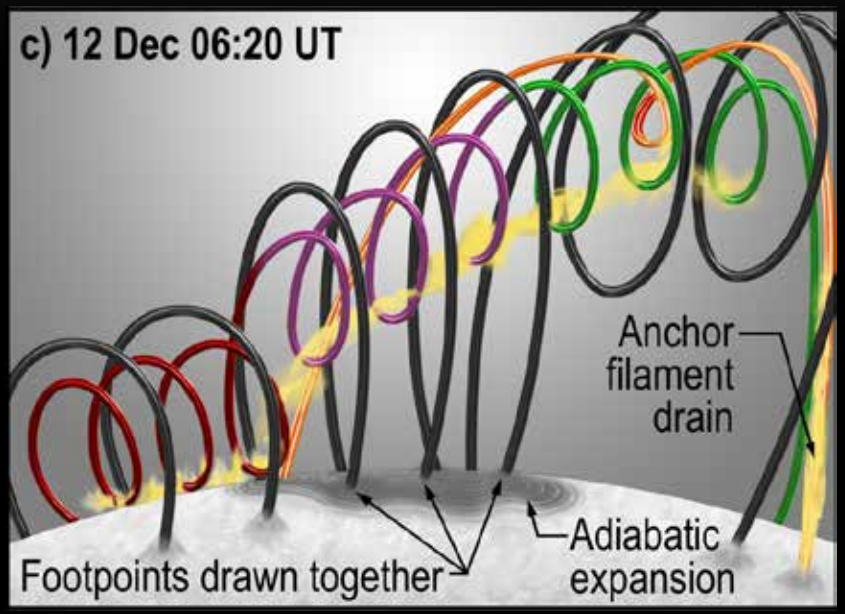
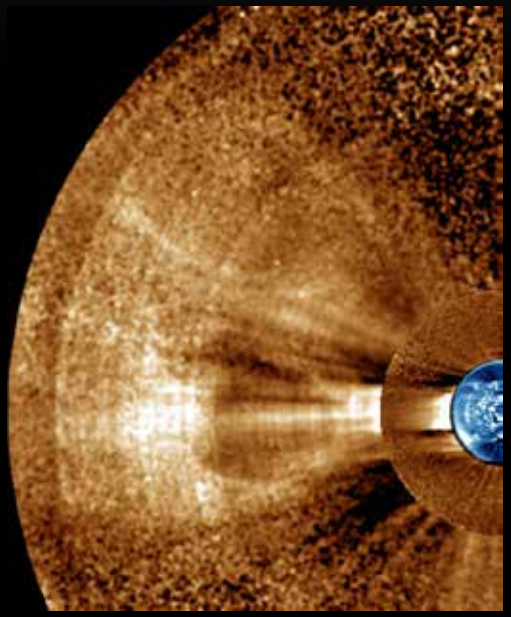
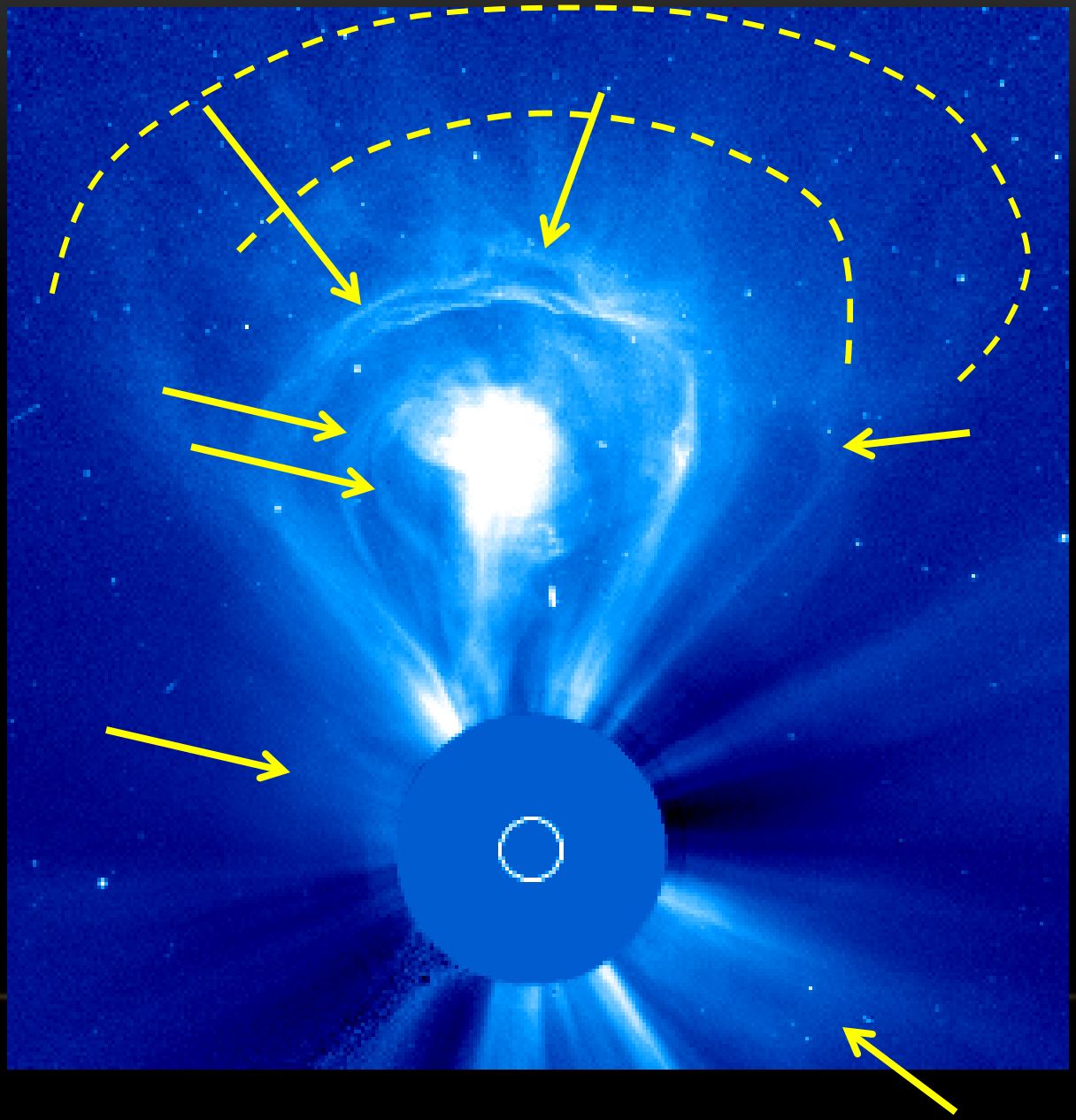
Processing and Analyzing Images of Coronal Mass Ejections



