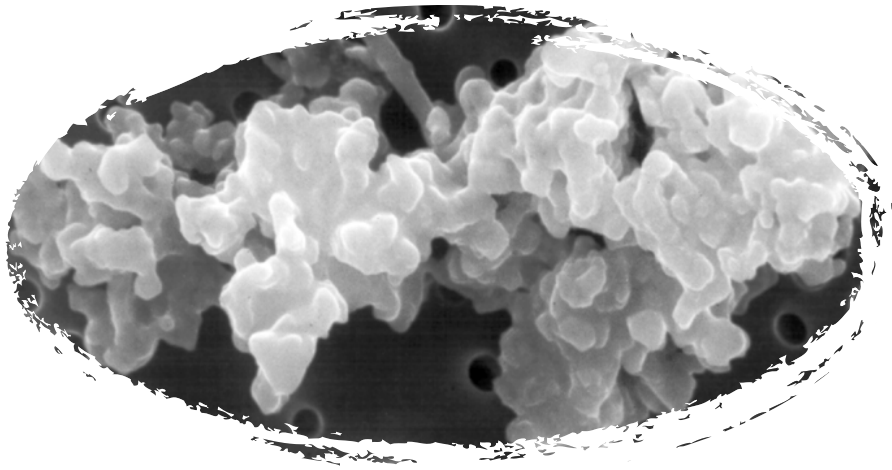
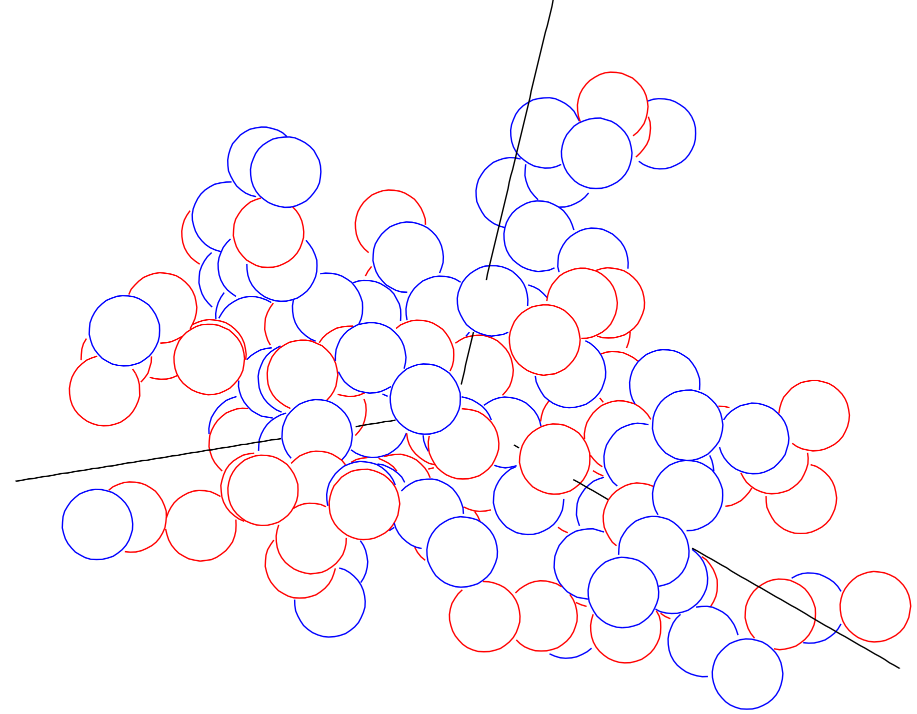
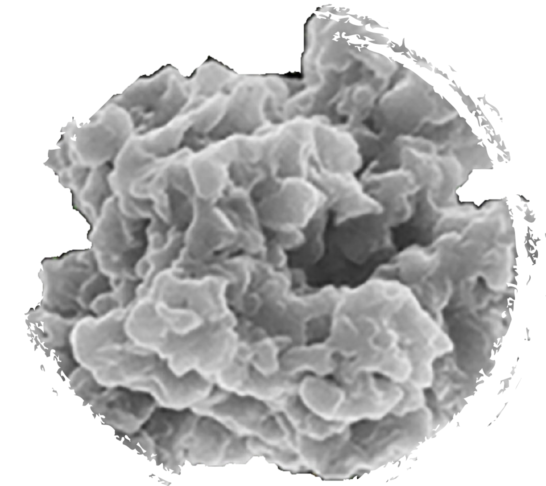




The submm properties of dust in the detached shells around carbon AGB stars

Matthias Maercker

Magdalena Brunner, Marko Mecina
Theo Khouri, Oscar Jaldehag

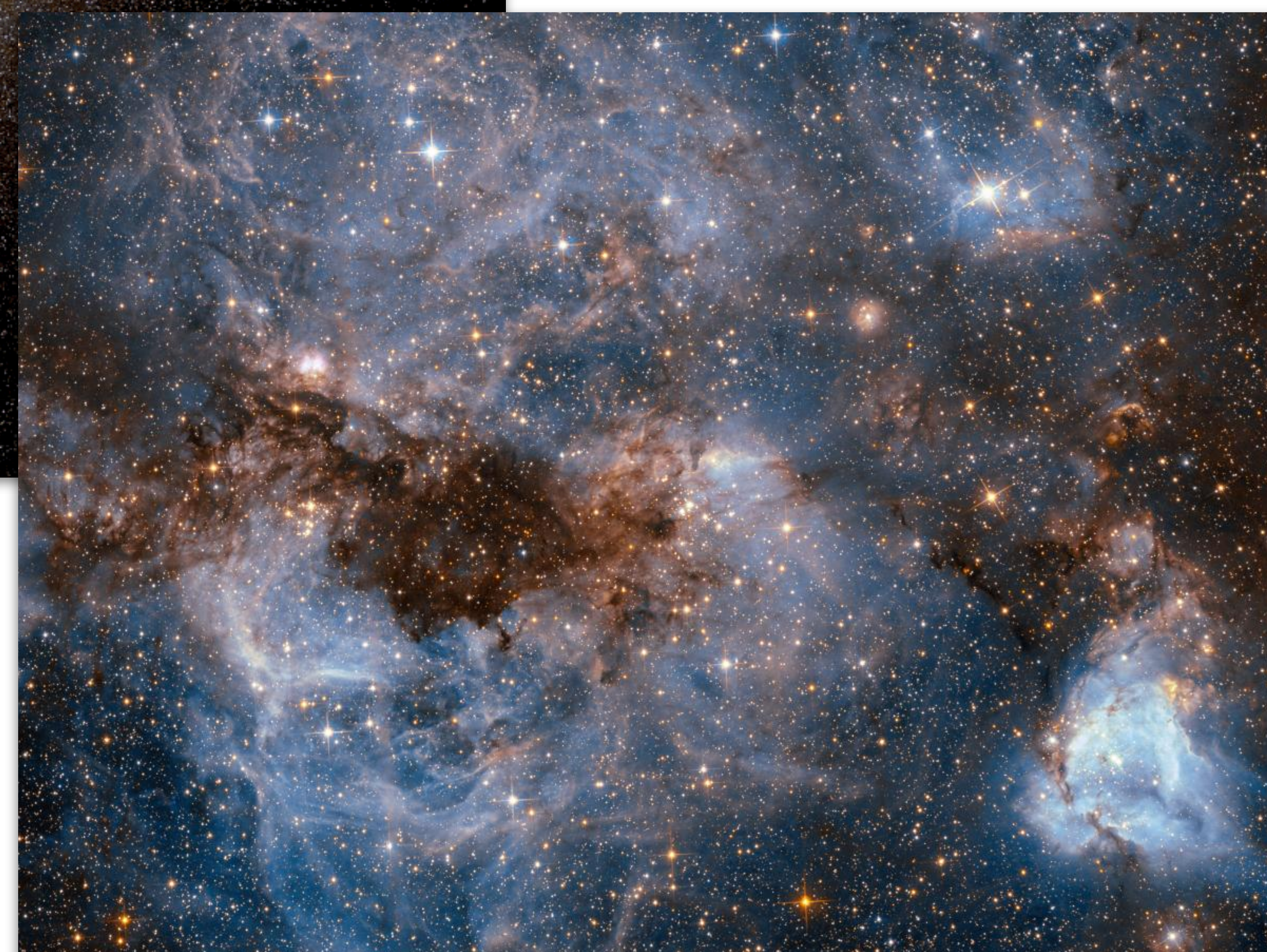
Department of Space, Earth and Environment
Nordic ALMA node, Onsala Space Observatory

