Leveraging Imaging to Disambiguate U/J Bursts from Atmospheric Effects on Type III Spectra

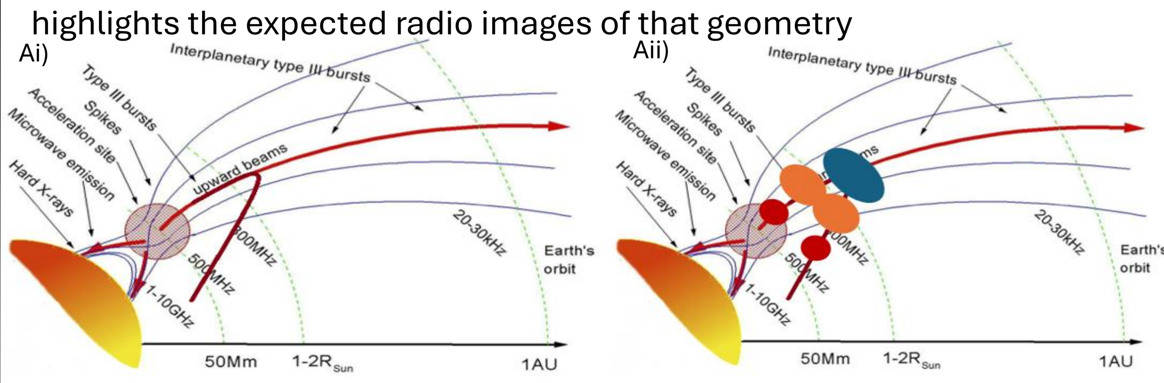
Brian O'Donnell, Dale Gary - New Jersey Institute of Technology – Center for Solar Terrestrial Research – (beo6@njit.edu, gary@njit.edu)

1) Type III Bursts, U- and J- Bursts

As electrons are energized on and/or released onto large magnetic loops in the solar atmosphere, they radiate in radio frequencies as they gyrate around the magnetic field lines. The intensity of this gyrosynchrotron radiation depends on the magnetic field and particle energies. However, at MHz frequencies the emission is instead dominated by plasma emission at a frequency determined simply by its density by the following equation

I) $$\omega_p^2 = \frac{ne^2}{m\epsilon_o}$$

Due to the tendency of the solar coronal density to fall off with height, a link between radiation frequency and coronal height is well established (cite). Type III solar radio bursts can, in this context, be thought of as fast-moving electrons quickly leaving the "FOV" of the frequency range, while the less frequent U/J bursts can be thought of as electrons that reach the top of the loop they are trapped in within that "FOV." J bursts just reach the top while U bursts make it past the apex and travel down the other side. Figure A shows the geometry of Type IIIs and J/U Burst, with Aii) highlights the expected radio images of that geometry



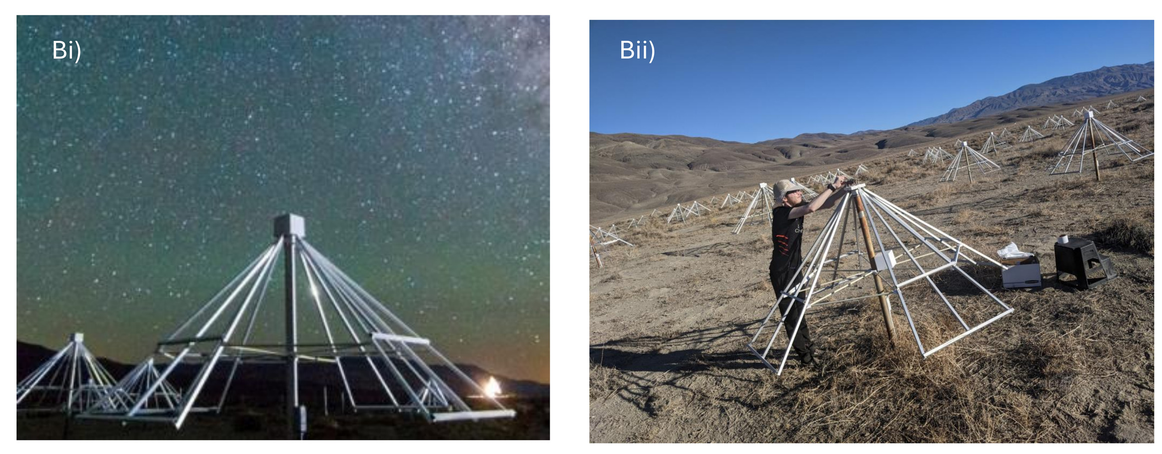
Ai) A model of a solar flare exciting type IIIs and J/U Bursts *adapted from www.issibern.ch/teams/electronflare/*. Aii) The same model with model Radio images of a U Burst at ~400MHz (Red), 300MHz (Orange), 200MHz (Blue). (Notice the source splitting is expected at higher frequencies)

