UCL DEPARTMENT OF SPACE AND CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Europlanet 2020 PSWS: Comet Tail Solar Wind Speeds and Spacecraft Tail Crossings

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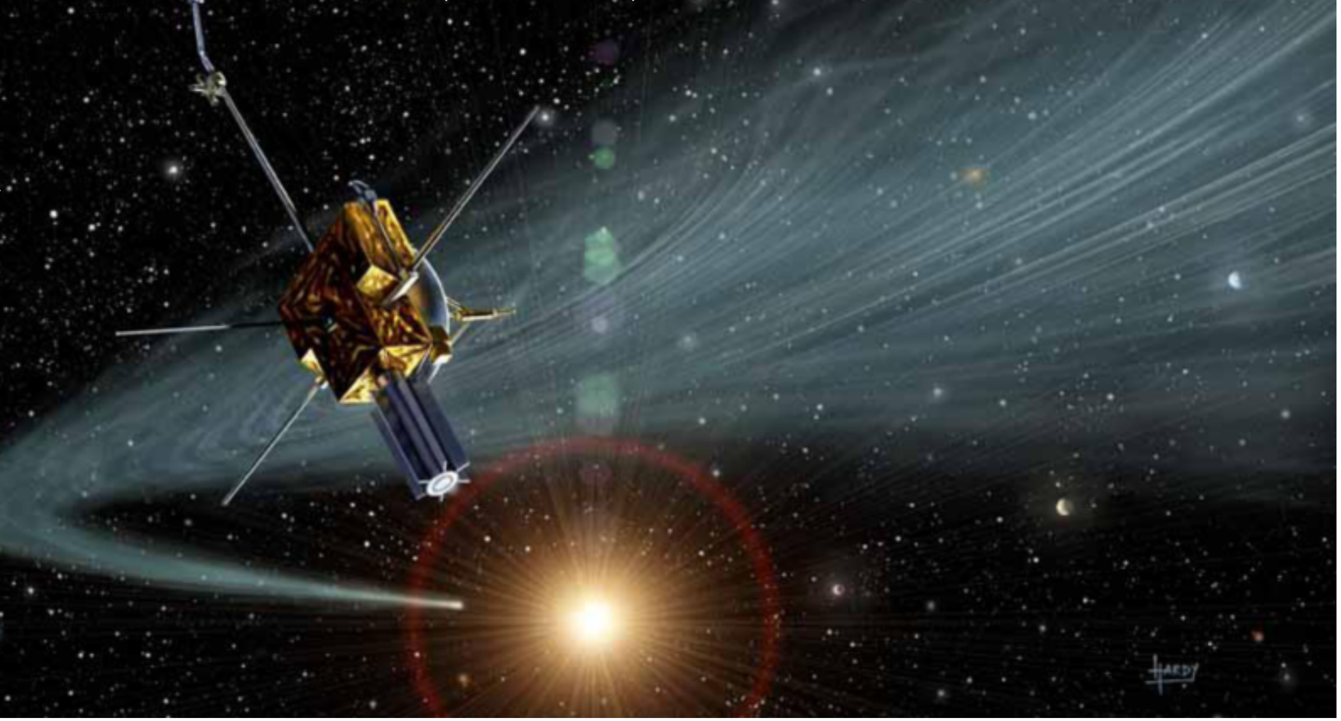

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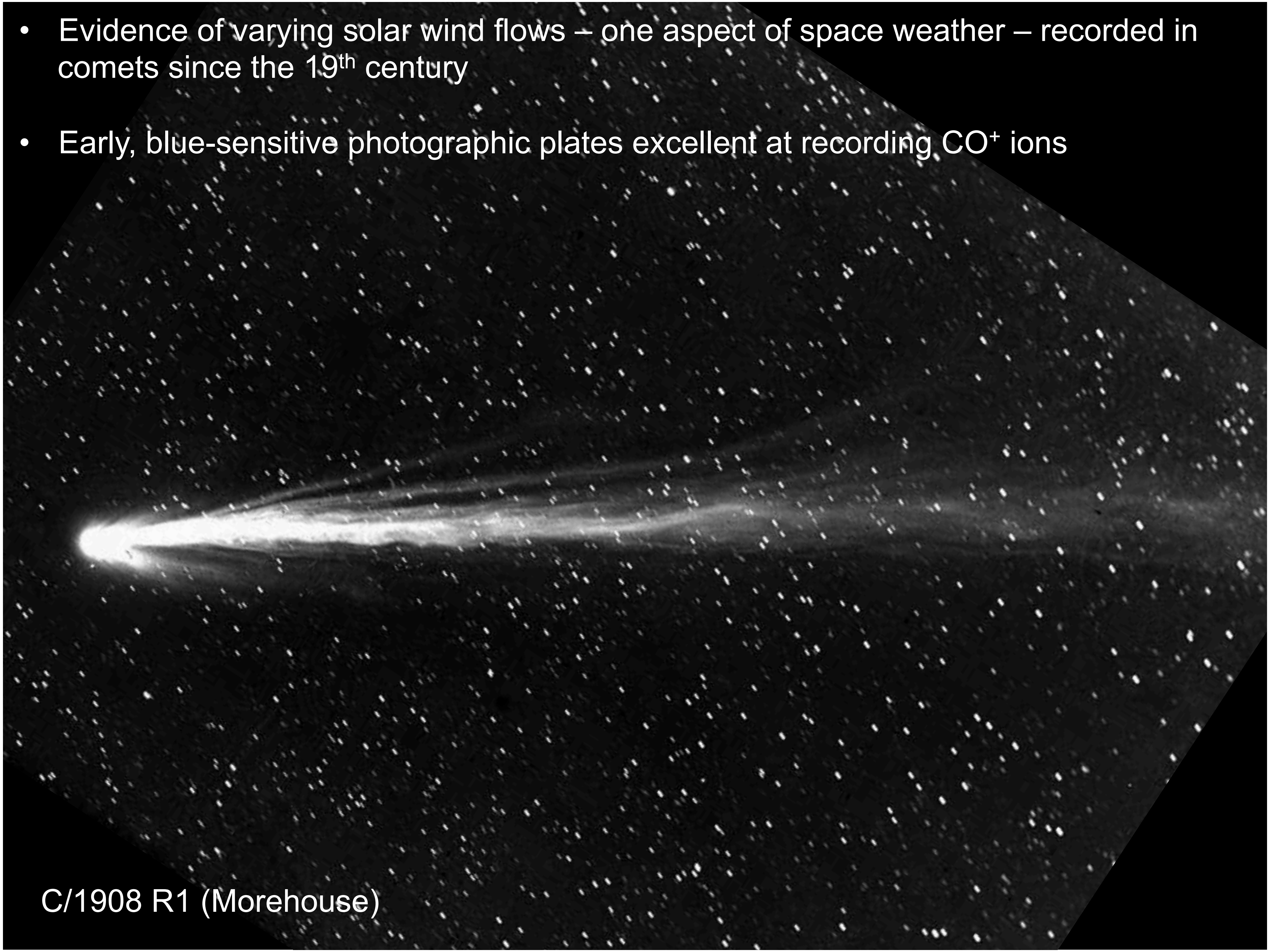
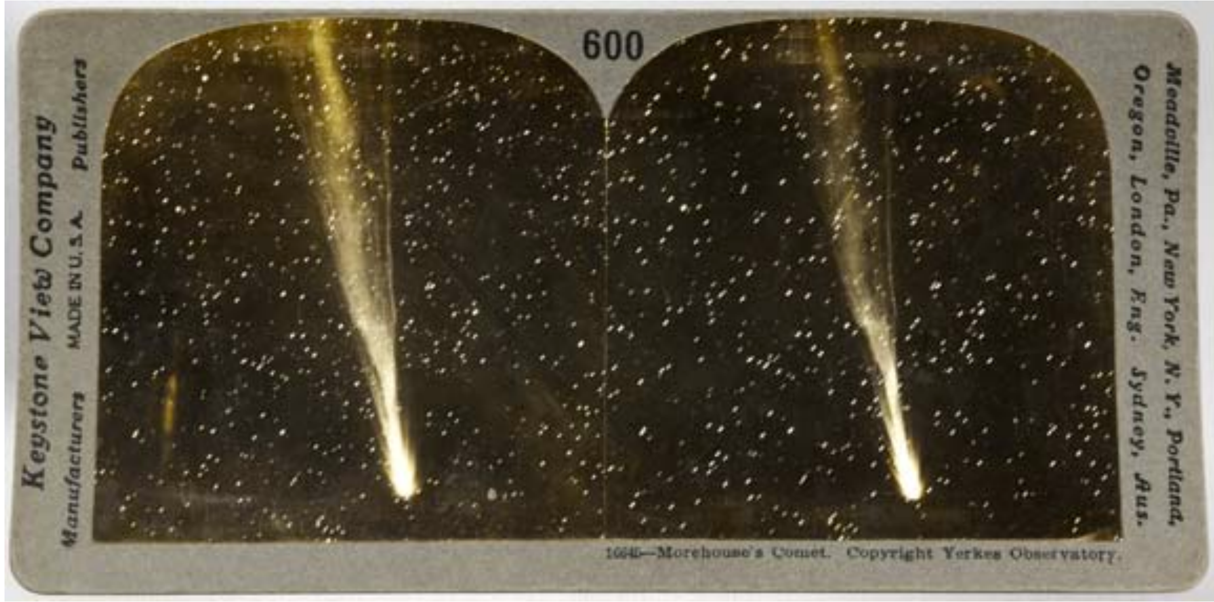
- Evidence of varying solar wind flows – one aspect of space weather – recorded in comets since the 19th century

- 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

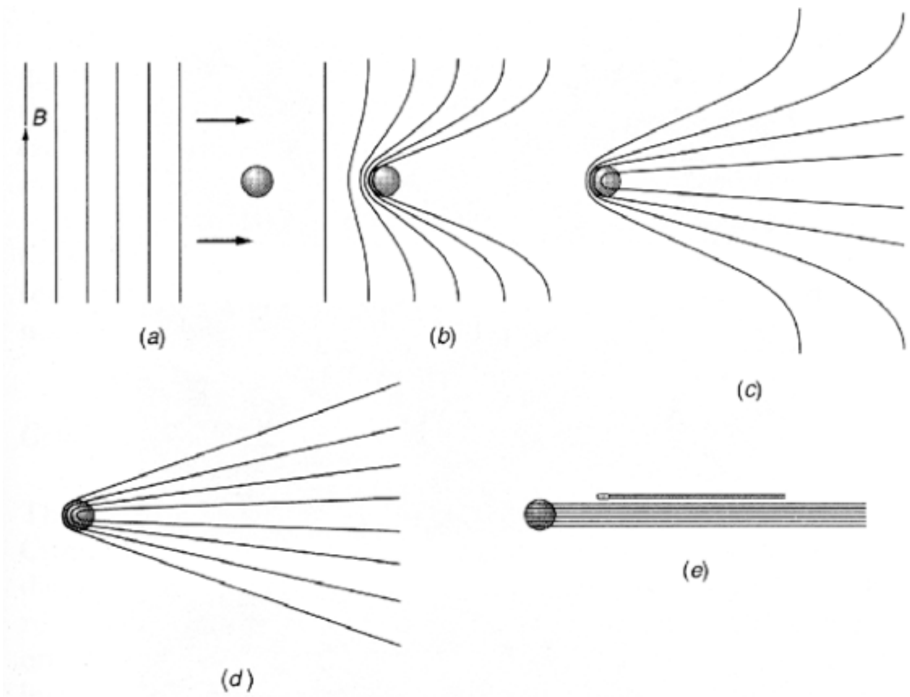
- Biermann suggested that cometary ions were being swept away by Chapman & Bartels's corpuscular radiation, with a speed of a few 100 km/s.

- 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.

