Shock-induced formation and survival of dust in the dense CSM surrounding Type IIn supernovae

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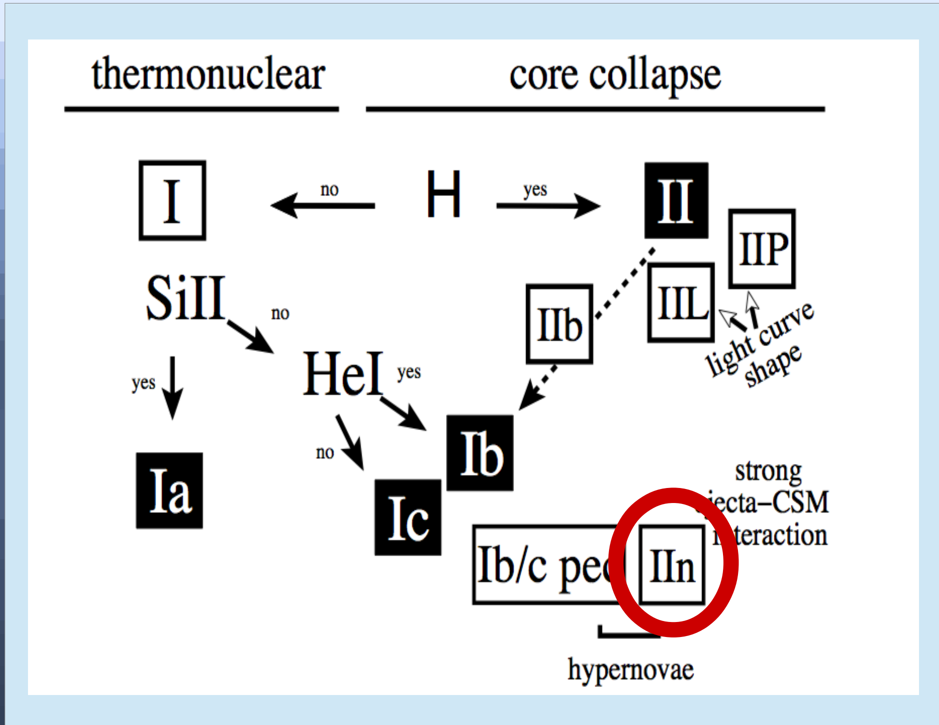
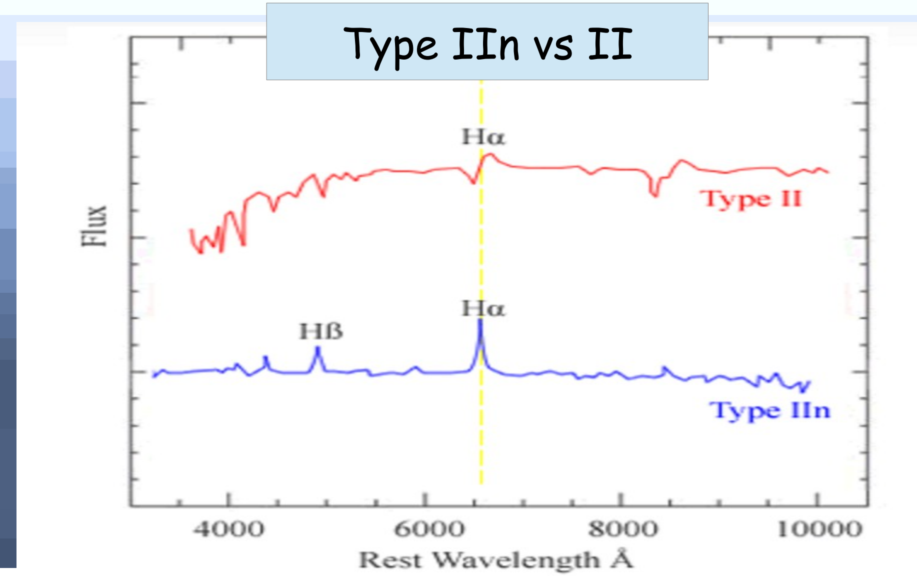
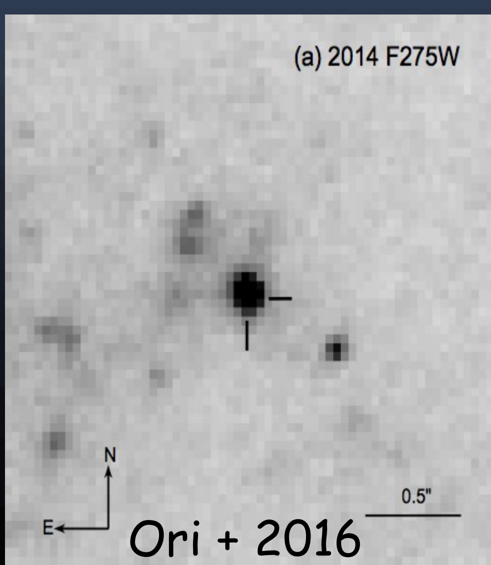
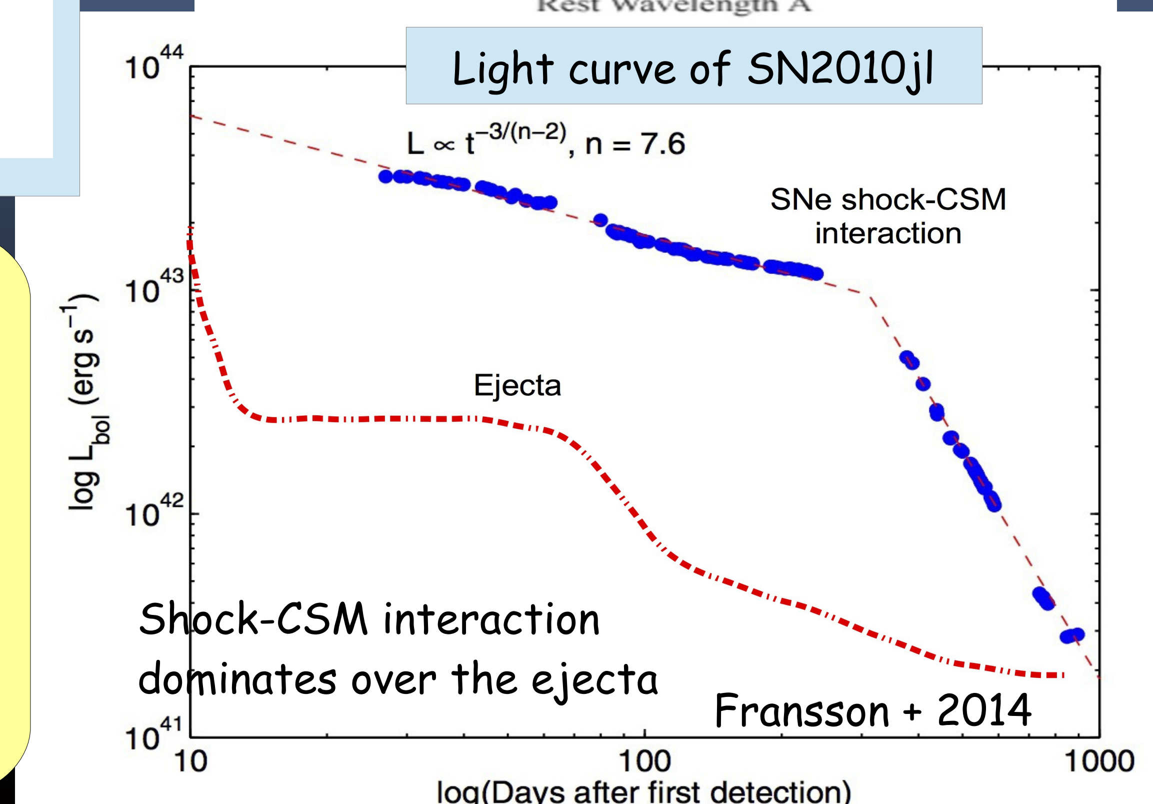
Type IIn supernovae & SN2010jl







Discovery:
Nov 2010
Abs. Mag -20
UGC 5189A
(49 Mpc)
CSM > 10 M_{sun}
(Ofek + 2013)



