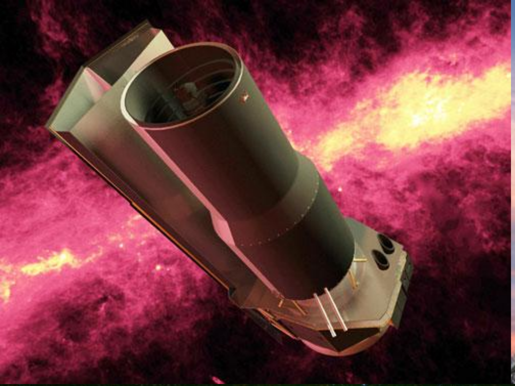
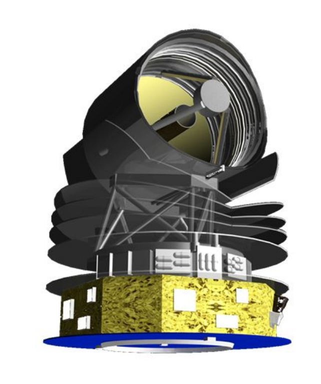


PROduction of Dust In GalaxIES (PRODIGIES)

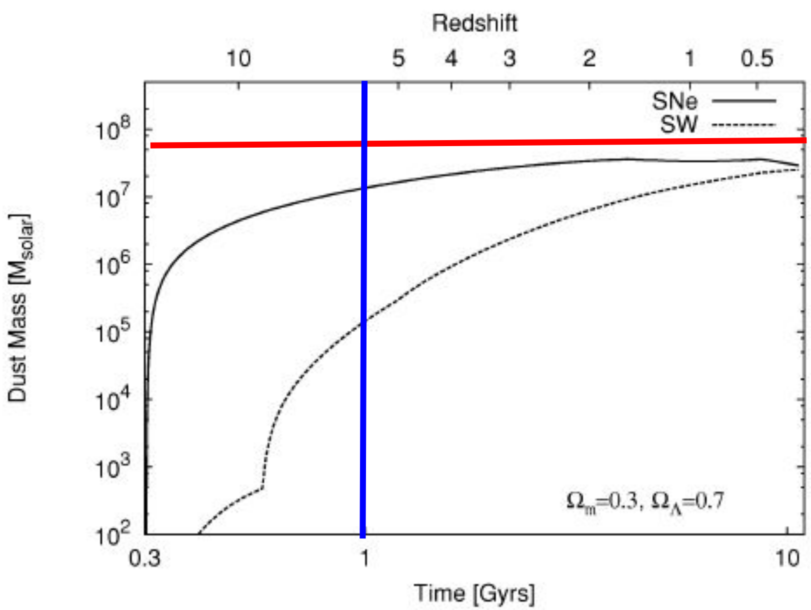
Ciska Kemper

European Southern Observatory & Academia Sinica

The dust budget problem

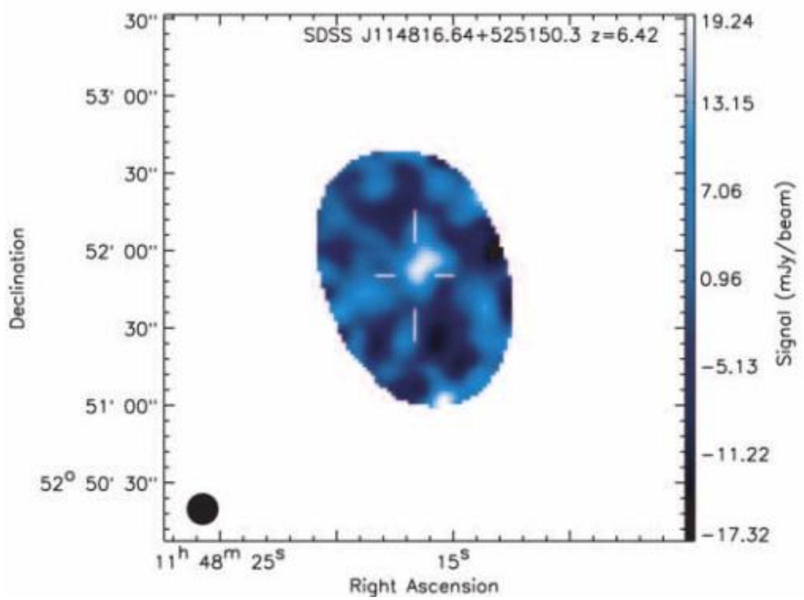
z~6: $10^{8\text{-}9}$ M_{sun} of dust

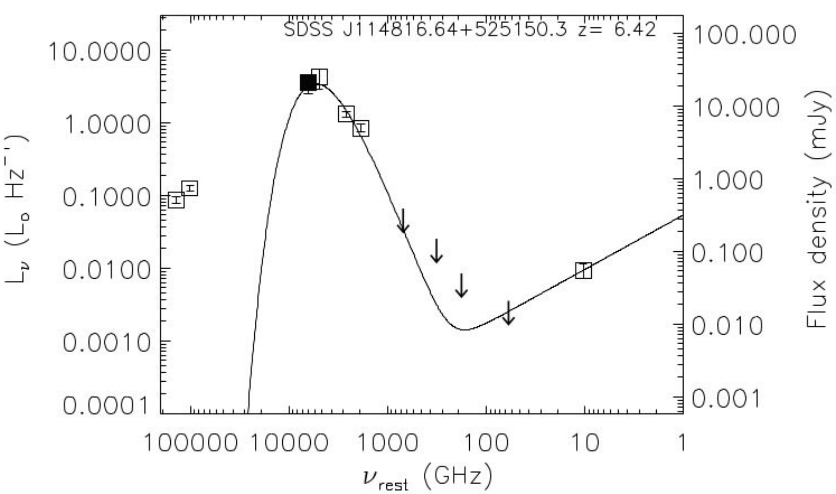
cannot be explained with stellar dust sources: AGB stars, supernovae



(Morgan & Edmunds 2003)

(Beelen et al. 2003)



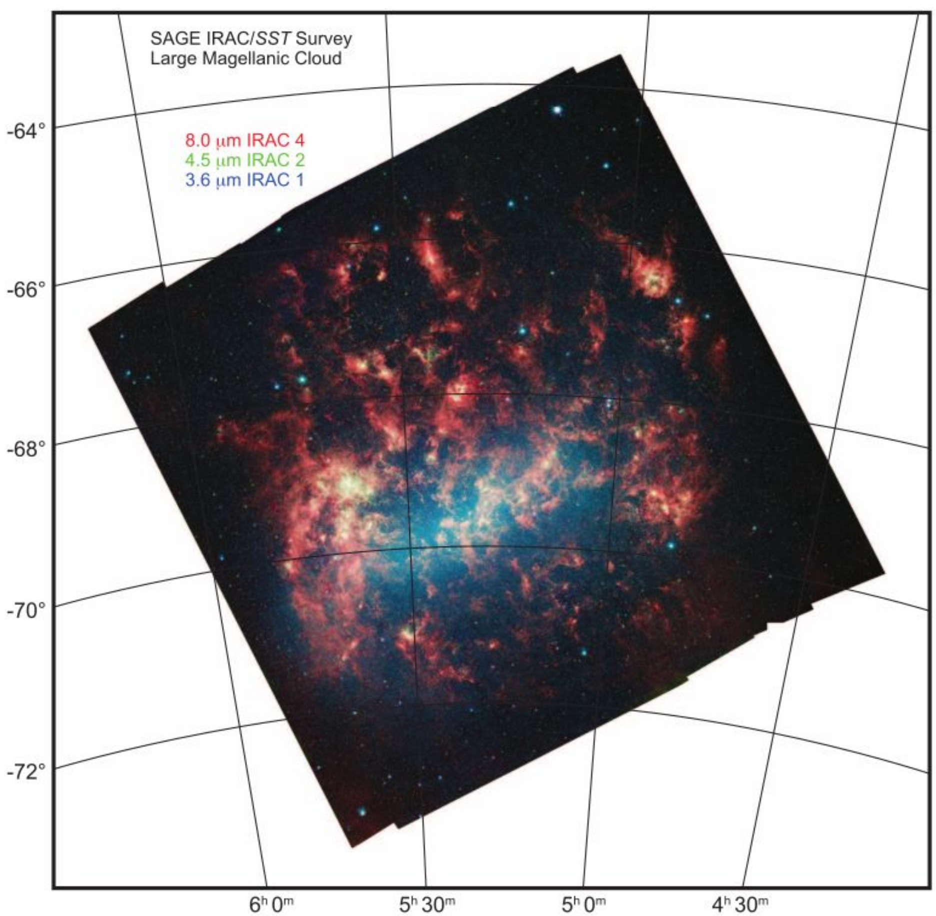


Dust production in galaxies

- Are AGB stars responsible for the interstellar dust reservoir of galaxies?
- How well do we know the mass of the interstellar dust reservoir of galaxies?
- Does star formation activity affect the mineralogy of the interstellar dust reservoir?
- What kind of dust forms in the extreme conditions of AGN winds?

Galactic dust production rate by AGB stars

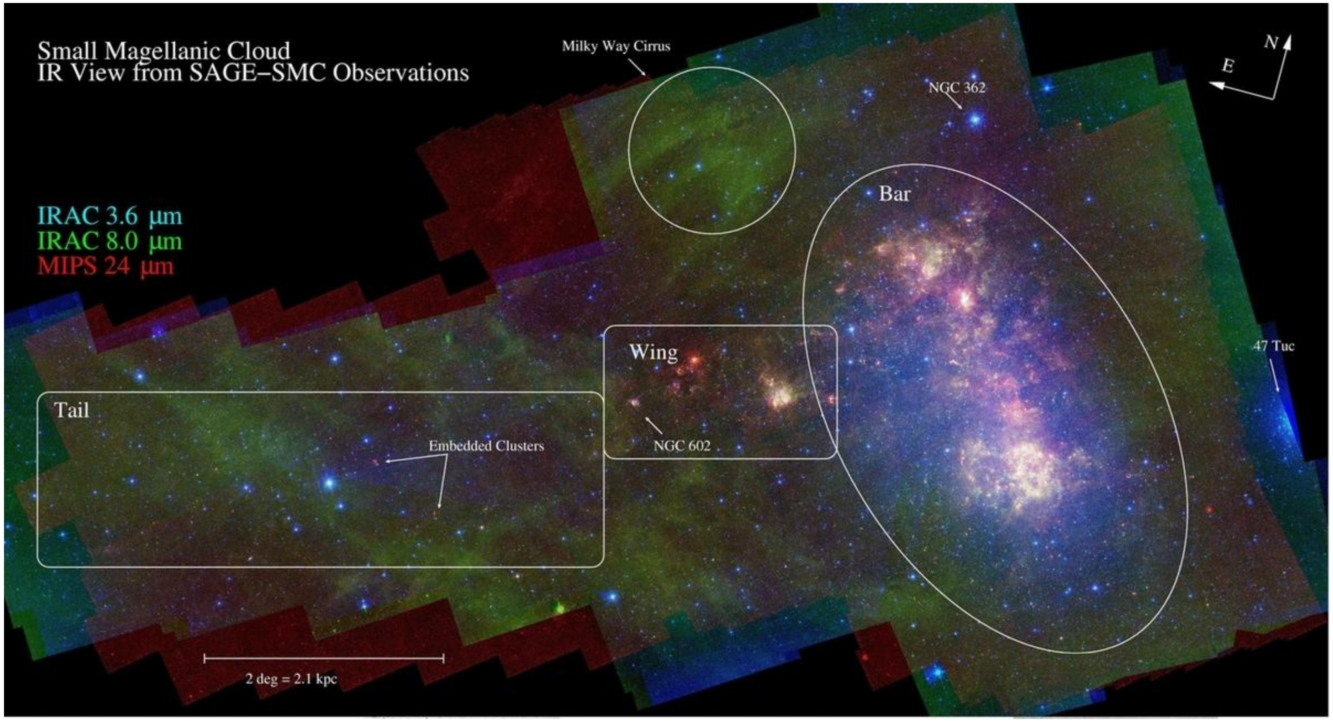
SAGE-LMC: The Large Magellanic Cloud in the infrared



(Meixner et al. 2006)

- Global view of nearby galaxy
- $Z \sim 0.5\, Z_\odot$
- D = 50 kpc
- 8.5 million IR point sources
- IRAC-[3.6]; [4.5]; [5.8]; [8.0]
- MIPS-[24]; [70]; [160]

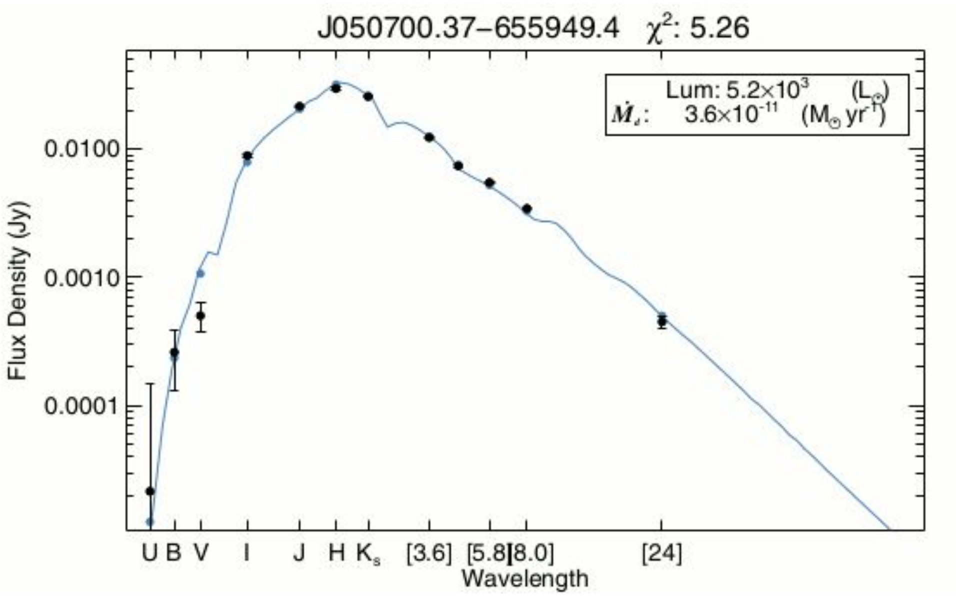
SAGE-SMC: The Small Magellanic Cloud in the infrared

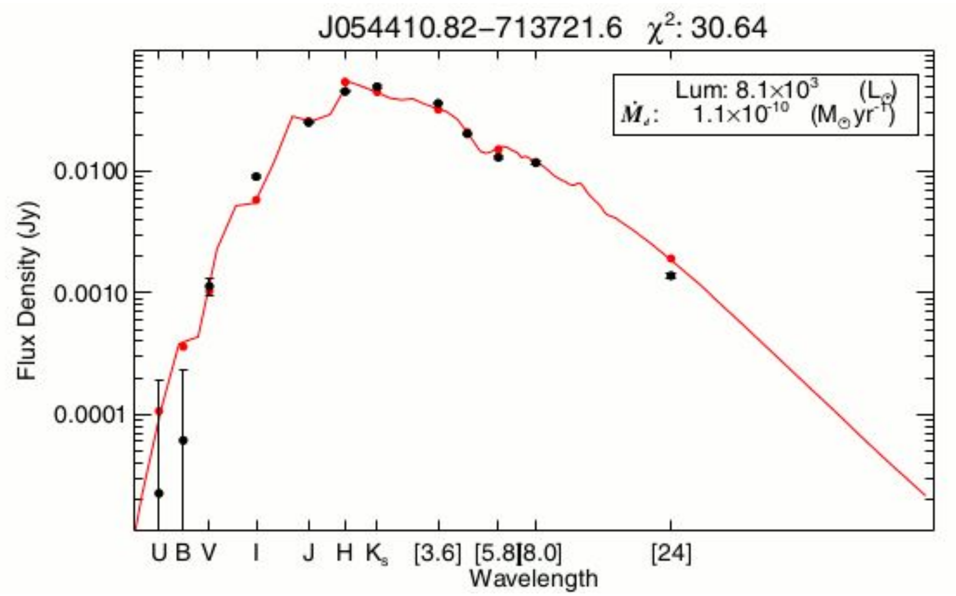


(Gordon et al. 2011)

