Predictions for the Interstellar Dust that Interstellar Probe Could Detect

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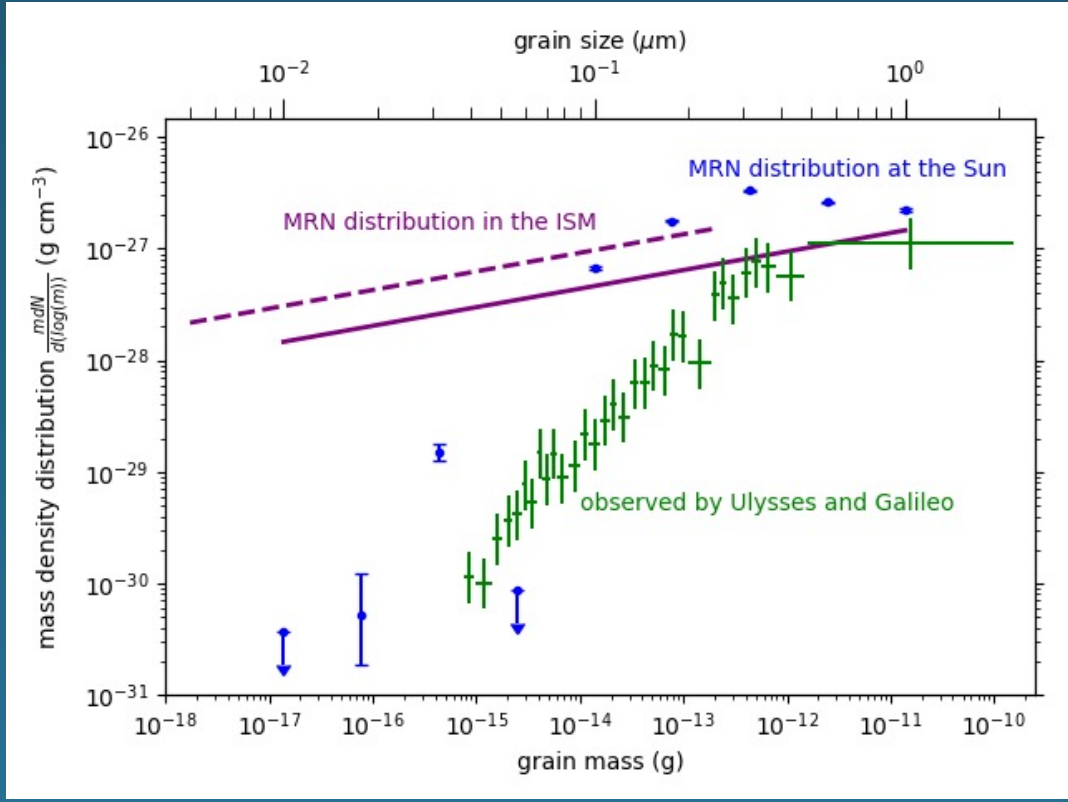
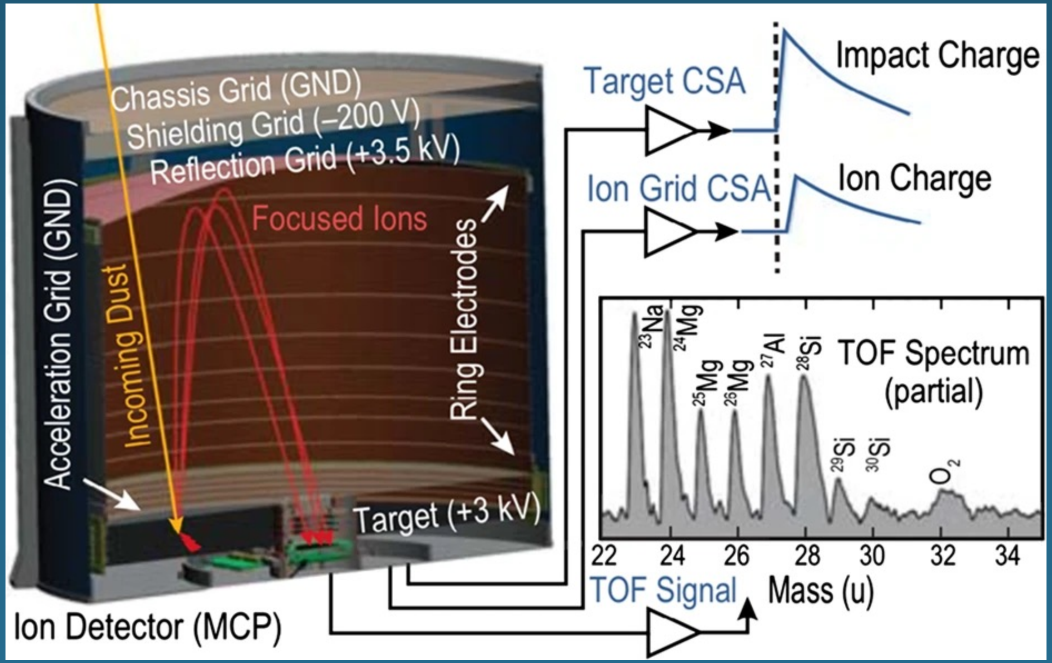
Mysteries of the interstellar dust in the heliosphere

