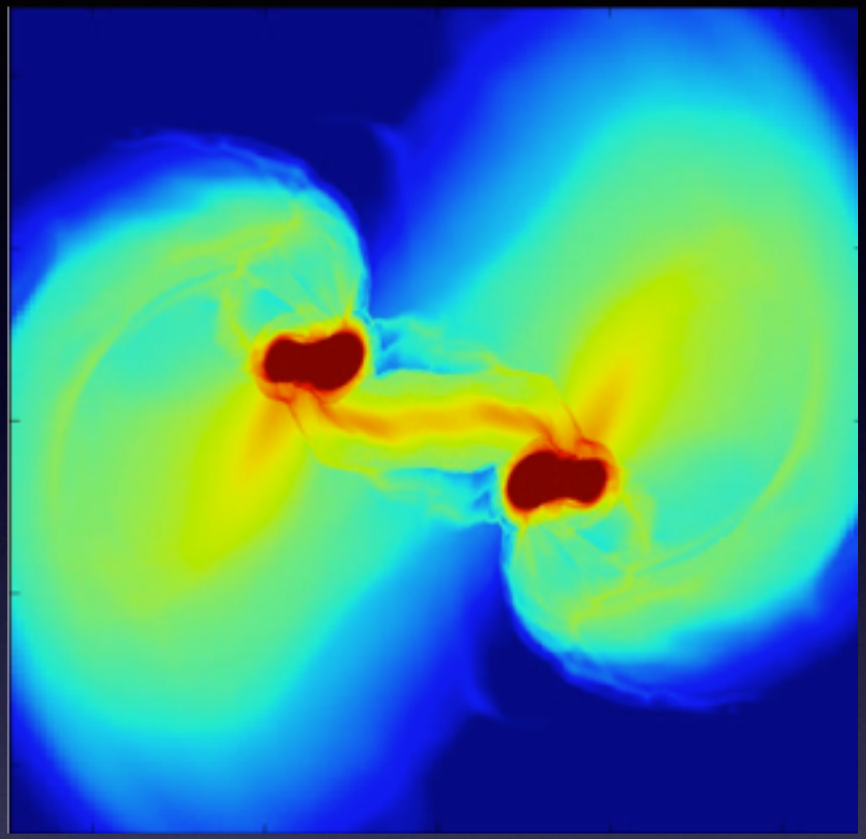


Dynamical mass ejection from eccentric binary neutron star mergers

Filippo Galeazzi
Institute for Theoretical Physics, Frankfurt am Main, Germany

David Radice
Caltech, USA

Workshop on Binary Neutron Stars
Thessaloniki, Greece

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HIC for FAIR
Helmholtz International Center

Outline of the talk

- Eccentric binary neutron star mergers: overview
- Numerical simulations
- Ejected mass: properties and implications
- Conclusions

Eccentric binary neutron star mergers

- Circular binaries are the most likely candidates to be detected by the 2nd generation GW interferometers (Abadie et al. `12, Dominik et al. `13)

- **<u>Large uncertainties</u>** in the estimate of the event rates

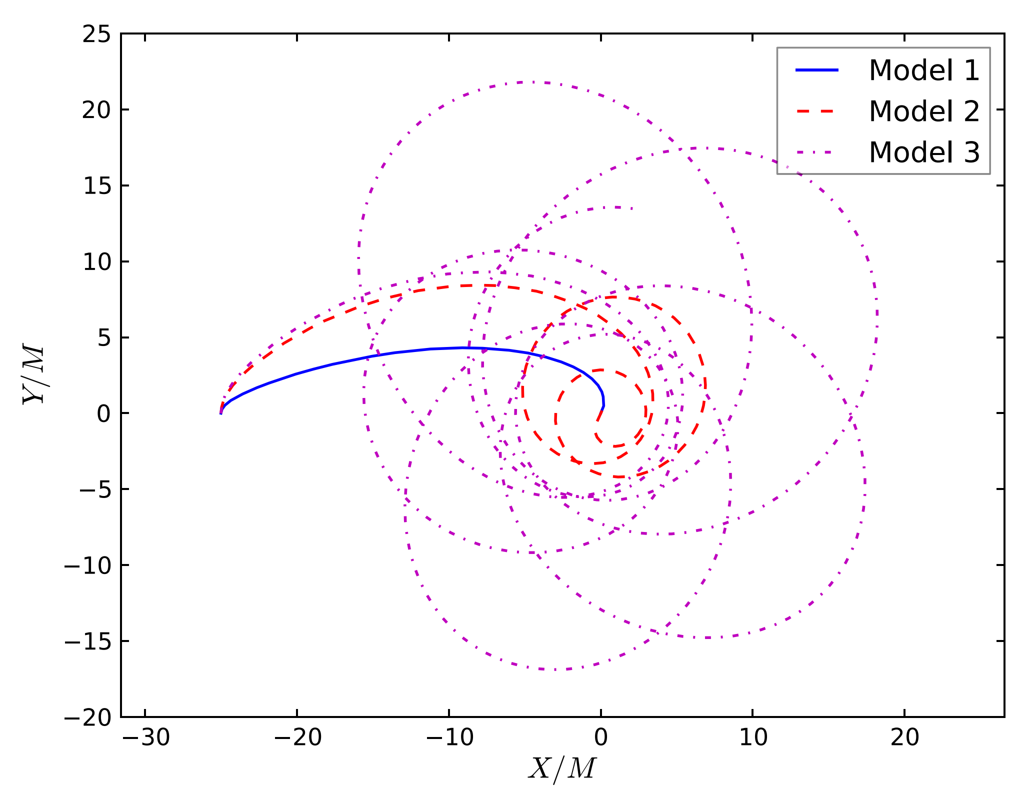
  - Population synthesis models for isolated binaries or extrapolation from galactic BNS

- **<u>Dynamical formation</u>** of binaries in dense stellar environments

  - Tidal captures, effective at r_p 30-40 GM/c^2 (Lee et al. `10)

  - Gravitational-wave induced captures, at r_p 600–700 GM/c^2 (Gold et al `12, East et al. `13, Rosswog et al. `13)

