Radio Heliophysics Science and Applications relevant to NESS

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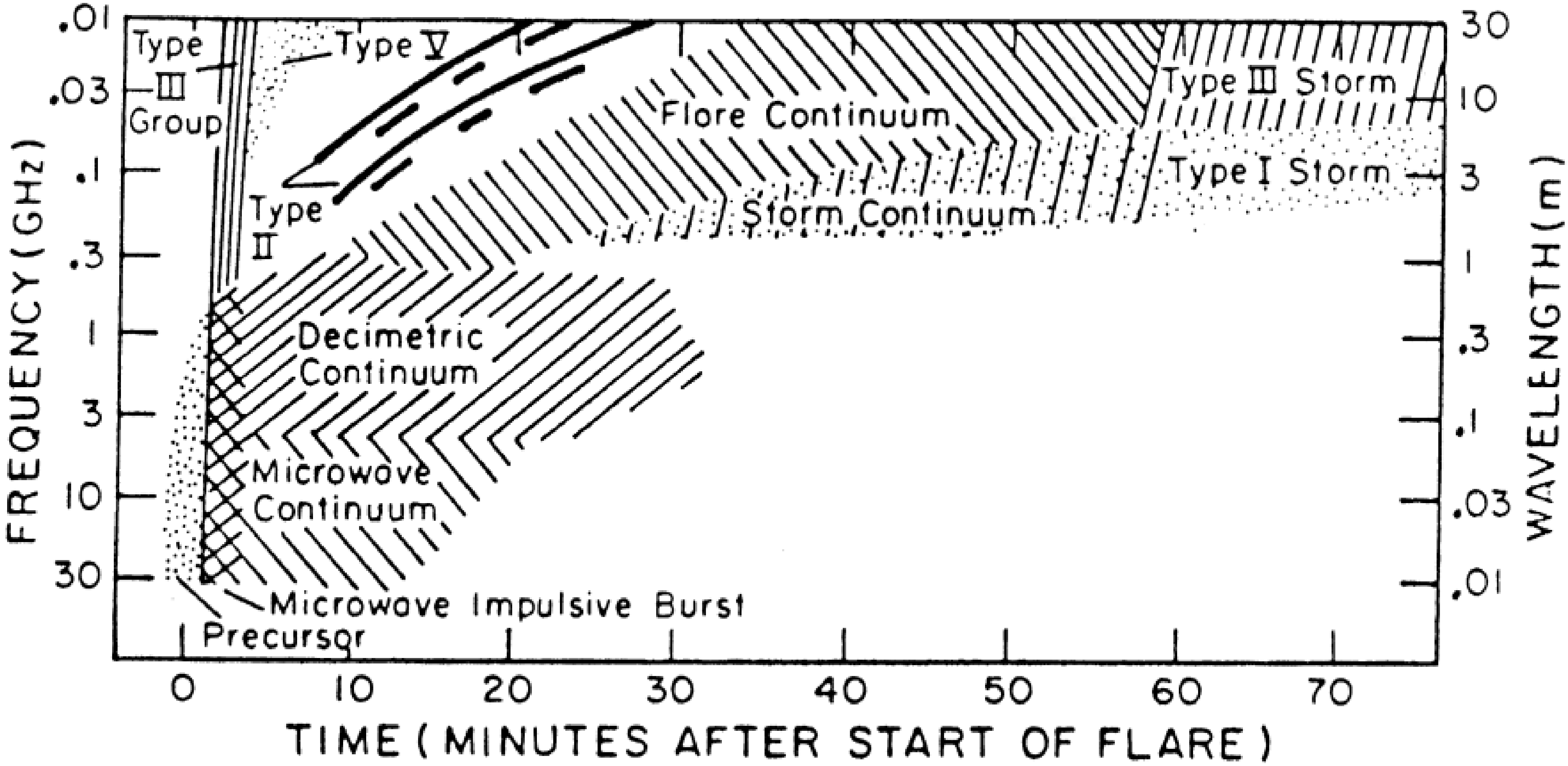
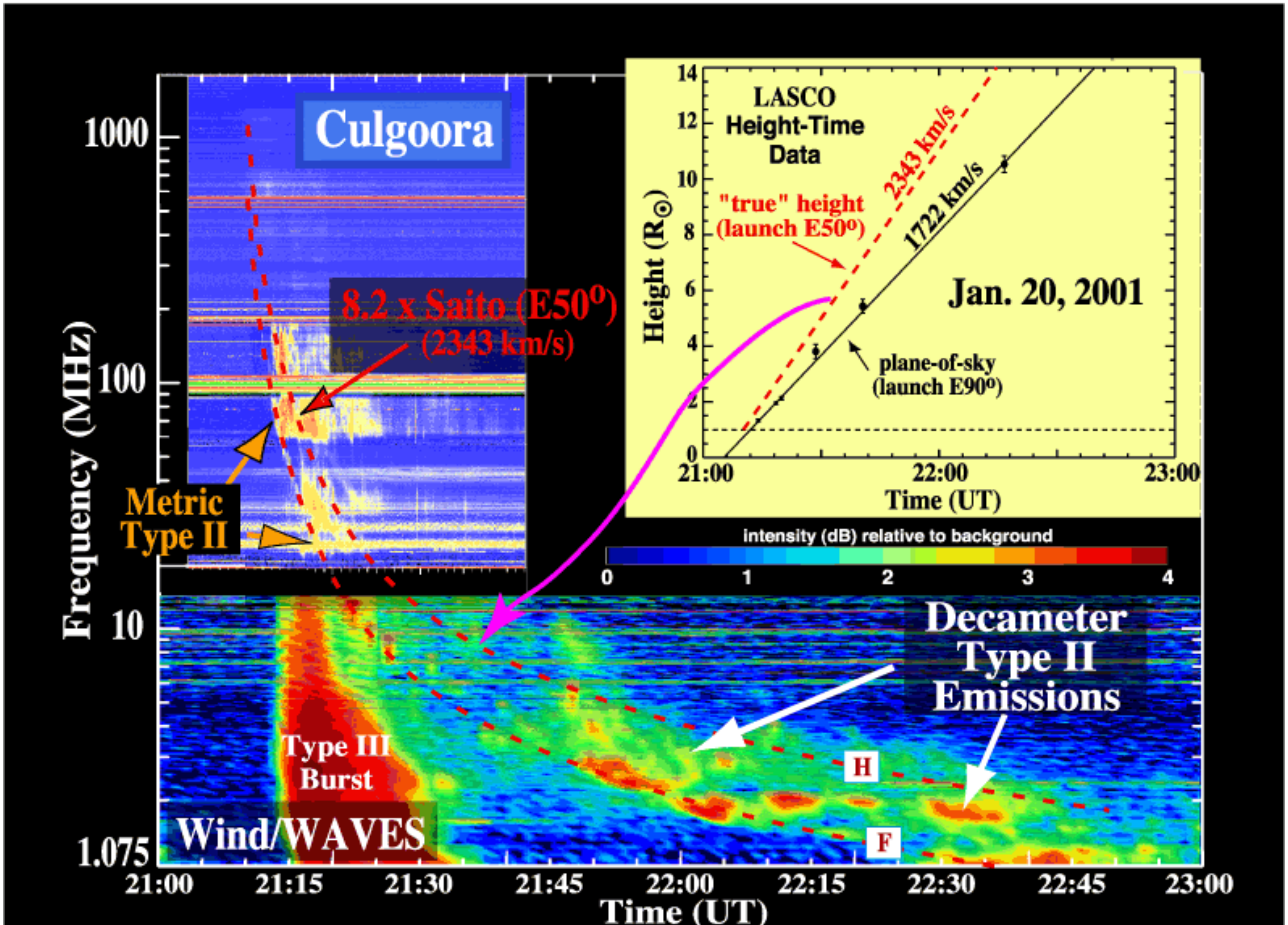
et al.