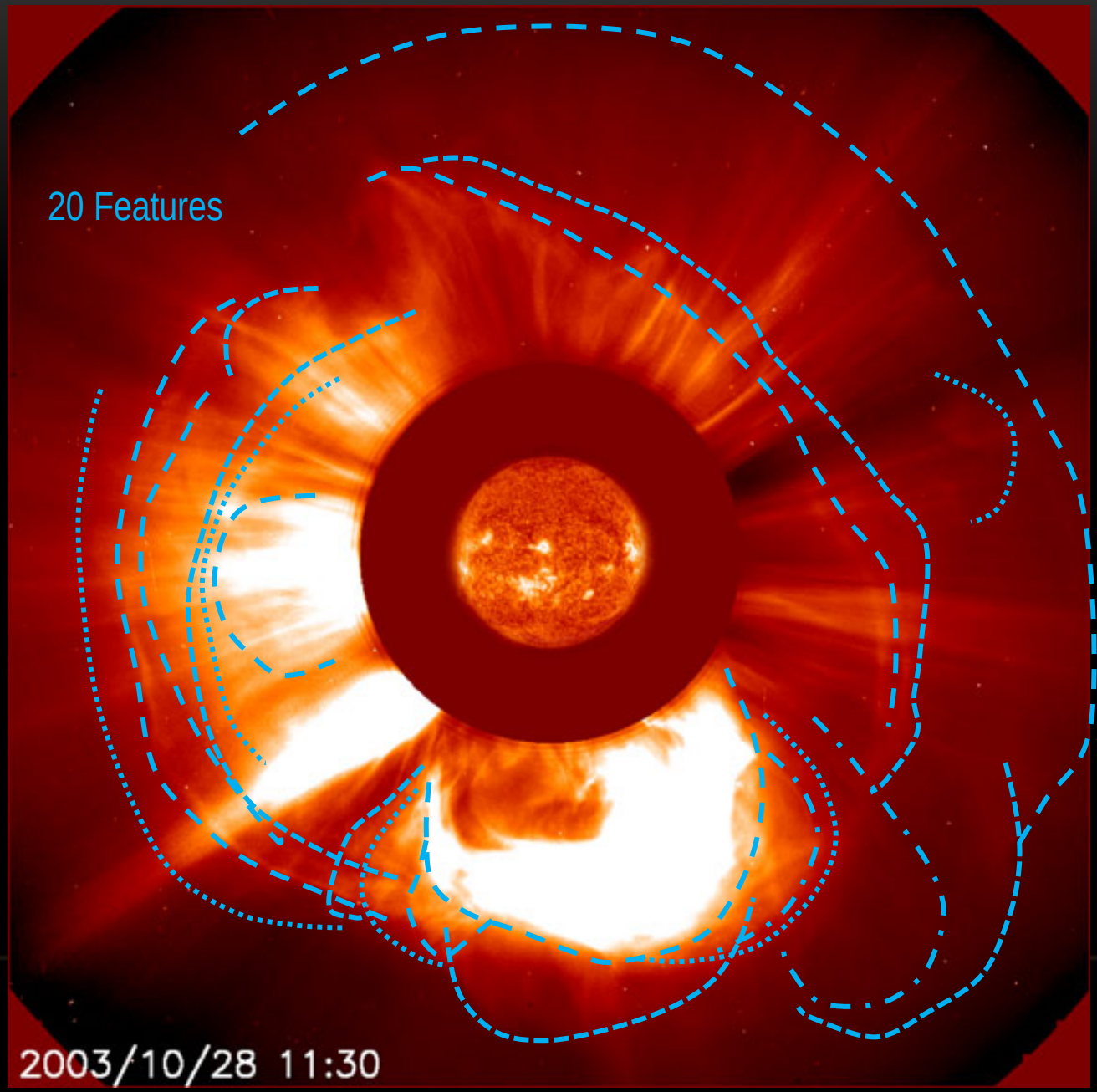


T.A. Howard
Southwest Research Institute, Boulder, CO, USA

What is a CME?



How about a Halo?



What's Going on here?

Physical?

- "CMEs" consist of many parts (e.g., leading edge, cavity, filament)
- Is it a single eruption? (e.g. multiple or sympathetic eruptions)
- How do associated eruptions (flares, EUV waves, filaments, PEAs) come into play?

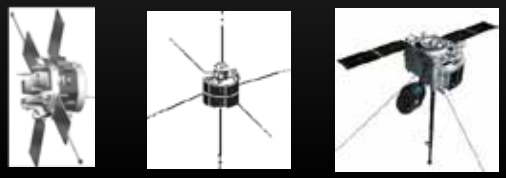
"How do we account for these multiple structures inside a "single" CME?

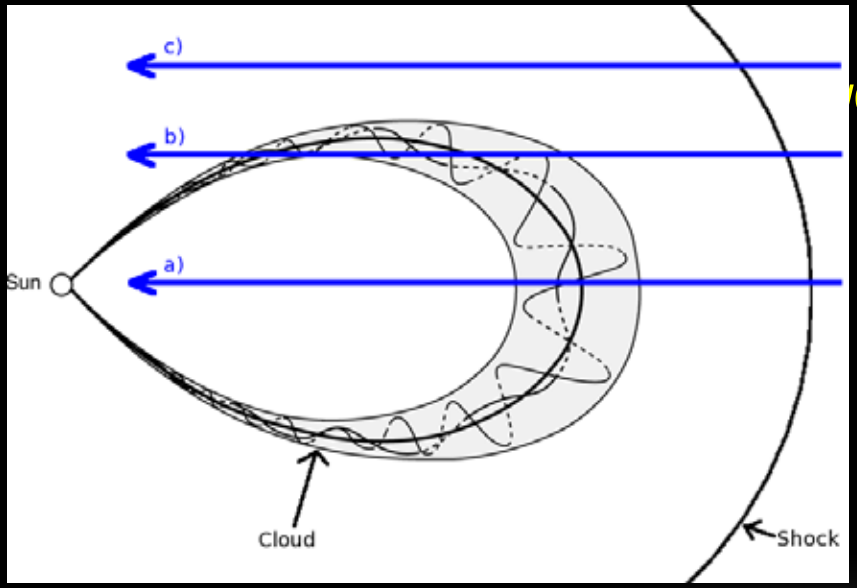
Observational?

- Definition of a CME: Jets? Streamer-blowouts? Disconnections? Blobs?
- Which part do we measure?
- 3-D perspective effects?

The Problem

In-situ





ve detect CMEs?

Lots of detail (B field, density, ionic composition, SEPs, temperature, etc).

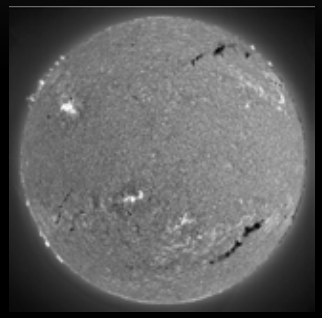
But only along a 1-D track and only at a single point in 3-D space

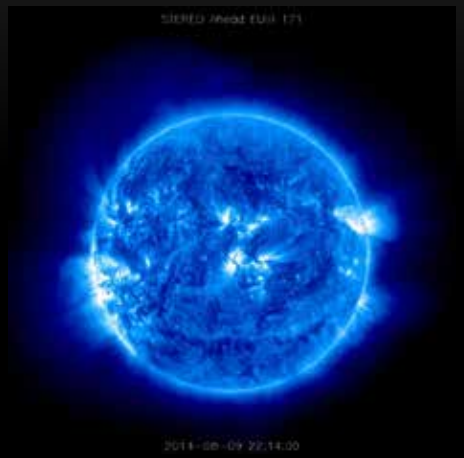
– no global context.

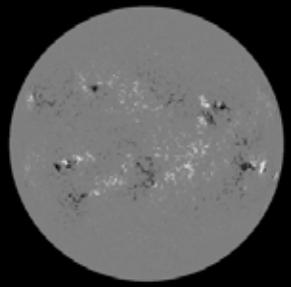
The Problem

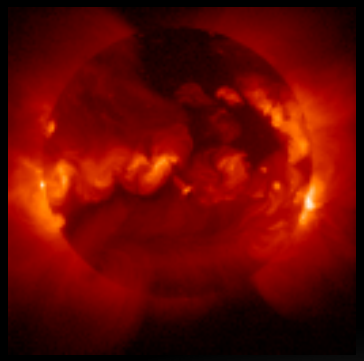
How do we detect CMEs?

Solar Disk Imagers









Searching for things associated with the CME – flares, filaments, active regions, sunspots, EUV/Moreton waves, dimming, PEAs, sigmoids.

3-D Global Perspective.

But rarely (if ever) observe the actual CME.

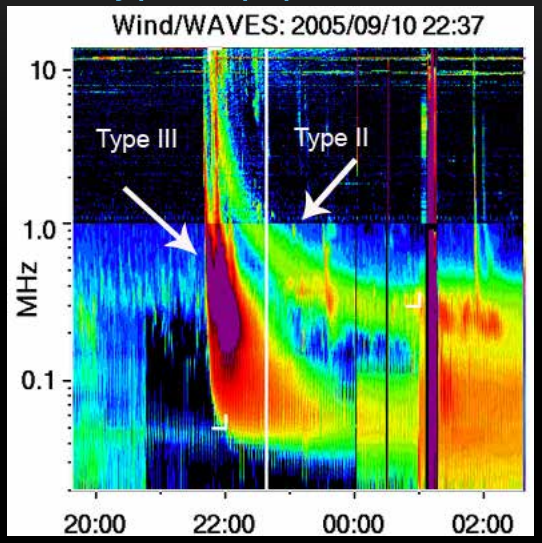
Sometimes you can find a part of it, if you're lucky and know exactly what to look for.

The Problem

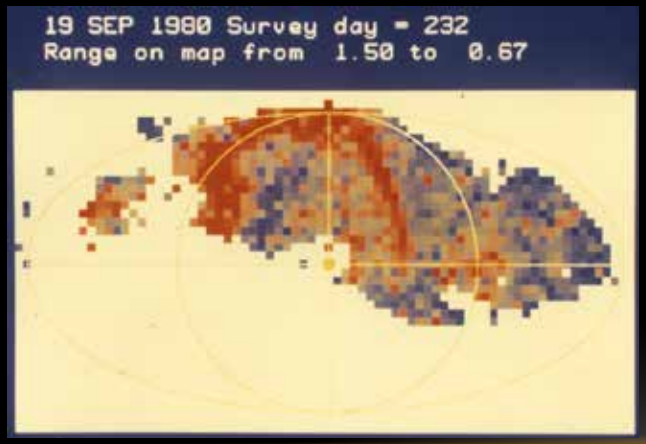
How do we detect CMEs?

Radio, Microwave

Type II (III) Bursts



IPS



Global Perspective.

Track CME progress across large distances in the sky.

But no fine structure.

