The Origin and Nature of Dust in Core Collapse Supernovae

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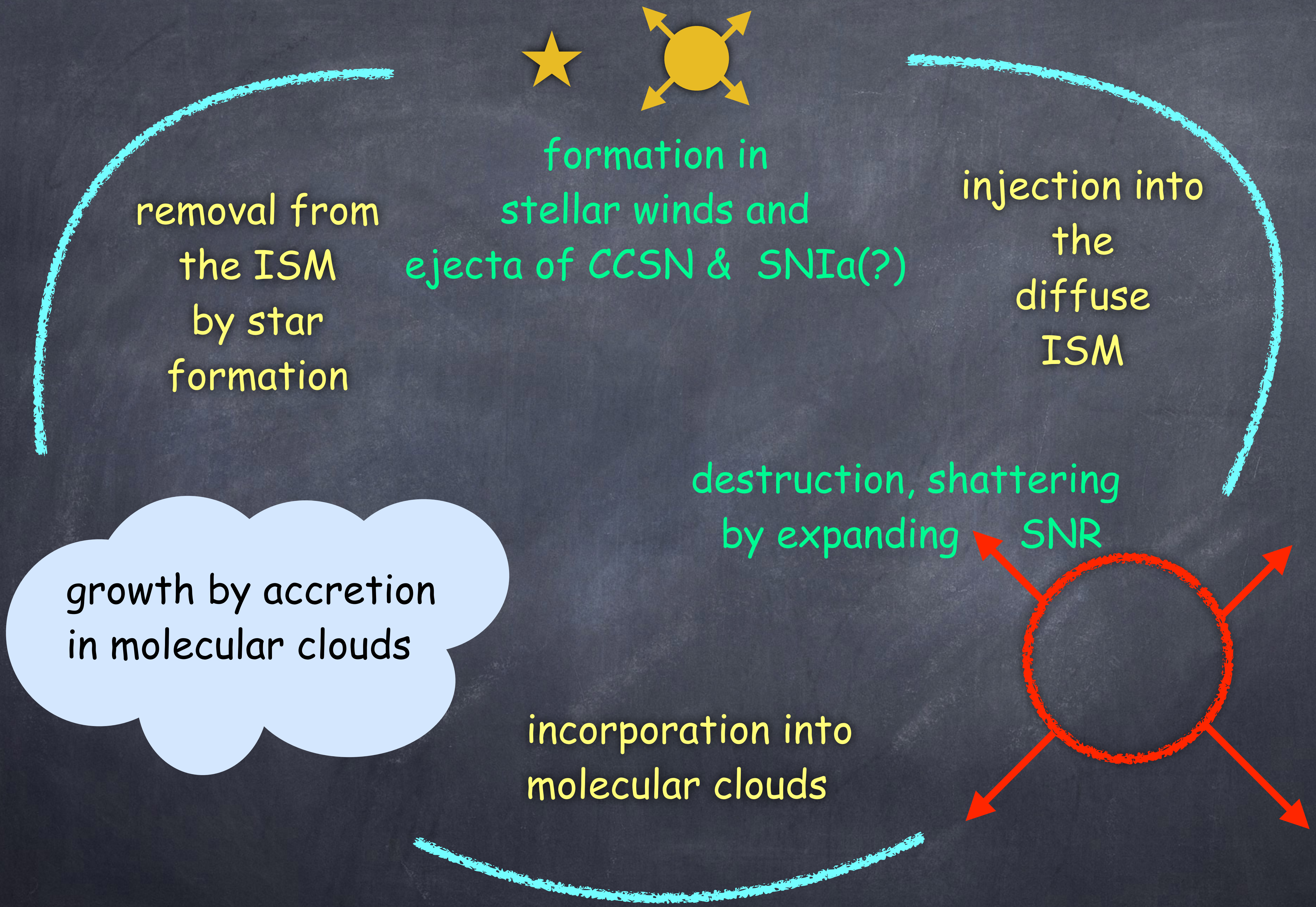
HST image of the Carina Nebula


formation in
stellar winds and
ejecta of CCSN & SNIa(?)
injection into
the
diffuse
ISM
destruction, shattering
by expanding SNR
incorporation into
molecular clouds
growth by accretion
in molecular clouds
removal from
the ISM
by star
formation

The double role of Supernovae

- Core collpase supernova (CCSNe) are important sources of interstellar dust
  - dust forms in the expelled radioactive ejecta

- The are the most important destroyers of interstellar dust during:
  - the reverse shock phase of the expansion
  - during the remnant phase of the expansion

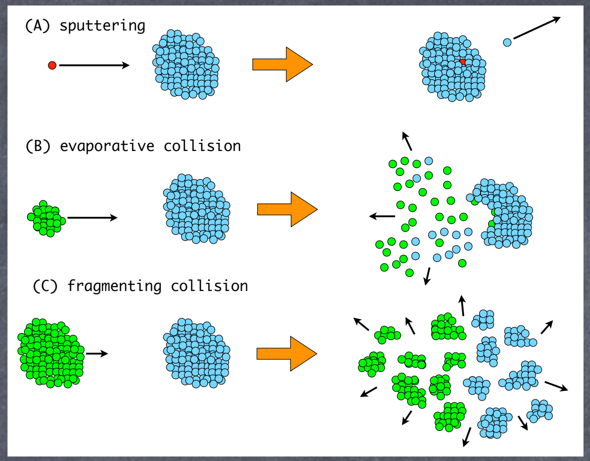
- Are CCSN net producers or destroyers of interstellar dust?

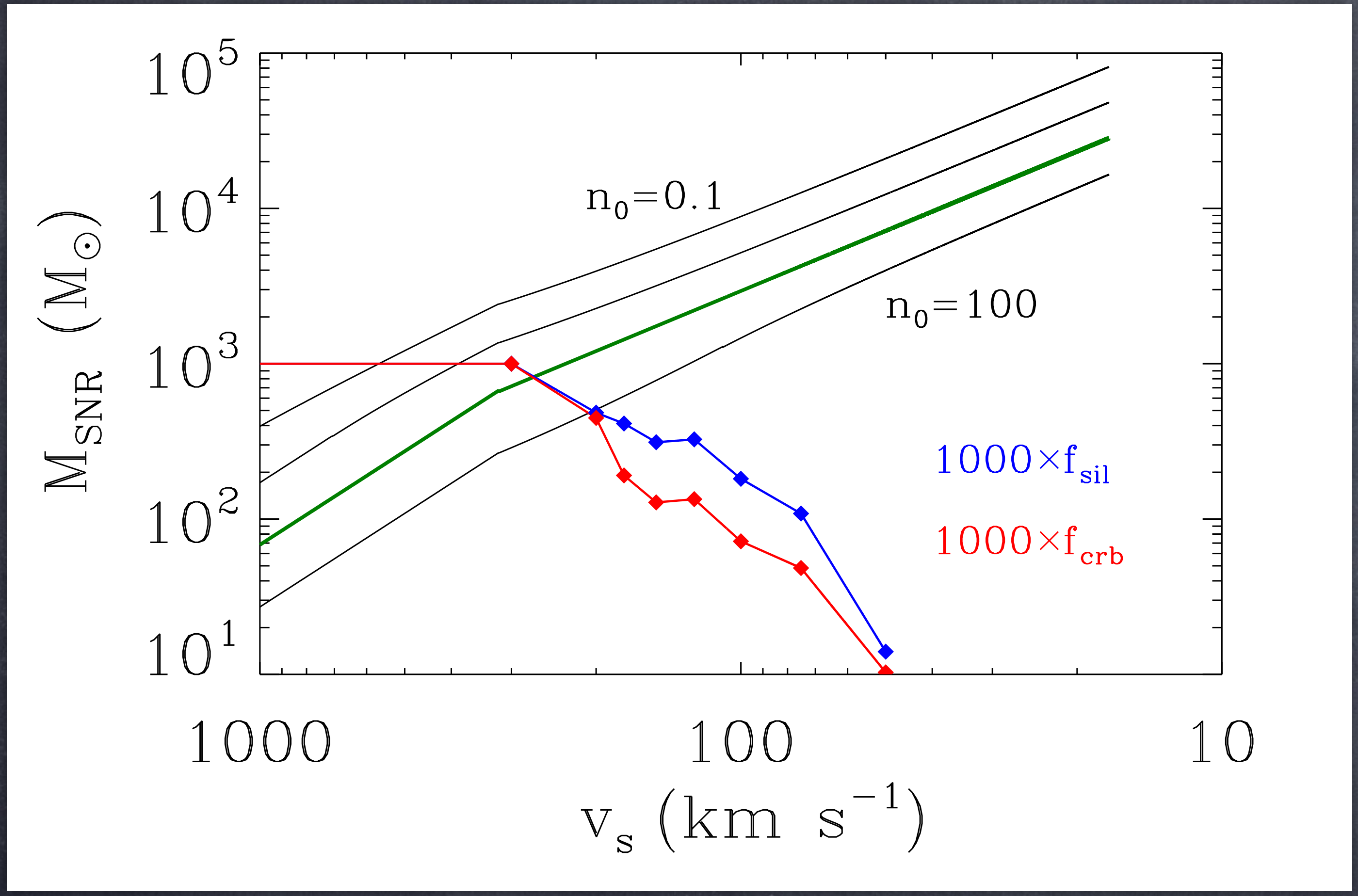
- Can they produce observable amounts of dust in the early universe?

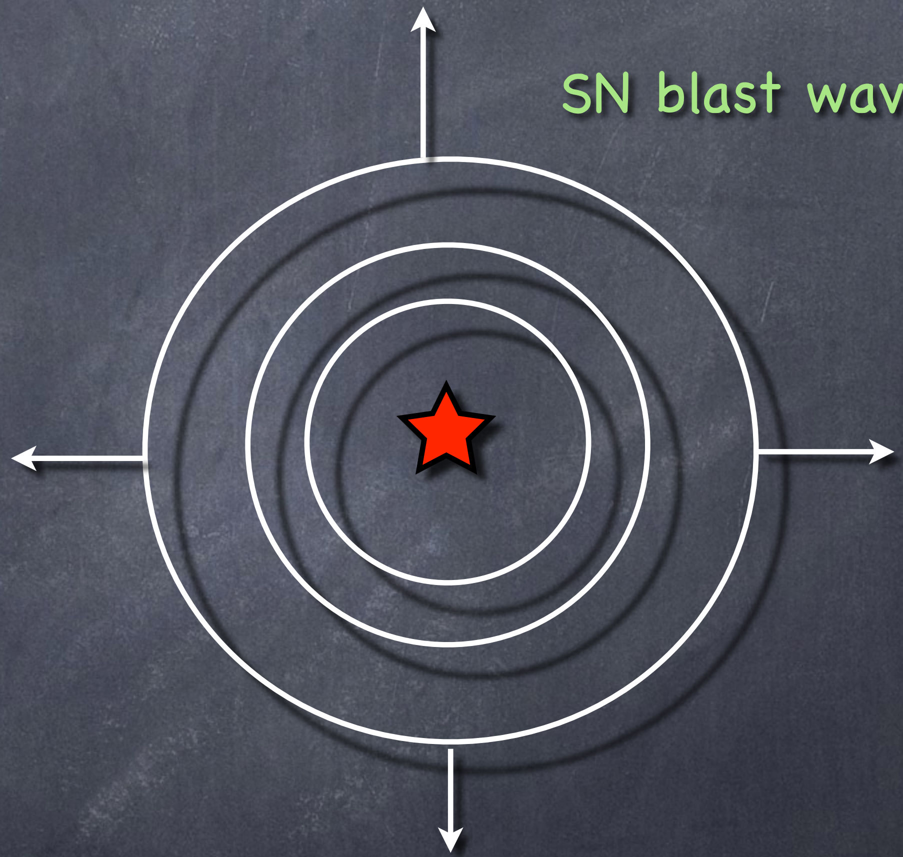
GRAIN DESTRUCTION BY SUPRNOVA REMNANTS

Grain destruction by supernova remnants

(Temim+2015)







