Dust formation in supernovae - type II-P SNe with the eyes of Spitzer

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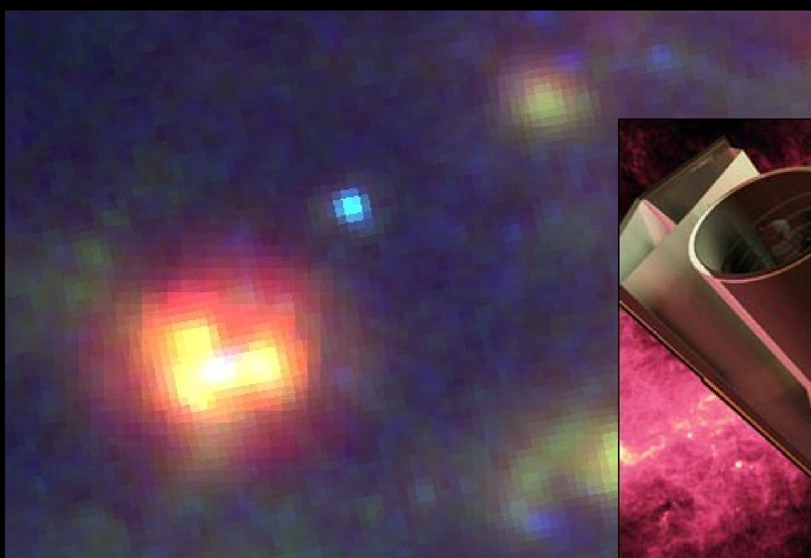
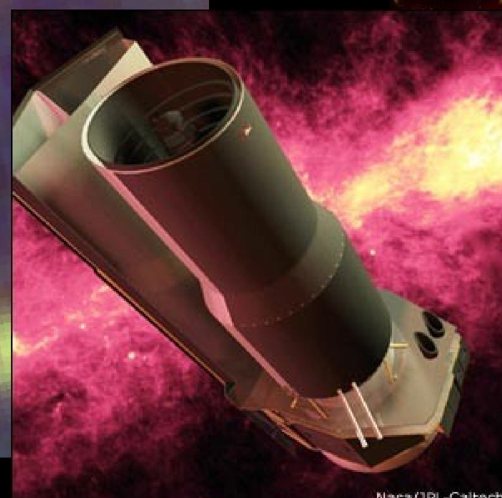
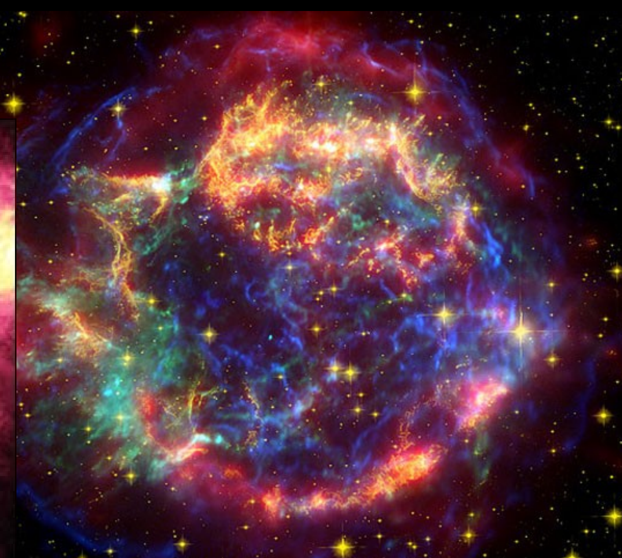






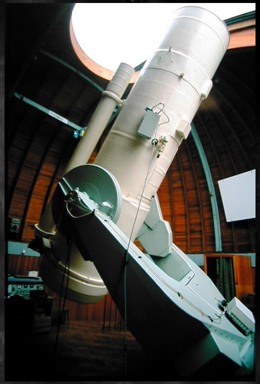
6th Workshop of Young Researchers in Astronomy and Astrophysics

The Multi-wavelength Universe from Starbirth to Star Death

3-6 September 2012 – Budapest, Hungary

Supernova research at the University of Szeged

- Astrophysics Group at University of Szeged (since 1998, leader: Dr. József Vinkó)




Collaborations:

