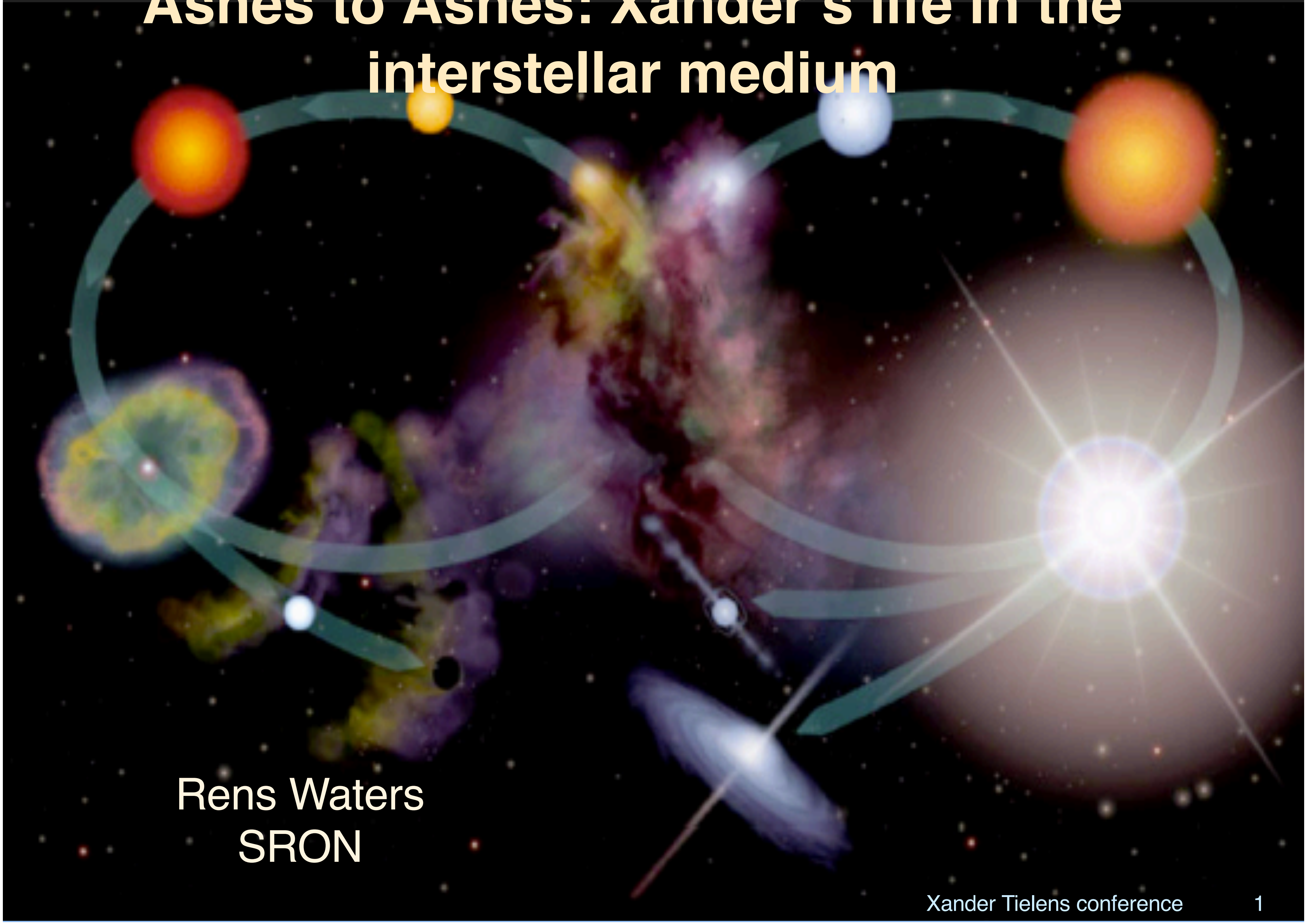
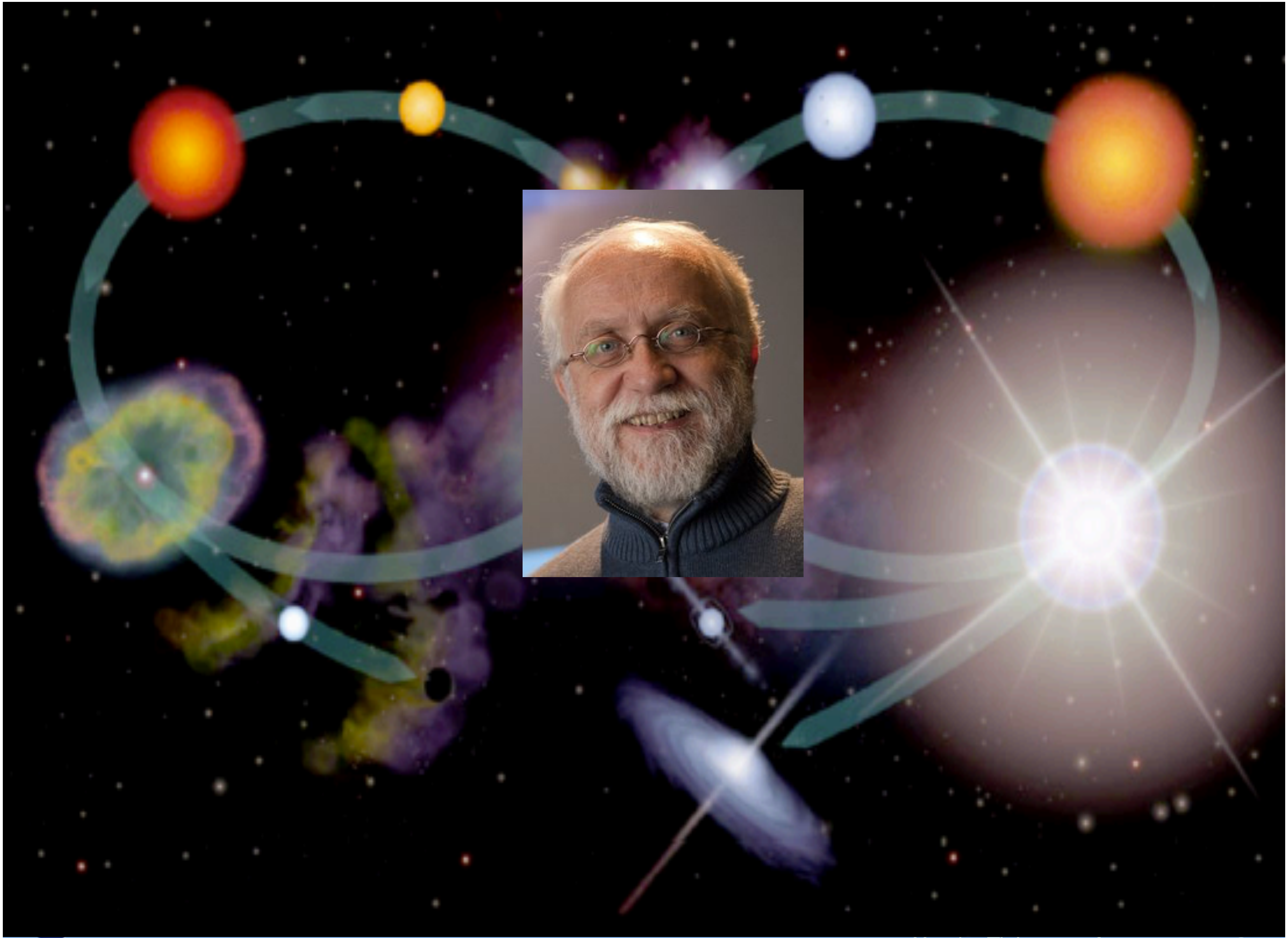
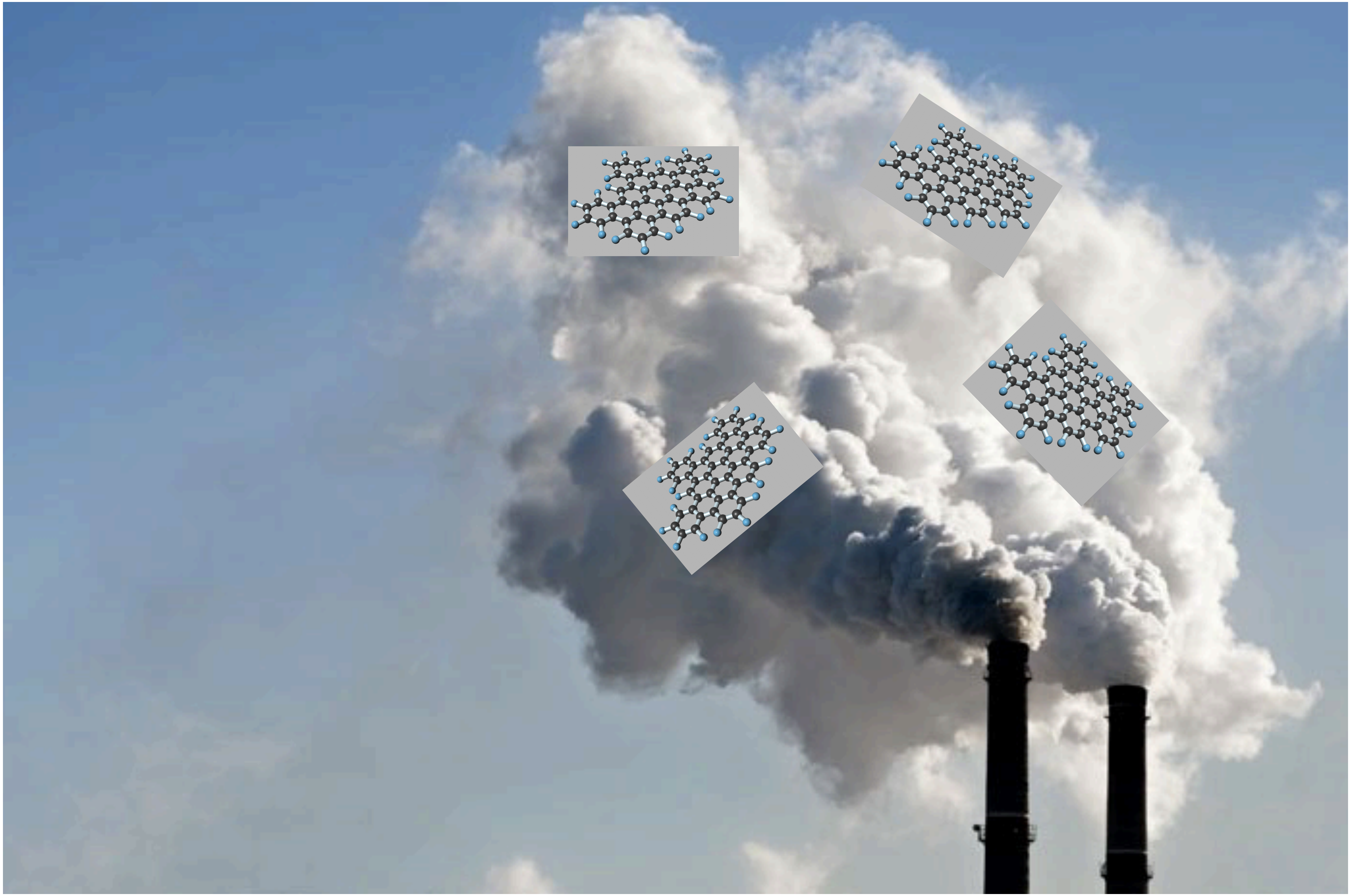
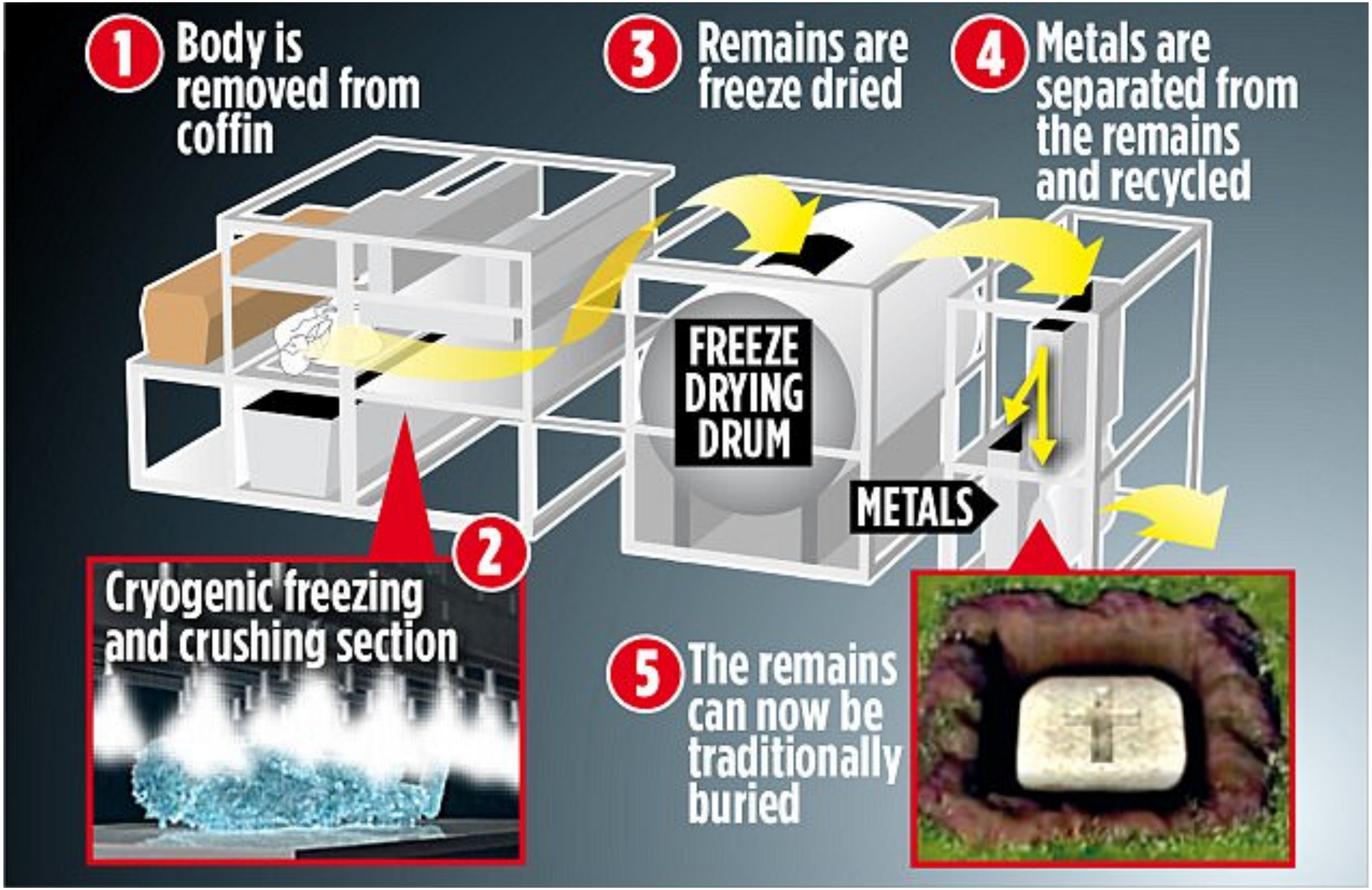
Ashes to Ashes: Xander’s life in the interstellar medium



