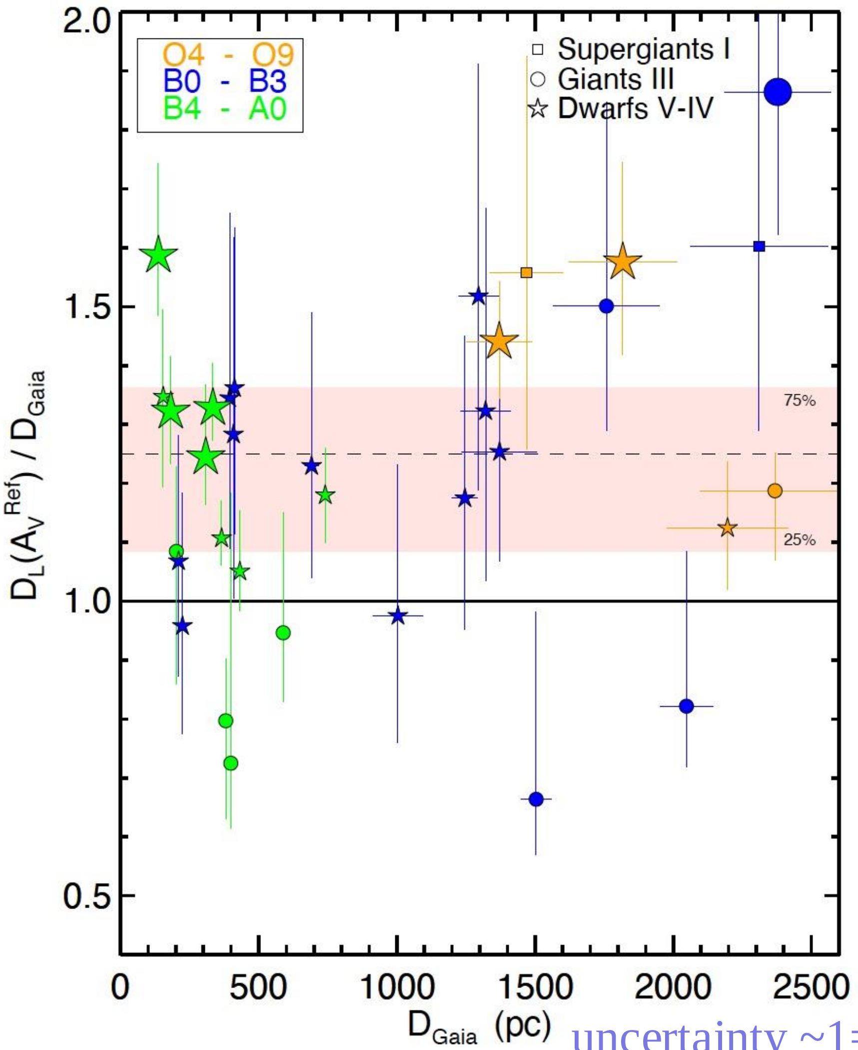
Luminosity distance and grey extinction

- The distance to the stars
- Dust model of the diffuse ISM (S23)
- Scrutinizing MW reddening curves (S23+)
- Model of the absolute reddening towards stars
- Unification of distances (astroph)
- Discussion: HH108 + new data

The distance puzzle



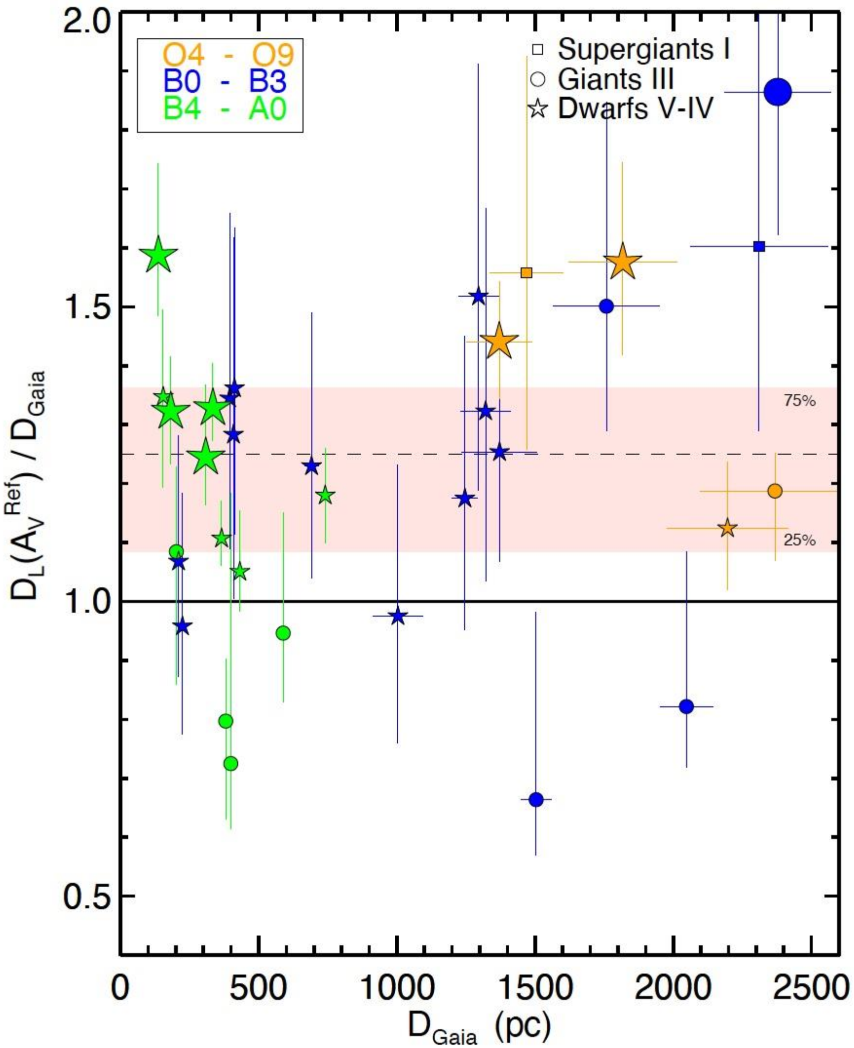
uncertainty ~1=2%

$$5 \log(\mathbf{D_L}) = 5+V-M_V - \mathbf{A_V}$$

A_V ~ E (B-V) * R_V
Valencic+04, Fitzpartick&Massa07, Gordon+09

M_V : Bowen+08, Wegner+07

The distance puzzle



$D_L > D_{GAIA}$

- Compensate overestimate of luminosity distance by dimming of light
- enhance $\mathbf{A_V}$

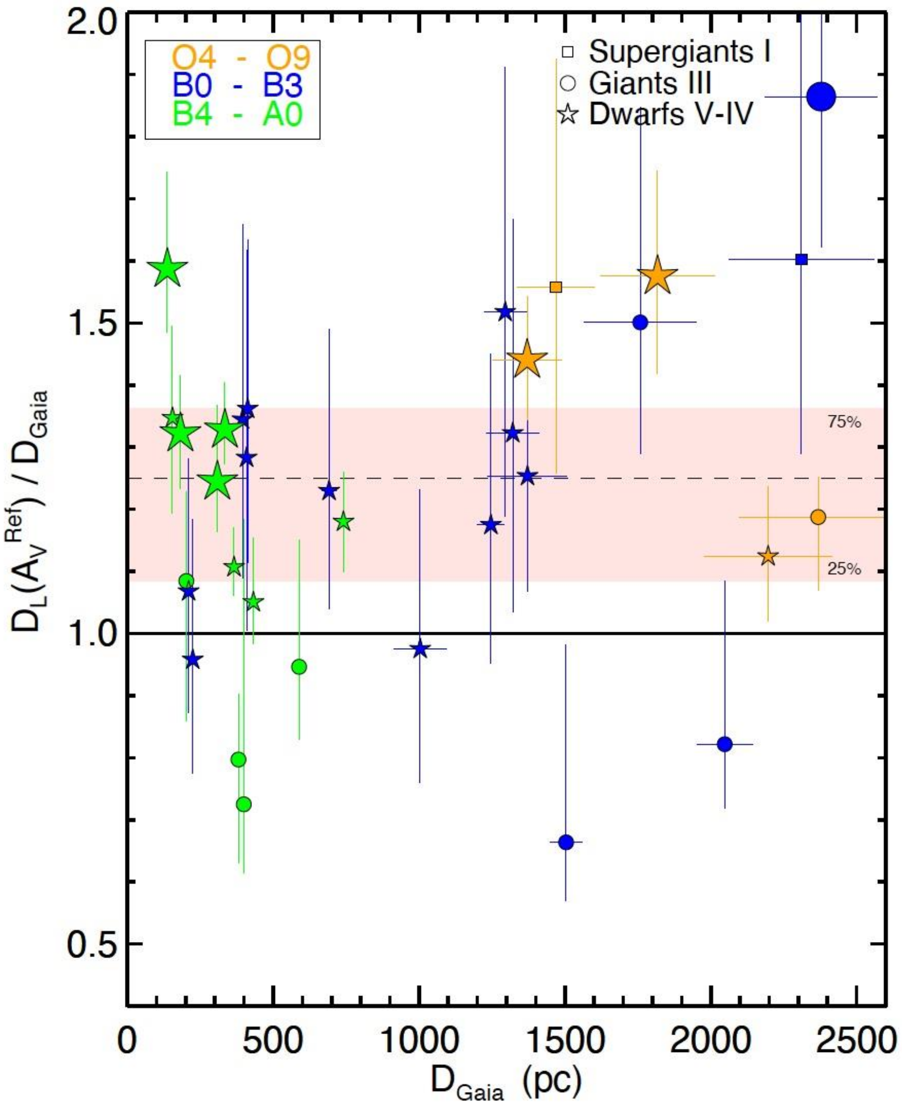
$$5 \log(\mathbf{D_L}) = 5 + V - M_V - \mathbf{A_V}$$

