Overview of White Light & Radio Signatures of CMEs

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Lecture Outline

- **Related Lectures:**
  - **<u>Overview</u>: Space weather**
  - **<u>CME/SEP Obs & Models</u>: SEPs, Coronal/IP Shocks**
  - **<u>Basic Physics</u>: Reconnection, radio seminars**
  - **<u>Practicum</u>: In-situ measurements, Radio instrumentation**

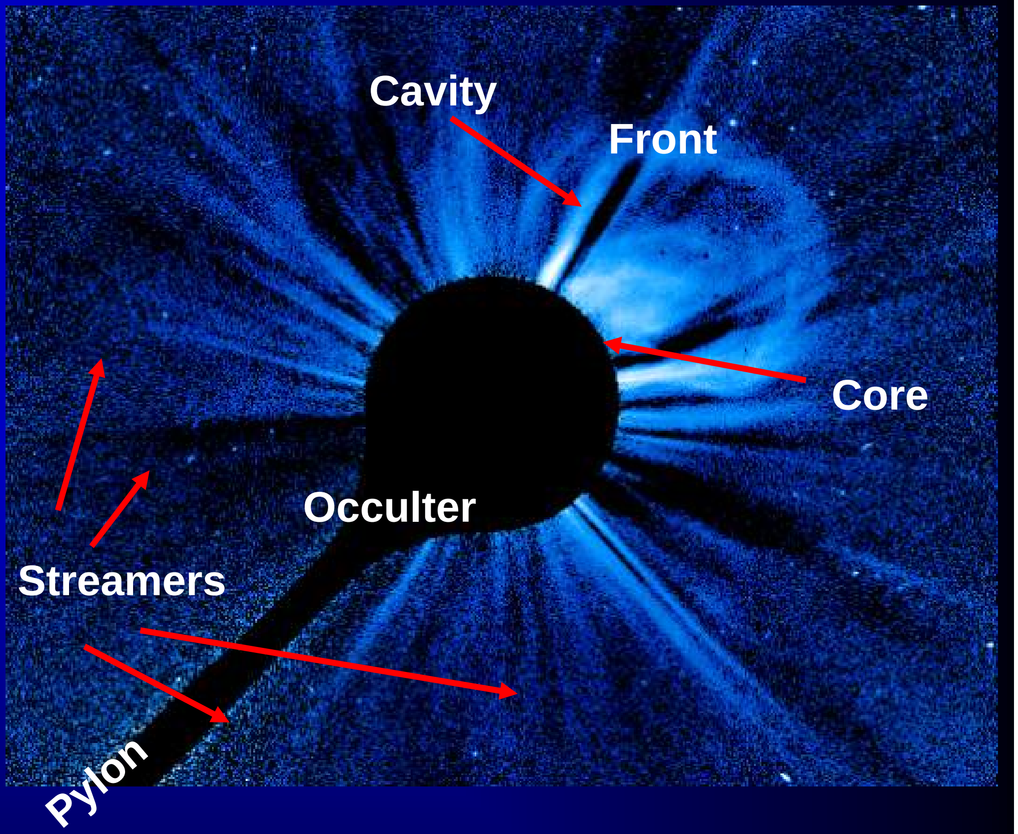
- **Outline:**
  - **Overview of radio & white light (WL) emissions**
  - **Highlights of joint WL & radio observations of CMEs**
  - **Open questions/research topics**
  - **Review**

Why treat radio & WL together?

- **Both emissions are due to coronal electrons**
  - **THERMAL radio emission goes as $N_e^2\, dl$**
  - **WL emission goes as $N_e\, dl$**
- **Both emissions are insensitive to the temperature of the plasma**
- **Both are probes of the extended corona & heliosphere**
- **Radio observations are possible on the disk (no occulter) AND trace CMEs (indirectly) all the way to the Earth**

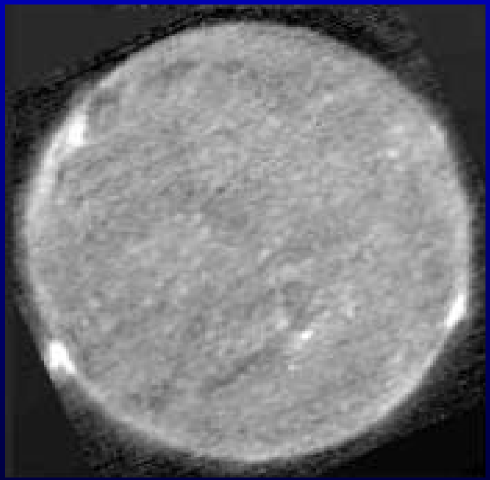
Review of White Light Emission

- A feature can be <u>bright</u> because:
  - It is extended ALONG the line of sight (many electrons)
  - It has mass (many electrons)
  - It is close to the plane of max. scattering
- A feature <u>disappears</u> because:
  - It was carried away (in a CME)
  - It was pushed AWAY from plane of max. scattering

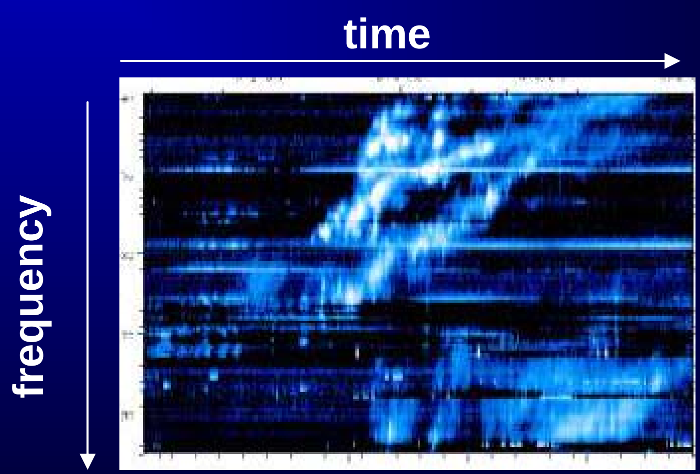


Review of Radio Emission

- **Emission Mechanisms**
  - Thermal
  - Non-Thermal
- **Range of Observations**
  - Chromosphere (GHz)
  - Aurora (KHz)
- **Types of radio data**



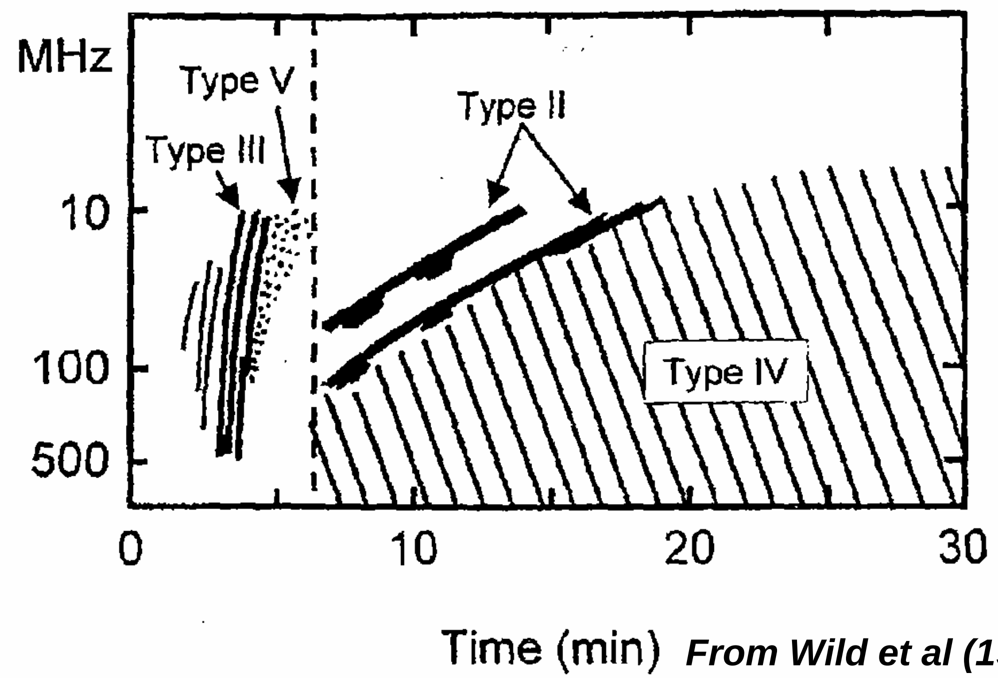
SSRT 5.7 GHz Image



AIP Spectrum

Review of Radio Bursts

- **Type III: relativistic electrons (.3c)**
- **Type II: shock-related (~1000 km/s)**
- **Type IV: post-CME reconfiguration**



From Wild et al (1963)

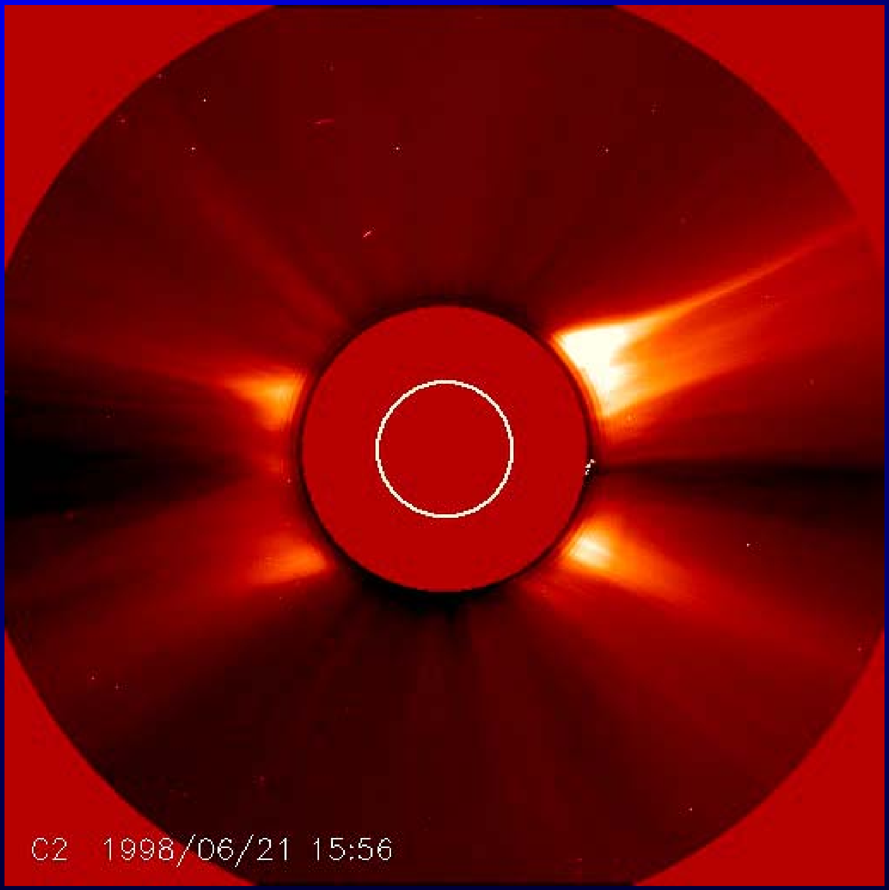
How we use WL & radio observations?