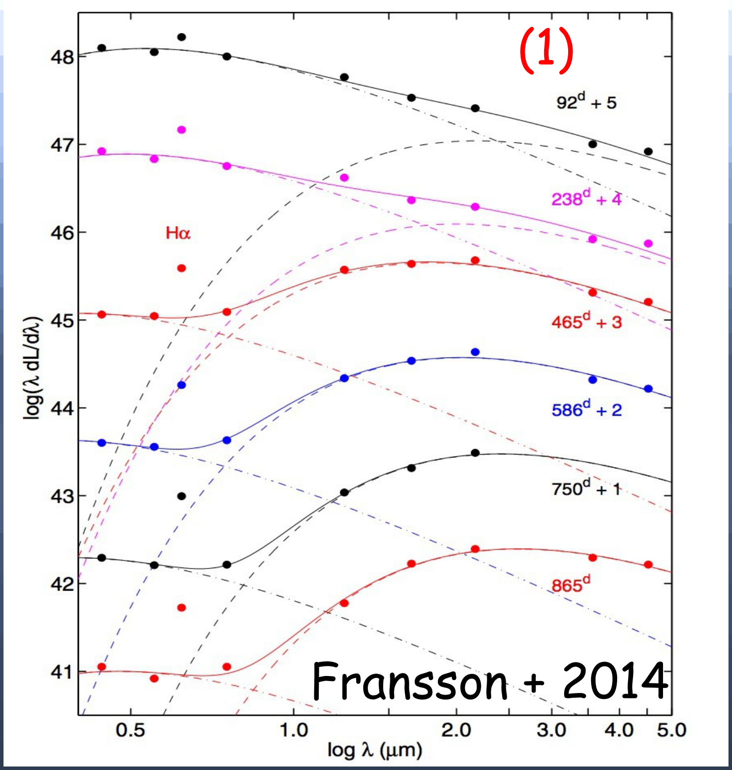
UVO & NIR studies of SN 2010jl

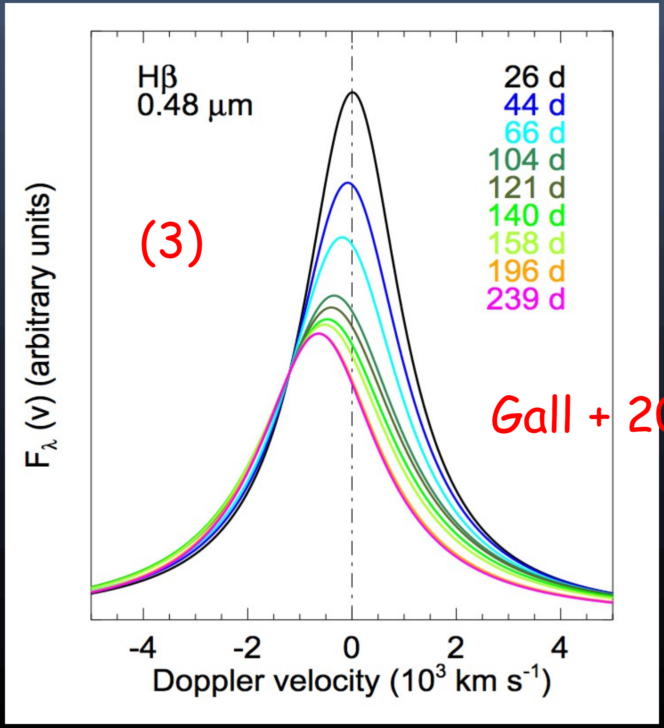
1) IR excess due to thermal emission from hot dust

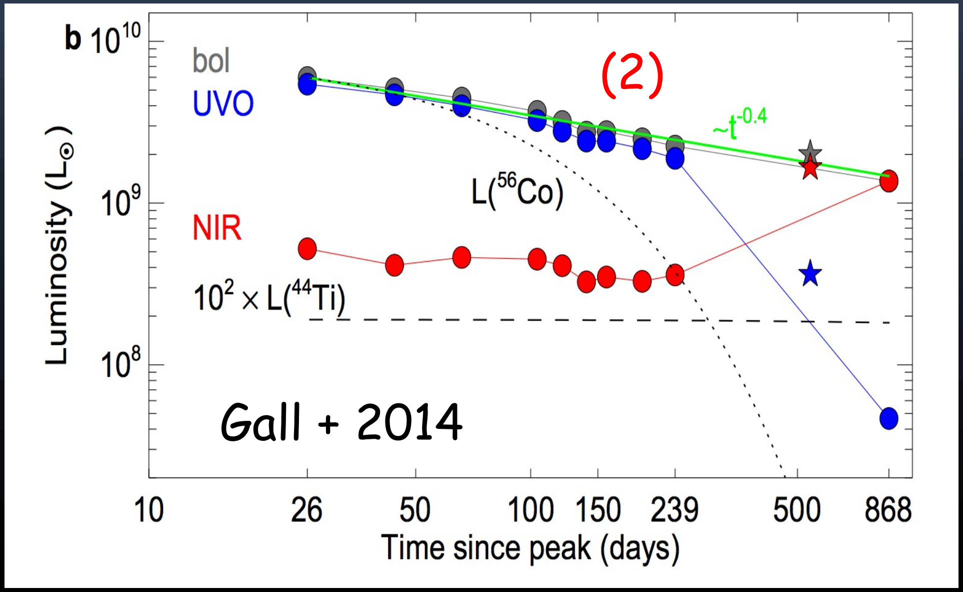
2) Increased rate of fading of optical flux

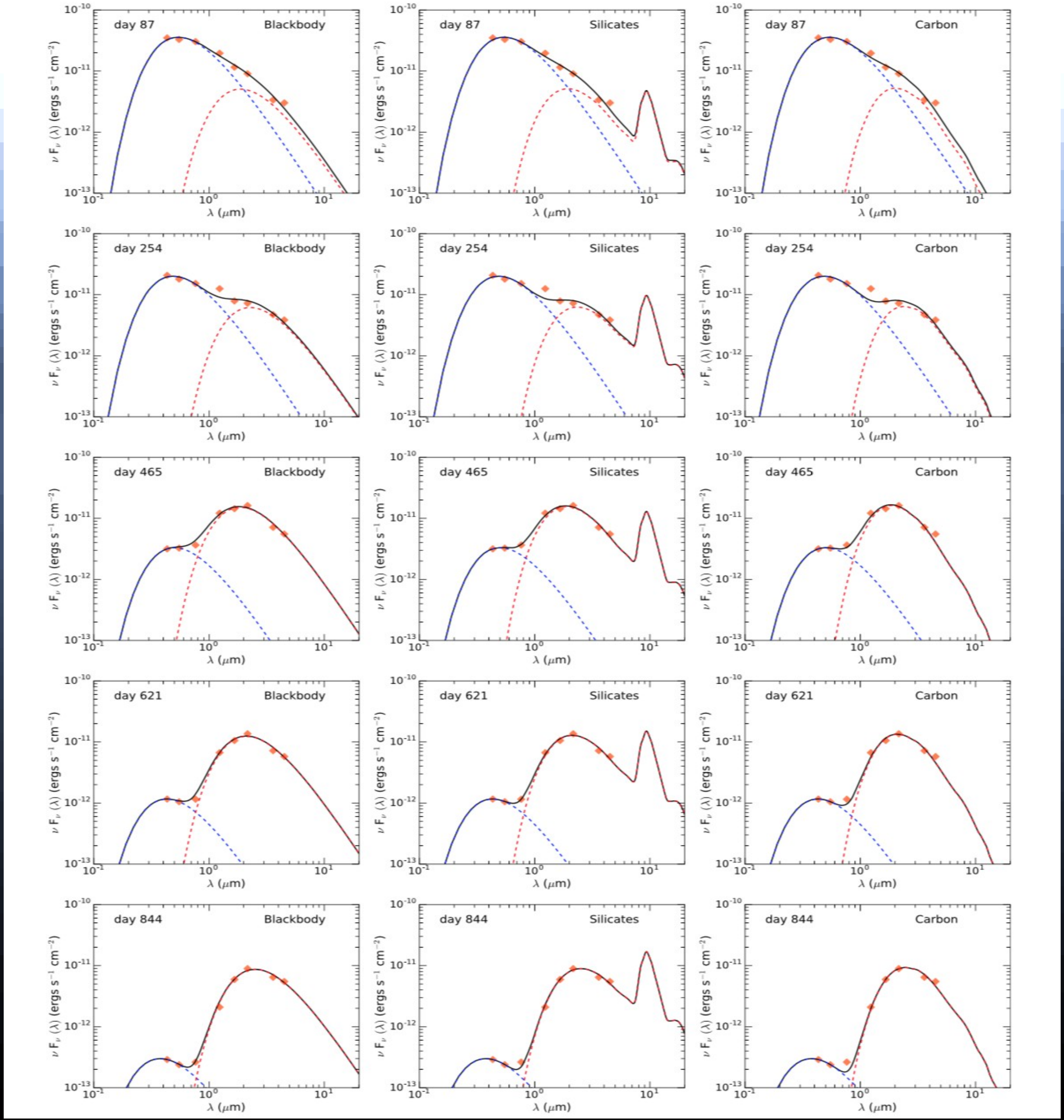
3) Progressive blueshift of emission lines

Early traces of dust formation??







