Zodiacal Dust Cloud Observations from the PUNCH Mission

R.A. Howard

JHU APL

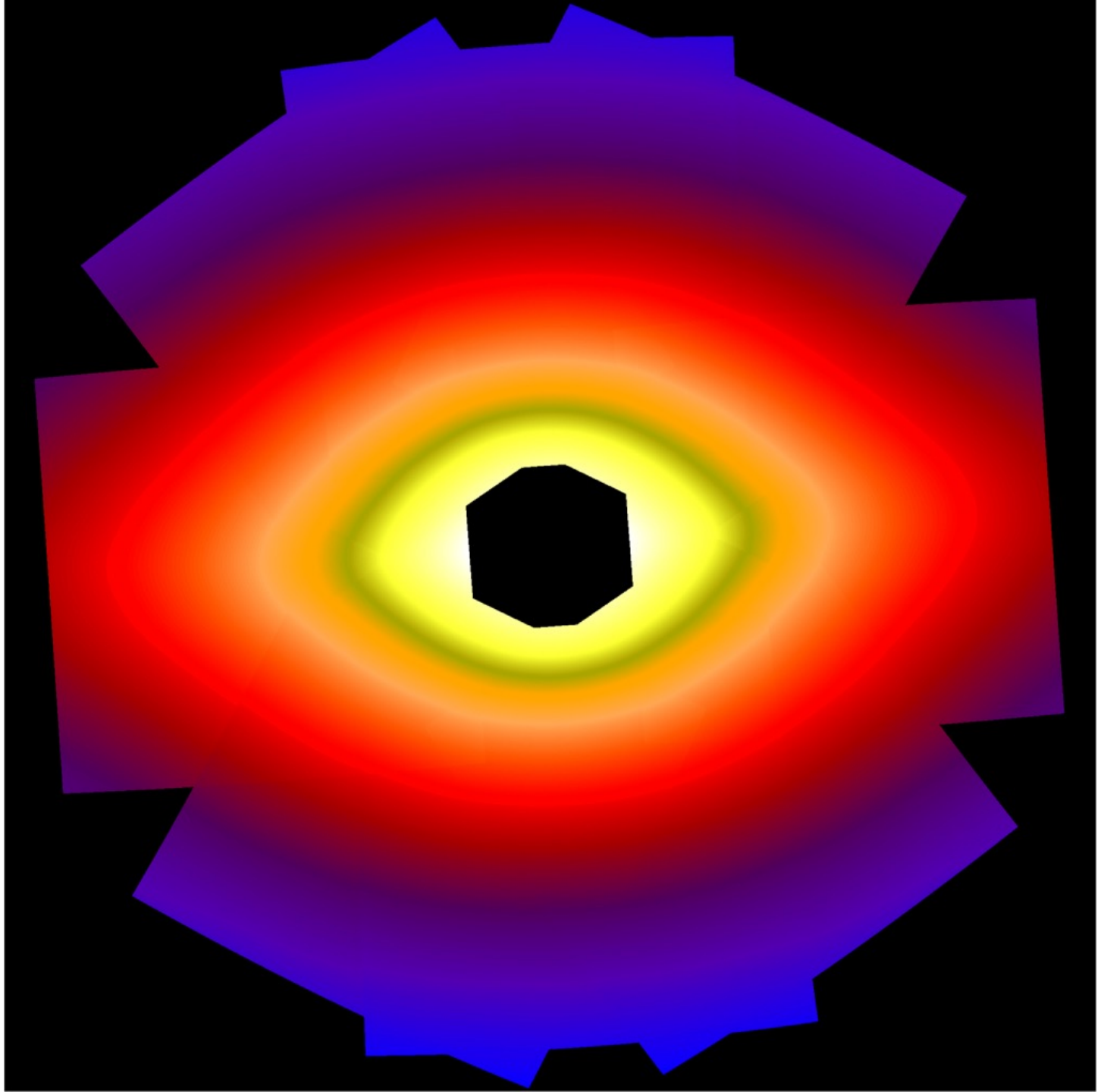
Punch SWT, San Luis Obispo, CA, 25-26 Feb 2025

Very Abbreviated History

- There have been five major contributions defining the visible light properties of the F-corona/Zodiacal Light from space
  - Helios A/B (ZLP) – 1974/76 – 1981-86 (Papers by Leinert and Grun +)
  - Skylab WLC -1973/4 – (Paper by Saito, Poland, Munro defining background F)
  - Balloon (Paper by Kimura and Mann)
  - STEREO/SECCHI 2007-2012 (Still ongoing) (Papers by Stenborg & Howard +)
  - Parker Solar Probe/WISPR 2018-Present (Papers by Stenborg & Howard +)
- We originally thought the F-corona was constant and uninteresting and our goal was to develop ways to remove it, not to study it. But, there are small variations in local areas, but the overall structure is amazingly constant in time.
- Punch will definitely be able to significantly contribute due to its increased sensitivity, full 2D FOV and polarization

The F-corona/ZL from 5-25^{o} (~20-100 Rs) constructed from 8 individual images from the SECCHI-HI1 instrument during a calibration roll.

