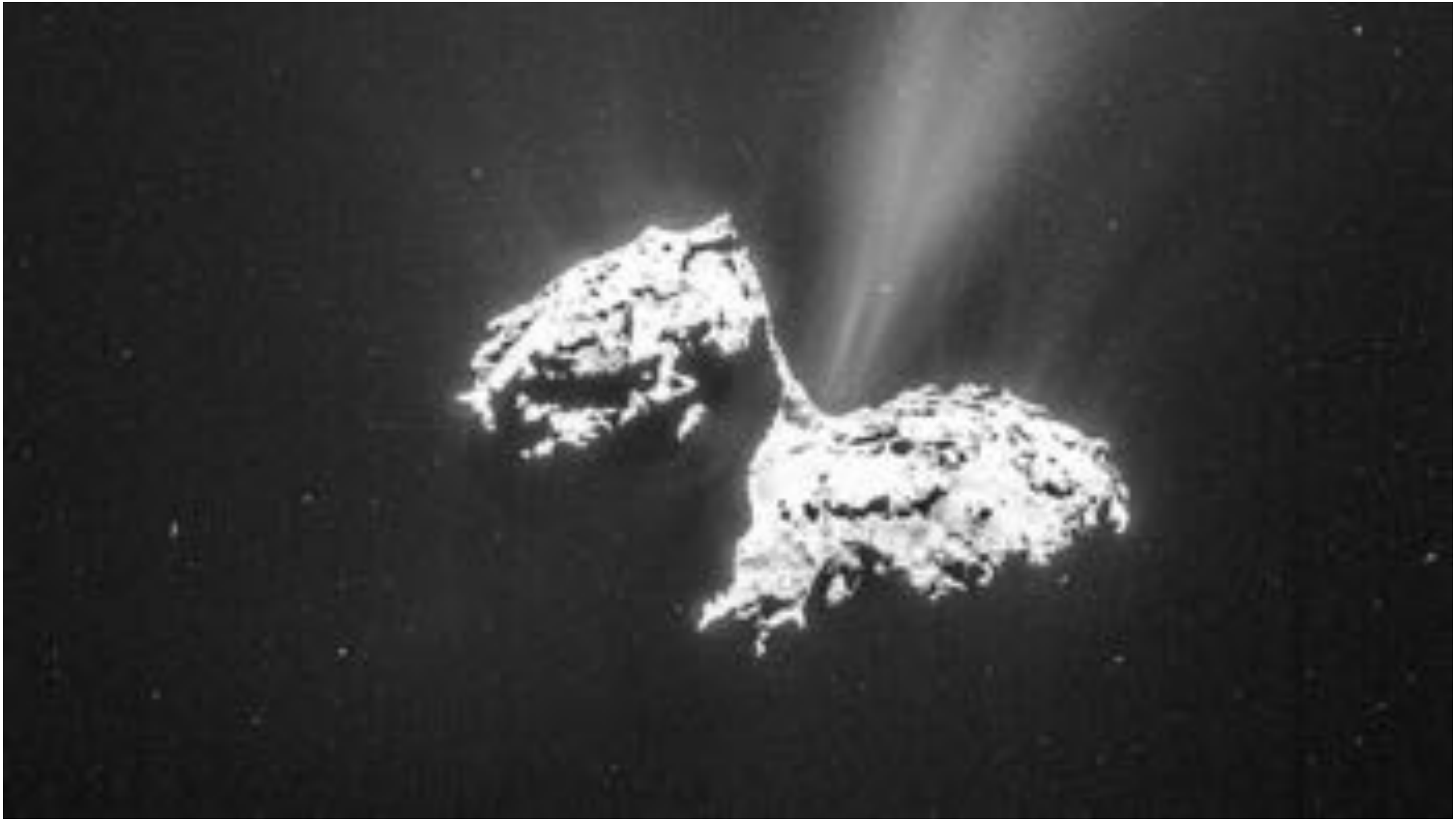
Cometary observations and derivation of Solar Wind properties

Geraint H. Jones

Mullard Space Science Laboratory, University College London, UK

Centre for Planetary Sciences at UCL/Birkbeck, London, UK

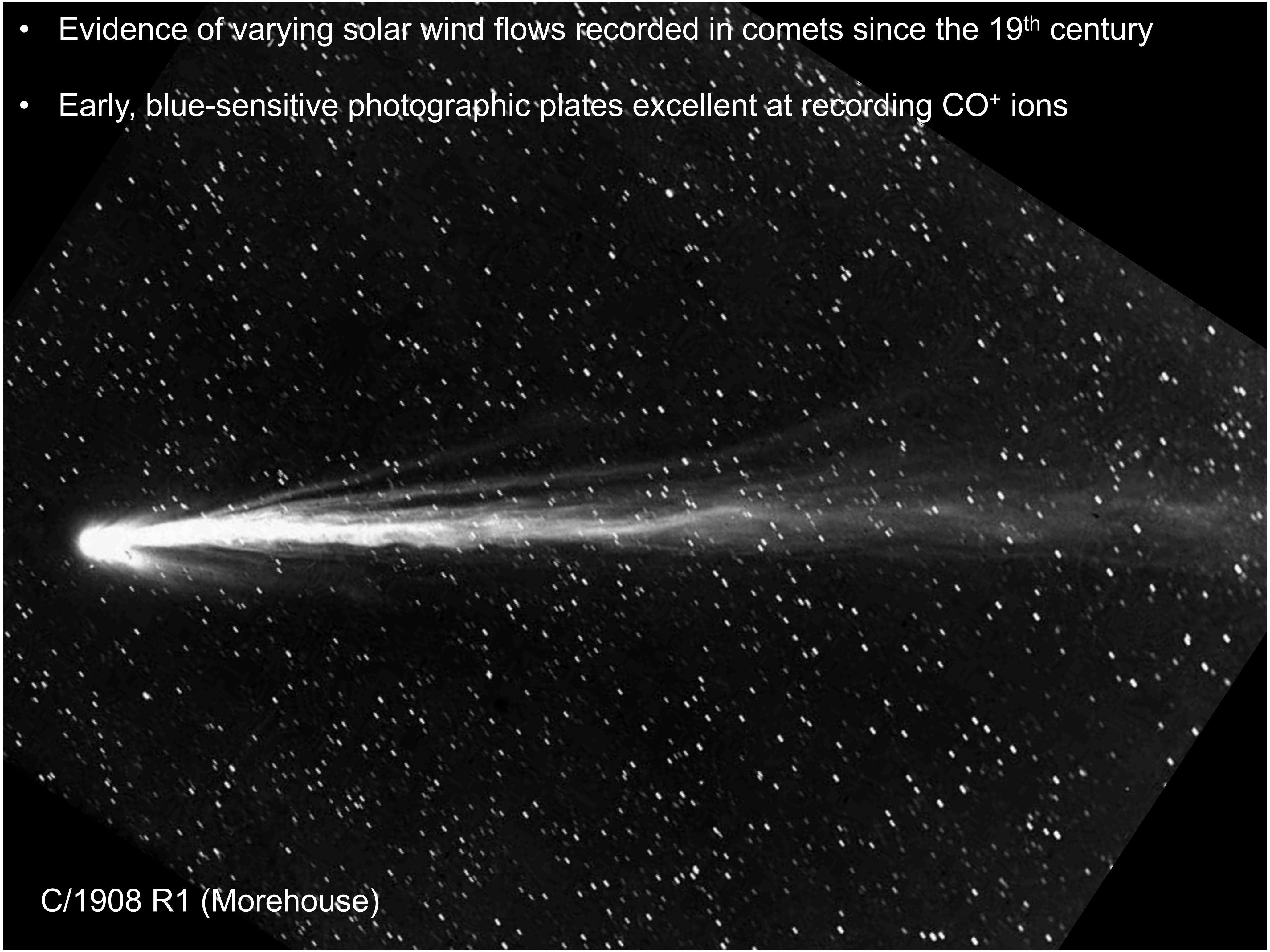
g.h.jones@ucl.ac.uk



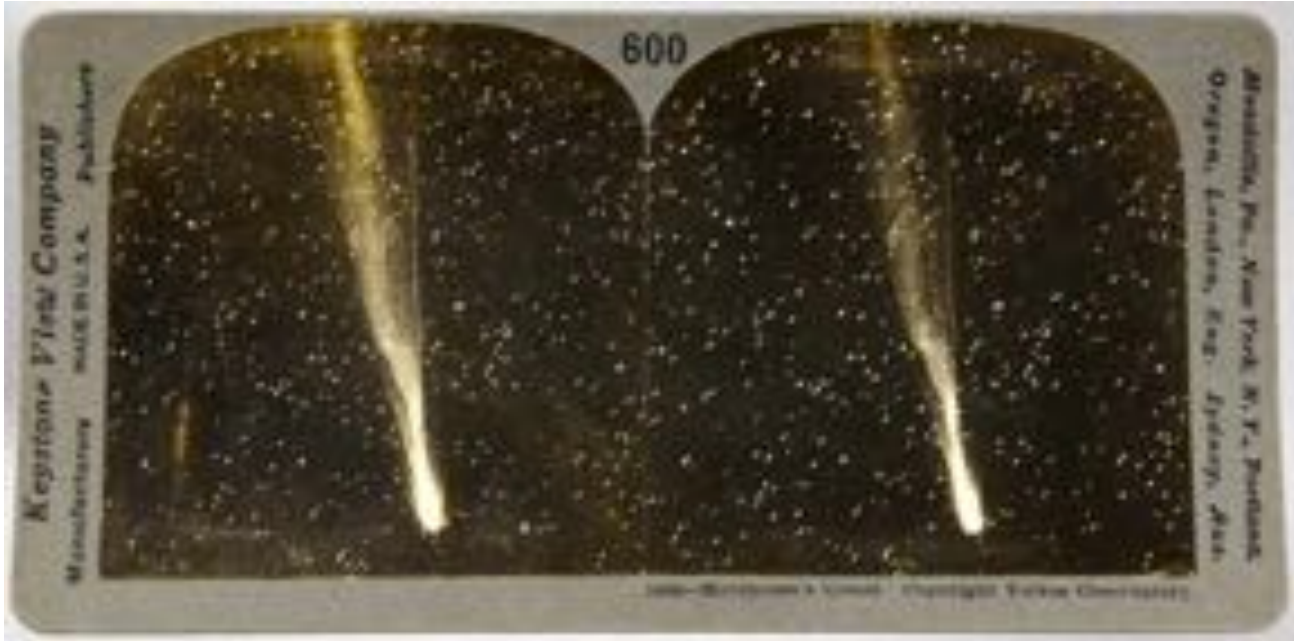
ESA

G. Rhemann

- Evidence of varying solar wind flows recorded in comets since the 19th century
- Early, blue-sensitive photographic plates excellent at recording CO^+ ions



C/1908 R1 (Morehouse)



Comets provided first evidence for solar wind's existence

•Evidence of a solar "corpuscular radiation" first hypothesised by Chapman & Bartels (1940)

•In 1943, Hoffmeister noted the difference of a few degrees in direction between cometary plasma tails and the anti-sunward direction, i.e. these ions carried in a medium moving at a finite speed

•1951: Biermann published statistical study of this anomaly; average tail direction ~3° from radial direction

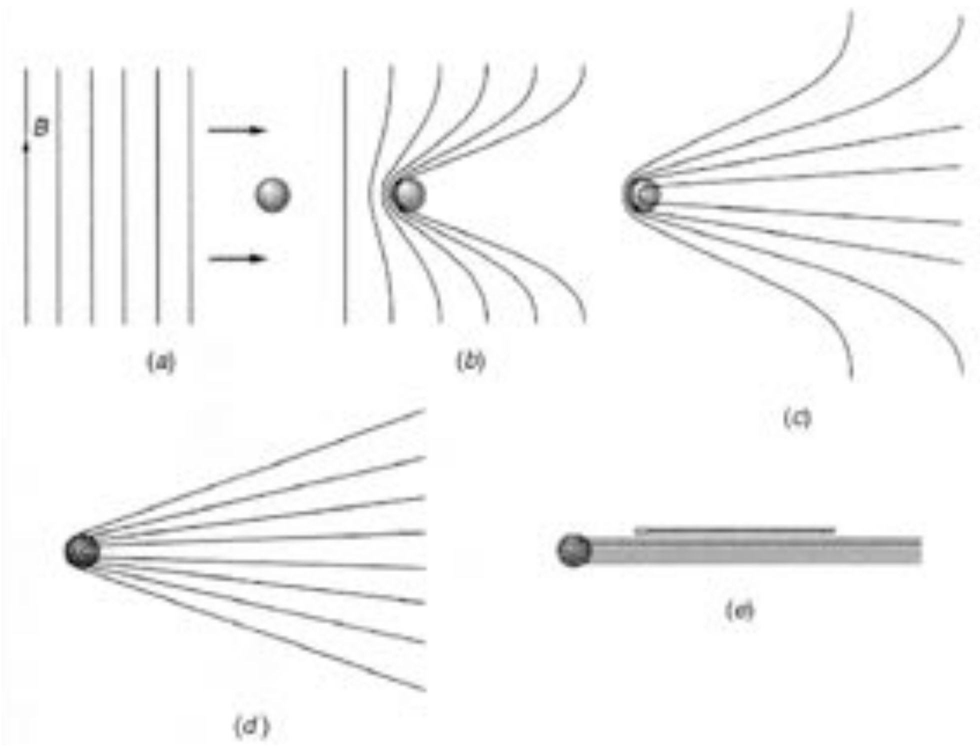
- Biermann suggested that cometary ions were being swept away by Chapman & Bartels's corpuscular radiation, with a speed of a few 100 km/s.

- For momentum coupling between solar plasma and cometary ions by Coulomb collisions, Biermann invoked too high a plasma density.

- Alfven (1957) solved this by proposing that solar wind had frozen-in magnetic field.

- Also that comet tail ray features were tracing solar wind flow through cometary coma & tail.

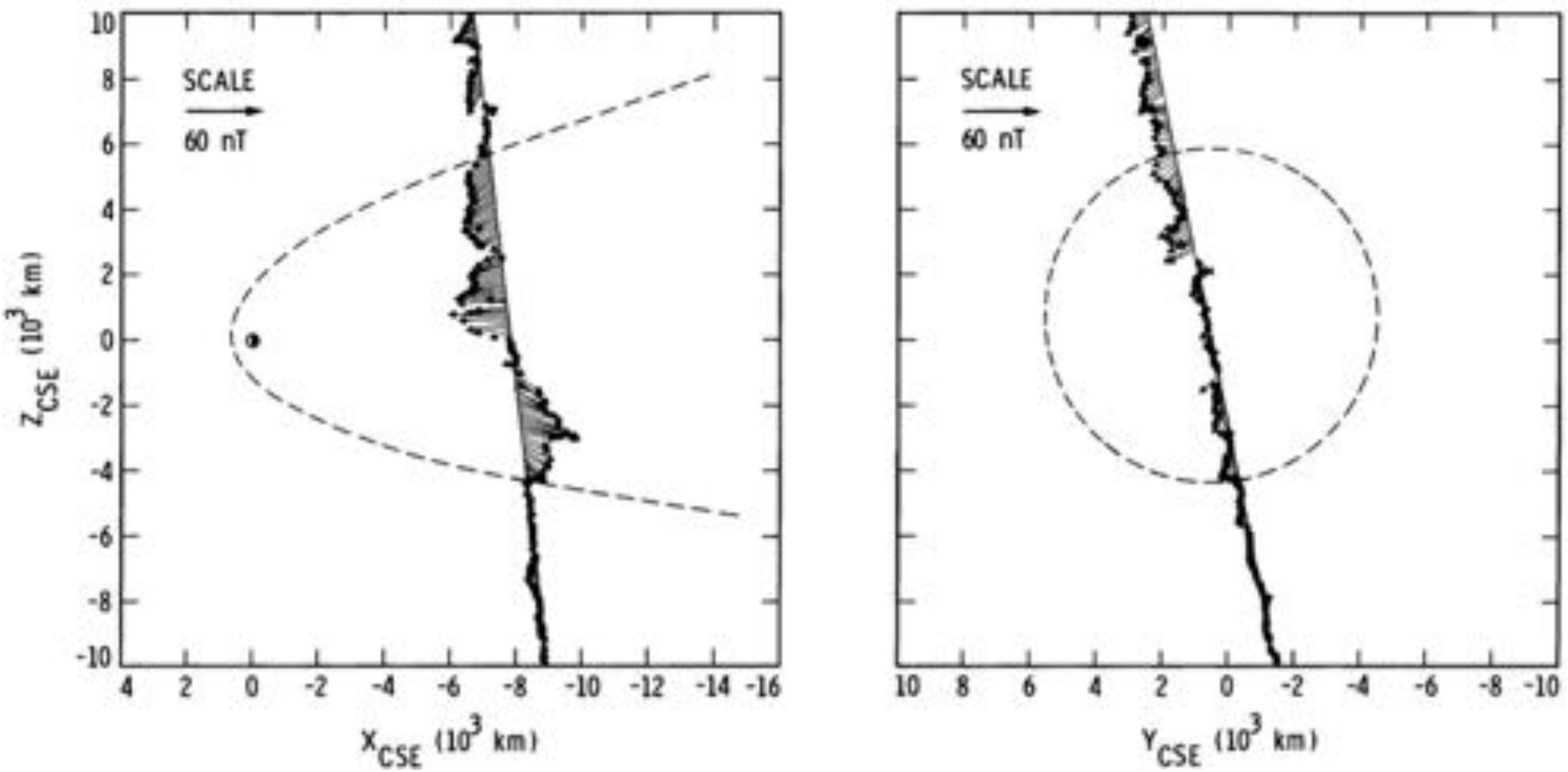
- Comets have induced magnetotails; comet-solar wind interaction region of very different scale to planetary magnetospheres due to freely-expanding atmosphere (Biermann et al. 1967)



