Radio CME Observations in the m-dm Regime and the Future of NRH

Angelos Vourlidas
Naval Research Laboratory

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 imaging is possible on the disk (no occulter) AND traces both flare and CMEs development

See reviews by Pick & Vilmer (AARev, 16, 2008), and Vourlidas (2004)
ISSI book on CMEs (2006), CESRA Papers (Sol. Phys., 253, 2009)

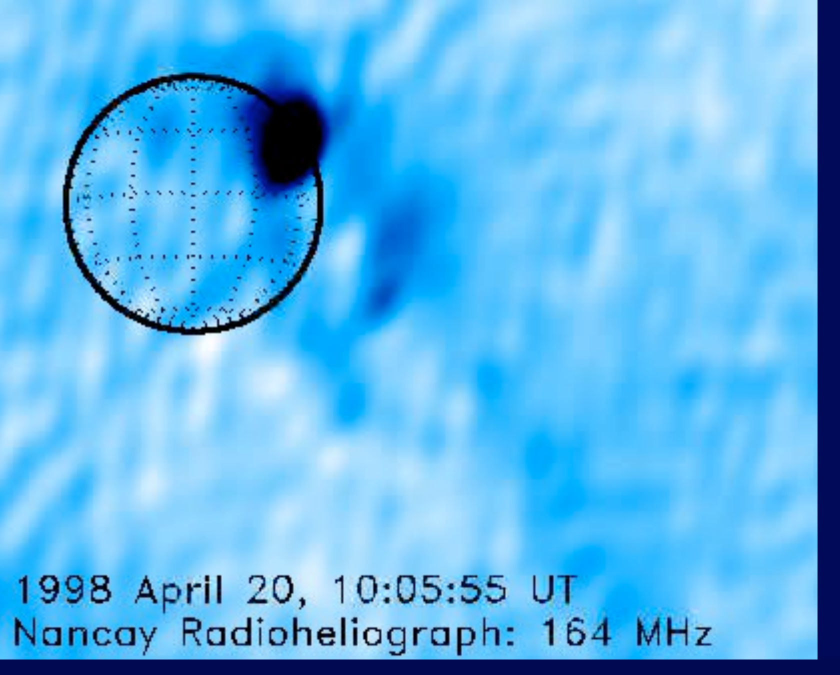
How can NRH contribute?

or

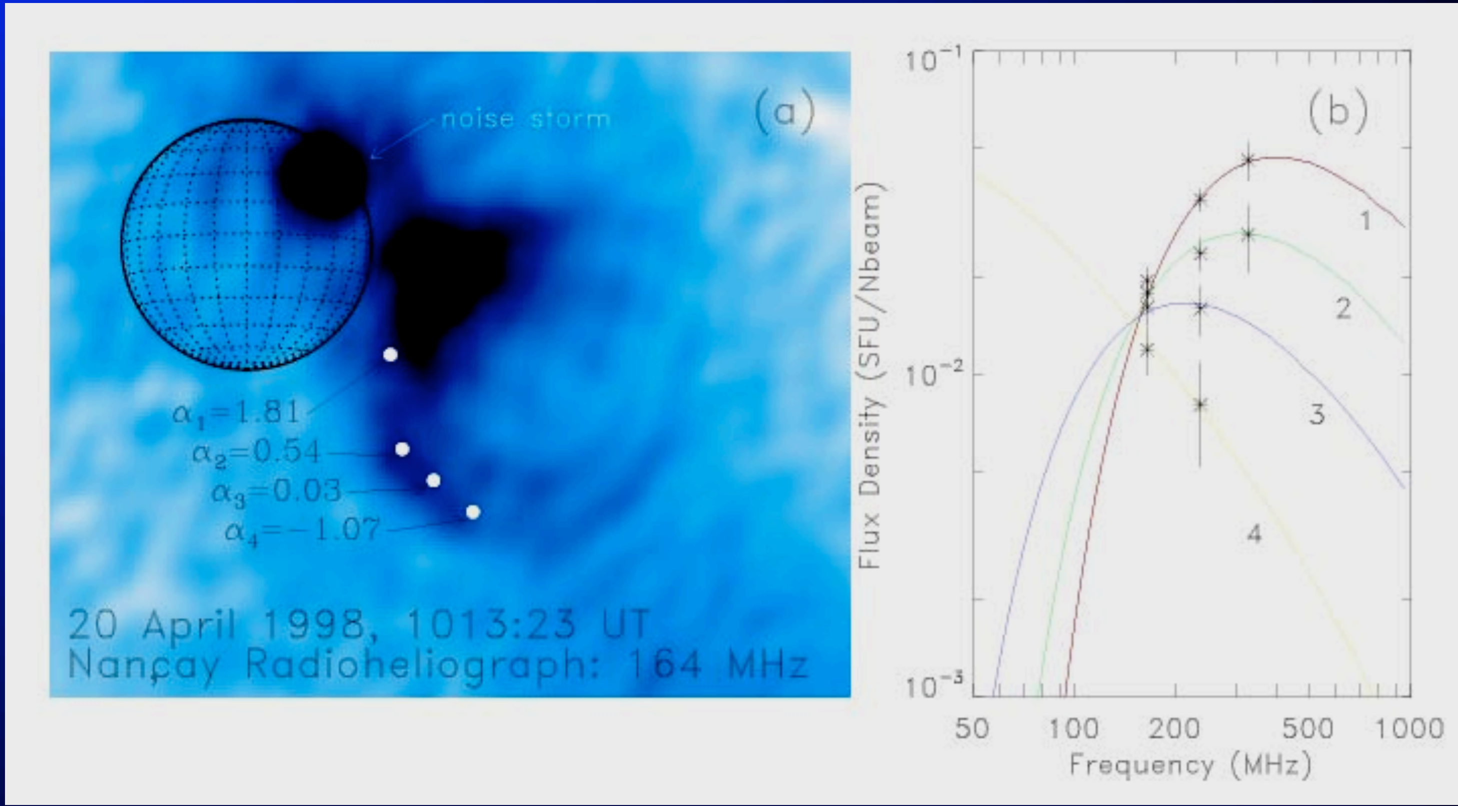
what CME science is accessible below in m-dm?

