Probing the Origin of Fast Radio Bursts by Simulations of Binary Neutron Star Merger

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Outline of Talk

1. Binary Neutron Star Merger Models
2. Motivation
3. Simulation Data
4. Result & Discussion
5. Summary

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NS-NS merger model for FRBs

- Possible origin of non-repeating FRBs (Totani '13, Wang+ '16, Zhang '16)
- Pulsar-like emission at the time of merger (Totani '13) / Curvature radiation during in-spiral phase via unipolar inductor mechanism (Wang +'16)
- Dynamical timescale of merger may explain FRB duration (~ms)
- Energetics : OK

Image Credit : NASA

Associations with

Gravitational Waves
Short GRBs
Kilonova/ Macronova

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Motivation

- Theoretical studies predict possible electromagnetic emissions during in-spiral phase (e.g. Hansen & Lyutikov '00, Lai '12, Totani '13, Wang+'16).
- However, the region surrounding the site of the merger may be polluted by mass ejected dynamically during the in-spiral phase.
  → **Suppression of radio emission ?**
- **How much is the time lag between the enhancement of the dipole rotation and the expansion of ejecta ?**
- We focus on the expansion of dynamical ejecta from simulation results and test the consistency of the NS-NS merger model for FRBs.

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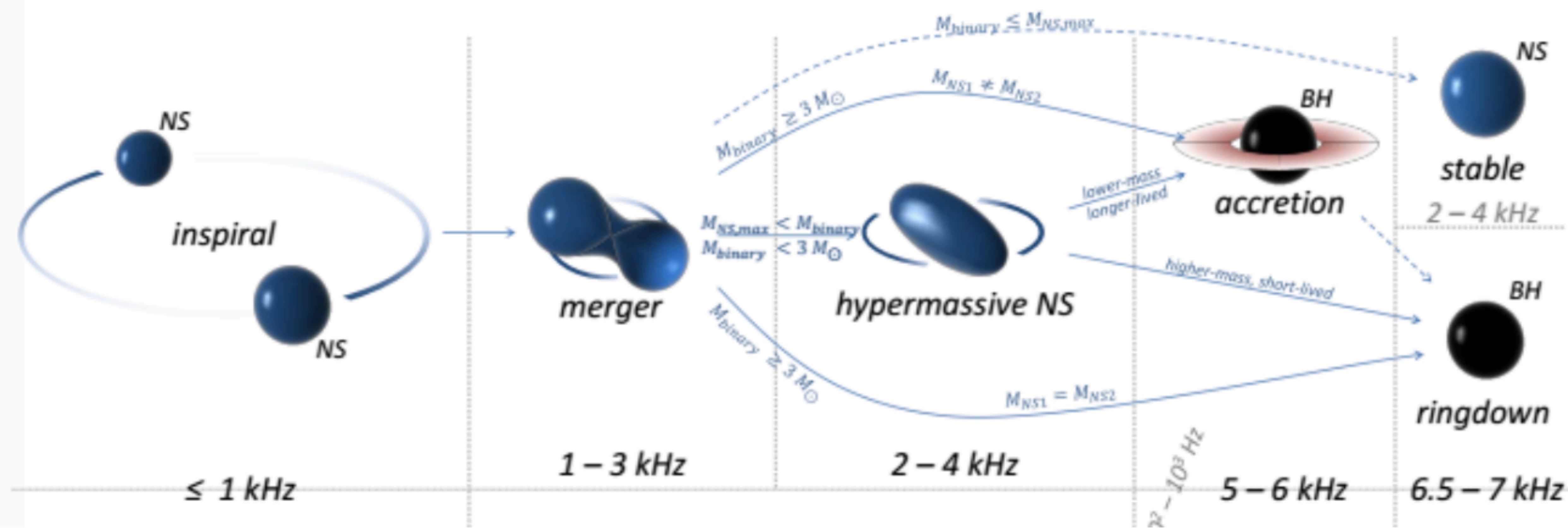
Simulation Setups



- High resolution 3D numerical-relativity simulations (Kiuchi +'14)
- We employ H4 equation of state with which total BNS mass is 2.7 M_{SUN} (equal mass system) without B field
- The computation follows about an in-spiral orbit, and the merger outcome is a HMNS with its lifetime > 40 ms

