UiT The Arctic University of Norway

Translating SolO Dust Insights for Advancing PSP Dust Collection Model

Samuel Kočiščák,
Audun Theodorsen,
Ingrid Mann

samuel.kociscak@uit.no

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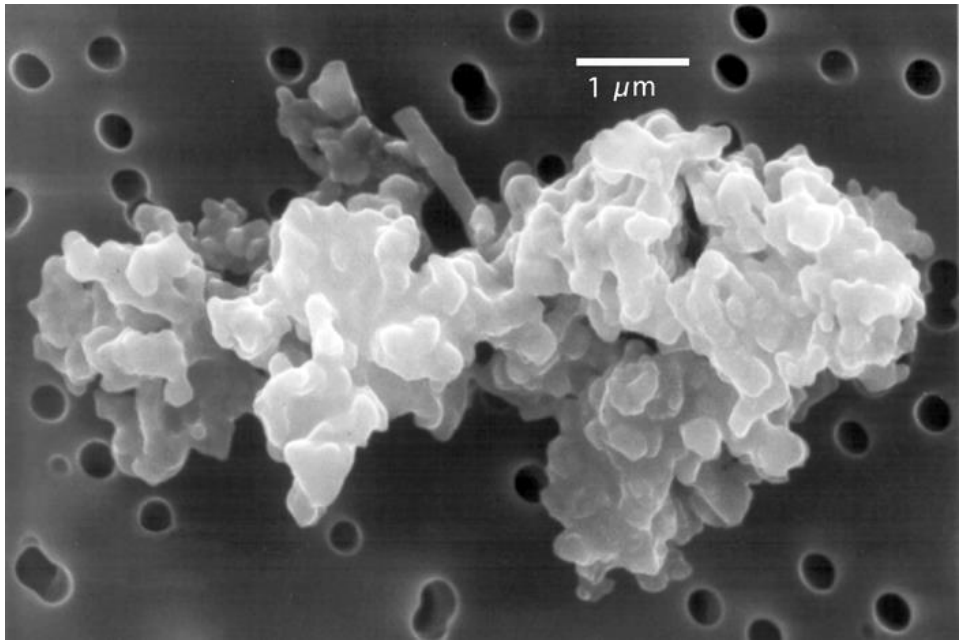
Outline

1. Impact ionization
   - Dust detection with antennas
2. Fitting SolO /RPW
   - Dust identification
   - The model
3. Fitting PSP /FIELDS
   - Model adaptation

1. Impact ionization

Dust in the solar system

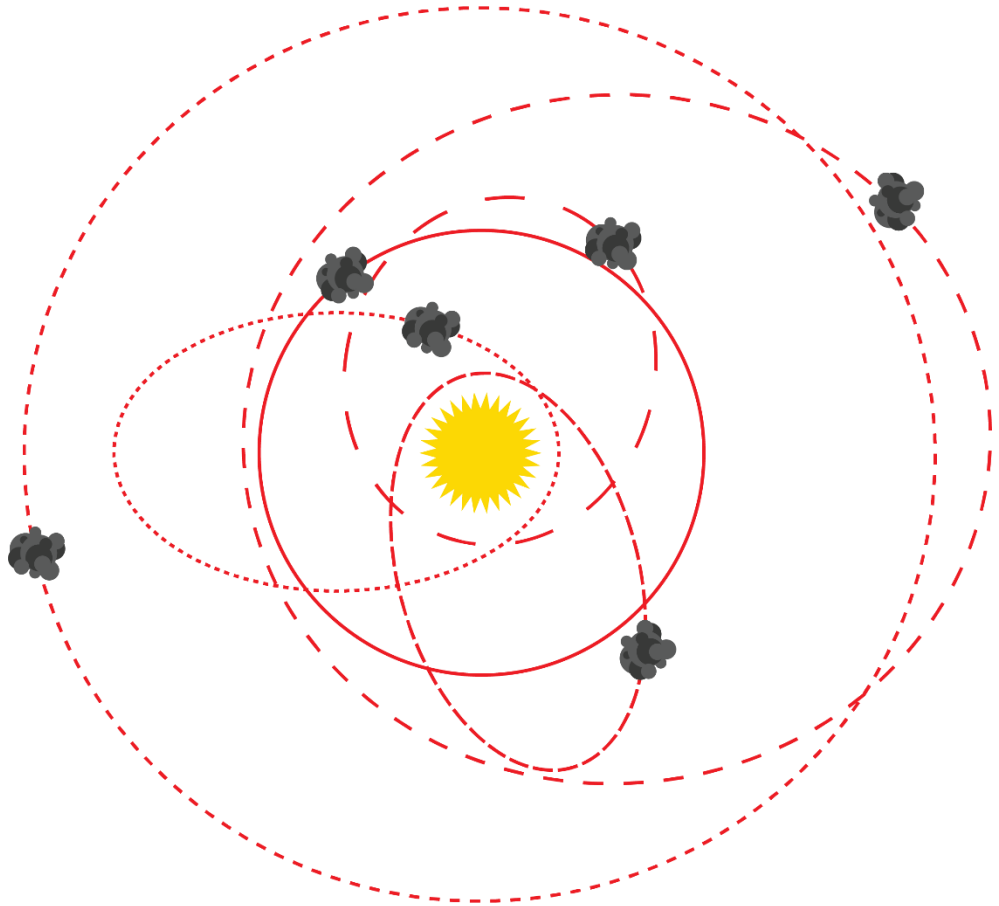
- Debris $nm < r_{dust} < cm$
  - Rock, Ice
  - Comets, asteroids
- Carries charge
  - Interaction with fields
- Many described populations



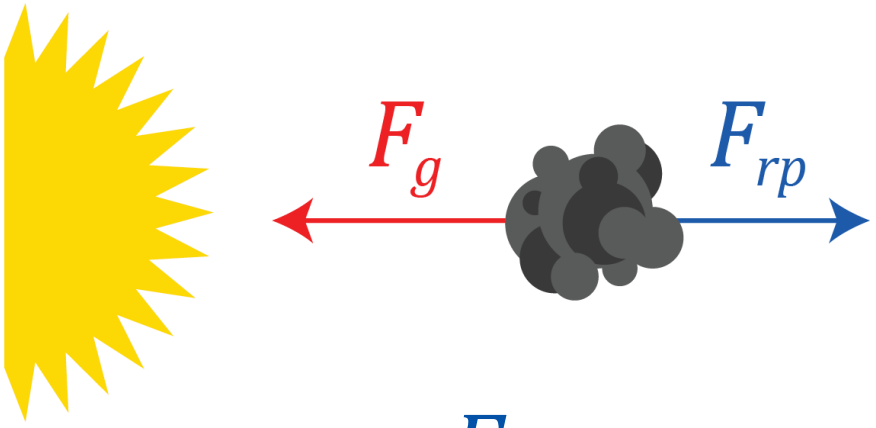
SEM scan of a porous chondrite IDP by
Donald E. Brownlee and Elmar Jessberger, CC-BY-2.5

Keplerian dust

- Asteroid-like orbits
- Broad range of eccentricities
- Evolution of the orbit
  - P-R drag
  - Sublimation
  - Sputtering

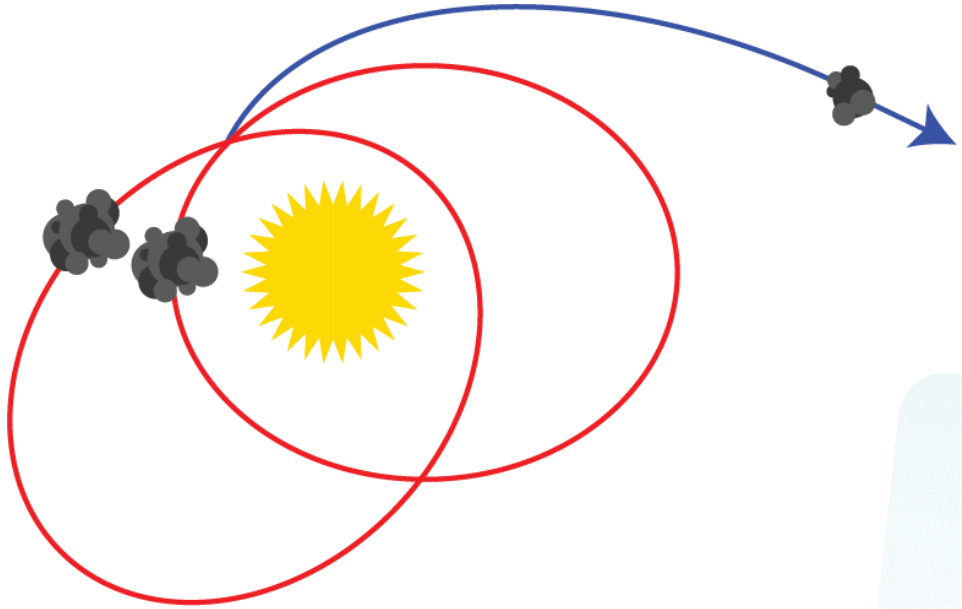


β-meteoroids



$$\frac{F_{rp}}{F_g} = \beta$$

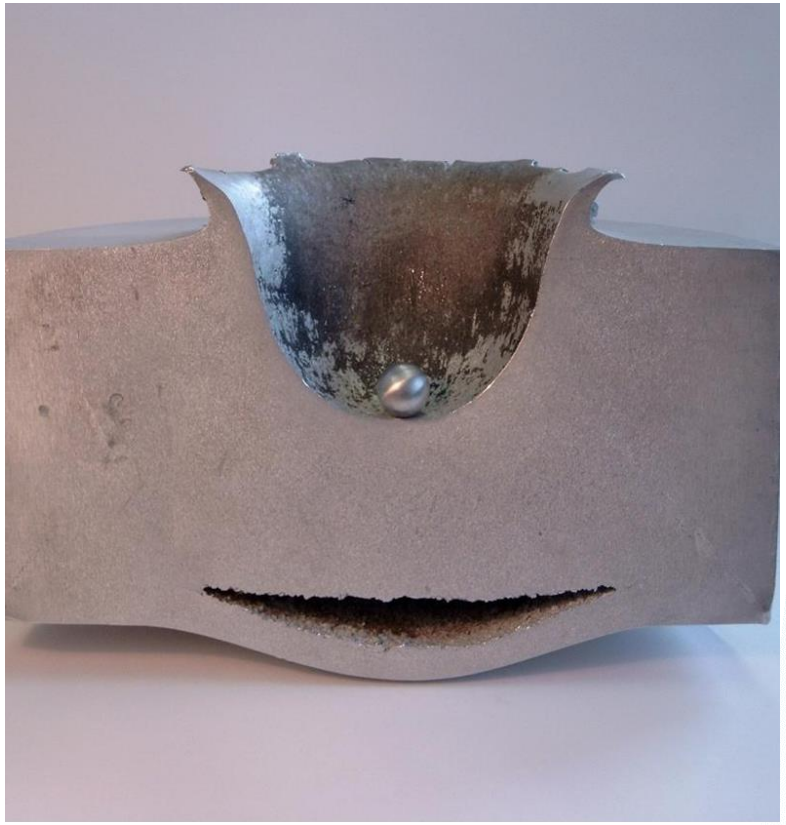
$$F_g^{effective} = (1 - \beta) \cdot F_g$$



$$v_{escape} = f(\beta)$$

Hypervelocity collisions

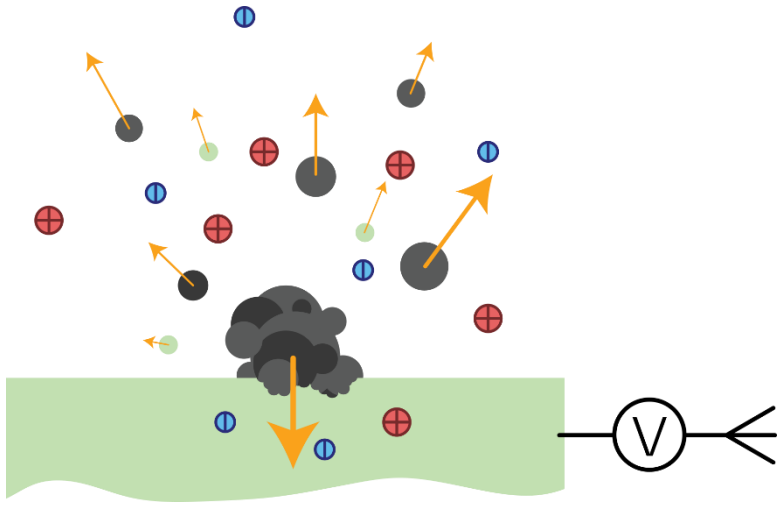
- Material strength ≪ inertial stress
  - Melting steel: $1\ MJ/kg \Rightarrow 1{,}4\ km/s$
  - Burning coal: $24\ MJ/kg \Rightarrow 6{,}9\ km/s$
  - Ionizing Na: $21\ MJ/kg \Rightarrow 6{,}5\ km/s$
  - Ionizing H: $0.55\ GJ/kg \Rightarrow 23\ km/s$
- Speeds in space:
  - Earth‘s orbital speed $\approx 30\ km/s$
  - Sun relative to ISM $\approx 25\ km/s$
- Ionization



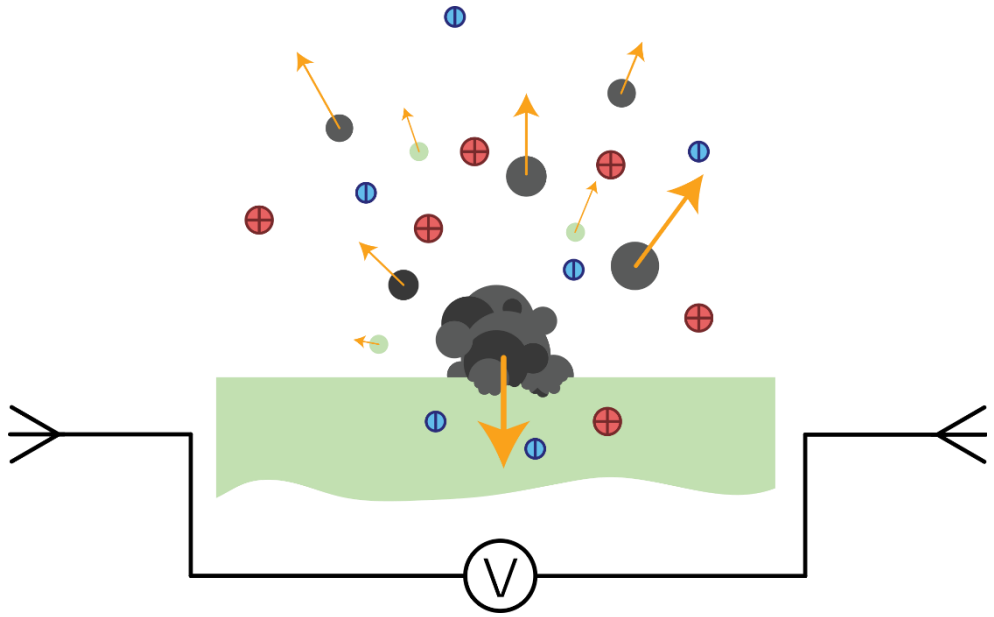
© ESA, from Wikipedia

Two antenna configurations

Monopole



Dipole



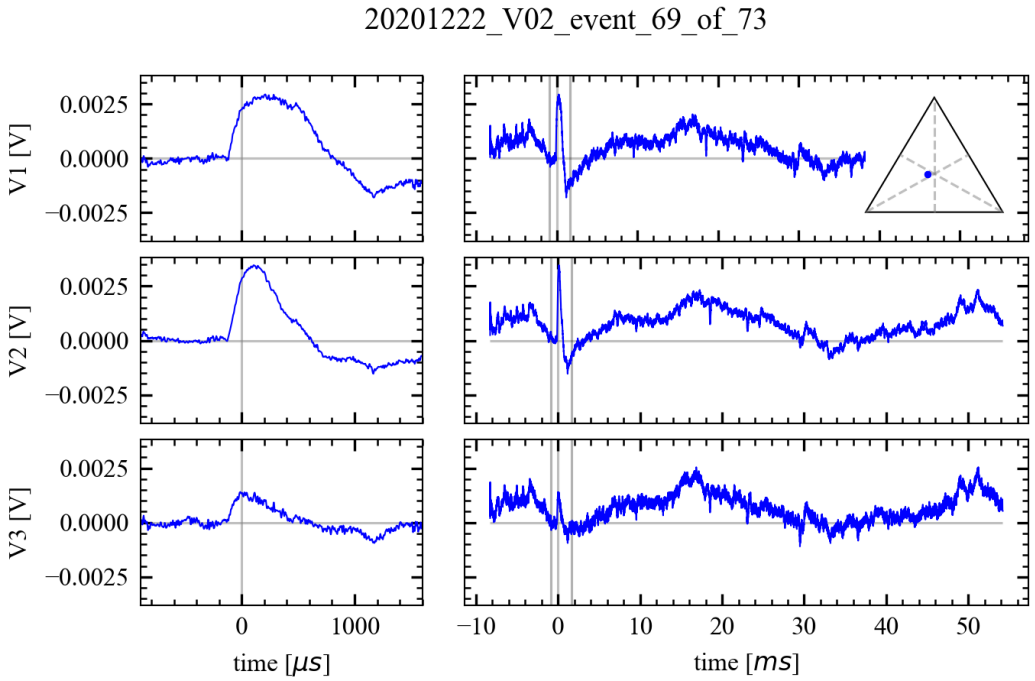
Takeaway 1.