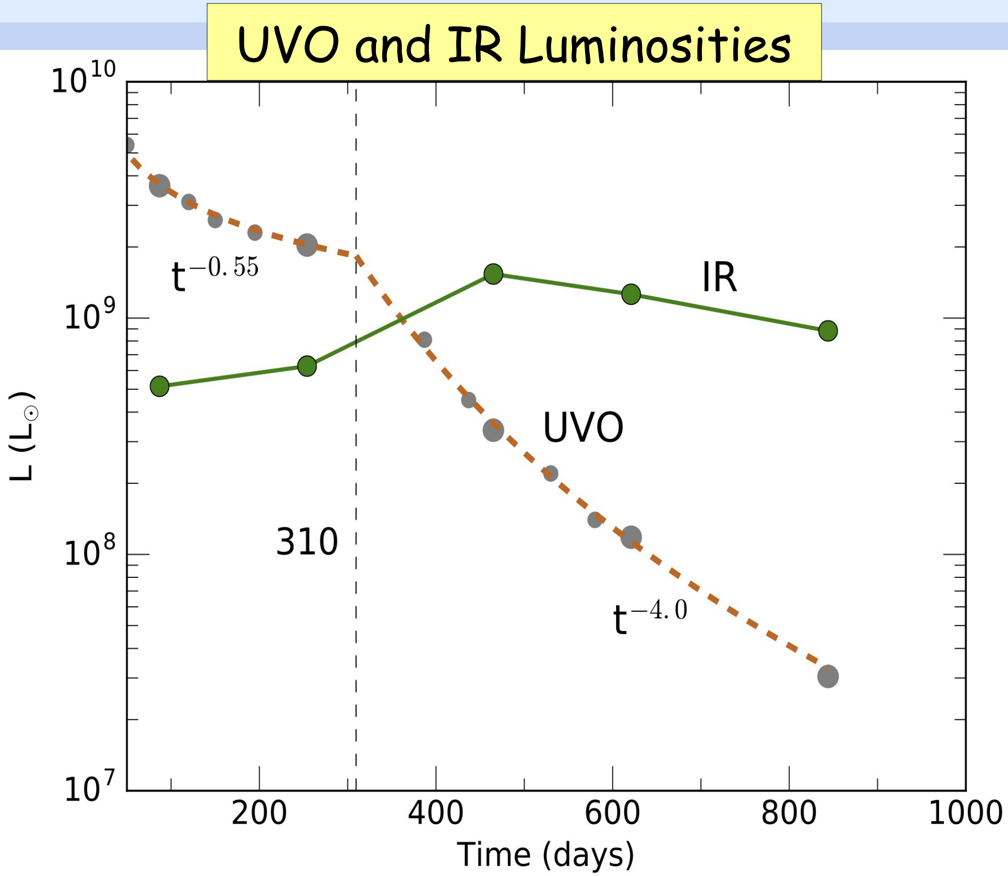


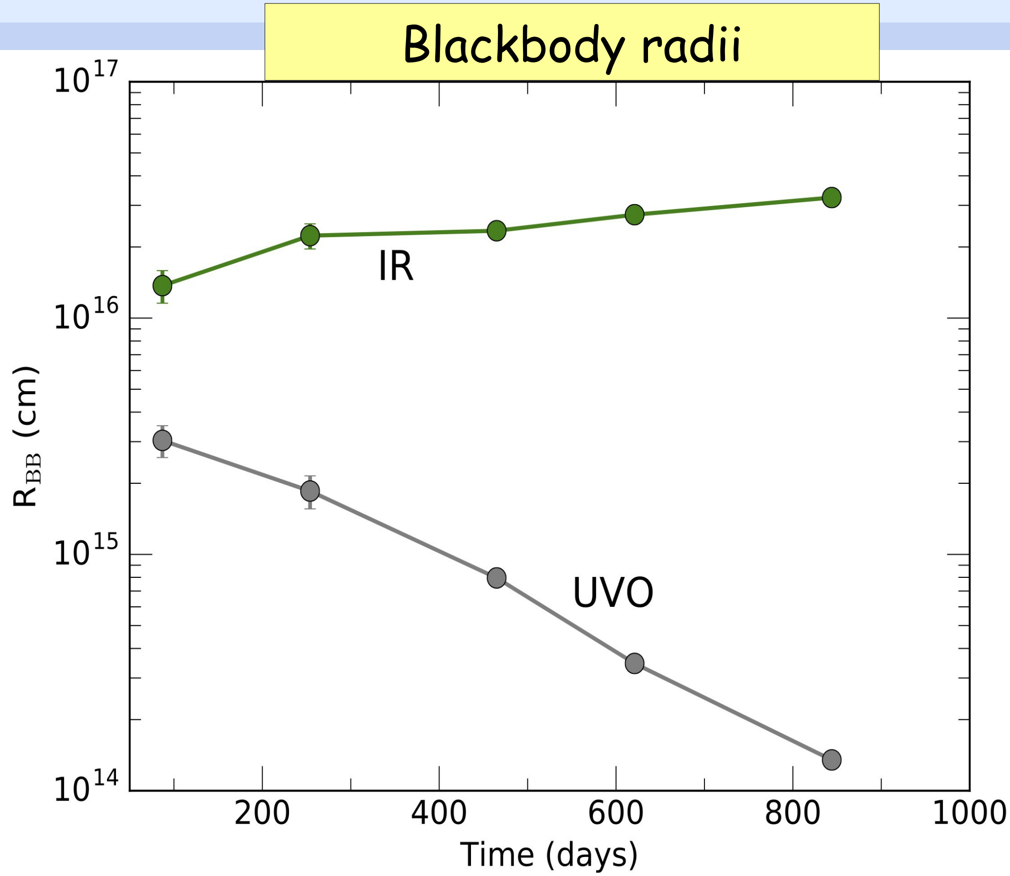
Fitting the optical and NIR spectra using 2-component Fit-model

UVO component:
- Blackbody

IR component:
a) Blackbody
b) Ast. Silicate
(optically thin)
c) Am-Carbon
(optically thin)

Parameters derived from the fit





… and we also calculate the temperatures of the spectra
And the possible dust masses

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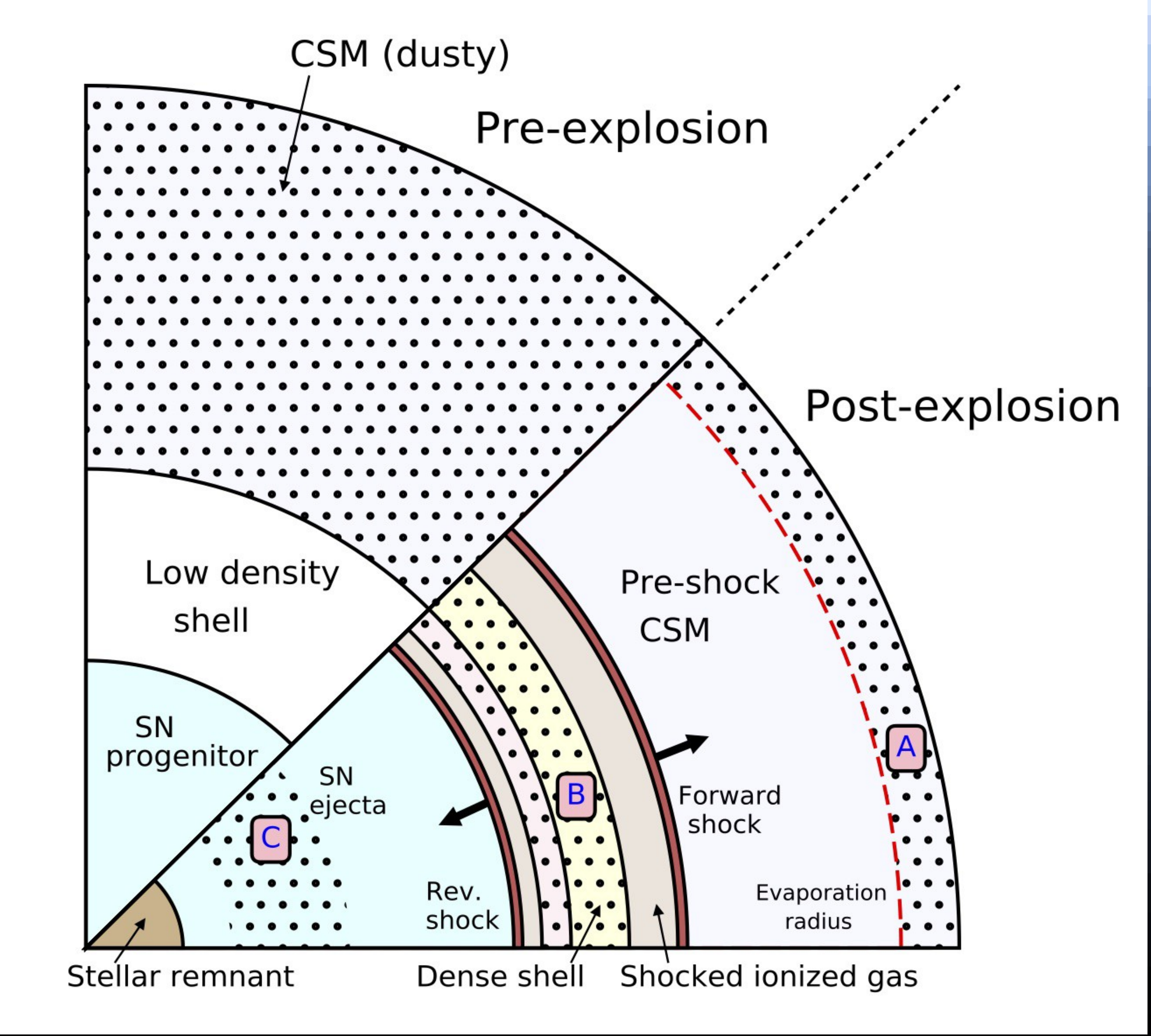
Pre-explosion progenitor & post-explosion Type IIn SN



