Solar Radio Bursts and Space Weather

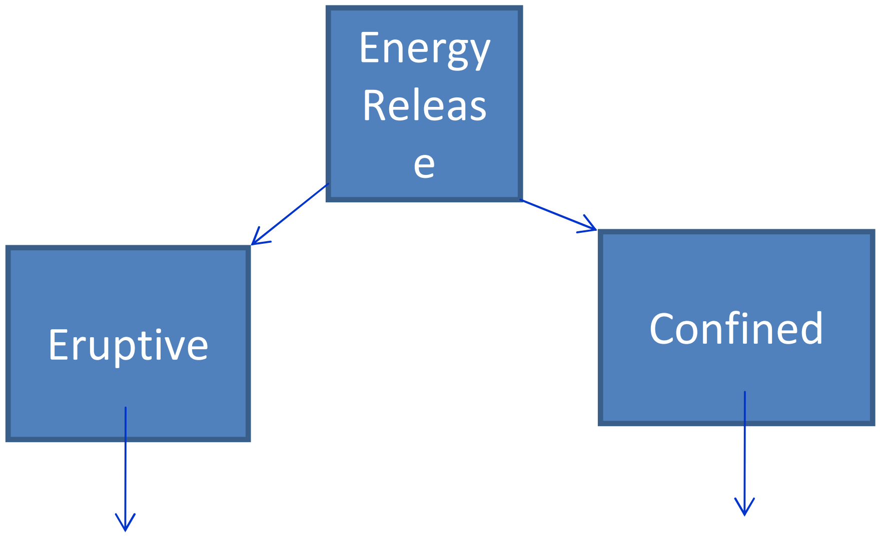
Nat Gopalswamy

NASA/GSFC

Type II bursts
shocks
CMEs
SEPs
ESP
Sudden commencement

ISWI workshop, Quito, Ecuador, October 8, 2012

Radio Bursts

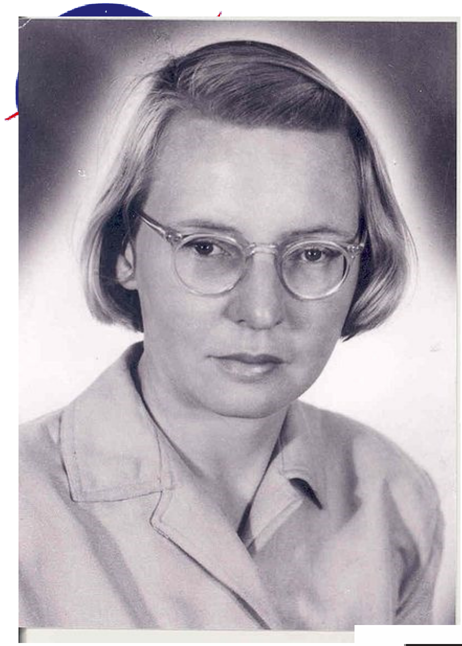


X-ray, Microwave bursts, γ-rays
(Sunward electrons, ions)
Shocks, CMEs
(outward electrons), SEPs

X-ray, Microwave bursts, γ-rays
(Sunward electrons, ions)

Radio bursts are due to accelerated electrons from ~1 keV to >1 MeV
Indicate acceleration of ions – important for space weather
Indicate shocks and CMEs – important for space weather (mag. storm)

Radio Bursts Reveal Matter Leaving the Sun



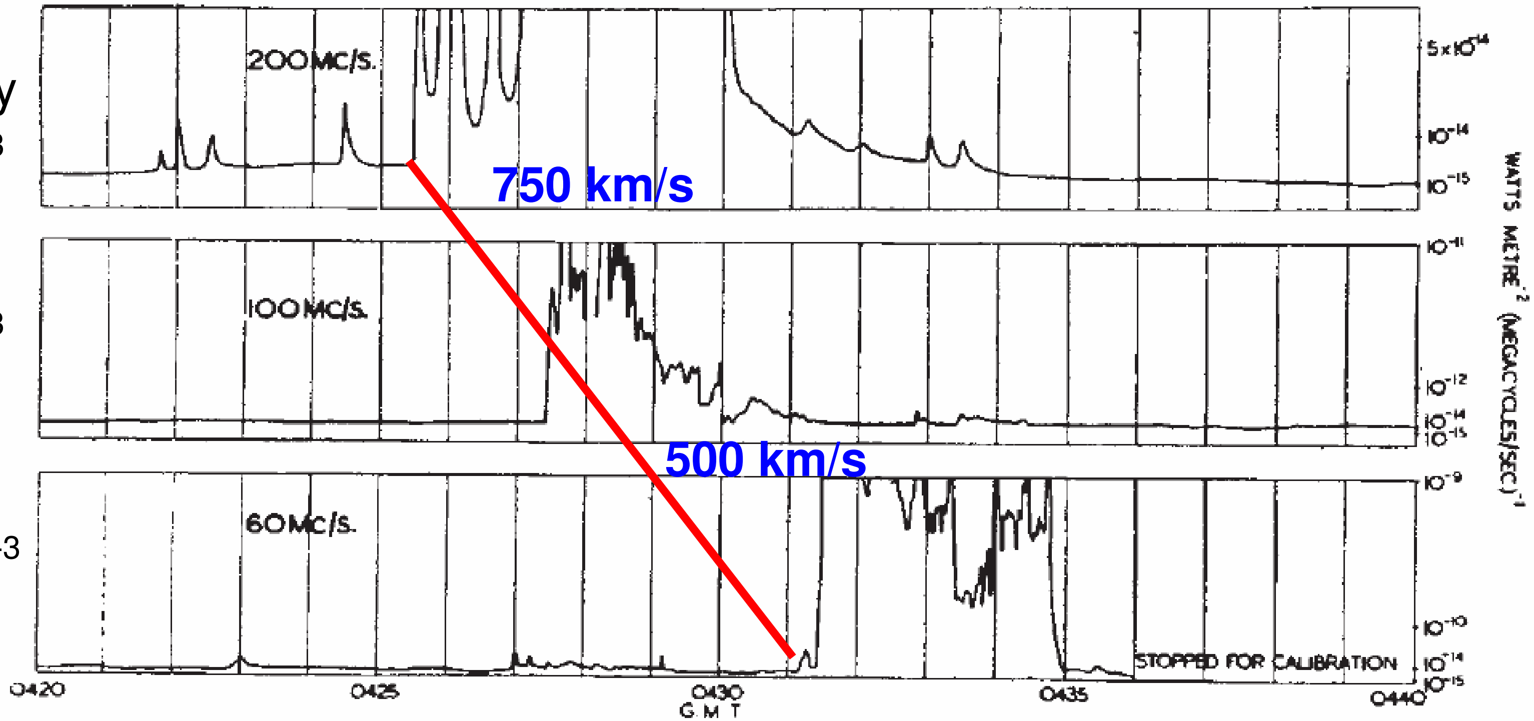
Ruby Payne-Scott
1912 – 1981

The whole pattern drifts;
140 MHz in 6 min
df/dt = 0.4 MHz/s

Plasma density
5.0×10^8 cm^{-3}

1.2×10^8 cm^{-3}

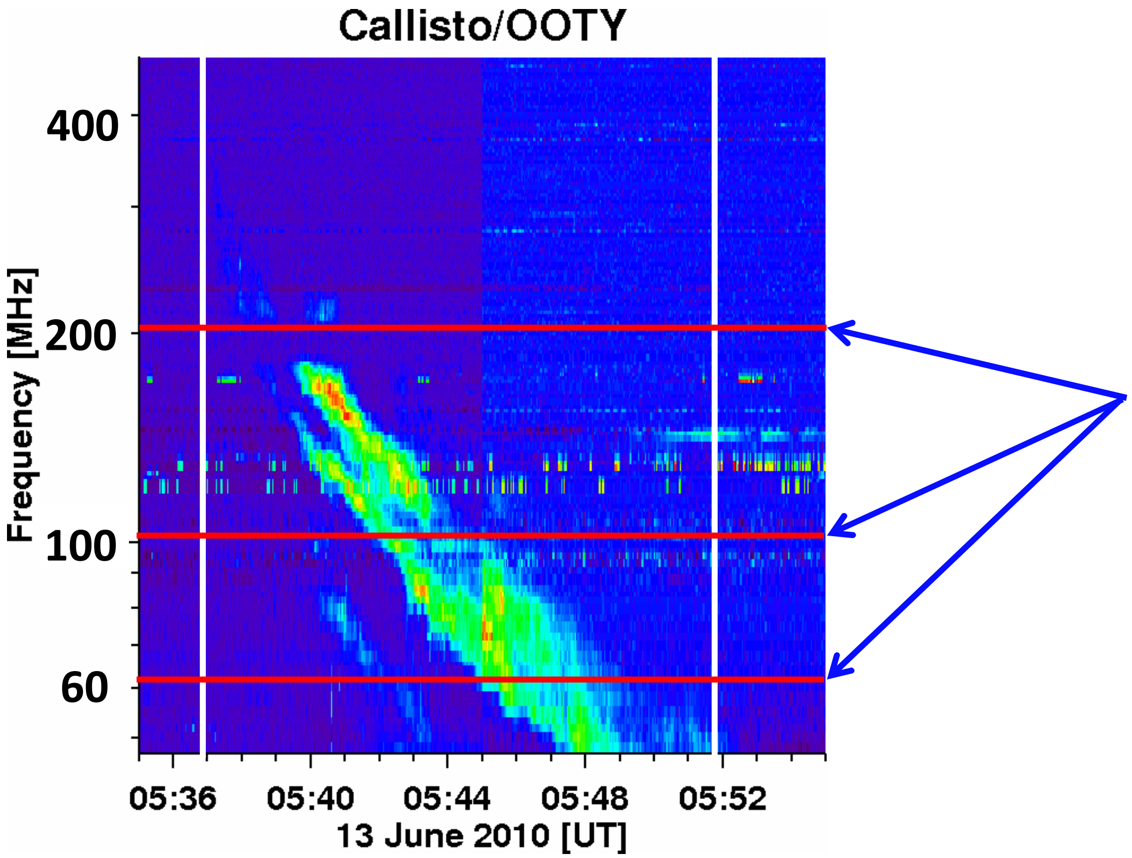
0.4×10^8 cm^{-3}



Nature 260, 256, 1947

LARGE OUTBURST OF MARCH 8, 1947

Dynamic Spectrum from ISWI Instrument CALLISTO



The three frequencies used by Payne-Scott et al

Radio bursts and mass ejection

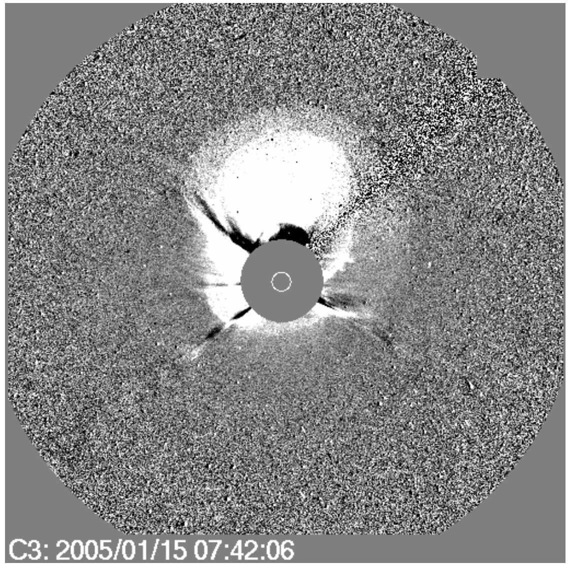
- "The successive delays between the onsets at 200, 100, and 60 Mc/s suggest that the outburst was related to some physical agency moving from high frequency to low frequency levels."
- "It is noteworthy that the derived velocities are the same order as those of prominence material (some hundreds of kilometers per second) …"

Payne-Scott et al. 1947

Physical Agency = Shock

- "… the velocity of type II burst could be more naturally associated with the hydromagnetic shock front velocity" (Uchida, Y. 1960 PASJ)
- Disagreed with acoustic shock proposed by Wild (1954) and Westfold (1957)

IP Shock Proposed

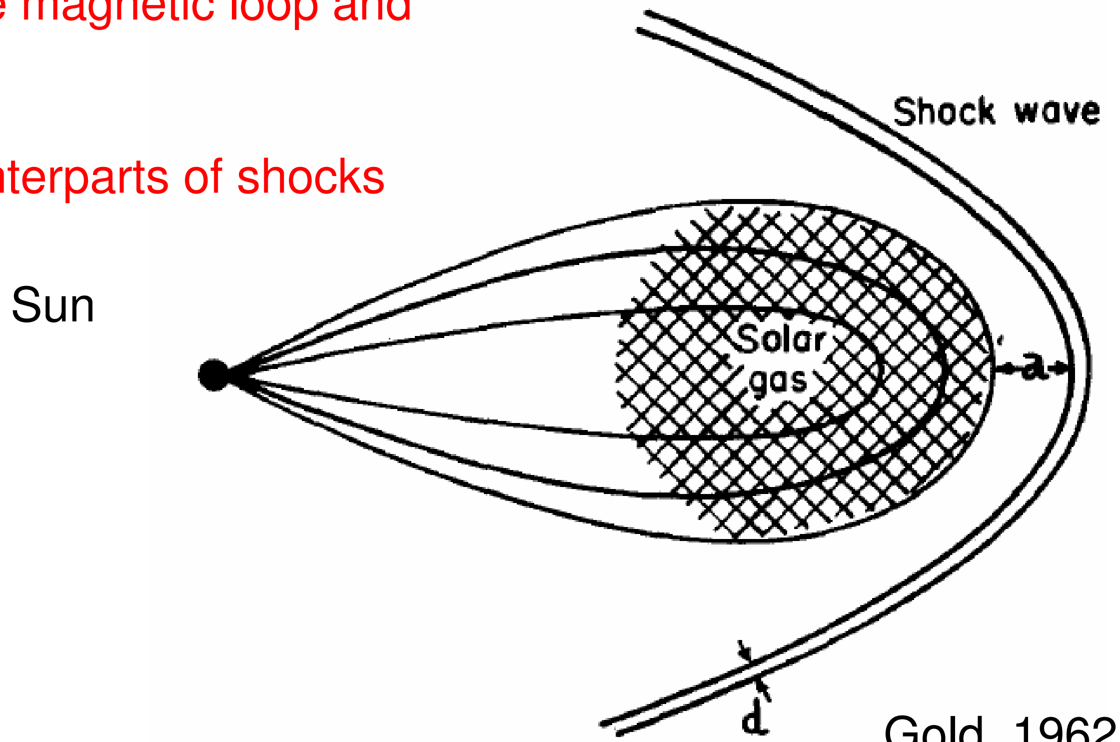


In 1953 T. Gold proposed IP shock to explain Sudden Commencement (Gas Dynamics of Cosmic Clouds, North Holland Publishing, 1955)

Mariner 2 Detects IP shock. Sudden commencement follows.

