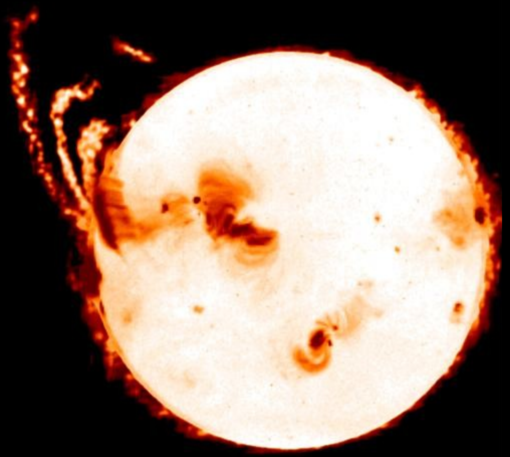
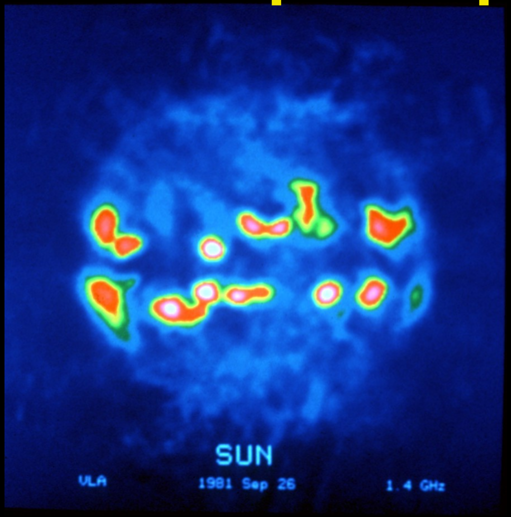
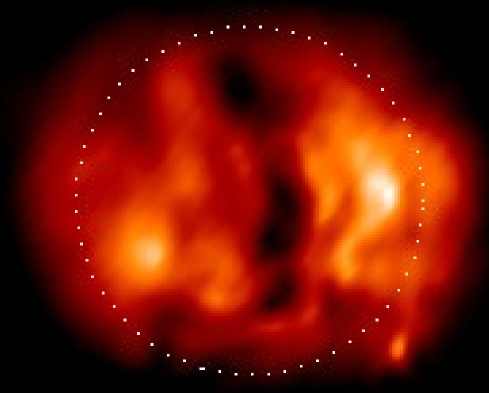
Solar radio physics with LOFAR : constraints & perspectives



NoRH 17 GHz / 1.8 cm



VLA 1.4 GHz / 21 cm



NRH 0.327 GHz / 91 cm

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Radio observations of the solar corona

- Radio waves from the solar atmosphere :
  - Propagation at $\nu > \nu_{pe} \sim \sqrt{n_e} \Rightarrow$ *emission frequency decreases with increasing altitude*
  - Radio imaging = sounding of different heights at different frequencies

- Emission processes :
  - free-free (quiet Sun)
  - (gyro)synchrotron (bursts, cm-m-λ)
  - collective emission at ν_{pe} or $2\nu_{pe}$ (bursts, dm-m-λ)

Observations of the solar corona at m-λ : why ?

- Plasma diagnostics of the quiet corona (n_e, T, B) and the nascent solar wind

- The Sun as a particle accelerator (high corona) :
  - « Quiet-time » non thermal e^--populations
  - e^- accelerated during CME and at coronal shocks
  - Energetic particle propagation (corona, IP space)

- Coronal magnetic topology, mass ejections (*CME)*, shocks

Limitations to solar radio imaging at m-λ

- Spatial resolution limited by propagation effects :
  - Corona : scattering $\Rightarrow$ broadening
    - Modelling : apparent source sizes ~ 5′ at 100 MHz (Bastian)
    - Observation : no structure <60″ (236 MHz, NRH - GMRT)
    - Baselines < 10 km needed for solar observations
  - Ionosphere : (unpredictable) gravity waves, esp. in winter, ray deviation $\sim\nu^{-2}$
    - Apparent shifts of source centroids
    - Image distortion, possible destruction (focussing)
    - Variable due to flare-produced EUV & XR (large flares)
- Imaging at ν<60 (?) MHz may be difficult

