Solar corona with *LOFAR*

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Scheme of the talk

- Interest of imaging the sun at several frequencies :
  - dynamics of suprathermal particles,
  - *CME*s, coronal shocks, and type II bursts,
  - type III bursts (produced by electron beams).
- What can *LOFAR* bring ?
  - Specificities of solar radio observations,
  - Possible studies.
- What solar observational mode for *LOFAR* ?

Interest of solar radio observations : 1) dynamics of suprathermal particles

- Direct diagnostic of fast particles, where they are produced and exist (as compared to other diagnostics, more sensitive to thermal properties). For plasma emission at f_p or 2 f_p ($f_p=9\sqrt{n_e}$), n_e is related to frequency, giving acces to local electron density along electron beam trajectories.
- During flares, electrons are accelerated at levels where f_p ~ *0.5 - 1 GHz.* (D1) Yet no imaging in this range (*NRH* range is 150 - 450 *MHz*)
  → interest for *FASR* .
- In the absence of flares, near active regions, electrons can be accelerated up to few *keV* over a wide altitude range → radio noise storms in *m* and *dam* λ range. Transition in character at ~ 80 *MHz*. Poorly understood. No (*no more*) imaging below 150 *MHz* → interest for *LOFAR* .
- "SA" electrons beams related to schocks (*dam* λ range).

Interest of solar radio observations (ctd)
2) *CMEs*, coronal shocks, and type II bursts

- Radio imaging of *CMEs* can be done :
  - in the low corona at high frequencies (500 MHz) ⇒ insight on initiation,
  - in the high corona a lower frequencies, ⇒ insight on evolution,
  - on the disk ⇒ perspective effects are reduced or different,
  - examples (D2).
- Radio emision mechanisms :
  - gyrosynchrotron emission of fast electrons (→ 1 MeV). The spectrum over a wide frequency range (including f_{peak}) provides *B* and the maximum energy of electrons (Bastian *et al* 2001, Maia *et al* 2006).
  - Thermal emission ($\propto n_e^2$) should also be detectable (Bastian, Gary 1997). The spectrum on a wide frequency range (for both optically thin and thick cases) should give n_e .

⇒ frequency coverage should be as wide as possible.

Interest of solar radio observations (ctd)
3) type II and type III bursts

- Type II bursts :
  - plasma emission from upward shocks at f_p / 2 f_p , drifting slowly from high to low frequencies, often seen below 150 *MHz*, but up to 500 *MHz,*
  - most often associated to *CME*s,
  - multifrequency imaging gives access to their trajectories.
- Type III bursts :
  - plasma emission from fast electron beams (~c/5) at (f_p) / 2 f_p,
  - follow ***B*** lines, often through the whole corona, with fast frequency drift,
  - weak circular polarisation (at 2 f_p) prop. to *B*.
- Multi-frequency imaging provides :
  - trajectories of beams (along field lines) and shocks up to ~ 1 R_s,
  - *B* can be deduced from polarisation of type III bursts.

Preliminary remarks on solar radio imaging : 1) spatial resolution is reduced by propagation effects

- No reported sources < 40" of arc at 327 *MHz* (*VLA*, *NRH* + *GMRT*). Studies with time resolution < 1 sec (*NRH* + *GMRT)* are in progress.
- Corona and interplanetary medium (*IPM*) are turbulent. Using simplifying assumptions, Bastian (2004) finds :
  - even for background source the nominal resolution of *LOFAR* will be reached only at >90° from the Sun,
  - coronal point sources should have apparent sizes ~ 5-10' at 100 *MHz*.
    ⇒ only baselines < 10 km are useful for the sun (core and nearest stations).
- Ionosphere
  - daytime ionosphere is denser and more perturbed, particularly in winter. The effects (apparent shifts and distorsion of images) are stronger at low elevations. Focussing effects are observed in Nançay at ~ 50 *MHz*
    ⇒ images could be totally corrupted ! (D3).
- The sun is probably the worst source for *LOFAR* !

Preliminary remarks on solar radio imaging (ctd) : 2) particularities of the sun itself

- The sun can be a rapidly varying source, with time scales down to < 0.1 sec ⇒ fast snapshot imaging.
- The sun (+ *CMEs)* is wide ⇒ short baselines
  – The constraint is strongest at the highest frequency, since the width of the sun increases less than λ (the scale height for n_e is < 1 R_s)
  – At 240 MHz the visibility at origin should be sampled with a step 40 λ, at most (D4).

