Type Ia Supernova progenitors

White Dwarfs from Physics to Astrophysics

Ruediger Pakmor, 16.11.2011, Santa Barbara

Type Ia Supernovae: What we know

- Energetic explosions: E ~ 10^{51}erg
- Ejecta mass ~ 1Msun
- Composition dominated by alpha and iron group elements, no hydrogen or helium

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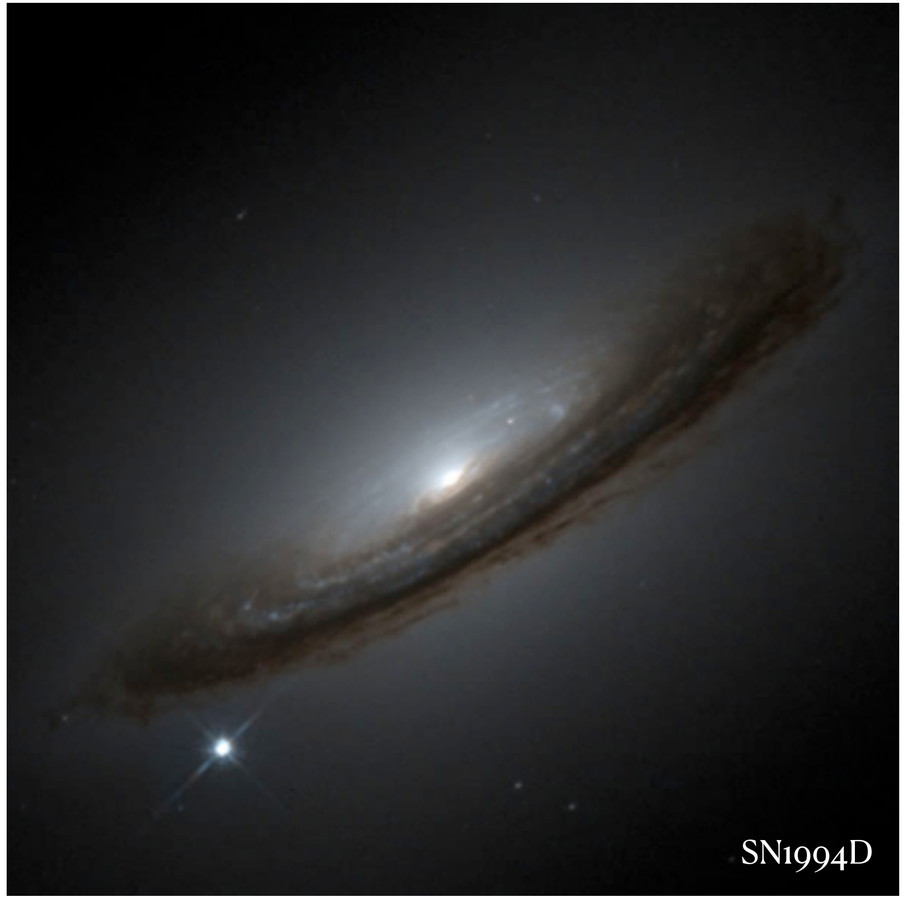
Thermonuclear explosions of carbon-oxygen white dwarfs



Type Ia Supernovae: What we know

- Isolated white dwarfs are inert
- Long delay times (many Gyrs)
- No single parameter sequence

Thermonuclear explosions of carbon-oxygen white dwarfs in binary systems

Type Ia Supernovae: What we don't know

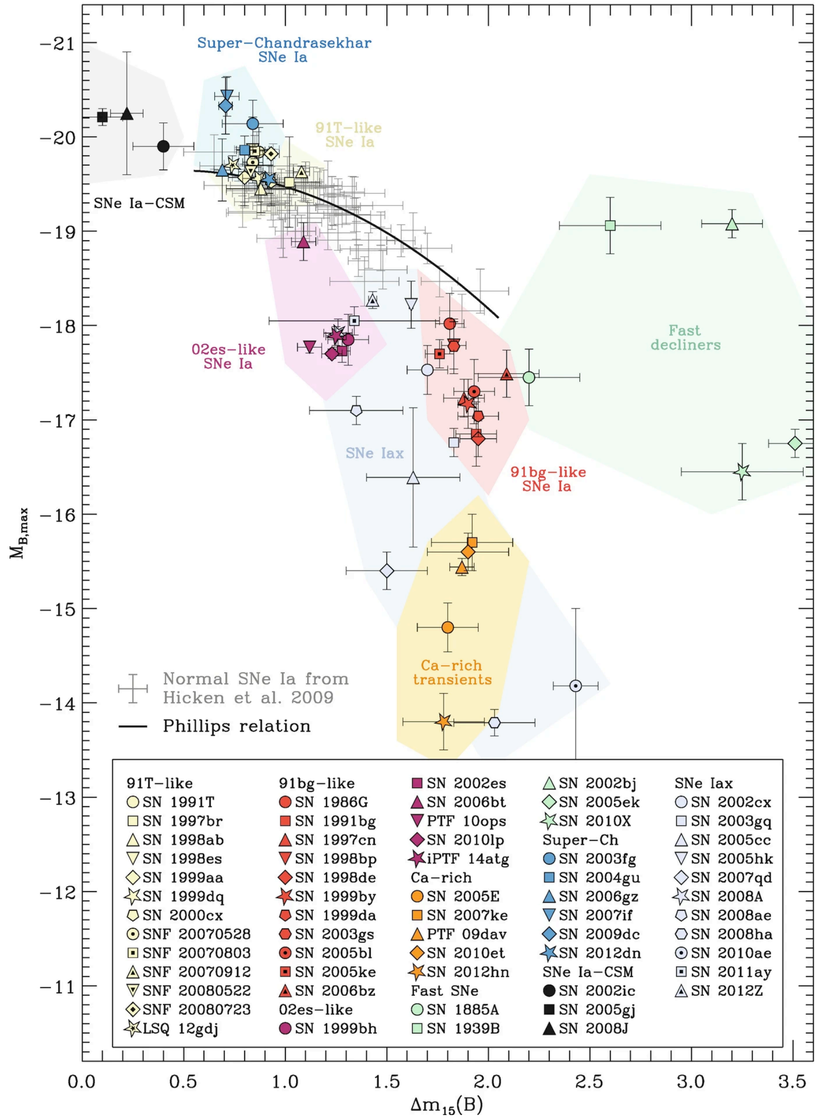
- Mass of (primary) white dwarf: Chandrasekhar-mass or below (or above?)
- Nature of companion: white dwarf or non-degenerate star?
- Explosion mechanism!

