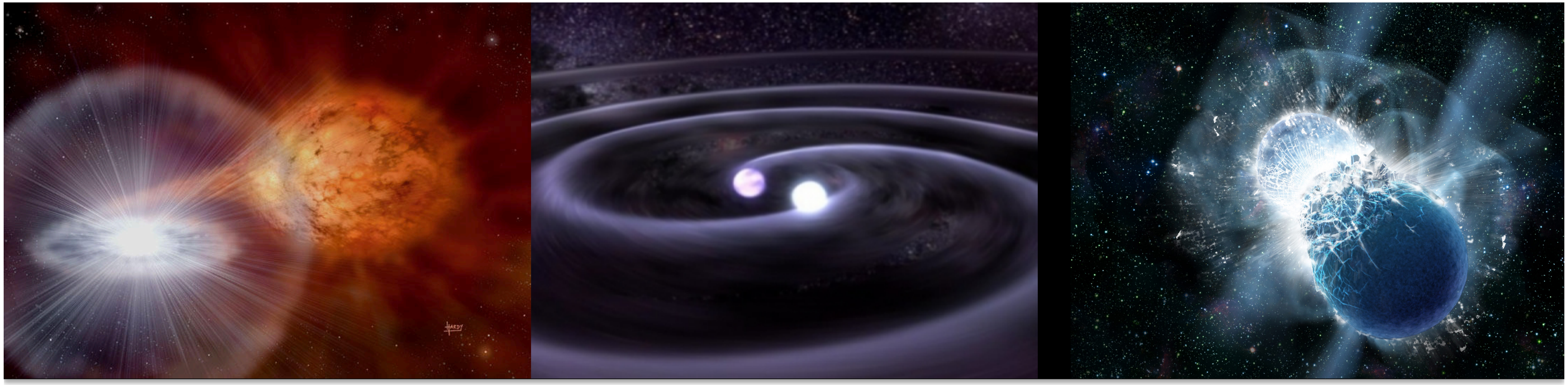

The case for multiple progenitor channels for Type Ia supernovae from radiative-transfer simulations

Stéphane Blondin

Laboratoire d'Astrophysique de Marseille

Luc Dessart

Observatoire de la Côte d'Azur

John Hillier

University of Pittsburgh

Alexei Khokhlov

University of Chicago

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SN Ia Standard Model

Thermonuclear disruption of a ***C-O White Dwarf*** *star (Howle & Fowler 1960)*

$M_{\mathrm{MS}} \lesssim 8\ \mathrm{M}_{\odot}$ - → $M_{\mathrm{WD}} \lesssim 1\ \mathrm{M}_{\odot}$

Planetary Nebula

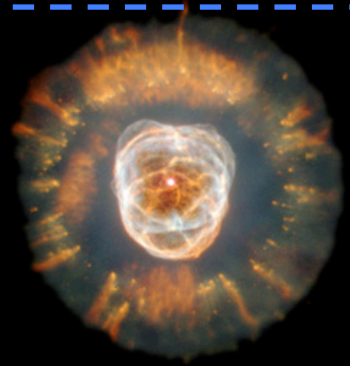
Stellar Cloud
with
Protostars

Small Star

H → He

Red Giant

He → C+O



C+O core contracts
H+He envelope expelled

White Dwarf

C-O White Dwarf
$R \sim \mathrm{R}_{\oplus}; M \sim \mathrm{M}_{\odot}$
$\Rightarrow \rho \sim 1\ \mathrm{ton/cm^3}$!

Mass limit for relativistic, degenerate electron gas:
(Chandrasekhar 1931)

$$M_{\mathrm{Ch}} \approx 1.46(2Y_e)^2\ \mathrm{M}_{\odot}$$

Requires **accretion from star** or **merger with WD**

SN Ia Energetics

Runaway carbon fusion as WD approaches $M_{Ch} \approx 1.4\ M_{\odot}$

$T_C \approx \text{few } 10^8\ K\ ; \quad \rho_C \gtrsim 2 \times 10^9\ g\ cm^{-3}$

