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Theoretical Studies

Improvements to modelling tools for Type Ia Supernovae –A focus on ratiation transport

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Heidelberg Institute for Theoretical Studies

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Content

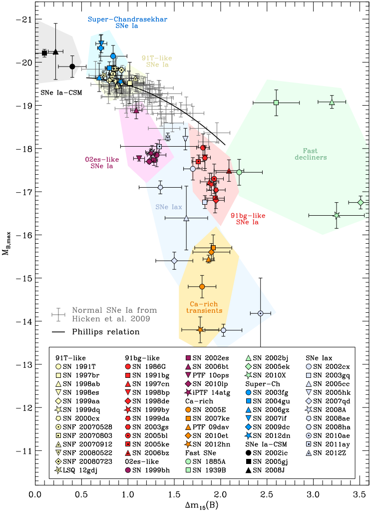
Introduction – SNe Ia in a nutshell

- Thermonuclear explosions of carbon-oxygen (CO) white dwarfs (WDs)
- Progenitor scenario(s) still unclear

(Credit: ESO/L. Calçada)

Introduction – SNe Ia in a nutshell

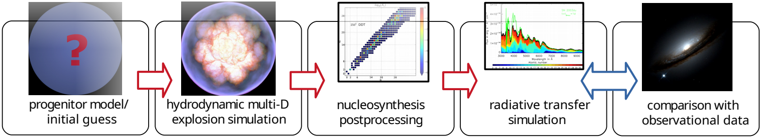
- Thermonuclear explosions of carbon-oxygen (CO) white dwarfs (WDs)
- Progenitor scenario(s) still unclear
- "Zoo" of observable subclasses
- Various progenitor scenario candidates:
  - **sub M_{Ch}** models (double detonation, merger, etc.)
  - **M_{Ch}** models (pure deflagration, delayed detonation etc.)



(Taubenberger 2017)

Introduction – Radiative Transfer in SN Modelling

(Röpke and Sim 2018)



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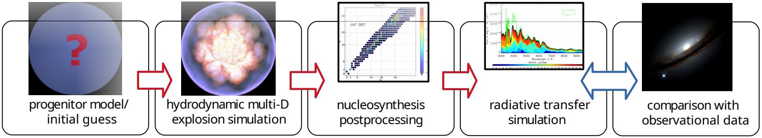

- Ejecta distribution
- Velocities
- Temperature
- ...

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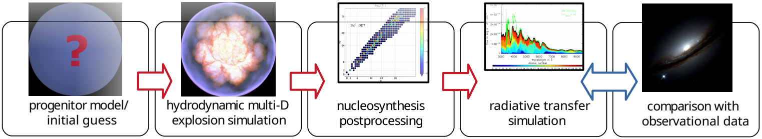

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- Abundance distribution
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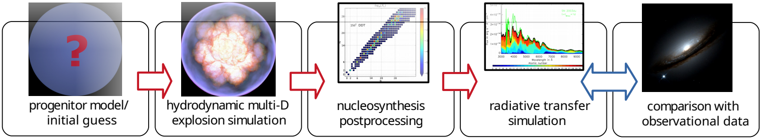

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- Light curves
- Polarisation
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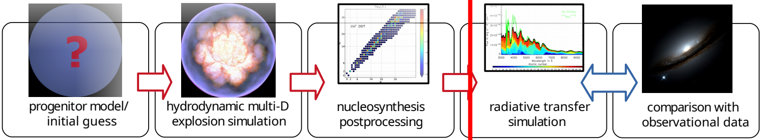

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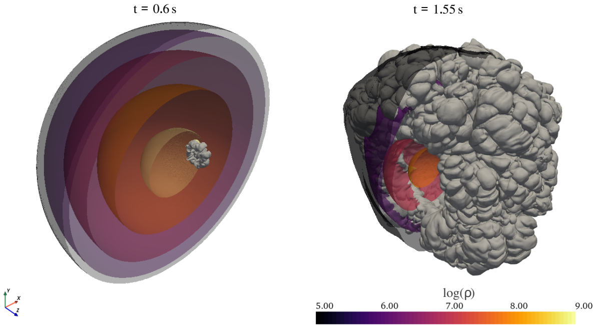
Identifying SNe Ia Progenitors

Hydro-simulations of deflagrations in M_{Ch} WDs



(Lach et al. 2022)

