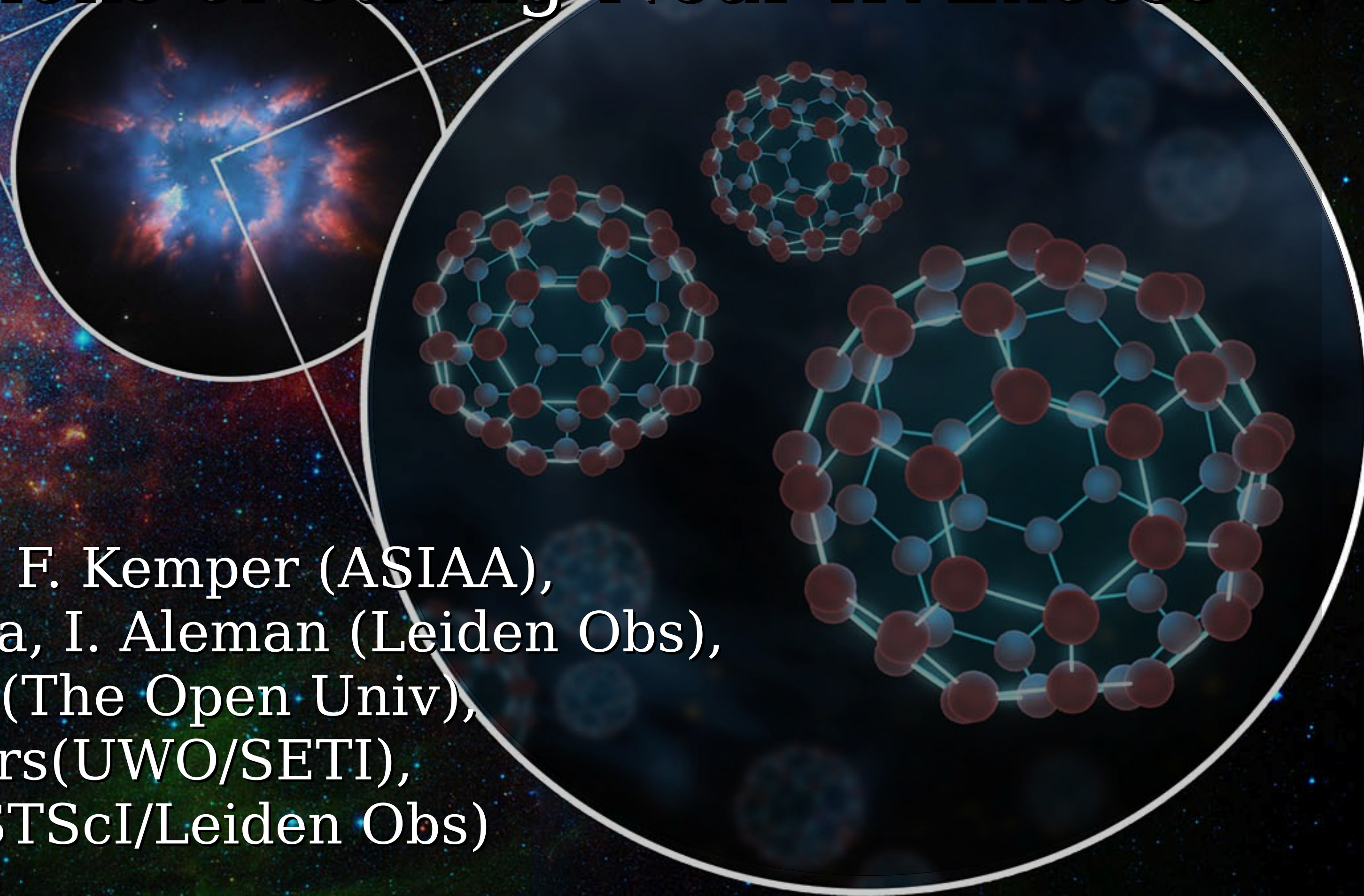
Physical Properties of Fullerene C60-Containing PN Lin49 in the SMC; Explanations of Strong Near-IR Excess