What can *LOFAR* bring to solar studies ?
Within the limits of preceding remarks :

- *LOFAR* fills the gap between ground and space radio observations,
- *LOFAR* completes higher frequencies observations for phenomena involving dynamics of the corona, occurring in a wide range of altitu-de, and appearing usually first at higher frequencies :
  - CMEs, shocks (type II bursts),
  - electron beams (type III bursts) ⇒ mapping of coronal field *B* along trajectories.
  - etc.
- *LOFAR* allows studies of phenomena which are specific to coronal altitude range correponding to its frequency range :
  - "SA" (shock associated) type III bursts, which are generated by electron beams which seem to originate from shocks producing type II, at frequencies ≤ 50 *MHz*.
  - Change in character of noise storms (signature of suprathermal particles produ-ced in the absence of flares),
  - Rich variety of radio bursts (theory of plasma instabilities).
  - etc.

Data products for solar studies with *LOFAR*

- Only short baselines are needed (up to 10 km ?),
- Time resolution < 1 sec (0.1 sec better at 200 *MHz*),
- Bandwidth ~ 100 *kHz* or more for most studies,
- Several frequencies (10 ?) regularly spaced, including ratios of 2 (for fund/harm emissions) and intercalibration with *NRH* (*). Avoiding the gap 80-120 MHz we suggest tentatively:

  19 38 60 75 120 151* 180 236* *MHz*

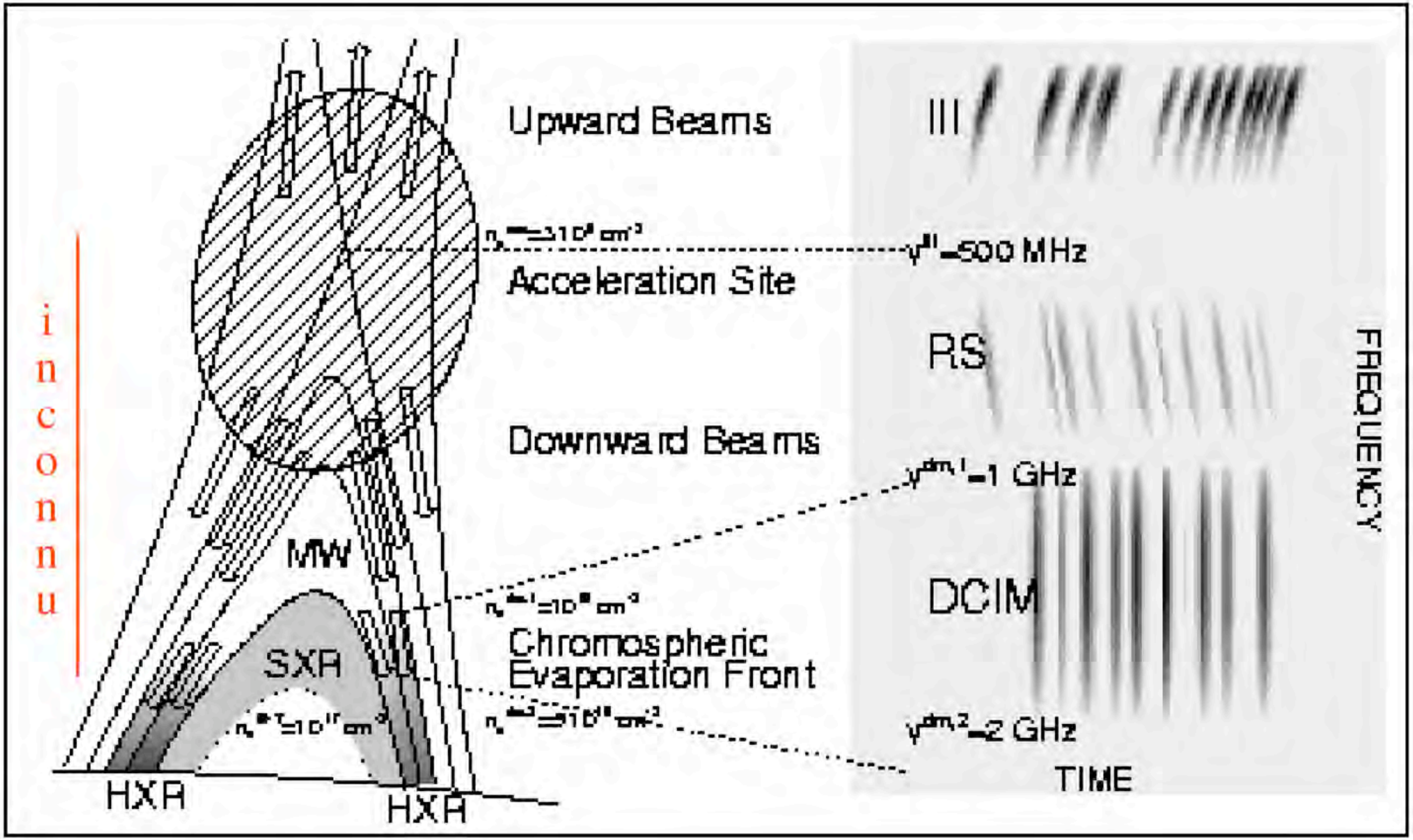
- Dense uv coverage near origin (sampling step < 40 λ) for a wi-de field for quiet sun and *CME*s (use of correlations between sub-stations ?)
- Observations in winter will probably be difficult below 100 *MHz* because of ionosphere.