$A_V \sim E(B\text{-}V) * R_V$

Valencic+04, Fitzpartick&Massa07, Gordon+09

M_V : Bowen+08, Wegner+07

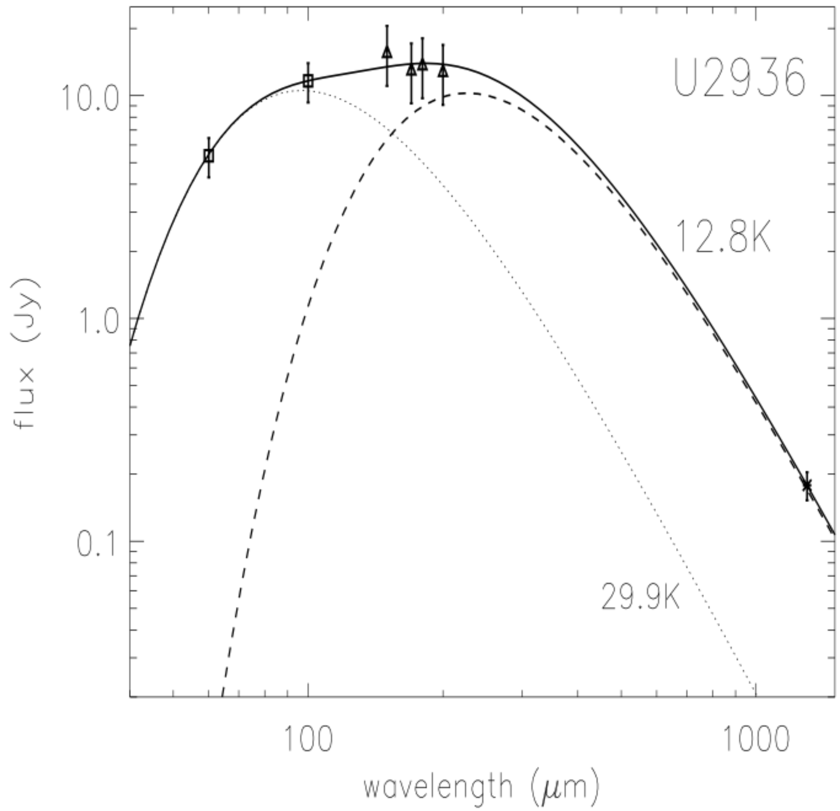
Distance unification



Dimming by :

- ‘meteoritic bodies’(Trumpler, 1930)
- subμm –sized grains (S23)

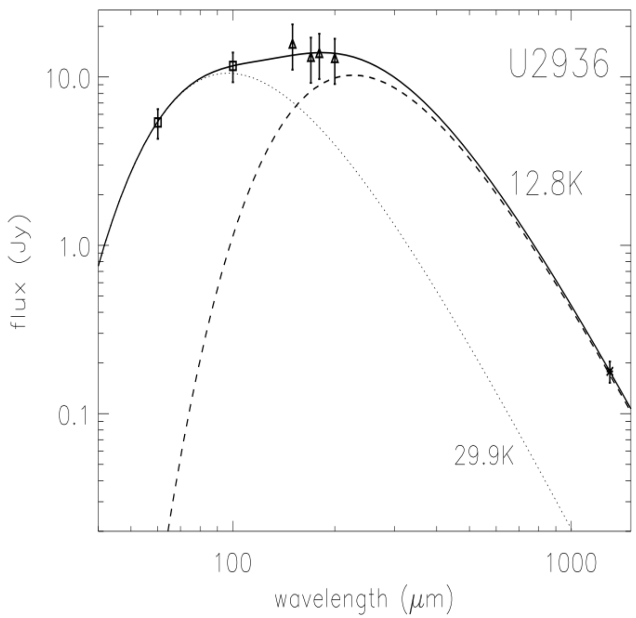
The distance puzzle and very cold dust emission in Galaxies



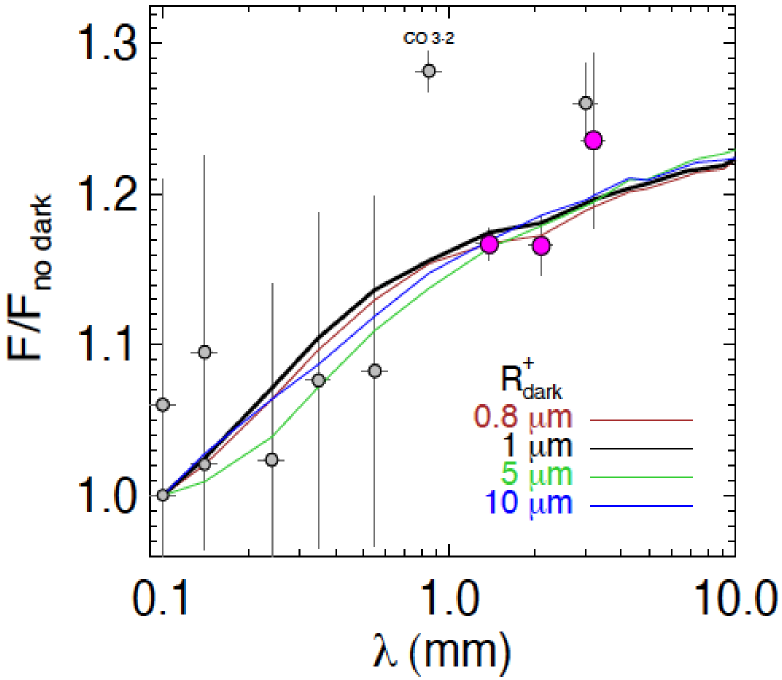
Submm excess galaxies:
- ISO – Spirals (Siebenmorgen+99)
- Herschel (Remy-Ryter+15)
- ALMA (Galiano+, Galametz’14)

Degeneracy in SED fit:
- Chance of slope β (commonly applied)
- Very cold dust (Chini+93, KS95, S99)

Submm slope vs. very cold dust emission



PLANCK (Guillet+18): mm-excess in the MW



Degeneracy in SED fit:

- Chance of slope β (commonly applied)
- Very cold dust (S99) → enhance $\mathbf{A}_V$ for distance unification

Observational constraints (Hensley & Draine 21)

a) Solid phase element abundances

b) Wavelength dependant reddening

c) Star-light polarization

d) Dust emission of polarized + unpolarised light

e) Account for emission in the mm continuum (PLANCK: Guillet'18)

f) + … distance unification $D_L = D_{Gaia}$ (Siebenmorgen+24)

A&A 670, A115 (2023)

Dark dust

II. Properties in the general field of the diffuse ISM

R. Siebenmorgen

Three component dust model

a) Nano-particles	< 6 nm	vSi, vGr, and PAH
b) Amorphous spheroids	6 nm < a < 300 nm	aC and silicates (aSi)
c) Sub-µm grains	mean radius < 1µm	grown to fluffy Si + C conglomerates

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Notation:

Dark dust — There is dark gas why not dark dust but provocative …

Gray extinction
Non-selective reddening
Constant extinction
} only in the optical/UV

Micrometer grains
- In-situ detected by spacecrafts (Ulysses, Galileo, Stardust)
- Introduced by Wang+15 to account for flat IR reddening
- Number at ppm level compared to 10Å particles

Sub-µm grains — Reflects the mean grain radius

Three component dust model

a) Nano-particles	< 6 nm	vSi, vGr, and PAH
b) Amorphous spheroids	6 nm $< a < 300$ nm	aC and silicates (aSi)
c) Sub-µm grains	mean radius $< 1\mu$m	grown to fluffy Si + C conglomerates

Model parameters

- Abundances [X]/[H] or specific mass (%) of 6-1 dust components
- Size parameters: exponent q, upper radii: r^+_{Si}, r^+_C, r^+_μ
- Polarization alignment radii r^p_{Si}, r^p_C

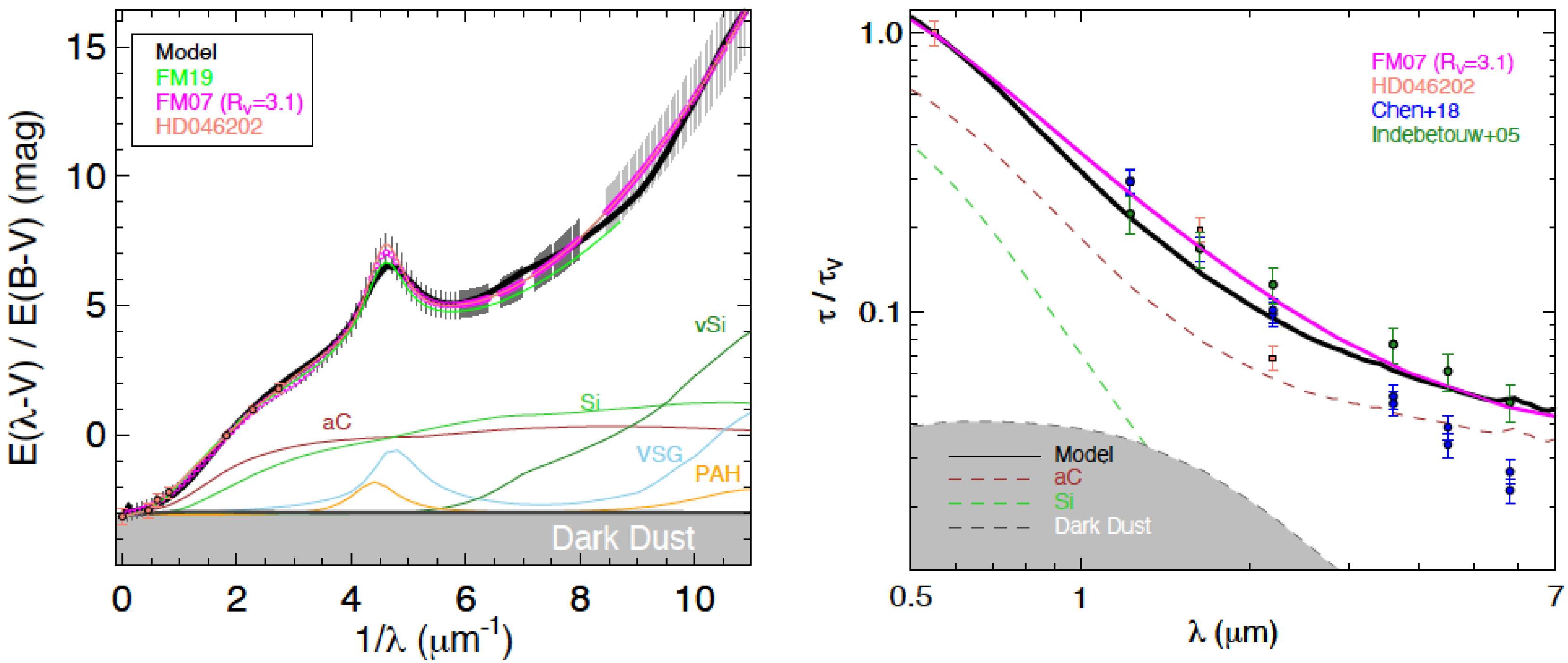
Dust in the general field of the diffuse ISM

