Overview of White Light & Radio Signatures of CMEs

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Lecture Outline

• Related Lectures:
  – **Overview**: Space weather
  – **CME/SEP Obs & Models**: SEPs, Coronal/IP Shocks
  – **Basic Physics**: Reconnection, radio seminars
  – **Practicum**: 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 **bright** 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 **disappears** 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 (0.3c)
- **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 \((\text{when cadence allows})\) for hours (days in \textit{streamer-blowouts}) before the CME erupts
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.
CMEs are not ‘puffs of coronal smoke’

- WL: CMEs contain large structures (e.g., filaments)
Follow Eruptive Filaments.

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

NRH (410 MHz)
NoRH (17GHz)
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 $\text{H}\alpha$ 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.

1998 April 20, 10:05:55 UT
Nancay Radioheliograph: 164 MHz
Physical Properties of CMEs

- Image fine-scale CME structures.
- Derive physical parameters:
  \[ B_{\text{CME}} \sim 0.1\text{-few G}, \ E \sim 0.5\text{-}5\text{MeV}, \ n_{\text{th}} \sim 10^7 \text{cm}^{-3} \]
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: launch time, position angle and type-II source region
CMEs can interact with each other

LASCO C2: 2000/06/10 14:08:05

LASCO C2: 2000/06/10 17:30:05

LASCO C3: 2000/06/10 18:18:05

LASCO C3: 2000/06/10 21:18:37

CME1

CORE

CME2

CORE (CME1)

CME2

CORE (CME1)
Radio signs of CME interaction

Wind Waves RAD2 receiver: 2000/6/10

Radio Enhancement

Height [R/Rsun]

09:00 12:00 15:00 18:00 21:00 00:00

CME1

CORE (CME1)

CME2

05:00 10:00 15:00 20:00 25:00 00:00

Position Angle [deg]

09:00 12:00 15:00 18:00 21:00 00:00

Start Time (10-Jun-00 09:00:00)
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
A Fast Limb CME: 31 May 2003

LASCO C3; 31, 04:18
Radio mapping of ICMEs

IPS Mapping of CMEs.

15 July 2000
15/16 July 2000

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:

FASR
Frequency-Agile Solar Radiotelescope
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
Noise Storms

![HFRAS Spectrum](image)

**HFRAS (25-2500MHz R+L) 08/04/10**

- Frequency (MHz) vs. Time (UT)
- Observed spectrum showing noise storms at different frequencies and times.
May 2, 1998 Radio CME

• 10 min of the radio CME

May 2, 1998
NRH 236 MHz
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.