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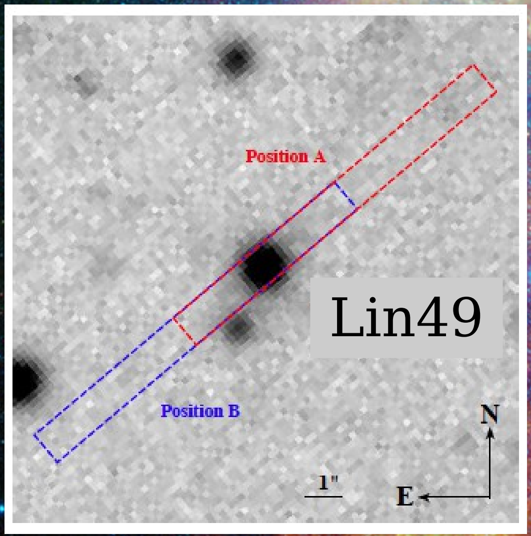
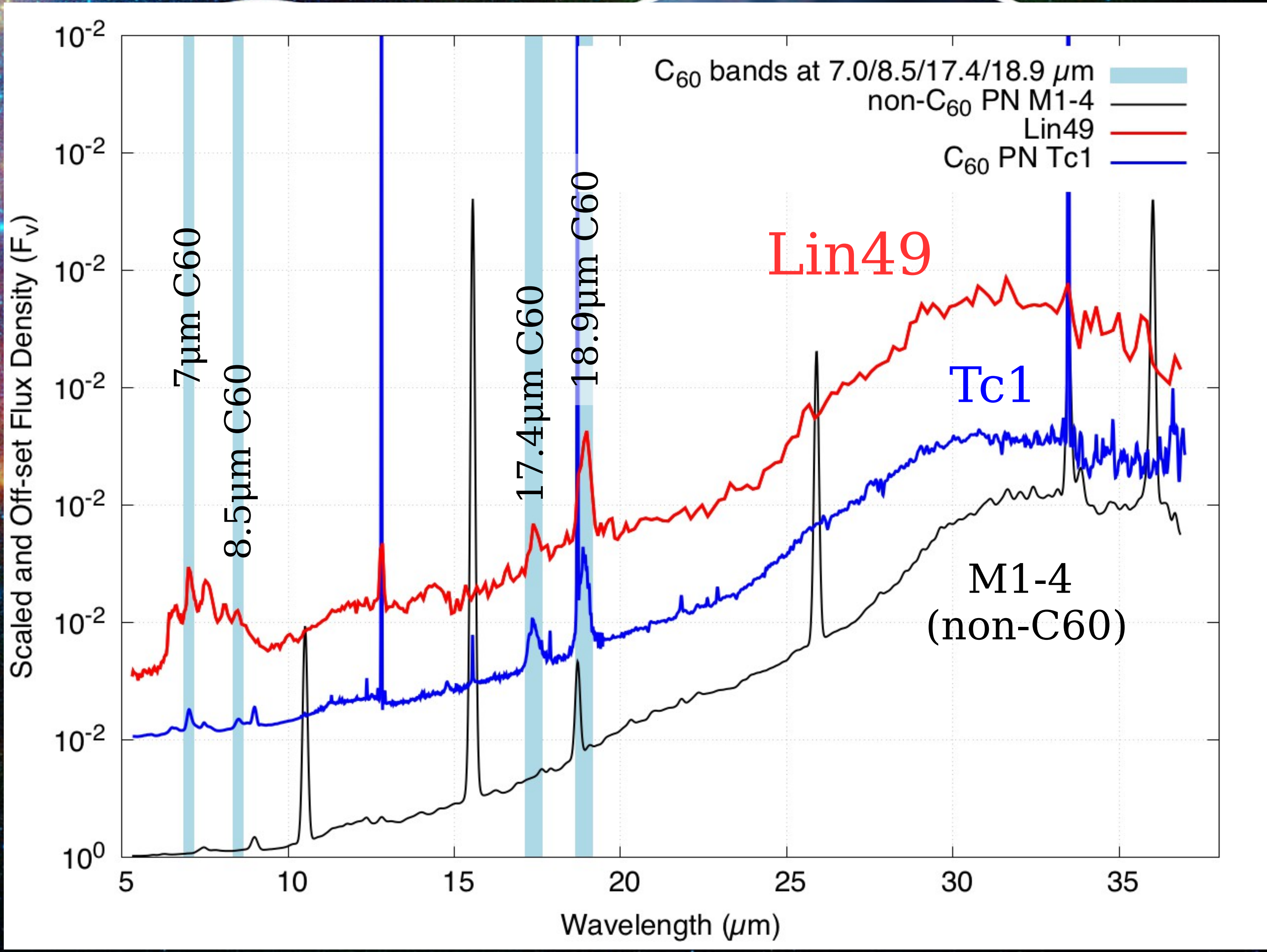
New detection of the C60 bands in Lin49



X-SHOOTER guide camera image



Known Properties of “Galactic” C60 PNe

- Cool central star and metal deficient nebula, about MC metallicity
- The origin (i.e., initial/current mass) of C60 PNe is unclear due to
  1. **Surface gravity** (Log g)
  2. **Distance**

