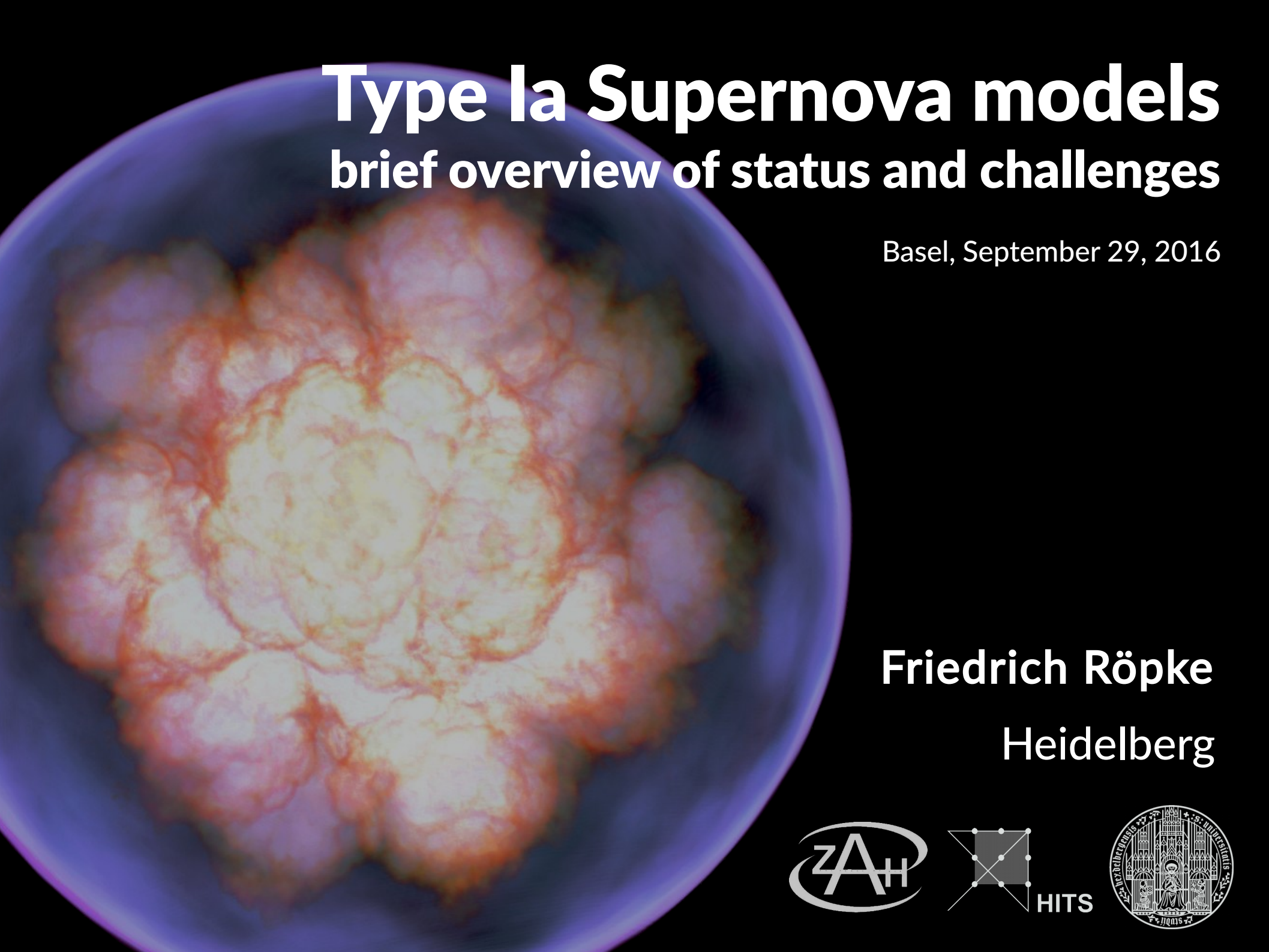


Type Ia Supernova models
brief overview of status and challenges

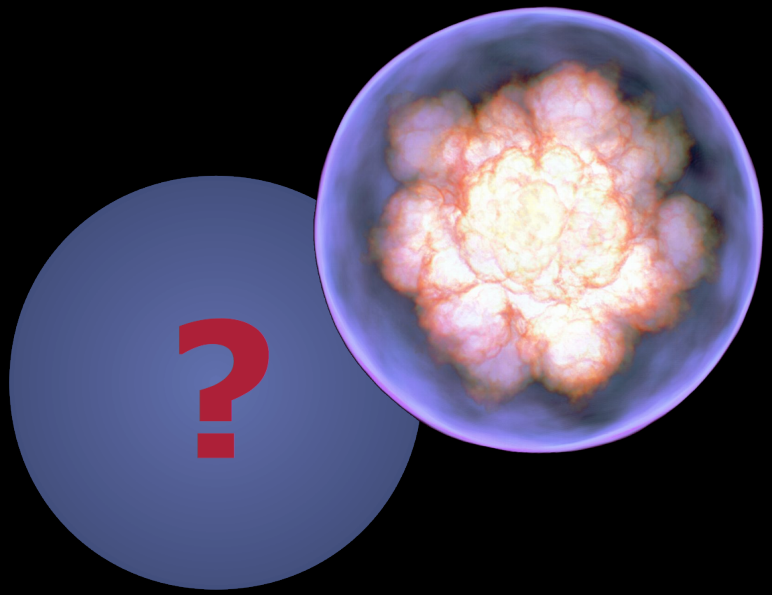
Basel, September 29, 2016

Friedrich Röpke

Heidelberg

Consistent multi-D modeling pipeline

Consistent multi-D modeling pipeline



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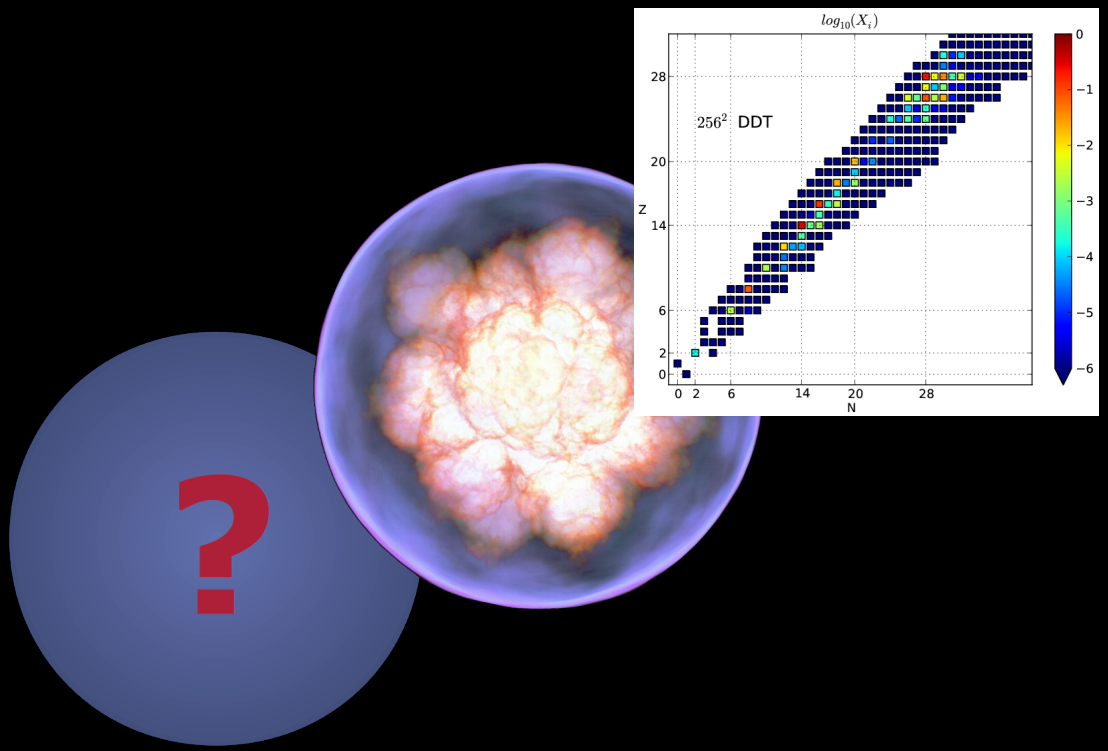

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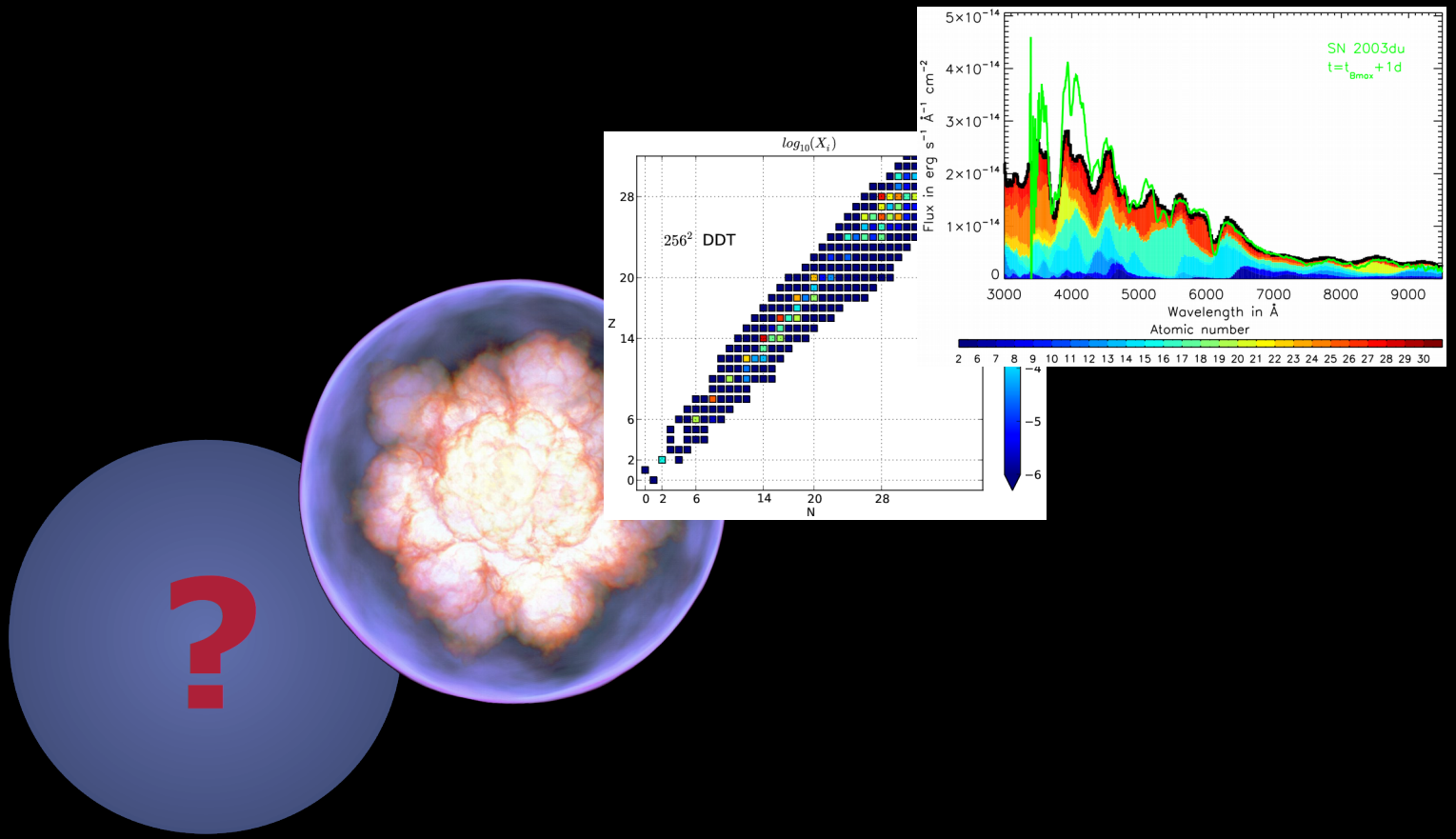

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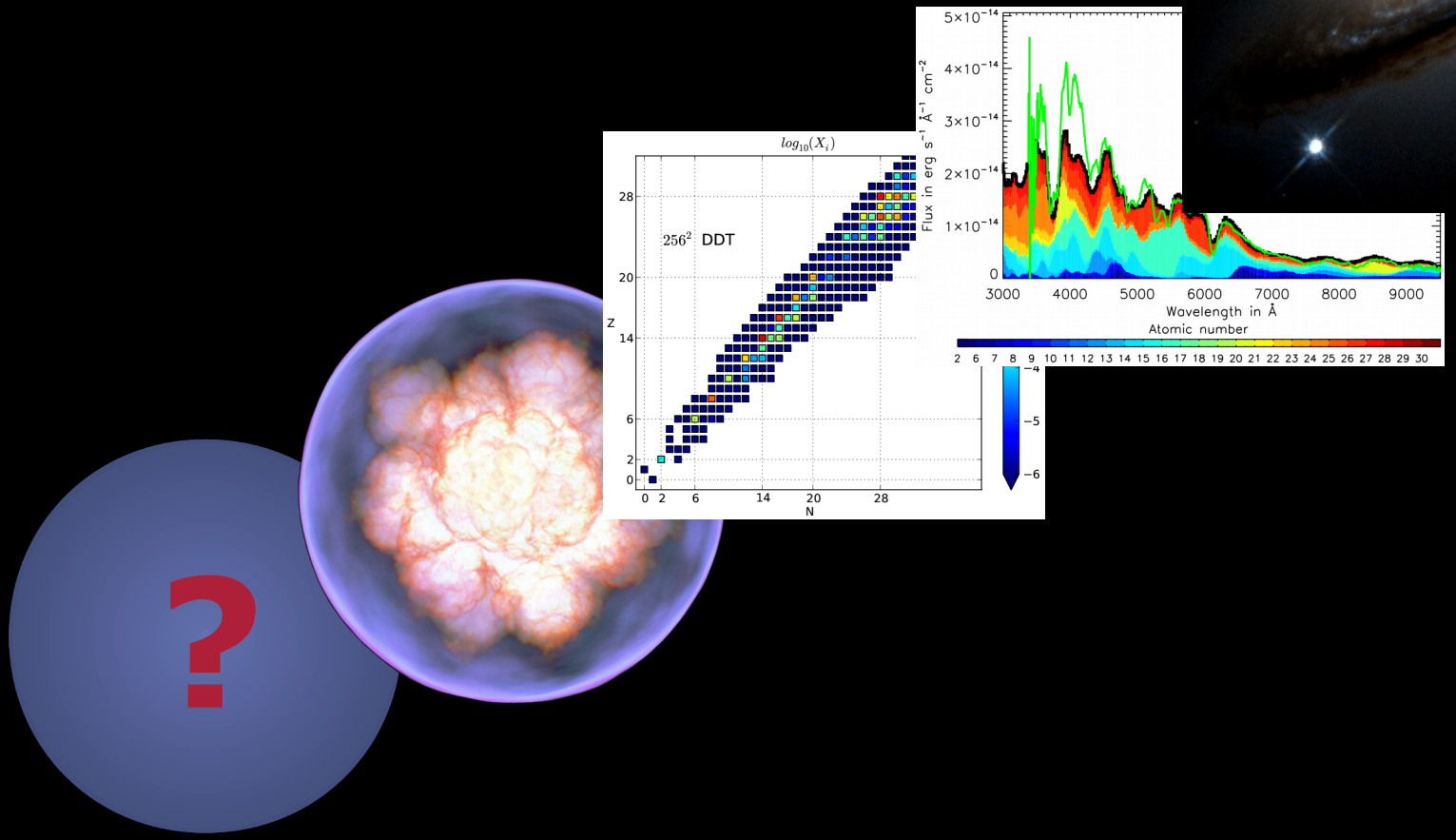