Requirements for solar radio imaging

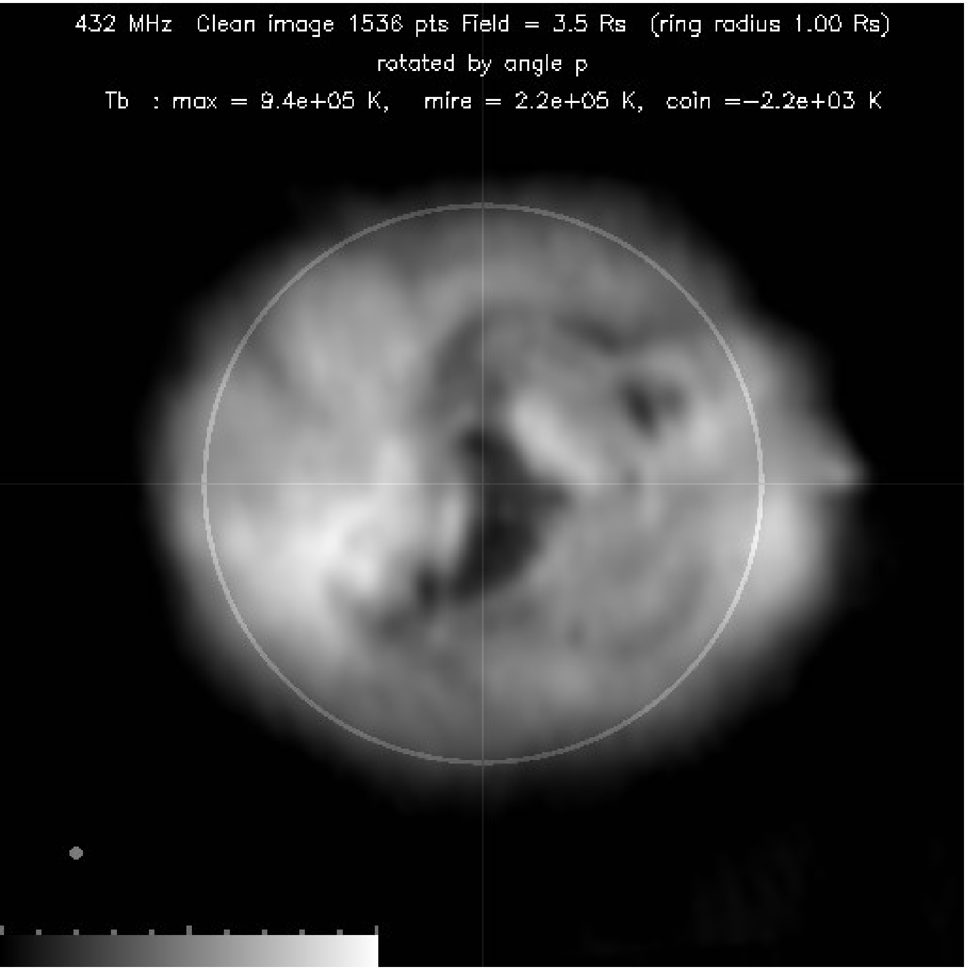
- A highly variable and unpredictable radio source :
  - VLA, NRH+GMRT : limited usefulness of campaigns
  - « alert » modes preclude studies of impulsive bursts and initial phases of flare activity (but : data buffer ?)

  $\Rightarrow$ Dedicated long-term observations at high time resolution

- Spectrum : no lines, but structured features covering wide frequency range

  $\Rightarrow$ Imaging over wide frequency range, (5-10) frequencies (may be adapted to specific programmes).