Study on MC C60 PNe can overcome these problems

- useful for Galactic C60 PNe as well as MC C60 PNe

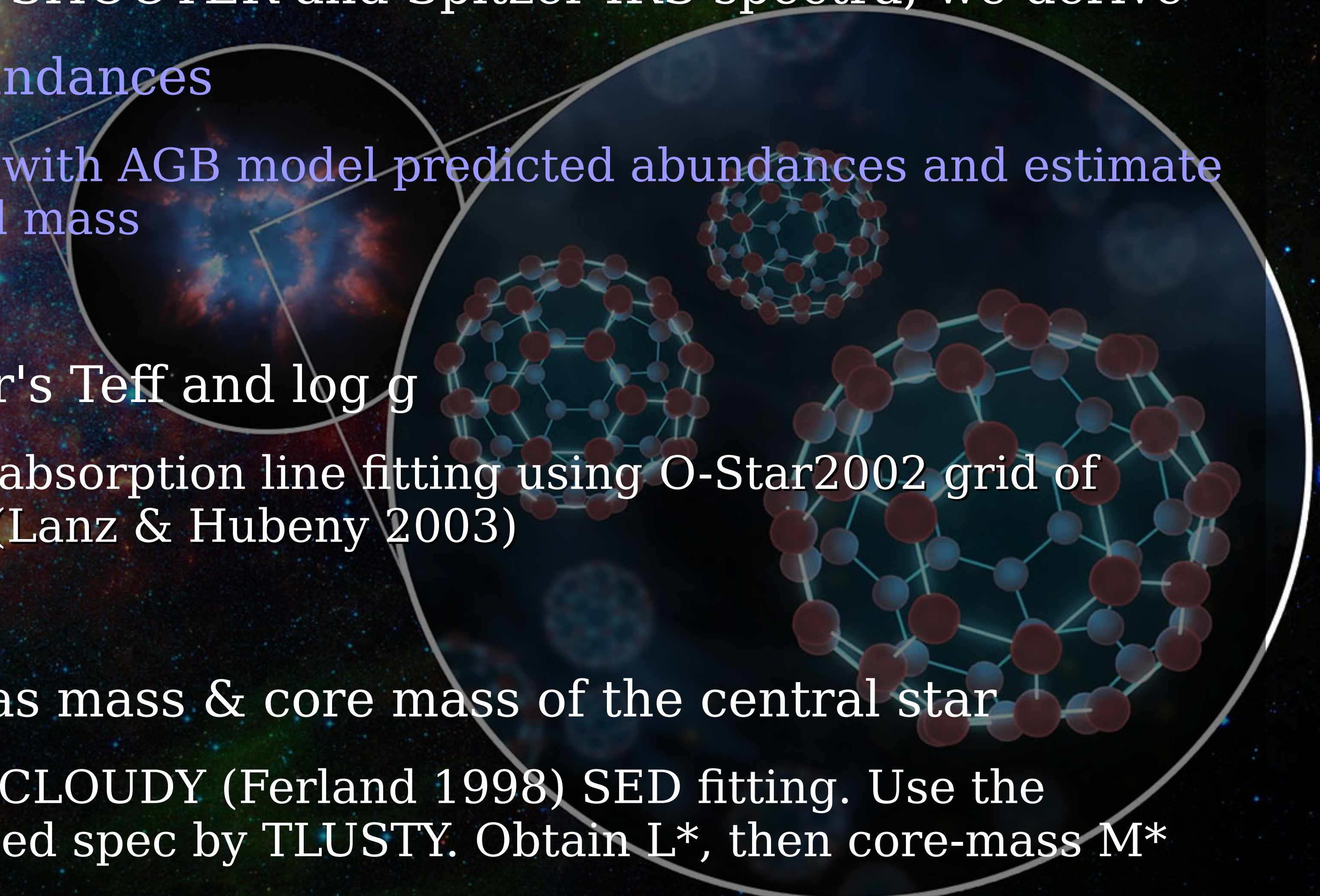
We investigate properties of Lin49

Objects	<Teff>	<log g>	<[Ar/H]>
Galactic C60 PNe (11 objects)	38600	3.80	-0.60
C60 SMC PNe (7 objects)	37600	?	-0.97
Lin49 in the SMC	30500	3.29	-1.07

Ref. Garcia-Hernandez et al. 2010, 2011, 2012; Otsuka et al. 2013, 2014, this work

Outline

With VLT X-SHOOTER and Spitzer IRS spectra, we derive

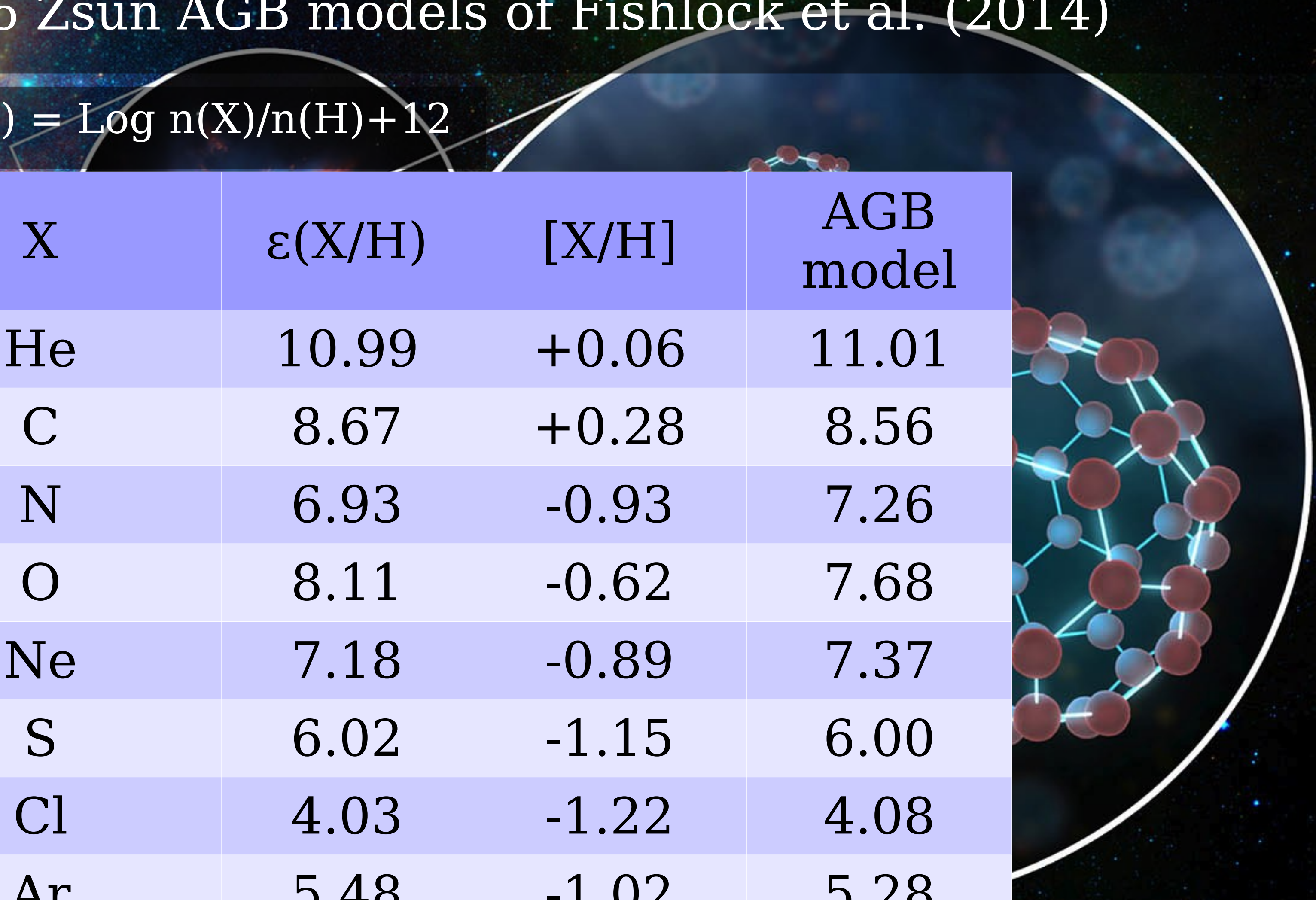


- Nebula abundances
  - compare with AGB model predicted abundances and estimate the initial mass
- Central star's Teff and log g
  - Through absorption line fitting using O-Star2002 grid of TLUSTY (Lanz & Hubeny 2003)
- Dust and gas mass & core mass of the central star
  - Through CLOUDY (Ferland 1998) SED fitting. Use the synthesized spec by TLUSTY. Obtain L*, then core-mass M*

$$M^* = g\, L^* / 4\pi\, G\, \sigma\, T_{eff}^4$$

Nebular Abundances

The abundances could be explained by the initially 1.25 Msun with Z = 0.06 Zsun AGB models of Fishlock et al. (2014)