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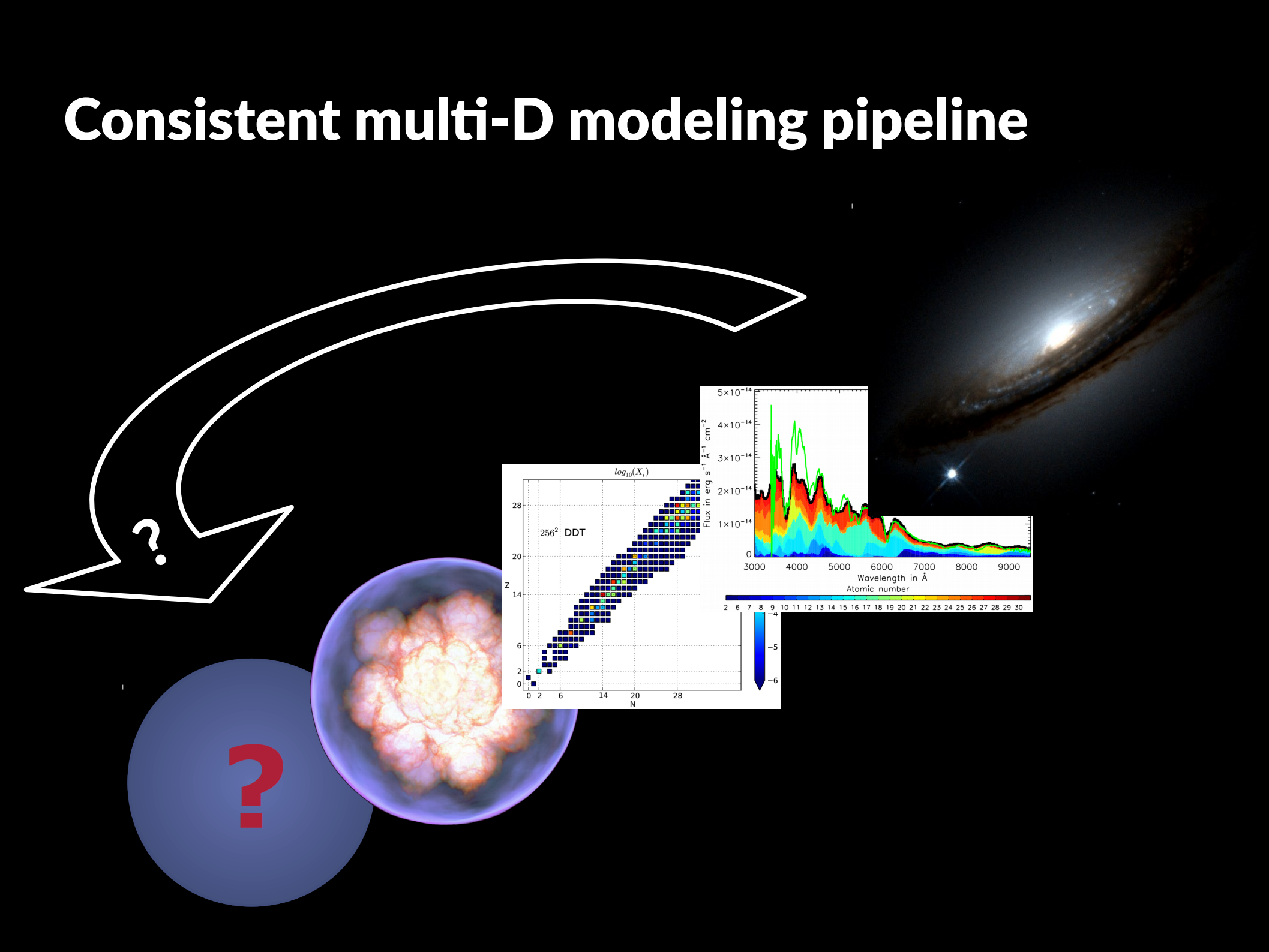

Problem of initial conditions

progenitor systems **not established observationally**

- identification of progenitor would help

  → constrain progenitor scenario (would one observation be sufficient?)

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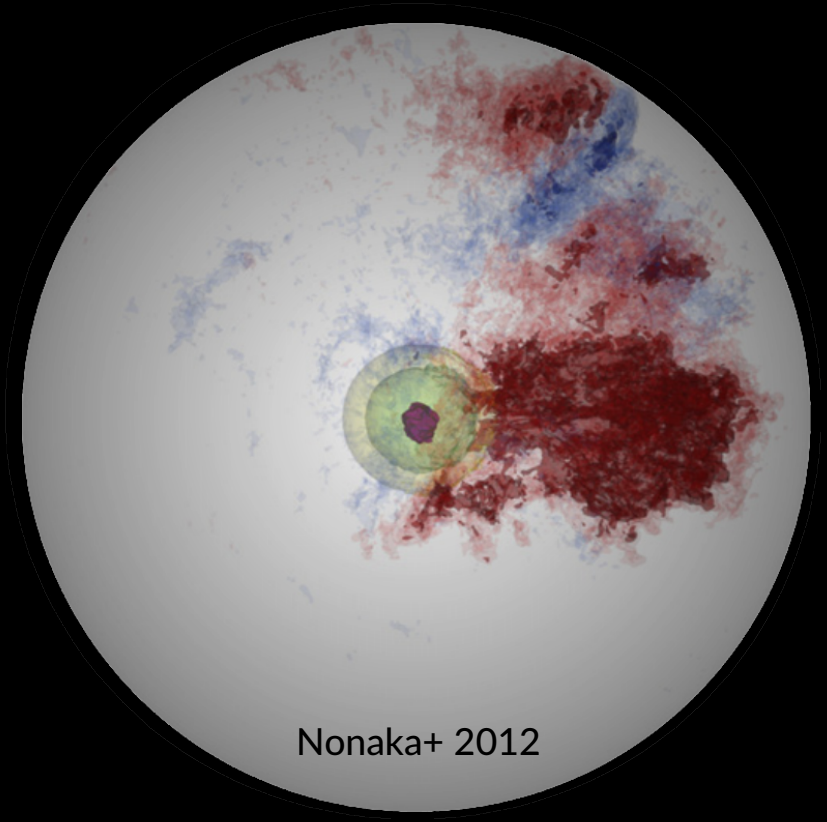
- identification of progenitor would help

  → constrain progenitor scenario (would one observation be sufficient?)

- but not solve all problems

  → progenitor structure and ignition
  still have to be modeled



Nonaka+ 2012

Problem of initial conditions

This is a **fundamental obstacle to SN Ia modeling:**

- hyperbolic system poses initial value problem
- solution in principle completely determined by IC
- not in practice (modeling approximations, numerics)
- but needs to be accounted for in interpreting results

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This is a **fundamental obstacle to SN Ia modeling:**

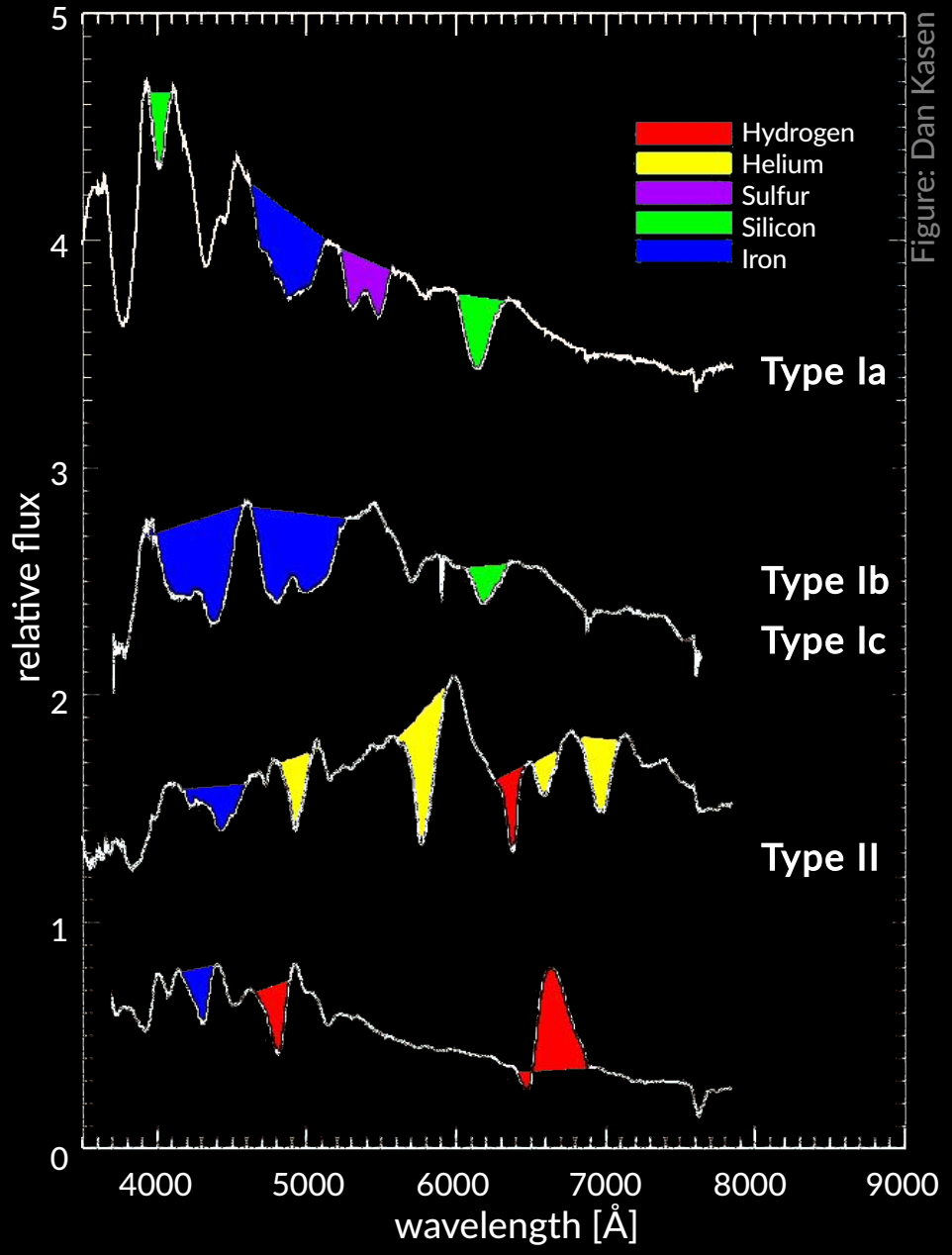
- hyperbolic system poses initial value problem
- solution in principle completely determined by IC
- not in practice (modeling approximations, numerics)
- but needs to be accounted for in interpreting results

→ What can we really learn? → **avoid conclusions based on results dominated by arbitrary choice of ICs**

Scenarios and simulations

(incomplete, biased to Garching/Würzburg/Heidelberg results)

Requirements for viable explosion scenario



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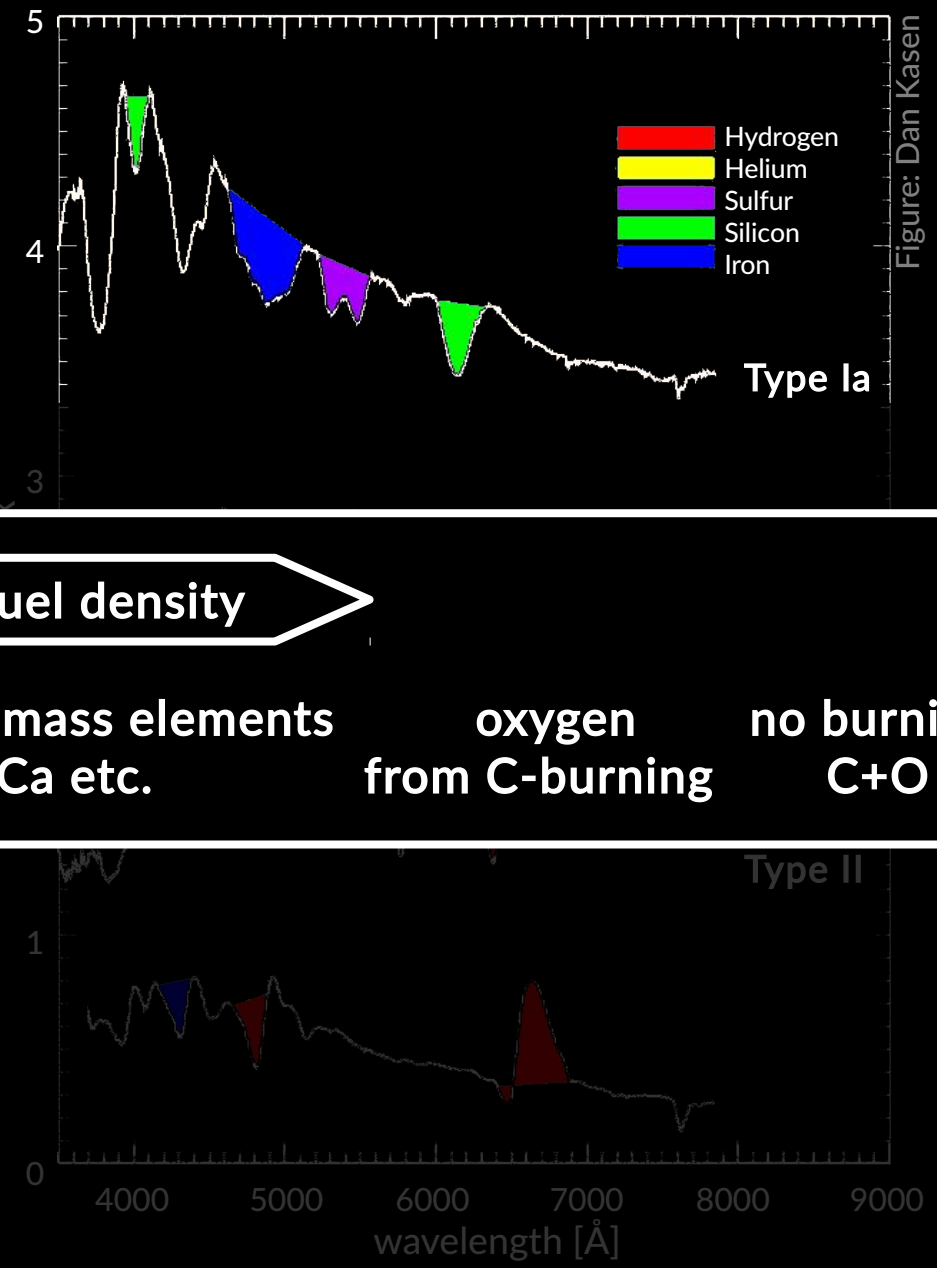

decreasing fuel density

nuclear statist. equilibrium (iron group elements)	intermediate-mass elements Si, S, Ca etc.	oxygen from C-burning	no burning C+O