1. Radio CMEs

Image directly the radio CME (Bastian et al, Maia et al)



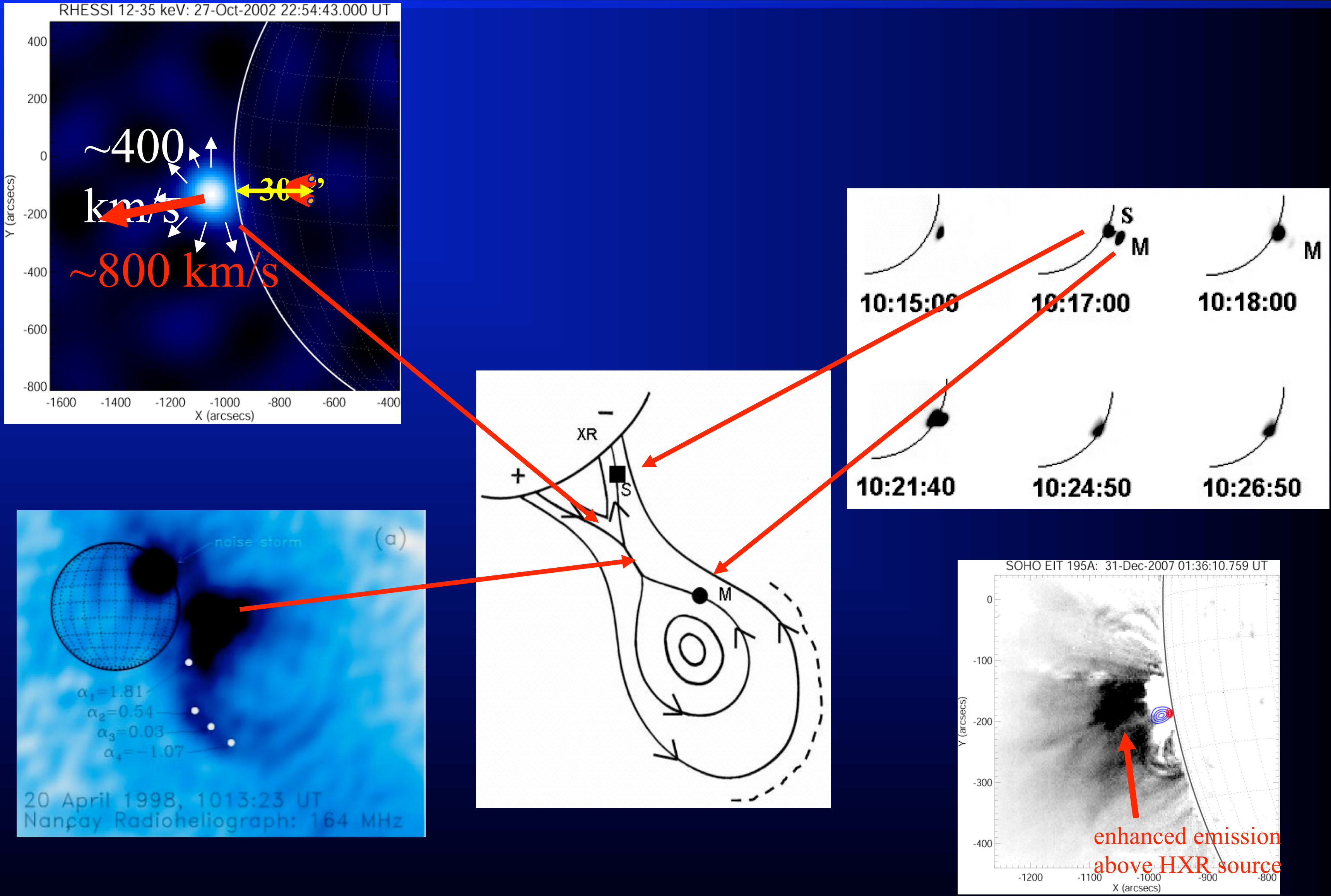
Why Radio CMEs are important?