$\varepsilon(X/H) = \mathrm{Log}\ n(X)/n(H)+12$

X	ε(X/H)	[X/H]	AGB model
He	10.99	+0.06	11.01
C	8.67	+0.28	8.56
N	6.93	-0.93	7.26
O	8.11	-0.62	7.68
Ne	7.18	-0.89	7.37
S	6.02	-1.15	6.00
Cl	4.03	-1.22	4.08
Ar	5.48	-1.02	5.28
Fe	4.55	-2.91	6.38

Outline

With VLT X-SHOOTER and Spitzer IRS spectra, we derive

- Nebula abundances
  - compared with AGB model predicted abundances and estimated the initial mass of ~1.25 Msun
- Central star's Teff and log g
  - Through absorption line fitting using O-Star2002 grid of TLUSTY (Lanz & Hubeny 2003)
- Dust and gas mass & core mass of the central star
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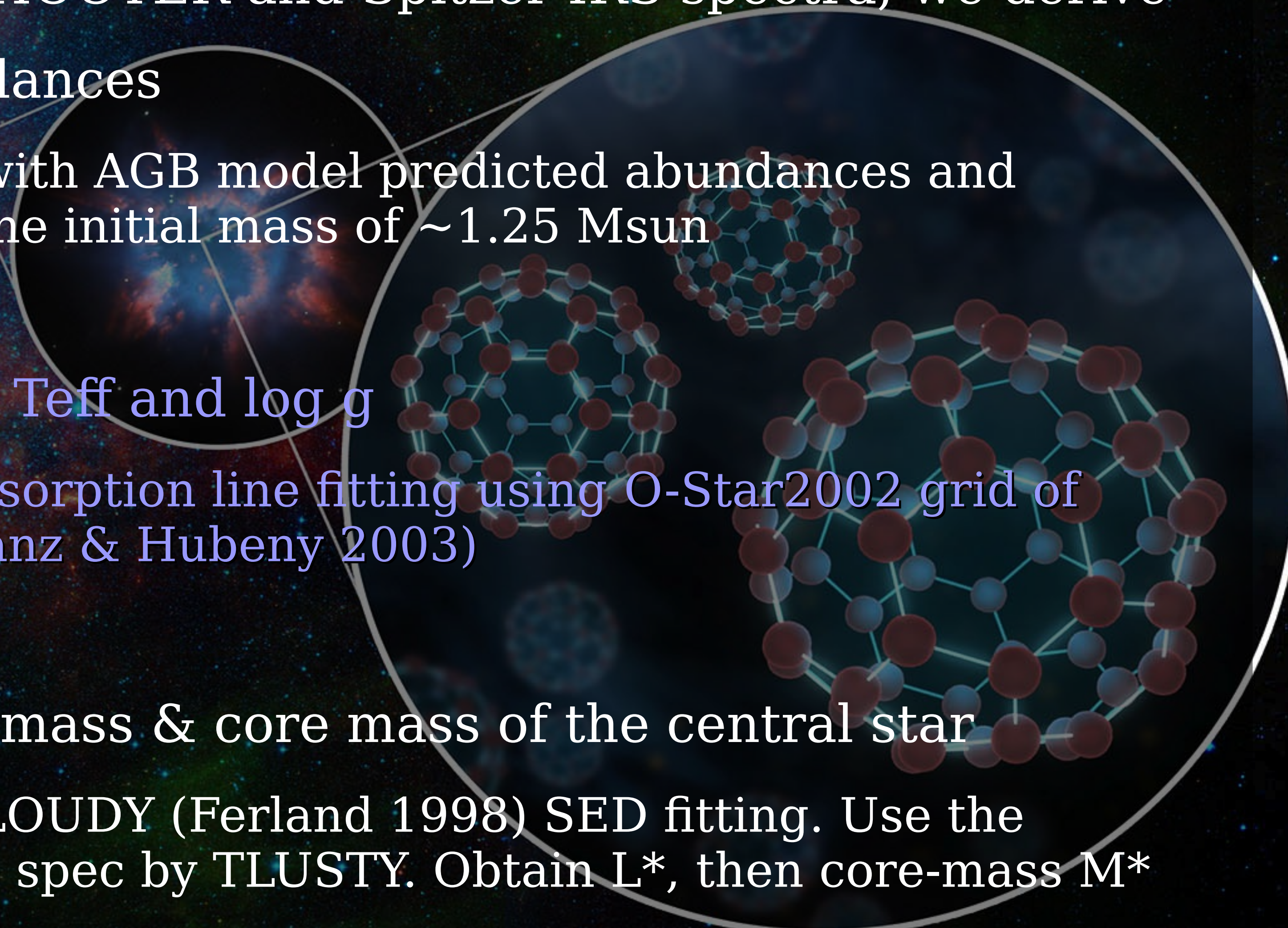
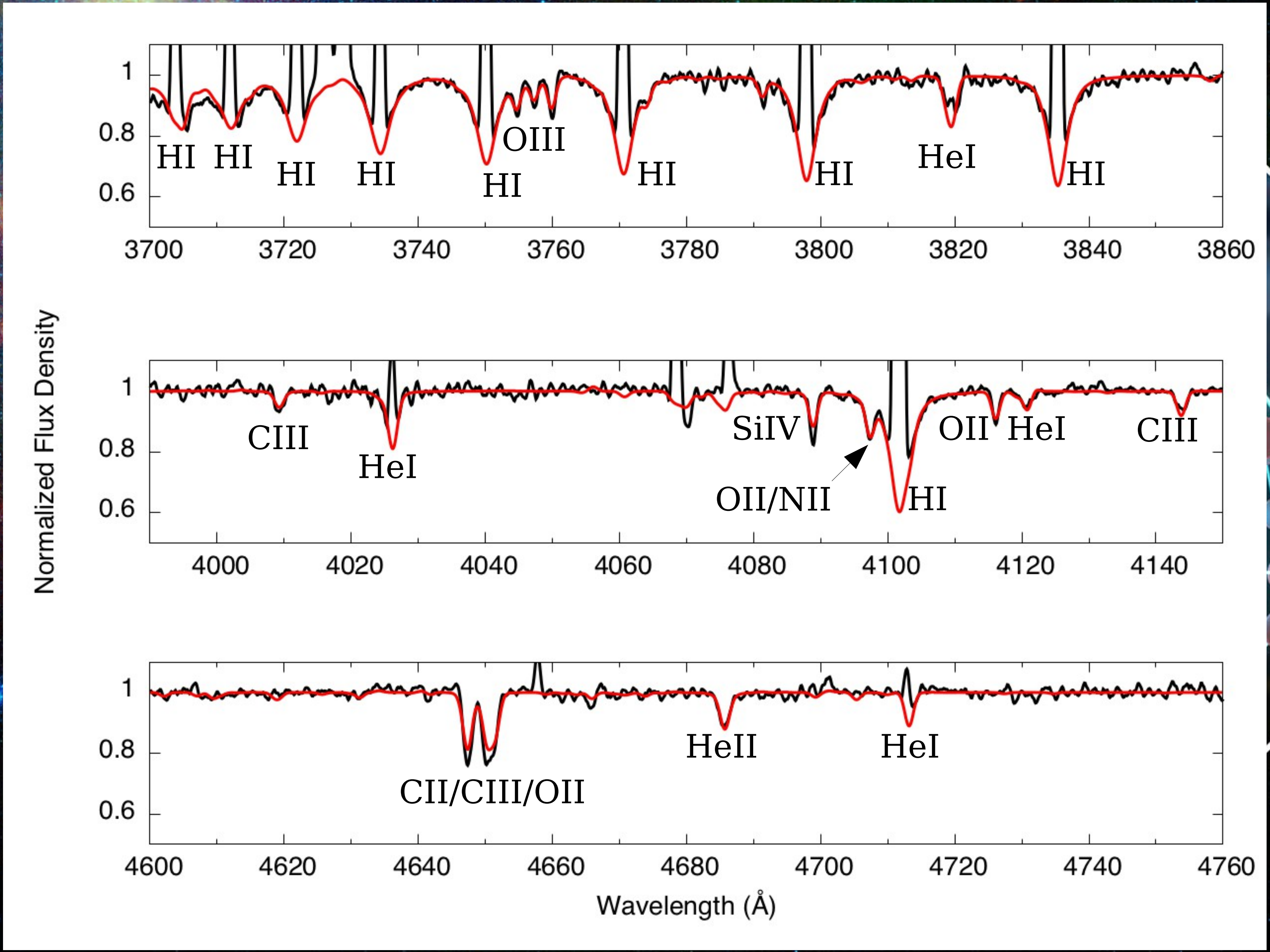


