIAL NULLING INTERFEROMETRY: DEMONSTRATION OF DEEP NULLING AND INVESTIGATIONS OF POLARIZATION EFFECTS.

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A major goal of the ESA Darwin mission is to provide data in the infrared from which it will be possible to evaluate evidence of life. After observations aiming at detecting planets around stars, spectroscopic observations will try to put in evidence presence of spectral lines of chemical elements considered as reliable indicators of life. Nulling interferometry is the technique chosen for that purpose. The Darwin mission requires stable starlight rejection to an efficiency around $10^6$ over the whole spectral band. MAI$^2$ (Multi Aperture Imaging Interferometer) is a nulling laboratory breadboard developed by Alcatel Alenia Space in the frame of technical developments funded by ESA for Darwin. Deep extinction ratio capability has already been reported with this bench in single-polarized and mono-chromatic conditions using coaxial integrated optics beam combination. In this paper we report on the experimental verification of deep nulling based on multiaxial beam combination on MAI$^2$, for which the breadboard was modified and optimized. Nulling depth results at the $10^5$ level using a polychromatic source ($\Delta\lambda/\lambda \sim 5\%$) are presented with both the coaxial and multi-axial beam combination schemes. Rejection ratios but also stability have been greatly improved with respect to the former configuration of the bench. Furthermore, this bench enabled us to investigate the coupling into the modal filter in the multiaxial beam combination configuration, in the frame of the Fibre Optic Wavefront Filtering (FOWF) technological activity led by Kongsberg under ESA contract 18772. Particular efforts were made at the polarization level. Results are discussed in this paper. Finally we briefly present the next experimental steps involving MAI$^2$.

Notes

# USING ADAPTIVE OPTICS AND LONG BASELINE INTERFEROMETRY TO STUDY COMPLEX DUSTY OBJECTS

**Olivier Chesneau et al.**
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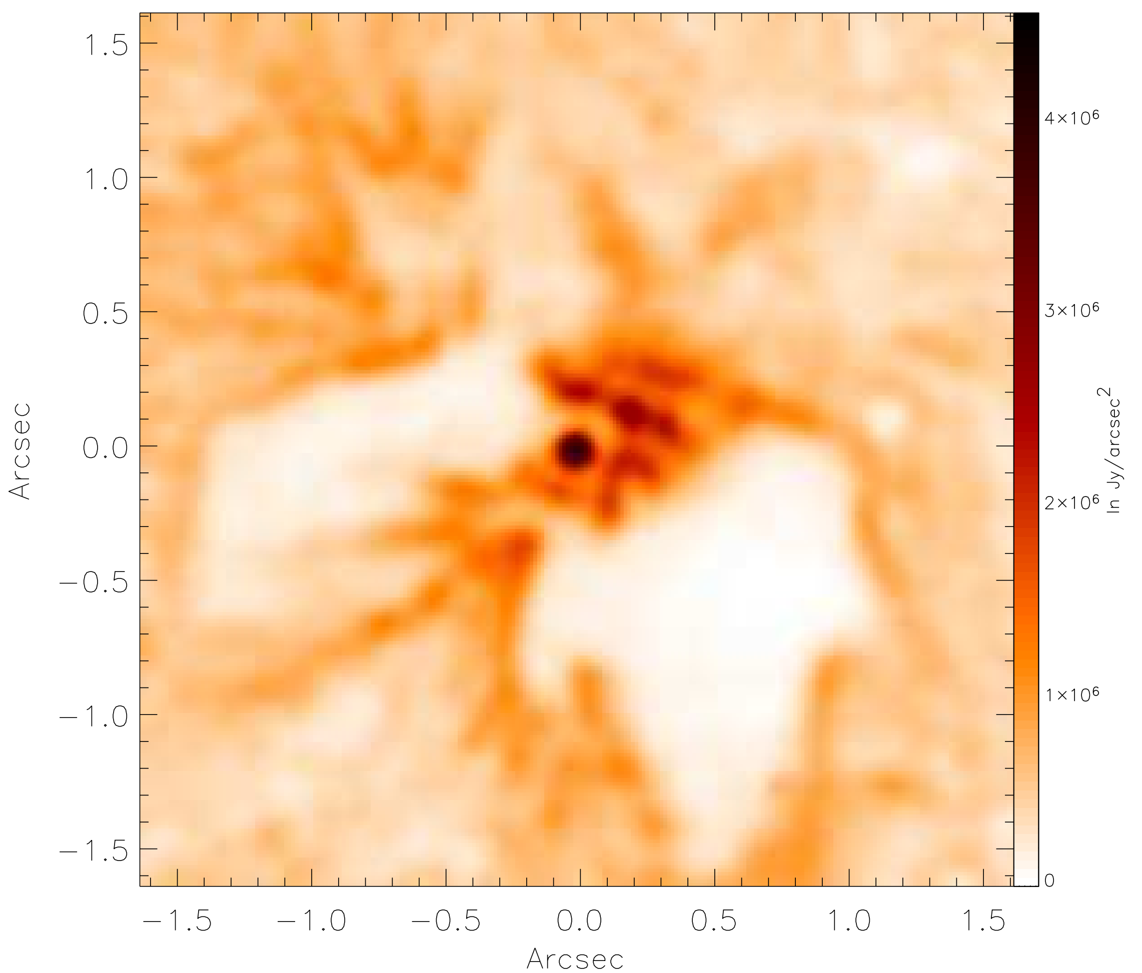
Combining MIDI and NACO observation in thermal infrared allows to obtain high spatial resolution observations of dusty environments. The typical resolution of NACO in L' band is about 100mas and the strehl ratio provided by the AO allows to reach a resolving power up to 40-60mas using deconvolution techniques. MIDI used with UTs provides acquisition images improved by the MACAO AO system with a typical resolution of 230mas at 8.7$\mu$m, that can also be increased up to 120-150mas. MIDI in interferometric mode, provides a typical resolution of 20mas, but usually only a handful of visibility measurements are recorded, limiting the complexity of the geometrical information extracted. Hence, the complementary use of NACO is well suited to observe complex extended objects. Several examples are shown: Eta Car, the AGB star RY Sgr and the planetary nebulae CPD-568032 and QX Pup.



