# COSPAR Capacity Building Workshop 2020: Overview

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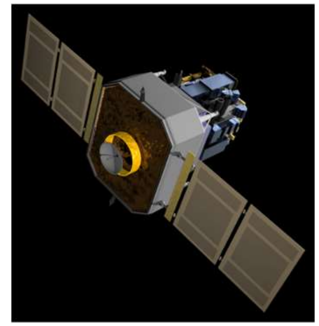
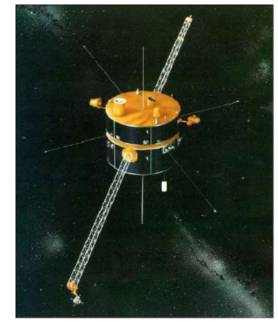
NASA/GSFC

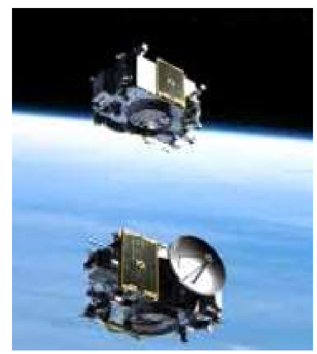
Kodaikanal January 6, 2020

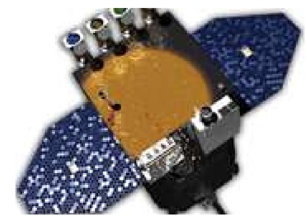
# COSPAR Capacity-Building Workshops: Objectives

- Encourage the scientific use of space data by scientists in developing countries
- Provide a highly practical training in the use of space data from current missions
- Space-based coronagraph observations (SOHO, STEREO, SDO, Wind) and radio spectral observations from space (Wind/WAVES, STEREO/WAVES) and ground (RSTN, CALLISTO, Gauribidanur) to study shocks driven by coronal mass ejections.
- Workshop: First week – lectures; second week – data analysis
- Lectures include software tools and hands on activities
- Participants form groups; each group to analyse one or two events in detail and test the concepts learned



