A little Bit of Dust Goes a Long Way; or The Impact of Dust on a Stellar Wind-Blown Bubble

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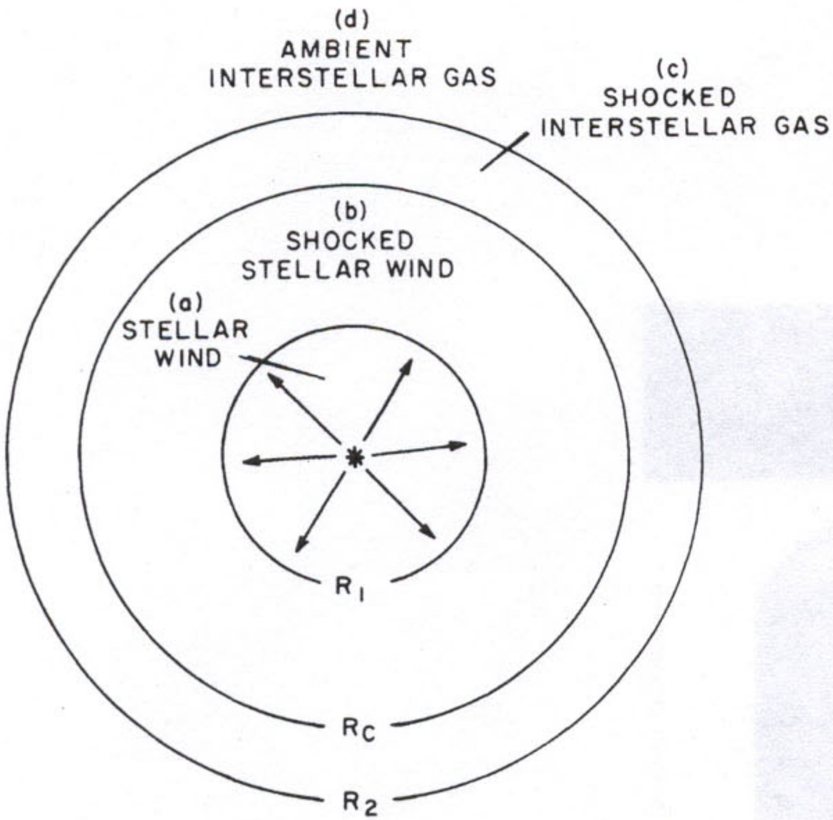
SOFIA Teletalk

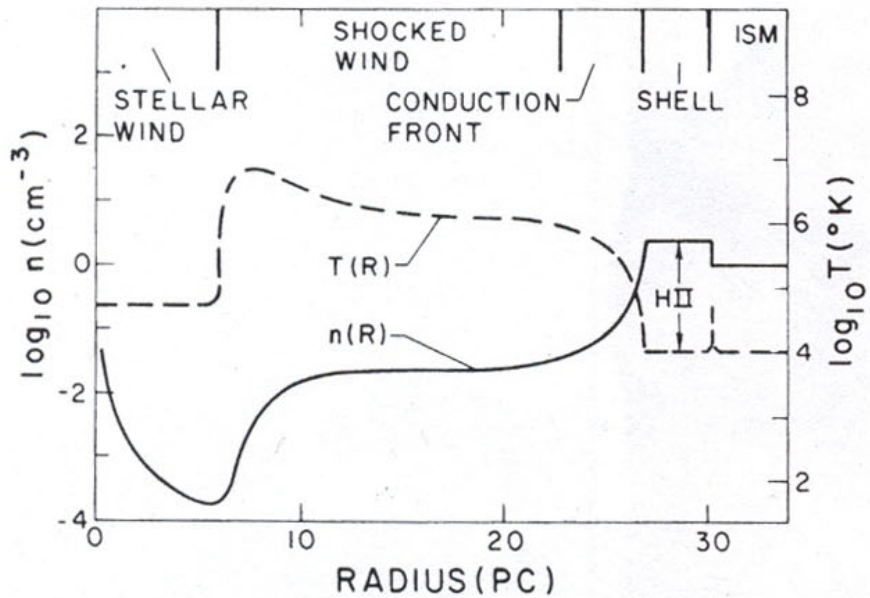
Overview

- View of wind-blown bubbles up to 1977
- Observed properties of IR bubbles (IR, radio, X-ray)
- A model of a wind-blown bubble including dust
- A Revised view of wind-blown bubbles
- Summary and opportunities for SOFIA

Weaver et al. (1977)

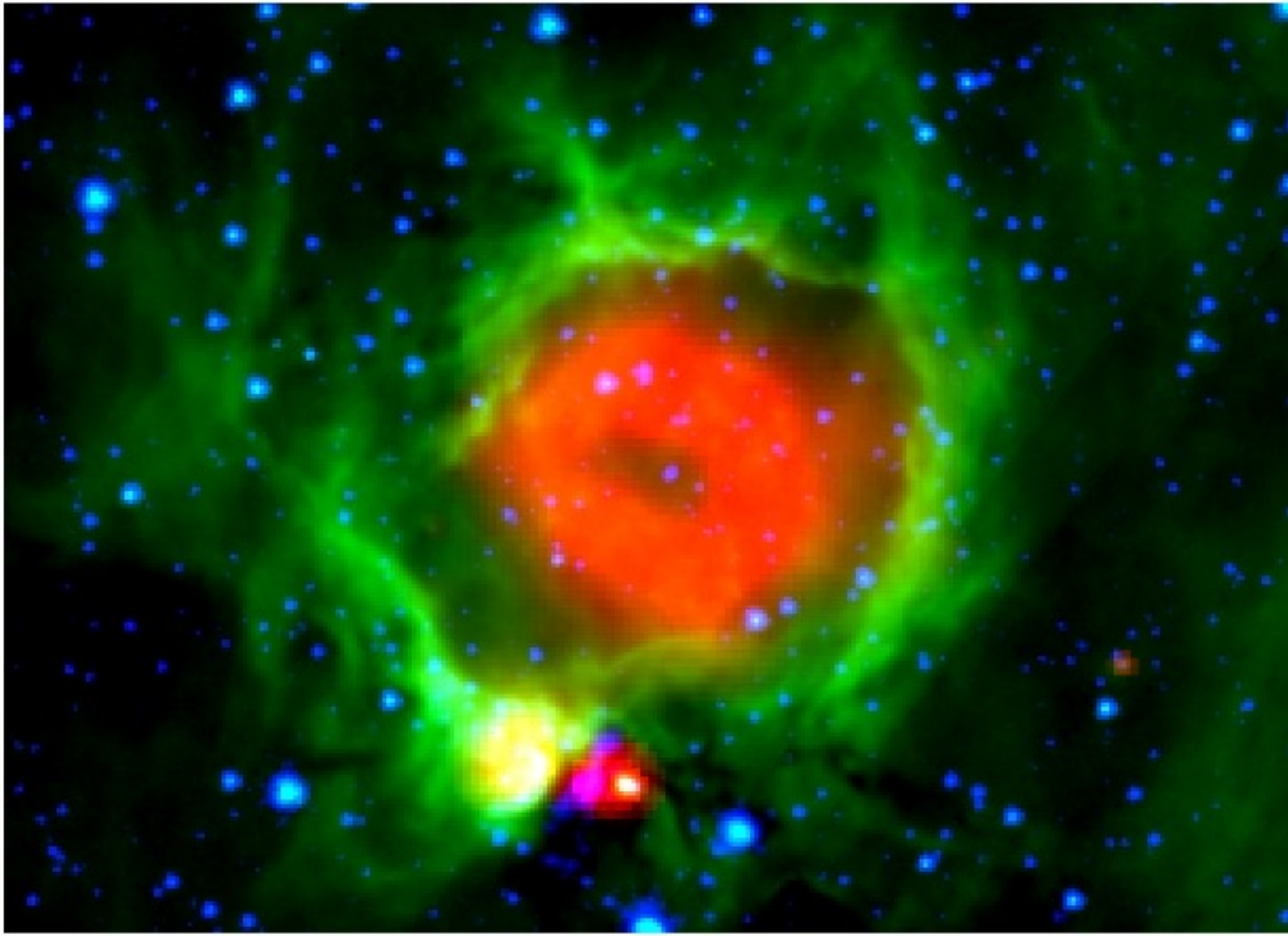


—Schematic sketch indicating the regions and boundaries of the flow.