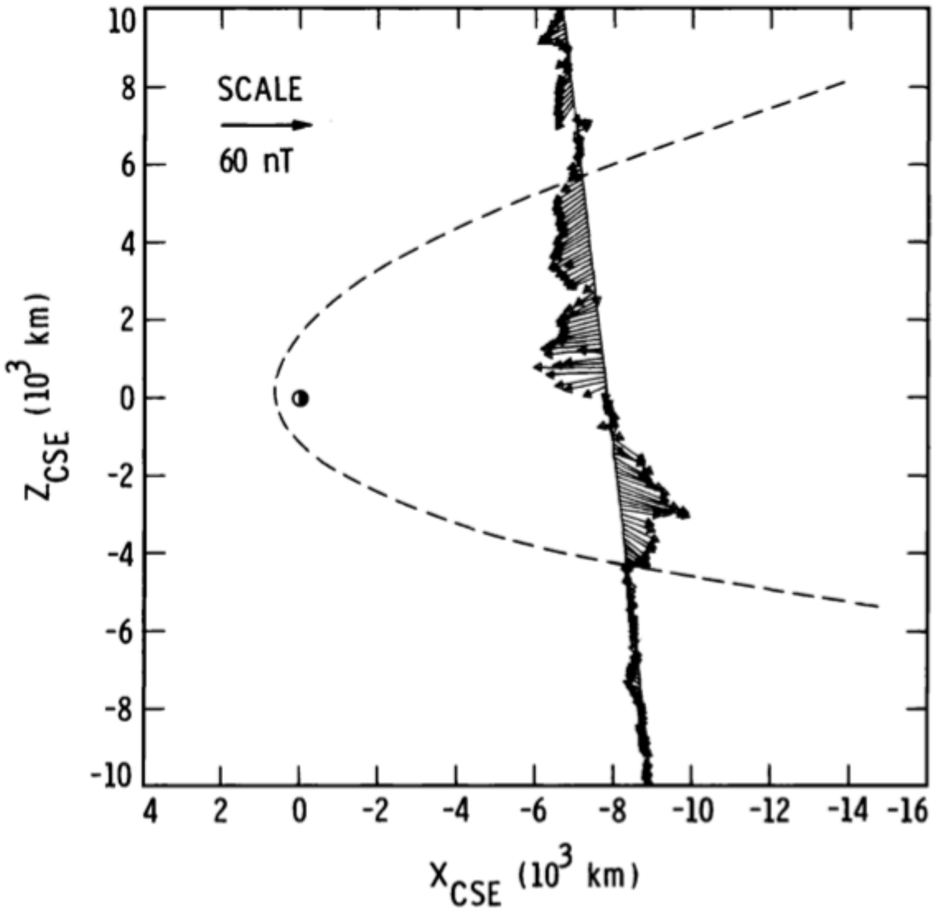
- Comets have induced magnetotails; comet-solar wind interaction region of very different scale to planetary magnetospheres due to freely-expanding atmosphere (Biermann et al. 1967)

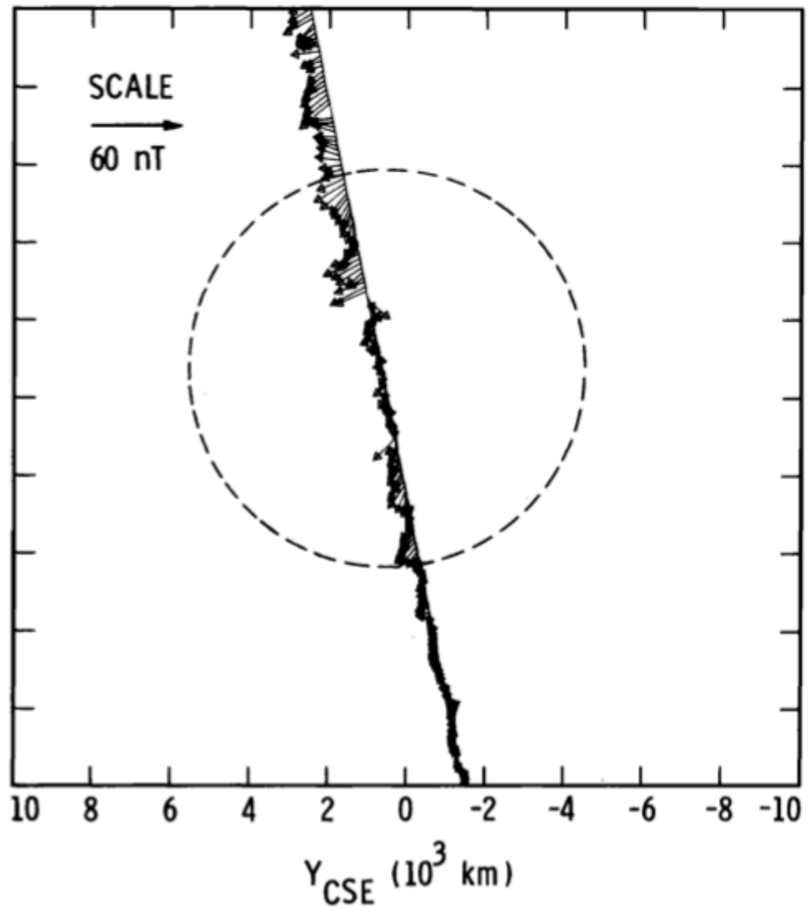


Brandt & Chapman (1992), after Alfven (1957)

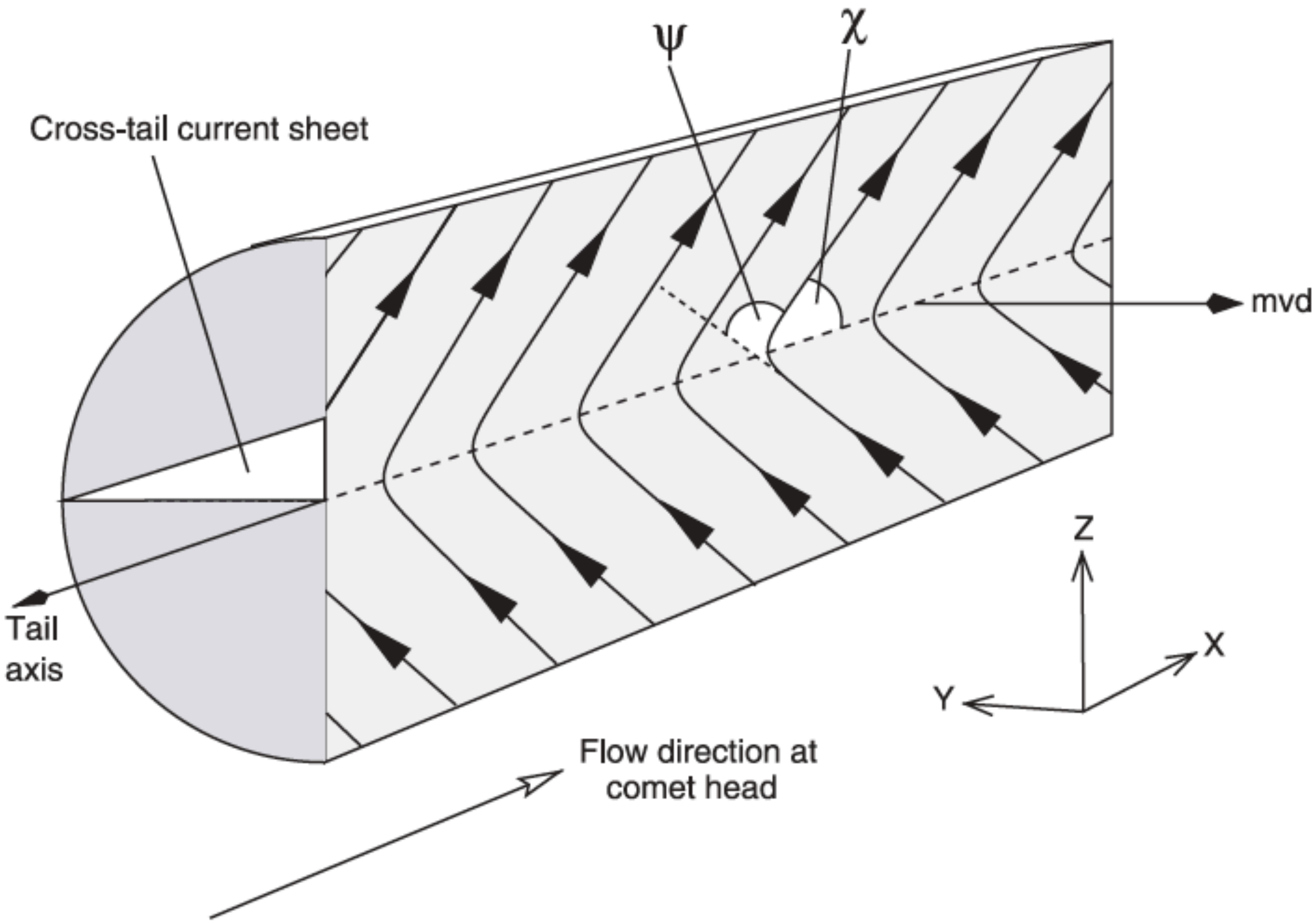
ISEE-3/International Cometary Explorer at 21P/Giacobini-Zinner

Induced magnetotail confirmed by in situ magnetic field observations





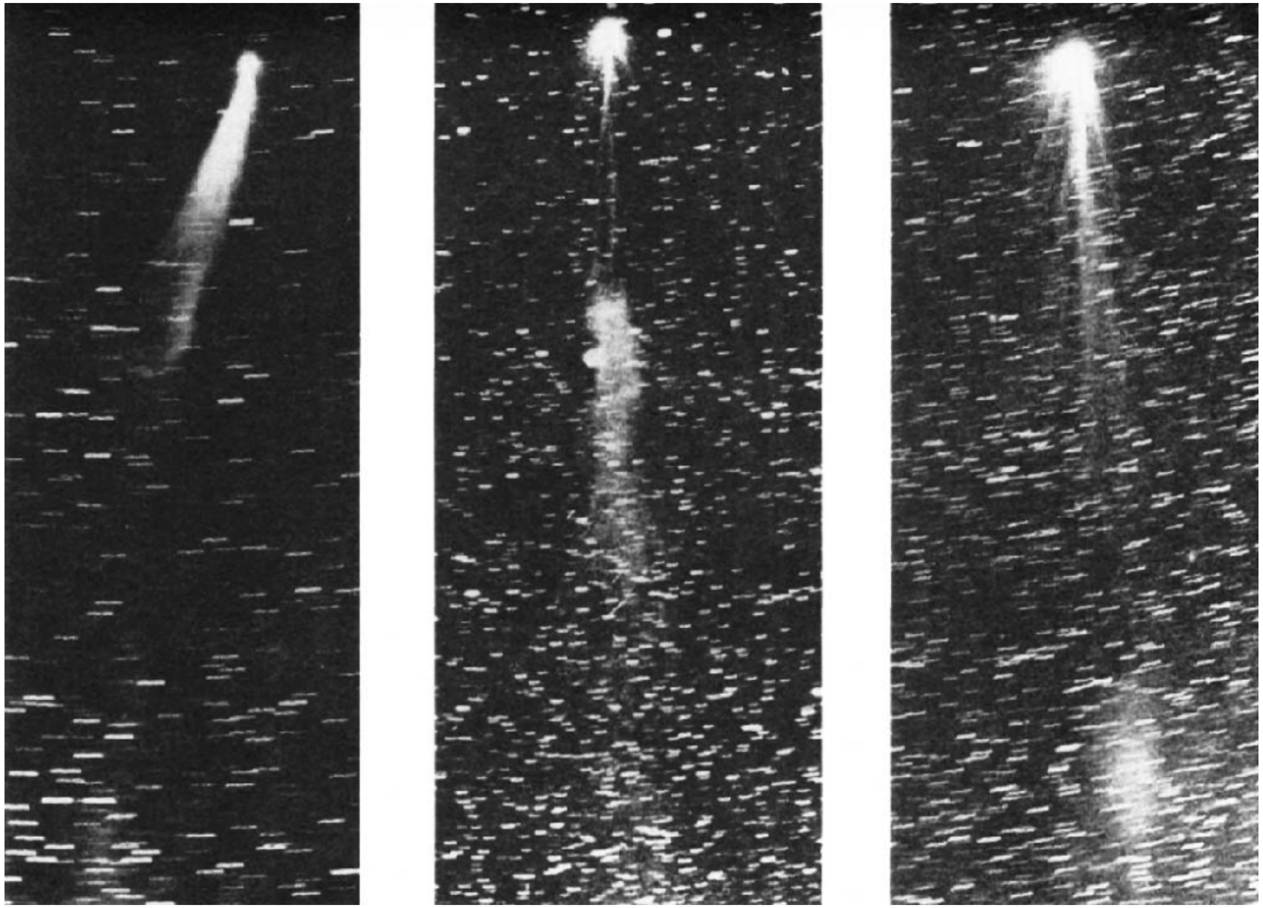
Slavin et al. (1986)


