STEREO-WAVES (S/WAVES) Dust Detections and Their Apparent Association with Known Spacecraft Anomalies

False dawn, *gegenshein*, and the rest of the zodiacal band of light, visually crossed by the *Milky Way*. [Credit: ESO/P. Horálek via Wikipedia]

27 March 2024

STEREO-WAVES (S/WAVES) Dust Detections and Their Apparent Association with Known Spacecraft Anomalies

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Team

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[4] Independent Consultant
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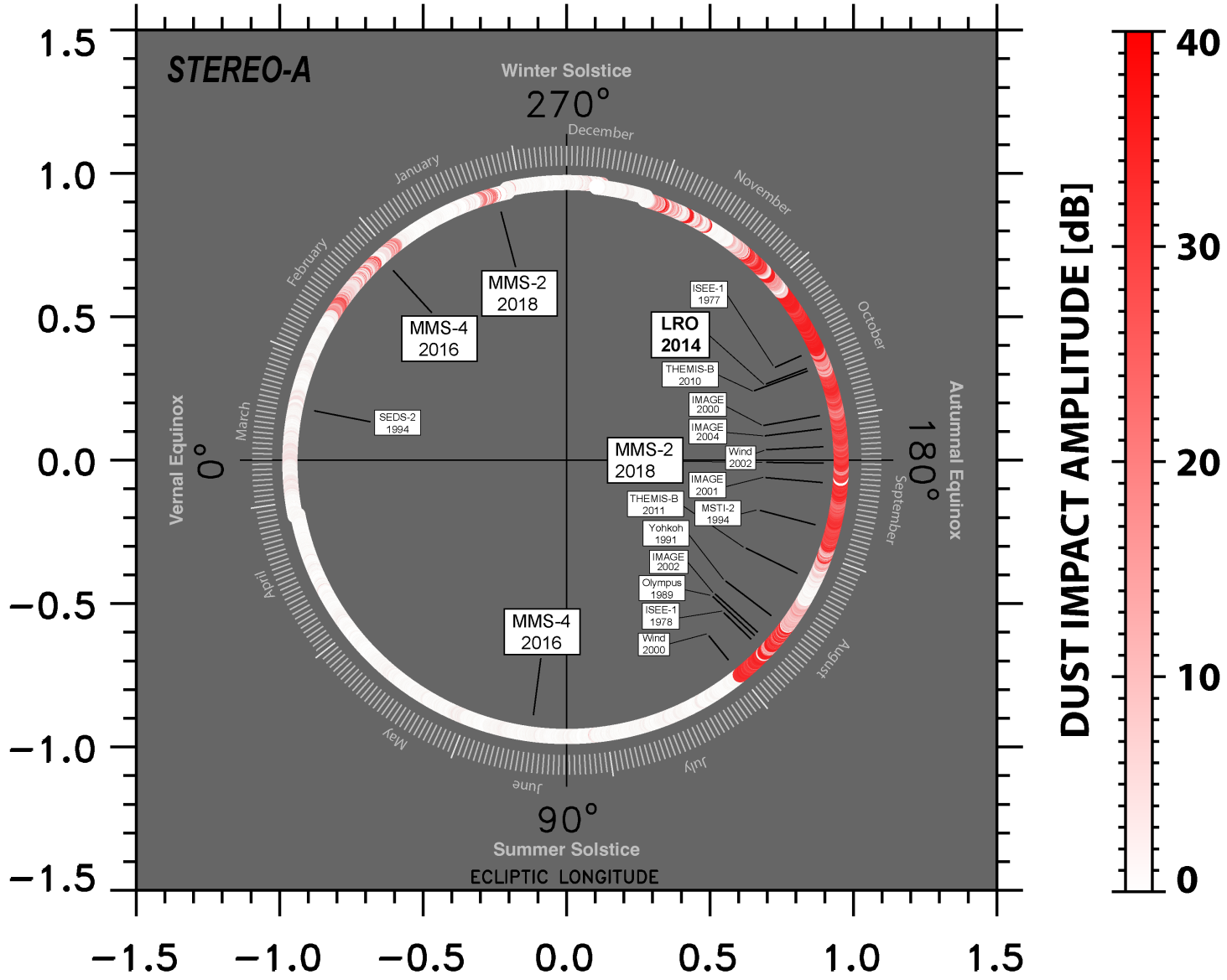
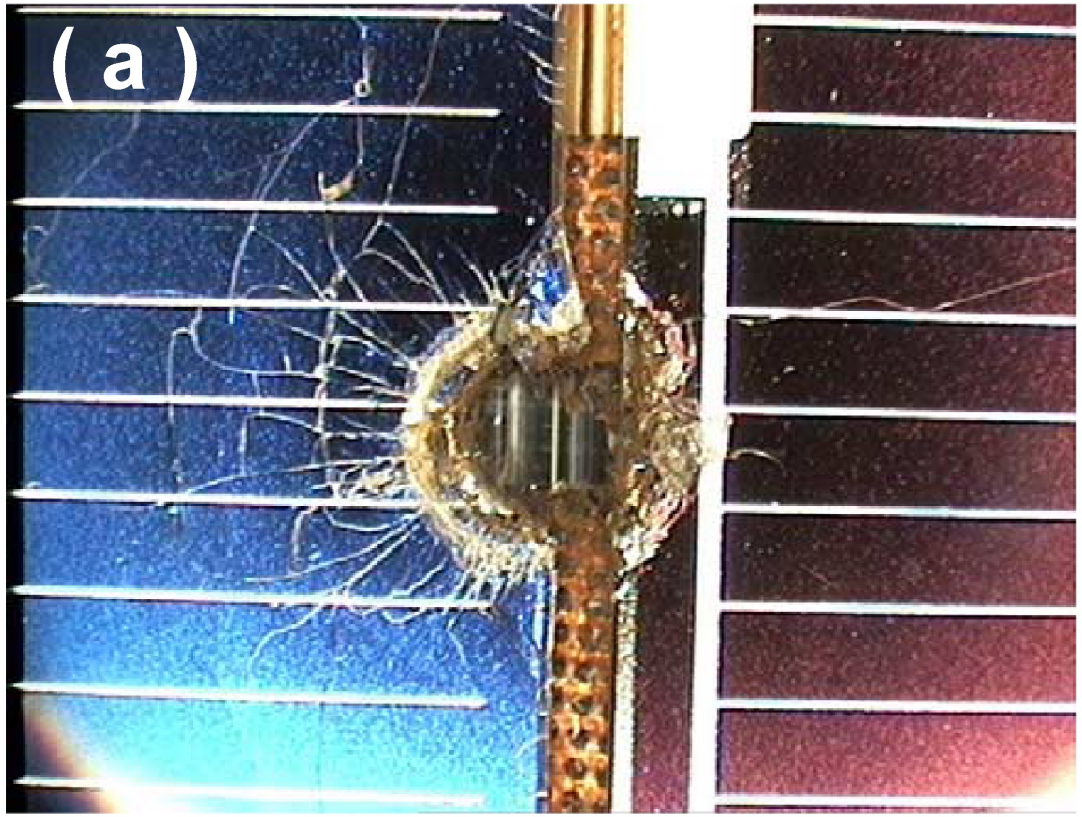
The Takeaways are….

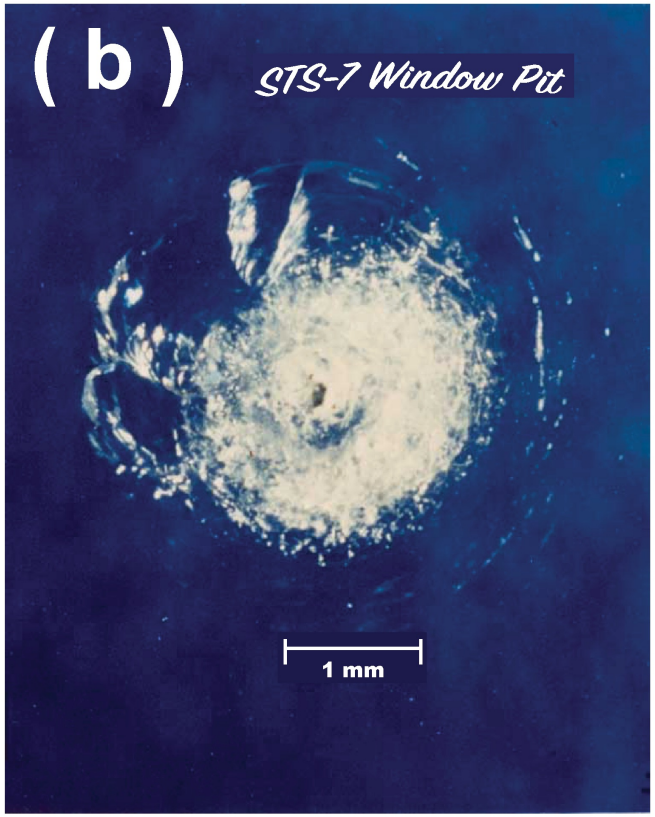


- ***A survey of hourly maximum S/WAVES Time Domain Sampler (TDS) amplitude in decibels (dB) is used as an indicator/proxy of inferred dust impacts on the STEREO spacecraft.***
- ***S/WAVES TDS amplitudes reveals a unique distribution of dust clouds at 1-AU [Kaiser et al., 2007; St. Cyr et al., 2009].***
- ***A majority of historically known spacecraft anomalies or failures attributed to micrometeoroid impact appear spatially associated with S/WAVES dust detections.***
- ***Unique distribution naturally leads to a question of sources.***

The Danger of Hypervelocity Impact….

"The retrieved solar array wings exhibit thousands of craters, many of which are visible to the naked eye." [*Moussi et al.*, 2005]





Note that through the first 60-STS missions flown over 14- years, the outer windows of the Shuttle fleet experienced 177 impact features due to on-orbit encounters with space debris/micrometeorites (~3 impacts per flight). Of these features, 45 impacts resulted in damage requiring window replacement [*Edelstein,* 1995].

(a) A large front-to-back penetration (clear hole diameter: 1-mm; maximum damage: 6.5-mm) of the ***HST*** solar array [*Moussi et al.*, 2005; doi: 10.1016/j.asr.2005.03.060]. **(b)** A non- critical impact crater on one of the windows for ***Space Shuttle Challenger*** following a collision with a micrometeoroid during STS-7 in 1983 [Credit: *NASA*].

S/WAVES Dust Detections (~1μm)

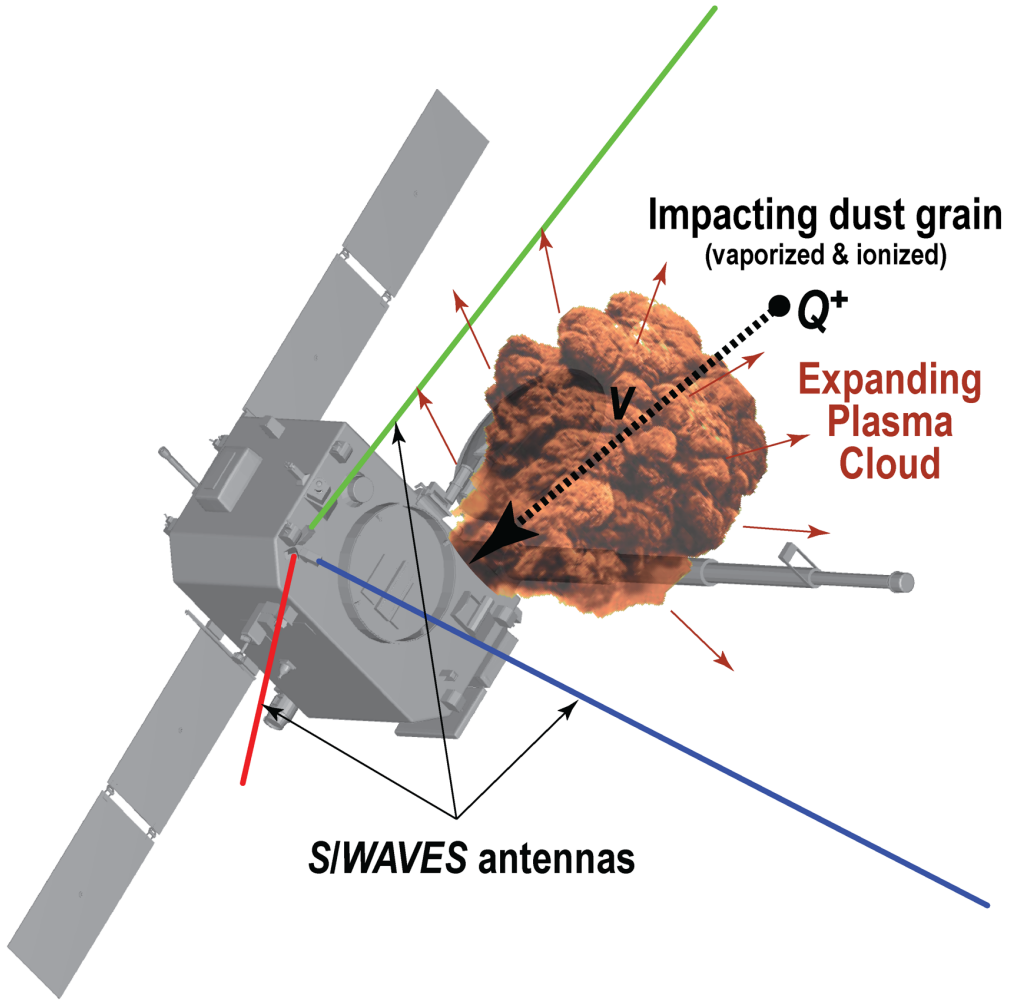


Figure 1(a). Plasma cloud model used to explain electric antenna detection of an impulsive voltage signal produced as a result of a dust grain impacting a spacecraft.