Solar radio burst terminology



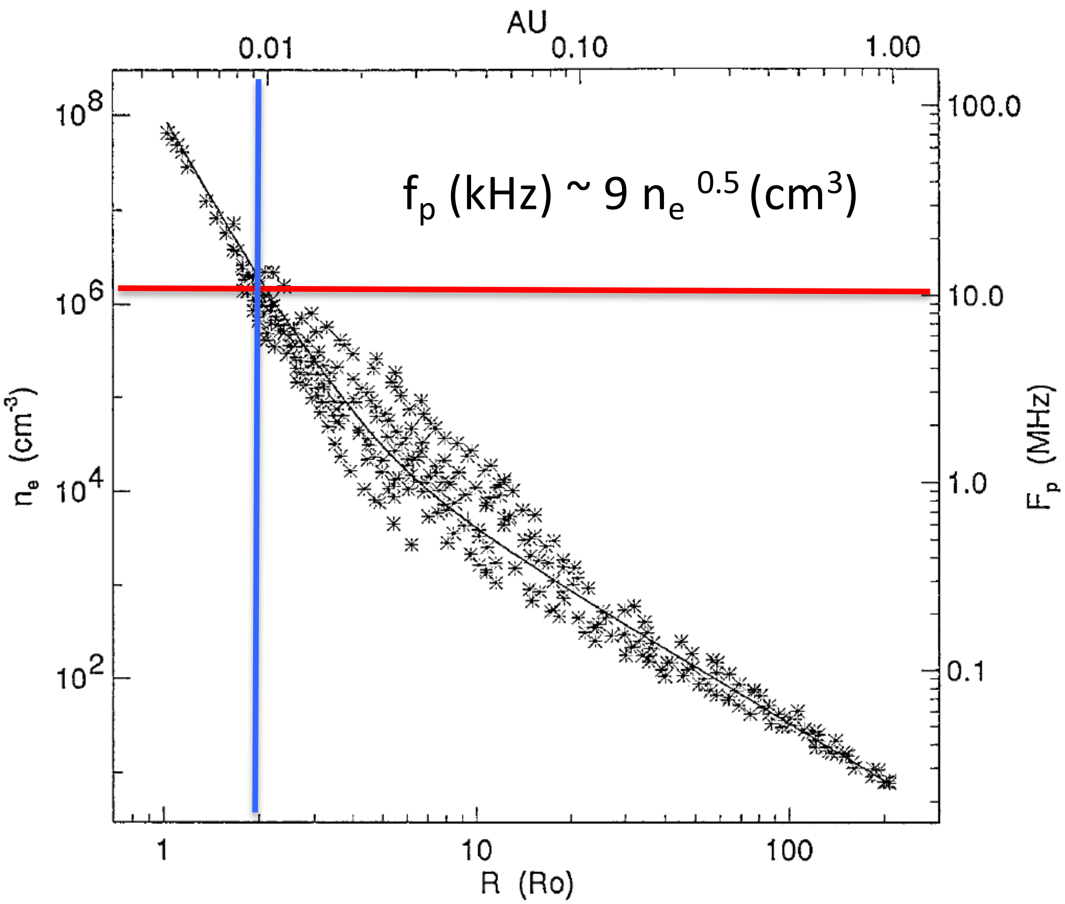
From Wild, et al., 1963, regarding metric radio data

Solar radio bursts and coronal mass ejections

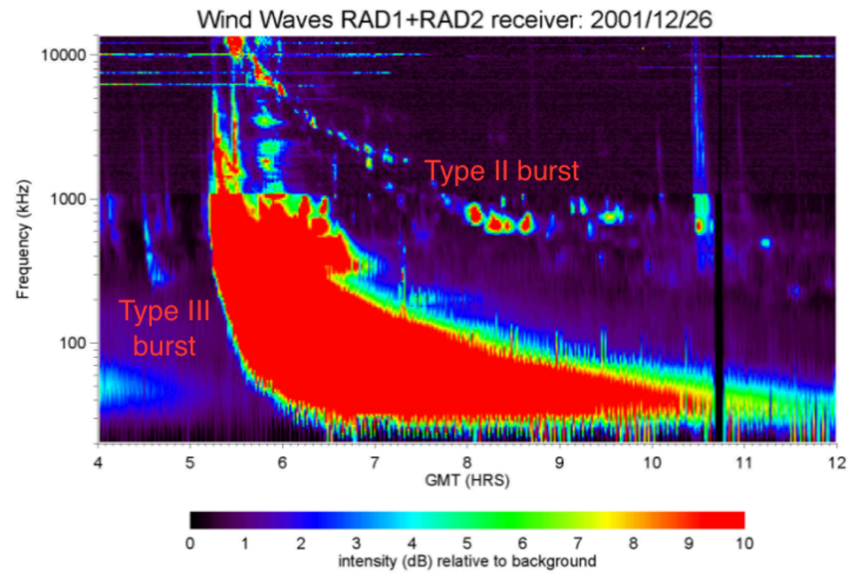


M. Reiner

Heliospheric density scale

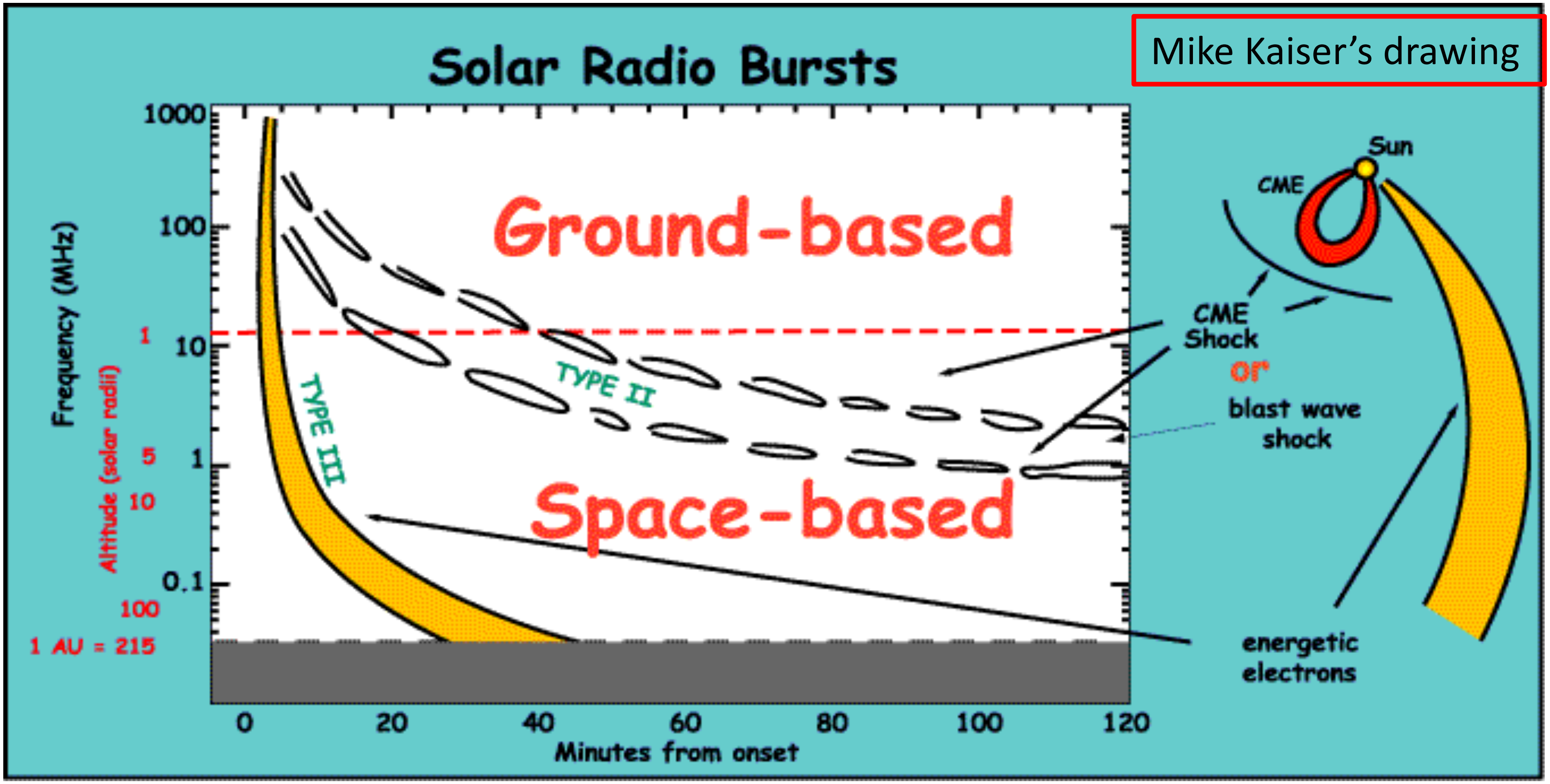


Density vs distance from Sun (R_o) derived from solar Type III radio bursts (Leblanc et al, 1998, Solar Physics)



- Different frequencies of the radio burst come from different distances from the Sun
- Can see from the plot at left that 10 MHz corresponds to ~ 1 R_o altitude
- Essentially all of space outside of the sphere of radius 2 R_o centered on the Sun has radio emission at lower frequencies

