Metallicity dependence of Crystalline Silicates in Evolved Stars

Olivia Jones – JBCA, Manchester

Ciska Kemper – ASIAA

& The SAGE-Spec team

Overview

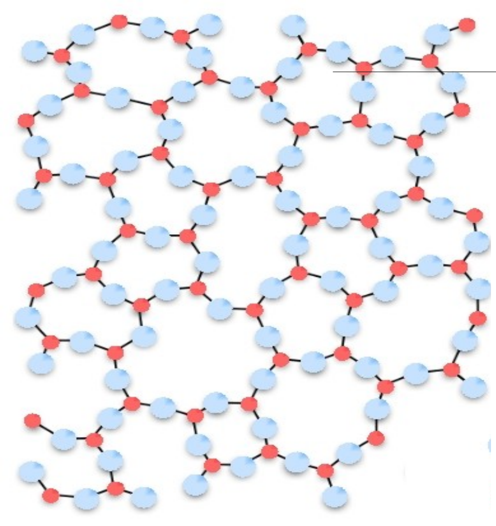
(1) Formation of crystalline silicate grains

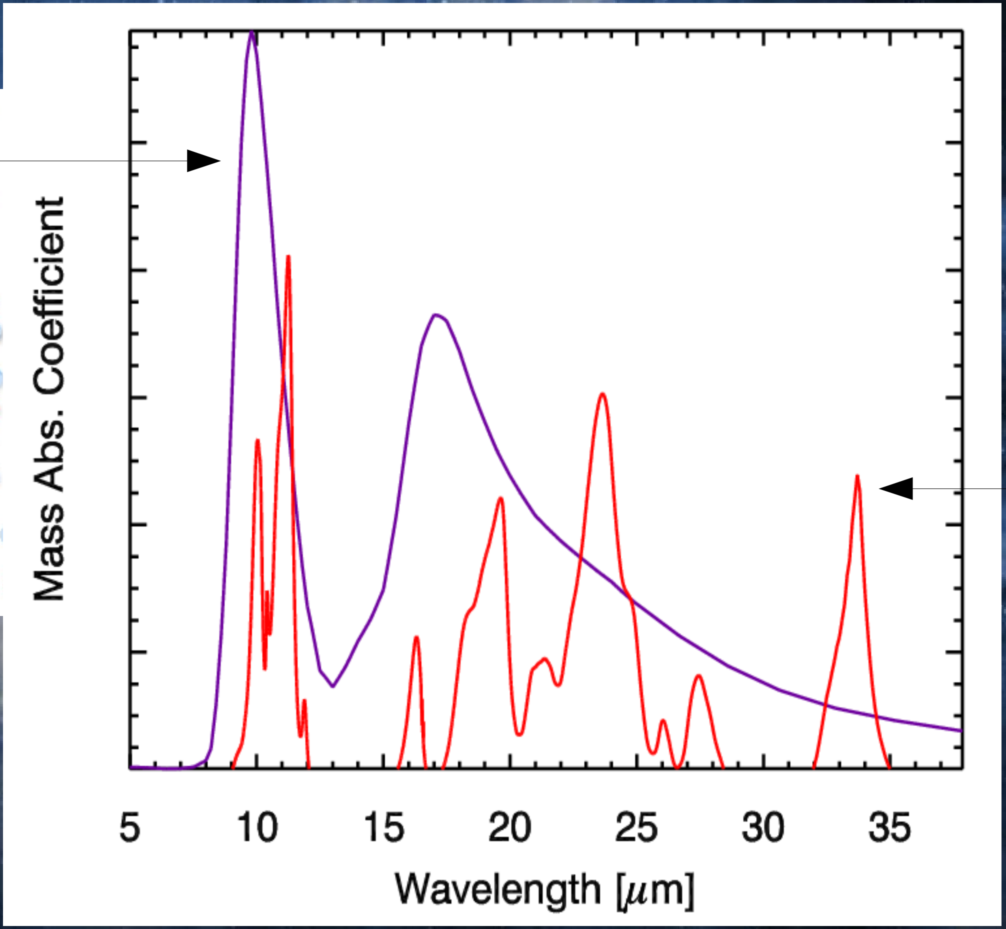
(2) Metallicity effects on crystalline silicate mineralogy

Silicate dust: mineralogy

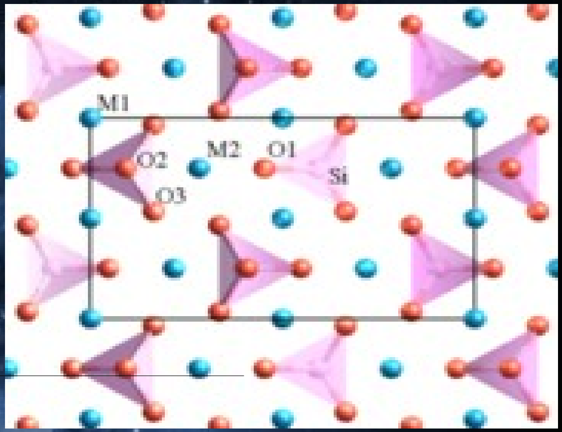
Si-O O-Si-O

Amorphous





Crystalline



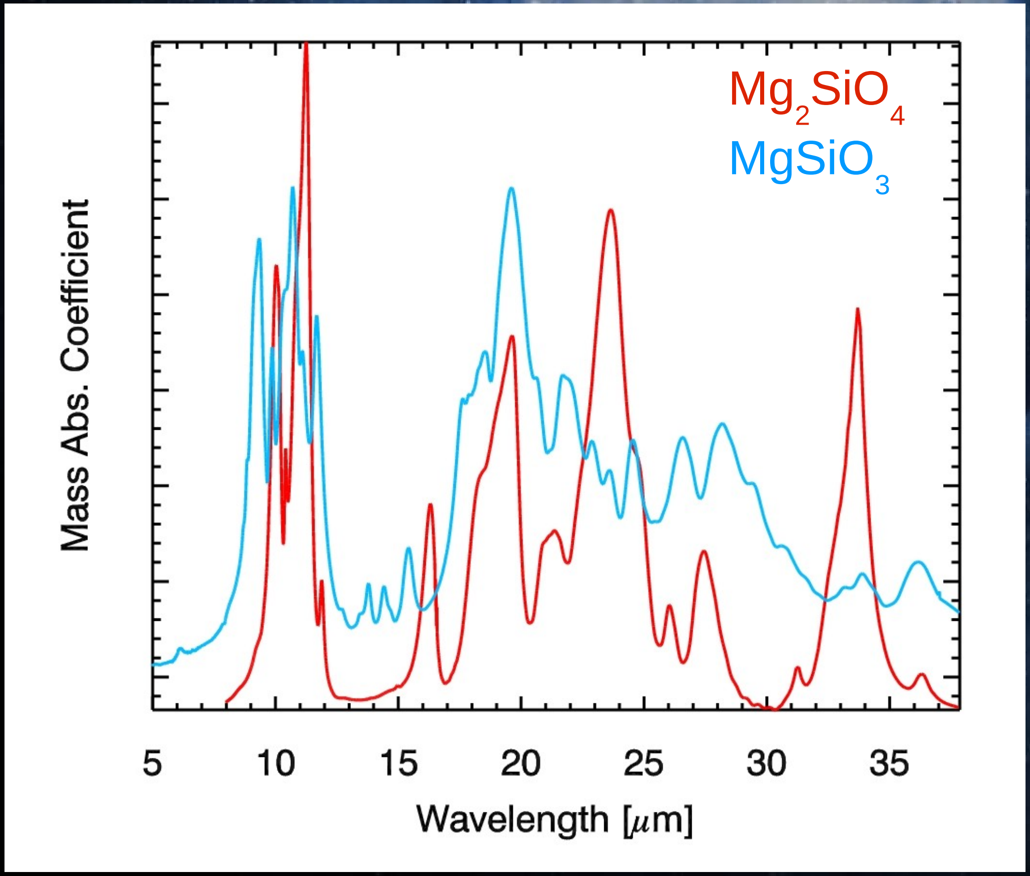
Tcond < **Tglass**: immediate freeze out → **amorphous** silicate

Tcond > **Tglass**: atoms in mineral are mobile, **crystallisation** may occur

The glass temperature **Tglass ~1000 K** for silicates

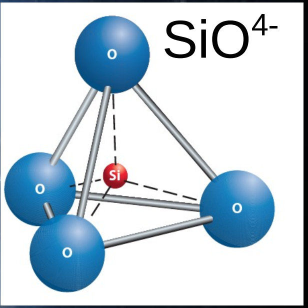
Silicate dust: mineralogy

Variations in grain shape, size, lattice structure, temperature & composition alter the feature profile.



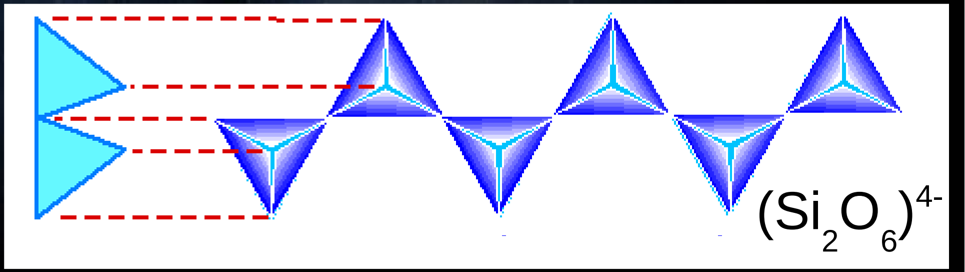
Olivine: $Mg_{2x}Fe_{(2-2x)}SiO_4$
with 1 ≥ x≥ 0

- Orthosilicate (tetrahedral)
- Saturated in oxygen.