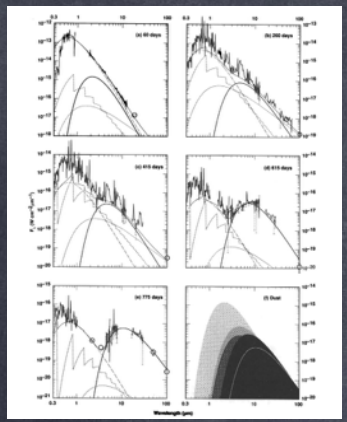
Supernova remnants clear all the dust contained in ≈ 1,000 - 2,000 M_{sun} of ISM gas

(Slavin, Dwek, & Jones 2015)

DUST FORMATION IN CORE COLLAPSE SUPRNOVAE

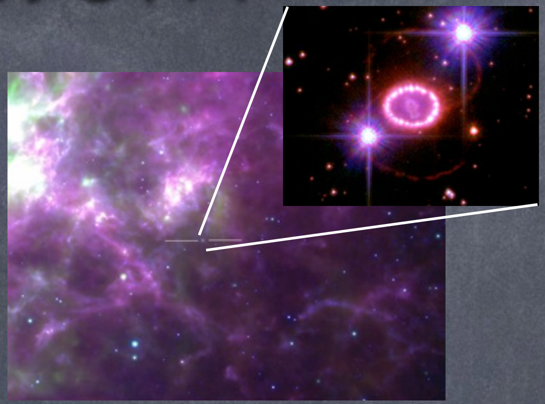
Dust formation in core collapse SN

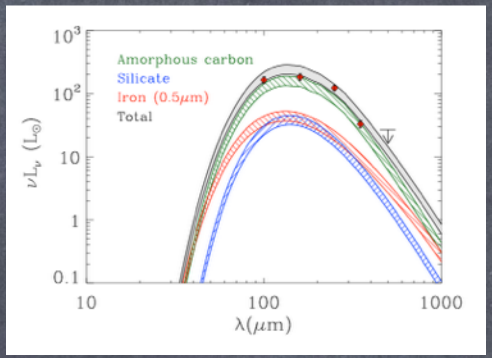
SN1987A



(Wooden et al. 1989, 1993)

$M_{dust} \approx 10^{-3}\ M_{sun}$

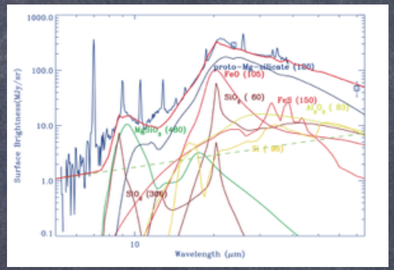


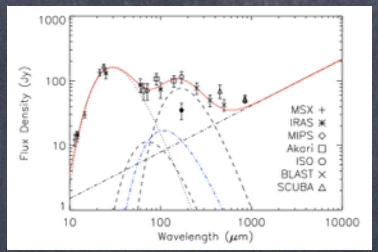


(Matsuura + 2011, 2015)

$M_{dust} \approx 0.5\ M_{sun}$

Cas A





Spitzer spectral image
$\approx$ 0.04-0.12 M_{sun}
of dust

(Rho et al. 2008, Arendt+2014)

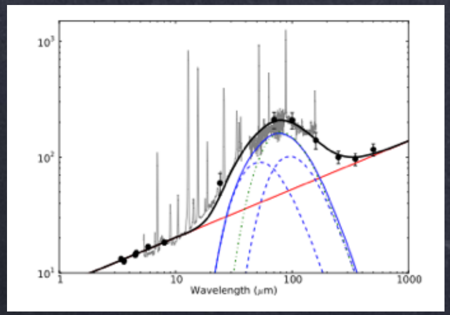
Akari/Blast/Herschel
search for warm (~ 35 K) dust

$\approx$ 0.08 M_{sun}

Sibthorpe et al. 1999
Barlow et al. 2010

Crab

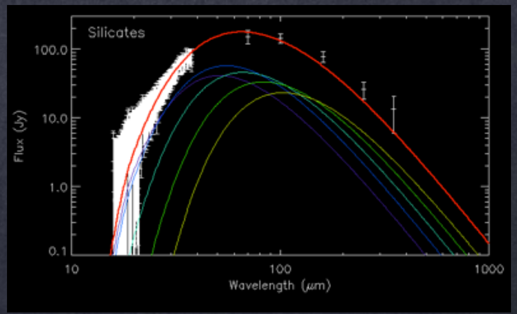
2-temperature components



Gomez + 2012

$M_d \approx 0.24\ M_{sun}$

multi-temperature physical model



Temim + 2013

$M_d \approx 0.12\ M_{sun}$

When are CCSNe net dust producers?

Rate of grain destruction	=	SN rate	X	ISM mass cleared of dust by single SNR	X	dust-to-gas mass ratio

$\sim 1000\ M_{sun}$ X D2G

Rate of grain destruction	=	SN rate	X	net dust yield in CCSNe

$\sim 0.1\ M_{sun}$

CCSN are net dust producers when D2G $\approx 10^{-4}$

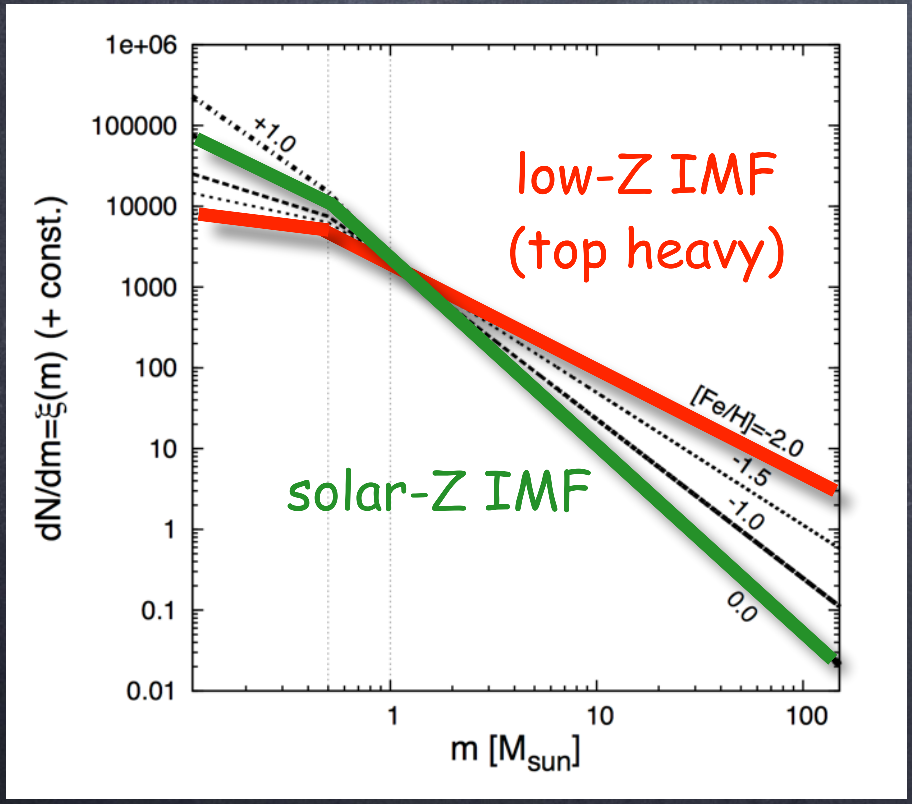
Very early universe

DUST FORMATION IN THE EARLY UNIVERSE

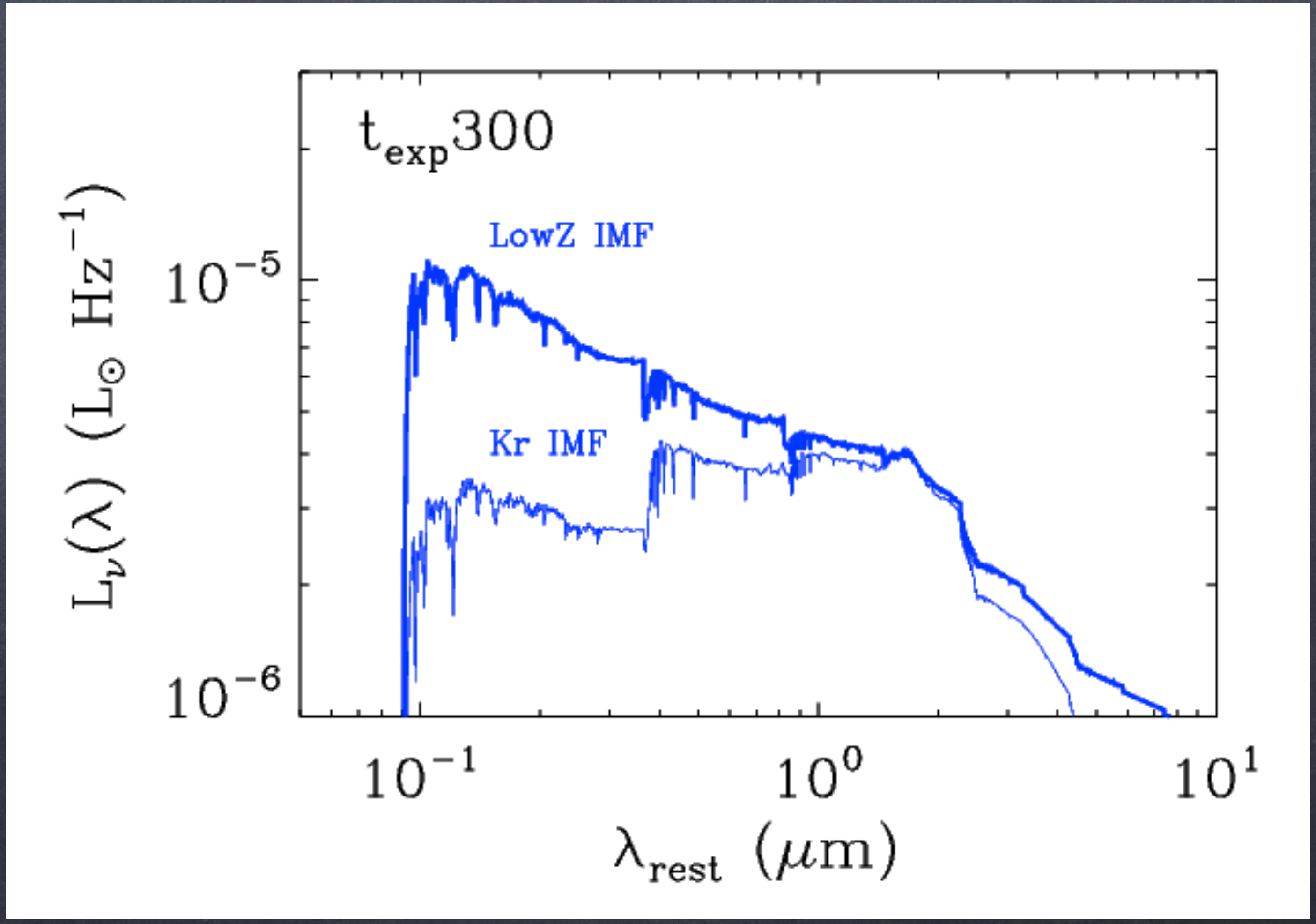
How to make a dusty high-z galaxy II: need rising UV and efficient dust formation