CHALMERS

Vetenskapsrådet

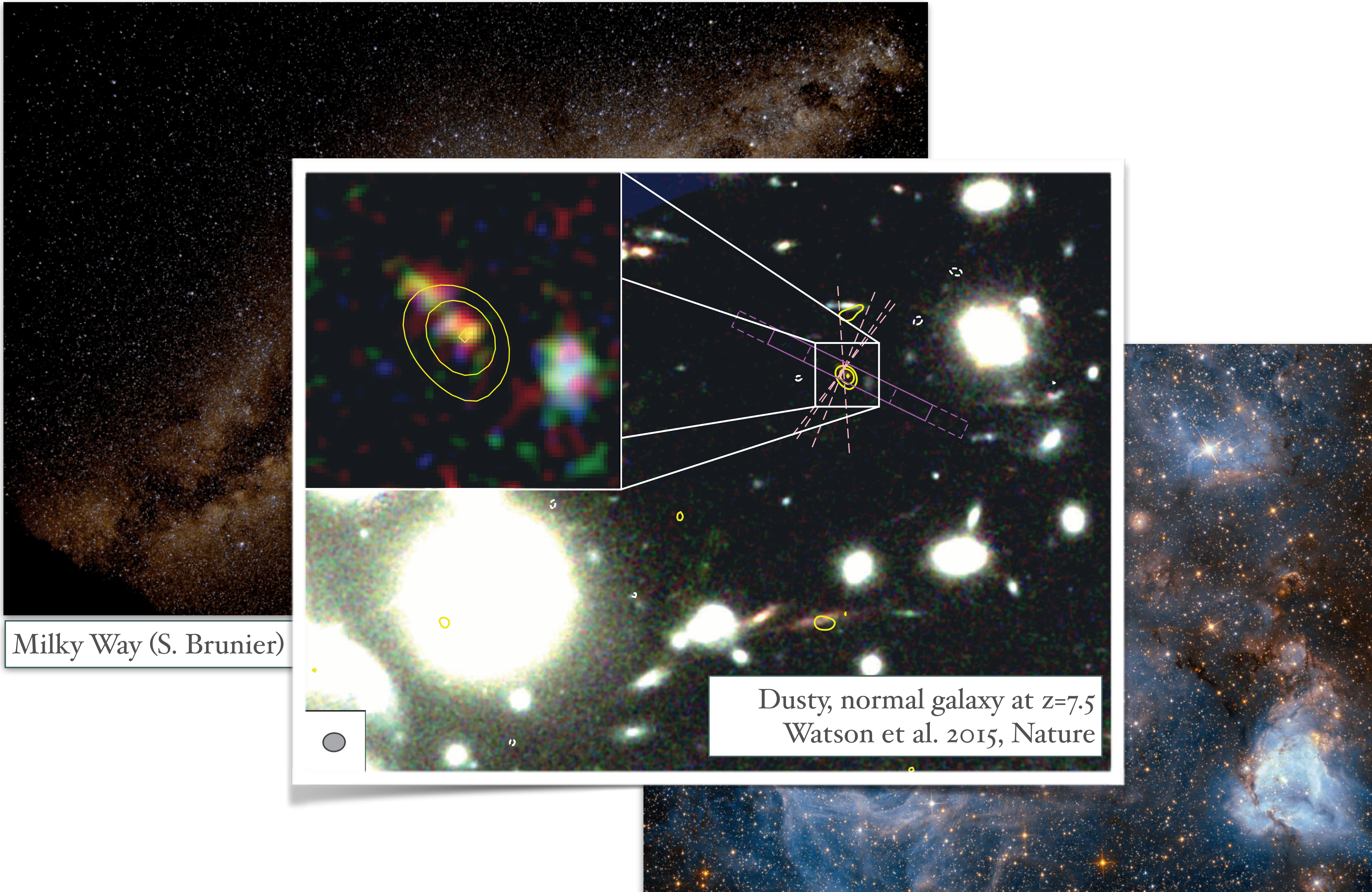
Galaxy evolution

Milky Way (S. Brunier)



LMC (ESA/Hubble & NASA)

Galaxy evolution

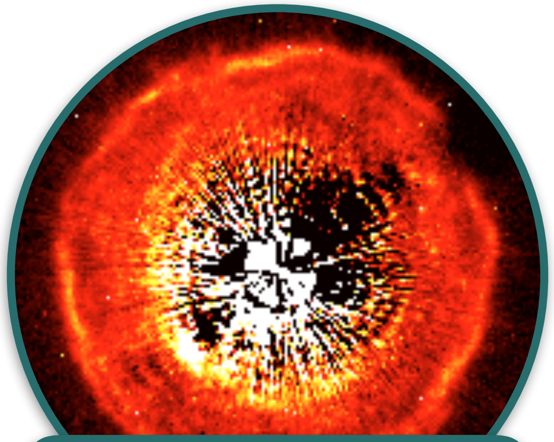


Milky Way (S. Brunier)

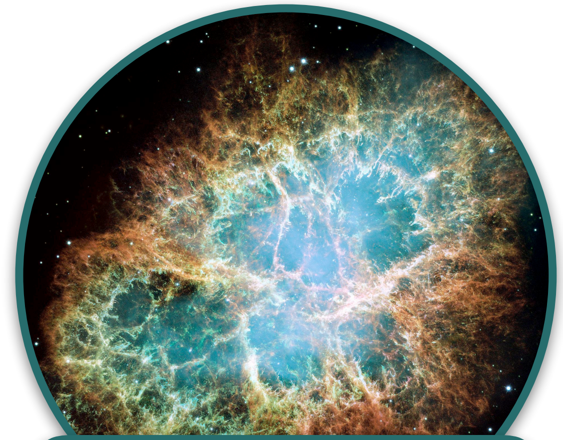
Dusty, normal galaxy at z=7.5
Watson et al. 2015, Nature

LMC (ESA/Hubble & NASA)

Galaxy evolution - where does the dust come from?