Thank you for your attention

End

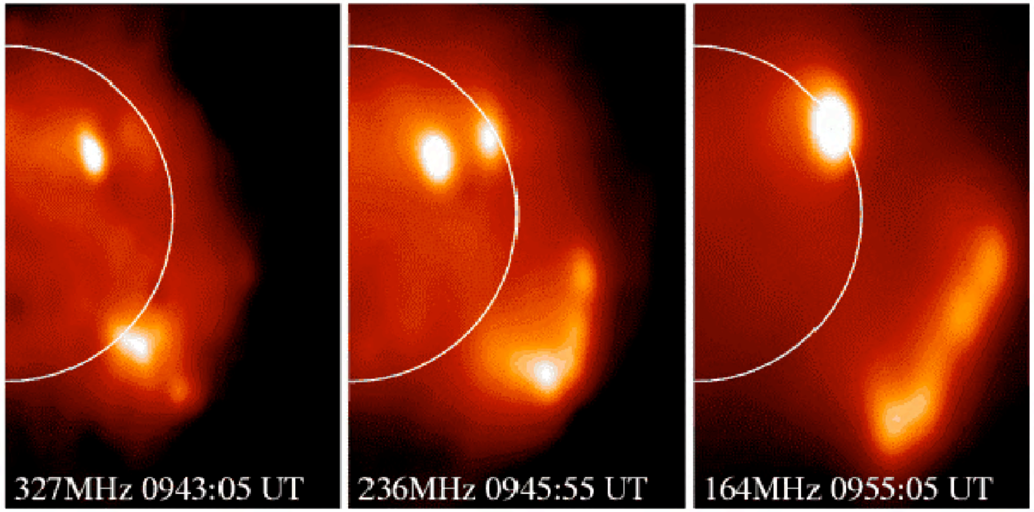
Documents

Meter-decimeter radio emissions during flares



from Aschwanden & Benz 1997

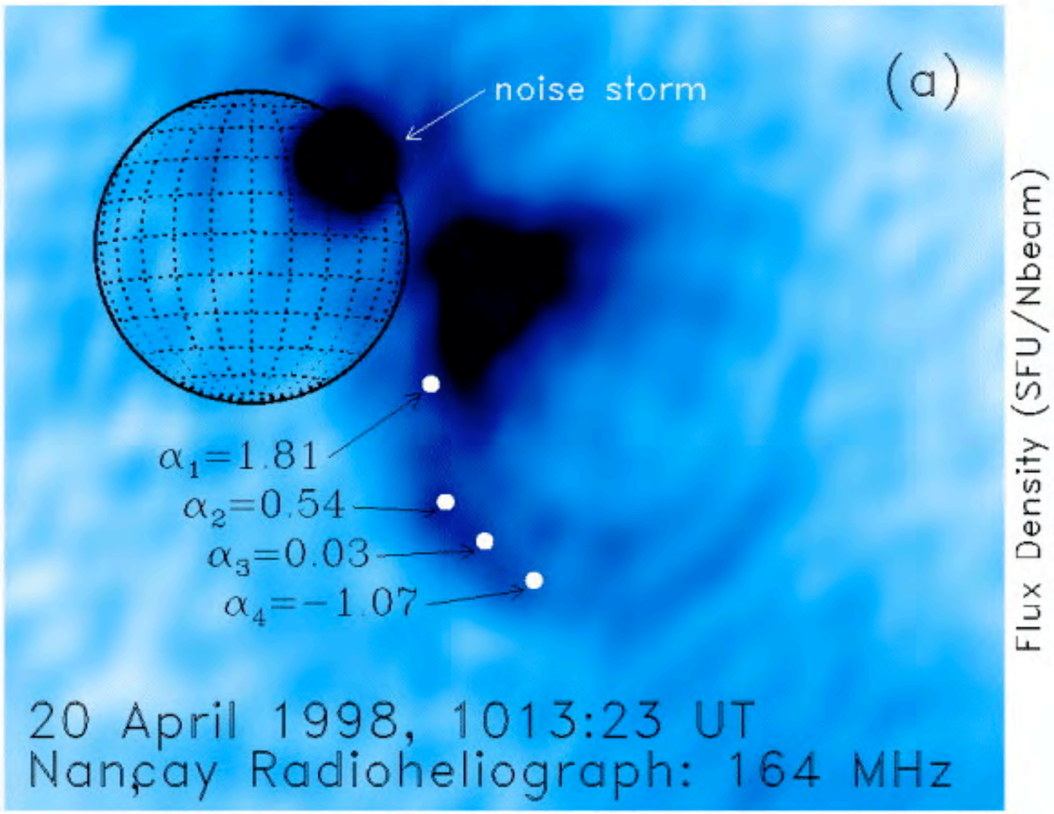
Detection of weak emissions

