Herschel Imaging of Galactic Supernova Remnants - New Constraints on the Dust Production of SNe

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Dust Production by Supernovae

- Core collapse SNe are long-known producers of dust grains. Observational evidence for condensation in the SN ejecta:

(I) Decline in optical light-curve, thermal MIR excess and red-blue asymmetry of photospheric lines (Lucy et al. 1989 – SN1987A)

(II) MIR emission coinciding with ejecta in galactic SNRs (Lagage et al. 1996)

(III) Isotopical composition of presolar grains (Clayton 1982)

- However, yield and composition are much under debate.
  - Observations confused by IR echoes / ISM dust
  - Dust destruction by SN shocks and UV/optical flash

- 0.1-1 M☉ of dust per SN is required to form to explain large dust content (>$10^8 M_☉$) and rapid enrichment at high-z galaxies (Morgan & Edmunds 2003; Maiolino et al. 2006; Dwek et al. 2007)
SNR targets of the MESS Key Program

| ~1680  | IIb          | (Cas A) |
| 1604   | Ia (?)       | (Kepler) |
| 1572   | Ia           | (Tycho)  |
| 1181 (?)| II (pulsar)  | (3C58)   |
| 1054   | II (pulsar)  | (Crab)   |

- nearby and young - swept-up ISM mass low
- Herschel imaging / spectroscopy
Cas A

- Prototypical shell-type, core–collapse SNR with central compact object
- Exceptionally well studied across the EM spectrum
- Extreme O- and Si-group abundances from explosive nucleosynthesis
- Nitrogen-rich, fast moving ejecta → massive Wolf-Rayet progenitor
- Distance 3.4 kpc (1arcmin = 1pc)
Stochastic heating of newly formed dust

IRAS/Spitzer/ISO: $8 \times 10^{-5} - 3 \times 10^{-3} \, M_\odot$ warm (80-300K) dust within Cas A
(Warm) dust mass and composition

Spitzer/IRS decomposition by Rho et al. (2008)

Total dust mass 0.02 - 0.054 $M_\odot$ - crucially depends on the coolest component
SCUBA observations – Cold dust in Cas A

SCUBA 850 μm map – dominated by non-thermal emission

Dunne et al. 2003

Submillimeter excess in the north highly polarized (Dunne et al. 2008)
SCUBA observations – Cold dust in Cas A

850 µm, synchrotron-subtracted

Spectral energy distribution

Dunne et al. 2003

Submillimeter excess in the north highly polarized (Dunne el al. 2008)
OH first radio detection of a molecule in space toward Cas A (Weinreb et al. 1963)

Faint visible appearance of SN1680

850 µm submm excess towards Cas A consistent with interstellar dust in line of sight;

0.2 M☉ upper limit for cold dust within Cas A

850 µm emission + OH absorption

ISM contamination toward Cas A

Krause et al. 2004
Cas A SDP observations
PACS 70,100,160 μm composite

Warm SN dust

Cool SN dust
(+ [OII] line contribution)

interstellar clouds
SPIRE 250, 350, 500 μm composite

Non-thermal emission
Emission component separation

Non-thermal
Warm SN dust
Cool SN dust

ISM ➔
Herschel SDP results

MIPS/PACS composite 24,70,100 µm

- Shocked warm dust
  \(3 \times 10^{-3} M_\odot\) - \(T \sim 80\) K

- Unshocked cool dust
  \(0.075 M_\odot\) - \(T \sim 35\) K

Upcoming PACS and SPIRE spectroscopy will provide more details on the ejecta/dust relation

- First high-resolution images of the cool dust component
- Previously inferred by Tuffs et al. (2005; 60-200 µm ISOPHOT) and Sibthorpe et al. (2010; 65-500 µm AKARI/BLAST).
Infrared echoes near Cas A

Krause et al. 2005, Science 308, 1604

15 arcmin = 15 pc

Krause et al. 2005
Kim et al. 2008
Optical light-echo spectroscopy - Cas A was a (rare) type IIb SN

(Initial) stellar mass $13-20 \, M_\odot$
Mass at explosion $3-6 \, M_\odot$
Hydrogen envelope mass $\sim 0.1-0.5 \, M_\odot$
Core mass $\sim 3-5 \, M_\odot$
Total ejecta mass $1-2 \, M_\odot$

Krause et al. 2008
Dust formation and evolution in a stripped-core, type IIb SN

Nozawa et al. 2010

- Nucleation calculations yield initially $0.17 \, M_\odot$ of newly synthesized dust
- Small envelope mass $\rightarrow$ early arrival of the reverse shock and strong dust destruction by sputtering
- Currently $0.008 \, M_\odot$ of shock-heated warm dust and $0.072 \, M_\odot$ of unshocked cool dust in the remnant’s interior
- Virtually all new dust will be destroyed unless shielded in very dense clumps
Conclusions

- High quality HERSCHEL data have been obtained on Cas A

- PACS and SPIRE images resolve the cool unshocked dust component in Cas A, yielding a total dust mass of $0.08 \, M_\odot$ within the remnant

- There is no evidence for significant ($\sim 1 \, M_\odot$) amounts of cold dust in the remnant previously concluded from SCUBA observations in addition to the foreground ISM

- The results are consistent with recent models of the type IIb supernova Cas A in which $0.17 \, M_\odot$ of dust were originally formed but will likely be destroyed by interaction with the hot plasma.
Outlook – The Crab Nebula

HST/Hester et al.  Herschel/PACS