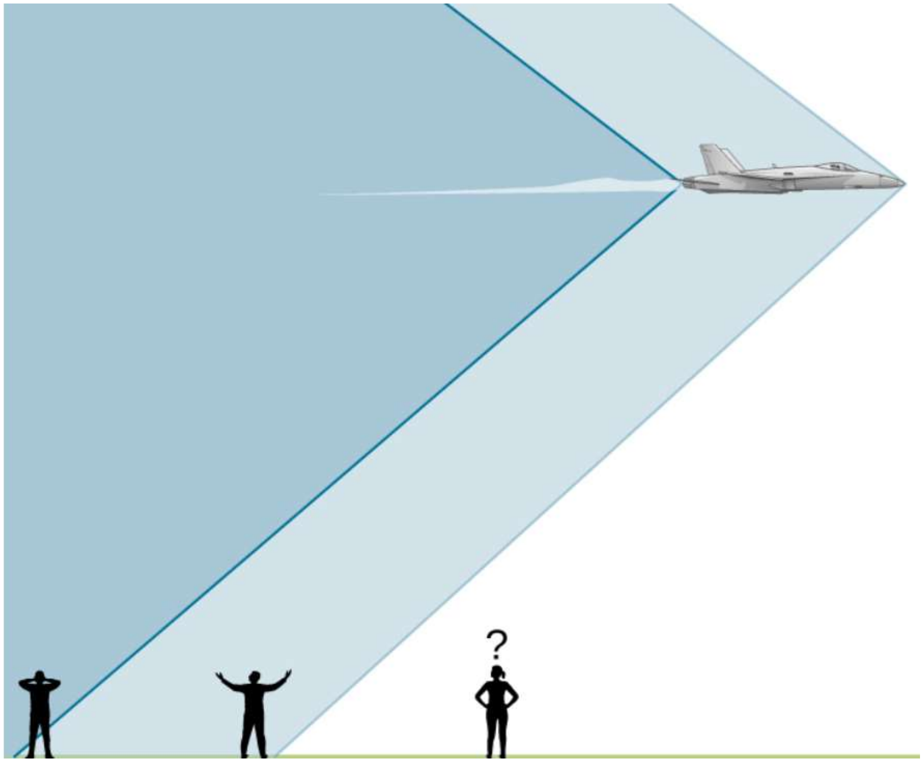




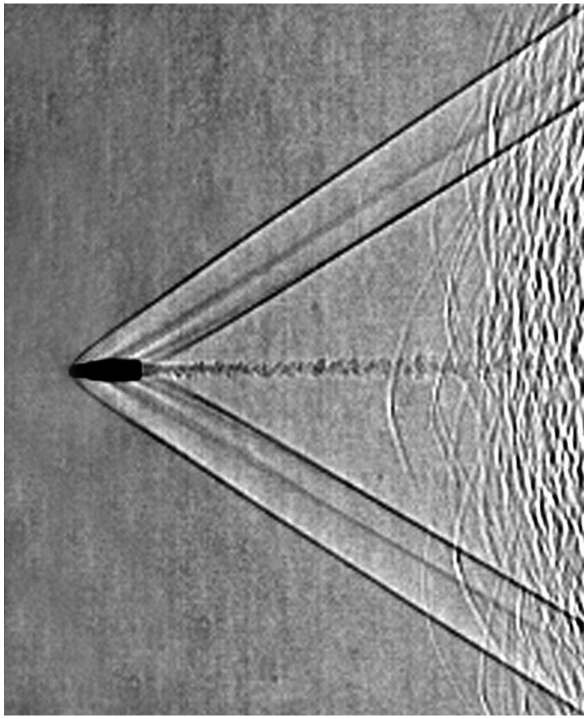


# Sonic Boom: supersonic motion

Medium (up & downstream)
Moving object
Shock
Characteristic speed




Lumen



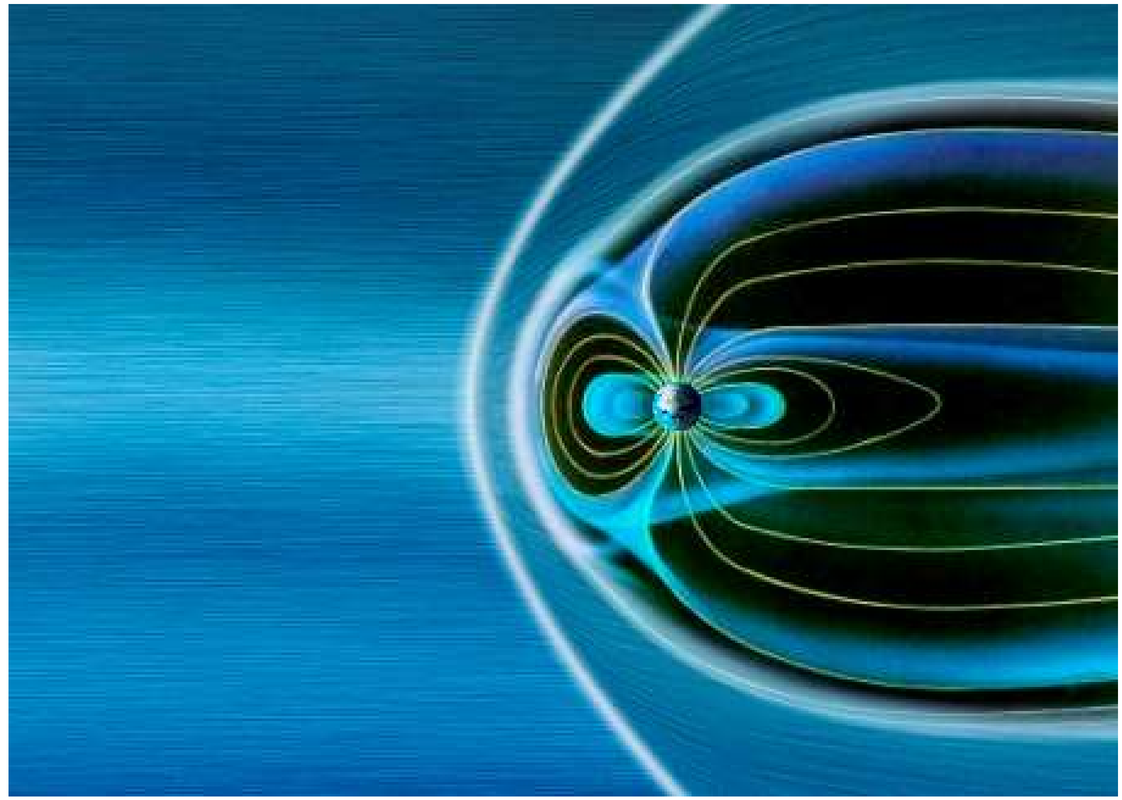
Settles

# Astrosphere and bow shock

**Bow shock around the very young star LL Ori**

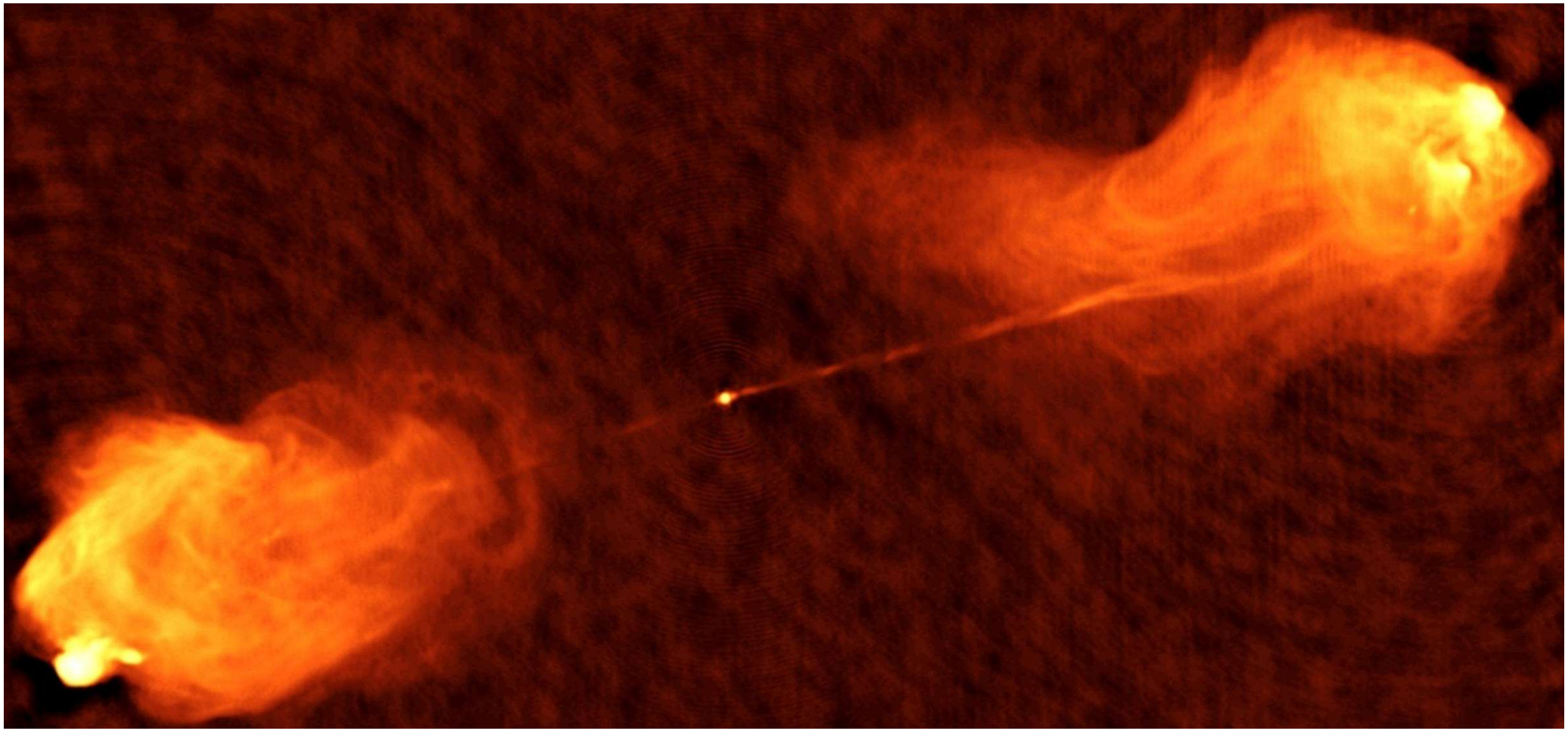
NASA and The Hubble Heritage Team (STScI/AURA)

# Earth's bow shock



•ESA/AOES Medialab

# Shocks form when galactic jets interact with the surrounding medium

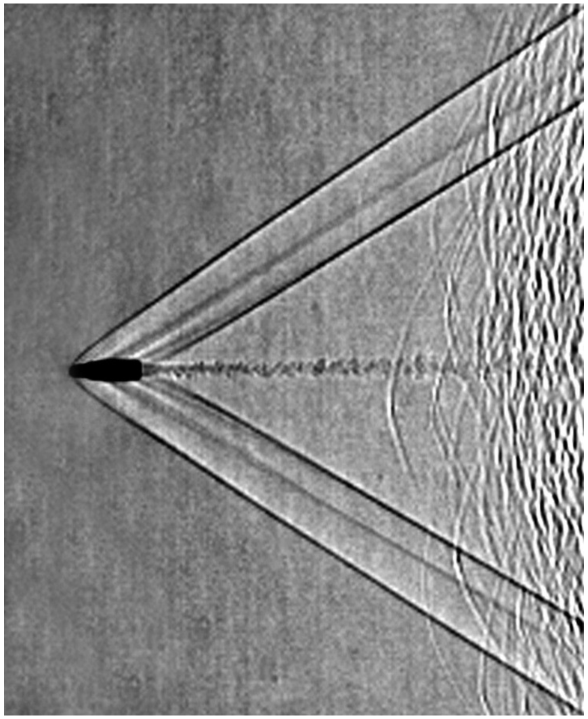


Cygnus A NRAO/AU

Medium (up & downstream)
Moving object
Shock
Characteristic speed

# Coronal/interplanetary shocks

Medium: Corona/interplanetary medium
Moving object: CME flux rope
Shock: Fast-mode MHD shock
Characteristic speed: Magnetosonic speed

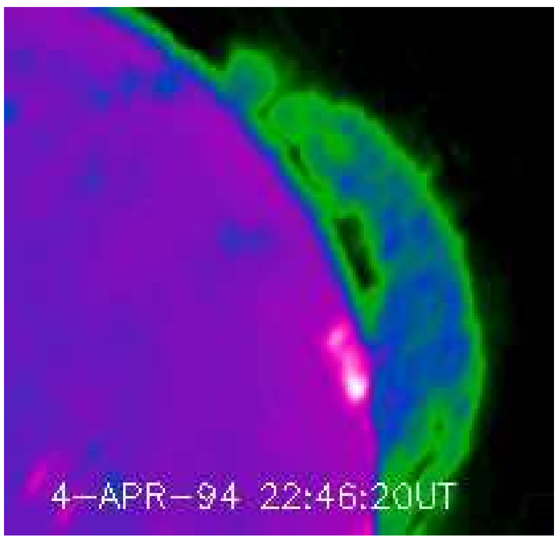


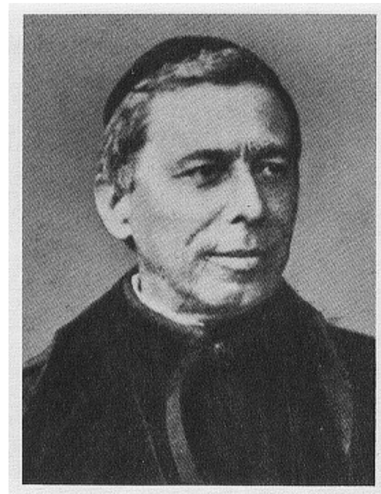
Settles

# Prominence Eruptions Known by the End of 19th Century

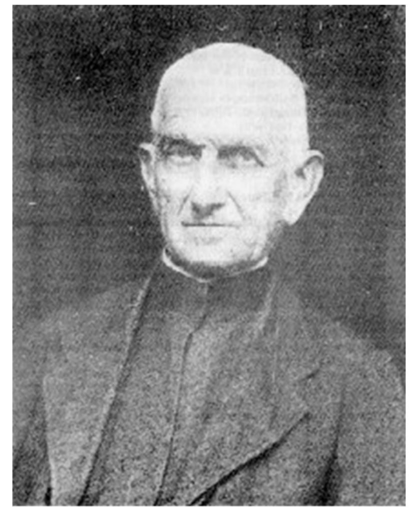
Prominences form the core of CMEs

Nobeyama Radioheliograph



Angelo Secchi



Gyula Fenyi

1868: Janssen & Lockyer demonstrated that prominences could be viewed outside of eclipses using spectroscope

1871: Secchi classified active and quiescent prominences
1892: Fenyi: Prominence eruptions have speeds exceeding 100s of km/s

