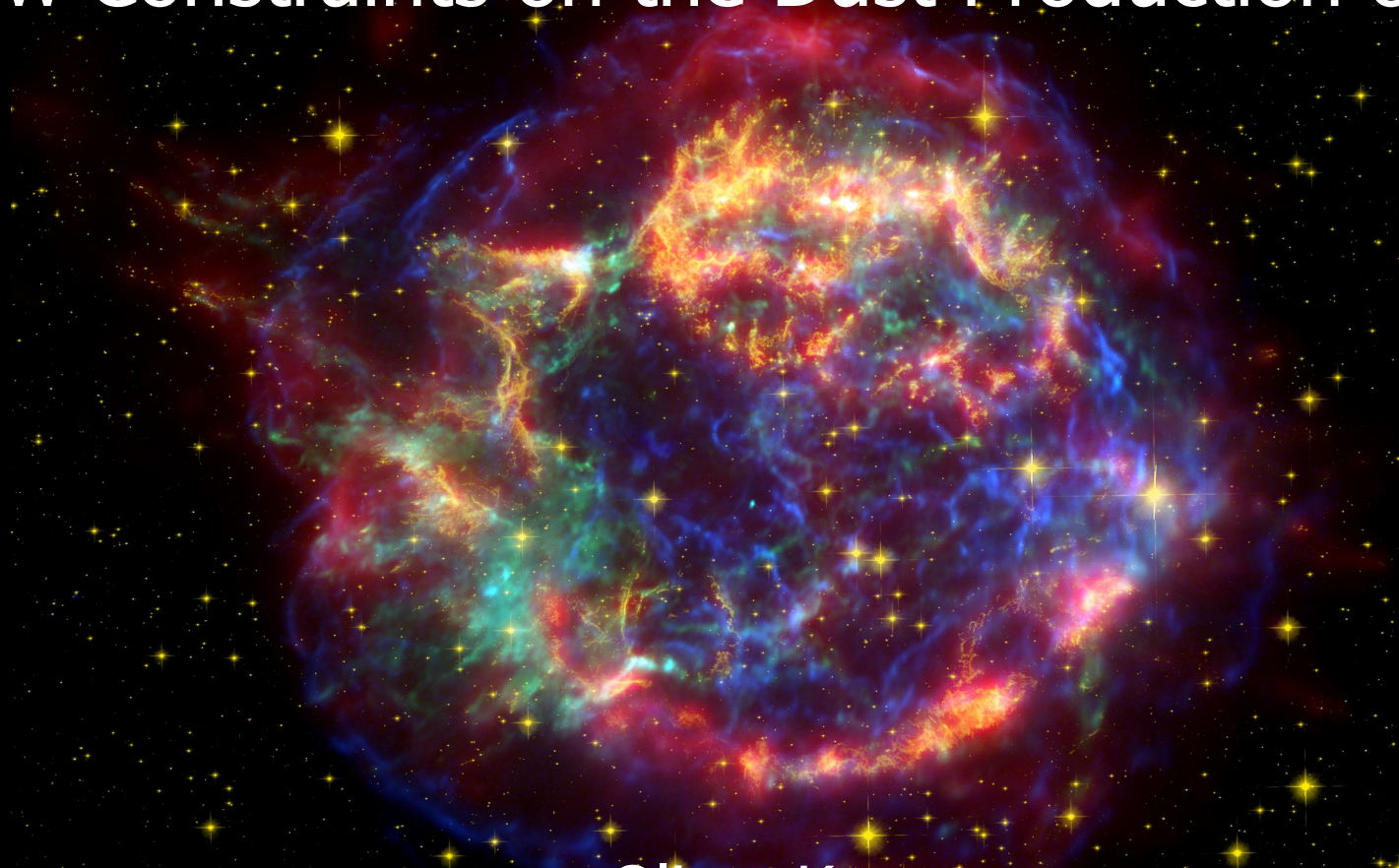
Herschel Imaging of Galactic Supernova Remnants - New Constraints on the Dust Production of SNe



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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) Isotopal composition of presolar grains (Clayton 1982)

- However, yield and composition are much under debate.

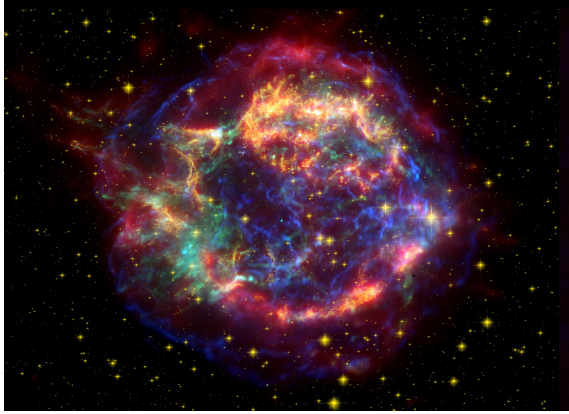
  - Observations confused by IR echoes / ISM dust
  - Dust destruction by SN shocks and UV/optical flash

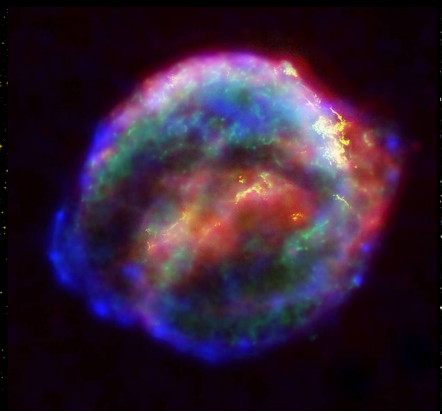
- 0.1-1 $M_{\odot}$ of dust per SN is required to form to explain large dust content ($>10^8 M_{\odot}$) and rapid enrichment at high-z galaxies (Morgan & Edmunds 2003; Maiolino et al. 2006; Dwek et al. 2007)

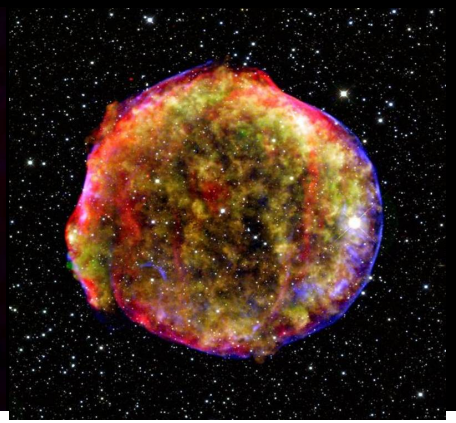
SNR targets of the MESS Key Program

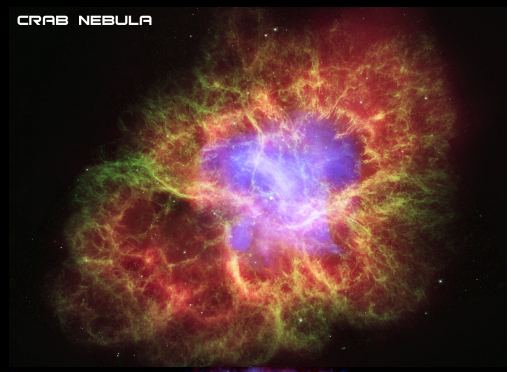
~ 1680	IIb	(Cas A)
1604	Ia (?)	(Kepler)
1572	Ia	(Tycho)
1181 (?)	II (pulsar)	(3C58)
1054	II (pulsar)	(Crab)