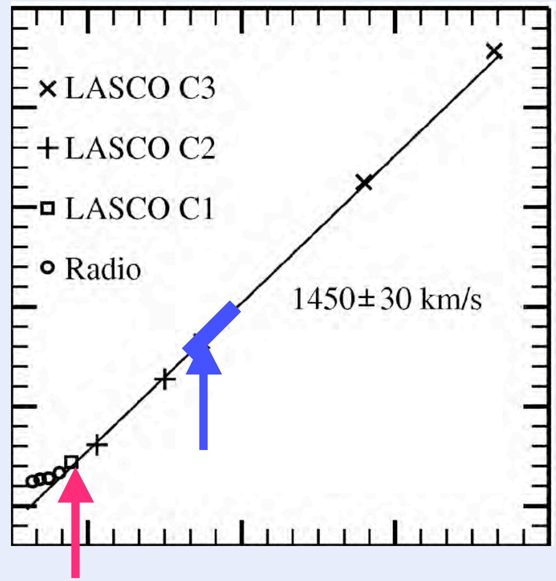


CME-Driven shock
Plasma front
(Maia et al., 2001

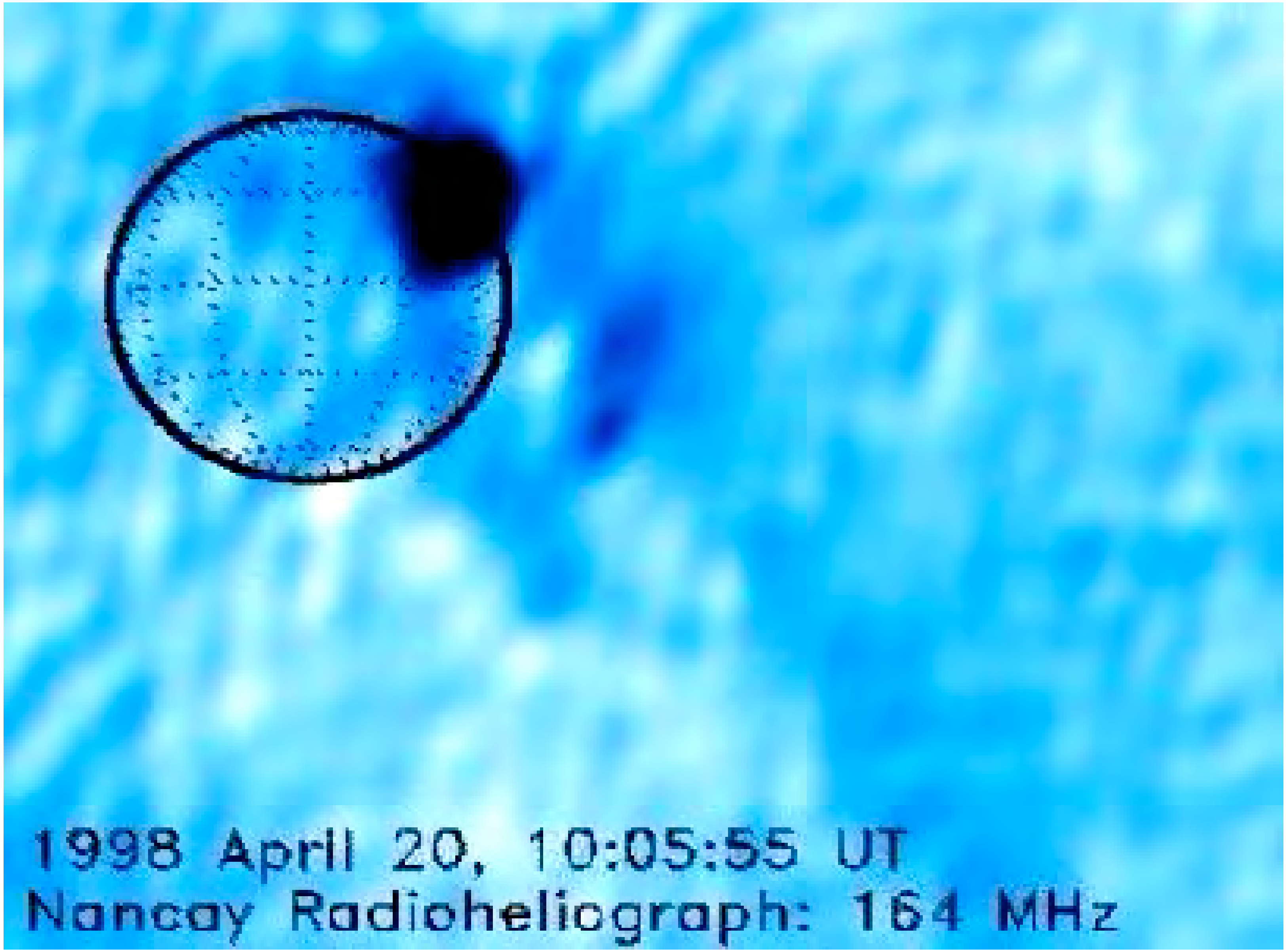
CME Radio imaging

- ***(Bastian et al.,2001)***





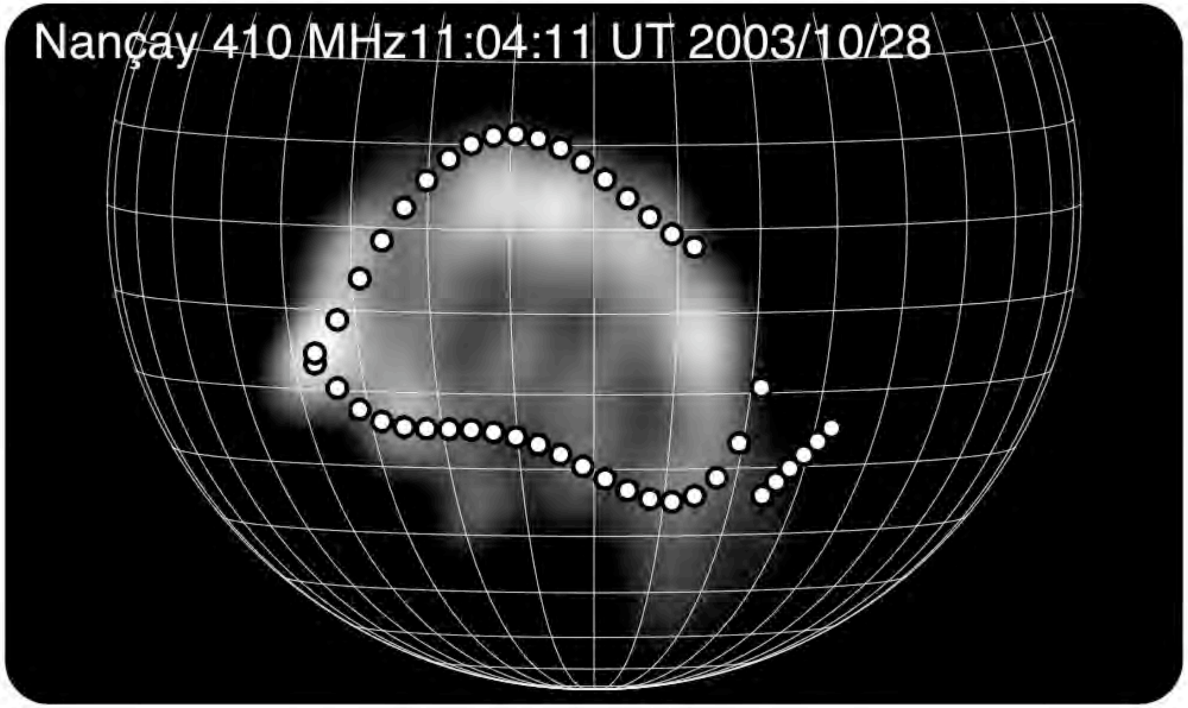
More cases now, association with particles is space
Maia et al., 2005



Bastian et al. (2001)

NRH: CMEs

- Direct observation of on-the-disk CMEs



The lateral expansion of the CME is outlined by non thermal radio emission, over-lying the disturbance initiated by the flare.

