Electron Cyclotron Maser Emission and The Brightest Solar Radio bursts

Stephen White (AFRL) et al

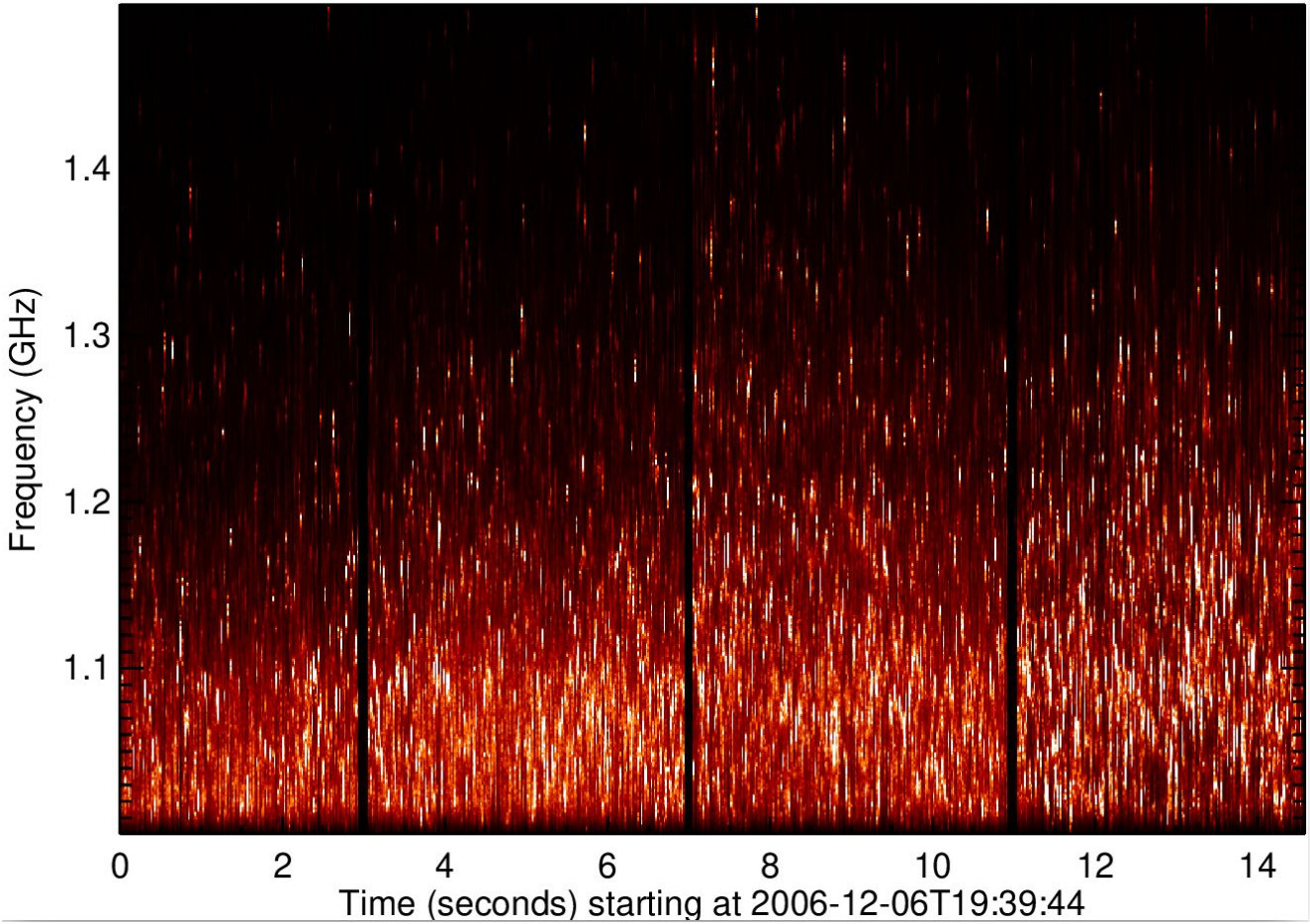
Two questions:

- What is the brightest solar radio flux we can expect in 100 years?
- Is it due to electron cyclotron maser emission?

