

Un nouvel âge d'or de la radioastronomie au sol



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Onde lumineuse

- Onde e.m. transverse (\mathbf{E} , $\mathbf{B} \perp \mathbf{k}$) \rightarrow propagation en ligne droite à c dans le vide

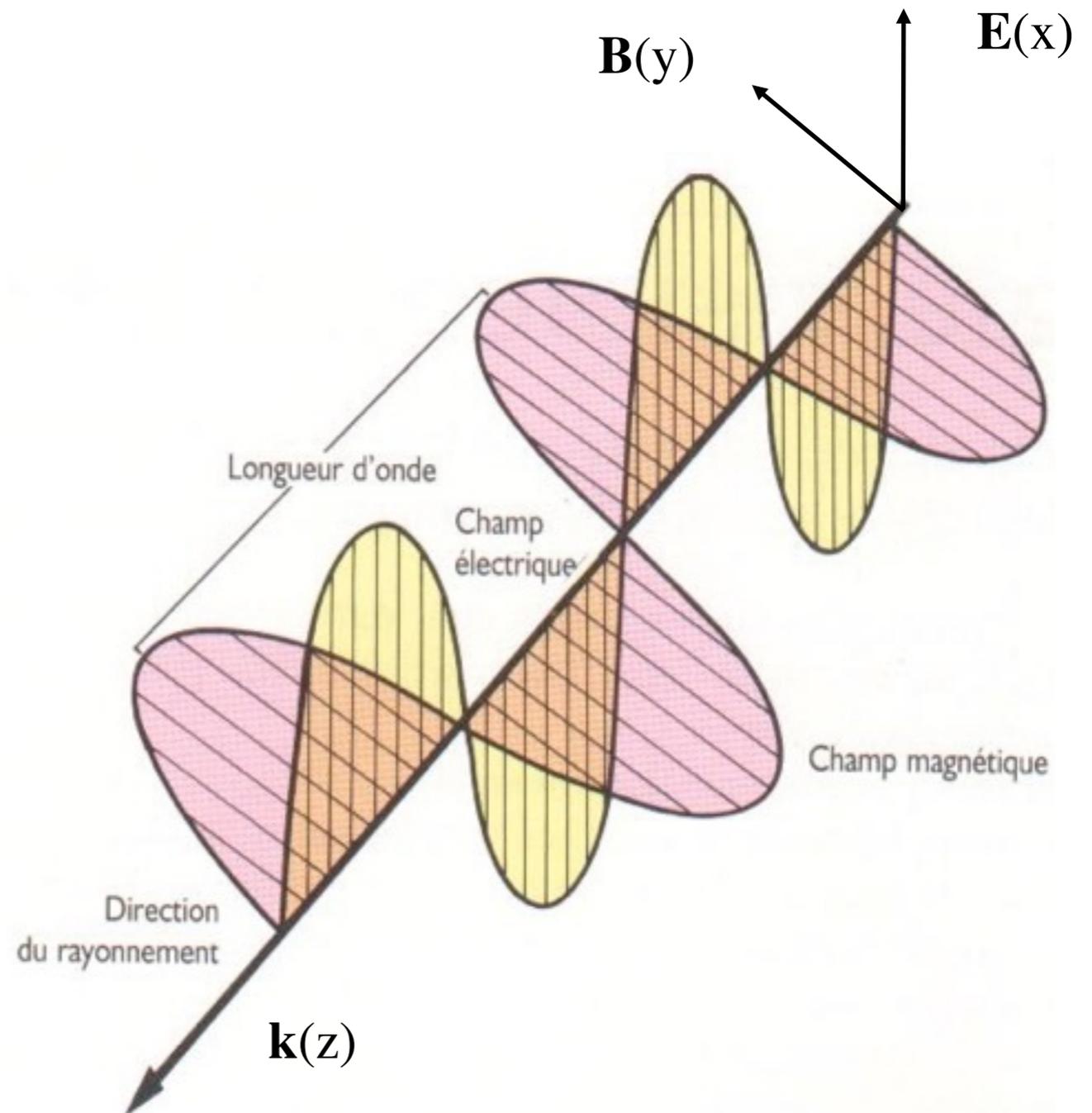
Longueur d'onde : λ [m]

Fréquence : ν [Hz] = $c / \lambda = 1 / T$

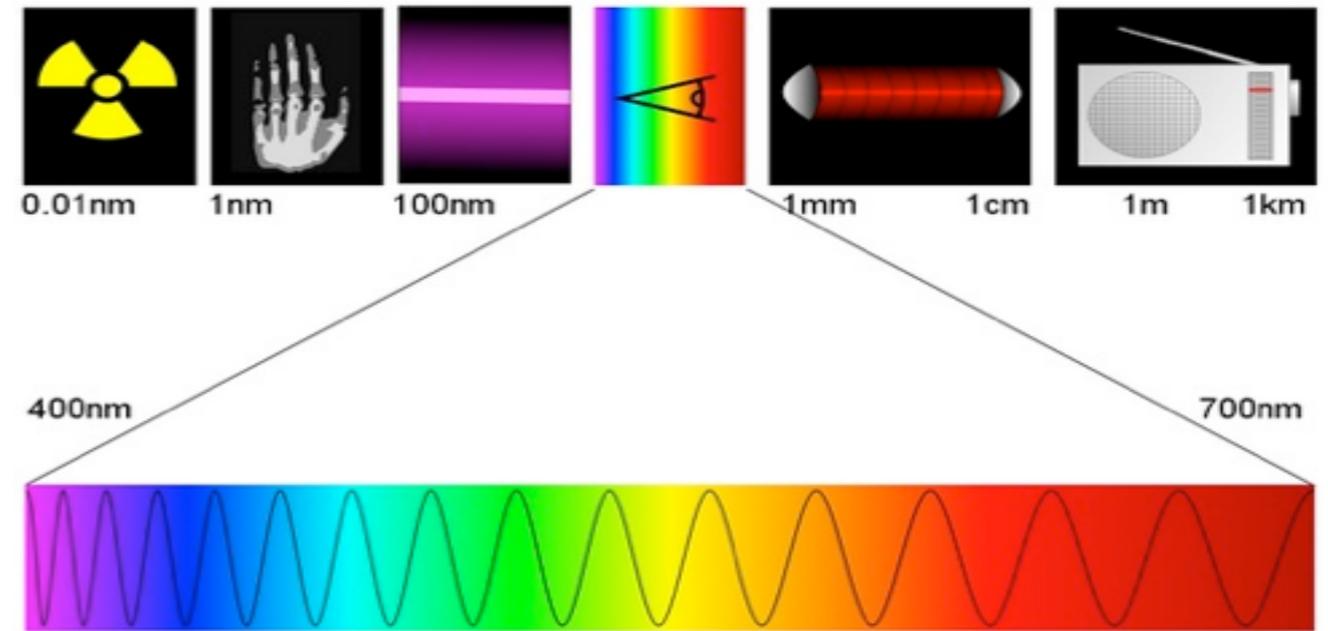
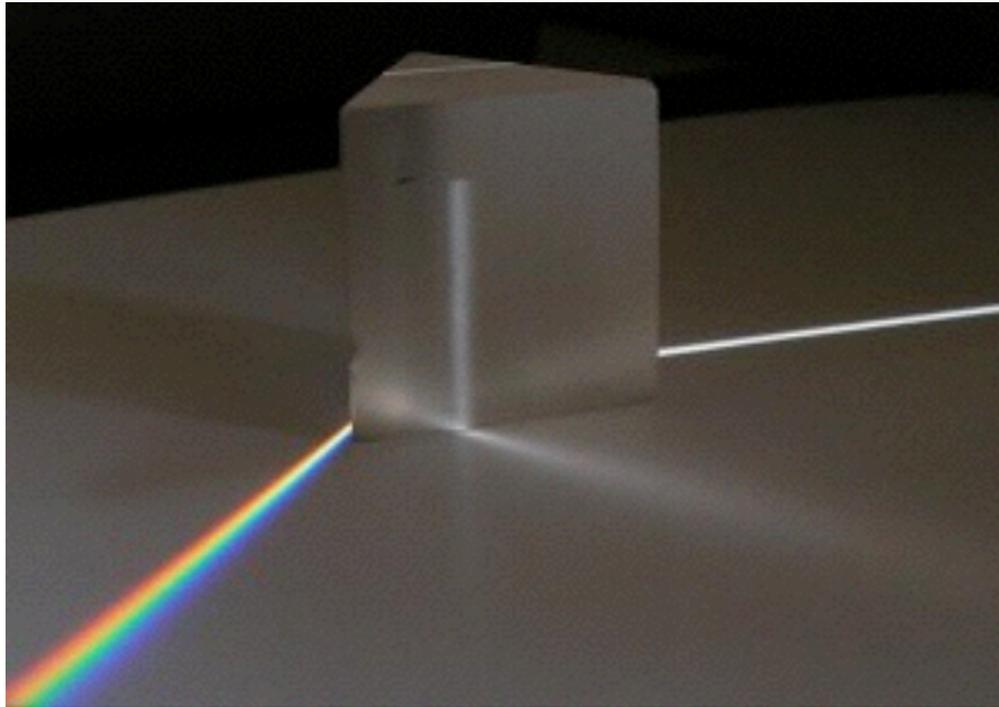
ν [MHz] = $300 / \lambda$ [m]

Energie : $E = h \nu$ [J]

Vecteur d'onde : $\mathbf{k} = 2\pi/\lambda$



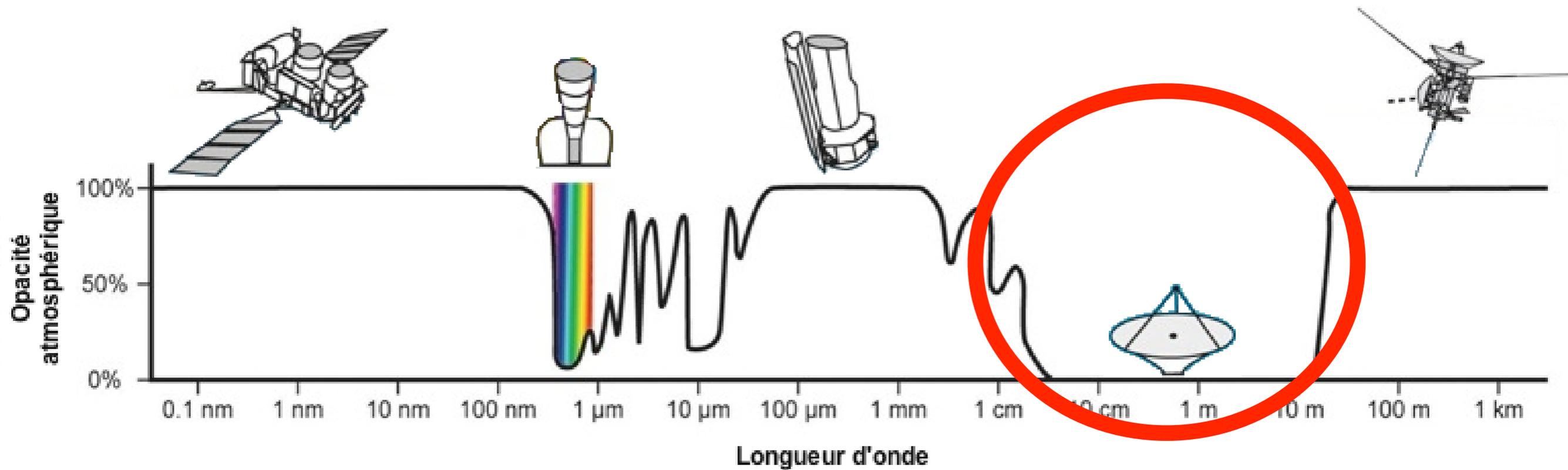
Spectre électromagnétique



Rayons gamma	Rayons X	UV	Infrarouge (IR)	Radars micro onde	Radio				
					FM	TV	SW	AM	
10^{-14}	10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	1	10^2	10^4
Longueur d'onde (en mètres)									



Transparence de l'atmosphère terrestre



+ détection cohérente (E)

→ Radioastronomie

Bandes de fréquences radio

Table of ITU Radio Bands

Band Number	Symbols	Frequency Range	Wavelength Range[†]
4	VLF	3 to 30 kHz	10 to 100 km
5	LF	30 to 300 kHz	1 to 10 km
6	MF	300 to 3000 kHz	100 to 1000 m
7	HF	3 to 30 MHz	10 to 100 m
8	VHF	30 to 300 MHz	1 to 10 m
9	UHF	300 to 3000 MHz	10 to 100 cm
10	SHF	3 to 30 GHz	1 to 10 cm
11	EHF	30 to 300 GHz	1 to 10 mm
12	THF	300 to 3000 GHz	0.1 to 1 mm

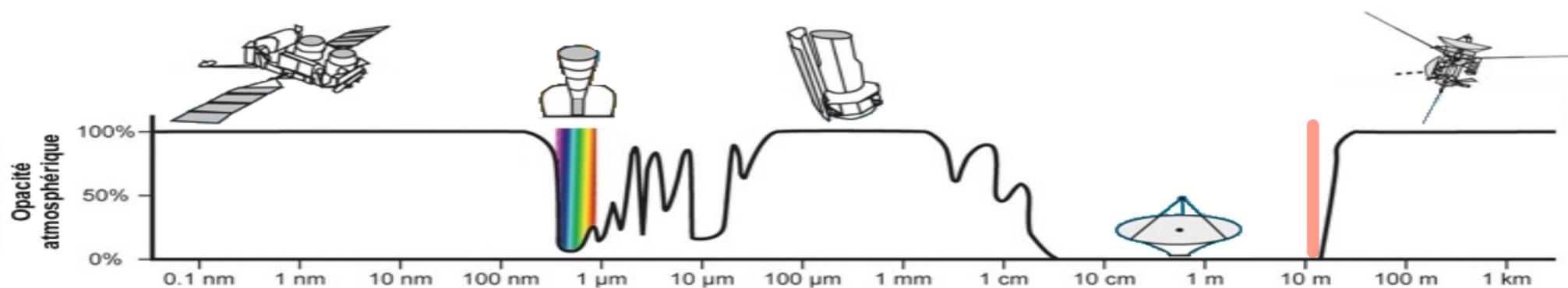
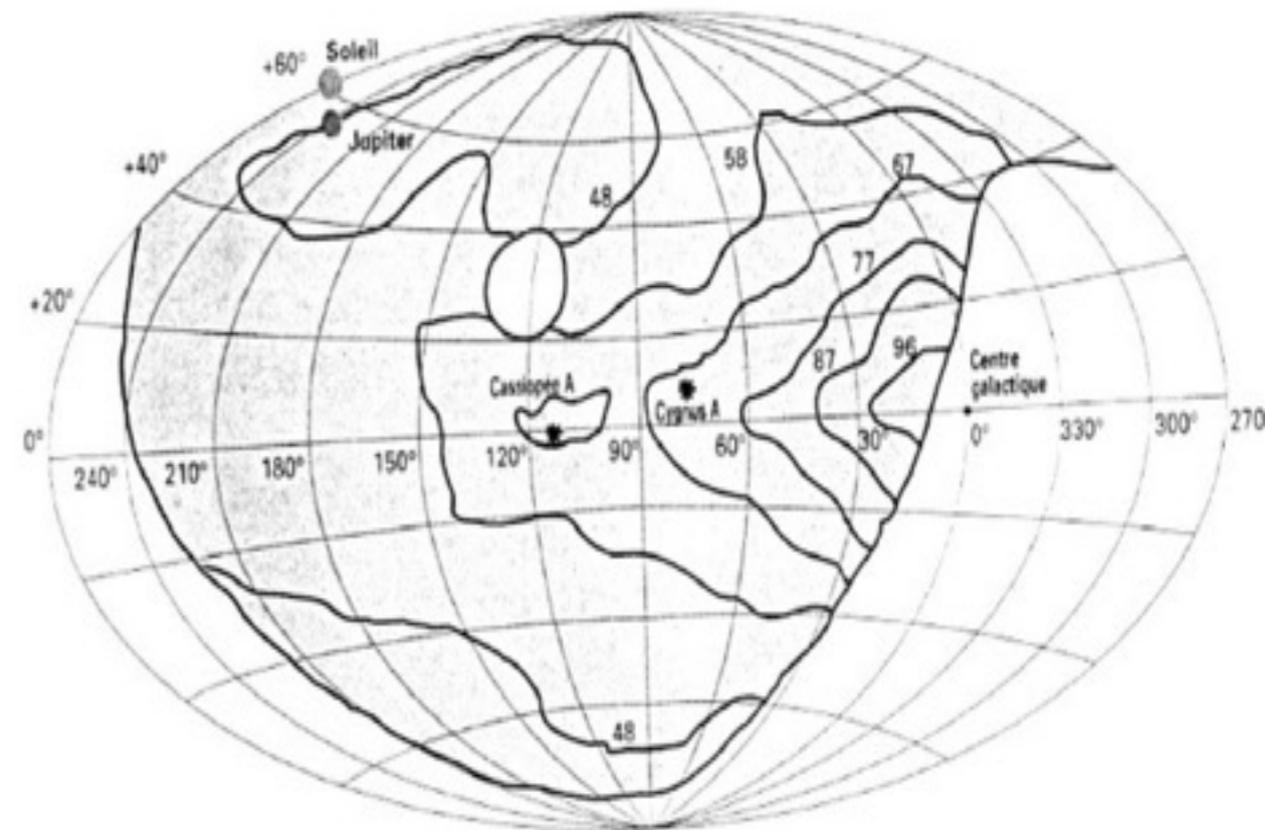
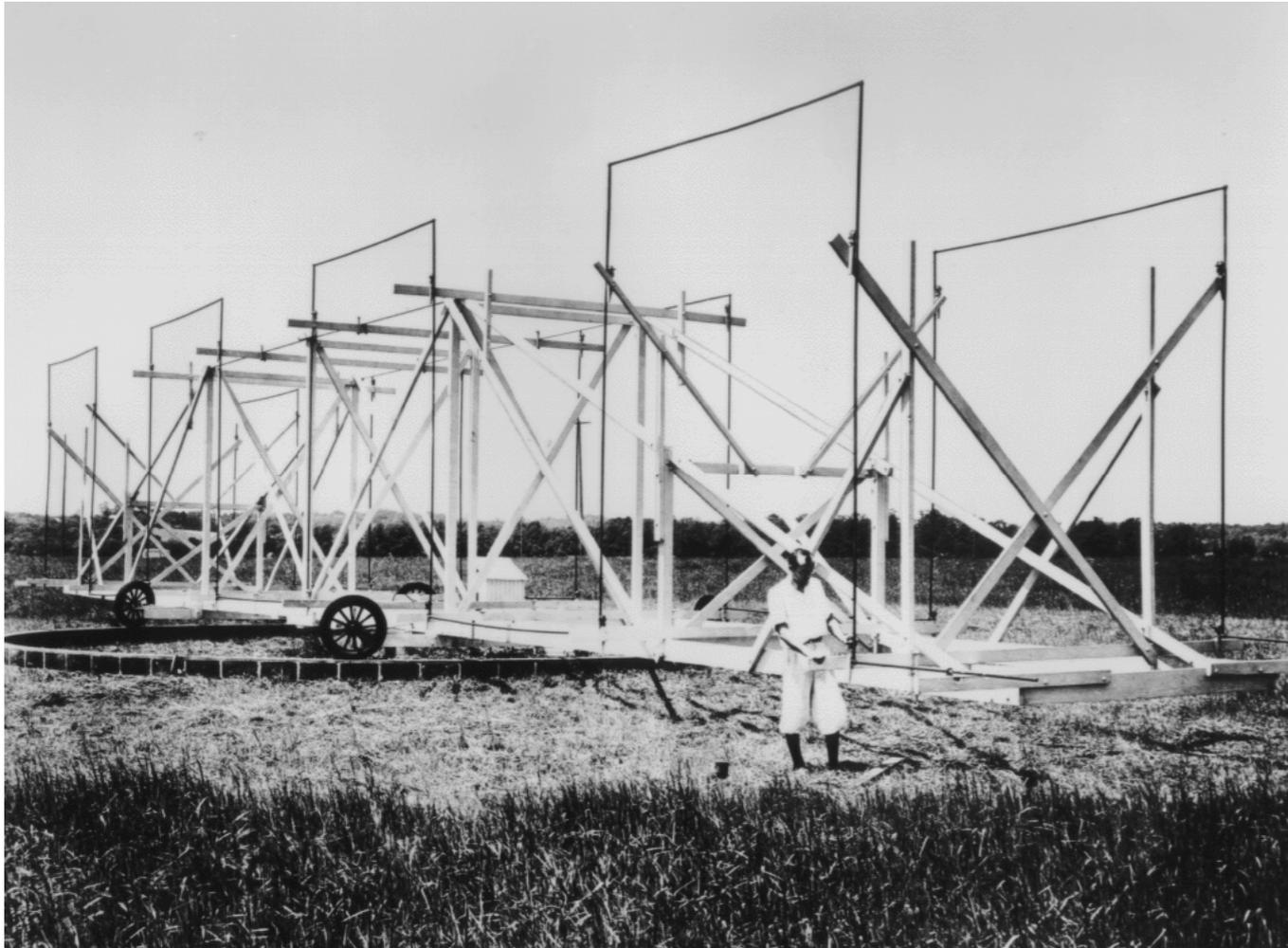
→ non utilisées en astronomie: HF \geq cm, LF \leq dm

Un peu d'Histoire et de Technique

Naissance de la Radioastronomie

1930-33 Naissance de la radioastronomie : $\nu = 20.55 \text{ MHz}$ ($\lambda = 14.6 \text{ m}$)
→ éclairs d'orages + émission du centre galactique (fixe en TS)

Karl Jansky



Ciel basses fréquences (BF) brillant

$$T(\text{K}) \sim 1.15 \times 10^8 / f^{2.5} \quad (f \sim 3 - 300 \text{ MHz})$$

f (MHz)	λ (m)	T (K)
1	300	$>10^7$
10	30	$\sim 3 \times 10^5$
100	3	$\sim 10^3$
1000	0.3	~ 5

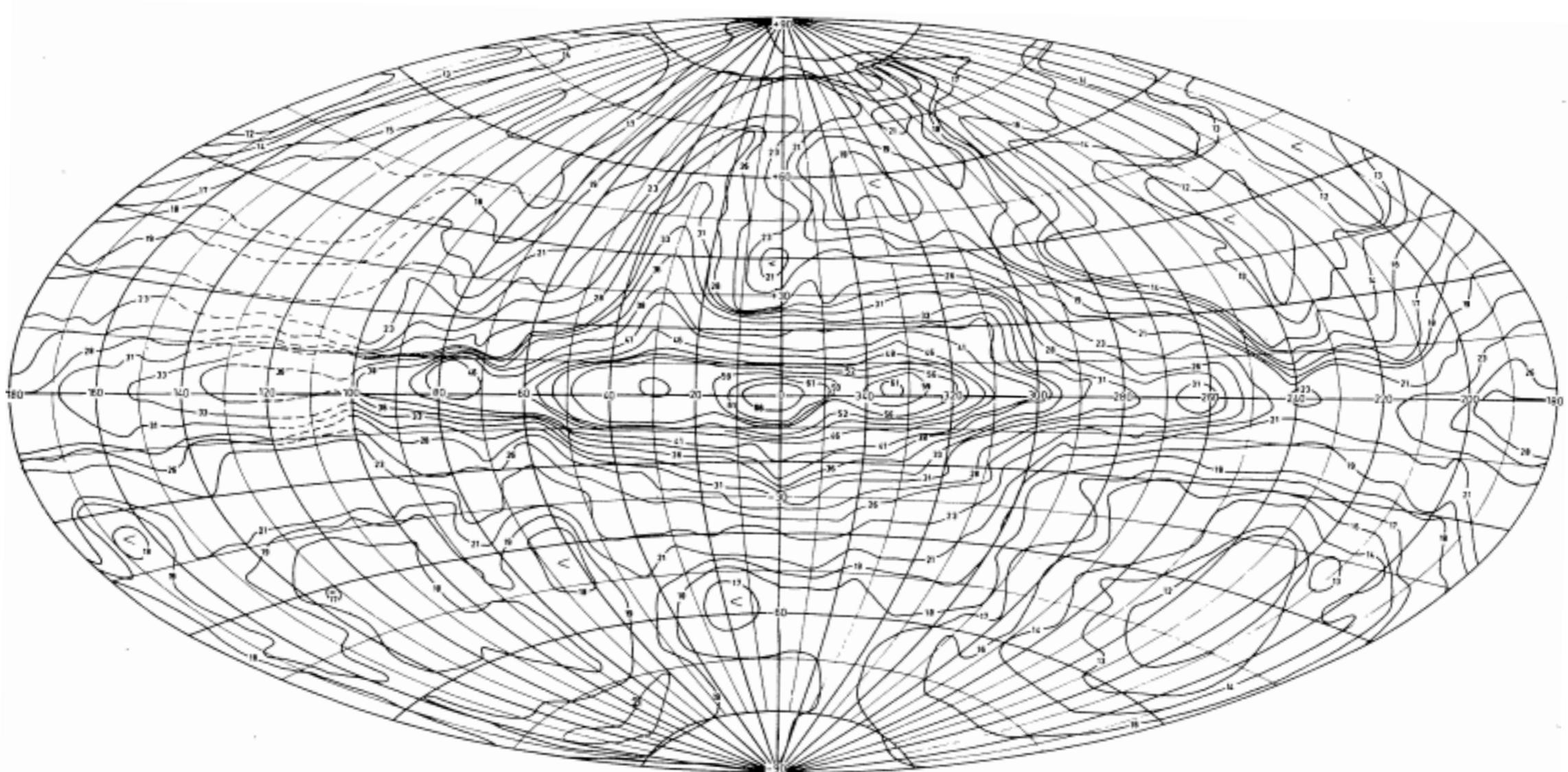
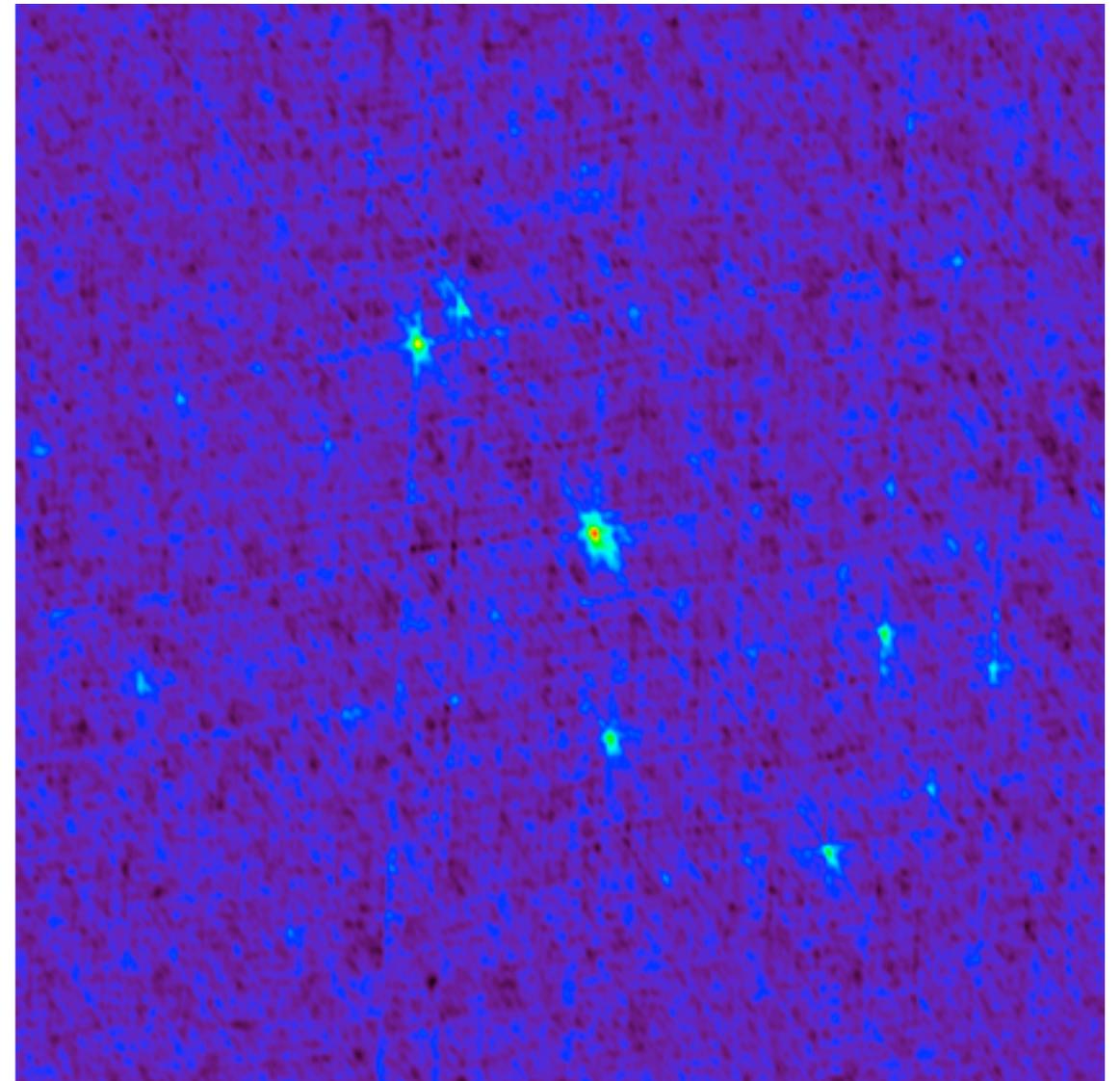
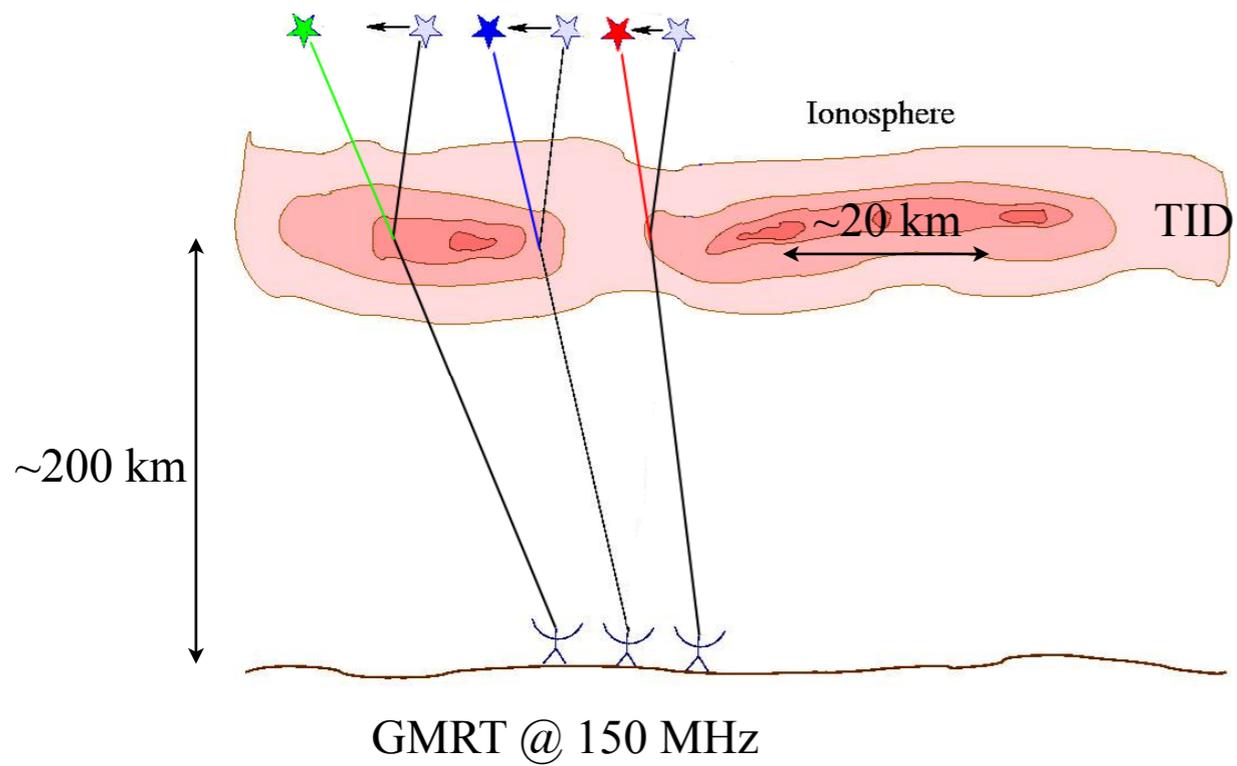


Fig. 1. Contour map of 30 MHz brightness temperatures plotted on a Hammer equal-area projection in galactic coordinates. The contour unit is 1000 K.

Ionosphère perturbatrice aux BF



Parasites radio (RFI)

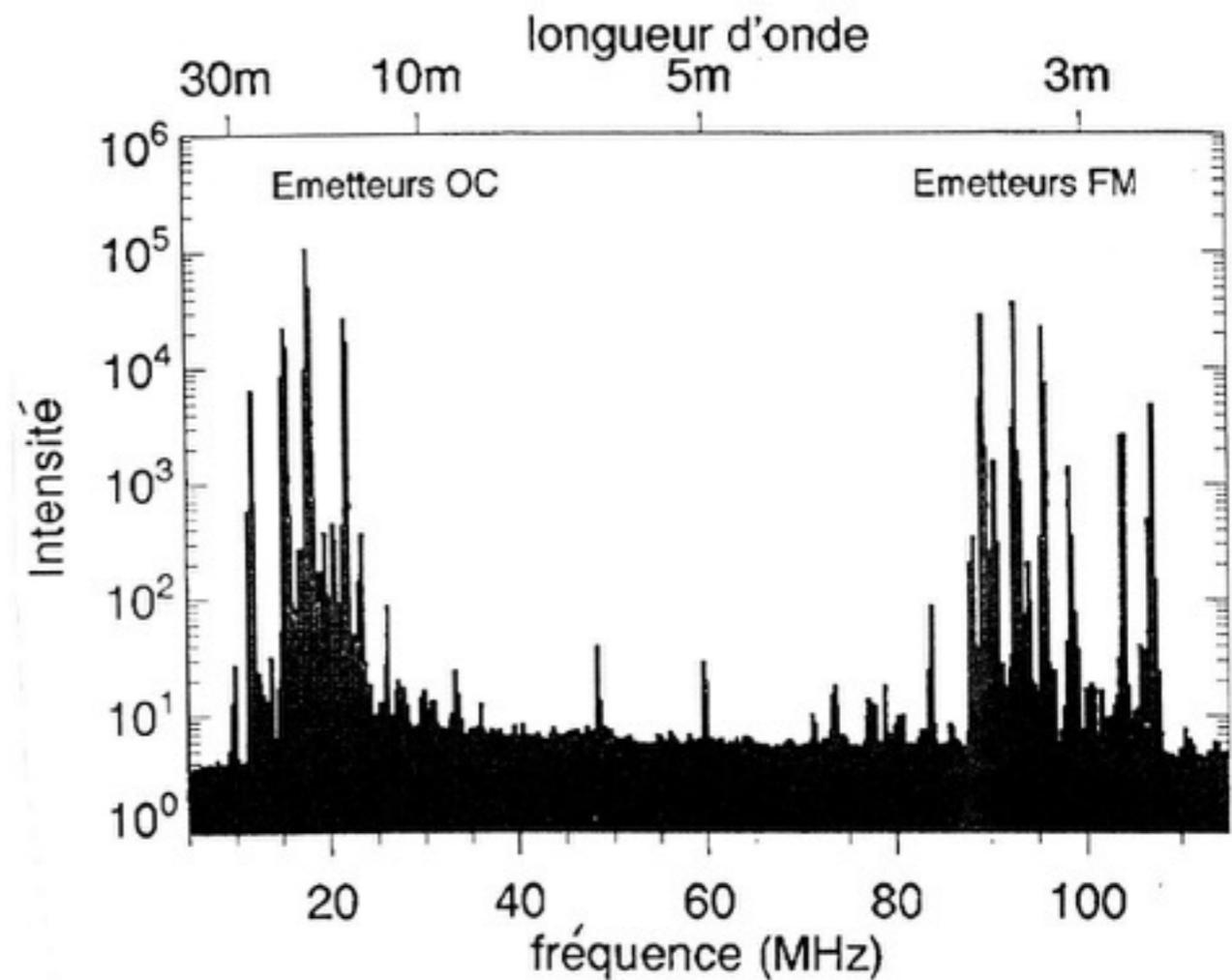
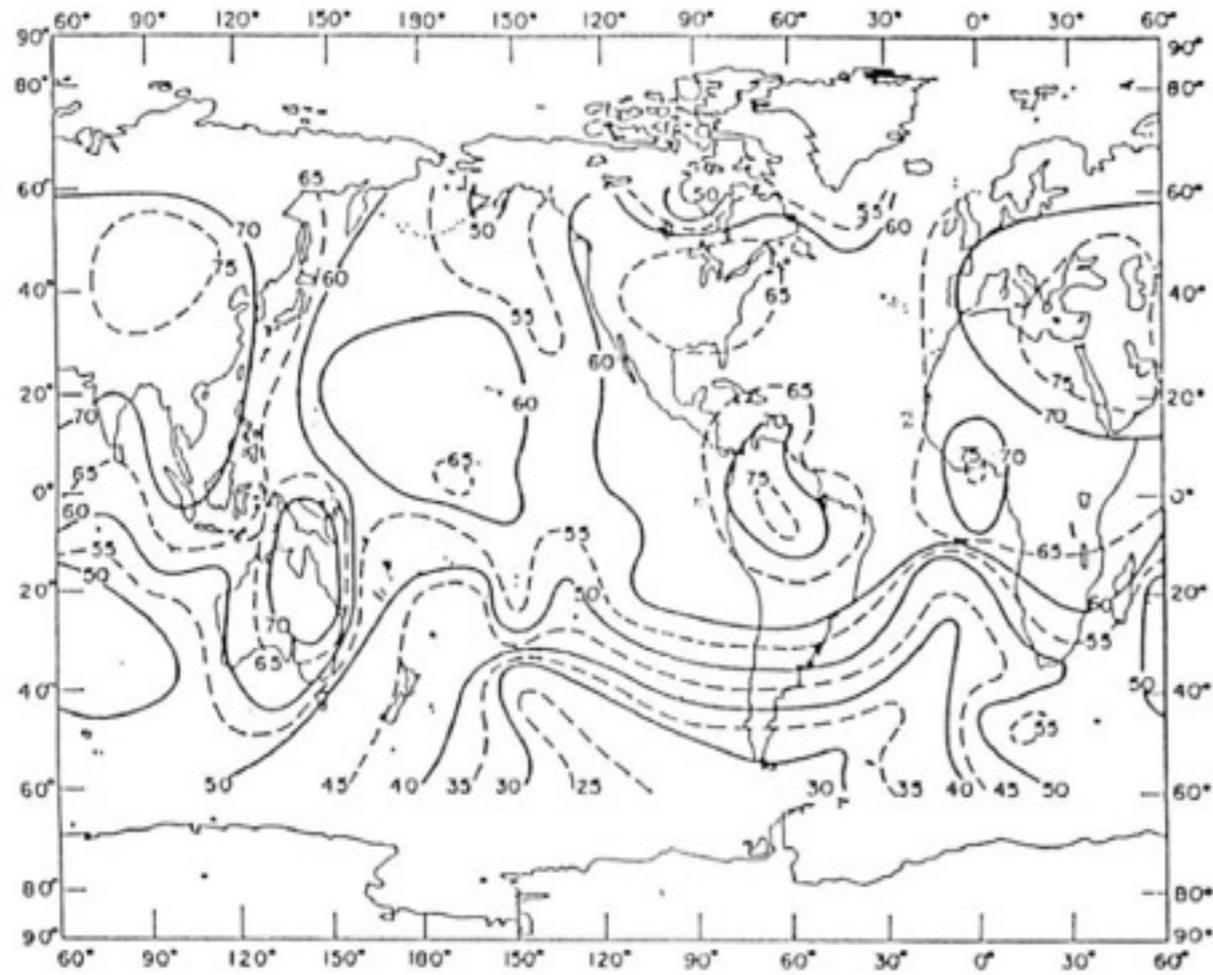
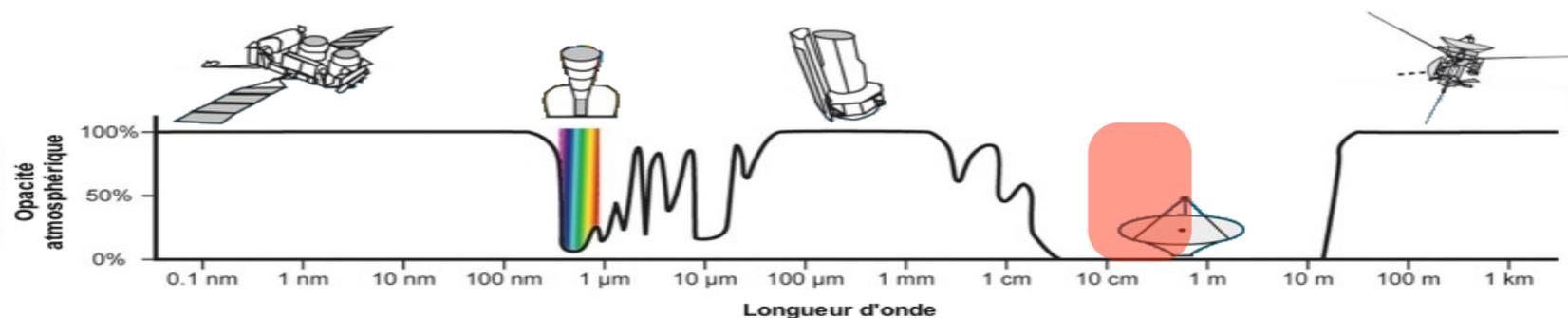