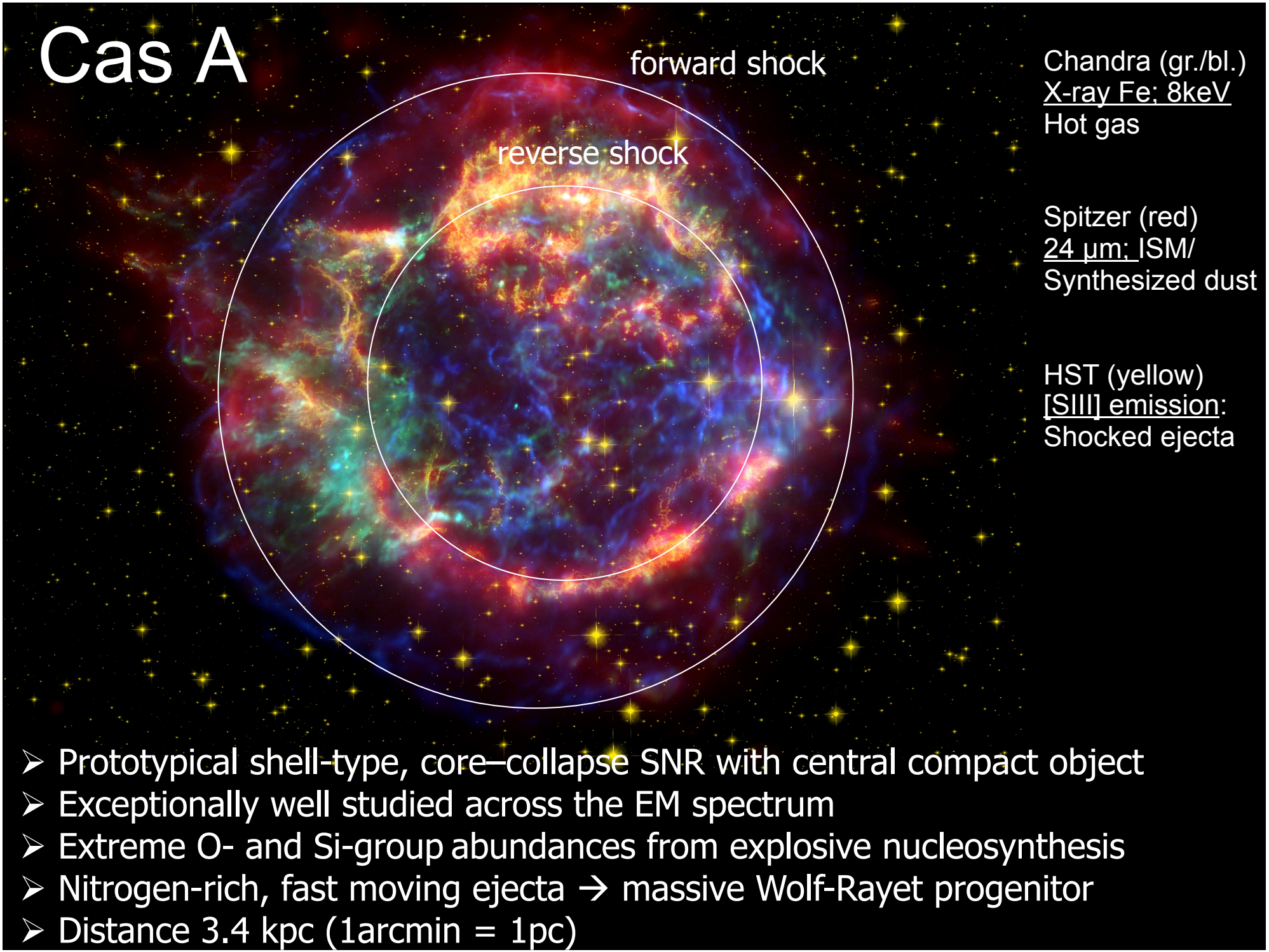
- nearby and young - swept-up ISM mass low
- Herschel imaging / spectroscopy