## THE ANTARCTIC PLATEAU AS A SITE FOR A DARWIN GROUND-BASED PRECURSOR

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While DARWIN needs a ground based demonstrator, this preparatory mission is better carried out by an integrated experiment (optimized at the system level) than by an instrument constrained by an existing infrastructure. Because the quality of the site (seeing, emissivity) is the main contributing factor to an interferometer's performance, this experiment should be located on the best accessible site. We argue therefore that the ground based preparation to DARWIN should be carried out from the top of the ground turbulence layer on the Antarctic plateau. Simulations on a possible antarctic instrumental concept (ALADDIN) show that a pair of even relatively modest collectors (1 m) on a small baseline (up to 40 m) are sufficient to achieve a sensitivity (in terms of detectable zodi levels) which is about twice better than that of a nulling instrument on a large interferometer (such as GENIE at the VLTI), and to reach the 20-zodi threshold value identified to carry out the DARWIN precursor science.

# PRIMA FOR THE VLTI: SCIENTIFIC GOALS AND TECHNICAL STATUS

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The various sub-systems of PRIMA, the Phase-Referenced Imaging and Micro-arcsecond Astrometric facility for the Very Large Telescope Interferometer, are nearly completed and are in the process of being tested individually and as a full system. The VLTI is being prepared to receive this important enhancement in 2007. We hope to offer this facility to the community in 2008. The various scientific objectives of PRIMA will be recalled. Faint object imaging with an increase of the VLTI limiting magnitude by several magnitudes should be possible if a proper bright reference source can be found close by, increasing signitifcantly the number of extra-galactic targets accessible to the VLTI. Differential phase (with respect to a reference object) will also give additional imaging information on circum-stellar matter, galaxy dust tori, PRIMA being complementary to the phase-closure technique. Finally, narrow angle astrometry will be possible with a very high accuracy allowing studies of extra-solar planets and micro-gravitational lensing among others. The status of the various sub-systems as well as the results of their tests will be presented. The global performances that we hope to reach with PRIMA in Paranal will be extrapolated.

# HETERODYNE INTERFEROMETRY WITH A FREQUENCY COMB - THE CORNERSTONE OF OPTICAL VERY LONG BASELINE INTERFEROMETRY?

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Over the last decade astronomical observations with interferometers have come of age producing a number of very interesting scientific results notably with the VLTI. As envisioned in 1983 (P. Léna, ESO Conf Proc 17, 129-140, 1983), Michelson/Fizeau amplitude interferometry prevailed over intensity and heterodyne interferometry and provided the majority of scientific results. Intensity interferometry suffers from the lack of phase information and a low sensitivity, and heterodyne interfermetry combines a modest sensitivity with a limitation to basically the N-band.