Brandt & Chapman (1992), after Alfven (1957)

ISEE-3/International Cometary Explorer at 21P/Giacobini-Zinner

Induced magnetotail confirmed by in situ magnetic field observations

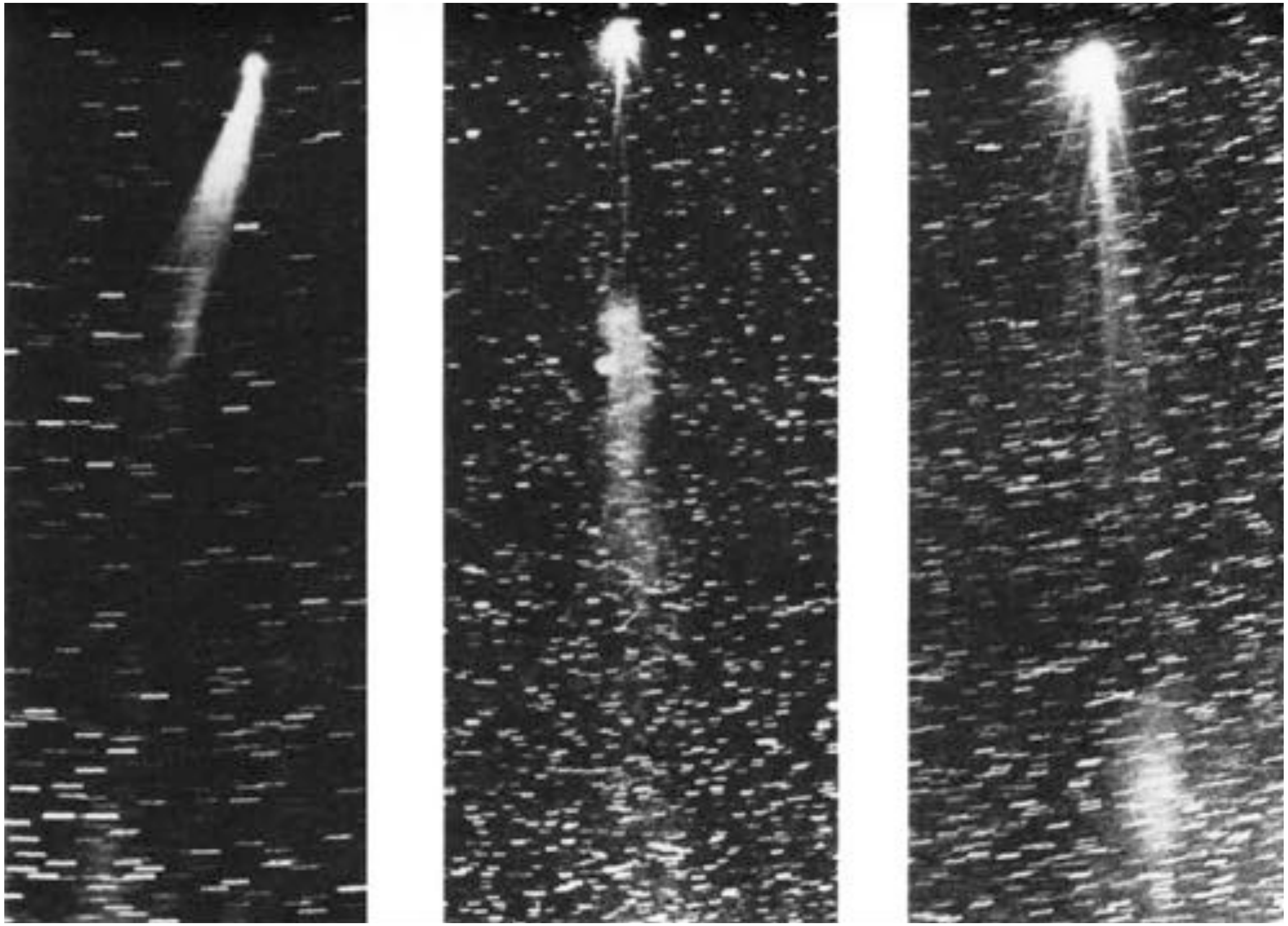


Slavin et al. (1986)

Comets trace the solar wind – what do they show us?

Disconnection Events

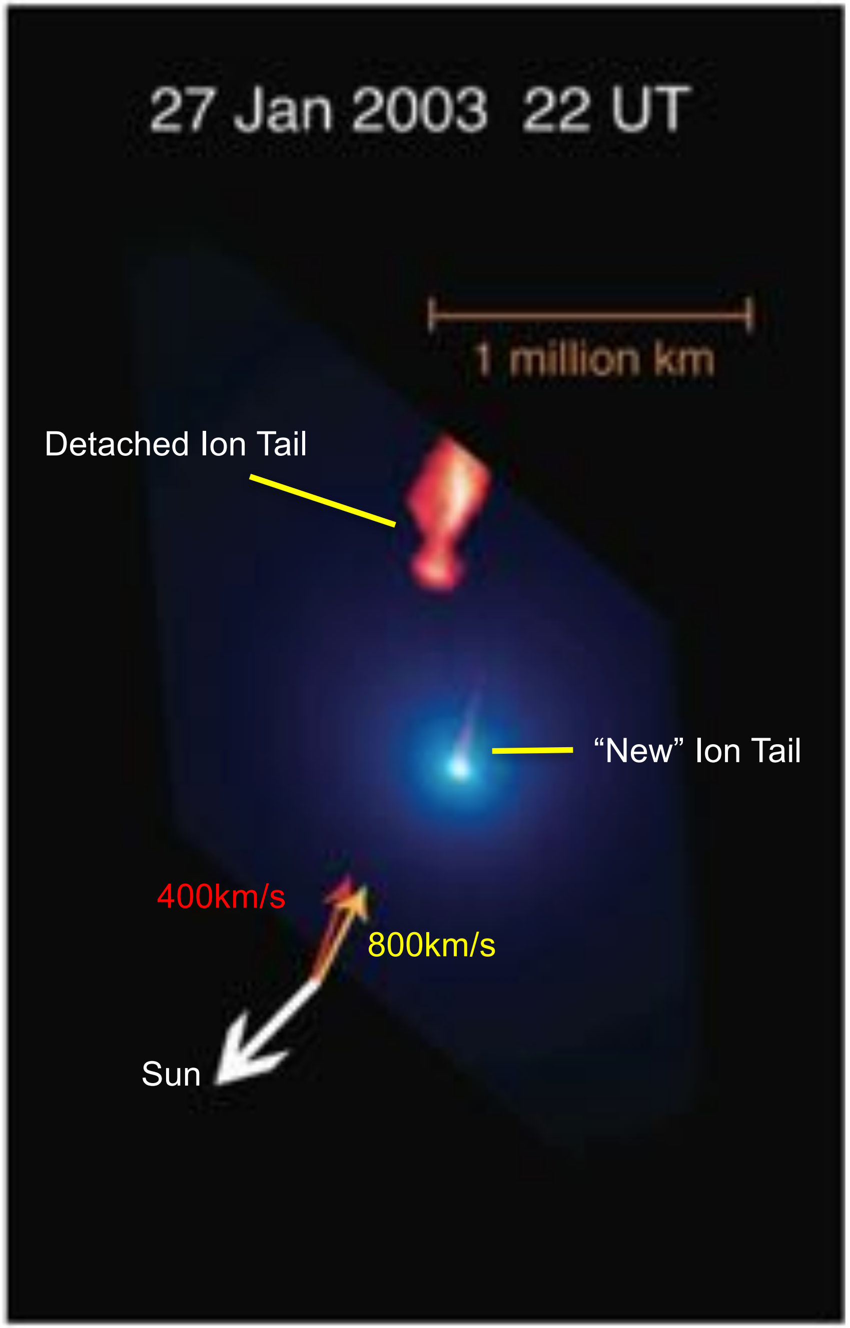
- Comet's ion tail detaches completely and regrows
- Usually crossings of the Heliospheric Current Sheet, some appear correlated with fast ICMEs



Comet Morehouse (1908)

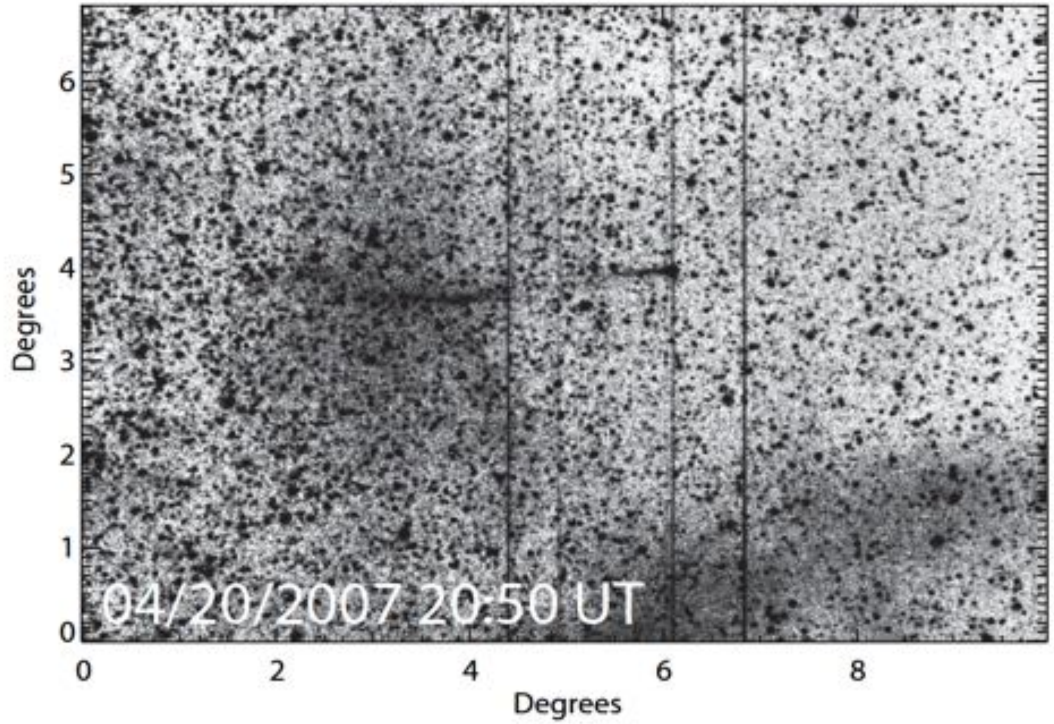
Comet C/2002 X5 (Kudo-Fujikawa)

Observation of C^{2+} ion tail by UVCS on SOHO (Povich et al. 2003)

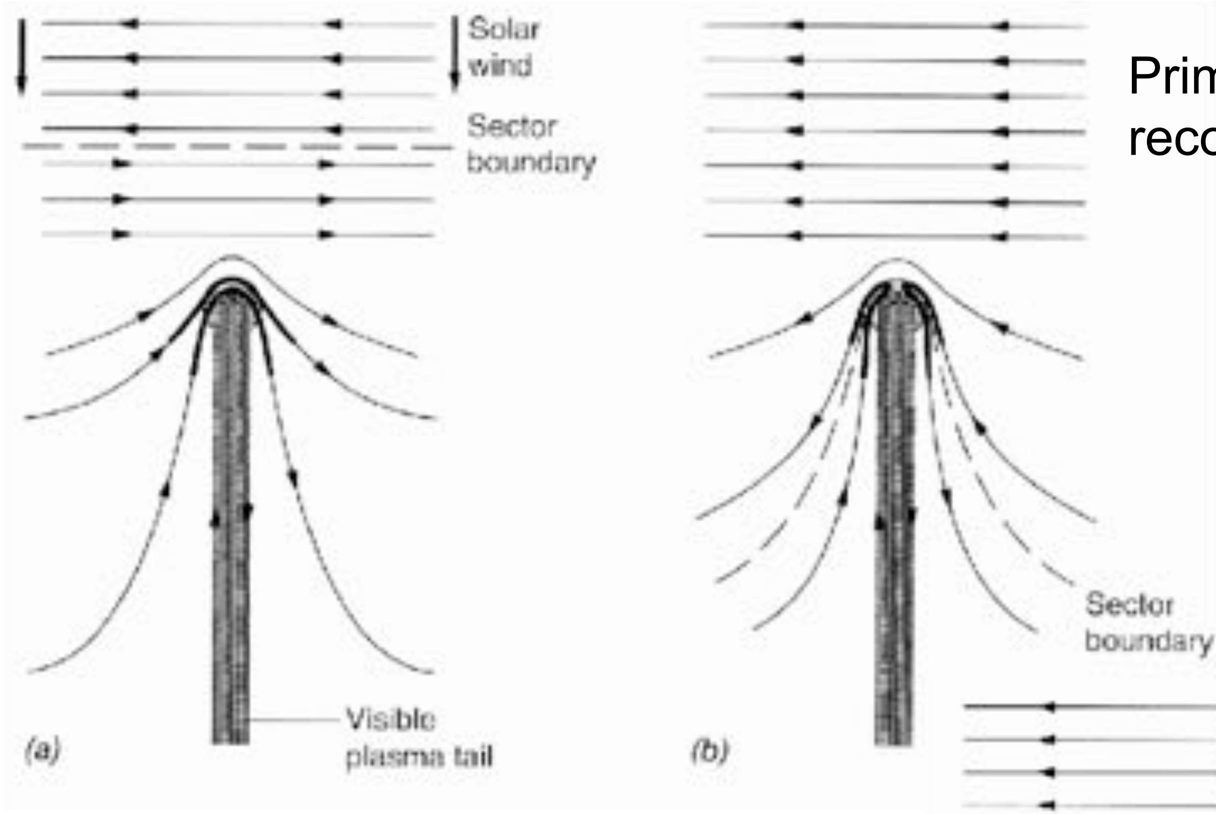


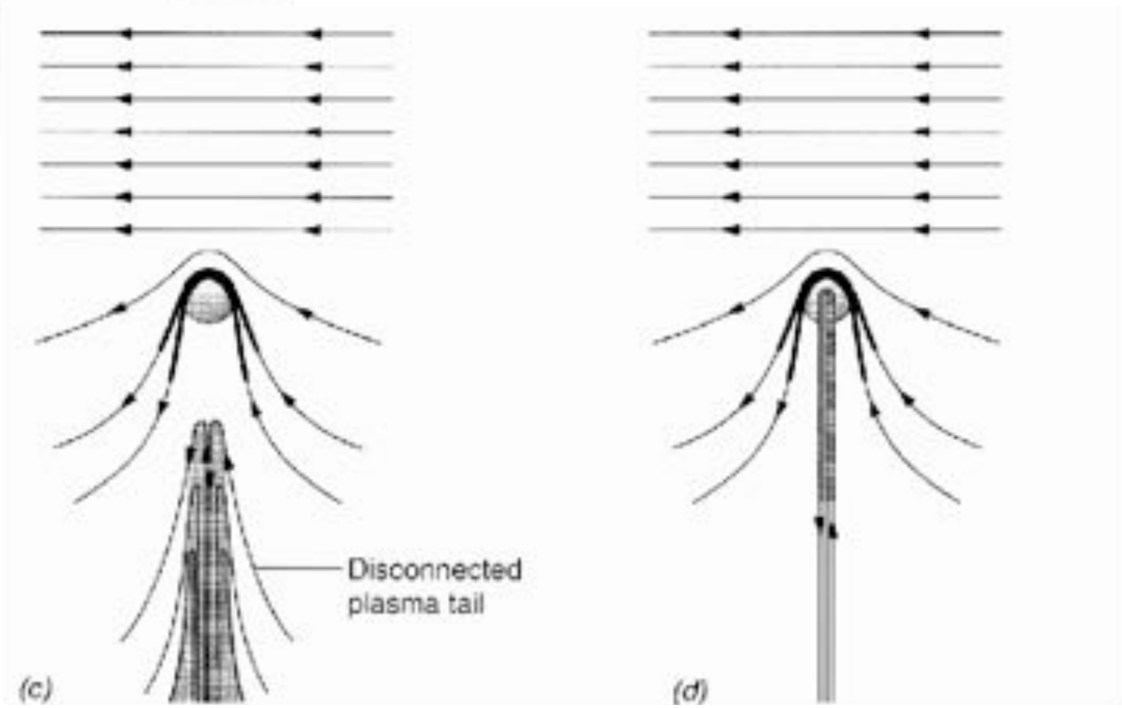
Comet 2P/Encke

STEREO SECCHI observation of tail disconnection associated with ICME (Vourlidas et al. 2007)



Primary cause of disconnection events: reconnection when crossing the HCS.

