ICE INSTITUT DE CIÈNCIES DE L'ESPAI

CSIC Consejo Superior de Investigaciones Científicas

IEEC

ICREA

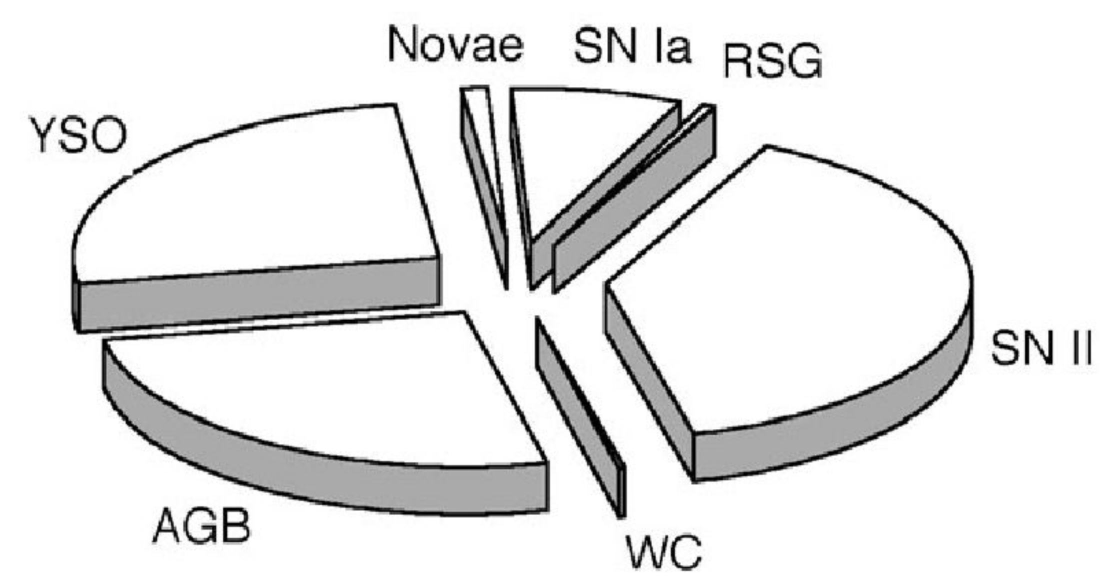
Dust in extreme environments (observational)

ICE Summer School "Life Cycle of Dust"

6 July 2023

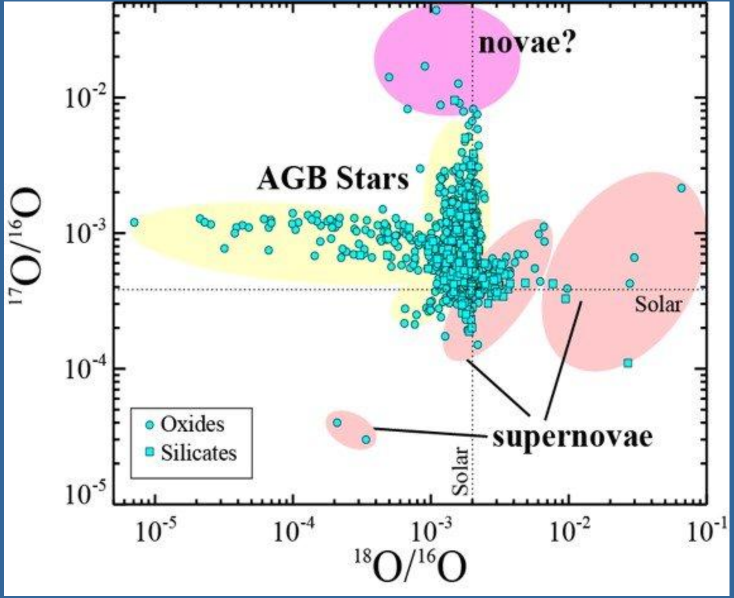
Ciska Kemper (ICE-CSIC / ICREA / IEEC)

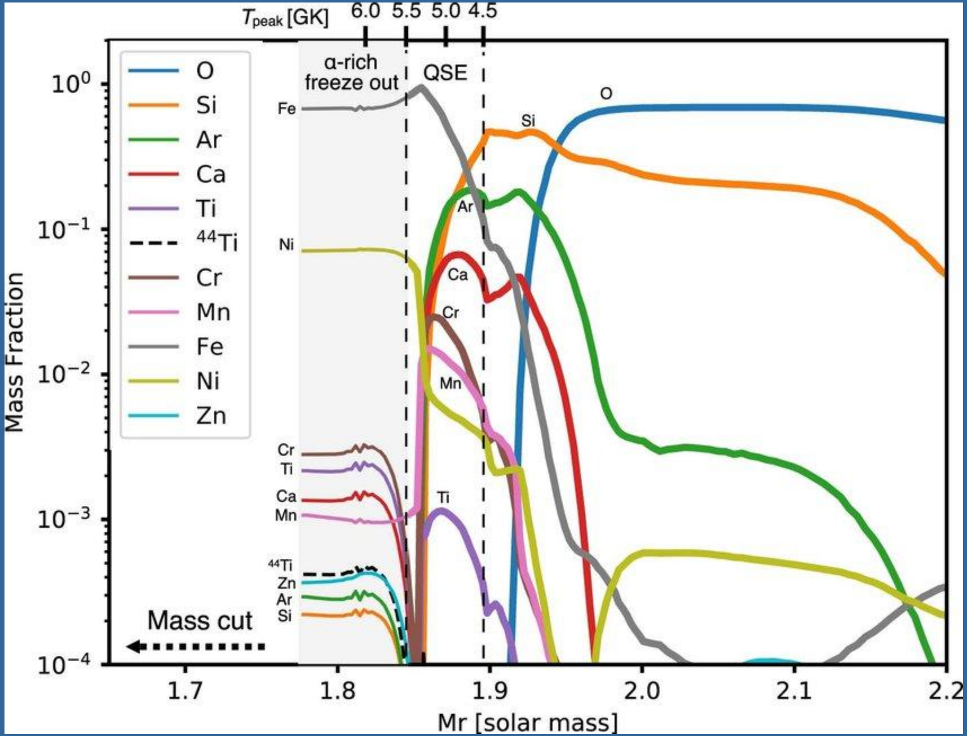
Dust in Supernovae



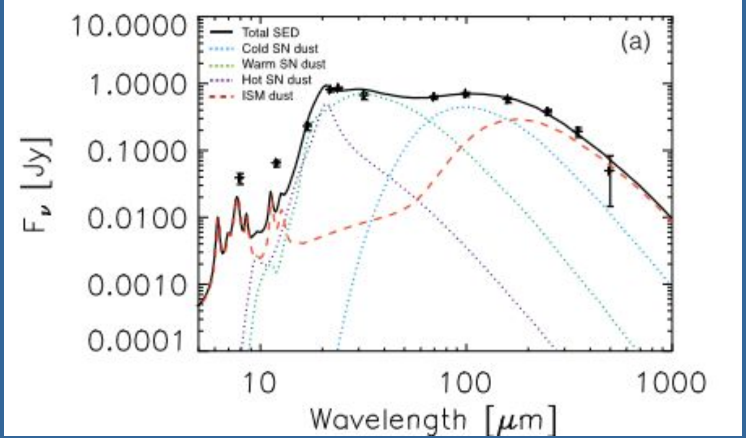
Tielens et al. 2005

Supernova grains





Dusty supernova remnants

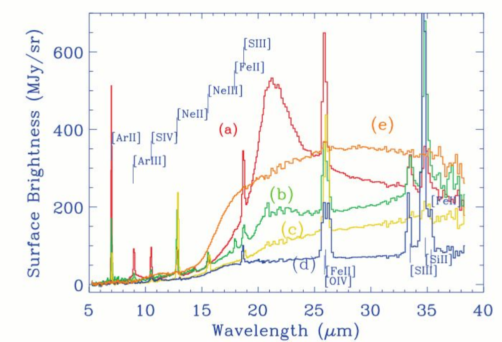


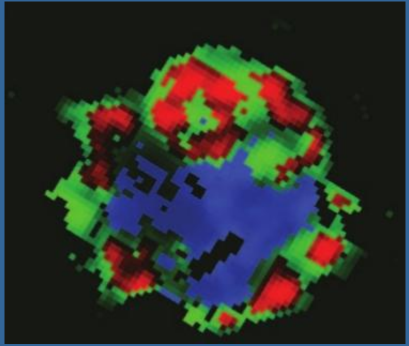
De Looze et al. 2017

Early condensates & amorphous silicates

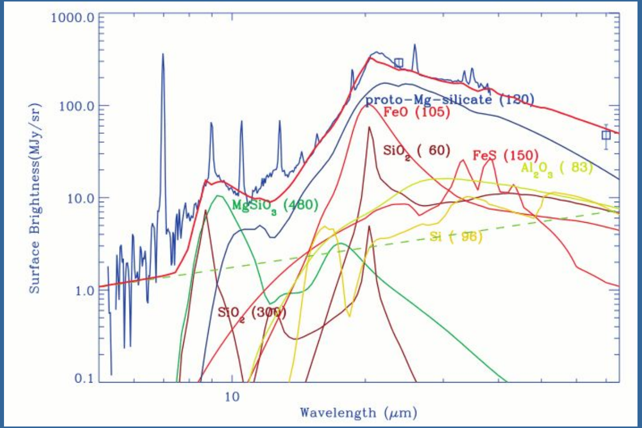
Dust mass ~0.5 $M_\odot$

What do we know about SN dust?





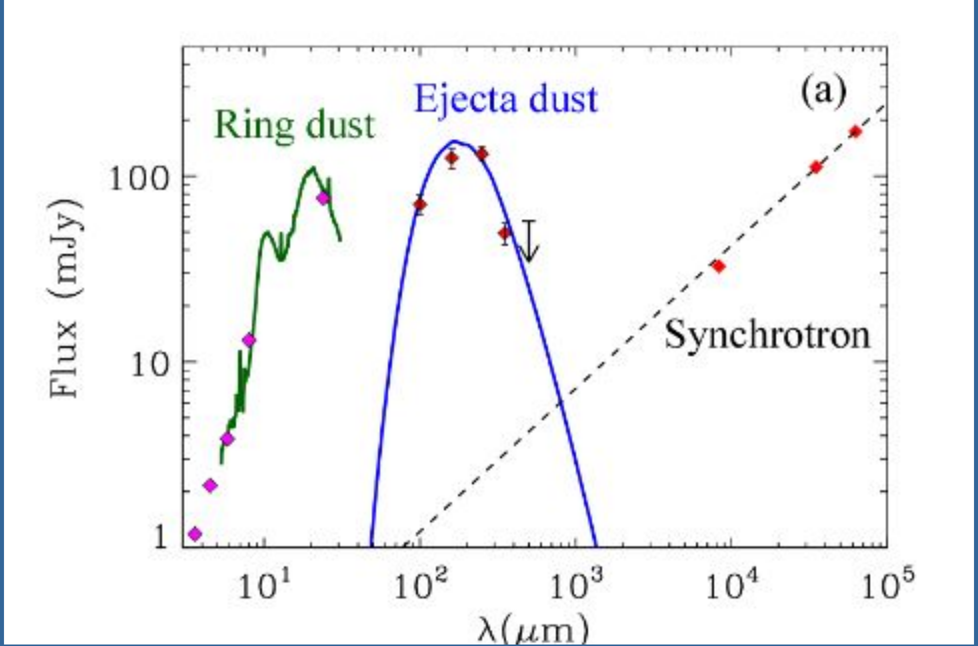
No crystalline silicates observed



Rho et al. 2008

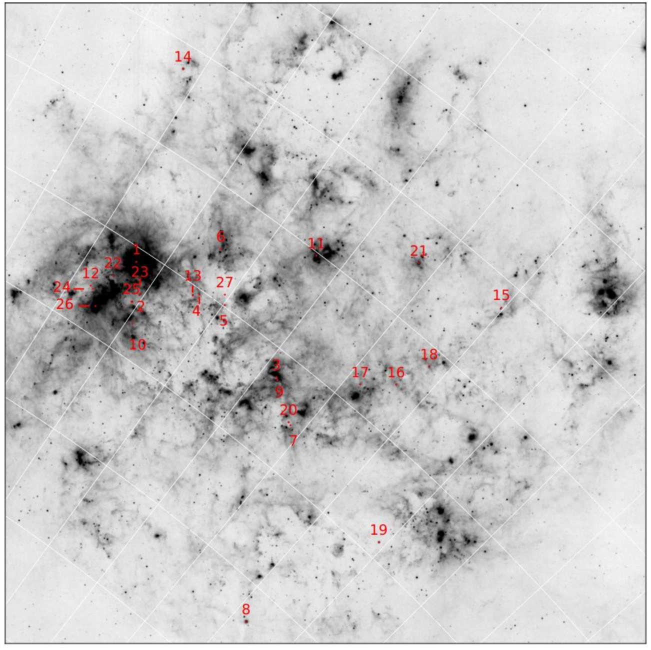
Most prominent feature in Cas A:
21 micron

