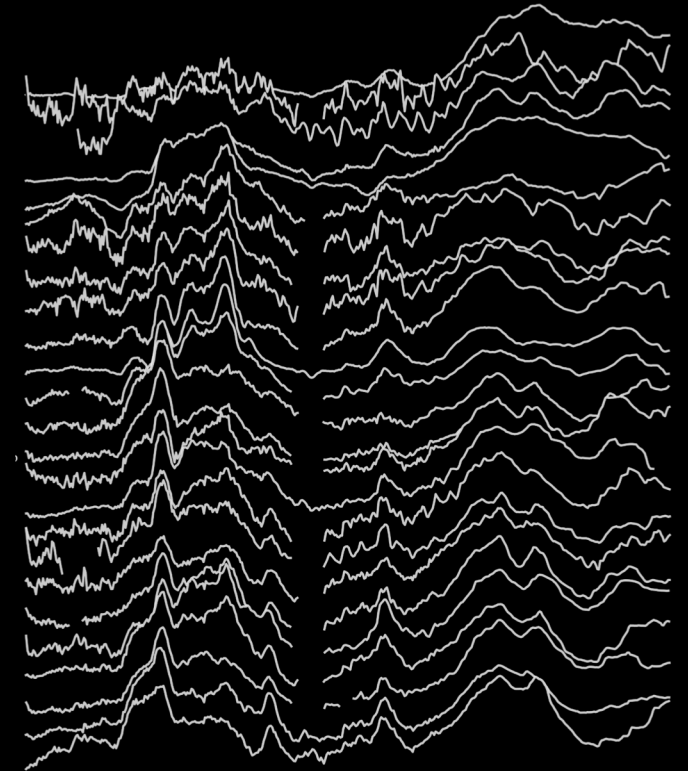


MINDS survey of silicates in T Tauri disks

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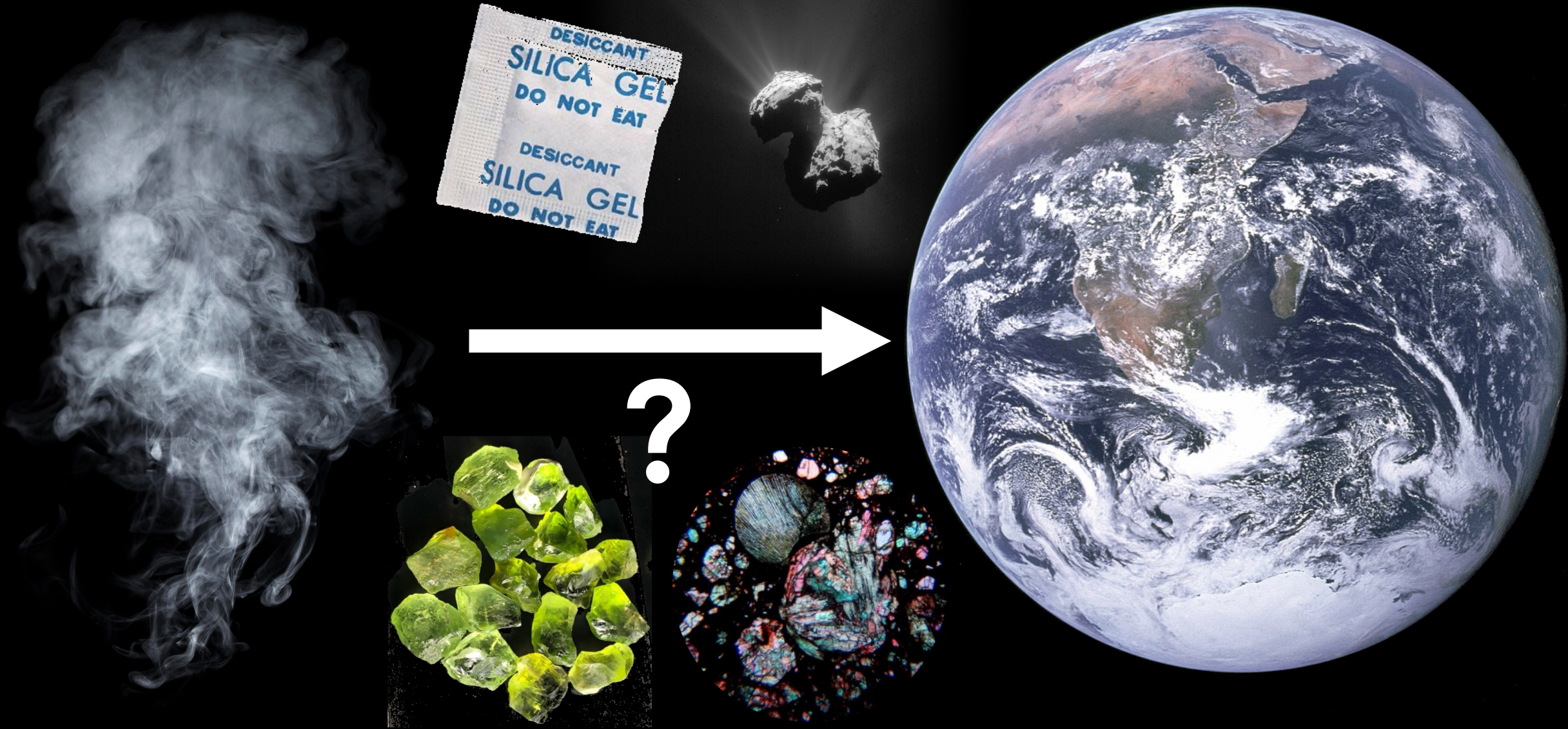
Thomas Henning, Rens Waters, Inga Kamp, Ágnes Kóspál,
Péter Ábrahám, Hyerin Jang, Sierra Grant, Giulia Perotti,
and the MINDS team



Perspectives of Planet and Star Formation
MPIA Heidelberg, Germany
24 Jun 2026

Why study dust in YSOs?