- $Z \sim 0.2\ Z_\odot$
- D = 60 kpc
- ~2 million infrared point sources

Total dust production





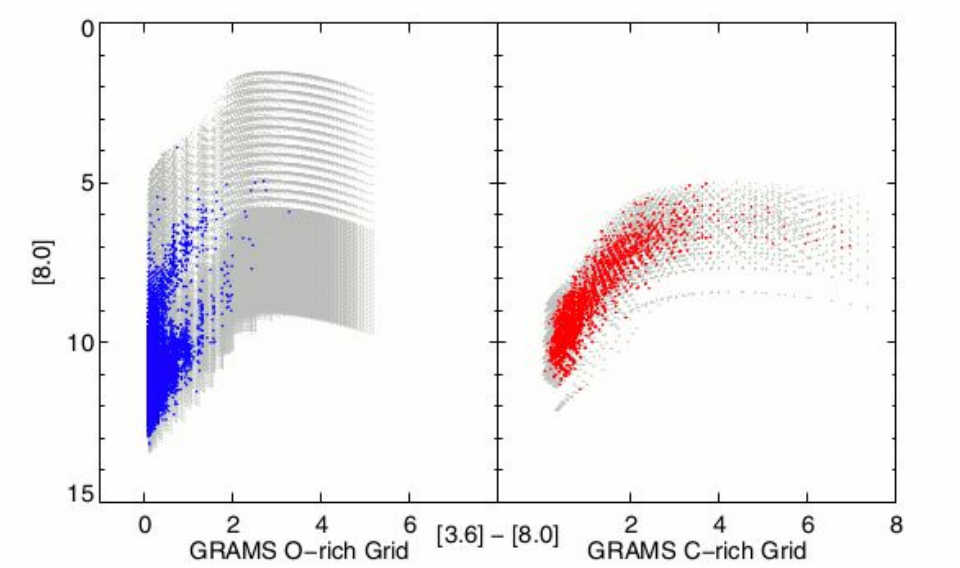


Table 9
Total $\dot{M}_d$ by Population

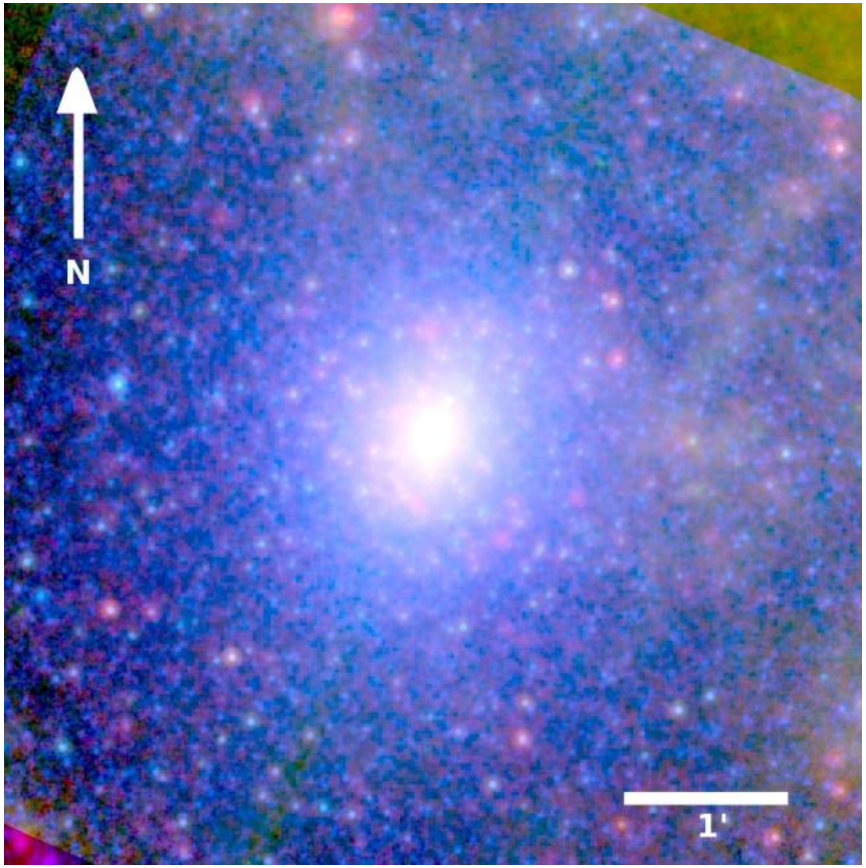
Population	Total $\dot{M}_d$ ($\times 10^{-6}\ M_\odot\ \mathrm{yr}^{-1}$)	Percent of Total
All Sources	21.1 ± 0.6	100.0%
C-rich AGBs	13.64 ± 0.62	64.6%
O-rich AGBs	5.5 ± 0.2	26.0%
RSGs	2.0 ± 0.1	9.4%
Extreme AGBs	15.7 ± 0.6	74.2%

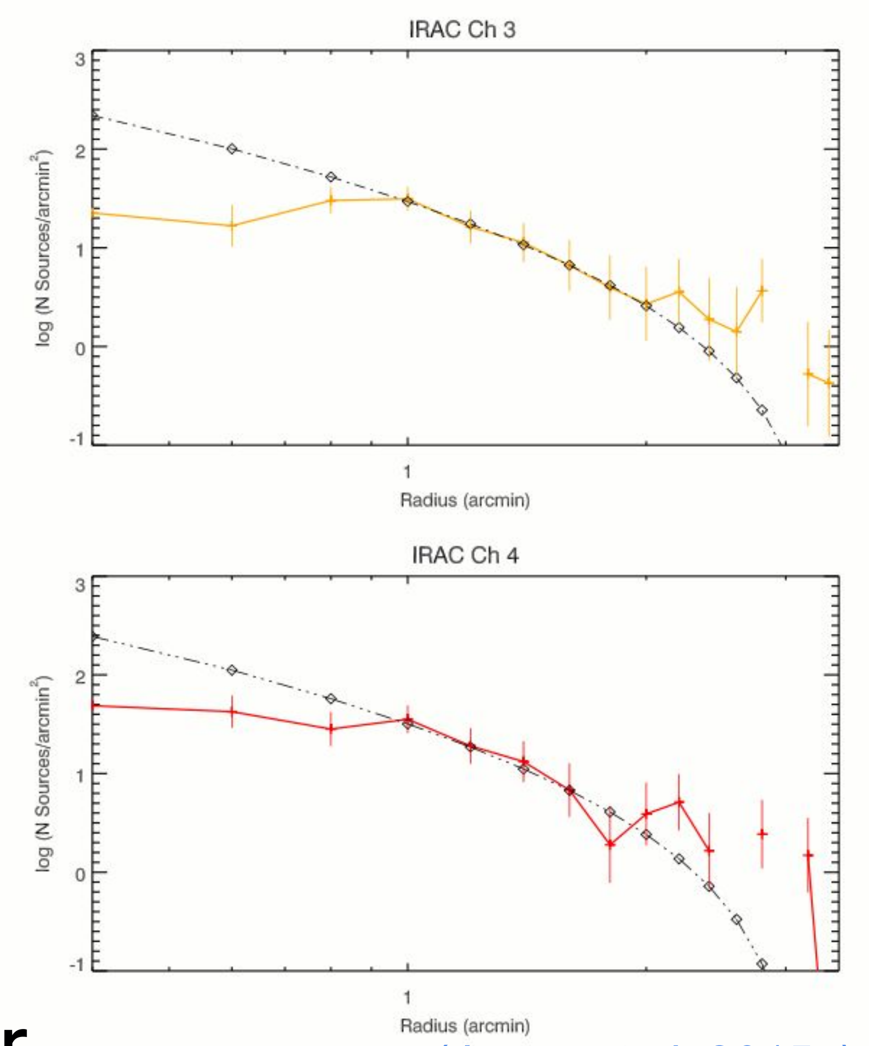
(Riebel et al. 2012)

For SMC, total dust production a factor of ~15 lower.

(Srinivasan et al. 2016)

AGB Dust production in other galaxies: M32



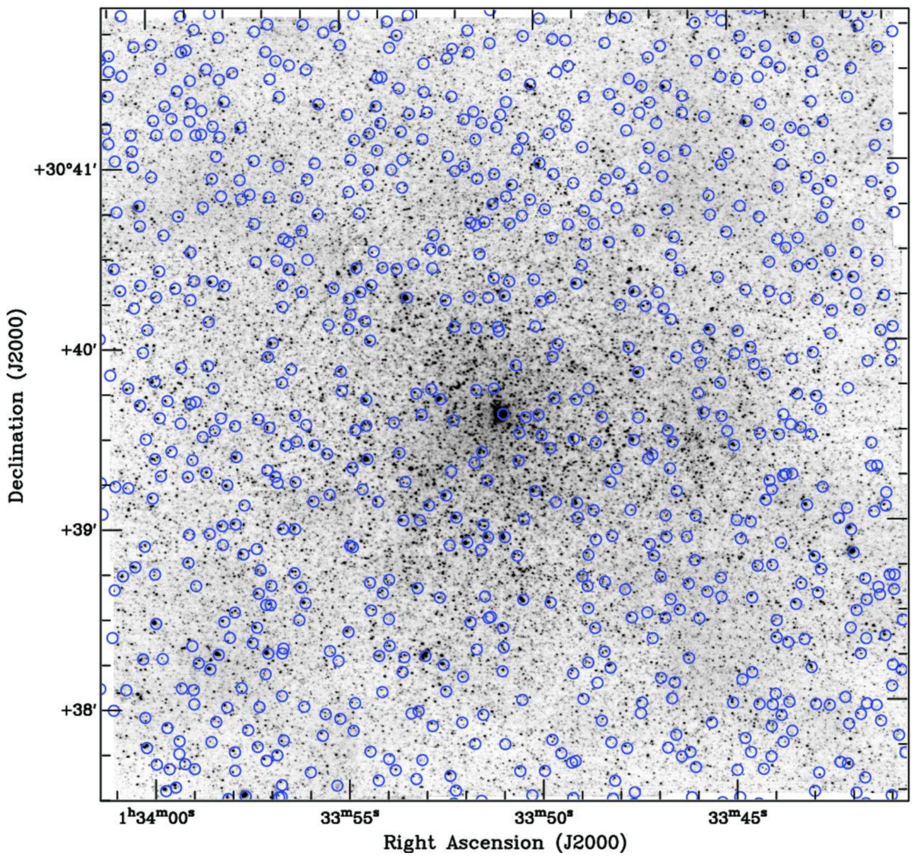


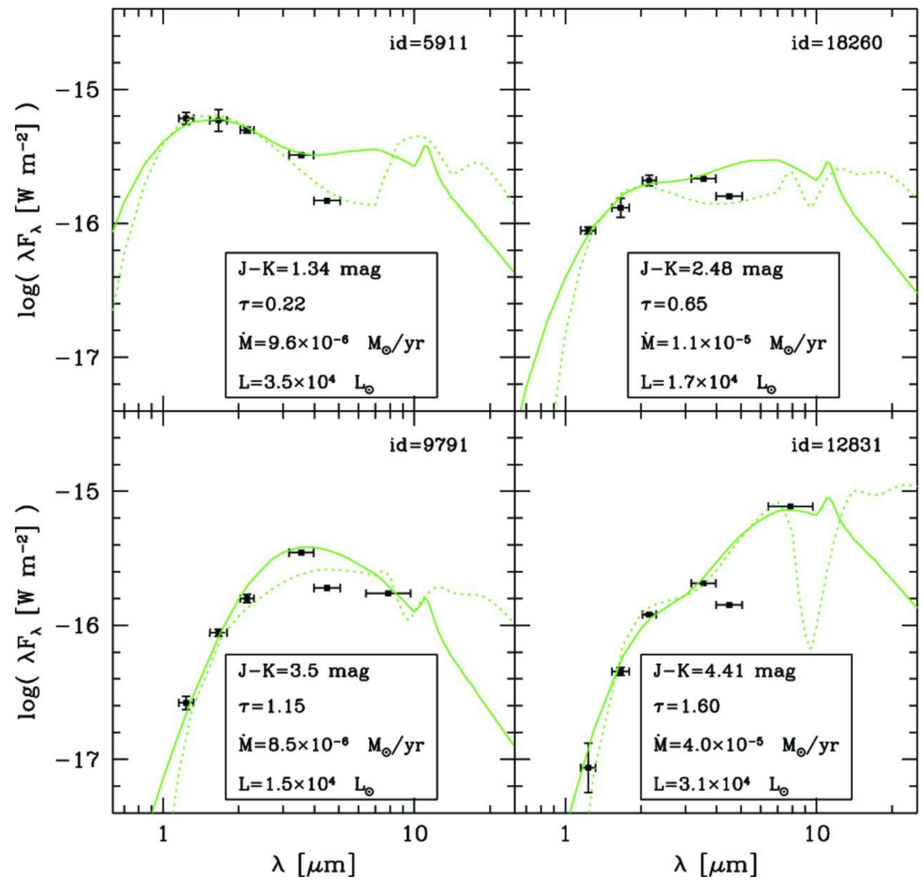
Derived DPR: $1.5 \times 10^{-4}\ M_{\odot}$/yr

5 most extreme sources: 30% of DPR

(Jones et al. 2015a)
(Davidge 2014)

AGB Dust production in other galaxies: M33



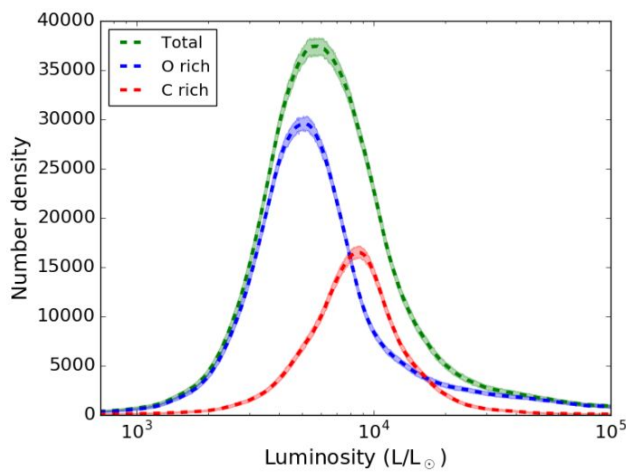


DPR: ~5 x 10^{-5} $M_\odot$/yr
problem: 8 µm excess

(Javadi et al. 2013)
(Srinivasan et al. in prep.)

AGB dust production in the Solar Neighborhood

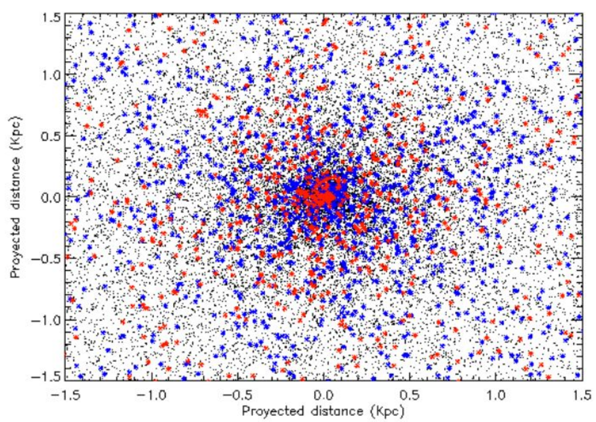
- Volume-limited sample (2 kpc)
  - All-sky IR surveys (IRAS, WISE, 2MASS, AKARI)
  - High dynamic range
  - Nearest targets are extended and sometimes saturated
  - Distances and therefore luminosities not well known
  - But: statistics is your friend
  - And: most prolific dust producers are the brightest 60 micron sources
- DPR determination using GRAMS
- Extrapolation to entire Milky Way

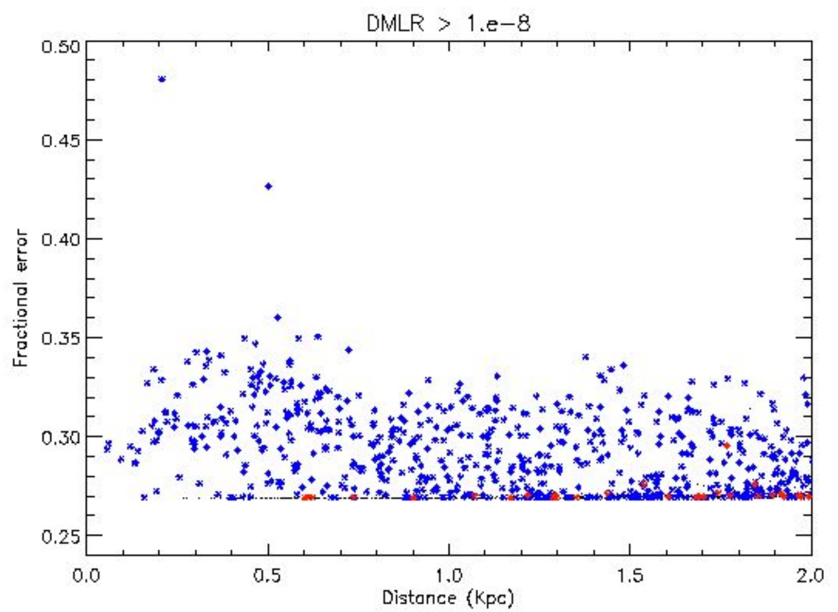


DPR < 2 kpc:

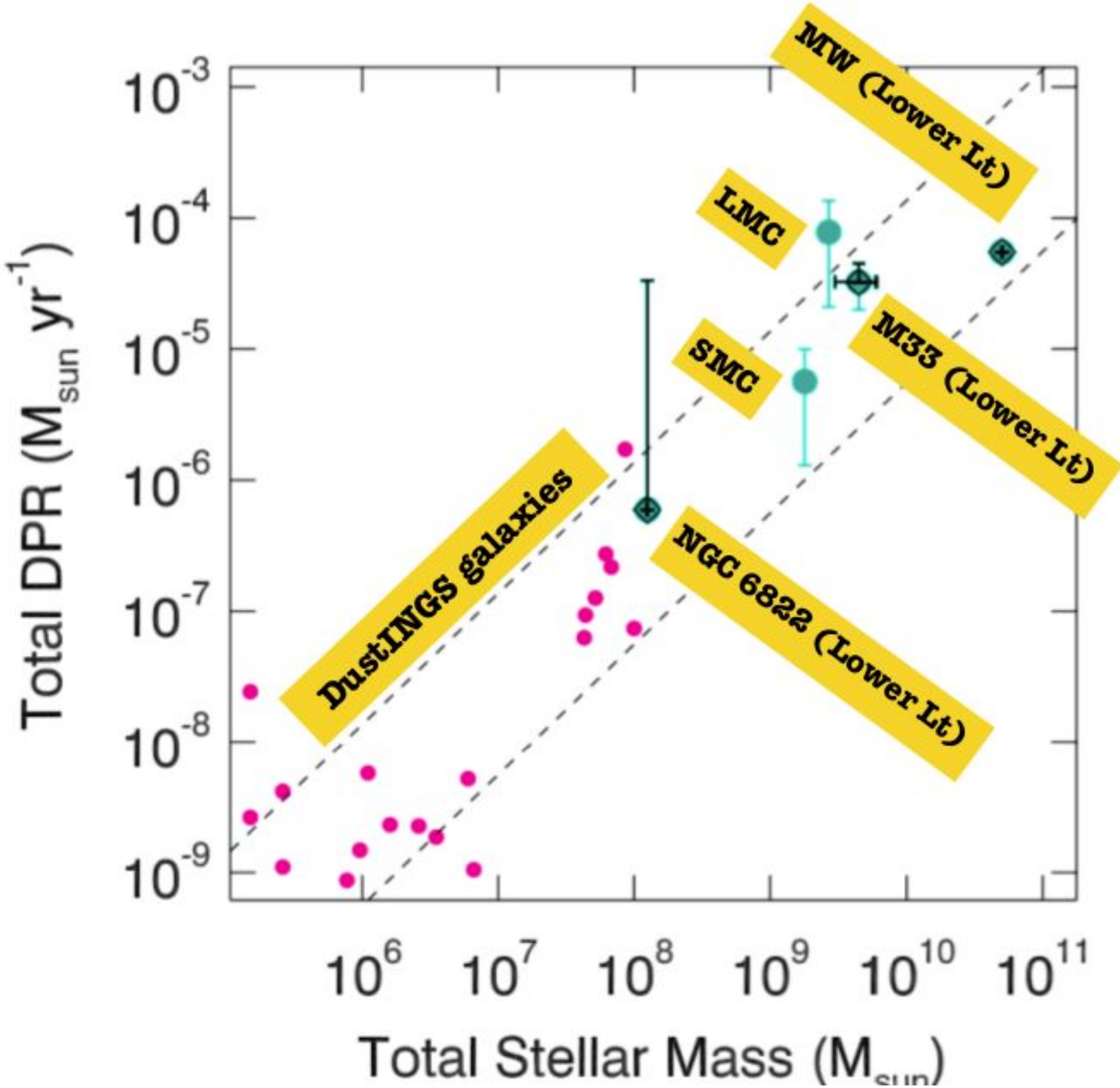
$4.1\times10^{-5}\ M_{sun}/yr$

(Trejo et al. in prep.)