AGB stars



Supernovae

dust formed in the expanding circumstellar envelopes

dust formed in ejecta from supernova explosion

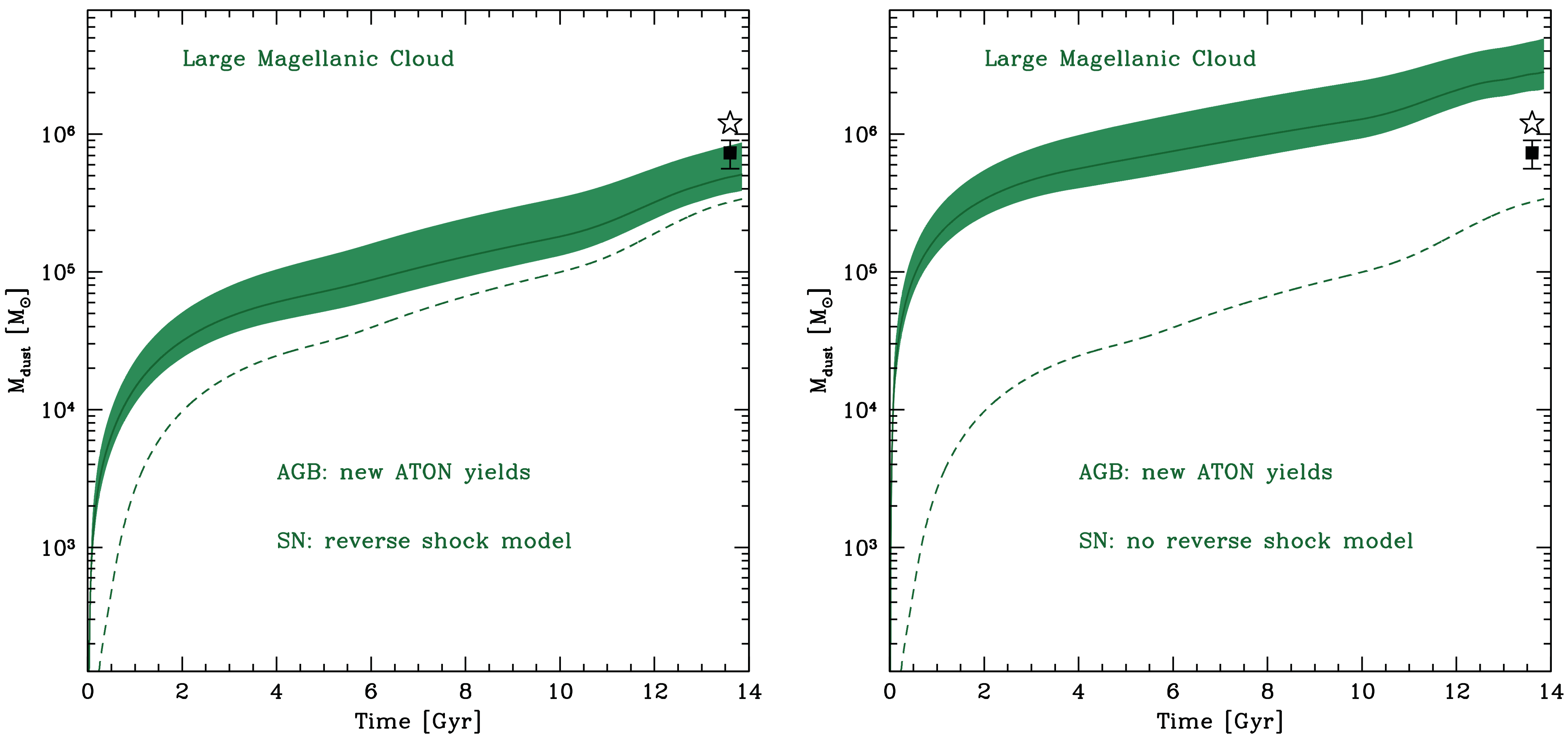
timescales
mass-loss rates
dust properties

IMF

reverse shock
dust yields
dust properties

Galaxy evolution - where does the dust come from?

Dust production in the LMC



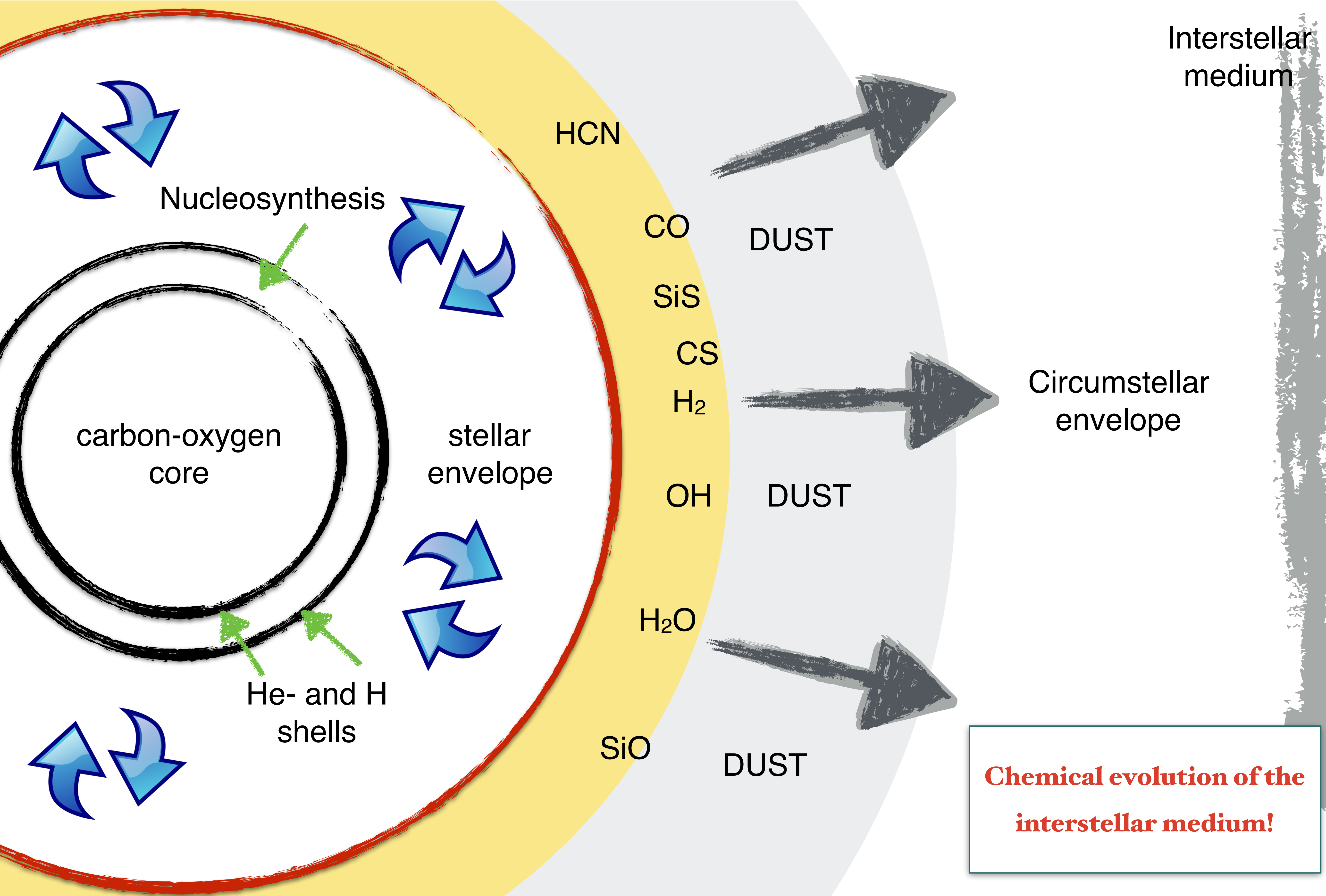
AGB stars only
Data points show observed dust masses (Schneider et al. 2014, MNRAS)

Dust production in high-z galaxies

- In 3 out of 6 z>4 galaxies, AGB stars can explain observed dust mass
- Requires a dust production of approx. 0.03-0.07 $M_\odot$ per star (2.5 $M_\odot < M < 8\ M_\odot$)
- At the upper limit of what is estimated for AGB stars today
- Depends on mass-loss mechanism and evolution, and dust properties

(Michalowski et al. 2010, ApJ)

Dust in AGB stars



Chemical evolution of the interstellar medium!

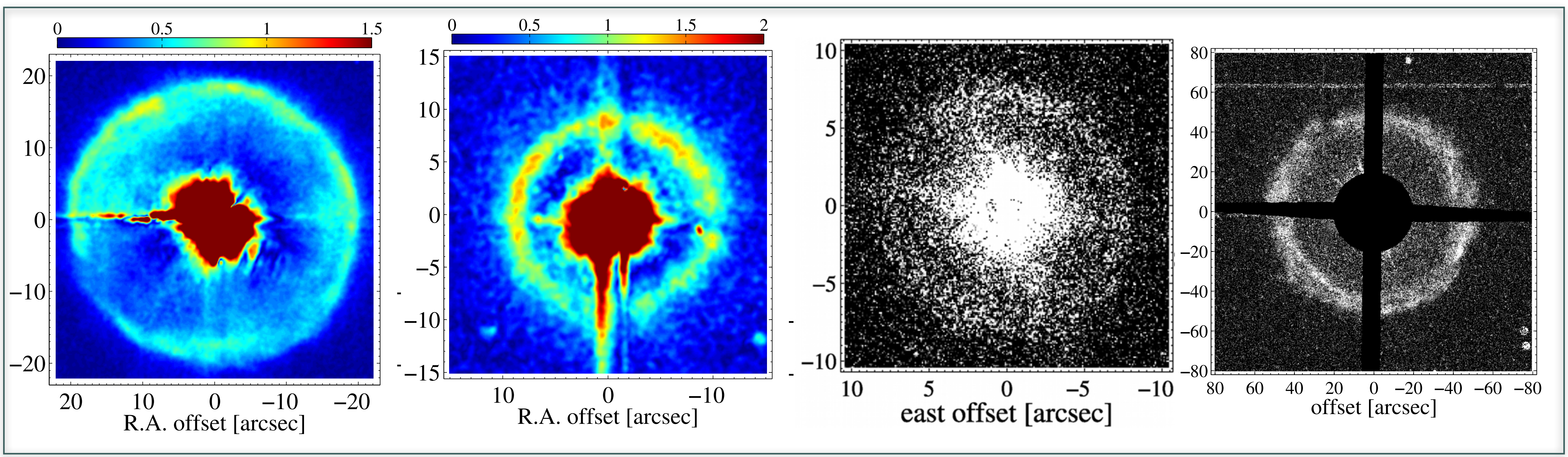
Detached shells and thermal pulses

Geometrically thin shells of dust and gas around carbon AGB stars

- Created during recent thermal pulses
- Observed around 7 carbon AGB stars
- Polarised, dust-scattered stellar light images reveal spatially well constrained shells

Spatial constraints fix the distance to the central stars

Grain temperature depends on grain properties!

