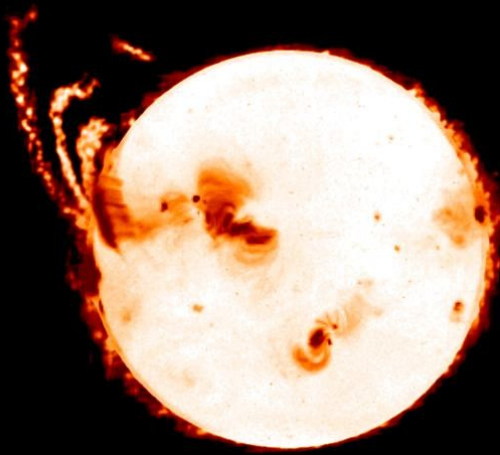
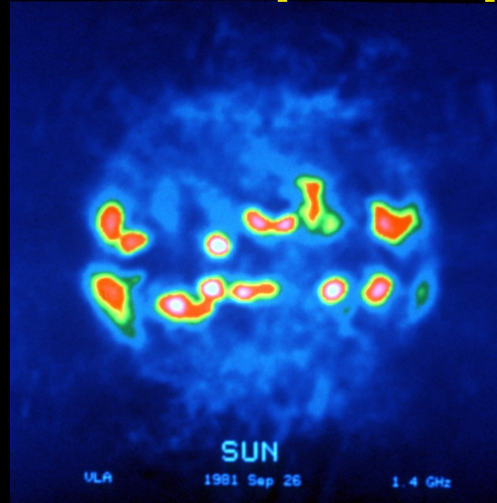


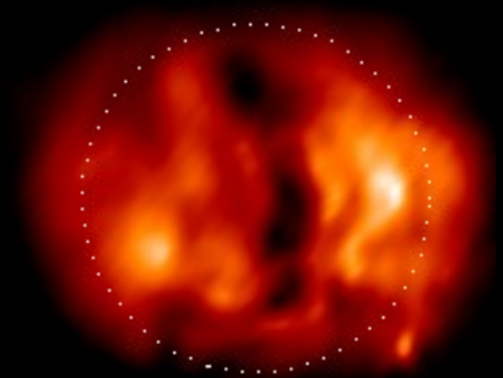
Solar radio physics with LOFAR : constraints & perspectives



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 $m\text{-}\lambda$

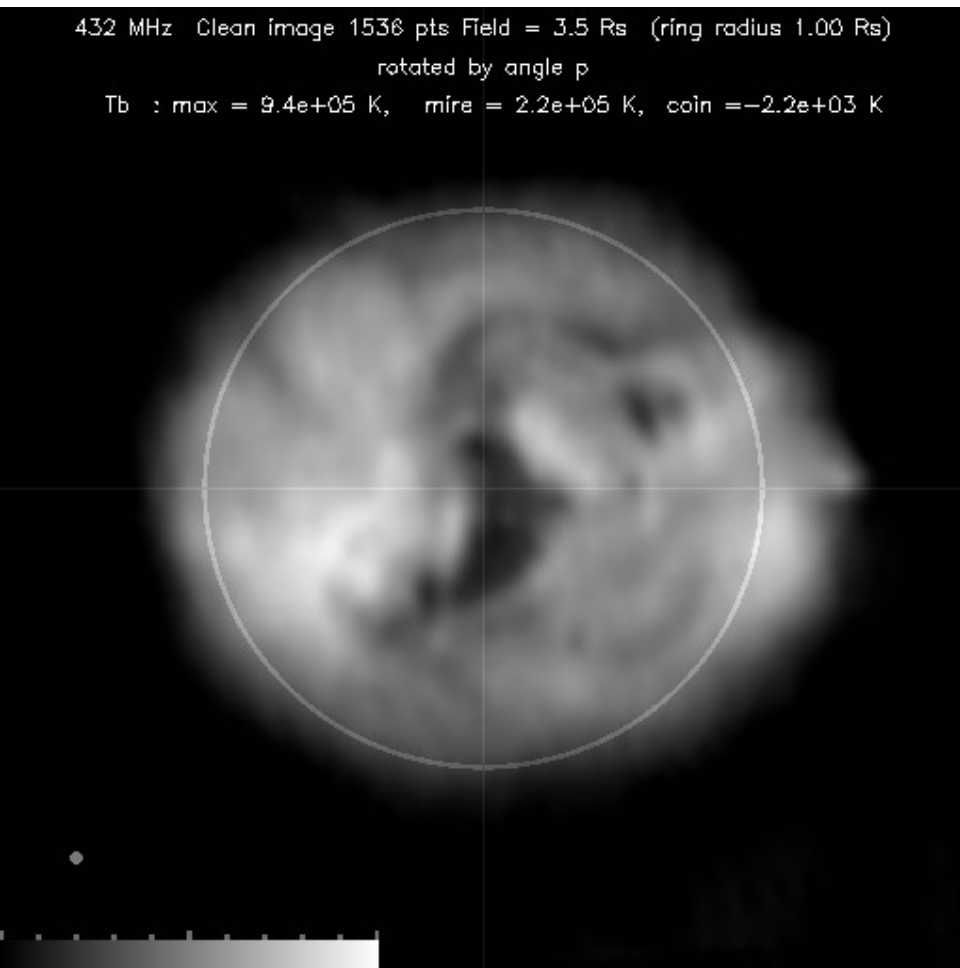
- Spatial resolution limited by propagation effects :
 - Corona : scattering \Rightarrow broadening
 - Modelling : apparent source sizes $\sim 5'$ at 100 MHz (Bastian)
 - Observation : no structure $< 60''$ (236 MHz, NRH - GMRT)
 - Baselines < 10 km needed for solar observations
 - Ionosphere : (unpredictable) 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 $\nu < 60$ (?) 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 ?)
 - ⇒ Dedicated long-term observations at high time resolution
- Spectrum : no lines, but structured features covering wide frequency range
 - ⇒ Imaging over wide frequency range, (5-10) frequencies (may be adapted to specific programmes).

