HITS

Recombination energy in the common envelope phase

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Collaborators: F. Röpke (HITS), R. Pakmor (HITS), V. Springel (HITS), E. Müller (MPA, Garching)

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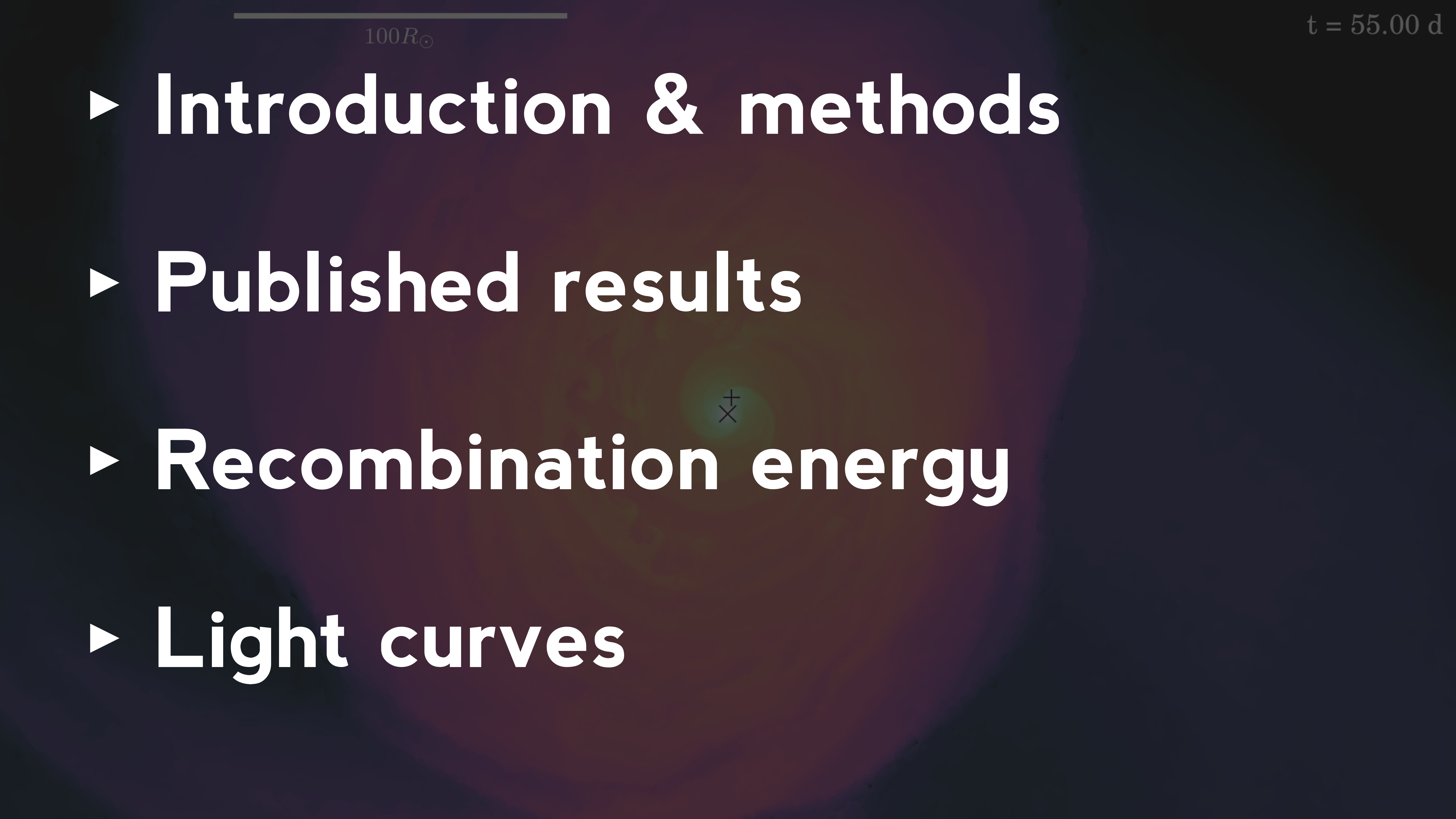

- Introduction & methods
- Published results
- Recombination energy
- Light curves

$100 R_\odot$

$t = 55.00$ d

- **Introduction & methods**
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Why common envelope?

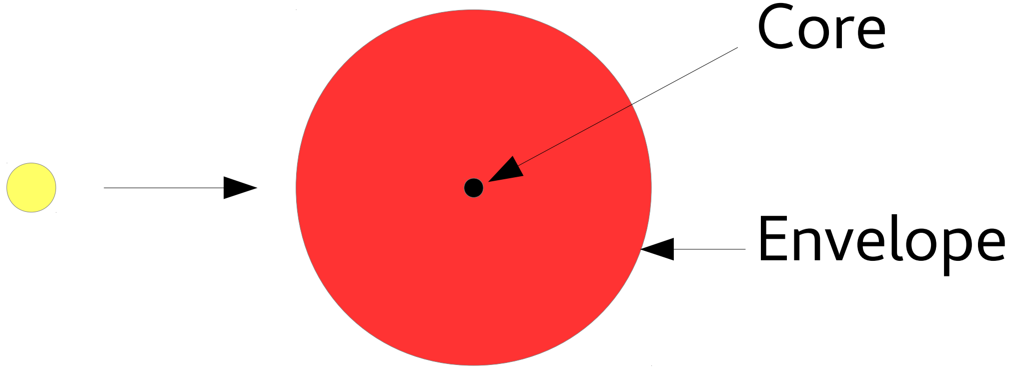
- Compact stars in close binary systems
- Reduction in binary orbit needed
- Examples:
  - Type Ia supernovae
  - Planetary nebulae
  - Black hole binaries
  - ...

Major source of uncertainty in modeling!