2) OVRO-LWA

20-88 MHz, with a maximum baseline of 2.6 km
Resolution of 5 arcmin at 88 MHz
It is capable of sampling 48 antennas at 0.1s resolution, and the full 352 antennas at 10s resolution, for spectrograms or images

Continuous data has begun to be collected as we finish commissioning.
Solar data products include; Fast mode solar spectra for all times
One 10 s full array image per minute
Ability to request imaging data at full resolution (time and frequency) be saved long-term for up to a week after an event

Full data access will be open for the community this fall!



Bi) the OVRO-LWA at Night. Bii) The OVRO-LWA undergoing expansion

3) Earth Based Distortions of Radio Spectra

Obviously, there is a great deal of human made radio traffic in the atmosphere at a given time, from satellites to songs. But in general, these sources of interference tend to be localizable and removable from spectra by use basic beamforming to "Phase up" the array to the current location of the Sun

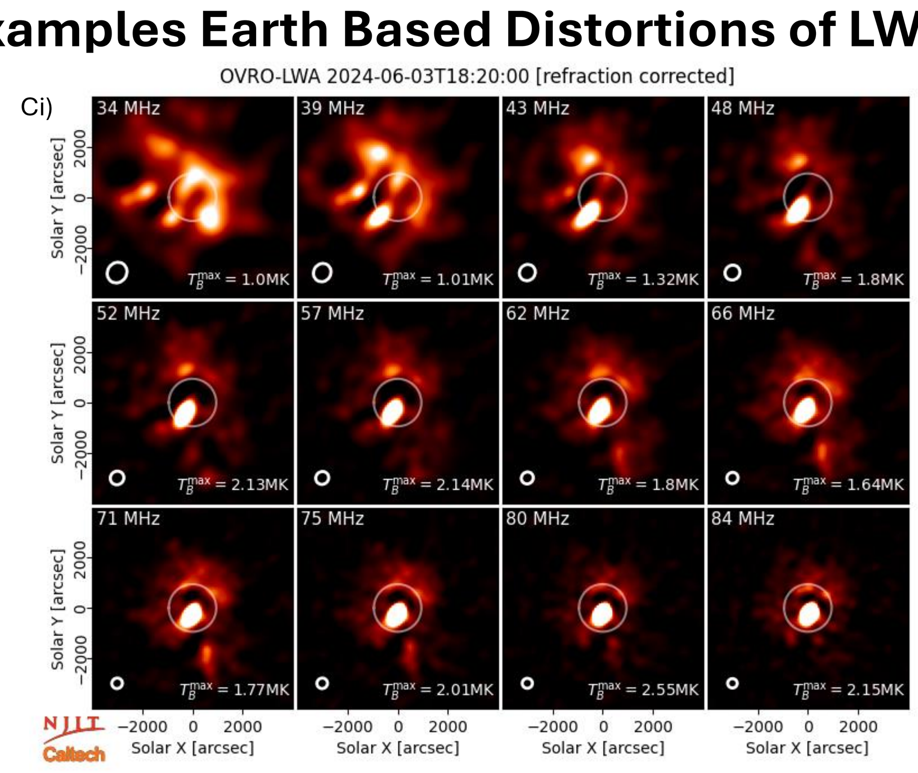
Beyond human-made sources however, we must consider atmospheric transmission capacity. The magnetic field of the Earth and the existence of the charged ionospheric plasma, make for refraction of the rays through the ionosphere.