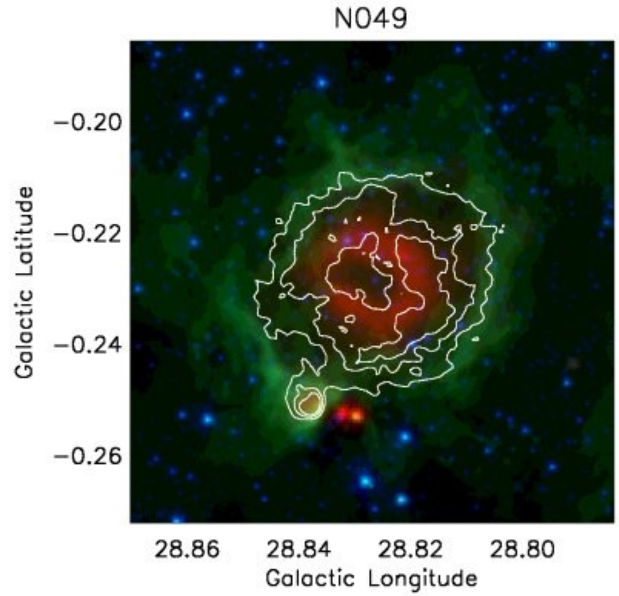


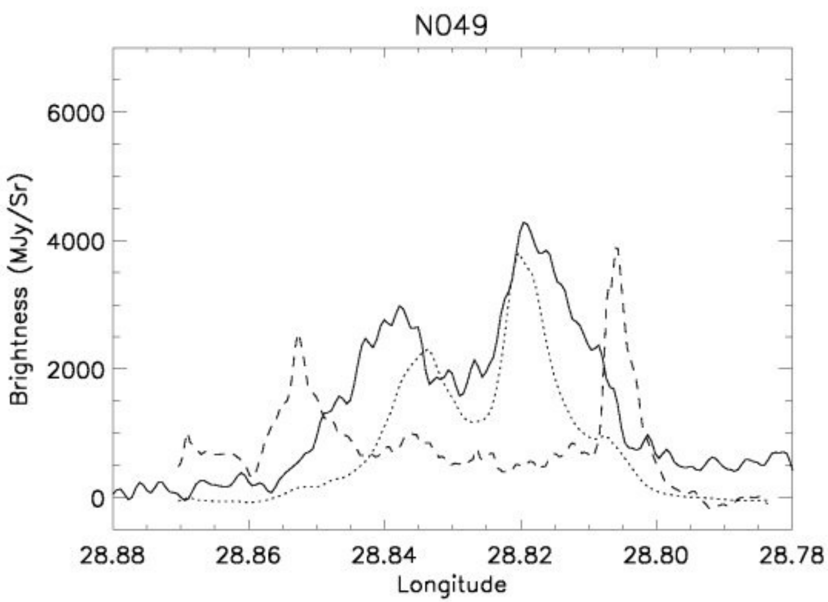
—The large-scale features of the temperature and density structure of an interstellar bubble for which $L_w = 1.27 \times 10^{36}$ ergs s^{-1}, $n_0 = 1$ cm^{-3}, and $t = 10^6$ yr. ISM means ambient interstellar medium. For a typical O7 I star, the H II region would extend to $\sim 3\ R_2$.