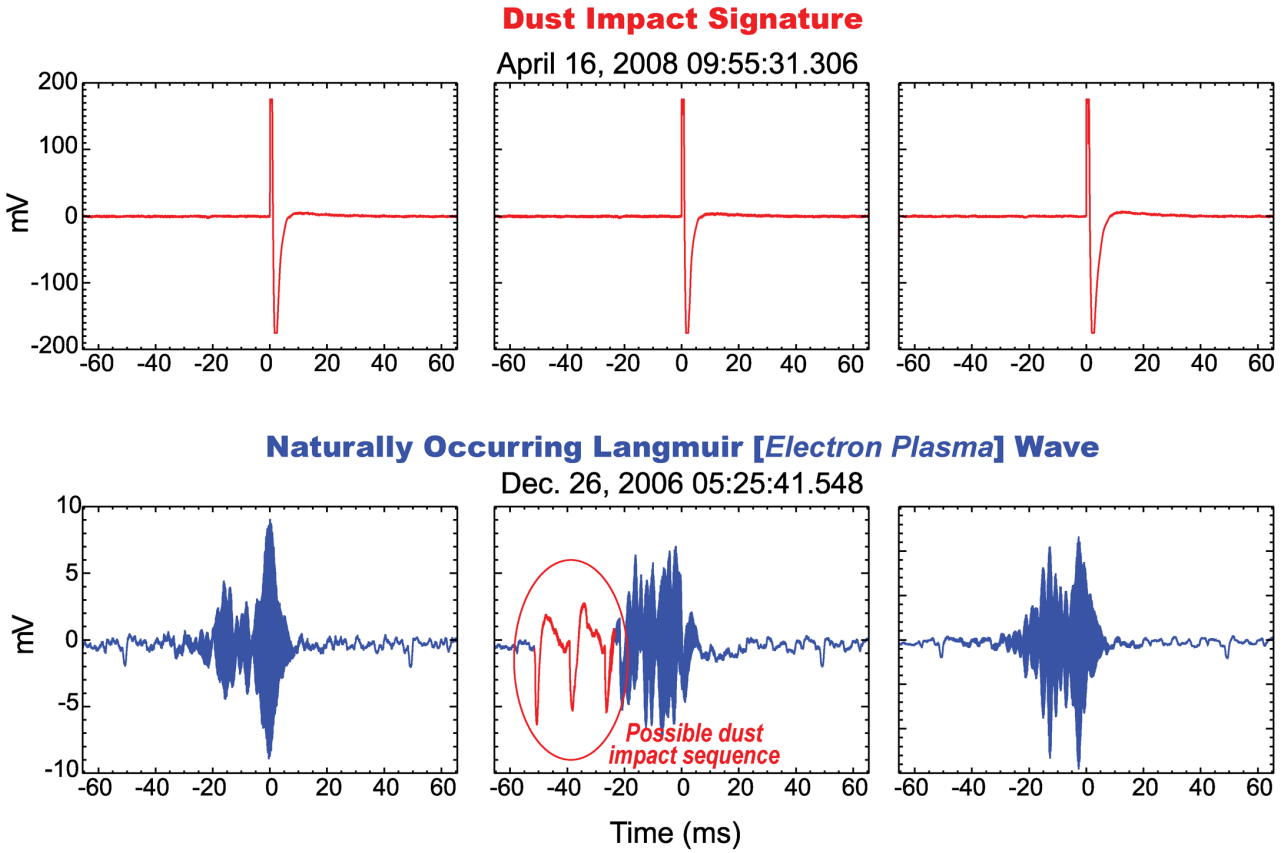


Figure 1(b). Examples of an impulse-like events recorded by all three electric antennas connected to the S/WAVES TDS instrument on the Ahead spacecraft. [Adapted from *St. Cyr et al.*, 2009]

S/WAVES Dust Detections (~10nm)

Solar Phys (2009) 256: 463–474
DOI 10.1007/s11207-009-9349-2

Dust Detection by the Wave Instrument on STEREO: Nanoparticles Picked up by the Solar Wind?

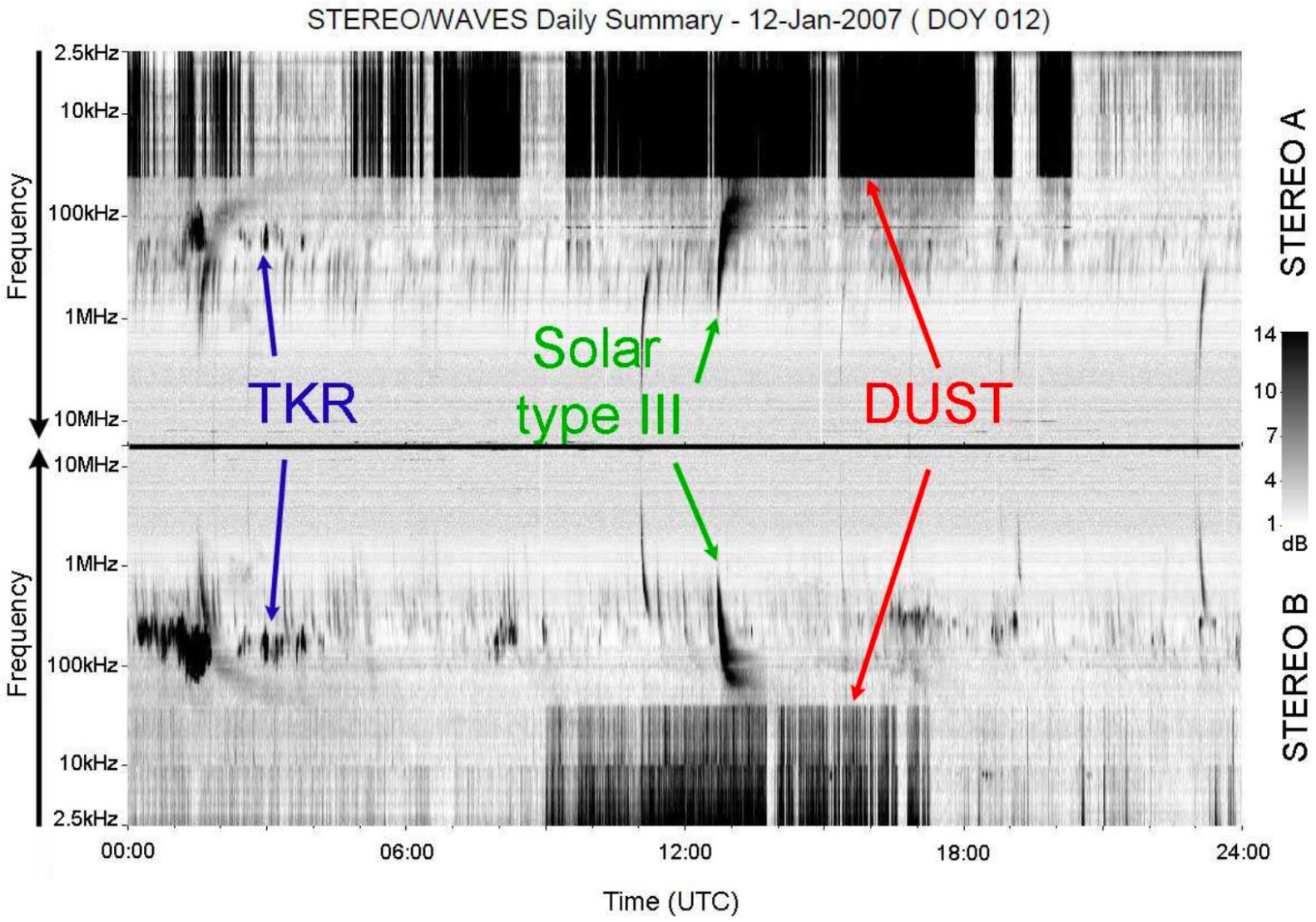
N. Meyer-Vernet · M. Maksimovic · A. Czechowski · I. Mann · I. Zouganelis · K. Goetz · M.L. Kaiser · O.C. St. Cyr · J.-L. Bougeret · S.D. Bale

Received: 28 November 2008 / Accepted: 31 March 2009 / Published online: 11 April 2009

Abstract The STEREO wave instrument (S/WAVES) has detected a very large number of intense voltage pulses. We suggest that these events are produced by impact ionisation of nanoparticles striking the spacecraft at a velocity of the order of magnitude of the solar wind speed. Nanoparticles, which are half-way between micron-sized dust and atomic ions, have such a large charge-to-mass ratio that the electric field induced by the solar wind magnetic field accelerates them very efficiently. Since the voltage produced by dust impacts increases very fast with speed, such nanoparticles produce signals as high as do much larger grains of smaller speeds. The flux of 10-nm radius grains inferred in this way is compatible with the interplanetary dust flux model. The present results may represent the first detection of fast nanoparticles in interplanetary space near Earth orbit.

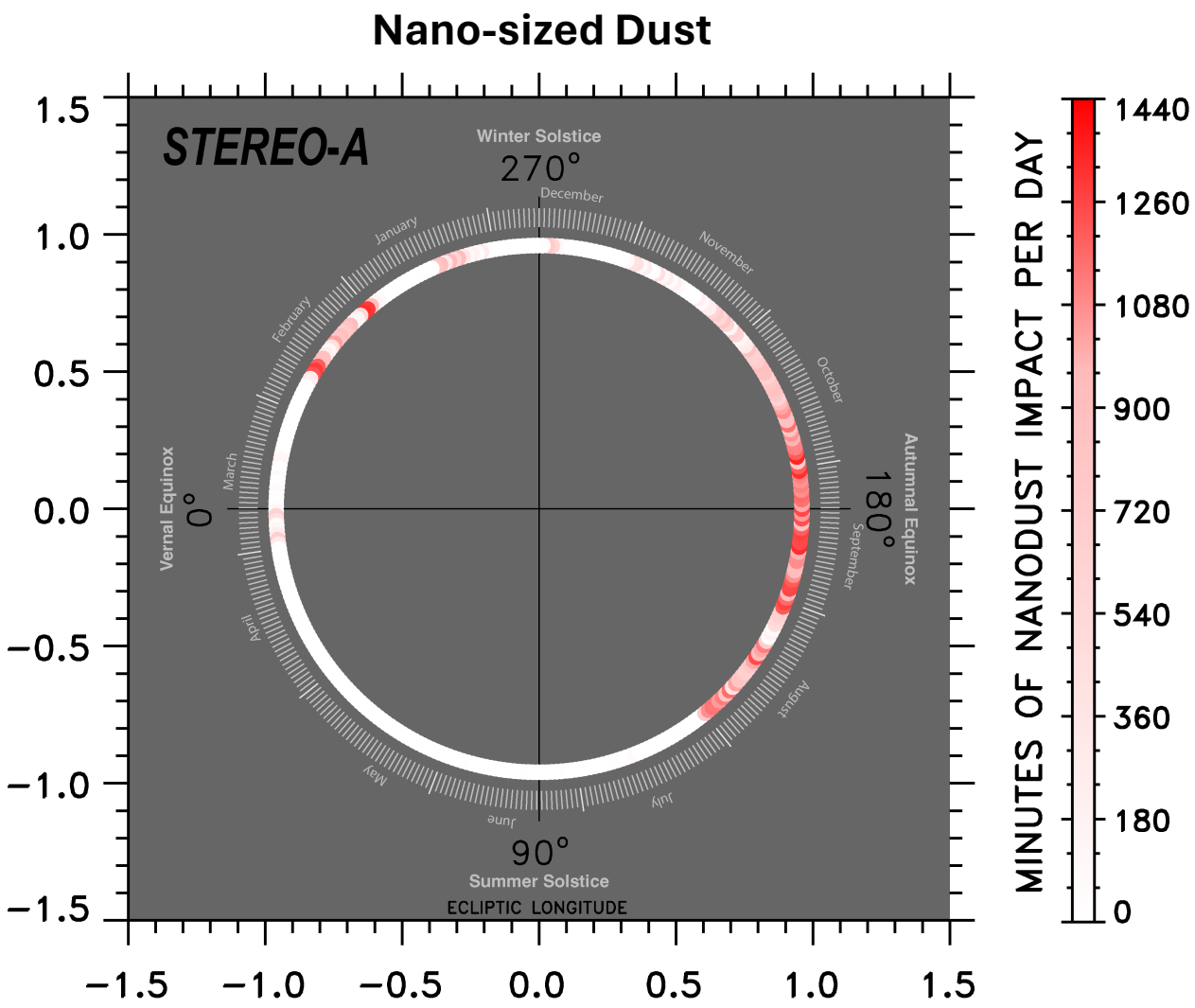
Keywords Plasma physics · Solar wind · Waves, plasma

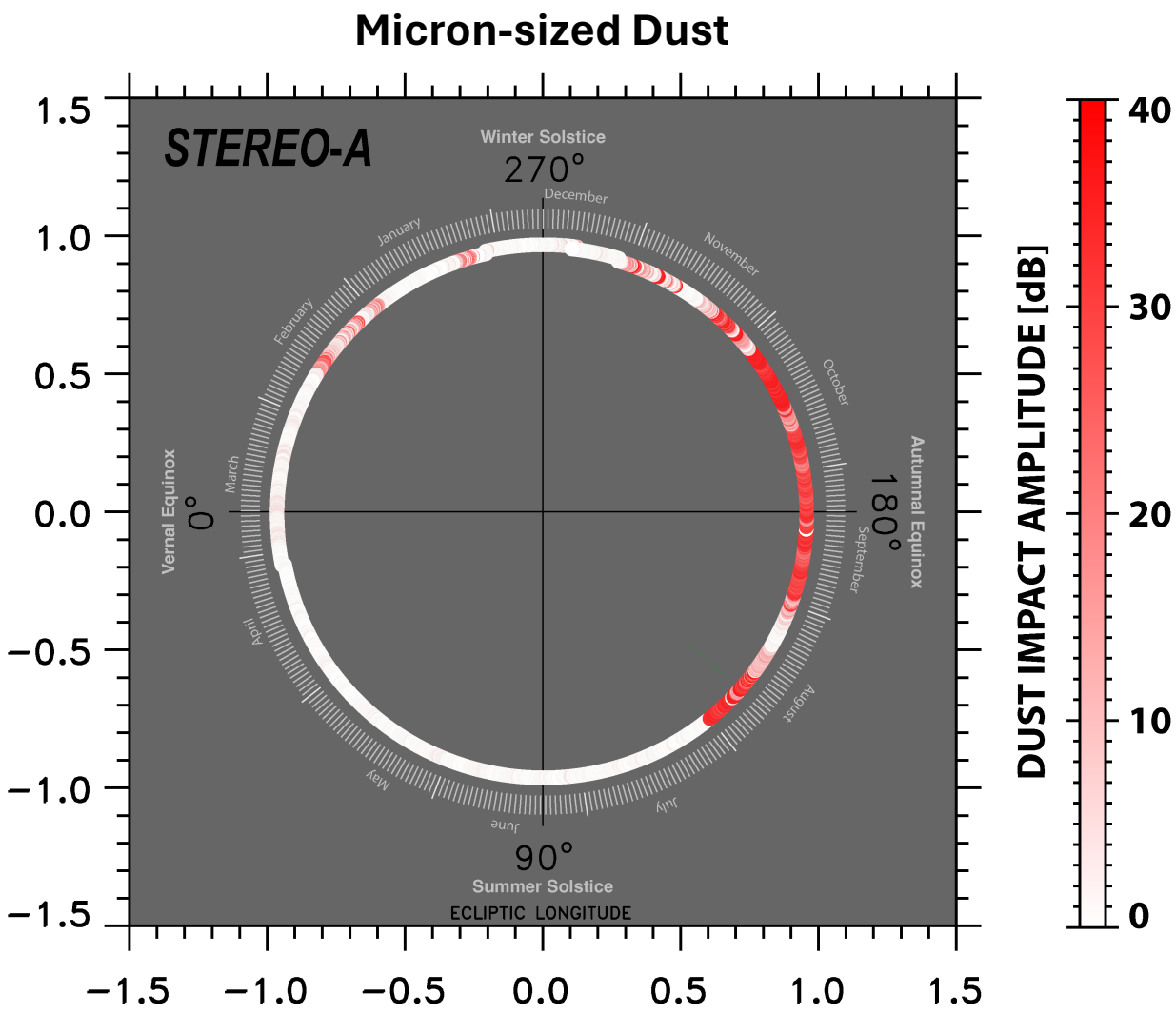
Springer



Spectrally, virtually identical to the sound of rain hitting the ground/your windshield....