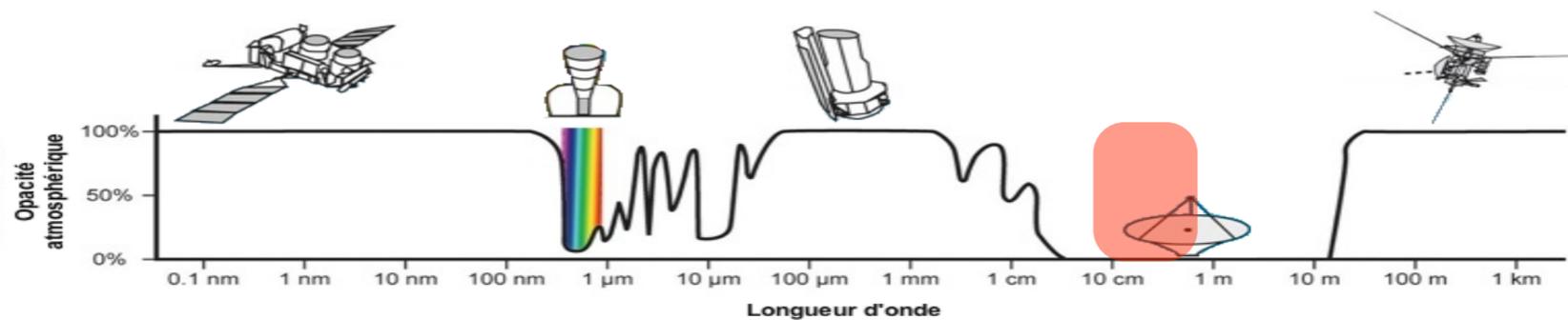
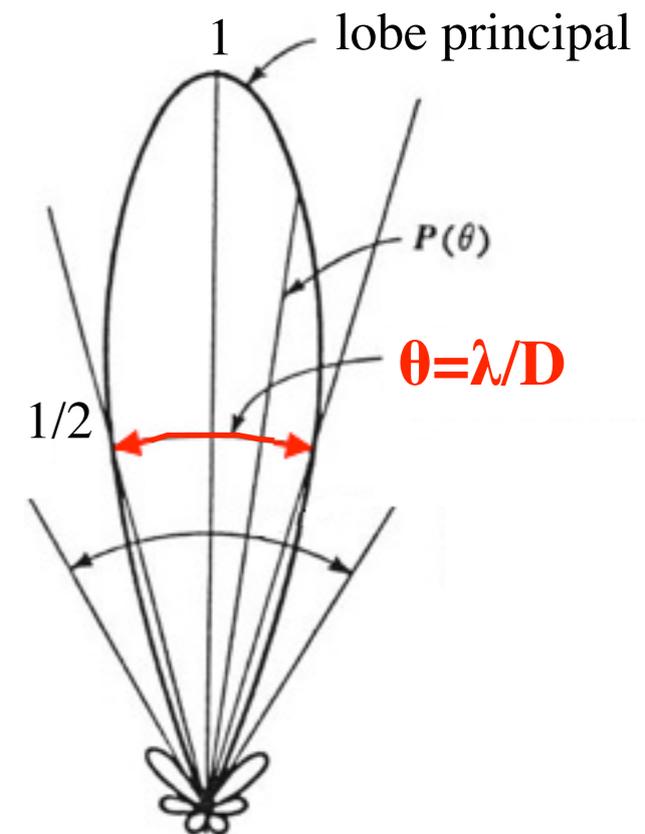
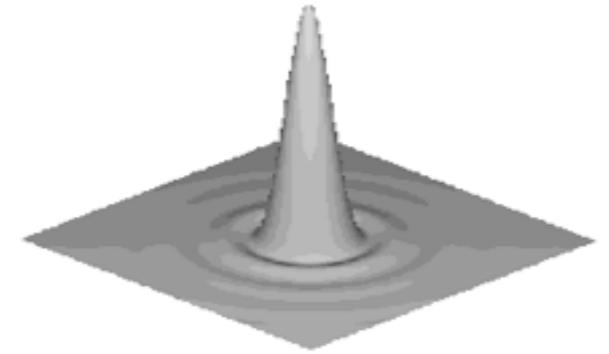
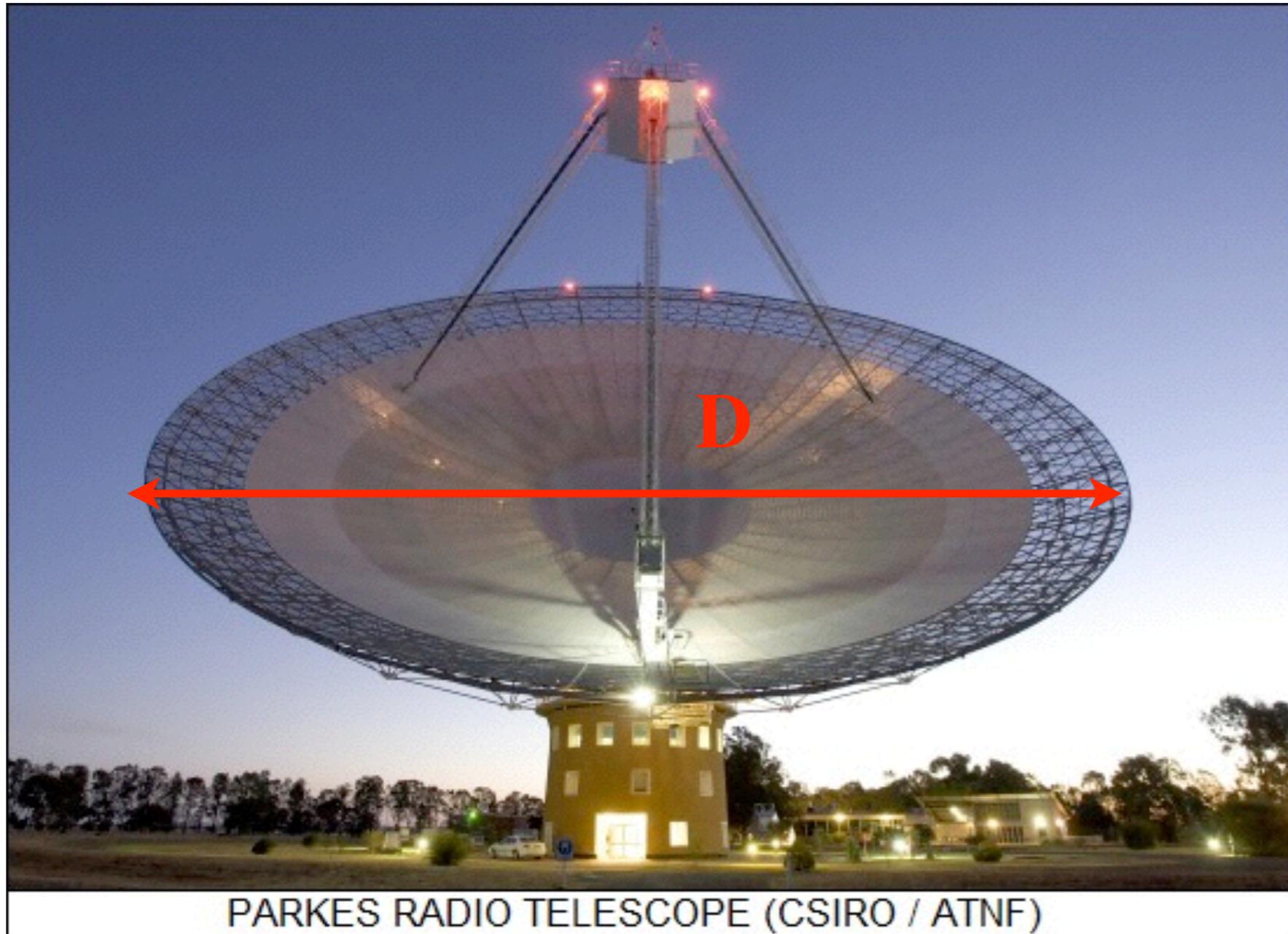
Figure 2. The terrestrial radio noise distribution derived from the RAE-1 (height 6000 km) lower "V" data at 9.18 MHz for December 2-6, 19-68. The secondary peaks in activity over the mid-Pacific and northern Australia are believed to be correlated with local thunderstorm activity. Contour levels are db above 288 K. The Galactic background on this scale would be about 31 db and the receiver saturated at 75 db. (from Herman et al, 1973)

→ montée au GHz

L'âge des grandes paraboles :
le premier âge d'or
de la radioastronomie



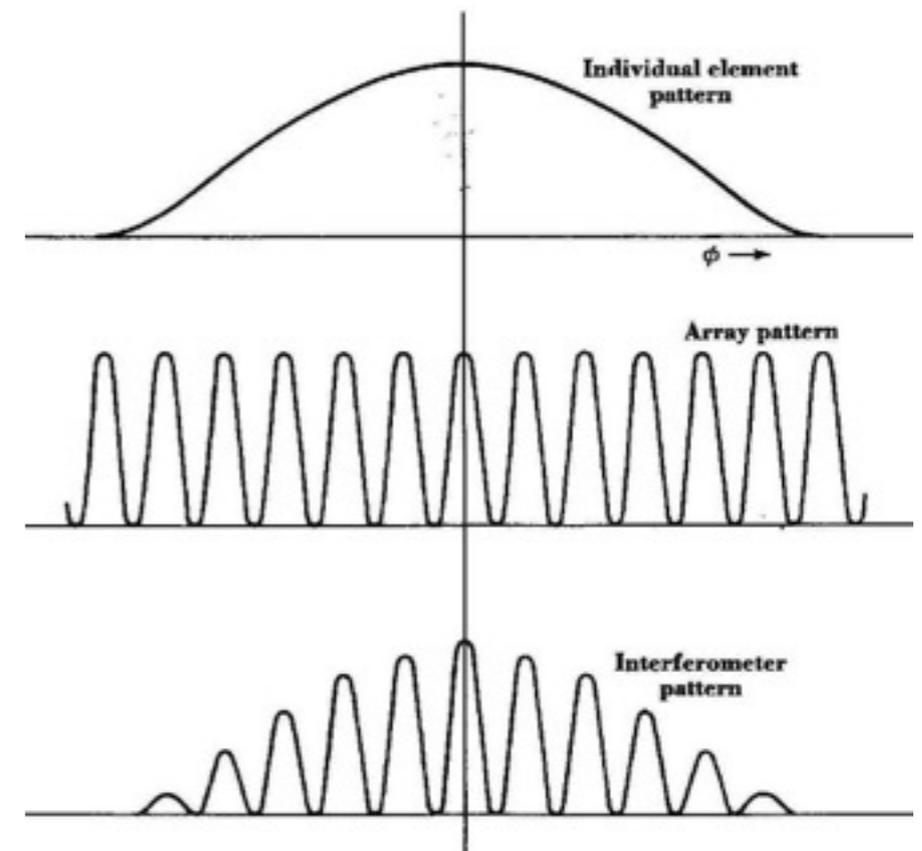
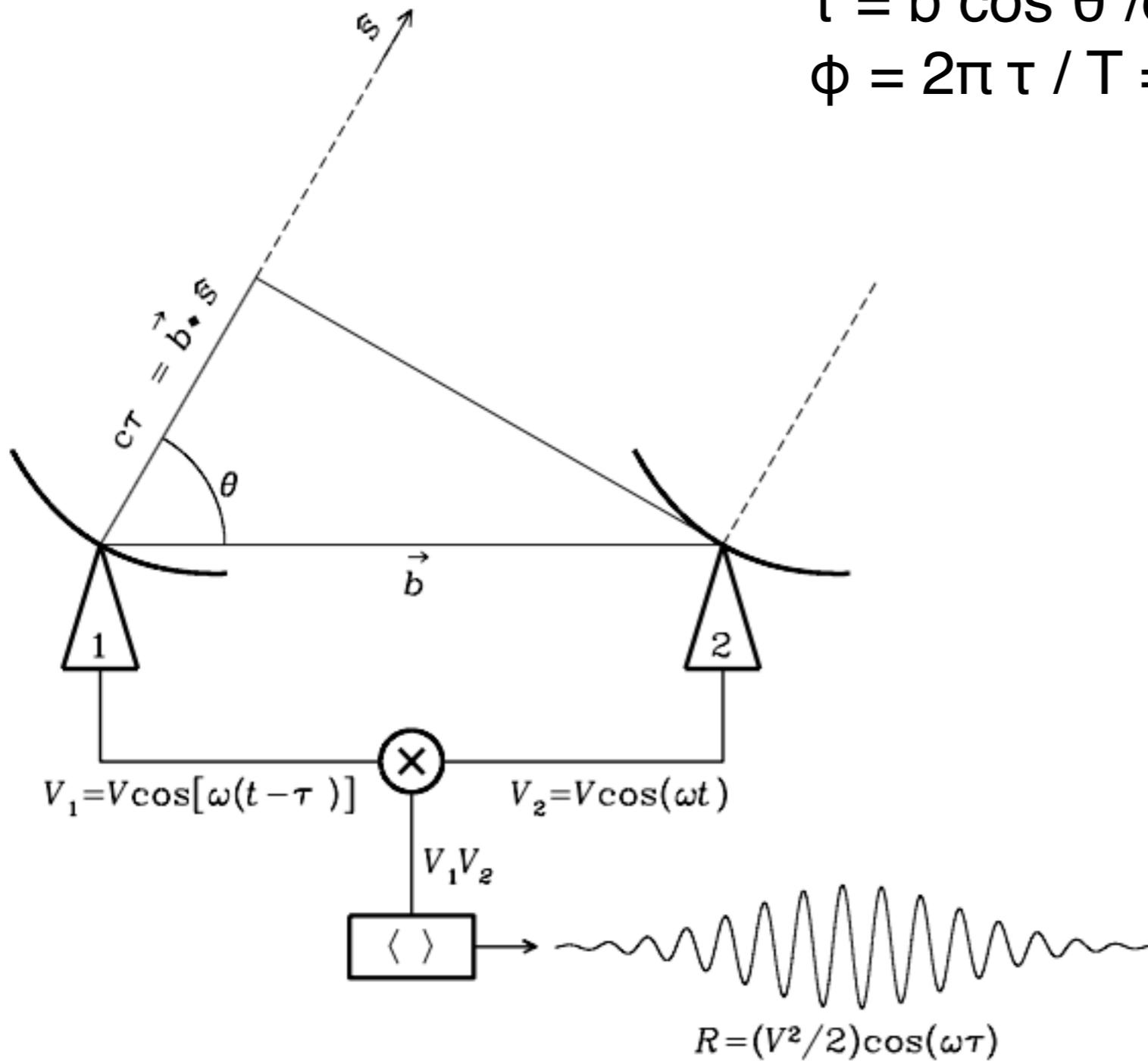
Sensibilité = surface collectrice
Résolution = extension linéaire



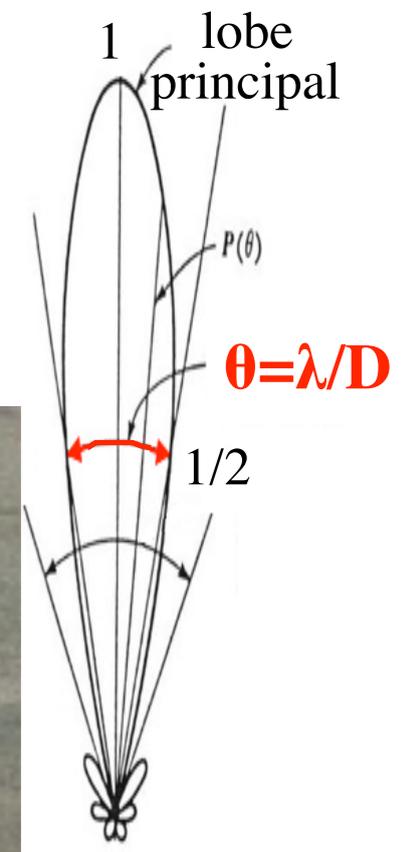
Interférométrie

$$\tau = b \cos \theta / c$$

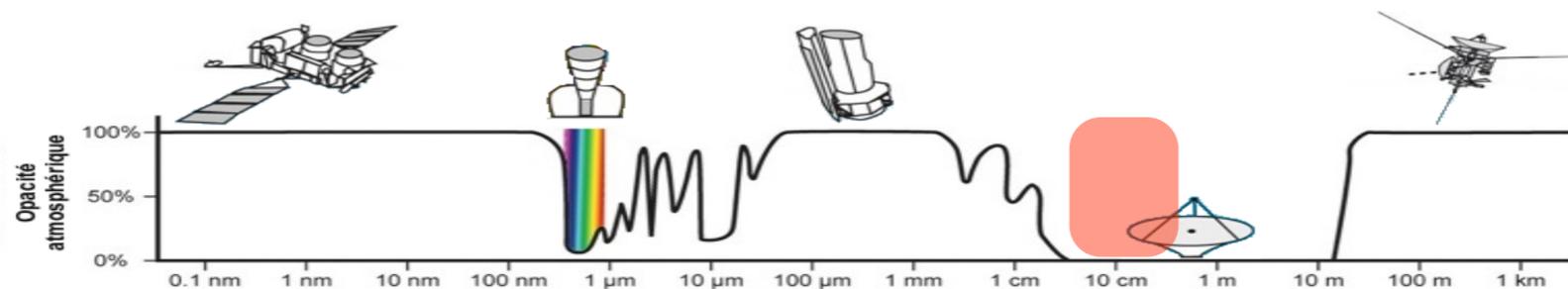
$$\phi = 2\pi \tau / T = 2\pi \nu \tau$$



Interféromètre



VLBI (interférométrie à très longues bases)

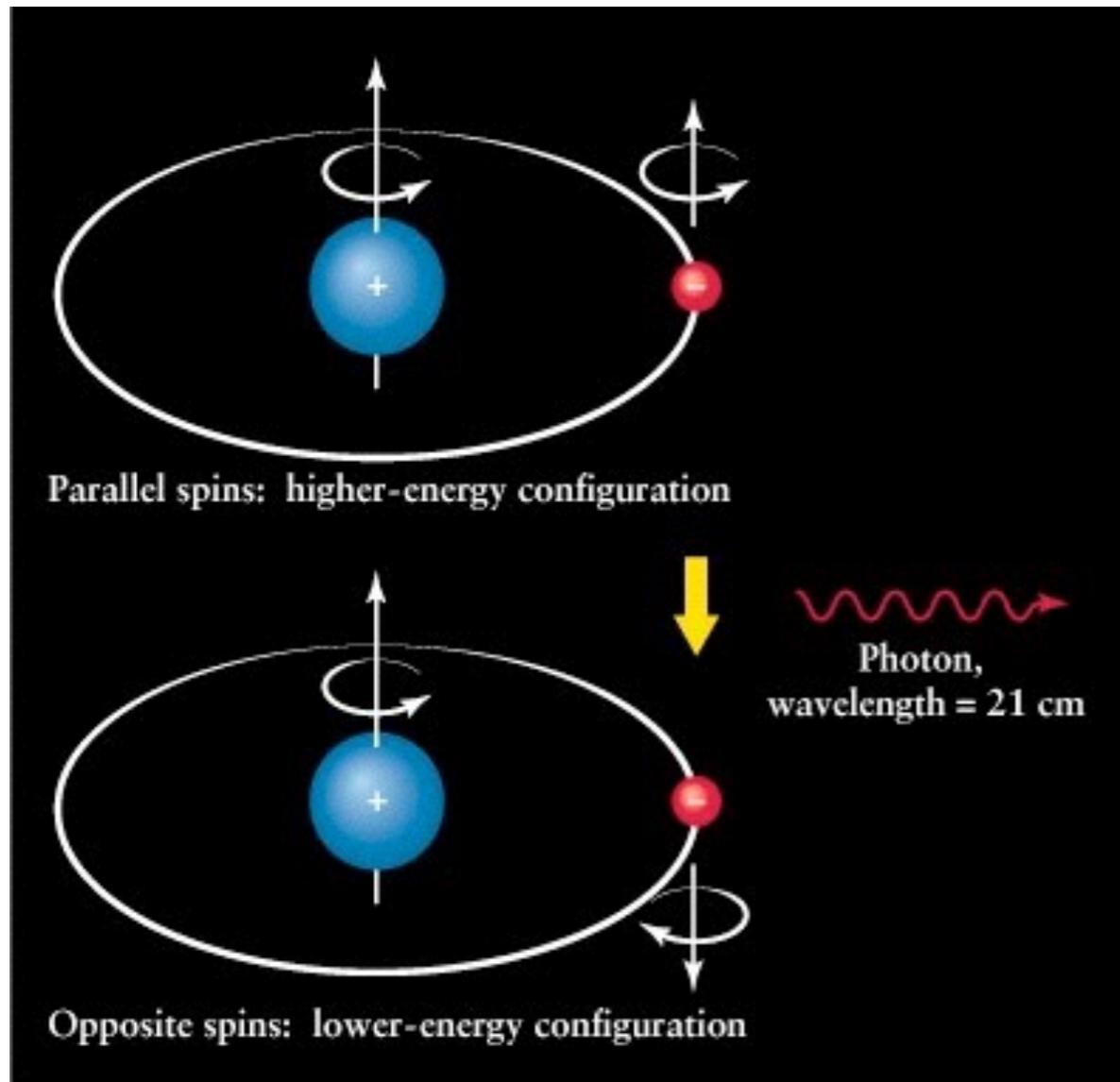


Quelques découvertes

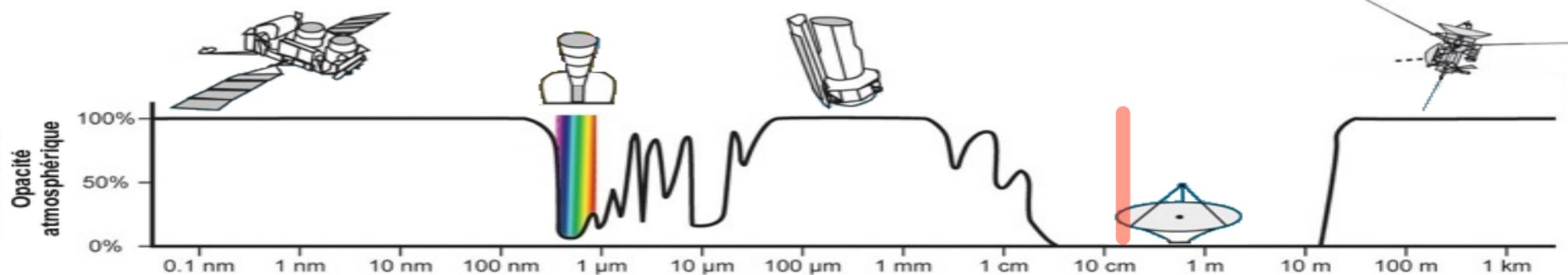
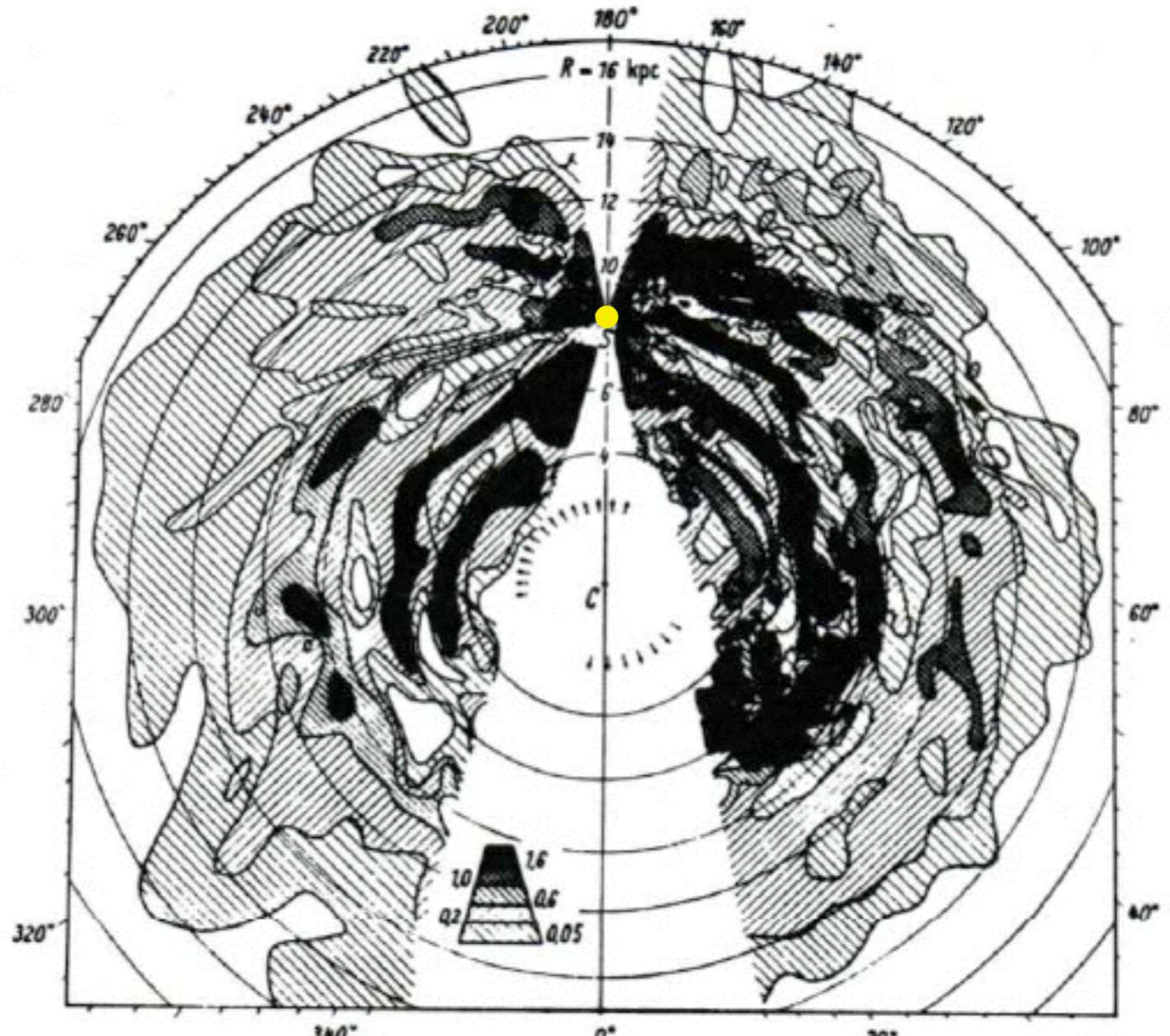
1951-63

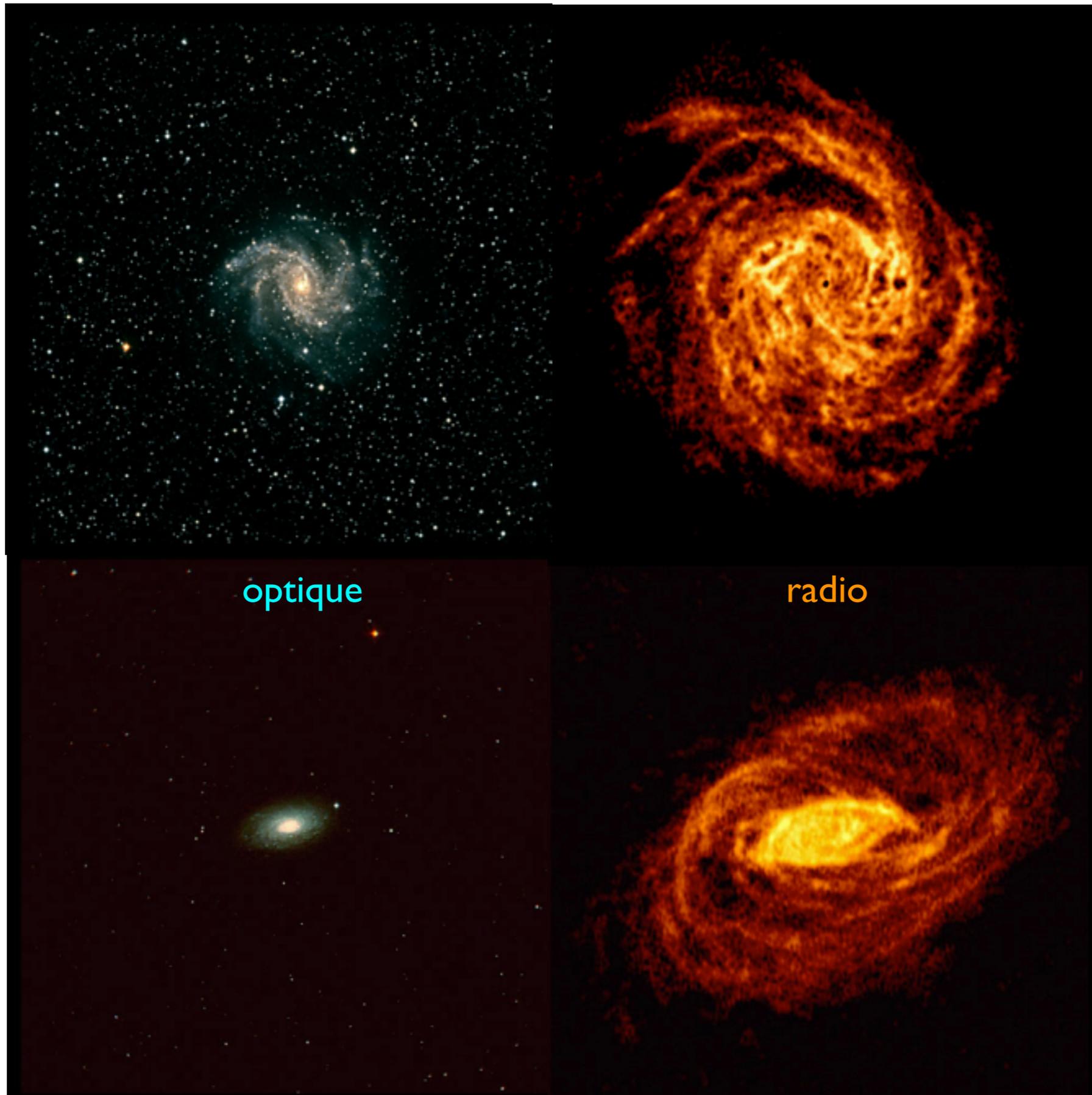
Raie H_I à $\lambda \sim 21$ cm ($\nu = 1420$ MHz) \rightarrow omniprésente
 \rightarrow essor de la Radioastronomie
 \rightarrow structure galactique spirale

(Hendrik van de Hulst)
Harold Ewen & Edward Purcell
Jan Oort



b

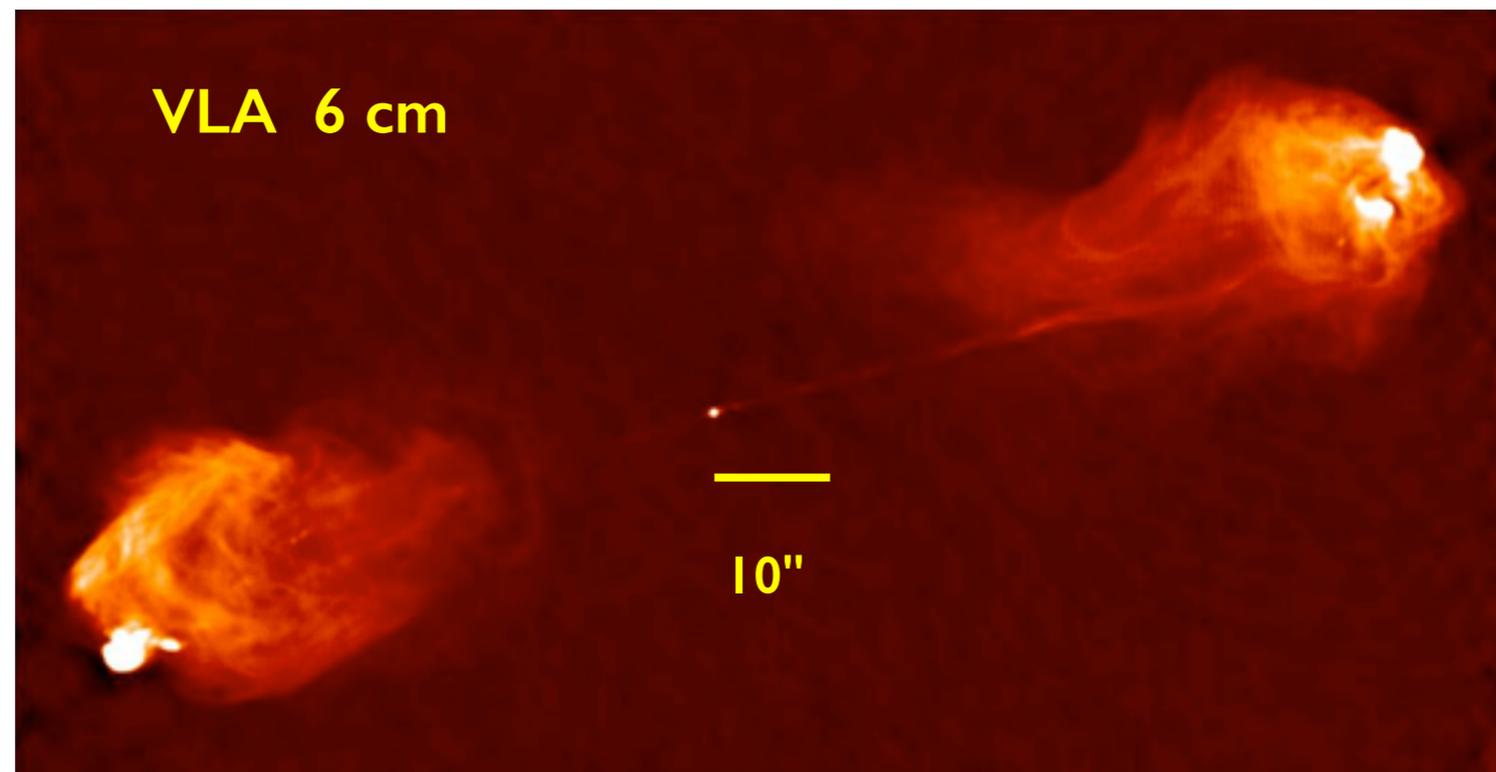
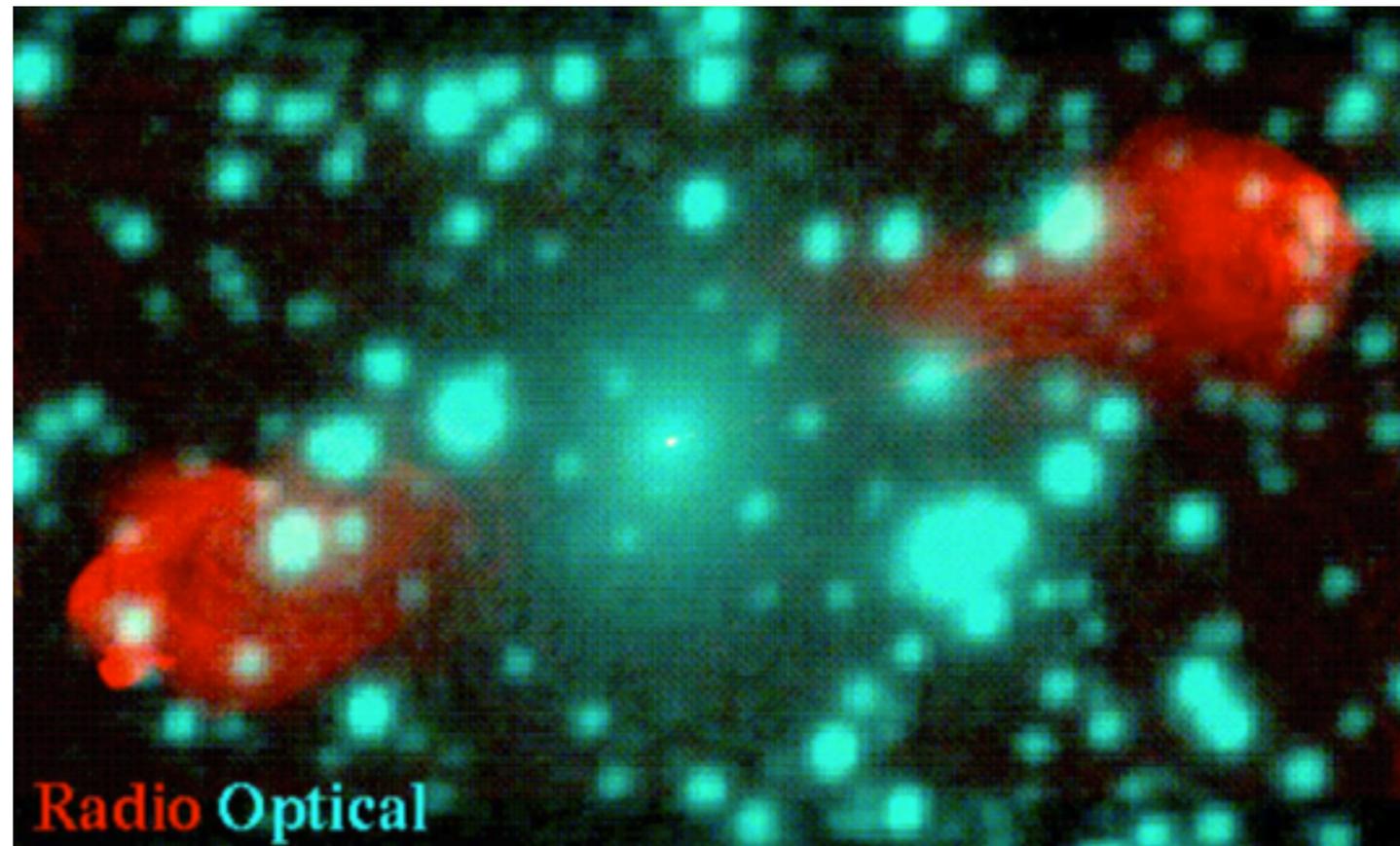