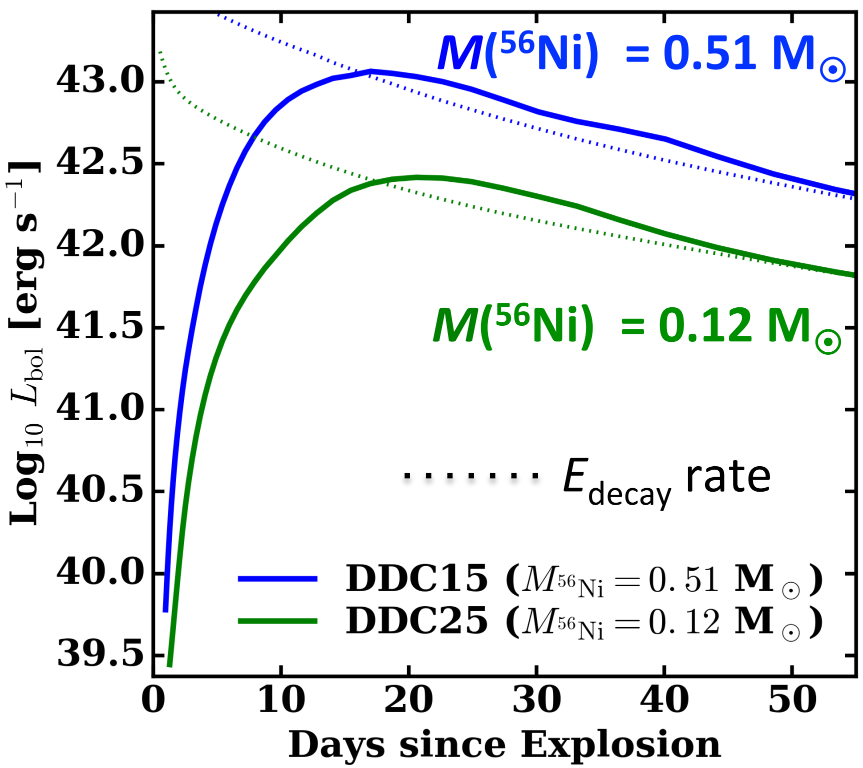
Nuclear energy release unbinds the star ($t_{exp} \sim 1$ s)

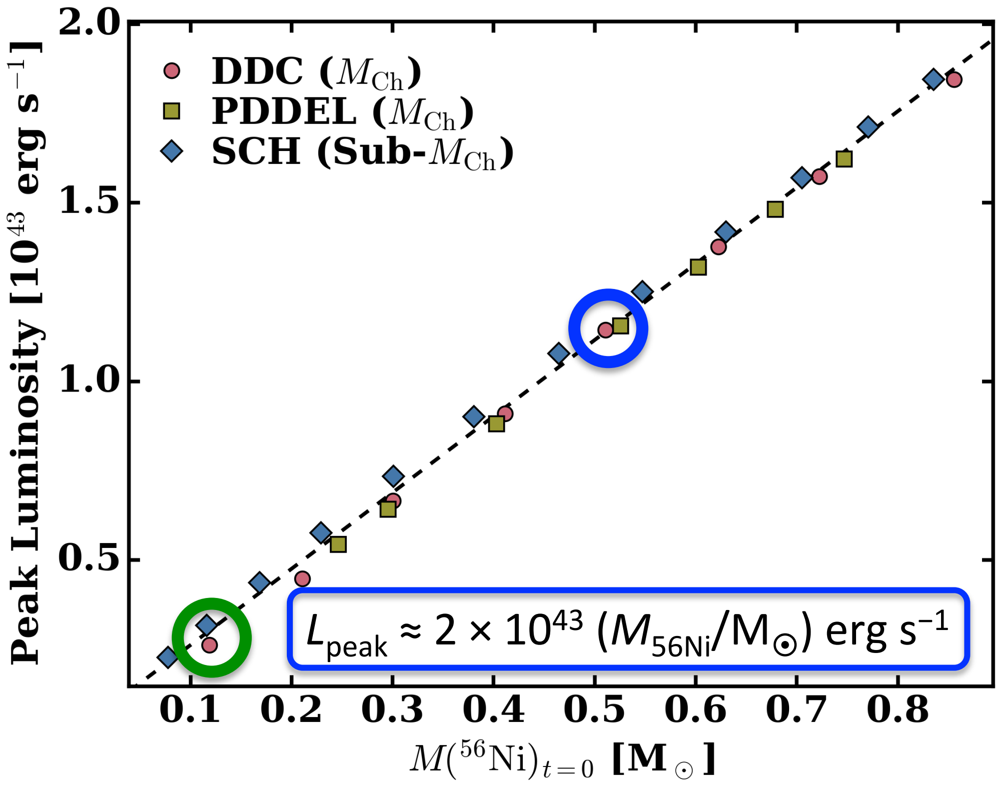
$E_{nuclear} \approx -E_{binding} + E_{kinetic} \approx 10^{51}\ erg$

Radioactive heating powers the light curve ($t_{LC} \sim 10$ d)
(Colgate & McKee 1969)

$^{56}\mathrm{Ni} \xrightarrow[Q_\gamma = 1.7\,\mathrm{MeV}]{t_{1/2}=6.1\,\mathrm{d}} {}^{56}\mathrm{Co} \xrightarrow[Q_\gamma = 3.6\,\mathrm{MeV}]{t_{1/2}=77.2\,\mathrm{d}} {}^{56}\mathrm{Fe} \approx 10^{43}\ erg\ s^{-1}$ *peak luminosity*

