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Solar radio imaging: true and apparent

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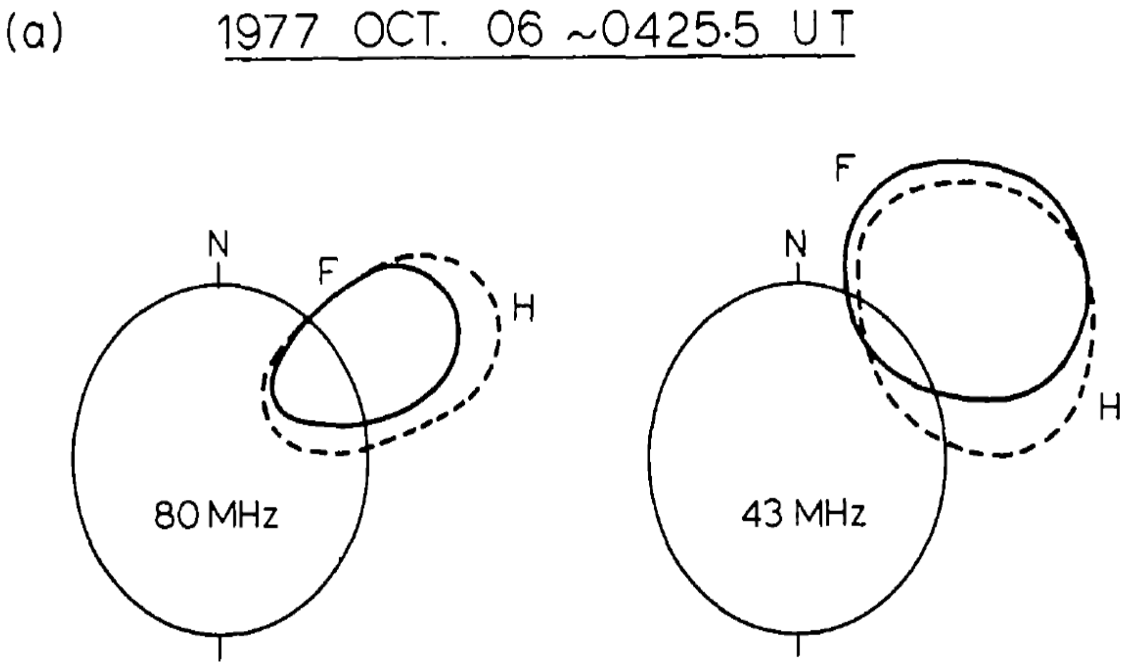
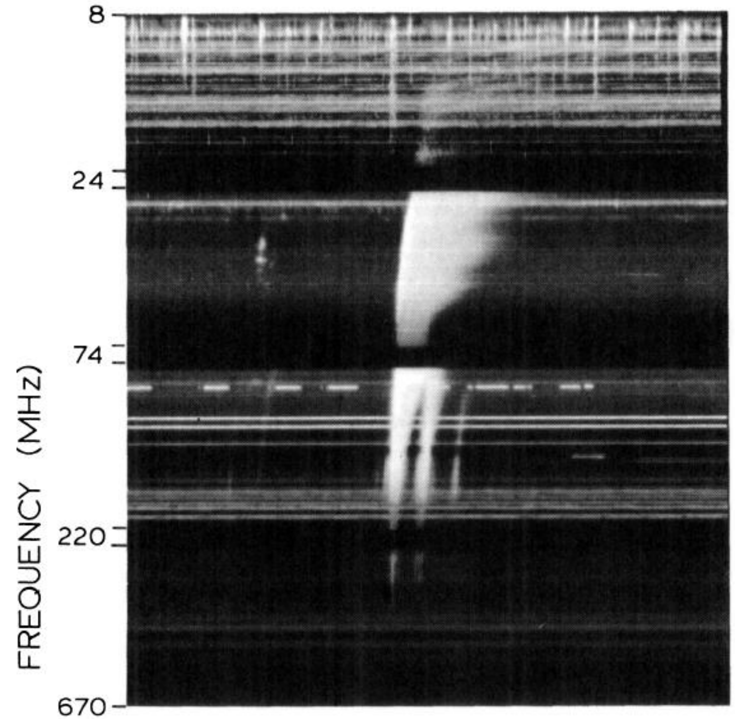
Solar radio imaging dilemma





Dilemma in solar radio imaging …
How to interpret the images?

F=Fundamental
H=Harmonic

What **chiefly** determines the observed positions and sizes of solar radio sources? Intrinsic properties of the emitter or the radio wave propagation effects?

Radio wave propagation

Since the first solar radio observations, the radio wave propagation was studied

Fokker, 1965; Steinberg et al., 1971, Steinberg, J.-L. 1972, Riddle, A. C. 1974 Pick et al 1981; ….

Radio wave in the corona are affected

- **refraction**
- **scattering**
- **absorption**

The observed source size is:

$$\theta = \sqrt{\theta_0^2 + \langle \Delta\theta^2 \rangle}$$

"true" source size

The dispersion relation for electromagnetic waves

$$\omega(k)^2 = \omega_{pe}^2 + k^2 c^2$$

The refractive index in unmagnetized plasma is given by:

$$n^2 = 1 - \frac{f_{pe}^2}{f^2}$$

=> **Waves close to plasma frequency (plasma emission) are strongly affected by propagation affects.**

Radio wave propagation effects

Radio wave propagation affects:

- Time-profiles of the bursts (decay is normally longer)
- The position of the source (frequency dependent)
- The size of the sources
- Polarization of the bursts