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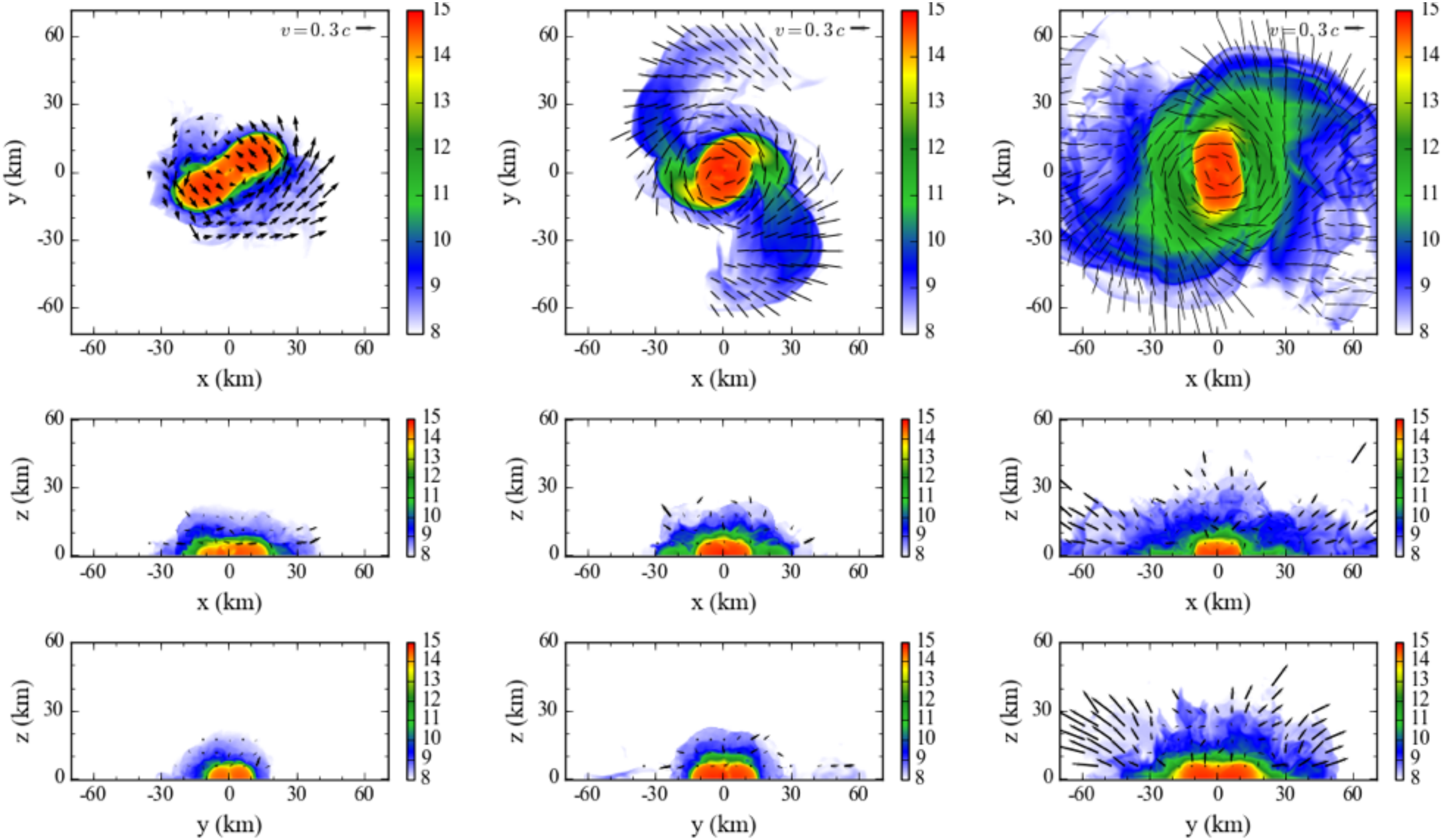