- Konkoly Observatory (Schmidt + RCC)
- Baja Observatory (BART)

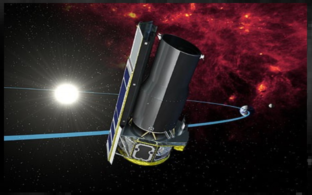
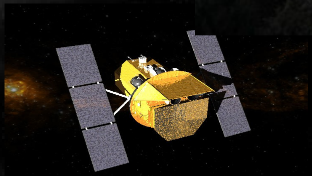
→ photometric follow-up of SNe

- University of Texas (J. C. Wheeler) + McDonald Observatory (**HET**)

→ optical spectroscopy, HETDEX survey (from 2013)

- **SALT** (opt. spectroscopy), CfA Supernova Group

- Public data of space telescopes (Swift, Spitzer, HST)

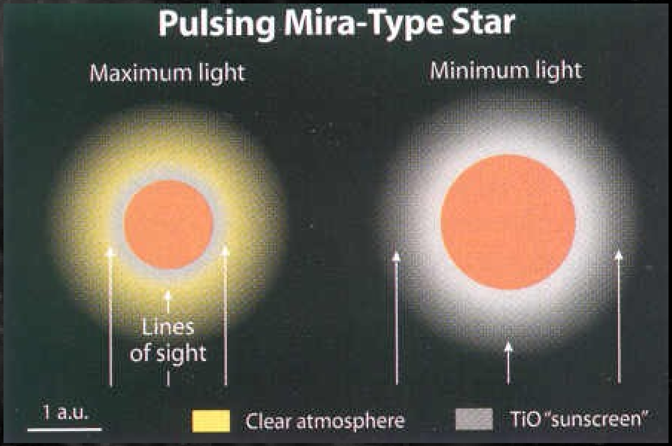
About the origin of the interstellar dust

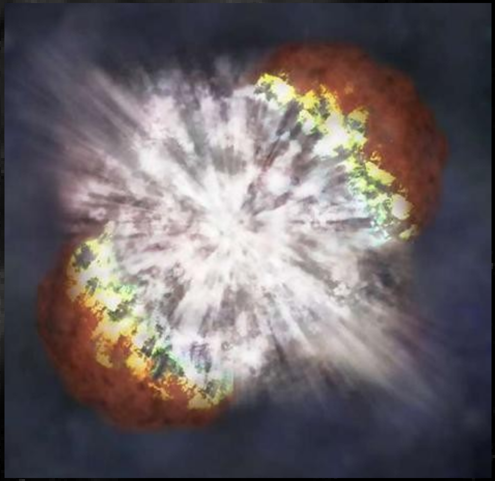
- Grain condensation works only in special cases

Possible sources:

- Stellar winds of AGB stars (intensive convection)
- Quasar winds
- Core-collapse supernovae

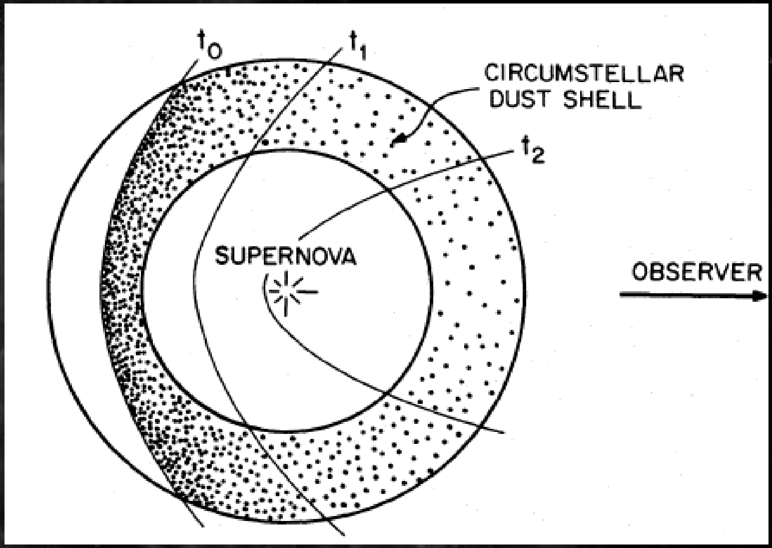
- IR excess after explosion (first: SN 1987A)
- Sub-mm excess and strong polarisation by older SNRs
- Isotopic anomalies in meteorites
- Large dust amount of high-redshift galaxies





