Calculating the average opacity of core-collapse SNe

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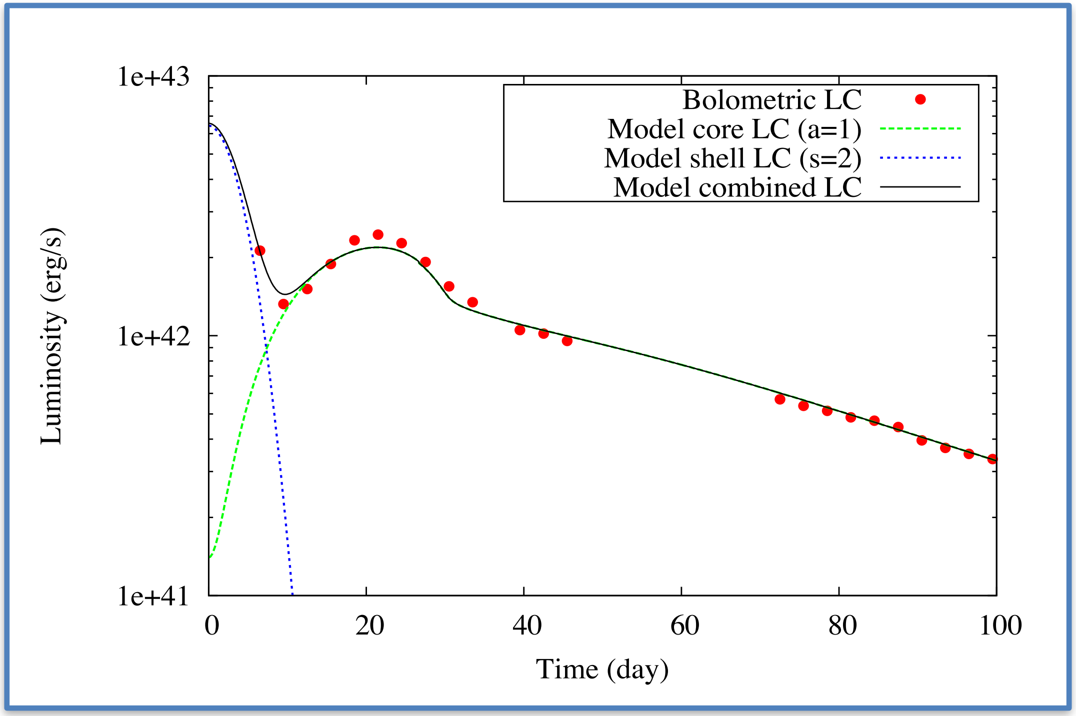
ANALYTIC MODELS OF SUPERNOVAE

Analytic models in general

- 1 dimensional simulations
- Simplified structure
- Non-rotating envelop
- Many assumptions