We will review how the joint analysis of coronagraph and radio data can lead to insights in the following:

- **CME Initiation**
- **Structure of CMEs**
- **Early CME evolution**
- **Physical properties of CMEs**
- **CME shocks, accelerated particles**
- **CME propagation**

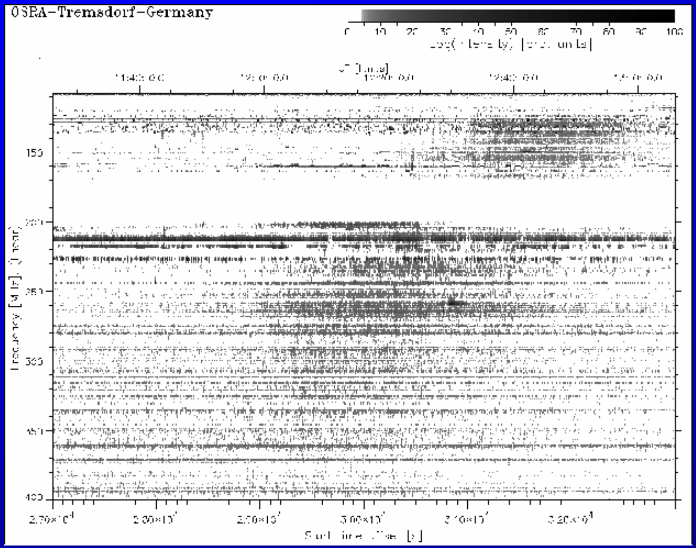
What about CME Precursors?

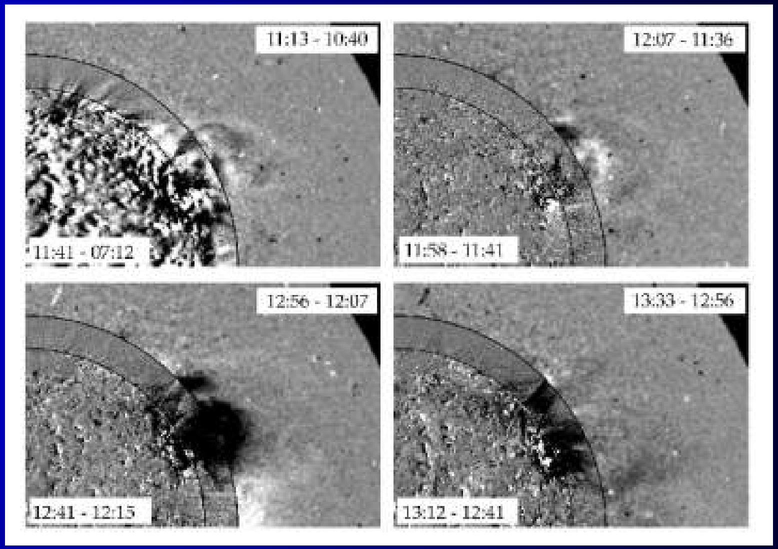
- **WL: Rising and expanding streamer (*when cadence allows*) for hours (days in *streamer-blowouts*) before the CME erupts**



Radio Precursors of CMEs

Drifting continuum sources may mark the CME birth.





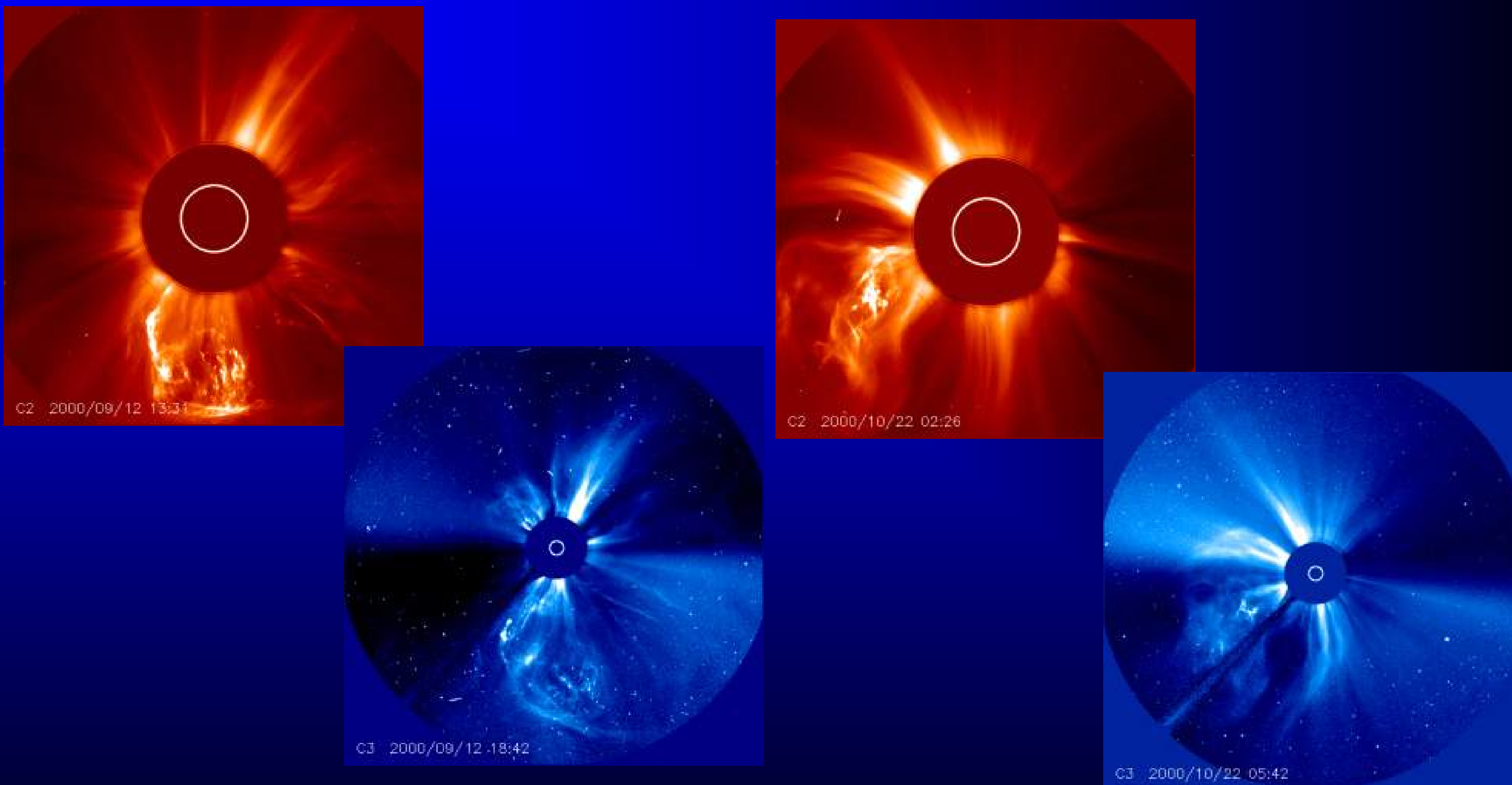
The role of <u>Noise Storms</u> remains controversial.

- **Some noise storm changes correlate with CME.**
- **Noise storm sometimes starts before CME and sometimes after.**

More work is needed to establish reliable radio precursors for CMES.

CMEs are not ‘puffs of coronal smoke’

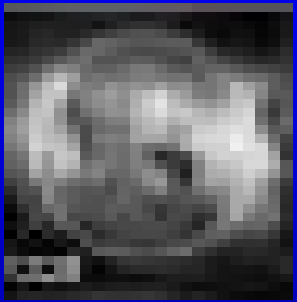
- **WL: CMEs contain large structures (e.g., filaments)**

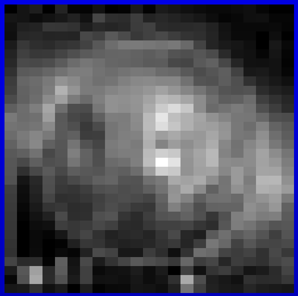


Radio imaging of CME features

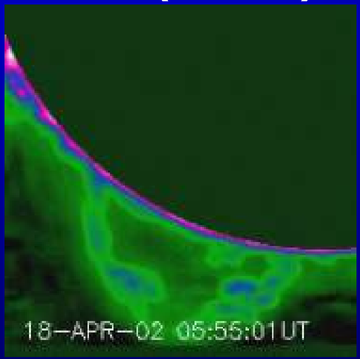
Follow Eruptive Filaments.

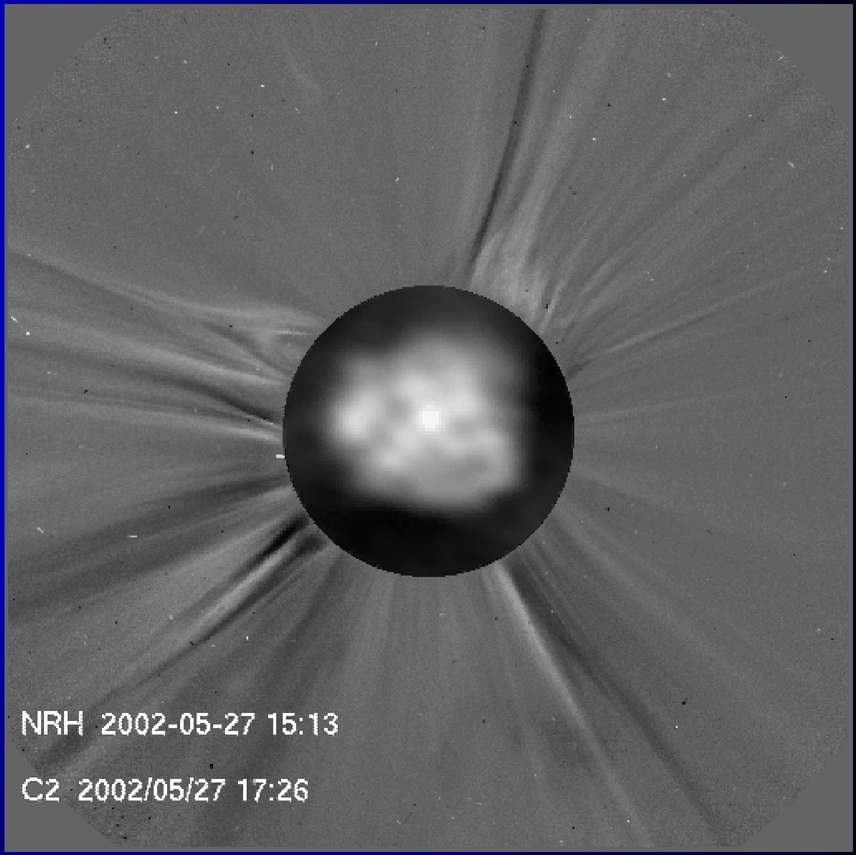
NRH (410 MHz)





NoRH (17GHz)