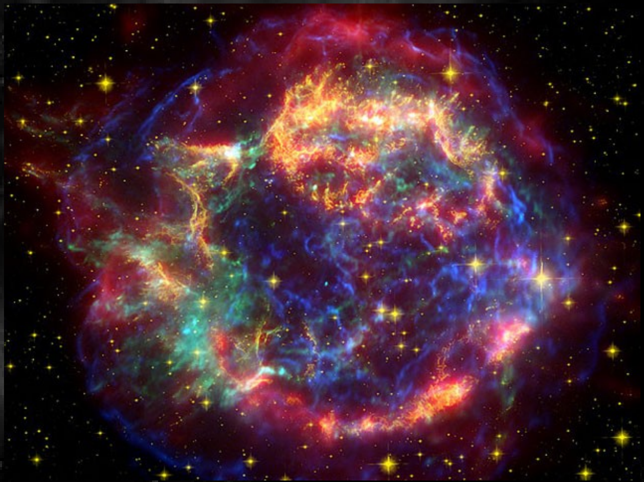
What do we see in mid-infrared?

- Thermal radiation of pre-existing CSM re-heated by the SN (IR echo)
- Newly-formed, warm dust in the ejecta (~3-500 days after explosion)
- Grain condensation in a cool dense shell (CDS) between forward and reverse shock waves



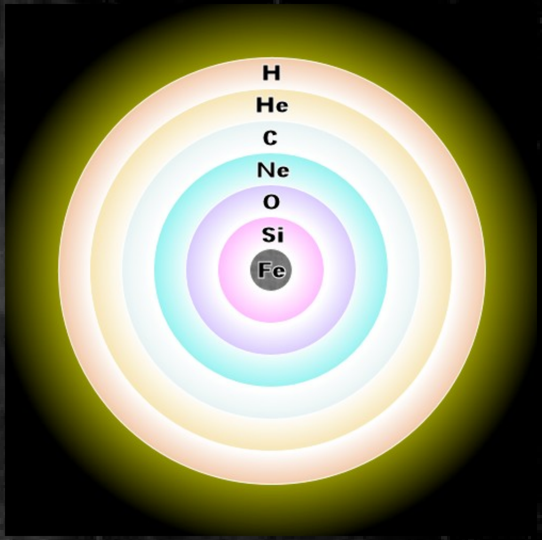
Other evidences of fresh dust:

- Strong decrease of optical fluxes and increase of MIR fluxes in the same time
- Attenuation / blueshift of optical emission lines



Core-collapse SNe and dust formation

- Evidences of dust-formation only by a few SNe (long-term MIR observations are necessary), mostly by Type II-P ones (smaller v_{eject} of C, O, Si layers)
- Amount and size-distribution of grains depend on the environment (type) of the SN