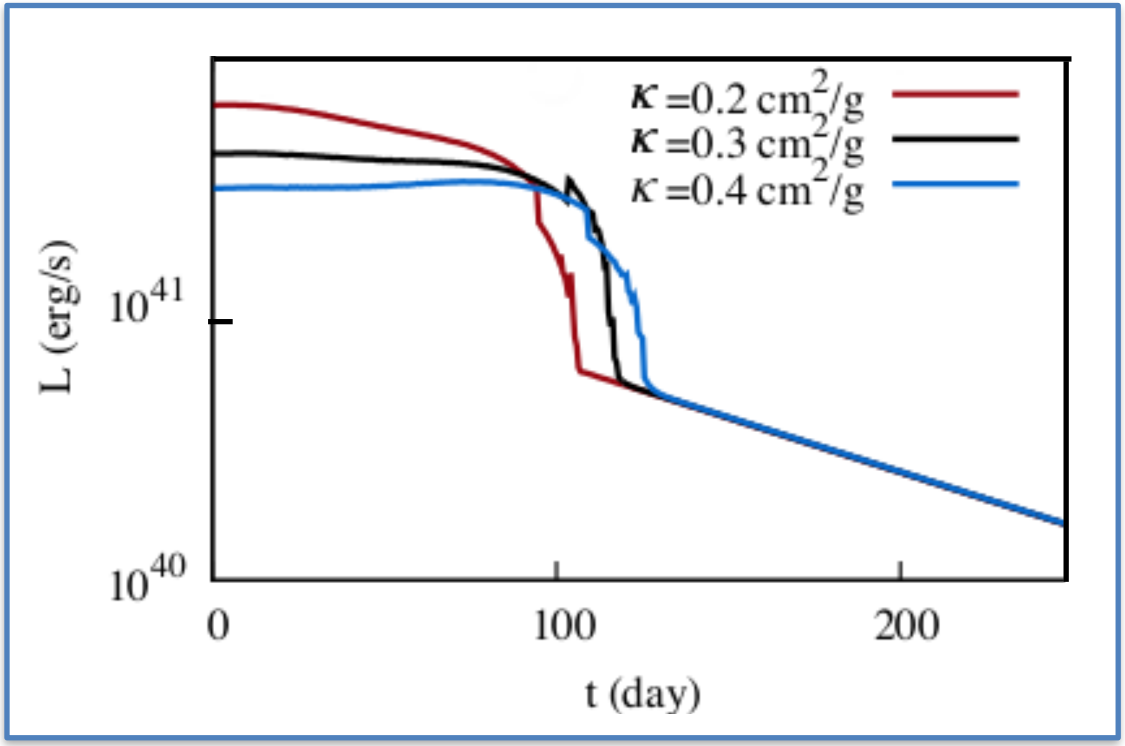
Two-component LC model

- compact dense core
- extended, low-mass outer shell
- components have common center
- energy loss driven by radiation transport
- first peak: adiabatic cooling of the shock-heated H envelop (shell)
- second peak: powered by the radioactive decay and recombination (core)

Bersten et al. 2012; Kumar et al. 2013; Nagy & Vinkó, 2016

CONSTANT OPACITY ASSUMPTION

- one of the strongest simplification of the semi-analytic models
- constant Thompson-scattering opacity = average opacity of the ejecta
- Thompson-scattering opacity only depends on the chemical composition



Arnett & Fu, 1989; Nagy et al., 2014

$$\kappa(x,t) = \begin{cases} \kappa_t & ,T \geq T_{ion} \\ 0 & ,T < T_{ion} \end{cases}$$

If we choose the opacity wisely, we are able to predict the chemical composition of the SN envelop.

CALCULATING AVERAGE OPACITY

- create AGB stellar evolution models with MESA
- varying the input physical parameters (initial mass, metallicity, etc.)
- synthesize light curves from stellar models with SNEC
- at a given time we define $\kappa(M_{ph})$ by integrating Rosseland mean opacity from mass coordinate of the neutron star up to the mass coordinate of the photosphere

$$\kappa(M_{\rm ph}) = \frac{1}{M_{\rm ph} - M_0} \int_{M_0}^{M_{\rm ph}} \kappa \, \mathrm{d}m$$