S/WAVES Dust Detections: 1st Orbit





Known Anomalies/Failures

- *Historical record of spacecraft anomalies/failures attributed to micrometeoroid impact.* [*Koons et al., 1999*]
- *Update with list of contemporary spacecraft anomalies.*
- *19 total events; 13 high-altitude.*

➢ *Does NOT include JWST.*

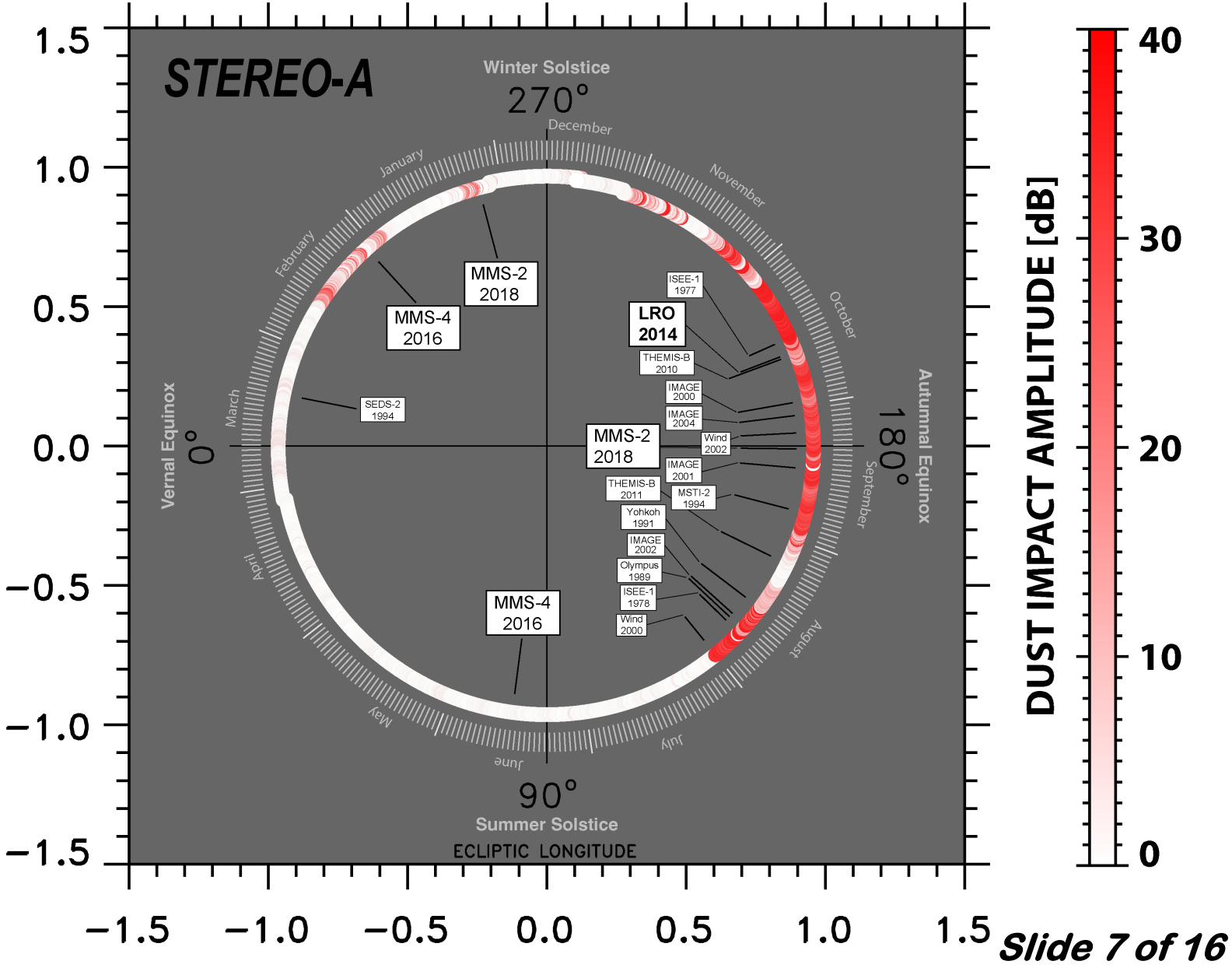
Mission	Anomaly Date	Anomaly Time (UTC)	Geocentric Solar Ecliptic (GSE) in R_E			
			X	Y	Z	*R*
ISEE-1	10/15/1977	12:00:00‡	NO DATA	NO DATA	NO DATA	NO DATA
ISEE-1	08/07/1978	00:00:00†	9.12	17.97	5.53	20.89
Yohkoh	08/15/1991	12:00:00‡	NO DATA	NO DATA	NO DATA	1.10
Olympus	08/12/1989	12:00:00‡	NO DATA	NO DATA	NO DATA	5.67
SEDS-2	03/13/1994	12:00:00‡	NO DATA	NO DATA	NO DATA	1.05
MSTI-2	09/06/1994	12:00:00‡	NO DATA	NO DATA	NO DATA	1.07
Wind	08/01/2000	12:00:00‡	2.99	–49.82	–4.40	50.11
	09/20/2002	23:48:00†	56.65	5.66	3.58	57.04
IMAGE	10/03/2000	14:37:00	–1.72	–2.73	6.38	7.15
	09/18/2001	07:52:00	–0.22	–3.01	6.74	7.39
	08/09/2002	13:24:00¶	4.73	3.52	5.65	8.17
	09/30/2004	13:21:00	4.41	1.13	–0.25	4.56
THEMIS-B	10/12/2010	06:04:56	1.93	68.35	0.17	68.38
	08/27/2011	21:27:00	56.40	–2.16	–4.80	56.65
MMS	02/03/2016	15:21:00	0.30	–7.65	–0.71	7.69
	06/14/2016	06:00:00	–11.59	0.44	–1.14	11.65
	01/06/2018	01:51:22	20.43	6.21	6.62	22.35
	09/21/2018	06:04:45	–11.49	19.57	7.73	23.98
LRO	10/13/2014	21:19:02	–22.43	–57.30	–5.46	61.77

LEO	Proximate GEO	High Altitude

† No historical record of anomaly time exists. Assumed maximum radial distance.
‡ No historical record of anomaly time exists.
¶ No historical record of anomaly time exists. Assumed apogee.

Dust–Anomaly Spatial Associations

- ***Spacecraft anomalies and/or failures overlaid upon S/WAVES distribution of detected ~1μm-sized dust.***
- ***SEDS-2 (March 1994) and MMS-4 (June 2016)* appear to be outliers.**

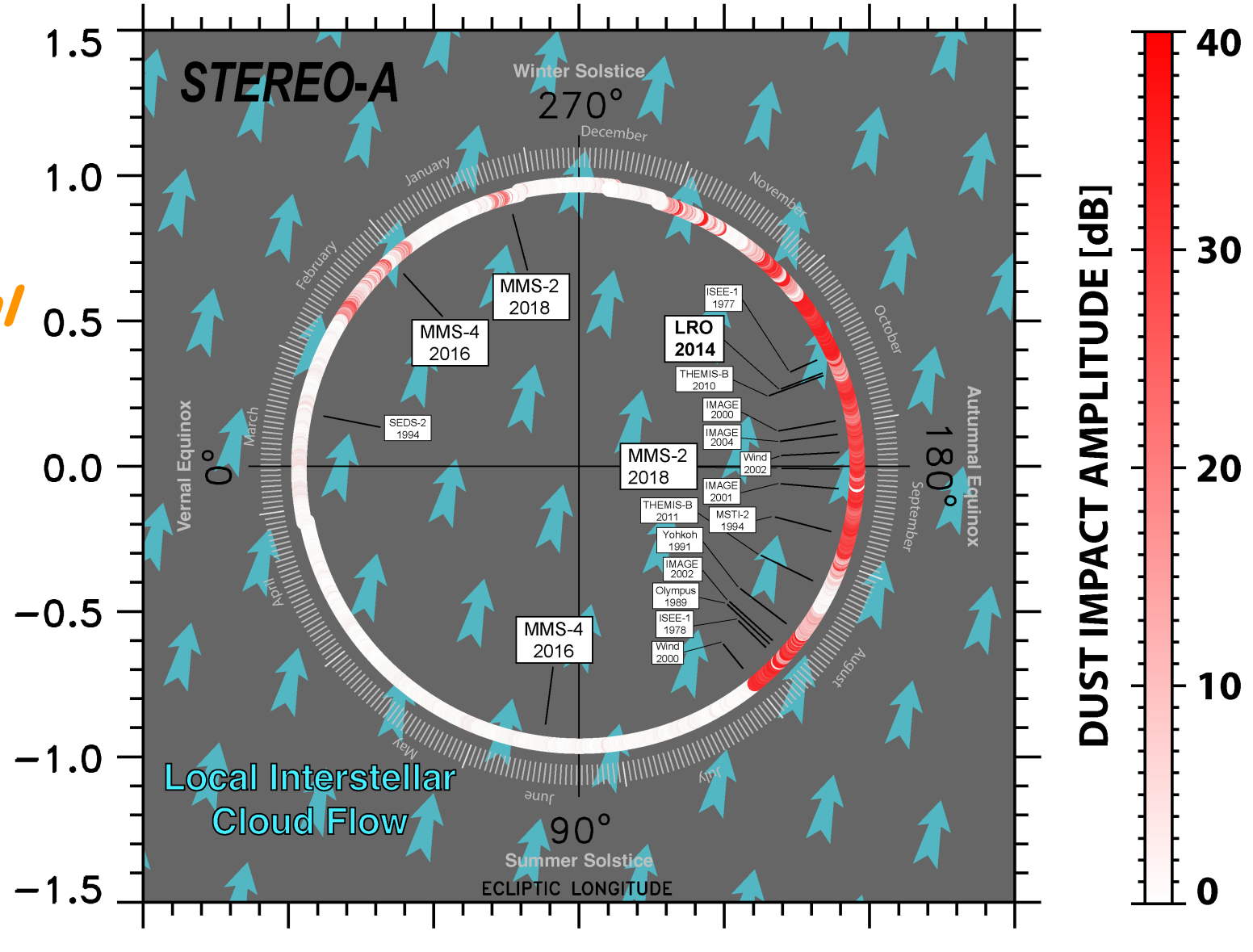


Possible Sources… Interstellar Dust

- ***What's the relationship between S/WAVES dust distribution and the local interstellar cloud flow*** **[*Frisch*, 2000; *Collier et al.*, 2004].**

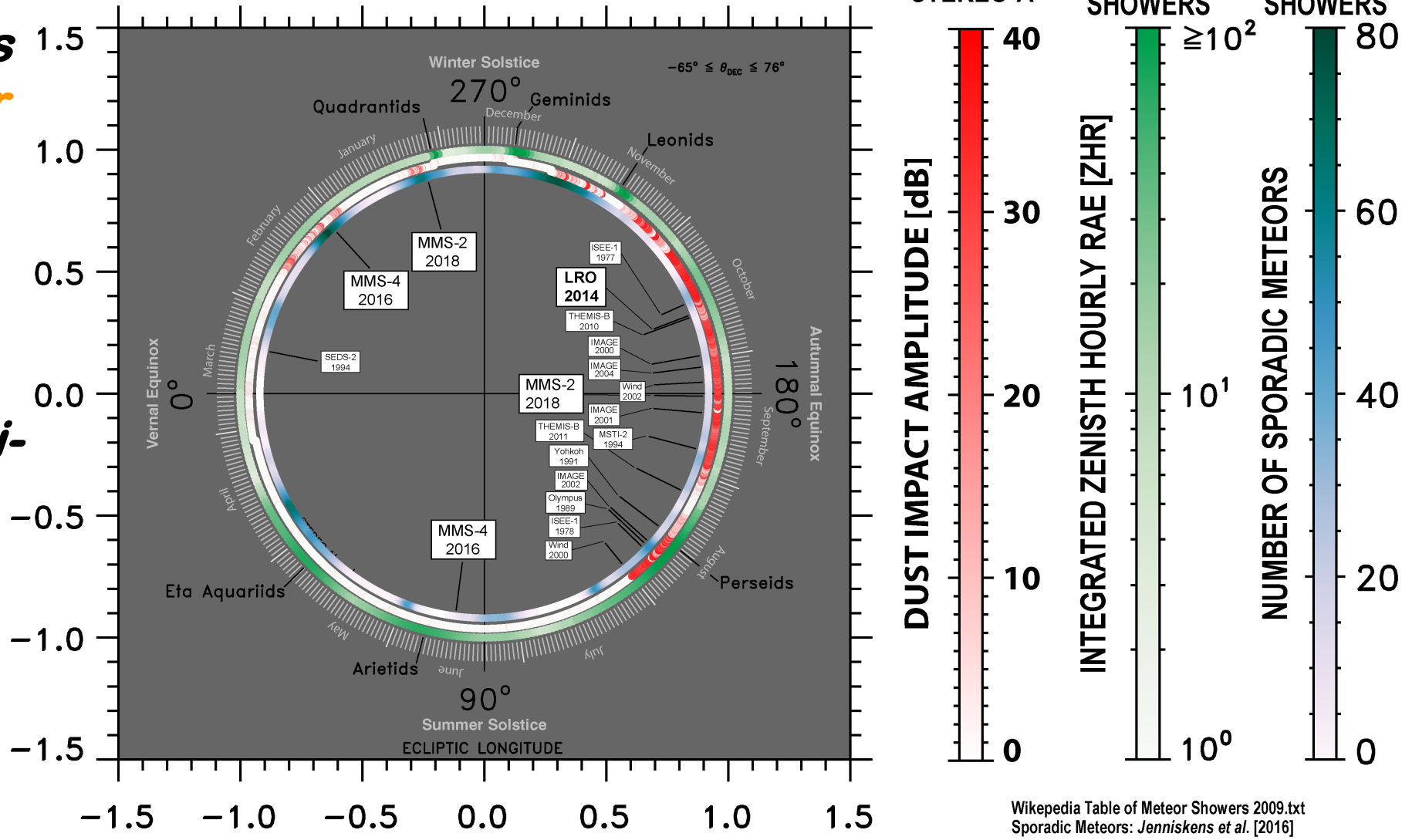
"…the Earth passes upstream of the Sun in the main neutral gas flow in early June of every year, about June 5 (day 156)."