The common envelope phase

The common envelope phase

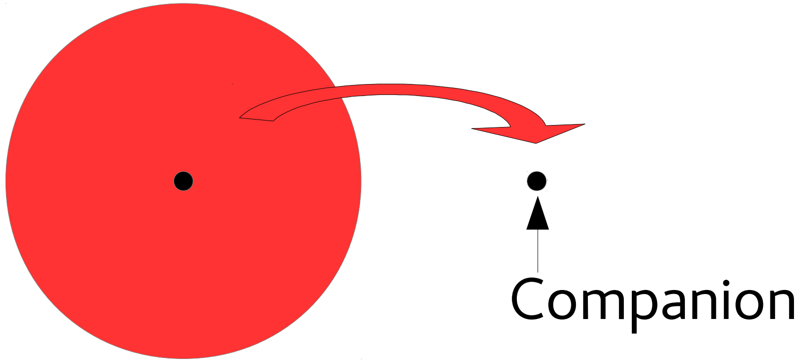
Primary star grows



The common envelope phase

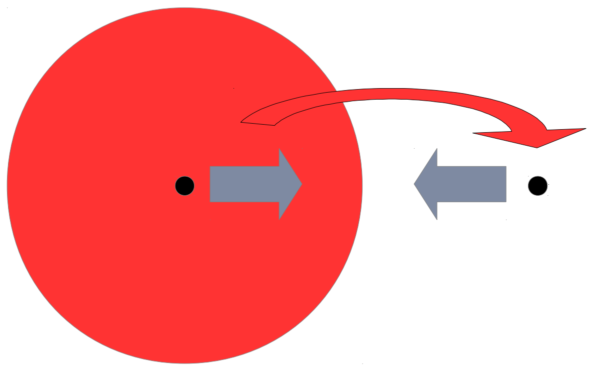
Primary star grows

Mass transfer



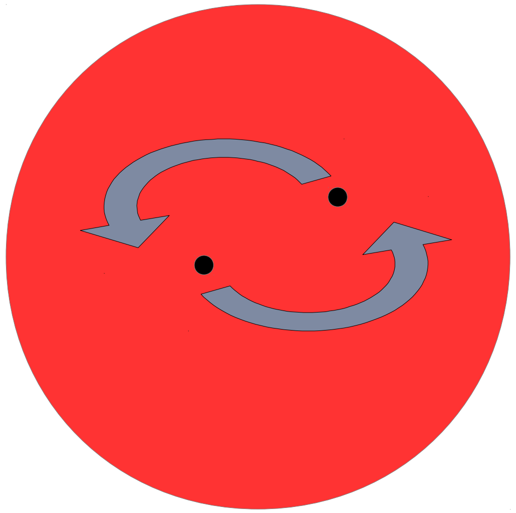
The common envelope phase

Primary star grows → Mass transfer → Orbit shrinks



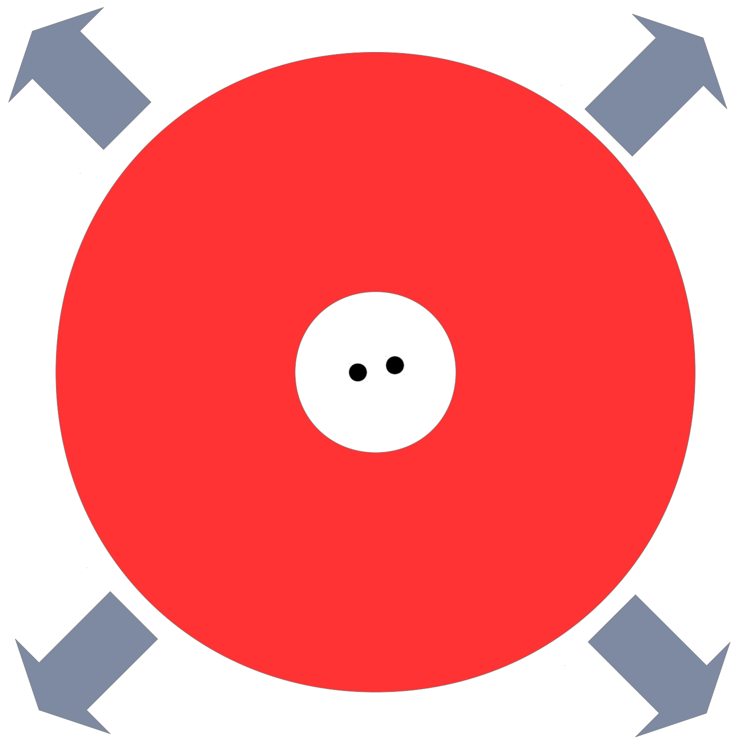
The common envelope phase

Primary star grows → Mass transfer → Orbit shrinks → Spiral-in



The common envelope phase

1. Primary star grows
2. Mass transfer
3. Orbit shrinks
4. Spiral-in
5. Ejection of envelope



The common envelope phase

Primary star grows → Mass transfer → Orbit shrinks → Spiral-in → Ejection of envelope

→ Compact stars in close systems

Problems in modeling

- 3D geometry
- Wide range of scales (time, space)

