Probing silicates in disks around T Tauri stars with Spitzer IRS

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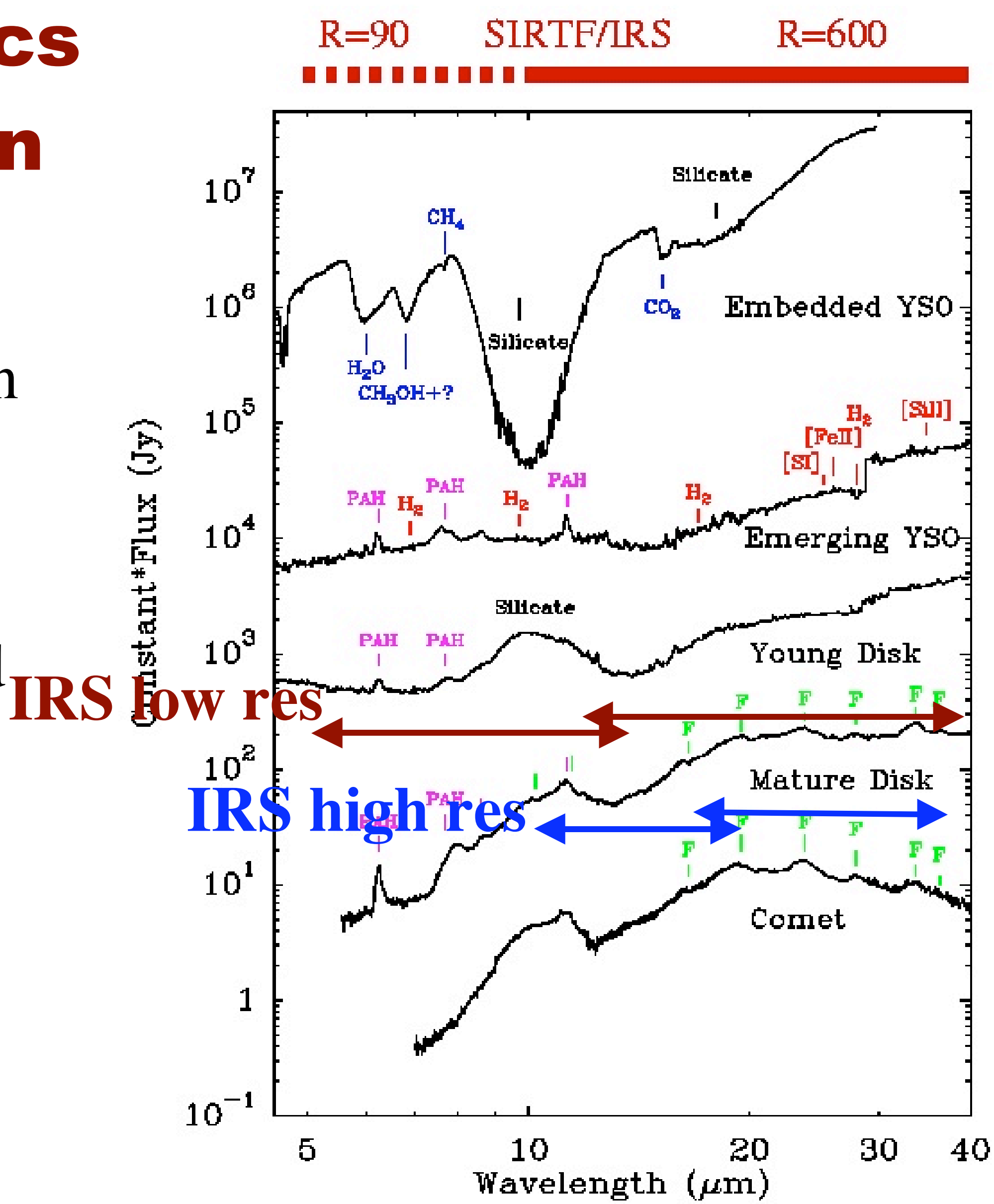
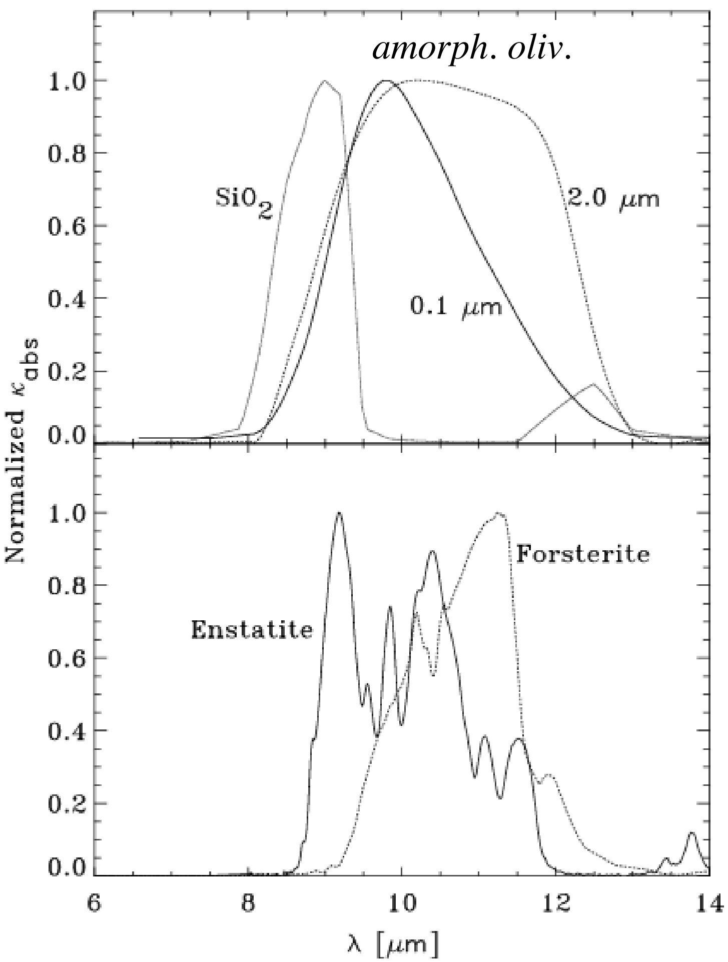
Spectral diagnostics of stellar evolution

- Inventory of dust and ice composition for comparison to comets, Kuiper belt objects, and asteroids
- Diagnostics of physical and chemical states of young circumstellar environments
- Dust coagulation and gas (H2) dissipation timescales



Silicate emission as a probe of dust size and composition

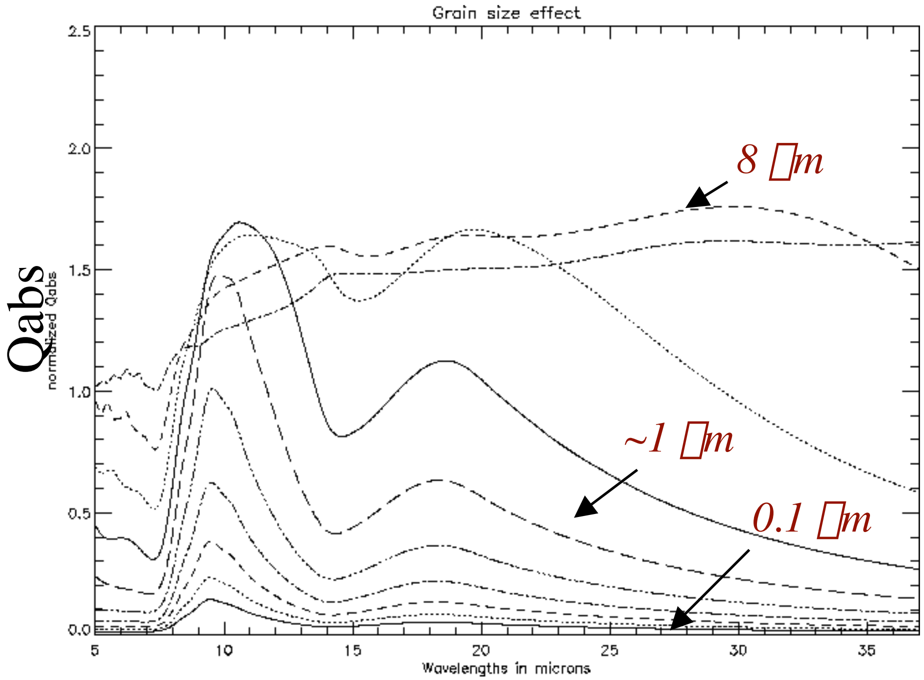


most previous IR spectra
of TTs are from ground-based
observations in the 10 μm window

- only warm grains are probed
- diagnostic features of crystalline silicates are blended with very broad amorphous olivine emission

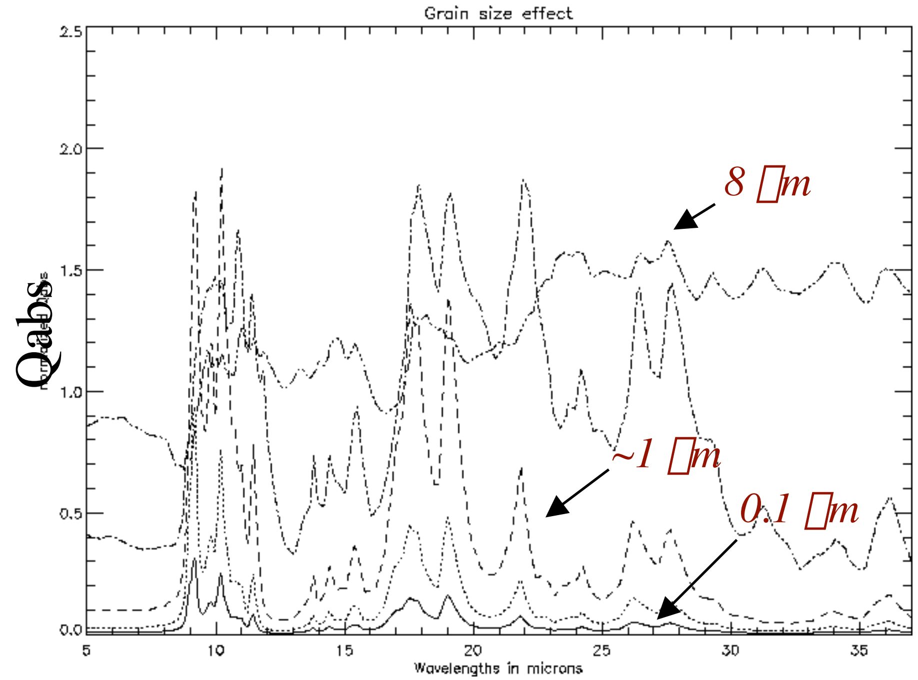
Silicate emission as a probe of dust size and composition

Amorphous olivine



Wavelength [μm]

Crystalline Enstatite



Wavelength [μm]

Science Goals

Trace silicate growth and compositional changes in TTs in order to:

- compare with HAEBE stars studied with ISO (Meeus 2001, van Boekel 2003, Acke 2005; grain sizes: 0.1-2um, ~1/4 HAEBE has crystalline silicates emission at 1.3um.)
- compare with ISO and ground-based observations of TTs (similar grain growth, very few sources with crystalline silicates)
- relate to stellar/disk properties and test theories of disk structure/evolution
- compare with comets and disks around more evolved stars

c2d IRS Observations

- First look: known embedded and PMS stars
  - $M < 2M_{sun}$, ages < 5Myr
  - observed with IRS staring mode in SL, SH, LH (except GTO overlap)
  - S/N: ~ 100 SL, >50-100 SH, LH

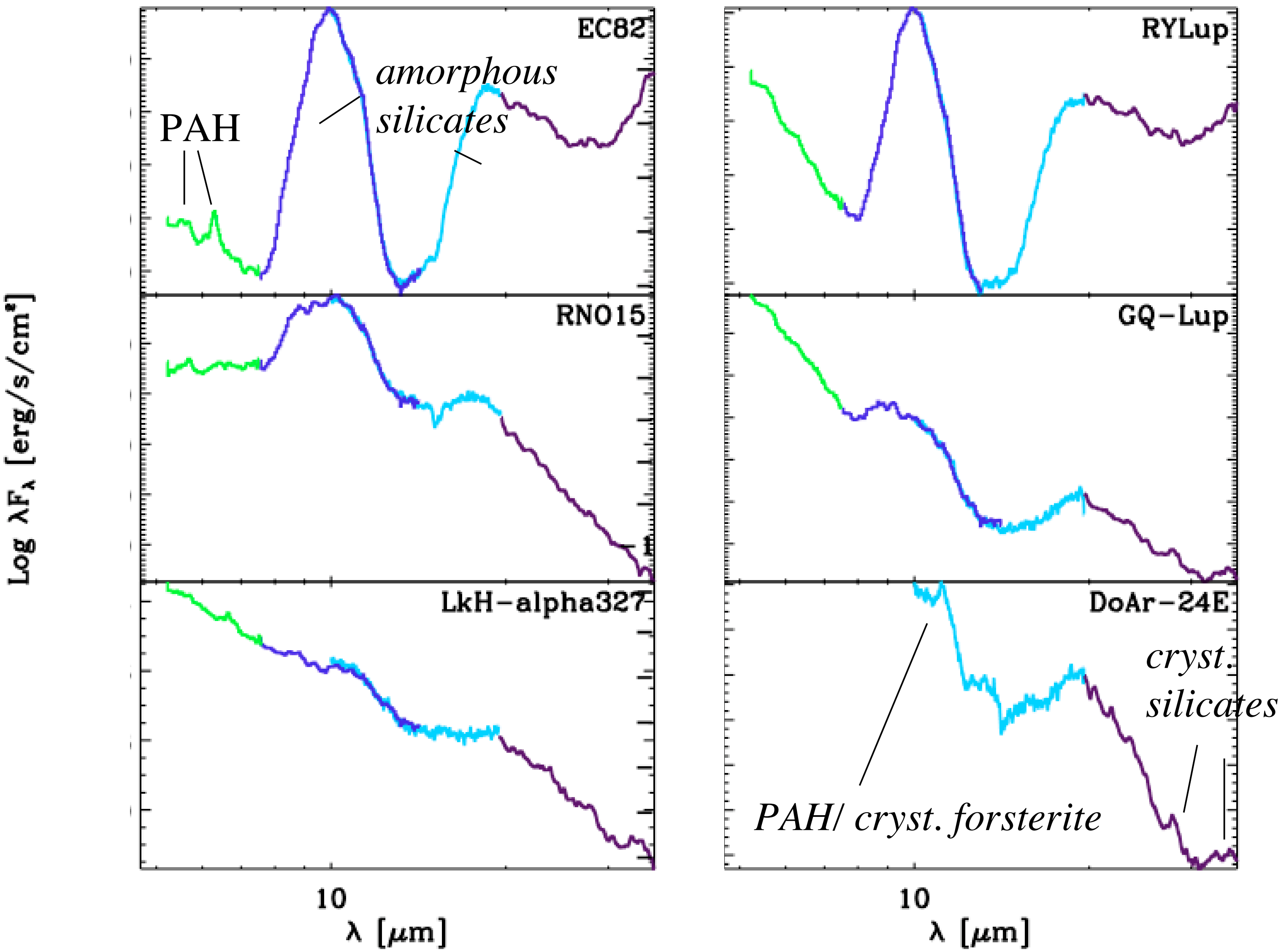
mapped by C2D

Cloud	Class 0	Class I	Class II	Herbig Ae	Background Stars
	Number of Sources of Type:				
Chameleon	0	5	14	1	1
Lupus	1	2	20	1	0
Perseus	0	10	7	0	0
Ophiuchus	2	9	31	1	2
Serpens	5	1	7	1	3
Taurus	0	0	6	1	5
CrA	2	5	0	0	0
Other	7	5	2	3	0