Coronal plasma diagnostics : EUV and radio

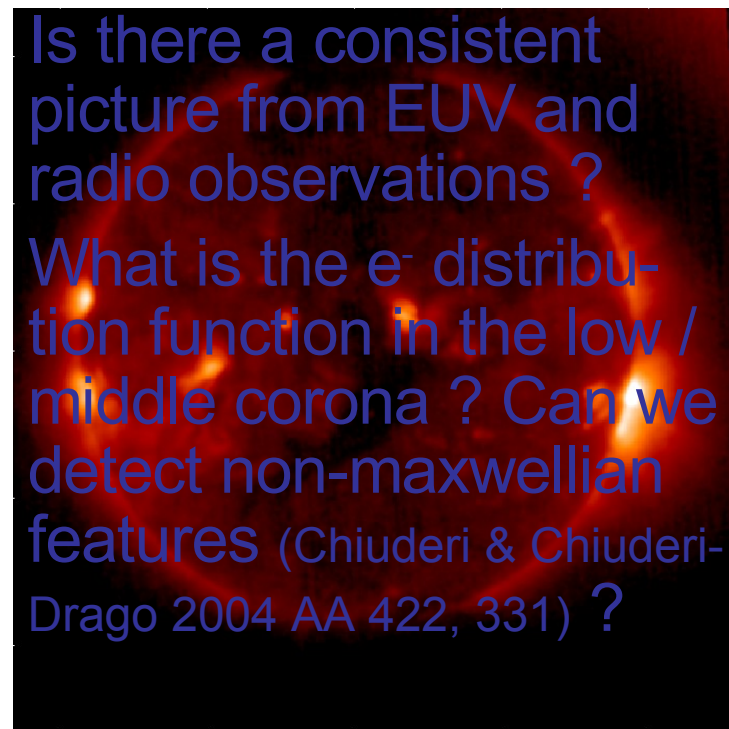
432 MHz Clean image 1536 pts Field = 3.5 Rs (ring radius 1.00 Rs)
rotated by angle ρ
Tb : max = 9.4e+05 K, mire = 2.2e+05 K, coin = -2.2e+03 K



NRH (432 MHz): C. Mercier

- What is the density and temperature structure in the quiet corona ?

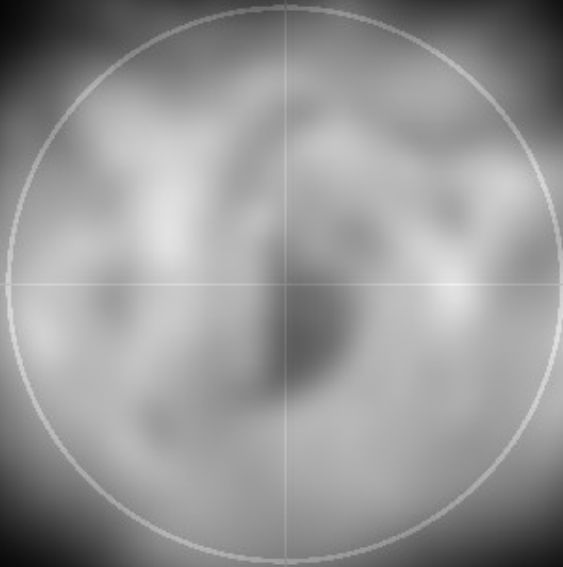
- Is there a consistent picture from EUV and radio observations ?
- What is the e^- distribution function in the low / middle corona ? Can we detect non-maxwellian features (Chiuderi & Chiuderi-Drago 2004 AA 422, 331) ?