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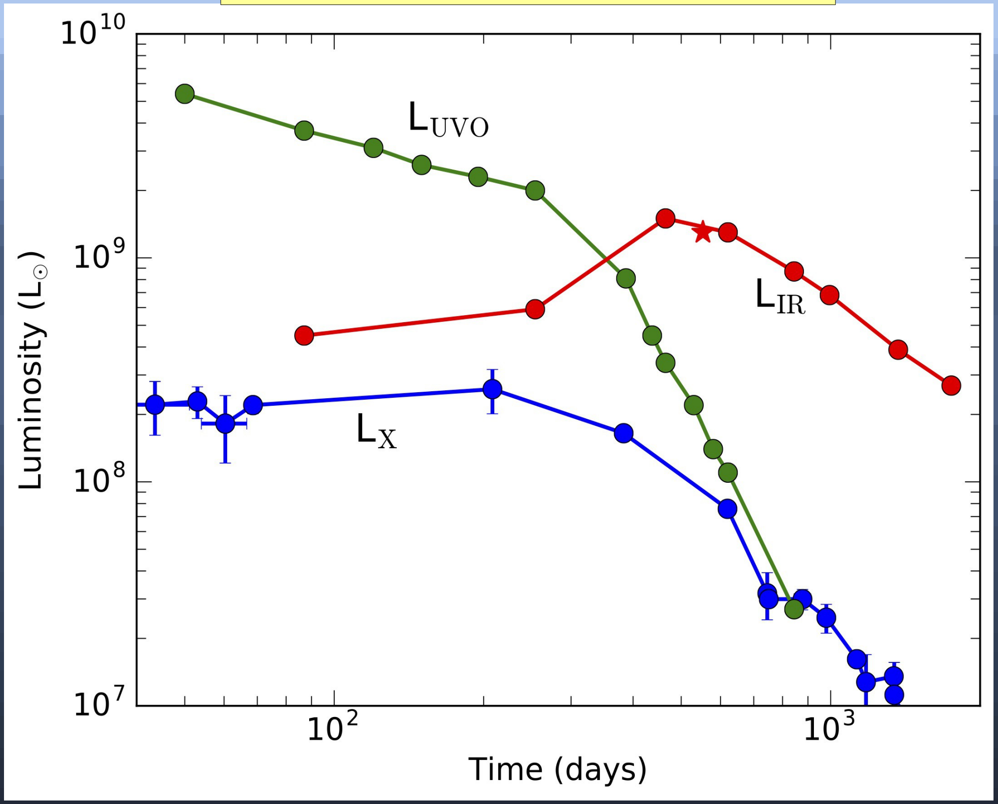
Constraints provided by X-rays

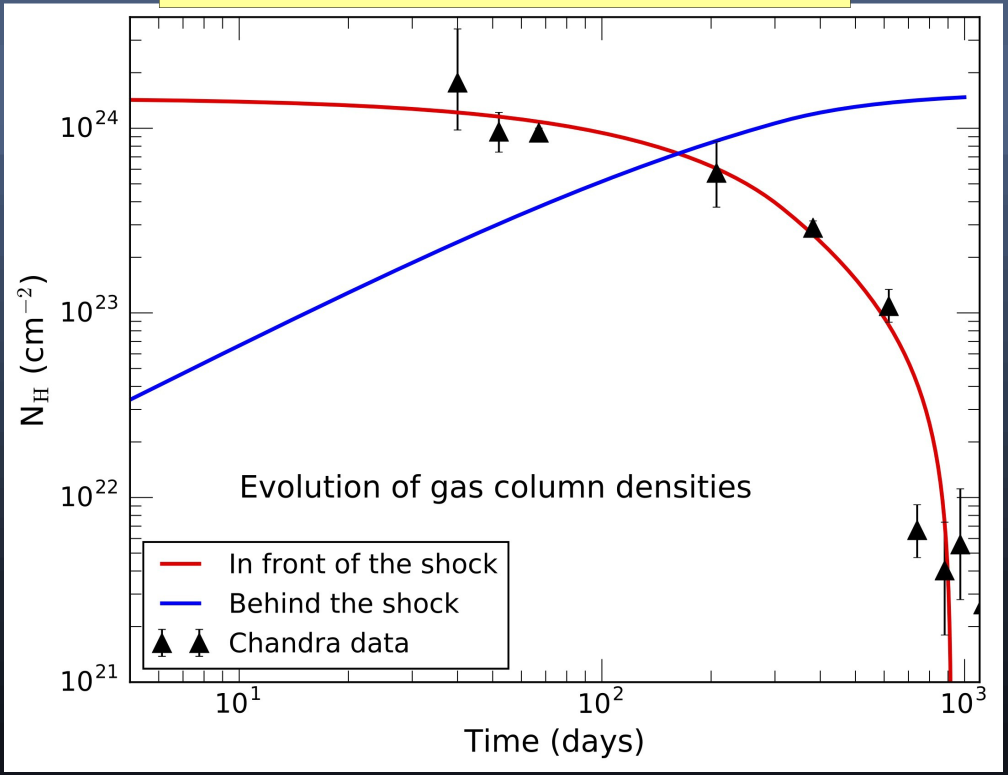
X-ray Luminosity



X-ray data: Chandra + 2015

Best-fit scenario of the H-column densities along the line of sight obtained from X-ray observations

Evolution of column densities



Shock velocity, shock radius,
CSM density at shock front and the mass distribution are derived using the luminosity and the column density evolution

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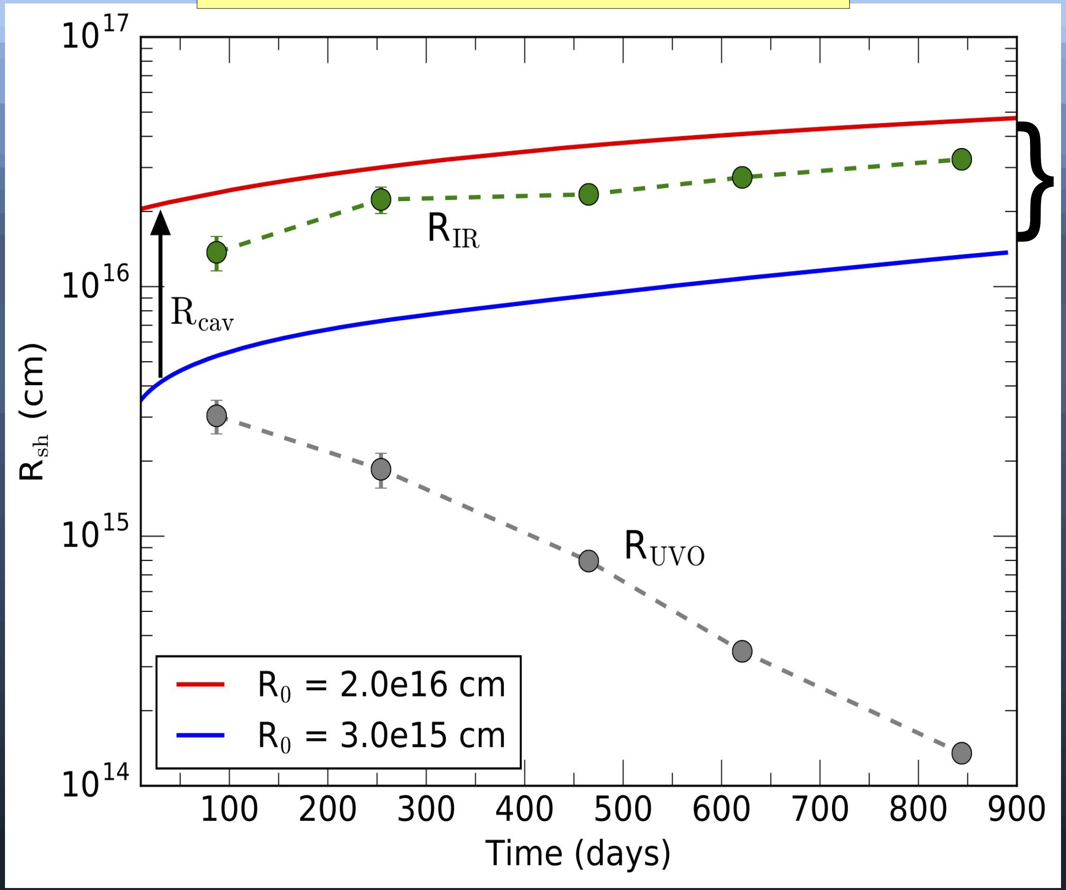
Presence of a low-density shell