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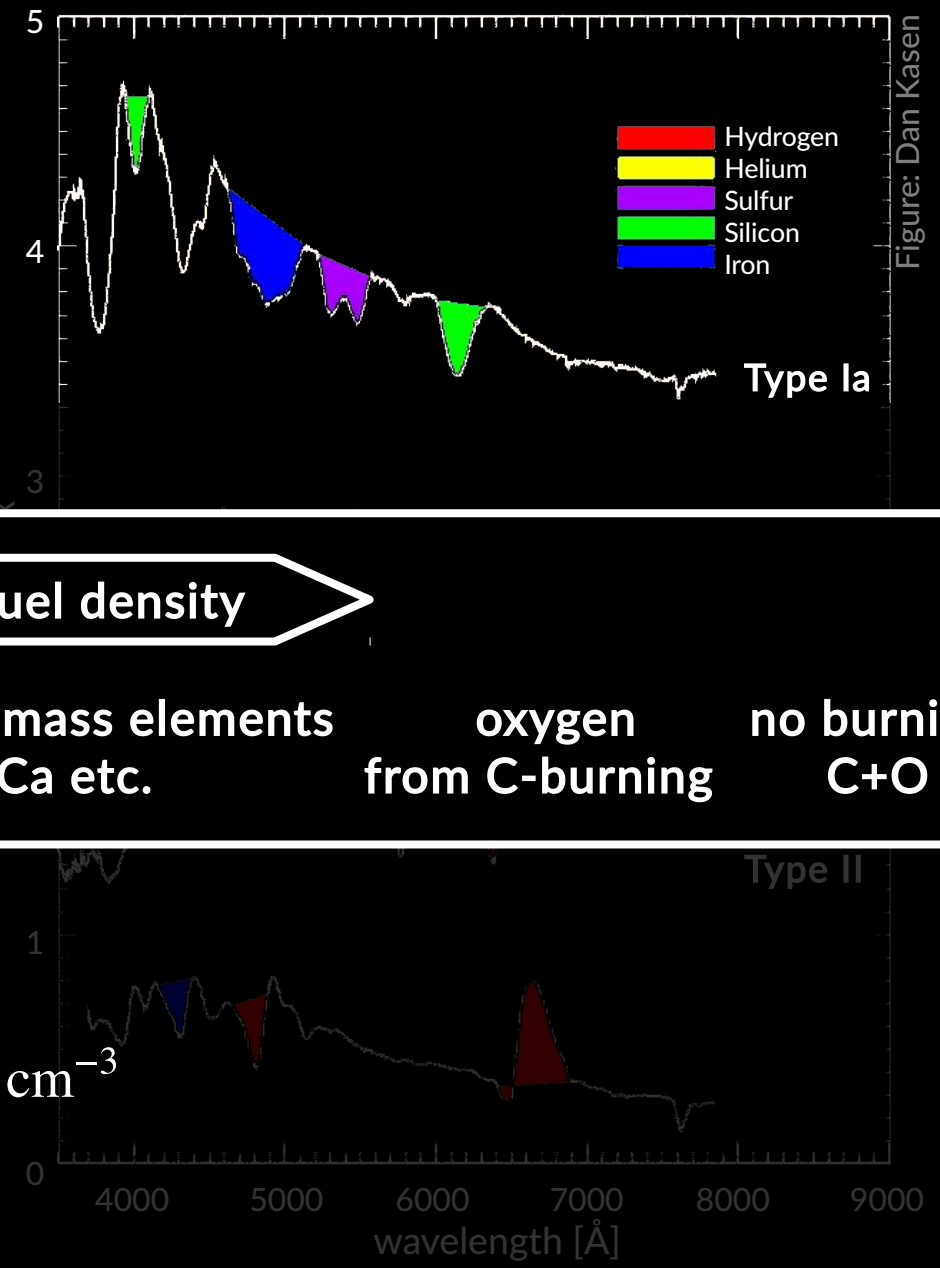


decreasing fuel density

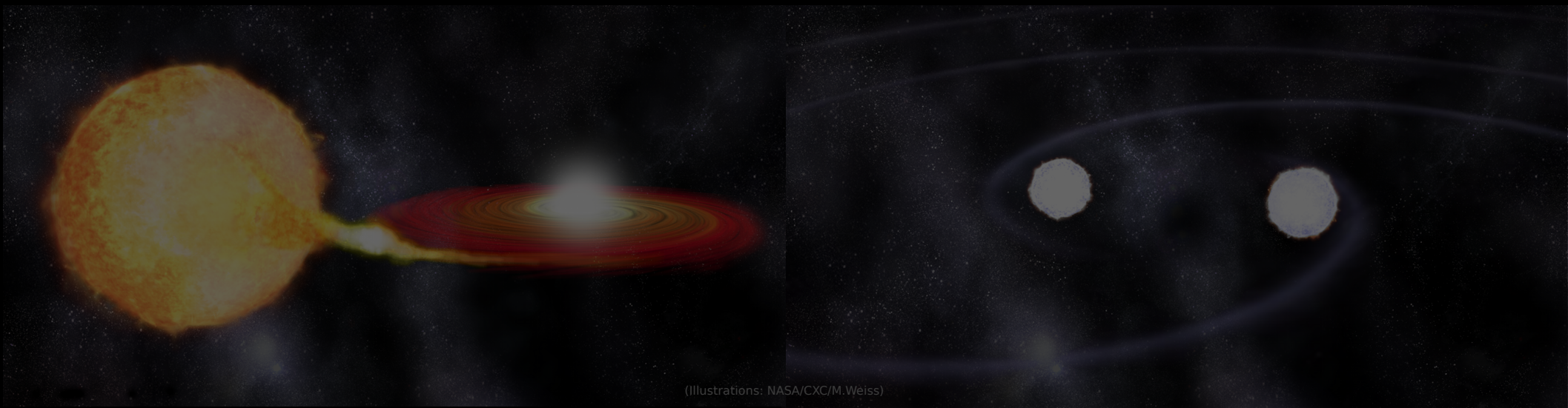
nuclear statist. equilibrium (iron group elements)	intermediate-mass elements Si, S, Ca etc.	oxygen from C-burning	no burning C+O

→ substantial burning below $\rho_{\mathrm{fuel}} \sim 10^7\,\mathrm{g\,cm^{-3}}$ necessary

Requirements on burning mode

burning must

1) pre-expand an **M_{Ch} WD** → deflagration
2) proceed as detonation in pre-expanded **M_{Ch} WD** → delayed detonation
3) proceed as detonation in **sub-M_{Ch} WD**



(Illustrations: NASA/CXC/M.Weiss)

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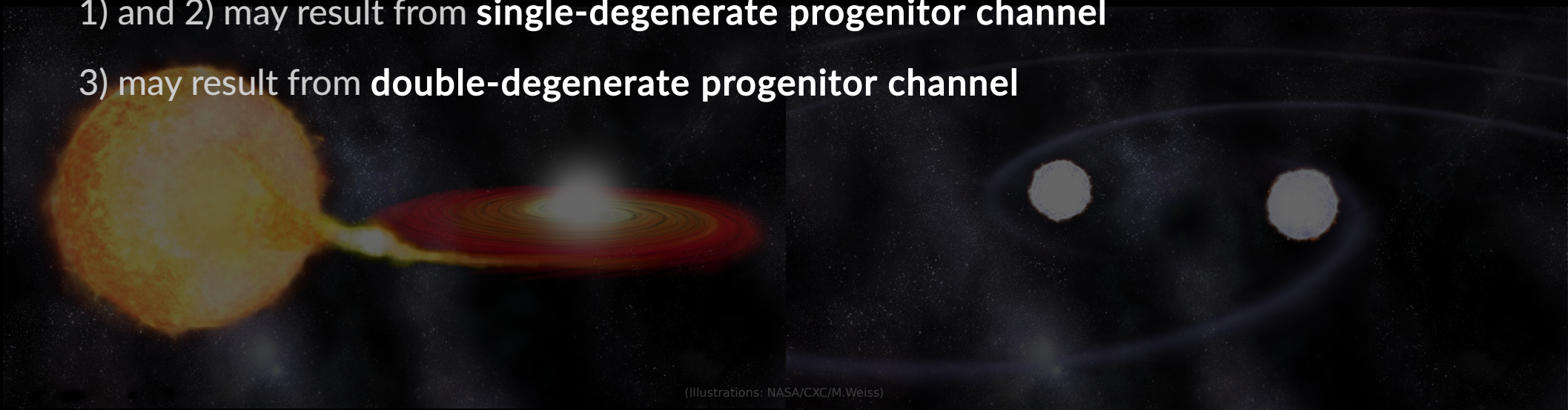
→ this sets the initial conditions for the explosion models and connects to the progenitor problem of SNe Ia

1) and 2) may result from **single-degenerate progenitor channel**

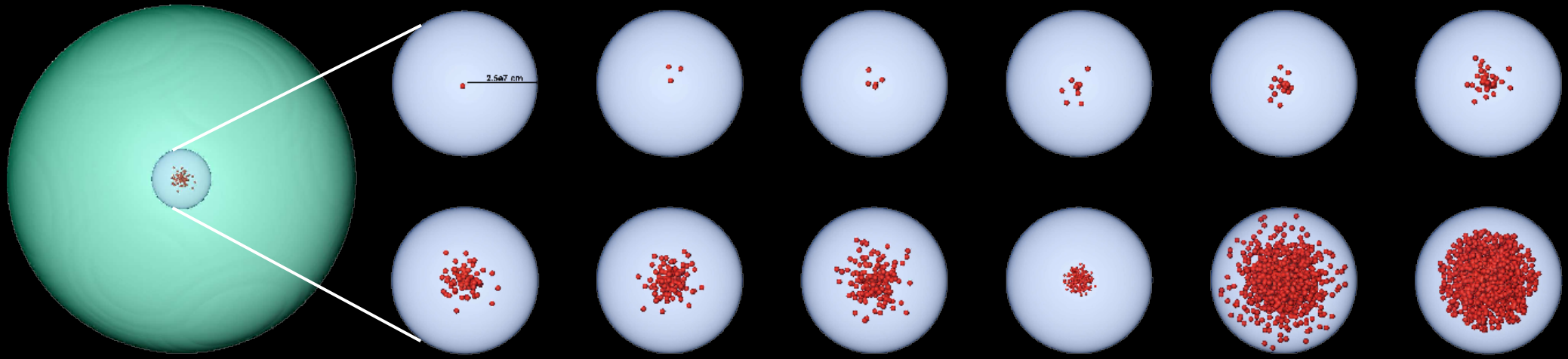
3) may result from **double-degenerate progenitor channel**



(Illustrations: NASA/CXC/M.Weiss)

Deflagrations in M_{Ch} WDs

- turbulent deflagrations
- outcome sensitive to ignition geometry (e.g. FR+ 2006, Schmidt+ 2006, FR+, 2007, Fink+ 2014)