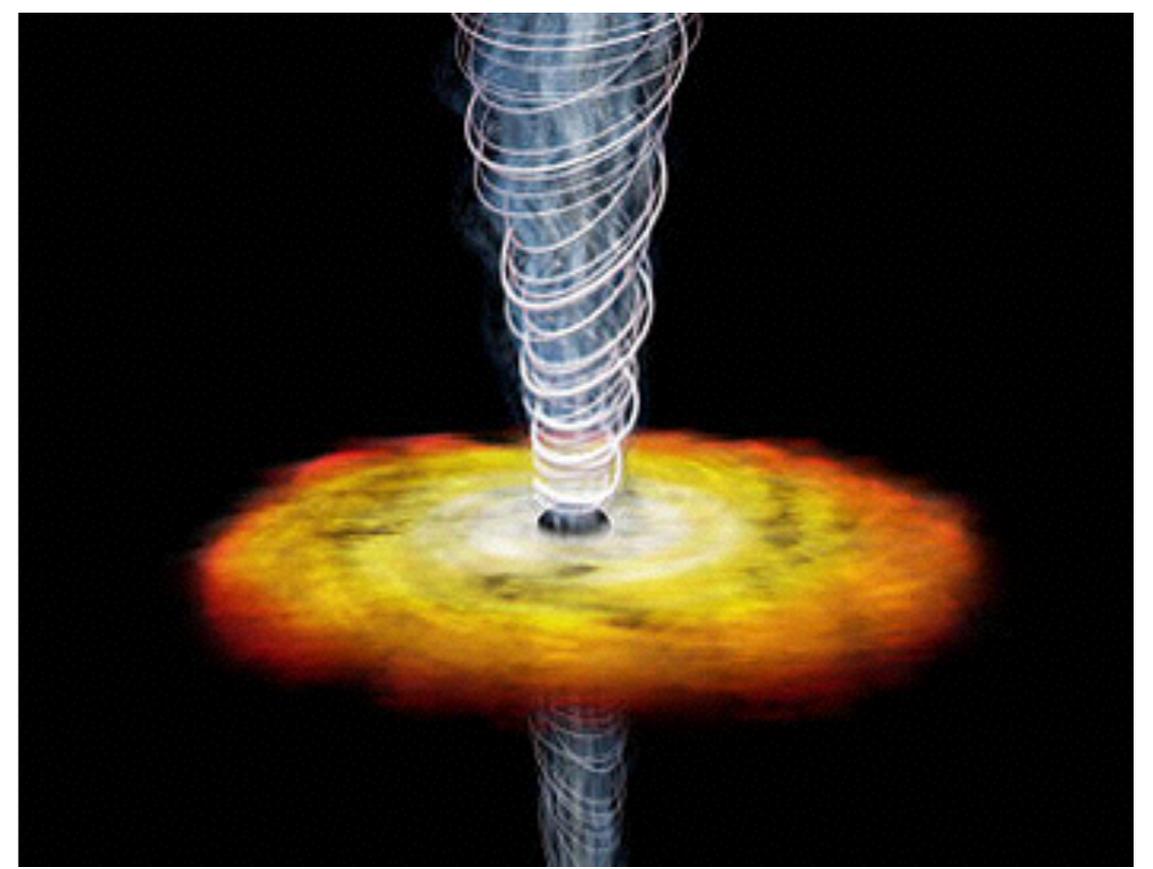
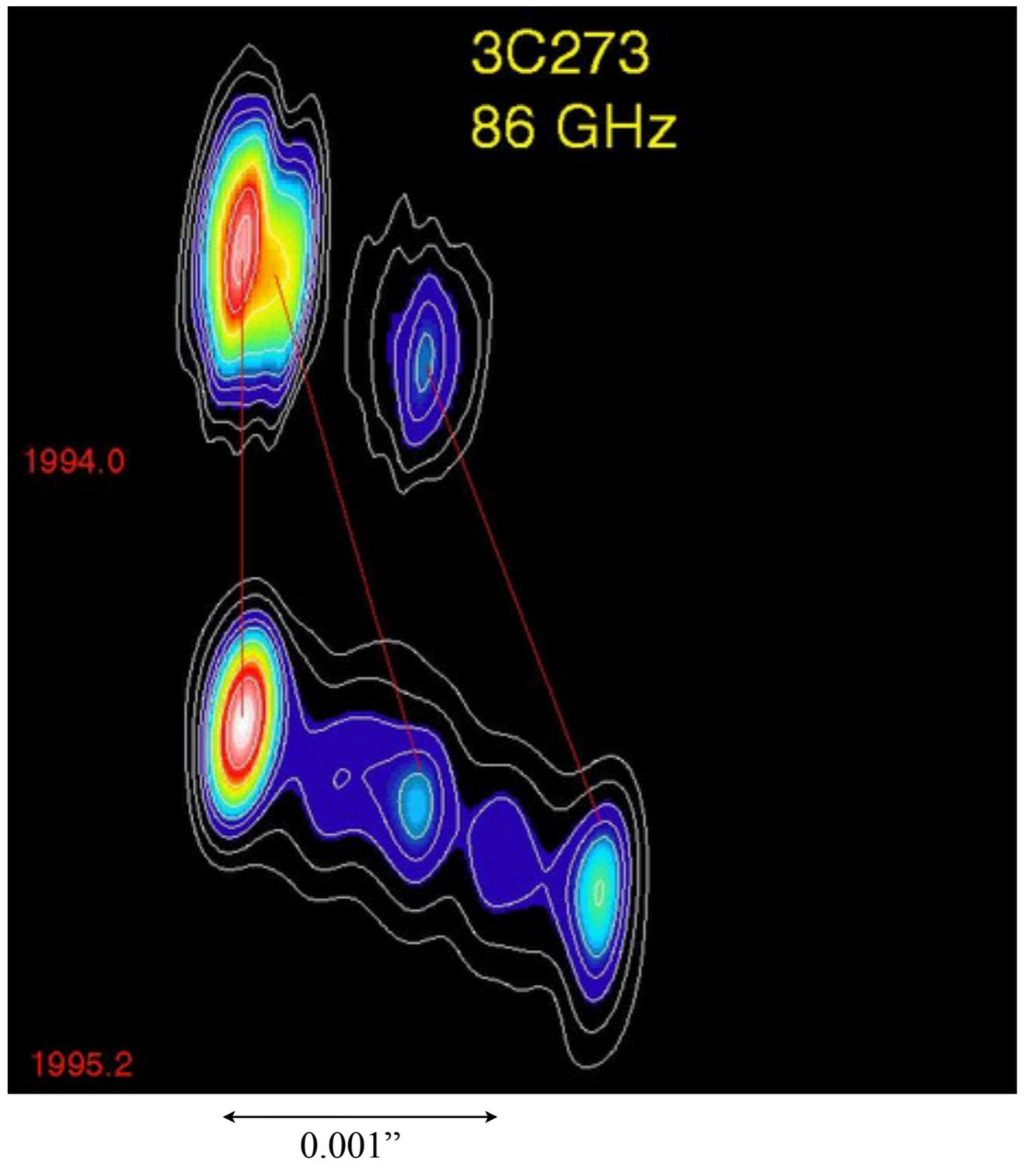


Champs magnétiques

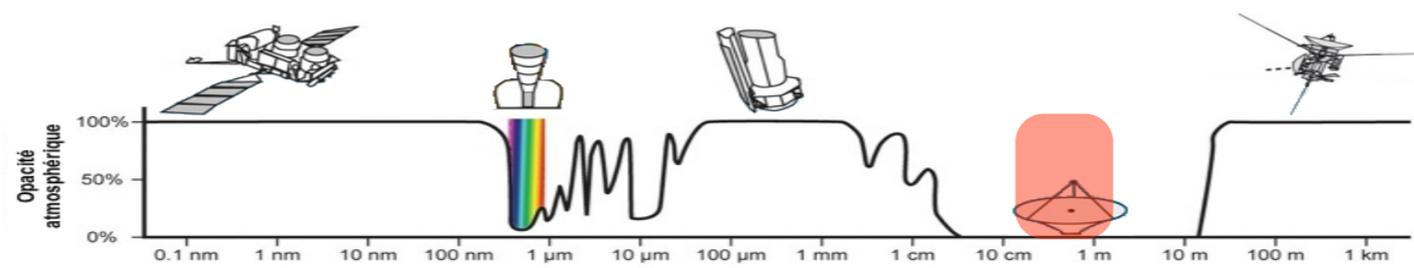
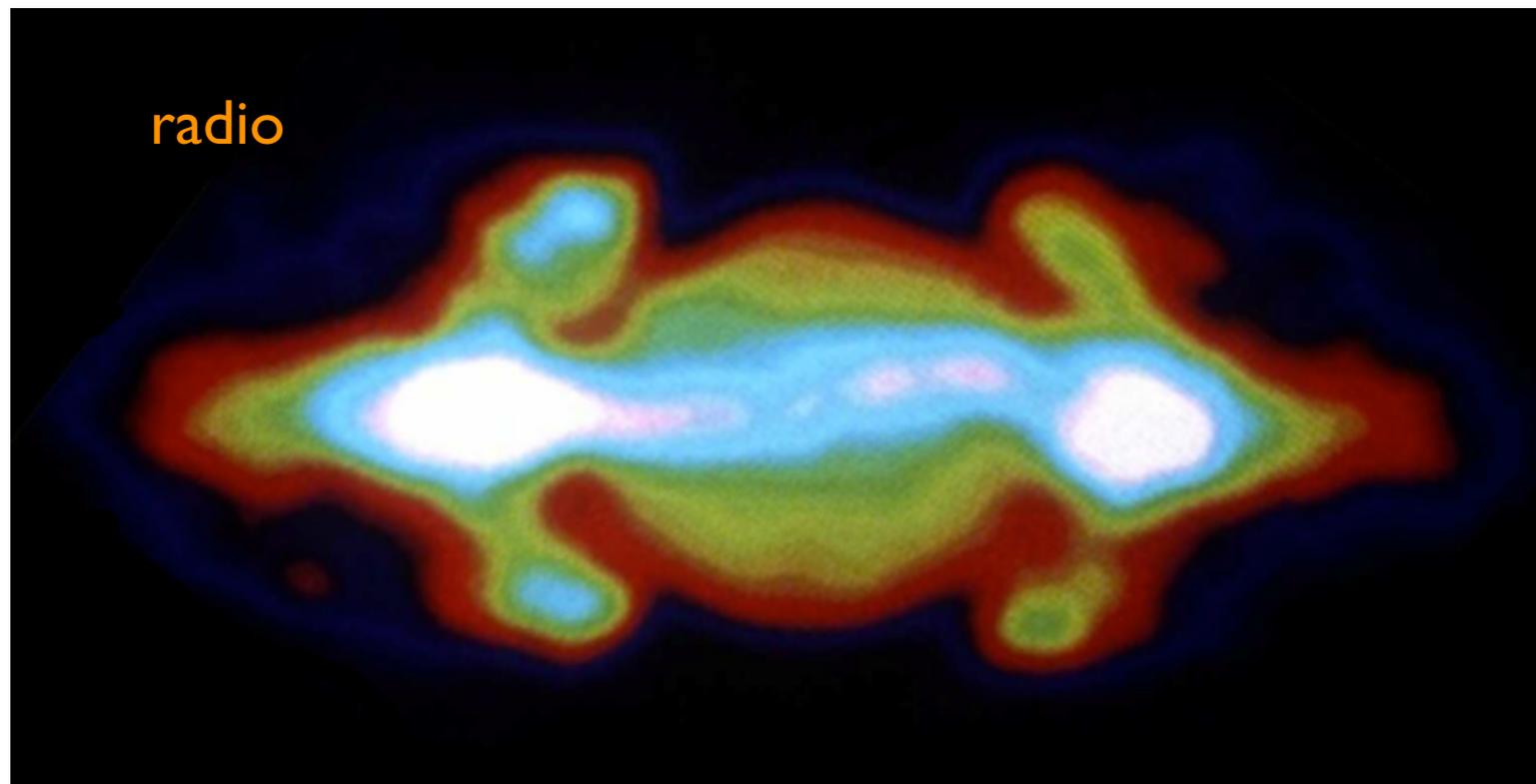


Jets galactiques

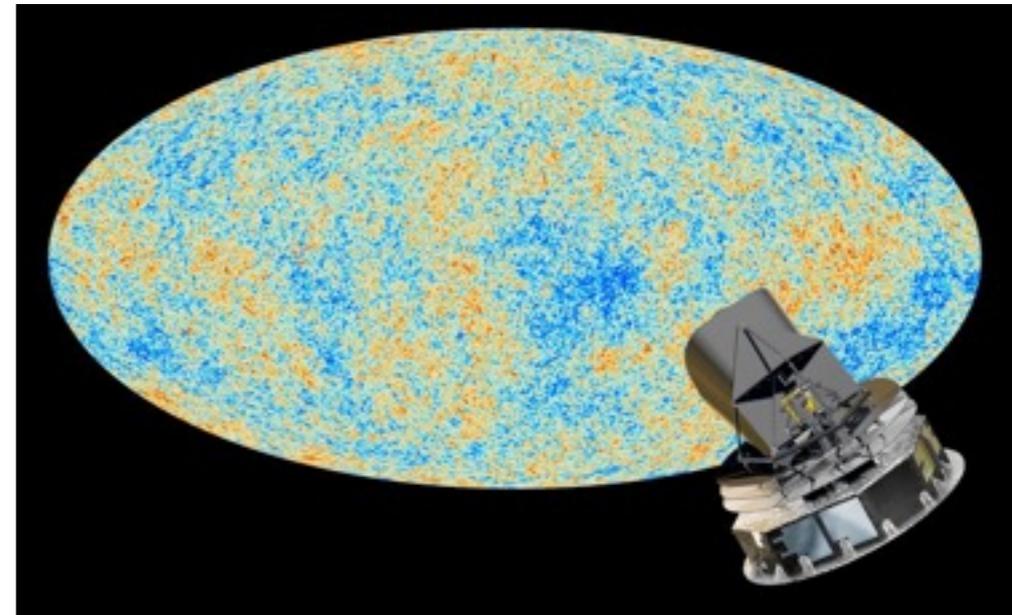
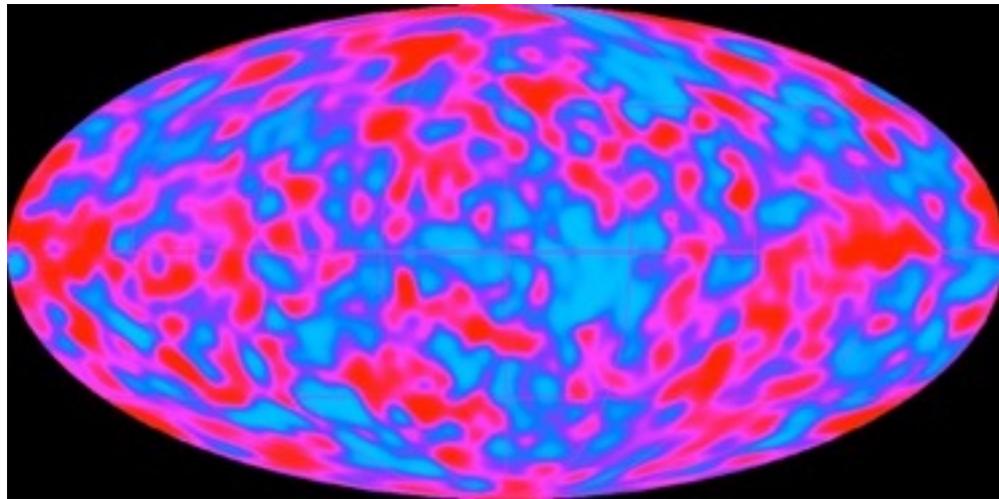
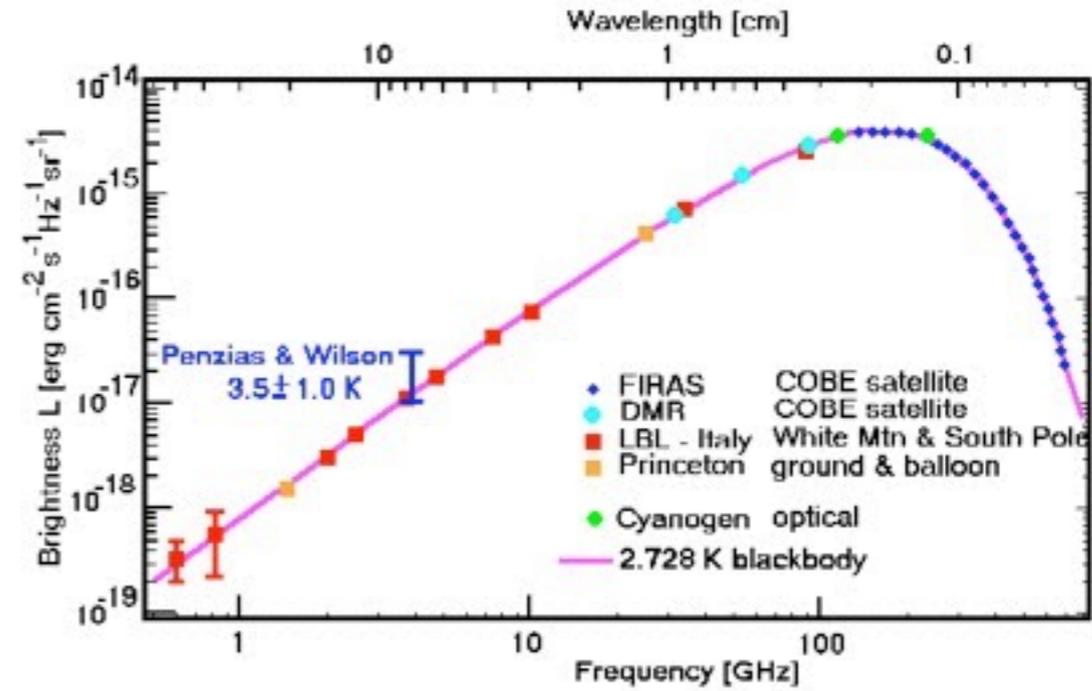
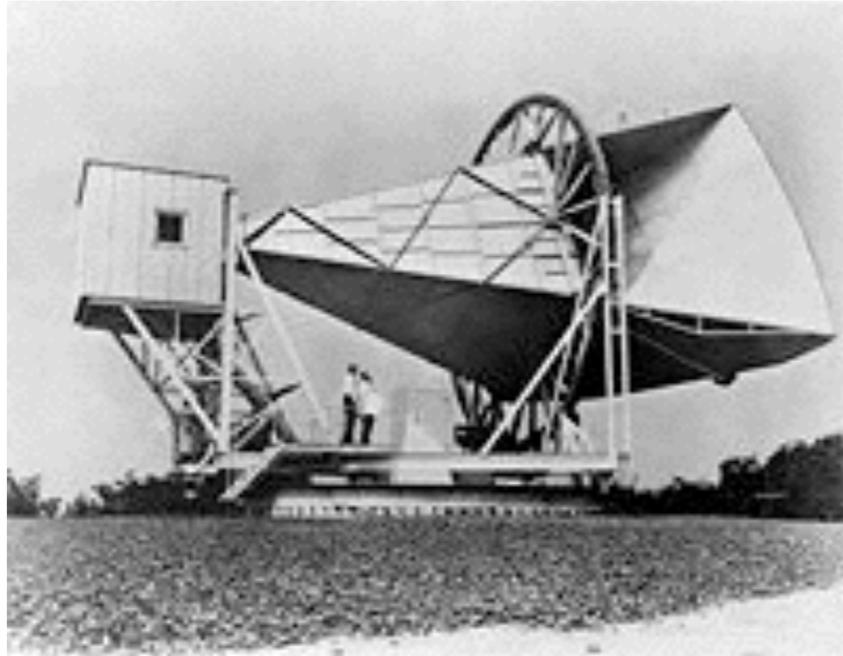




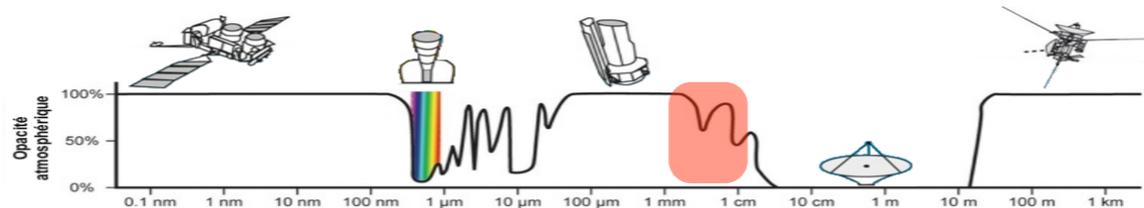
Jupiter



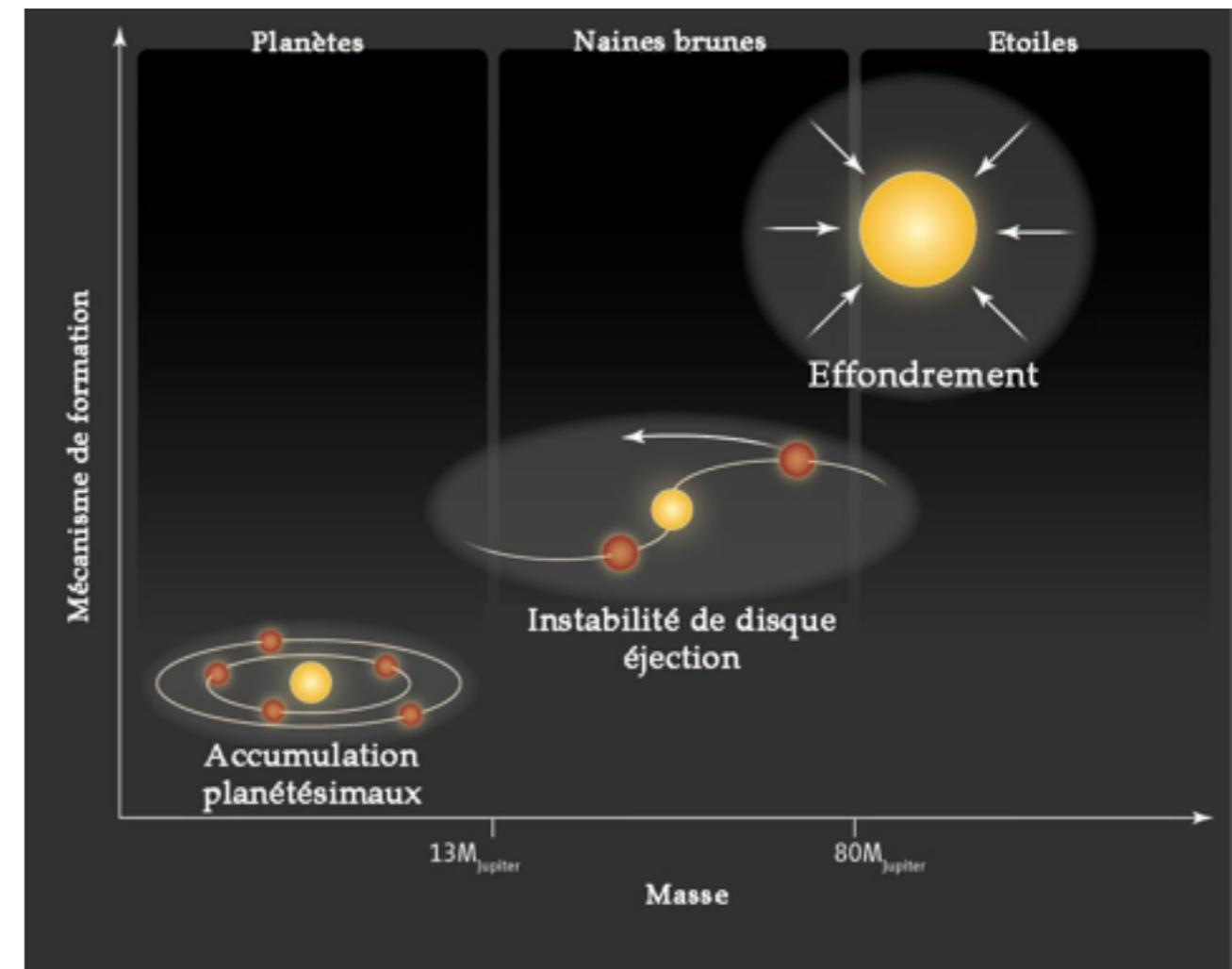
1965	Rayonnement cosmologique à 3 °K ($\lambda \approx \text{mm}$)	Arno Penzias & Robert Wilson
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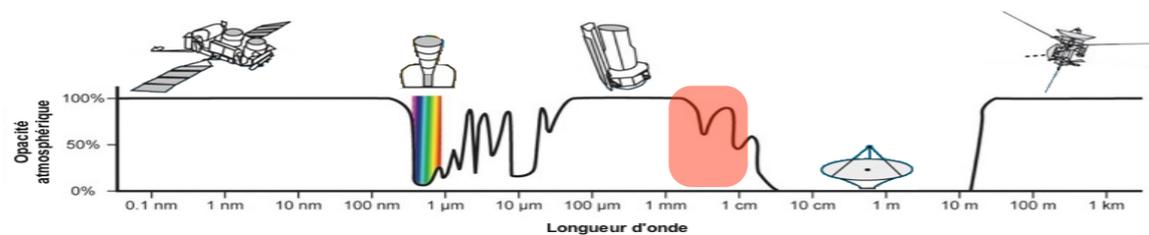
1990's	COBE : fluctuations du fond cosmologique	George Smoot & John Mather
2010's	Planck	



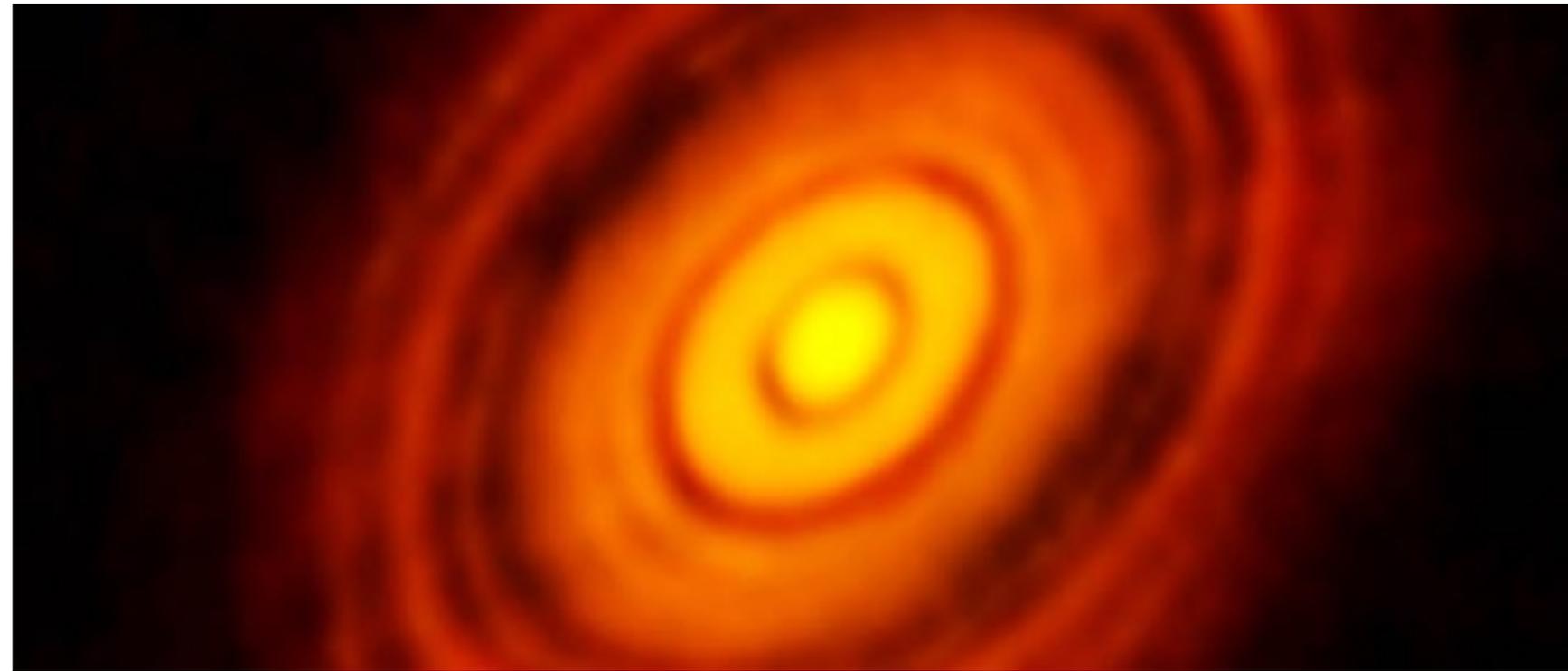
Formation stellaire & planétaire



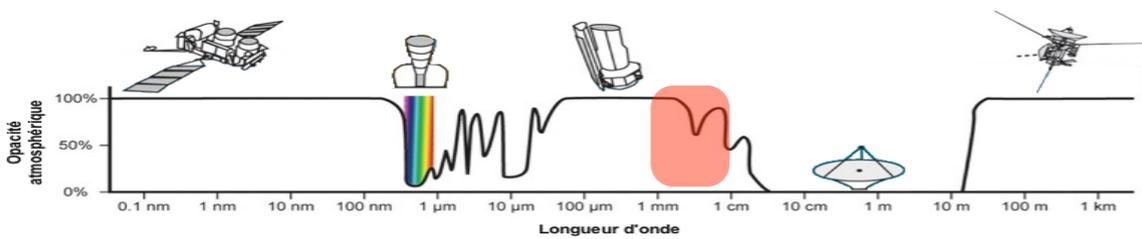
IRAM



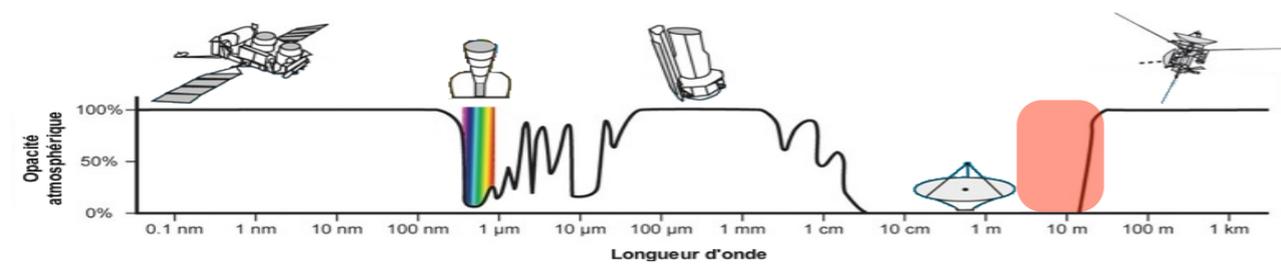
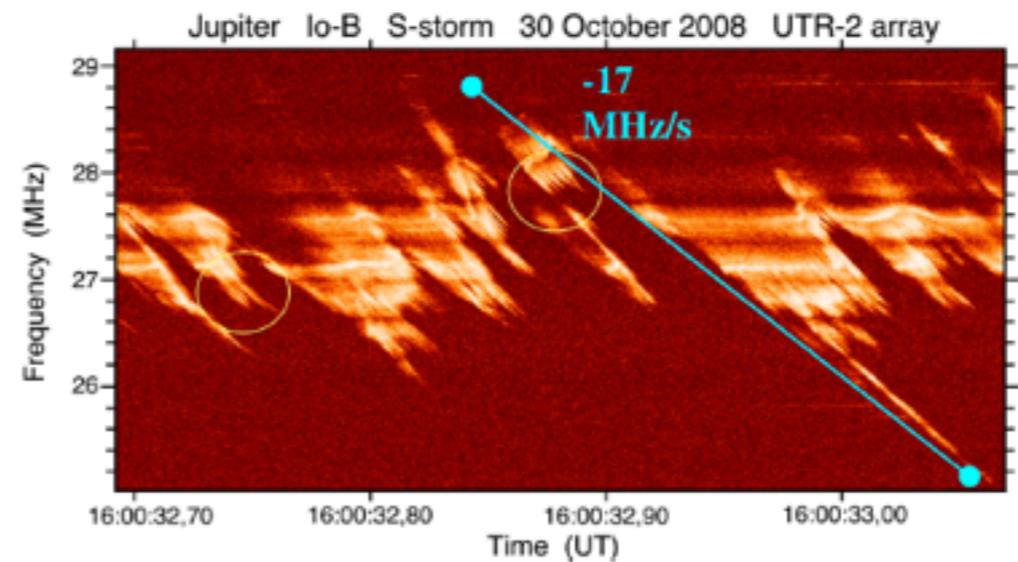
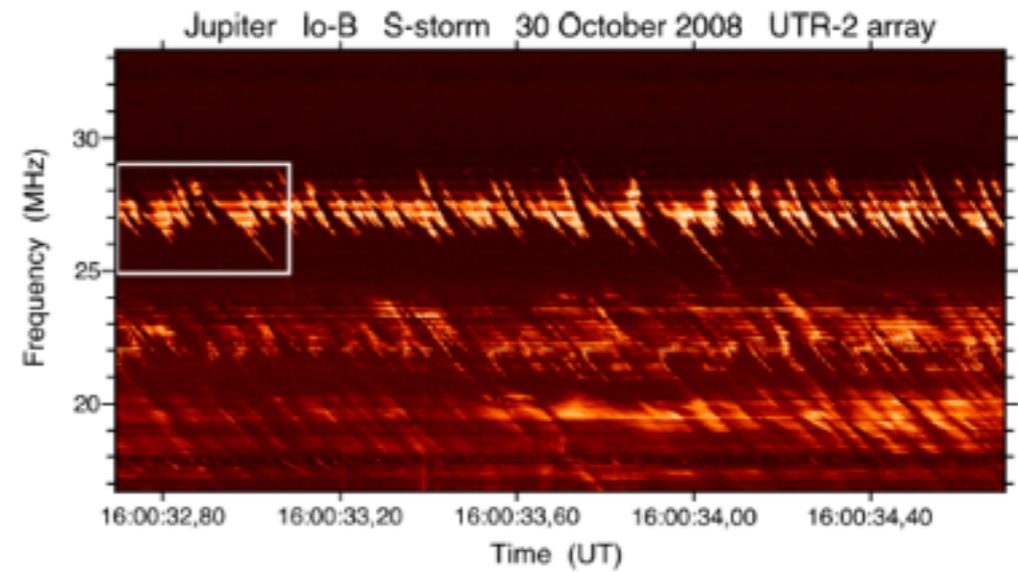
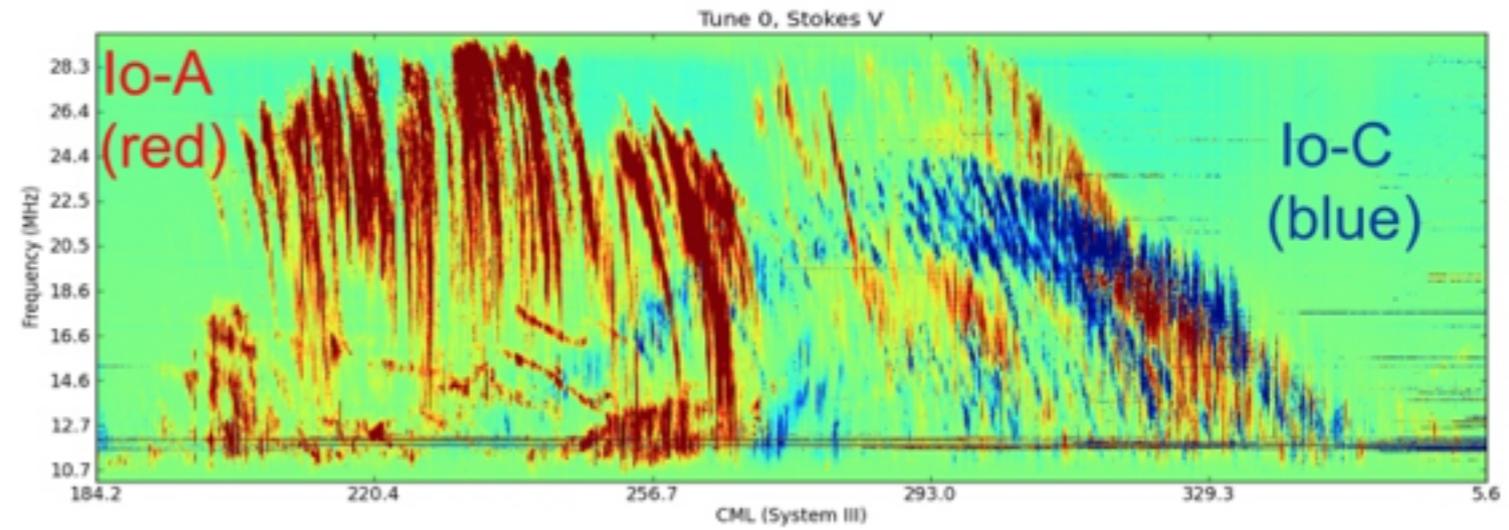
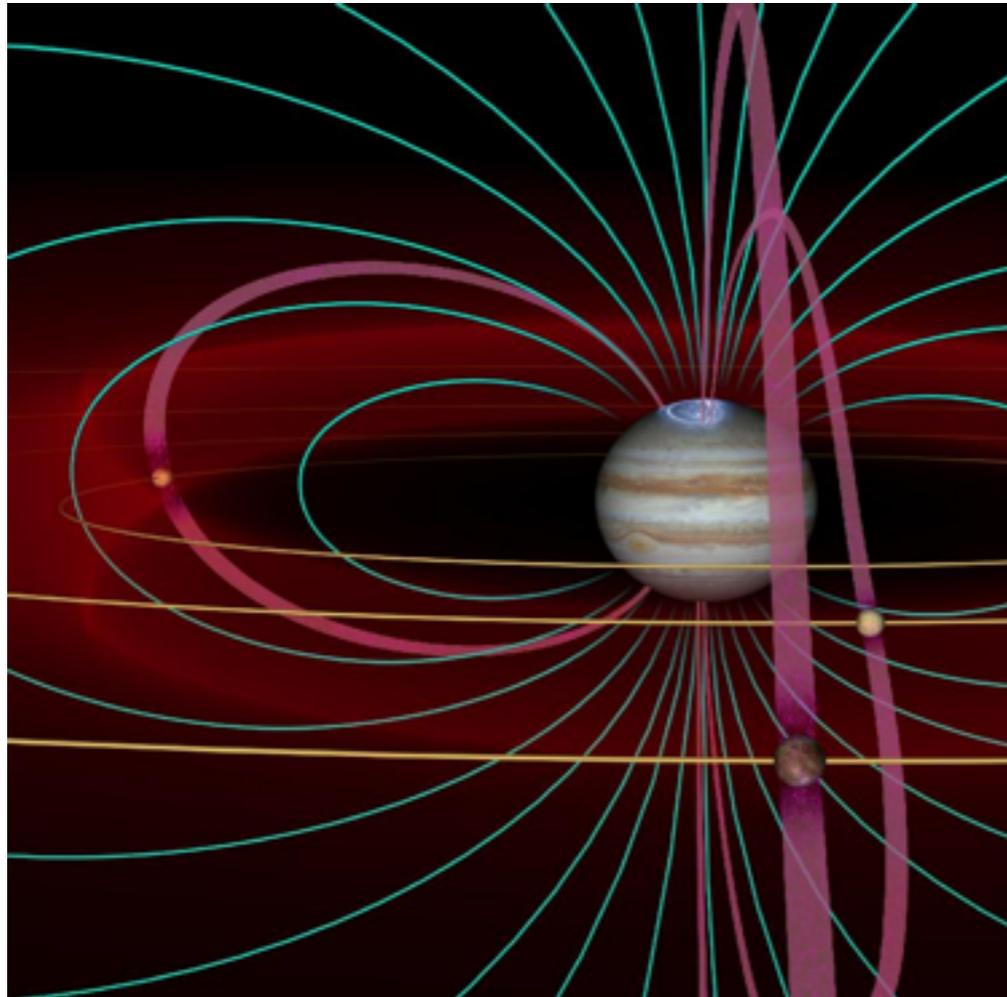
Disque proto-planétaire

