Parker Solar Probe Observations of a Dust Trail in the Orbit of 3200 Phaethon

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WISPR observes stars, Milky Way, planets, asteroids, dust (*lots of dust*), solar wind and CMEs.
A faint trail is seen following the orbit of asteroid 3200 Phaethon is seen in Enc. 1 and 2.

(3200) Phaethon:
‘Active asteroid’ / ‘Rock comet’
Discovery: 1983
Size ~ 5.8km
Earth MOID ~0.019AU (PHA)
P ~1.43yr
q ~ 0.14AU

→ Parent of the Geminid meteor shower
We fortuitously observe the perihelion portion of Phaethon’s orbit throughout the encounter, with Phaethon near aphelion during this period.

PSP’s distance from the visible portion of the trail varied from 0.1 - 0.5au.
Q1: **Why** can WISPR see the trail?
   - Why has (e.g.) SOHO or STEREO/HI-1 never seen the trail?
   - Why did recent dedicated Hubble and ground-based surveys fail to find the trail?

Q2: **What** are we seeing?
   - Are we seeing the Geminids (formed ~2kyr ago)?
   - Are we seeing dust released by Phaethon’s perihelion activity?
The dust trail is embedded in instrument noise, so photometrically challenging to isolate.

Using a number of methods we determine a visual magnitude of $15.8 \pm 0.3$ per pixel. This equates to a surface brightness of $25.0 \text{ mag arcsec}^{-2}$

- SOHO/LASCO has a limiting surface brightness of $17.2 \text{ mag arcsec}^{-2}$
- STEREO/HI1 has a limiting surface brightness of $22.3 \text{ mag arcsec}^{-2}$
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Using the surface brightness, we can make some assumptions about the dust to estimate the total mass of dust in the orbit.

Assuming:
• Trail is 14 WISPR pixels wide (~110,000km) along entire (~6 au) orbit
• Average grain radius 0.5mm (likely far too low, but that’s ok)
• Dust albedo ~0.1066 (i.e. grains are ”mini-Phaethons”)
• …and a couple of other things...

We find the mass of dust to be \((0.4 - 1.3) \times 10^{12}\) kg.

Various studies place the mass of the Geminid stream at \(10^{12} - 10^{15}\) kg
→ Our dust mass estimate is at the low end of this range

Phaethon produces \(~10^8\) kg dust per orbit at perihelion
→ Our dust mass estimate is far larger than this.
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- Why has (e.g.) SOHO or STEREO/HI-1 never seen the trail?
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WISPR is more sensitive than SOHO and STEREO.

Q2: **What** are we seeing?
- Are we seeing the Geminids (formed ~2kyr ago)?
- Are we seeing dust released by Phaethon’s perihelion activity?

We either *somewhat underestimate* the mass of the Geminids, or *massively overestimate* dust production at perihelion.
→ We are seeing some portion of the Geminid stream
Since the 1970’s, a number of studies of Geminids have calculated individual orbits for observed meteors.

Geminids do not follow Phaethon’s orbit (or Phaethon would intersect with Earth... which would be bad).

These streams diverge significantly at aphelion (~0.2au) but compress near perihelion (~0.0006au).
Why haven’t ground observers or Hubble seen the trail, despite many dedicated efforts? E.G. Jewitt (2018) observed with limiting magnitude of 27.8 mag arcsec$^{-2}$ -- much deeper than WISPR’s 25.0 mag arcsec$^{-2}$

Key factors affecting trail visibility from Earth/Hubble:

1. **Heliocentric distance**: trail get fainter as you move further from it
2. **Orbital spreading**: individual Geminid streams diverge as they move away from perihelion (trail gets fainter)
3. **Velocity clustering**: dust in orbit moves slower near aphelion and "clusters" together (trail is brighter)
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Key factors affecting trail visibility from Earth/Hubble:

1. **Heliocentric distance**: trail get **fainter** as you move further from it
2. **Orbital spreading**: individual Geminid streams diverge as they move away from perihelion (trail gets **fainter**)
3. **Velocity clustering**: dust in orbit moves slower near aphelion and ”clusters” together (trail is **brighter**)

Correcting WISPR’s 25.0 mag arcsec$^{-2}$ for these yields:

<table>
<thead>
<tr>
<th>[units of mag arcsec$^{-2}$]</th>
<th>At 1 au</th>
<th>At 2.4 au</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heliocentric distance correction</td>
<td>+4.1</td>
<td>+6.0</td>
</tr>
<tr>
<td>Orbital spreading</td>
<td>+3.0</td>
<td>+3.8</td>
</tr>
<tr>
<td>Orbital velocity (clustering)</td>
<td>−1.3</td>
<td>−3.1</td>
</tr>
<tr>
<td>Net Effect</td>
<td>+5.8</td>
<td>+6.7</td>
</tr>
<tr>
<td>Estimated trail brightness</td>
<td>30.8</td>
<td>31.7</td>
</tr>
</tbody>
</table>
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- Why has (e.g.) SOHO or STEREO/HI-1 never seen the trail?
- Why did recent dedicated Hubble and ground-based surveys fail to find the trail?

**WISPR is more sensitive than SOHO and STEREO.**

**Trail near Earth is far too dispersed for almost any existing ground-based facility to detect.**

**Q2: What are we seeing?**
- Are we seeing the Geminids (formed ~2 kyr ago)?
- Are we seeing dust released by Phaethon’s perihelion activity?

We either *somewhat underestimate* the mass of the Geminids, or *massively overestimate* dust production at perihelion.

⇒ We are seeing some portion of the Geminid stream.
WISPR made the **first white-light detection** of a dust trail in the orbit of near-Sun “active” asteroid 3200 Phaethon.

We find a trail surface brightness of **25.0 mag arcsec**⁻², and an estimated mass of ~**10^{12} kg**.

We conclude that must be observing **some portion of the Geminid stream** (as opposed to recent Phaethon activity).

We demonstrate why this trail had yet to be detected in dedicated surveys – a consequence of a ~**31 mag arcsec**⁻² surface brightness in accessible sky regions.

This discovery is of **high relevance to the JAXA DESTINY+ mission**, launching 2022 on a 4yr mission to study Phaethon and its dust environment.
Parker Solar Probe (PSP)
- NASA Heliophysics mission, launched 2018
- Makes successively close encounters to the Sun in 24 orbits, with the help of 7 Venus flybys
- Next perihelion (#4) Jan 29, 2020 (0.129 au)
- Final (proposed) perihelion, mid-2024 (0.06 au)

Wide-field Imager for Parker Solar Probe (WISPR)
- Only imaging instrument on PSP
- Pair of overlapping, broadband, white-light Heliospheric imagers
- Inner camera (WISPR-I) – 13.5°-53° fov (elongation); \(1.2 \text{ arcmin/px}\)
- Outer camera (WISPR-O) – 50° – 108° fov (elongation); \(1.7 \text{ arcmin/pix}\)
- Observations only recorded during each ~12-day encounter