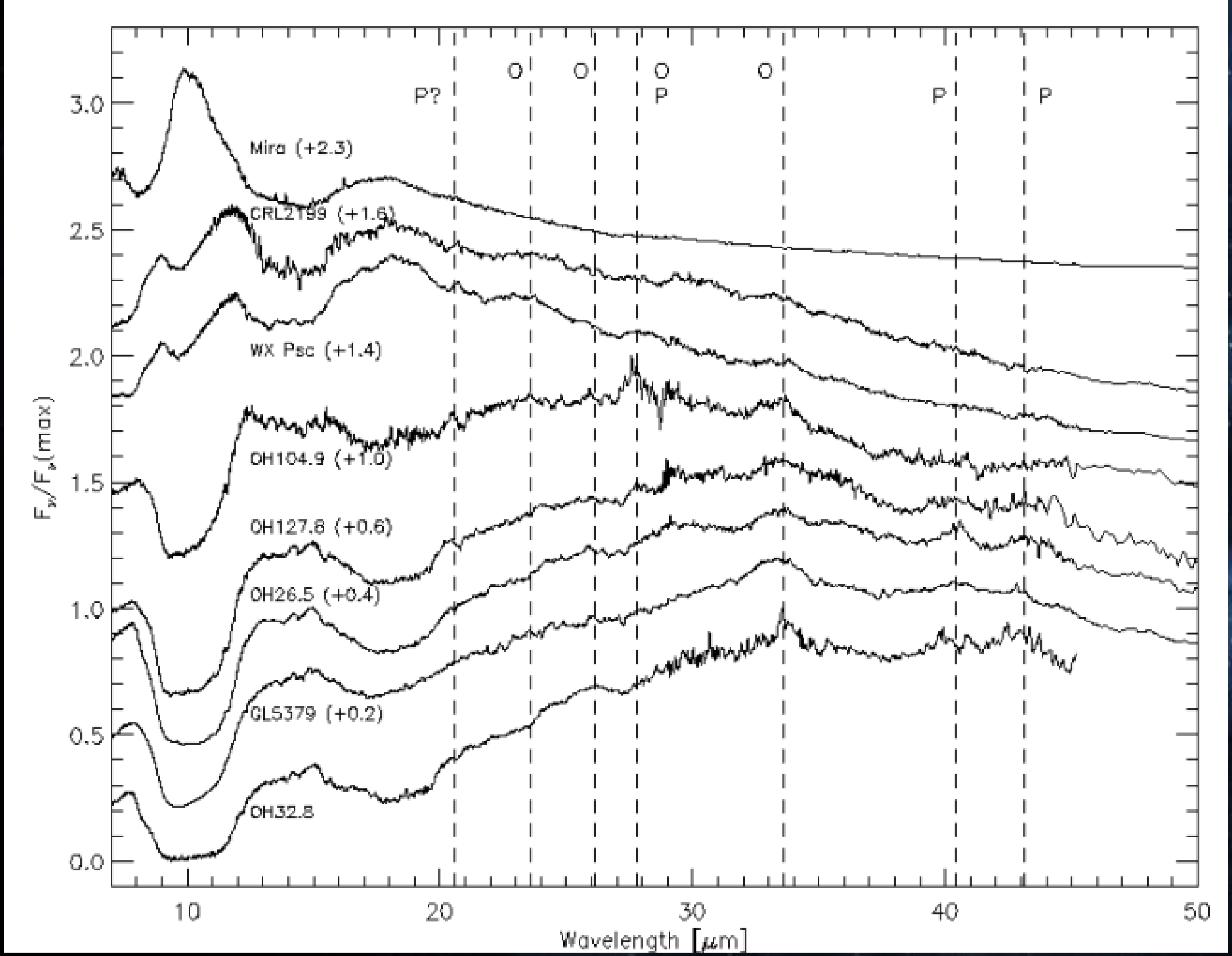


Pyroxene: $Mg_xFe_{1-x}SiO_3$
with 1 ≥ x≥ 0

- Inosilicates (Single Chain)
- Share oxygen with other units.



Why do we care about crystalline silicates?



In evolved stars they tend to be found in stars with high mass-loss rates.

Questions on the formation:

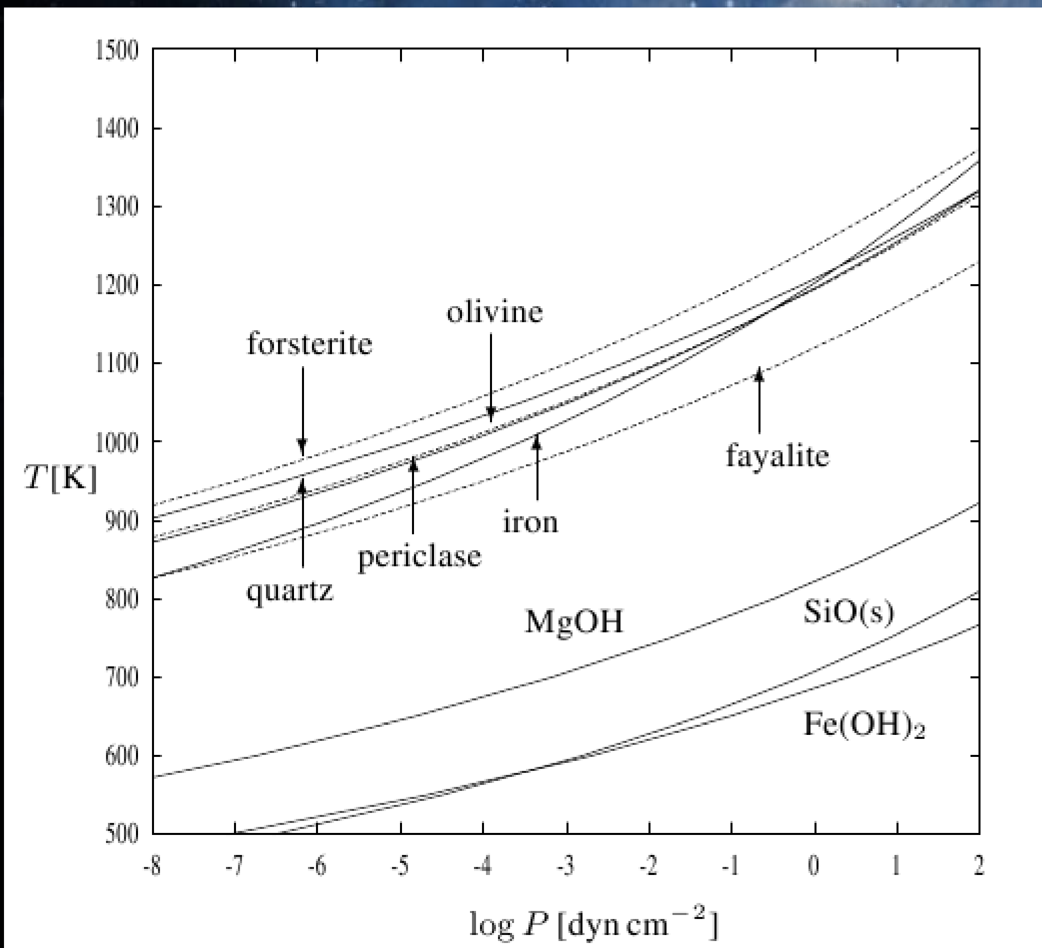
Form directly as crystalline grains or by annealing of amorphous grains?

What determines the onset of crystallinity:

The critical density of gas
Or
The critical density of dust?

Sylverster et al. 1999

Formation of crystalline silicates by Direct condensation?



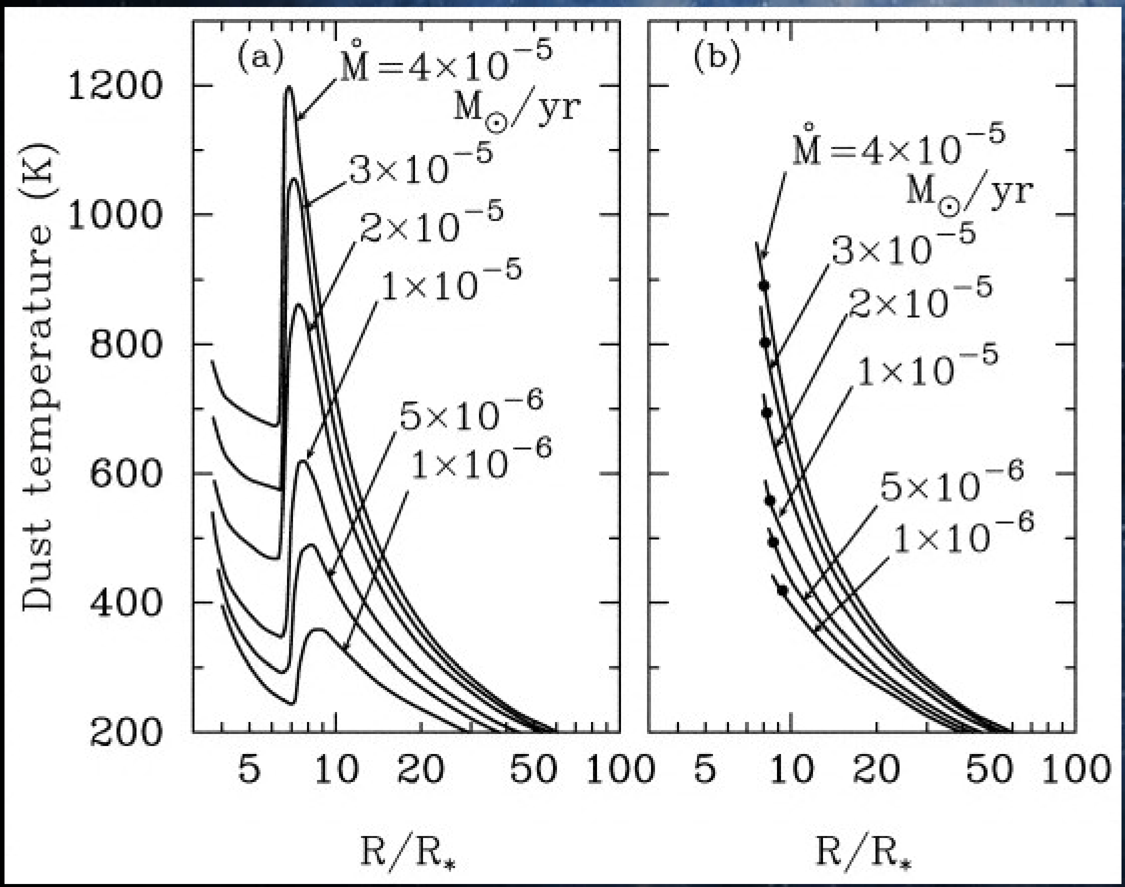
[1760-1300K]
Al_2O_3, Alumina
↓
[1625-1400K]
$Ca_2Al_2SiO_7$, Gehlinite
↓
[1450-1100K]
$CaMgSi_2O_6$, Diopside
↓
[1360-1000K]
$CaAl_2Si_2O_8$, Anorthite

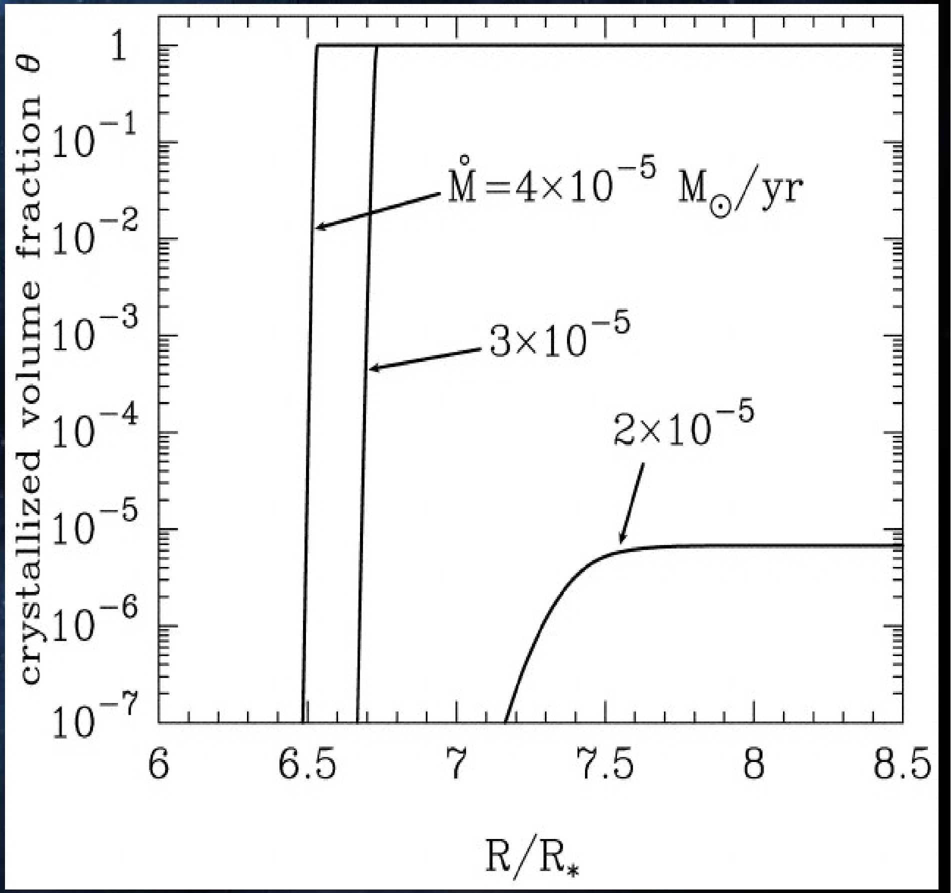
[1440-1050K]
Mg_2SiO_4, Forsterite
↓
[1350-1040K]
$MgSiO_3$, Enstatite
↓
[1100-950K]
$[Mg,Fe]_2SiO_4$, Olivine