Here, we present a concept for the enhancement of heterodyne interferometry taking advantage of the frequency comb recently decorated with the Nobel Prize. The frequency comb, locked to a suitable atomic transition, allows stabilizing lasers to typically $10^{-17}$ surpassing the presently best such systems based on Cesium fountains. This in turn will allow to stabilize the local oscillators in astronomical heterodyne receivers absolutely to a few times $10^{-4}$ Hz. Two identical such systems in different observatories will have a mutual phase drift of less than 5 degree per minute. Thus, independent frequency combs at different observatories can be used to stabilize $CO_2$-lasers as local oscillators to port the idea of Very Long Baseline Interferometry (VLBI) from the radio/submm domain into the infrared regime. This could be the enabling technology for baselines beyond several 100 m up to many 100 km when a physical link between the telescope is close to impossible.

## GRAVITY, PROBING SPACE-TIME AND FAINT OBJECTS IN THE INFRARED

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We introduce a new infrared adaptive optics assisted multiple-beam instrument for the VLTI infrastructure. GRAVITY (standing for General Relativity Analysis via VLT InterferometrY) will allow simultaneous observations of two objects by phase-referenced interferometric imaging and narrow angle astrometry with a high sensitivity.

For those reasons, GRAVITY is particularly suited for observing various types of faint targets of deep interest in the near-infrared such as AGNs, starclusters, intermediate black holes, substellar objects, planets...

Precisely, one of the main goal of GRAVITY is to probe space time around the intermediate mass black hole at the center of our galaxy. We will able to detect relativistic effects at a few Schwarzschild radii of the center of the black hole thanks to an astrometric accuracy of 10 micro arcseconds.

We will present the instrumental concept of GRAVITY and discuss some of the future scientific prospects that it will offer.

## MATISSE, PERSPECTIVE OF IMAGING IN THE MID-INFRARED AT THE VLTI

**B. López, S. Lagarde and the all MATISSE consortium.**
*OCA*

MATISSE stands for Multi-AperTure mid-Infrared SpectroScopic Experiment. It is a project proposed in the frame of second generation VLTI instruments. MATISSE allows imaging interferometry based on simultaneous multi-band observations in the 3 to 26 $\mu$m wavelength range with 4 telescopes and 3 spectral resolutions (from 30 to 1000). Its scientific potential is both provided by a combination of imaging, spectroscopy and the use off all mid-infrared bands accessible at the VLTI..

MATISSE constitutes an evolution of the two-beam interferometric instrument MIDI by increasing the number of recombined beams up to four. MIDI is a very successful instrument which offers a perfect combination of spectral and angular resolution. New characteristics present in MATISSE will give access to the mapping and the distribution of the material (typically dust) in the circumstellar environments or in the tori of Active Galactic Nuclei by using a wide mid-infrared band coverage extended to L, M, N and Q spectral bands. The four beam combination of MATISSE provides an efficient UV-coverage (6 visibility points measured in one set instead of one) and will moreover allow measurement of 4 closure phase relations thus providing for the first time aperture synthesis images in the mid-infrared spectral regime.

The MATISSE instrument concept, its characteristics and performances will be described in this presentation.

# 10 MICRON INTERFEROMETRY OF THE DISK AND WIND OF THE MASSIVE YOUNG STAR MWC349A

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We present VLTI-MIDI (Mid-Infrared Interferometric Instrument) observations of MWC349A, which are a prime example of the power of combined spatial and spectral resolution for addressing complex astrophysical phenomena.

Previous observations of the peculiar emission line star MWC349A suggest that it is a young massive star in the short-lived phase of already having dissipated its parent cloud, but still being surrounded by the accretion disk, which is seen nearly edge-on. It is believed that the unique hydrogen recombination line maser / laser activity of MWC349A from mm to infrared wavelengths is also a consequence of this viewing angle.

We have taken 13 measurements with MIDI at the VLTI (Very Large Telescope Interferometer) in the GRISM mode covering the N band (8 to 13 microns) at a spectral resolution R=230. The wavelength dependence of the continuum visibility agrees with model calculations for circumstellar dust disks. In addition, the signatures of at least a dozen emission lines have been identified in the interferometric data.

We will present the analysis of visibility amplitudes as well as of differential phase data, and discuss the correction of the phases for instrumental effects and dispersion. The differential phases show changes at the position of emission lines, clearly indicative of an asymmetry between the emission line region and the region emitting the continuum flux. As one can measure these relative phases to an accuracy of a few degrees, we obtain information on spacial scales of order 100 microarcseconds, which corresponds to a fraction of an AU at the distance of MWC349A.