ψ
χ
Cross-tail current sheet
mvd
Tail
axis
Z
X
Y
Flow direction at
comet head

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

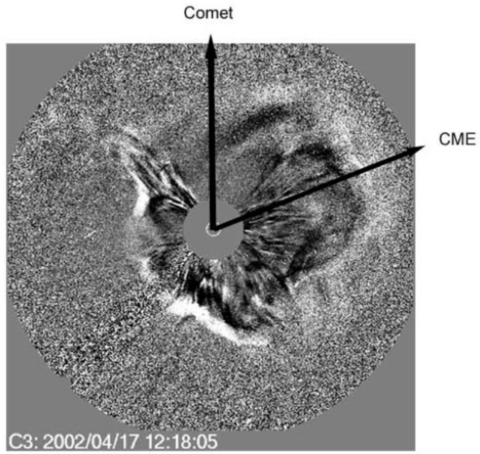
Disconnection Events

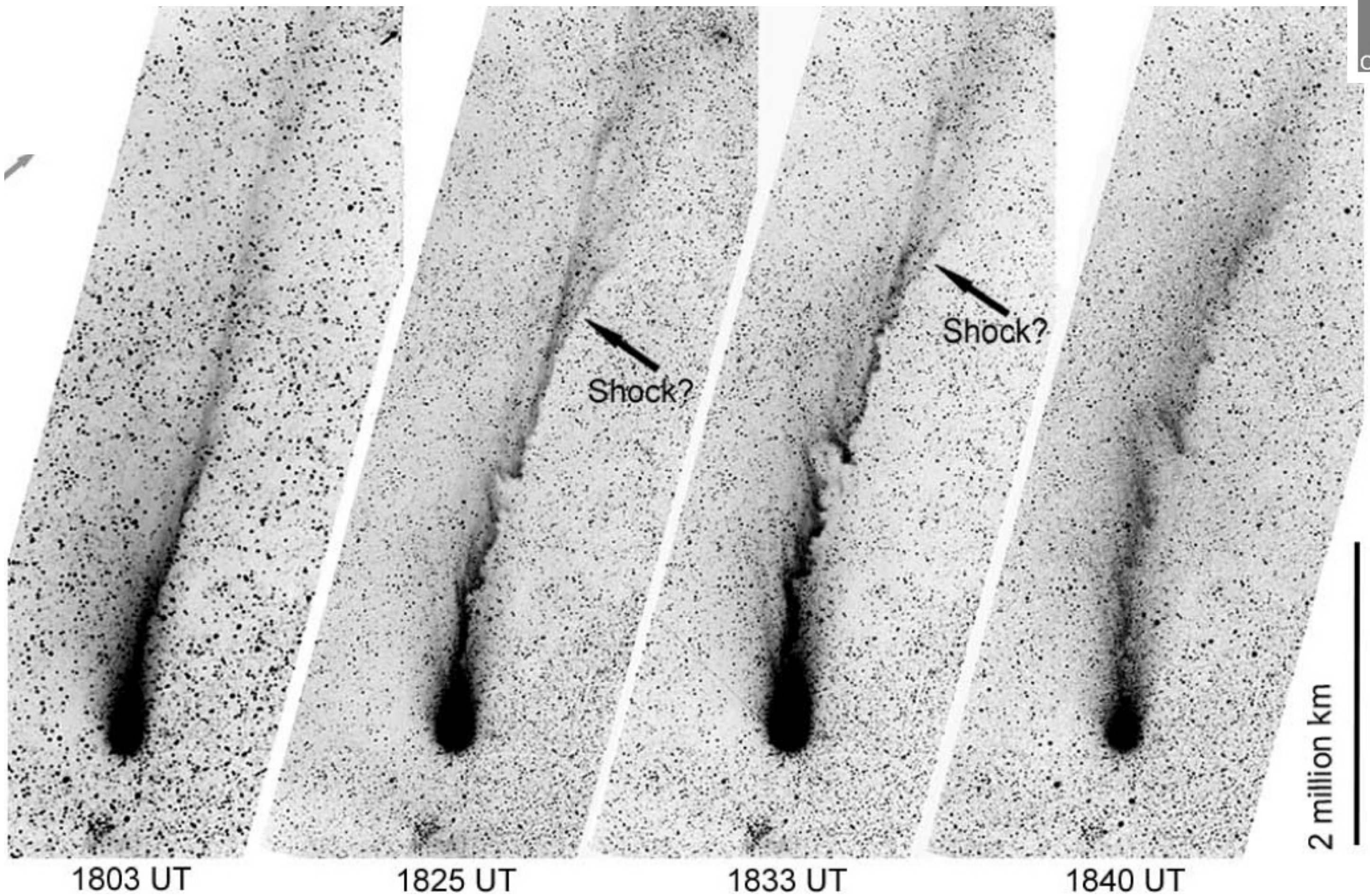
- Comet’s ion tail detaches completely and regrows
- Usually crossings of the Heliospheric Current Sheet, some appear correlated with fast ICMEs



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

Solar Wind Speeds from Comet Images

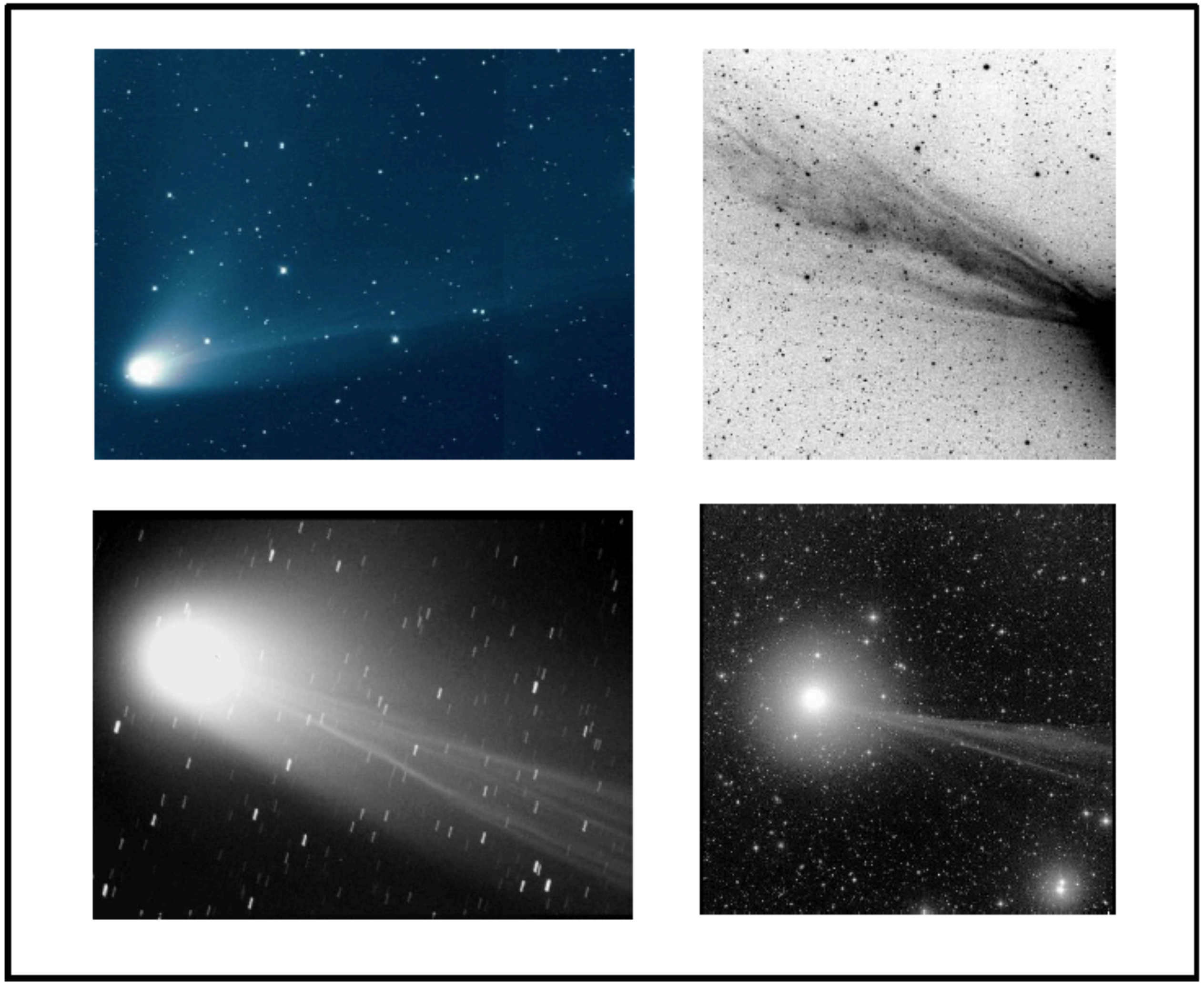
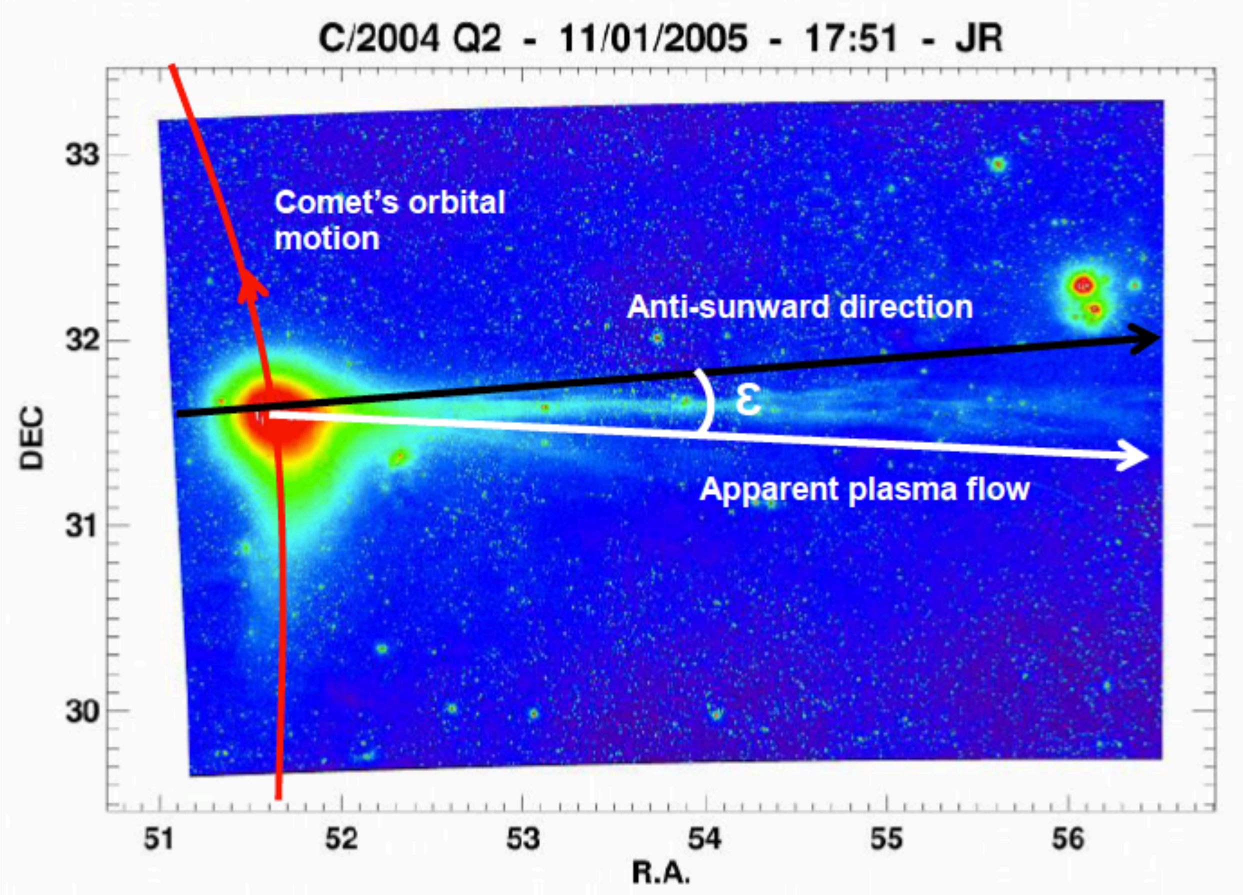
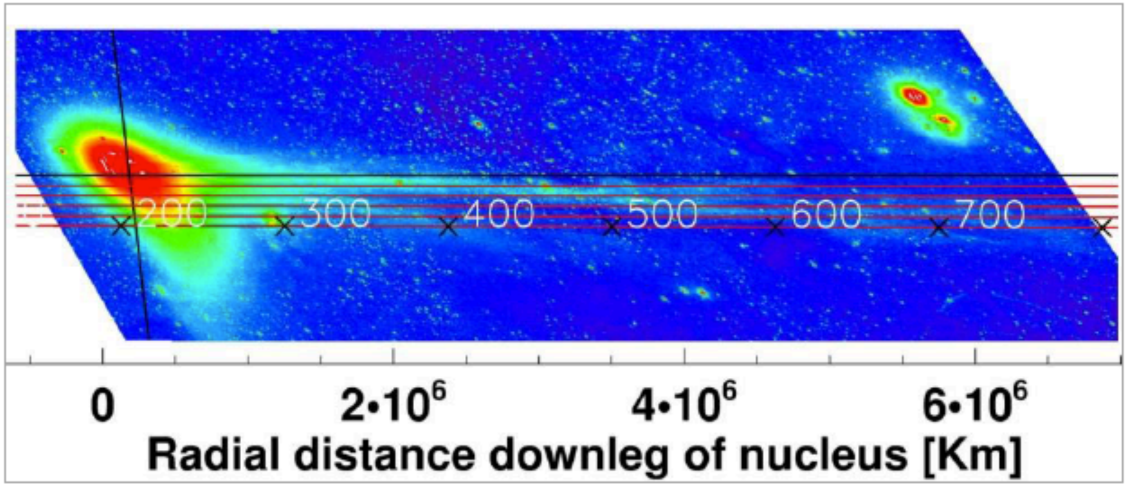


Figure 3.1: The images above show the variation of image formats available in our catalogue. Image credits, from top left to bottom right, are as follows: Mikuz (C/2001 Q4), Holloway (C/2004 Q2), Jäger and Rhemann (C/2001 Q4) and Mobberley (C/2014 Q2)