- ***Apparently…*** 🤔



Possible Sources… Cometary Debris

- ***S/WAVES detections compared to meteor showers.***
- ***Periods of possible spatial association (i.e., Perseids).***
- ***Periods of clear anti-association (i.e., Leonids, Geminids, η-Aquariids).***
- ***This is ~12% of 966 IAU Working List of Meteor Showers.***

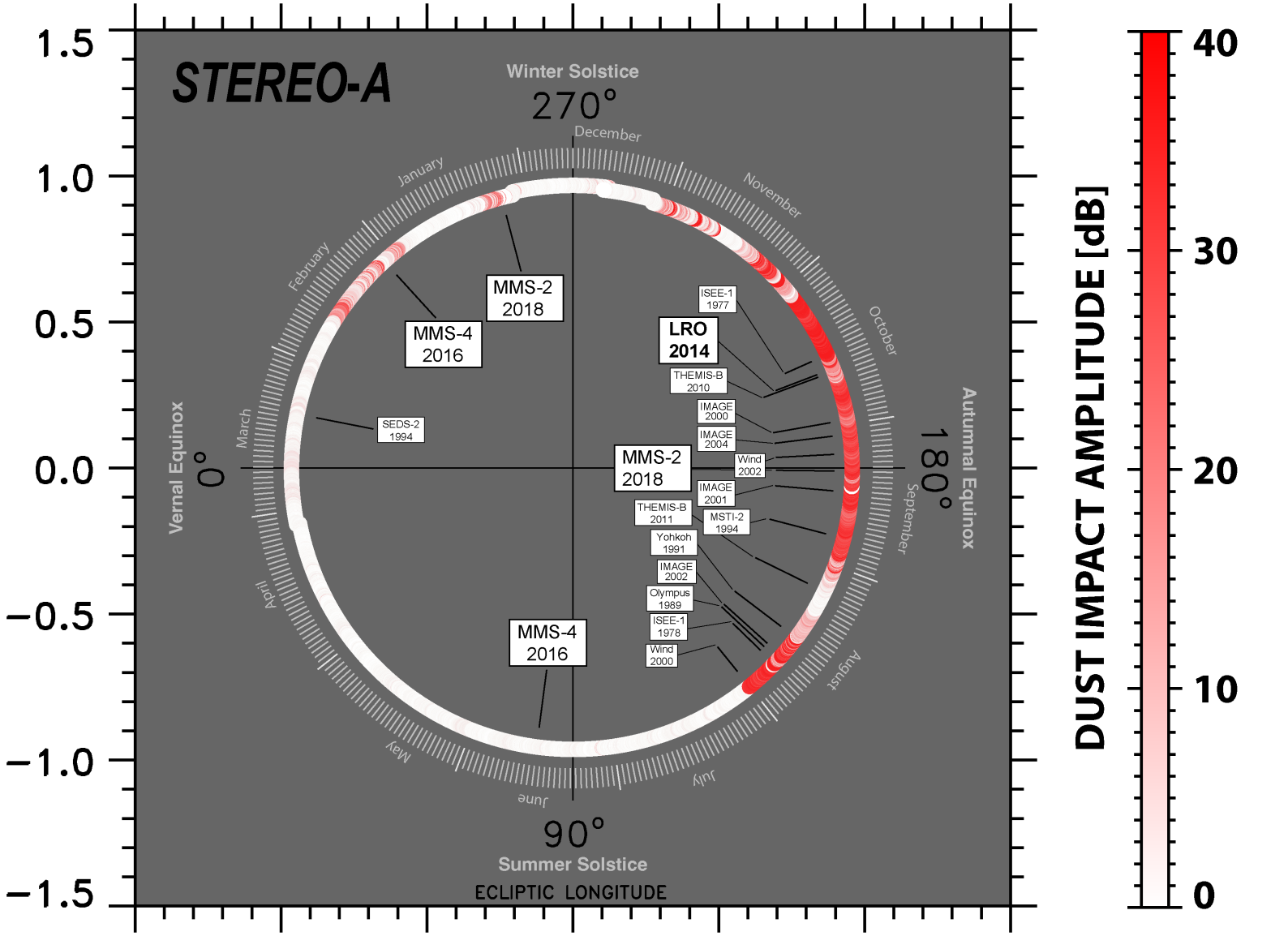


Wikepedia Table of Meteor Showers 2009.txt
Sporadic Meteors: *Jenniskens et al.* [2016]

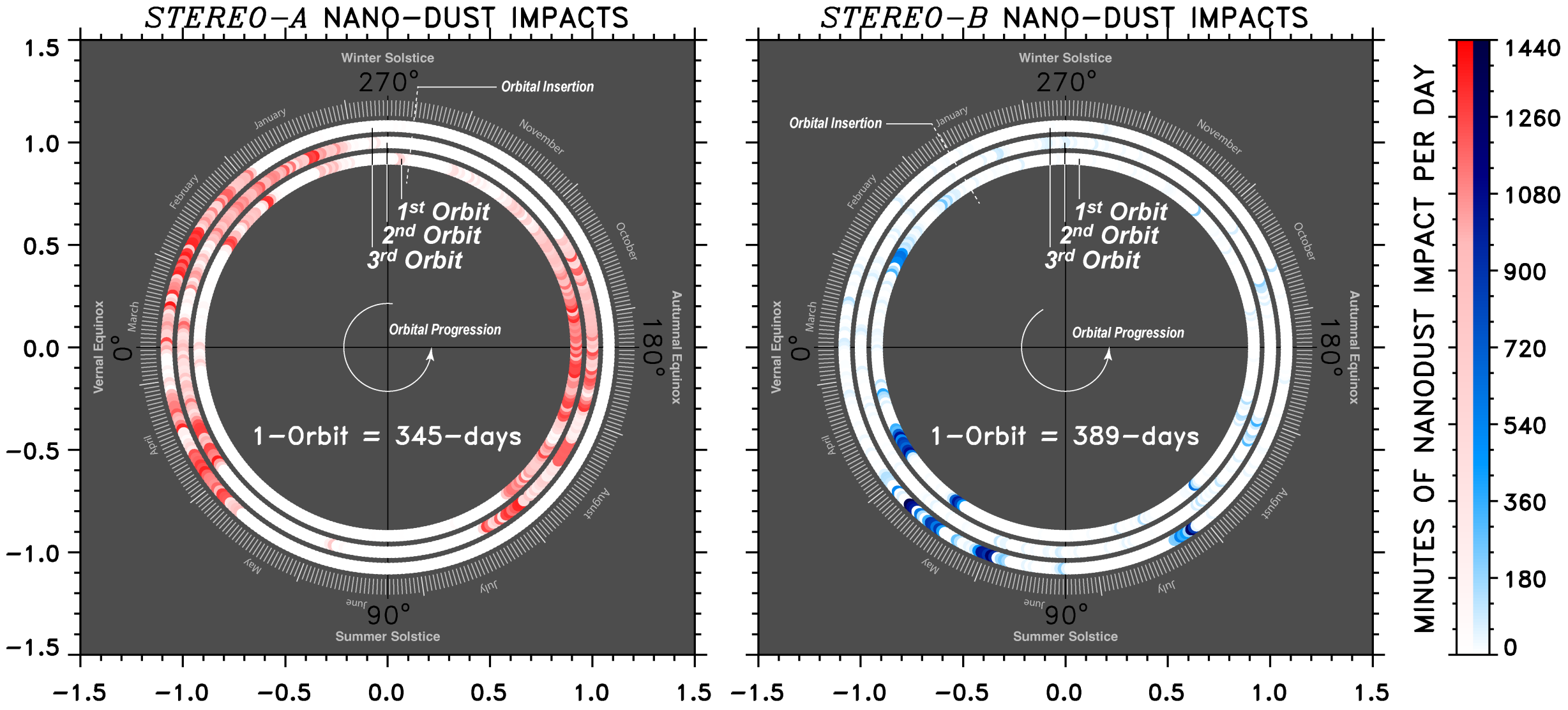
Dust–Anomaly Spatial Associations

Now… the apparent association between the S/WAVES observed distribution of dust and ~41-years of known spacecraft anomalies-failures might lead one to conclude that there's some period of temporal stability…

🤔



A Question of Temporal Stability …



Is Gravitational-Resonance… Playing a Role…??

1994 ARTICLES

A circumsolar ring of asteroidal dust in resonant lock with the Earth

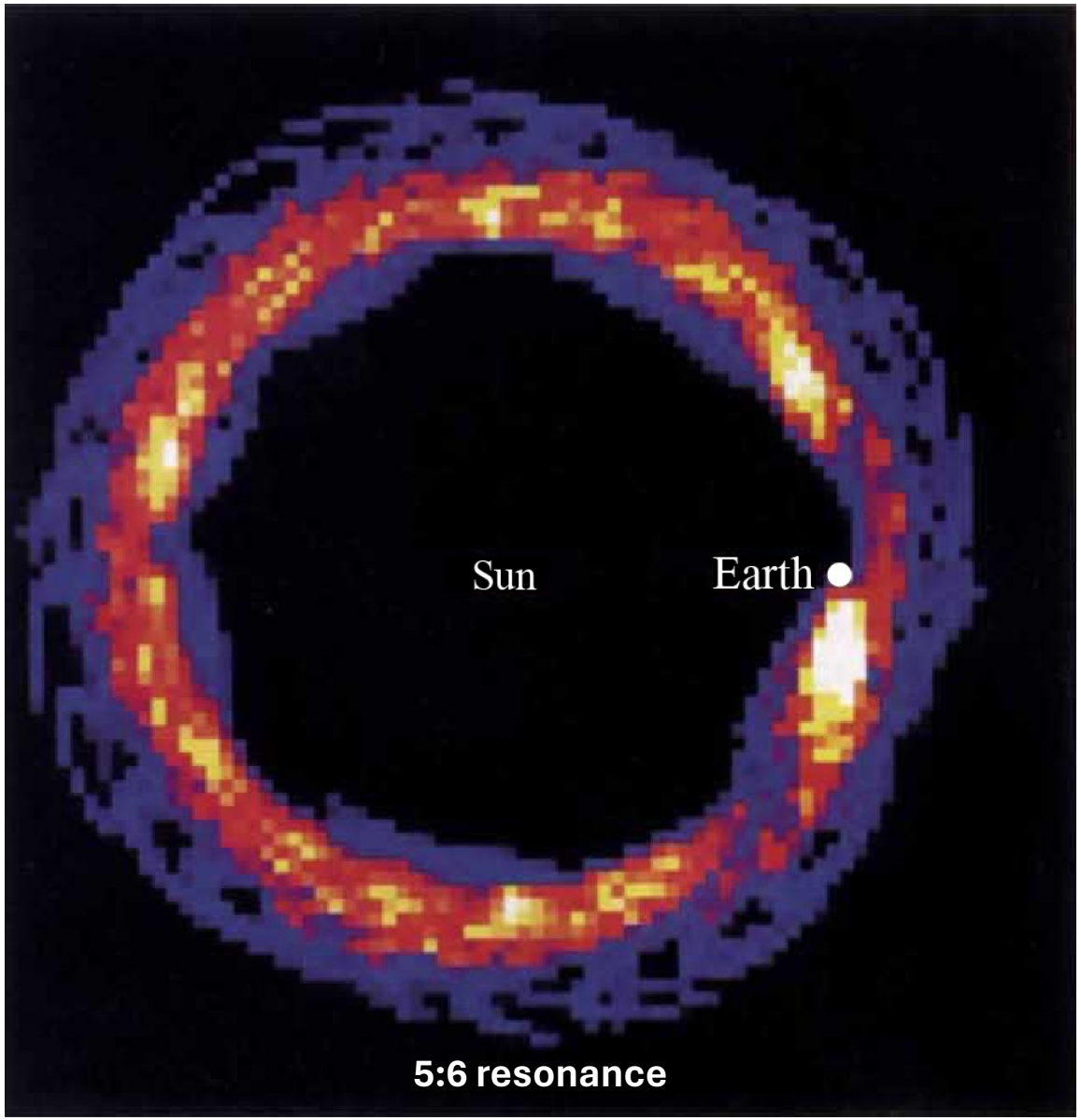
Stanley F. Dermott, Sumita Jayaraman, Y. L. Xu, B. Å. S. Gustafson & J. C. Liou

Department of Astronomy, PO Box 112055, University of Florida, Gainesville, Florida 32611-2055, USA

Numerical simulations of the orbital evolution of asteroidal dust particles show that the Earth is embedded in a circumsolar ring of asteroidal dust, and has a cloud of dust permanently in its wake. This could account for the asymmetry of the zodiacal cloud observed by the Infrared Astronomical Satellite (IRAS). The resonant trapping and subsequent release of dust particles by the ring may provide a mechanism by which carbonaceous material is transported from the asteroid belt to the Earth.