- A dust impact onto SC is accompanied by electrical phenomena due to impact ionization
- The phenomena are detected with electrical antennas

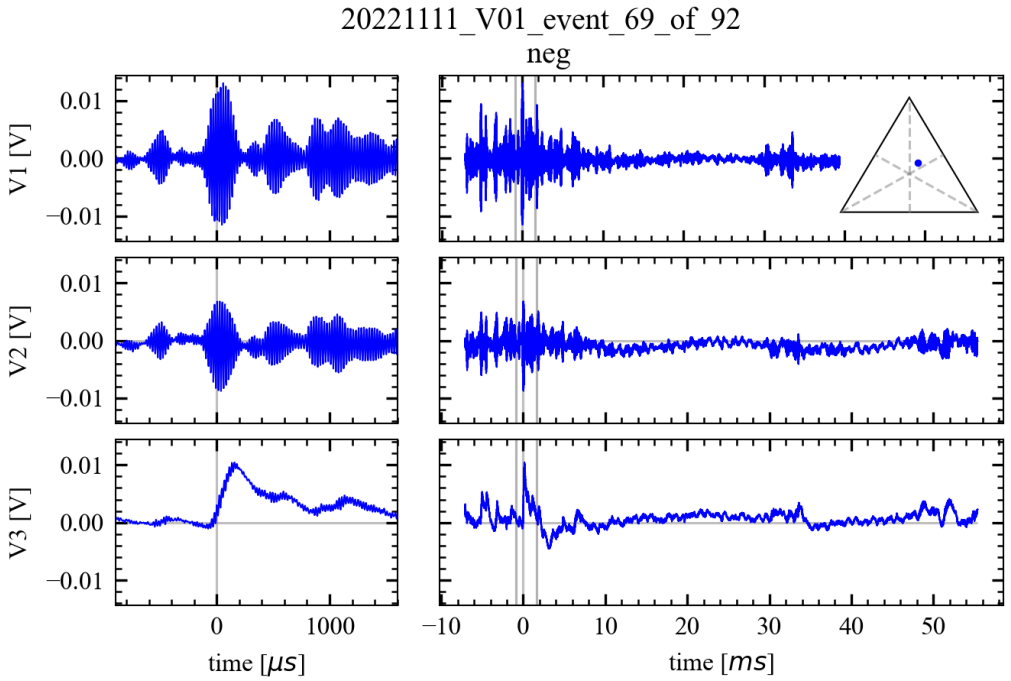
2. SolO/RPW dust fitting

SolO/RPW data

- Triggered waveforms (TDS_SURV_TSWF_E)



A dust impact event on Solar Orbiter



A Langmuir wave event on Solar Orbiter

Impact recognition

- 6.2% or 3.1% duty
- Onboard selection
- Ground CNN analysis
  - ≈ 97% sensitive
  - ≈ 96% specific
- So we get the count for each day

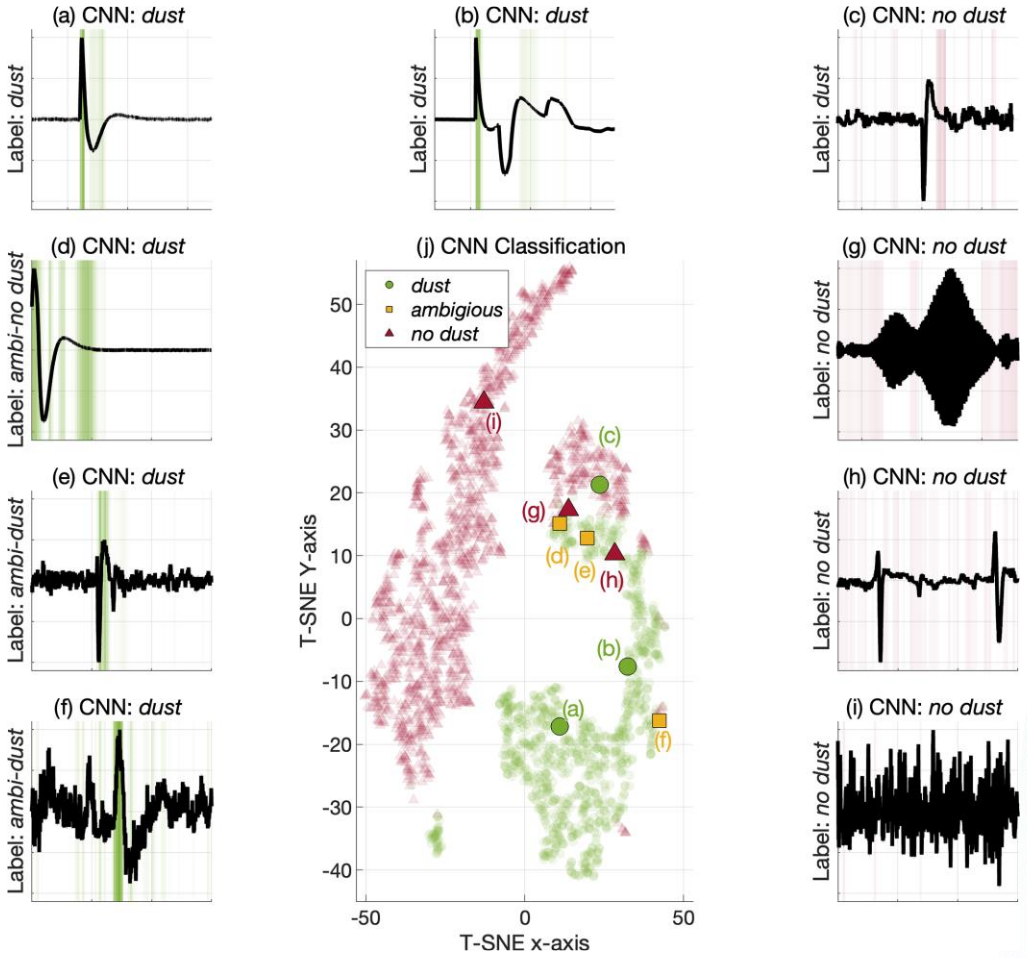
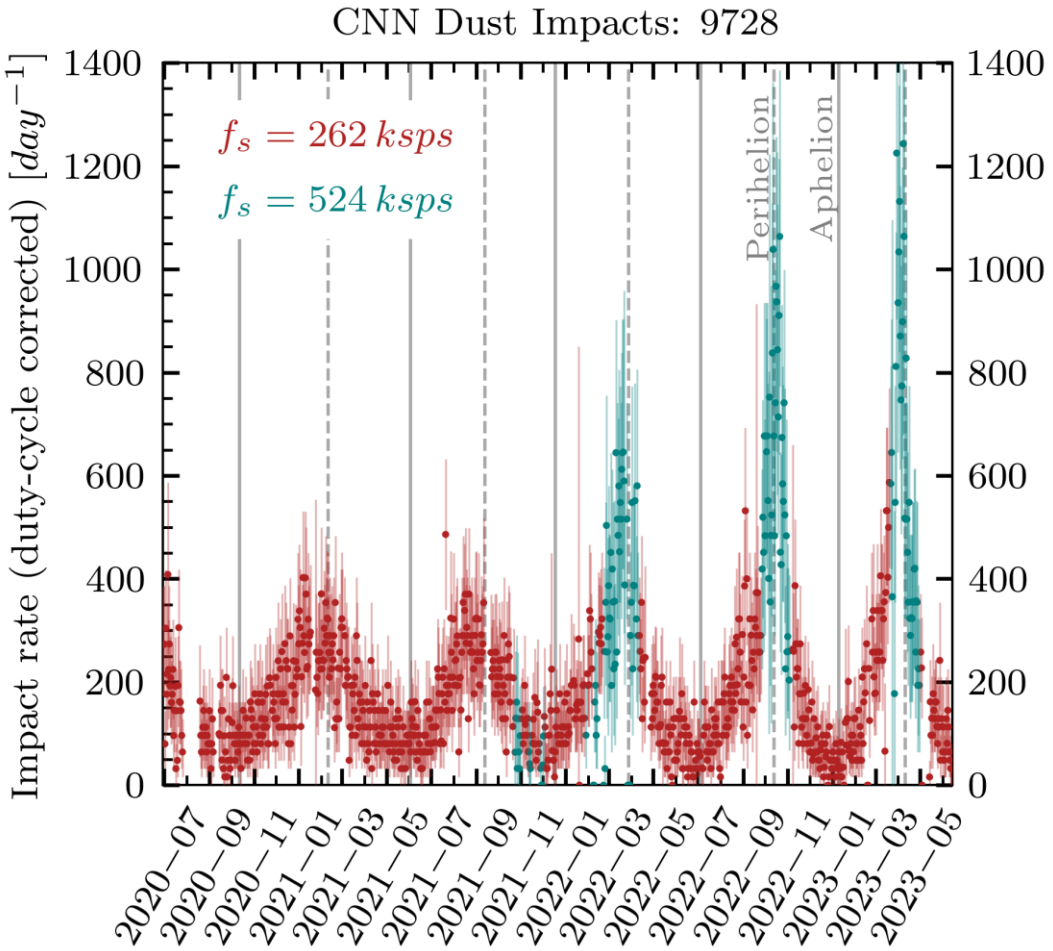
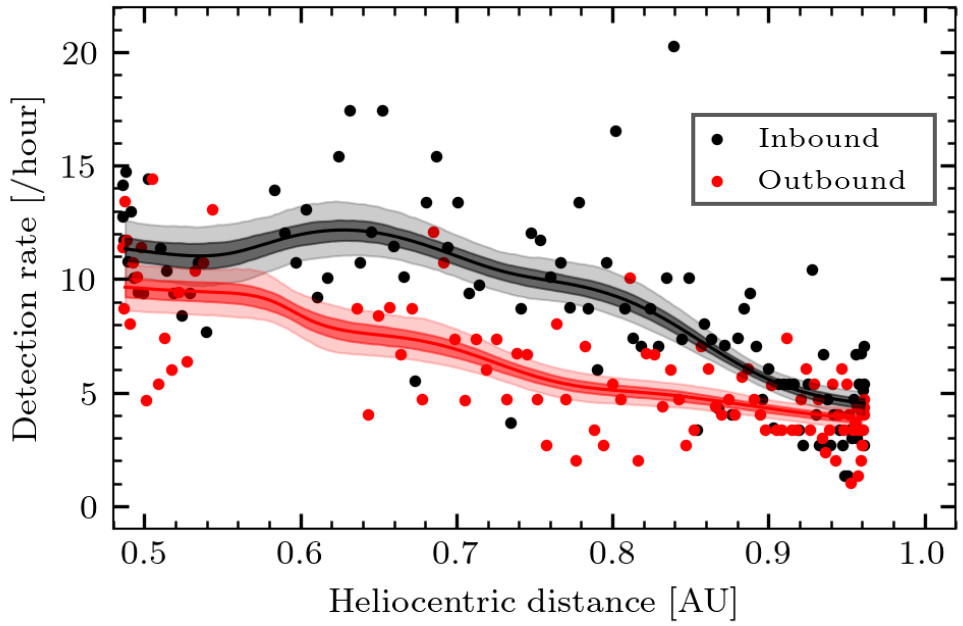


Fig. 9 from Kvammen et al. (2023)

The problem at hand: fitting





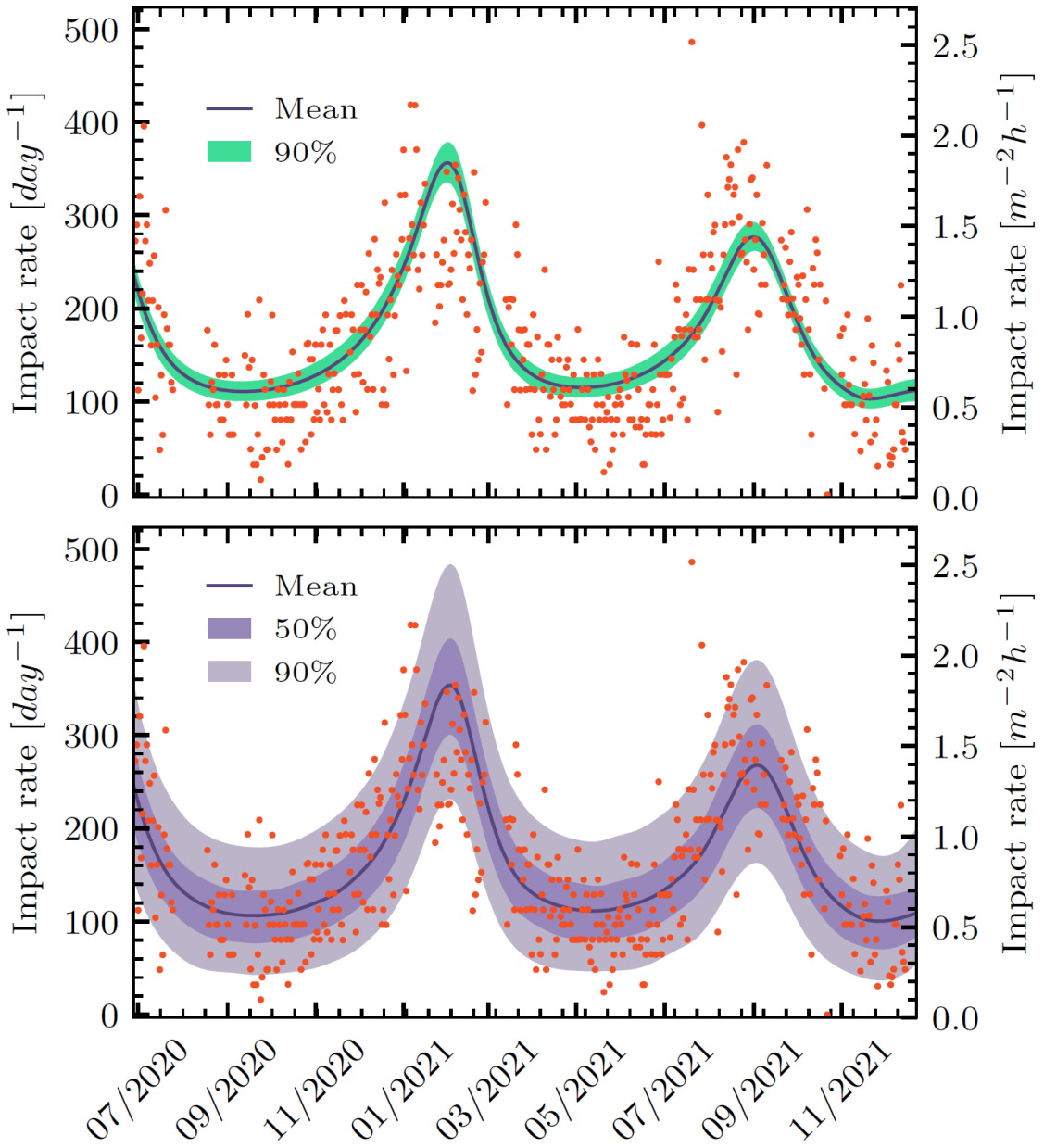
- Mostly β dust, but not all
- We chose: β + const.