Rens Waters
SRON

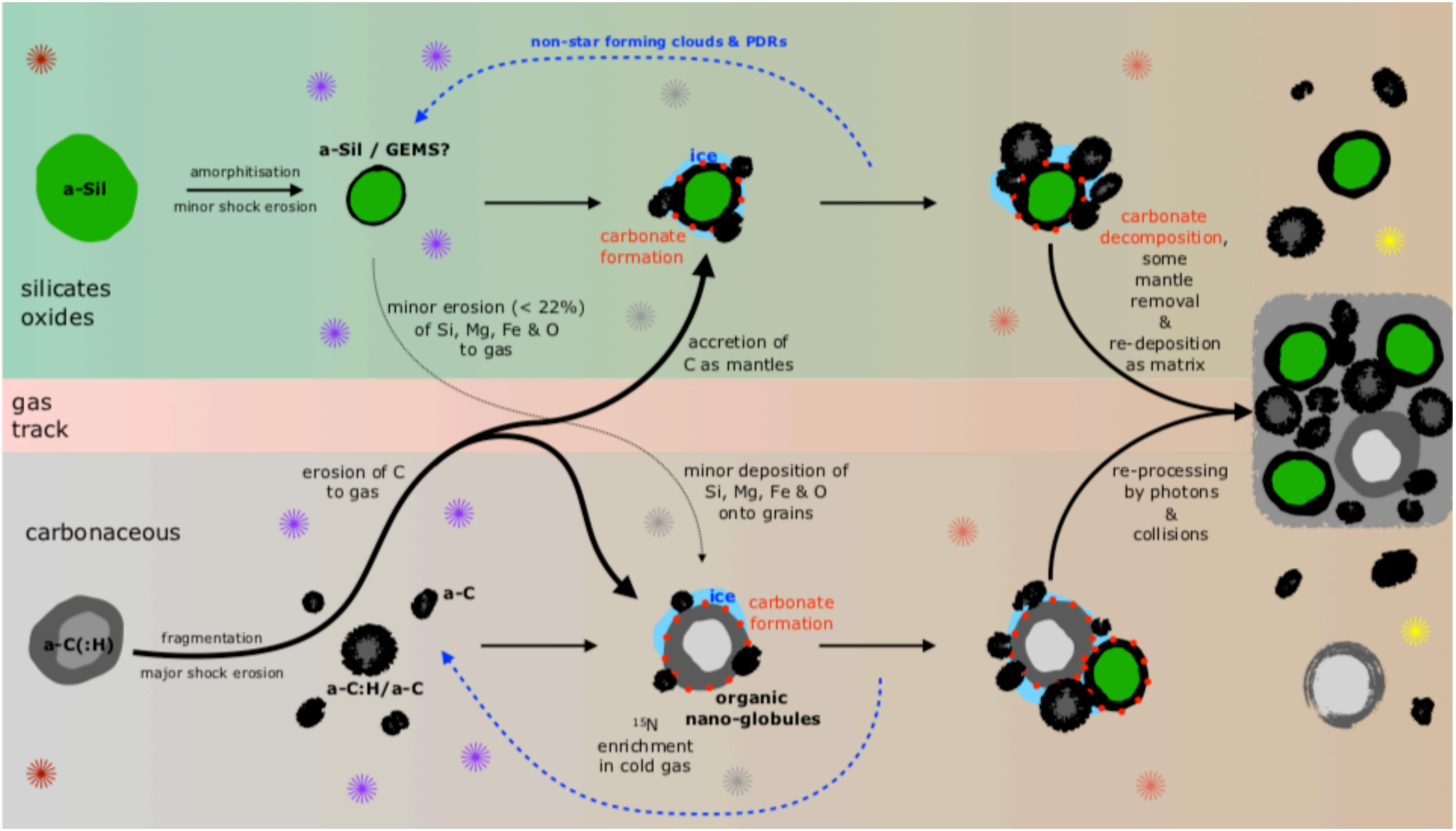




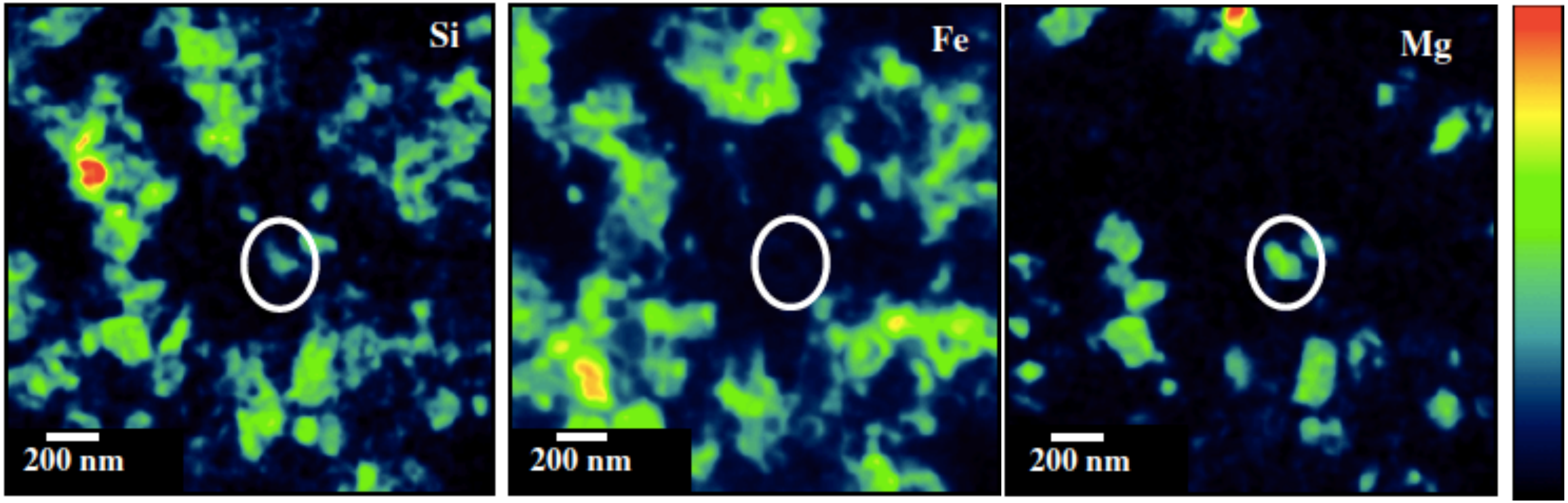

1 Body is removed from coffin
3 Remains are freeze dried
4 Metals are separated from the remains and recycled
FREEZE DRYING DRUM
METALS
2
Cryogenic freezing and crushing section
5 The remains can now be traditionally buried

Dust processing

Jones & Ysard 2019



Bose et al. 2010



CIRCUMSTELLAR DUST

Presolar grains mostly formed near thermodynamic equilibrium (crystalline)
Presolar silicates show a more diverse formation history
Nguyen et al., 2016 ApJ

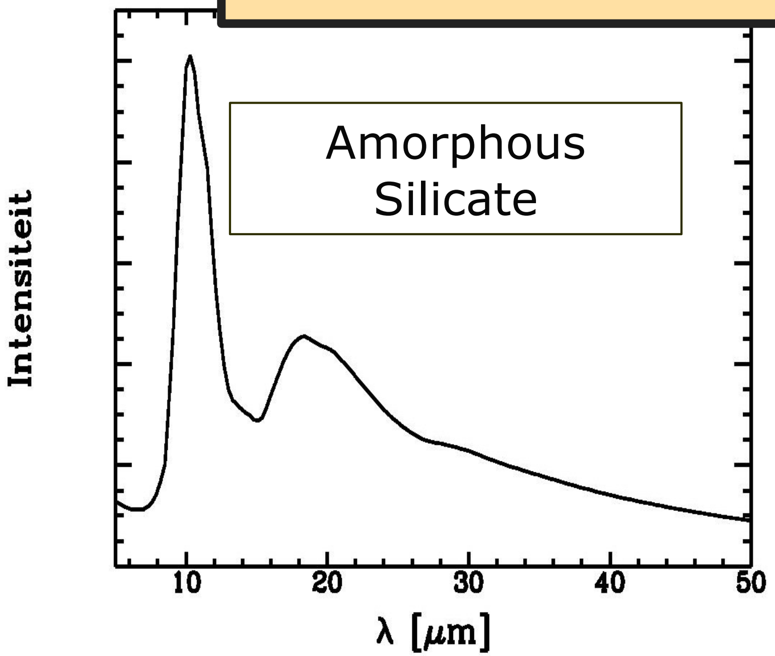
What can we measure using infrared spectroscopy?

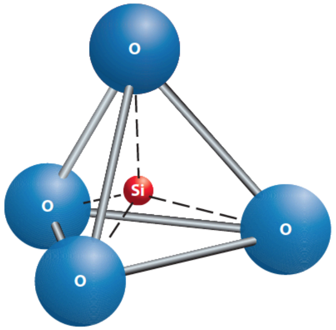
Limitations:

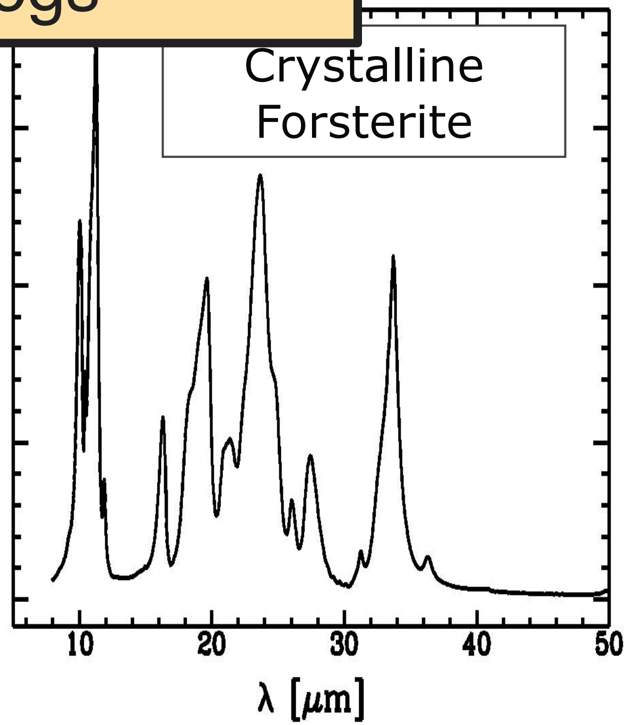
- dust species without IR resonances (Carbon, metallic Fe…)
- Small (often sub-micron-sided) grains
- Depends on grain model and optical constants of cosmic dust analogs

ilicates

Si-O stretch







Henning (2010)

A. G. G. M. Tielens

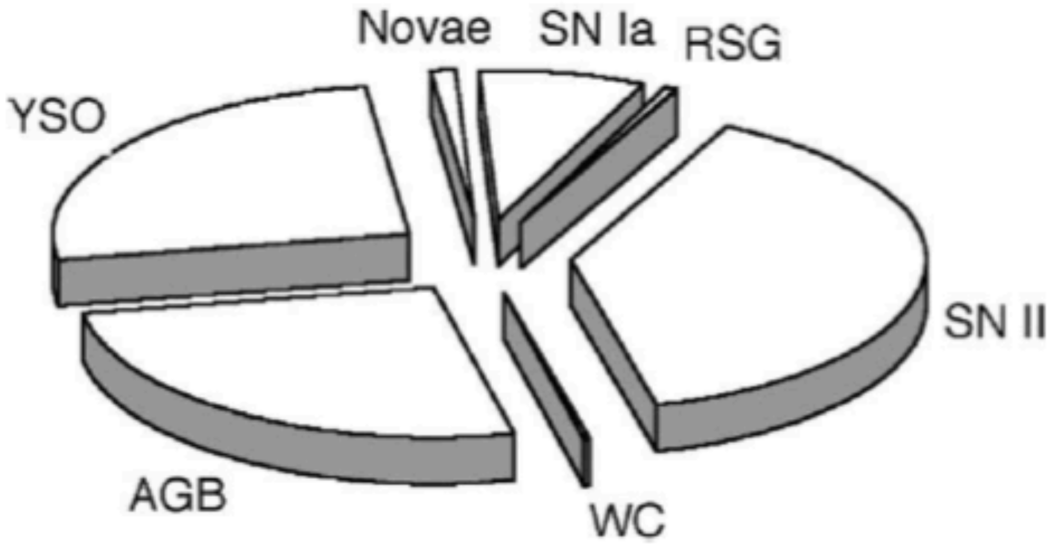
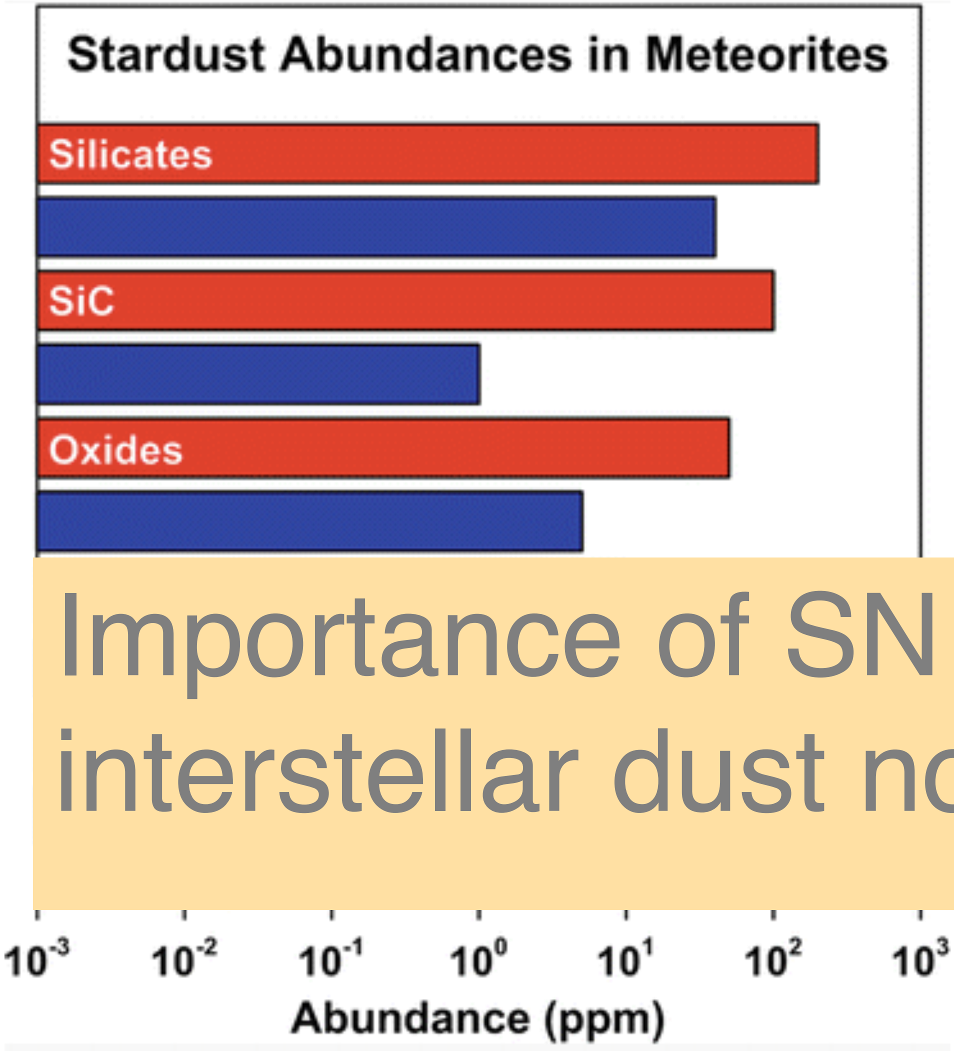


