Is stardust made by stars?

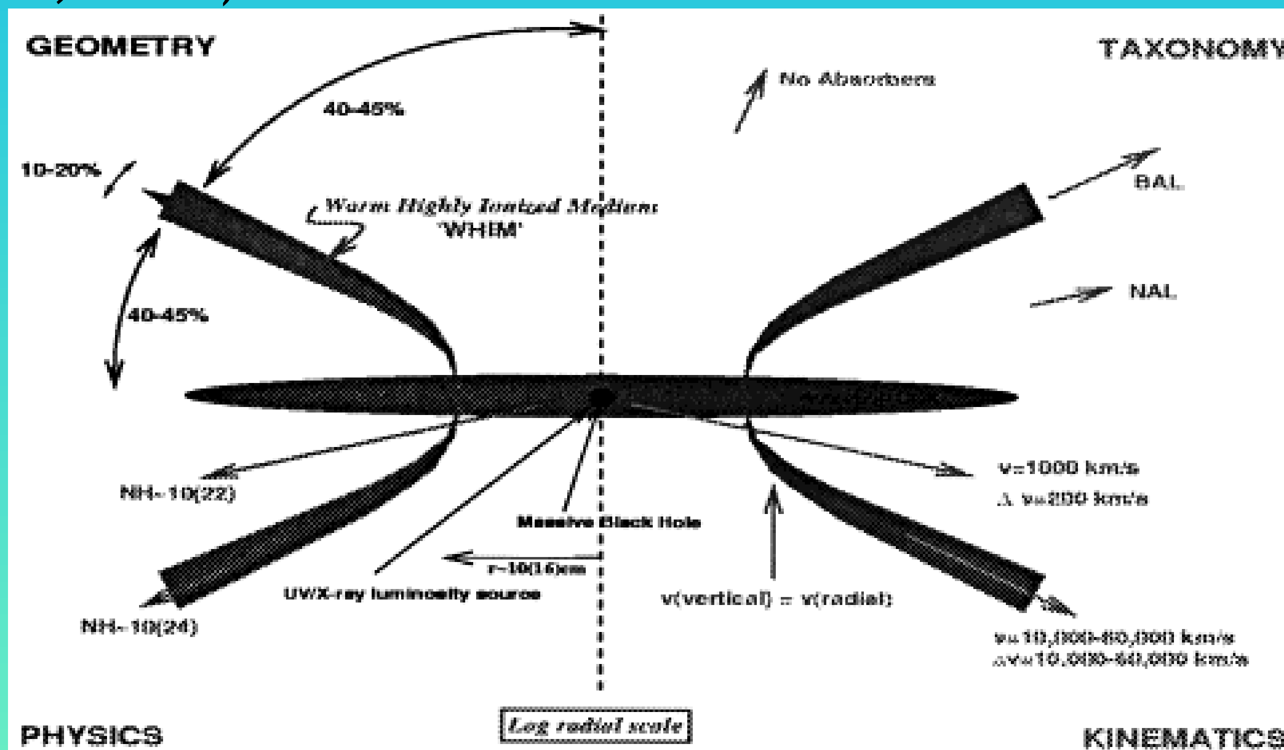
- **G. Schilling, 2007, Science, 318, 379**
  Space sighting suggests stardust doesn't have to come from stars
- **F. Markwick-Kemper, S. C. Gallagher, D. C. Hines, J. Bouwman, 2007, ApJ, 668, L107**
  Dust in the wind: crystalline silicates, corundum, and periclase in PG 2112+059
- **M. Elvis, M. Marengo, M. Karovska, 2002, ApJ, 567, L107**
  Smoking quasars: a new source for cosmic dust

Source of dust

- in local universe AGB stars (e.g. Draine 2003)
- significant amount of dust can be produced only 1 Gyr after the birth of first low mass stars (Morgan & Edmunds, 2003)
- BUT: dust observed in early times
  - ▷ *quasar host galaxies at* $z \sim 6$*:* $10^8 - 10^9 \mathrm{M}_\odot$ *of dust (sub-mm, far IR)* (Priddey et al., 2003, Beelen et al, 2006)
  - ▷ *extinction curves of quasars and GRB* (Maiolino et al., 2004, Stratta et al. 2007)
- quasar winds predicted to produce dust (Elvis et al, 2002)
- up to $10^7 \mathrm{M}_\odot$ - can explain only part of the observed amount

Broad absorption line (BAL) quasars

- cca 10-20% of observed quasars
- broad blueshifted (~ 10000 km/s) absorption in UV transitions (C IV, Lyα, O IV)