Compact core ↔ dilute envelope

- Approximations necessary:
  RG core and companion as point masses

→Spiral-in on dynamical time

The AREPO code

- Developed by V. Springel for cosmological applications
- New feature:

adaptive, moving mesh

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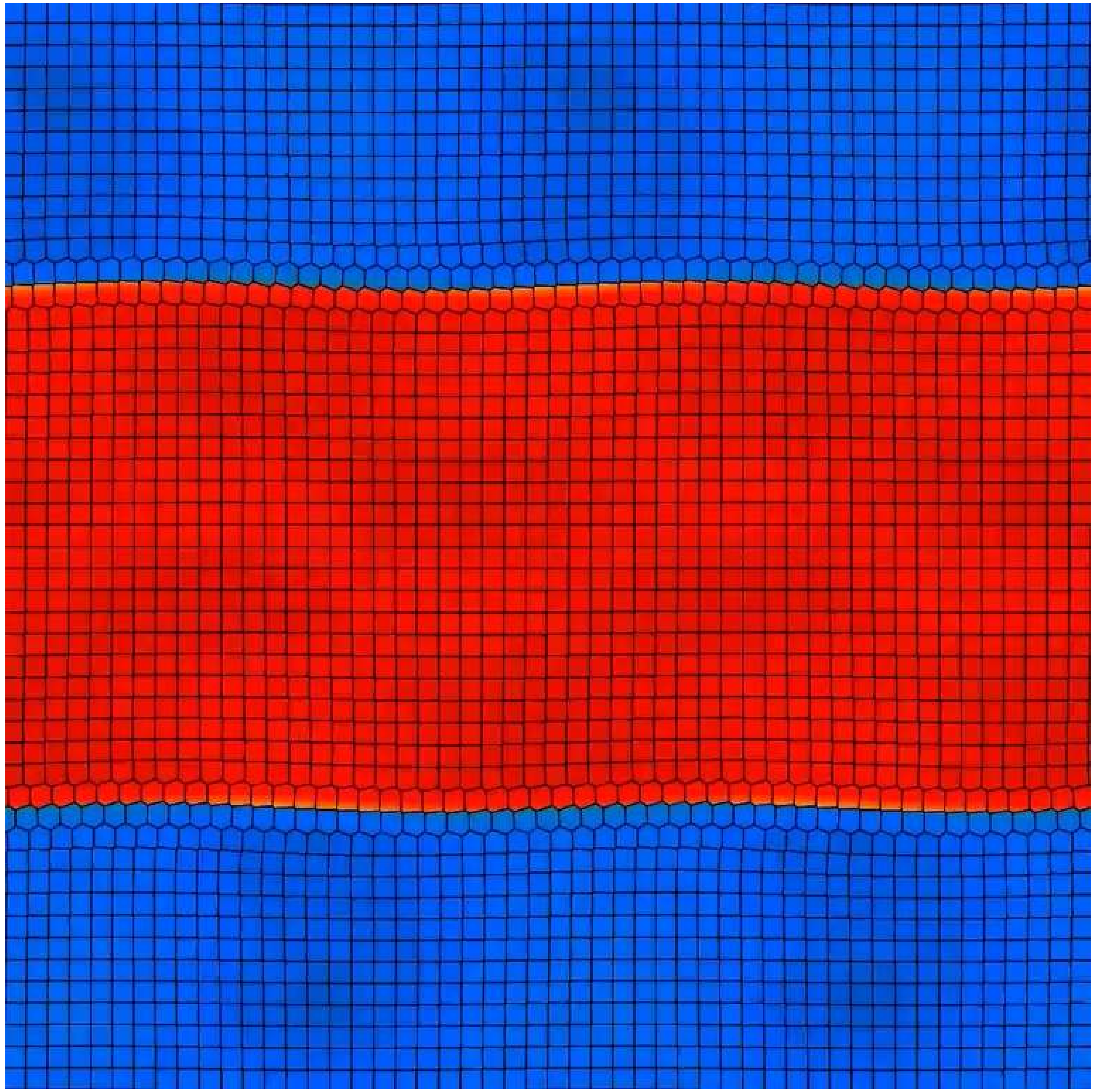
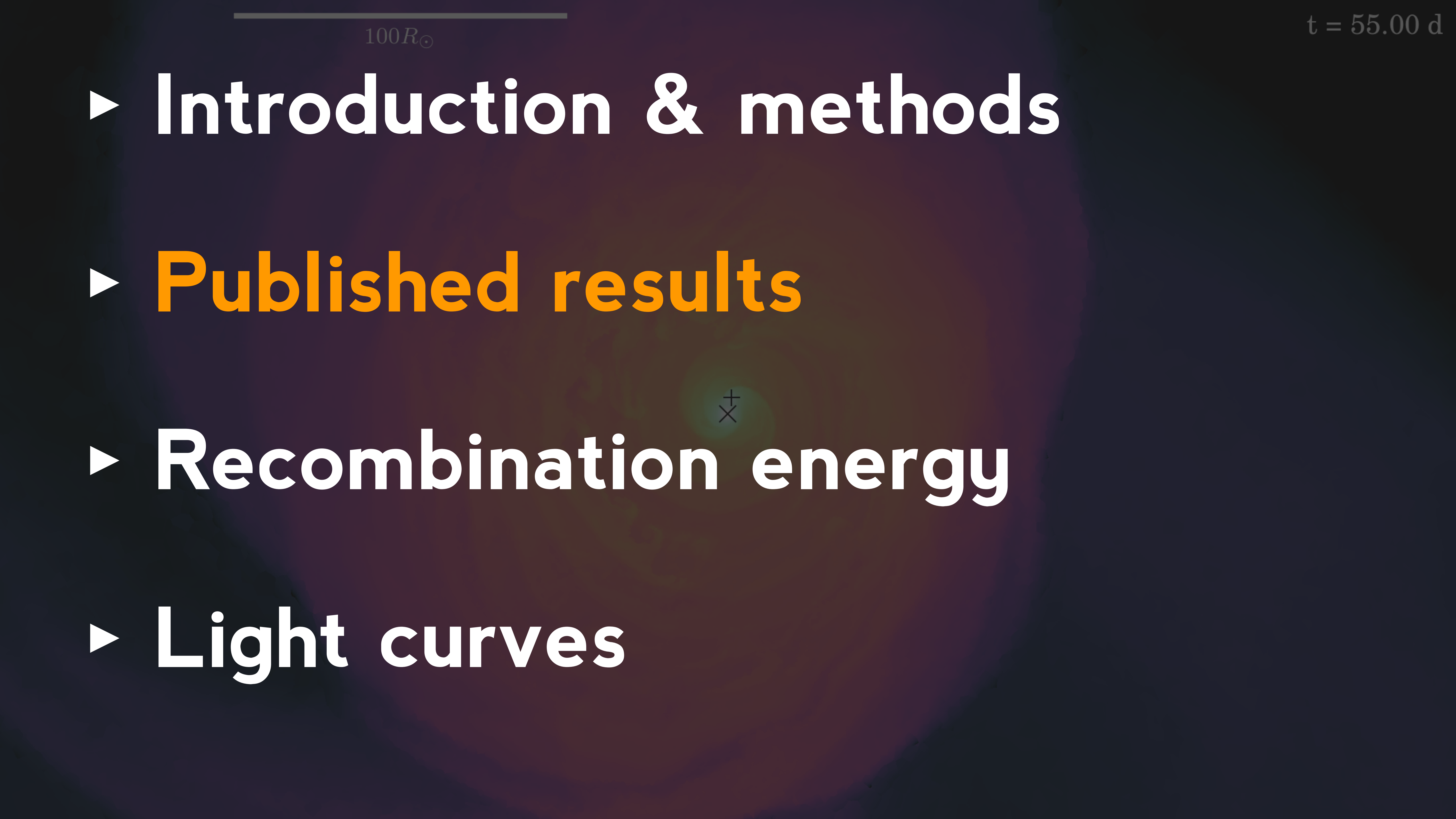
- Convergence
- Shocks