Radio wave propagation effects

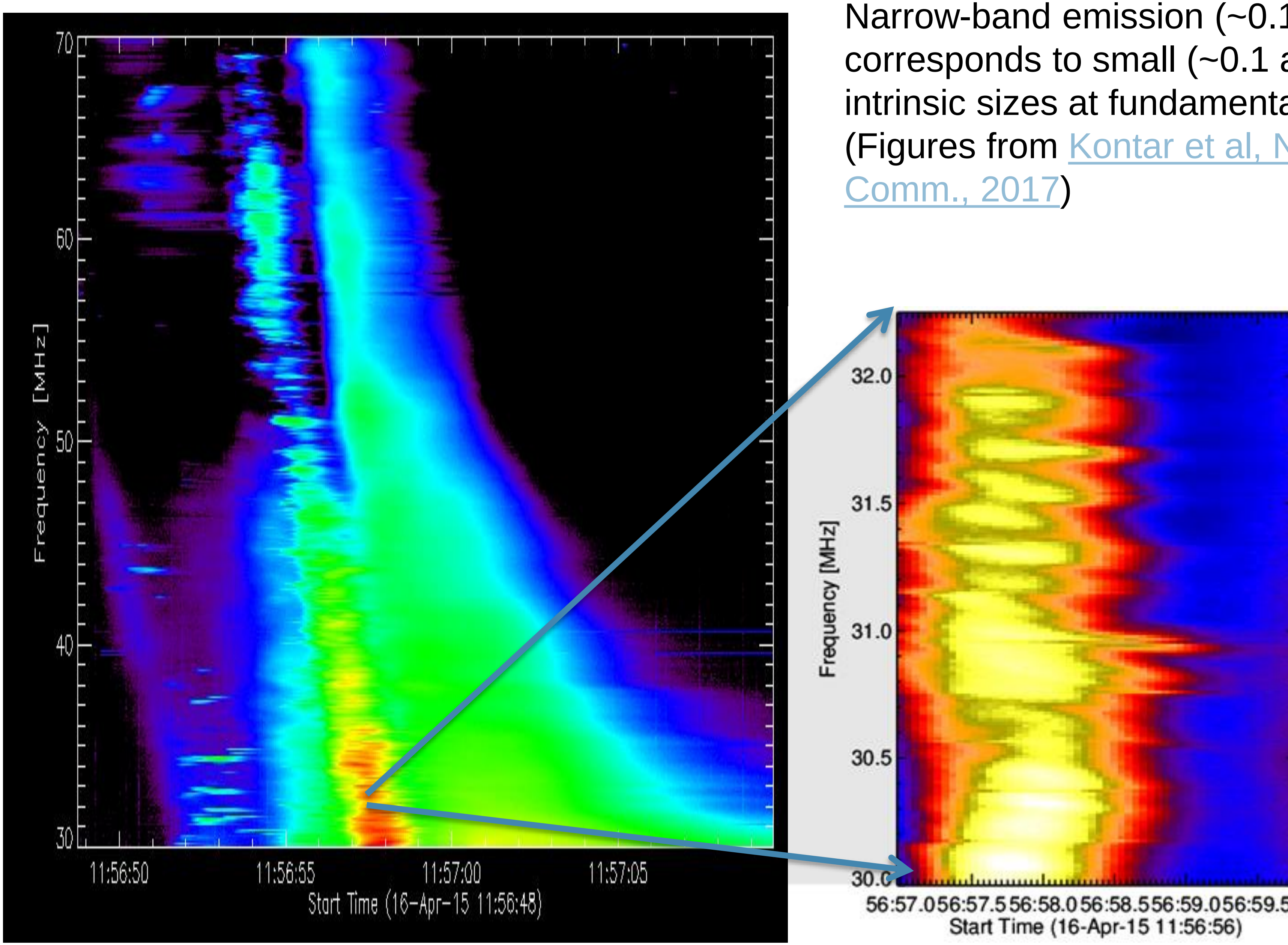
How to address the solar imaging dilemma:

- Theoretically (requires simulations of electron transport, radio emission generation and radio wave propagation) => **too difficult!**

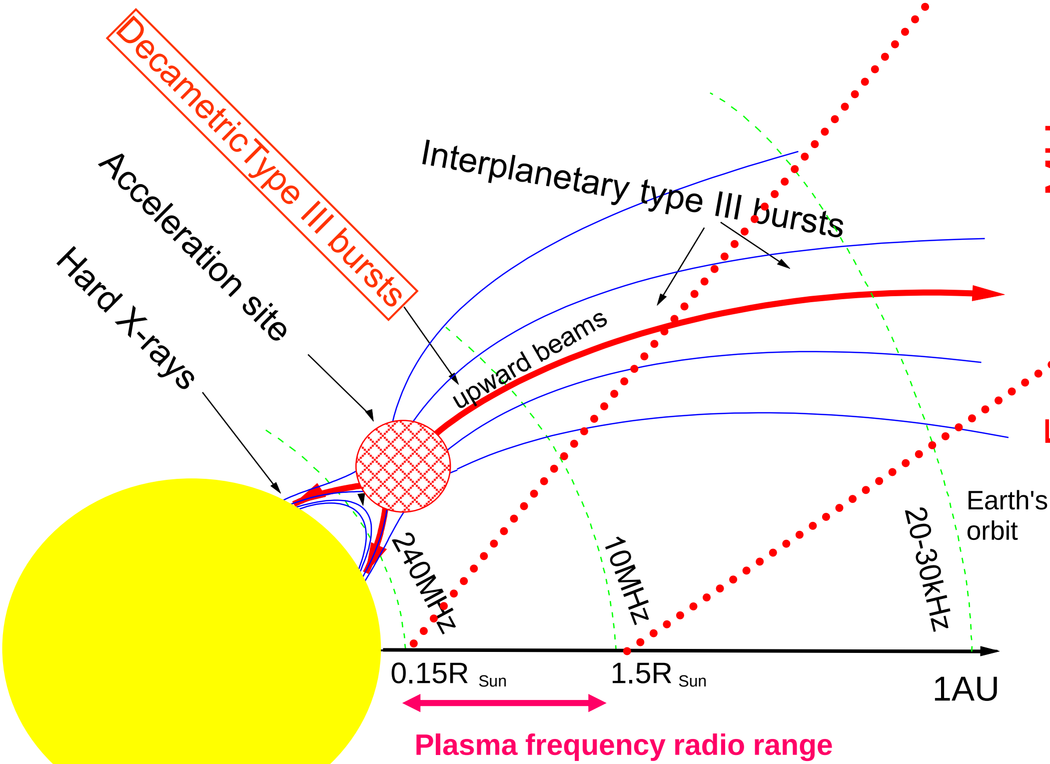
- Observationally design observations where the true source is small in 2015 we designed such observations with LOFAR using high time and frequency resolution).