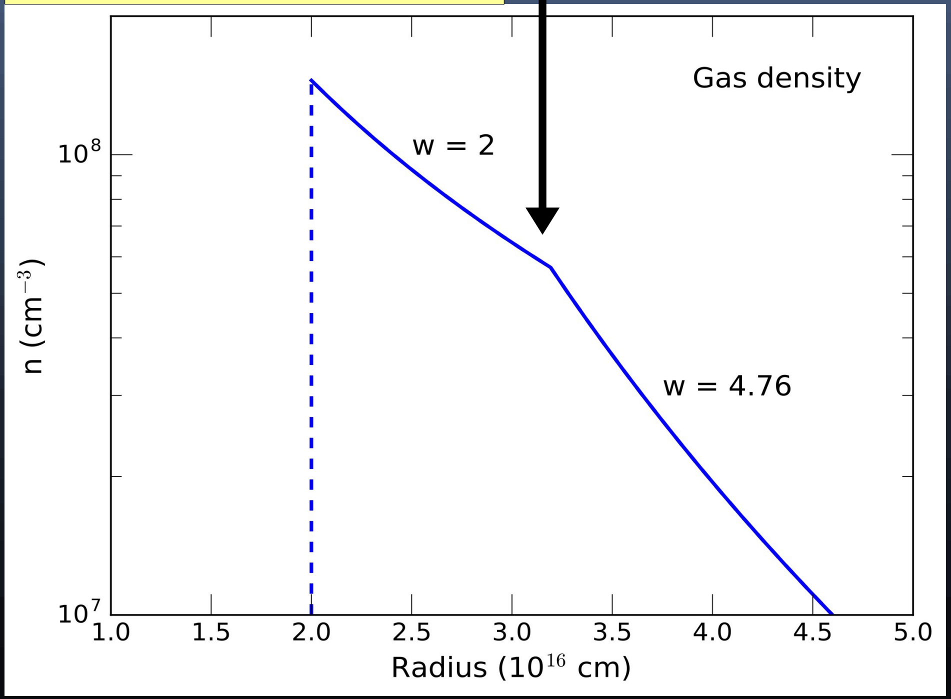
Shock_R & dust BB radius



offset

And a break in the density-index

CSM density profile



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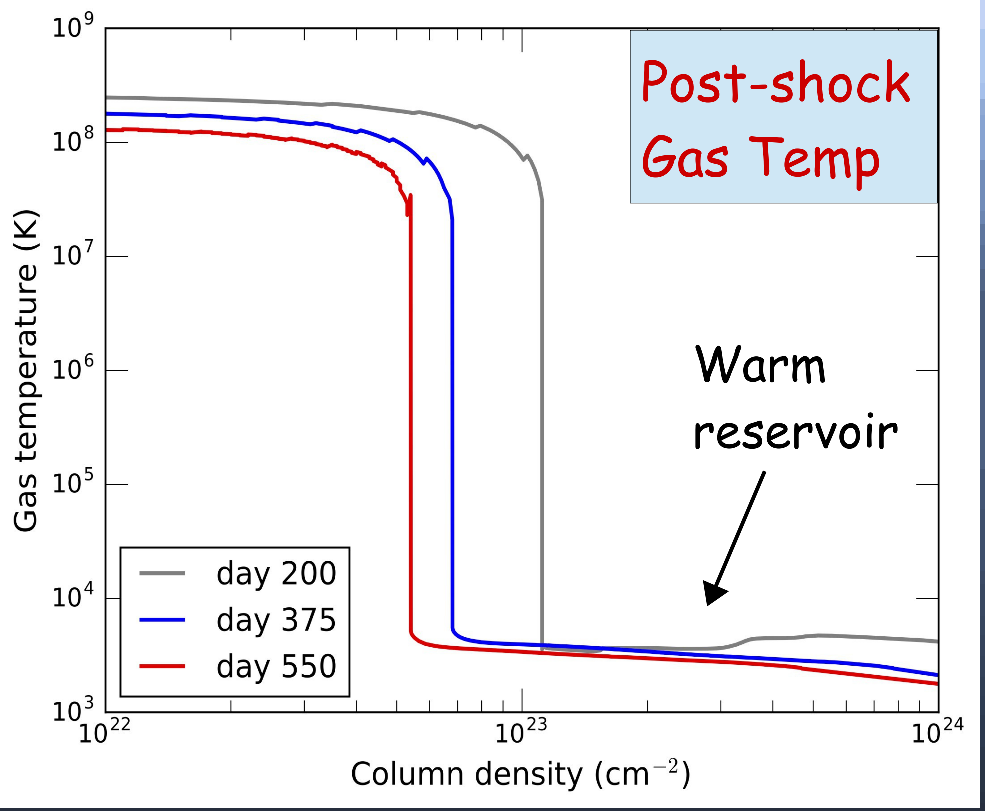
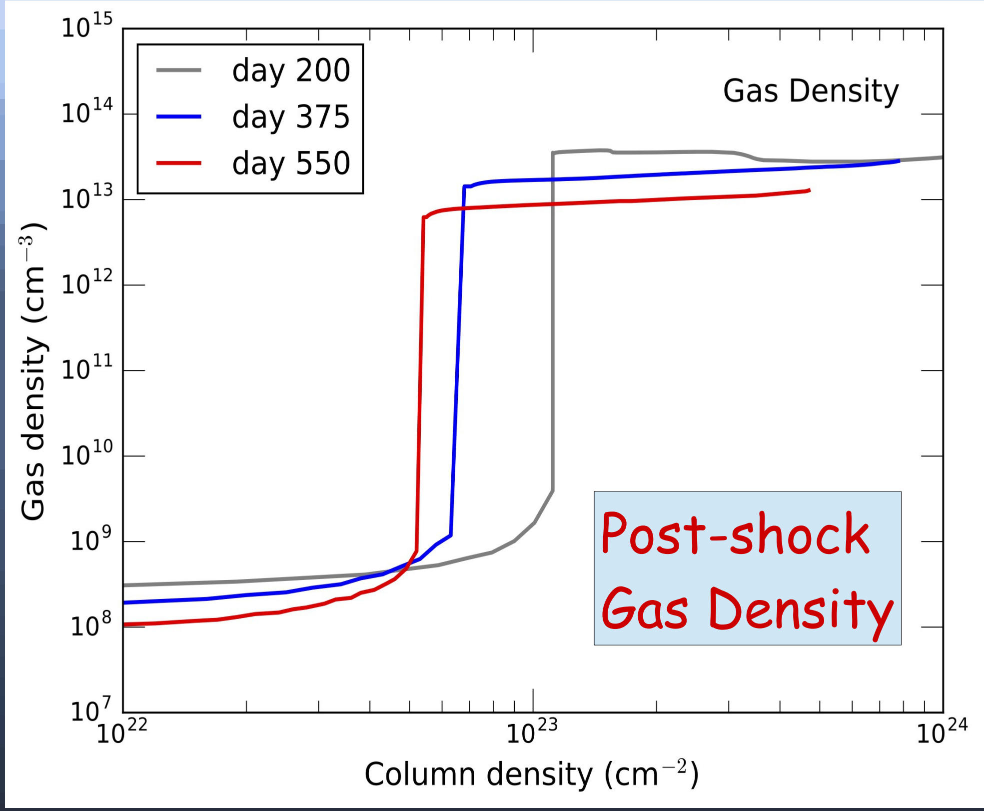
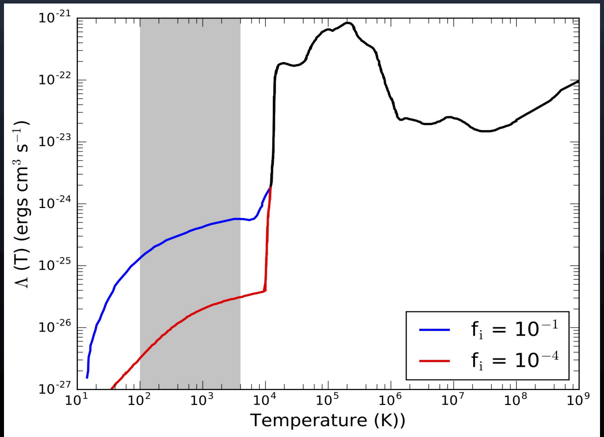
Cooling of the post-shock gas