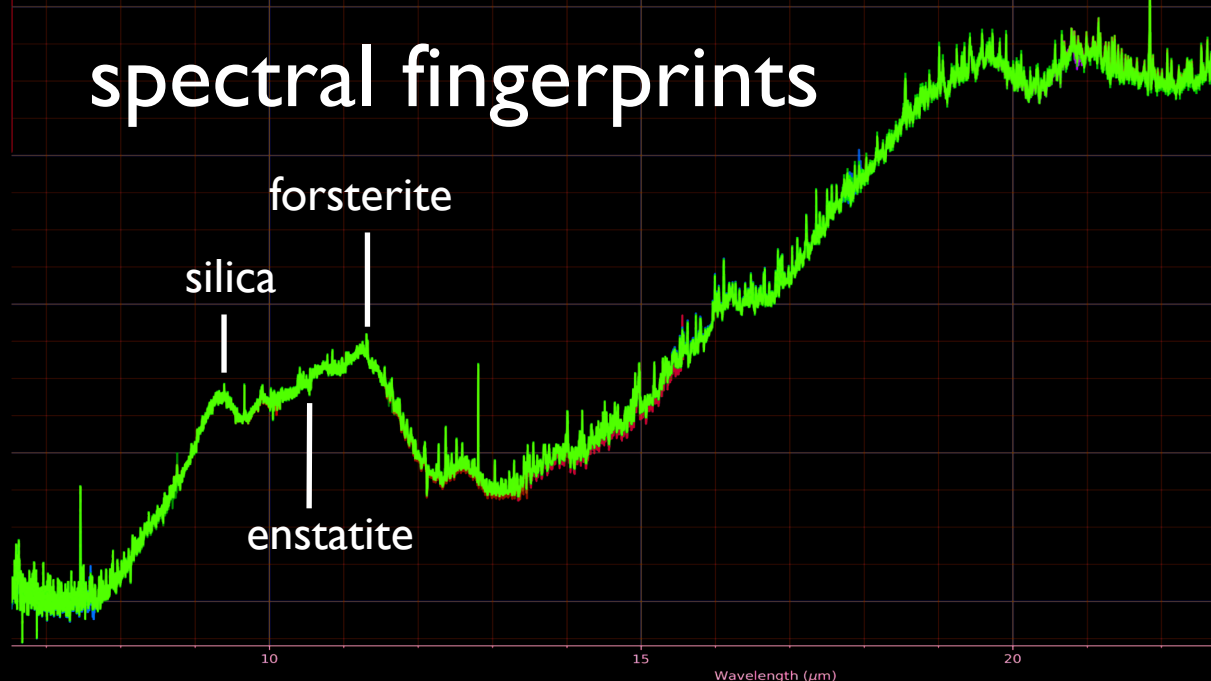
2



Circumstellar dust

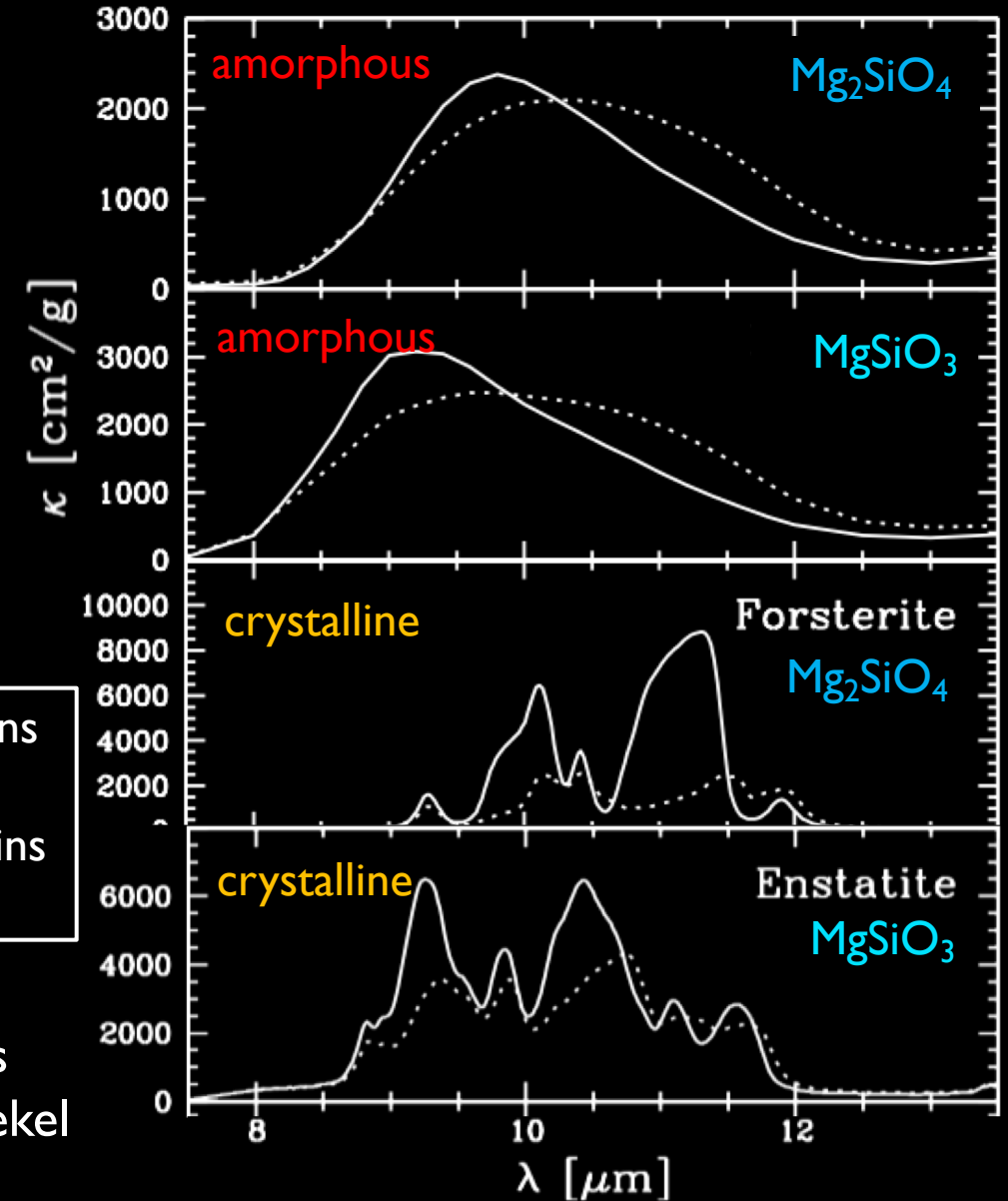
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- composed mainly of:
 - Mg-rich silicates and silica
 - carbon, iron
- micron-sized silicates: detectable in mid-IR
- different minerals have their own spectral fingerprints



— small grains
(0.1 μm)
..... large grains
(1.5 μm)