  - Tsang `13 rate few tens $Gpc^{-3}\ yr^{-1}$

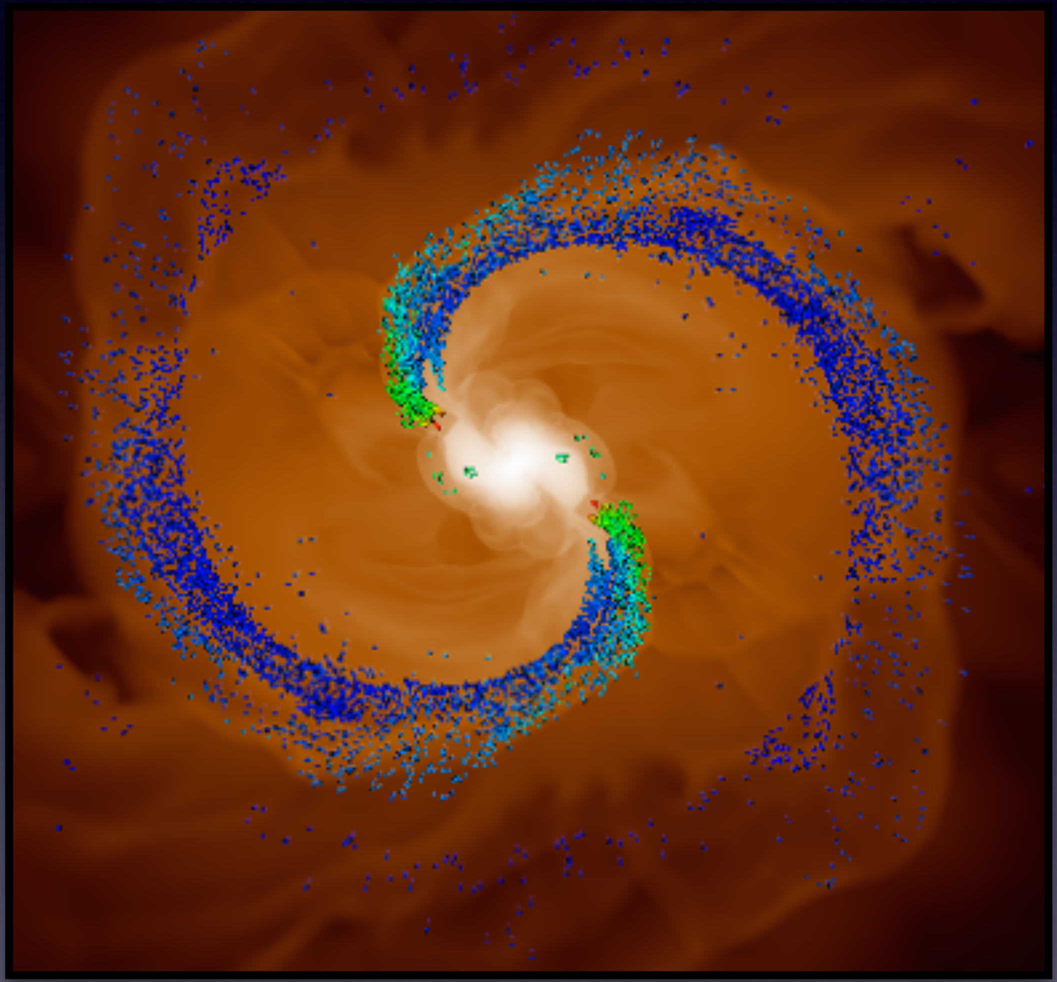


Gold et al. '12

What about the ejected material?

Ejected mass from BNS mergers

- Ejected mass and its properties are affected by:
  - Binary mass and mass ratio *(Bauswein et al. `13, Hotokezaka et al. `13)*
  - NS EOS *(Bauswein et al. `13, Hotokezaka et al. `13)*
  - Neutrinos (*Sekiguchi et al. `15*)
  - Magnetic fields (*Siegel et al. `14*)
  - NS Spin (*See Kastaun and Paschalidis' talks*)
  - Binary orbital properties



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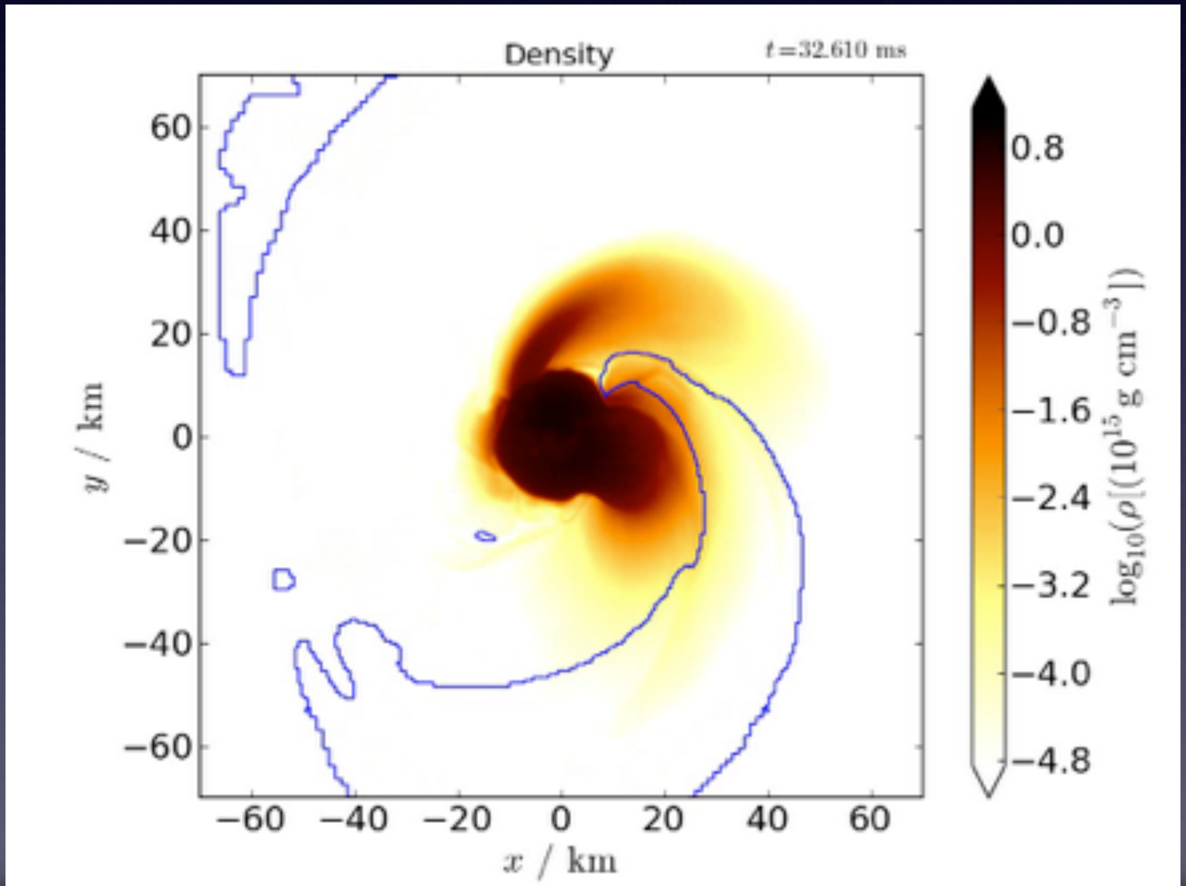