Shear instability



Credit: V. Springel



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Simulating the CE phase

- Initial conditions: giants in hydrostatic equilibrium (Ohlmann et al., 2017, *A&A*, **599**, A5)
- Core → point mass
- Relaxation method → stable giant models

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- Only 8% of envelope mass ejected
- Instabilities: shear → convection

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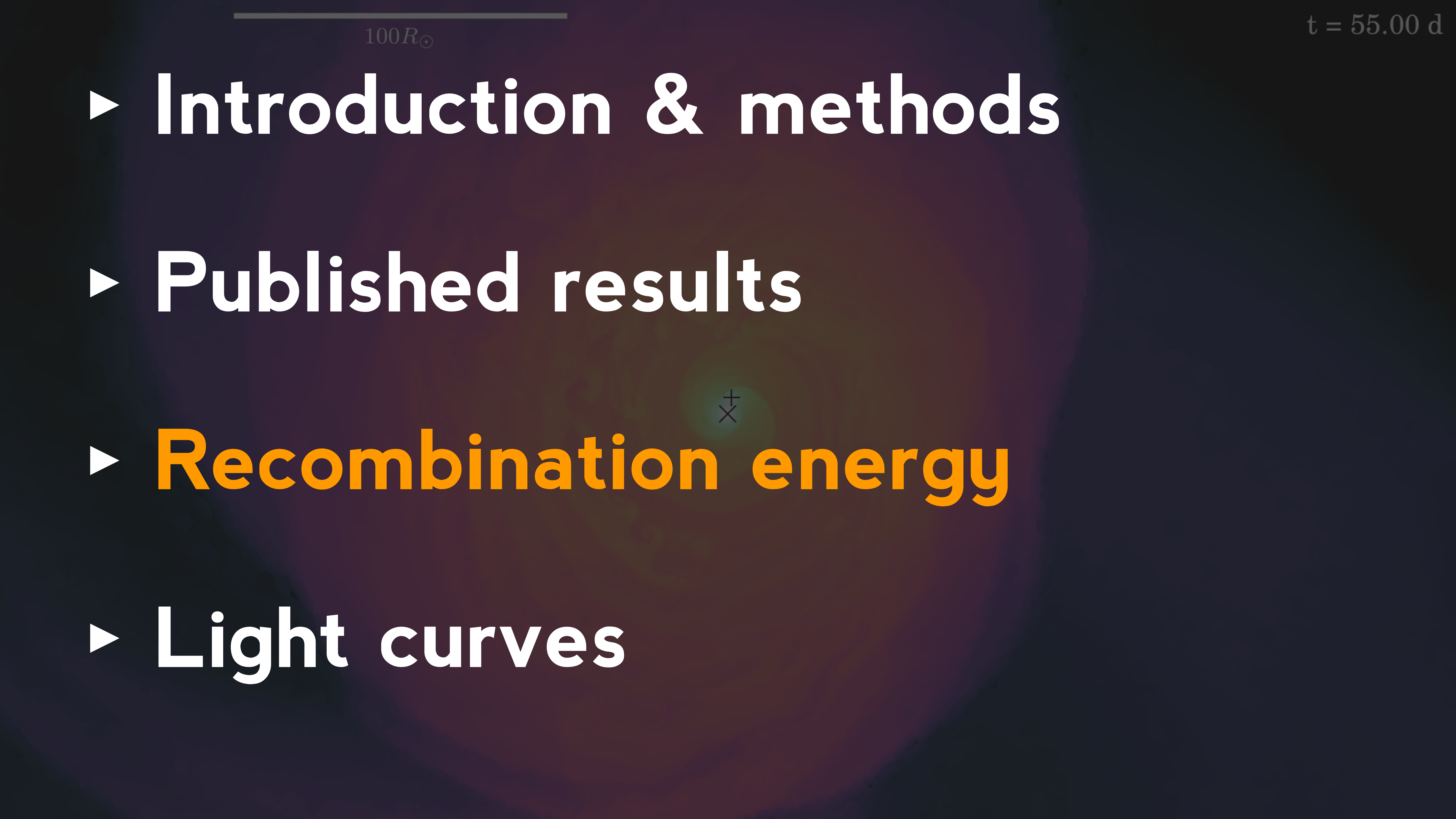
- First MHD simulations (Ohlmann et al. 2016, *MNRAS*, **462**, L121)
- Strong amplification → 10 – 100 kG, probably MRI
- Not strong enough for magnetic WDs