48 disks w/silicate emission so far

- Second look:
  - Follow-up observations -- ~50 sources total for each
  - MIPS-SED observations: FIR continuum, long silicate/ice features

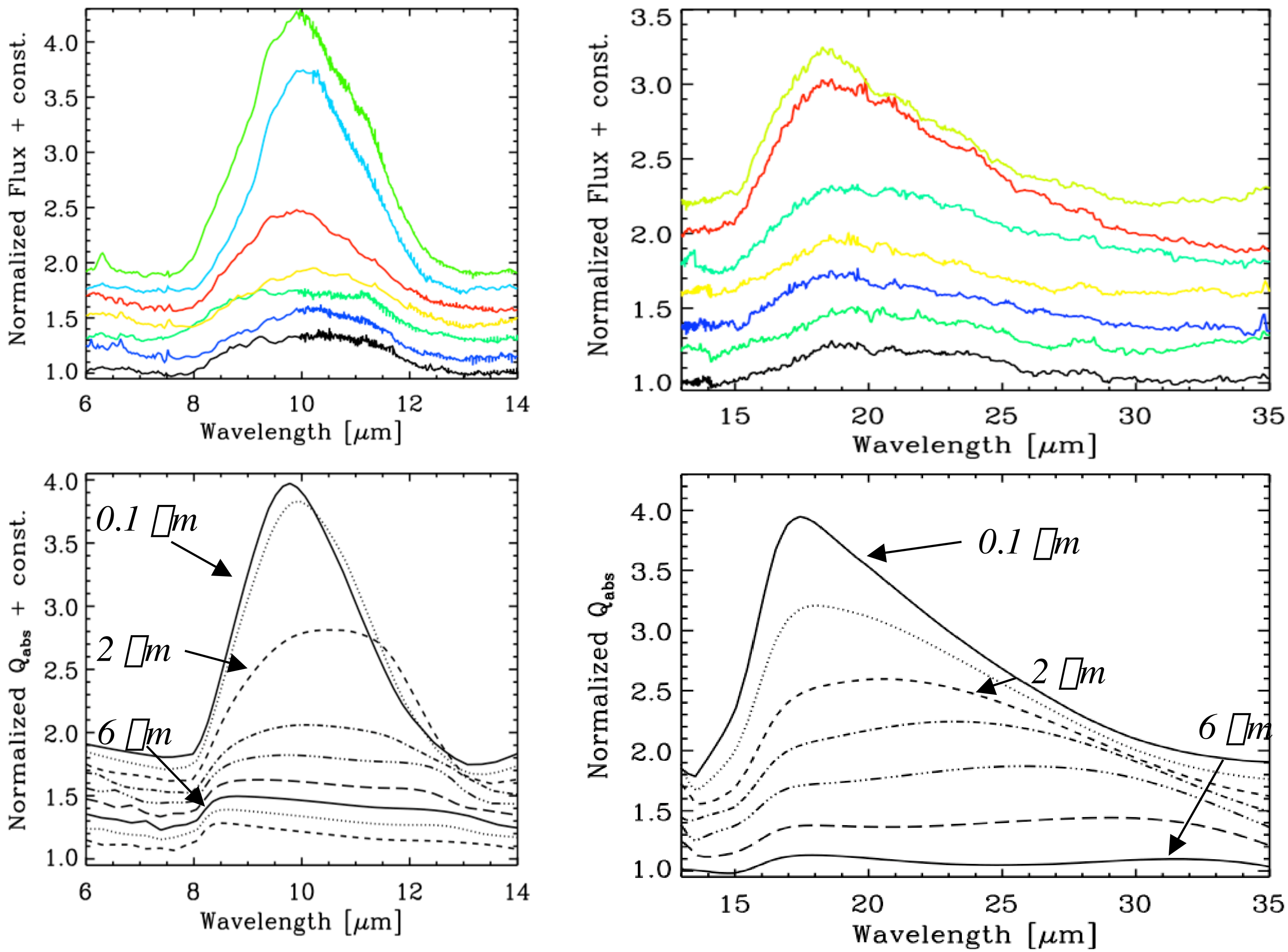
Typical spectra



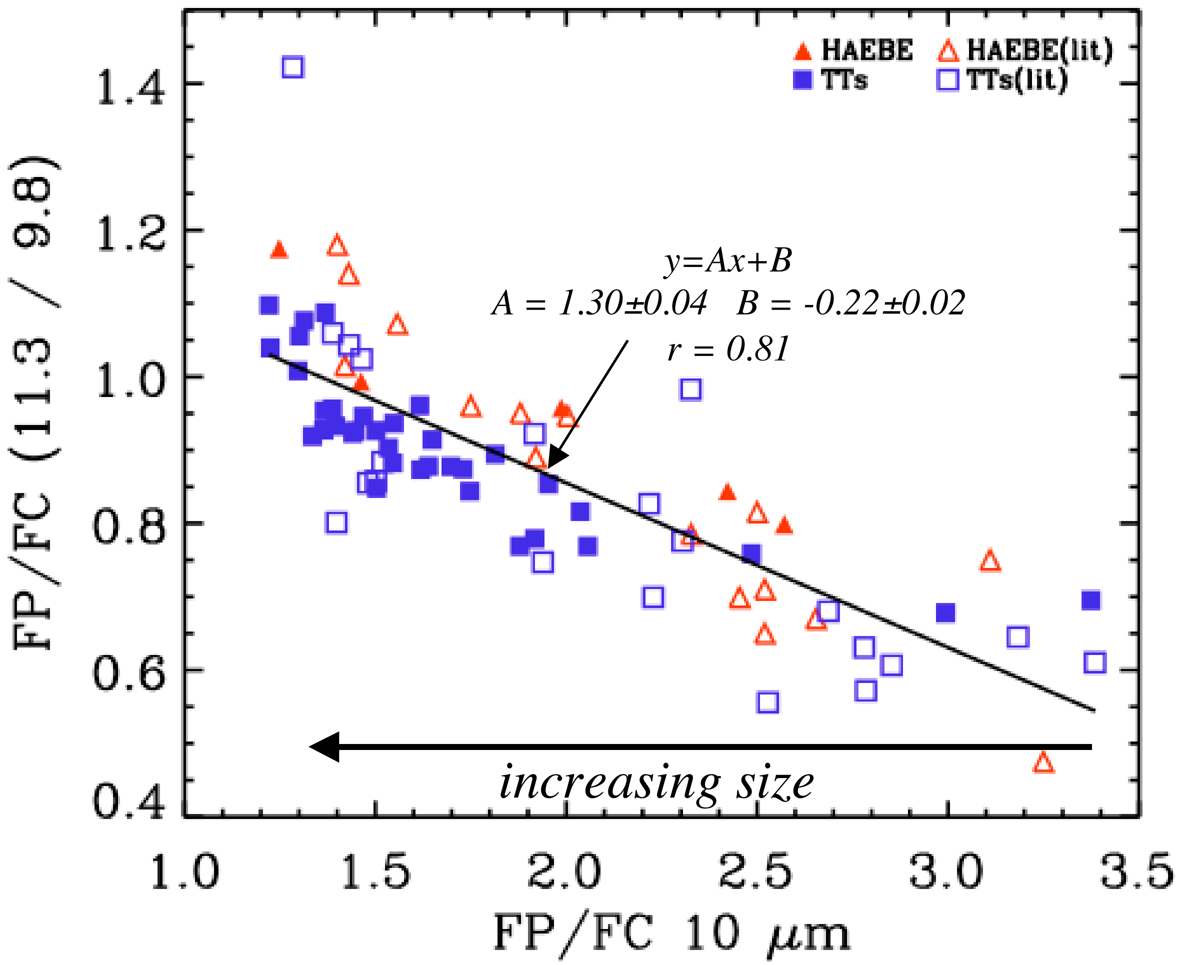
Grain growth

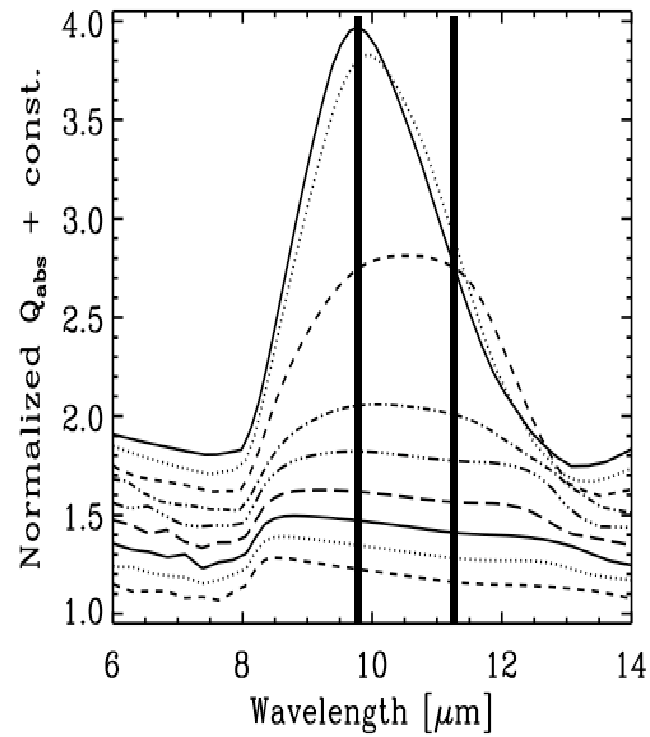
obs.

amorph.
olivines
(hard
spheres)



Grain growth statistics: 10 m



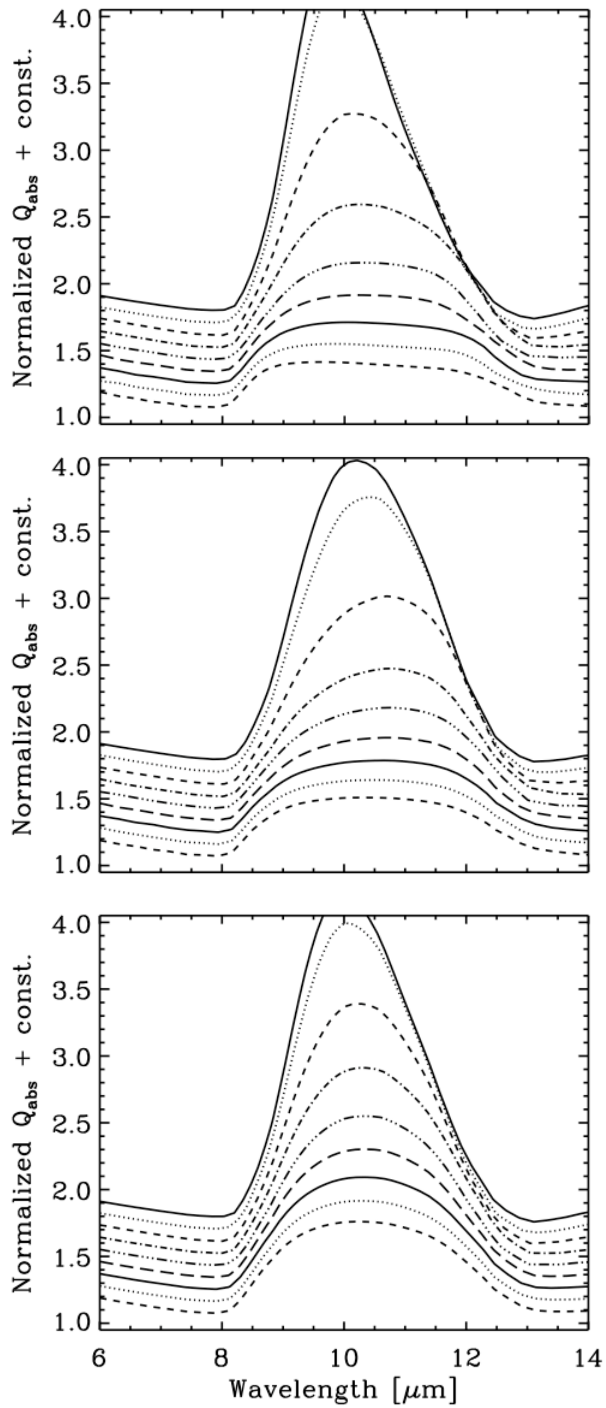


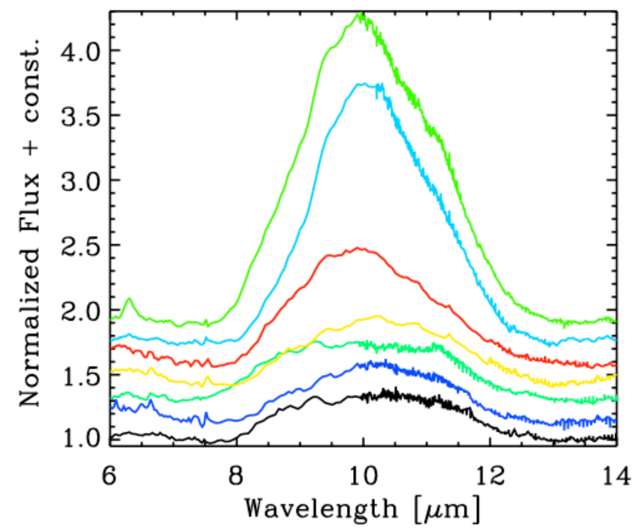
lit = van Boekel 2003, Przygodda 2003, Kessler-Silacci 2005

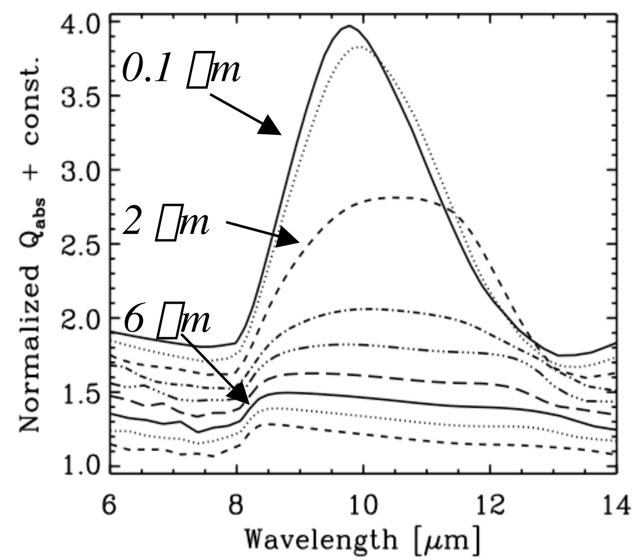
geo: hard spheres
comp: 70% olivine
30 % graphite