(Dwek, Staguhn, Arendt et al. 2014)

Kroupa stellar initial mass function (IMF)



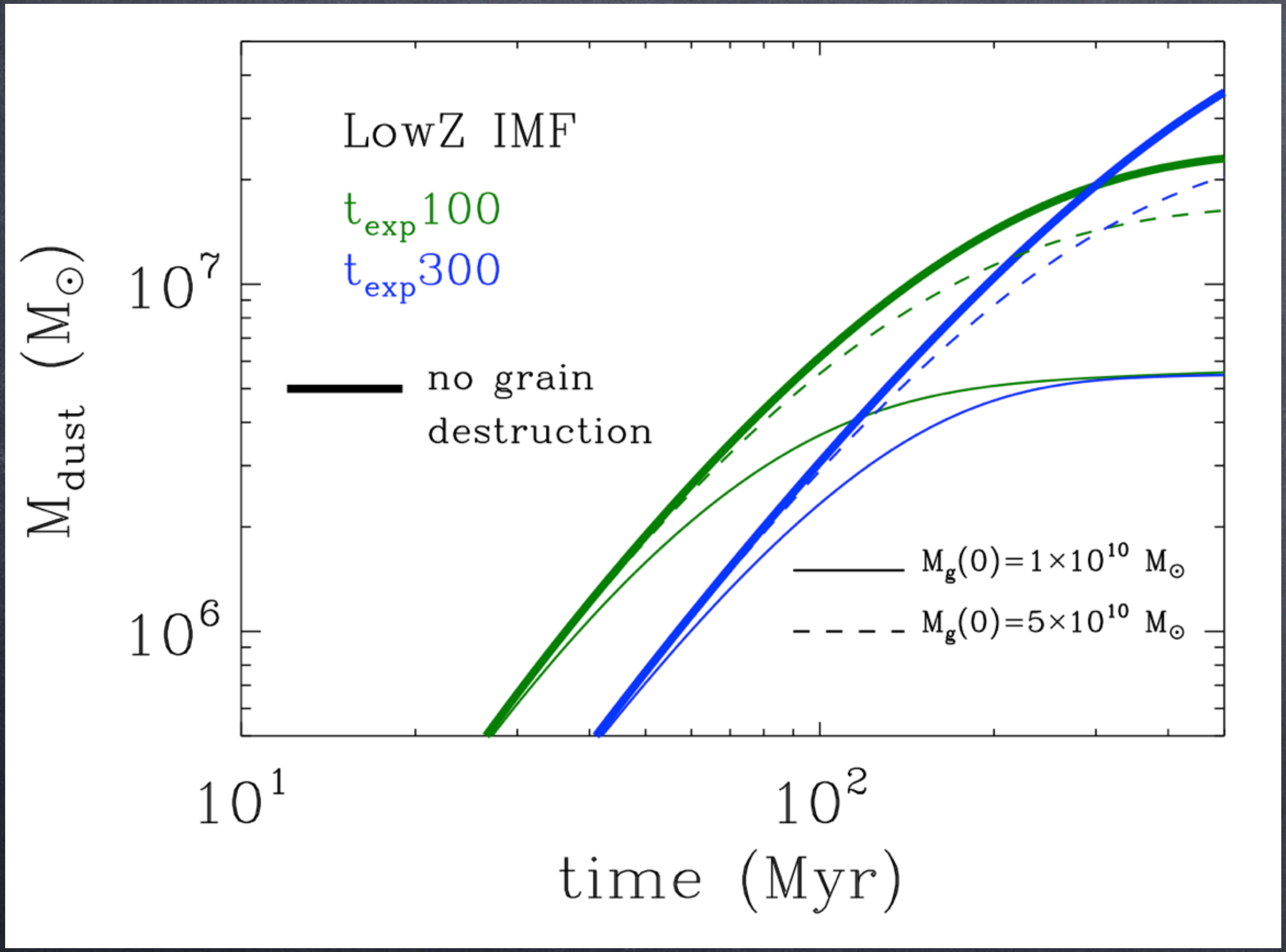
Low-metallicity IMF produces more UV



Second constraint: Dust production

Dust mass inferred from the energy constraint
must be produced within ~ 500 Myr

Only considered dust production by CCSN



Dust evolution models correlate the following quantities:

Star formation rate
Stellar IMF
Stellar mass
Dust mass
Gas mass
Dust destruction

Optical Depth in the early universe

$$\tau(\lambda) \approx \frac{M_d}{\pi R^2} \kappa(\lambda)$$

For a dust mass of 10^7 M_{sun}

and a mass abs coef. of 10^4 cm^2 gr^{-1}

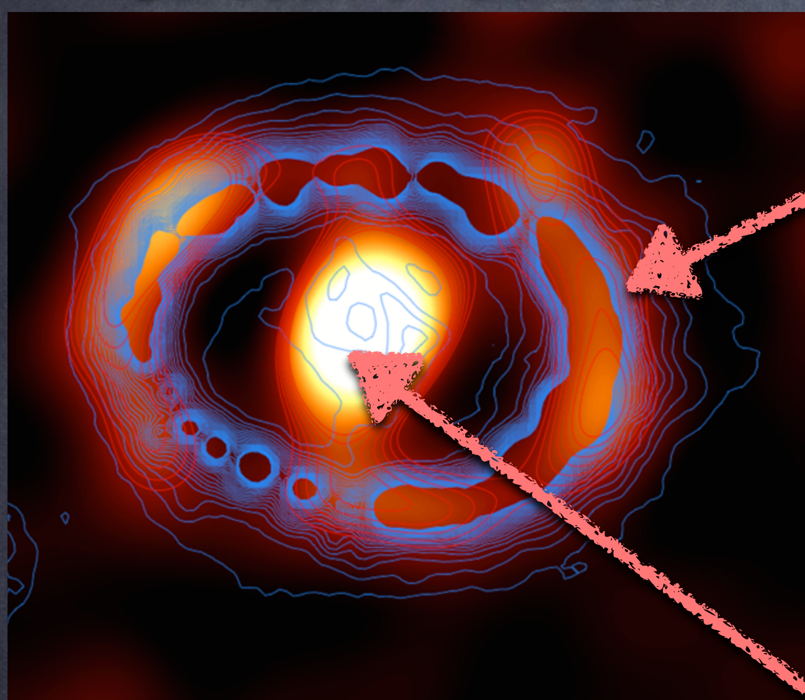
$$\tau(UV) \approx \frac{10}{R(kpc)^2}$$

