Are VERY Large Grains Present in the Interstellar Medium?

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Plan

1. Data from ***Ulysses***, Arecibo, AMOR -- very large grains in the ISM?
2. Conflict with our current view of interstellar dust
3. "***Brilliant Pebbles***" -- A method for detection of very large grains in the ISM

Dust in the Local Interstellar Cloud

Assumptions: *interstellar dust and gas are well-mixed, and LIC dust properties are "typical".*

LIC has $N(H) \approx 10^{18.0} cm^{-2}$

$\Rightarrow$ **$E(B-V) \approx 1.7\times10^{-4}$ mag, $A_V \approx 5.3\times10^{-4}$ mag**

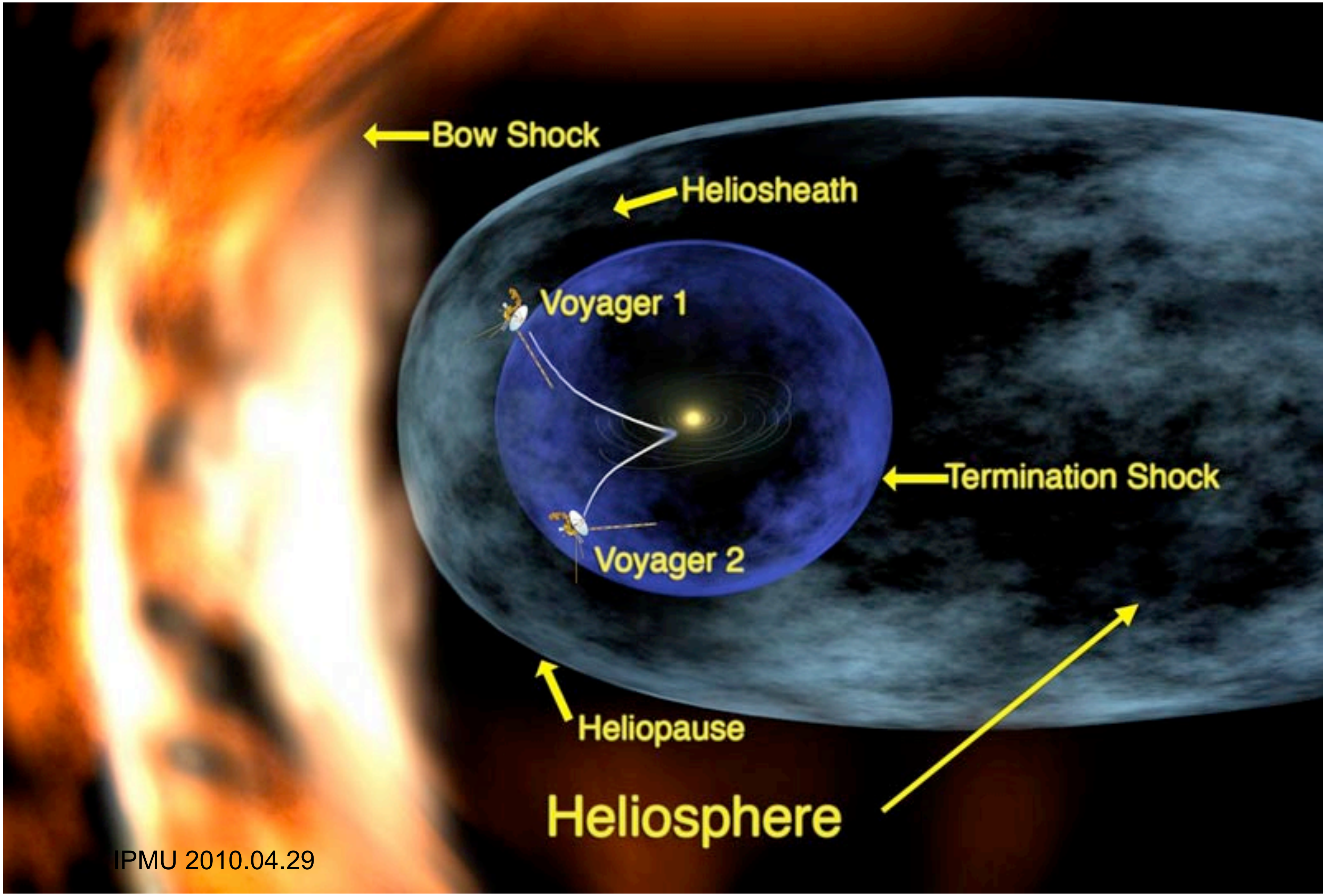
Impossible to measure such small E(B-V) or A_V

$p_V < 0.09\ E(B-V) \approx 1.6\times10^{-5}$

Very *hard to measure $p_V \approx 10^{-5}$:* "…instrumental polarization has been eliminated to about 3×10^{-5}" (Tinbergen 1982).

IR emission: LIC contribution overwhelmed by general background with $N_H \approx 500 \times N_{H,LIC}$

Conclusion: unable to study dust in LIC via reddening, extinction, polarization, or IR emission.