geo: hollow spheres
comp: 100% olivine

geo: hollow spheres
comp: 70% olivine
30 % graphite



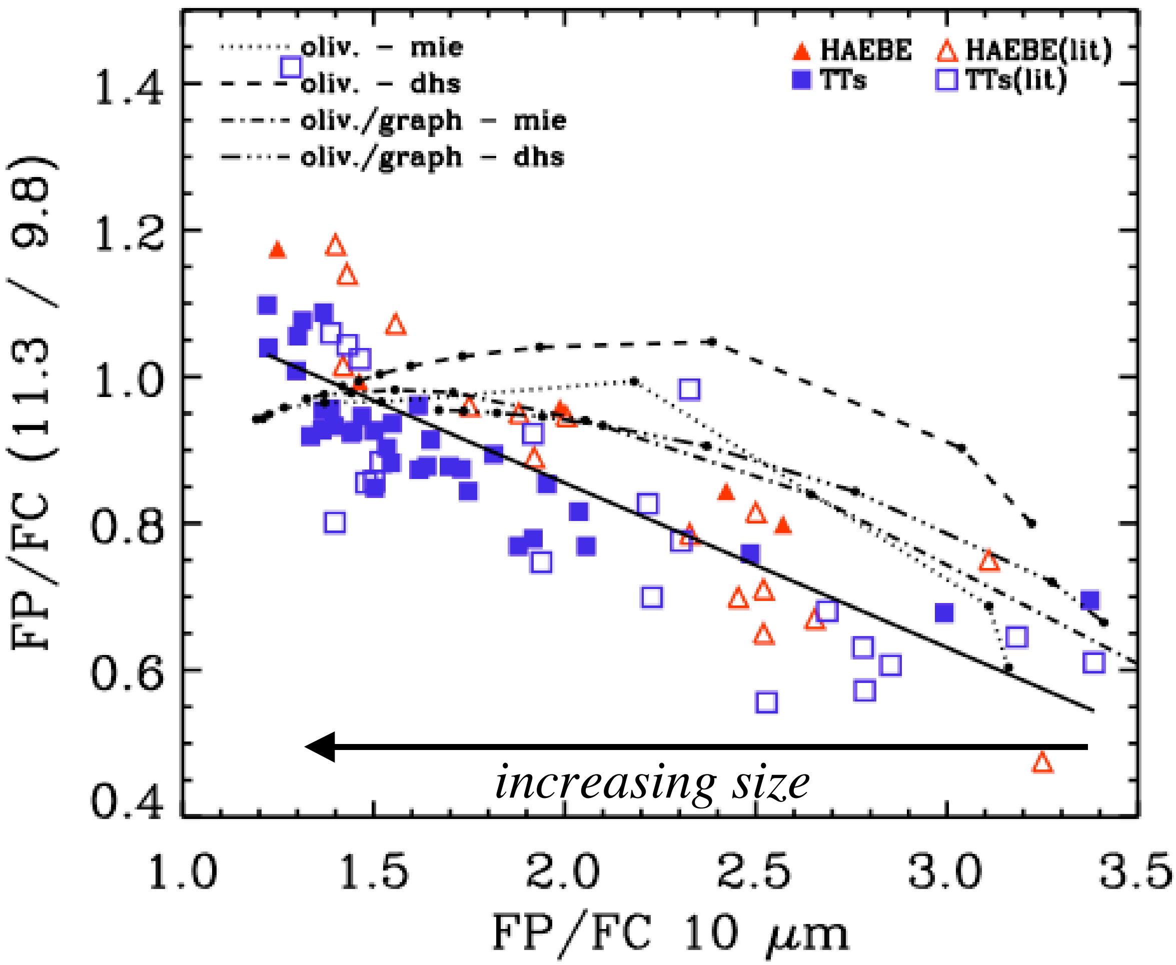


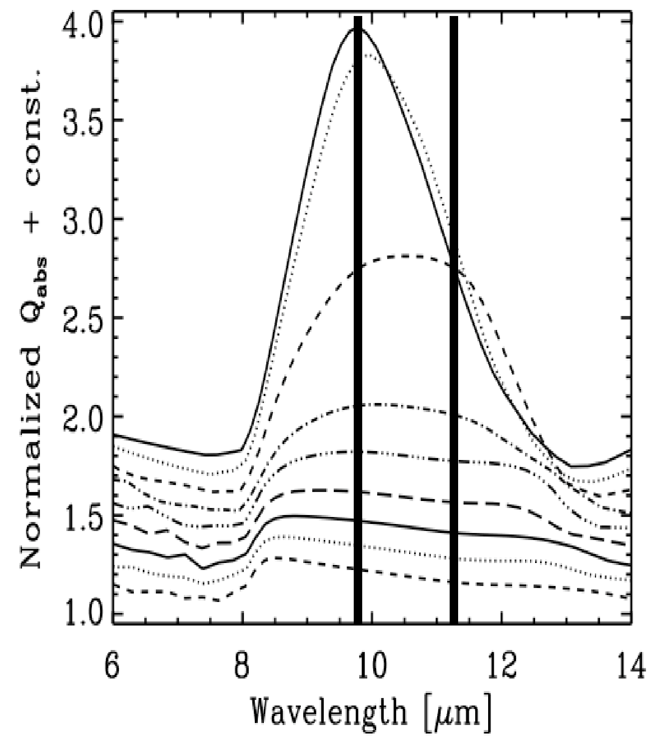


geo: hard spheres
comp: 100% olivine

dhs: Min et al.(2005)
olivine: Glassy Olivine (Mg2xFe2-2xSiO4 x=0.5)
(Dorschner et al. 1995)
graphite: Elemental carbon
(Draine & Lee (1984); Laor & Draine 1993)

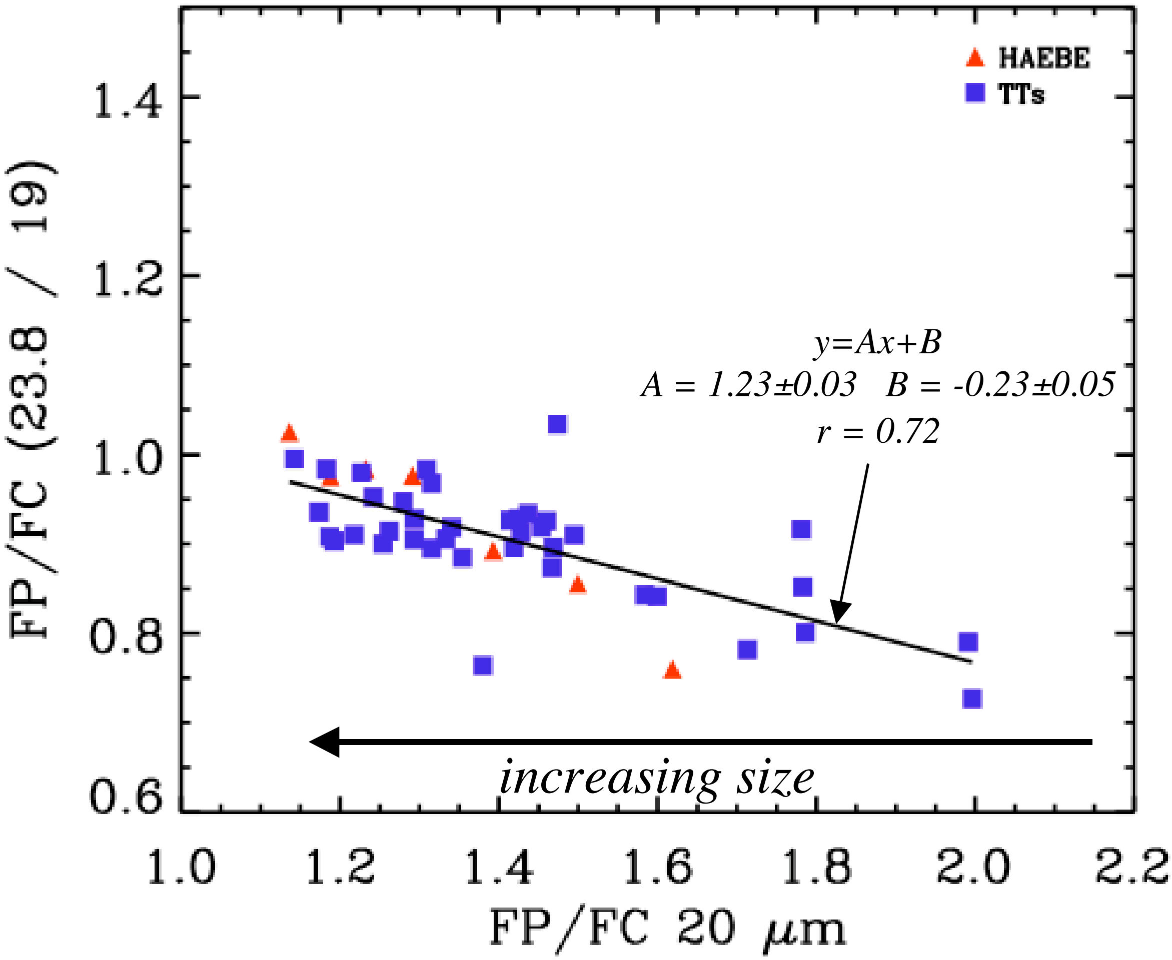
Grain growth statistics: 10 m

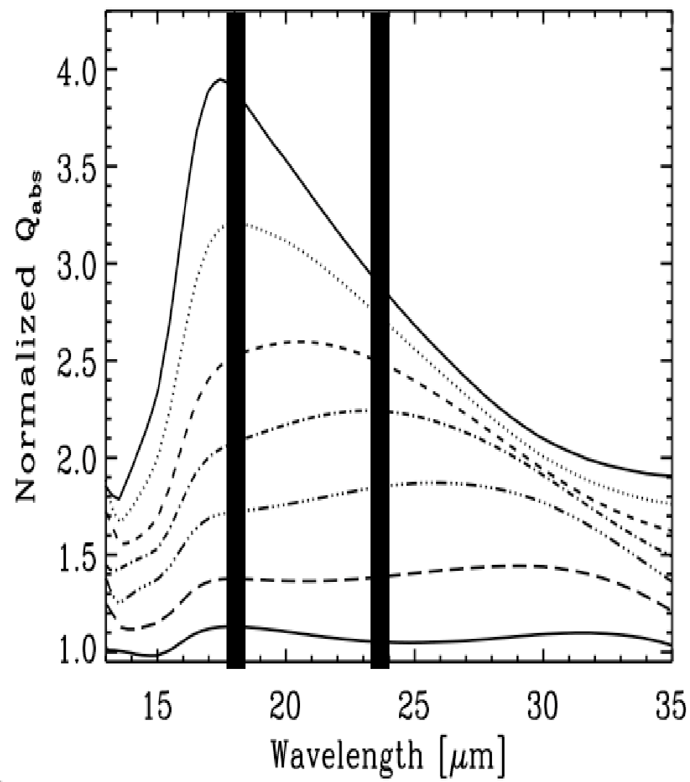




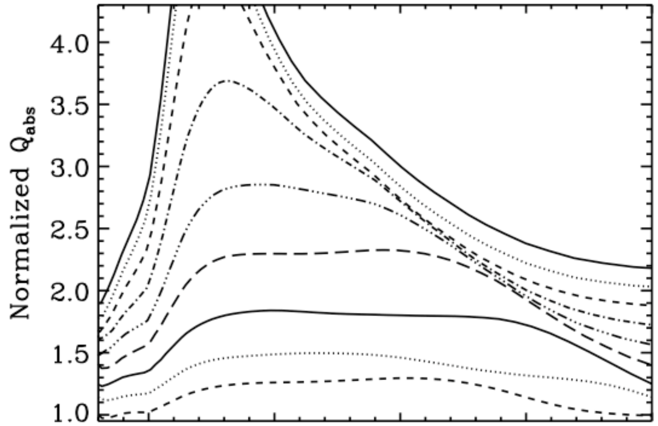
lit = van Boekel 2003, Przygodda 2003, Kessler-Silacci 2005

Grain growth statistics: 20 m

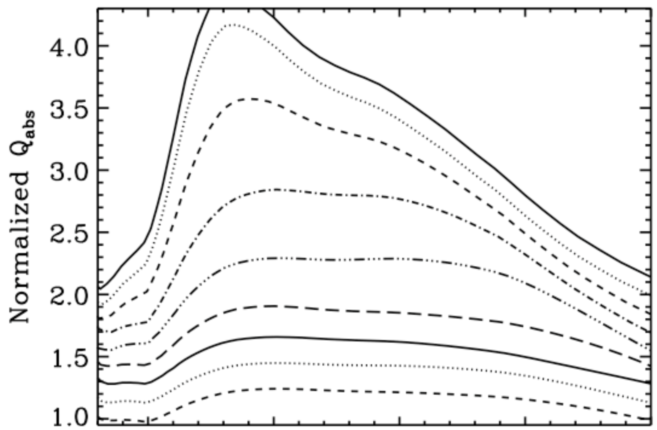




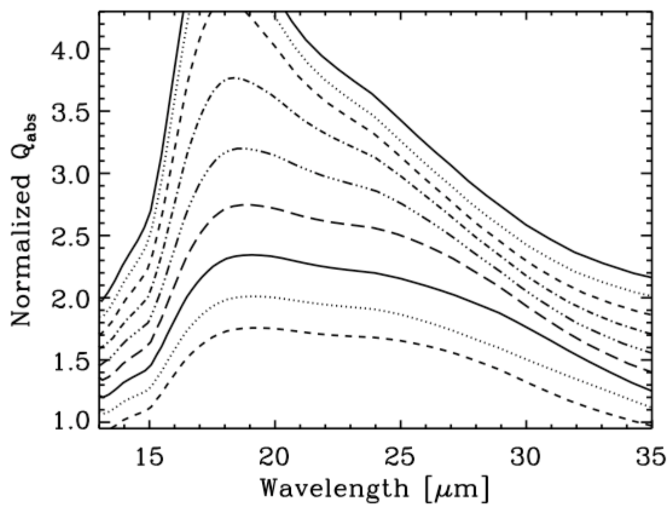
geo: hard spheres
comp: 70% olivine
30 % graphite