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

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

Radio images the site of the magnetic energy release



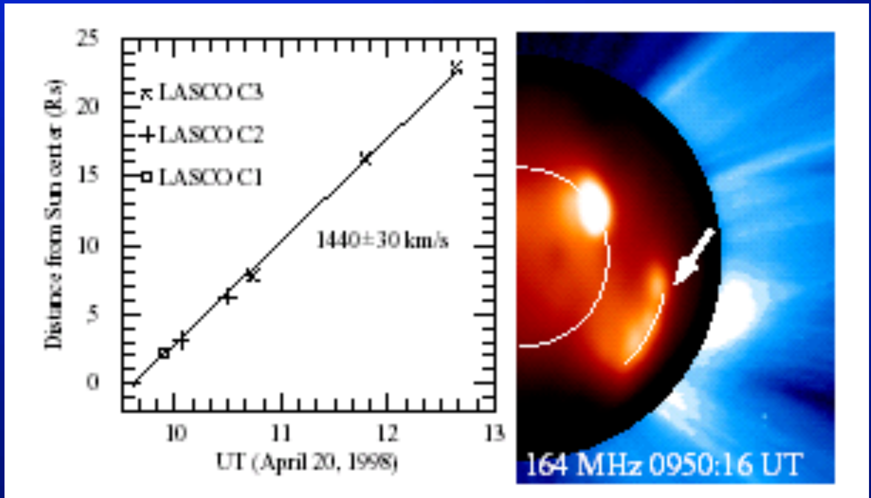
Why Radio CMEs are important?

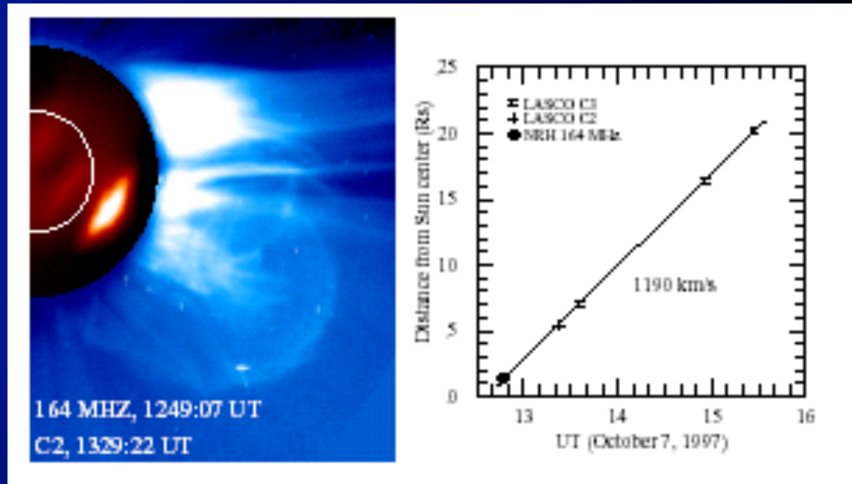
OPEN QUESTIONS:

- Does every CME have a radio counterpart?
  - Only fluxrope-type CMEs?
- Is the emission gyrosynchrontron?
- Connectivity to low corona?
  - Understand the origin of all radio sources.
- Can we understand SEPs through radio CMEs?

2. 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.

Why Radio Shocks are important?

- **Clarify origin/driver of type-II emission (*once and for all!*).**
- **Understand physical conditions that give rise (or not) to type-II emission.**

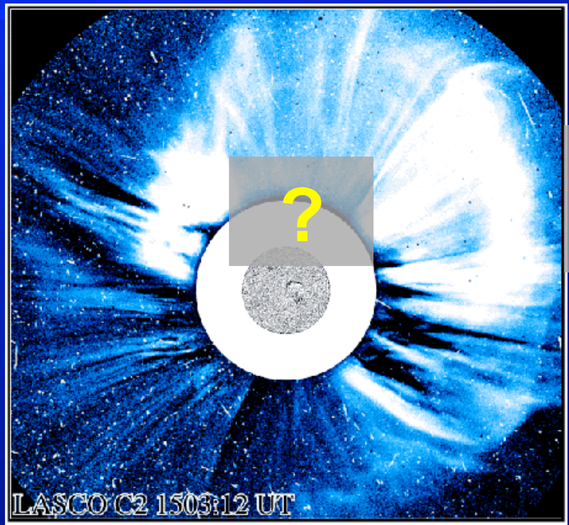
OPEN QUESTIONS:

- **Does the shock lead to other remote acceleration sites?**
- **What is the relation between type-IIs and SEPs?**
- **Can we use the type-II as a tracer/locator of the CME propagation?**

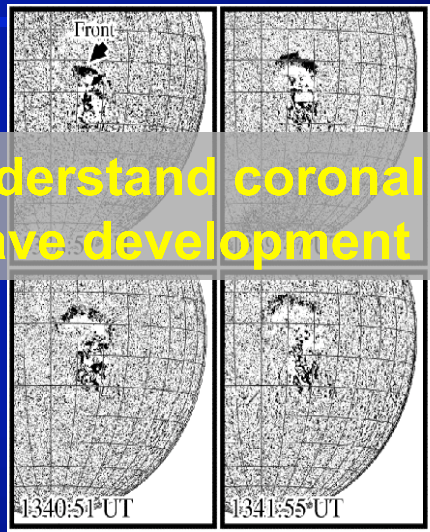
3. Trace CME Initiation & Development

- 10 min of the radio CME
- 10 sec cadence
- Reveals sites of electron acceleration