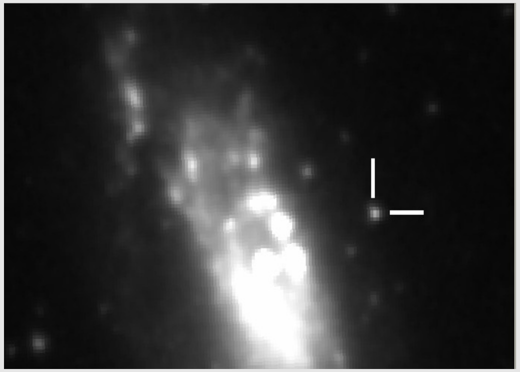


http://en.wikipedia.org

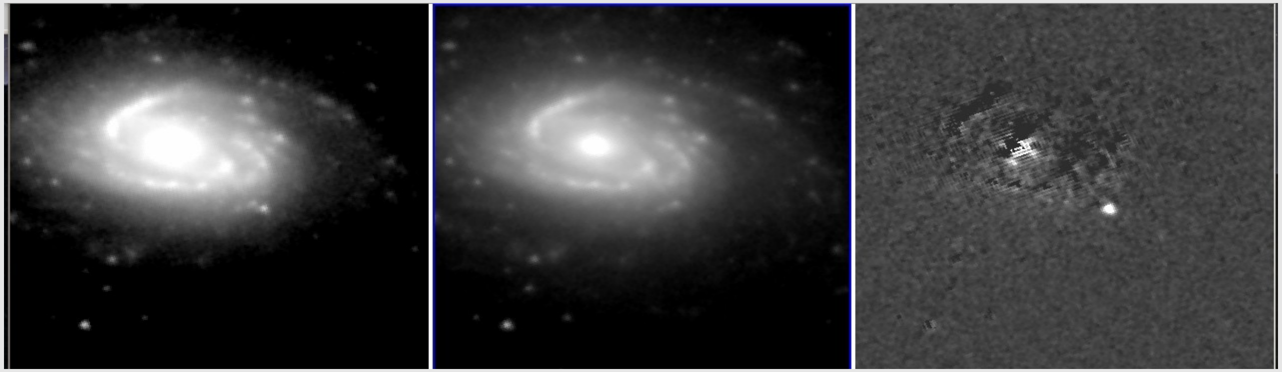
- Observed dust masses (< 0.02 M_{Sun}) are much lower than predictions of models (0.1-1 M_{Sun}) → other sources of dust in the early Universe?
  - Note 1: difficulties by dust mass calculations (model dependencies, clumps, grain parameters, very cold dust)
  - Note 2: other possibilities (larger contribution of AGBs, top-heavy IMF, grain growth in the ISM)

Mid-IR Spitzer data of Type II-P SNe

- Public data from Spitzer database:
  Mid-IR photometric data: IRAC (3.6, 4.5, 5.8, 8.0 μm), MIPS (24 μm)
  + broadband photometry (IRS/PUI, 13.5-18 μm), IRS spectra (5-30 μm)
- Study of 13 Type II-P SNe → successful identification in 10 cases
- Aperture (and sometimes PSF) photometry (IRAF, MOPEX)
- IRS spectra: reduction with SPICE and IRAF (checking: CASSIUS)
- <u>Outputs</u>: light curves, flux-calibrated spectra, dereddened mid-IR SEDs