The fit

Rate λ

Likelihood

Observation N

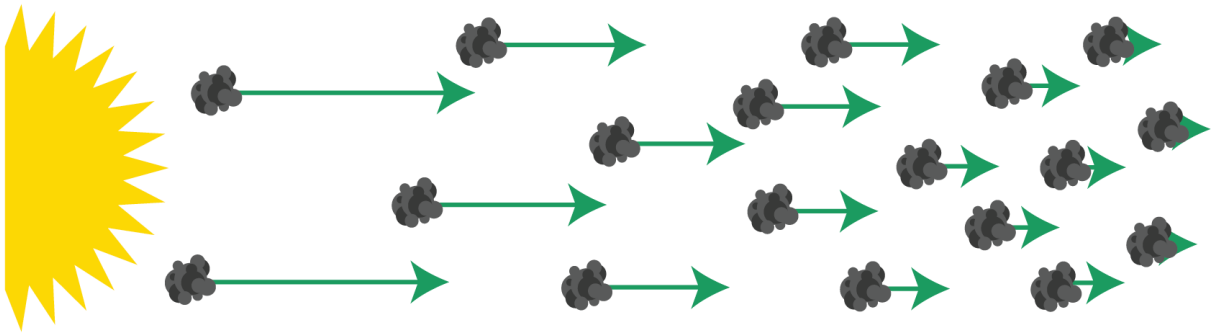


Spatial distribution

Solar attraction

⇓

Accumulation

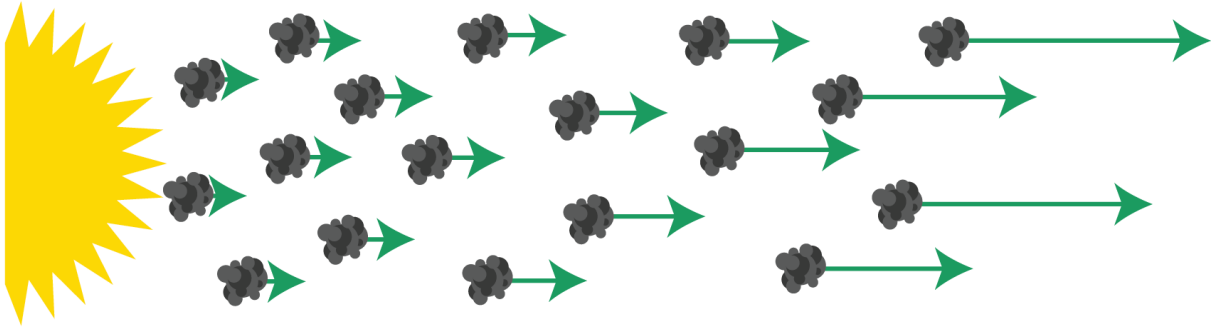


$\beta < 1$

Solar repulsion

⇓

Depletion



$\beta > 1$

Takeaway 2.

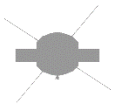
- Dust count is obtained day-by-day from SolO/RPW triggered wavefrom data
- Well working model
  - β dust with a correction for other populations
- Deceleration of the β dust is found

3. PSP/FIELDS fitting

PSP vs. SolO – detection area

PSP - frontal view

$6.11m^2$
$(1.64m^2)$



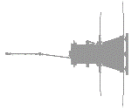
PSP - lateral view

$4.62m^2$



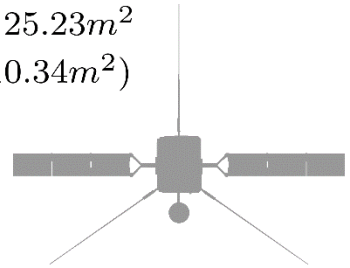
PSP - top view

$4.58m^2$



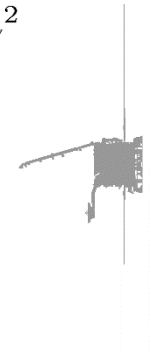
SolO - frontal view

$25.23m^2$
$(10.34m^2)$



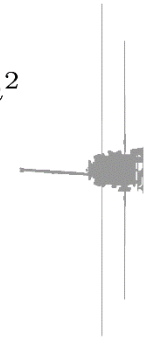
SolO - lateral view

$8.24m^2$



SolO - top view

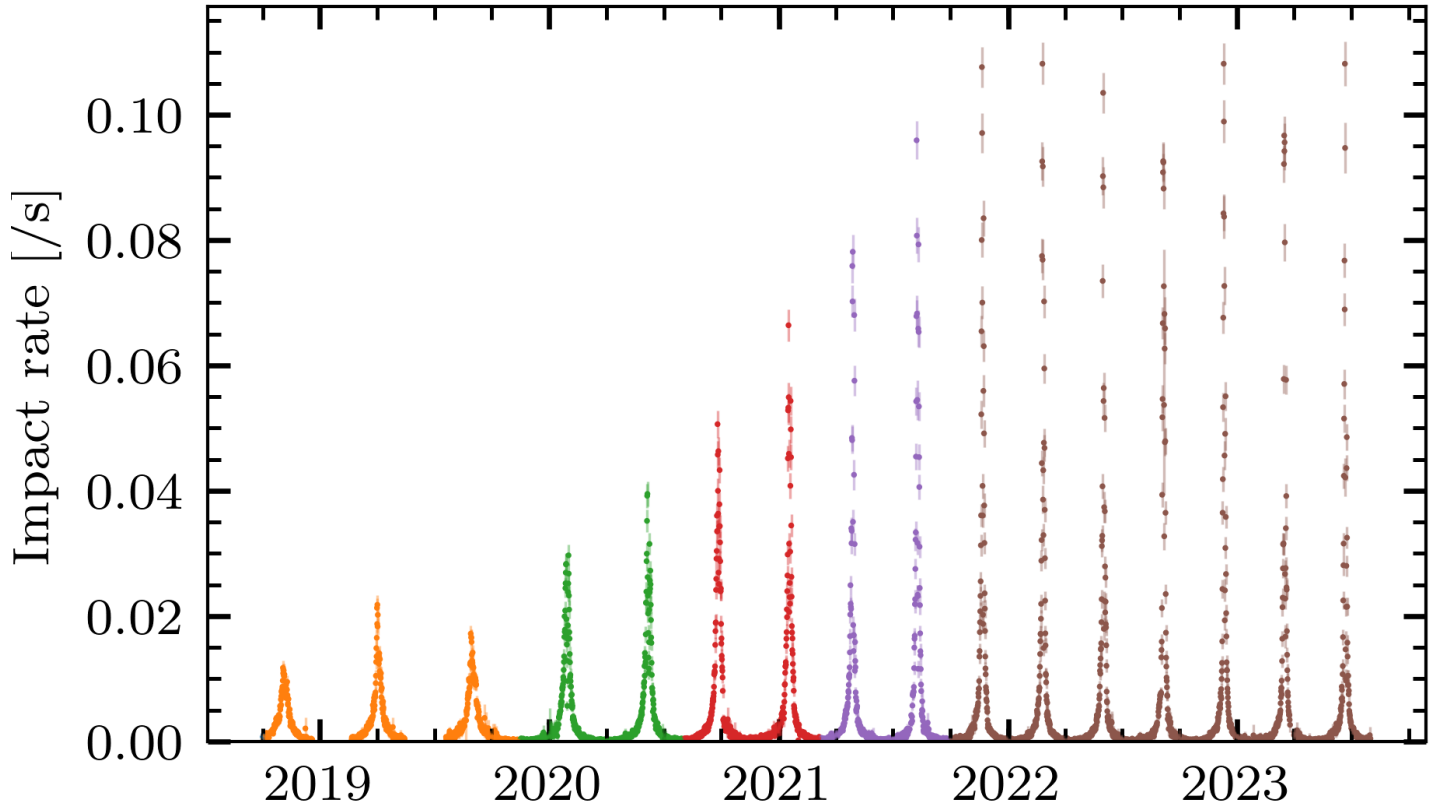
$6.71m^2$



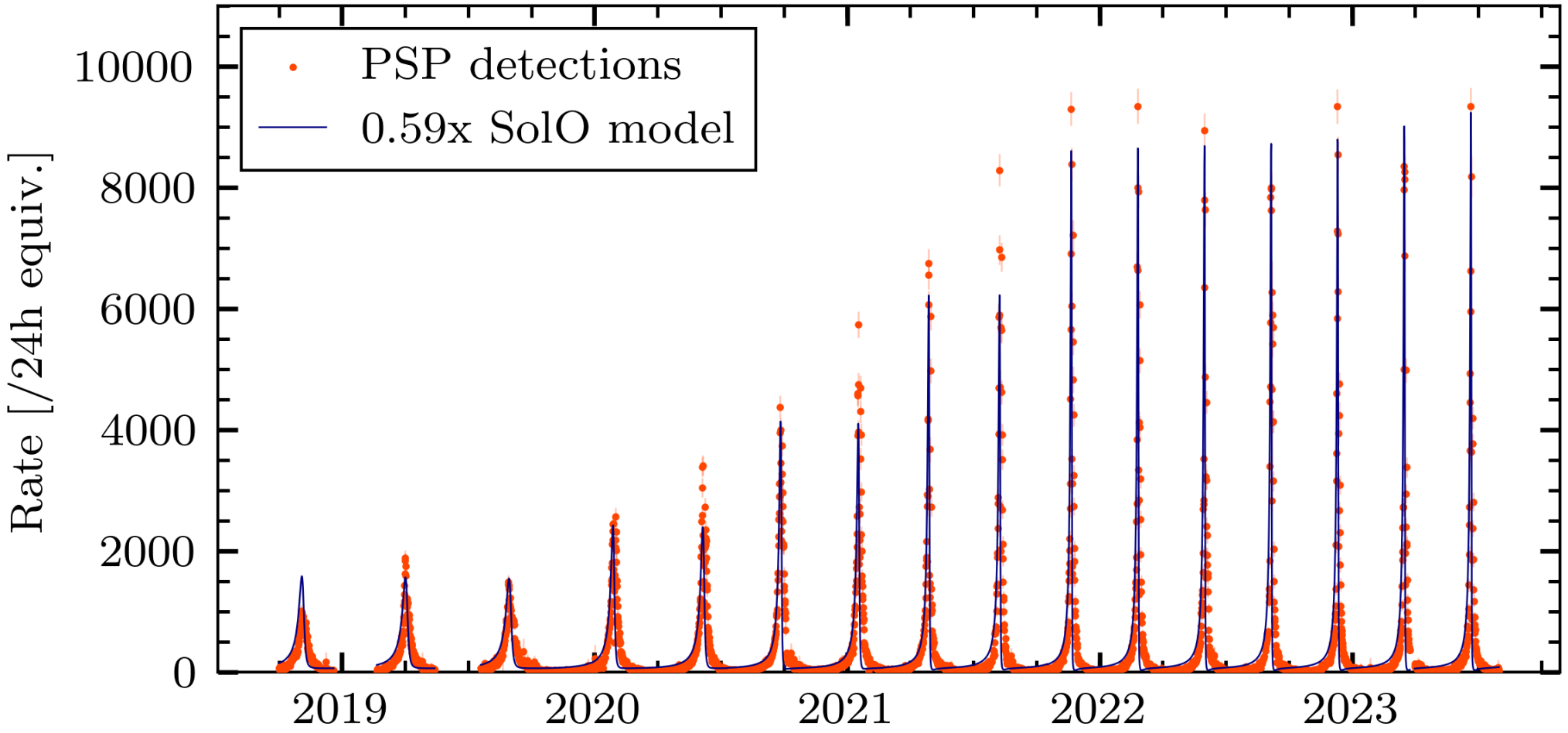
$\approx 0.59\times$

Data - Malaspina et al. 2023

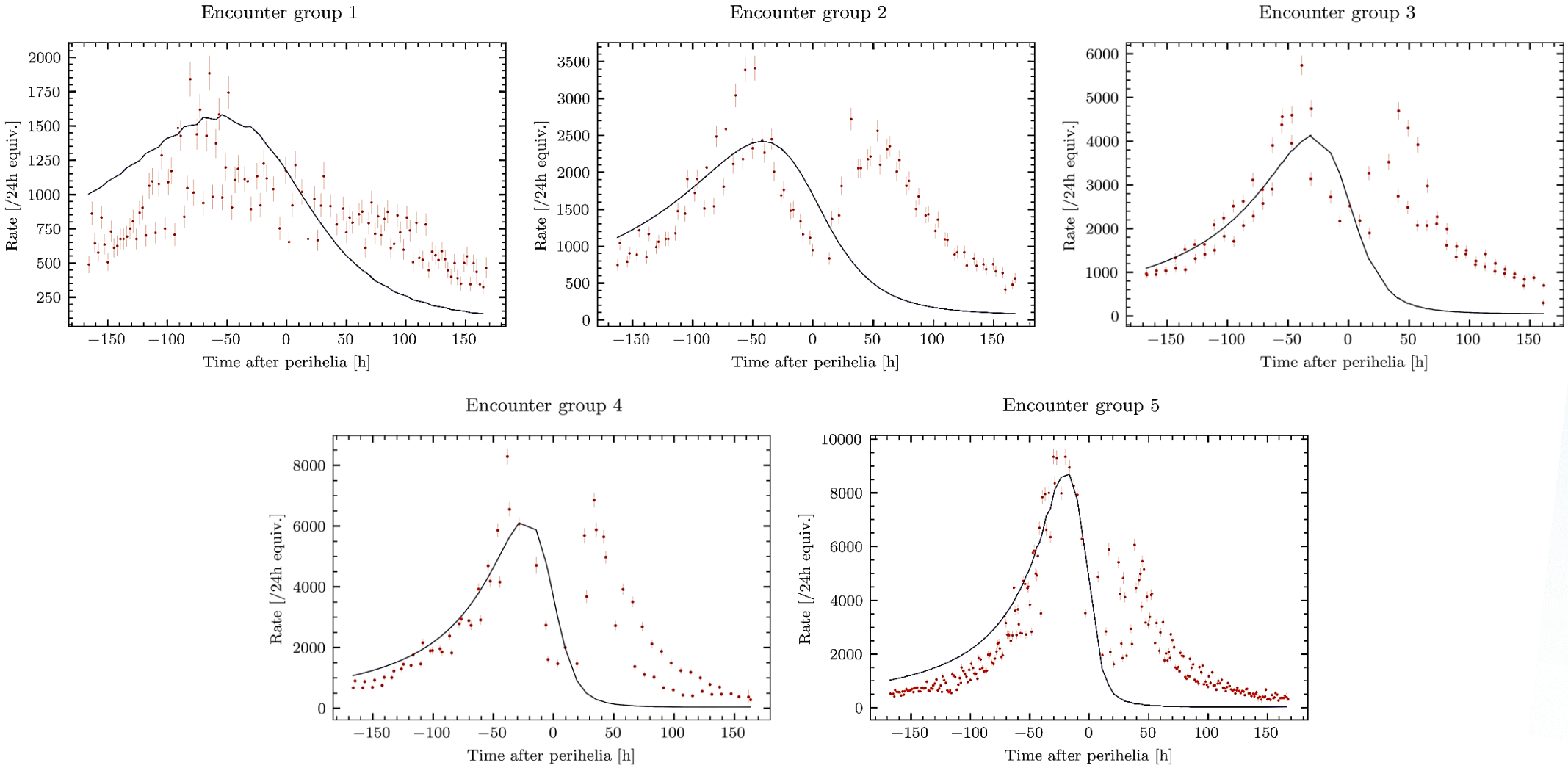
- TDSMax, with the available corrections



