Constraints on the rotational disruption of dust based on the survival of the zodiacal cloud

Kedron Silsbee (UTEP)

in collaboration with Brandon Hensley, Jamey Szalay, and Petr Pokorny

Maximum rotation rate of a grain

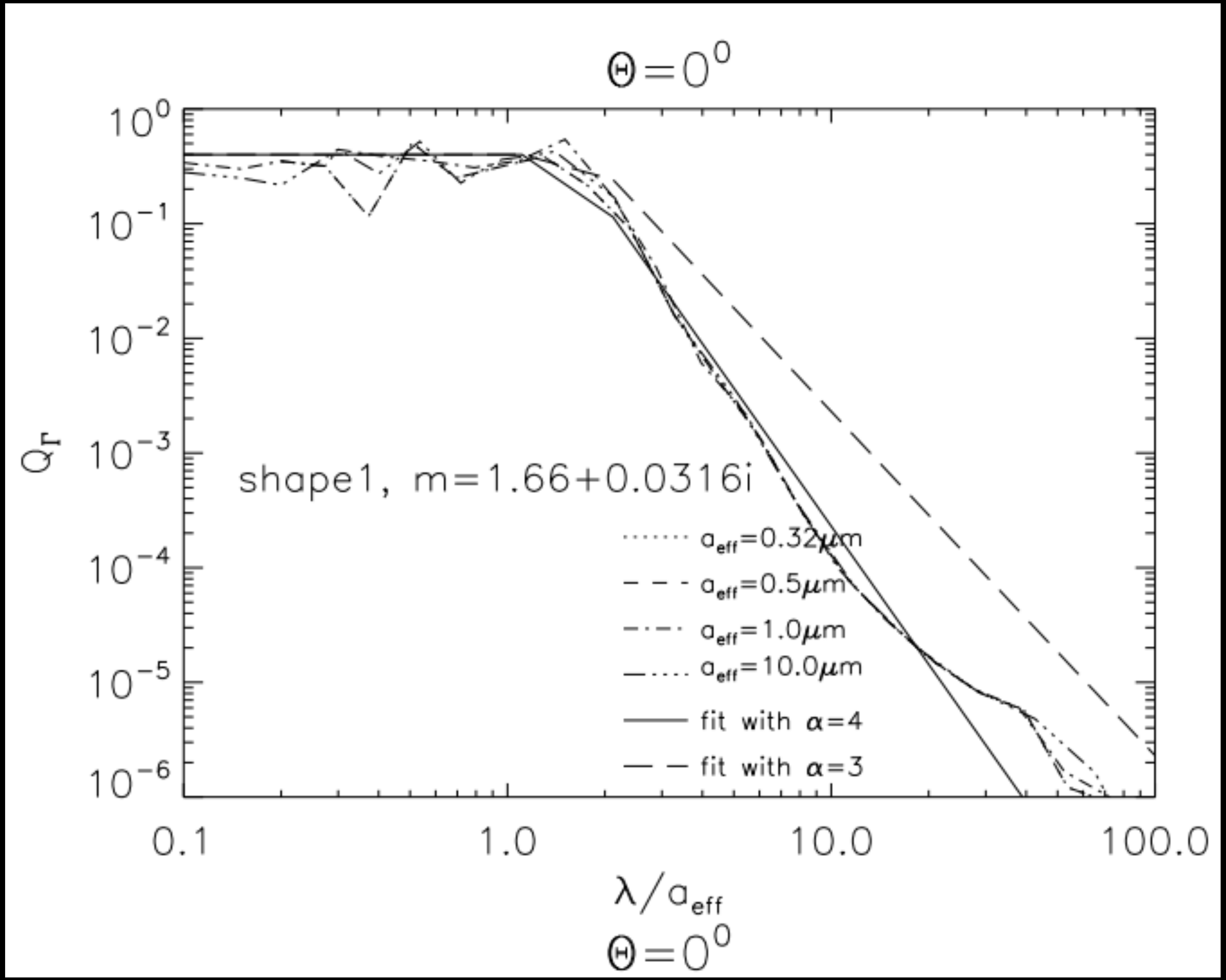
Equate the centrifugal force pulling the two hemispheres of the grain apart with the yield stress times the grain cross-section

$$\omega_{\max} = \frac{2}{a}\sqrt{\frac{S_{\max}}{\rho}}$$

$S_{\max}$ = breaking tensile strength.