Ruby Payne-Scott
1912 – 1981

# Radio Bursts Reveal Matter Leaving the Sun

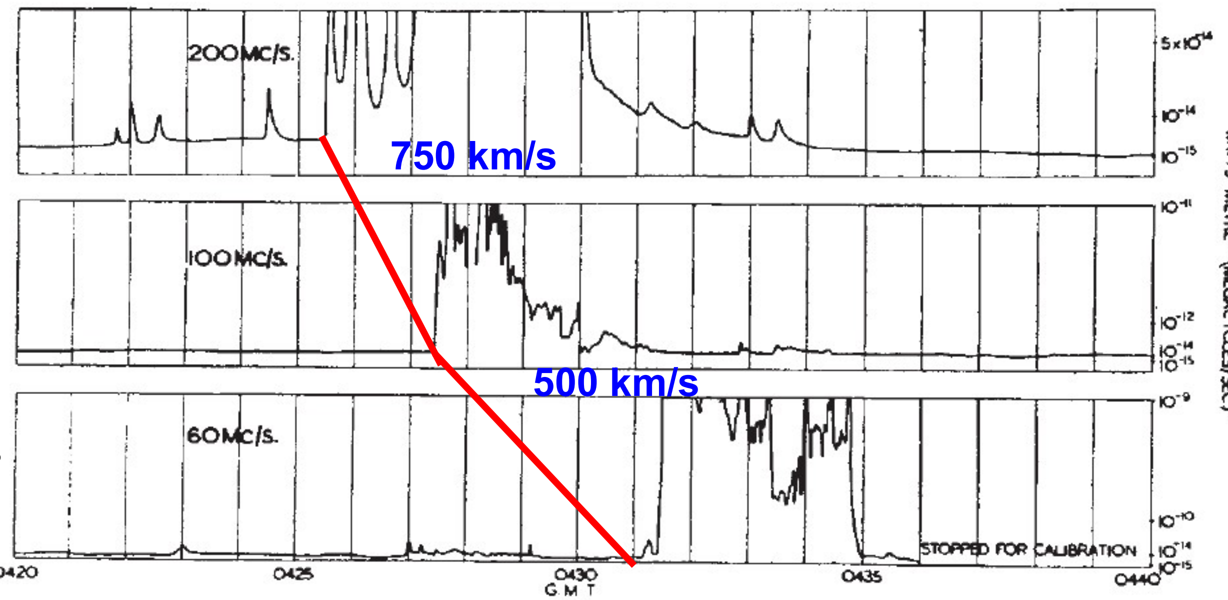
The whole pattern drifts; 140 MHz in 6 min → df/dt = 0.4 MHz/s
"…the derived velocities are of the same order as that of prominence material…"

Payne-Scott et al. 1947, Nature 260, 256

Plasma density
5.0 x10$^8$ cm$^{-3}$

1.2 x10$^8$ cm$^{-3}$

0.4 x10$^8$ cm$^{-3}$



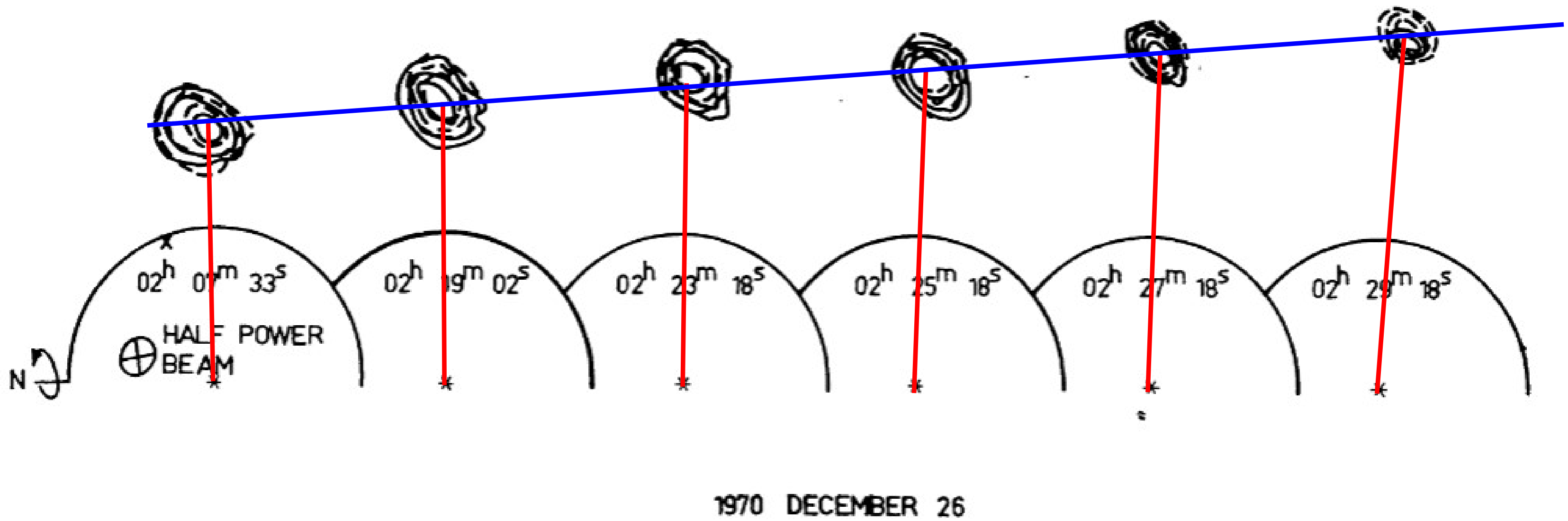

LARGE OUTBURST OF MARCH 8, 1947

- classified as type II radio bursts caused by ~10 keV electrons accelerated in MHD shocks (Uchida 1960)

# A moving type IV burst observed by the Culgoora Radioheliograph in Australia

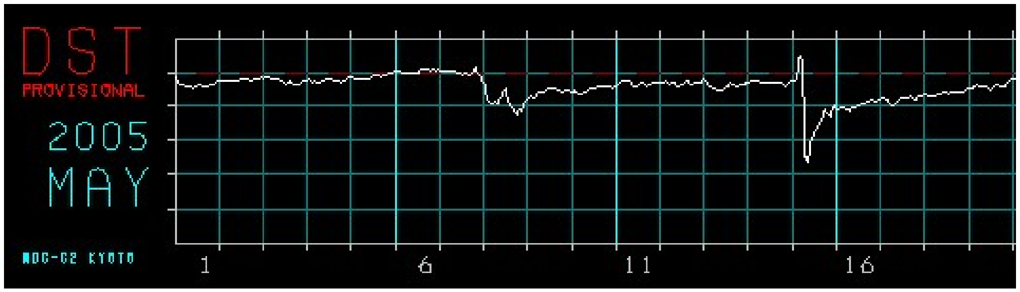
~MeV electrons trapped in magnetic structures emitting at 80 MHz
Originally discovered by A. Boischot in 1957

350 km/s

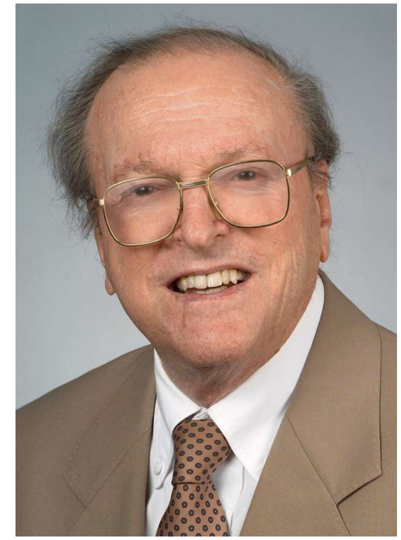



Schmahl 1972

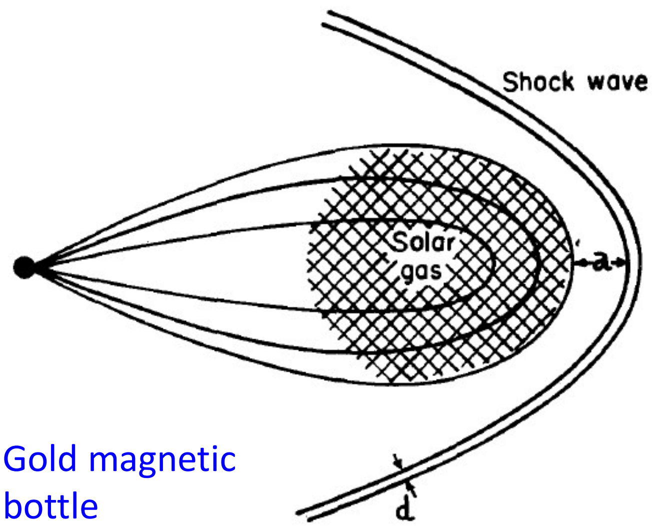
# Shocks in the IP medium




1953: Gold proposed Interplanetary shock to explain the Sudden Commencement



T. Gold (1920 – 2004)




Gold magnetic bottle

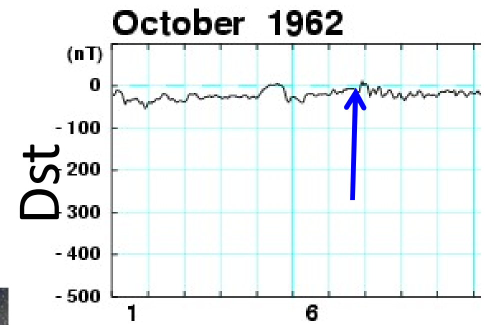
1962: “Idealized configuration in space, showing solar plasma cloud, the drawn-out field and the shock wave ahead”