Gail & Sedlmayr 1999

Tielens 1990

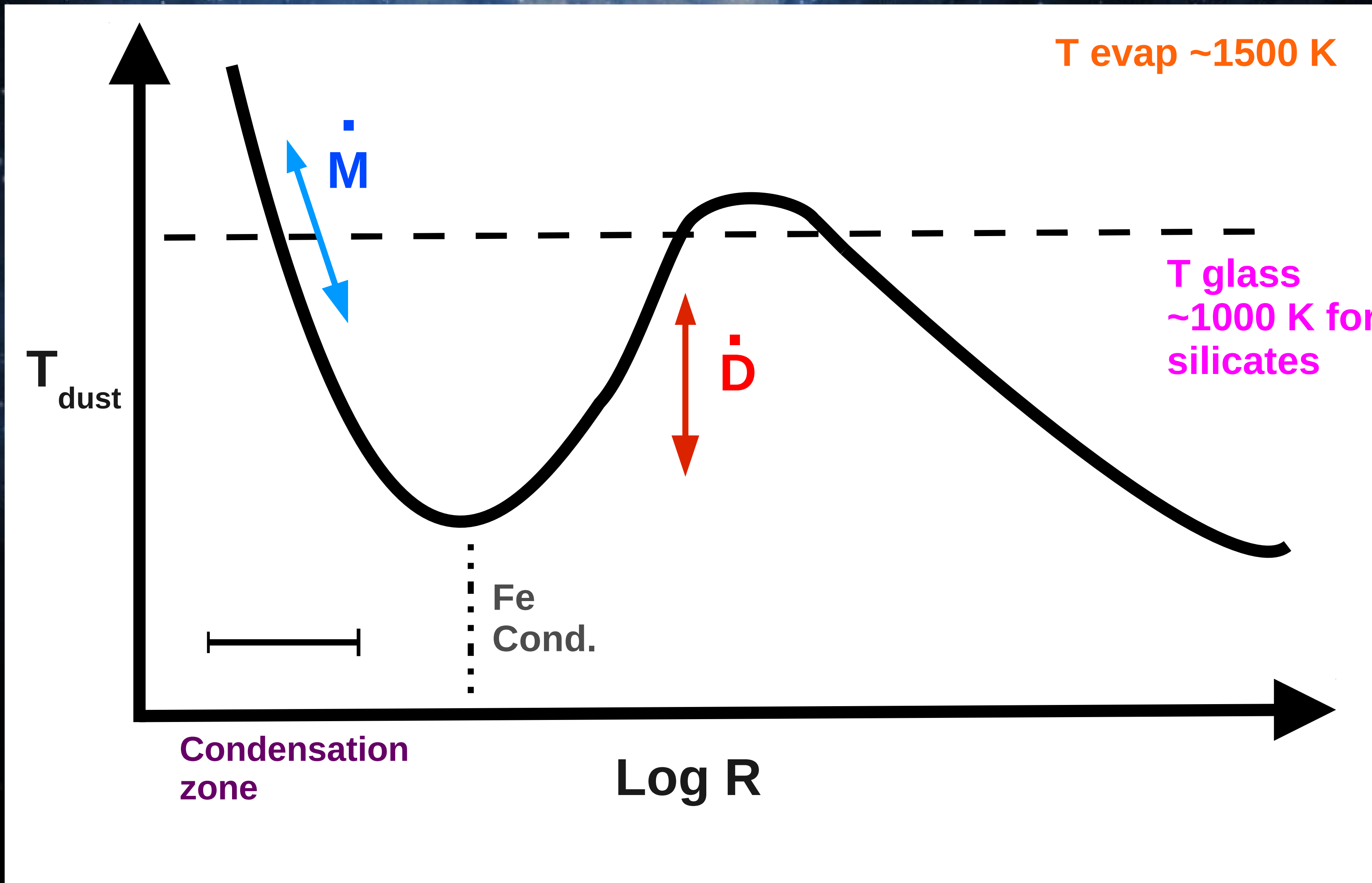
Formation of crystalline silicates by **Thermal Annealing**?



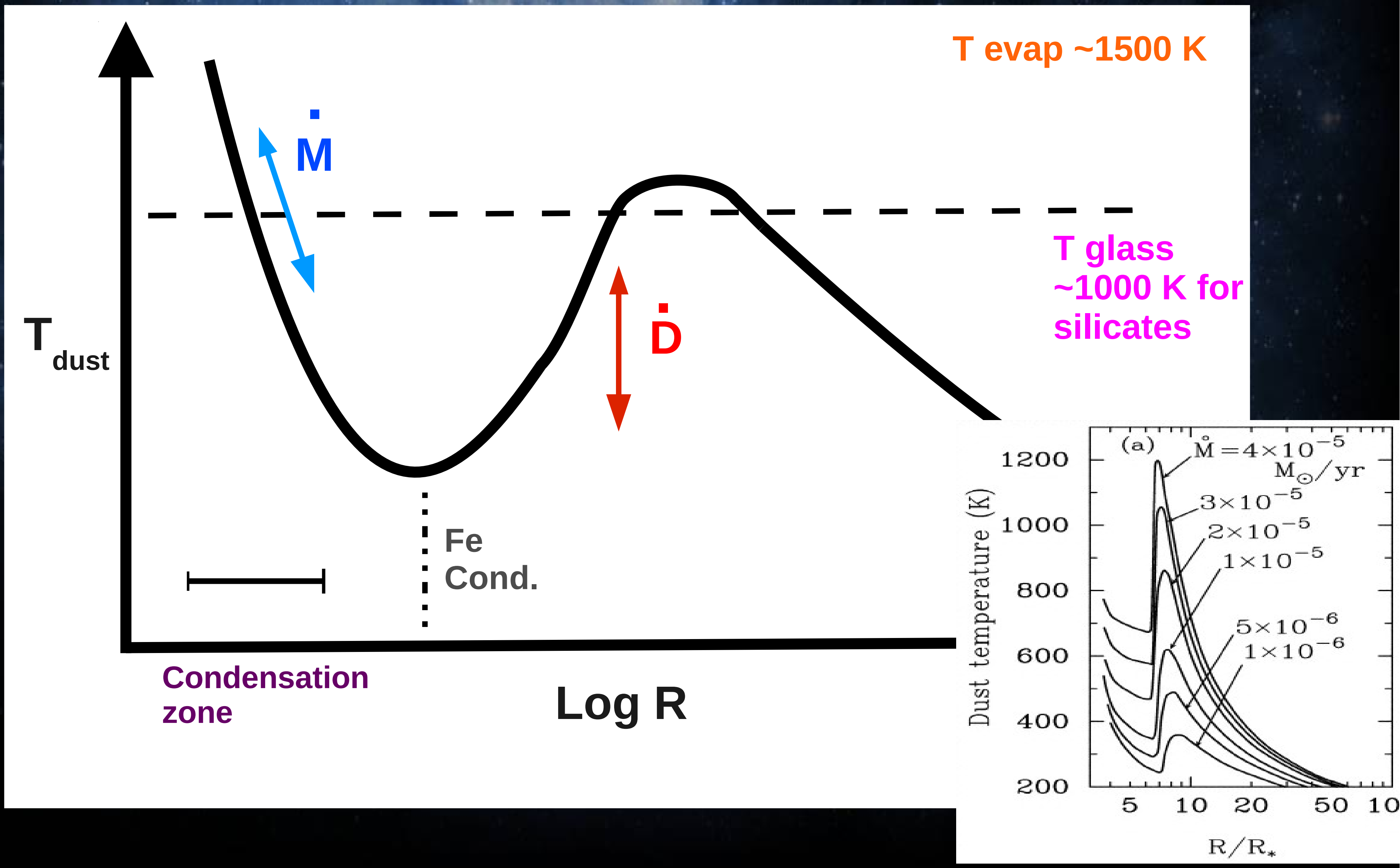


Sogawa & Kozasa 1999

Does the crystalline fraction depend on the gas density or the dust column density?



Does the crystalline fraction depend on the gas density or the dust column density?



Does the crystalline fraction depend on the gas density or the dust column density?

LMC

$Z_{LMC} \sim 0.5\ Z_{\odot}$

SMC

$Z_{SMC} \sim 0.2\ Z_{\odot}$

Milky Way

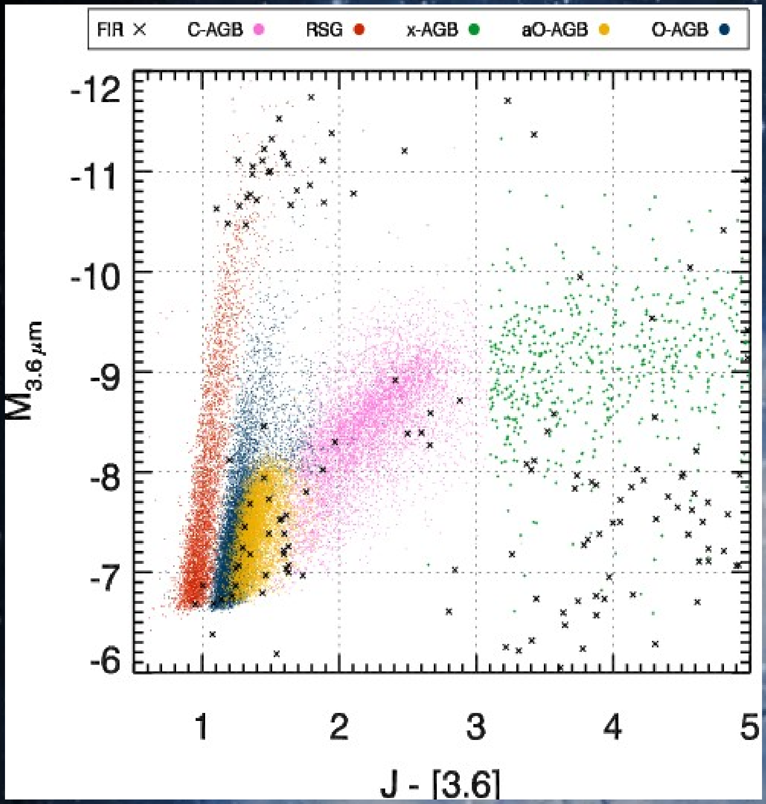
$Z_{MW} \sim 1\ Z_{\odot}$

Globular Clusters

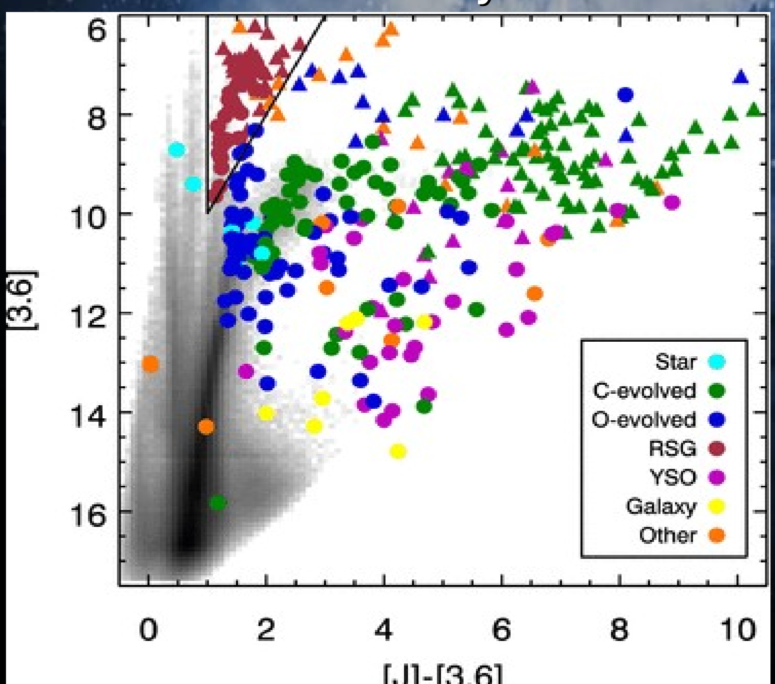
$Z_{GLC} < 0.2\ Z_{\odot}$

We can investigate this by varying the metallicity (and thus the gas/dust ratio).