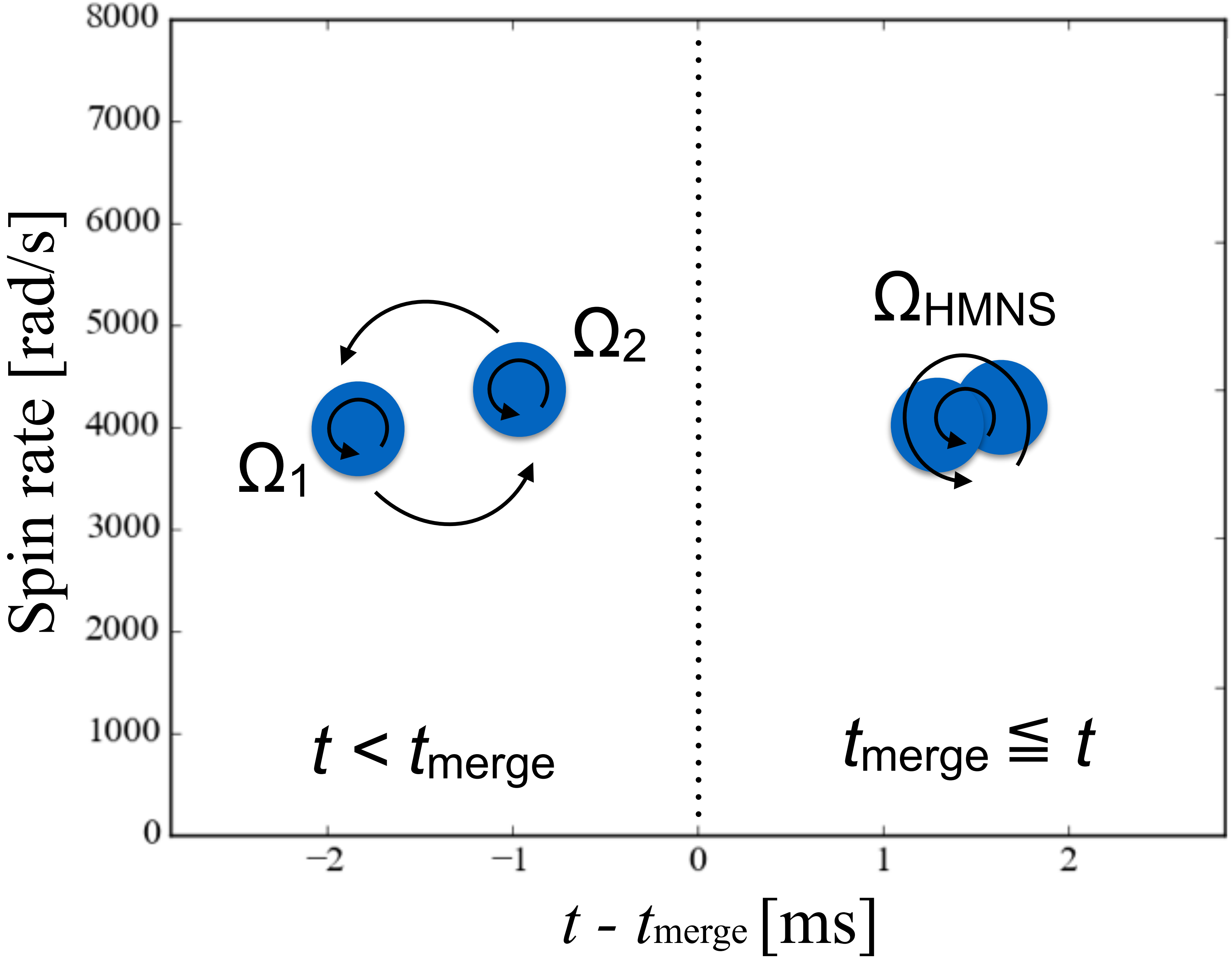
Snapshots of the density profile