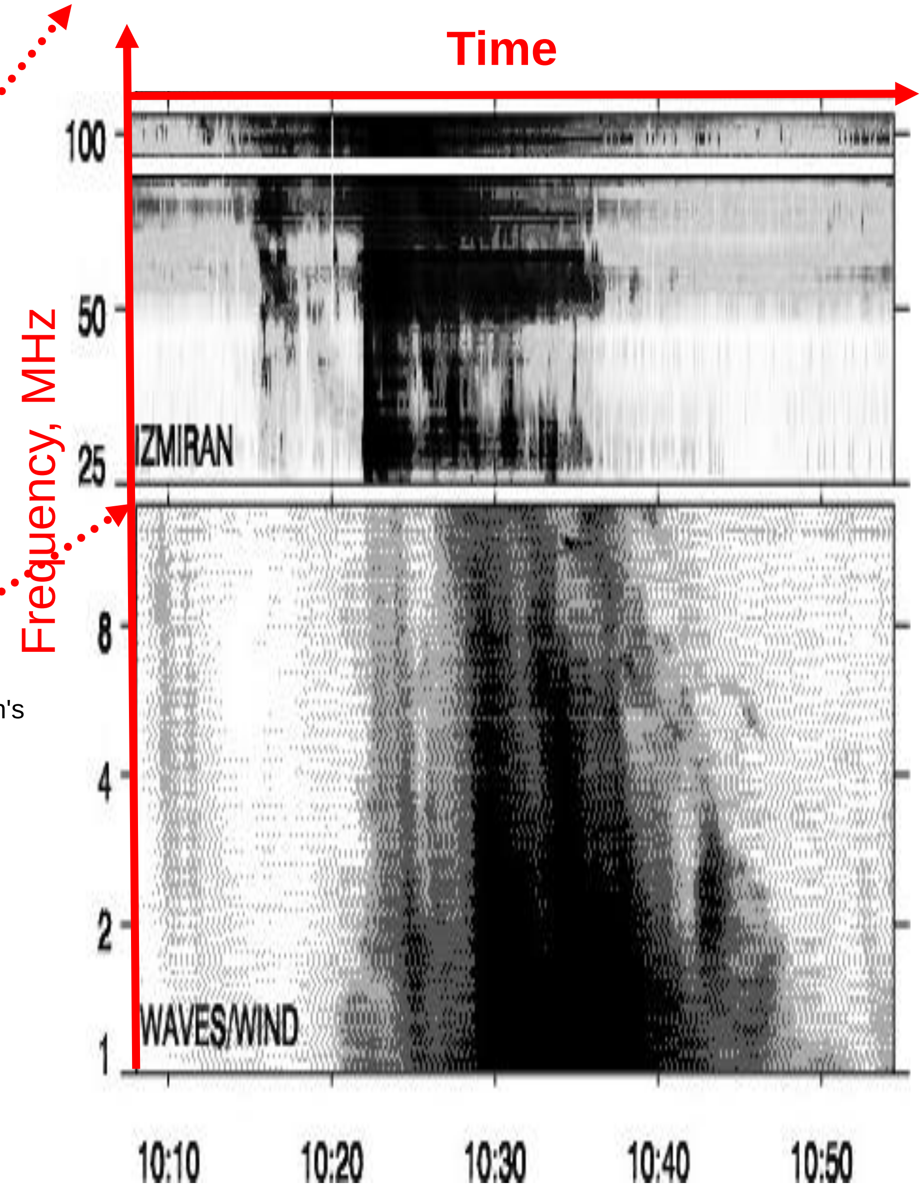
Fine radio structures

Narrow-band emission (~0.1 MHz) corresponds to small (~0.1 arcmin) intrinsic sizes at fundamental. (Figures from Kontar et al, Nature Comm., 2017)