SAGE-Spec



Boyer et al. 2011



Woods et al. 2011

Spitzer IRS spectra (λ = 5.2–38 μm)

~1000 IRS observations in LMC
(including 197 from SAGE-Spec legacy program*)

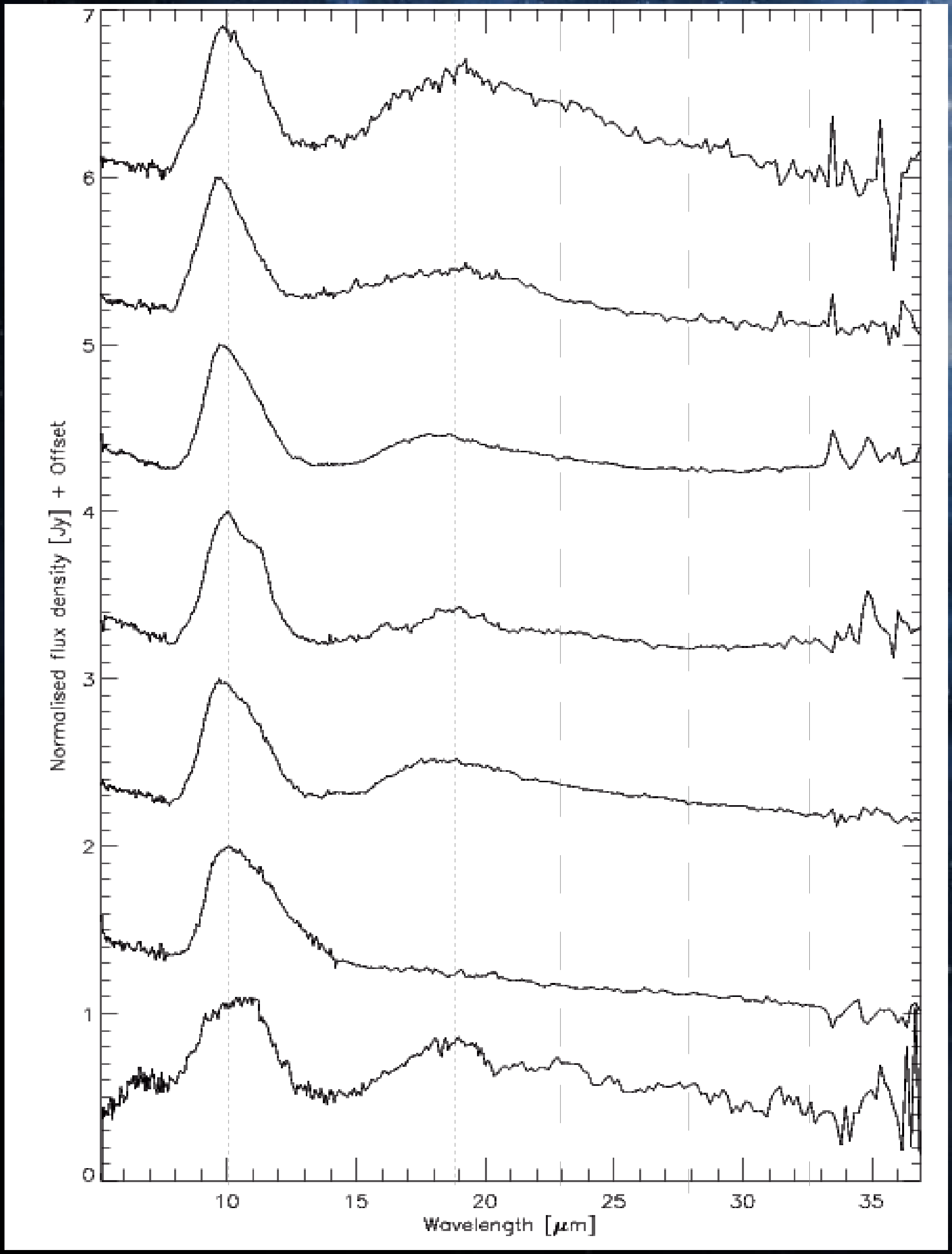
~250 IRS observations in SMC

Use spectral information to verify photometric classification

Characterise dust composition of object classes

* Kemper et al. 2010

The sample .....



Selection Criteria:

- Classified as O-AGB or RSG
- M_{bol} < -7.1 for RSG
- O-rich silicate features in emission

134 MW (ISO SWS & Spitzer IRS)

114 LMC (Spitzer IRS)

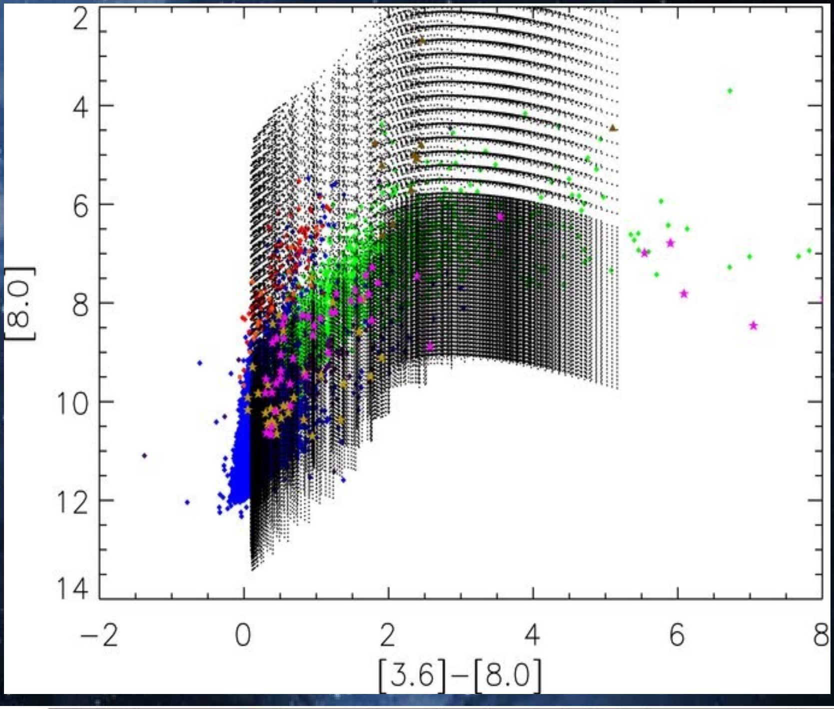
32 SMC (Spitzer IRS)

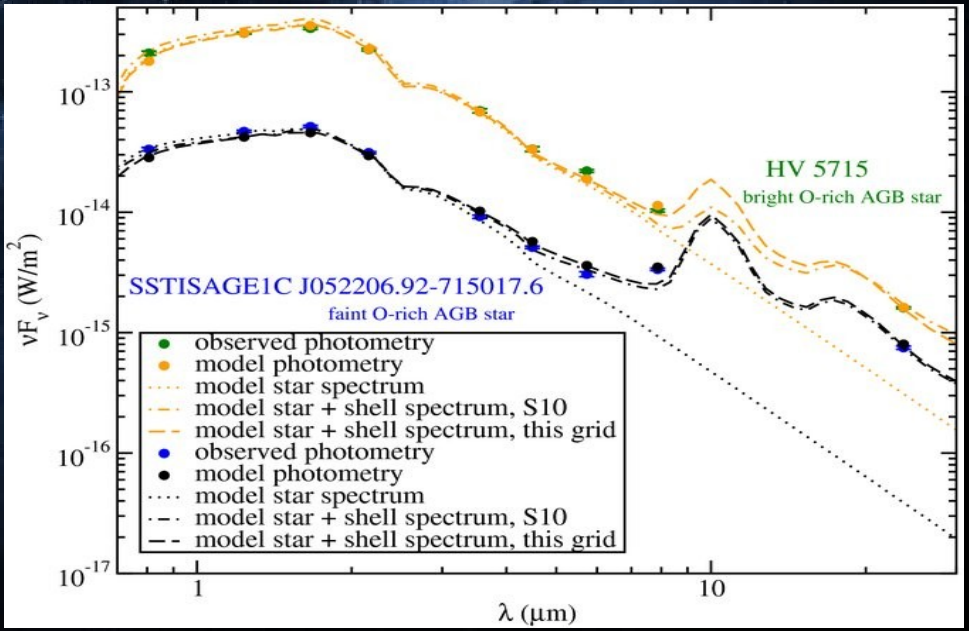
39 Spitzer IRS from 14 Galactic Globular Clusters

GRAMS Models

O-rich grid of **68000** GRAMS models

Parameter	Range of Values	Increment
Star		
$T_{\rm eff}$ (K)	2100–4700	+200
$\log(g)$	−0.5	...
$\log(Z/Z_{\rm sun})$*	−0.5	...
$L_{\rm star}(L_\odot)$	10^3–10^6	$\times 1.08$, $\times 1.3$[a]
Dust grains		
$\rho_{\rm dust}$ (g/cm^3)*	3.3	...
γ*	−3.5	...
$a_{\rm min}$(μm)*	0.01	...
a_0(μm)*	0.1	...
Assumed values		
$R_{\rm max}/R_{\rm min}$*	10^3	...
$v_{\rm exp}$ (km s^{-1})*	10	...
Dust shell		
τ_{10}	10^{-4}–26	$\times 2$, +1[b]
$R_{\rm min}(R_{\rm star})$	3, 7, 11, and 15	+4
$\dot{M}_{\rm dust}(M_\odot\ {\rm yr}^{-1})$	3×10^{-13}–3×10^{-5}	...