The Power of Radioactivity

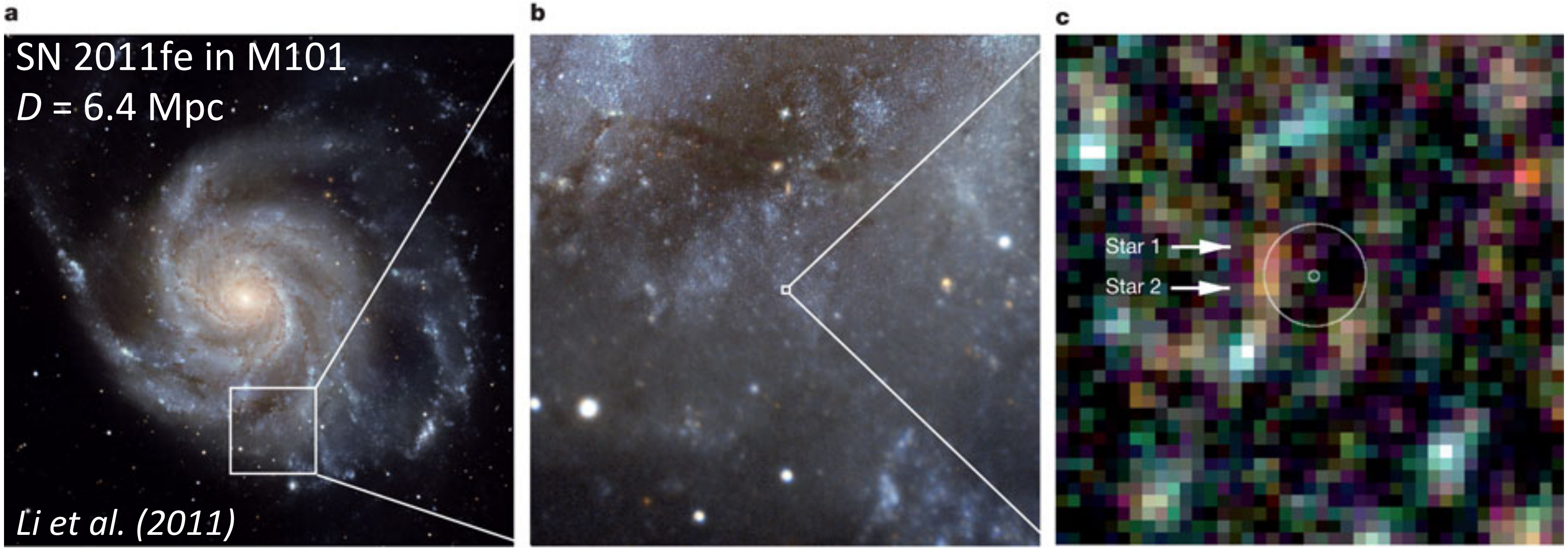




More ^{56}Ni** implies **larger luminosity

Difficulties in Constraining SN Ia Progenitors

No direct detection of SN Ia progenitors (binary companion)



Li et al. (2011)

Indirect constraints from:

- ✧ interaction with binary companion + CSM
- ✧ surviving companion star in SN remnants

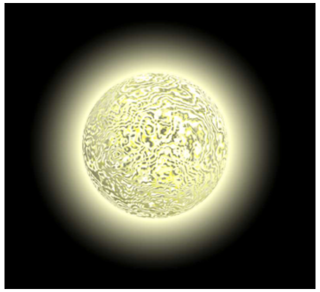
*Need constraints from **numerical simulations**!*