No clear observation of a progenitor system

No direct or indirect sign of any companion star before the explosion, during the explosion, or in remnants!

Type Ia Supernovae: the population

- Zoo of objects: connect observed populations to different models!
- “normal Ia’s” poorly understood
- Primary parameter sets brightness, correlates with host galaxy properties!
- Secondary parameter(s) for scatter
- Metallicity is neither of those!



Taubenberger 2017

Type Ia Supernovae: Theory

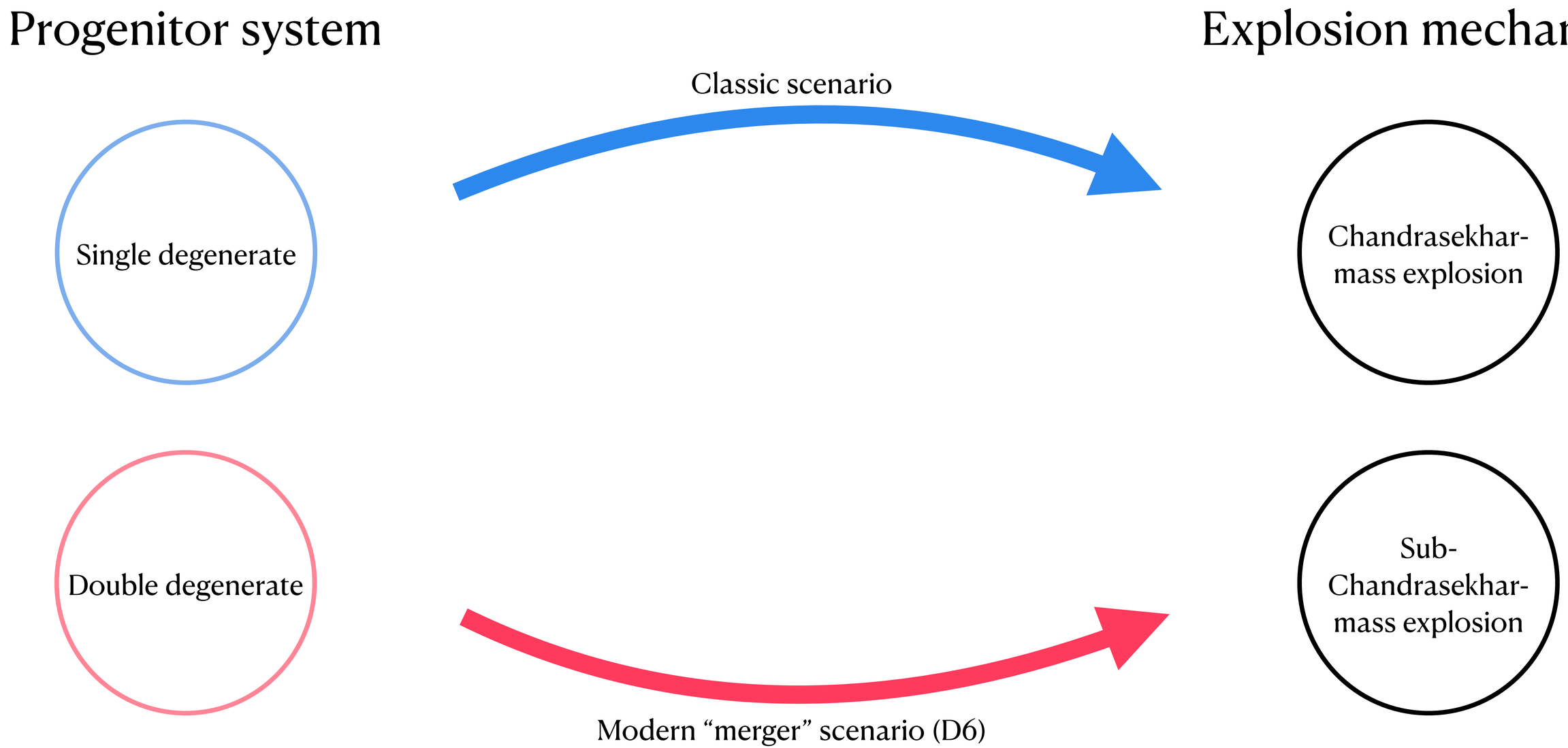