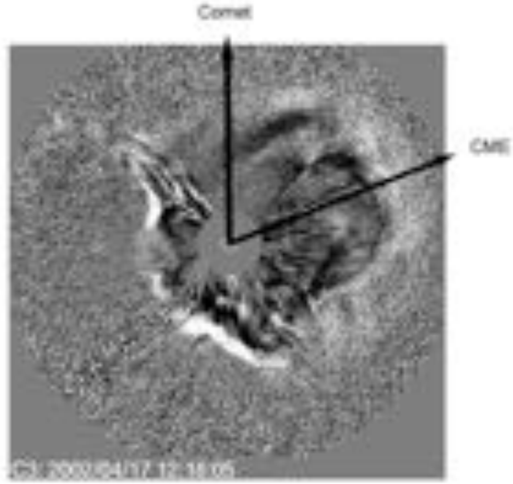


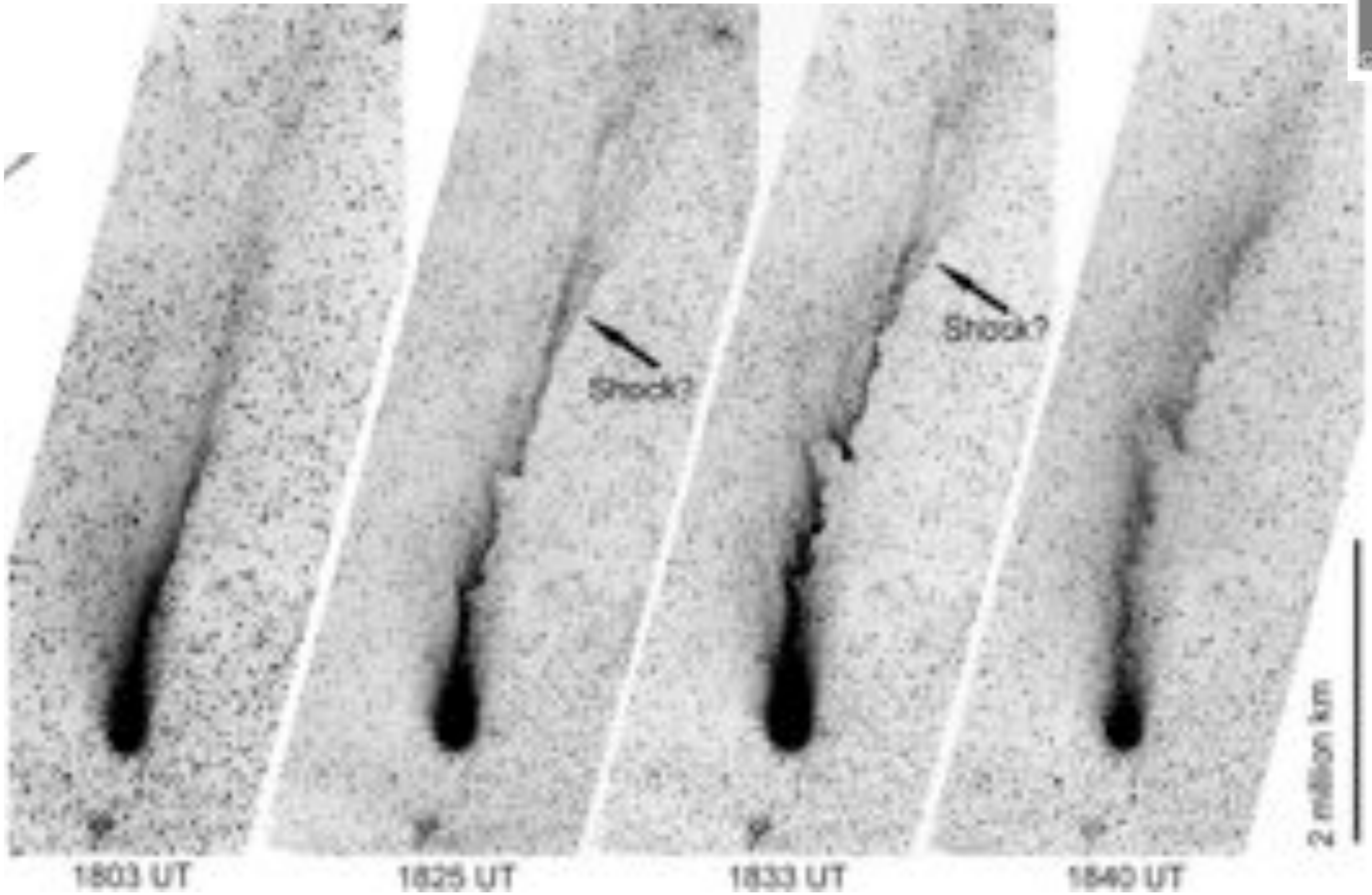


Niedner & Brandt (1978)

Abrupt Tail Disruptions

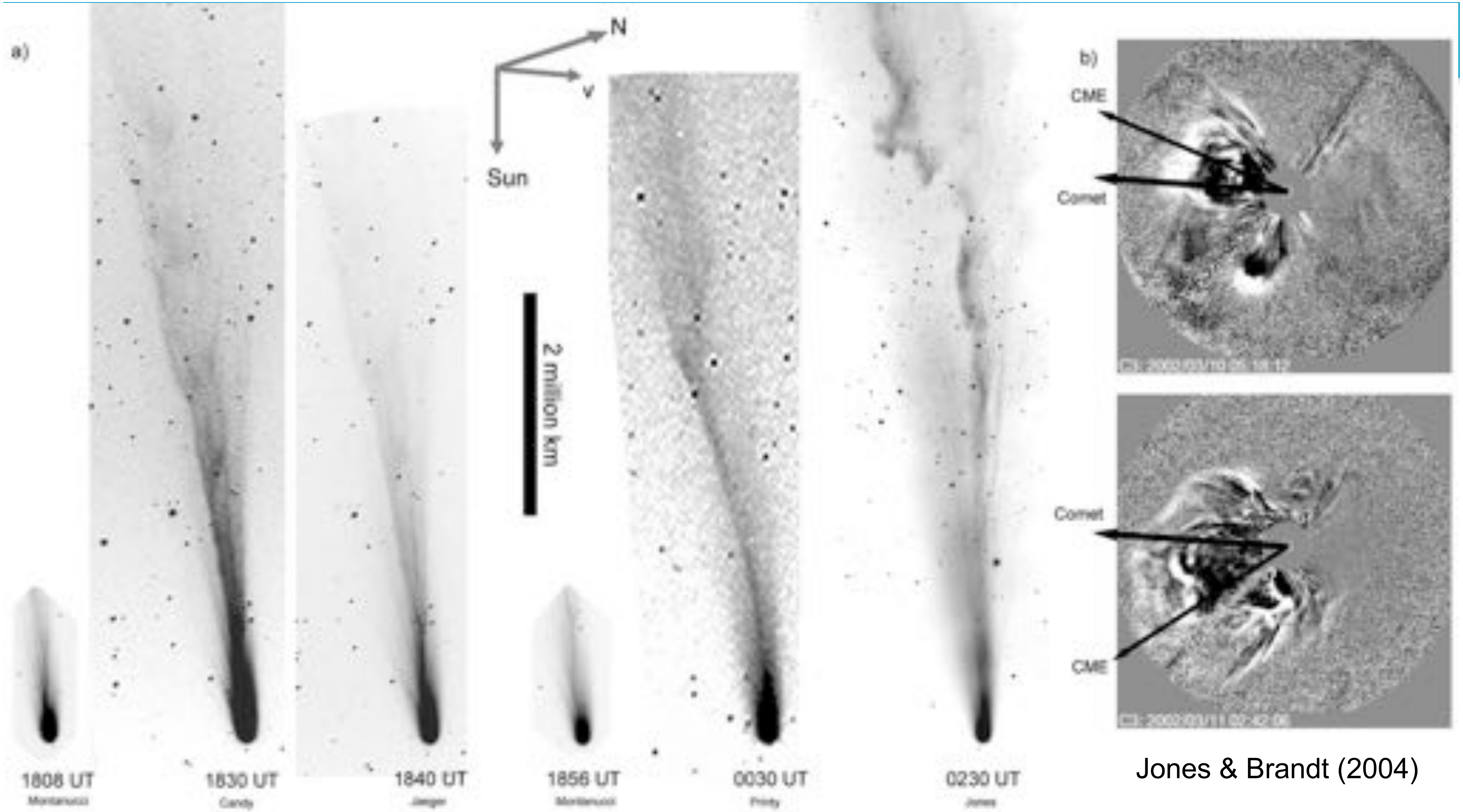
- Rapid change in ion tail appearance
- Jockers (1986) proposed term “cometary substorms”
- Jones & Brandt (2004) associated events in Comet 153P with fast ICME, plane-of-sky velocity ~1200 kms^{-1}
- ICME overtakes ion tail, forming scalloped features





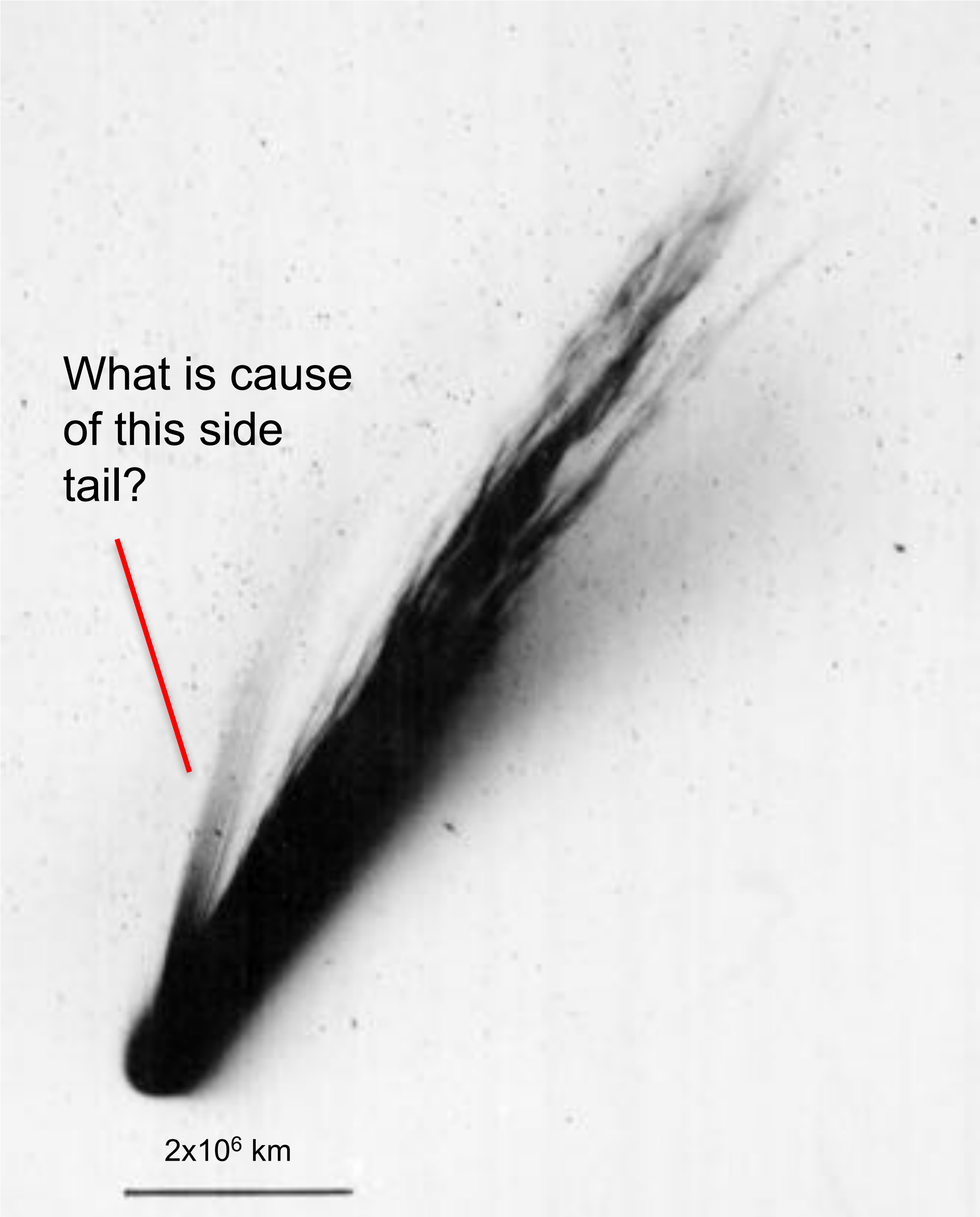
Jones & Brandt, 2004

Comet 153P/ Ikeya-Zhang



Jones & Brandt (2004)

- Another example from Comet 153P/Ikeya-Zhang
- Images gathered from amateur astronomers in several countries
- Arrival of two ICMEs seen: second one overtakes the first, resulting in abrupt tail disruption. Plane-of-sky velocities ~600 and 1093 $\mathrm{km s^{-1}}$



- Many complex tail features not yet understood, presumably associated with solar wind features.
- Example: Comet C/1957 P1 (Mrkos) (Miller, 1988)

Exploitation of archival data

INTERPLANETARY GAS. XII. A CATALOGUE OF COMET-TAIL ORIENTATIONS*

MICHAEL J. S. BELTON AND JOHN C. BRANDT†
Kitt Peak National Observatory,‡ Tucson, Arizona

Received August 31, 1965

ABSTRACT

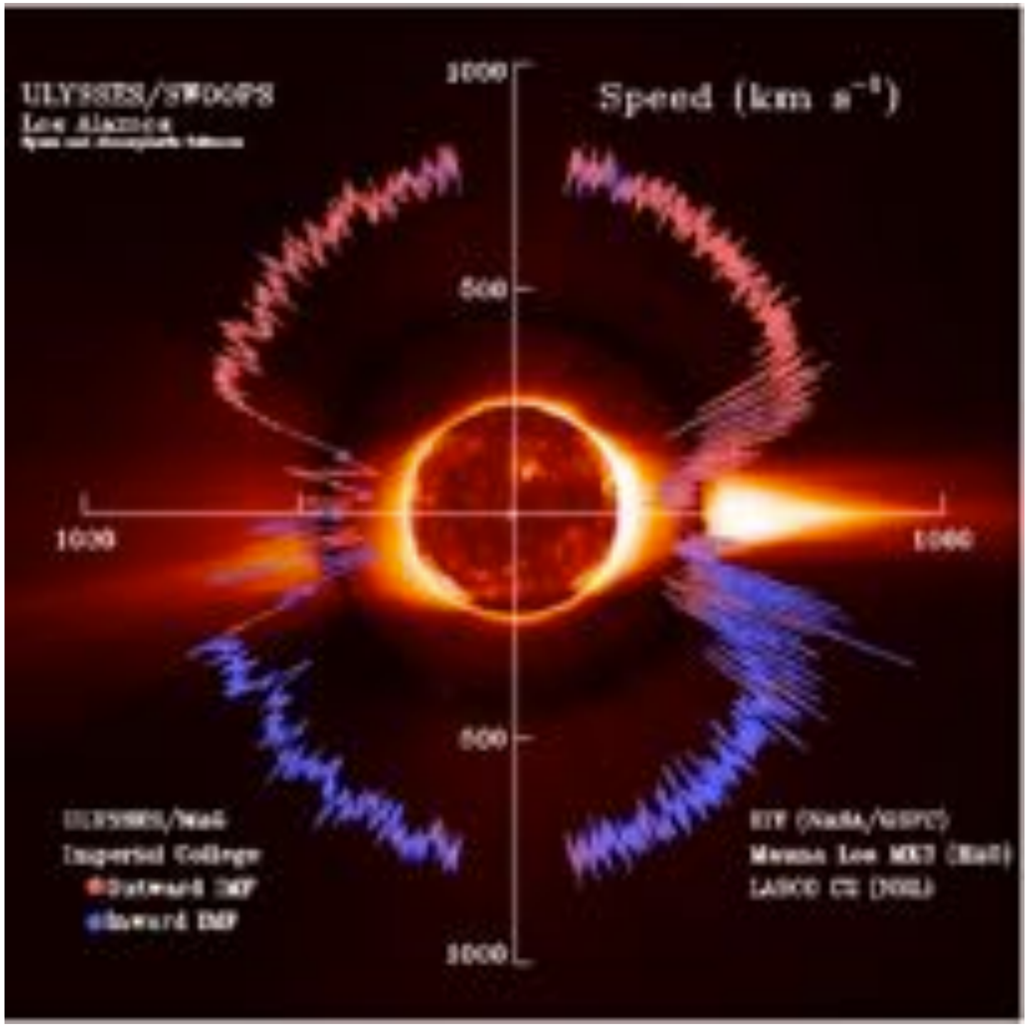
Some 1600 observations of the position angle of comet tails, including both original and published measurements, are reduced to orientations in the plane of the orbit of the comet. Measured and computed quantities are given together in the tabulation. Also given are the vectors which describe the geometrical circumstances at the time of observation.