Bow Shock
Heliosheath
Voyager 1
Termination Shock
Voyager 2
Heliopause
Heliosphere

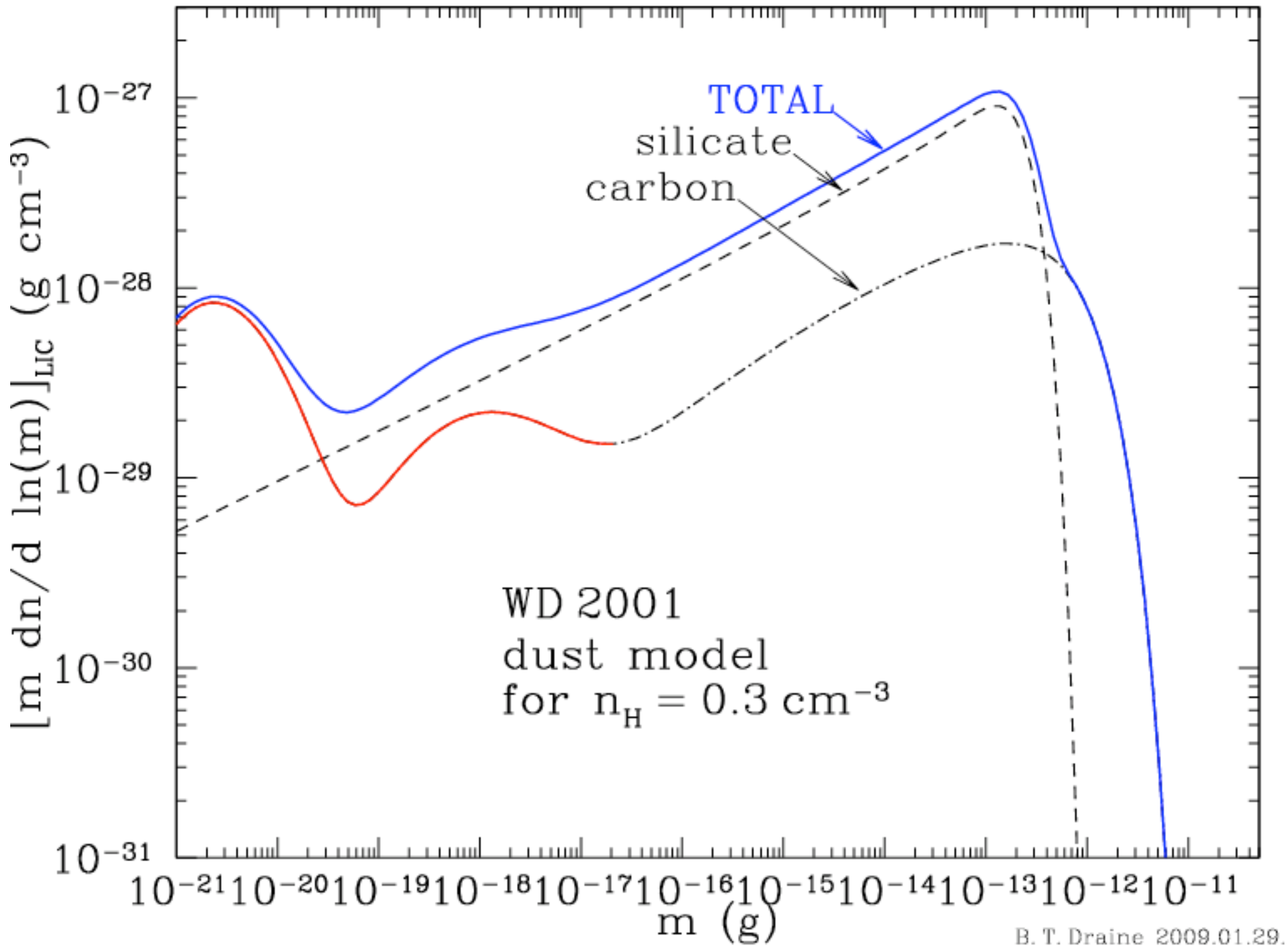
LIC dust entering the heliosphere

- size distributions from realistic models:
  - (total H mass)/(dust mass) ≈ 100
  - $\sim 50\%$ of dust mass above/below $\sim 0.15\,\mu$m
- $n_{\rm H,LIC} \approx 0.3\,{\rm cm}^{-3}$, $v_{LIC,\odot} \approx 26\,{\rm km\,s}^{-1}$
- predicted dust mass flux