AGB Dust production in galaxies: The Local Group

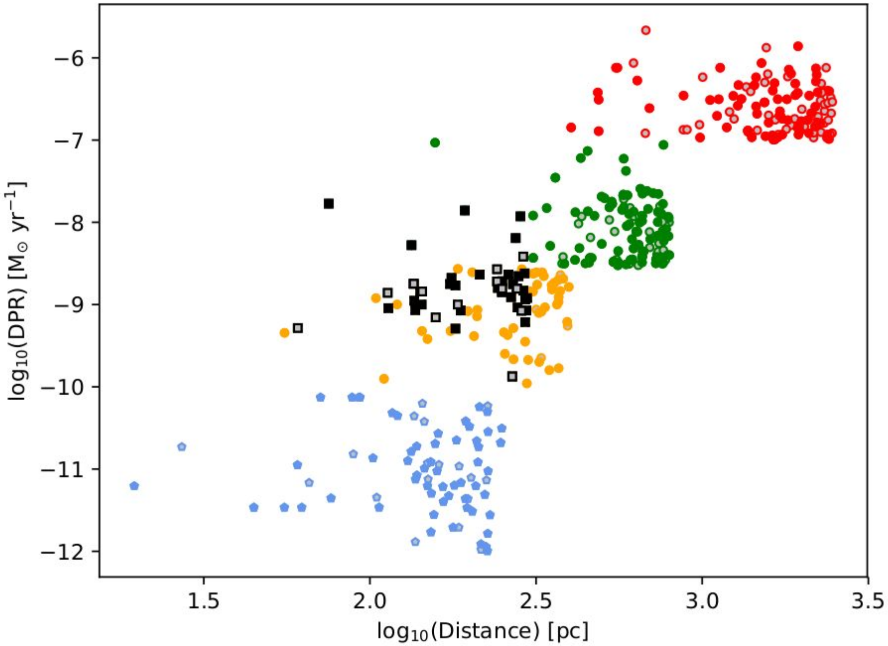


(Srinivasan et al. in prep.)

The Nearby Evolved Stars Survey (NESS)

Nearby Evolved Stars Survey

(Scicluna et al. in prep.)



JCMT+APEX: 39 nearest dusty AGB stars + wedding-cake survey within 2 kpc (400 stars)

submm continuum + CO line transitions

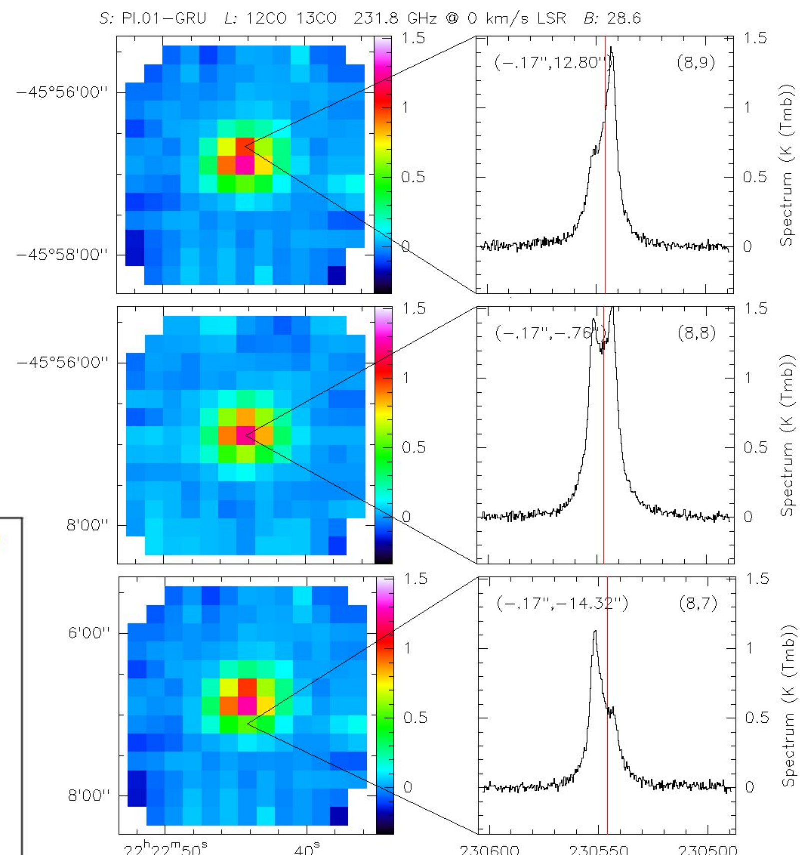
565 hrs JCMT (PI: Scicluna)
60 hrs APEX (PI: Wallstrom)
90 hrs Nobeyama (PI: Scicluna)

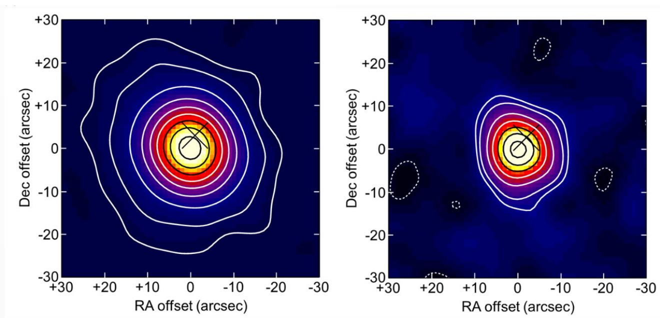
future plans:
SMA/ALMA-ACA
SOFIA
10 micron spectroscopy

Goal: to spatially resolve the mass loss history

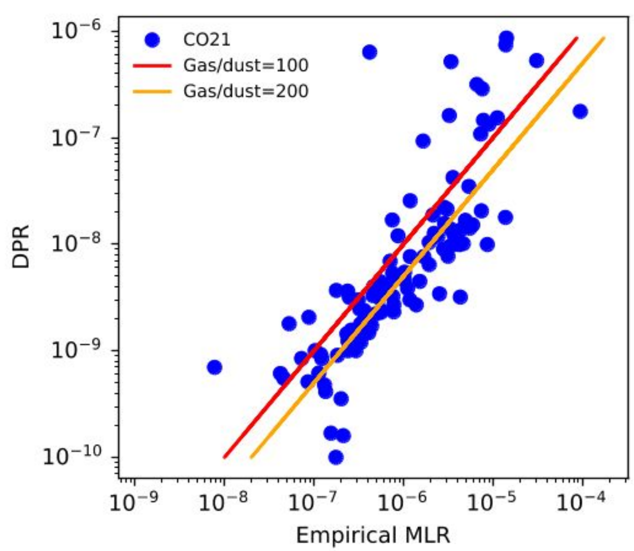
The Nearby Evolved Stars Survey (NESS)

- Total gas and dust return to ISM
- Gas-to-dust ratios
- Mass-loss history
- Submm dust properties
- 13CO/12CO
- Galactic dust production
- Deviations from spherical symmetry





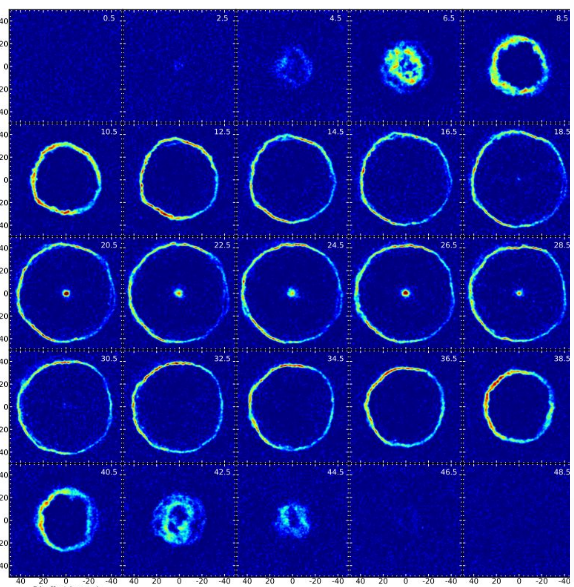
(Scicluna et al. in prep.)



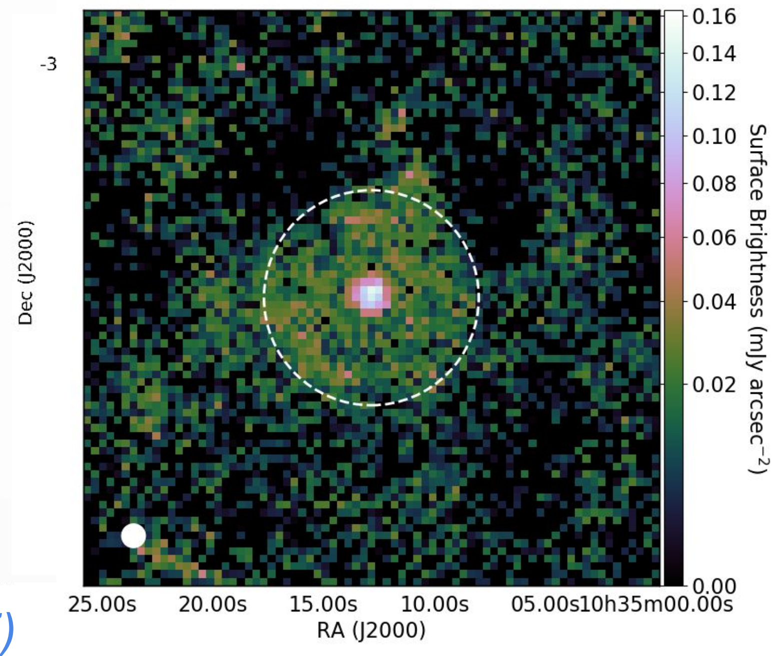
(Wallström et al. in prep.)

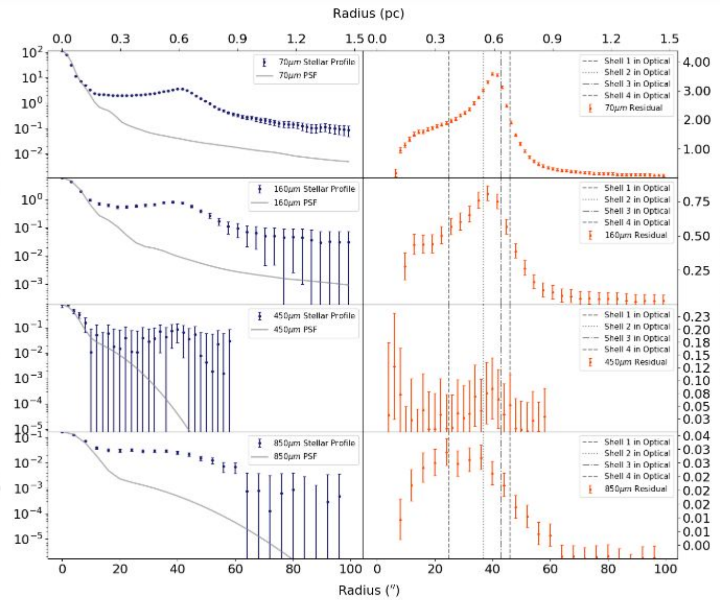
The Nearby Evolved Stars Survey (NESS)

The detached shell in U Ant in submm continuum emission



(Kerschbaum et al. 2017)





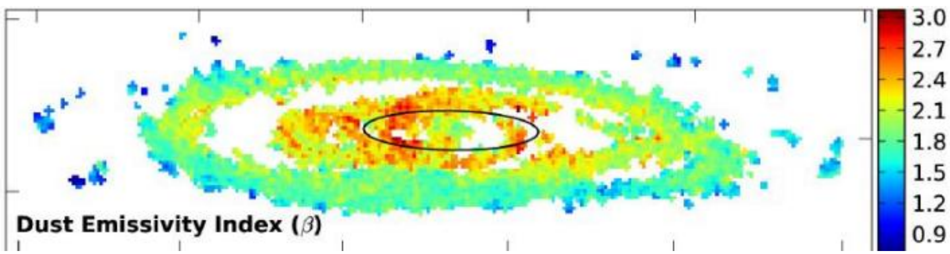
(Dharmawardena et al. 2019)

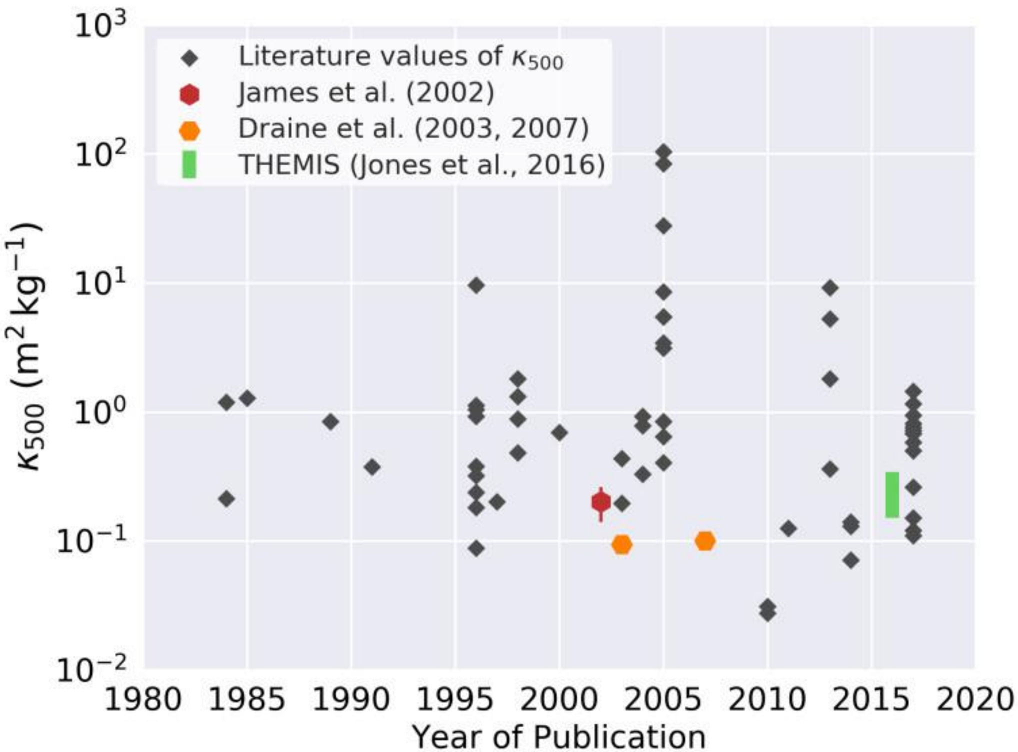
The interstellar dust mass

Determining the interstellar dust mass

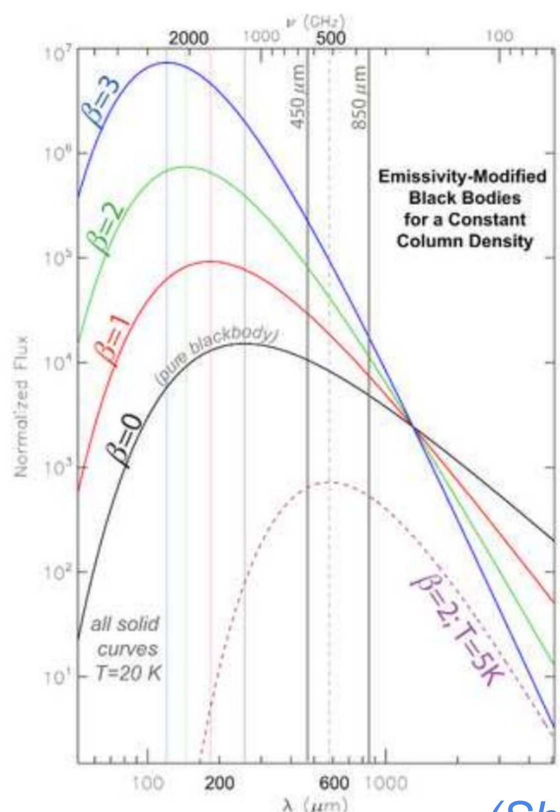
- Modified black body
- Opacity: $\lambda^{-\beta}$
- Single or few temperature components

(Smith et al. 2012)



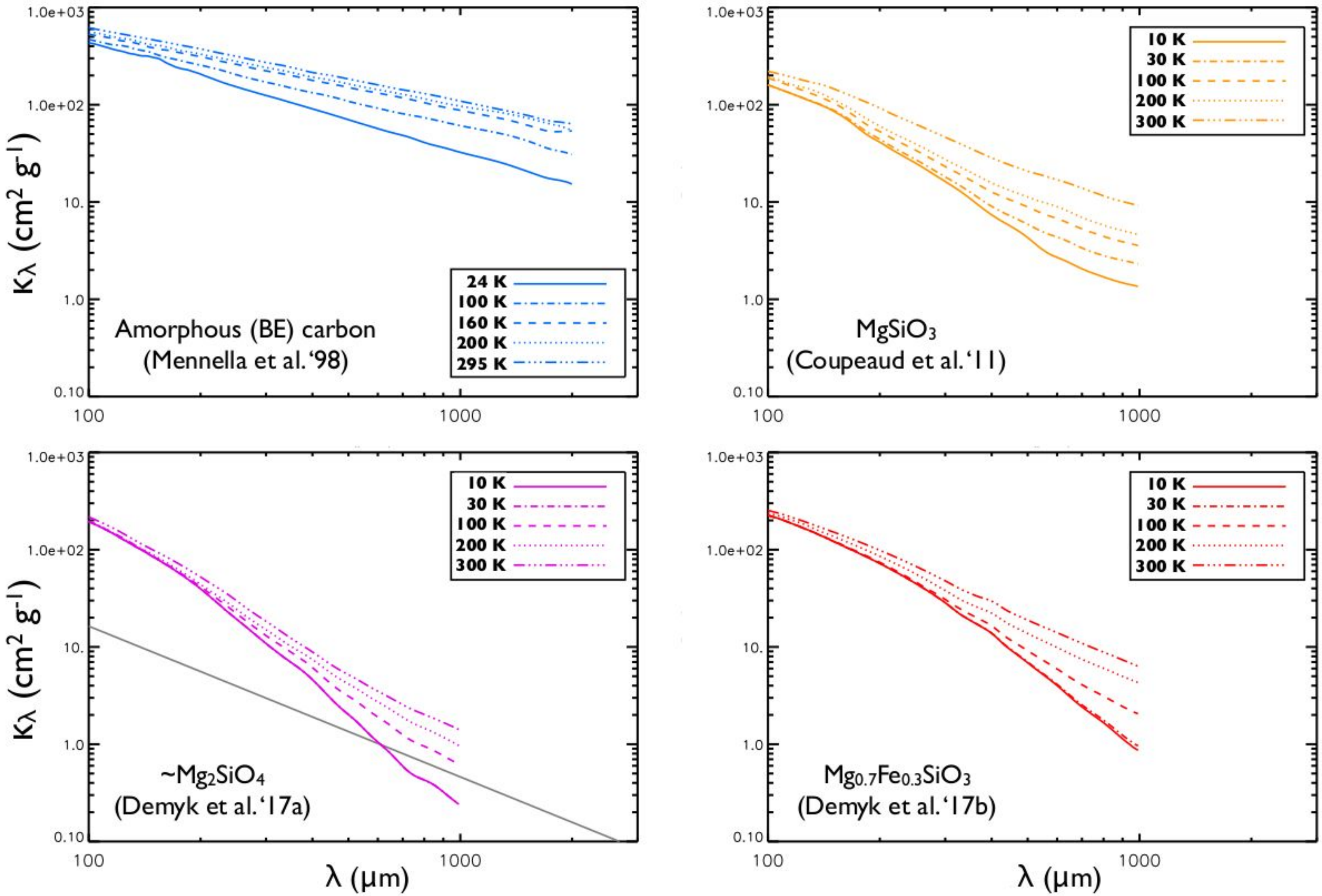


(Clark et al. 2016)