$t = t_{\rm merge} - 0.7$ ms　　$t = t_{\rm merge}$　　$t = t_{\rm merge} + 0.7$ ms



Spin rate evolution : $\Omega_{\rm star}(t)$

$$\Omega_*(t) \equiv \begin{cases} [\Omega_1(t) + \Omega_2(t)]/2 & (t \leq t_{\rm merge}) \\ \Omega_{\rm HMNS}\,(t) & (t_{\rm merge} \leq t) \end{cases}$$



Rapid increase of $\Omega_{\rm star}$ at -1 ms $\lesssim t - t_{\rm merge} \lesssim 0$ ms

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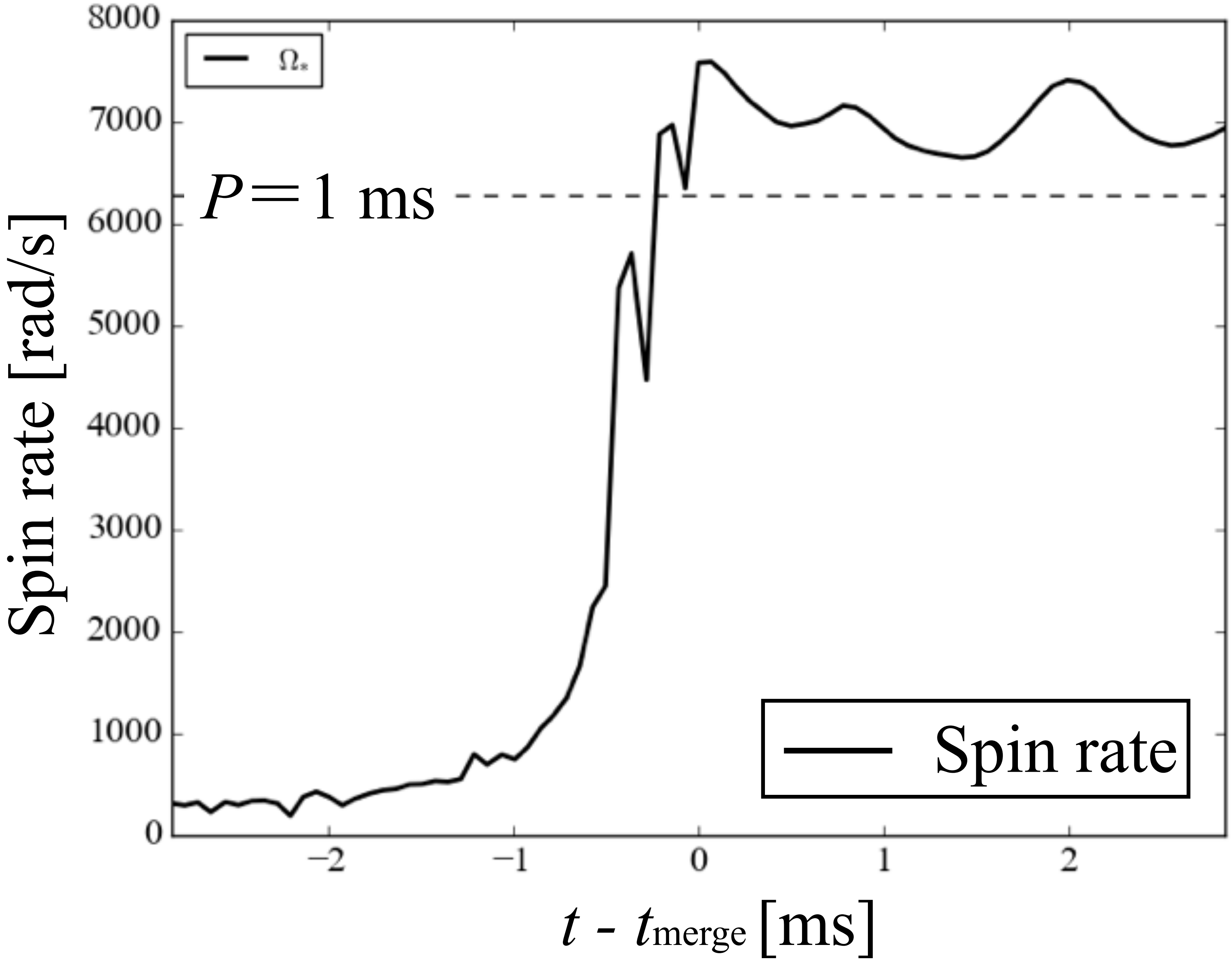

