Nanodust Released in Interplanetary Collisions

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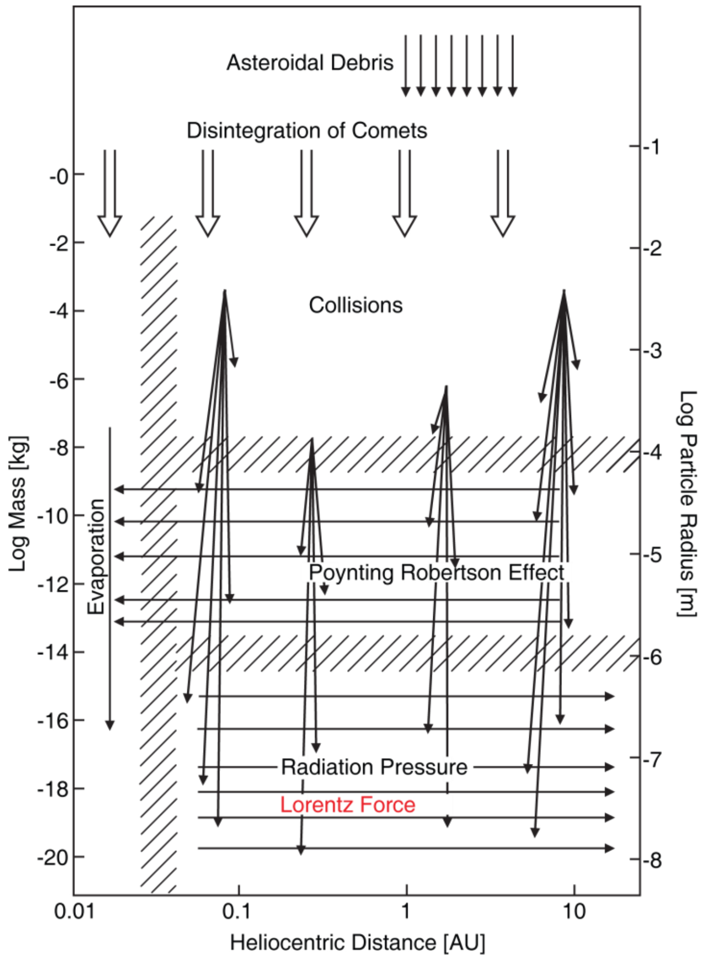
Outline

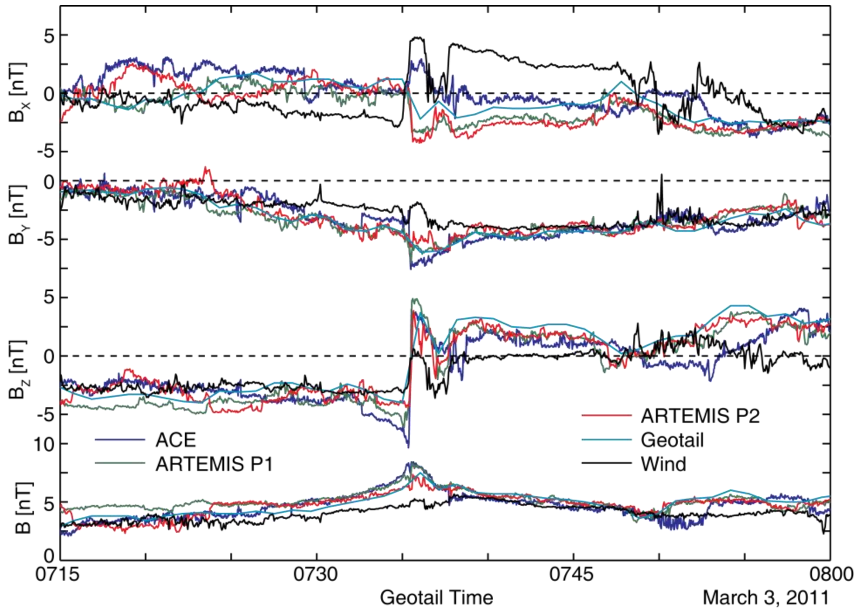
- Collisional signatures in the solar wind: Interplanetary field enhancements (IFEs)
  - IFEs are solar wind interacting with clouds of nanoscale dust released in collisions
  - IFE properties
- Inferred properties of interplanetary collisions
  - Based on IFE observations
  - Based on collisional models
- Summary