The roll took a few hours and there are slight gaps between images.



Ways for Punch to Contribute

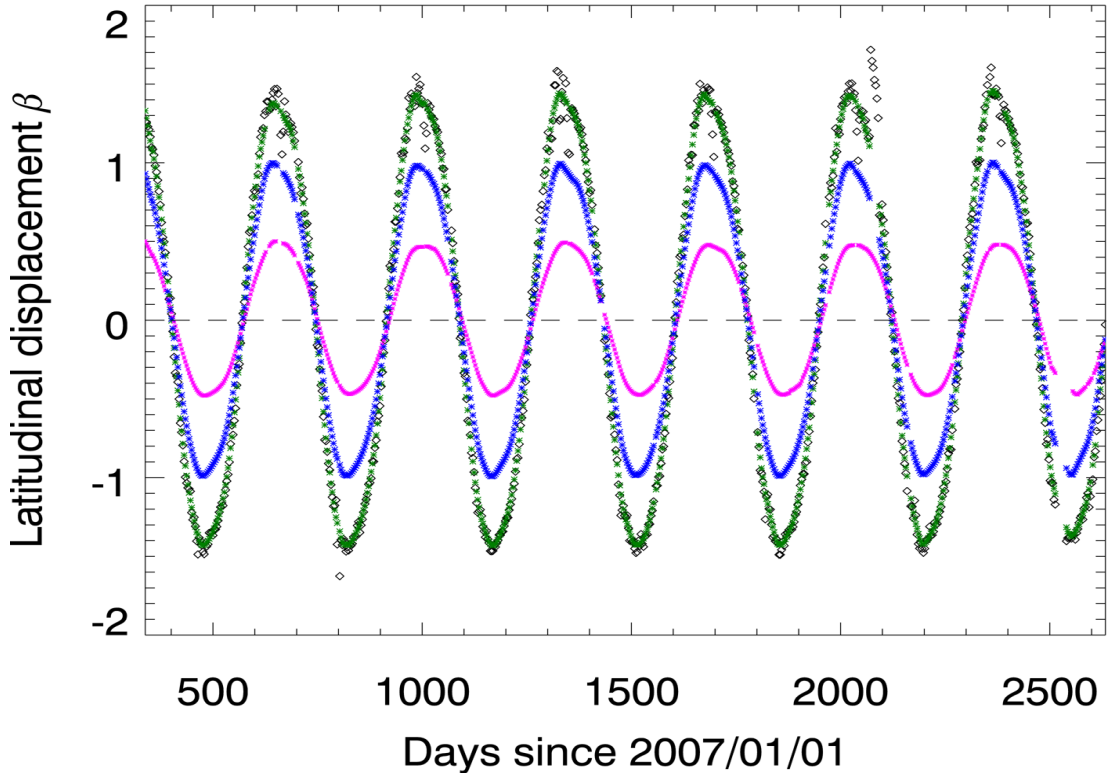
- Brightness Distribution
- Brightness Asymmetry (Gravitational Effects)
- Polarization Properties
- Brightness Oddities: Interstellar dust, Dust in orbits of Venus & Mercury, Earth and ??, Sublimation Zones

Brightness Distribution

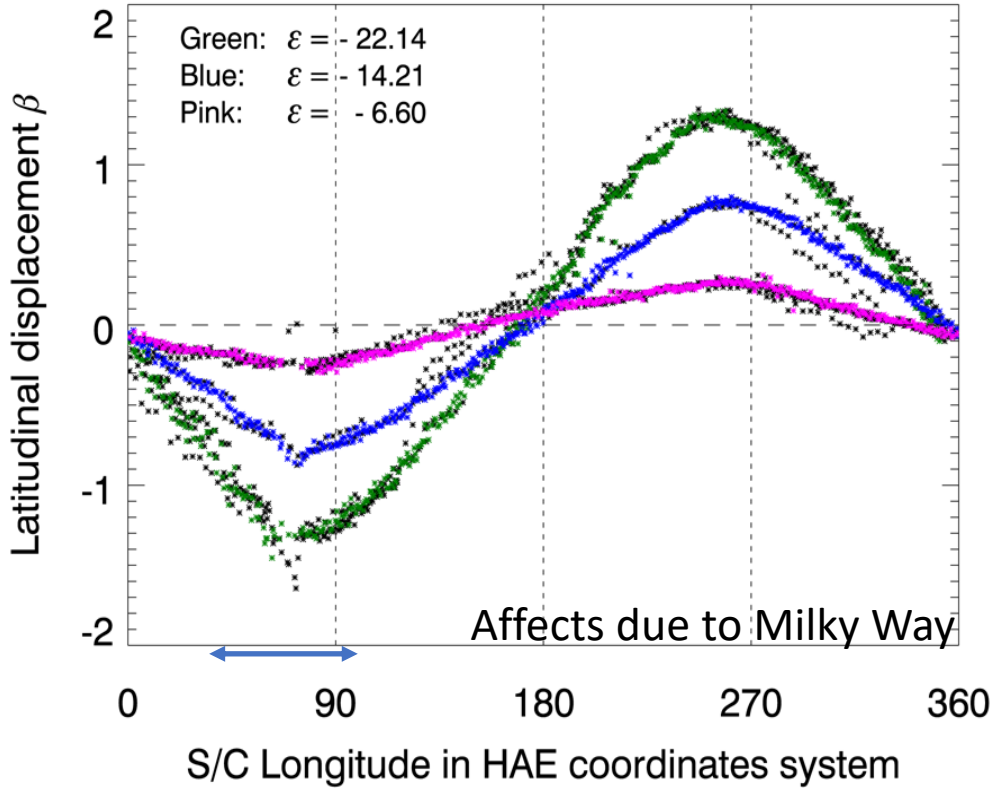
- Evolution of the symmetry axis 12/2007-3/2014 shows constancy over nearly 8 years.
- The slope agrees with Helios from 1974-1980+
- These data are for elongations of about 5°-25° (~19 Rs – 94 Rs)