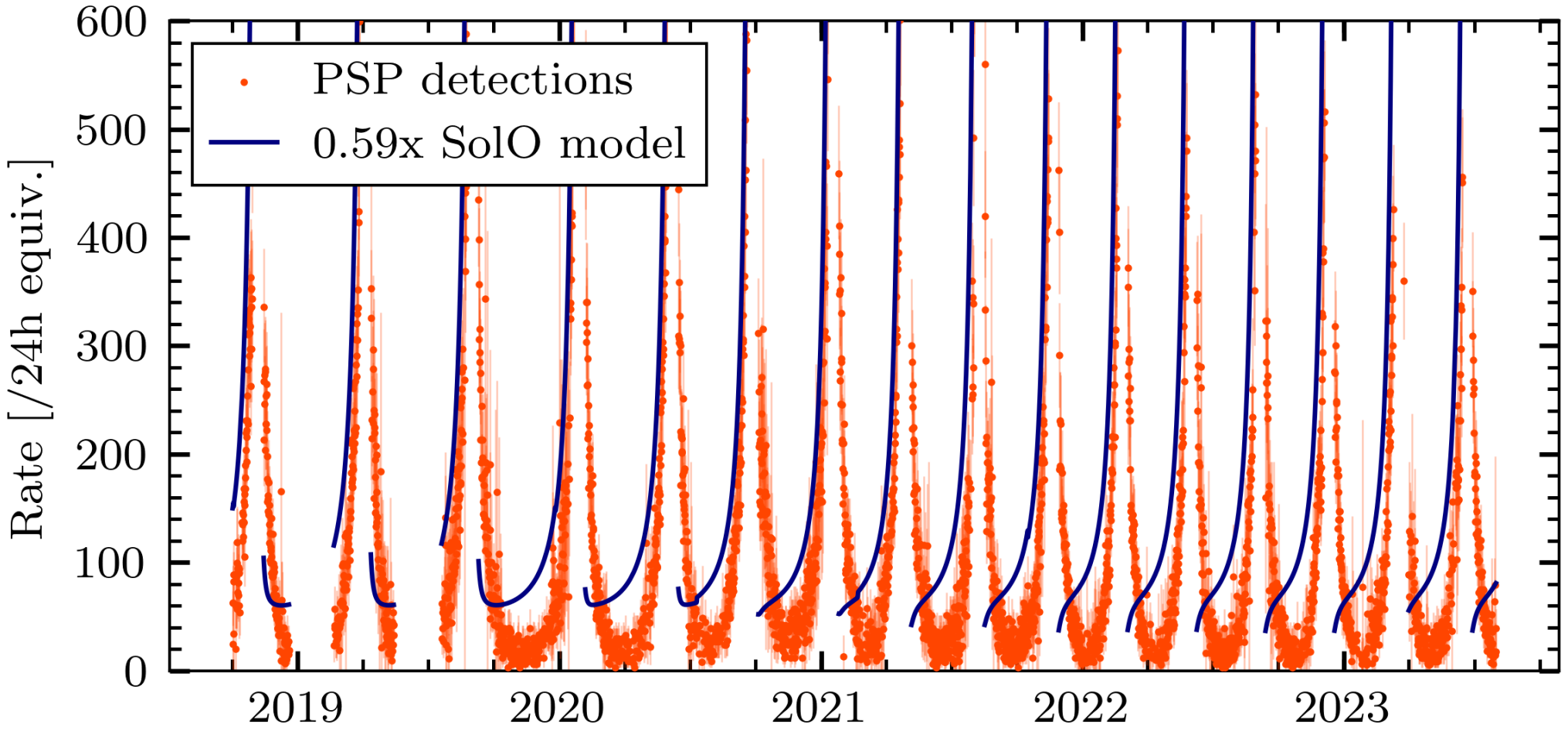
Naive overplot



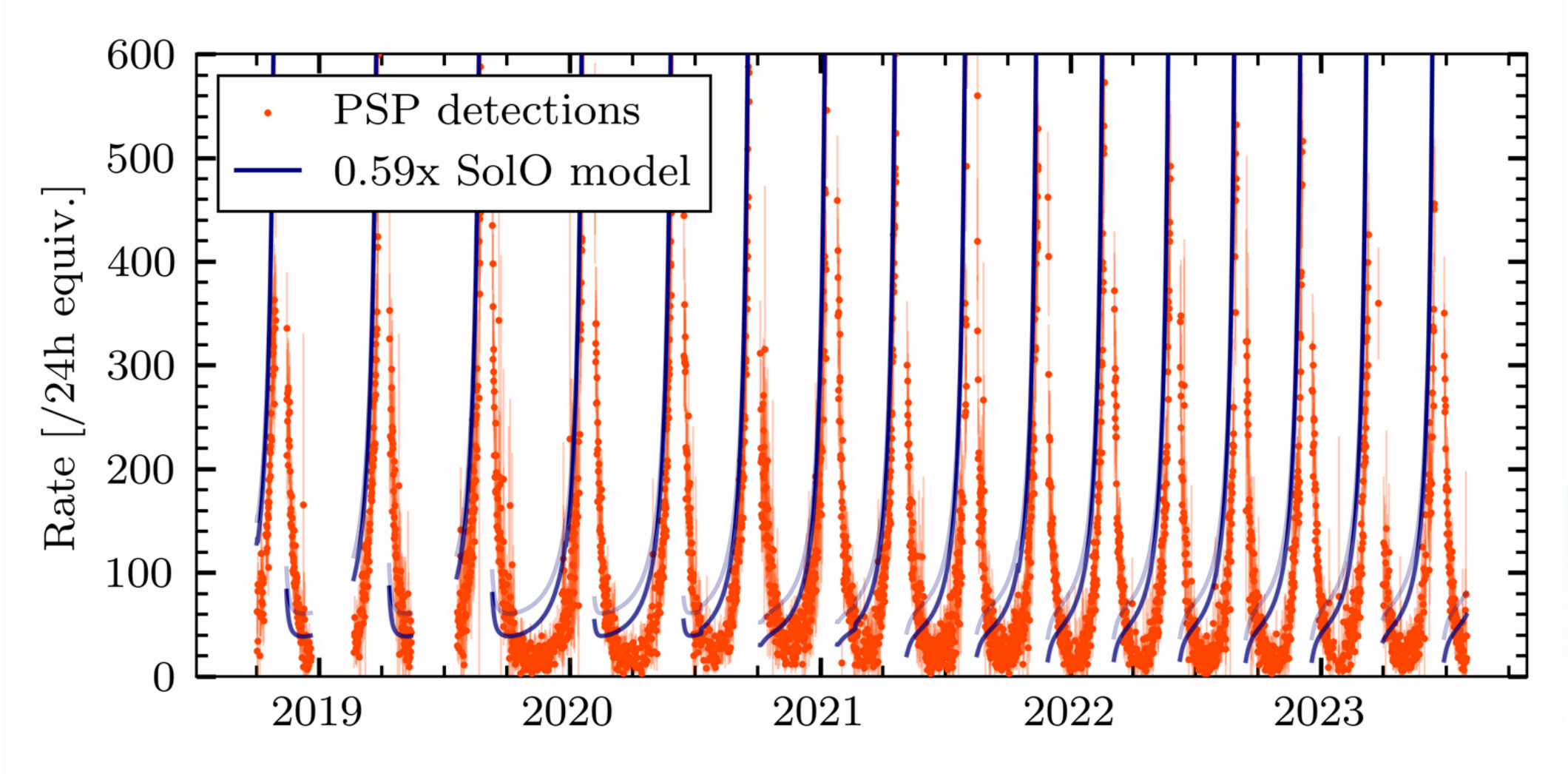
Naive overplot – maxima



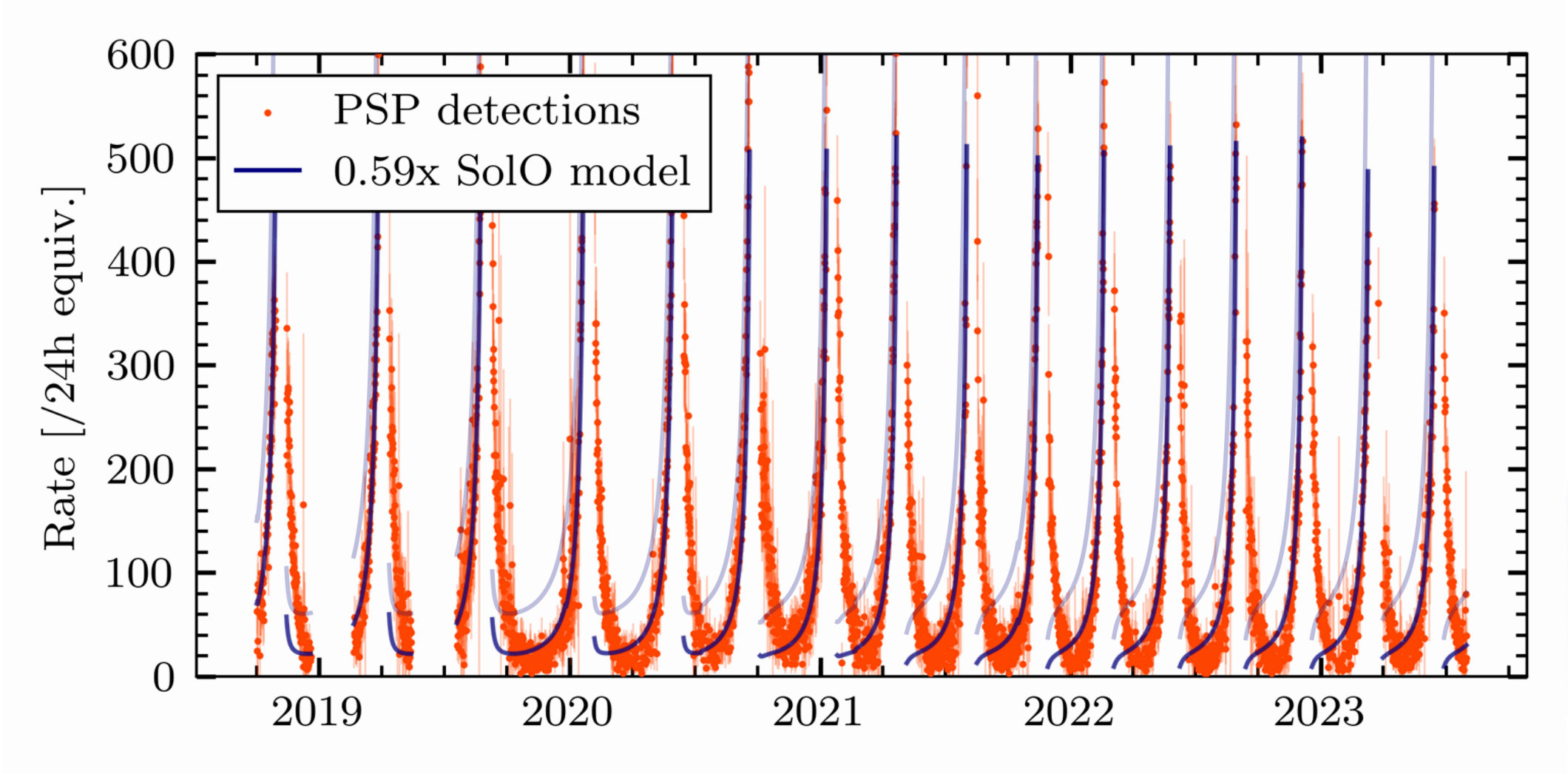
Naive overplot – minima



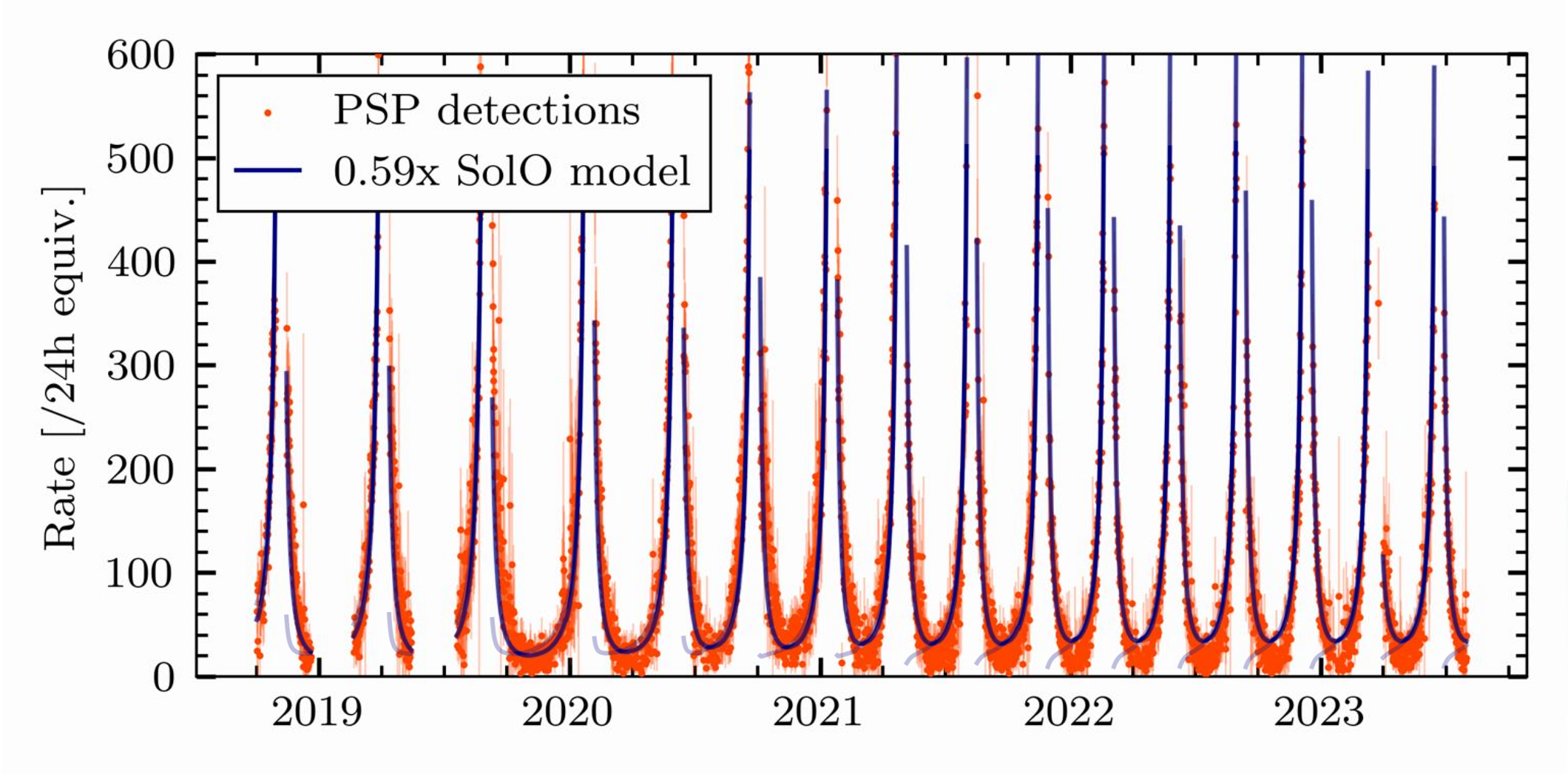
Background removed



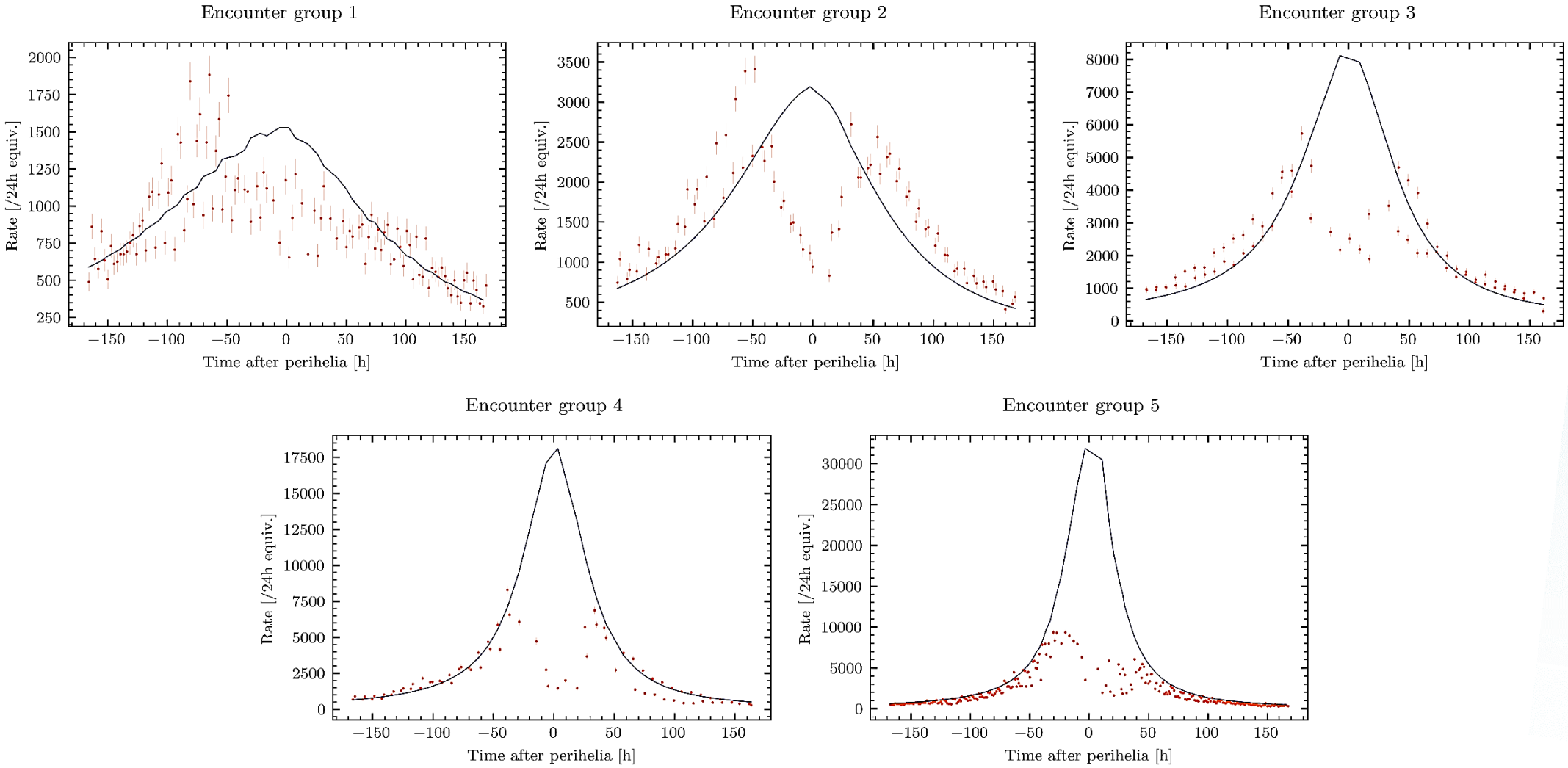
Less sensitive heat shield



Circular dust added



Adapted model – maxima zoom



Conclusions 3.