IR Radiation Distribution of a Wind-Blown Bubble:N49

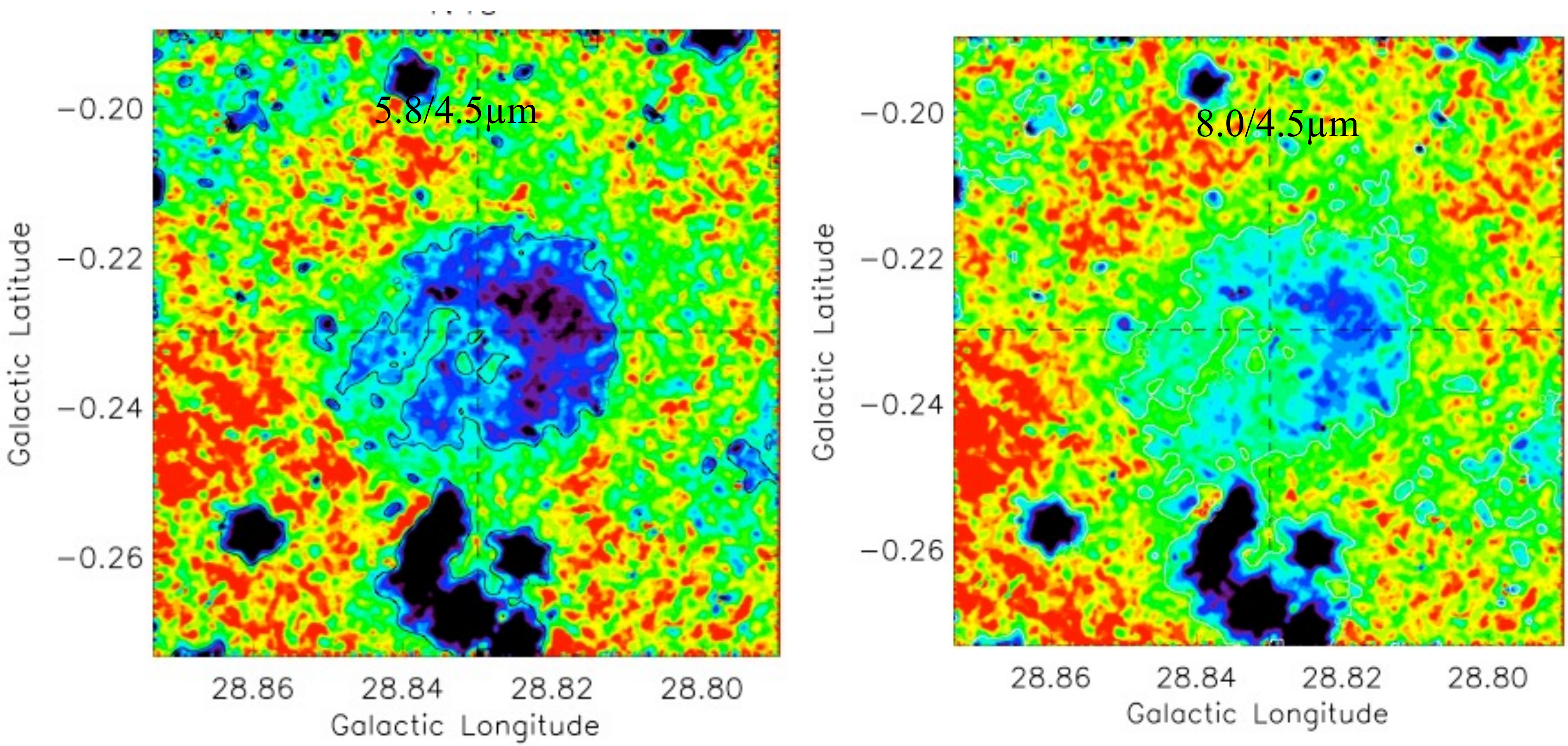


N49 IR/Radio Image



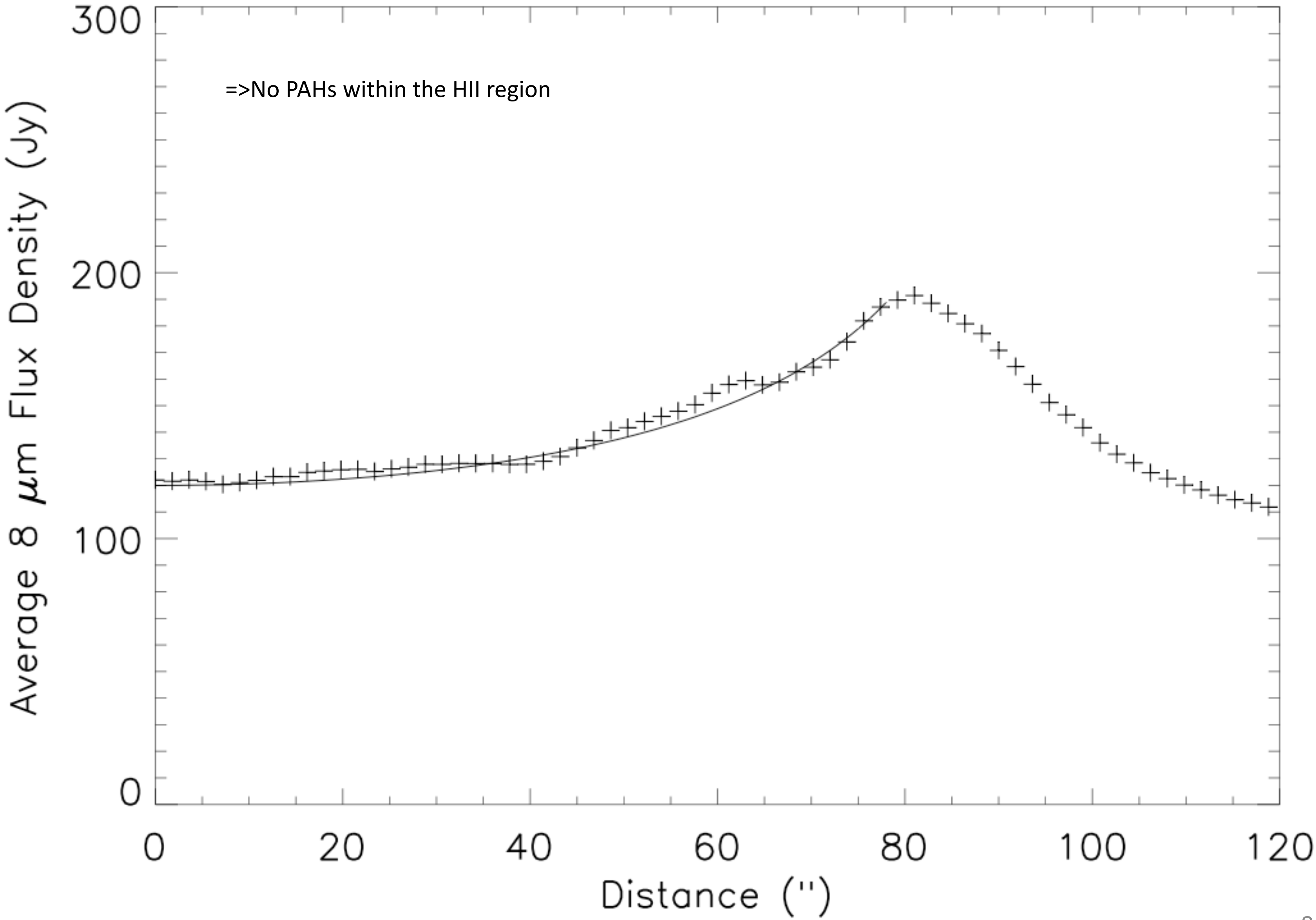


PAHs are absent inside HII regions



Ang. Diameter ~0.03^{0} @ 5.7 kpc => R~1.5 pc

8μm Observations Azimuthally averaged (+);
Model of 8μm Shell Emission (solid curve)



Dust Model Properties

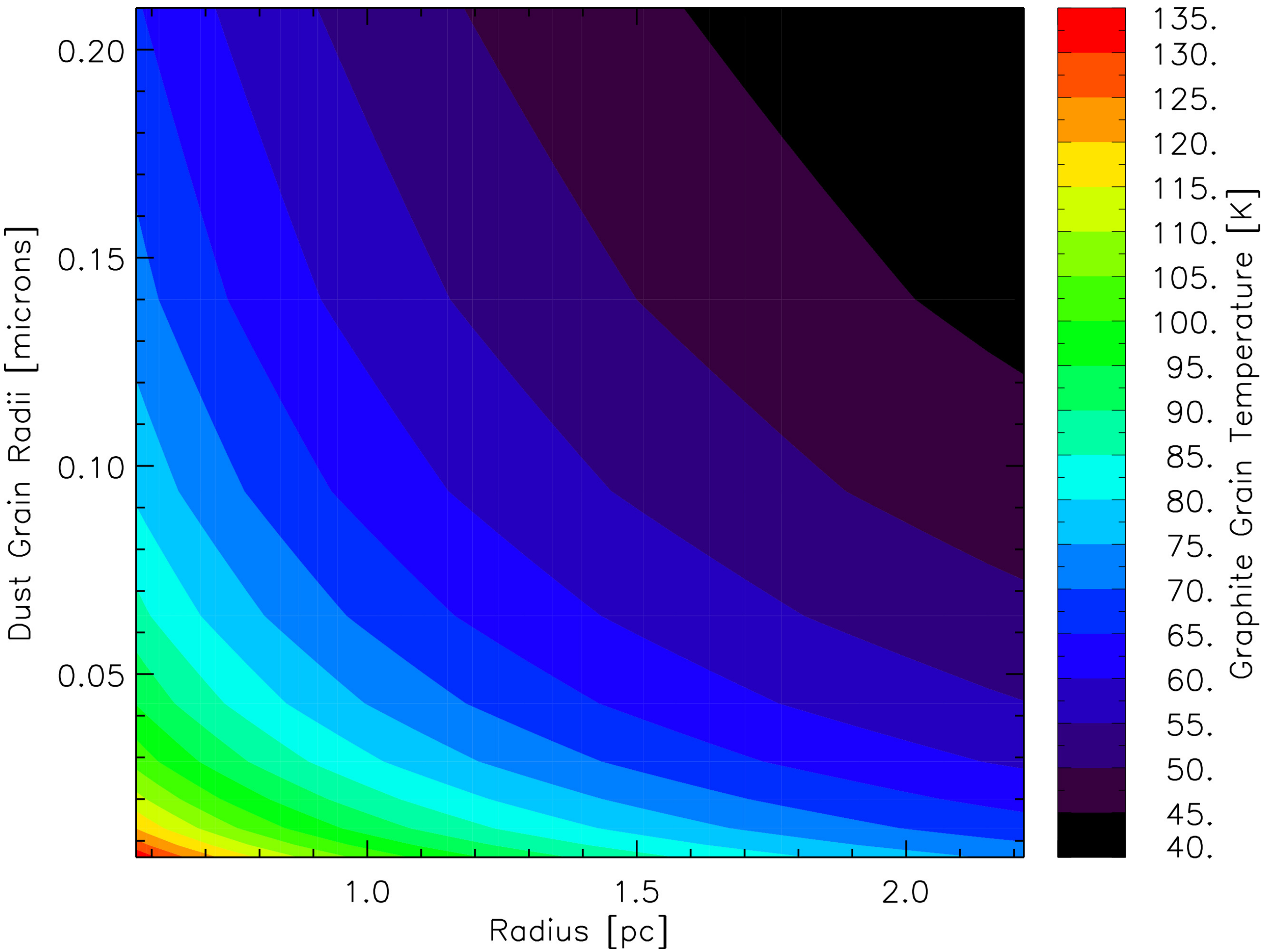
Assume a static, uniform temperature, dusty bubble using Cloudy (Ferland 1998) and Cloudy_3D (Morisset, 2004). Input parameters for the model are:

Parameter	*Value*	*Reference*
central star	O5V	Watson et al. (2008)
$\dot{M}_{\rm wind}$	$1.5 \times 10^{-6}\ M_\odot\ {\rm yr}^{-1}$	Vink et al. (2001)
distance	5.7 kpc	Churchwell et al. (2006)
age	$\sim 10^6$ yrs	Watson et al. (2008)
$< n_{\rm inner,\ dusty\ gas} >$	19.1 $\rm cm^{-3}$	(Best-Fit, 24 μm data)
gas & dust density power law: r^α	α = -2	*Assumed*
$r_{\rm inner}$	0.6 pc	(Best-Fit, 24 μm data)
$r_{\rm outer}$	2.2 pc	interface of PDR shell
dust	ISM grain distribution	Mathis et al. (1977) van Hoof et al. (2004)
$T_{\rm e,bubble}$	3.5×10^6 K	Our dynamical model (Section 4.2)

Dust Properties in a Wind-Shocked Environment

- Grain Temperatures
- Sputtering Timescales
- Grain Residence times
- Average Grain Charge
- Dust Cooling Fraction

Low Grain Temperatures =>Thermal Dissociation Unimportant
Most emission at Mid-FIR Wavelengths