SXR : SXI (NOAA)

Coronal plasma diagnostics : EUV and radio

236 MHz Clean image 1536 pts Field = 3.5 Rs (ring radius 1.00 Rs)
rotated by angle ρ
Tb : max = 1.0e+06 K, mire = 4.7e+05 K, coin = -7.2e+03 K

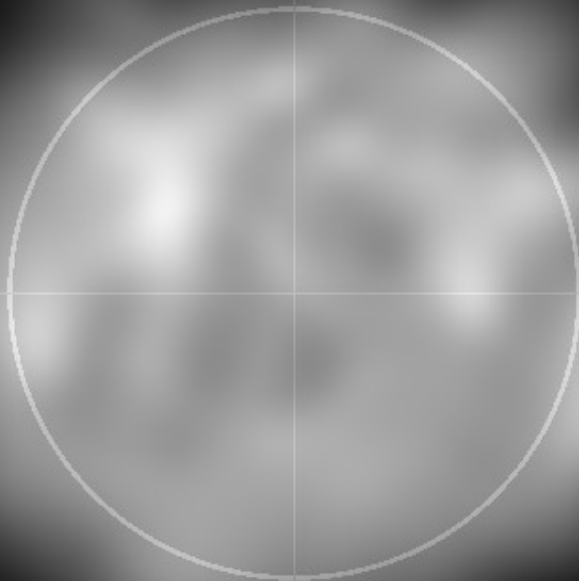


- What is the density and temperature structure in the quiet corona ?
- Is there a consistent picture from *EUUV* and radio observations ?
- What is the e^- distribution function in the low / middle corona ? Can we detect non-maxwellian features (Chiuderi & Chiuderi-Drago 2004 AA 422, 331) ?

NRH (237 MHz): C. Mercier

Coronal plasma diagnostics : *EUUV* and radio

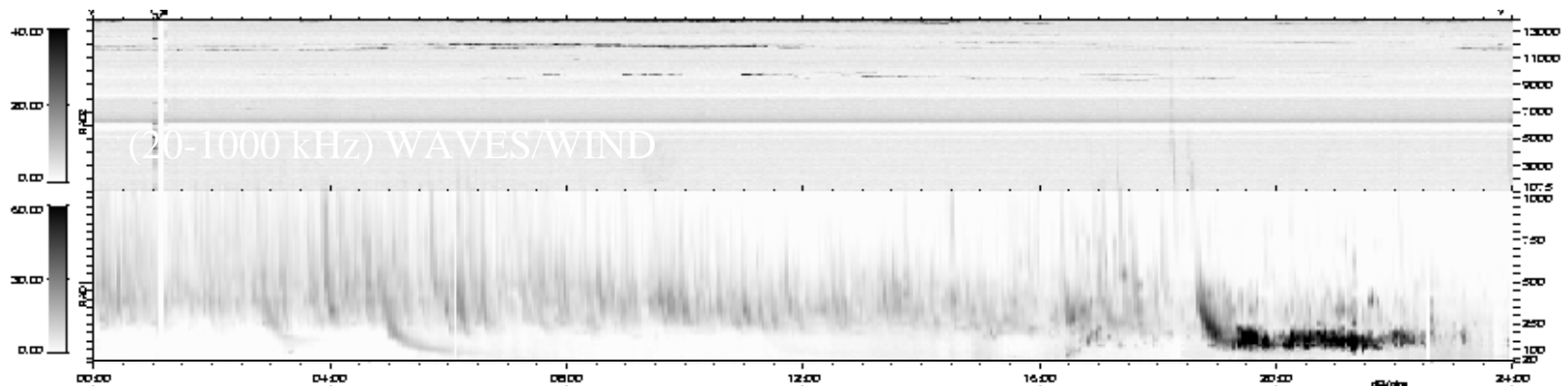
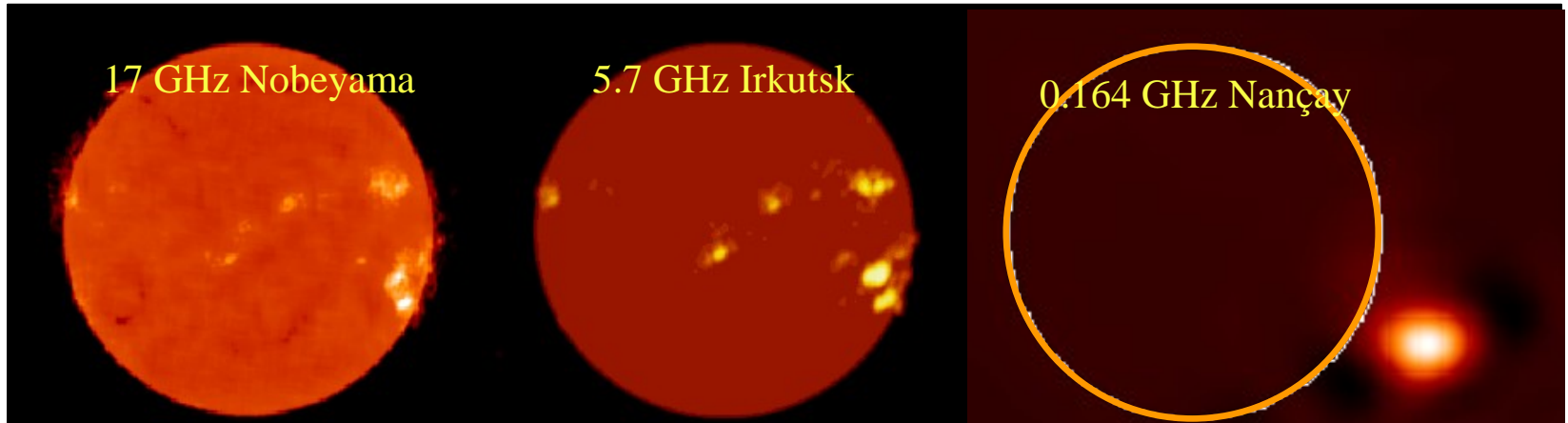
164 MHz Clean image 1536 pts Field = 3.5 Rs (ring radius 1.00 Rs)
rotated by angle ρ
Tb : max = 9.0e+05 K, m1re = 6.0e+05 K, coin = -7.7e+03 K