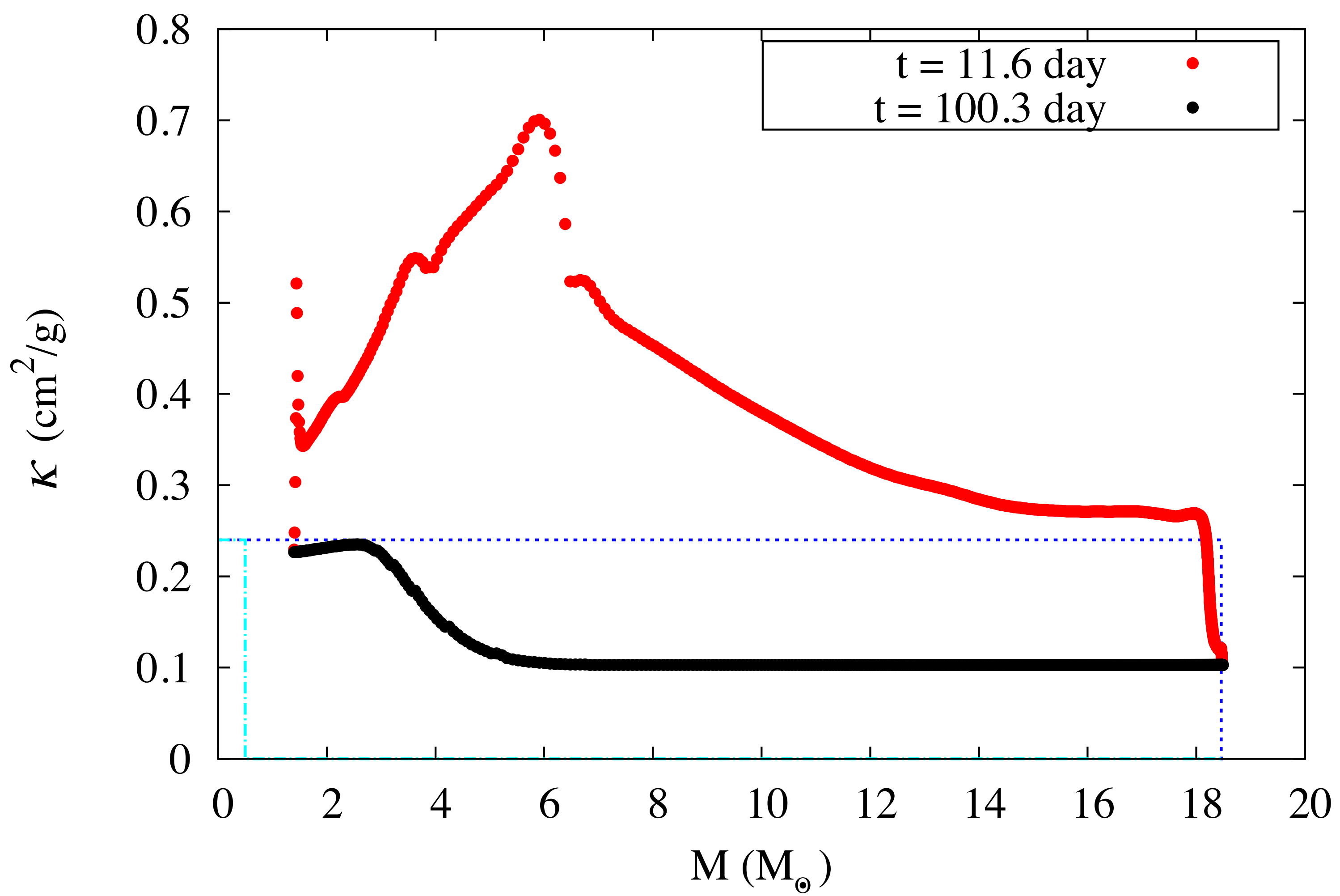
- compute the average opacity by integrating $\kappa(M_{ph})$

$$\bar{\kappa} = \frac{1}{t_{\rm end} - t_0} \int_{t_0}^{t_{\rm end}} \kappa(M_{\rm ph}) \, \mathrm{d}t.$$

- separately determine the average opacity for both the cooling and the photospheric phase

Paxton et al. 2013; Morozova et al. 2015; Nagy & Vinkó, 2016

CALCULATING AVERAGE OPACITY



RESULTS - CHANGING INITIAL MASS

- No stellar wind

	15M	20M	25M	30M	35M	40M	45M
t_{shell} (day)	11 ± 1	13 ± 1	15 ± 1	17 ± 2	19 ± 2	32 ± 4	27 ± 2
κ_{shell} (cm^2/g)	0.364 ± 0.07	0.379 ± 0.1	0.367 ± 0.06	0.40 ± 0.08	0.43 ± 0.06	0.299 ± 0.12	0.373 ± 0.07
κ_{core} (cm^2/g)	0.166 ± 0.01	0.179 ± 0.01	0.190 ± 0.03	0.274 ± 0.05	0.247 ± 0.05	0.214 ± 0.07	0.209 ± 0.06
κ_{total} (cm^2/g)	0.182 ± 0.01	0.199 ± 0.01	0.210 ± 0.01	0.295 ± 0.01	0.27 ± 0.004	0.24 ± 0.03	0.232 ± 0.02