$$M^* = g\, L^* / 4\pi\, G\, \sigma\, T_{eff}^4$$

Stellar absorption fitting with TLUSTY
Teff=30500 K and Log g = 3.29 cm s^{-2}



Outline

With VLT X-SHOOTER and Spitzer IRS spectra, we derive

- Nebula abundances
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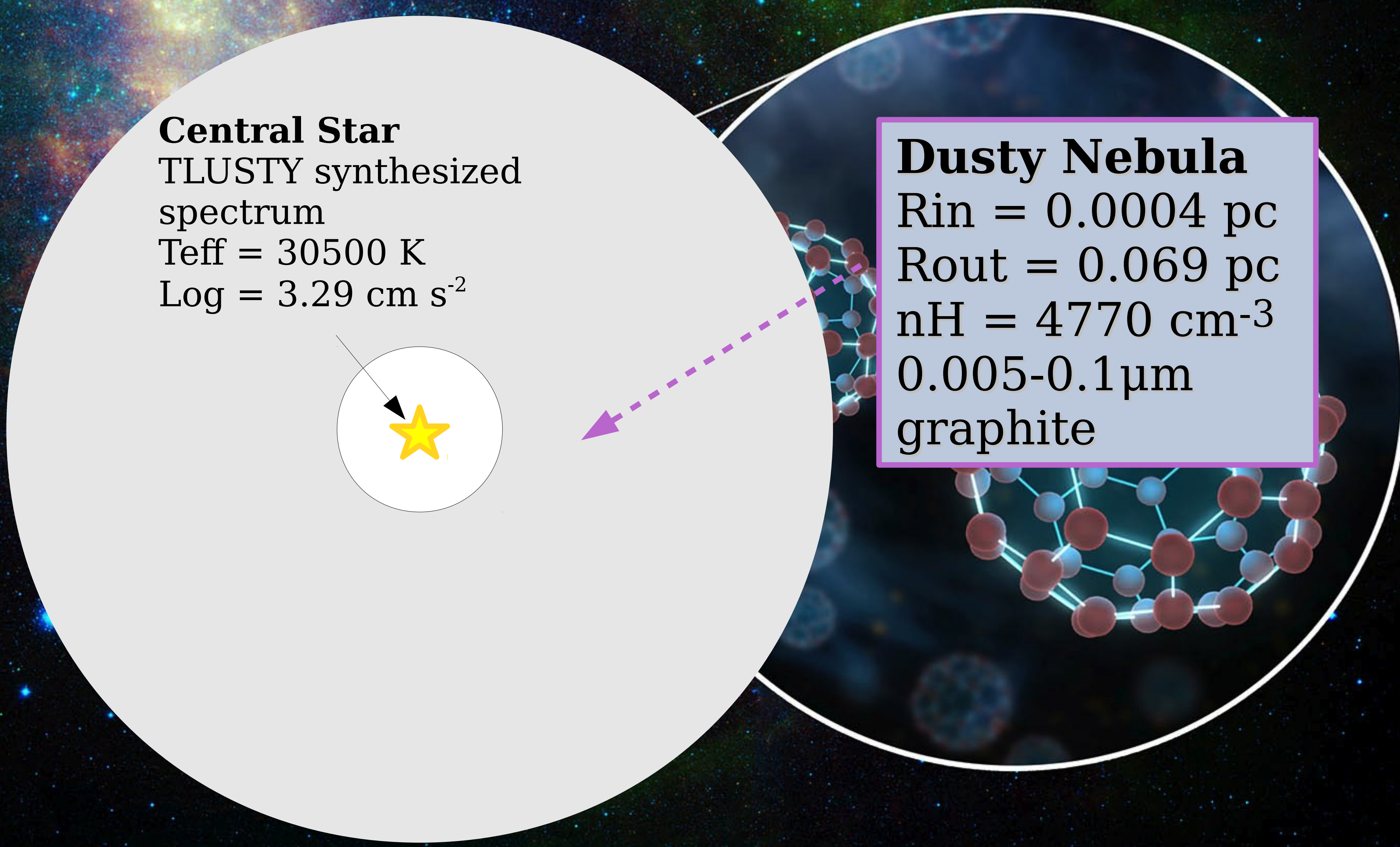
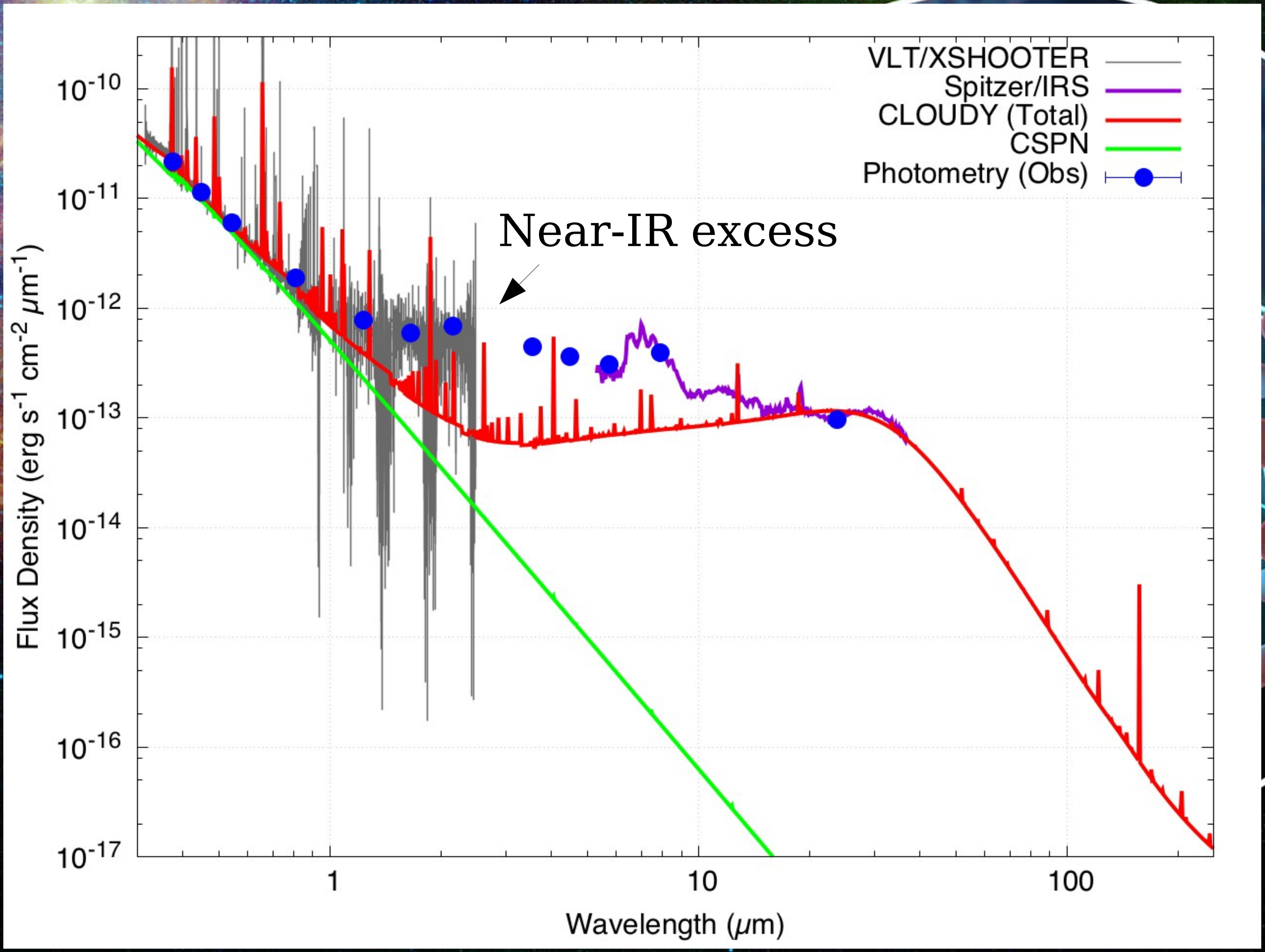
SED model with CLOUDY



The NIR-IR data cannot be fittted with a normal ISM grain size



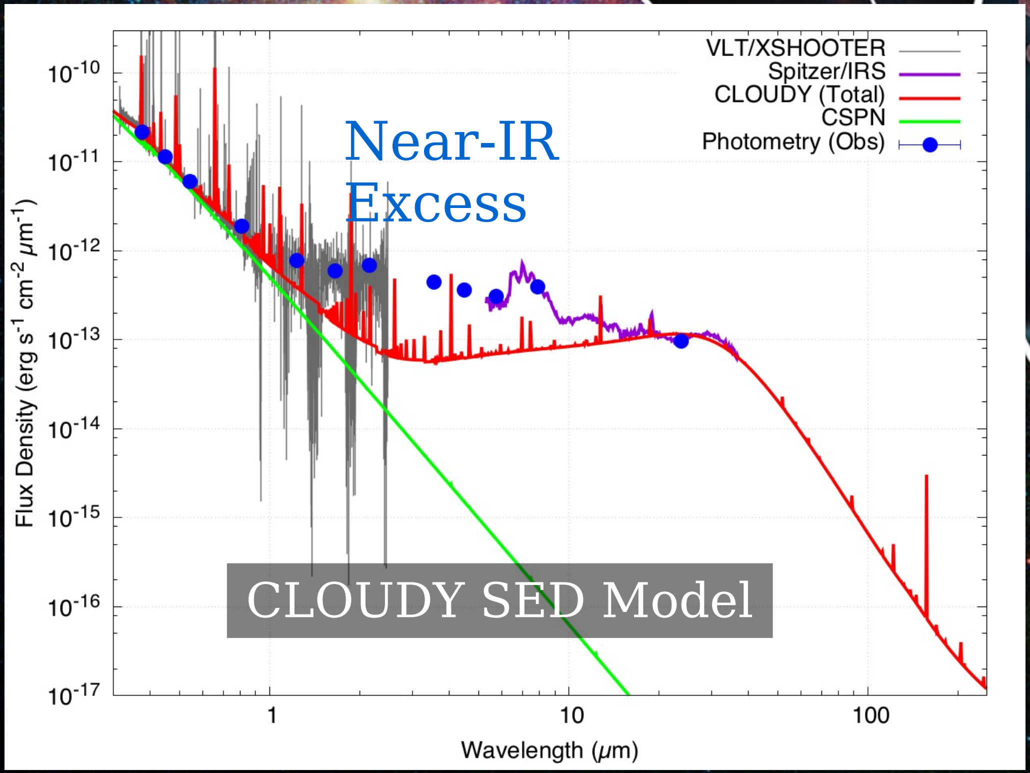
Near-IR Excess;
Stochastic heating by small particles?