- PSP dust counts may be fitted with a modified SolO model (SolO posterior - background + 2 parameters)

- Compatible with $\approx 70\%$ front side miss rate
- Compatible with $15/m^2h$ of bound dust (at $1AU$)

Next steps

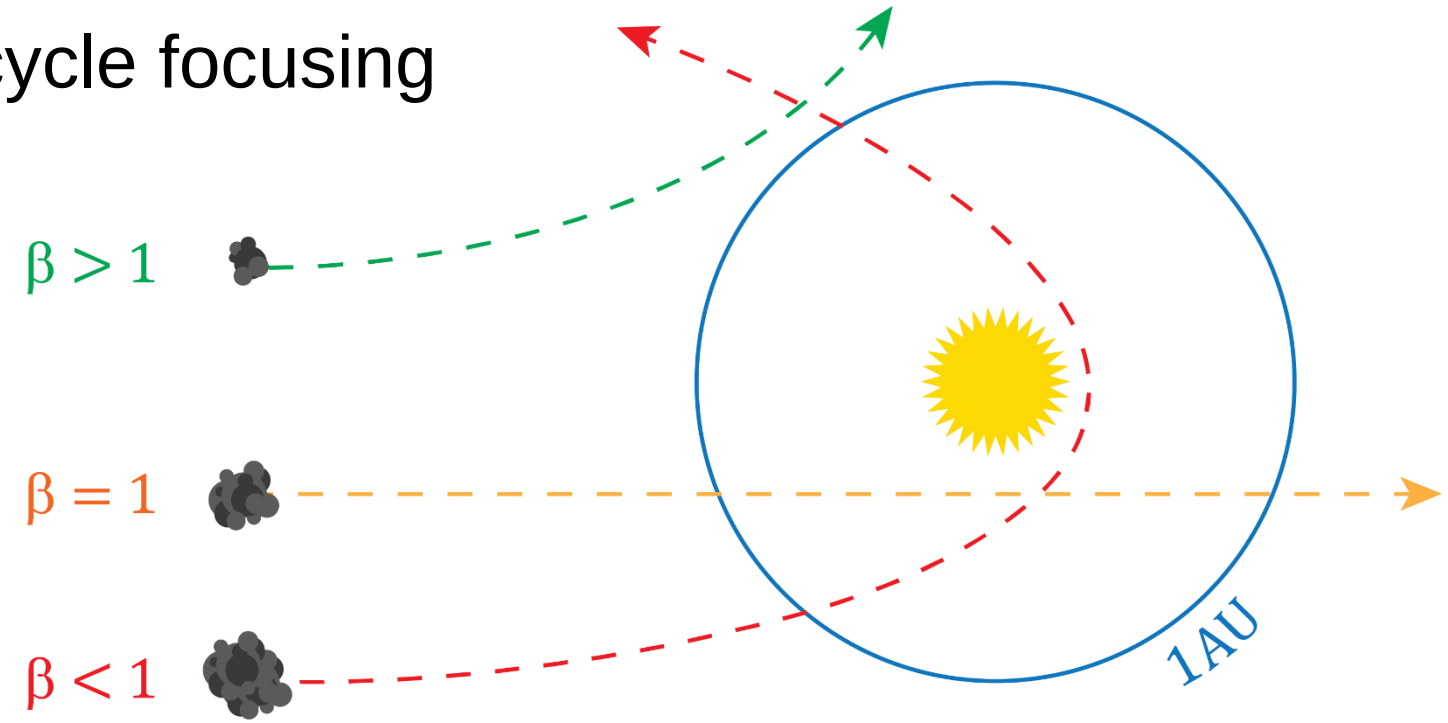
- Actually fit this (fit by eye shown so far)
- See how close to the Sun we can get a good fit
- Now we know we should fit SolO data with a bound dust component

Thank you for your questions!

Backup

Interstellar dust: λ_{ISD}

- Size filter
- Comes from the ecliptics
- Charge ⇒ Solar cycle focusing



Nanodust: λ_{nano}

- Too small for radiation pressure
- Large $Q/m \Rightarrow$ carried by SW
  - Can get trapped at $< 0.1AU$
- Solar cycle focusing

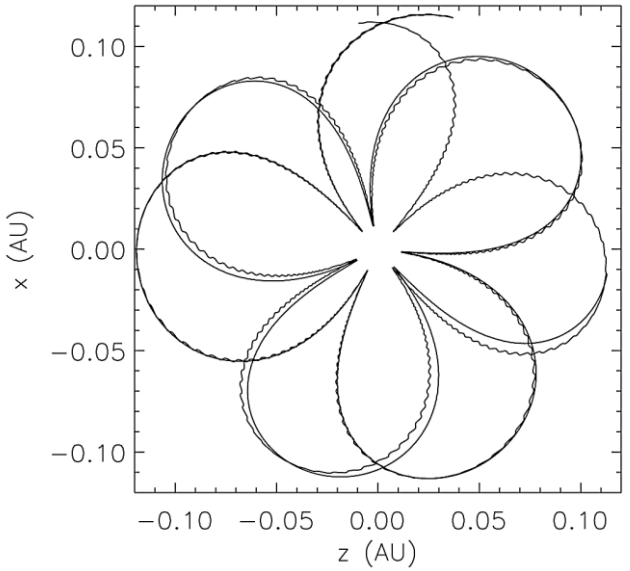
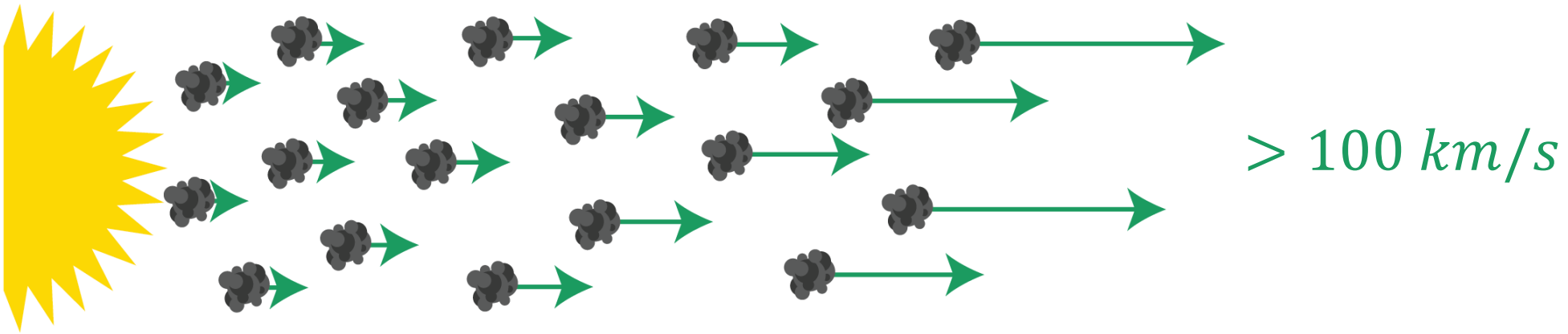
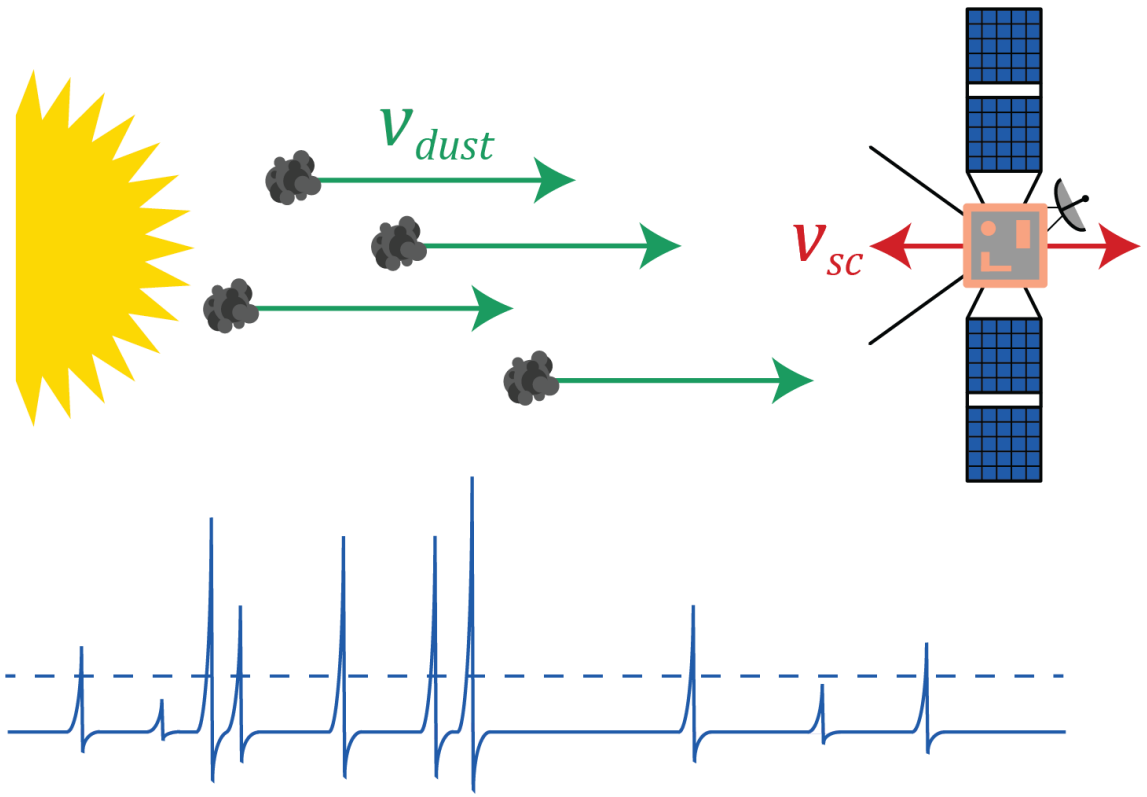


Fig. 4 from Czechowski & Mann (2010)



Solar Orbiter



$$N \sim Poiss(E \cdot R)$$

A *rate function*:

$$R \propto S \cdot \frac{1}{r^2} \cdot v_{rel} \cdot v_{rel}^{\alpha\delta}$$

$$Q \propto m v^{\alpha}$$

$$F(m) = F(m_0)\left(\frac{m}{m_0}\right)^{\delta}$$

! $$v_{rel} = |\boldsymbol{v_{SolO}} - \boldsymbol{v_{dust}}|$$

$$\boldsymbol{v_{dust}} = f(\boldsymbol{r})$$

The statistical view on fitting

- Poisson Process

$$N \sim Poisson(\lambda \cdot E); [\lambda] = s^{-1}$$

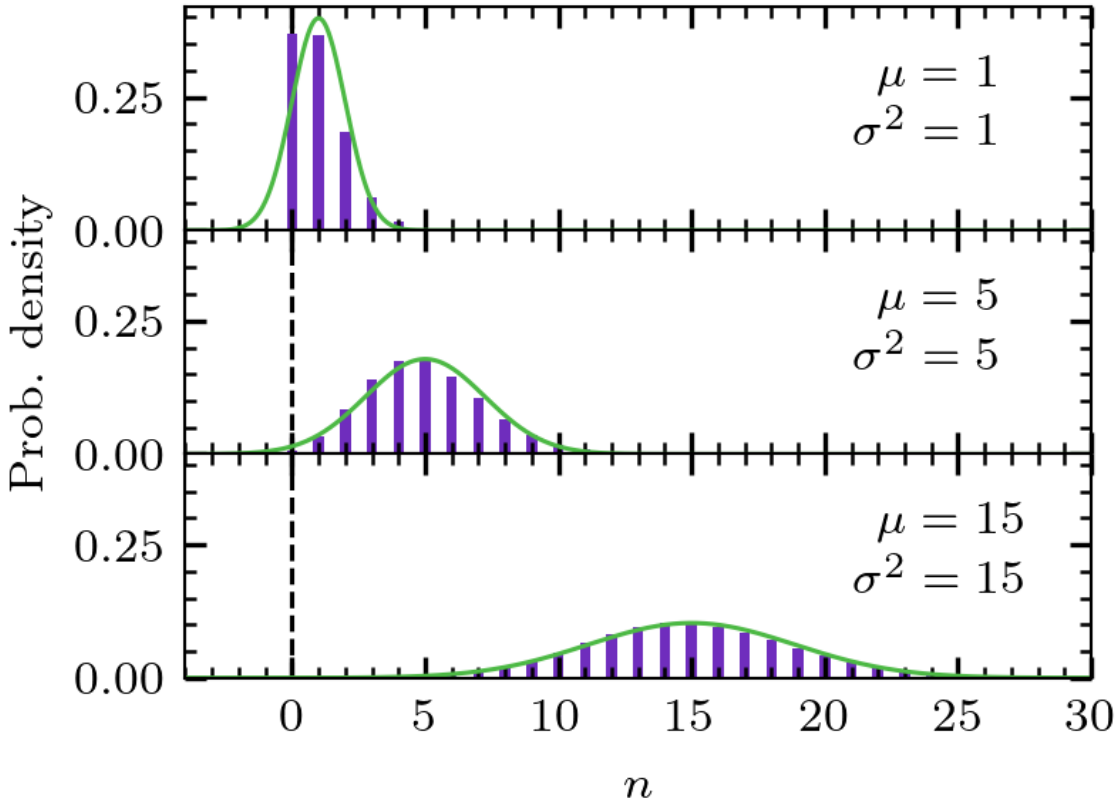
- Several populations make up λ

$$\lambda = \lambda_{\beta} + \lambda_{Kepler} + \lambda_{ISD} + \lambda_{nano} + \lambda_{other}$$

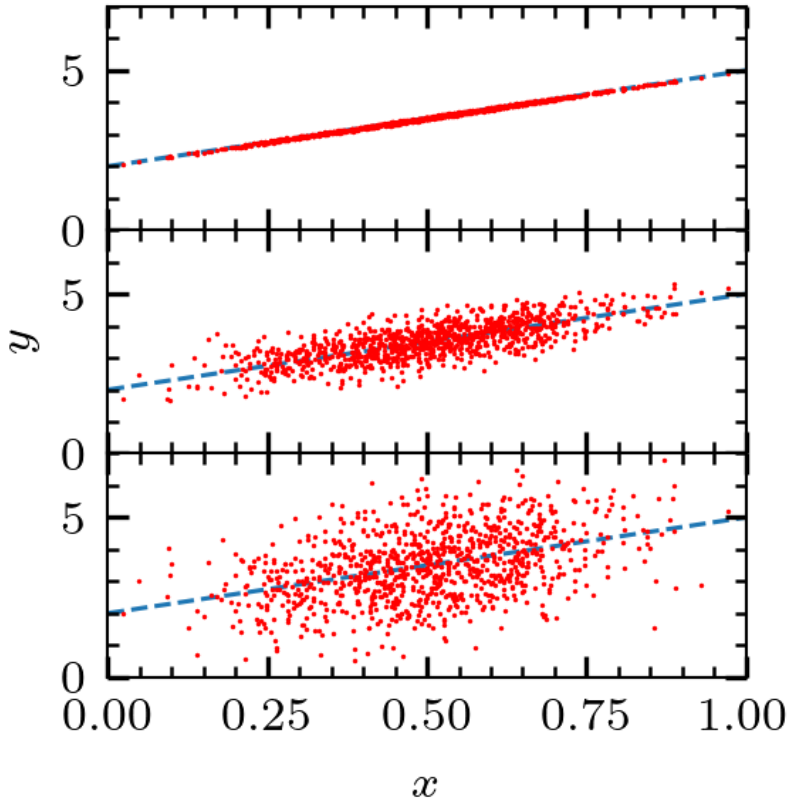
- We can't identify the population from a single impact – demands statistics