Material	tensile strength (MPa)
ice	~2
concrete	5
meteoritic iron	500

Rotational excitation



From Lazarian & Hoang, (2007)

Rotational excitation due to scattering of incident solar photons.

$$\Gamma = Q \times (\gamma \mu \pi r^2) \times \frac{\lambda}{2\pi}$$

Efficiency factor

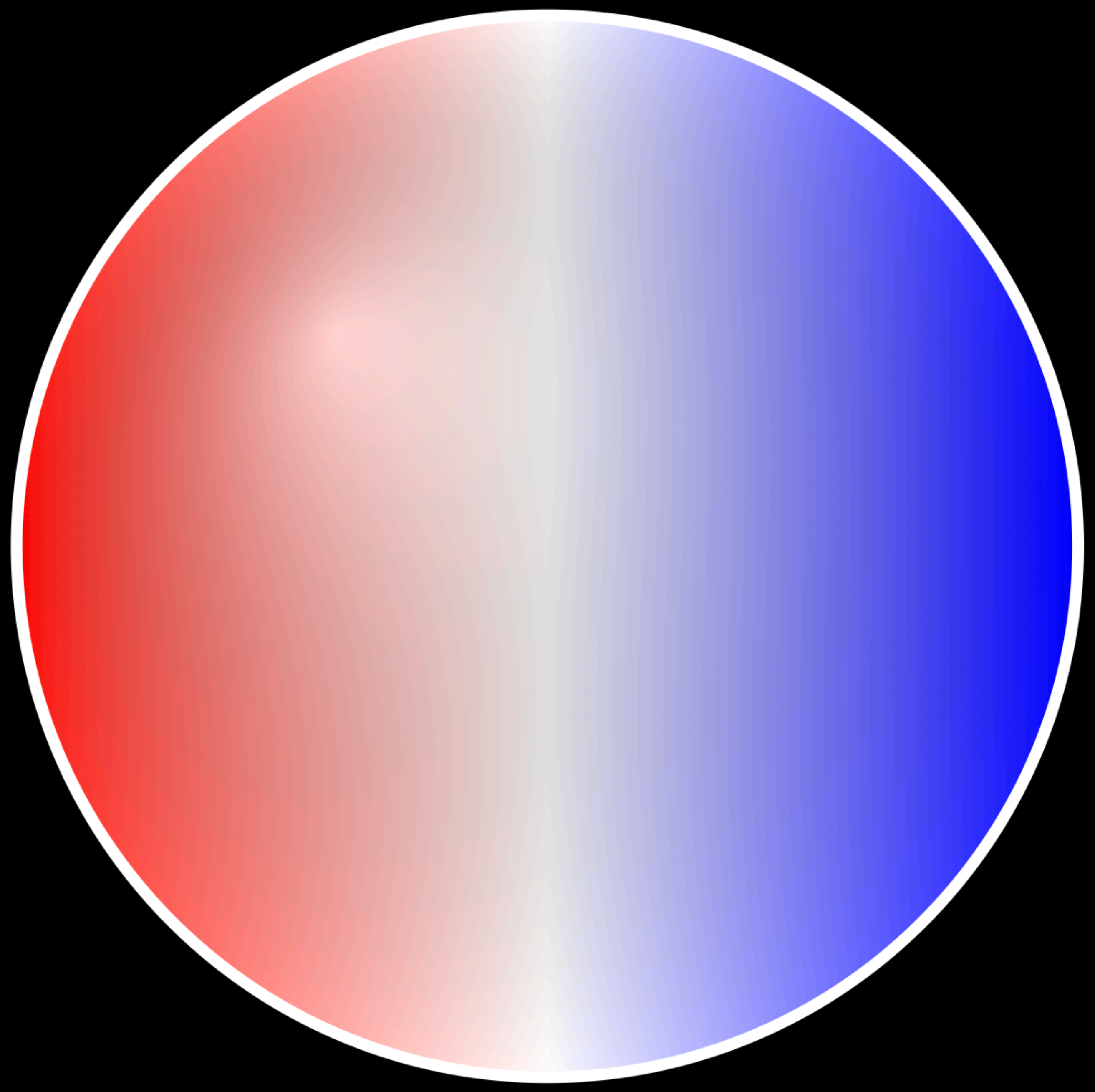
Radiation pressure force

Lever arm

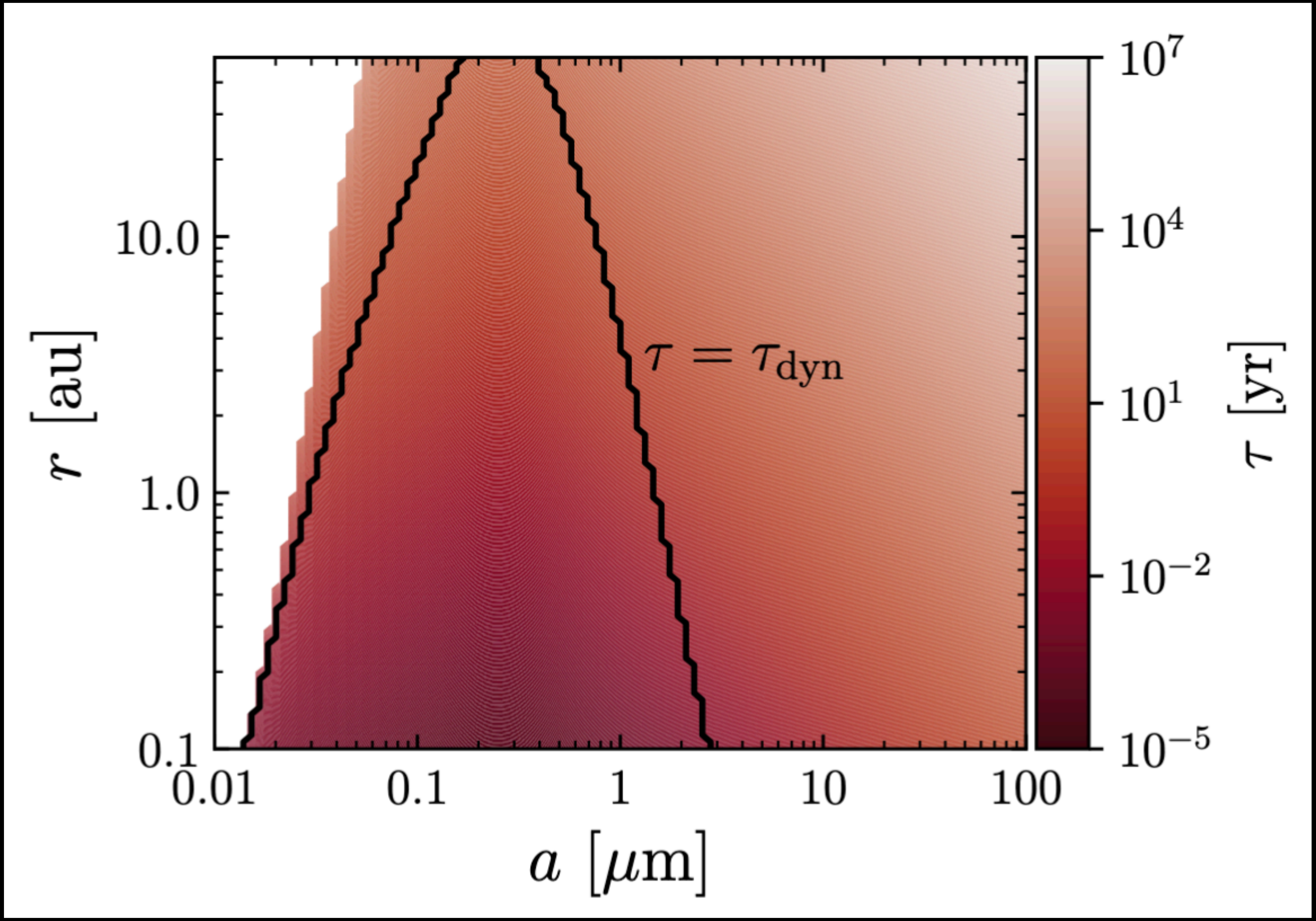
Rotational damping

Dominated by emission of infrared photons;

Because of relativistic aberration, these photons slow the sphere down.