These observations are of value not only from the standpoint of the physics of comet tails but also in computing the velocity of the solar wind and/or for testing models of the interplanetary plasma.

- 1600 observations analyzed
- Solar wind speed estimated from orientation of tail
- Removing dust tails, “impossible” directions, reduces number to 1038

- Dataset is relatively sparse

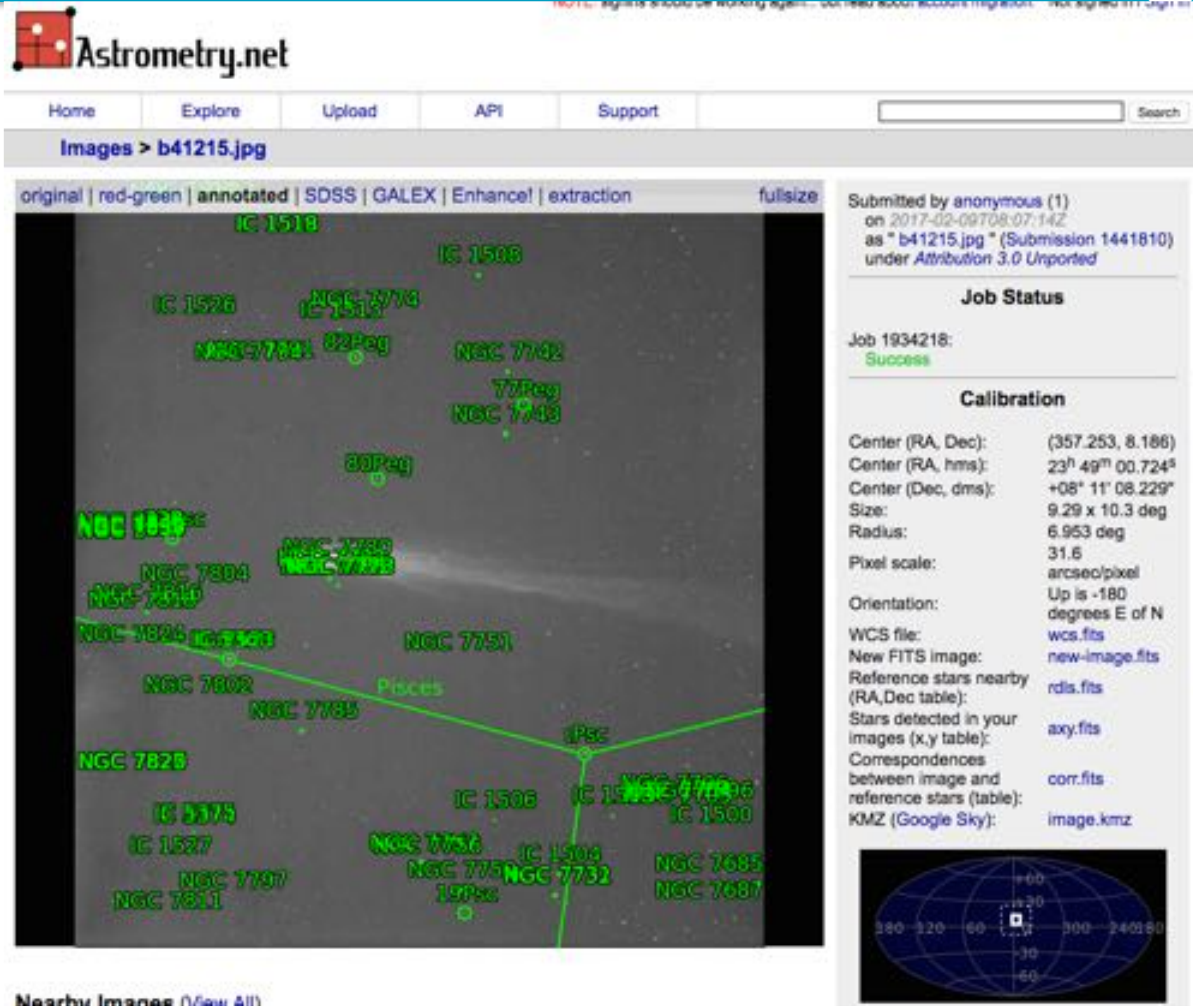
- Despite this, Pflug (1965) reported that lowest solar wind speeds are observed when comets are at lowest latitudes, consistent with known solar wind structure at solar minimum (McComas et al.)



New Analysis Techniques

Comet 1P/Halley
April 21, 1910
Arequipa, Peru

(Digital Access to a Sky Century @ Harvard)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IC 1500
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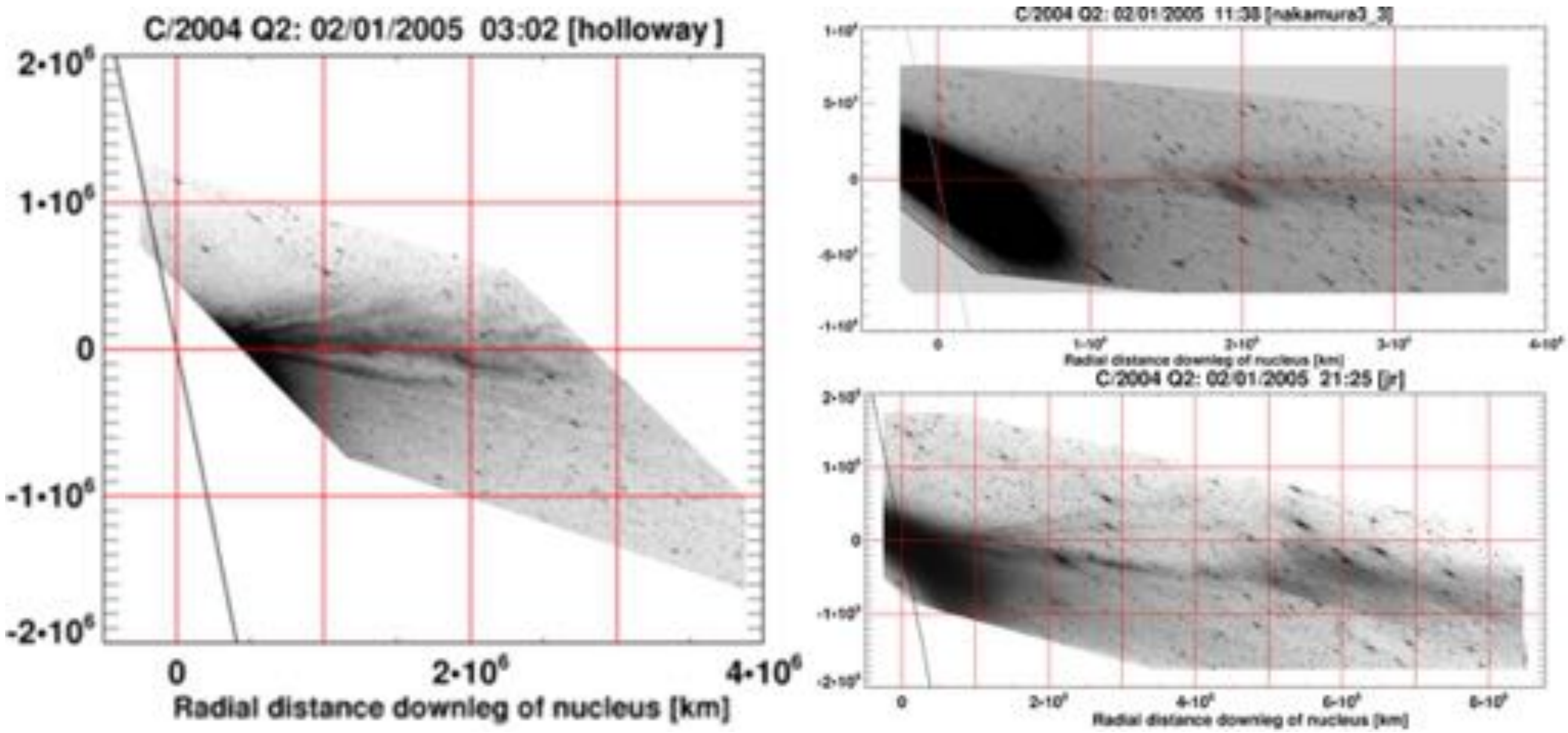
Submitted by anonymous (1)
on 2017-02-09T08:07:14Z
as " b41215.jpg " (Submission 1441810)
under Attribution 3.0 Unported
Job Status
Job 1934218:
Success
Calibration
Center (RA, Dec): (357.253, 8.186)
Center (RA, hms): 23h 49m 00.724s
Center (Dec, dms): +08° 11' 08.229"
Size: 9.29 x 10.3 deg
Radius: 6.953 deg
Pixel scale: 31.6 arcsec/pixel
Orientation: Up is -180 degrees E of N
WCS file: wcs.fits
New FITS image: new-image.fits
Reference stars nearby (RA,Dec table): rdls.fits
Stars detected in your images (x,y table): axy.fits
Correspondences between image and reference stars (table): corr.fits
KMZ (Google Sky): image.kmz
Nearby Images (View All)



- Yudish Ramanjooloo (2015) developed code to analyse comet tail images in detail.
- Technique found to be very sensitive to orbit plane angle: if Earth close to comet's orbital plane, technique is <u>not</u> reliable

- From each image, several solar wind speed estimates can be obtained

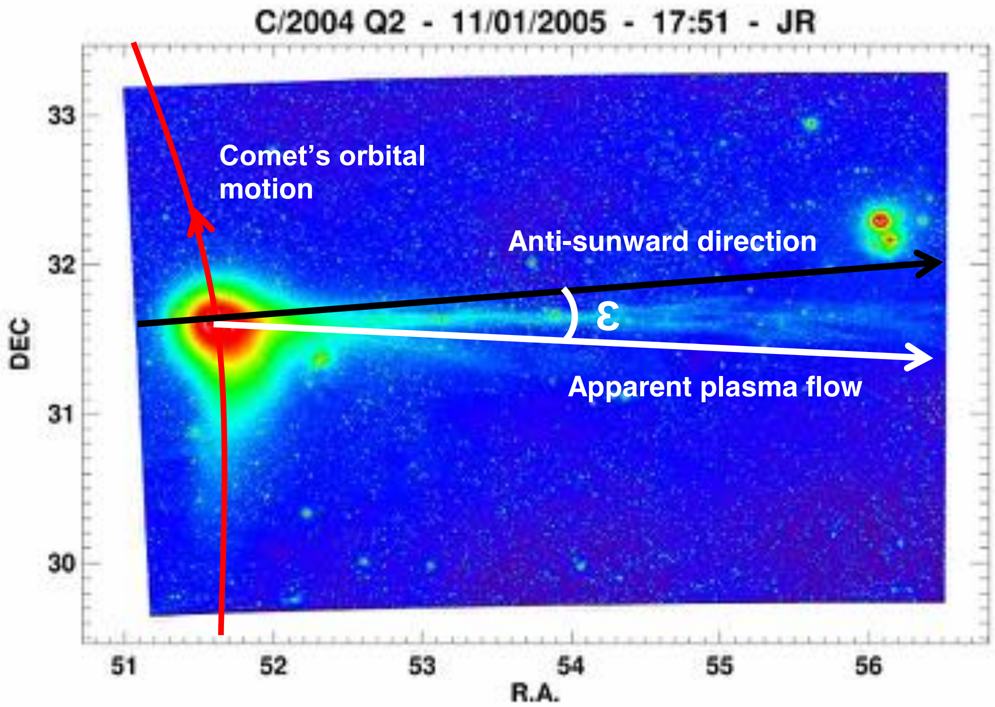
- Image field of view recognized with astrometry.net

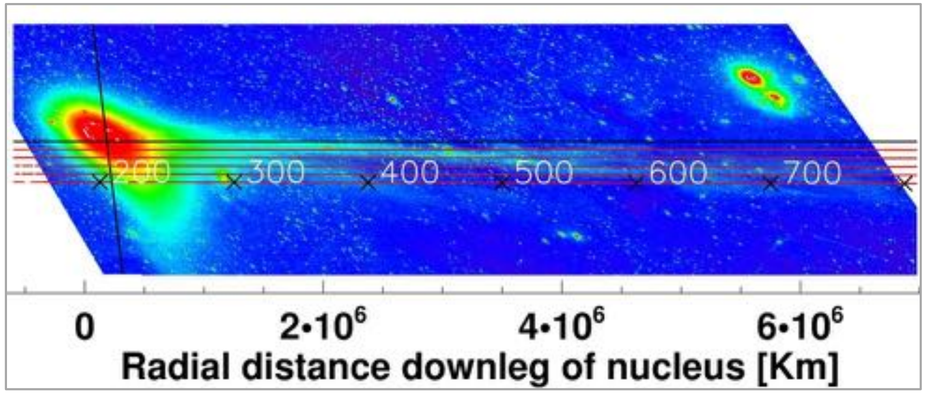
- Image mapped onto comet's orbital plane

- Sun-comet line horizontal

- User identifies several points along the tail.

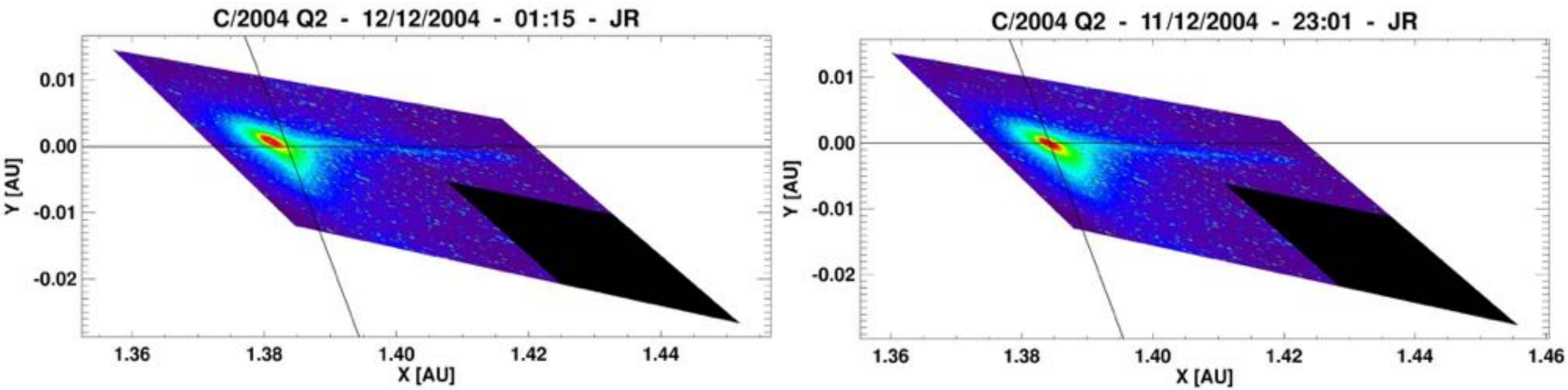
- Distance from orbit of each section of tail, and time elapsed since nucleus at that position gives a solar wind speed estimate.



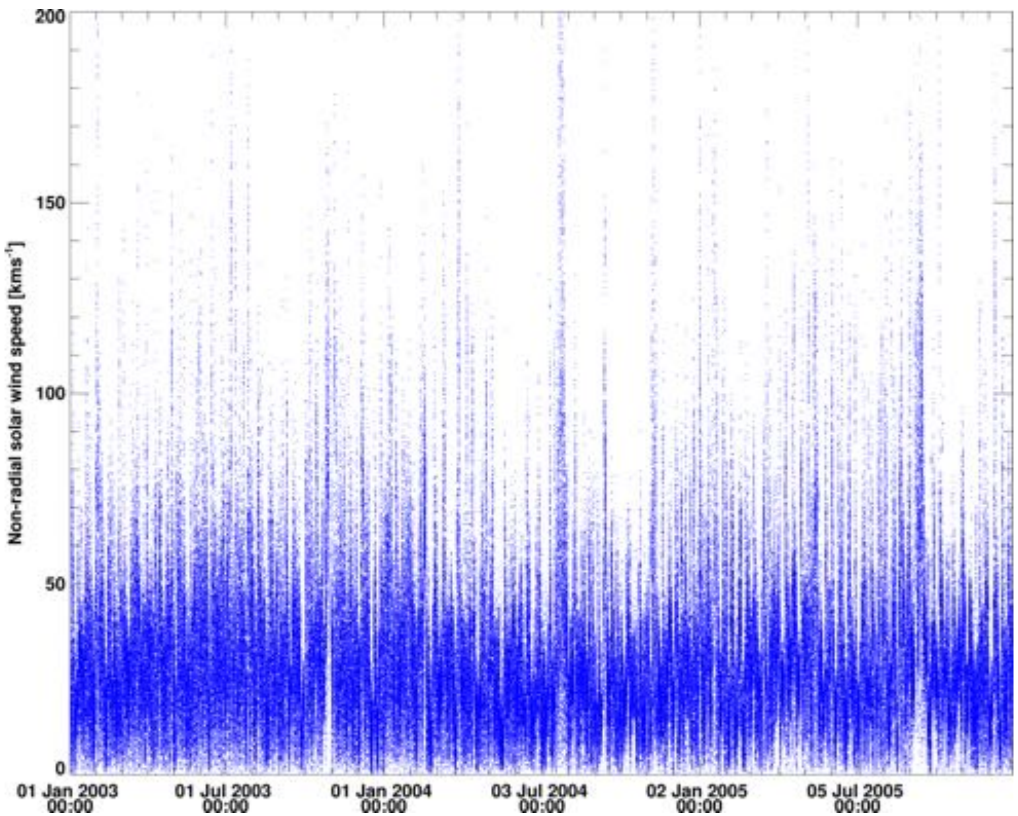


For best results:

- Comet orbit plane angle has to be large (observer not near orbital plane of the comet)
- Phase angle not too large or too small (not observing “along” tail; linked to orbit plane angle)
- Time of observation very important! Centroiding technique can provide good estimates of observation time.



