Herschel Detects a Massive Dust Reservoir in Supernova 1987A

Based on the paper published in Science express on 7th July 2011

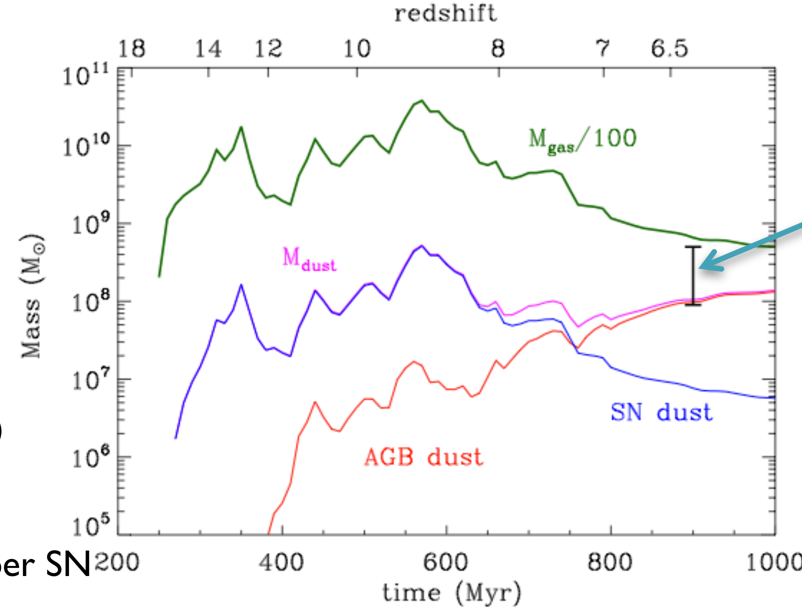
Mikako Matsuura
University College London
E. Dwek, M. Meixner, M. Otsuka, B. Babler, M. J. Barlow, J. Roman-Duval, C. Engelbracht, K. Sandstrom, M. Lakicevic, J. Th. van Loon, G. Sonneborn, G. C. Clayton, K. S. Long, P. Lundqvist, T. Nozawa, K. D. Gordon, S. Hony, P. Panuzzo, K. Okumura, K. A. Misselt, E. Montiel, M. Sauvage

This work uses the HERITAGE data, Herschel Large Program of Magellanic Survey

Importance of measuring dust formed in SNe

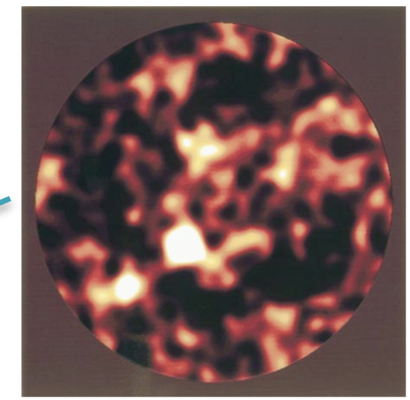
- Interest to explain the dust in high-redshift galaxies

Model of the dust evolution in galaxies



Dwek & Cherchneff (2011)

Average of 0.15 Msun dust per SN

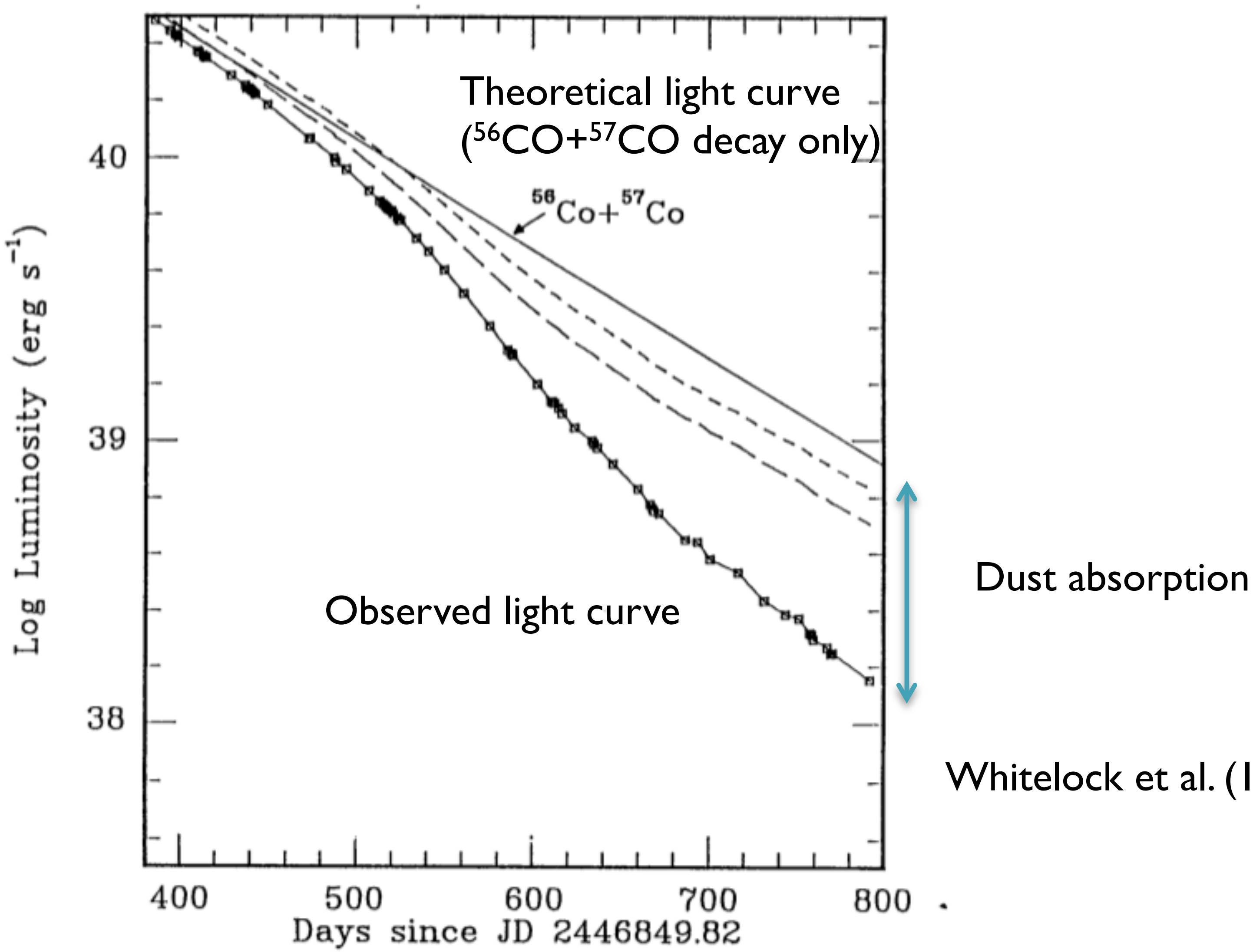


Submm galaxy
At z~6.4; ~0.4 Giga years
(e.g. Bertoldi et al. 2003)

- Dust: influence on elemental abundance analysis
- SN 1987A: proxy to test the formation of dust

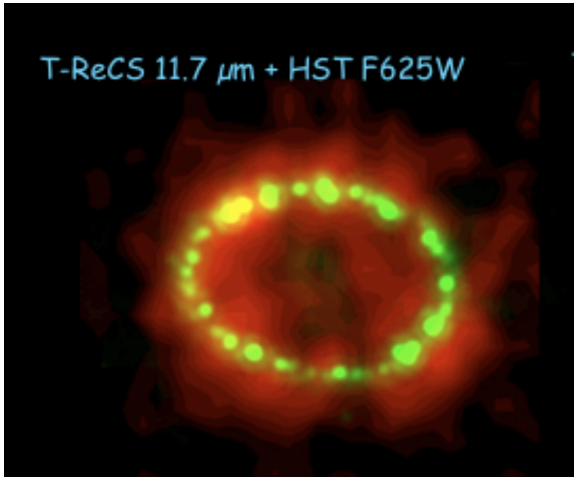
Herschel Detects a Massive Dust Reservoir in SN 1987A

SN 1987A: Evidence of dust formation in early days



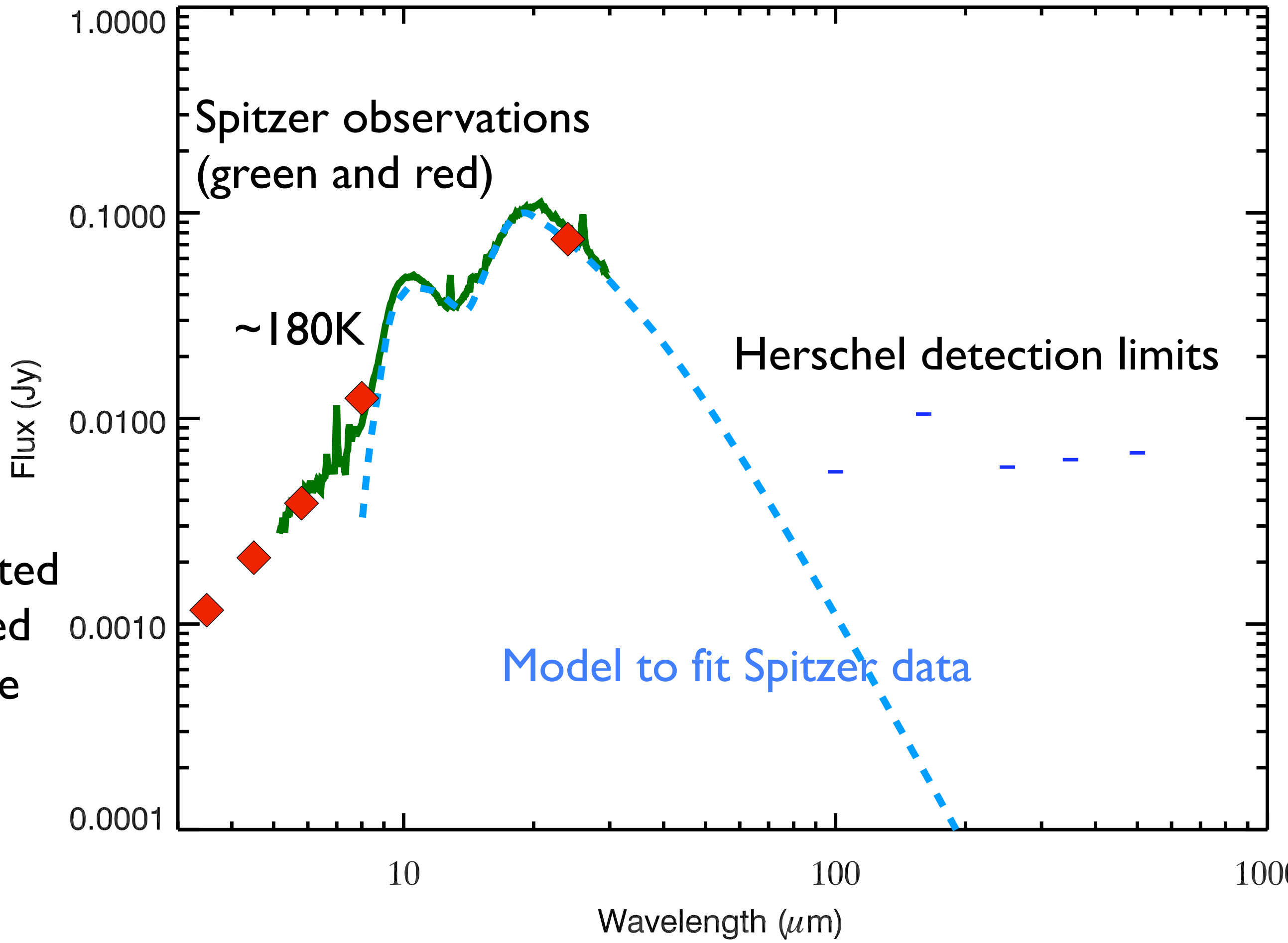
Whitelock et al. (1989)