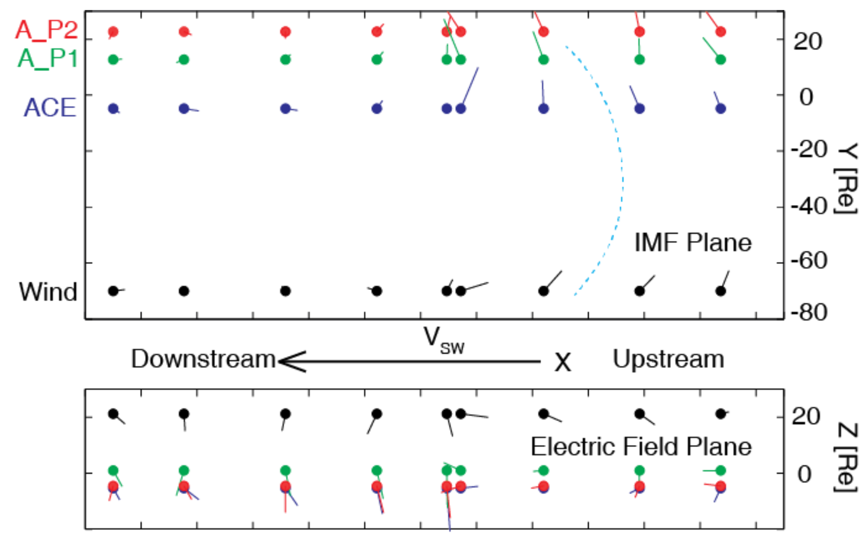
Collisional Cascade of Interplanetary Objects



- The collisional cascade grinds up the interplanetary objects.
- Big debris (≥ 1μm) spirals into the Sun.
- Small debris (~nm) is accelerated away from the Sun by radiation pressure or solar wind electromagnetic force.
- When the solar wind passes through a cloud of charged nanoscale dust, it can pick up the dust coherently.
- In return, the interplanetary magnetic field will be perturbed.