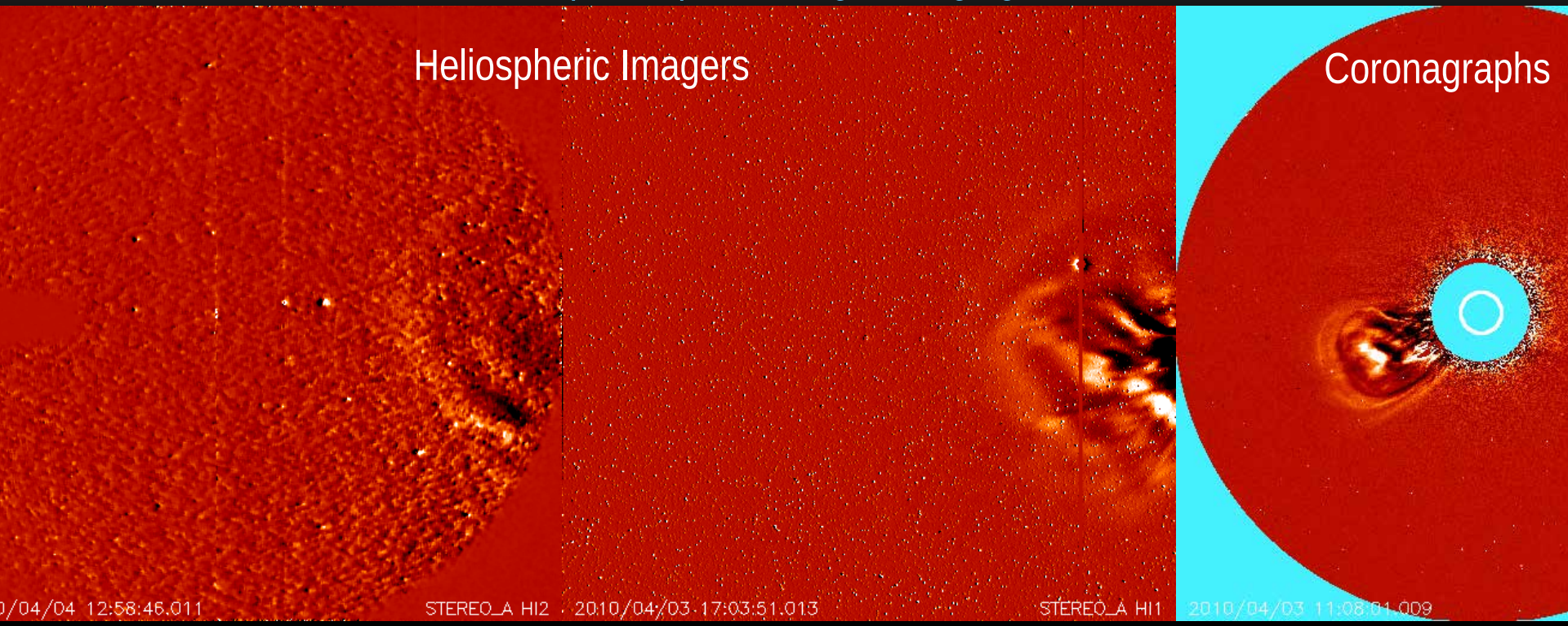
Not observing actual CME.

Little 3-D information.

The Problem

How do we detect CMEs?

(Visible) White Light Imaging



Enables both local and global perspective.

Track CME progress across large distances in the sky.

Enables comparison with other observations

Features difficult to detect against background.

Nature of plasma and Thomson scattering: difficulties for geometry, 3-D location, kinematic tracking.

The Solution

Must utilize and combine ALL of these observing capabilities

Then add some careful data analysis

And a generous helping of luck

Start with white light data – that's our binding agent

White Light Imaging

What Do We Know?

Observing Thomson scattered light → electron density

Optically thin medium → No “solid” objects

Contained within a much brighter background → F corona, stars, planets

No 3-D information directly available → We observe everything along each LOS

Problems to Overcome

Extracting the CME from the bright background

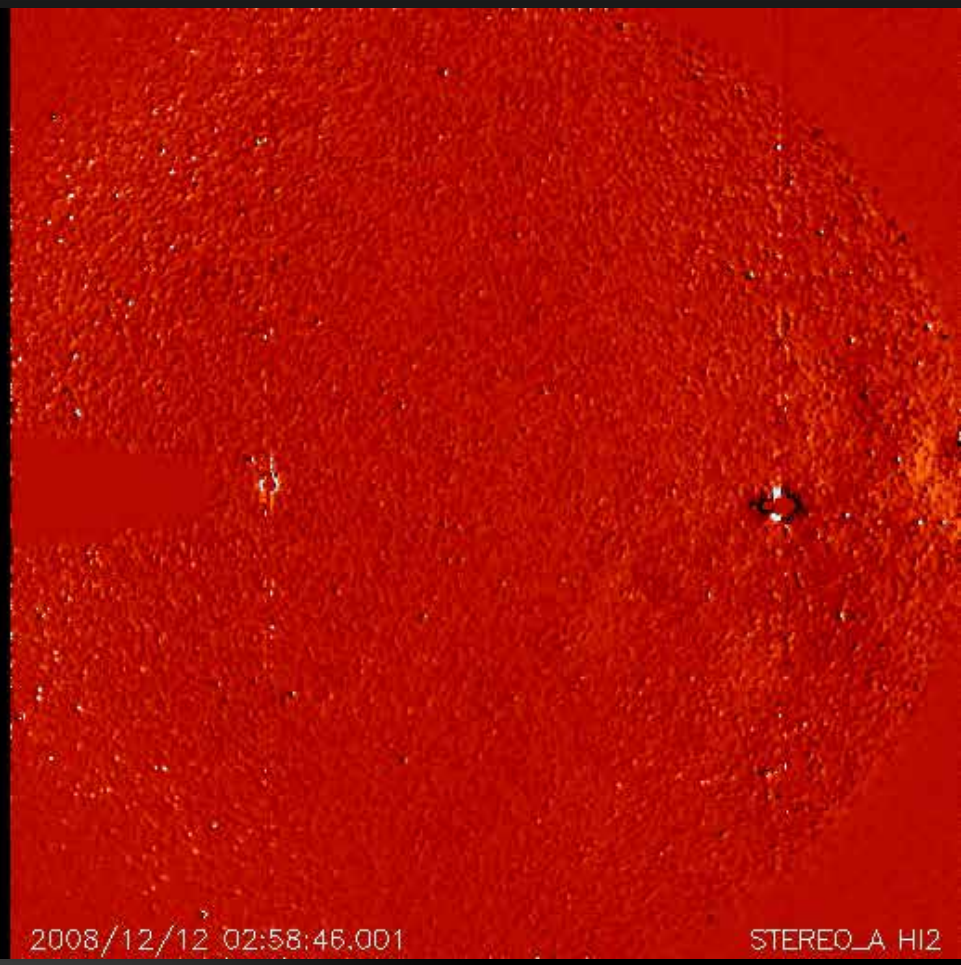
Identifying and continuously tracking a particular feature