S & H ApJ, 2017

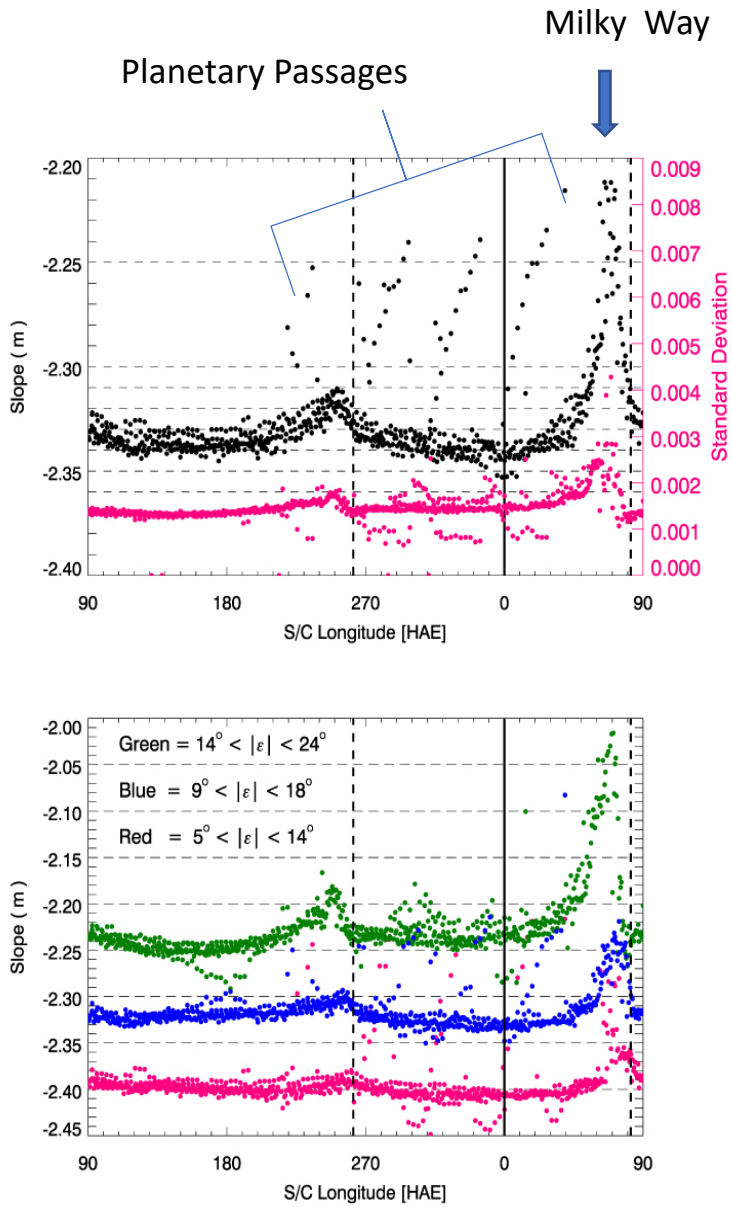
With Time



With Spacecraft Position



- These plots show the constancy of the slope of the linear fits to the brightness of the symmetry axis.
- Top plot is the entire interval
- Lower plots show the increasing steepness closer to the Sun and the circularization of the corona (on one side).