- ***Earth-Sun gravitational field.***
- ***Poynting-Robertson $\beta \sim 0.1$.***
- ***Weak solar wind interaction.***

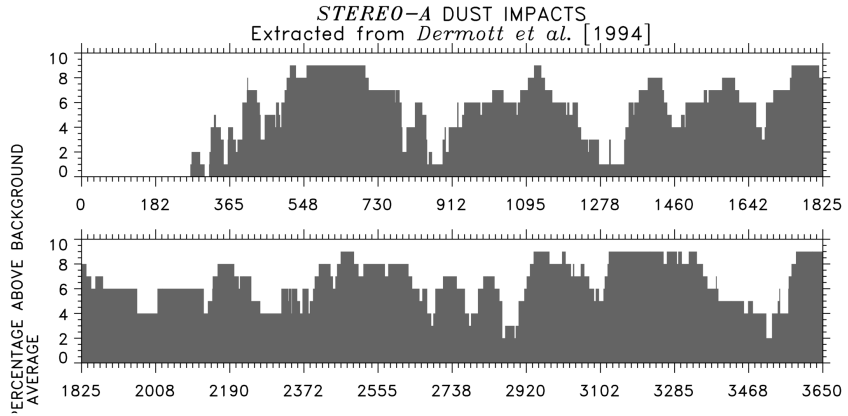
➢ ***Results in a circumsolar, corotating ring distribution.***

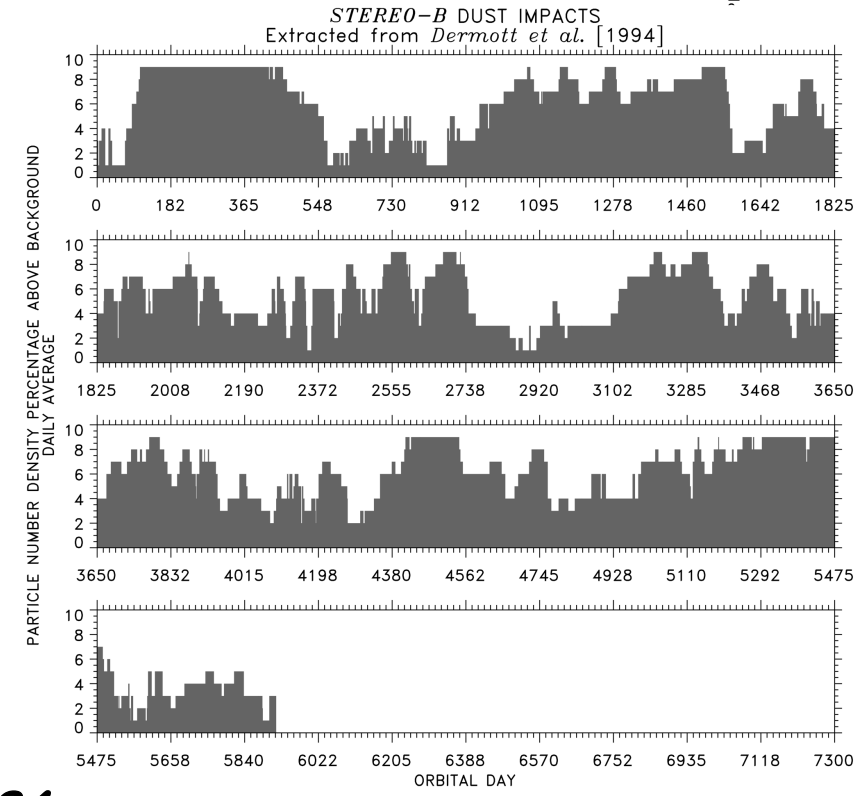


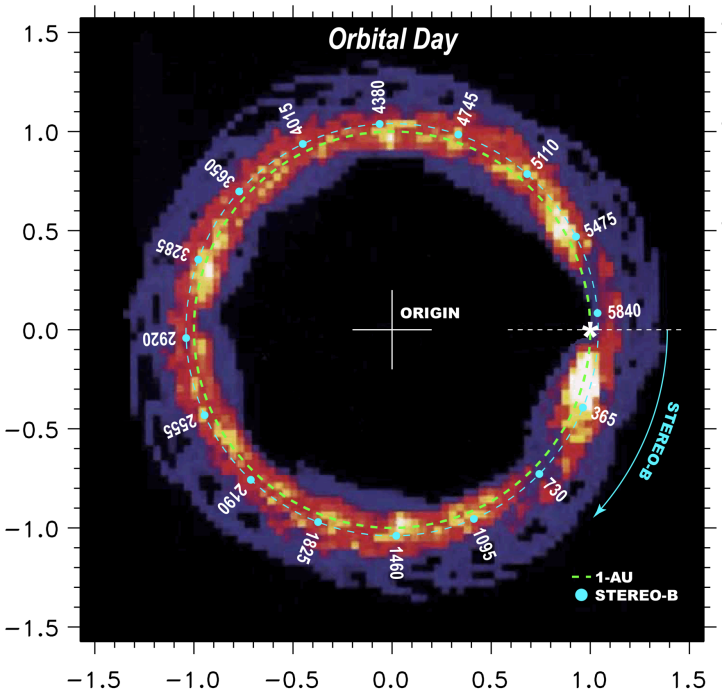
5:6 resonance

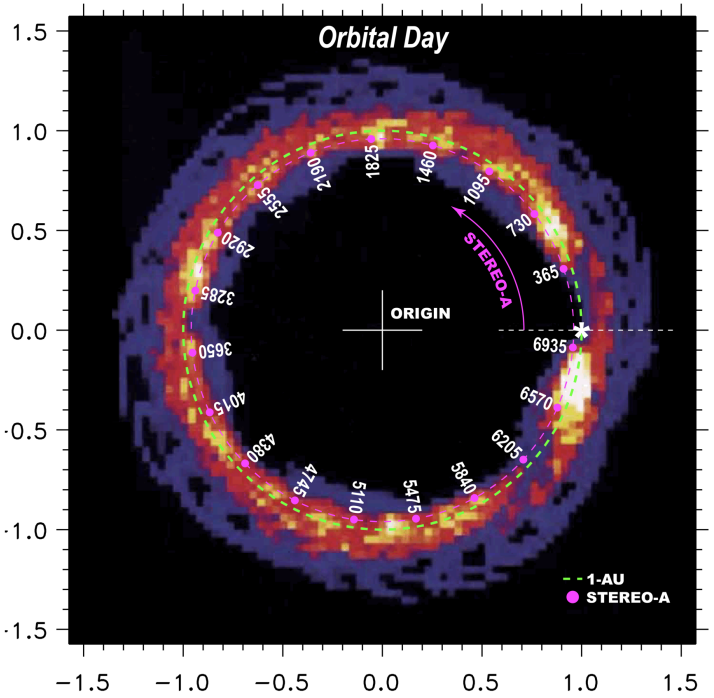
The Flight of Virtual STEREOs…

Time-series predictions of virtual STEREO-A & -B through the simulated, corotating distribution of Dermott et al. [1994].





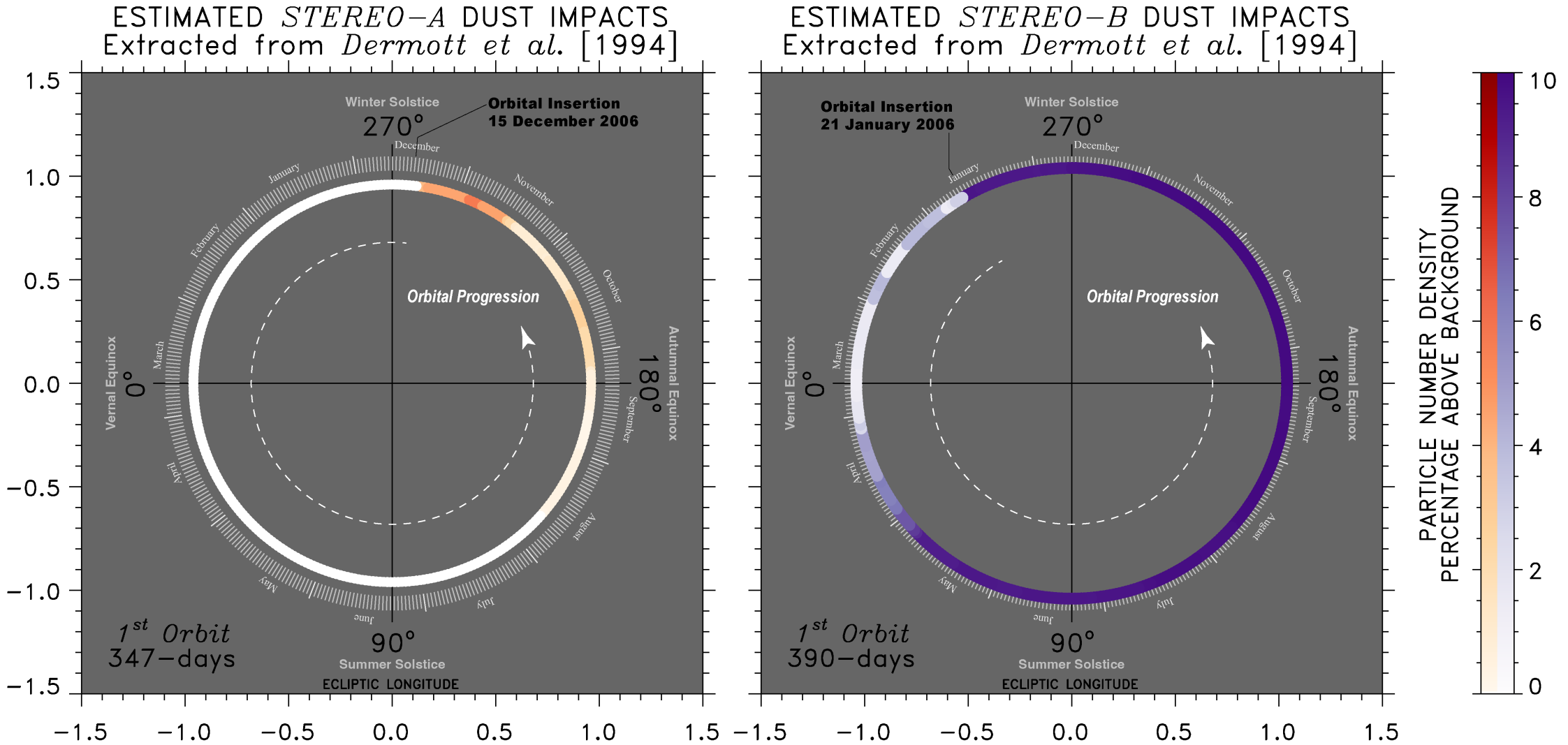




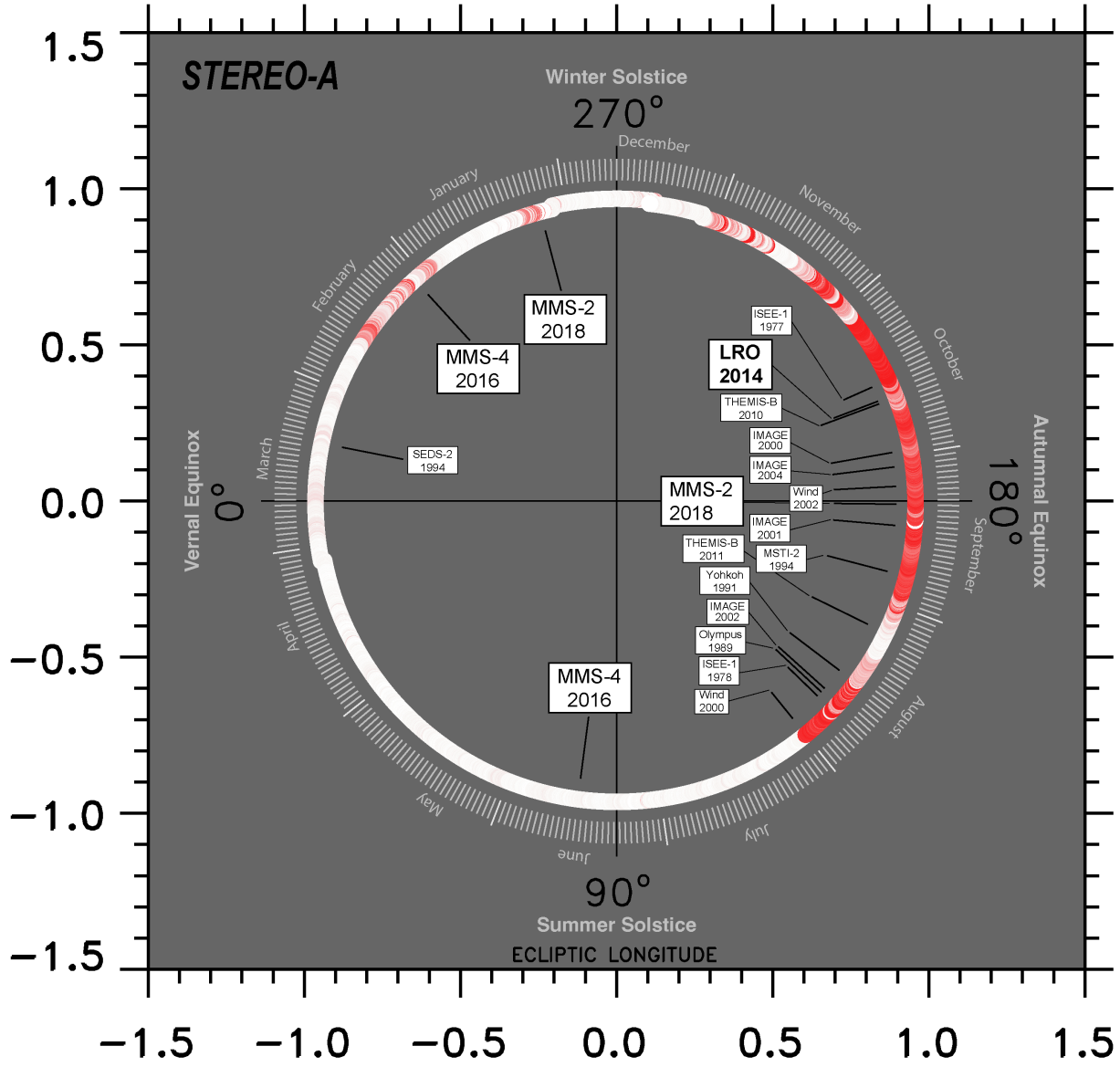
Each S/WAVES experiences a different, unique environment… orbit-to-orbit.

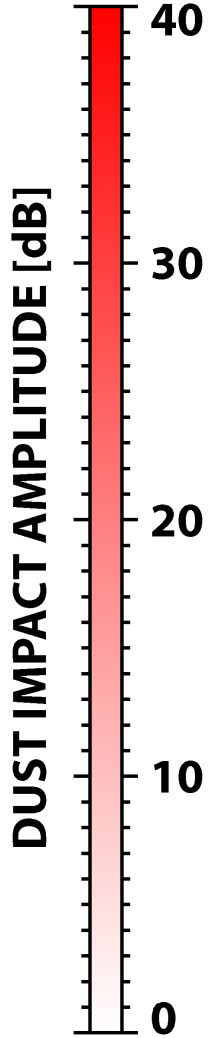
The Flight of Virtual STEREOs...

Virtual 1st Orbit Detections



The Takeaways are….