Space observation requirement for Type II & Type III bursts

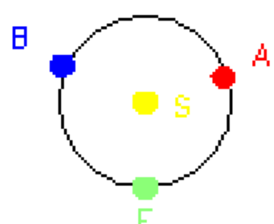


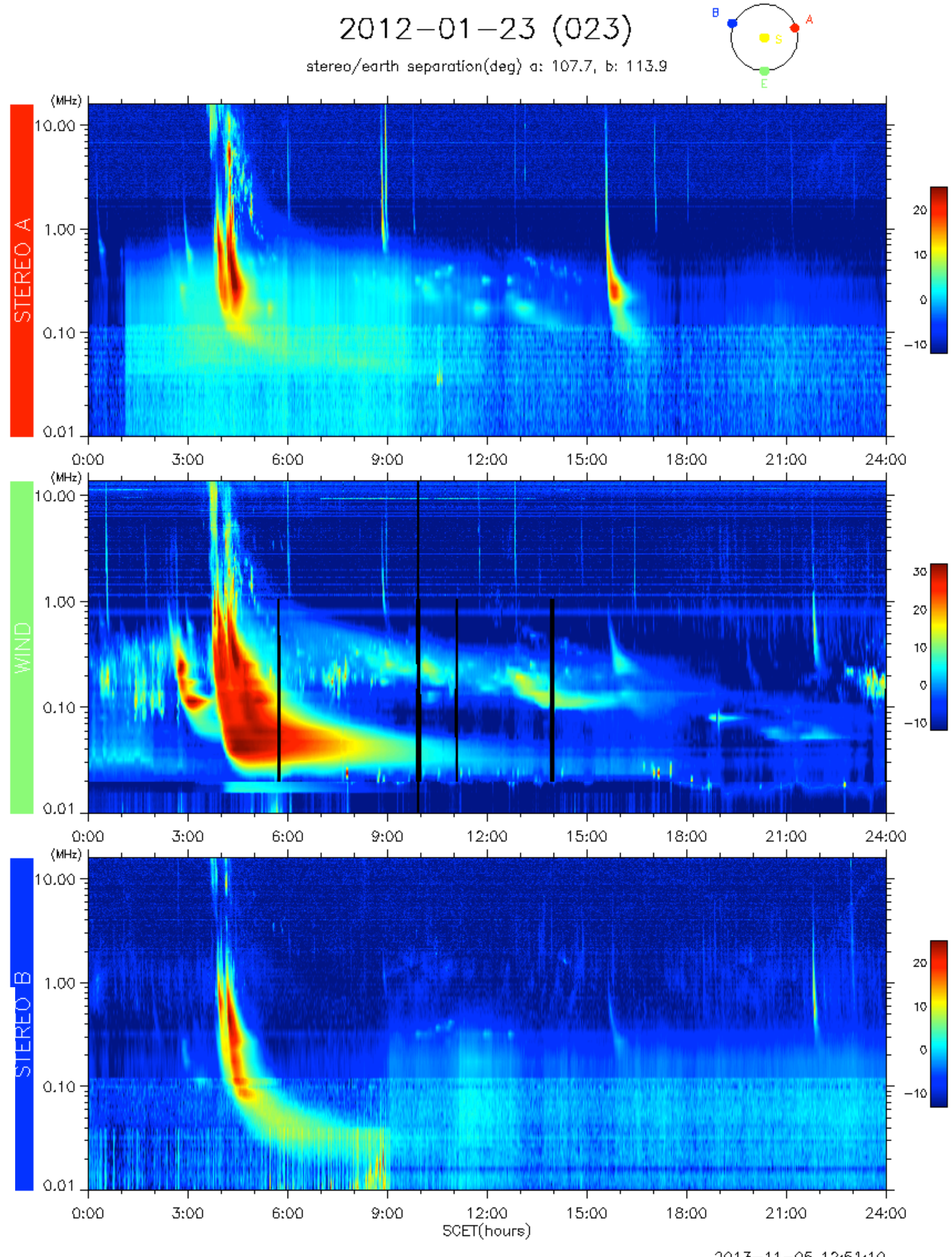
- Ground-based observations down to ~10 MHz, correspond to an altitude above the solar surface of 1 R_solar. So, lower frequency radio bursts inside 1 AU that must be observed from above Earth's ionosphere correspond to > 99% of the total volume.

Typical studies of solar radio bursts

- Direction finding relating to magnetic fields, sources of particle acceleration, and other solar wind structures
- Electron beam – plasma instabilities theory
- Shock acceleration of electrons (and other particles)
- Precursors of CME's and other magnetic field structures

- But we have no images so far





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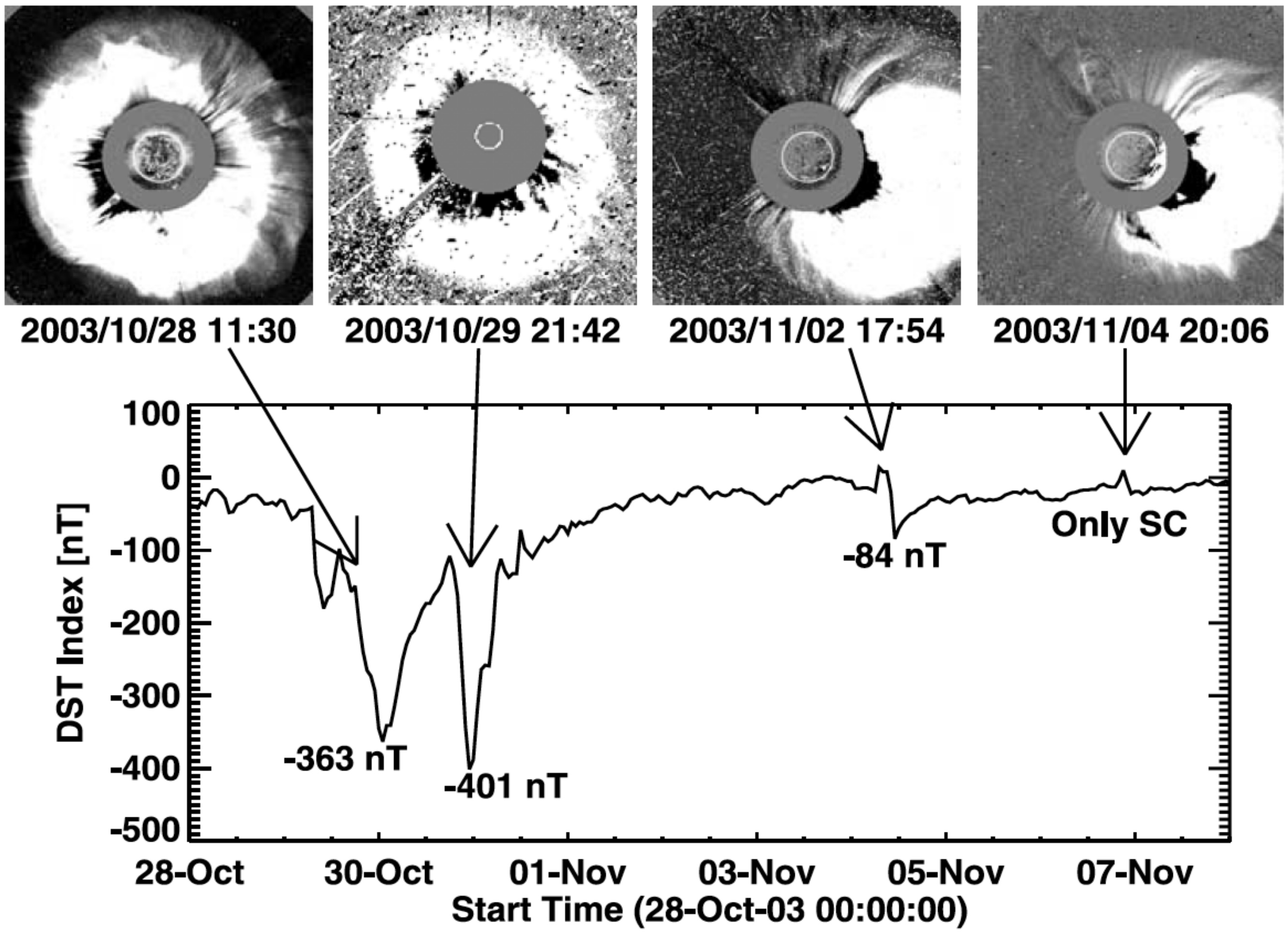
Solar radio burst science traceability