Stenborg. Howard & Stauffer ApJ, 2018

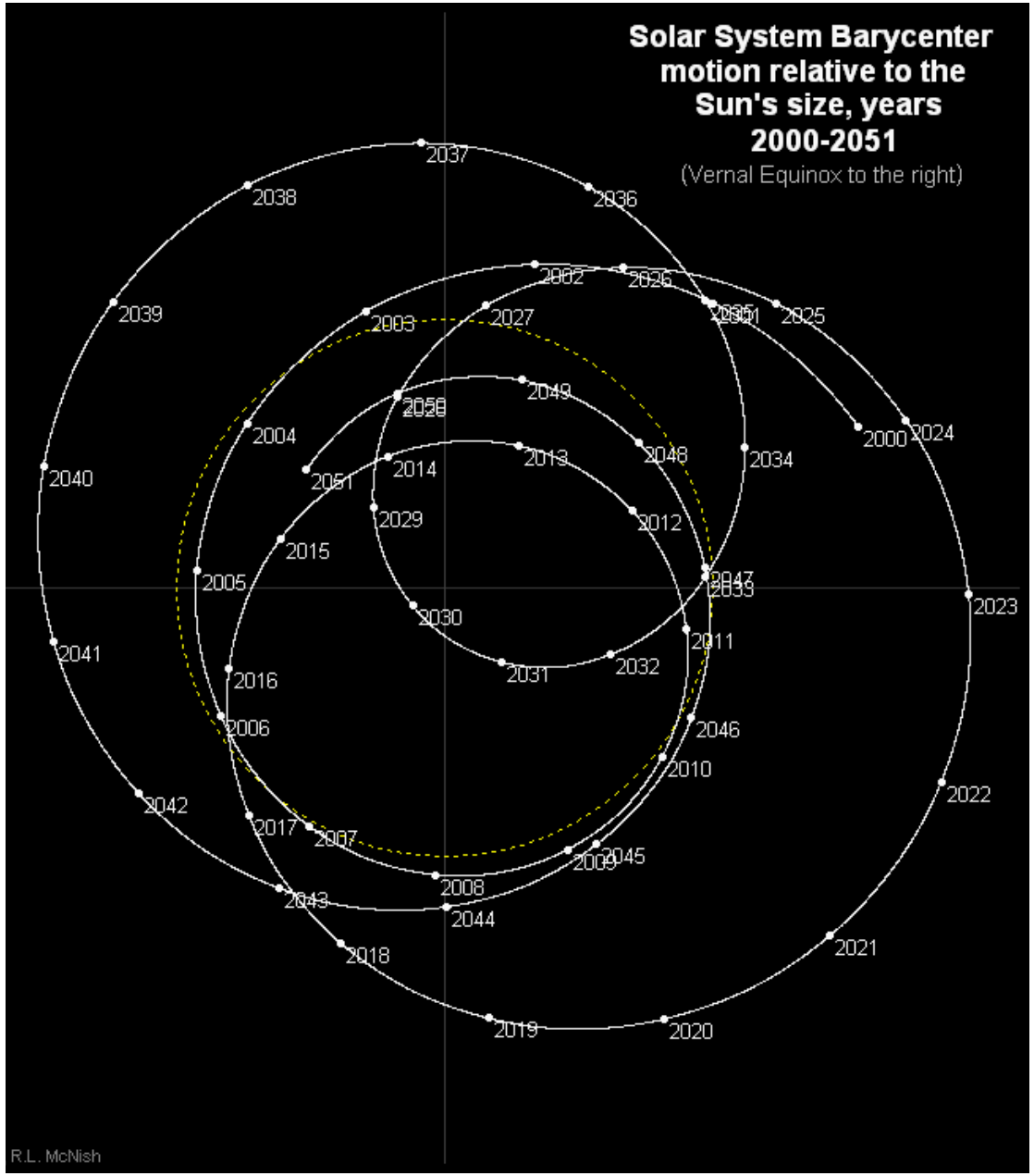
Contributions of Punch To ZL Brightness

- Does the overall radial variation of the symmetry axis agree with previous measurements (Helios, SECCHI/HI1)?
- Can temporal variations be seen orbits of Venus & Mercury? Mars? There could be small temporal variations in the planetary dust? Mercury was very difficult – can it be improved upon?
- Can slight enhancements be detected anywhere? Possible asteroids? Possible dust sublimations (see later)?
- What is the brightness distribution as a function of latitude (position angle)?
  - Does it agree with Helios (Leinert+ 1980)
  - Is there an asymmetry in latitude? (see later discussion)
  - Are there temporal brightness variations? If so what scale? (see later discussion)
  - Can comets, asteroids, etc be seen?
- Can enhancement be seen due to InterStellar Dust (ISD)? This would occur in the hemisphere – centered at about 259◦ ecliptic longitude and 8◦ ecliptic latitude.