Variation of disruption time with heliocentric distance and grain size

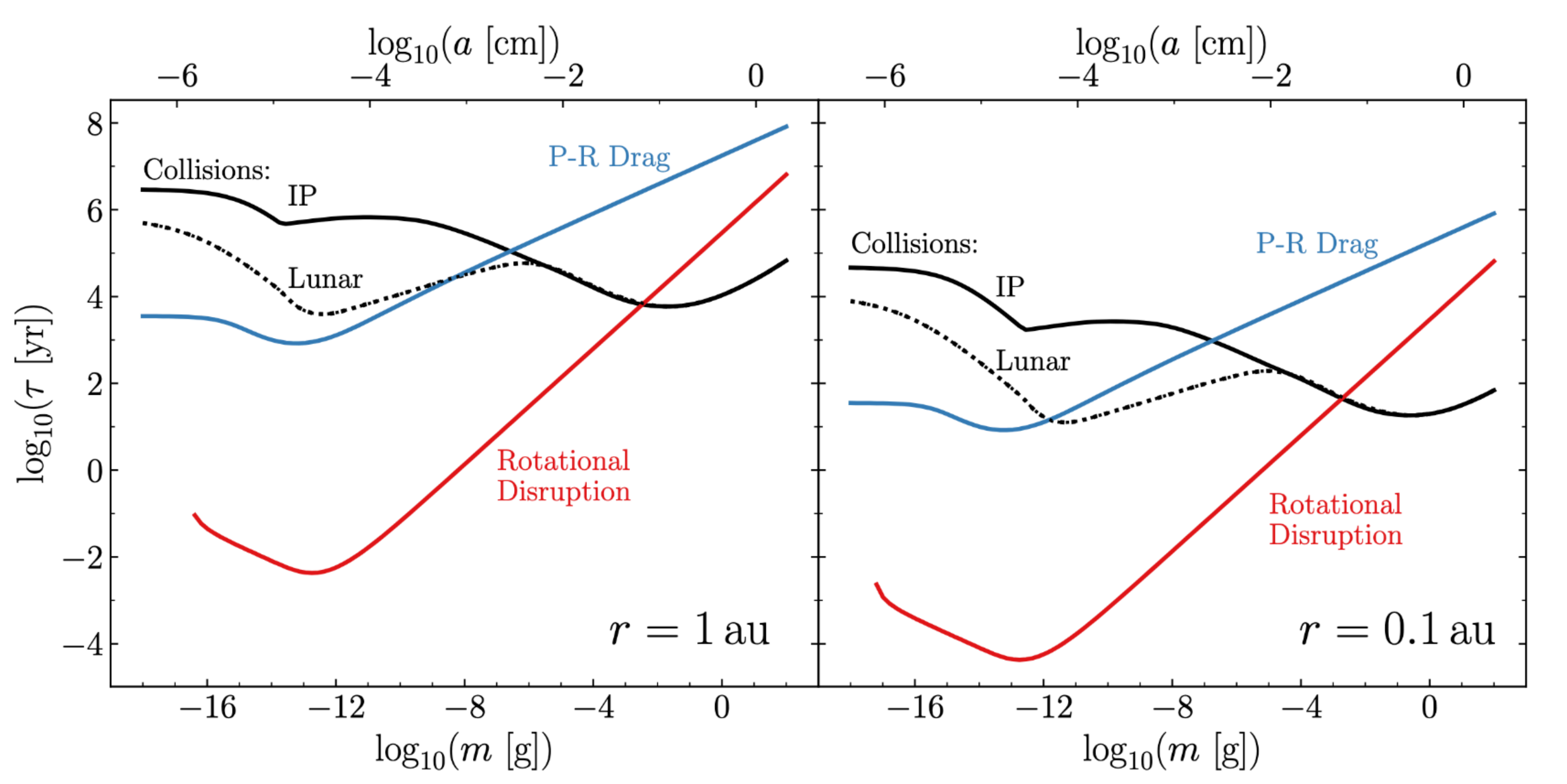


From Silsbee et al., in prep

Note that at 1 AU, a substantial range of grain sizes are disrupted in less than one orbit.

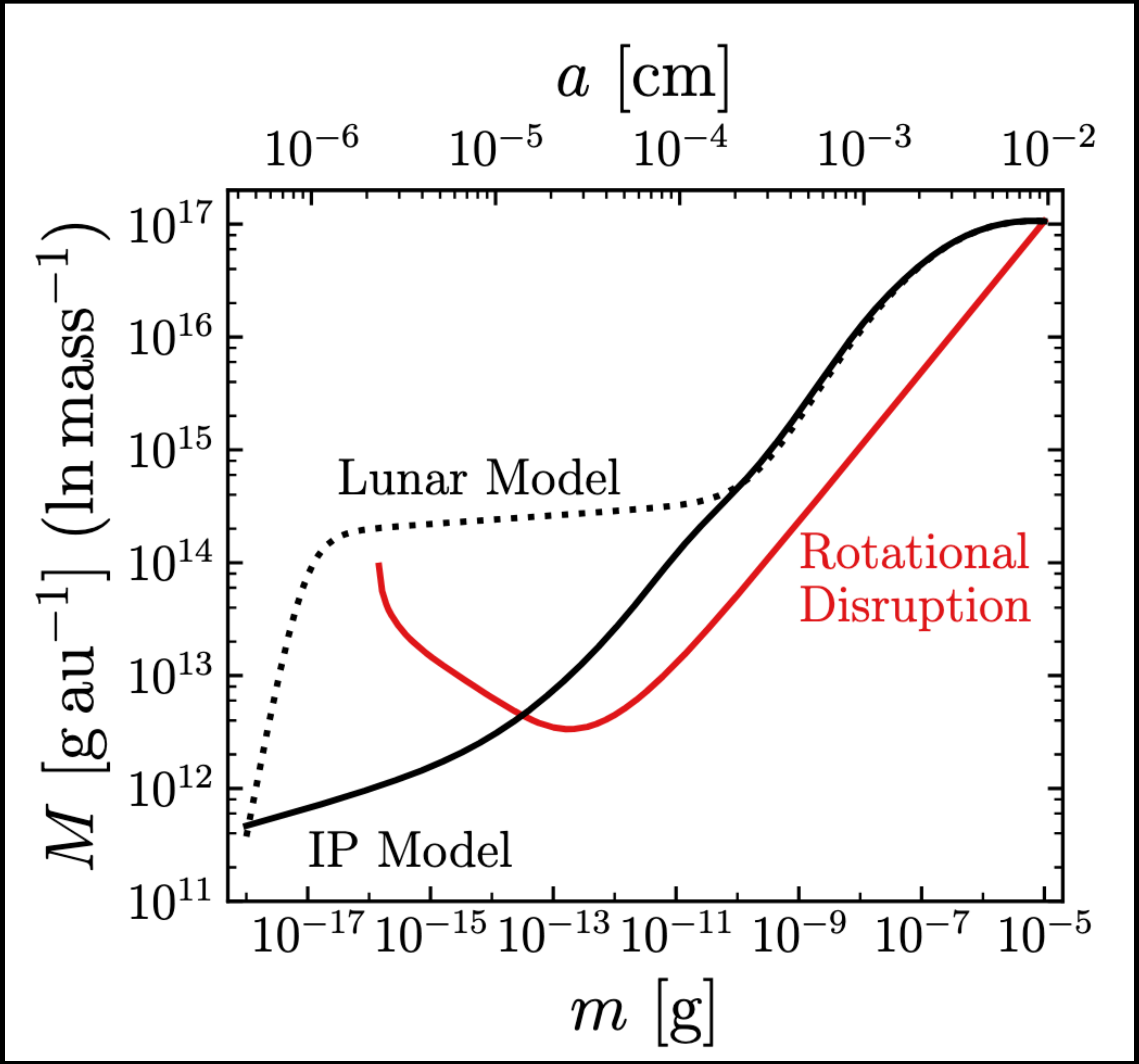
Known as the RATD (RAdiative Torque Disruption mechanism (Hoang et al. (2019).