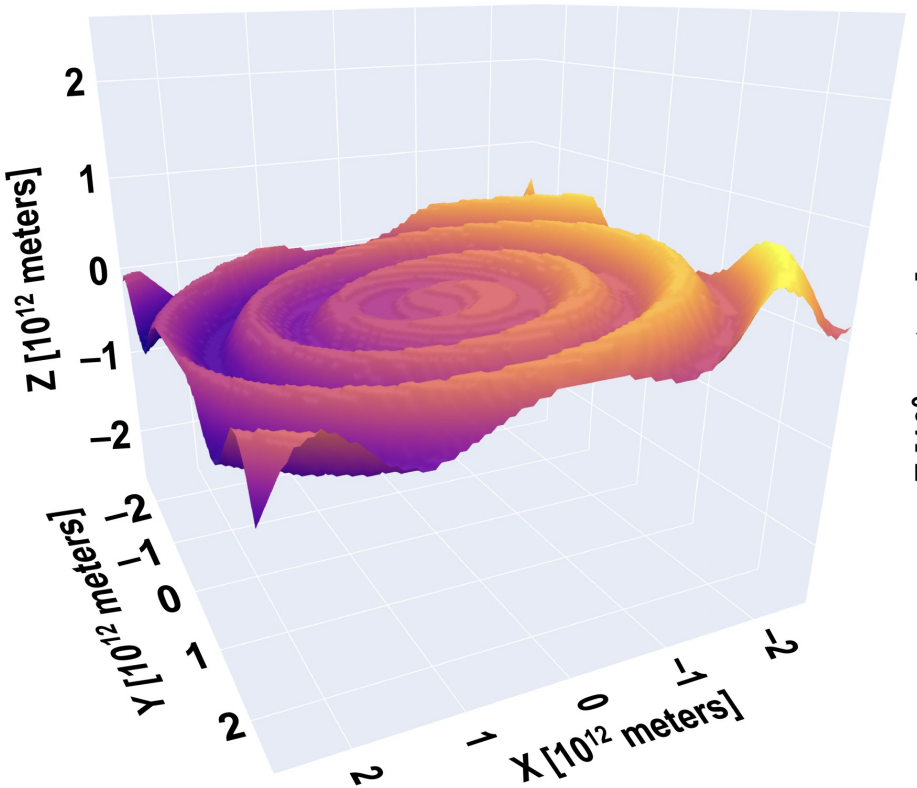


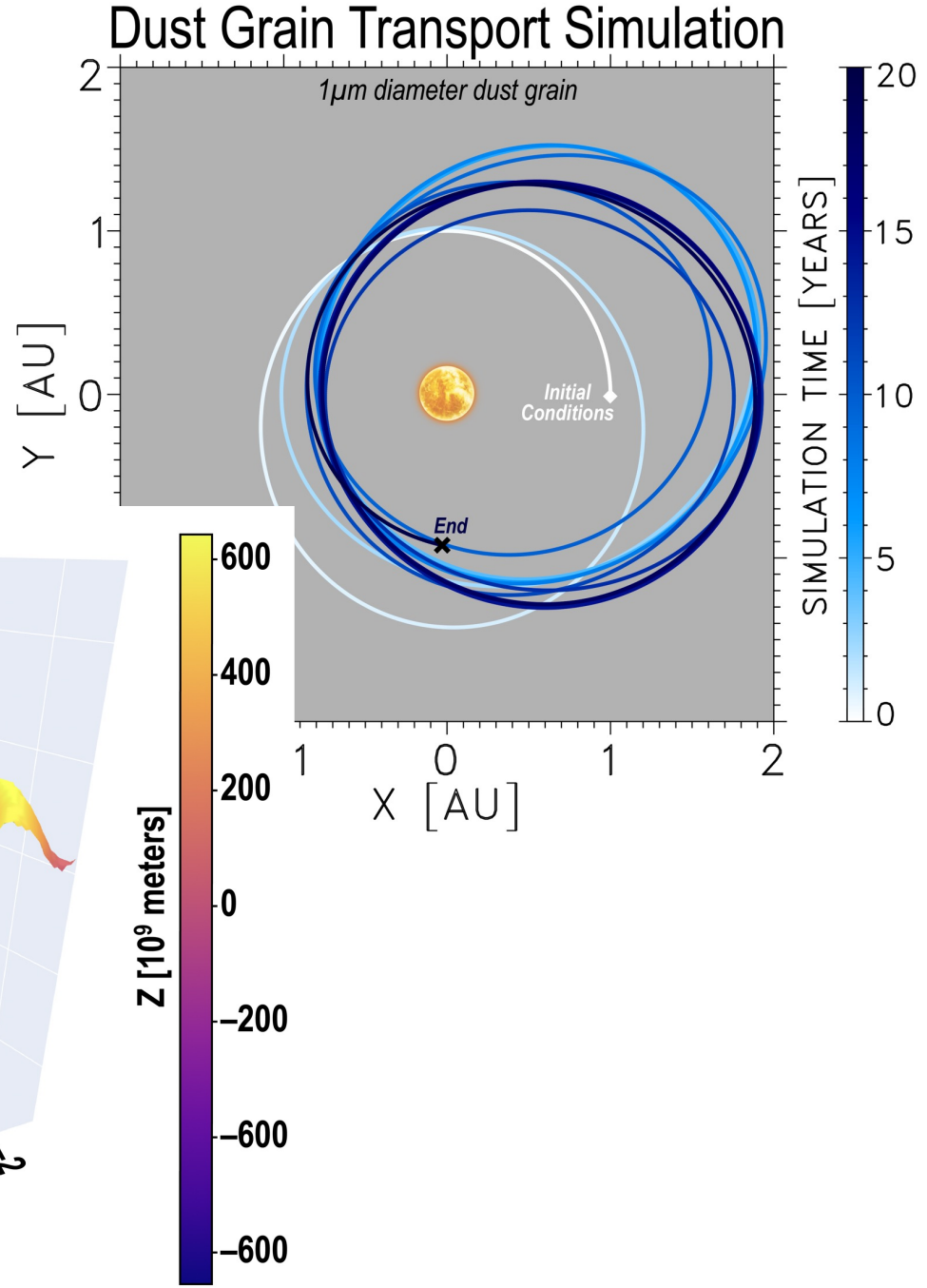


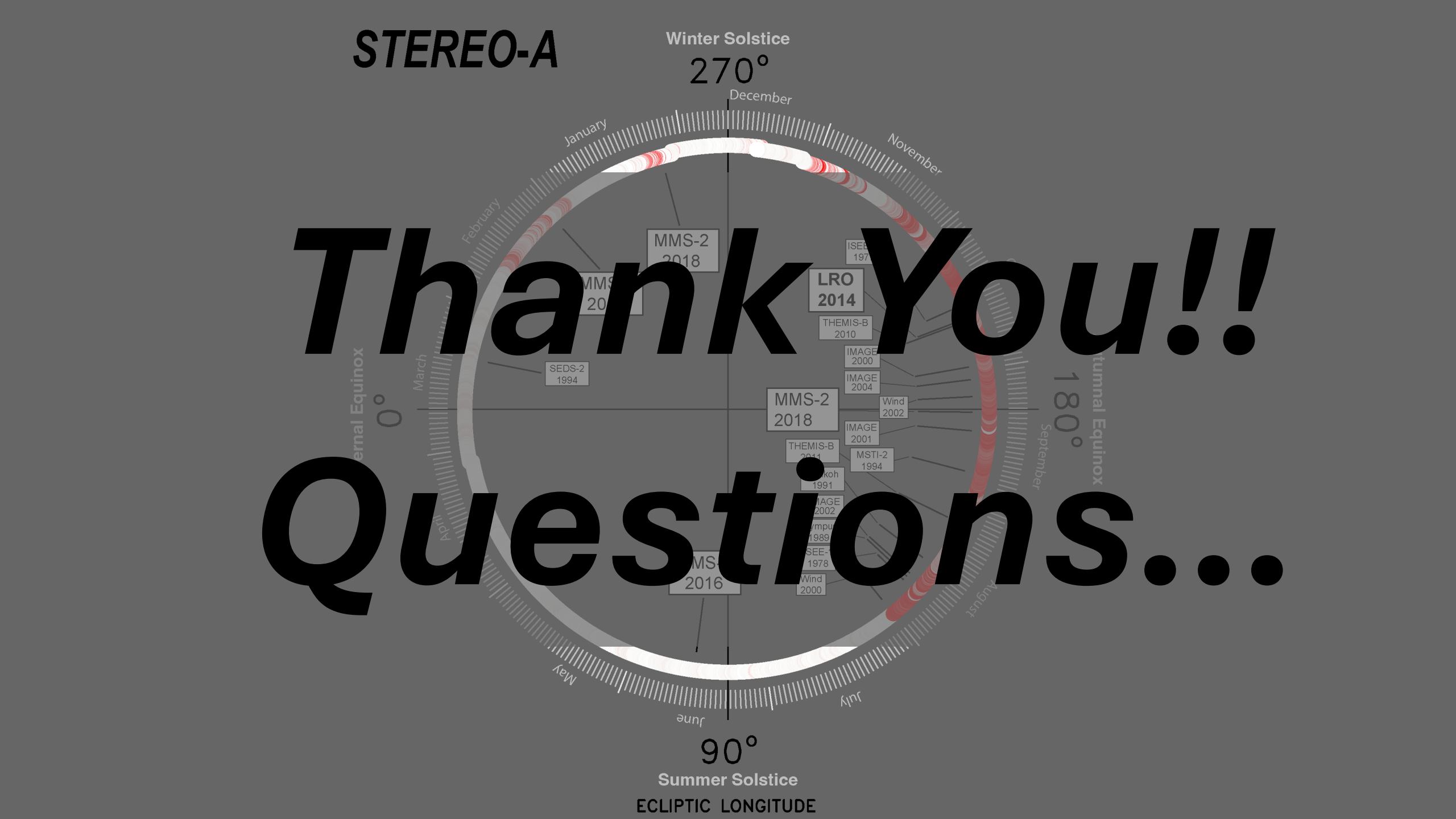
- ***S/WAVES TDS amplitudes reveals a unique distribution of dust clouds at 1-AU [Kaiser et al., 2007; St. Cyr et al., 2009].***
- ***A majority of historically known spacecraft anomalies or failures attributed to micrometeoroid impact appear spatially associated with S/WAVES dust detections (STEREO-A 1st Orbit).***
- ***Evidence of temporal variability??***
- ***Or evidence of the influence of gravitational resonance effects??***

Dust in Our Future….

- *Continued analysis of S/WAVES data for successive years.*
- *Analysis of MMS accelerometer detections of dust impact.*
- *Analysis of Wind-WAVES dust catalog prior to arrival at L1.*
- *Explore the impact of CME passage on dust distribution.*
- *Development of fully E&M model of dust transport under influence of solar dipole and solar wind.*
- *Develop a dedicated mission concept to map dust from cis-Venusian through cis-Martian space.*






STEREO-A
Winter Solstice
270°
December
January
November
February
March
April
May
June
July
August
September
0°
180°
90°
Summer Solstice
ECLIPTIC LONGITUDE
MMS-2
2018
LRO
2014
THEMIS-B
2010
IMAGE
2000
IMAGE
2004
SEDS-2
1994
Wind
2002
IMAGE
2001
MSTI-2
1994
MMS-2
2018
MMS
2016
Wind
2000
Thank You!!
Questions...

Back-Ups

Dust Grain Topology…

NOTE: ***It is highly unlikely that dust grains are spherical.***

Icarus **157**, 349–361 (2002)
doi:10.1006/icar.2002.6849

Radiation Pressure and the Poynting–Robertson Effect for Fluffy Dust Particles

Hiroshi Kimura

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Hajime Okamoto

, Graduate School of Sciences, Tohoku University, Sendai 980-8578, Japan

and

Tadashi Mukai

d Technology, Kobe University, Nada, Kobe 657-8501, Japan

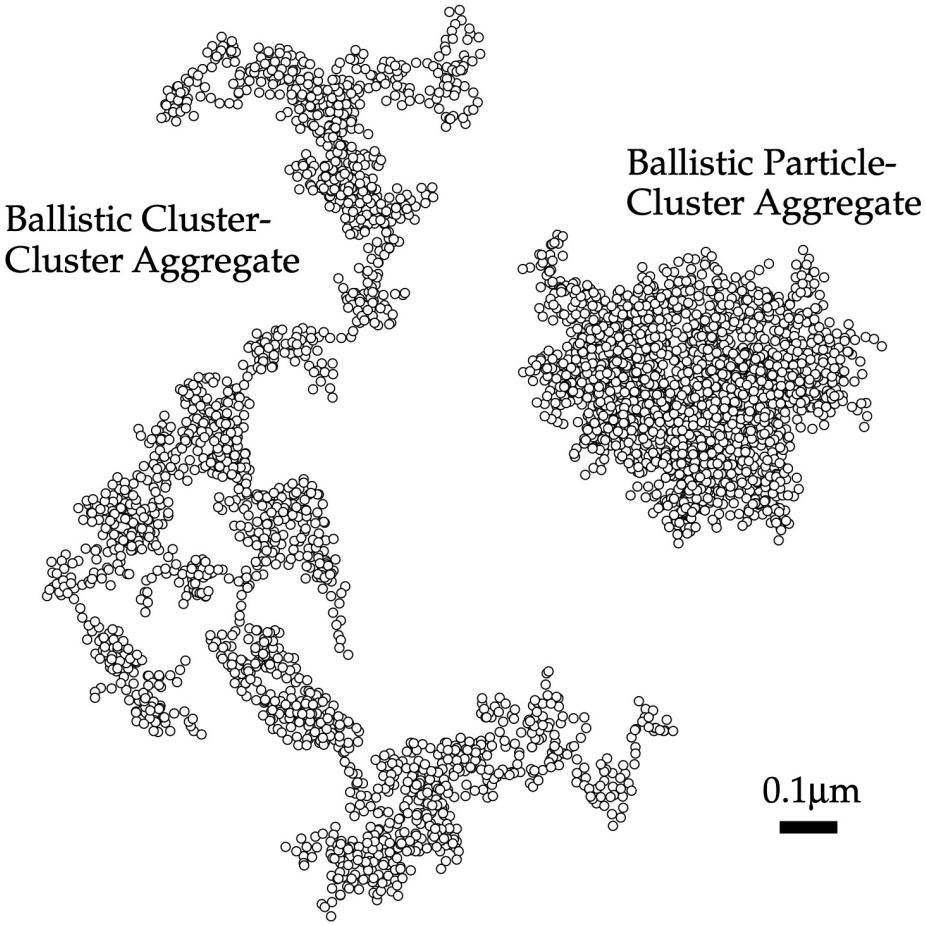
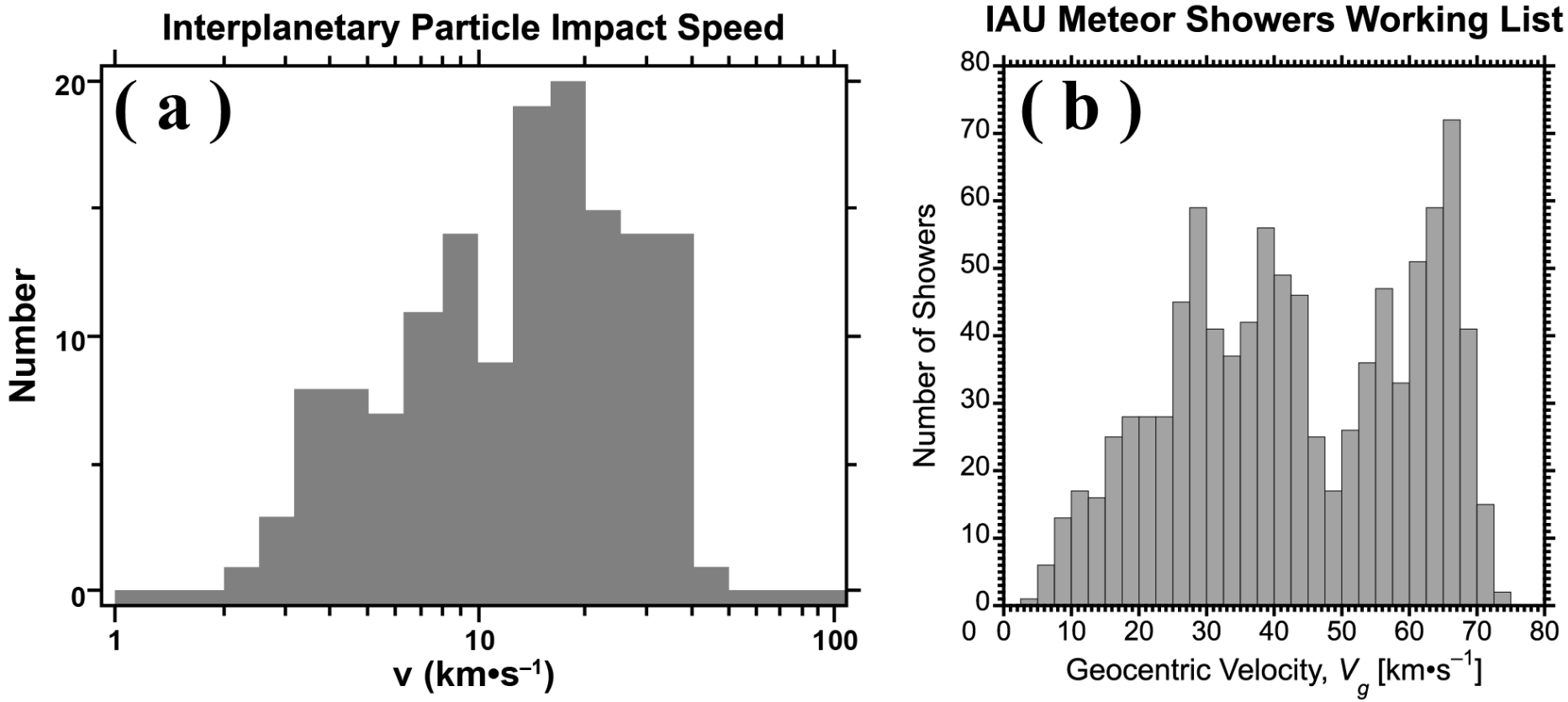