Collisional Signatures in the Solar Wind: IFEs

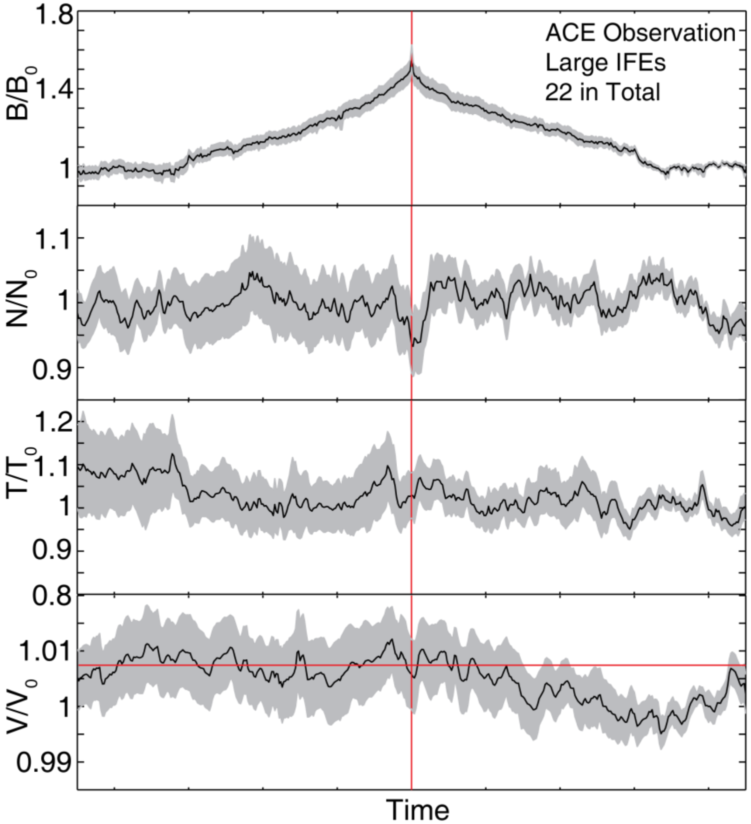


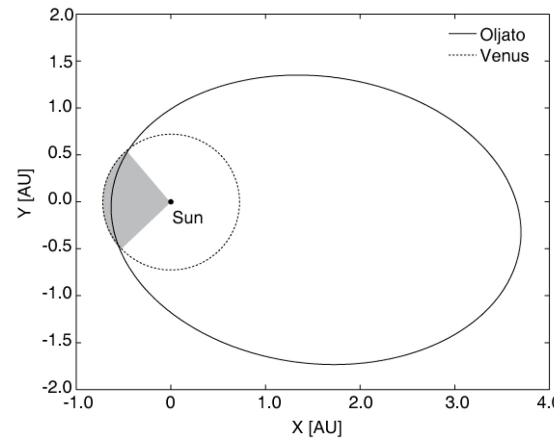


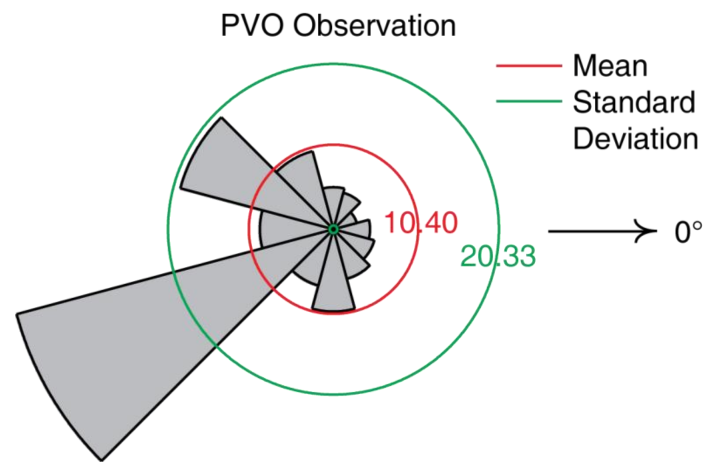
[Lai et al. 2015]

- Upstream: magnetic field is draped around the IFE, extracting momentum from the solar wind in order to push the IFE out of the Sun’s gravitational well.
- Downstream: the magnetic field has been twisted in the direction of the electric field.
- Both signatures are consistent with solar wind interacting with a cloud of charged dust [Jia et al., 2012].