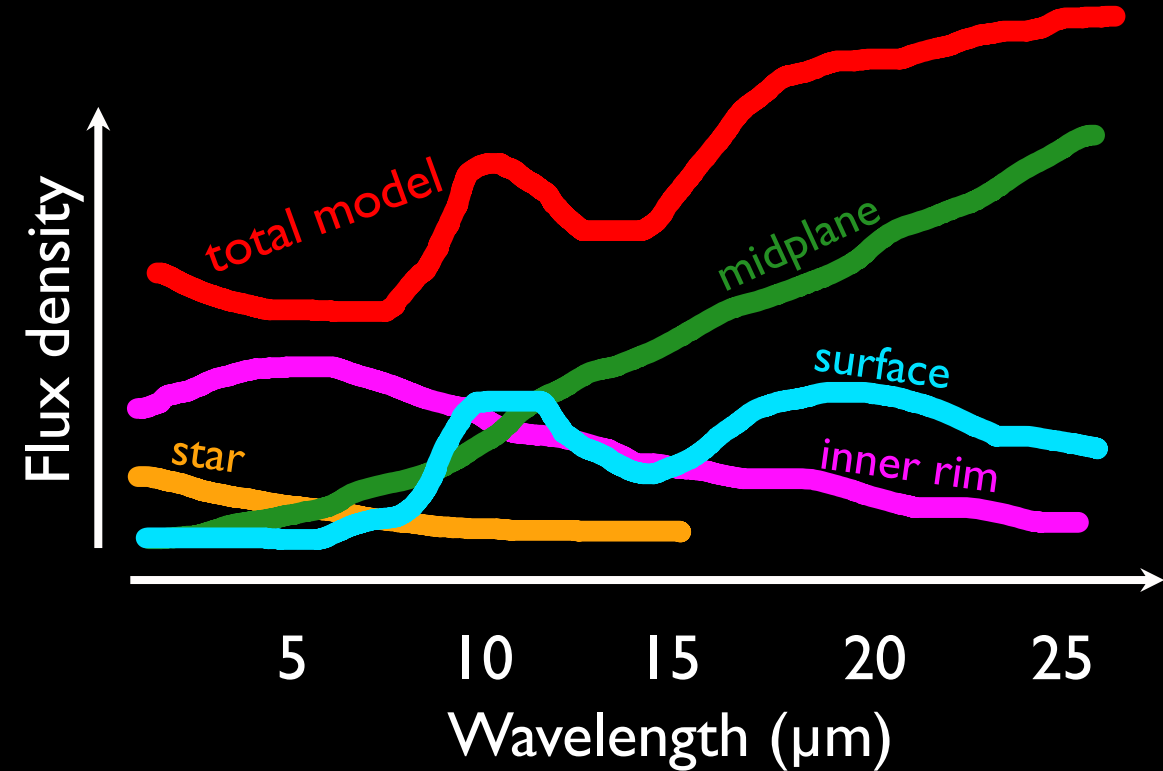
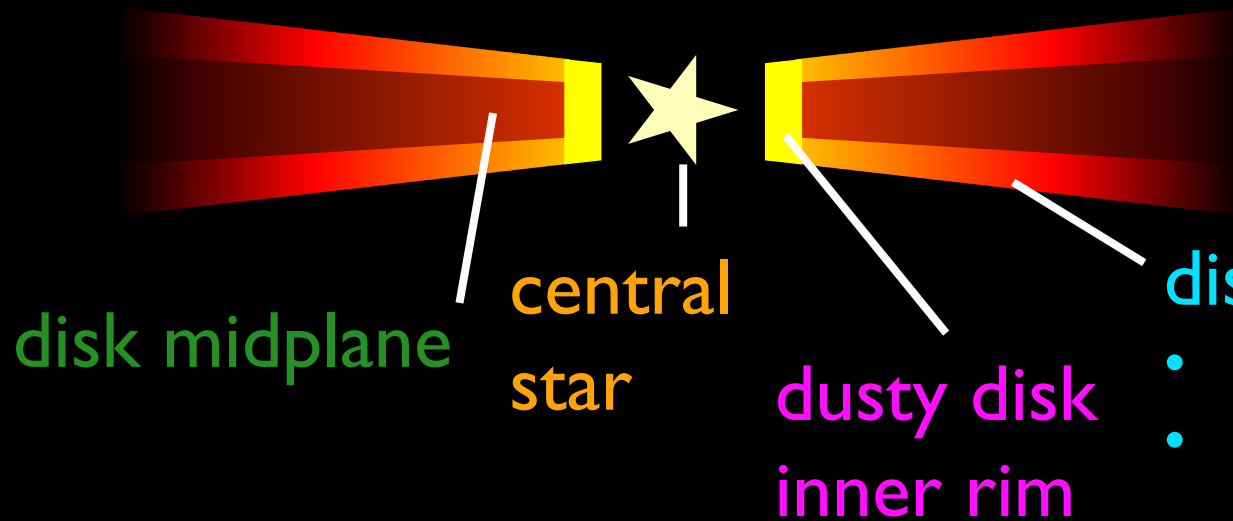
silicate
opacities
(van Boekel
+2005)



- aims:
 - constrain dust composition in a statistically meaningful sample
 - less common minerals?
 - gas – dust connection?
- 26 targets
- SpT range M0 – G5
- T_{eff} range 3300 – 5700 K
- L_* range 0.16 – 5.7 $L_{\odot}$

Object	SpT	d (pc)	T_{eff} (K)	L_* ($L_{\odot}$)
CX Tau	M1.5	126.7	3487	0.34
CY Tau	M1.5	124.3	3516	0.37
BP Tau	K5/7	128.2	3777	0.83
FT Tau	M2.8	129.9	3415	0.44
DF Tau	M3	176.4	3900	3.89
DL Tau	K7	159.5	4276	1.47
DM Tau	M2	144.8	3715	0.16
AA Tau	K5	137.7	3762	0.72
DN Tau	M1:	127.2	3806	0.69
LkCa 15	K5	154.8	4276	1.12
DR Tau	K5	186.9	4202	3.71
RW Aur A	K0 ^a	150.0	4870	0.83
RW Aur B	K6.5 ^a	150.0	4160	0.50
SY Cha	K5	180.7	4060	0.43
TW Hya	K6	59.9	4000	0.34
VW Cha A	K7	188.1	4060	2.21
WX Cha A	M1	189.3	3710	1.13
XX Cha	M3	194.6	3340	0.29
Sz 50	M3	148.9	3400	0.41
PDS 70	K7	112.3	4138	0.38
GW Lup	M1.5	155.2	3632	0.33
IM Lup	M0	153.8	4350	2.57
Sz 98	M0.4	156.2	4060	1.51
V1094 Sco	K6/K5	152.4	4205	1.15
RNO 90	G5	114.9	5662	5.7
WA Oph 6	K6	122.5	4169	2.88

- new tool: DustComp
 - blackbody components
 - single temperature or radial temperature gradient
 - fit opacity templates with linear least squares (optically thin)



disk surface

- include dust opacities
- caveat: materials with featureless opacity curves cannot be inferred (e.g., carbon, iron)