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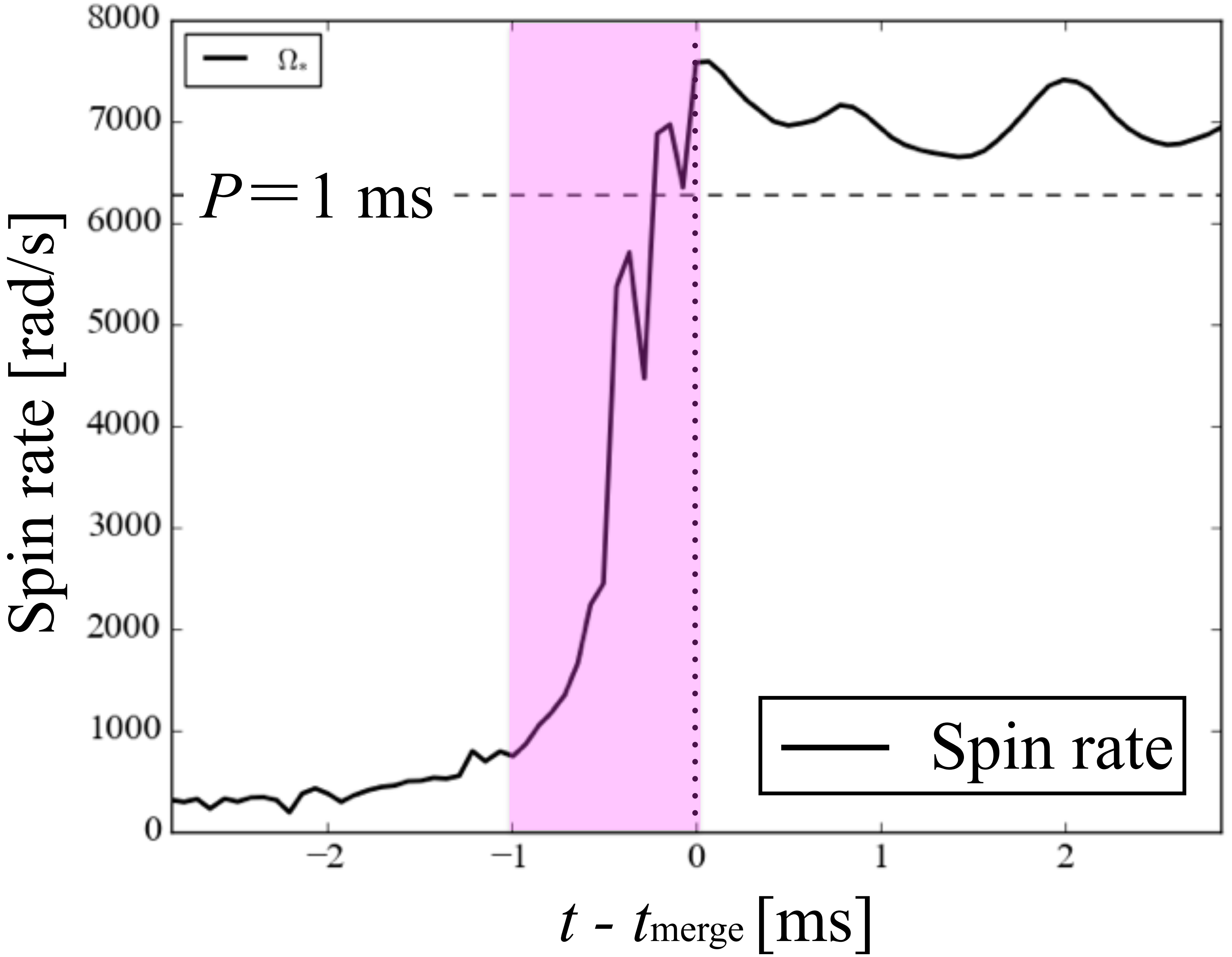