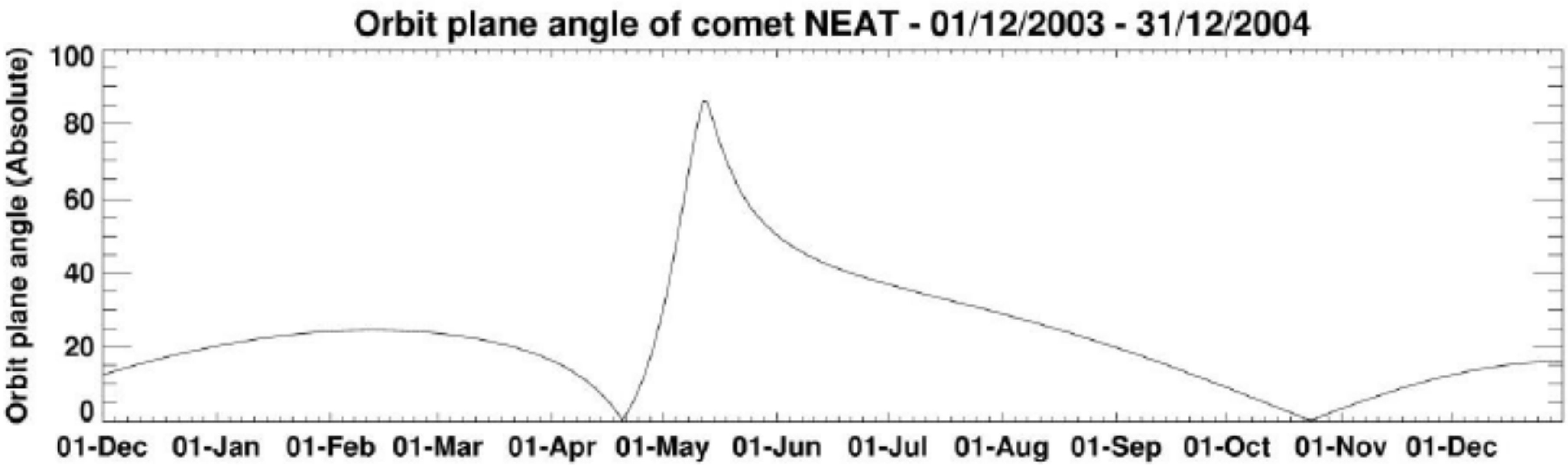




UCL

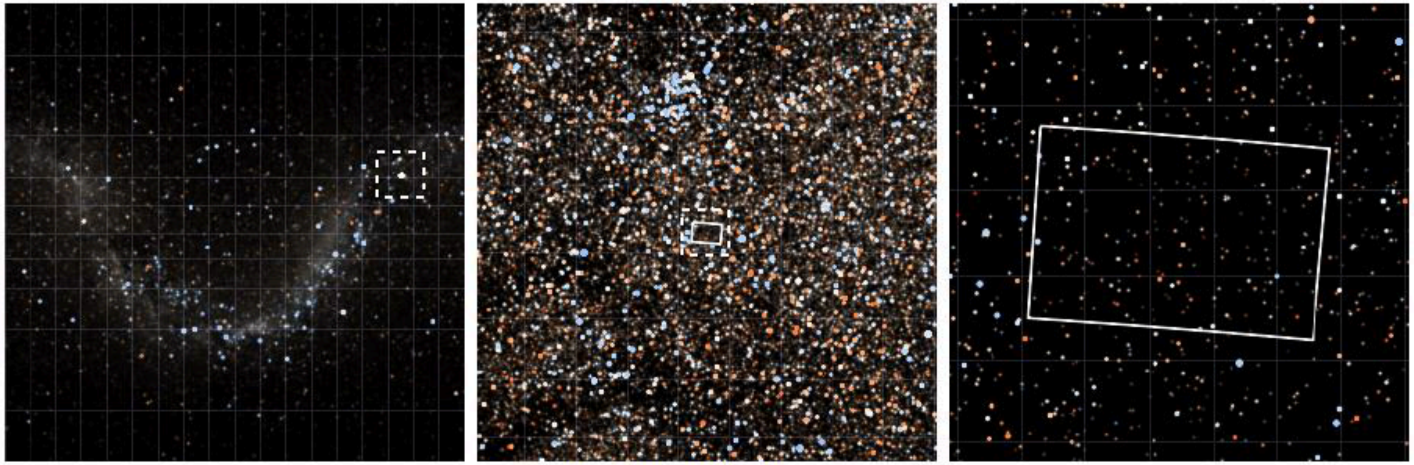
Solar wind speed estimate technique

Yudish Ramanjooloo
PhD project

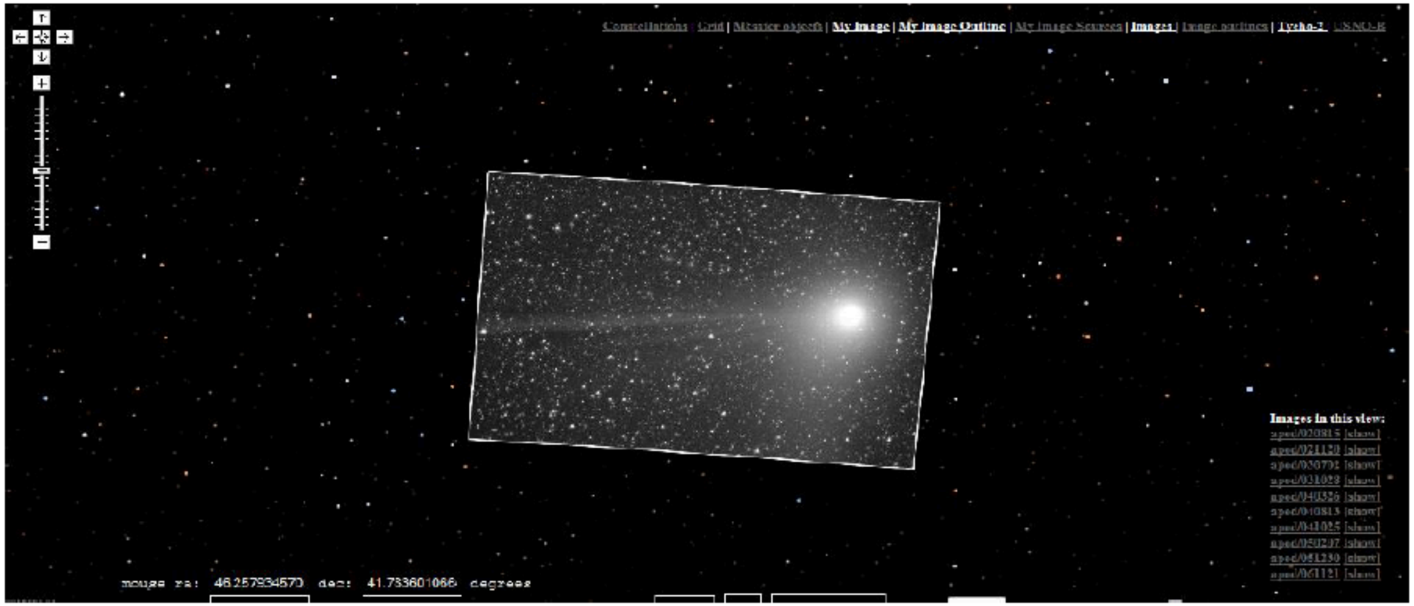


Orbit plane angle of comet NEAT - 01/12/2003 - 31/12/2004
Orbit plane angle (Absolute)
100
80
60
40
20
0
01-Dec
01-Jan
01-Feb
01-Mar
01-Apr
01-May
01-Jun
01-Jul
01-Aug
01-Sep
01-Oct
01-Nov
01-Dec

Automatic star field detection – astrometry.net



View in Google Maps browser



Technique gives an indication of solar wind speed, not precise measurements

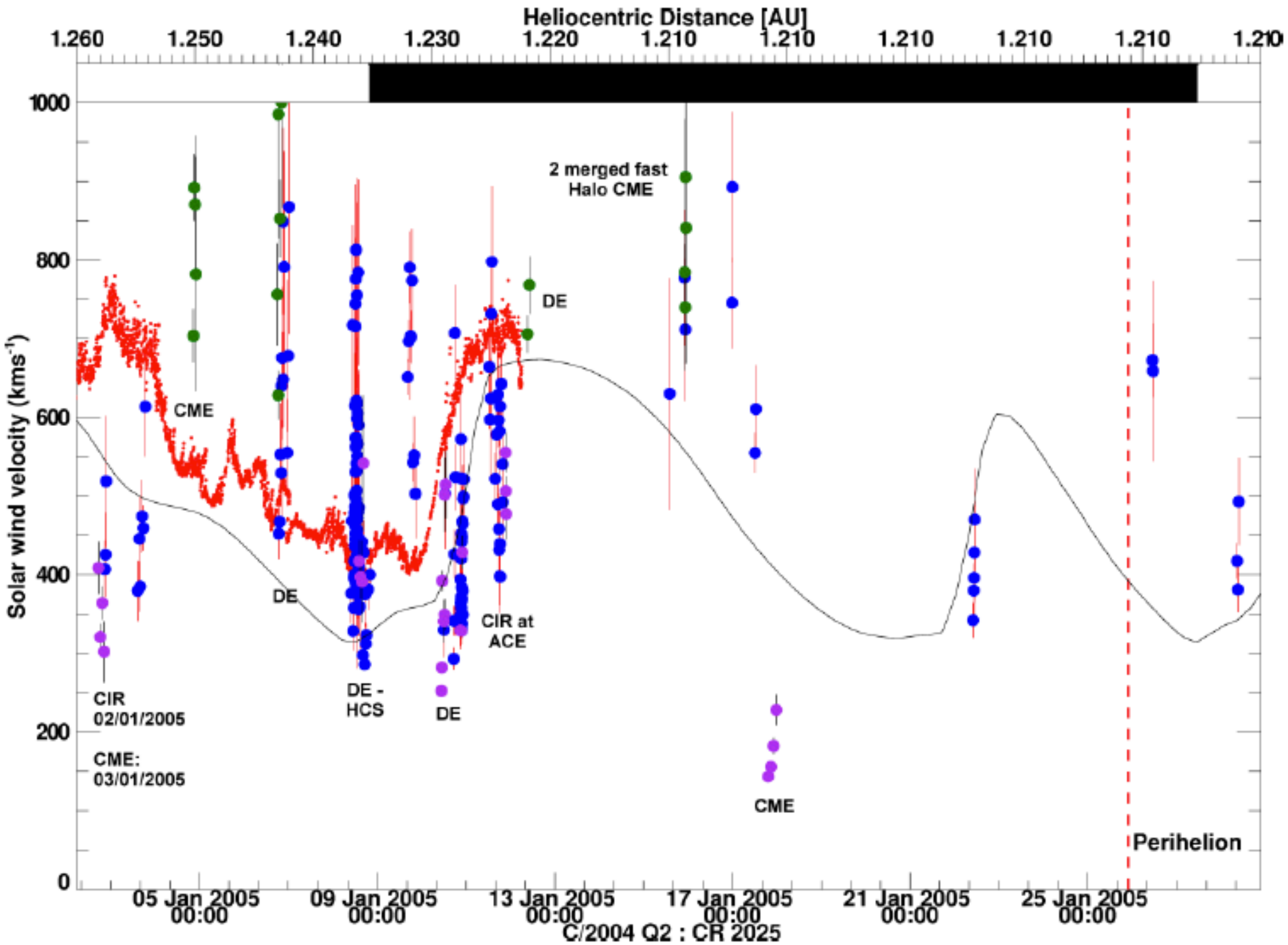
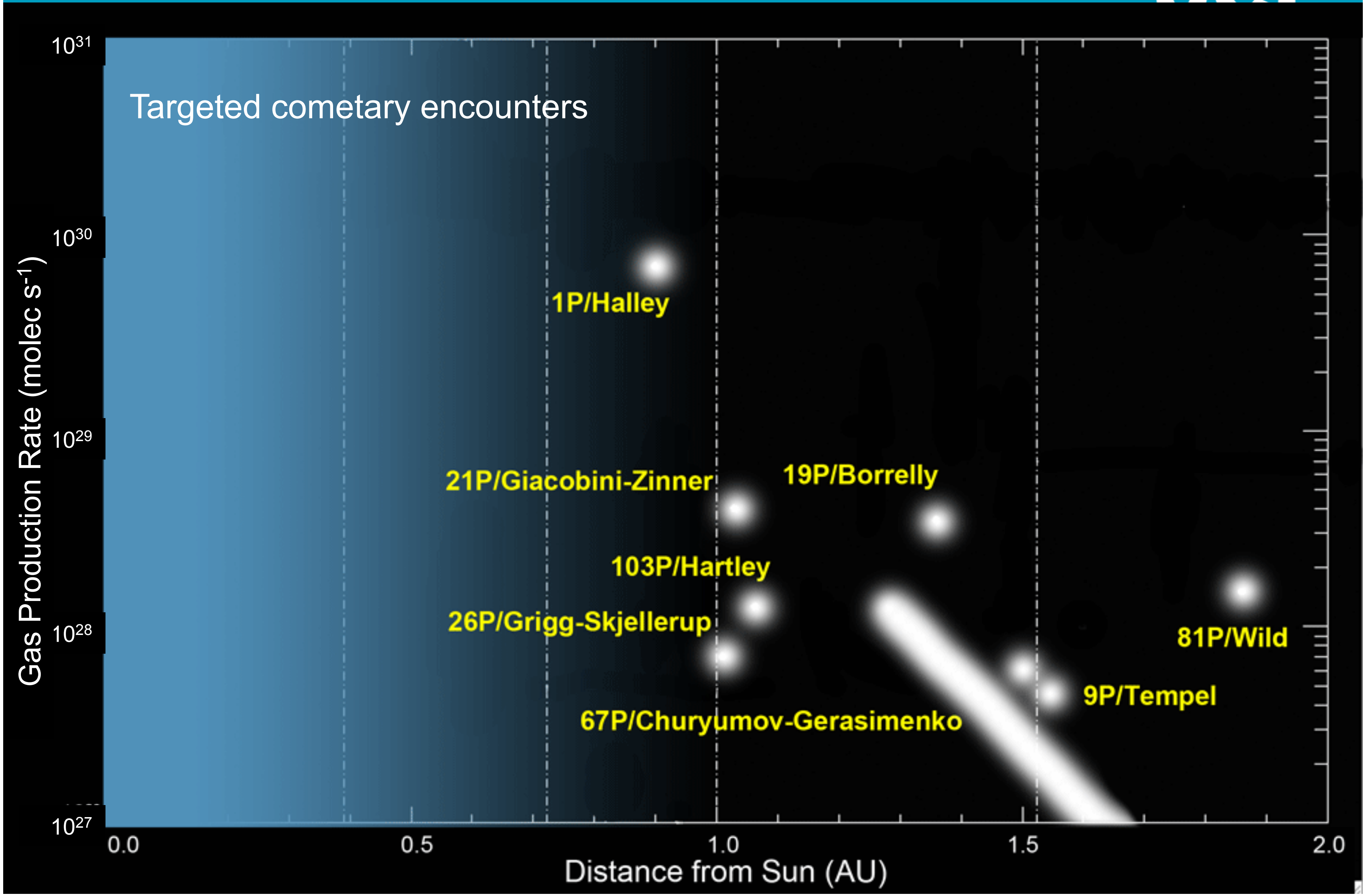
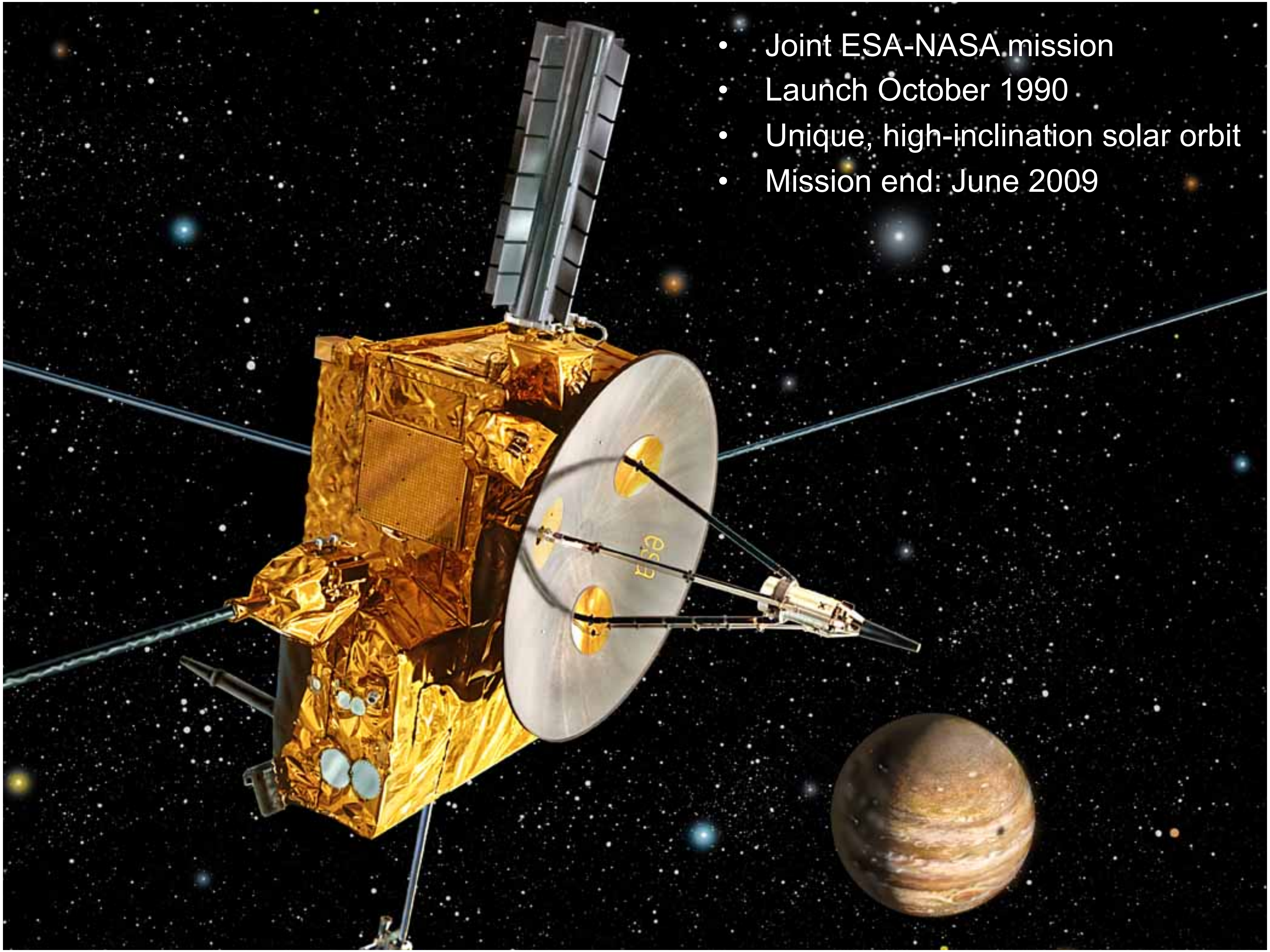