- dust size distribution observed by Ulysses isn't consistent with that derived for the interstellar medium in general
  - extends to large grain sizes, $a > 1$ µm
  - lacks small grains, $a < 0.04$ µm
  - mass distribution is more highly weighted toward the high end
- filtration by the heliospheric B field is expected, but how much is uncertain – depends on details of time dependence, heliospheric current sheet



Interstellar Probe's dust detector will provide unprecedented information on interstellar dust

- variation of the dust density with distance in the heliosphere
- variation of the dust size distribution with distance
- dust composition, which may vary with distance
- finally, **the unfiltered dust density and size distribution in the Local Interstellar Cloud**



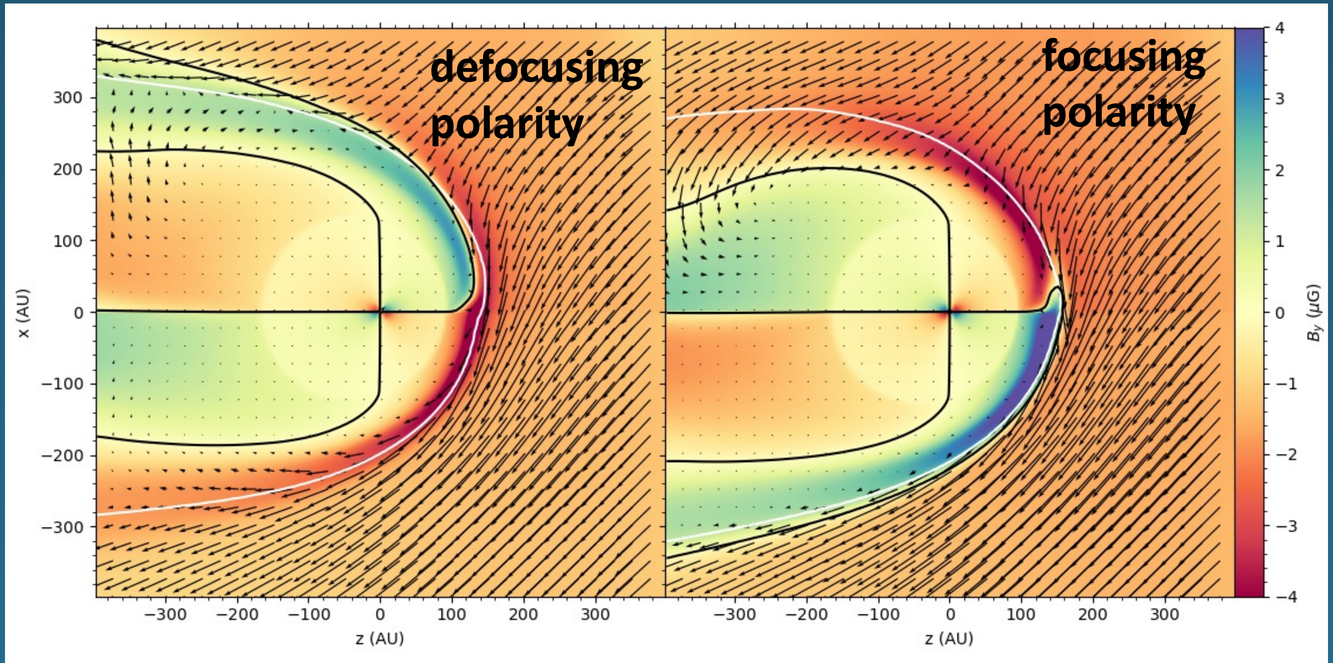
Functional drawing of IMAP's dust detector (IDEX) which will allow measurement of dust composition. ISP's detector should have such capabilities (from McComas et al. (2018))