Progenitor system

- Single degenerate
- Double degenerate

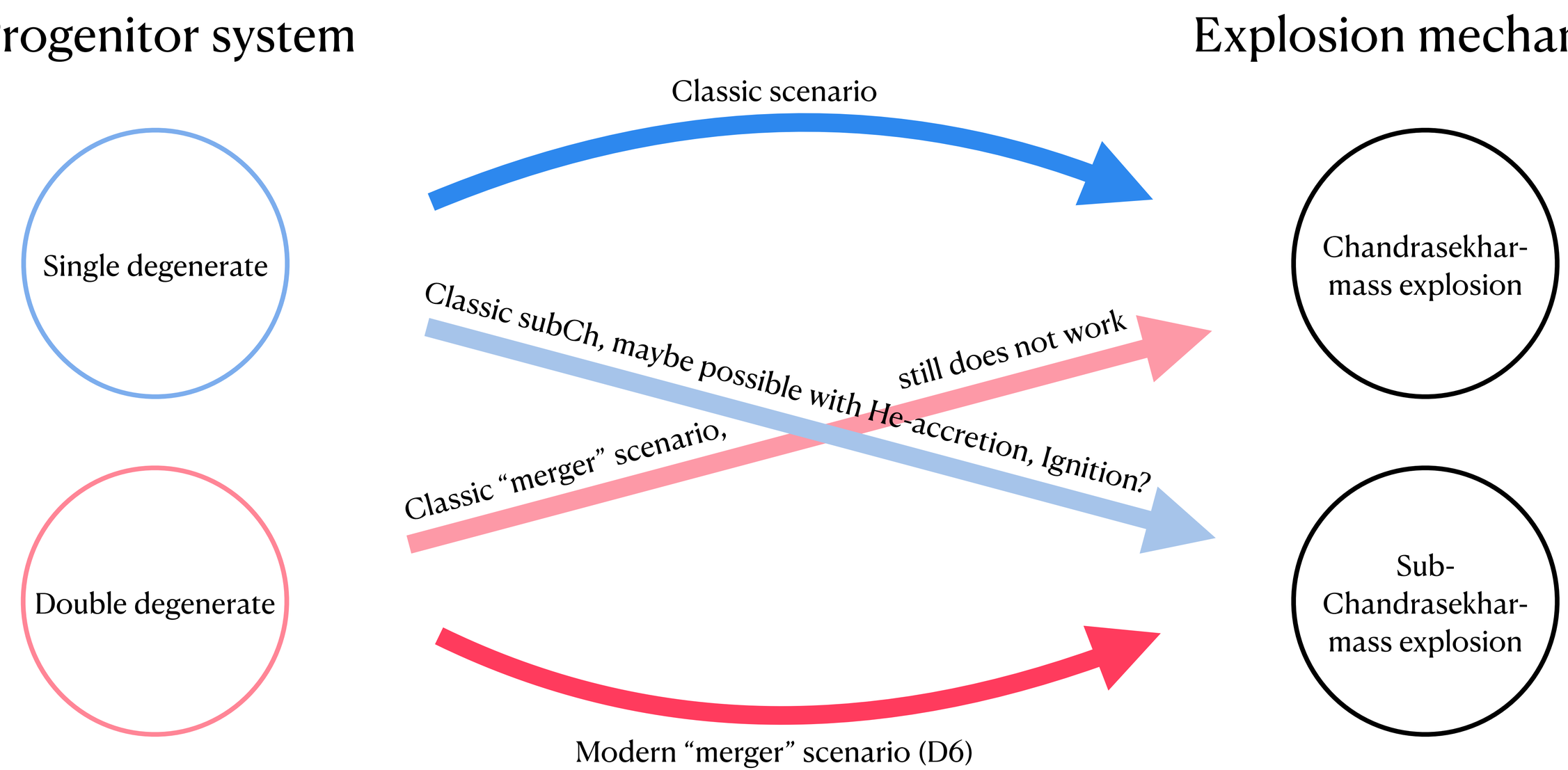
Explosion mechanism

- Chandrasekhar-mass explosion
- Sub-Chandrasekhar-mass explosion

Type Ia Supernovae: Theory

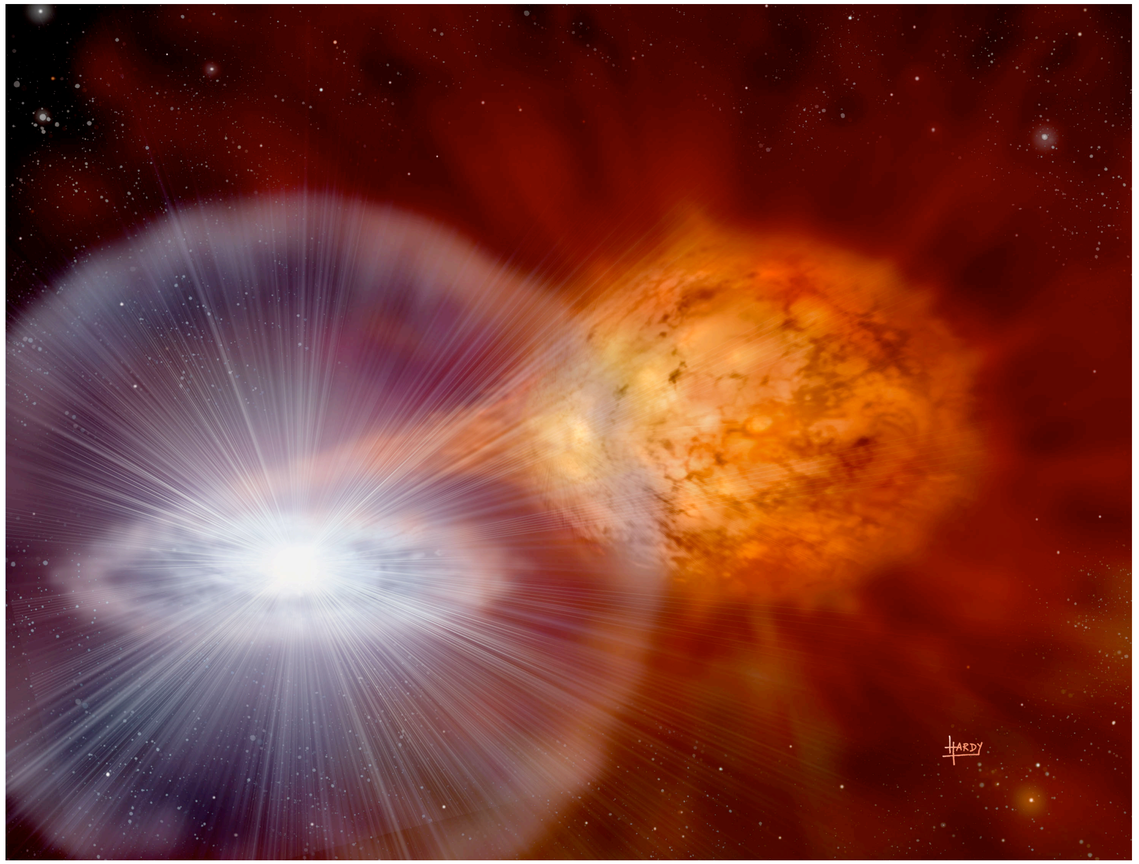


Type Ia Supernovae: Theory

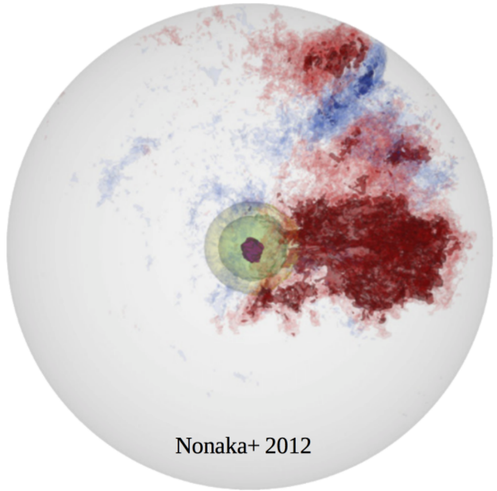


Single degenerate Chandrasekhar-mass explosions

- MCh-WDs exist, but unclear if CO WDs
- Hard to explain all constraints companion stars
- Rate estimates way too low