Extracting 3-D information

Combining observations with auxiliary datasets

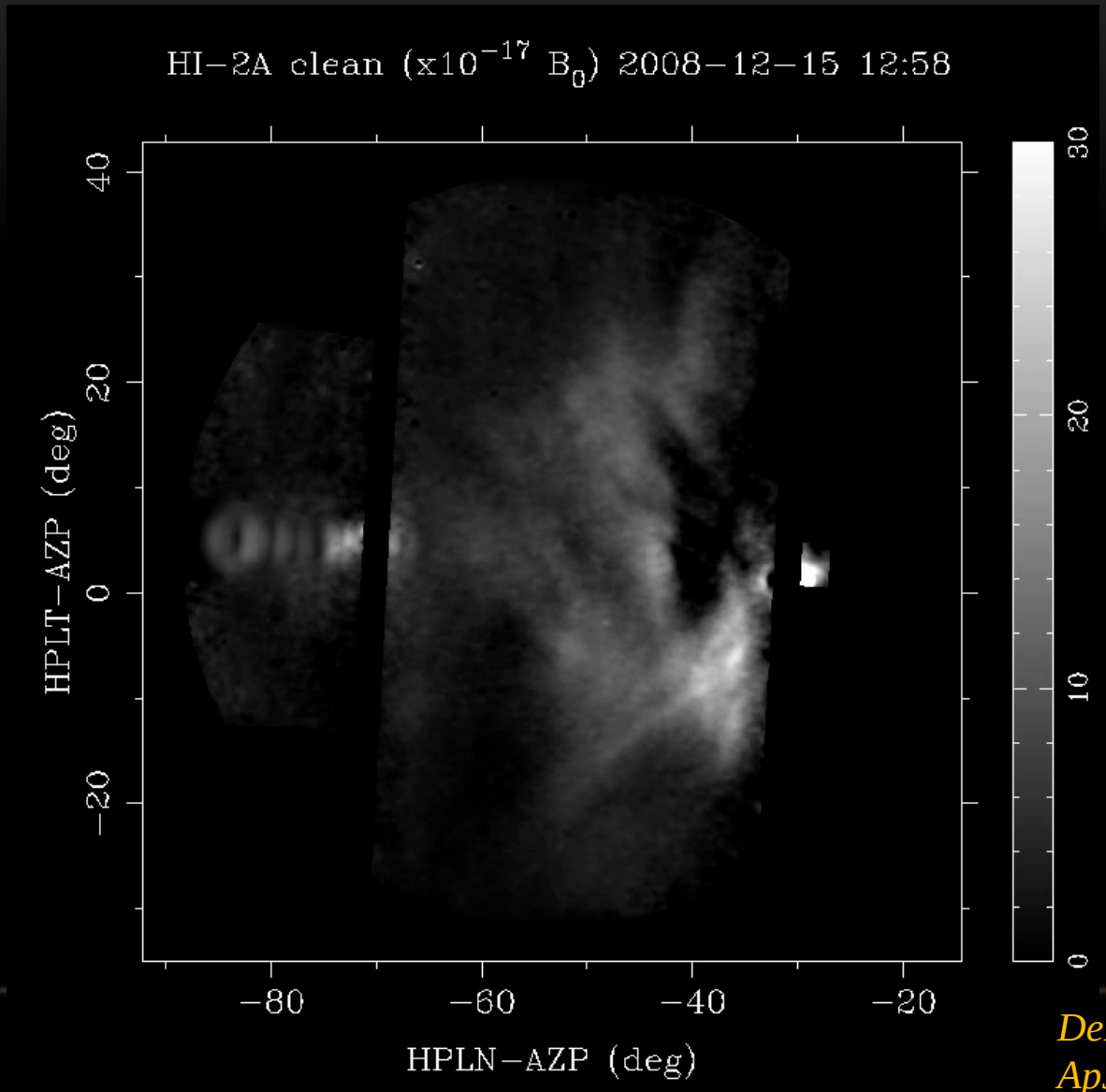
White Light Imaging

Extracting the CME from the Bright Background



White Light Imaging

Extracting the CME from the Bright Background

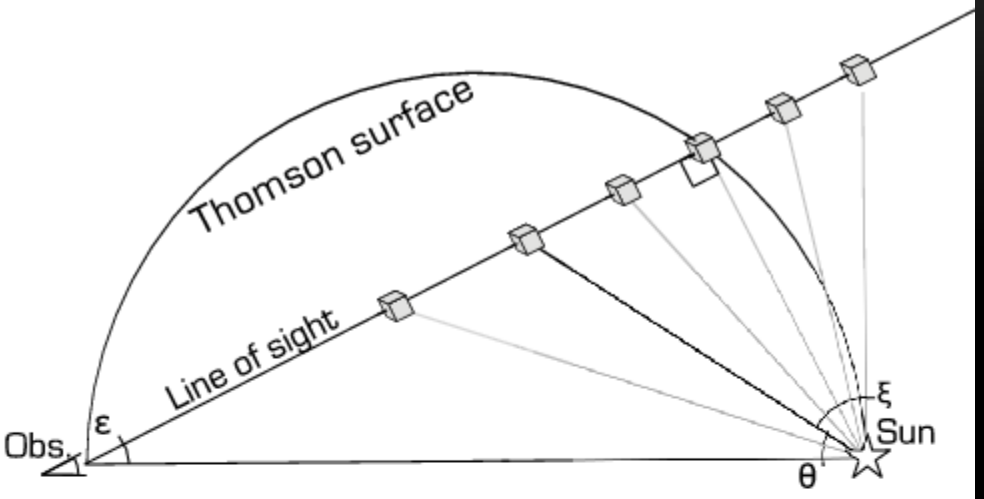


*DeForest et al., ApJ, **738**, 103, 2011*

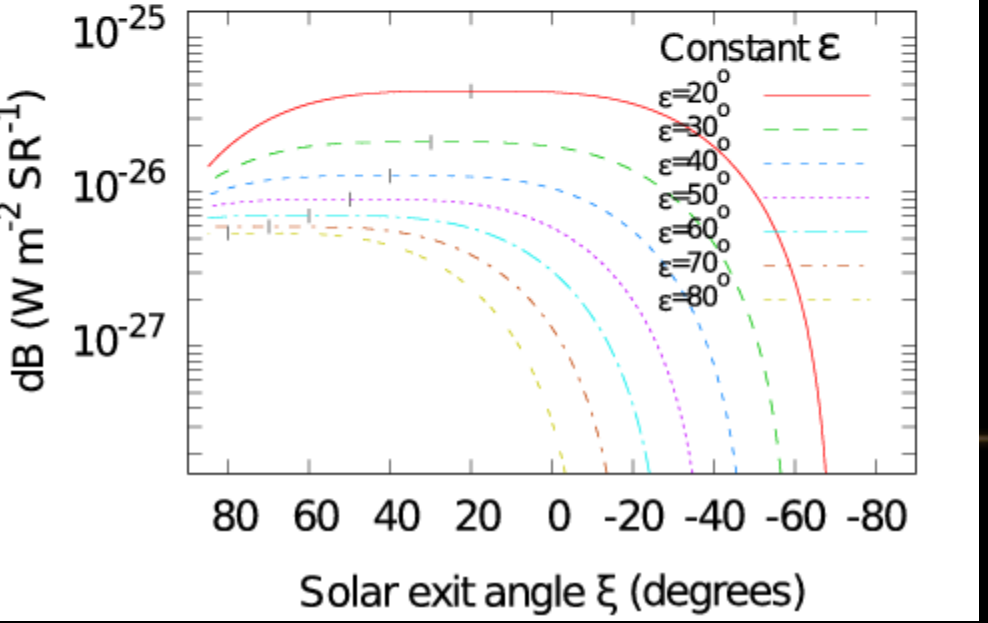
White Light Imaging

Thomson Scattering + Optical Thinness of the Corona & Solar Wind

Recall:
What an imager measures is the brightness per solid angle



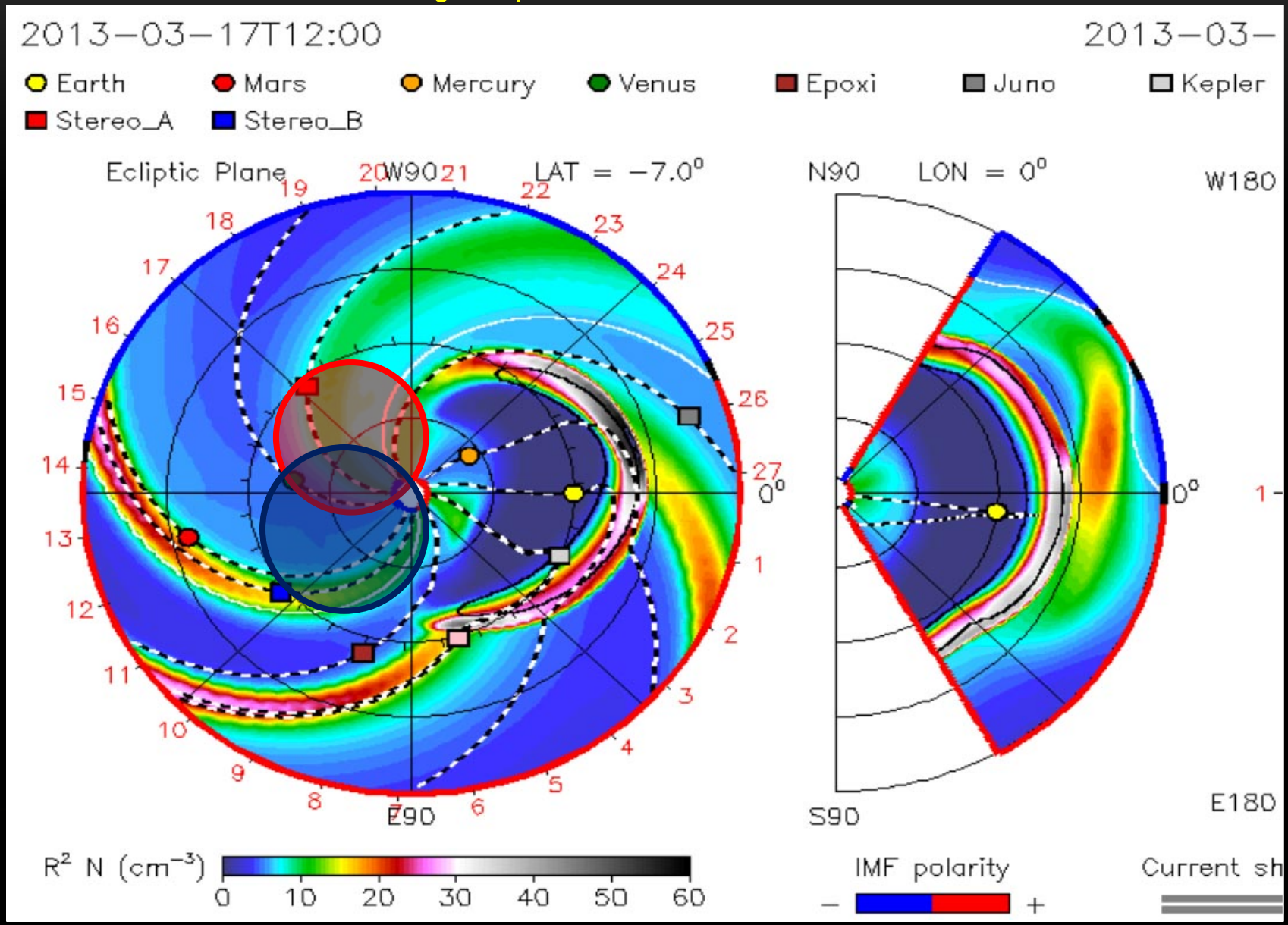
Radiance dB is the average pixel response within a feature.