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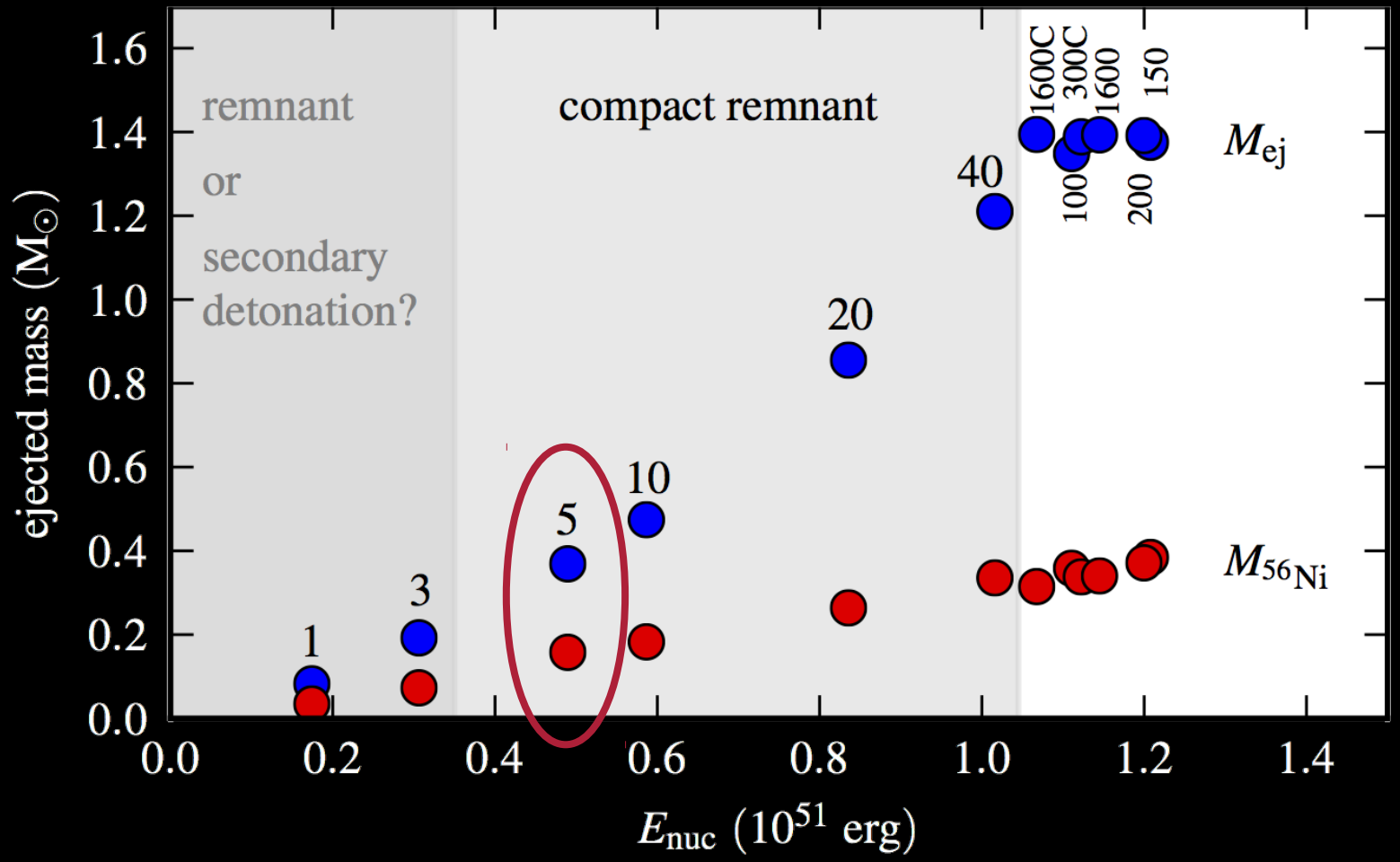
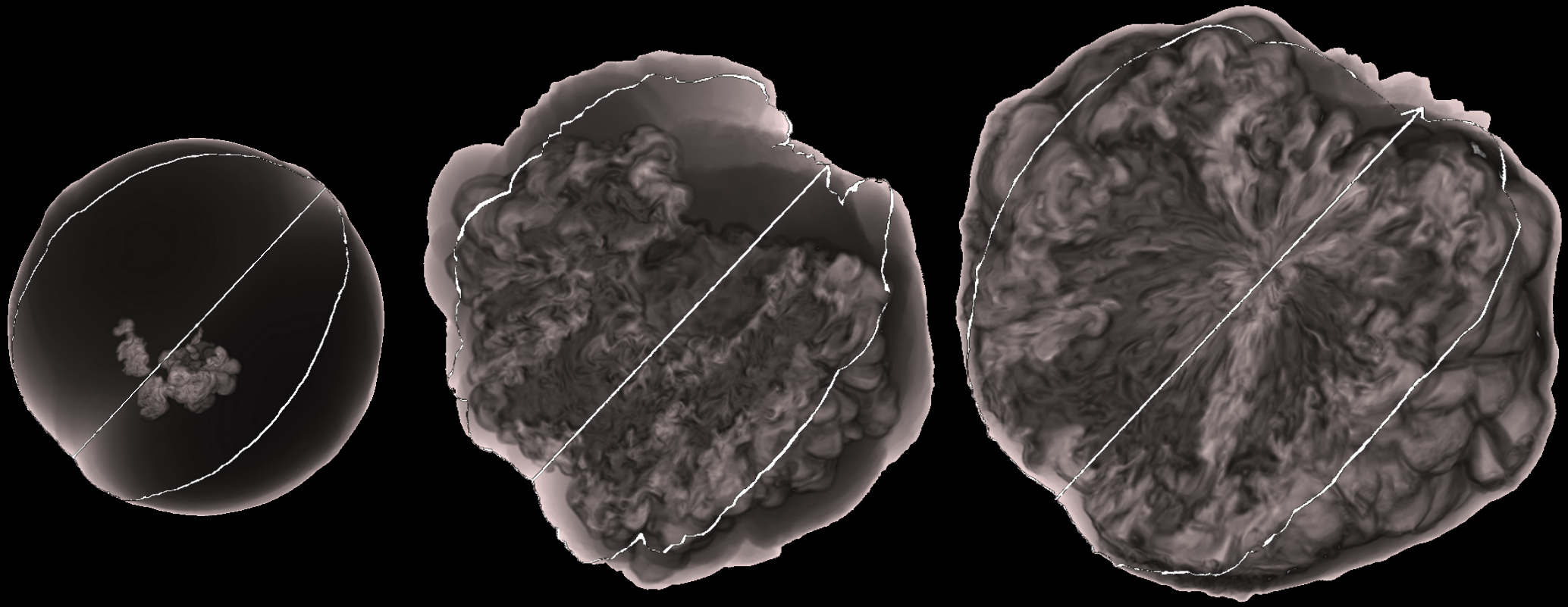


Deflagrations in M_{Ch} WDs

- models with asymmetric ignition reproduce some sub-classes well (Jordan+ 2012, Kromer+ 2013)



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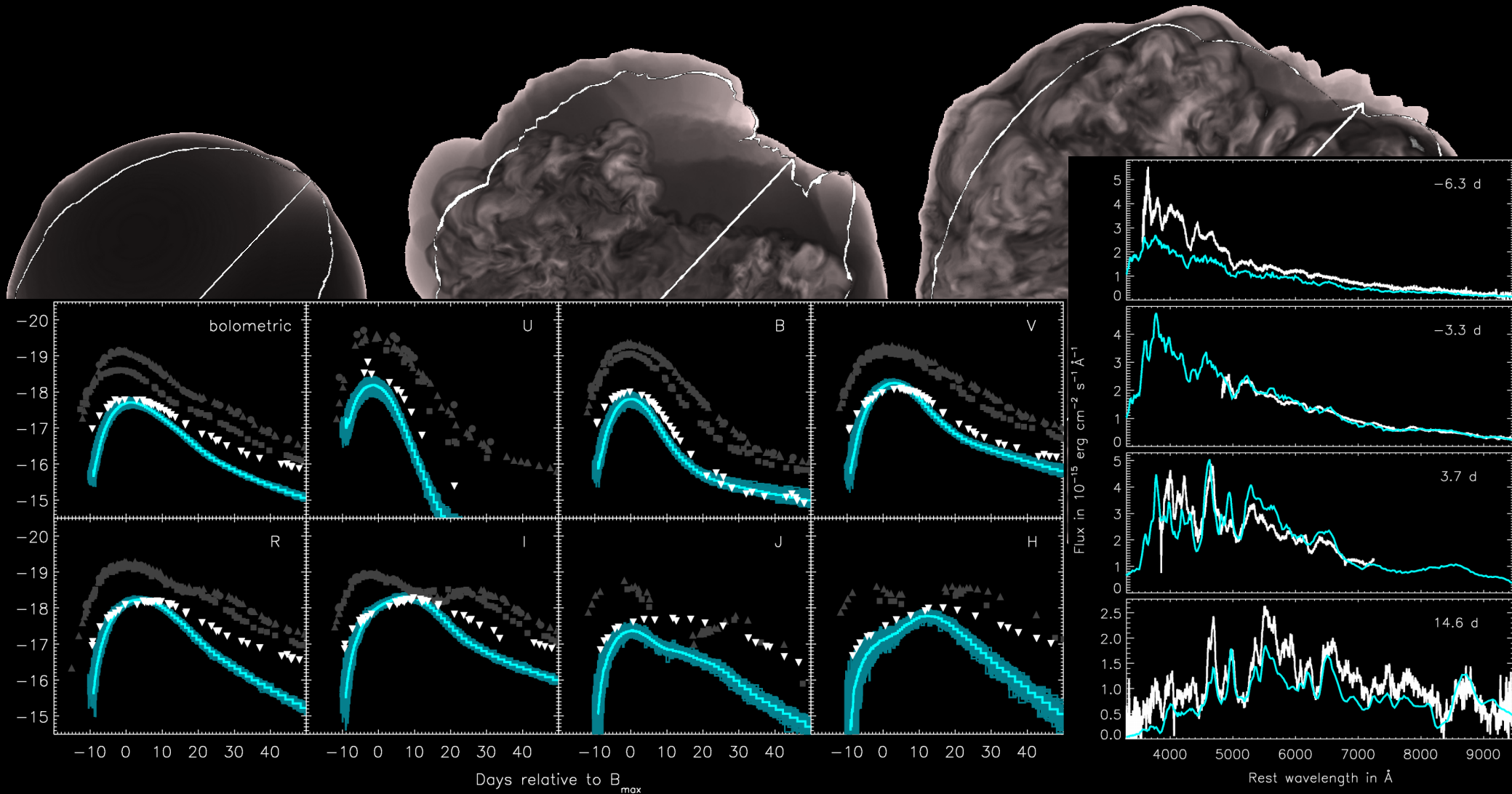


Deflagrations in M_{Ch} WDs

physical parameters:

- WD central density at ignition
- WD chemical composition at ignition
- WD rotation
- ignition geometry

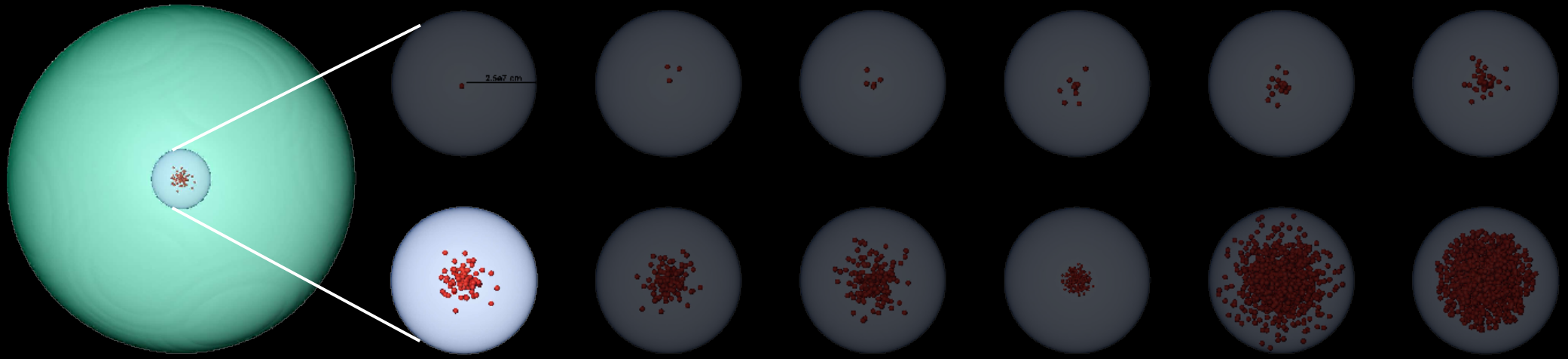
uncertainties of the model:

- flame-turbulence interaction

Delayed detonations in M_{Ch} WDs

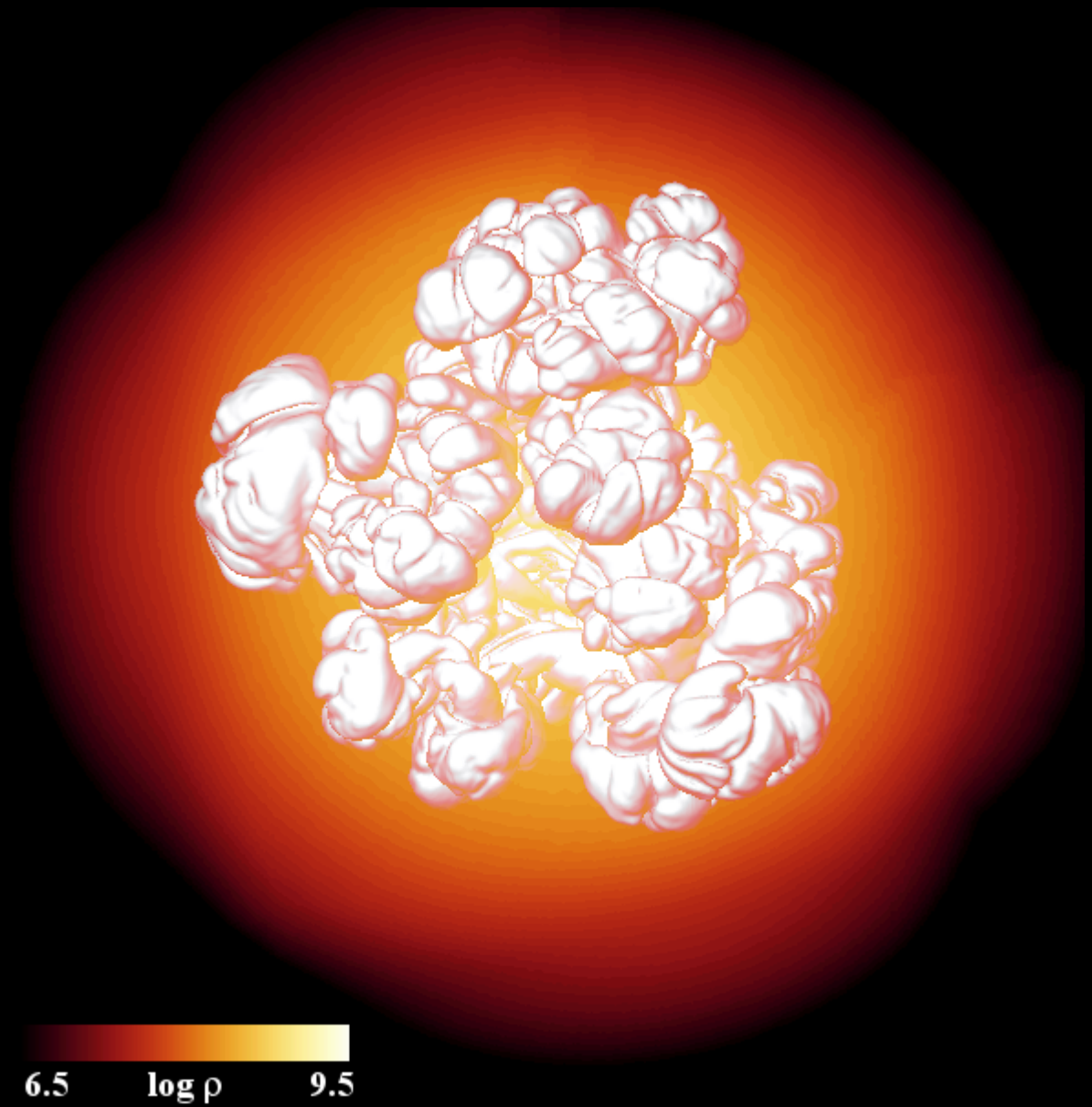
- suggested by Khokhlov 1991 (3D simulation by Gamezo 2005)
- needs rather strong deflagration, otherwise detonation produces too much ^{56}Ni