a) Solid phase element abundances

All models respect: $[C] / [Si] < 5.2$

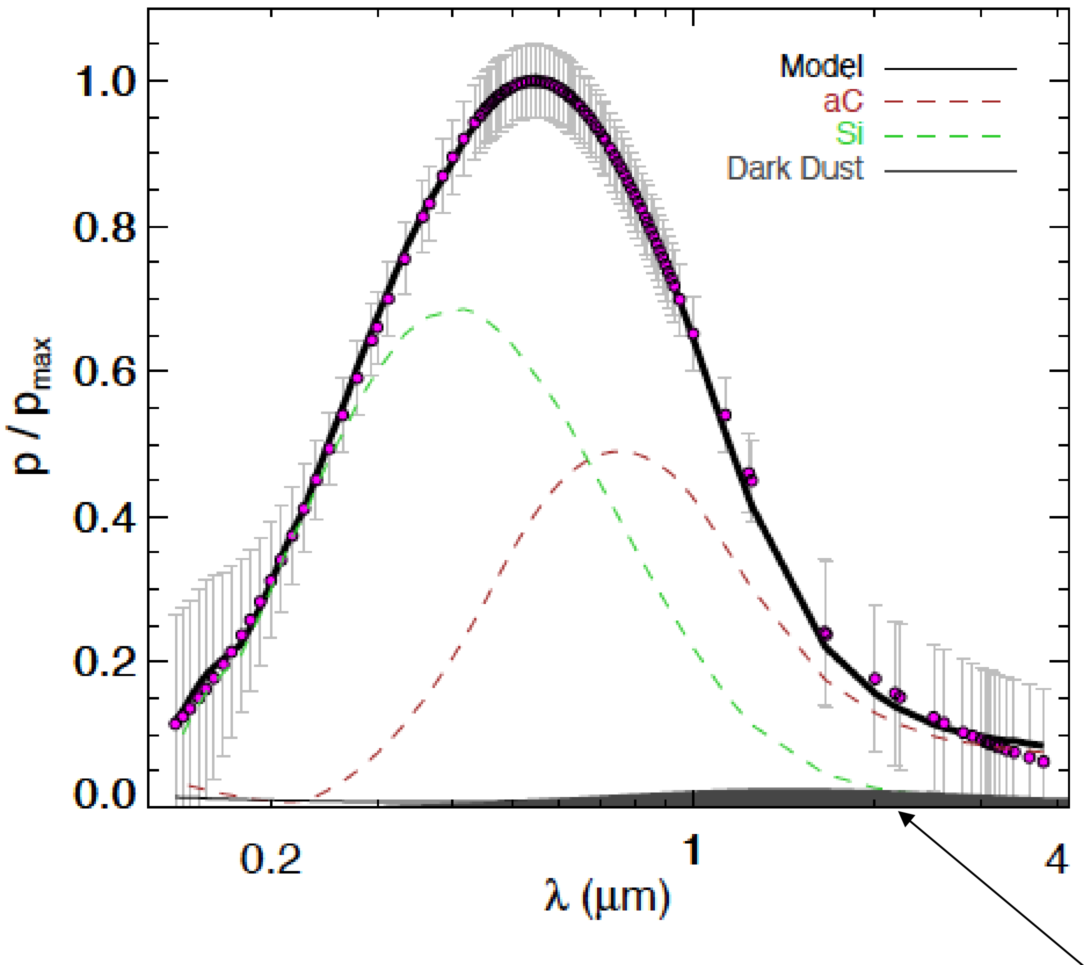
This simple constraint + assumed stoichiometry fit the observed and still debated depletion of main absorbing elements.

Dust in the general field of the diffuse ISM
b) Reddening



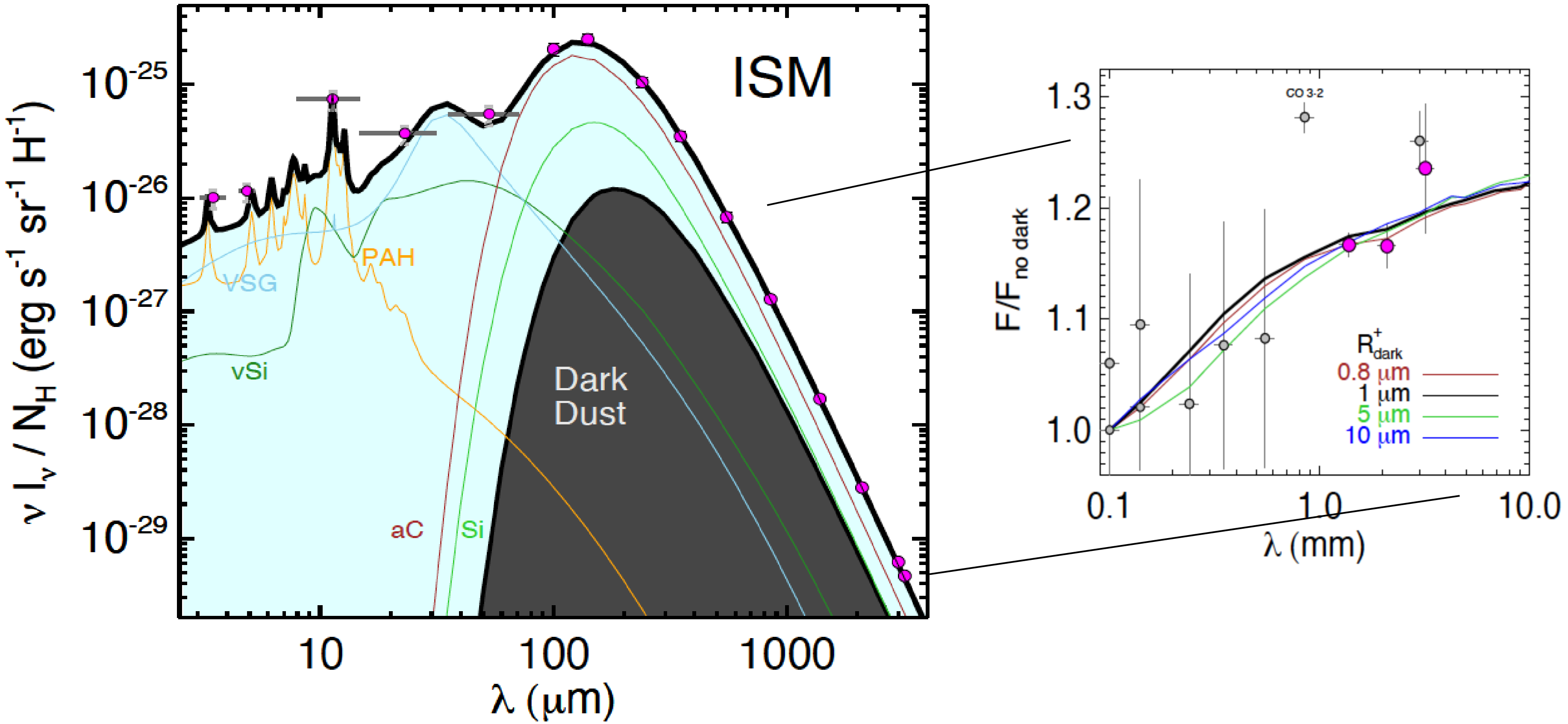
Dark dust reddening at $\lambda \leq 1\mu m$ is flat, non-selective, gray

