Dust formation and type II Supernovae

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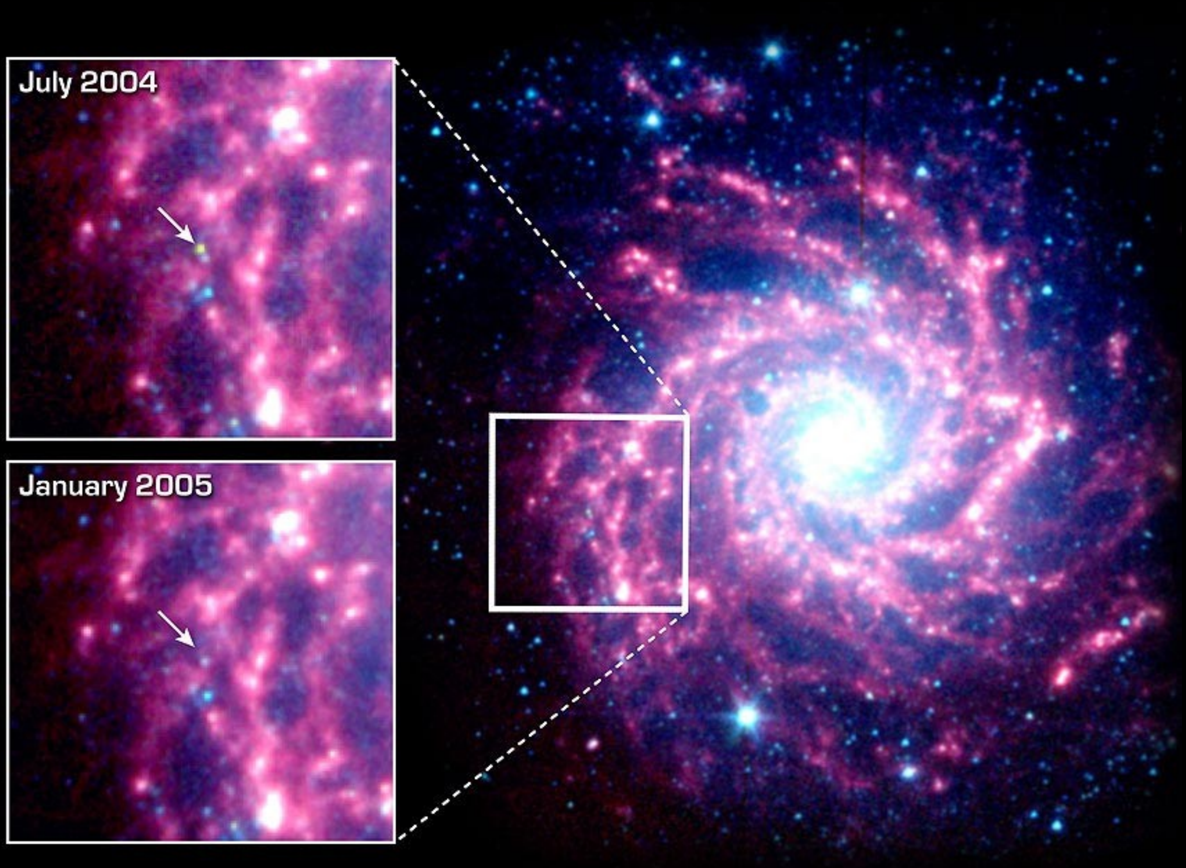


Supernova Dust Factory in Galaxy M74
NASA / JPL-Caltech / Ben E. K. Sugerman (STScI)

Spitzer Space Telescope • IRAC
sig06-018

Core Collapse SNe as dust factories

•Nucleosynthesis & recycling of heavy elements.
•Massive progentiors ($M > 8\ M_{\odot}$)
⇒ Large mass loss (dusty CSM?)
+ Short lifetimes,
+ dust production during explosion?

Dust from SNe interesting because:

- Source of dust ($\geq 10^{8}\ M_{\odot}$) in high z (≥ 6) galaxies?
- If typical $M_{\mathbf{dust}} \sim 10^{-2}\ M_{\odot}$, what is the primordial star formation rate?
- Determining $M_{\mathbf{dust}}$

→ estimation of $M_{\mathbf{progenitor}}$,
+ final evolutionary stage:

- Luminous Blue Variable (LBV) (2009ip)?
- Red Super Giant (RSG)?
- Pair instability event (2006gy, 2007bi)?

Dust origins, heating & survival in SNe.