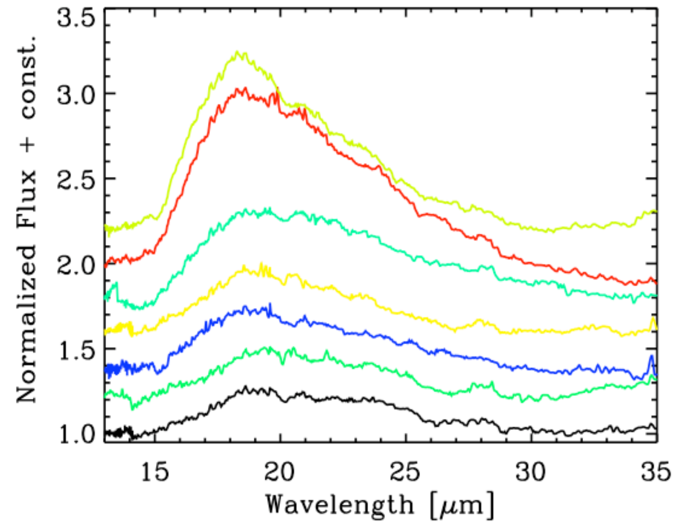


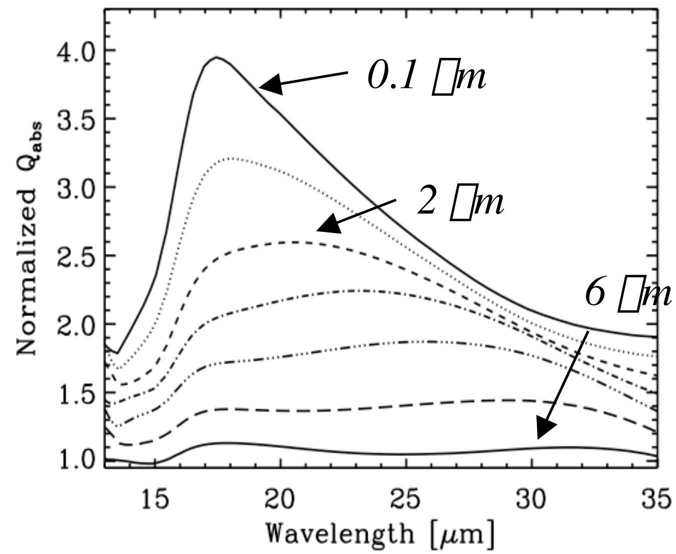
geo: hollow spheres
comp: 100% olivine



geo: hollow spheres
comp: 70% olivine
30 % graphite

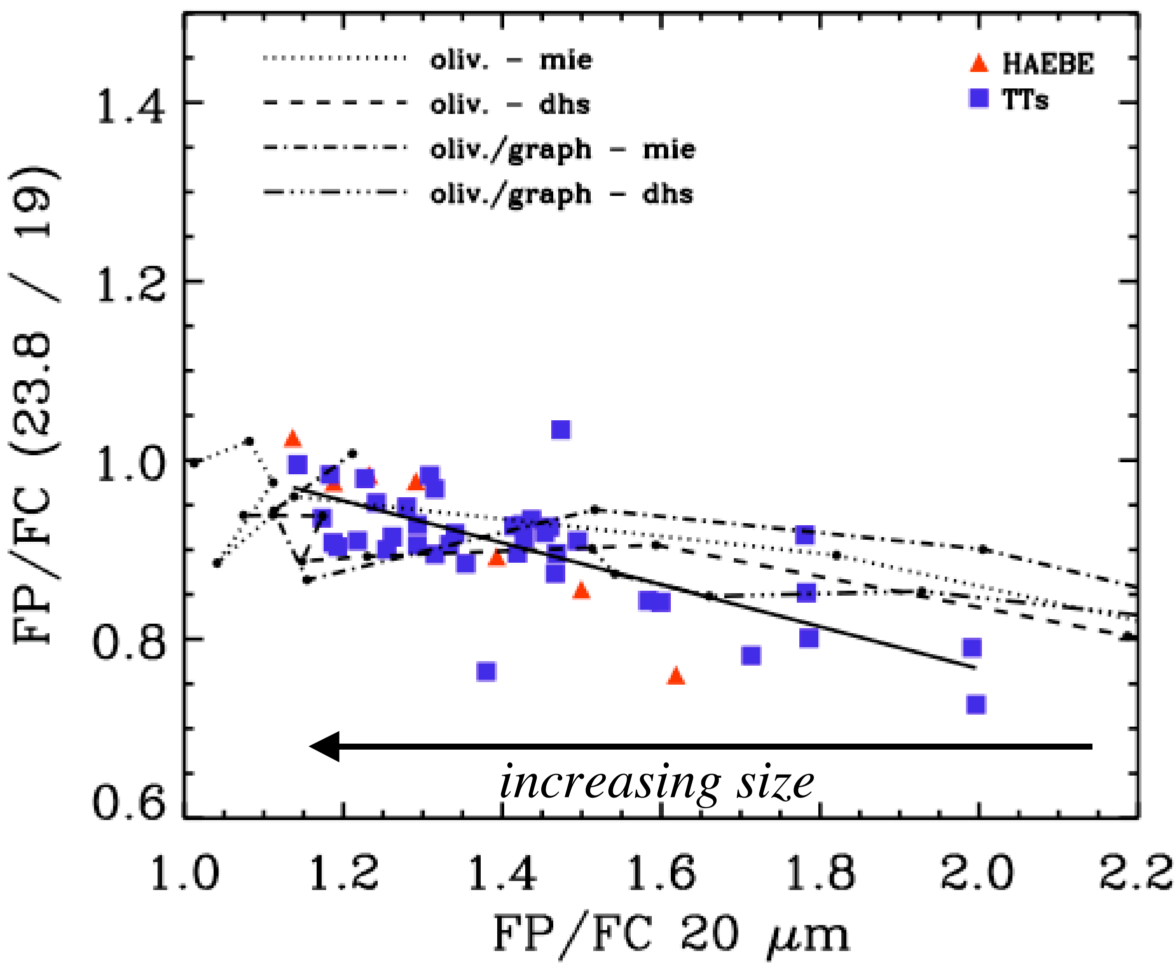


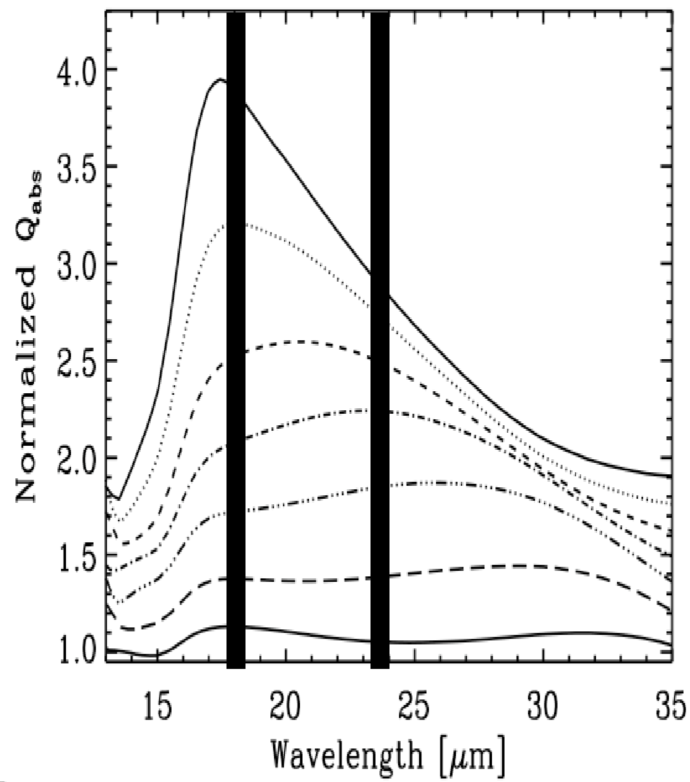




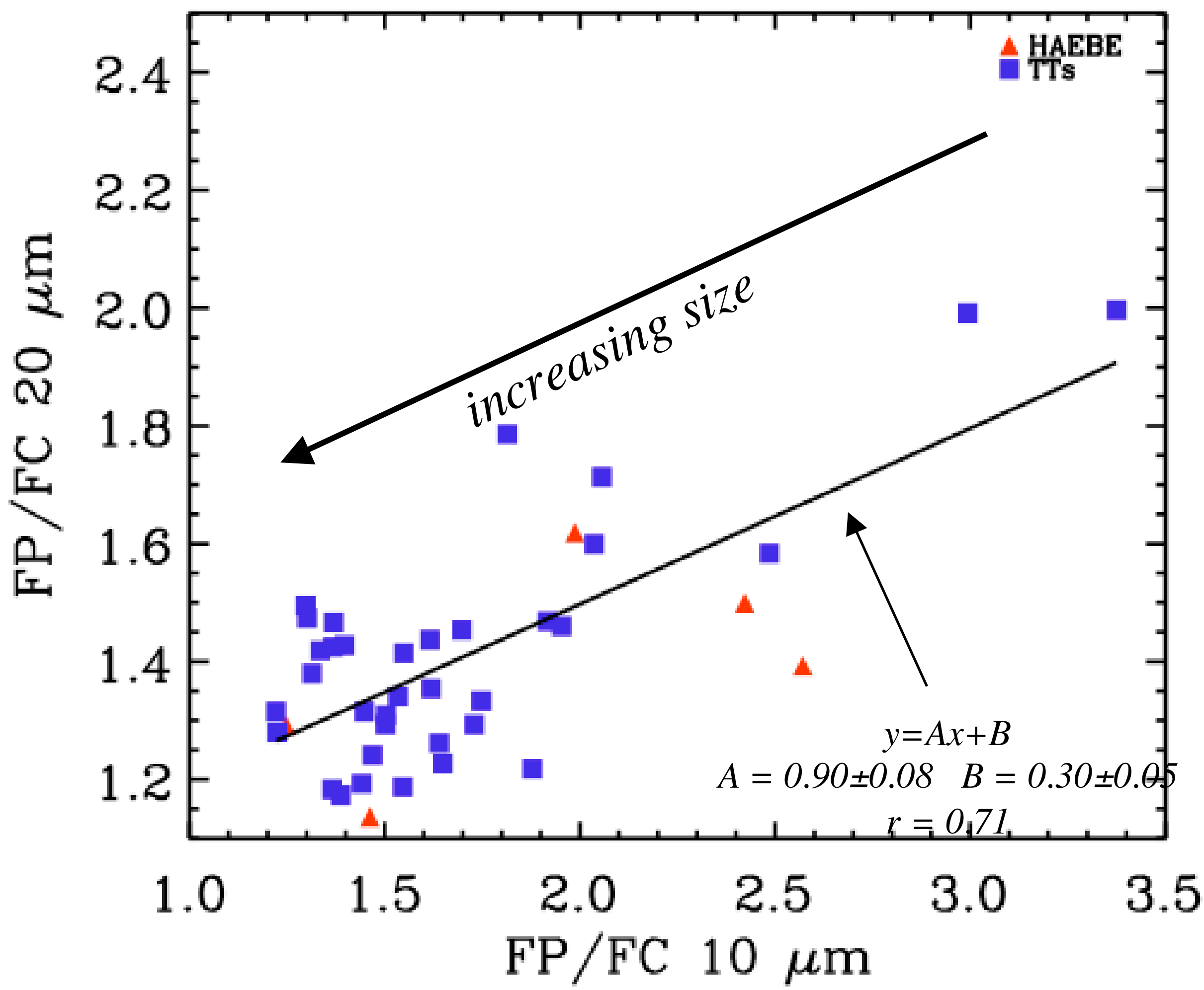
geo: hard spheres
comp: 100% olivine

Grain growth statistics: 20 m

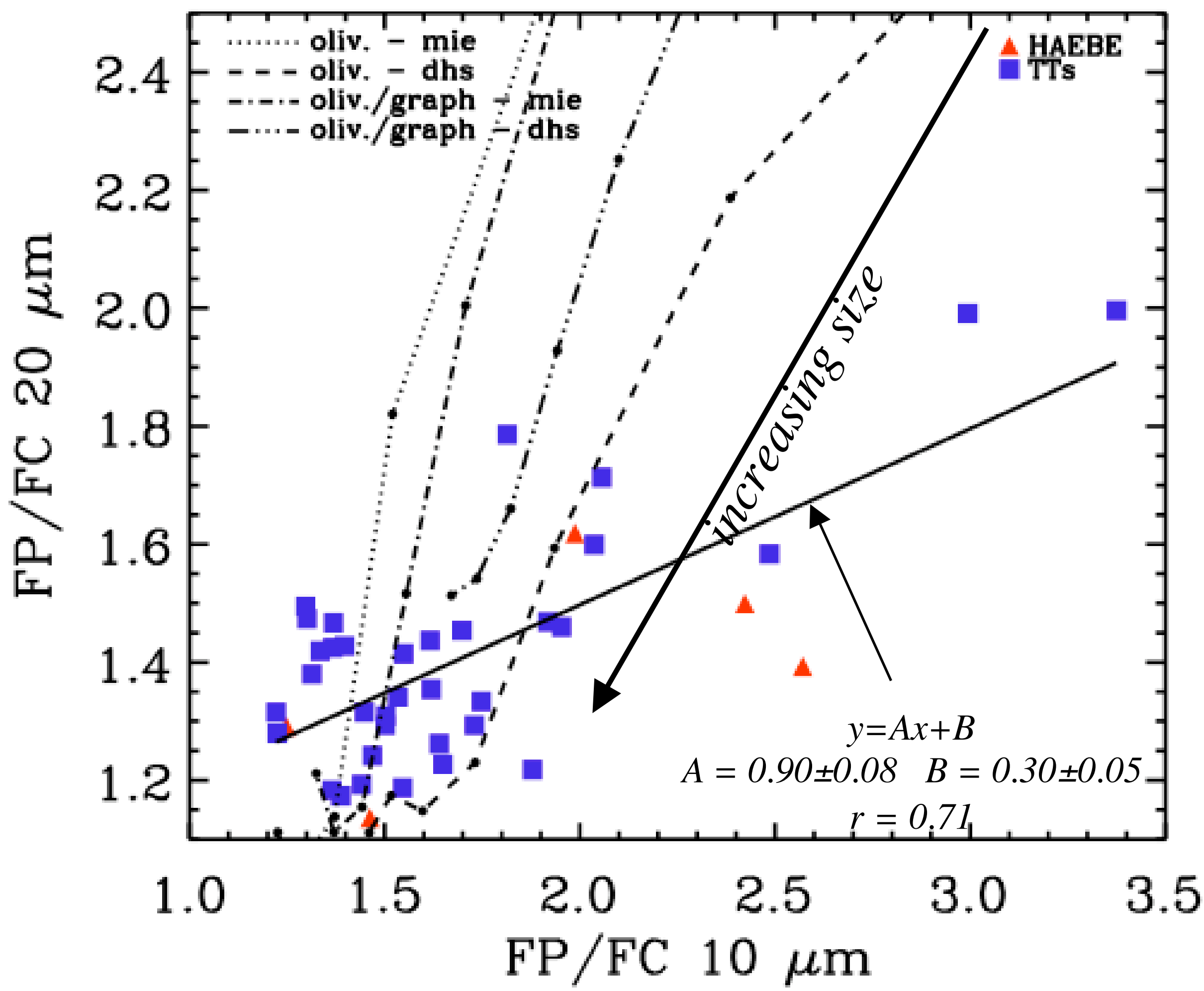




10 vs 20 m feature strength

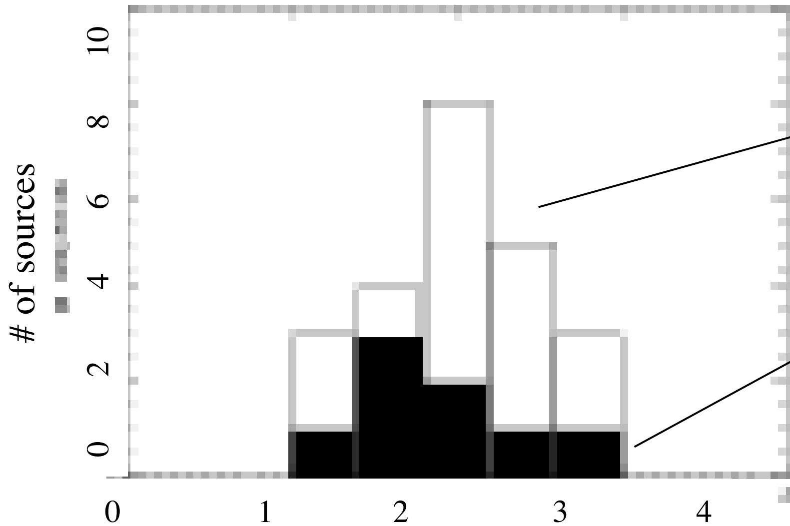


10 vs 20 m feature strength



Peak-to-continuum ratios

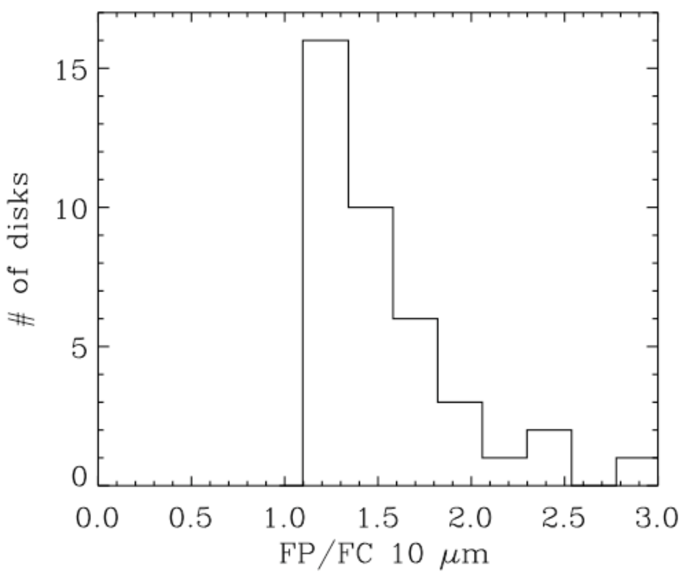
ISO data: HAEBE stars (Acke 2004)