Burlaga et al. (1981) identified the magnetic loop and sheath behind the shock

Only recently, the white-light counterparts of shocks identified



Gold, 1962

“Idealized configuration in space, showing solar plasma cloud, the drawn-out field and the shock wave ahead” (Gold 1962)

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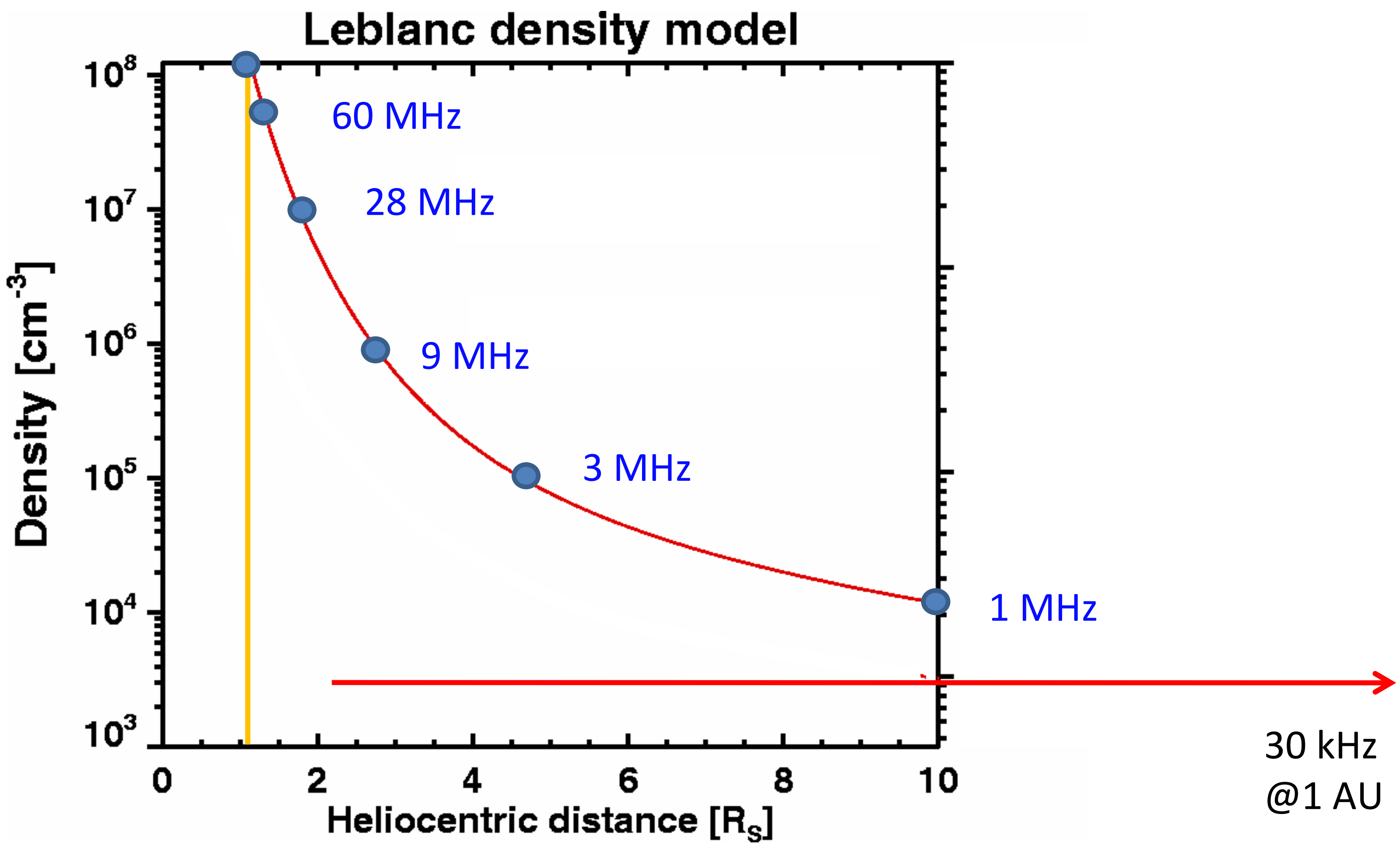
Density Decrease in the Corona → drift



1 Rs = 700,000 km. Earth at 214 Rs.

Plasma frequency = $9 \times 10^{-3} n^{1/2}$ MHz

How to get the shock speed?

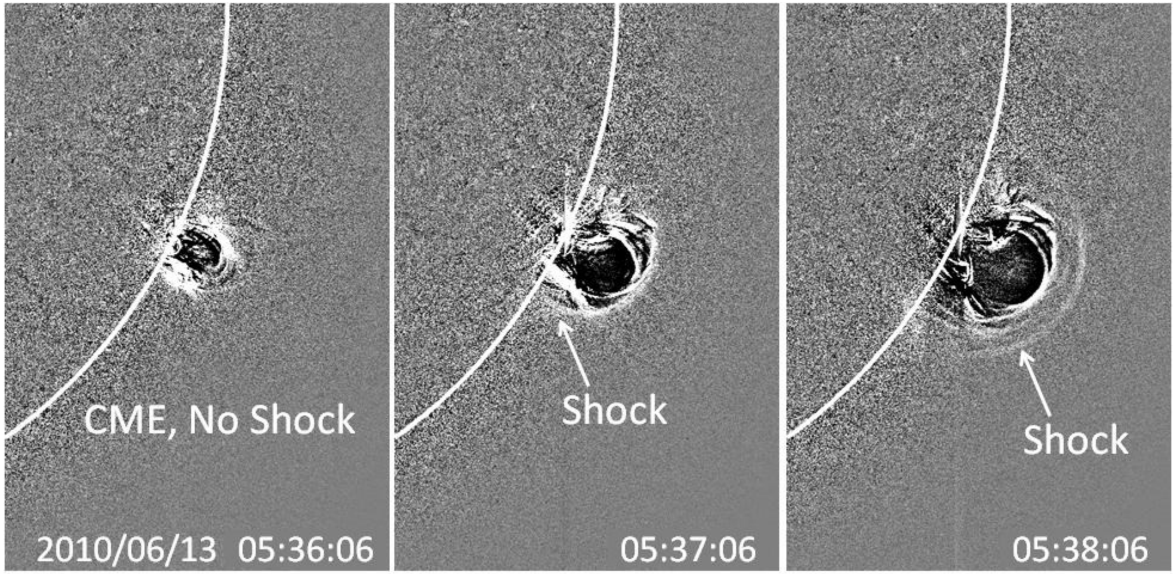
- $f = 9x10^{-3}n^{½}$ MHz plasma frequency (emission takes place at this frequency or its harmonic)
- $df/dt = (df/dr)(dr/dt) =(V/2)\ f\ n^{-1}(dn/dr)$ using the relation between f and n; V is the shock speed (dr/dt)
- $(1/f)\ df/dt = (V/2L)$, with $L = |(1/n)dn/dr|^{-1}$

From the dynamic spectrum

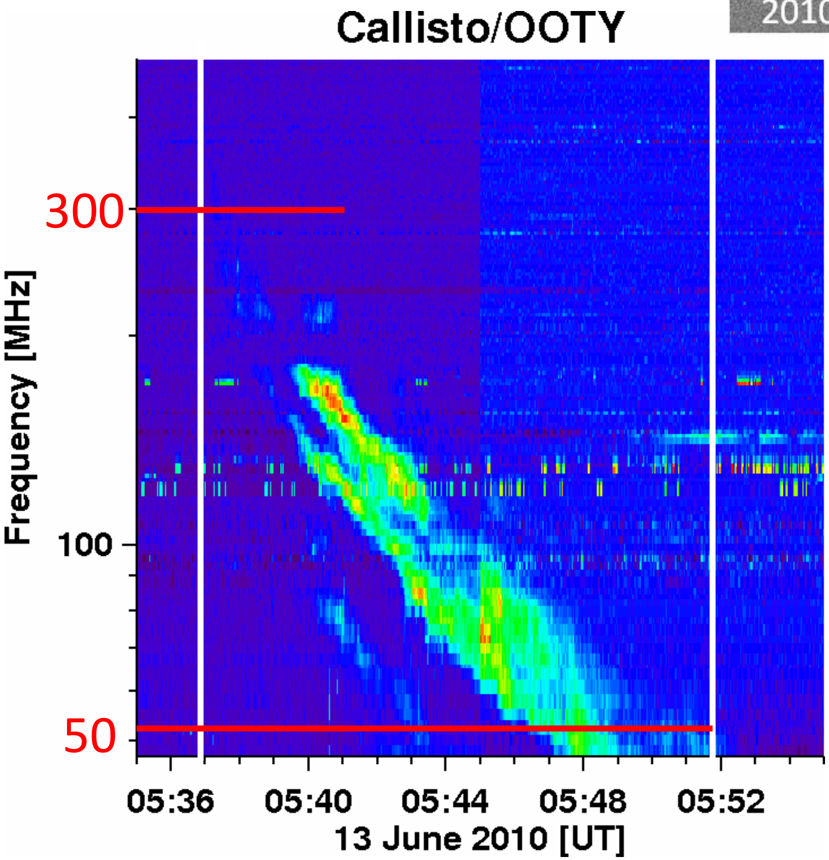
From the density model

- $V = 2L.\ (1/f)\ df/dt$

CALLISTO Type II Burst: 2010 June 13



Solar Dynamics Observatory



Type II burst starts exactly at the time the shock appears in the corona at 1.2 Rs

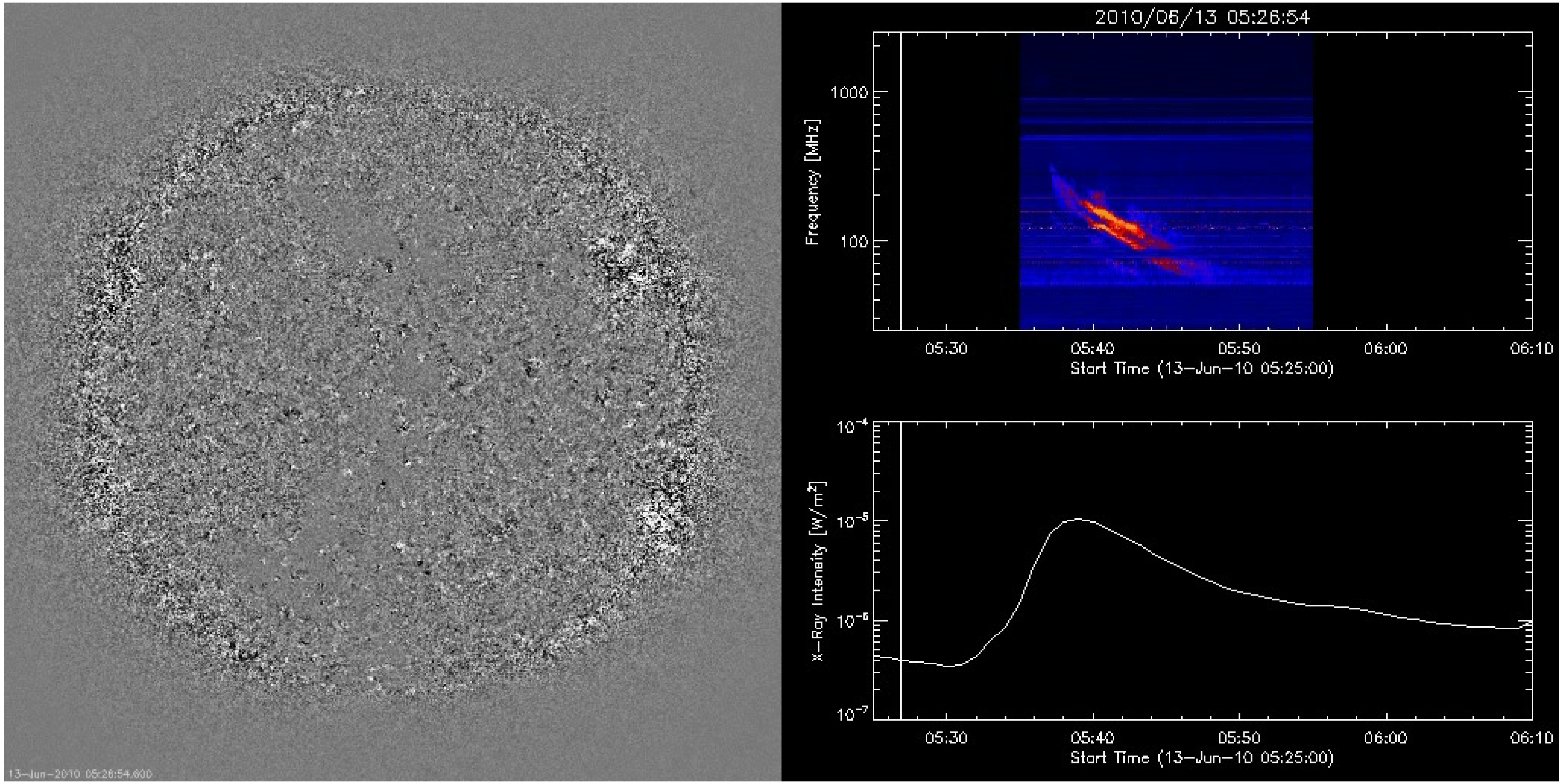
We can probe the coronal medium as well as the shock structure by combining type II and EUV/coronagraph observations