- without stellar wind, we can’t make self-consistent models

RESULTS - CHANGING INITIAL MASS

- “Dutch” wind-scheme

	15M	20M	25M	30M	35M	40M	45M
t_{shell} (day)	11 ± 1	13 ± 1	15 ± 1	15 ± 1	16 ± 2	24 ± 2	17 ± 2
κ_{shell} (cm²/g)	0.356 ± 0.07	0.368 ± 0.07	0.379 ± 0.07	0.352 ± 0.06	0.332 ± 0.03	0.375 ± 0.05	0.365 ± 0.05
κ_{core} (cm²/g)	0.158 ± 0.01	0.172 ± 0.02	0.187 ± 0.02	0.255 ± 0.05	0.218 ± 0.05	0.207 ± 0.06	0.186 ± 0.04
κ_{total} (cm²/g)	0.175 ± 0.01	0.19 ± 0.002	0.208 ± 0.01	0.267 ± 0.01	0.23 ± 0.004	0.237 ± 0.01	0.202 ± 0.01

- slightly lower (0.18 - 0.2 cm^2/g) opacities for a 8-10 M ejecta that the usually used in the literature

RESULTS - CHANGING STELLAR WIND INTENSITY

- Different scaling factor values for "Dutch" wind-scheme

	20M_0.2η	20M_0.4η	20M_0.6η	20M_0.8η	20M_1.0η
t_{shell} (day)	12 ± 1	12 ± 1	13 ± 1	13 ± 1	14 ± 1
κ_{shell} (cm²/g)	0.377 ± 0.11	0.377 ± 0.11	0.365 ± 0.10	0.366 ± 0.09	0.355 ± 0.08
κ_{core} (cm²/g)	0.182 ± 0.007	0.182 ± 0.007	0.178 ± 0.017	0.175 ± 0.016	0.173 ± 0.02
κ_{total} (cm²/g)	0.199 ± 0.002	0.199 ± 0.002	0.195 ± 0.002	0.193 ± 0.002	0.191 ± 0.002

$$\dot{M} = \eta \cdot \dot{M}_{Dutch}$$

RESULTS - CHANGING METALLICITY

- Different X and Z content (Y = 0.28)

	20M_z1m1	20M_z2m2	20M_z2m3	20M_z2m4	20M_z2m5
t_{shell} (day)	15 ± 1	13 ± 1	70 ± 5	59 ± 3	60 ± 3
κ_{shell} (cm²/g)	0.333 ± 0.07	0.368 ± 0.07	0.362 ± 0.10	0.406 ± 0.09	0.396 ± 0.06
κ_{core} (cm²/g)	0.169 ± 0.021	0.172 ± 0.017	0.152 ± 0.23	0.173 ± 0.17	0.173 ± 0.19
κ_{total} (cm²/g)	0.199 ± 0.005	0.190 ± 0.002	0.245 ± 0.09	0.245 ± 0.13	0.248 ± 0.13