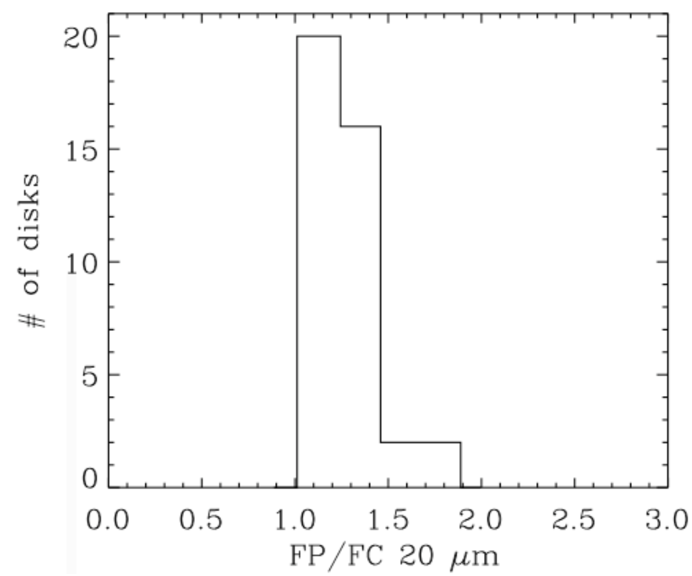
Meeus group I *(flared)*
mean=2.03

Meeus group II *(self-shadowed)*
mean=1.85

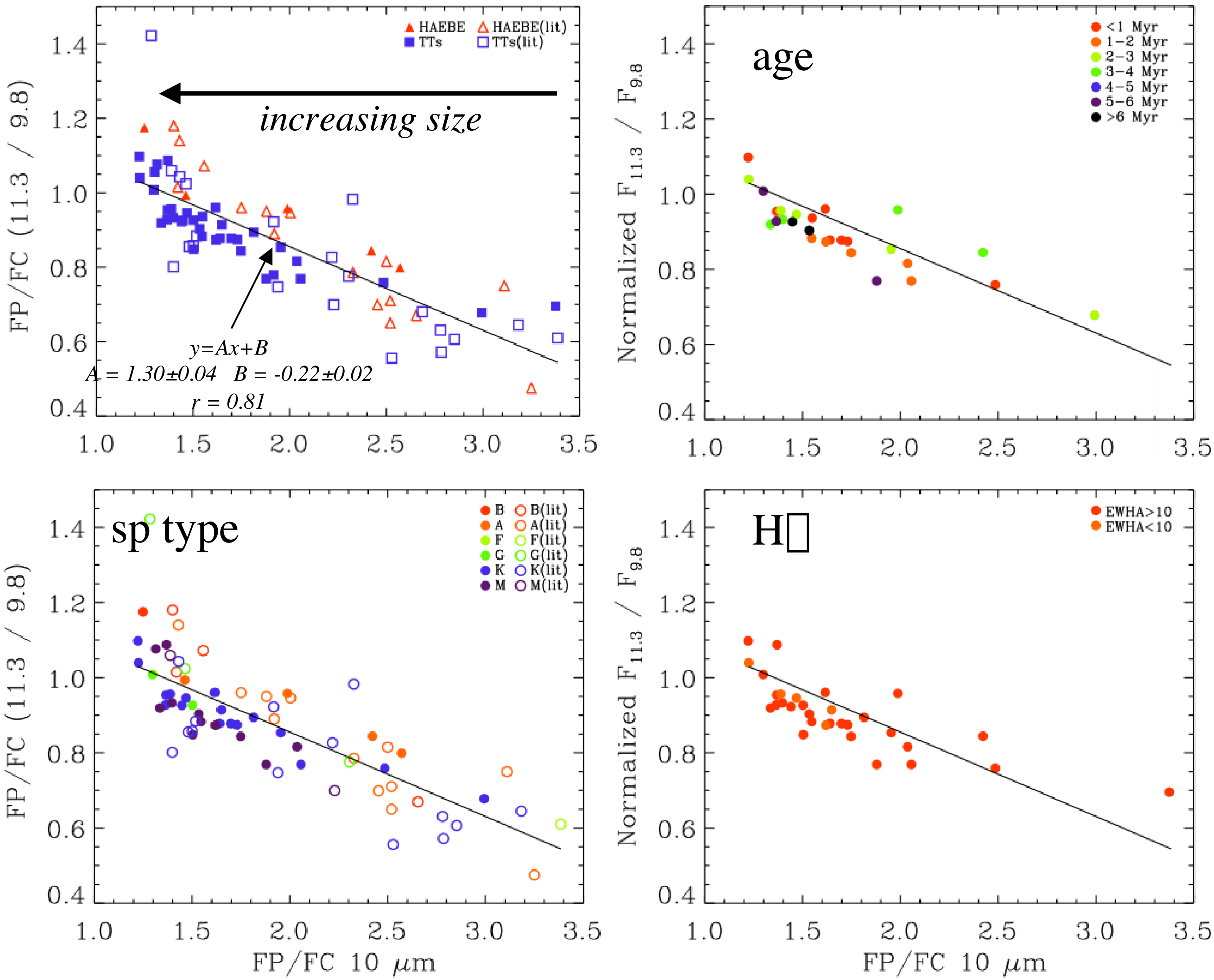
c2d data: low-mass stars

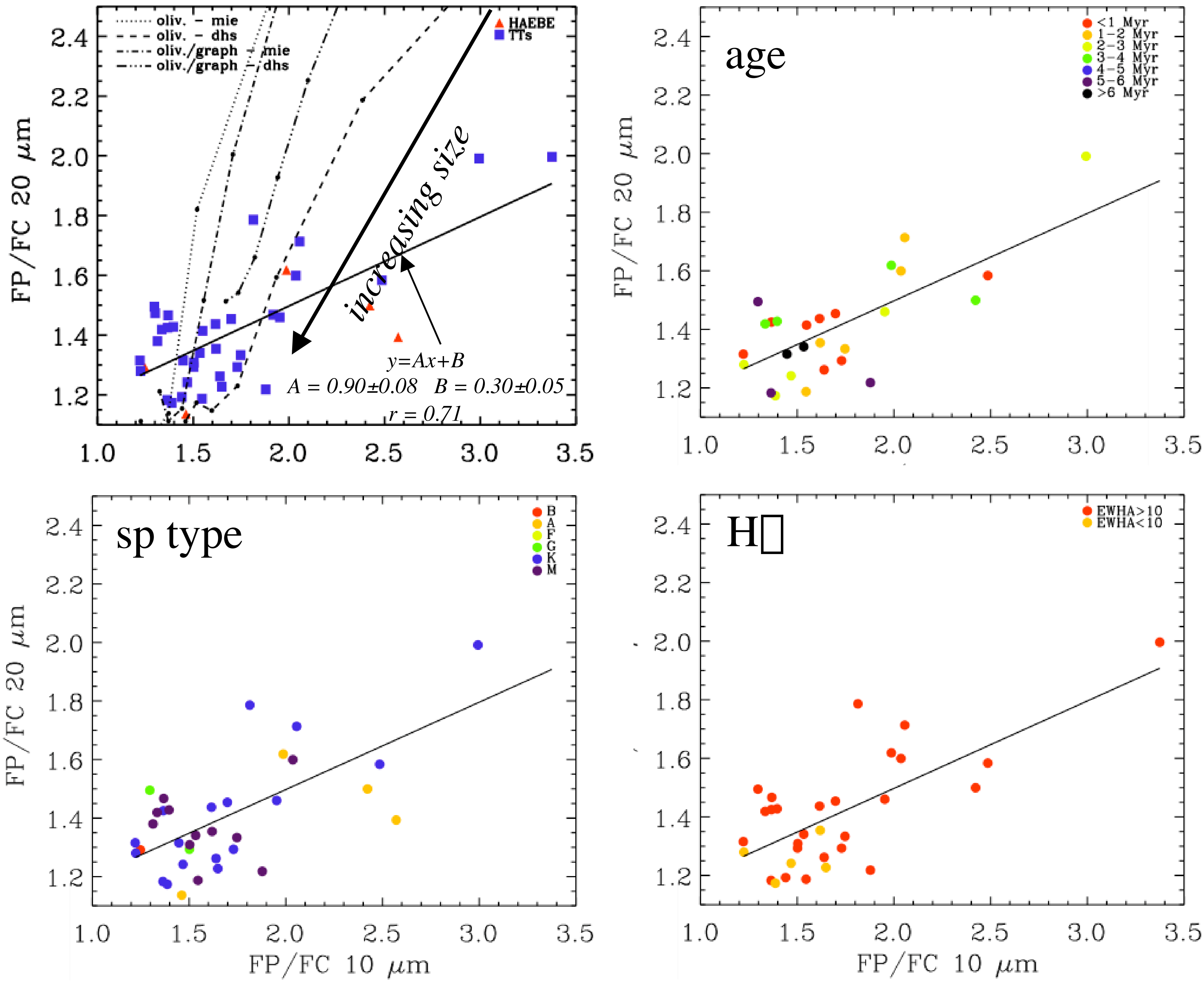


mean=1.71+-0.48



mean=1.41+-0.20


HAEBE
HAEBE(lit)
TTs
TTs(lit)
increasing size
y=Ax+B
A = 1.30±0.04 B = -0.22±0.02
r = 0.81
FP/FC (11.3 / 9.8)
age
<1 Myr
1-2 Myr
2-3 Myr
3-4 Myr
4-5 Myr
5-6 Myr
>6 Myr
Normalized F11.3 / F9.8
sp type
B
A
F
G
K
M
B(lit)
A(lit)
F(lit)
G(lit)
K(lit)
M(lit)
EWHA>10
EWHA<10
FP/FC 10 μm



oliv. – mie
oliv. – dhs
oliv./graph – mie
oliv./graph – dhs
HAEBE
TTs
increasing size
y=Ax+B
A = 0.90±0.08 B = 0.30±0.05
r = 0.71
FP/FC 20 μm
age
<1 Myr
1–2 Myr
2–3 Myr
3–4 Myr
4–5 Myr
5–6 Myr
>6 Myr
sp type
B
A
F
G
K
M
EWHA>10
EWHA<10
FP/FC 10 μm

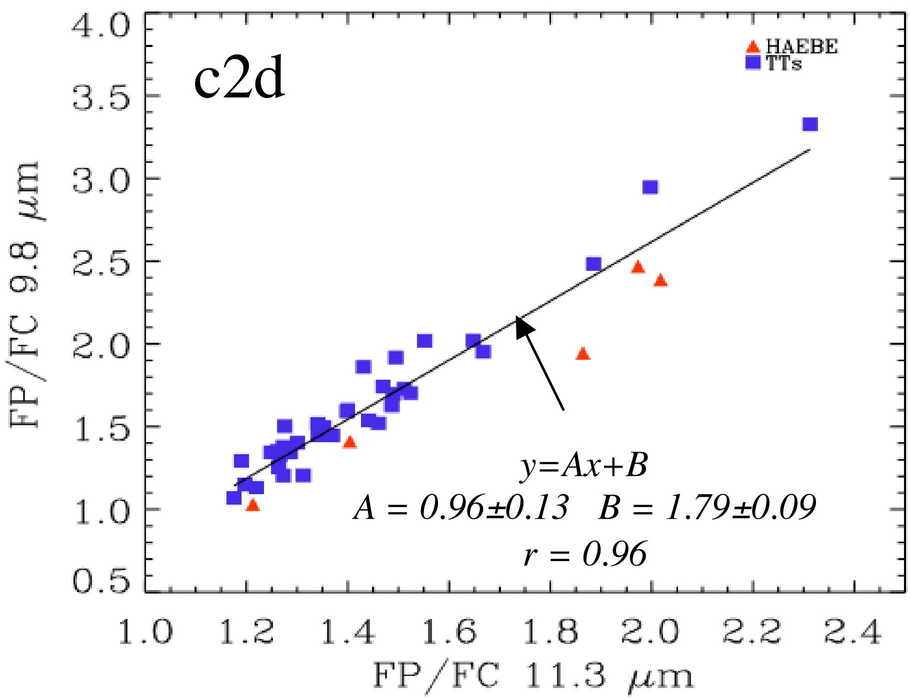
Conclusions

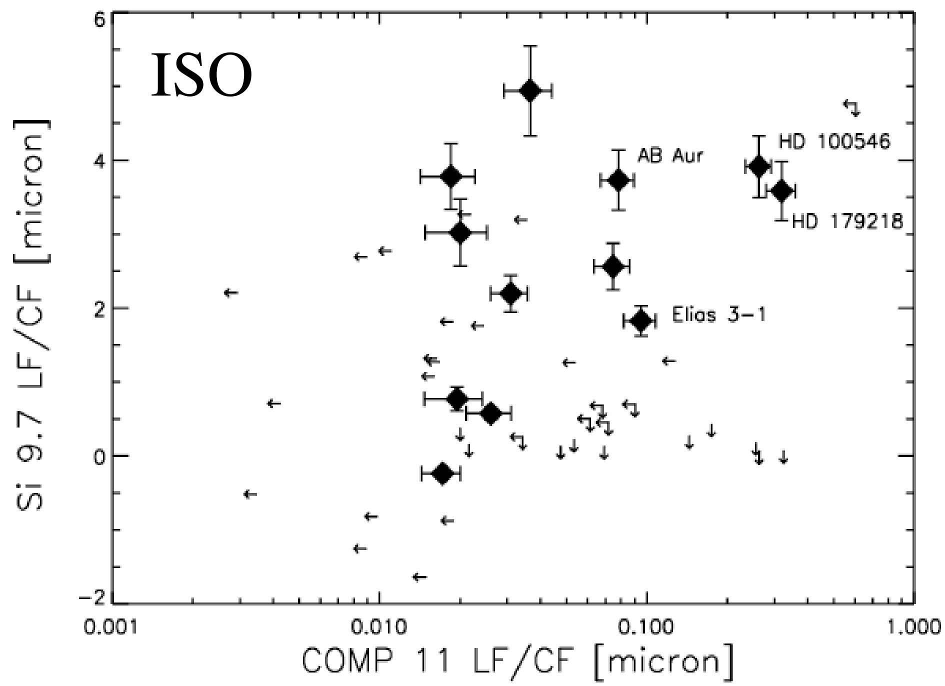
- Silicate features at 10 and 20 μm are prominent toward class II TTs with dust sizes of **1-10 μm**.
- Statistical analysis indicates that the features are similar to amorphous olivine/graphite mixtures (dhs/hard spheres), with a **degeneracy between grain sizes vs dust structure**.
- The ratio of the 10 vs. 20 μm feature strengths can't be reproduced with the same size grains for 10 and 20 μm features, indicating different populations of dust grains
- The statistical trends indicating grain growth in TTs do not appear to be related to spectral type or age, but **may be related to Hα** (larger grains in wTTs) $\rightarrow$ related to clearing of the central disk?