Dust in the general field of the diffuse ISM
c) Starlight polarisation

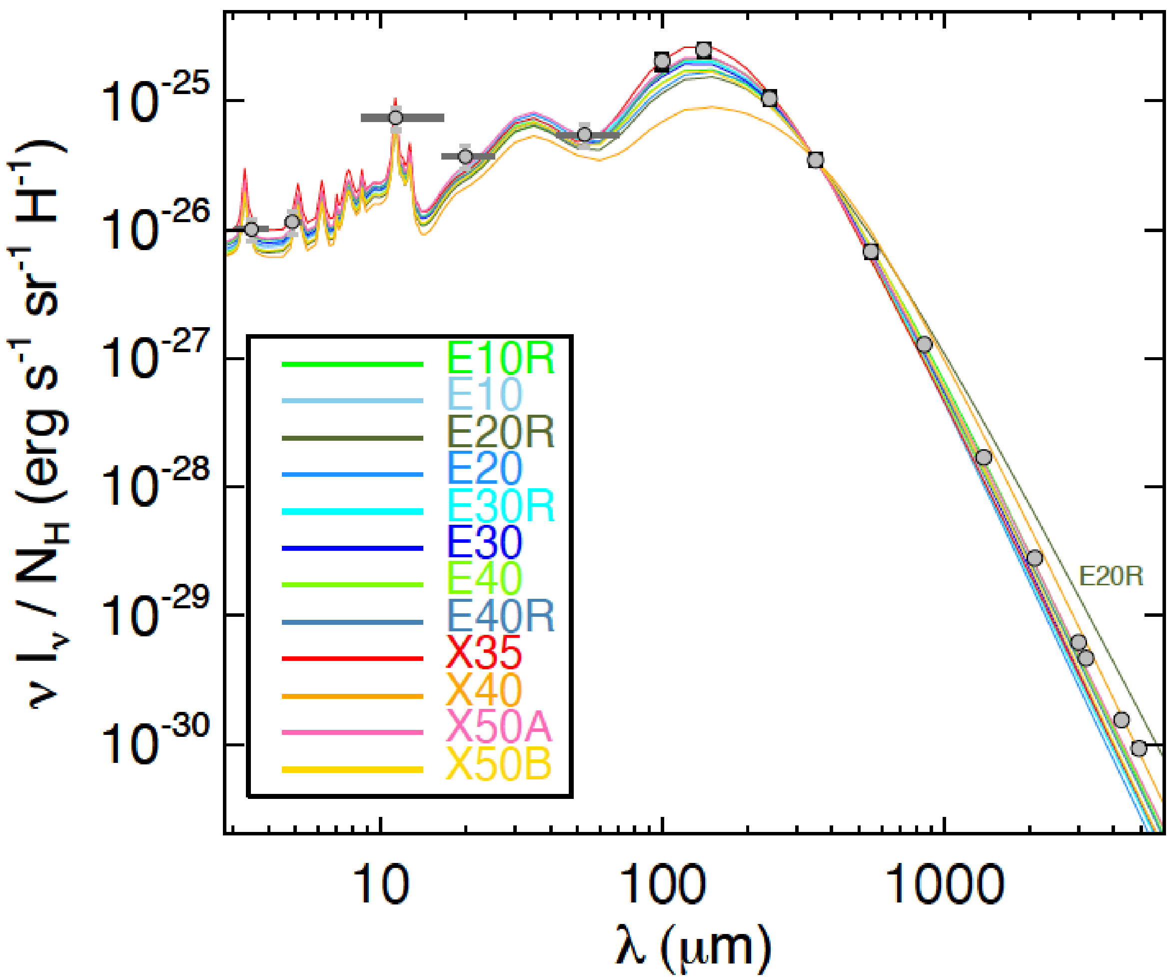


Sub-µm grains: no /marginal contribution to the optical / IR

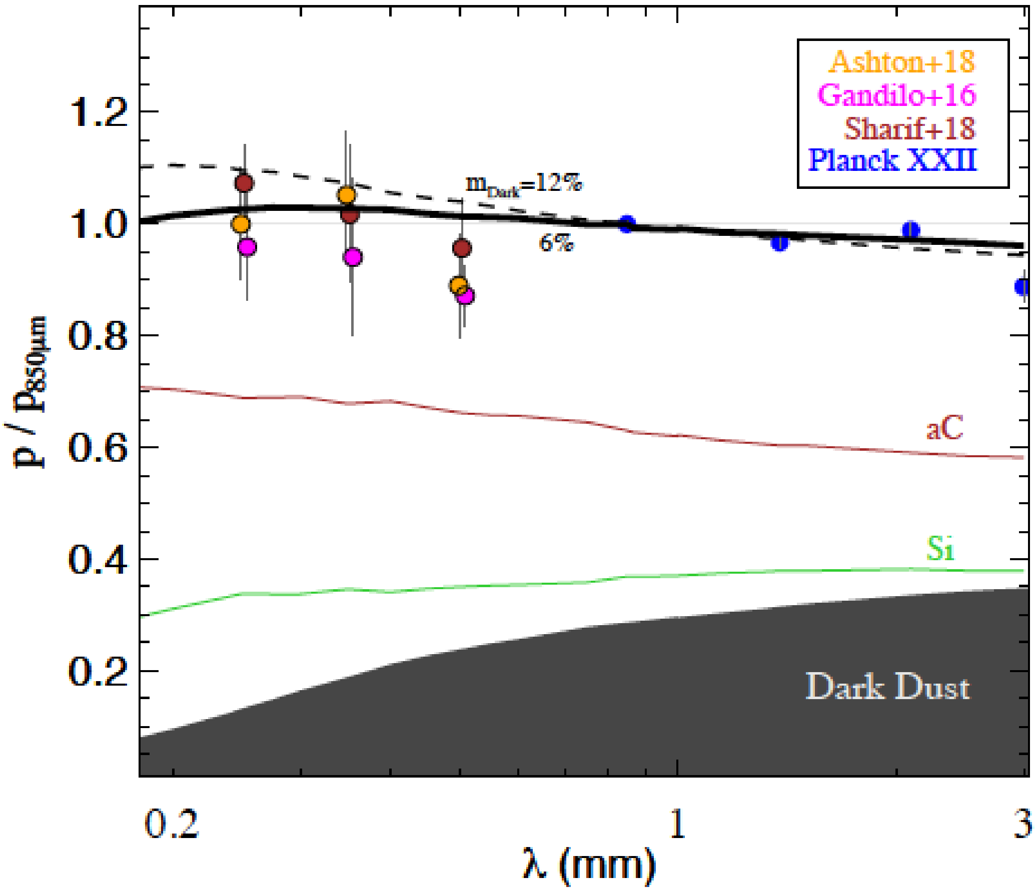
Dust in the general field of the diffuse ISM
d) Emission + mm excess



Dust in the general field of the diffuse ISM
Mix of new (n,k) of amorphous Si (Demyk+22)



Dust in the general field of the diffuse ISM
d) Polarised emission



← contribute

Submm/optical polarisation:

$$p_{850\mu m} \Big/ (p_V/\tau_V) = 4.3$$ (PLANCK- Guillet+18)

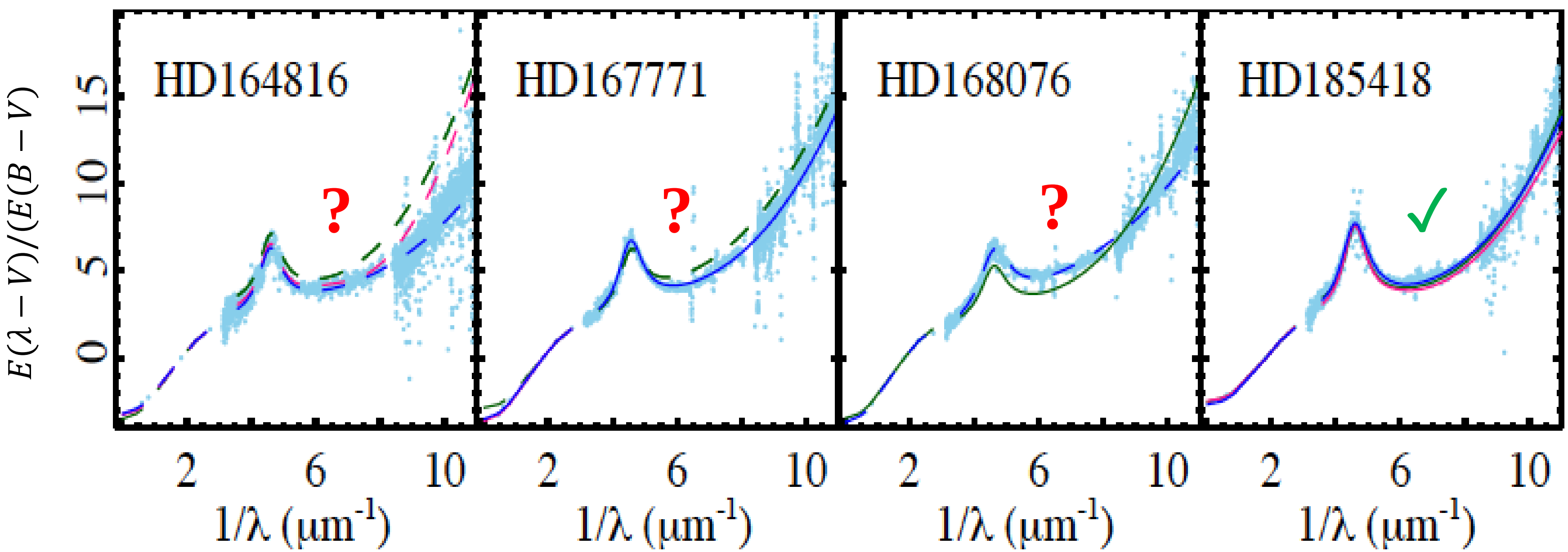
From the general field

to

individual sightlines / stars

Dark Dust. III. The high-quality single-cloud reddening curve sample. Scrutinizing extinction curves in the Milky Way.

R. Siebenmorgen[1], J. Smoker[2,3], J. Krełowski[4], Karl Gordon[5], and Rolf Chini[6,7,8] A&A 2023



544 stars IUE, FUSE

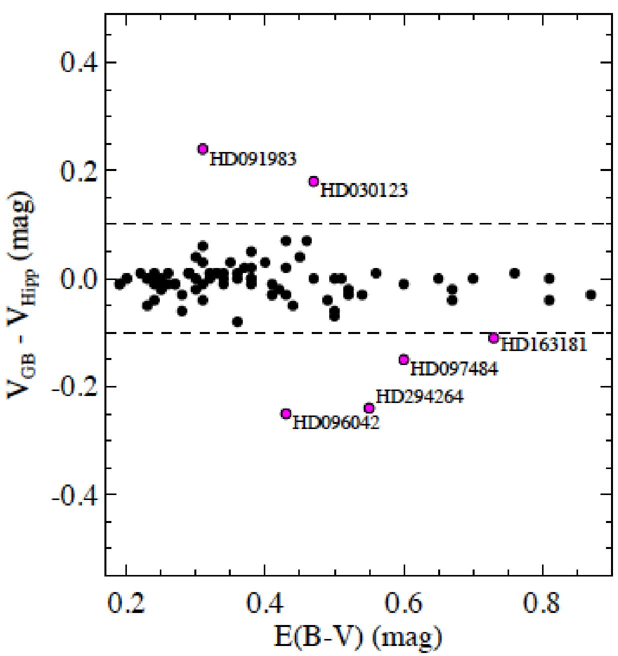
186 " UVES spectroscopy

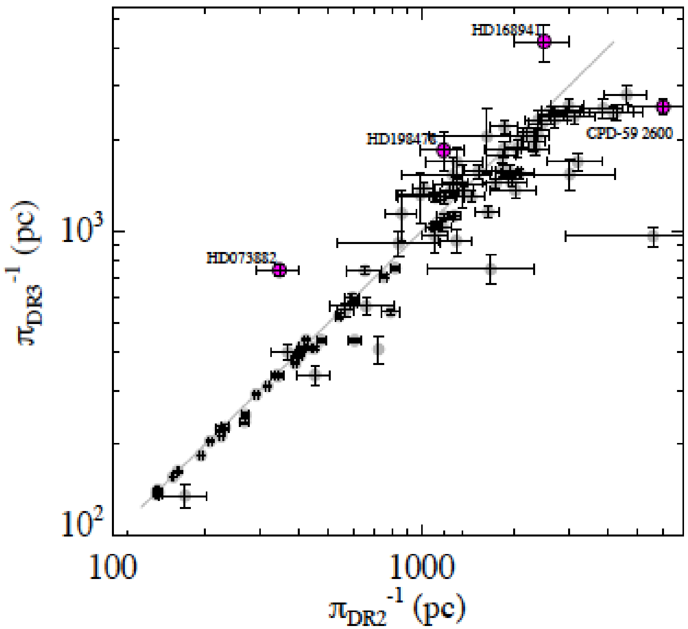
110 " Large IS Polarisation Survey

50 in high-quality sample

Dark dust III - High-quality sample of reddening curves

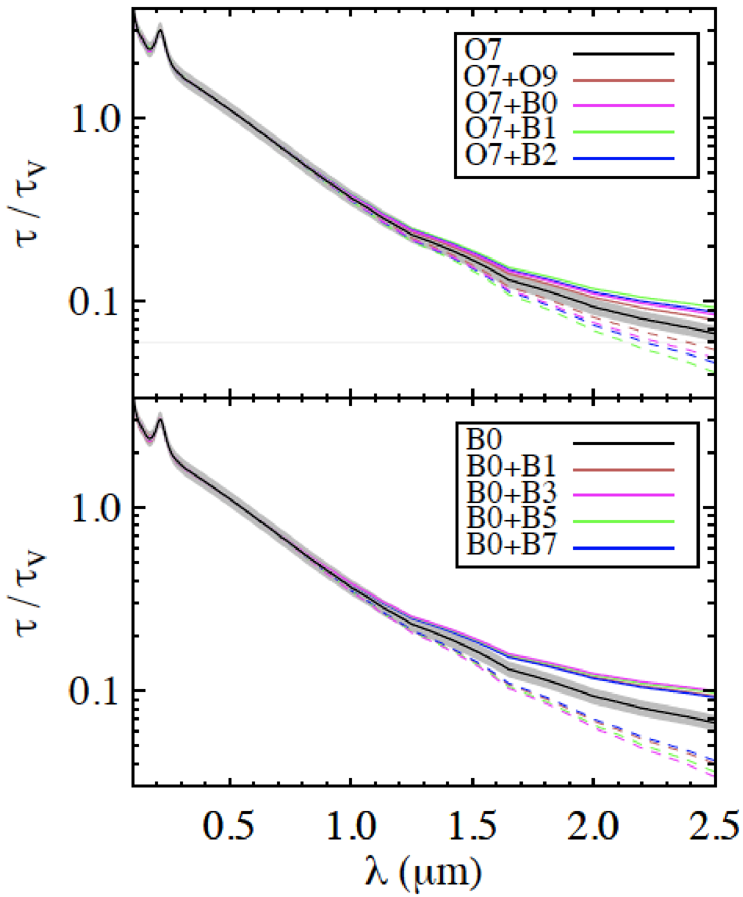
1. No multiple bright sources within 10" ~IUE apertures
2. No variability in photometry
3. No variability in GAIA parallax
4. IR reddening: no emission components
5. Spec type + lum class of reddened +unreddened stars agree and confirmed by UVES