Additionally, the Sun energizes the Earth's atmosphere, ionizing some of the atoms and increasing the Total Electron Content (TEC) of the atmosphere, freeing these charges to interact with each other, but also with the field lines and incoming radio signal in the atmosphere. Causing distinct Day/Night behavior, and transition regions between.

On top of all of this, the ionosphere, as part of the Earth system, is affected by the weather and geophysical disturbances. Large storm systems can cause Traveling Ionospheric Disturbances (TIDs) which can hinder normal radio propagation. Most strikingly in (cite) where the Wave/Retract/Wave cycle of a Tsunami were shown makes a Propagating TID Waves.

Such propagating disturbances are thought to be the cause of the irregular/temporally active shape of the sun shown in the next section. Where Figure Ci) is thought to be a time of a highly active atmosphere causing a greatly disturbed Sun across frequency space, and Cii) where a propagating TID seems to temporarily distort/break apart the solar image.

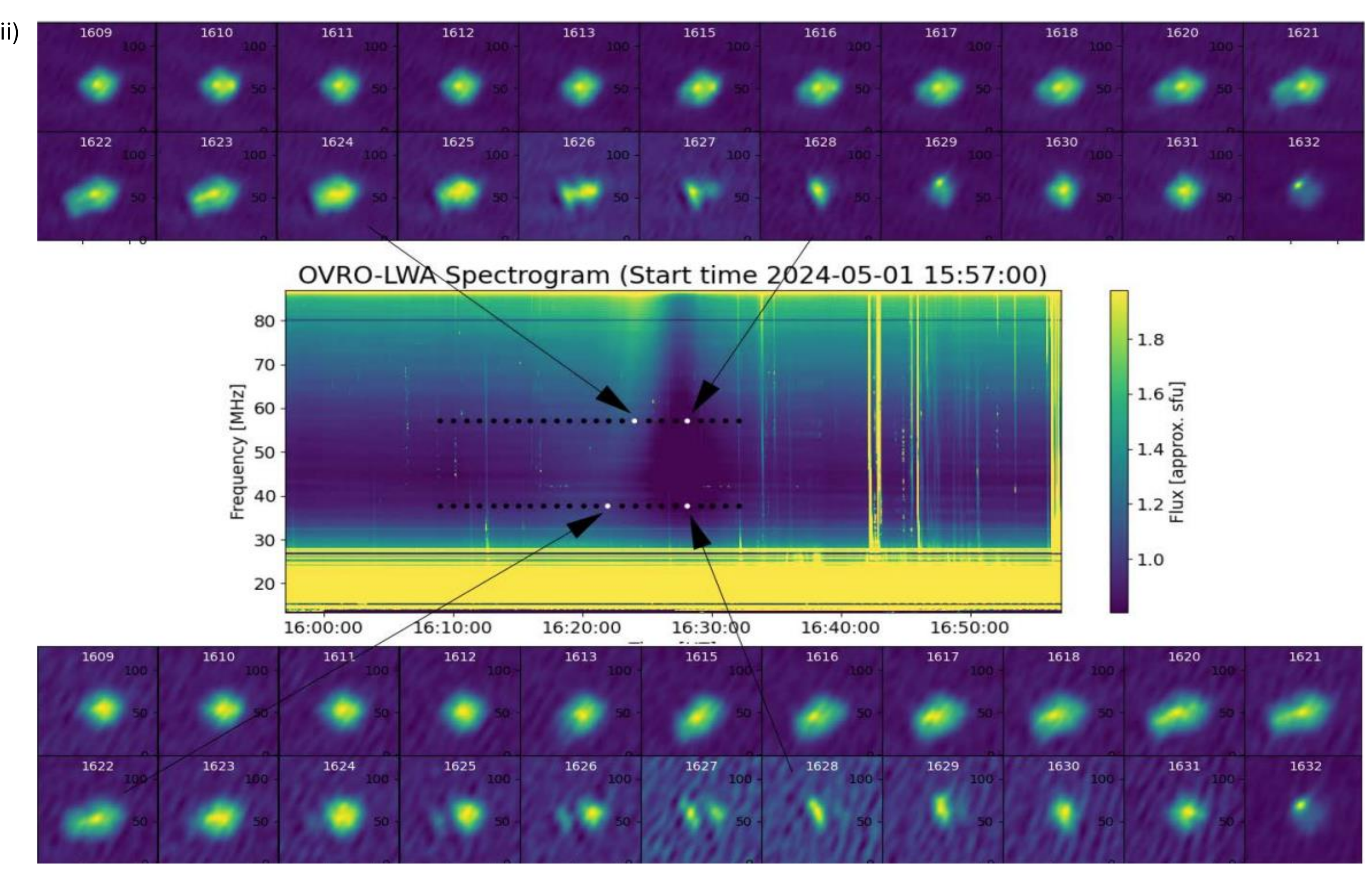
4) Examples Earth Based Distortions of LWA Spectra and Images