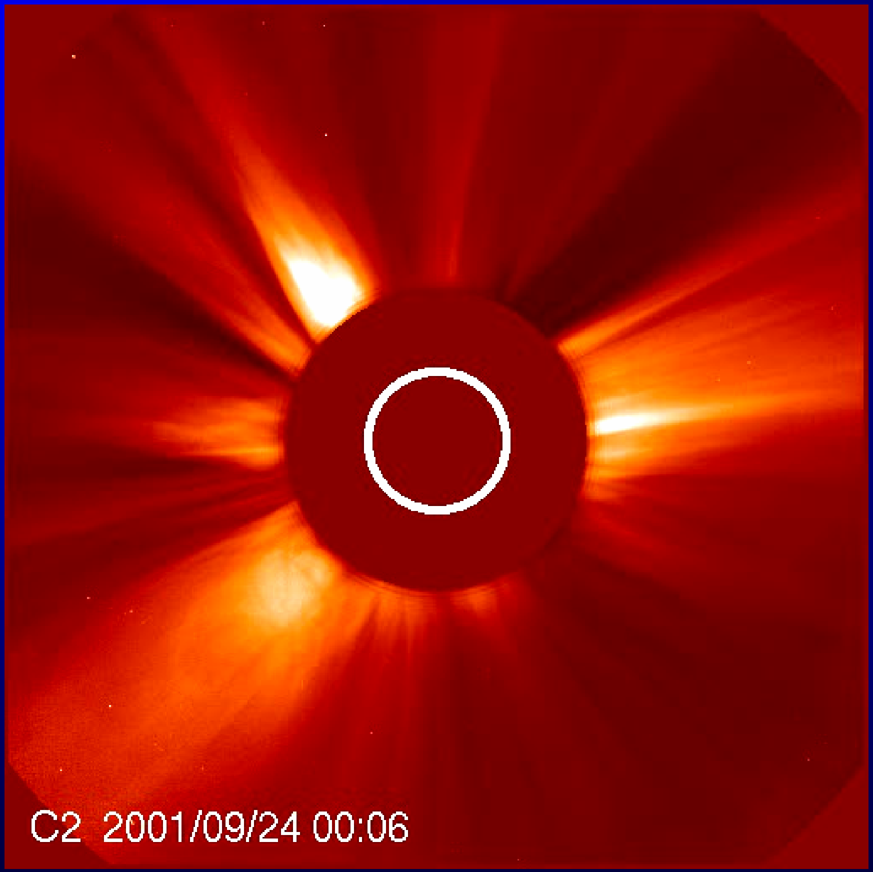




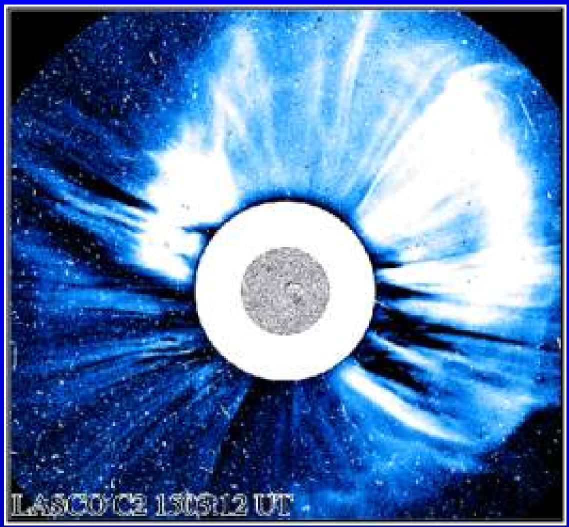
- Follow the initial activation with high cadence.
- Trace the coronal structures that participate in the eruption.

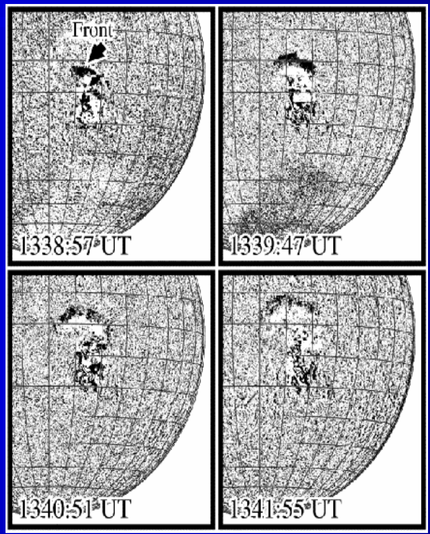
Does the CME evolve before appearing in the coronagraph?

- **WL: Observe CME evolution only above ~2 R**
- **WL: Often CME expands over the whole disk**

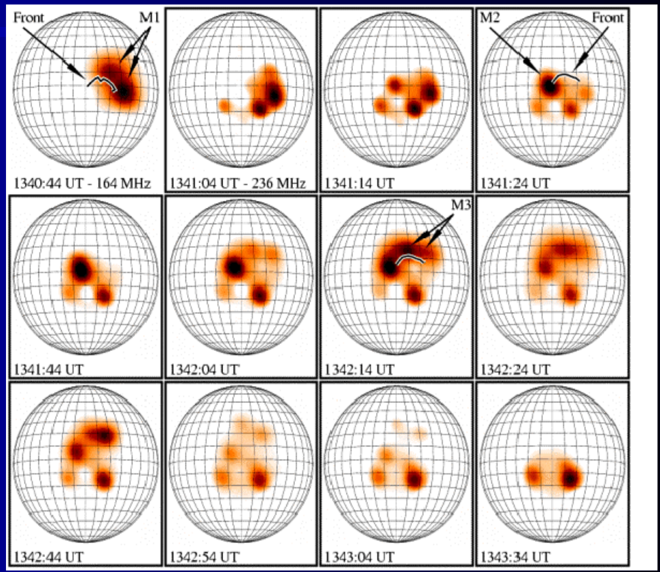


Radio Imaging of on-disk CMEs

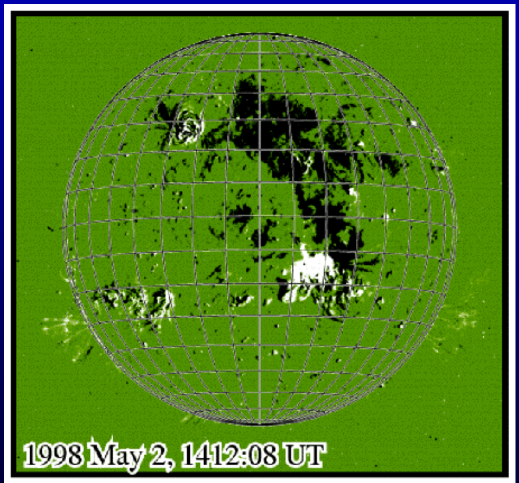




Kanzelhohe Hα images

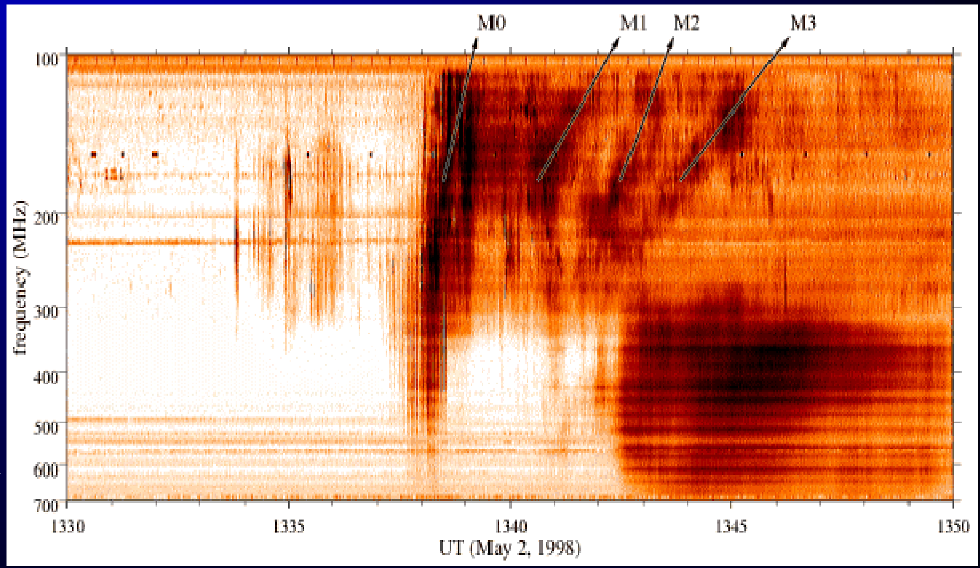


NRH sources at 236 MHz



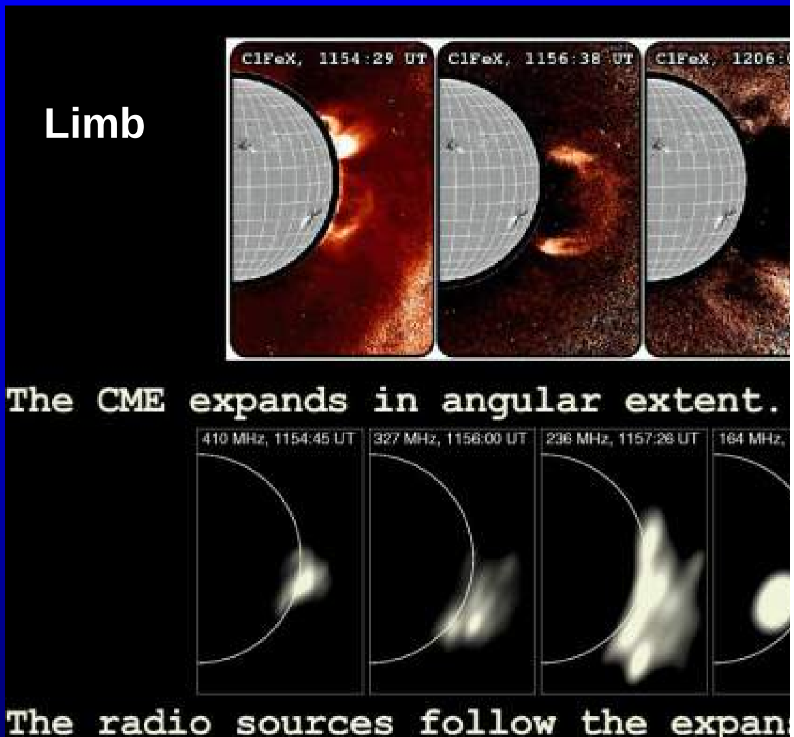
EIT dimming

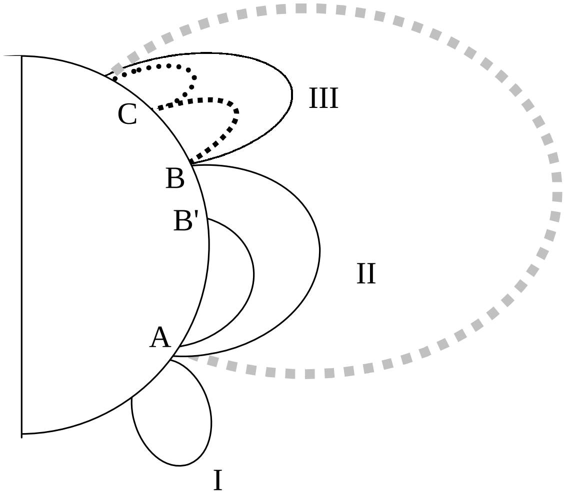
Artemis IV spectrum



Radio Imaging of Limb CMEs

Trace the CME initiation and development in the low corona.