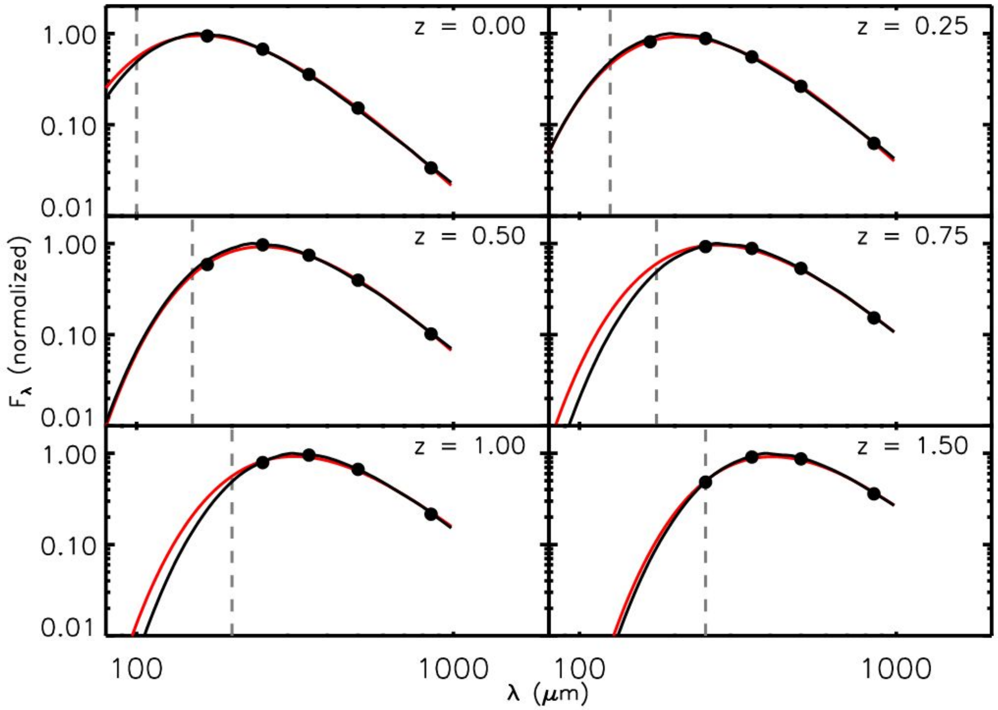


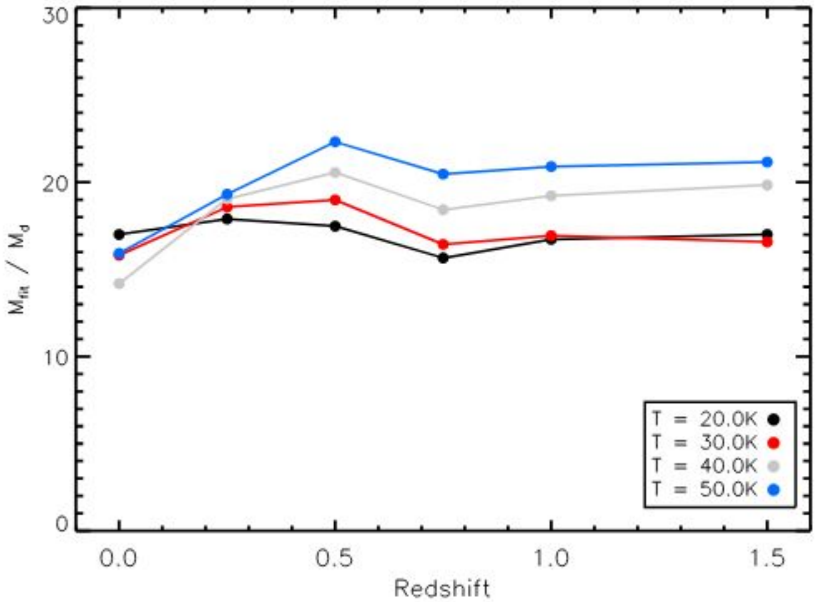
(Shetty et al. 2009)

Determining the interstellar dust mass



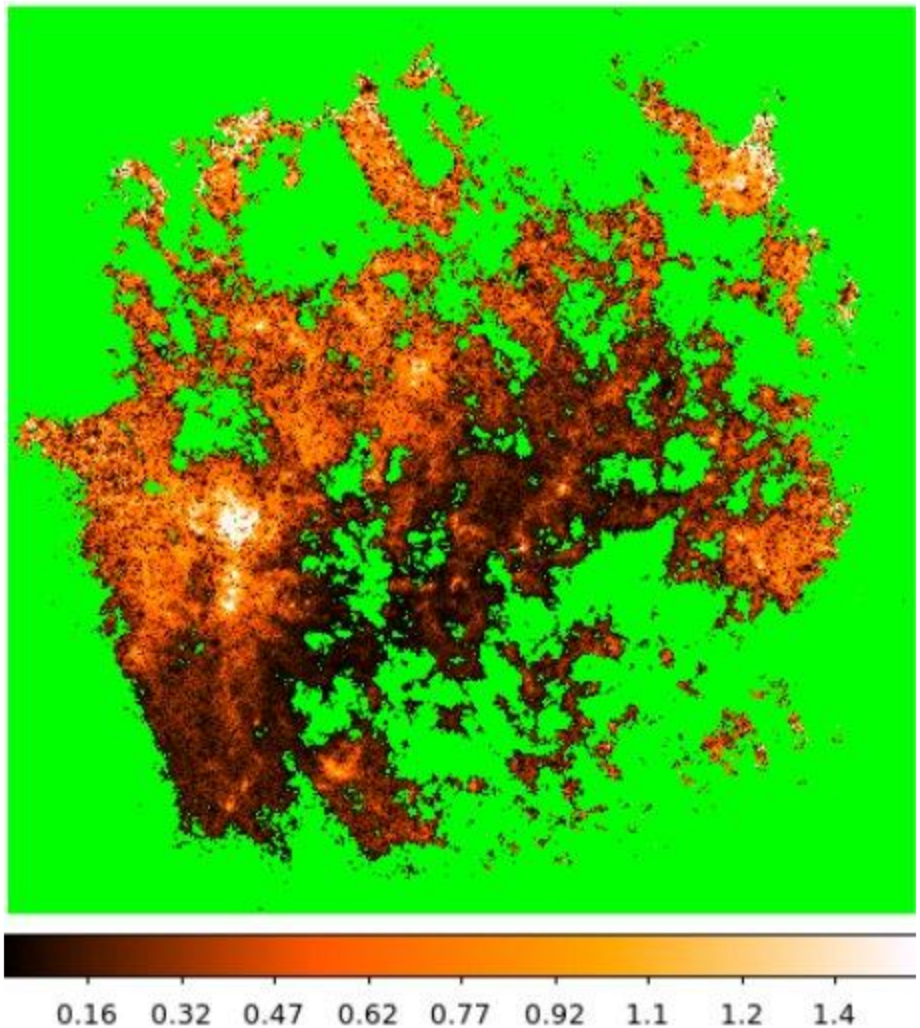
Determining the interstellar dust mass





(Fanciullo et al. in prep.)

Comparison DPR with ISM dust and SFR in the LMC



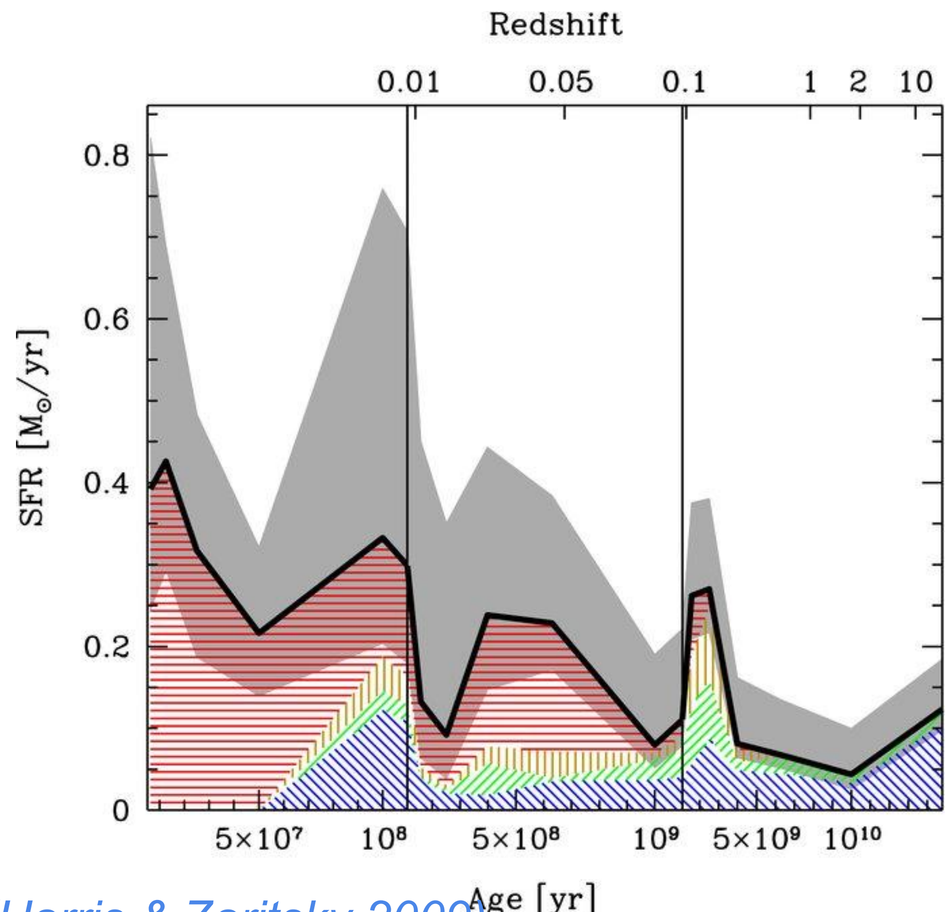
(Skibba et al. 2012, Gordon et al. 2014)

- ISM dust mass:
  $(7.3 \pm 1.7) \times 10^5\ M_\odot$
- Dust MLR: $(2\text{-}4) \times 10^{-5}\ M_\odot/yr$
- Star Formation Rate:
  $0.38\ M_\odot/yr$ (gas)
  $\rightarrow 8 \times 10^{-4}\ M_\odot/yr$ (dust)

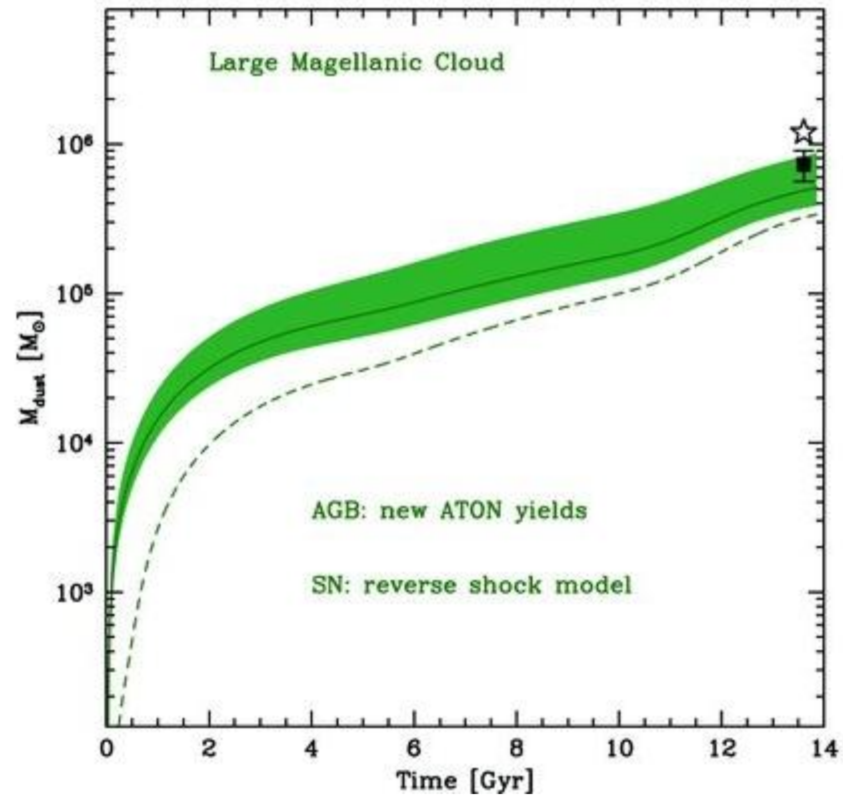
- replenishment time scale:
  10^{10} yr (comparable to age of LMC)
- astration time scale: 10^8 yr

Not taken into account:
Dust destruction & formation

Modelling the dust production history in the LMC



(Harris & Zaritsky 2009)



(Schneider et al. 2014)

theoretical dust yields of AGB stars
over the entire SFH of the LMC
no interstellar dust destruction

ISM dust comparison

Table 9
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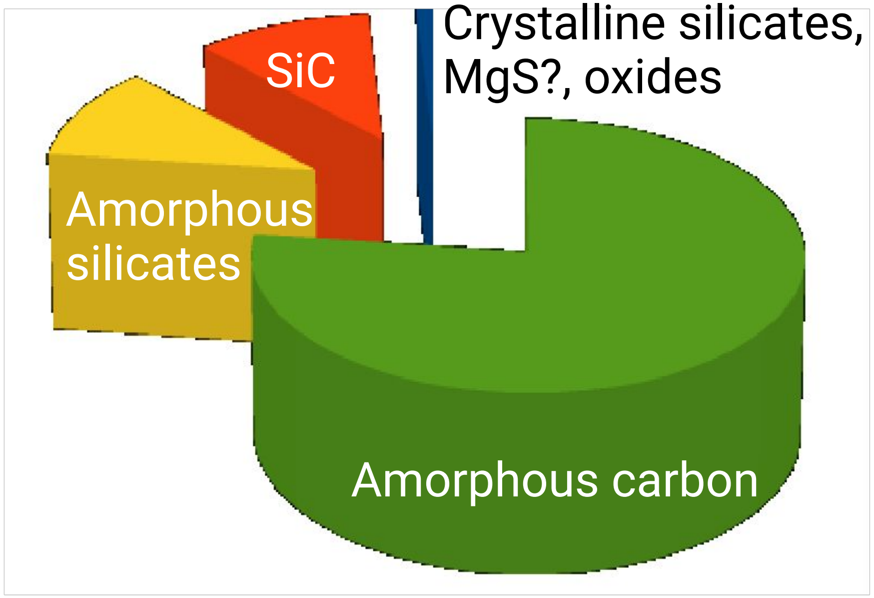
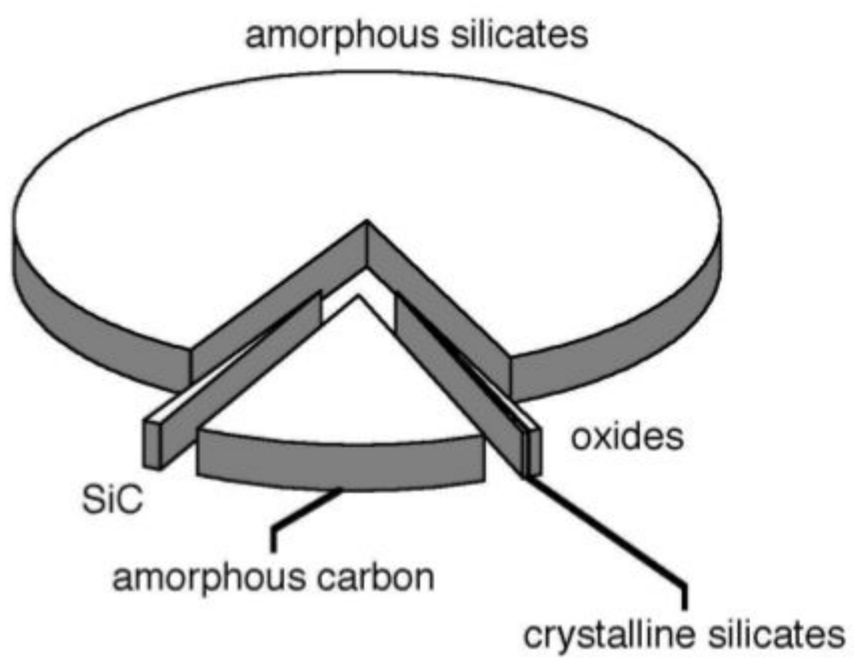
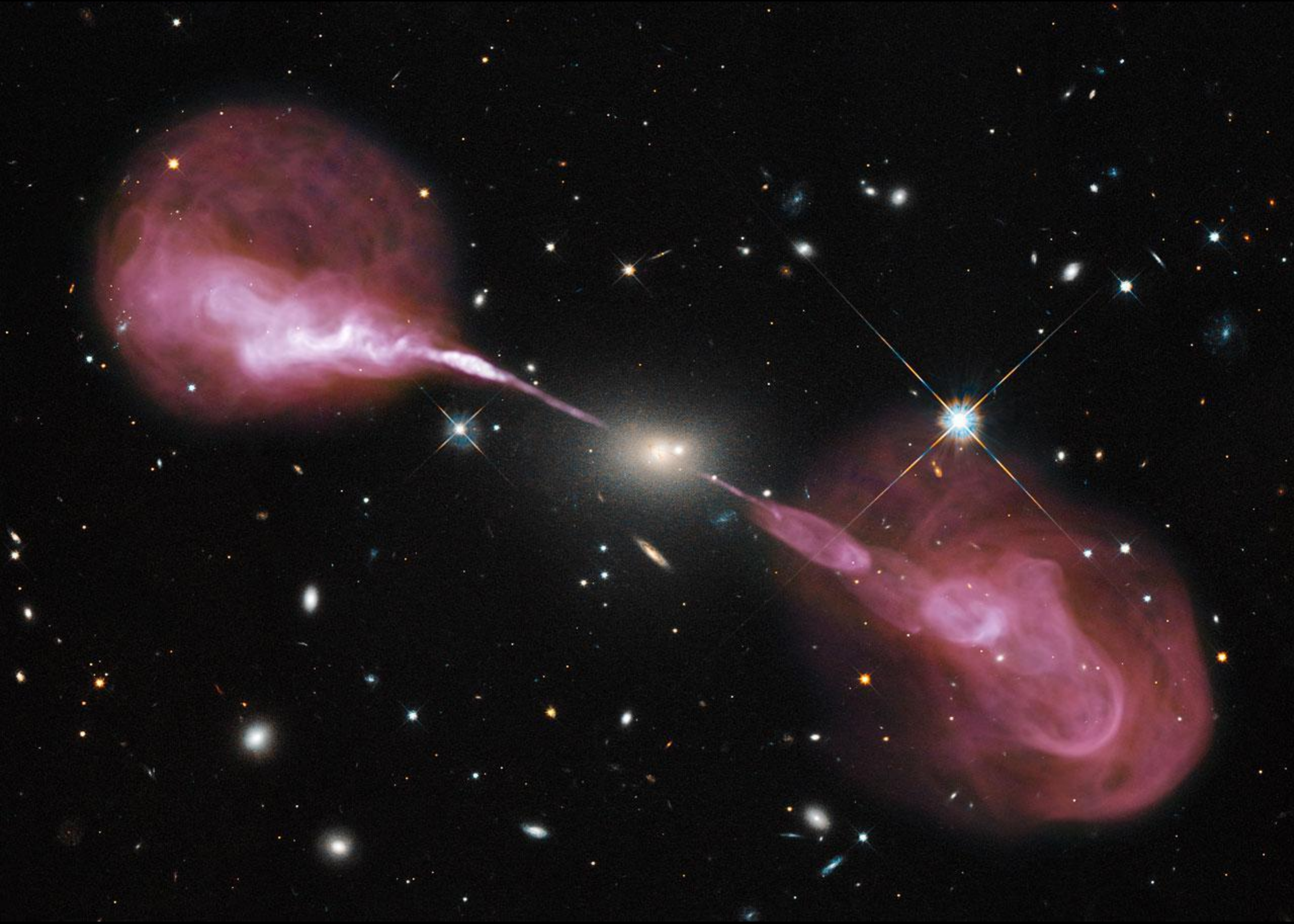