SN 1987A also shows no crystallinity

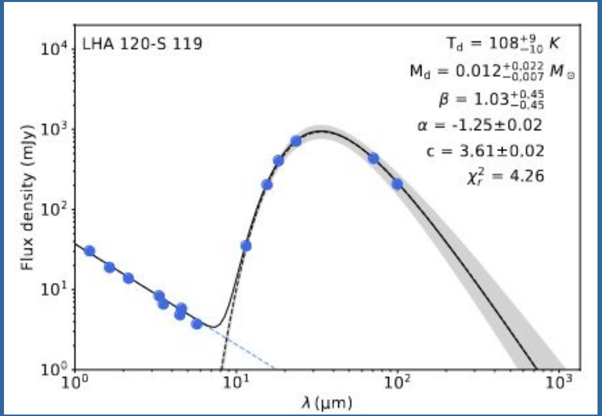


Matsuura et al. 2011

Dust in WR stars

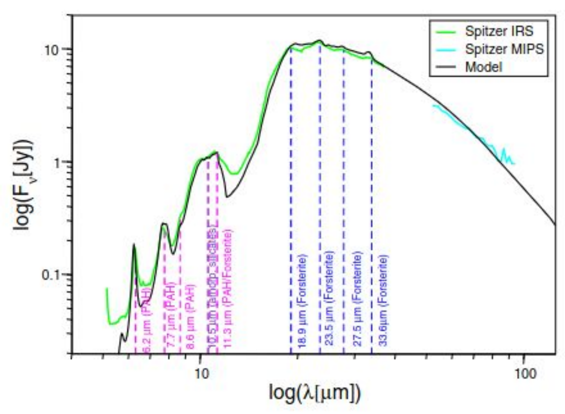


Agliozzo et al. 2021

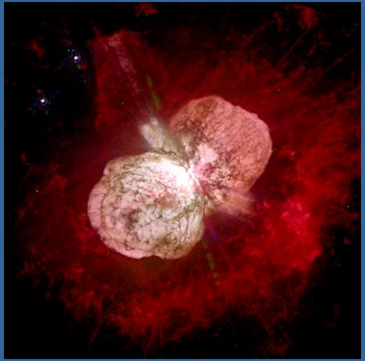


18 LBVs produce roughly the same integrated dust mass as 1500 extreme AGB stars

Composition of LBV dust

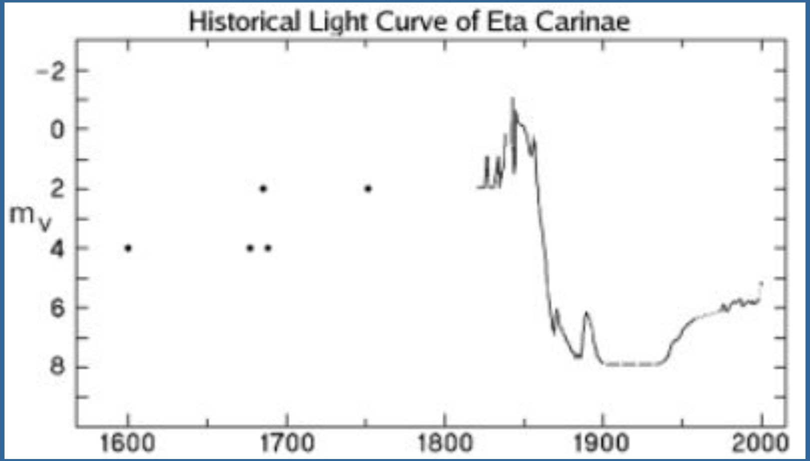


R71: amorphous and crystalline silicates; PAHs *(Guha Niyogi et al. 2014)*



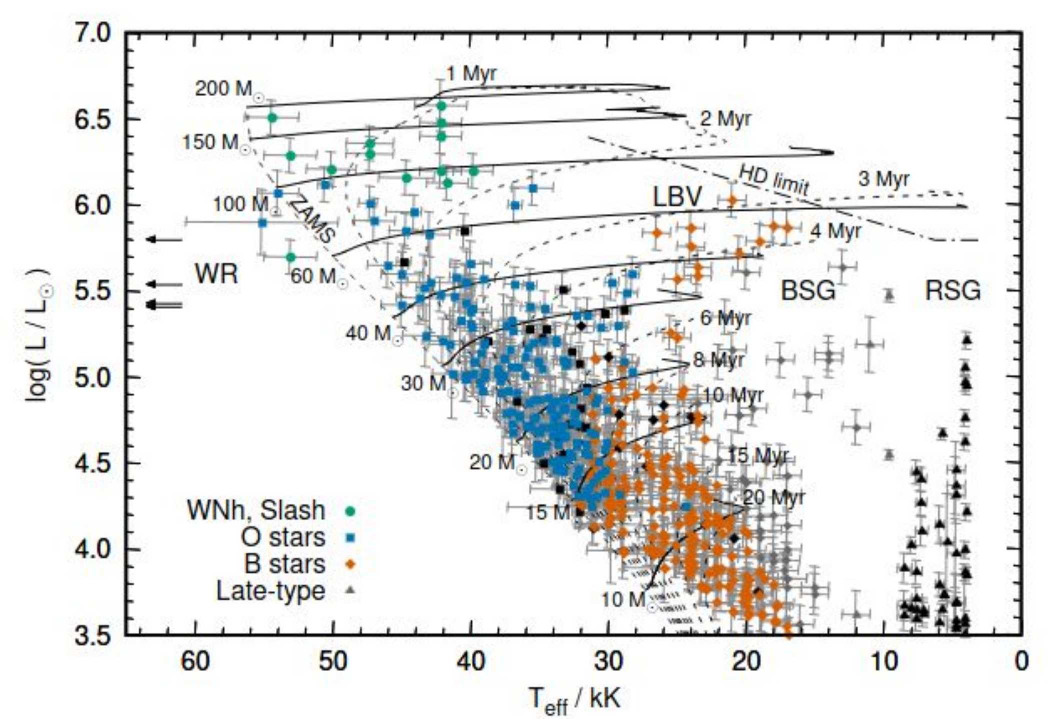
η Car (one of the brightest IR objects in the sky) has similar composition *(Morris et al. 2017)*

η Car lightcurve



Most dust was ejected in a single event

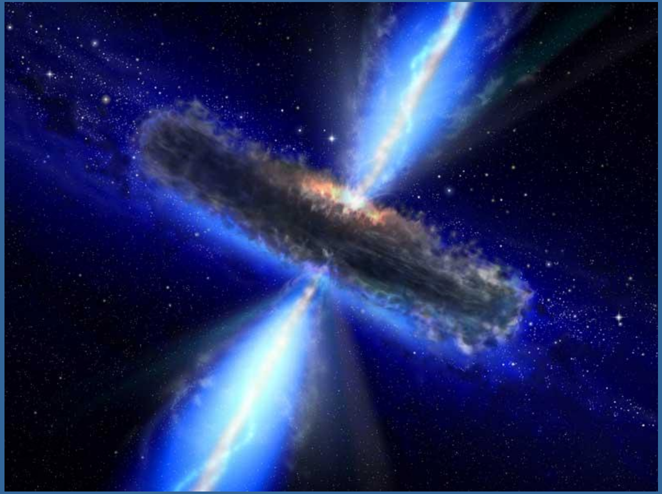
Relative importance of LBVs



Stellar wind is line driven

Not all LBVs produce dust

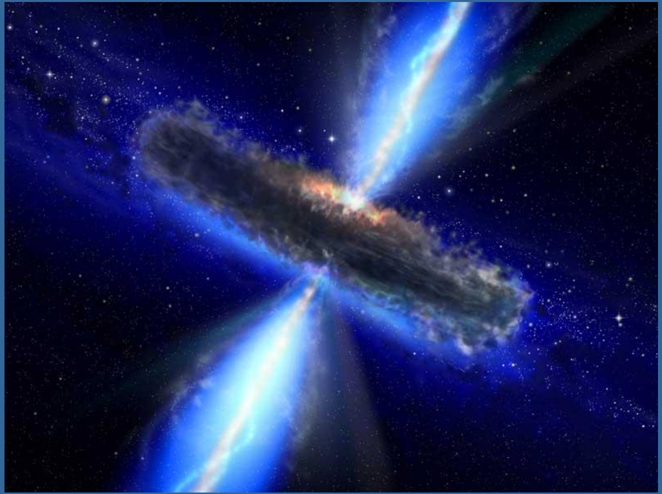
Highly energetic environments



Quasars / AGN

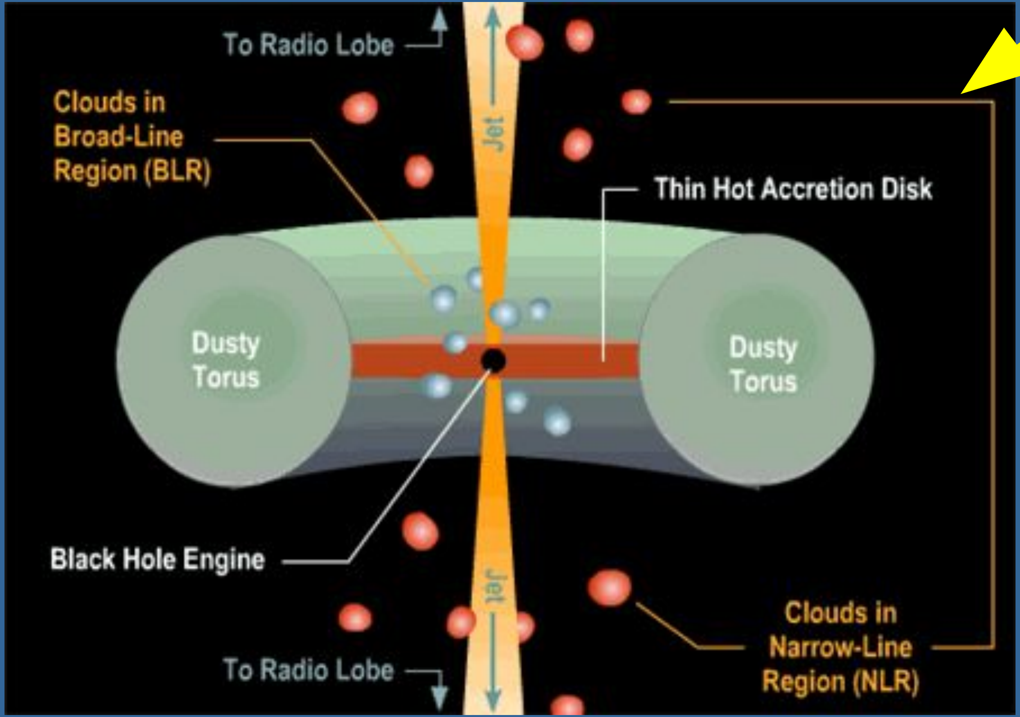
Starburst galaxies

Highly energetic environments



Quasars / AGN

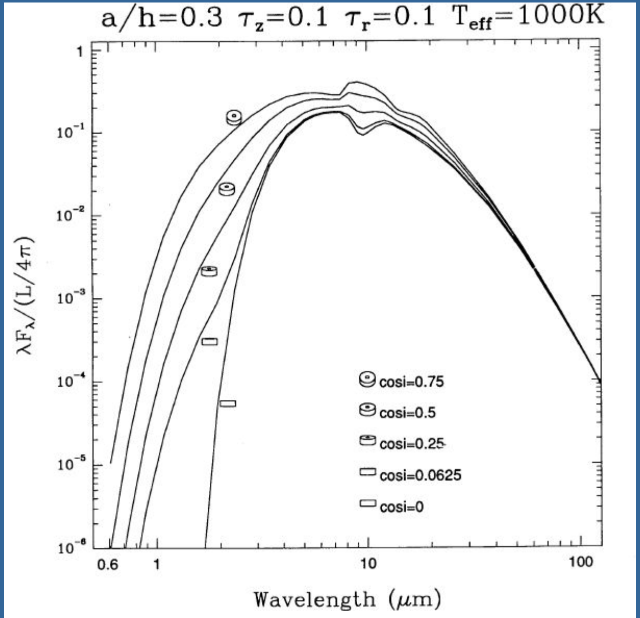
Dust in AGN



Type 1 (quasar)

Type 2 (quasar)

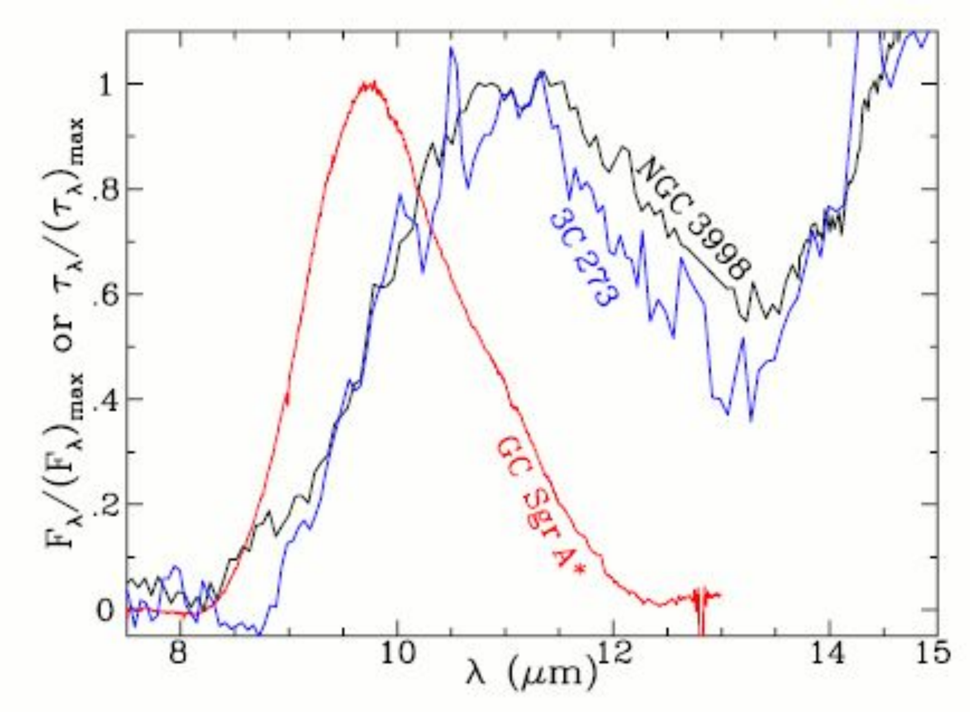
Spectral Energy Distributions



Pier & Krolik 1992

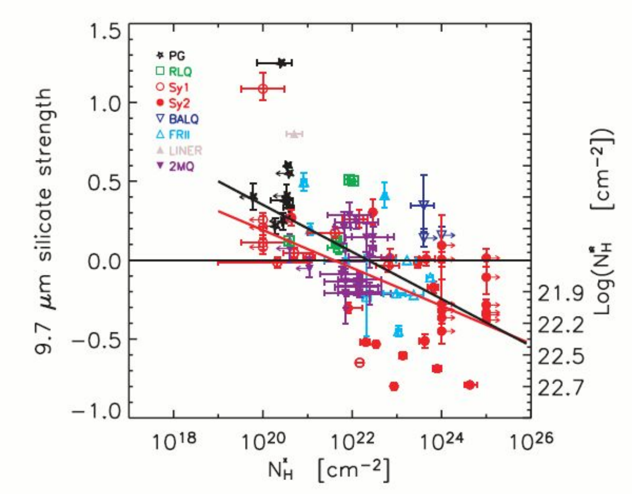
- Pier & Krolik 1992, 1993
- Nenkova et al. 2002
- Van Bemmel & Dullemond 2003
- Hönig et al. 2006
- Fritz et al. 2006
- …