MHD shock theory: de Hoffmann & Teller 1950
Parker applied it to interplanetary shocks in 1963

# Mariner 2 Detects IP Shock

C P Sonett (1924 -2011)

Mariner II




1962/10/07 15:46 UT

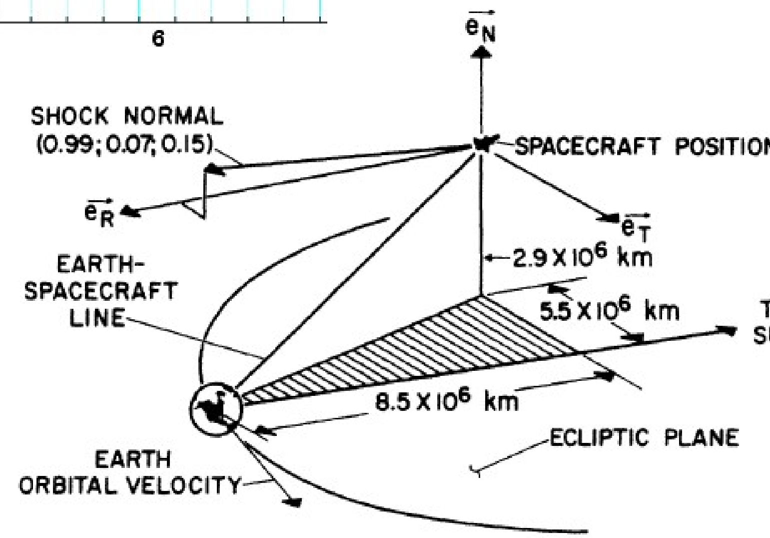
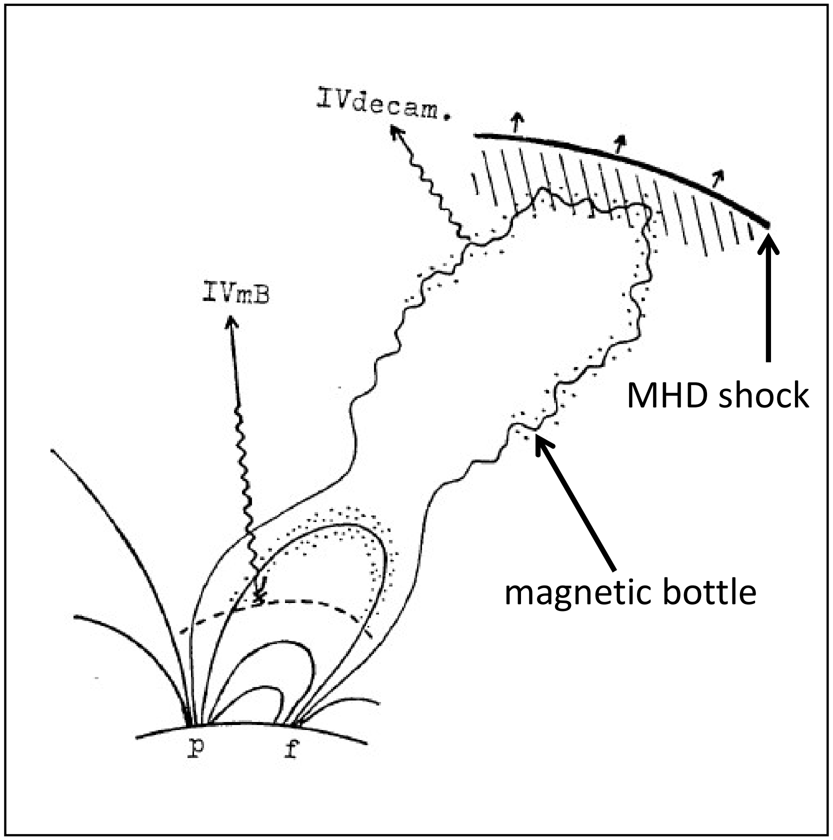


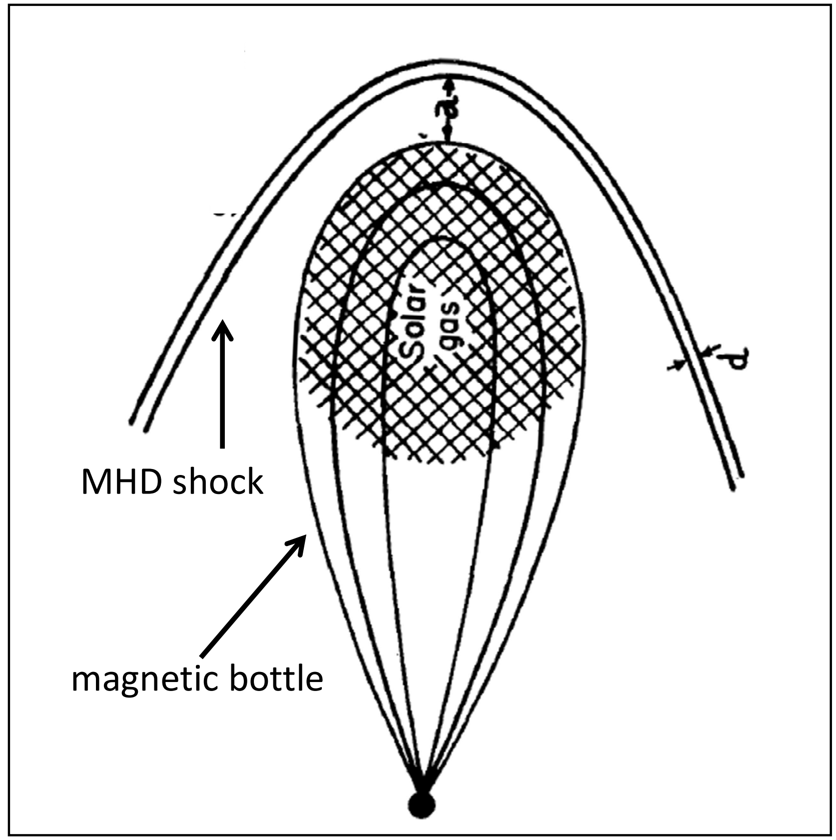

FIG. 1. Geometry of the Mariner II orbit on 7 October 1962. The shock normal direction computed from the change in the magnetic field is indicated. $\vec{e}_R, \vec{e}_N, \vec{e}_T$ are unit vectors defining a coordinate system along the radius vector from the sun, toward the ecliptic north pole, and along $\vec{e}_N \times \vec{e}_R$, respectively.