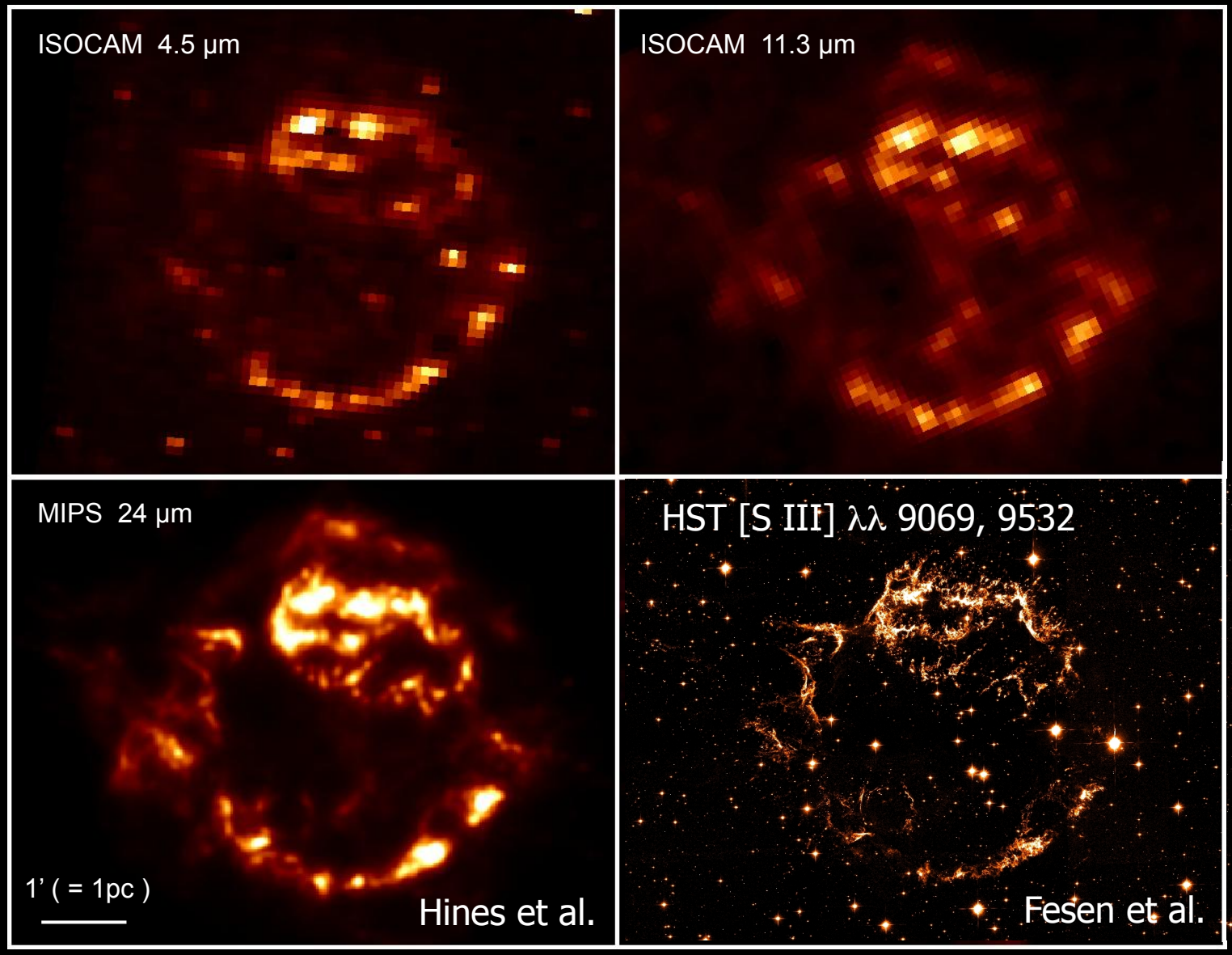






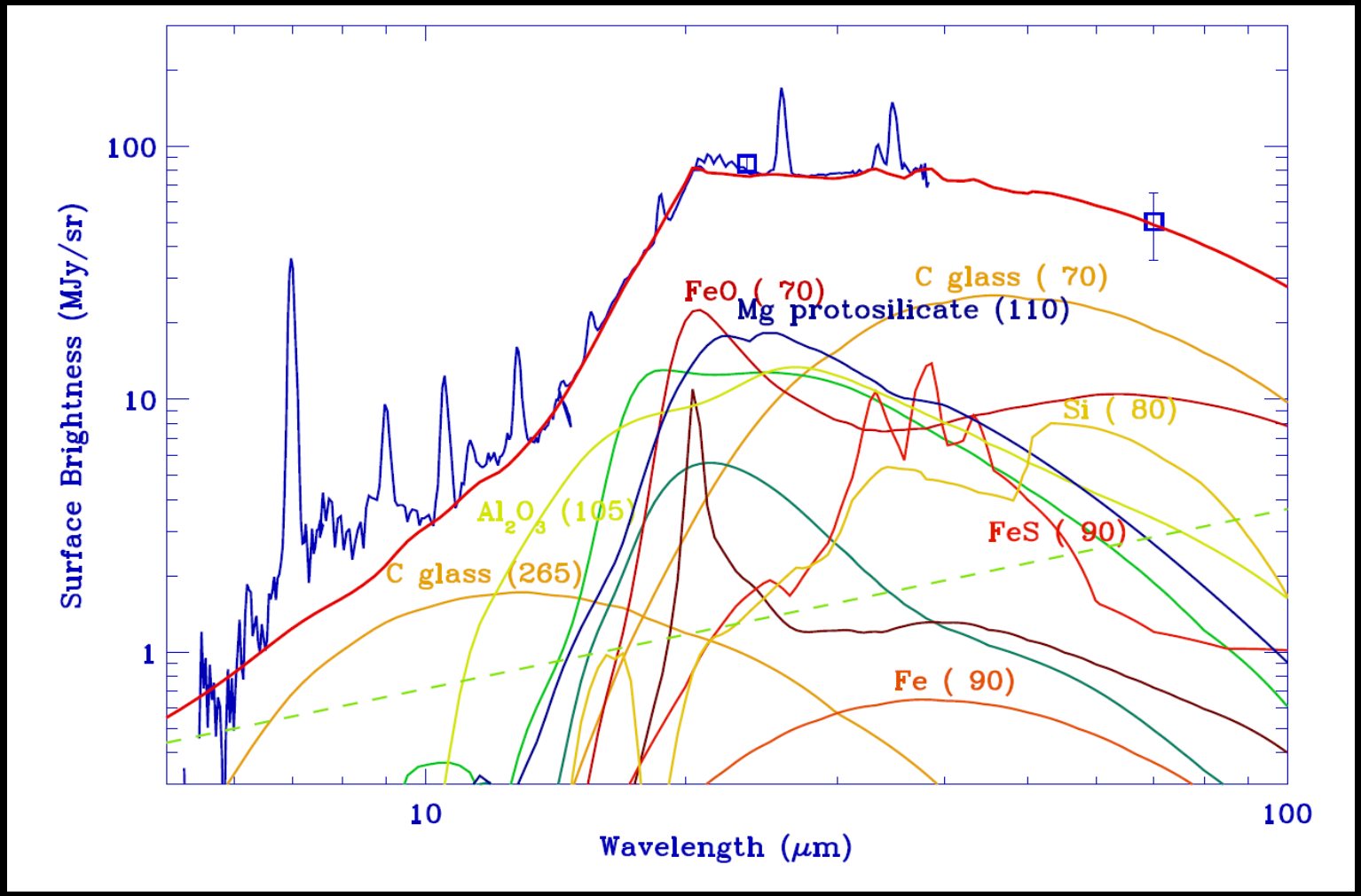

Cas A
forward shock
reverse shock
Chandra (gr./bl.)
X-ray Fe; 8keV
Hot gas
Spitzer (red)
24 μm; ISM/
Synthesized dust
HST (yellow)
[SIII] emission:
Shocked ejecta
➢ Prototypical shell-type, core–collapse SNR with central compact object
➢ Exceptionally well studied across the EM spectrum
➢ Extreme O- 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: 8×10^{-5} - 3×10^{-3} $M_{\odot}$ warm (80-300K) dust within Cas A
(Arendt, Dwek & Moseley 1999; Douvion 2001; Hines 2004)

(Warm) dust mass and composition

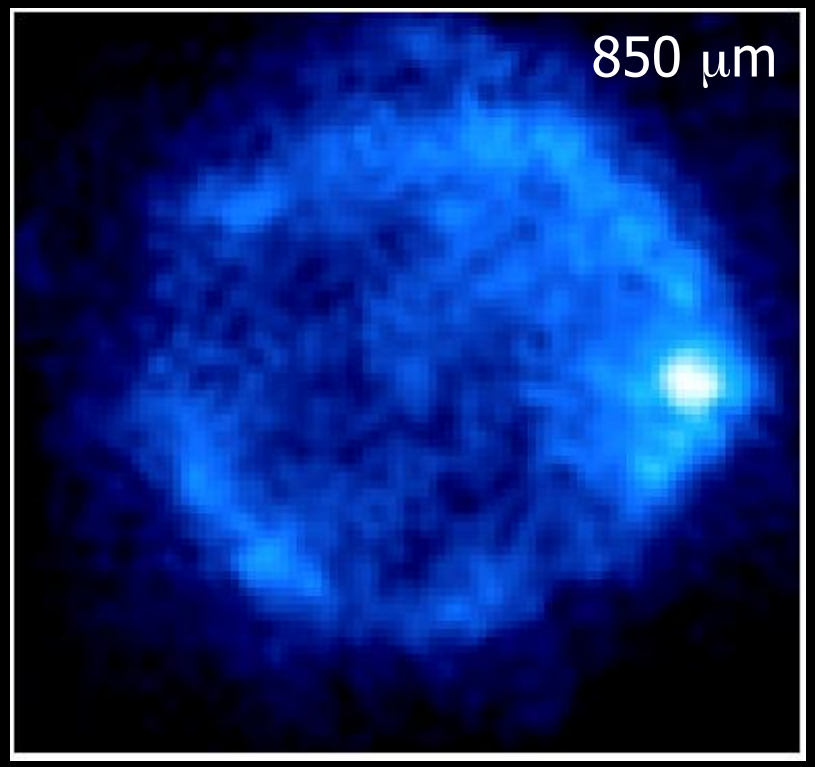


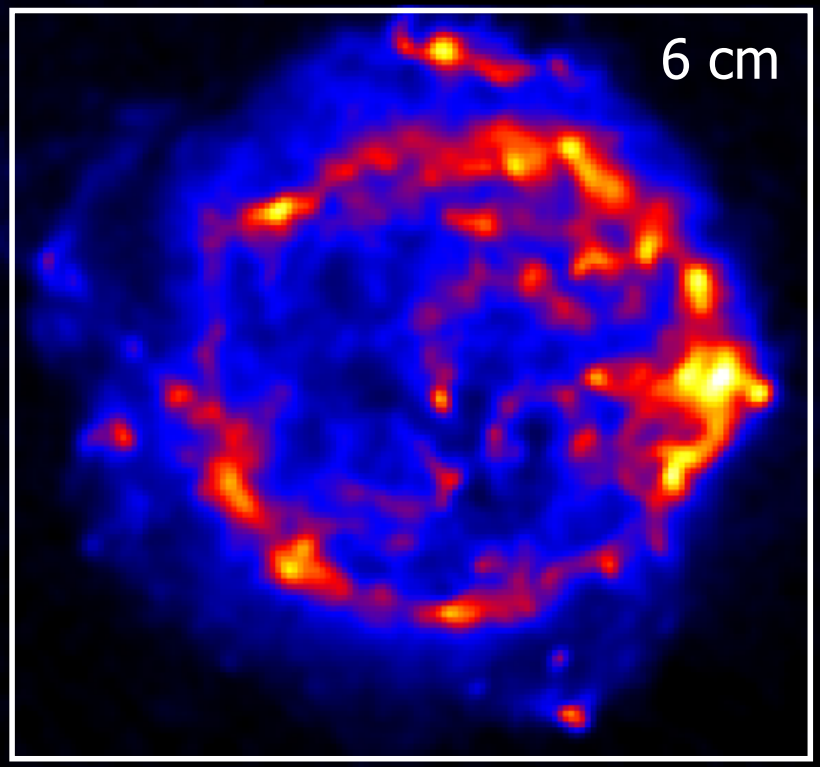
Spitzer/IRS decomposition by Rho et al. (2008)