Solar radio bursts: emission mechanisms

There are 3 emission mechanisms that are responsible for solar radio bursts:

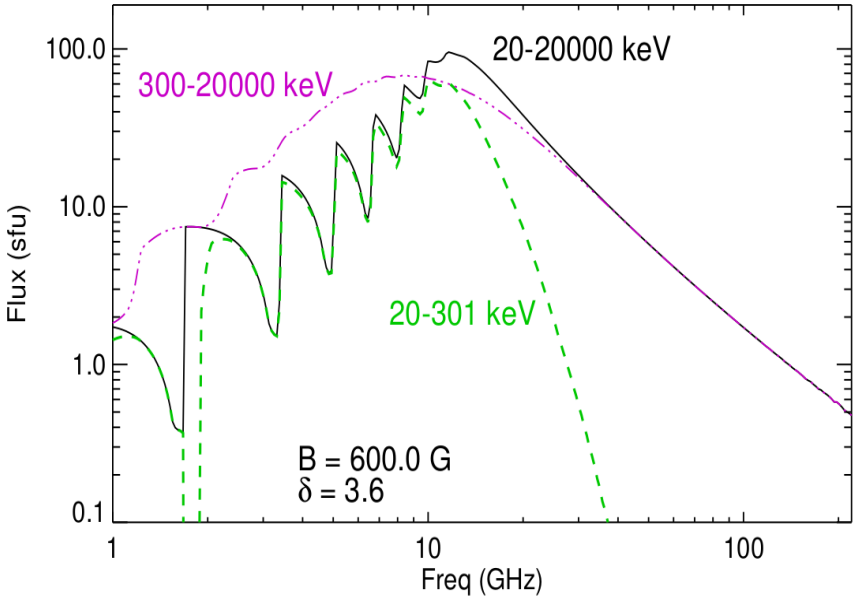
- Plasma emission: largely confined to low frequencies (below 500 MHz), intrinsically narrowband emission at a frequency that depends on electron density ($\sqrt{n_e}$) so should be strongly collisionally damped at higher frequencies
- Gyrosynchrotron emission: the mildly-relativistic version of synchrotron, incoherent emission from nonthermal 100-keV electrons: most bursts above 3 GHz are gyrosynchrotron
- Electron cyclotron maser emission: high brightness temperature, high circular polarization emission at electron cyclotron frequency due to structure (eg, loss cone) in 2D velocity distribution, fine with keV electrons: responsible for terrestrial AKR and Jovian DAM, hot topic in exoplanets and brown dwarves