df/dt = 0.28 MHz/s; (1/f)df/dt = (0.28/175) s^{-1}

V = 600 km/s; L = 189,000 km

2010/06/13

f_p = 150 MHz → n_p =2.8×10^8 cm^{-3}

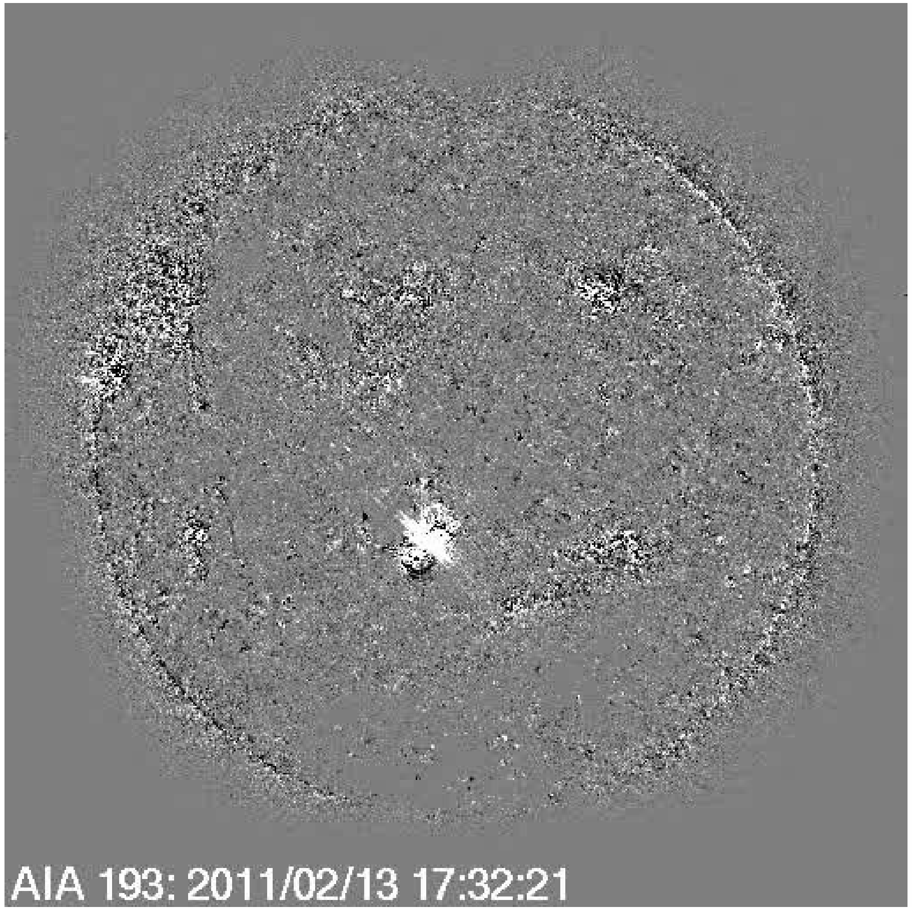


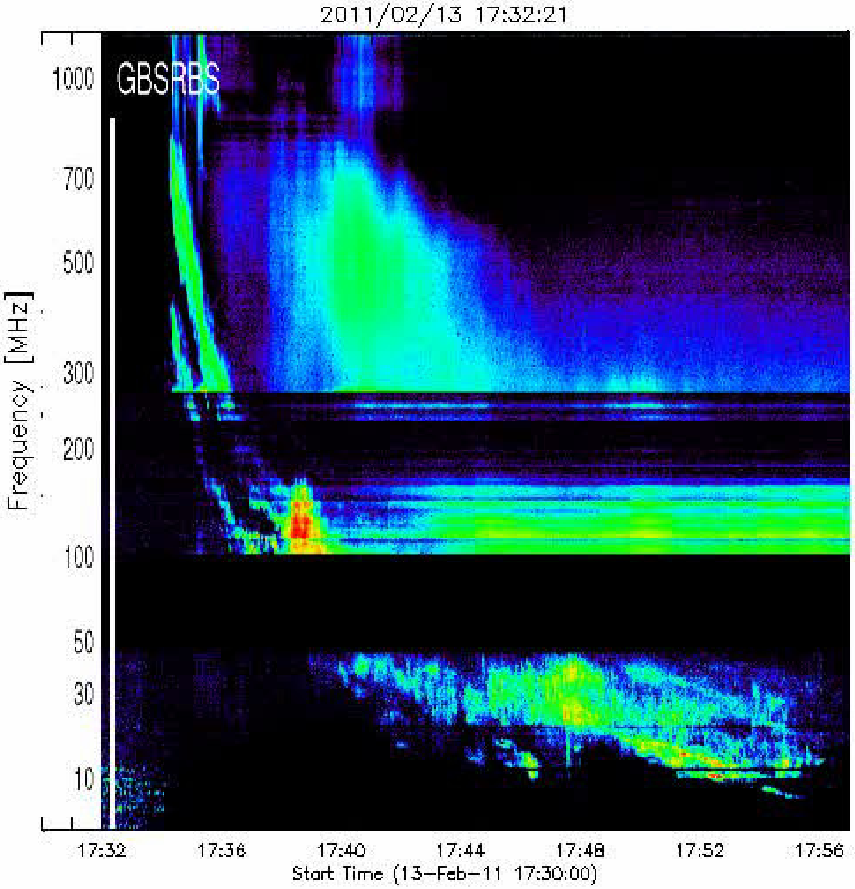
CME starts at 5:34 at 1.13 Rs; Type II starts at 5:36 when the CME at 1.17 Rs; shock 1.19 Rs

Gopalswamy et al., 2012 ApJ

2011/02/13 Very High Starting frequency
(400 MHz → $n_p = 1.98 \times 10^9\ cm^{-3}$)

S20E04



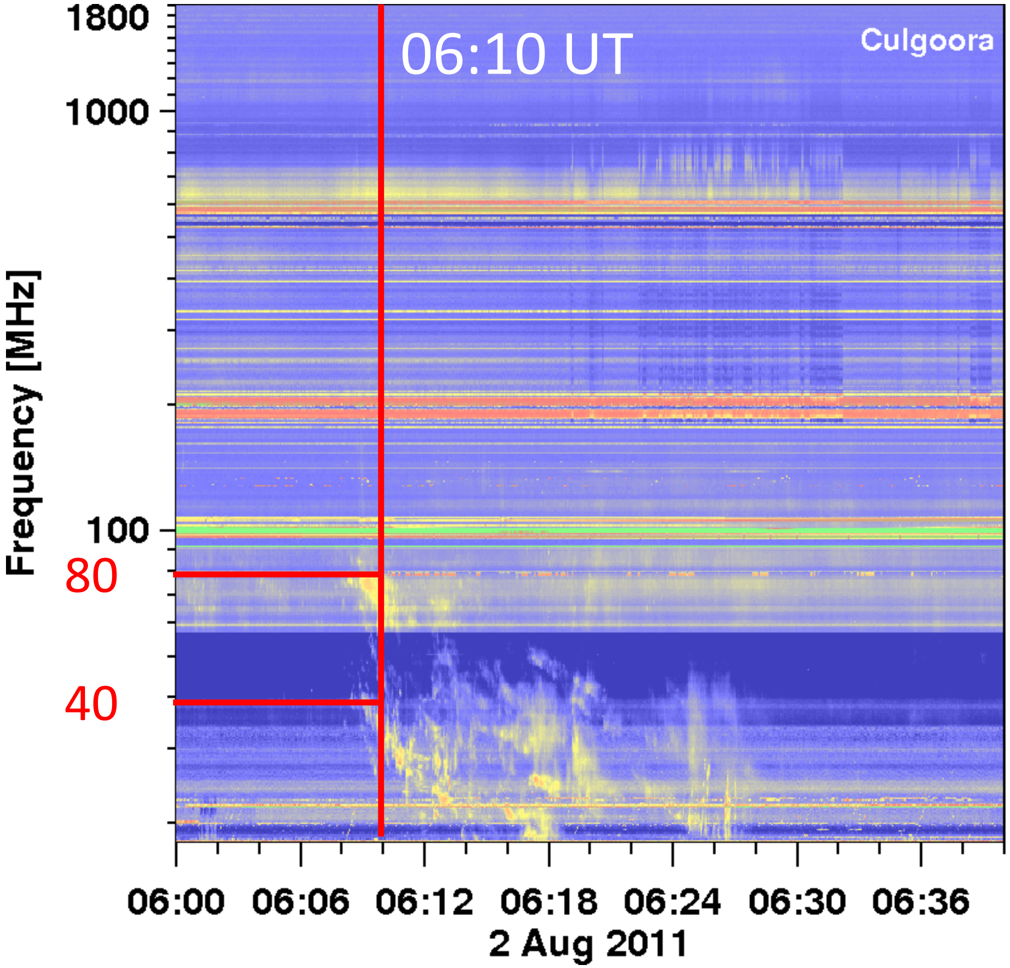


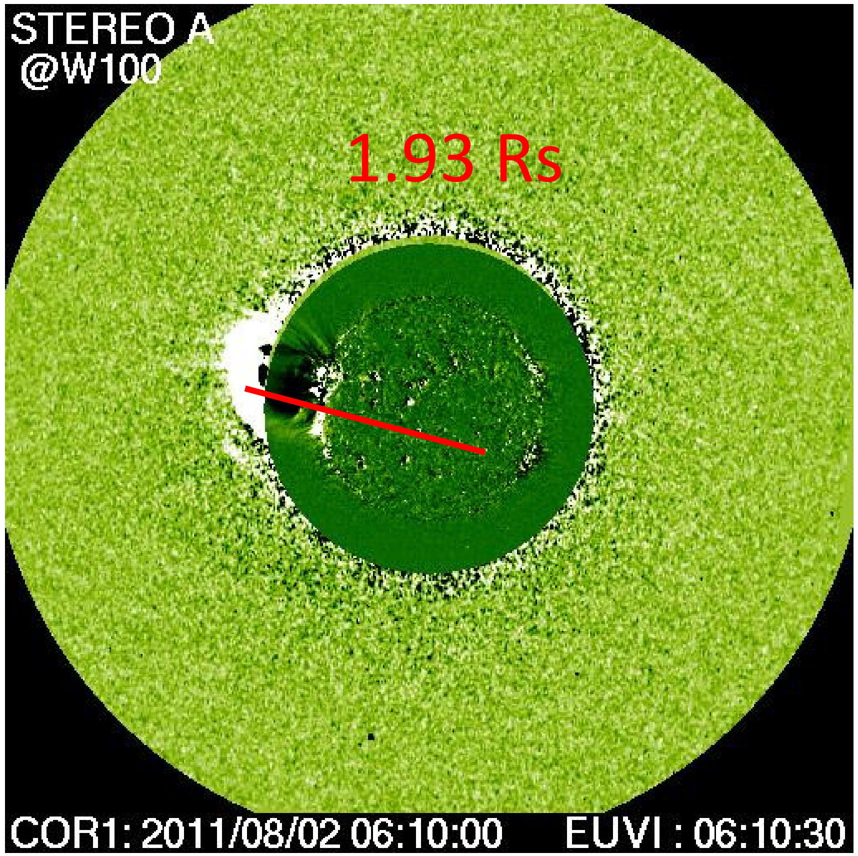
AIA wave radius = 0.14 Rs = Disturbance height in EUVI

Aug 2 2011 Type II & CME

Leading Edge Method

COR1 + EUVI



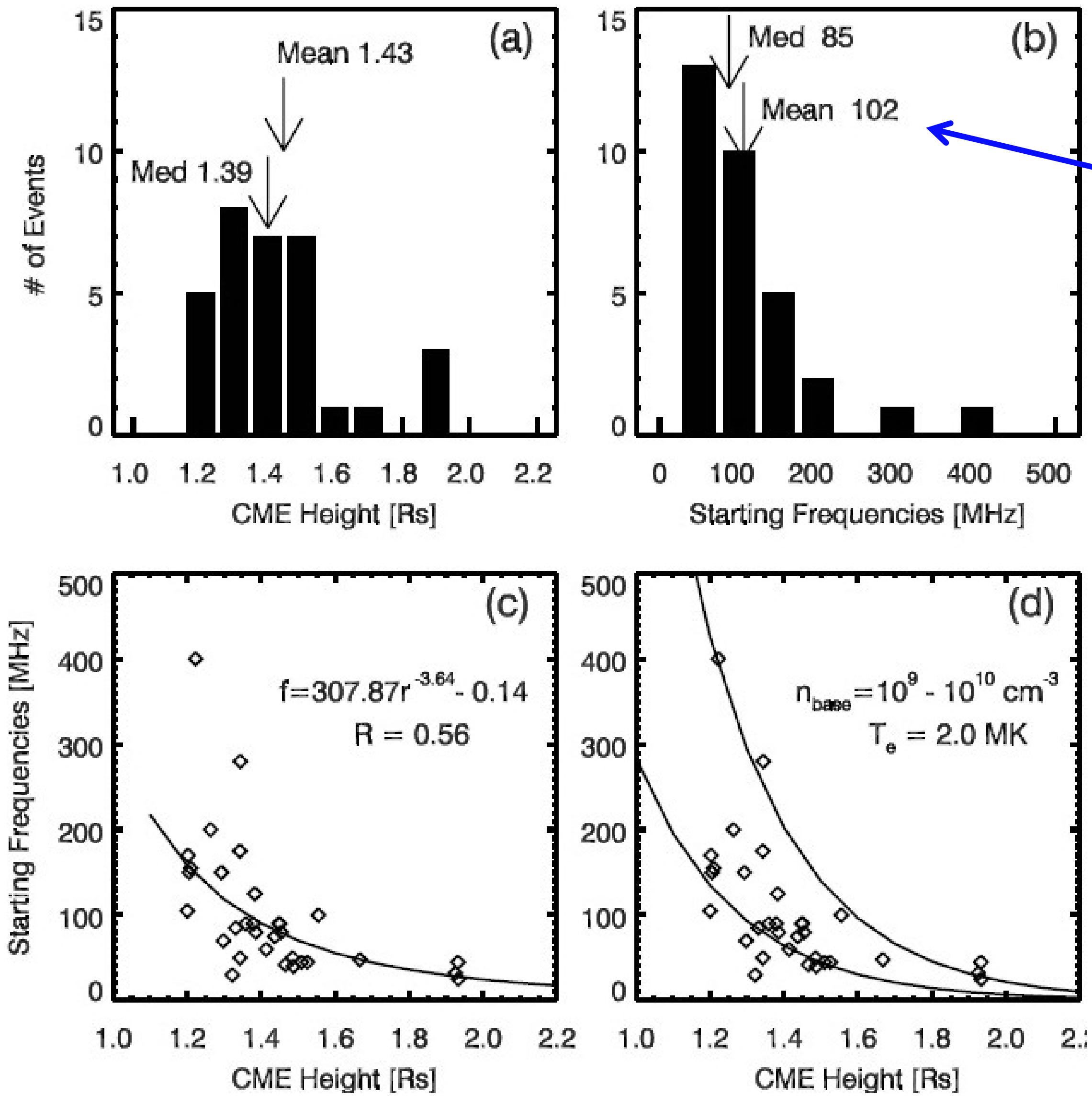


40 MHz → 1.98×10^{7} cm^{-3}

Where in the Corona do shocks form?