Brightness Asymmetry

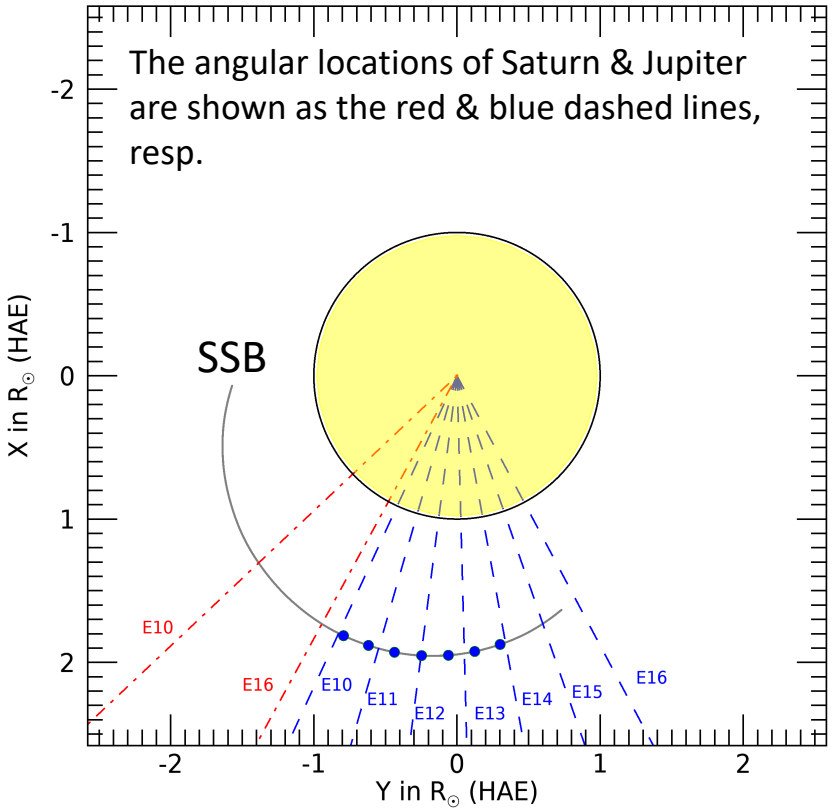
Brightness Asymmetry

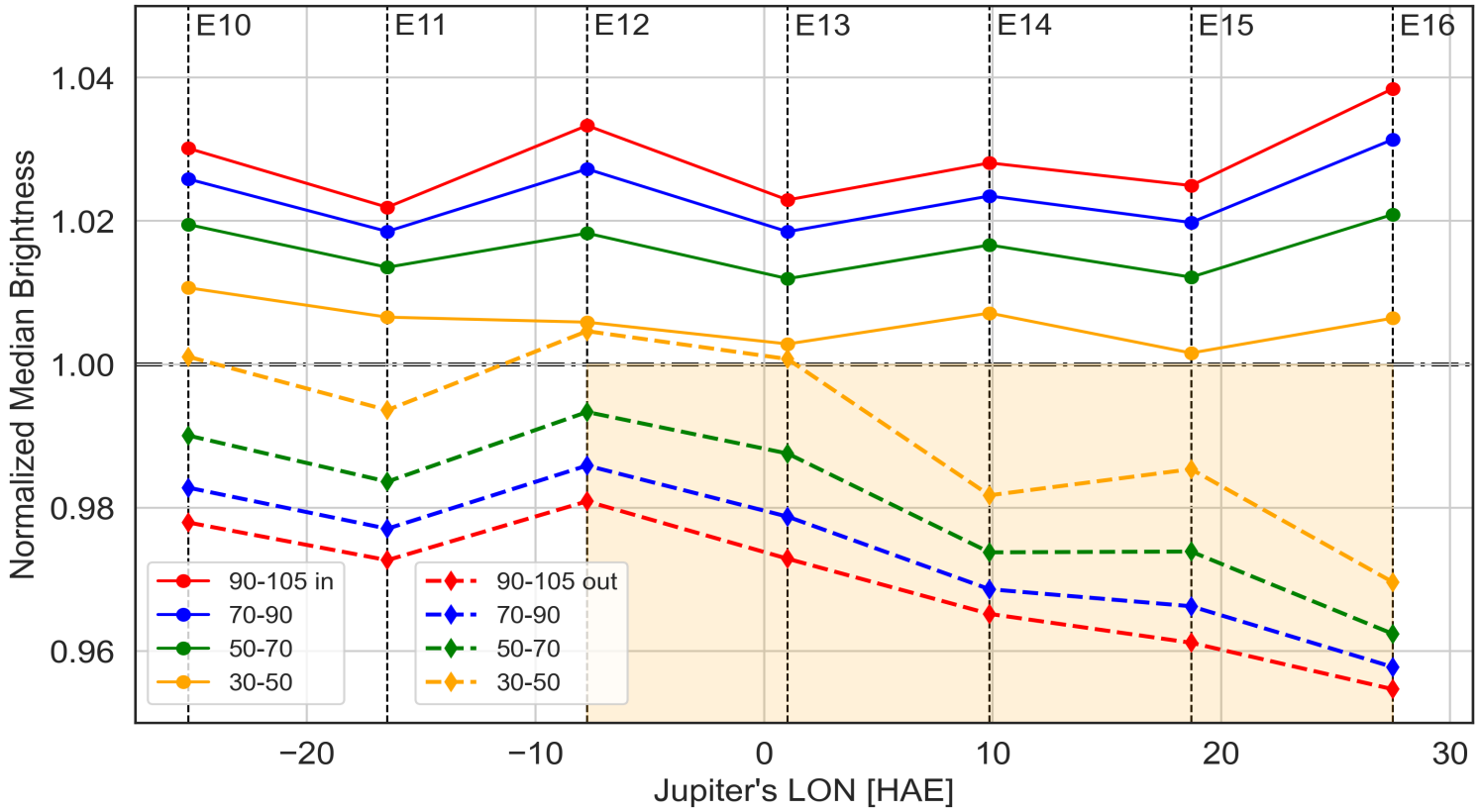
- The question of asymmetry of the ZL/F brightness had been unconfirmed for years. The F near the Sun did not seem to have an asymmetry. Leinert et al (1981) did see an asymmetry in Helios but argued that it was an instrumental effect.
- STEREO/SECCHI did observe a slight asymmetry of 0.5 Rs in the direction of Jupiter when the SSB was about 0.7 Rs from Sun center.
- Parker Solar Probe has confirmed the existence of an asymmetry of the ZL/F brightness following the combined (probably) effects of the solar system barycenter (SSB) and the position of Jupiter.
- The asymmetry appeared to be in the direction of the SSB. PSP only could define an East West asymmetry. PUNCH will see the true 3D direction.
- PUNCH will be able to observe and record the degree of asymmetry as a function of heliocentric distance, latitude (PA) and perhaps ecliptic longitude.