Figure 5.22: Solar wind velocity for comet C/2004 Q2 during CR 2025. ACE/SWEPAM measured solar wind (in red) has been extrapolated to the comet's orbit. Longitudinal difference between the comet and the extrapolated solar wind is converted into a timing offset for the solar wind data.

Comet Tail Crossings

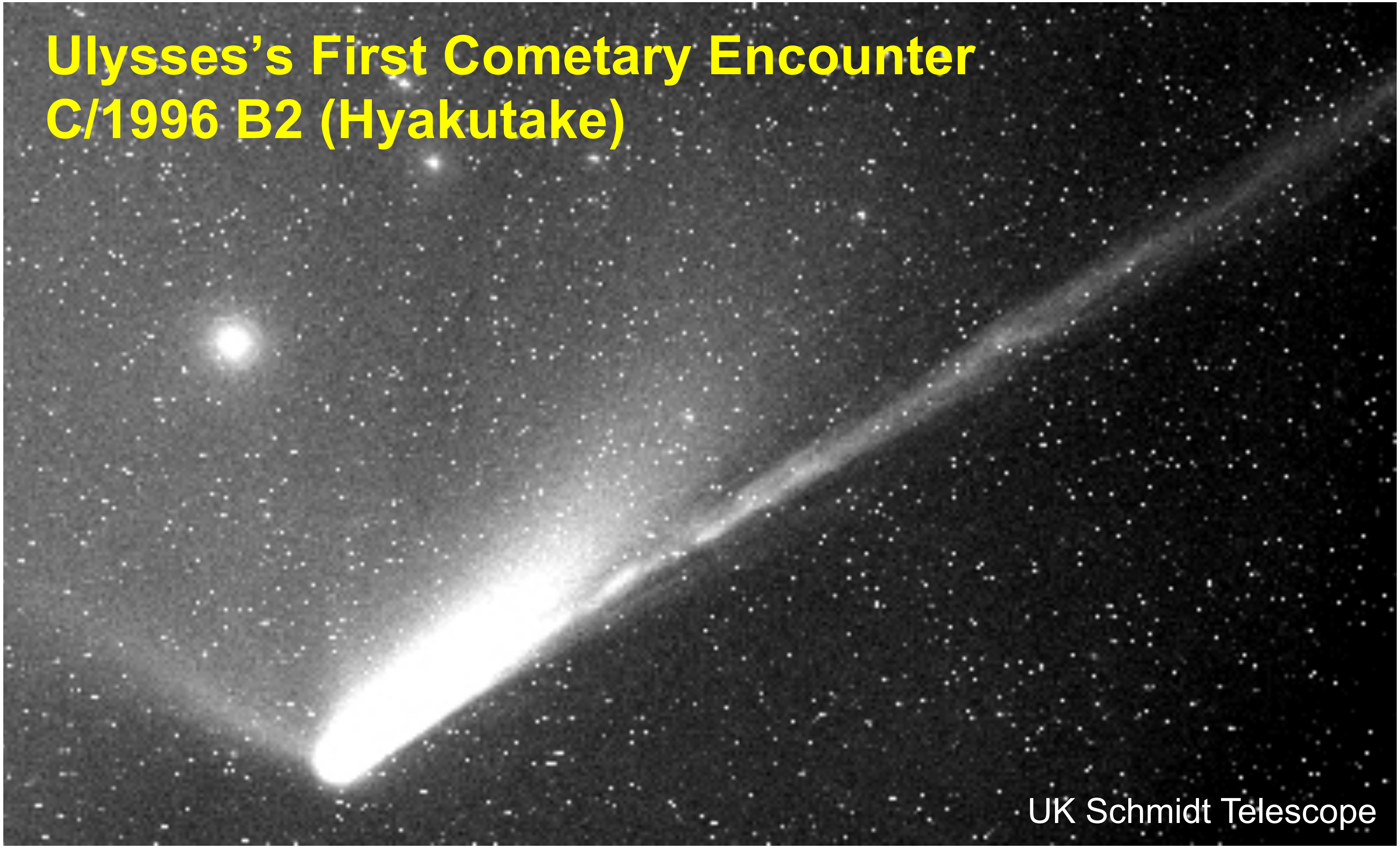


103P: Dello Russo+ (2011) 9P: Schleicher+ (2006) 81P:Fink+ (1999) 19P:Young+ 2004 1P:Krankowsky (1986)
26P: Johnstone+ (1993) 21P: Neugebauer+ (2007) & refs. therein



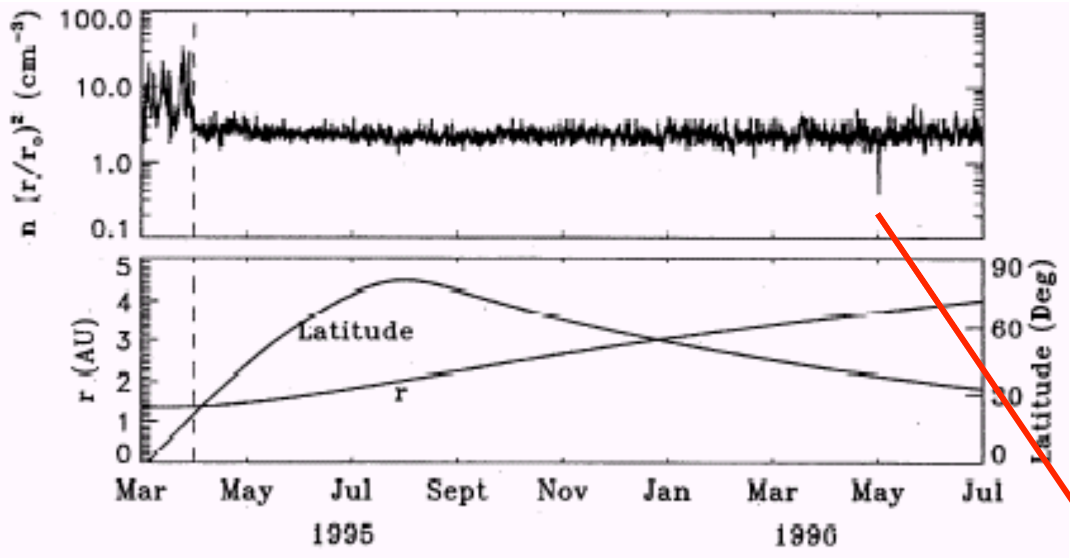
• Joint ESA-NASA mission
• Launch October 1990
• Unique, high-inclination solar orbit
• Mission end: June 2009

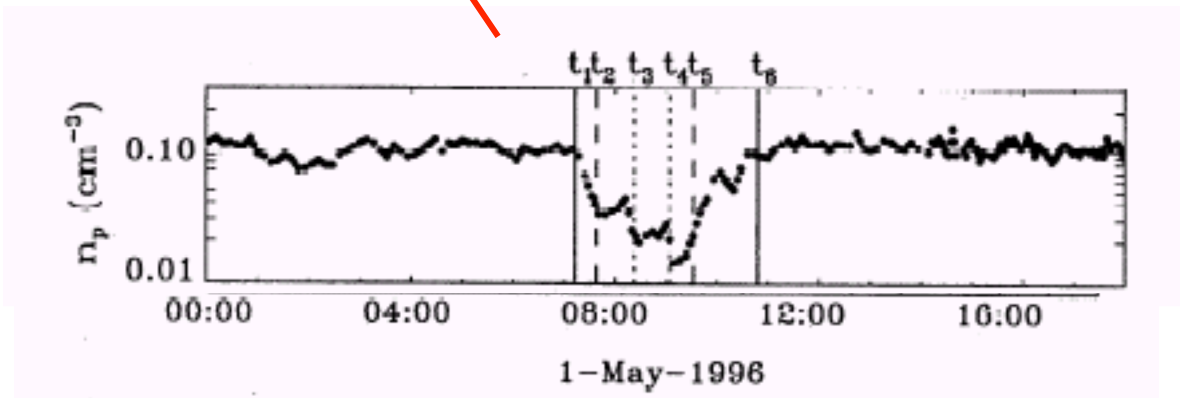
Ulysses's First Cometary Encounter
C/1996 B2 (Hyakutake)