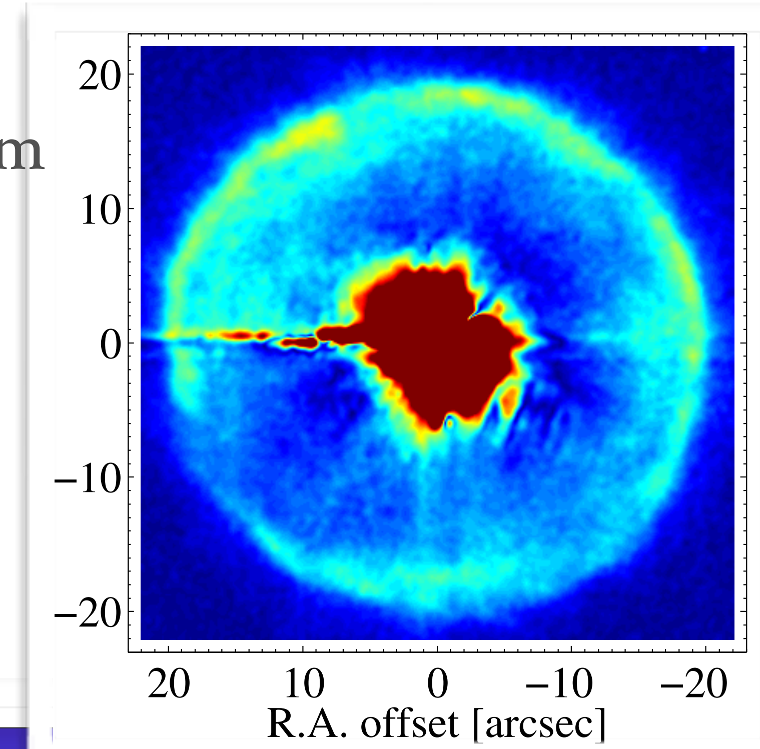


R Scl (Maercker et al. 2014) | V644 Sco (Maercker et al. 2014) | DR Ser (Ramstedt et al. 2011) | U Ant (Maercker et al. 2010)