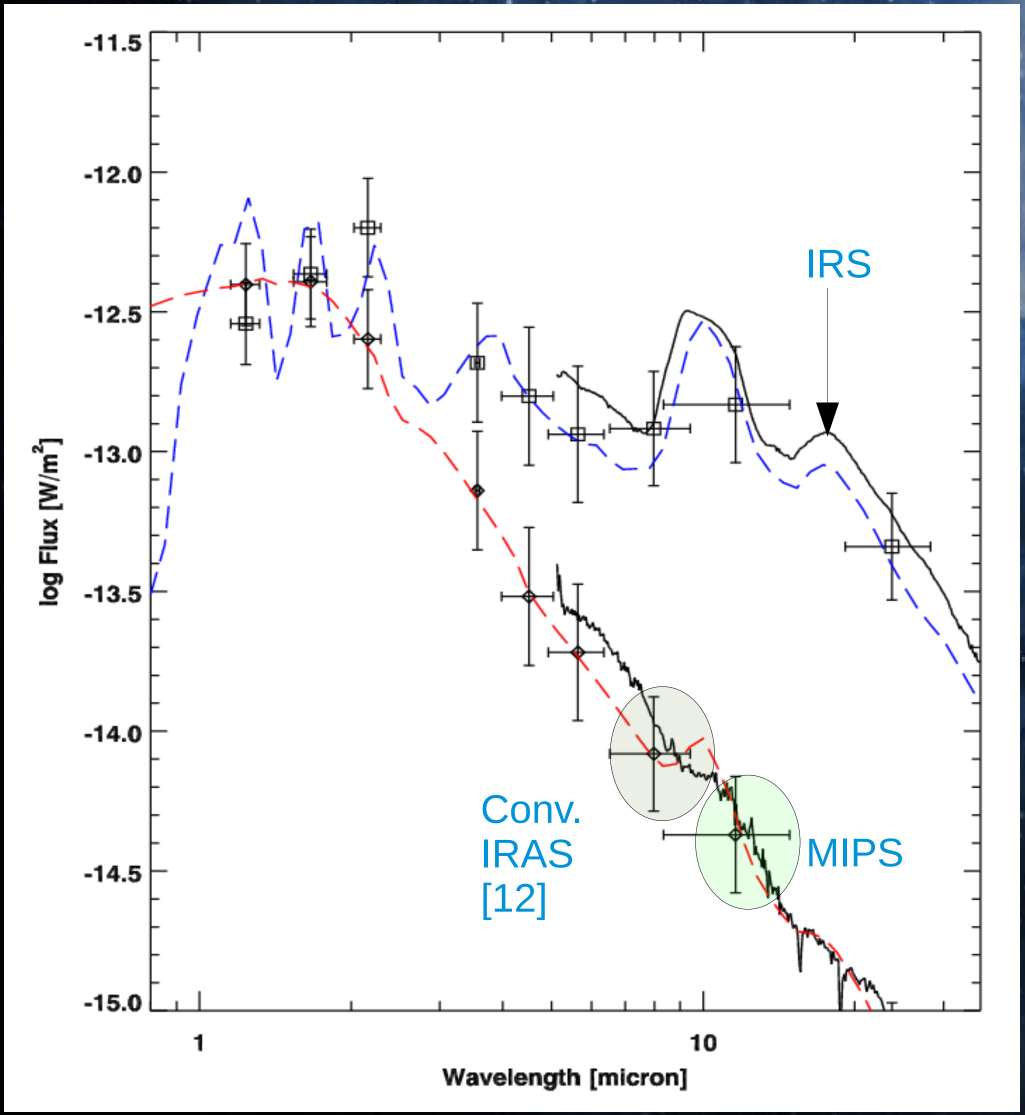


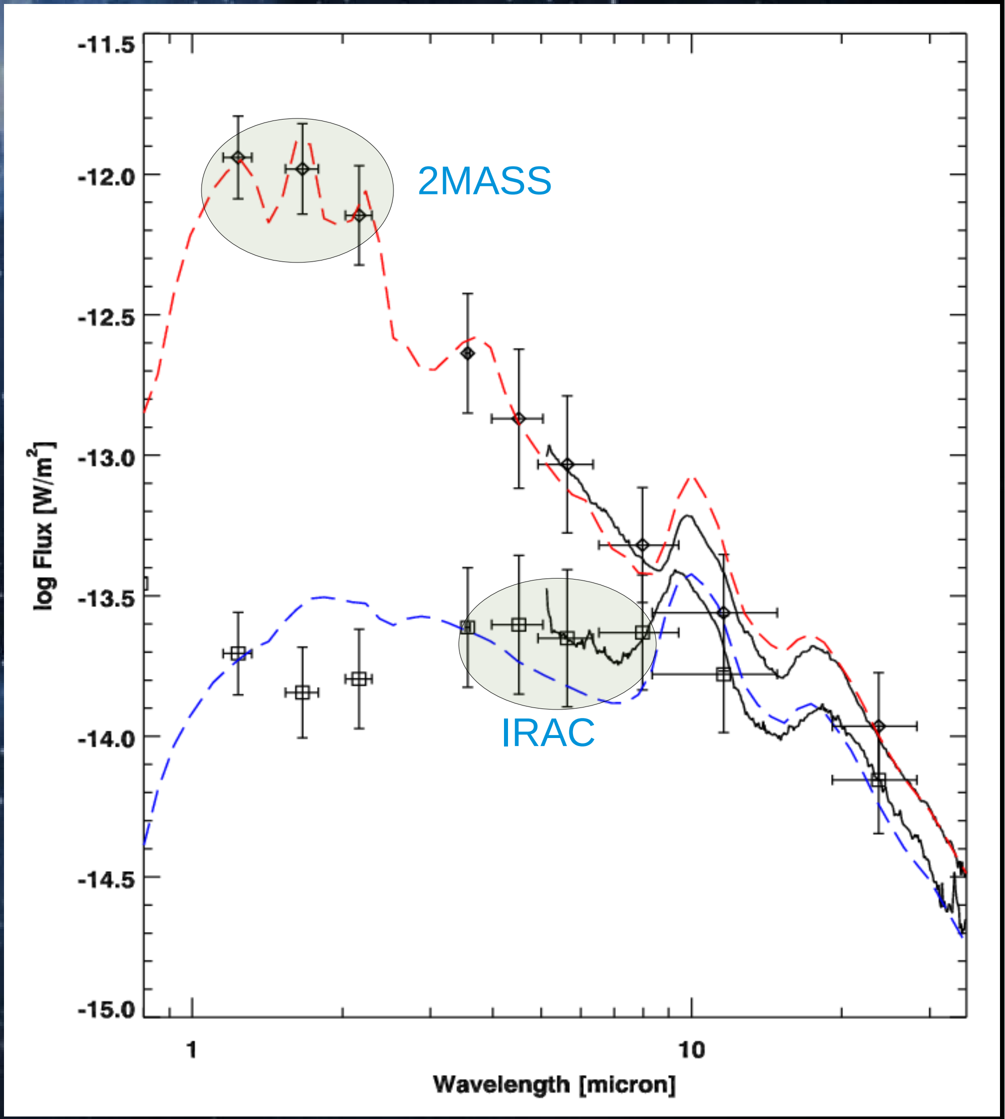
Dust-MLR = 10^{-13} - 10^{-5} $M_\odot$ yr^{-1}