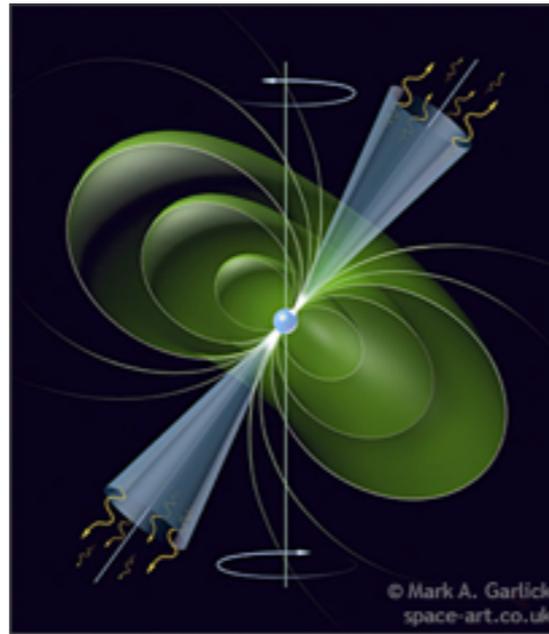
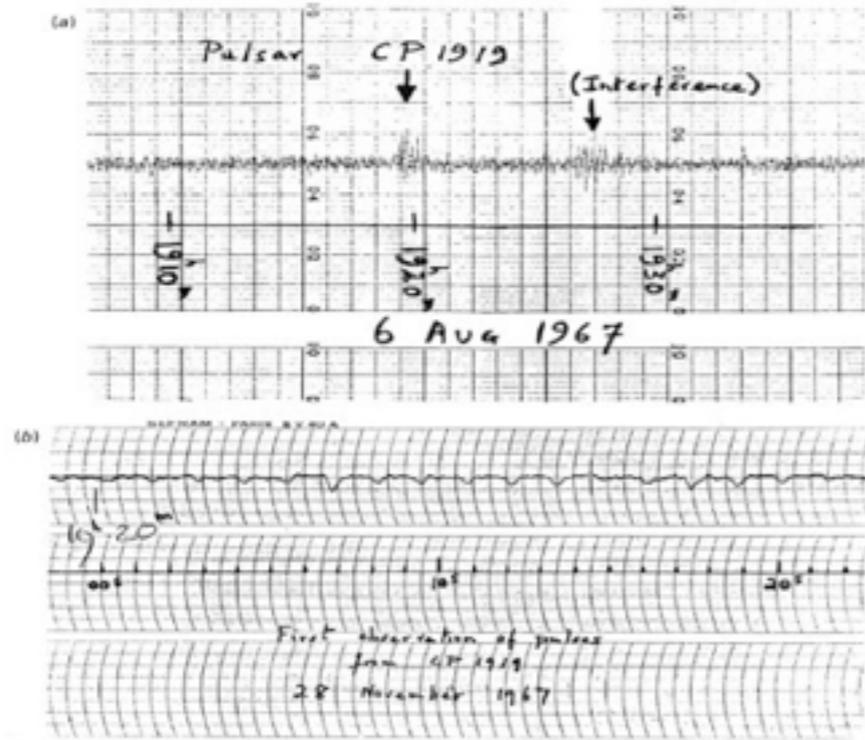


ALMA

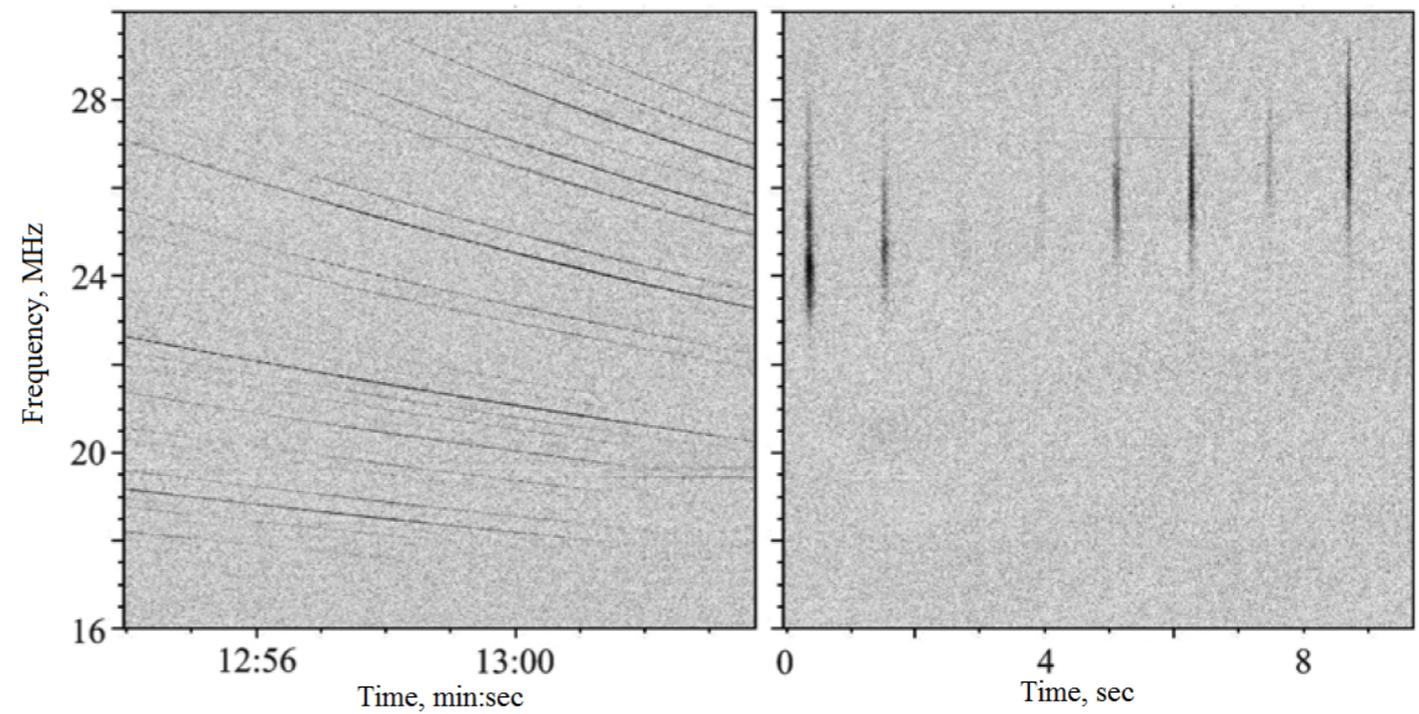
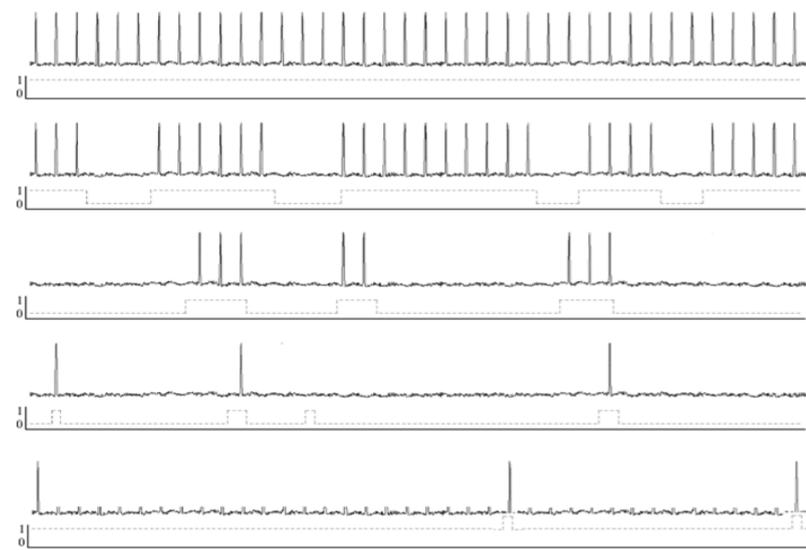


Observations temps-fréquence

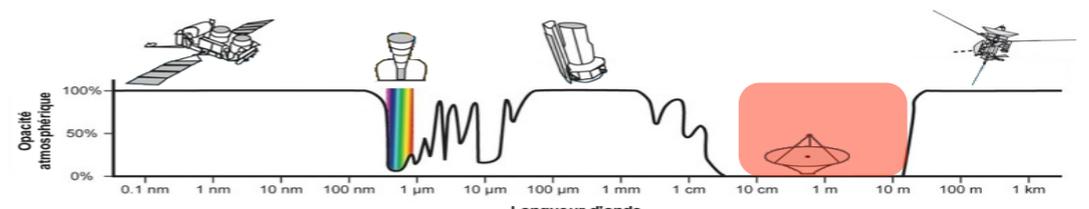




Dispersion : $\Delta t (f_1 \text{ } f_2) = K [DM] (1/f_1^2 - 1/f_2^2)$

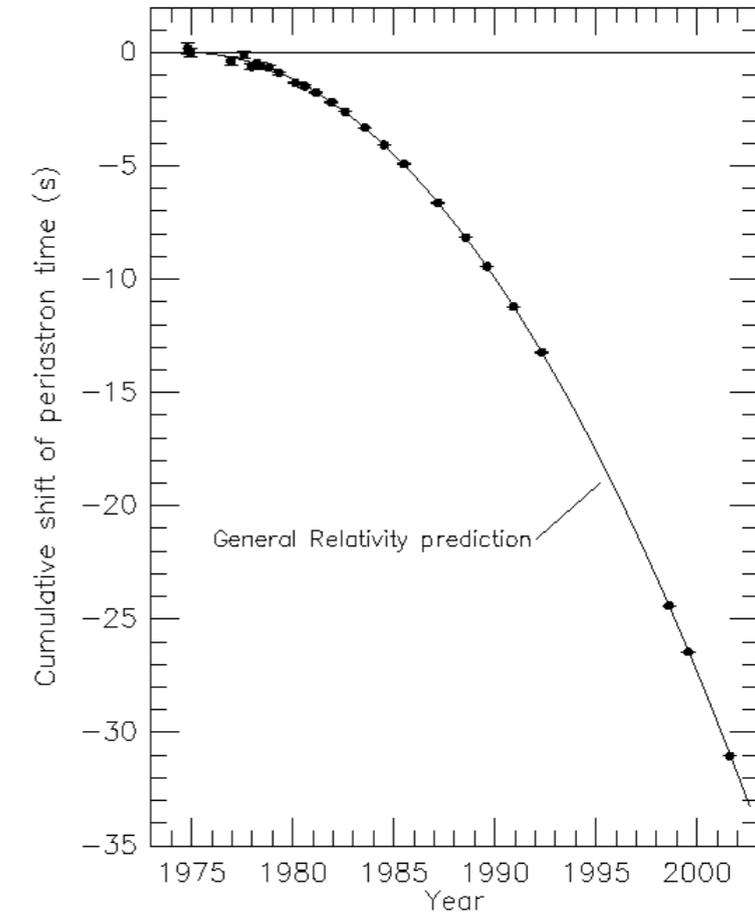
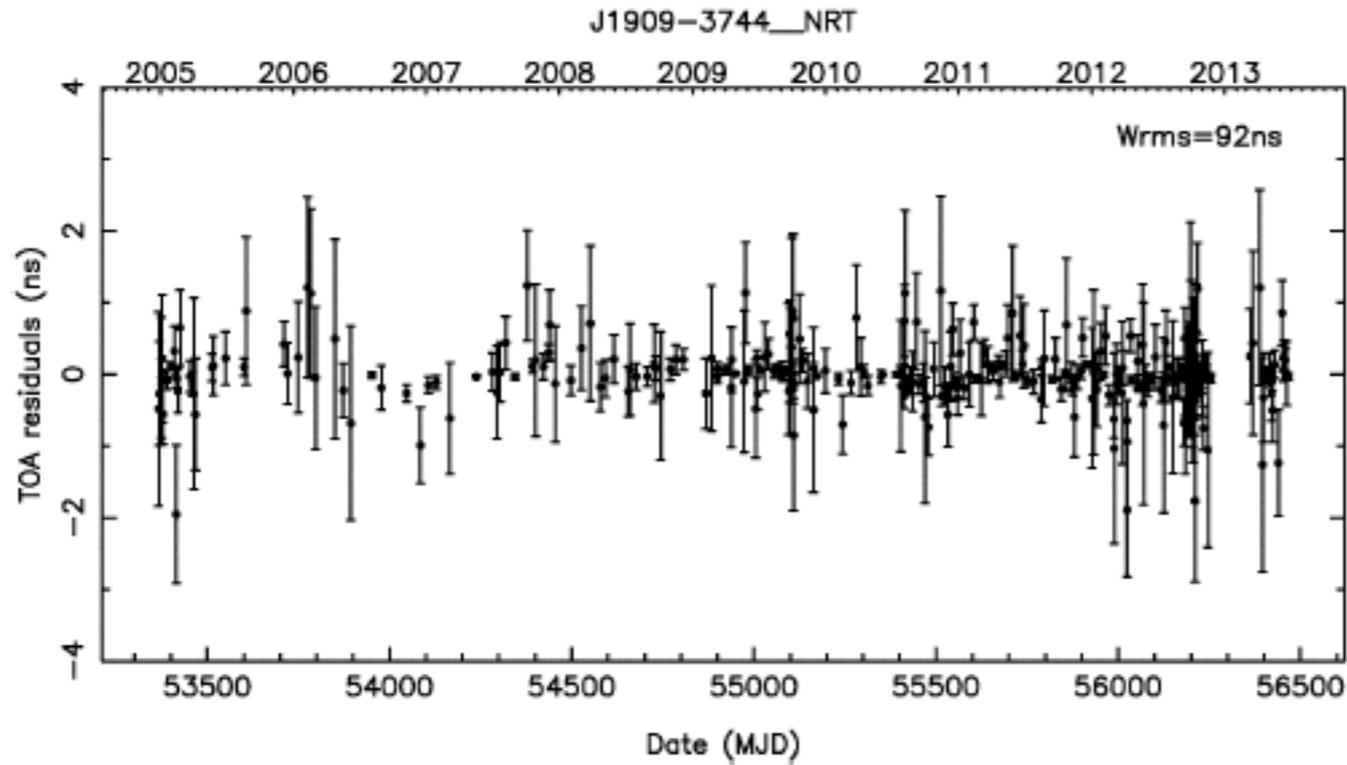


+RRATS, FRBs



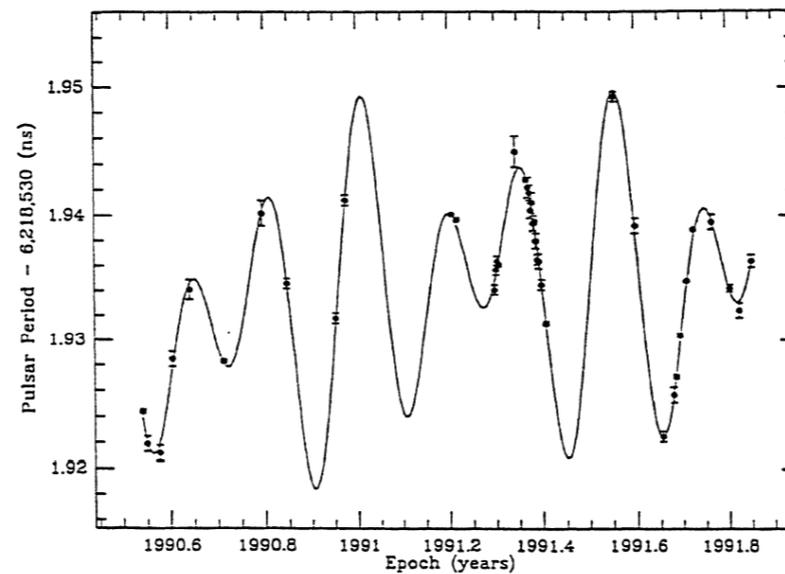
1974-93 Chronométrage de pulsar milliseconde & rayonnement gravitationnel

Russell Hulse & Joseph Taylor



1992 1^{ère} exoplanète autour d'un pulsar

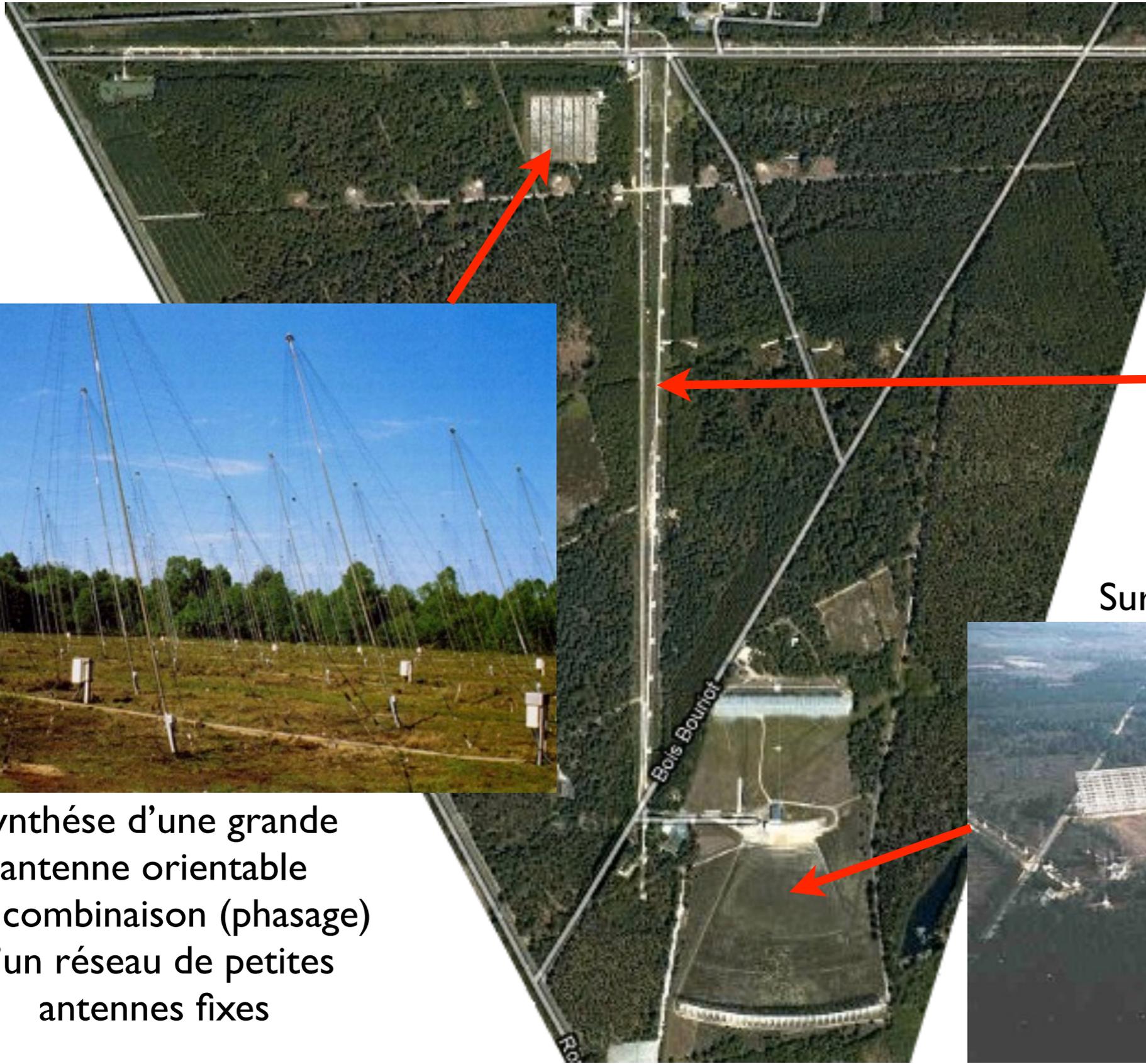
Alexander Wolszczan



Une révolution en route

Nançay

Extension linéaire
(résolution = finesse des détails)



Surface collectrice (sensibilité)



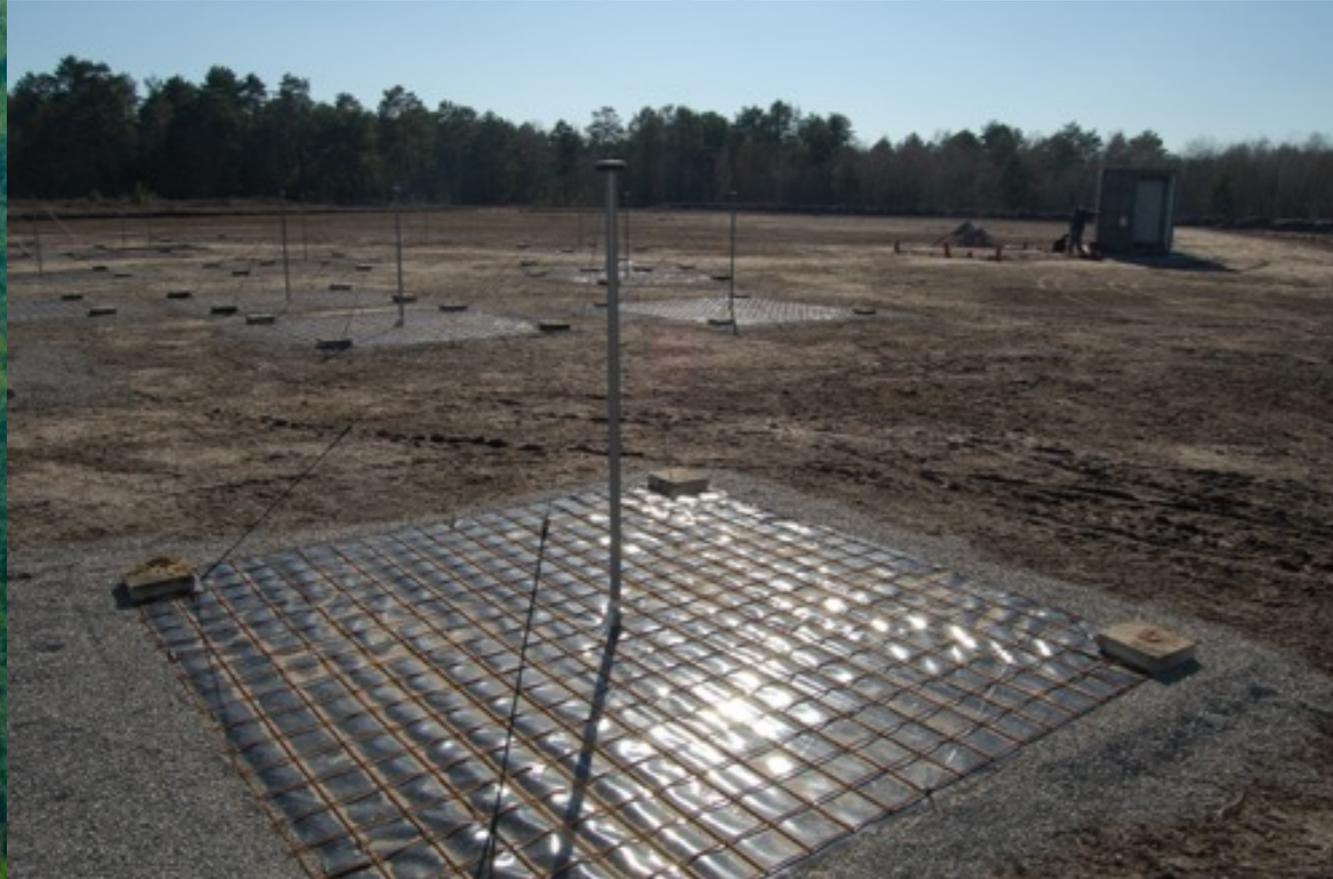
Synthèse d'une grande
antenne orientable
par combinaison (phasage)
d'un réseau de petites
antennes fixes



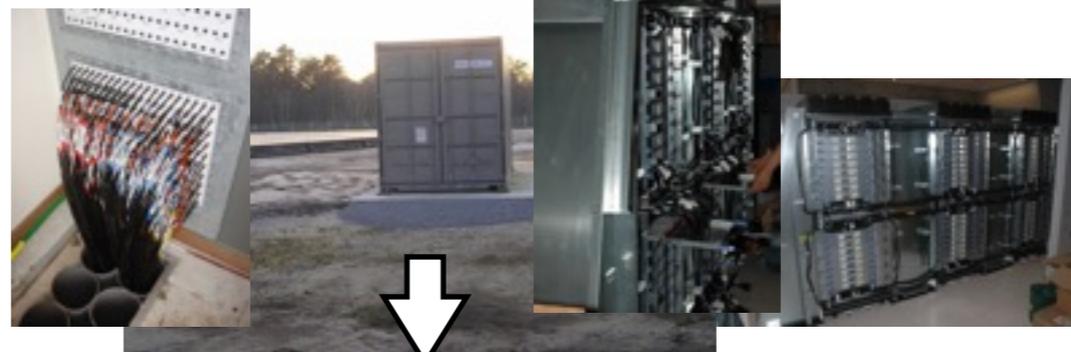
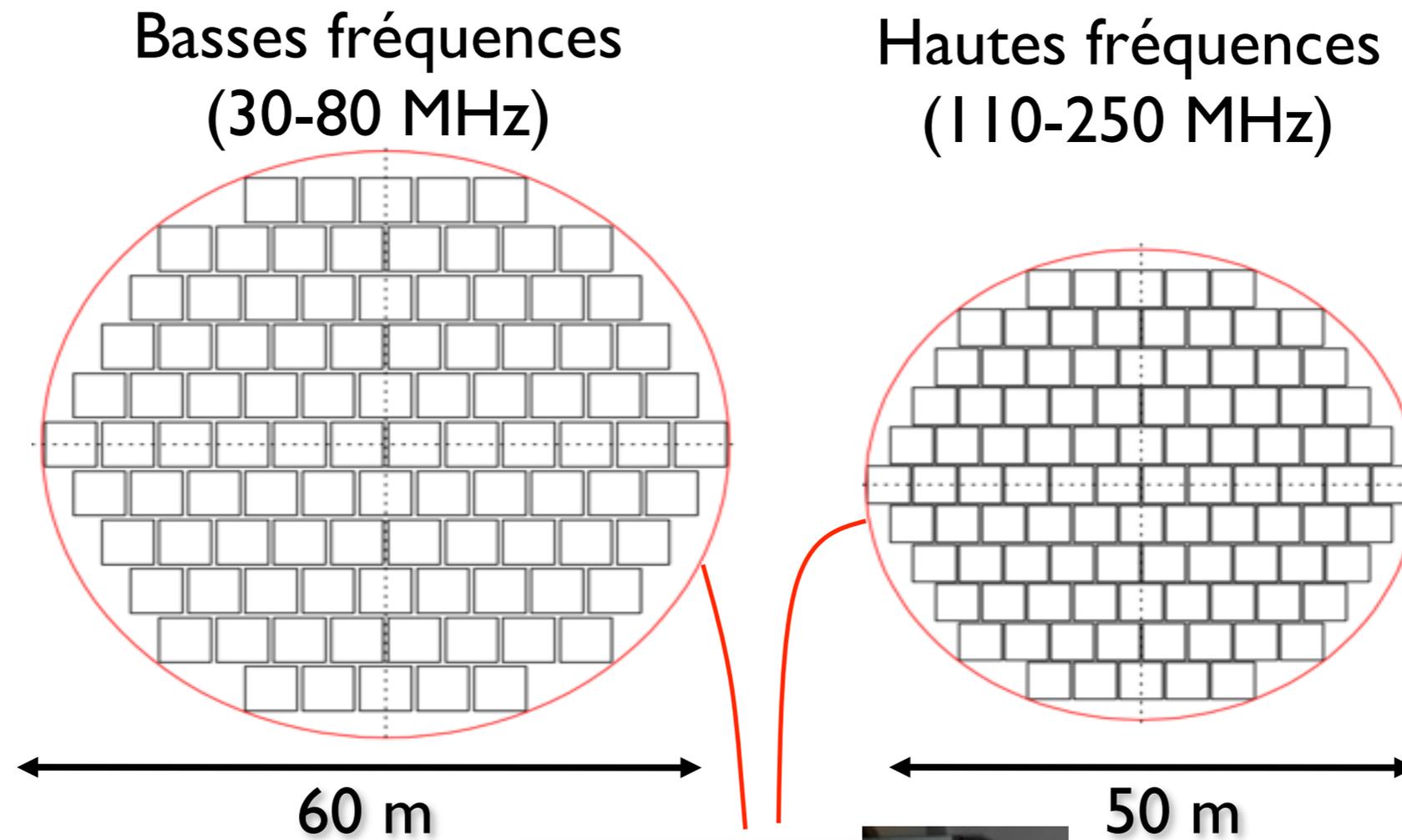
Un nouvel instrument : LOFAR