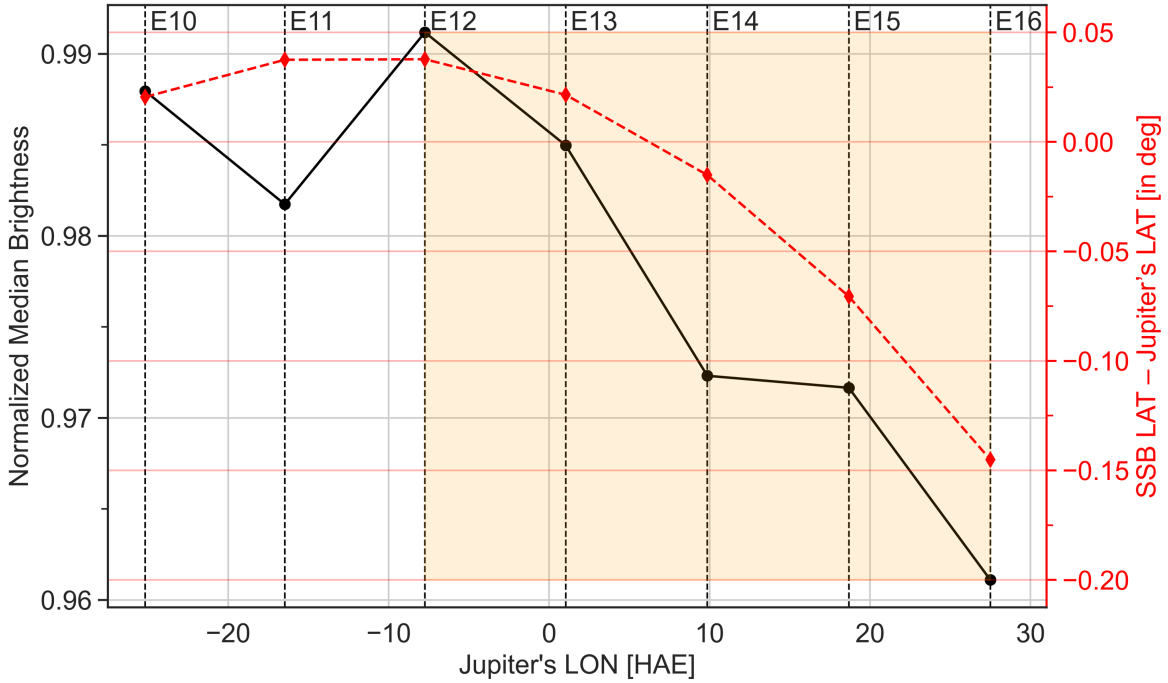
- PSP has shown that the locations of the solar system barycenter and Jupiter both play roles in distorting the brightness distribution. The SSB is about 1 Rs from the limb during the PSP encounters 10-16, from 11/2021-6/2023.
- The brightness of the inbound (outbound) segment is 2-4% higher (1-4% lower) than the average of both. The strange increase in the outbound segment is due to Jupiter (next).