FIG. 1. An example of the ballistic particle–cluster aggregate and the ballistic cluster–cluster aggregate used in the calculations. The number N and radius s_m of the constituent particles are $N = 2048$ and $s_m = 0.01$ μm, respectively.

Dust/Meteor Hyper-velocity…



An overview of the probable velocity distribution of dust in the heliosphere. **(a)** The distribution of interplanetary particle impact speed as measured by the micrometeoroid detectors on ***Helios-1***.† **(b)** The distribution of geocentric velocities of meteor shower dust particles for 961 of 966 meteor showers currently listed by the ***IAU-MDC***.

† Grün E., N. Pailer, H. Fechtig, and J. Kissel [1980], Orbital and physical characteristics of micrometeoroids in the inner solar system as observed by Helios 1, *Planet. Space Sci.*, *28*, 333-349, doi: 10.1016/0032-0633(80)90022-7.

“Rainfall” model of “Nano-dust” impact…

In analogy to gaming efforts to model the sound of rainfall… I have modeled nano-dust impacts as the result of a limited distribution of impactor sizes — as scaled by impact-induced voltage pulse — and impact rates.

In essence… I’ve simulated a nano-dust “hailstorm”….

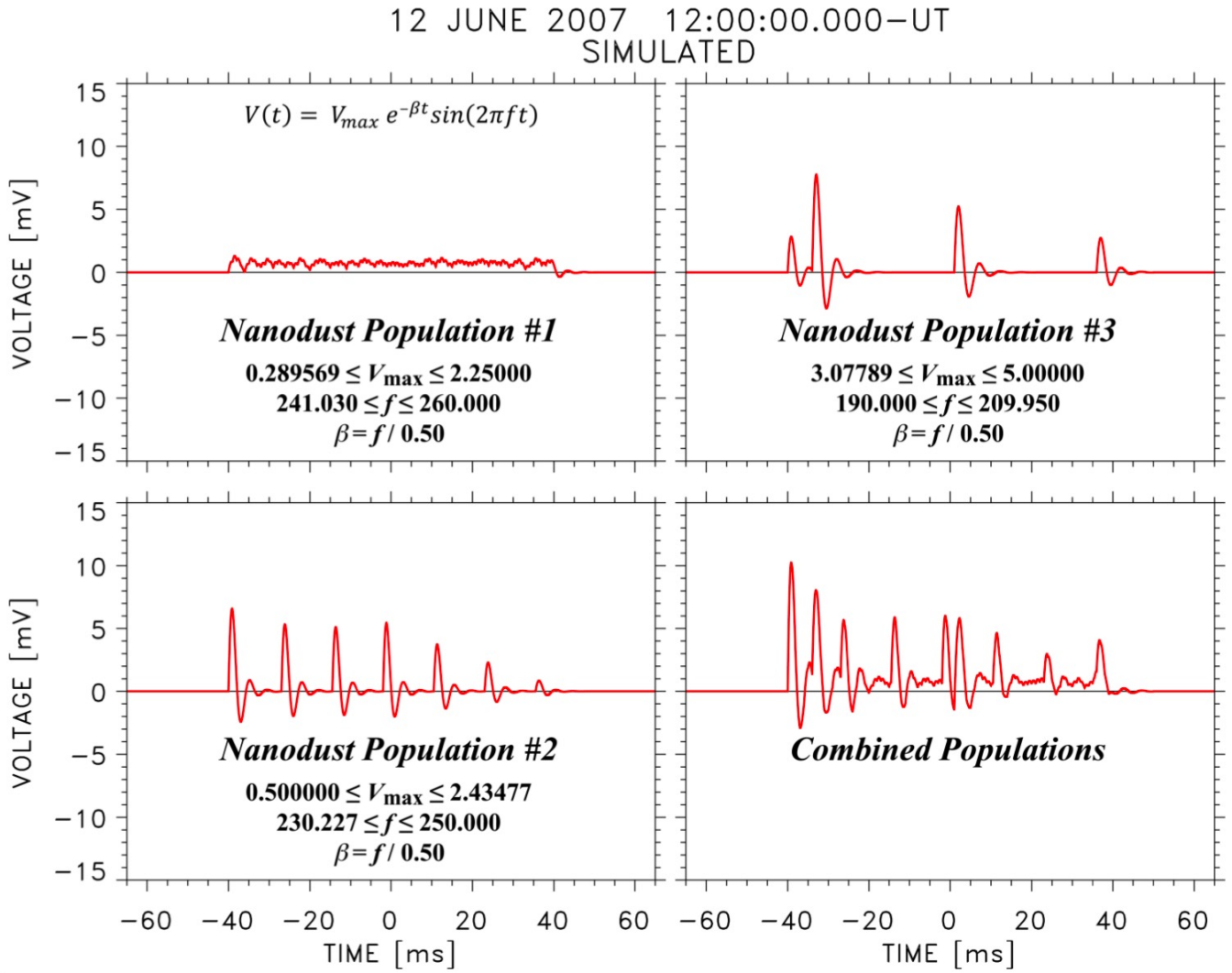
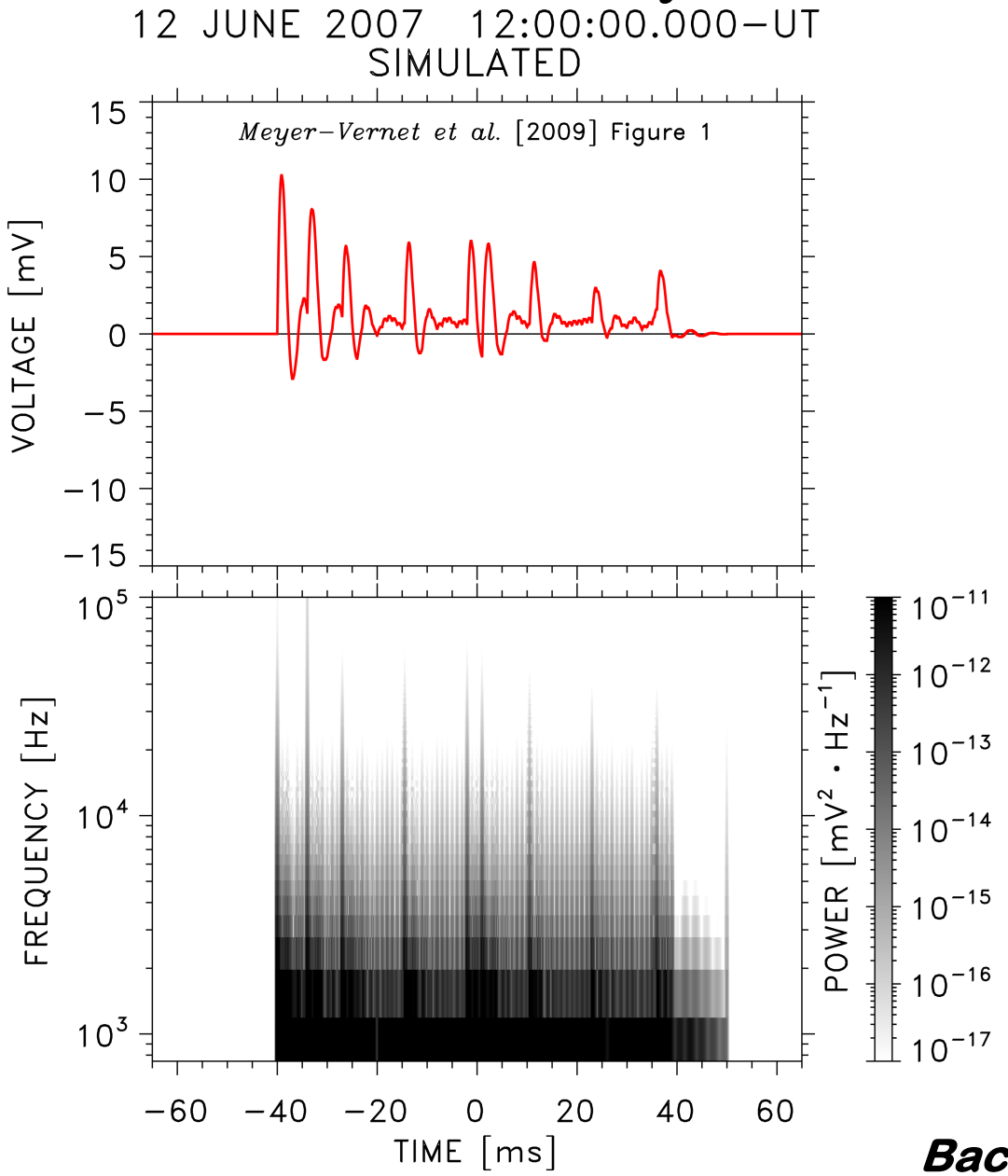


Figure 4. Summary of simulated nano-dust impact waveform signatures as a function of nano-dust population.

"Rainfall" model of "Nano-dust" impact…

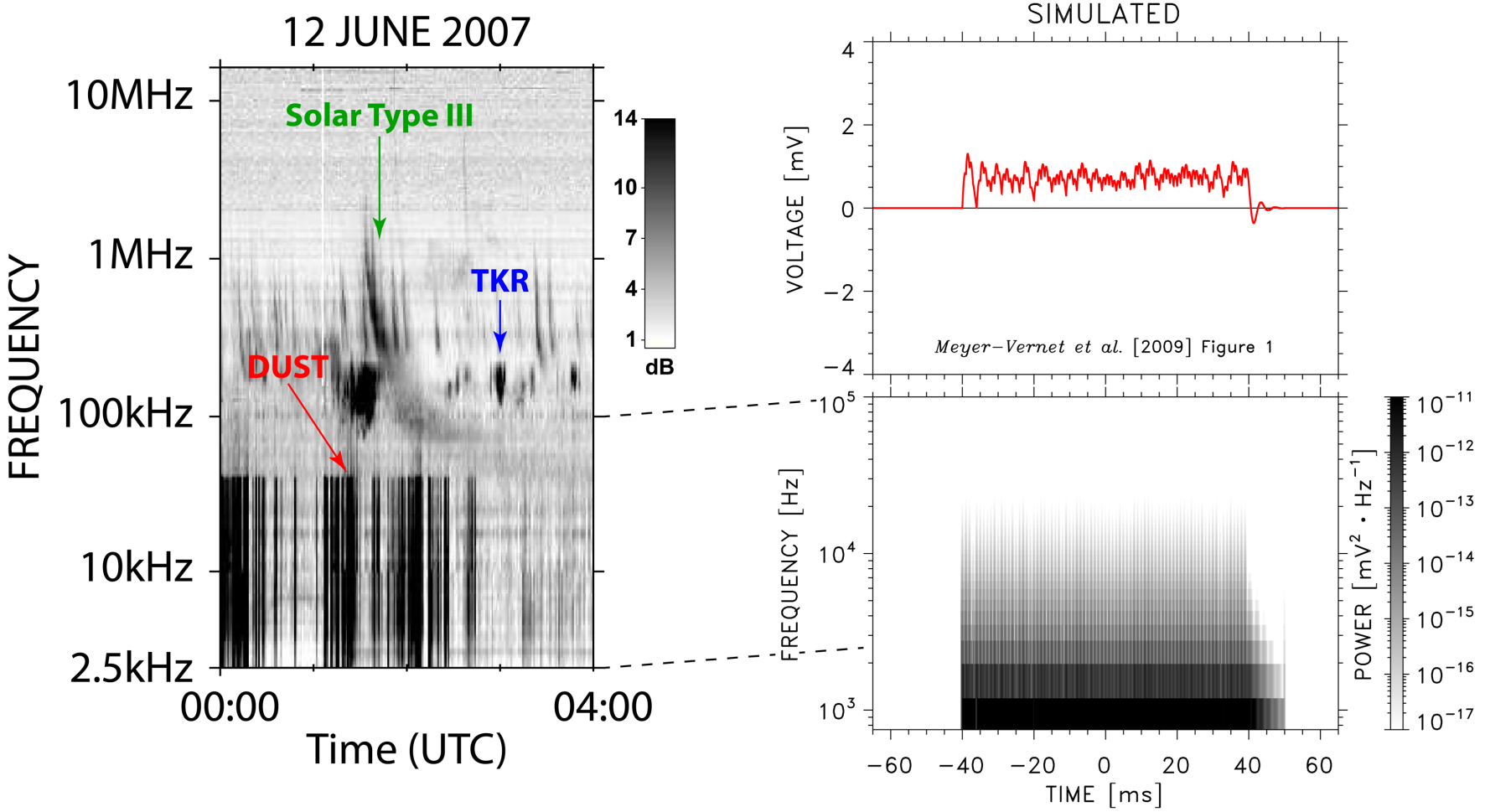
Sampling this nano-dust "hailstorm" at rates comparable to a standard radio receiver operating at rates comparable to S/WAVES….