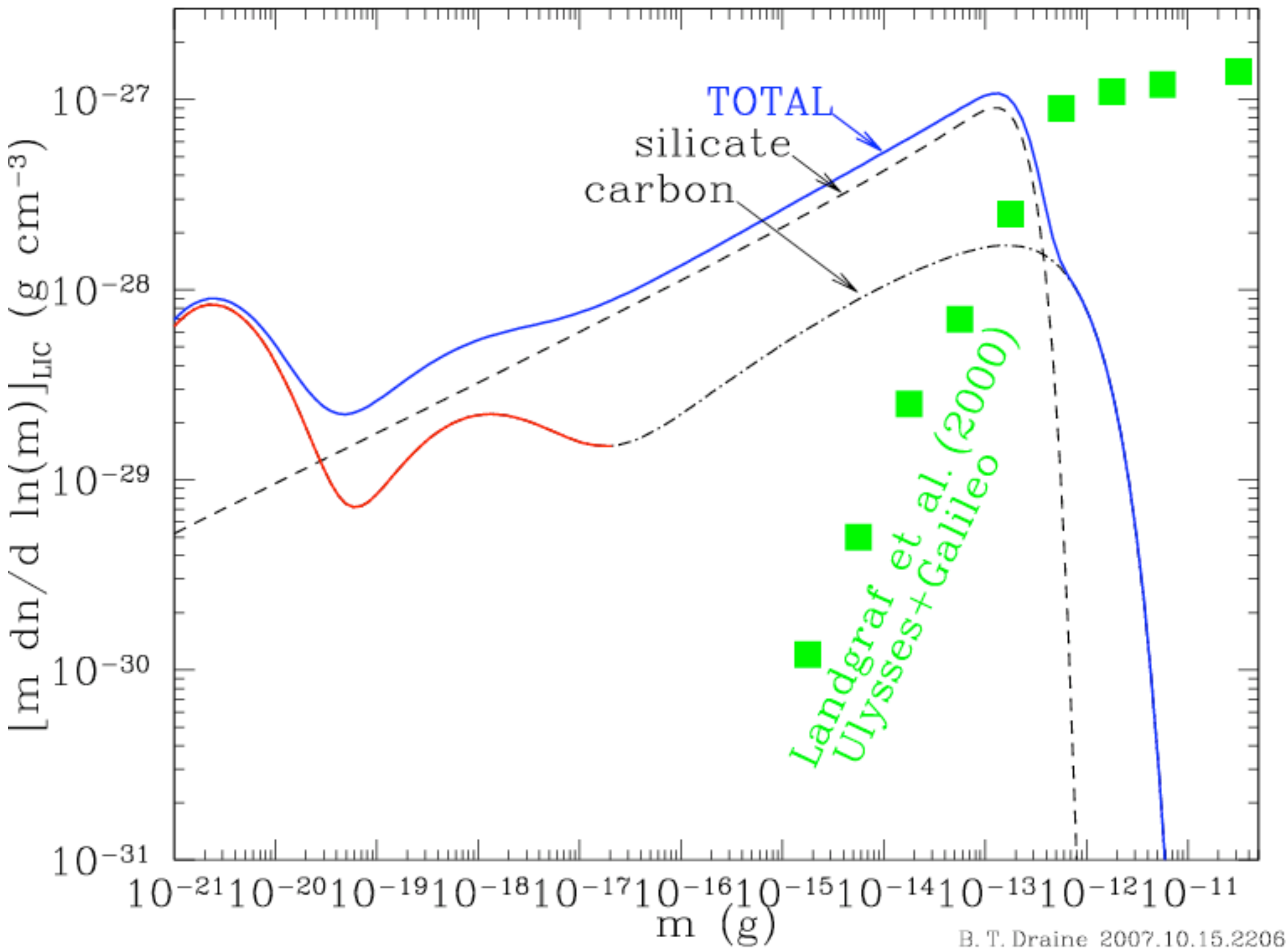
  $\rho_{\rm dust} v_{LIC,\odot} \approx 0.01\, n_{\rm H}\, m_{\rm H}\, v_{LIC,\odot} \approx 1.3{\times}10^{-20}\,{\rm g\,cm}^{-2}\,{\rm s}^{-1}$
  but very little in $a \gtrsim 0.5\,\mu$m ($M \gtrsim 10^{-12}$ g) particles.

Problem: *Ulysses* **found flux** $2{\times}10^{-9}\,{\rm cm}^{-2}\,{\rm s}^{-1}$ **of** $M > 10^{-12}$ g **particles, or mass flux** $\sim 4\times10^{-21}\,{\rm g\,cm}^{-2}\,{\rm s}^{-1}$**.**
Such large particles are inconsistent with average extinction curve, and are difficult to accomodate with cosmic abundance constraints.

Silicate-Graphite-PAH Dust Model



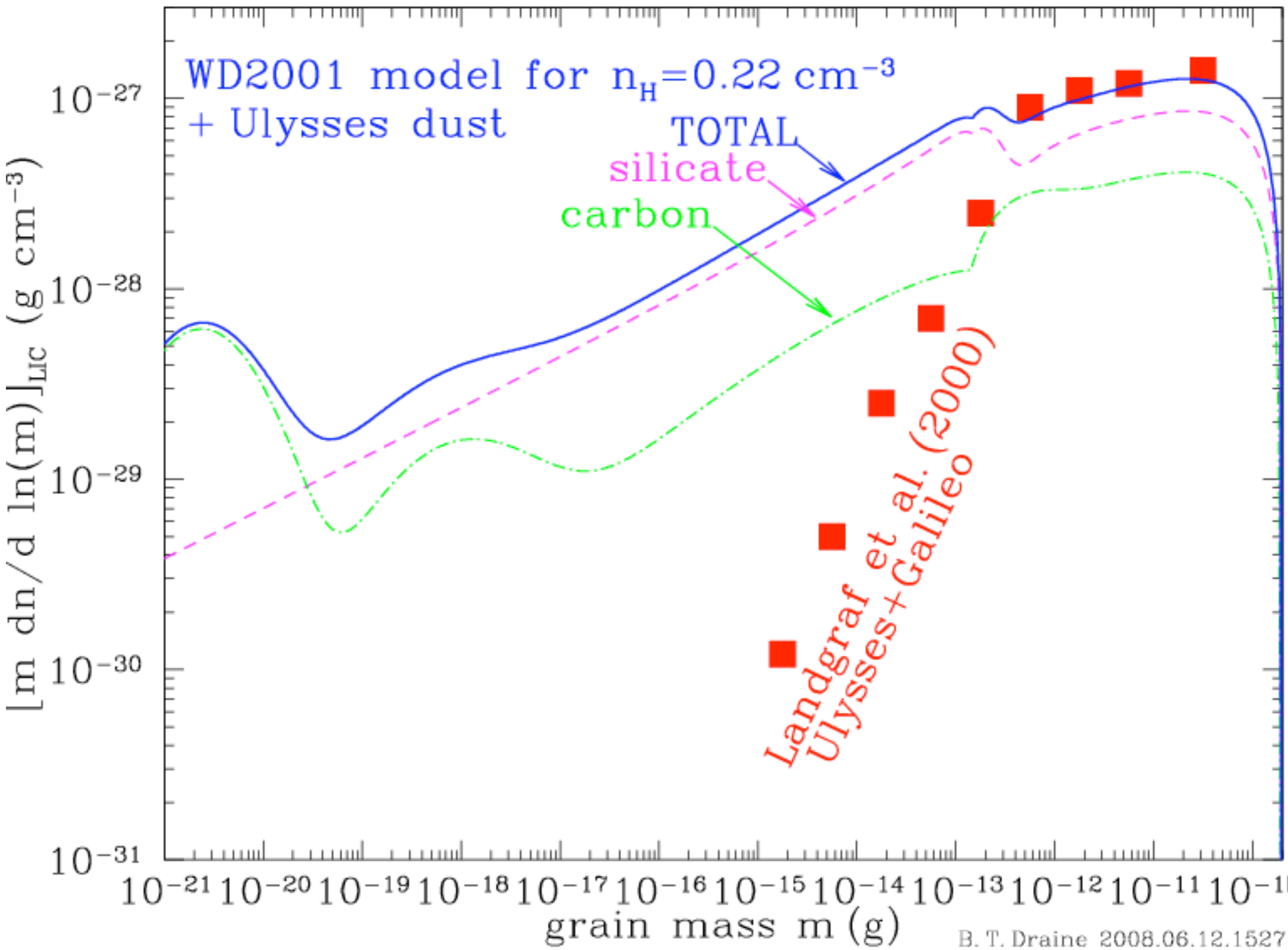
Silicate-Graphite-PAH Dust Model vs. Ulysses…