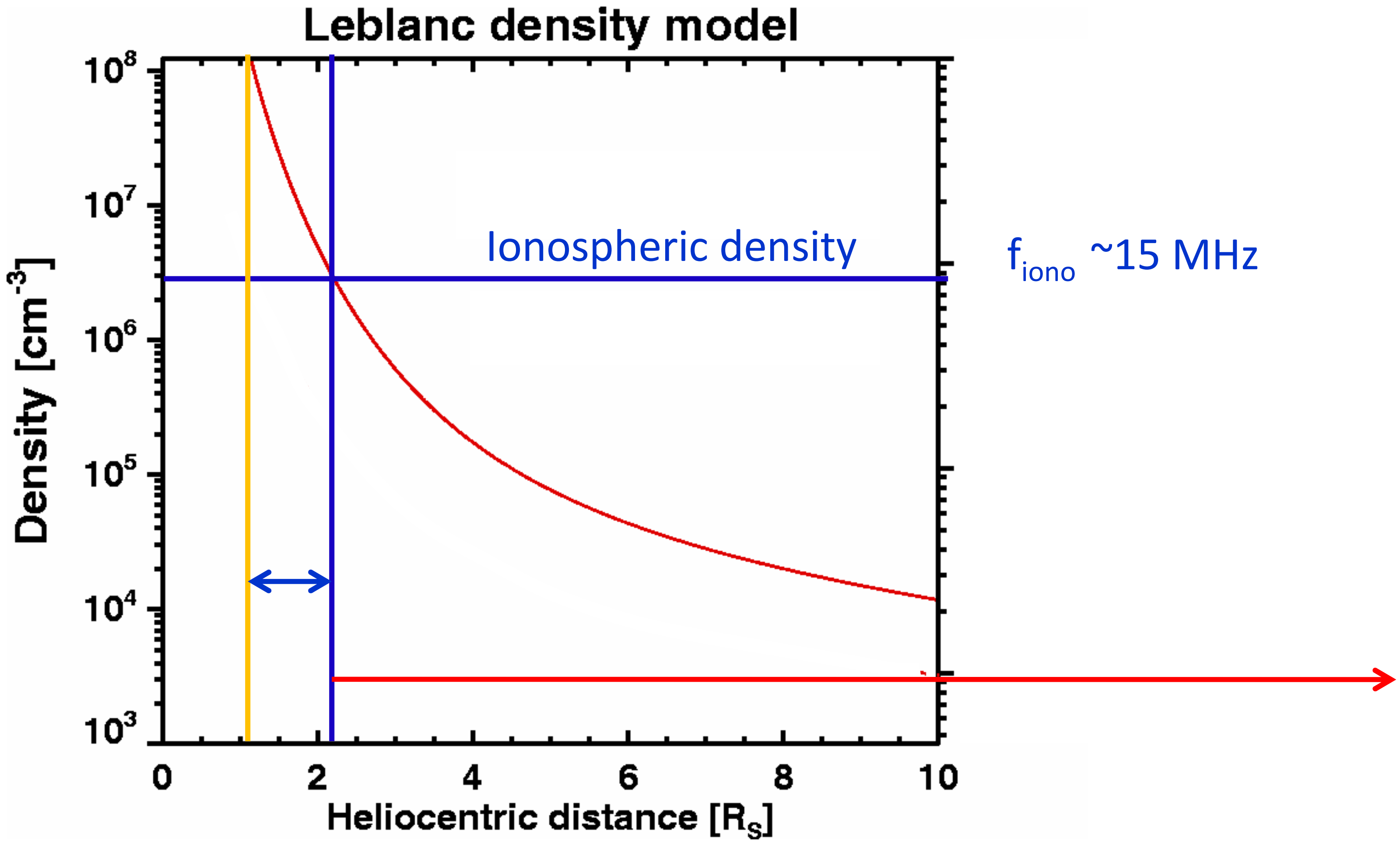
32 Type II bursts
STEREO CMEs

Type II heights indicate overall density decline with height



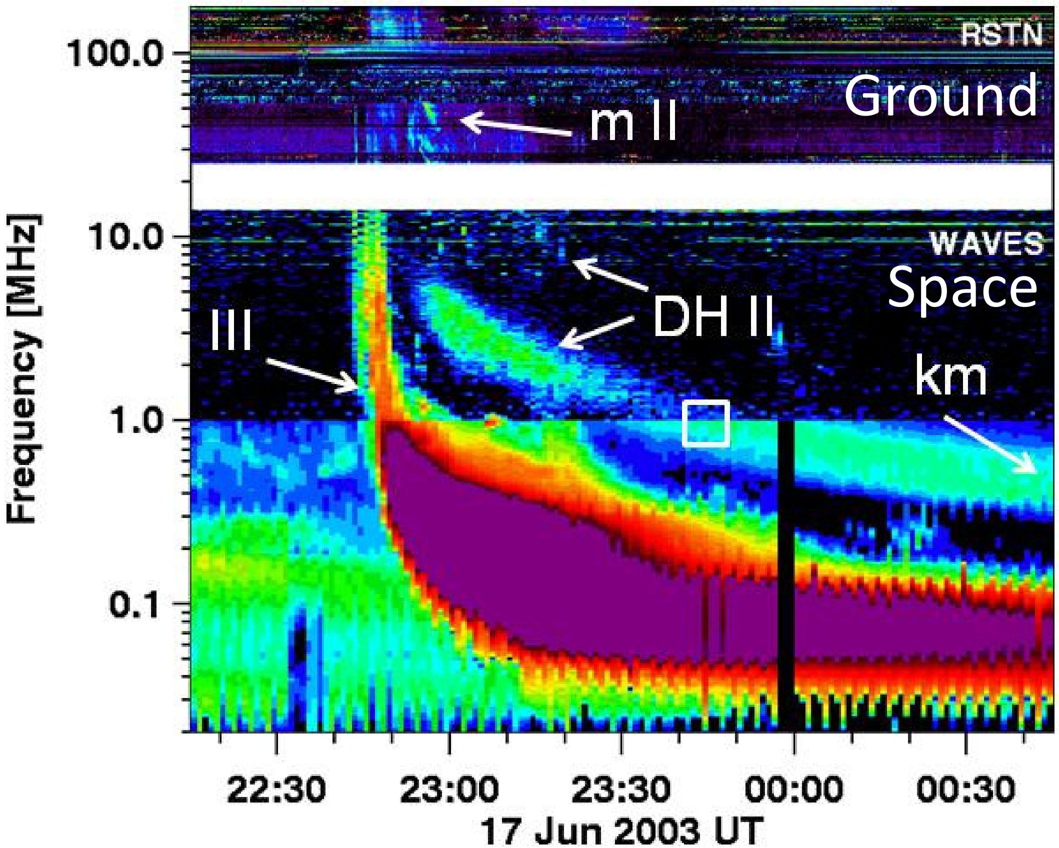
$n = 1.2\times10^{8}$ cm^{-3}

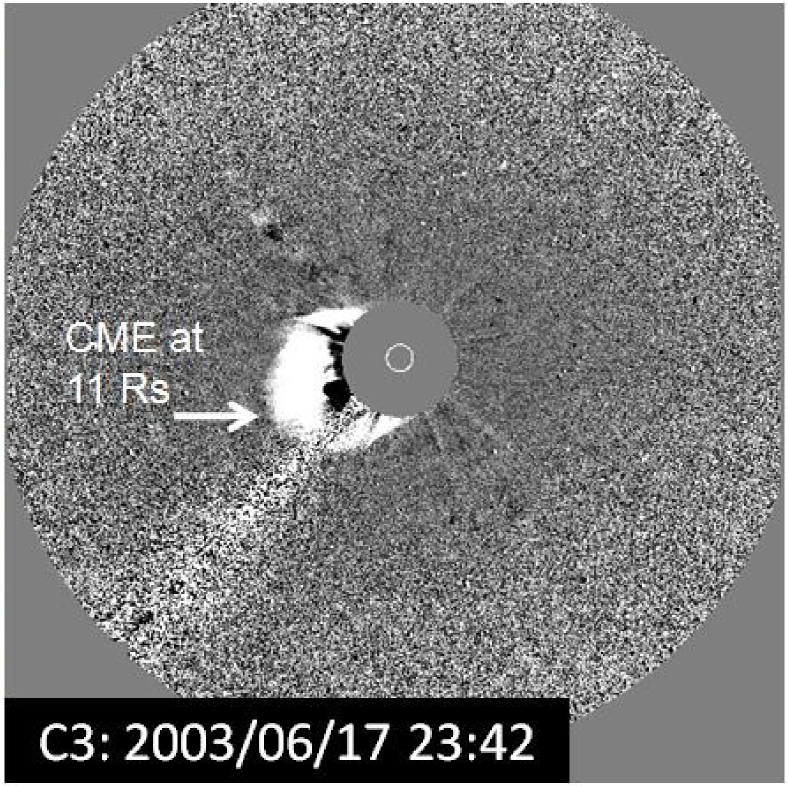
Coronal density = Ionospheric density at 2 Rs



f < f_{iono} cannot reach Earth

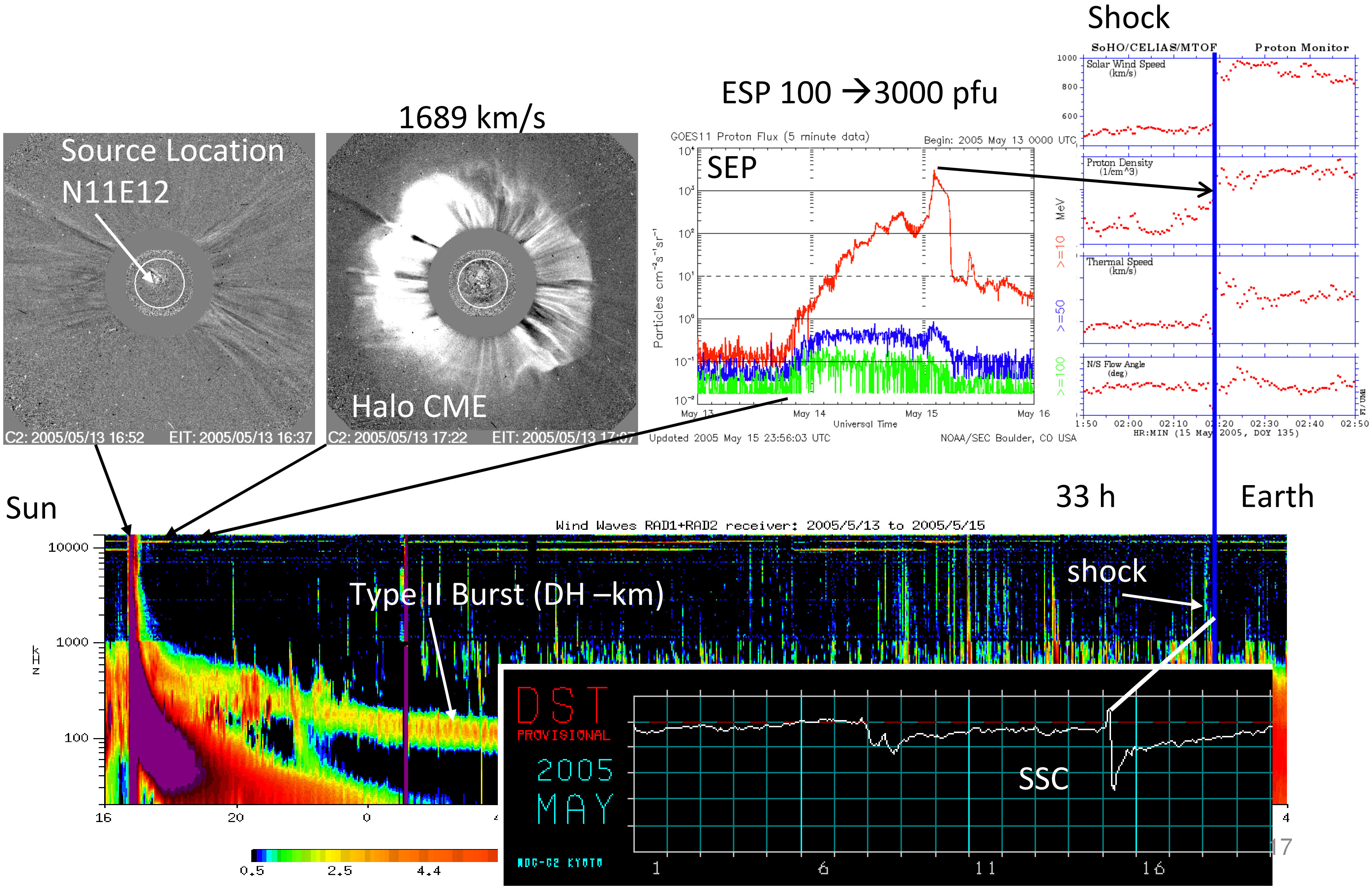
Ground + Space Data: Cover the Sun-Earth Space



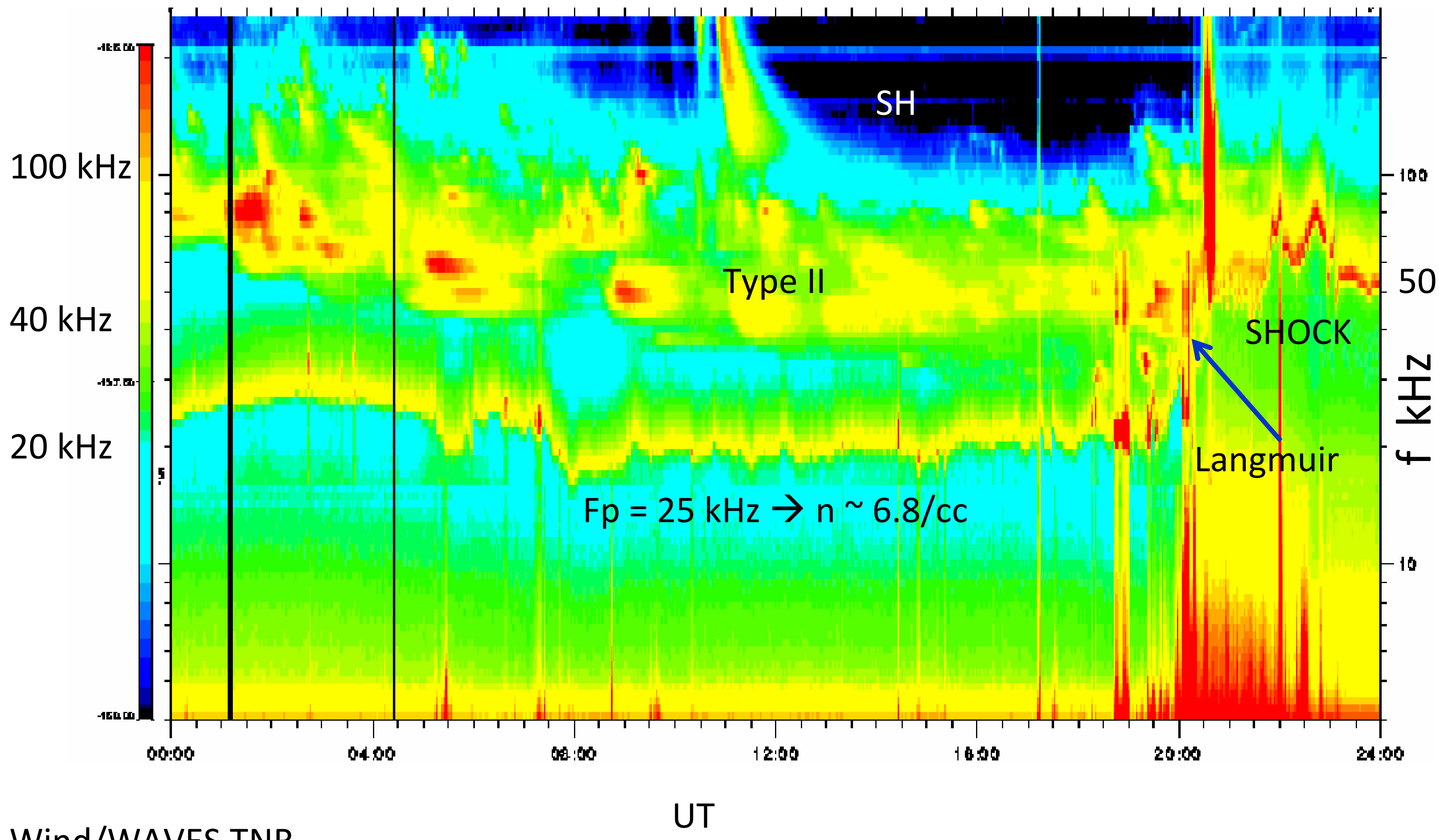


http://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html

A CME with Type II, SEP event. & Shock at 1-AU:

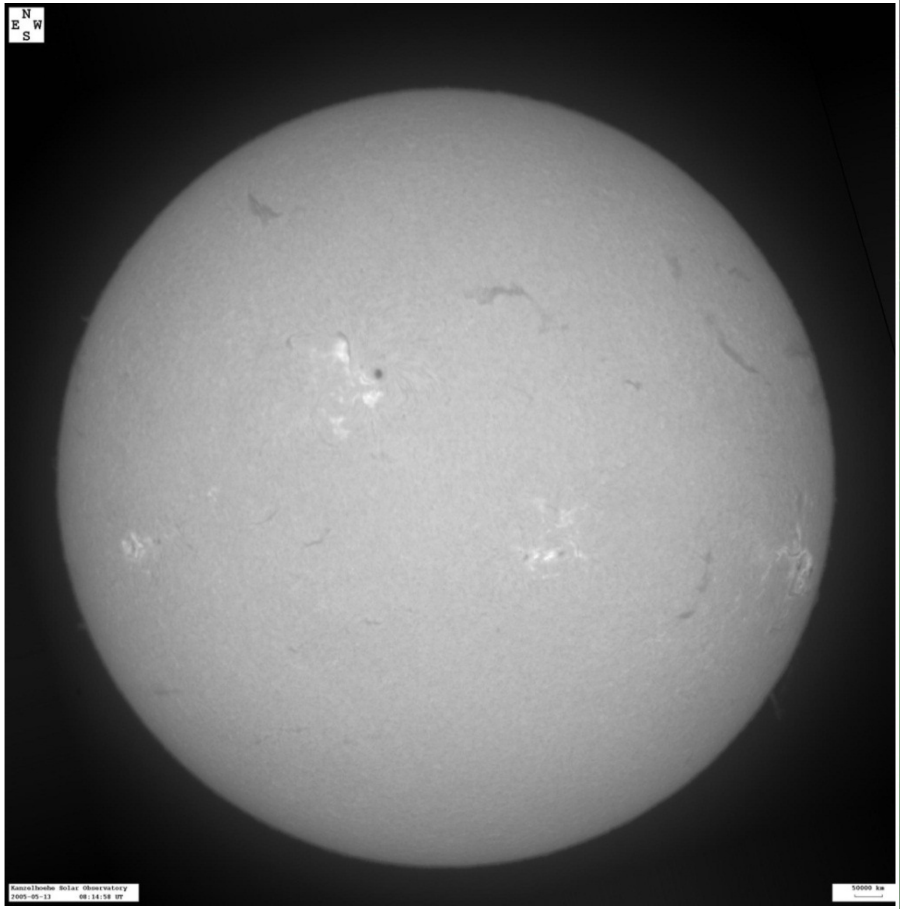


Shock, Type II, & Langmuir Wave at Wind S/C

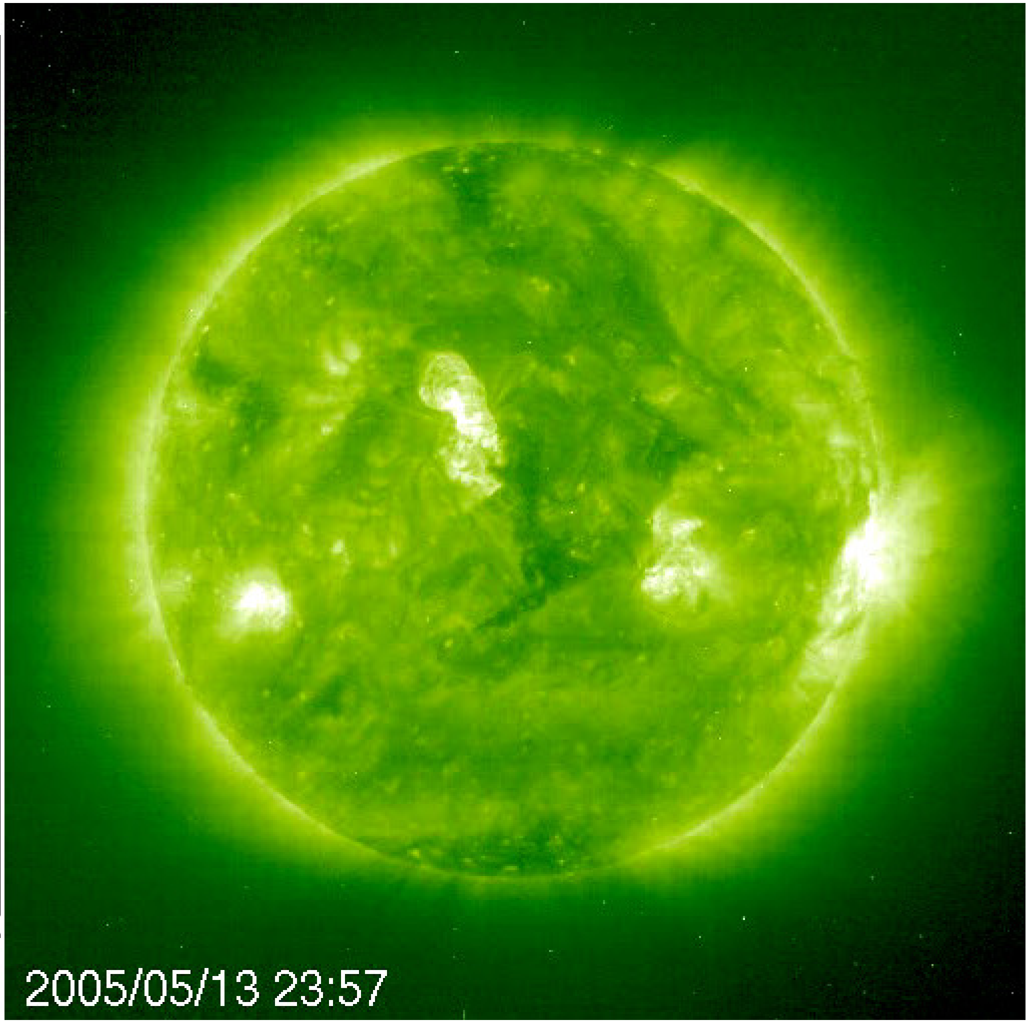


Wind/WAVES TNR

Sun & Corona



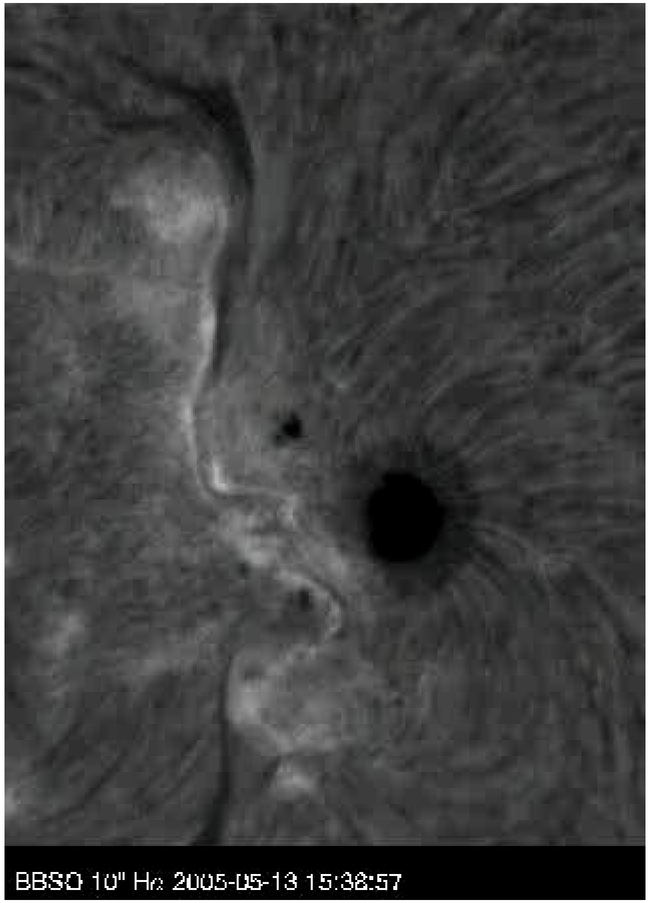
H-alpha

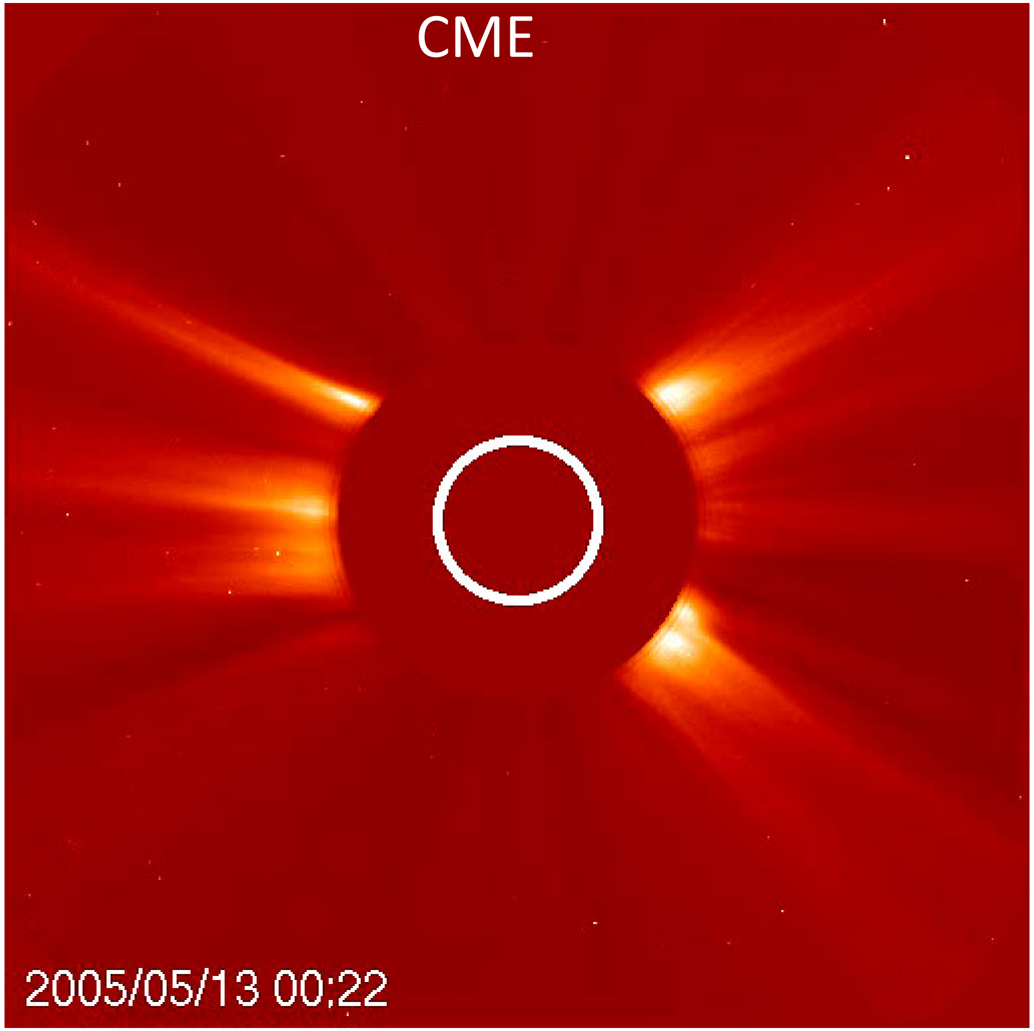


EUV

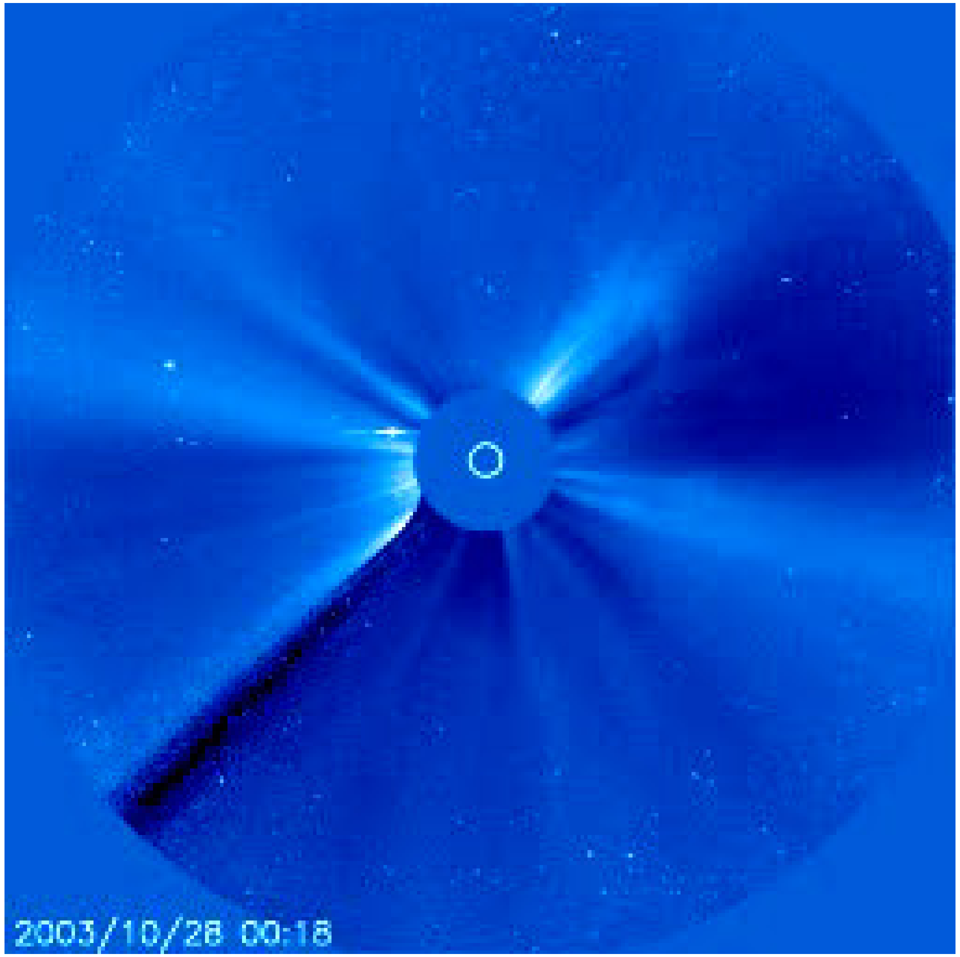
Two elements of eruption

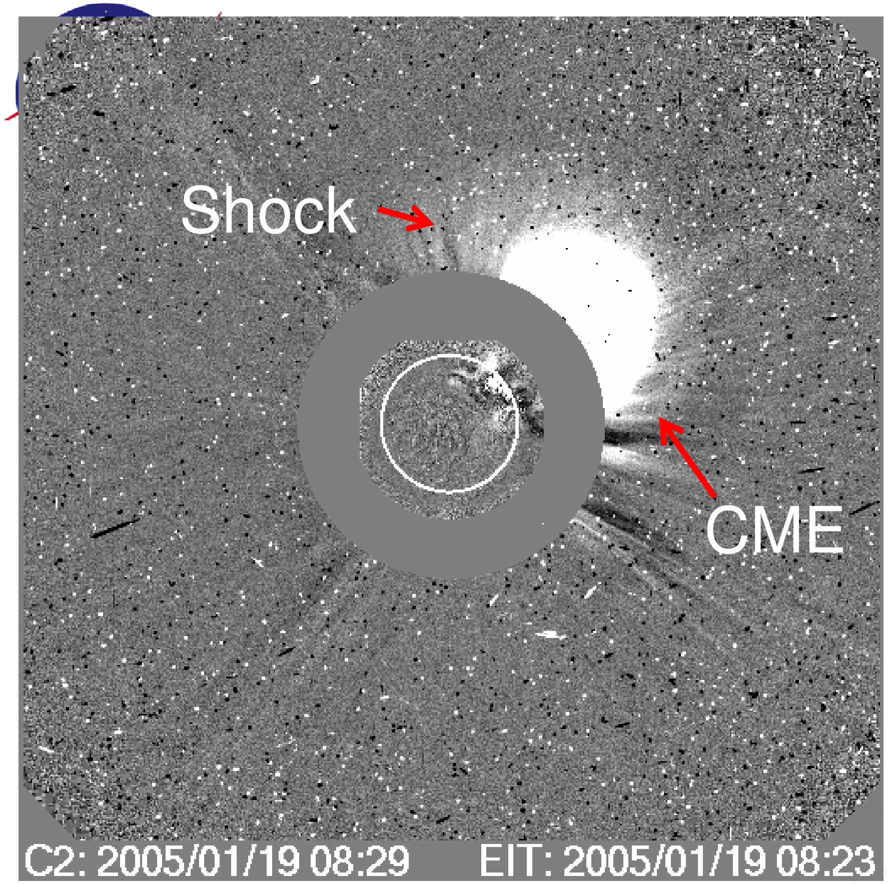
Flare

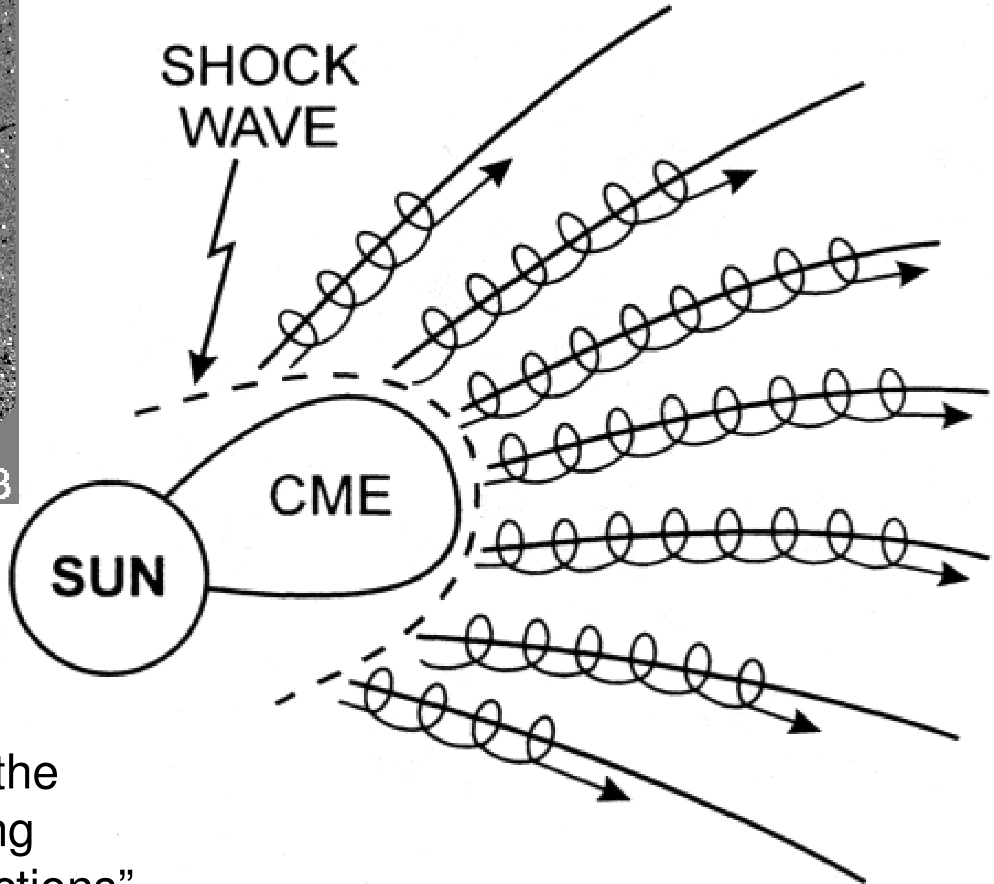




A CME heading toward Earth



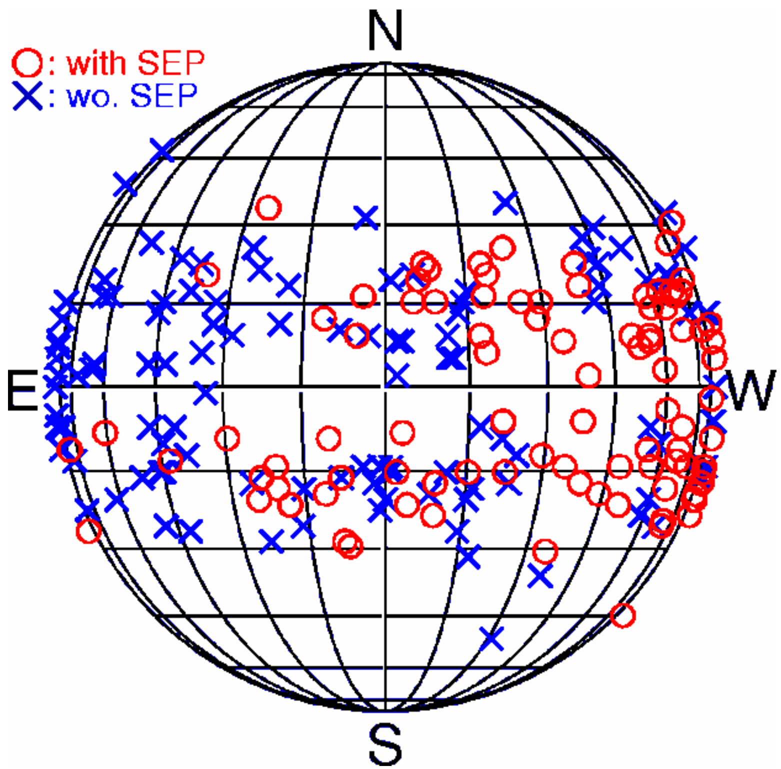




"energetic protons are accelerated in the shock front just ahead of the expanding loop structures observed as mass ejections"
Kahler, Hildner, & Van Hollebeke (1978)

Type II Radio bursts and SEPs

Sources of CMEs associated with type II bursts



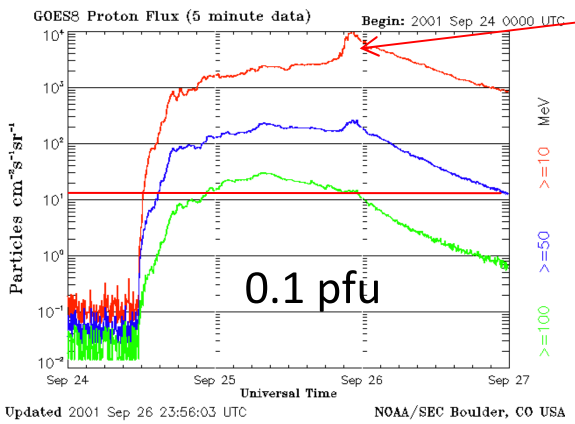
Answer: About 50%

Interplanetary shocks

- Accelerate electrons and ions (solar energetic particle events)
- Are responsible for energetic storm particle (ESP) events
- Mark the start of geomagnetic storms (storm sudden commencement)
- Are indicative of the arrival of ICMEs, which cause Forbush decrease