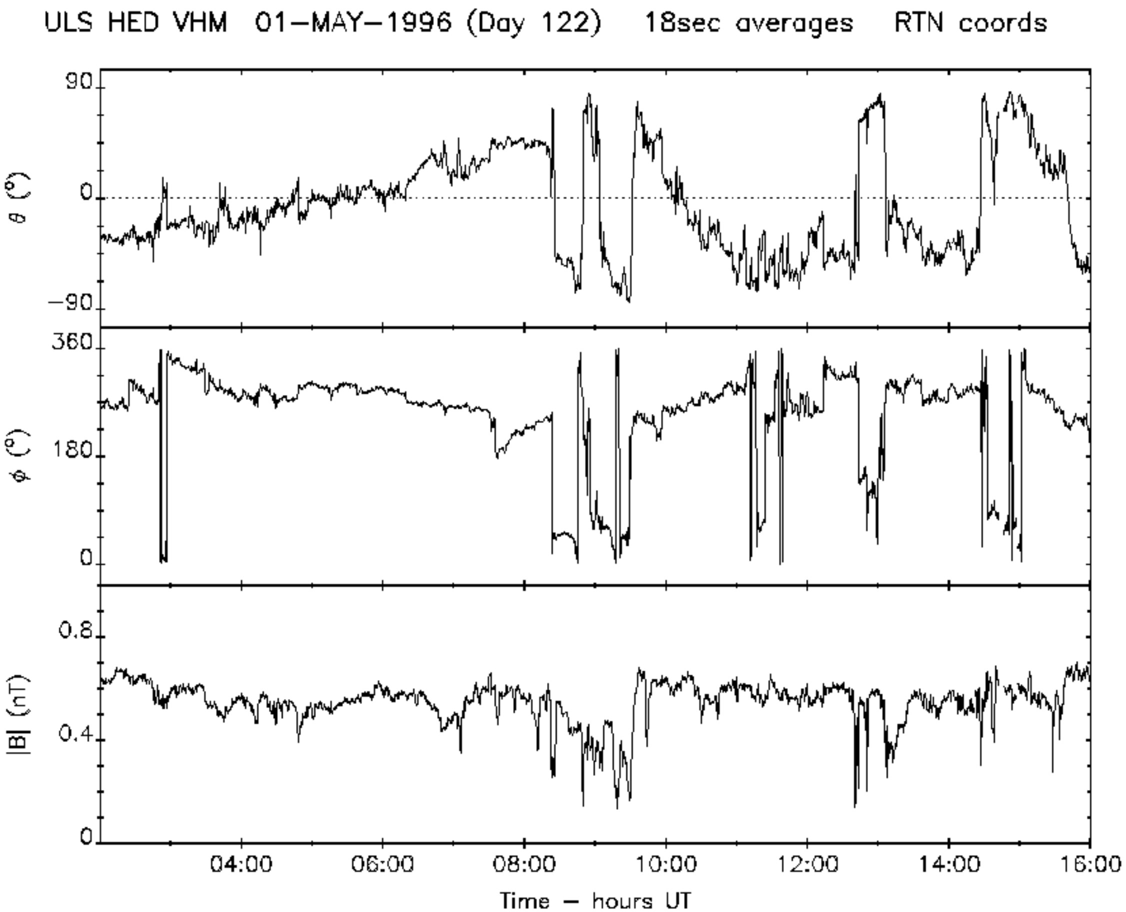
UK Schmidt Telescope

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





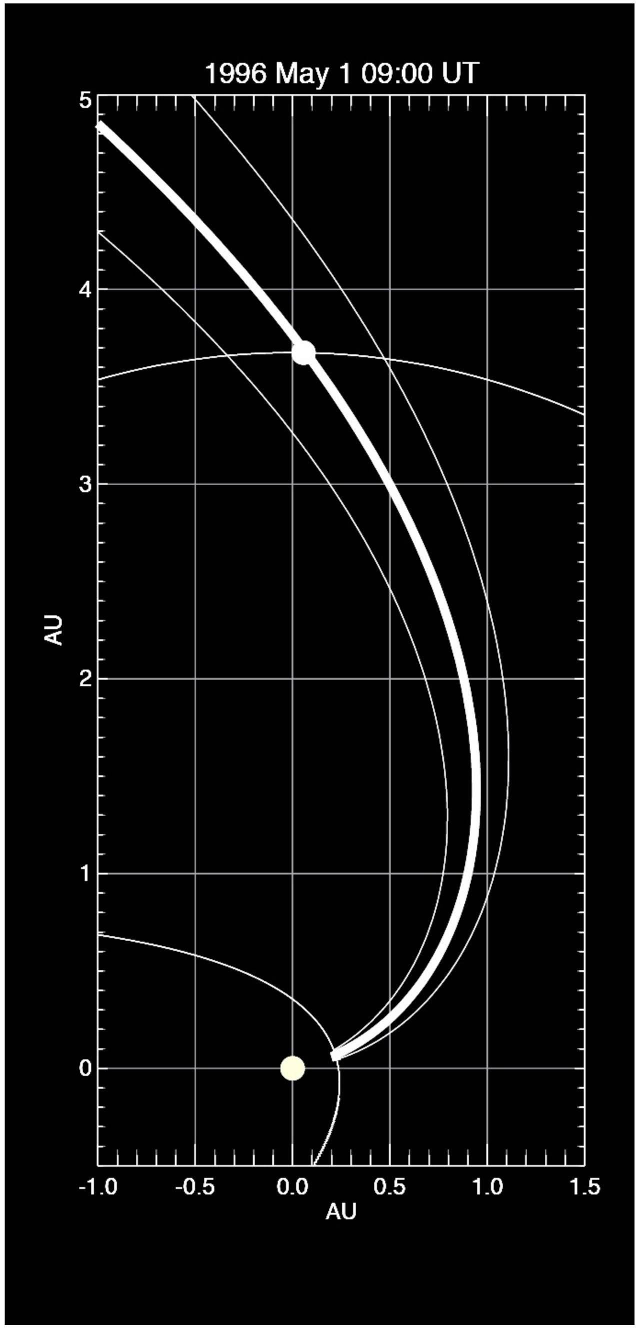
- Coincident with the proton “hole” were magnetic field signatures reminiscent of draping patterns expected at a cometary ion tail

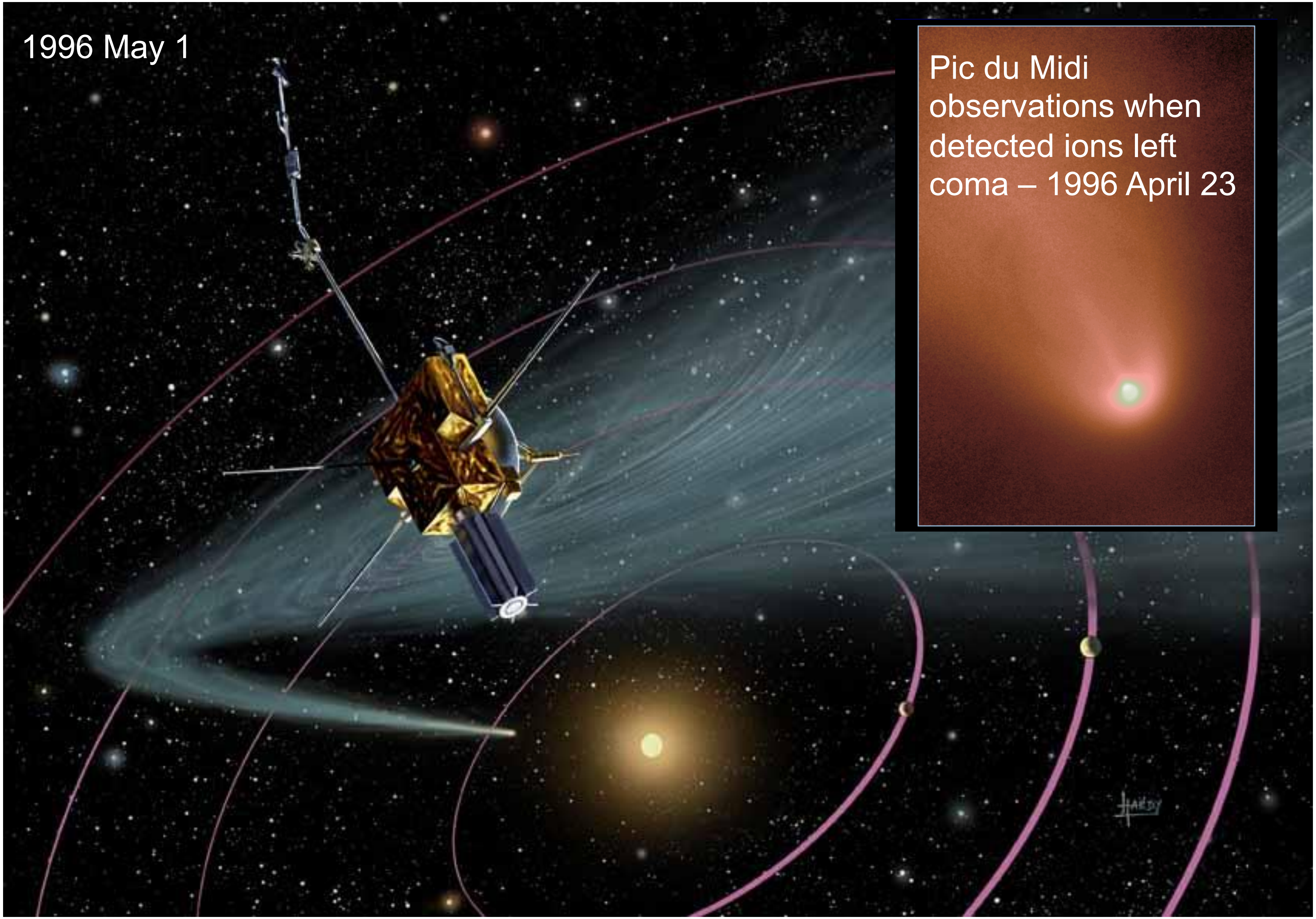


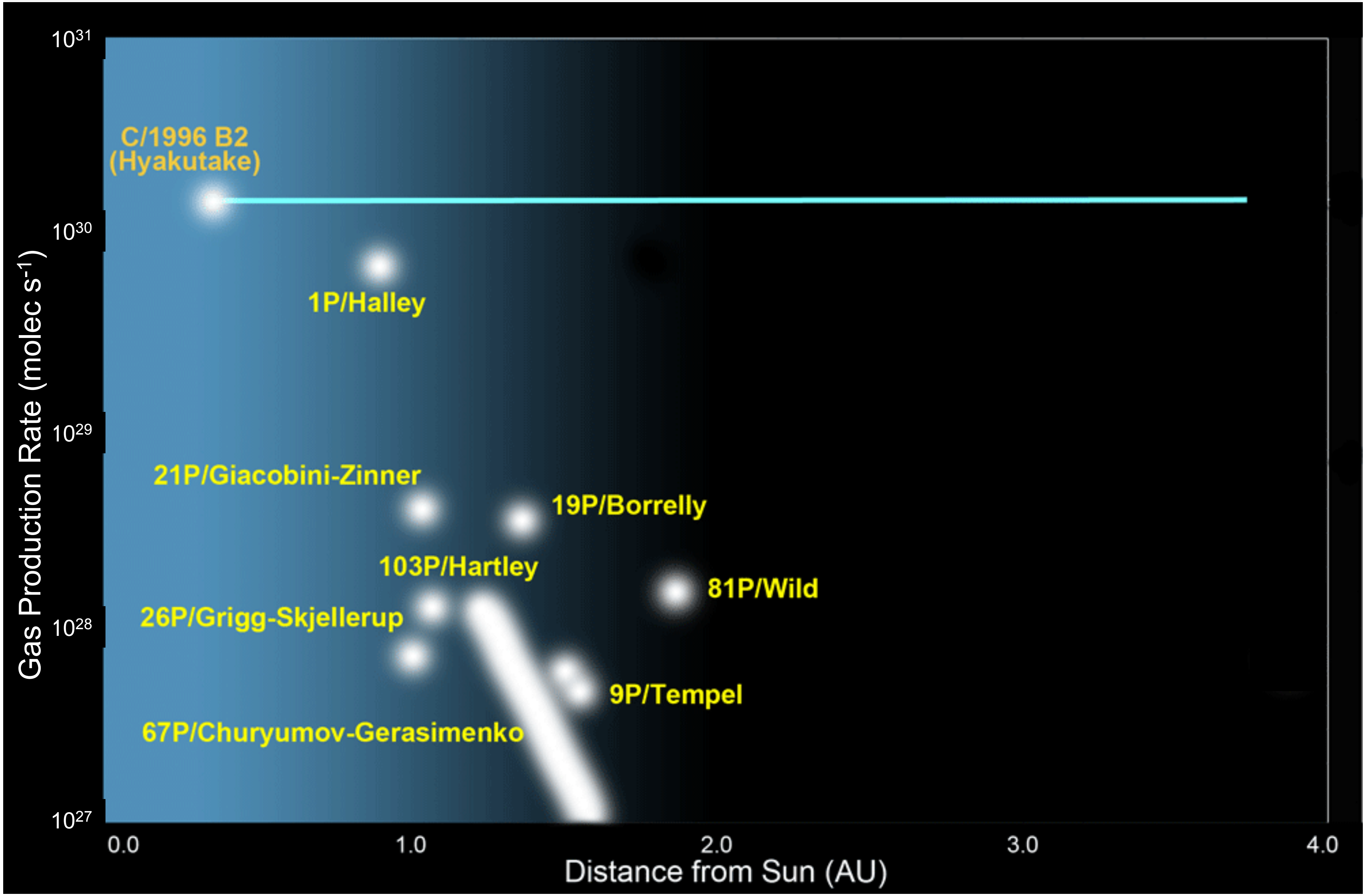
- Search was conducted for possible source comets
- C/1996 B2 (Hyakutake) alignment found

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
Pic du Midi observations when detected ions left coma – 1996 April 23



Gas Production Rate (molec s-1)
10^31
10^30
10^29
10^28
10^27
C/1996 B2
(Hyakutake)
1P/Halley
21P/Giacobini-Zinner
19P/Borrelly
103P/Hartley
81P/Wild
26P/Grigg-Skjellerup
9P/Tempel
67P/Churyumov-Gerasimenko
0.0
1.0
2.0
3.0
4.0
Distance from Sun (AU)