Future analysis

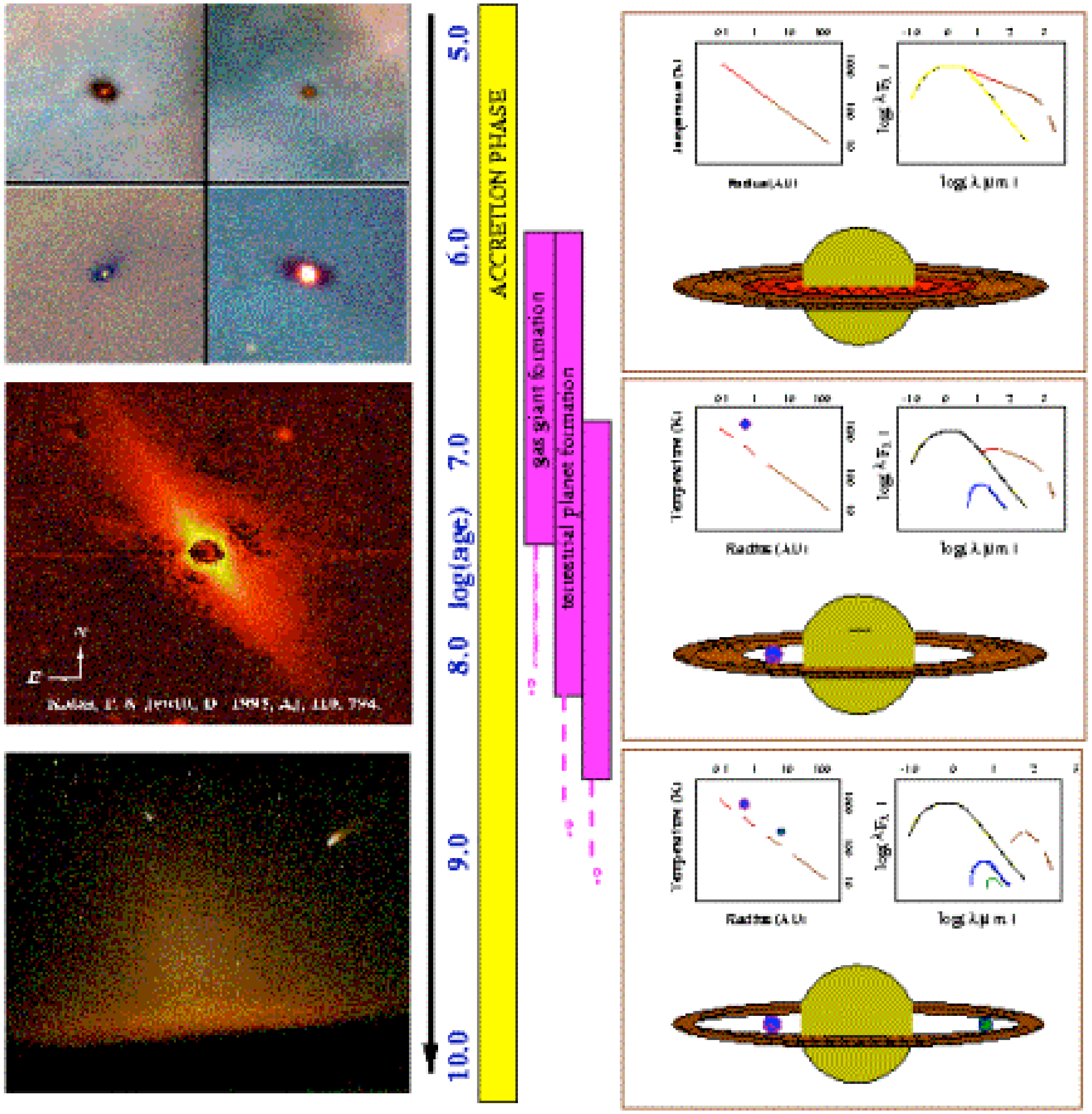
- Detailed fitting of silicate features for individual sources (crystalline Mg-rich silicates, olivines, pyroxenes, carbonaceous grains)
- Comparison of PAH and silicate emission (PAHs in c2d IRS: V. Geers, B. Merin, in prep)
- Comparison of SED properties disk structure and silicate emission (SEDs for c2d IRS: J.-C. Augereau, B. Merin, in prep)

Relation between amorphous and crystalline silicates and PAHs





Legacy Programs



c2d program

IR spectra of

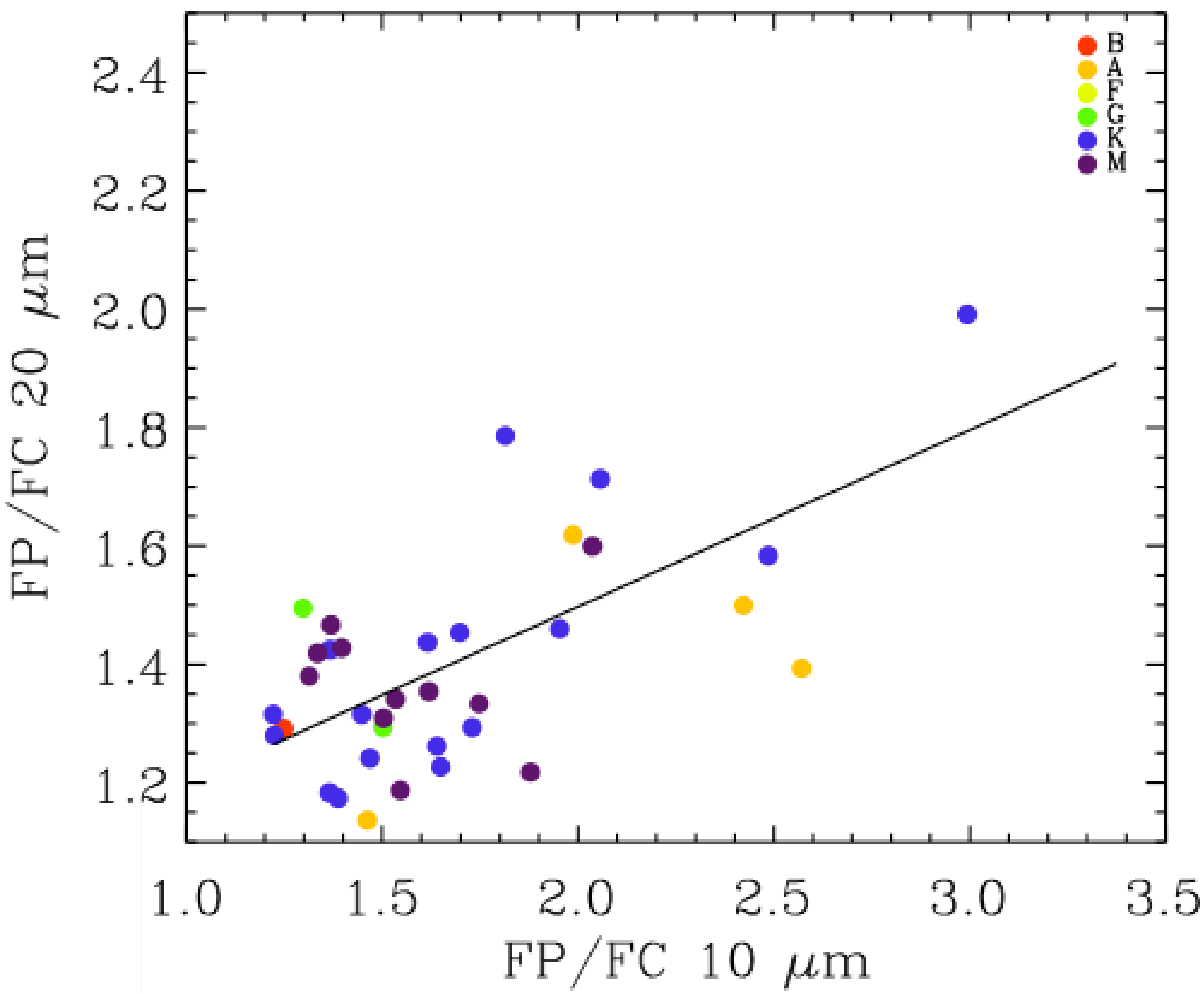
~200 sources

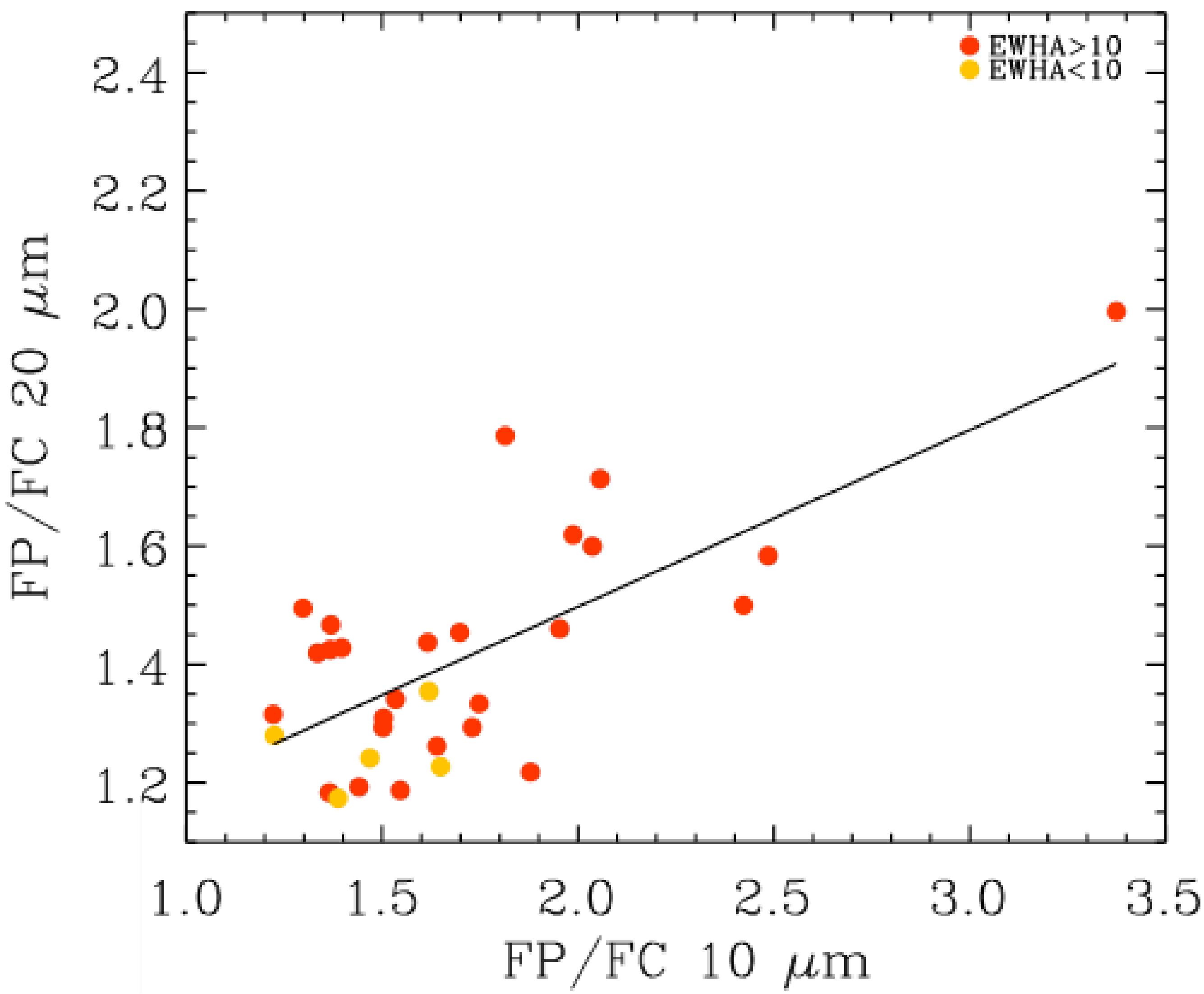
Cores → disks

FEPS program

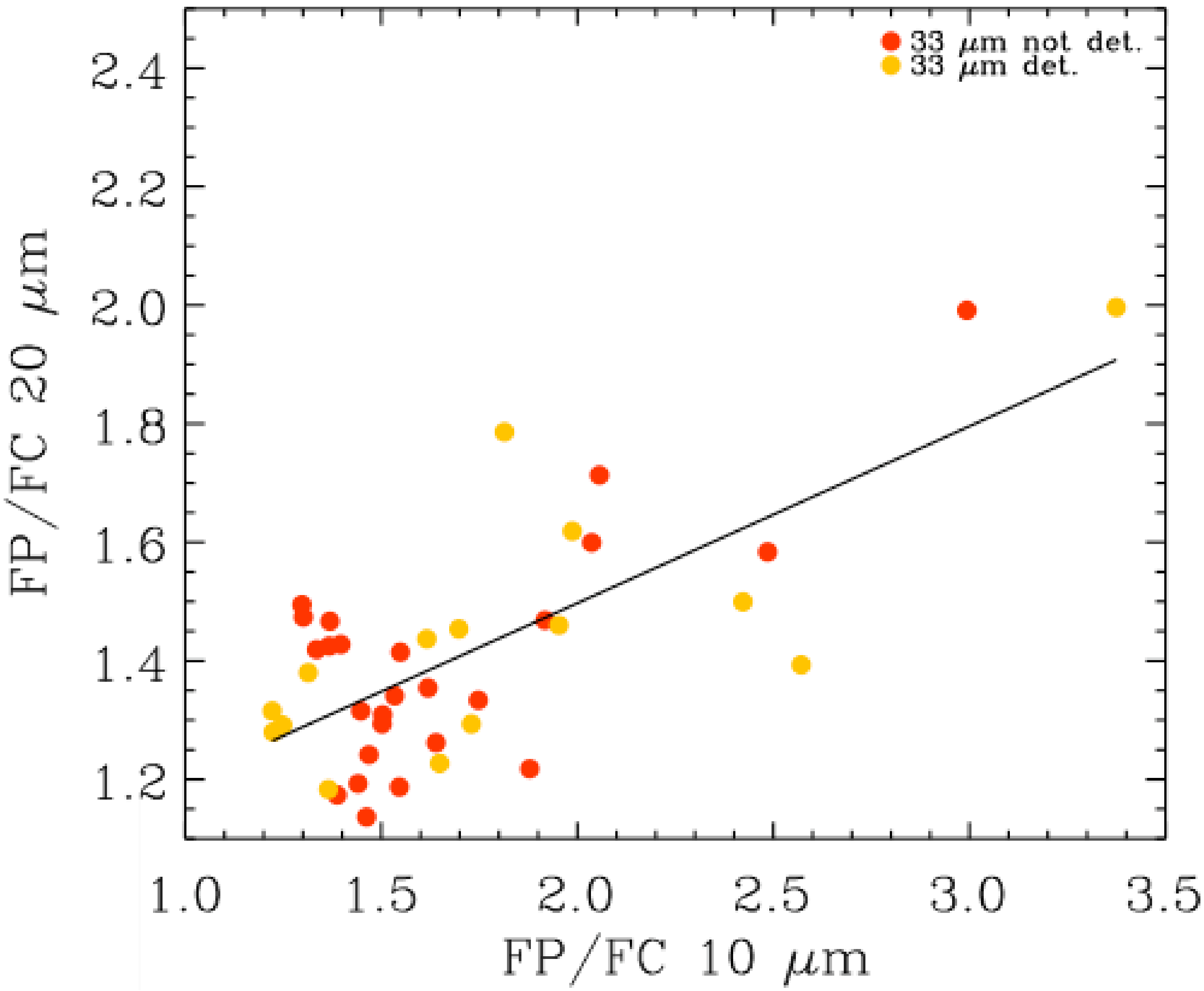
~300 2nd gen. disks

3Myr – 3 Gyr


B
A
F
G
K
M
2.4
2.2
2.0
1.8
1.6
1.4
1.2
FP/FC 20 μm
1.0
1.5
2.0
2.5
3.0
3.5
FP/FC 10 μm

