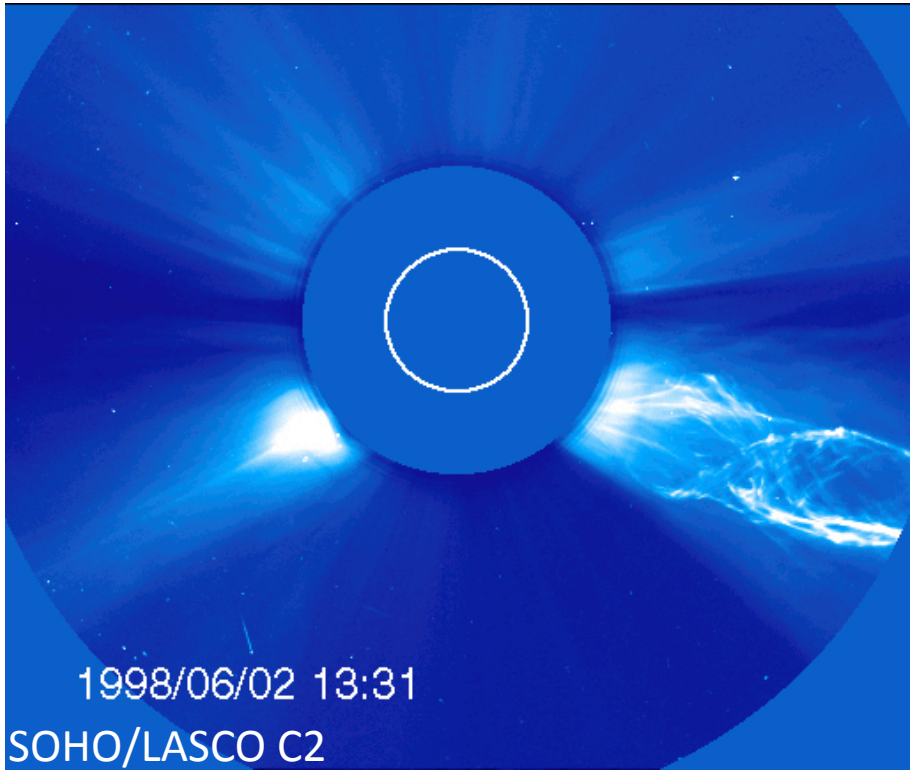
Space Weather CME analysis tools



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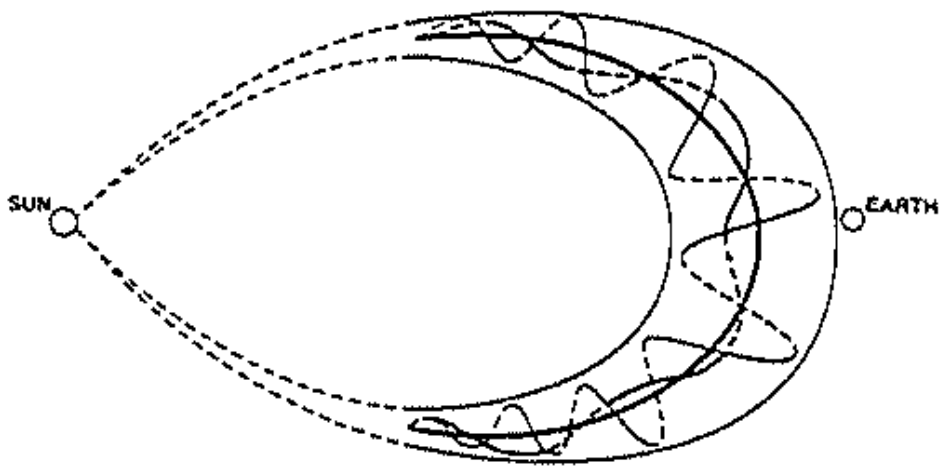
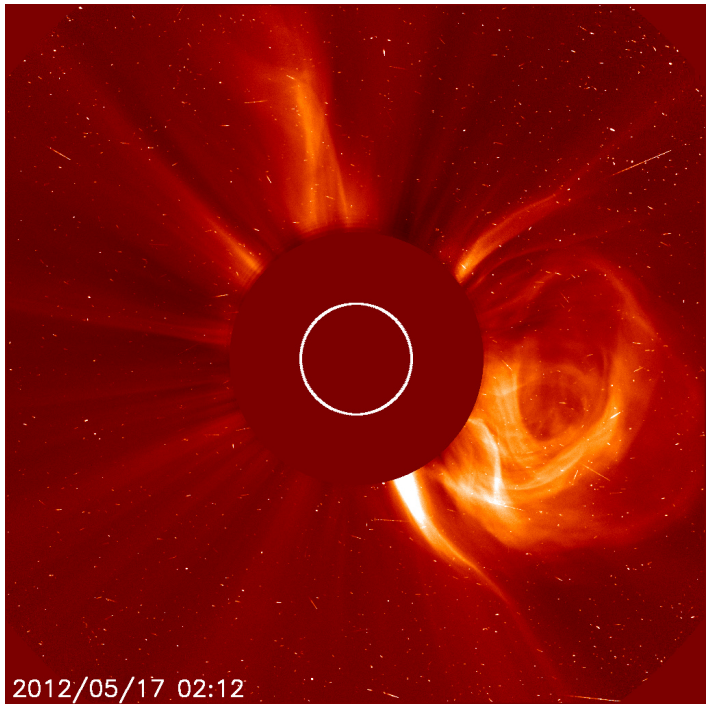
SW REDI 2013 June 3-14

Coronal Mass Ejections are important drivers of space weather activity.
Their shocks can accelerate particles (SEPs).
Earth directed CMEs (CMEs that propagate towards Earth's location) produce the majority of geomagnetic storms.



Purpose of this lesson: Learn how to measure the kinematic properties of CMEs (CME parameters) and determine their qualitative features.

Motivation: CME parameters are used as initial conditions of CME propagation models. These models are used to estimate the CME path and arrival time at various locations.