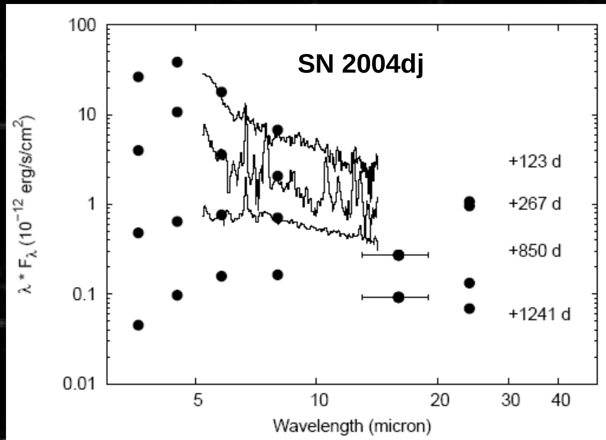


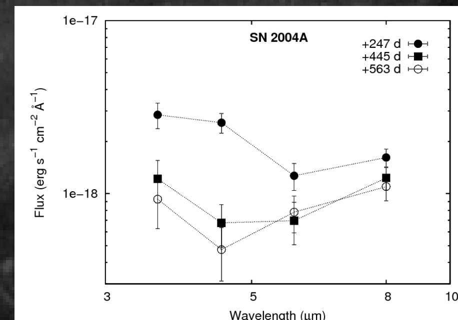
SN 2004A

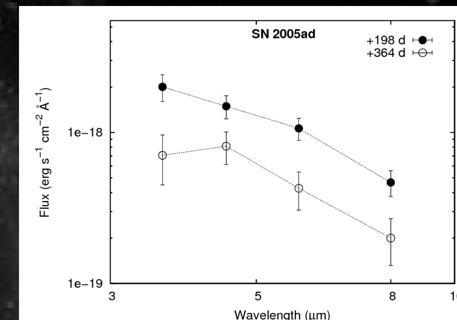


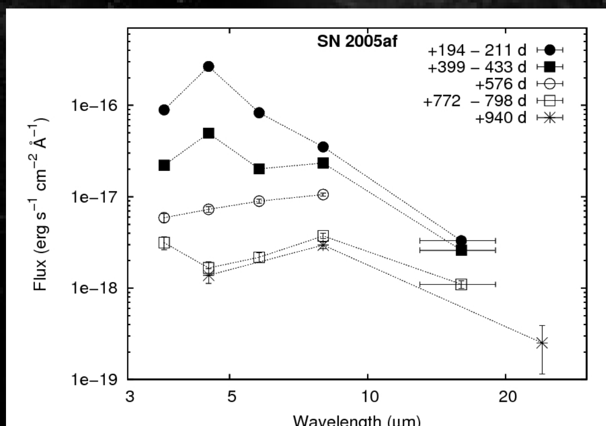
SN 2006my

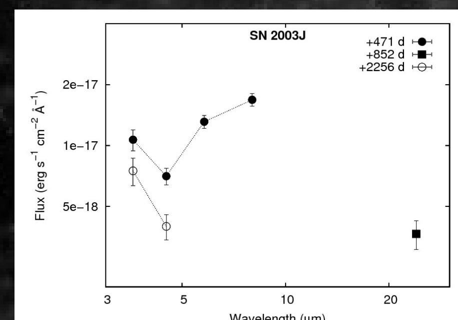
First step: temporal changes of the mid-IR SEDs of the studied SNe