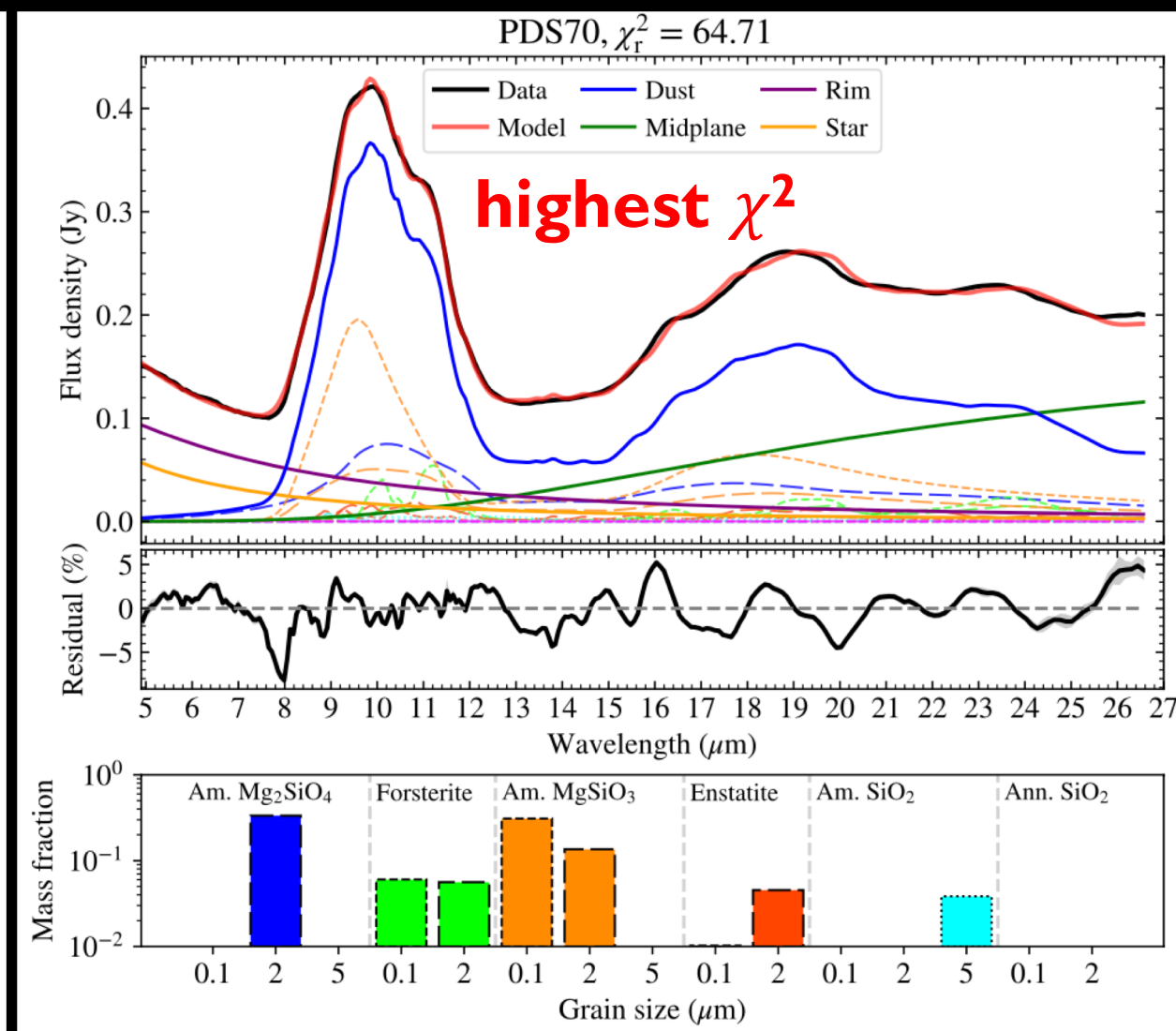
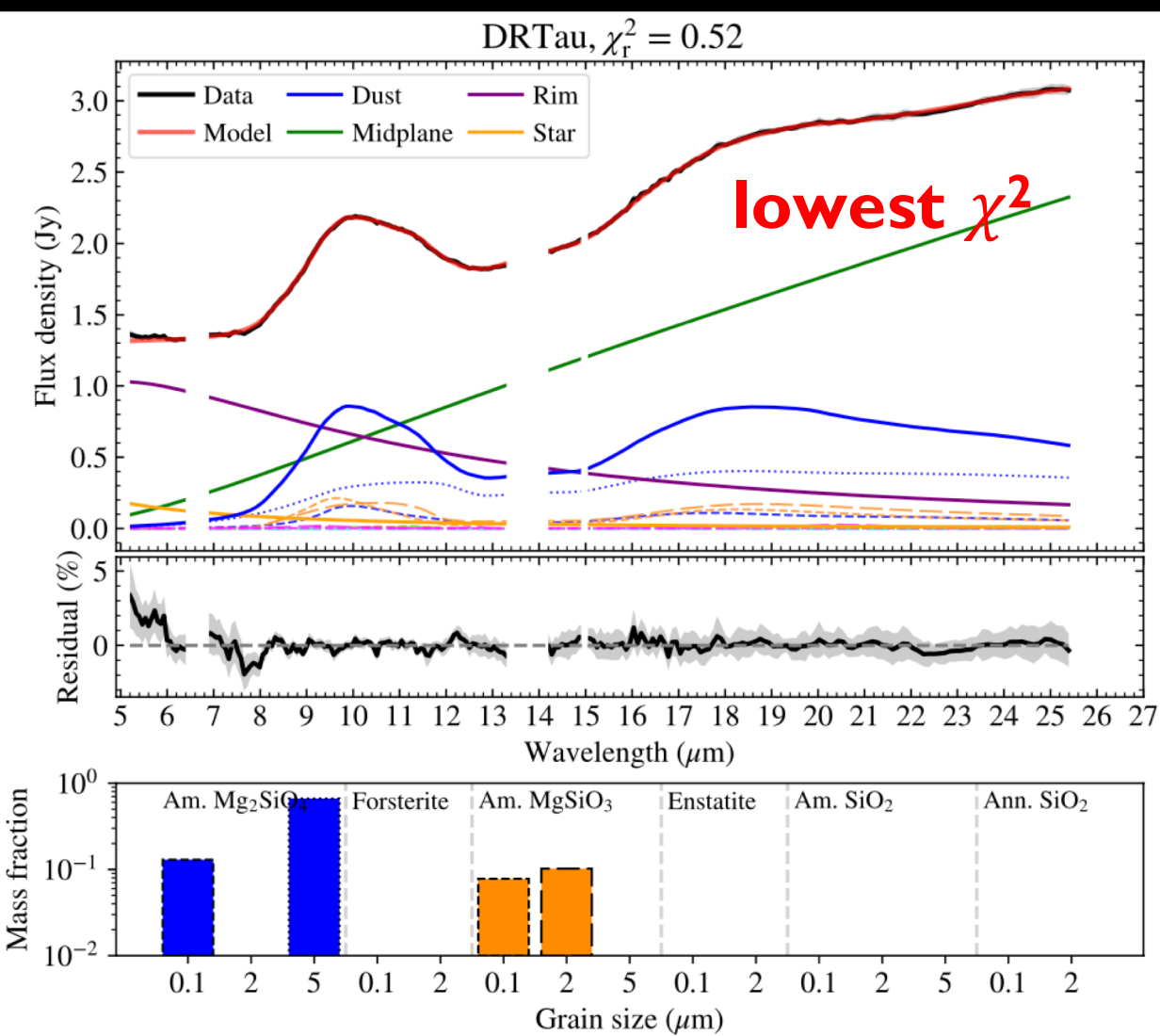
Stoichiometry	Amorphous species	Crystalline species
Mg_2SiO_4	amorphous Mg-silicate	forsterite
MgSiO_3	amorphous Mg-silicate	enstatite
SiO_2	amorphous silica	annealed silica

Opacity sets	Grain shape model	Note on optical data
DHS_nat	distribution of hollow spheres (DHS)	natural and synthetic materials