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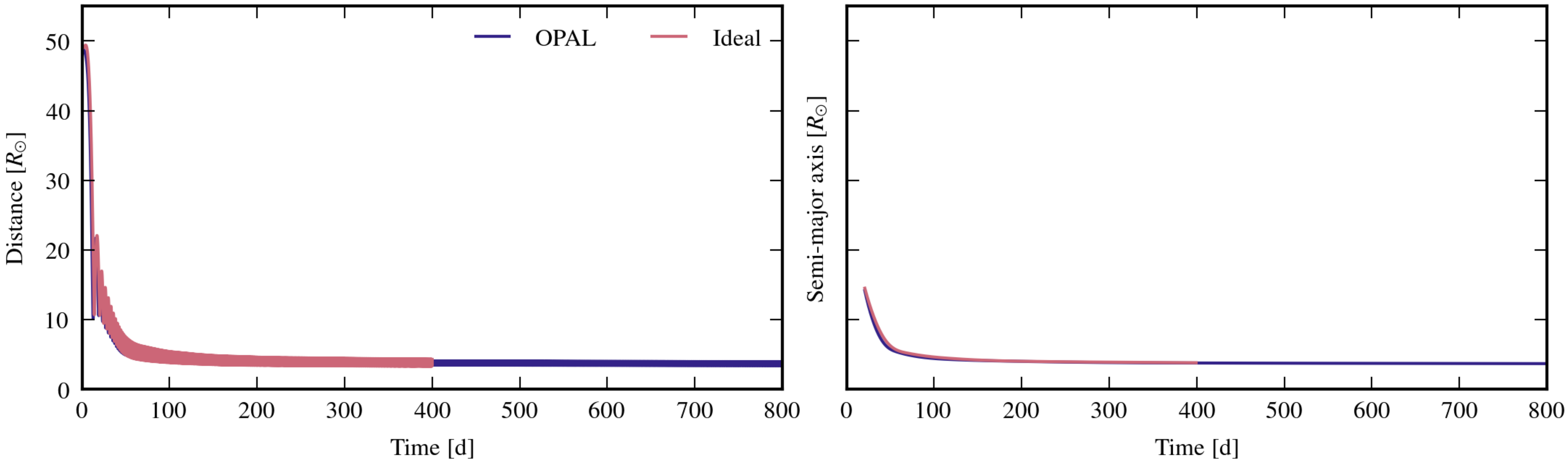
Ionization state

- Recombination energy might help ejecting the envelope
- Long discussion (Livio 1989, ..., Nandez+ 2015, 2016)
- First SPH simulations (Nandez+ 2015, 2016) show ejection of envelope when including recombination energy

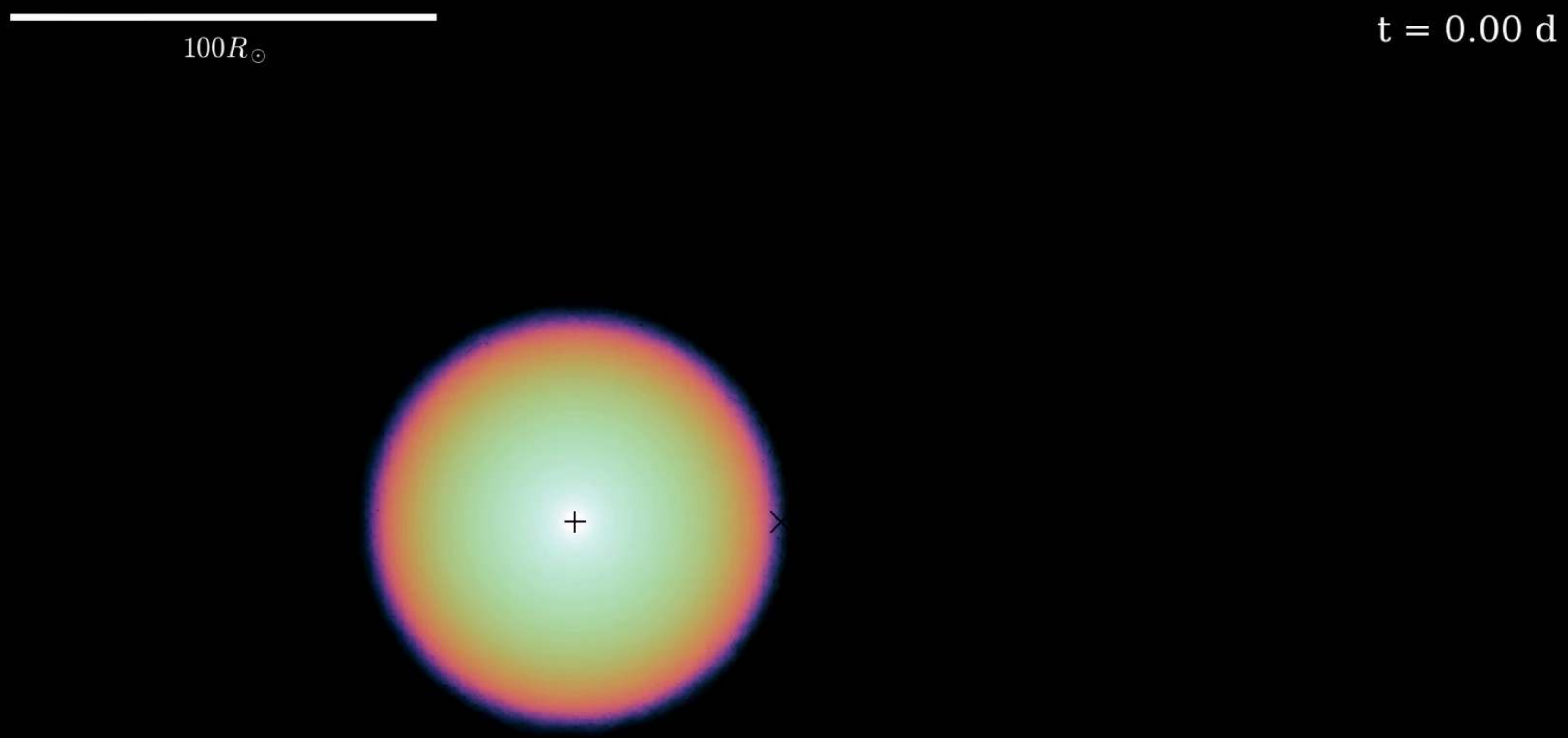
- Included by using OPAL equation of state
- Assumption: radiation is trapped
- Radiative transport?