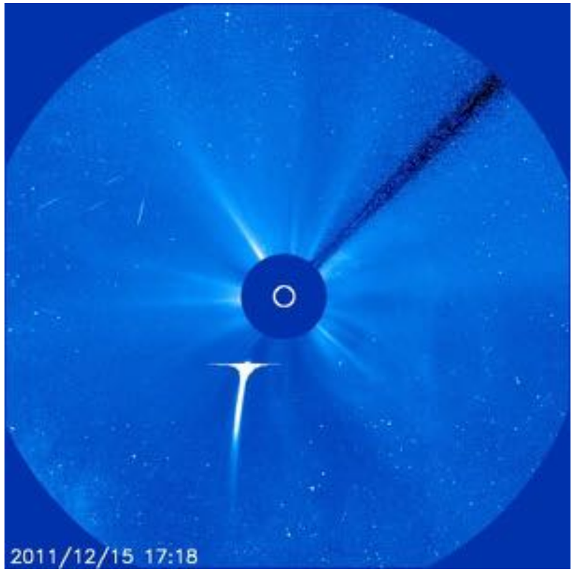
- Yudish’s code being adapted for use via a web interface as part of PSWS activities. IDL source code will be made available in any case.

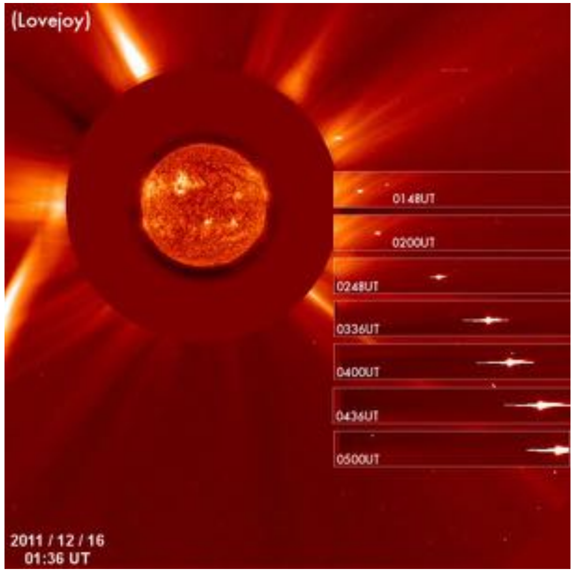


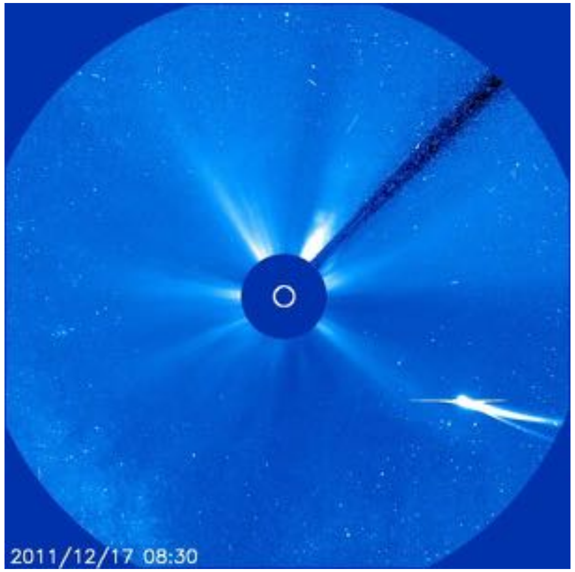
Final Caveat:

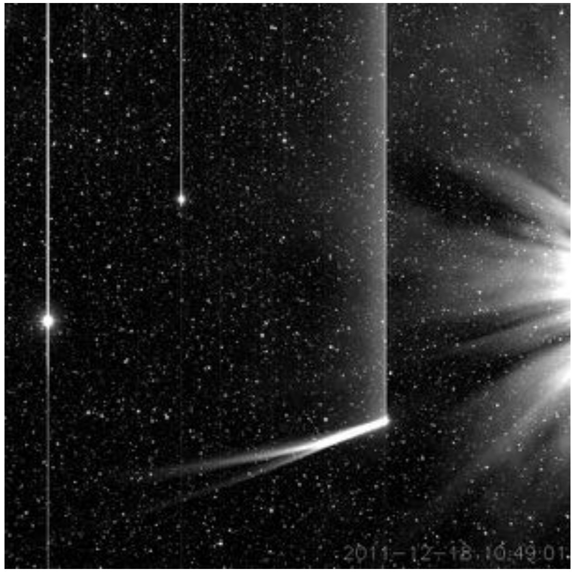
- This technique relies on solar wind flow being radial
- This is untrue for much of the time;
  mean non-radial components at ACE: 30 km/s

C/2011 W3 (Lovejoy)

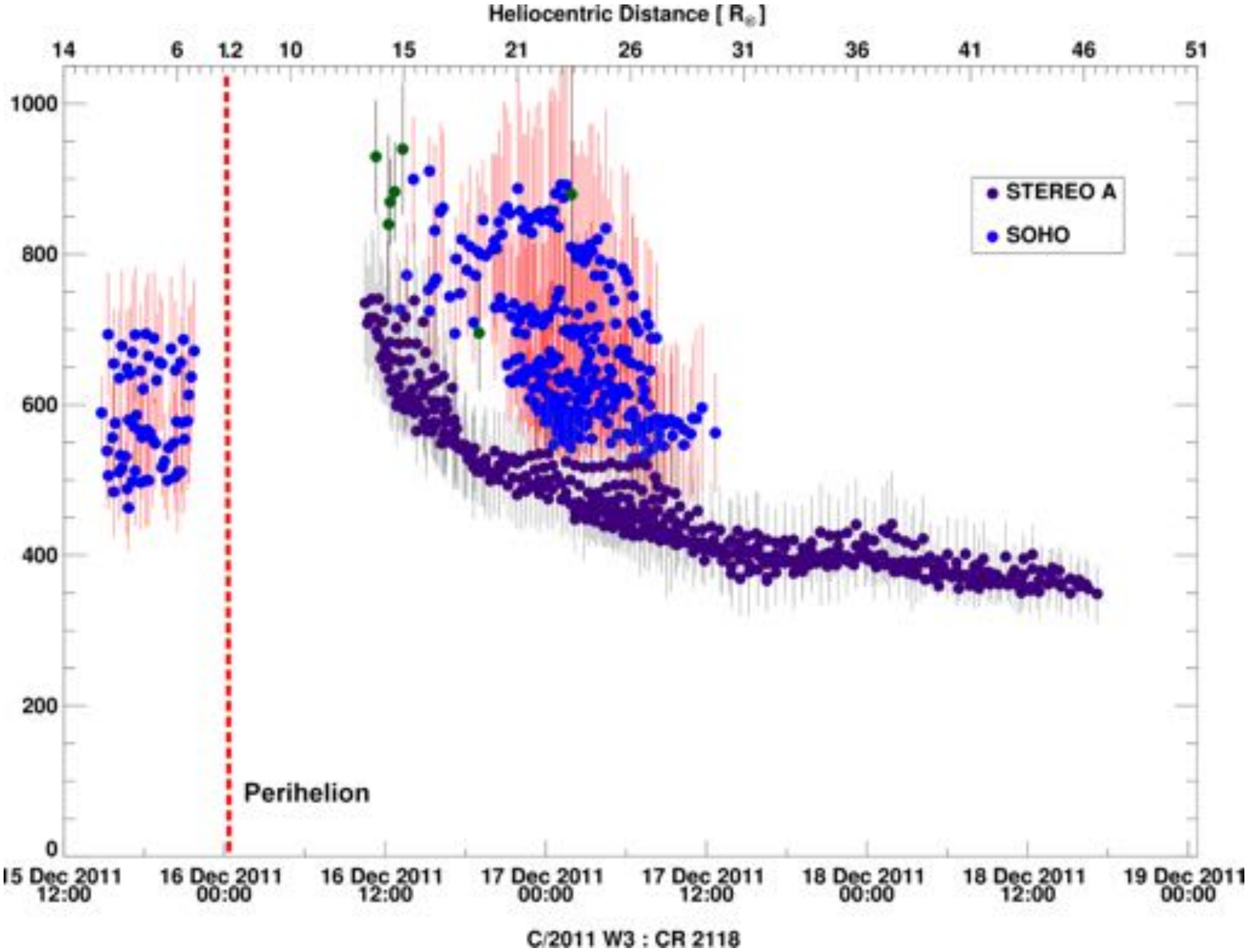








C/2011 W3 (Lovejoy) – evidence of non-radial solar wind



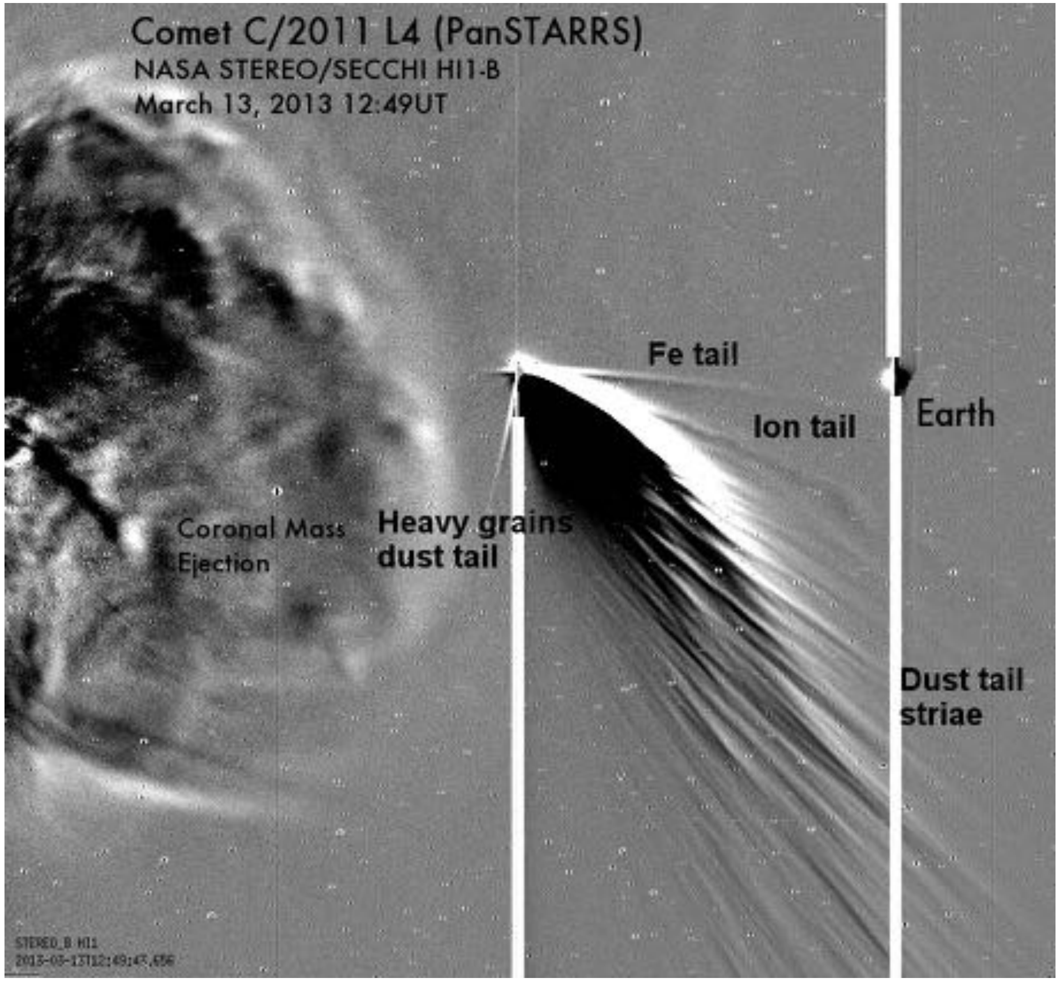
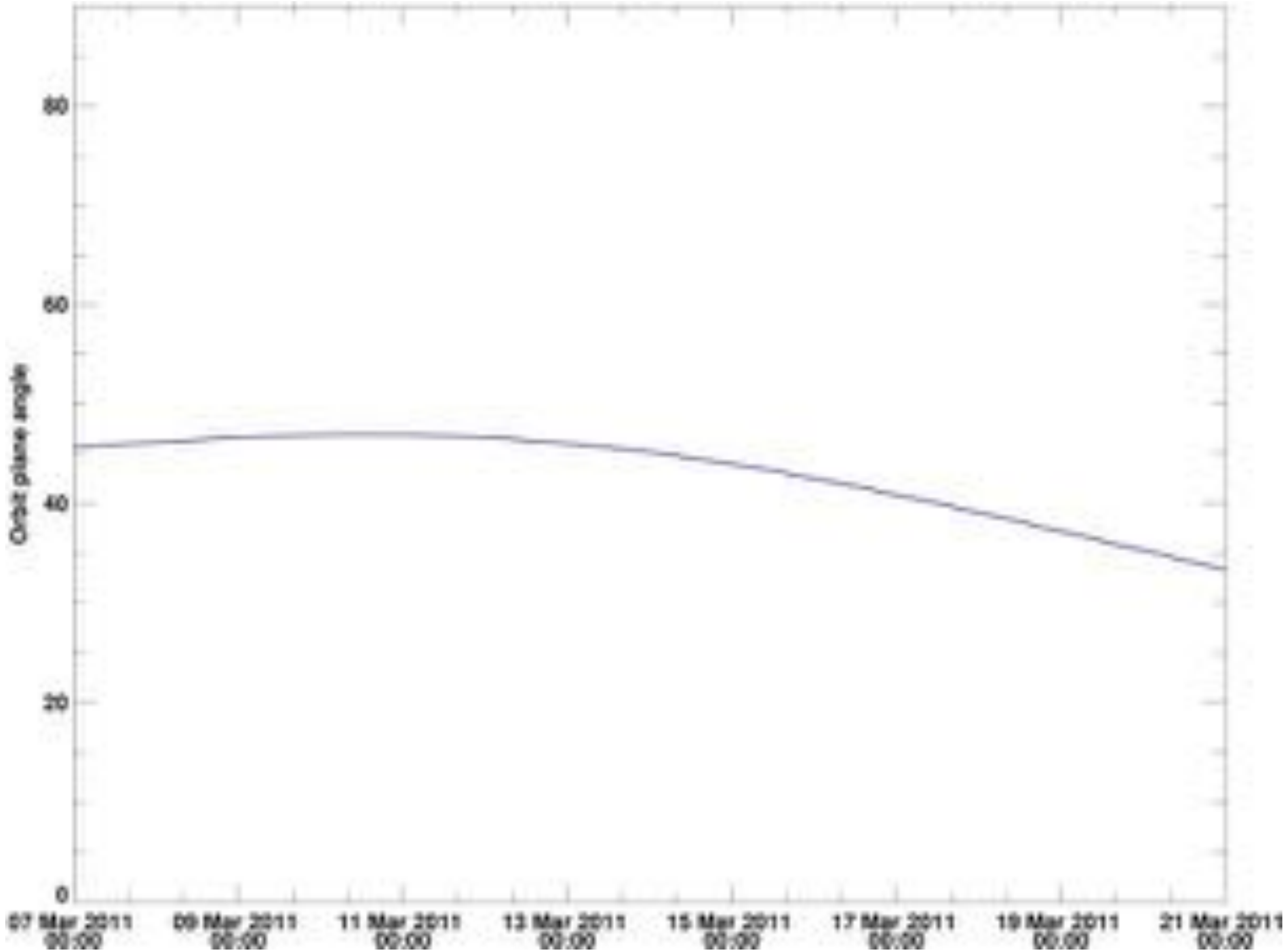
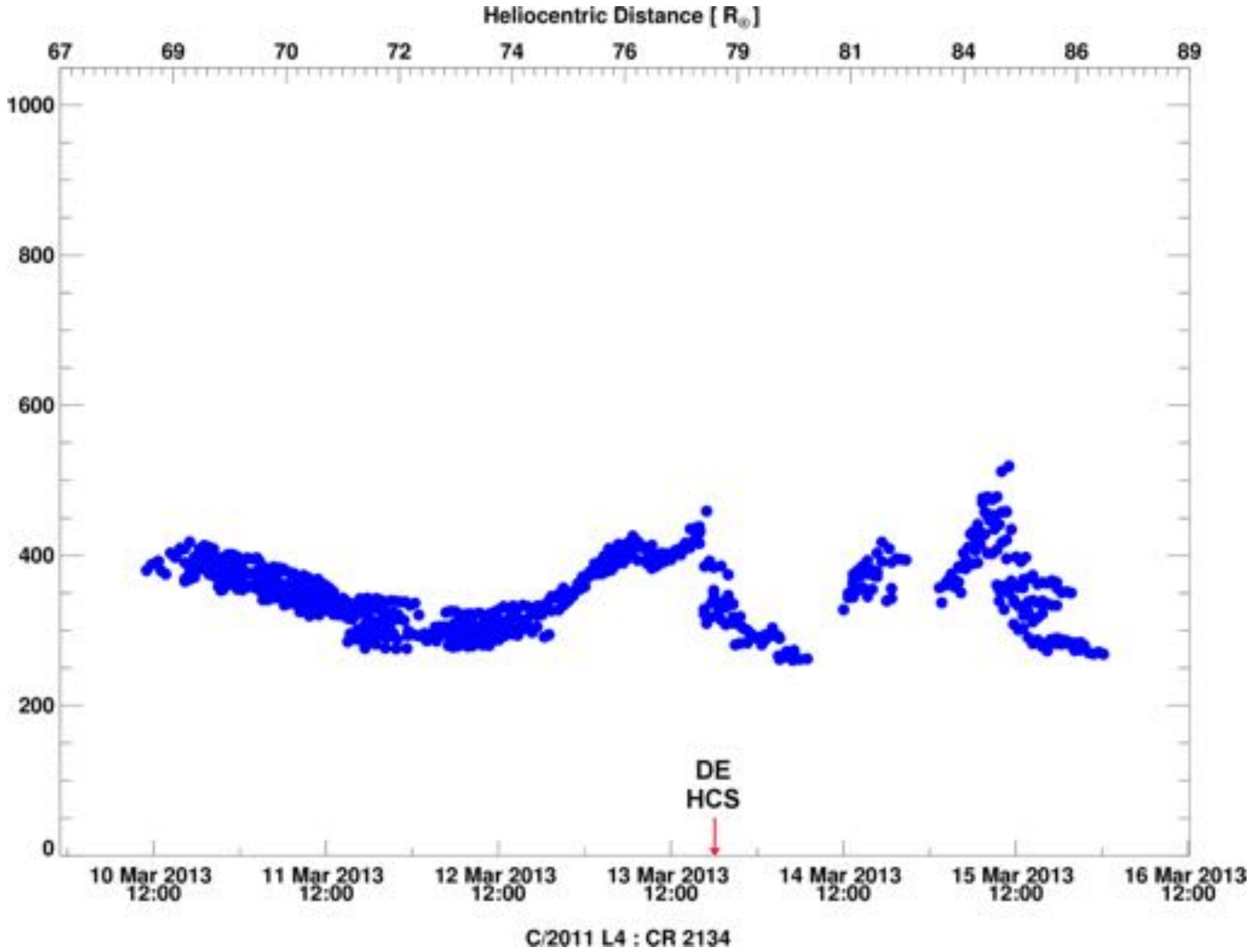