Flares and accelerated particles

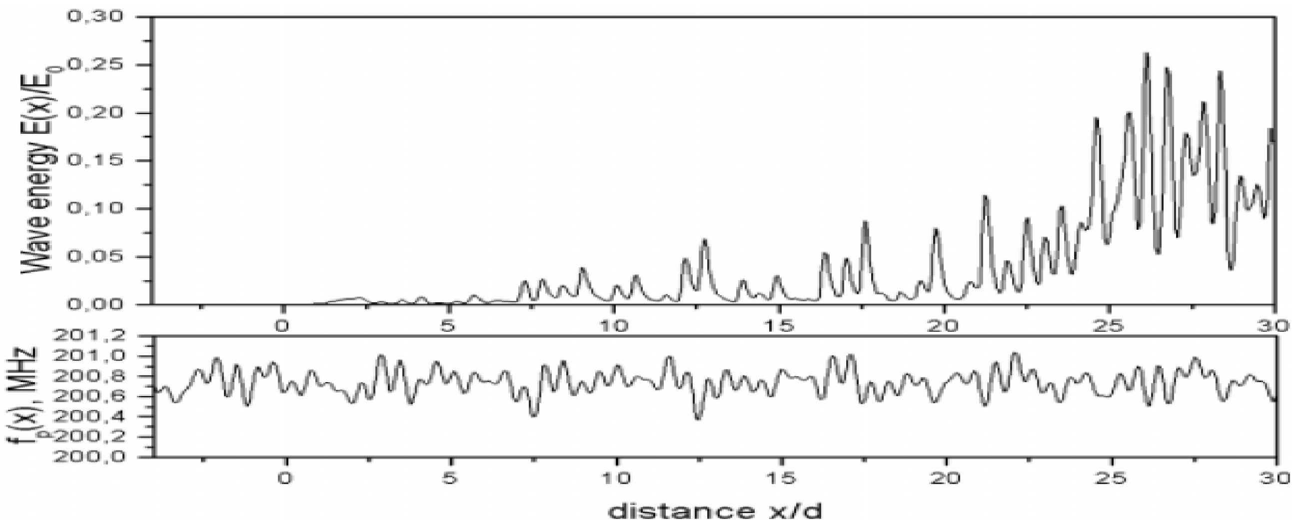


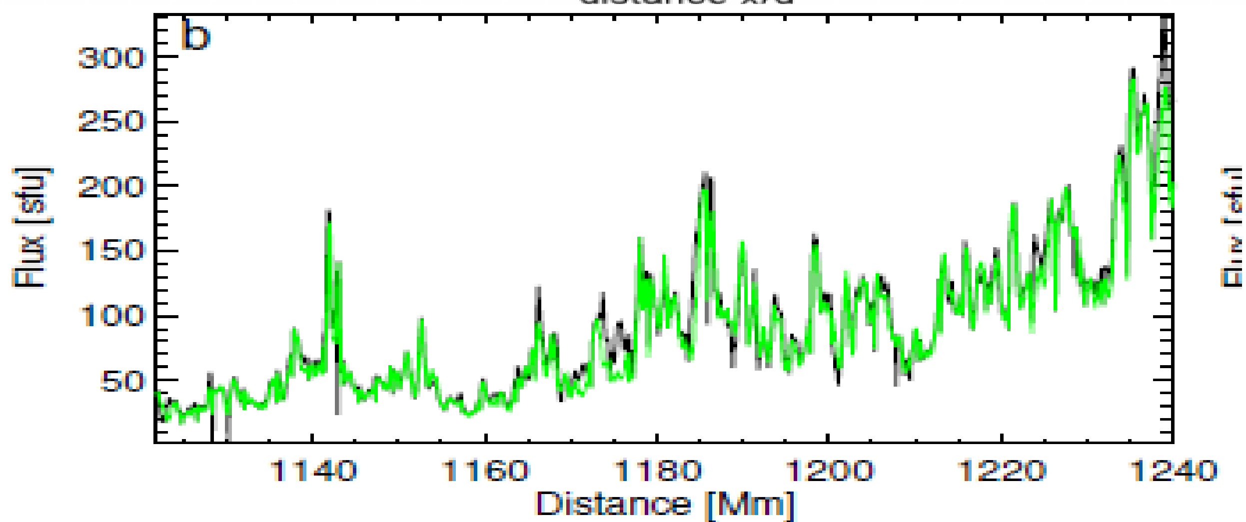


$$\nu_p = \sqrt{\frac{n_e e^2}{\pi m_e}},$$ <= plasma frequency

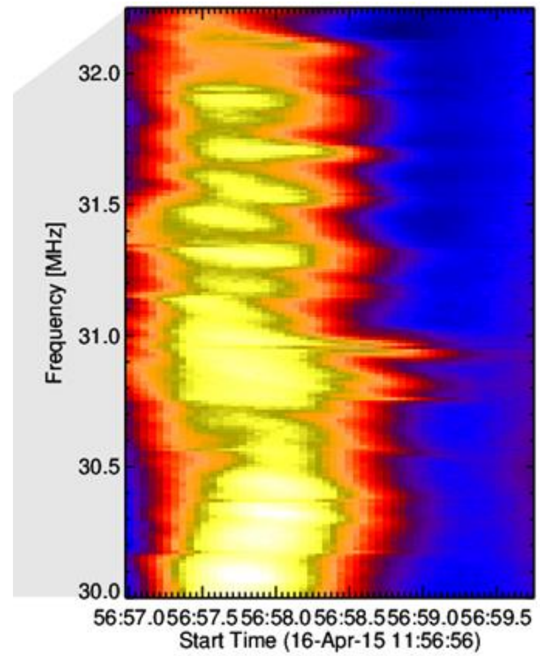