Grain sizes (μm)	Note
[0.1, 2, 5 am.]	5 μm -size for am. only

Modeling results: example fits

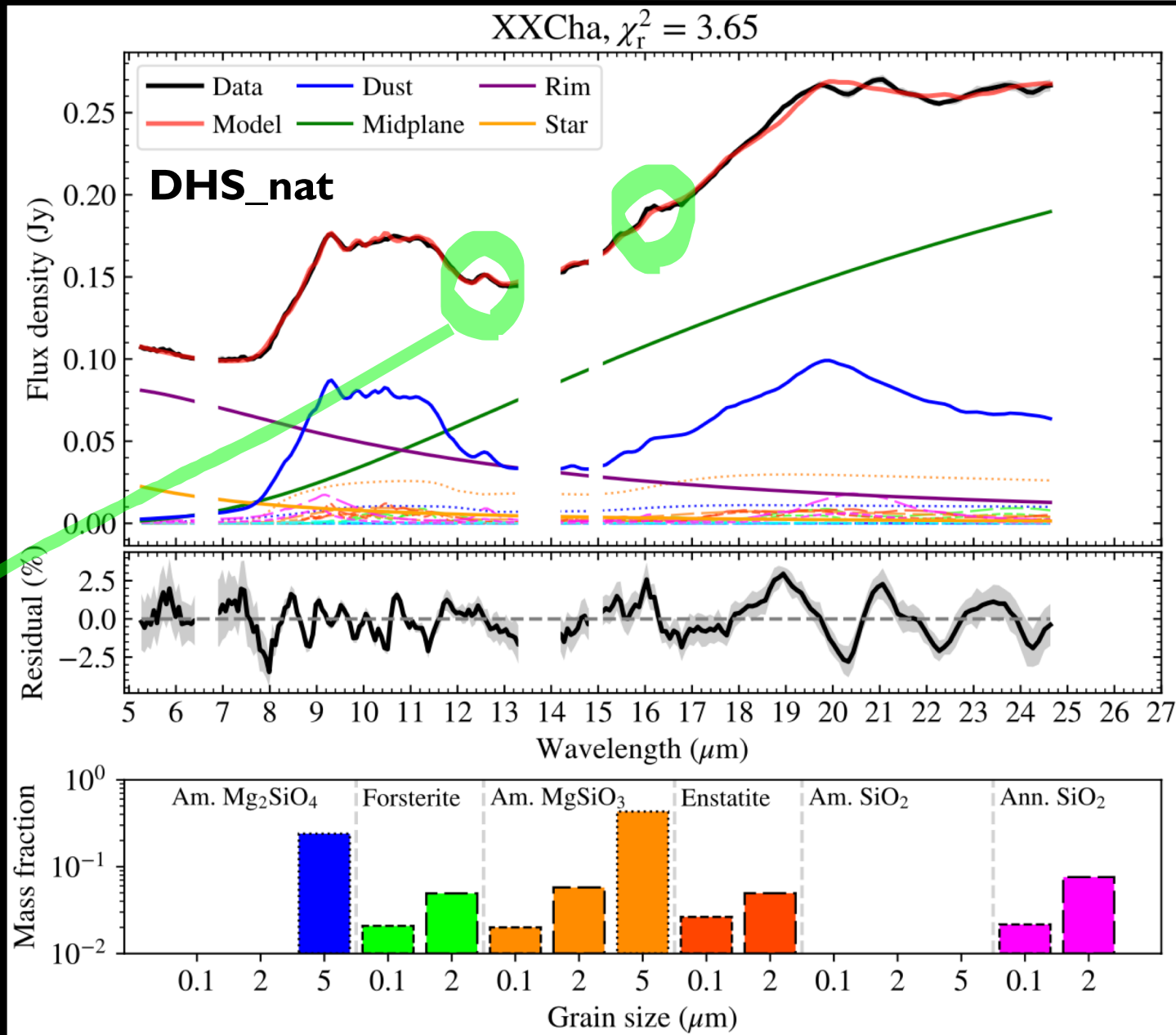
8



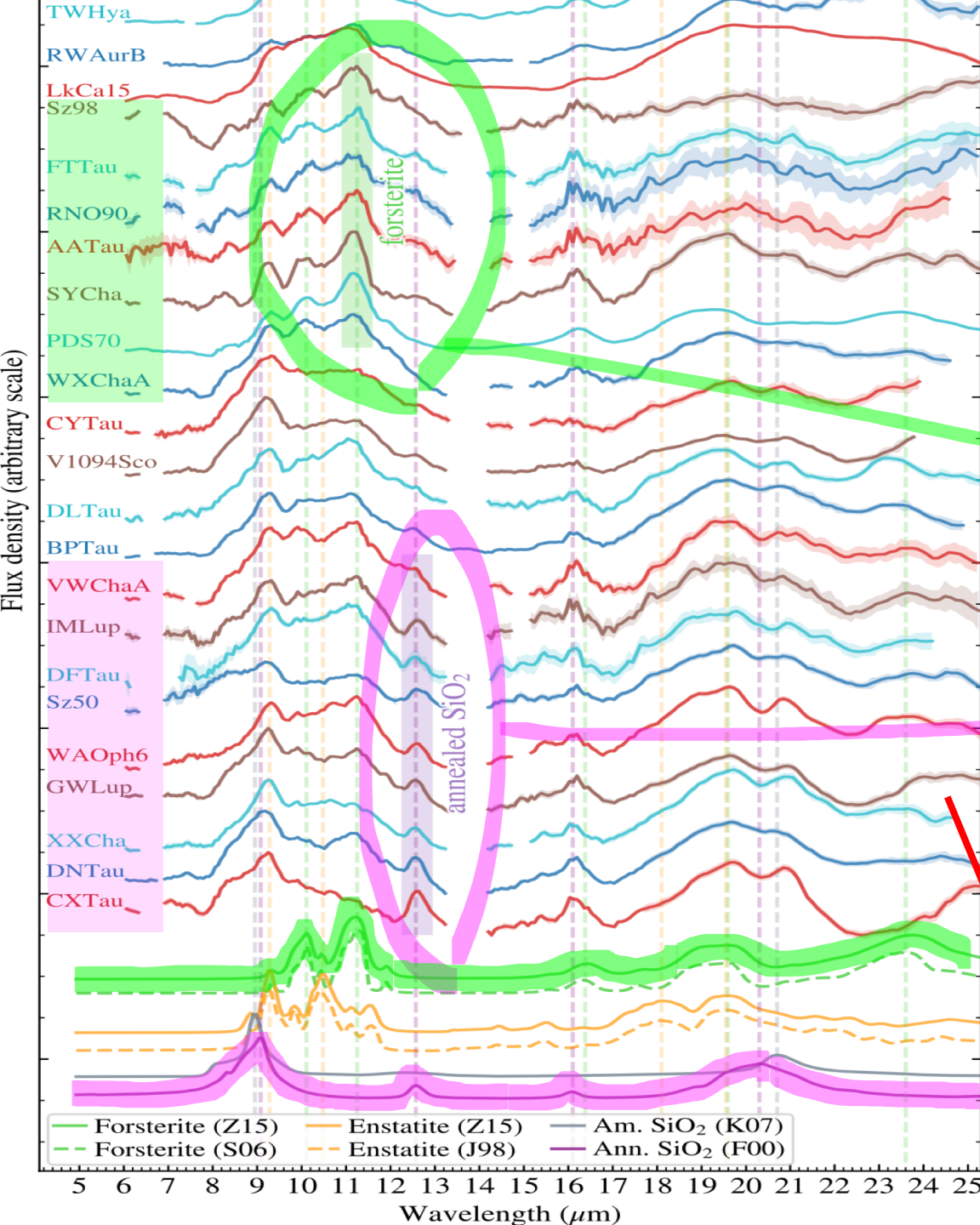
Modeling results: example fit

9

- Residuals usually within 3%
- 3 grain sizes are enough
 - 0.1, 2, 5 μm
 - large, 5 μm -sized amorphous grains are needed
- minor features at 12.6 and 16.1 μm
 - annealed silica