The ensemble distribution of "impacts" generates a broadband, extremely low-frequency (BB-ELF) spectral emission.



Observation vs. Simulation…

The simulated broadband extremely low-frequency (BB-ELF) emission is qualitatively similar in character to the emissions observed by S/WAVES.



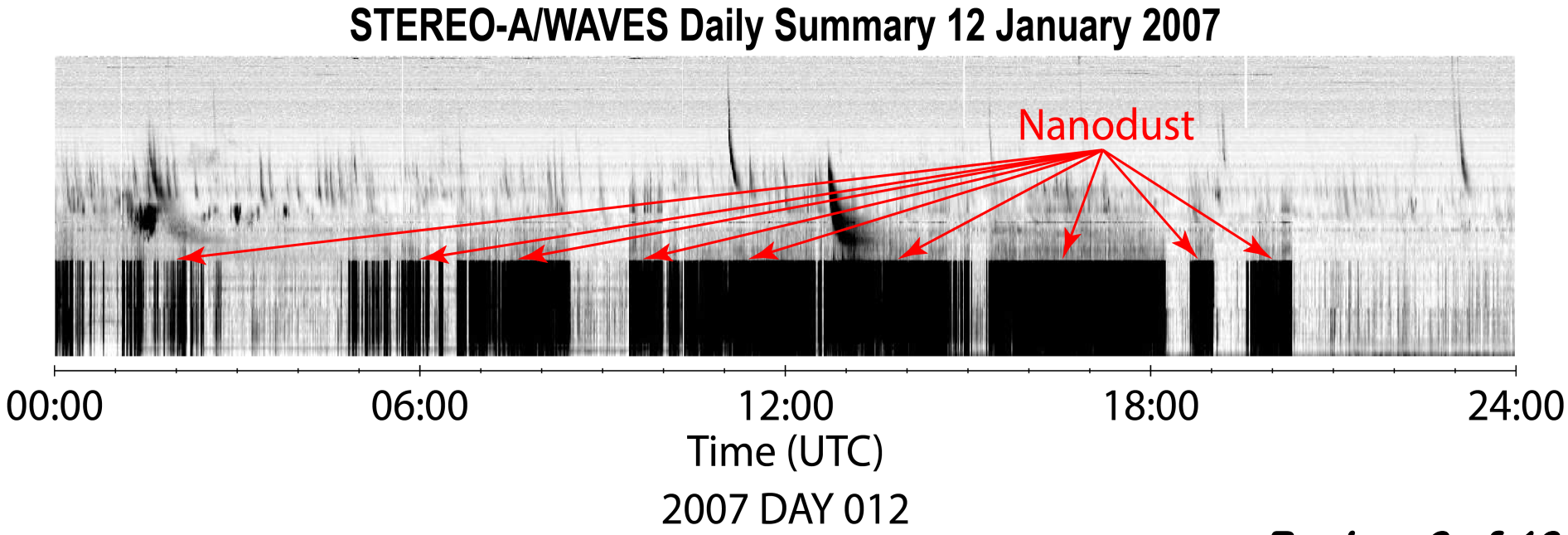
Desire to roughly Quantify Nano-dust impact…

Initial efforts to quantify nano-dust impact rates based upon impactor repetition rates employed in the simulation are astounding…

Average period between dust impacts, $\langle \tau_0 \rangle$	$\sim 4ms$	$\sim 1ms$
➠ f_{impact}	~250Hz	~1kHz
➠ R_{impact}	~15k•min^{-1}	~60k•min^{-1}
	~900k•hr^{-1}	~3.6M•hr^{-1}

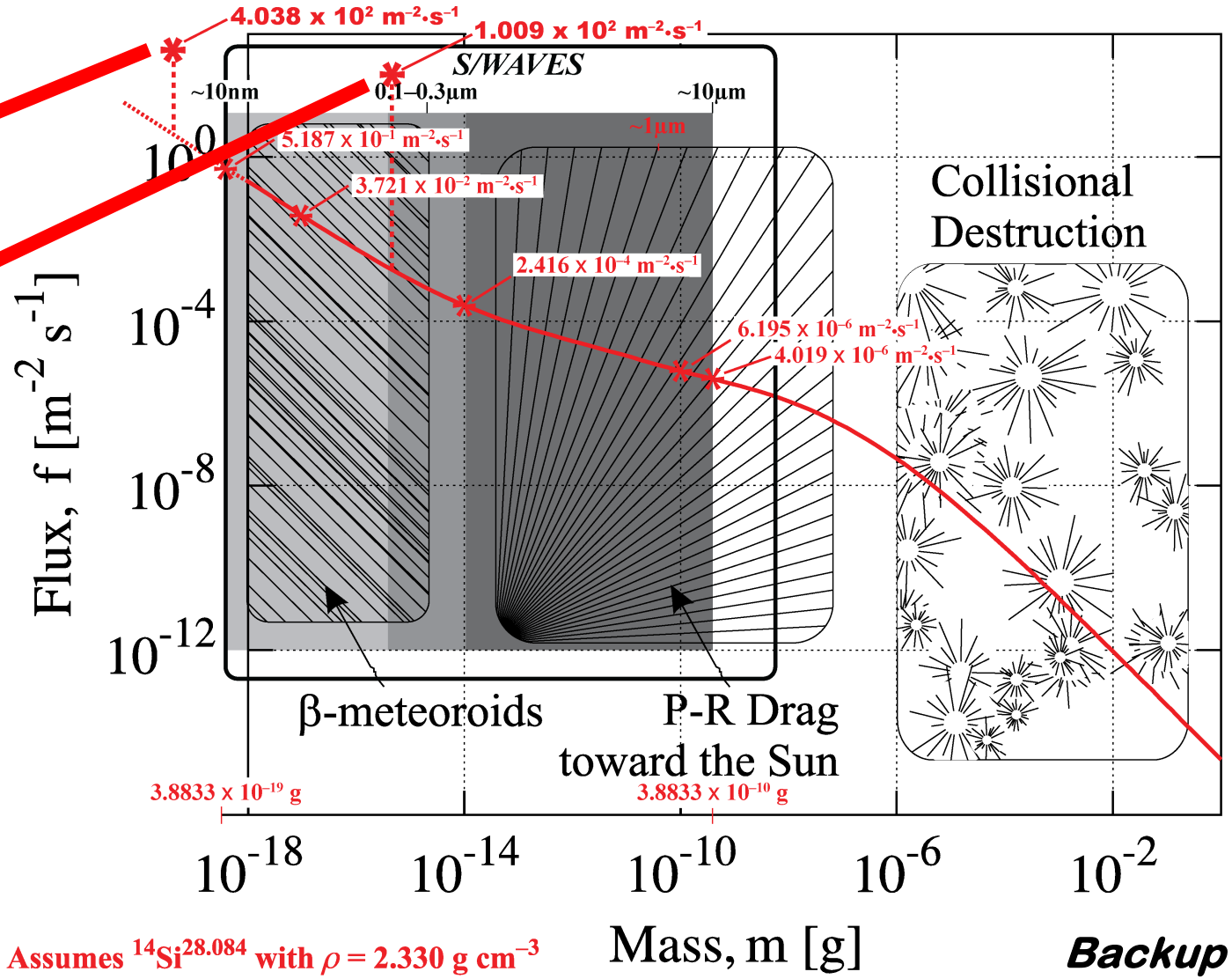
~52,027.4649sec
~14:27:07.4649s

➠ ***13.01M – 52.03M Impacts***



S/WAVES Estimated Nano-Dust Flux Range Comparison to Grün et al. [2004]…

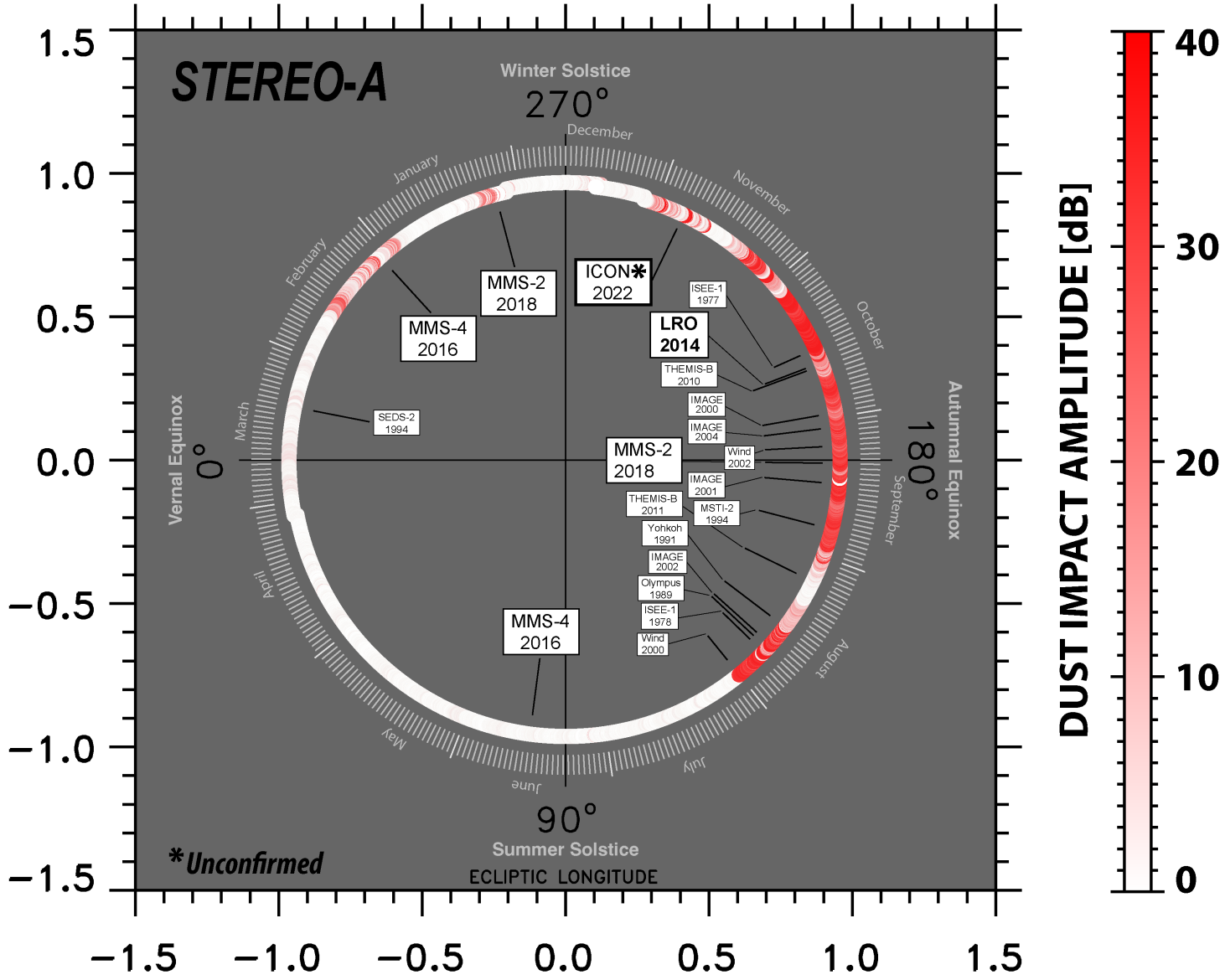
- *Estimated nano-dust flux levels are ~2-orders of magnitude above those predicted by Grün et al.* [2004].
- *Again, Grün et al.* [2004] *assumes dust generated by/from a specific family of JFCs.*



(*T = 2.96; U = 0.2u*$_{Jovian}$)

Assumes $^{14}Si^{28.084}$ with $\rho = 2.330$ g cm^{-3}

Curiosity got the best of me…



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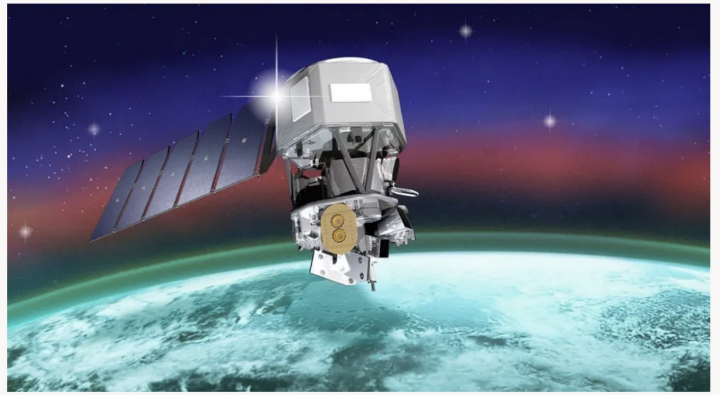
NASA loses contact with ICON spacecraft

Jeff Foust December 8, 2022



NASA's ICON spacecraft has been out of contact since Nov. 25 after experiencing some kind of malfunction. Credit: NASA GSFC/Mary Pat Hrybyk-Keith

WASHINGTON — A NASA space science spacecraft launched three years ago has been out of contact with controllers for nearly two weeks after suffering some kind of technical problem.

NASA said it has ruled out damage to the spacecraft from an explosion of debris impact, noting that observations of the low Earth orbit spacecraft by the Defense Department's Space Surveillance Network concluded that ICON is intact.

While *Tripathi et al.* [2023] have "*ruled out an MMOD impact*" as a probable cause… that change of attitude and rate are particularly suggestive… given the event's location relative to *STEREO* dust.

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