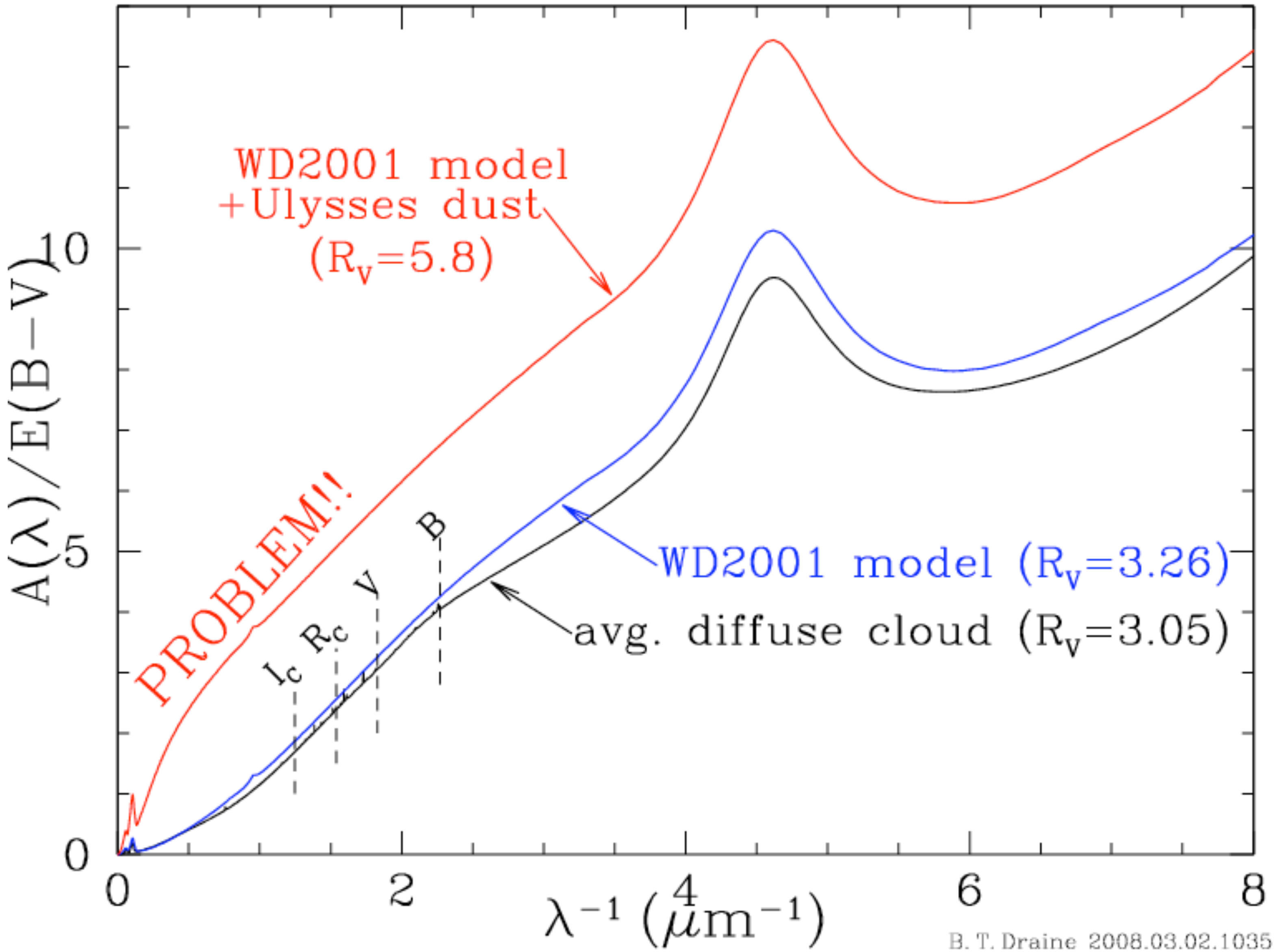
TROUBLE

- Ulysses + Galileo do not measure the abundance of $M < 10^{-12.5}\,\mathrm{g}$ grains expected for average IS dust size distribution. This is understandable as "filtration" by heliospheric $\vec{B}$.
- Ulysses + Galileo infer
  $$\rho_{LIC} \approx 7 \times 10^{-27}\,\mathrm{g\,cm^{-3}} \text{ in } 10^{-12.5} < M < 10^{-10}\,\mathrm{g} \text{ particles}$$
  These particles **alone** overconsume our expected mass budget of $\sim 0.01 \times n_{\mathrm{H}} m_{\mathrm{H}} = 5.0 \times 10^{-27}\,\mathrm{g\,cm^{-3}}$!
- **Ulysses-Galileo abundance of $M > 10^{-12.5}\,\mathrm{g}$ grains is inconsistent with overall "metal" abundances in average diffuse ISM.**
- **Size distribution *cannot* be characteristic of ISM – inconsistent with obervations of interstellar reddening.**

Size distribution for local dust?