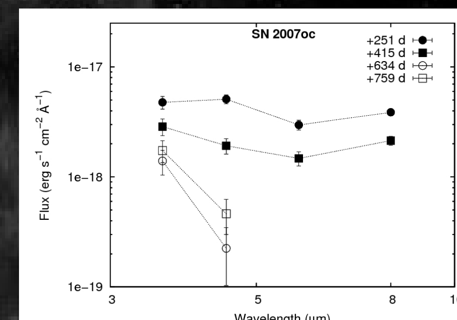


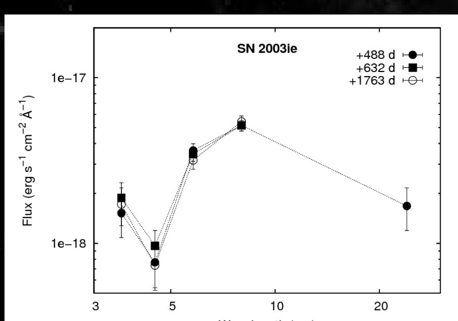


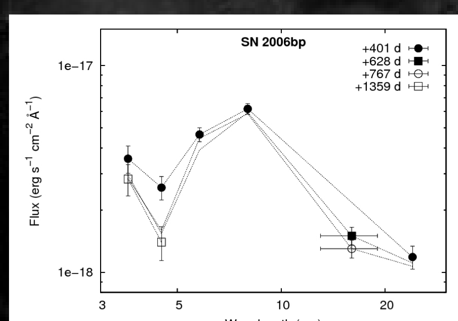


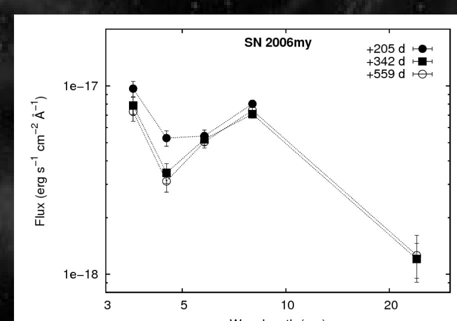


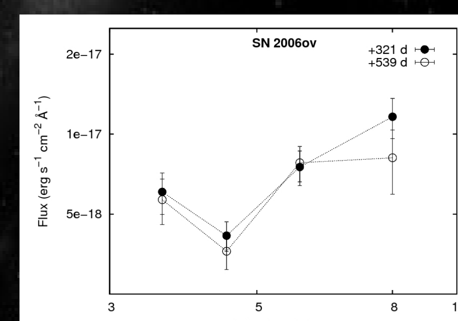




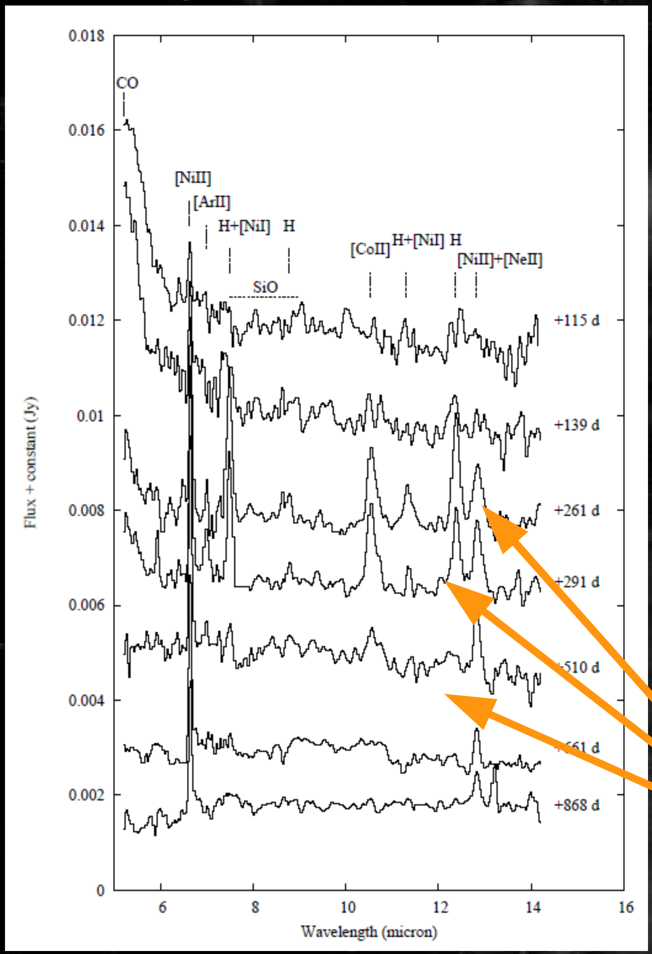




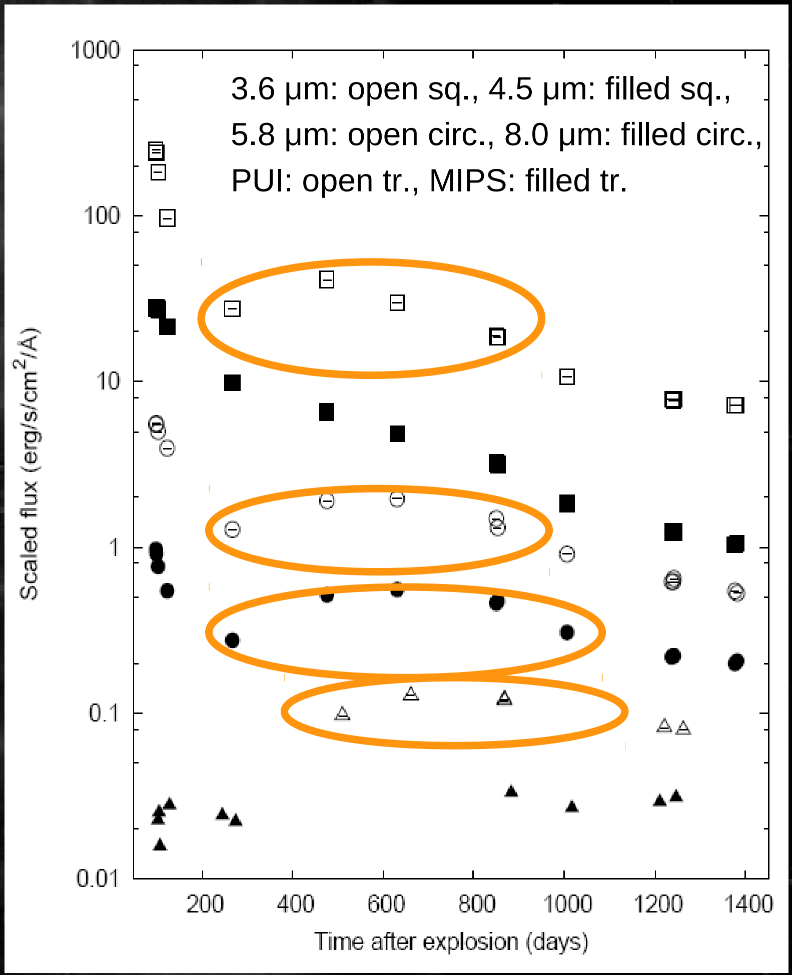




Direct signs of dust formation



SN 2004dj



Disappearing of nebular lines (left) and a „bump" on the mid-IR light curves (right) after +300 days.