La station LOFAR de Nançay



Station LOFAR : 2 réseaux phasés + électronique

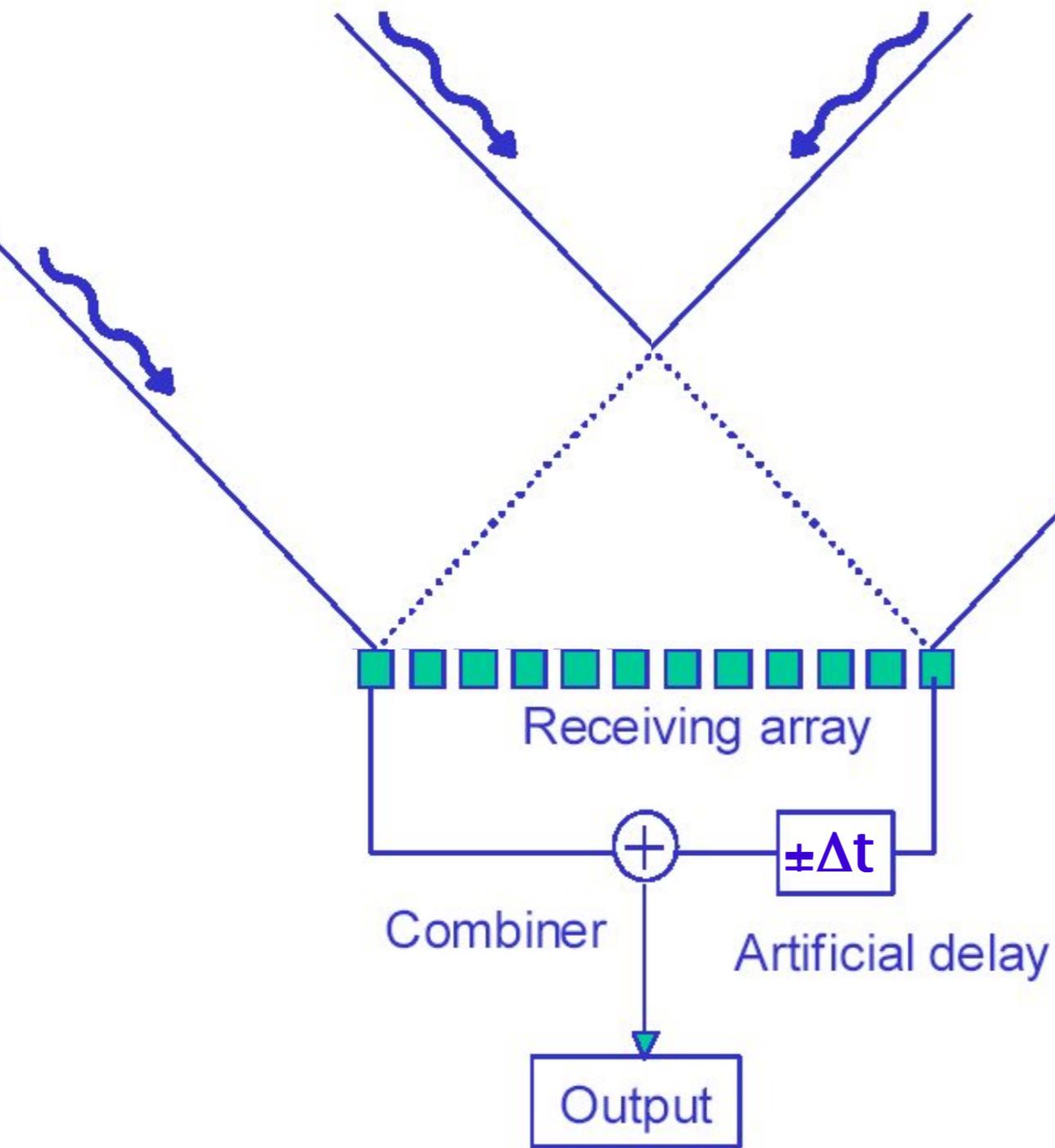


Lien à 3+ Gbit/sec

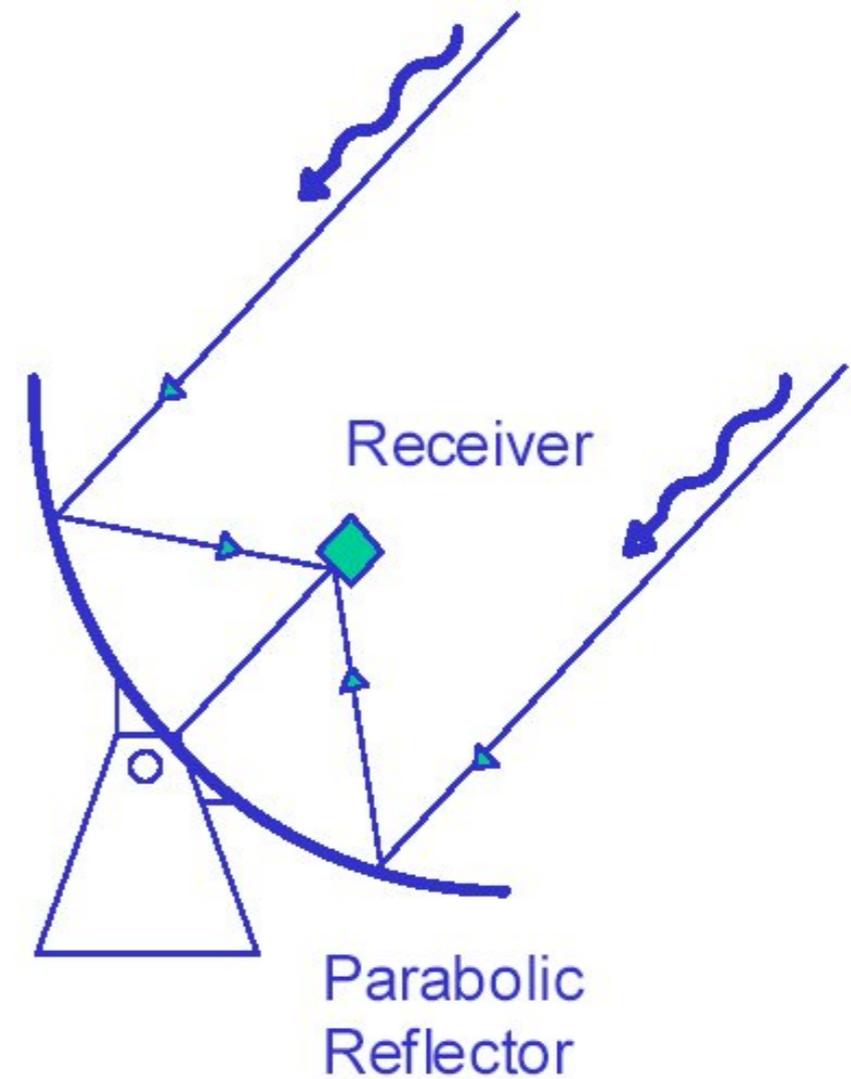
Corrélateur : cluster de GPU



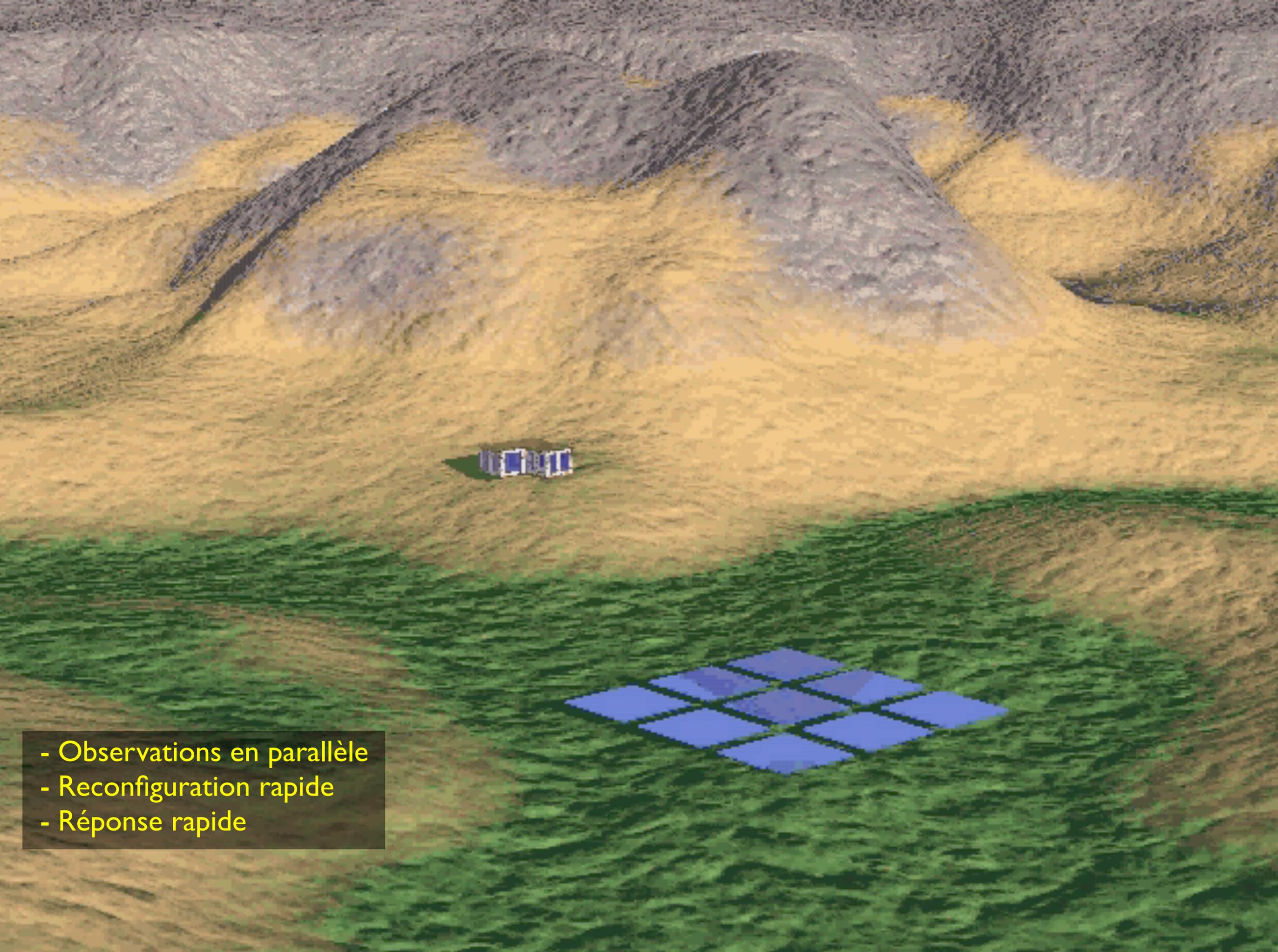
Réseaux phasés d'antennes



Pointage électronique



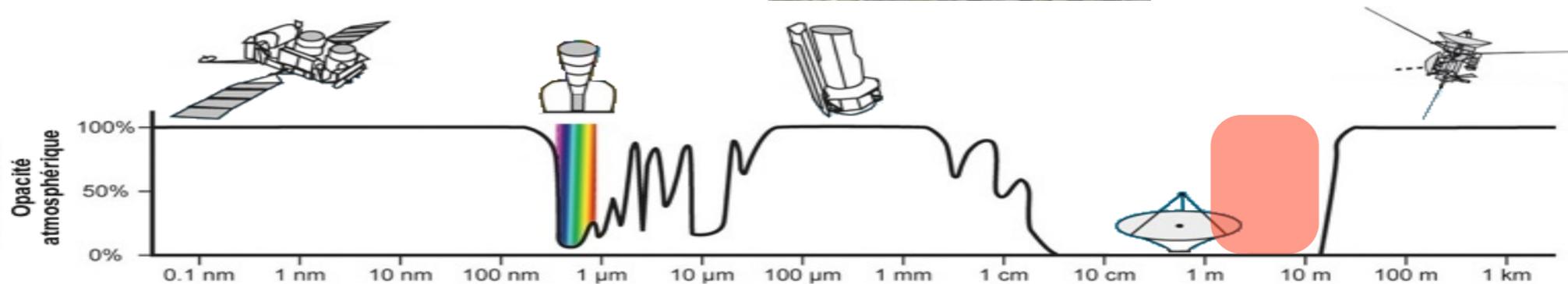
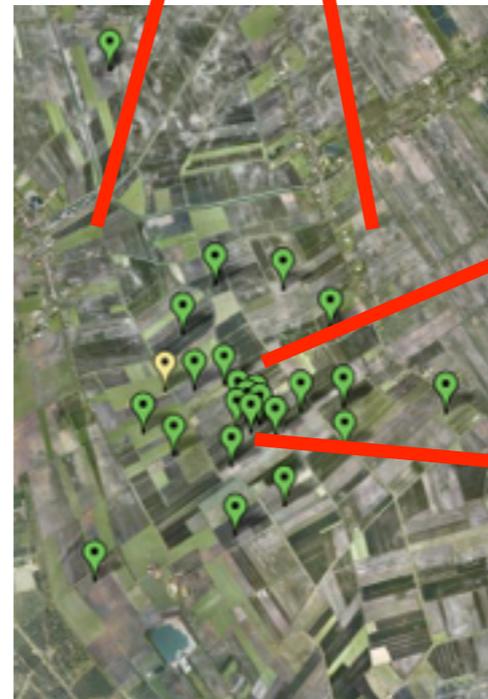
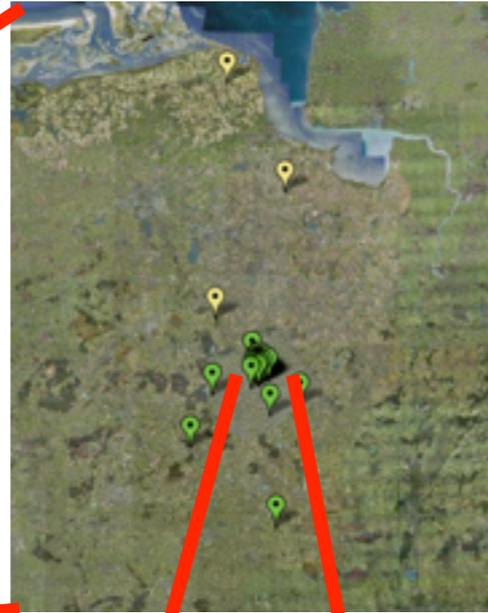
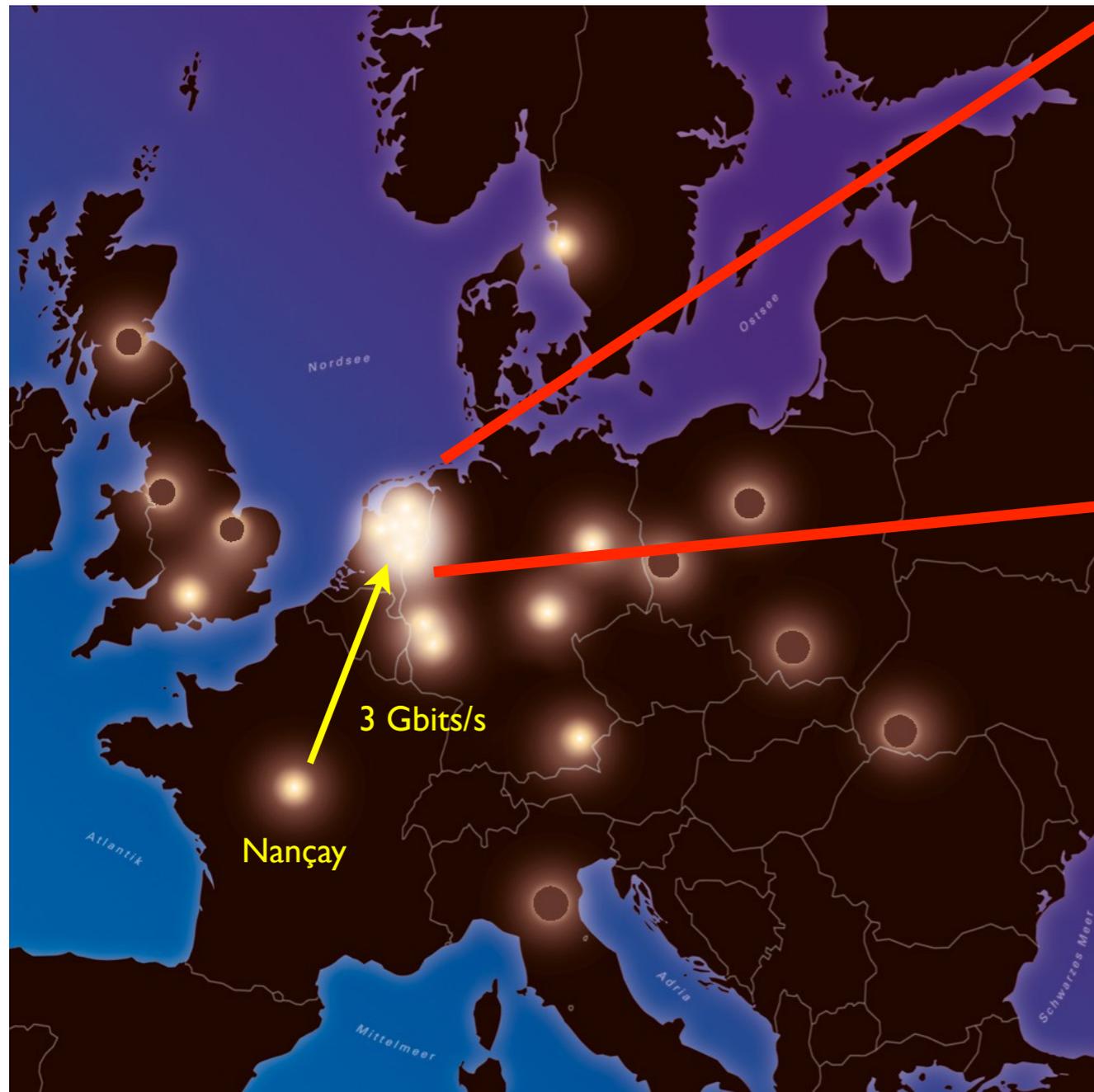
Pointage mécanique



- Observations en parallèle
- Reconfiguration rapide
- Réponse rapide

LOFAR : réseau phasé + interféromètre multi-échelles

développement ≥ 2000 ; exploitation $\geq 1/12/2012$

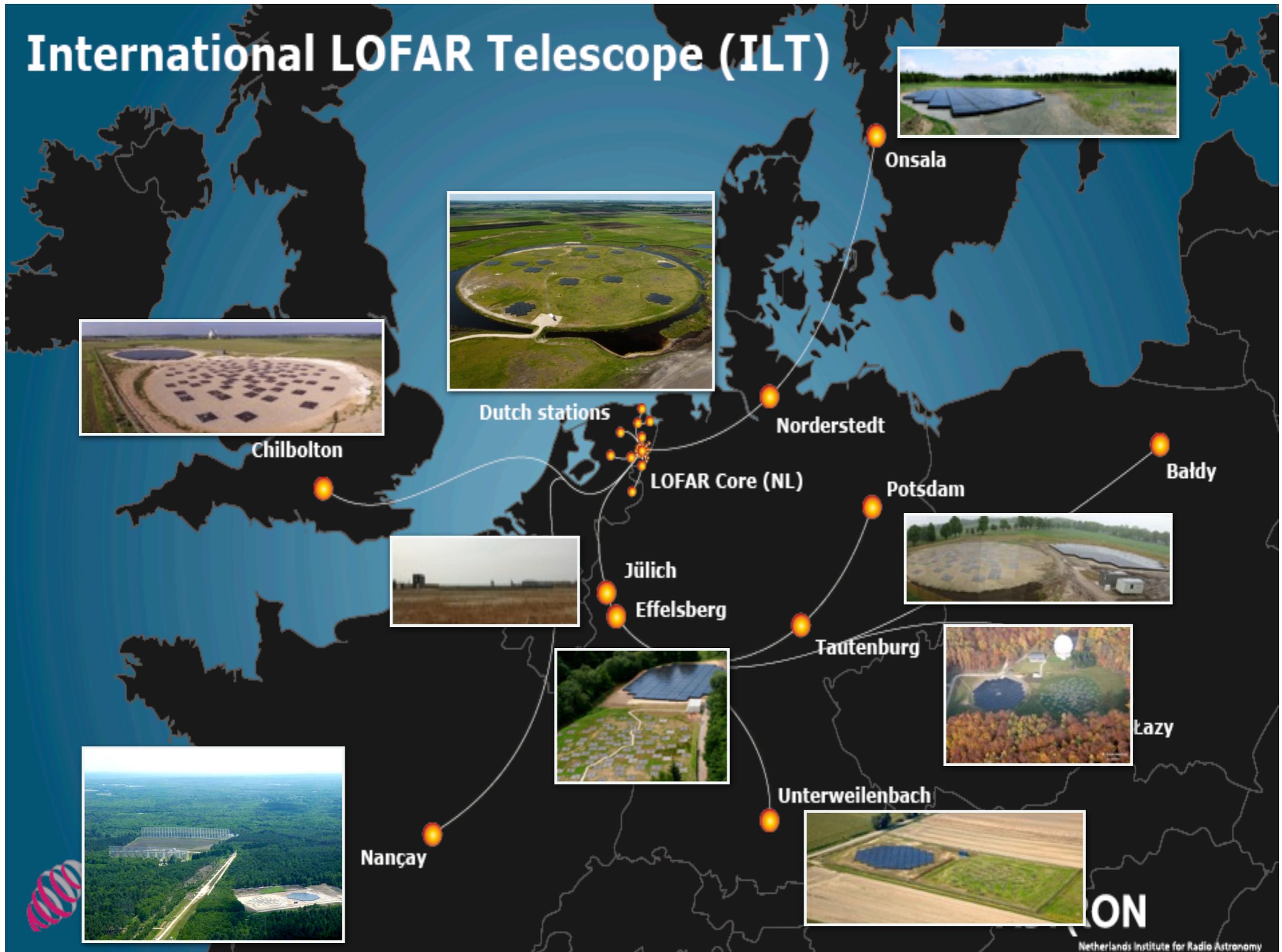


Un "software" télescope



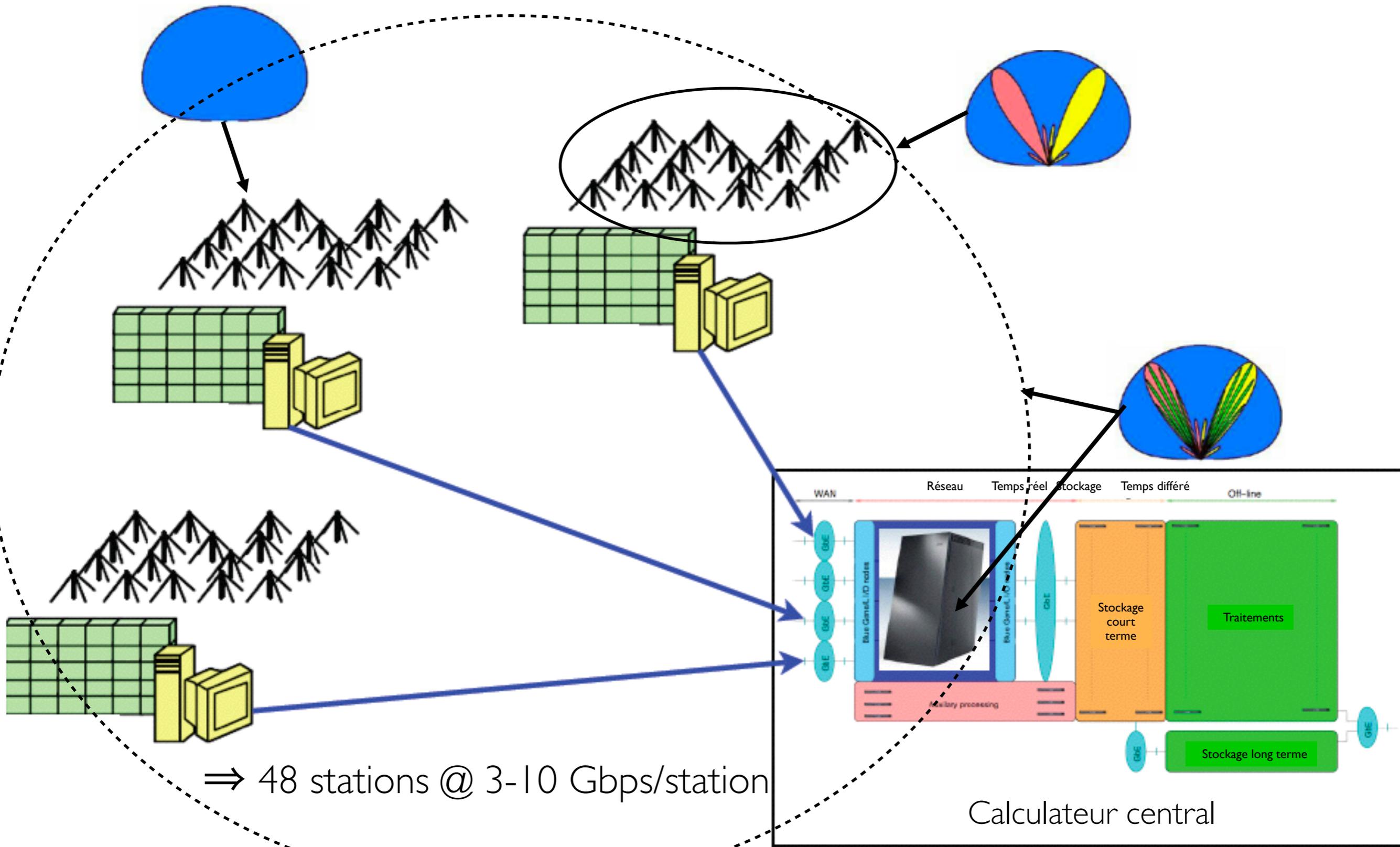
Un radiotélescope Européen

International LOFAR Telescope (ILT)



Le réseau LOFAR

- Traitements «station» : amplification, numérisation, filtrage, beam-forming, buffers «transitoires» (TBB)
- Calculateur central : compensation des délais, corrélation / sommation, étalonnage, trait^s scientifiques

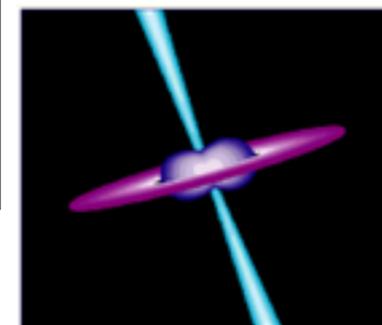
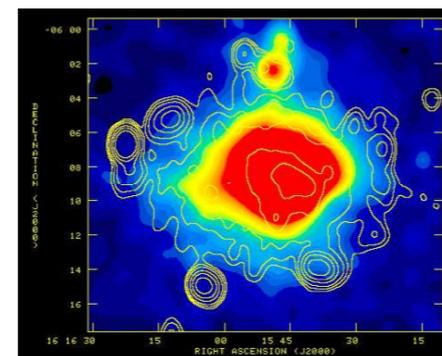
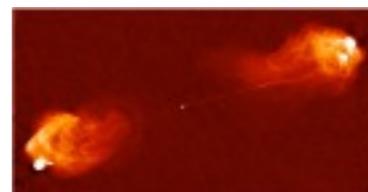
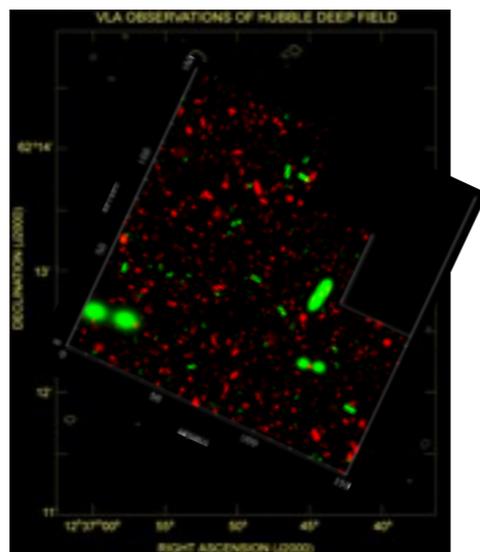
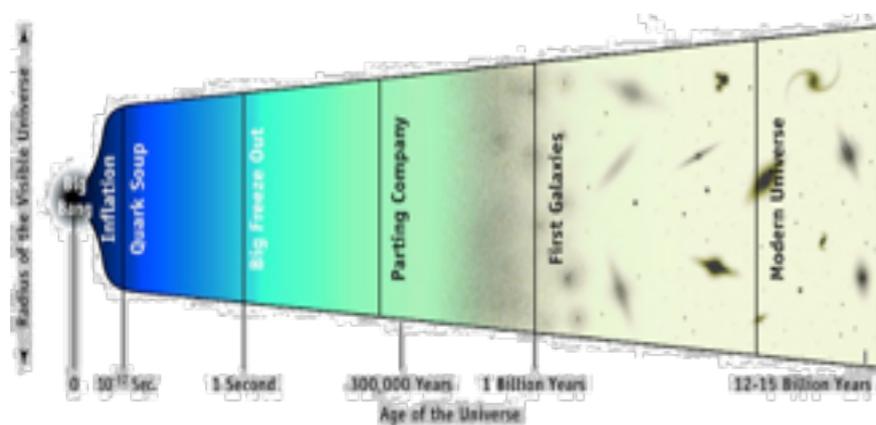


Caractéristiques techniques de LOFAR

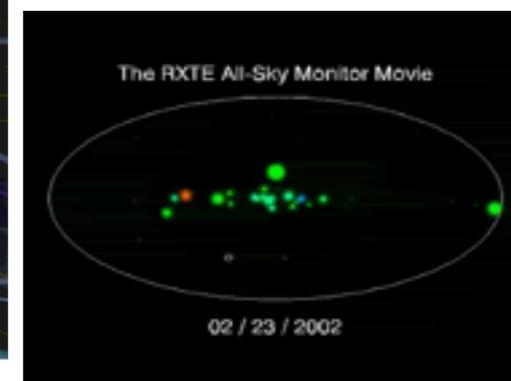
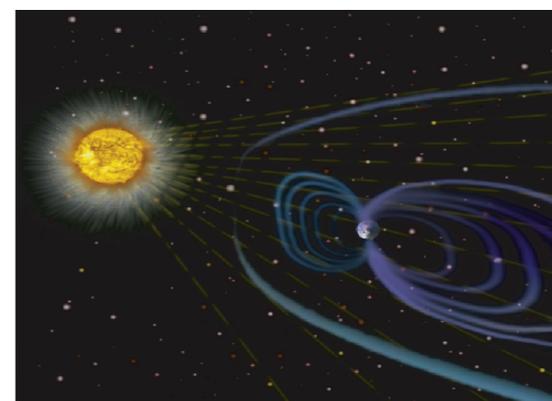
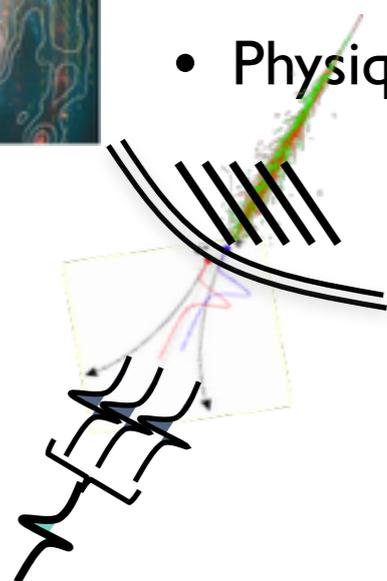
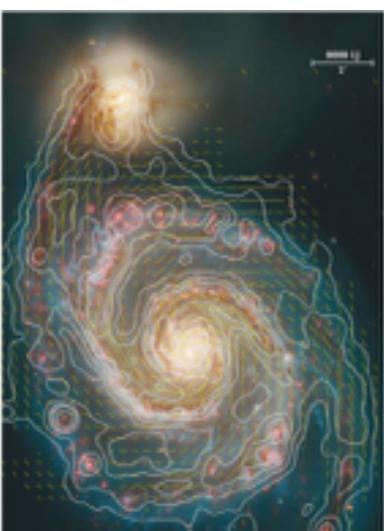
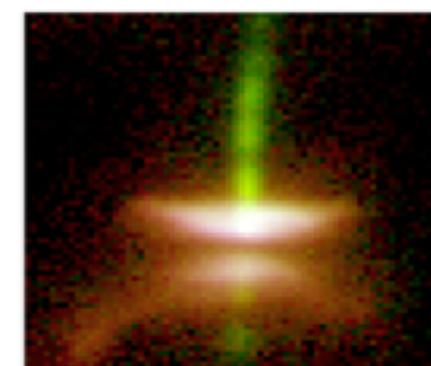
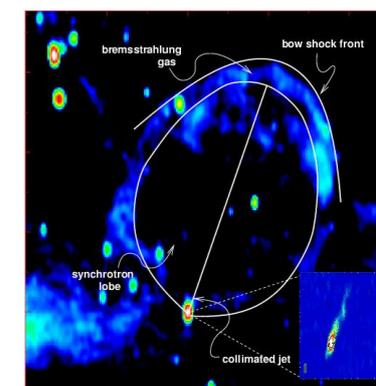
<http://www.lofar.org/>

- « Interféromètre » de « Réseaux phasés » Européen
- 24 stations «coeur» + 16 distantes + 8 internationales
- Diamètre ~100 km (NL) → 1000 km (Europe)
- Aire collectrice ~ 100 000 m² ($\propto \lambda^2$)
- Gamme de fréquences = 30-80 & 110-250 MHz ($\lambda=1.2-10\text{m}$)
- Modes imagerie + Faisceaux cohérents + Mesures ultrarapides
- Résolution ~ 0.1 " - 10 ", grand champs ($\sim 10^\circ$)
- Sensibilité < mJy ($10^{-29} \text{Wm}^{-2}\text{Hz}^{-1}$)
- Résolutions → 1 msec × 1 kHz, Polarisation complète
- Élimination des parasites, « optique adaptative » ionosphérique
- Premier spectro-imageur Basses Fréquences « généraliste »
- 1^{er} «pathfinder» de SKA

La Science de LOFAR



- Cosmologie / Réionisation, Ières étoiles (Groningen)
- Surveys profonds, formation stellaire, AGN, amas... (Leiden)
- Transitoires = Sources sporadiques (Amst./Manch./NRAO/Obs. Paris)
- Rayons cosmiques, neutrinos/Lune (Nijmegen)
- Magnétisme galactique (Bonn)
- Physique solaire & spatiale (Potsdam)

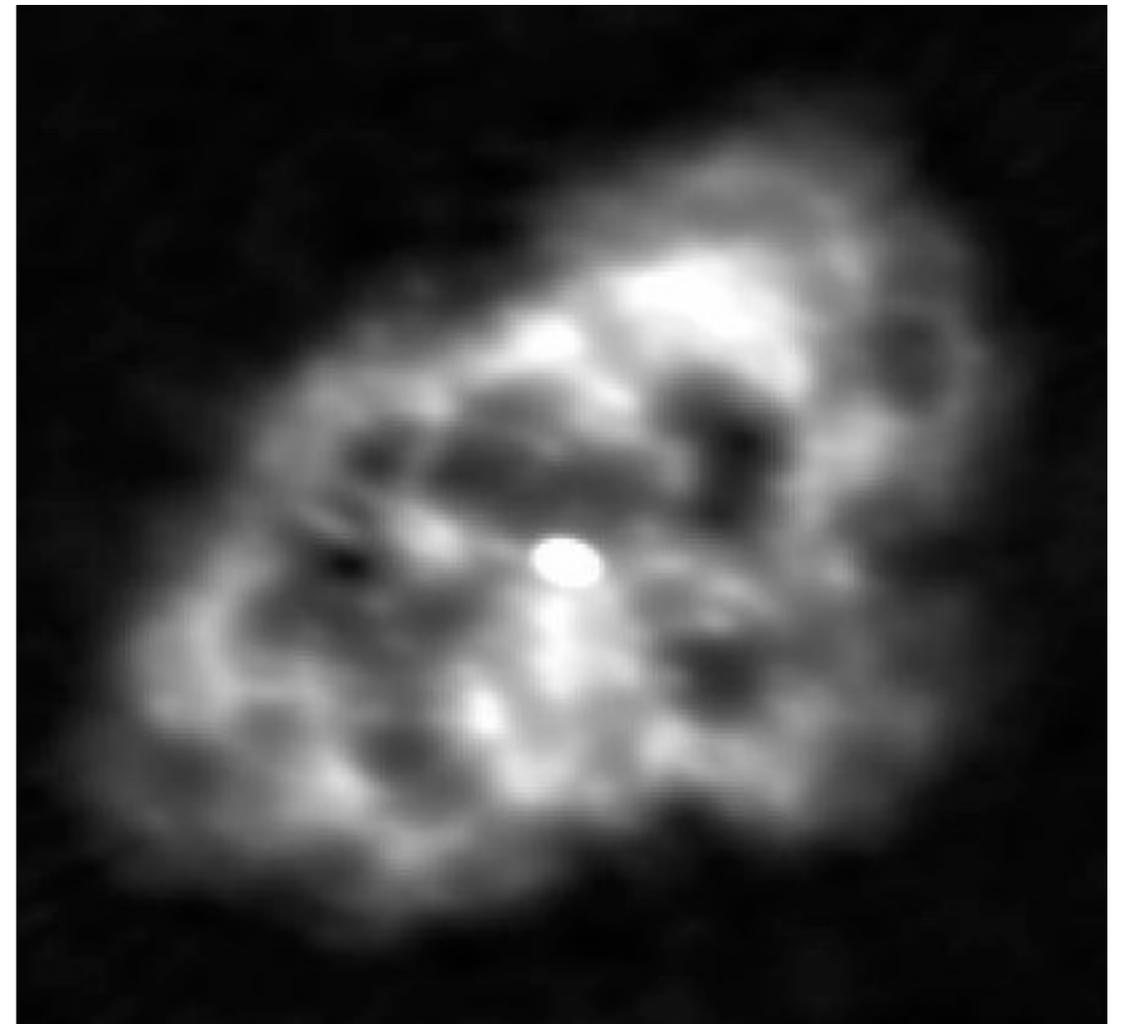


Nébuleuse du Crabe (Taurus A)

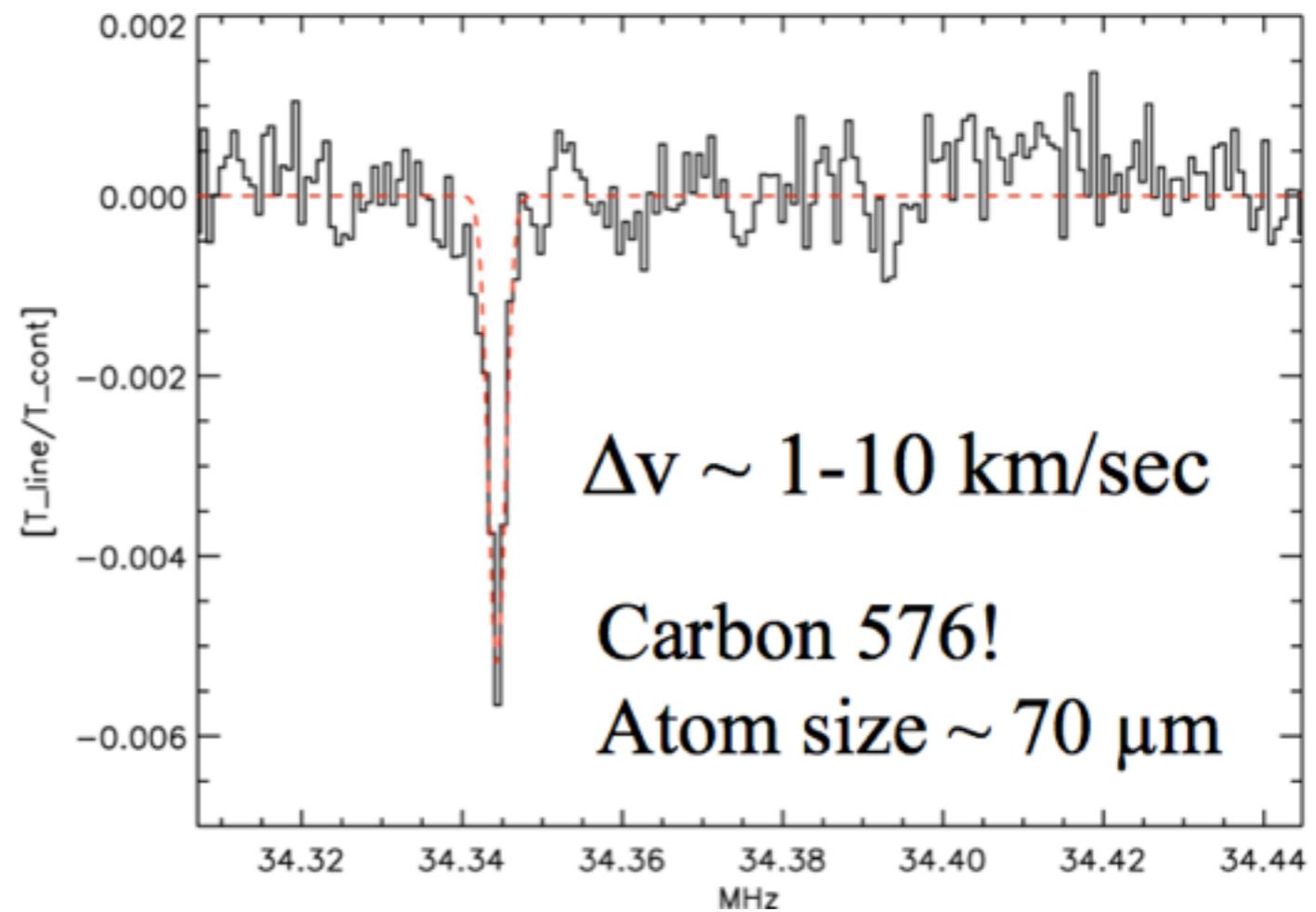
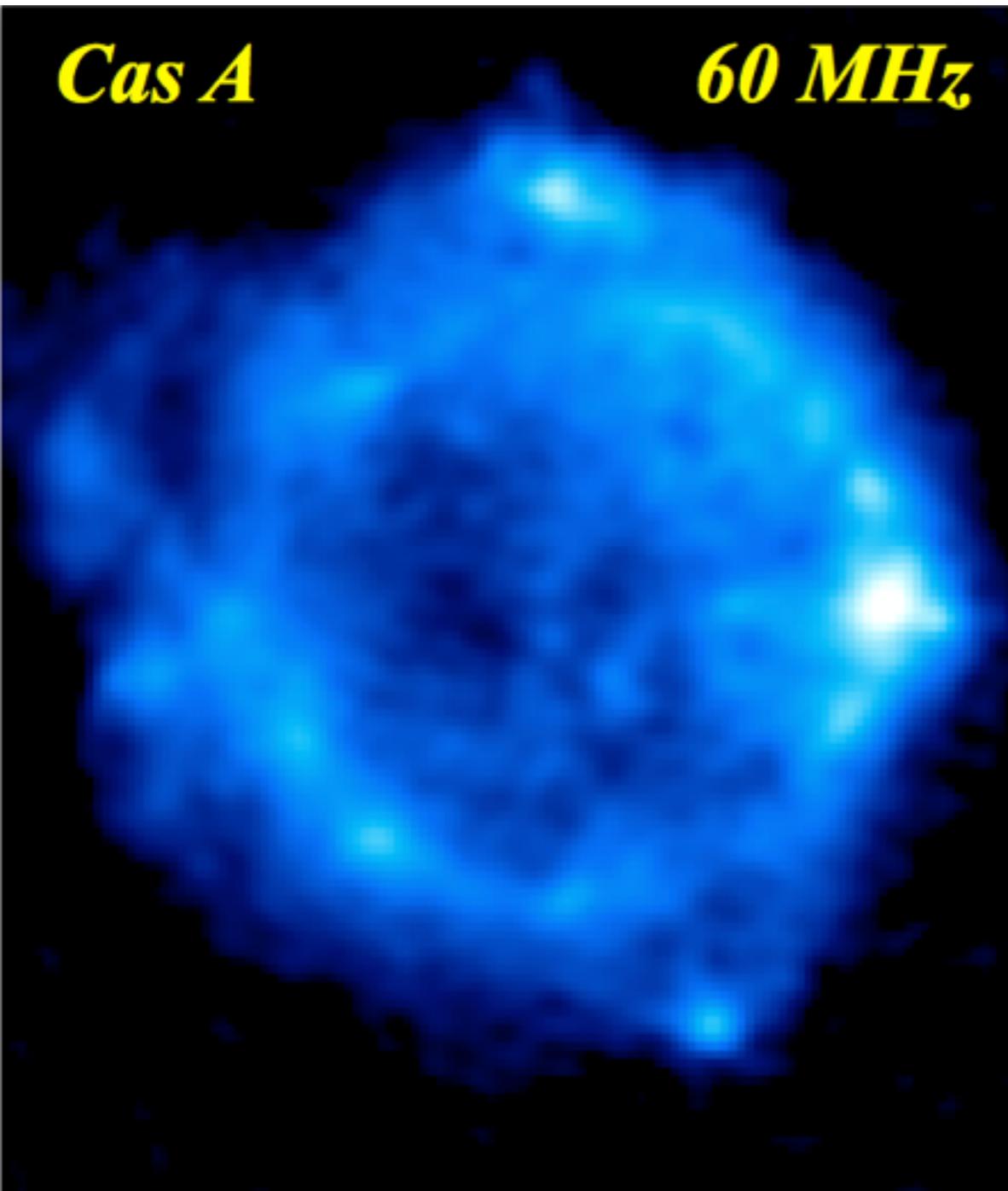
Optique/X