Comparison of rotational disruption with other processes



From Silsbee et al., in prep

steady-state rotational cascade



From Silsbee et al., in prep

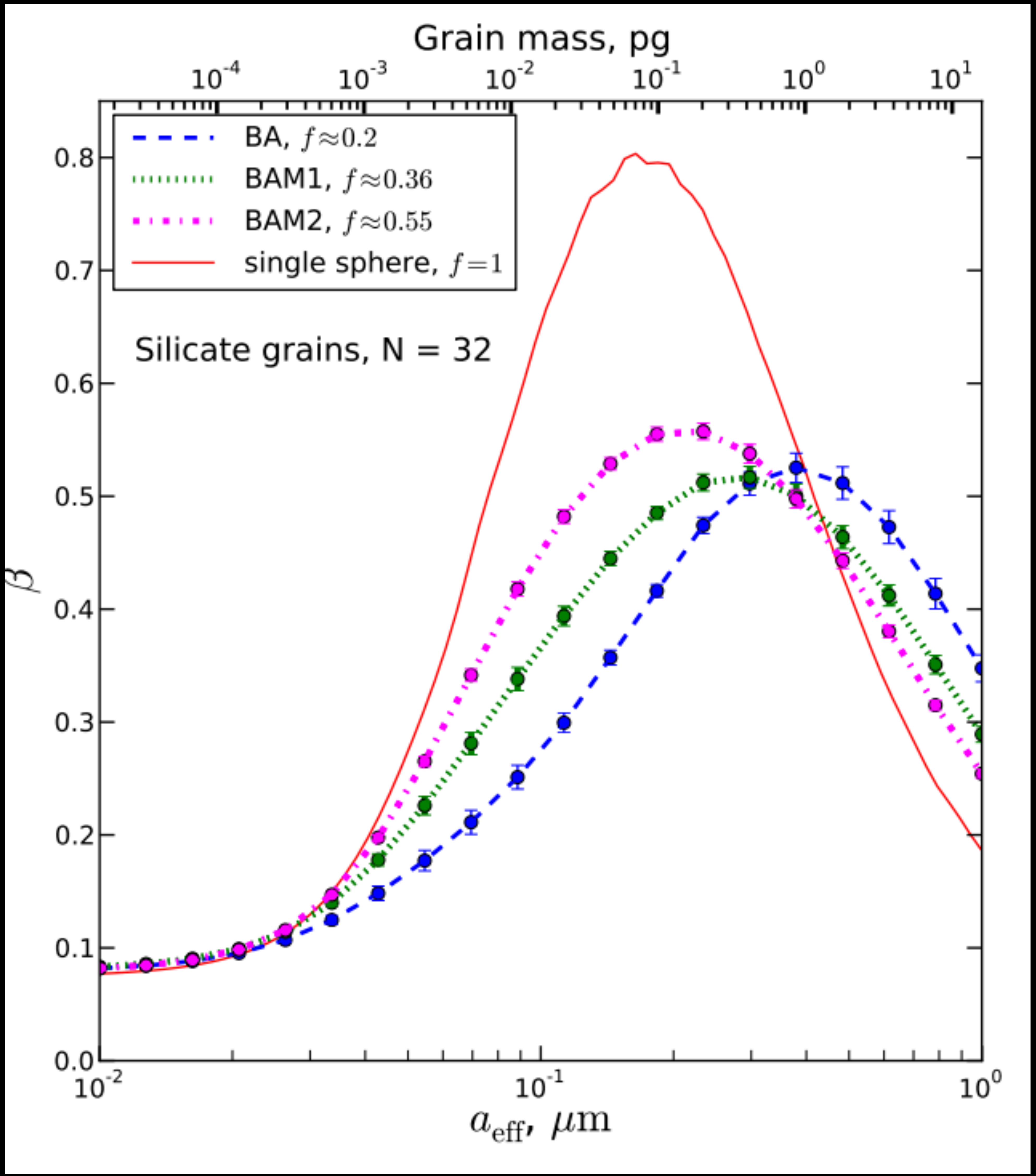
$$\frac{dn(m)}{dt} = \frac{n(m)}{\tau(m)} + 4\frac{n(2m)}{\tau(2m)}$$

$$\rightarrow n(m) = n(m_0)\left(\frac{m_0}{m}\right)^2 \frac{\tau(m)}{\tau(m_0)}$$

Given size distribution from 1-10 microns, total mass flux is about 10^8 g/s, compared with an observational estimate of 10^5 g/s.

Estimated supply from comets:
$3 \times 10^5 \mathrm{g/s} - 3 \times 10^7 \mathrm{g/s}$

β meteoroids



From Silsbee & Draine, 2016

$$\beta = \frac{F_{\rm rad}}{F_{\rm grav}}$$

Small particles are blown out of the solar system by radiation pressure.