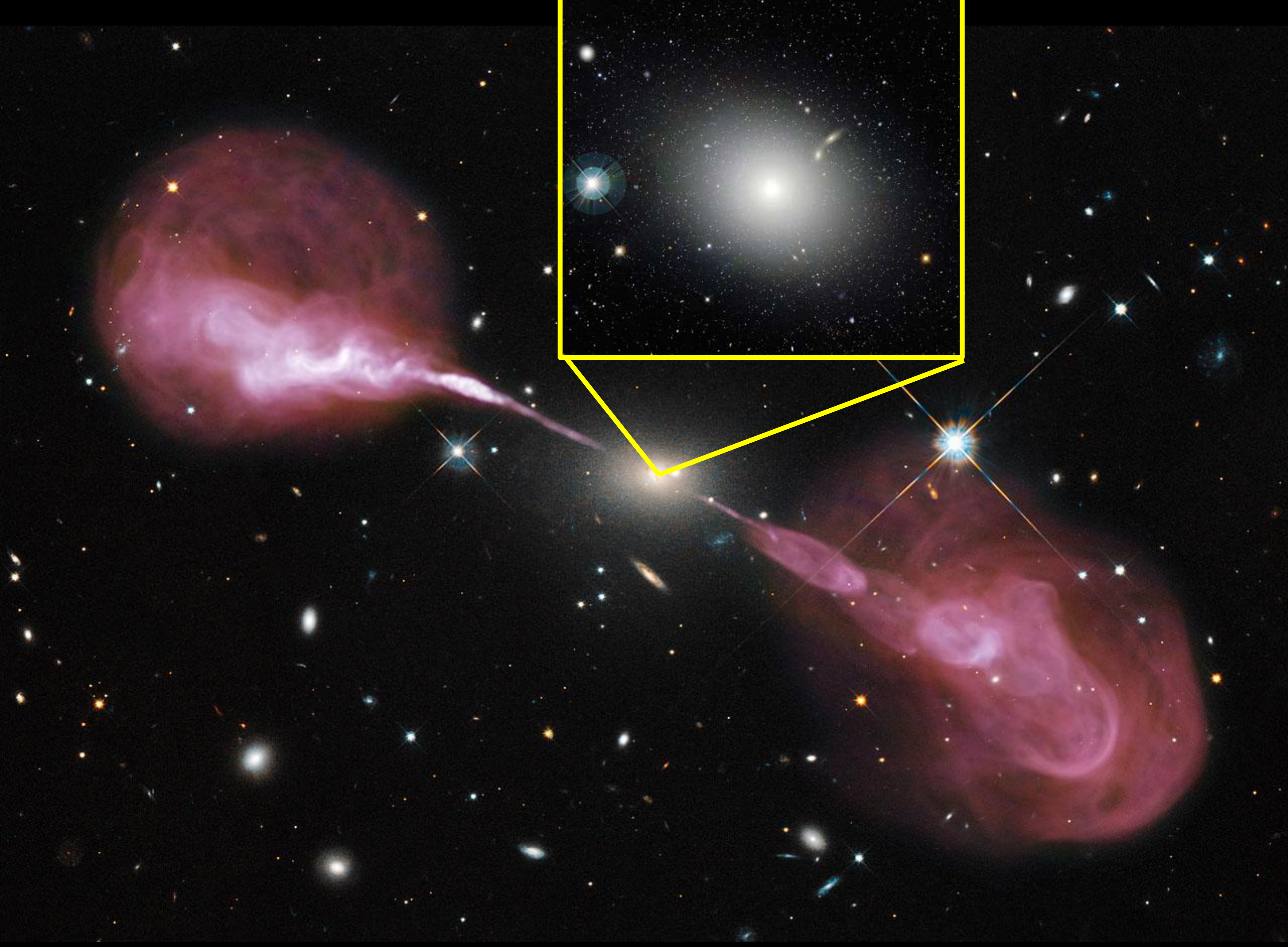
LMC injection *(Kemper 2013)*

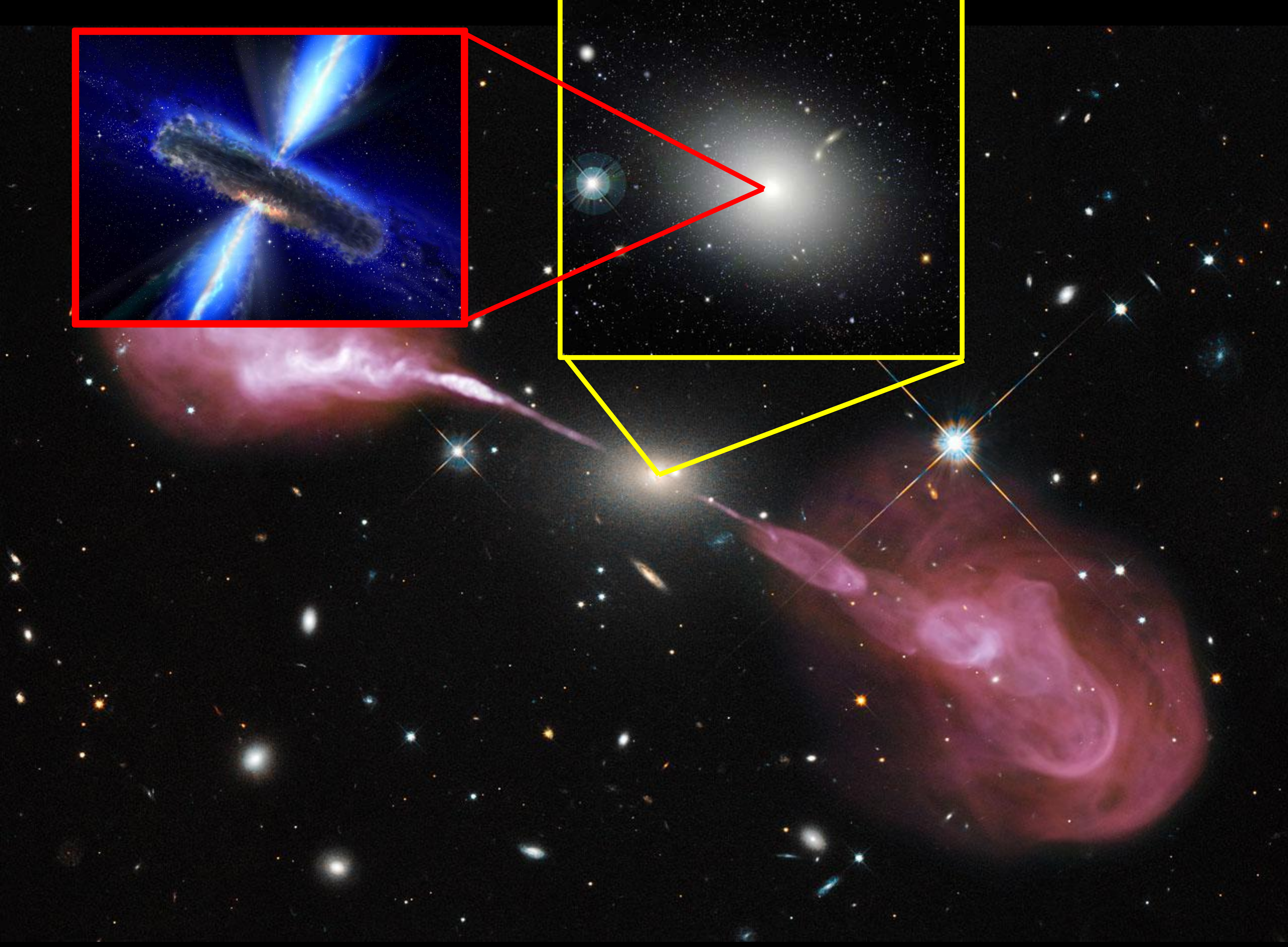


MW ISM composition *(Tielens et al. 2005)*

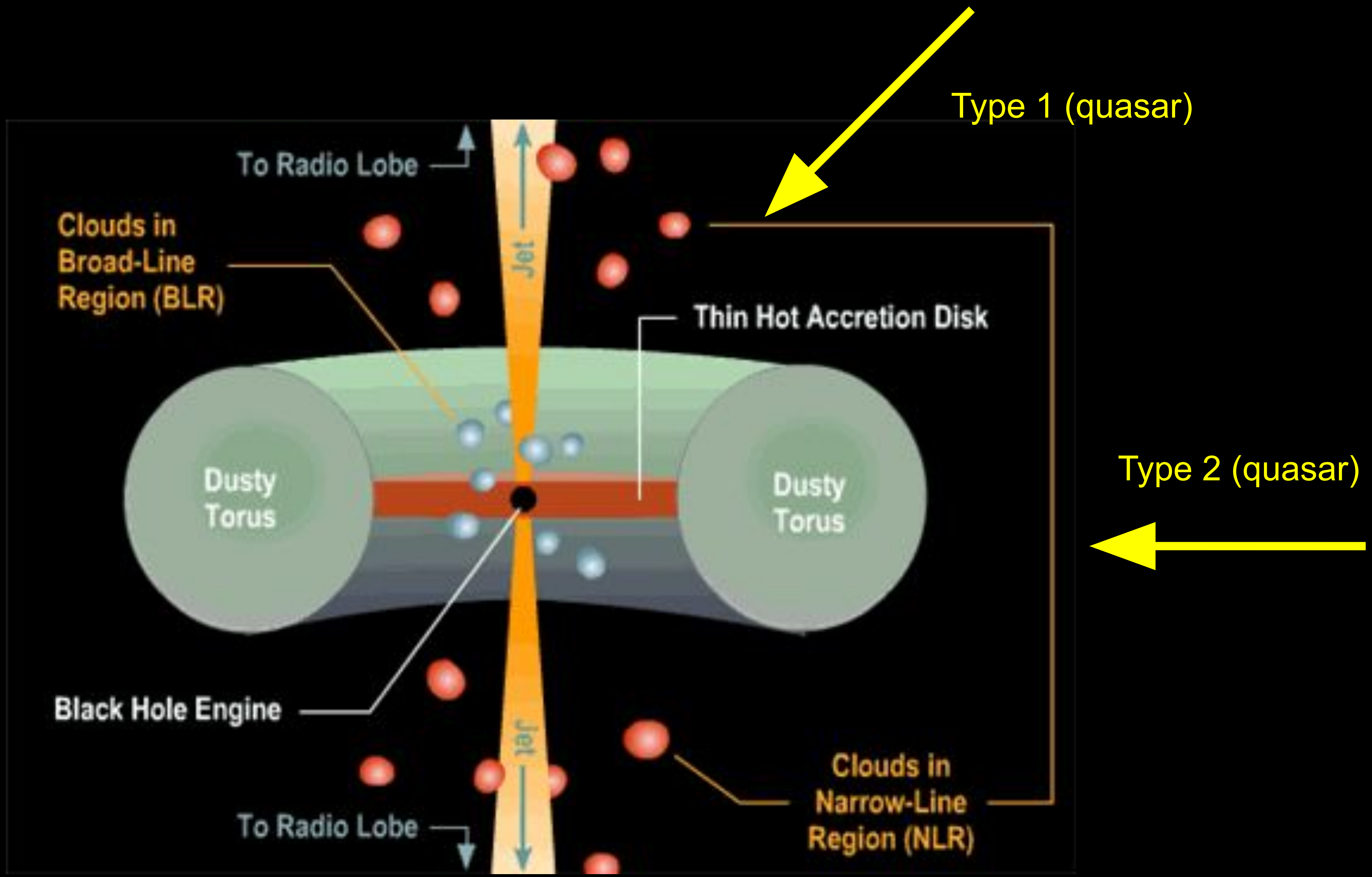
The mineralogy of AGN dust



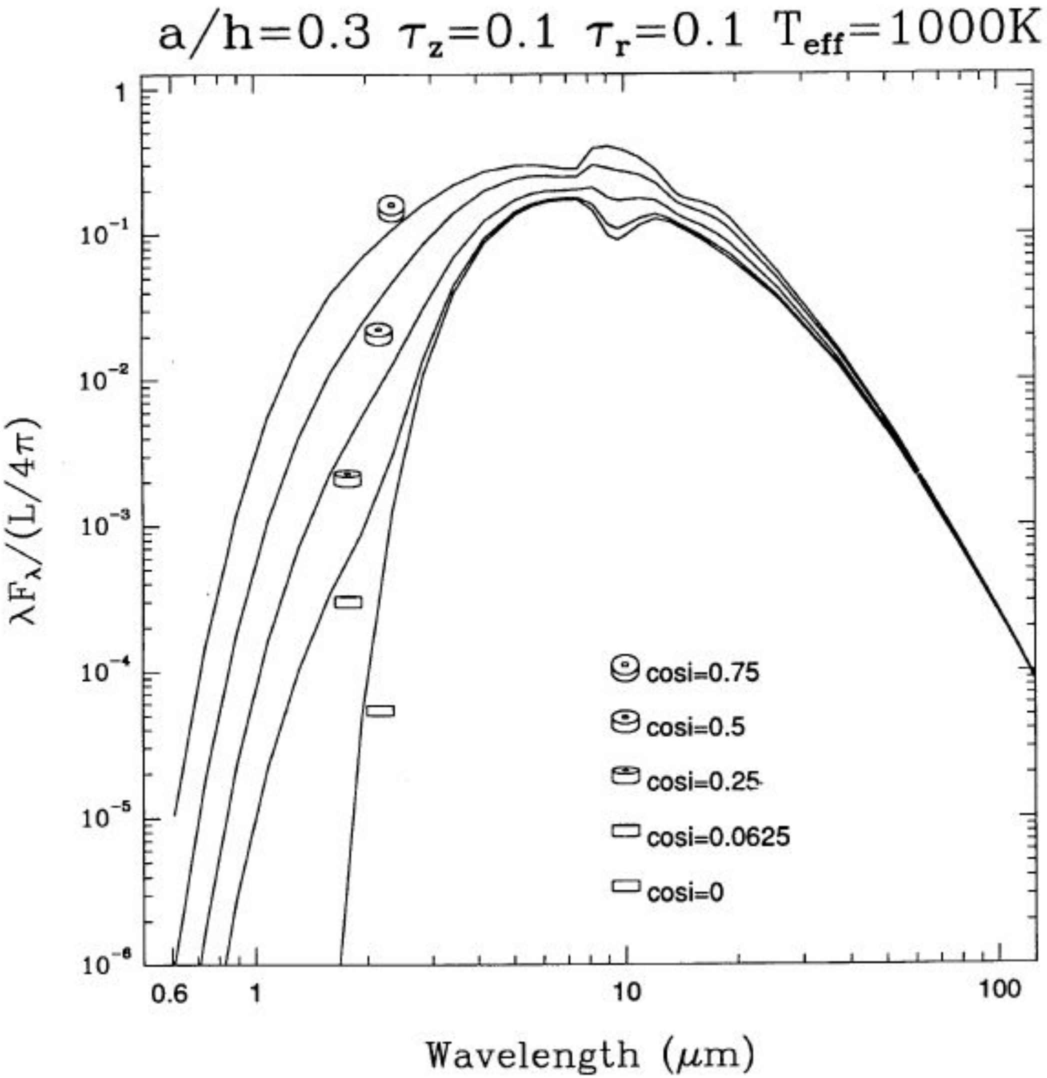




The physical model for AGN

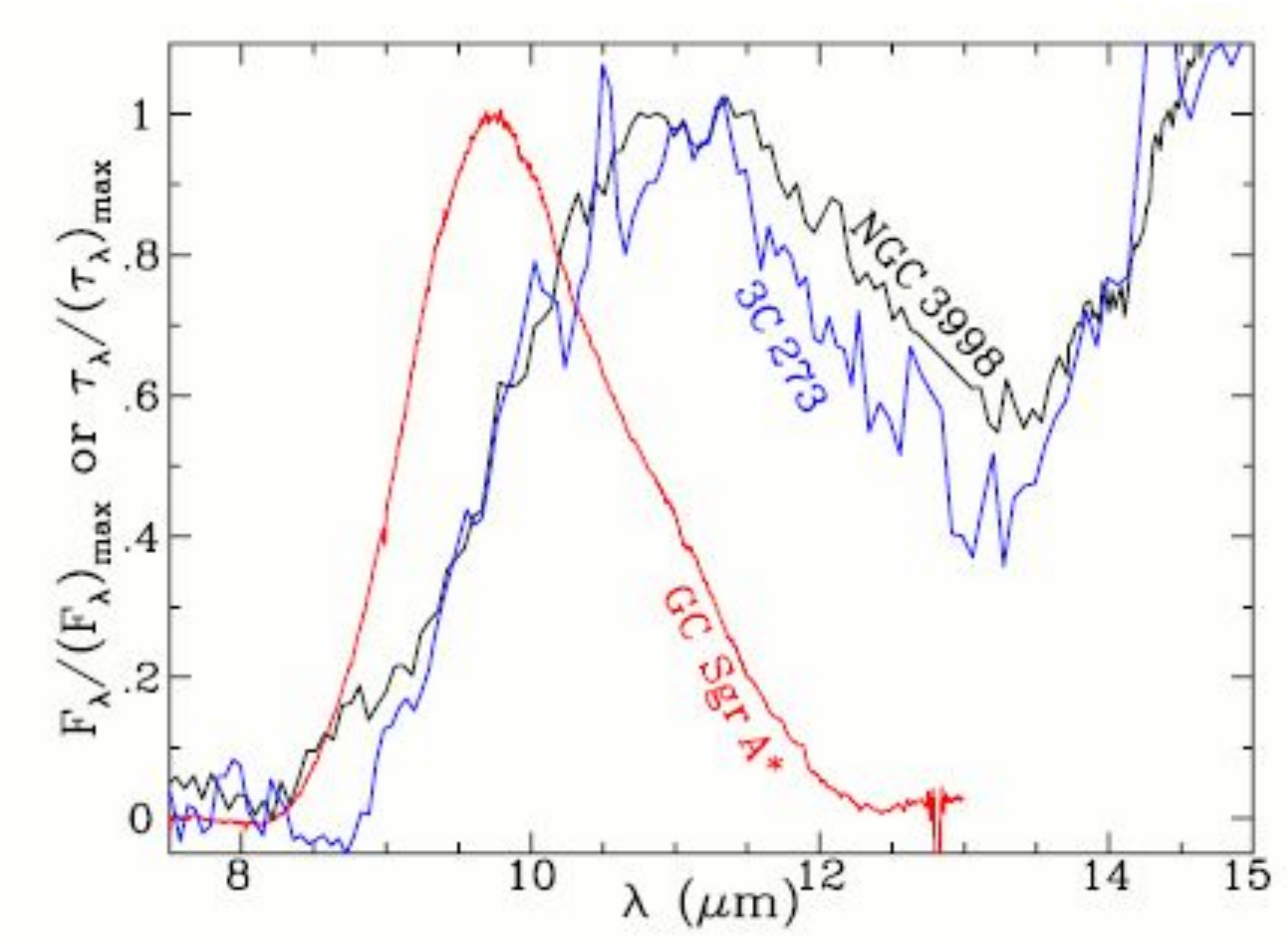


Spectral Energy Distributions



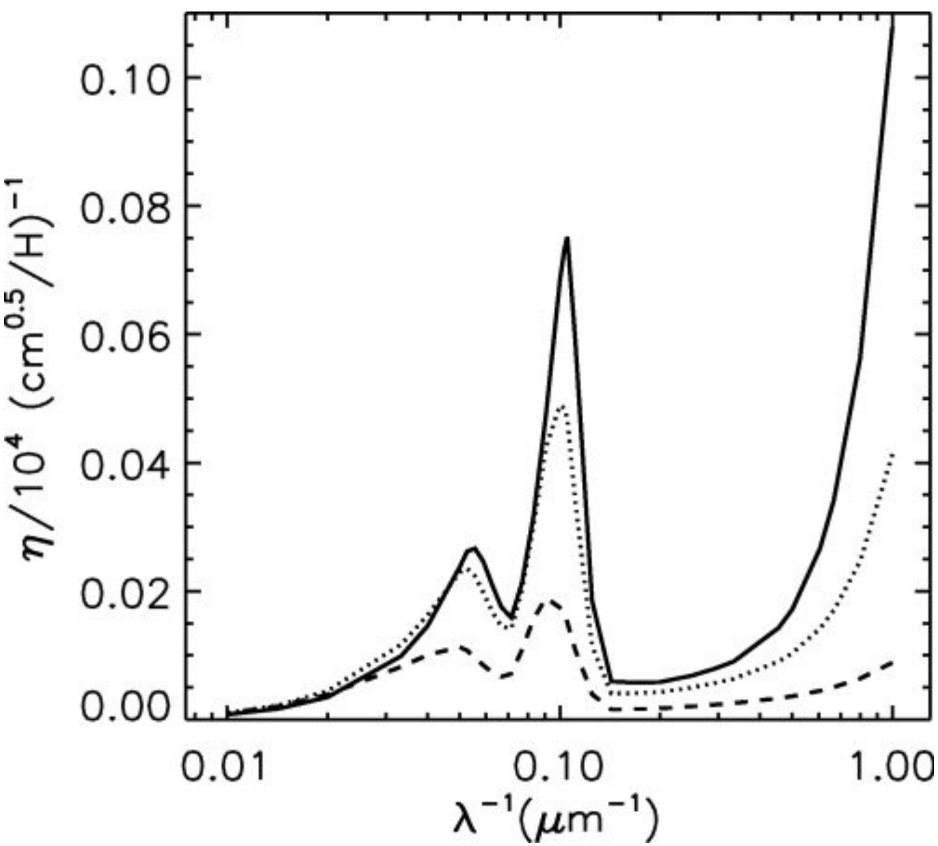
(Pier & Krolik 1992)