Figure 2. The contribution of different stellar sources to the interstellar dust budget. For details, see § 3. Note that all these values are very uncertain. (Taken from Tielens 2001).

Minor fraction of stardust is from supernovae

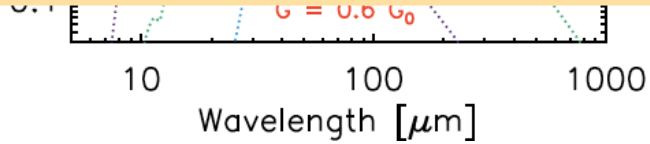


Hoppe (2015)

Supernova dust composition From IR/mm emission:

- mostly assuming a chemical composition of the dust
- C-rich and O-rich dust found

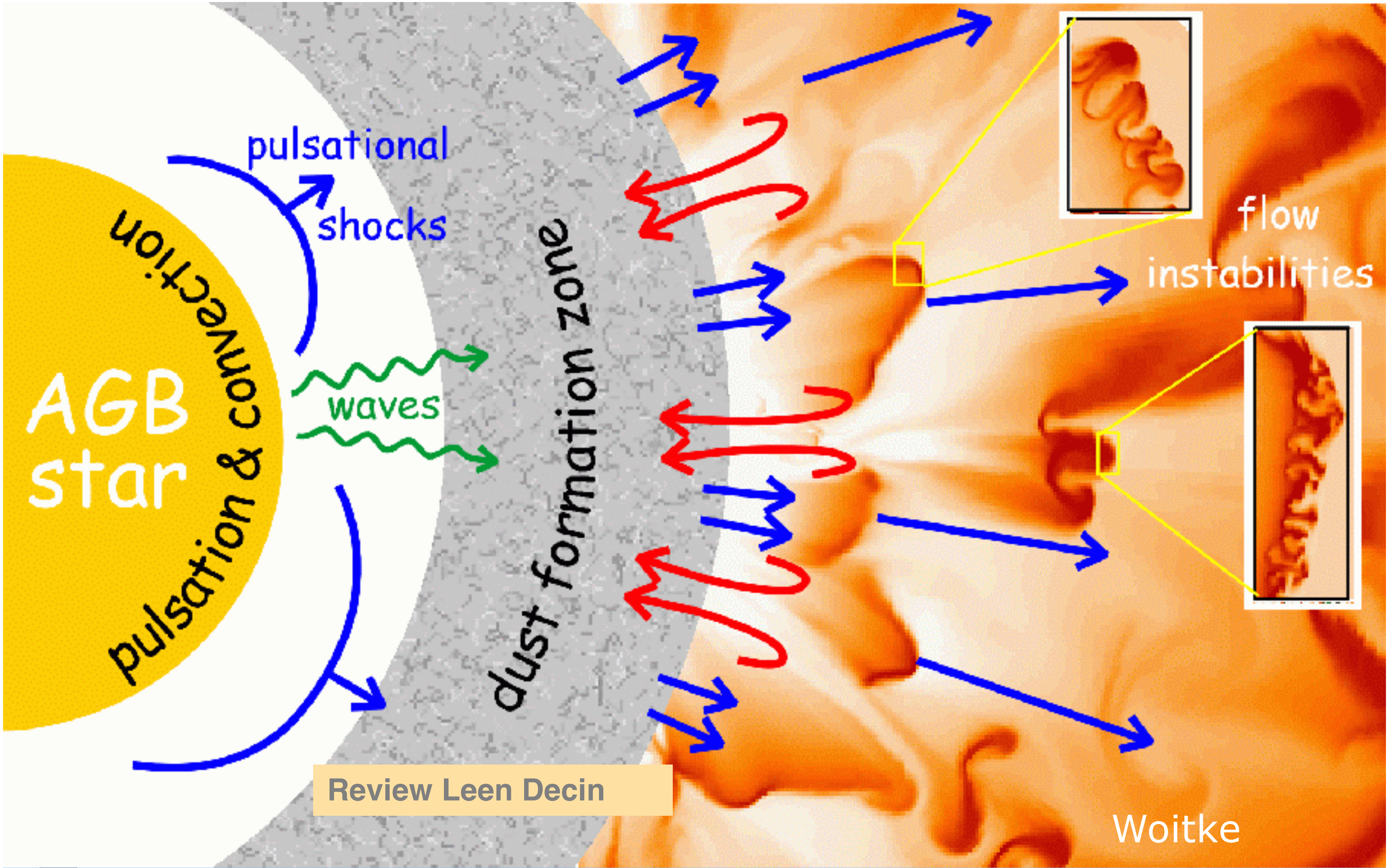
Importance of SN as source of interstellar dust not well constrained



De Looze et al. Cas A

SRON

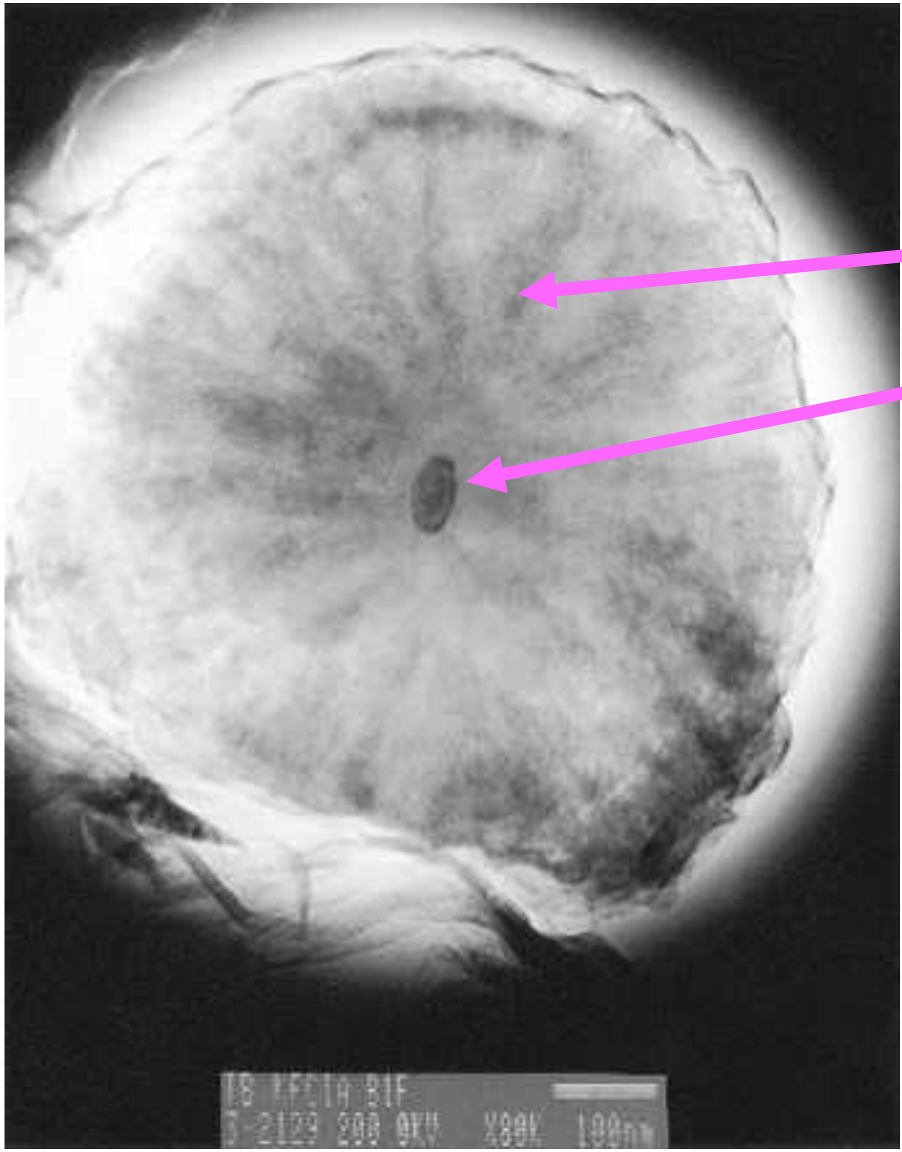
Physical structure of red giant winds

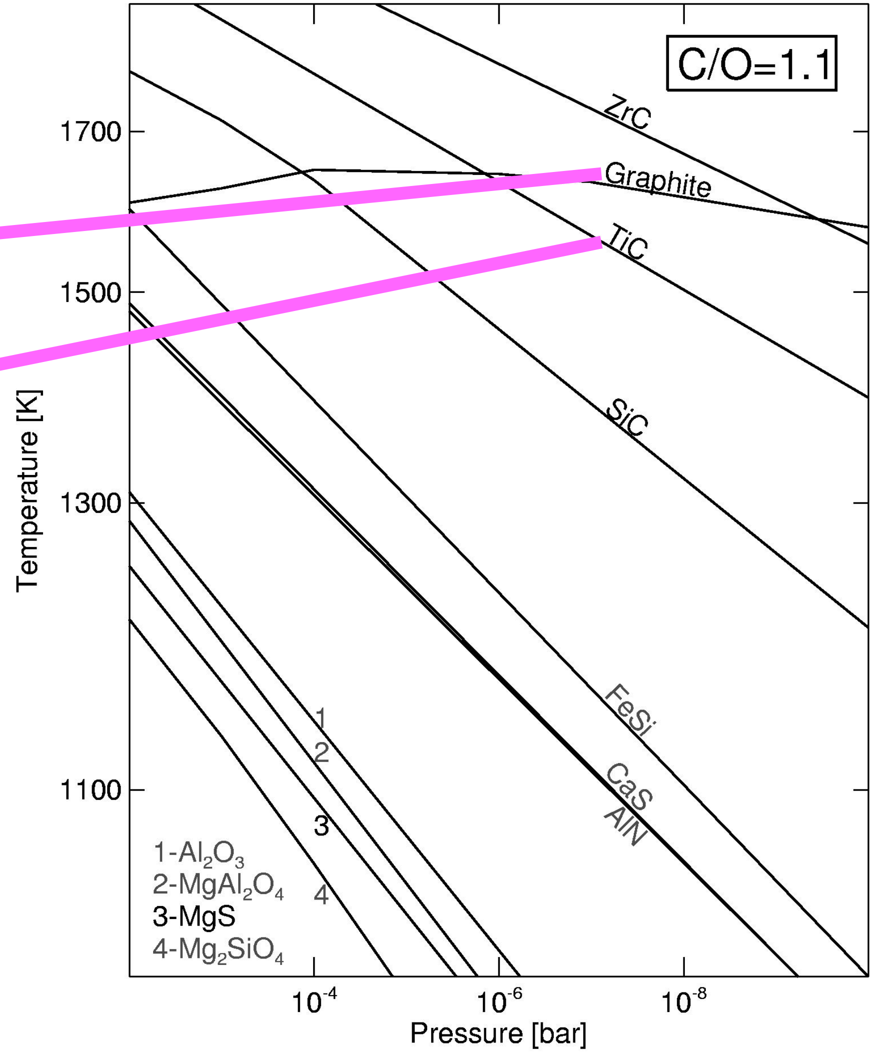


Circumstellar dust species identified in (post)-AGB stars

Species	Presolar grains	IR Spectroscopy
SiC	✓	✓
Amorphous Carbon/Graphite	✓	Amorphous carbon
MgS	-	? (30 μm band)
TiC	✓	? (21 μm feature)
ZrC	✓	-
MoC	✓	-
FeC	✓	-
$AlMg_2O_4$ Spinel	✓	✓ (?)
Al_2O_3 Corundum	✓	✓
$CaAl_{12}O_{19}$ Hibonite	✓	
FeO	✓	✓
Ti Oxide TiO_2	✓	
Amorphous Silicates	✓	✓
Forsterite Mg_2SiO_4	✓	✓
Enstatite $MgSiO_3$	✓	✓
Silica SiO_2	✓	✓
Calcite $CaCO_3$	-	✓