Dust found in SN 1987A before

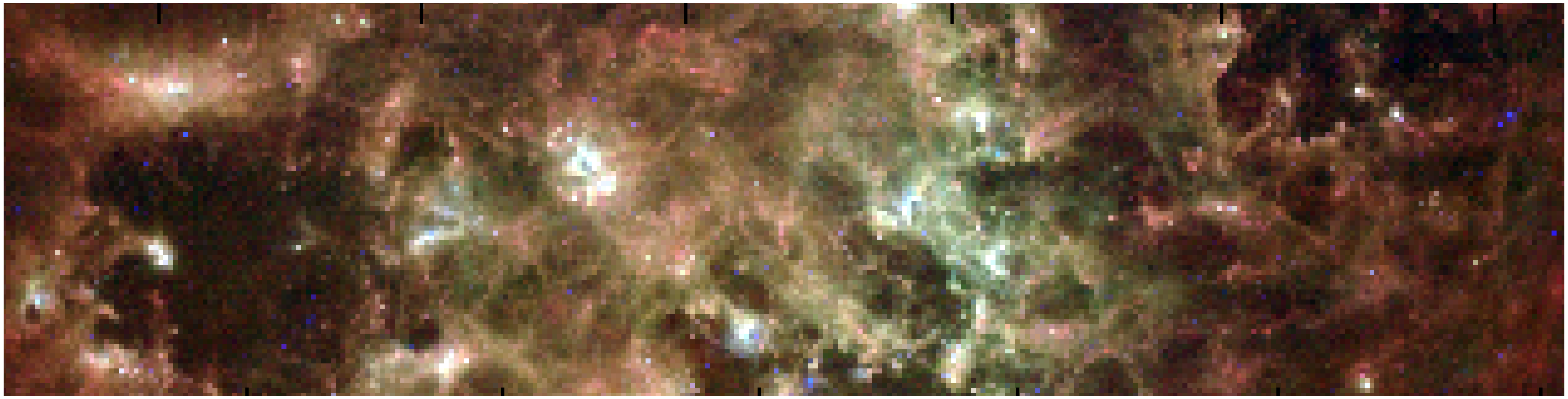


Bouchet et al. (2006)

Spitzer and Gemini have detected dust in the ring, i.e., dust formed during the red supergiant phase



Expected to be below the detection limit of the Herschel



Heritage

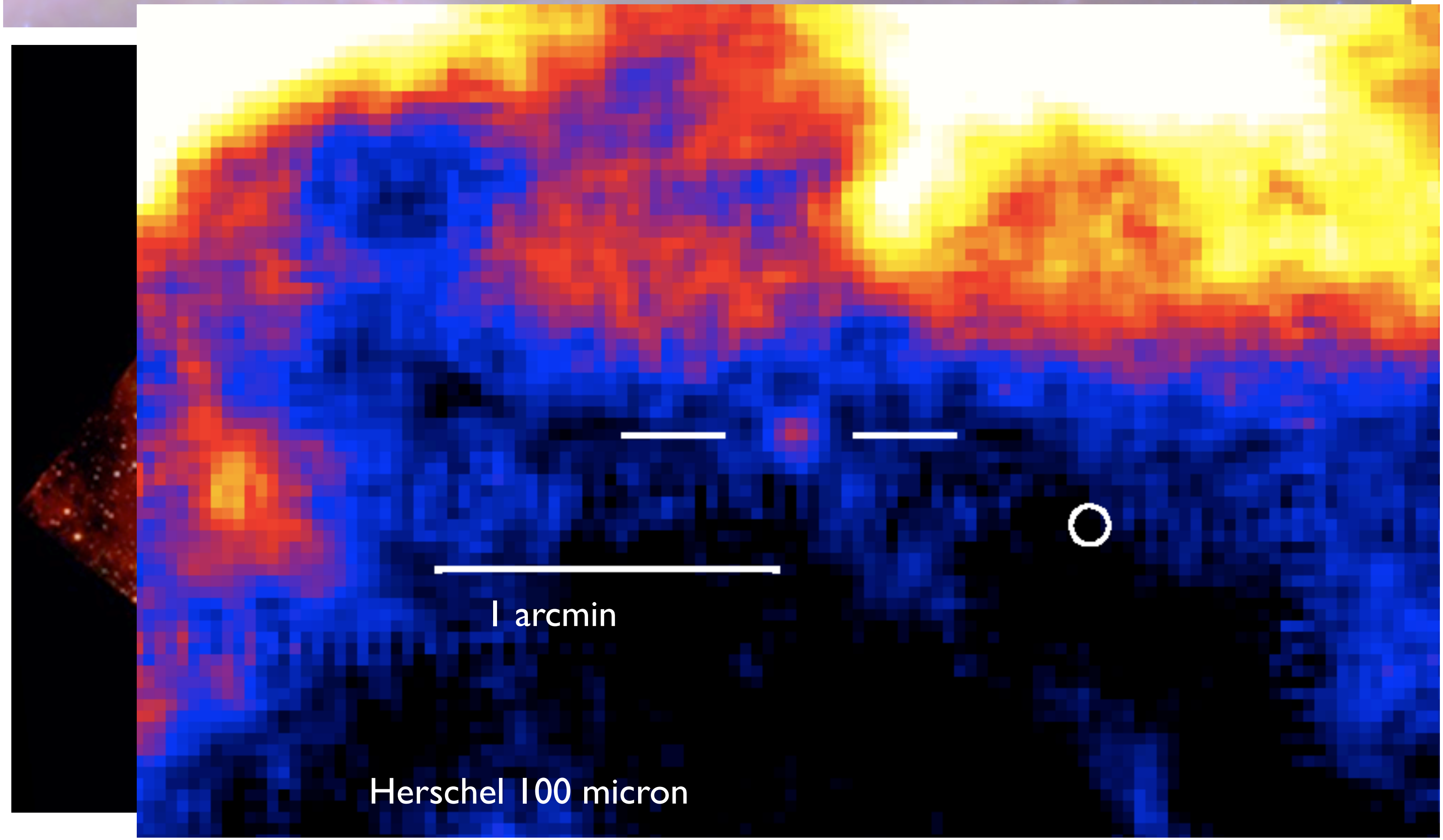
HERschel Inventory of The Agents of Galaxy Evolution: the Magellanic Cloud Survey

Meixner et al. (2010)