Origins:

Newly formed?

- Condensed in expanding SN ejecta
- Cool, dense shell between forward and reverse shocks

Pre-existing dust from progenitor?

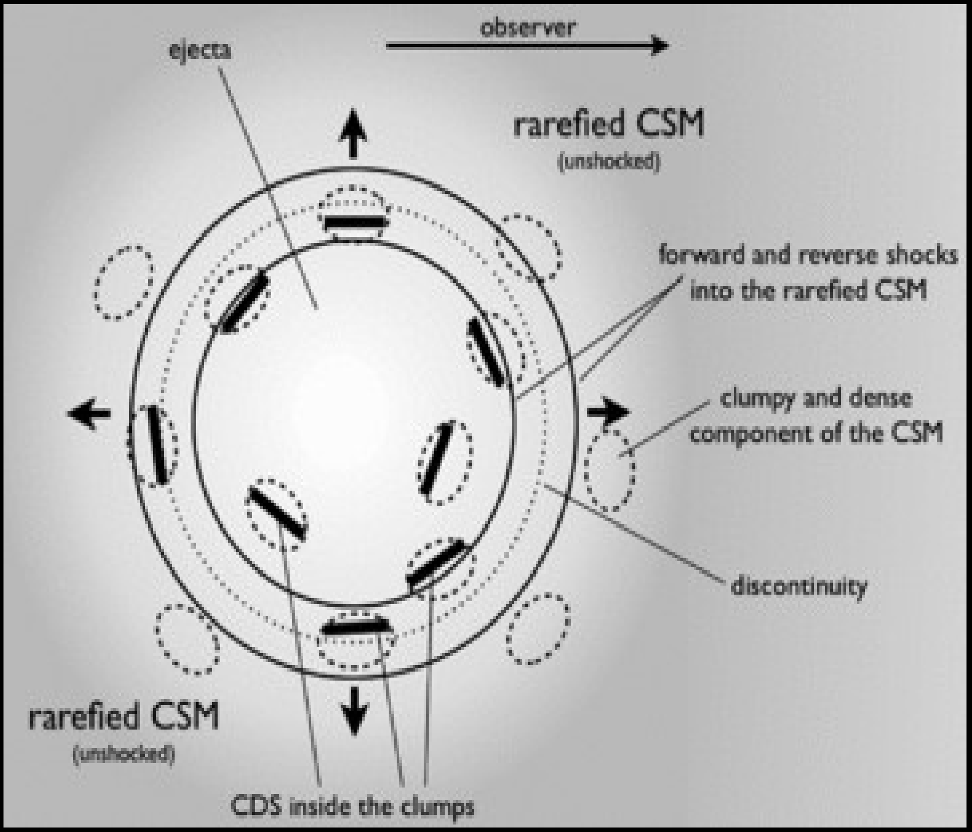
Heating mechanisms:

- Radiative heating via reprocessing UV flux – IR light echo possible.
- Collisional heating by hot shocked gas.

Survival:

- Pre-existing dust up to R_{evap} may be vaporised via shock heating.

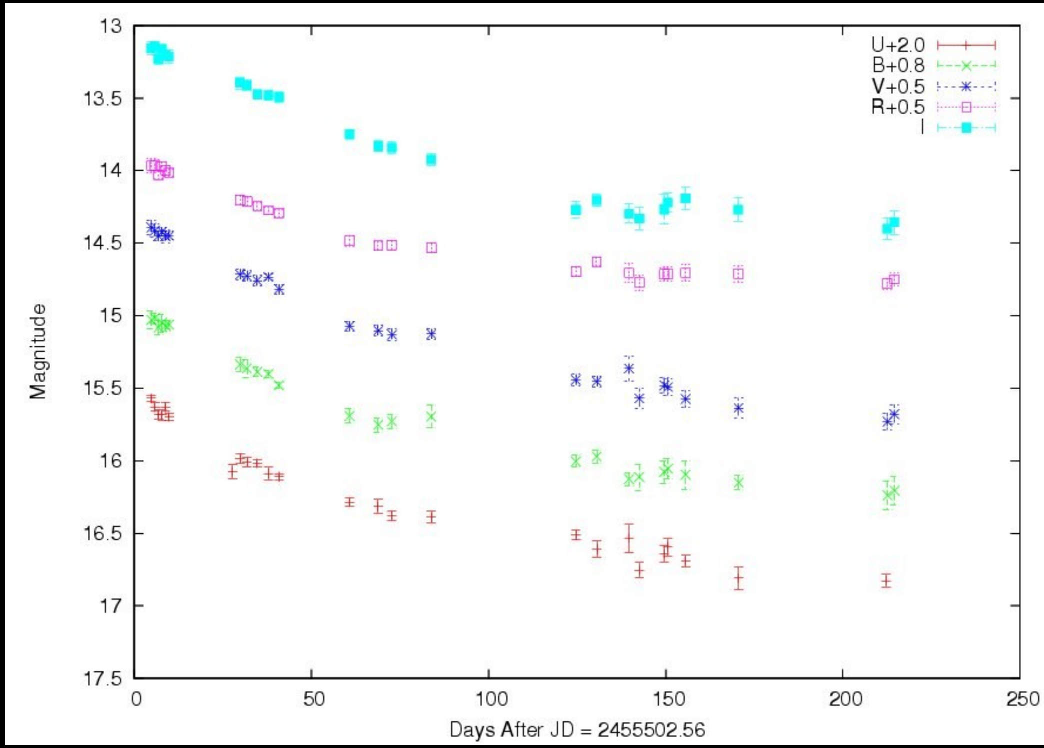
$$R_{evap} = \left(\frac{L_{peak}}{16 \pi \sigma T_{evap}^4} \right)^{1/2}$$