Analytic models for dust

Analytic model (Meikle et al. 2007)

$$L_\nu = 2\pi^2 R^2 B_\nu(T)[\tau_\nu^{-2}(2\tau_\nu^2 - 1 + (2\tau_\nu + 1)e^{-2\tau_\nu})]$$

$$\tau_\nu = \frac{4}{3}\pi k \rho \kappa_\nu R \frac{1}{4-m}[a_{max}^{4-m} - a_{min}^{4-m}]$$

- Grain types: AC, C-Si-PAH
- m = 3,5, a_{min} = 0,005 μm; a_{max} = 0,05 μm
- Dust formation within a spherical shell
- Fitted parameters: ***T***, ***R***, ***k***

MRN-distribution (Mathis et al. 1977)

- Total mass of dust: $$M_d = \frac{4\pi R^2 \tau_\nu}{3\kappa_\nu}$$

(Lucy et al. 1989)

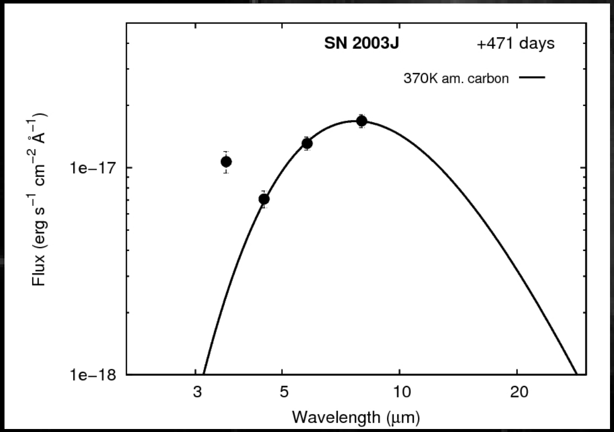
Components of mid-IR radiation:

- „warm” dust (~250 – 1000 K): AC or C-Si-PAH
- „cold” dust (< 250 K): blackbody → excess at 24 μm
- hot (gas) component (>3000 K): blackbody → excess at 3.6 μm

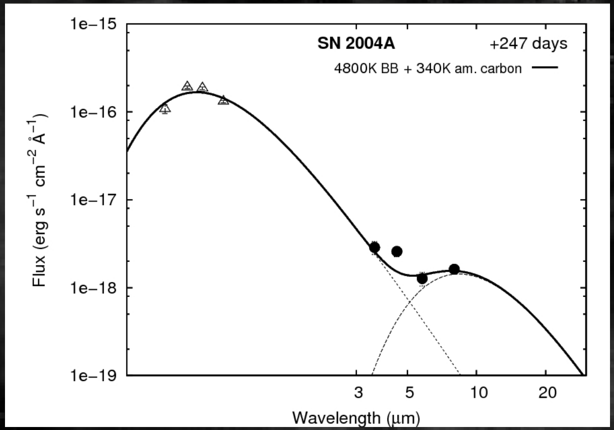
→ complementing optical data are necessary

Output parameters could be limits for the presence of newly-formed dust:

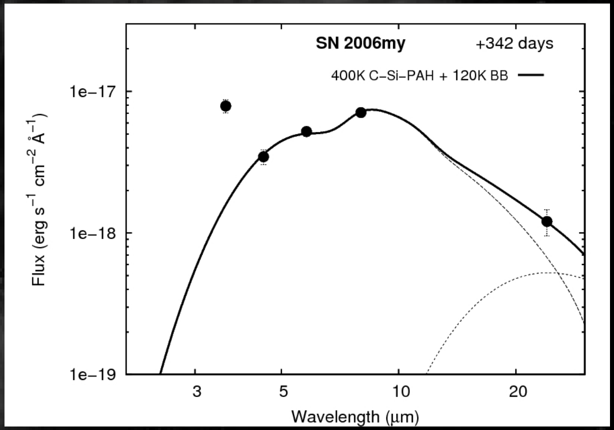
- varying (cooling) temperatures
- $v_{ejecta} < 5000$ km s^{-1} (upper limit for inner layers)