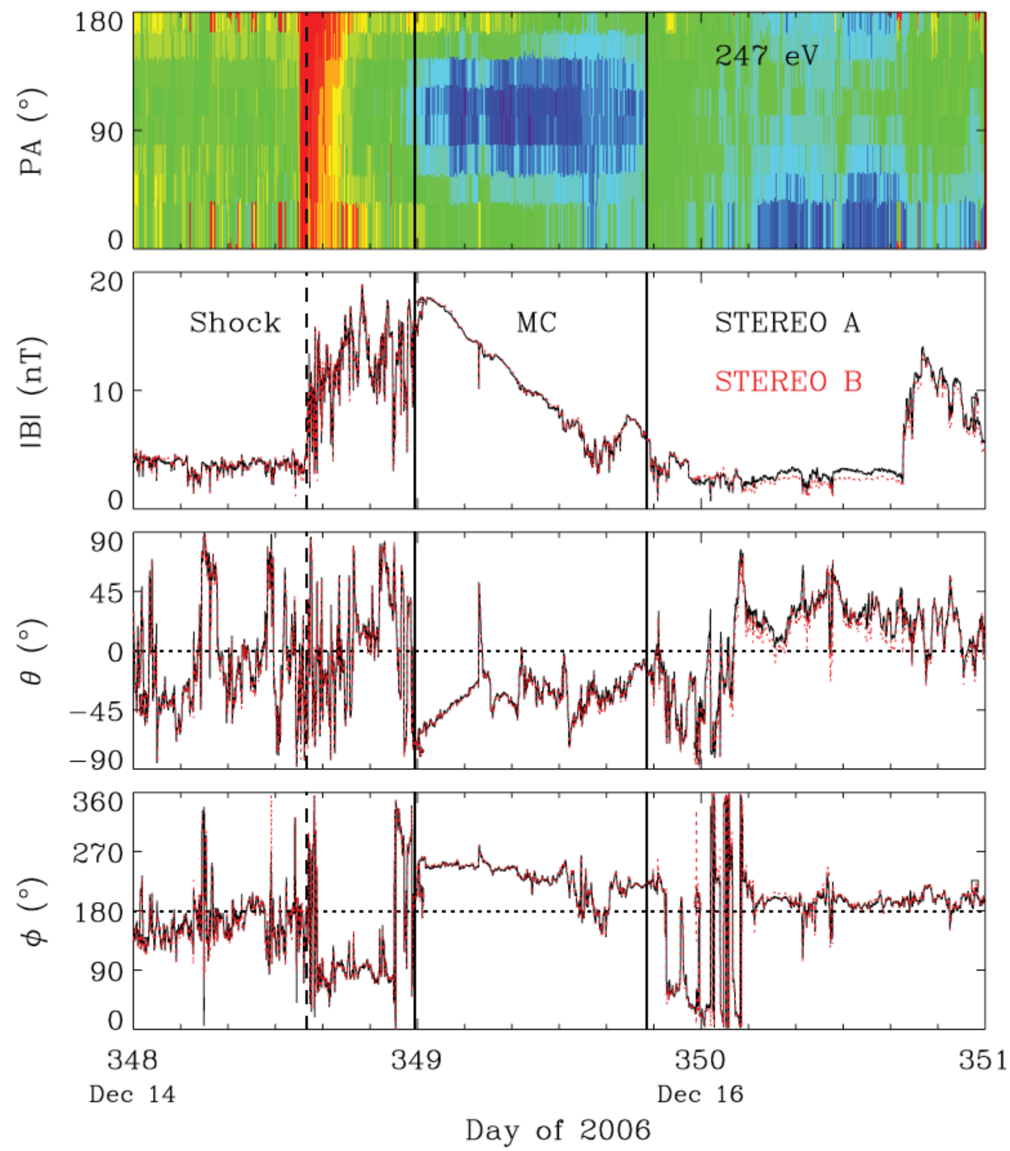
Science Traceability Matrix			
Decadal Science Goals	**Science Objectives**	**Science Measurements**	**Instrument requirements**
1) How do the heliosphere and planetary space environments respond to solar variability?	1) Where do solar radio bursts indicate that type II burst electrons are accelerated?	1) Image solar radio bursts with angular resolution < 2 degrees 2) Cover the freq. range 100 kHz-10 MHz 3) Obtain images every 10 sec or less 4) Continue observations for >1 yr during solar maximum	1) Aperture synthesis radio array on lunar surface 2) Radio receivers, timing system, etc., to provide data for synthesis 3) Hardware that is radiation & thermally tolerant to survive the lunar environment 4) Deployer for chosen antenna design
	2) What are the sources of unusually complex type III radio bursts?		
2) What are the impacts on humanity?	3) How can we use the detailed information from solar radio burst imaging to improve their diagnostic indications of energetic particles/space weather at 1 AU?		

CMEs, shocks, & space weather alerts



N. Gopalswamy et al., JGR, 2005; various papers show that the CME-driven shock produces type II radio emission. Tracking the type II burst, preferably with imaging, provides additional detail for a space weather alert.

Interplanetary CME magnetic field component



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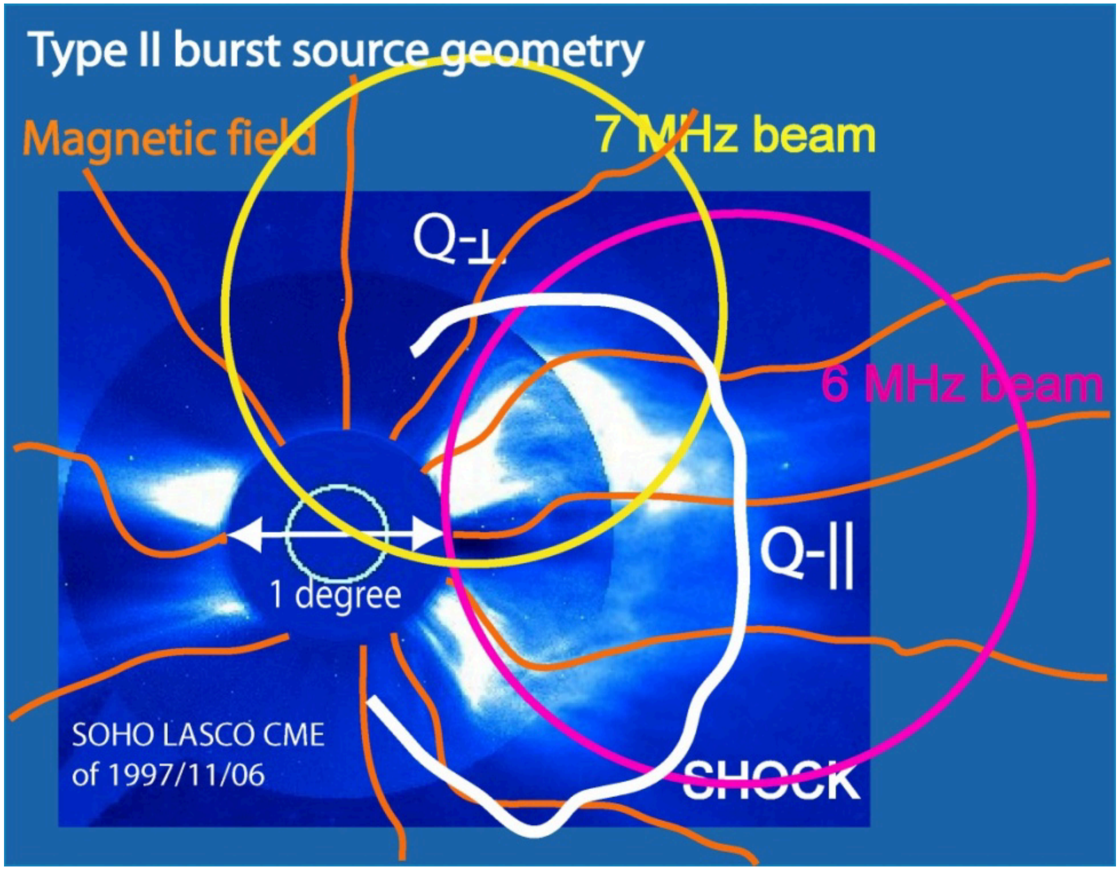
Solar radio burst science background