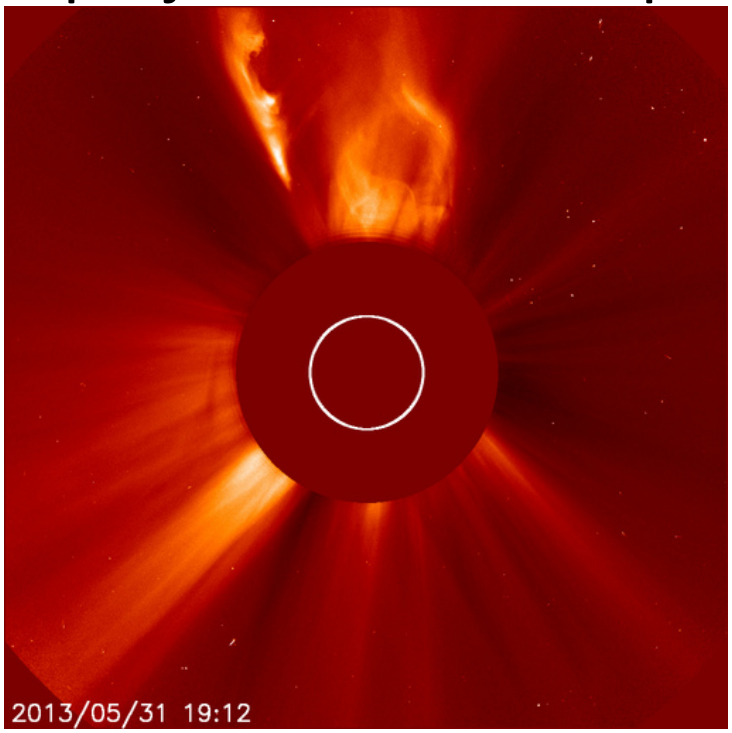


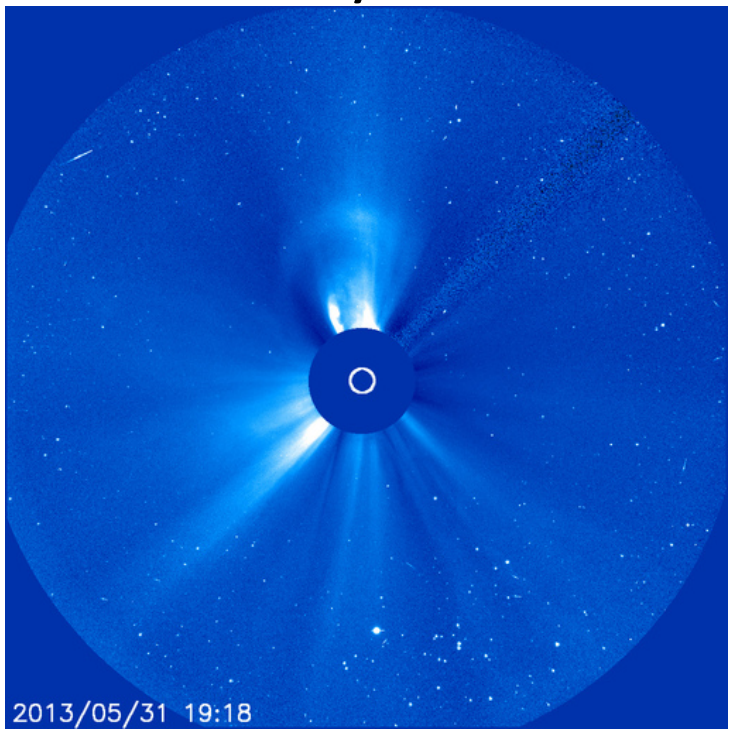
Coronal Mass Ejections

- Removal of magnetic field and mass from the solar corona – clouds of magnetized plasma
- 10^{12} – 10^{13} kg mass
- CMEs originate from closed magnetic field regions, such as active regions, filament regions.
- Appear as bright loops moving away from sun in **coronagraphs**

Coronagraphs block out the direct light of the Sun in order to view the faint corona.

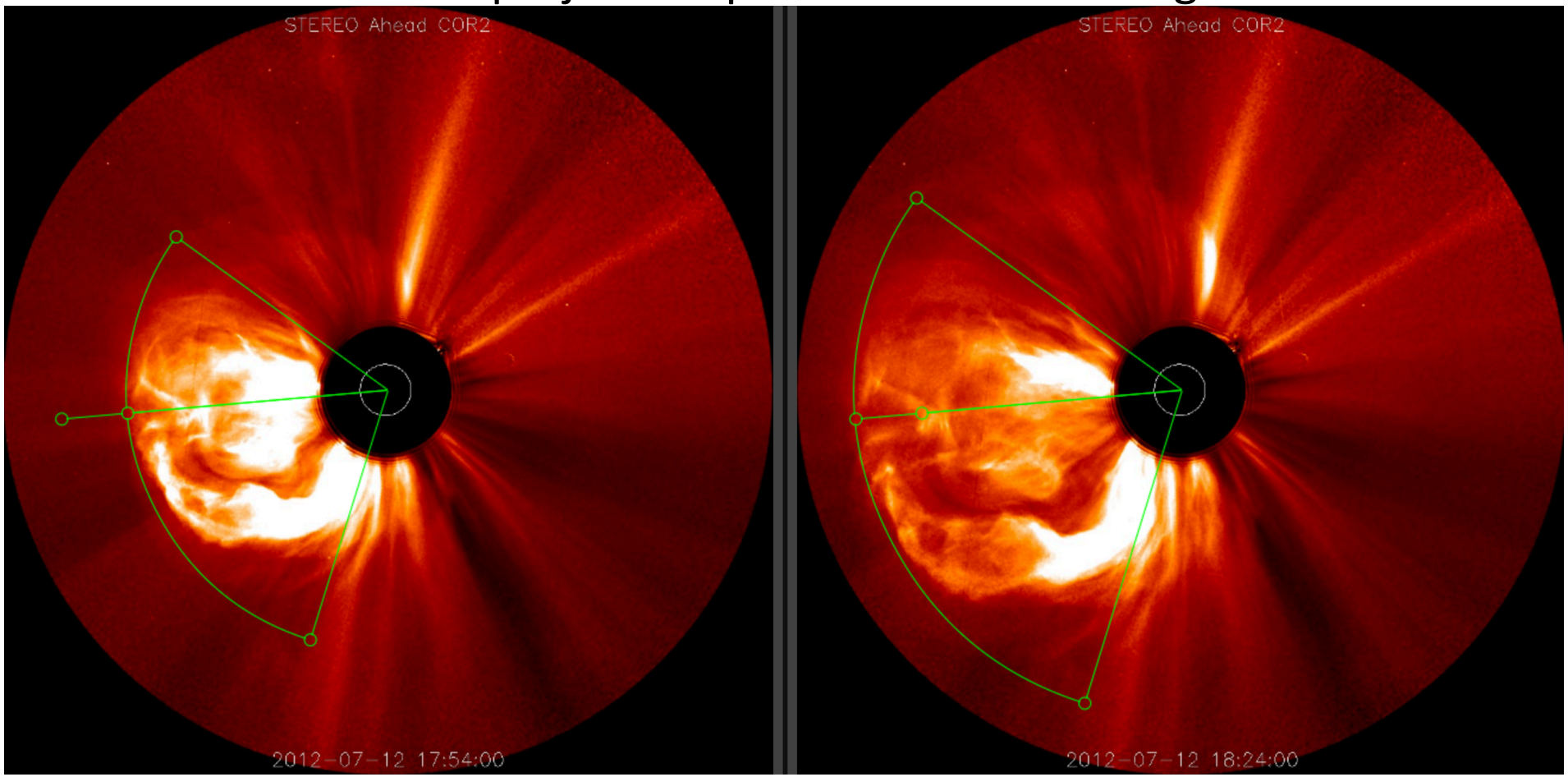
They are white light images, line of sight integrated scattered light from the Sun from the coronal electrons. You are seeing the CME projected onto the plane of the sky