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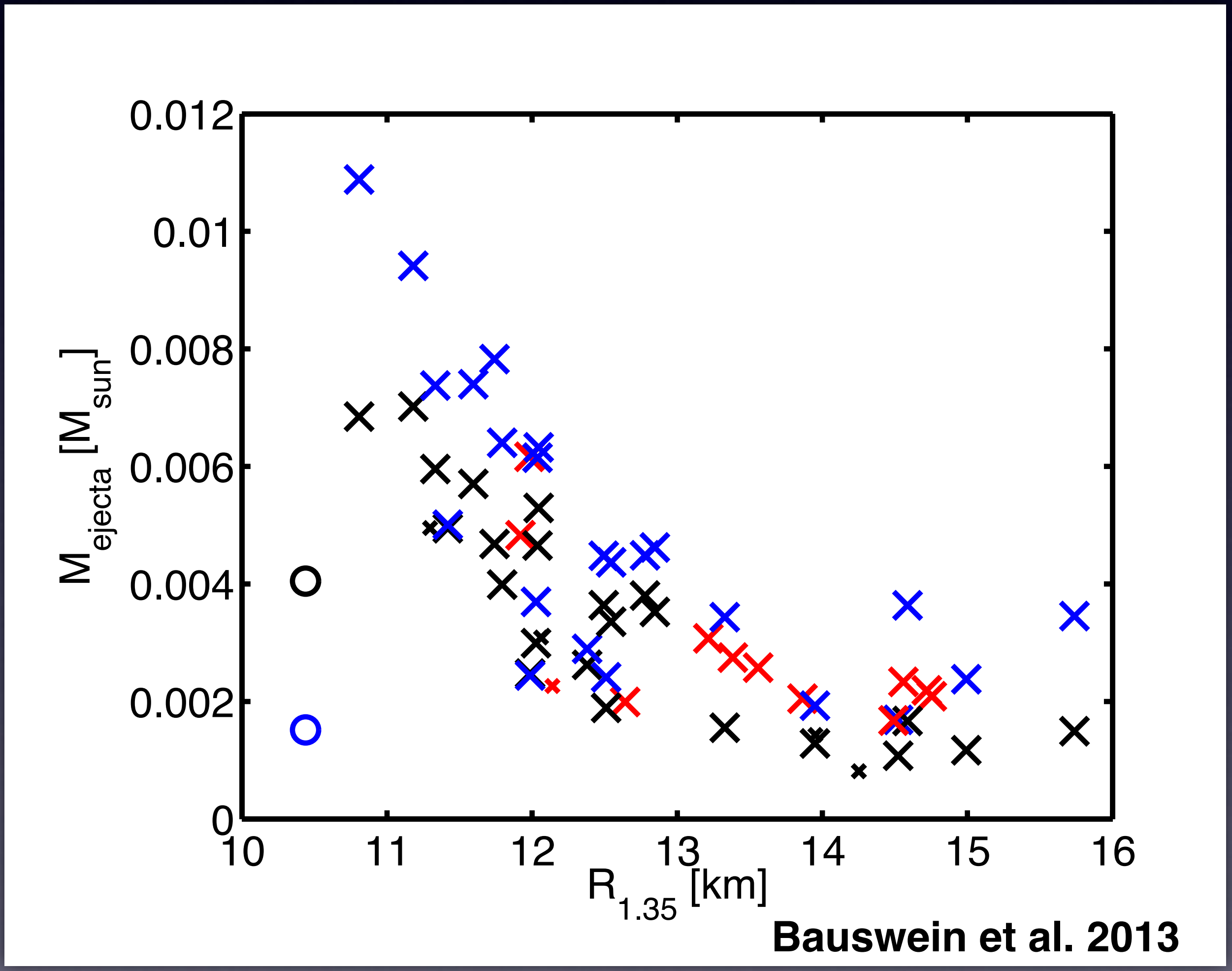

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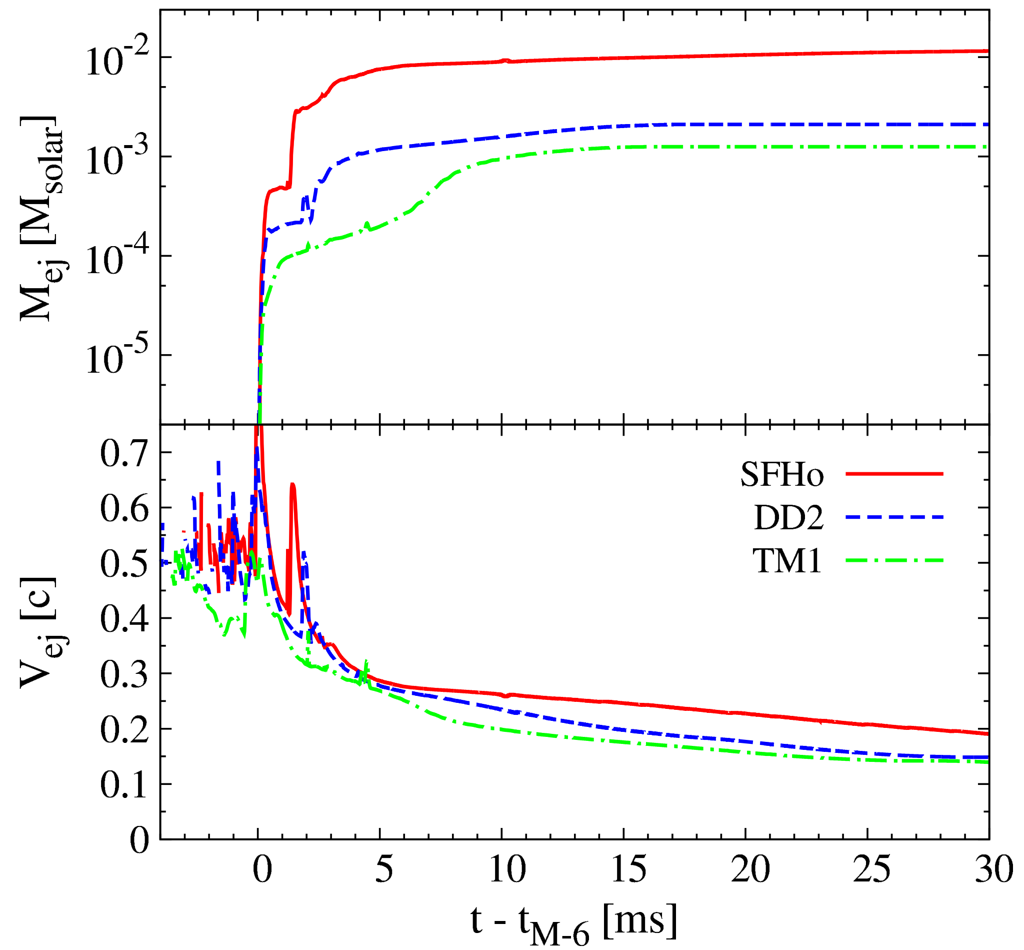