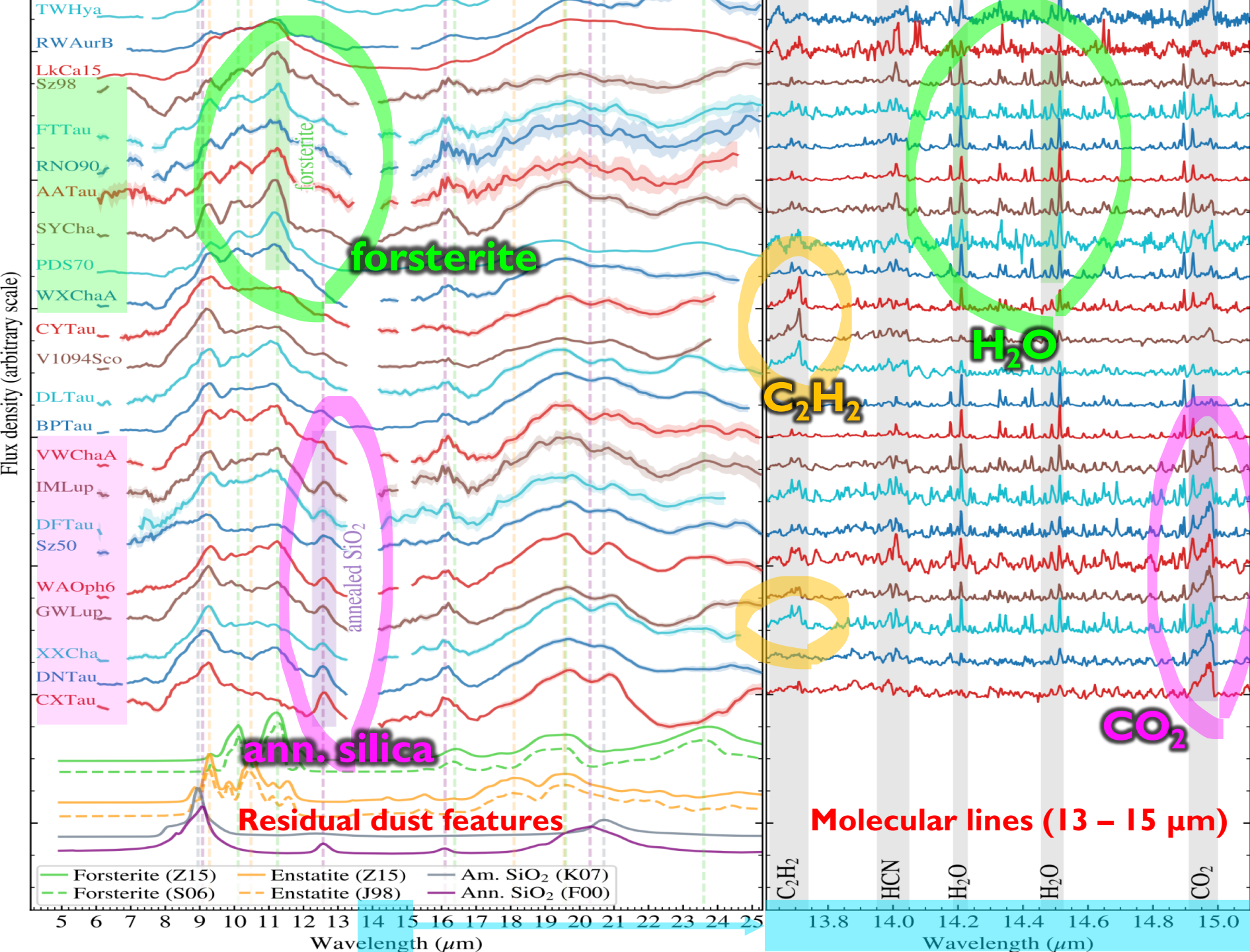
Residual dust features



forsterite

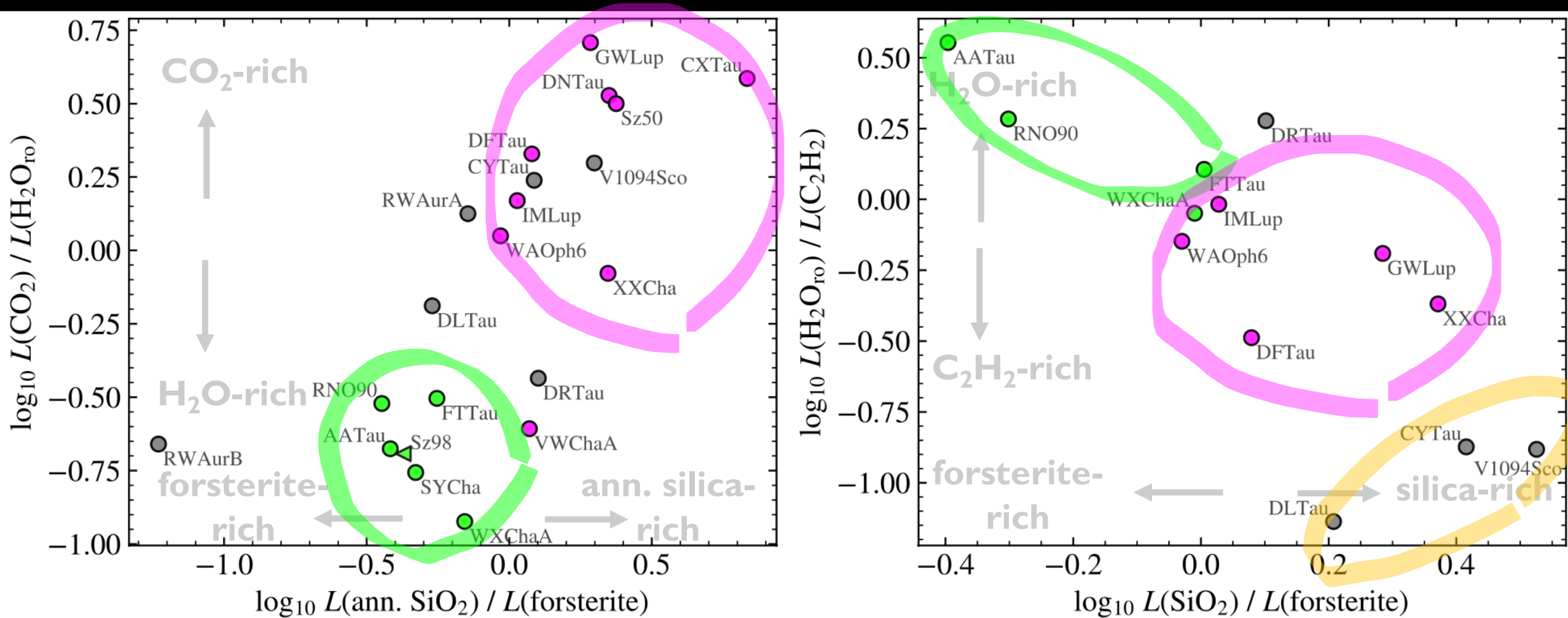
annealed silica

Residual dust features (amorphous Mg-silicate and featureless components subtracted)