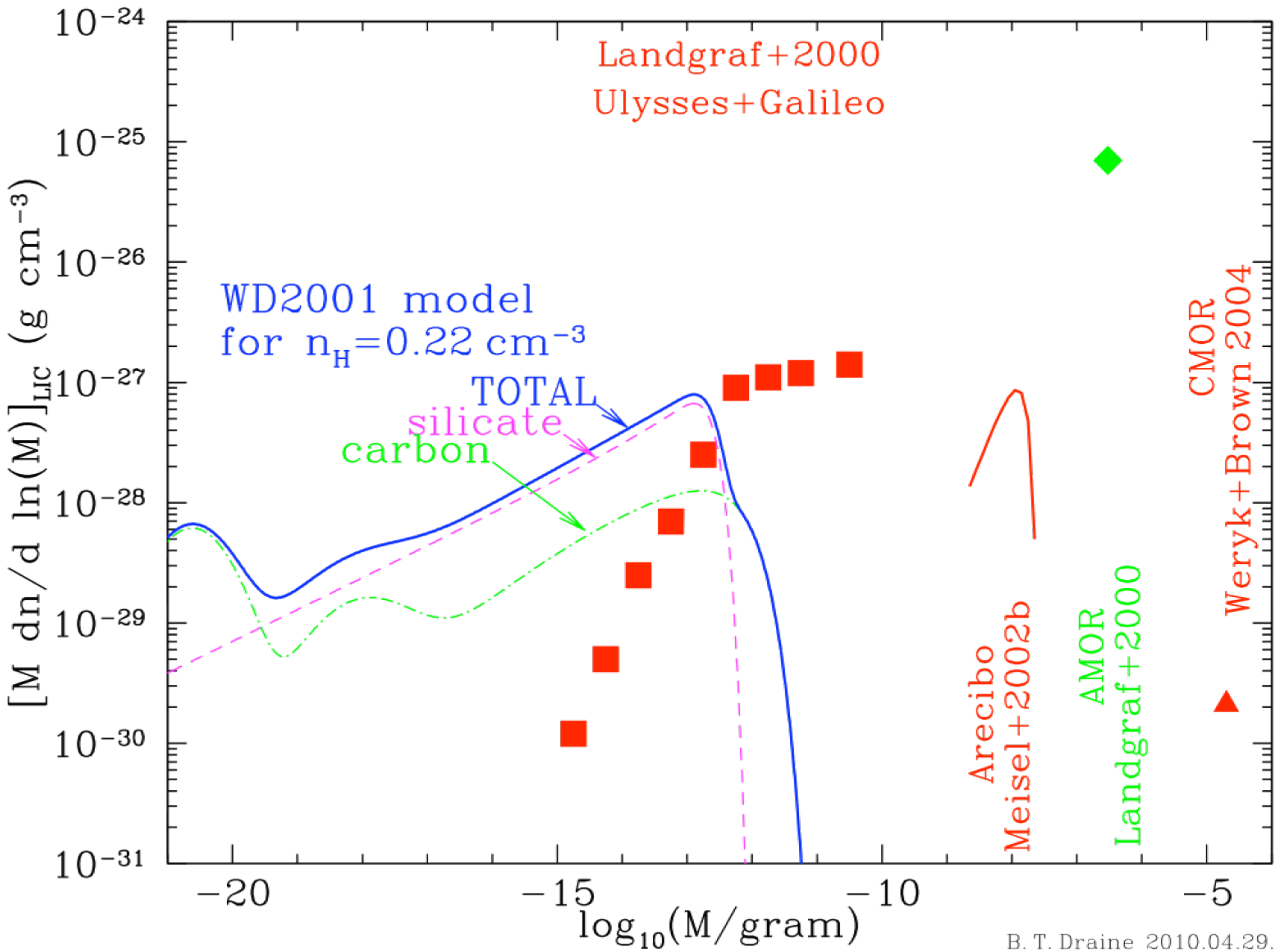


Extinction curve for local dust?



Things get worse…

Radar observations of "Interstellar Particles" (micrometeors on solar-hyperbolic trajectories)



Suppose these very large grains are actually present in the ISM.

Is there any way to detect them?

1. Grains with 0.5 - few μm will produce an unacceptable reddening curve -- but maybe we are making some mistake…
2. Submm emission excess -- but this depends on submm opacities…