Fine structures are believed to be produced due to density fluctuations in plasma Takakruka (1976) and numerical simulations Kontar (2001).

Numerical simulations

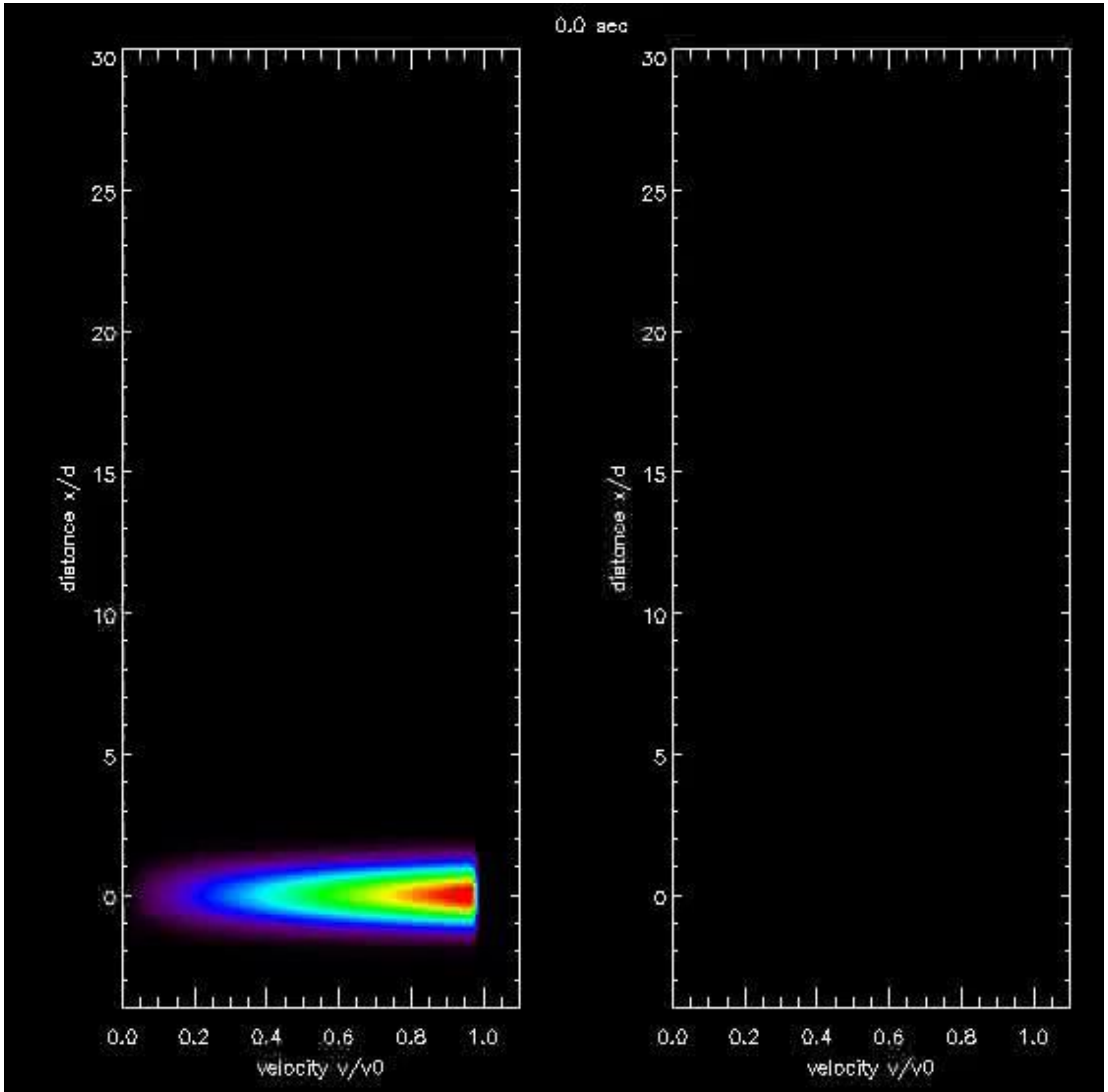




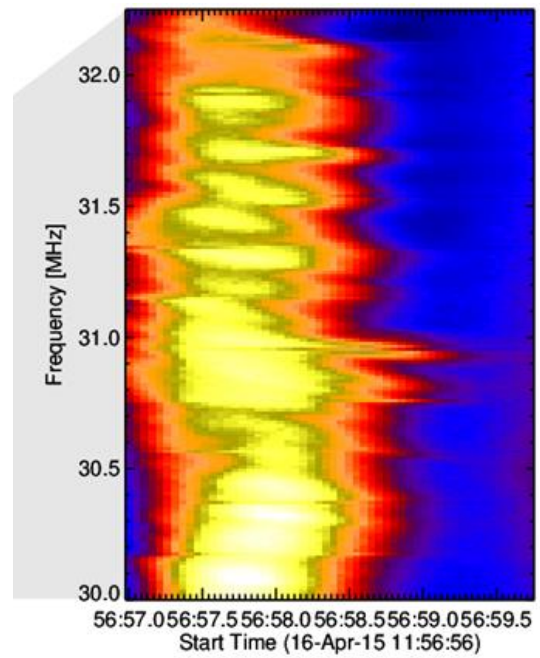
Observations:



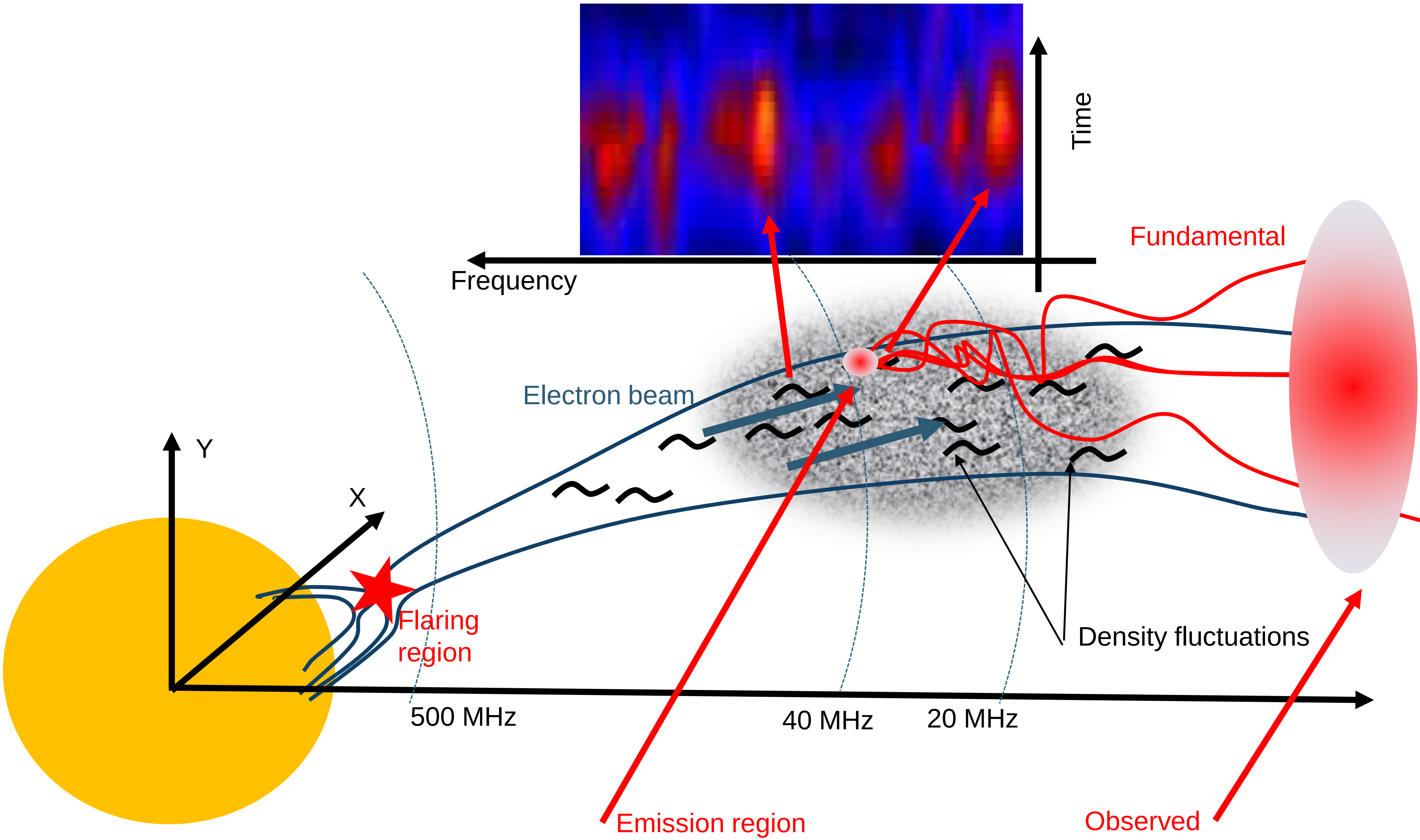
Electrons Waves



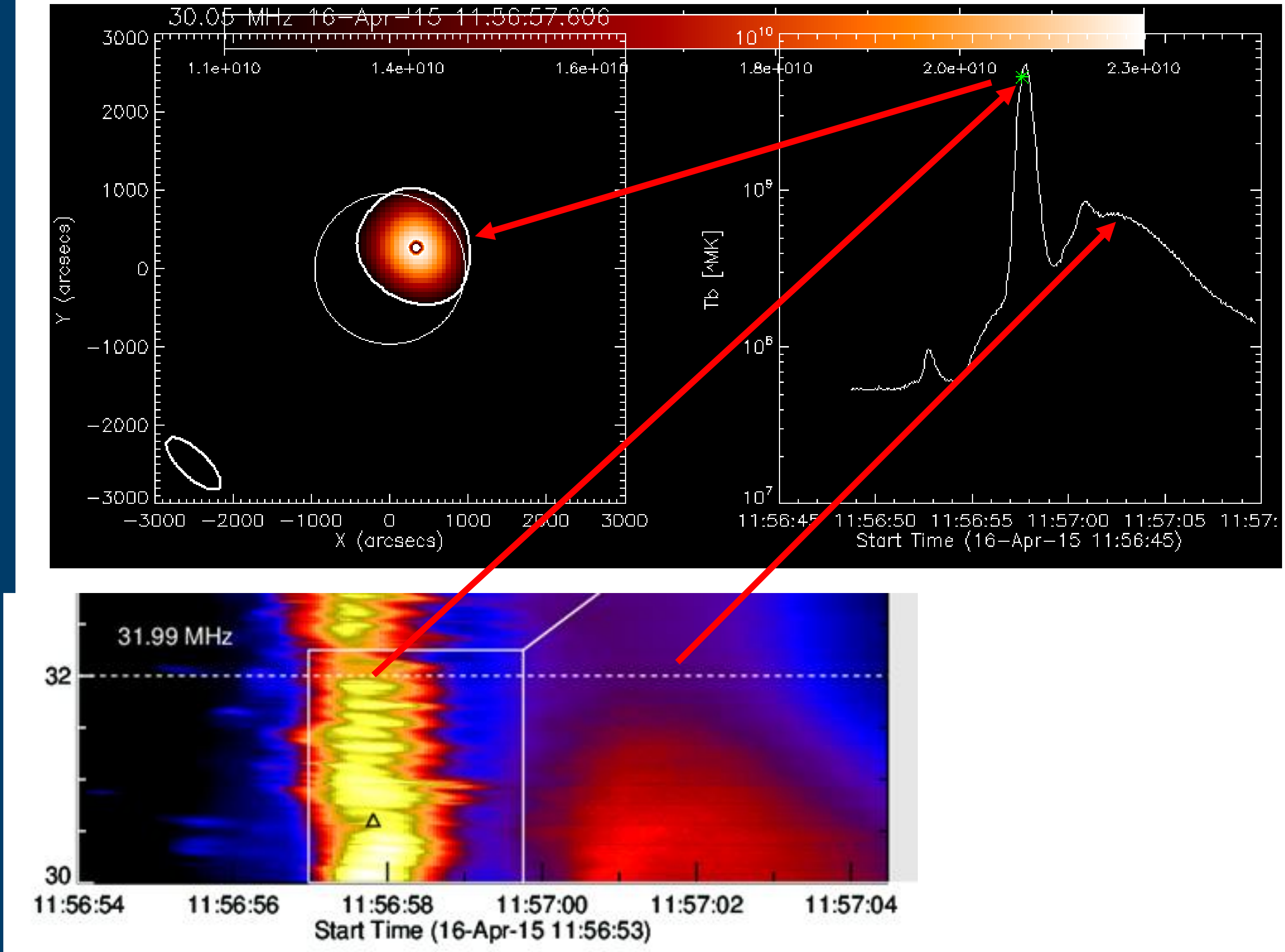
Numerical solution of kinetic equations: inhomogeneous plasma e.g. Kontar A&A 2001 Reid & Kontar 2010