Ci) A large scale ionospheric disturbance distorts OVRO-LWA images of Quiet Sun June 03, 2024.
Additive and complex (think light refracted to the bottom of a pool)

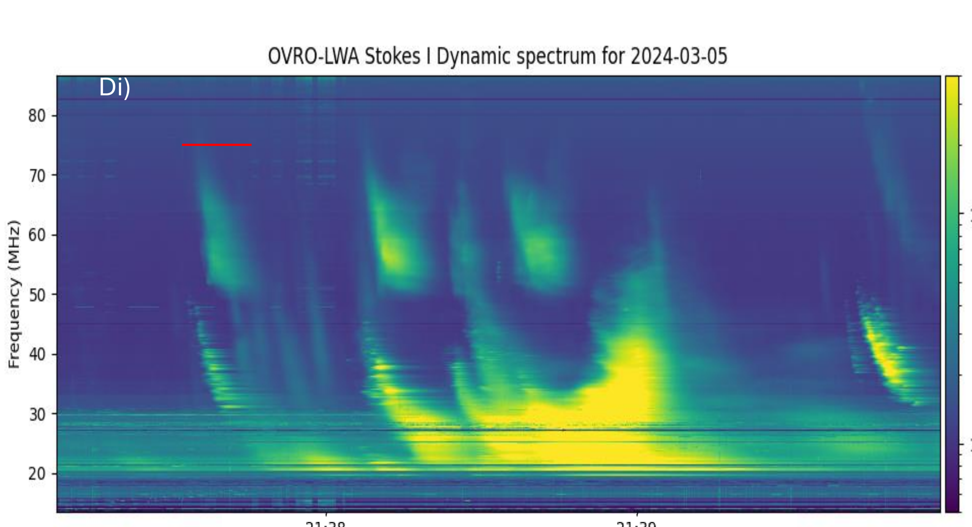
Cii) Time Slit diagram at two frequencies of a disturbance passing at a more active Sun.

Notice at t=1626-1628 UT the whole sun is split in both frequencies as the disturbance passes