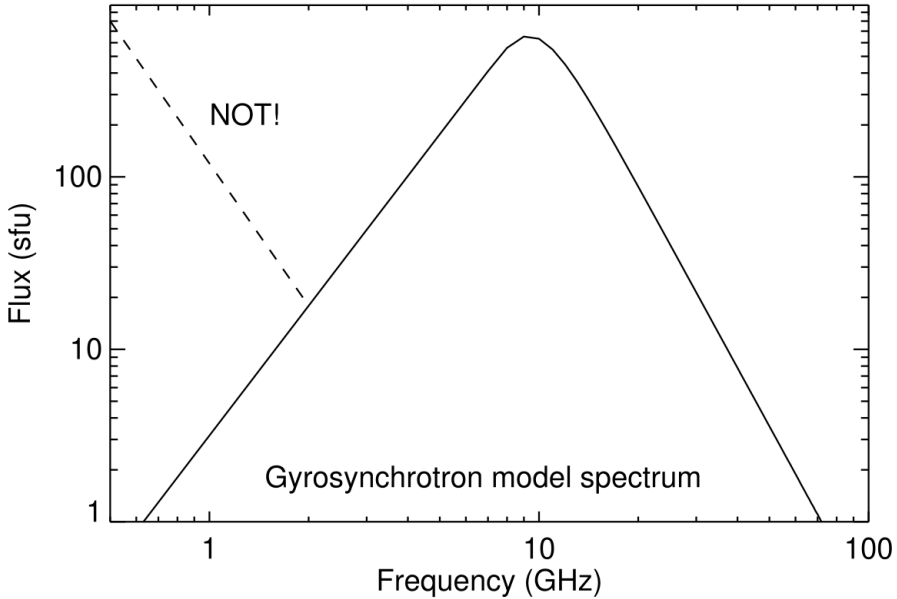


Spike bursts in the famous 2006 Dec 06 flare that knocked out GPS.

Suitable conditions for ECM must be able to reform quickly!

This well-studied example suggests that solar ECM consists of such spikes.