Sekiguchi et al. 2015

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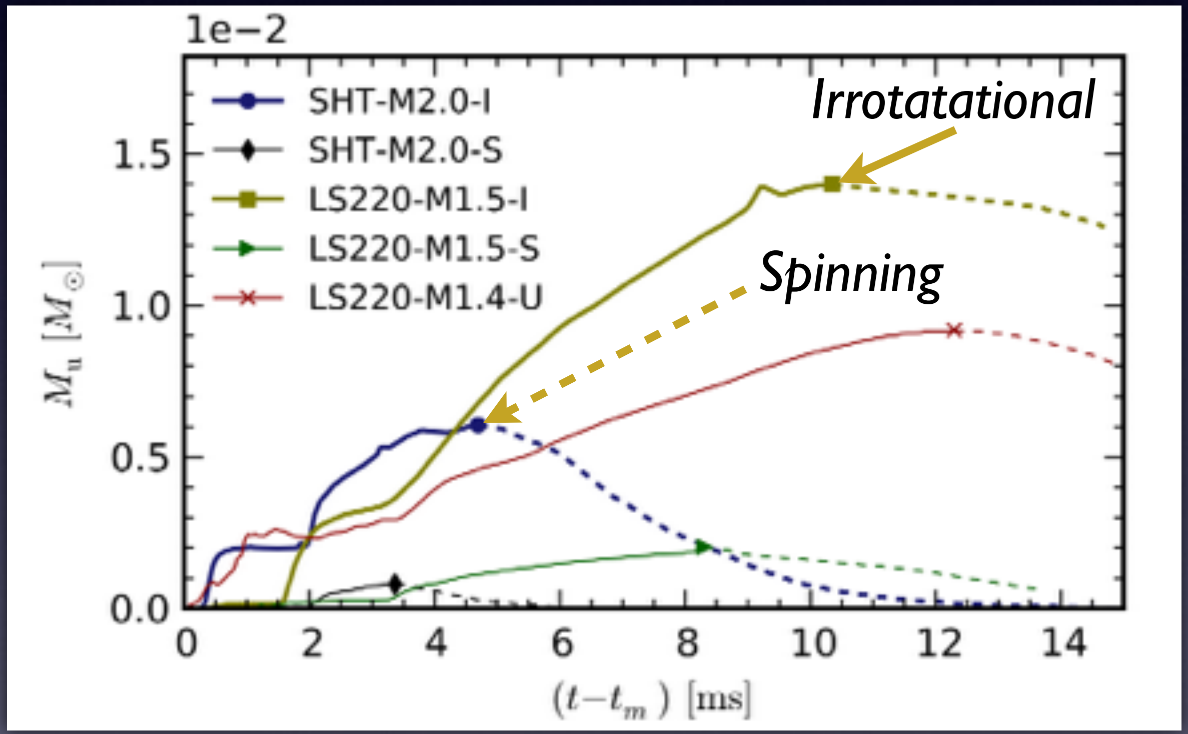
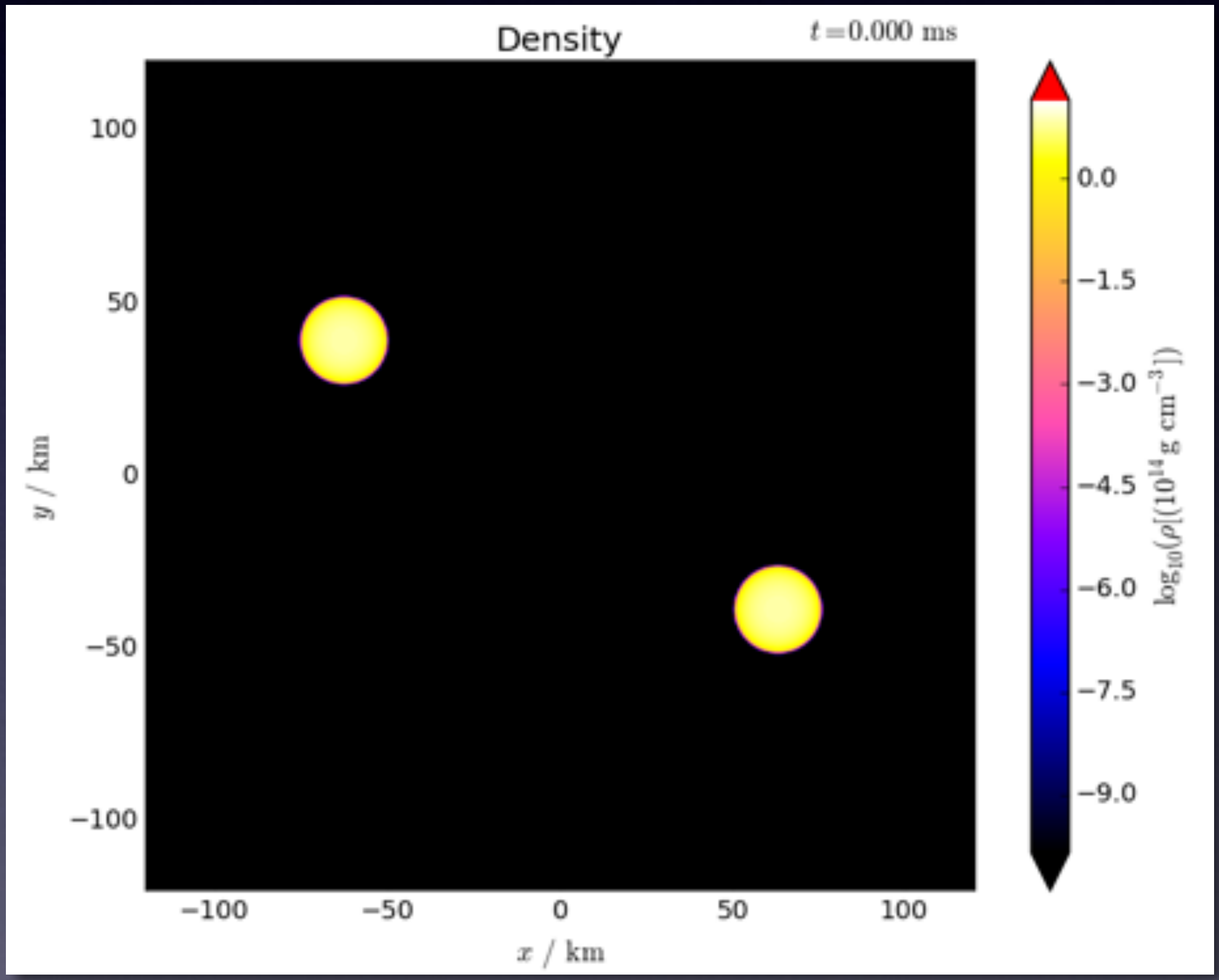


Eccentric binary neutron star merger simulations

- Superposition of boosted TOVs, not solving for the hydrostatic equilibrium or the constraints

- Equal mass NSs system
  - Lattimer-Swesty EOS (1991) K = 220
  - M_{NS}=1.389 $M_\odot$, R =12.7 km
  - separation 150 km
  - Newtonian periastron at r_p = 0.0, 5.0, 7.5, 10.0, 15.0 $M_\odot$

- Numerical grid
  - 6 refinement levels (R_{out}=750 km)
  - dx = 0.221 km (120 points across the star)
  - moving boxes



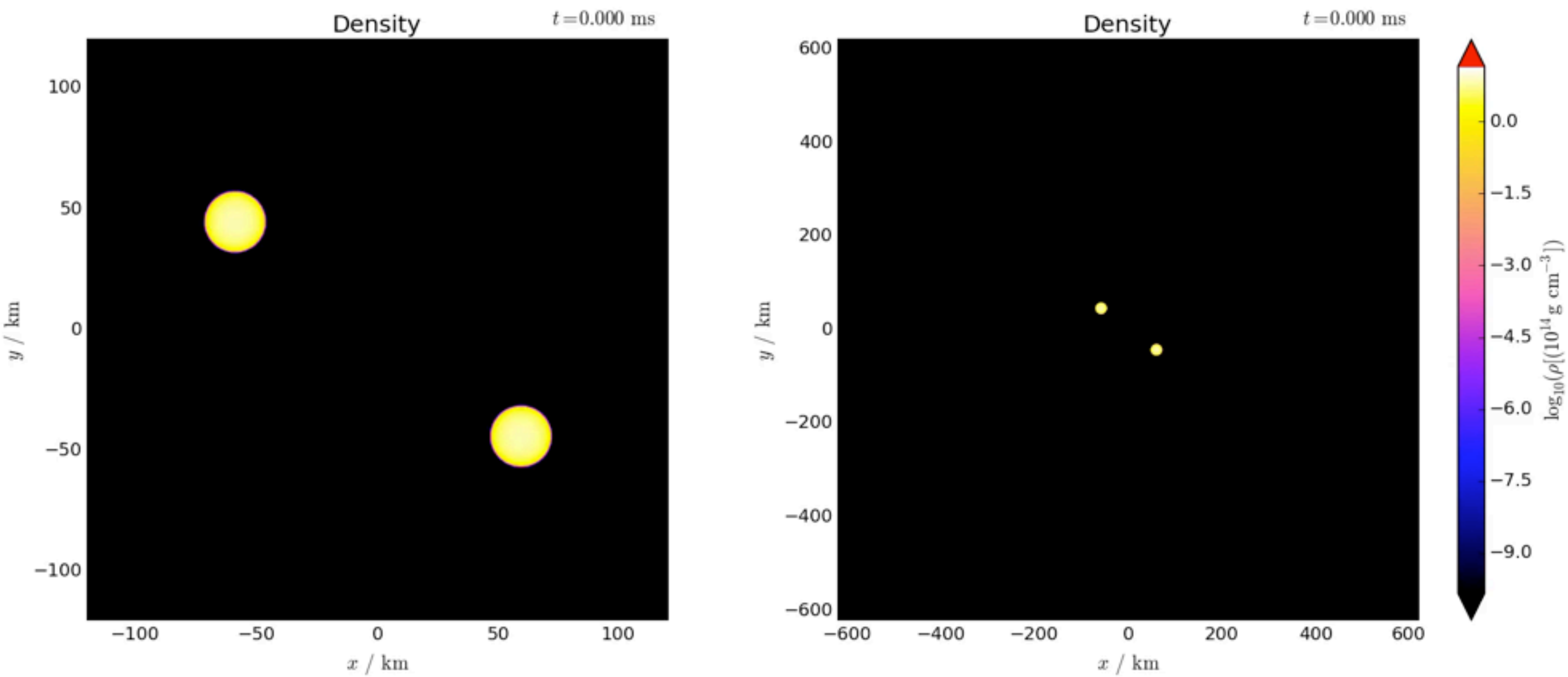
WhiskyTHC

- **Templated-Hydrodynamics Code** (THC) is a highly modular and versatile code to solve the GRHD equations (*See Rezzolla's talk*)