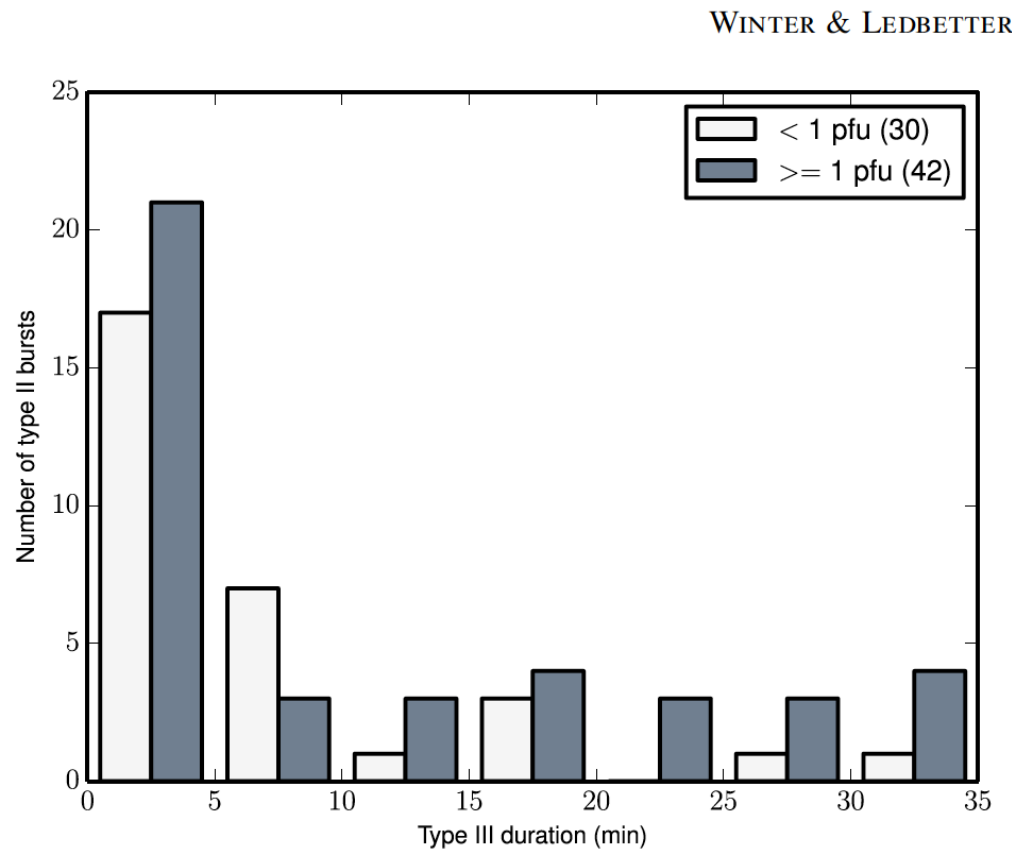


Where at the shock does electron acceleration occur, yielding type II radio emission (Q-|| vs. Q-⊥ shock)?

- Coronal mass ejection (CME) observed by SOHO LASCO instrument
- Fast CME drives a shock (white line)
- Over the extent of the shock, the shock normal has Q-|| and Q-⊥ geometries with the nearly-radial magnetic field (orange lines)
- Different acceleration mechanisms likely apply in the different geometries

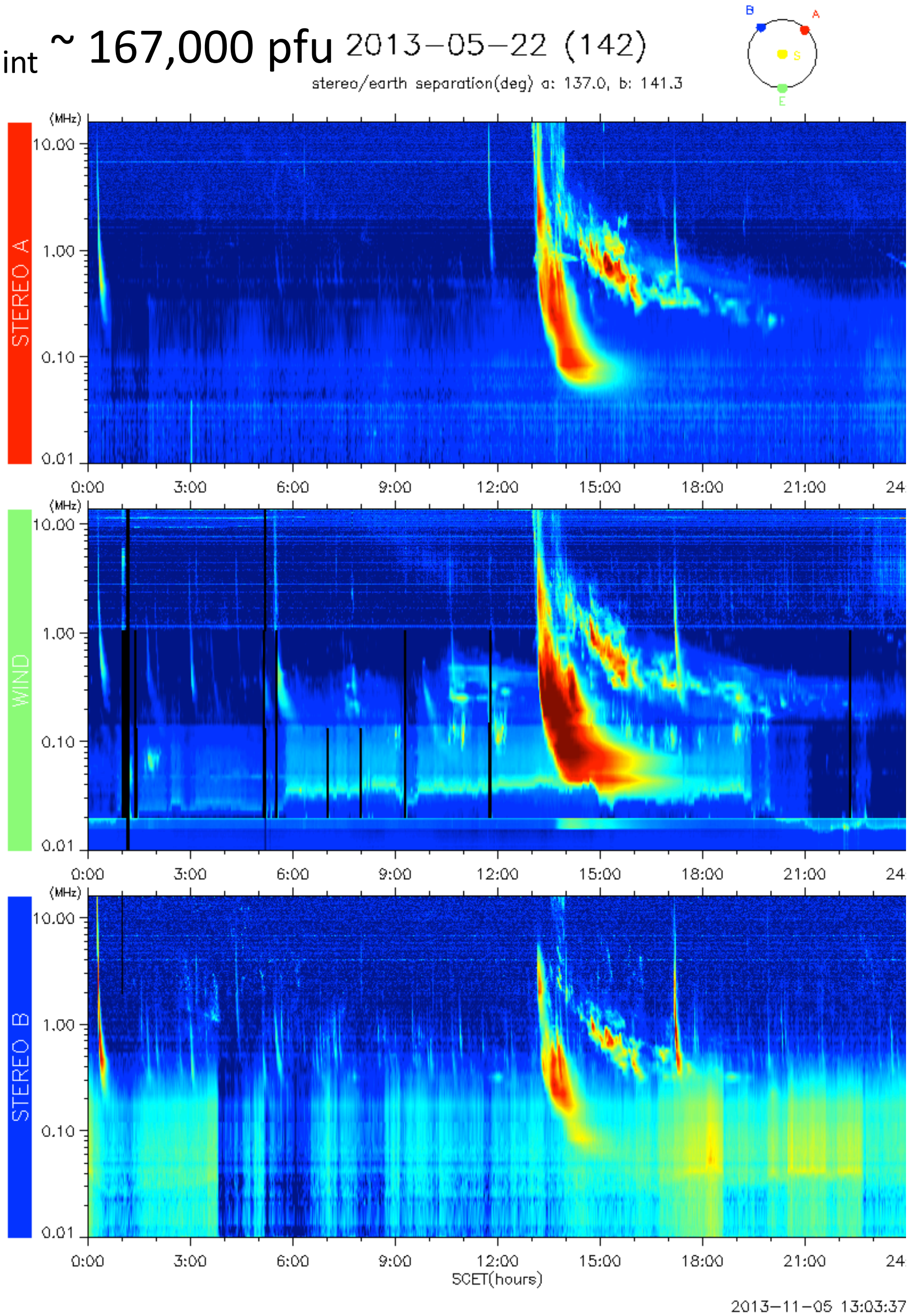
L. M. Winter & K. Ledbetter, Type II and Type III Radio Bursts and Their Correlation with Solar Energetic Proton Events, ApJ 2015

- Focused on type II events – 123 type II events observed by Wind/Waves from 2010-2013
- 27 SEP events > 10 MeV observed by GOES-13 and GOES-15 during the same interval
- Considerable statistical analysis, like that at right
- Also calculate proton flux for the events based on radio and Langmuir wave parameters, can be used to predict SEPs