*Howard & DeForest, ApJ, **752**, 130, 2012*

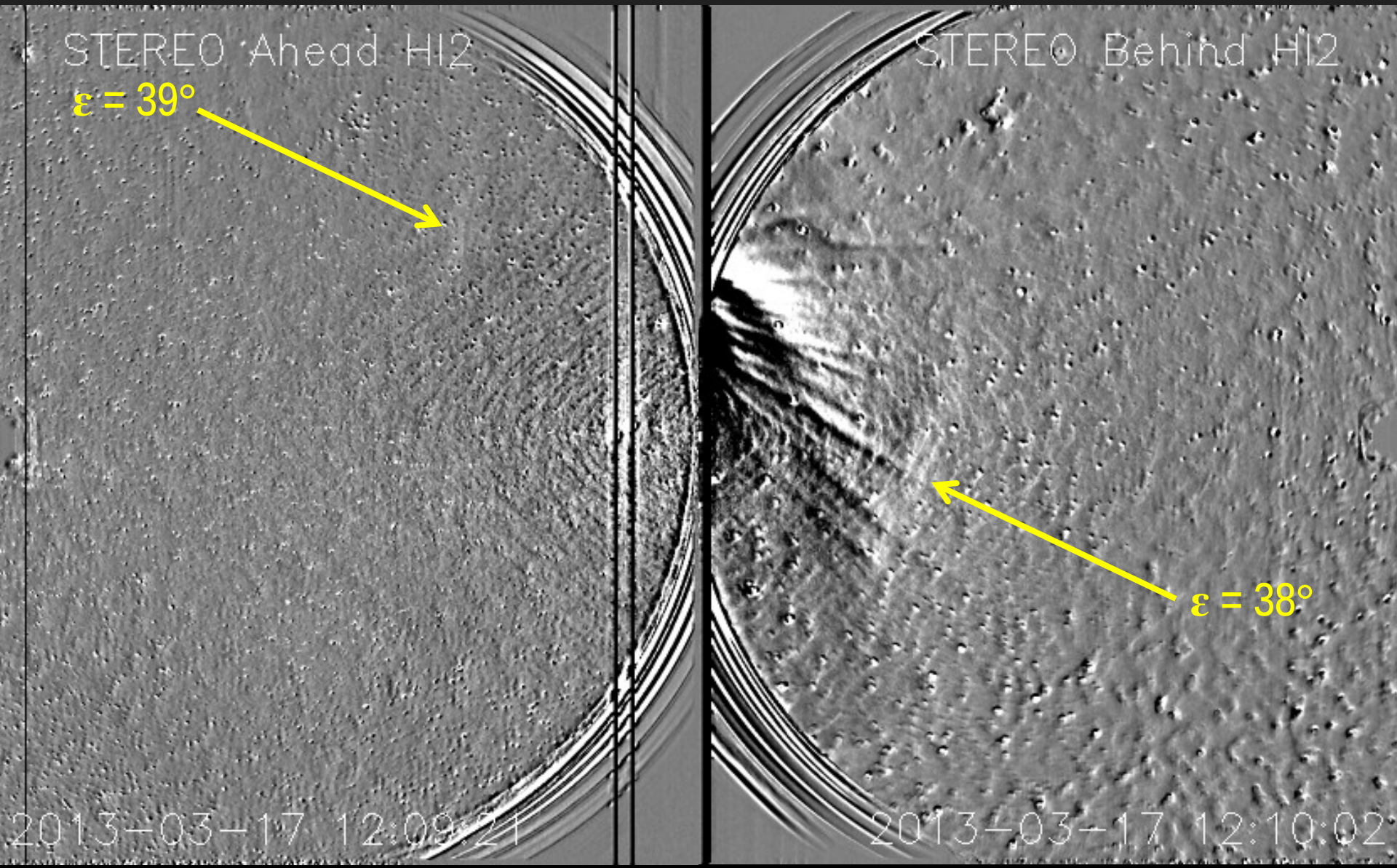
White Light Imaging

Thomson Scattering + Optical Thinness of the Corona & Solar Wind



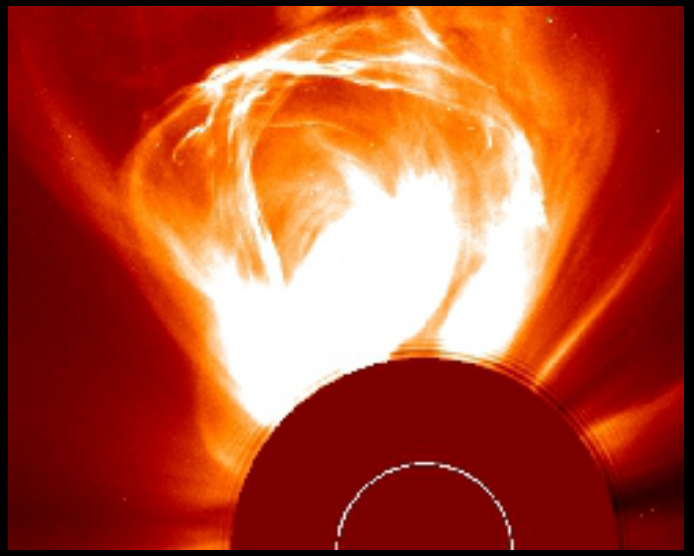
White Light Imaging

Thomson Scattering + Optical Thinness of the Corona & Solar Wind



White Light Imaging

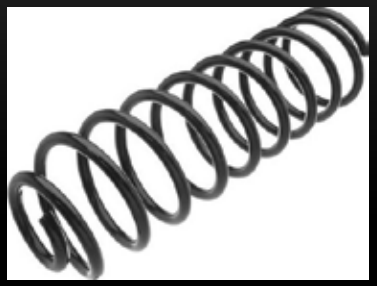
3-D Nature of CMEs

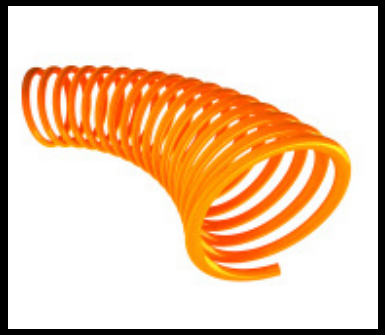


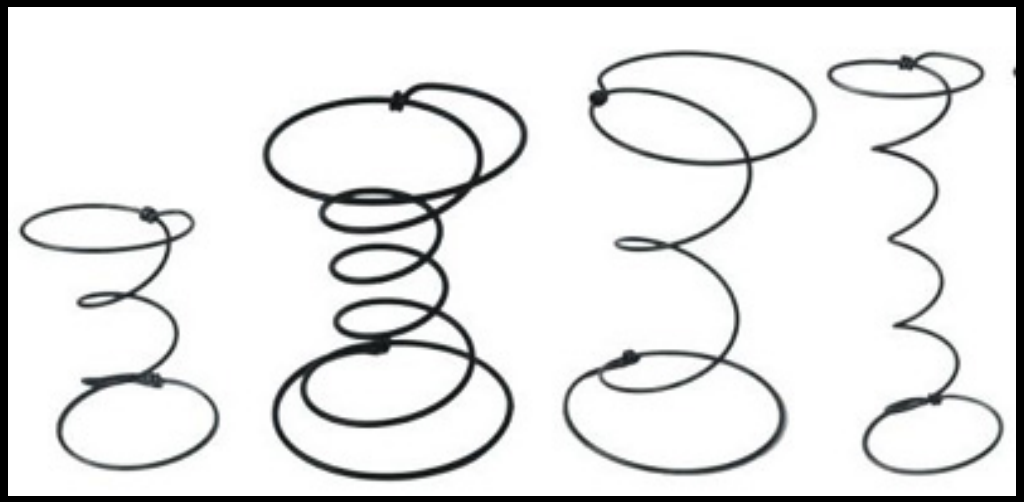
CMEs are optically thin

White Light Imaging

3-D Nature of CMEs







White Light Imaging