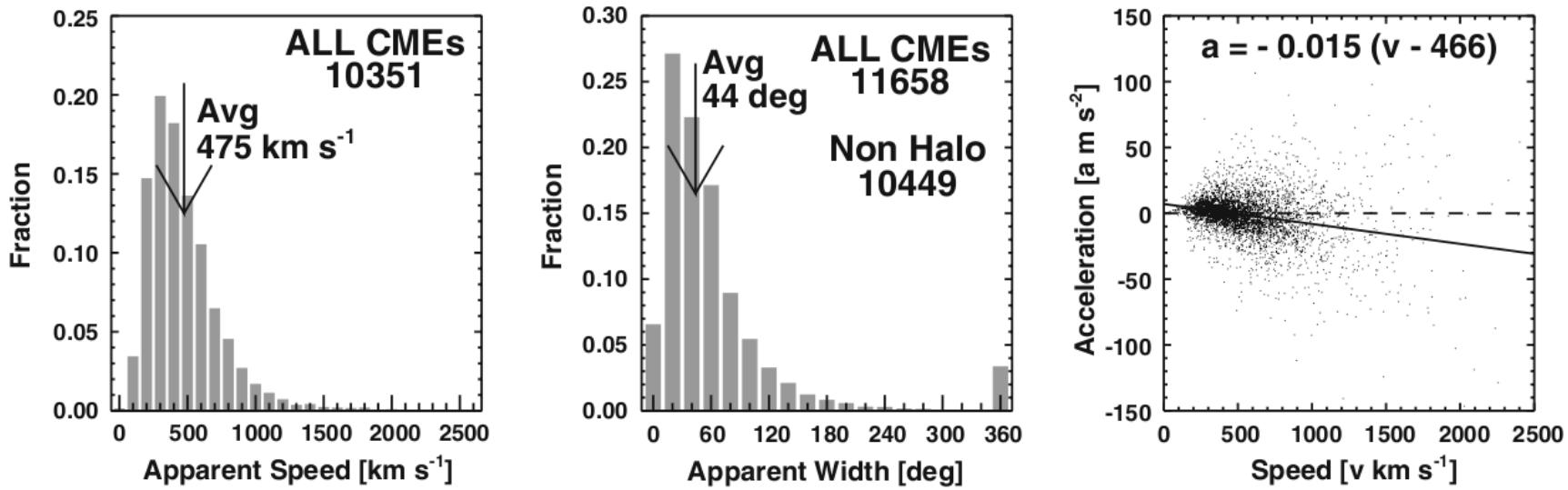
Example movies

With **coronagraph** data you can measure the leading of the CME at different times. From this you can determine the "**plane-of-sky**" speed by measuring the position of the **leading edge** of the CME at two times. By using **coronagraphs** on various spacecraft, you can get a measurements of this projected speed from various angles.



Coronal Mass Ejection Parameters

- Average speed ~475 km/s, width~44 deg

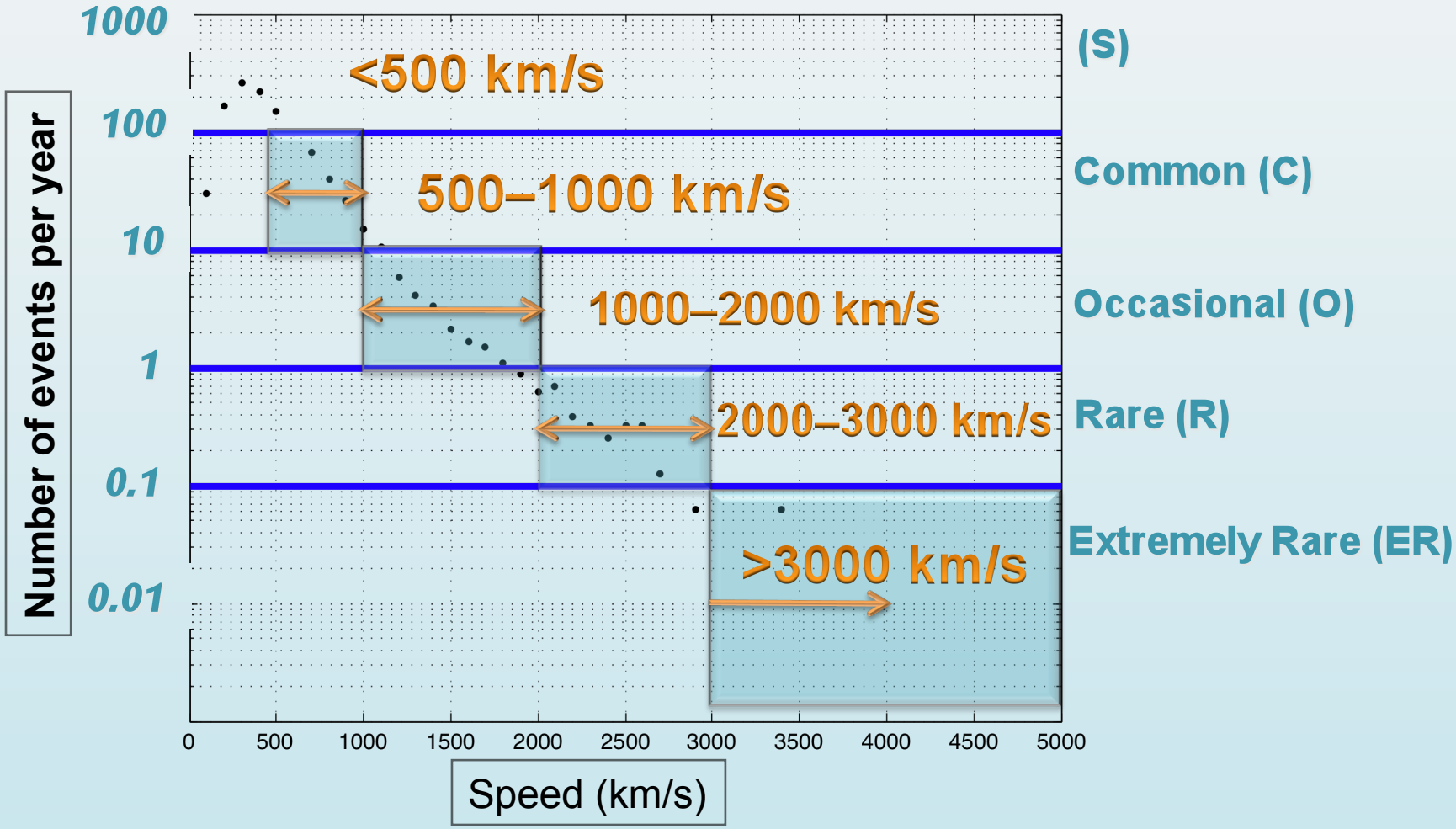


(Gopalswamy et al., 2010)