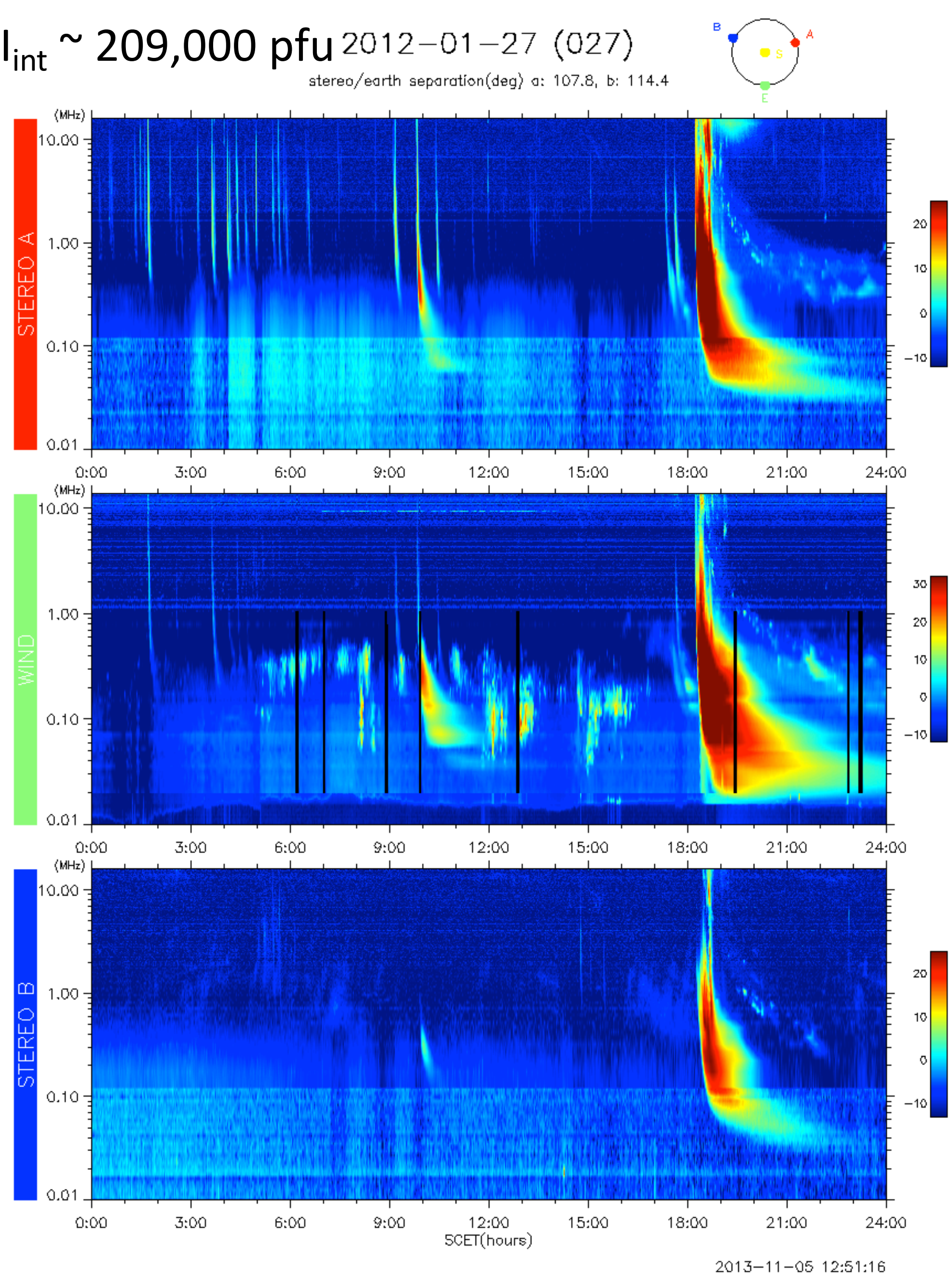


Complex solar Type III bursts – correlated w/SEPs (I_{peak} > 100 pfu)

I_{int} ~ 167,000 pfu



I_{int} ~ 209,000 pfu



Value of solar radio bursts for space weather alerts

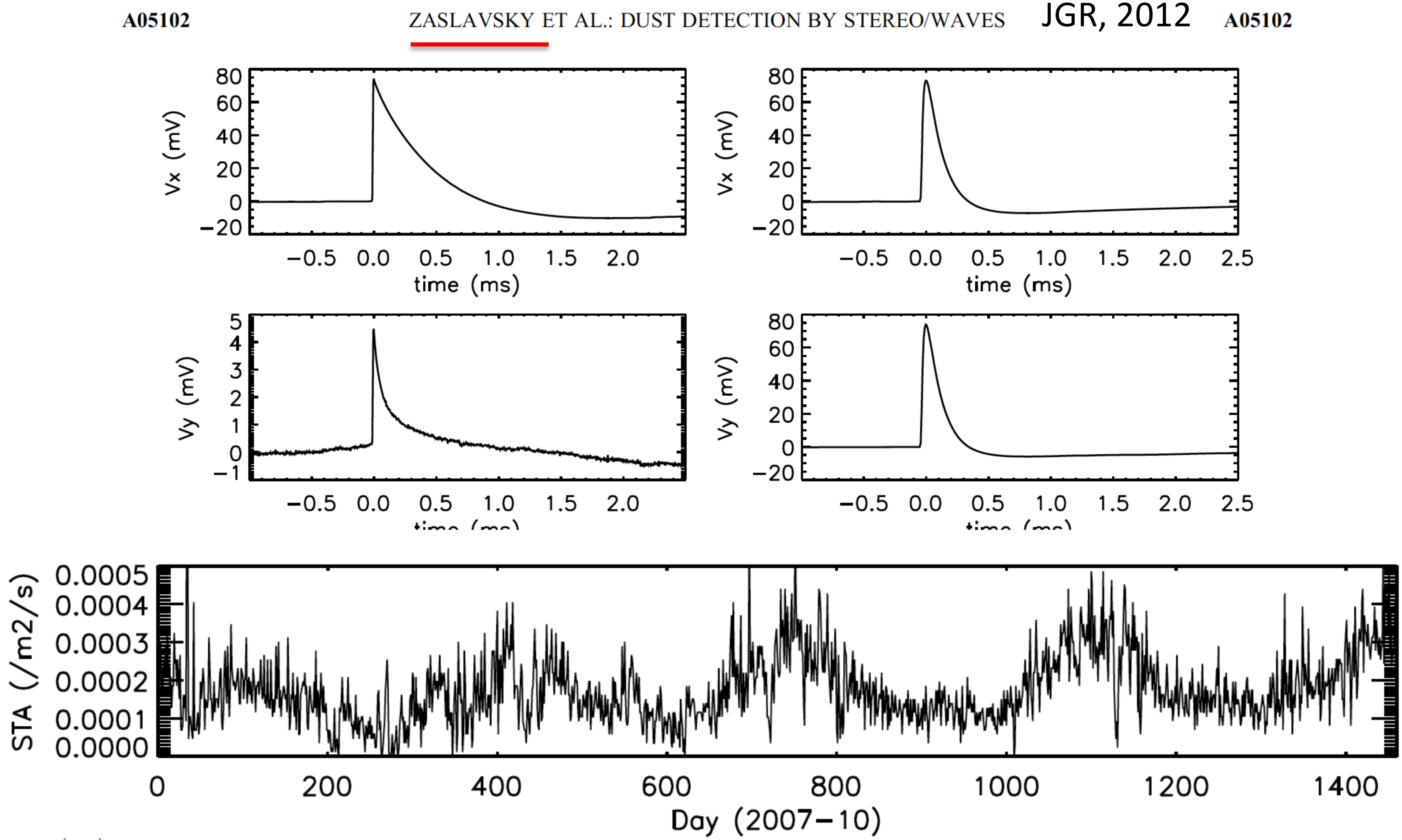
- There are essentially no dangerous Solar Energetic Particle (SEP) events without the related complex type III bursts and intense type II bursts.
- The solar radio burst events can supplement the white light coronagraph observations.
- If we could get a pathfinder Lunar Radio Telescope Array on the Moon for this solar Maximum (~ 2022-2024), we could directly demonstrate the value of the data as an SEP alert for astronauts (and hardware).
- It's critical to develop an algorithm that is reliable.

Requirements for imaging these radio sources from the lunar surface

Table 3.4.1. Summary of ROLSS parameters

Parameter	Value	Comment
Wavelength (Frequency)	30–300 m (1–10 MHz)	• Matched to radio emission generated by particle acceleration in the inner heliosphere • Provide context for observations during Solar Probe Plus perihelion passes • Detect lunar ionosphere • Operate at frequencies below the terrestrial ionospheric cutoff
Angular Resolution	2° (at 10 MHz)	• Localize particle acceleration sites of CME shocks and Type III solar bursts • Order of magnitude improvement from present
Bandwidth	≥ 100 kHz	Track time-evolution of particle acceleration
Minimum Lifetime	~1 year	Obtain measurements during several solar rotations; avoid solar minimum