3. Small-angle scattering of starlight -- "brilliant pebbles" (Socrates & Draine 2009).

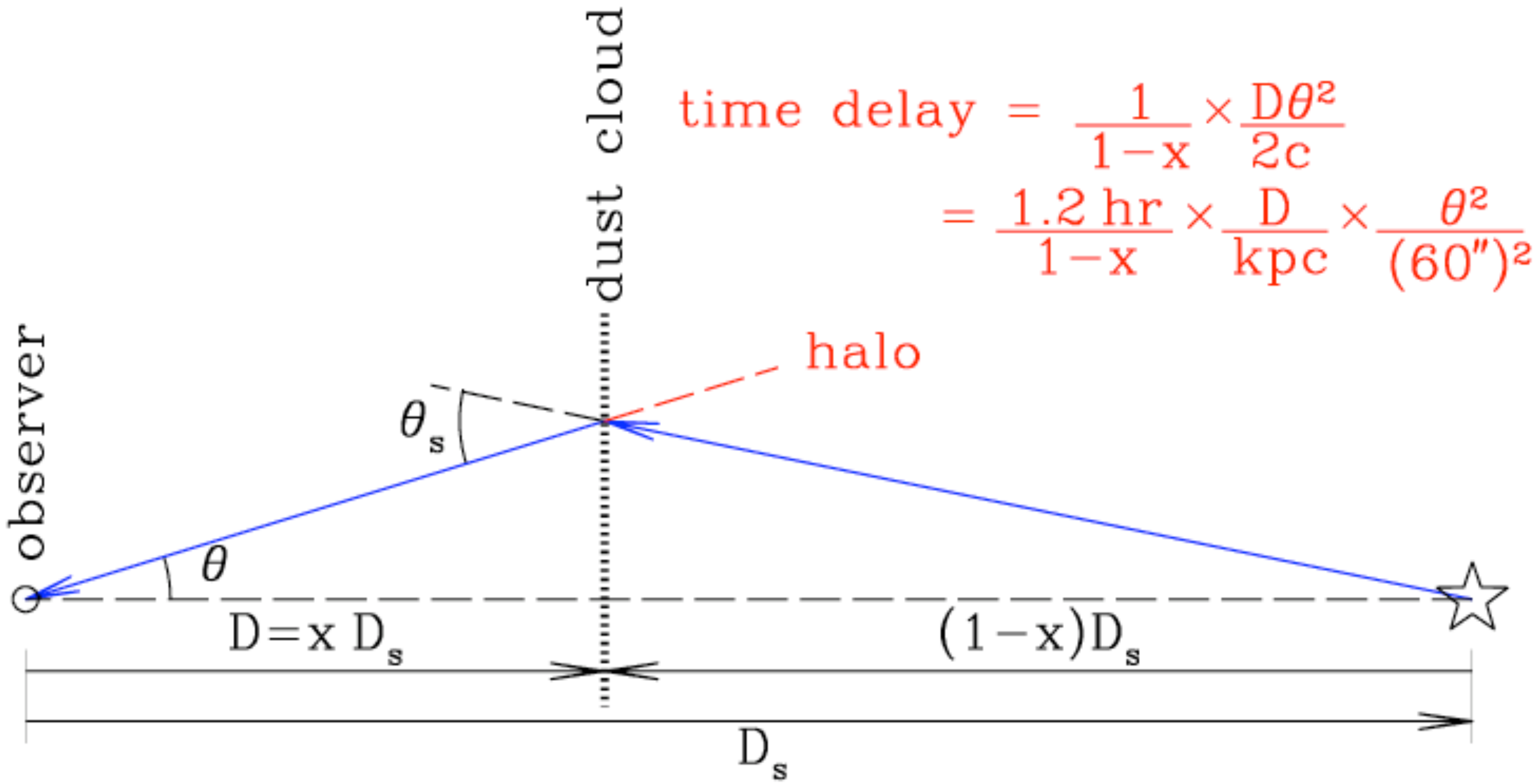
brilliant pebbles

- **Dust grains scatter light through characteristic angle**

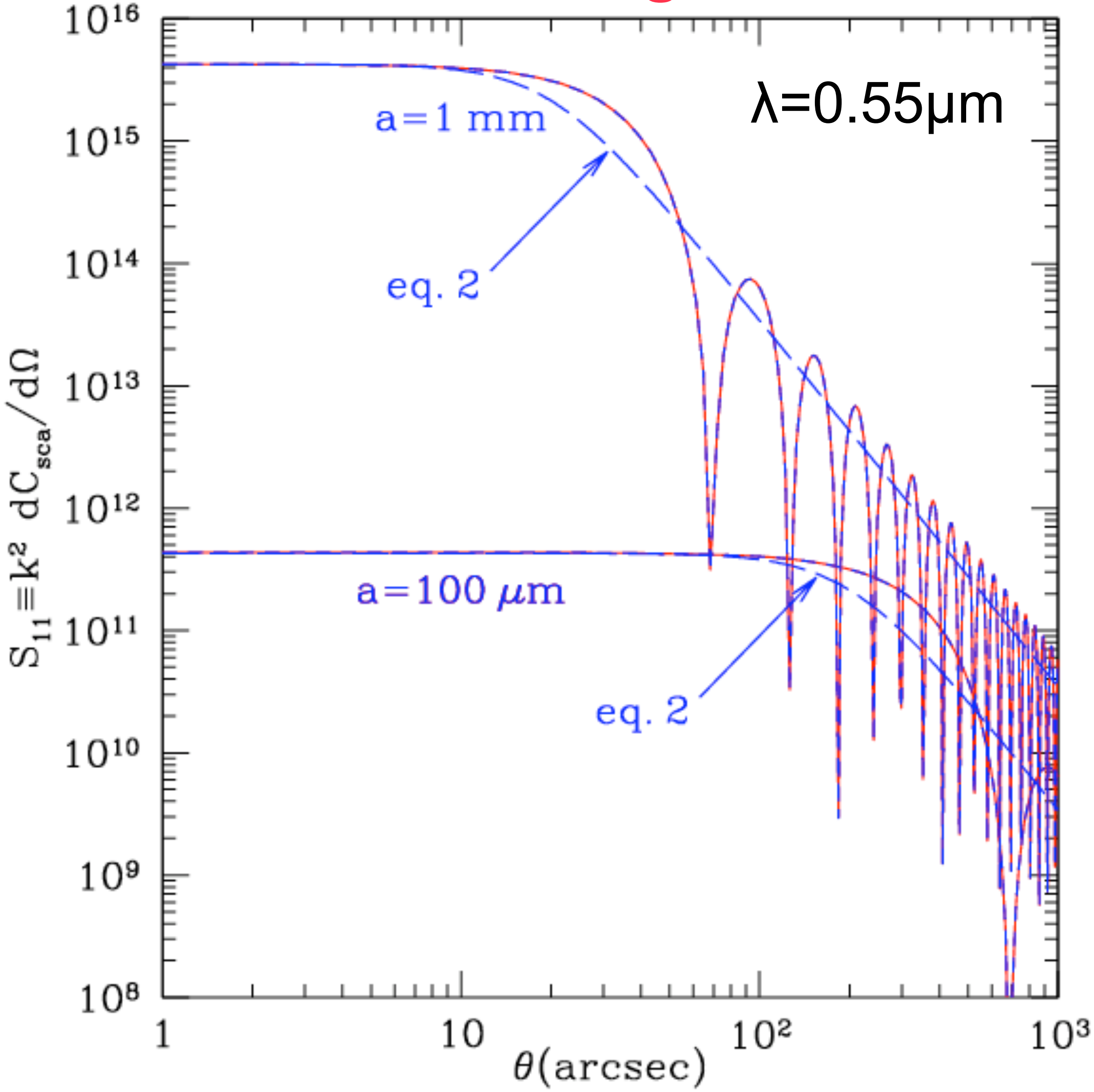
$$\theta_s \approx \min\left(\frac{\lambda}{\pi a}, \frac{\pi}{2}\right)$$