Solving the shock-equations





Cooling function at different ionization fractions



Dalgarno & McCray 1972

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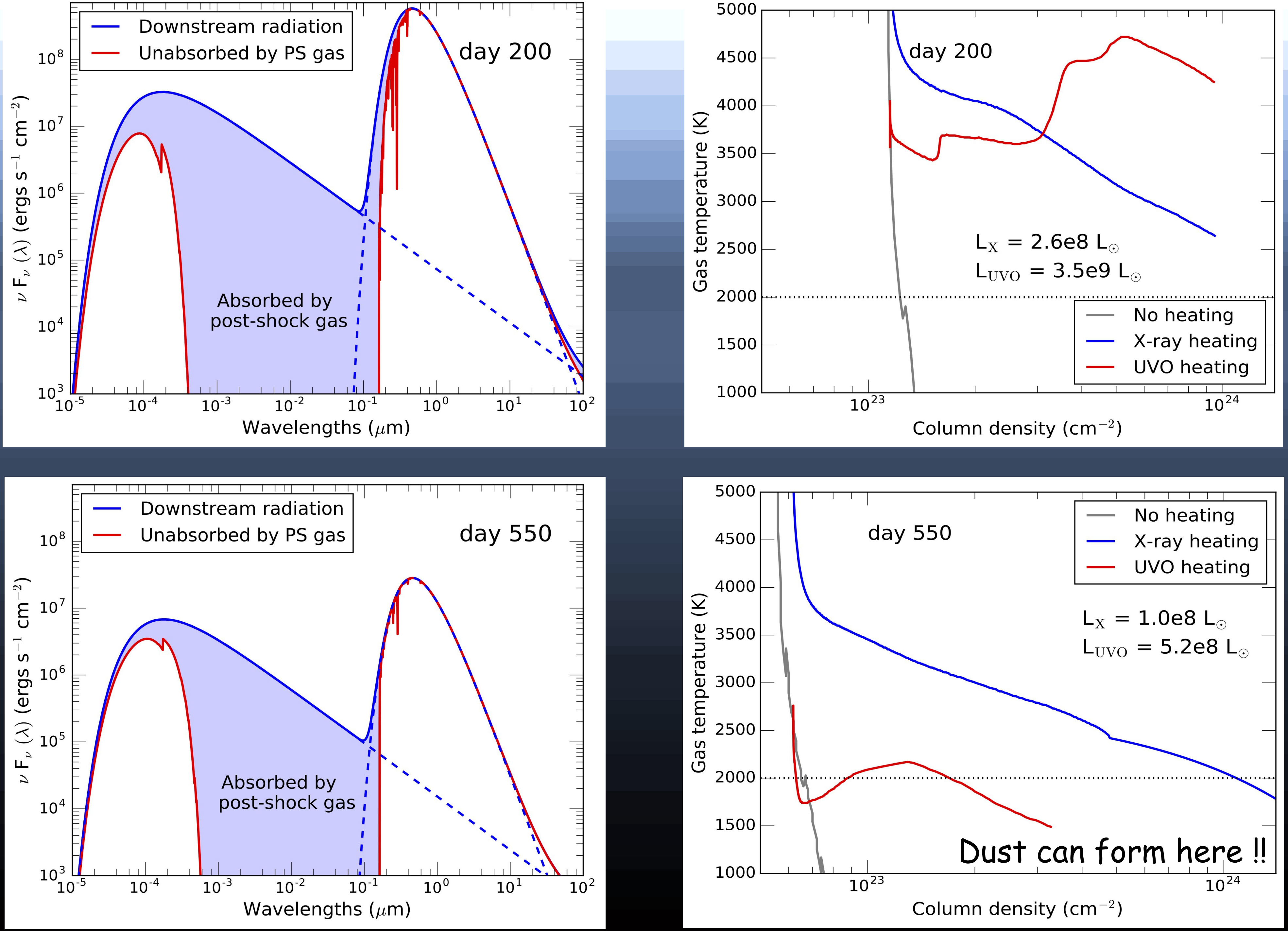
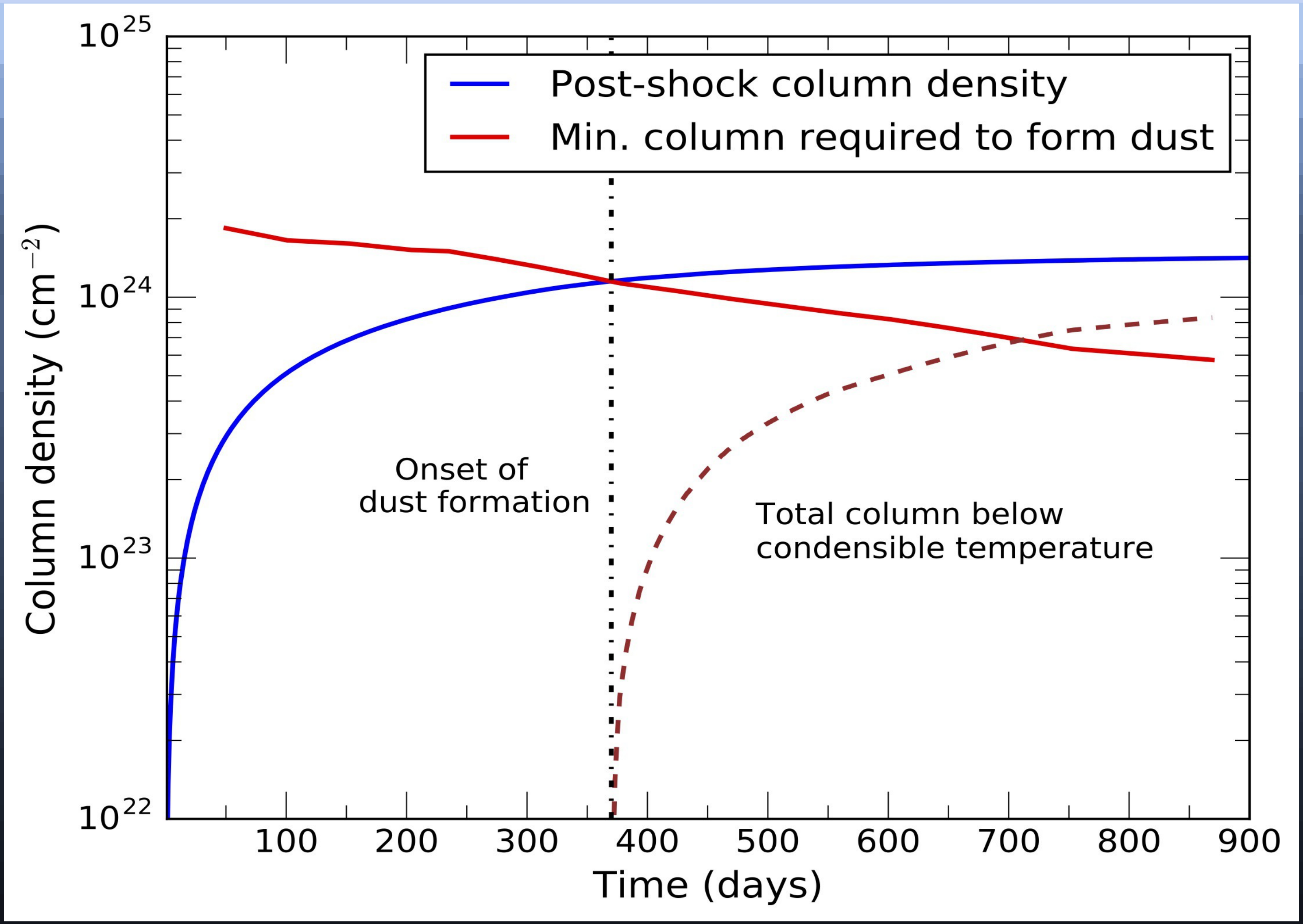
Heating by the downstream radiation from the shock front



Delayed dust formation due to heating by downstream radiation



Dust forms in the post-shock gas after day 380

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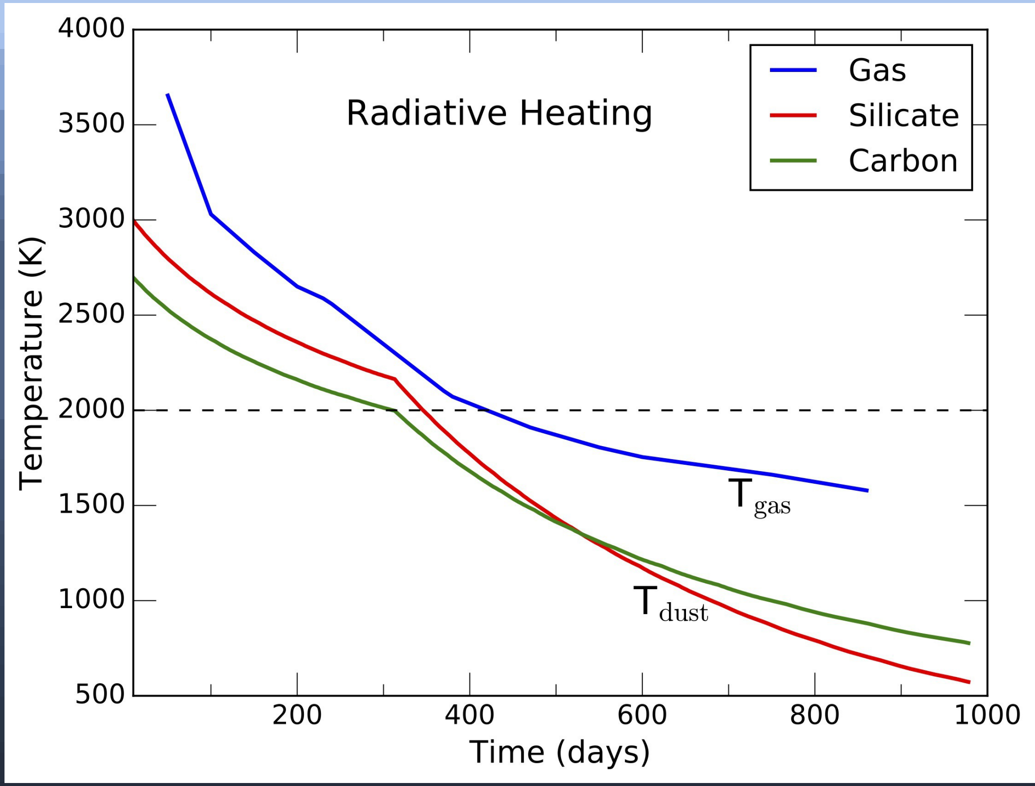
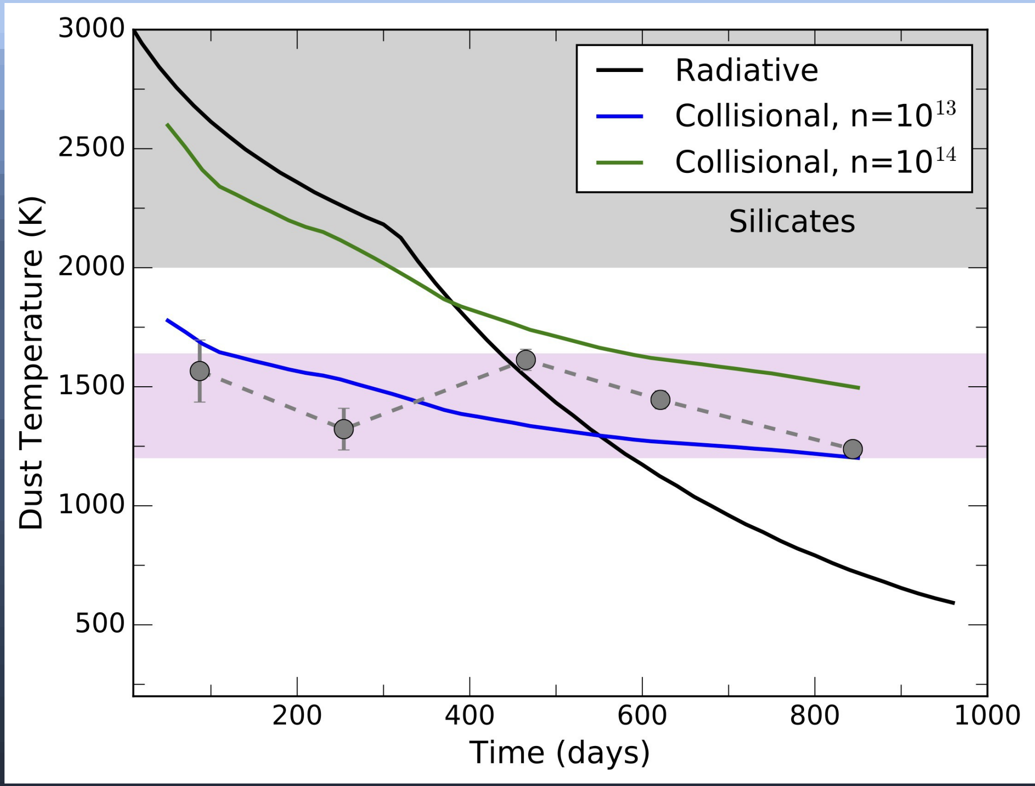
Dust temperatures from radiative and collisional heating