  (e.g. FR & Niemeyer 2007, Mazzali+ 2007, Kasen+ 2009, Seitenzahl+ 2012, Sim+ 2013)



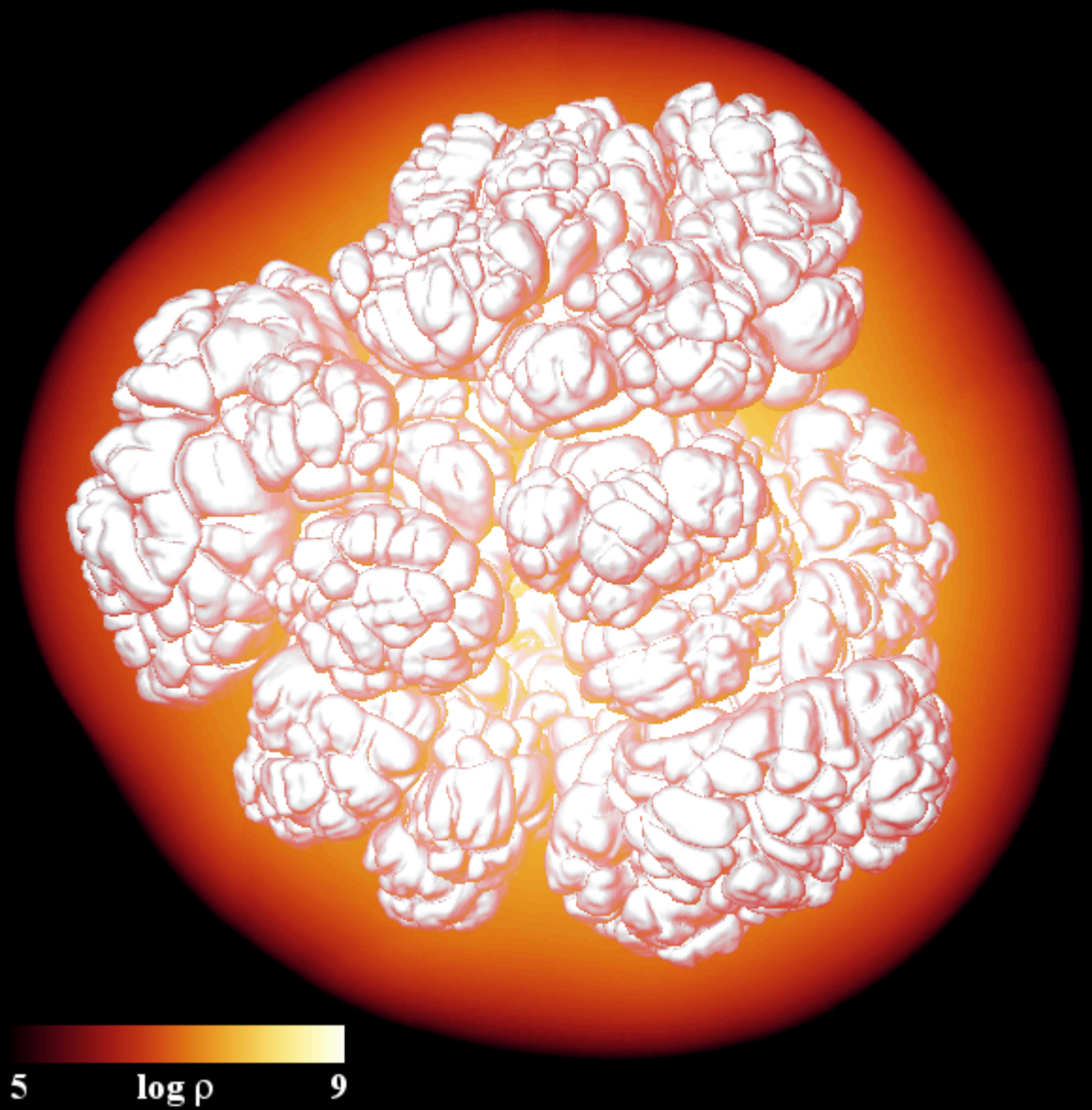
Example: delayed detonation model N100

t = 0.70s



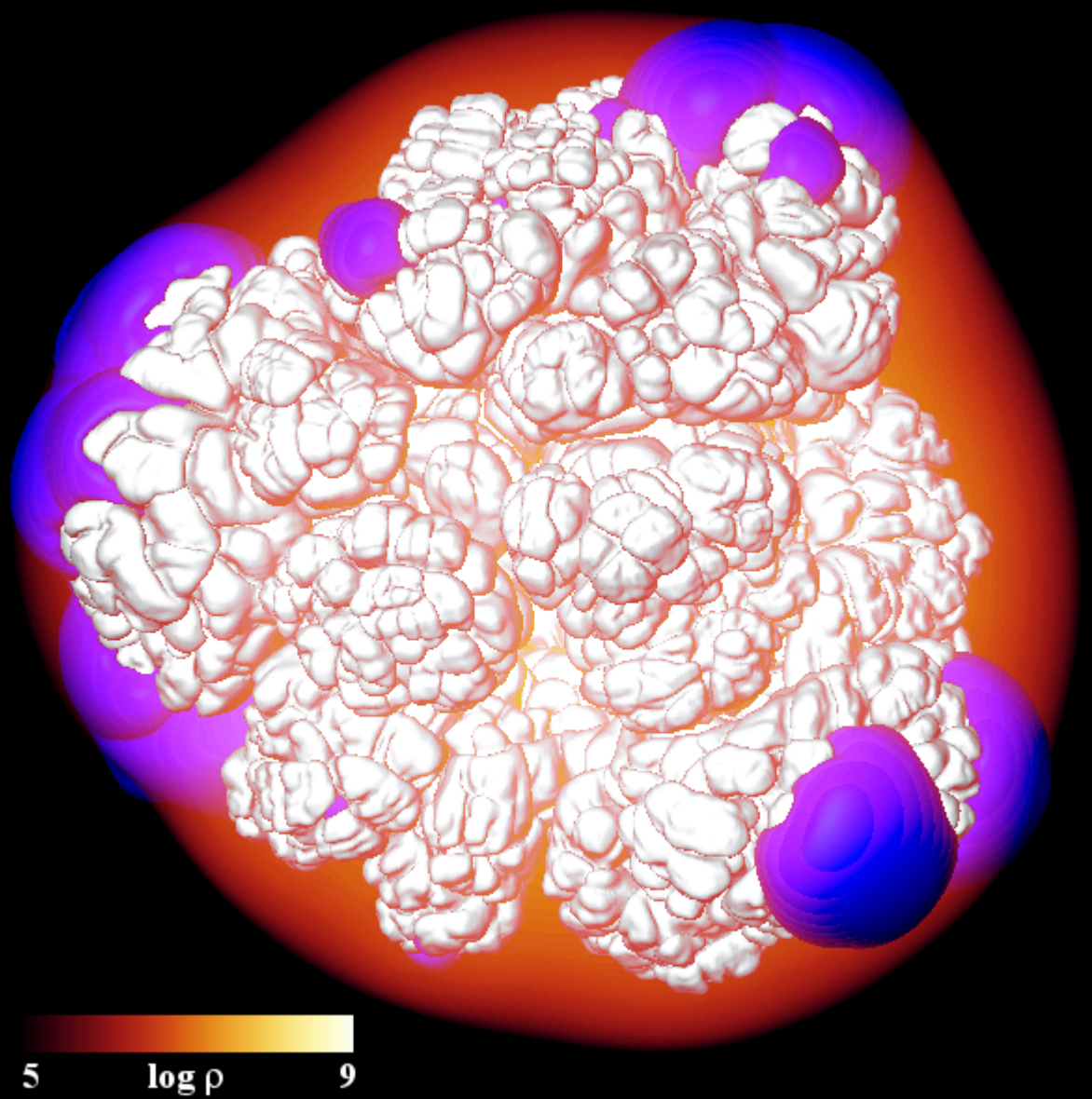
Example: delayed detonation model N100

t = 0.93s



Example: delayed detonation model N100

t = 1.00s



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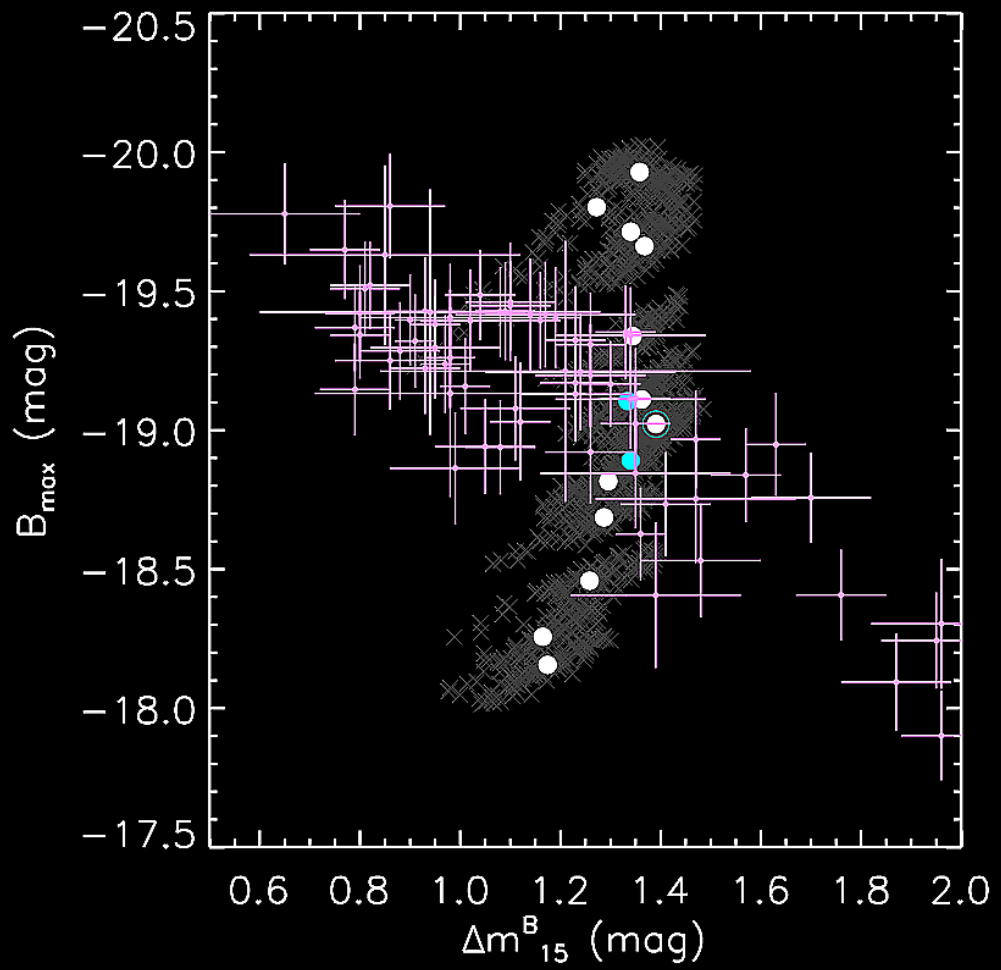

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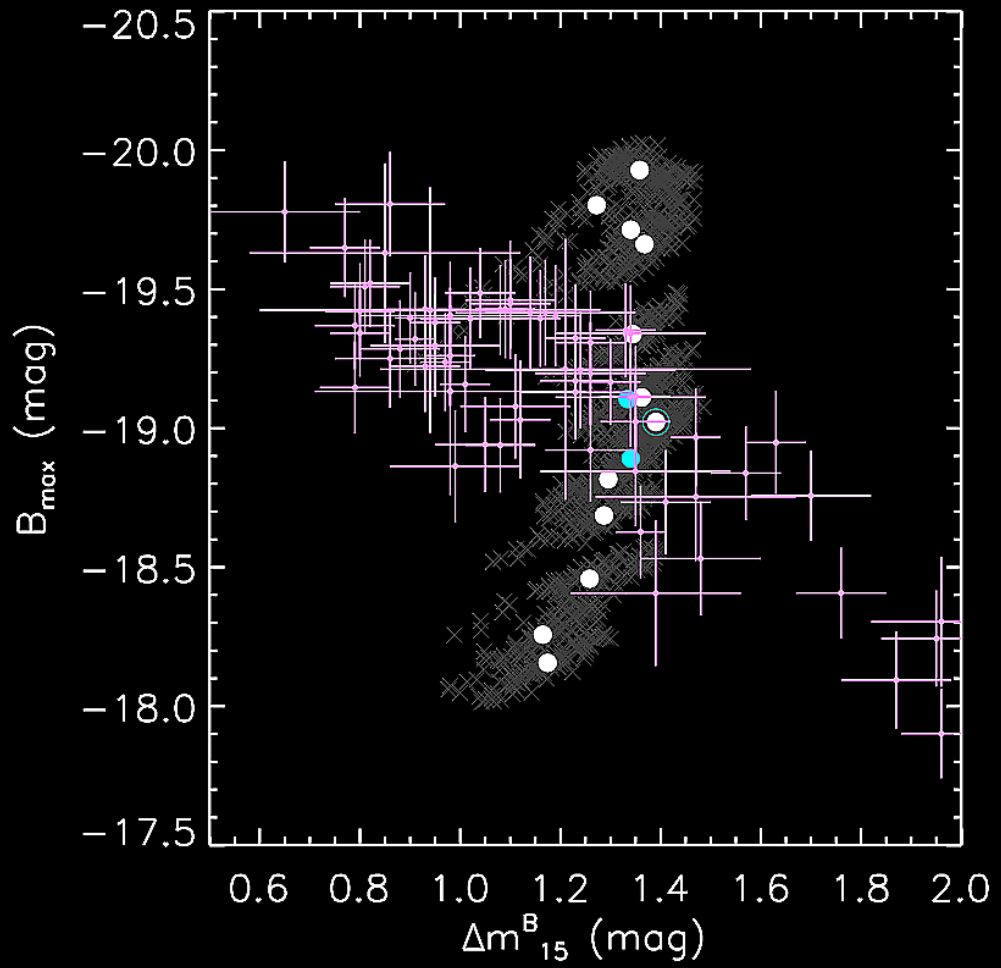
- **Main problem:**