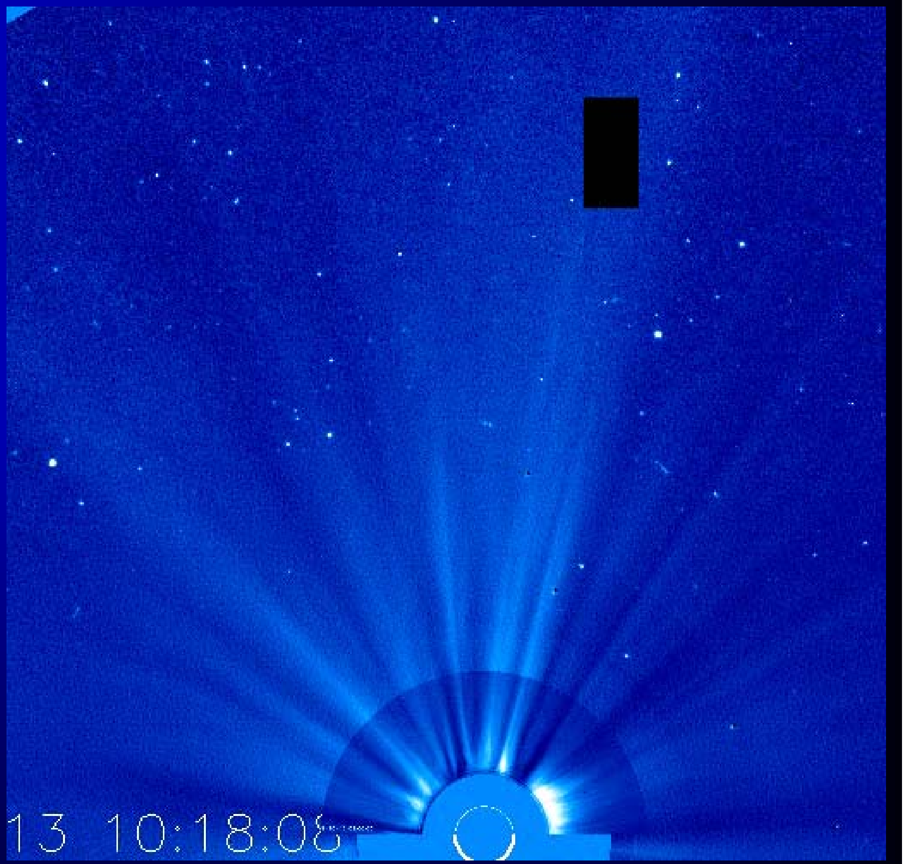




- **Full CME expansion < 10 min.**
- **Indications of long range interactions.**
- **Erupted systems can be identified.**

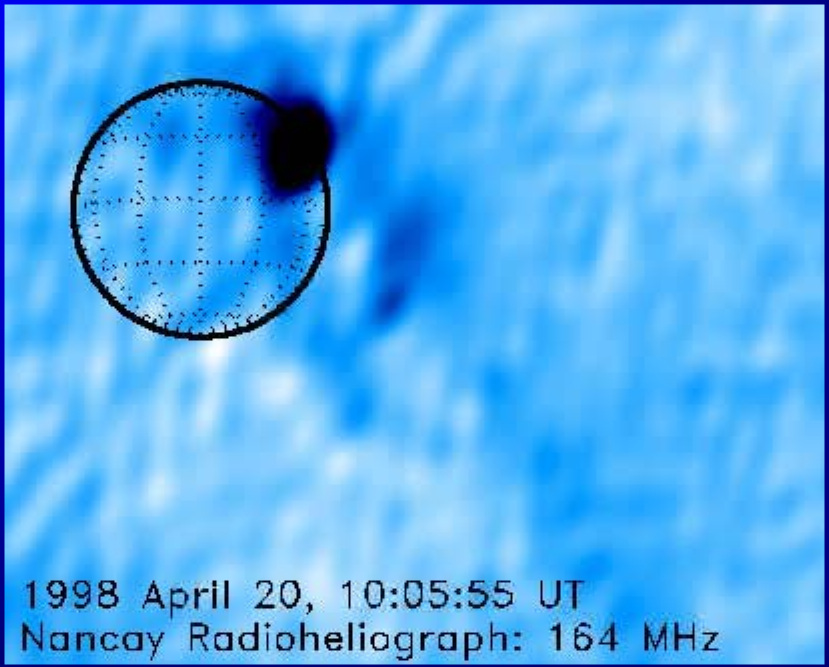
CMEs are magnetic entities

- **WL: CMEs contain magnetic structures (filaments)**
- **WL: Propagate as coherent systems**
- **In-situ: observations are fitted with fluxrope models**

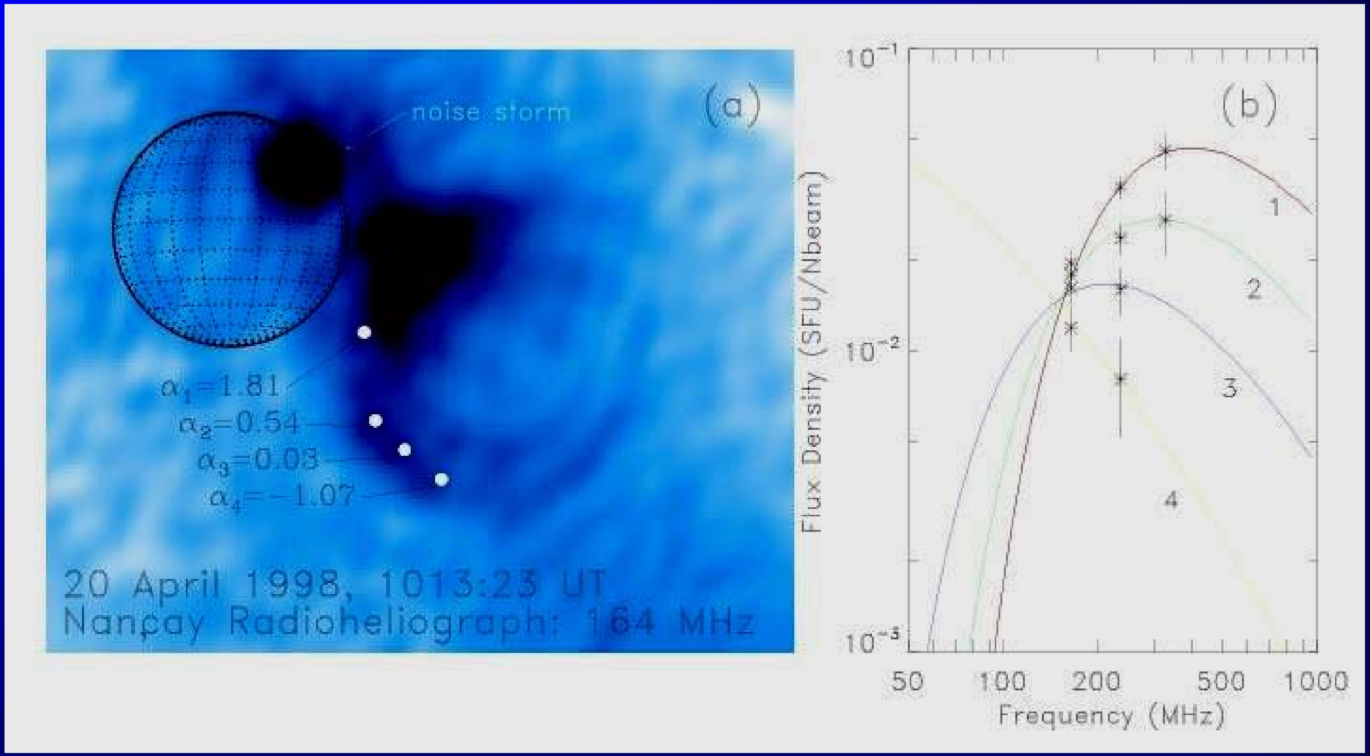


Physical Properties of CMEs

Image directly radio CME loops for the first time.



Physical Properties of CMEs

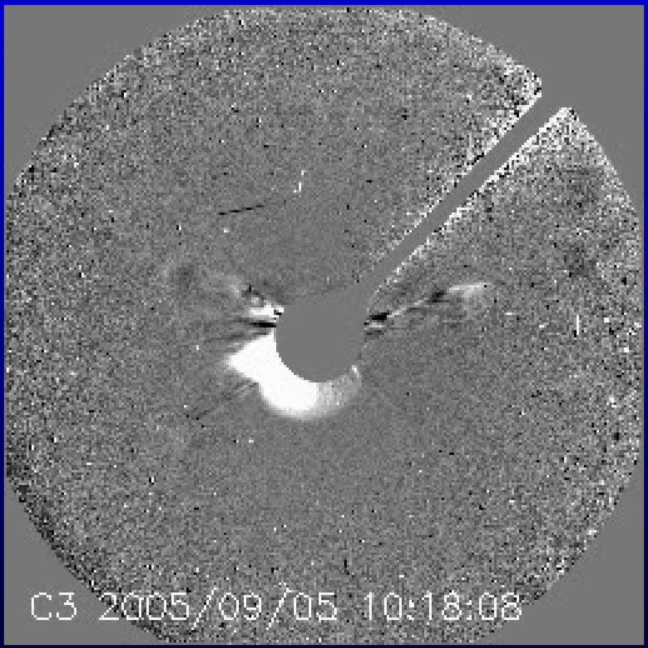


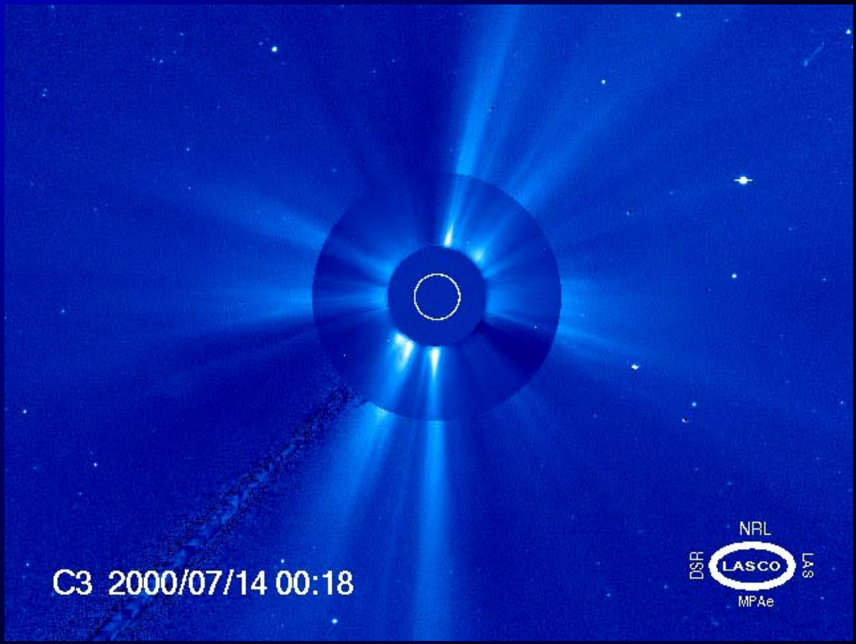
- **Image fine-scale CME structures.**
- **Derive physical parameters:**

B_{CME} ~0.1-few G, E ~ 0.5-5MeV, n_{th} ~10^7 cm^{-3}

CMEs can drive shocks & accelerate particles

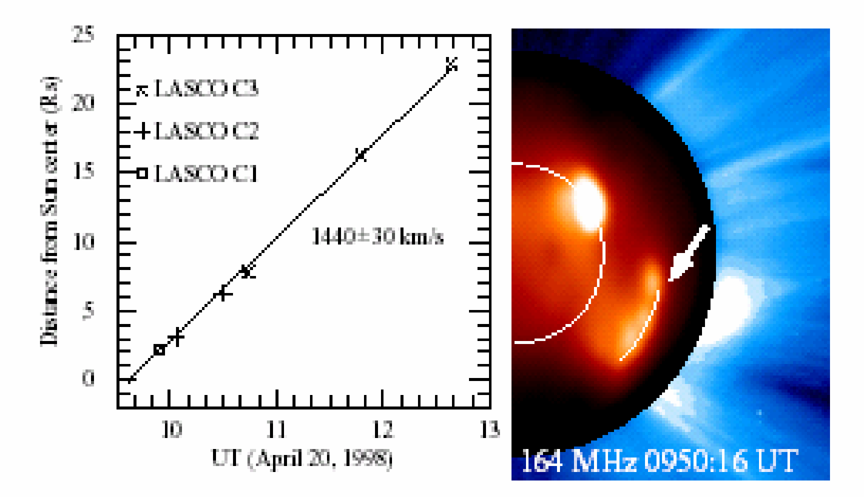
- **WL: CME-driven shocks are a long-sought feature. Likely visible in many LASCO CMEs.**
- **WL: Accelerated particles cause "snow storms" on LASCO CCDs.**