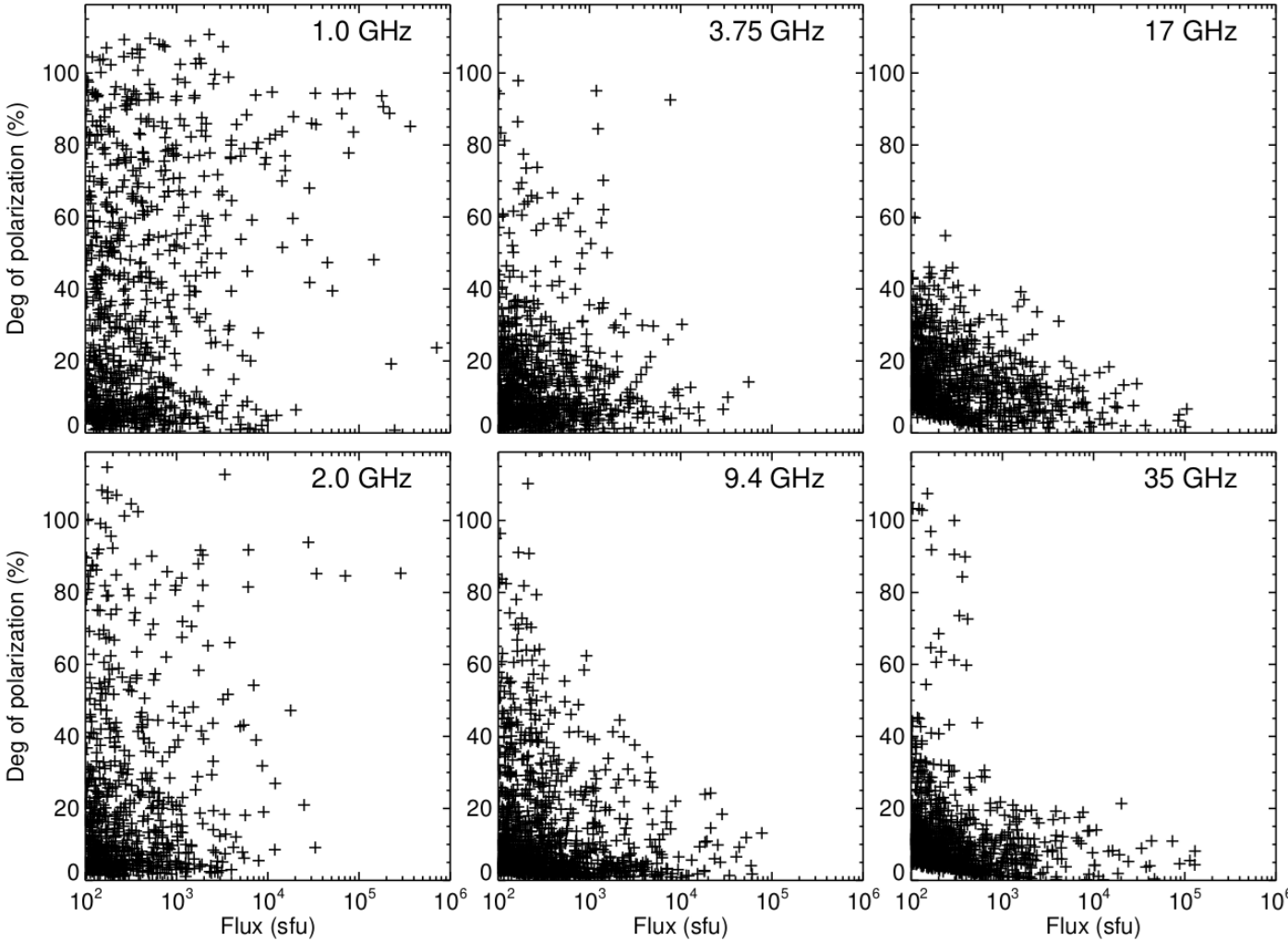




We distinguish ECM from standard gyrosynchrotron (GS) emission via spectra: GS is generally optically thick and increasing with frequency below 5 GHz. It is widely believed that ECM occurs at 1 GHz, so bursts in which the 1 GHz flux exceeds the 3.75 GHz flux are likely coherent emission.

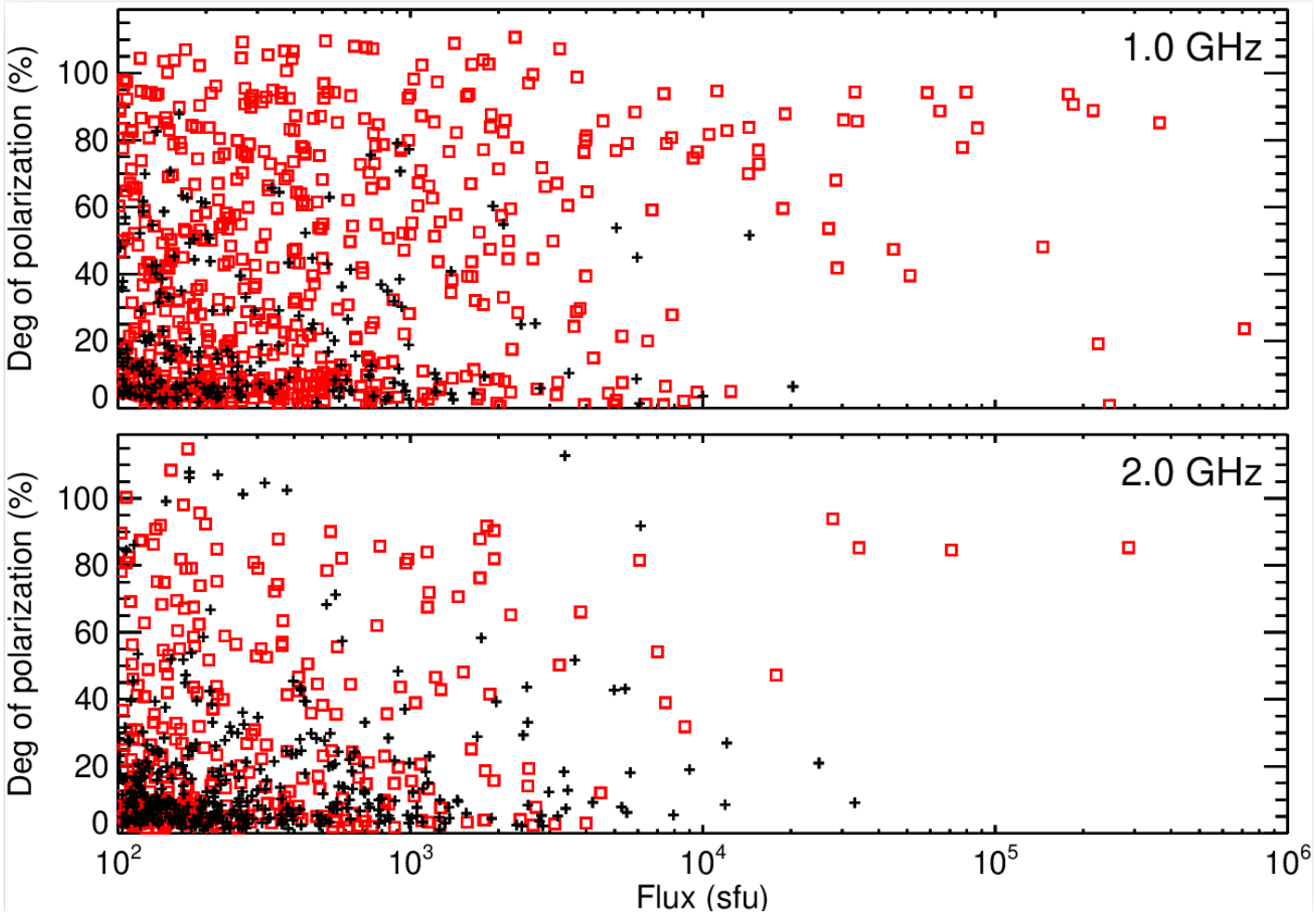
Solar radio burst catalog: Nobeyama Radio Polarimeters