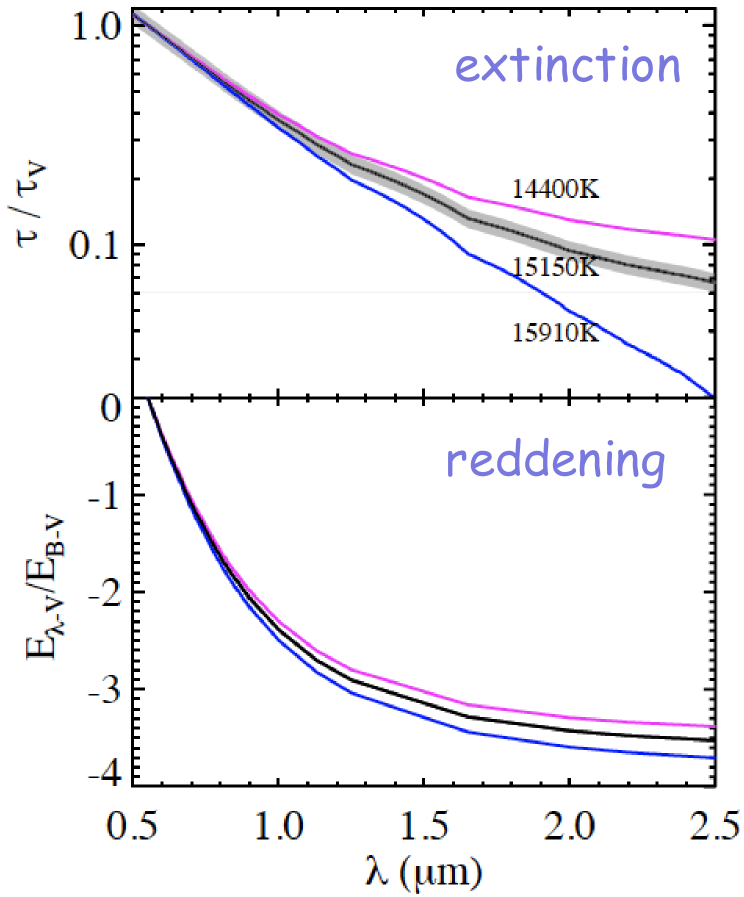


Scrutinizing extinction reddening curves

Impact of binaries



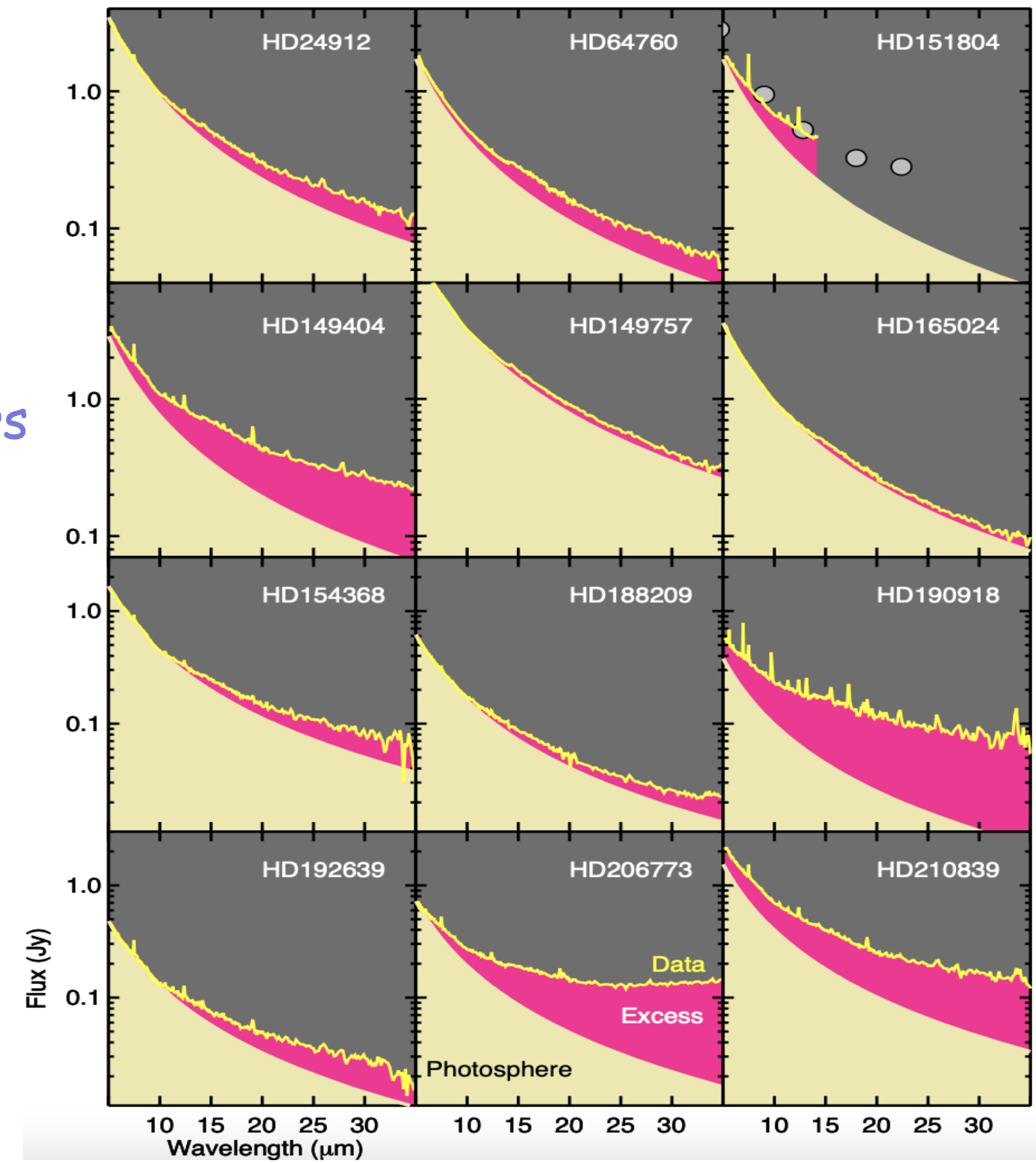
SpL of F_{obs} and F_{nd} differ



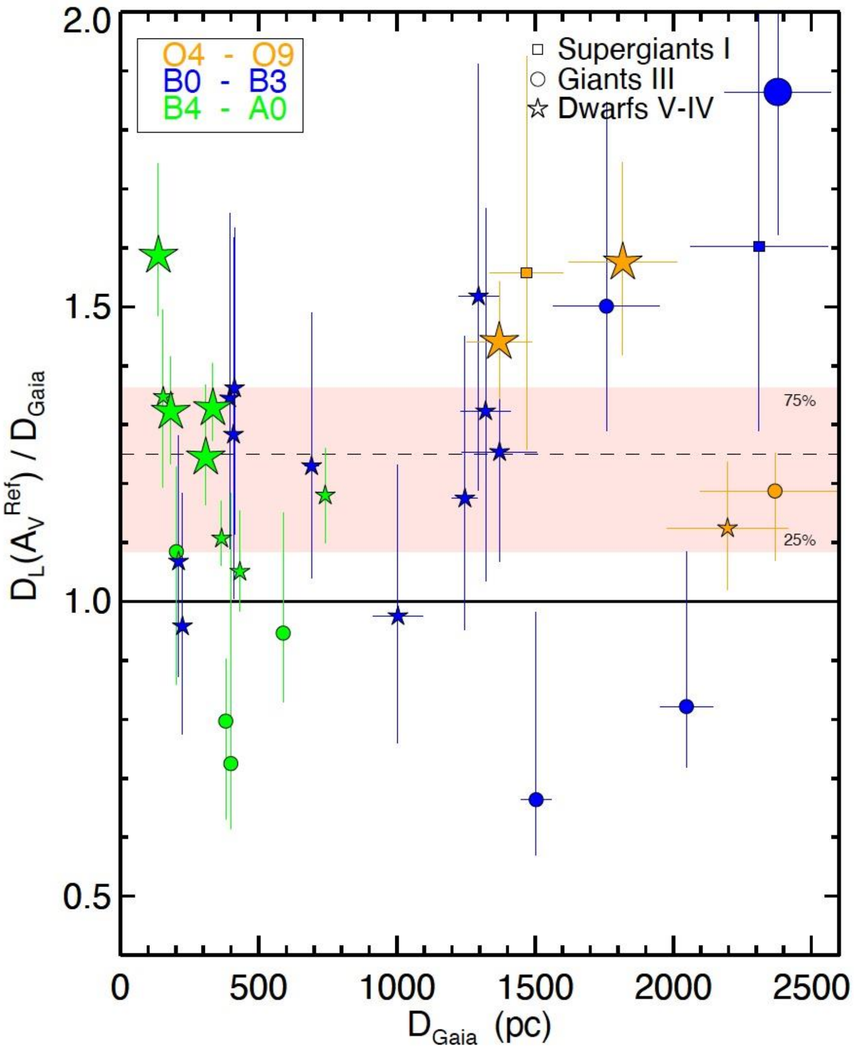
Impact on reddening in the NIR is large

Scrutinizing MIR reddening curves

~50% of OB stars show MIR/FIR excess emission



The distance puzzle



Extrapolated number

$A_V \neq R_V\, E(B-V)$

$A_V = ?$

$$5 \log(\mathbf{D_L}) = 5 + V - M_V - \mathbf{A_V}$$

Distance unification by sub-μm dust

1) Estimate A_V by inserting D_{GAIA} in photometric equation:

$$A_V = V - M_V - 5 \log D_{GAIA} + 5.$$

(1) $\tau_V = N^n K^n_V + N^\mu K^\mu_V$ Extinction cross section K

2) Normalize $N^{n,\mu}$ by observed E(B-V)