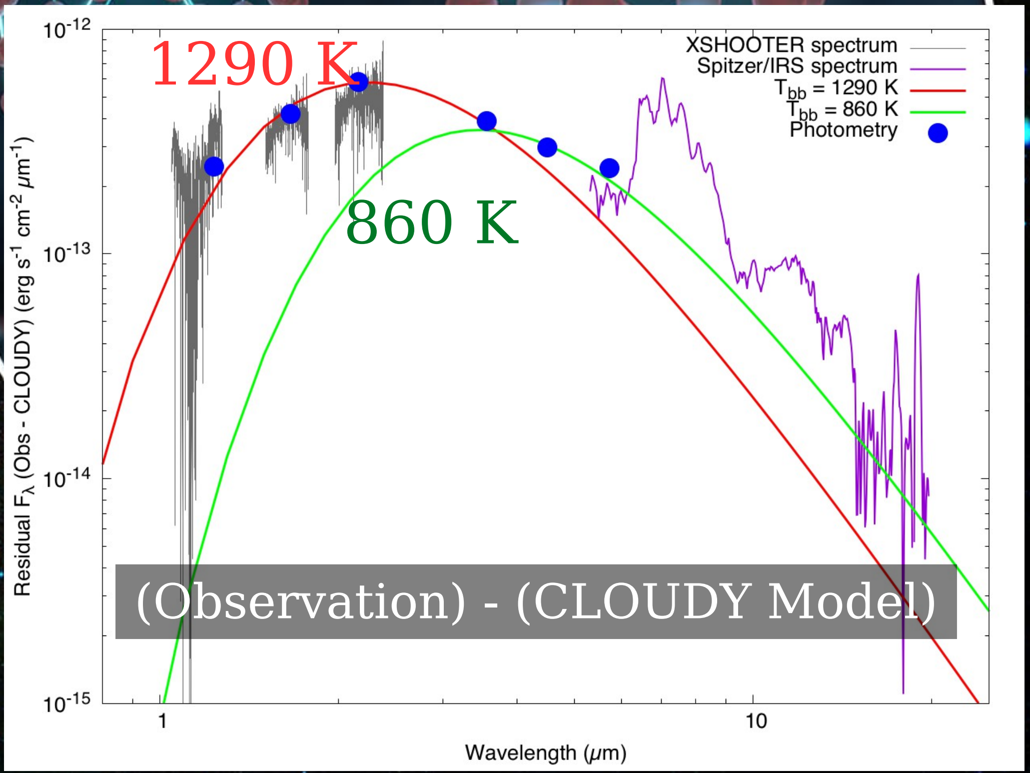
For extremely small grains, a photon energy *Eph* produces the difference between the max and min temperatures ΔT written by

$$\boldsymbol{\Delta T = Eph/3Nk} \quad (N\text{: the number of the atoms in a molecule})$$

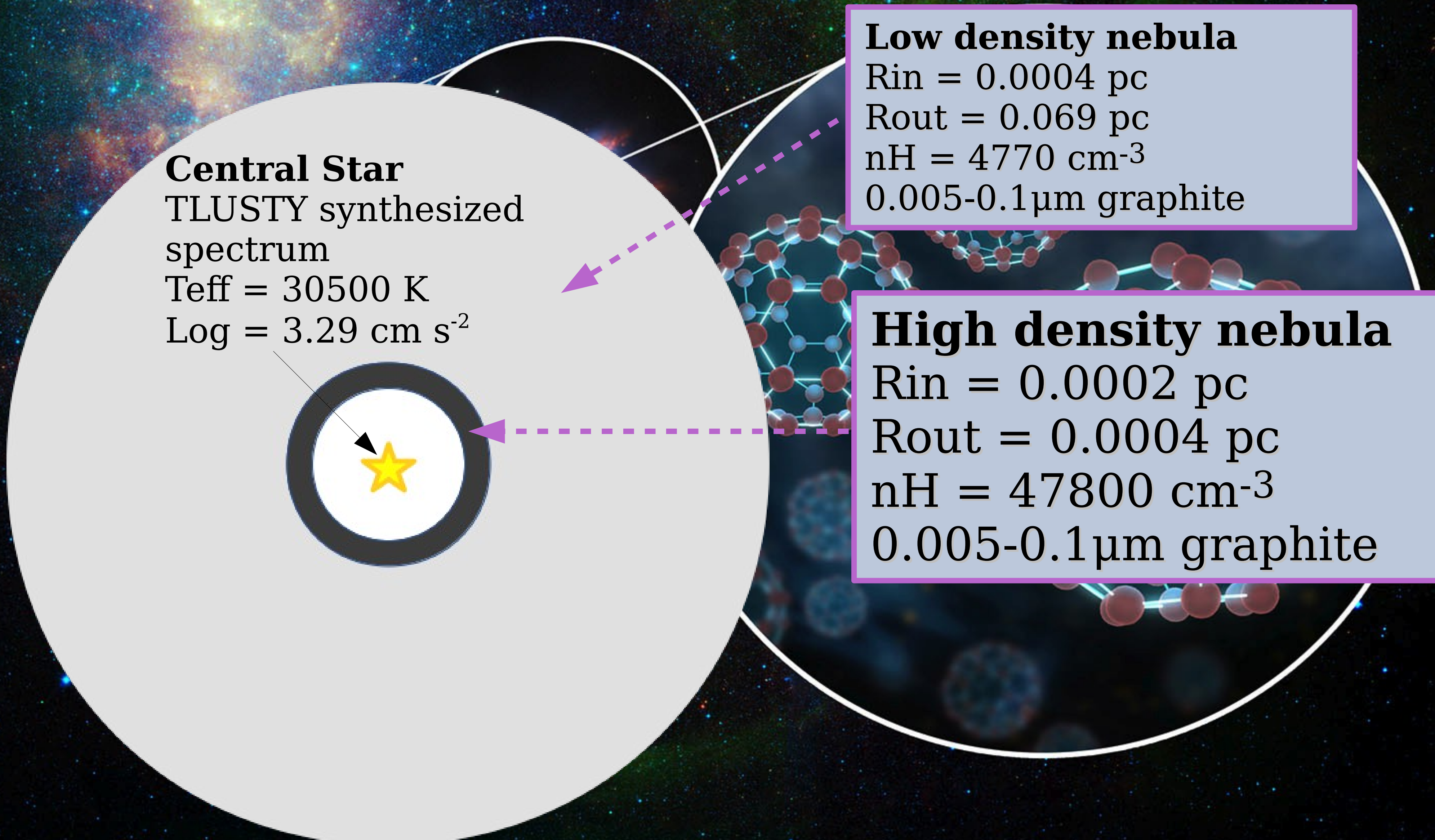
(Sellgren 1984; Whittet 2003)