SOHO LASCO CME Catalog

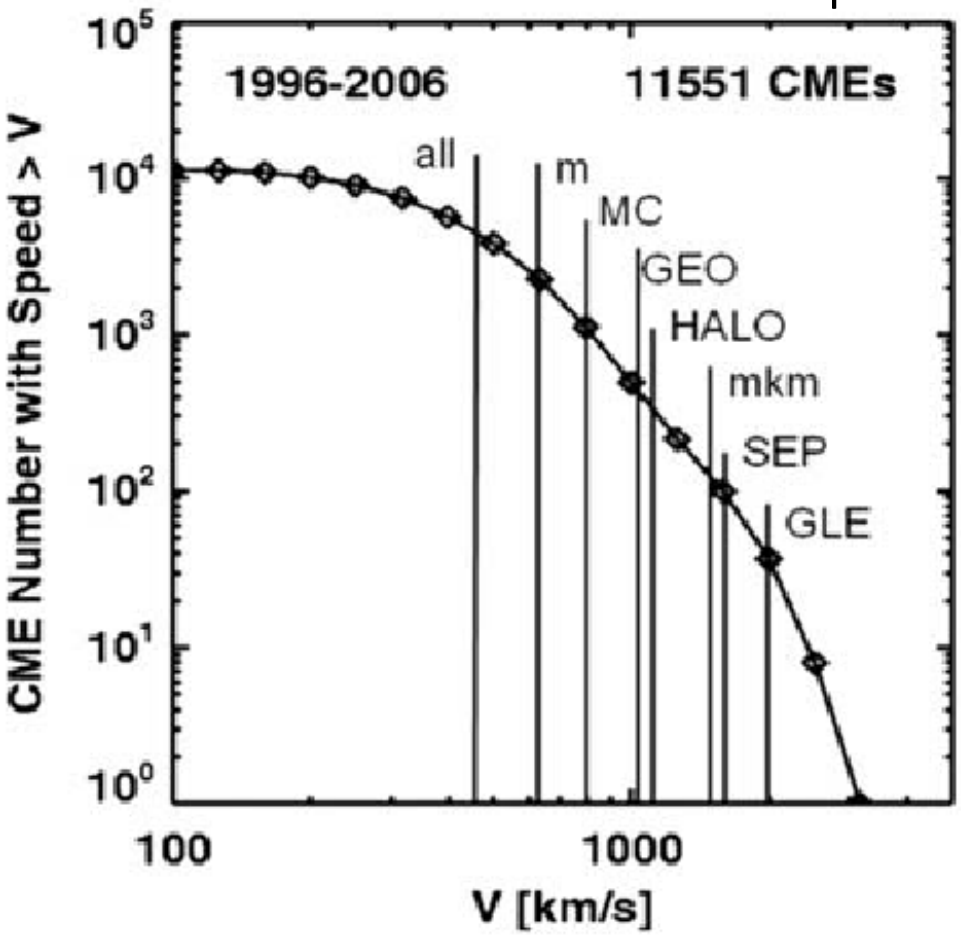
http://swrc.gsfc.nasa.gov/main/score

NASA GSFC Space Weather Research Center
CME Types (SCORE scale based on speed)

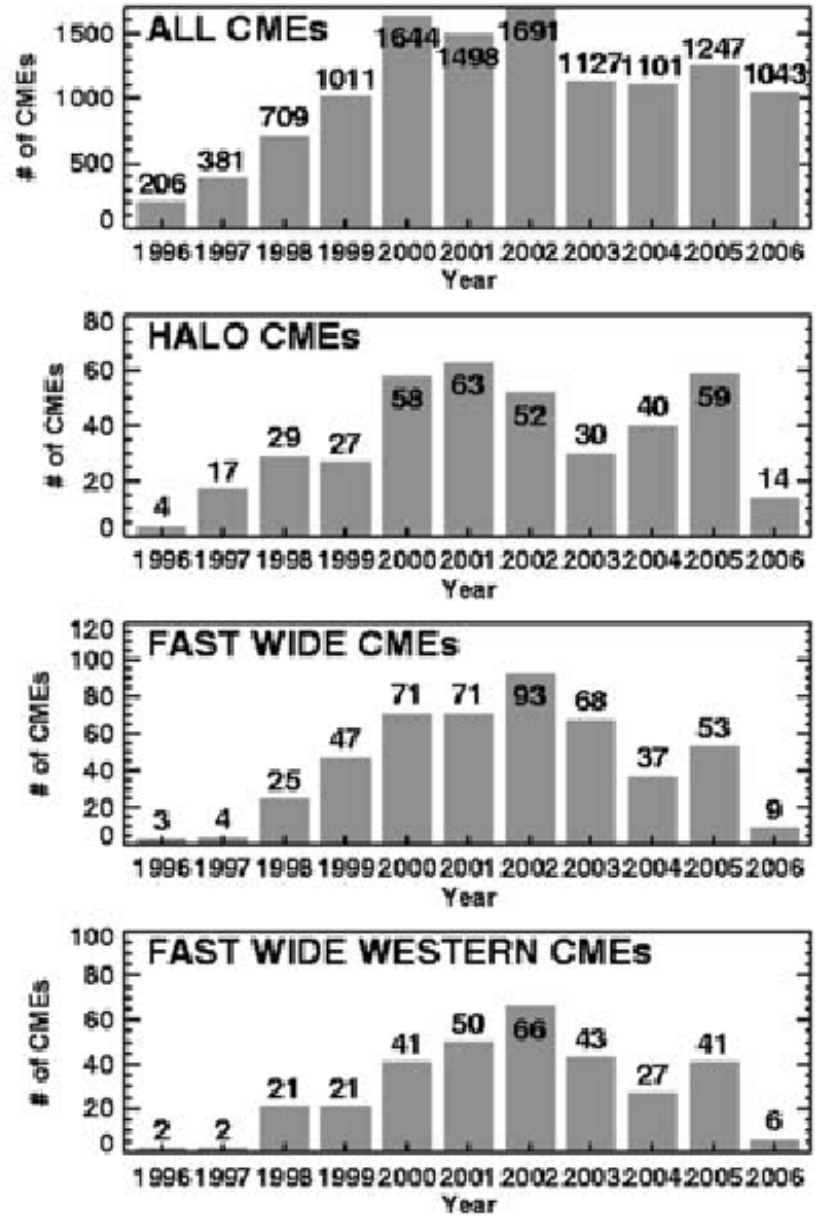


* Data: CDAWeb SOHO Lasco CME Catalog (linear speed)