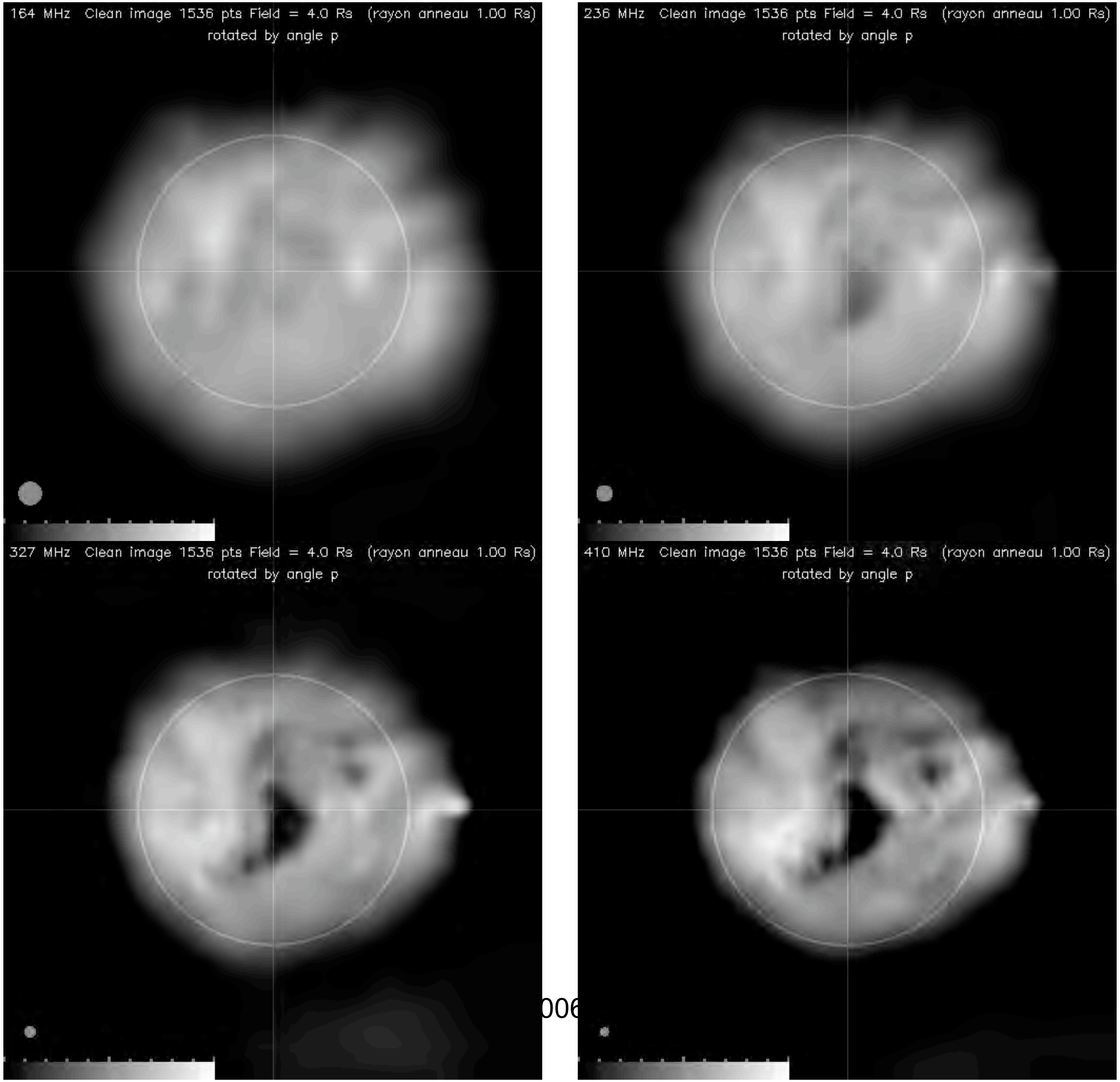
Moreton wave front: white spots

Pick M. et al, 2005

aperture synthesis with *NRH* (7h)