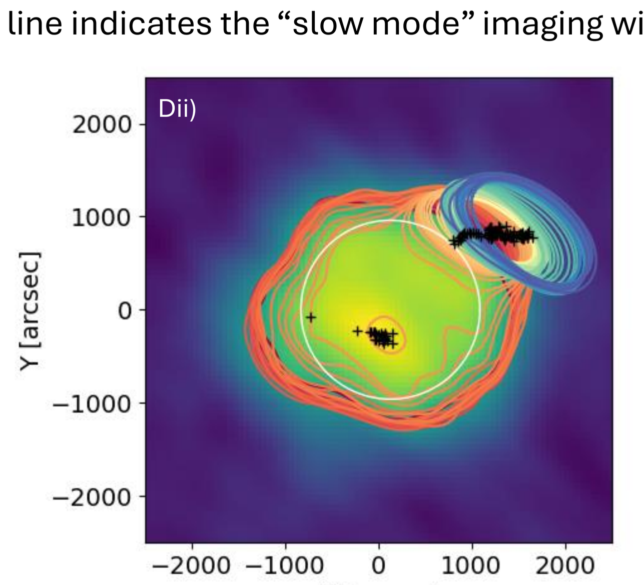


5) Comparing of Two Apparent J-Burst Events

5a) March 05, 2024, Burst Storm

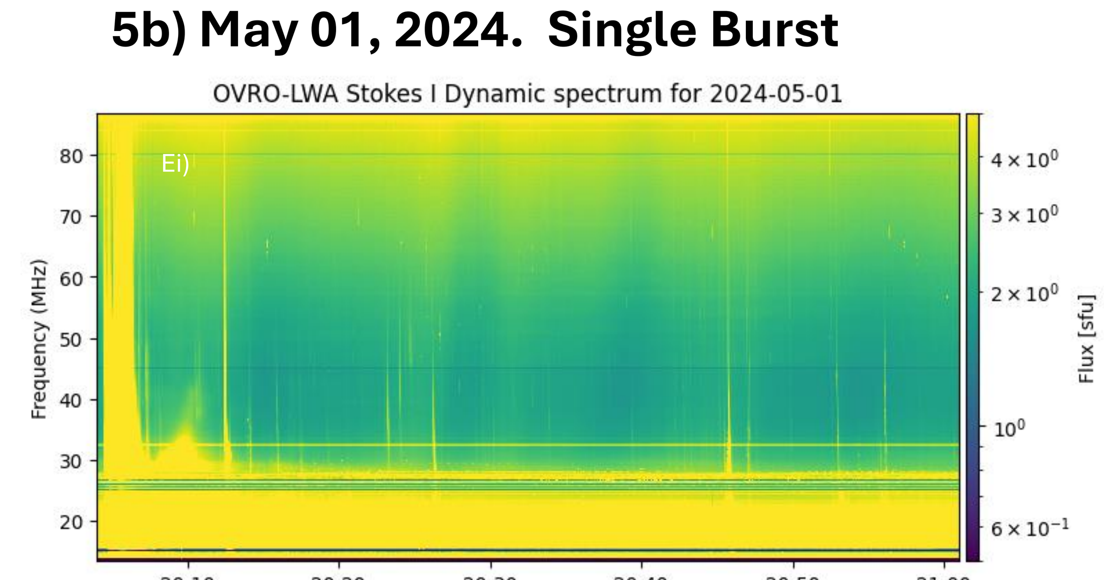


Di) LWA Spectra of a series of Bursts from March 05, 2024.
Red line indicates the "slow mode" imaging window, used in Figure Dii)



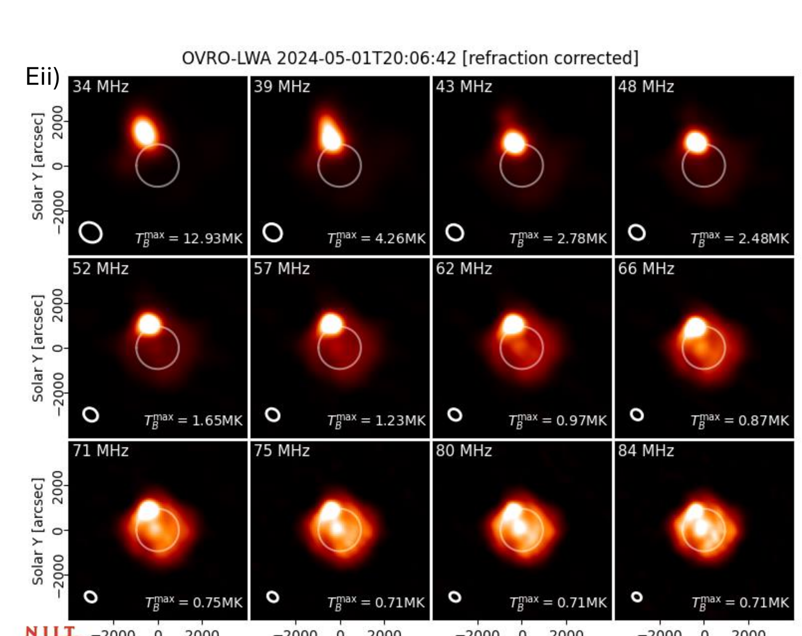
Dii) 80 MHz LWA Image of the burst time overlayed with 50% contours for 144 frequency windows down to 29 MHz: 10-sec averaged "slow mode" images, Note: The imaging window (noted in figure Di)) only contains the first J-burst