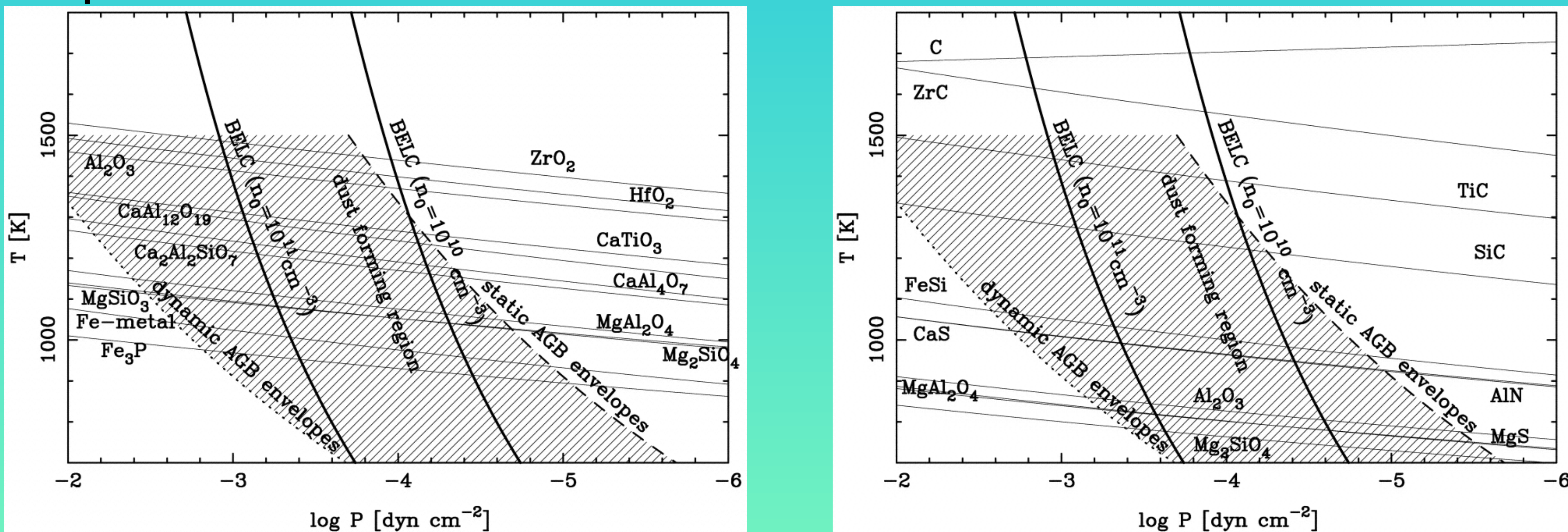


Elvis, M., 2000, New Astr. Rev., 44, 559

Formation of dust in Quasar wind

- broad emmision line clouds (BELC): (Osterbrock, 1989)

  $T \sim 10^4$ K, $v \sim 3000 - 15000$ km/s, $n_0 \sim 10^9 - 10^{11}$ cm$^{-}3$
- cool phase in equil. with a warmer (10^6 K) highly ionized wind
- outflow, BELC will expand (initial $c_s = 10$ km/s), cool down
- phase transition lines for Orich and C-rich medium:



(Elvis et al, 2002)