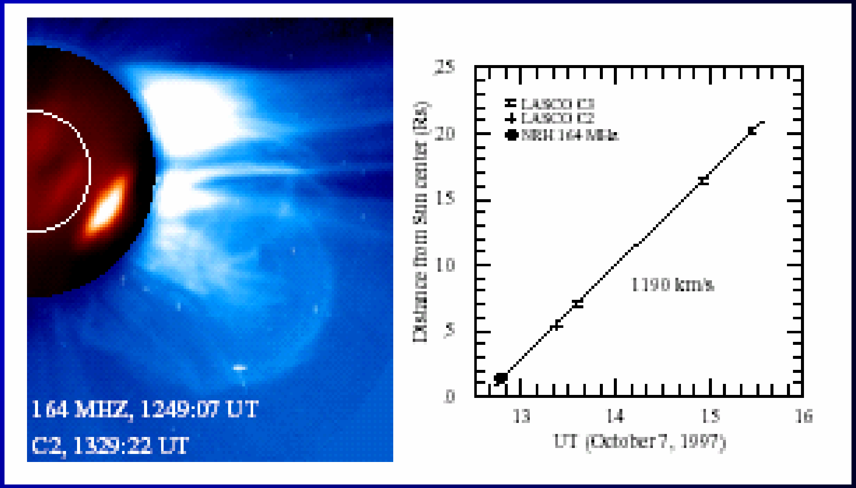




Radio imaging of CME shocks

Identify the shock at the CME front.



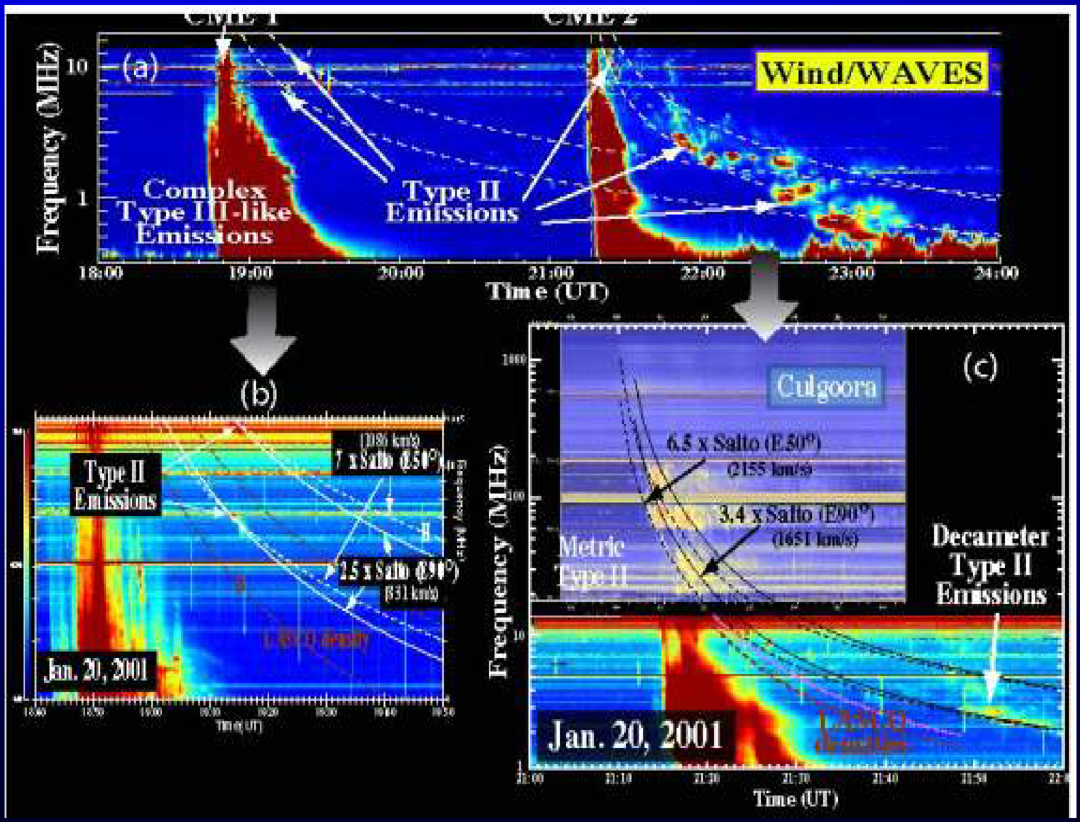


- **Radio CME front is faint.**
- **Several candidates for Type-II emission can be identified.**

Type-II Emissions and CMEs

Type-II bursts remain unreliable proxies of solar eruptions

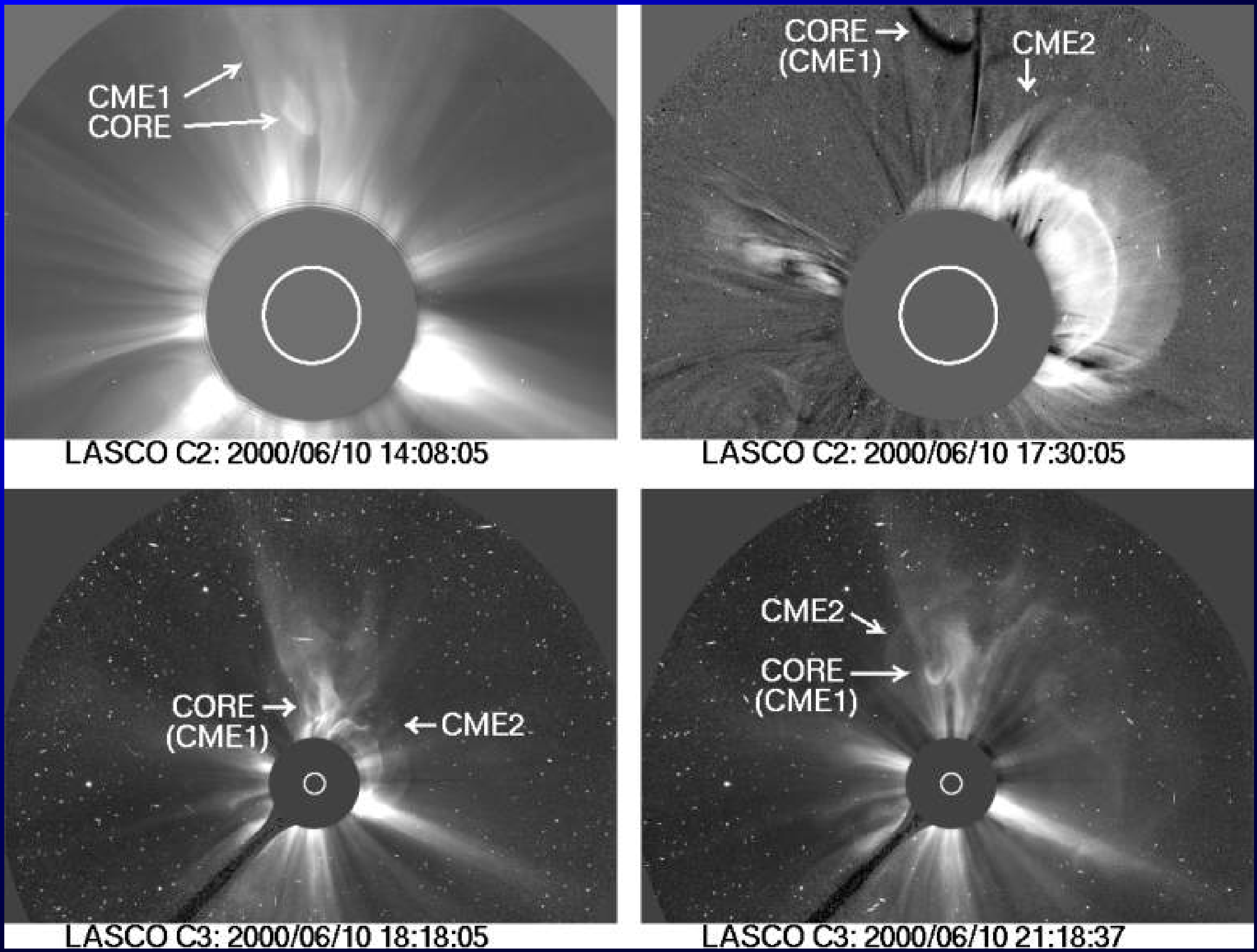
- 90% of EUV waves are associated with metric Type-IIs
- But EUV waves are better correlated to CMEs
- Type-IIs are blast waves (30%), CME-driven (30%) or behind CME (30%)



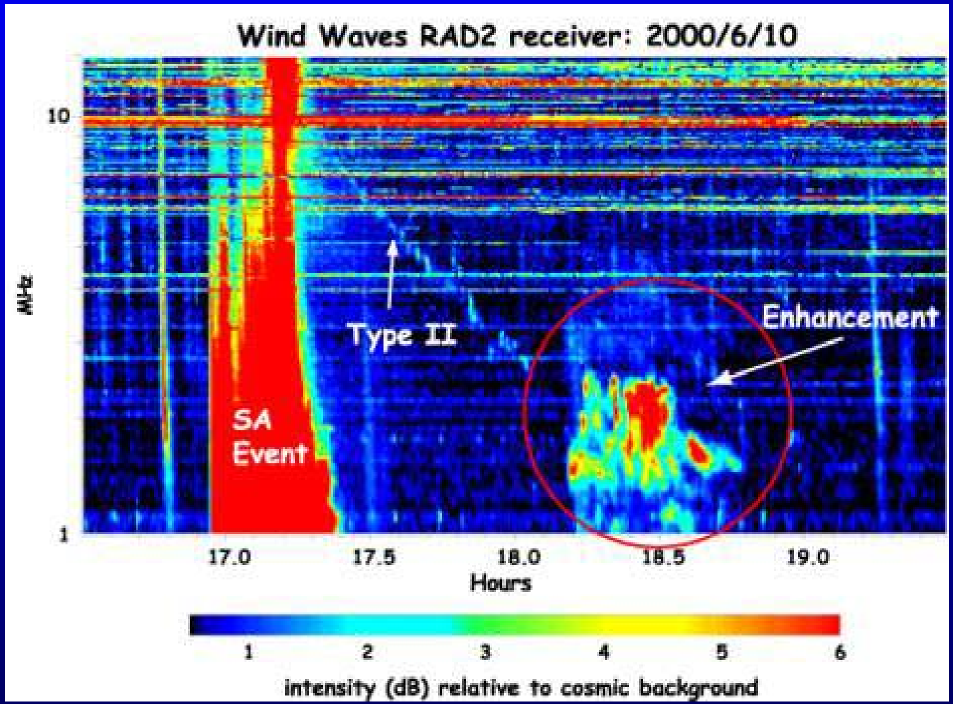
A technique for Type-II / LASCO analysis.