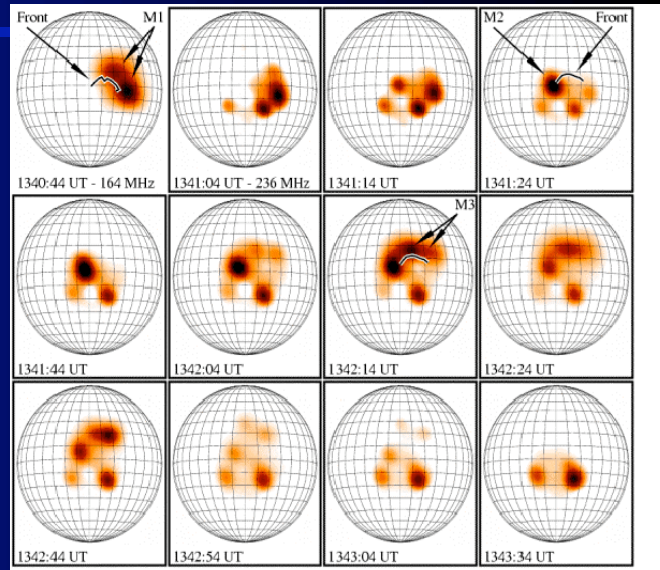
Why Radio Imaging of on-disk CMEs is important?