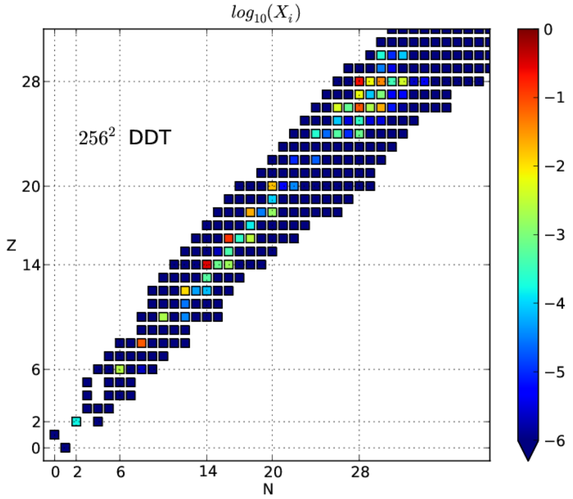


Forward modelling Type Ia Supernova explosions

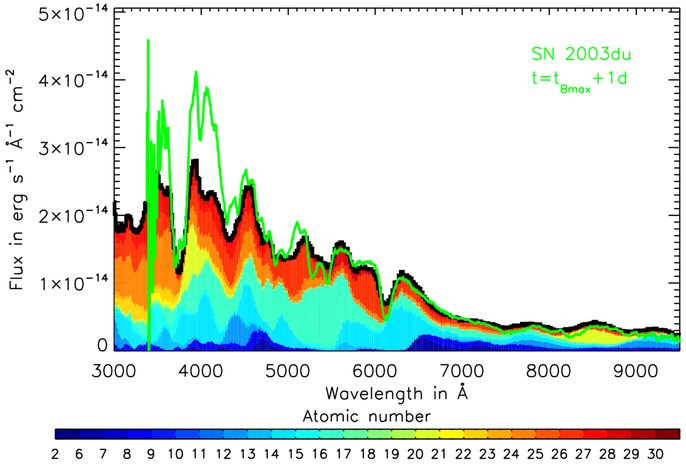


Ignition: slow burning

Explosion: fast burning



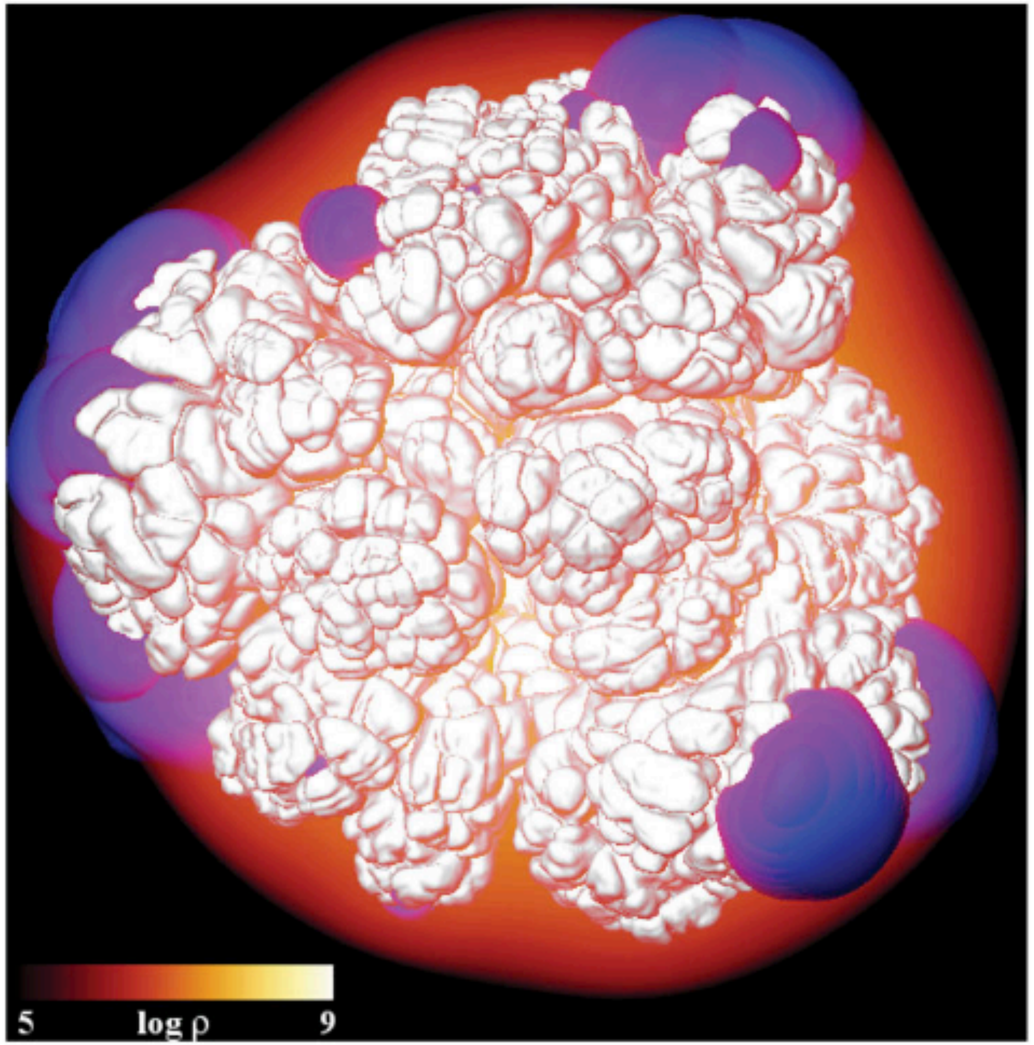
Detailed nucleosynthesis



Synthetic observables

Single degenerate Chandrasekhar-mass explosions

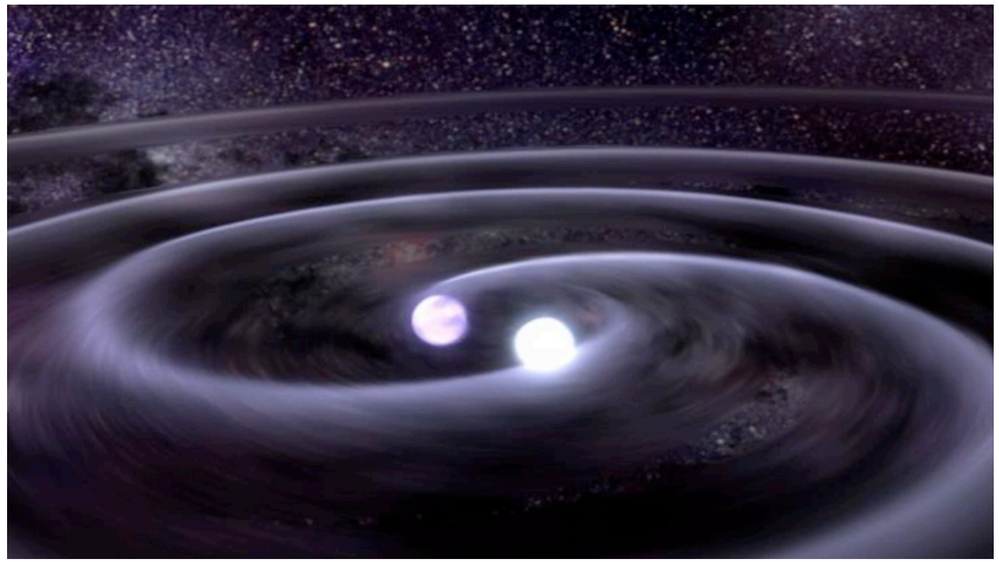