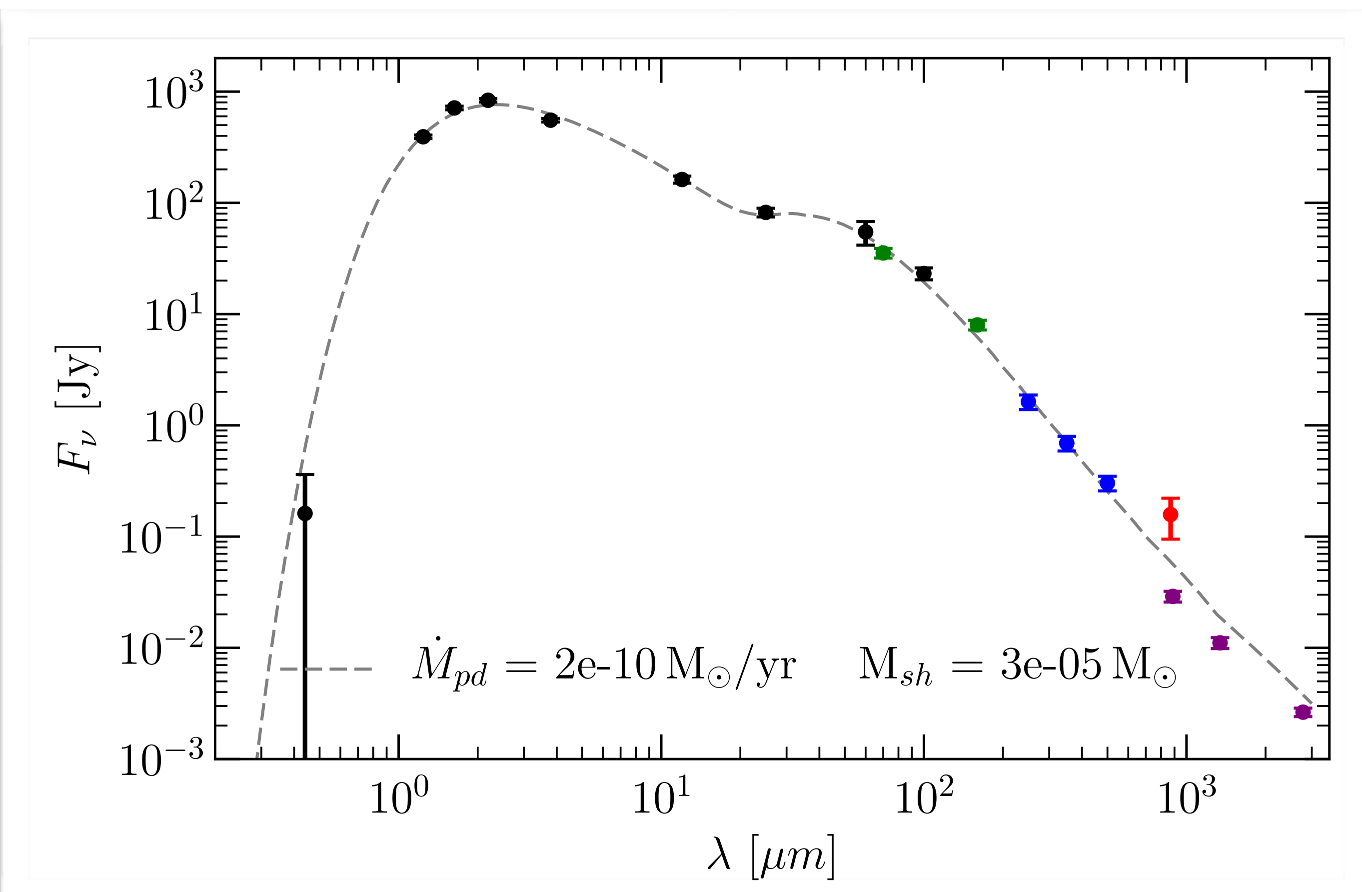
SED models of R Scl

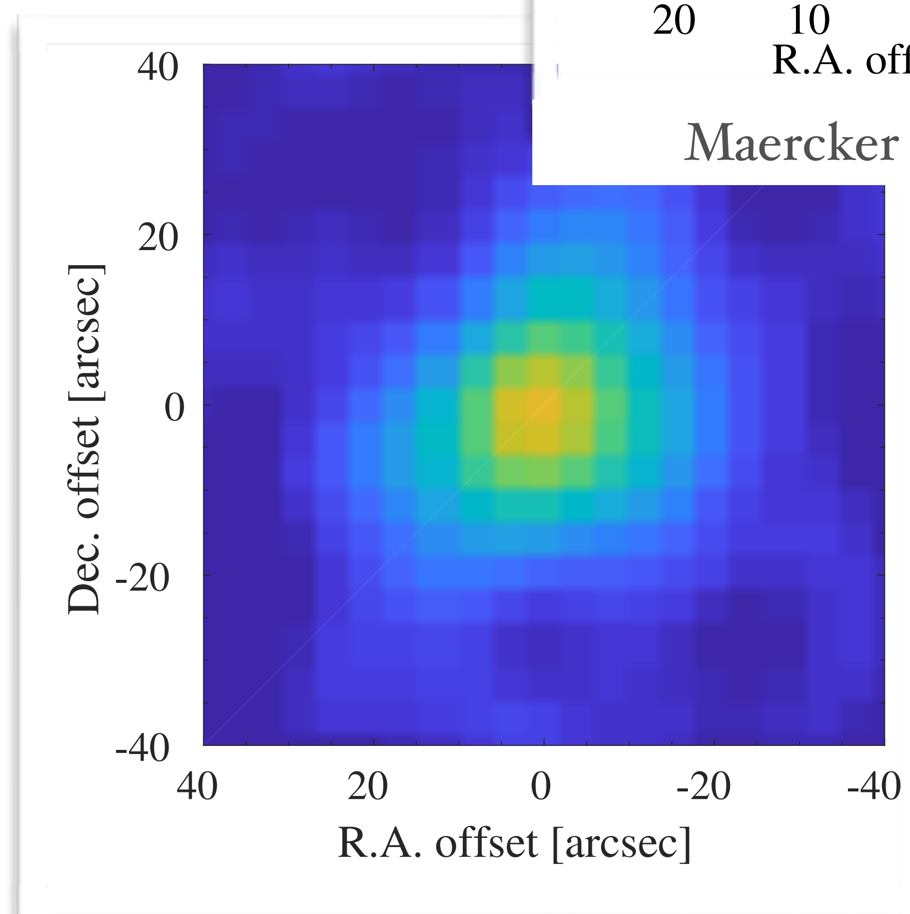
Radiative transfer models to constrain the dust properties in the detached shell

- Observations from optical to submm
- **Spatially resolved** observations from APEX/LABOCA at 870 μm
- Test of different dust properties to fit the SED:
  - different lab measurements of opacities
  - grain sizes
  - composition
  - geometry (hollow vs. solid, fluffy grains)