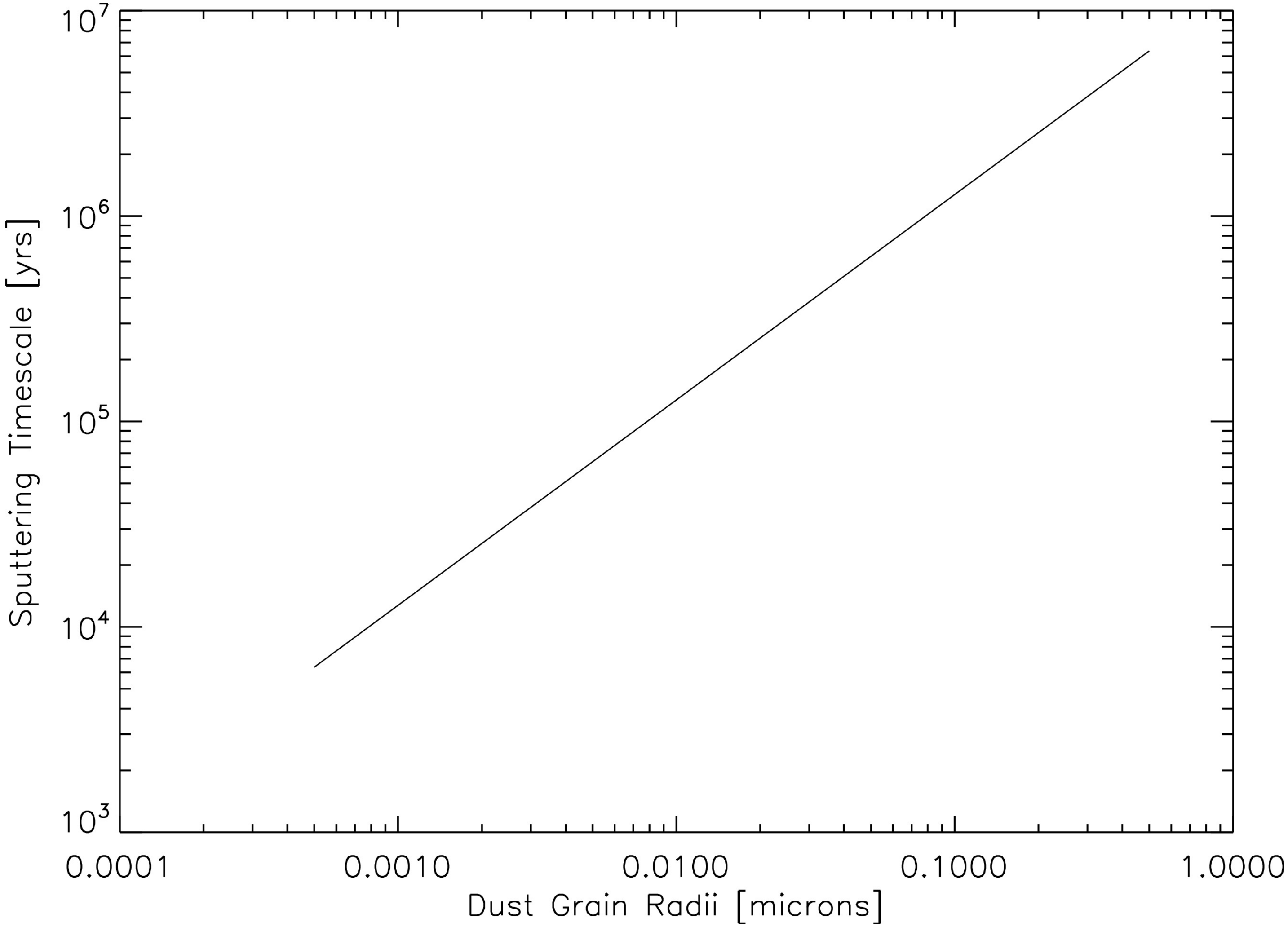


Graphites slightly warmer than the silicates at same radius and grain size

Larger grains cooler than smaller grains at same radius

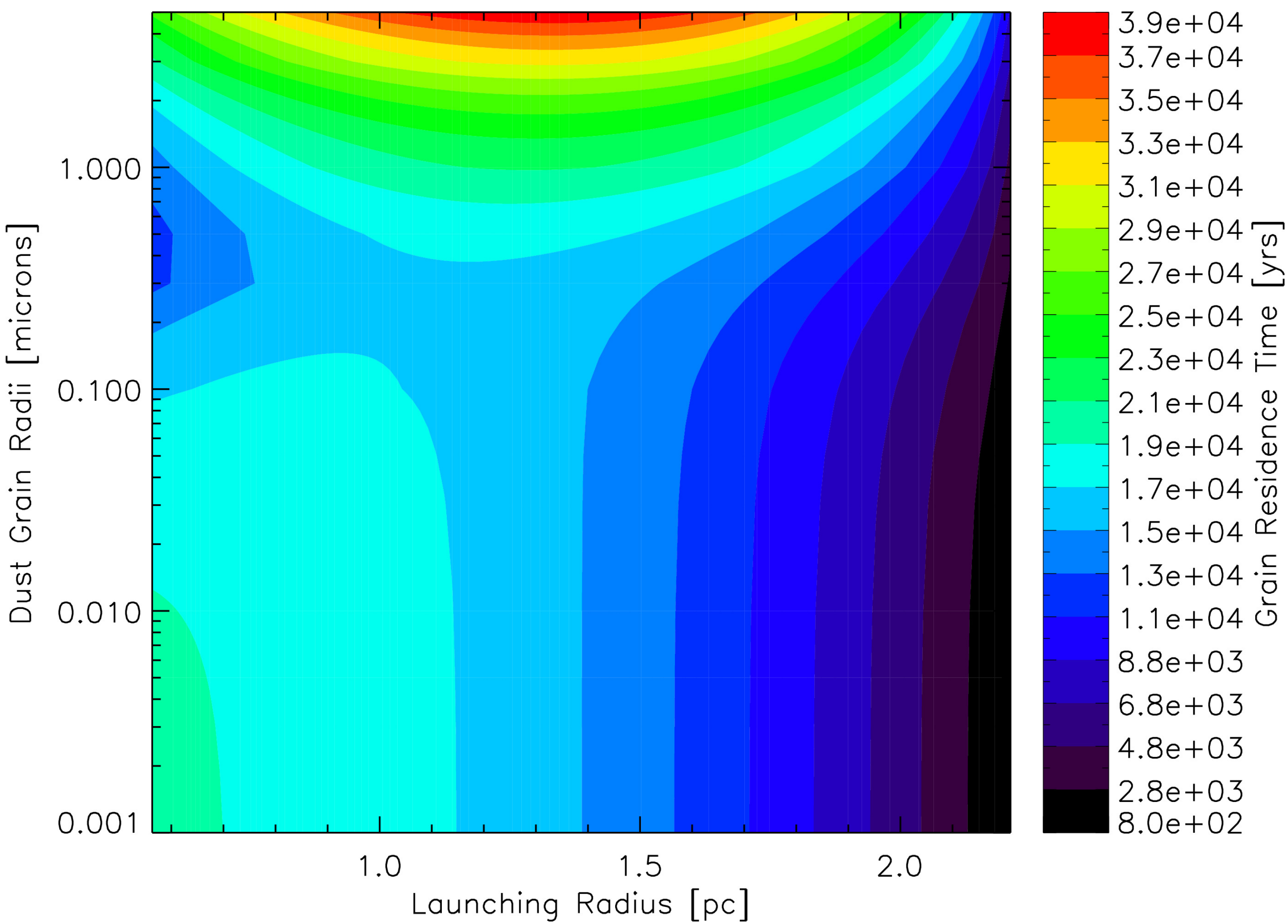
Decrease in temp with radius for grains of a given size is only ~20-30%

Sputtering: Grains<0.01μm are short-lived, larger grains long-lived



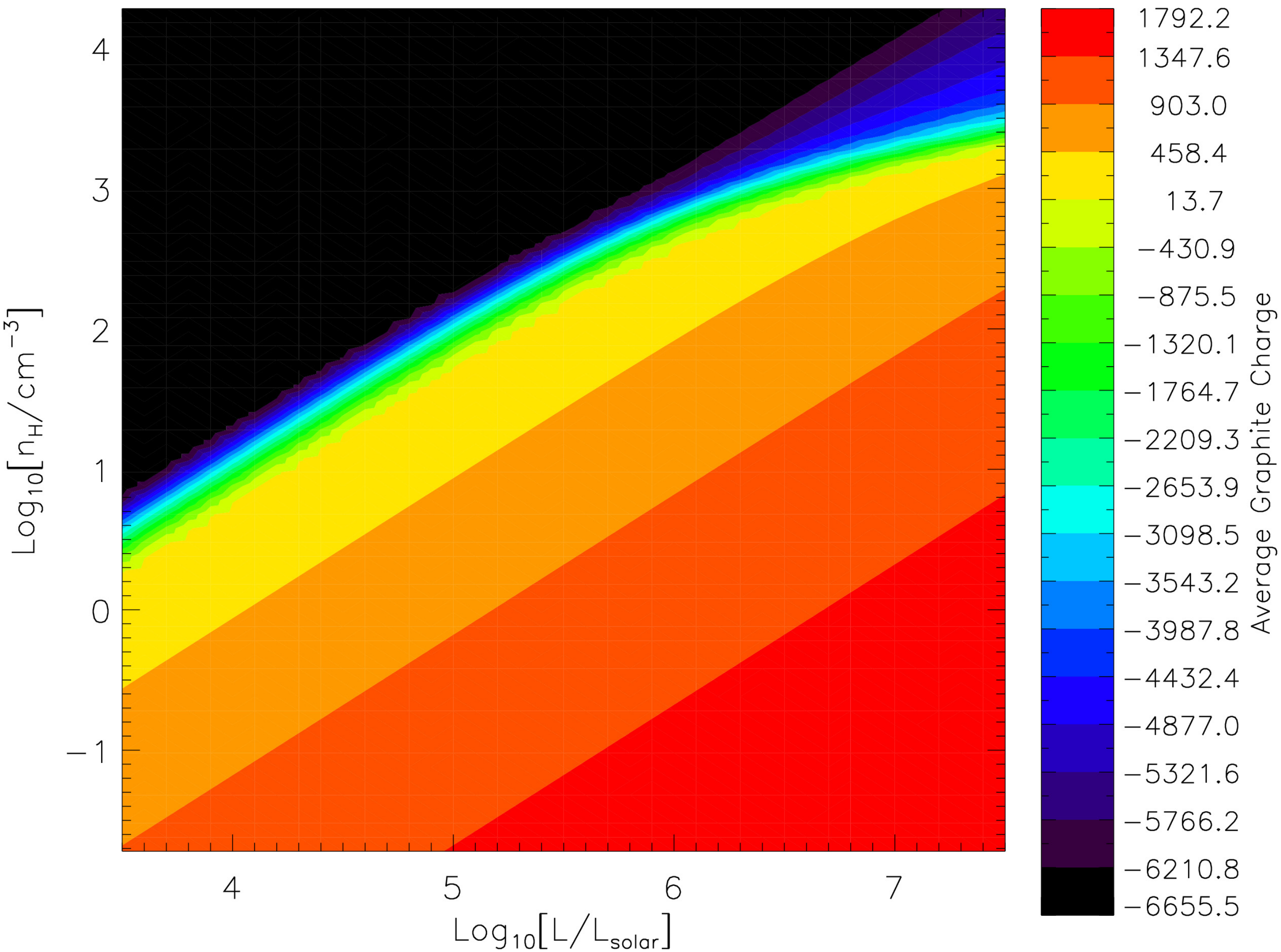
Very small grains are destroyed by sputtering on short timescales
(Sputtering timescales about the same for graphite & silicates.)