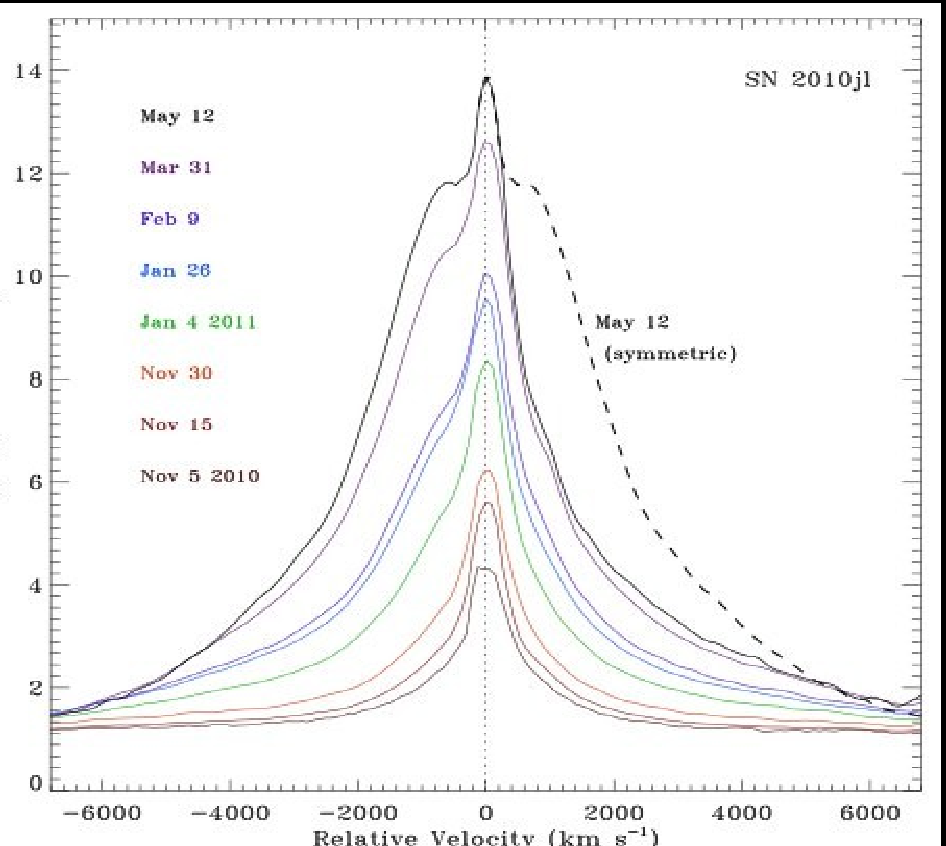
Schematic showing the geometry and interaction of newly formed dust in SN2007od (Inserra et al. 2011).

Observable signatures of dust formation

- IR excess due to thermal emission.
- Increased rate of fading of optical light curve.