Issues with least squares fitting

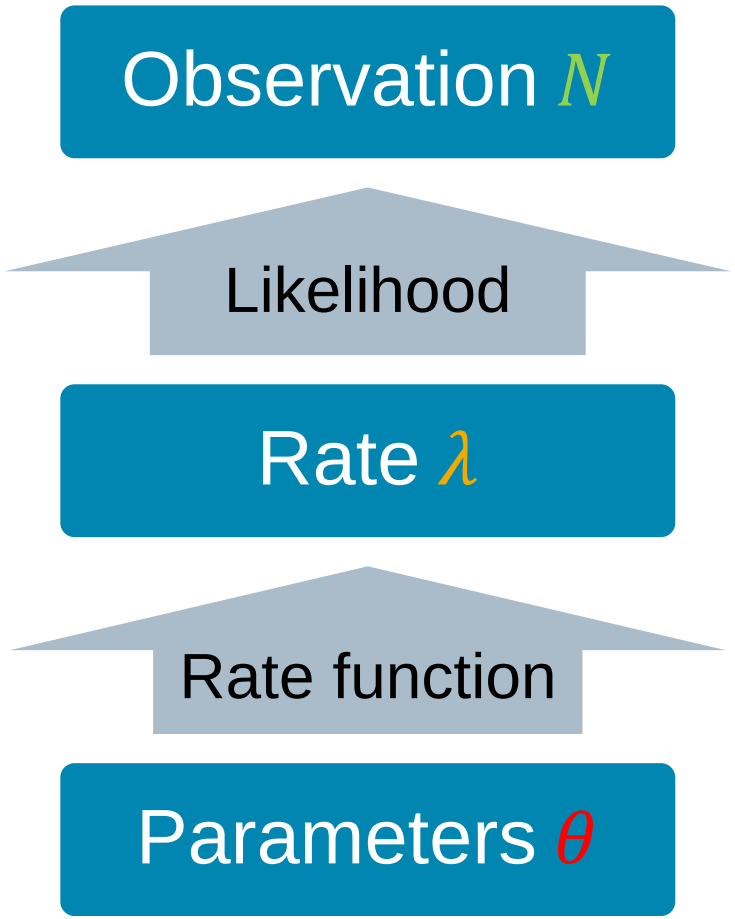
Assumes normal residuals



Unknown confidence



Model with INLA



$$N|\lambda, \boldsymbol{\theta} \sim Poiss\left(E \cdot \lambda(\boldsymbol{\theta})\right)$$

$$\lambda(\boldsymbol{\theta}) = \lambda_\beta \cdot v_{impact}^{\epsilon_v} \cdot r^{\epsilon_r} + \lambda_{bg}$$

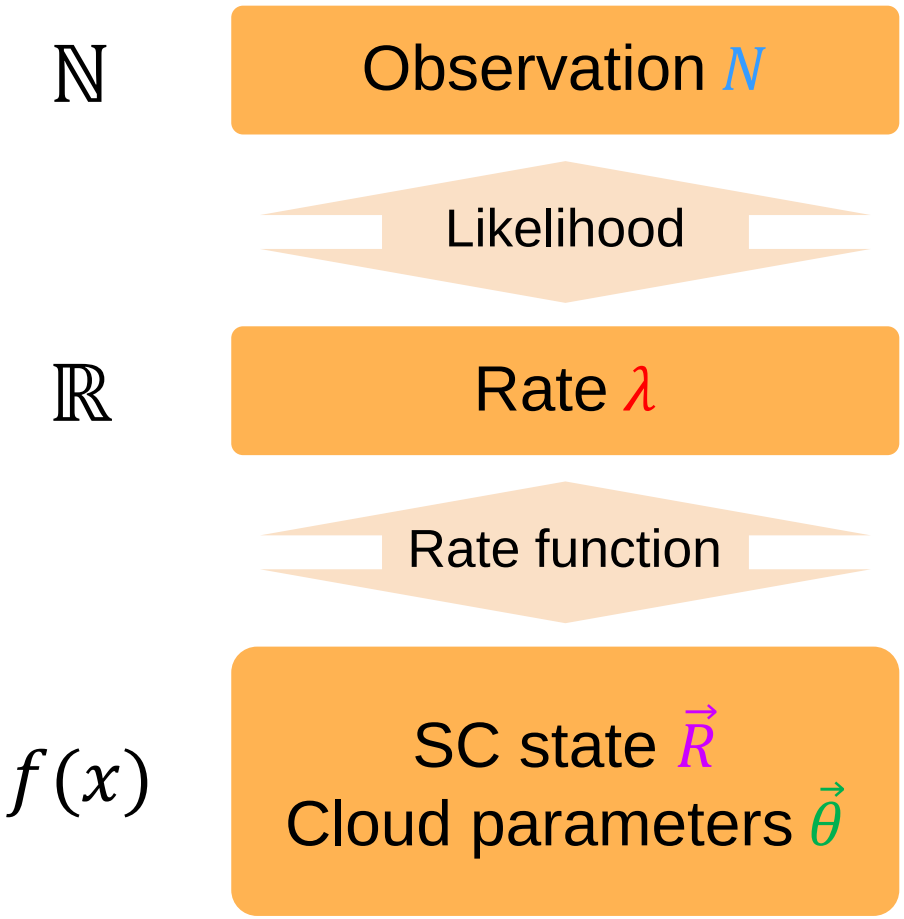
$$\theta = \begin{pmatrix} \epsilon_v \\ \epsilon_r \\ \lambda_\beta \\ \lambda_{bg} \\ v_r \end{pmatrix}$$

$$v_{impact} = \frac{|\boldsymbol{v_{SolO}} - \boldsymbol{v_{dust}}|}{50km/s}$$

$$v_{dust} = v_r \cdot \boldsymbol{e_r} + v_a \cdot \boldsymbol{e_\phi}$$

$$v_a = 12km/s \cdot \frac{0.75AU}{|\boldsymbol{r}|}$$

Bayesian fitting scheme



$$\vec{R} = \begin{pmatrix} \overrightarrow{r_{sc}} \\ \overrightarrow{v_{sc}} \\ S \end{pmatrix}$$

→ SC speed (daily)

→ SC location (daily)

→ Detection area

$$\vec{\theta} = \begin{pmatrix} \epsilon_v \\ \epsilon_r \\ \lambda_\beta \\ \lambda_{bg} \\ v_r \end{pmatrix}$$

→ Velocity exponent

→ Distance exponent

→ Amount of β dust

→ Amount of backg. dust

→ Speed of β dust

Fitting results

$\epsilon_v = 2.04 \pm 0.20$

$2.04 = 1 + \alpha\delta$

$\epsilon_r = -1.61 \pm 0.16$

$1.61 < 2 \Rightarrow slowing$

$\lambda_\beta = 1.96 \pm 0.38$

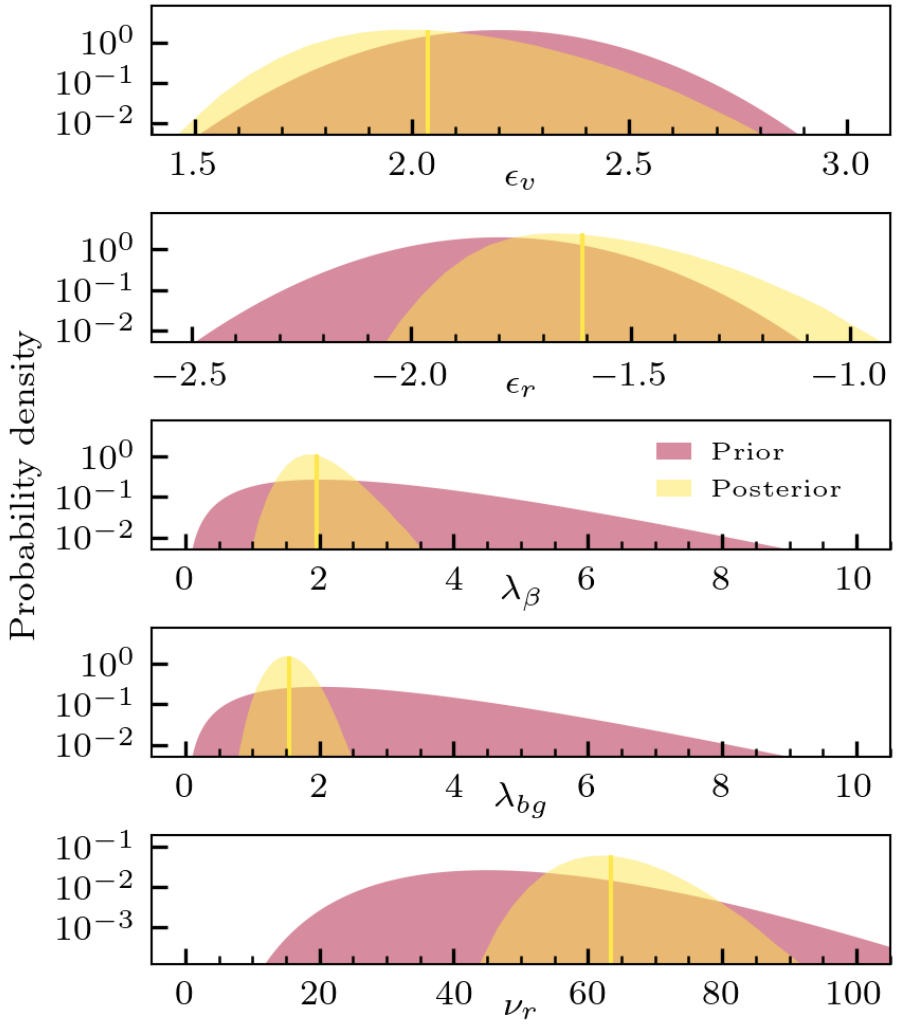
$no\ physics, sadly$

$\lambda_{bg} = 1.54 \pm 0.25$

$about\ 22\% \pm 4\%$

$v_r = 63.4 \pm 6.7$

$rather\ fast$ ☺



A different interpretation

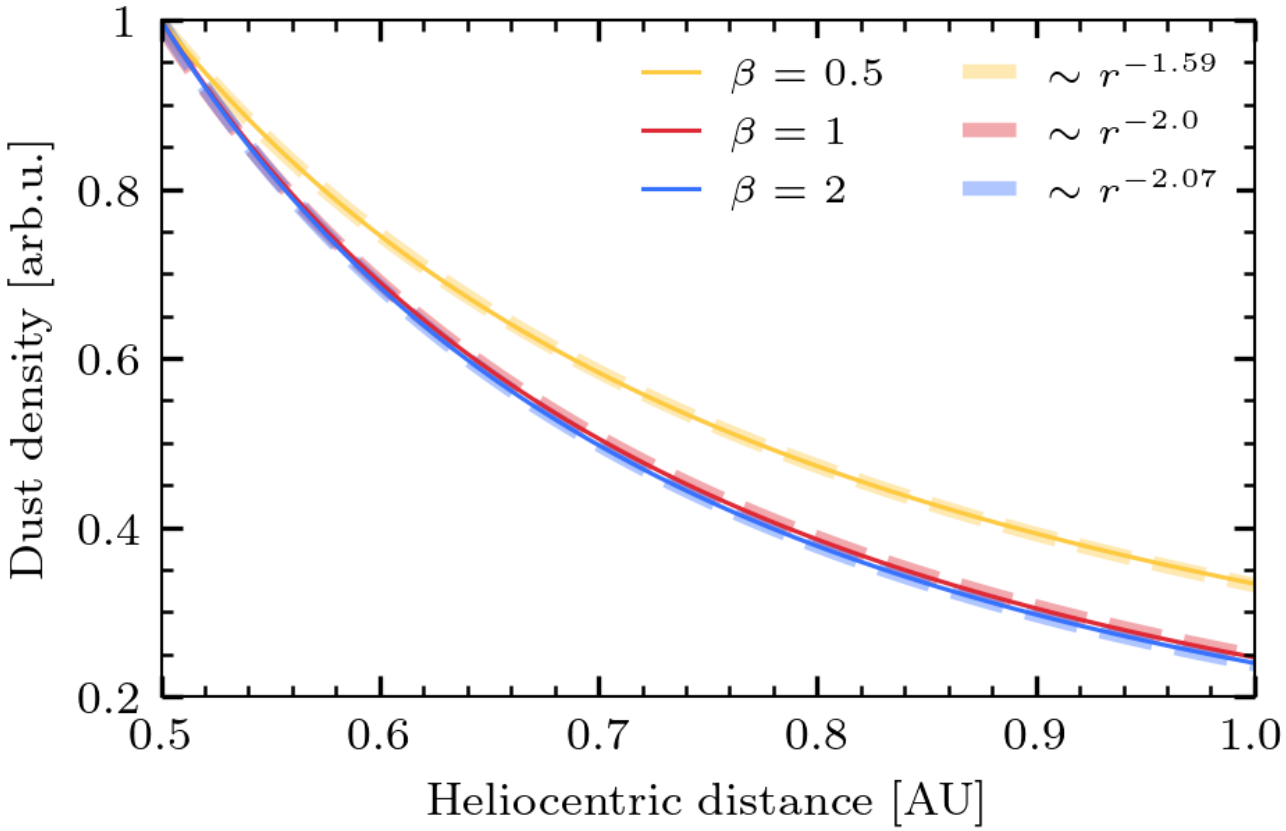
$$R \propto S \cdot \frac{1}{r^2} \cdot \frac{v_{rel}}{v_{rad}} \cdot v_{rel}^{\alpha\delta}$$

$$\Downarrow \; v_{rad} \propto r^{\xi} \; \Downarrow$$

$$R \propto S \cdot \frac{1}{r^{\epsilon}} \cdot v_{rel} \cdot v_{rel}^{\alpha\delta}$$

$$\epsilon = 2 + \xi$$

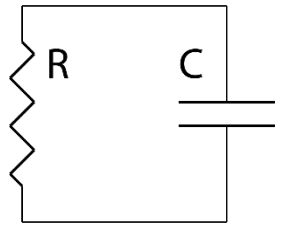
$$F_{effective} = (1 - \beta) \cdot F_{gravity}$$