More Evidence

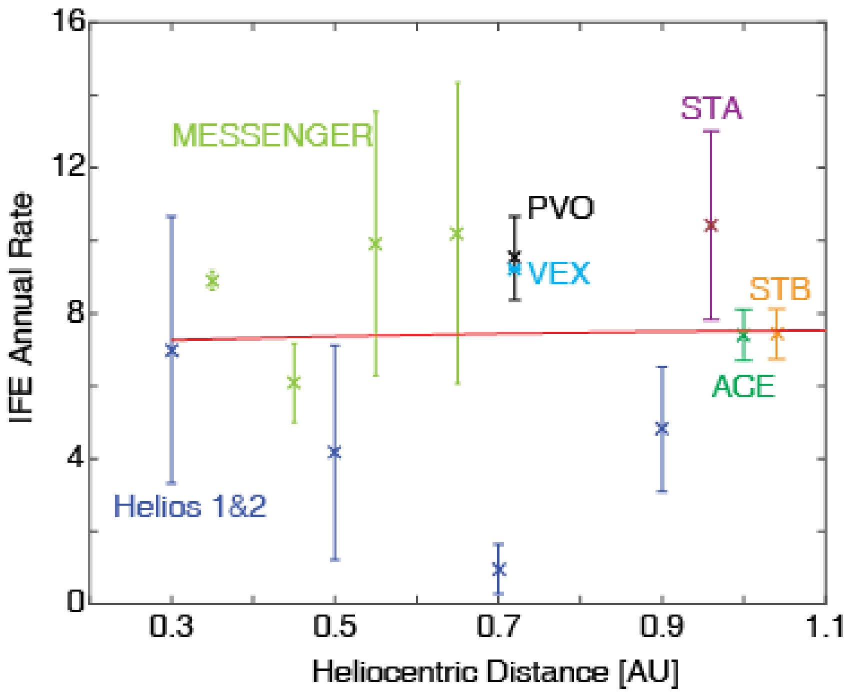






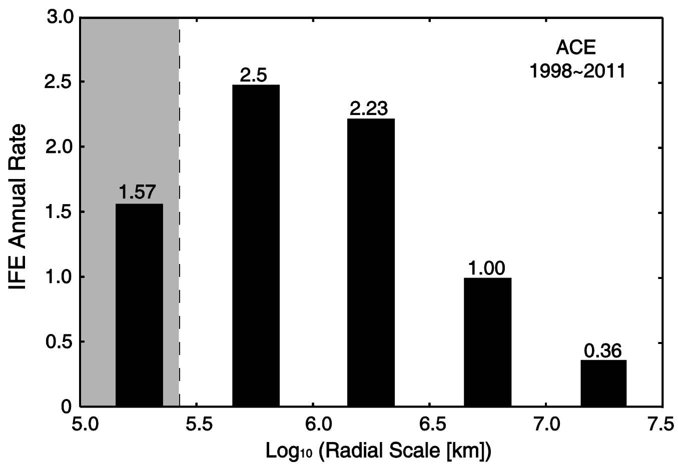
- Solar wind is slowed down (~0.5%) in order to accelerate the dust clouds.
- Occurrence of IFEs is associated with passages of interplanetary objects.

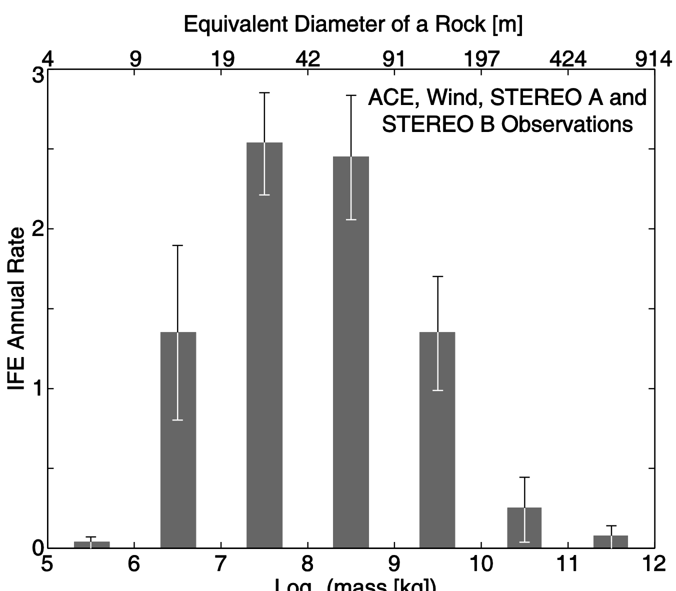
Radial Evolution of IFE Occurrence



- The collisional speed and the number density of the interplanetary object increase as the heliocentric distance decreases, resulting more collisions closer to the Sun.
- However, since IFEs are swept to the downstream and detected by the S/C there, the cumulative effect increases the detecting ability in large heliocentric distance.

Inferred Size of the Collisions at 1AU



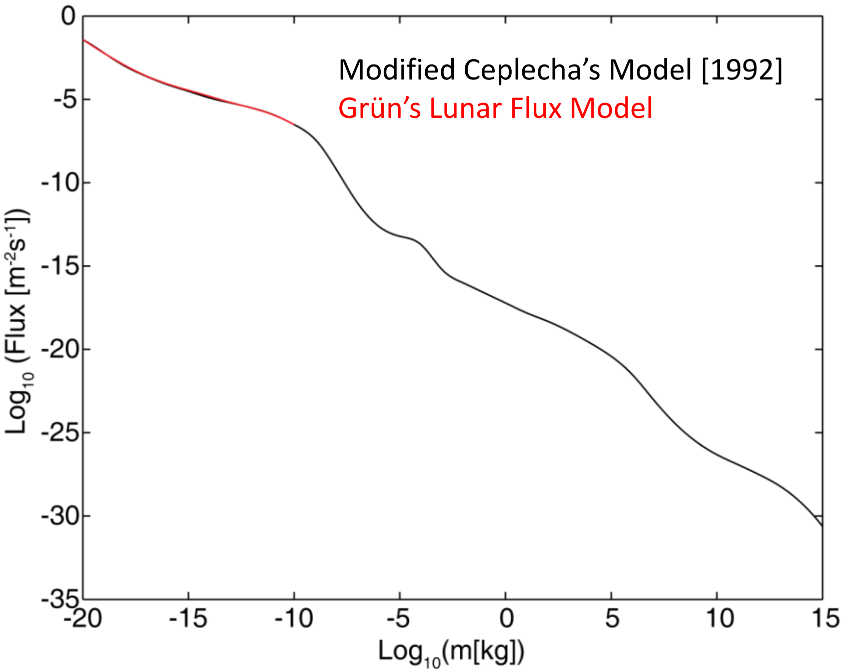


- Radial scale: duration × solar wind speed
- Radial scale range: 10^5 to 10^7km.
- Mass: balance the pressure gradient force with the solar gravity
- Mass range: 10^5 to 10^{11}kg (rocks of 10s meters in diameter).