Note that this does not require $\beta > 1$

Number flux of β-meteoroids

Recent observations suggest several X 10^{-9} cm^{-2} s^{-1}

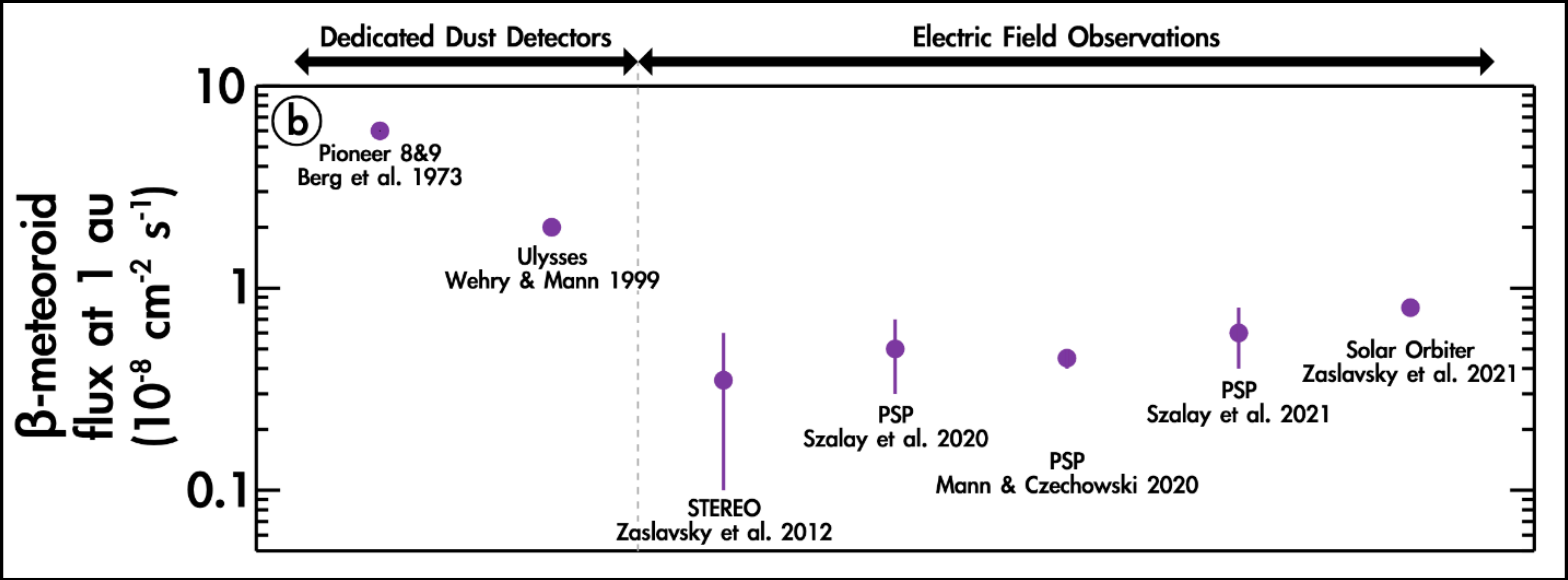