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



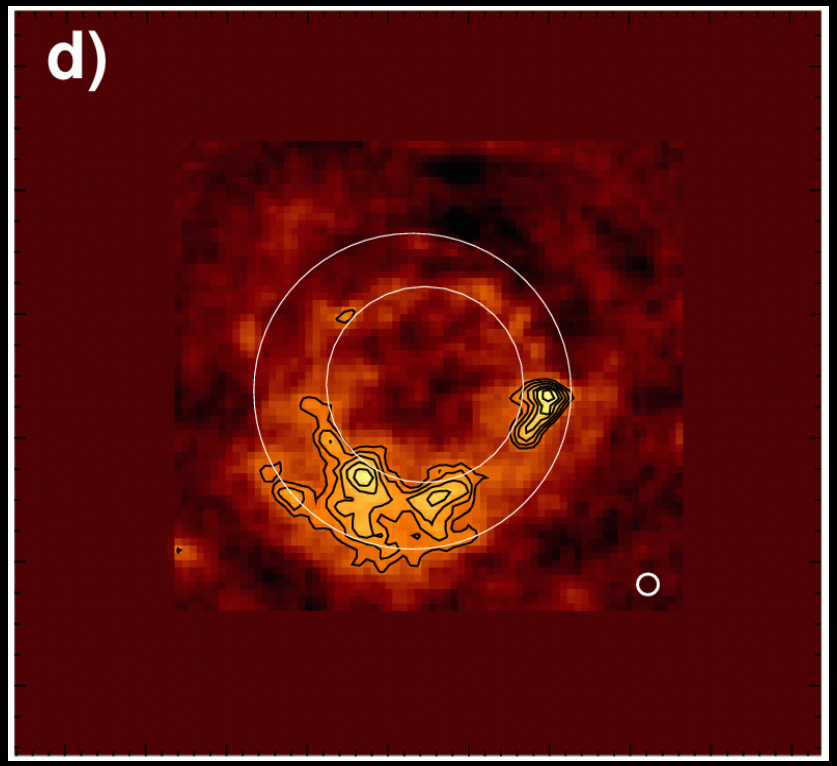


Dunne et al. 2003

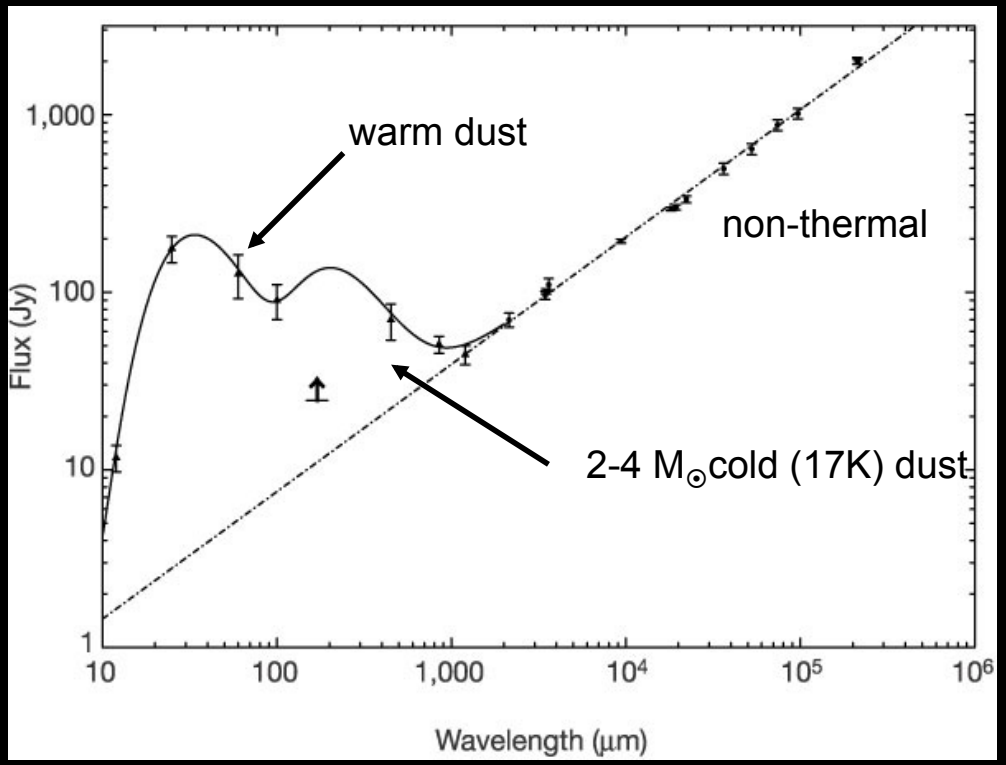
Submillimeter excess in the north highly polarized (Dunne el al. 2008)