UBVRI light curves of SN2010jl showing rapid fading in the early light curves **(Sutaria et al. 2011)**



Emission line profile increasingly asymmetric with more absorption in red. (Hα profiles of SN2010jl; Smith et al. 2011)

Dust & SNe-II classification

SNe-IIn: Narrow emission lines from slow moving CSM (<~ 700 km) intermediate component from decelerated forward shock front (1000 – 5000 km/s), broad component from rapidly expanding SN ejecta (5000 -- 6000 km/s). $M_{dust} \sim 10^{-3}$ to 10^{-2} $M_{\odot}$. (SN 2010jl)

SNe-IIP: Broad emission lines, clear p-cygni progile, large H-envelope, little evidence of clumpy CSM, $M_{dust} \sim 10^{-4}$ $M_{\odot}$. (SN2007od)

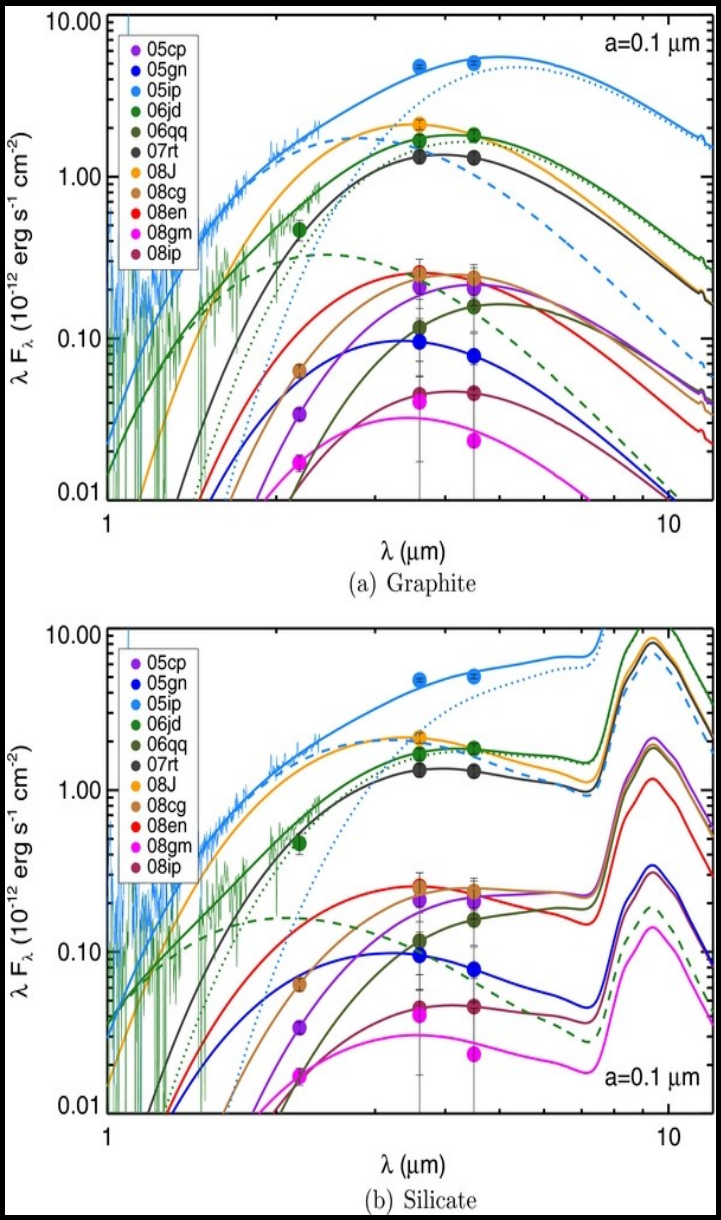
SNe-IIL: Broad emission lines, small H-envelope, very low M_{dust}.

SN 1987A: Peculiar type II, small H-envelope, far-IR observations reveal cool dust (~20 K) with $M_{dust} \sim 0.4\text{-}0.7 M_{\odot}$.

Except SN 1987A, all M_{dust} estimated from IR excess. Sampling effect or property of SN-II peculiar?