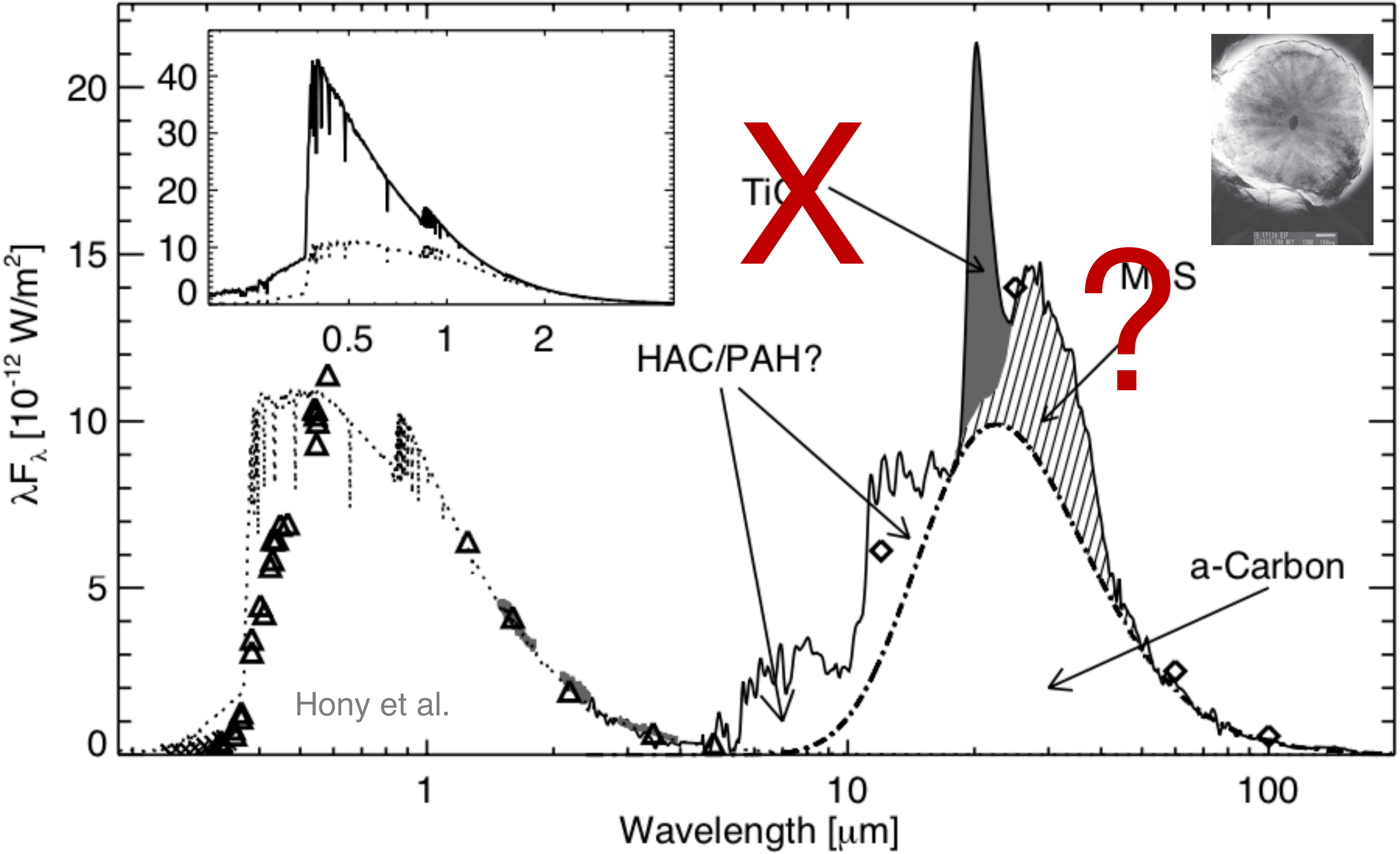
C-rich condensation sequence



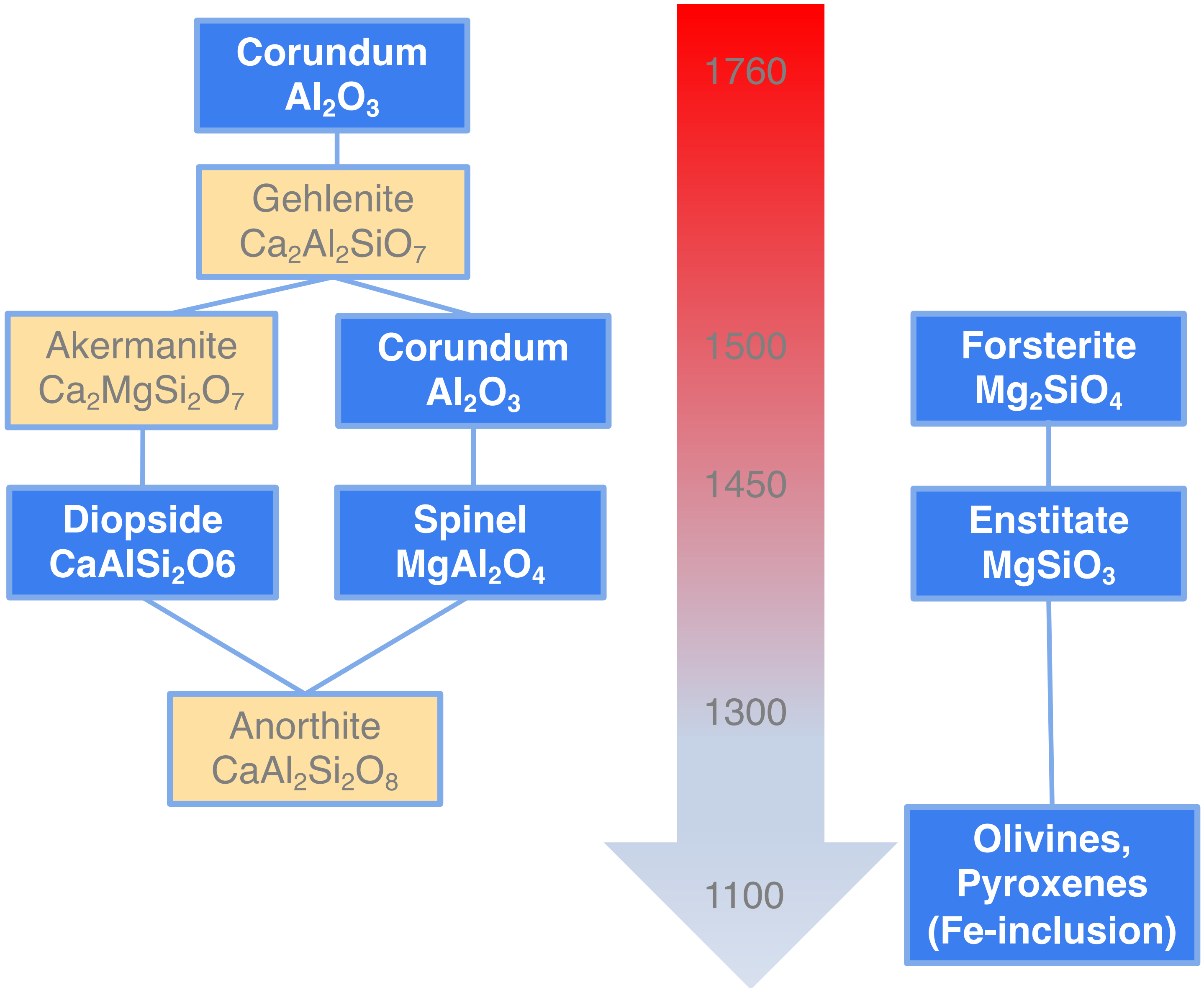


Lodders & Fegley

Dust composition of IR carbon stars/post-AGB stars



O-rich Equilibrium chemistry dust condensation sequence



Based on Grossman & Larimer (1974)

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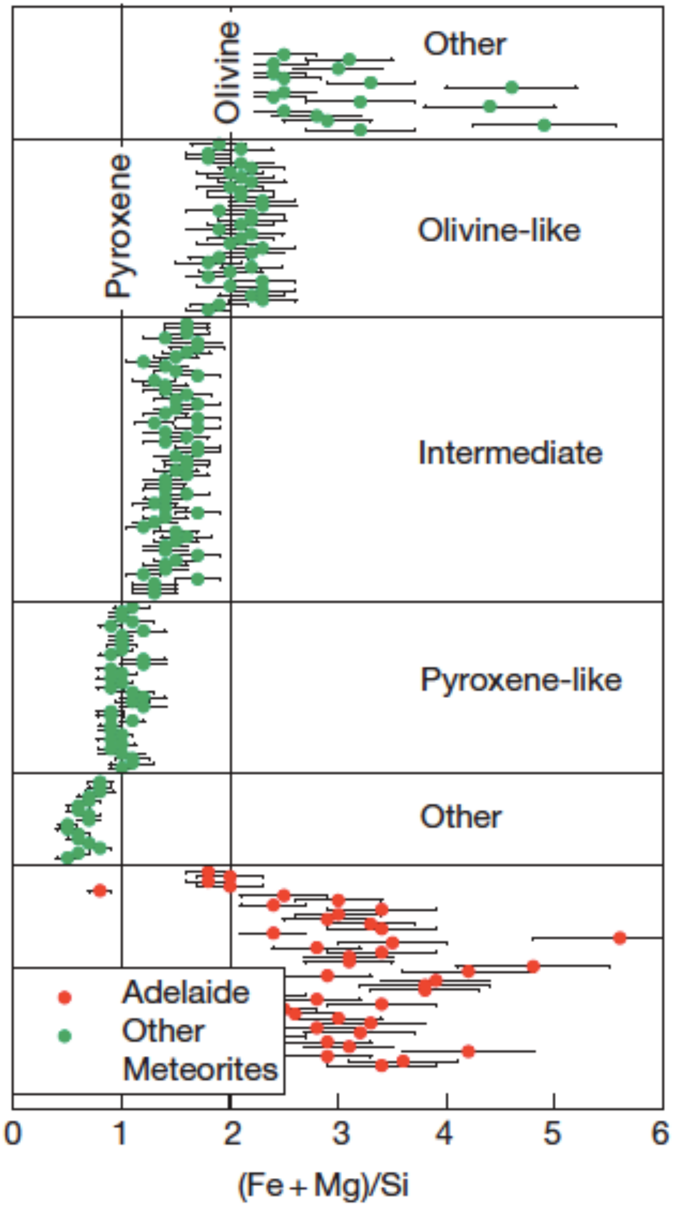
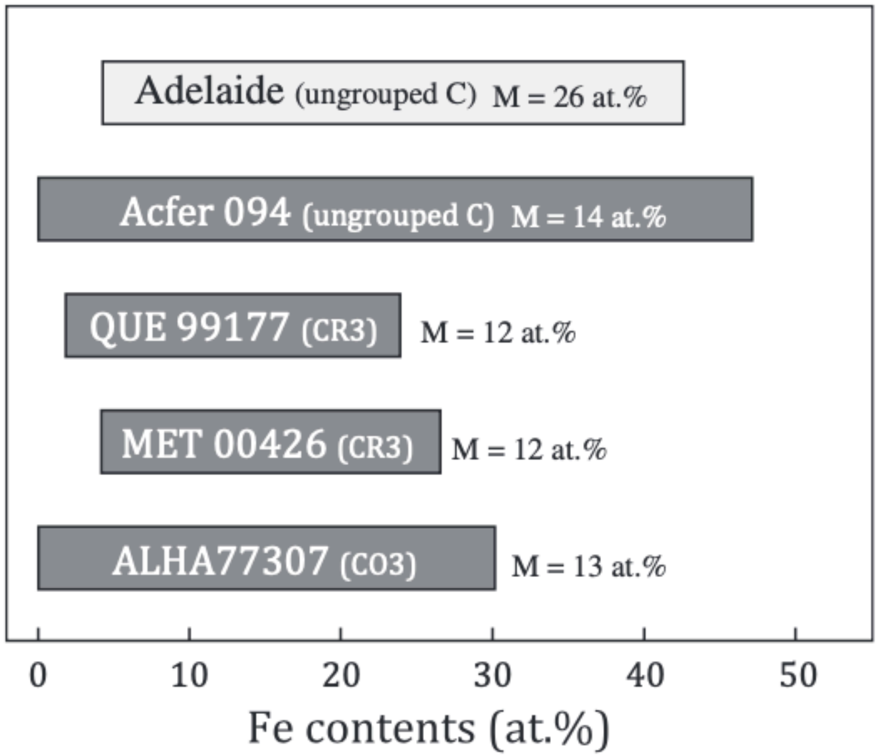


Zinner (2014)