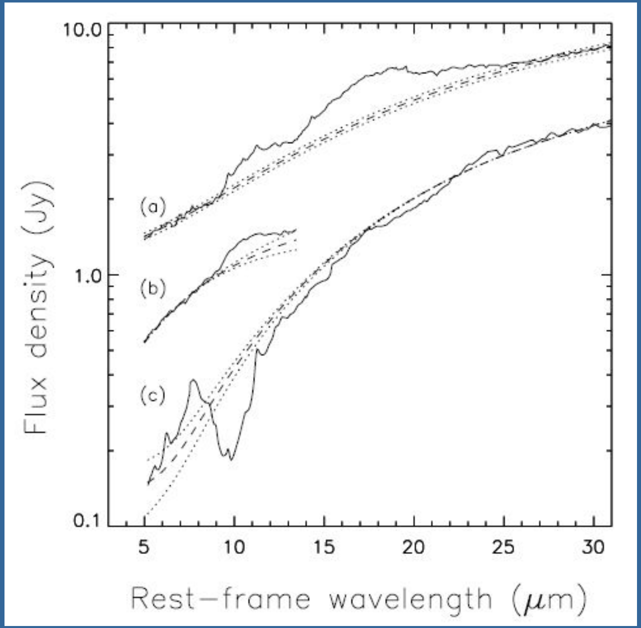
Early detections of silicates in emission



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

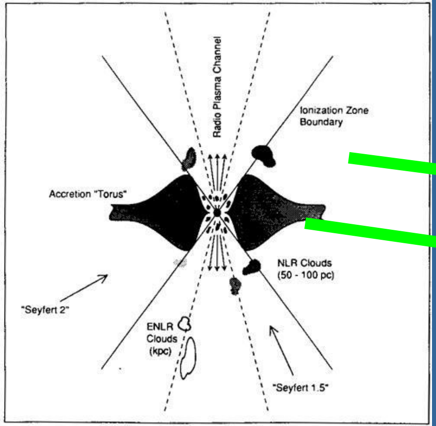
Silicates in AGN: optical depth, emission & absorption