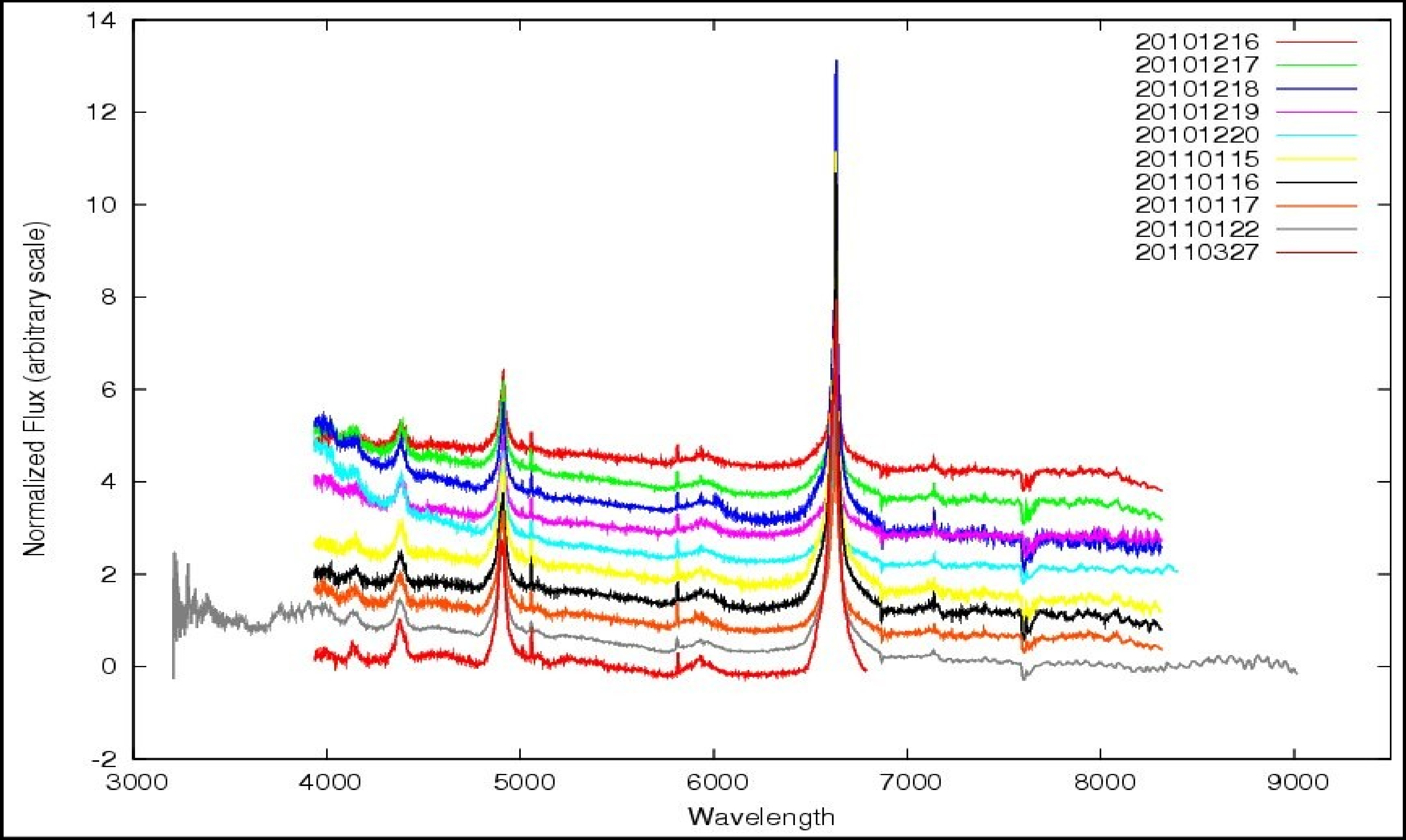
A Spitzer study of dust in SNe-IIn

- Over a sample of 68 SN-IIn (10 detections):
- For grain size of 0.01-3.0 μm,
- Grain composition of:
  - (a) Amorphous C
  - (b) Silicates
- M_{dust} 10^{-5} to 10^{-2} $M_{\odot}$
- T_{dust} : 600 to 900 K
- L_{dust}: 10^{6} to 10^{8} $L_{\odot}$
- IR excess seen for up to > 5000 d after explosion
- IIn may continue to brighten in IR long after fading out optically.