Understand coronal wave development



Hα images

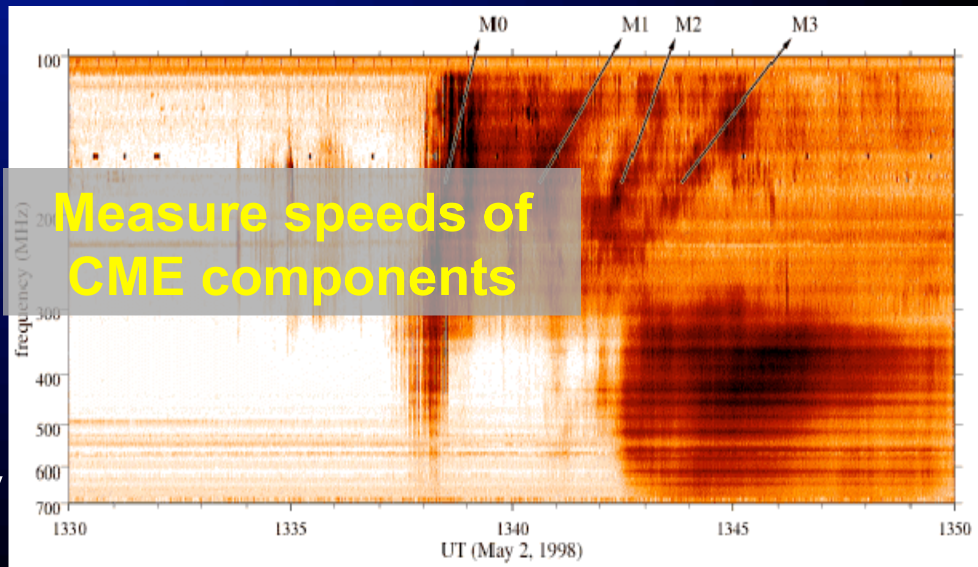


NRH sources at 236 MHz

Observe timing/ location of ejected structures

EIT dimming

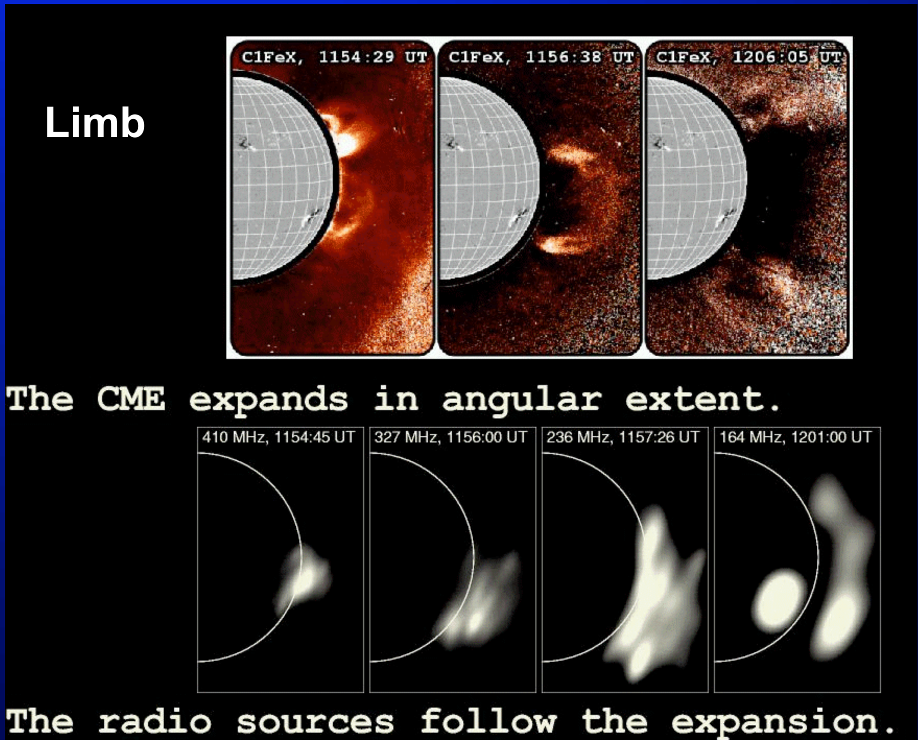
Artemis IV spectrum

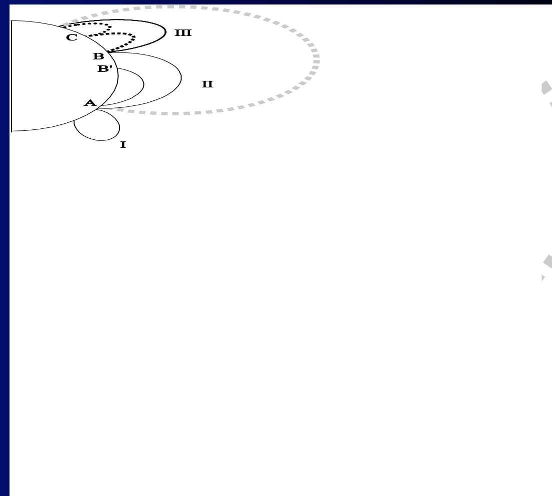


Measure speeds of CME components

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.

Why Radio Imaging of CME initiation is important?

- Fast radio cadence offers the best way to monitor CME development
- Can observe both flare and CME development

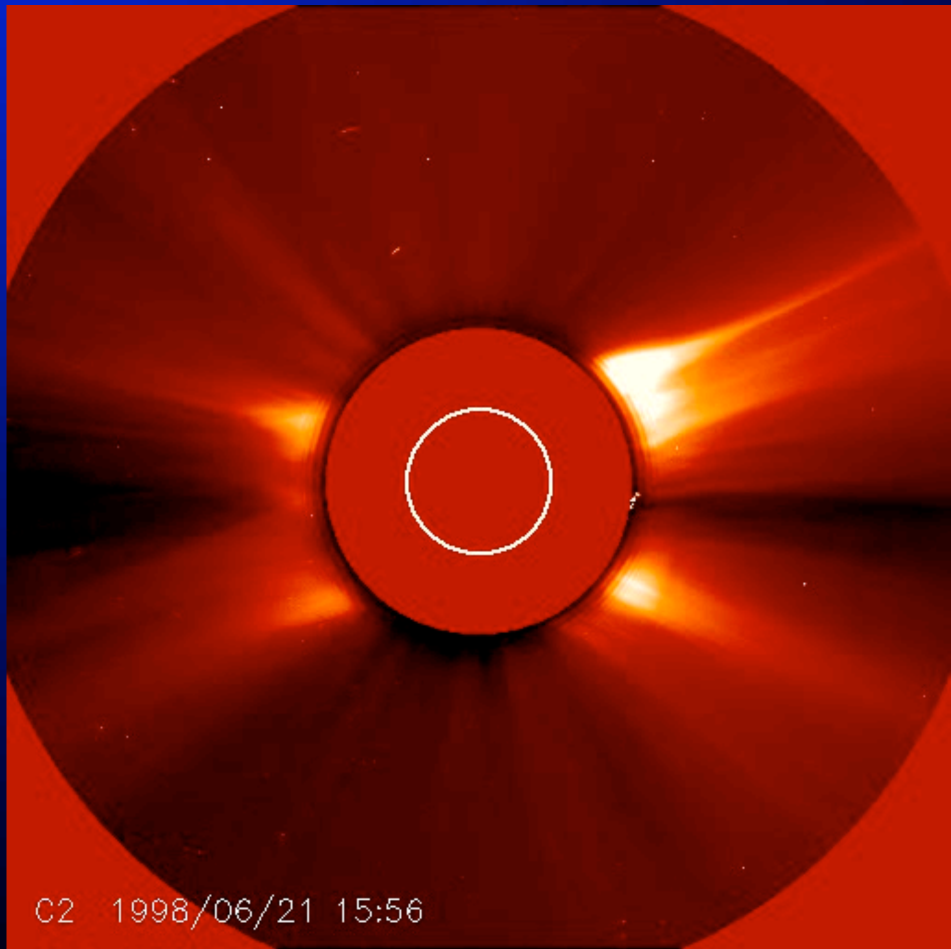
OPEN QUESTIONS:

- Can we locate the sites of SEP acceleration?
- Can we separate non-thermal from thermal radio emissions?

- Can we use the radio observations as a proxy/replacement of EUV/ WL imaging?

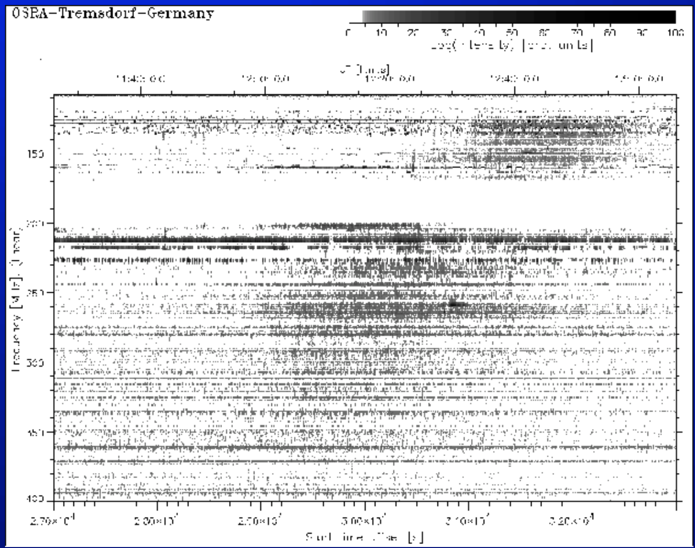
4. Radio precursors of CMEs (?)

