Circumstellar, interstellar and extragalactic dust

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Circumstellar & Interstellar dust
Old stars have young dust...
Dusty winds & O-rich AGB stars

(Bedijn 1987)
Crystallization of silicates

Sylvester et al. (1999)  
Kemper et al. (2001)
What do we know about SN dust?

Rho et al. 2009
...mid-life in the ISM...

Brucato et al. (2004)
Featureless broad resonance at 10 micron

Most silicate grains in the ISM are amorphous

Kemper et al. 2004; Chiar & Tielens 2006
...and young stars have old dust

Bouwman et al. 2001
Disks & Crystallization (in evolved stars)

Gielen et al. (2008)
Molster et al. (1999)
Spatial variations within protoplanetary disk

van Boekel et al. (2004)
Dusty galaxies
Dust masses in the far-IR/submm

- Example: M81 (Bendo et al. 2010)
- Fitting SEDs
- Bulk of dust is cold -> far-IR/submm
- Dust mass derived: $3.4 \times 10^7 \, M_{\odot}$
Dust at $z=6.42$

SHARC II @ CSO - 350 micron (Beelen et al. 2006)

Dust mass: $4.2 \times 10^8 \ M_\odot$

AGB stars have not built up sufficient amounts of dust; the Universe is $< 1 \text{ Gyr old}$
Dust at high redshift

$z \sim 6$ quasar host galaxies: $10^8 - 10^9 \, M_\odot$

of dust \cite{Priddey2003, Beelen2006}

The Universe is only $<1$ Gyr old at that point

AGB evolution does not produce enough dust \cite{Morgan2003}

Supernovae?
The physical model for AGN

Type 1 (quasar)

Type 2 (quasar)
Spectral Energy Distributions

- Pier & Krolik
- Nenkova et al.
- Van Bemmel & Dullemond
- Höning et al.
- Fritz et al.
- ...

Pier & Krolik 1992
Silicates in AGN: typically only optical depth, emission & absorption

Shi et al. 2006
A case of extreme emission: host galaxy hardly detected

Hony et al. 2011

No star formation

Modest old stellar population
Extreme silicate emission

Hony et al. 2011
Odd mineralogies: NGC 1068

Innermost ~2 pc of the NGC 1068 nuclear dust region.

(a) Dust Torus
(b) Clouds
(c) Black hole

9.7 \mu m
Silicate
"Type 1" (emission)

9.7 \mu m
Silicate
"Type 2" (absorption)

\lambda \text{ [nm]}

\lambda F_\lambda [\text{arb. units}]

Galactic Center (\lambda_0)
NGC 1068 (\lambda F_\lambda)
Odd mineralogies: gehlenite (Al-Ca-silicates) in NGC 1068?

Correlated flux, baseline = 72 m, PA = 2°

Jaffe et al. 2004
Odd mineralologies: SiC in NGC 1068?

Köhler & Li 2010
Odd mineralogies: Porous silicates

Hao et al. 2005; Sturm et al. 2005
Porosity shifts & weakens 10 micron feature

Iati et al. 2001

Li et al. 2008
Spatial variations in NGC 1068 silicate: grain sizes

Rhee & Larkin 2006
Starburst galaxies: crystallinity

Spoon et al. 2006
Further reading

• A&A special issue on Herschel results: Volume 518, 2010

• Astromineralogy, lecture notes in physics 815, ed. Thomas Henning: chapter 2 & 3