- Initial ignition of central deflagration at high density
- Normal Ia's require very uncertain, stochastic transition to detonation
- 3D models generally less good than 1D models that don't have buoyancy
- No robust evidence for high density burning products in normal Ia's



Seitenzahl+2012, N100 1s after ignition

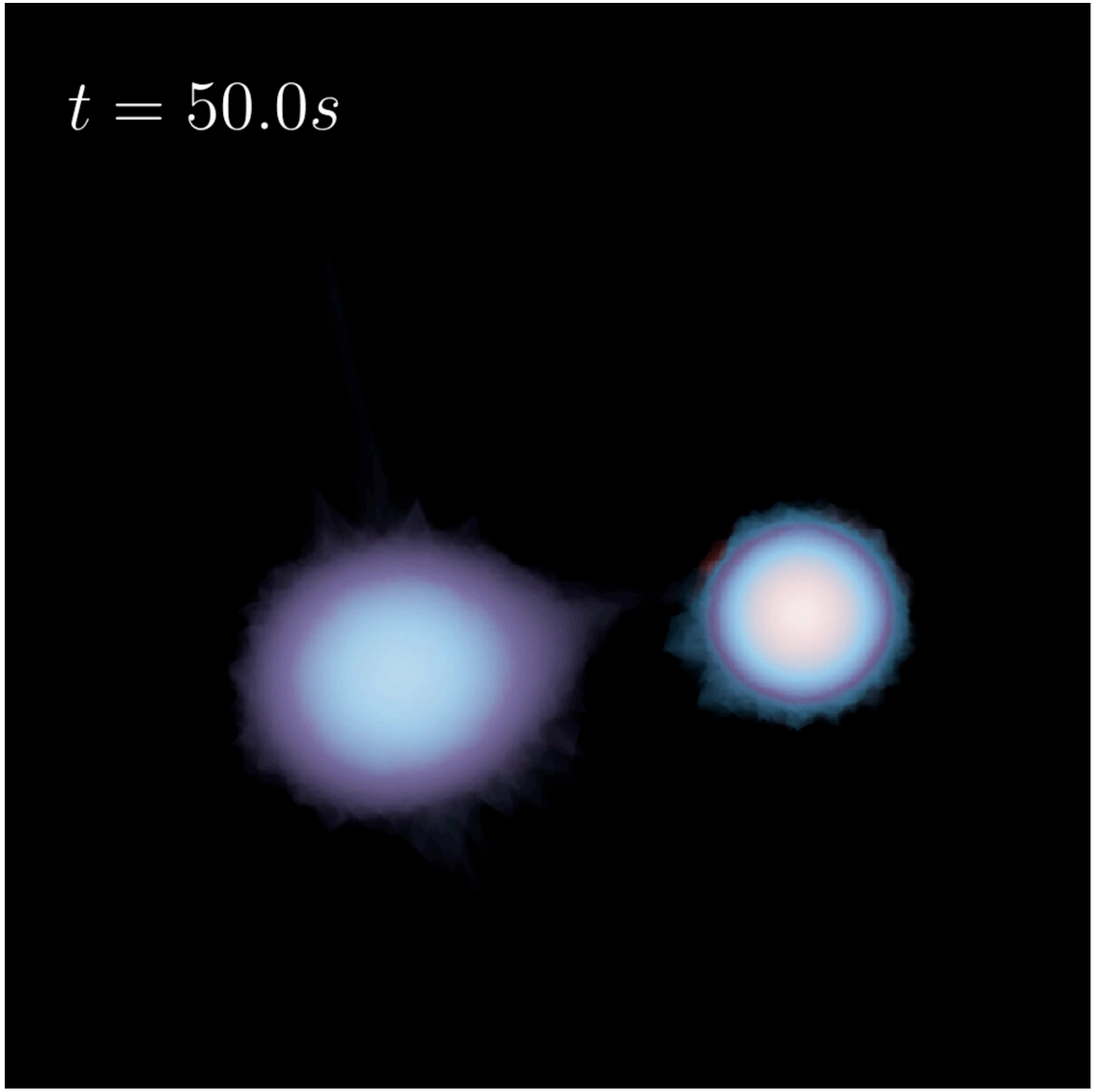
Double degenerate sub-Chandrasekhar-mass explosions