# INTERFEROMETRIC DETECTION OF AMORPHOUS ALUMINA GRAINS IN BETELGEUSE

**T. Verhoelst(1,2), L. Decin(1), R. Van Malderen(1), S. Hony(1), J. Cami(3), K. Eriksson(4), G. Perrin(2), P. Deroo(1), B. Vandenbussche(1), and L. B. F. M. Waters(1&5)**
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We present a study of the extended atmosphere of the late-type supergiant $\alpha$ Orionis. Infrared spectroscopy of red supergiants reveals strong molecular bands, some of which do not originate in the photosphere but in a cooler layer of molecular material above it. Lately, these layers have been spatially resolved by near and mid-IR interferometry. In this contribution, we try to reconcile the IR interferometric and ISO-SWS spectroscopic results on $\alpha$ Ori with a thorough modelling of the photosphere, molecular layer(s) and dust shell. From the ISO and near-IR interferometric observations, we find that $\alpha$ Ori has only a very low density water layer close above the photosphere. However, mid-IR interferometric observations and a narrow-slit N-band spectrum suggest much larger extra-photospheric opacity close to the photosphere at those wavelengths, even when taking into account the detached dust shell. We argue that this cannot be due to the water layer, and that another source of mid-IR opacity must be present. We show that this opacity source is probably neither molecular nor chromospheric. Rather, we present amorphous alumina ($Al_2O_3$) as the best candidate and discuss this hypothesis in the framework of dust-condensation scenarios.

# Session 4:
# Astrophysics, Science, Development and Education

*Astrophysique, Science, Développement et Éducation*

# 4.1. The tree of astronomy development

## PIERRE LENA AND THE DEVELOPMENT OF THE VLT

**L. Woltjer**

n/a

# TIME, VISION, EUROPE

**Jean-Pierre Swings**
*Université de Liège*

n/a

# LE HASARD ET LA NÉCESSITÉ

**François Roddier**

n/a

# L'OUVERTURE DU SPECTRE SOLAIRE (OU: DE VERSAILLES À BILDERBERG)

**Jean-Claude Pecker**
*Collège de France*

Au lendemain de la seconde guerre mondiale, le spectre *visible* du Soleil était bien exploré. On commençait à connaître aussi assez bien les domaines centimétrique et décimétrique. Mais du côté de l'UV, on était limité vers 300 nm; et dans l'infrarouge, on n'allait pas très loin non plus.

L'ère spatiale commençante permettait d'aborder (ce fut une importante partie du *"programme de Versailles"*) ces deux domaines à peine connus, avec une précision suffisante; pour l'infrarouge, il fallait surtout un beau ciel, et des détecteurs sensibles de la nouvelle génération, celle dont a pu disposer Pierre Léna, à Sacramento Peak, puis à Meudon et ailleurs.

Or, aux alentours de 4000-7000 K (photosphère), le maximum de la brillance du corps noir se situe dans le visible; comme de plus, l'opacité du gaz solaire est minimum dans le visible, on peut trouver en UV et en IR deux bandes d'opacité comparable; les données IR mesurent une température moyenne. En revanche les données UV doivent fournir une valeur plus proche des valeurs les plus élevées de la température des couches solaires responsables; la combinaison des deux groupes de données doit permettre l'étude du $\Delta T$ associé à la granulation solaire.

On aboutit ainsi, grâce à l'étendue du spectre, à un modèle solaire de l'atmosphère, le *"modèle de Bilderberg"*, qui marque un stade important dans l'édification d'une description précise de l'atmosphère du Soleil. Pierre Léna a contribué de façon majeure à cette étape essentielle.

# A STORY OF FILIATION

**Daniel Rouan**
*LESIA, Observatoire de Paris.*

How a coherent network of talentuous researchers built under the action of Pierre Léna will be shortly described.

# 4.2. Visions for vision

J.-A. Sahel
À QUOI BON VOIR LES PHOTORÉCEPTEURS DE LA RÉTINE ?
abstract no available

# OPHTHALMIC APPLICATIONS OF ADAPTIVE OPTICS

**Marie Glanc(1), Francois Lacombe(2), Laurent Vabre(1), and Caren Bellmann(3)**
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*3: Hopital des XV-XX, France*

The optical properties of the human eye are far from being perfect as time-depending aberrations degrade the performances of our optical system. The most uncomfortable visual defects for the patient can be –quite well– compensated by spectacles. However, the visual distortions (including those of higher orders) represent a severe limitation for in vivo retinal imaging, important for the diagnosis of numerous retinal diseases.