SCUBA observations – Cold dust in Cas A

850 μm, synchrotron-subtracted



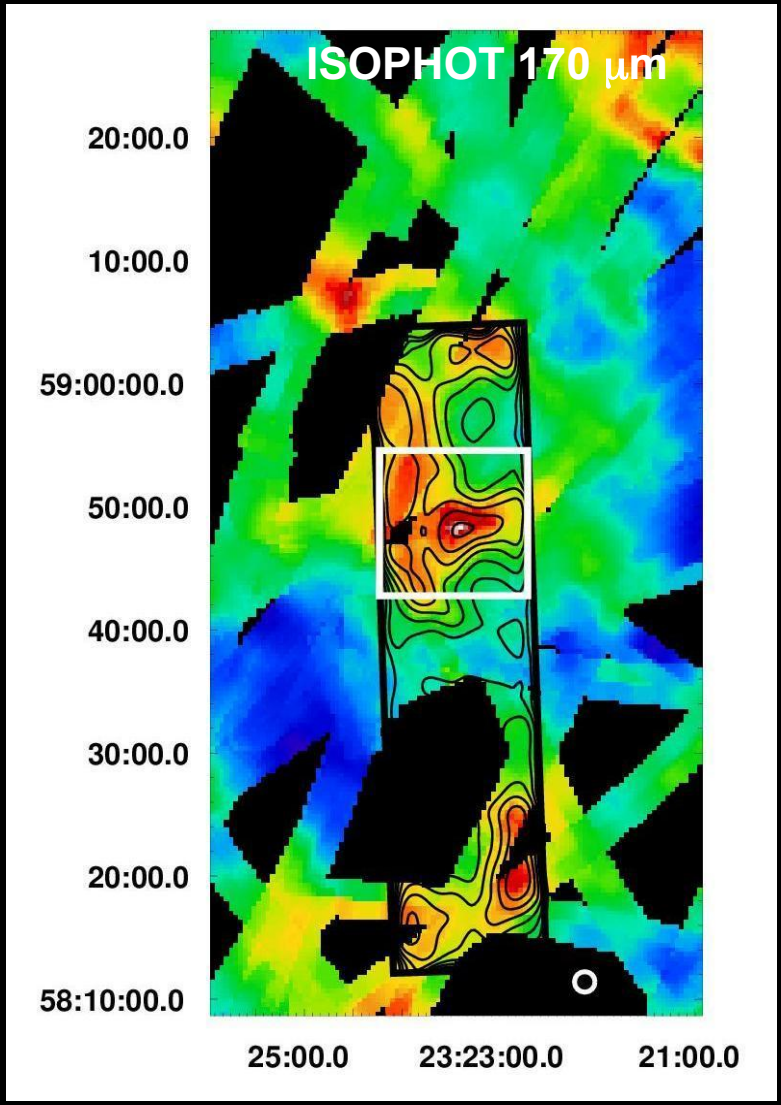
Spectral energy distribution

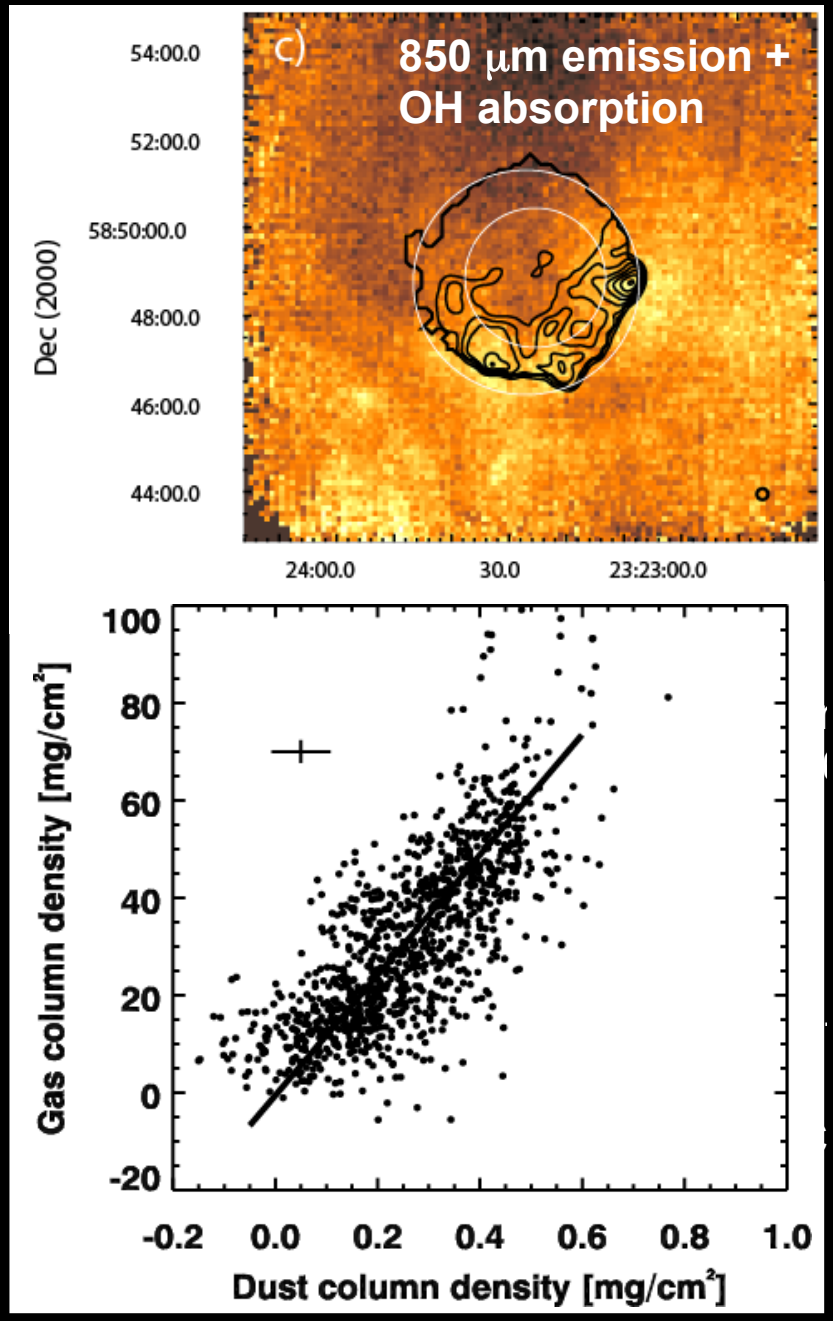


Dunne et al. 2003

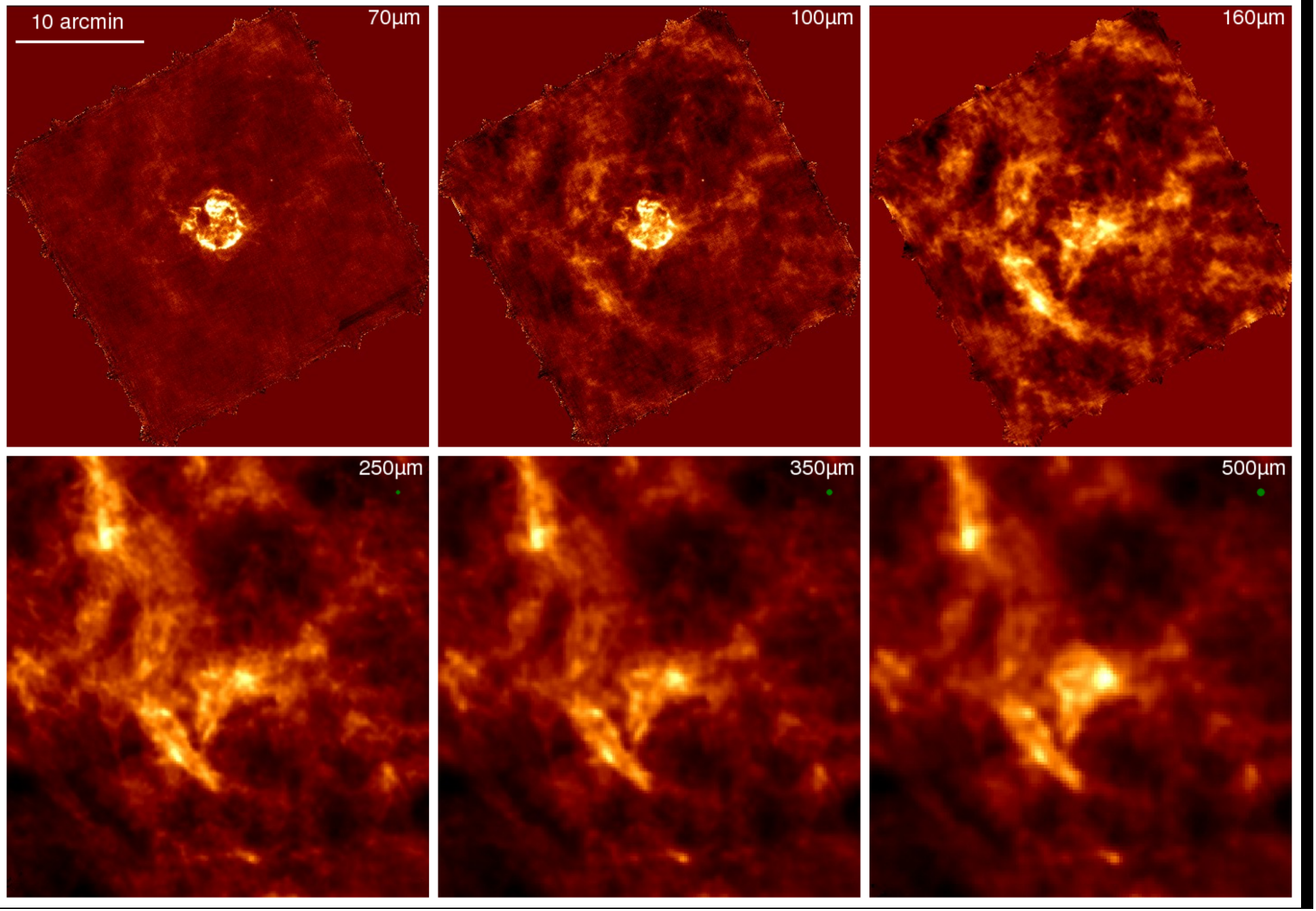
Submillimeter excess in the north highly polarized (Dunne el al. 2008)