Cumulative distribution of CME speeds



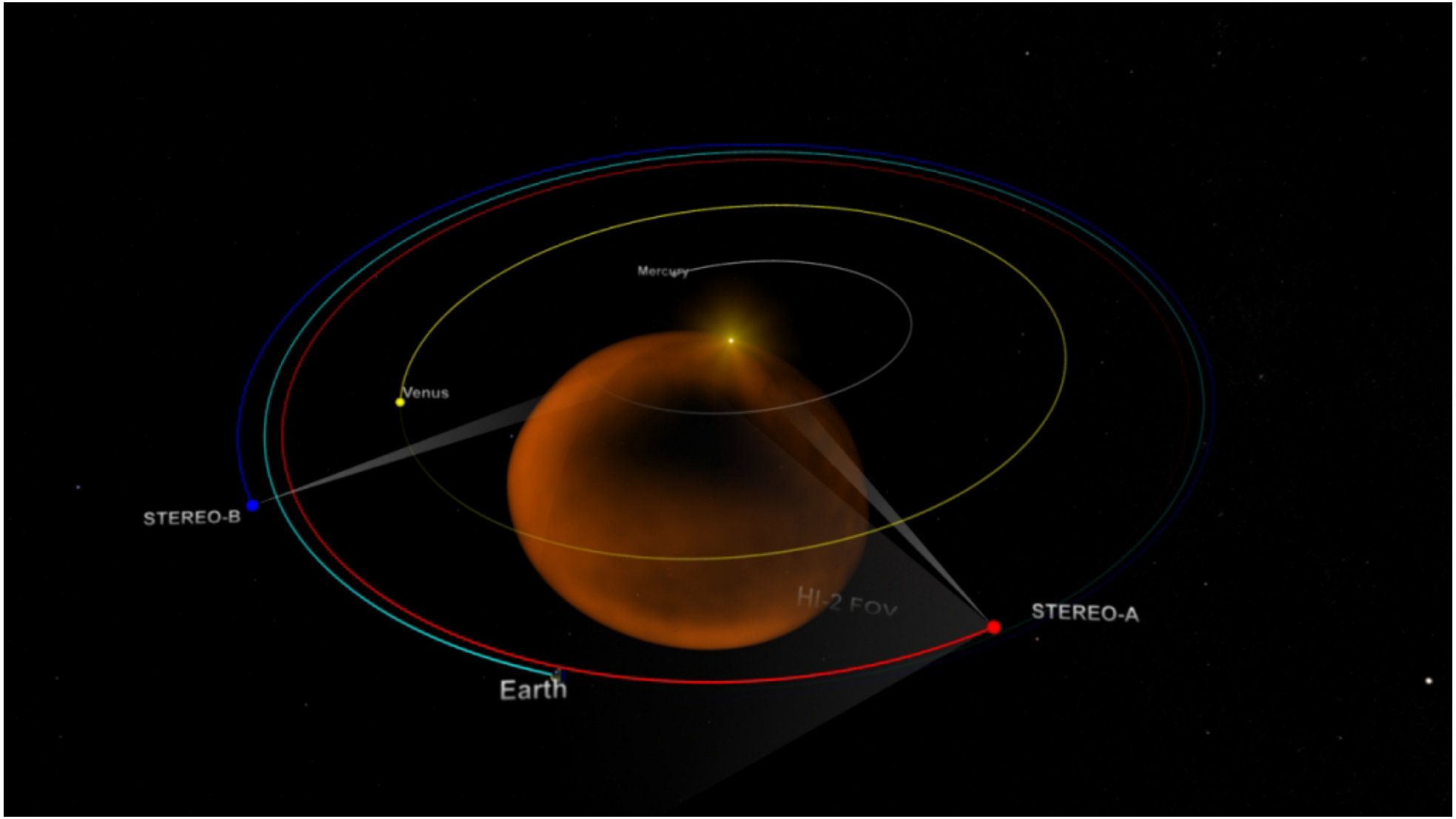
Annual number of different CMEs



(Gopalswamy et al., 2010)

The two STEREO spacecraft observe the sun from two viewpoints

Link: View the STEREO spacecraft orbits movie
http://www.nasa.gov/multimedia/videogallery/index.html?media_id=59559661

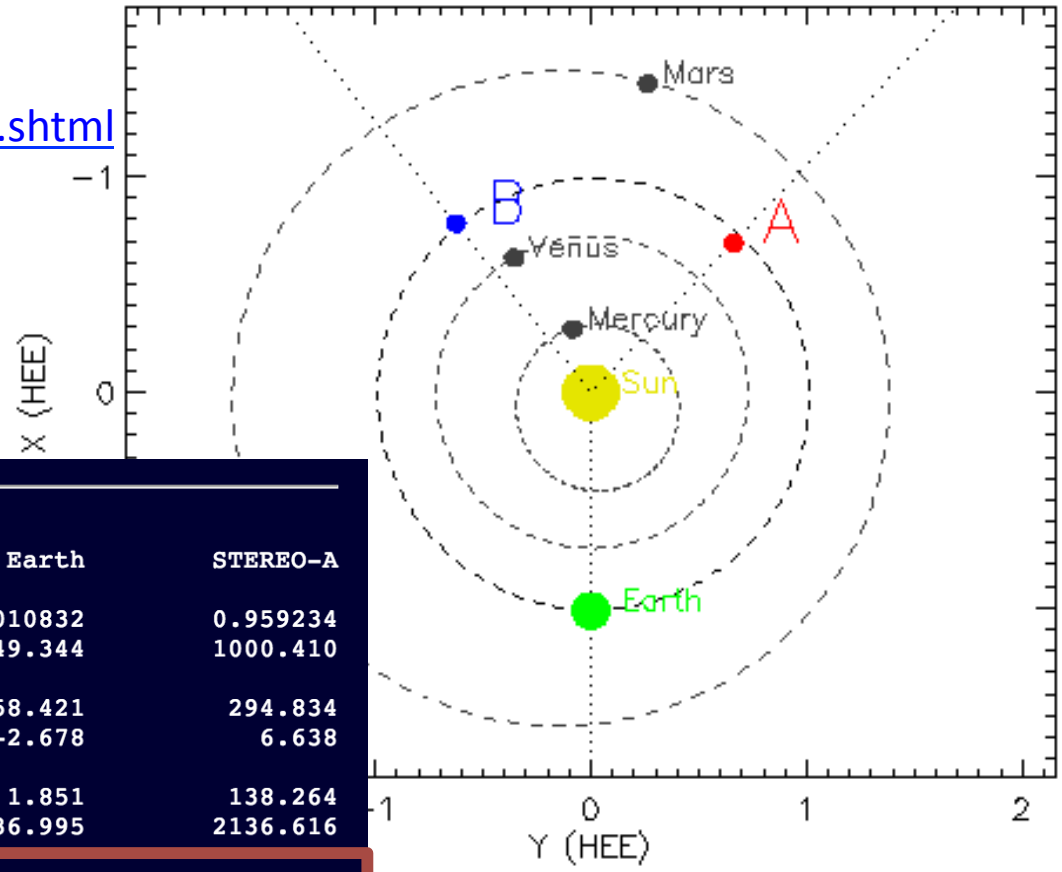


Where is STEREO?

http://stereo-ssc.nascom.nasa.gov/where.shtml

Click “STEREO Orbit Tool”

Longitude is measured
0 to 180˚ counterclockwise
0 to -180˚ clockwise



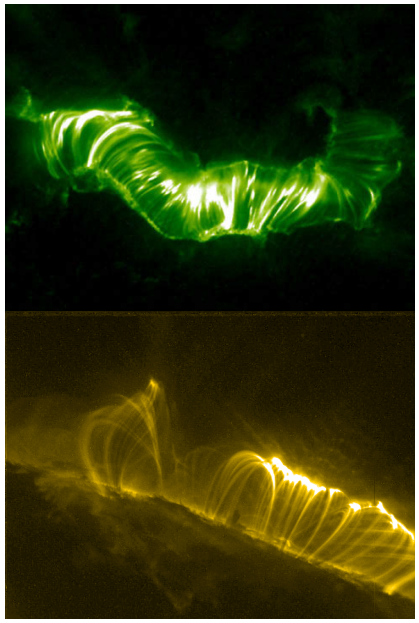
	STEREO-B	Earth	STEREO-A
Heliocentric distance (AU)	1.005357	1.010832	0.959234
Semidiameter (arcsec)	954.514	949.344	1000.410
HCI longitude	16.630	158.421	294.834
HCI latitude	-1.820	-2.678	6.638
Carrington longitude	220.059	1.851	138.264
Carrington rotation number	2137.389	2136.995	2136.616
Heliographic (HEEQ) longitude	-141.791	0.000	136.413
Heliographic (HEEQ) latitude	-1.820	-2.678	6.638
HAE longitude	92.490	234.029	10.422
Earth Ecliptic (HEE) longitude	-141.539	0.000	136.393
Earth Ecliptic (HEE) latitude	0.266	-0.000	0.051
Roll from ecliptic north	-0.335		0.055
Roll from solar north	6.612		3.094
Light travel time to Earth (min)	15.834		15.214
Separation angle with Earth	141.539		136.393
Separation angle A with B		82.067	