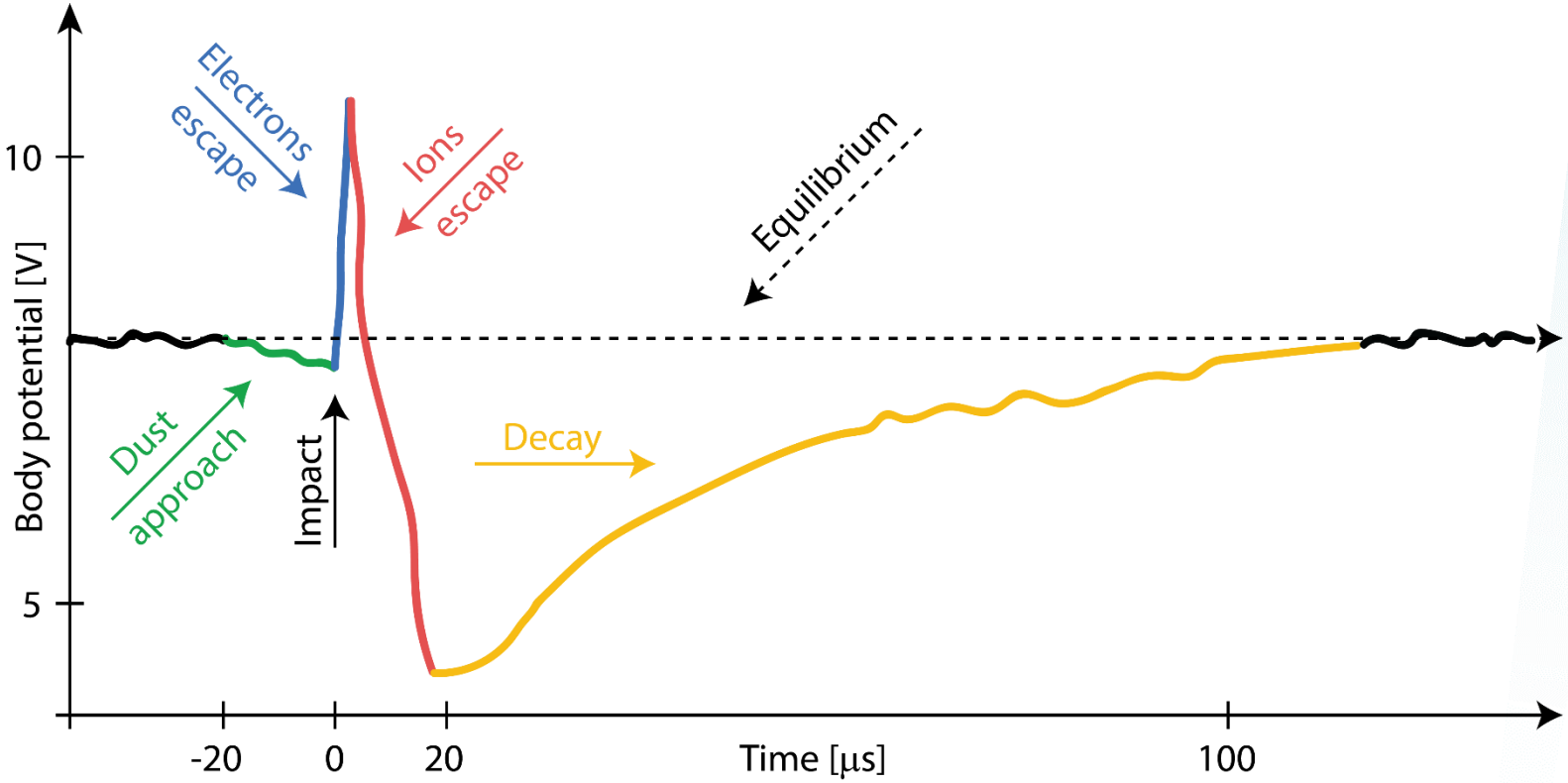


The monopole signature

- Plume is neutral in the beginning, except for the grain‘s charge

- Positive SC
- Negative grain
- RC decay:

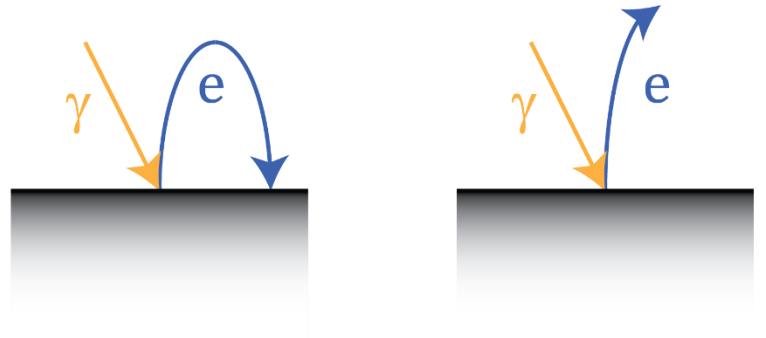




Spacecraft body‘s potential - sunlight

- Equilibrium:

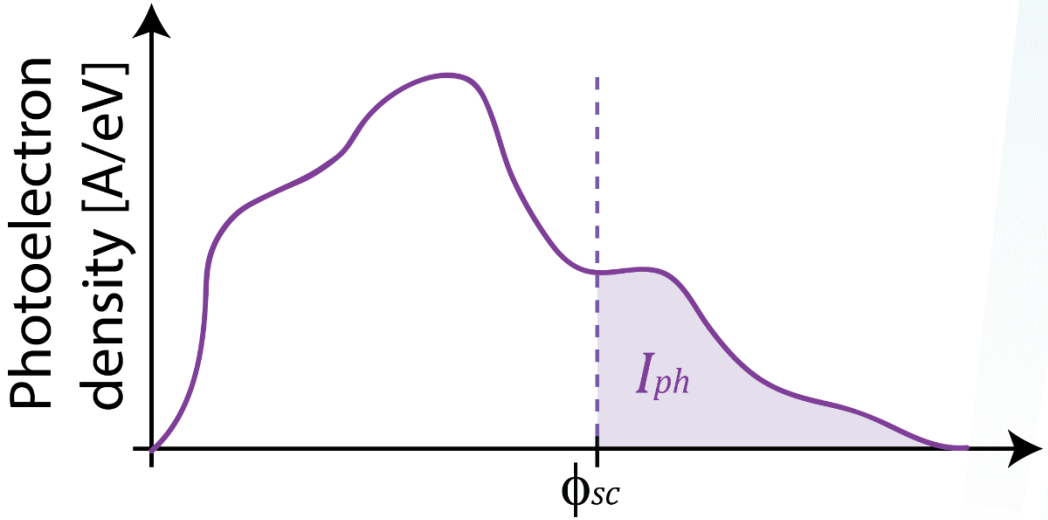
$$0 = I_{SW}^{+}(\phi) - I_{SW}^{-}(\phi) + I_{ph}^{-}(\phi)$$



- Potential ϕ_{sc} such that:

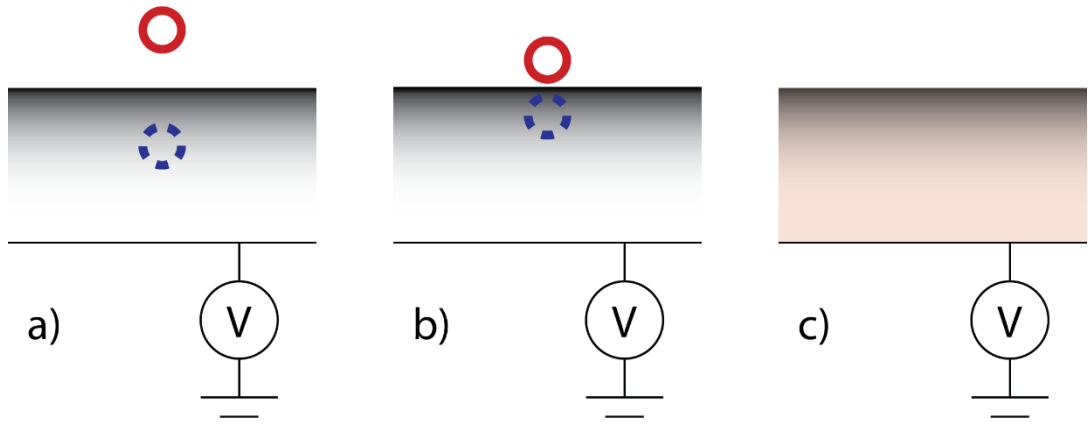
$$I_{ph}^{-}(\phi_{sc}) \approx I_{SW}^{-}(\phi_{sc})$$