- Systems not directly observed
- Explosion triggered by dynamics just before merger (by detonating helium shell on the primary white dwarf) or during (violent) merger
- Primary parameter is mass of more massive white dwarf
- Optimistic rate estimates consistent with observations
- Explains most constraints from non-detections, but hard to make testable positive (!) predictions



Double degenerate sub-Chandrasekhar-mass explosions

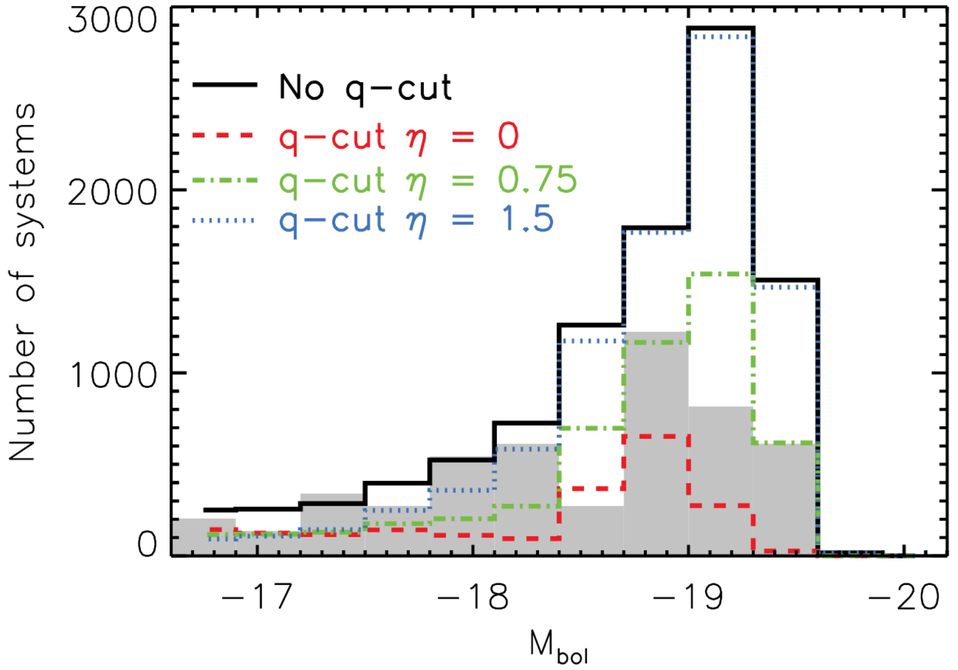
- Dynamical accretion of helium on more massive WD ignites its helium shell
- Helium detonation converges in center to ignite CO core -> SN Ia
- Similar to centrally ignited WD + He shell ashes
- Helium shell critical but poorly understood (size, temperature, mixing)



Pakmor+2022

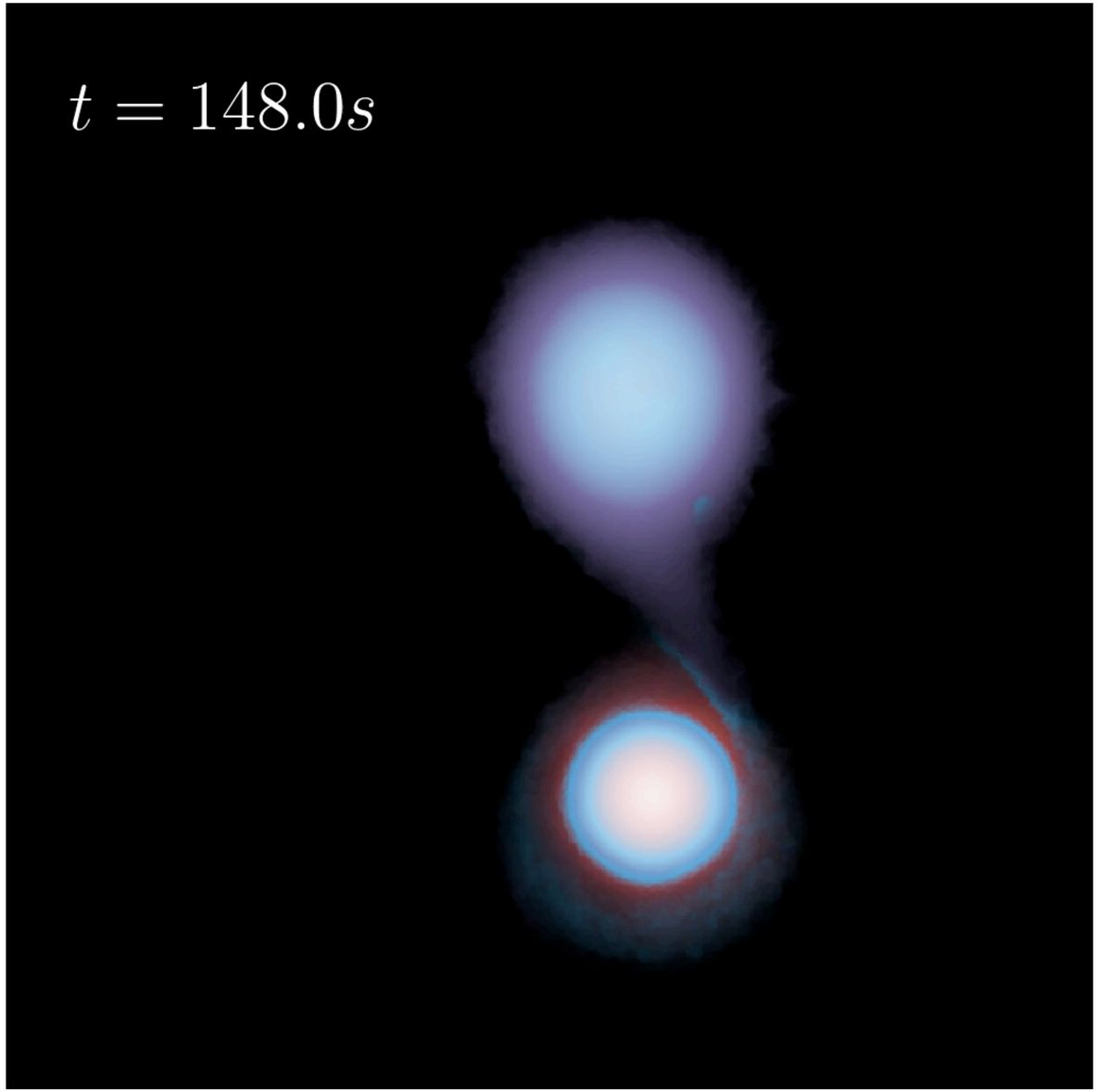
Double degenerate sub-Chandrasekhar-mass explosions