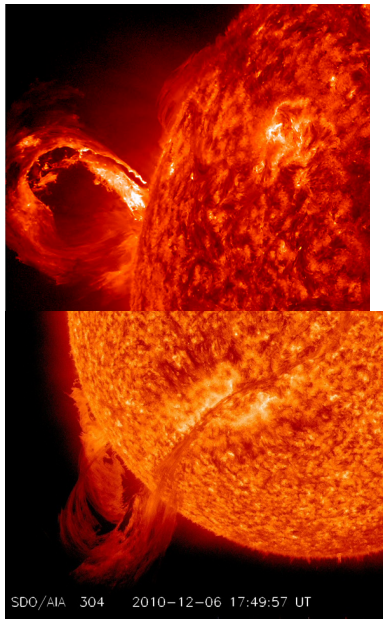
Date: 14 May 2013 Time: 21 : 00 UTC

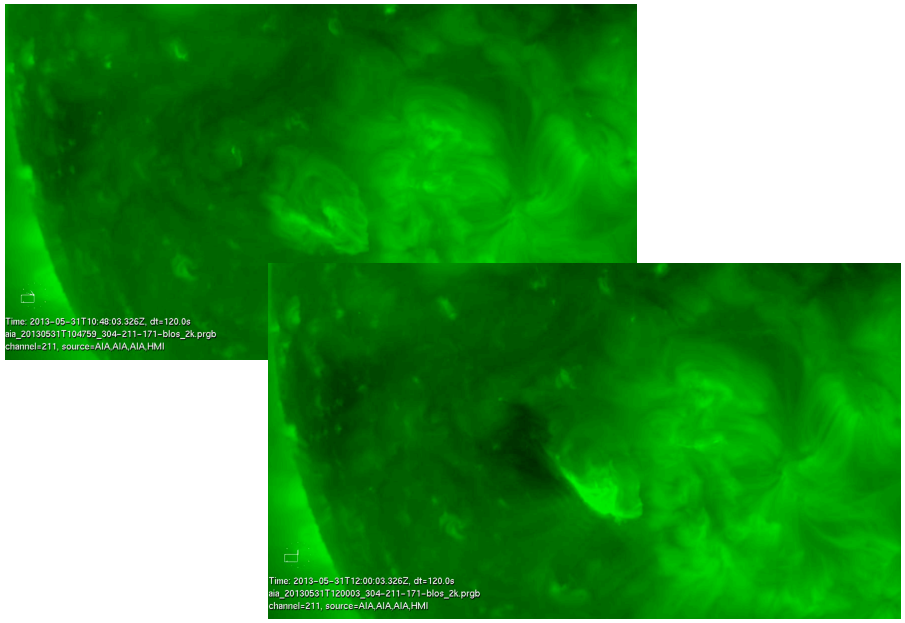
HEEQ:
Heliocentric Earth Equatorial
Z=North pole of solar rotation axis
X=intersection between solar equator and solar central meridian as seen from Earth

CME source locations/EUV lower coronal signatures of CMEs

* CMEs can originate from active regions and/or from filament eruptions.
* Some CMEs are associated with flares.
* EUV signatures include post eruption arcades, rising loops, coronal dimming, and prominence eruptions (click for example movies).







post eruption arcade prominence eruption coronal dimmings.

filament eruption

Important! Always determine the source location of every CME you analyze.
This can help you decide which coronagraph combinations to choose, and assess the accuracy of the CME parameters you obtain.

Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths

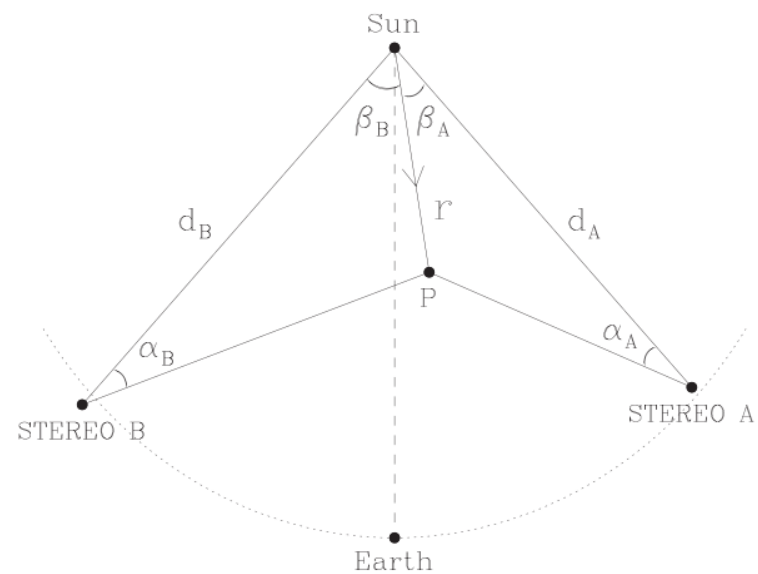
Geometric Triangulation

- Measuring the **same feature** (assumption) in two coronagraphs and using simple geometric relations to derive CME position and speed
- Observations are integrated line-of sight information through a 3D structure – projection effects impact the feature being measured

$$\frac{r\,\sin(\alpha_A + \beta_A)}{\sin\alpha_A} = d_A,$$

$$\frac{r\,\sin(\alpha_B + \beta_B)}{\sin\alpha_B} = d_B,$$

$$\beta_A + \beta_B = \gamma,$$



CME analysis Procedure

* Identify the CME and the start time. (The CME start time is the time it is first observed by any of the four coronagraphs)

* Observe all available coronagraph images in motion. Look for the same CME leading edge feature in various spacecraft.

* Look at EUV images in motion near the CME start time and identify the source location and any lower coronal signatures (post eruption arcade, dimming, rising loops, filament eruption).

Go to the CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/

* Select two overlapping times for each spacecraft pair available. Times should be around 45-75 minutes apart, and try to choose times just before the CME leading edge has left the field of view. It is useful to refer back to the CME movies while selecting images.

* Perform plane of sky measurements CME leading edge and obtain triangulation results if appropriate. Determine final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

Resources & iSWA layouts

** CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/*

** 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*

** Where is STEREO? http://stereo-ssc.nascom.nasa.gov/where.shtml and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*

** Solar Images with grid overlays http://www.solarmonitor.org/*

CME analysis tips/notes

* Make sure you are measuring the same feature in each spacecraft.
* If you cannot see the leading edge of the CME in image (halo), then it is not appropriate to use the triangulation method. In this case, estimate the plane of sky speed. It may be cautiously used for an asymmetric halo.
* Don't forget to determine the source location and signatures. Use these to assess the accuracy of your results (which spacecraft pairs will give the best results), or to derive the radial velocity from the plane of sky speed.
* Measure each CME about 10 times with various time and spacecraft pairs to get a feel for the parameters and the measurement error.
* The two selected times should be around 45-75 minutes apart for each spacecraft.
* The time between each spacecraft pair should be less than 10 minutes.
* Try to choose times just before the CME leading edge has left the field of view.
* Bear in mind that plane of sky speeds are always lower than the derived radial velocity.

Resources & iSWA layouts

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and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif

* Solar Images with grid overlays http://www.solarmonitor.org/

CME analysis in-class workshop, morning 6/5 completion is optional

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

```
CMEs starting at
0a) 2013-06-04T23:36Z
0b) 2013-06-05T09:12Z
```

```
and CMEs starting at
1) 2012-10-05T03:24Z
2) 2012-07-12T16:54Z
3) 2013-02-26T14:06Z
```

Fill out the form: http://bit.ly/swcme0

a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).

b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).

c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?

d) Which coronagraph instrument first observed the CME at the start time?

e) What are your final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

f) Submit your "Save URL" of your measurements.