ISM contamination toward Cas A

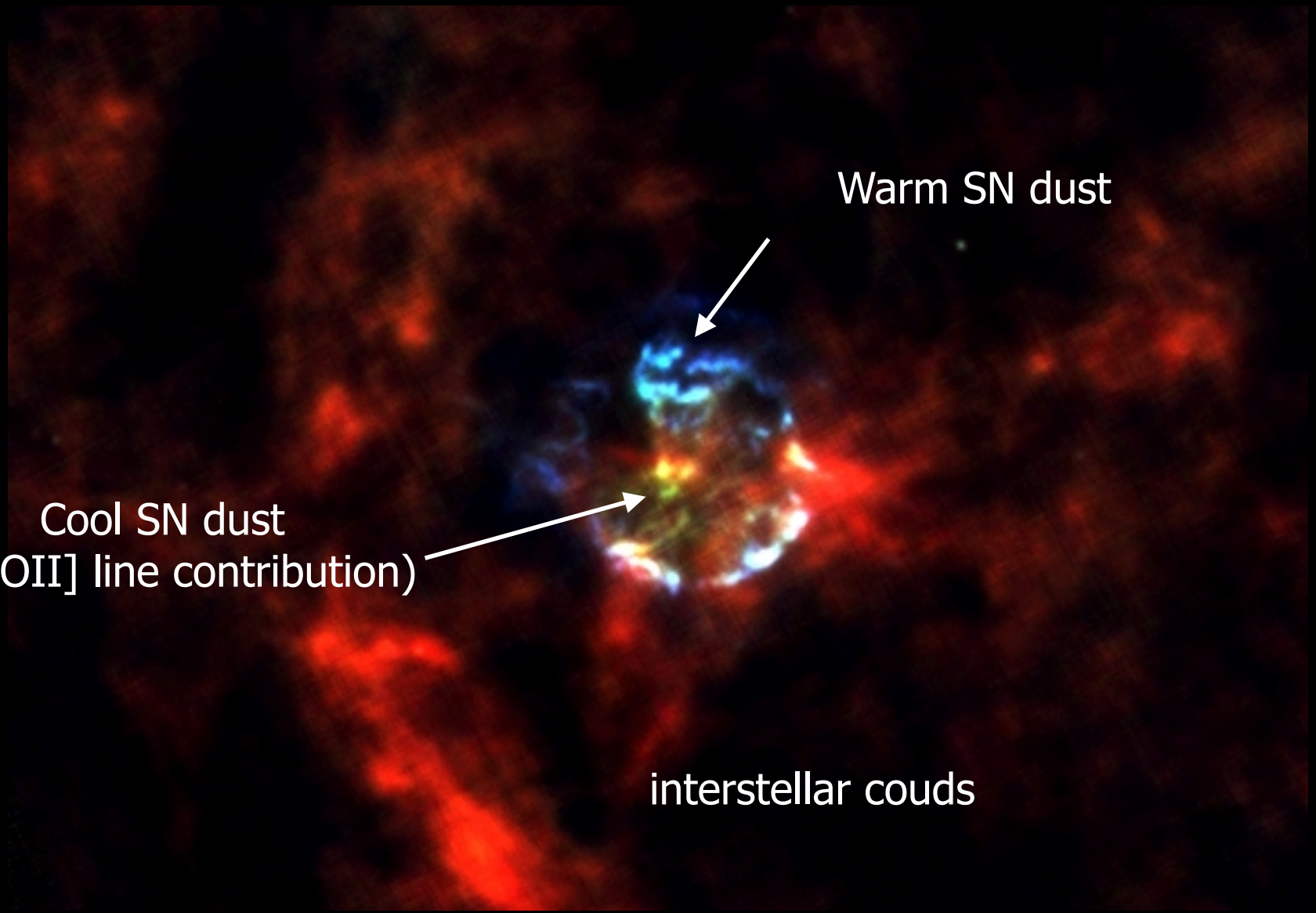




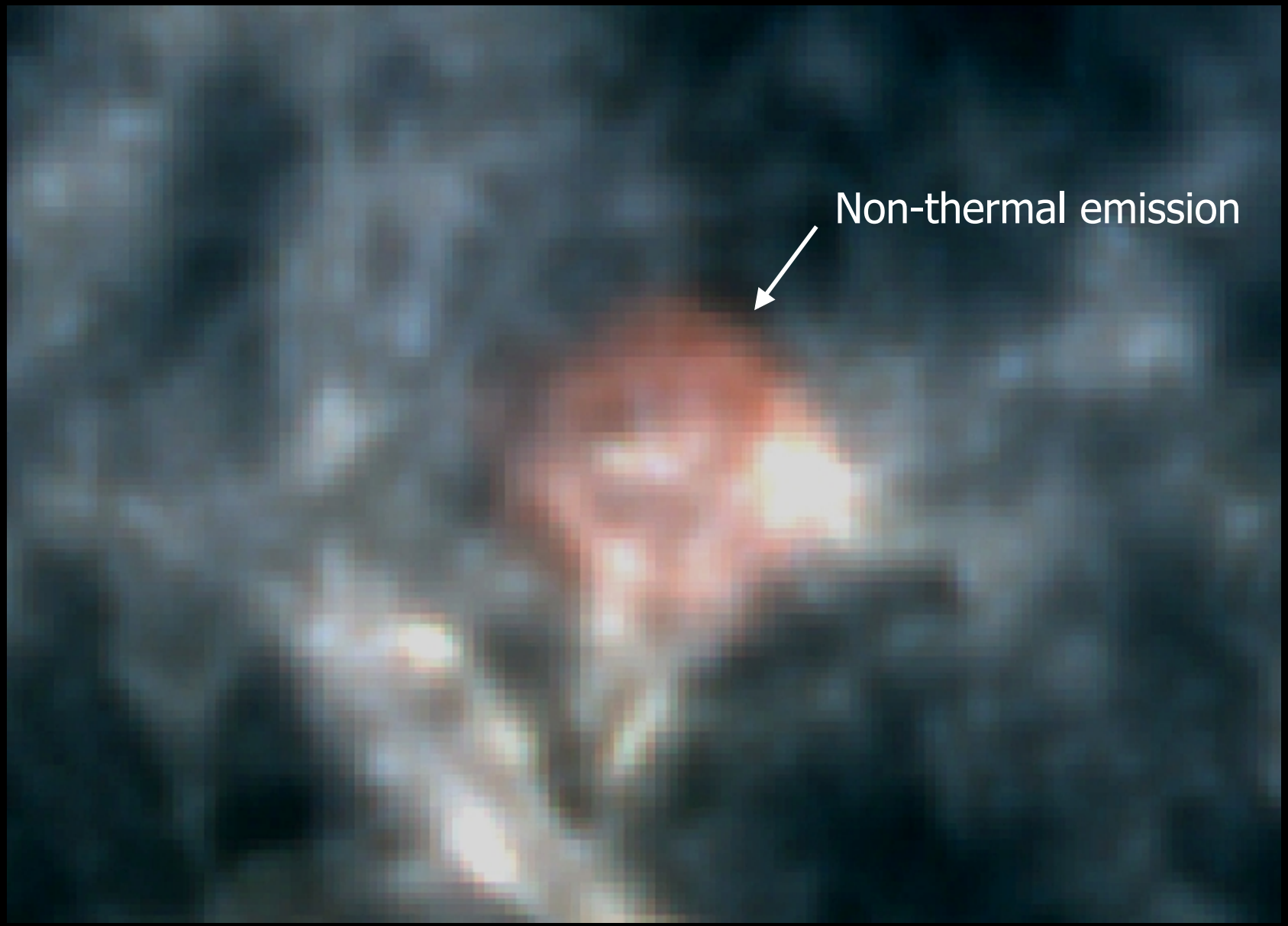
Cas A SDP observations



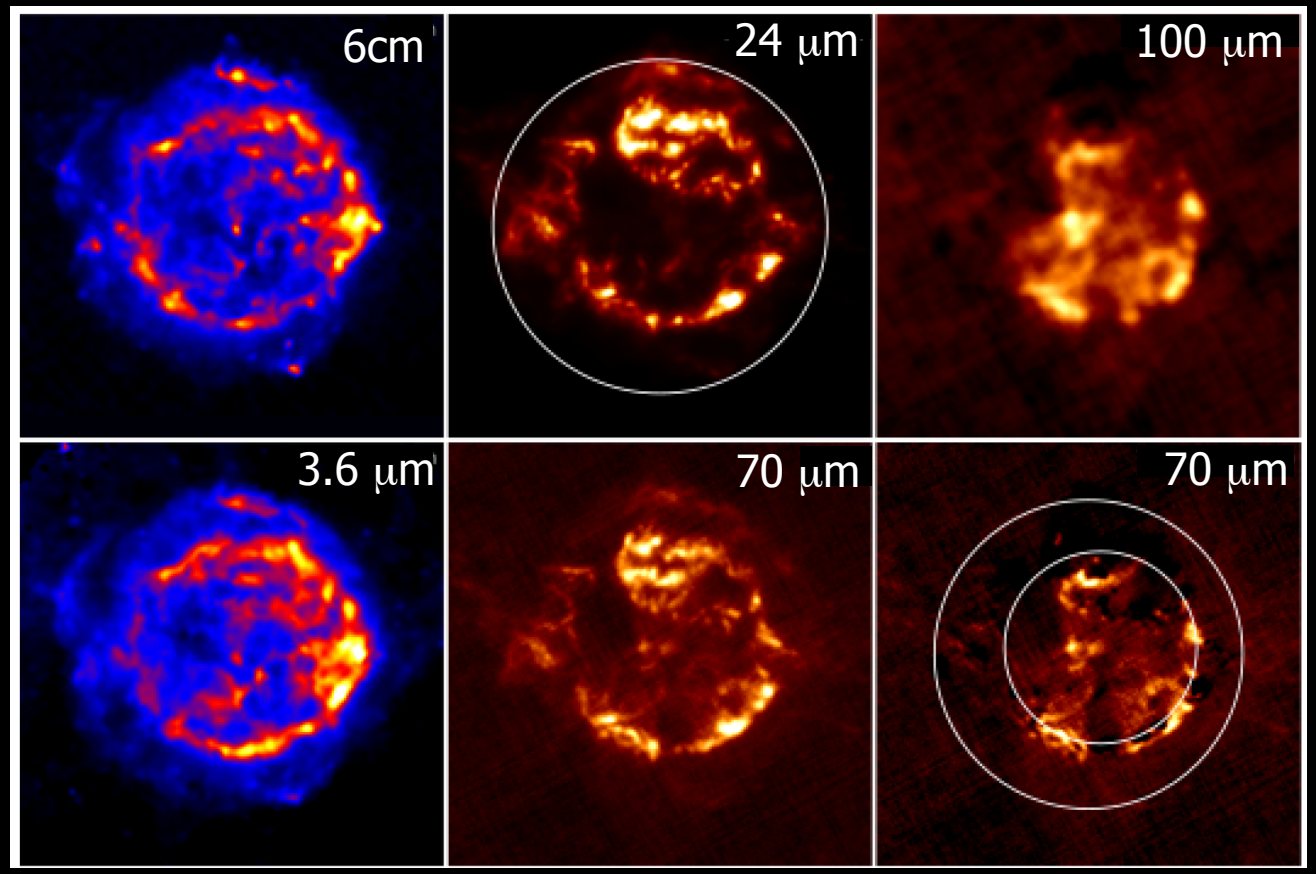
PACS 70,100,160 μm composite



SPIRE 250, 350, 500 μm composite



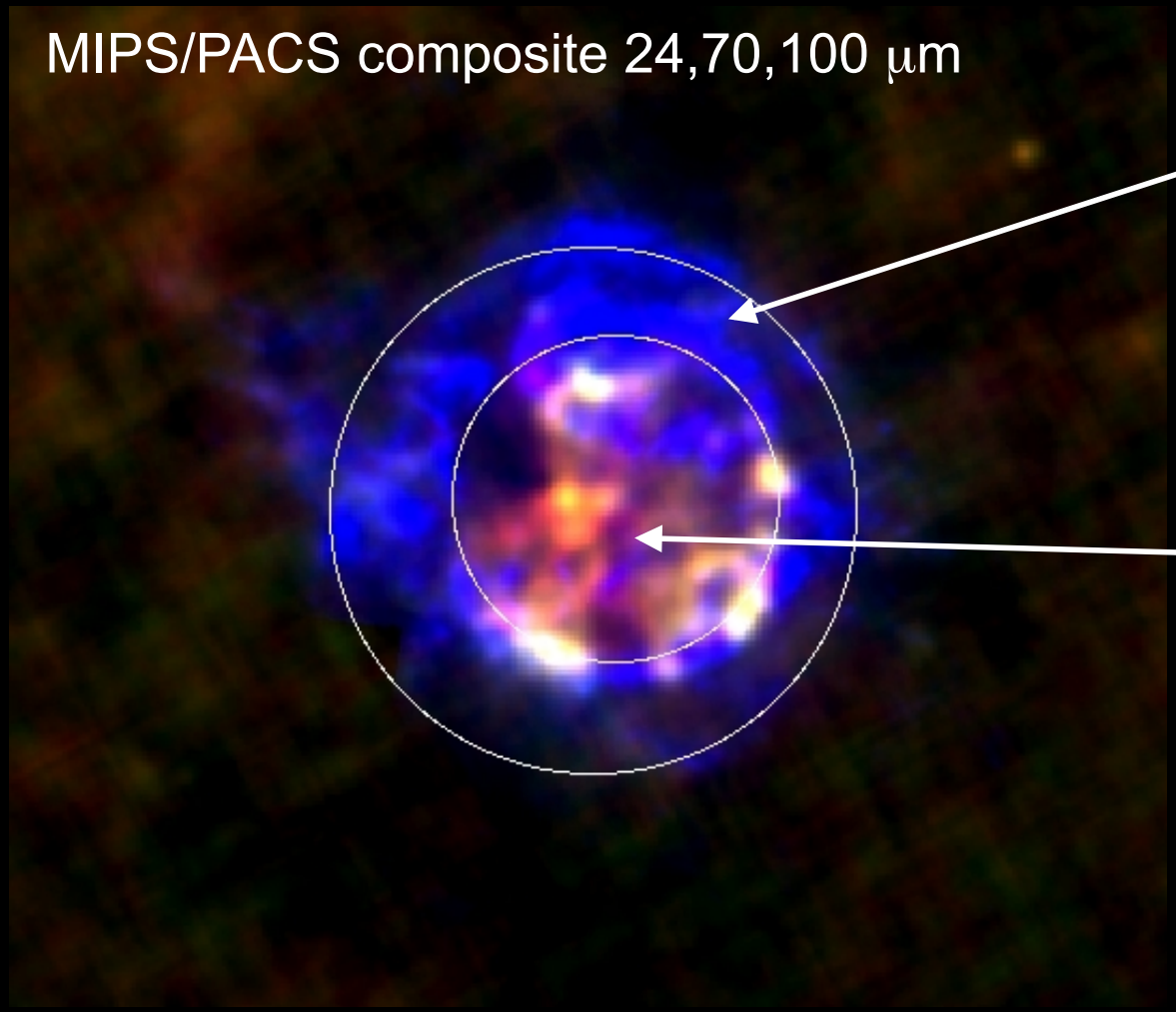
Emission component separation



Non-thermal Warm SN dust Cool SN dust

ISM →