Figure 6.31: STEREO B FOV of a CME and the multiple tails of C/2011 L4 on 13/03/2013 12:49 UT. Note that it is not necessary that the CME will have interacted with the comet. The CCD blooming has been masked by the white columns.

Orbit plane angle of C/2011 L4 from STEREO-B



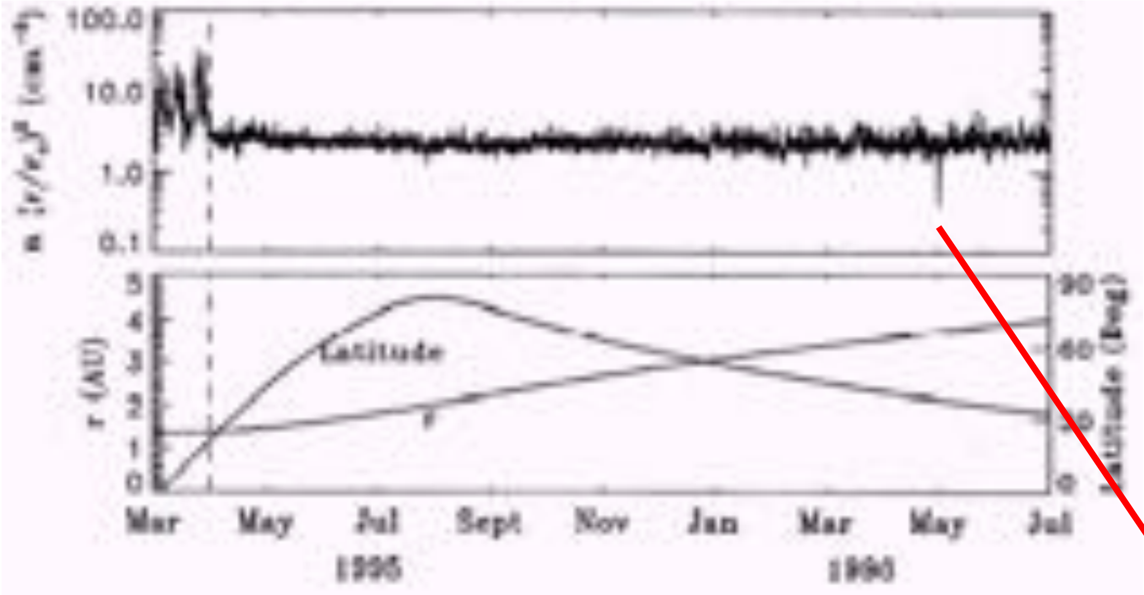
Pan-STARRS (C/2011 L4) using STEREO-B SECCHI HI data

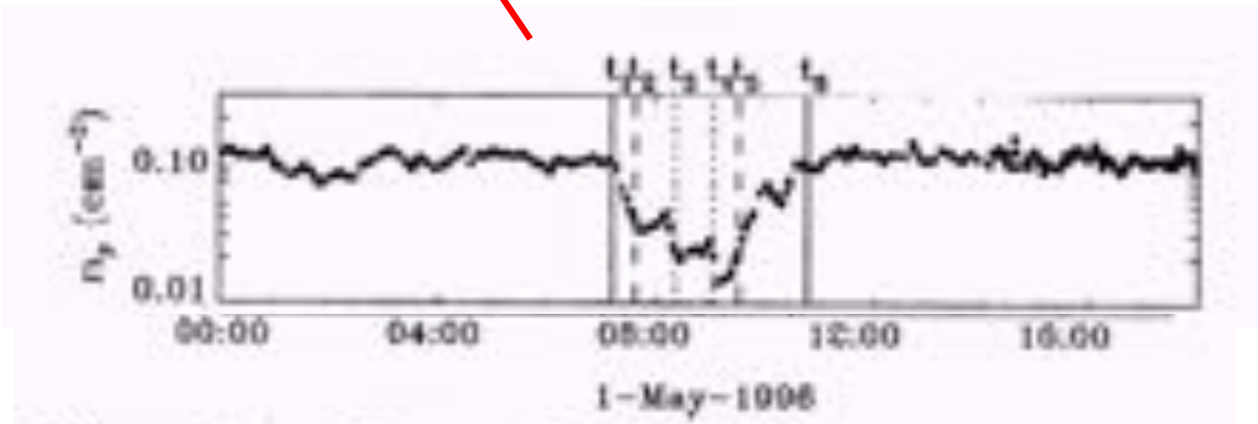


Comet Tail Crossings

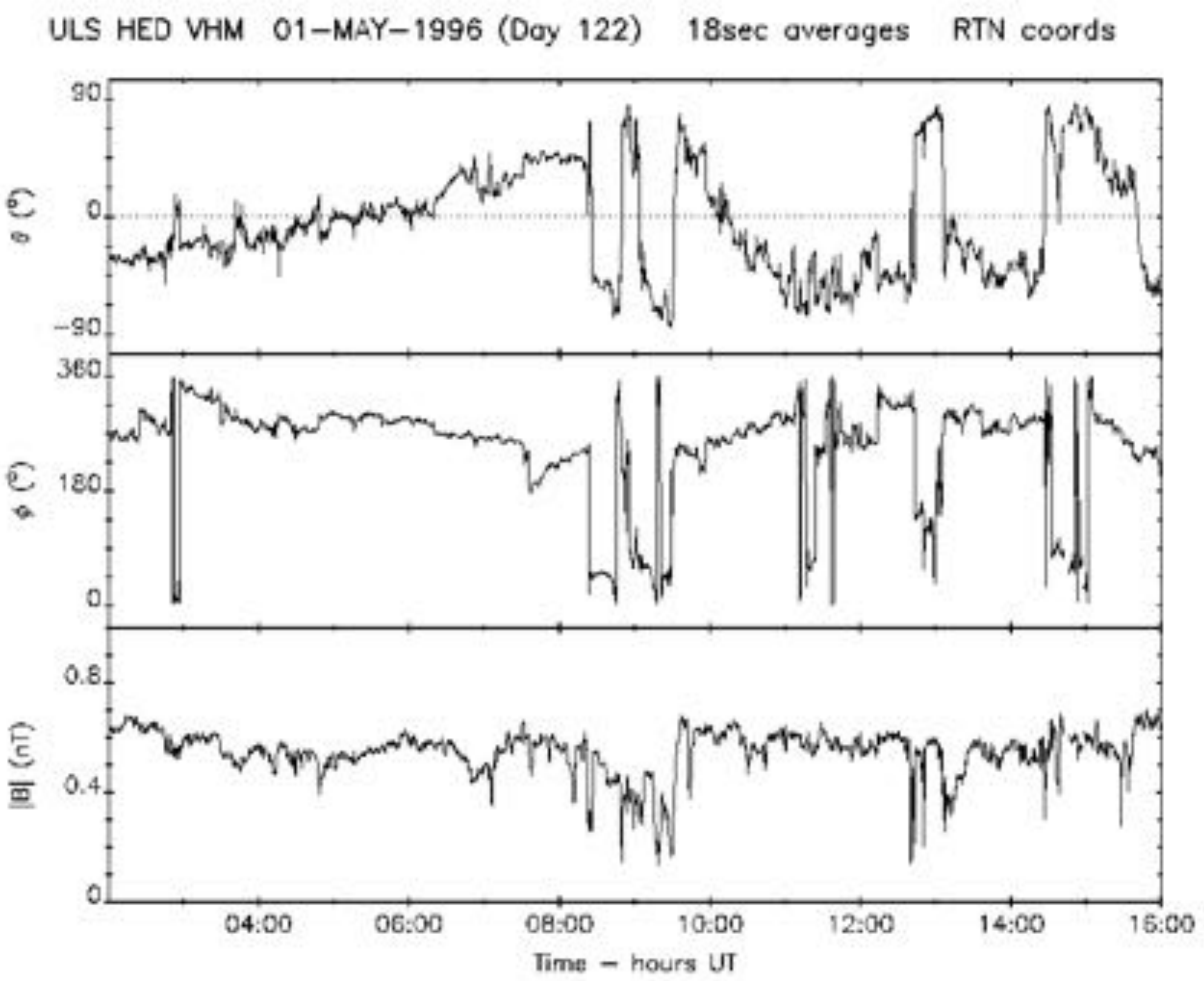
Ulysses's First Cometary Encounter
C/1996 B2 (Hyakutake)

- Riley et al. (1998) reported a proton “hole” in Ulysses SWOOPS data
- Unprecedented drop in proton number density

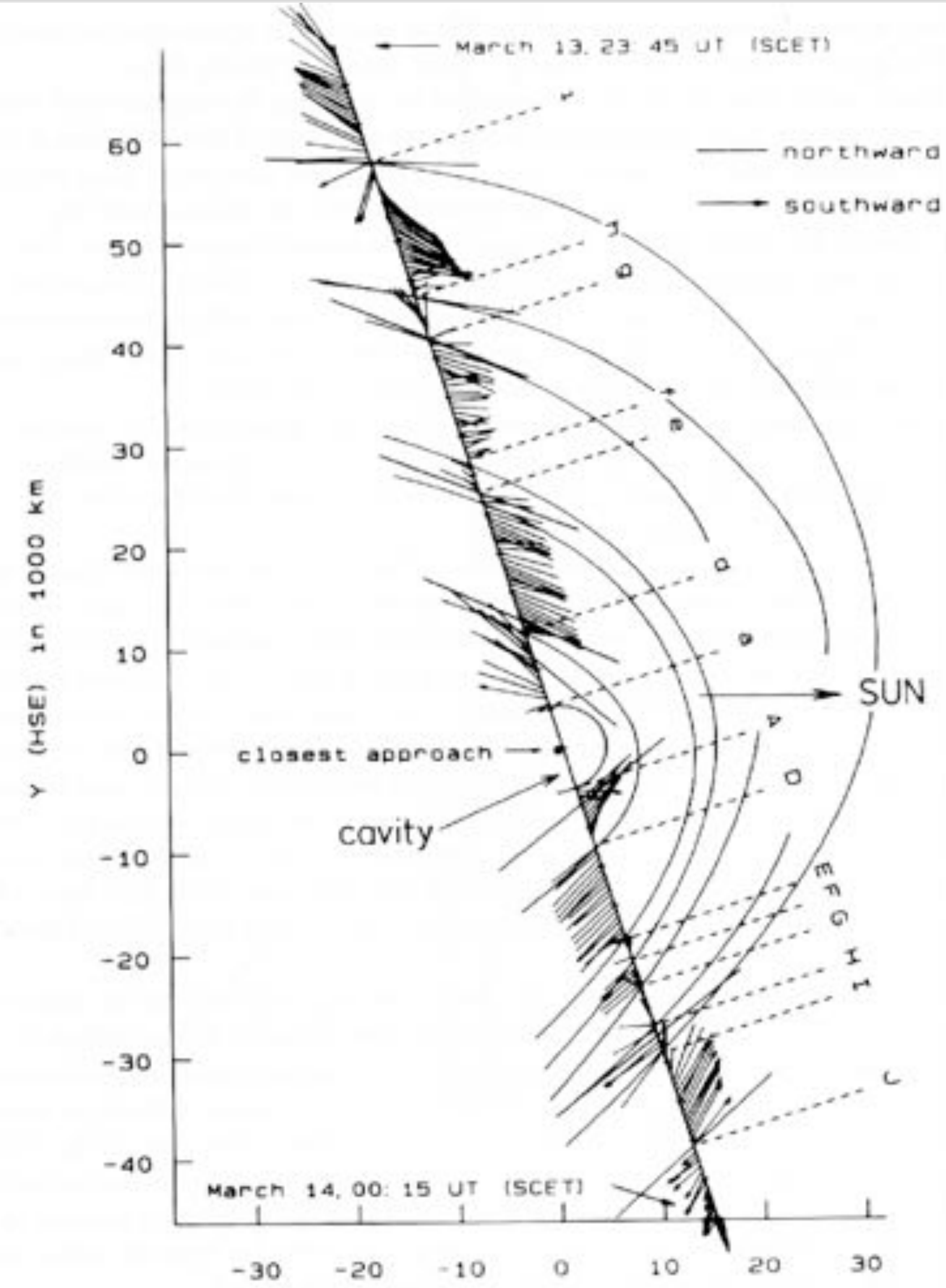




- Coincident with the proton "hole" were magnetic field signatures reminiscent of draping patterns expected at a cometary ion tail



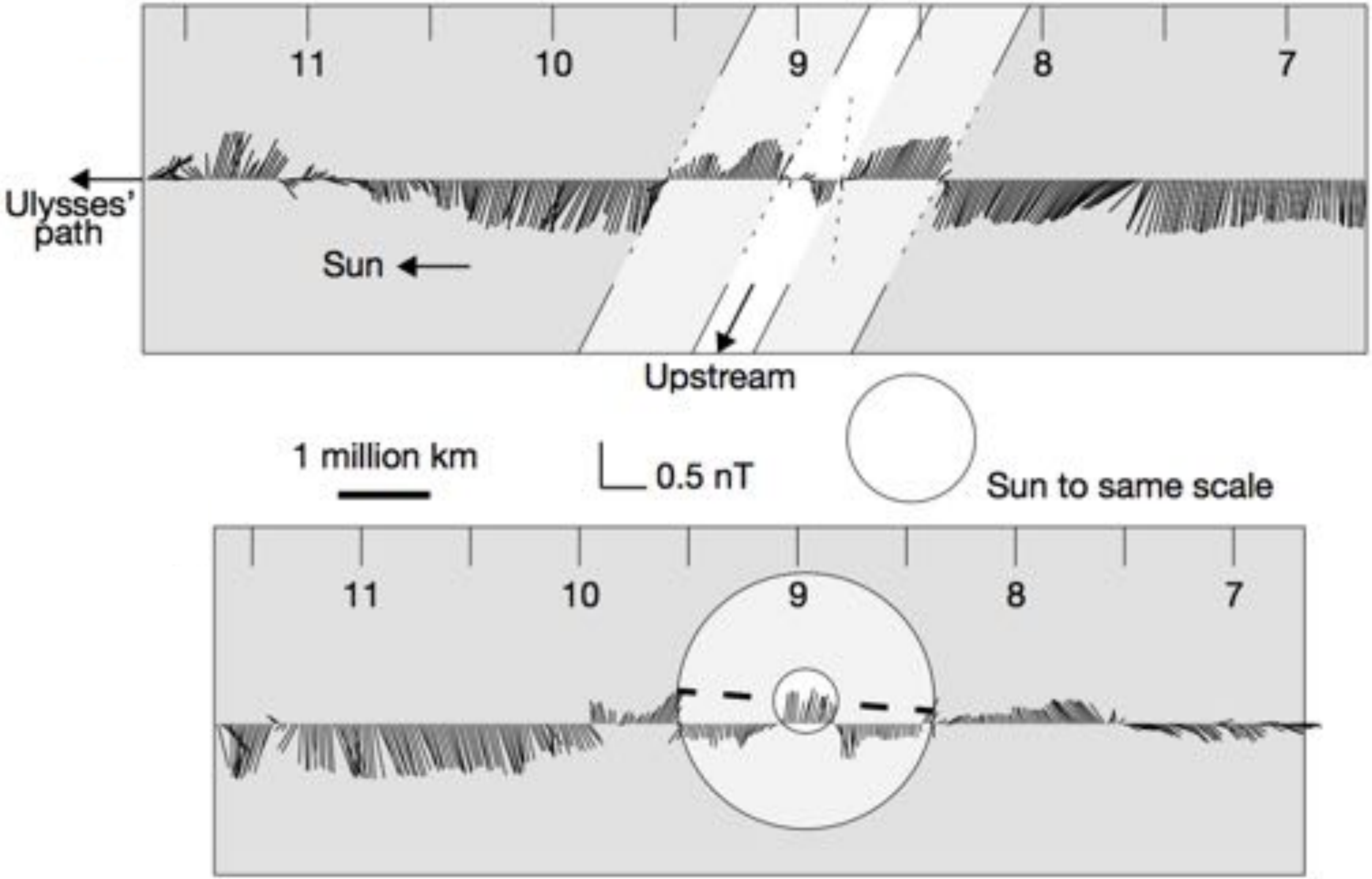
- Search was conducted for possible source comets
- C/1996 B2 (Hyakutake) alignment found (Jones et al. 2000)



Draping observed at 1P/Halley

Observations of the magnetic field directions along the trajectory of Giotto from 23:45 on March 13 to 00:15 on March 14.