- What is the density and temperature structure in the quiet corona ?
- Is there a consistent picture from *EUUV* 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 (164 MHz): C. Mercier

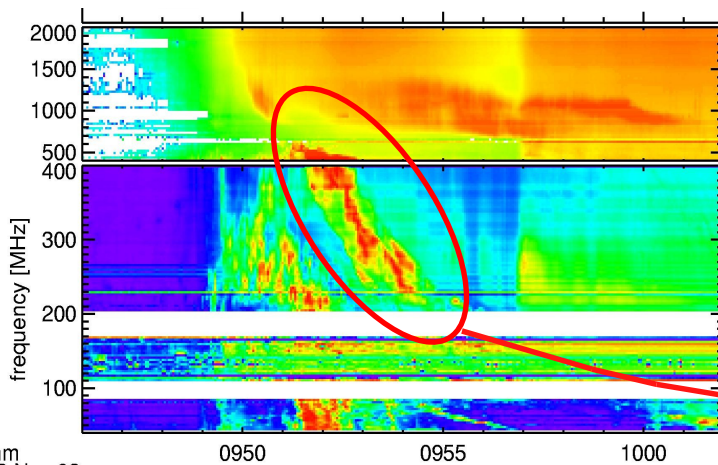
Mapping non thermal radio sources outside flares



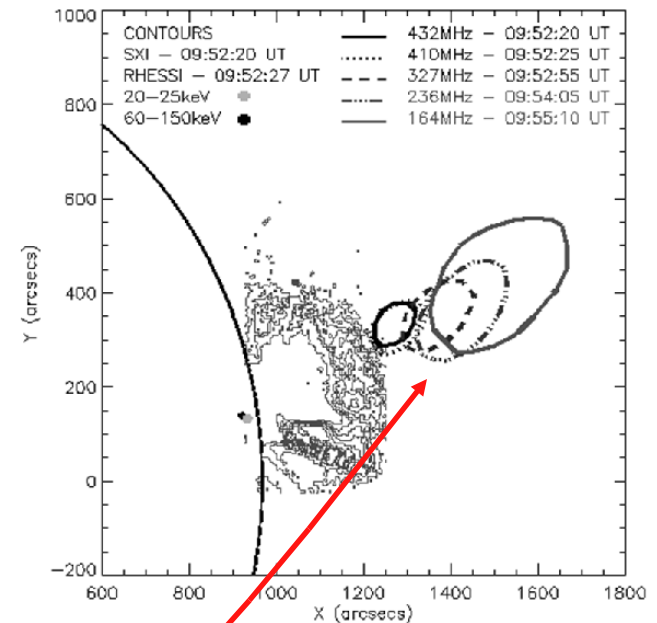
- Non thermal e^- (some keV) in/above non-flaring *AR*. Multi- λ mapping : Where ? Trajectories? Circular polar : *B*.
- Origin of nonmaxwellian e^- populations in *IP* space ?