Luminosity = 10^3 - 10^6 $L_\odot$

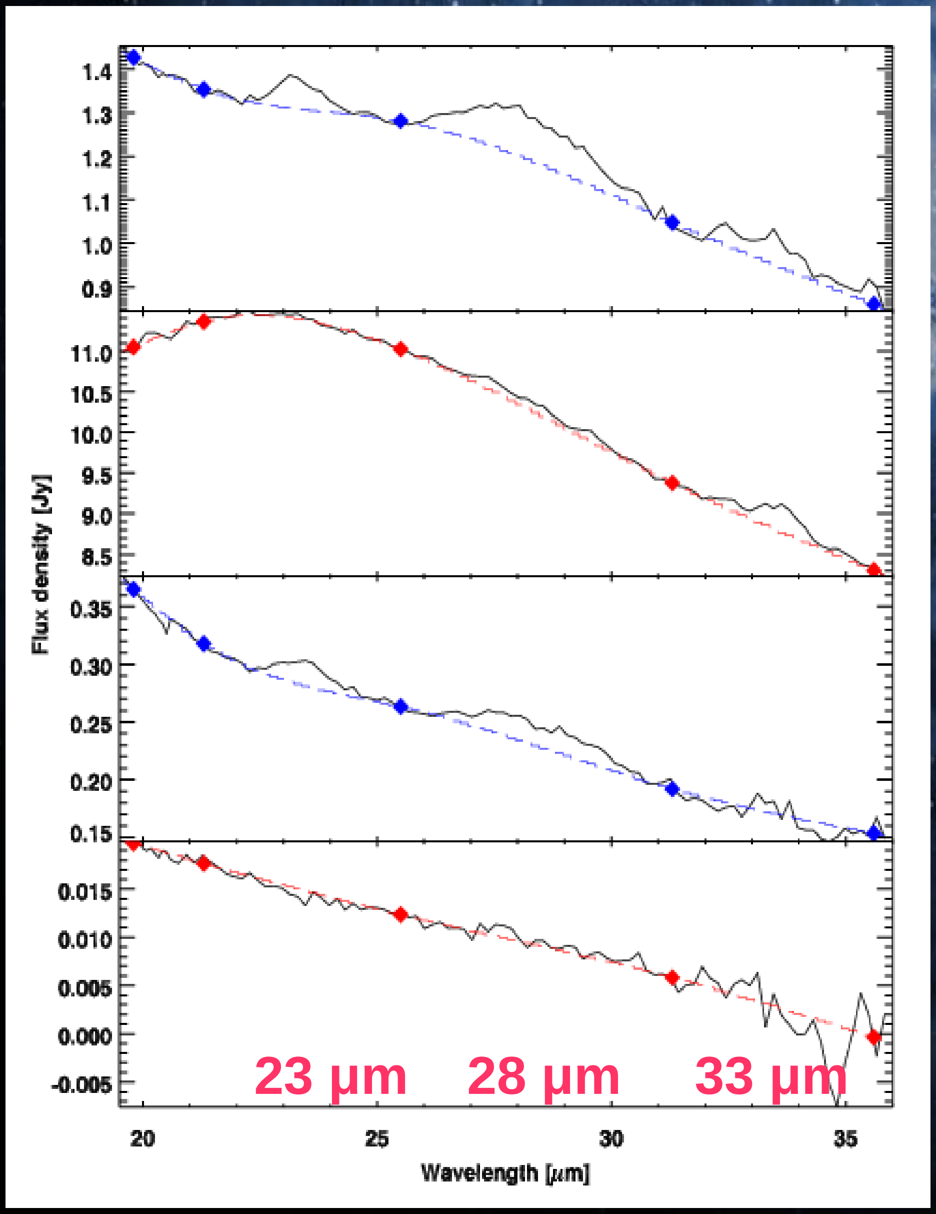
Sargent et al. 2011

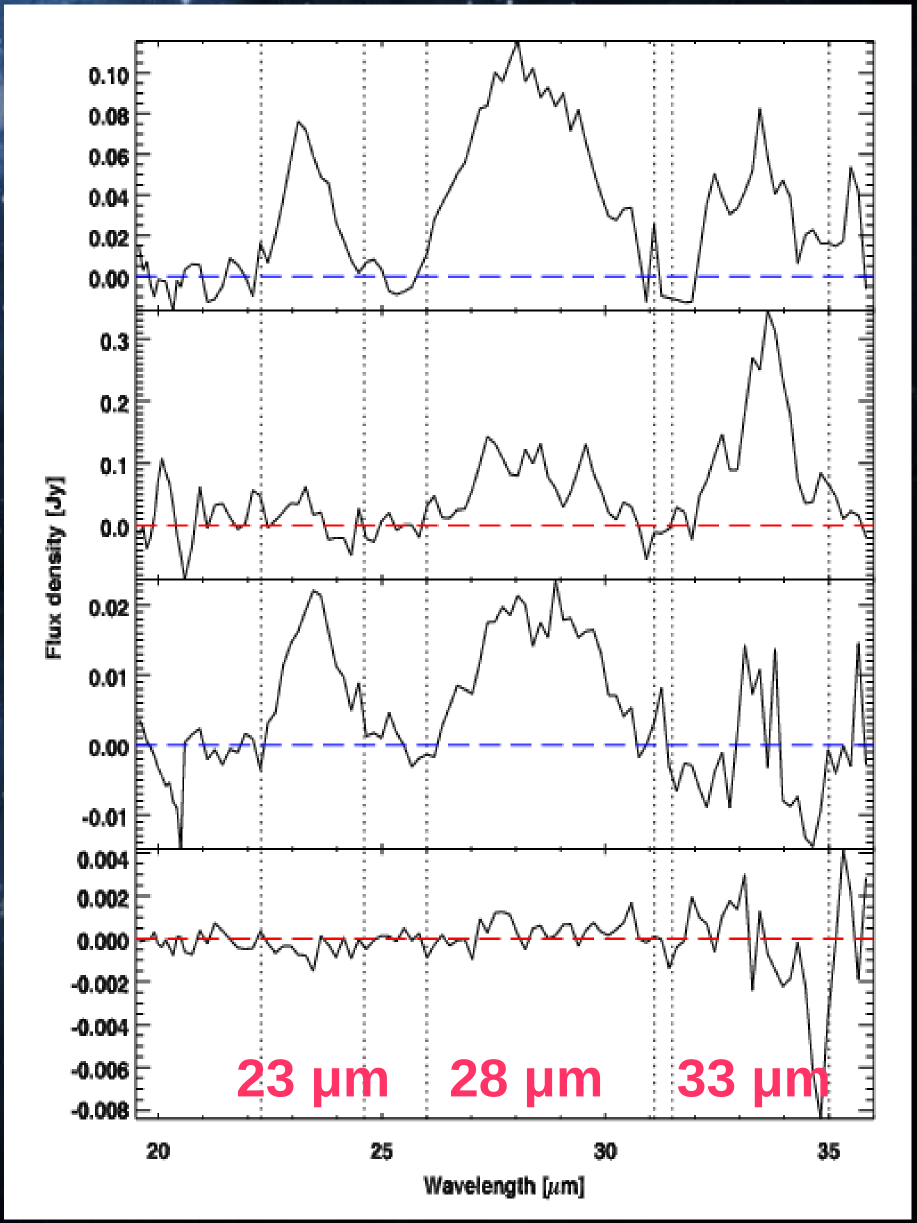
GRAMS models: dust mass-loss rate



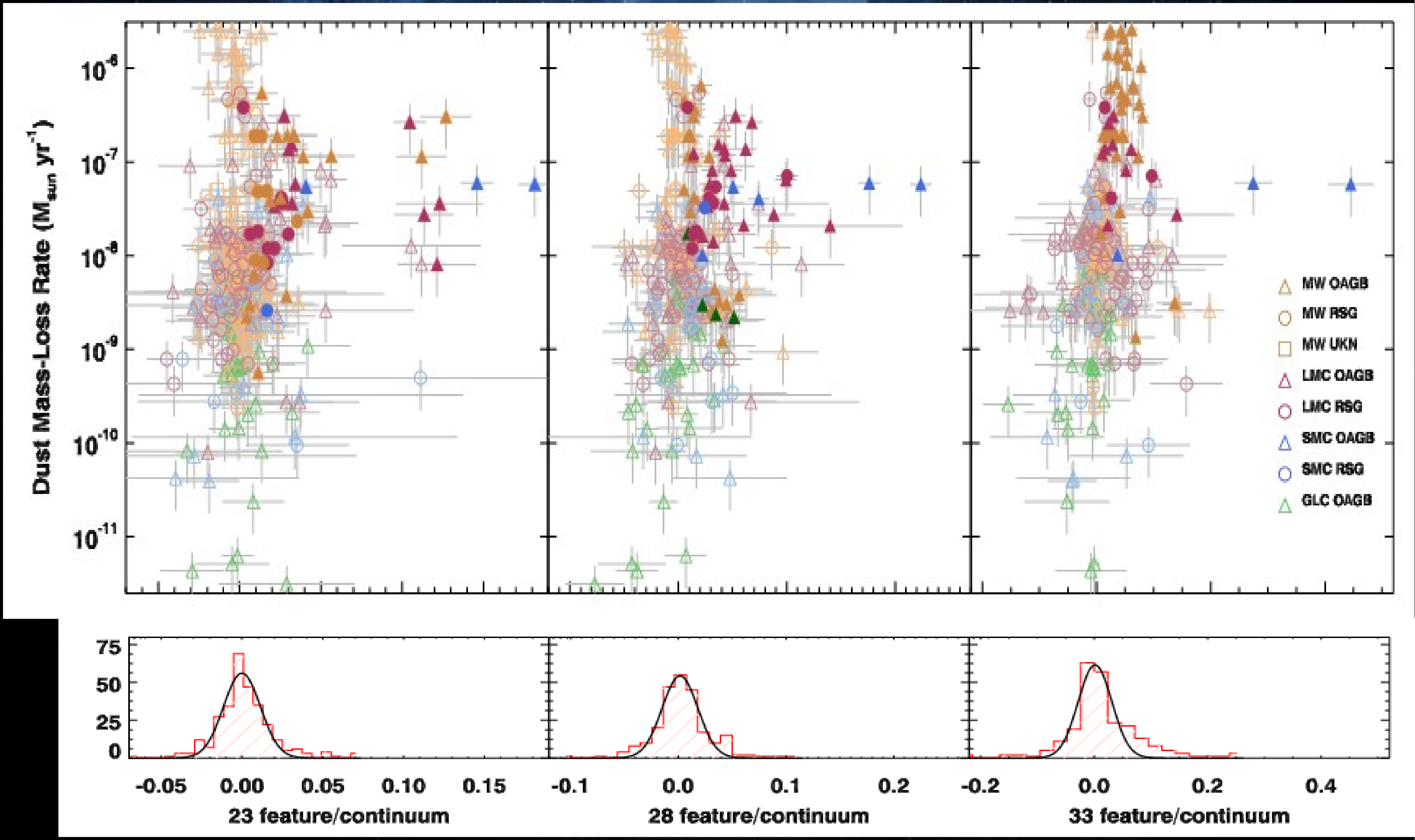


Crystalline Silicate Feature Strength



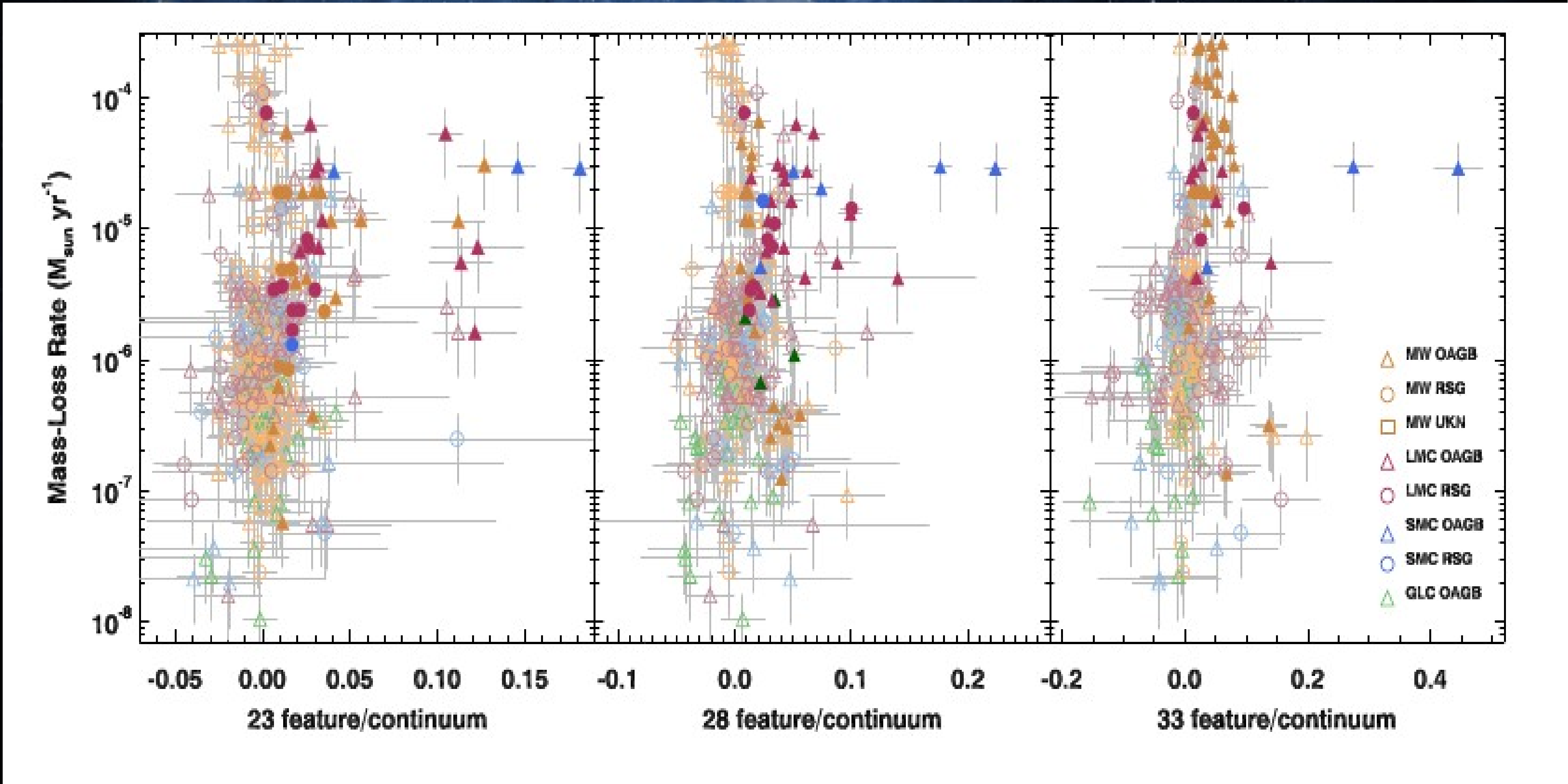


Dust Mass-Loss rate vs Feature Strength



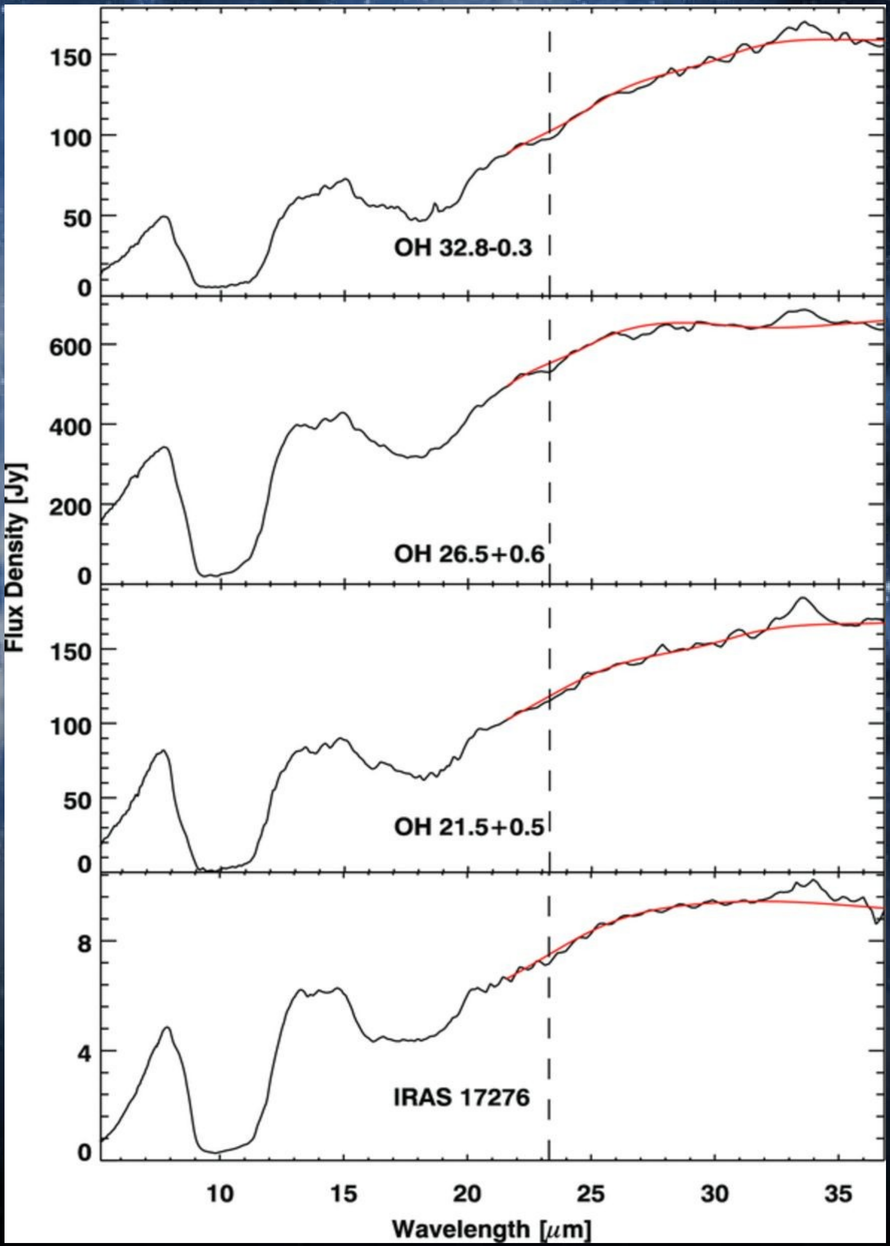
Jones et al. 2012

Total Mass-Loss rate vs Feature Strength



Jones et al. 2012

Crystalline silicate absorption features



Does the crystalline fraction depend on the gas density or the dust column density?