Grain Dwell Time in the HII Region is Short



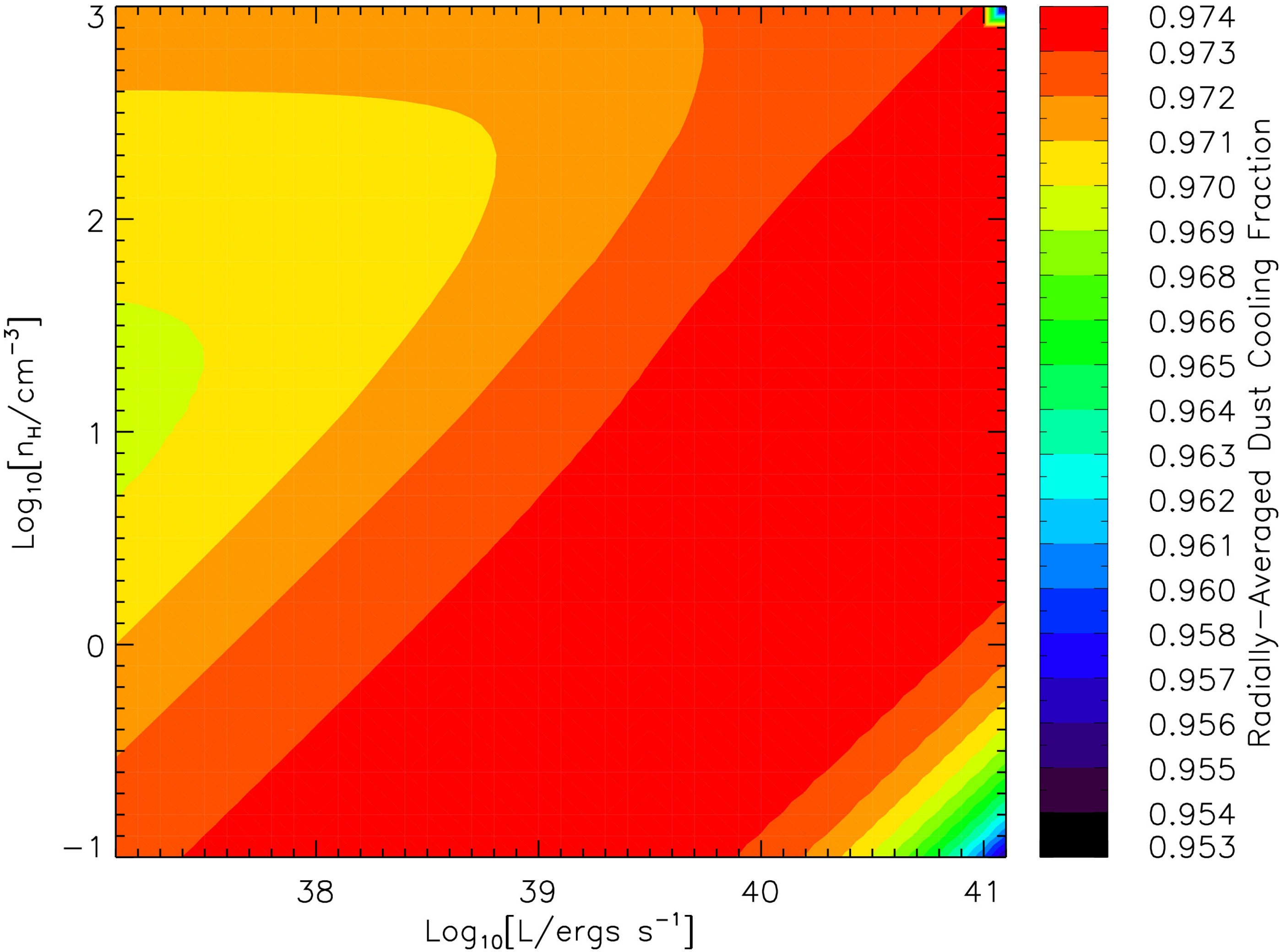
All grains are removed by a combination of wind drag, radiation pressure, and sputtering in less than 4 x 10^4 yrs launched from any point in the nebula, a small fraction of the age of the HII region!

Average Graphite Grain Charge: All Sizes



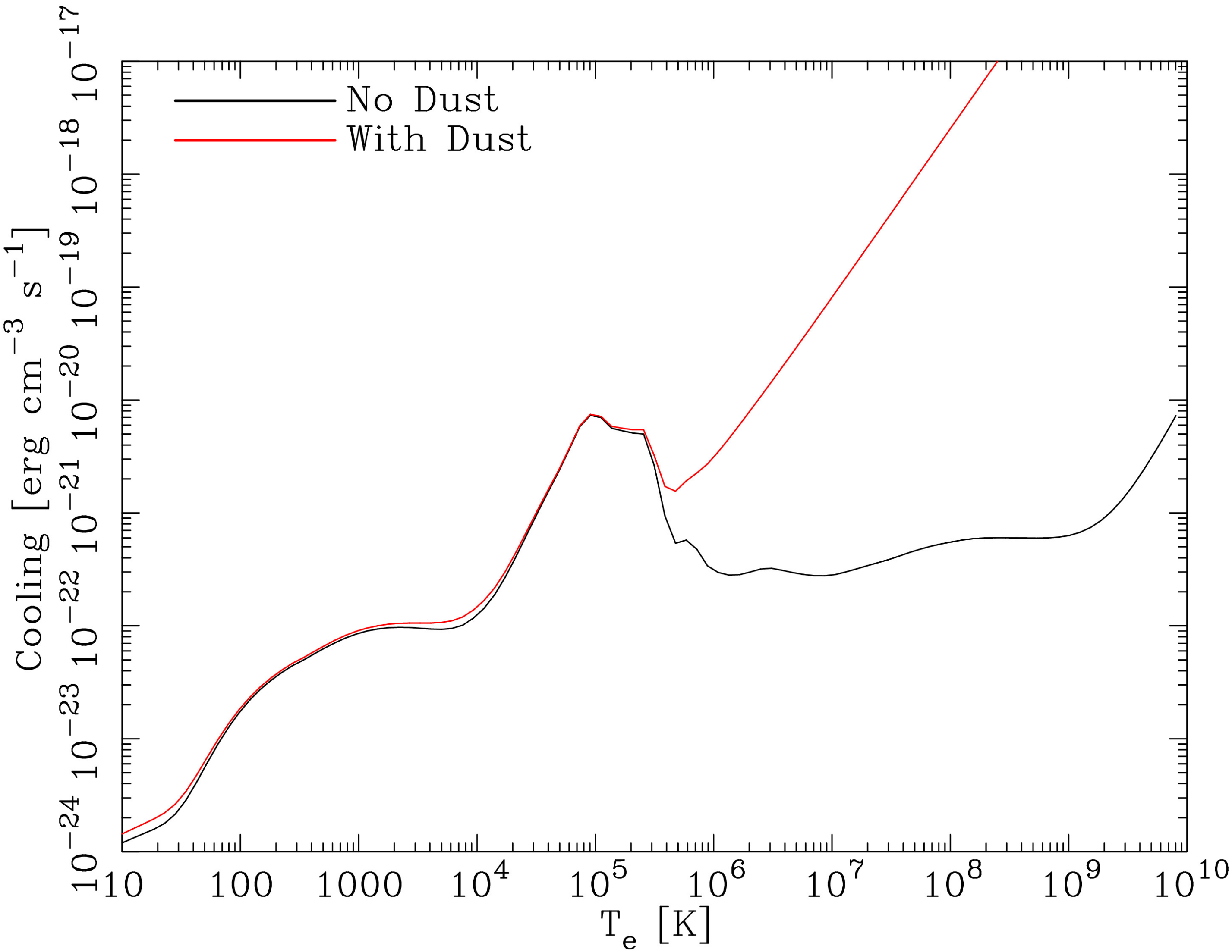
Silicate grain charge is similar to that of graphite grains