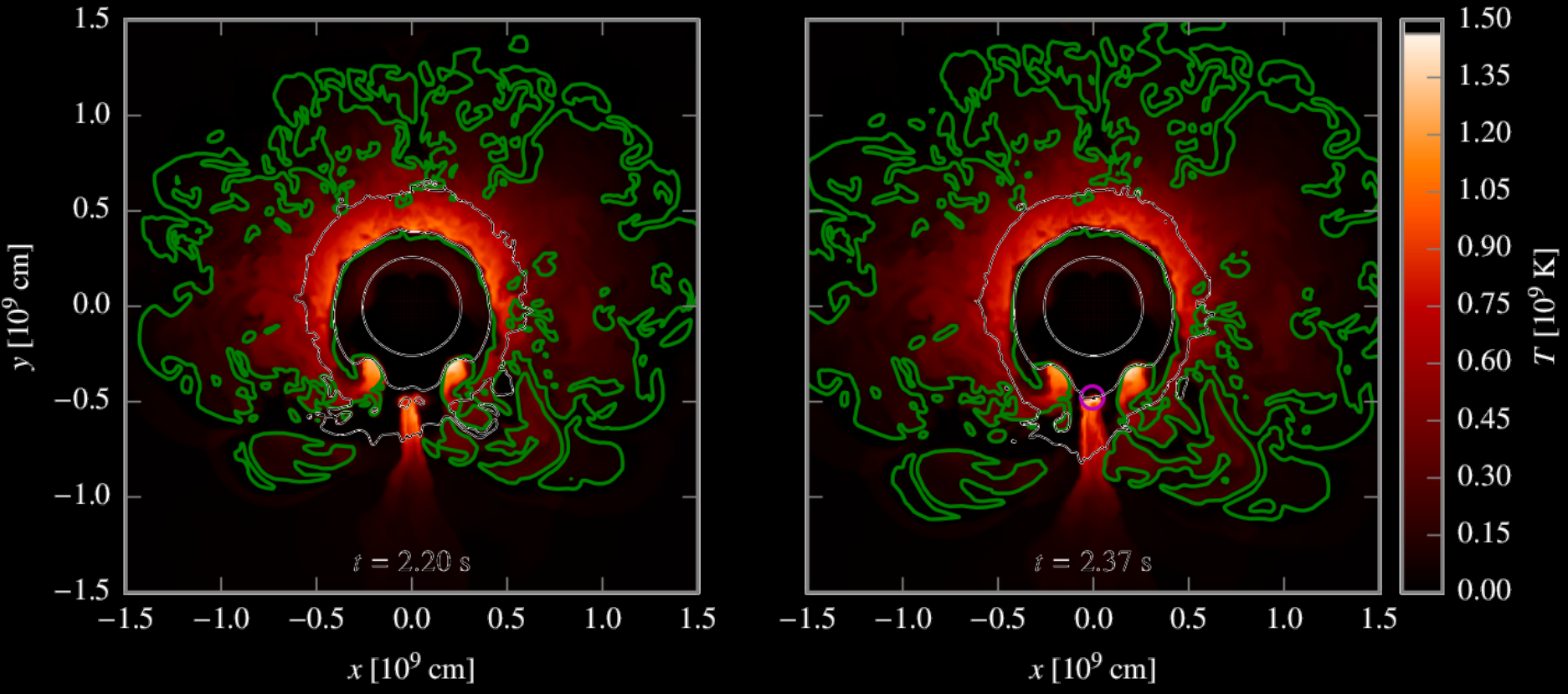
  Fixed mass → not enough fidelity for reproducing range of observables (?)



Other delayed detonation M_{Ch} models

GCD: gravitationally confined detonations (Plewa+ 2004)

- model run over full pipeline → result disagrees with known SNe Ia (Seitenzahl+ 2016)



→ similar results expected for pulsational models (Bravo+ 2009, Jordan+ 2012)?

Delayed detonations in M_{Ch} WDs

physical parameters:

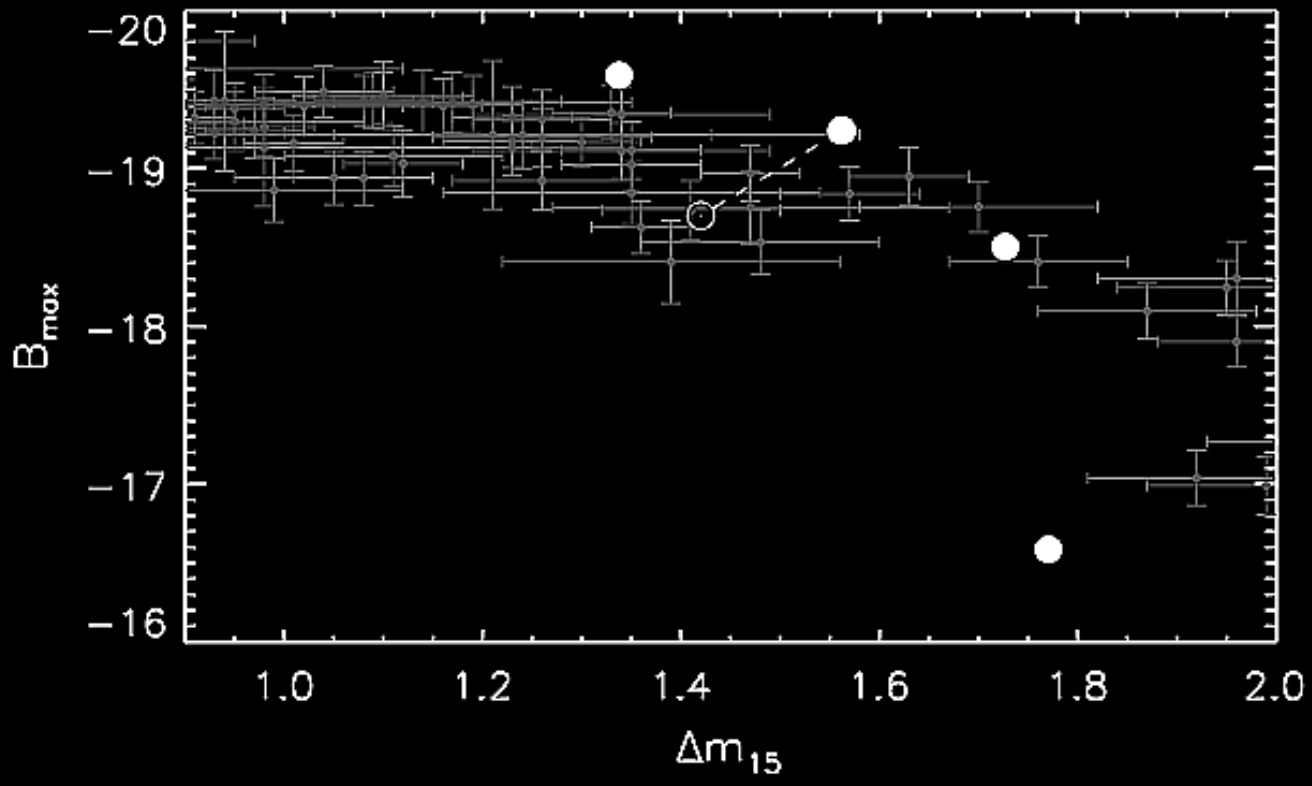
- WD central density at ignition
- WD chemical composition at ignition
- WD rotation
- ignition geometry

uncertainties of the model:

- flame-turbulence interaction
- **deflagration-to-detonation transition or triggering of detonation**

Detonations in sub-M_{Ch} WDs

- promising scenario (Sim+ 2010)



- **primary parameter** driving trends: **mass of exploding WD** (Pinto & Eastman 2000)

Detonations in sub-M_{Ch} WDs

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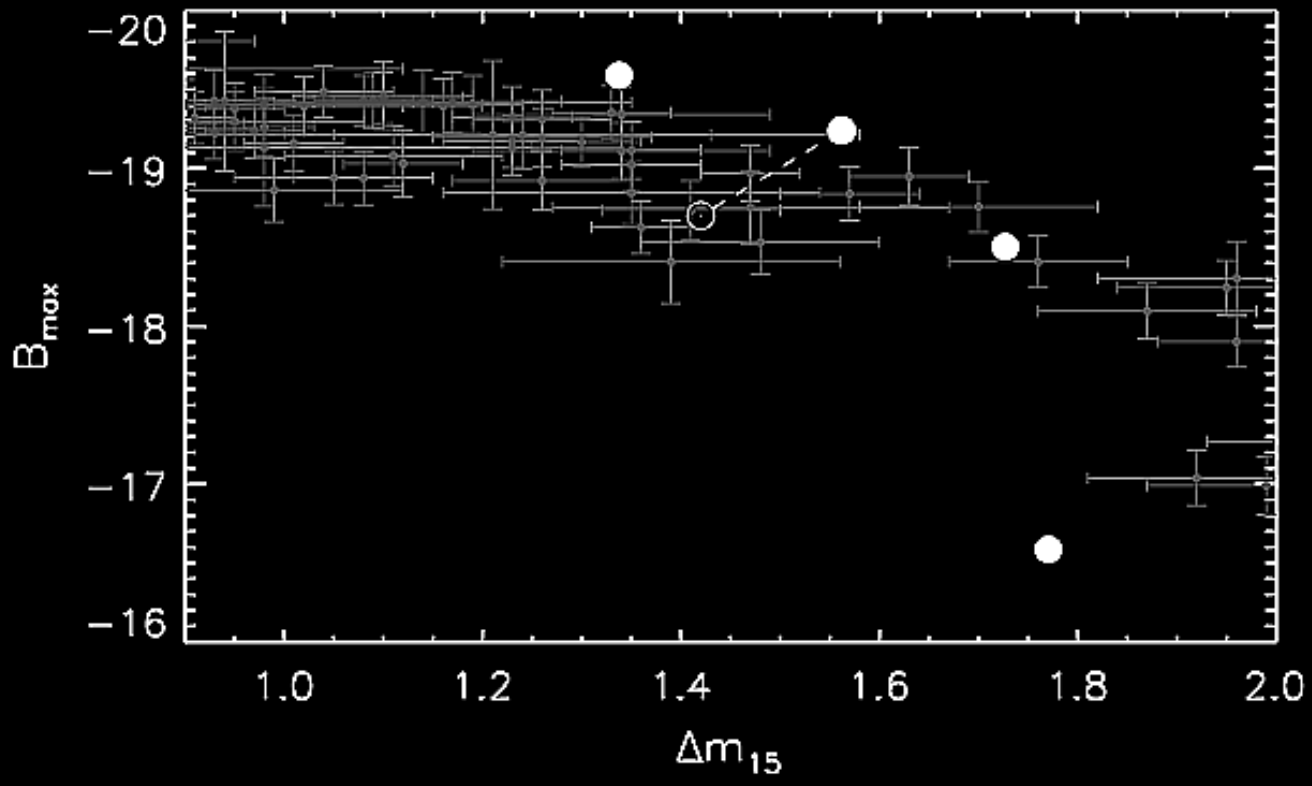
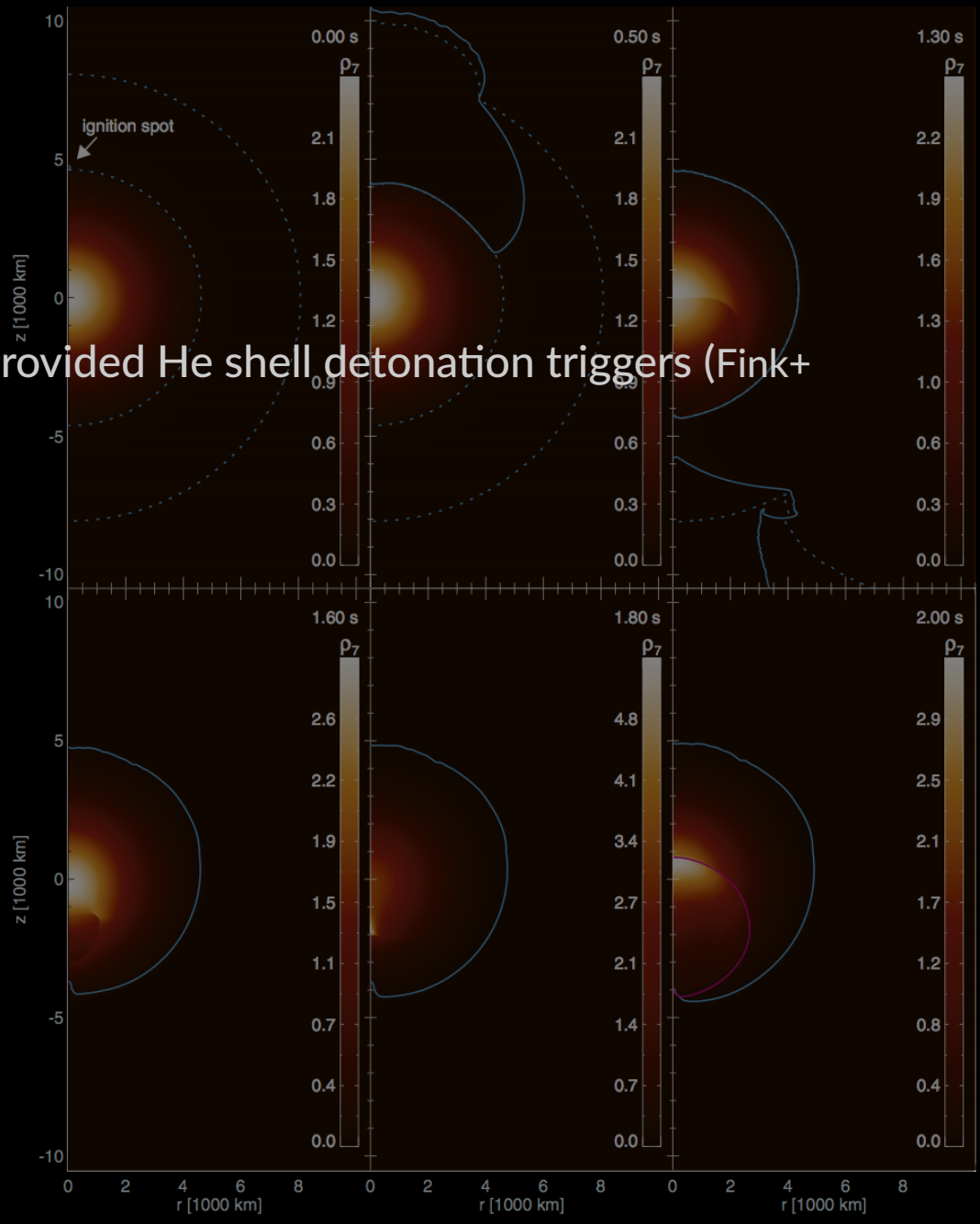