- $a \approx 0.1\,\mu\text{m}$, $\lambda \approx 0.5\,\mu\text{m} \rightarrow \theta_s \approx 0.3$ **rad.**
  $\rightarrow$ **"Diffuse Galactic Light"**
- **Suppose that there are grains with $a \approx 1\,\text{mm} \gg \lambda$ Then**
  - $\theta_s \approx 36$ **arcsec**
  - $C_{abs} + C_{sca} = \mathbf{2}\pi a^2$ **(the "extinction paradox")**
    $\Delta C_{sca} = \pi a^2$ **from diffraction "around" obstacle.**
  - **Star will have "halo" around it.**
- **"Halo" will look like extended psf, but:**
  - **Halo strength $\propto$ E(B-V)**
  - **Variable sources (e.g., nova):**
    Halo will have a time-lag.

Scattering Geometry



Differential Scattering Cross Section



Socrates & Draine 2009

Sensitivity to Large Dust Grains

Suppose

- Dust grains with $a \approx 1\,\mathrm{mm}$ contribute 3% of total dust mass.
- Variable star with $m_V \approx 7$, $E(B-V) \approx 0.3\,\mathrm{mag}$

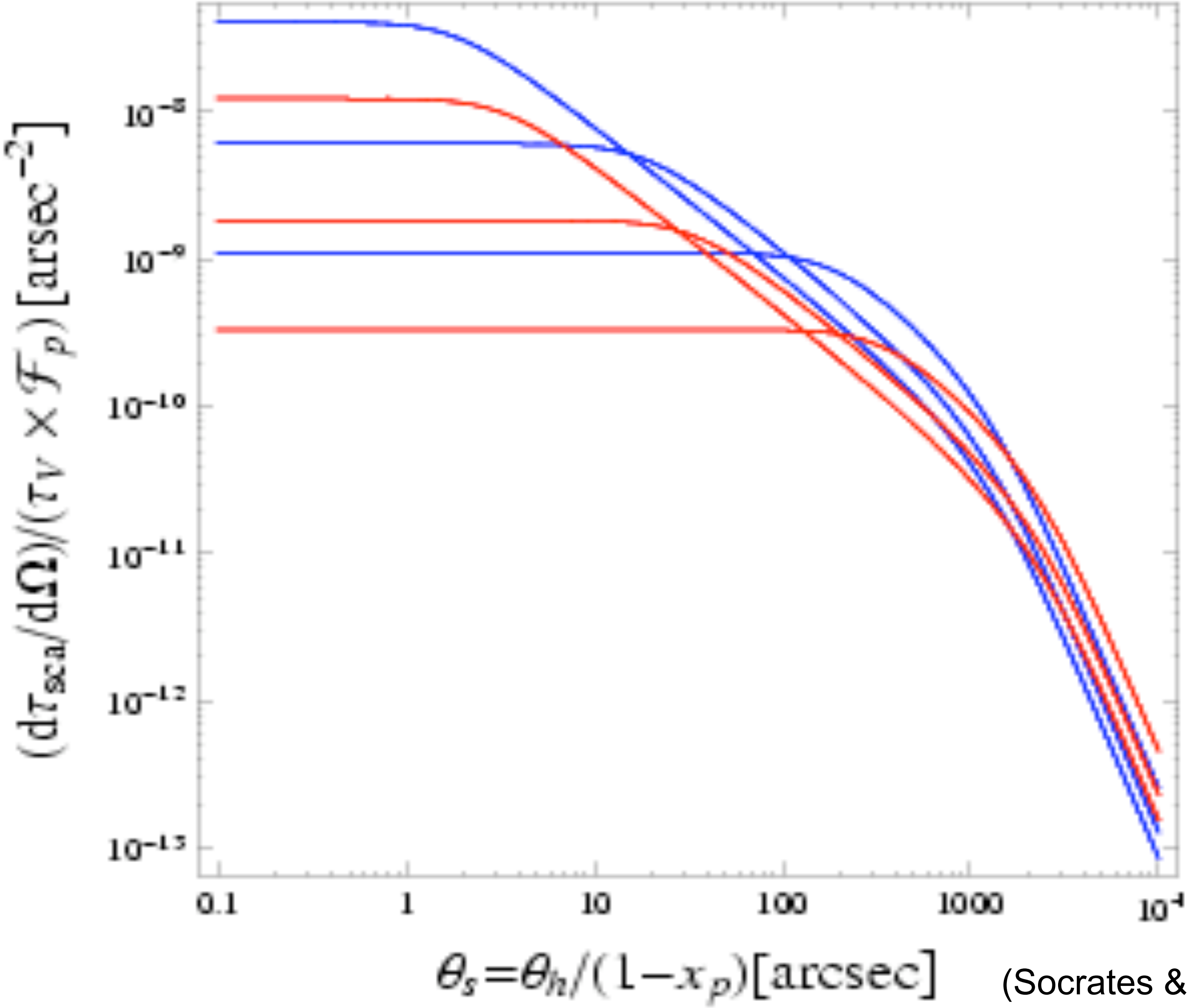
Then halo surface brightness ($\theta \lesssim 18\,\mathrm{arcsec}$)