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)



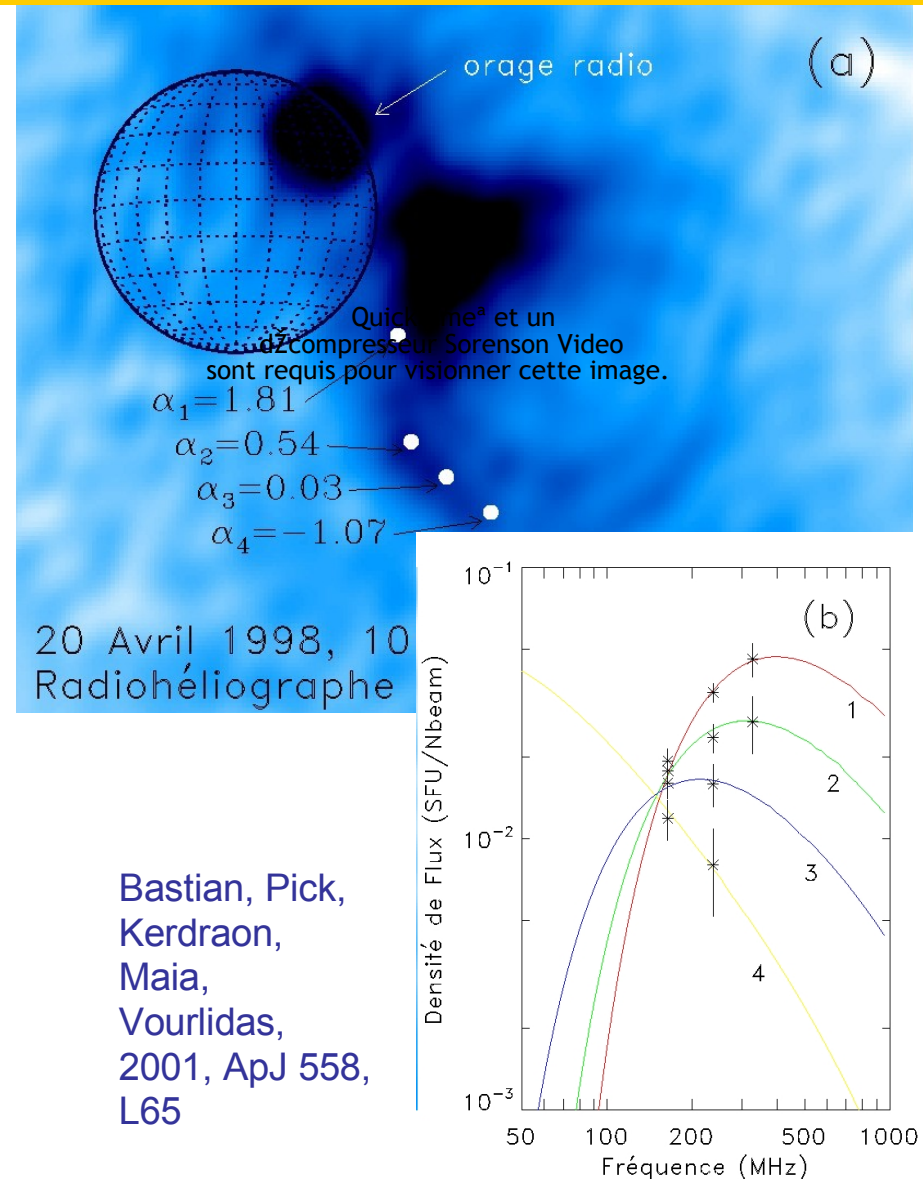
Where do shocks develop ? How are they related with *CME*, where are they located w/r to the white-light signature of a *CME* (front ? flanks ?) ? Piston-driven ? Blast ?

Mapping *CME* loops : relativistic electrons

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

QuickTime^a et un
d'Źcompresseur MPEG-4 vidŹo
sont requis pour visionner cette image.

SoHO/LASCO



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)
 - Coronagraphic observations (*STEREO* ...)

Solar-dedicated radio imaging

Wave band	Instrument	Angular resolution	Time resolution	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)