Spacecraft dust detection



Dust impacts on spacecraft/antennas

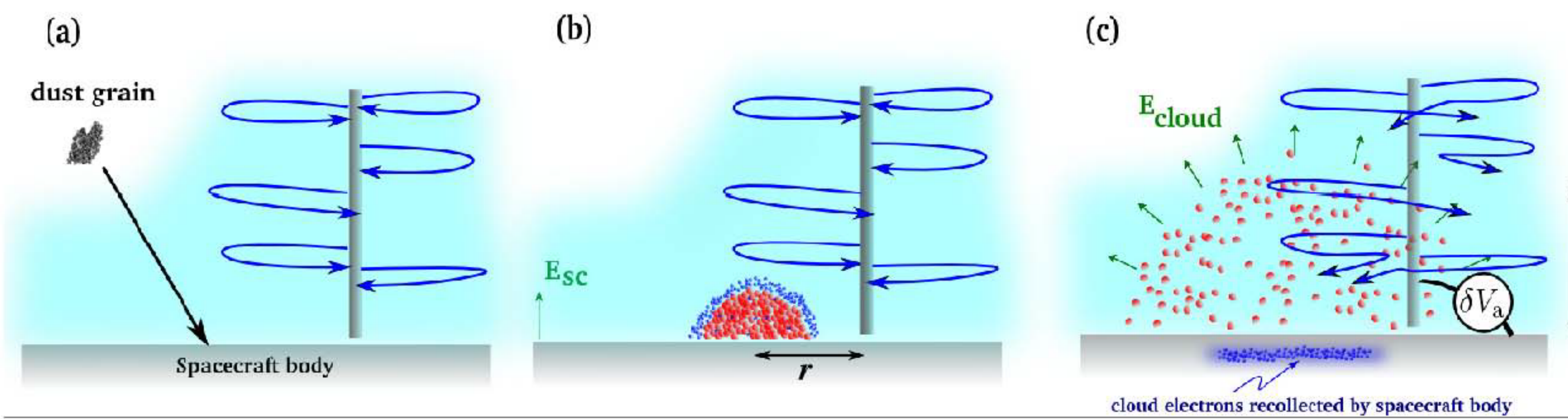
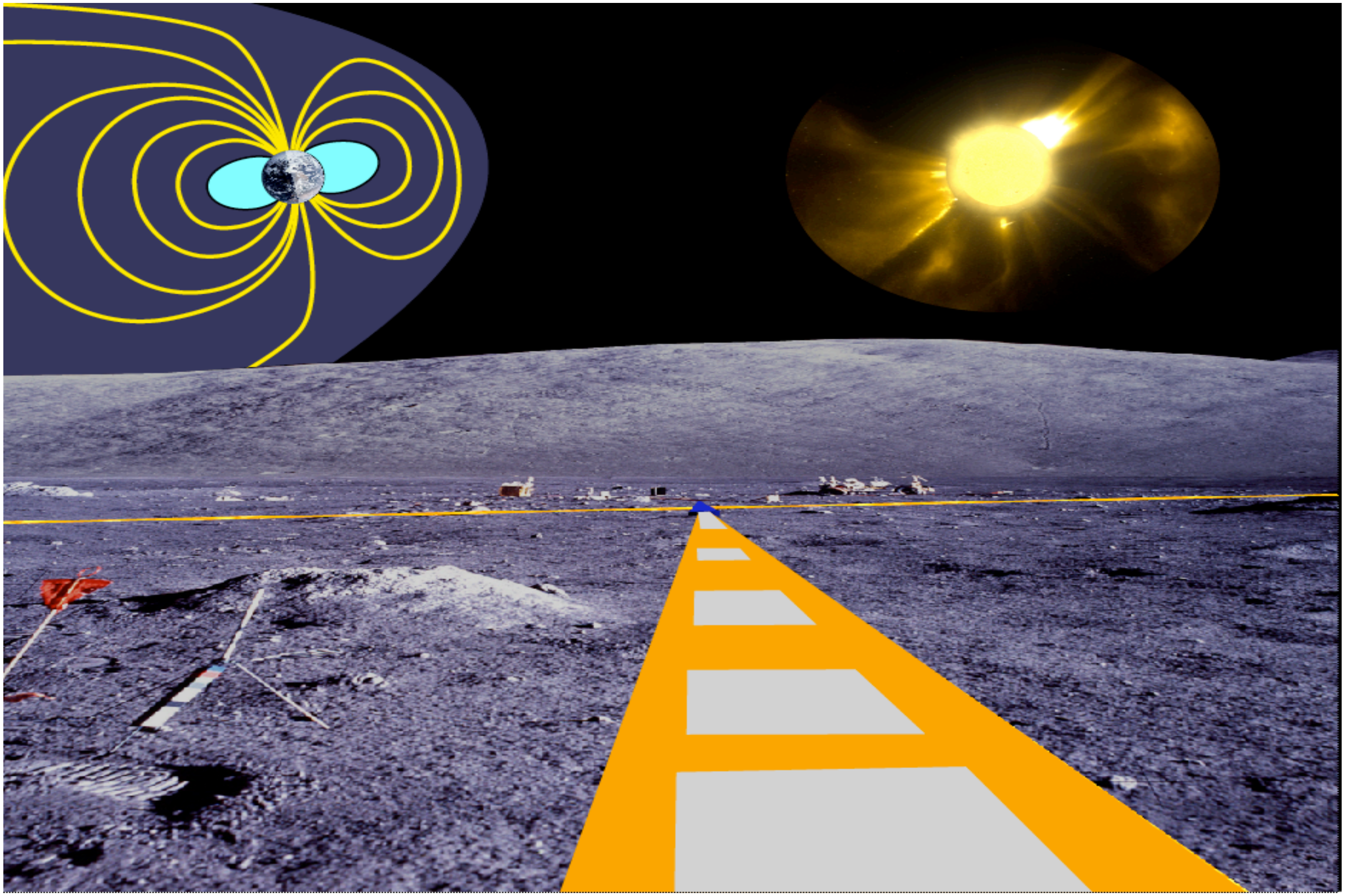


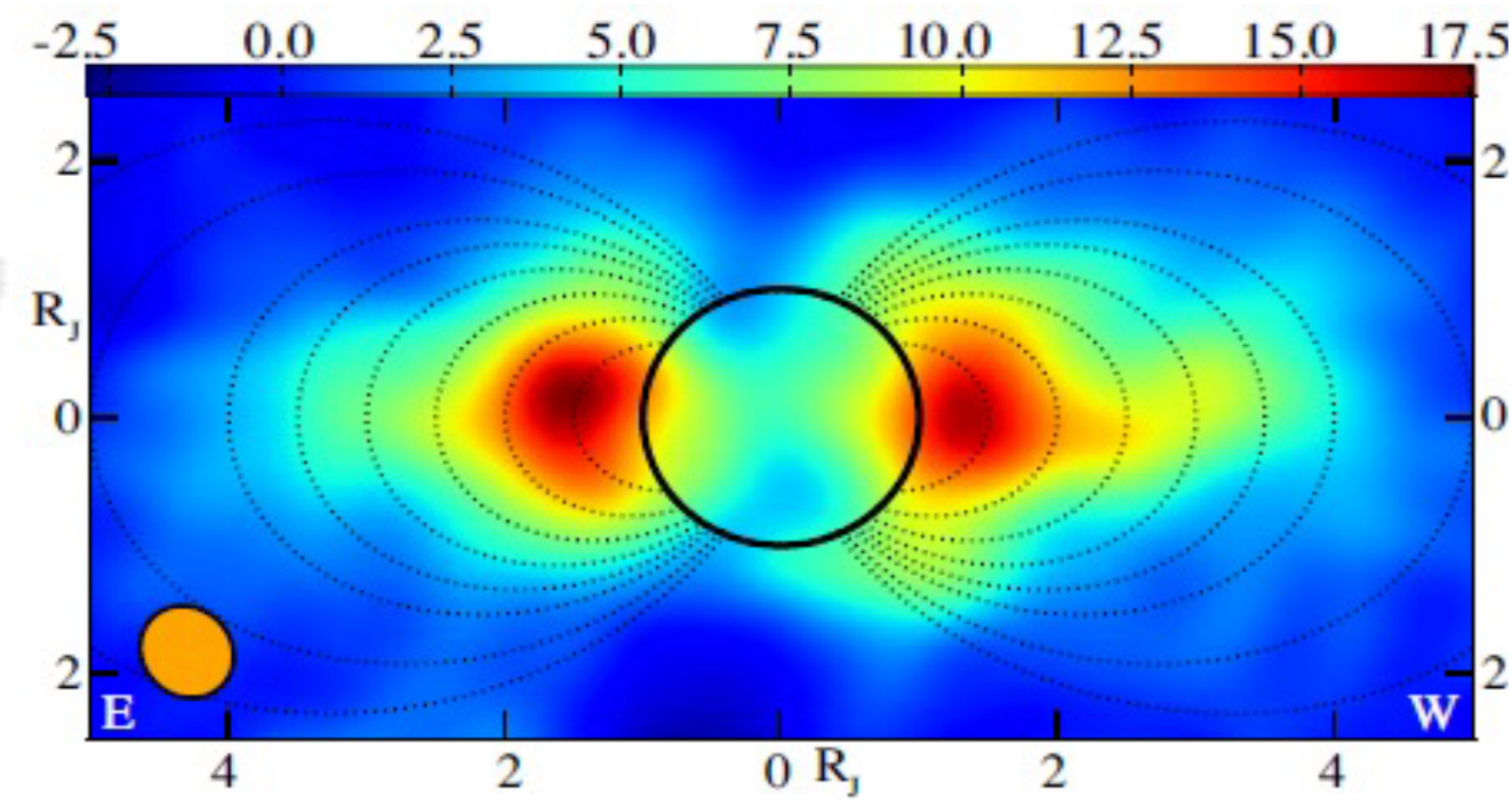
Fig. 3.4.6. NESS will use sensitive radio observations to measure nanodust impacts on the lunar surface. Following a dust impact on a spacecraft (a) a plasma cloud expands radially (b) at some distance r from an antenna. The cloud electrons are quickly recollected by the spacecraft via electrostatic field (c). This field is strong enough to perturb the photoelectrons moving on highly eccentric orbits so that the antenna no longer collects them. The antenna thus increases its positive charge so that its voltage rises by δVa. (From Pantellini et al. 2012)