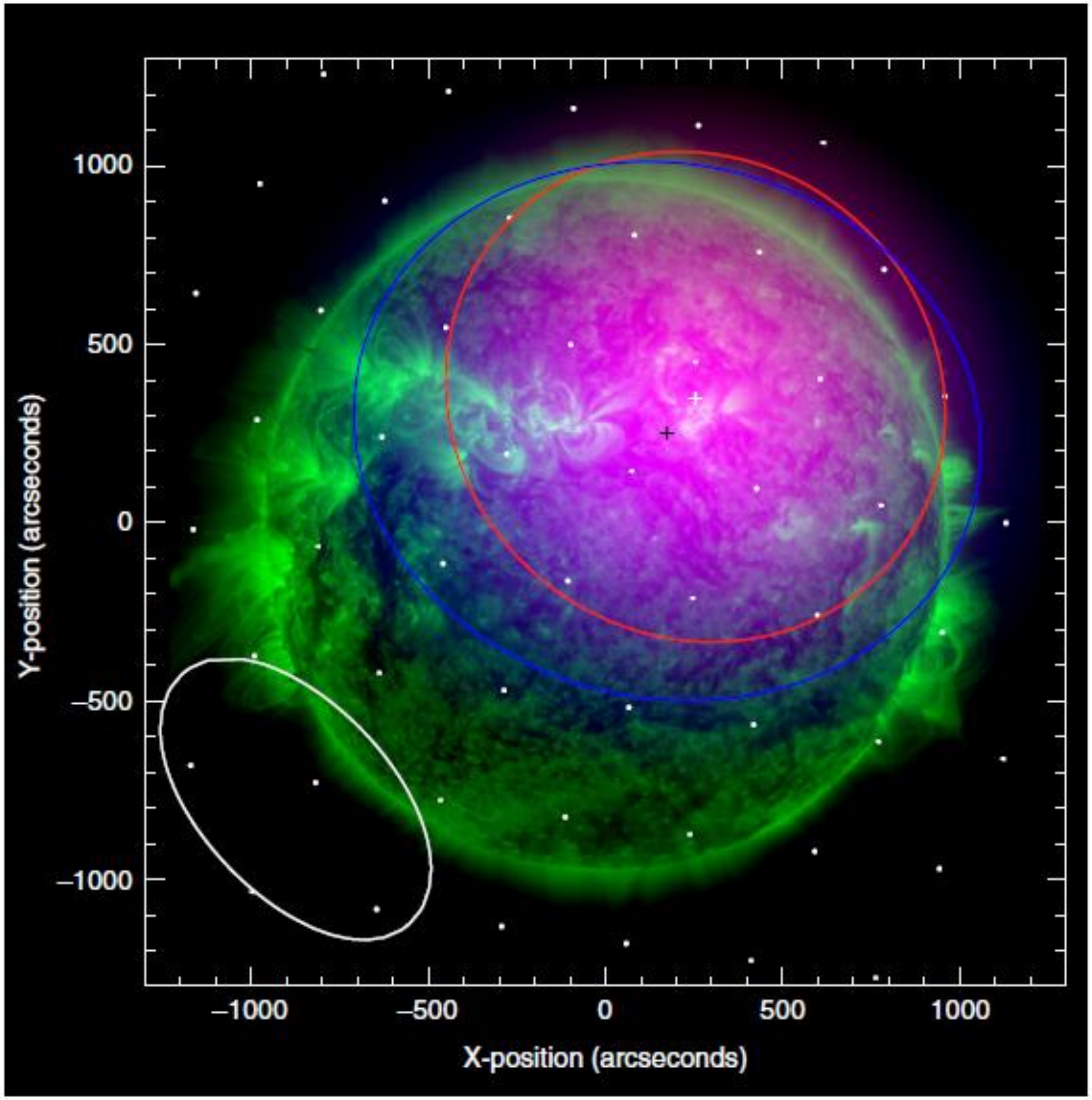
Observed radio structures



Imaging fine structures



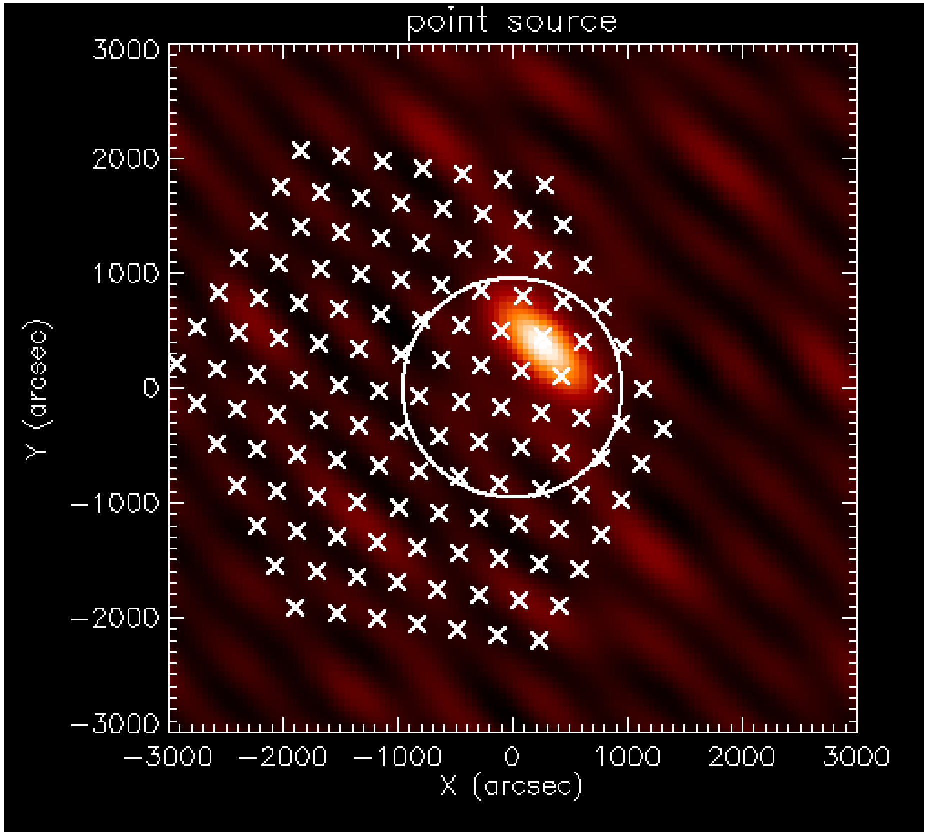
Images at 32 MHz



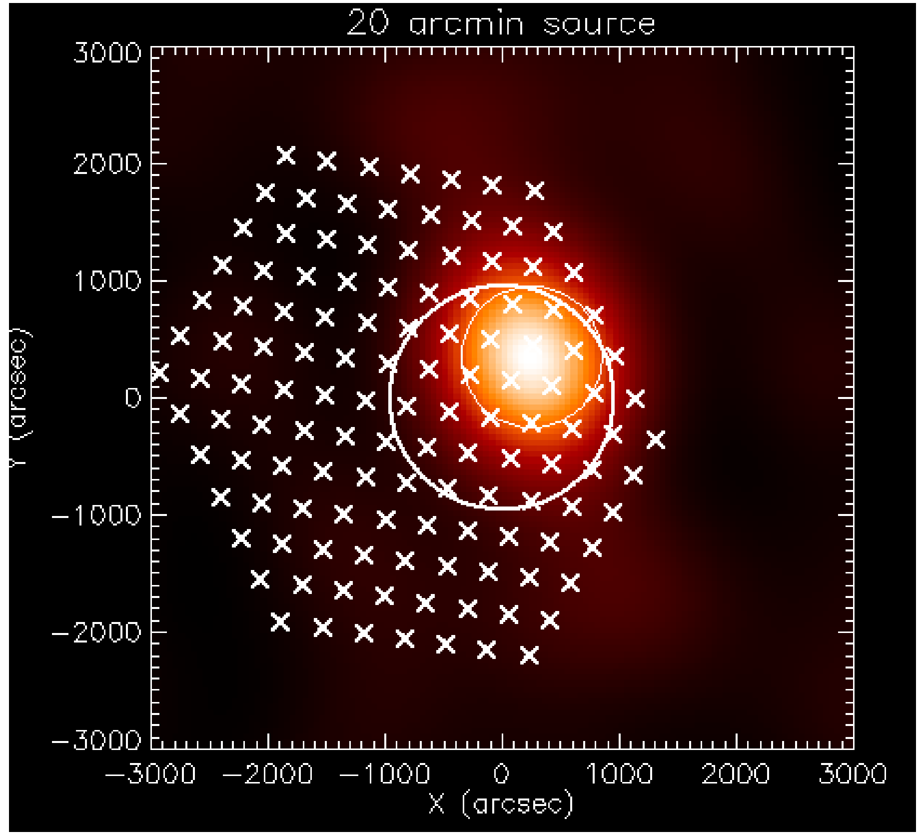
Radio images of the fine structure components of the burst. Superimposed images of the Extreme Ultra-Violet (EUV) and radio emission at the selected 32.5 MHz frequency Red: radio fundamental plasma frequency (F) component at 11:56:57.5 UT; Blue: second-harmonic (H) radio component at 11:57:01 UT. The full width at half-maximum (FWHM) ellipses are made using two-dimensional Gaussian fits to the data. The white dots show the phased array beam locations and the oval shows the half-maximum synthesized Low Frequency ARray (LOFAR) beam.

Simulated LOFAR radio sources

Sources convolved with LOFAR TAB PSF:

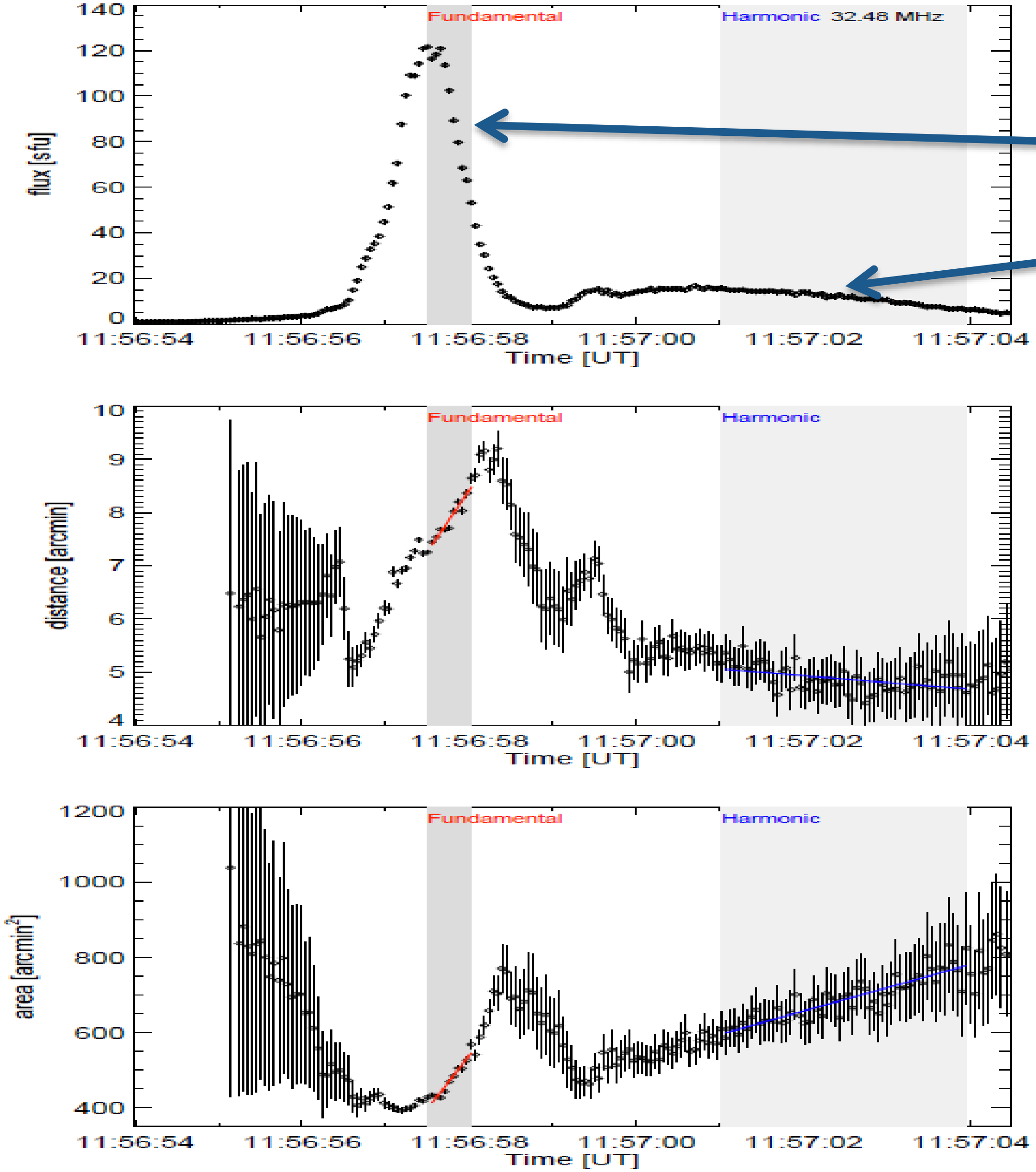


Point source (~1 arcmin) required by plasma emission model



20 arcmin sources

LOFAR



Fundamental

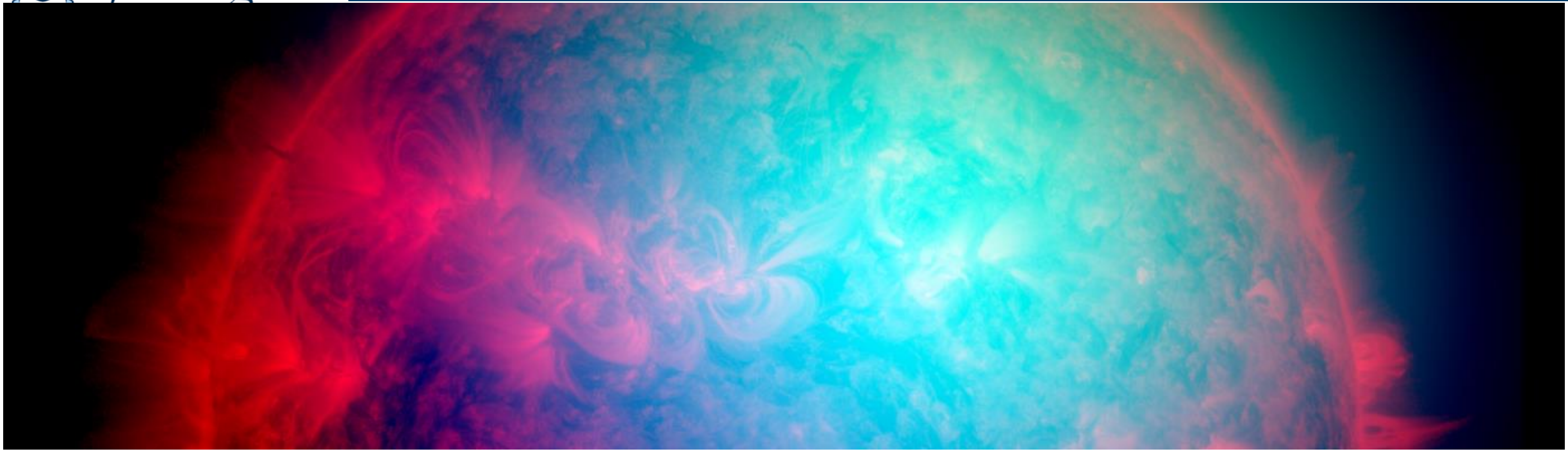
Harmonic

Radial Position change

AREA expansion

=>Imaging radiowave propagations

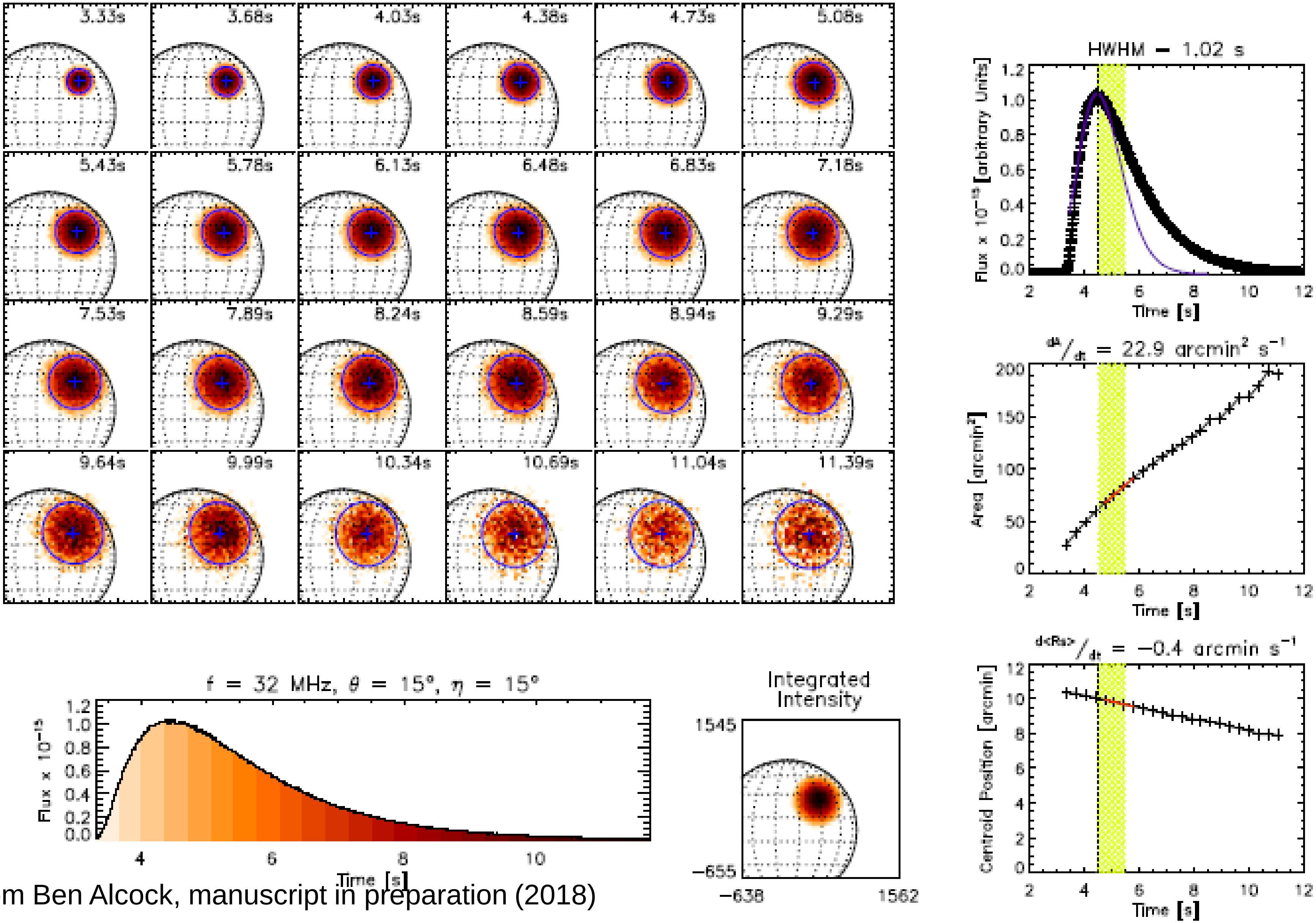
Summary



- First spectroscopic imaging observations of fine structures of type IIIb
- The results are consistent with 'light propagation' in the scattering solar atmosphere.
- The tied array beam image source sizes are inconsistent with small sources required by plasma emission.
- The intrinsically small source sizes (~0.1 arcmin) are observed as 20 arcmin sources.
- Help to observationally investigate the radio wave propagation effects and provides observational limitations on the turbulence in radio emission region.

For details see [Kontar et al, Nature Comm., 2017]

Simulations of radiowaves



From Ben Alcock, manuscript in preparation (2018)