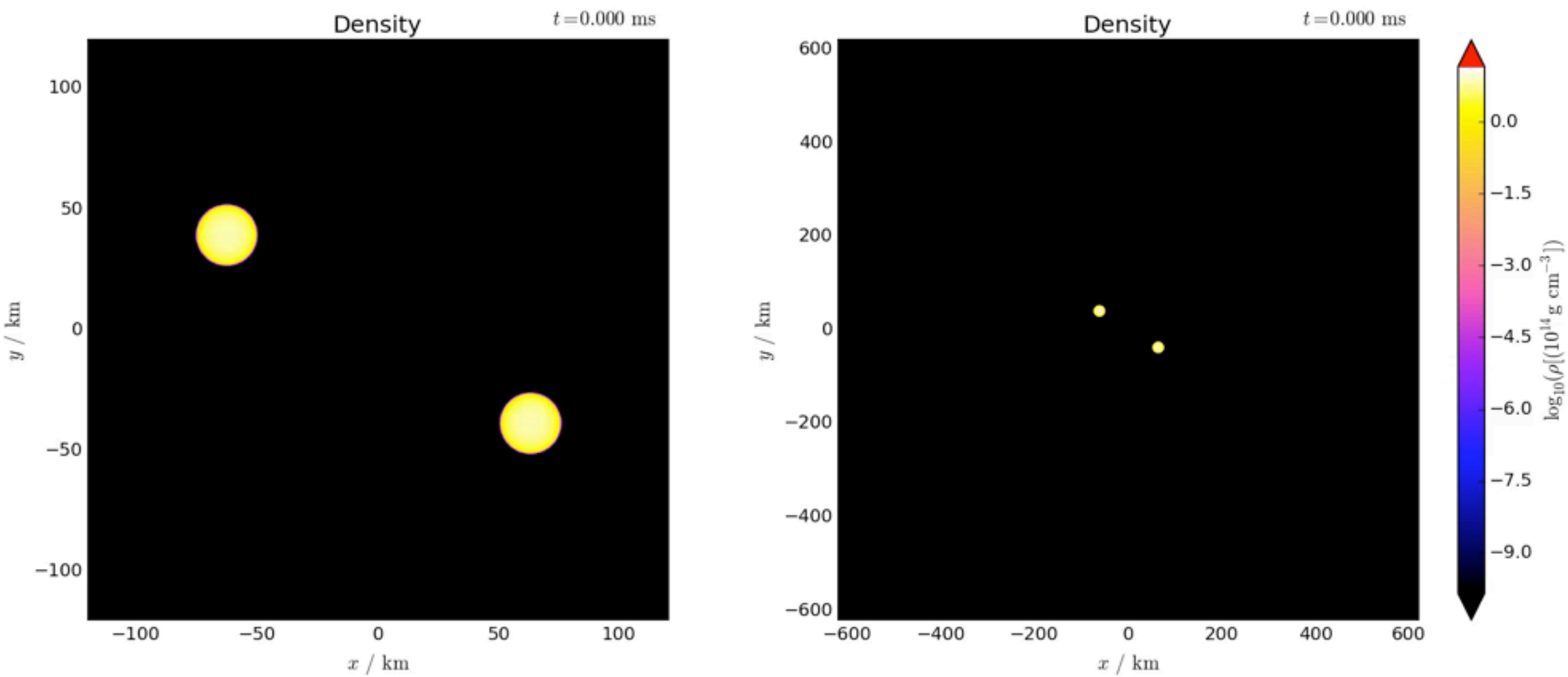
In this study we use the following setup

- Finite-Volume methods (MP5, HLLE)
- Runge-Kutta third-order for the time stepping (method of lines)
- BSSN equations: 4th order, finite-differencing
- Equation of state : tabulated nuclear
- **Neutrino treatment**: leakage scheme (Ruffert and Janka `96, Rosswog & Liebendörfer `03, Galeazzi et al. `13, Neilsen et al. `13)