100, 160, 250, 350 and 500 micron imaging survey

Herschel Detects a Massive Dust Reservoir in SN 1987A

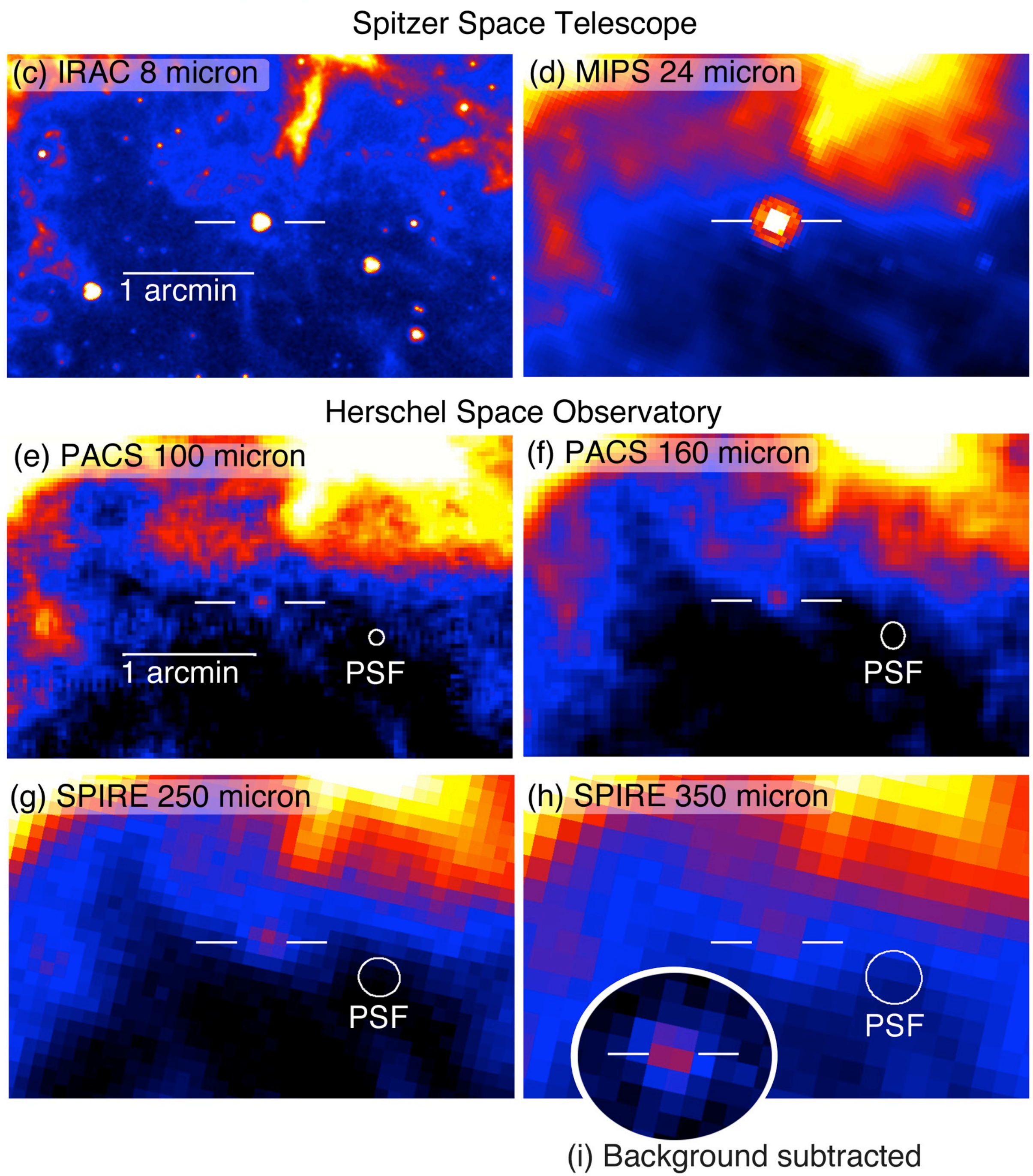
Herschel detection of SN 1987A



Herschel Detects a Massive Dust Reservoir in SN 1987A

Spitzer Space Telescope

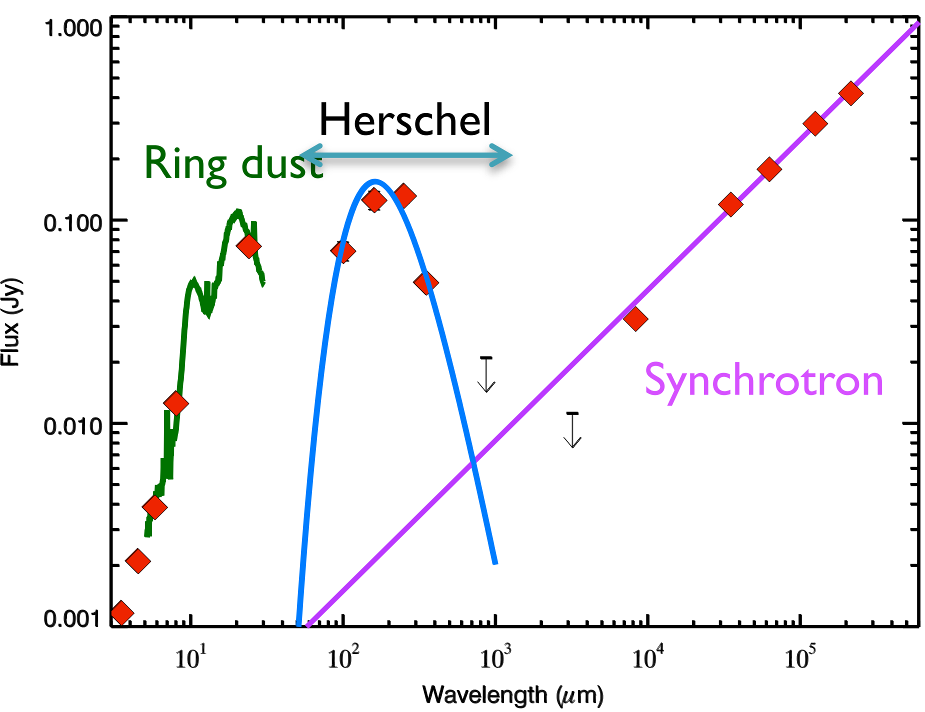
Herschel Space Observatory



Herschel Detects a Massive Dust Reservoir in SN 1987A

Possible source of far-infrared emission

- Synchrotron emission
- Emission from lines
- Dust emission



- **Expected synchrotron spectrum model**
- **Expected line intensities** from Mattila et al. (2010)
  - Much below the detected flux level

Wave (micron)	Line	Expected intensities (10^{-15} erg s^{-1} cm^{-2})
88	[OIII]	0.5
122	[NII]	1.2
158	[CII]	0.1
205	[NII]	0.2

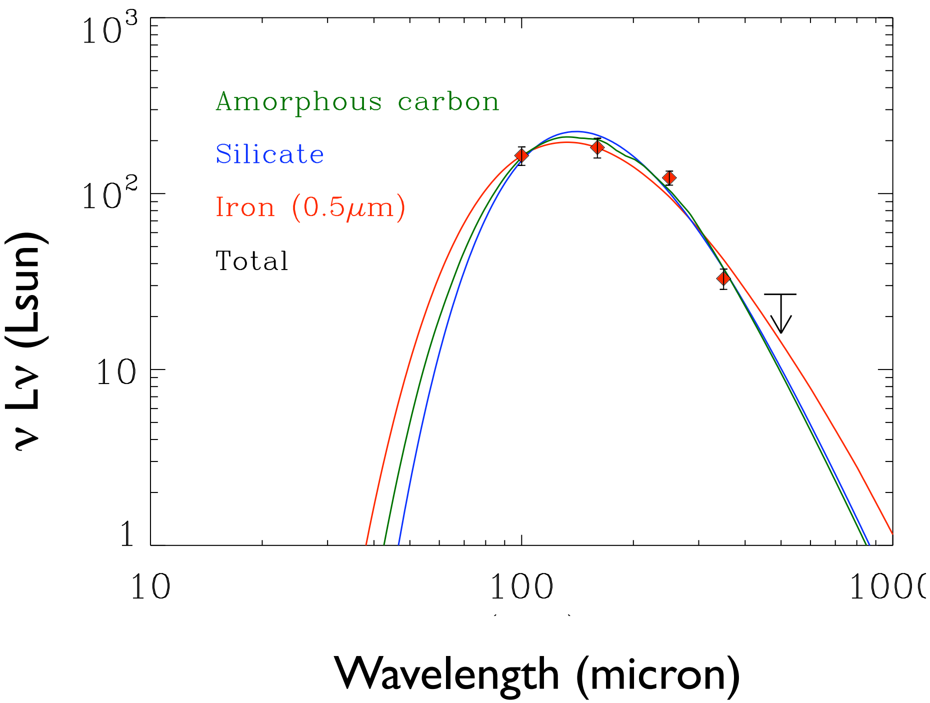
  - Line fluxes are equivalent to a 0.2 % contribution to the total Herschel in-band flux

Origin/location of the dust

- Dust formed before the SN explosion
- Ejecta : Dust formed in SN
- Ambient ISM dust

Information of dust mass and temperature needed

Estimated mass of dust with a single specie



Dust species	Dust mass (Msun)	Dust temperature (K)
Amorphous carbon	0.35	21.2
Silicate	2.4	17.7
Iron (a=0.1 micron)	3.4	19.2
Iron (a=0.5 micron)	0.34	25.7

Origin/location of the dust

- Ambient ISM dust
- Dust formed before the SN explosion
- Ejecta : Dust formed in SN

- SN sweeps-up dust from the ambient ISM
  - Estimated mass of ISM dust for SN 1987A is 3×10^{-6} Msun
    - 6000 km s^{-1} SN wind speed
    - 1 hydrogen per cm^3
    - Gas-to-dust ratio of 300
  - Herschel estimate of more than 0.4 Msun dust
- Unlikely to be ISM dust

Herschel Detects a Massive Dust Reservoir in SN 1987A

Origin/location of the dust

- Ambient ISM dust
- Dust formed the SN explosion
- Ejecta : Dust formed in SN

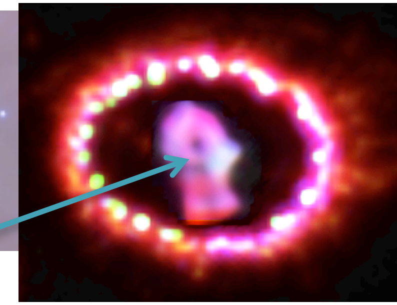
- Dust formed during red-supergiant (RS) phase
  - Progenitor of SN 1987A ejected 8 Msun of the gas during the RS phase
  - This suggests about 0.03 Msun of silicate dust formed in the RS
  - Required silicate dust to explain Herschel flux is 2.4 Msun
- It is unlikely that the dust is formed during RS phase

Origin/location of the dust

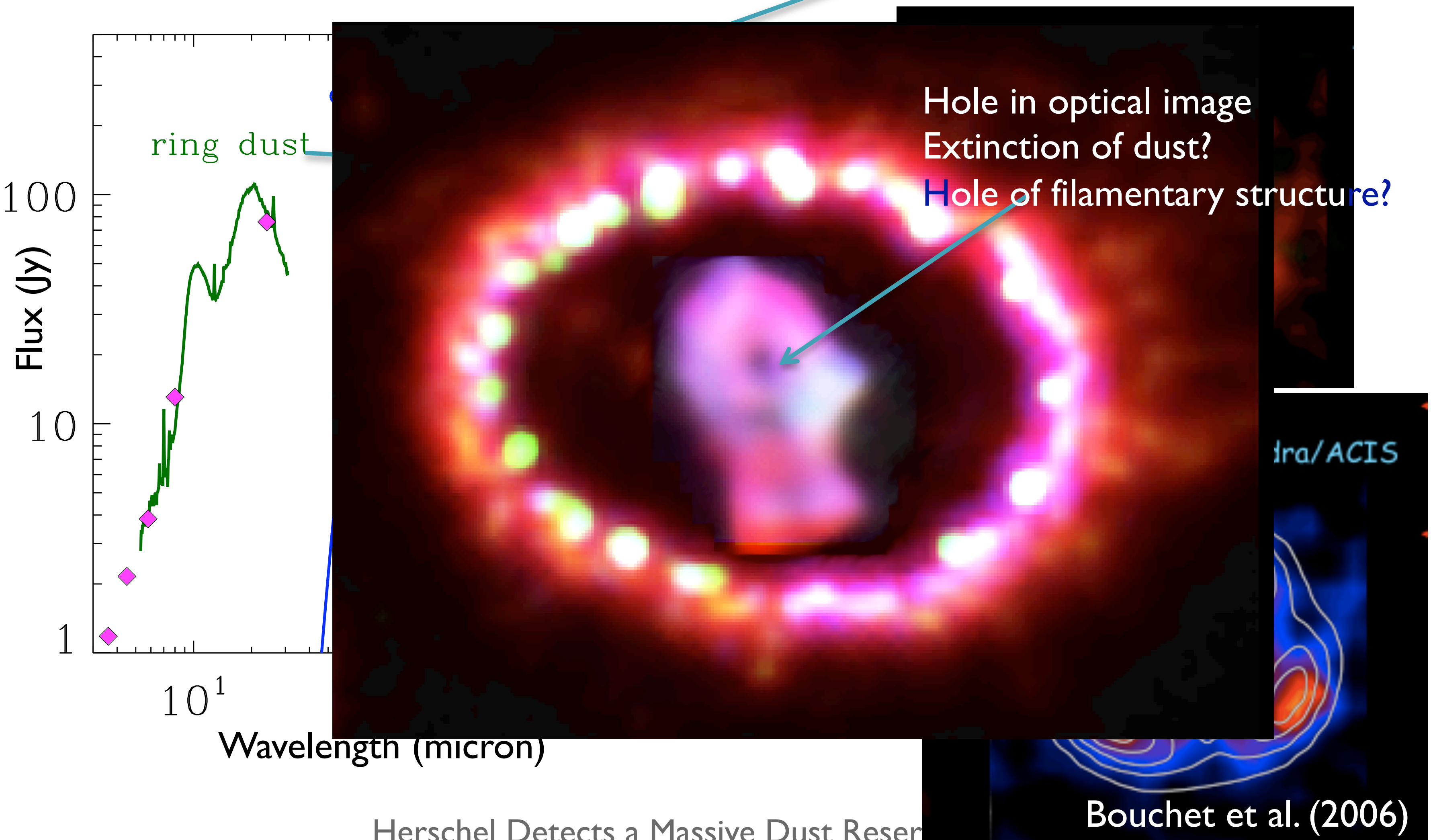
- Ambient ISM dust
- Dust formed the SN explosion
- Ejecta : Dust formed in SN

- Dust observed by the Herschel needs to be dust formed in the ejecta
- Some elements synthesized in the SN are condensed into dust

Dust in SN 1987A



HST optical



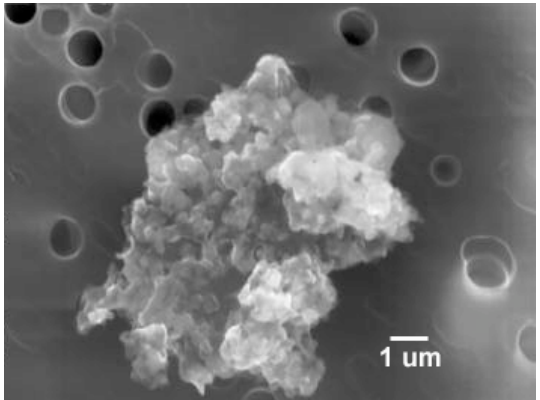
Herschel Detects a Massive Dust Reser

Origin of the cold dust

- The maximum dust mass is restricted by the mass of major refractory elements

Dust compositions

- Oxides / silicate
  - SiO_2
  - Olivines : $Mg_{2x}Fe_{(2-2x)}SiO_4$
  - Pyroxenes : $Mg_xFe_{1-x}SiO_3$
- Metalic iron
  - Fe
- Carbonaceous dust
  - Graphite : C
  - Amorphous : C