- Type II bursts help remote-sense shocks when they are near the Sun

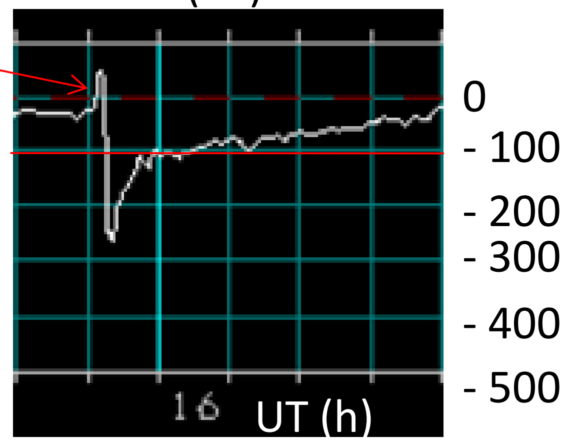
Type II Bursts & Space Weather

10,000 pfu



shock

Dst (nT)



CMEs

On the way and upon arrival

SEPs

Magnetic storms

Upon arrival at Earth

Shock-driving Capability is Crucial
$V_{CME} - V_{SW} > V_{MS}$

Space systems
Airplanes
atmosphere

Space systems
Magnetosphere
Ionosphere
Atmosphere
Ground

CME's Magnetic Structure Is Crucial (Bz <0)

Radio Bursts

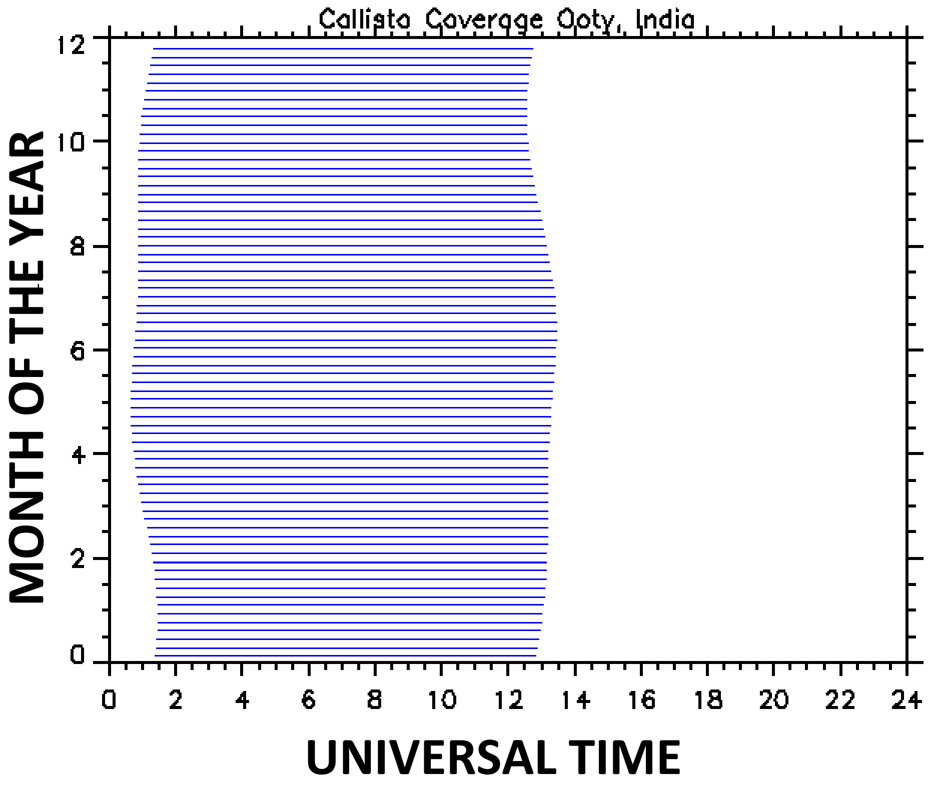
- Type I bursts are due to evolution of active regions
- Type II radio bursts due to shocks
- Type III radio bursts due to electron beams
- Type IV bursts are due to electrons trapped in moving or stationary magnetic structures during an eruption
- Type V bursts are variants of type III bursts
- To study solar eruptions, one uses type II, Type III & Type IV
- Note that radio bursts are produced by energetic electrons, that need to be accelerated to keV energies
- Connection to particle acceleration → Space weather