Lunar surface dust detection



ROLSS polyimide sheet array has surface area of 1500 m^2

Imaging synchrotron emission from Earth's radiation belts



LOFAR image of Jupiter's radiation belts from 127-172 MHz. (Girard et al. 2016)

Space weather connection

Freidel et al, 2002, JASTP

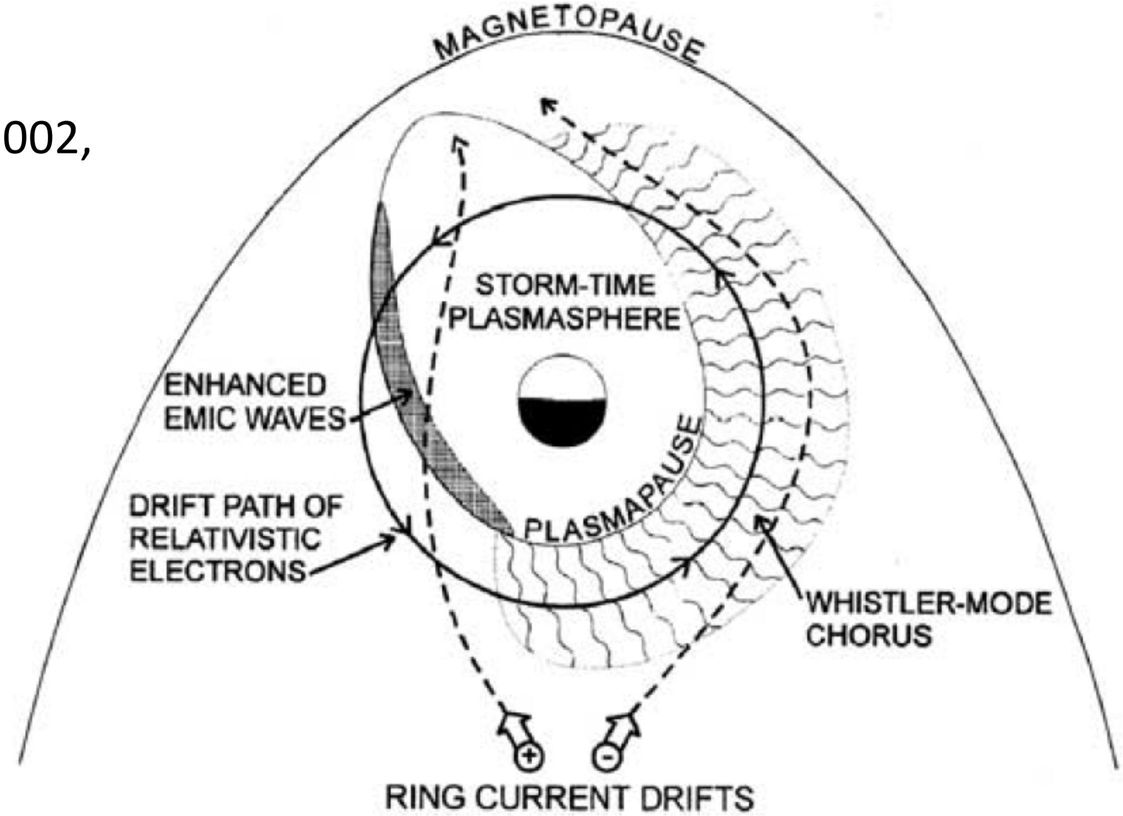


Fig. 10. Schematic diagram showing spatial distribution of whistler mode chorus and EMIC waves during magnetic storms in relation to the position of the plasmapause and the drift paths of ring current (10–100 keV) electrons and ion and relativistic (∼ 1 MeV) electrons. This map is taken from Summers et al. (1998); the regions of wave activity are determined empirically from published data

Radio Heliophysics Summary

- Solar radio bursts at frequencies < 20 MHz have never been imaged.
- The timing and location of the bursts provides an indication of energetic particle acceleration, and therefore, the potential of space weather alerts.
- Imaging the bursts will also provide data on the locations of electron acceleration, answering magnetic field configuration and other questions.
- Radio observatory antennas on the lunar surface will also be large dust detectors, especially if the unrolled-polyimide antenna substrate is used.
- We realized during the proposal development that a near side radio array might be able to observe synchrotron radio emissions from the Earth's radiation belts. This emission is also controlled by space weather events.
- Requirements for the pathfinder lunar surface radio telescope are modest, except for surviving the thermal environment, which includes surviving 14 days of lunar night. OK, maybe getting to the surface is still an issue…

Radio Observatory on the Lunar Surface for Solar studies (ROLSS)

Parameter	Value	Comment
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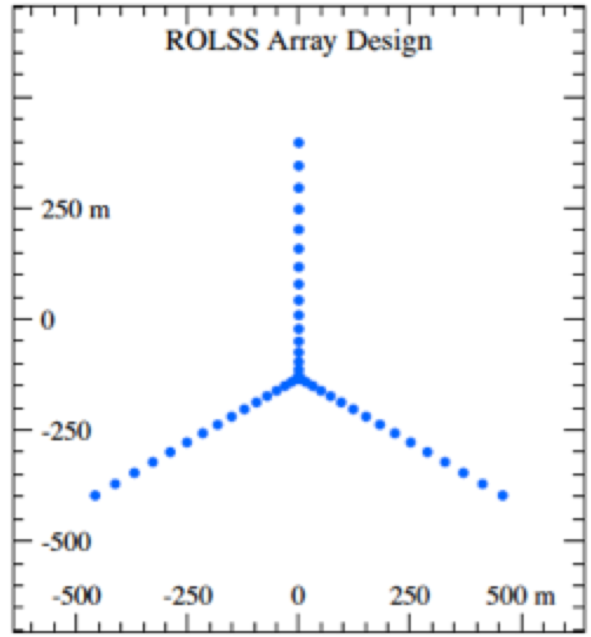
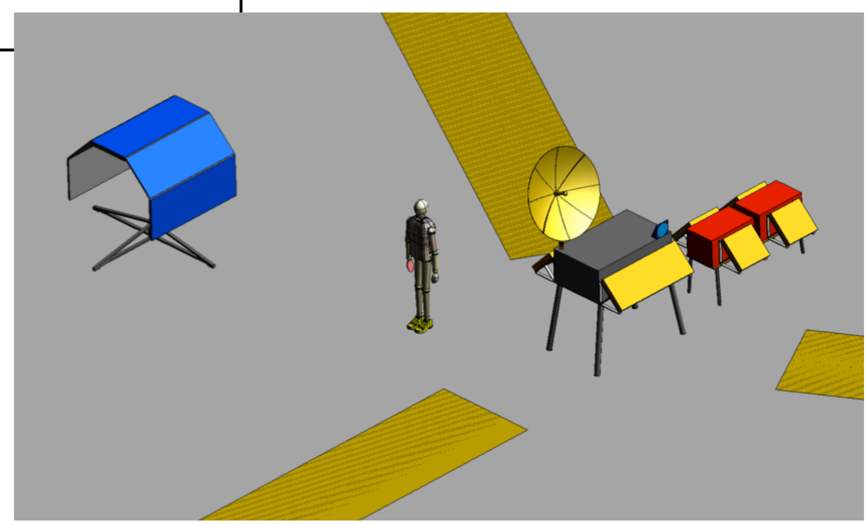
Bandwidth	≥ 100 kHz	Track time-evolution of particle acceleration
Minimum Lifetime	>1 year	Obtain measurements during several solar rotations; avoid solar minimum



- Would likely go to lower frequencies than indicated for ROLSS, permitting detection of the lunar photoelectron sheath ~ 100 kHz, at least during solar wind events.
- Also consider other data, such as electric fields from dust particles hitting the Kapton



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Plans of the NESS team

- Review all info from ROLSS and similar studies
- Conduct trade studies to determine what fraction of the generic Lunar Radio Observatory works for all radio sources – solar to extrasolar planet magnetospheres, etc.
- Identify the most efficient path to implement a flexible design that could be implemented as a small pathfinder (~10 antennas) or a large station (100 or more antennas)
- Procure hardware to build and test a fully-functional model, increasing the TRL of the Low-frequency Radio Observatory on the Lunar Surface
- Work with commercial (or other) providers of payload delivery to the lunar surface to complete the flight plan