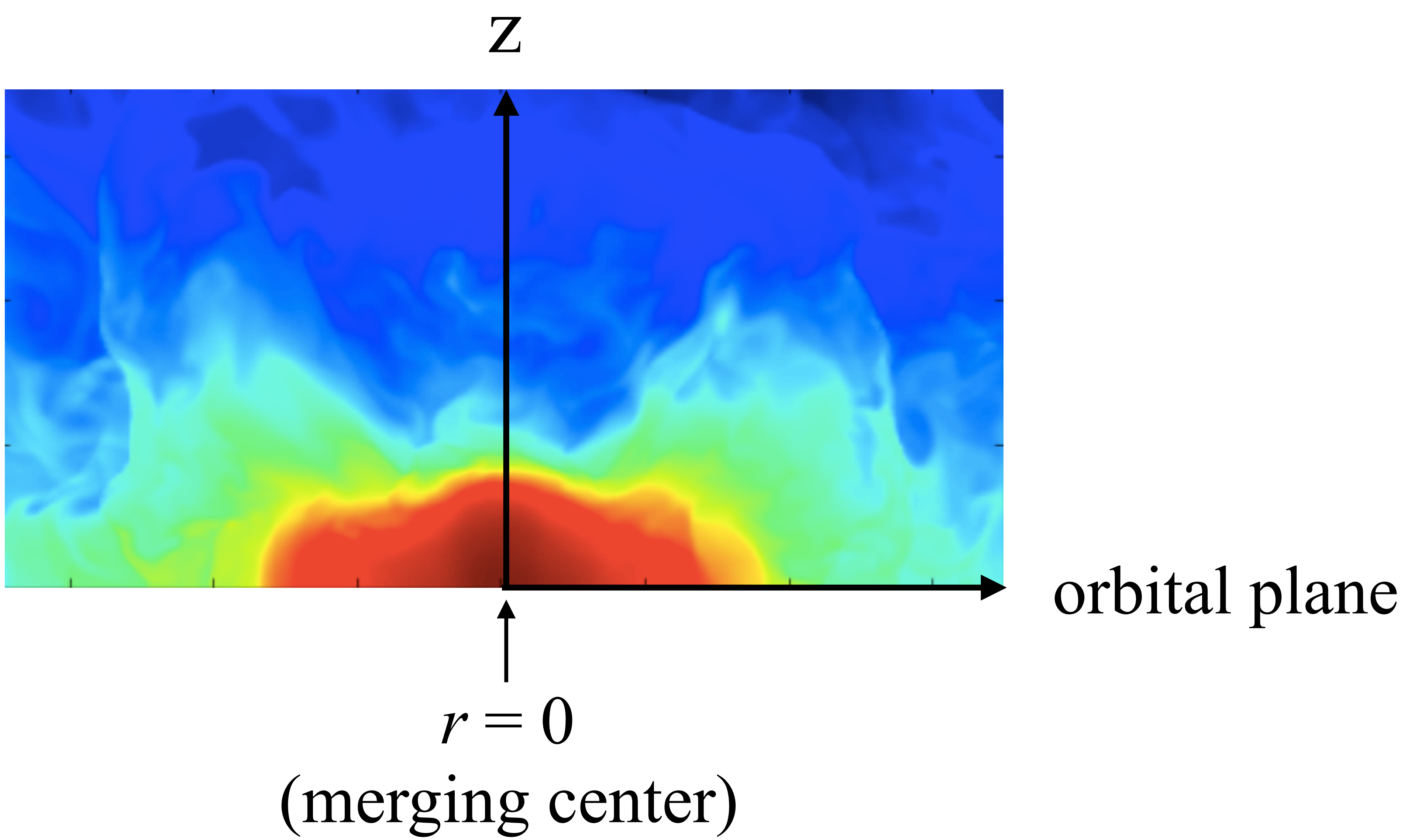
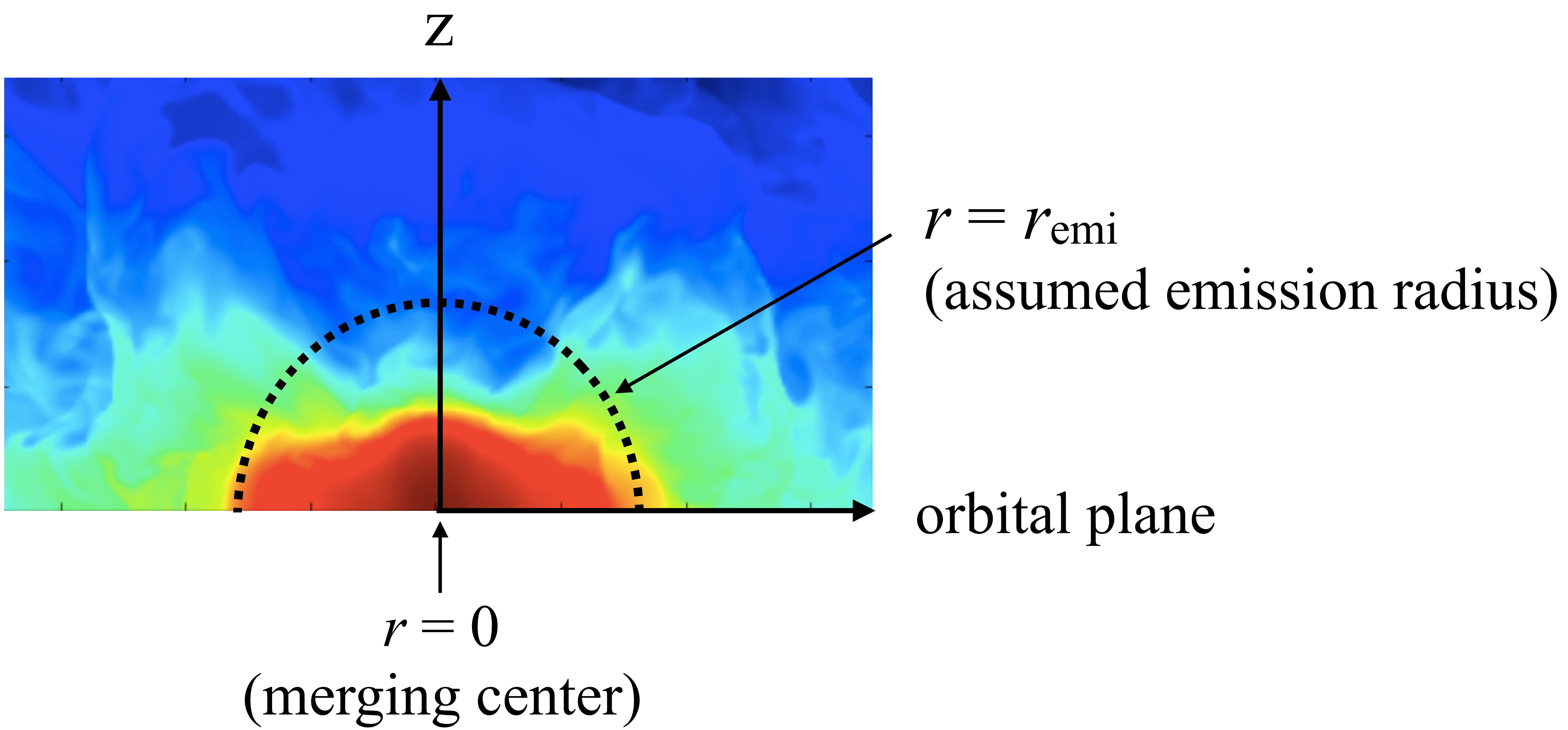