Modeling interstellar dust transport through the heliosphere

In Slavin et al. (2012) we modeled dust transport through the heliosphere starting in the undisturbed ISM.

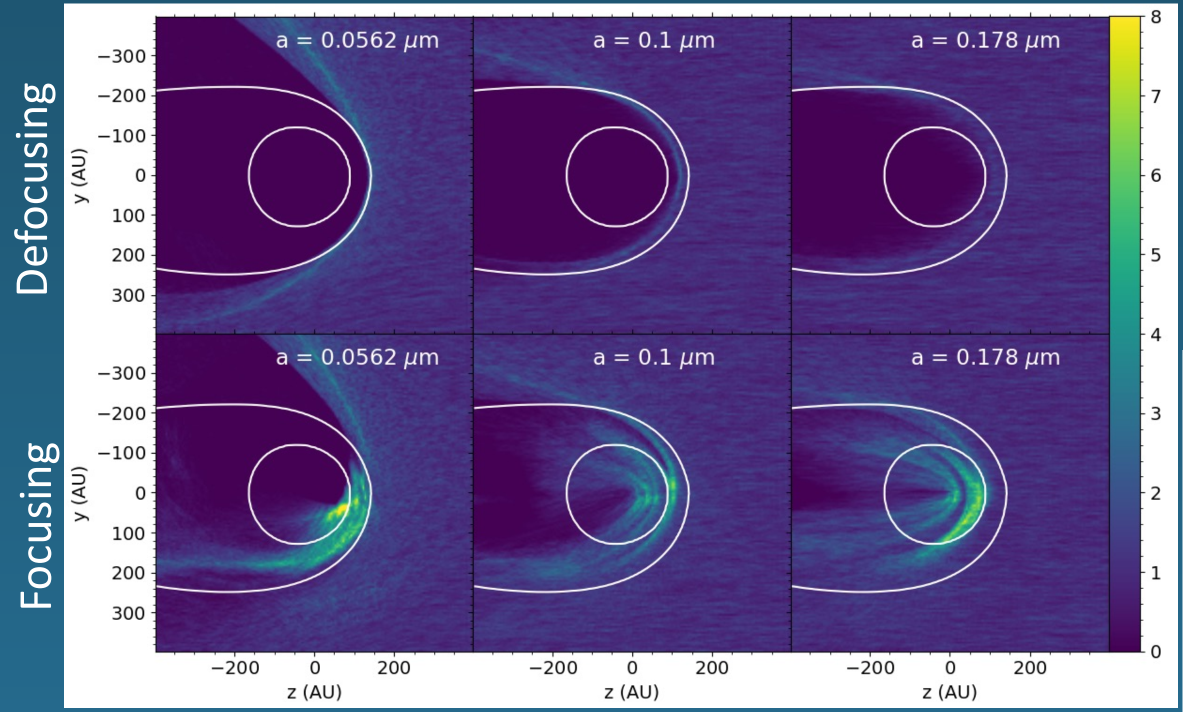
We used two steady flow, non-evolving heliosphere models – one for each polarity of the solar wind magnetic field

Others, e.g. Landgraf (2000), Czechowski & Mann (2003), Sterken et al. (2013), Alexashov et al. (2016), have also modeled aspects of the dust transport, with varying assumptions.