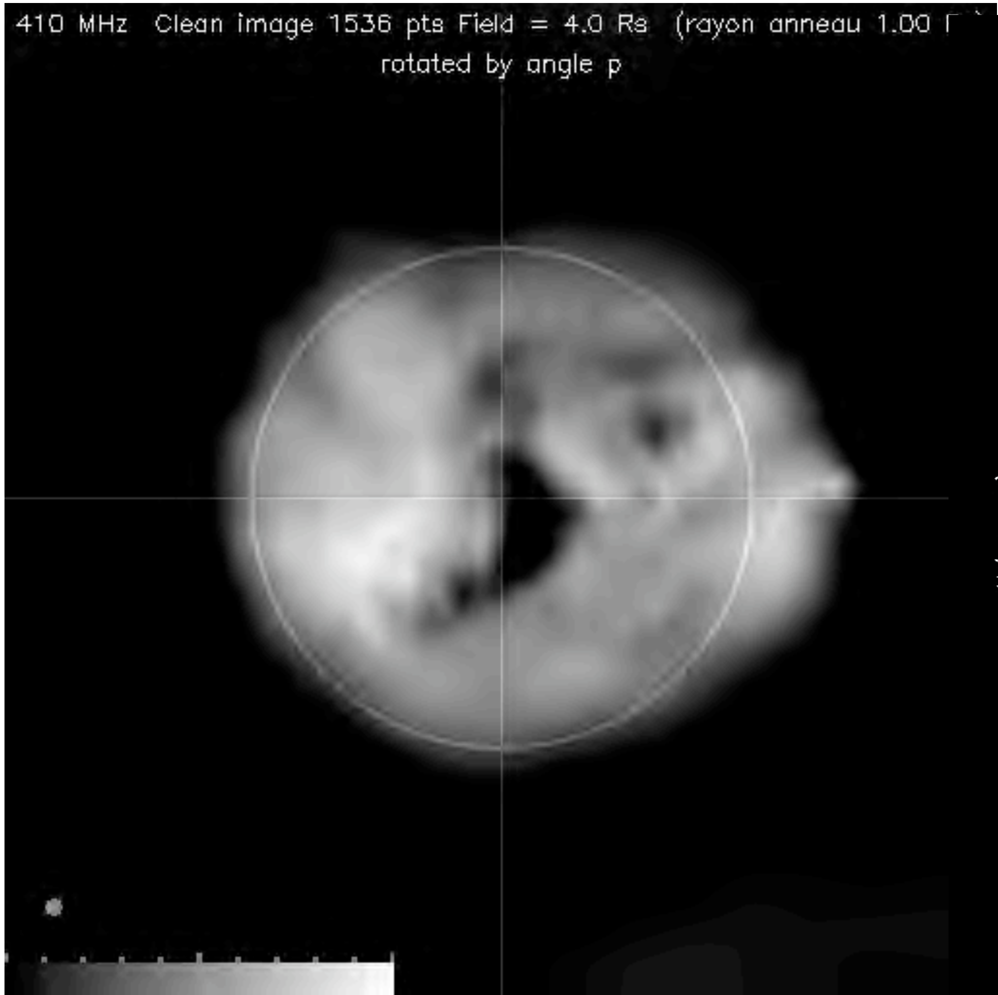
thermal sun at
164 236
327 410
MHz

june 27, 2004

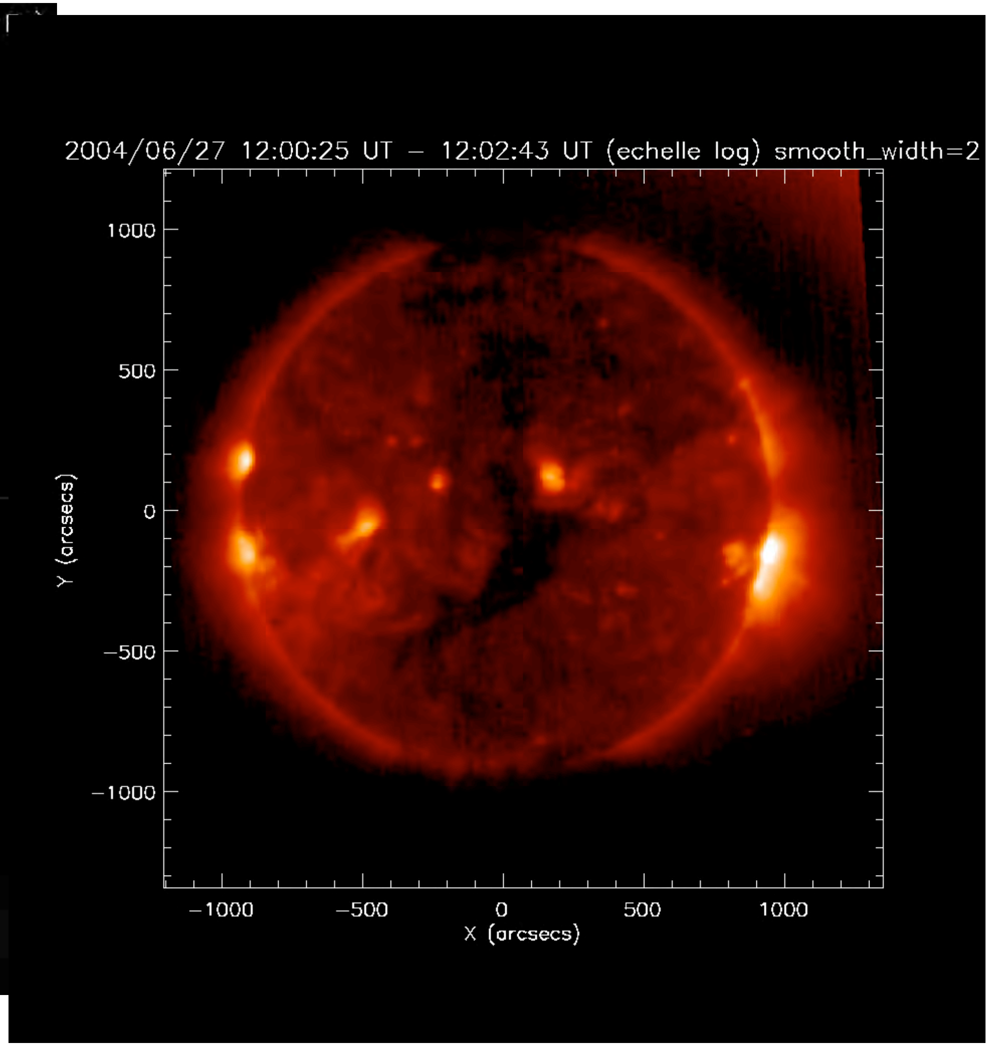


Thermal emissions : radio and soft *X*-rays

7h synthesis at 410 MHz (NRH)



soft *X*-rays (SXI)



Effect of ionospheric gravity waves