CCSN DUST YIELDS IN THE LOCAL UNIVERSE

THE NATURE OF DUST IN SN1987A

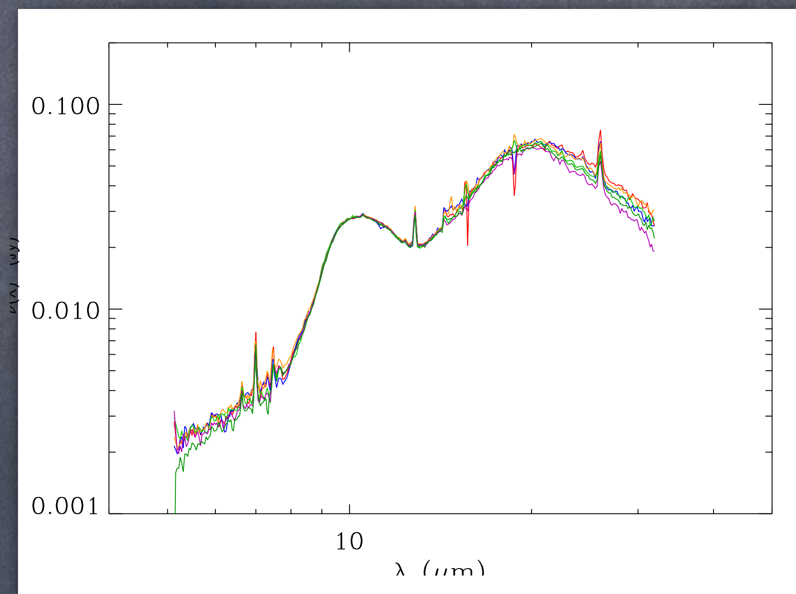
Dust in SN1987A

Zanardo et al. 2014
Larsson et al. 2011



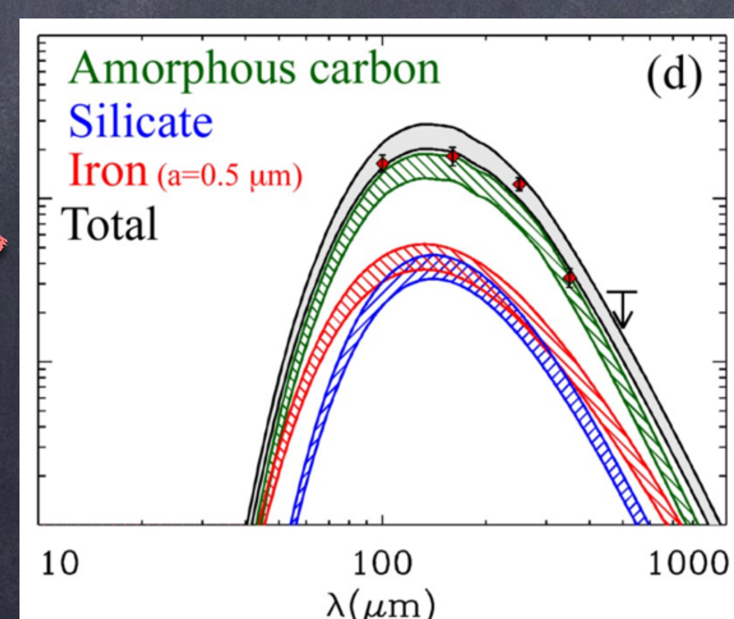
HST ALMA 870 μm

SN shock-ring interaction
Collisionally-heated dust



Dwek et al. 2010
silicate
$T_d \approx 180$ K
$M_d \approx 10^{-5}$ M_{sun}

Dust that formed in the SN ejecta

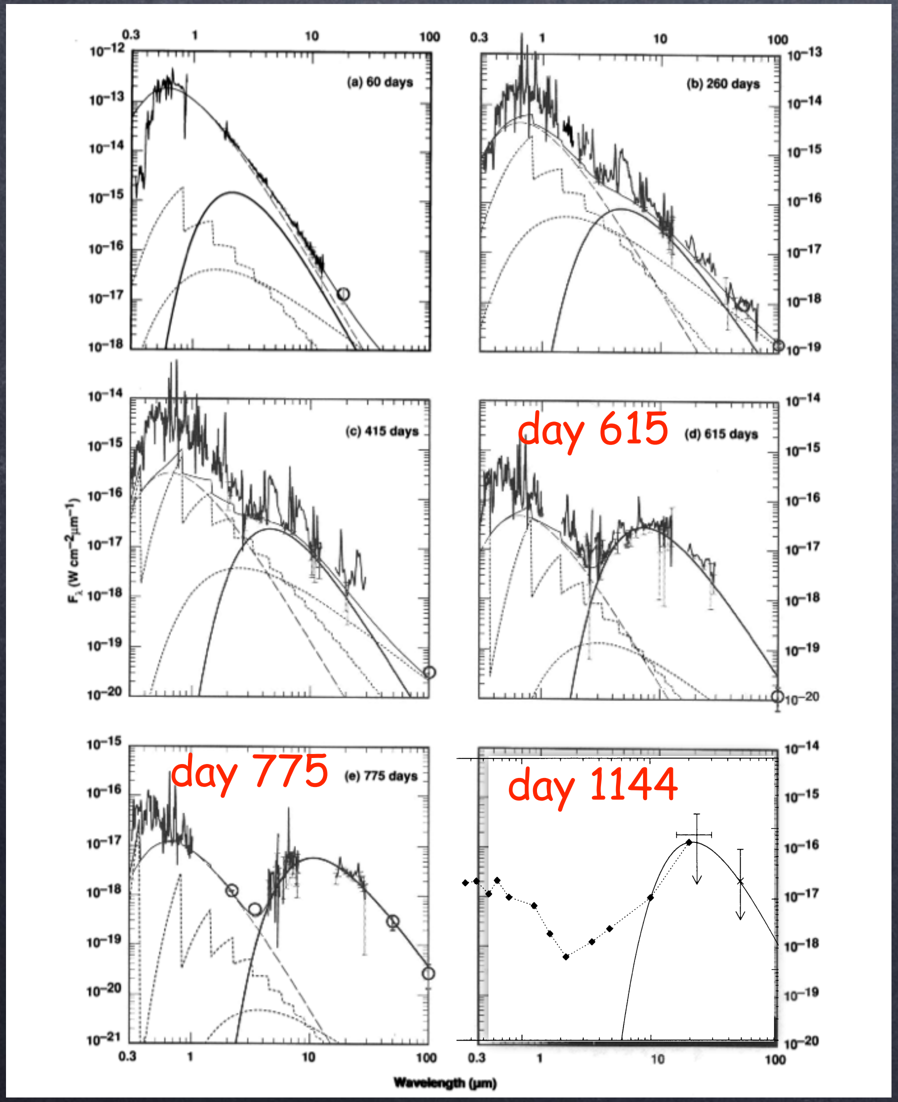


Matsuura et al. 2011, 2015
mostly carbon
$T_d \approx 20$ K
$M_d \approx 0.4$ M_{sun}

Mass of dust evolved by cold accretion

Wooden et al. 1993
Dwek et al. 1992

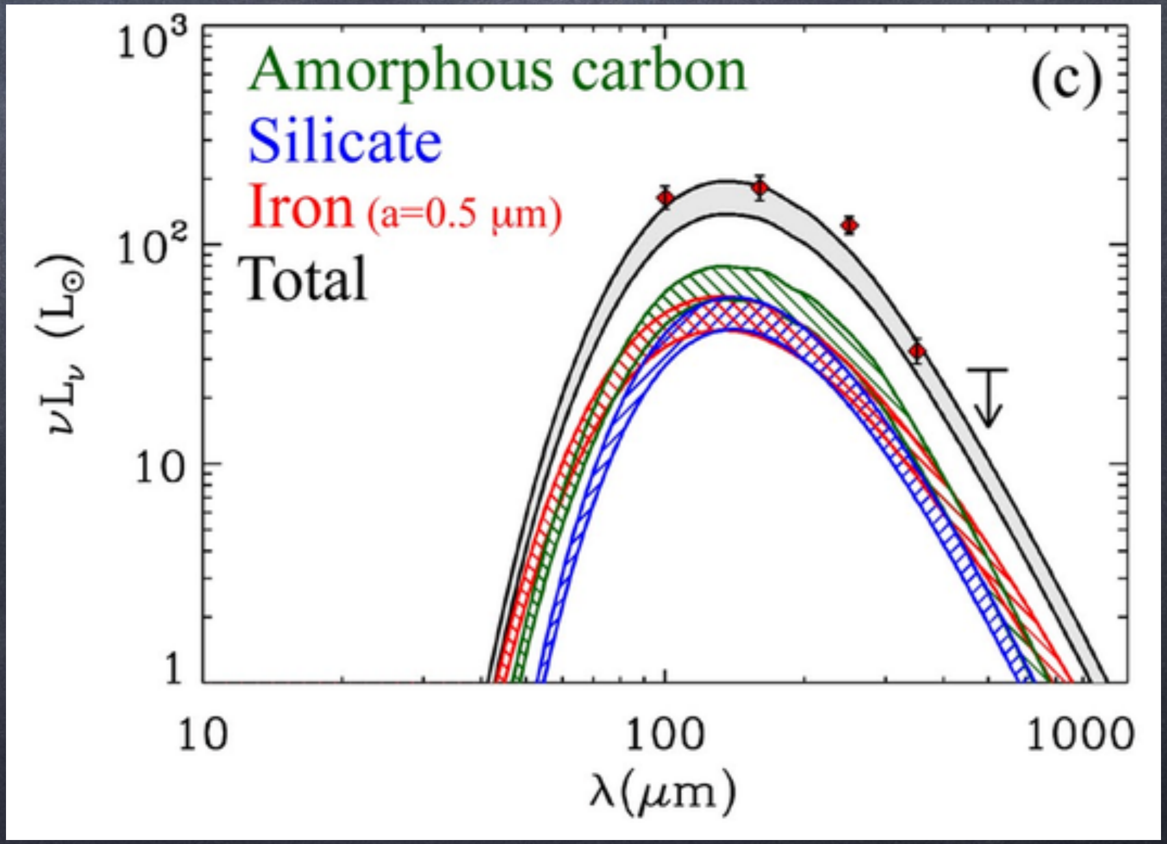
~ 10^{-3} M_{sun} of carbon dust



Matsuura et al. 2011, 2015
Wesson, Barlow, et al. 2015

Amorphous carbon ~ 0.5 M_{sun}
Silicate ~ 2.4 M_{sun}
Iron ~ 0.4 M_{sun}

Amorphous carbon ~ 0.3 - 0.5 M_{sun}
Silicate ~ 0.5 - 0.07 M_{sun}

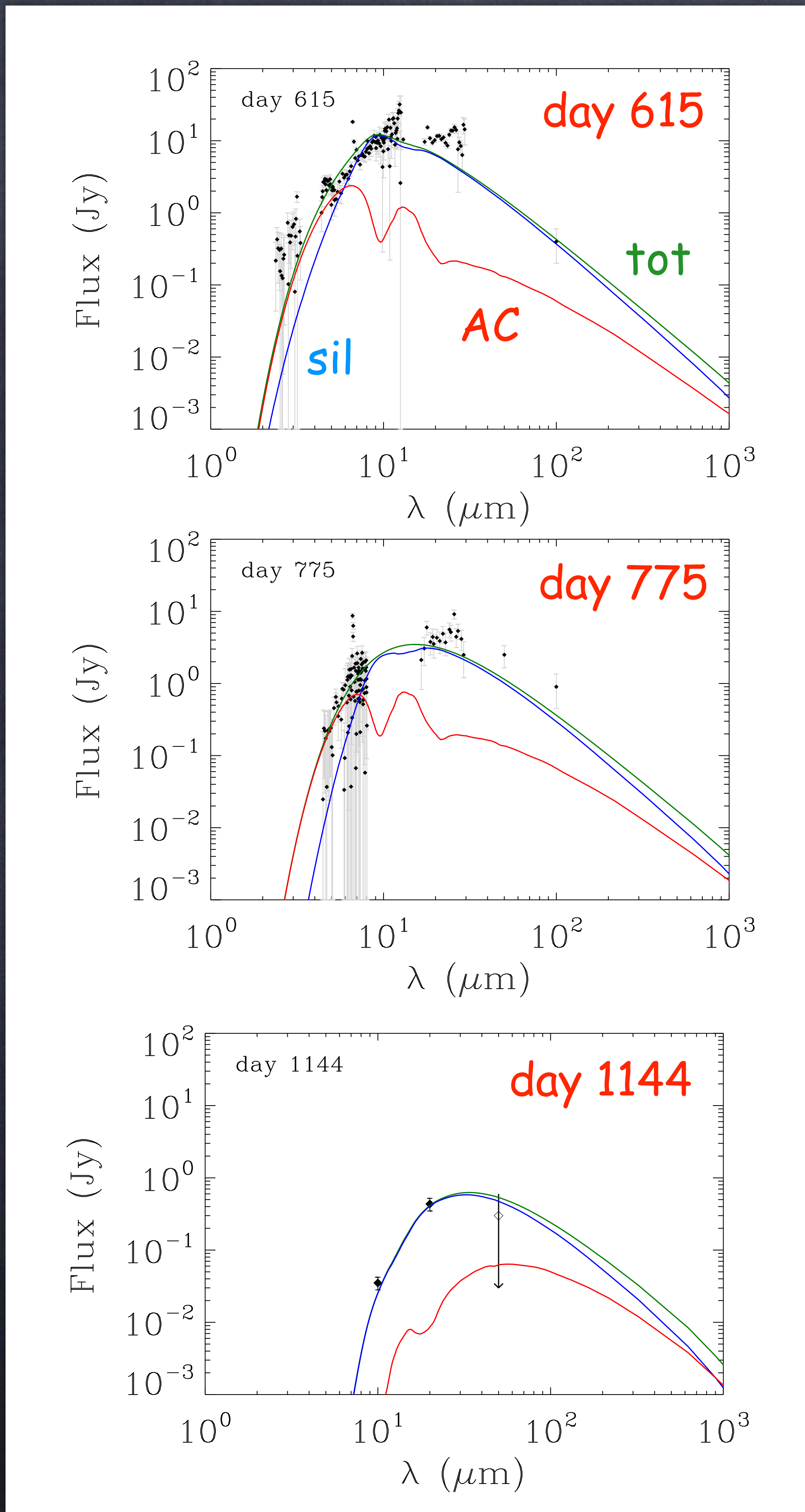


Problems with this evolutionary model

- Abundance violation
  - – Uses more material (primarily C) than available in ejecta
- Predicts no silicates from CCSN
  - - featureless spectrum interpreted as evidence for the absence of silicates
  - - Silicates are an important component in Cas A spectrum
  - - Silicate features absent at earaly times because of optical depth effects
- Cold accretion
  - - Most of the dust growth/formation occurs at $T < 500$ K
  - - Loosely bound mantles will not survive reverse shock
  - - Dust will not give rise to silicate features

Hiding the dust in optically-thick clumps

(Dwek & Arendt 2015)



T(sil) = 610 K

T(ac) =450 K

$\tau(20\ \mu m) \approx 9100$

$R_{ej} = 4.8 \times 10^{15}\ cm$

T(sil) = 330 K

T(ac) =330 K

$\tau(20\ \mu m) \approx 5700$

$R_{ej} = 6.1 \times 10^{15}\ cm$

T(sil) = 150 K

T(ac) =250 K

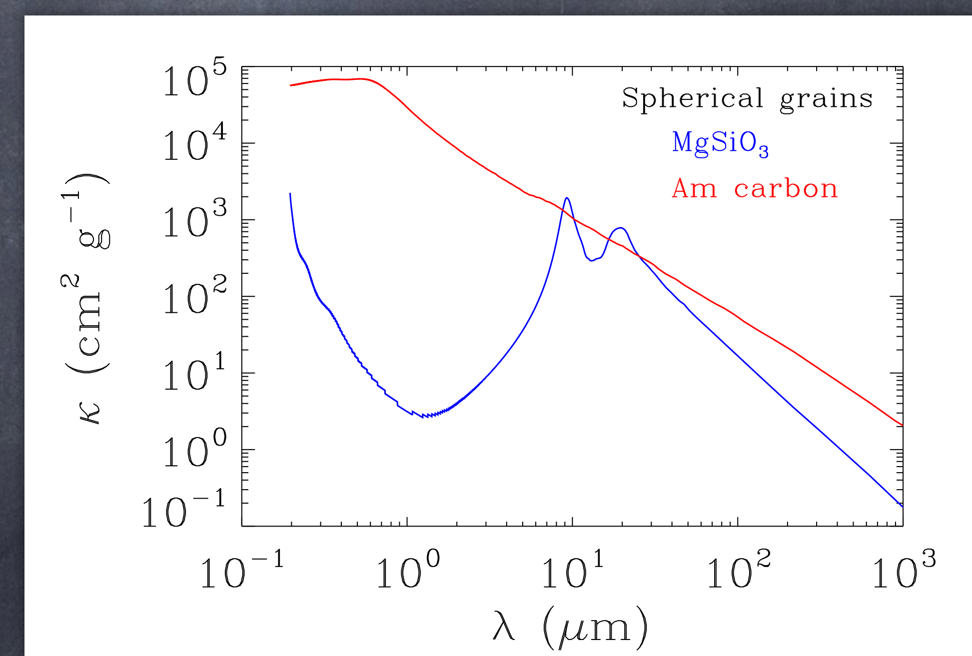
$\tau(50\ \mu m) \approx 250$

$R_{ej} = 9.0 \times 10^{15}\ cm$

fixed parameters:

M(Si), M(Mg), M(C), R_{ej}

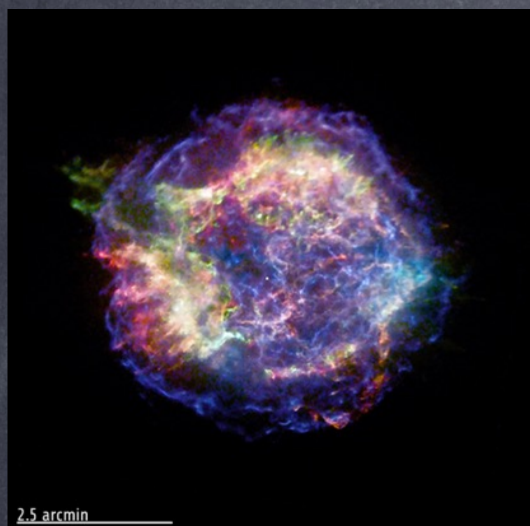
free parameter: T_{dust}

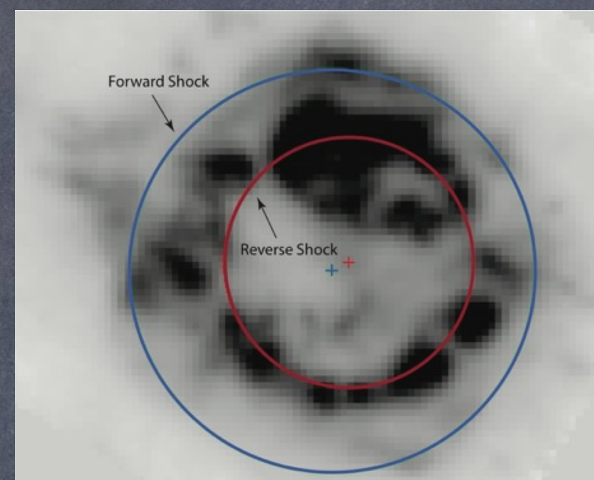


THE MASS AND COMPOSITION OF UNSHOCKED DUST IN CAS A SNR

How much dust will survive the reverse shock?