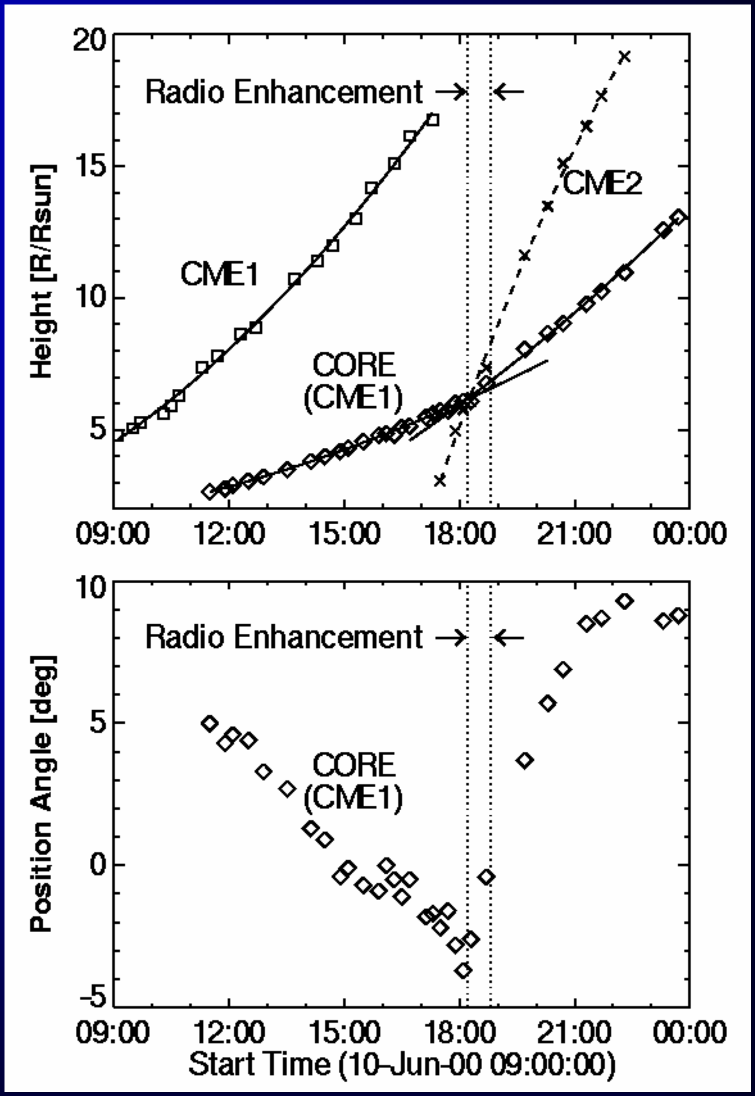
Consistency between LASCO densities and Type-II profiles can pinpoint the CME:
<u>launch time</u>,
<u>position angle</u>
and type-II <u>source</u> region

CMEs can interact with each other



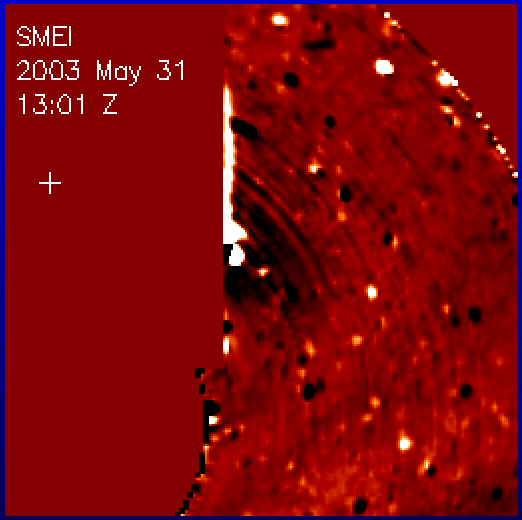
Radio signs of CME interaction

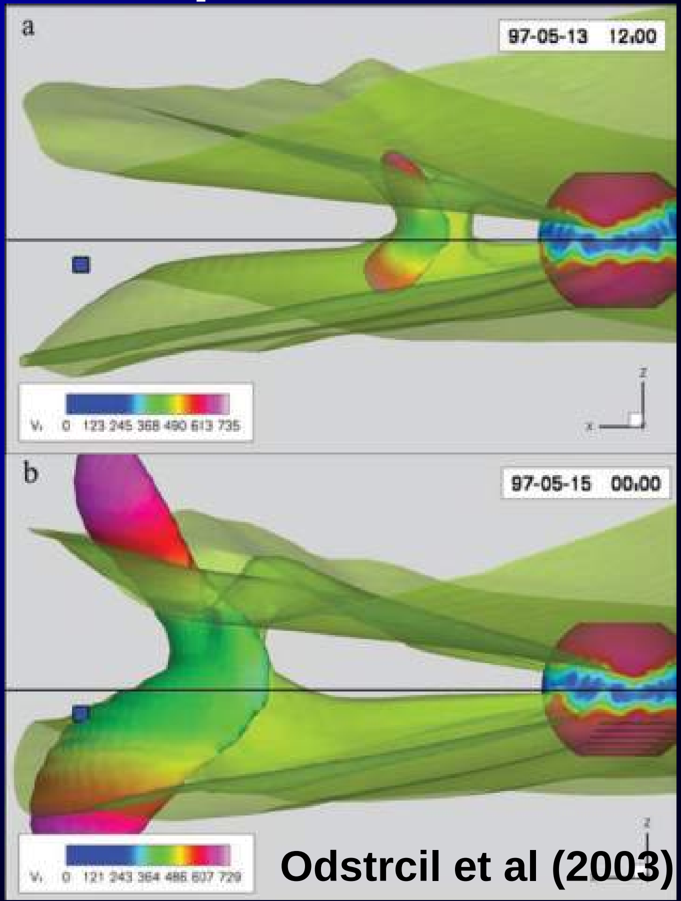




CMEs evolution in the heliosphere?

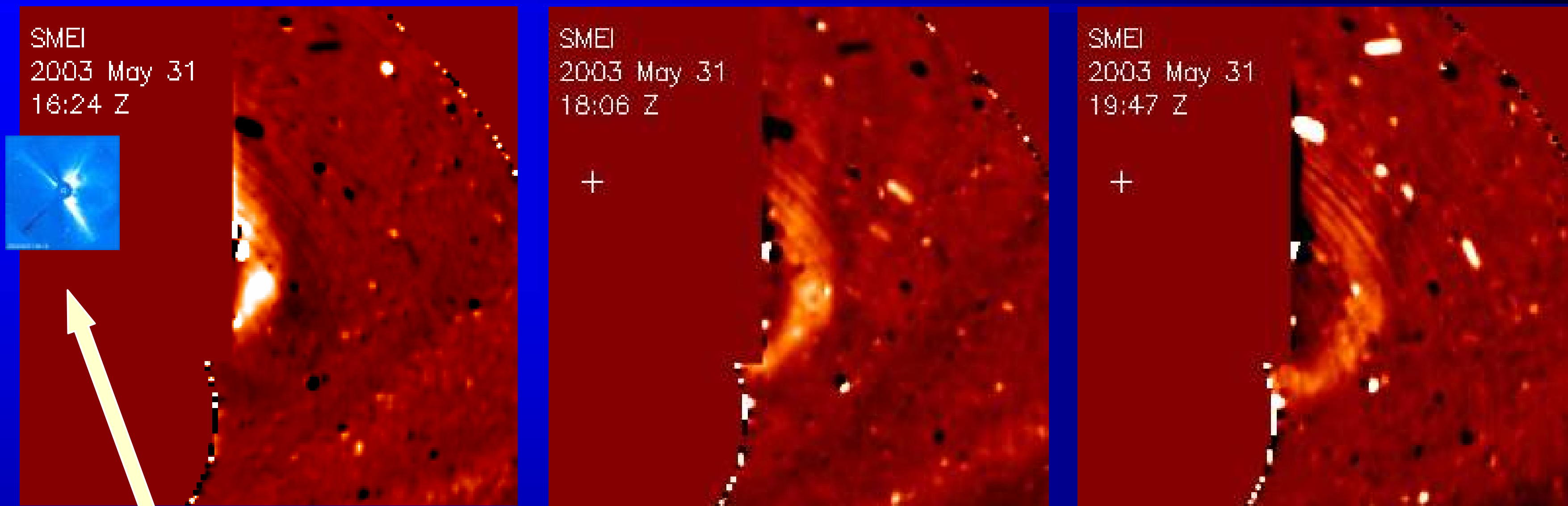
- **WL: Observational gap between 30 R (C3 FOV) and 80 R (inner edge of SMEI).**
- **Models: CMEs over-expand out of the ecliptic and compress radially**

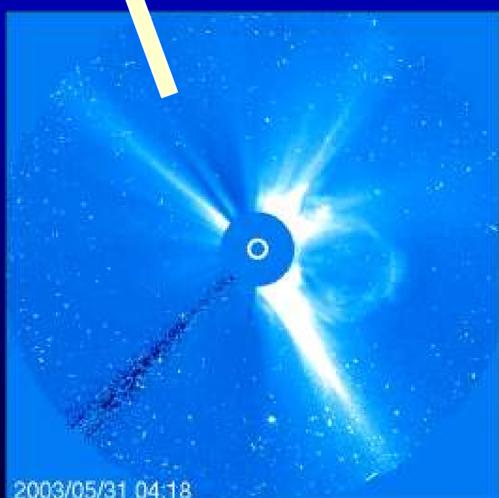




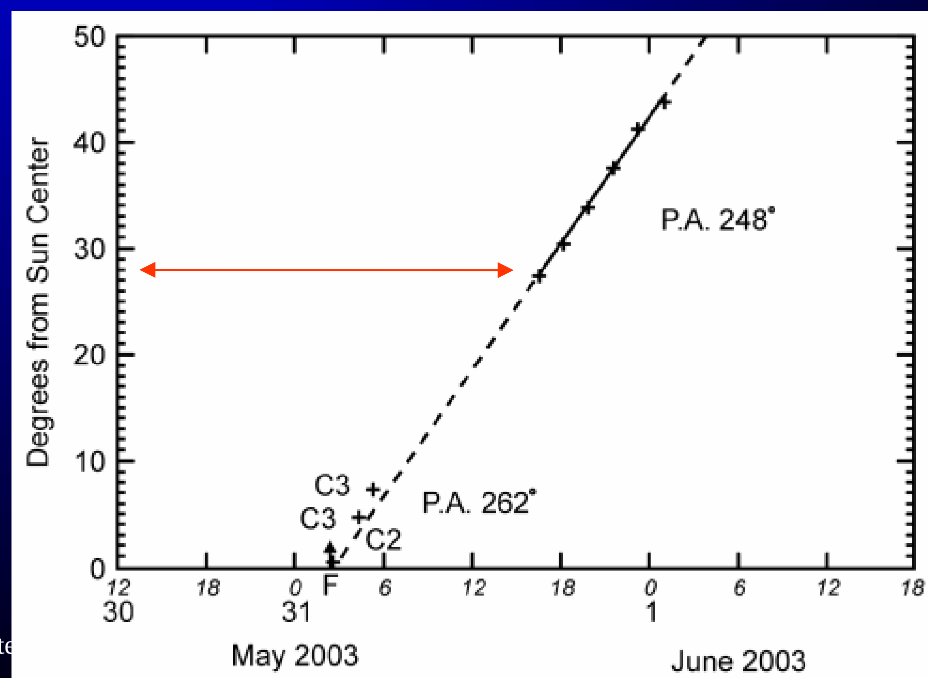
Odstrcil et al (2003)