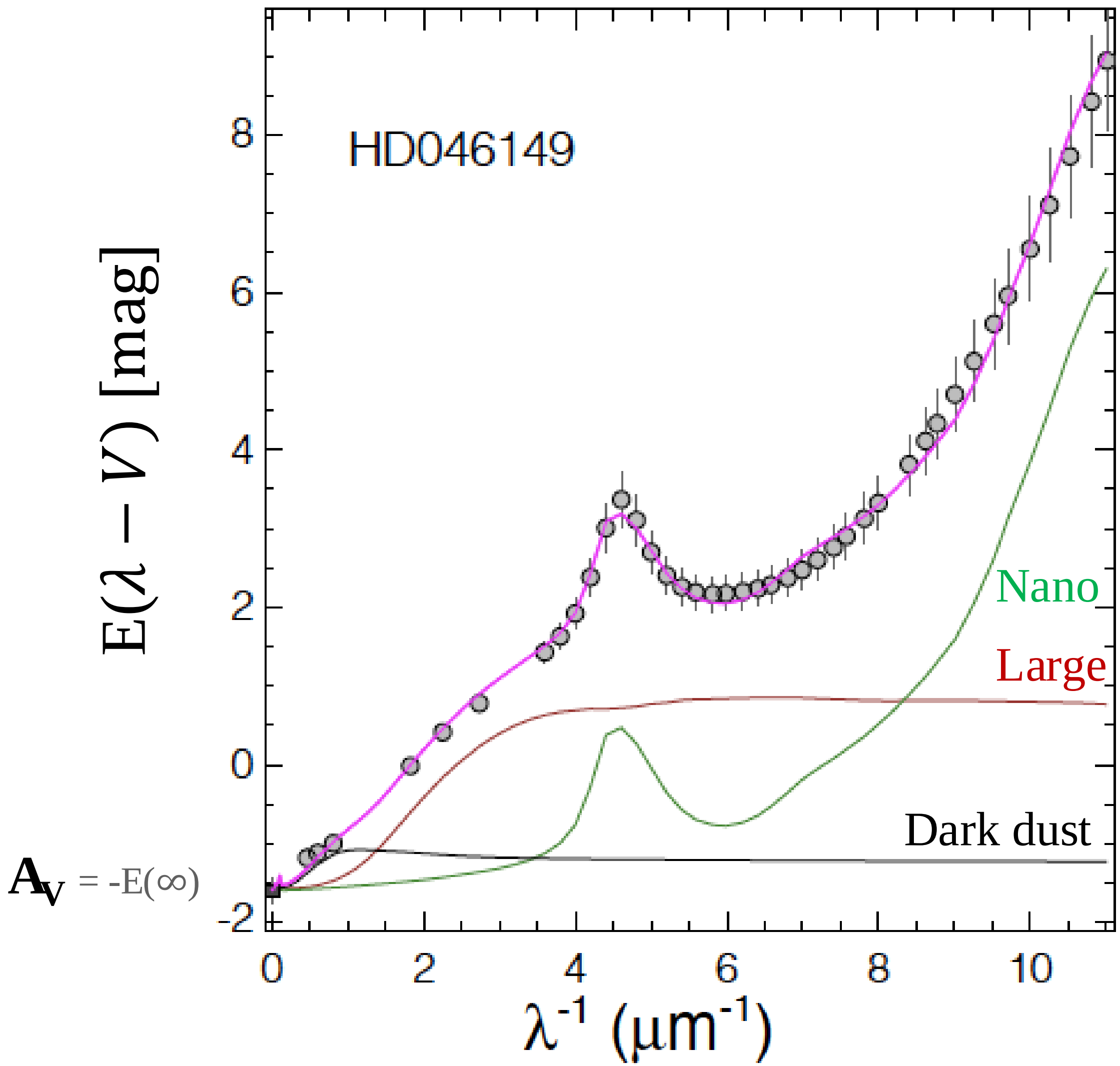
$$E(B-V) = 1.086 (\tau_B - \tau_V)$$

(2) $(\tau_B - \tau_V) = N^n (K^n_B - K^n_V) + N^\mu (K^\mu_B - K^\mu_V)$

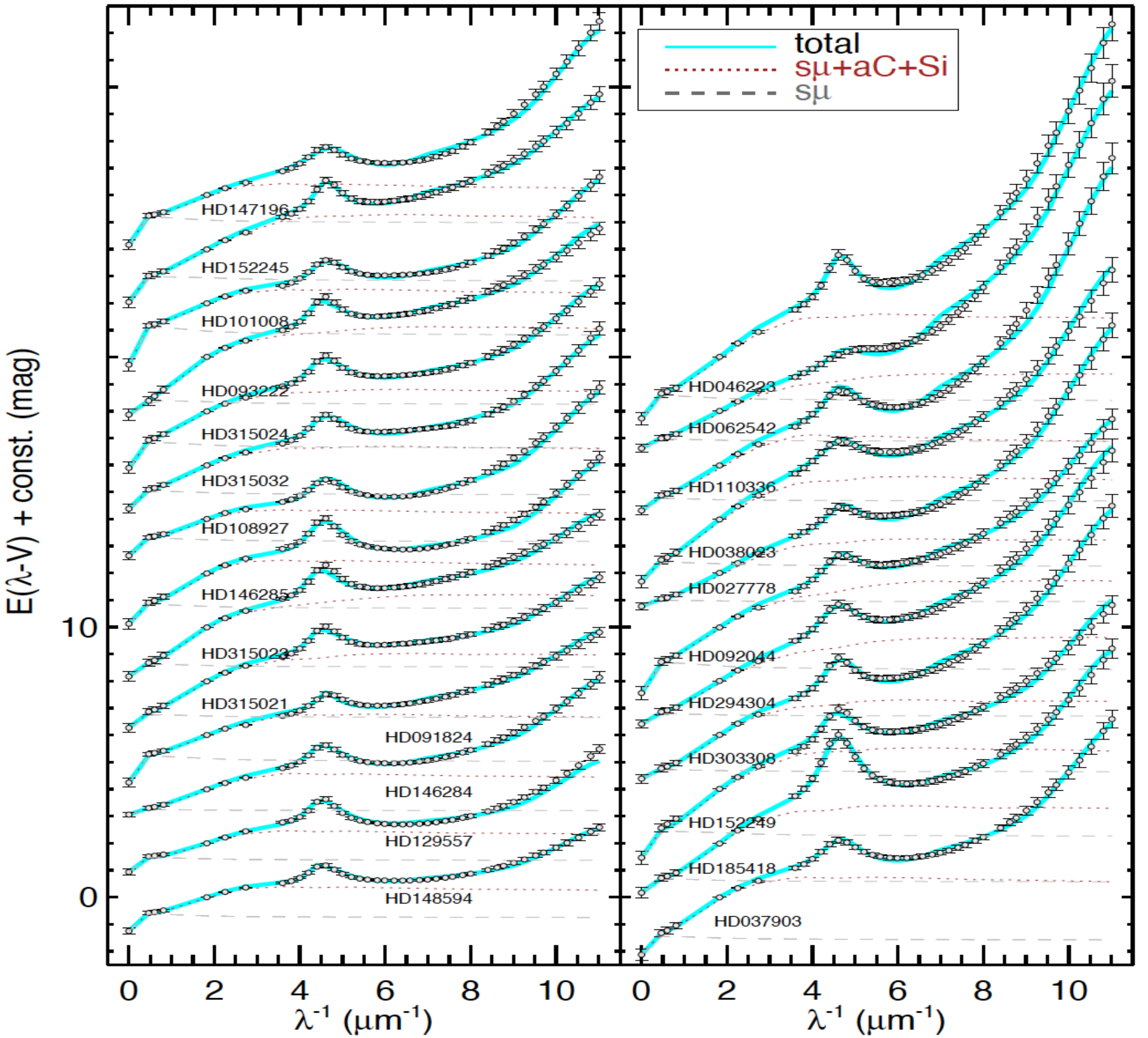
$\Rightarrow$ Model of the absolute reddening