Cas A: emission from dust

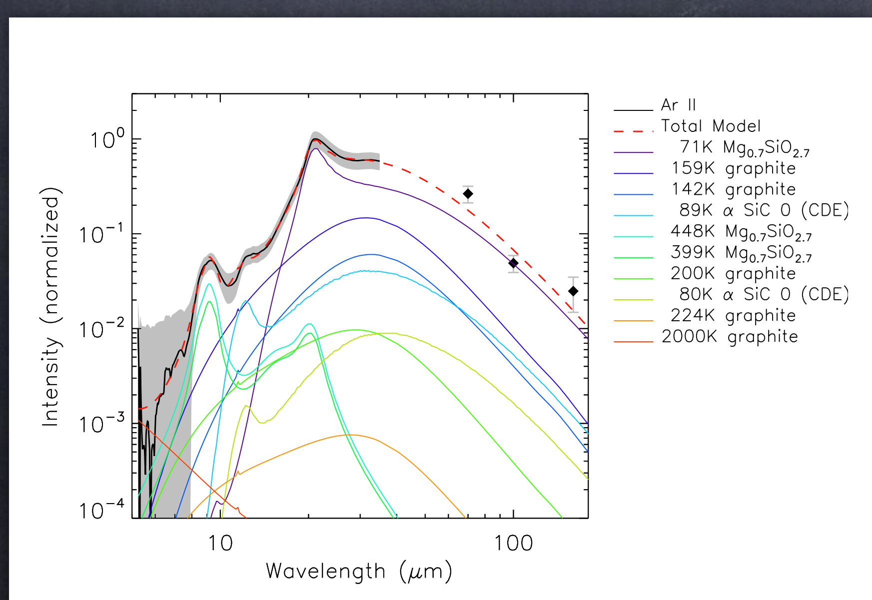




Arendt, Dwek + 2014

$M_d \approx 0.04\ M_{sun}$ shocked dust

$M_d \approx 008\ M_{sun}$ not yet shocked dust

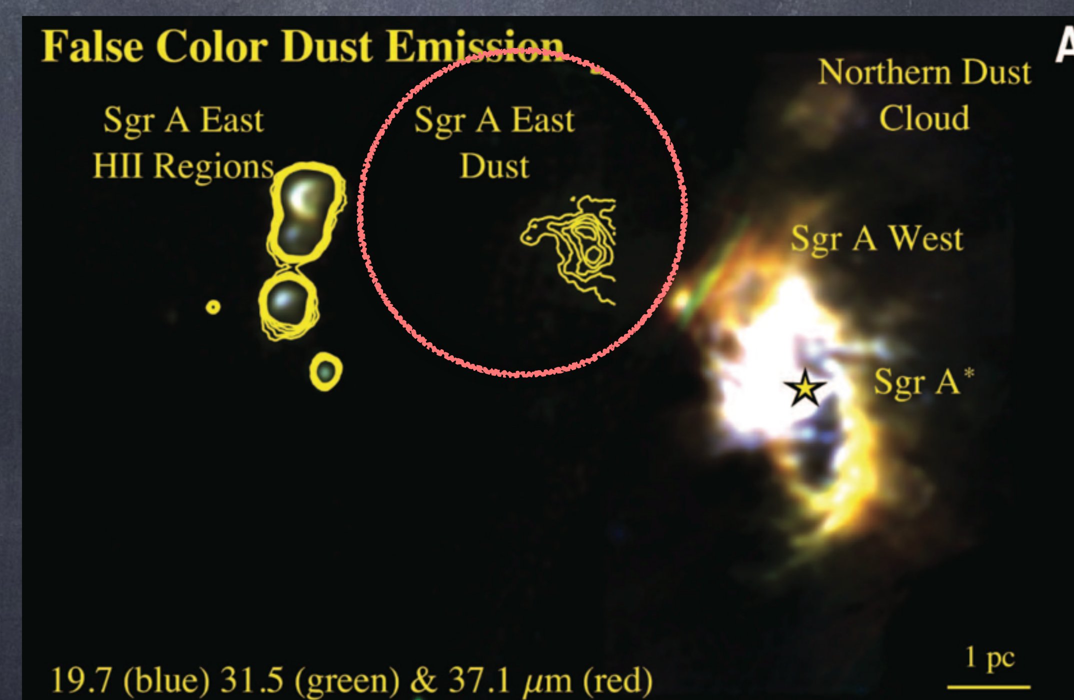


Old SNR near Galactic center

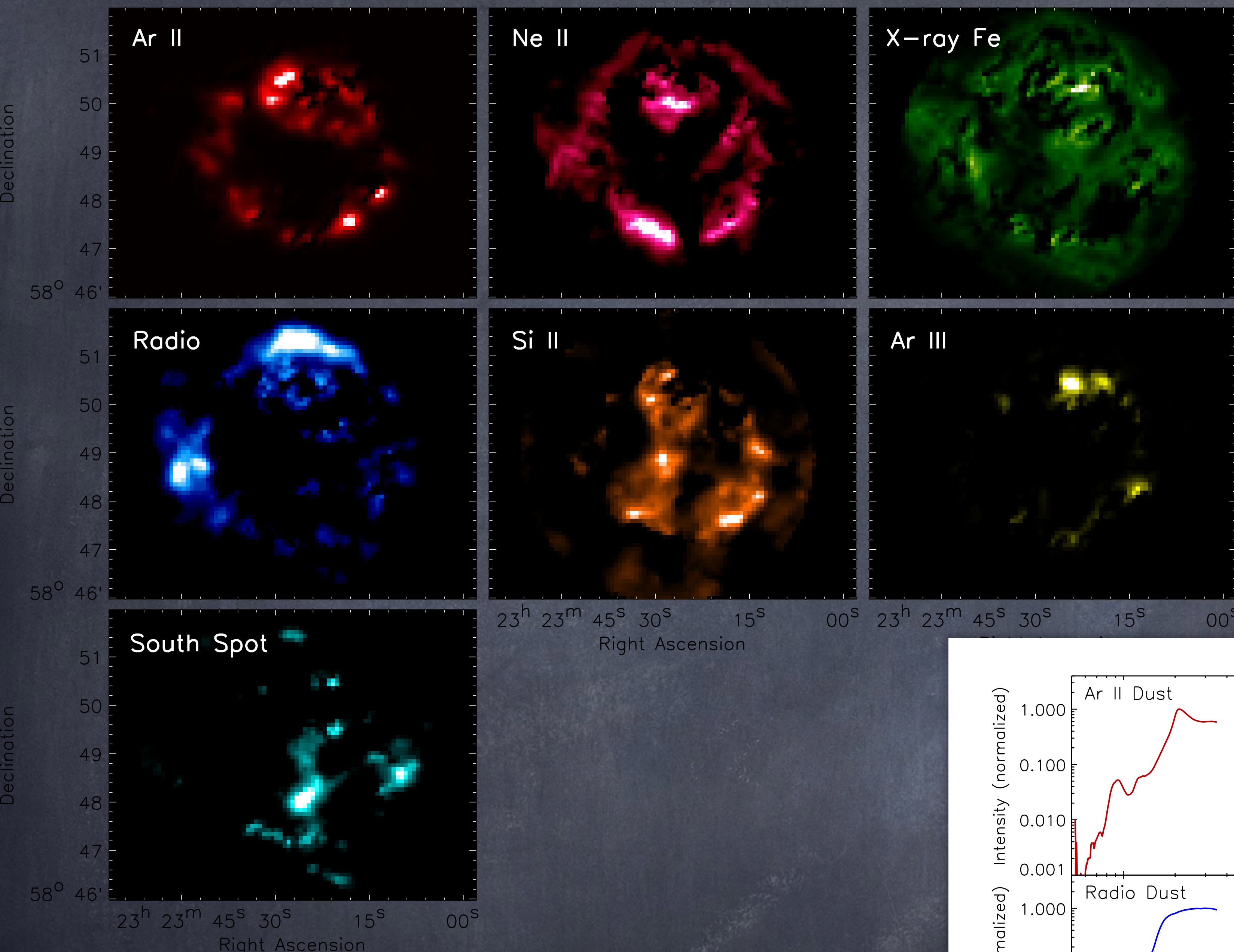
Lau et al. 2015

$M_d \approx 0.02\ M_{sun}$

shocked dust



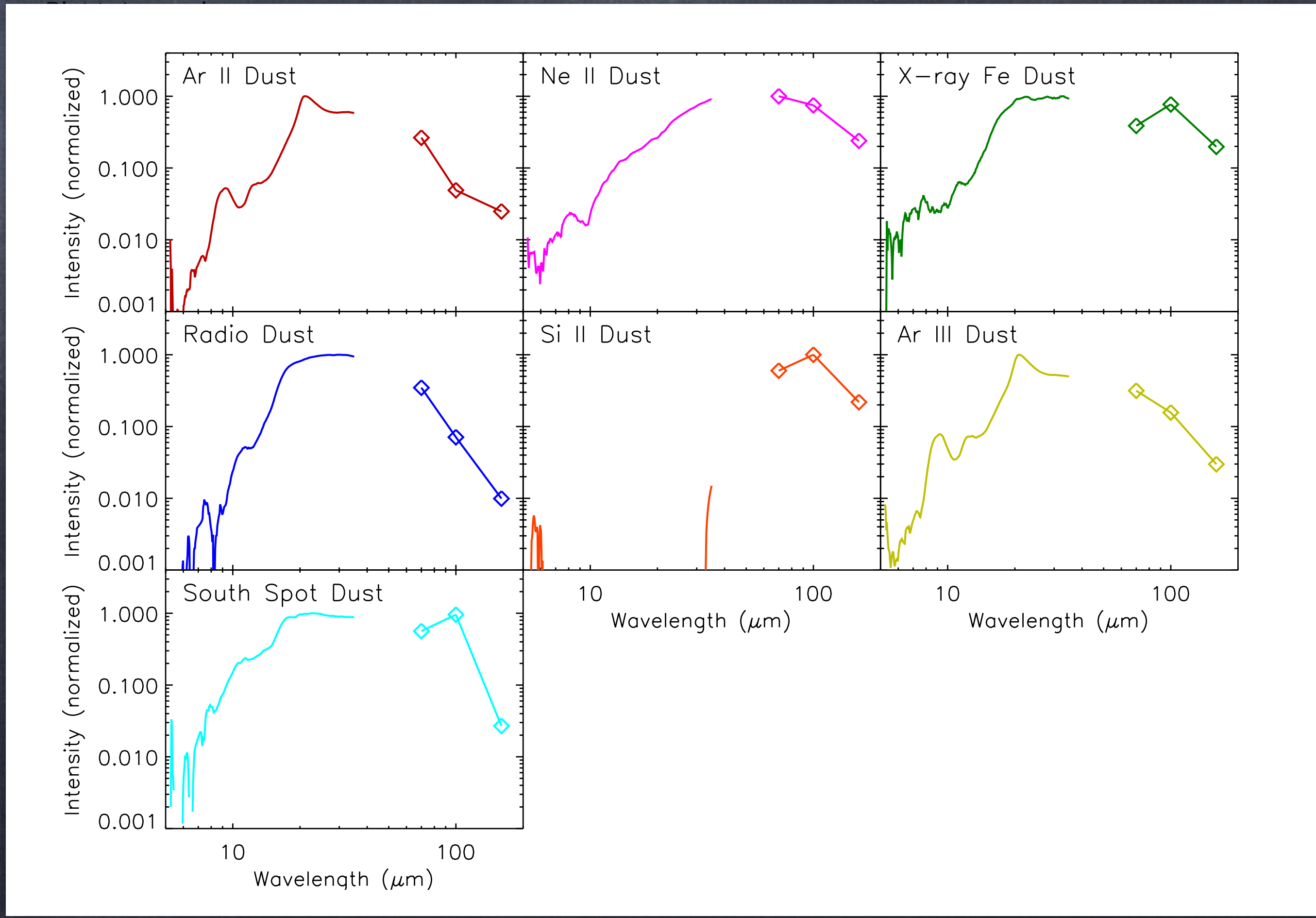
Line emitting regions



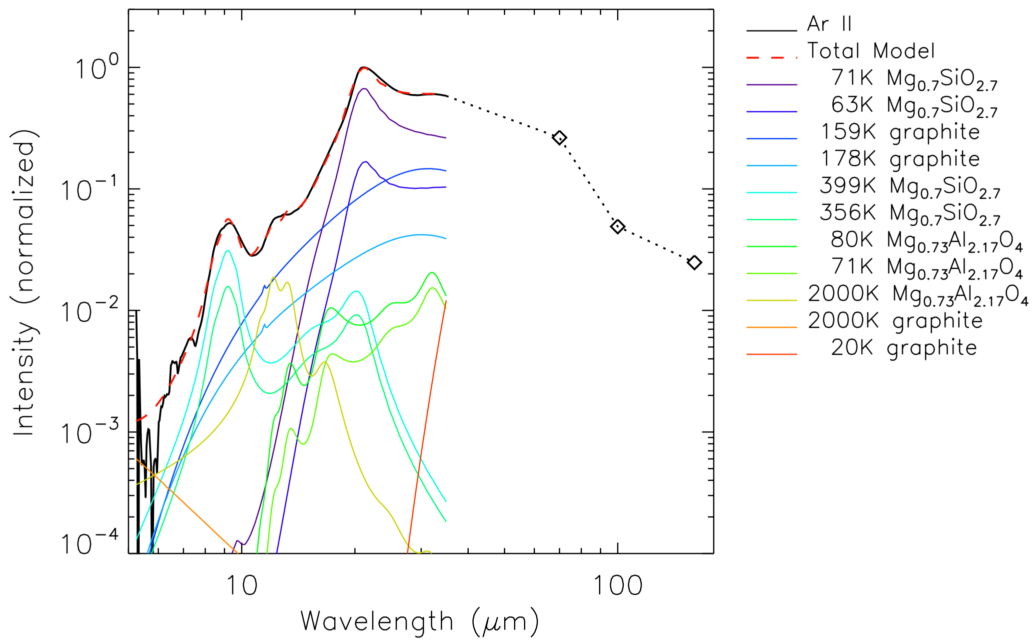
Spatial decomposition of the IR dust emission in Cas A

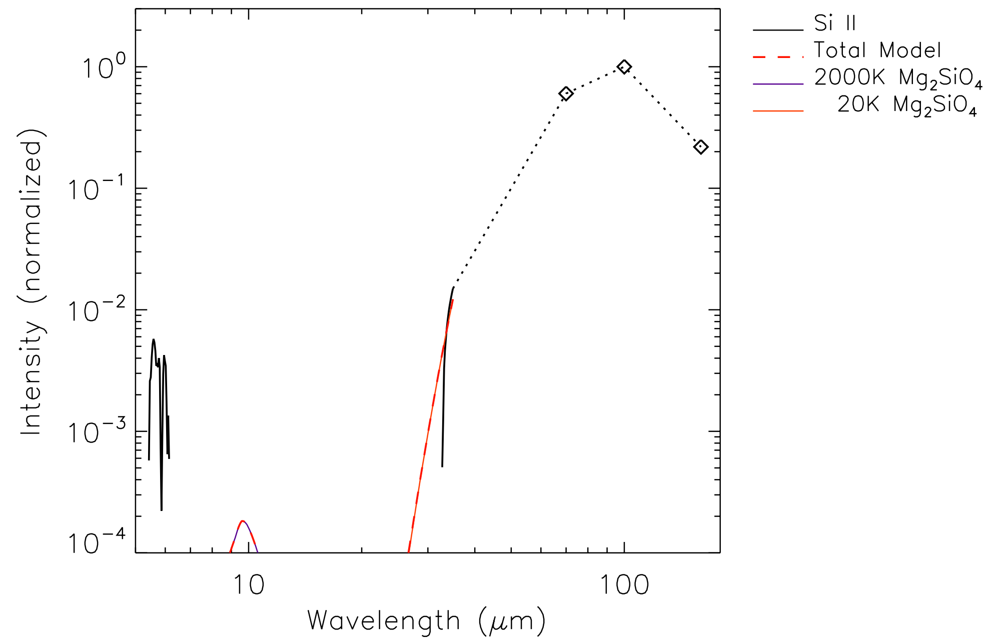
Arendt, Dwek + 2014

Dust emission spectra from the different regions



Determining the composition of the unshocked dust in Cas A





Shocked dust

- correlated with ArII emitting region
- contains fraction of dust mass
- composition dominated by silicate dust

Unshocked dust

- correlated with SiII emitting region
- contains most dust mass
- composition UNKNOWN

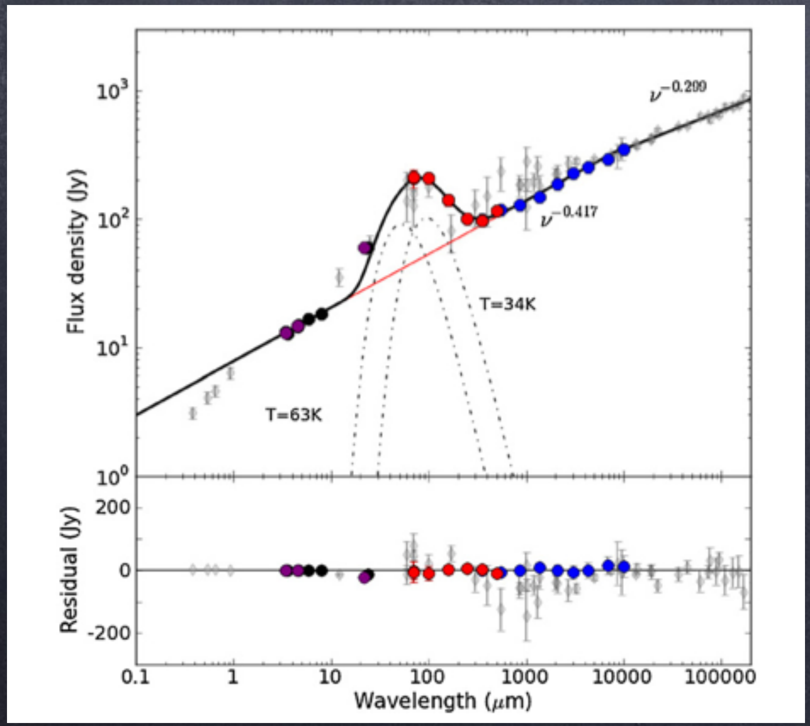
(see also Barlow et al. 2010)

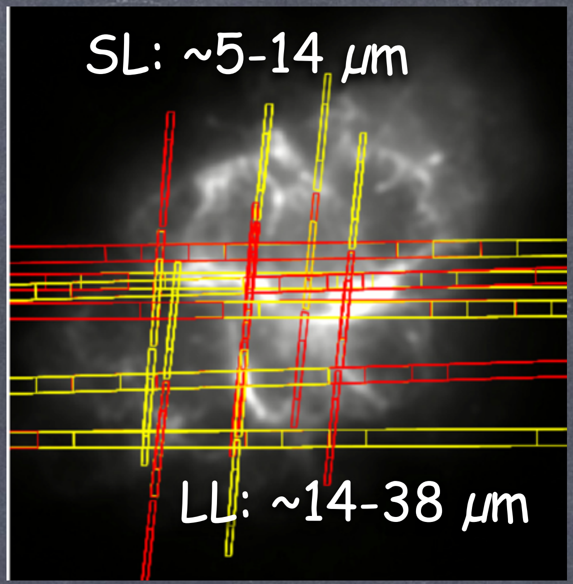
THE MASS AND COMPOSITION OF DUST IN THE CRAB NEBULA