In the beginning of the 90th, the implementation of Adaptive Optics in telescope systems allowed the Astronomer to improve the image resolution of one order of magnitude in the observation of stars. The similar situation of Astronomer and Ophthalmologist (time varying aberrations, need for a 10-fold gain in resolution min.) has helped to raise the idea applying Adaptive Optics in the field of Ophthalmology.

Our Adaptive Optics 2D setup for ophthalmic imaging is currently under clinical evaluation at the 15/20 hospital. This system allows the Ophthalmologist to obtain high-resolution surface retinal images in healthy subjects and more recently as well in patients. The testing of a second prototype (3D) at the Paris Observatory will be finished in the near future. It will provide Ophthalmologists with surfacic and tomographic ultra high-resolution images of the retina in eyes for better understanding of underlying disease pathomechanisms and evaluation of novel treatment approaches.

# 4.3. Science and ethic

## DE LA SCIENCE À L'ÉTHIQUE, ET RETOUR

**Jean-Michel Besnier**
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n/a

# 4.4. Science and education

### LES SCIENTIFIQUES ONT-ILS UN RÔLE À JOUER DANS L'ENSEIGNEMENT SCOLAIRE ?

**Yves Quéré**
*Académie des Sciences*

n/a

## CONSTRUIRE UN ESPACE EUROPÉEN POUR L'ENSEIGNEMENT DES SCIENCES À L'ÉCOLE PRIMAIRE : QUAND L'ASTRONOMIE OUVRE LA VOIE.

**David B. Jasmin**

L'opération La main à la pâte (www.inrp.fr/lamap) vise à rénover et amplifier l'enseignement scientifique à l'école primaire en France, et à y contribuer dans de nombreux pays. Elle préconise à ce titre la mise en œuvre par les enseignants d'une démarche d'investigation associant exploration du monde, apprentissages scientifiques, expérimentation, maîtrise de la langue et argumentation, afin que chaque enfant approfondisse sa compréhension du monde qui l'entoure. Au cours des cinq dernières années, cette approche s'est propagée avec l'aide de la communauté scientifique dans plusieurs dizaines de pays donnant lieu à de nombreux échanges de pratiques et de ressources tant au niveau des écoles que des instances éducatives. Sous l'impulsion de Pierre Léna, des projets pédagogiques en Astronomie ont ouvert la voie à un travail collaboratif entre des classes de différents pays. Ces projets sont maintenant relayés, étayés et amplifiés par des programmes de coopération plus ambitieux à l'exemple de POLLEN qui vise à créer à l'horizon 2009 de villes pépinières de sciences dans 12 pays de l'Union. Au cours de mon intervention, je reviendrai sur la construction progressive de ce réseau international de rénovation de l'enseignement des sciences à l'école primaire en l'illustrant d'exemples qui touchent à la pratique de l'astronomie dès le plus jeune age.

# RÔLE DE LA COMMUNAUTÉ SCIENTIFIQUE DANS LE PROJET LA MAIN À LA PÂTE (RUKA U TESTU) EN SERBIE

**Stevan Jokic**
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La main à la pâte a été lancé en Serbie en 2001, à l'initiative de Stevan Jokic ( Vinca Institute et Société de physique serbe), est soutenu par le Ministère de l'éducation et du sport, le Ministère de sciences, technologie et développement, l'Institut de sciences nucléaires VINCA, Euroscience-section pour la Serbie et Montenegro, le Ministère des Affaires Etrangères Direction de la Coopération Culturelle et du Français et le service de Coopération et d'Action Culturelle de l'Ambassade de France à Belgrade dans le cadre de son programme d'aide à la publication, ainsi que un grand nombre de professeurs de l'université et chercheurs. Depuis 2003, le Ministère de l'éducation serbe a décidé d'introduire la Main à la Pâte - Découvrir le Monde comme une option dans les classes de première, deuxième et troisième primaire (équivalent en France aux classes :CP, CE1 et CE2). Monsieur Pierre Léna a été le premier qui nous a présenté l'idée de projet en Serbie.

## LA FILIÈRE DE L'ENSEIGNEMENT DE L'ASTRONOMIE EN ILE DE FRANCE (TBC)

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