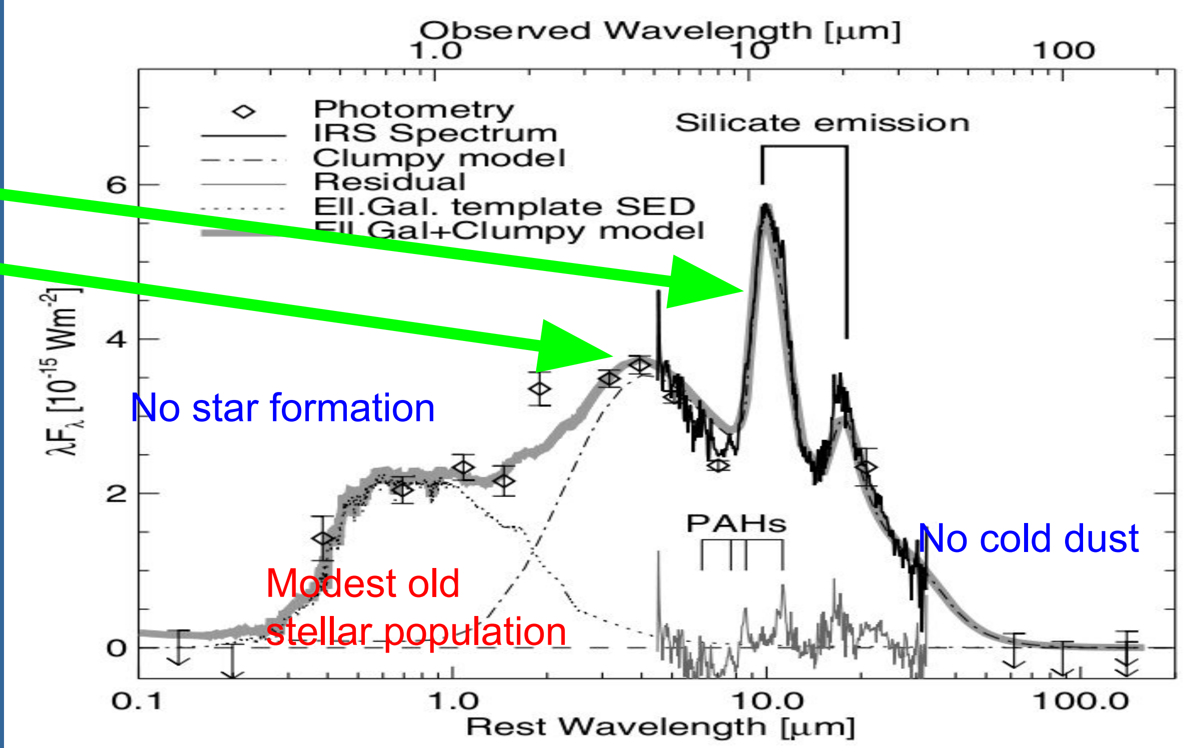




Shi et al. 2006

A case of extreme emission: host galaxy hardly detected





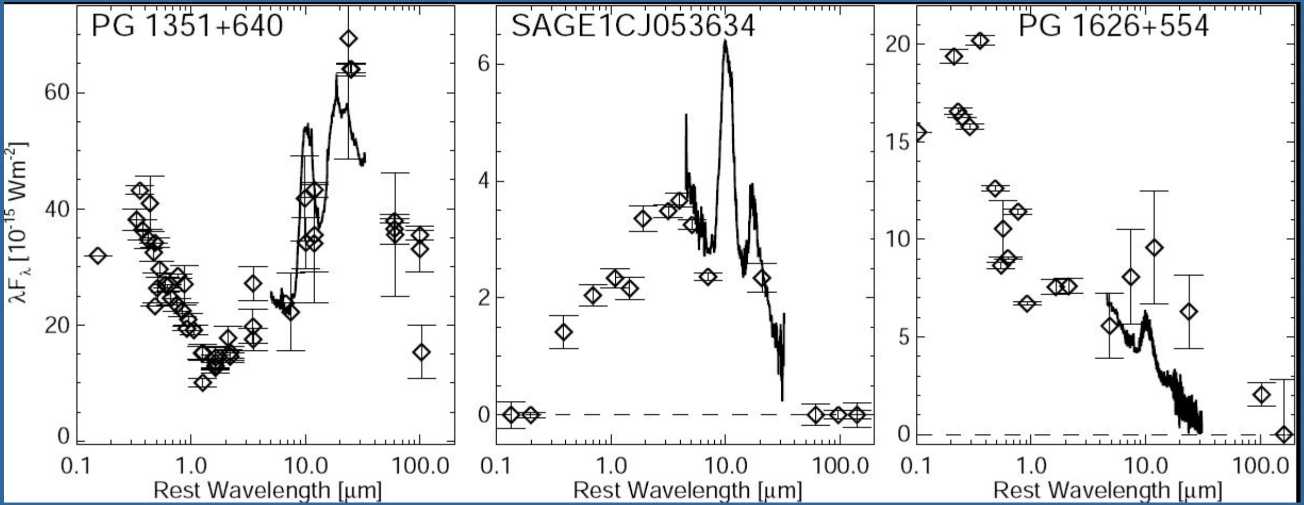
No star formation

Modest old stellar population

No cold dust

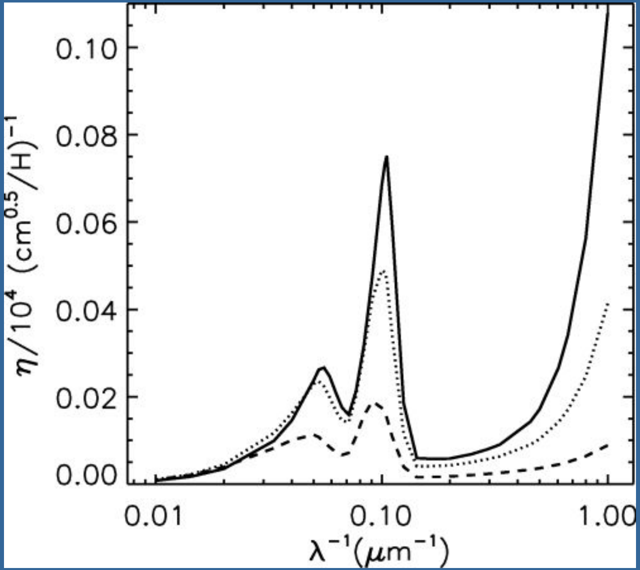
Hony et al. 2011

Extreme silicate emission

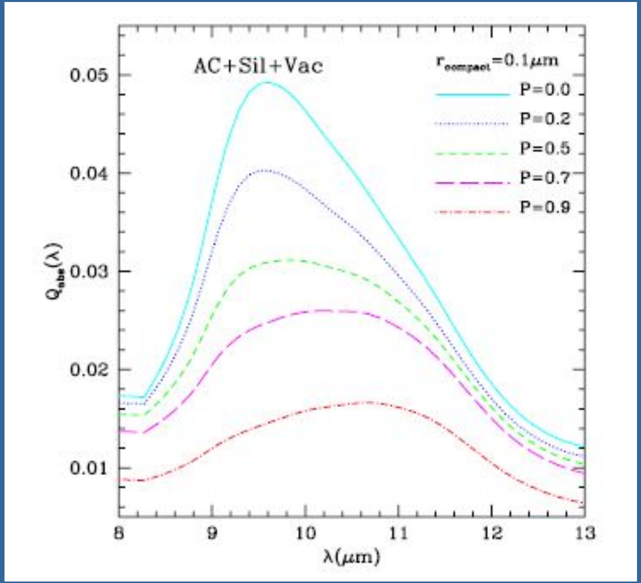


Hony et al. 2011

Porosity shifts & weakens 10 micron feature

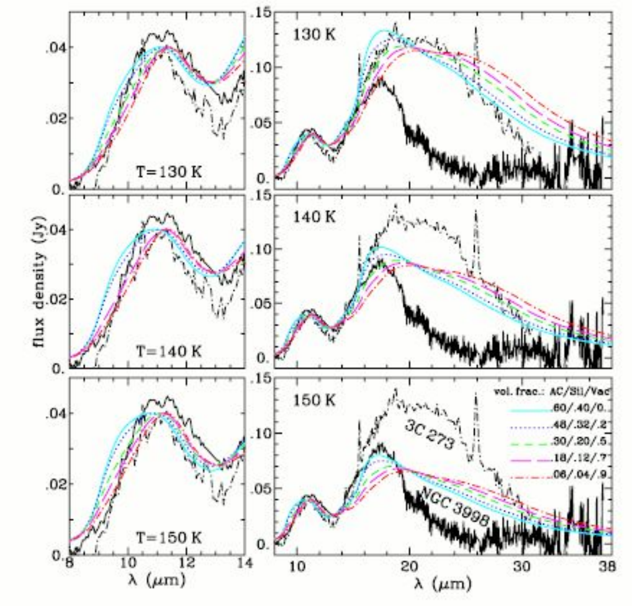


Iati et al. 2001

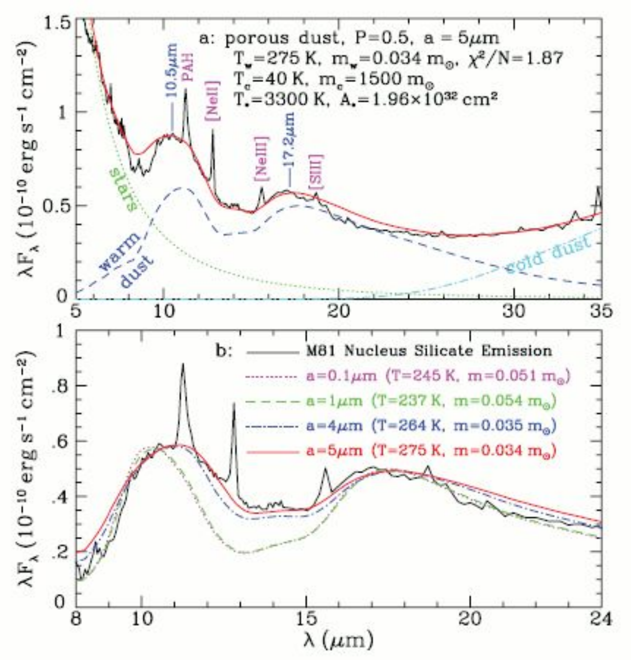


Li et al. 2008

Porous silicates associated with 3 AGN

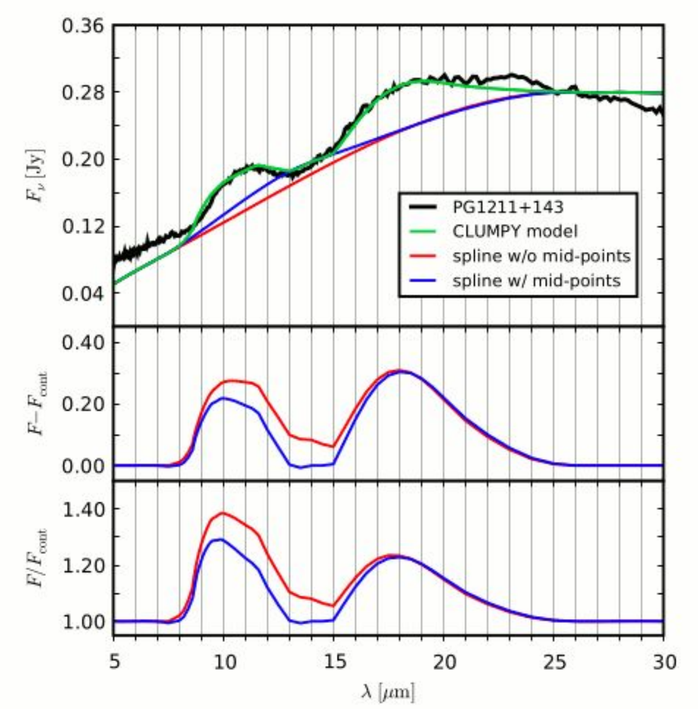


Li et al. 2008

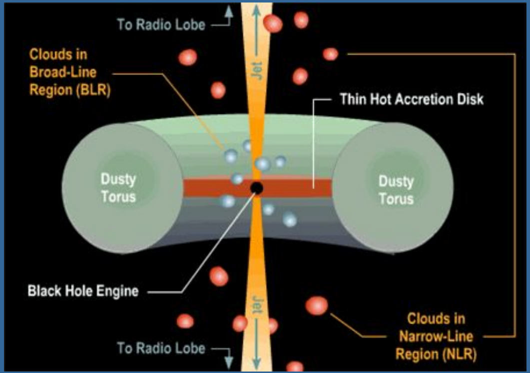


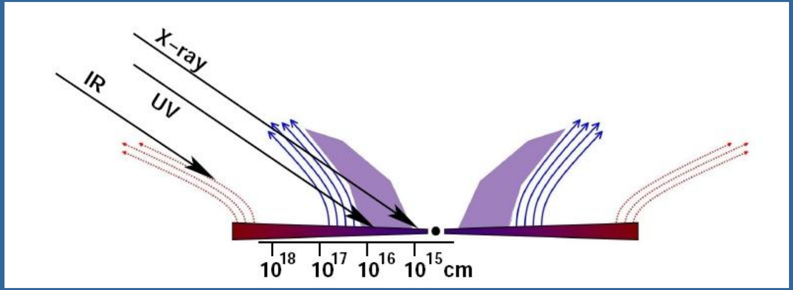
Smith et al. 2010

Optical depth effects



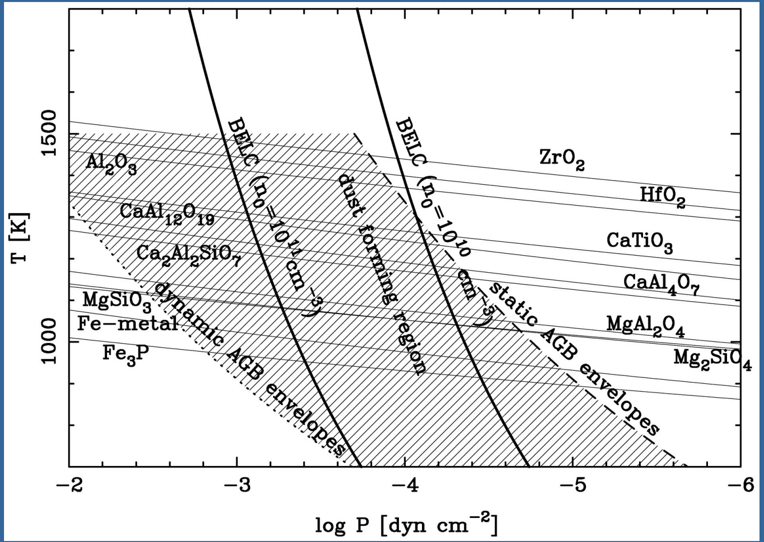
(Nikutta et al. 2009)



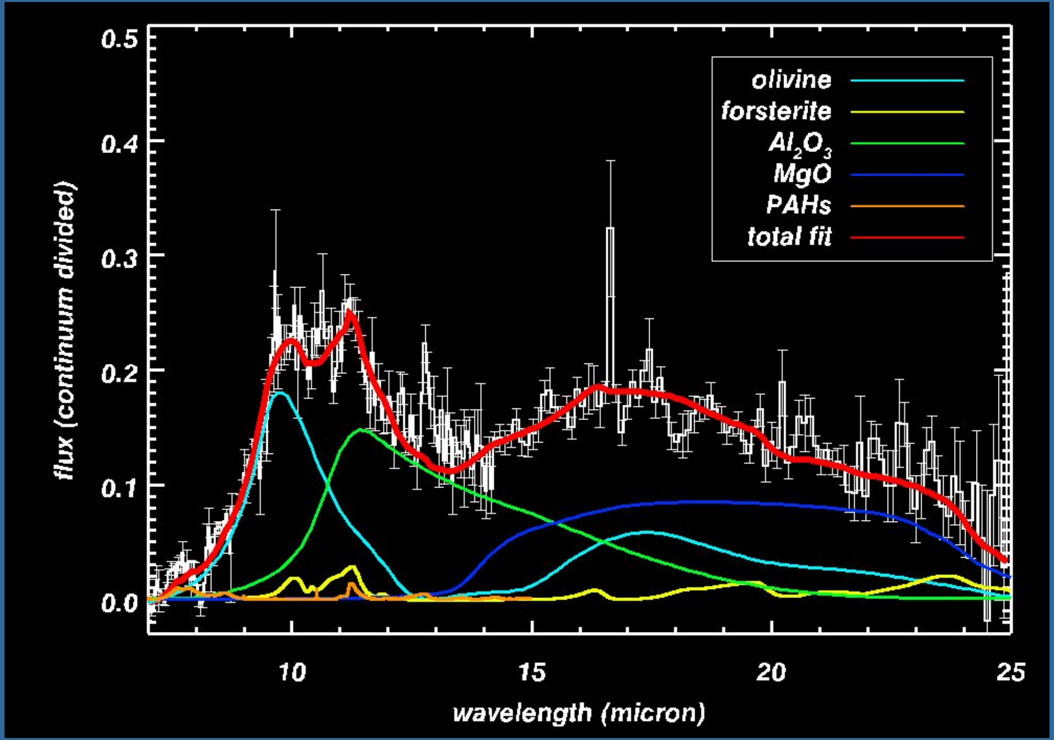


Dust formation in disk wind *(Elvis et al. 2002)*

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



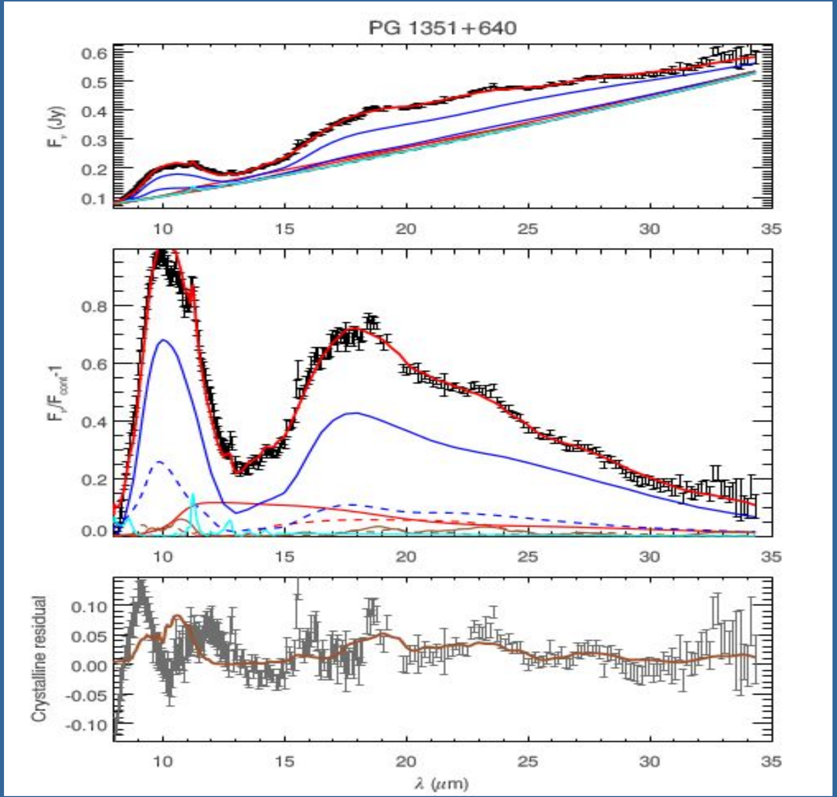
Mineralogy: ~5% crystallinity in quasar winds

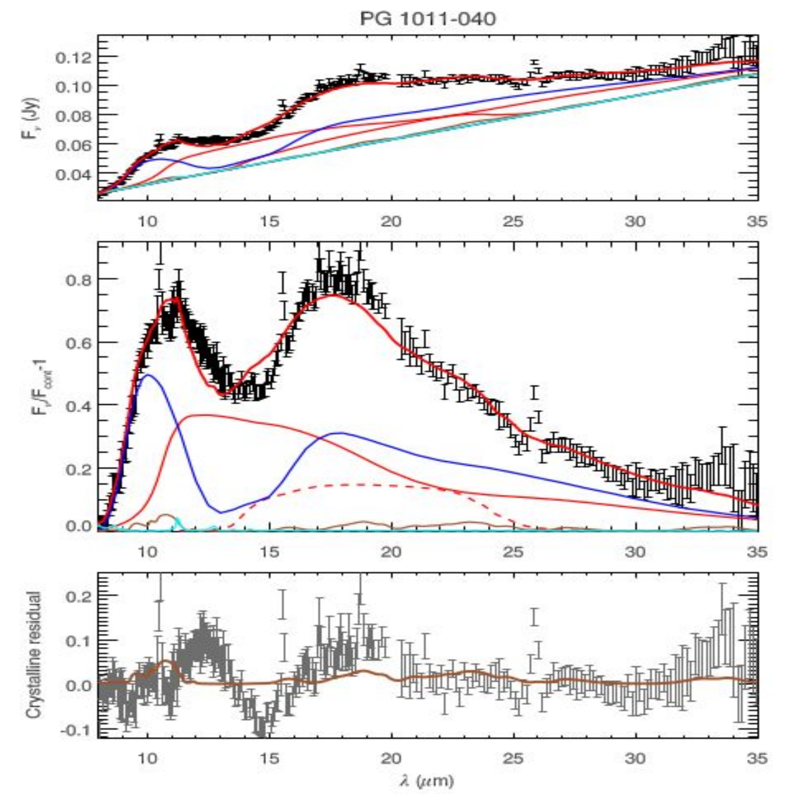


Markwick-Kemper et al. 2007

Further fits

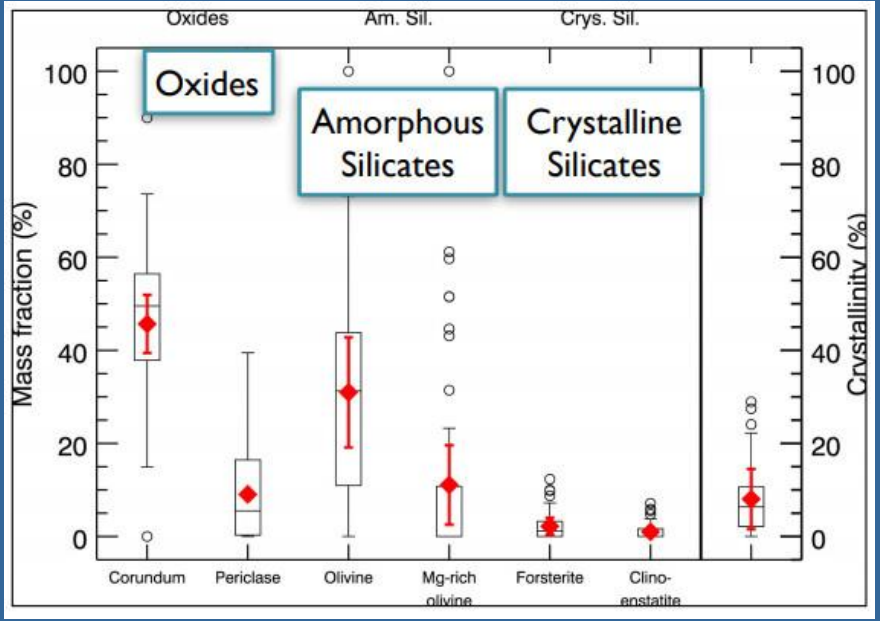
(Srinivasan et al. 2017)





Results for a small sample

(Srinivasan et al. 2017)



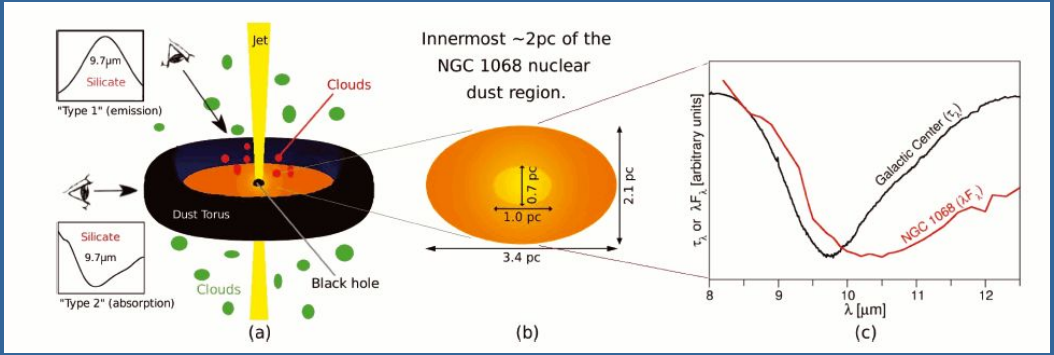
PG sample from Petric et al. (2015)