Dust Cooling Fraction in Shocked Wind

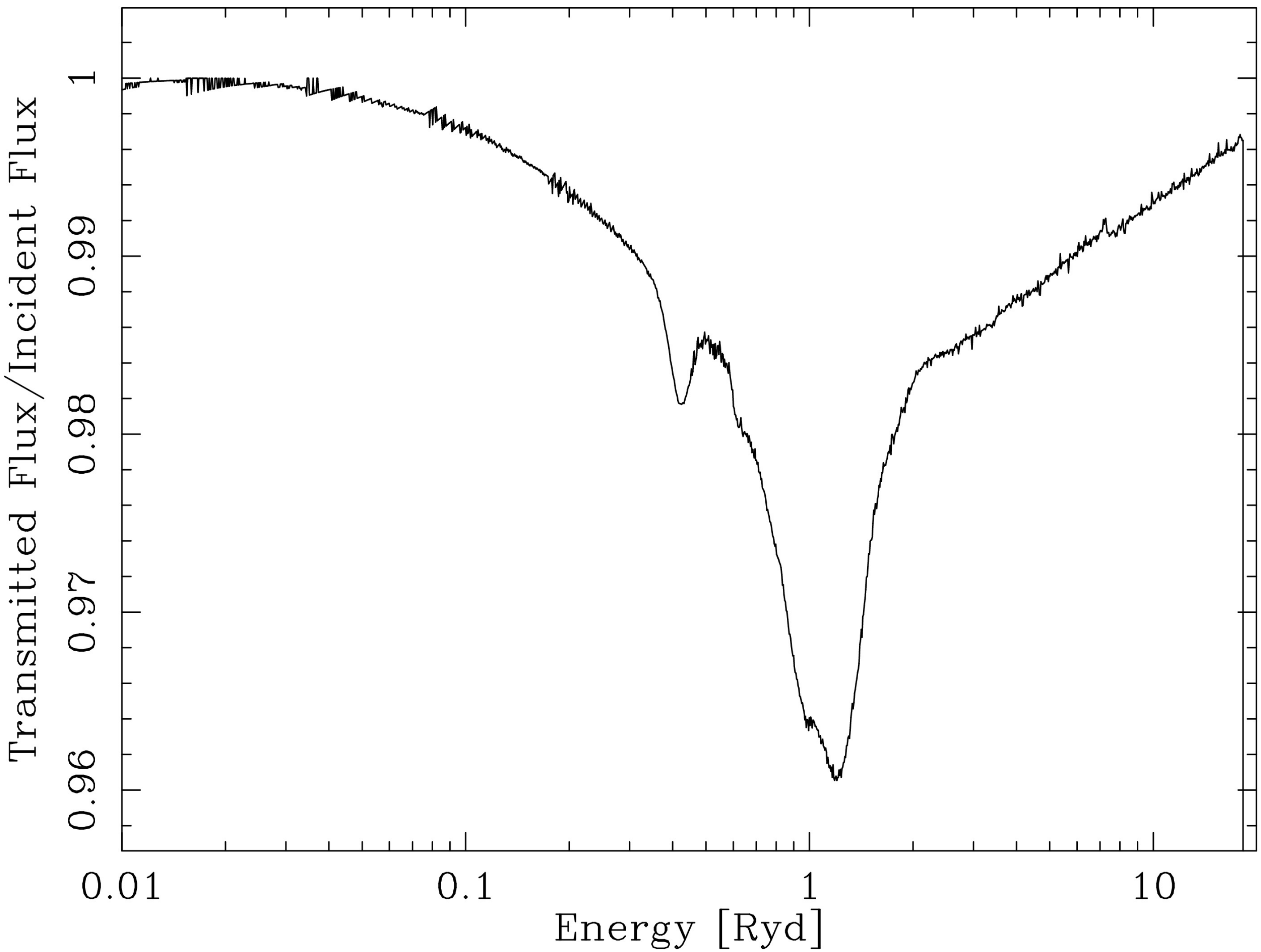


Dust dominates the cooling until Compton cooling becomes important at large luminosities and small densities. Cooling due to collisions plus photoelectric effect.

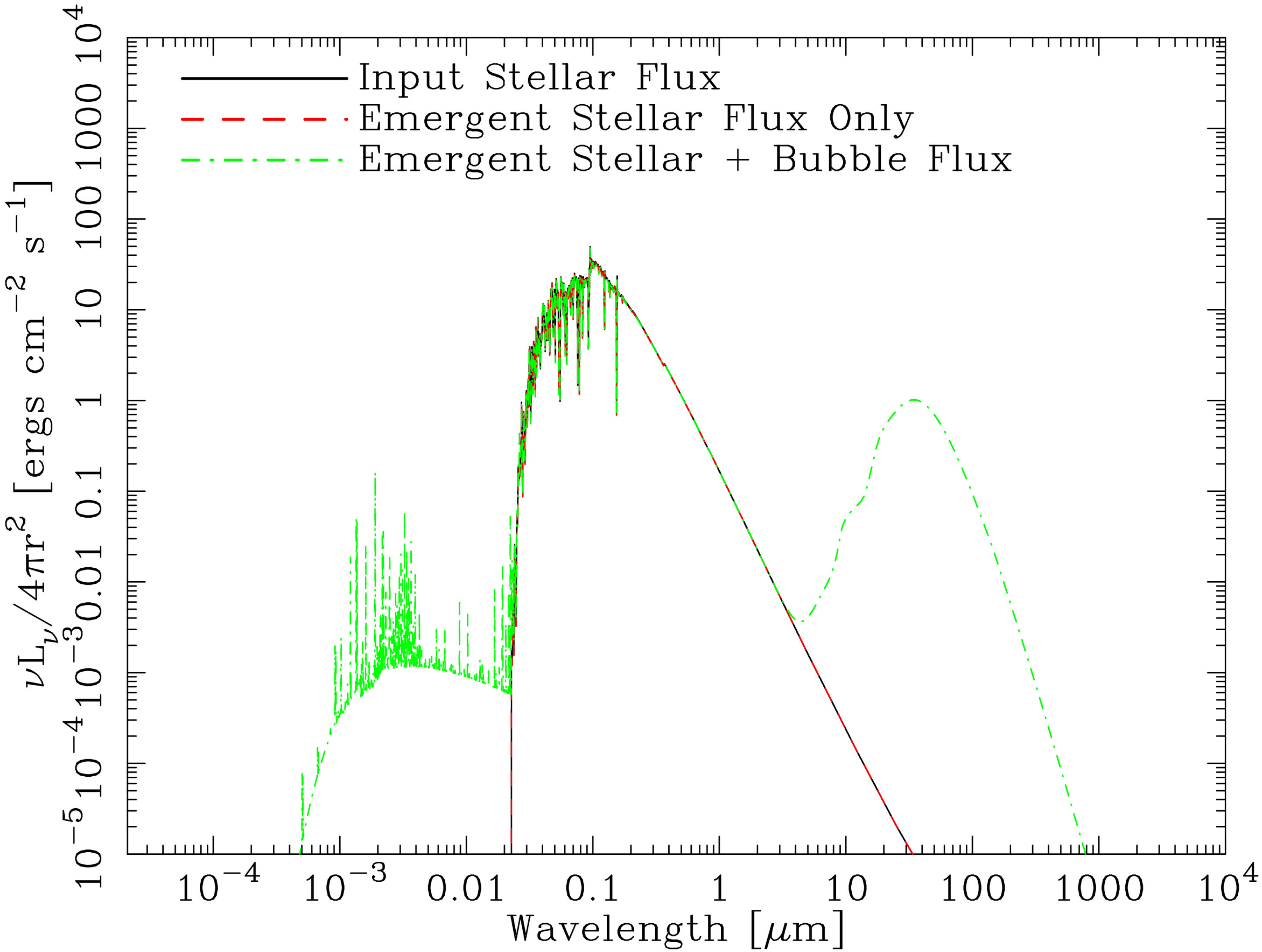
Dust dominates cooling at Temps >a few x 10^5 K



Fraction of the stellar UV flux absorbed in the wind-shocked region (out to the 10^4K gas)