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

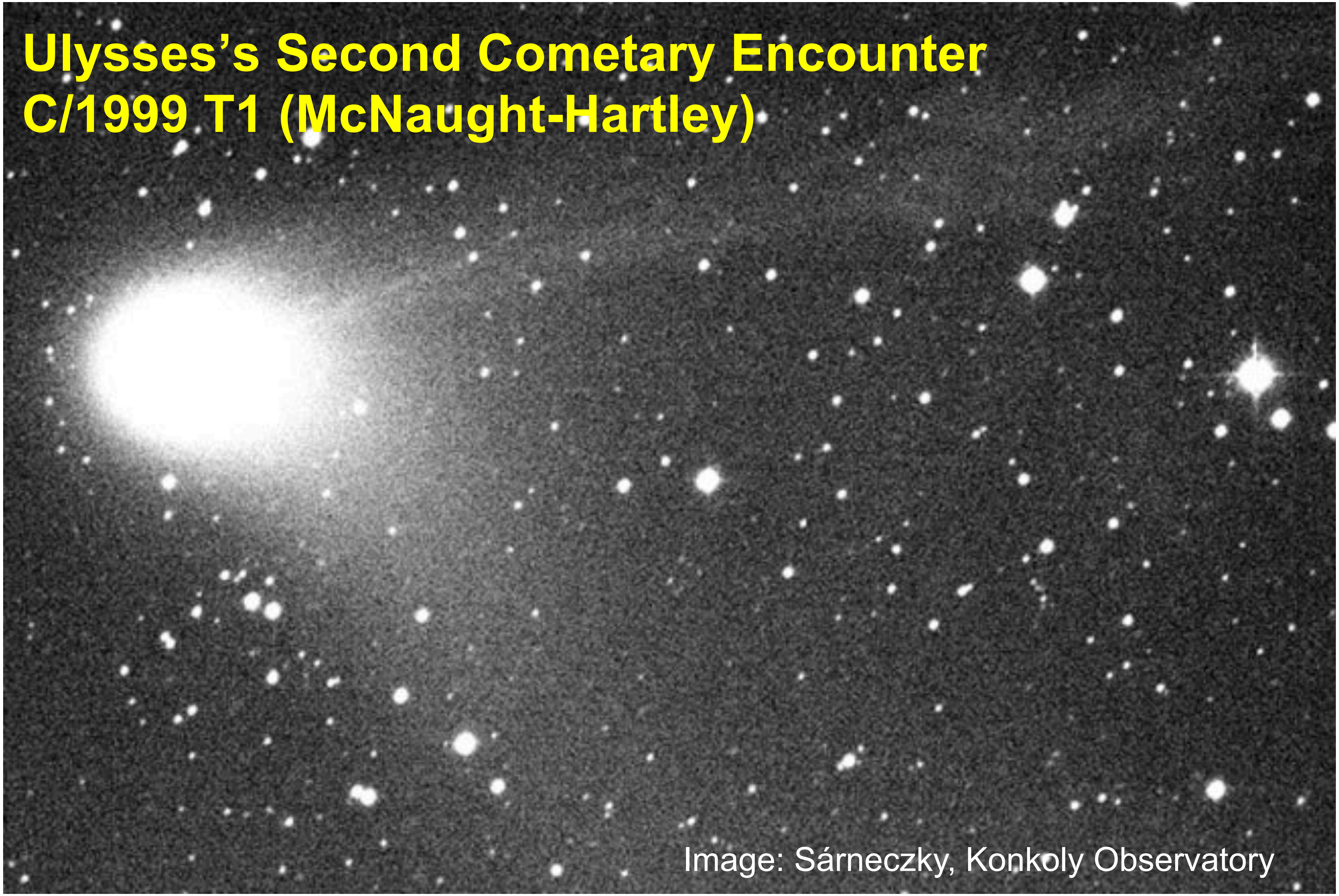
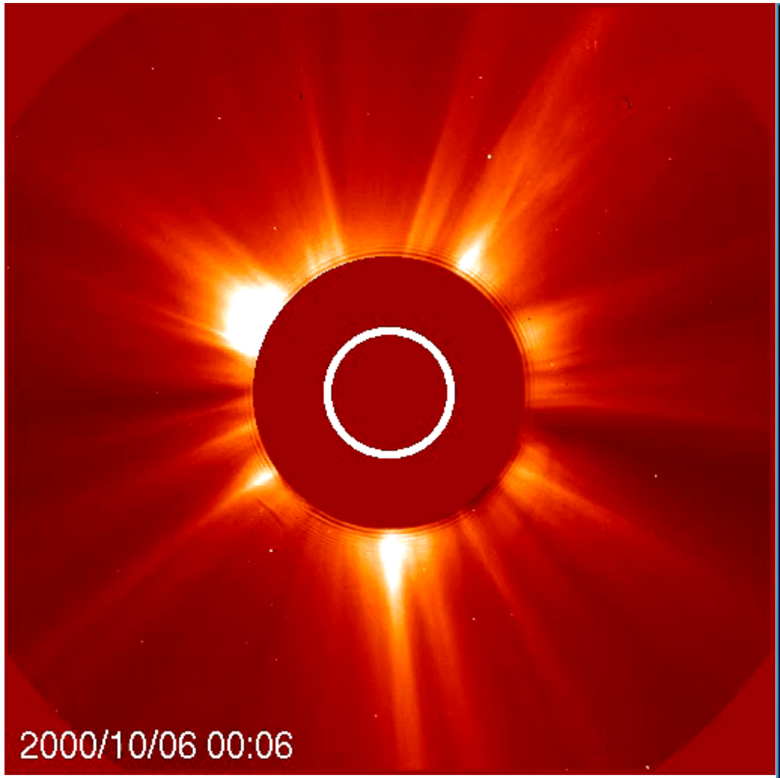
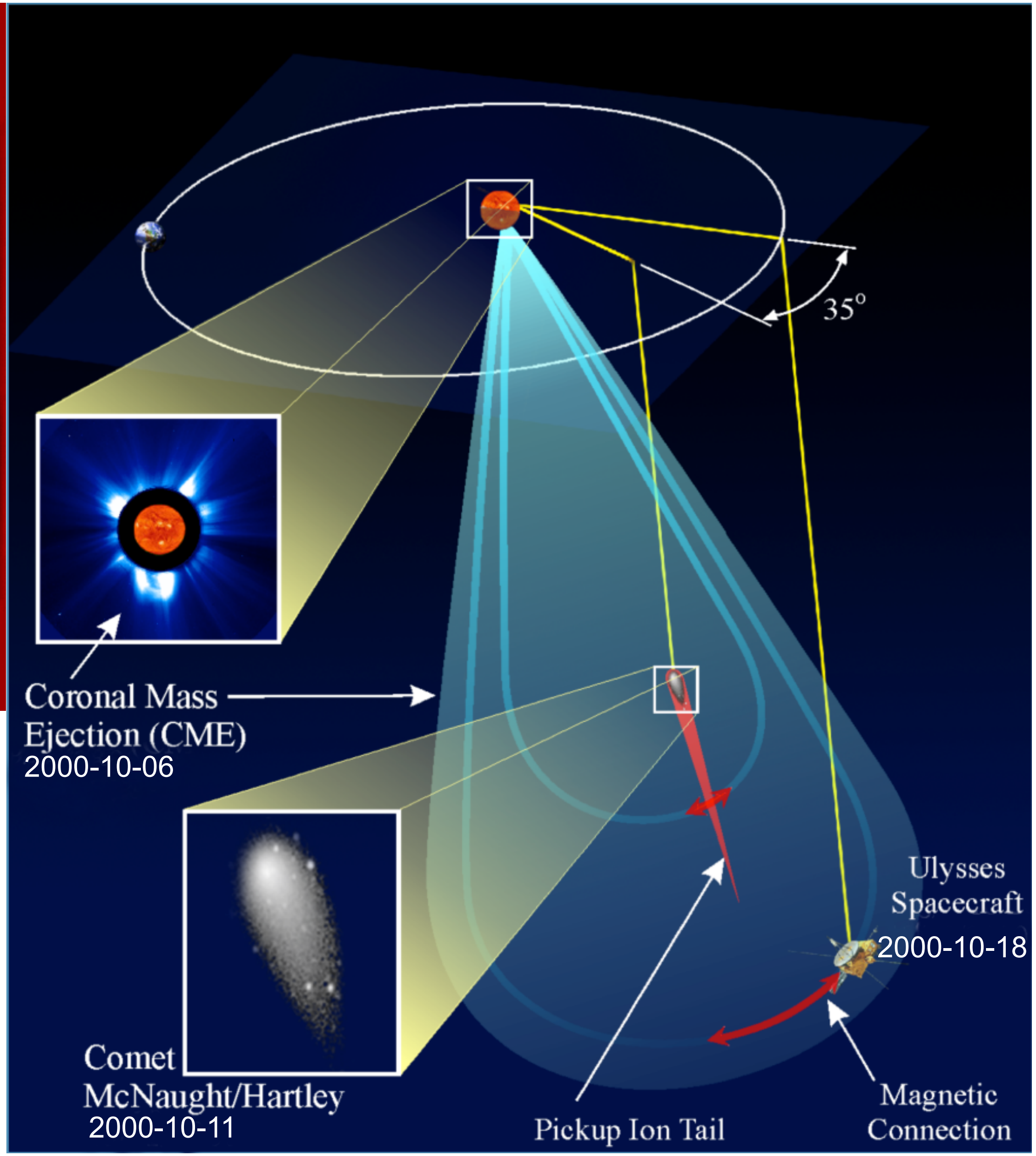
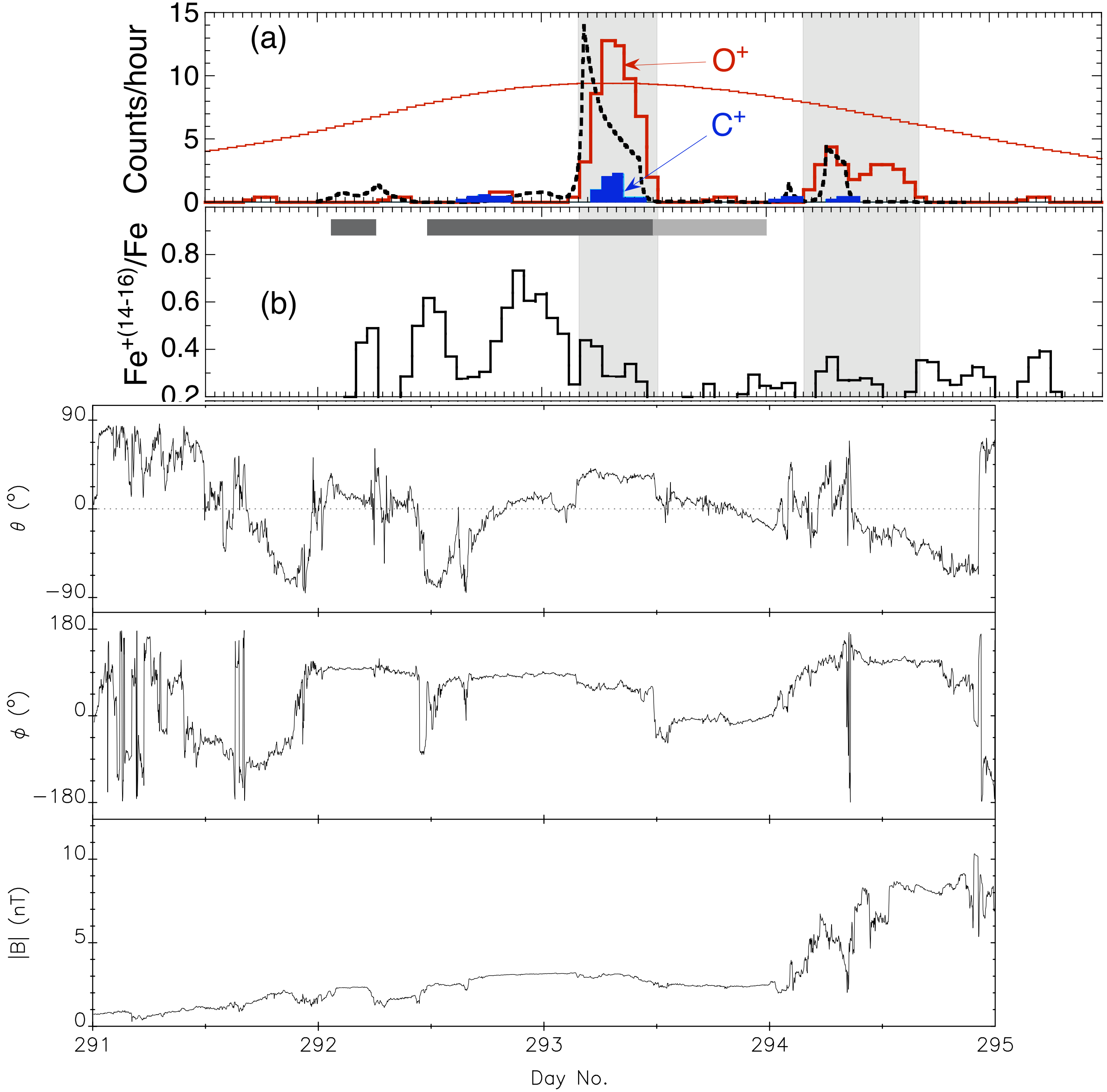