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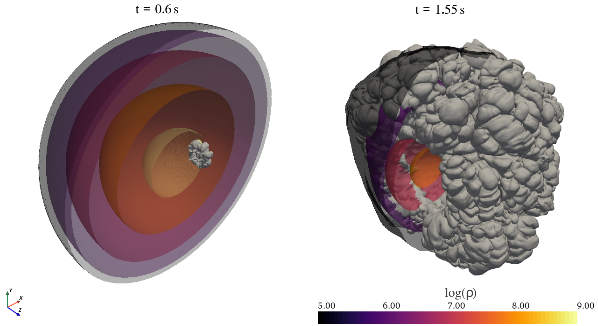
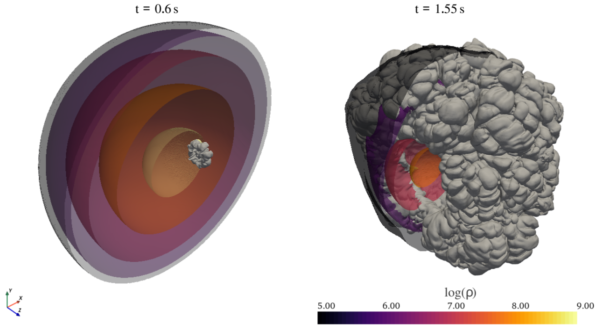


(Lach et al. 2022)

- Full-star simulations with varying central densities using the LEAFS code
- **Goal:** Finding progenitors of the SNe Iax subtype

Identifying SNe Ia Progenitors

Hydro-simulations of deflagrations in M_{Ch} WDs



(Lach et al. 2022)

Hydro-simulations and derived quantities (e.g. produced ^{56}Ni mass) provide first insight into feasibility as progenitor scenario

⇒ Conclusive statements require **synthetic observables** through **radiative transfer** simulations

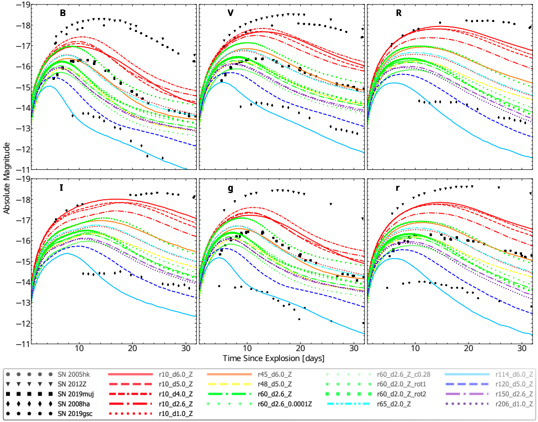
⇒ Radiative transfer code **ARTIS** (Sim 2007; Kromer Sim 2009)

Identifying SNe Ia Progenitors

Synthetic light curves:

- Good agreement for some models
- Red bands tend to show **faster decline** than observed
- Red bands capture **rise time** better than blue bands

(Lach et al. 2022)

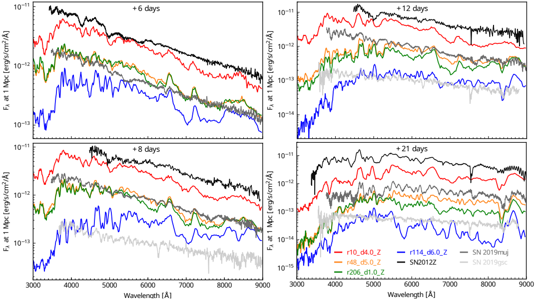


Identifying SNe Ia Progenitors

- Good agreement at **later epochs** for brighter models
- Poor agreement at **early epochs** for all models

⇒ **Systematic differences** in spectroscopic evolution not accounted for by models

(Lach et al. 2022, adapted)



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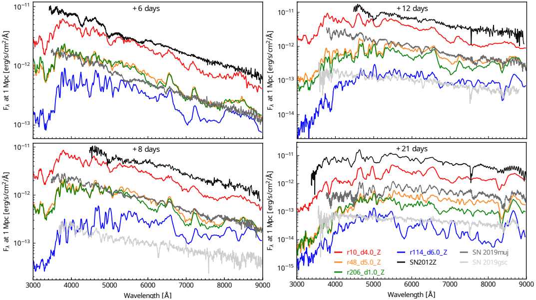

⇒ **Inaccuracies due to LTE treatment in radiative transfer needs to be quantified!**

Improvements to Radiative Transfer

So far:

Radiative transfer with **approximate NLTE** ionisation balance

⇒

Only valid until ~ **few months** after explosion

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Now:

Radiative transfer with full **NLTE**

Improvements to Radiative Transfer

Improvements included with the new full-NLTE ARTIS version:

- Radiation field treatment
- Atomic dataset
- NLTE ionization and population solver
- Non-thermal energy deposition
- Non-thermal degradation (Spencer-Fano)

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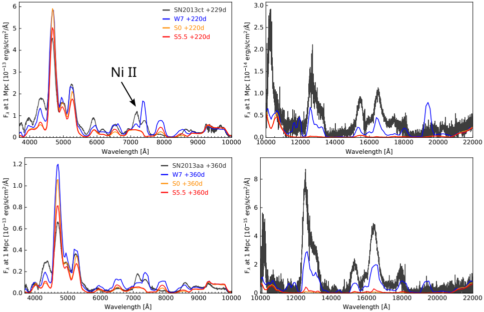
(Shingles et al. 2020, adapted)