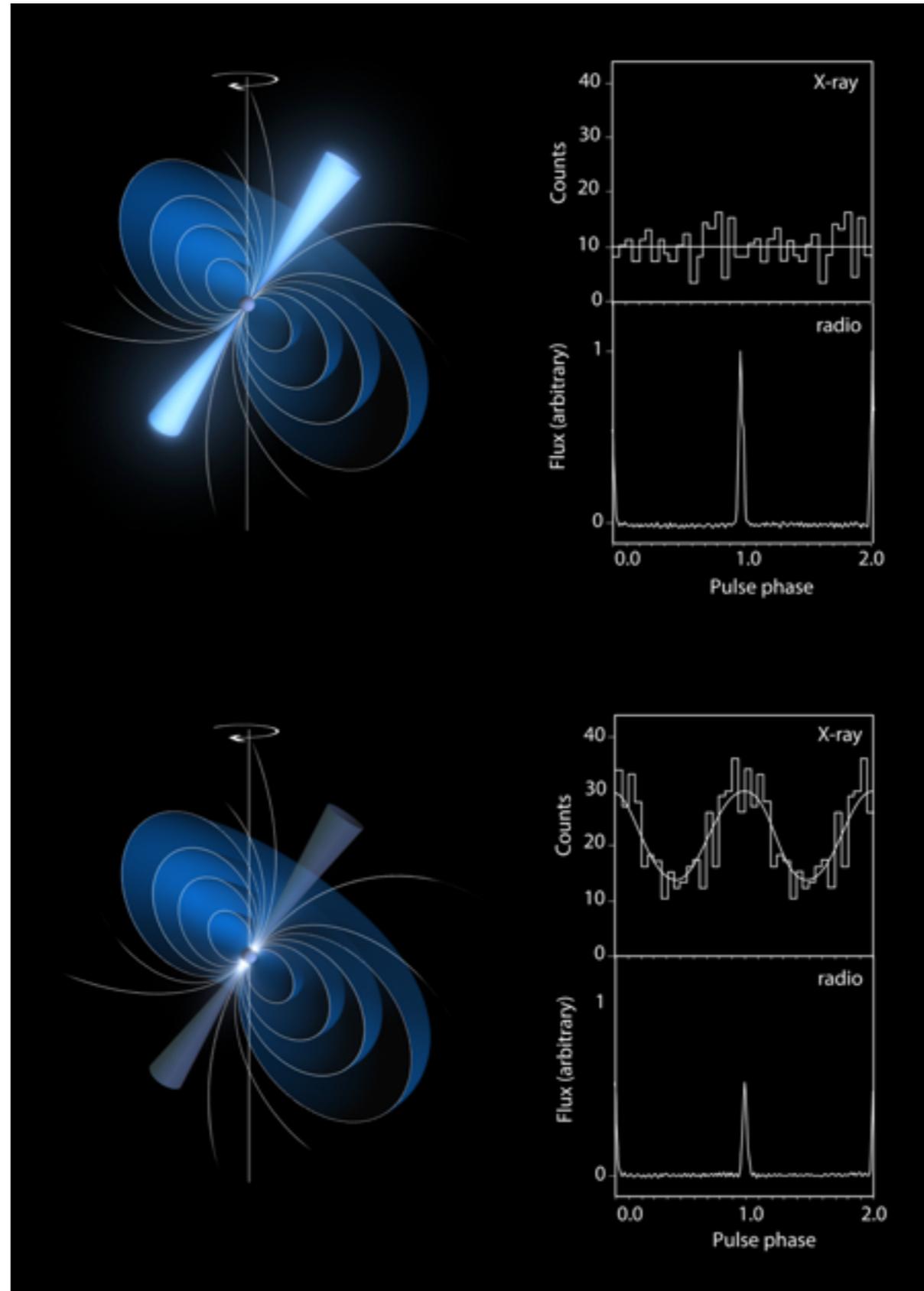
LOFAR 250 MHz



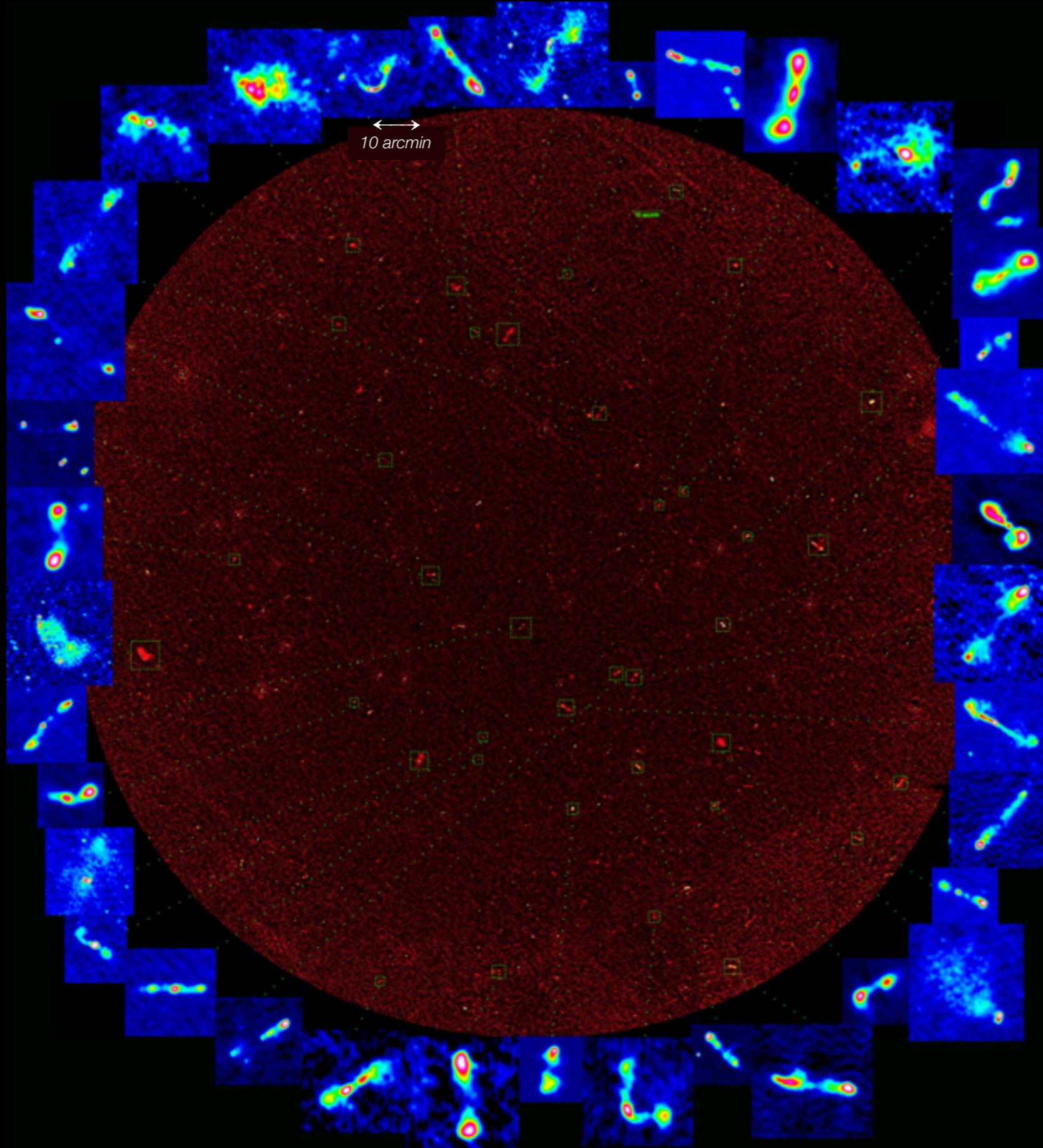
Raies de recombinaison atomiques



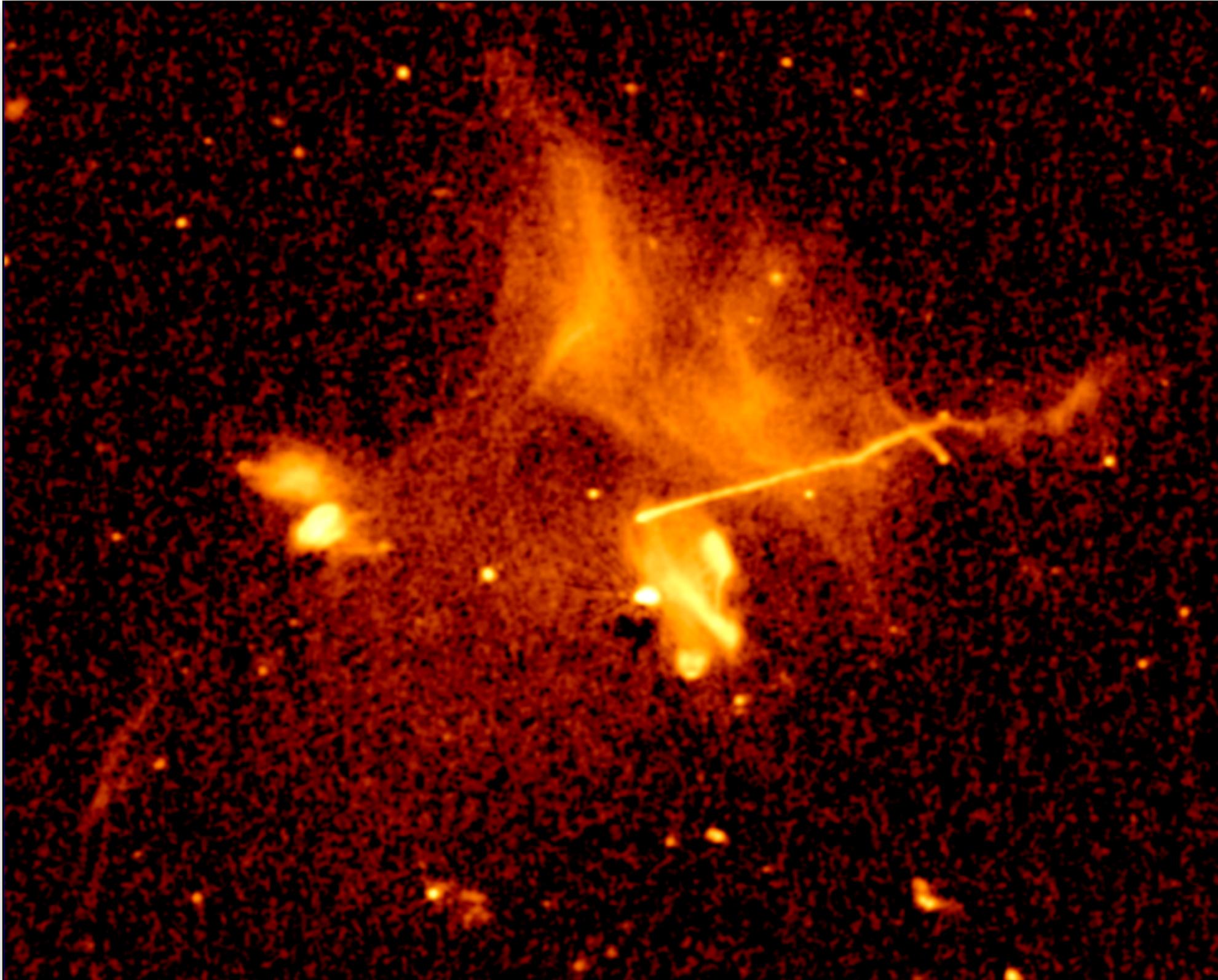
Pulsar X-radio



Galaxies

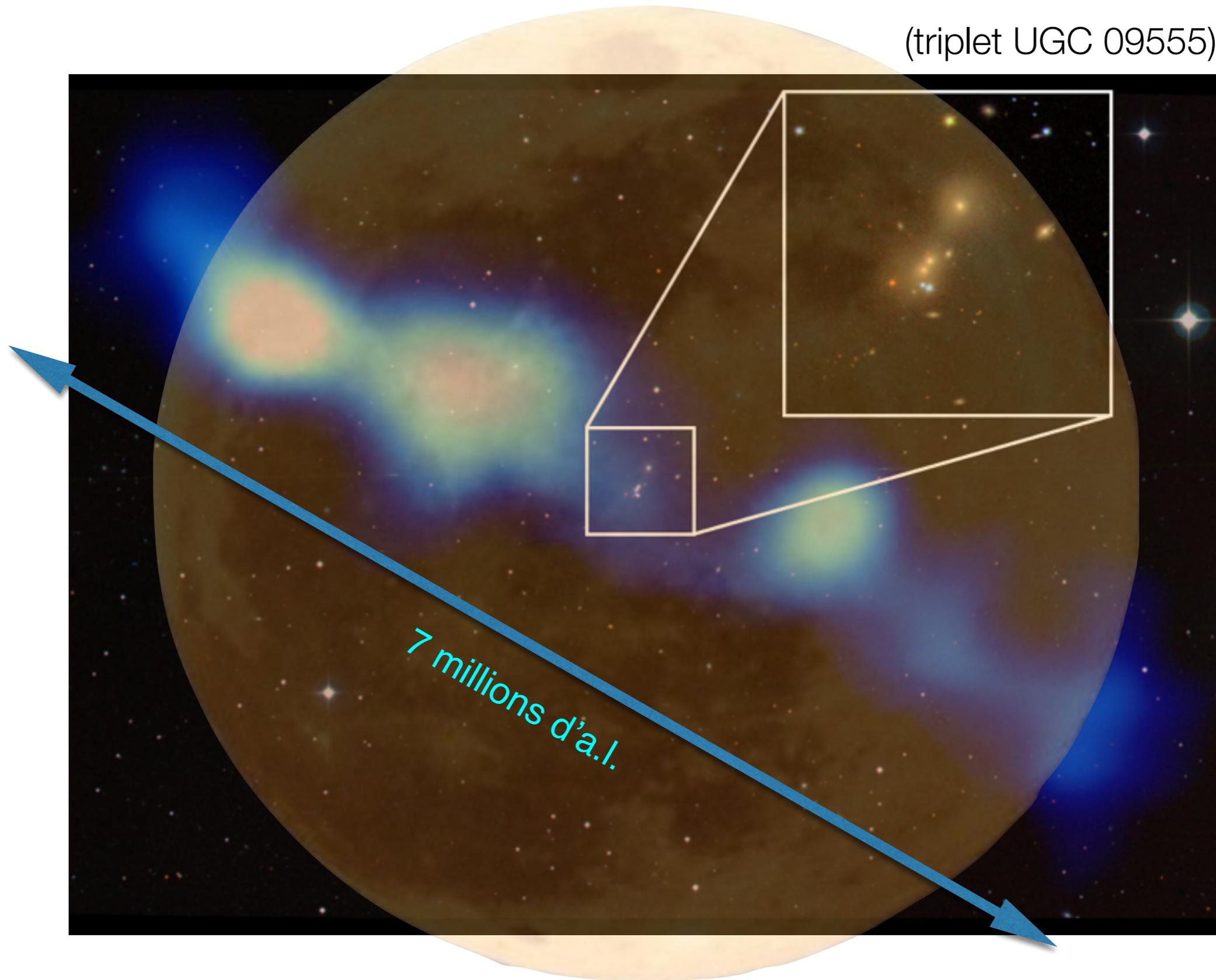


Galaxies

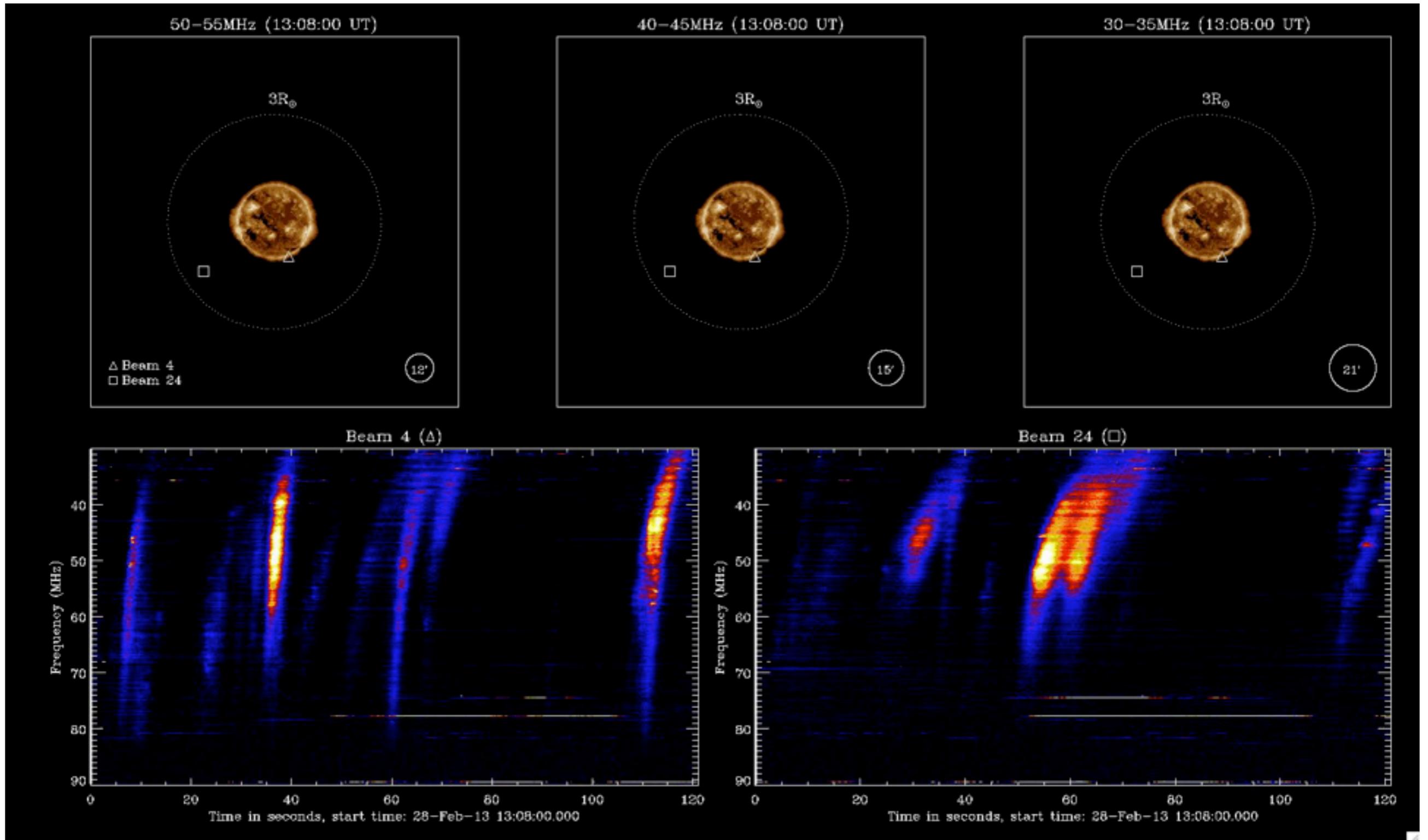


Radiogalaxie géante

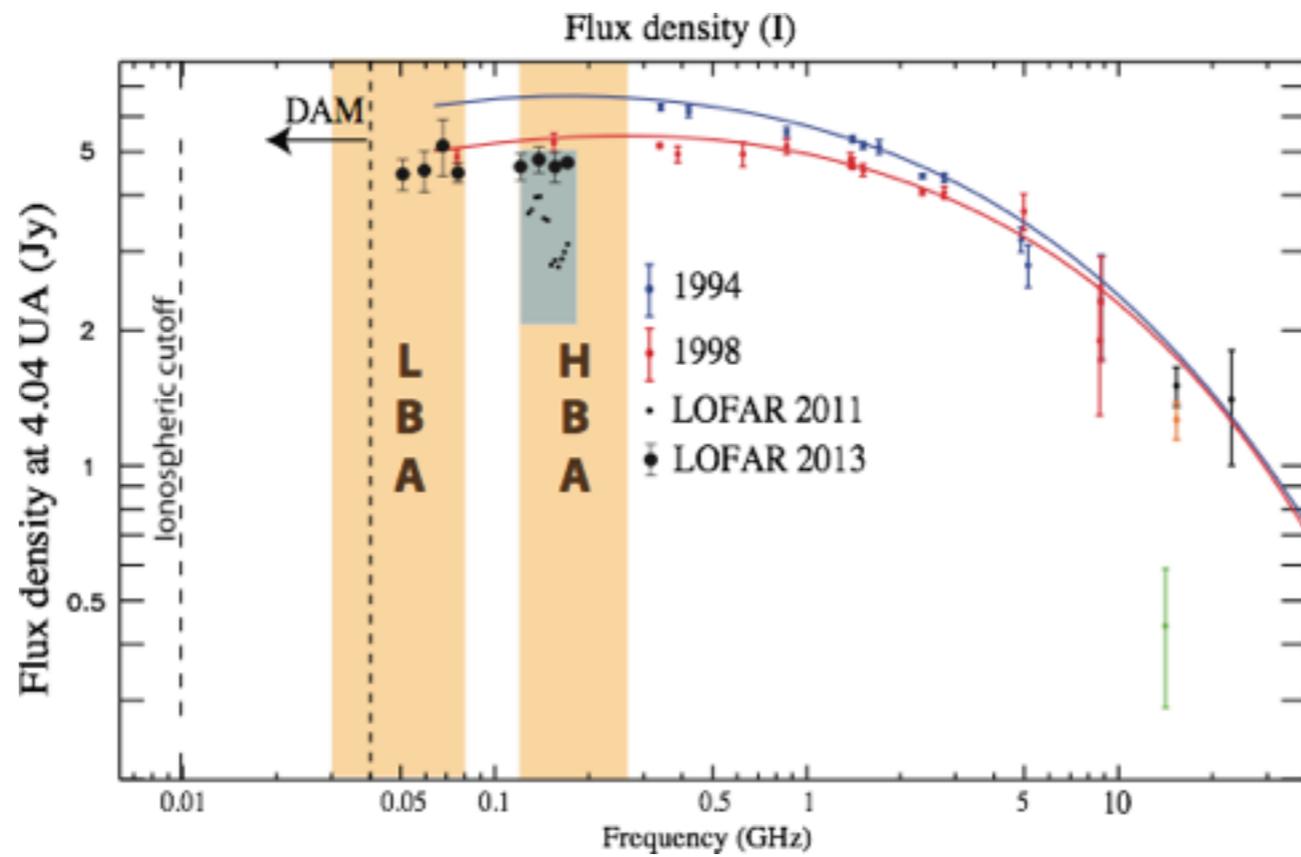
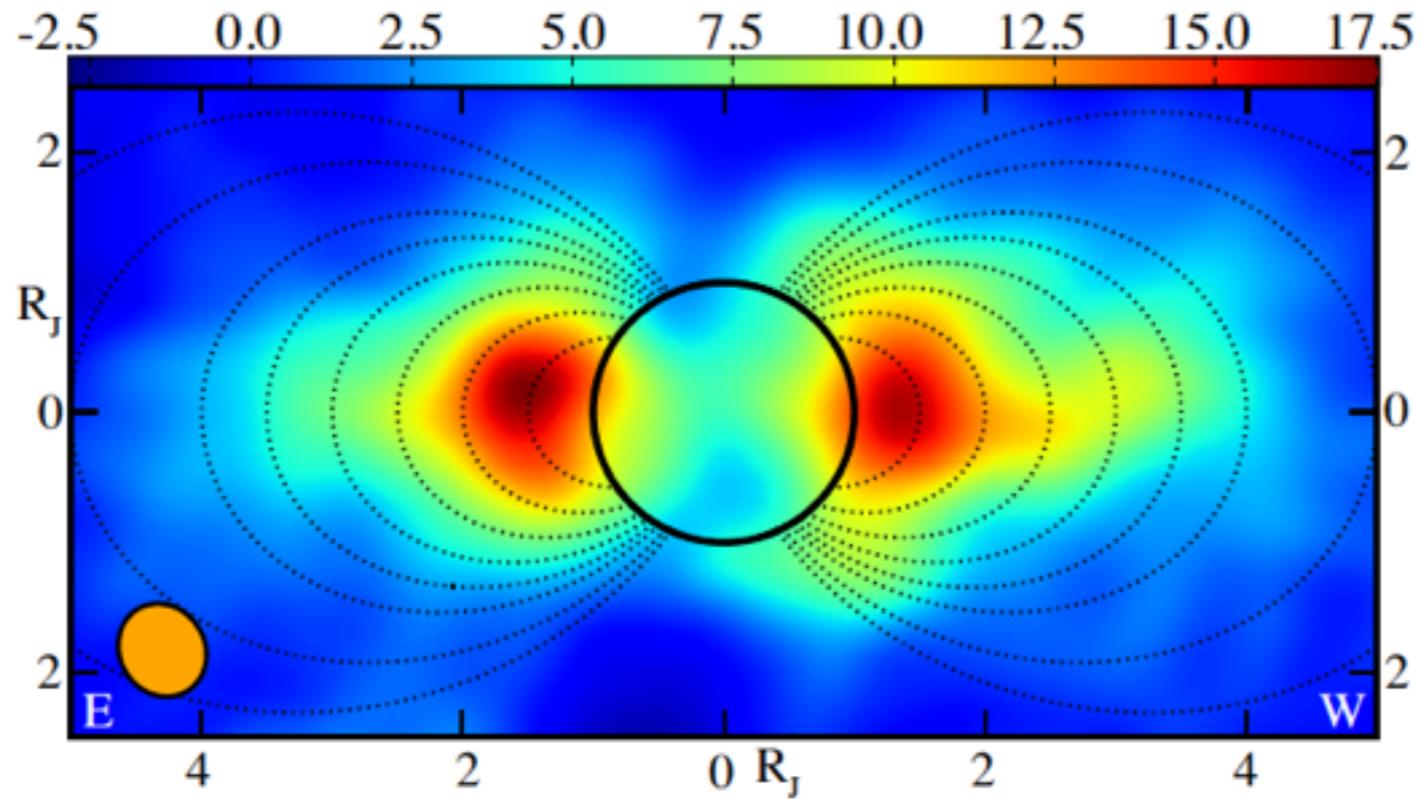
(triplet UGC 09555)



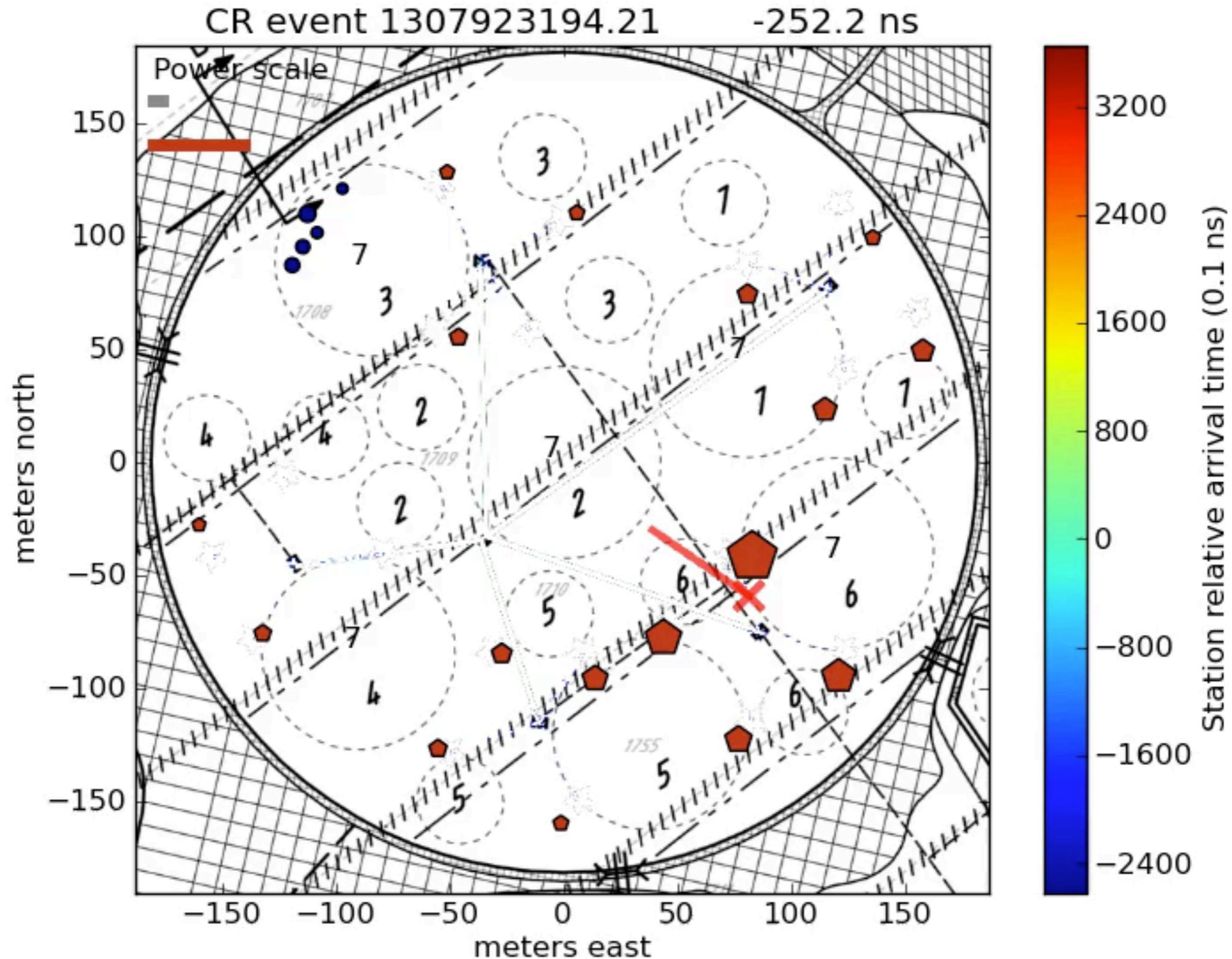
Sursauts solaires



Jupiter

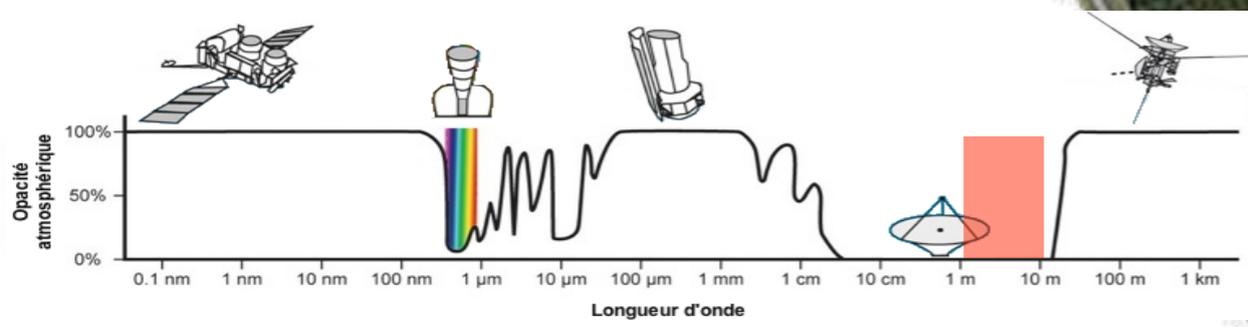


Rayons cosmiques



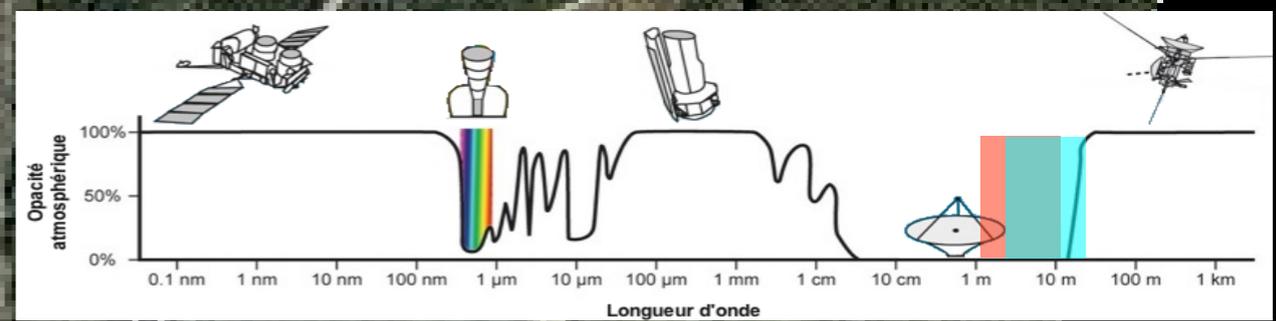
Circles: LOFAR antennas, Pentagons: LORA particle detectors, size denotes signal strength

De LOFAR à ...



... NenuFAR

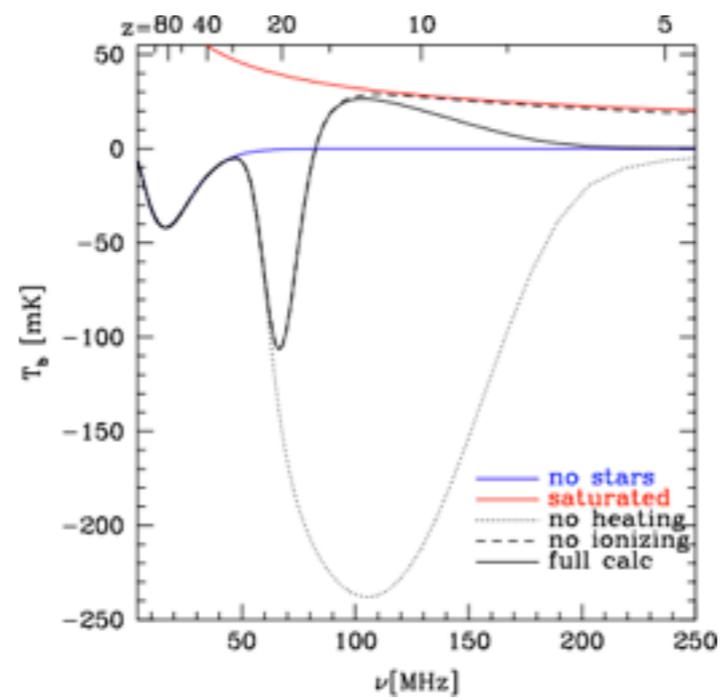
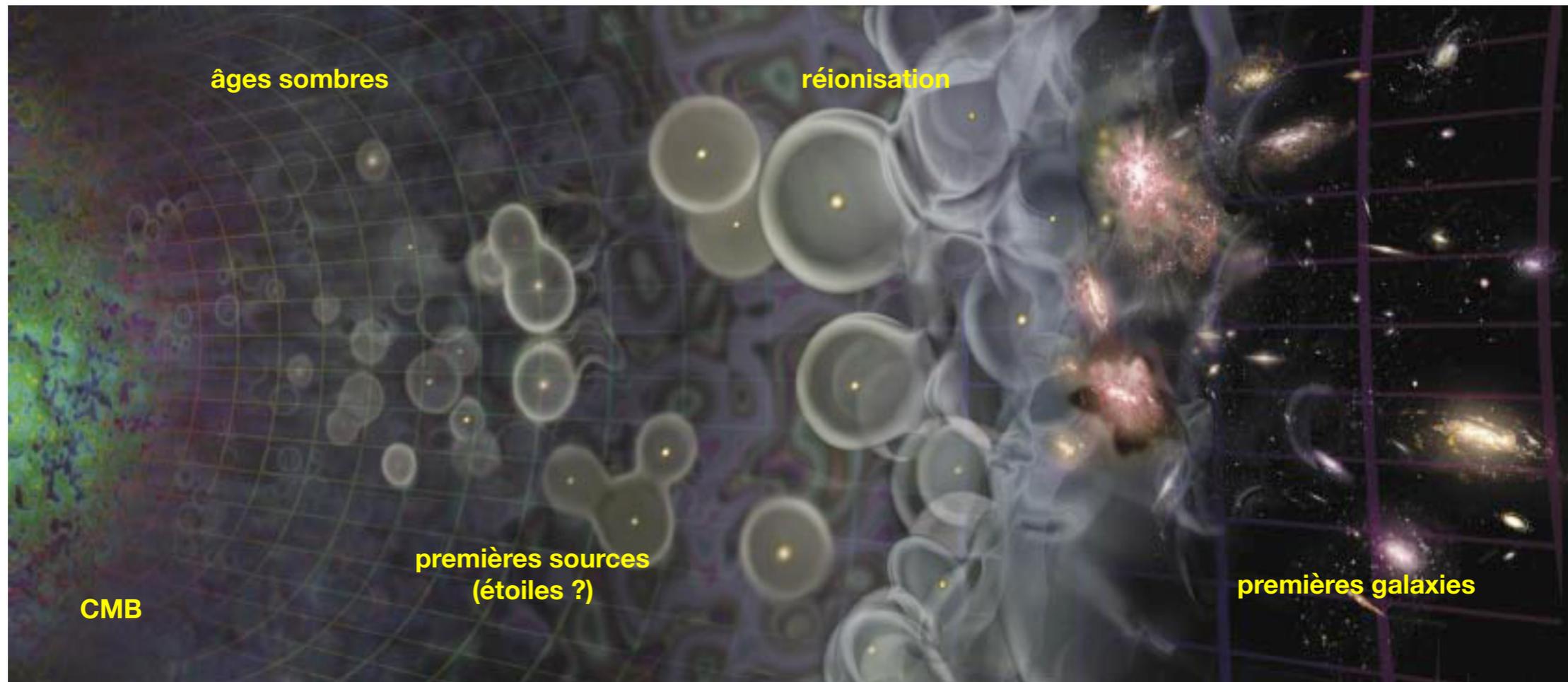
New extension in Nançay upgrading LOFAR



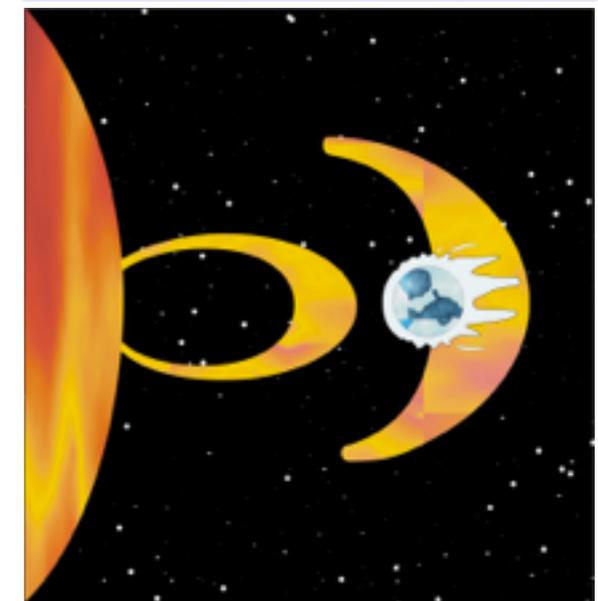
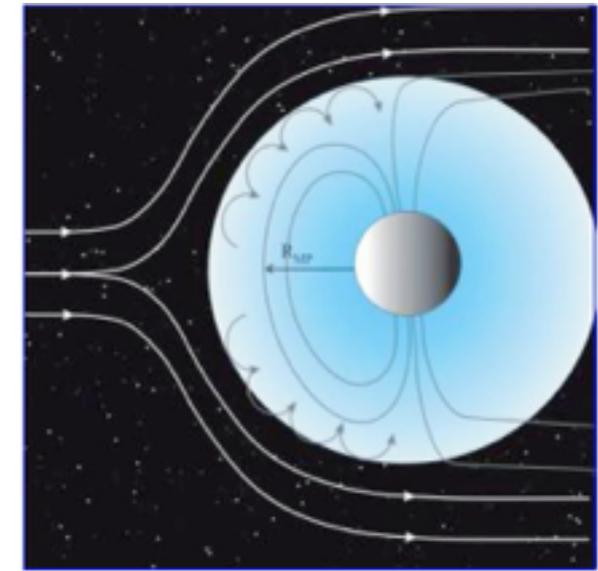
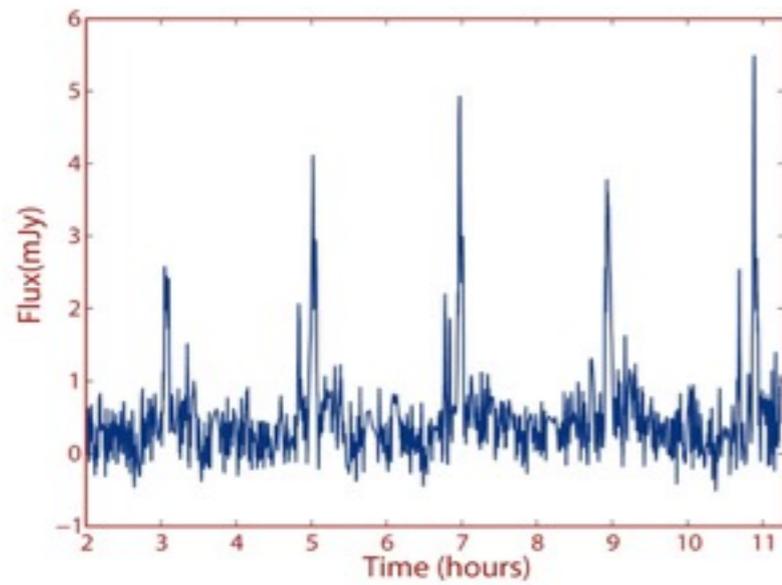
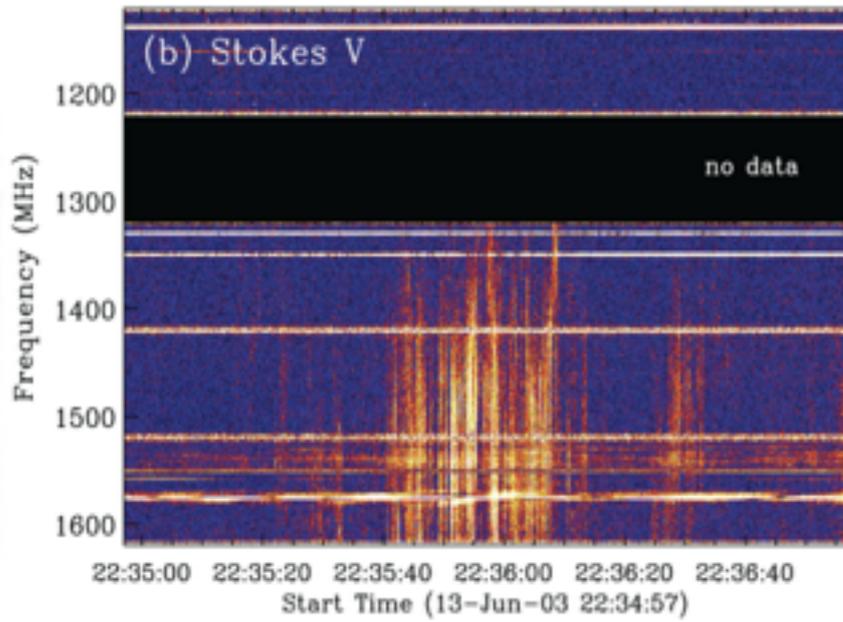
NenuFAR



L'aube cosmique



Étoiles éruptives et exoplanètes

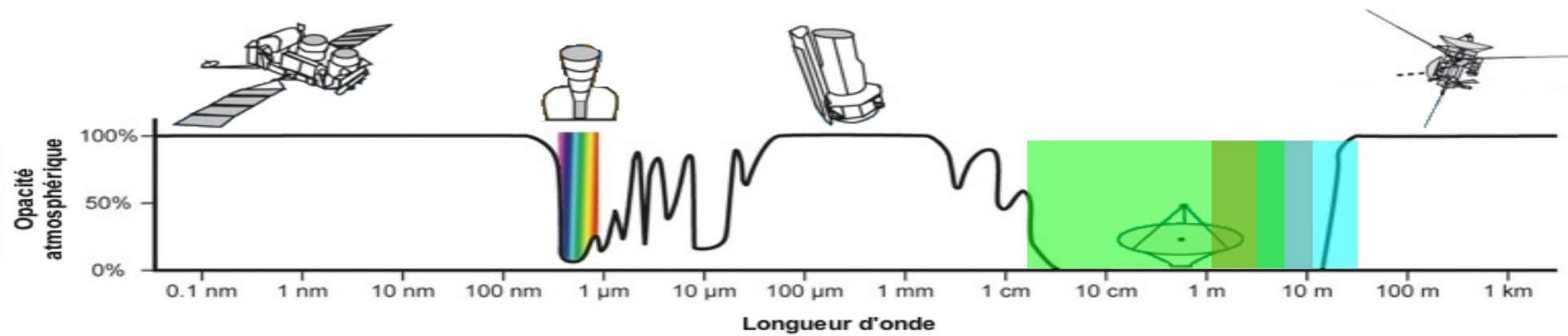


The background is a collage of green leaves, some showing signs of aging and brown spots. Overlaid on this are numerous circular images, each showing a white, multi-armed irrigation system (likely a center pivot system) in a green field. The text is written in a stylized, hand-drawn font.