Collisional Models

- Interplanetary flux model
- Catastrophic collisional model
- Debris distribution model
- Volume of detectable collision rate model

Interplanetary Flux Model



- The differential spatial number density at 1AU

$$\frac{dN(m,r_0)}{d(logm)} = \frac{dF(m,r_0)}{d(logm)}\frac{k}{v_0}$$

$$v_0 = 20\mathrm{km/s}$$

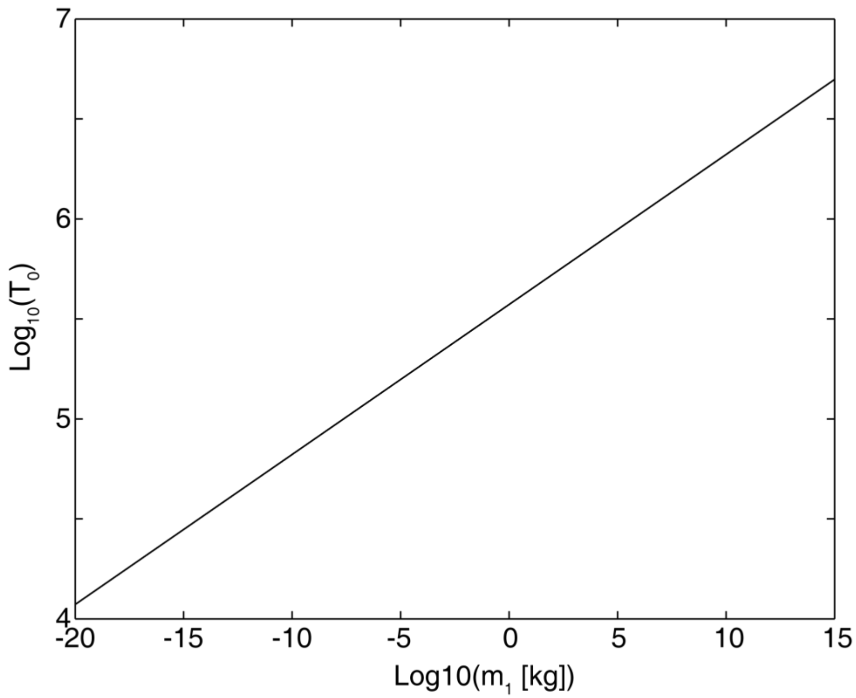
- Inside 1AU

$$\frac{dN(m,r)}{d(logm)} = \left(\frac{r}{r_0}\right)^{-1.5}\frac{dN(m,r_0)}{d(logm)}$$

$$v(r) = v_0\left(\frac{r}{r_0}\right)^{-0.5}$$

Catastrophic Collisions Model

- $m_2 \geq \frac{m_1}{\mathrm{T}}$
- $\mathrm{T}(r) = \mathrm{T}_0 \left(\frac{r}{r_0}\right)^{-1}$ [Grün et al. 1985]
- $Rate(m_1, r) = \frac{dN(m_1,r)}{d(\log m_1)} \int_{m_1/\mathrm{T}}^{M_\infty} \sigma(m_1, m_2) v_r \frac{dN(m_2,r)}{d(\log m_2)} d(\log m_2)$