Coronal plasma diagnostics : EUV and radio

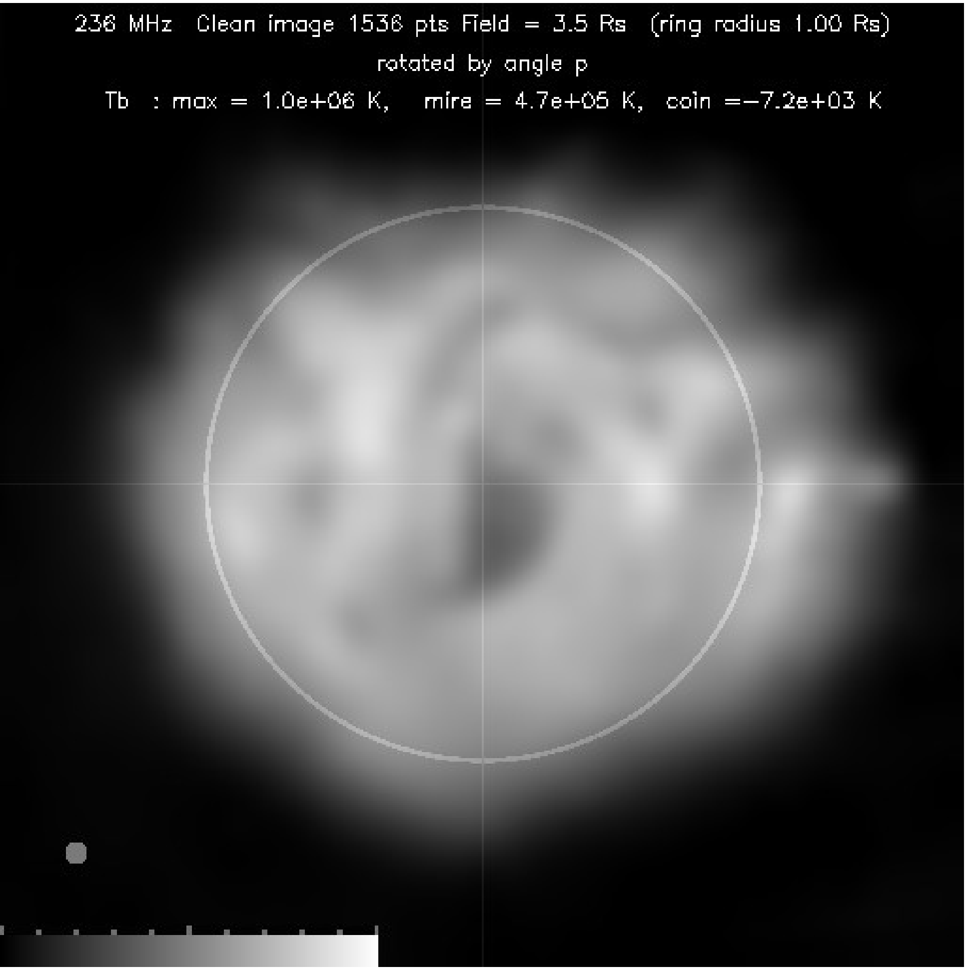


- What is the density and temperature structure in the quiet corona ?
- Is there a consistent picture from EUV and radio observations ?
- What is the e⁻ distribution function in the low / middle corona ? Can we detect non-maxwellian features (Chiuderi & Chiuderi-Drago 2004 AA 422, 331) ?

NRH (432 MHz): C. Mercier

SXR : SXI (NOAA)