M_{NS}=1.4 $M_\odot$ R_P 10 Leakage

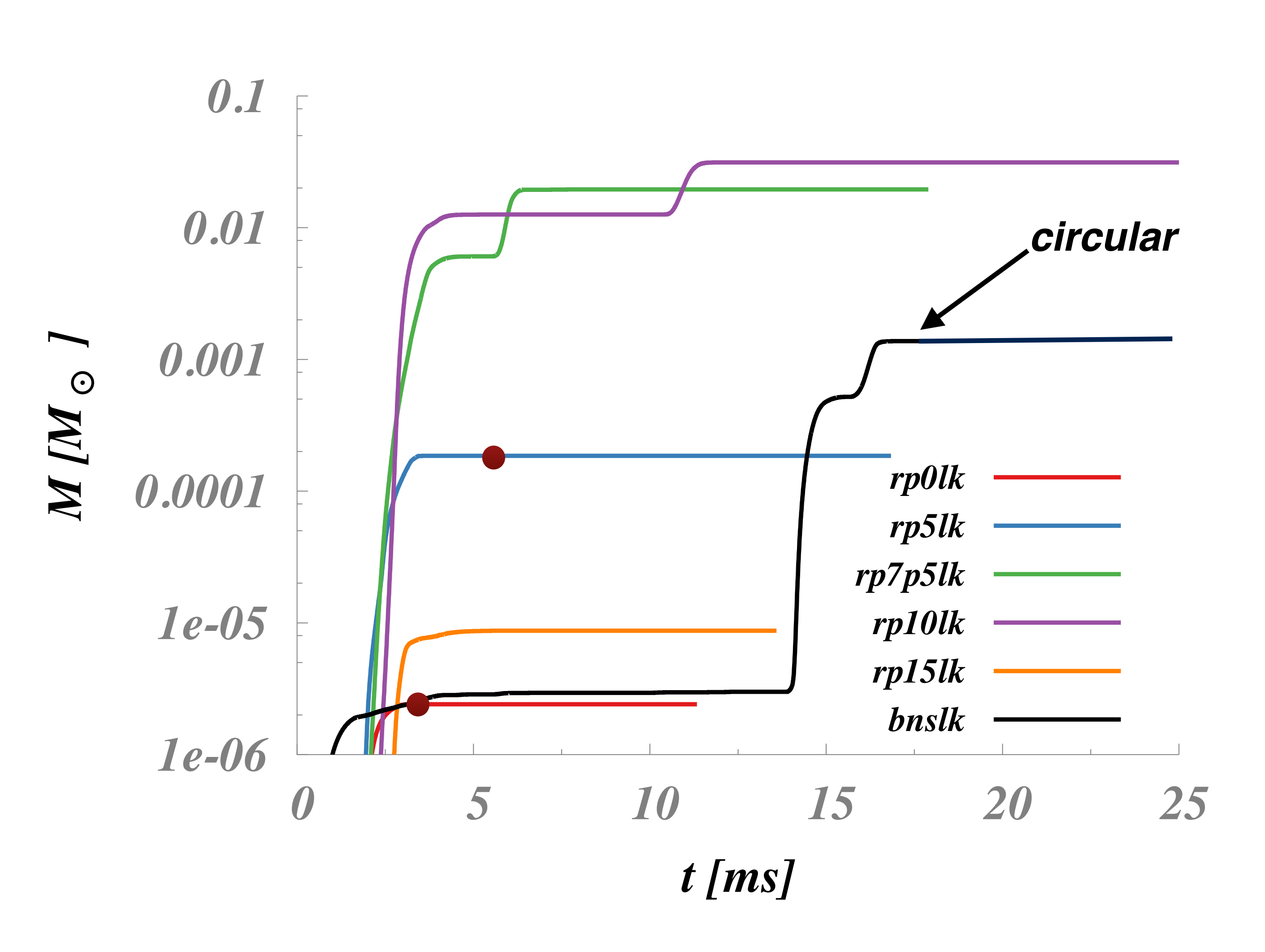


M_{NS}=1.4 $M_\odot$ R_P 7,5 Leakage



Ejected mass

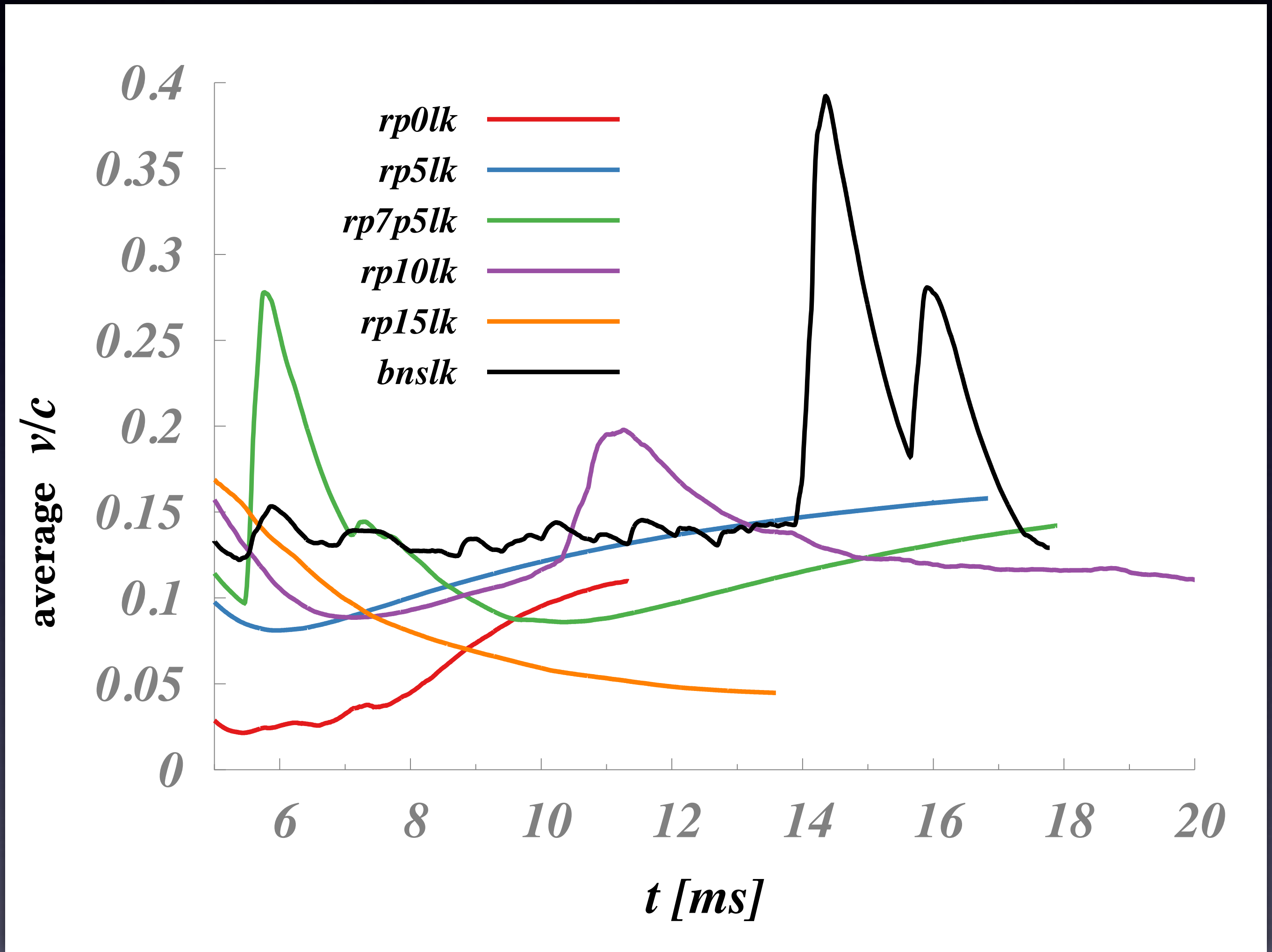
- substantial amount of ejecta compared to the circular case (East & Pretorius `12)
- Large parameter space, fix the EOS, mass, mass ratio and change the periastron
    - $r_p \lesssim 5$ prompt BH formation: few ejecta
    - $5 < r_p < 10$ few encounter and formation of HMNS
    - $r_p > 10$ multiple encounters
- geodesic criteria ($u_t < 1$) applied to the material which crosses a sphere at 150 km distance (similar results are found at larger radii)



mass ejection is sensitive to the neutrino cooling

Ejecta properties

- Ejecta are only mildly relativistic v/c ~ 0.1-0.4
- The average electron fraction varies from Y_e=0.14 for rp10lk to Y_e=0.18 rp7,5lk
- the angular distribution is mostly on the plane for the rp10lk
- when the HMNS forms the ejecta move away from the orbital plane (rp7.5lk)