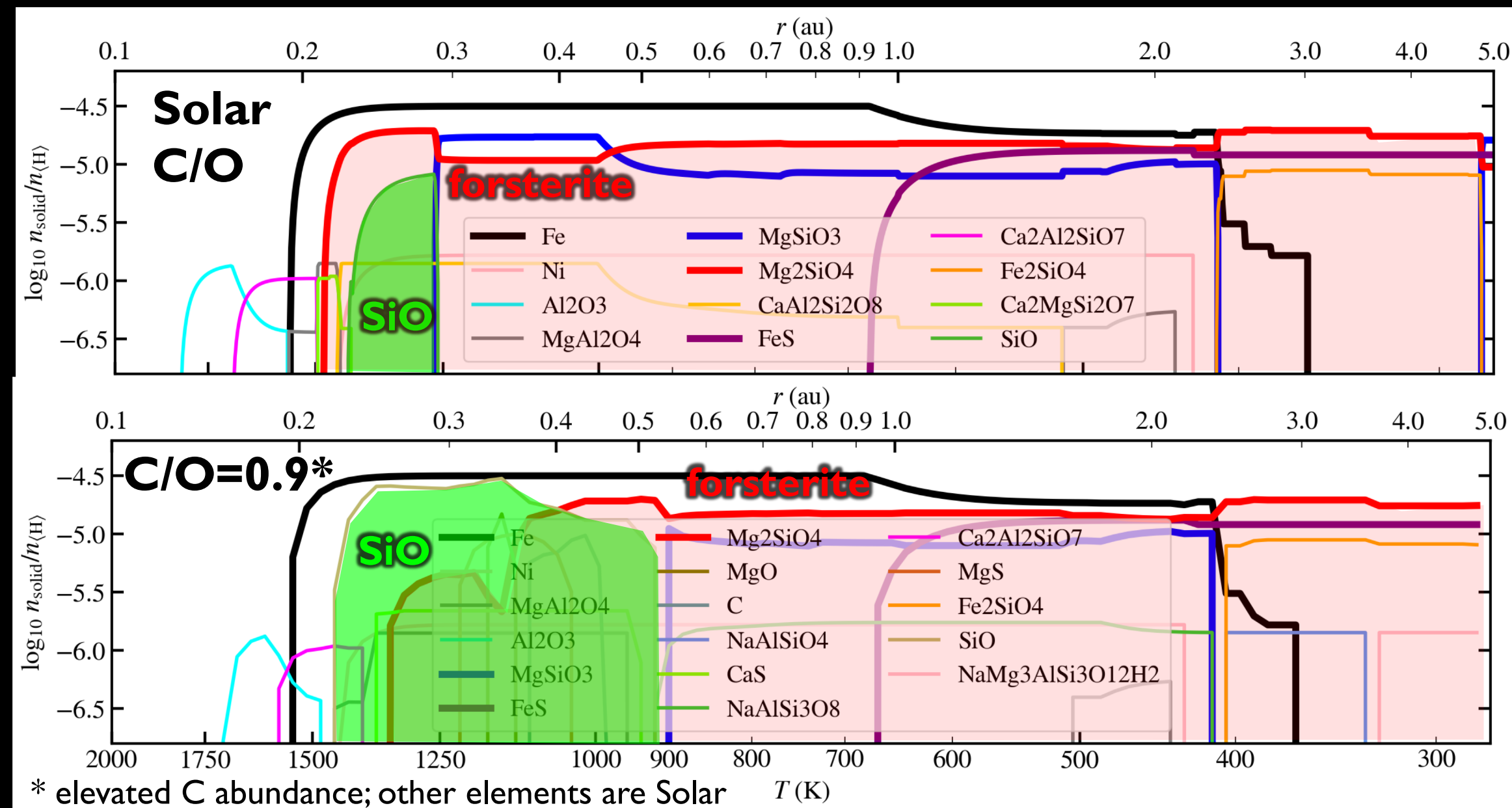
Correlation between dust and gas

12



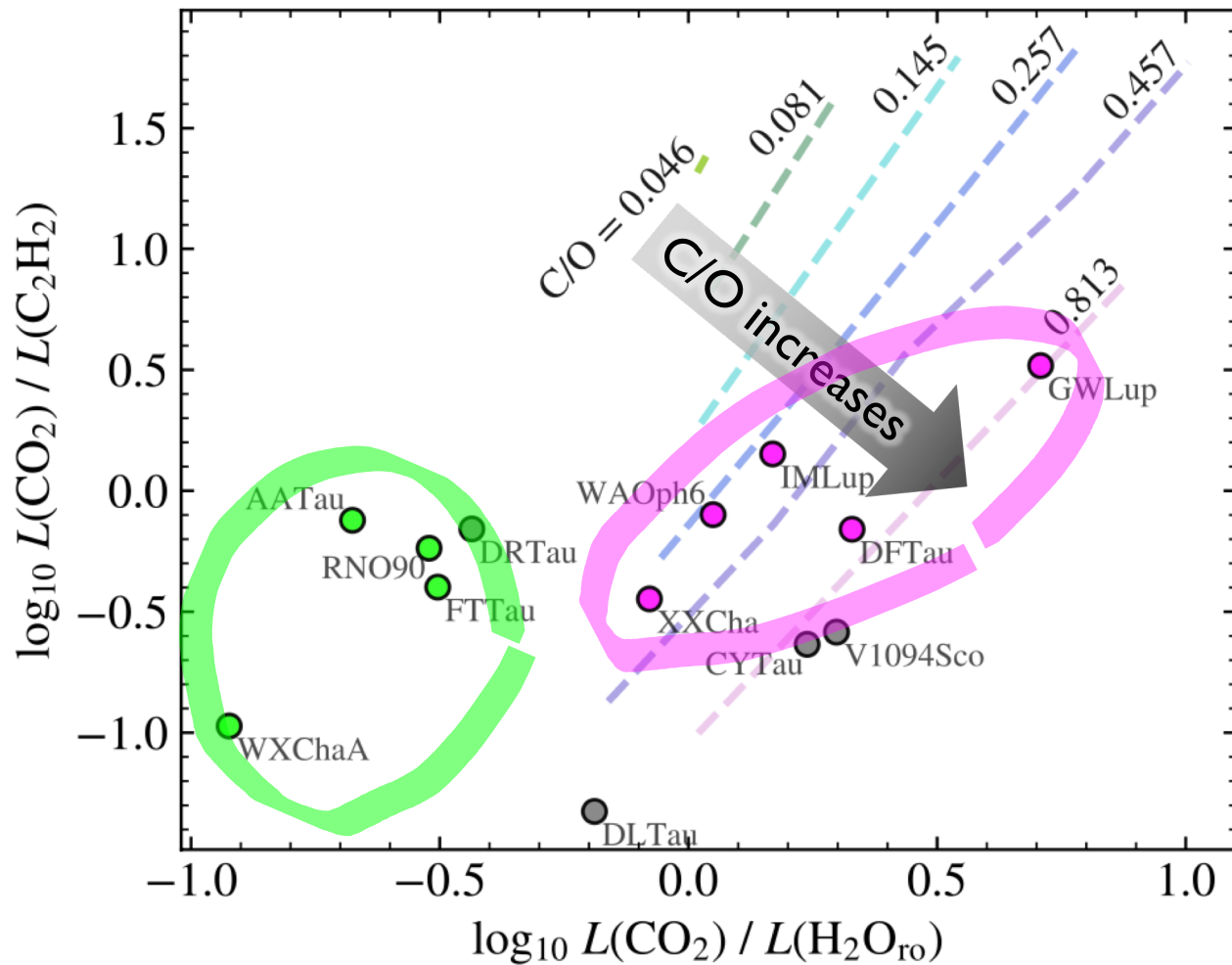
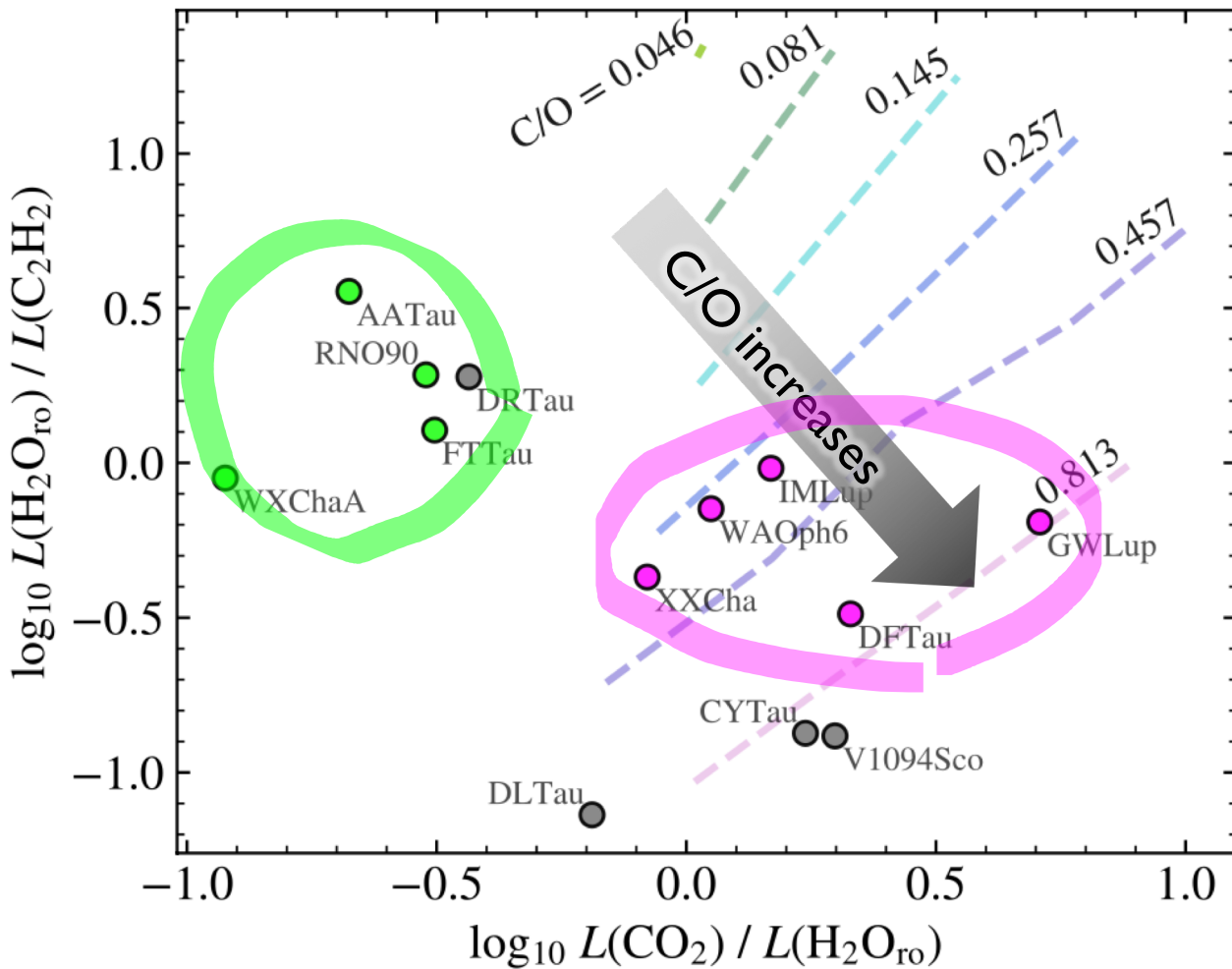
Solids in chemical equilibrium (GGchem)