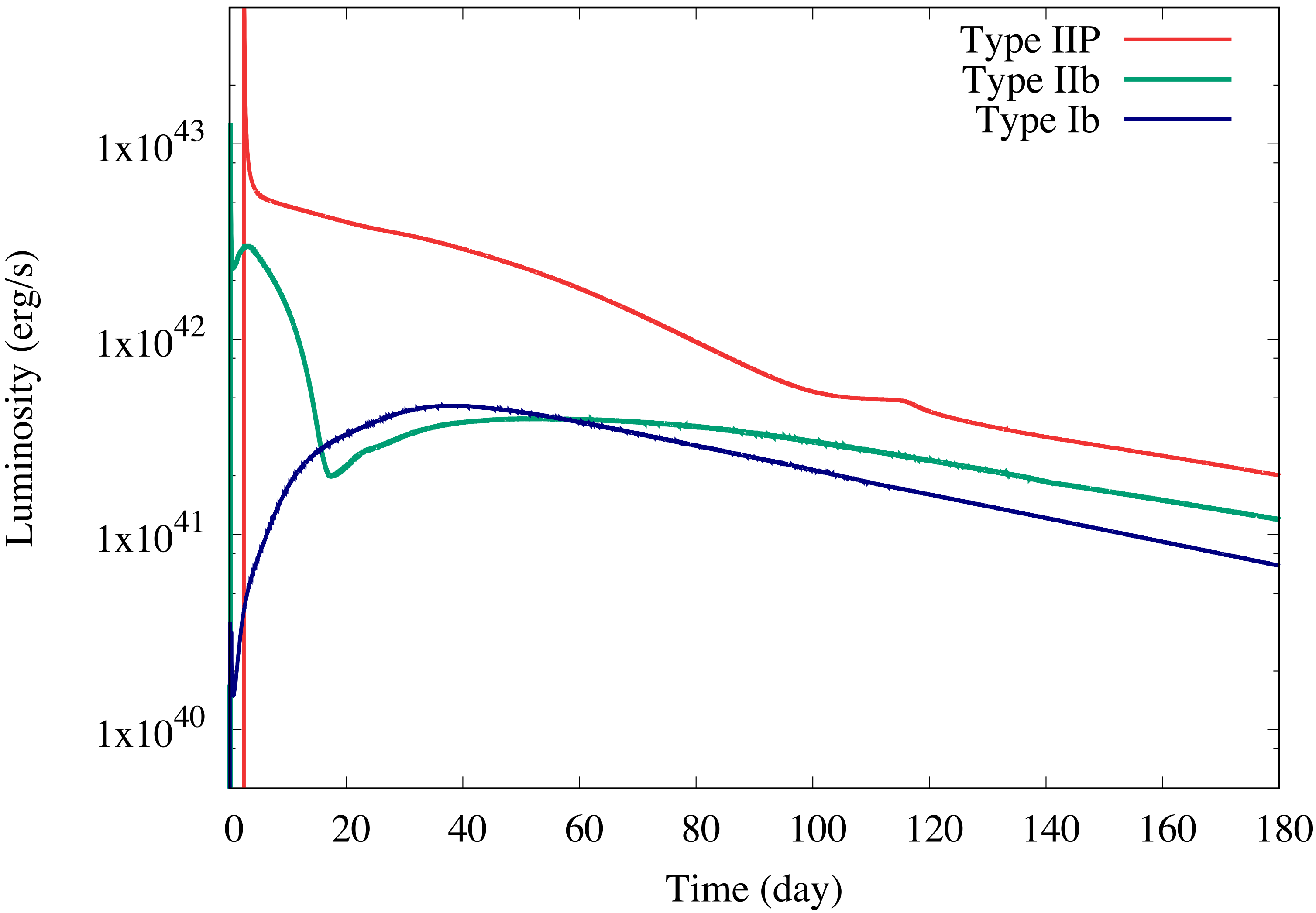
RESULTS - CHANGING ROTATION

- Different scaling factor values for critical surface velocity

	20M_0v	20M_0.2v	20M_0.4v	20M_0.6v	20M_0.8v
t_{shell} (day)	15 ± 1	15 ± 1	14 ± 1	14 ± 1	13 ± 1
κ_{shell} (cm^2/g)	0.358 ± 0.06	0.375 ± 0.08	0.362 ± 0.08	0.362 ± 0.09	0.366 ± 0.09
κ_{core} (cm^2/g)	0.169 ± 0.021	0.180 ± 0.019	0.174 ± 0.019	0.174 ± 0.019	0.175 ± 0.016
κ_{total} (cm^2/g)	0.193 ± 0.003	0.199 ± 0.001	0.193 ± 0.003	0.193 ± 0.003	0.193 ± 0.003

$$v = \varepsilon \cdot v_{break} = \varepsilon \cdot \sqrt{\frac{G \cdot M}{R}}$$