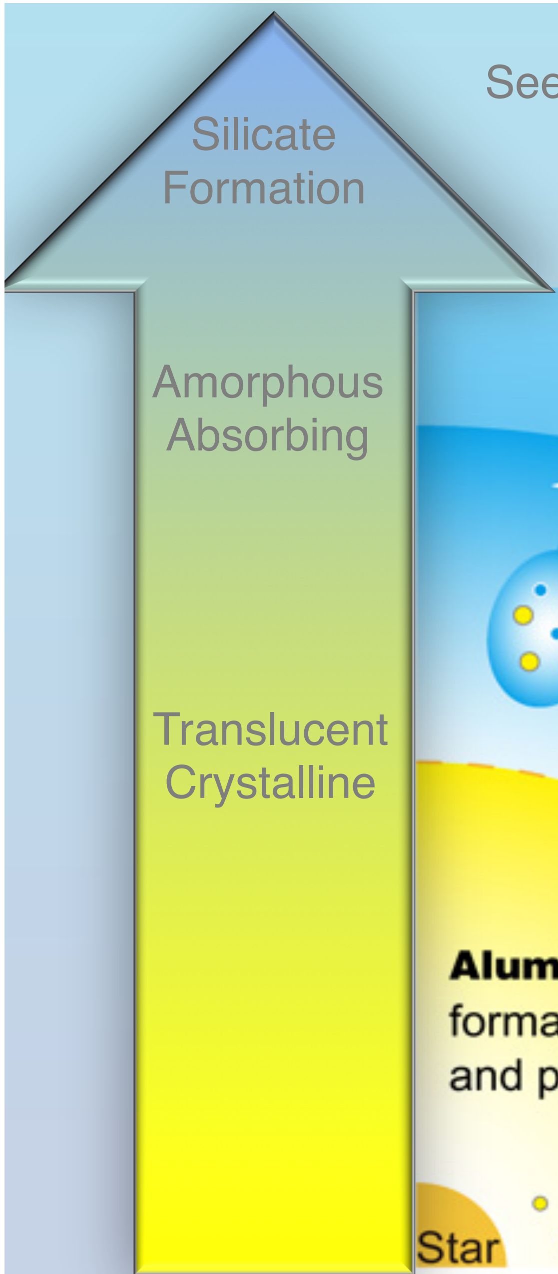


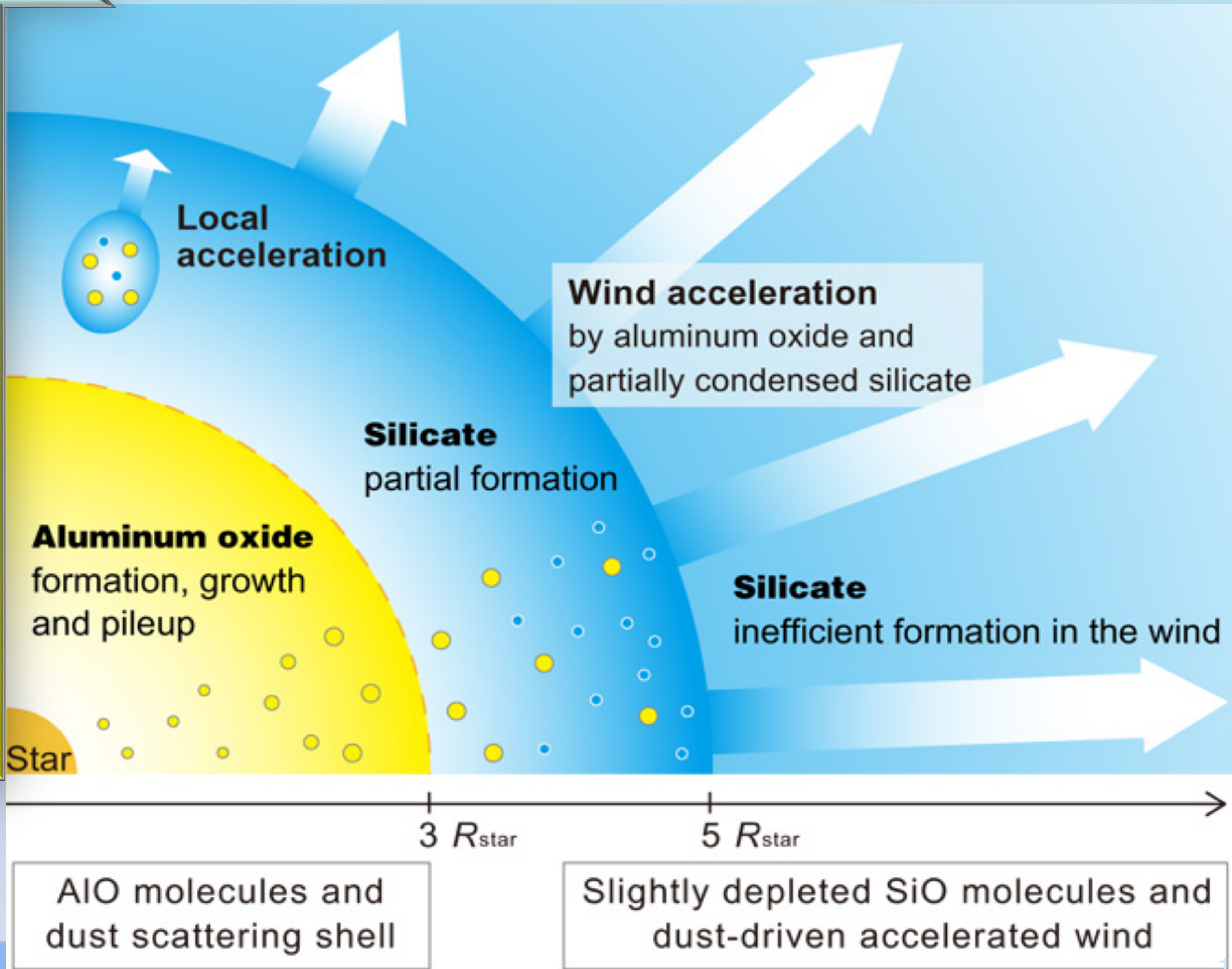
Floss & Stadermann 2012

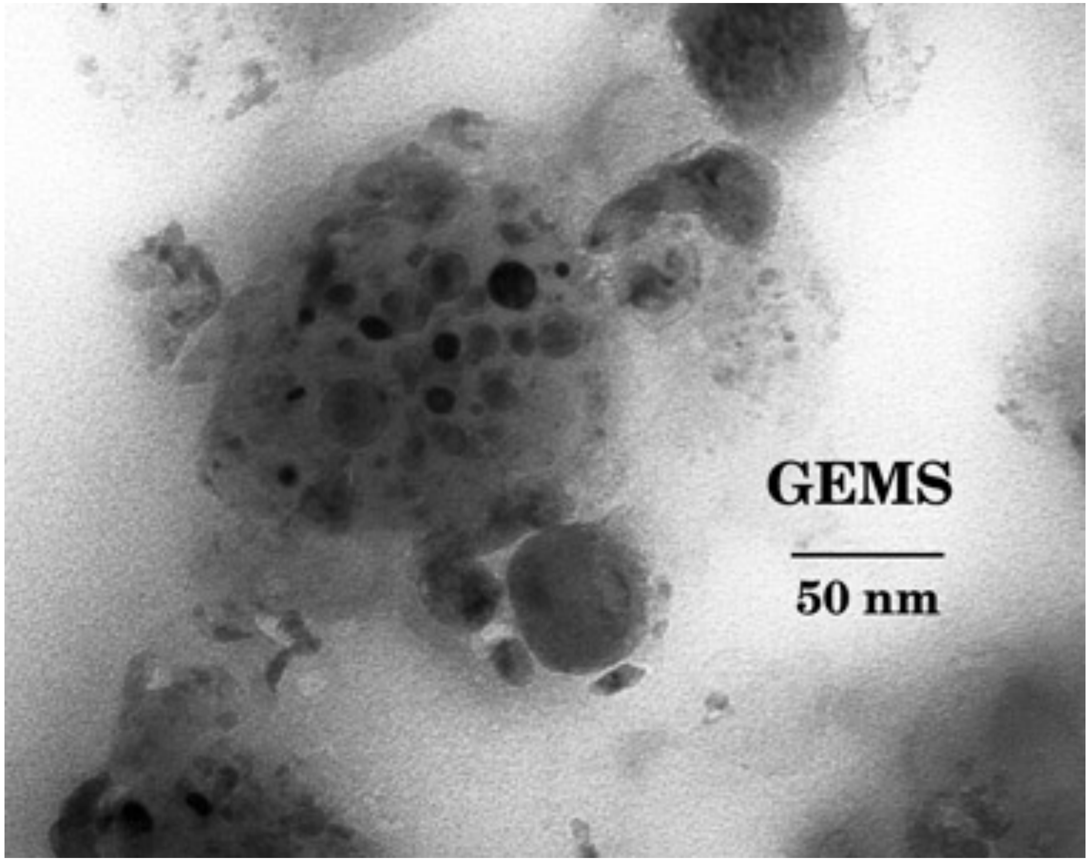
Presolar silicates are Fe-rich and have wide range of stoichiometry, amorphous and crystalline forms

See talk by Decin

AGB wind models: high gas/dust ratio ~1000
Amorphous silicates do NOT drive the wind







Glass with
Embedded
Metals (Fe/Ni) and
Sulphur (FeS)

INTERSTELLAR SILICATES

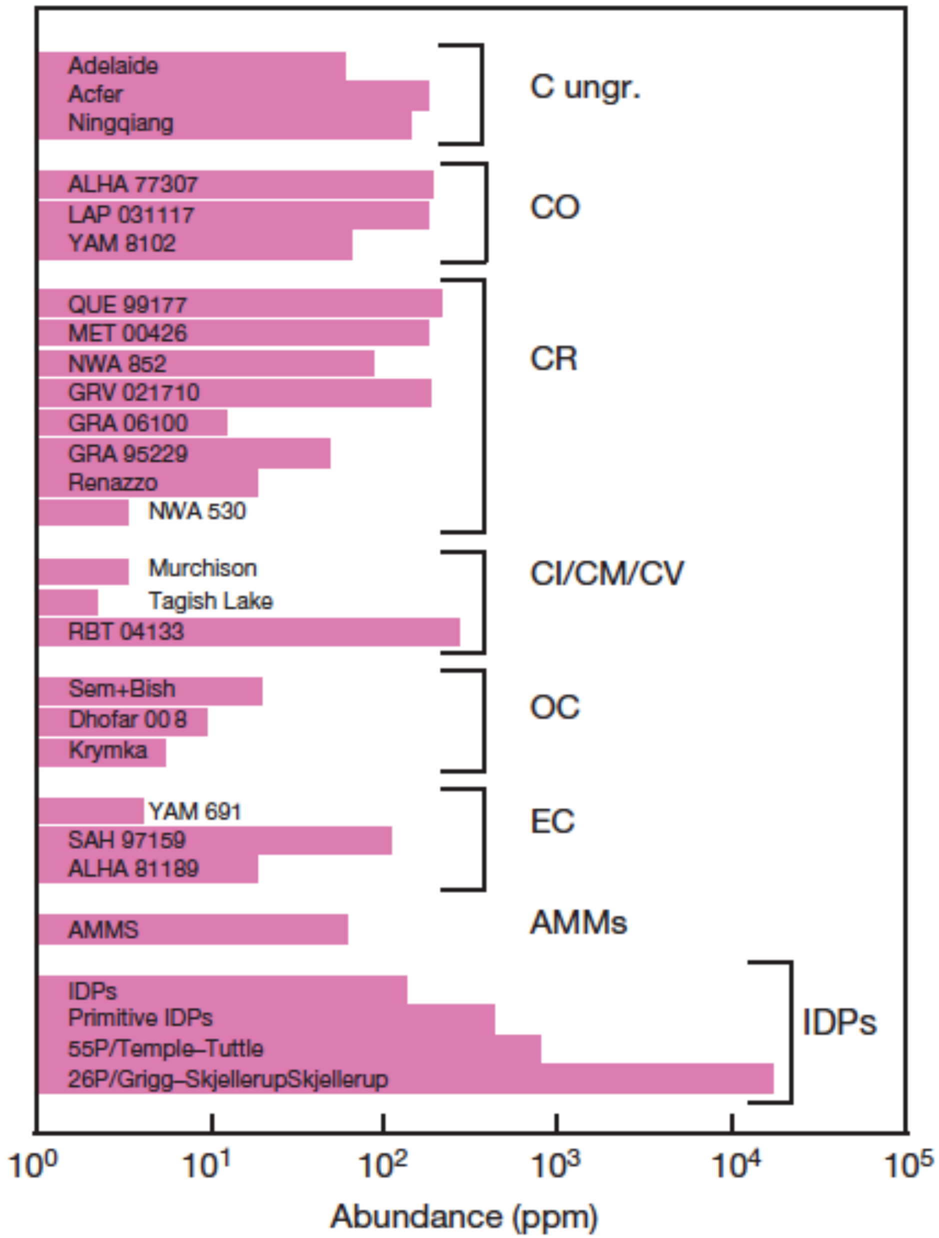
Bradley, Brownlee, Keller, Messenger

IDPs: 1-6 % are presolar (Keller & Messenger 2011)

So what fraction of interstellar dust is stardust, and what fraction is formed in the ISM?

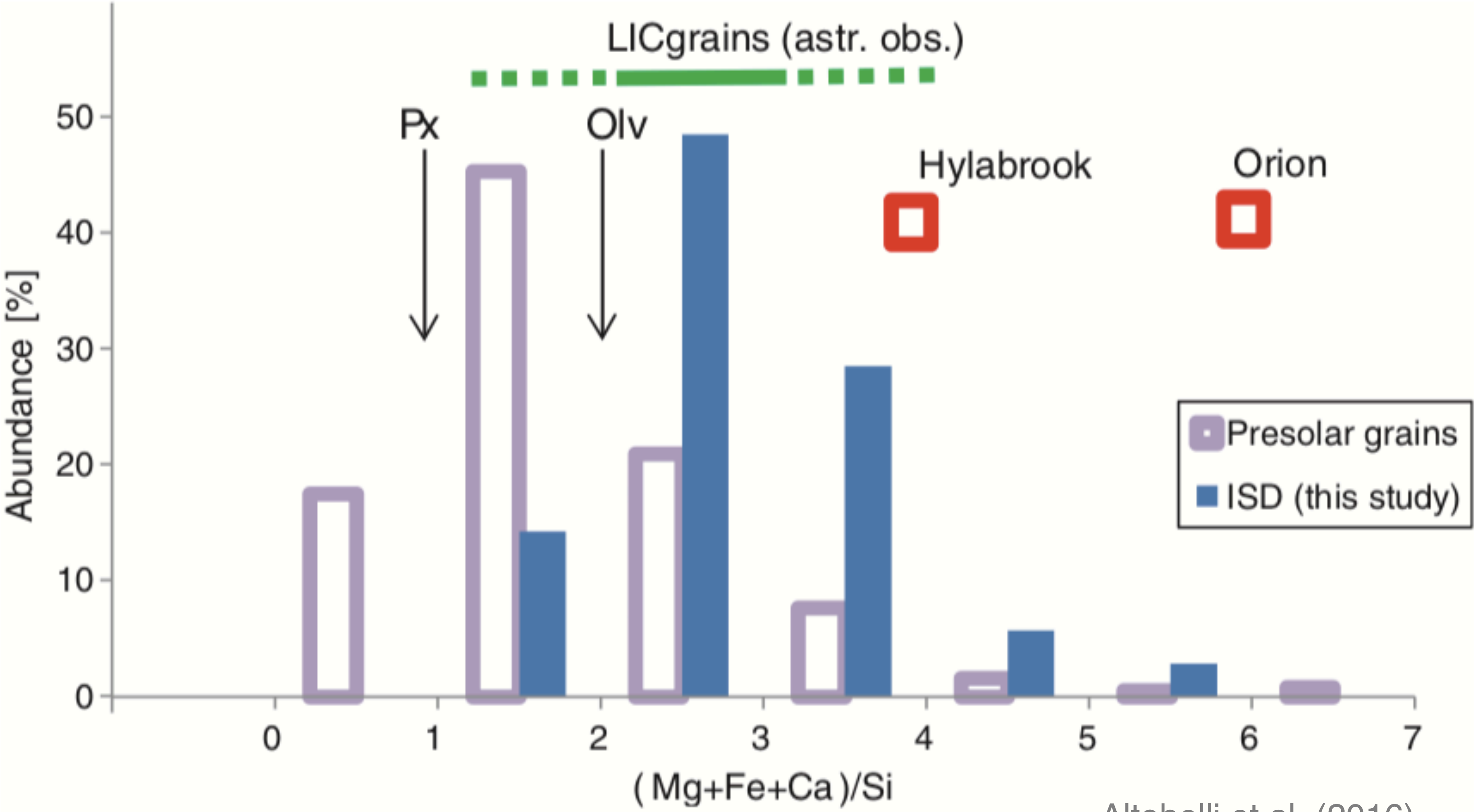
Jones & Nuth (2011):