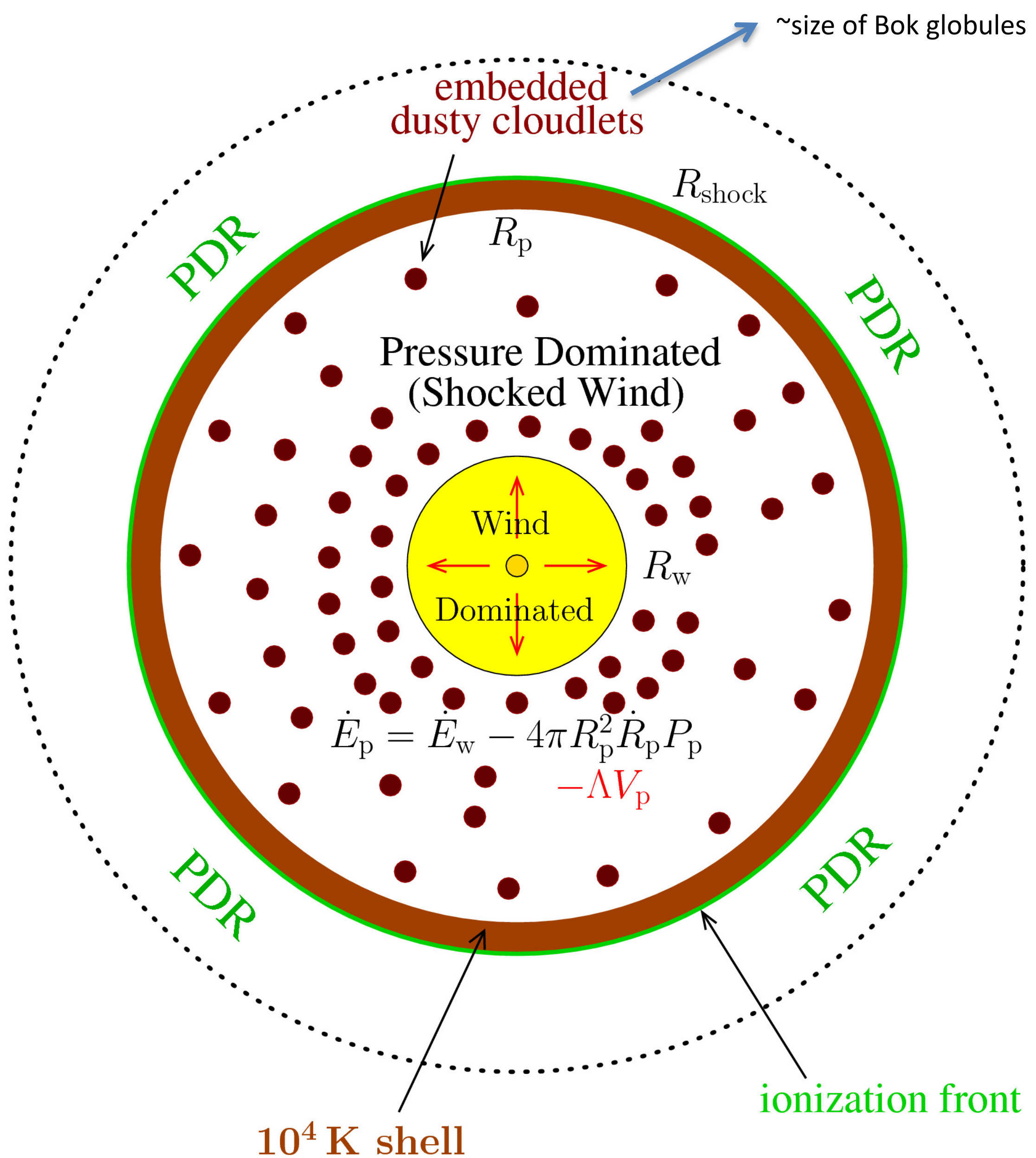
Spectral Energy Distribution of N49



Issues

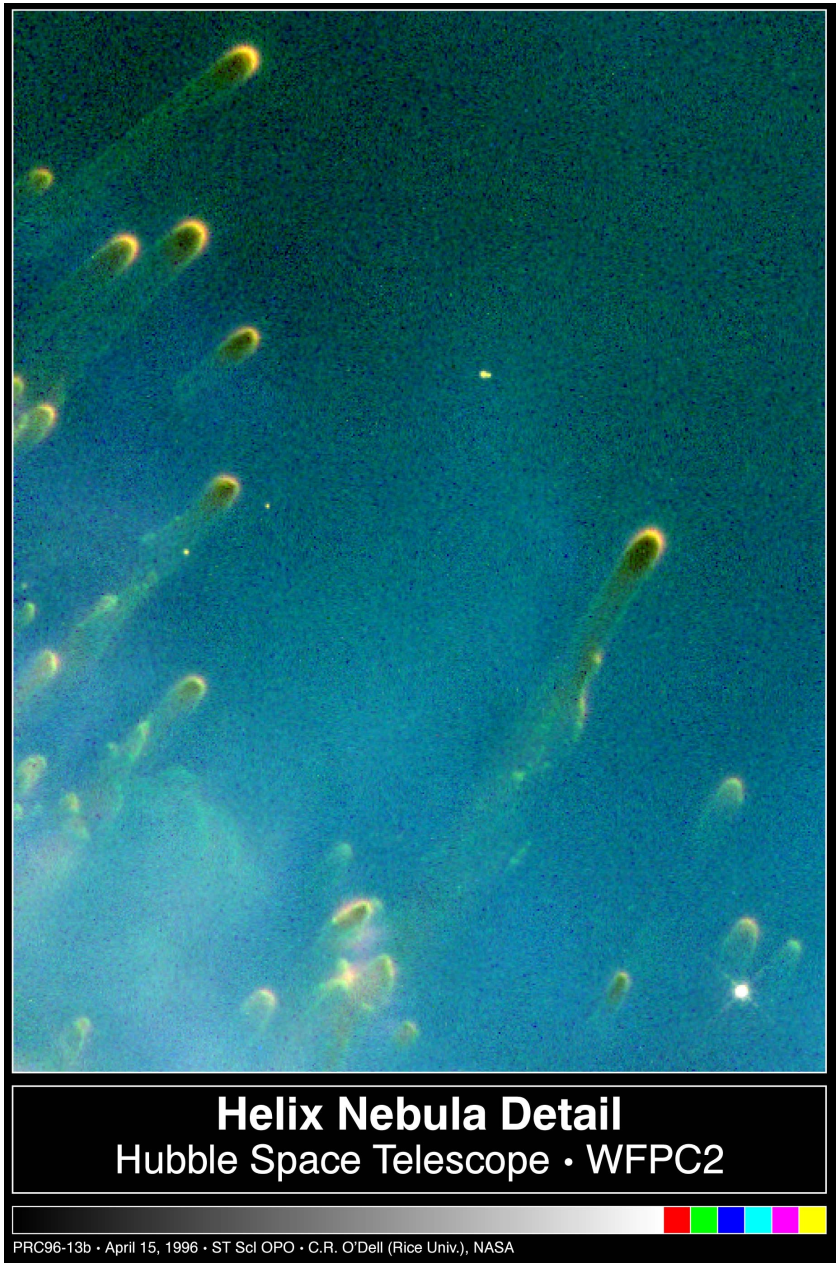
- 24μm emission => Dust exists within HII regions (even the hot, wind-shocked regions)
- Dust residence timescales are small relative to the age of bubbles =>Why are grains in HII regions?
  - Need a continuous source of grains
    - Perhaps from pre-existing, embedded, neutral cloudlets (Bok Globules)?
    - Entrainment of neutral condensations from the PDR of the HII region?
    - Release of dust from circumstellar disks around young, lower mass stars associated with formation of a massive YSO?
    - Or some combination of the above