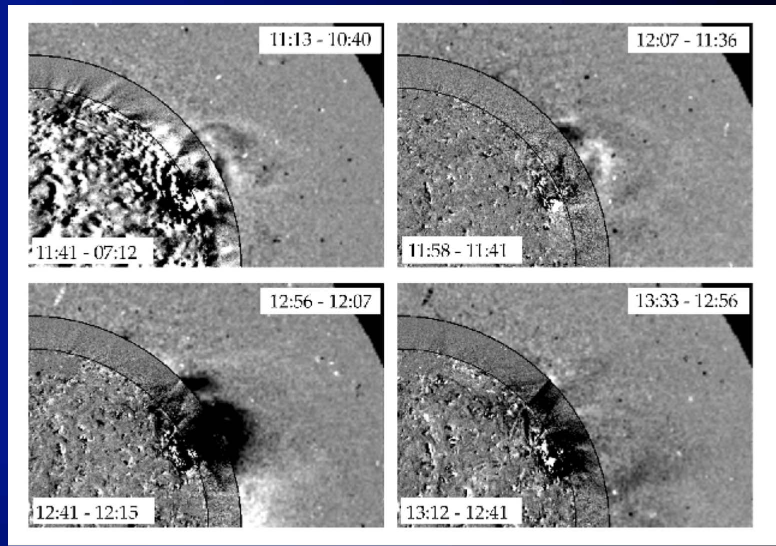
- **WL & EUV: Rising and expanding EUV loops and/or streamer loops for minutes/hours (days in *streamer-blowouts*) before the CME erupts**



4. Radio Precursors of CMEs

Drifting continuum sources may mark the CME birth.





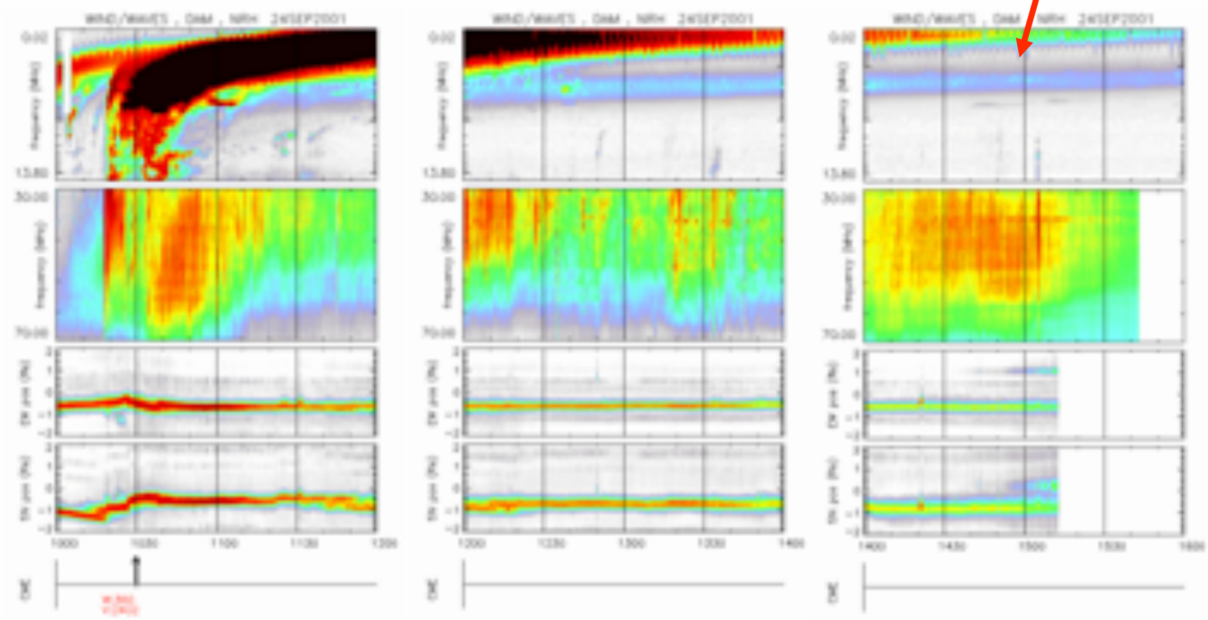
The role of Noise Storms remains controversial.

- 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.

5. Post-CME Sources

Is this a signature of the streamer reforming?