Model fits of emission from optically thin, warm (400 – 800 K) dust.
(Fox et al. 2011)

Spectral evolution of SN-IIn SN2010jl

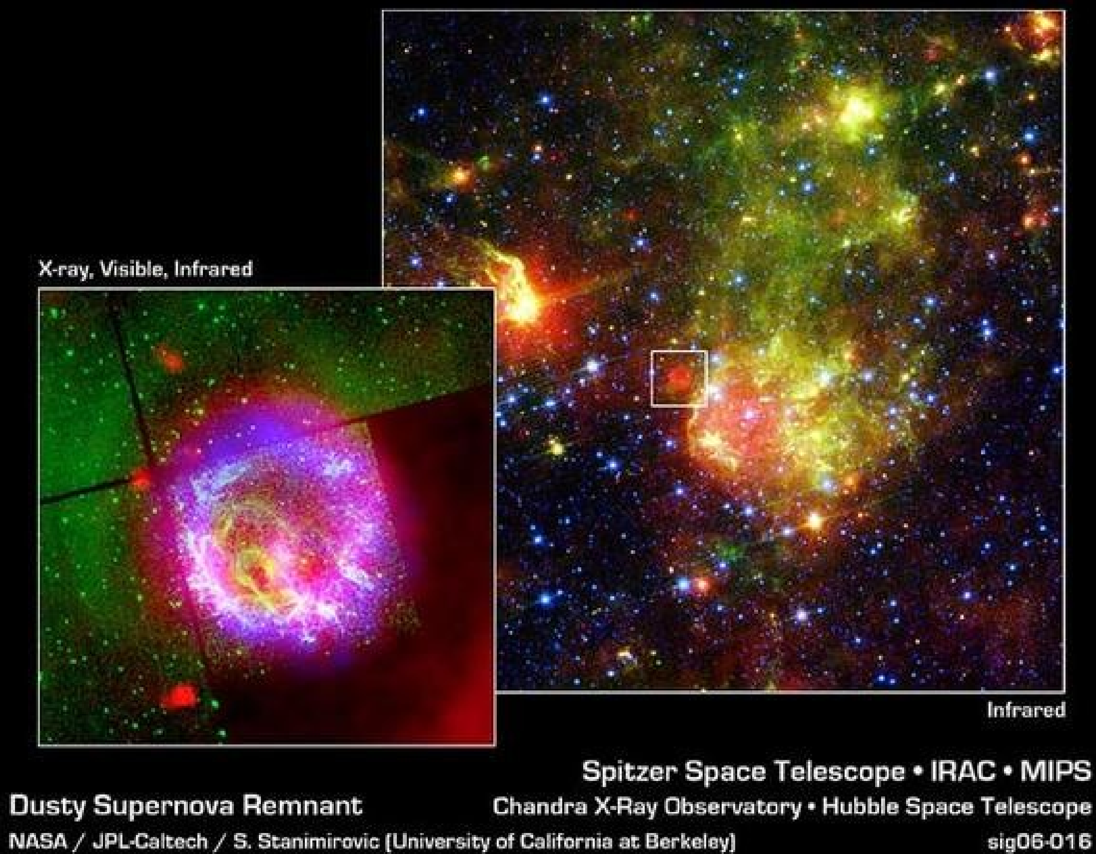


IGO data showing spectral evolution of SN2010jl from 16/12/2010 to 27/03/2011 (Sutaria et al, 2011, in preparation). Continuum temp. ~ 7000 K. The narrow emission features are characteristic of Type IIns.

Dust in SN-IIn SN2010jl

- T_{dust}~ 750K, cool pre-existing dust.
- No evidence for Cool Dense Matter CDM.
- $M_{\mathbf{dust}}$~ 0.03 – 0.35 $M_{\odot}$,
- CSM mass of 3-35 $M_{\odot}$.
- Geometry: Torus;
  - i=60° to 80°,
  - R_{in}~ 6 x 10^{17} cm,
  - Δ R ≅ Rin.
- $R_{\mathbf{evap}}$: 6 x $10^{\mathbf{16}}$ (C-rich CSM).
  - 3 x $10^{\mathbf{17}}$ (O-rich CSM).
- No dust between $R_{\mathbf{in}}$ & $R_{\mathbf{evap.}}$
- Dust formed 300-2000 yr before SN.
- $v_{\mathbf{dust}}$ at time of explosion ~ 100 – 600 km/s.
- LBV progenitor > 30 $M_{\odot}$.

(Andrews et al. 2011)



SNR 1E0102.2-7219 in N76 shows the dusty torus likely to exist in SN2010jl.

Conclusions & open questions

- Late time IR emission most likely from pre-existing dust.

- Dust geometry: Shell-like, interior dust evaporates via shock interaction.

- ProgenItors of SN-IIn are most likely LBV.

- SN-IIn largest supernovae contributors of dust?

- Little evidence for cool dense shell. Is most of the dust vaporised? Shock may destroy the dust shell eventually. If so, is the dust in dusty SNRs newly formed?

- Recent observations of SN1987A (with Herschel) resolves the dust deficit?