Early detections of silicates in emission

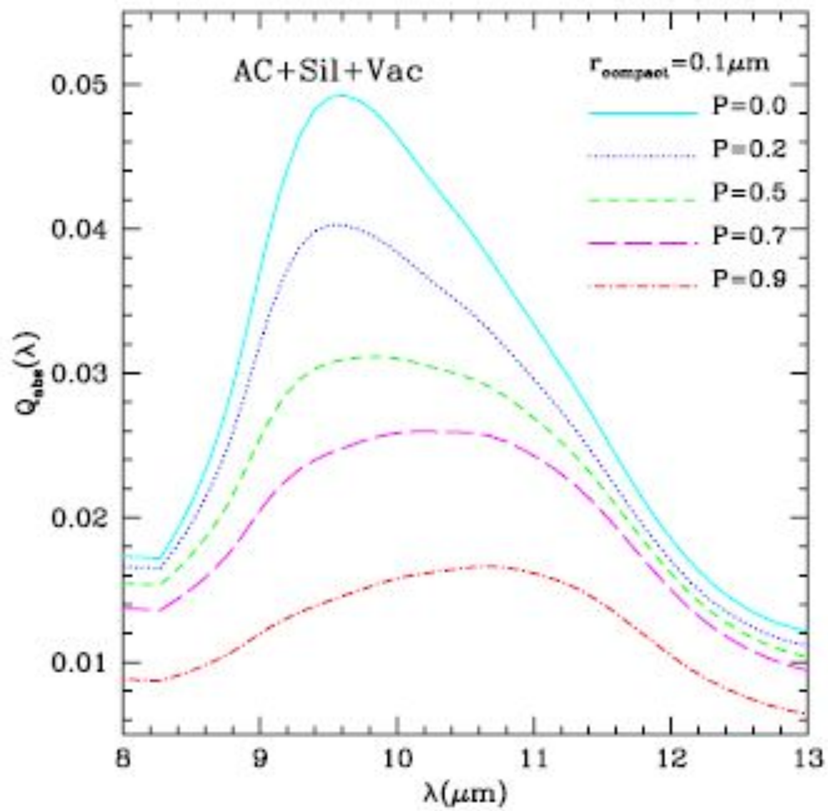


(Hao et al. 2005; Sturm et al. 2005; Siebenmorgen et al. 2005)

Porosity shifts and weakens 10 micron feature

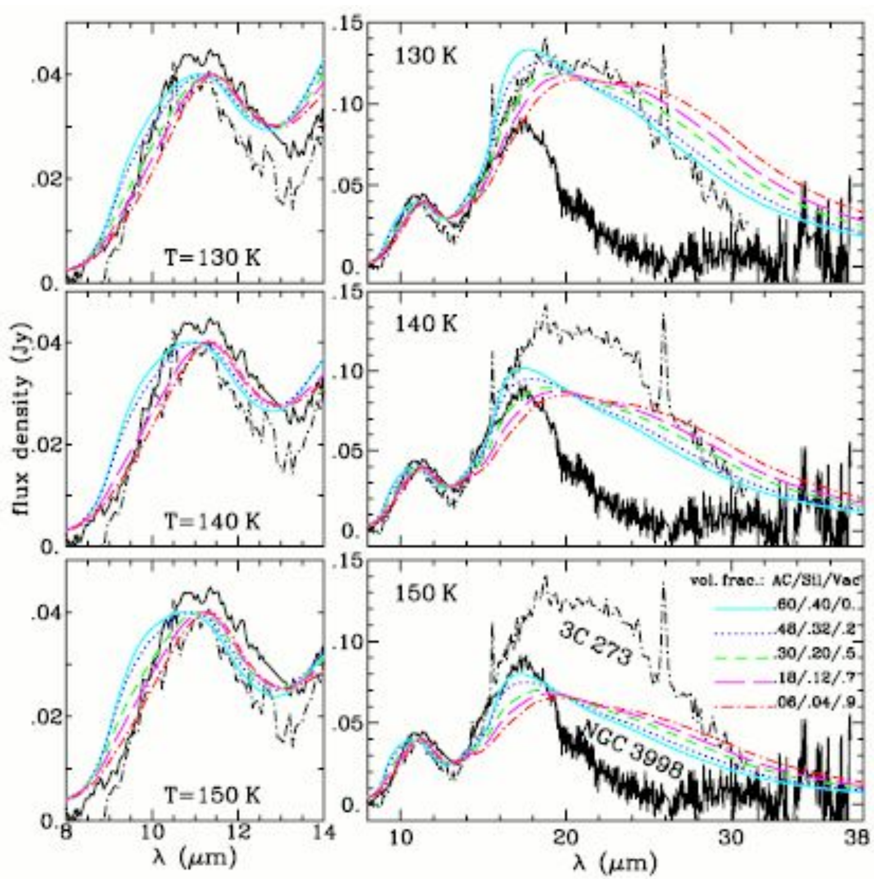


(Iati et al. 2001)

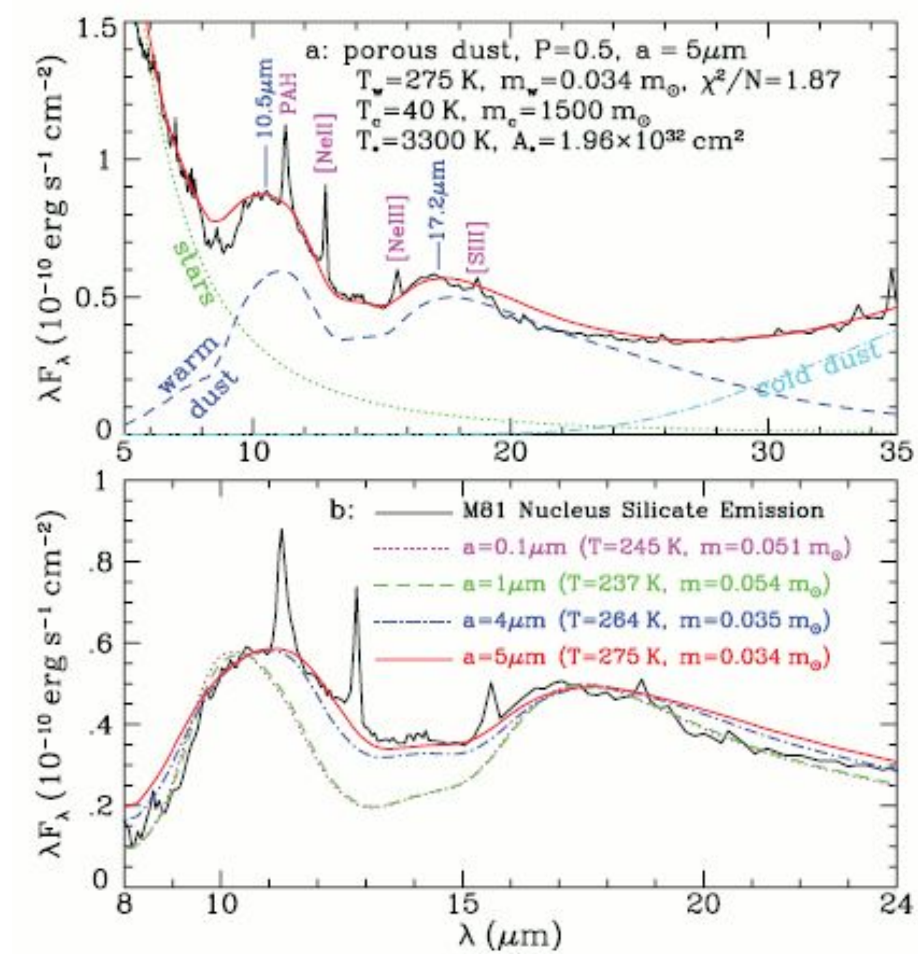


(Li et al. 2008)

Porous silicates associated with 3 AGN

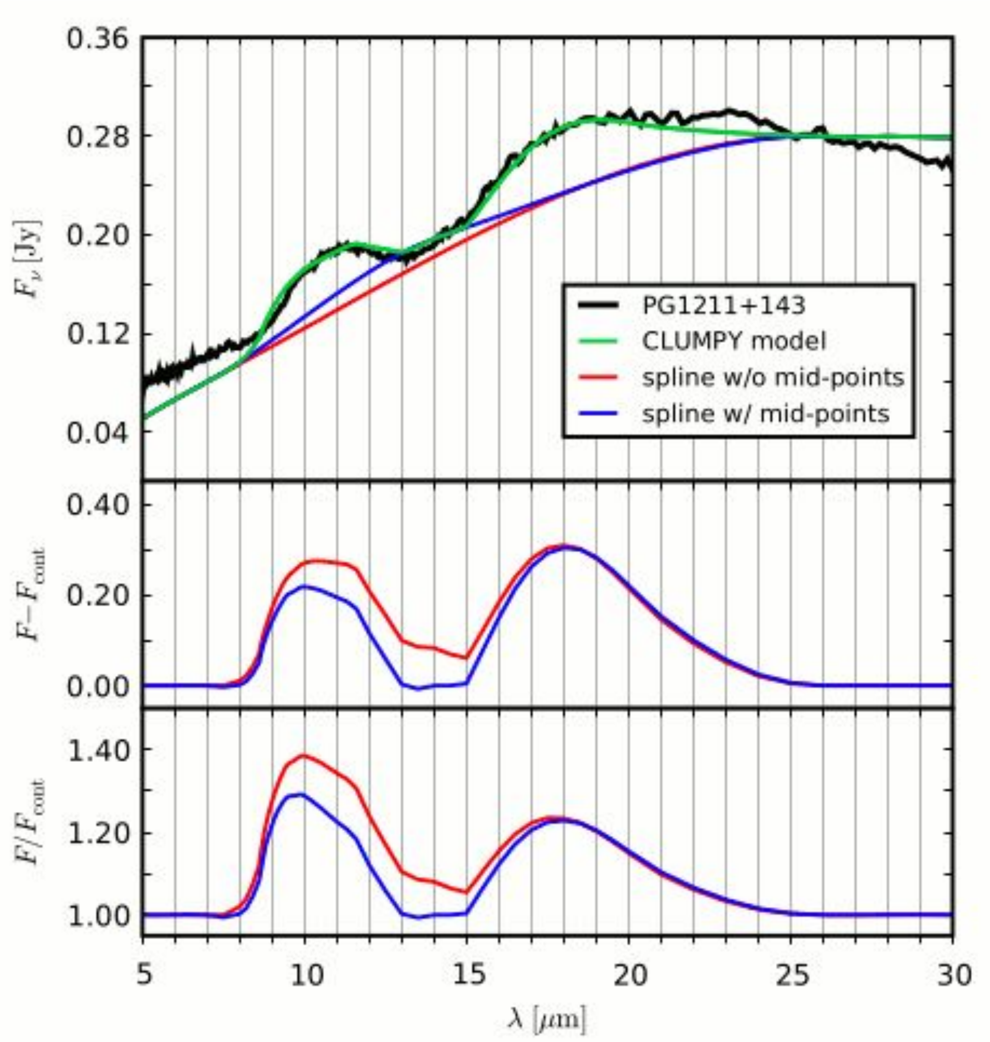


(Li et al. 2008)