WENUFAR

Le projet dans les temps

Le futur : SKA, le réseau d'1 km²



SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

SKA Phase 1



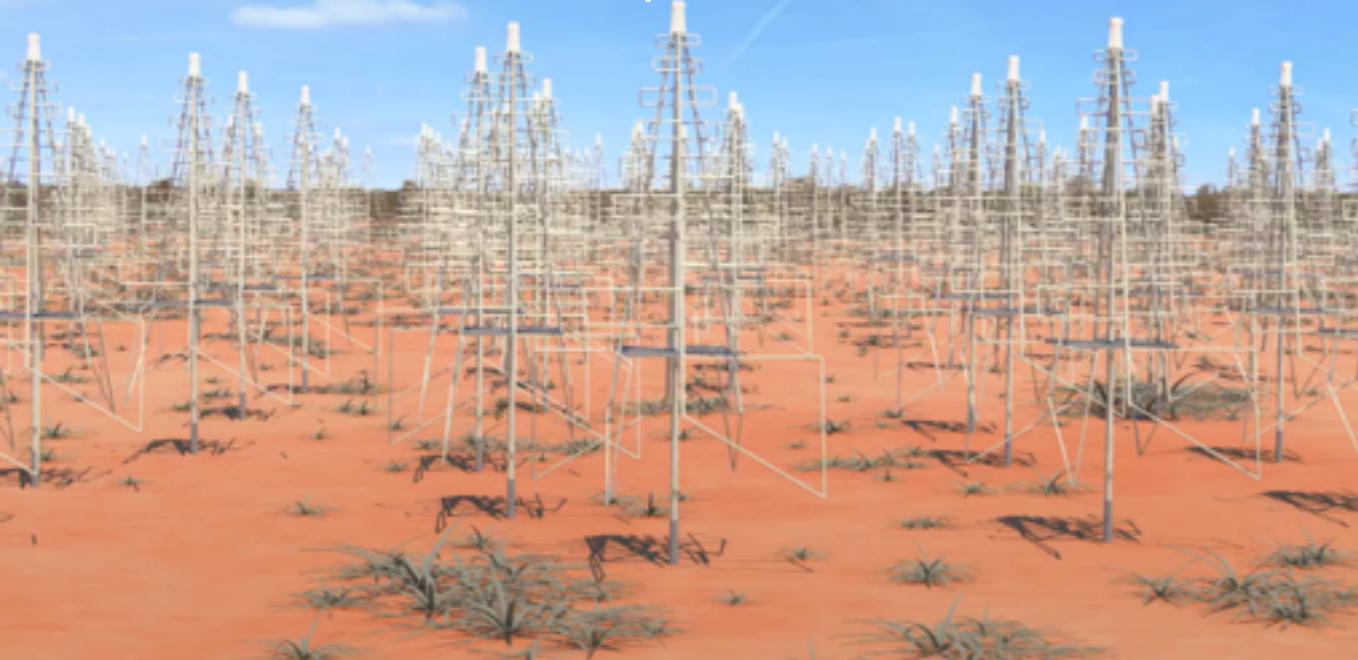
2 sites (Afrique du Sud, Australie);
3 telescopes; 1 Observatoire
Frequencies : 50 MHz – 14 GHz

Coût visé: 650 M€
Construction: 2018 – 2023
Début exploit. Sci.: 2020
SKA Phase 2: 2023 - 2030

SKA-Mid: ~ 190 paraboles de 15m + MeerKAT, RSA



SKA-Low: ~ 250,000 dipôles BF, AUS



SKA-Survey: ~ 60 paraboles de 15m + ASKAP, AUS

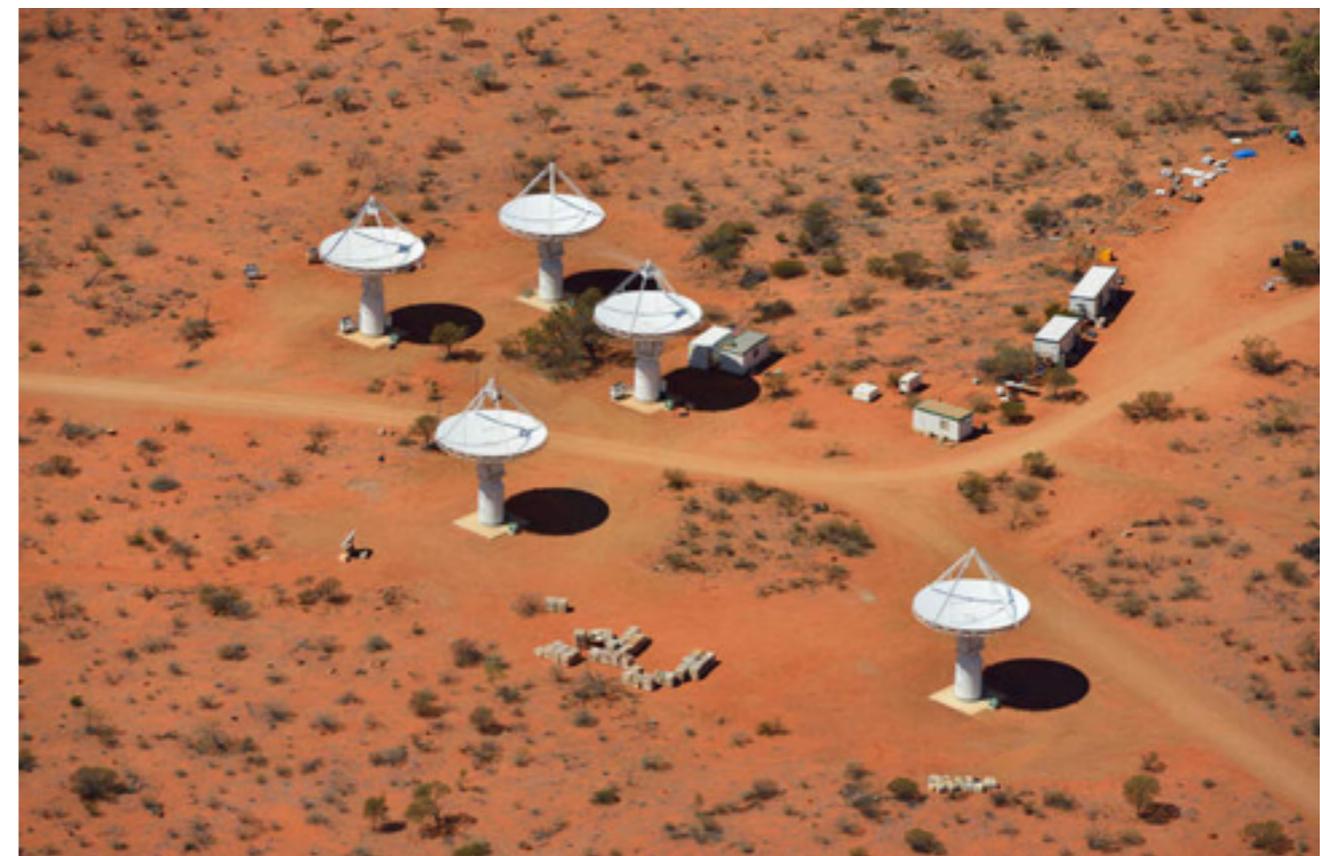


SKA Phase 1



Précurseurs:

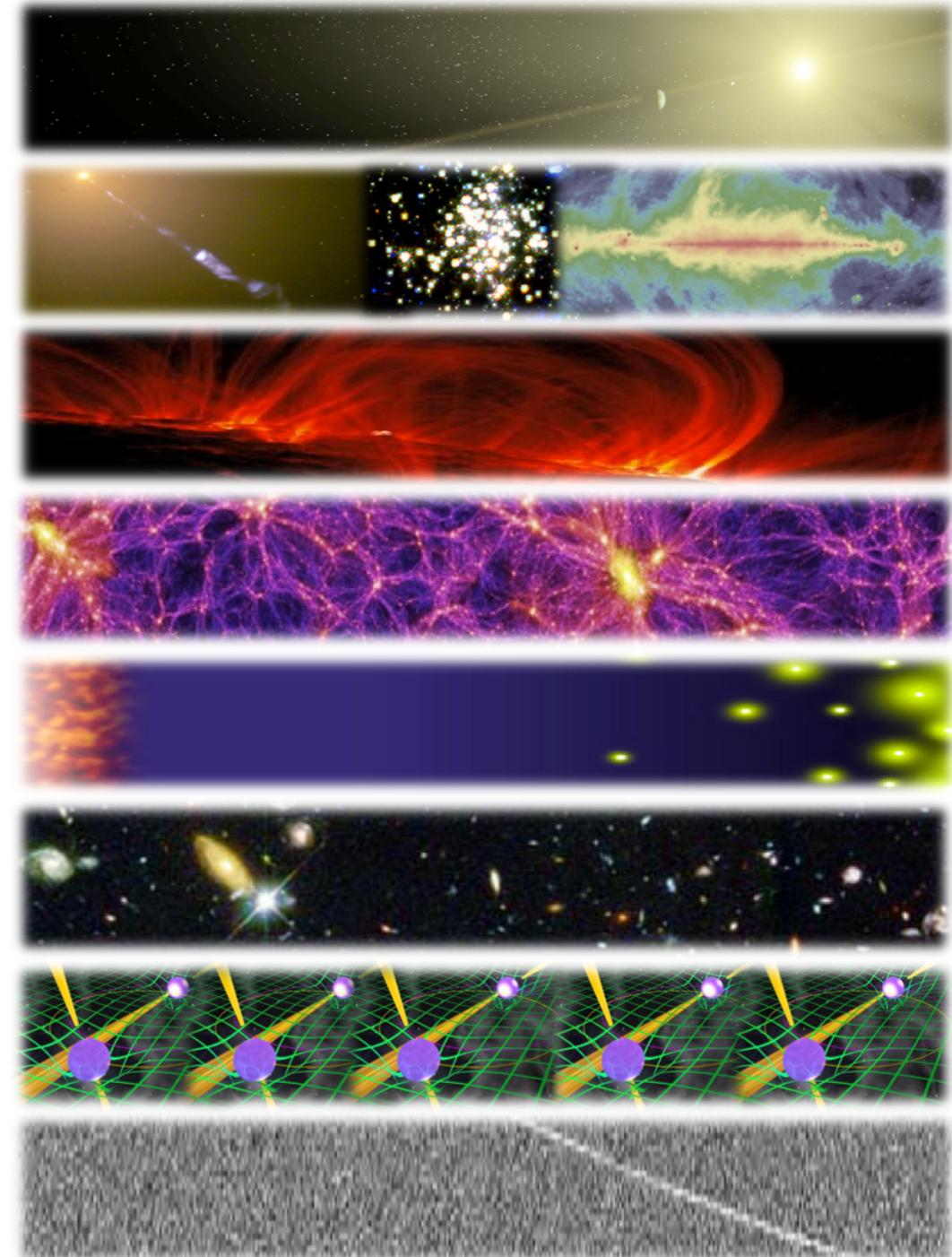
- Embrace (Nançay)
- MeerKAT (Afrique du Sud)
- ASKAP (Australie)



The Science Working Groups



- **Astrobiology (“The Cradle of Life”)**
 - *Project Scientist:* Tyler Bourke
 - *Working Group Chair:* Melvin Hoare
- **Galaxy Evolution – Continuum**
 - *Project Scientist:* Jeff Wagg
 - *Working Group Chairs:* Nick Seymour & Isabella Prandoni
- **Cosmic Magnetism**
 - *Project Scientist:* Jimi Green
 - *Working Group Chairs:* Melanie Johnston-Hollitt & Federica Govoni
- **Cosmology**
 - *Project Scientist:* Jeff Wagg
 - *Working Group Chair:* Roy Maartens
- **Epoch of Reionisation & the Cosmic Dawn**
 - *Project Scientist:* Jeff Wagg
 - *Working Group Chair:* Leon Koopmans
- **Galaxy Evolution – HI**
 - *Project Scientist:* Jimi Green
 - *Working Group Chairs:* Lister Staveley-Smith & Tom Osterloo
- **Pulsars (“Strong field tests of gravity”)**
 - *Project Scientist:* Jimi Green
 - *Working Group Chairs:* Ben Stappers & Michael Kramer
- **Transients**
 - *Project Scientist:* Tyler Bourke
 - *Working Group Chair:* Rob Fender



Exploring the Universe with the world's largest radio telescope

SKA Members



Australia (Dol)

China (MOST)

Italy (INAF)

New Zealand (MED)

Sweden (Chalmers)

India (Tata/DAE)

Canada (NRC-Herzberg)

Germany (BMBF)

Netherlands (NWO)

South Africa (DST)

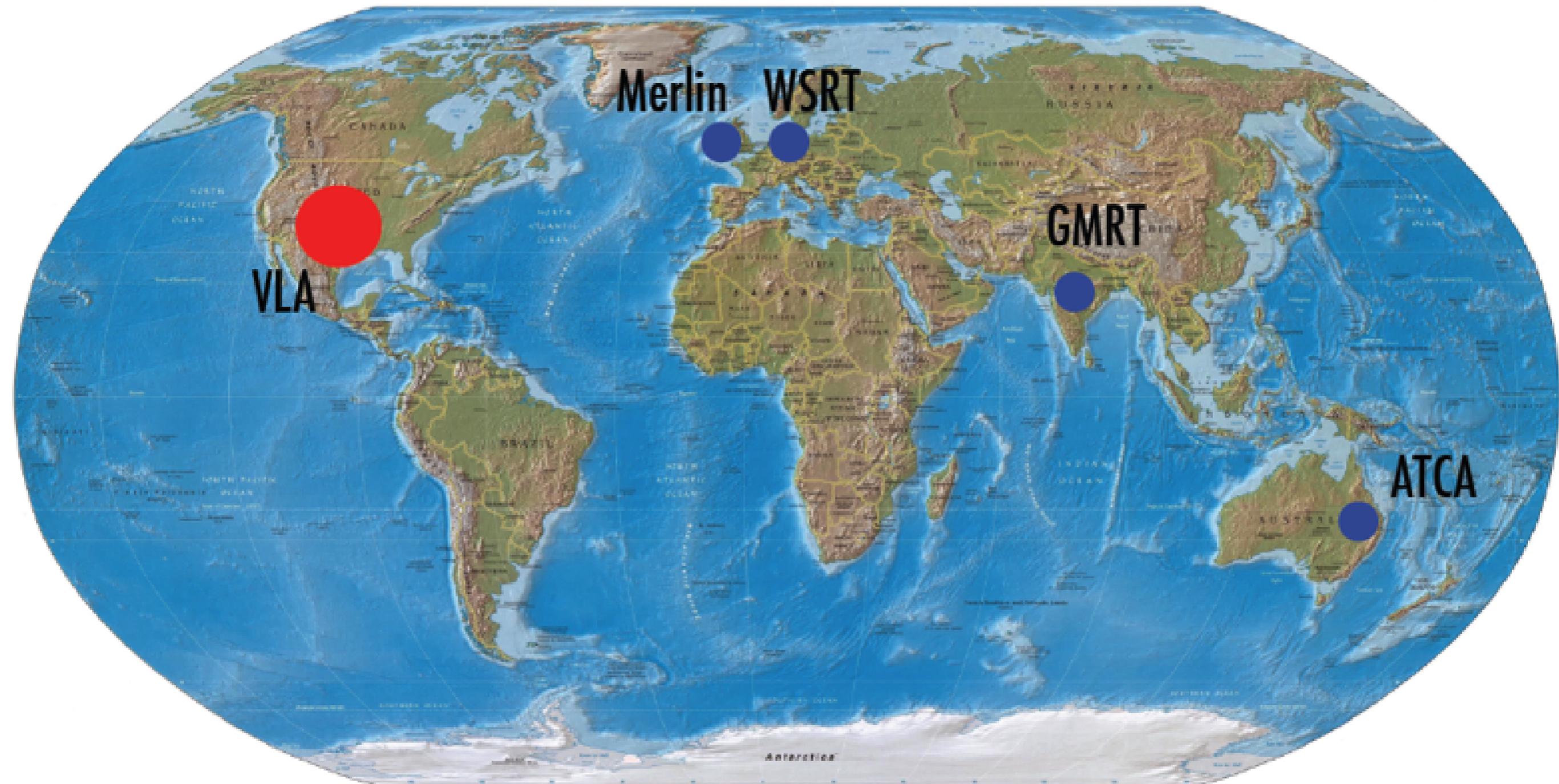
UK (STFC)

- International organization ~ ESO ?

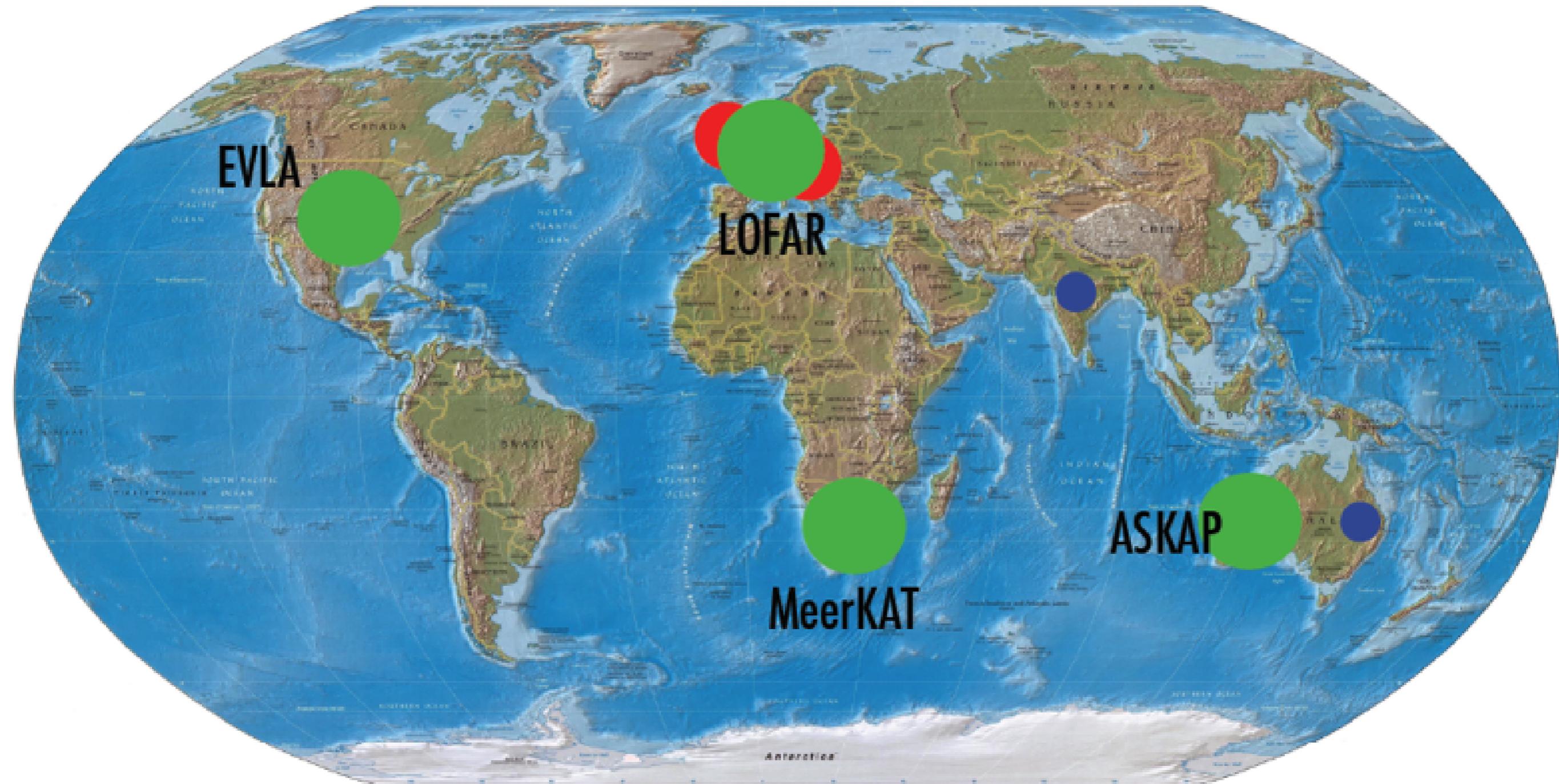


L'âge des grands
réseaux d'antennes :
le deuxième âge d'or de
la radioastronomie

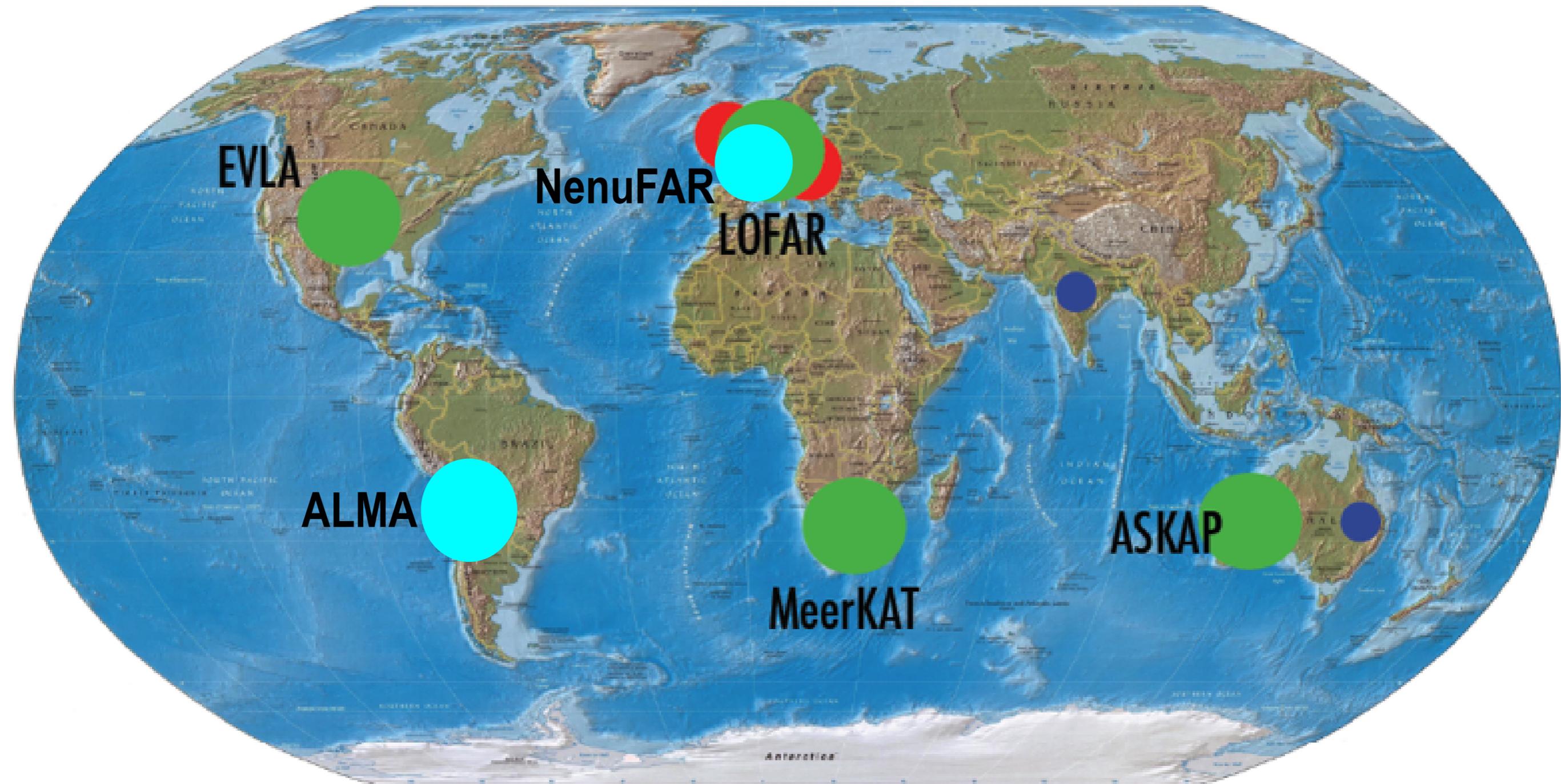
La radioastronomie en 2005



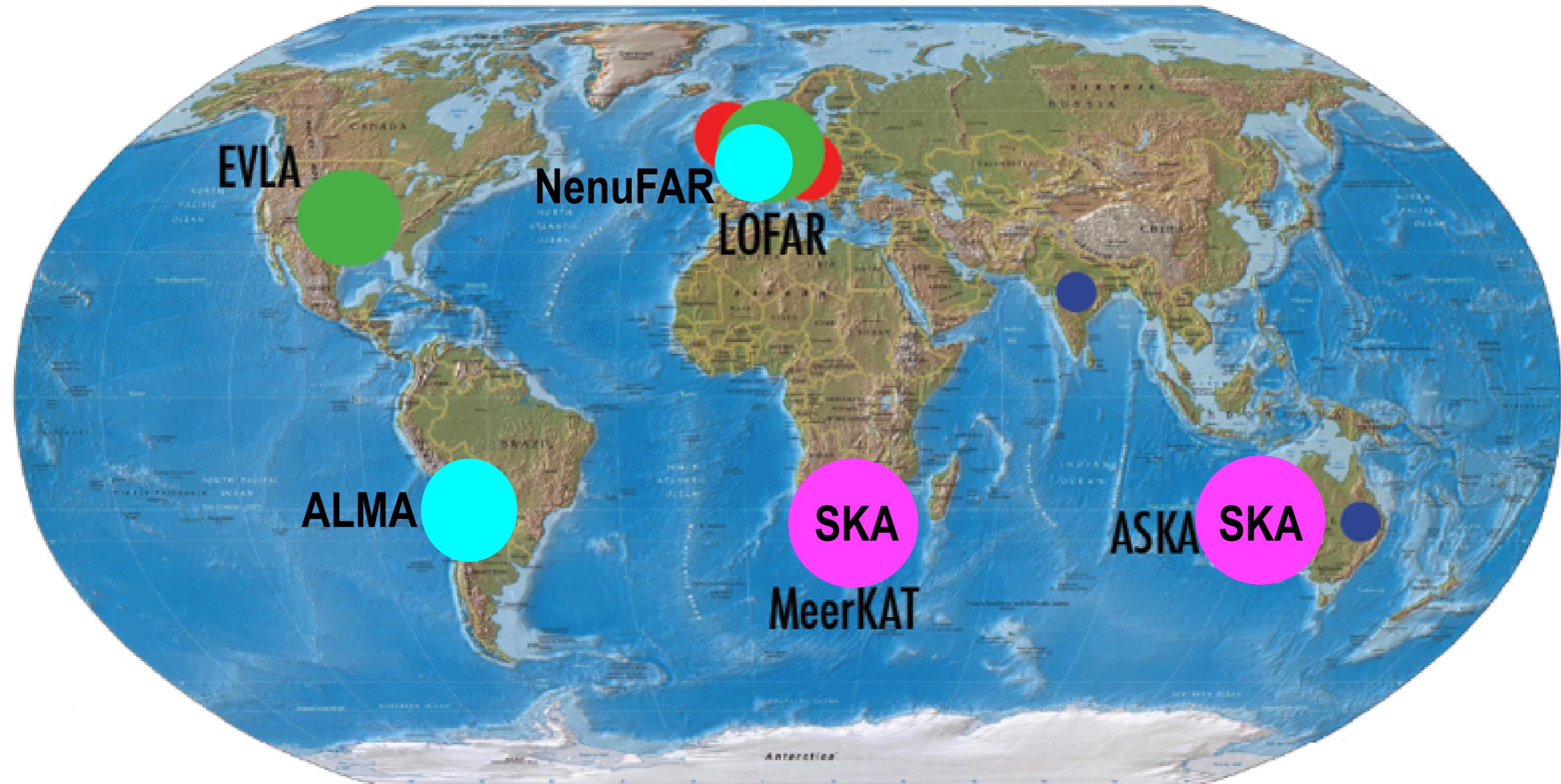
La radioastronomie en 2010



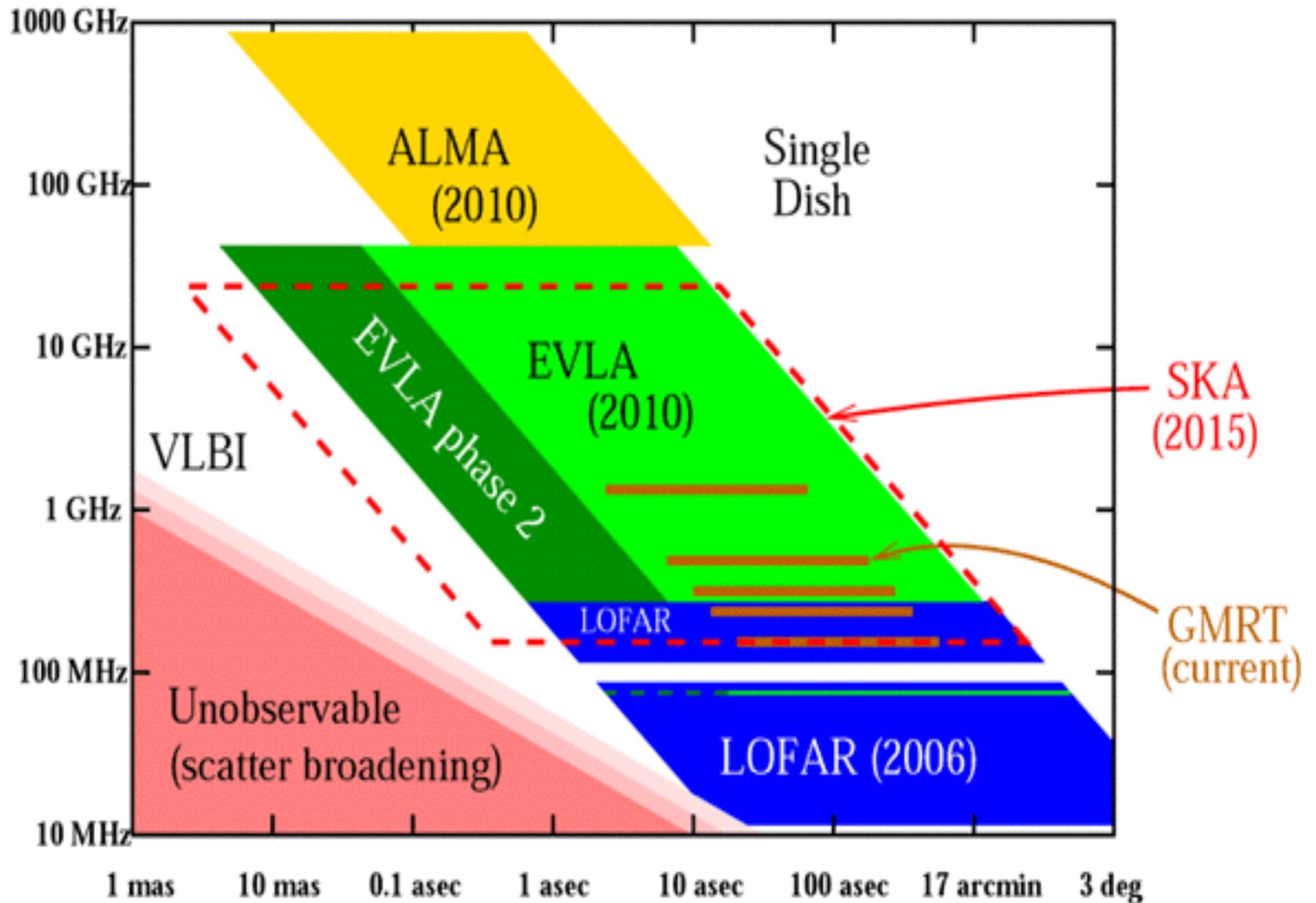
La radioastronomie en 2015



La radioastronomie en 2020

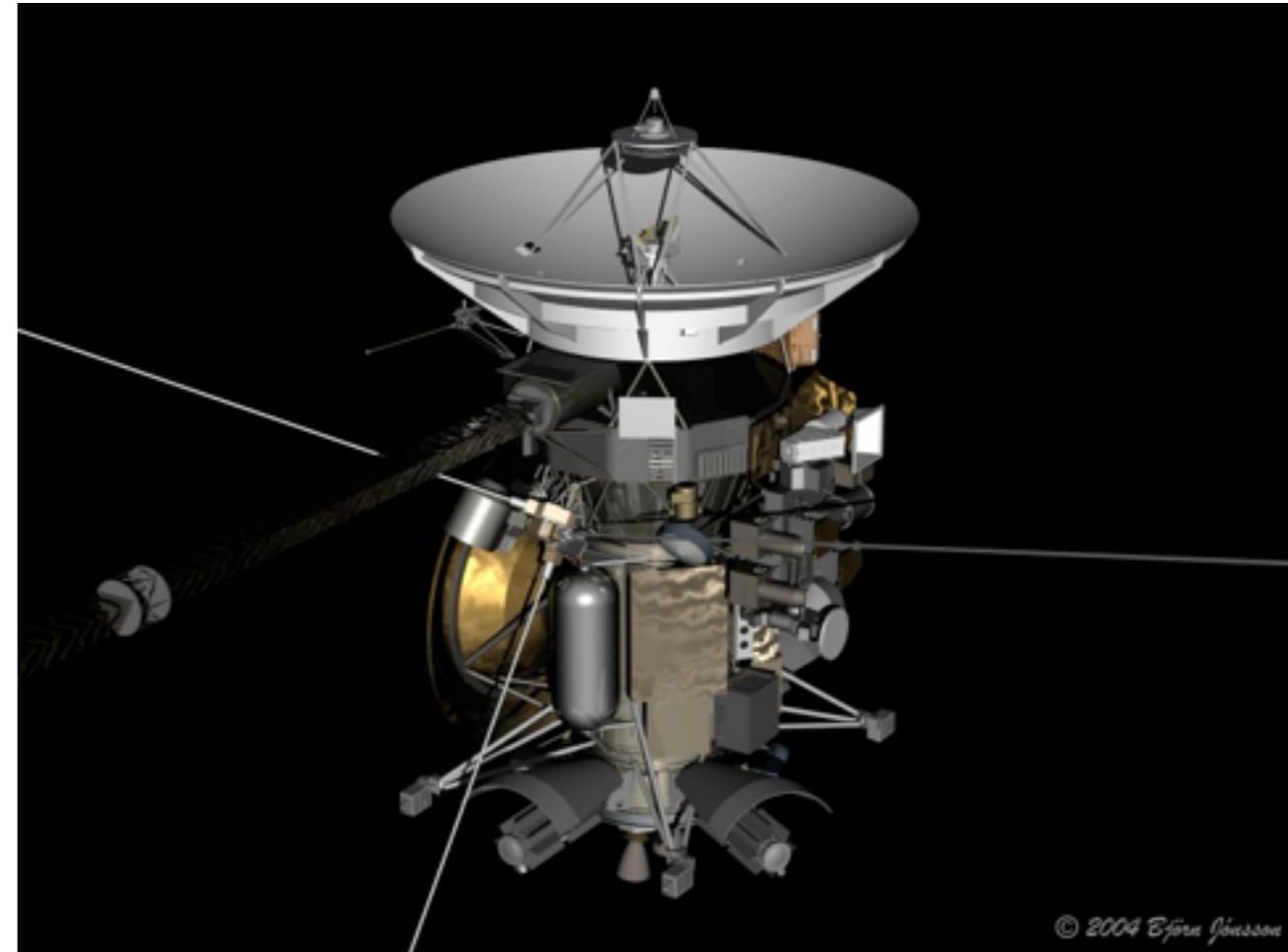
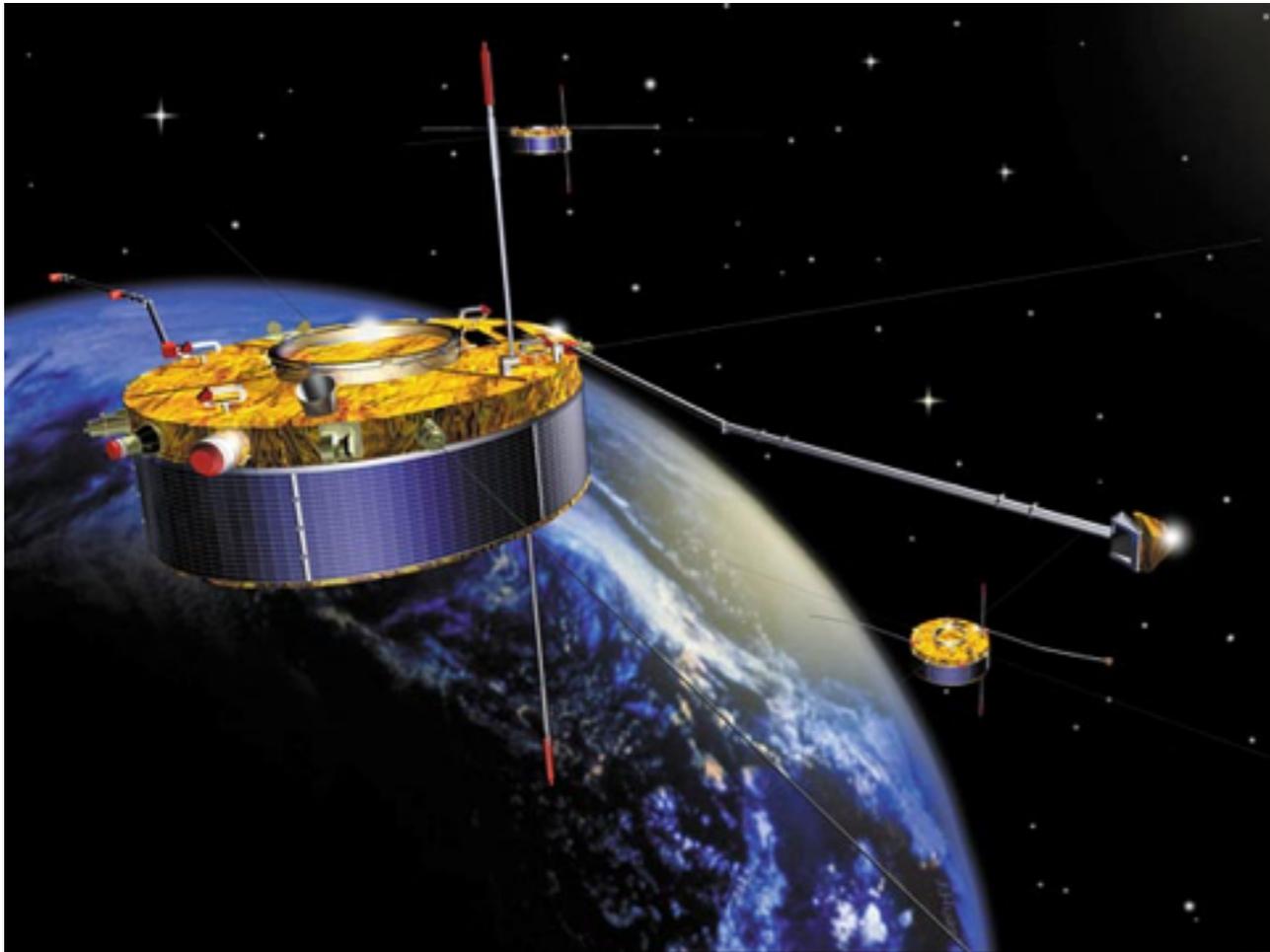


La fin de l'Histoire ?