13



C/O diagnostic plots (after Arabhavi+2026)

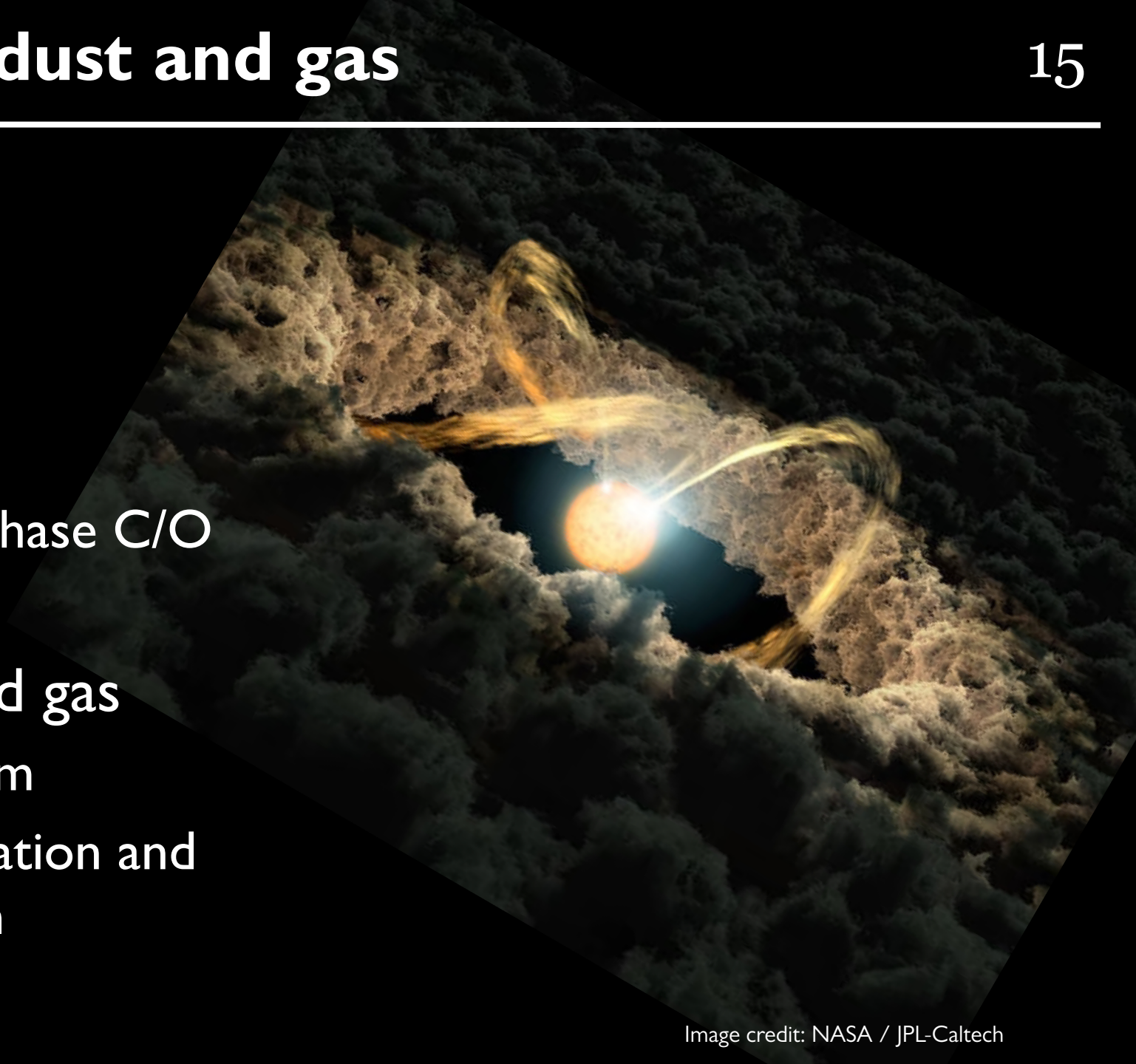
14



green: forsterite-rich group

purple: annealed silica-rich group

- Forsterite – H_2O
- Annealed silica – CO_2
- Silica-rich sources:
 - evidence for elevated gas-phase C/O
- coupling between dust and gas
 - thermo-chemical equilibrium
 - possible cause: dust sublimation and subsequent recondensation



- Dust
 - Mg-rich (Fe-poor) silicates
 - significant grain growth
 - evidence for (5 μm -size) large amorphous grains
 - evidence for annealed silica
- Correlation between dust and gas
 - forsterite – H_2O
 - annealed silica – CO_2 (& elevated C/O)
- Evidence for gas and dust approaching thermo-chemical equilibrium