Sonett et al., 1964, Phys. Rev. Lett

IP shock followed by a Sudden Commencement 4.7 h later - confirmed Gold (1953) suggestion

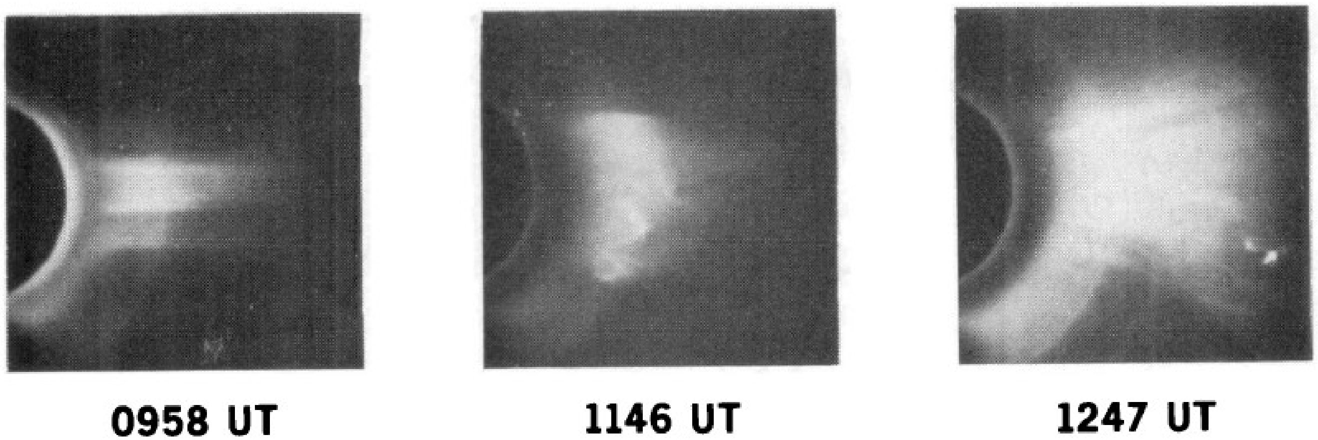
H. E.Taylor (1969): statistical study of IP shocks and SCs at NASA/GSFC as NRC Postdoc



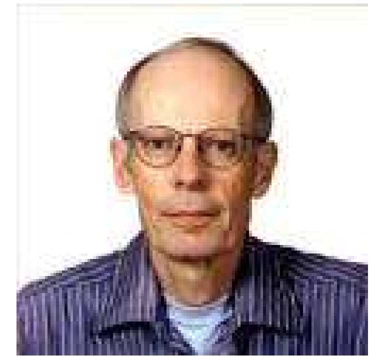




Gold 1962

The CME concept known well before their discovery in white light
See historical review: Gopalswamy 2016




Skylab CME on January 15, 1974



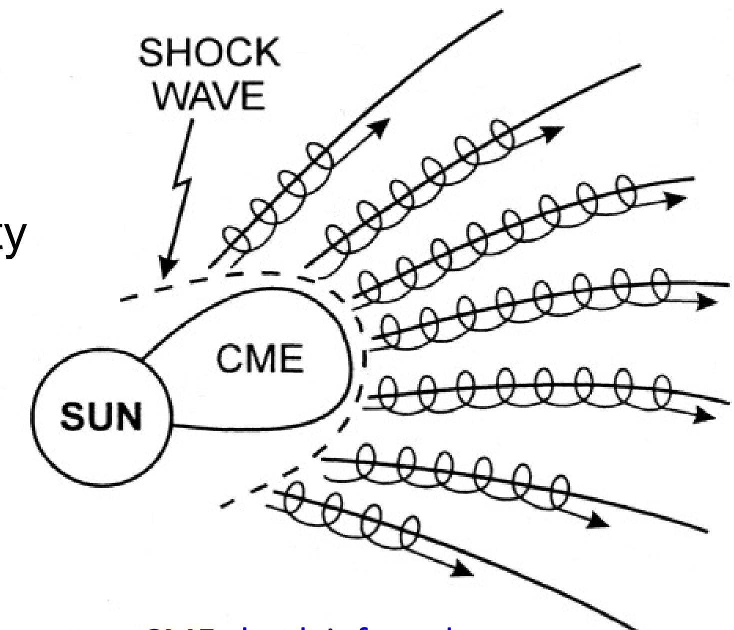
S. W. Kahler

Studied 16 Skylab CMEs; 14 had SEP events
Found correlation between CME speed and SEP intensity

"We suggest that energetic protons are accelerated in the shock front just ahead of the expanding loop structures observed as mass ejections"

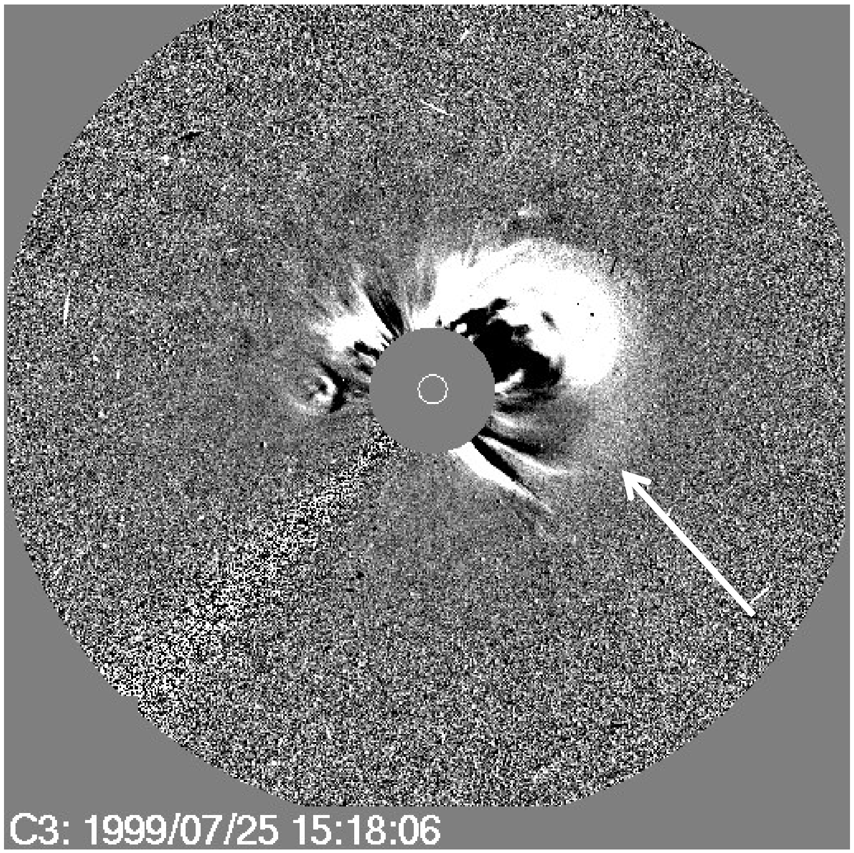
Kahler, Hildner, & Van Hollebeke (1978)

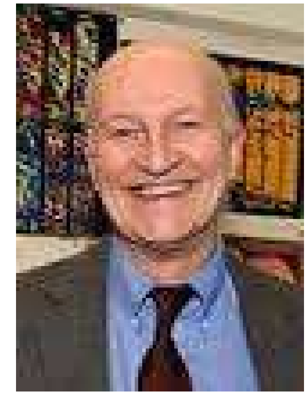
Cliver et al. 1982 for GLEs; Cane et al. 1988; Reames 1990




CME shock inferred

# Shock Identified in SOHO Images



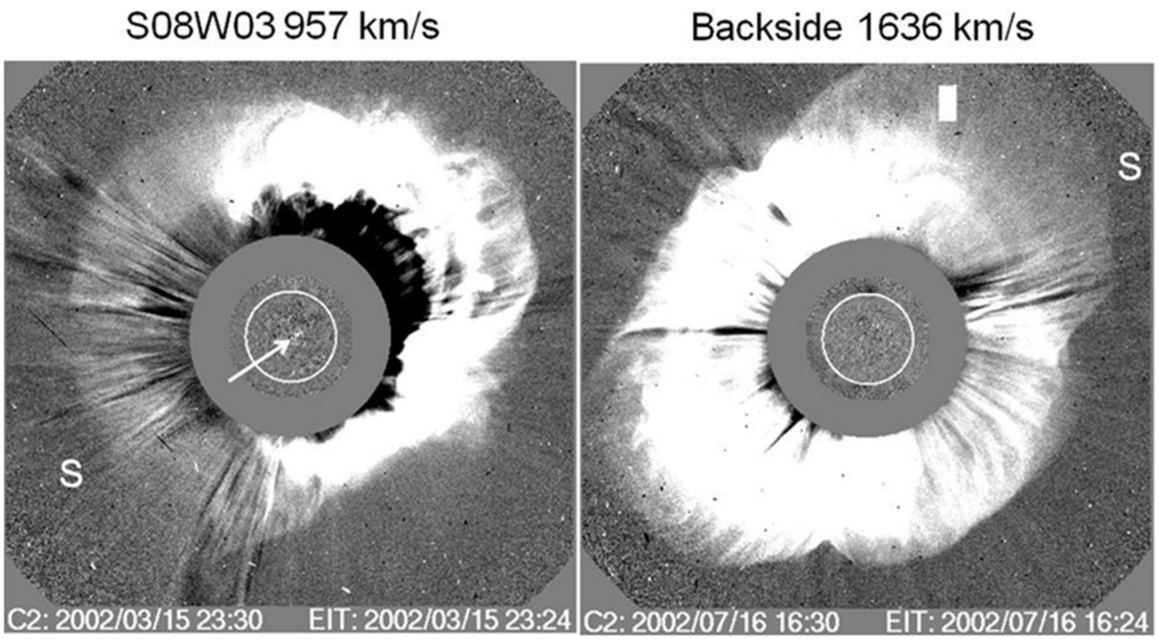



Neil Sheeley

"The disturbances are faintly visible ahead of the ejected material at the noses of the CMEs but are strongly visible along the flanks and rear ends….
these disturbances are shock waves…"