Origin of the cold dust

- The maximum dust mass is restricted by the mass of major refractory elements

Dust mass needed to fit Herschel measurements with a single specie of dust

Dust species	Dust mass (Msun)
Amorphous carbon	0.35
Silicate	2.4
Iron	<0.34

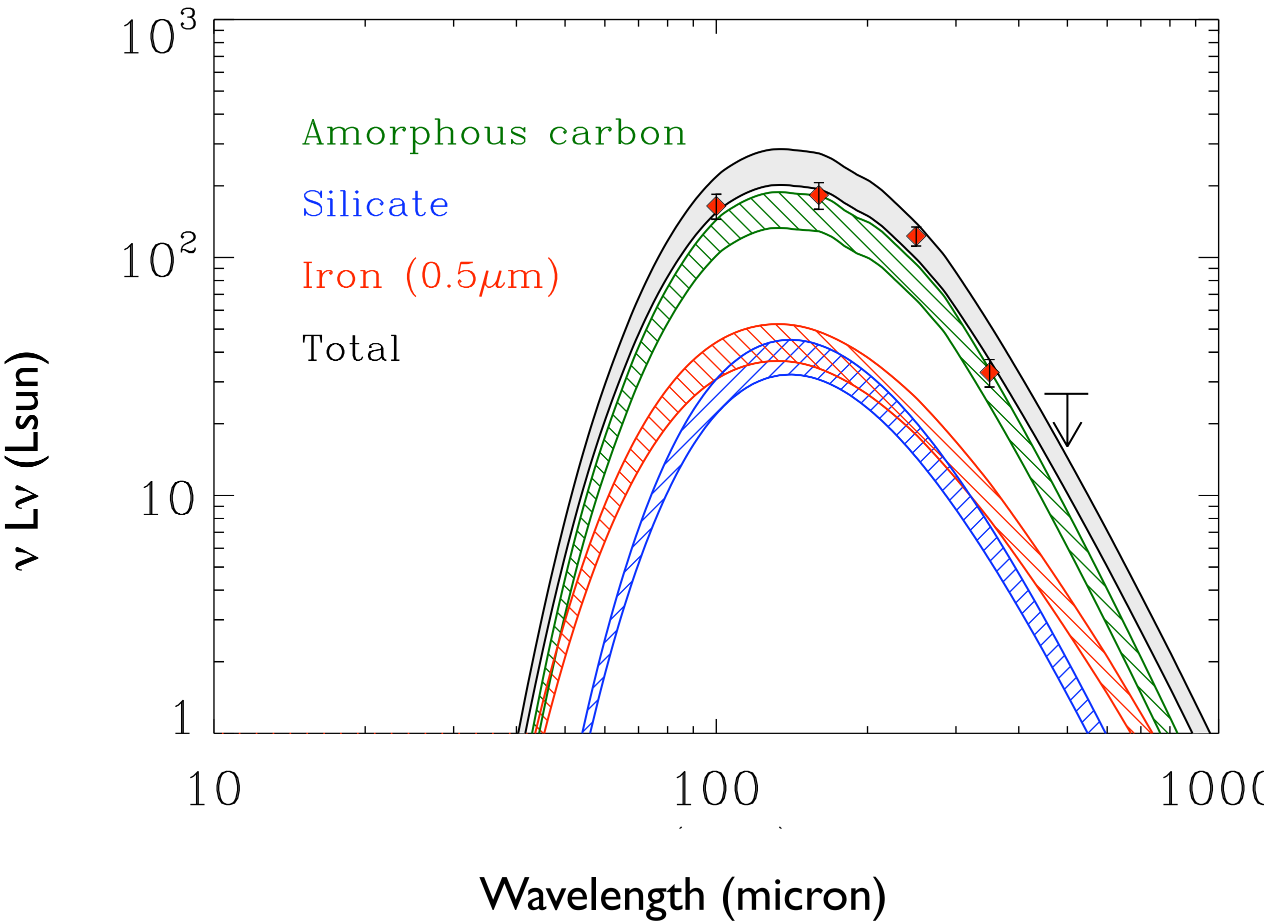
Maximum dust mass per dust specie restricted by elemental abundance

Dust mass (Msun) by model 1	Dust mass (Msun) by model 2
0.11	0.26
0.52	0.37
0.08	0.08

The far infrared emission could be due to the sum of the emission from several different dust species in the ejecta

Model 1: Thieleman et al. (1990)
Model 2: Woosley et al. (1988)

SED fits with combined dust speices



0.4-0.7 Msun of dust in total

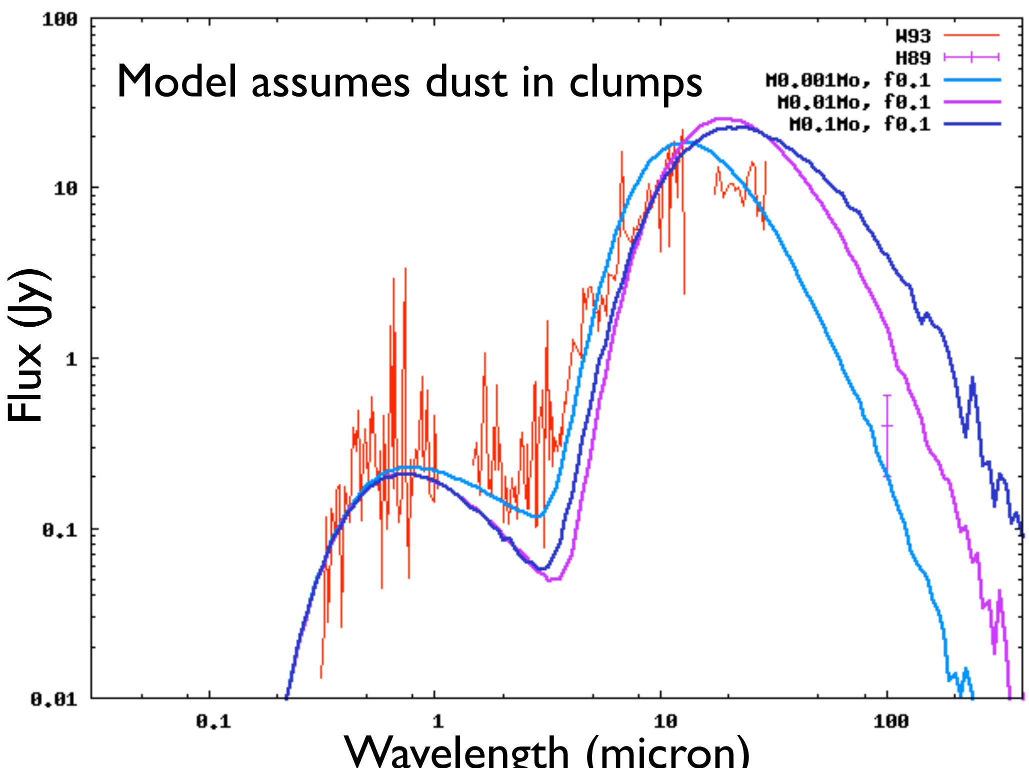
Herschel Detects a Massive Dust Reservoir in SN 1987A

Dust formation time scale

Dust formation: instantly at around day 600 or growth in 20 years?

- Initially, the reported mass was $>10^{-4}$ Msun (Wooden et al. 1993) at day 600;
- Ercolano et al. (2007) claimed the upper limit of 6×10^{-4} Msun for the same data

-> At day ~8500, the estimated mass was about 0.4-0.7 Msun



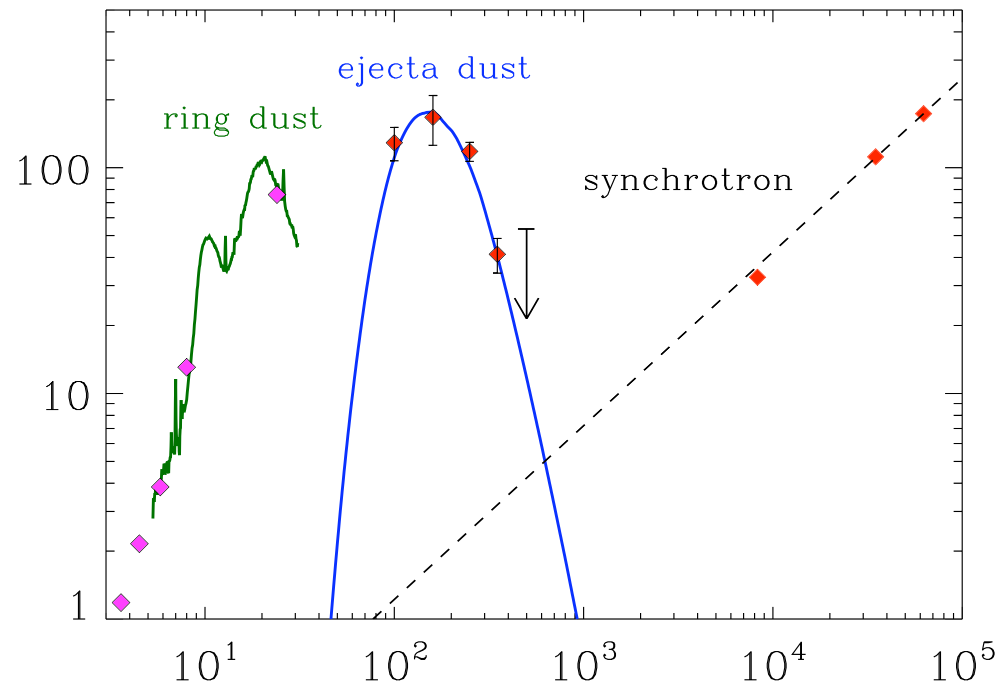
Re-analysis of the observed data at day 600, using the updated version of Ercolano et al.'s code

Near- and mid-IR data can give only lower limit of the dust mass

Wesson et al. (in preparation)

Heating source of dust grains

- Far-infrared/submm luminosity: 220 Lsun
- Possible heating source of dust grains
  - ^{44}Ti : 400 Lsun
  - X-ray : 500 Lsun
  - Ambient ISM radiation



Herschel Detects a Massive Dust Reservoir in SN 1987A

Summary

- Herschel detected SN 1987A at 100-350 micron
- Dust in the ejecta
- Estimated dust mass is 0.4-0.7 Msun

- SN can be major dust source in galaxies, from high-redshift and the local group galaxies

77.06

Far-IR Monitoring of SN1987A

P. Harvey, D. Lester, H. Dinerstein, B. Smith and C. Colome (U. Texas)

We present the results of a program in which we have been monitoring the 50 and 100 μm flux density of SN 1987A since 1987 November. The results of our photometry of the supernova itself are given in Table 1. In addition to these data we have searched for extended emission due to, for instance, thermal emission by dust in the light echoes. No such emission has been detected at a level of 2 Jy, 3σ, at any of the observed positions. Emission was seen from the "shoulder" of an IRAS source several arcminutes away from the supernova.