Dust and gas T due to radiation



Dust T by radiative+collisional heating



Observed dust_T band in pink

Dust temperatures are comparable to the observed range of temperatures post day 500

.. similar findings for carbon dust as well

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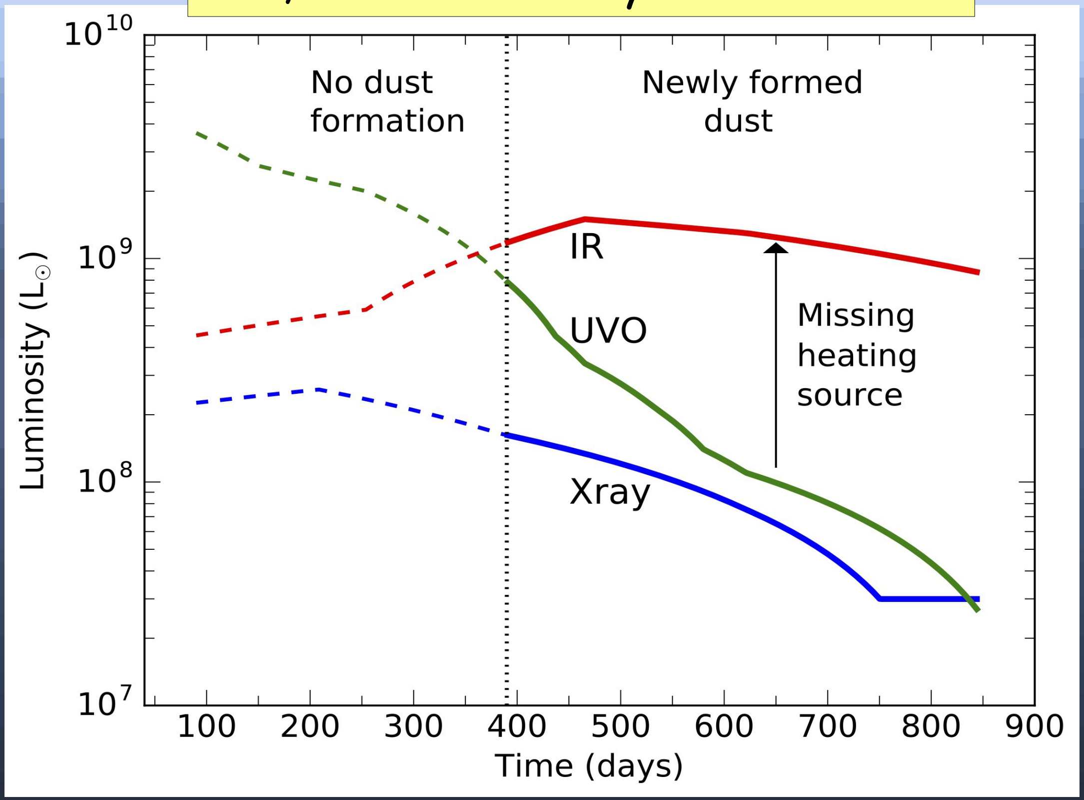
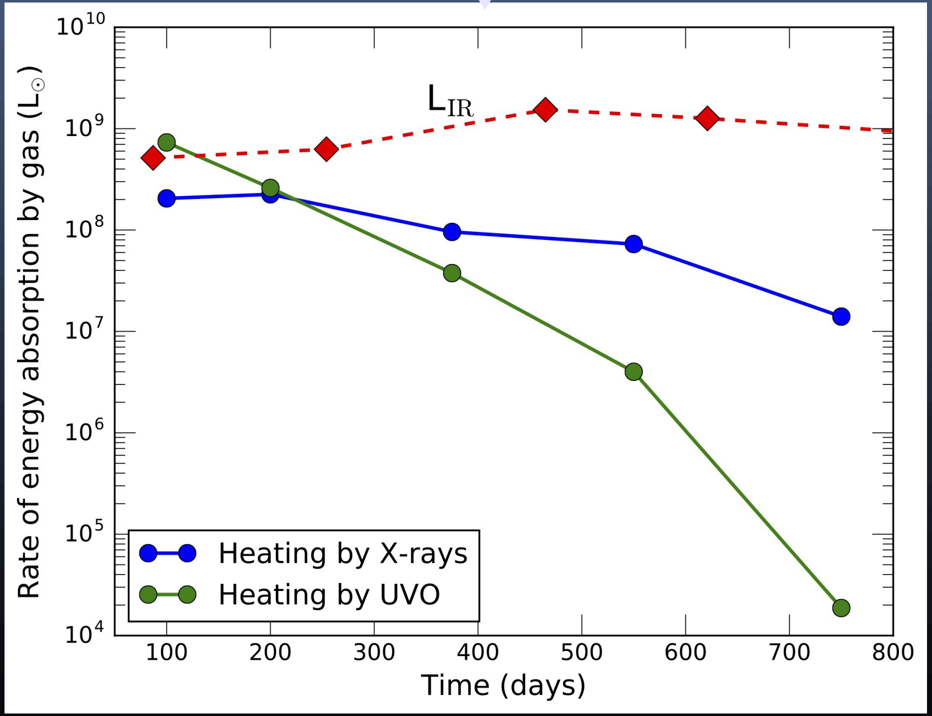
But what is the energy source thats is heating the dust ?

IR, UVO and X-ray luminosities



Rate of energy radiated away by the gas due to collision with the dust > energy absorbed by the warm gas



If dust forms in the post-shock gas
The UVO or X-ray source heating the dust must be visible along the line of sight.

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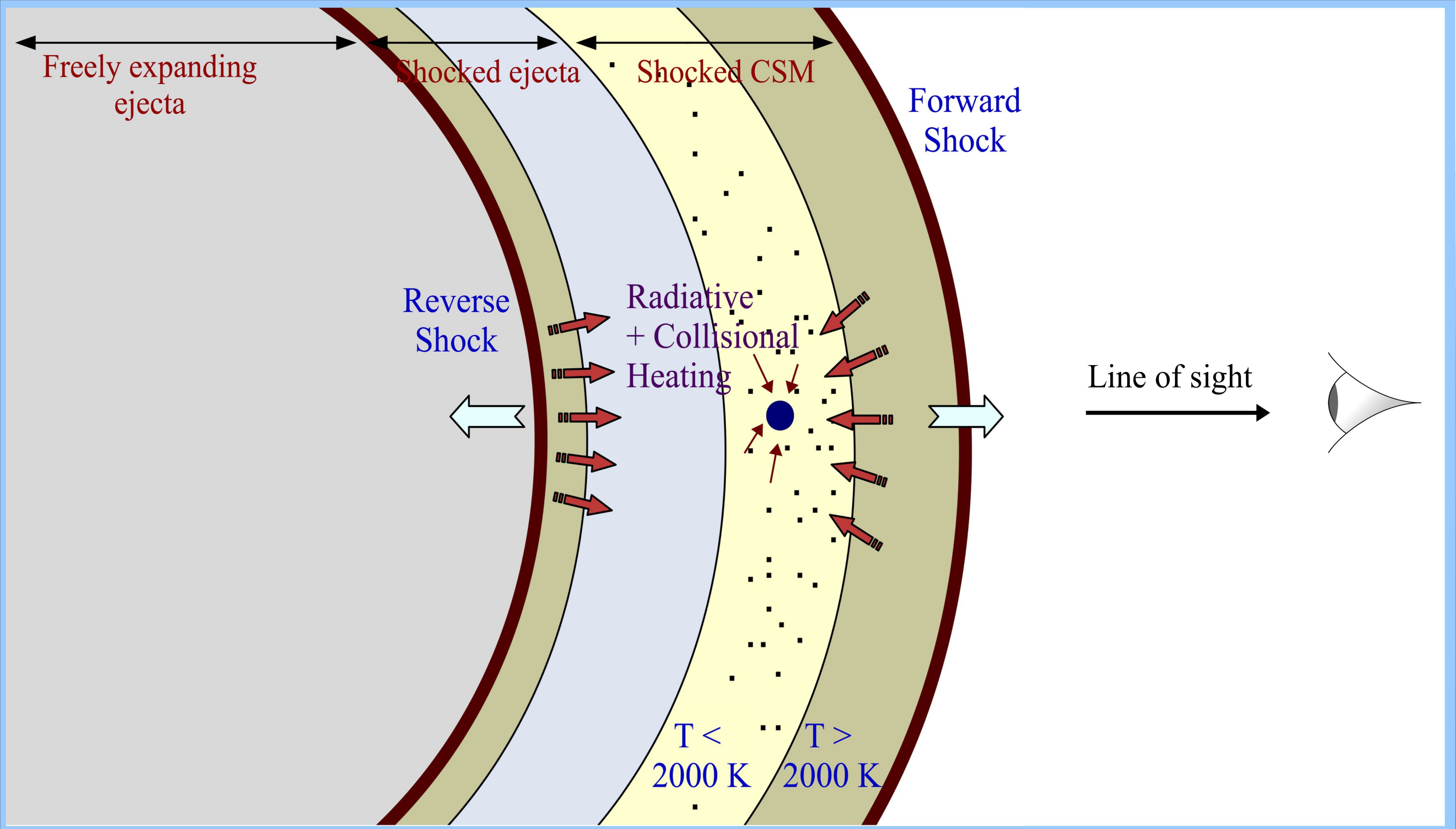