Figure credit: Jamey Szalay & Petr Pokorny

Mass distribution of measured meteoroids

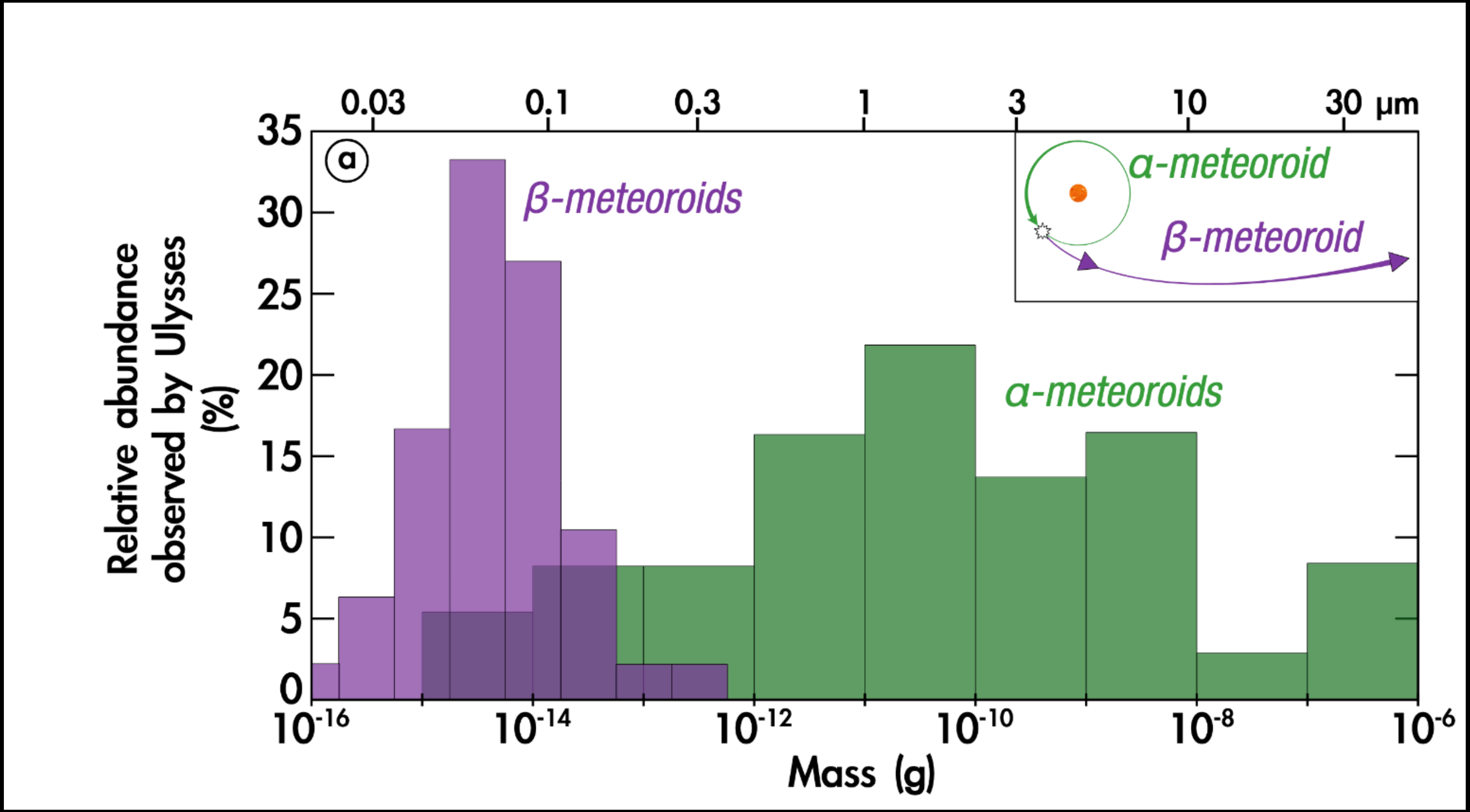
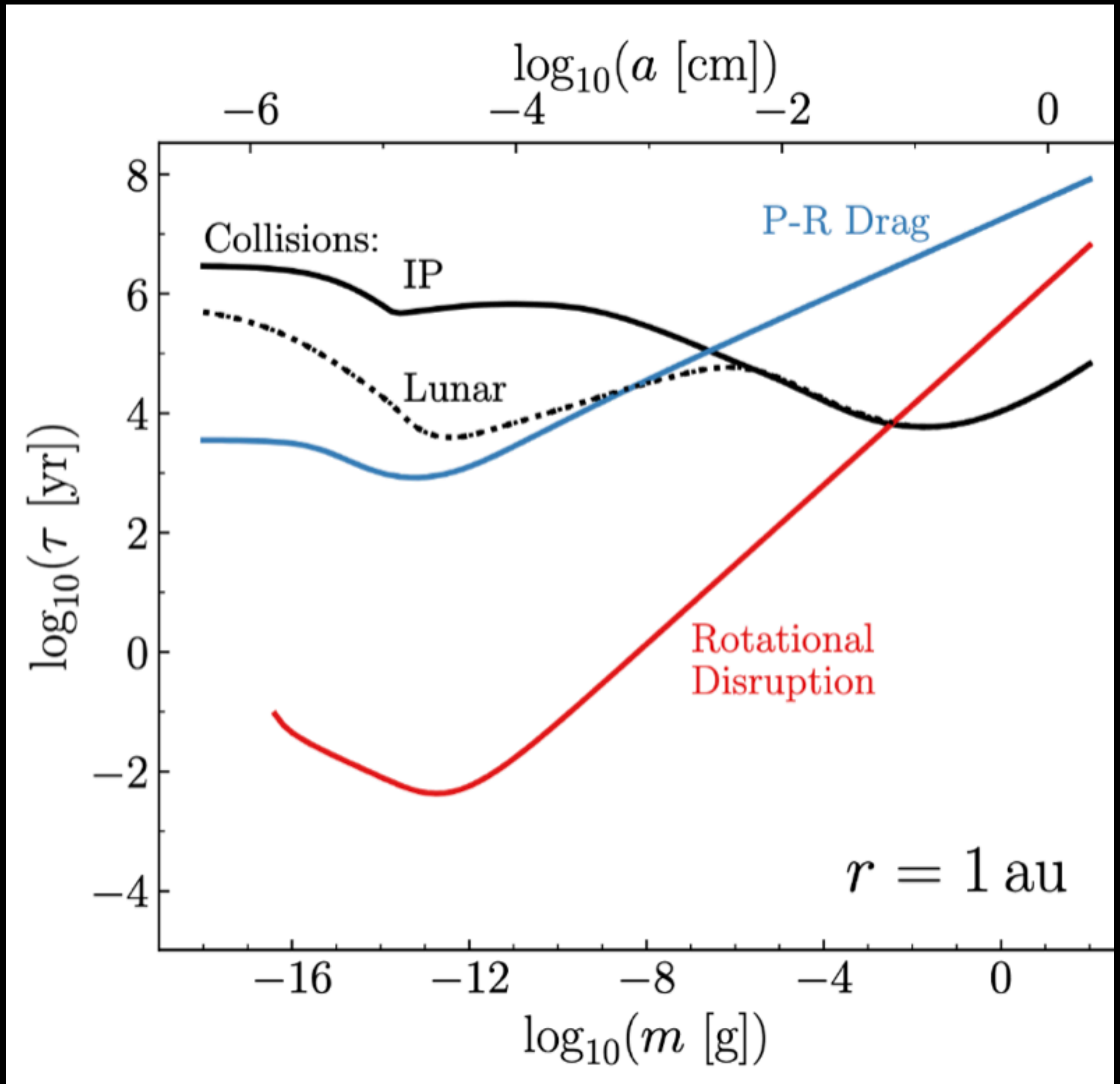