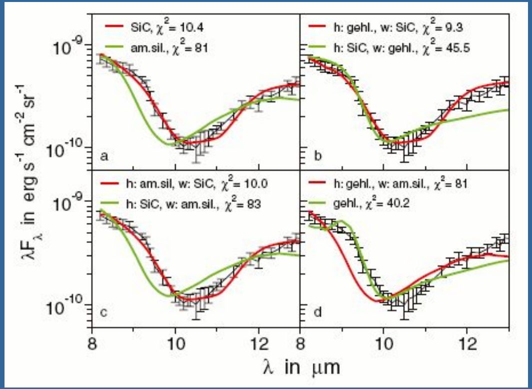
Herschel or MIPS 70 micron or AKARI 60 micron photometry to constrain continuum

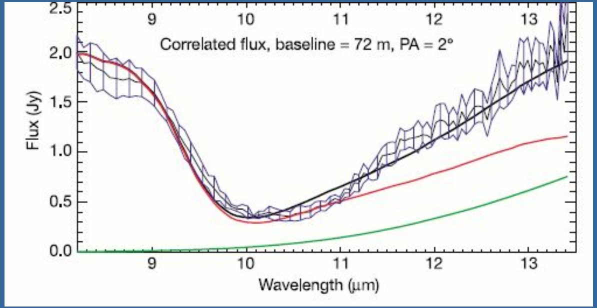
IRS spectra with clear dust emission features

=> 53 objects

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



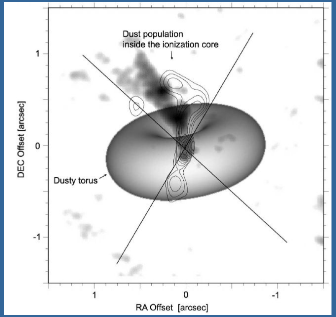


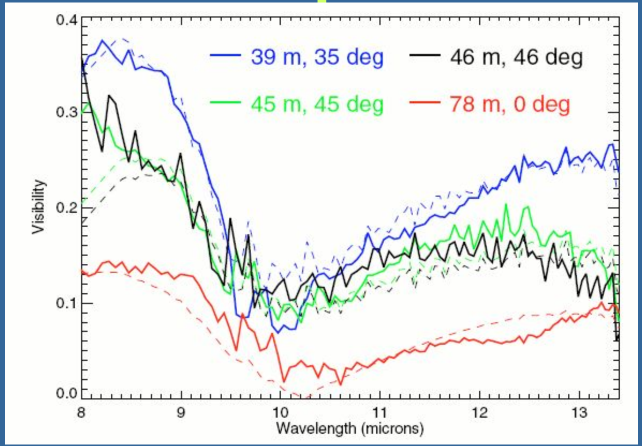


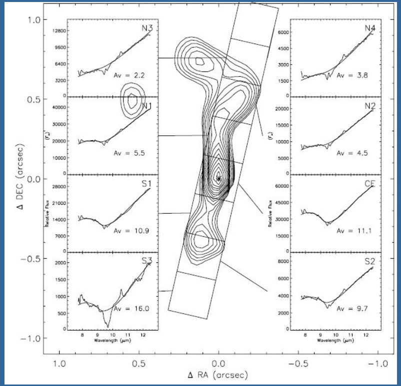
Köhler & Li 2010

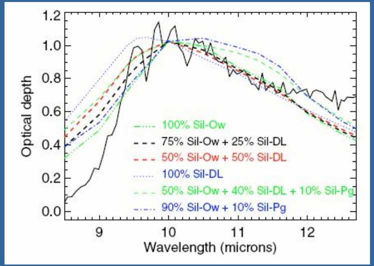
Jaffe et al. 2004

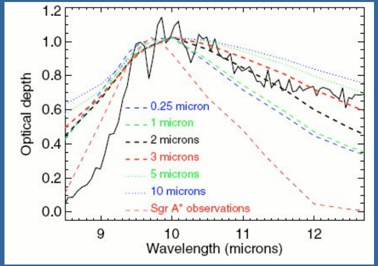
Spatial variations in NGC 1068 silicates: sizes and composition







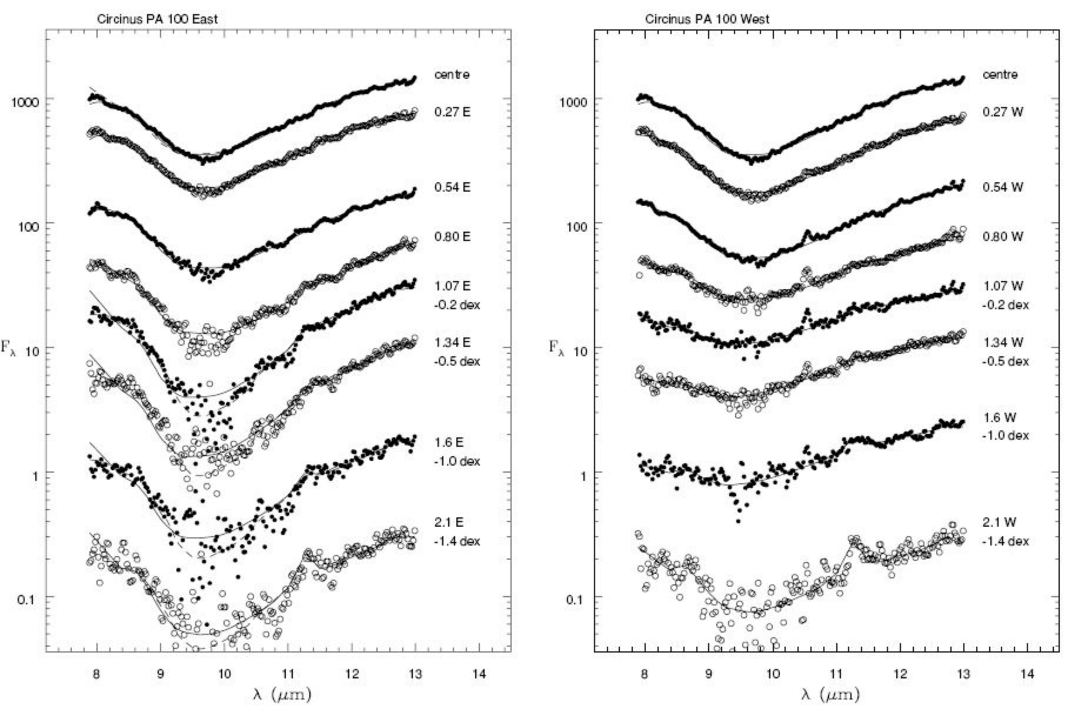




Rhee & Larkin 2006

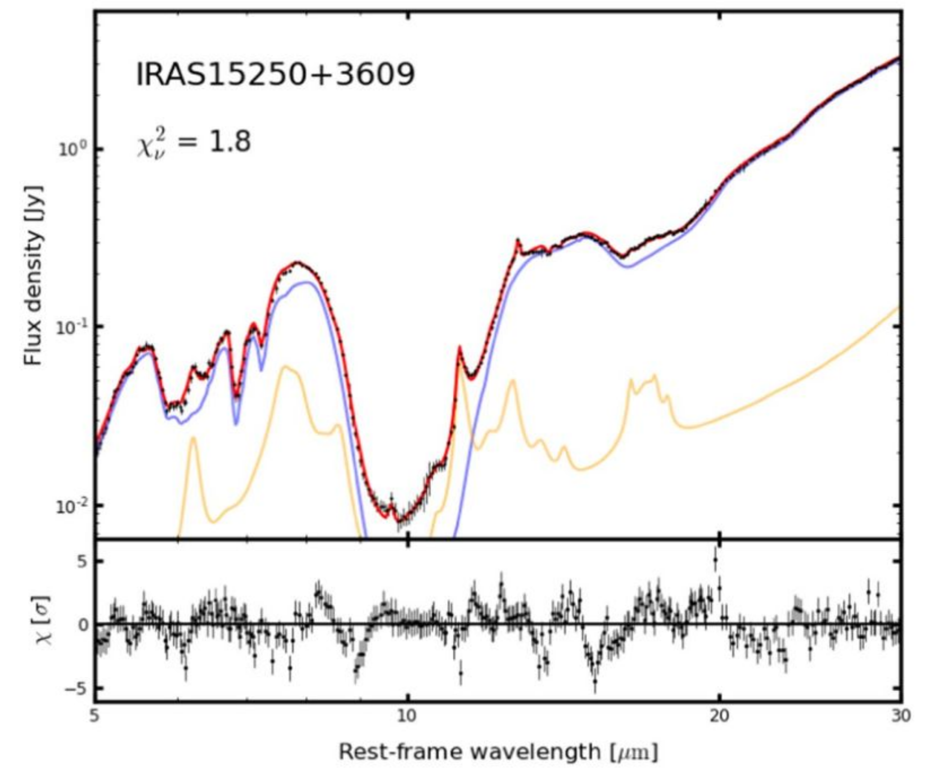
Poncelet et al. 2006

Spatial variations: Circinus galaxy



Roche et al. 2006

Heavily obscured AGN



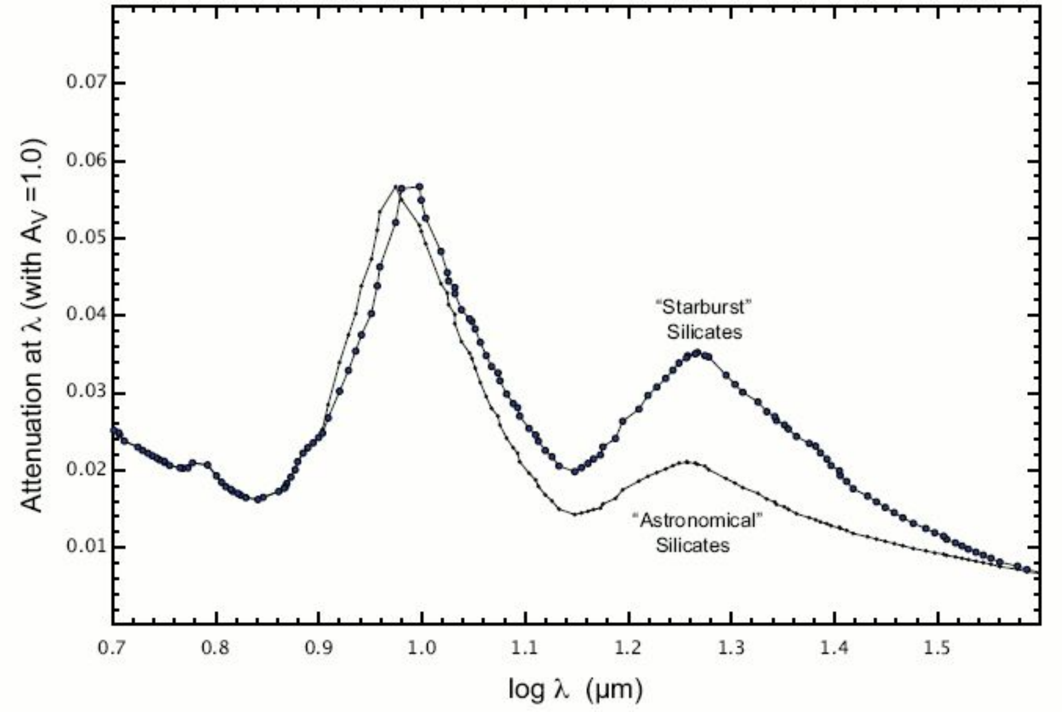
0-14% crystallinity in silicates towards ~100 obscured AGN

Tsuchikawa et al. 2022

Highly energetic environments

Starburst galaxies

Starburst galaxies: larger grain size

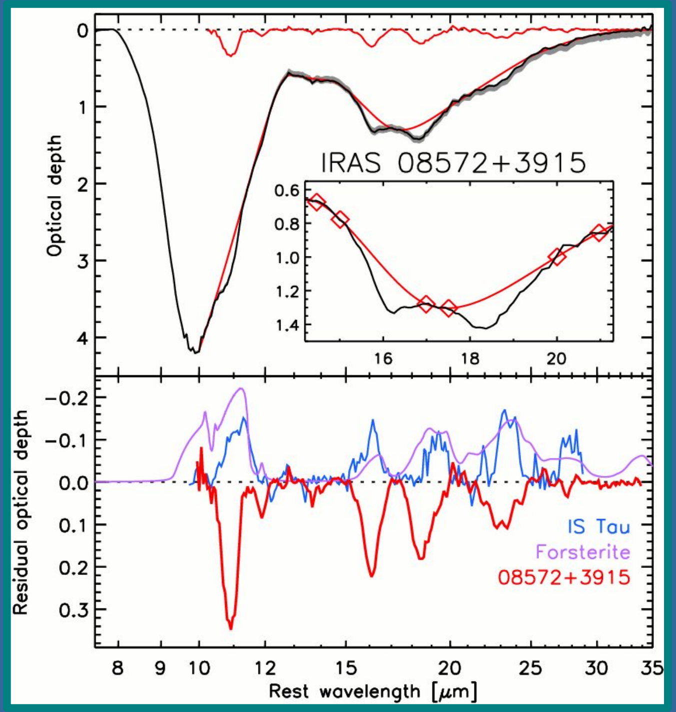


Dopita et al. 2010

Crystallinity in starburst galaxies

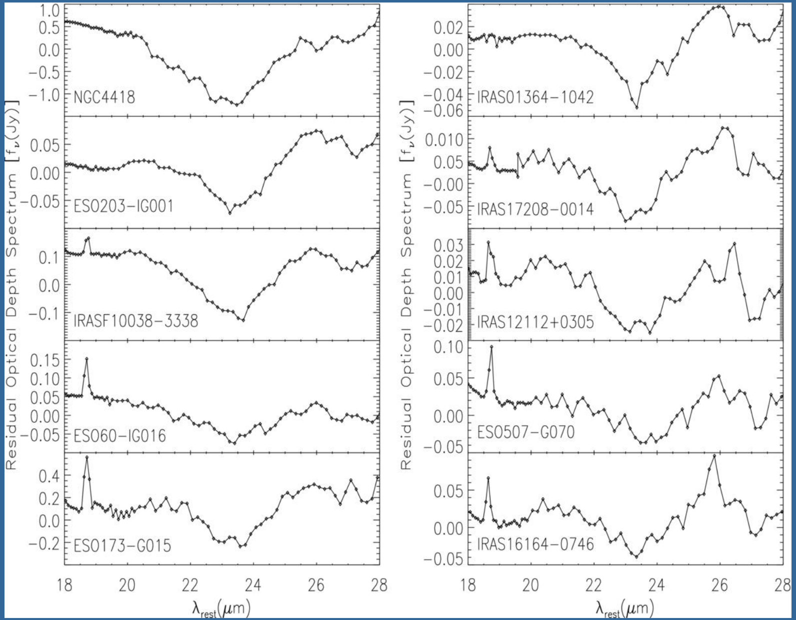
- 77 ULIRGs
- Crystalline silicates in 12
- Crystalline fractions: 6.5 – 13 %