Issues to Address

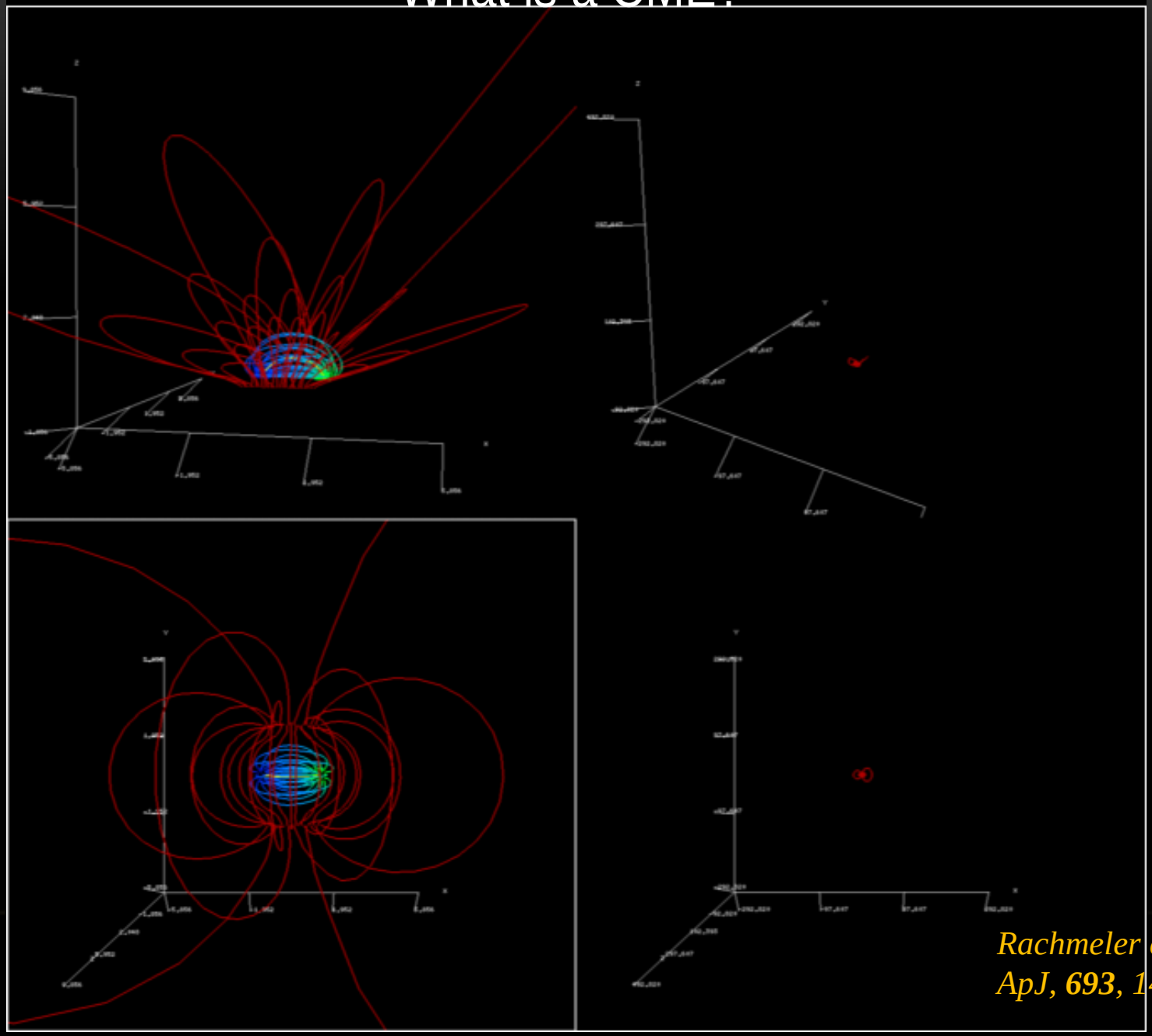
Problem	Solution
Background subtraction	Careful data processing
Thomson scattering	Fully understanding the theory and its implications
Geometry	Always think about projection; Try 3-D modeling

What To Do

Form a complete picture of CME anatomy using all datasets at your disposal

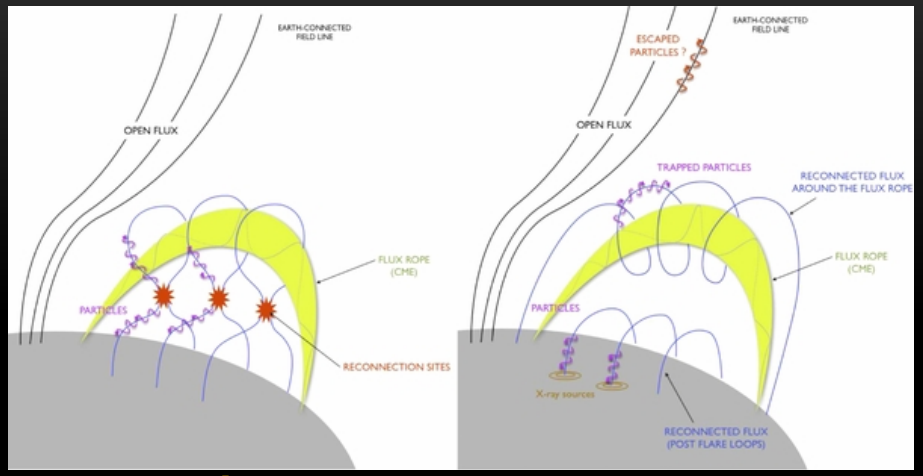
Need some luck to do this properly

What is a CME?

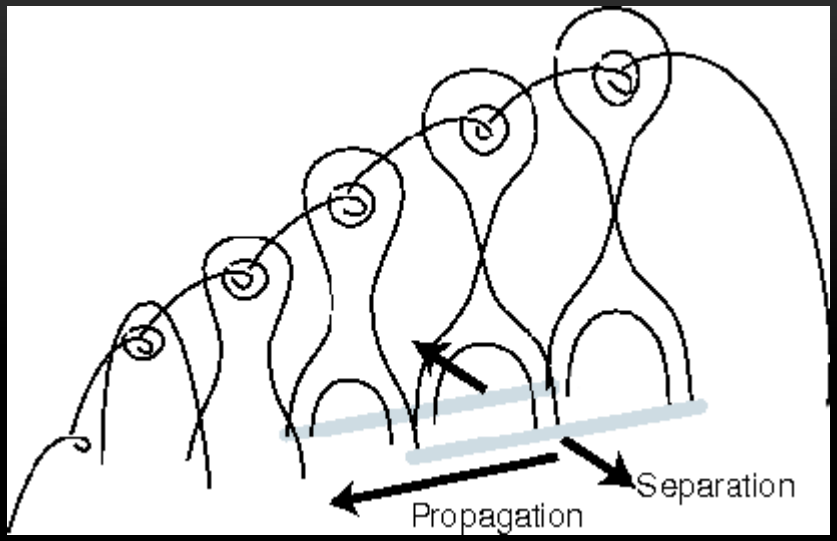


*Rachmeler et al., ApJ, **693**, 1431, 2009*

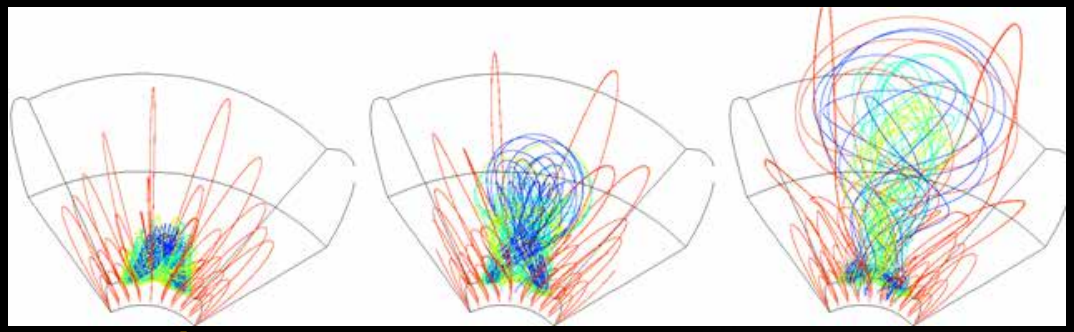
What is a CME?