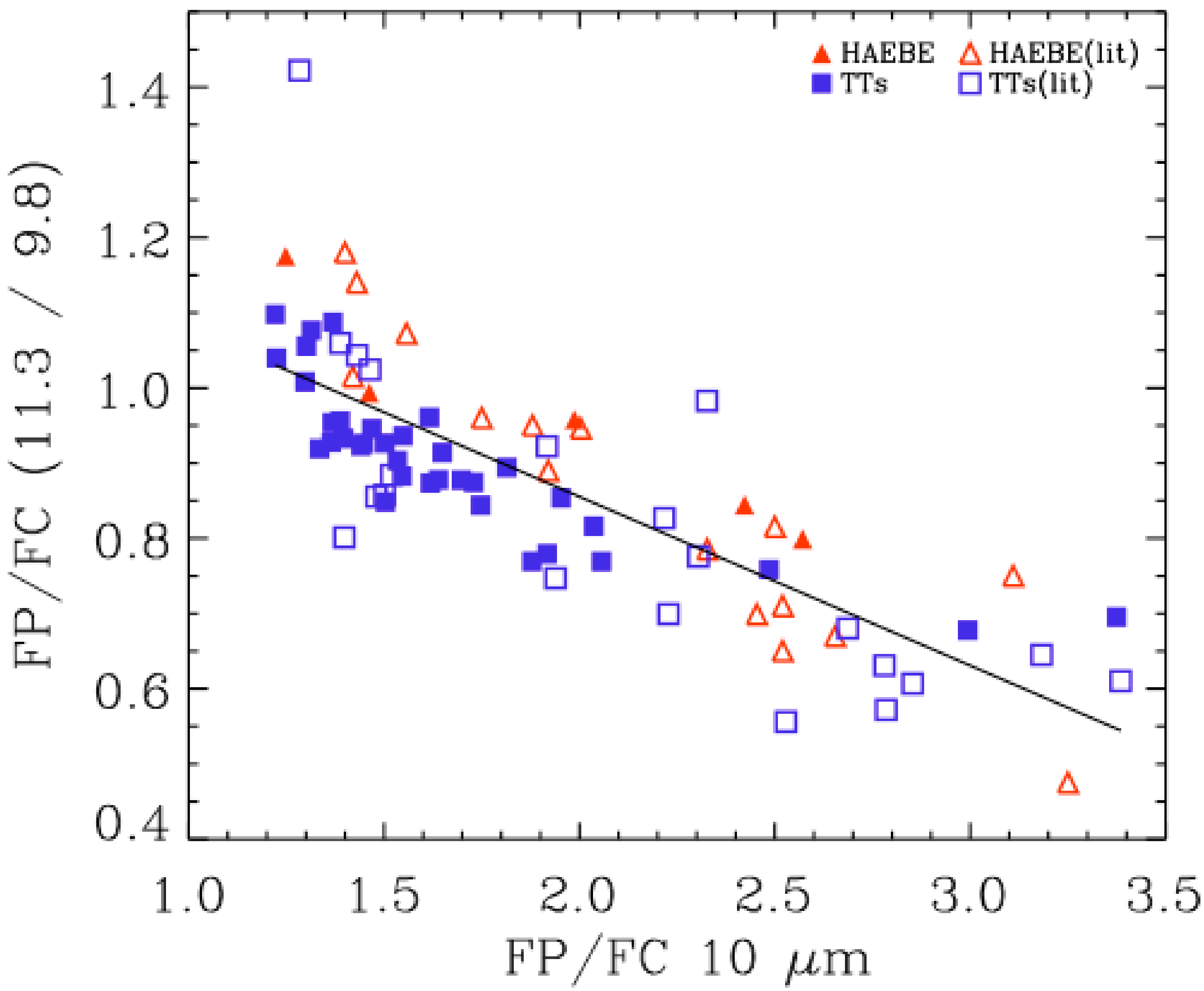


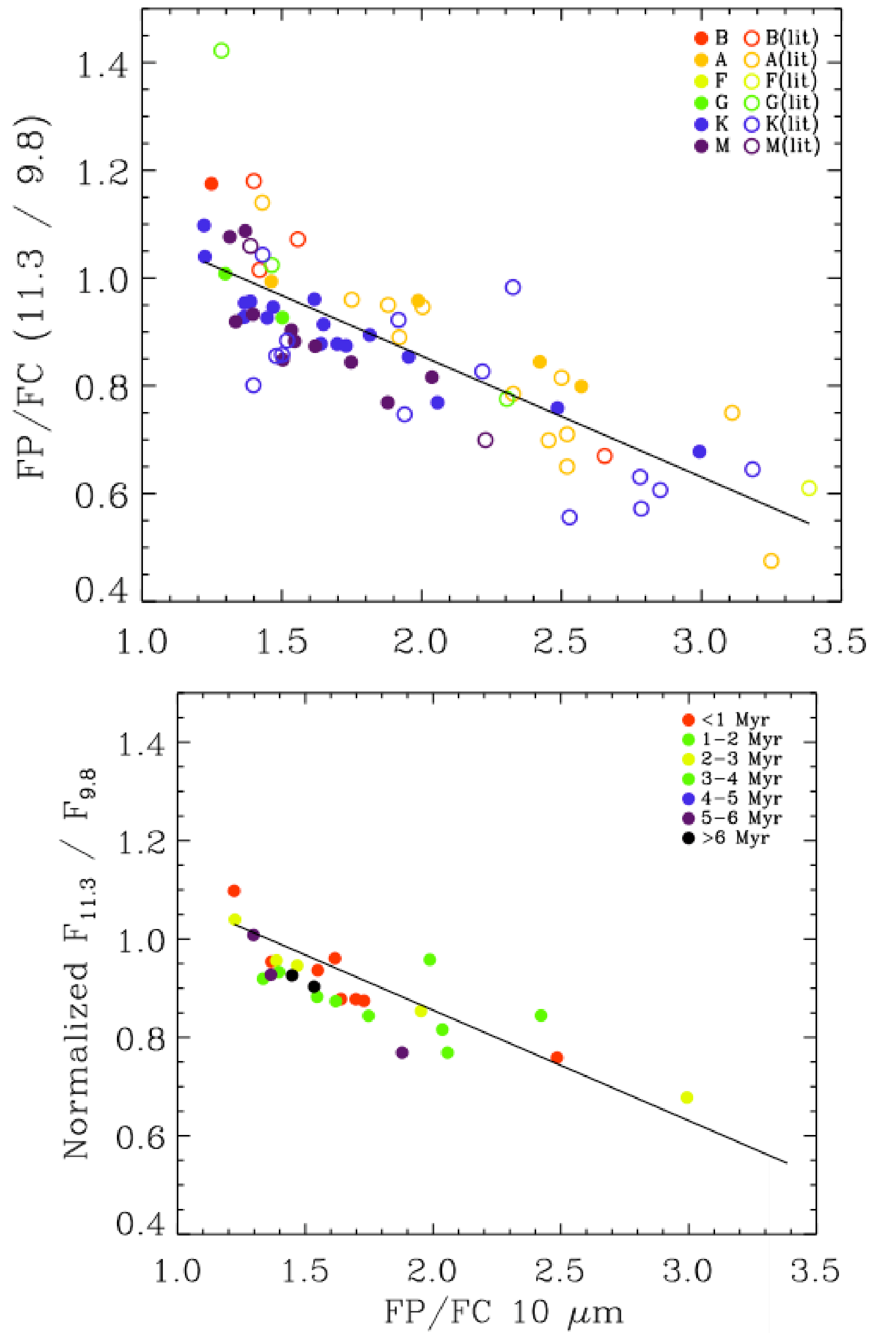
EWHA>10
EWHA<10
2.4
2.2
2.0
1.8
1.6
1.4
1.2
FP/FC 20 μm
1.0
1.5
2.0
2.5
3.0
3.5
FP/FC 10 μm



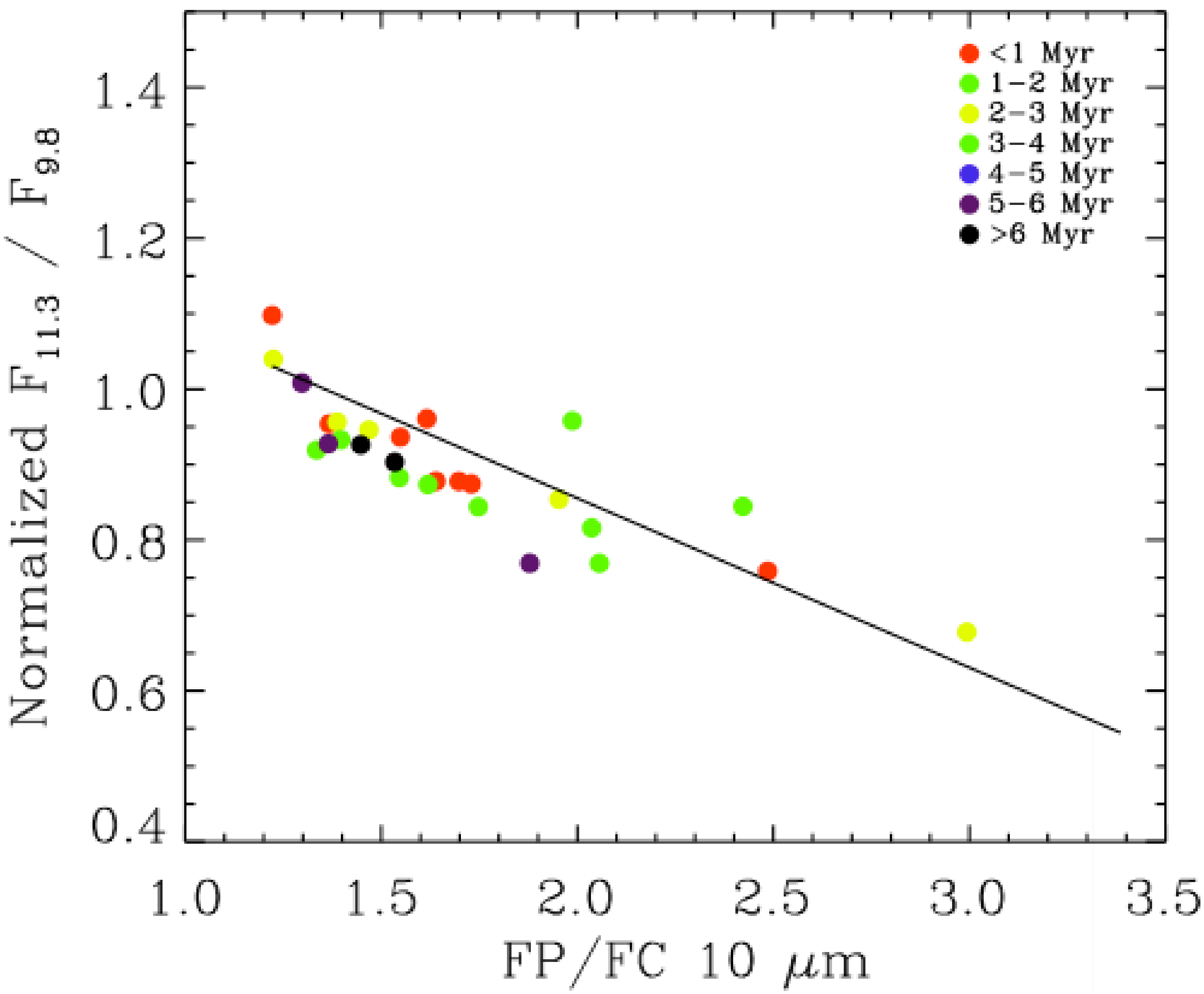
33 μm not det.
33 μm det.
2.4
2.2
2.0
1.8
1.6
1.4
1.2
FP/FC 20 μm
1.0
1.5
2.0
2.5
3.0
3.5
FP/FC 10 μm