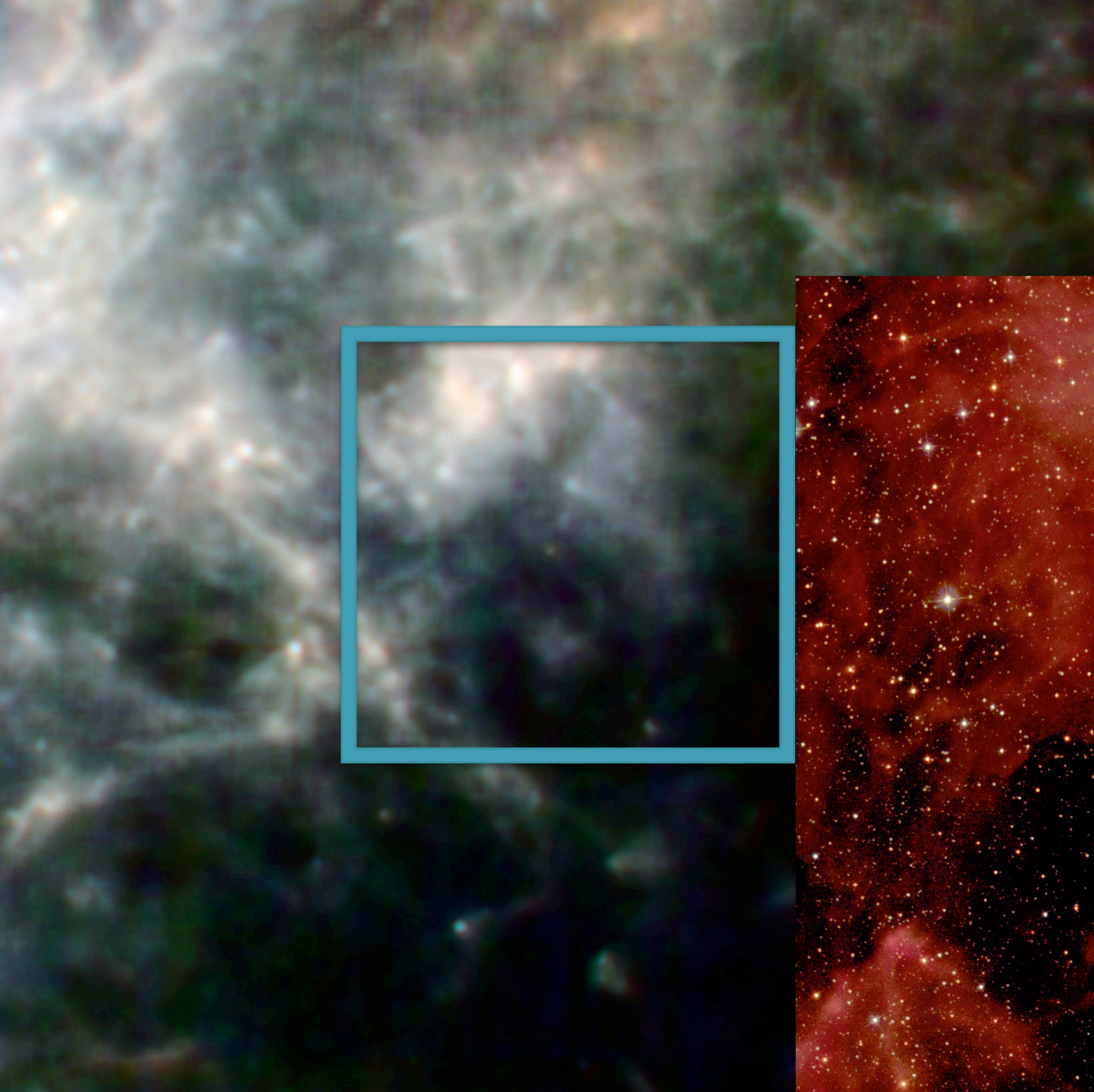
TABLE 1

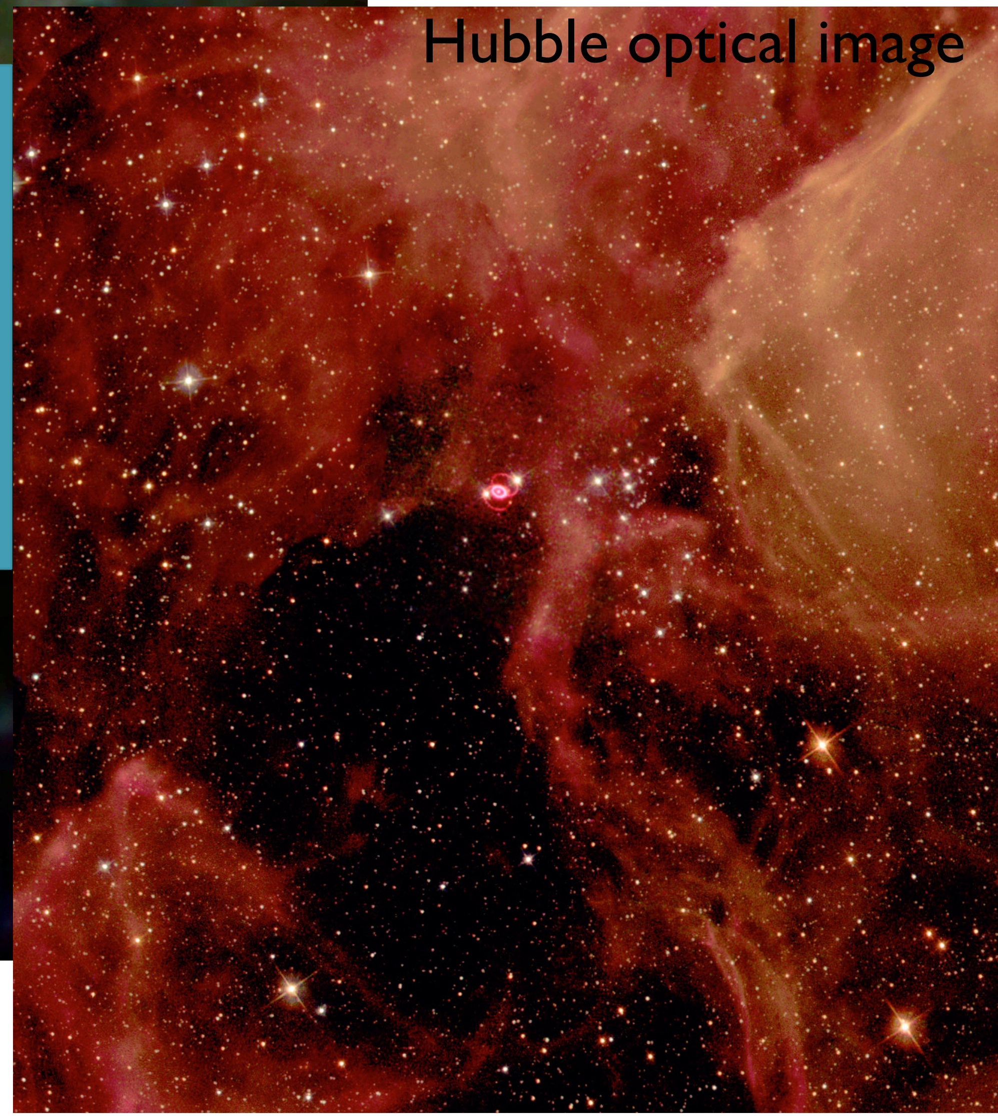
Date	F(50 μm)	(Jy)	F(100 μm)
22 Nov, 1987	7.7 ± 0.6		4.9 ± 0.4
16-23 Apr, 1988			1.1 ± 0.25
8-12 Nov, 1988			0.4 ± 0.2
24-28 Apr, 1989	2.5 ± 0.85		0.9 ± 0.45

We discuss these results in terms of models based on free-free emission in the early stages and possible dust emission in later stages.

Infrared view of SN 1987A and the surrounding

Herschel 250 micron + Spitzer 8 and 24 micron image





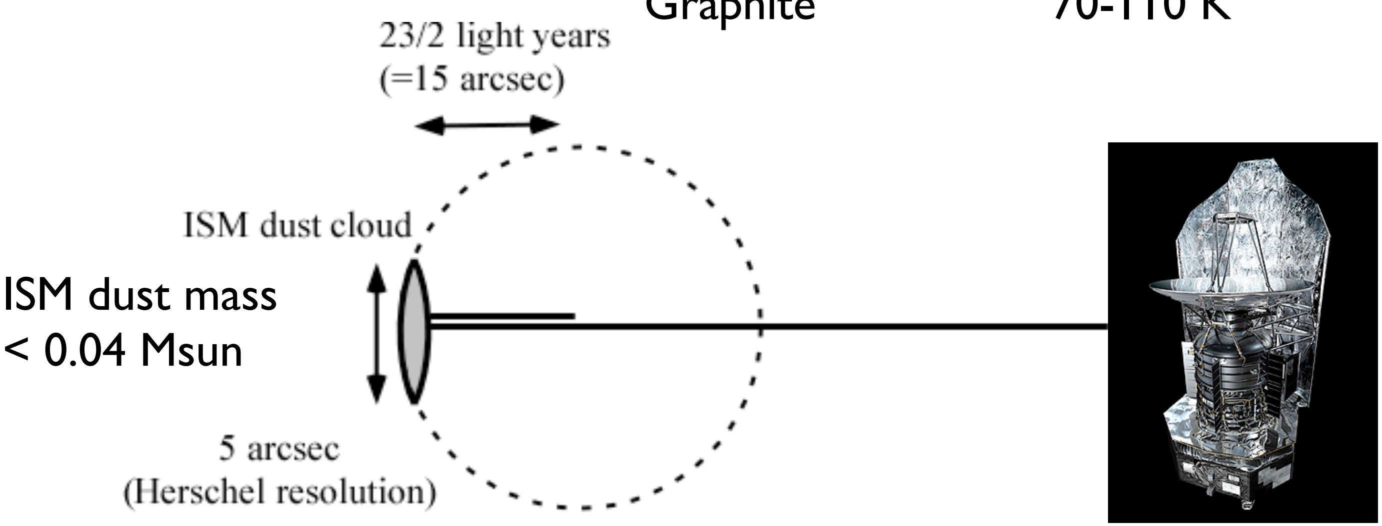
Far-infrared and submm view of SN 1987A and the surrounding

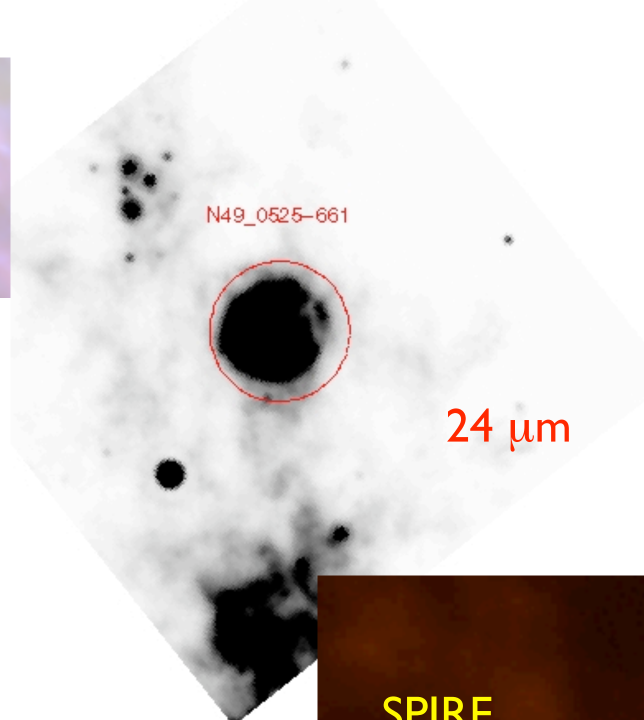
Origin/location of the dust

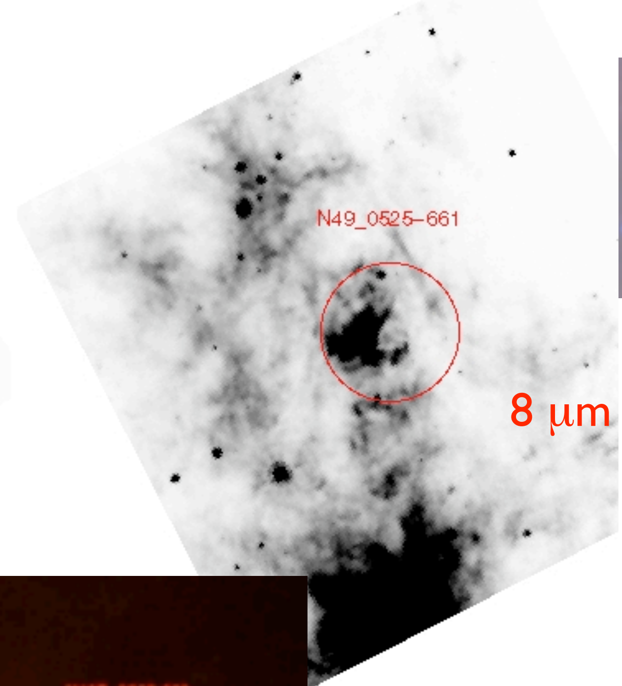
- Ambient ISM dust
- Light echo : (ISM dust)
- Dust formed before the SN explosion
- Ejecta : Dust form SN