Orbital Evolution



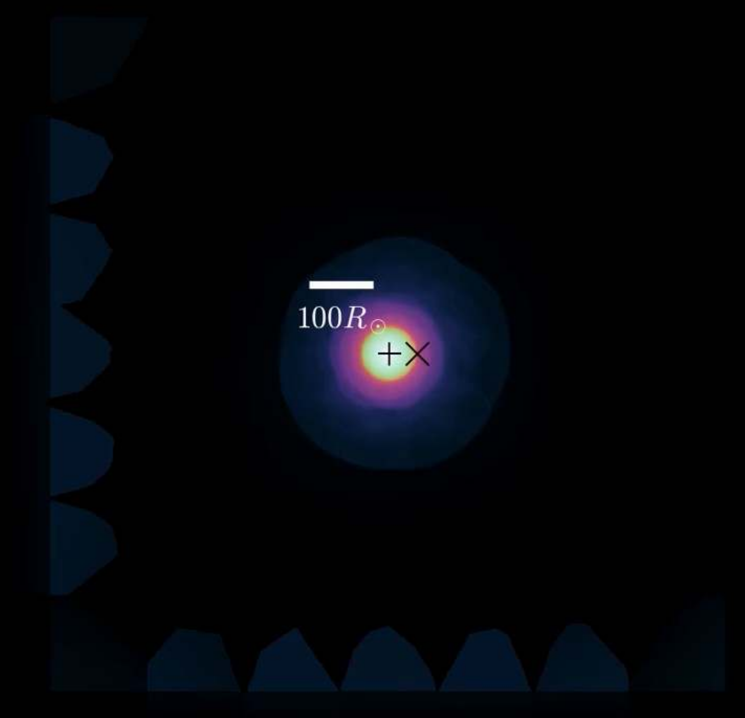
- Same 2 $M_\odot$ RG + 1 $M_\odot$ system
- Very similar orbital evolution → determined by gravitational interaction
- <5% difference in semi-major axis

Density evolution



Density evolution

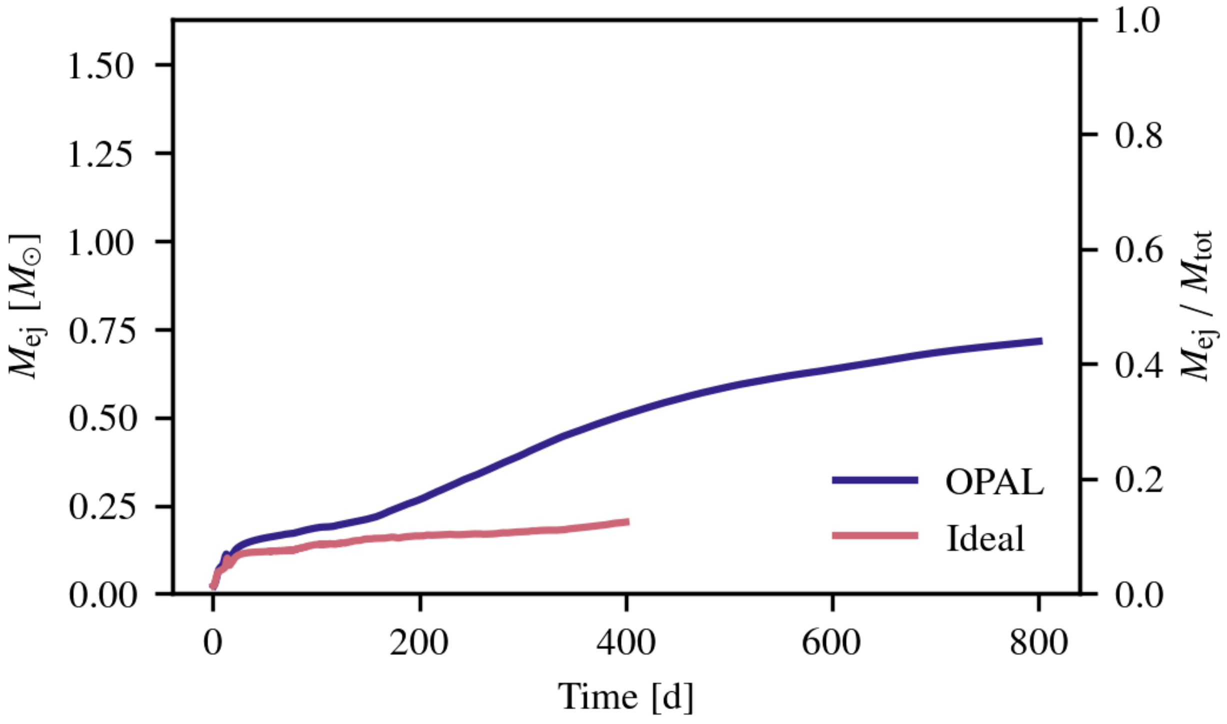
t = 0.00 d



Unbound mass

- Ideal EOS: only ~10% unbound
- OPAL:
  - ~ 50% after 800 d
  - Increases further to ~ 90% at 6000 d