The Crab Nebula

$M_{dust} \approx 0.24\ M_{sun}$

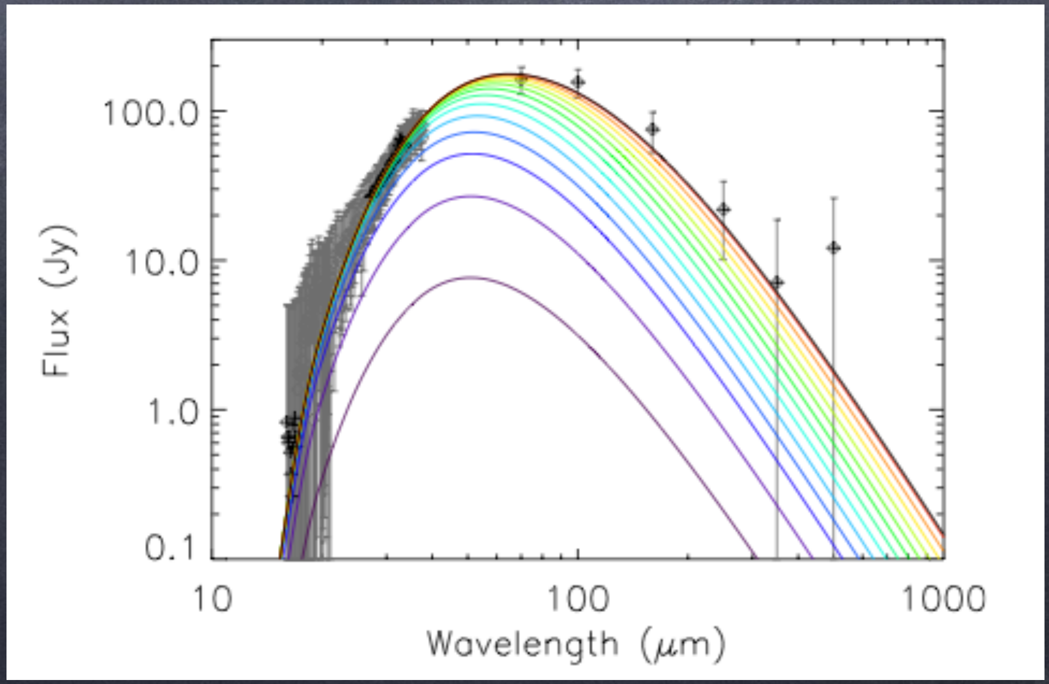
(Gomez et al. 2012)





$M_{dust} \approx 0.12\ M_{sun}$

(Temim et al. 2012)



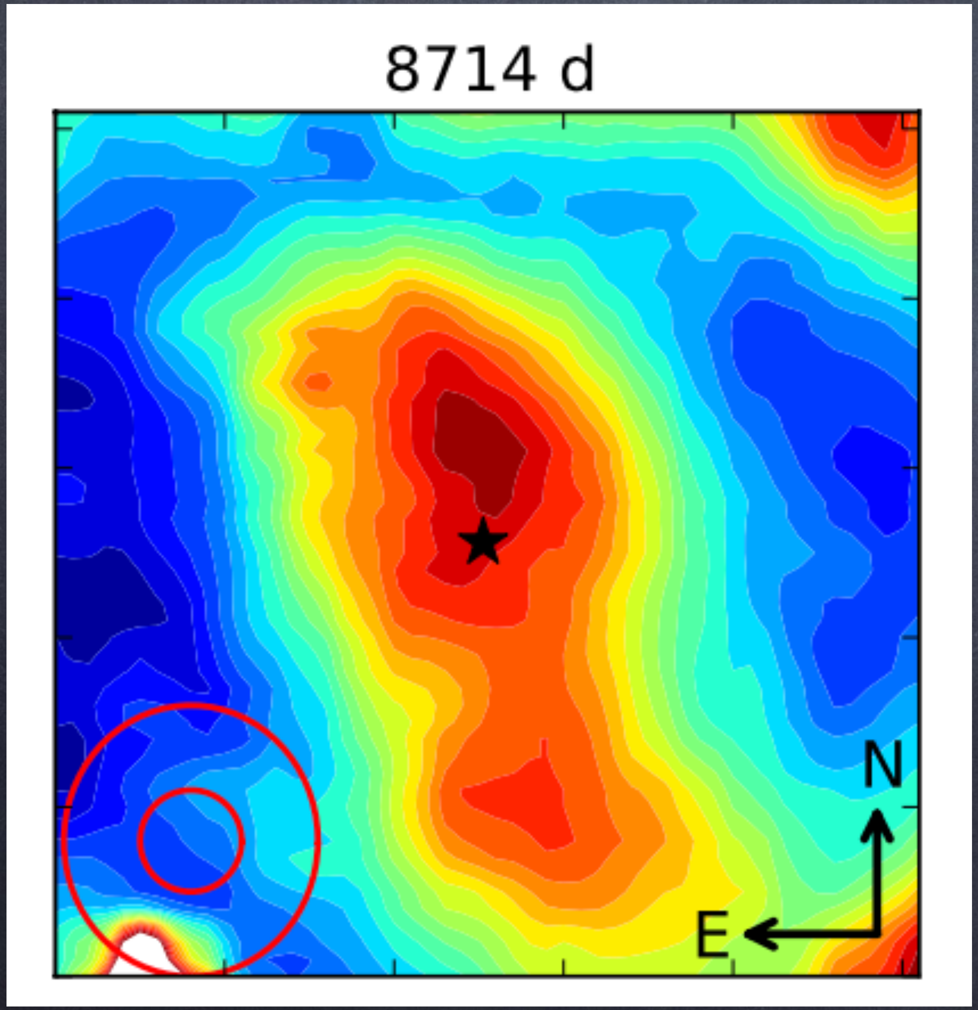
OBSERVING GRAIN DESTRUCTION BY THE REVERSE SHOCK IN SN1987A

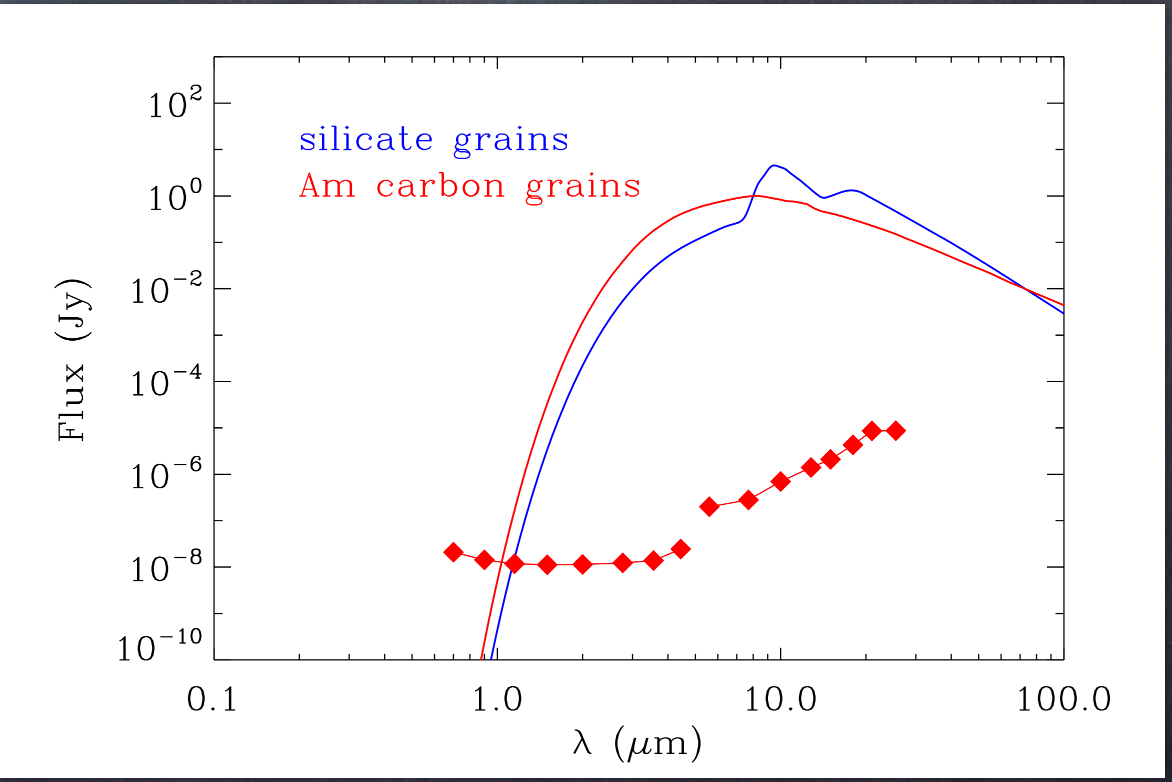
Observing the grain destruction phase in JWST

Ejecta morphology:
Ejecta heated by X-ray from the reverse shock
(Larsson et al. 2013)