Figure credit: Jamey Szalay & Petr Pokorny

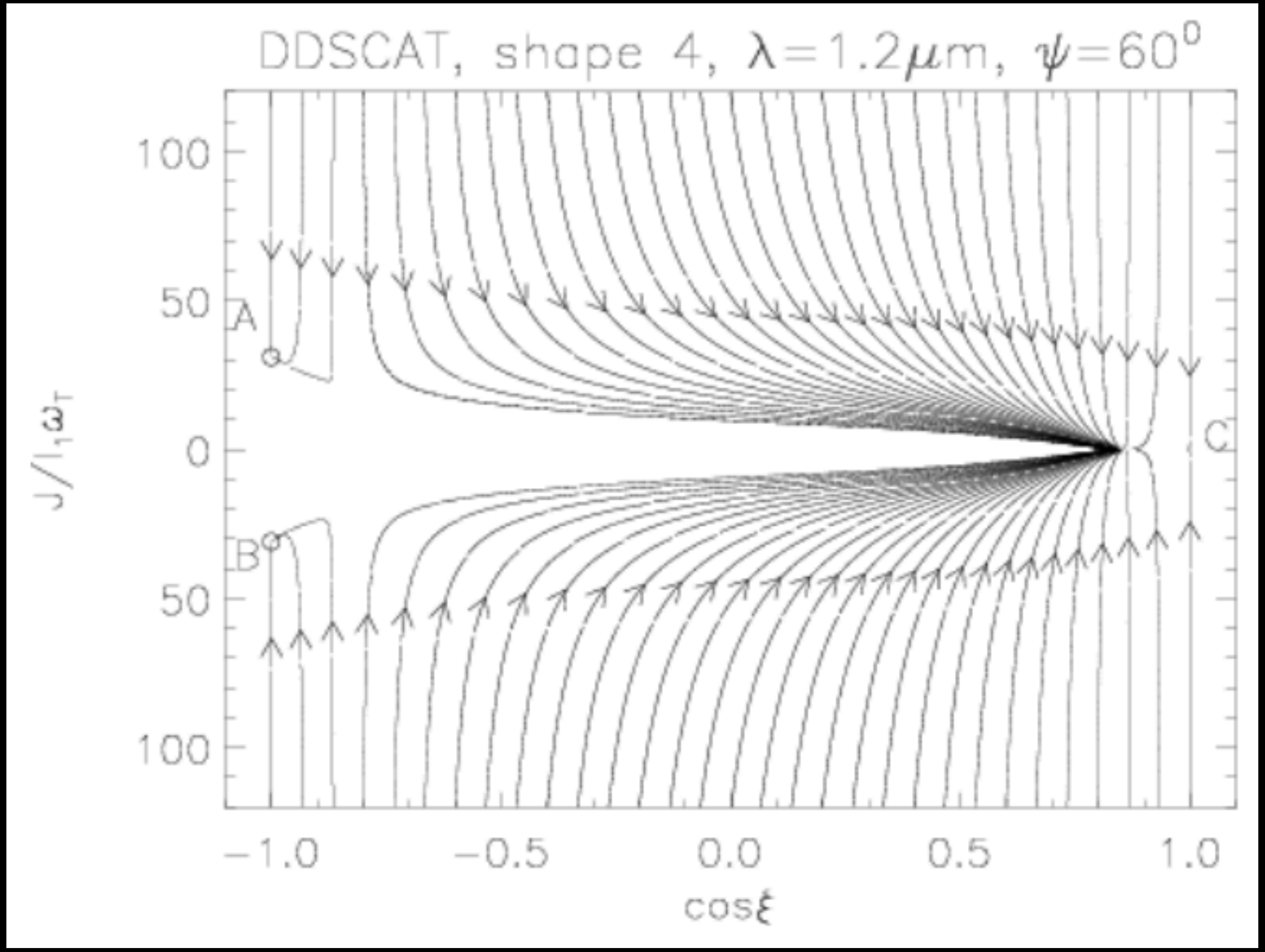
Mass flux calculated from rotational disruption implies a mean β-meteoroid mass of 10^{-11} g.

Conclusions/outlook

If grain dynamics work as described in Hoang et al., (2019), rotational disruption in the solar system would be much too rapid, and destroy the zodiacal cloud.



This suggests that the vast majority of grains in our solar system possess low-J attractor points



From Lazarian & Hoang, (2007)