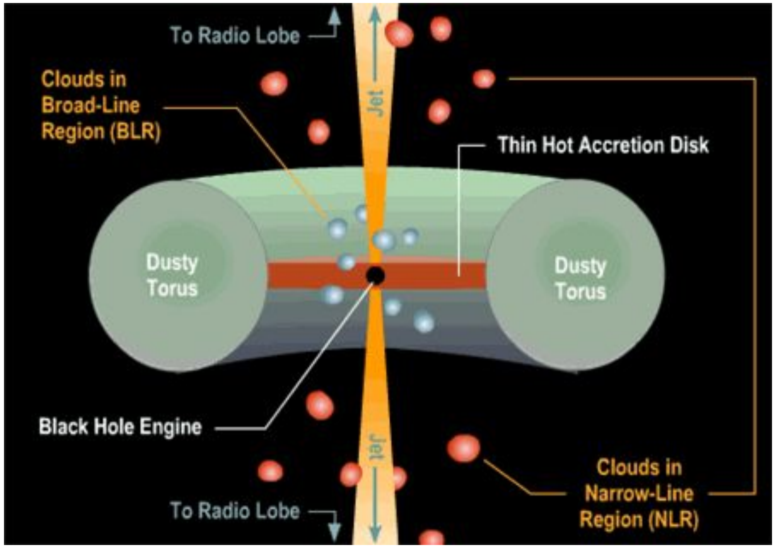


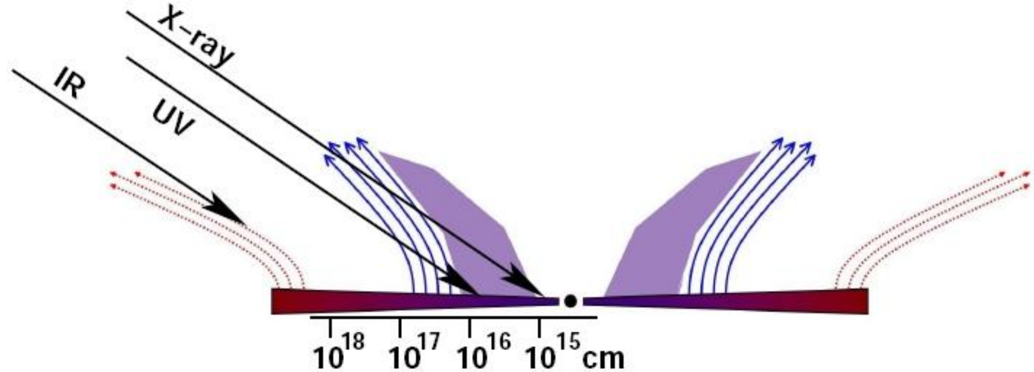
(Smith et al. 2010)

Optical depth effects



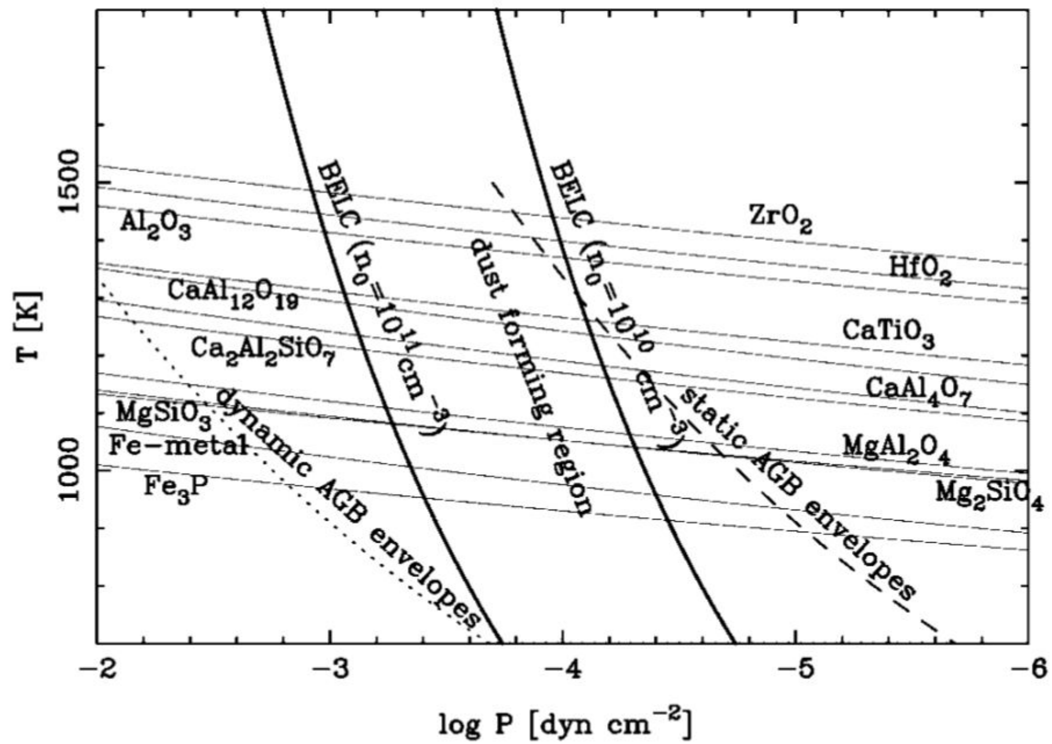
(Nikutta et al. 2009)



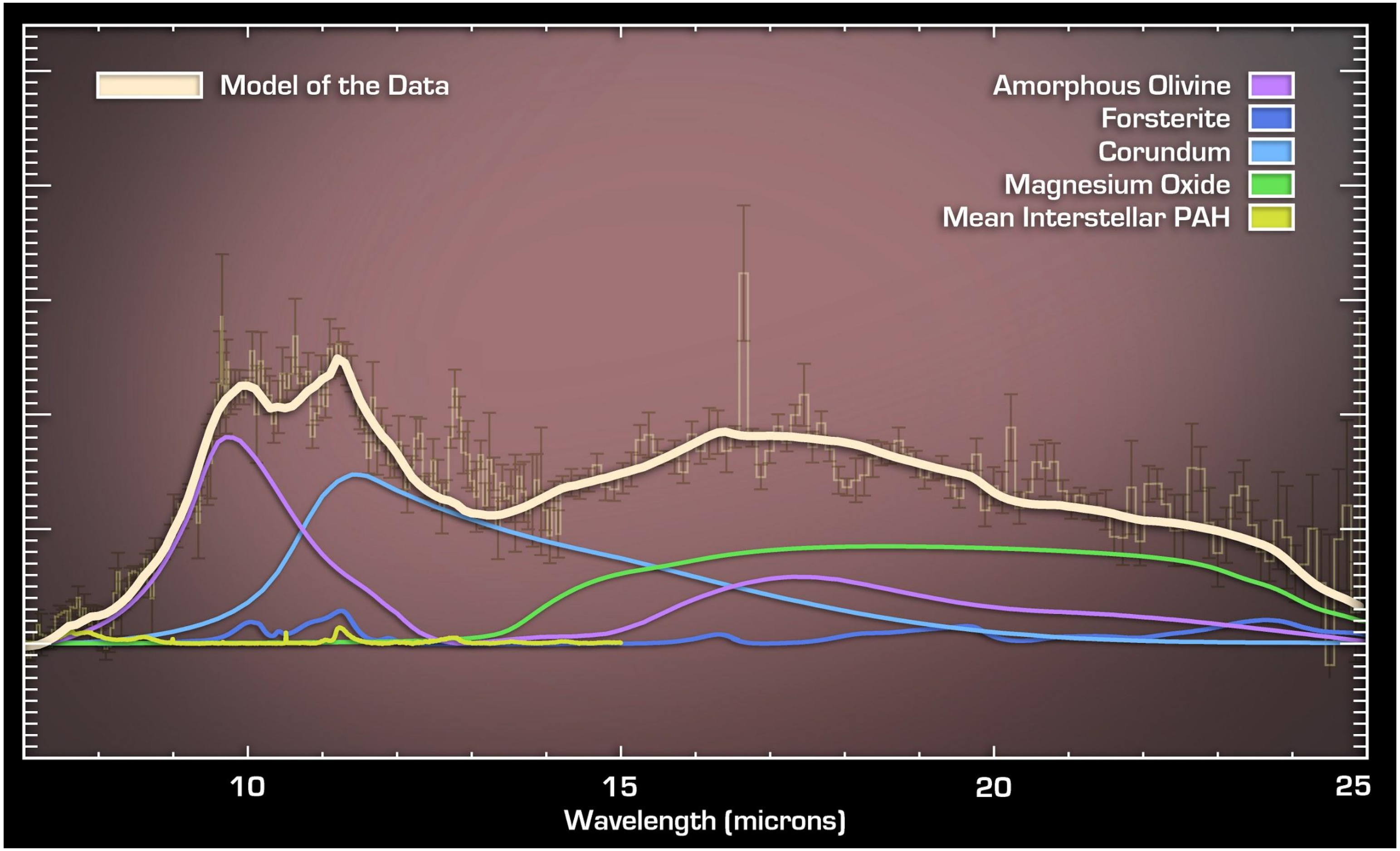


Dust formation in disk wind *(Elvis et al. 2002)*

Dusty disk wind as torus *(Elitzur & Schlossman 2008)*



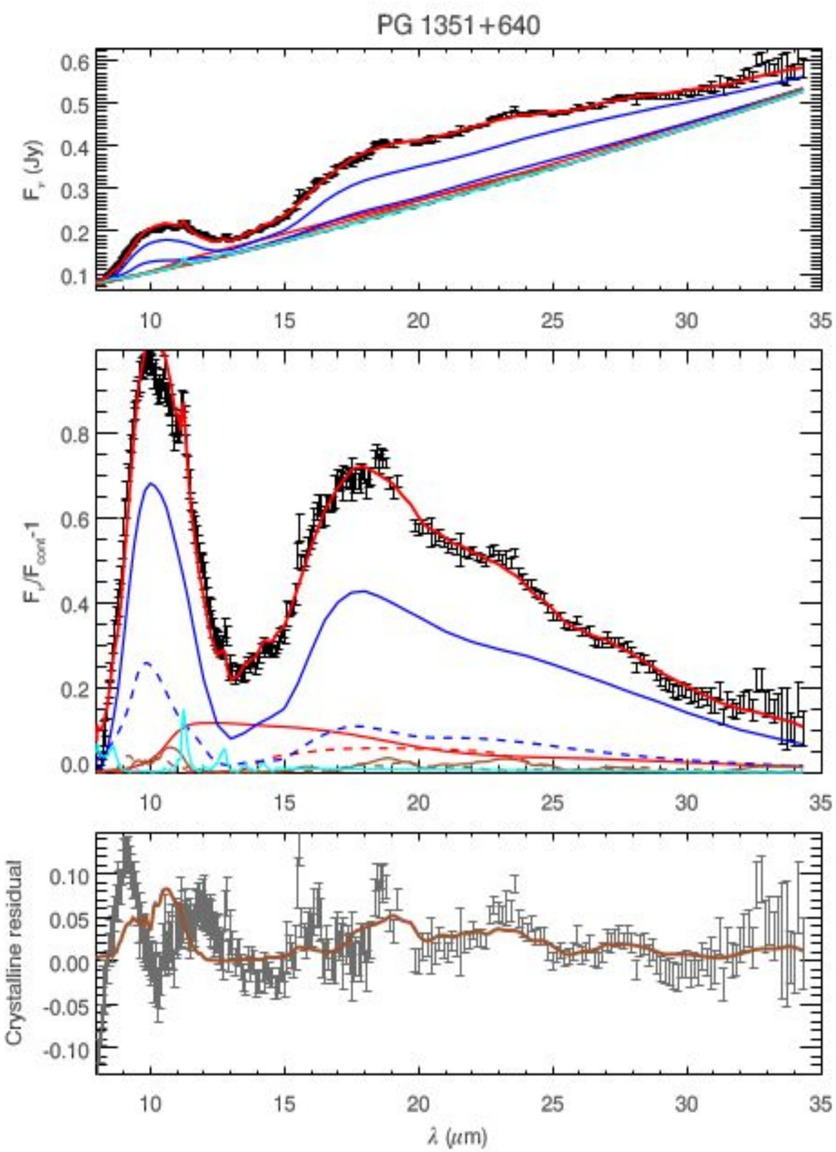
Mineralogy: composition differs from Galactic dust

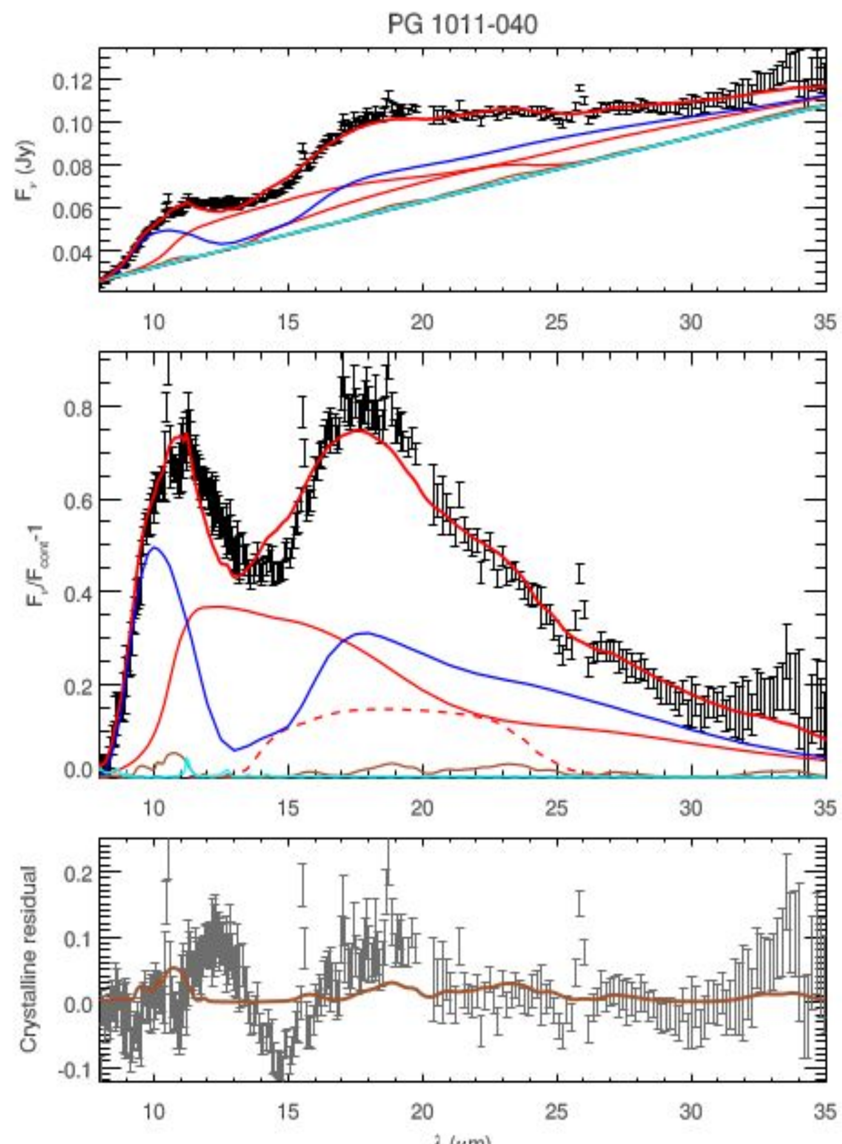


(Markwick-Kemper et al. 2007)

Further fits

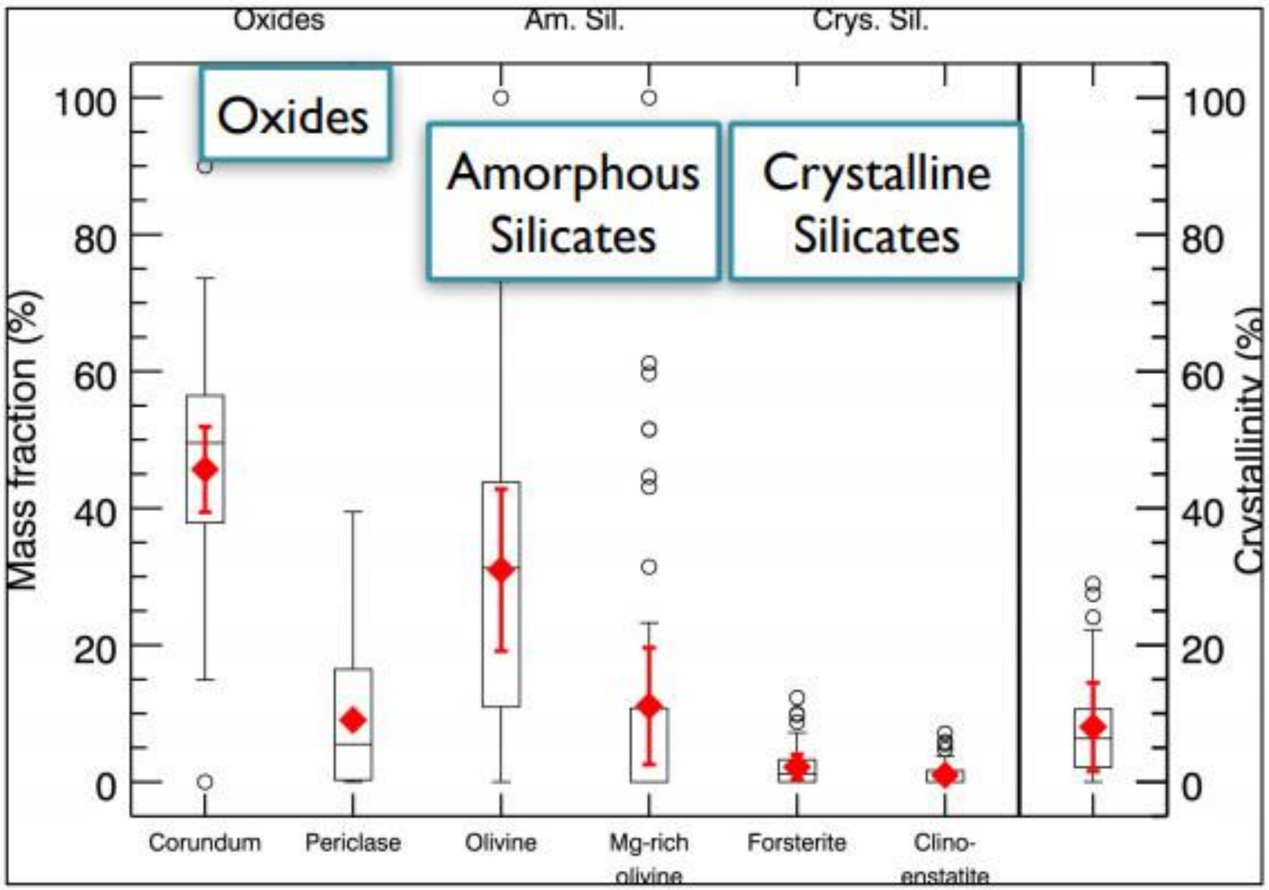
(Srinivasan et al. 2017)





Results for a small sample

(Srinivasan et al. 2017)