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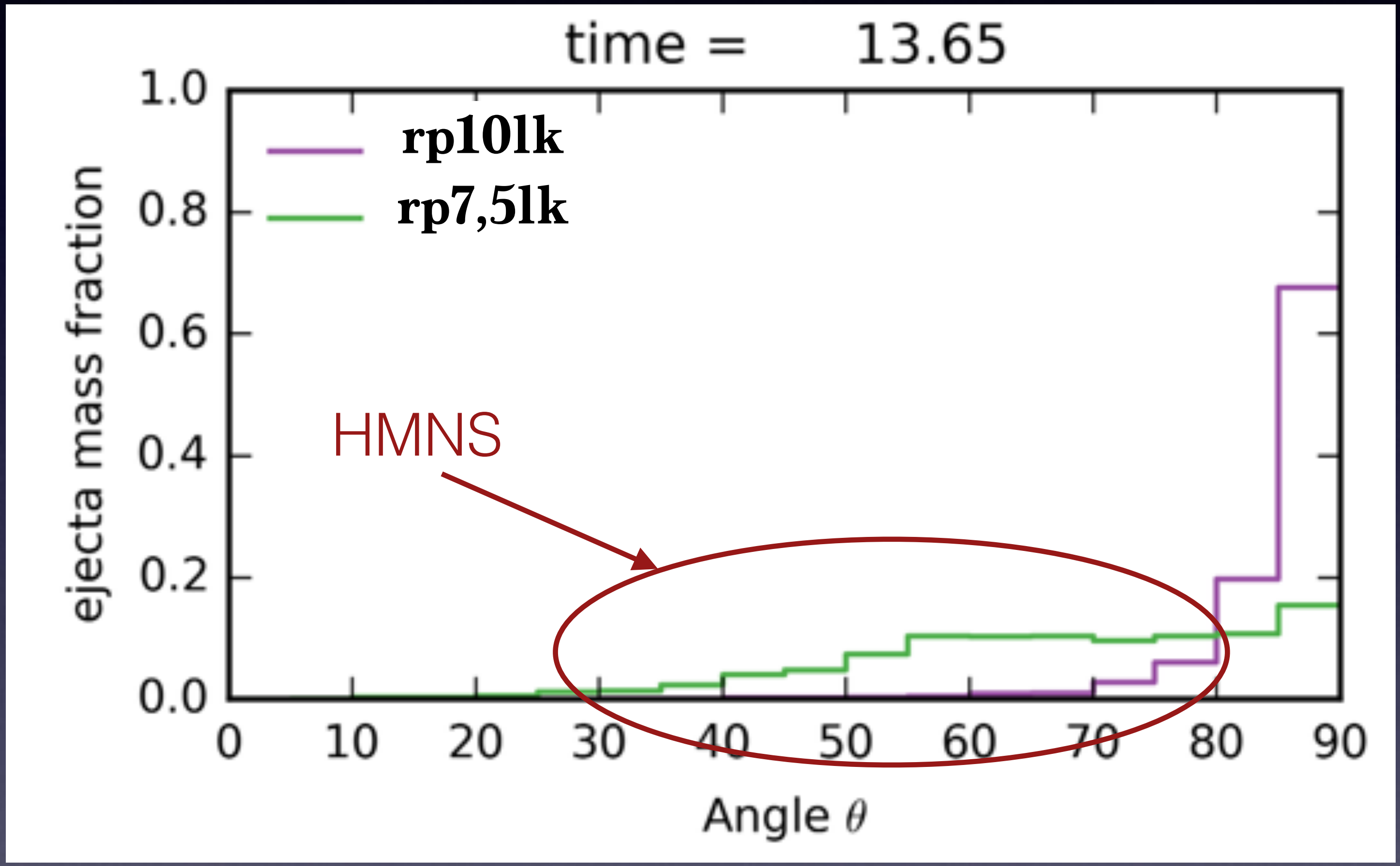
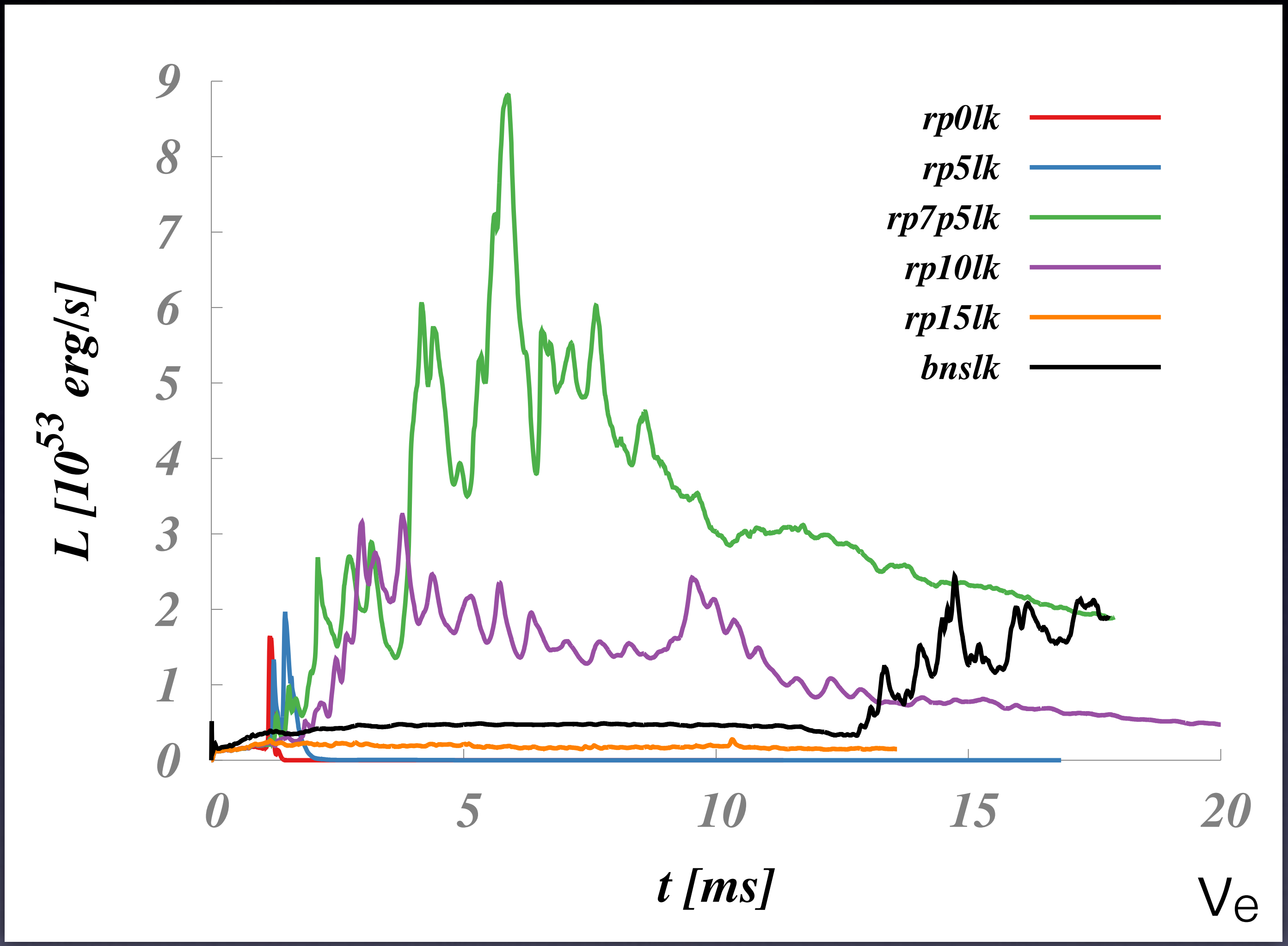