- Observes at 1.0, 2.0, 3.75, 9.4, 17.0 and 35.0 GHz (not using 80 GHz here)
- Measures I and V, regularly flux-calibrated against horn feed
- Data available at 1 second resolution since 1988
- Their own catalog was not done systematically in the early years, and ceased updates in 2015, so a new catalog was produced: number of events increased from 856 to 3818 (up to 2023)



Degree of circular polarization vs peak flux for bursts exceeding 100 sfu.

Note the large number of highly polarized bursts at the lower frequencies, not consistent with optically thick GS.



Bursts > 100 sfu

Black symbols: flux increases with frequency

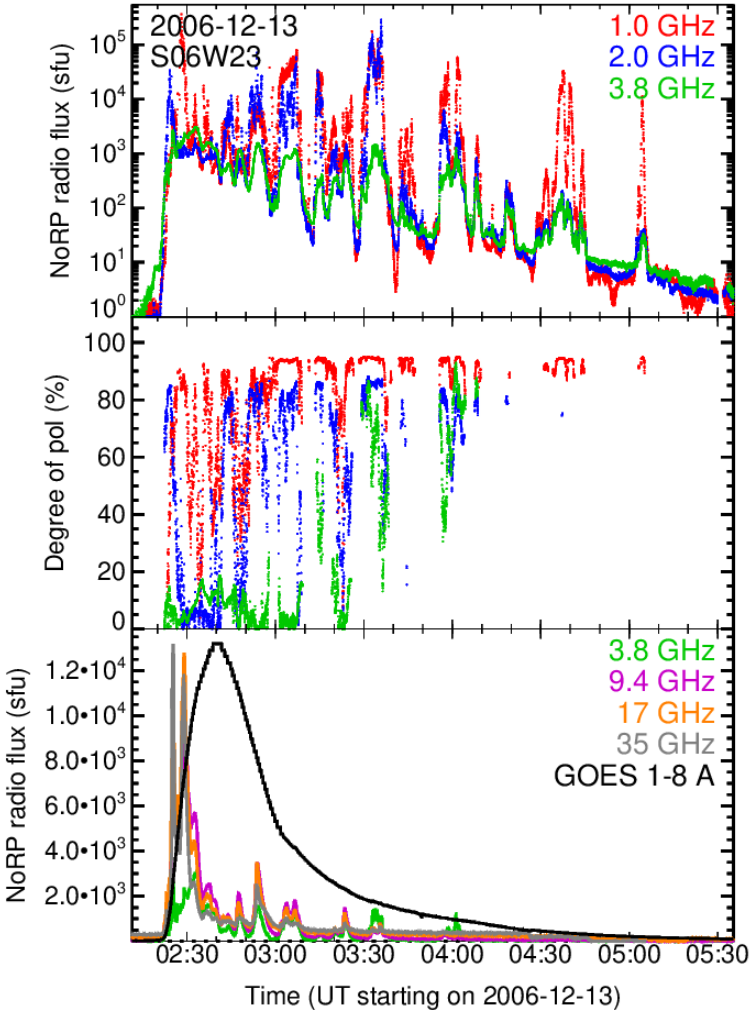
Red symbols: flux decreases from 1.0 GHz to 2.0 GHz