- **primary parameter** driving trends: **mass of exploding WD** (Pinto & Eastman 2000)
- **How to trigger detonation?**

Double detonations

- explosion mechanism **works robustly**, provided He shell detonation triggers (Fink+ 2007, 2010, Moll & Woosley 2011)



Double detonations

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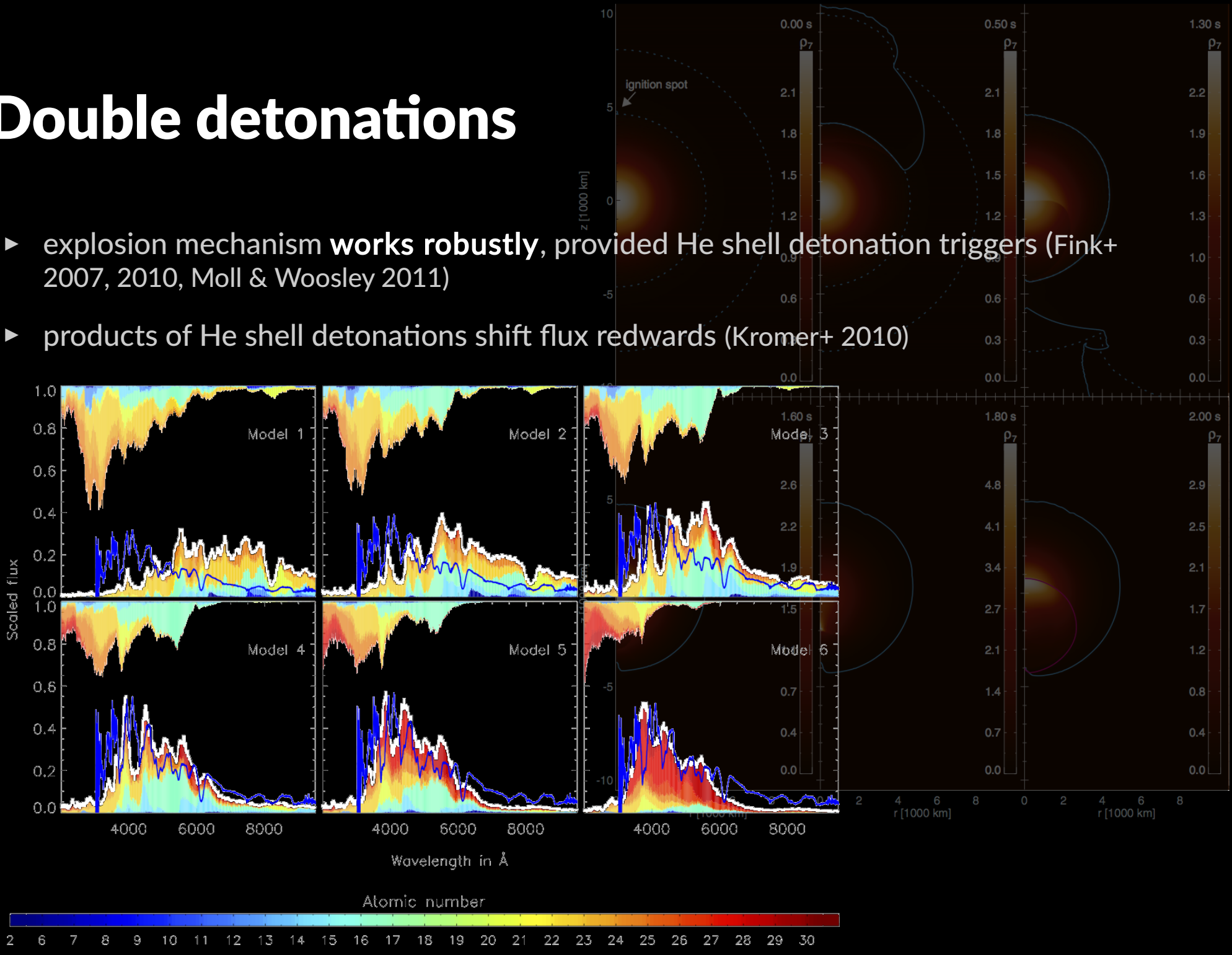
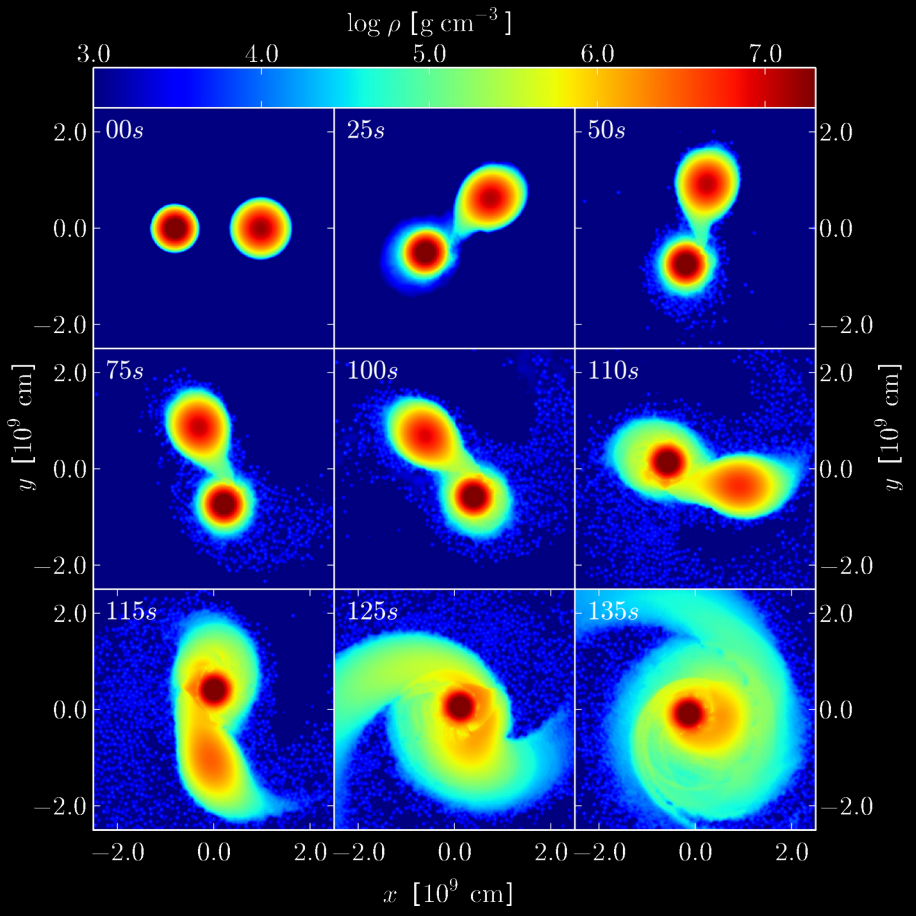
- products of He shell detonations shift flux redwards (Kromer+ 2010)



WD mergers

- most promising model (?): **violent merger** (Pakmor+ 2010,2011,2012)
- predicted observables seem to match data well



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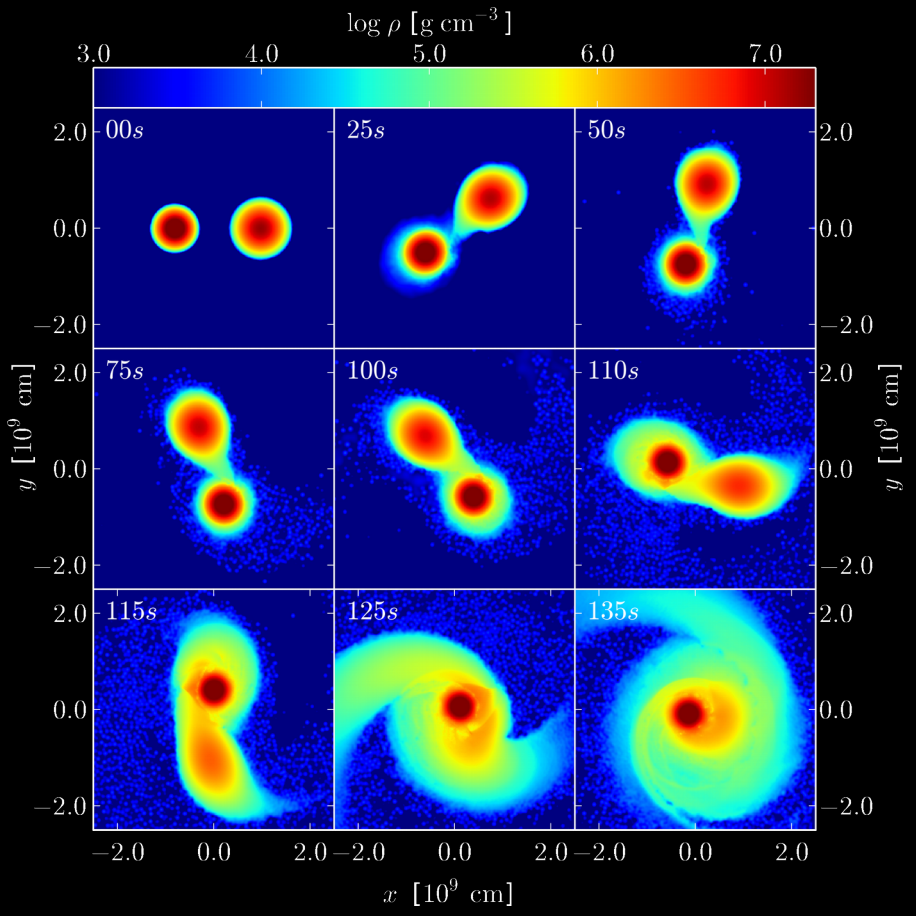
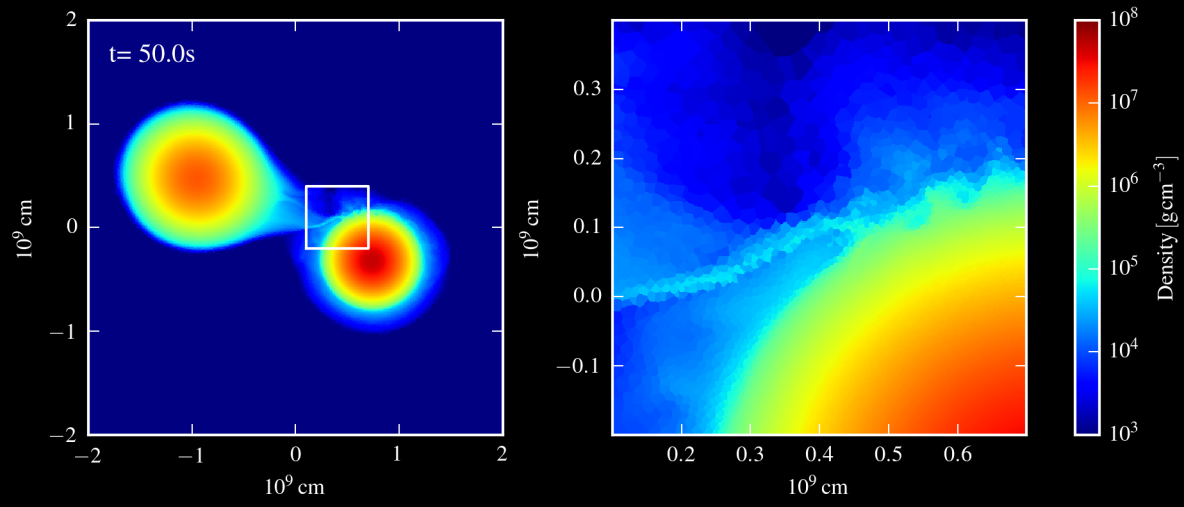


- possibly **He-ignited** (Pakmor+ 2013)

- **variant of sub-M_{Ch} detonation model**
- may reproduce observed brightness distribution of SNe Ia (Ruiter+ 2013)



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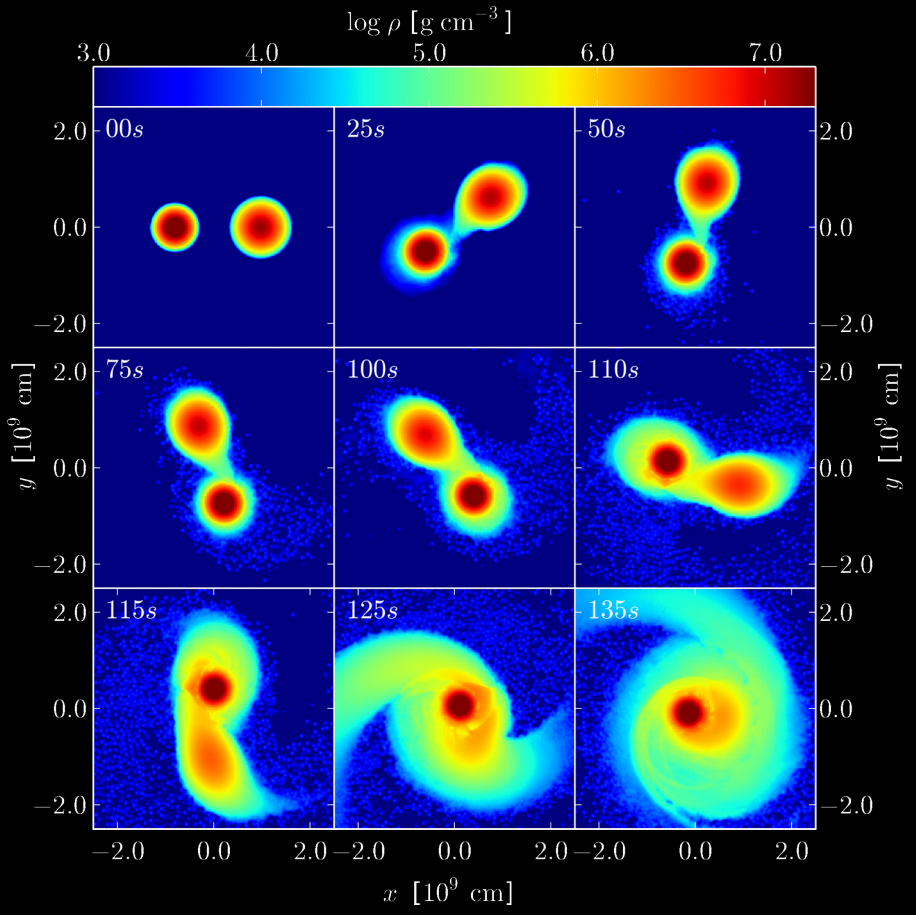