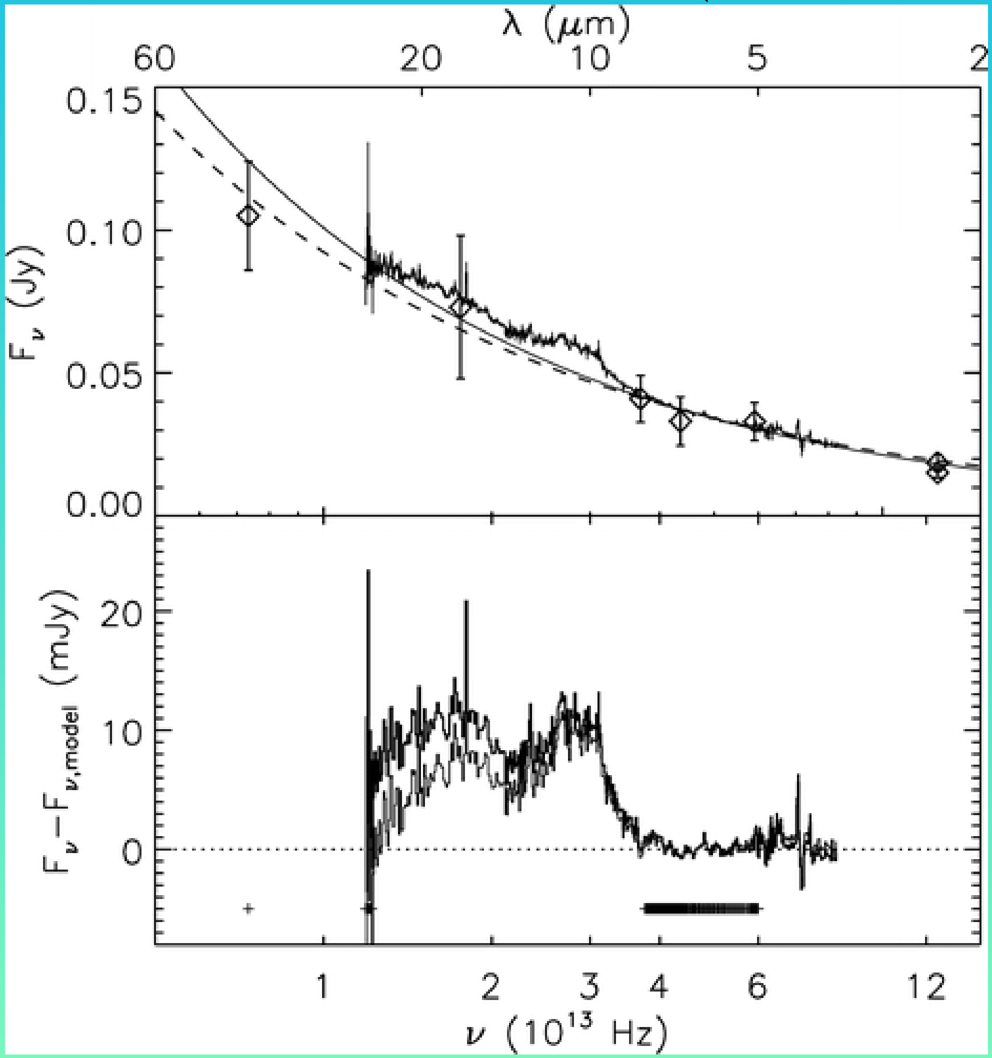
Spectroscopic observation of PG 2112+059

Markwick-Kemper et al., 2007

- InfraRed Spectrograpch (IRS) on board Spitzer
- 1 cycle (240s) with Short-Low modules ($5.2 - 14.5\mu$m) and 2 cycles (120s) with Long-Low modules ($14.0 - 38.0\mu$m)
- broad emmision bands at 10 and 18μm (amorphous silicates)
- $[NeII]$ transition (12.8μm)
- substructure in the solid state emmision 11.2μm