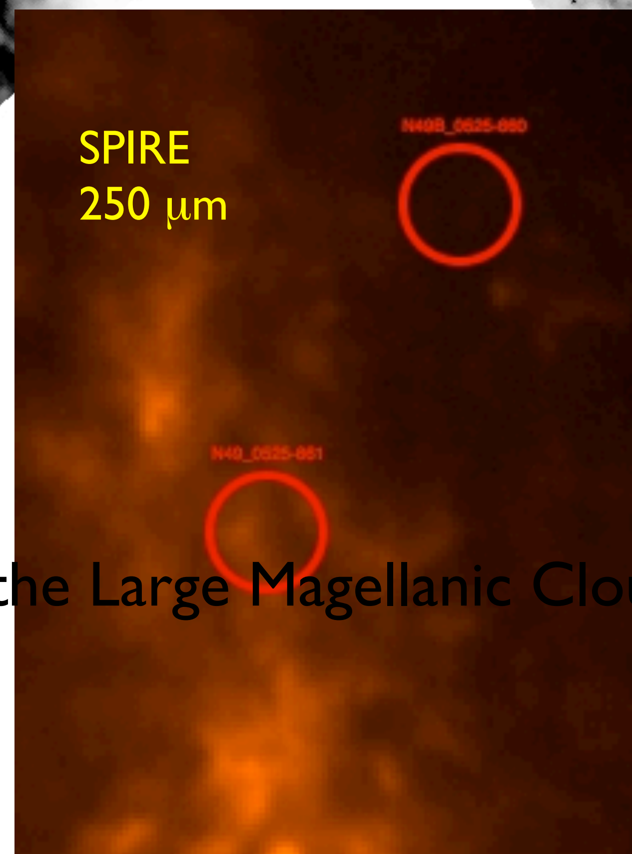
- Light echo
  - Unfavorable temperature geometry, and mass

	Expected temperature of light echo	Estimated temperature from Herschel flux
Silicate	40 K	18 K
Graphite	70-110 K	21 K







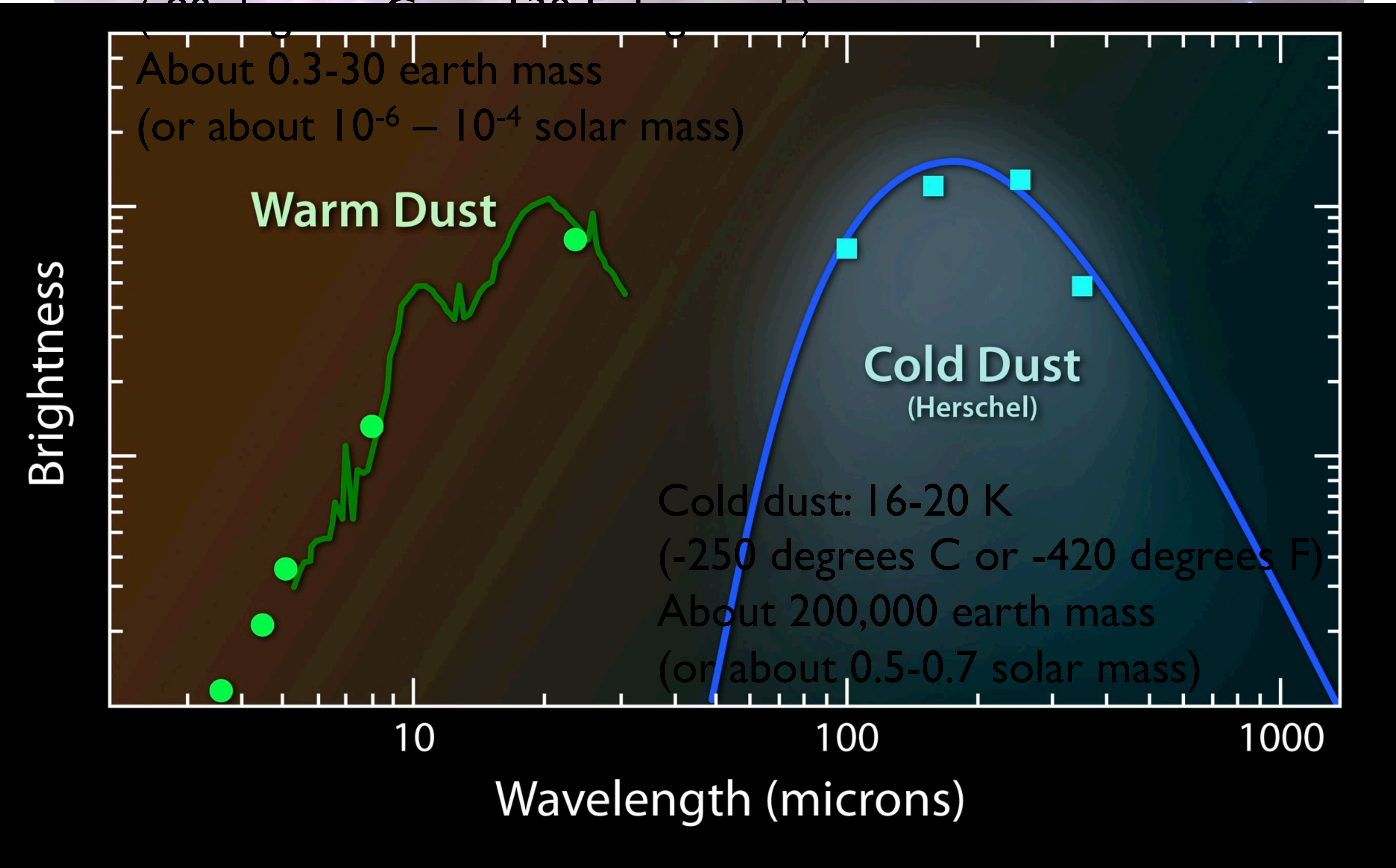


N49: Supernova Remnant in the Large Magellanic Cloud

Warm dust: 180 K

About 0.3-30 earth mass

(or about 10^{-6} – 10^{-4} solar mass)



Cold dust: 16-20 K

(-250 degrees C or -420 degrees F)

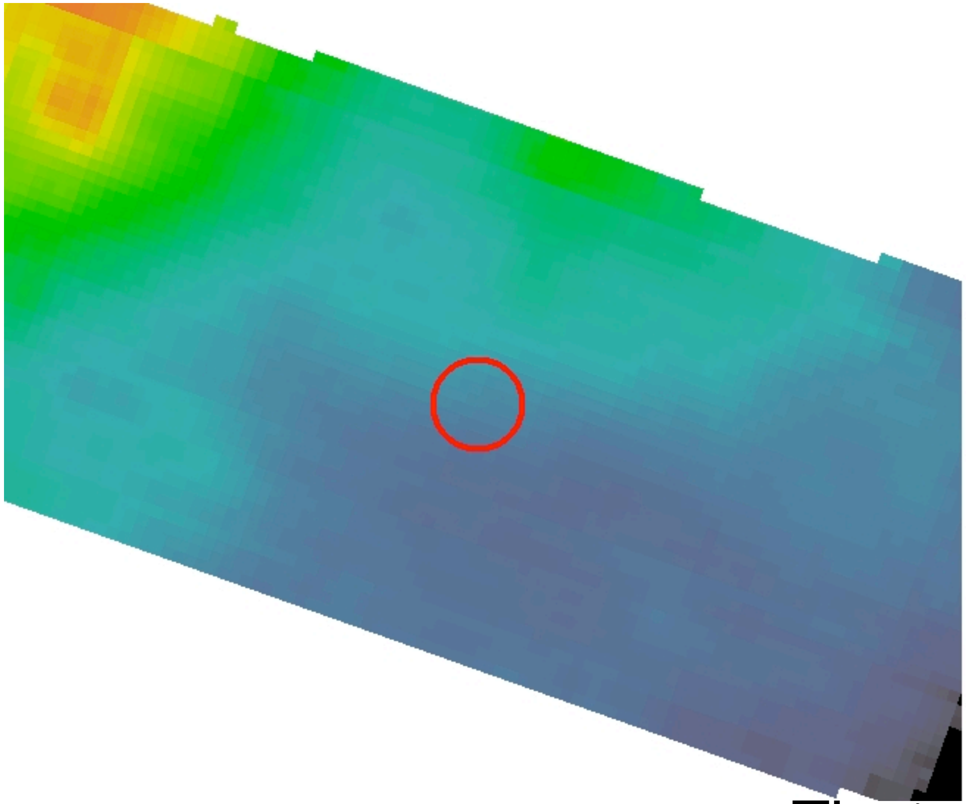
About 200,000 earth mass

(or about 0.5-0.7 solar mass)