Dust collisionally heated in a shocked O-rich gas.
Dust lifetime ~ 10 days

Assuming: $M_{dust} = 10^{-5}\ M_{sun}$
$T_{dust} = 450$ K

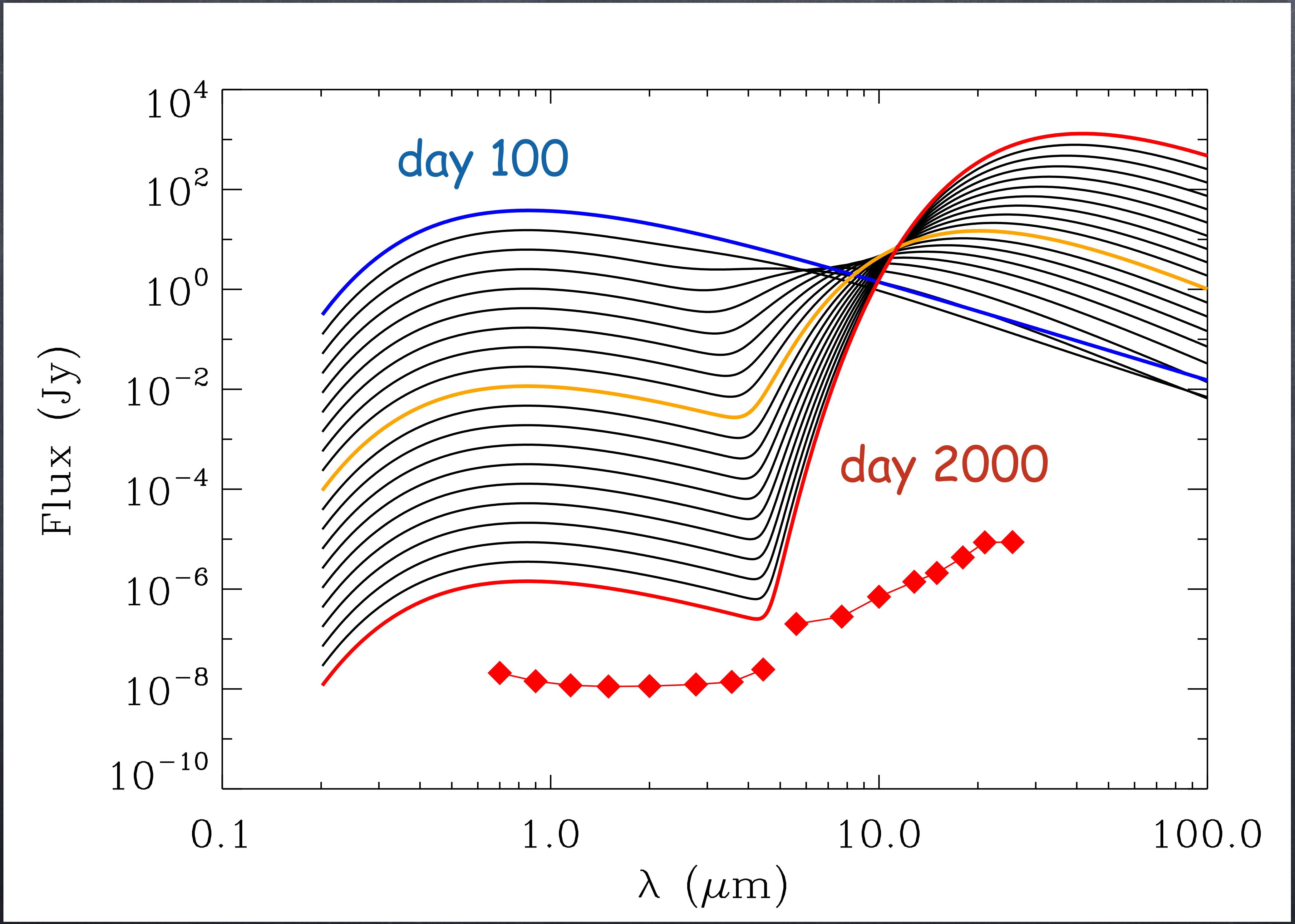




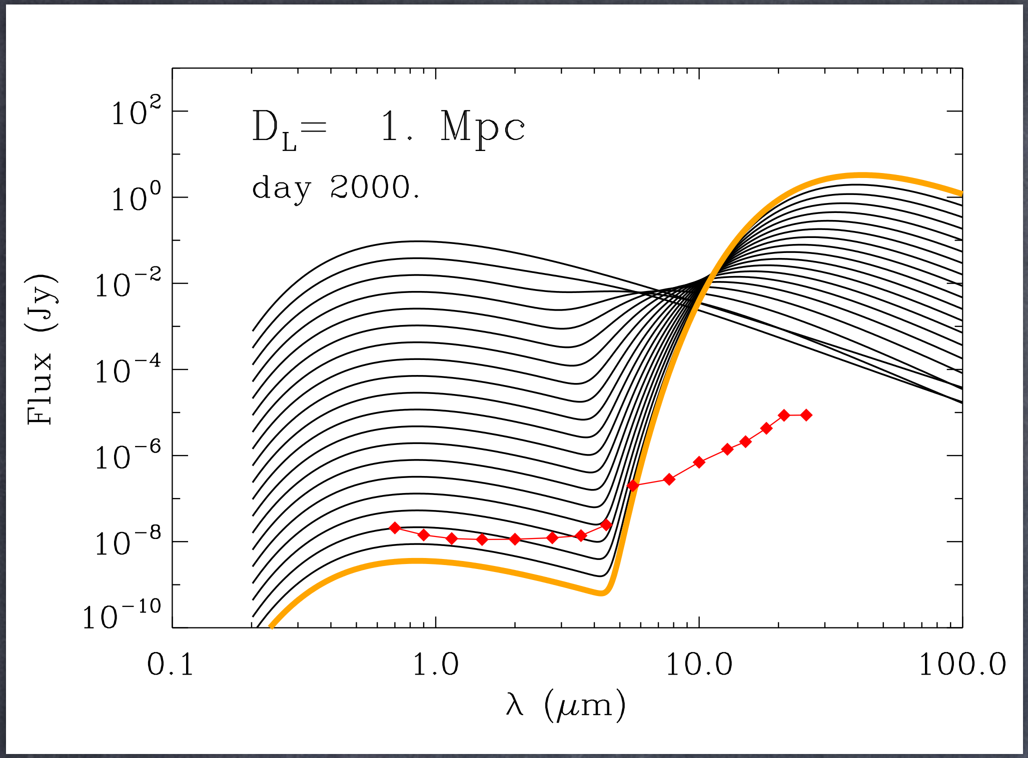
CATCHING DUST FORMING SUPERNOVAE INFRARED HANDED

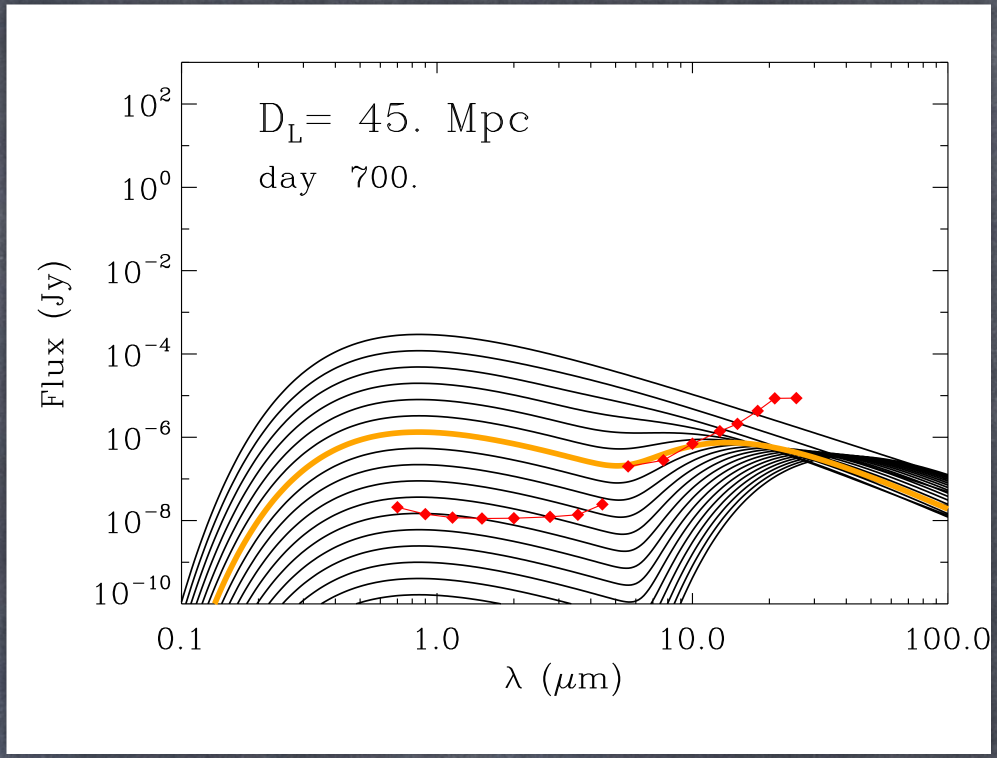
(looking at SN
that exploded in
the last ~ 6 years)

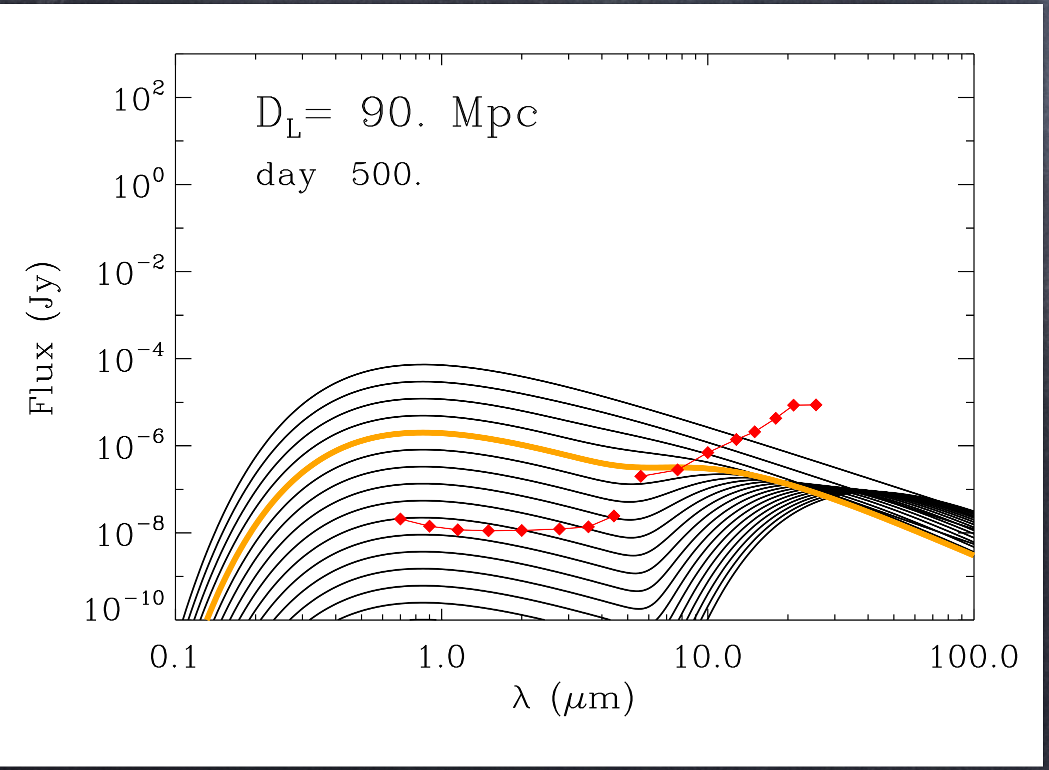
The evolution of the IR spectrum of SN1987A

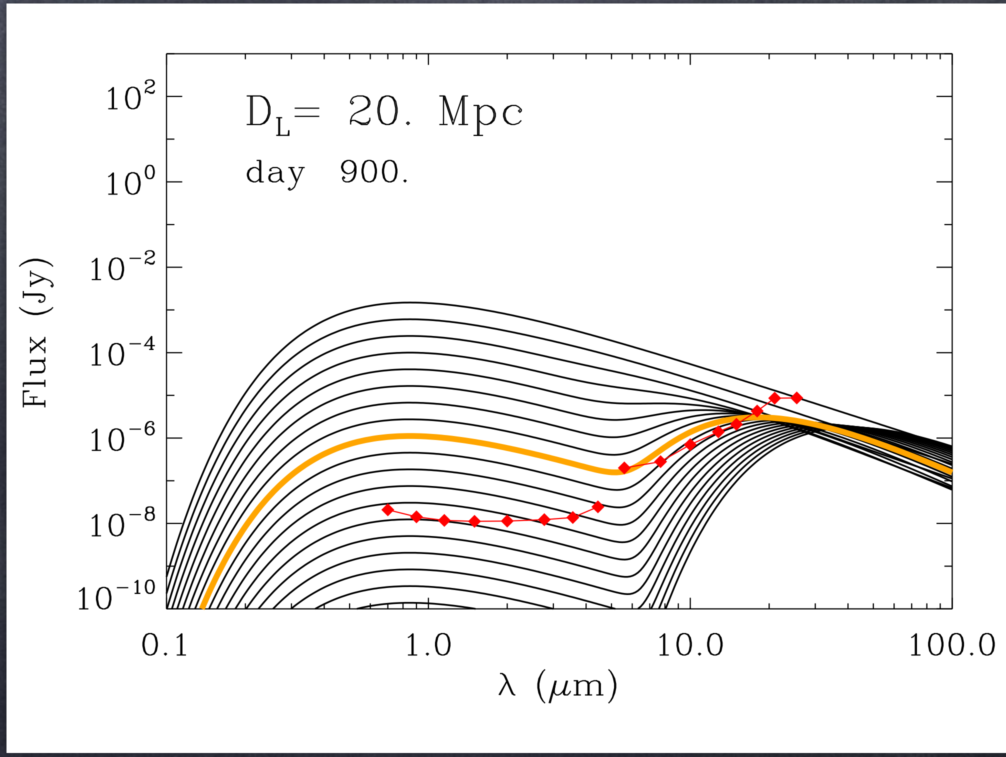


Observing the dust formation phase with JWST









SN dust Science with JWST

- Observations of SN 1987A
  - Grain destruction by reverse shock
  - Nature of dust, silicates of carbon, in the ejecta
- Observations of SNR
  - Cas A: mass and composition of unshocked dust
  - Crab Nebula: mid-IR mapping, spectroscopy?
  - yield of dust that survives the reverse shock
- Observations of young dust-forming SNe
  - looking at SNe that exploded withing the last ~ 3yrs
  - initial dust yield from CCSNe


END