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

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Galaxy evolution

Milky Way (S. Brunier)

LMC (ESA/Hubble & NASA)
Galaxy evolution

Dusty, normal galaxy at $z=7.5$

Watson et al. 2015, Nature
Galaxy evolution - where does the dust come from?

**AGB stars**
- Dust formed in the expanding circumstellar envelopes
- Timescales
- Mass-loss rates
- Dust properties

**Supernovae**
- Dust formed in ejecta from supernova explosion
- Reverse shock dust yields
- Dust properties

**IMF**
Galaxy evolution - where does the dust come from?

**Dust production in the LMC**

![Graph showing dust production in the LMC](image)

**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 $\text{M}_\odot$ per star ($2.5 \text{ M}_\odot < M < 8 \text{ M}_\odot$)
- At the upper limit of what is estimated for AGB stars today
- Depends on mass-loss mechanism and evolution, and dust properties

Dust in AGB stars

- Carbon-oxygen core
- Stellar envelope
- He- and H shells

Nucleosynthesis

- HCN
- CO
- SiS
- CS
- SiO
- OH
- H$_2$O
- H$_2$

Interstellar medium

Circumstellar envelope

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!
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)

\[ F_\nu = \frac{\lambda^2}{(1 + \lambda R_d)^{\alpha}} \]

\[ \dot{M}_{pd} = 2 \times 10^{-10} \, M_\odot/\text{yr} \quad M_{sh} = 3 \times 10^{-5} \, M_\odot \]

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 $M_{sh}=3.1 \times 10^{-5} \pm 0.5 \, M_\odot$, solid, spherical grains with radius 0.1 $\mu$m
- 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!

![Graph](image)

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.
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

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- 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 850$\mu$m, 1300$\mu$m, and 3000$\mu$m
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!