AC dust
(SN 2003J)



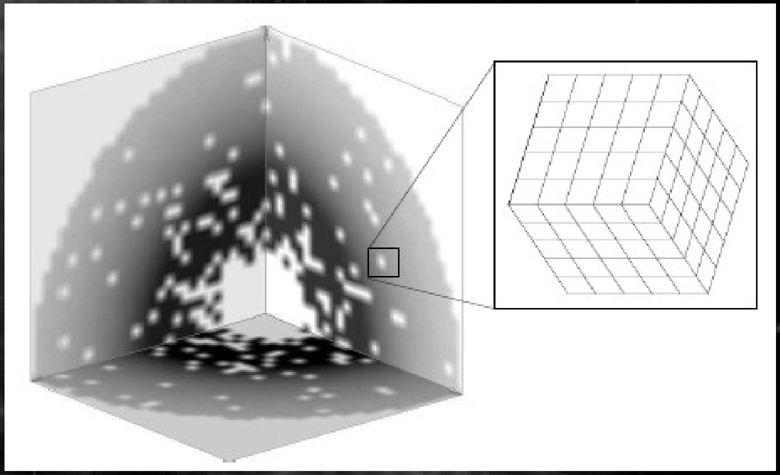
AC dust + hot component
(SN 2004A)



Si dust + cold component
(SN 2006my)

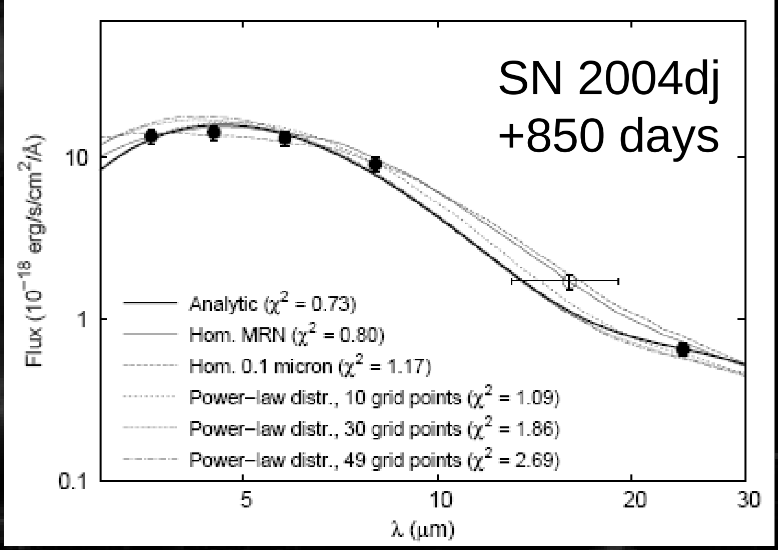
MOCASSIN 3D radiative transfer code
(Ercolano et al. 2003, 2005, 2007)

- Ray-tracing of energy packets in a shell containing specified medium (interactions)
- Cartesian grid



Inputs:
- Parameters of illuminating source
- Parameters of the shell (R_{in}, R_{out})
- Grain-size distribution (MRN, 0.005, 0.05, 0.1 µm)
- Average number density and density profile (homogenous, power-law)

Outputs:
- SED
- Total mass of dust



Conclusions

- Detectable, mainly newly-formed local dust by 3 SNe: 2004dj, 2005af, 2005ad
- Detectable, maybe partly newly-formed local dust (varying SEDs, but to large v_{ejecta}) by 3 SNe: 2003J, 2004A, 2007oc
- No detectable local dust (not varying SEDs) by 4 SNe: 2003ie, 2006bp, 2006my, 2006ov

- 16 II-P SNe with analysed and published Spitzer-data in all
  → *10 of them were analysed and published by our group*
- Dust masses (10^{-5} – 10^{-3} M_{sol}) are too low (<< 0.1 M_{sol})
  → other cosmic dust sources?
- *Herschel* may reveal much more cold dust in SNRs

Szalai T., Vinkó J., Balog Z. et al. 2011, A&A, 527, A61
Szalai T. & Vinkó J. 2012, Proceedings of the IAU, IAU Symposium 279, accepted
Szalai T. & Vinkó J. 2012, A&A, submitted

Thank You
for Your attention!