Debris Distribution Model

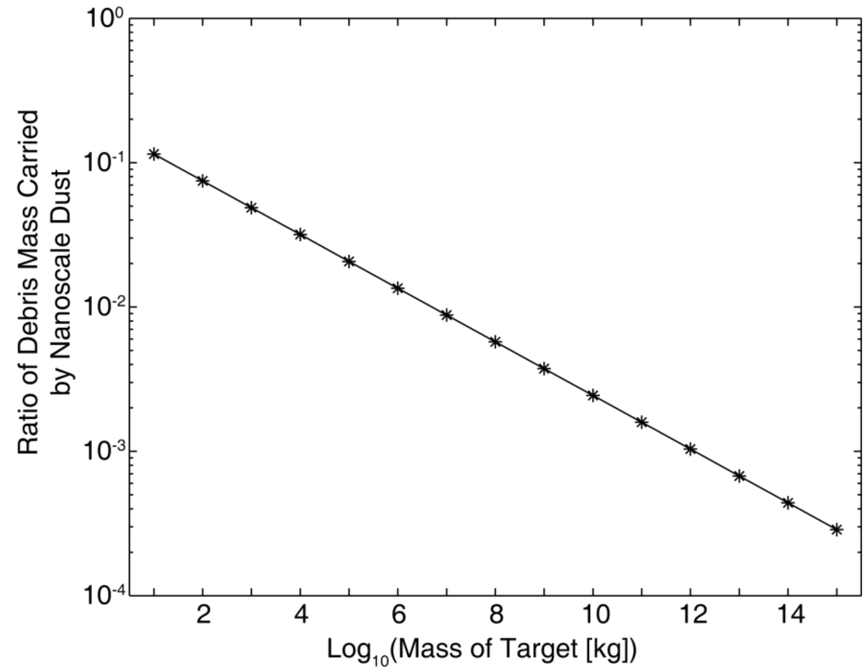
- $\frac{dG(m,m_1,m_2)}{d(\log m)} = c_1 m^{-0.83}$

  [Fujiwara et al., 1977]

- $\int_0^{m_L} m \frac{dG(m,m_1,m_2)}{d(\log m)} d(\log m) = m_1$

- $\frac{m_L}{m_1} \approx 9.26 \times 10^{-8} \left(\frac{m_2}{m_1}\right)^{-1.24} \cdot \left(\frac{r}{r_0}\right)^{1.24}$

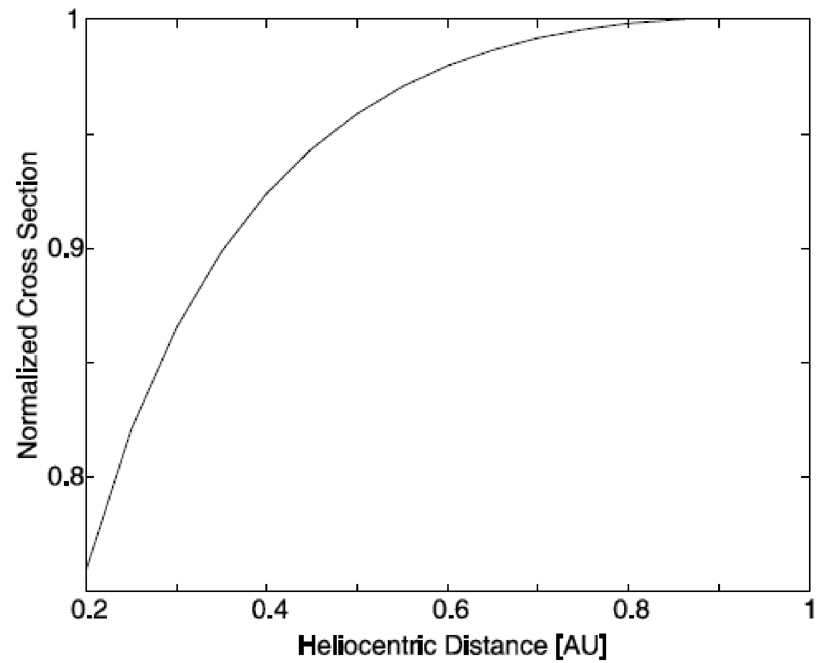
- $\int_0^{m'} m \frac{dG(m,m_1,m_2)}{d(\log m)} d(\log m)$