Sheeley et al., 2000

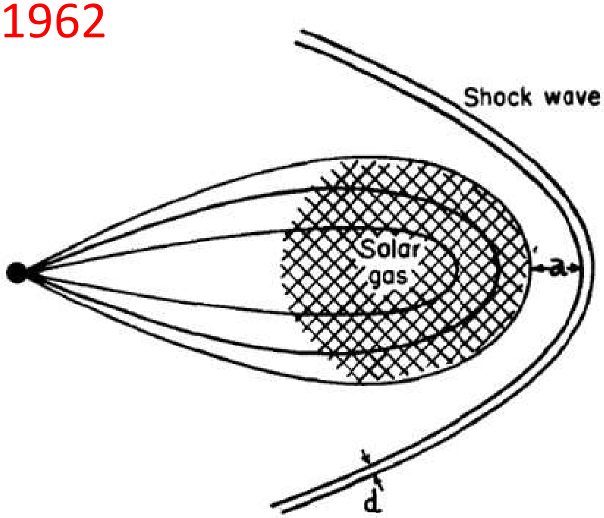
# Shocks Observed by SOHO



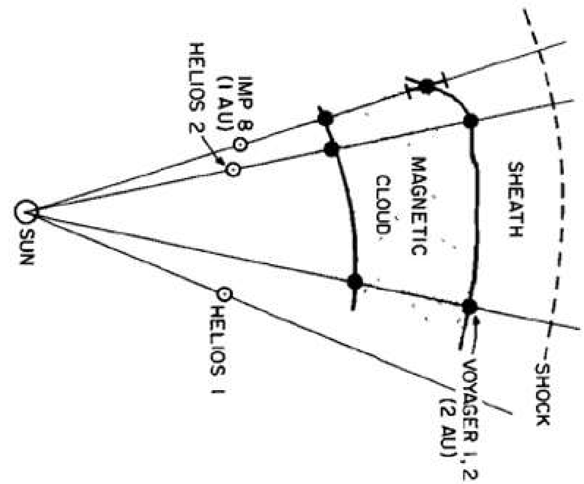

*The bright feature is the flux rope*
*The diffuse feature is shock signature*

# CME: Concept to Observations

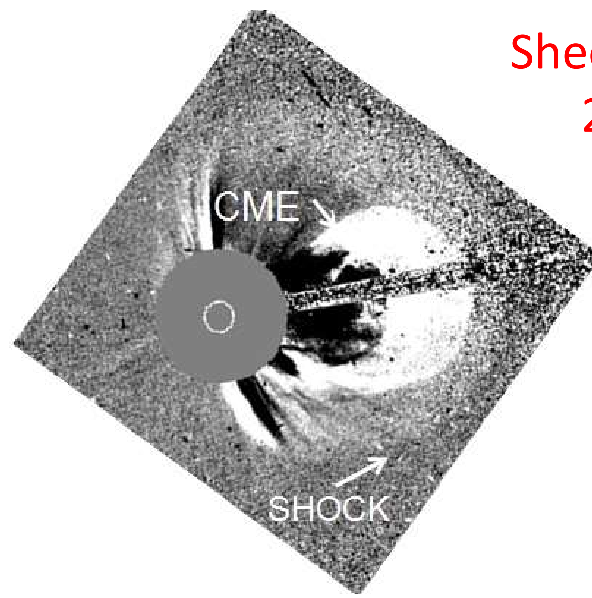
Gold 1962




Burlaga 1981



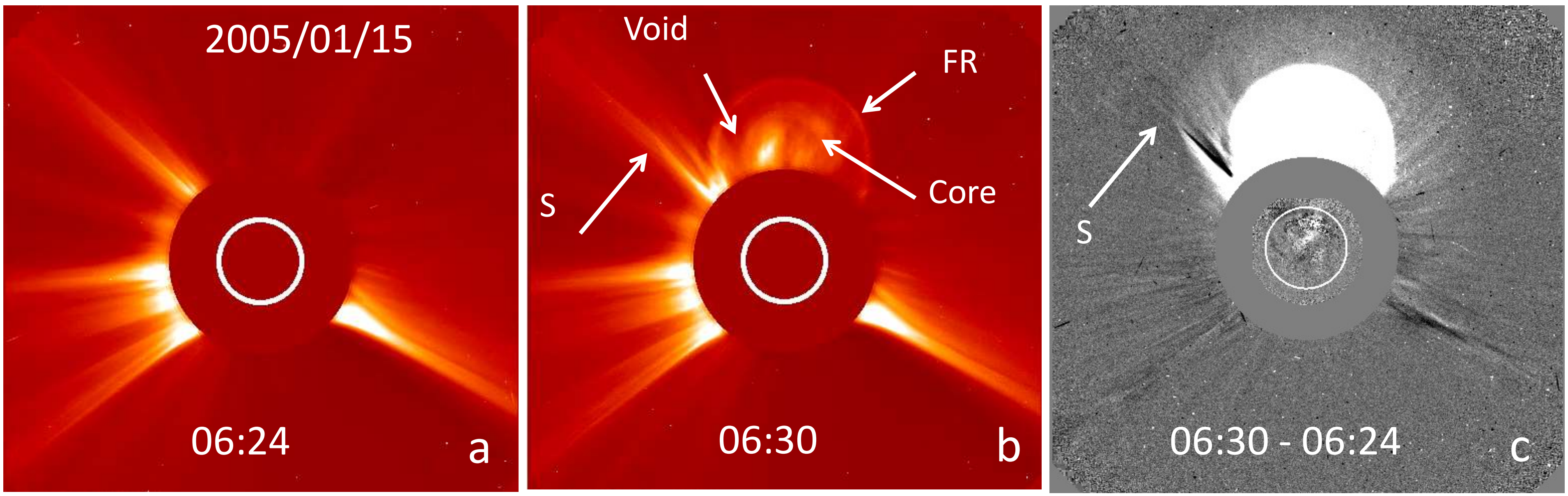

Sheeley 2000




Gopalswamy 2010

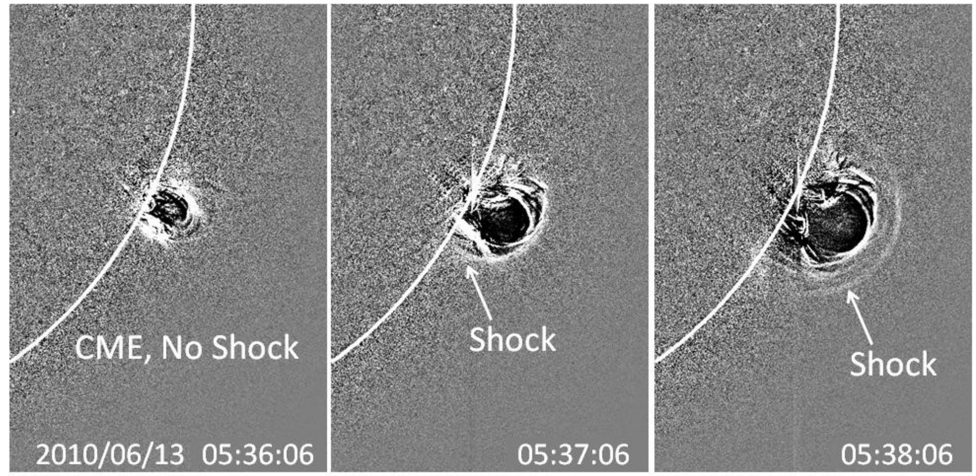
# Shock Structure in Difference Image

S= shock signature; FR = flux rope; Core = eruptive prominence
c = b – a  is the difference image that shows the fuzzy shock sheath