- Stable, reliable explosion mechanism (!?)
- Can explain rates of normal SNe Ia (?)
- Can explain brightness distribution of normal SNe Ia
- Synthetic observables consistent with real SNe Ia (?)
- Explains most nucleosynthesis constraints (Mn?)
- Predicts surviving, fast moving, contaminated white dwarfs! But: not enough found in GAIA (Shen+2018)



Ruiter+2012, brightness distribution of observed SNe Ia compared to prediction for double degenerate sub-Chandrasekhar-mass explosions

Double degenerate sub-Chandrasekhar-mass explosions



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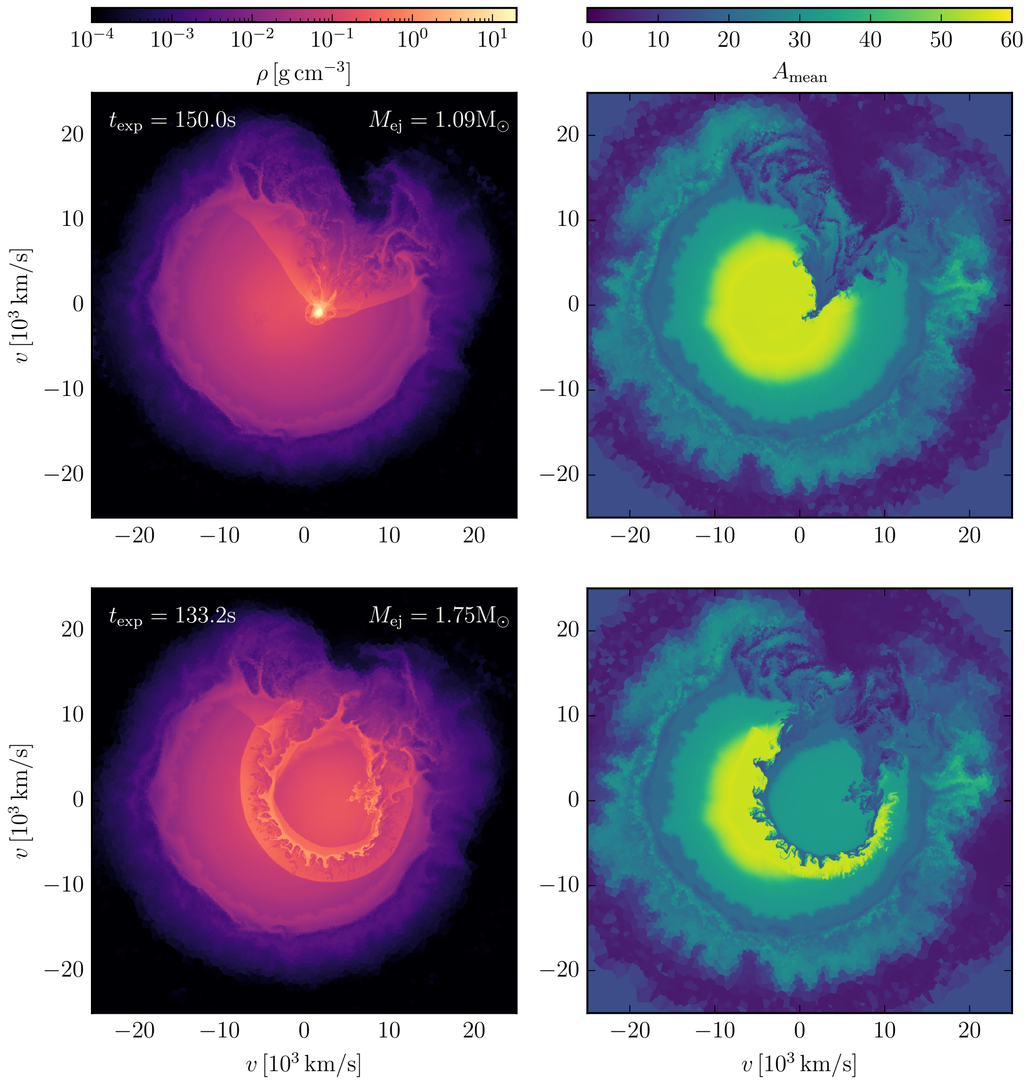
Double degenerate sub-Chandrasekhar-mass explosions