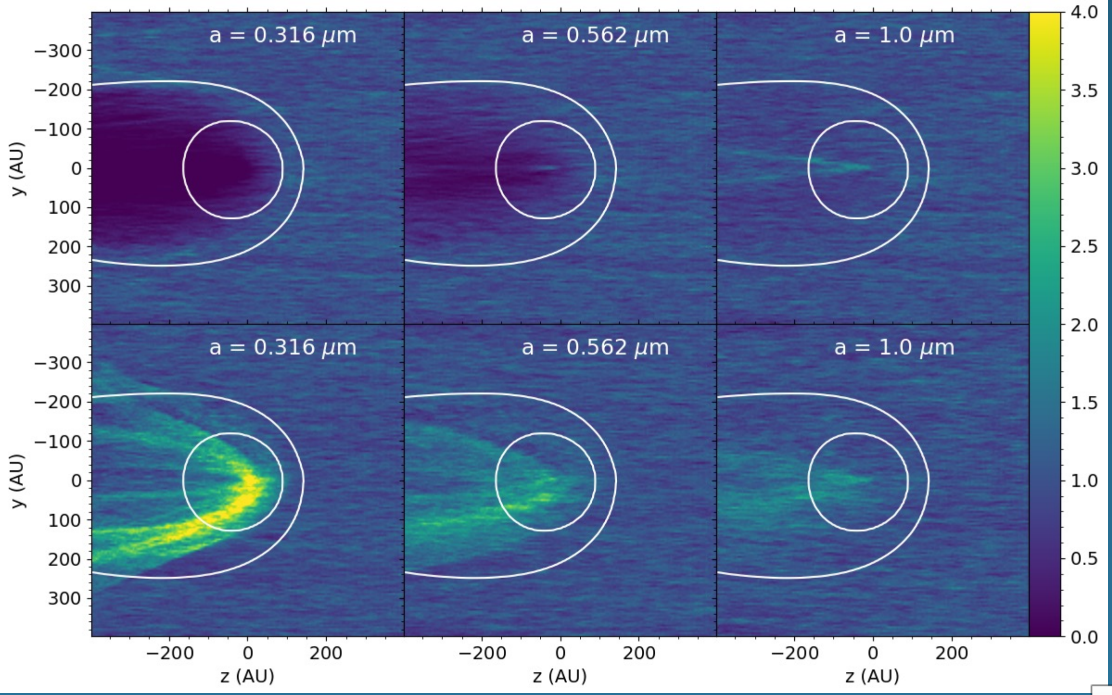
Magnetic field for the heliosphere models used for two different polarities of the solar wind magnetic field. In reality field flips about every 11 years. Arrows show projected strength and direction of the magnetic field, colors show strength of field in the y-direction (out of the screen). (From Slavin et al 2012)

Dust density results from Slavin et al. (2012)



Results for slice in the ecliptic plane. Top rows are for defocusing solar wind polarity, bottom rows for focusing polarity.

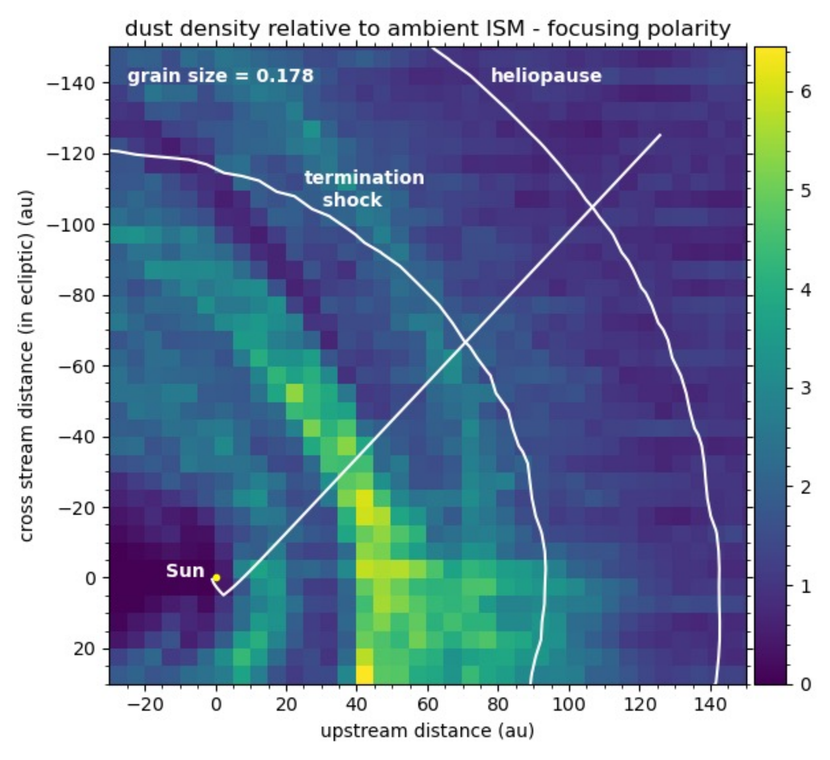
In reality grains pass through focusing and defocusing fields on their way into the heliosphere.