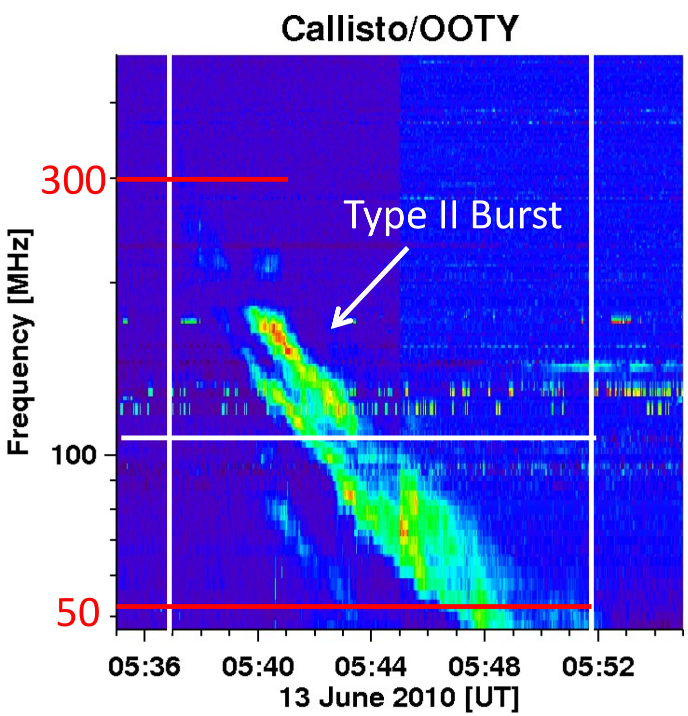

Gopalswamy, 2010 Springer book

# Shock Source: coronal mass ejections




**Solar Dynamics Observatory (EUV 193 Å)**

Type II burst starts exactly at the time the shock appears in the corona at 1.19 Rs (from the Sun center)




Slope of the type II radio burst is related to the shock speed:

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

$V = 2L\ 1/f)df/dt$; $L = |(1/n)(dn/dr)|^{-1}$

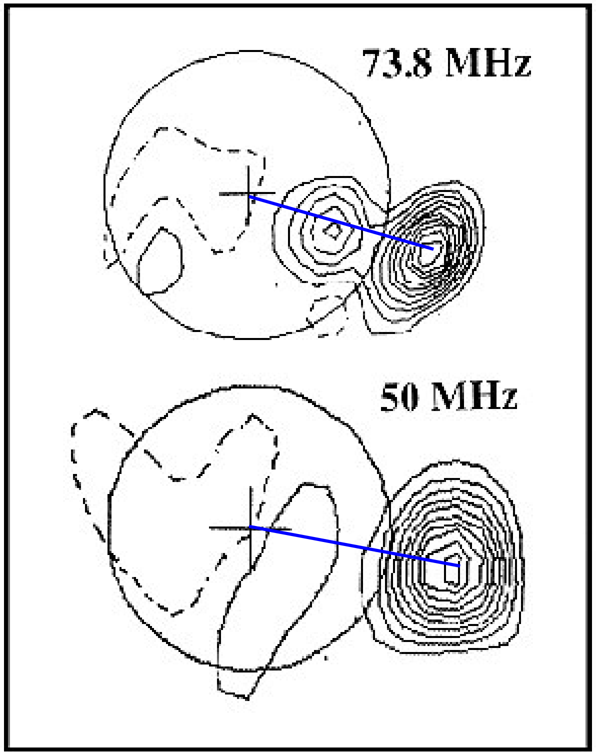
For $n = n_0 r^{-\alpha}$, $L = r/\alpha$

Measured V = 600 km/s → L = 189,000 km

$\alpha = r/L = 4.4$; compare $\alpha = 2$ in the IP medium

# Radio 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:

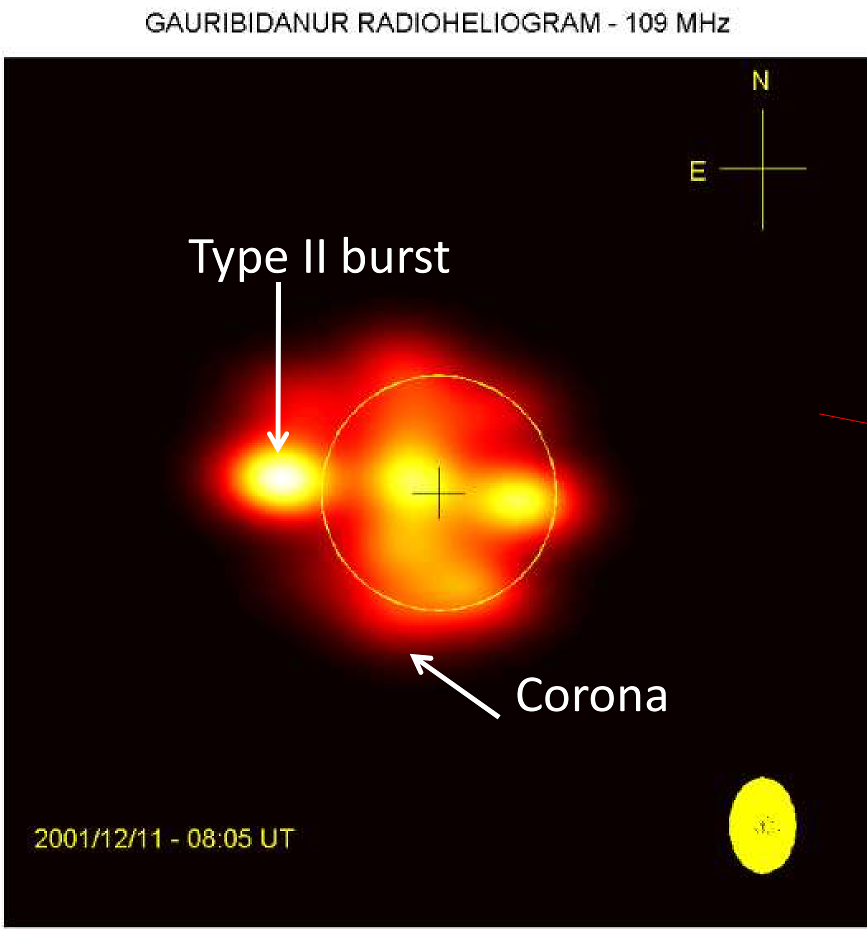
- Gauribidanur Radioheliograph (India)

-Nancay Radioheliograph (France)

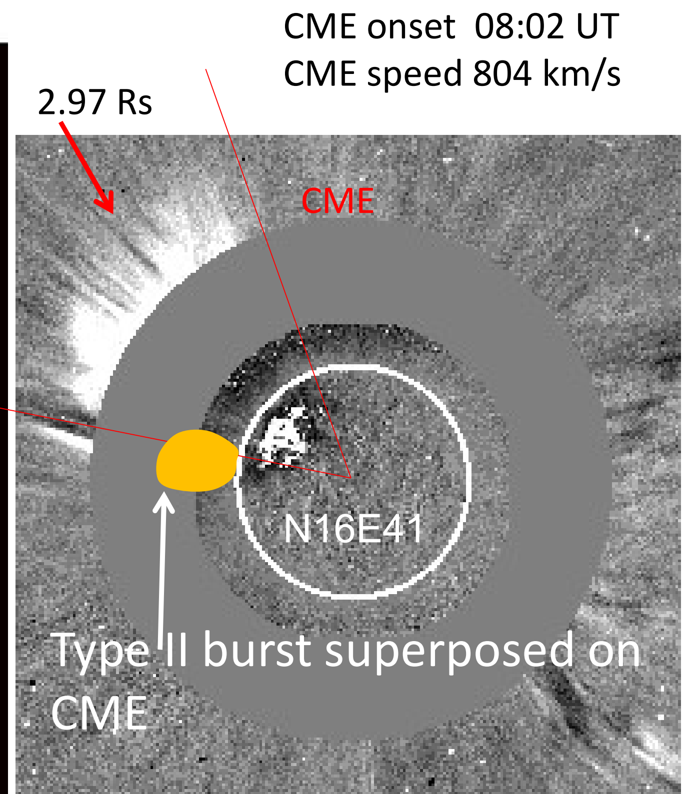
-Murchison Widefield Array (Australia), LOFAR (Netherlands)