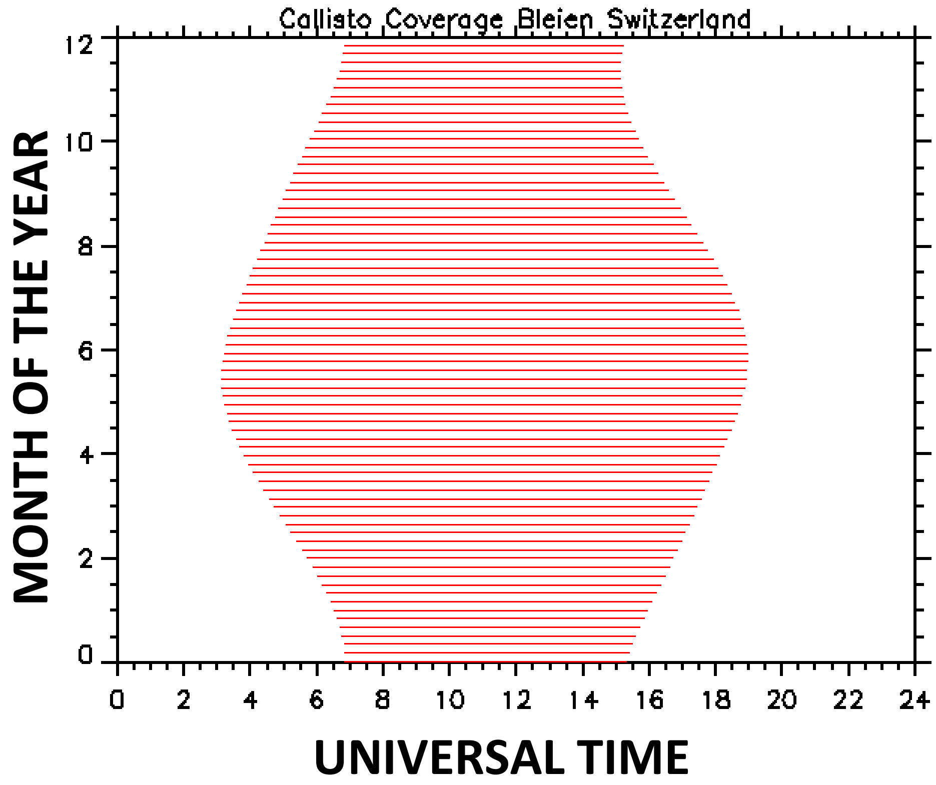
ISWI/CALLISTO

- Spectrometer Ooty/India operational
- Spectrometer Gauribidanur/India operational
- Spectrometer Badary/Irkustk/Russian Federation operational
- Spectrometer CINESPA/Costa Rica operational
- Spectrometer Unam, Mexico operational
- Spectrometer Switzerland 3 spectrometers (Bleien, Zurich and Freienbach) operational
- Spectrometer KASI Daejeon South Korea 2 spectrometers operational
- Spectrometer ROB/Humain operational
- … … … Austria, Germany
- In total, 36 spectrometers worldwide most of them operational
- More on the way: Ethiopia, Spain

CALLISTO Coverage of the Sun

courtesy: Monstein

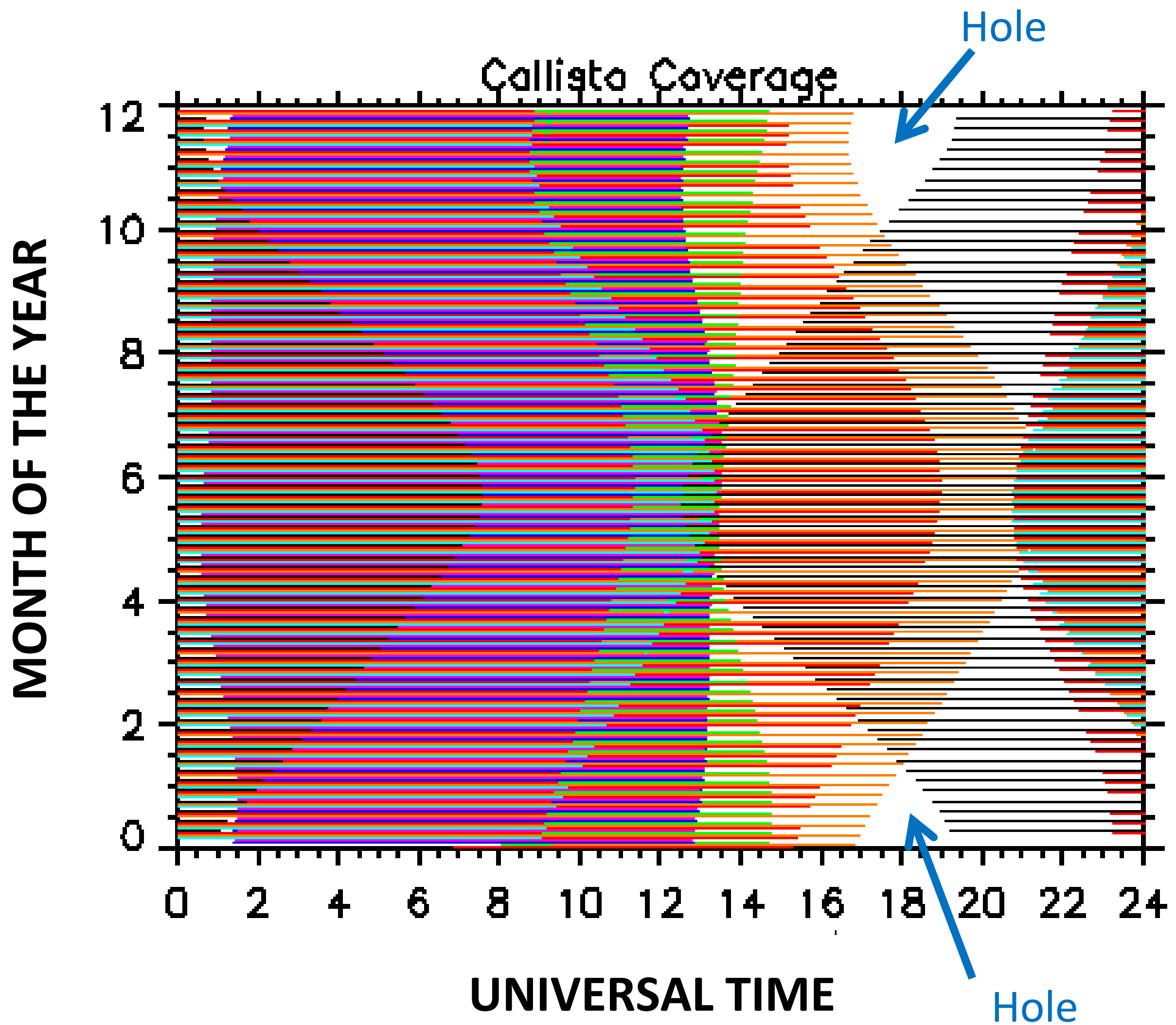




Low-latitude Station: Ooty, India
Uniform coverage throughout the year

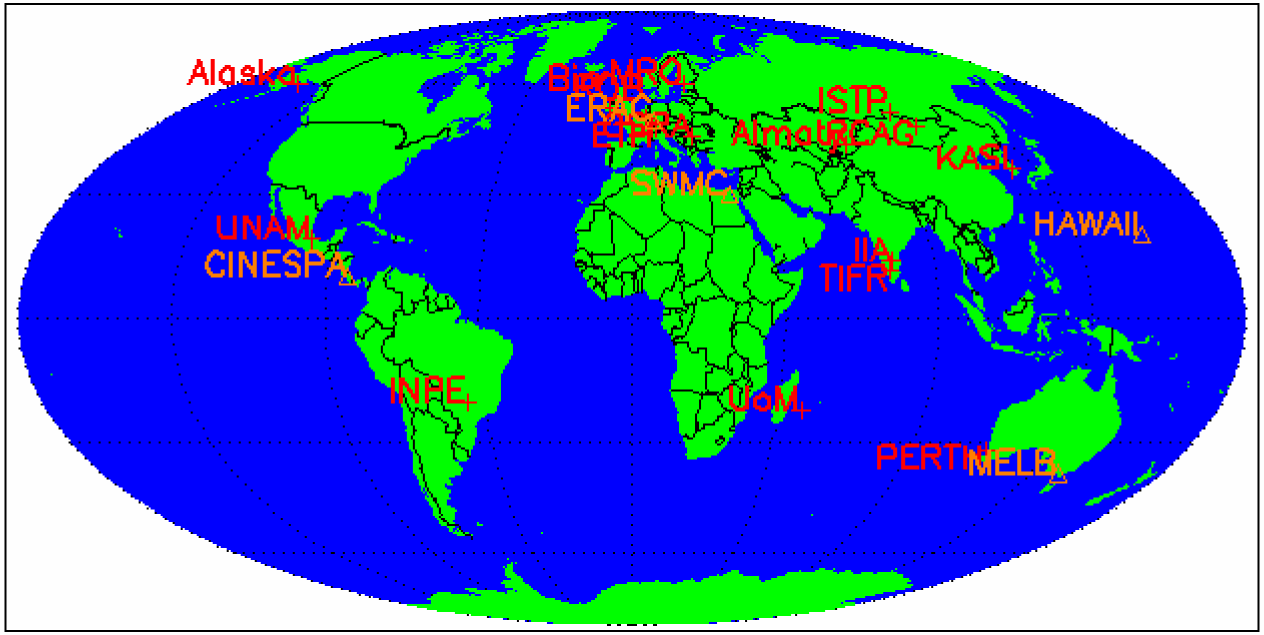
Mid-latitude Station: Bleien, Switzerland
More coverage during Summer months
Less coverage during Winter months

Current CALLISTO Coverage of the Sun



Data Access

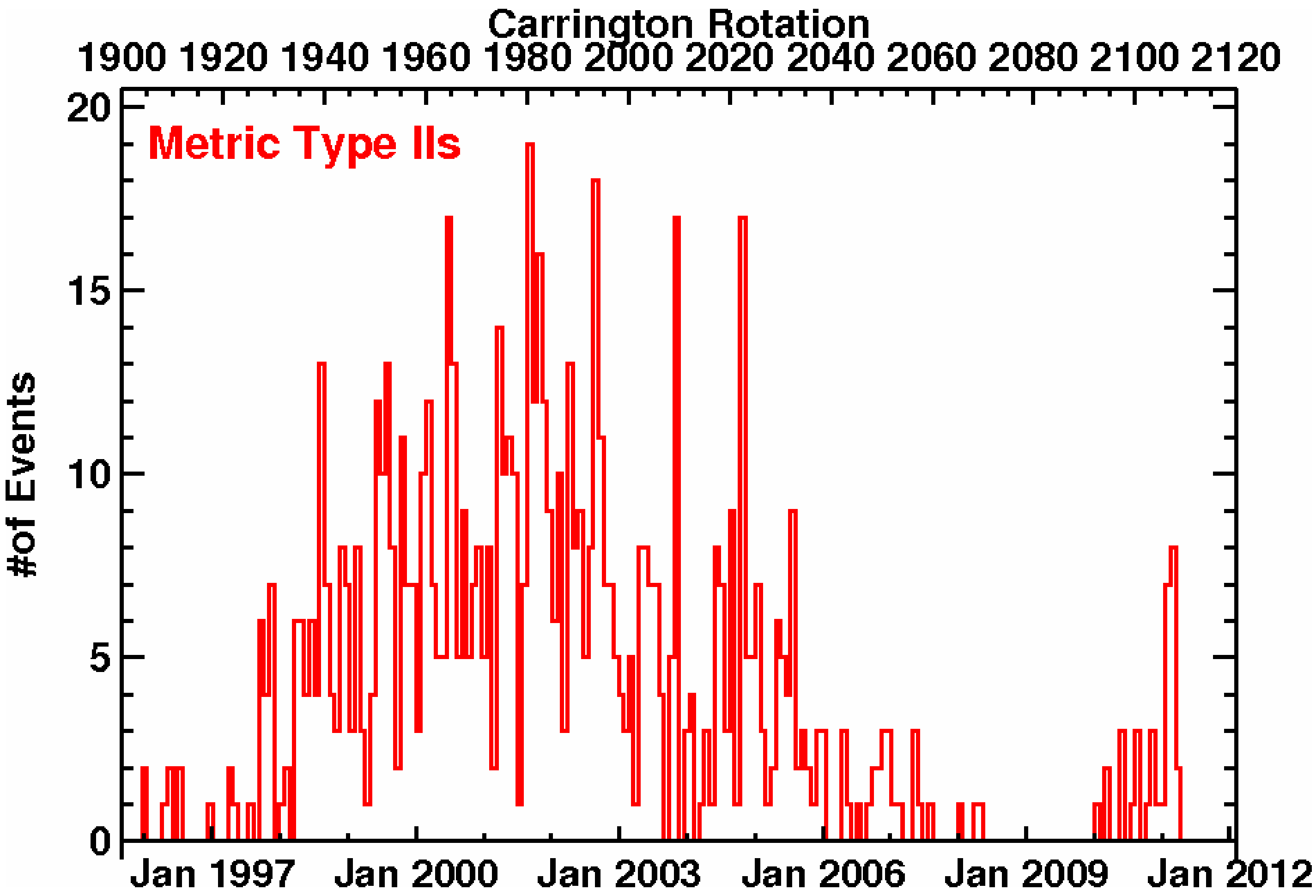
- Relevant links can be found here:
- http://e-callisto.org/
- All Data can be found here:
- http://soleil.i4ds.ch/solarradio/callistoQuicklooks/



Use CALLISTO Data!