Resources & iSWA layouts

** CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/*

** 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*

** Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*

** Solar Images with grid overlays http://www.solarmonitor.org/*

CME analysis assessment – week one, complete in afternoon 6/5

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

CMEs starting at
1) 2012-12-14T02:24Z
2) ~~2012-01-13T09:48Z~~
3) 2012-07-17T14:25Z

correction:
2) 2013-01-13T07:24Z

Fill out the form: http://bit.ly/swcme1

a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).

b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).

c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?

d) Which coronagraph instrument first observed the CME at the start time?

e) What are your final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

f) Submit your "Save URL" of your measurements.

Resources & iSWA layouts

* *CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/*
* *40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*
* *Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*
* *Solar Images with grid overlays http://www.solarmonitor.org/*

CME analysis in depth assessment – week two complete in afternoon 6/11

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

```
CMEs starting at
1) 2013-03-15T06:54Z
2) 2013-01-21T08:48Z
3) 2013-04-11T07:36Z
4) 2012-09-28T02:25Z
5) 2012-09-28T10:54Z
6) 2012-11-21T16:24Z
```

Resources & iSWA layouts

** CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/*

** 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*

** Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*

** Solar Images with grid overlays http://www.solarmonitor.org/*

Fill out the form: http://bit.ly/swcme2

a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).

b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).

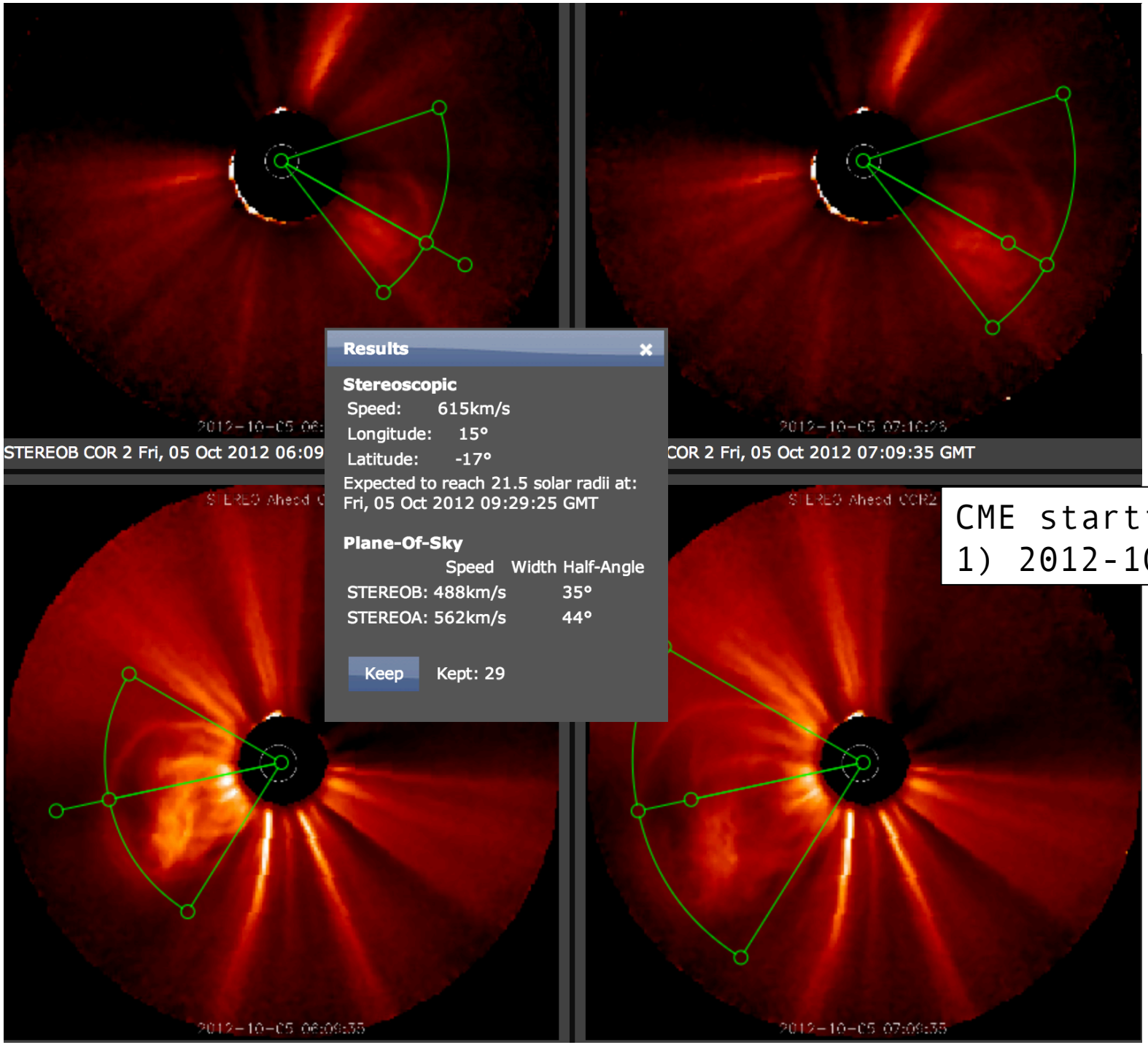
c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?

d) Which coronagraph instrument first observed the CME at the start time?

e) What are your final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

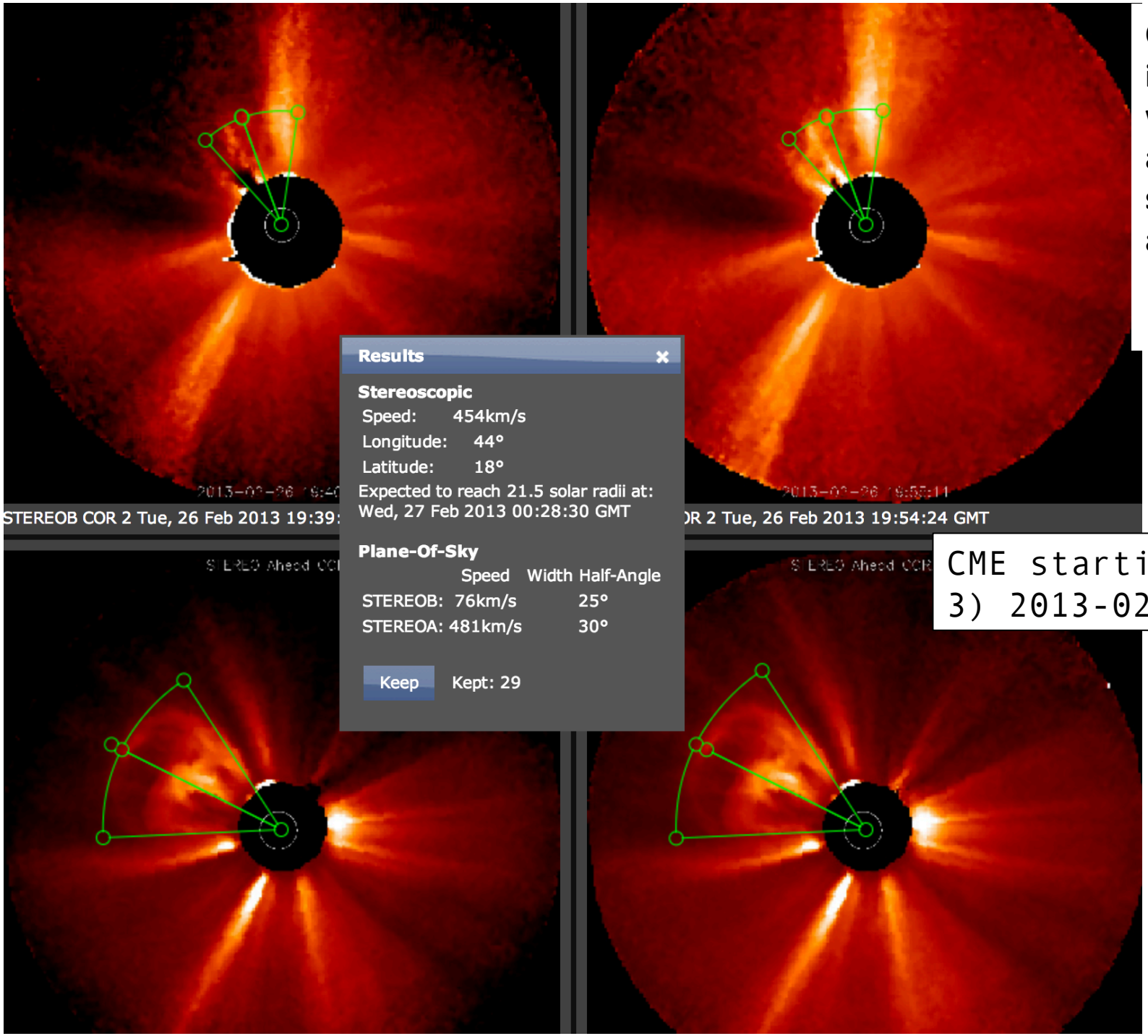
f) Submit your "Save URL" of your measurements.