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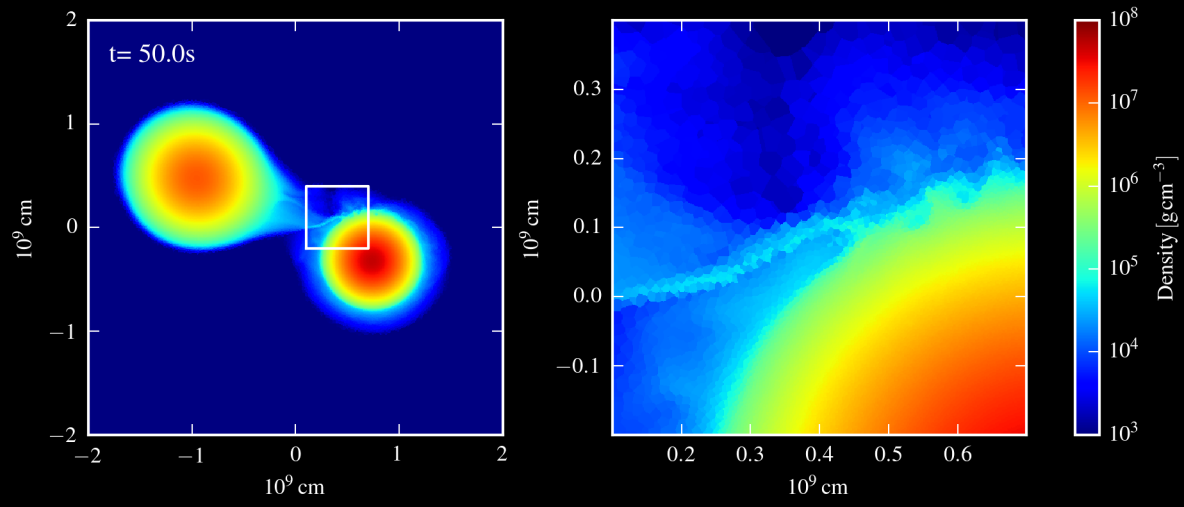


- parameter space not fully explored

Sub-M_{Ch} models

physical parameters:

- WD chemical composition at ignition
- **mass of exploding WD**
- mass of companion
- orbital parameters

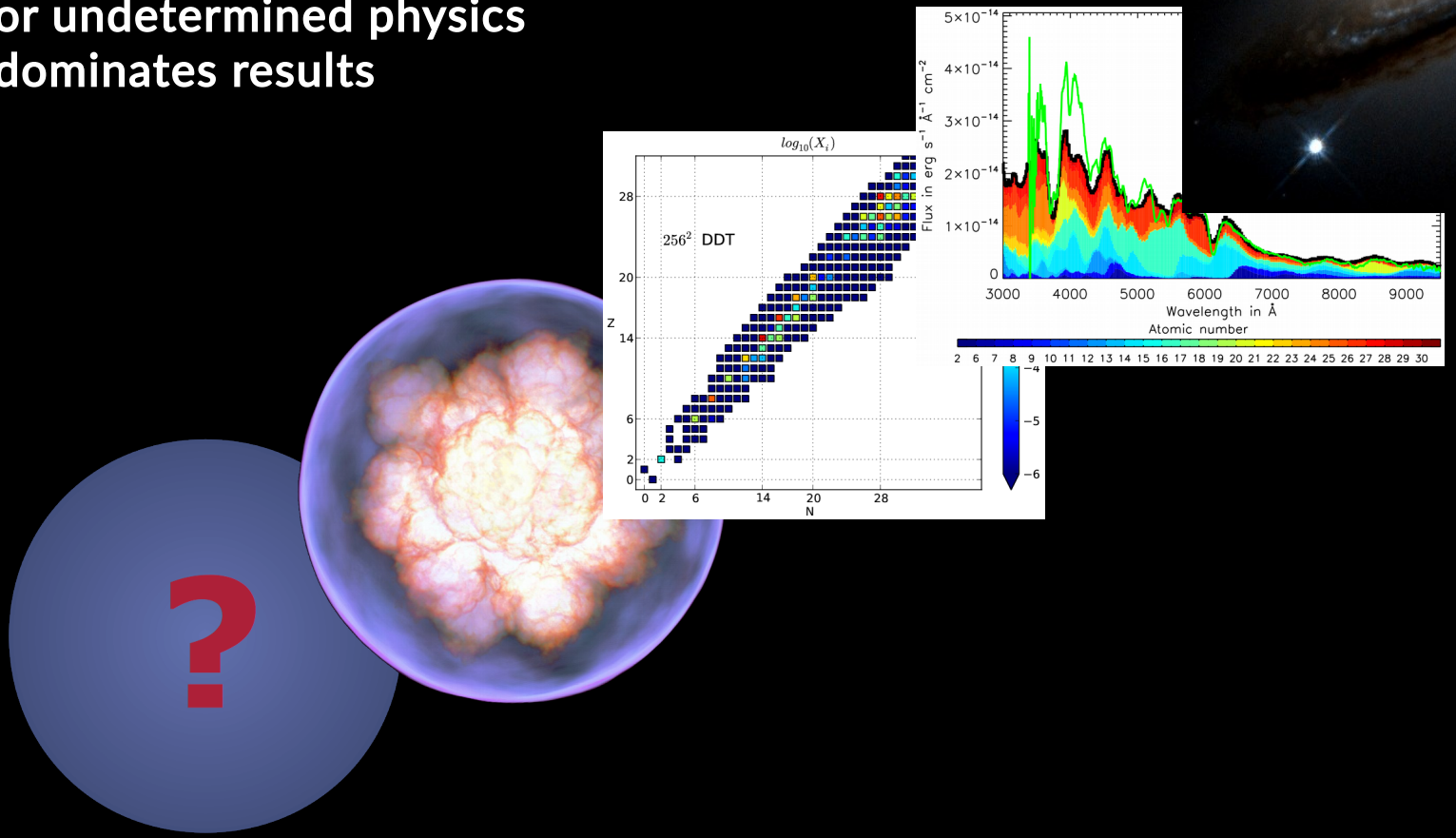
uncertainties of the model:

- **mechanism of detonation initiation**
- ignition and mass of He shell in double detonations
- fate of secondary in WD mergers

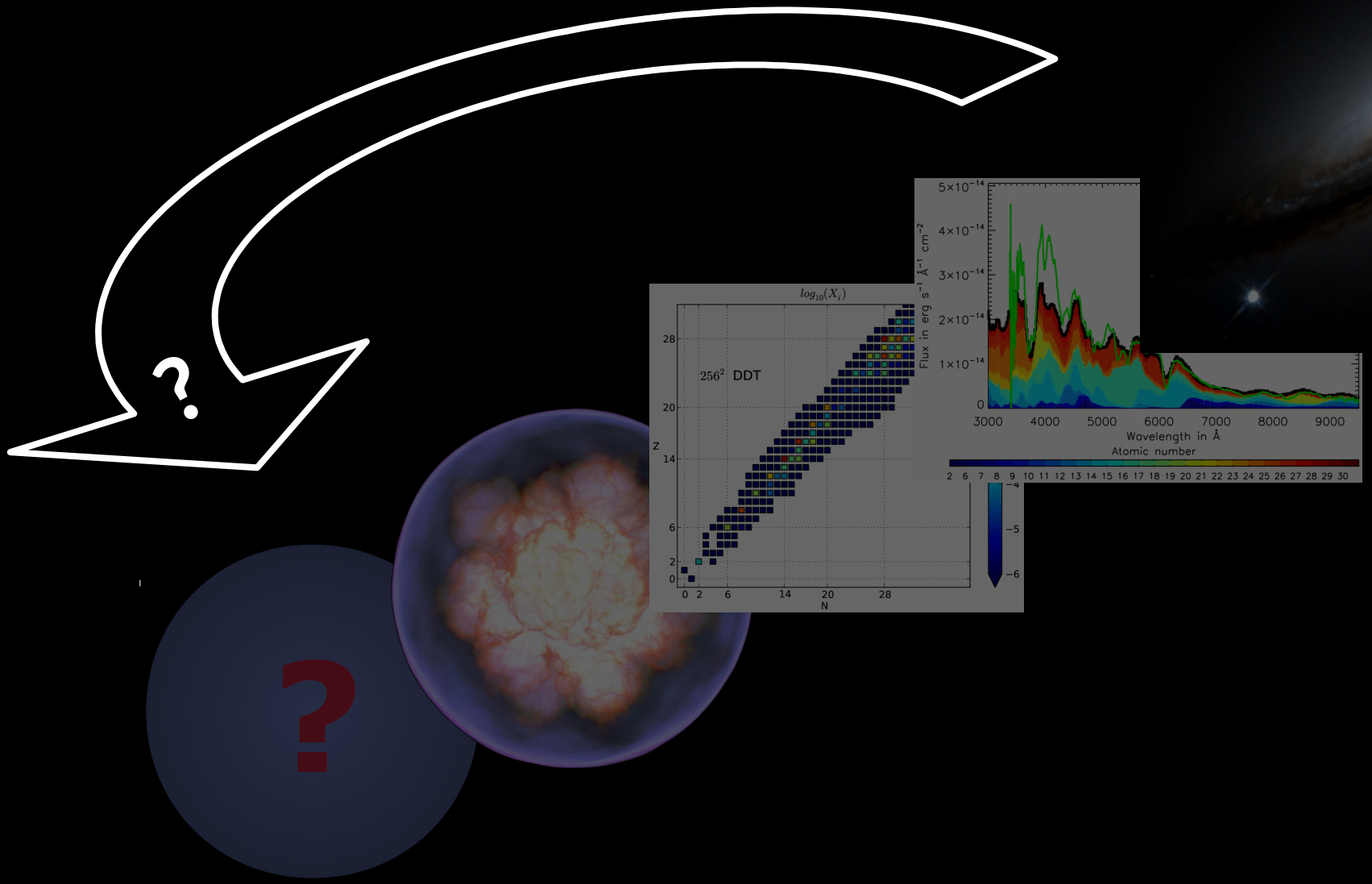
How can we make progress?

Consistent multi-D modeling pipeline

- much room for improvement in flame modeling, DDT, ignition etc.
- crucial for precise prediction of observables
- **avoid models in which numerical effects or undetermined physics dominates results**

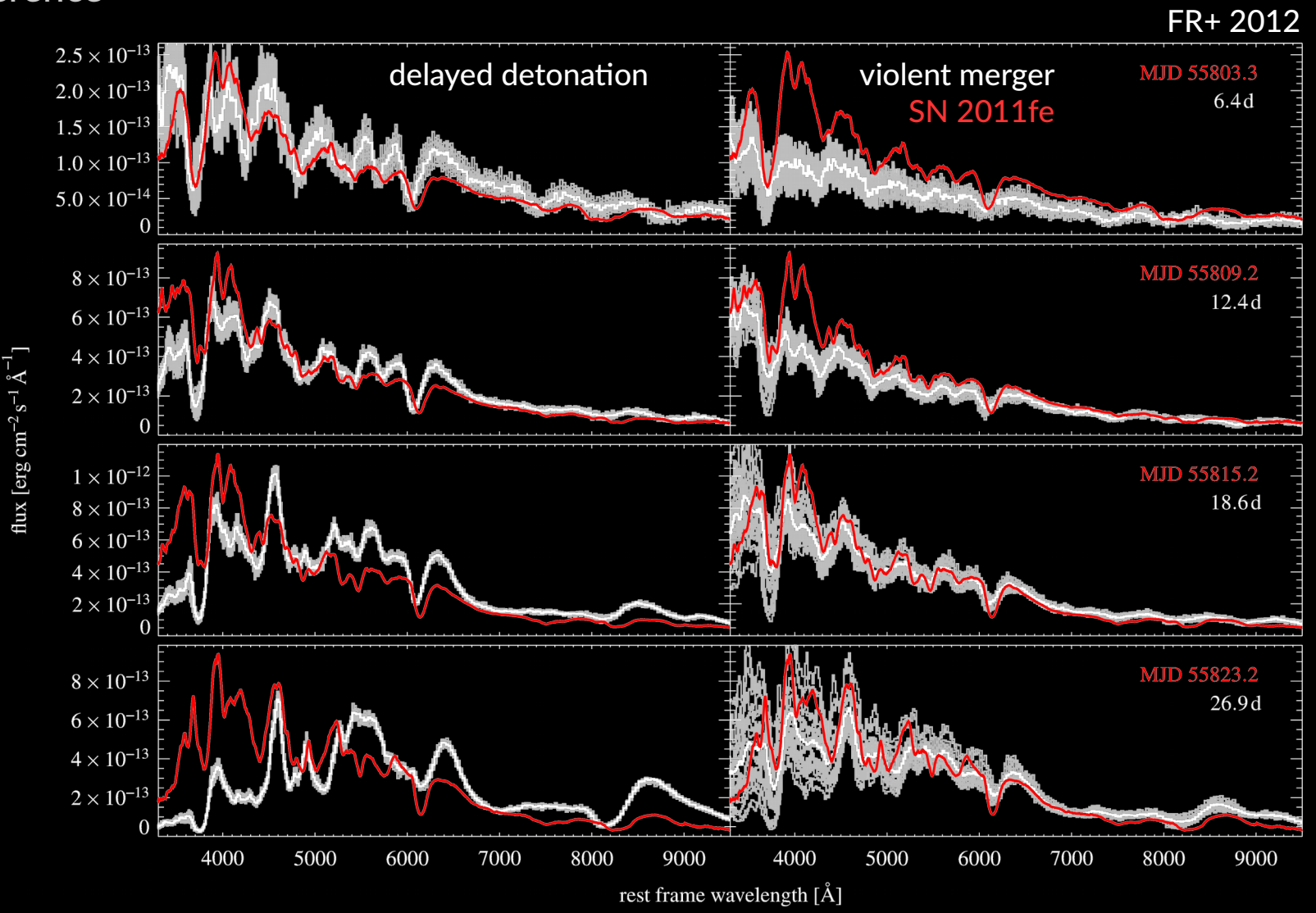


Derive discriminating observables



Identify discriminating observables

- Not much difference in optical
- Or not precise enough?



Identify discriminating observables

Promising alternatives:

- late observables (FR+ 2012)
- nucleosynthesis (Seitenzahl+ 2013)
- spectrapolarimetry (Bulla+ 2015, 2016)
- nebular spectra (Kozma+ 2005)
- gamma ray observables (Summa+ 2014)
- remnant studies (Badenes+ 2007)