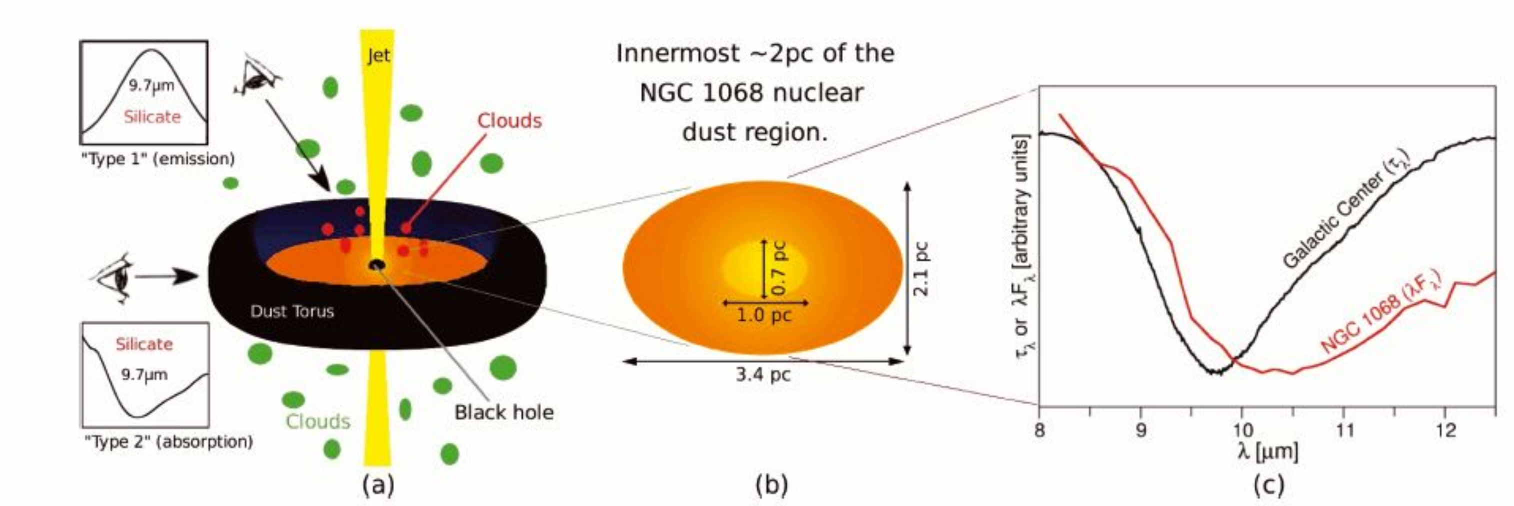
PG sample from Petric et al. (2015)

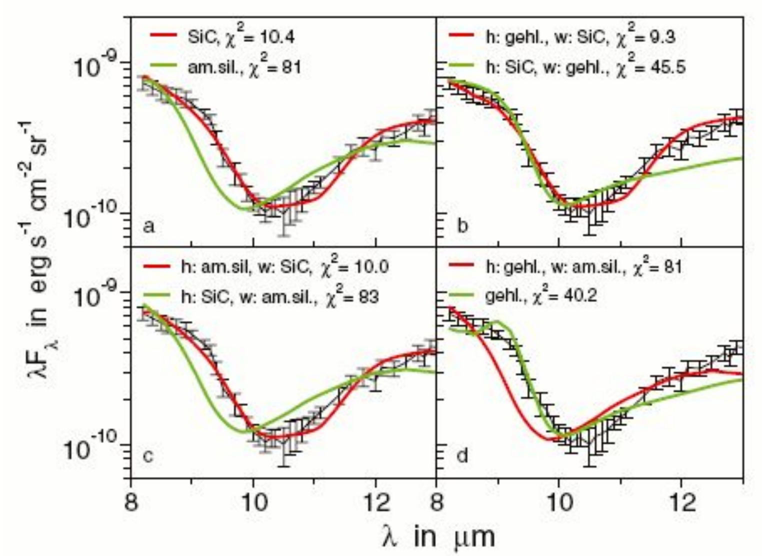
Herschel or MIPS 70 micron or AKARI 60 micron photometry to constrain continuum

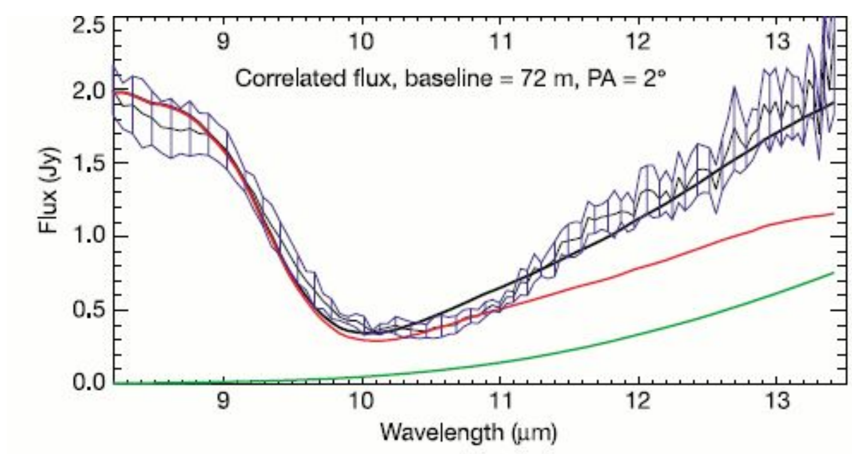
IRS spectra with clear dust emission features

=> 53 objects

Mineralogy: gehlenite (Al-Ca-silicates) or SiC in NGC 1068?



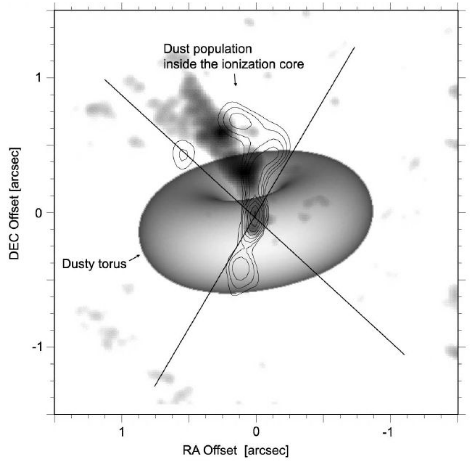


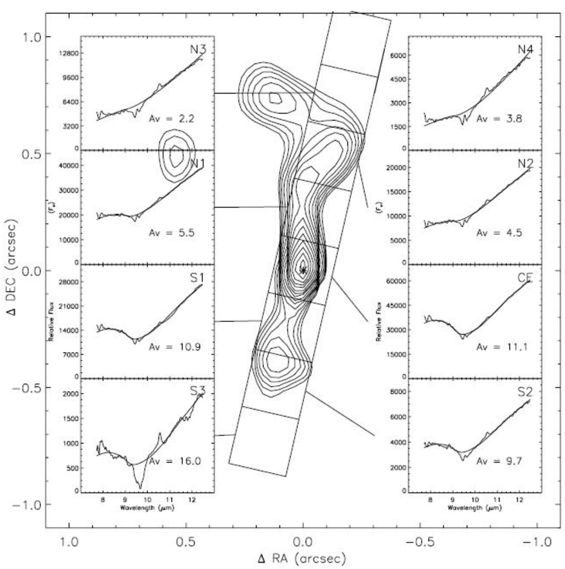


(Jaffe et al. 2004)

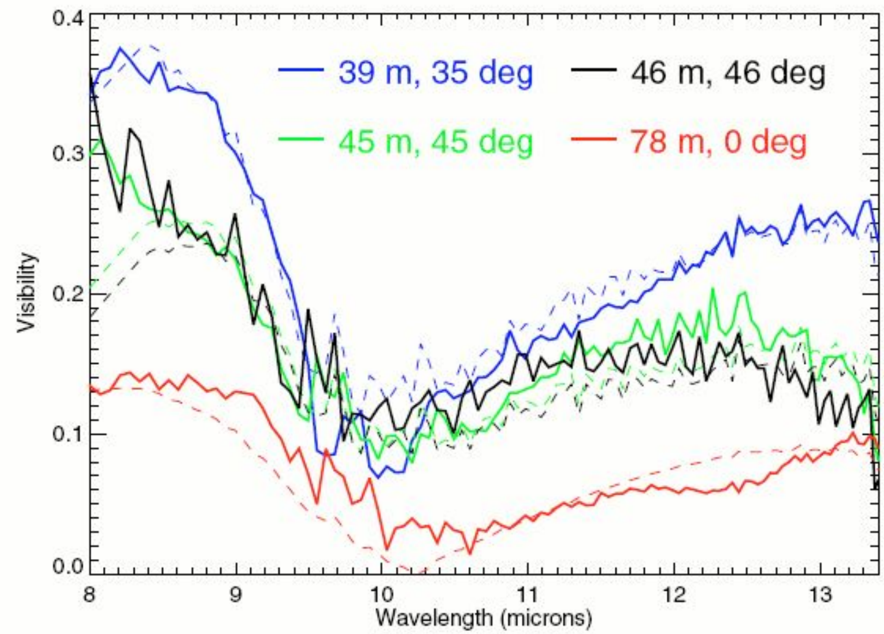
(Köhler & Li 2010)

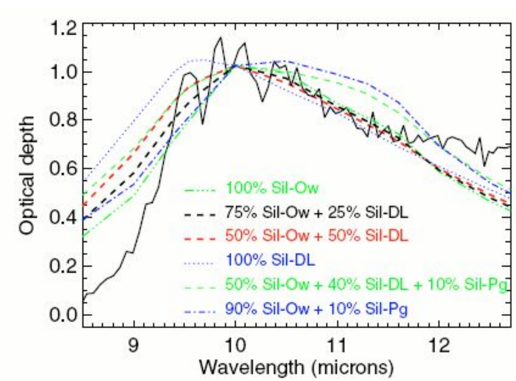
Spatial variations in NGC 1068 silicates: sizes and composition

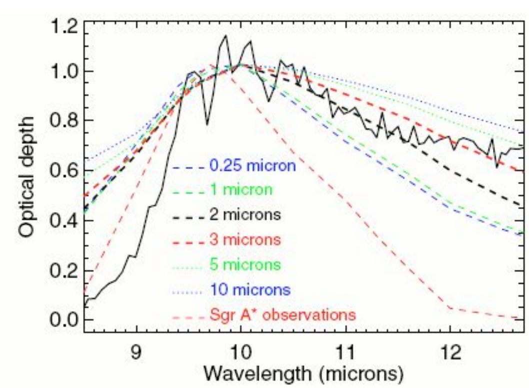




(Rhee & Larkin 2006)







(Poncelet et al. 2006)

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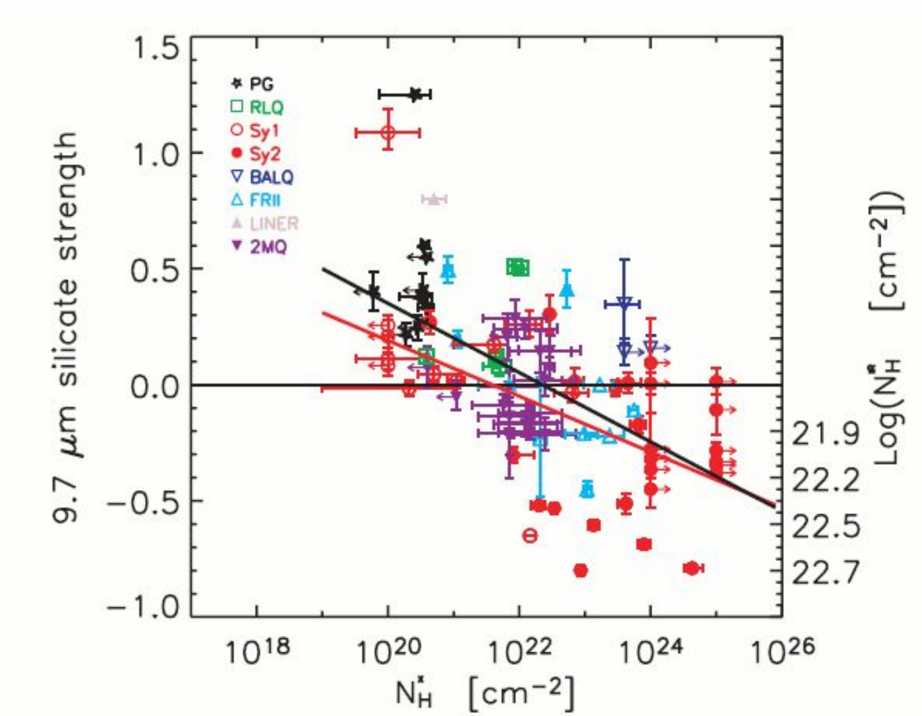
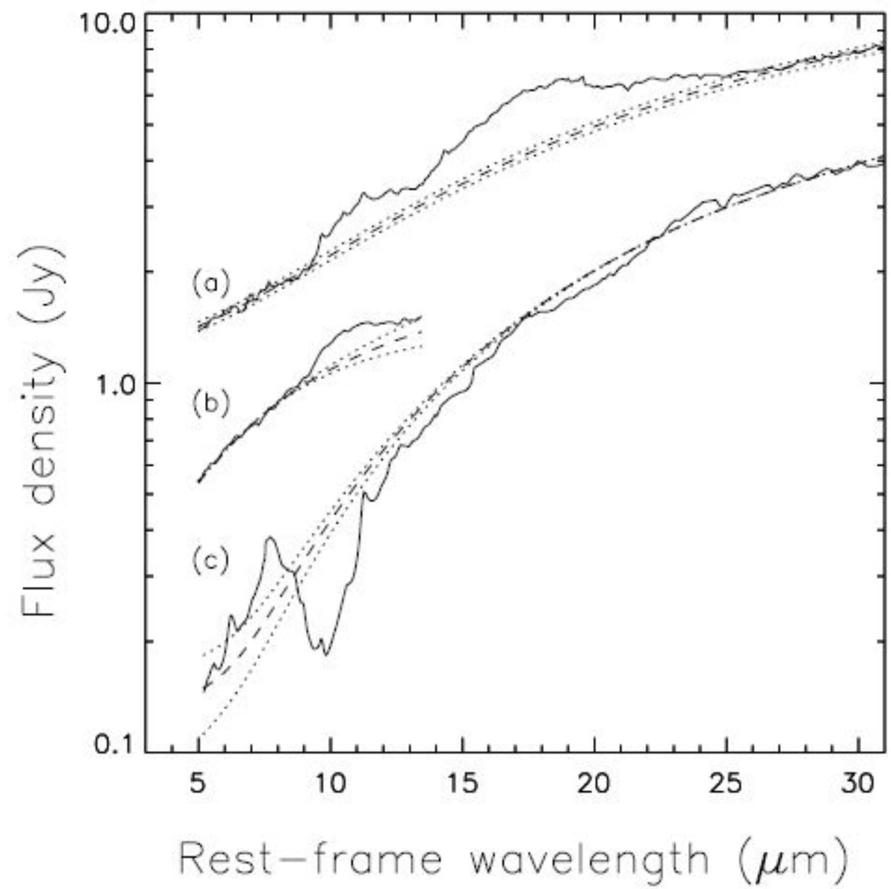
- Solutions?
  - re-evaluation interstellar dust masses; comparing dust masses at the same wavelength; taking into account abundance constraints
  - alternative sources of dust: interstellar grain growth and non-stellar sources

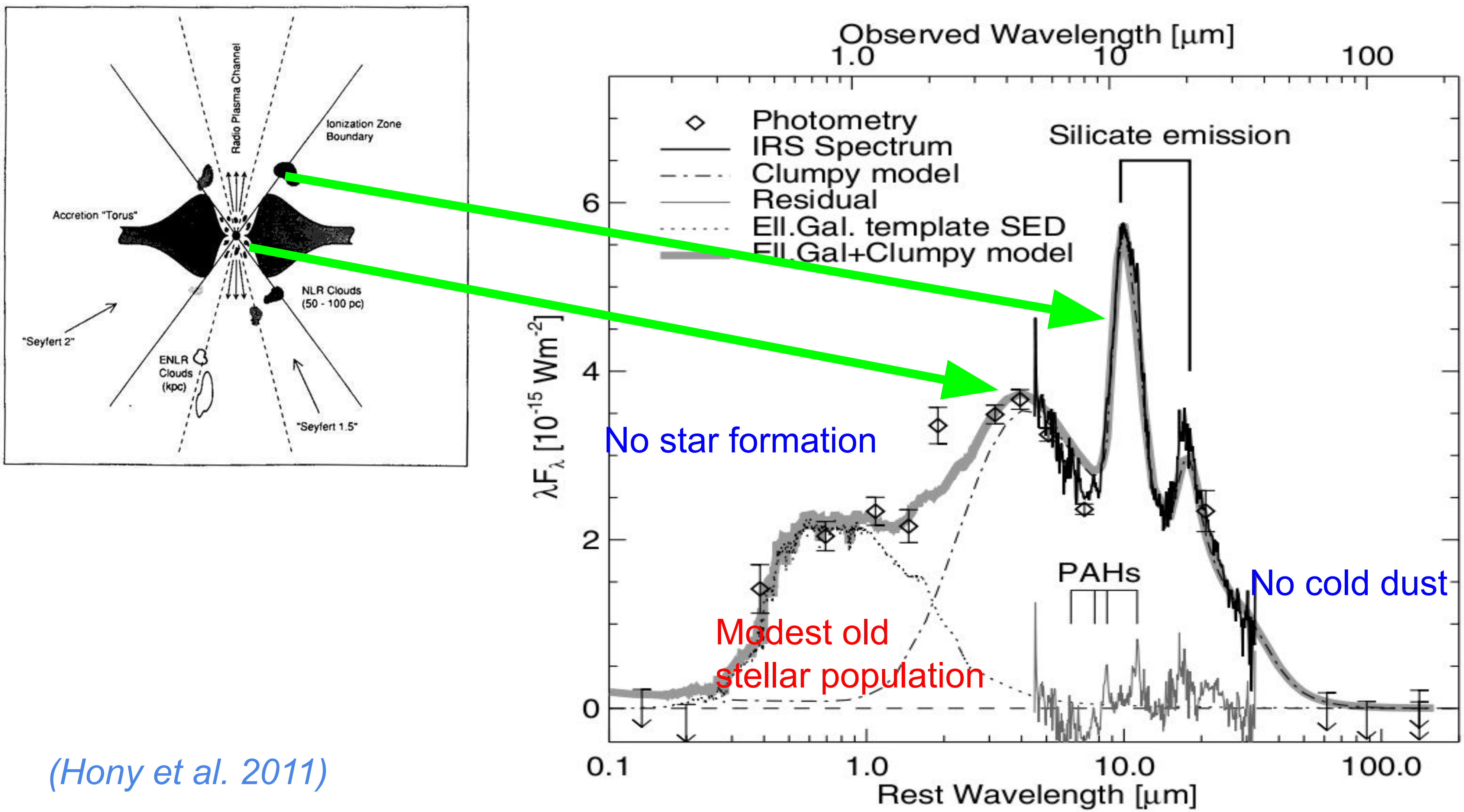
Silicates in AGN: optical depth, emission & absorption





(Shi et al. 2006)

A case of extreme emission: host galaxy hardly detected



(Hony et al. 2011)