CME analysis in-class workshop – approximate starting answers



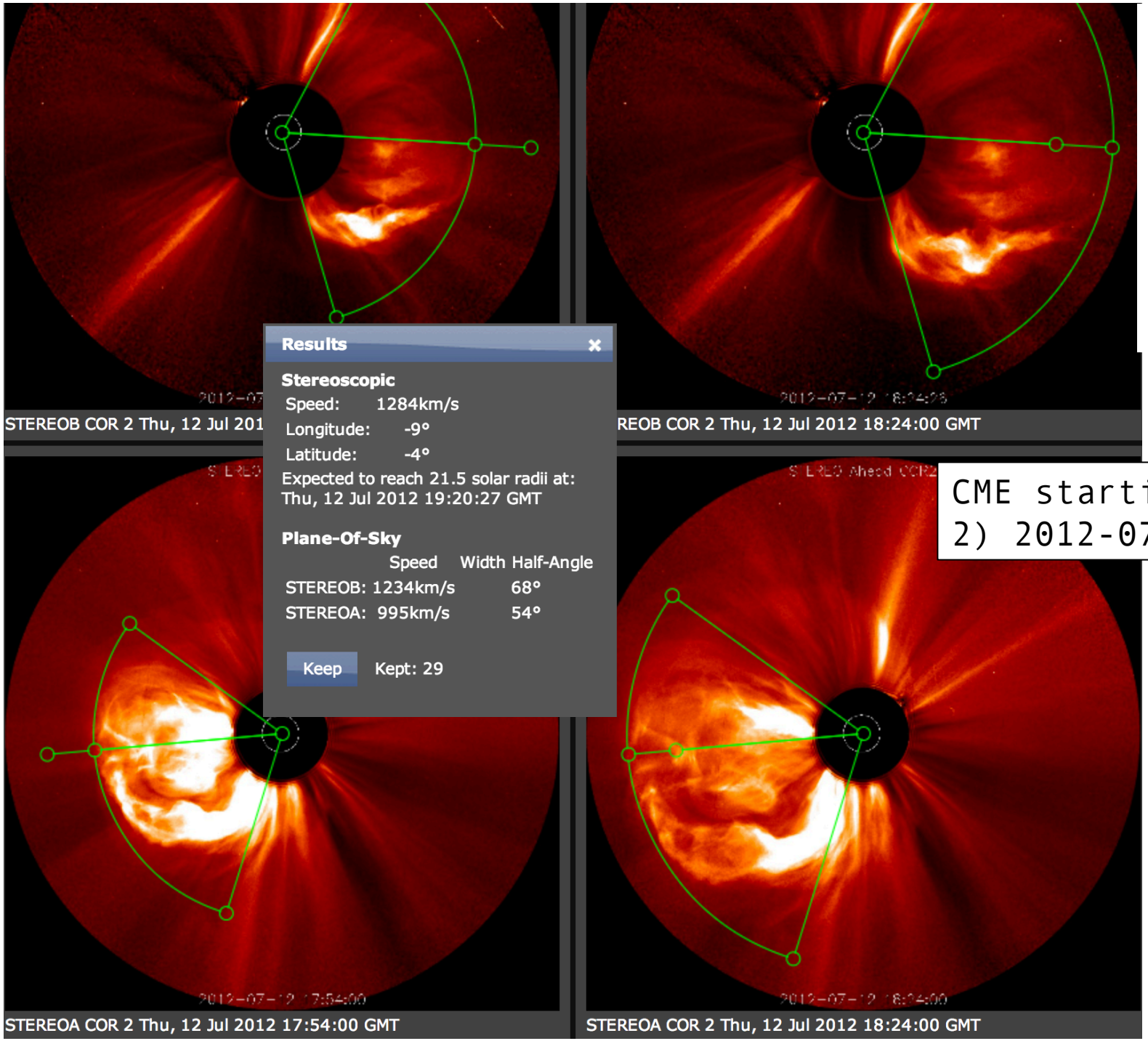
CME starting at
1) 2012-10-05T03:24Z

CME analysis in-class workshop – approximate starting answers



CME starting at
3) 2013-02-26T14:06Z

CME analysis in-class workshop – approximate starting answers



CME starting at
2) 2012-07-12T16:54Z

Slide link summary

Resources & iSWA layouts
* CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/
* 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK
* Where is STEREO?
http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
* Solar Images with grid overlays http://www.solarmonitor.org/

SW REDI website
http://ccmc.gsfc.nasa.gov/support/SWREDI/swredi.php
iSWA http://iswa.gsfc.nasa.gov
iSWA Cygnet Glossary http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Full_iSWA_Cygnet_List
iSWA Space Weather Glossary http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary
Example CME movie
http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=sta_cor2&stime=20120712_1500&etime=20120712_2000
http://helioviewer.org/?movieId=zZv95 http://helioviewer.org/?movieId=tZv95
Helioviewer solar visualization tool http://www.helioviewer.org/
SOHO LASCO CME Catalog http://cdaw.gsfc.nasa.gov/CME_list/
SWRC SCORE CME scale http://swrc.gsfc.nasa.gov/main/score
STEREO orbit movie http://www.nasa.gov/multimedia/videogallery/index.html?media_id=59559661
Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths
http://www.nasa.gov/mission_pages/sunearth/news/light-wavelengths.html

EUV lower coronal signatures of CMEs movies

post eruption arcade
http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=sta_e195&img2=sta_cor2&stime=20130526_1500&etime=20130527_0000
prominence eruptions http://go.nasa.gov/19Dni3v
http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=lasc2rdf&img2=sdo_a304&stime=20130430_2200&etime=20130501_0800
filament eruptions http://go.nasa.gov/12qcWDO
http://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T02:24:03.851/anny_AIA-304_20130531T113203-20130531T185203_120s_made_20130601T022253_720p.mpg
coronal dimmings
http://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T00:52:07.870/anny_AIA-211_20130531T094003-20130531T145203_120s_made_20130601T005102_720p.mpg
http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=stb_e195&stime=20120527_0300&etime=20120527_1600