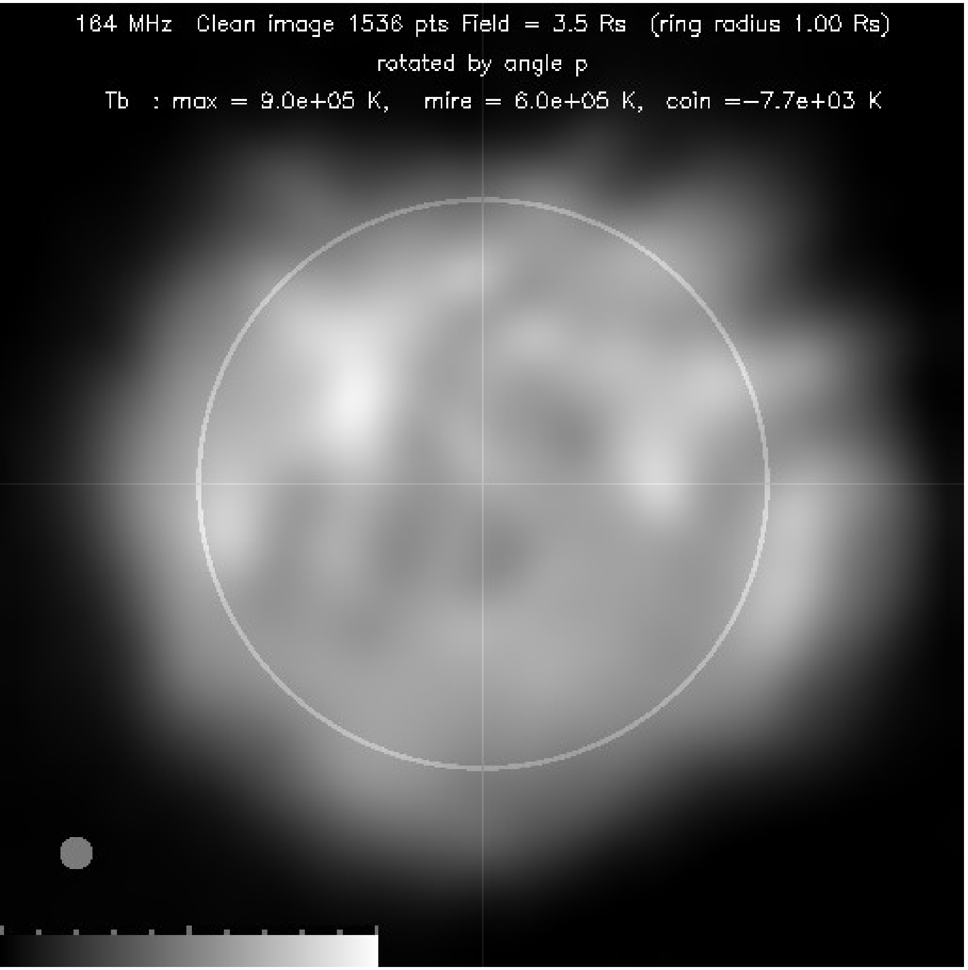
Coronal plasma diagnostics : EUV and radio



NRH (237 MHz): C. Mercier

- What is the density and temperature structure in the quiet corona ?
- Is there a consistent picture from *EUV* and radio observations ?
- What is the e^- distribution function in the low / middle corona ? Can we detect non-maxwellian features (Chiuderi & Chiuderi-Drago 2004 AA 422, 331) ?