m': 500nm particles

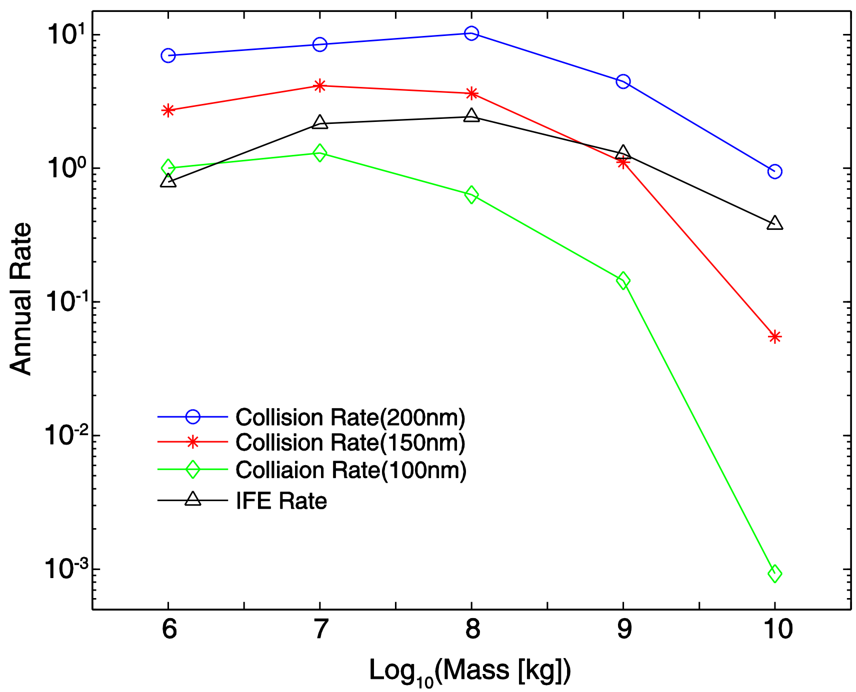
Volume of Detectable Collision Model

- IFEs are carried outward by SW and can be detected by S/C which they pass by.
- Detectable volume: truncated cone starts from 0.2AU to 1AU.
- $\frac{A}{A_0} = \frac{(\frac{B_0^2}{2\mu_0}+N_0kT_0)r_0^2}{(\frac{B^2}{2\mu_0}+NkT)\cdot r^2}$

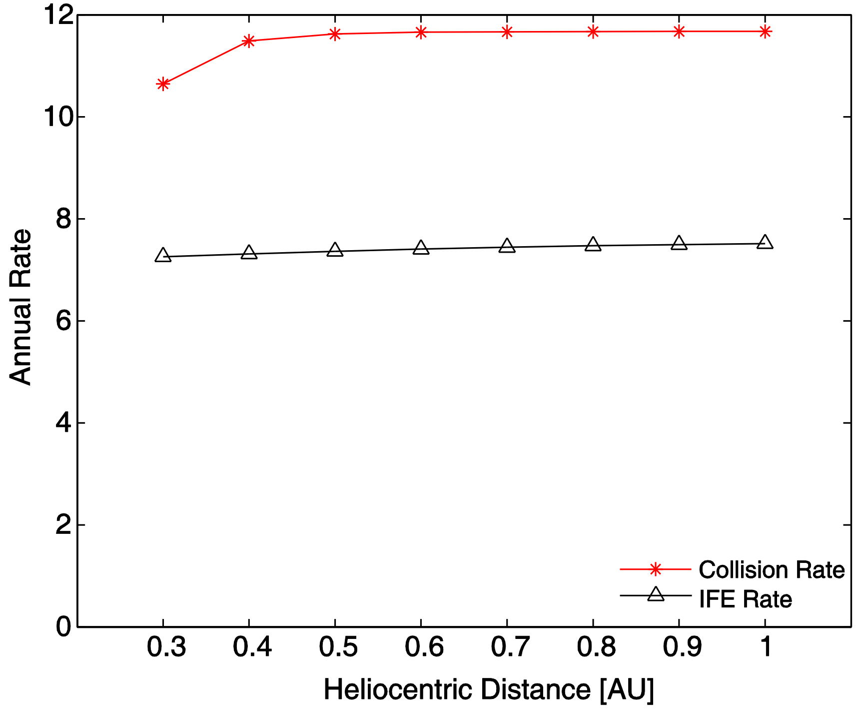


Rate Comparison

At 1AU



From 0.3 to 1AU



Summary

- Clouds of nanoscale dust released in interplanetary collisions can be picked up by the solar wind, perturb the background magnetic field, and create IFEs.
- With IFE observations, we can infer the size and rate of the collisions.
- The inferred properties are consistent with the properties estimated based on collisional models.
- Most of the IFE responsible interplanetary objects are of tens of meters in diameter, too small to detect by traditional optical methods.
- IFEs offer a new technique to monitor interplanetary collisions.
- This technique can be further developed into a NEO survey technique.