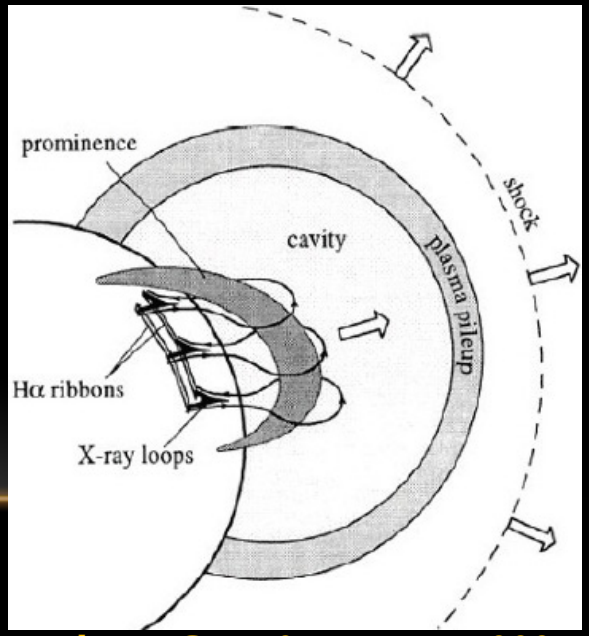
*Masson et al., ApJ, **771**, 82, 2013*



*Chifor et al., A&A, **472**, 967, 2007*

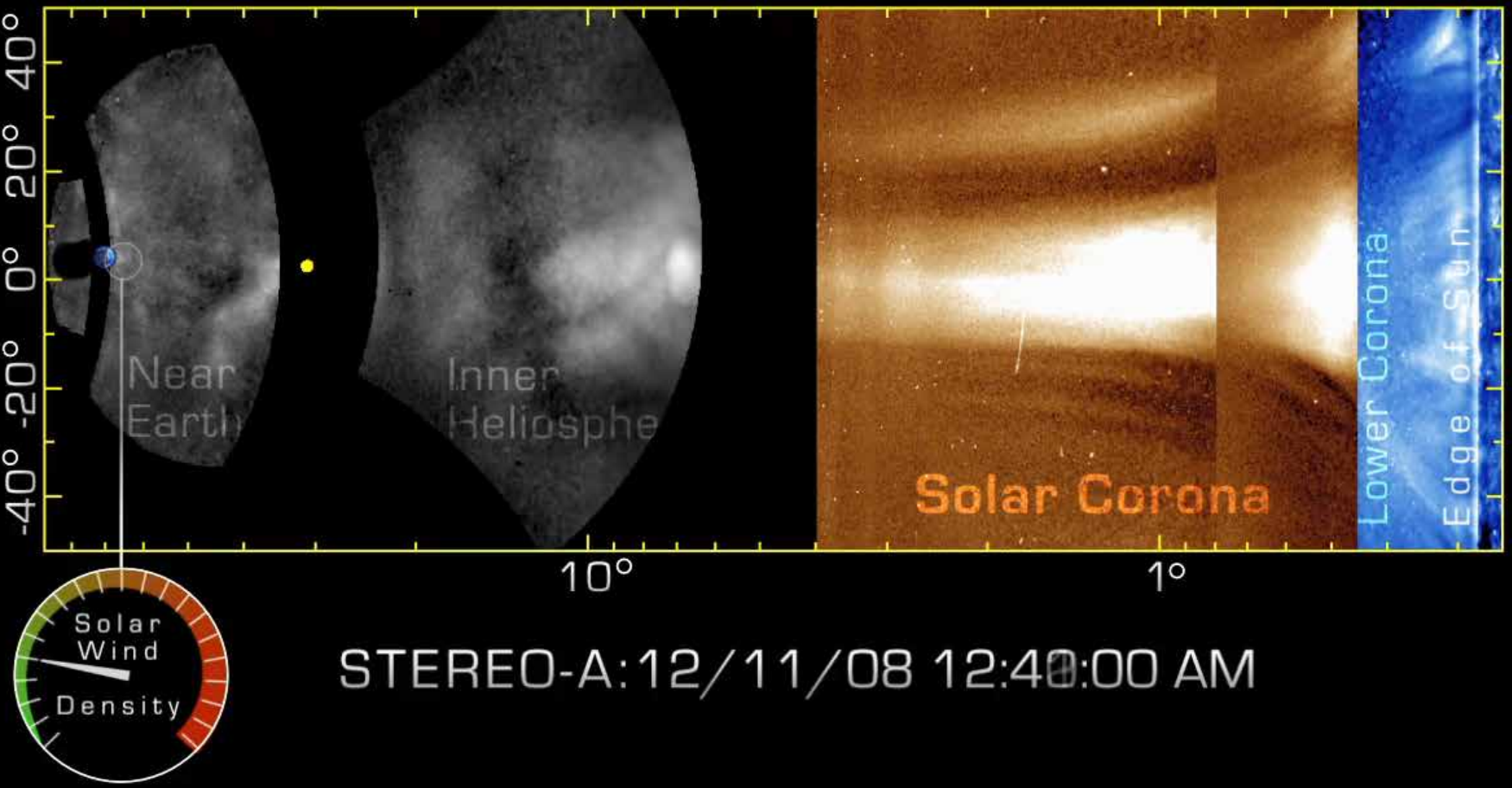


*Fan & Gibson, ApJ, **668**, 1232, 2007*

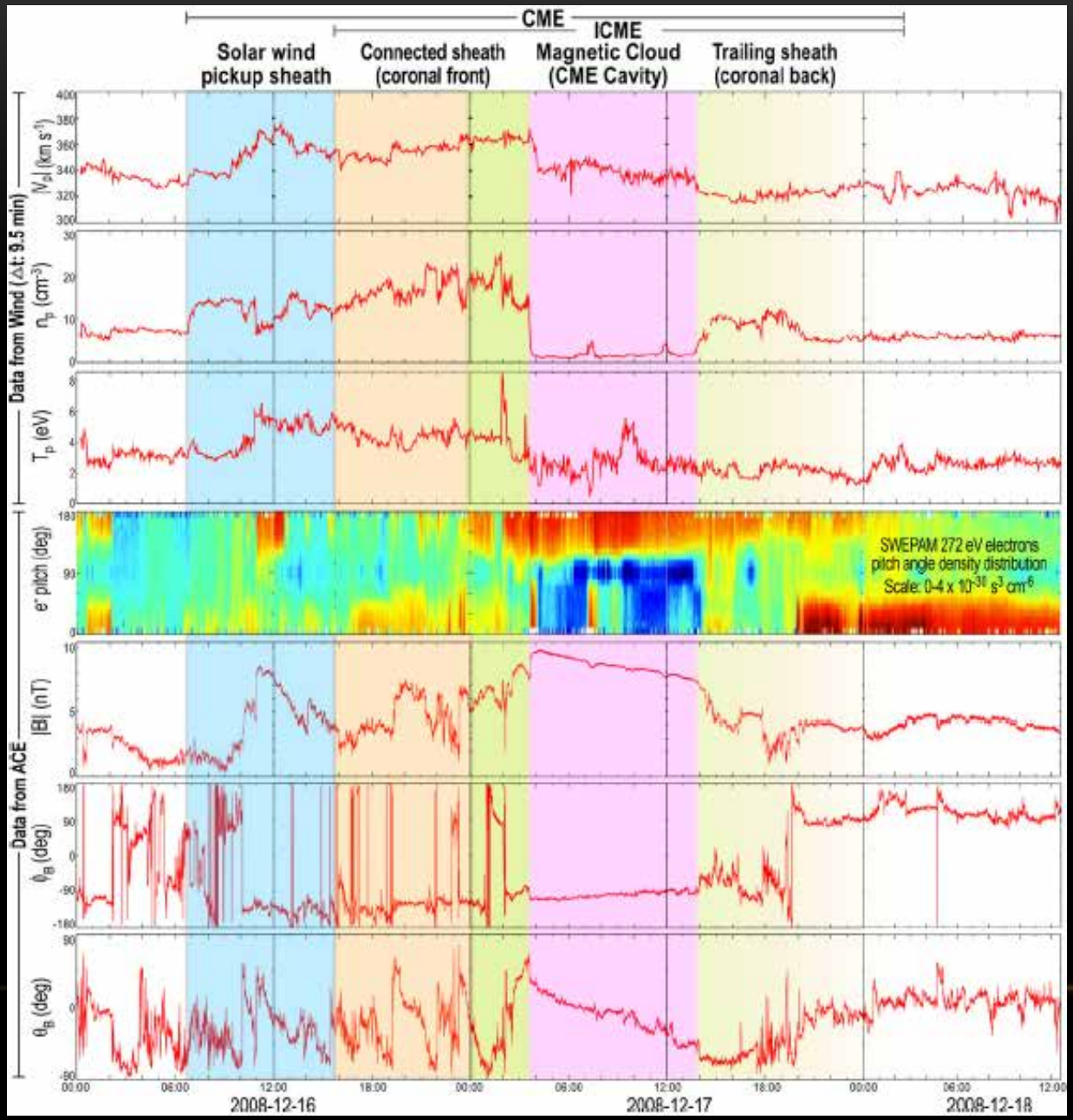


*Forbes, JGR, **105**, 23153, 2000*

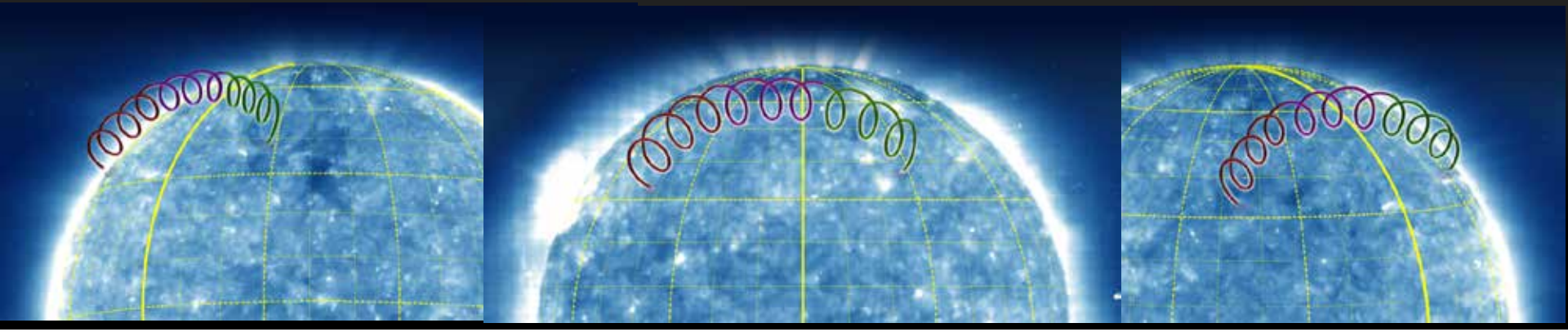
Putting It All Together

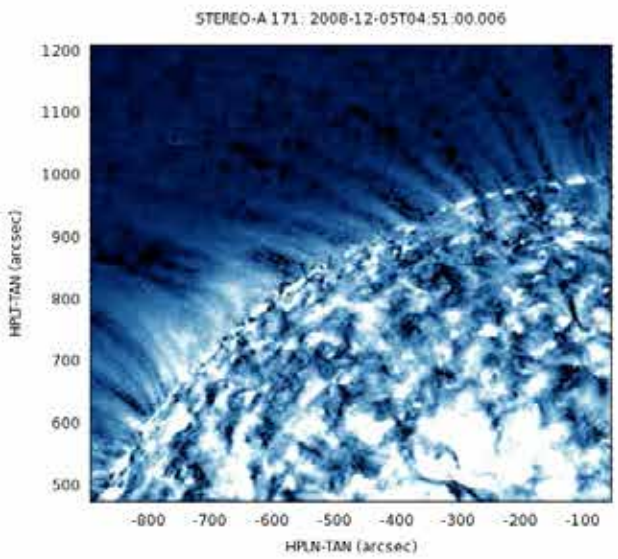


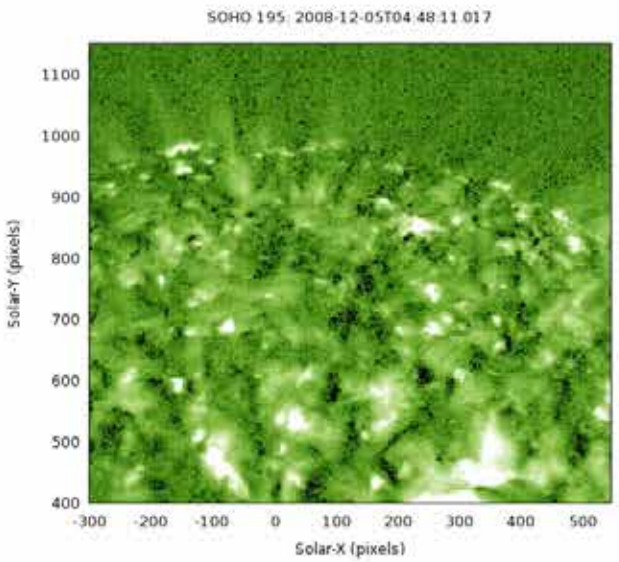
Putting It All Together

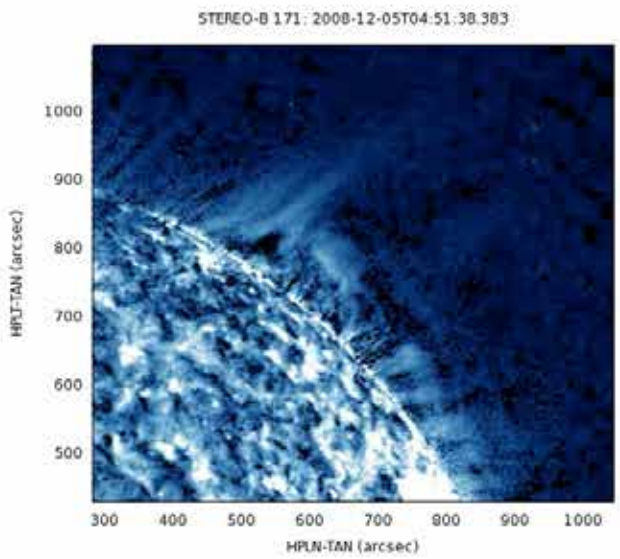


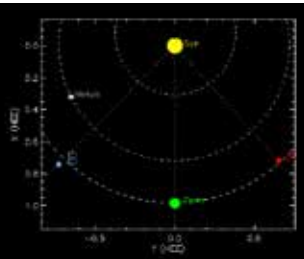
Putting It All Together





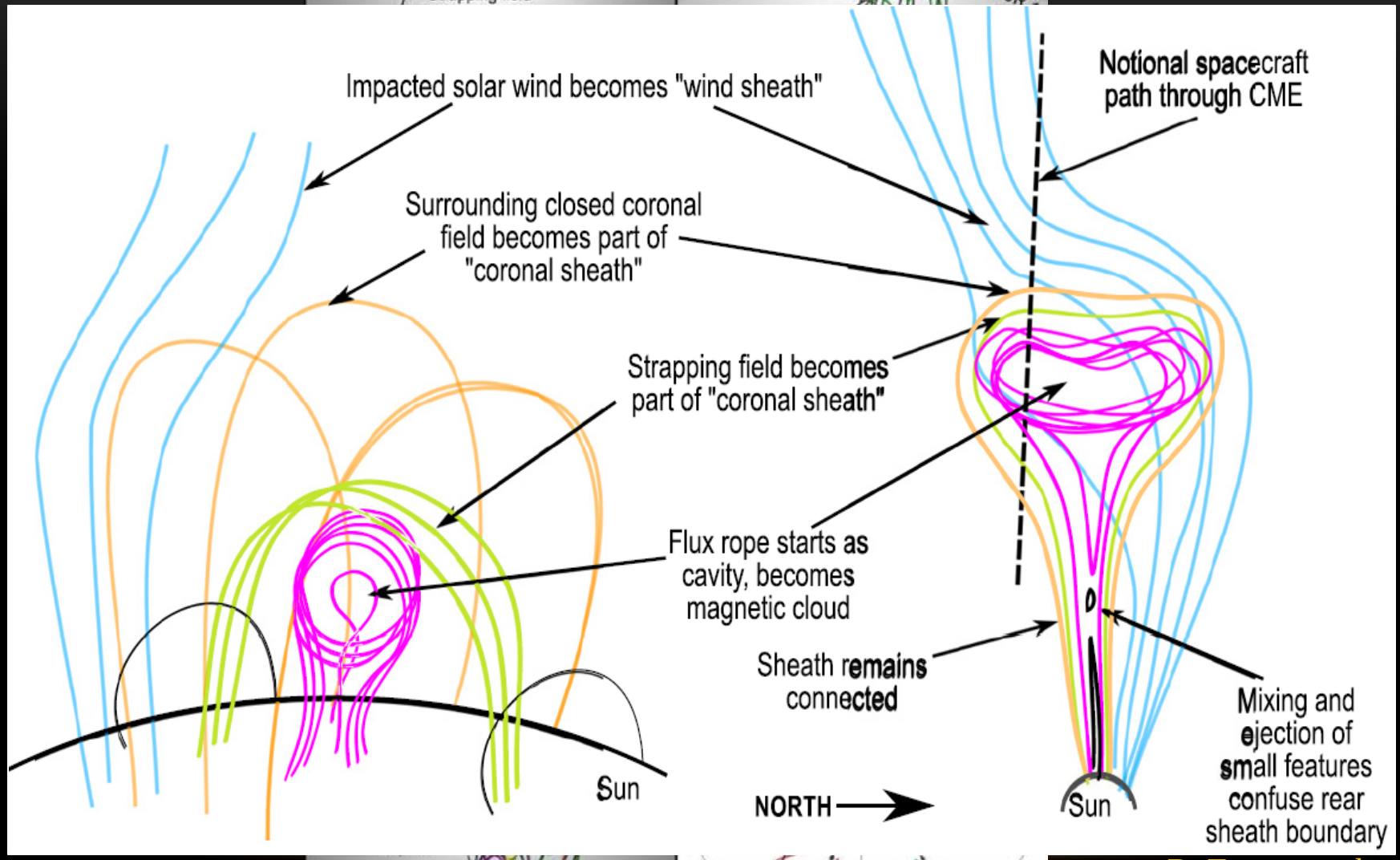


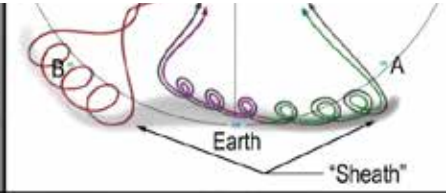




Howard & DeForest, ApJ, submitted.

Putting It All Together





Howard & DeForest, ApJ, submitted.

*DeForest et al., ApJ, **769**, 43, 2013.*

Concluding Remarks

We need to take a combined approach:

Utilize everything we can to assist us in overcoming the observational difficulties;

Look for every little detail – does it add to the narrative of what is going on?

Put everything into a physical context: Modeling helps, but should be used as a crutch and not a prosthetic.

Don’t Trust Your Lying Eyes!!!

Things are not as they appear in white light images:
Think 3-D,
Think optically thin,
Think Thomson scattering