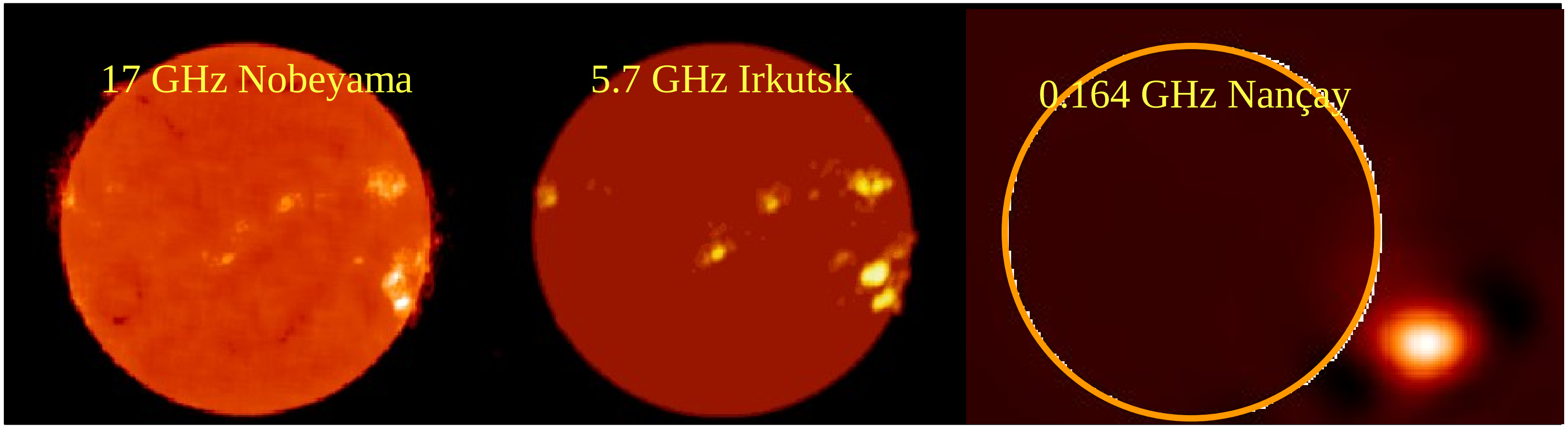
Coronal plasma diagnostics : *EUV* and radio

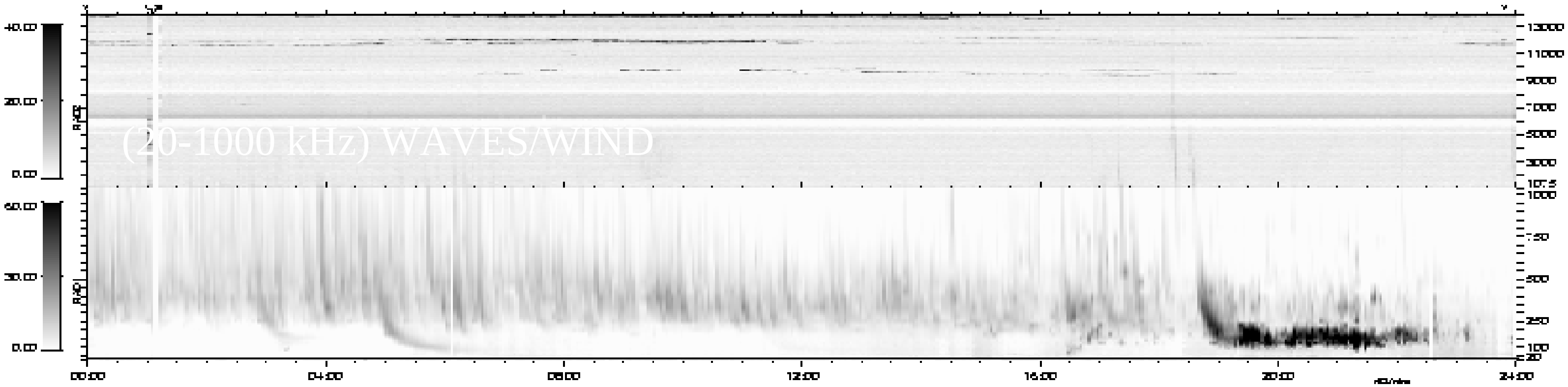


NRH (164 MHz): C. Mercier

- What is the density and temperature structure in the quiet corona ?
- Is there a consistent picture from *EUV* and radio observations ?
- What is the e^- distribu-tion function in the low / middle corona ? Can we detect non-maxwellian features (Chiuderi & Chiuderi-Drago 2004 AA 422, 331) ?