Numerical Setup for SN Ia Modelling

1. C-O WD

Hydrostatic

$X_C \approx X_O \approx 0.5$

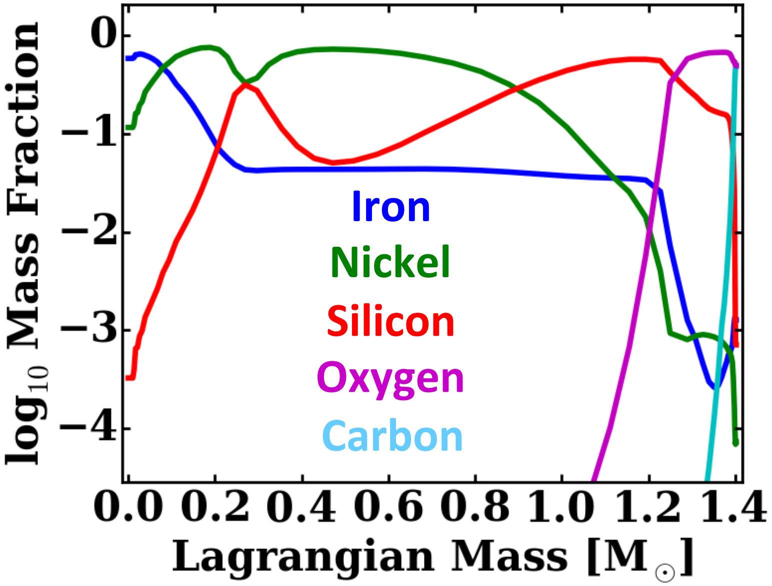


2. Explosion

1D hydro + burning

Homologous expansion

$v(r) \propto r$ @ $t_{exp} < 1$ min



3. Radiative Transfer

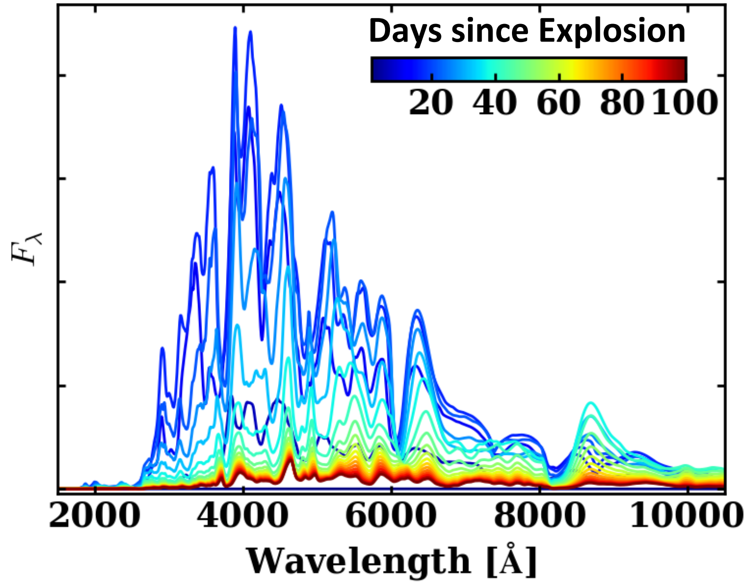
1D non-LTE (CMFGEN)