Herschel SDP results



shocked warm dust
(3×10^{-3} $M_\odot$ - T ~ 80 K)

unshocked cool dust
(0.075 $M_\odot$ - T ~ 35 K)

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

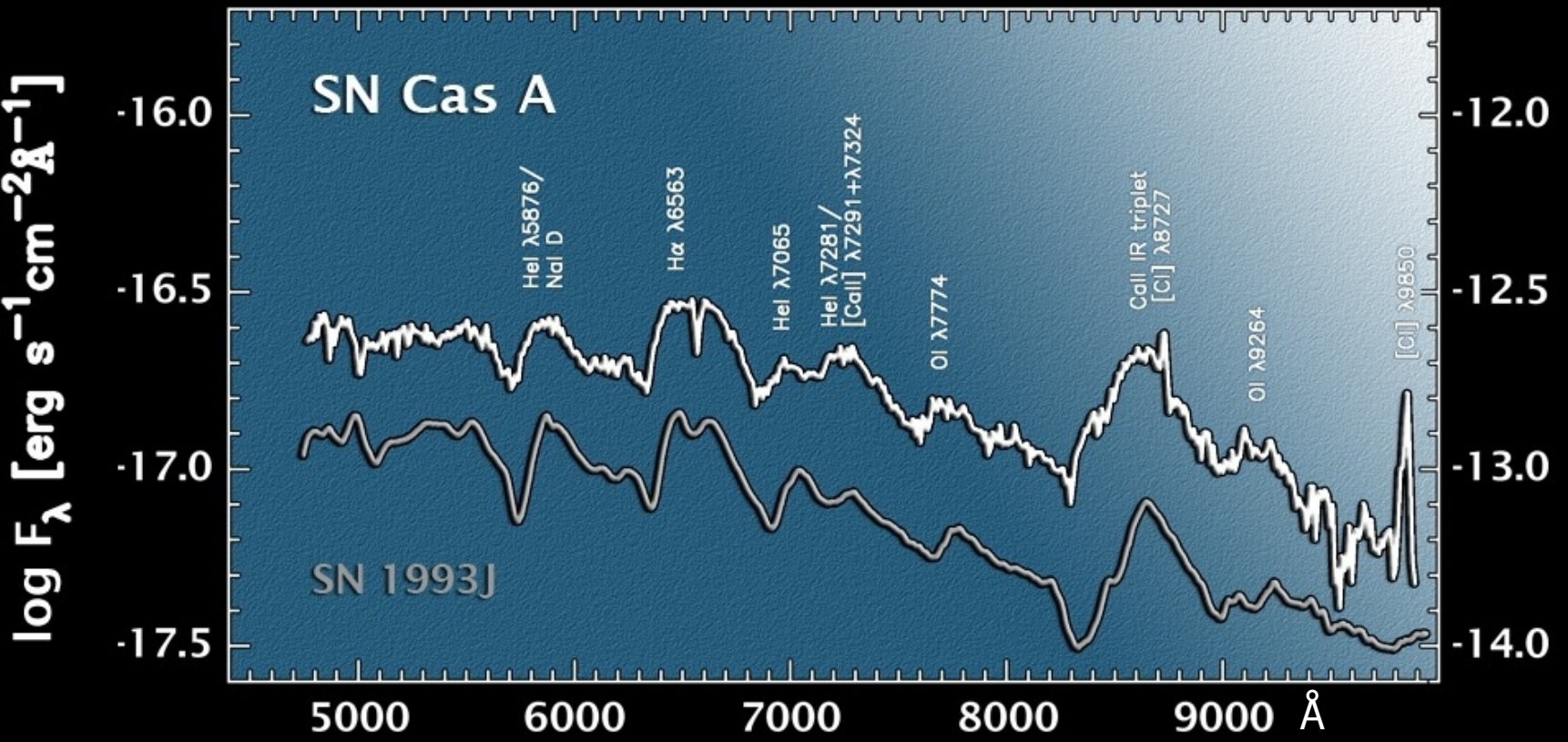
- First high-resolution images of the cool dust component
- Previously inferred by Tuffs et al. (2005; 60-200 μm ISOPHOT) and Sibthorpe et al. (2010; 65-500 μm AKARI/BLAST).