Explanation: stellar production

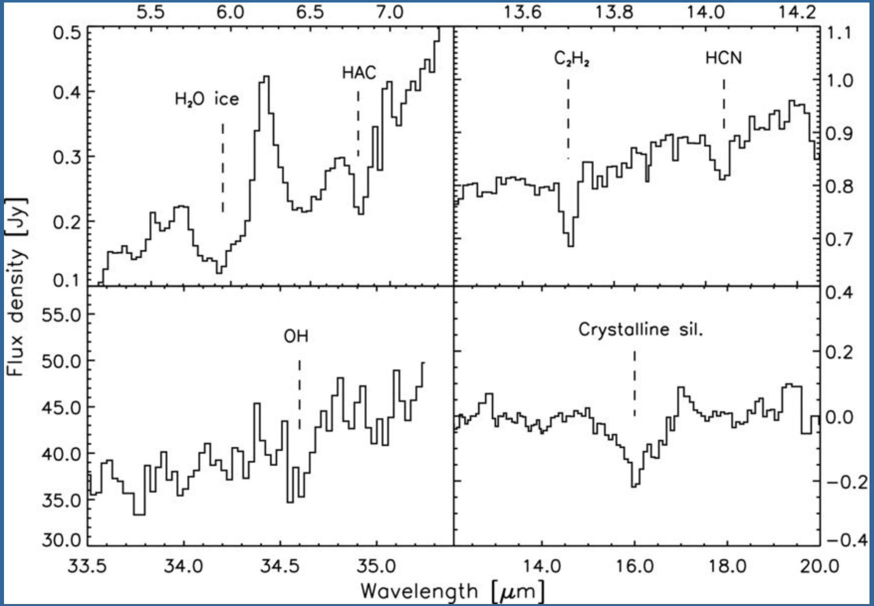


Spoon et al. (2006)

Further detections

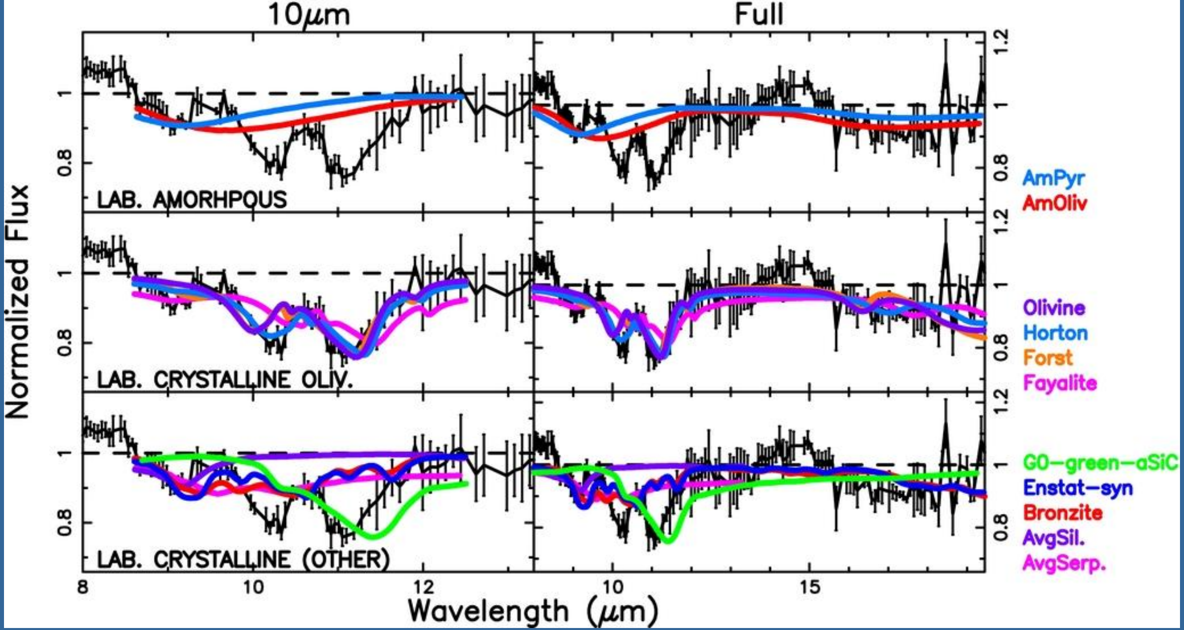


Stierwalt et al. 2014



Willett et al. 2011

Crystalline silicates in a high redshift absorber (z=0.89)



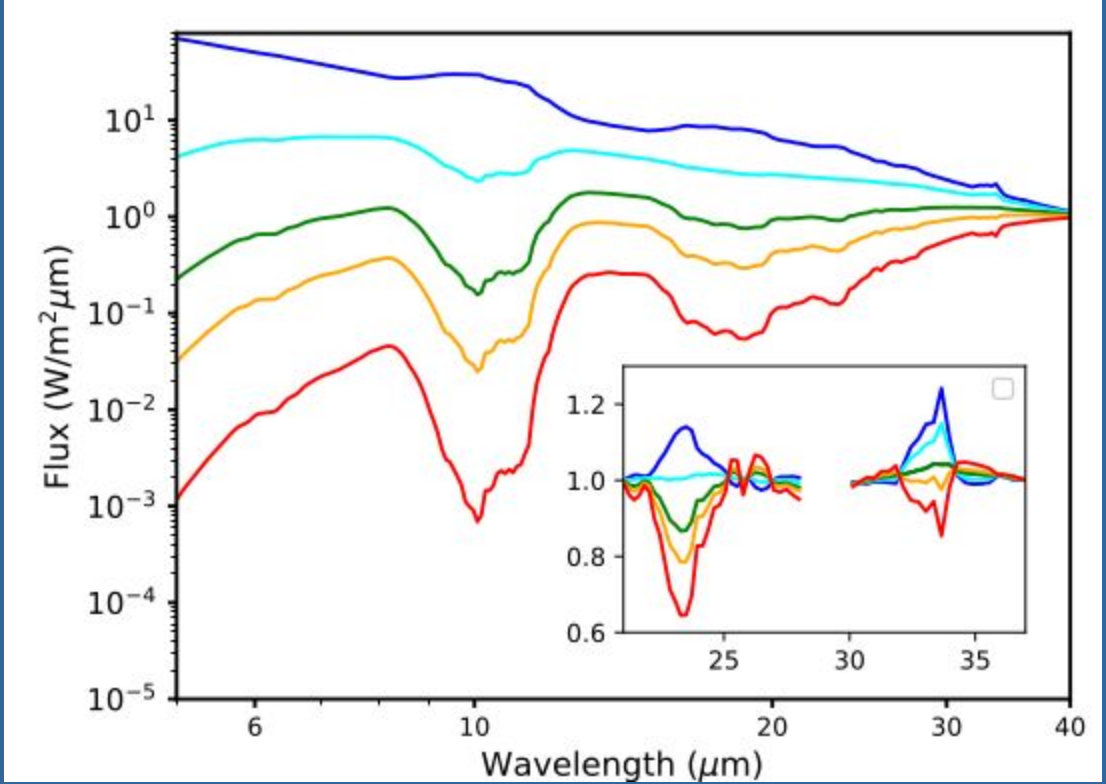
Aller et al. 2012

A search of the Spitzer archive

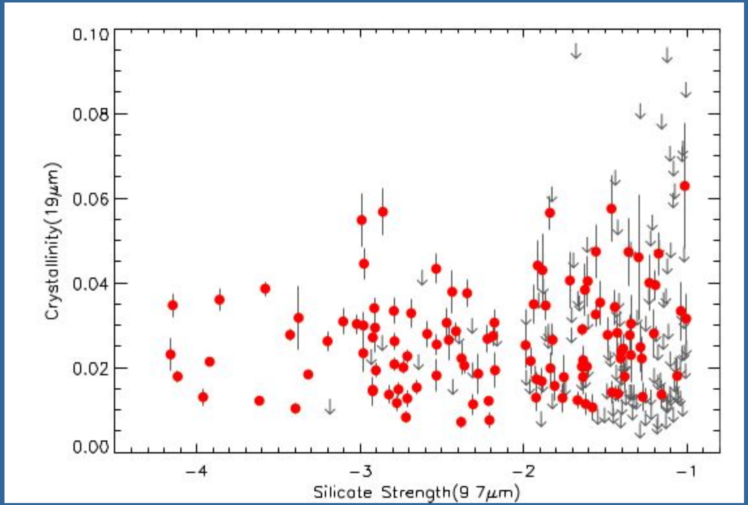
Spectral analysis revealed that
786 of 3335 galaxies (almost ¼) in the
Spitzer archive contained crystalline
silicates

(Spoon et al. 2022)