Neutrino luminosity

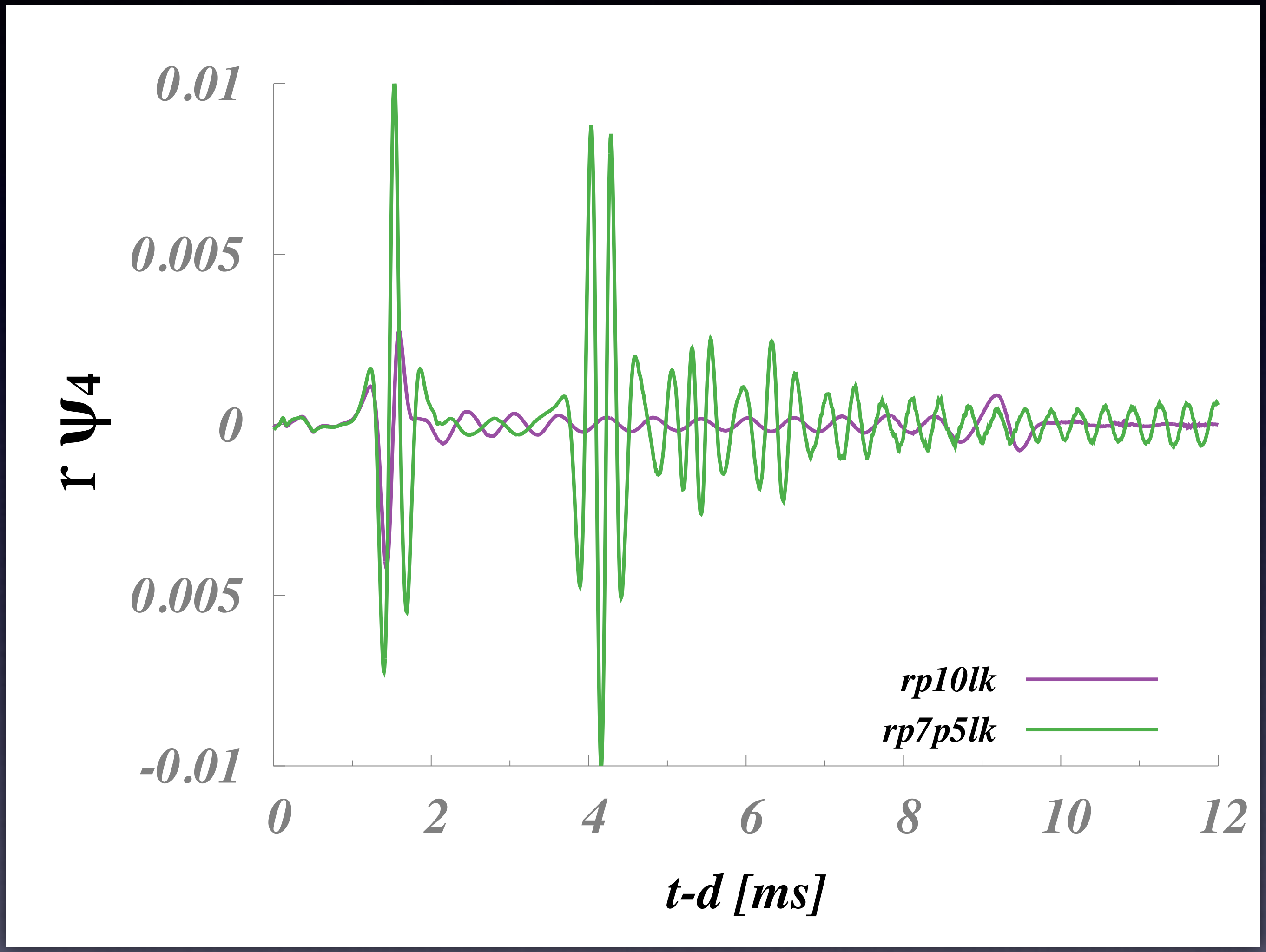
- Neutrino leakage scheme (Galeazzi `13) with simplified optical depth calculation from Neilsen et al. `14
- The leakage tends to overestimate the cooling (upper limit)
- As expected the eccentric mergers are more luminous (higher temperatures)
- the amount of mass ejected is affected by the cooling



a transport scheme is needed

Gravitational wave emission

- Pulsated signal at each close encounter
- f-mode excitation (Gold et al. `11)
- models with $r_p \lesssim 10$ form an HMNS in within 30 ms
- models with $r_p > 10$ are hard to follow (multiple encounters)
- significant SNR prior the merger, better sky localisation (Kyutoku & Seto `14)
- EM precursors?

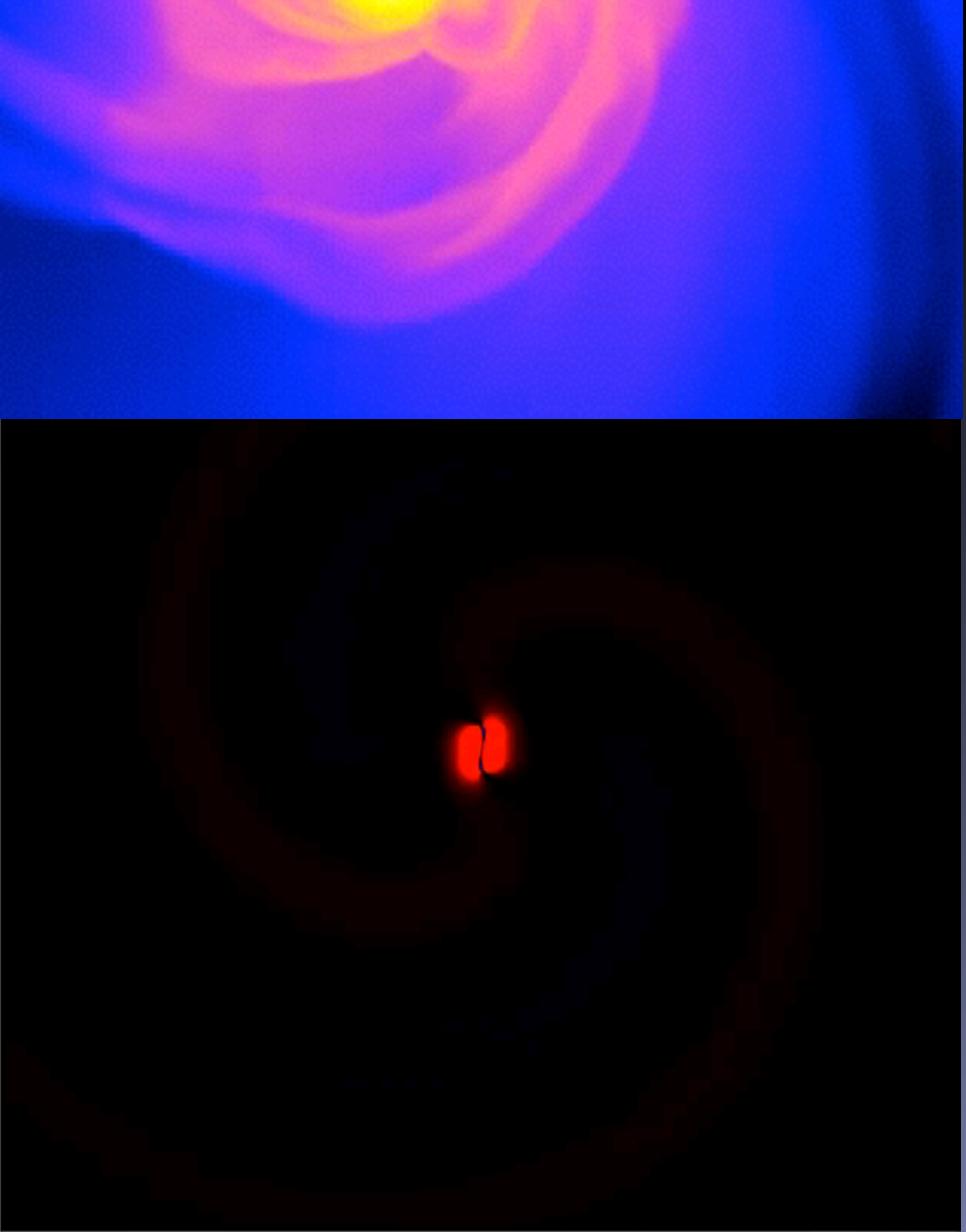


Outlook

- First simulations of eccentric neutron star mergers including the effects of nuclear EOS and neutrino cooling
- In contrast with quasi-circular BNS mergers, dynamical capture mergers can result in up to a few percent of a solar mass in ejecta
- The ejecta are very neutron-rich: sites for r-process nucleosynthesis

Next

- Study the formation of heavy-nuclei from the abundant ejecta
- Include the effects of neutrino absorption
- Consistent initial data (Moldenhauer et al. (2014))



Thank you for your attention