RSTN, CALLISTO have 24 – hour coverage

# Image of a type II burst

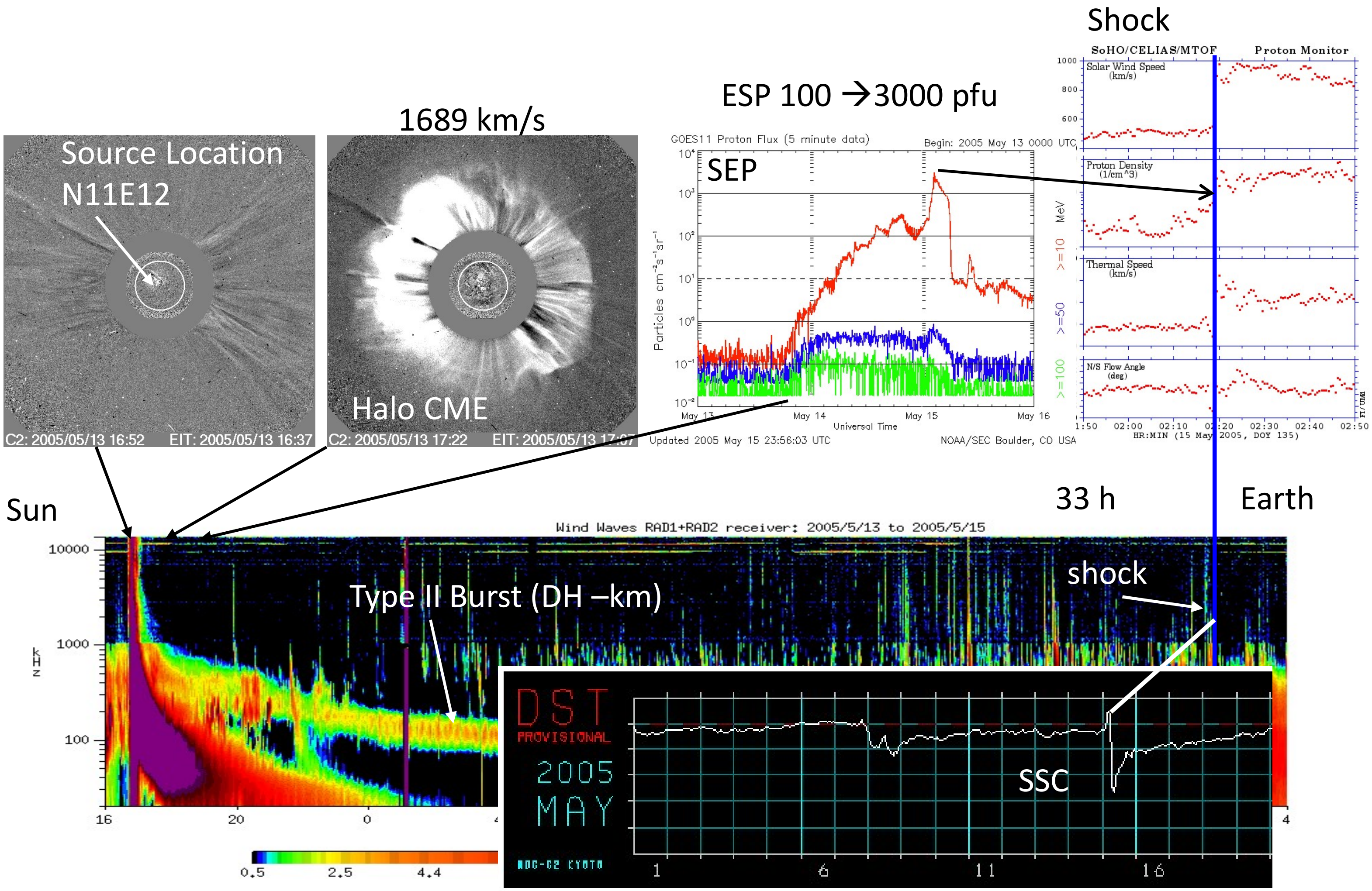



011211 POTS 0803.0 0836 II 2 40X 170U



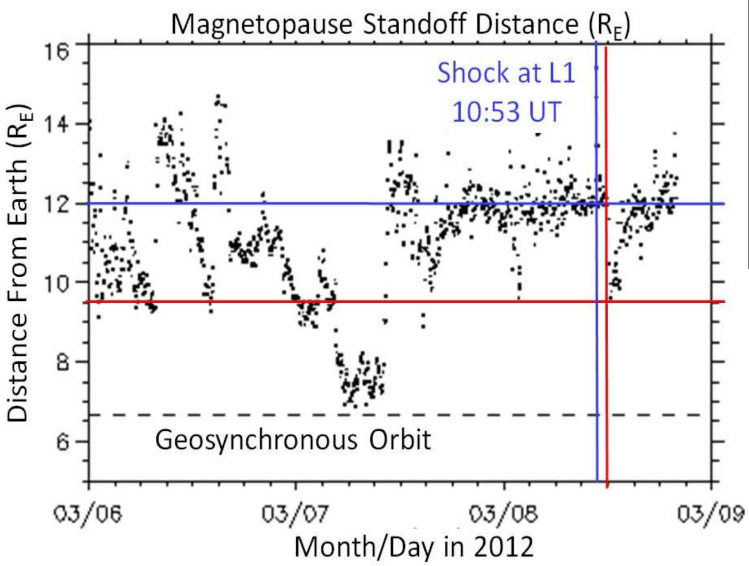

Imaging tells that the type II is from the flank of the CME. We cannot get this information from spectra

# A CME with Type II, SEP event & Shock at 1-AU: Radio helps track CMEs from the Sun to earth

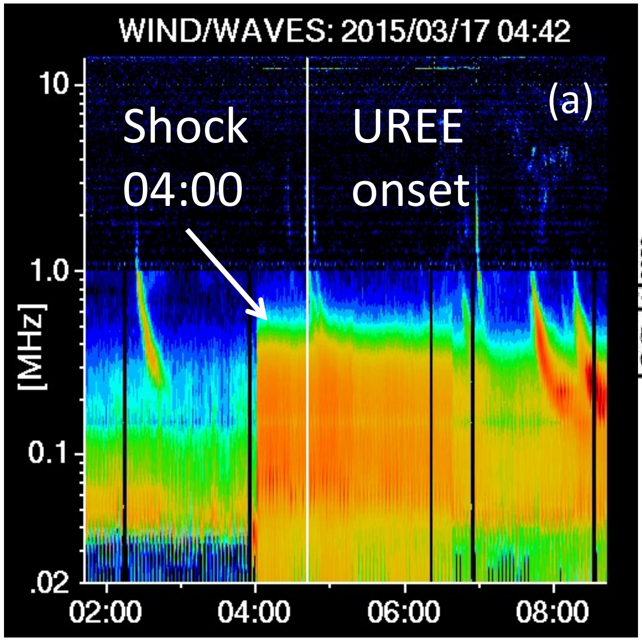


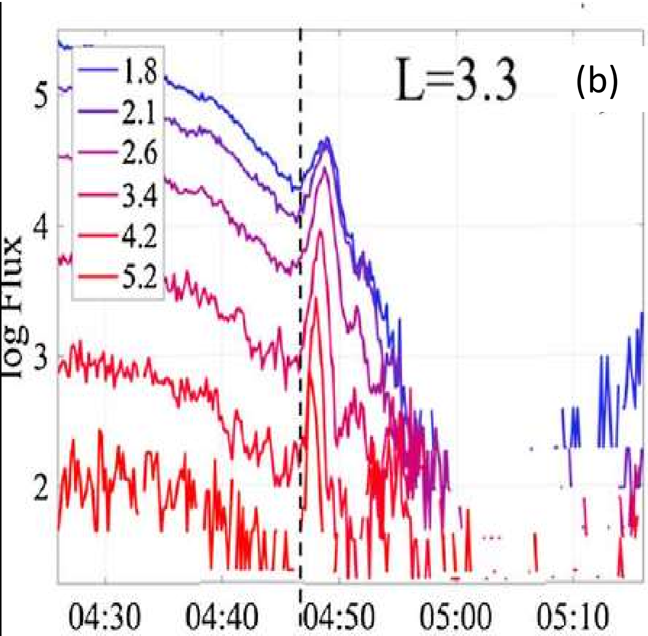
# Shock Effects

1. The magnetopause is pushed inwards toward the geosynchronous orbit due shock impact




2. SC/SI represents the ground manifestation of IP shocks and hence relates to GIC (large dB/dt)
GIC in low latitudes is also important (Ngwira+ 2013)




3. UREE events

- Shock encountered by Wind/WAVES at ~4:00 UT followed by the ultra relativistic electron enhancement (UREE) 45 min later
- The UREE event in various energy channels from 1.8 to 5.2 MeV (from Schiller et al. 2016)

4. ESP events observed inside the magnetosphere

5. Shock sheath causes geomagnetic storm

# Summary

- Shocks in the corona and interplanetary media provide an excellent opportunity to study shock physics and particle acceleration
- Shocks also help understand the physical state of the medium through which they propagate
- Shocks are a major source of space weather effects at Earth and other places in the solar system
- The COSPAR capacity building workshop will provide training to study shocks and the driving coronal mass ejections