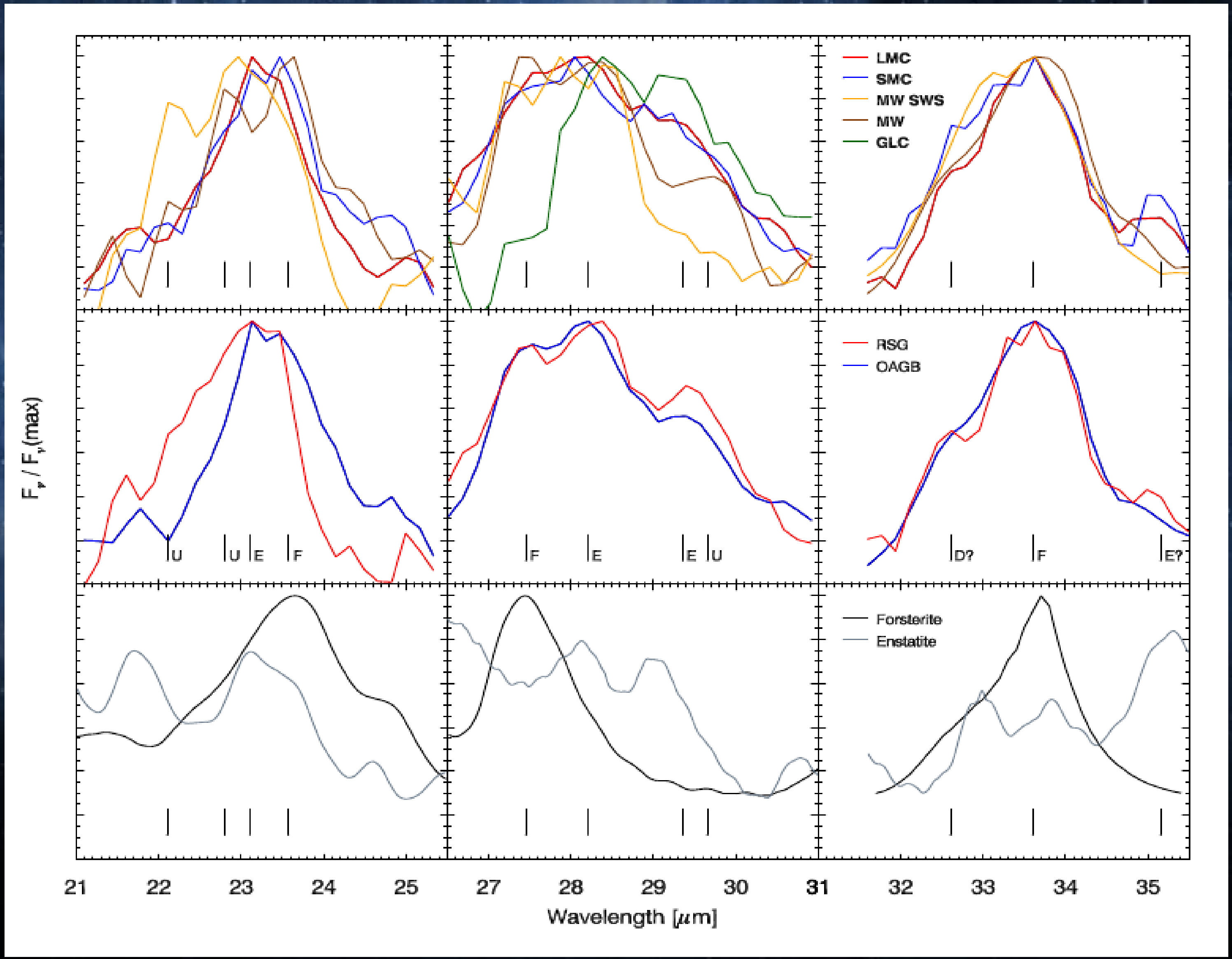
Crystalline silicates detected across 3 dex MLRs.

Crystalline silicates are more prevalent in higher mass-loss rate objects.

The dust mass-loss rate appears to have a greater influence on the crystalline fraction.

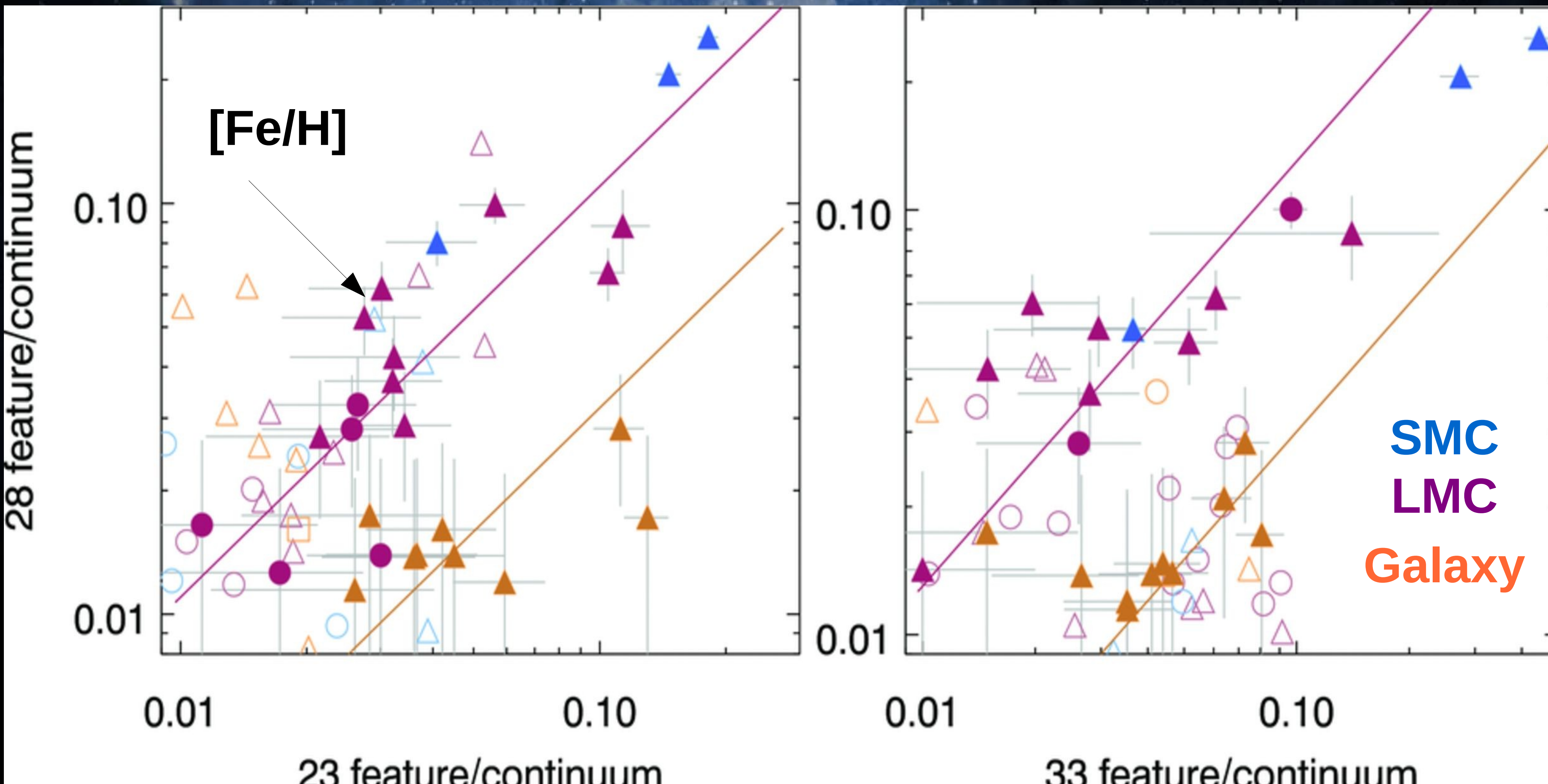
Does Crystalline Silicate dust production vary with metallicity?

Does Crystalline Silicate dust production vary with metallicity?



Forsterite **Enstatite** **Forsterite**

Does Crystalline Silicate dust production vary with metallicity?



Jones et al. 2012

Does Crystalline Silicate dust production vary with metallicity?

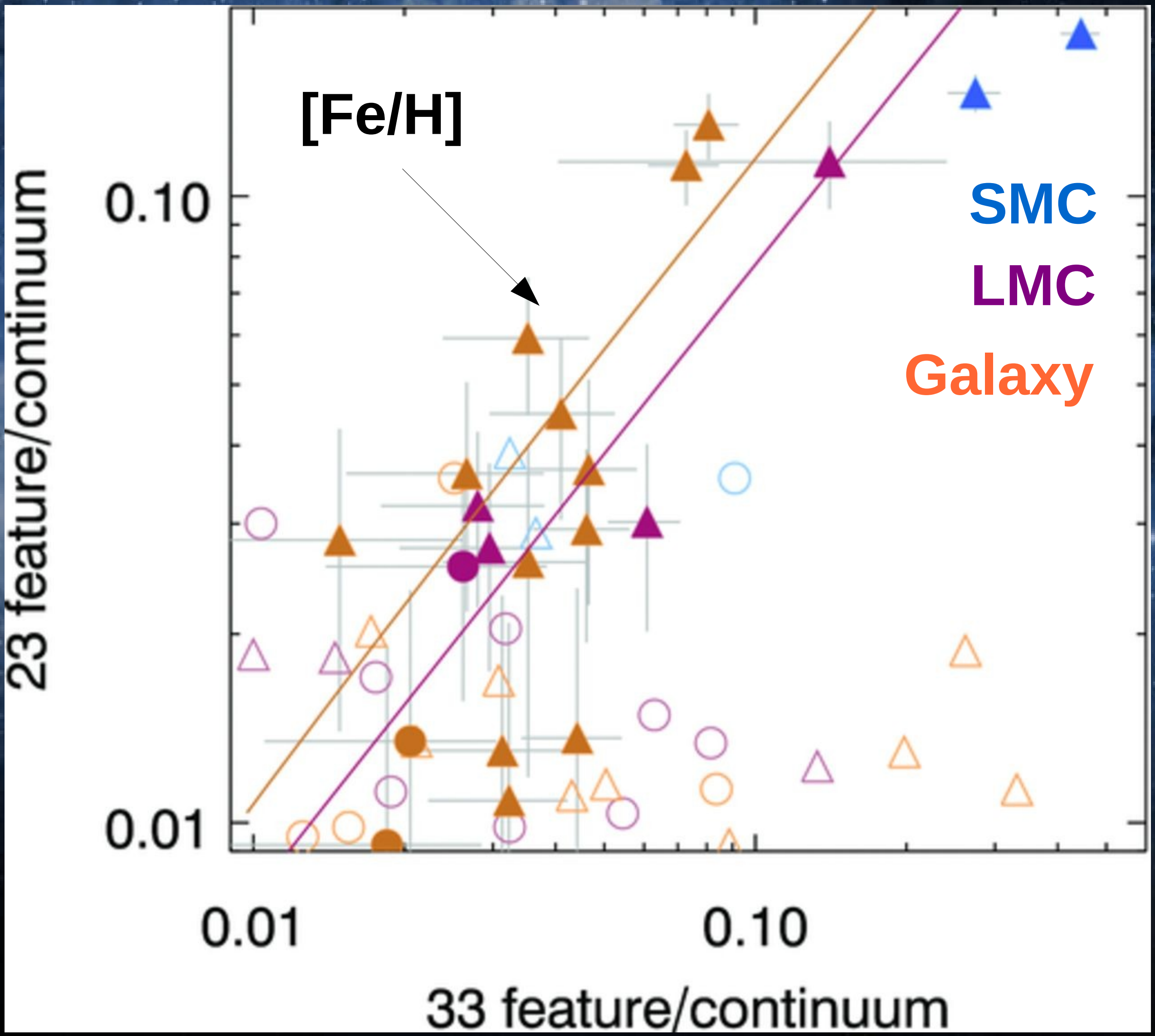
Oxygen-poor crystalline silicates may be more common at low metallicity.