A Fast Limb CME: *31 May 2003*



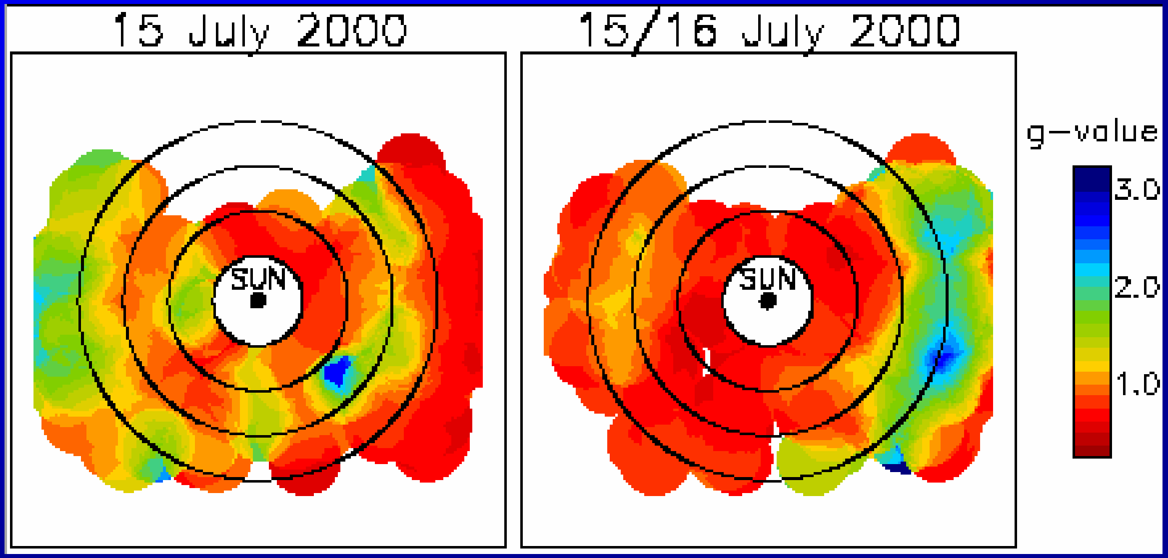


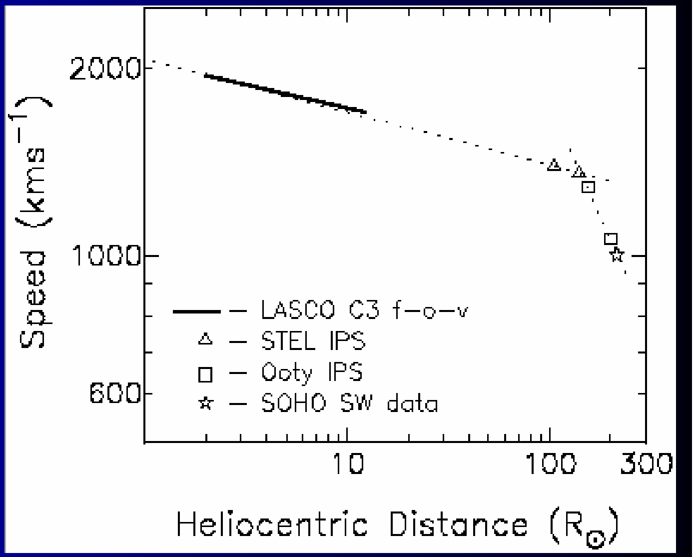
LASCO C3; 31, 04:18



Radio mapping of ICMEs

IPS Mapping of CMEs.



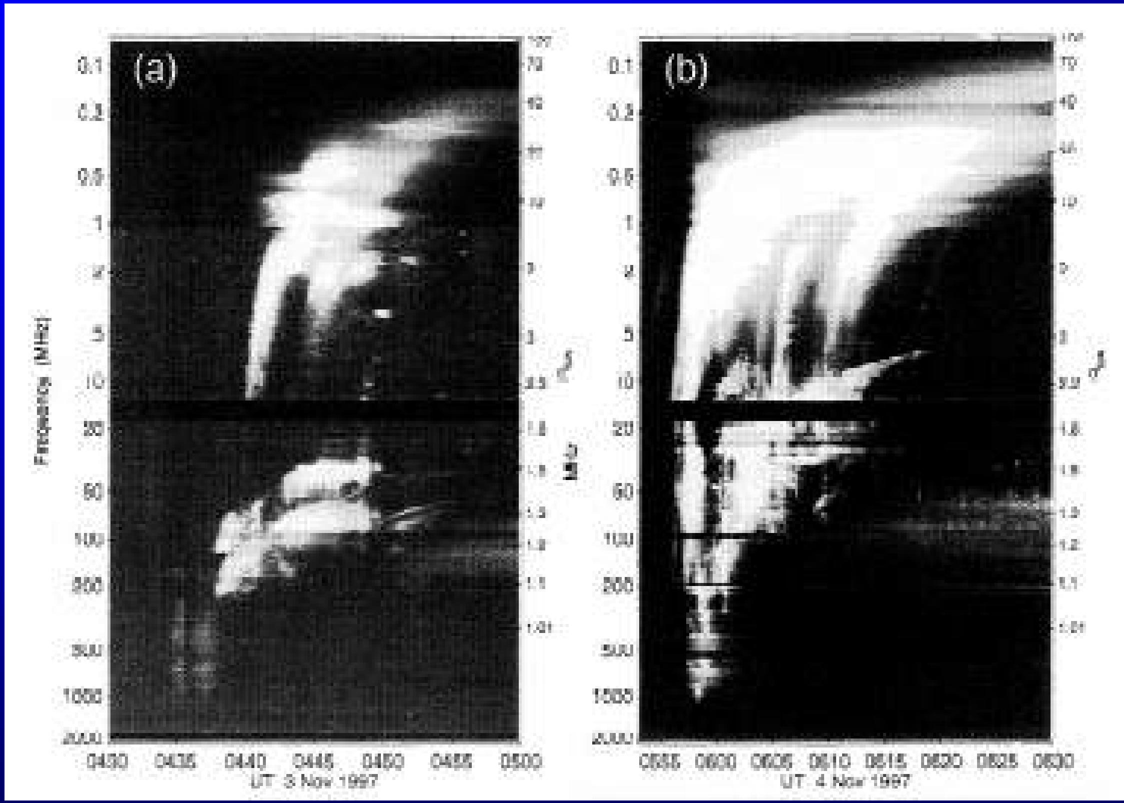


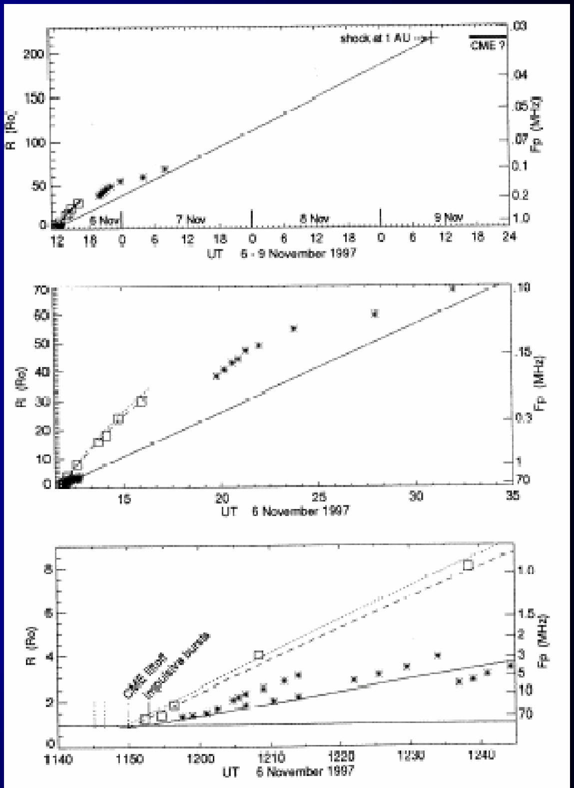
ORT (327MHz)

- **Follow the CME evolution in IP space.**

ICME tracking with radio spectra

Continuous Spectral Coverage of Radio Solar Emissions.





- Establish the flare/CME/Type-II temporal relation.
- Multiple Type-II sources.
- Evidence for shock-accelerated electrons.

Contributions of radio/WL observations

- **CMEs evolve/form rapidly in the low corona (~<15 mins).**
- **The features seen in WL could originate from a large area of the corona (front & back).**
- **CMEs are magnetic, large-scale structures.**
- **Electrons are accelerated in the low corona throughout the event.**
- **CMEs may interact with each other.**

Open Questions

- What do the radio signatures tell us about the initiation mechanism?
- Where to the accelerated particles originate (flare or CME shock)?
- Can we find a reliable CME precursor in the radio?
- What can we learn about the CME evolution in the heliosphere from radio?
- Can we probe the magnetic structure of a CME with radio?
- Can we detect the thermal emission from CMEs?

Advantages of radio observations for CME studies

- **Accurate timing of eruption initiation and development.**
- **Derivation of physical parameters in the eruptive structures (when thermal).**
- **Positional information on Type-II (shocks) sources.**
- **Identification of electron acceleration sites.**
- **Tracking the CME evolution from birth to Earth.**
- **Discovery of precursors to solar eruptions.**

Backup Slides

Summary

- **Shortcomings of Radio Observations:**
  - –**Inadequate imaging (few frequencies, hours, low sensitivity).**
  - –**Wide variation in the spectrometer characteristics (coverage, sensitivity) .**
  - –**Physics of Type-II emission are poorly understood.**

Solution

Broadband imaging spectroscopy from a solar-dedicated instrument:

Radio Type-II Emissions & CMEs

Detections of shocks in other regimes.

- UVCS detection of a shock (Raymond et al. 2000).
- Yohkoh/SXT detection of a shock (Khan & Aurass 2002).
- Detection of a 17 GHz signature of an EUV wave (Aurass et al. 2002; White et al. 2002).

Radio signatures of CME interactions.

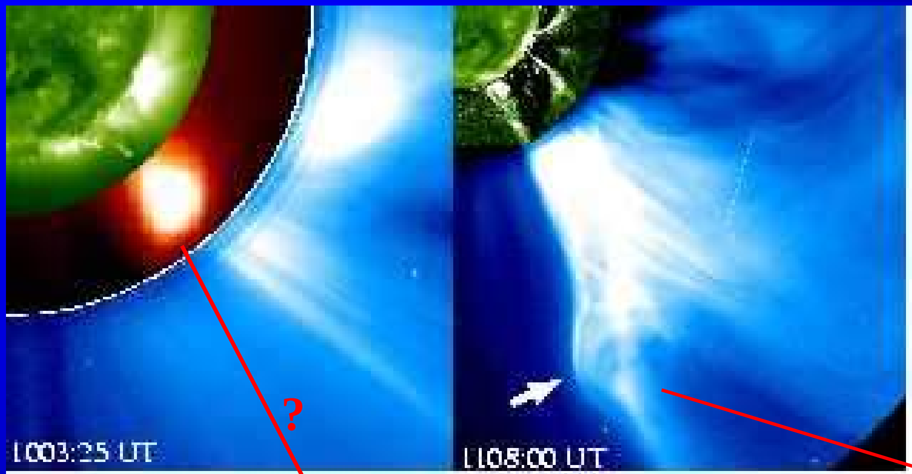
- Radio signatures of CME interaction at large distances (Gopalswamy et al. 2001; Reiner et al. 2002).