Mapping non thermal radio sources outside flares



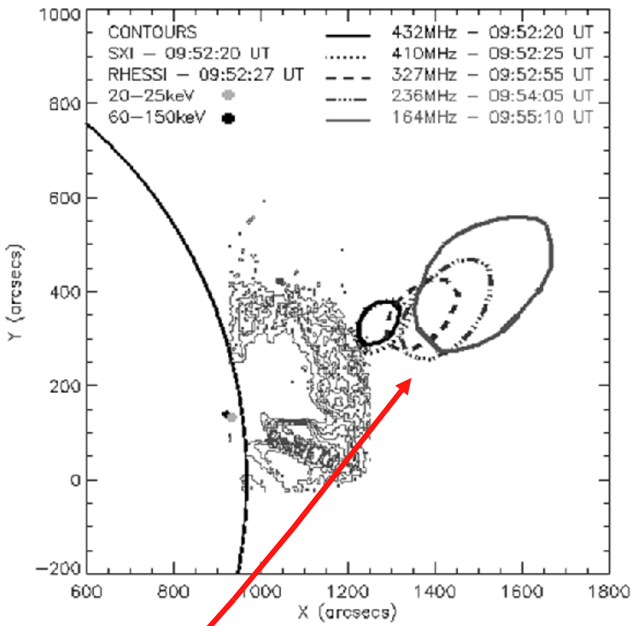


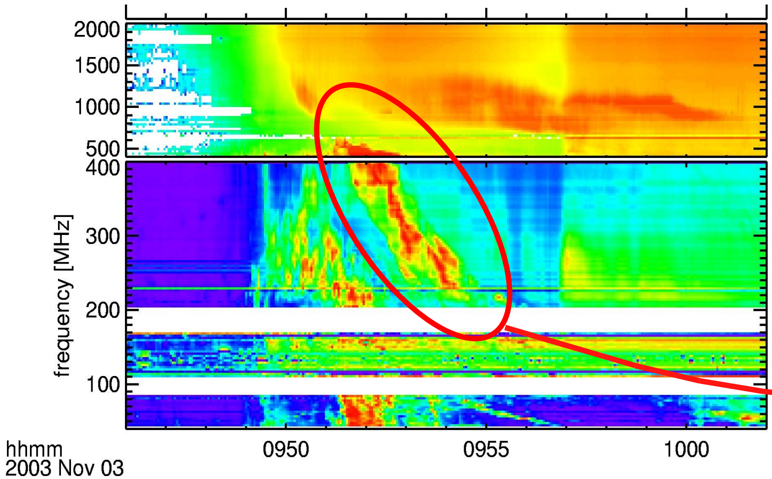
- Non thermal e^- (some keV) in/above non-flaring *AR*. Multi-λ mapping : Where ? Trajectories? Circular polar : *B*.
- Origin of nonmaxwellian e^- populations in *IP* space ?

Mapping coronal shock waves

- Radio emission most direct evidence of coronal shocks
- Occurs with different kinds of other bursts (gyrosynch, plasma) : complex spectra

SXI 09:52:20 UT NRH (432 MHz)





Where do shocks develop ? How are they related with *CME*, where are they located w/r to the white-light signature of a *CME* (front ? flanks ?) ? Piston-driven ? Blast ?

Dauphin et al. 2006 AA

Mapping *CME* loops : relativistic electrons

- Synchrotron radiation from relativistic e^-
- Where / when are they accelerated ?