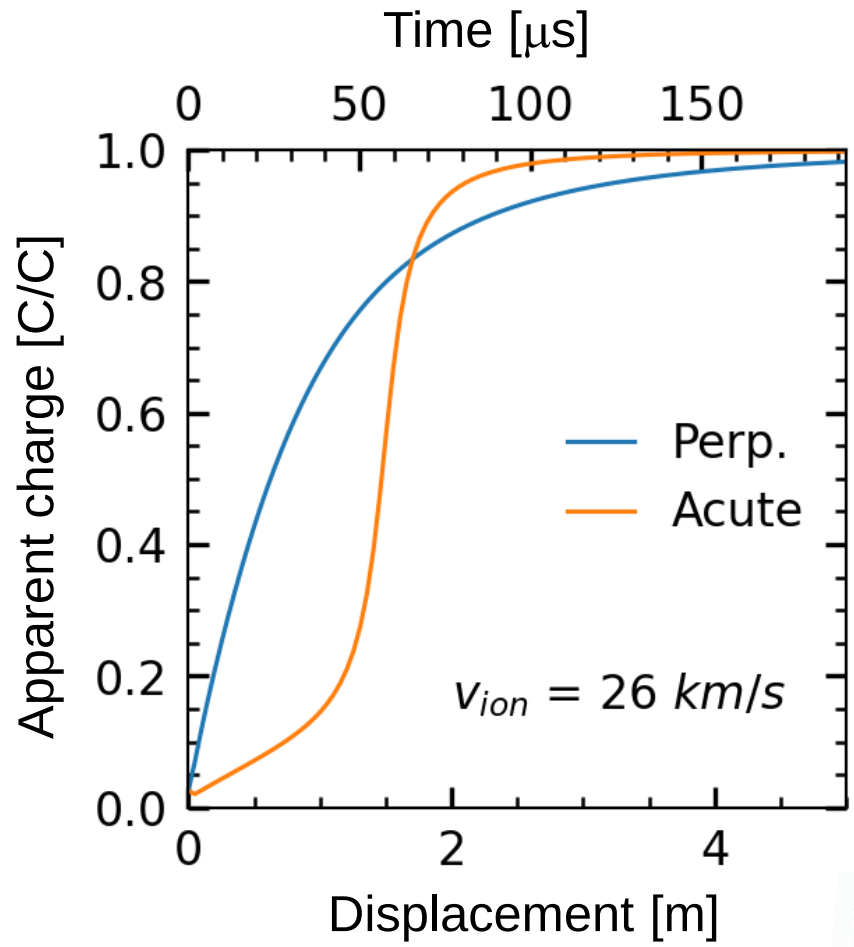
$$\phi_{sc} > 0$$



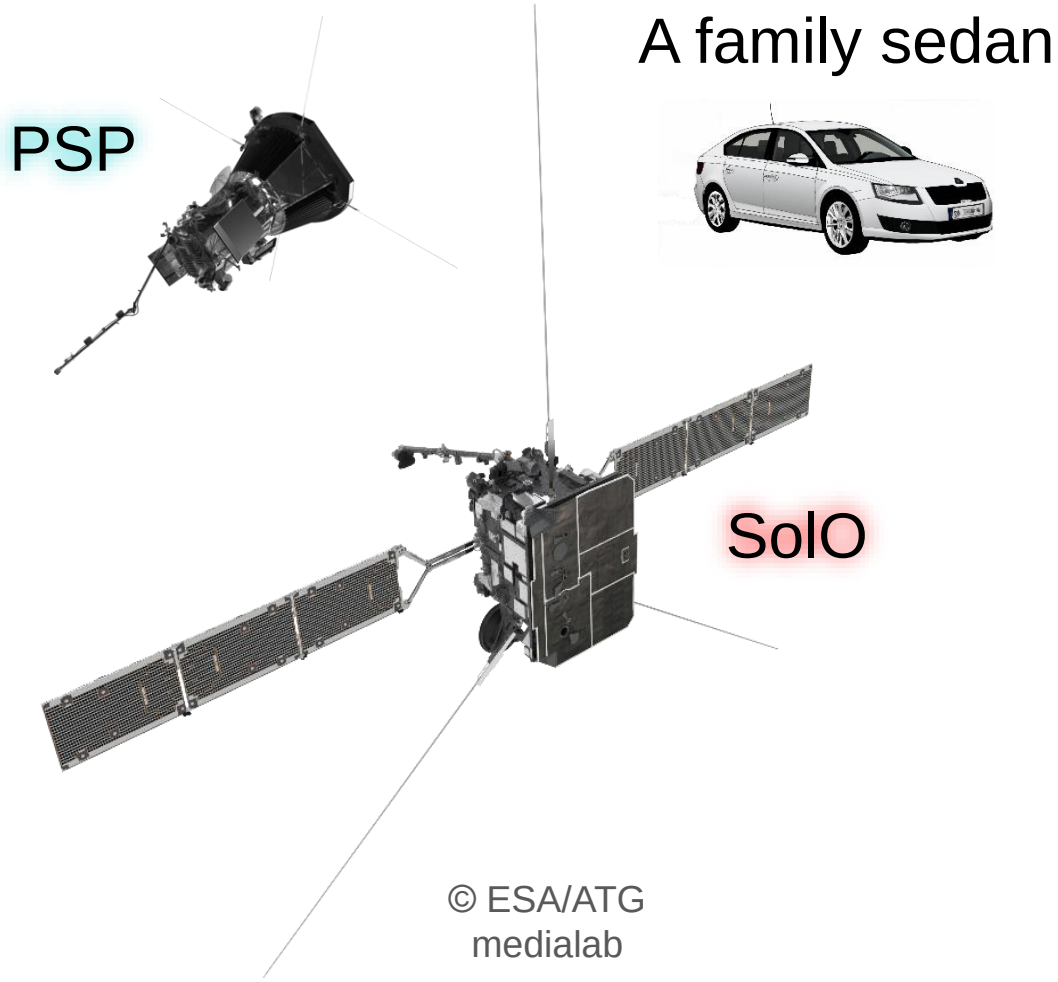
Escaping charges

- No difference between „close“ and „touching“
- We only see what escapes

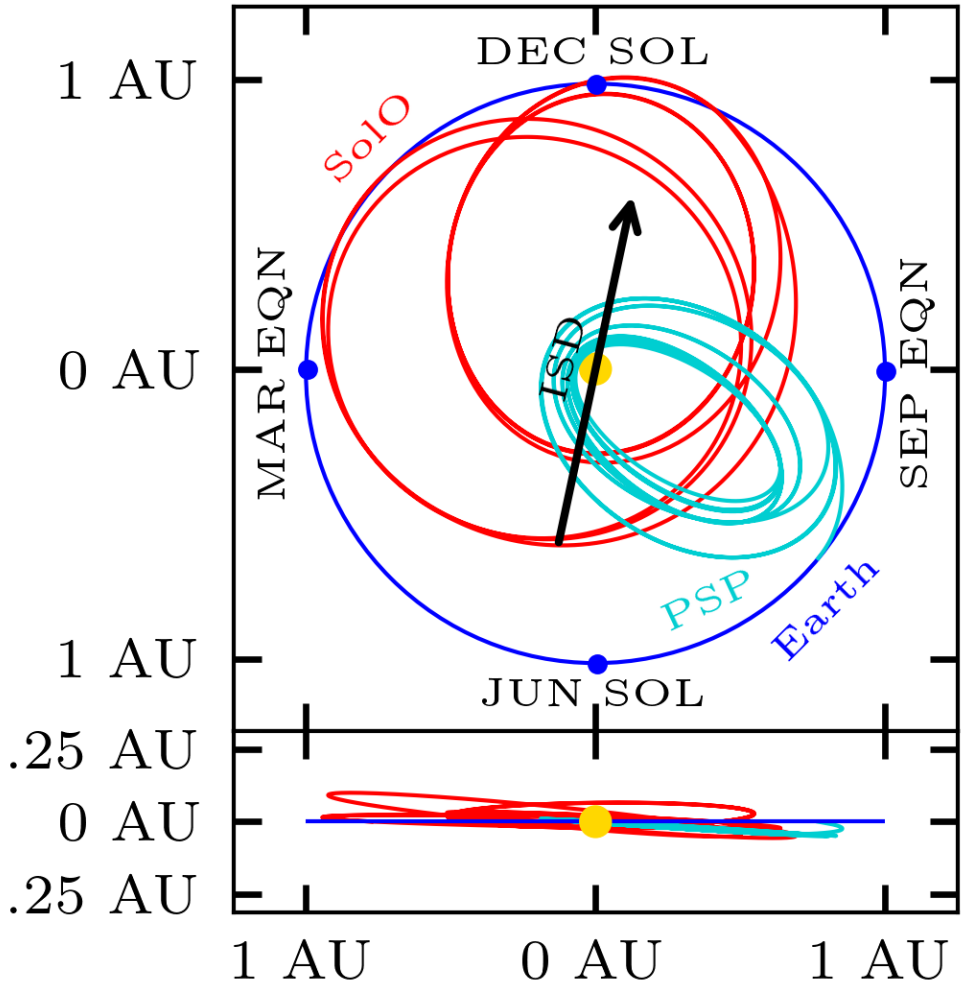




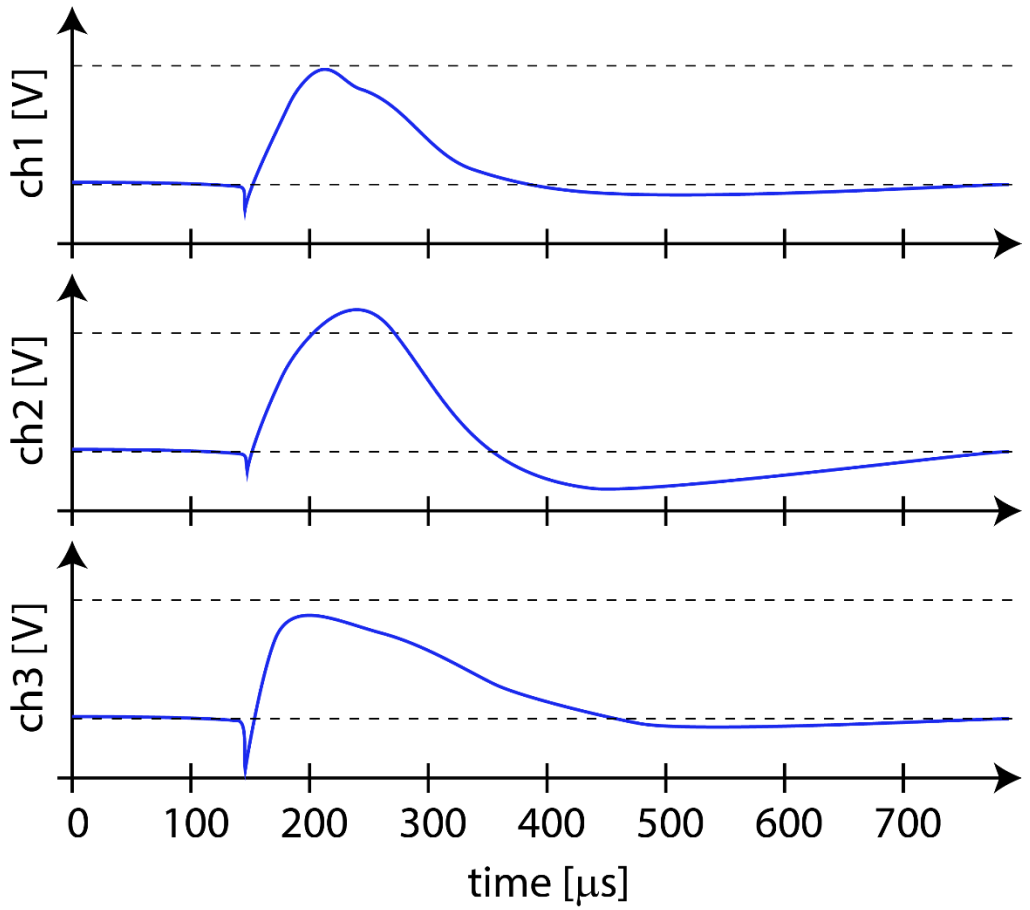
Solar Orbiter & Parker Solar Probe

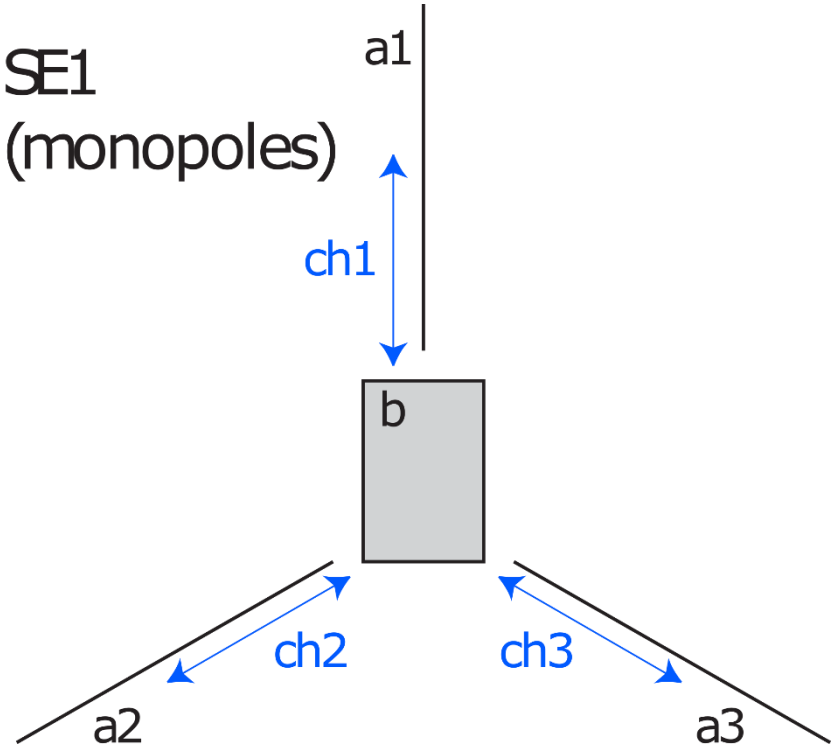


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medialab

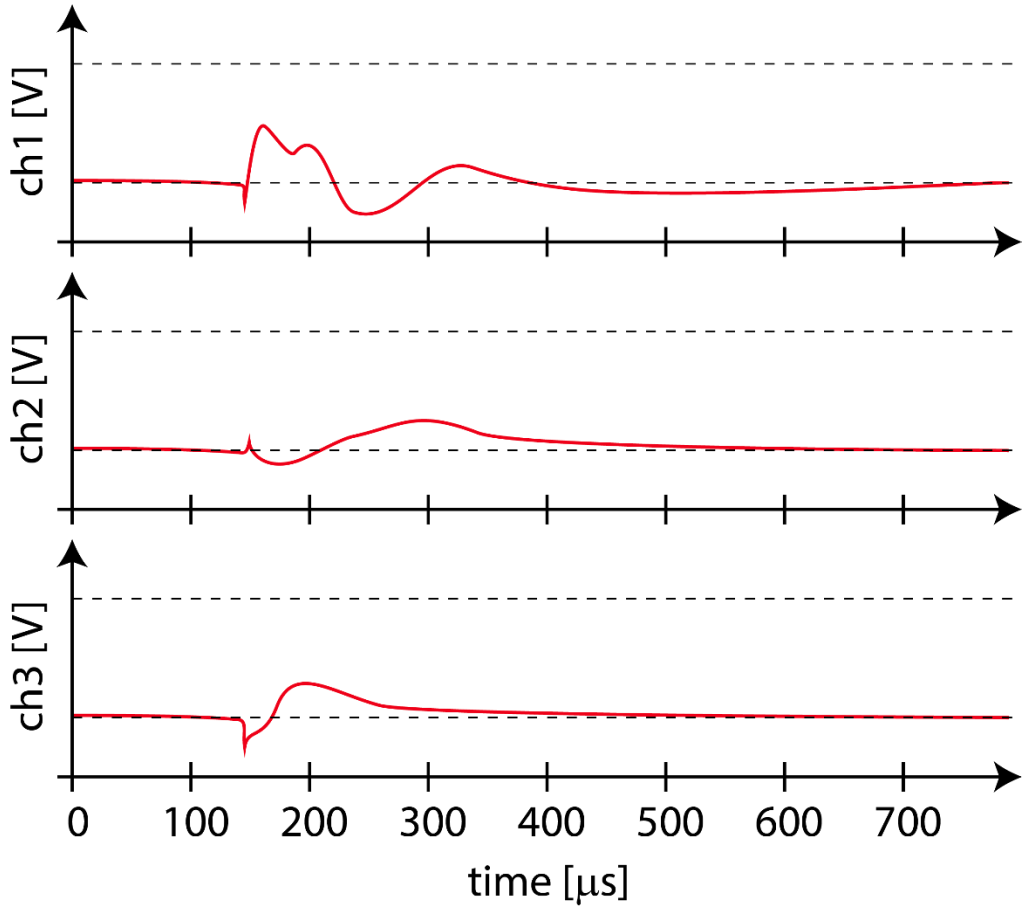


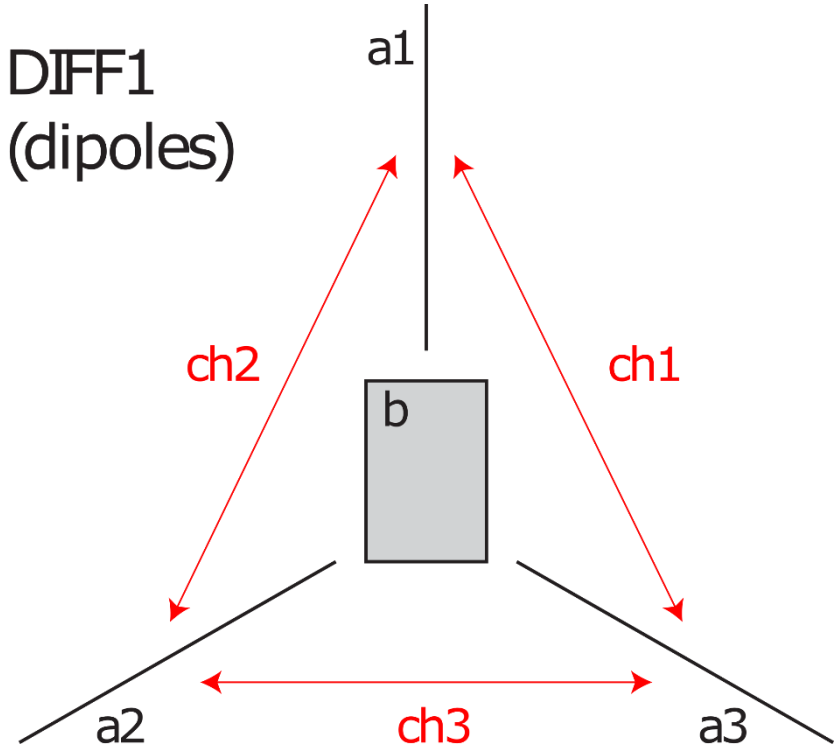
Solar Orbiter - Multiple monopoles





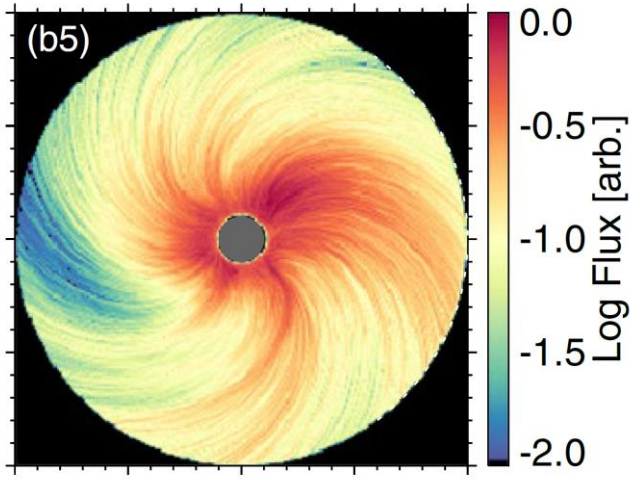
Solar Orbiter - Multiple dipoles



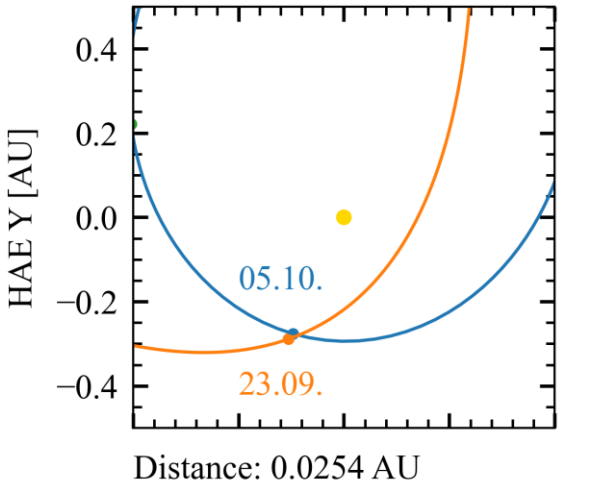


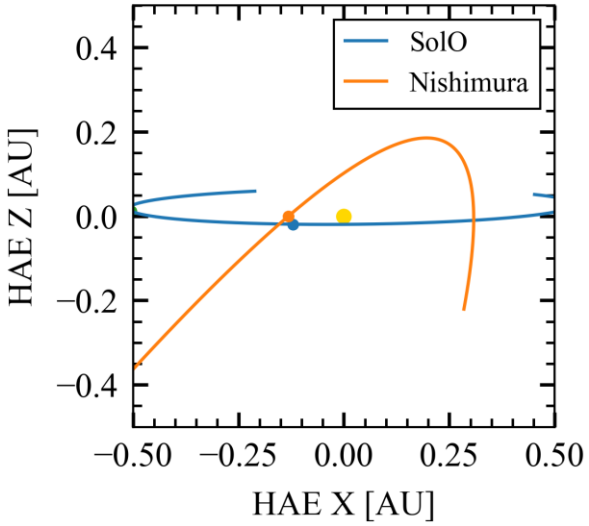
Outlook

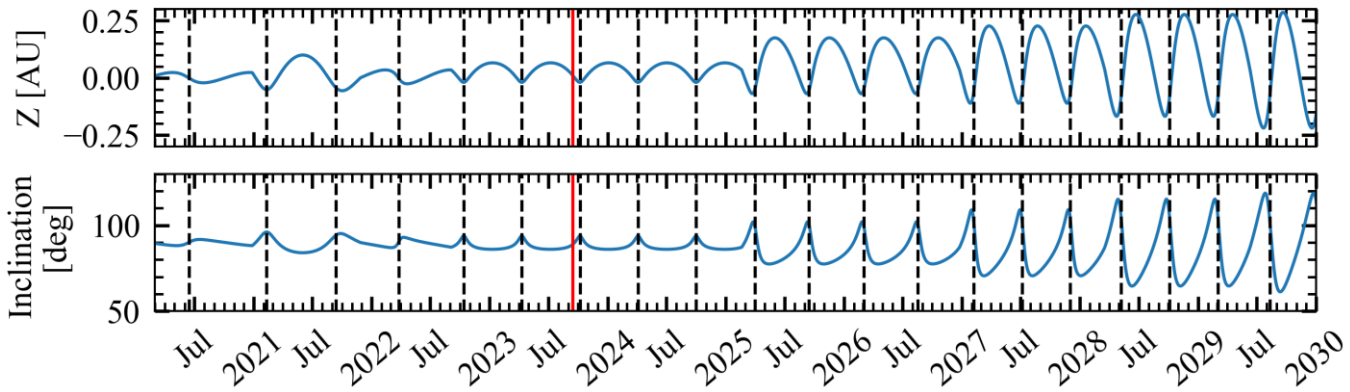
- Nanodust
- Comet nishimura
- Inclination



20 nm @ solar max.,
Fig. 3 from Poppe & Lee (2022)

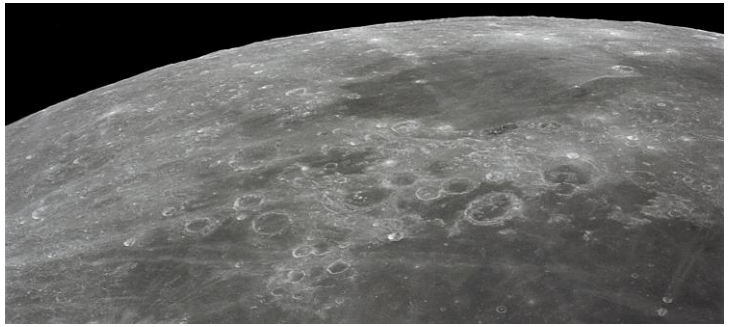






Numbers in perspective

- Flux measured by several means
- Small ≫ Large



d_{dust}	m_{dust}	$flux\ [\mathrm{m}^2 s]$	$\tau_{waiting}$
$100nm$	$10^{-15}g$	10^{-3}	$2min\ @Solar\ 0.$
$1\mu m$	$10^{-12}g$	$5 \cdot 10^{-5}$	$40min\ @Solar\ 0.$
$1mm$	$10^{-3}g$	$5 \cdot 10^{-11}$	$76yr\ @Solar\ 0.$
$1mm$	$10^{-3}g$	$5 \cdot 10^{-11}$	$140\mu s\ @Earth$

Dust flux near Earth, according to Grün et al. 1985

$$\sum_{Earth} dust\ intake \approx 40 \frac{t}{day}$$

$$m_{mesosph.} \approx 5 \cdot 10^{12} t$$

$$\Rightarrow 100\%\ in\ 300\ Myr$$
$$\Rightarrow 1‰\ in\ 300\ kyr$$