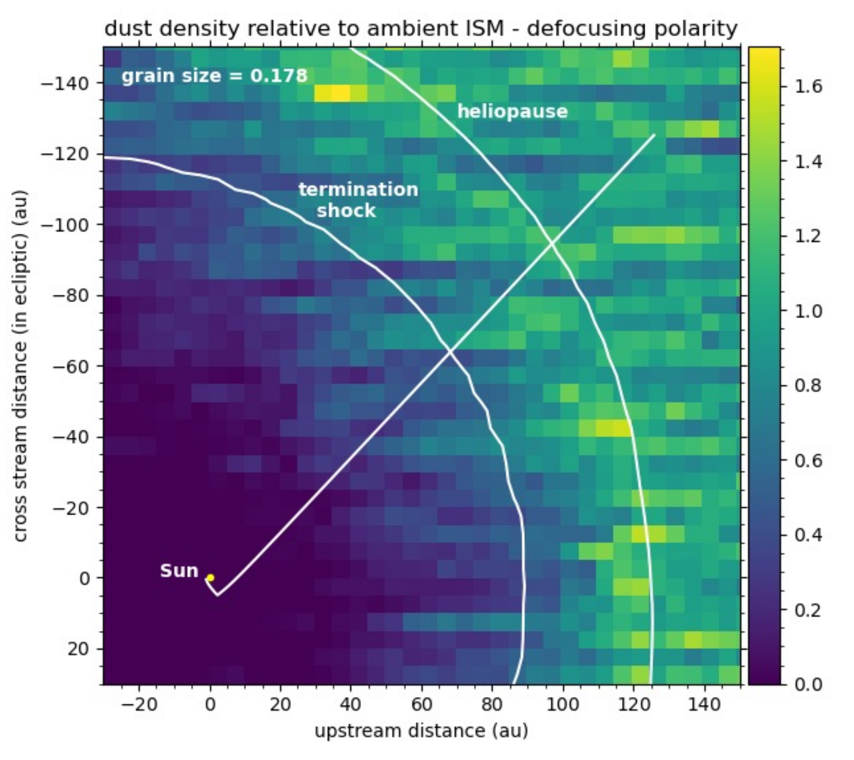


For defocusing polarity grains smaller than ~0.5 μm are excluded from the inner heliosphere. For focusing polarity grains as small as ~0.05 μm enter and for larger grains have enhanced density.