Positions of the SSB vs Time

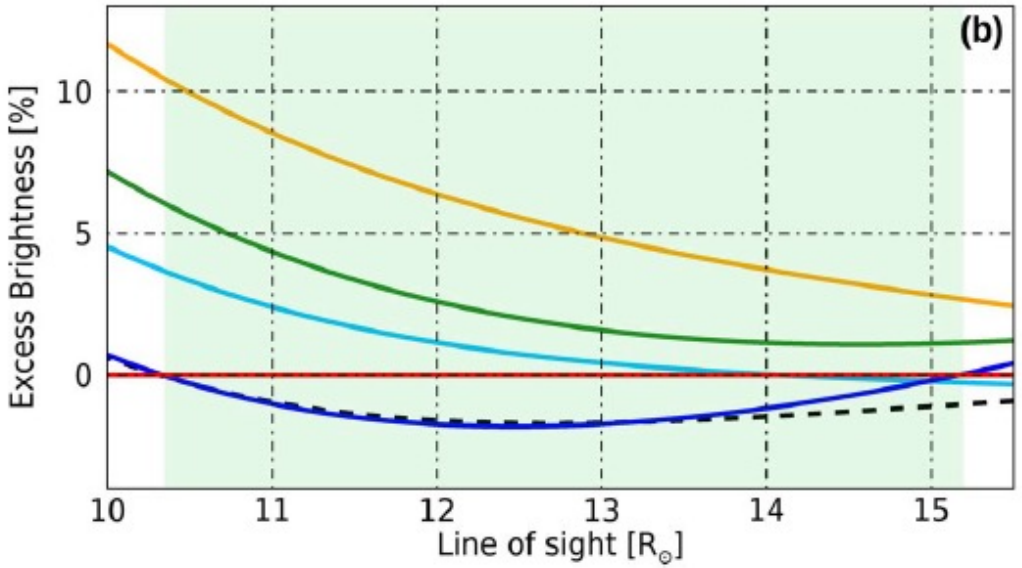




The strange behavior of the outbound segment for E12-E16 is correlated to Jupiter's location.



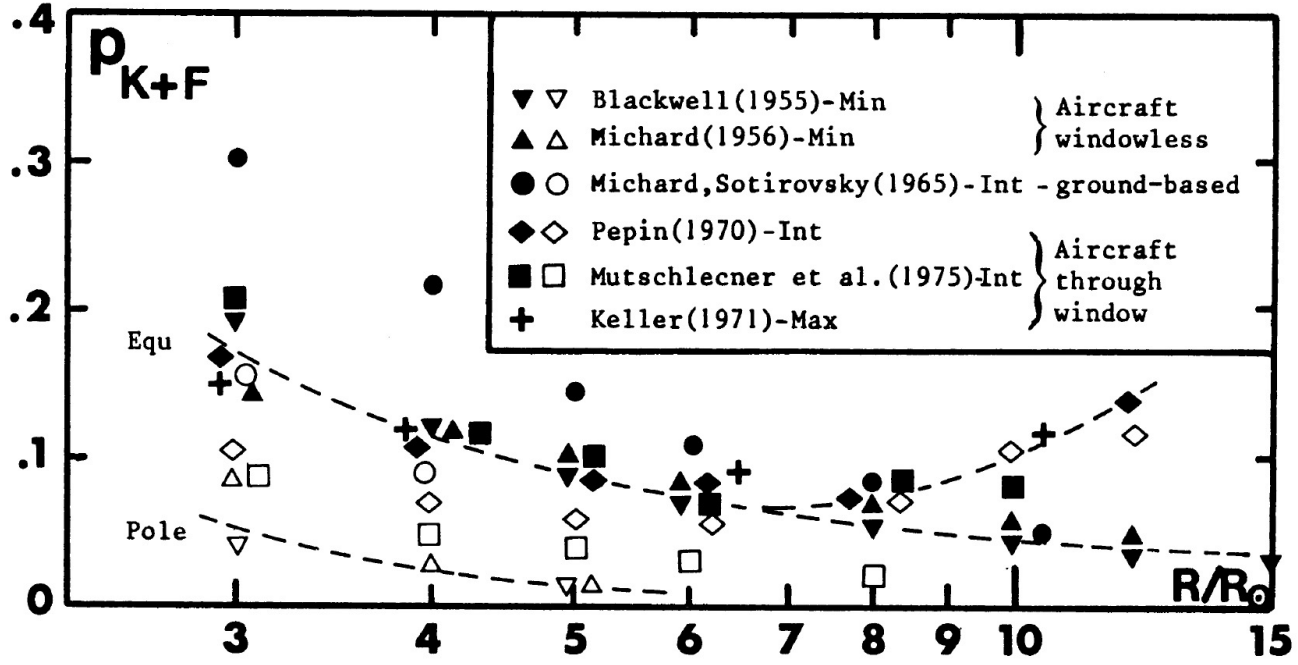
The 4 curves are the excess ratios of total B relative to the F-corona. Thus K can be ~10% of B. Note that behind a CME the F can be removed!



- Punch will be able to measure the magnitude and angle of asymmetry, both of which should be slowly time dependent. The issue at close distances is that the K-corona becomes a higher fraction of the total B.

Polarization Properties

- There have been very few studies of dust polarization. The LASCO and SECCHI observations of polarization have not been analyzed for the ZL polarizations. But they could be.
- Koutchmy & Lamy (1985) (below) show the polarization of K+F, but not the F. Also. no polarization measurements had been taken beyond 12 Rs. PUNCH will definitely contribute here.
- I don't know how to use the polarization, but certainly having it and reporting on any variations with scattering angle/distance will be important.