shape vs. strength

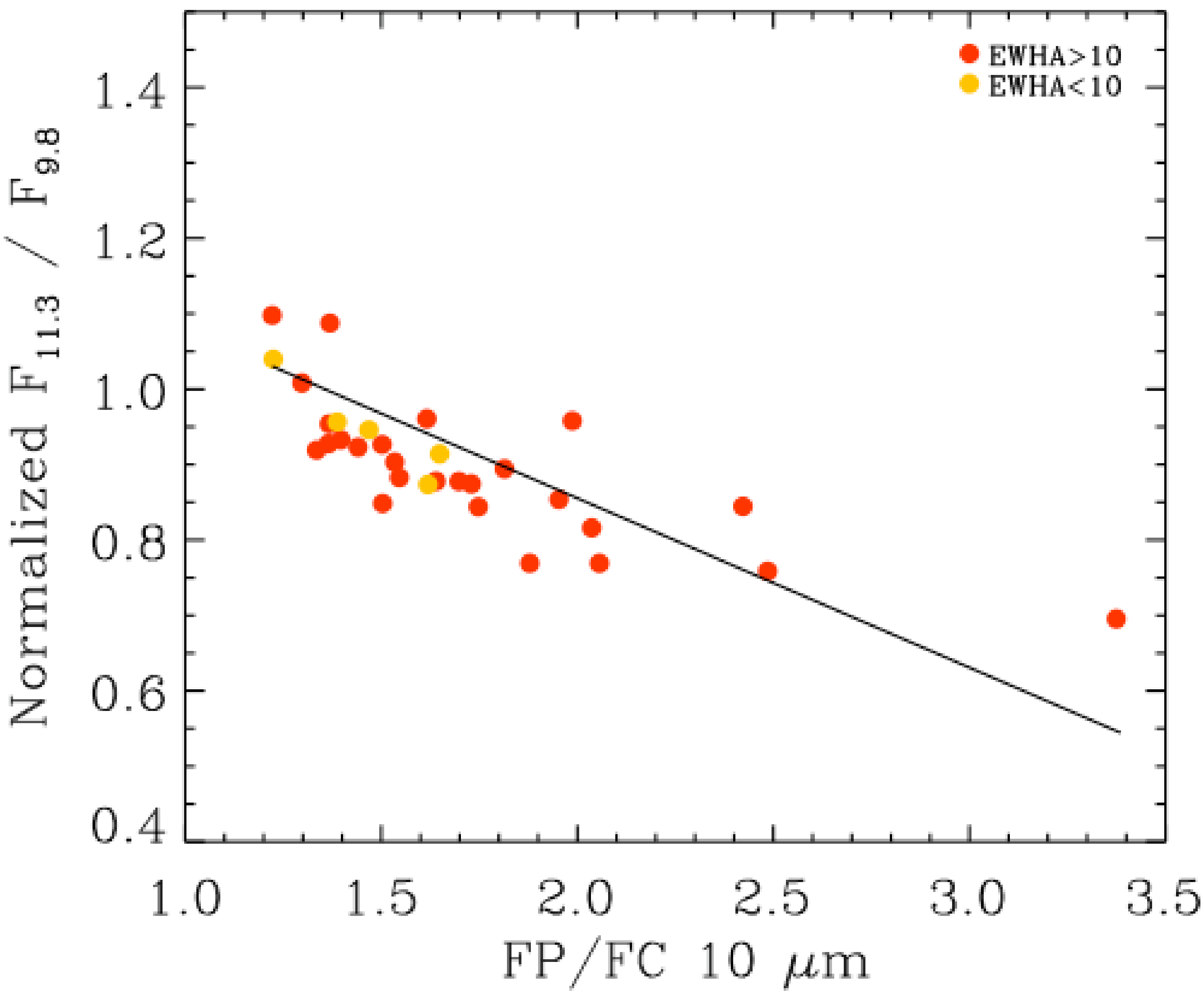




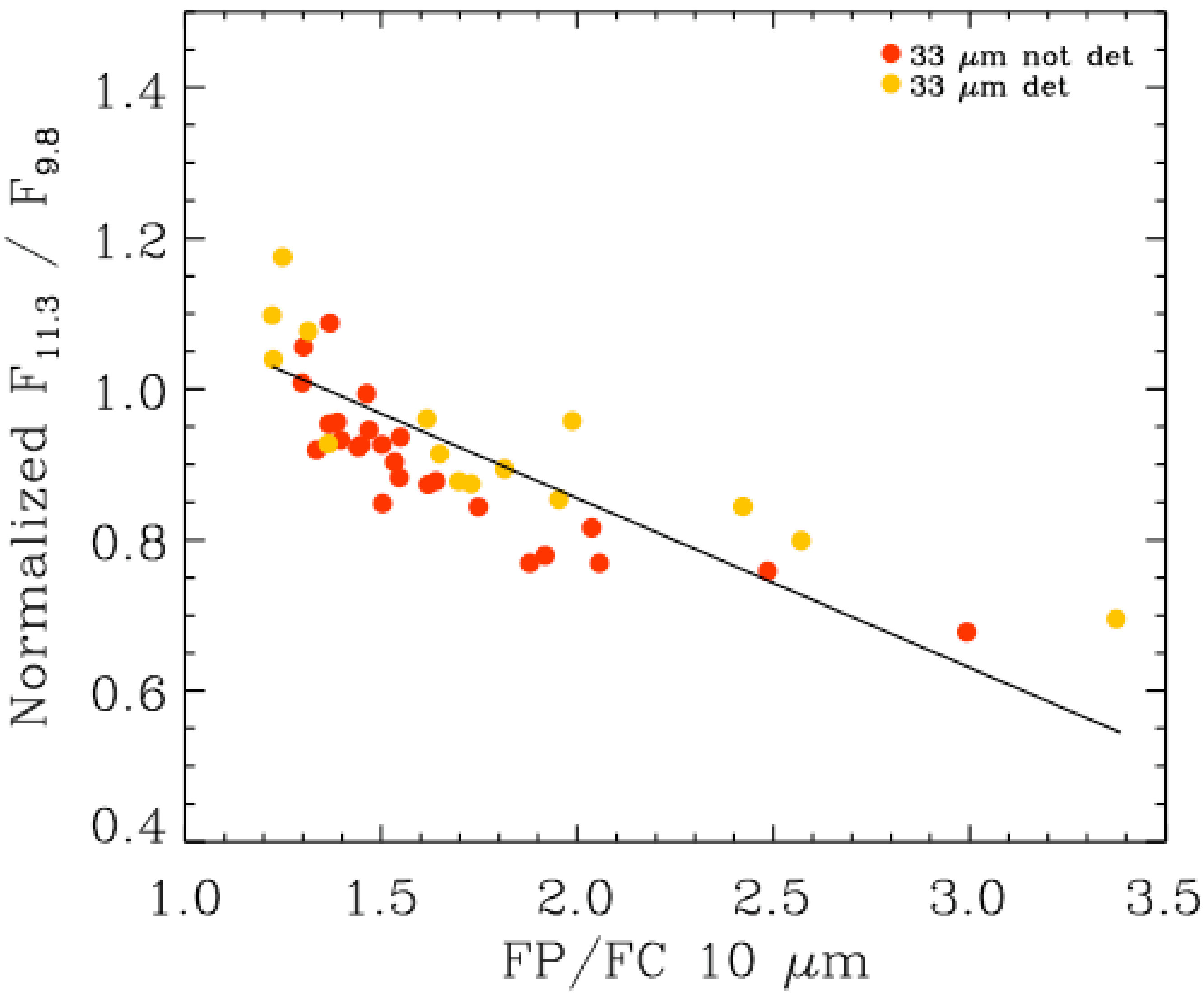
B
A
F
G
K
M
B(lit)
A(lit)
F(lit)
G(lit)
K(lit)
M(lit)
FP/FC (11.3 / 9.8)
<1 Myr
1-2 Myr
2-3 Myr
3-4 Myr
4-5 Myr
5-6 Myr
>6 Myr
Normalized $F_{11.3}$ / $F_{9.8}$
FP/FC 10 μm



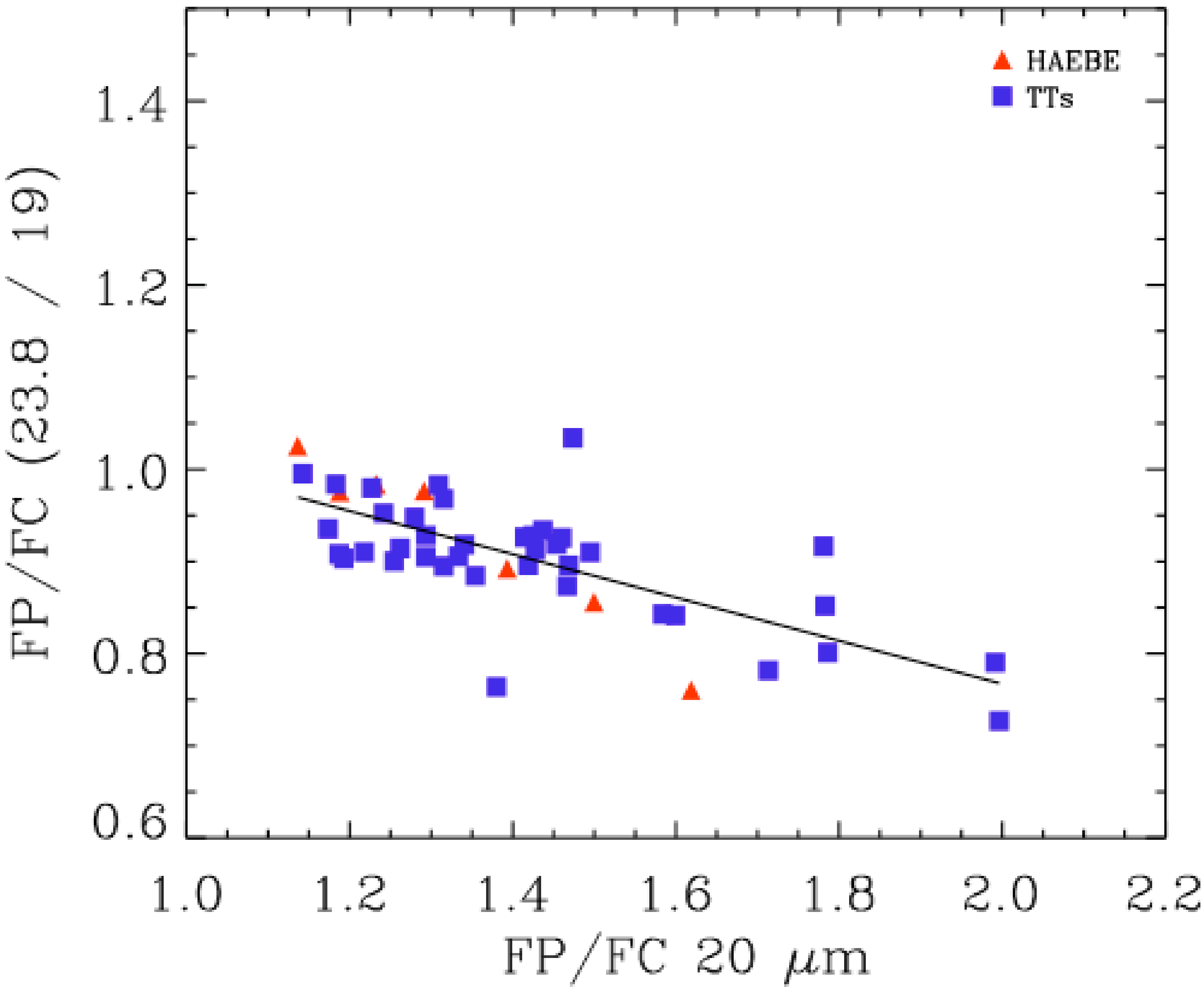
<1 Myr
1-2 Myr
2-3 Myr
3-4 Myr
4-5 Myr
5-6 Myr
>6 Myr
Normalized F11.3 / F9.8
FP/FC 10 μm
1.4
1.2
1.0
0.8
0.6
0.4
1.0
1.5
2.0
2.5
3.0
3.5



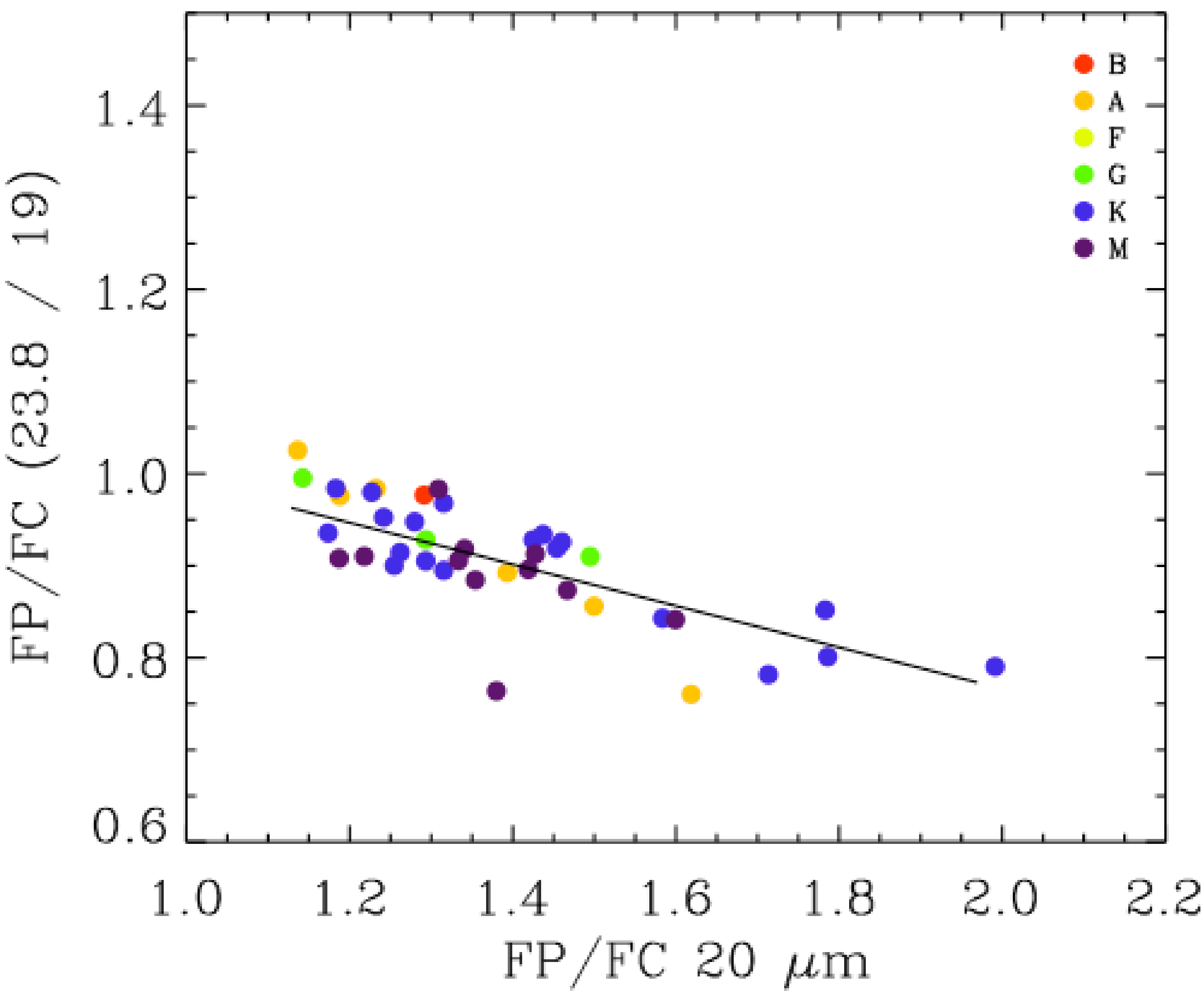
EWHA>10
EWHA<10
1.4
1.2
1.0
0.8
0.6
0.4
Normalized F11.3 / F9.8
1.0
1.5
2.0
2.5
3.0
3.5
FP/FC 10 μm



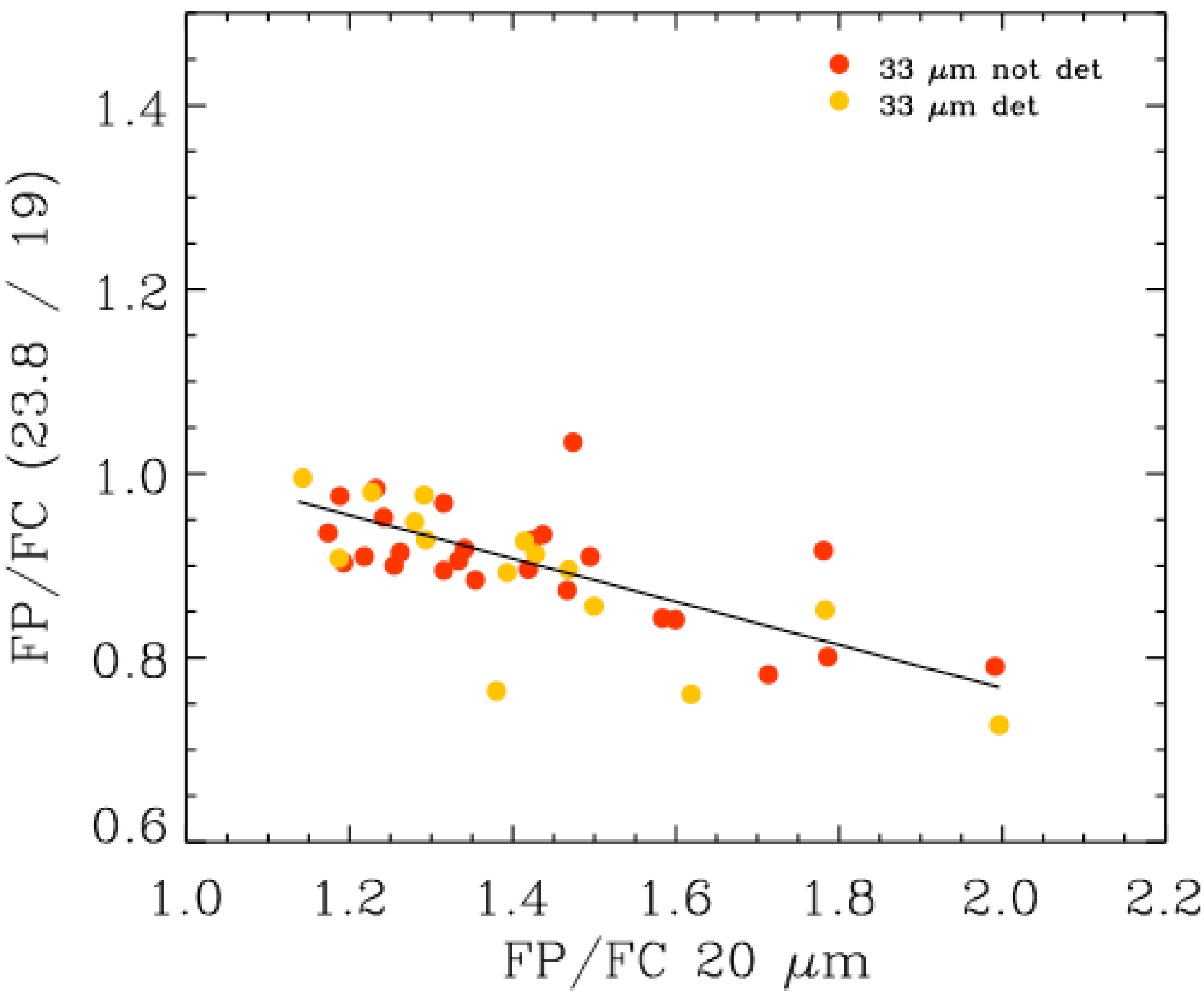
33 μm not det
33 μm det
1.4
1.2
1.0
0.8
0.6
0.4
Normalized F11.3 / F9.8
1.0
1.5
2.0
2.5
3.0
3.5
FP/FC 10 μm



HAEBE
TTs
1.4
1.2
1.0
0.8
0.6
FP/FC (23.8 / 19)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
FP/FC 20 μm



B
A
F
G
K
M
1.4
1.2
1.0
0.8
0.6
FP/FC (23.8 / 19)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
FP/FC 20 μm



33 μm not det
33 μm det
1.4
1.2
1.0
0.8
0.6
FP/FC (23.8 / 19)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
FP/FC 20 μm