$\Rightarrow$ $D_L = D_{GAIA}$

Model of the absolute reddening



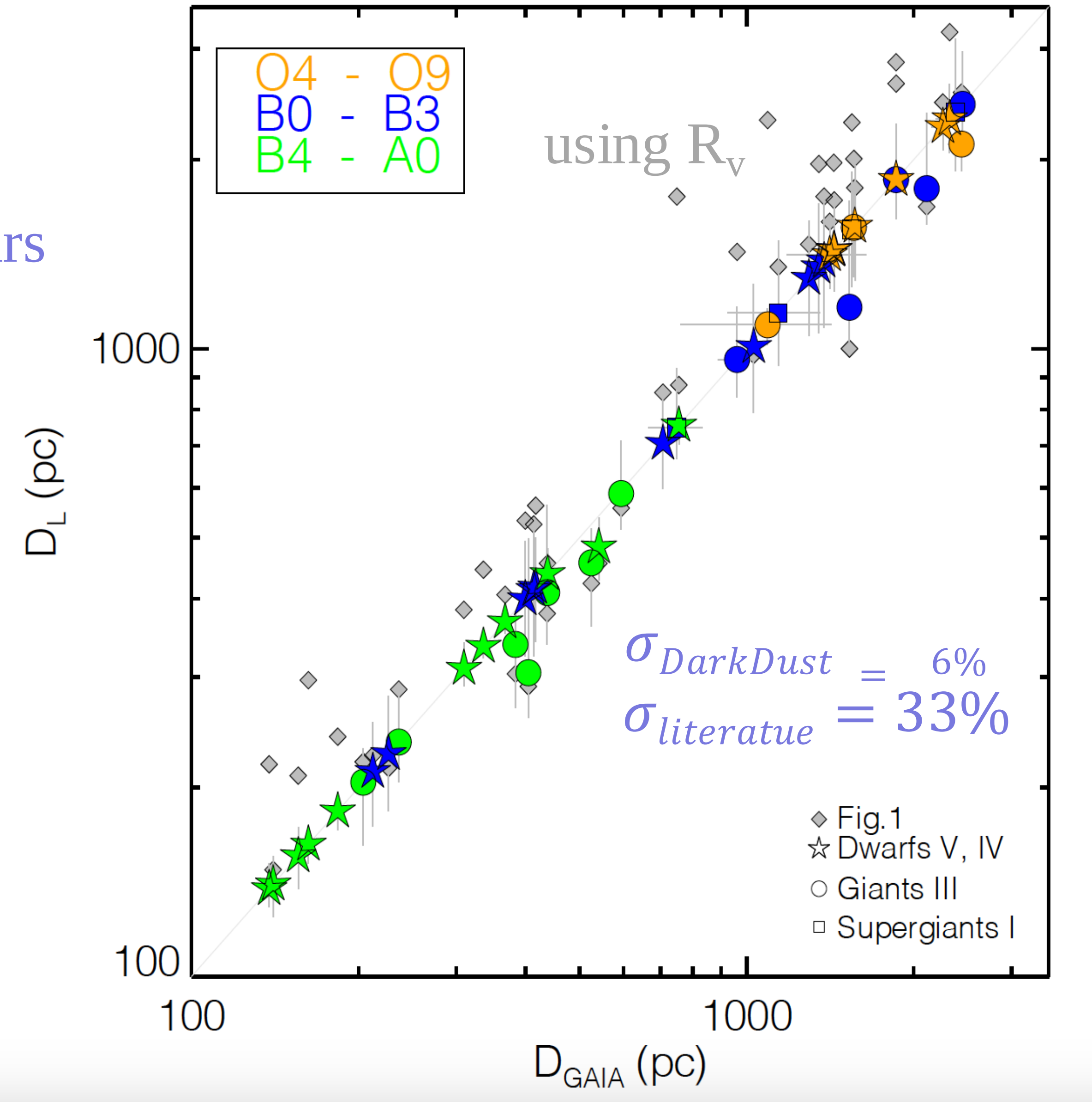
Model of the absolute reddening



27 stars fulfilling A_v + E(B-V) constraints

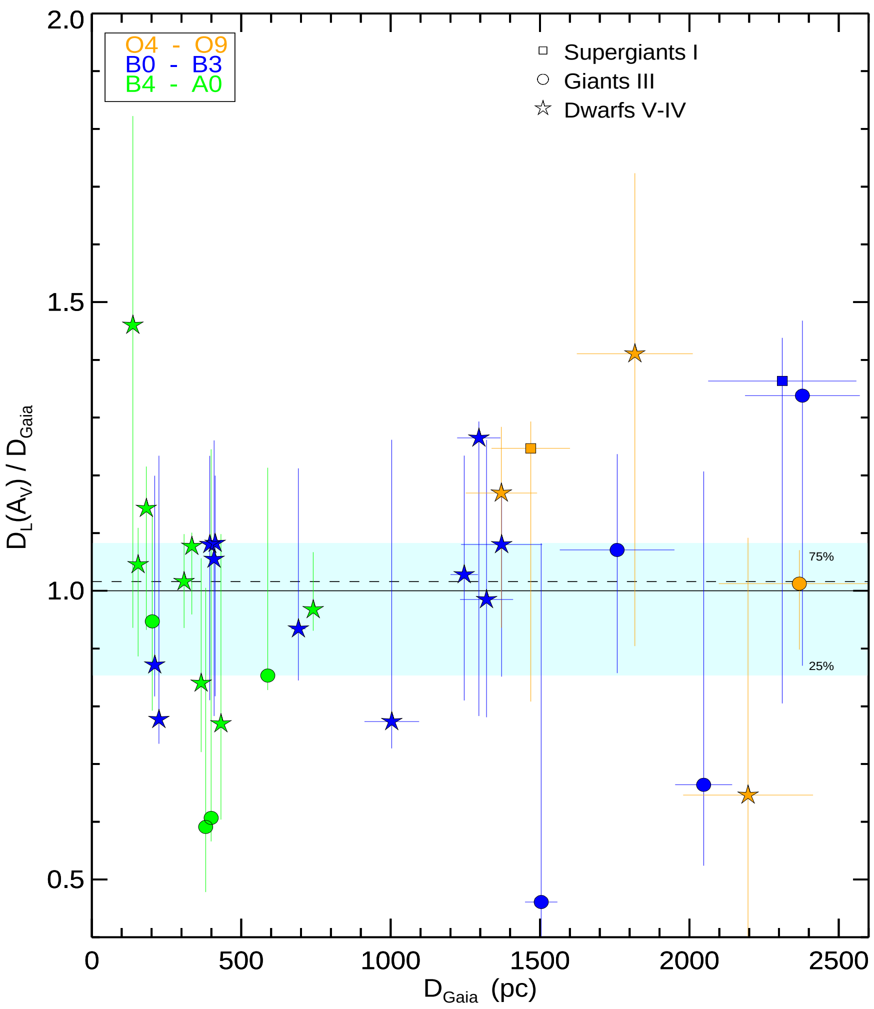
$D_L = D_{GAIA}$

for 27 out of 33 stars



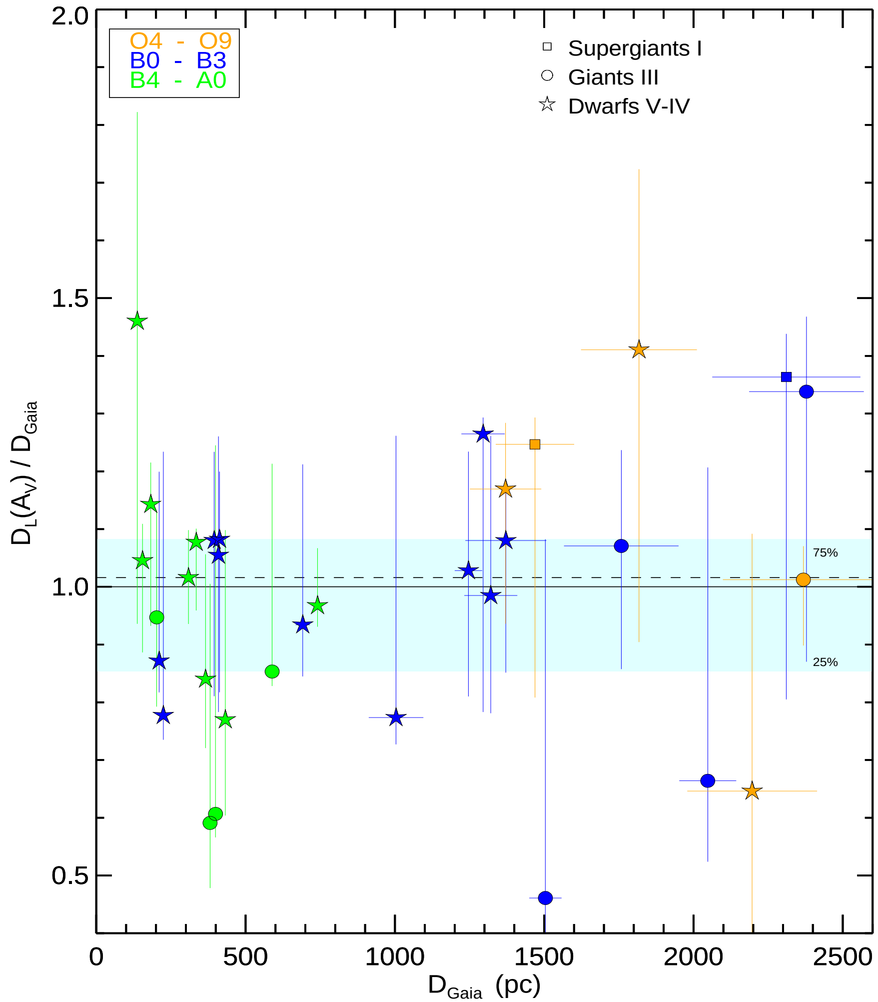
Luminosity distance without knowledge of the (Gaia) trigonometric distance ?

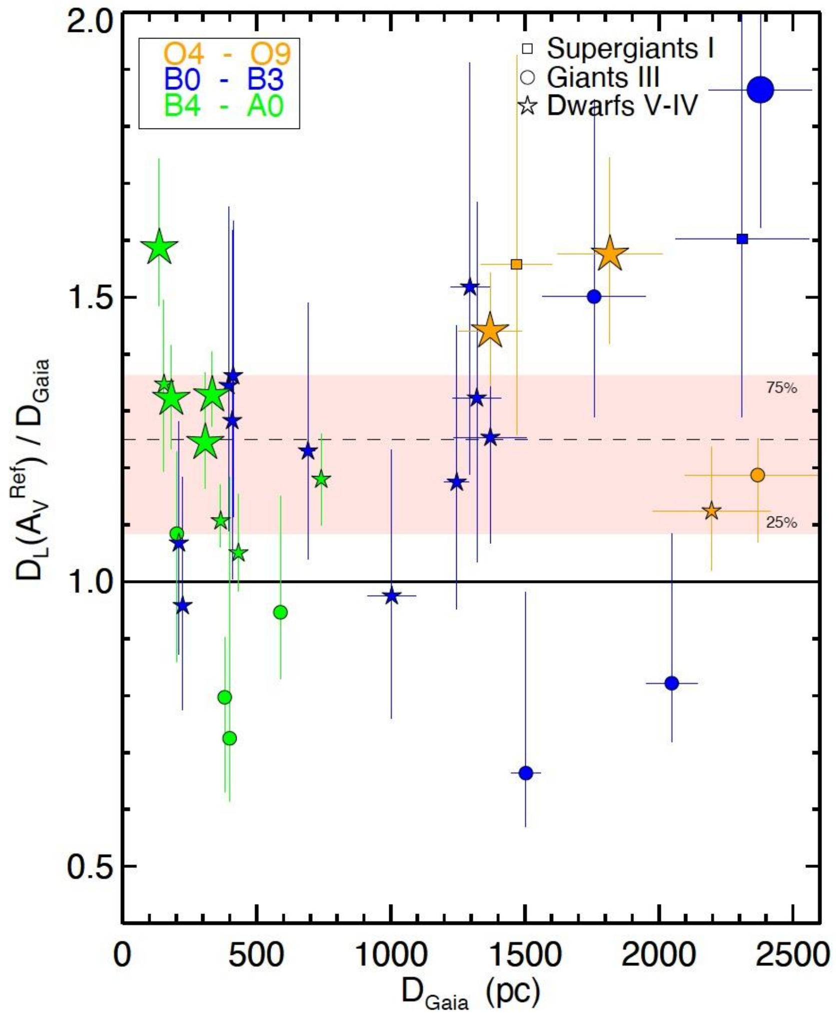
Luminosity distance without Gaia



Assume that half of the dust mass is in sub-μm grains

Luminosity distance without Gaia





Assume that half of the dust mass is in sub-µm grains

Luminosity distance and grey extinction

1. The distance puzzle and very cold dust emission
2. Sub-µm sized "Dark Dust" a not-so-new ISM component
3. Reddening of stars: NIR be careful
4. Do not use extrapolated R_V values
5. Model of the absolute reddening towards stars
6. Unification of distances: $D_L = D_{GAIA}$
7. Overestimate of the luminosity distance D_L can be corrected assuming 50% mass in sub-µm grains