Time-dependent *D/Dt*

Non-local energy deposition

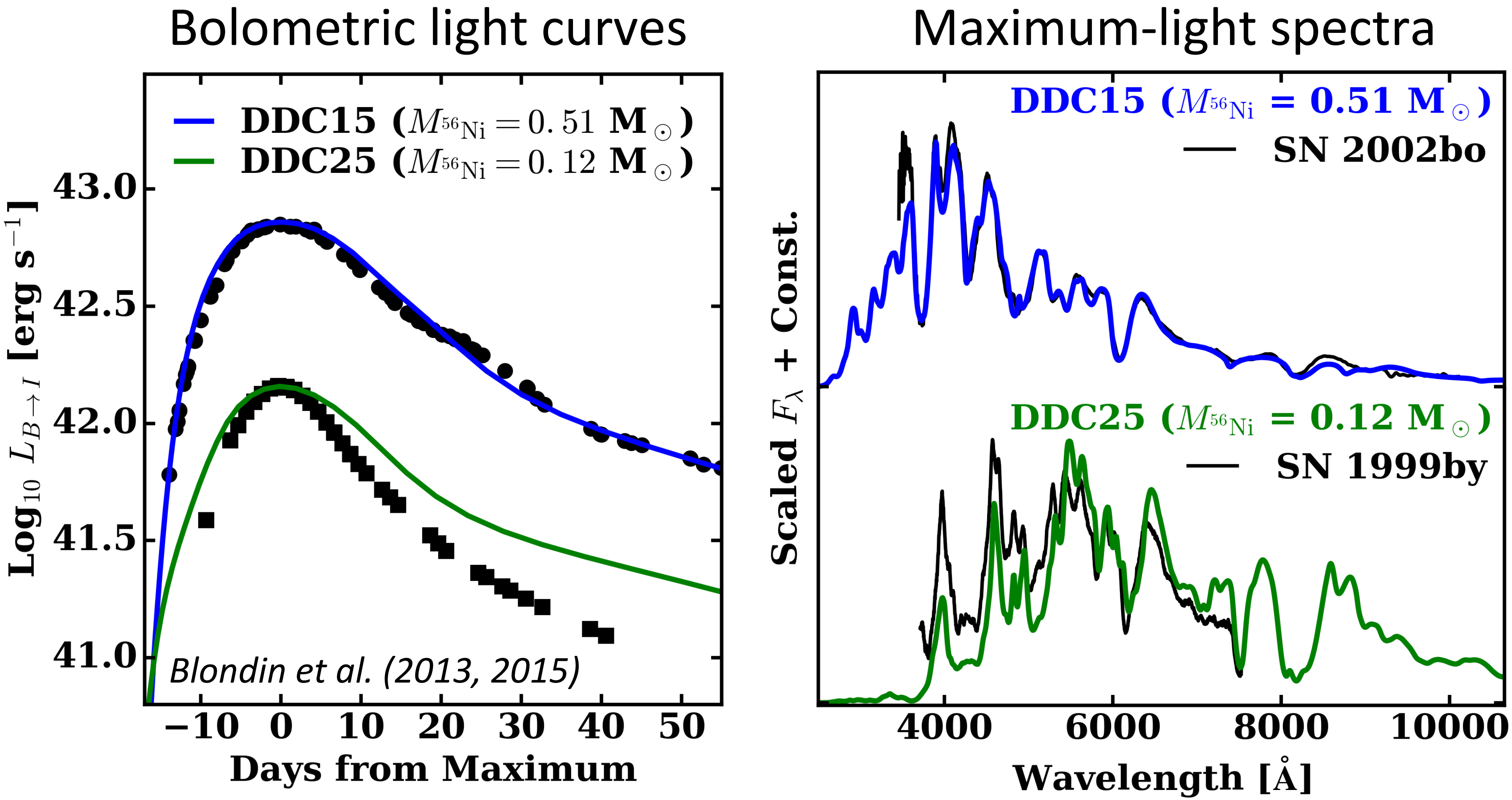
Non-thermal effects

Hillier & Dessart (2012)



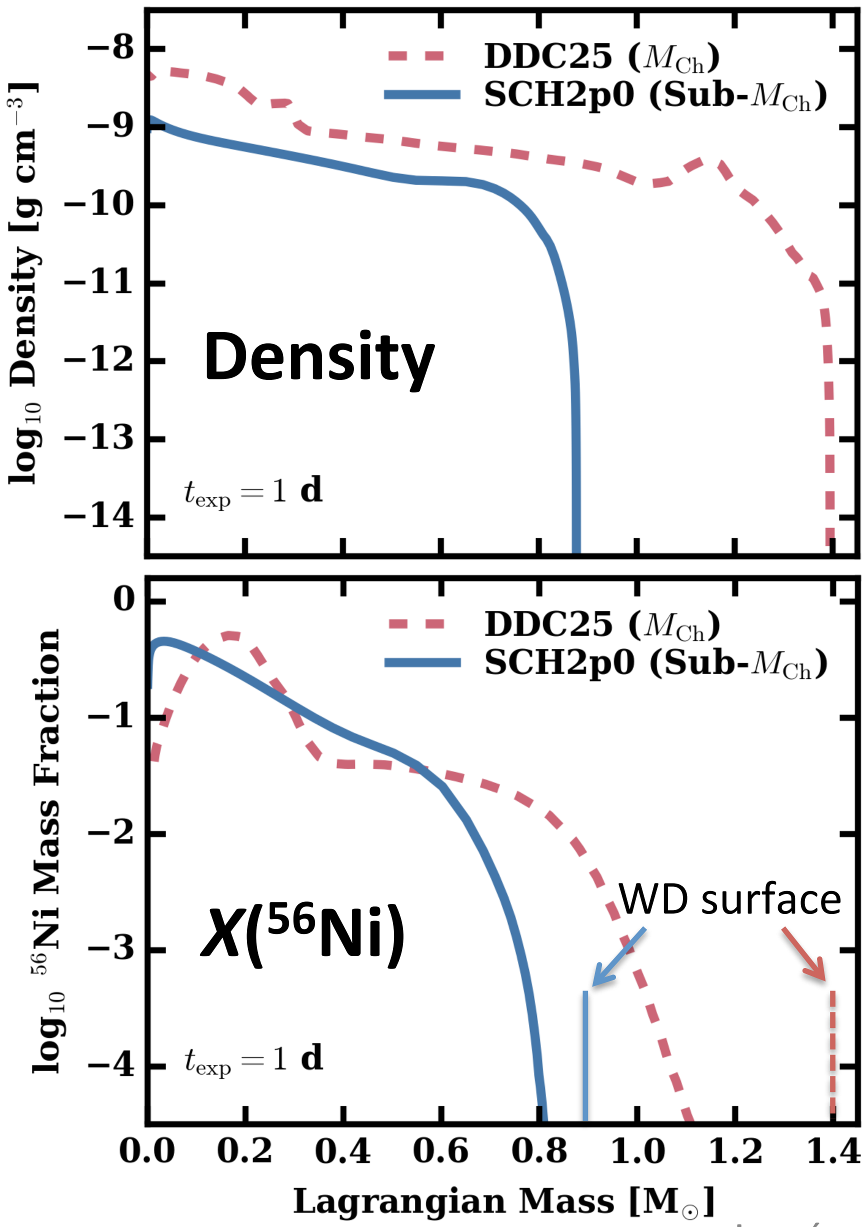
4. Comparison to Observations

Chandrasekhar-mass Delayed-Detonation Models



***Fainter** models have **too broad** light curves and are **too red** at maximum light*

Sub-Chandrasekhar-mass Models



Pure detonation of **sub-$M_{\rm Ch}$ WD**

(Blondin et al., in prep)