Infrared echoes near Cas A

15 arcmin = 15 pc

Krause et al. 2005
Kim et al. 2008

Optical light-echo spectroscopy - Cas A was a (rare) type IIb SN

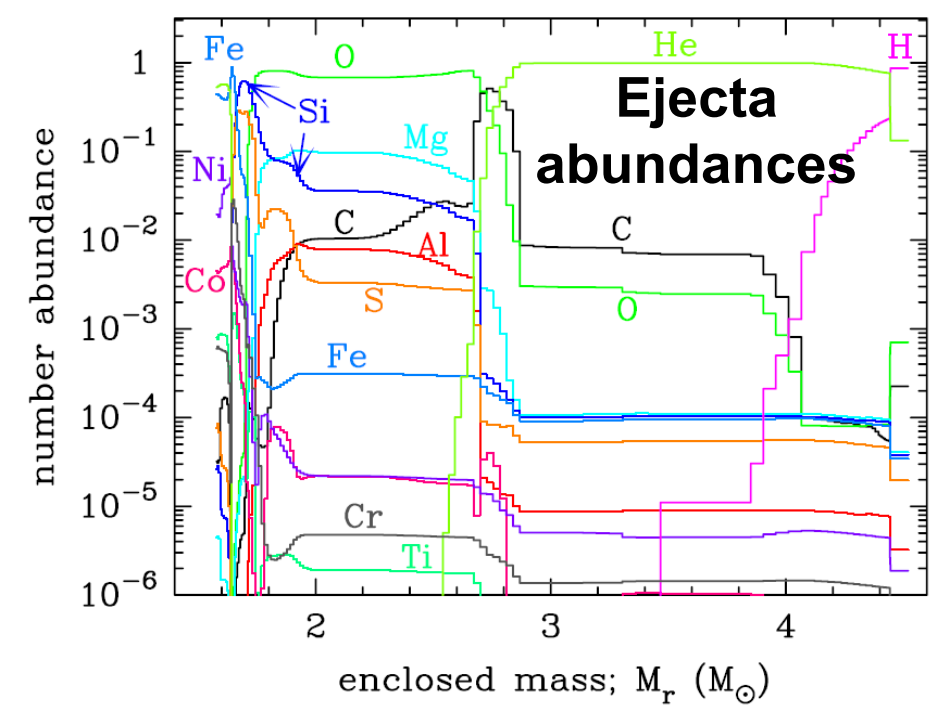


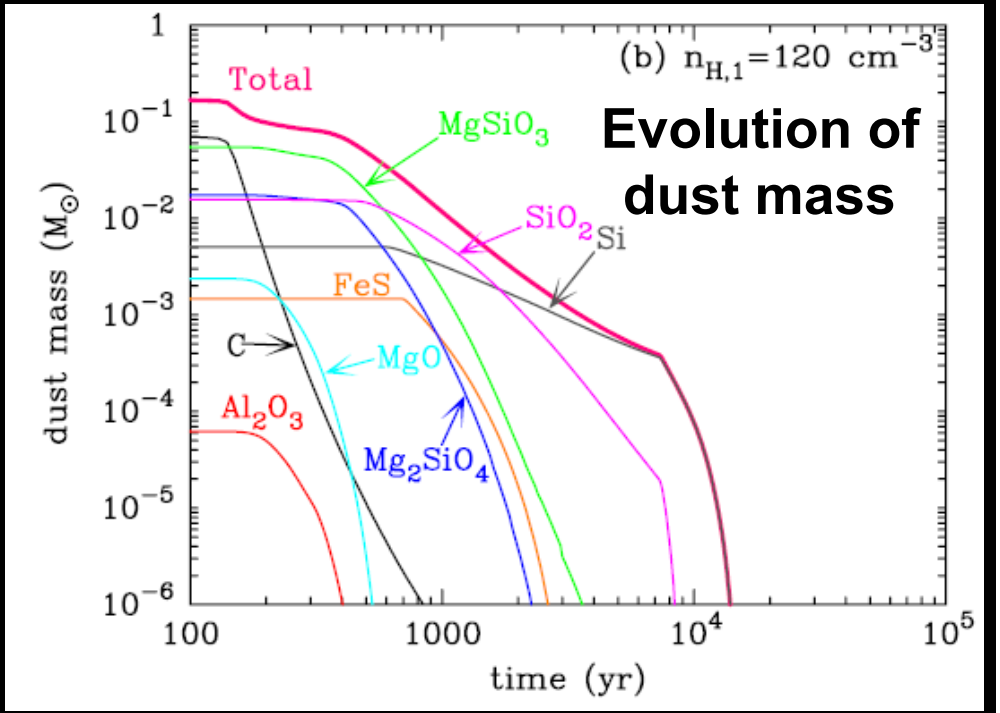
(Initial) stellar mass 13-20 $M_\odot$
Mass at explosion 3-6 $M_\odot$
Hydrogen envelope mass ~ 0.1-0.5 $M_\odot$
Core mass ~ 3-5 $M_\odot$
Total ejecta mass 1-2 $M_\odot$

Krause et al. 2008

Dust formation and evolution in a stripped-core, type IIb SN

Nozawa et al. 2010



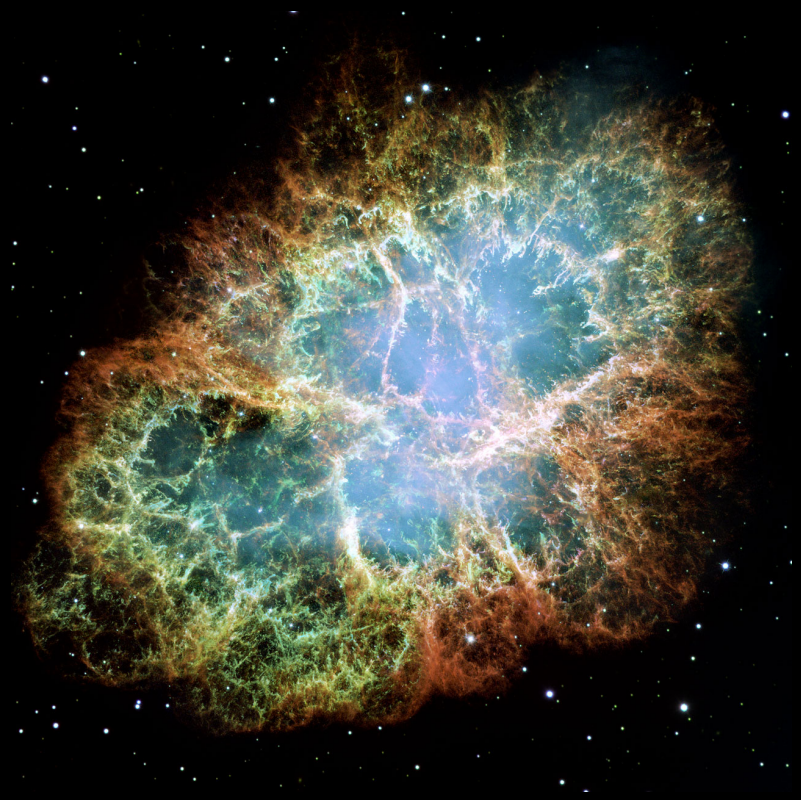


- Nucleation calculations yield initially 0.17 $M_\odot$ of newly synthesized dust
- Small envelope mass → early arrival of the reverse shock and strong dust destruction by sputtering
- Currently 0.008 $M_\odot$ of shock-heated warm dust and 0.072 $M_\odot$ of unshocked cool dust in the remnant's interior
- 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 (~ 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