AVERAGE OPACITY OF CORE-COLLAPSE SNE

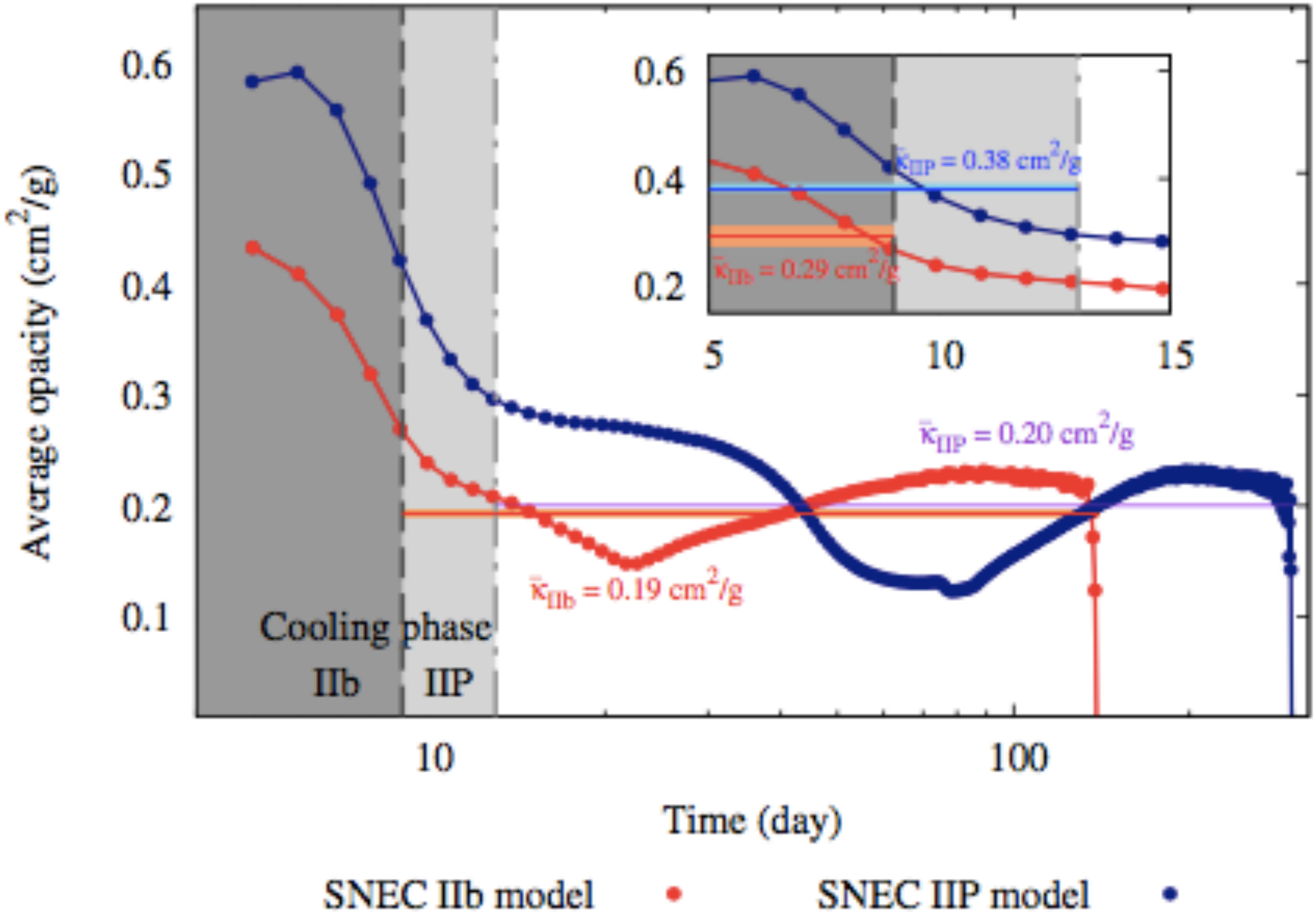


AVERAGE OPACITY OF CORE-COLLAPSE SNE

- Different explosion energy values in SNEC

	IIP	IIb	Ib	Ic
M_{ej} (M_{Sun})	16.5	7.5	4.5	3.5
t_{shell} (day)	13 ± 1	9 ± 1	-	-
κ_{shell} (cm²/g)	0.381 ± 0.007	0.293 ± 0.023	-	-
κ_{core} (cm²/g)	0.200 ± 0.002	0.193 ± 0.004	0.182 ± 0.013	0.100 ± 0.013
κ_{total} (cm²/g)	0.213± 0.028	0.195 ± 0.023	0.182 ± 0.013	0.100 ± 0.013

AVERAGE OPACITY OF CORE-COLLAPSE SNE



CONCLUSIONS AND FUTURE WORK

- Calculated average opacities are in reasonably good agreement with frequently used constant opacities in the literature
- Two-component model could be relevant due to the gained opacities for the shell and the core component
- Higher ejecta mass needed higher opacity during modelling
- Metallicity and surface rotation only have minor effect on the opacity value
- Unfortunately the physical parameters correlated, so we are not able to get better estimates for them only by using appropriate opacities
- In the future I would like to examine the effect of the magnetic field and other rotational schemes
- MESA binary and Wolf-Rayet models for Type IIb, Ib and Ic models

THANK YOU FOR YOUR ATTENTION!

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