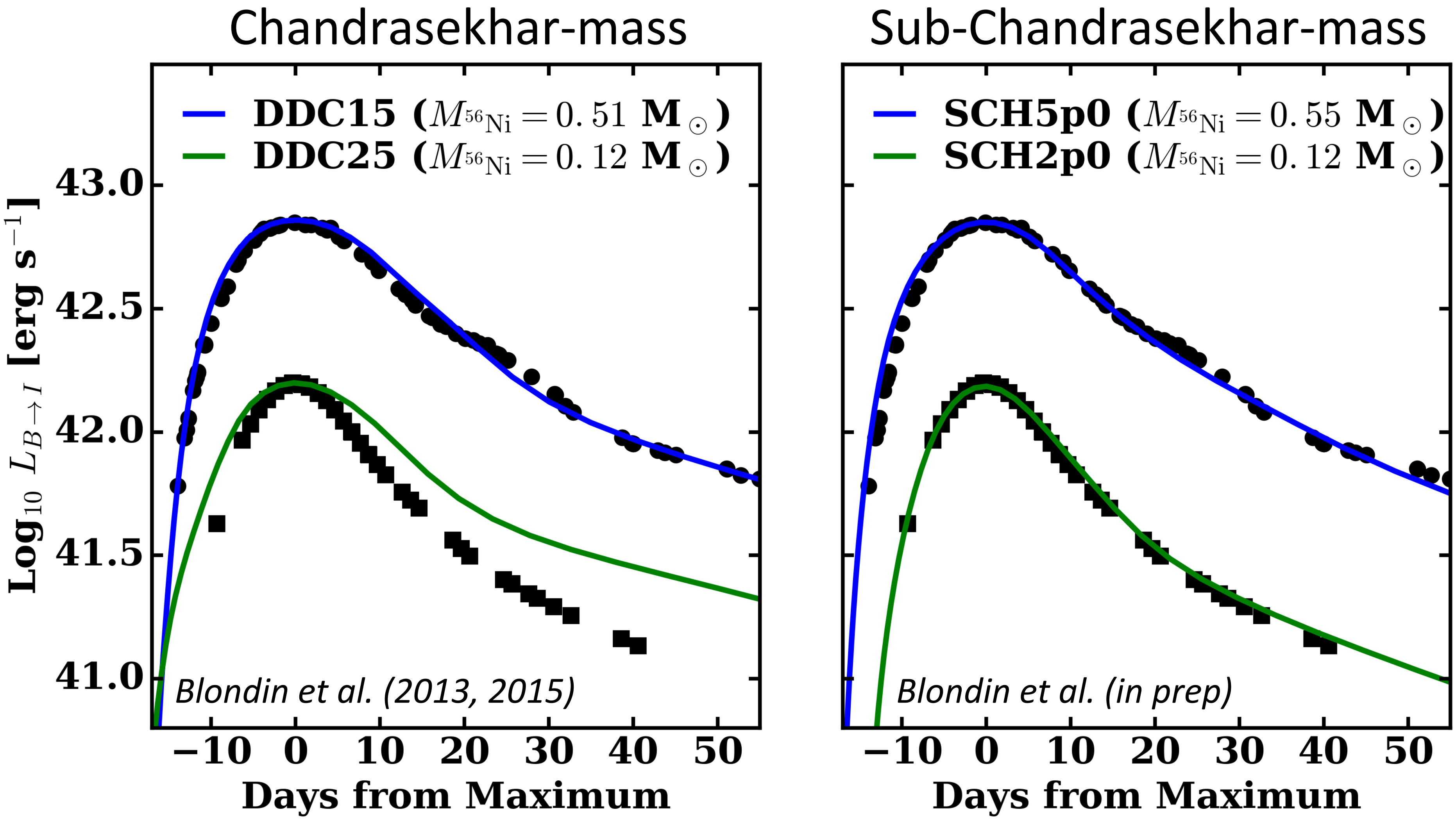
Model	$M(^{56}\mathrm{Ni})$ [M$_\odot$]	$M_{\rm tot}$ [M$_\odot$]
DDC25	0.12	1.41
SCH2p0	0.12	0.90