Power of the large mirror size of the Herschel

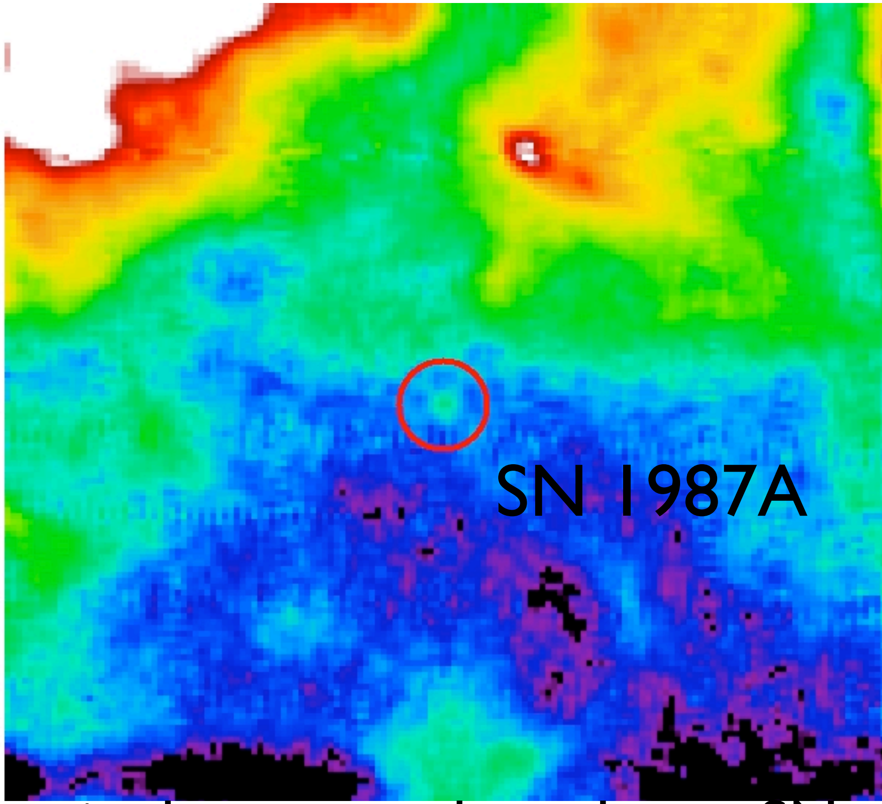
Spitzer 70 micron image

Mirror: 0.85 meters in diameter



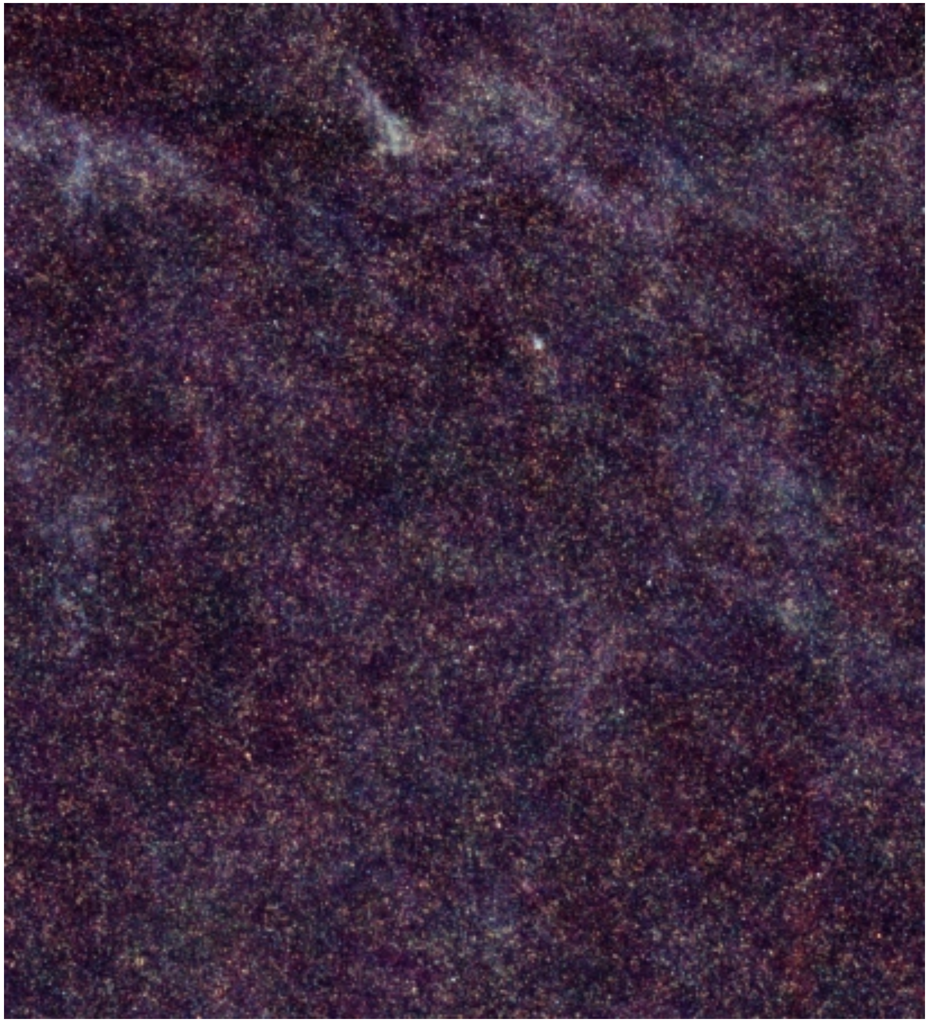
Herschel 100 micron image

Mirror: 3.5 meters in diameter



The image is sharp enough to detect SN 1987A

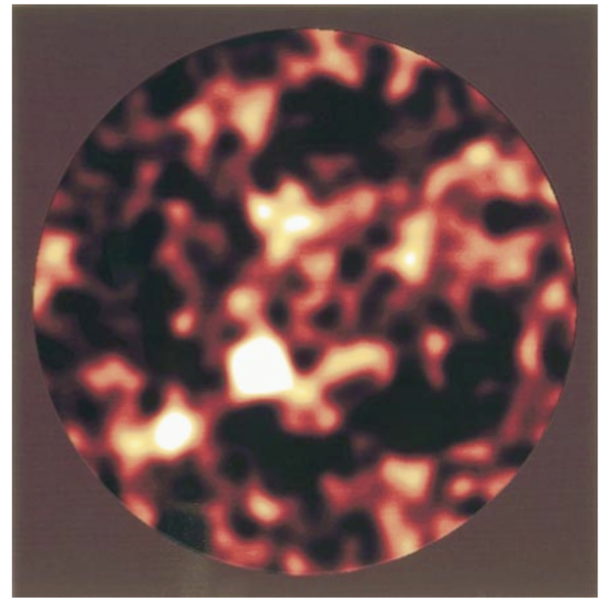
Dust in high-redshift galaxies



Herschel H-Atlas
Submm galaxies

Implications for high-z galaxies with dust

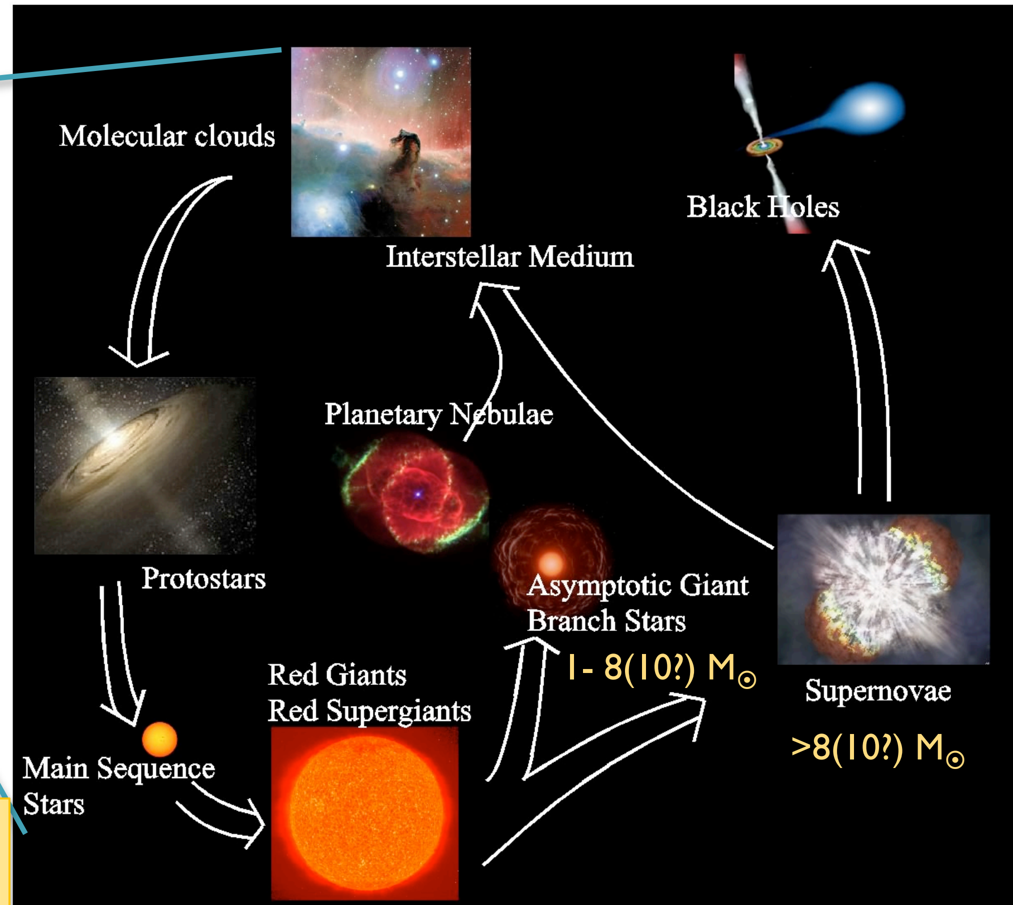
High-z galaxies
z~6.4; ~0.4 Giga years
(e.g. Bertoldi et al. 2003)



Dust sources: theoretical models predict at least 0.1 solar mass of dust per supernova required

Our new observations provide the direct and unshakable evidence that supernovae can make a significant amount of dust

Cycle of matter (gas and dust) in galaxies

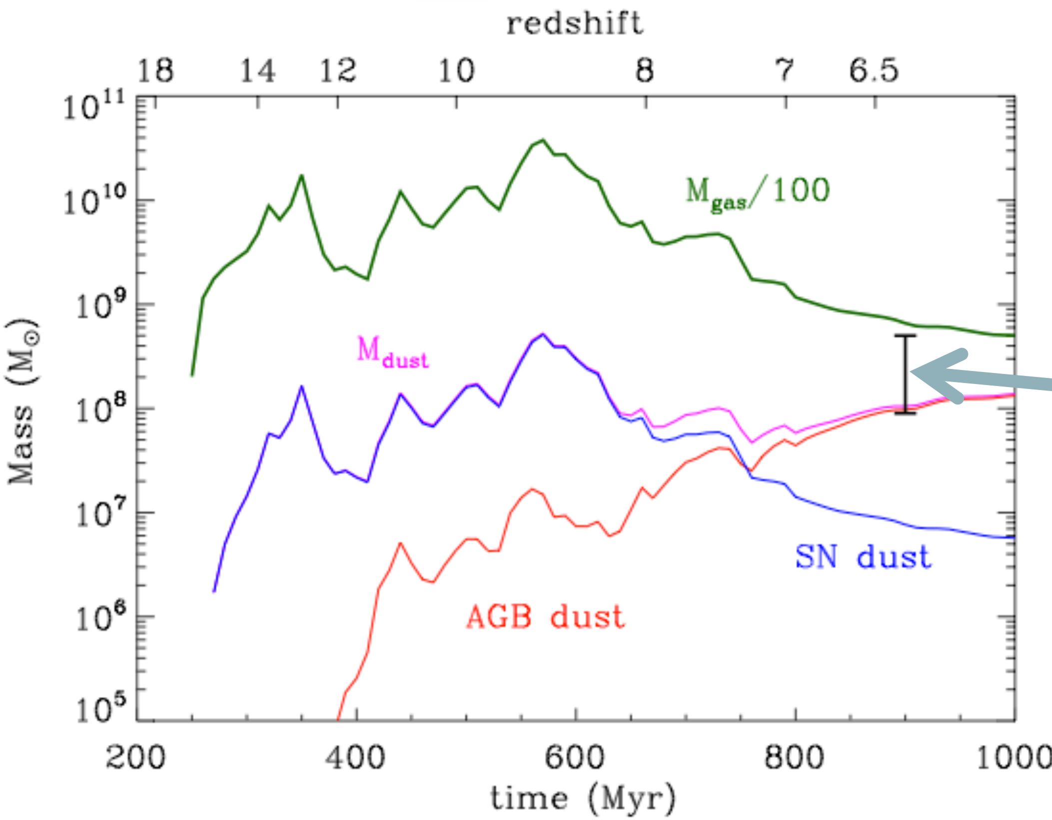


Concept of cycle of matter
Past: Theory/models
(chemical evolution of galaxies)

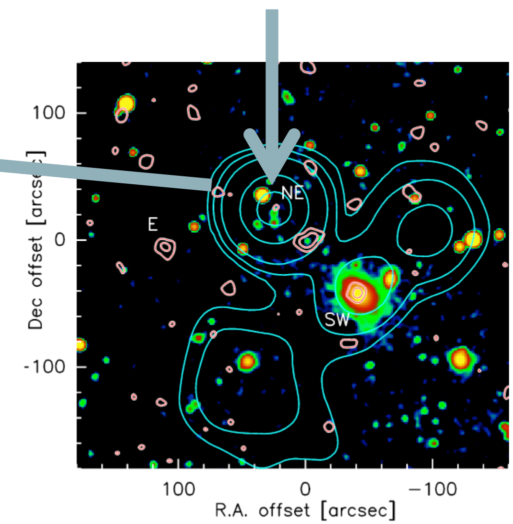
Current: measurements of dust
Can we account for ISM dust with stellar dust?