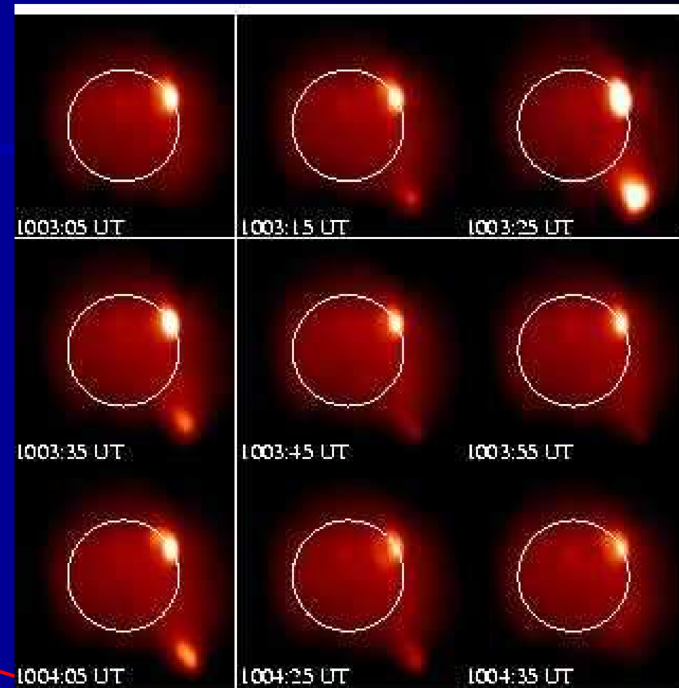
VLA observes at 75 MHz.

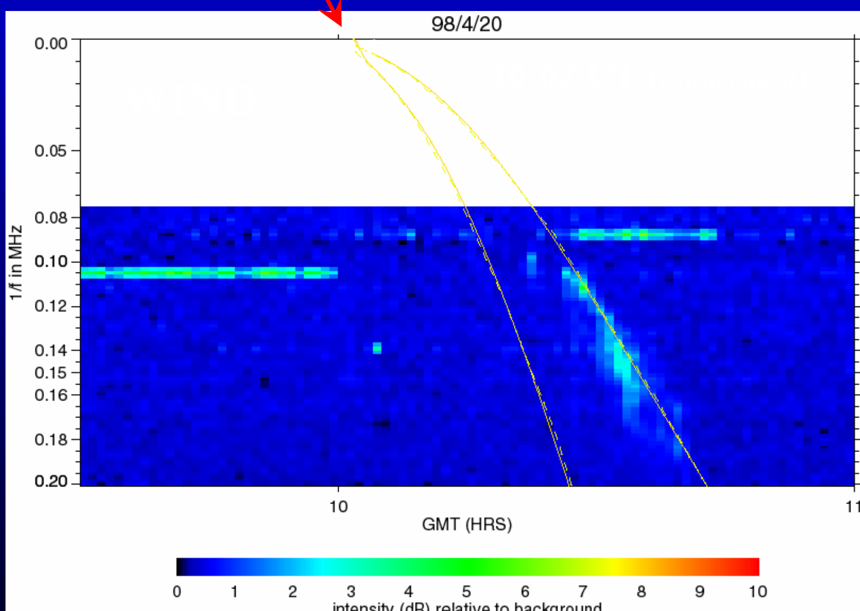
- Bursts seen around CME times suggest long-term particle acceleration (Willson et al. 1998; Willson 2000).
- No detection of thermal CME emission (Gary et al. 2003).

"*Type-II*"-like sources in white-light images

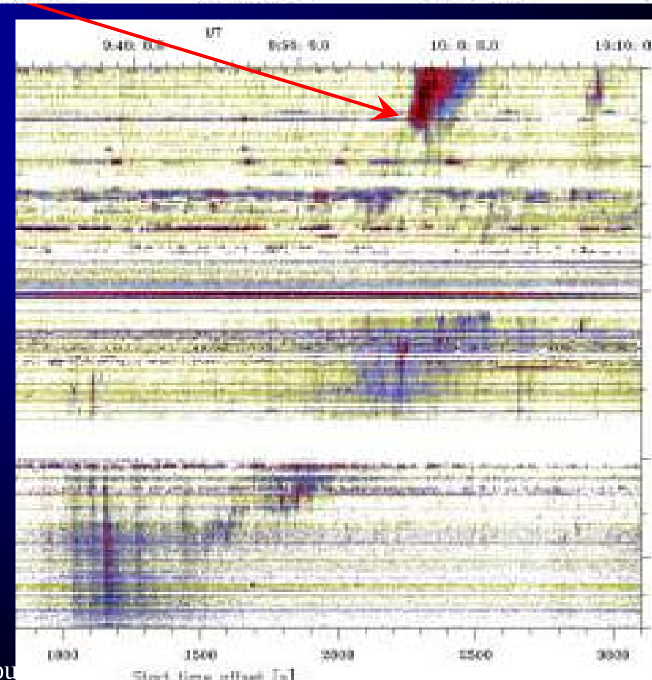
NRH



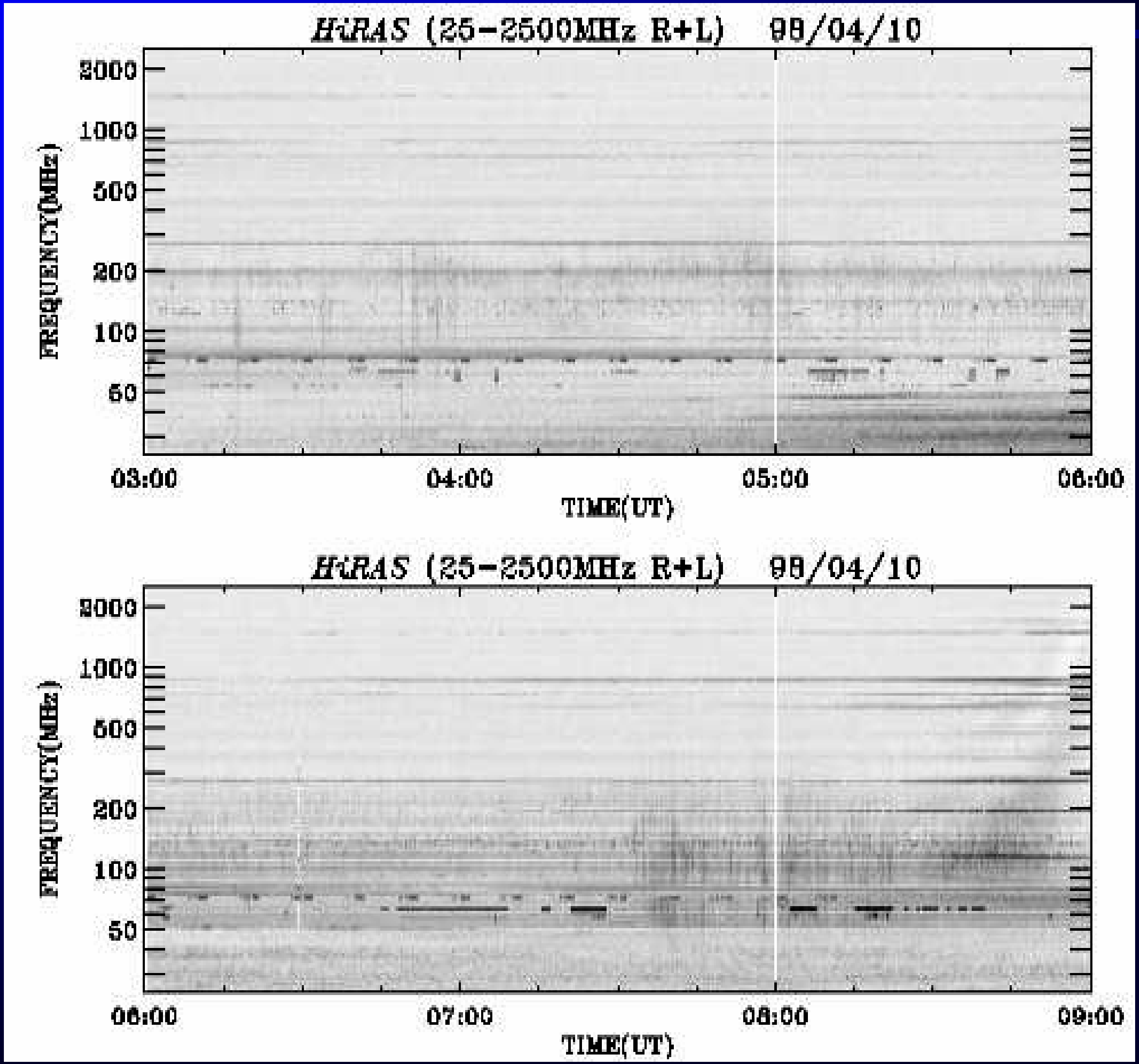




AIP

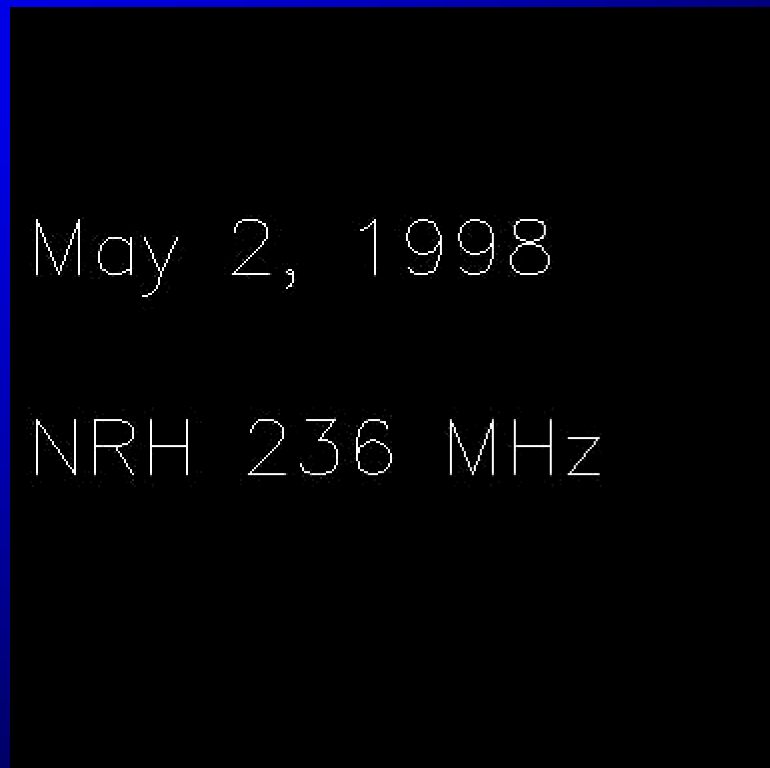


Noise Storms



May 2, 1998 Radio CME

- **10 min of the radio CME**



What’s New in Cycle 23

- **LASCO/EIT revolutionize the study of solar eruptions.**
- **Nançay radioheliograph acquires imaging capability.**
- **WAVES records radio bursts in the unexplored region <15 MHz.**
- **AIP, Culgoora, BIRS, Artemis and several other spectrographs are operational (none in US).**
- **VLA acquires 75 MHz capability.**
- **Nobeyama Radioheliograph analysis focuses on eruptions.**

- **Gauribidanur Radioheliograph is operational.**
- **Ooty telescope produces IPS maps of CMEs.**
- **GMRT has solar observing capability.**
- **Siberian Solar Radio Telescope observes in 5.7 GHz.**
- **Huairou spectrograph data become available.**
- **Solar Radio Burst Locator will come online soon.**