1. Lower **density** $\Longrightarrow$ More rapid **radiation escape**

^{56}Ni extends to outermost ejecta

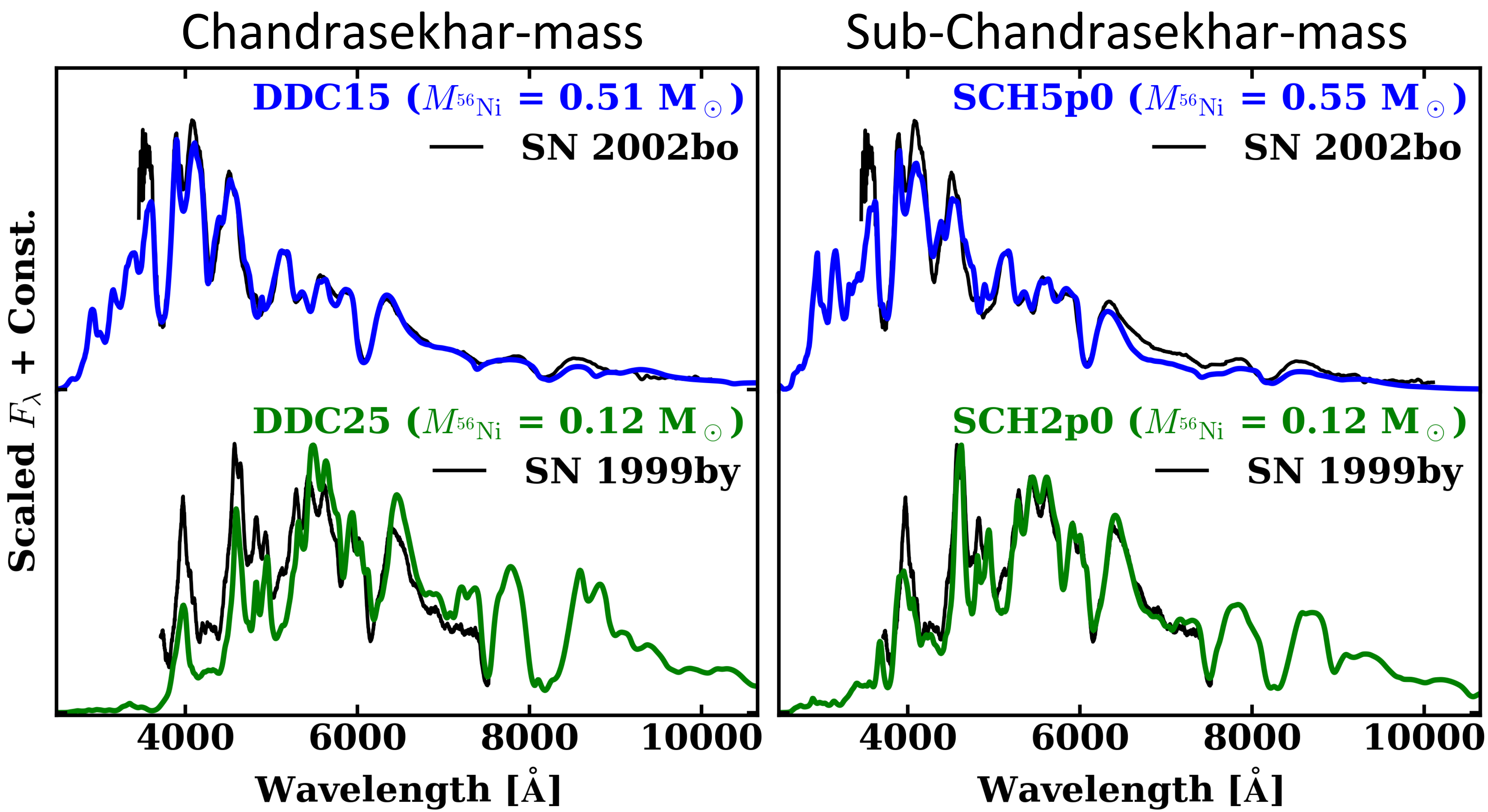
2. Higher $M(^{56}\mathrm{Ni})/M_{\rm tot}$ $\Longrightarrow$ More efficient **heating** of ejecta (per unit mass)