    → nearly unbound
- Energy budget: α ≈ 0.5



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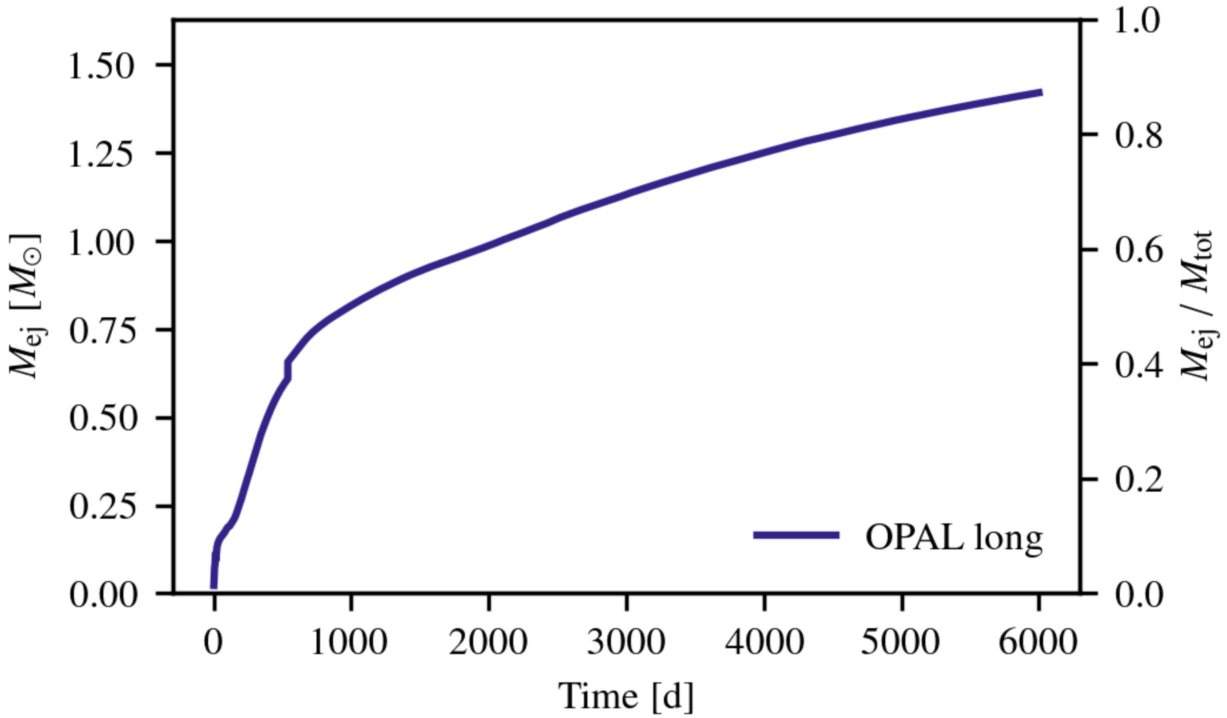

Unbinding mechanism

- First orbit: unbinding small amount
- Fast spiral-in: lift envelope to larger radii
- Expansion → lower T and rho
  → release of recombination energy
- This energy release drives slow mass ejection

$100 R_\odot$

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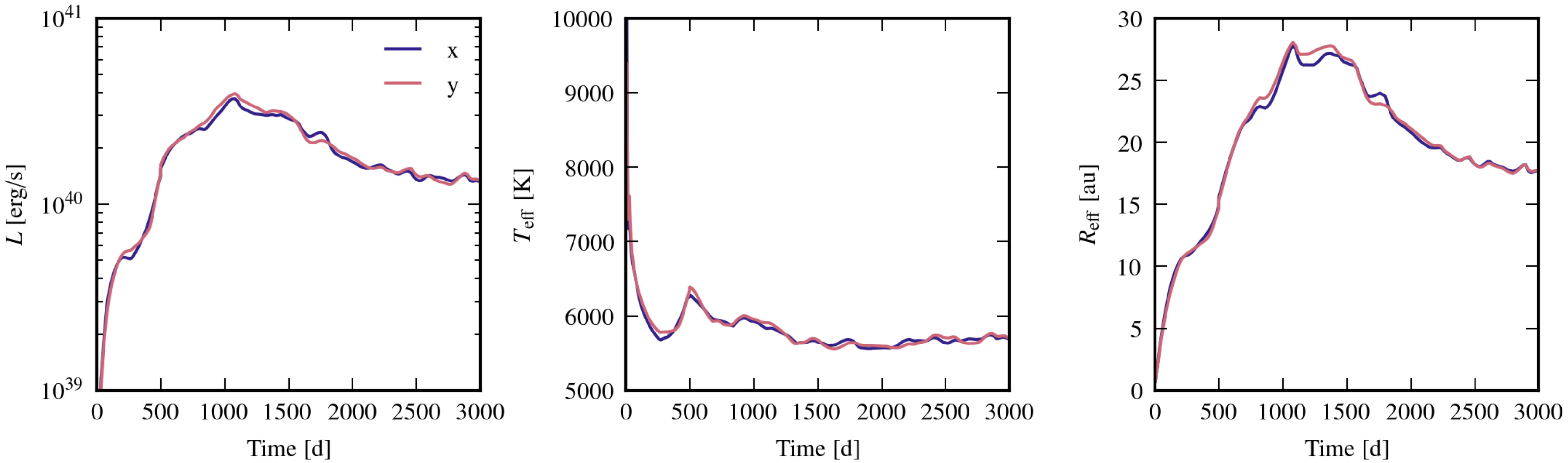
Light curves: method