$$\mu_V \approx 28\,\mathrm{mag\,arcsec}^{-2}$$

This is probably detectable.

Or: **Statistical search for psf $\propto E(B-V)$.**

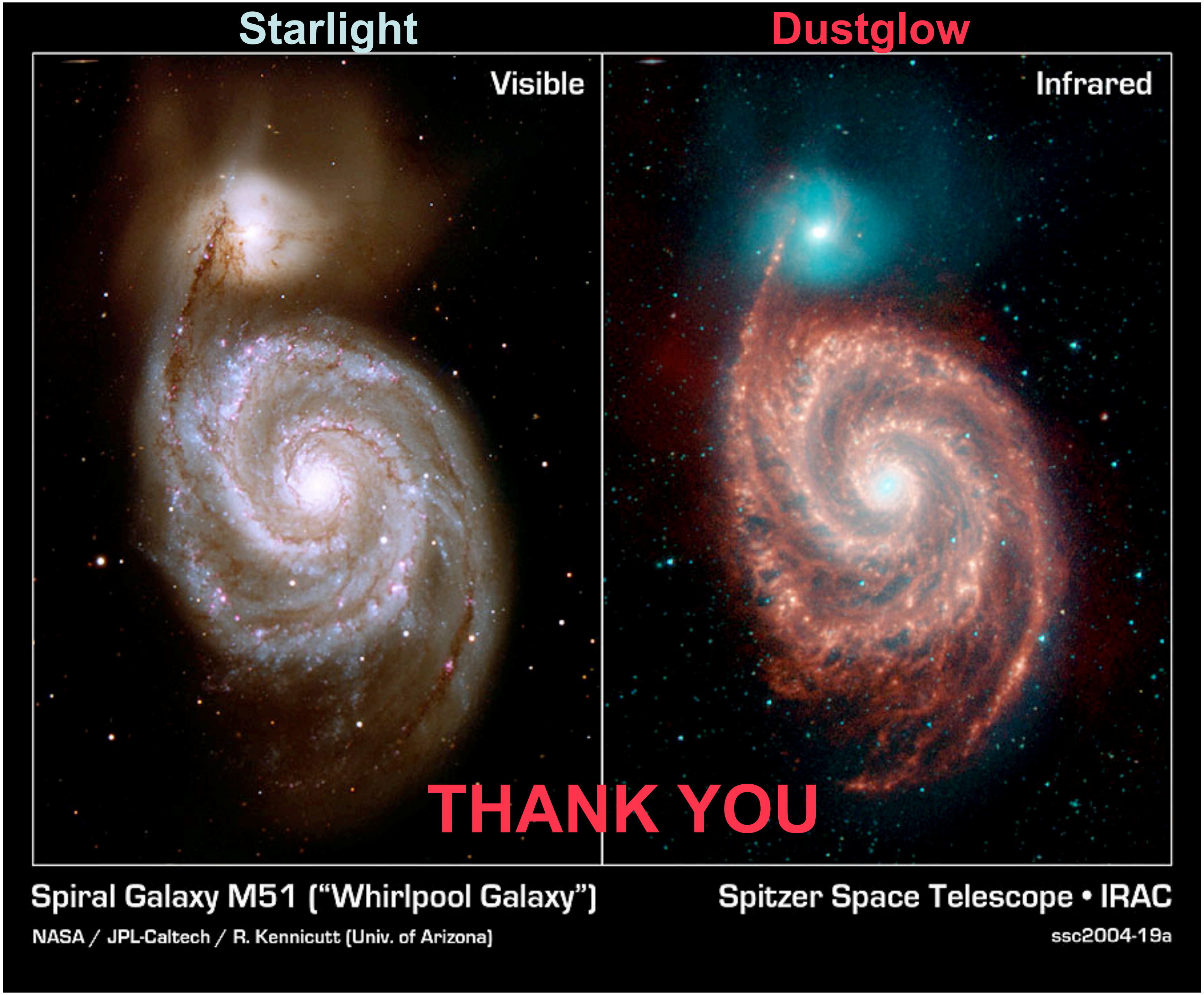
Halo profile depends on λ and on size distribution: can determine size dist.



(Socrates & Draine 2009)

Very Large Grains in the ISM

- Flux of large grains detected by Ulysses, Arecibo, and AMOR is incompatible with what we think we know about interstellar grains
- If flux is real, it may originate in extended Kuiper belt or Oort cloud (Rafikov...)
- If such large grains are actually present in the ISM – even at reduced levels – they can be detected by small angle scattering of optical photons


Starlight
Dustglow
Visible
Infrared
THANK YOU
Spiral Galaxy M51 ("Whirlpool Galaxy")
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / R. Kennicutt (Univ. of Arizona)
ssc2004-19a