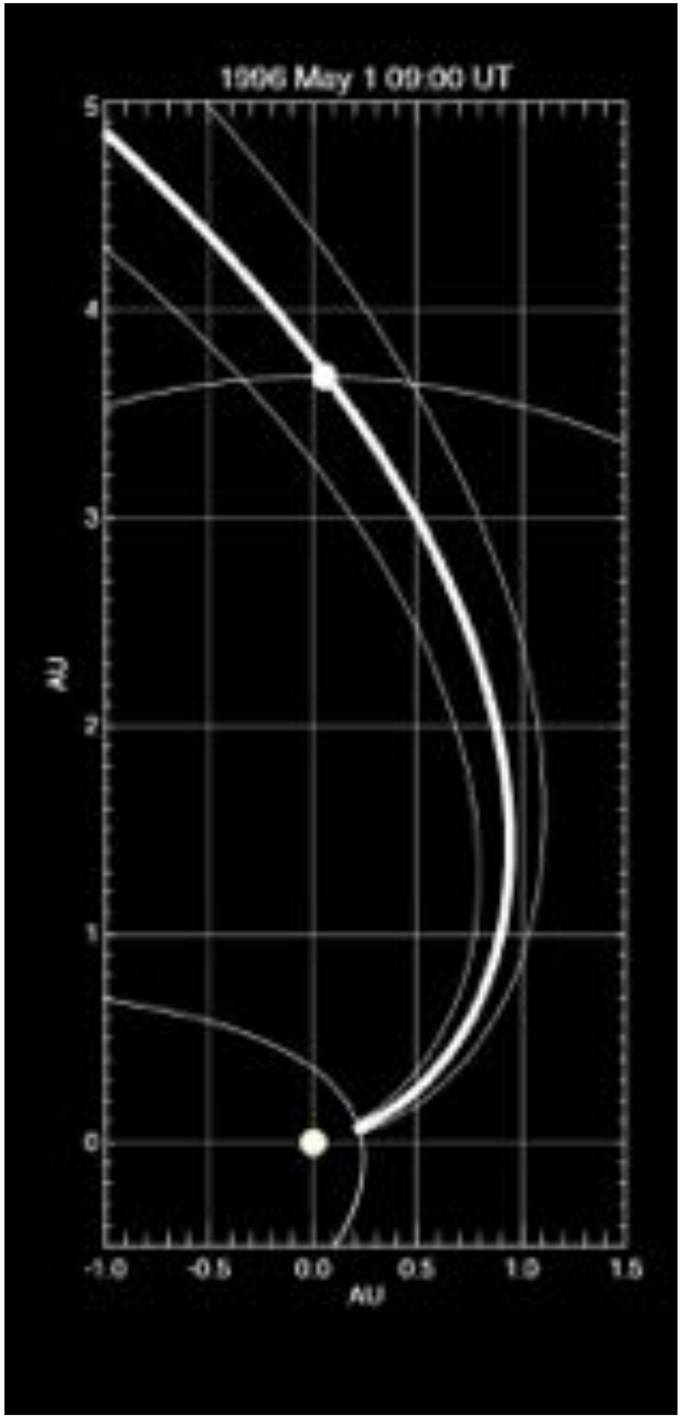
The parabolae show the possible shapes of the draped Tangential Discontinuities (Raeder et al 1987).


11
10
9
8
7
Ulysses' path
Sun
Upstream
1 million km
0.5 nT
Sun to same scale
11
10
9
8
7

Draped discontinuities: Magnetic field structure in an ion tail

Alignment with Hyakutake

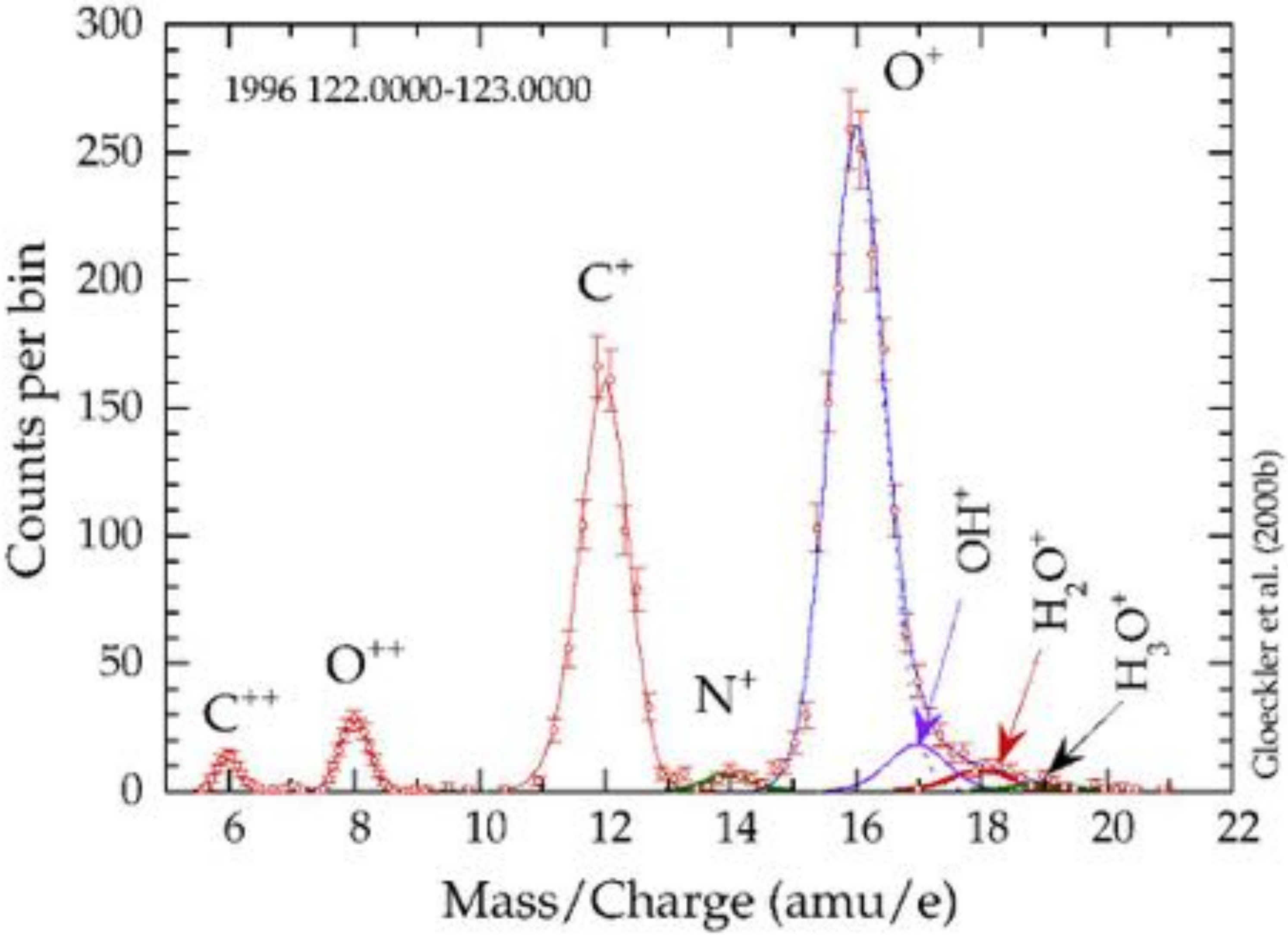
- On May 1, 1996, Ulysses, at 3.73 AU from the Sun, was aligned with position of Hyakutake around 8 days earlier, at 0.35 AU.
- Distance and relative timing consistent with ions being carried at around the solar wind velocity (~740 kms^{-1})
- Proton hole consistent with charge-exchange processes at the comet's head
- Magnetic field signatures and identification - Jones et al. (2000). Composition measurements – Gloeckler et al. (2000)




1996 May 1
SOHO LASCO
observation
on same day as
Ulysses tail crossing

- SWICS data revealed presence of pick-up ions (Gloeckler et al. 2000)

- Atomic:molecular ion ratio higher than at Halley, indicating a source closer to the Sun, consistent with Hyakutake.



Ulysses's Second Cometary Encounter
C/1999 T1 (McNaught-Hartley)

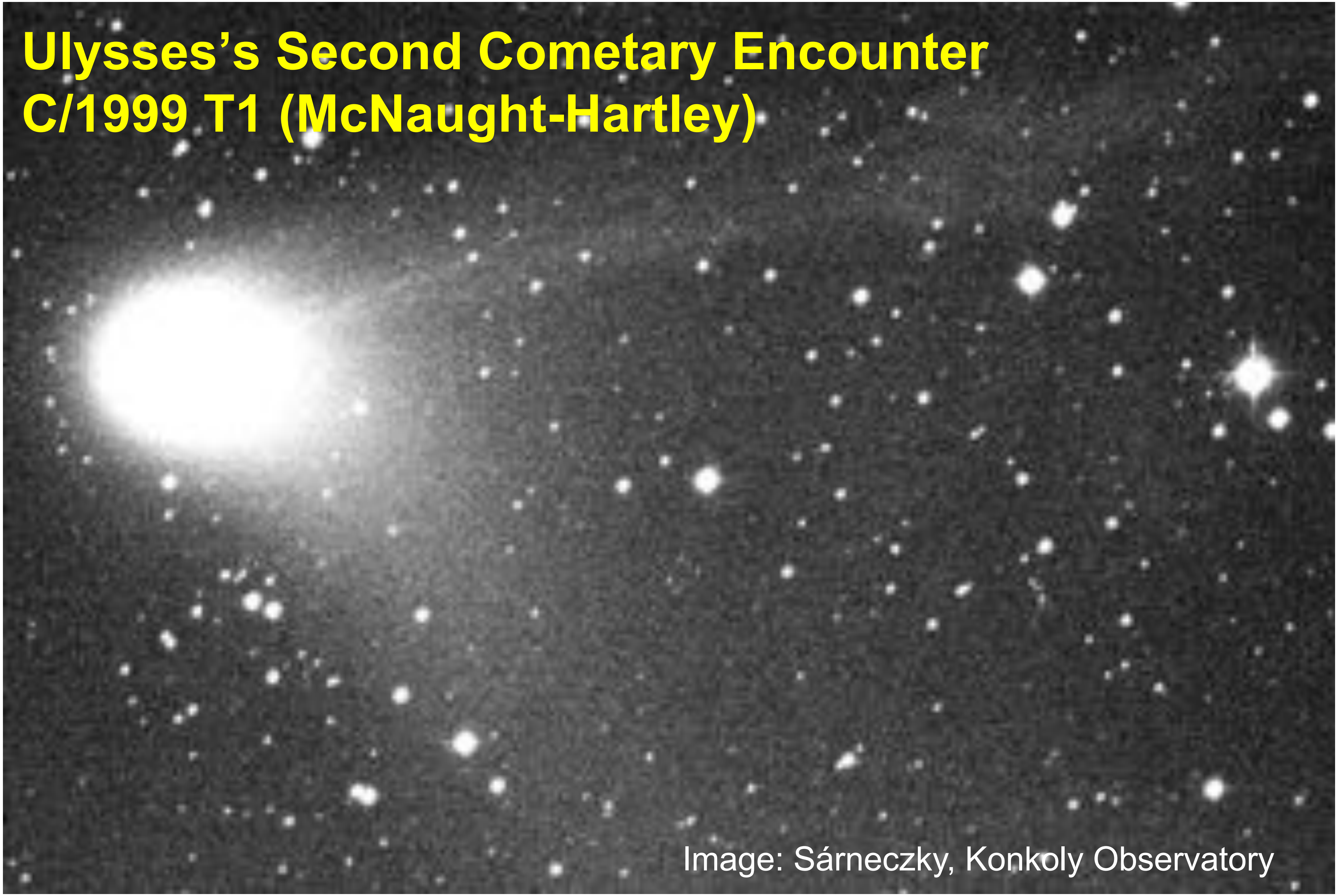
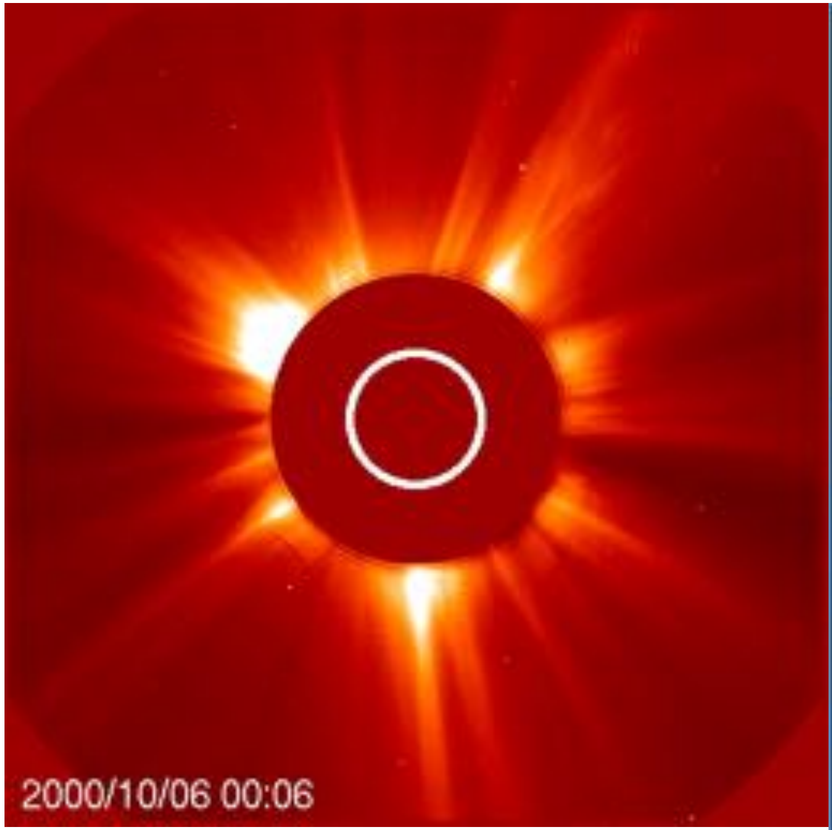
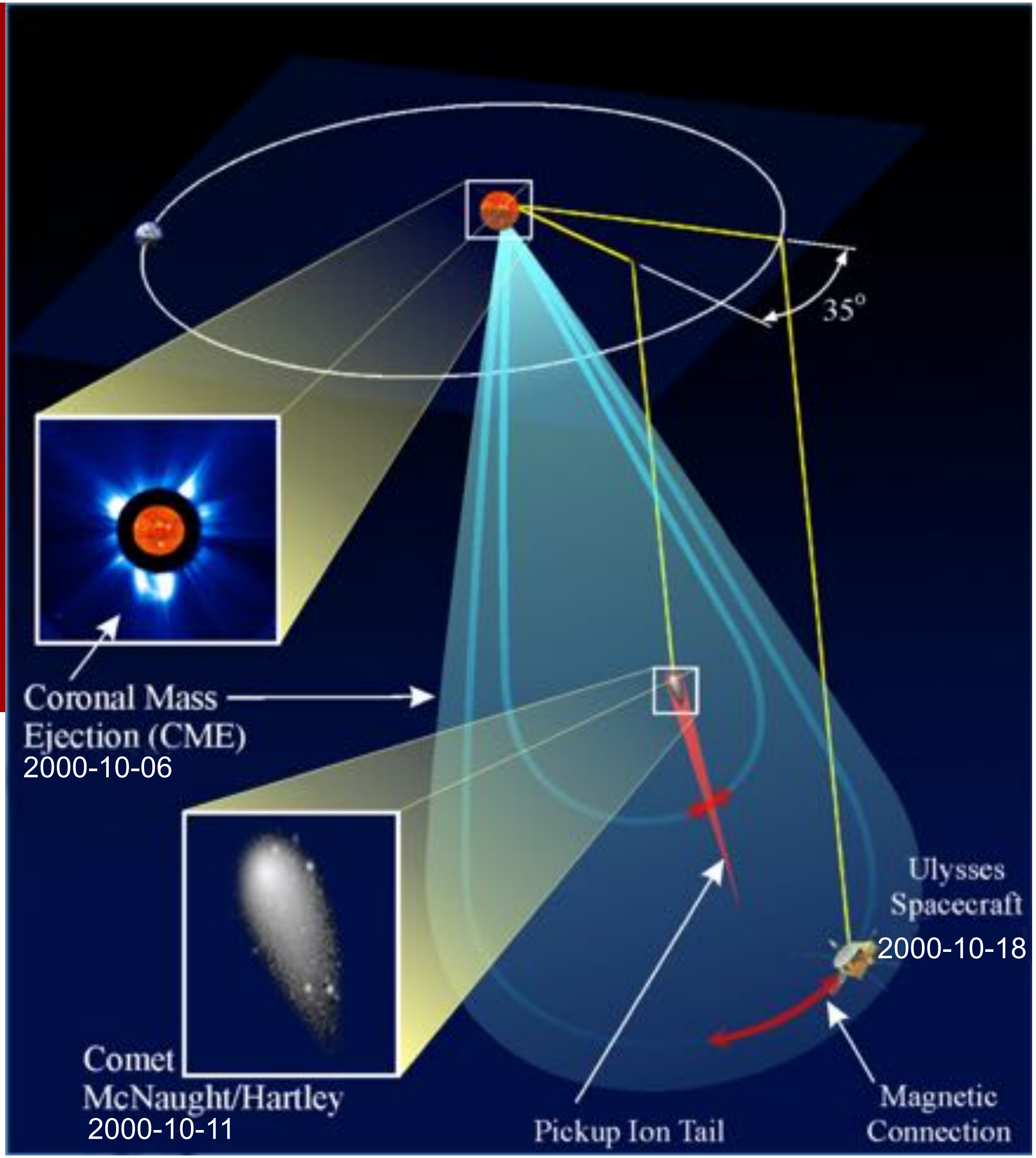