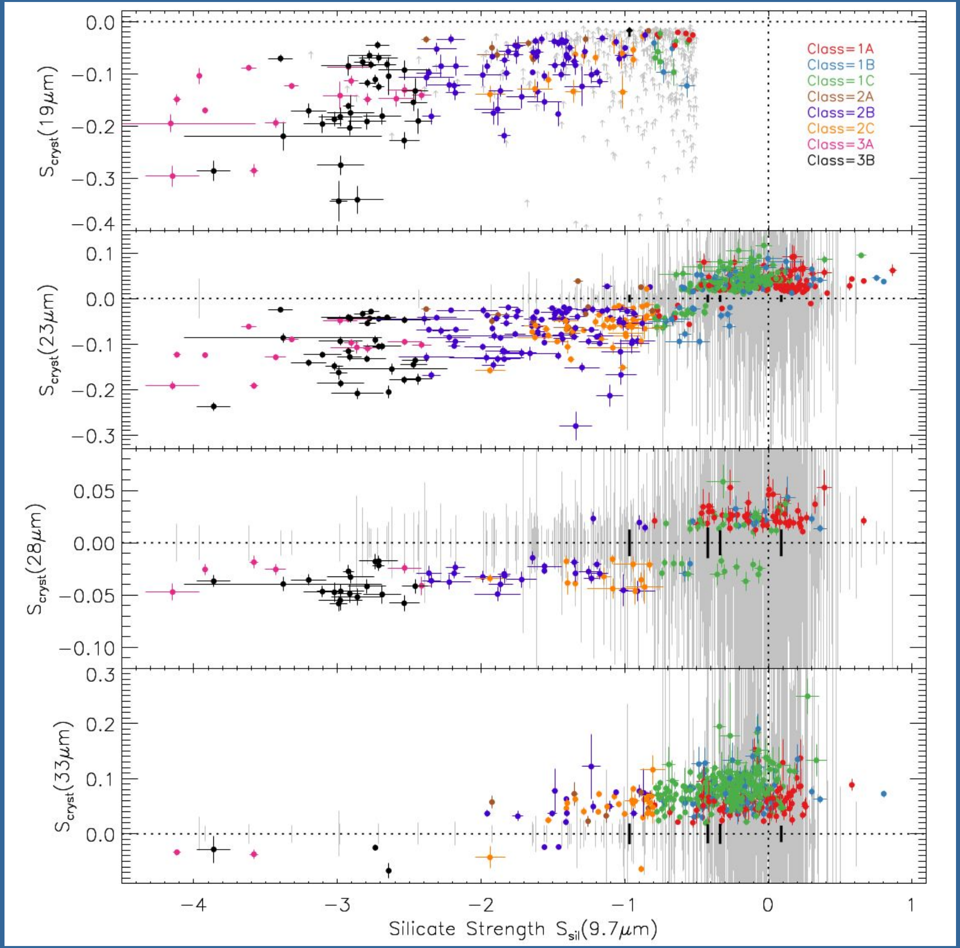
Radiative transfer simulations



Measurements

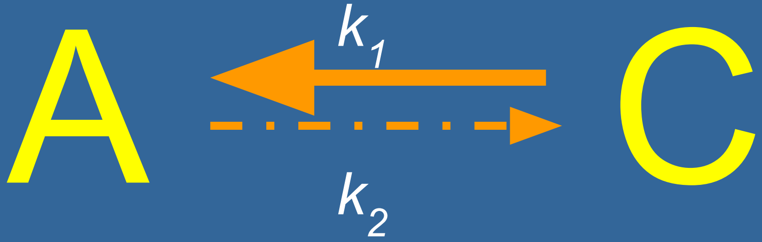


Detections x<5%

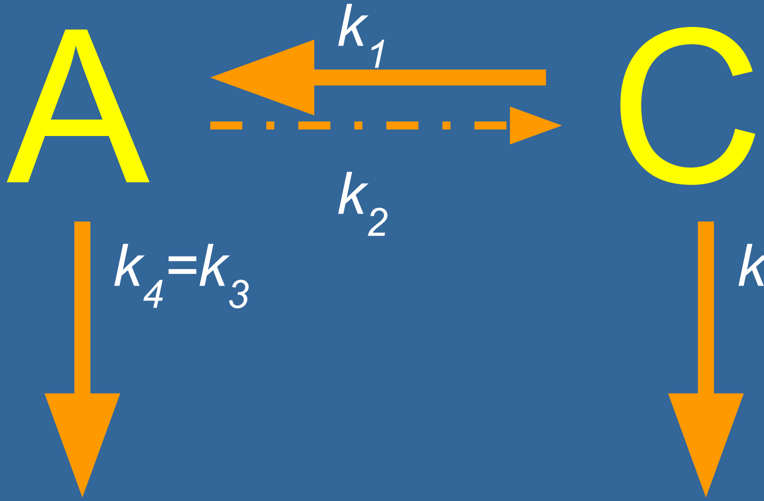


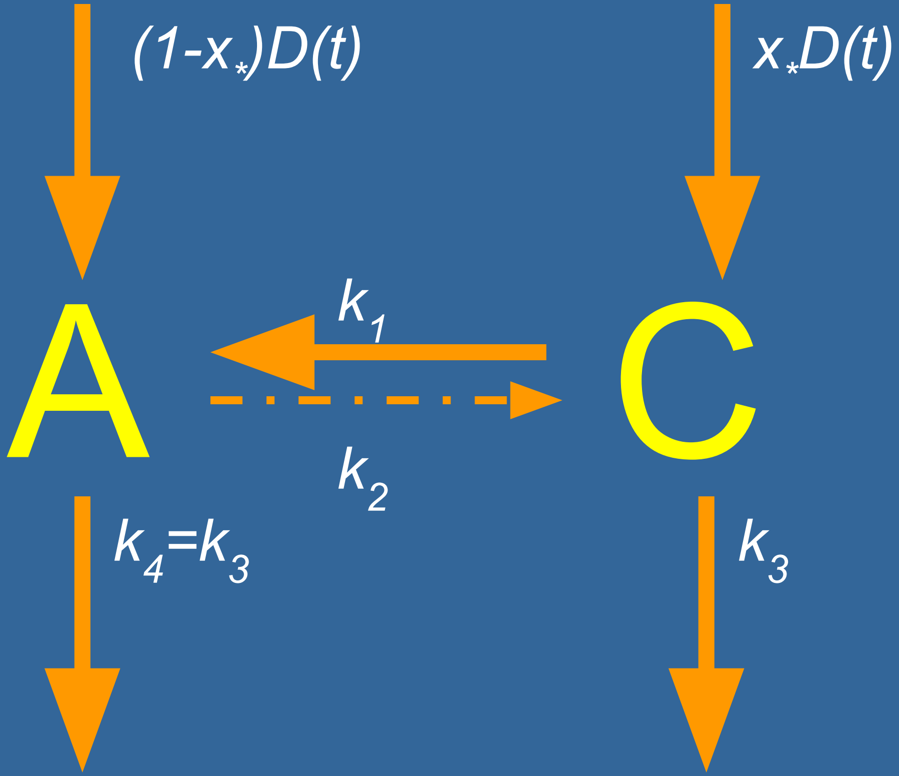
A

C



$$A \underset{k_2}{\overset{k_1}{\leftrightarrows}} C$$


A
k_1
k_2
C
$k_4=k_3$
k_3



$(1-x_*)D(t)$

$x_*D(t)$

A

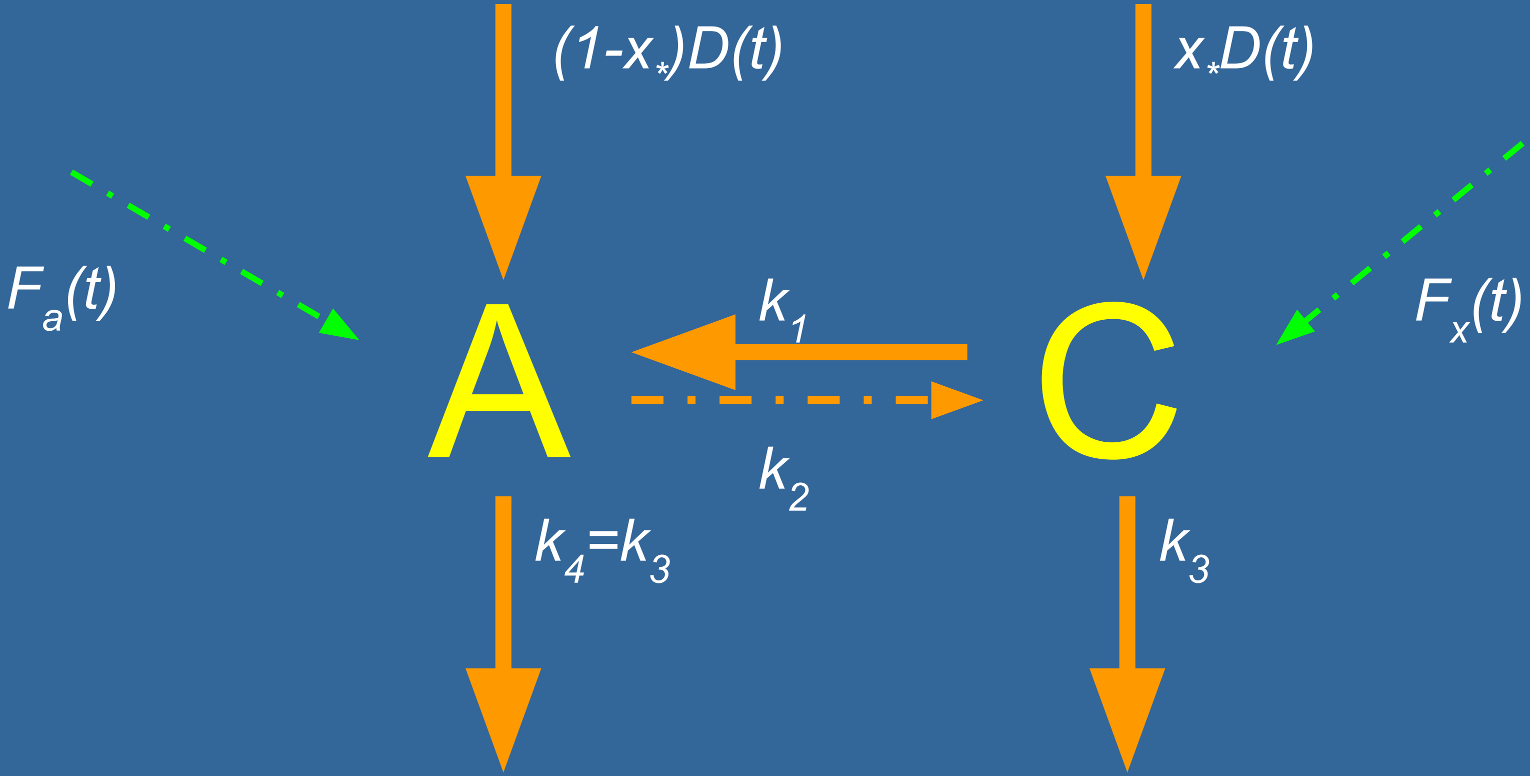
k_1

k_2

C

$k_4=k_3$

k_3



$(1-x_*)D(t)$

$x_*D(t)$

$F_a(t)$

k_1

$F_x(t)$

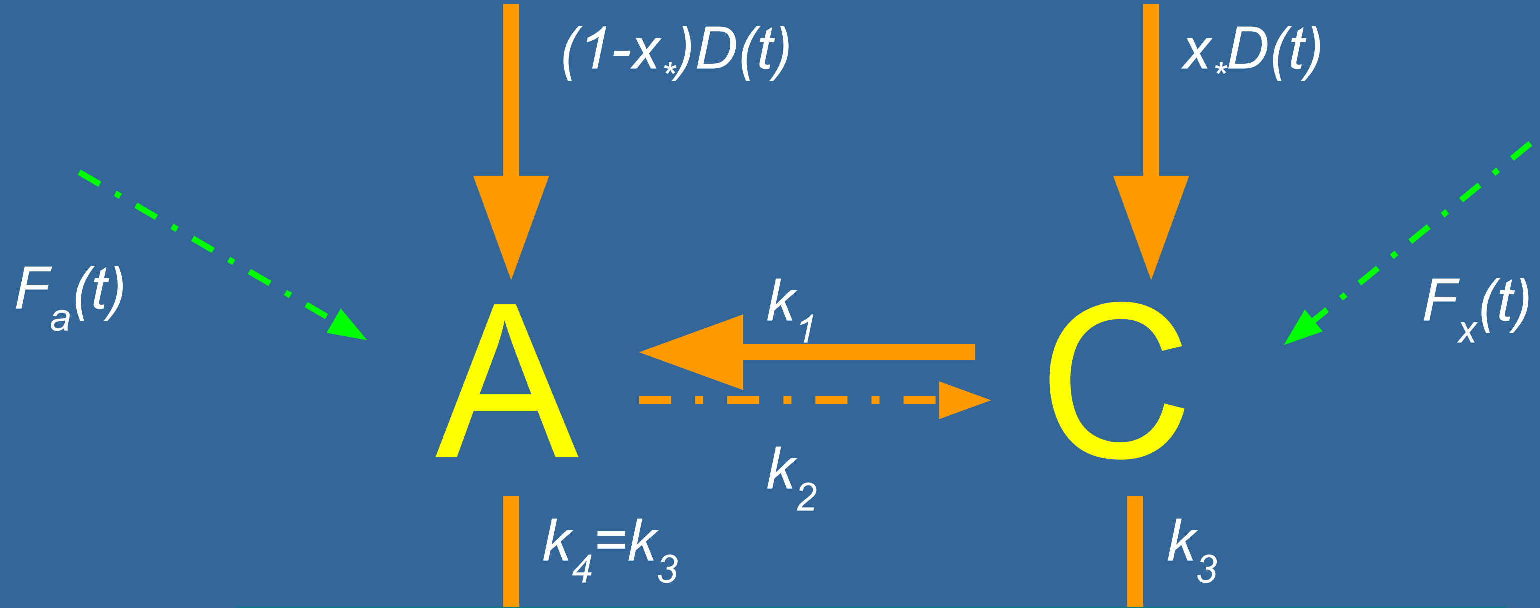
A

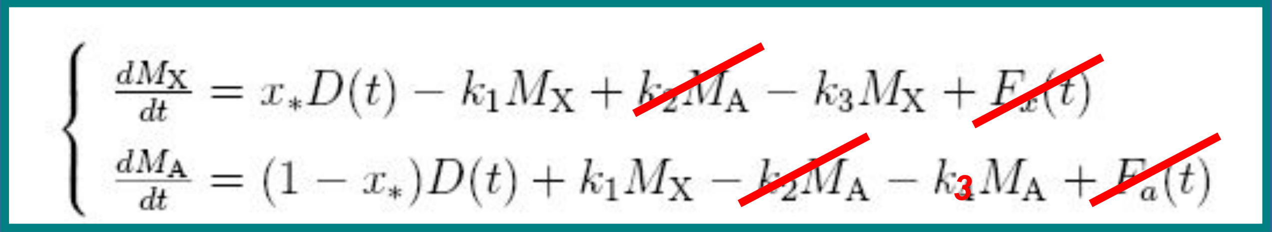
C

k_2

$k_4=k_3$

k_3





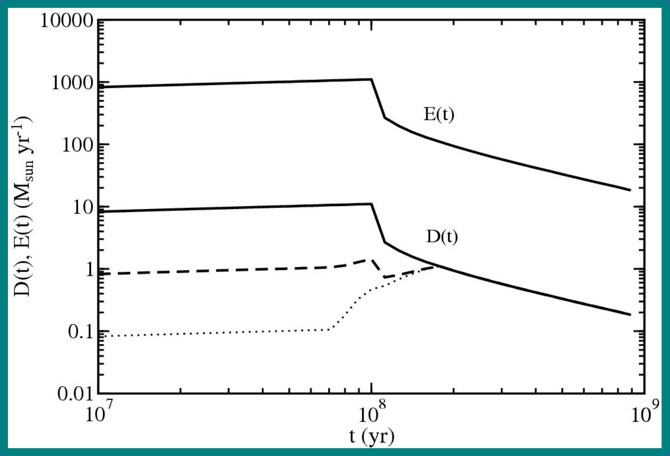
$$\begin{cases} \frac{dM_{\mathrm{X}}}{dt} = x_*D(t) - k_1M_{\mathrm{X}} + \cancel{k_2M_{\mathrm{A}}} - k_3M_{\mathrm{X}} + \cancel{F_x(t)} \\ \frac{dM_{\mathrm{A}}}{dt} = (1-x_*)D(t) + k_1M_{\mathrm{X}} - \cancel{k_2M_{\mathrm{A}}} - k_3M_{\mathrm{A}} + \cancel{F_a(t)} \end{cases}$$

Dust budget in a galaxy

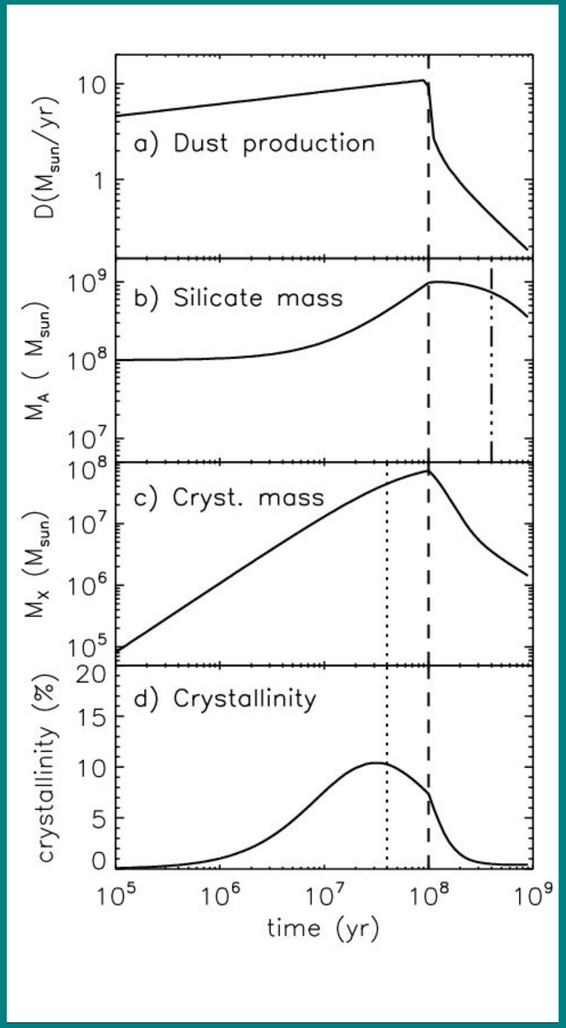
- *D(t): dust forms in stellar ejecta*
- Starburst duration: 10^8 years
- Kroupa (2001) IMF

$$w_m = \begin{cases} 0.109\, m + 0.394 & \text{for} \quad 1 \leqslant m < 8 \\ 1.35 & \text{for} \quad 8 \leqslant m < 25 \\ 0.1\, m & \text{for} \quad 25 \leqslant m \end{cases}$$