D6

D6 + secondary explodes as well

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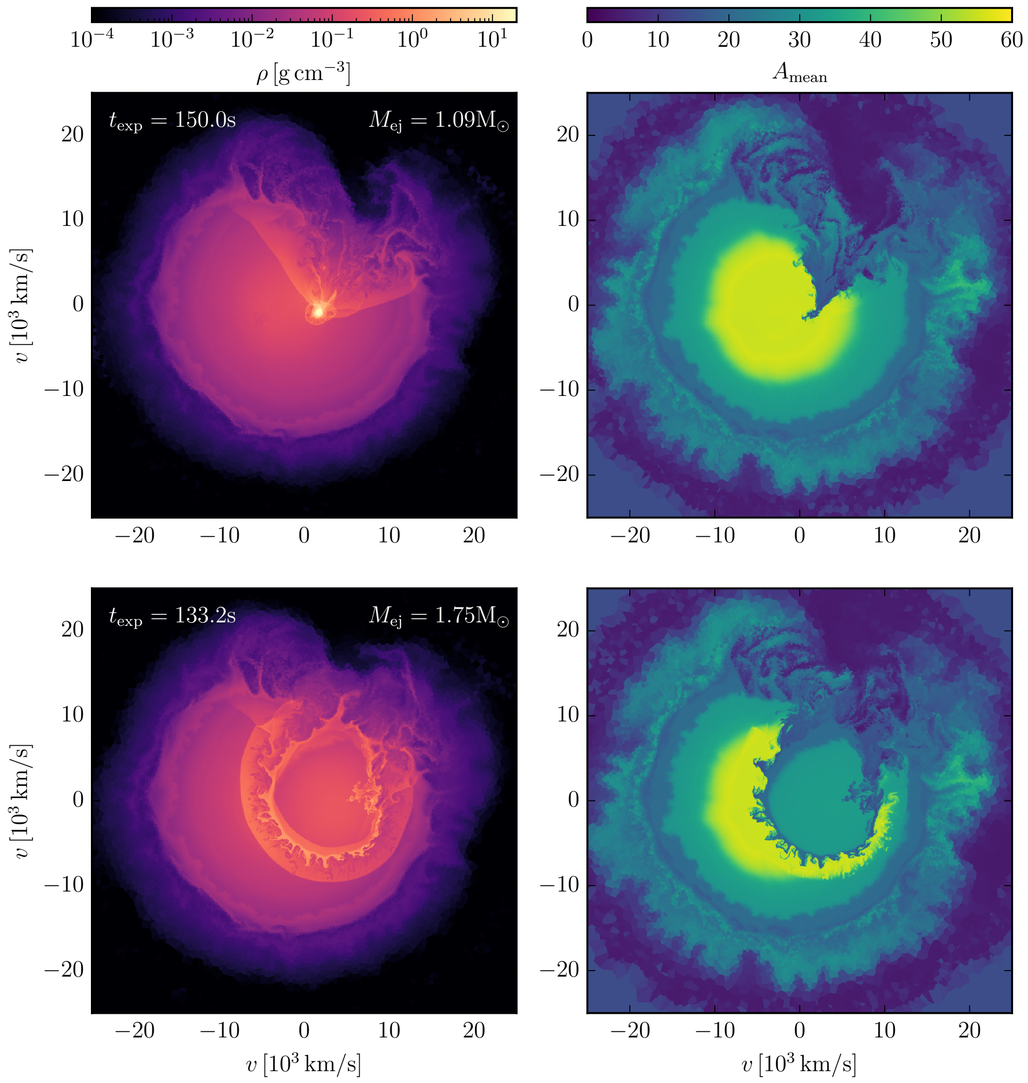
Double degenerate sub-Chandrasekhar-mass explosions



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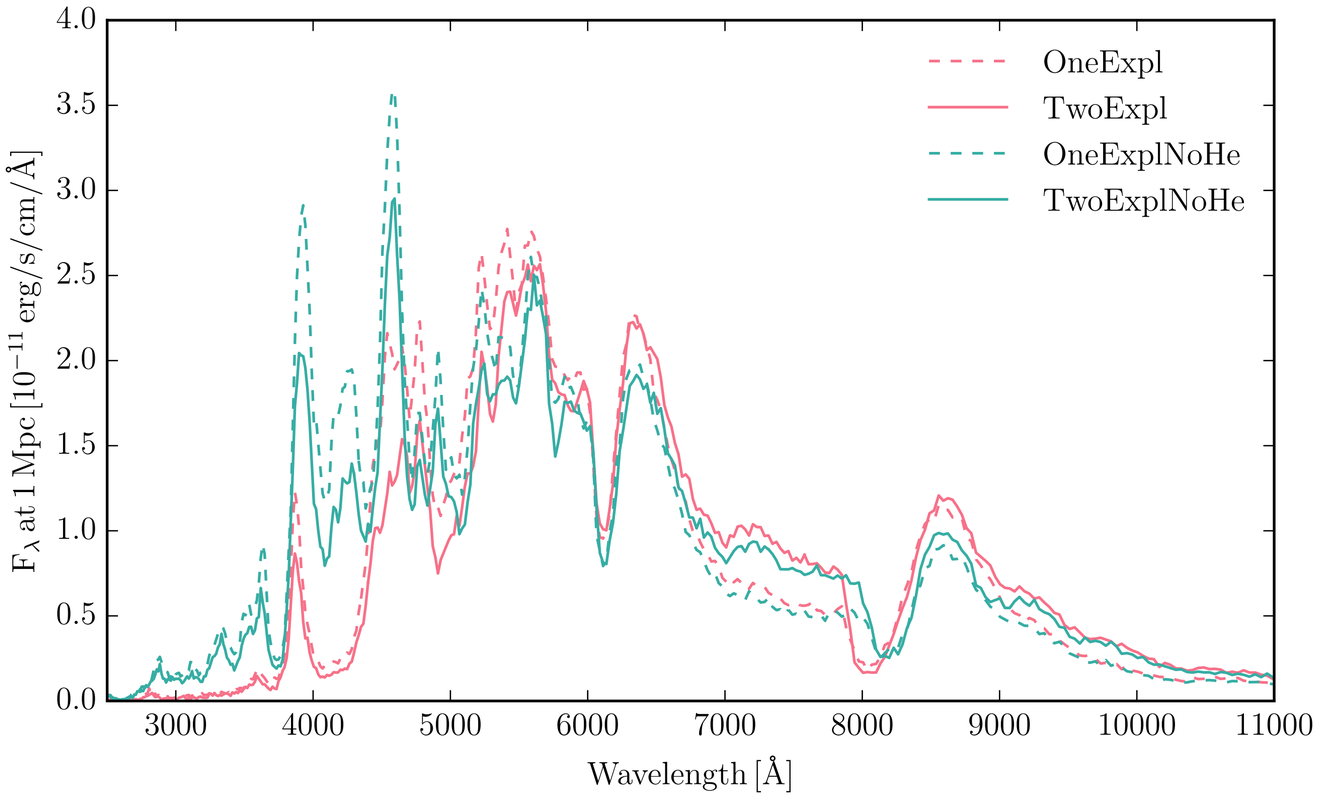

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Summary: Type Ia Supernova models

- Nature of progenitor system(s) and explosion mechanism are STILL open questions
- Currently most work on dynamical double degenerate scenarios
- Forward modelling has matured, but still many fundamental uncertainties: Not (yet) able to decide between models!
- Very hard / currently impossible to match all observational constraints in consistent picture
- Systematic limitations of models, and/or overlooked something fundamental?