- **less than 10% of ISM dust is stardust**
- **O-rich stardust survives ISM shocks more easily than C-rich stardust**



Zinner (2014)

Interstellar grains sampled with Cassini dust collector: Presolar silicates are not typical for ISM silicates



Altobelli et al. (2016)

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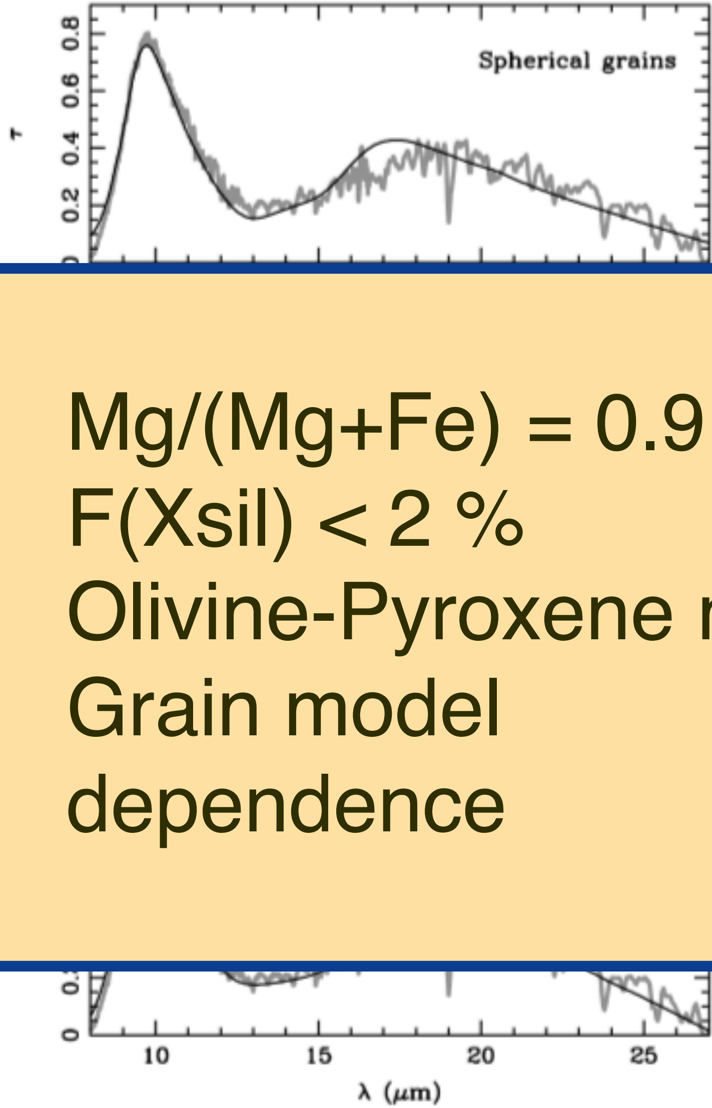
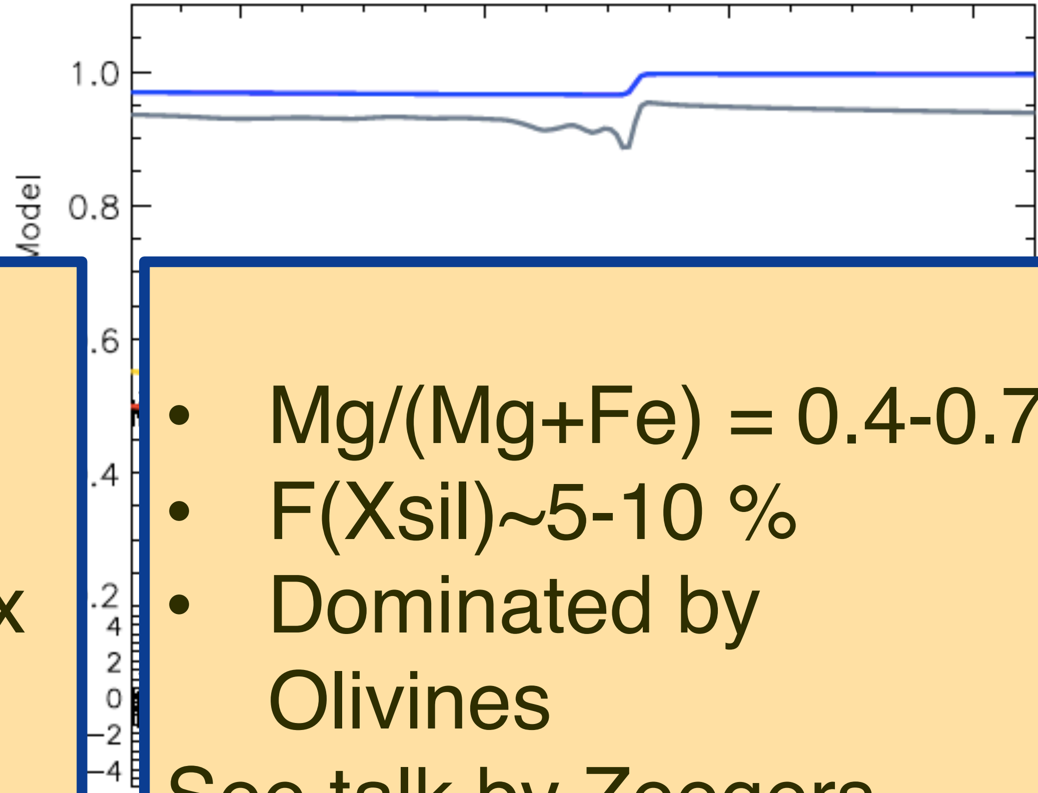
Composition of interstellar silicates

IR absorption spectra | **X-ray (Fe),Mg,Si edges**



- Mg/(Mg+Fe) = 0.9
- F(Xsil) < 2 %
- Olivine-Pyroxene mix
- Grain model dependence

Min et al. 2007

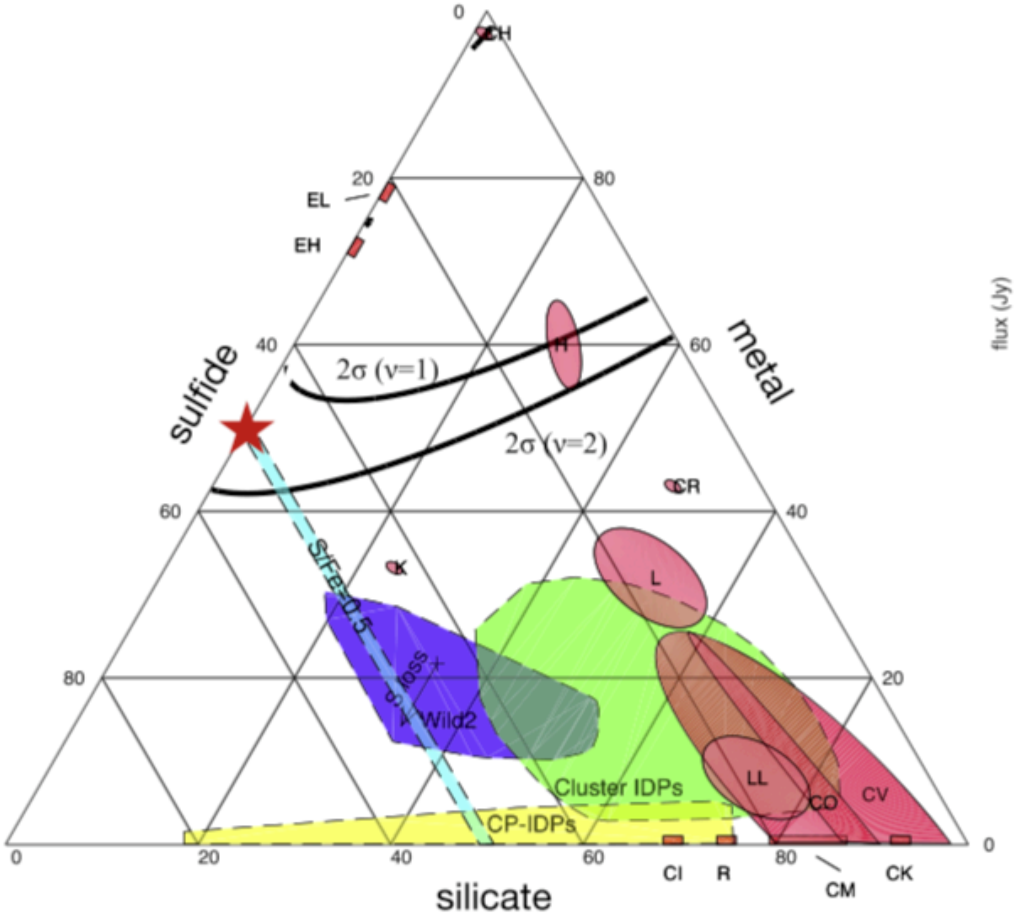


- Mg/(Mg+Fe) = 0.4-0.7
- F(Xsil)~5-10 %
- Dominated by Olivines

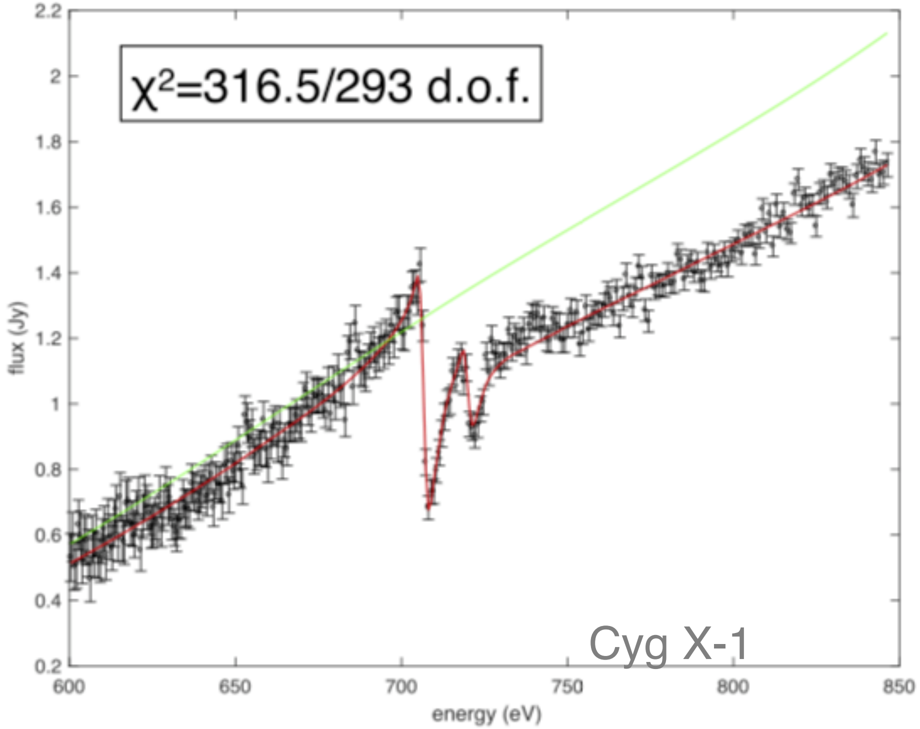
See talk by Zeegers

Costantini et al. 2012
Zeegers et al. 2019
Rogantini et al 2018, 2019

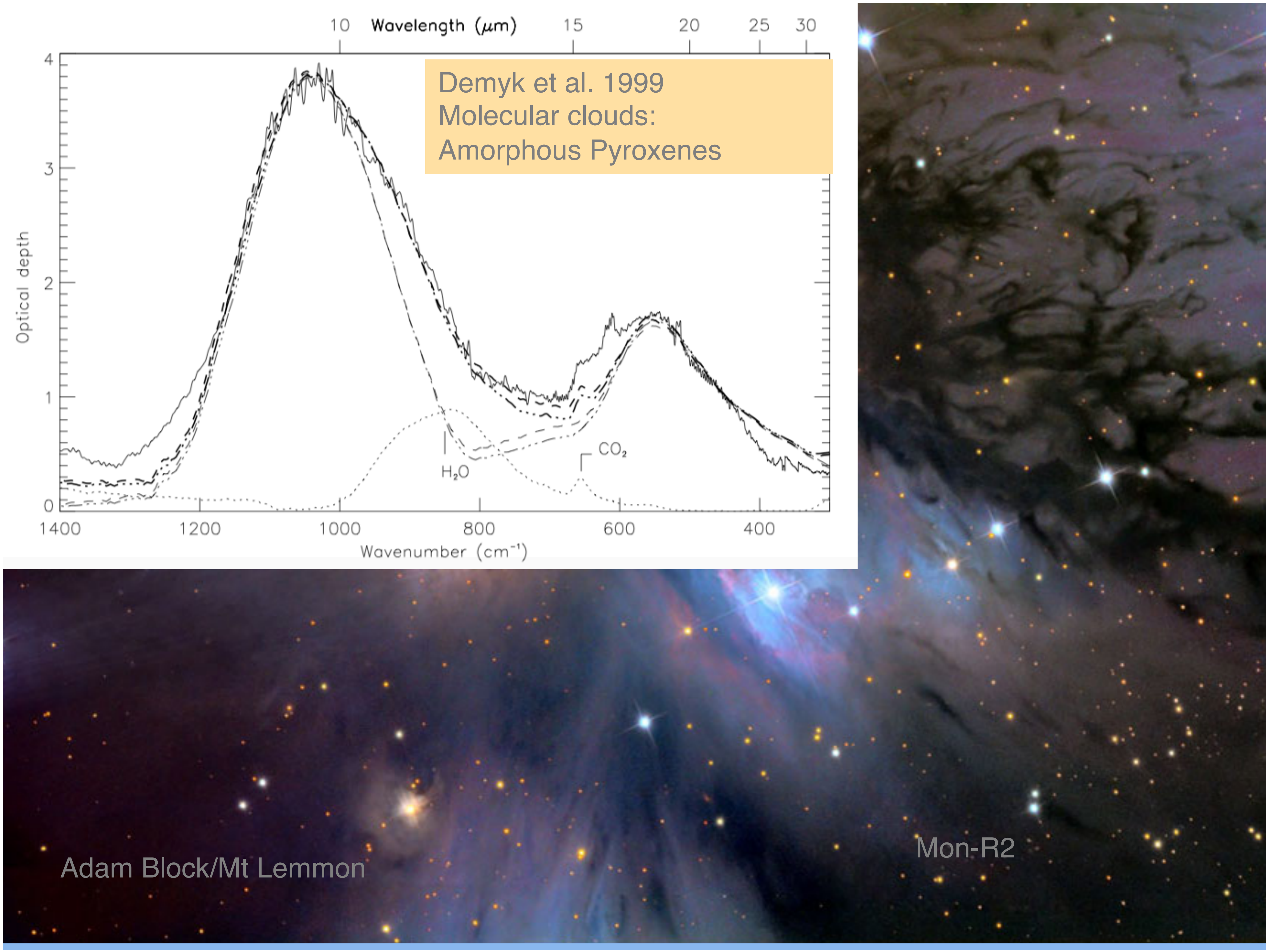
Fe L-edge modeling: GEMS composition inconsistent, Some Fe in amorphous silicates needed, up to ~38% of Fe