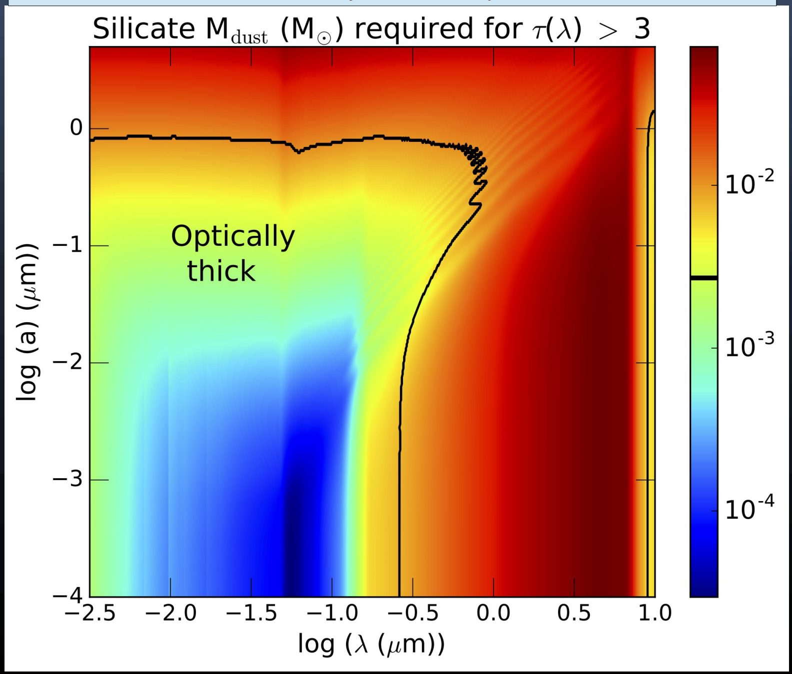
Additional heating by the reverse shock from interior

Dust must be thick to the incident radiation

How can we parametrize the reverse shock

1. The dust in the CSM must be thick to optical radiation.
2. The minimum $L_{\rm rev}$ is equal to $R_{\rm IR} - R_{\rm UVO} - R_{\rm X\text{-}ray}$ at a given time.
3. The reverse-shock velocity should be high enough such that the rate of mechanical energy generated is more than $L_{\rm rev}$.
4. The reverse-shock velocity should be low enough such that it does not produce hard X-rays by its interaction with the ejecta.

Condition of optically thick dust



Reverse shock velocity has be between 250 to 300 Km s^{-1}

Note: This also rules out dust in the ejecta as that is internal to both forward and reverse shock, so the heating source should be visible in UVO

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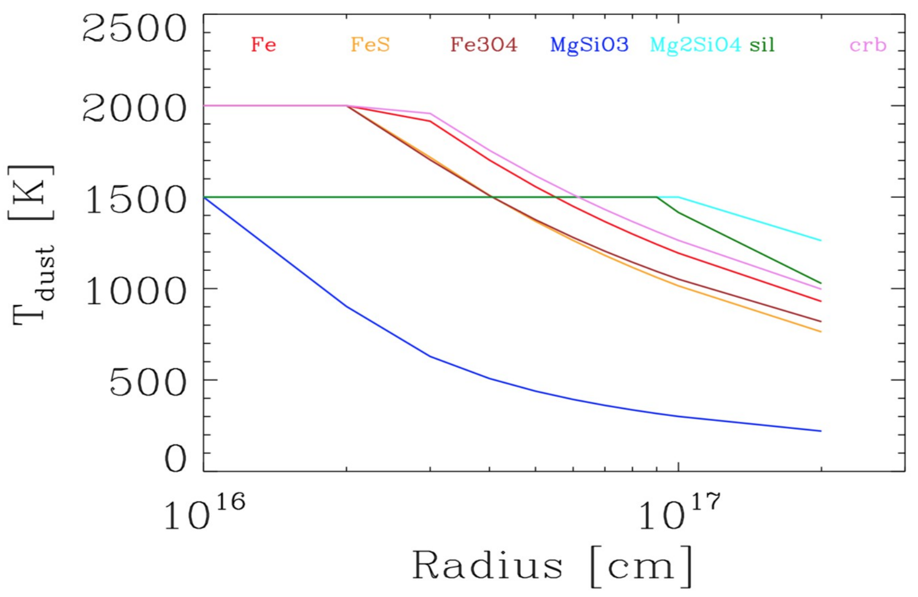
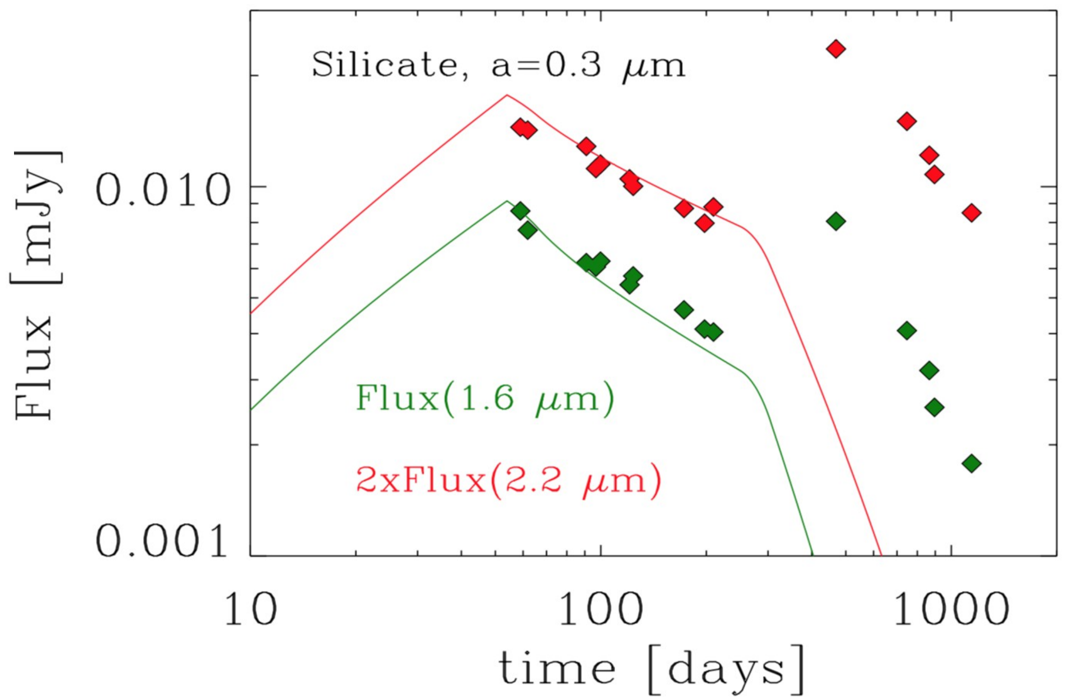
The echo from the pre-existing dust

Evaporation radii of grains



How far out is the pre-existing dust?

Early near-IR fluxes with silicate grains



How does the near-IR flux from the pre-existing dust evolve

Dwek + 2018 in prep

Endnote

- Dust formation in the interceding zone between the forward and reverse shock
- Depends on the intensity of ionizing radiation
    - after day 380 in SN 2010jl, dust mass ~ 5×10^{-3} M_{sun}
- Formation of the warm dense shell
    - provides the reservoir of warm gas where kinetic nucleation can take place
- Energy balance between gas and dust, both of which are radiatively and collisionally heated
- short cooling time (few week to couple of months) owing to high CSM densities
- the presence of the low density shell between the star and the CSM
- Ejecta encounters the reverse shock very early on, which dictates the its phases of dust formation
- Blueshift of lines: a) asymmetries in the geometry, b) electron scattering, c) dense shell thick to optical photons (Patat + 2011, Dessart + 2015, Fransson + 2014, Jencson + 2016) - We are yet to understand with certainty