Dust flux along possible ISP trajectory

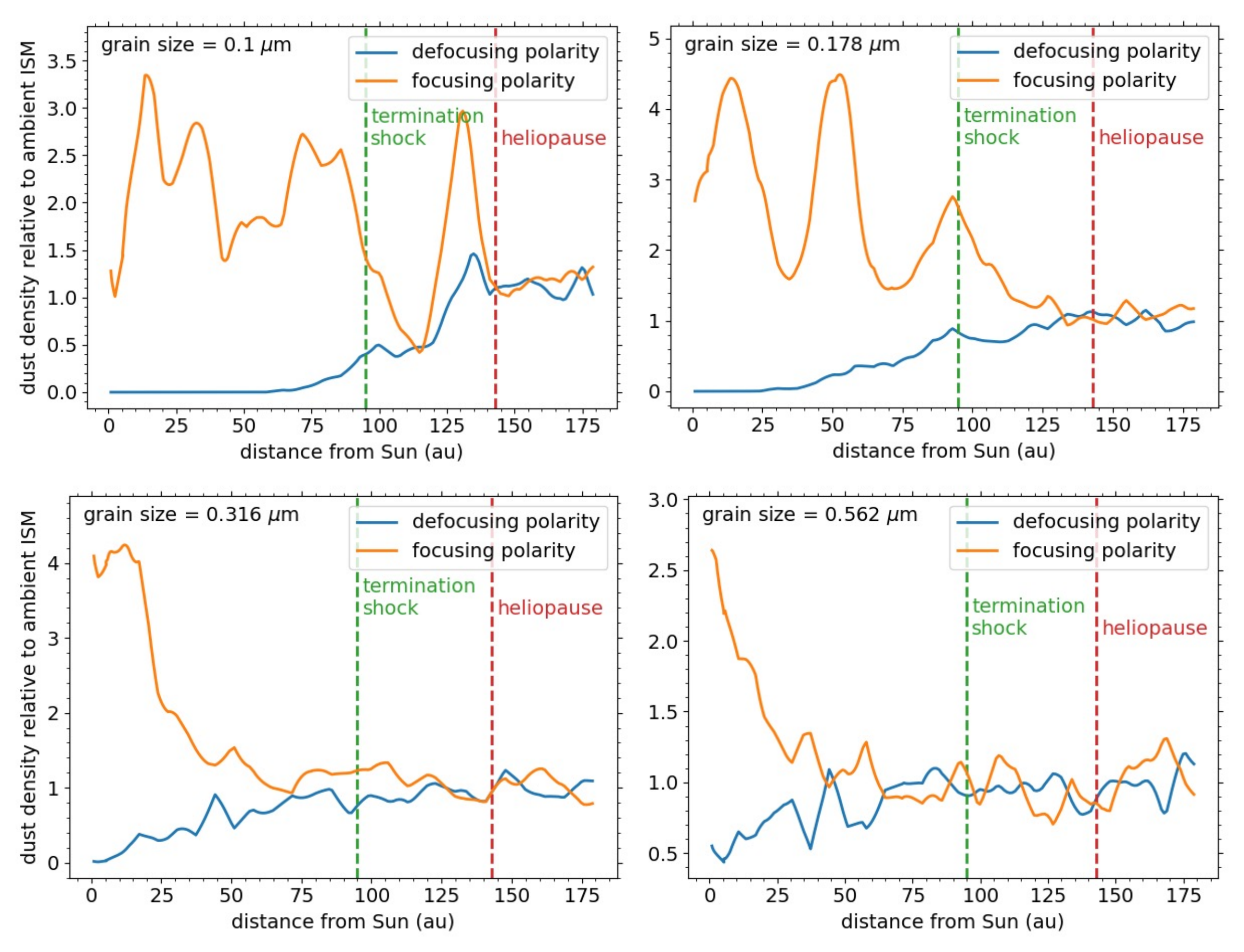
We use a possible trajectory for Interstellar Probe which includes an encounter with Quaoar (provided by Veerle Sterken & Silvan Hunziker) with a launch on 10 January 2040





Trajectory remains fairly close to the ecliptic plane and in generally upwind direction. Dust density enhancement should be somewhere between the cases shown in these two figures. (Note: scales differ between figures)