5b) May 01, 2024. Single Burst

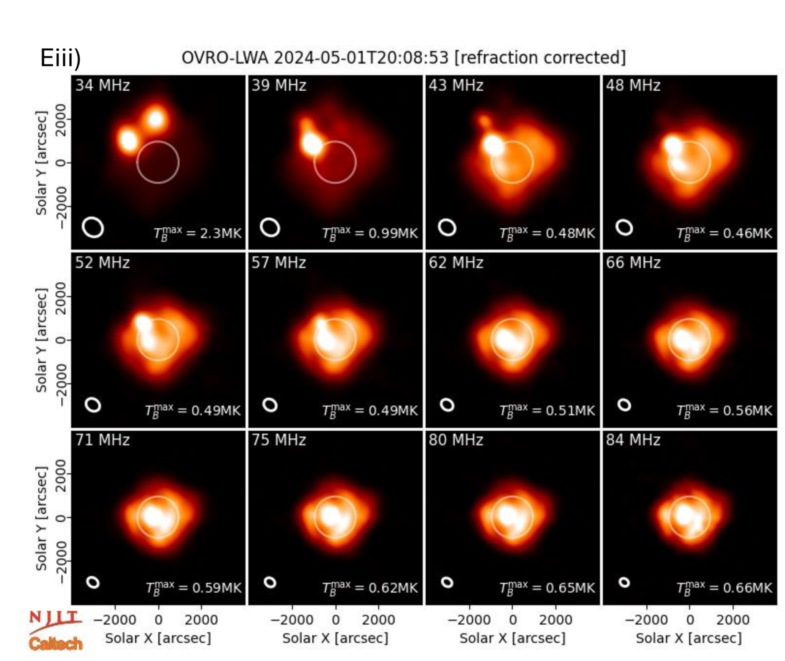


Ei) LWA Spectra of an apparent J Burst from May 01, 2024.

Using the previously studied March 05 D) event as an example of a J-burst, let us consider the event shown from May 01 E).
In Dii) where a True J-Burst was imaged the apparent height of the source at a given frequency decreases with increasing density/frequency as you might expect from the model A)
And Eii), which occurs during the early Type III like part of the May 01 event seems to show a very similar behavior.
But for Eiii) just a few minutes later when the spectrogram might imply a return journey of some plasma, not only has the centroid of the loop shifted unrealistically , but there is also mixing of heights and frequencies, distortion of the background Sun, and, most strikingly, a split in the lower-frequency images of the source but not at higher frequencies (opposite from the expectation of the model J burst in Fig. A.)
All these changes should be enough to imply that there was an ionospheric effect rather than solar behavior that caused the spectrogram to resemble a "J-Burst", especially considering figure Cii) was generated just hours before.



Eii) Quick look LWA images across frequency space of the early peak of the 2024 May 01 Type III at ~ 20:06



Eii) Quick look LWA images across frequency space of the apparent return leg of peak of the 2024 May 01 Type III at ~ 20:08.

May 01, LWA qlook Video-

6) The Atmosphere on 05/01/24

With multiple atmospheric disturbances showing up so clearly in our images in the same day, it was expected there would be some evidence of extreme weather, or geomagnetic activity, or something abnormal to cause these effects. But, to the extent that data could be reconstructed, the search turned up nothing obvious.

No earthquake, no Tsunami, no lightning storm, no geomagnetic activity, (the closest cyclone on earth was on Tanzania!). Which raises the interesting questions, what caused these distortions, and can we measure it.

There are avenues of exploration that a new event (or some help from other corners of the community) could help bring to light. This TID issue was noticed too late to get Total Electron Content maps of the atmosphere or detailed weather data like wind speeds from our normal sources, but for now the cause of this disturbance remains a mystery .

7) Interpretation/Discussion

The fact that the cause of this atmospheric disturbance is still at large raises the questions about how common they must be, and how easy to trigger, and makes some consideration of these sorts of distortions deeply important when trying to interpret the motions of solar plasma using radio measurements.

Importantly though, this study also underlines the power of combined imaging-spectroscopy as it is unlikely that either technique would have even properly identified these two events alone, let alone allow for understanding and comparison in such detail.

References

OVRO LWA