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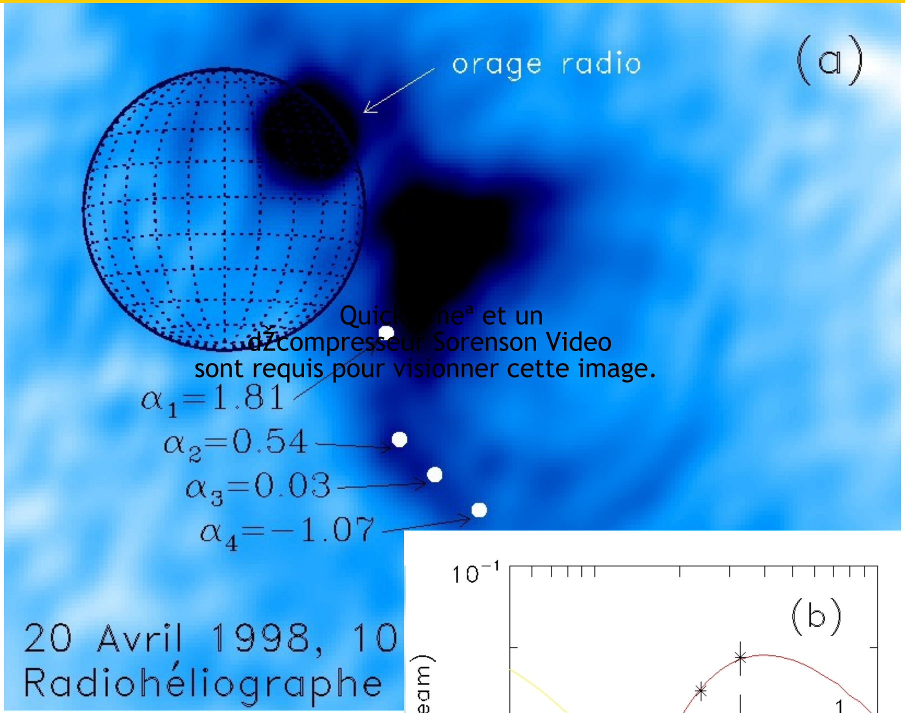
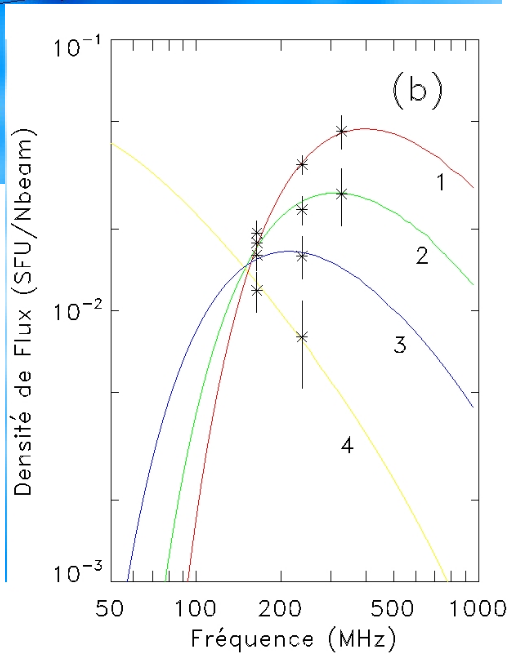
dŽcompresseur MPEG-4 vidŽo
sont requis pour visionner cette image.

SoHO/LASCO





Bastian, Pick, Kerdraon, Maia, Vourlidas, 2001, ApJ 558, L65

LOFAR's contribution to solar physics

- *LOFAR* can be a very useful tool for studying transient processes in the high corona related with flares and *CME*, provided :
  - Dedicated solar mode / long term observations
  - Mapping with high dynamic range ($>10^4$)
  - Multi-frequency mapping with sub-second cadence
  - Ionospheric corrections including changes during flares

- *LOFAR* will need complementary observations:
  - Simultaneous spectral coverage (whole Sun, dm-hm-λ)
  - Radio imaging at higher frequencies (relationship high corona - active region / primary flare signatures / *CME* origin)
  - Coronographic observations (*STEREO* …)

Solar-dedicated radio imaging

Wave band	Instrument	Angular resolution	Time re-solution	Frequencies
mm/cm	Nobeyama RH	10″	0.1 s	17 & 34 GHz
cm/dm	Owens Valley	10″	~1 s	1-18 GHz
dm/m	Nançay RH	~1′	125 ms	450 … 150 MHz (<10)
m	Gauribidanur RH	~5′	145 ms	40-150 MHz
(cm-m	FASR	20″ / 1 GHz	0.1 s	100-30,000 MHz)

- + occasional solar observations at dm-m-λ : VLA (327, 75 MHz), GMRT (620, 325, 235 MHz), UTR-2 Kharkov 20-30 MHz
- LOFAR fills gap between ground-based and space-borne radio observations (Wind, STEREO, Solar Orbiter + Sentinels)