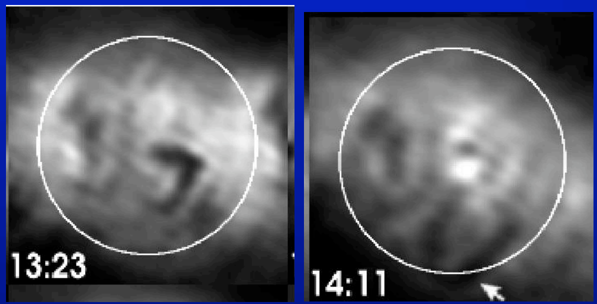


Vourlidas et al 2007

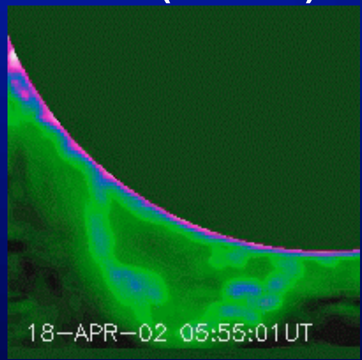
6. Other Radio imaging

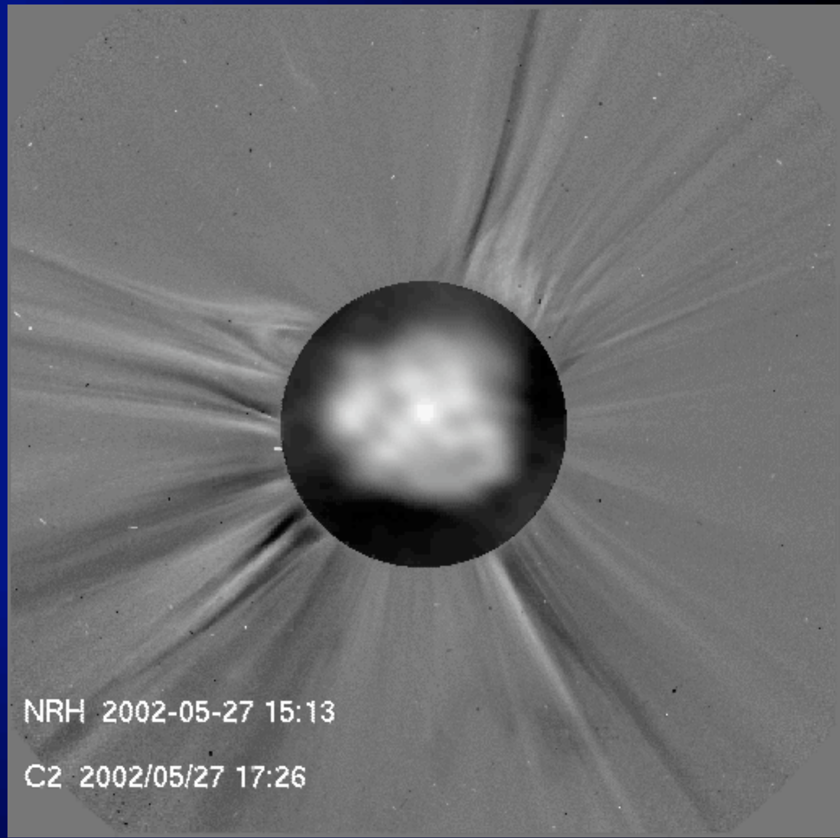
Follow Eruptive Filaments.

NRH (410 MHz)



NoRH (17GHz)





- Follow the initial activation with high cadence (<10sec).
- Trace the coronal structures that participate in the eruption.

Radio Filaments

3min cadence!