Maercker et al. 2014, A&A



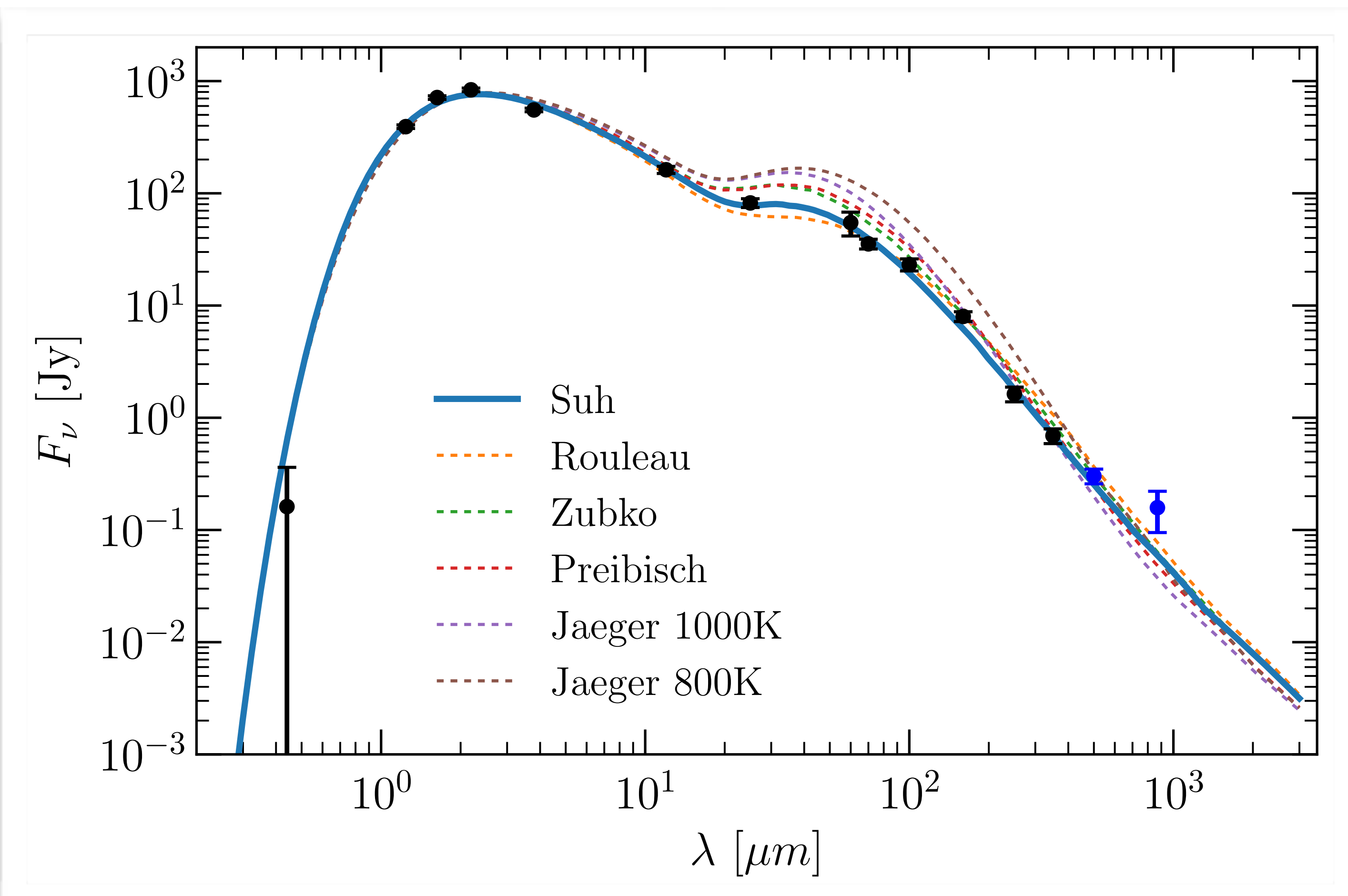


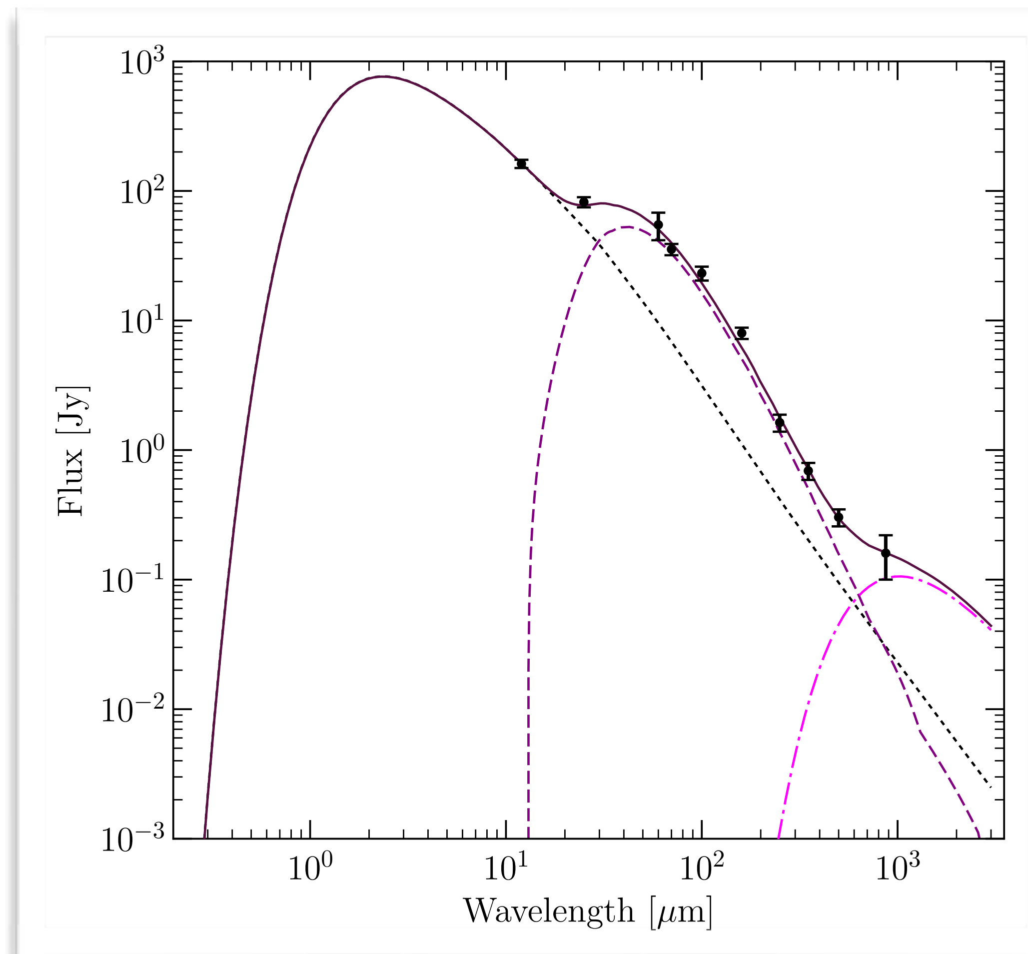
Brunner et al. 2018, A&A

SED models of R Scl

Radiative transfer models to constrain the dust properties in the detached shell

- Best-fit model gives $M_{sh}=3.1\times10^{-5}$ +/- 0.5 $M_{\odot}$, solid, spherical grains with radius 0.1 µm
- Strongest effect on total estimated mass through assumed hollow vs. solid and fluffiness
- No straight-forward explanation of the submm excess
  - SED shape in submm can not be reproduced
- Spatial constraints from the LABOCA observations show that excess originates in the shell
- **Cold component** explanation requires blackbody of 5 K!





Brunner et al. 2018, A&A

SED models of shells around U Ant, V644 Sco, DR Ser

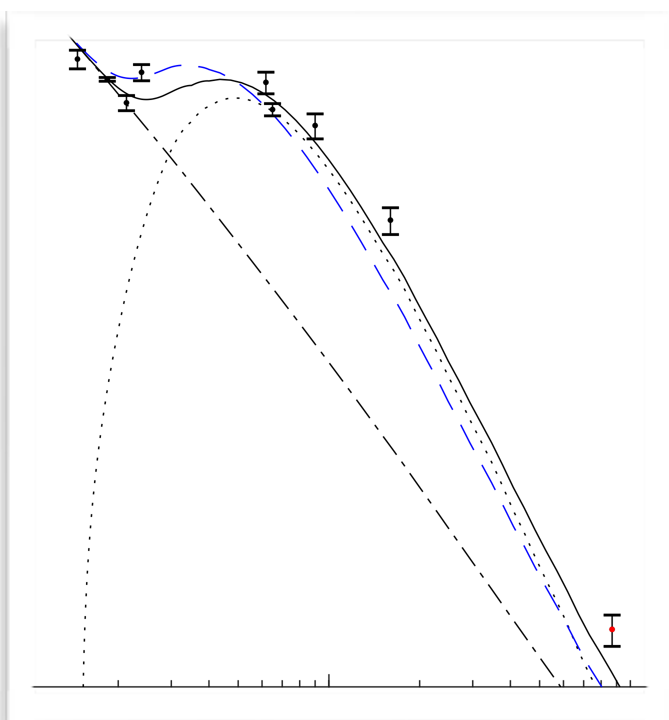
- Spatially constrained LABOCA observations
- As for R Scl, SED at FIR and submm wavelengths not affected much by opacities, geometry, composition
- Fixed distance from the star - grain temperature most strongly affected by grain size
- FIR points missing for DR Ser and V644 Sco

- **Indication** of large grains in all sources

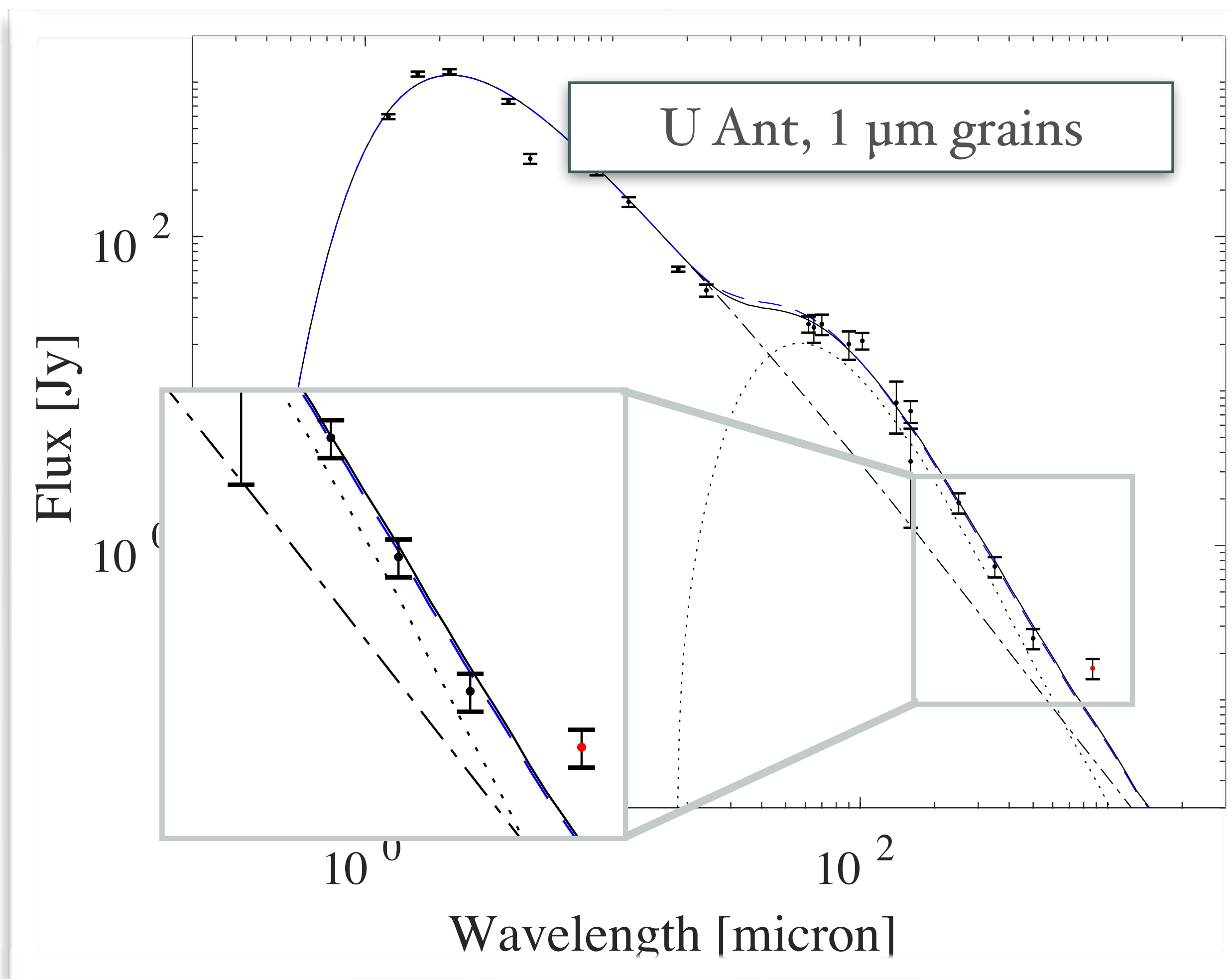
- Submm excess in all sources

Maercker et al. 2018, in prep.