- Dust-to-gas ratio:
  - 0.01 for AGB stars
  - 10^{-4} – 0.01 for SNe



Results



Initial silicate mass: 10^8 $M_\odot$

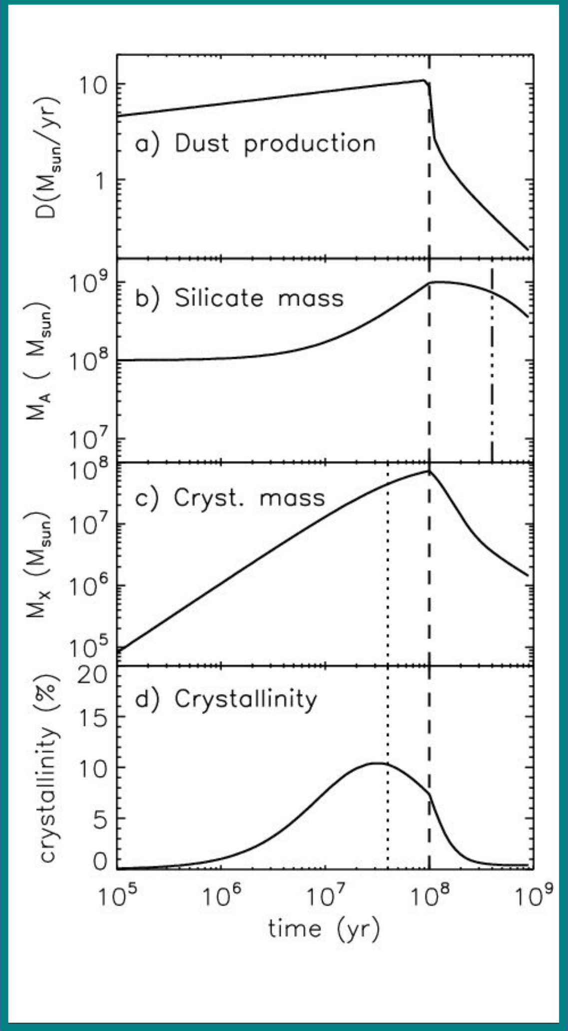
SFR: 1000 $M_\odot$ yr^{-1}

$x^* = 0.2$

Dust-to-gas ratio: 0.01 for SNe

⇒ crystallinity ~10 %

Results



Initial silicate mass: 10^8 $M_\odot$ → low

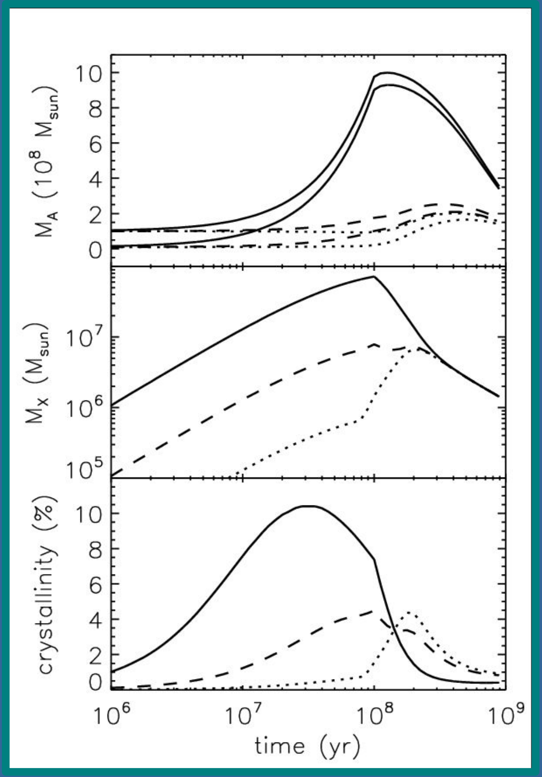
SFR: 1000 $M_\odot$ yr^{-1} → high

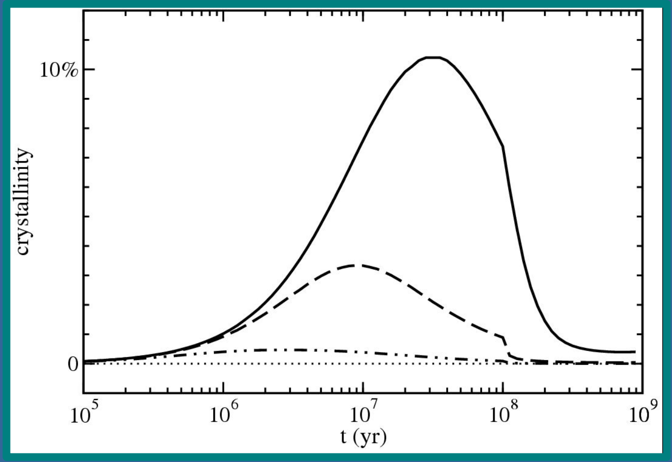
$x^* = 0.2$ → high

Dust-to-gas ratio: 0.01 for SNe → high

⇒ crystallinity ~10 %

Varying input parameters: the effect of supernovae

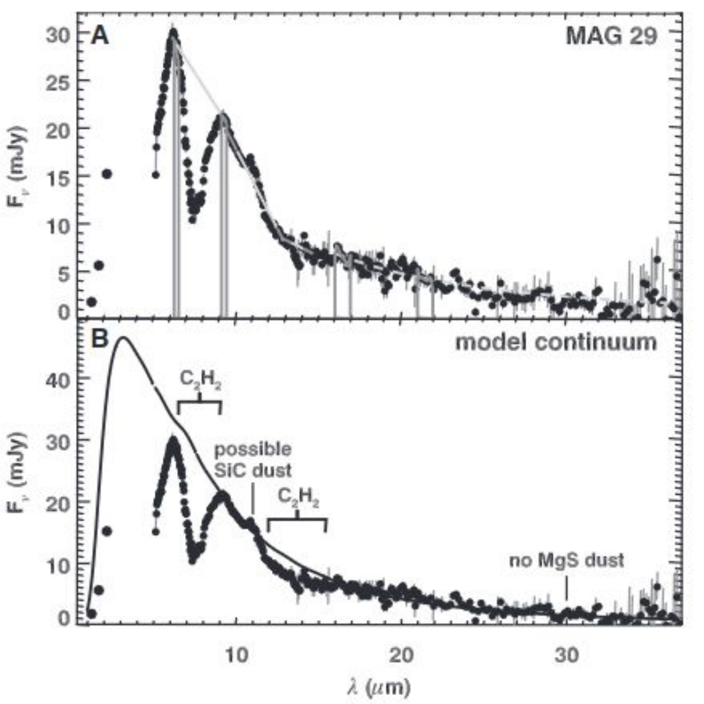




Amorphization rates

Dust production efficiency in SNe

Dust in low-metallicity environments

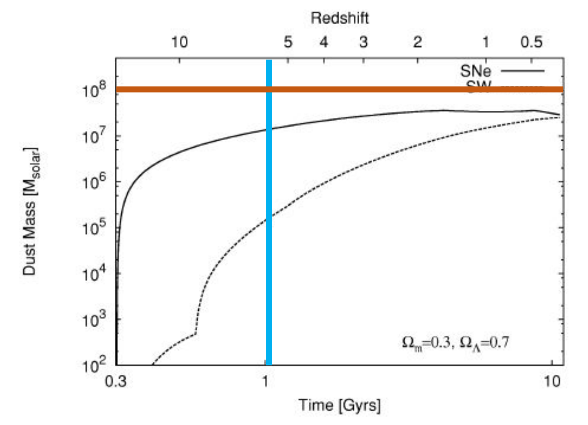


Dust formation in AGB stars in extremely low metallicity environments proceeds once enough C has been dredged up

No other dust features!

Sloan et al. 2009

Dust budget problem at high z



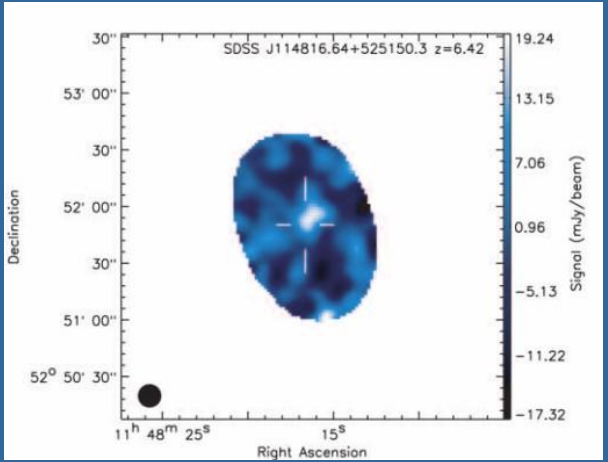
(Morgan & Edmunds 2003)

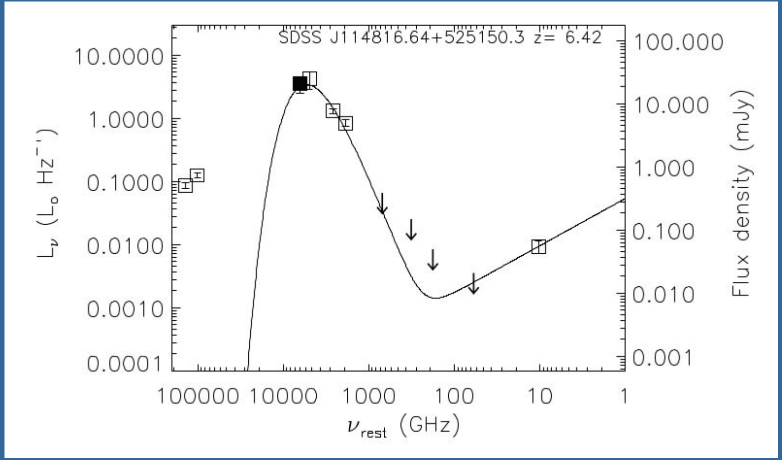
z>6: $10^{8\text{-}9}$ $M_\odot$ dust

Cannot be explained with stellar dust sources

AGB stars

Supernovae

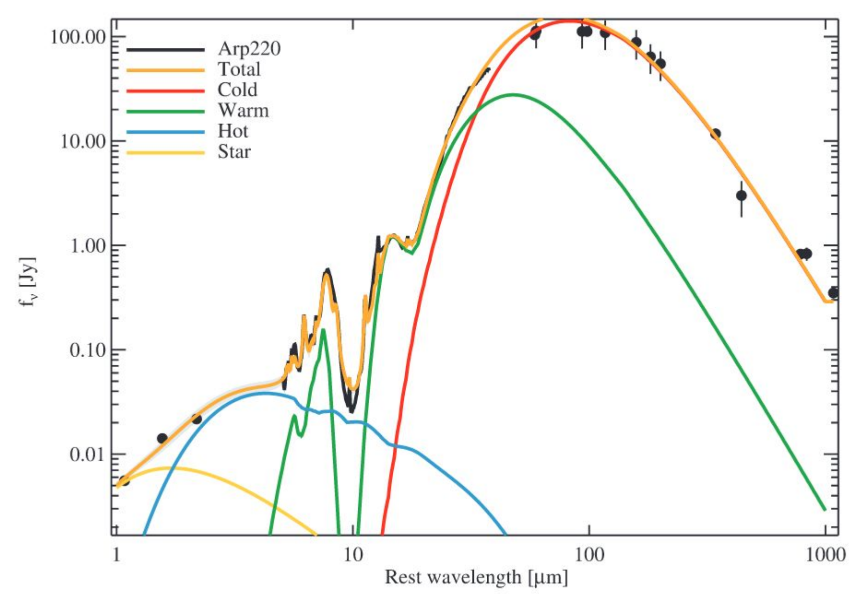




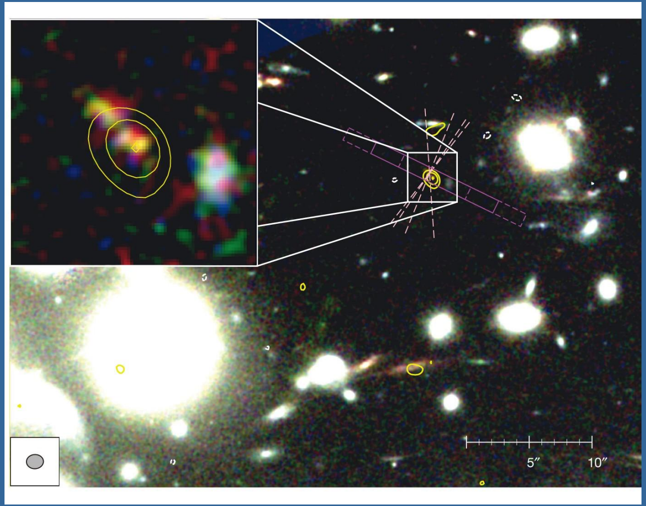
(Beelen et al. 2003)

Sampling of cold dust SEDs

(Watson et al. 2015)



(Armus et al. 2007)



Single ALMA photometry point

$z = 7.5$

$M_{dust} = 4x10^7\ M_{sun}$