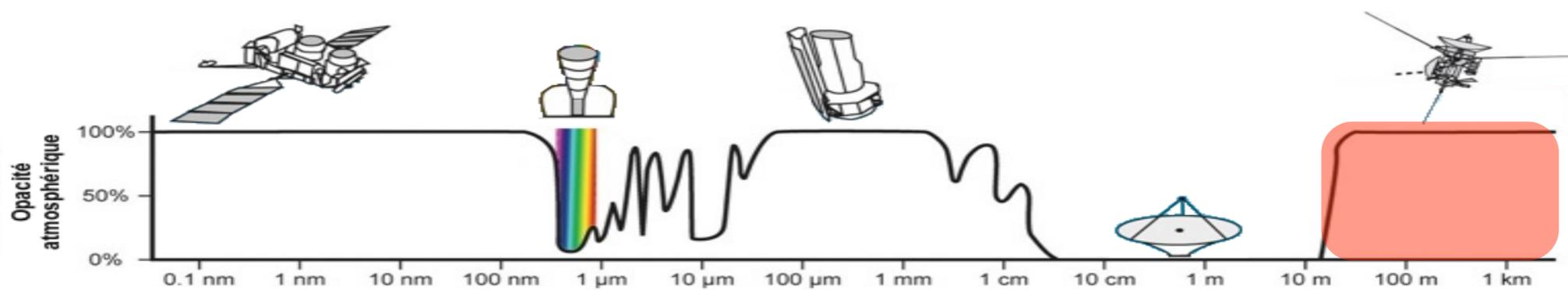
Pendant ce temps,
au-dessus de nos têtes

Radioastronomie Spatiale

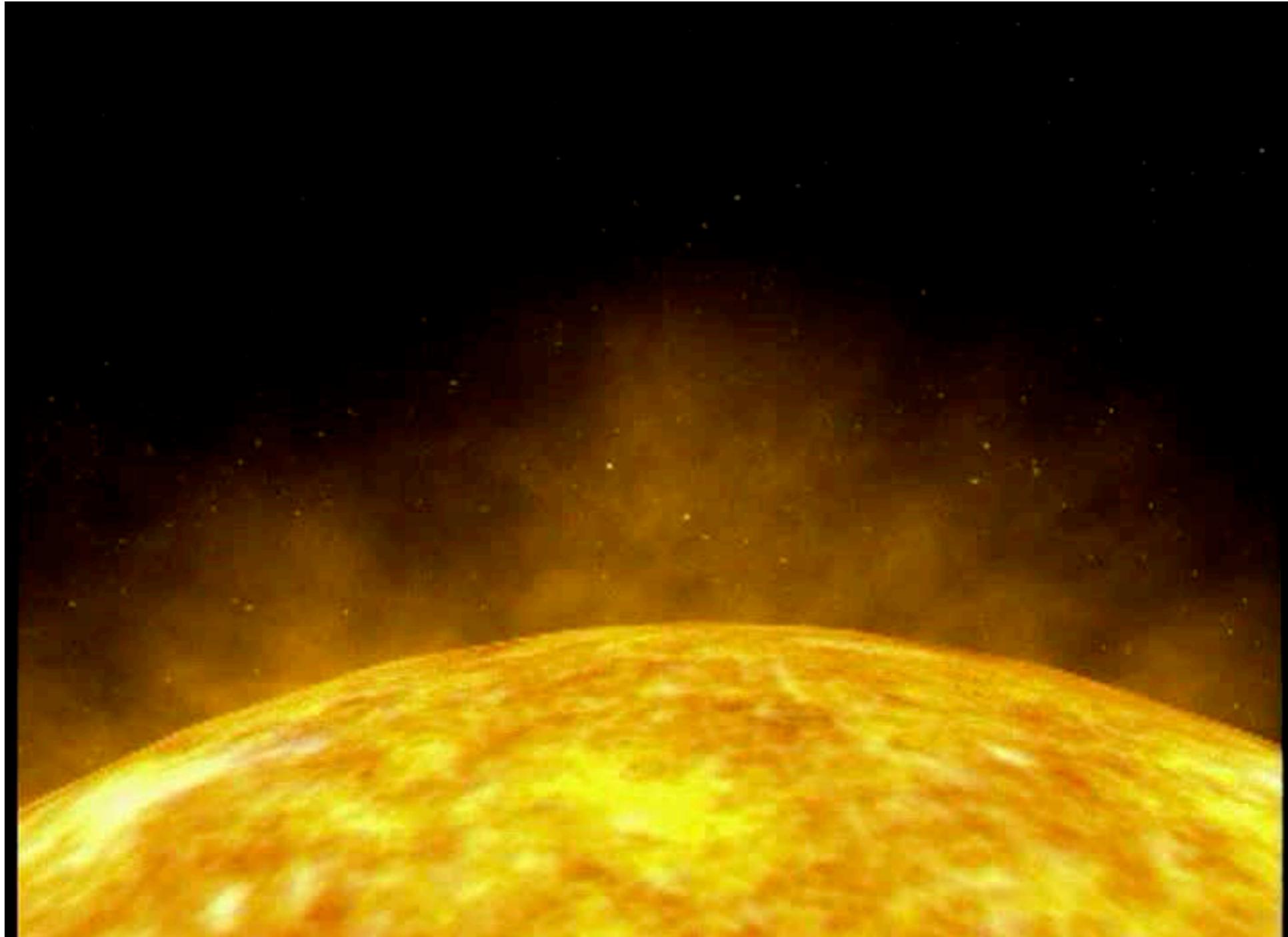


Cluster

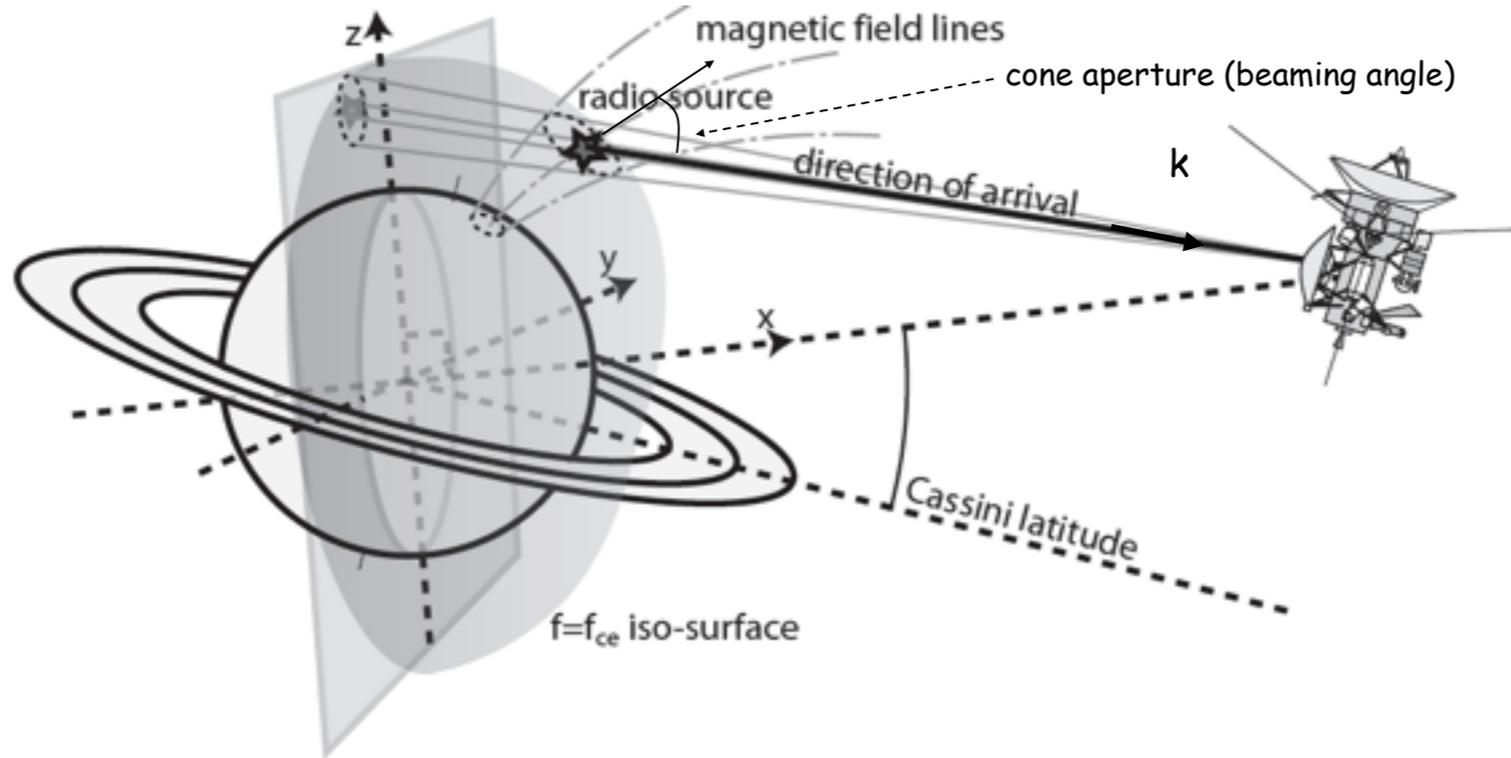
Cassini



Etude des magnétosphères planétaires

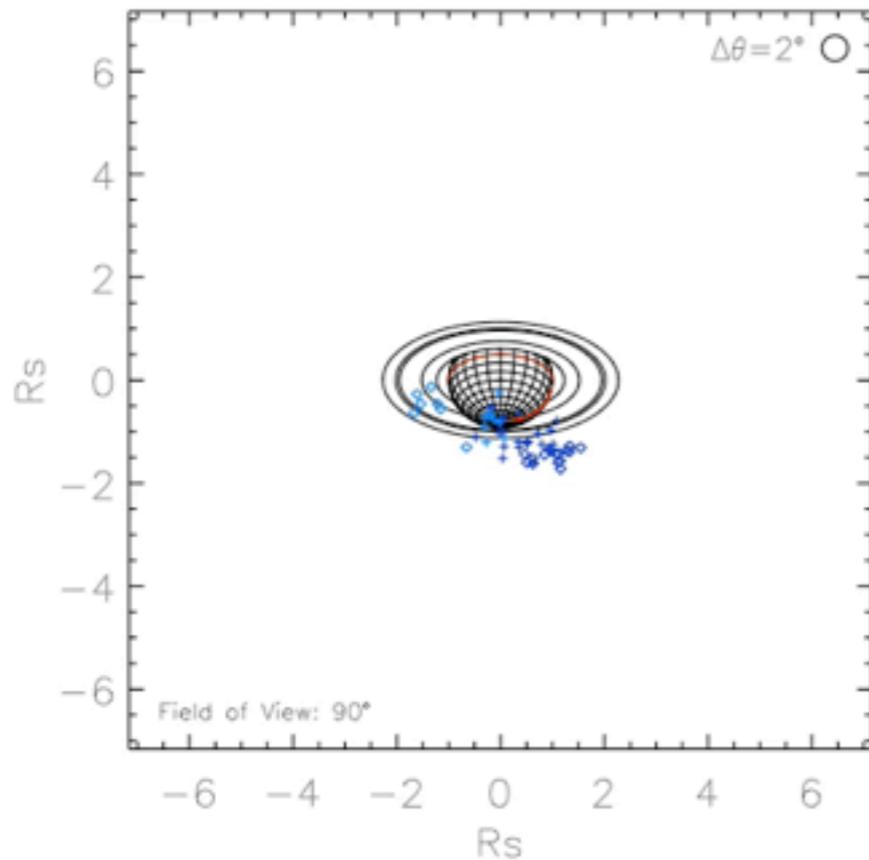


GoniPolarimétrie spatiale @ Saturne



SKR Source Localization (from Cassini/RPWS/HFR)

Cecconi, Lamy & Zarka © 2008



Ephemeris

2006268-10:00
2006268-10:05

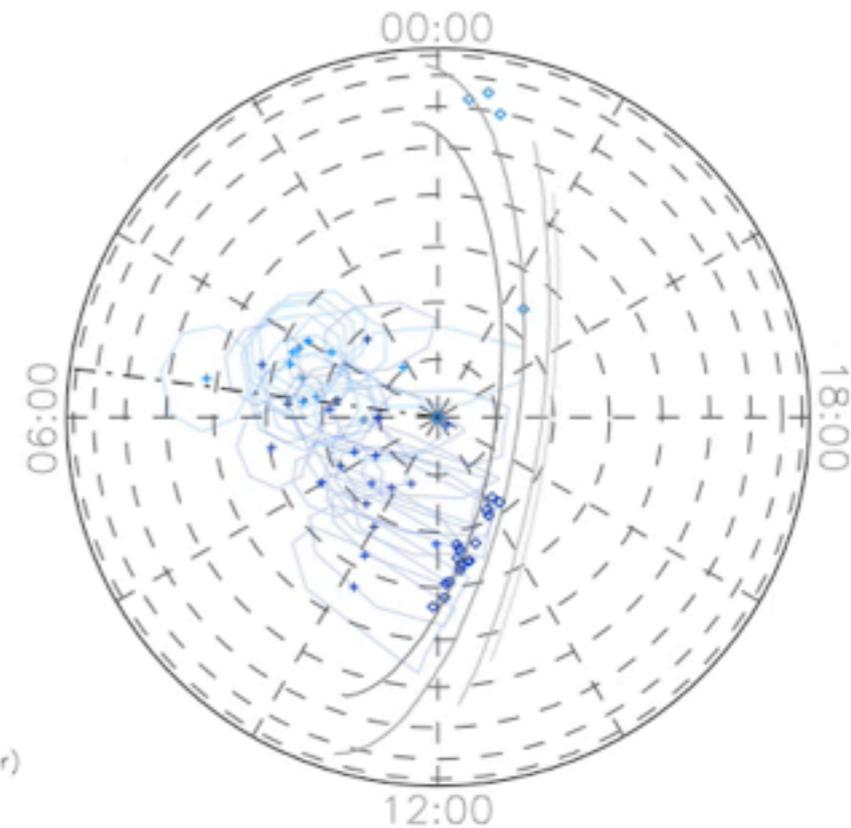
LT = 05:29
Lat = -29.7 deg
Dist = 7.2 R_s

Color Code

	LH	RH
100- 200 kHz	Dark Blue	Dark Red
200- 400 kHz	Blue	Red
400- 800 kHz	Light Blue	Orange
800-1000 kHz	Cyan	Yellow

Symbol Code

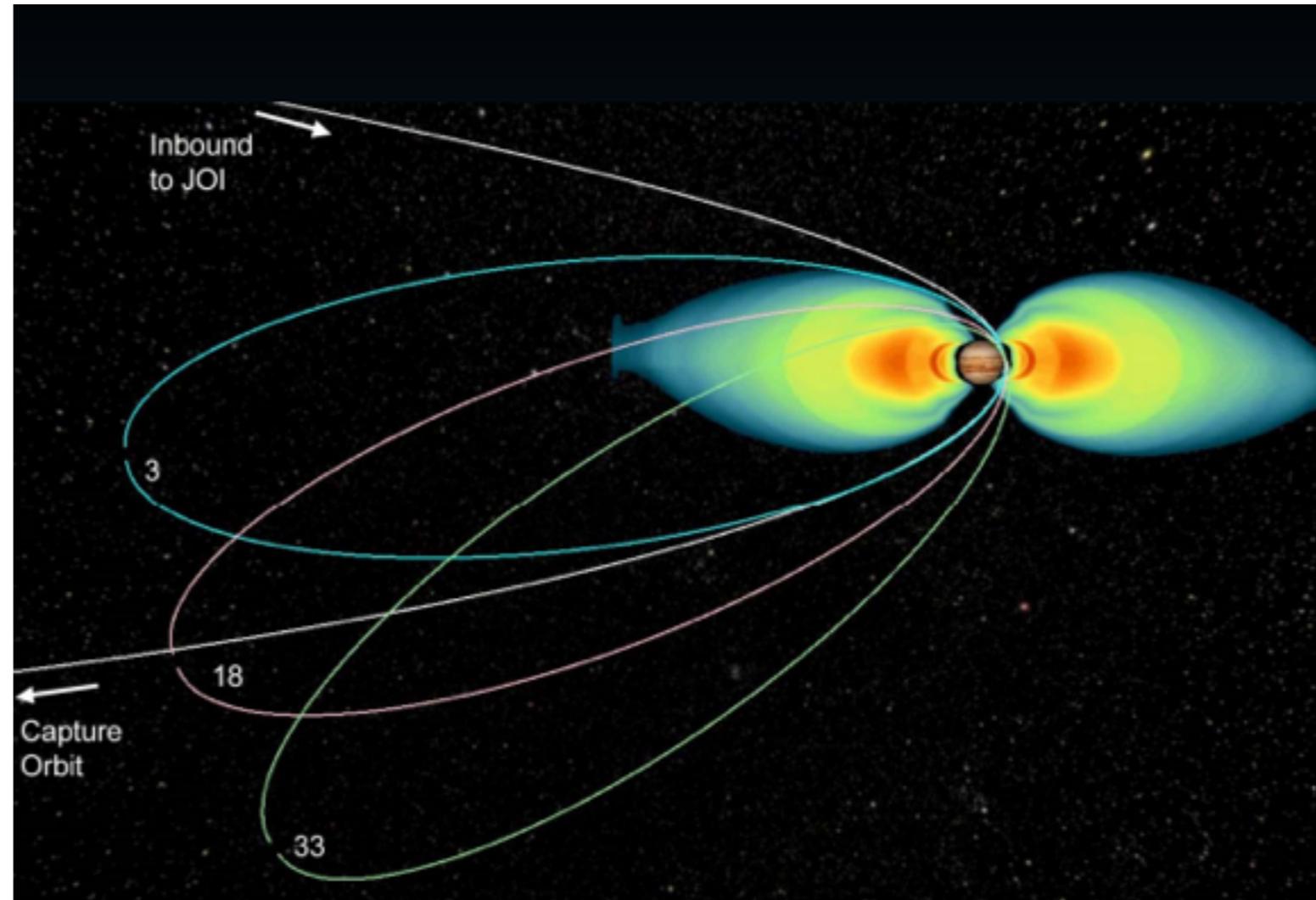
- \diamond out of iso-fc
- \oplus within iso-fc (2° error contour)



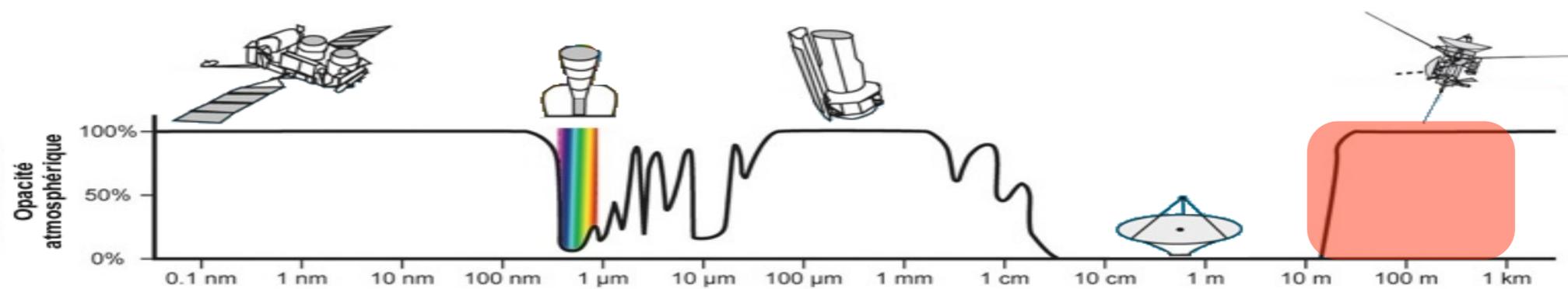
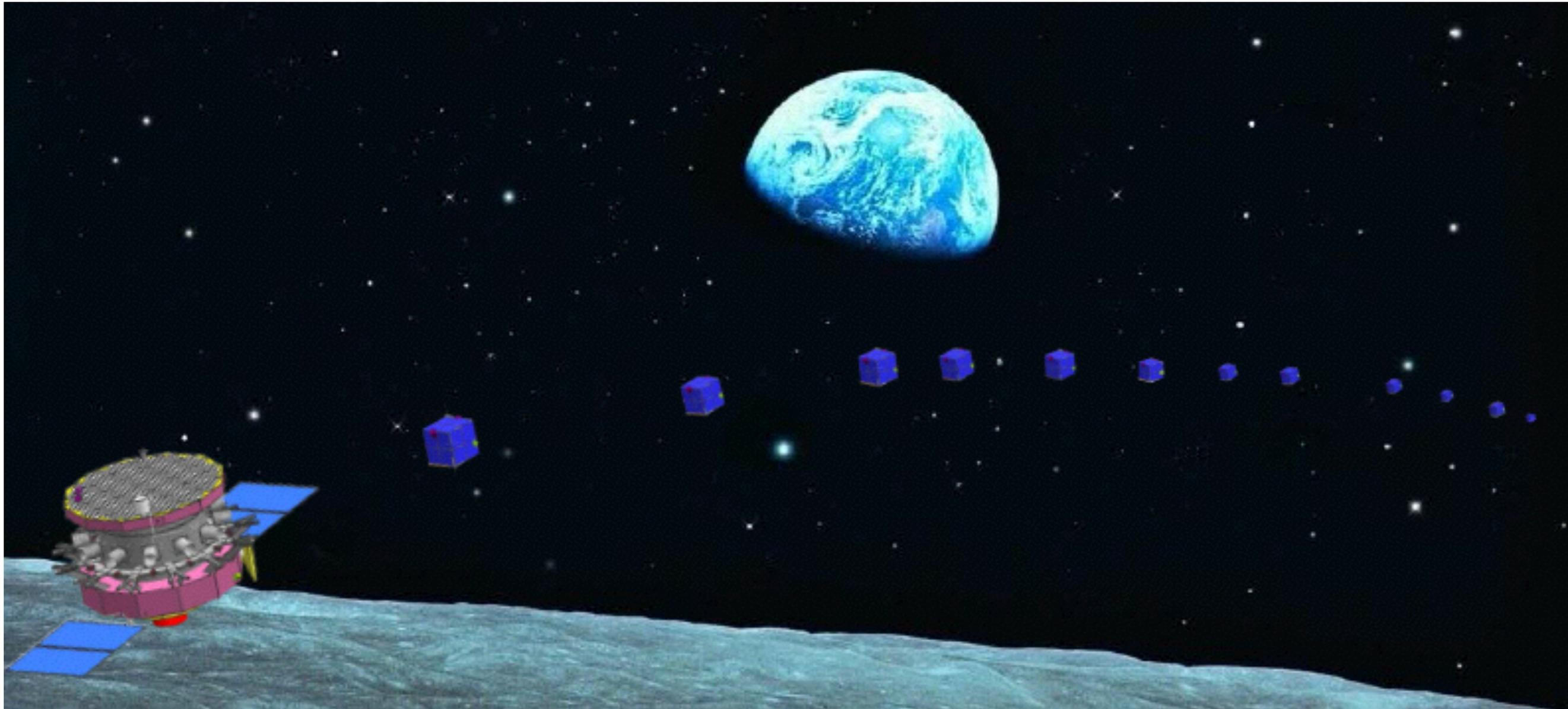
Active Magnetic Field Line Footprints

(SPV magnetic field model with current sheet)

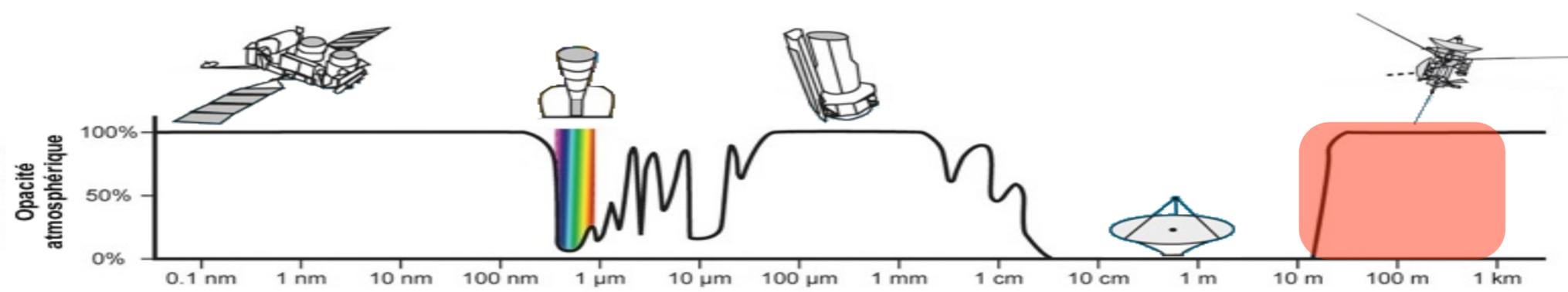
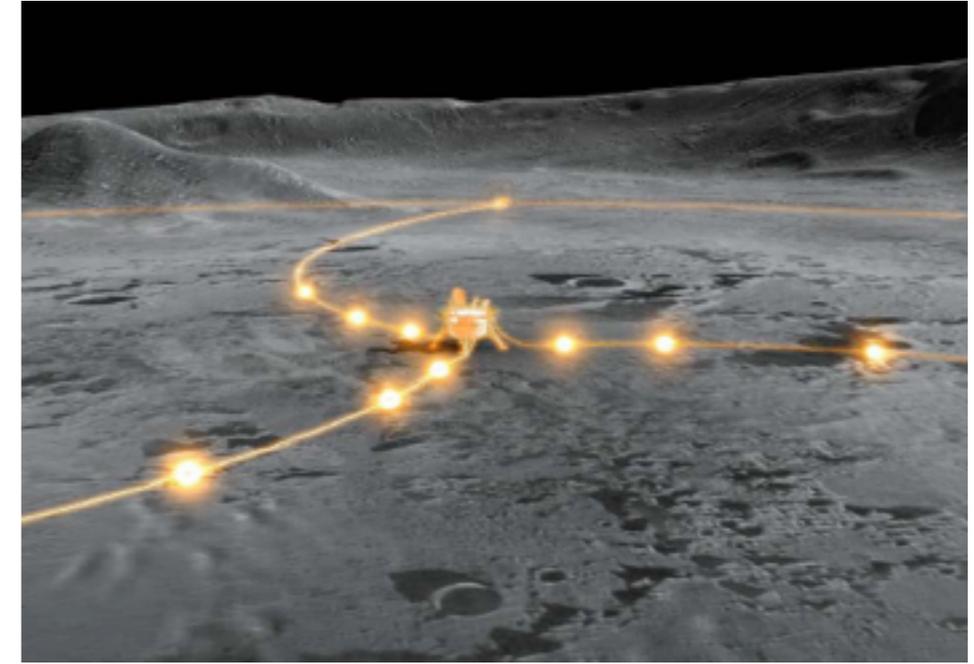
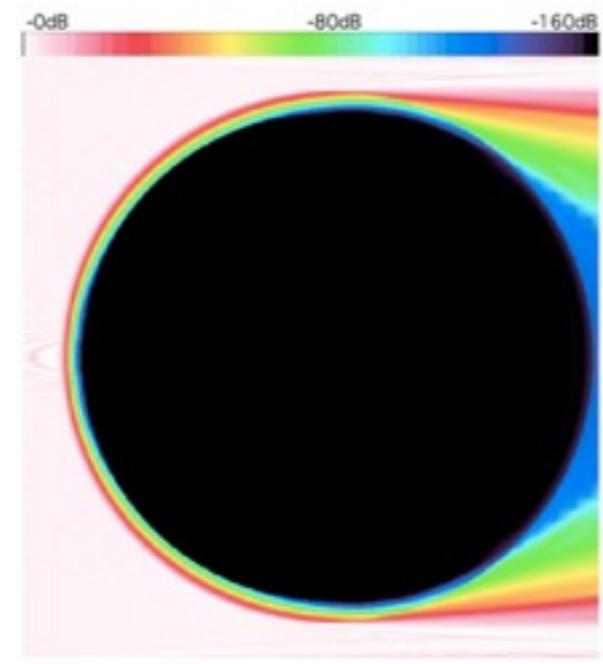
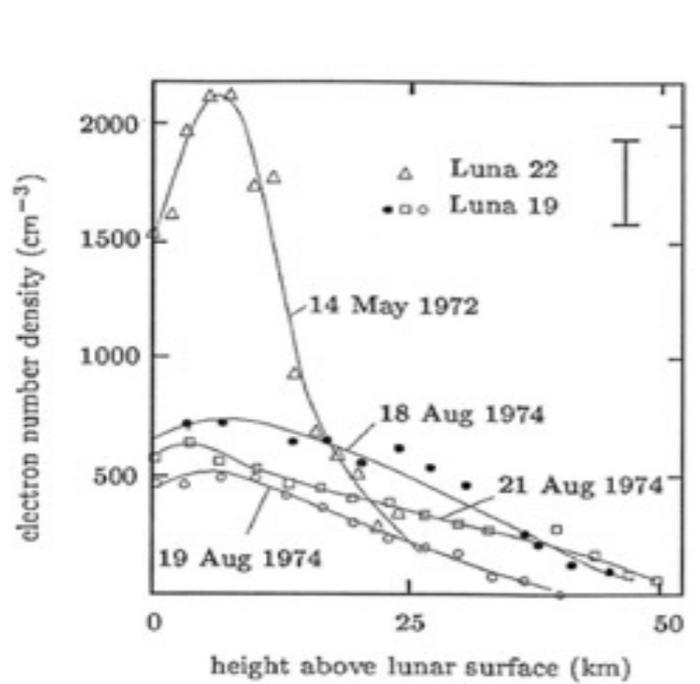
Mission Juno @ Jupiter



Interférométrie radio TBF dans l'espace

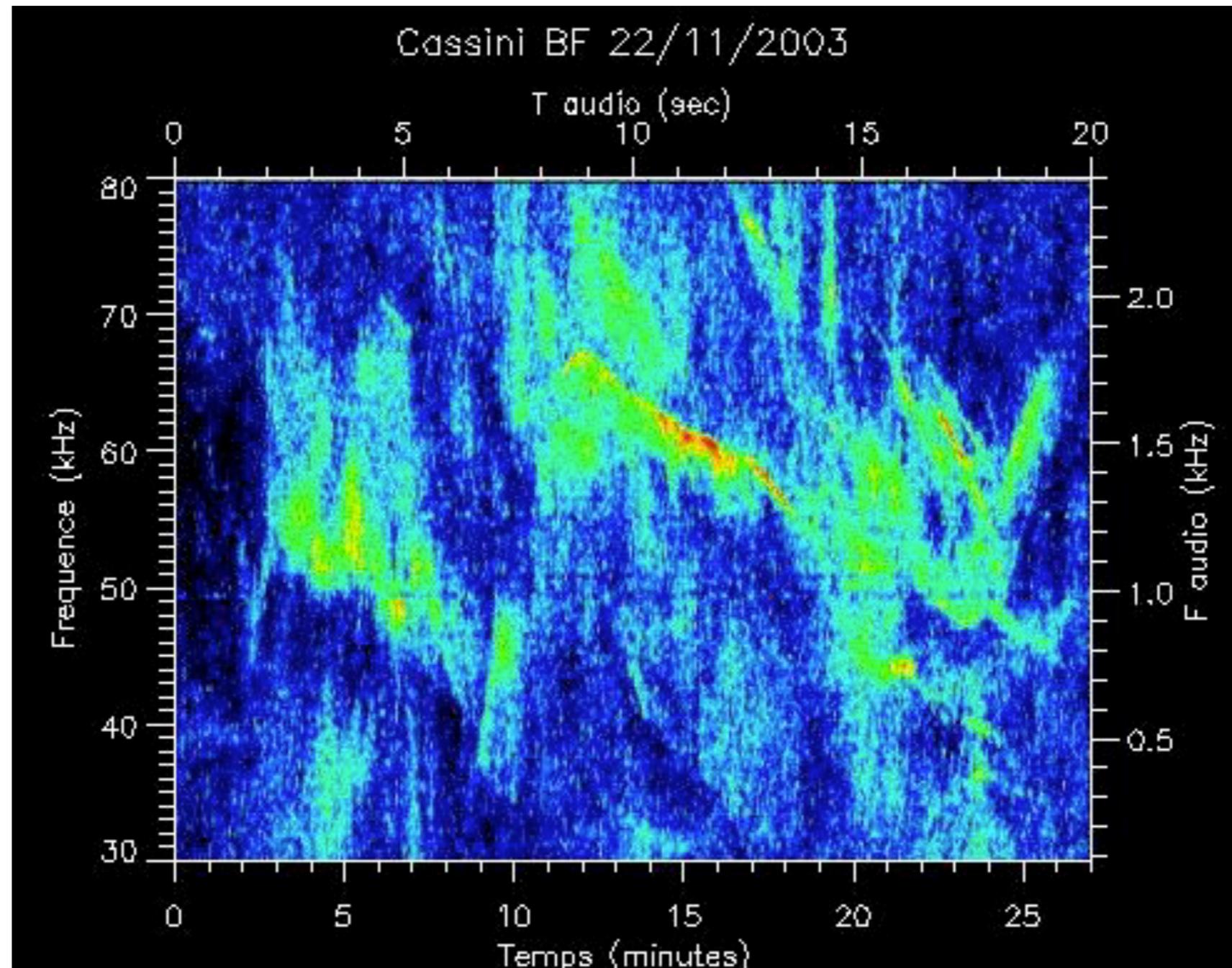


Un grand réseau d'antennes sur la Lune ?

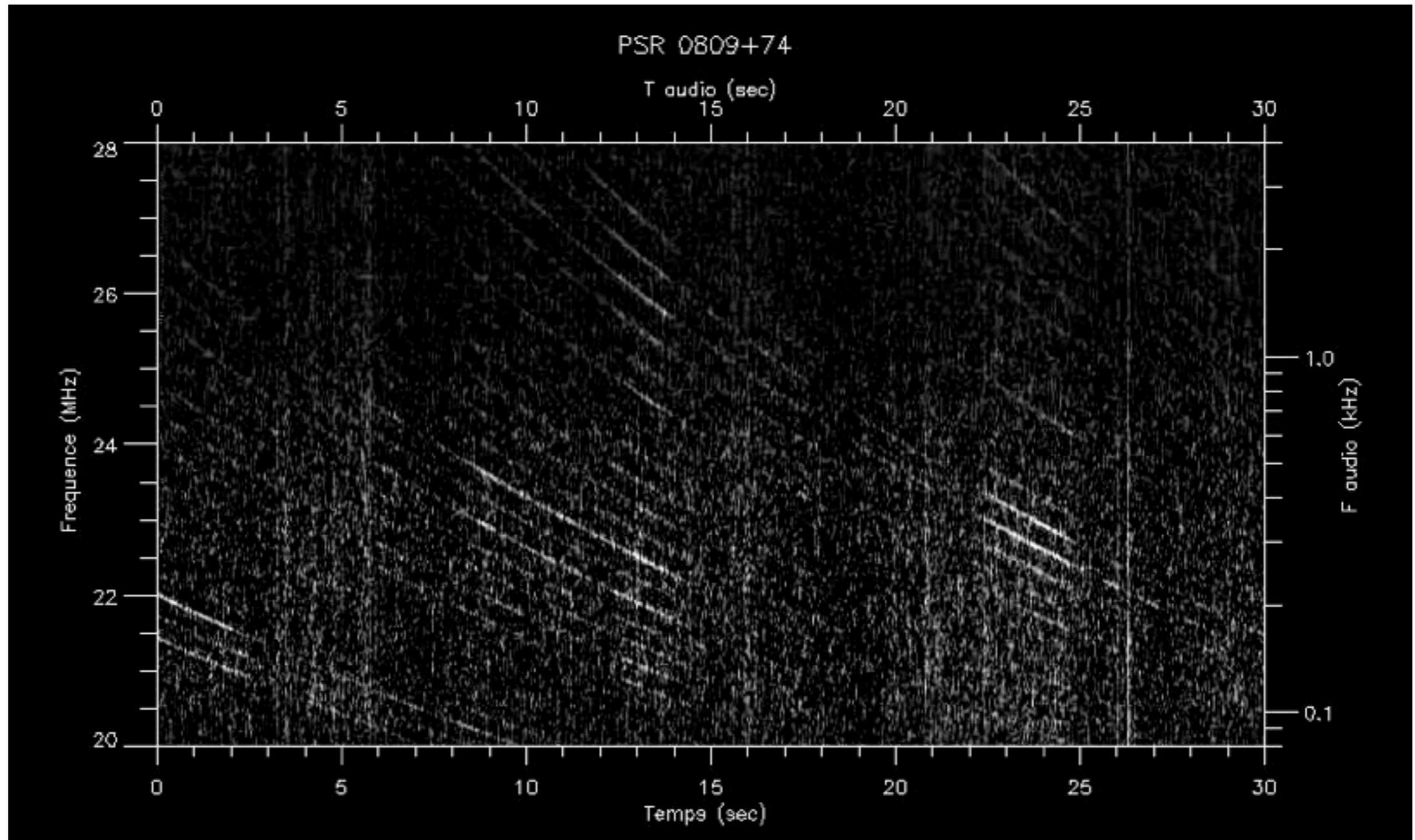


Grand finale :
les « chants du cosmos »

Saturne



Pulsar



A suivre ...