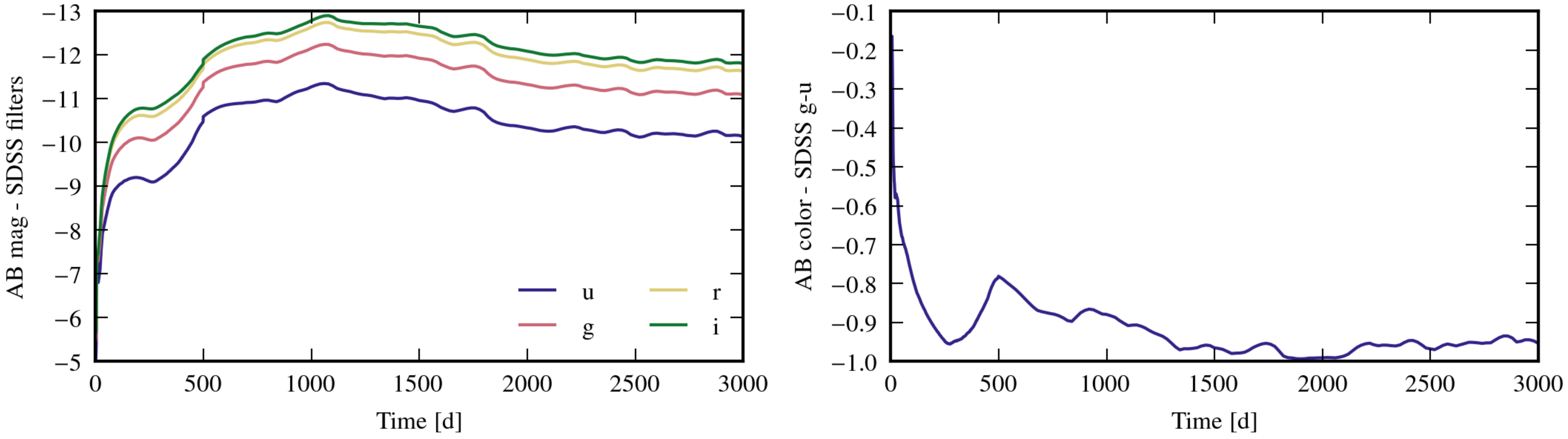
- Determine photosphere
  - Integrate opacities along rays → optical depth
  - Get T_{eff} at $\tau = 1$
- Assume blackbody radiation with T_{eff}
- Integrate over all rays → luminosity
- Convolution with band filters → bands, colors
- Slightly simpler method than Galaviz+ (2017)

Light curves



- Peak at ~ 3yrs, photosphere receding afterwards
- Temperature:
  - Recombination front (~ 6000 K)
  - Peaks due to shock layers being revealed

Light curves



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Comparison: observations

- CE phase connected to Luminous Red Novae (Ivanova+, 2013)
- Most observed objects:
  - Lower luminosity
  - Shorter plateau
- Estimate according to Ivanova+ (2013) for the simulation (SN IIP model)
  - L ~ 5.5e38 erg/s
  - plateau ~ 150 d

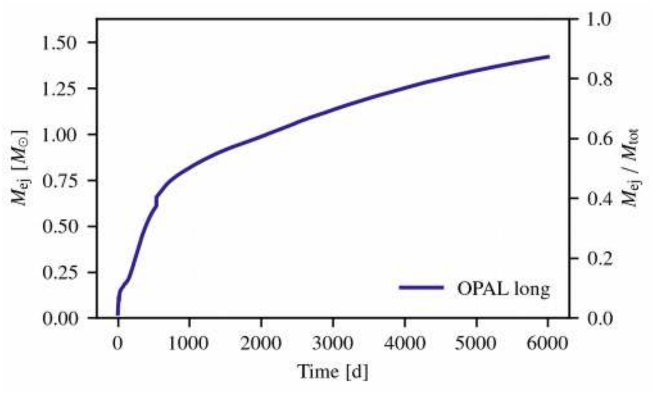
→ radiation treatment missing!

Modeling of radiation

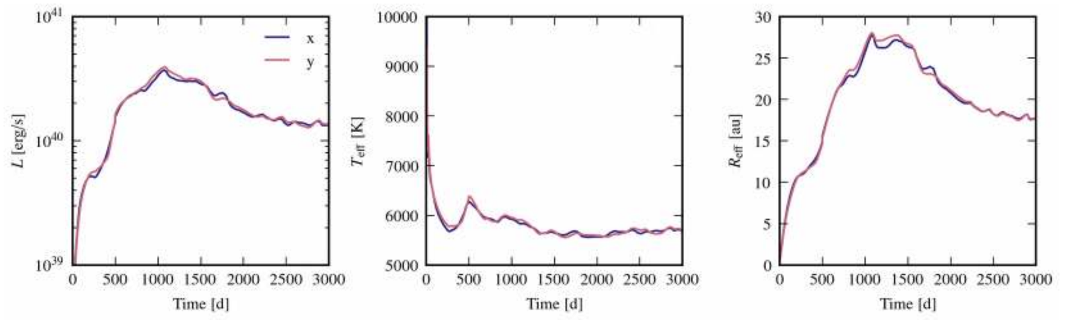
- Up to now:
  - Radiation pressure in EOS
  - Recombination radiation trapped
- But: radiated energy > binding energy
  → cooling should be included
- Future: couple radiation transport to simulation
  → **radiation hydrodynamics**

Conclusions

- **Recombination energy** helps ejecting envelope
  - Recombination energy drives slow ejection



- **Light curves**
  - Comparison to observations in reach



- Future:
  - Extension to other parameters
  - Radiation hydrodynamics

Thank you!