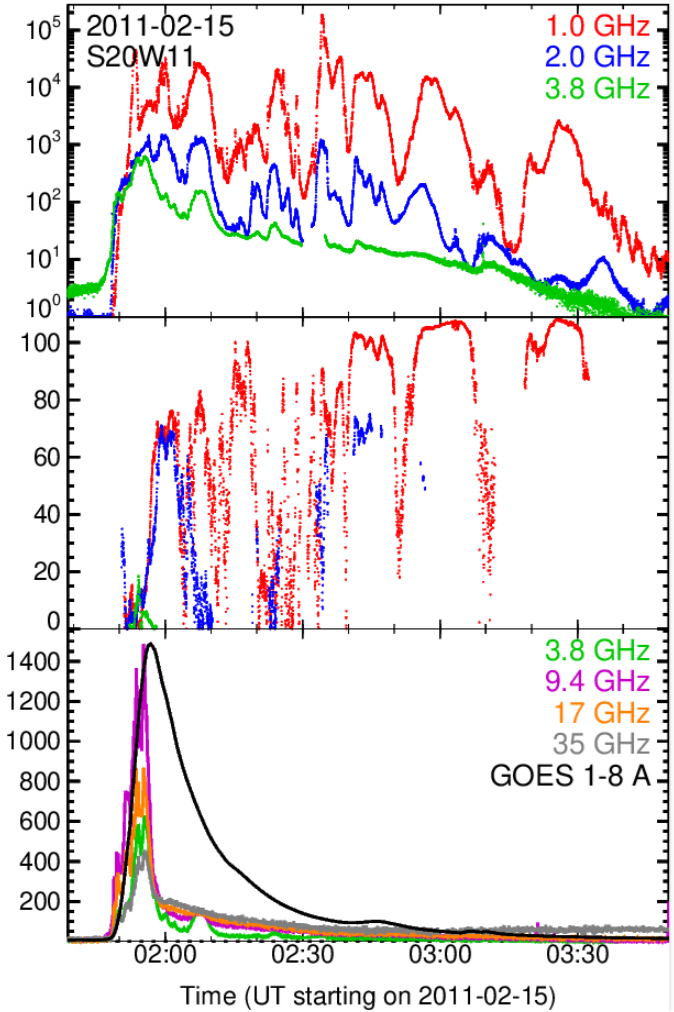
Statistics of coherent solar radio bursts at 1.0+2.0 GHz

- We find that 628 bursts at 1 GHz with peak flux over 100 sfu have a larger flux at 1.0 GHz than at 3.75 GHz,compared to 205 with lower 1.0 GHz flux.
- 328 bursts over 100 sfu at 2.0 GHz have larger flux than at 3.75 GHz, compared to 380 with lower flux.

- Thus ~75% of all solar radio bursts at 1.0 GHz and ~50% of bursts at 2.0 GHz over 100 sfu are dominated by coherent emission, likely ECM.