Enstatite ($MgSiO_3$) is seen increasingly at low metallicity, while forsterite (Mg_2SiO_4) becomes depleted.

Maybe a different condensation sequence operates at low metallicity?

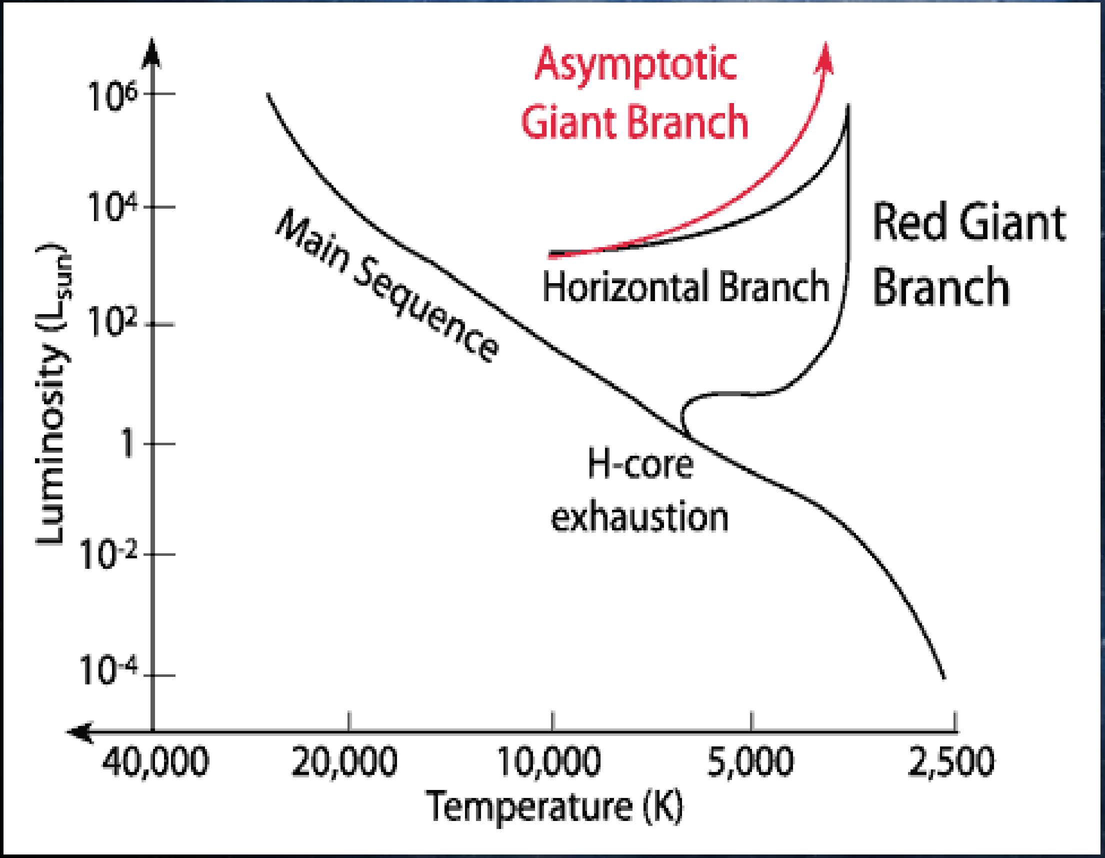
Thanks
& Questions?

Does Crystalline Silicate dust production vary with metallicity?



Jones et al. 2012

Background: AGB Stars

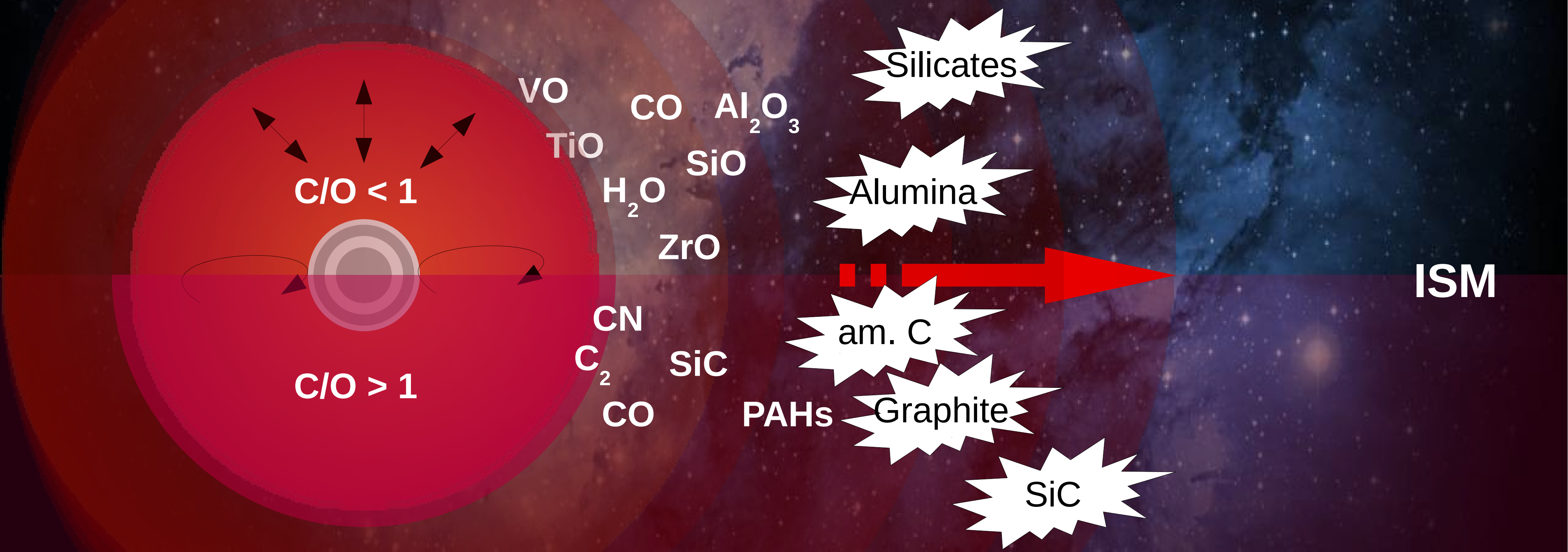


AGB stars: evolved low to intermediate mass stars ($1 \leq M \leq 8\ M_{\odot}$)

Bright populations in the infrared

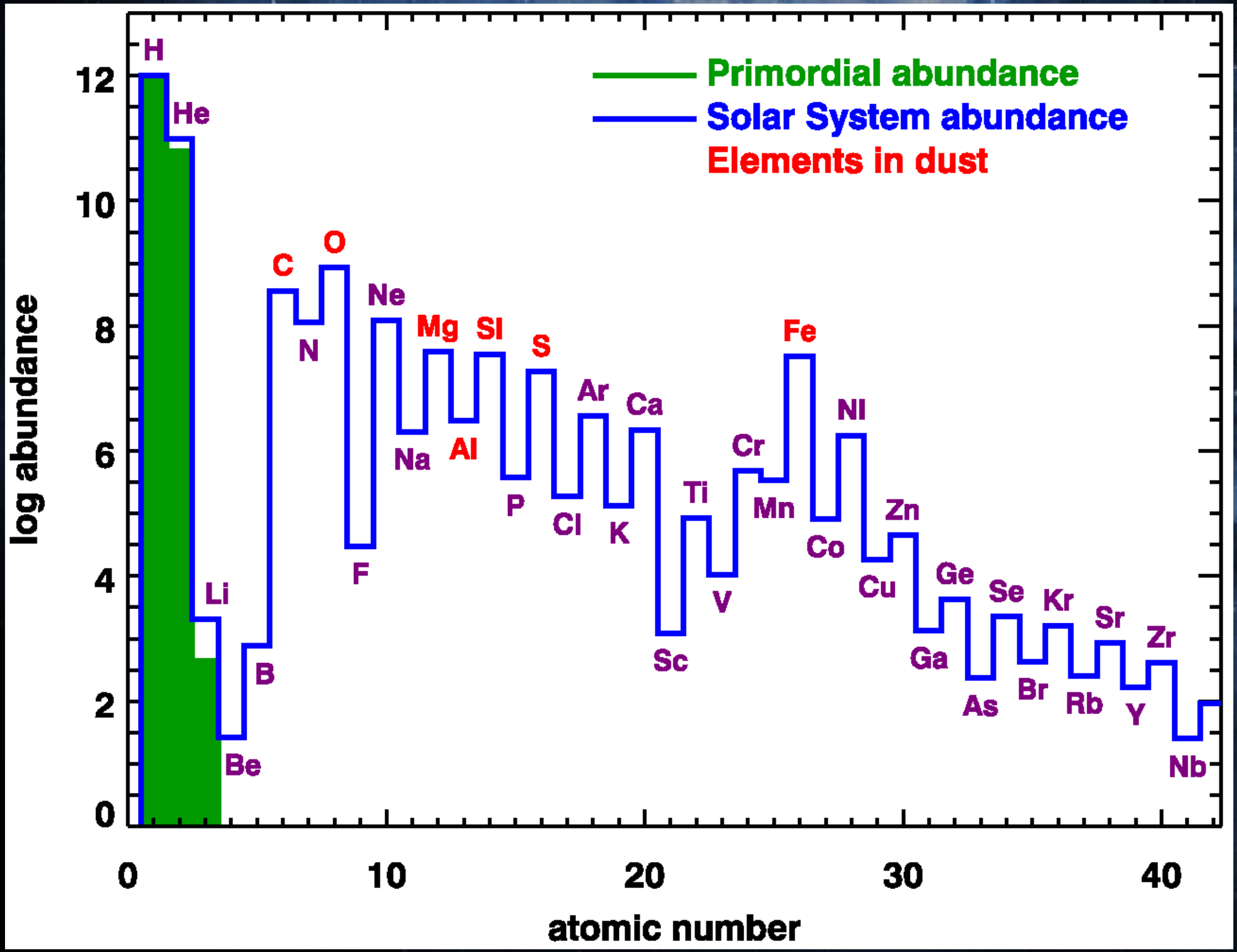
High mass loss rates: up to $10^{-4}\ M_{\odot}$ / yr

Dust production in AGB stars



Molecules condense into dust grains
T ~ 1000 K

Why do we care dust production in evolved stars?



Sources of Milky Way dust:

O-rich AGB stars: 67%

C-rich AGB stars: 20%

Red supergiants: 8%

Gehrz (1989)

Image courtesy of Greg Sloan