Luminosity distance and grey extinction

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Luminosity distance and grey extinction

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Luminosity distance and grey extinction

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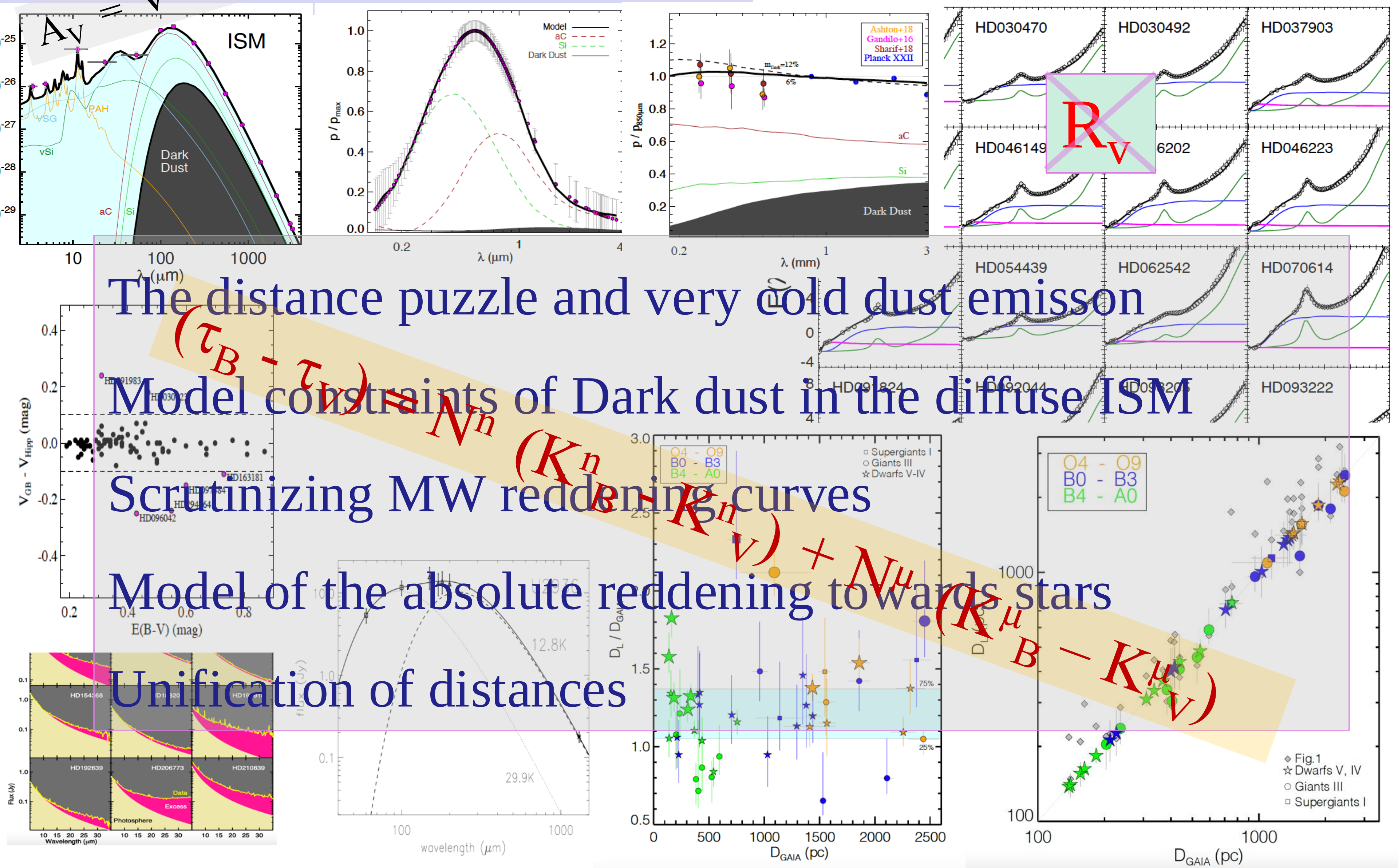
Sub - µm grains
The distance to the stars

$$A_V = V - M_V - 5 \log D_{GAIA} + 5$$



The distance puzzle and very cold dust emisson

Model constraints of Dark dust in the diffuse ISM

Scrutinizing MW reddening curves

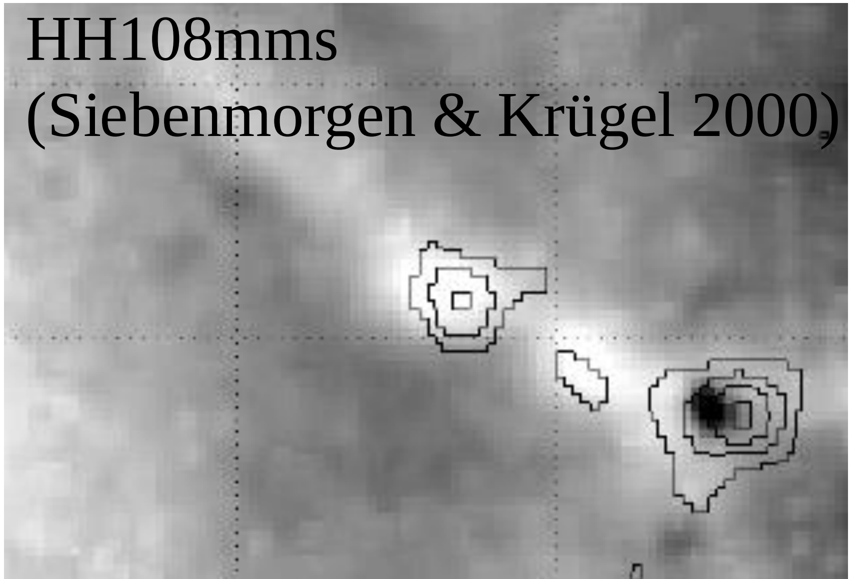
Model of the absolute reddening towards stars

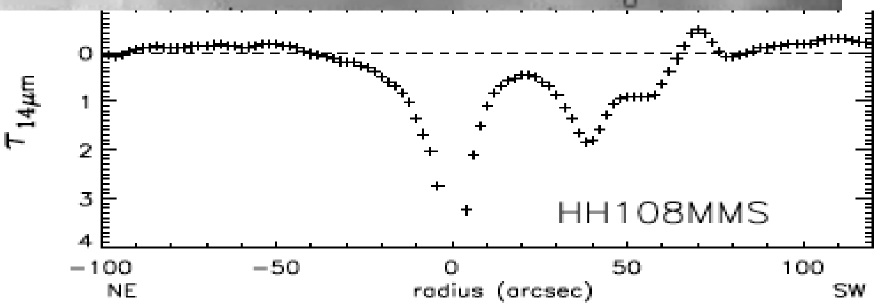
Unification of distances

$$(\tau_B - \tau_V) = N^n (K^n_B - K^n_V) + N^\mu (K^\mu_B - K^\mu_V)$$

Discussion: Dust in ISM vs. proto-planetary disks

HH108mms
(Siebenmorgen & Krügel 2000)



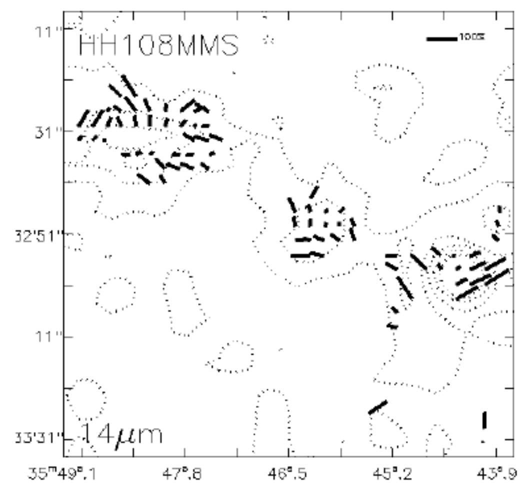


1) seen in absorption at $14\mu m$:

$$\frac{\kappa_{14\mu m}}{\kappa_{1.3mm}} = \frac{(\overline{\tau_2} + 2\tau_1)_{14\mu m}}{\tau_{1.3mm}} \sim 470$$

diffuse ISM ~ 2250 (S23)

2) MIR polarisation:
elongated grains



Discussion

1. Who 'believes' in dark dust - naming preferences?
2. Physics of grain growth in low density regions
3. Element depletion of C, Si, Mg, Fe, Al and O (!)
4. Ice in the diffuse ISM: Dark dust as "dirty water ice balls" ?
5. Reddening: far UV
6. Reddening: NIR/MIR by JWST; however sys errors at > 2 μm
7. MIR polarization: Silicate stoichiometry
8. Polarization ratio absoprtion/emission p(V)/ p(1mm) = FORS/BLAST -> grain shape
9. Circular polarization -> oblate/prolate grains
10. Trigonometric distances with VLTI instead of Gaia
11. Studies such as for HH108mms

Extinction fit

$$\left(\frac{\tau(\nu)}{\tau_V}\right)_{obs} \sim \left(\frac{K_{ext}(\nu)}{K_{ext,V}}\right)_{model}$$

Dust attenuation $A(\nu) = 1.086\,\tau_{ext}(\nu)$

$$K_{ext} = \sum_i \int_{r_-}^{r_+} K_{ext,i}(r)\,\mathrm{d}r$$

Dust extinction cross section

$$K_{ext,i}(r) = \frac{w_i}{\frac{4\pi}{3}\rho_i} \frac{r^{-q}}{\int_{r_{-,i}}^{r_{+,i}} r^{3-q}\,\mathrm{d}r} C_{ext,i}(r)$$

..of particle of population

$i \in \{\mathrm{Si}, \mathrm{aC}, \mathrm{sSi}, \mathrm{gr}\}$, of radius r and density ρ_i

$$w_{aC} = \frac{\Upsilon_{aC}\,\mu_C}{(\Upsilon_{aC} + \Upsilon_{gr} + \Upsilon_{PAH})\mu_C + (\Upsilon_{Si} + \Upsilon_{sSi})\mu_{Si}}$$

Specific mass requies realtive dust abundances

Siebenmorgen et al. (2014)