Punch contributions

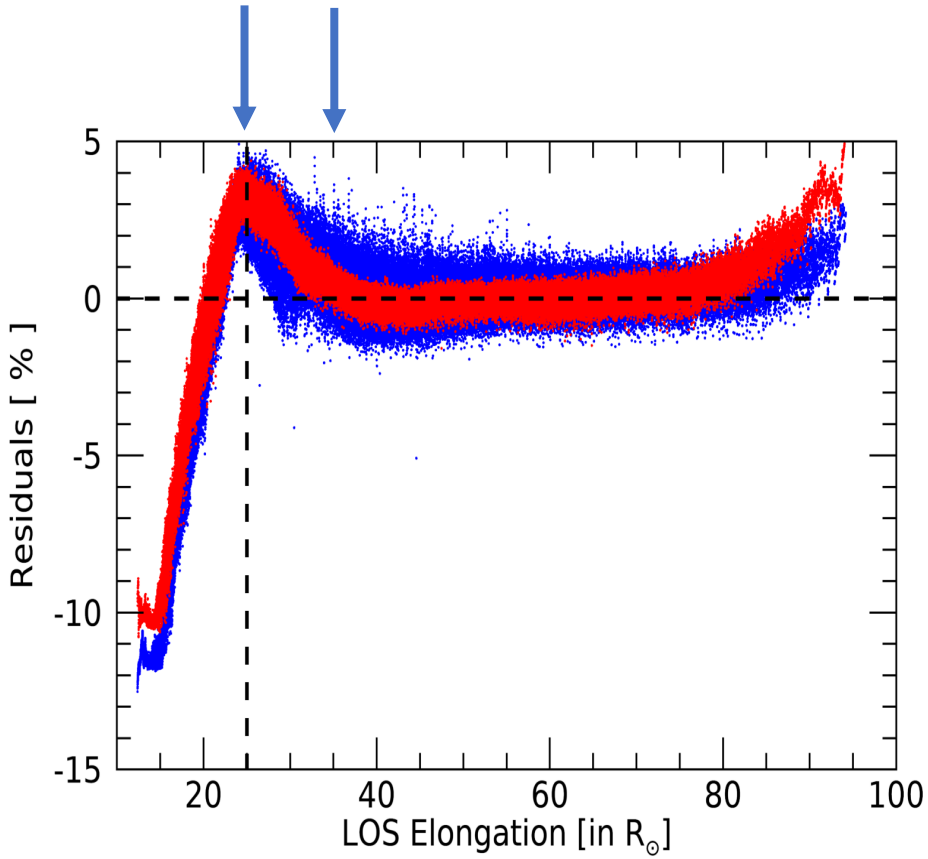
- What are the properties of the polarized brightness as a function of elongation?
  - i.e. what are the degree and angle of polarization for each elongation?
  - Do they change smoothly with elongation?
  - Is there a difference with position angle?
- Could contribute to the empirical Volume Scattering Function

Brightness Oddities

- Helios and STEREO/SECCHI found the brightness to be very stable in time with the same slope along the symmetry axis(R^-2.3).
- However, there may be an interstellar component:
  - It is absent during one of the 22 year cycles depending on the orientation of the solar magnetic field
  - During the other cycle, the ISD impinges on the heliosphere from a direction of 259^{o} longitude and 7^{o} latitude. The whole side of the heliosphere centered at 259^{o} will be affected, this translates to being observable from September to March.
- Enhancements have been observed in/near the orbits of Venus and Mercury.
  - Mercury's orbit was very faint in the SECCHI data. Punch could certainly improve on it.
  - The dust in the Venus orbit was observed nearly for the entire orbit.
- An enhancement at 25 Rs was due to dust sublimation and was not observable from > 35 Rs, but there could be other dust sublimation zones further out.
- Behind strong (at least) CMEs there can be a depletion of dust.

Sublimation Zones

- PSP found that sublimation starts to occur at 35 Rs, peaking at 25 Rs. The 4% increase was followed by constant depletion rate.
- The shapes (inbound-red, outbound blue) are indicating that the zone is present at all longitudes covered by PSP.
- But only 1 zone was discovered.
- The increased sensitivity of Punch (WFI) could possibly detect some small enhancements farther out.
- This zone is not visible from 1 AU due to the increase being followed by the decrease. This had the effect of shift the start of the zone from 25 Rs down do 20 Rs.



Punch Contributions to Brightness Variations

- With the increased sensitivity of Punch, looking for enhancements through the FOV would be an important study.
  - Possible Asteroid or comet trails
  - Depletion behind CIRs or CMEs
  - Sublimation zones at larger elongations
  - Depletions behind CMEs or CIRs
- Is there a brightness asymmetry visible from 1 AU? If so, does it vary with elongation? Does it vary with polar angle also?
- Does the polarization also change?

GO PUNCH