(Westphal et al. 2019)

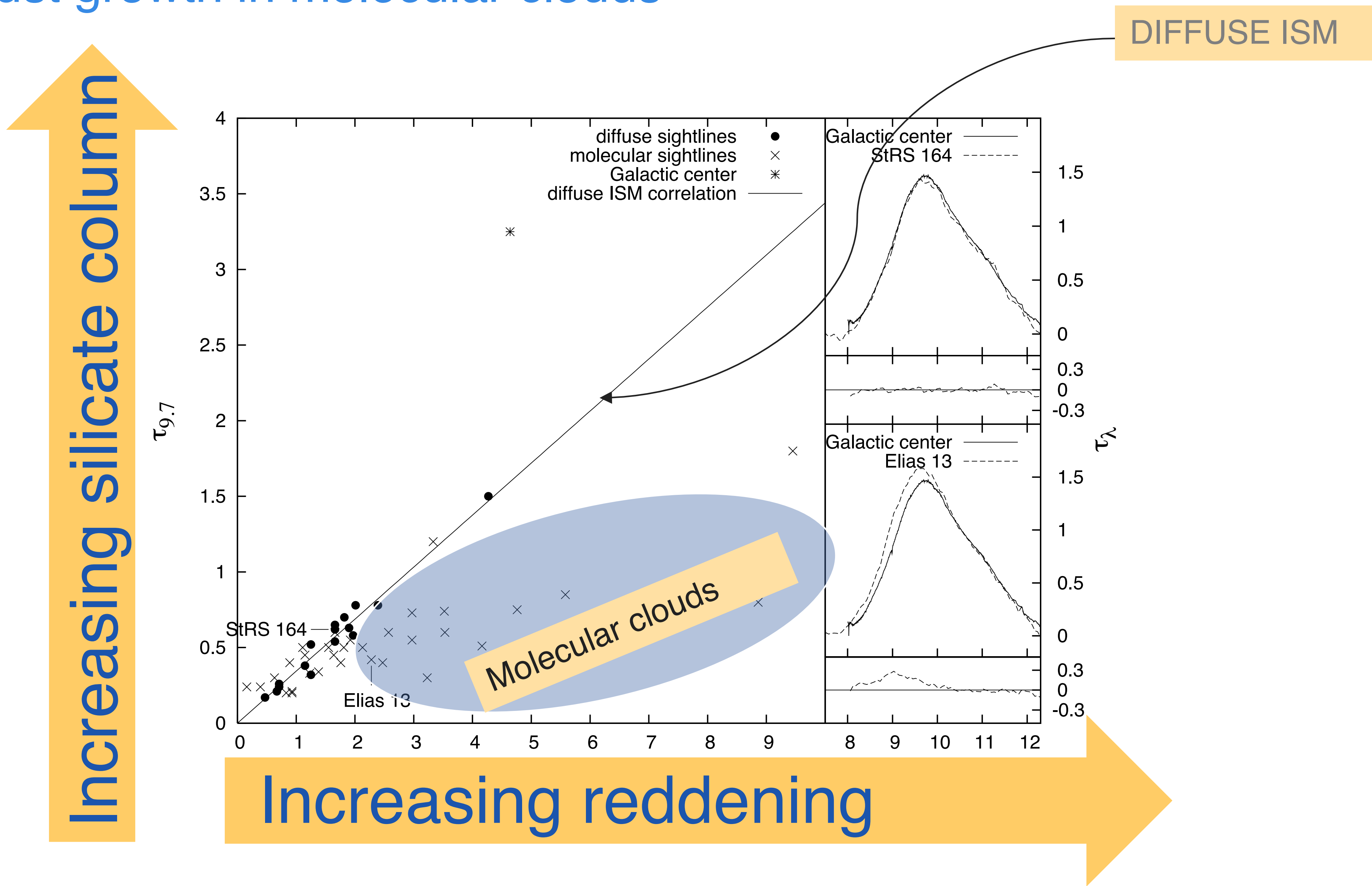


metal + sulfide + amorphous silicate
no Fe in gas phase
WD01 size distribution



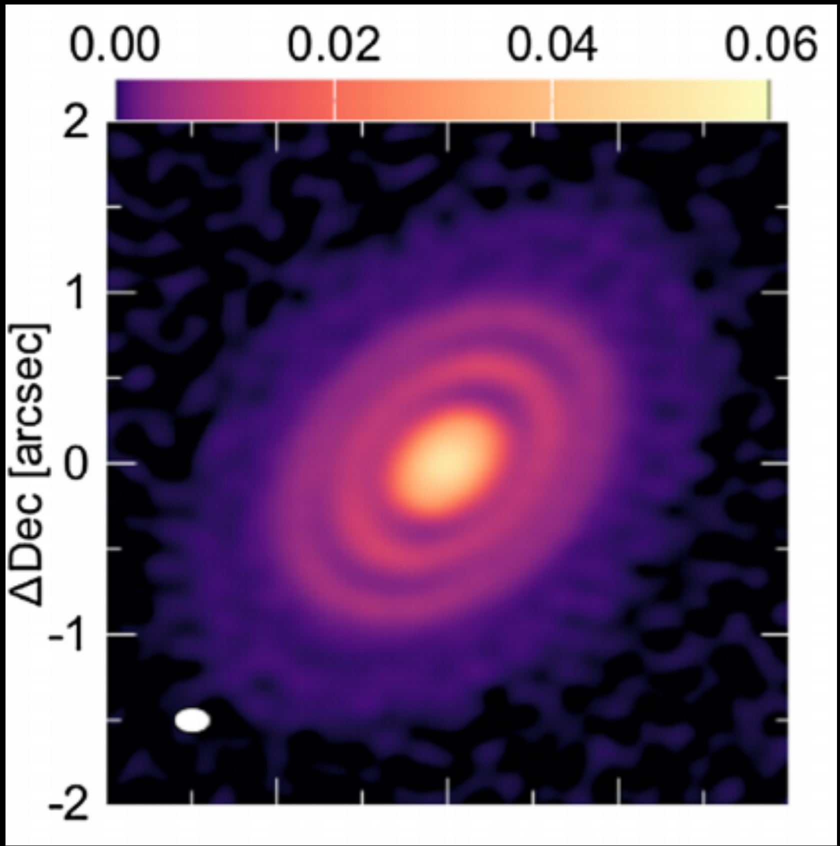
Demyk et al. 1999
Molecular clouds:
Amorphous Pyroxenes
Wavelength (μm)
10
15
20
25
30
Optical depth
4
3
2
1
0
H₂O
CO₂
1400
1200
1000
800
600
400
Wavenumber (cm⁻¹)
Adam Block/Mt Lemmon
Mon-R2

Dust growth in molecular clouds

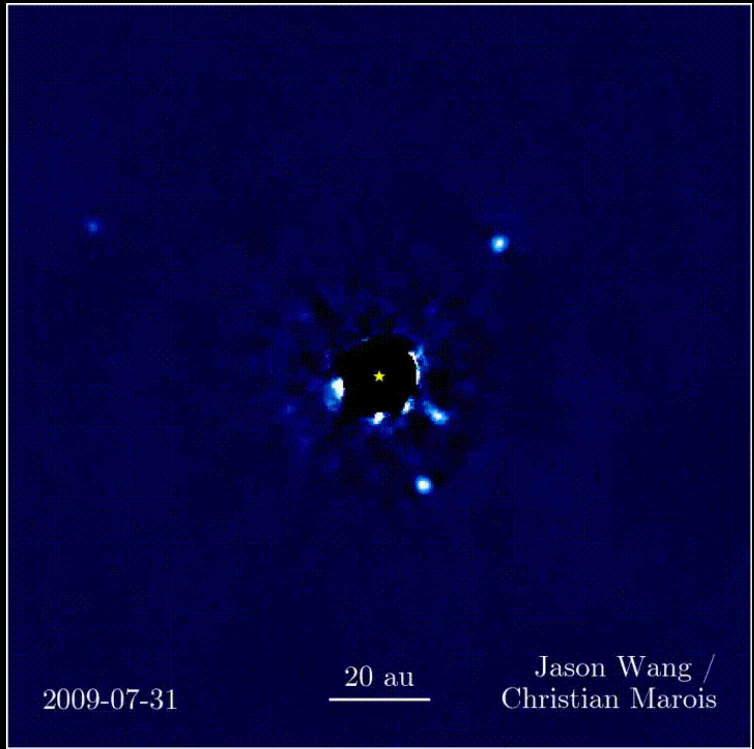


Chiar & Tielens; van Breemen et al.

Dust in proto-planetary disks

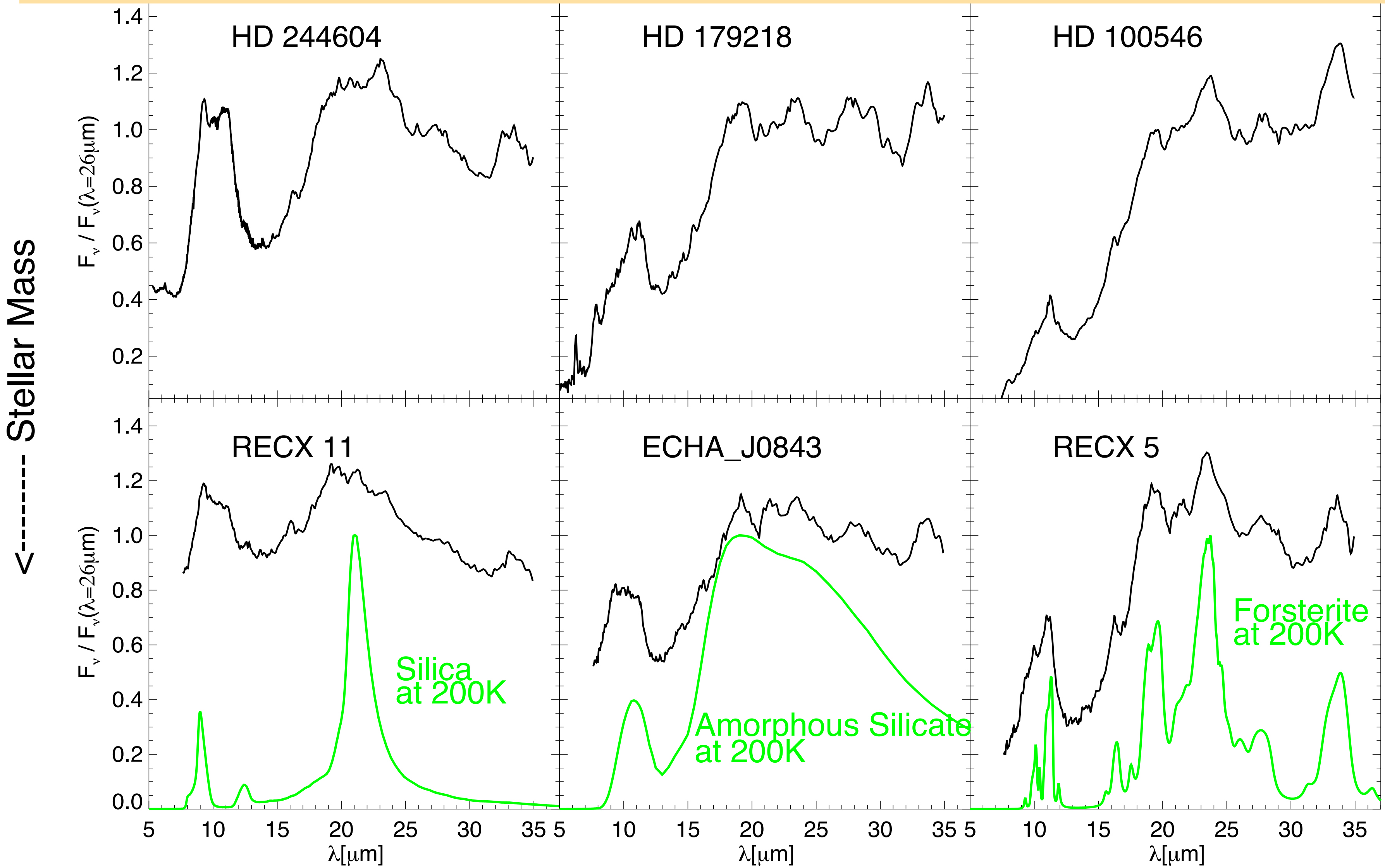


Isella et al. 2016



HR 8799

Crystalline silicates are Fe-poor: Forsterite, Enstatite, Silica



Bouwman et al.