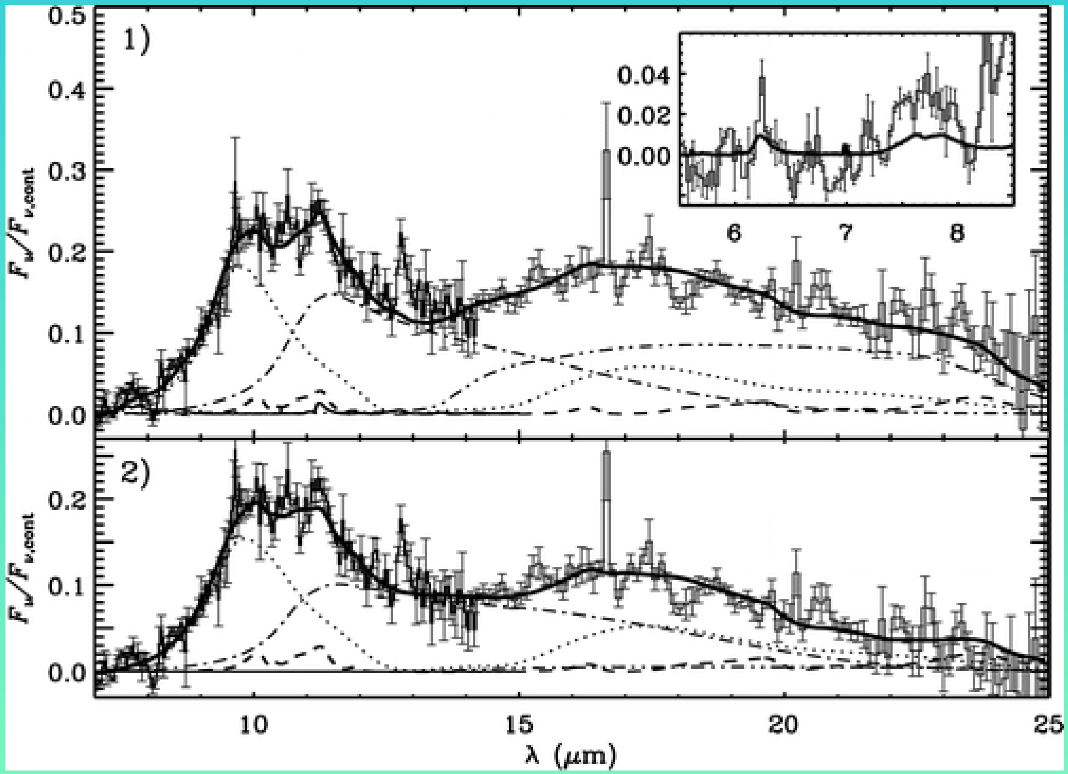
Emmision spectrum

- 2 continua defined and subtracted
- based on photometric observations (IRAS, ISO, Palomar)



Spectral feature analysis

- spectra compared to 512 models with varying dust composition
- laboratory spectra of minerals observed in AGB stars
  - *amorphous and crystalline olivines ($MgFeSiO_4$, Mg_2SiO_4),*
  - *corundum (Al_2O_3)*
  - *periclase (MgO)*
  - *polycyclic aromatic hydrocarbons (PAHs)*



Dust composition

- presence of silicates in AGNs known previously (absorption (Imanishi & Ueno, 2000)), and emmision (Sturm et al 2005)
- detection of corundum and periclase is new

TABLE 1

BEST $\Delta\chi^2$ FITS TO THE TWO CONTINUUM-DIVIDED SPECTRA OF PG 2112+059 (FIG. 2)

Fraction	Continuum 1 (wt.%)	Continuum 2 (wt.%)	Average (wt.%)
Silicates/total	54 ± 1	59 ± 1	56.5 ± 1.4
Corundum/total	37 ± 2	39 ± 2	38 ± 3
MgO/total	9 ± 2	2.7 ± 1.7	5.9 ± 2.6
Crystalline/silicates	4 ± 2	6 ± 2	5 ± 3
Mg_2SiO_4/amorphous silicates	70 ± 44	49 ± 40	...
$MgFeSiO_4$/amorphous silicates	30 ± 44	51 ± 40	...
Amorphous silicate composition	$Mg_{1.9}Fe_{0.1}SiO_4$	$Mg_{1.8}Fe_{0.2}SiO_4$	$Mg_{1.85}Fe_{0.15}SiO_4$

NOTES.—The first column shows the dust fraction considered, and the following columns show the mass fractions for both continuum fits and the average. The standard deviation on the results is determined from the spread of the mass fractions observed in those fits within the $\Delta\chi^2$ tolerance of a factor 2. The bottom line shows the average composition of the amorphous silicate dust.

Corundum

- condense at 1500 K (above silicates)
- at lower temperatures usually covered by silicates
- its presence suggests that gas density drops rapidly
- high luminosity and detection in emmision suggests that it is associated rather with quasar than with the host galaxy
- presence of both corundum and olivines indicate clumpy density structure

Periclase

- in slowly cooling gas Mg_2SiO_4 forms first and consumes all Mg
- indicates that the gas cooled rapidly

Crystalline silicates (fosterite)

- approximatelly $5 \pm 3\%$ of silicates crystalline
- not observed in ISM - destroyed by CR at timescale 40 Myr
- their formation requires higher densities than amorphous silicates
- quasar wind origin may explain their presence

Conclusions

- for the first time, composition of dust in a quasar has been determined
- some of dust properties similar to dust in other environments, some are different (presence of large amount corundum and periclase; presence of crystalline silicates), consistent with formation in quasar wind
- coexistence of corundum, crystalline and amorphous silicates suggests inhomogenous temperature and density structure
- quasar winds have high velocities ($v = 1000$km/s$> v_{\rm esc} \Rightarrow$ dust will be ejected into IGM where it may:
  - ▷ *may affect measurements of cosmological parameters* (Aguirre, 1999)
  - ▷ *alter gaseus IGM composition*
  - ▷ *contribute to FIR background*
  - ▷ *change galaxy evolution models* (Dwek, 1986; Aguirre & Haiman, 2000)
  - ▷ *alter Sunyaev-Zeldovich effect* (Sunyaev-Zeldovich, 1972)

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