- CALLISTO produces science quality data
- Detects tiny eruptions from the Sun
- CALLISTO data being utilized for a Indo-US project on solar eruptive events
- Need to identify a set of good instruments for continuous coverage over the whole frequency range
- CALLISTO is one of the success stories of ISWI instruments

Metric type II bursts follow the solar cycle: Energetic eruptions



Cycle 23 Cycle 24

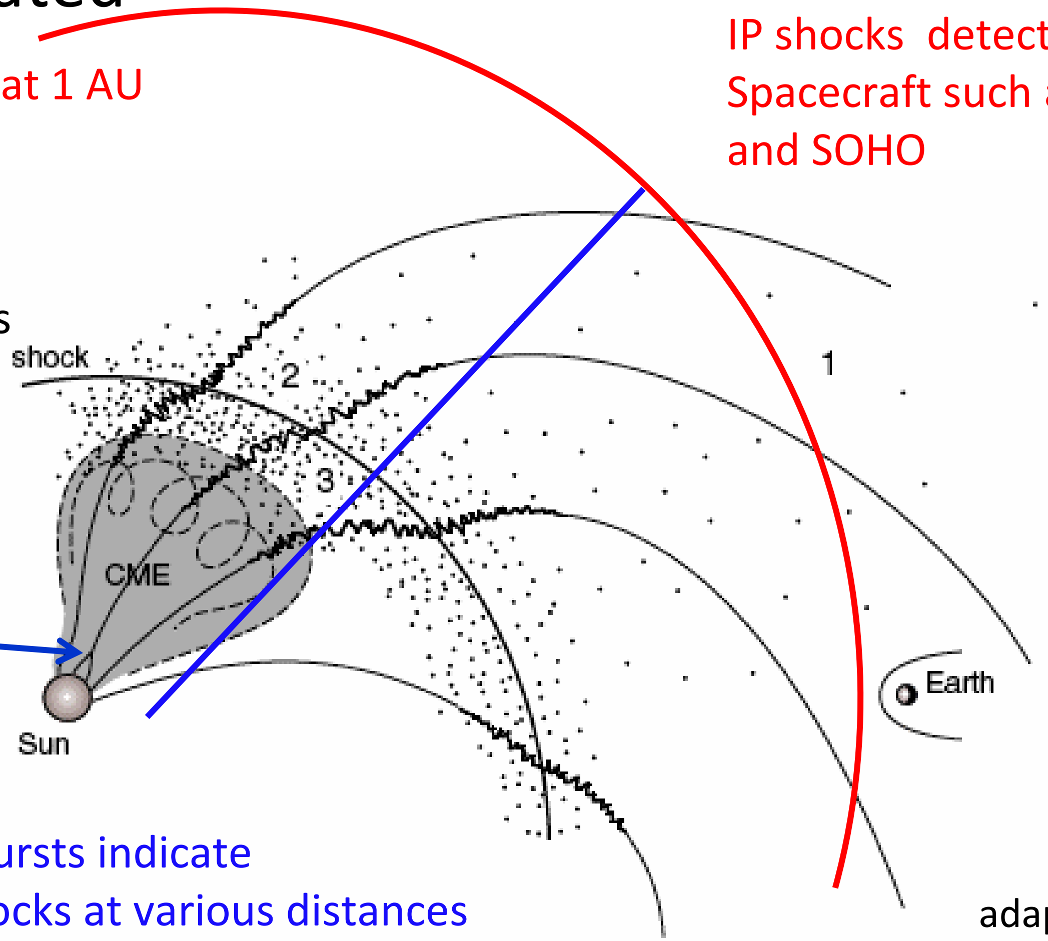
CME, Flare, Shock, Type II, SEP – All Closely Related

shock at 1 AU

IP shocks detected in situ by Spacecraft such as Wind, ACE and SOHO

Shocks accelerate electrons and ions

Type III bursts are due to electrons from flares



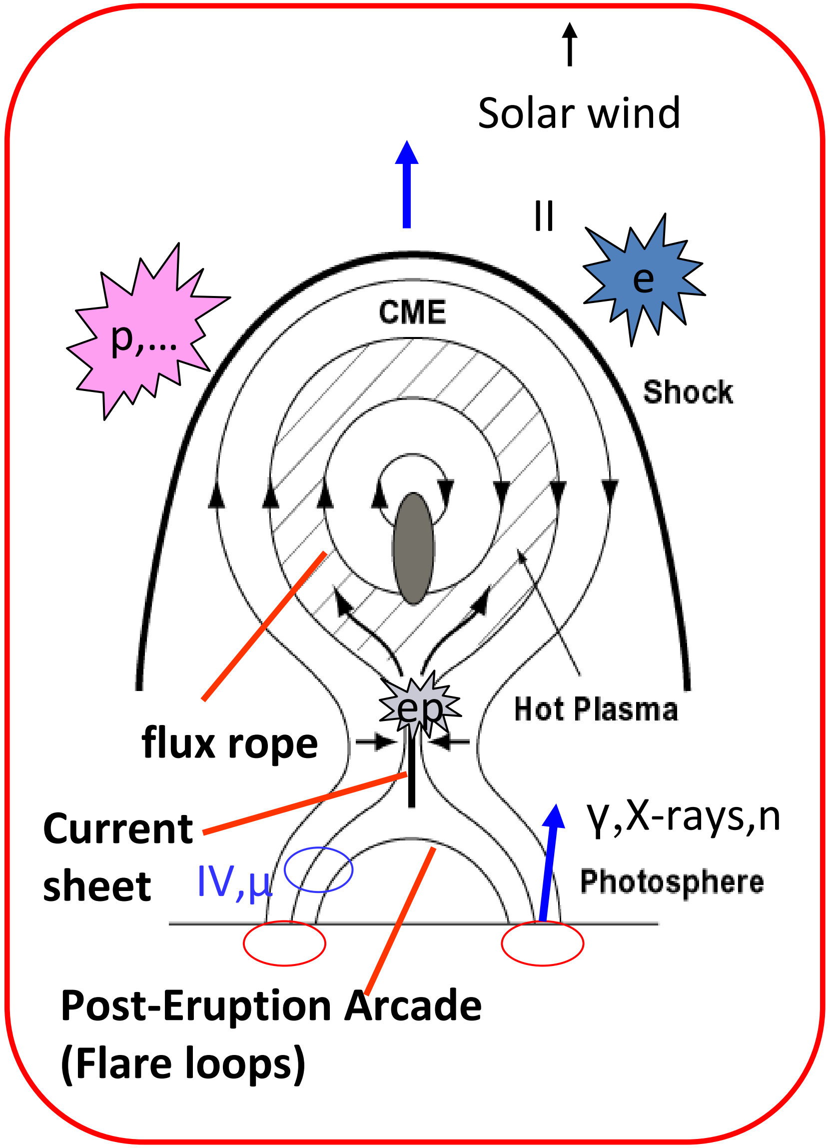
Type II Radio Bursts indicate
CME-driven shocks at various distances
from the Sun (emitted by accelerated electrons)

adapted from Lee 1997

Shocks studied using type II bursts, CMEs, and in-situ plasmag observations

Particle Acceleration & Radio Emission

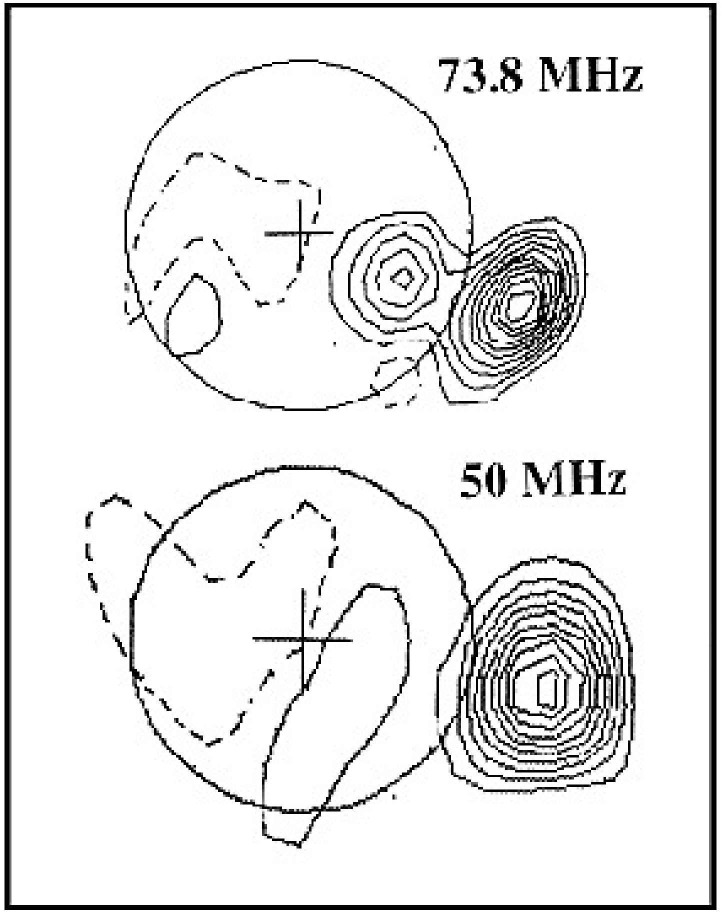
- Type III and Type II bursts are due to <10 keV electrons
- Type III bursts → particle acceleration by flares
- Type II bursts → Shock acceleration
- Implication to solar energetic particles (SEPs) produced by both flare and shock processes
- The CMEs following the shock produces intense geomagnetic storms



Two places where electrons (e) and protons (p) are accelerated

Type II observations

Type II burst from Clark Lake



Gopalswamy, 2000

- Mainly spectra:

- RSTN, CALLISTO, HiRAS, Potsdam, IZMIRAN, Nancay, … (ground based)

- Wind/WAVES, STEREO/WAVES (space)

- Imaging: only from ground:

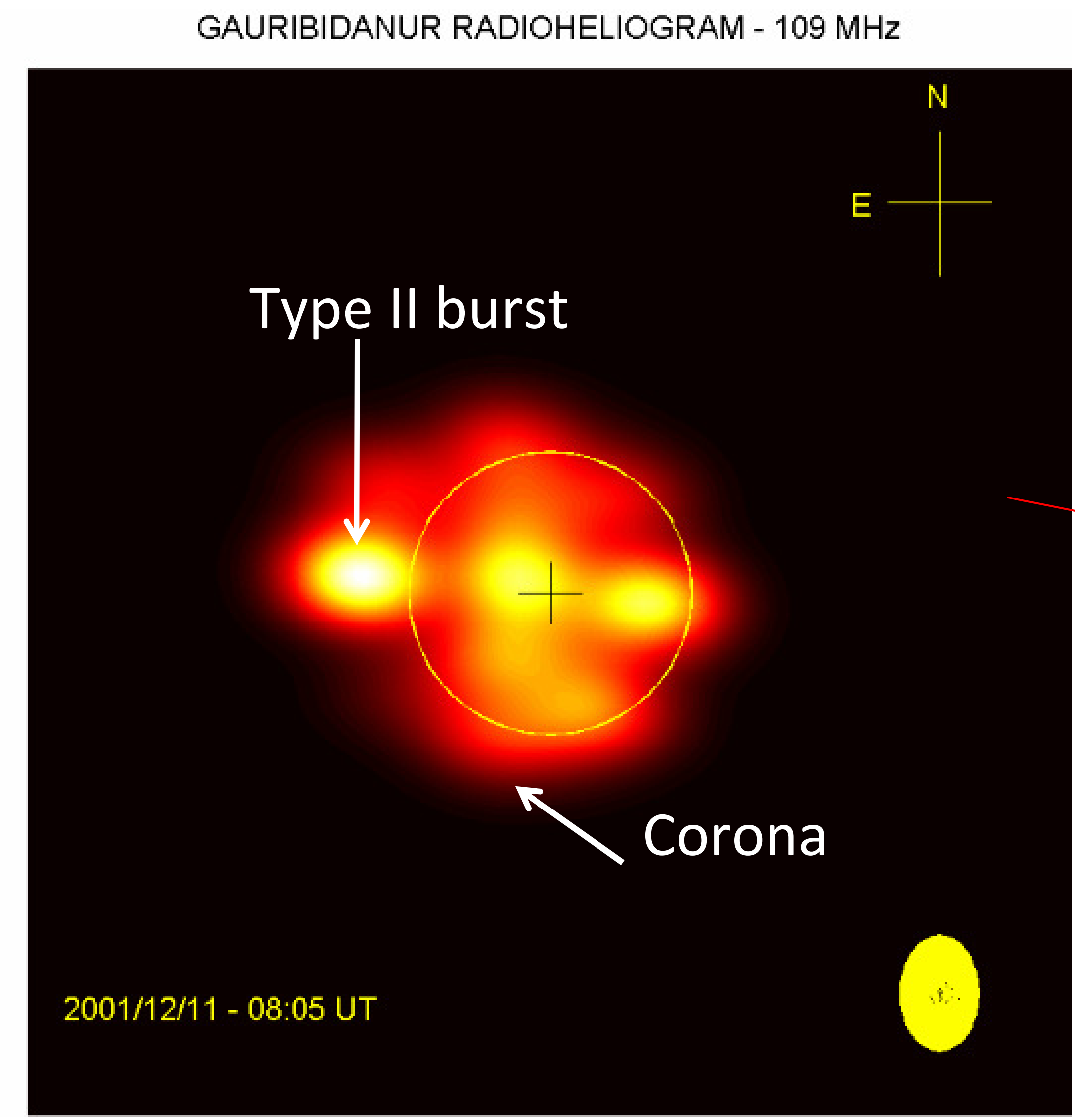
- Gauribidanur Radioheliograph (India)

-Nancay Radioheliograph (France)

-Murchison Widefield Array (Australia), LOFAR (Netherlands)

RSTN, CALLISTO have 24 – hour coverage

Type II Location relative to the CME



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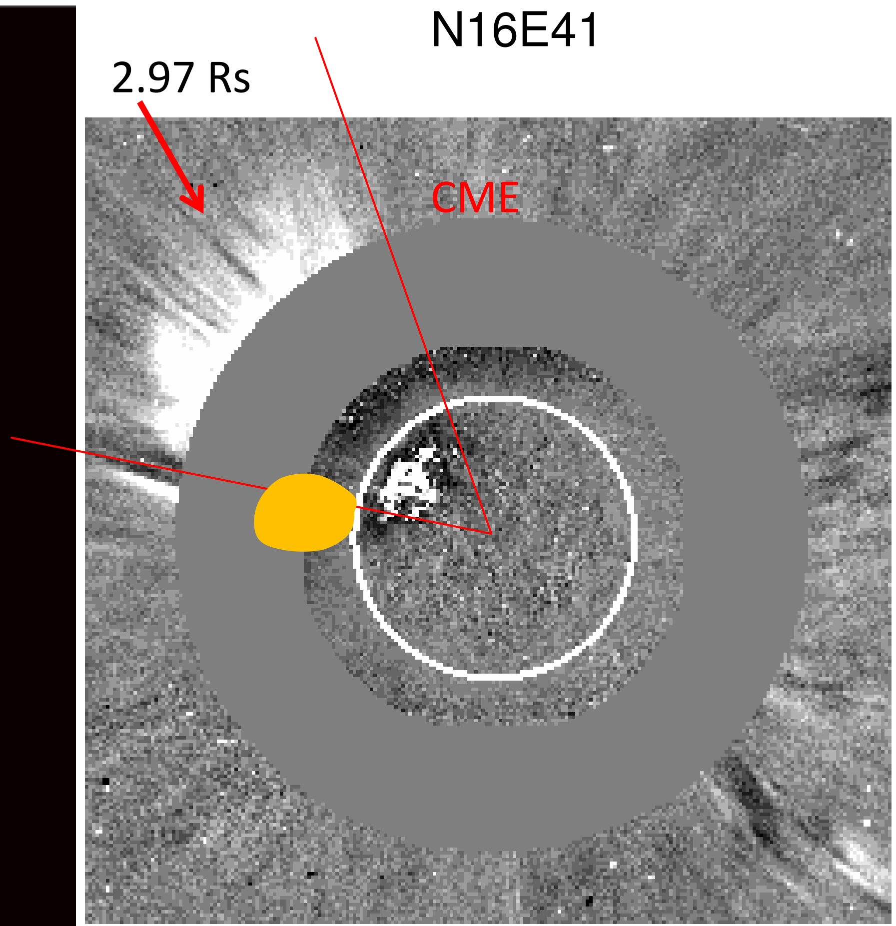

CME onset 08:02 UT
CME speed 804 km/s