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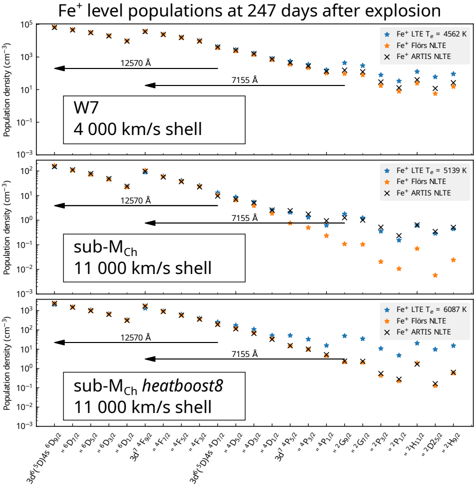


(Shingles et al. 2022, adapted)

Improvements to Radiative Transfer

So far:

Radiative transfer with **approximate NLTE** ionisation balance ⇒ Only valid until ~ **few months** after explosion

Now:

Radiative transfer with full **NLTE** ⇒

- Valid until the **nebular phase**

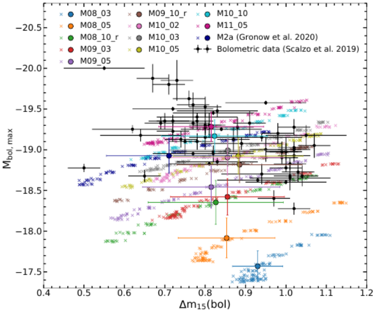
→ Not yet well tested for early times

→ Differences to LTE approximation at early times need to be quantified

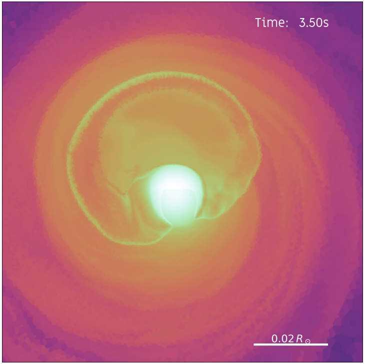
Testing ARTIS-NLTE

Goal: Investigating the **asymmetry** of sub-M_{Ch} WD explosions

(Gronow et al. 2021)



Models show more asymmetry than is observed!



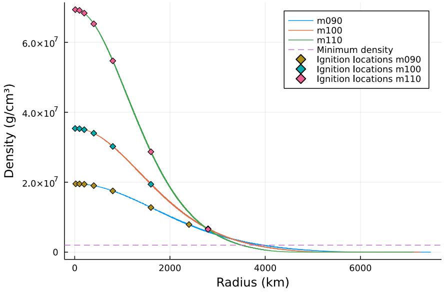
(Credit: J. Morán-Fraile)

→ Use well explored **sub-M_{Ch} WD explosion** scenario to further test differences between radiative transfer methods.

Testing ARTIS-NLTE

Setup:

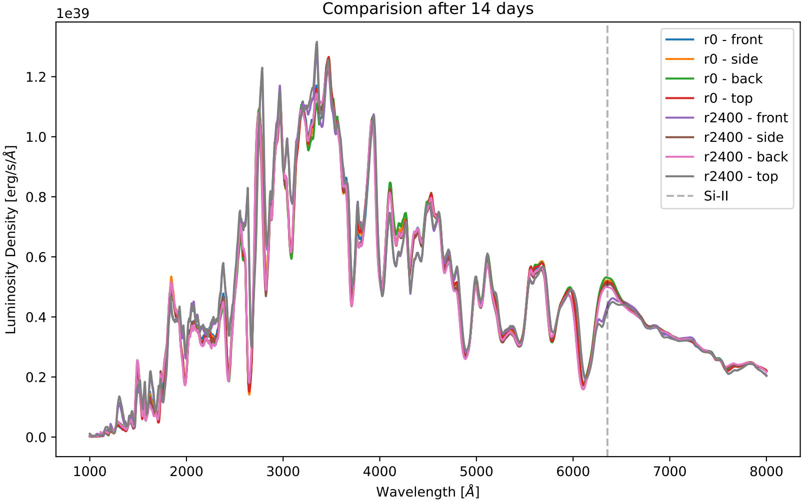
- Sub-M_{Ch} **carbon-oxygen WD** explosions for 3 initial masses
- **Systematically offset** ignition spots
- Ignition artificially triggered



Testing ARTIS-NLTE

First results: (Using TARDIS; Kerzendorf & Sim 2014)

$M_{WD} = 0.9\,M_{\odot}$



Testing ARTIS-NLTE

First results: (Using TARDIS; Kerzendorf & Sim 2014)

$M_{WD} = 1.1\,M_\odot$