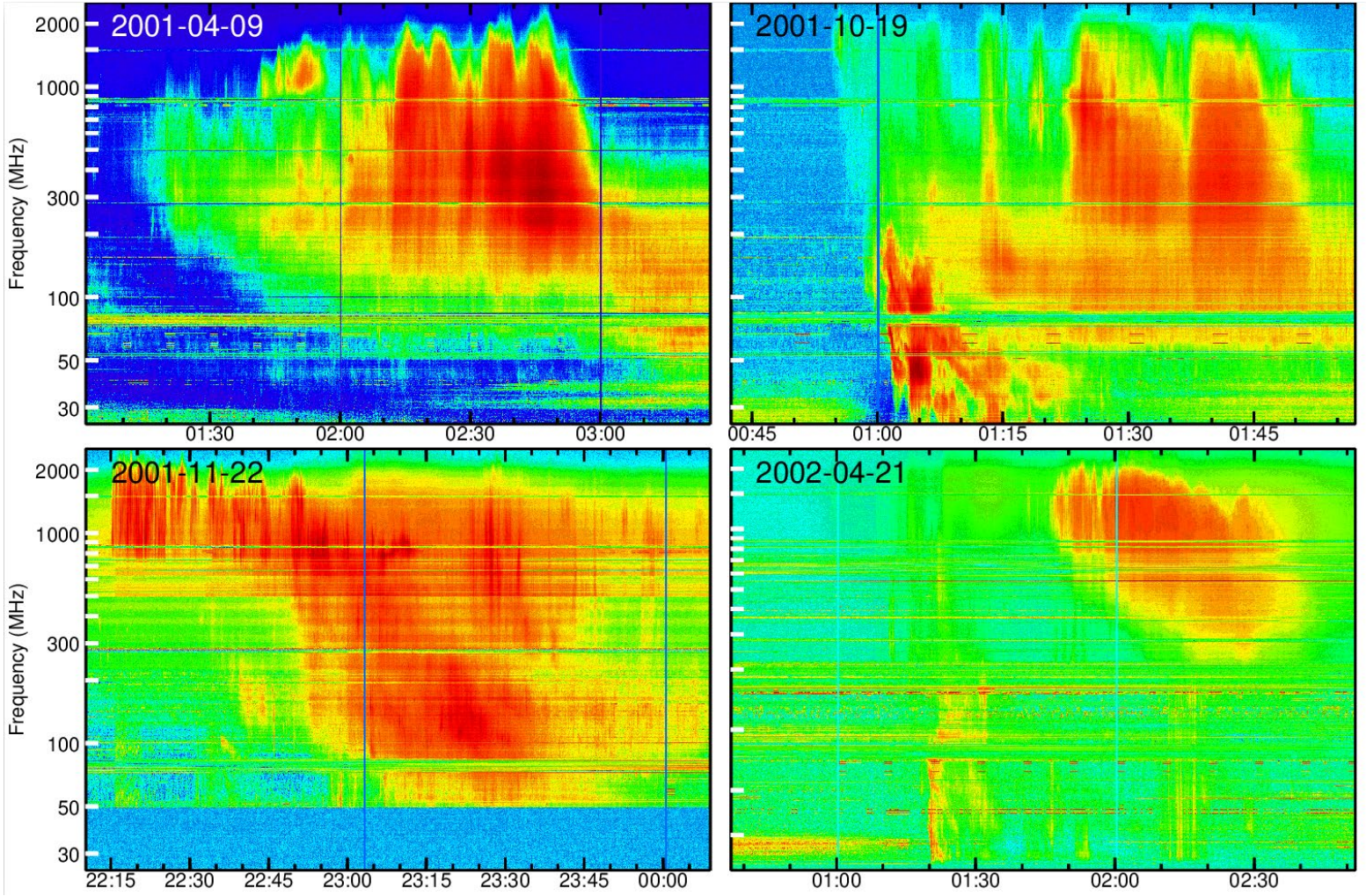
- 23 flares in the catalog have a flux over 10000 sfu at 1 GHz: this corresponds to 10^{11} K brightness temperature for a 20 arcsec-size source, in excess of the synchrotron limit, so cannot be incoherent nonthermal.