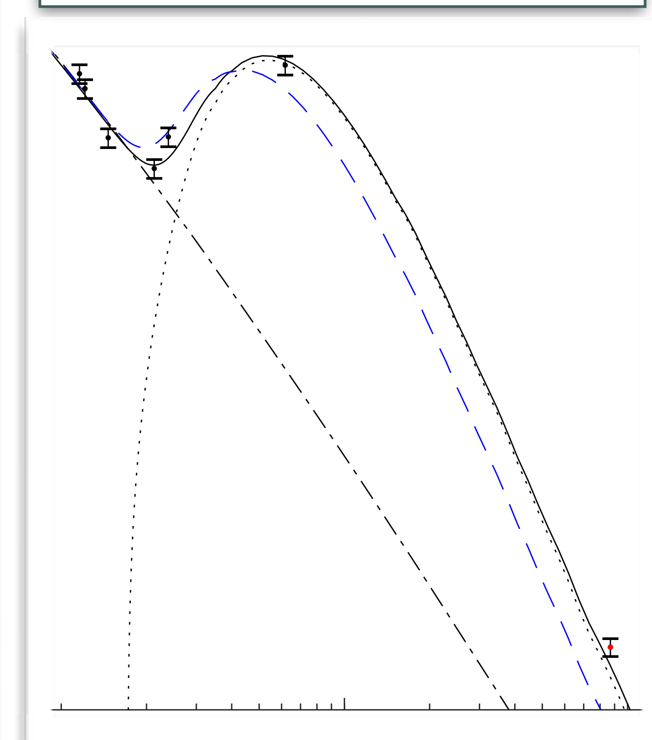
DR Ser, 2 µm grains



U Ant, 1 µm grains

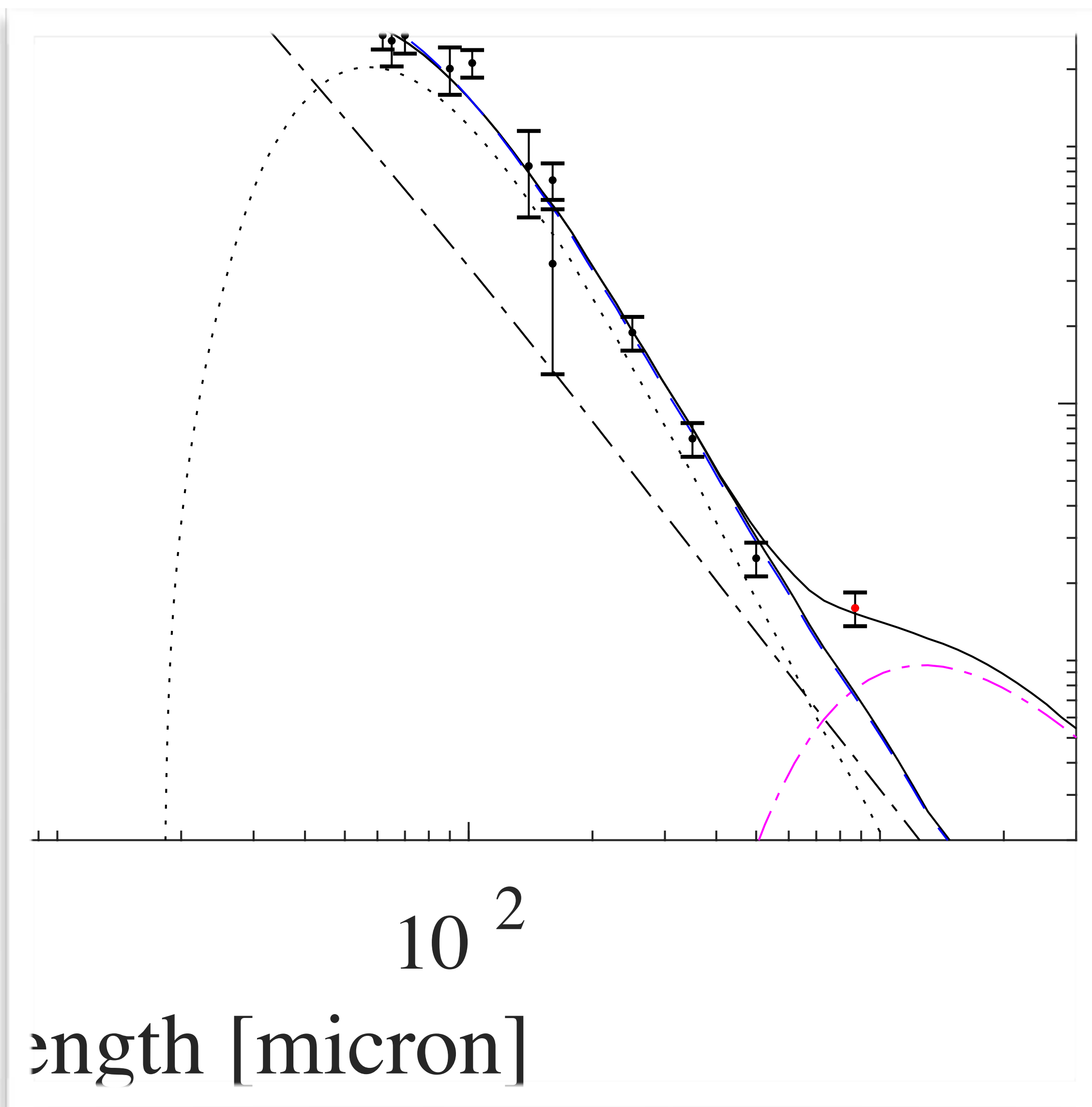


V644 Sco, 2 µm grains



Grain properties in detached shells

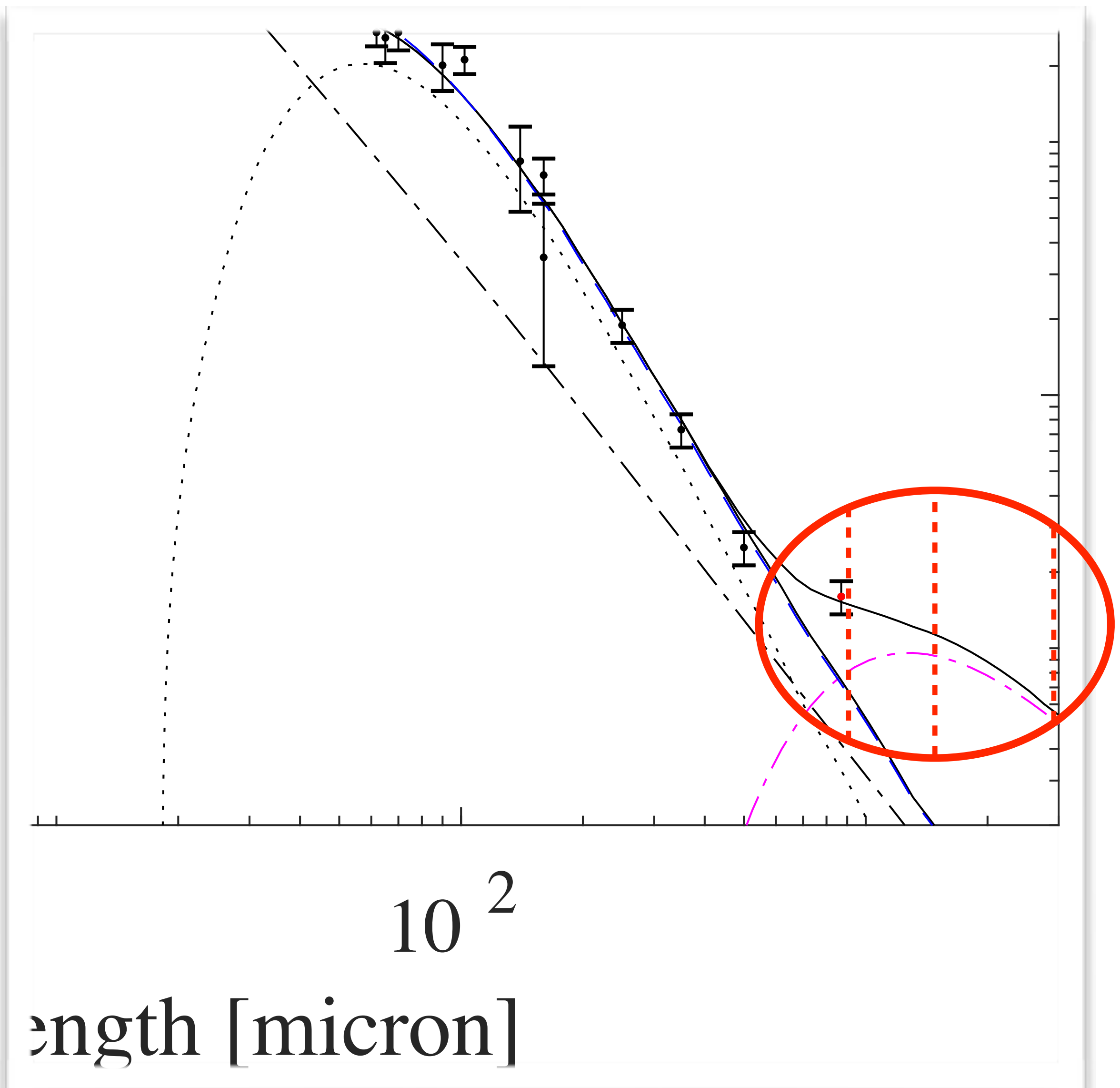
- Large grains **cannot** explain submm excess in the observed detached shell sources
- Simple two-blackbody model would required blackbodies of only a few K
- “cold” dust population would have to be distinct from “warm” dust
    - continuous distribution would not reproduce SED “knee”