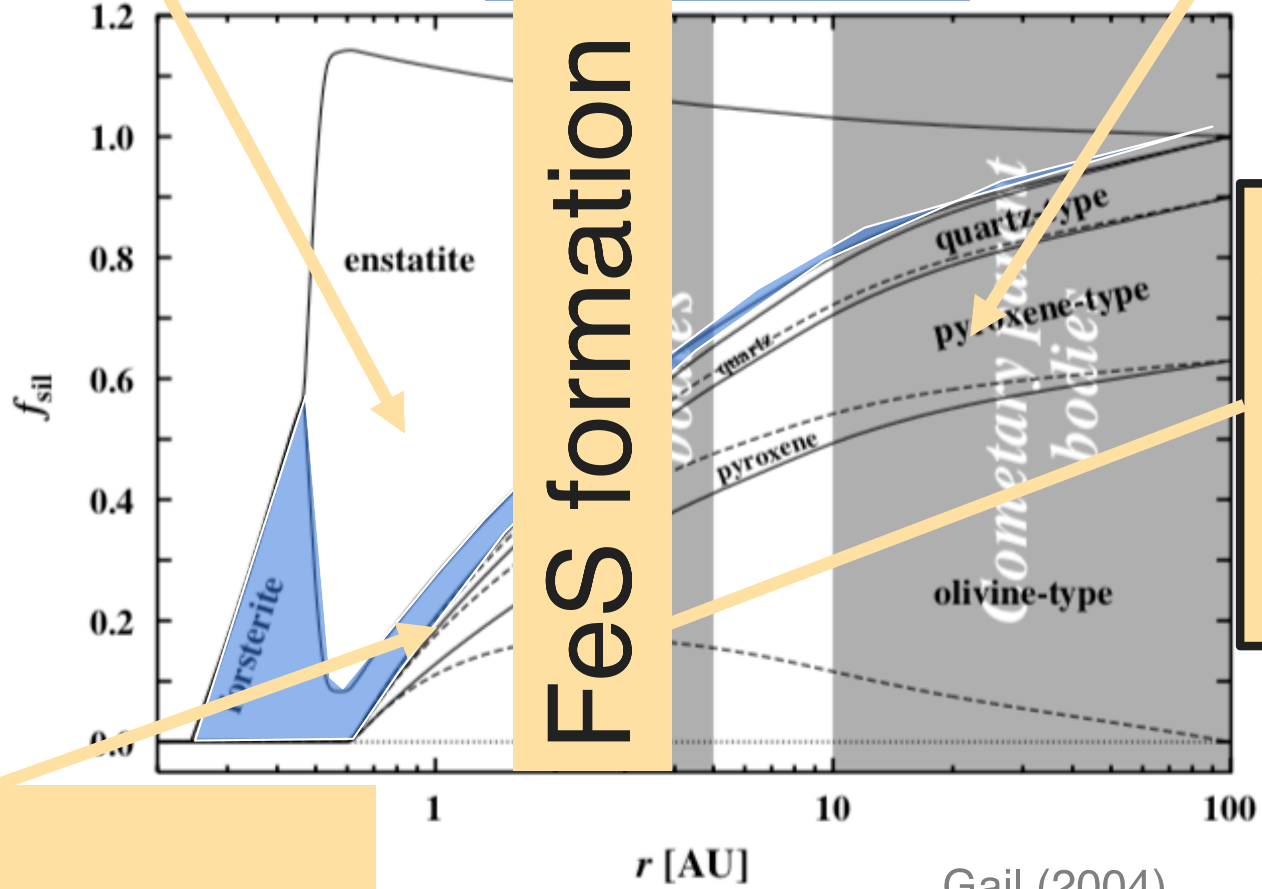
Combining inner disk and outer disk dust processing

Gas-phase condensation assuming equilibrium chemistry: formation of forsterite and enstatite

Thermal annealing of amorphous molecular cloud grains, depends on stochiometry of silicate grains

Mixing

FeS formation



Gail (2004)

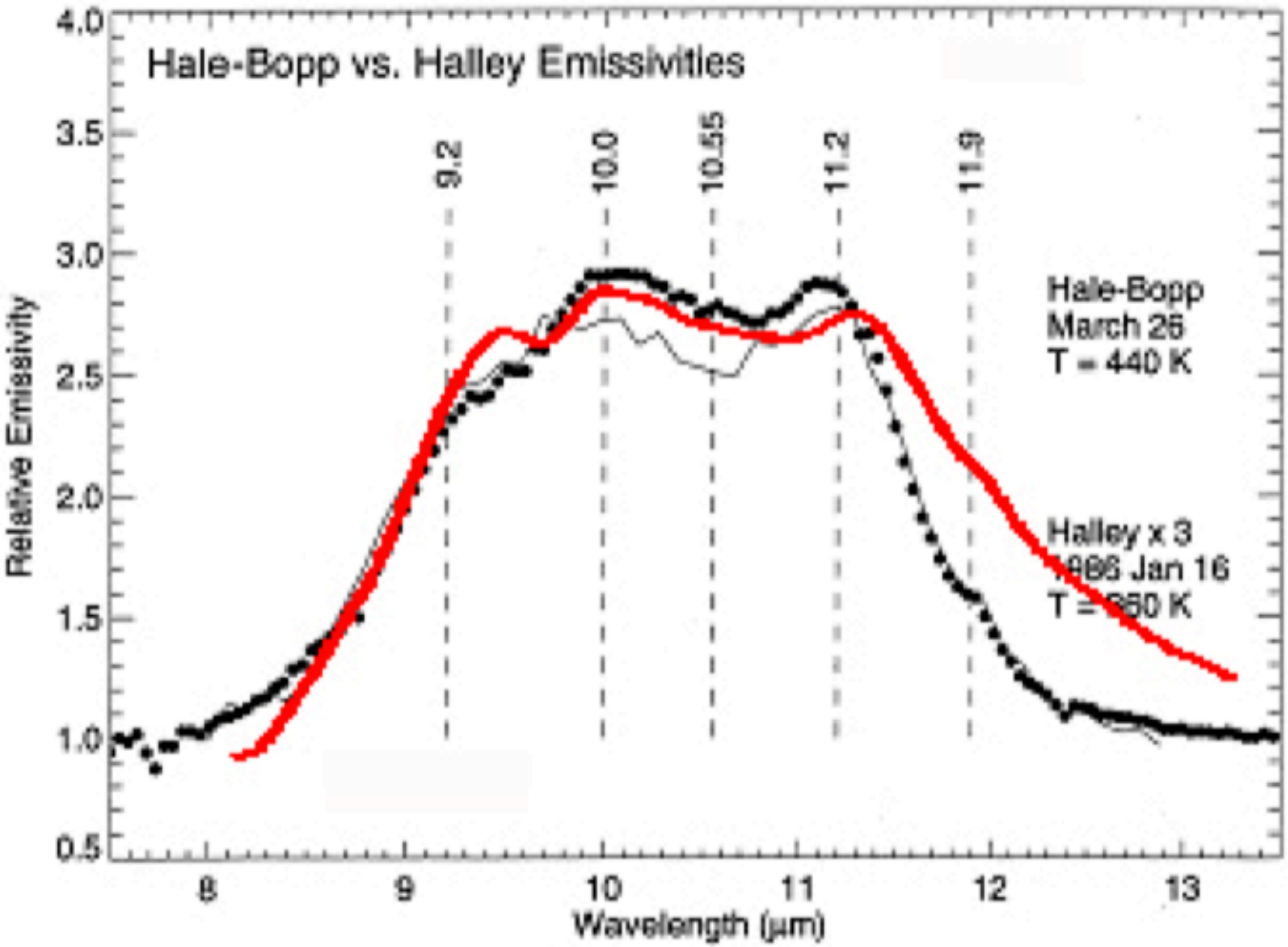
Fe inclusion in crystalline silicates:

- parent body processing
- Fe mobility in chemically inhomogeneous grains

Carbon combustion

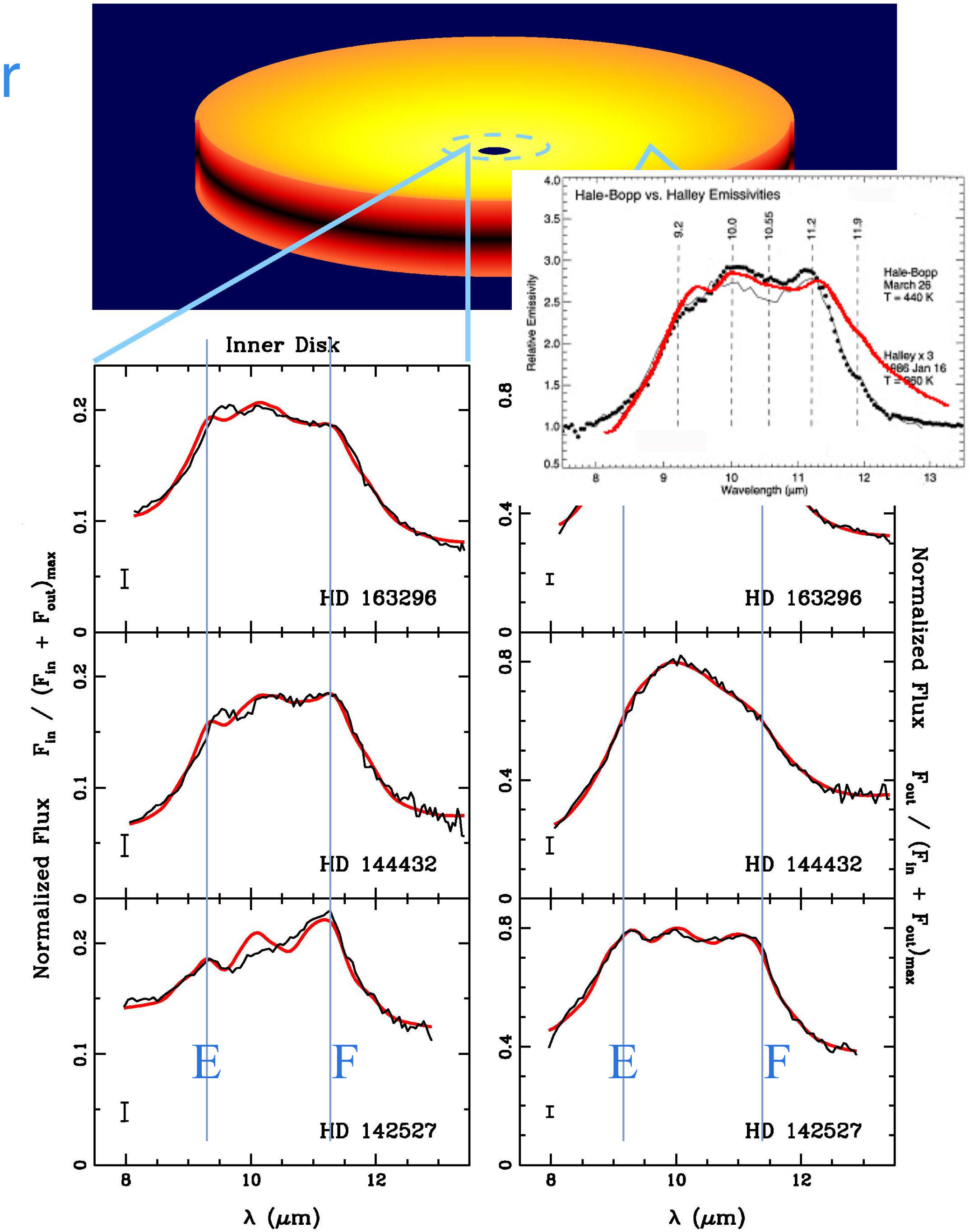
Average 10 micron spectrum of Anhydrous IDPs

Keller & Flynn (2008)



VLTI/MIDI: crystals form near the young star

(MATISSE results coming soon)



- Annealing, formation of Forsterite and Enstatite
- Chemical equilibrium condensation

Van Boekel et al. 2004

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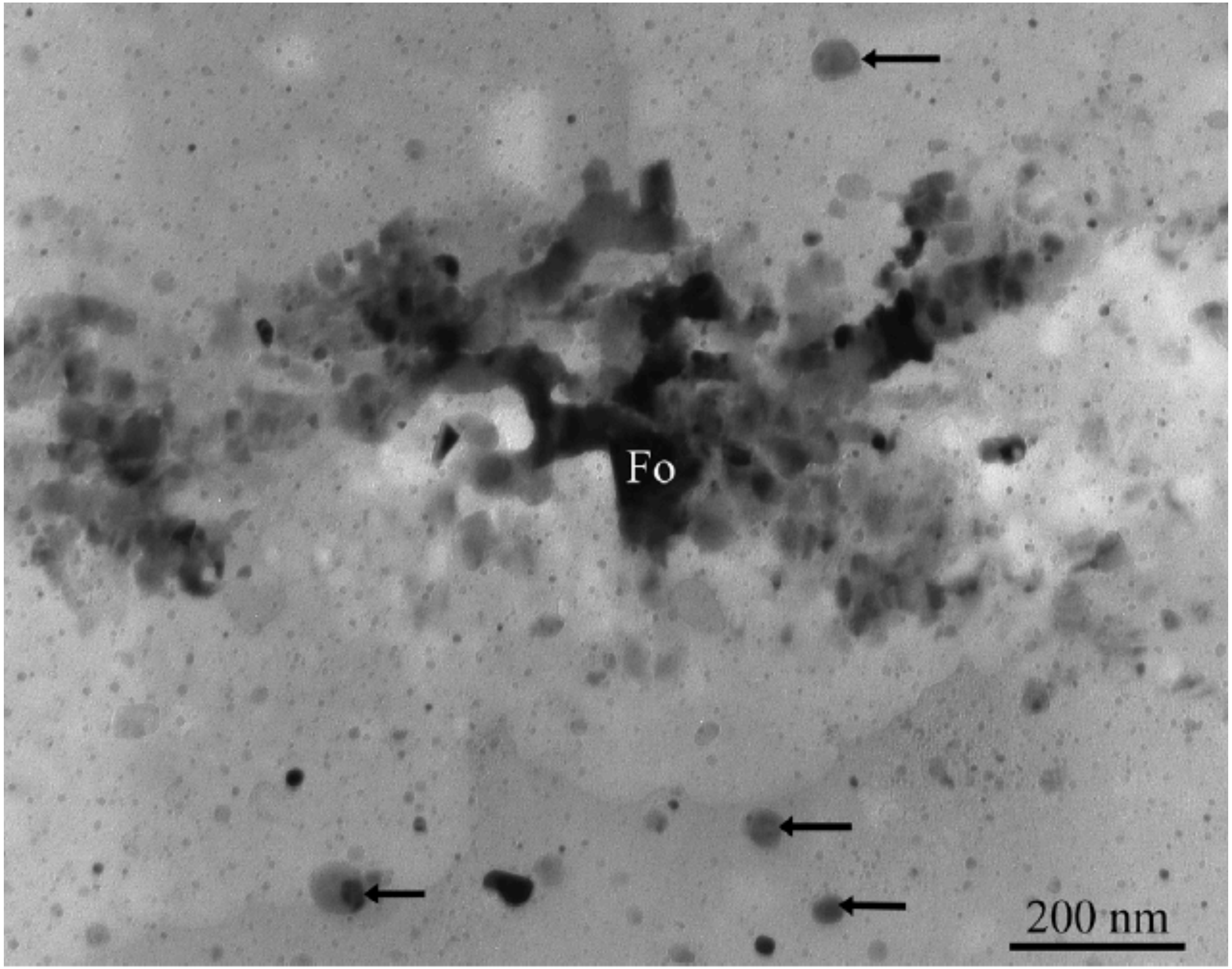
Annealing of amorphous silicates may produce GEMS-like material



Davoisne et al. 2006

Fe in lattice clusters to mettalic Fe

Silicate Glass becomes Mg-rich

GEMS have pyroxene stoiciometry

Stardust

ISM dust

Molecula

protoplan