Sub-Chandrasekhar Models: Luminosity Evolution



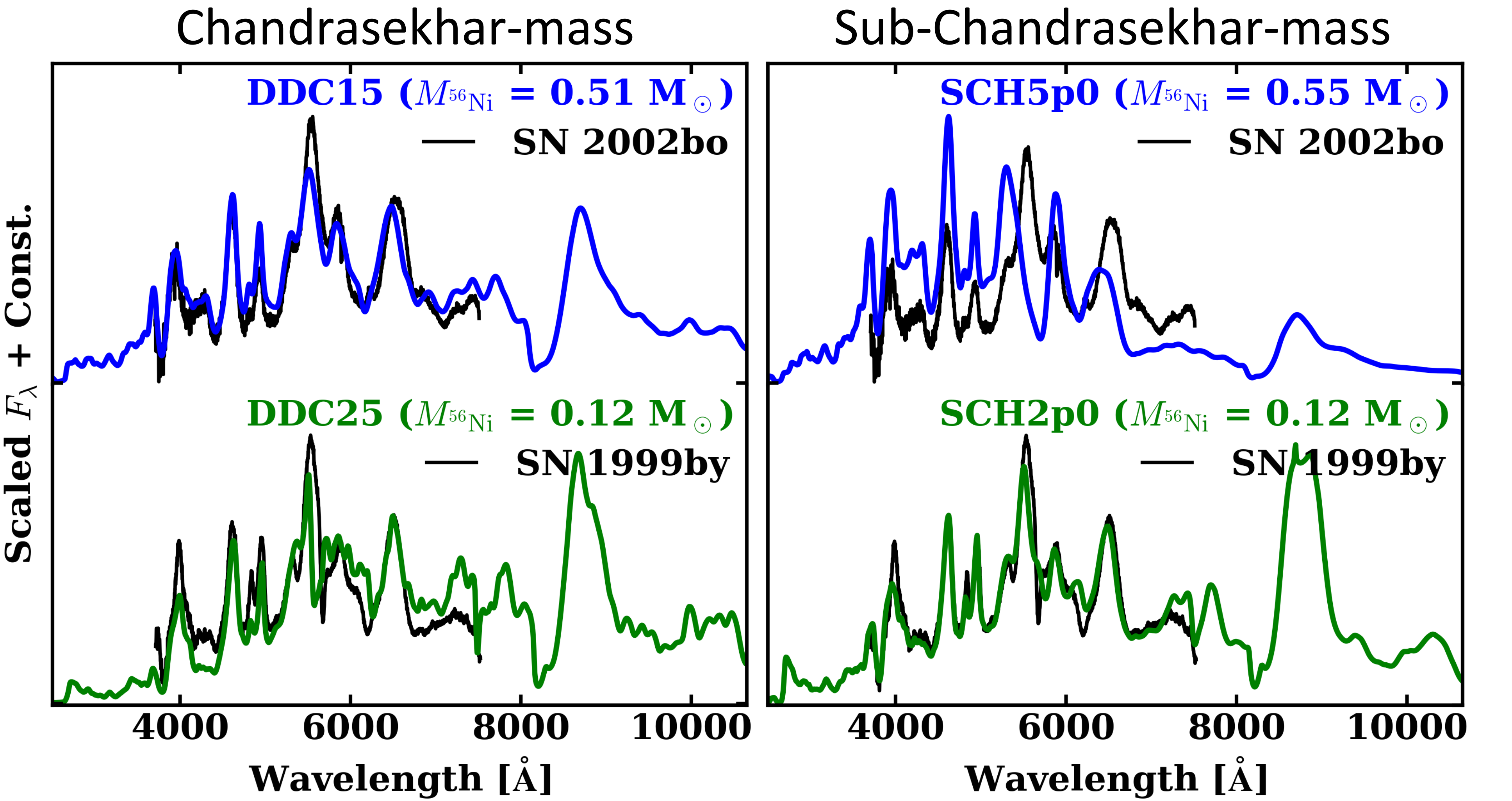
Sub-M$_{Ch}$ *models match light curves of* ***normal*** *and* ***low-luminosity*** *SN Ia*

Sub-Chandrasekhar Models: Maximum-light Spectra



Sub-M$_{Ch}$ *models match spectra of* ***normal*** *and* ***low-luminosity*** *SN Ia*

Sub-Chandrasekhar Models: Post-maximum Spectra



Sub-M$_{Ch}$ *models remain* ***too blue*** *past maximum for* ***normal*** *SN Ia*

Conclusions & Future Work

✧ Standard **Chandrasekhar-mass models** match **normal SN Ia**
(but fail to match low-luminosity events)

✧ **Sub-Chandrasekhar-mass models** match **low-luminosity** SN Ia
(but fail to match normal events)

✧ Key parameter: **specific heating rate** $\propto M(^{56}\mathrm{Ni})/M_{\mathrm{tot}}$

✧ **Multiple progenitor channels** as source of observed diversity?

All model inputs & results available at:

https://www-n.oca.eu/supernova/home.html