- ALMA ACA proposals to observe V644 Sco, DR Ser, U Ant, and R Scl in Bands 3, 6, and 7 during Cycles 5+6
- Spatially constrained measurements of the submm emission from the shell

Grain properties in detached shells

- Large grains **cannot** explain submm excess in the observed detached shell sources
- Simple two-blackbody model would required blackbodies of only a few K
- “cold” dust population would have to be distinct from “warm” dust
    - continuous distribution would not reproduce SED “knee”

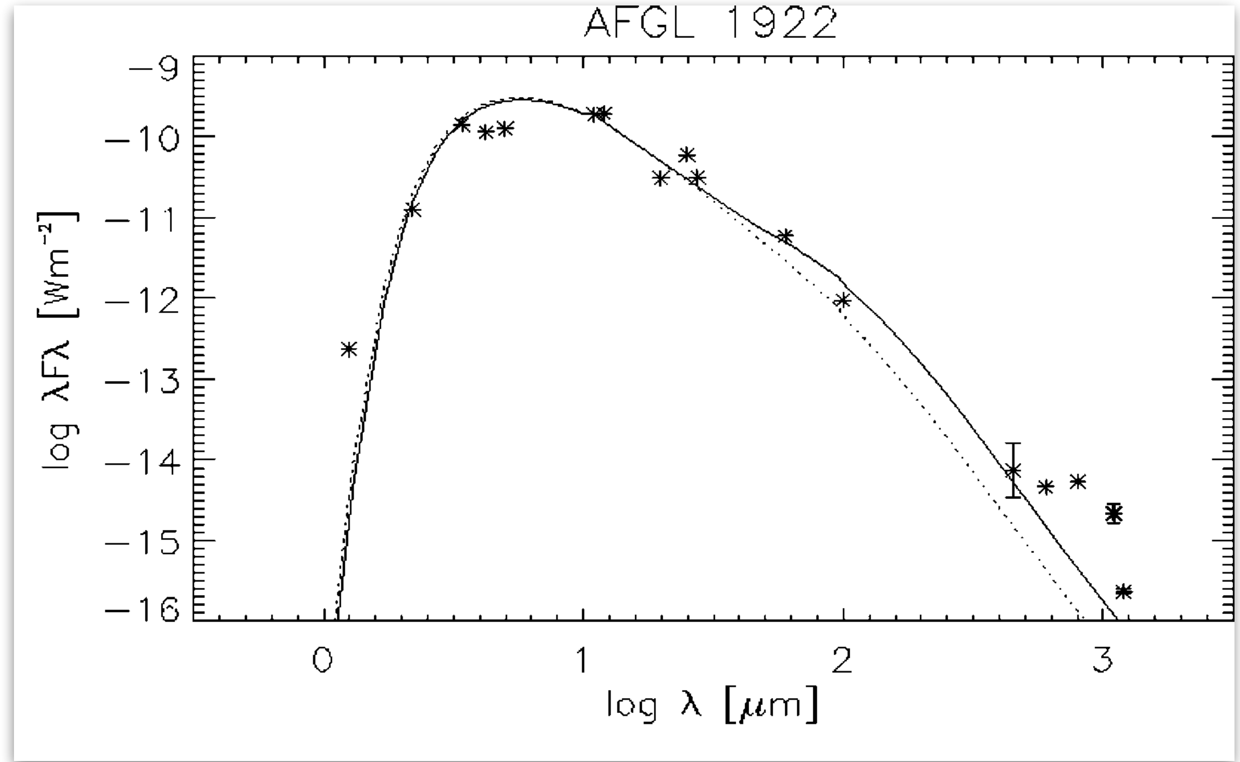


- ALMA ACA proposals to observe V644 Sco, DR Ser, U Ant, and R Scl in Bands 3, 6, and 7 during Cycles 5+6
- Spatially constrained measurements of the submm emission from the shell
- Observations will probe shape of submm excess at 850μm, 1300μm, and 3000μm

Submm excess from dust grains

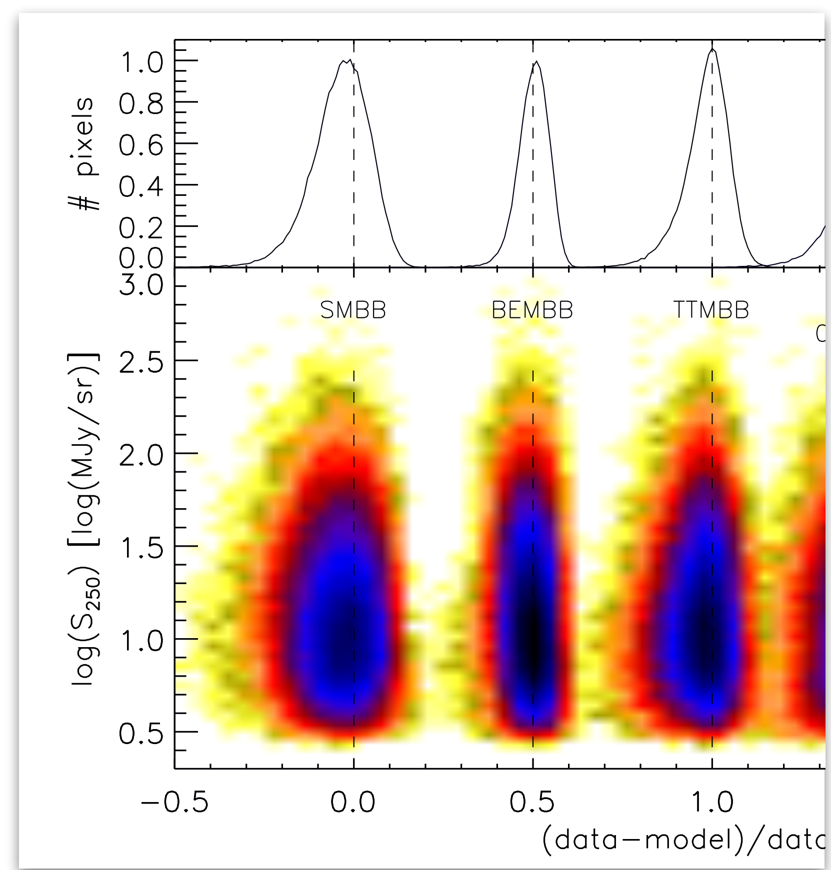
Dehaes et al. 2007

- Dust models of 32 AGB stars (M+C-type)
- Submm excess in 5 sources
- FIR + submm region not well sampled
- possible PAH emission?
- Spatial constraints in submm essential!



Gordon et al. 2014

- Herschel observations of the LMC and SMC
- 5 bands from 100 to 500 μm
  - Single-T BB with modified power-law emissivity
  - BB with broken power-law emissivity
  - Two-T BB with same power-law emissivity
- Best-fit given by BB with broken power-law emissivity
  - unknown dust properties in the submm
  - Not "simply" population of cold dust grains



Conclusions

- Improved dust models of detached-shell sources R Scl, U Ant, V644 Sco, and DR Ser
- Uncertainty in dust mass one order of magnitude lower than previous estimates
- Indication of larger grains in detached shells than generally assumed in AGB stars
- Unexplained submm excess indicates unknown dust properties

Spatially resolved observations in FIR and submm essential to constrain dust properties!

- similar excess observed around "normal" AGB stars, and in the LMC and SMC
- unknown origin of the submm excess
- simple cold component does not seem to explain the observations
- unknown dust properties and/or PAH emission?

Need to know dust properties to understand

origin and evolution of dust in galaxies!