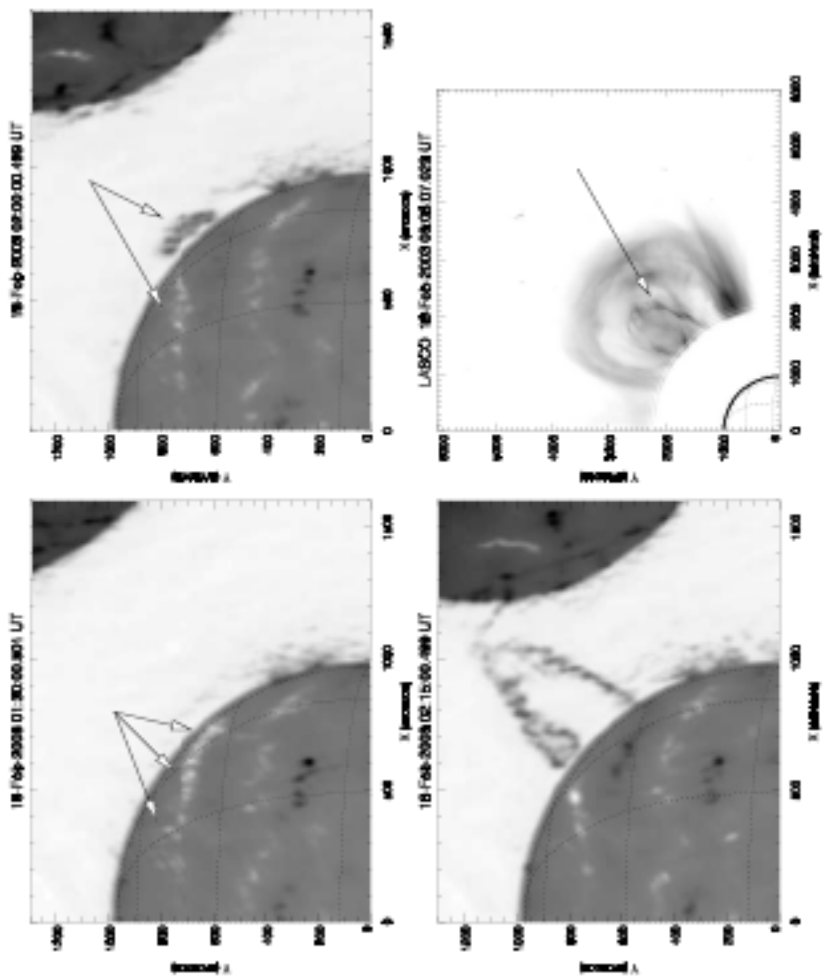
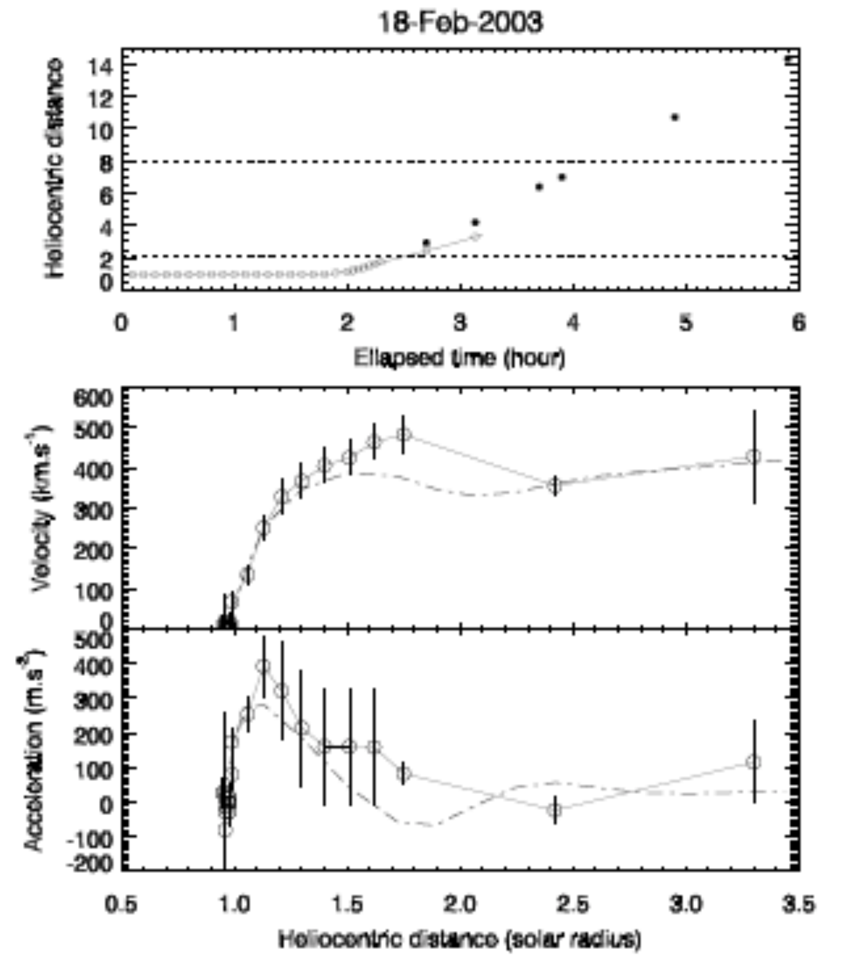


Fig. 6 — (a) Nobeyama Helioradiograph images and LASCO C2 image.



From Chen et al 2006

Advantages of radio (m-dm) CME observations

- Accurate timing of eruption initiation and development.
- Derivation of physical parameters in the erupted fluxrope (e.g., magn. field).
- Identification of electron acceleration sites (connection to SXR/ EUV signatures)
- Positional information on Type-II (shocks) sources.

- *Derivation of physical parameters in the eruptive structures (when thermal).*
- *Evidence for precursors to solar eruptions.*

- Tracking the CME evolution from birth to Earth (spectra).

Open Questions (for m-dm radio)

IMPORTANT

- **What do radio observations reveal about the initiation mechanism?**
- **Can we probe the magnetic structure of a CME with radio?**

VERY LIKELY

- **Where to the accelerated particles originate (flare or CME shock)?**
- **Can we find a reliable CME precursor in the radio?**

LESS PRIORITY

- *Can we detect the thermal emission from CMEs?*
- *What can we learn about the CME evolution in the heliosphere from radio?*

Suggestions

1. **Higher sensitivity (dynamic range)**
   Why? Image weak radio CME/thermal emission/faint type-II sources
   How? More antennas (how many?), upgrade receivers
2. **More frequencies**
   Why? Constrain spectra within the radio CME, Separate thermal/non-thermal sources, Better speed estimates for type II, III, IV
   How? Up to ~600MHz (connect w/ Artemis & Portuguese spectra)
   Down to ~74MHz (connect to AIP, observe more type-IIs)
3. **Improve self-cal procedures**
   Why? Higher SNR, fidelity imaging, Easier removal of bright sources/image the faint ones, Removal of refraction effects
   How? Monitoring/calibrating radio equipment, other ideas?
4. **Implement better RFI rejection schemes**
   Why? Imaging in more frequencies, better data quality
   How? Use experience from FASR development, narrowband receivers
5. **Concurrent spectra (GHz → kHz)**
   Why? Follow structures to heliosphere, connect w/ STEREO, etc
   How? Incorporate spectrographs (at least in same timerange) into a single ‘radio observatory’.

For discussion

- How many antennas?
- How many frequencies (10 currently)?
- Frequency range (600 – 80 MHz)?
- Which narrowband receivers?
- New correlator?
- RFI, ionosphere rejection?
- Formation of a joint imaging/spectral radio observatory (a sort of ‘FASR’)