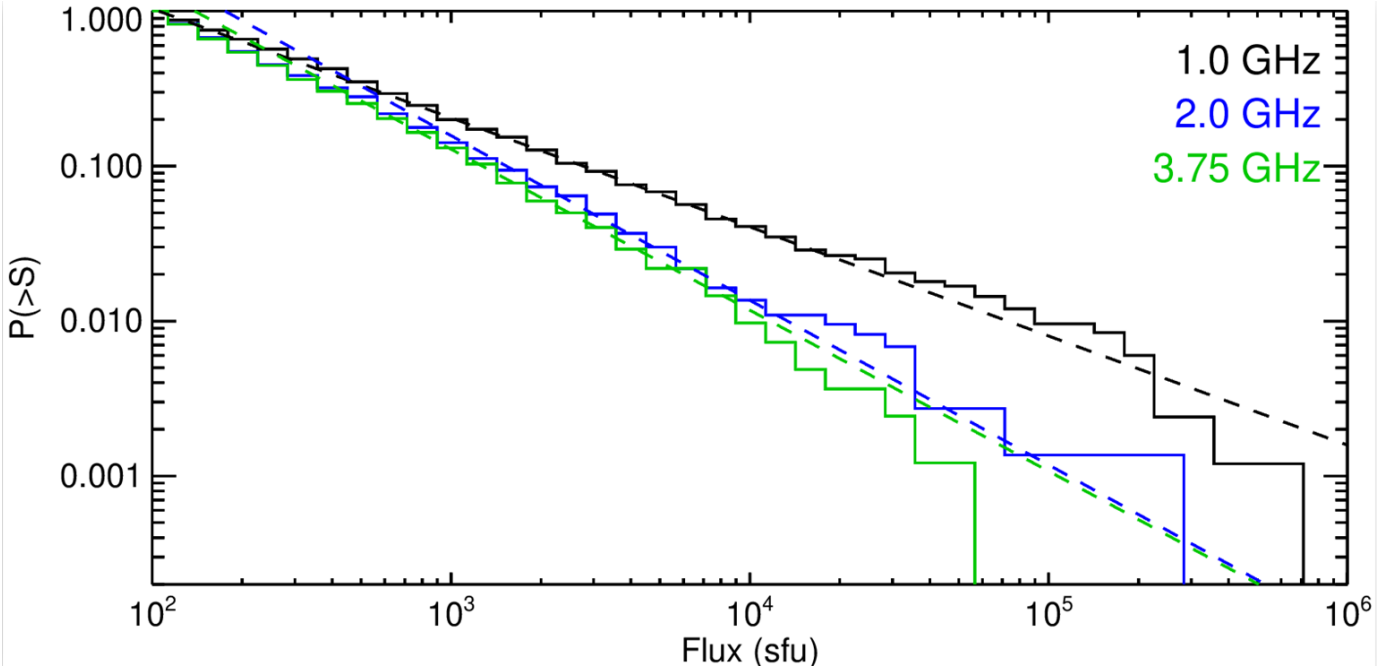


Radio and soft X-ray light curves for 2 events

- Low-freq I in top panel,
- Low-freq V/I in middle panel,
- High freq I + SXR in bottom panel



Dynamic spectra from 25-2000 MHz (NiCT, Japan)



Cumulative probability distributions for NoRP bursts above 100 sfu at 1.0, 2.0 and 3.75 GHz. Slopes are -1.7, -2.1 and -2.0 for fluxes, respectively, in the 10^3-10^4 sfu range.

- Extreme flux limits: following Riley (2012), we can estimate maximum fluxes from power-law fits to the burst flux distributions, relevant for space weather.
- If there is no mechanism limiting higher fluxes, there is a 50% chance of seeing 5 10^7 sfu at 1 GHz, 3 10^6 at 2 GHz and 1 10^6 at 3.75 GHz over 100 years.

Relevance for stellar radio emission

- This survey indicates that ECM is much more common in solar radio bursts than previously believed.
- The emission is strongly variable, can last for hours after the impulsive phase of the flare, and is generally highly circularly polarized, but often not 100%.
- Solar ECM may be dominated by spikes, which are quite different from the phenomena seen in ECM in terrestrial AKR and Jovian DAM bursts.
- The brightest solar bursts would produce mJy of flux at 10 pc distance
- Are brown dwarfs and magnetic B stars more analogous to AKR than to solar spike bursts? Solar bursts are associated with flares, but such flares probably don't occur in more dipolar magnetic configurations.
- AKR and DAM are influenced by solar wind impact on magnetospheres: can stellar ECM provide wind diagnostics?