Results for dust density along trajectory

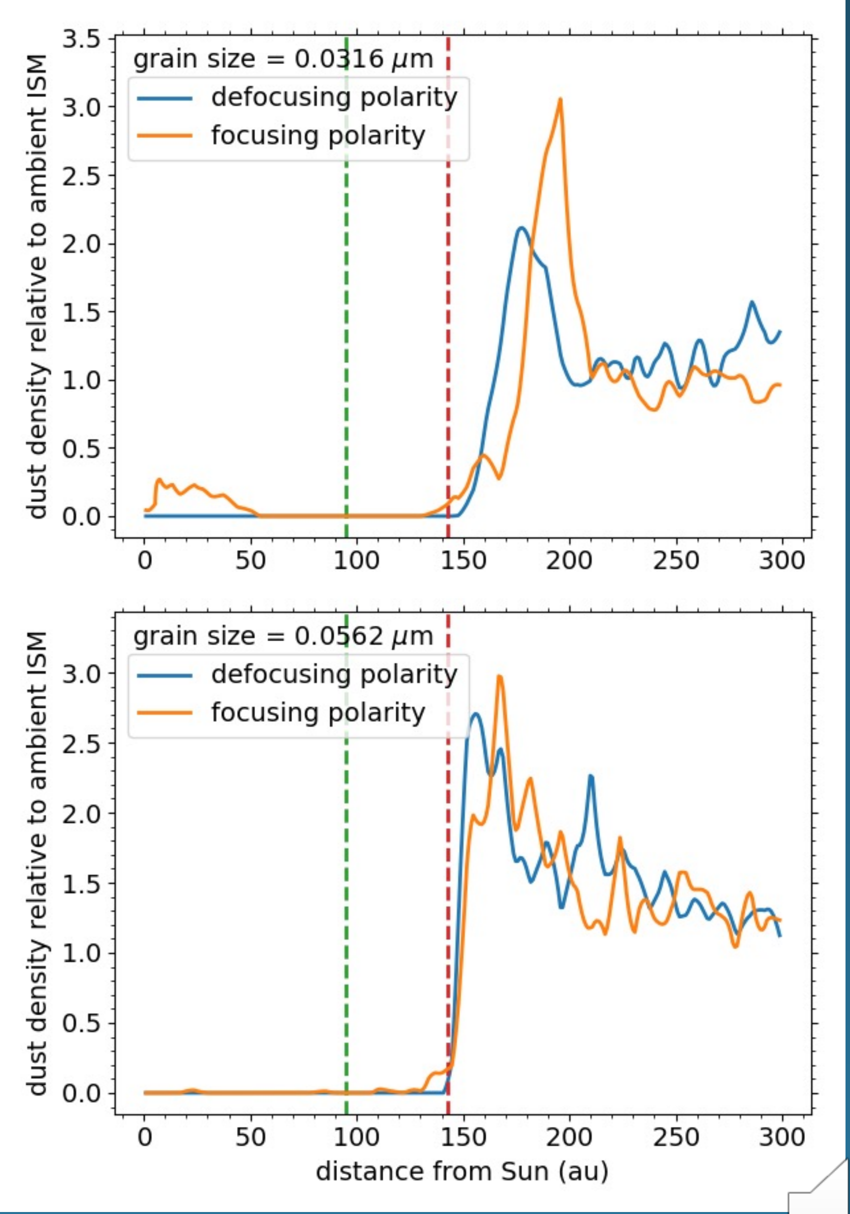


- There are stark differences between the predicted fluxes inside the heliopause for the focusing vs. defocusing models; differences are larger for smaller grains
- Outside the heliopause fluxes are essentially identical for the two models
- Inside the heliopause there is substantial structure in the flux for the focusing model

Accurate predictions for fluxes inside the heliosphere require use of an evolving heliosphere model in concert with a Monte Carlo dust model

Small grains: enhanced density near the heliopause

- For grains with sizes of 0.03 – 0.05 μm the ambient interstellar dust density is not reached until well beyond the heliopause
- Such grains are large enough that their gyroradii are ∼10 au in the outer heliosphere
- As interstellar B field is compressed upwind of the heliopause, grains slip at first
- B field compression then leads to smaller gyroradii and enhanced dust density



Summary

- Dust flux inside of the heliopause depends strongly on grain size and and likely changes with solar cycle - requires evolving heliosphere models for accurate prediction. Variations in flux of ~0.1 μm grains will contain clues to outer heliosphere structure.
- For large grains the flux reaches the interstellar value around the heliopause
- For small grains there is a long tail – density is high right at heliopause and slowly declines to interstellar value. Grains are more tightly coupled to B field, so will reflect compression of the field at the heliopause

ISP has the potential to reveal clues to the nature of ISD while still in the inner heliosphere, but needs to pass the heliopause to give a clear view of the ISD grain size distribution and total content.