the radiation peak energy of the central star is ~13.05 eV, N is **~40-60**





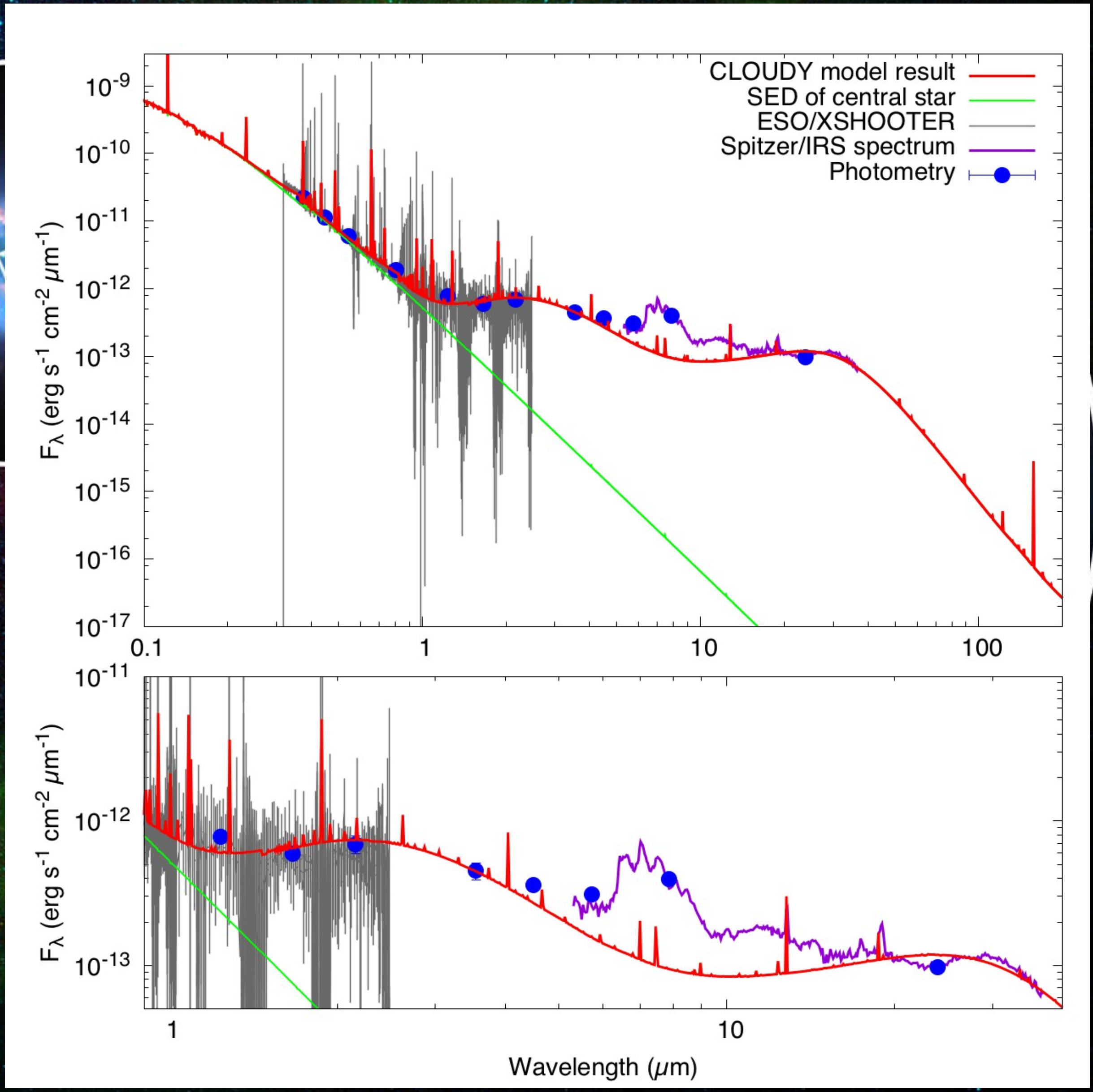
Near-IR Excess;
High density component nearby the central star?



Near-IR Excess;
two component model can fit the observation

Core-mass: 0.58 Msun
Luminosity: 6320 Lsun

Gas mass: 0.11 Msun
Dust mass: 4.14×10^{-5} Msun
Dust temp: 80-1420 K



Summary

Near-IR excess

- Stochastic heating by small particles?
  - What's type of particle? C60 precursors? smaller fullerene? (e.g., C36; Piskoti et al. 1998, Nature)
- High-dens. component nearby the central star?
  - Shell? flatten envelope? How did a ~1.25M sun star create?
- Is there a connection to C60 formation?
  - Near-IR excess is seen in C60 PNe