Image: Sárneczky, Konkoly Observatory





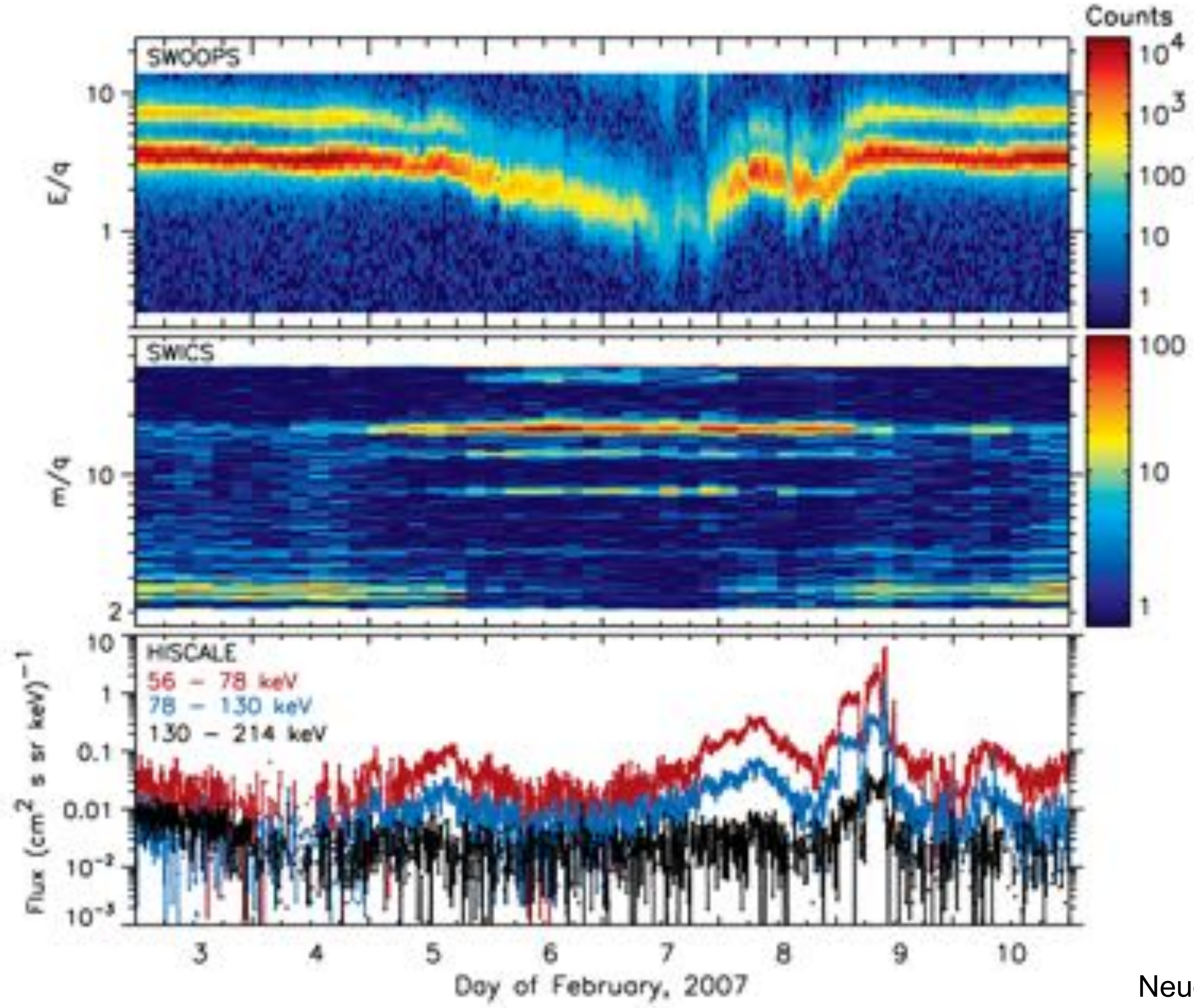
Gloeckler et al. 2004

Ulysses’s Third Cometary Encounter C/2006 P1 (McNaught)

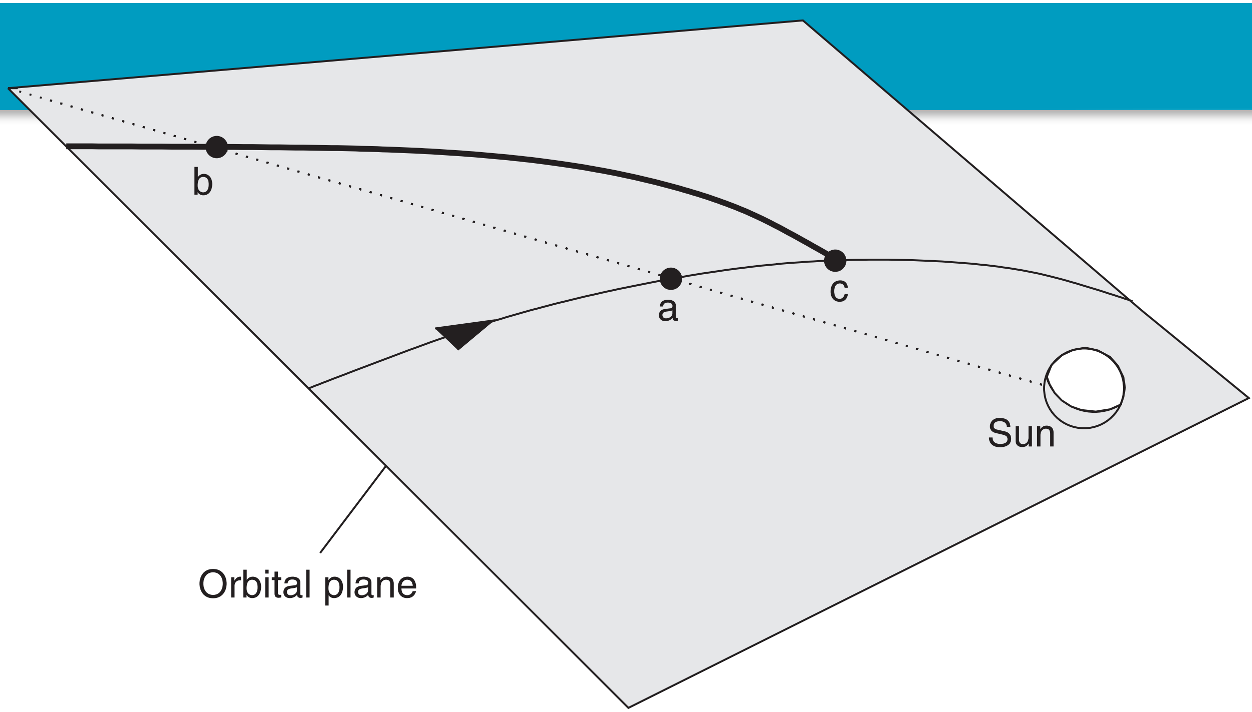
Credit: Sebastian Deiries

Comet McNaught over the Pacific

ESO Press Photo 05i/07 (19 January 2007)

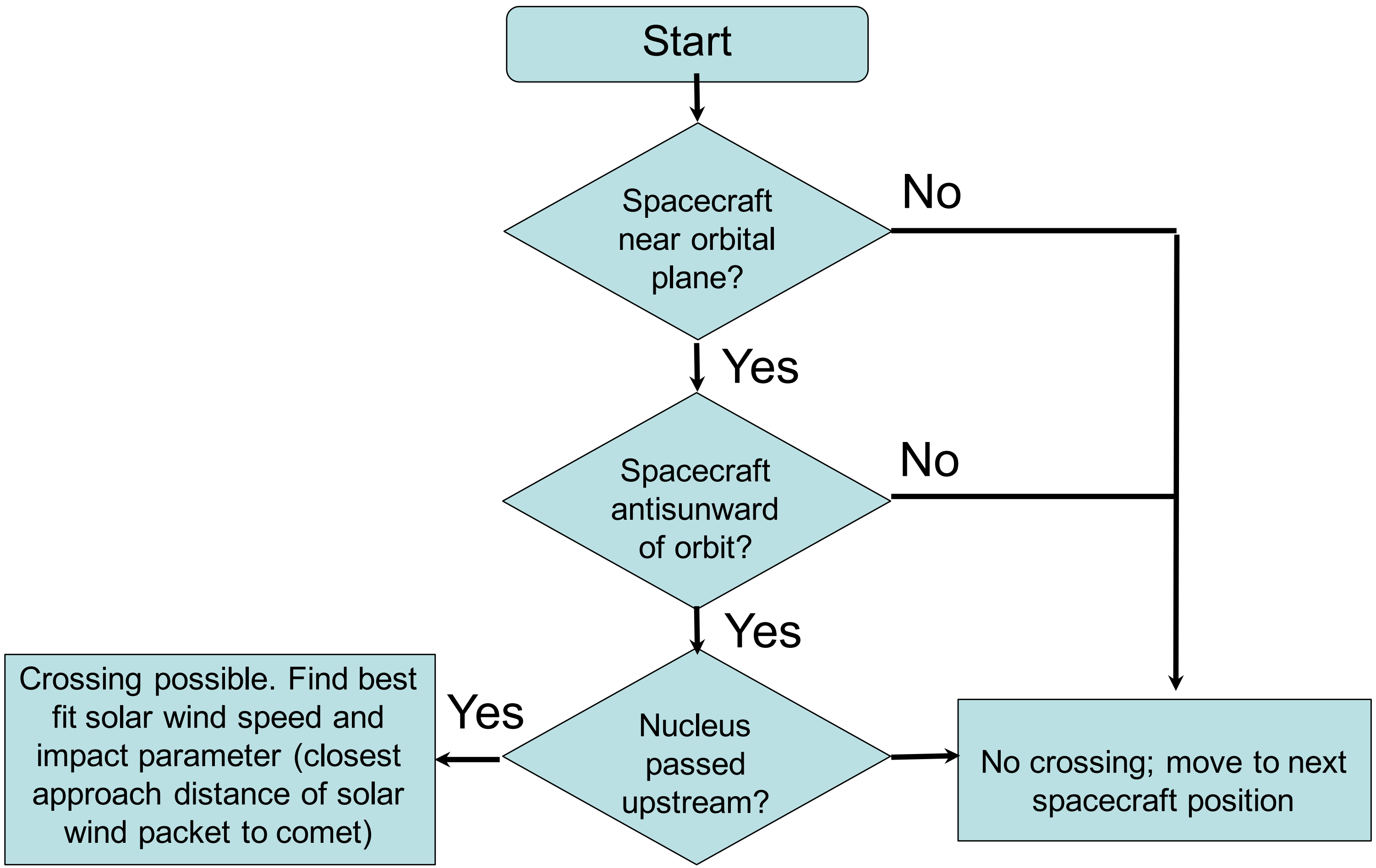


Neugebauer et al. 2007



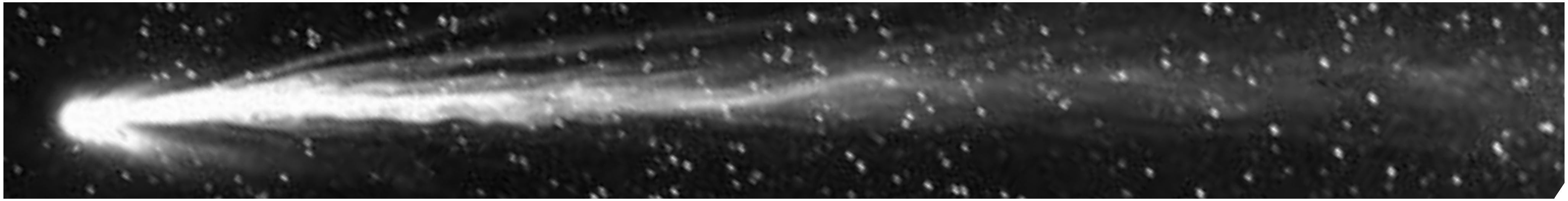
- For a tail crossing (b) to be possible, several conditions have to be met:
  - The spacecraft has to be close to a comet's orbital plane.
  - This plane crossing has to be anti-sunward (downstream) of the orbital path.
  - The nucleus (c) has to have passed upstream of the spacecraft position (a) shortly before the spacecraft was in that position (hours to weeks, depending on the relative geometry).
  - The solar wind speed has to be of the correct magnitude to "carry" the comet pickup ions past the spacecraft at the right time.

- Software being made available to search for comet tail crossings, as part of PSWS activities.
- Can provide list of times when tail crossings possible.
- If solar wind speed data available, accuracy much higher.



Summary (1)

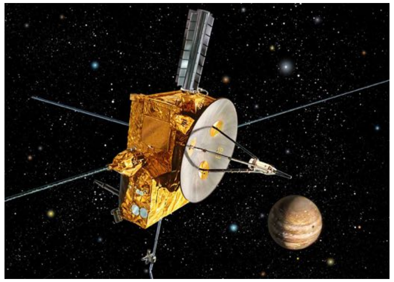
- Active comets provide tracers of solar wind at remote locations
- From archive comet images, we can study solar wind speeds and transient events from >100 years ago!
- Ion tails indicate solar wind speed at comet under favourable viewing geometries, routine links with fast solar wind streams, etc. (Ramanjooloo et al., in prep.)
- Disconnection events can reveal location of heliospheric current sheet
- Abrupt tail disruptions usually reveal arrival of fast ICMEs at comets
- Tails orientation analysis routines to be provided to wider community via Europlanet-funded project (2018)
- Code will be available to all to derive solar wind speeds from comet images



Summary (2)

• Comets' ion tails can persist as coherent magnetic field structures for at least several AU, even when disrupted by transient solar wind structures

• Code will be made available to search for possible comet tail crossings, with and without in situ solar wind speed data



Future Work

•A search for all possible comet tail crossings:

- comprehensive survey of comets' trajectories and all spacecraft in solar wind
- follow-up to search for magnetic field signatures, proton dropouts, and compositional information, when available

g.h.jones@ucl.ac.uk