Herschel Detects a Massive Dust Reservoir in SN 1987A

Modeling evolution of dust mass



J114816.64+5251
z = 6.4, age ~400 Myrs
Mdust = 2x10^8 Msun



Bertoldi et al. (2003)

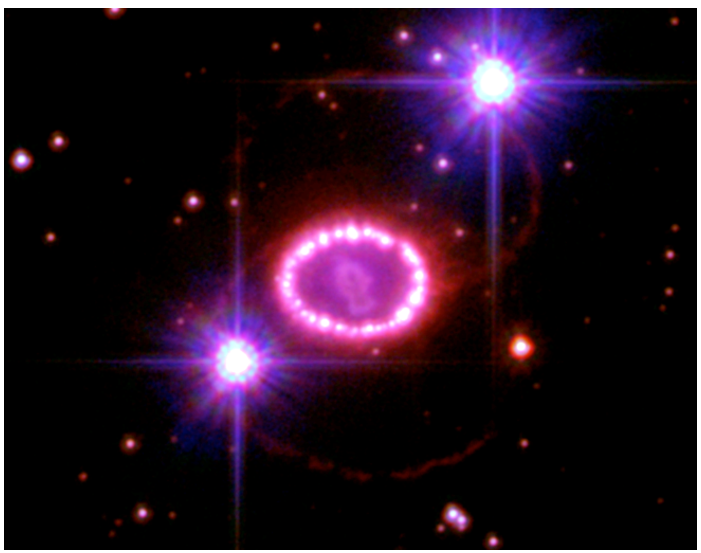
Dwek & Cherchneff (2011) Average of 0.15 Msun dust per SN

C.f. Michałowski et al. (2010)

Herschel Detects a Massive Dust Reservoir in SN 1987A

Prospects

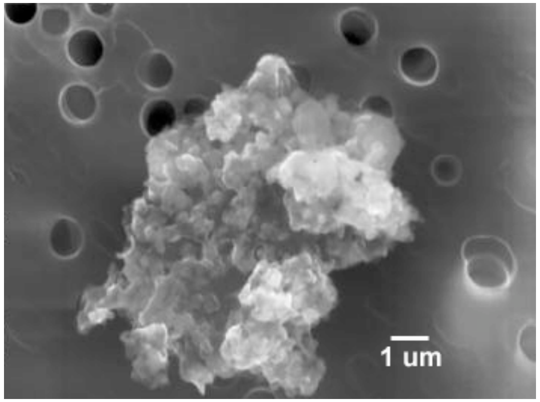
- Possibility to observed destruction of dust by SN shocks
- Add a figure about the destruction



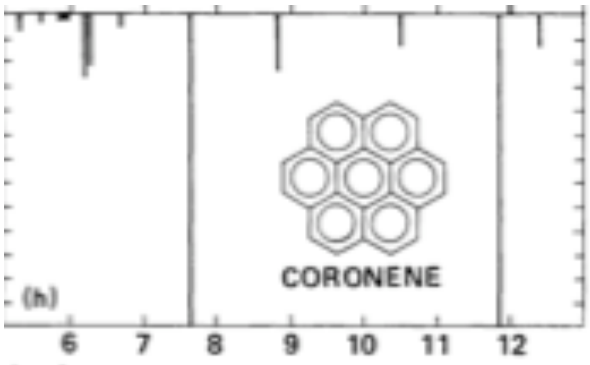
Herschel Detects a Massive Dust Reservoir in SN 1987A

Dust compositions

- Oxides / silicate
  - SiO_2
  - Olivines : $Mg_{2x}Fe_{(2-2x)}SiO_4$
  - Pyroxenes : $Mg_xFe_{1-x}SiO_3$



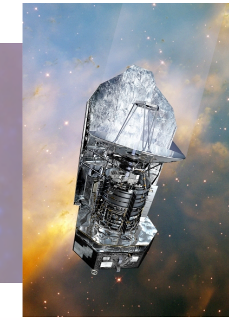
- Carbonaceous dust
  - Graphite : C
  - Amorphous : C
  - Polycyclic aromatic hydrocarbons (PAHs)



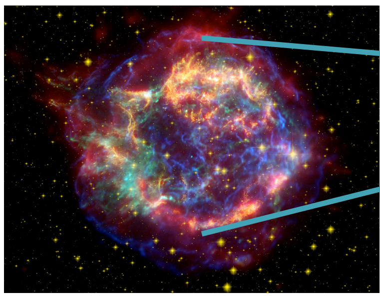
- Metalic iron
  - Fe

Herschel Detects a Massive Dust Reservoir in SN 1987A

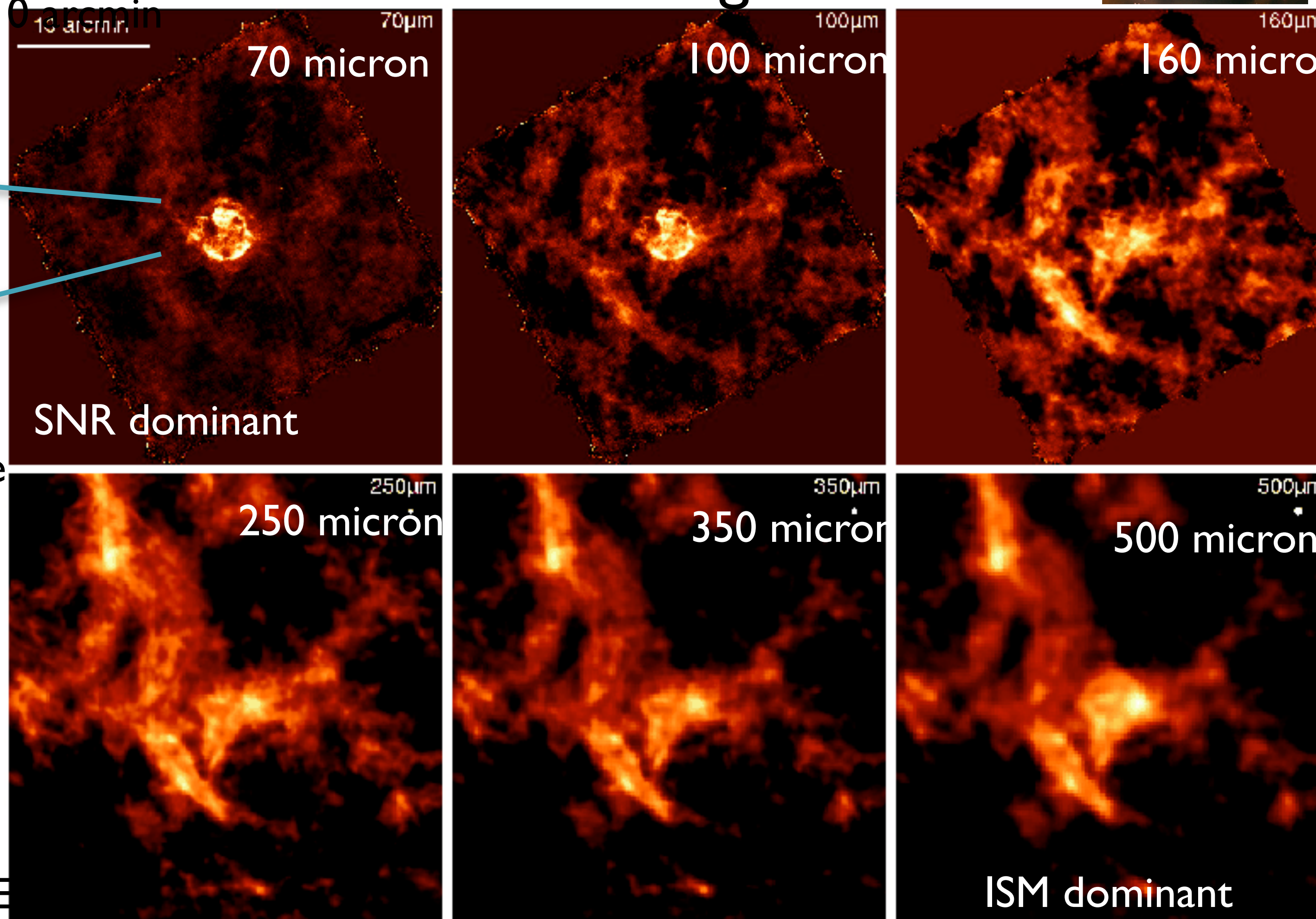
Supernova Remnant: Cas A



Far-infrared image



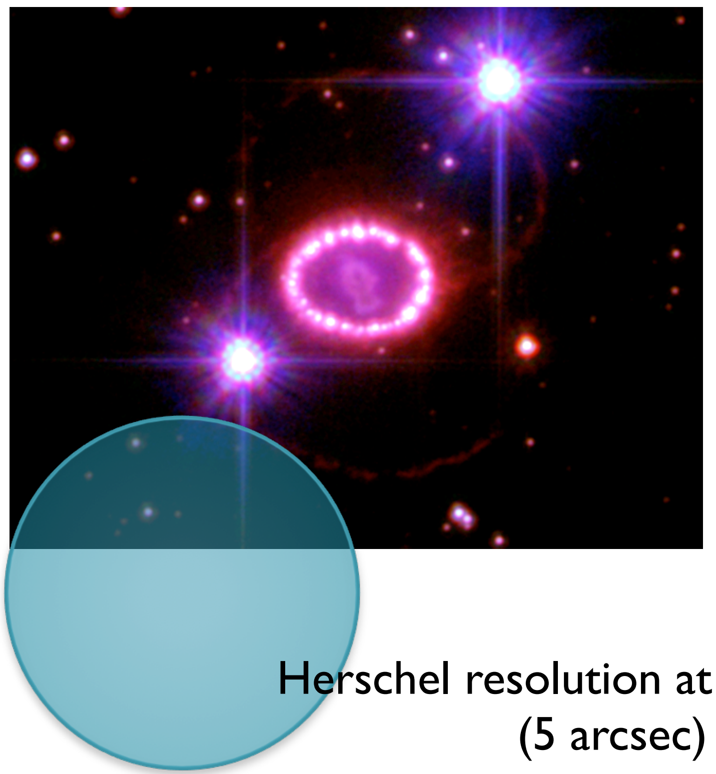
Optical and X-ray image



Barlow et al. (2010)
Herschel PACS & SPIRE

Prospects

- ALMA
  - Location of the cold dust within the SN remnant
  - In future, the interaction between the ring and the ejecta could cause the destruction of dust



Herschel resolution at 100 micron
(5 arcsec)