A New Schematic of a Dusty Wind-Blown Bubble

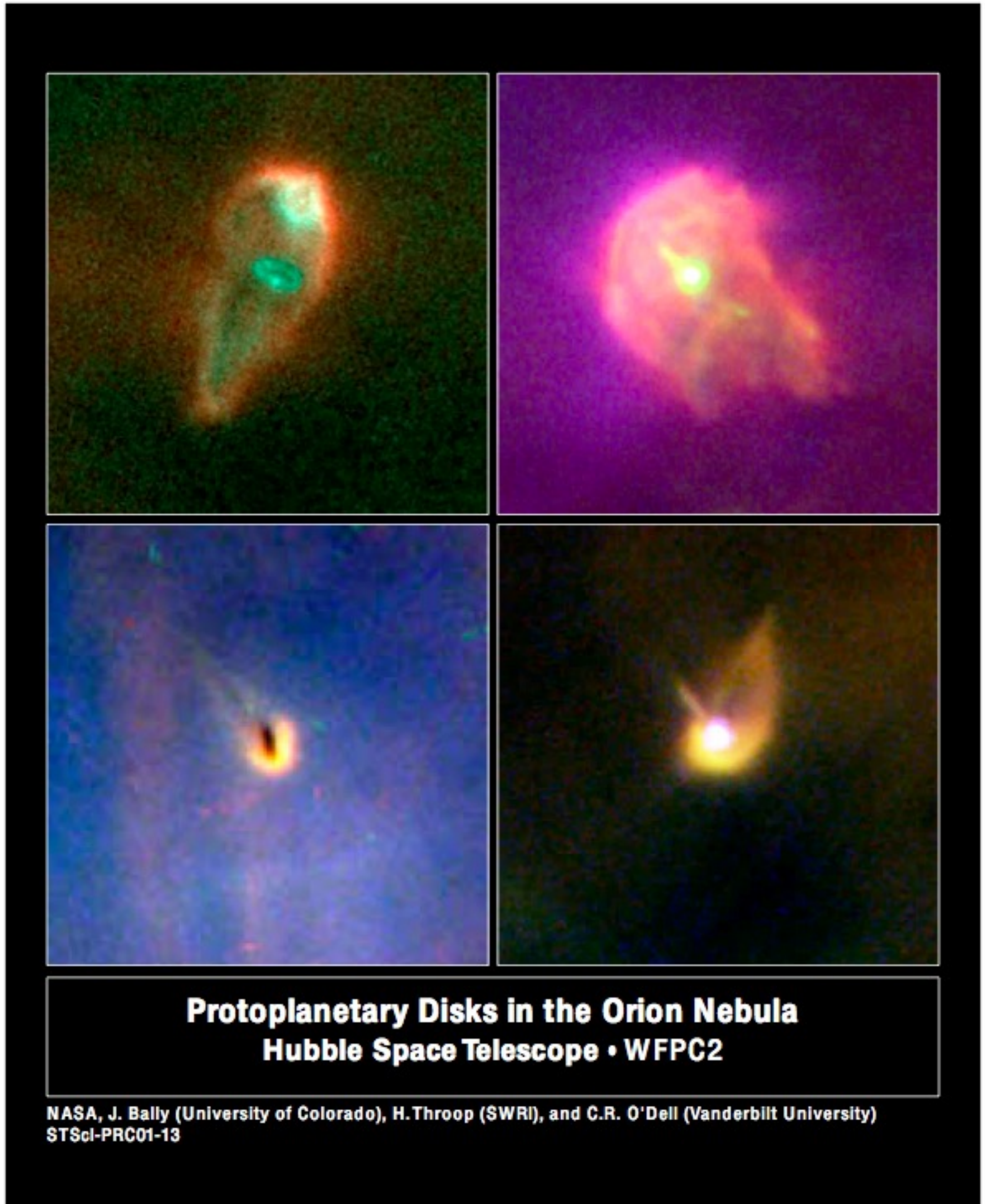


Close-up: Helix Nebula

Helix Nebula: Close-up



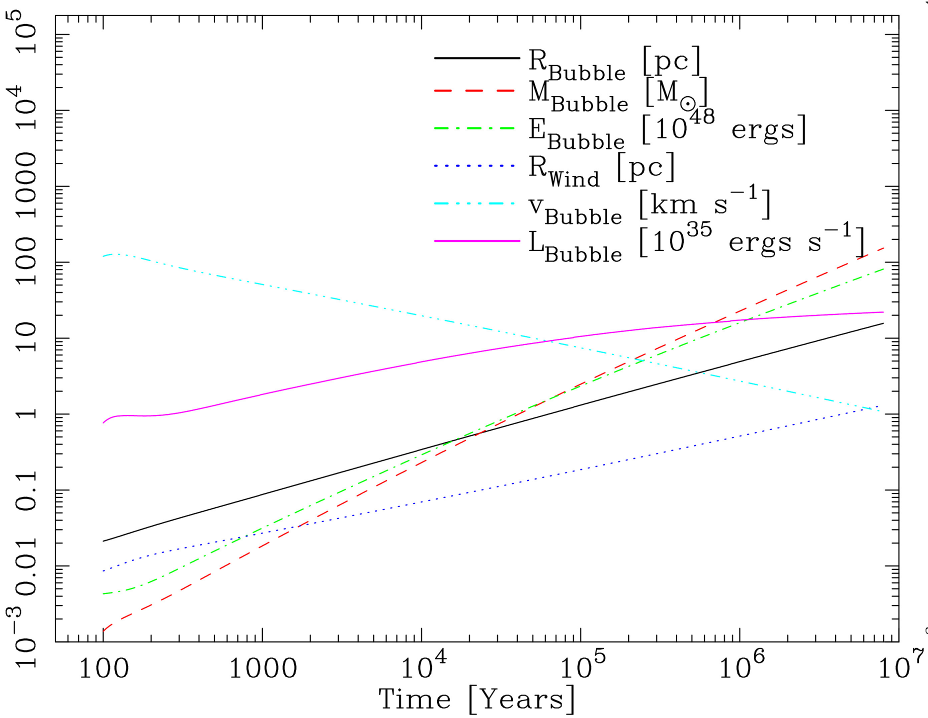
Orion Proplids

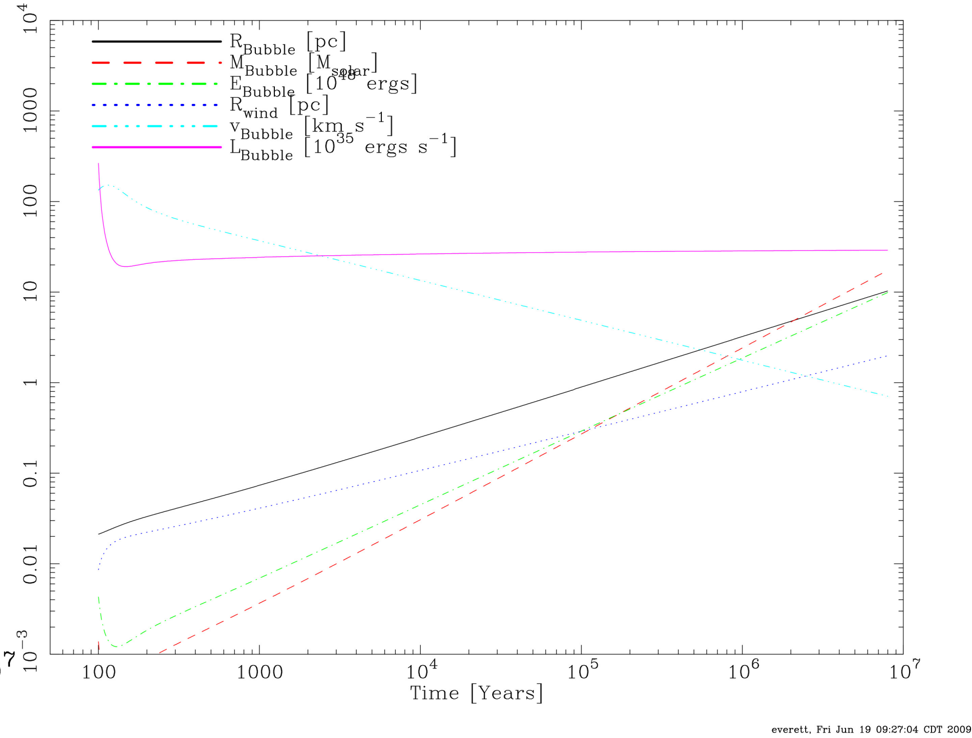


Orion Proplids

Evolution with no dust

Evolution with dust





L ~constant => R^2 Te^4 ~constant with time

E(dust)<<E(no dust)

M(dust)<<M(no dust)

Evol with & without dust very different

Summary and some opportunities for SOFIA

- **Dust Impacts on wind-blown HII regions**
  - Dust is well mixed with the hot, shocked gas—Need MIR-FIR SEDs (grain size distributions & total stellar luminosities) =>SOFIA/FORECAST/HAWK
  - Dust is strongly positively charged in low density, high temp. shocked gas
    - Mag. field strength & config,; Polarization? –SOFIA?
  - Dust dominates cooling in the wind-shocked gas and reduces X-ray emission—MIR/FIR spectral line/cont. intensity distributions=>SOFIA
  - Temperatures (gas) and energy much lower than in absence of dust—need SOFIA relative ionic line intensity ratios, GREAT, FIFI, CASIMIR, SAFIRE, EXES
  - Radii smaller for age and ambient density than expected in absence of dust => age estimates not simply related to size and ambient ISM density
  - Ionization structure => looks like a cooler central star than the actual star—SOFIA spectrometers: nebular atomic ion (NeII, III, IV, & V) line intensity ratios with images; PDRs (H_2(0-0, S(0-8)).
  - Velocity Structure of H^+ & PDR—SOFIA spectrometers (wind mass loading, shocks)
  - MIR-FIR brightness much greater than in absence of dust—a perfect class of objects for SOFIA (bright and good match with SOFIA resolution)
  - Theoretically grains of all sizes do not survive long enough to play an important role, however we see grains of all sizes =>must include dust in evolution models
  - Kinematic impacts due to dust?
    - Relative dust-gas drift velocities are fairly large
- **Need more accurate dynamical models to better assess evolutionary effects**