Image: Sárneczky, Konkoly Observatory





Gloeckler et al. 2004



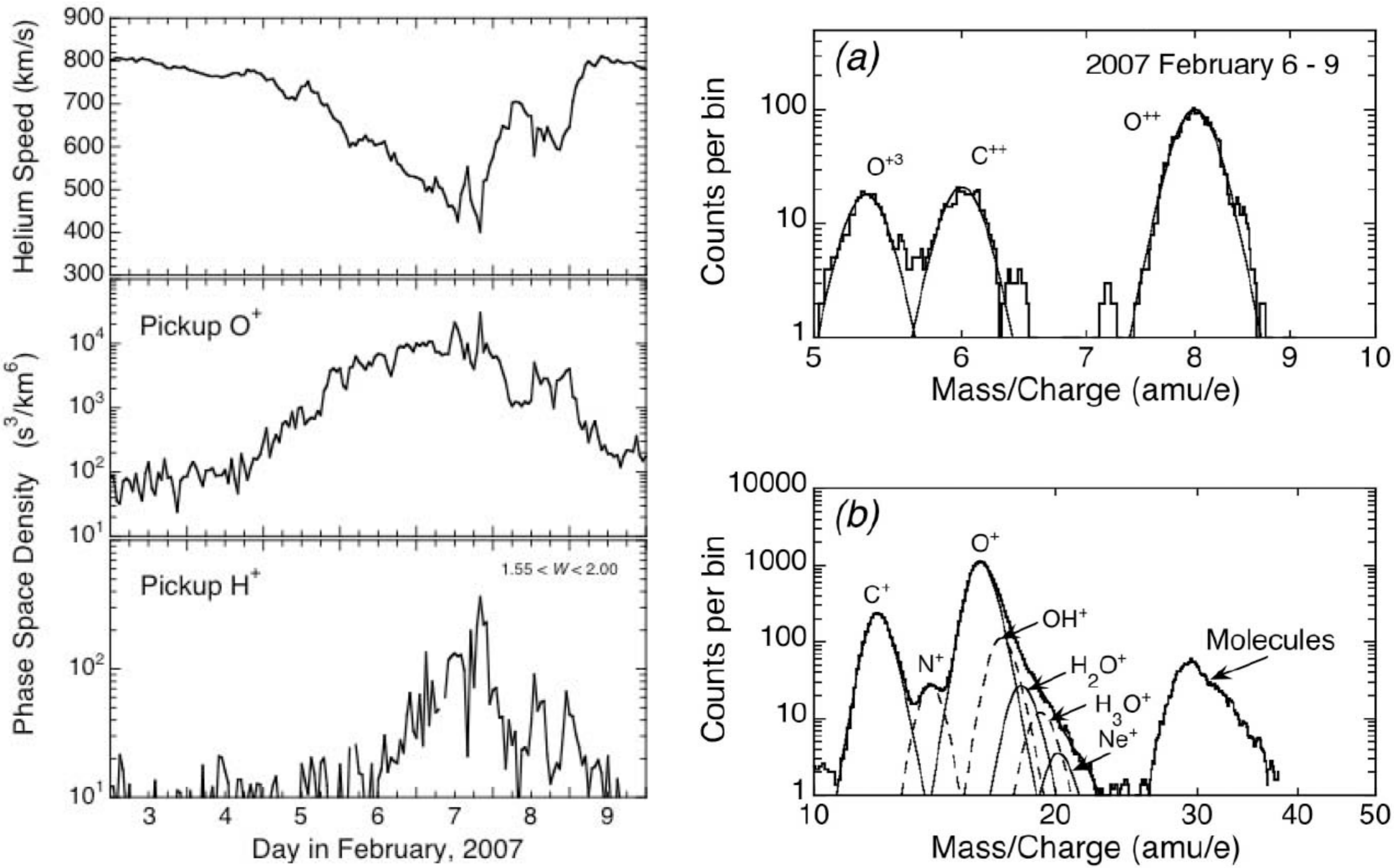
Gloeckler et al. 2004

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

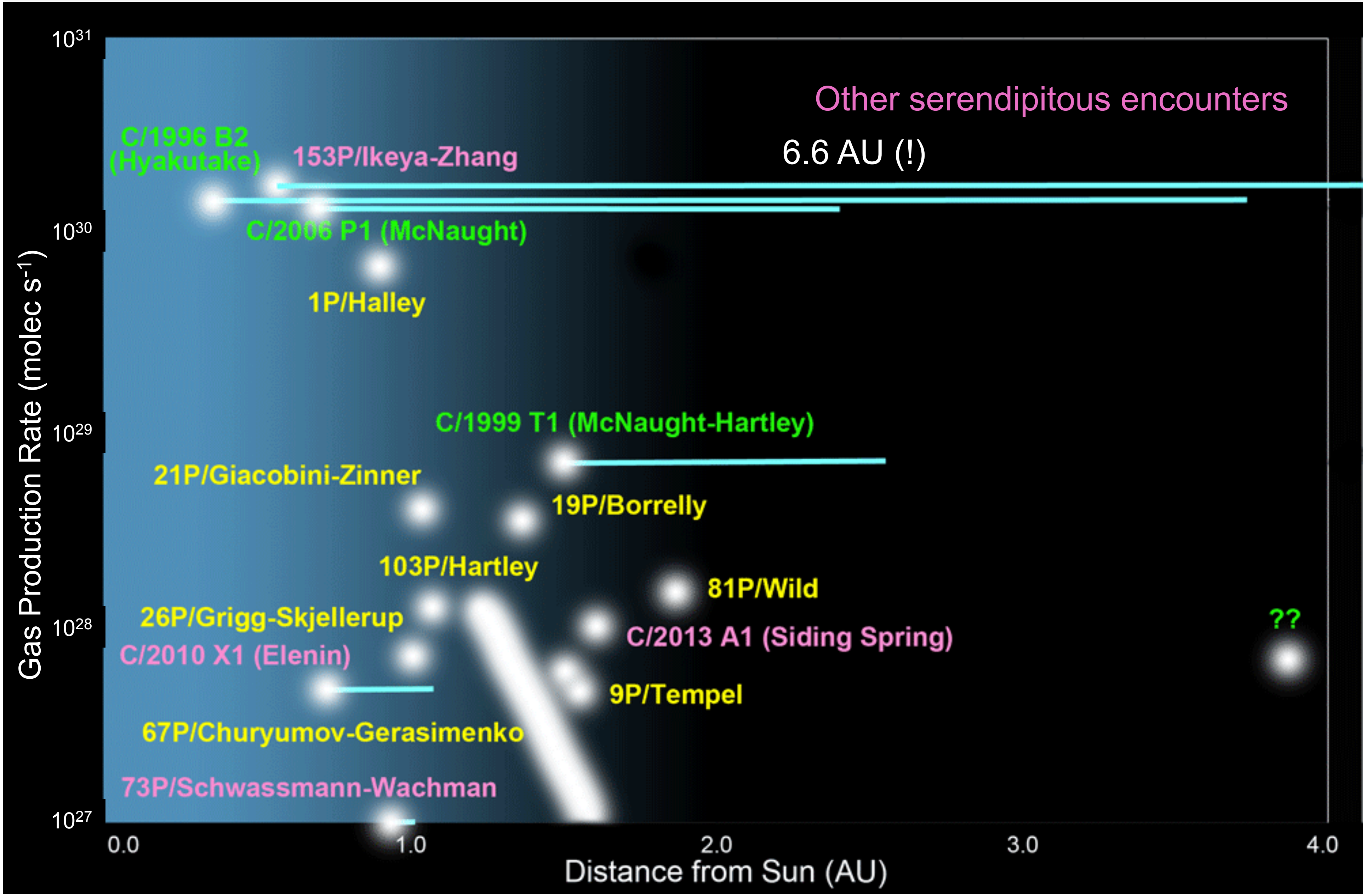
Credit: Sebastian Deiries

Comet McNaught over the Pacific

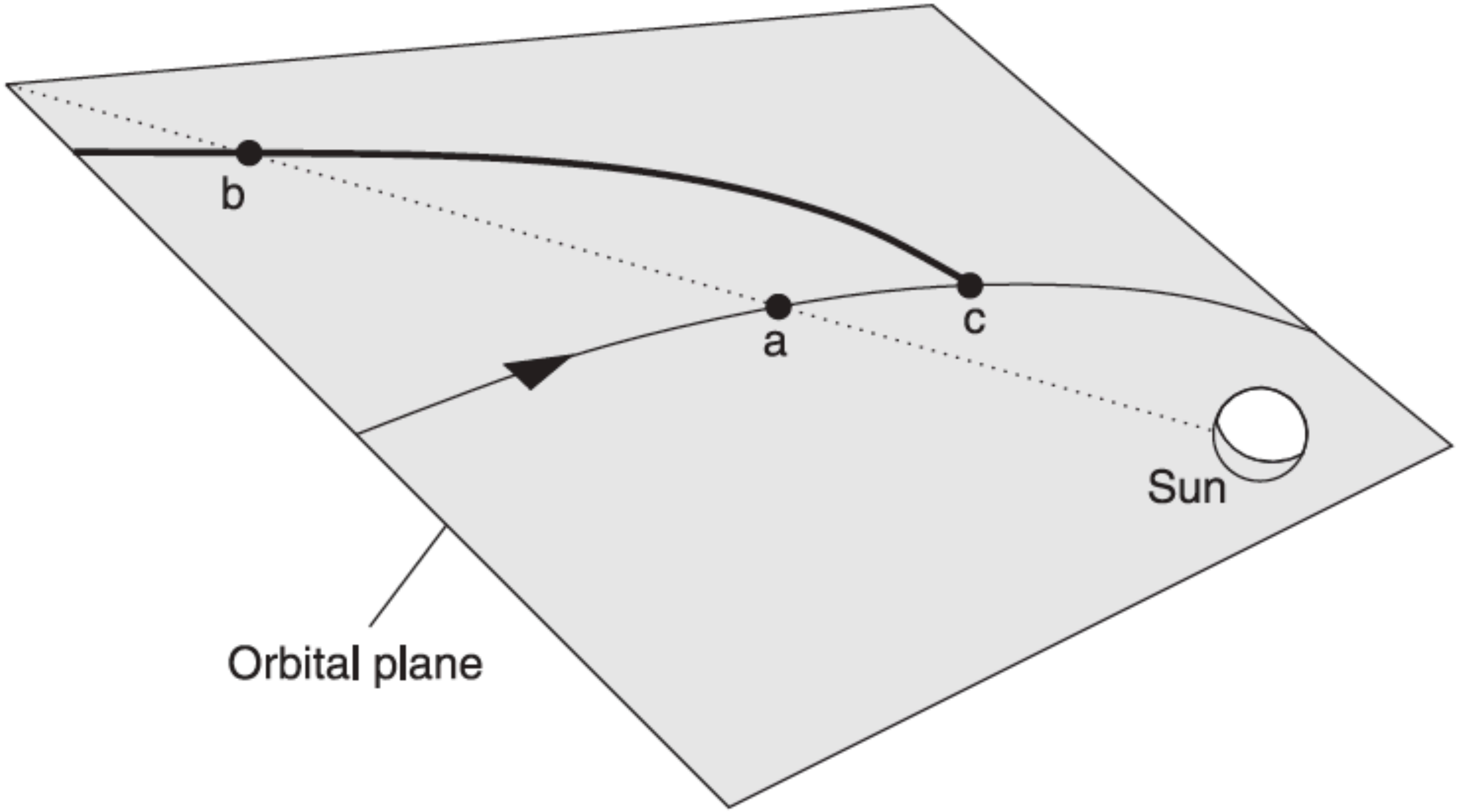
ESO Press Photo 05i/07 (19 January 2007)



Neugebauer et al. 2007



73P: Gilbert+ (2015)   C/2010 X1: Galvin+ (Fall AGU 2013)   C/2013 A1: Espley+   153P: Jones+ (subm.)



- For a comet tail crossing, spacecraft (b) has to be close to comet's orbital plane
- Comet has to pass upstream of spacecraft's position (a)
- Solar wind speed has to be in correct range to carry tail past spcaecraft during the orbit plane crossing

Conclusions (1/2)

Task 1: Comet Tail Crossing Catalogue

- A list of all known comets is available
- Trajectories of all spacecraft in the solar wind will be surveyed for periods when a comet orbital plane was being crossed, JPL Horizons likely source
- Ephemeris of each comet will be checked: if comet passed between Sun and spacecraft, promising periods will be highlighted and ideal solar wind speeds for detection noted
- Search will be made in data for evidence of crossings
- List will be made publically available, hosted on a website, for others to conduct searches too
- Obvious checks: Known Ulysses tail crossings

Conclusions (2/2)
Task 2: Solar wind speeds

- IDL code exists for analysis of ion tail orientations, courtesy Yudish Ramanjooloo (now at University of Hawai'i)
- Code takes images, and with identity of the comet, can identify the date and time of the image within ~5 minutes
- Code maps image onto orbital plane; user then marks axis of the ion tail
- Each of these tail axis identifications gives a solar wind speed estimate: a time history of solar wind speeds at the comet

- Aim: web-based interface
  - for professionals, IDL source code and documentation can be made available
  - for amateurs, web-based interface that is foolproof is more challenging

- Conversion to Python is already underway; this will at least allow amateurs to run the code licence-free
- Postdoc will be employed for ~3 months to attempt coversion to a web interface.

- Timescale starting at least 6 months from now.

- *Reasonable to ask all users to have their results stored for a large survey?*