- $\Omega_{\rm star}$ increases by a factor of **>15**
- Energy loss rate: **dE/dt ∝ Ω⁴**
- Luminosity gets **>10⁴** × larger

Column density of ejected matter

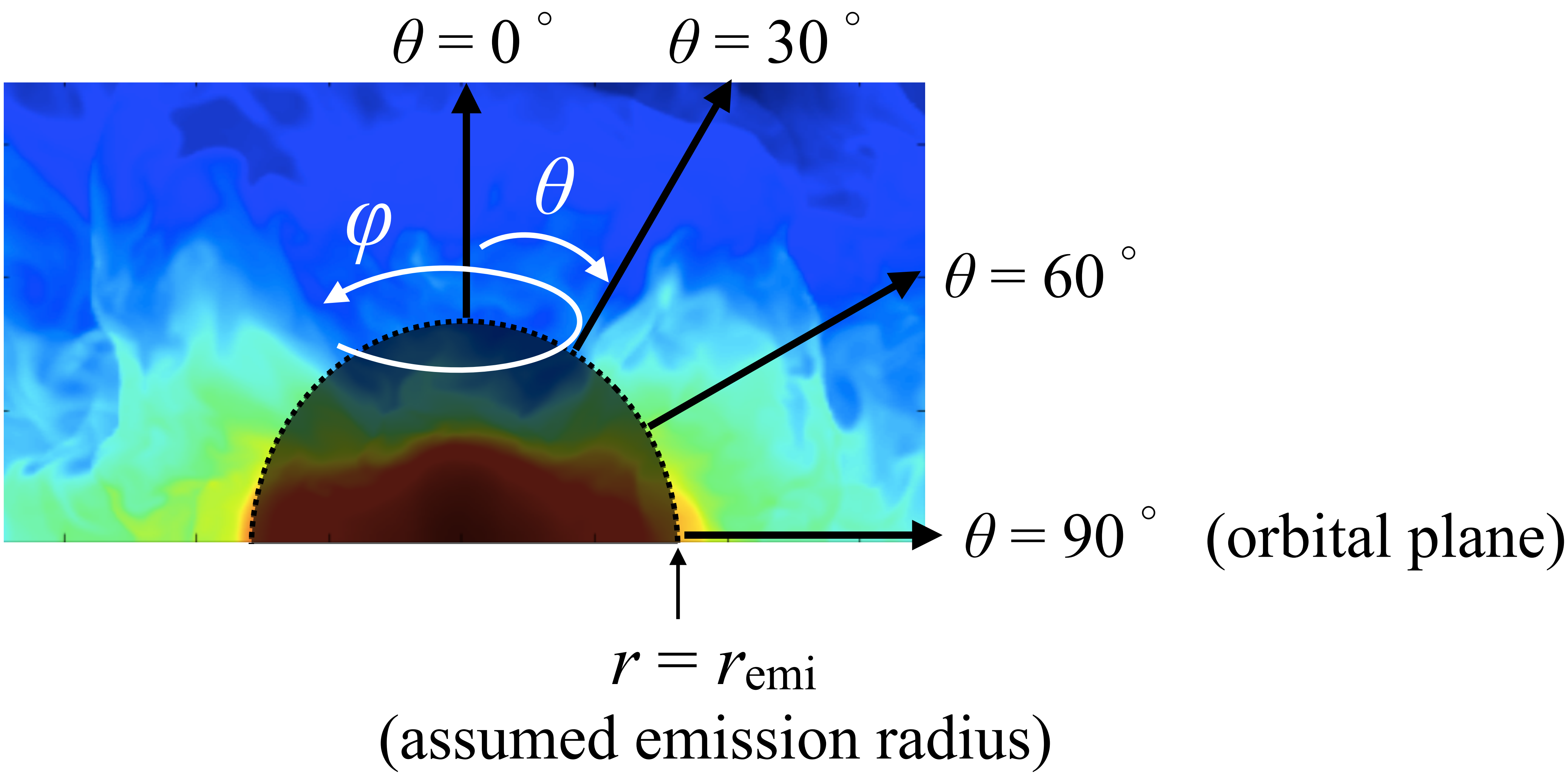


Column density of ejected matter

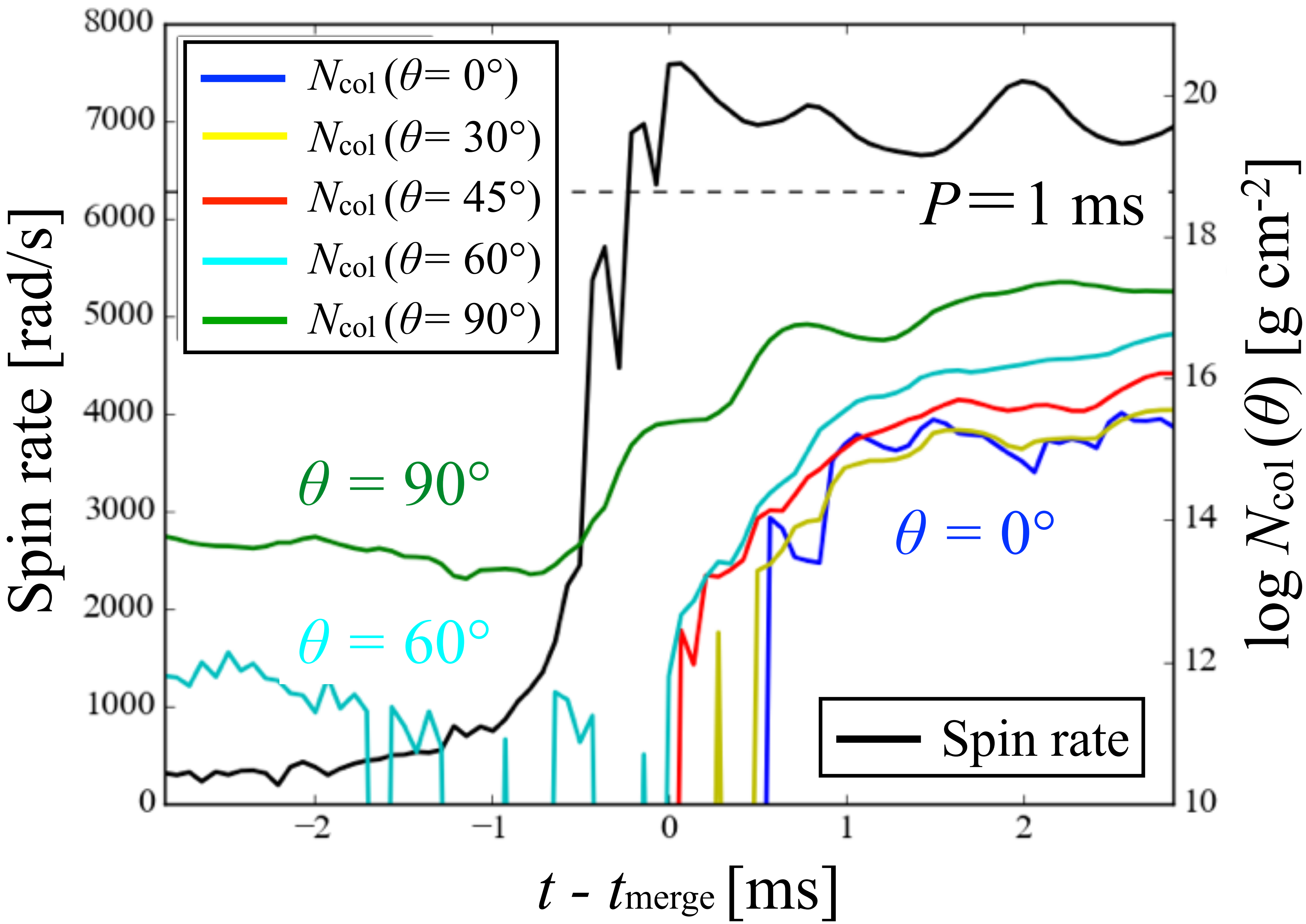


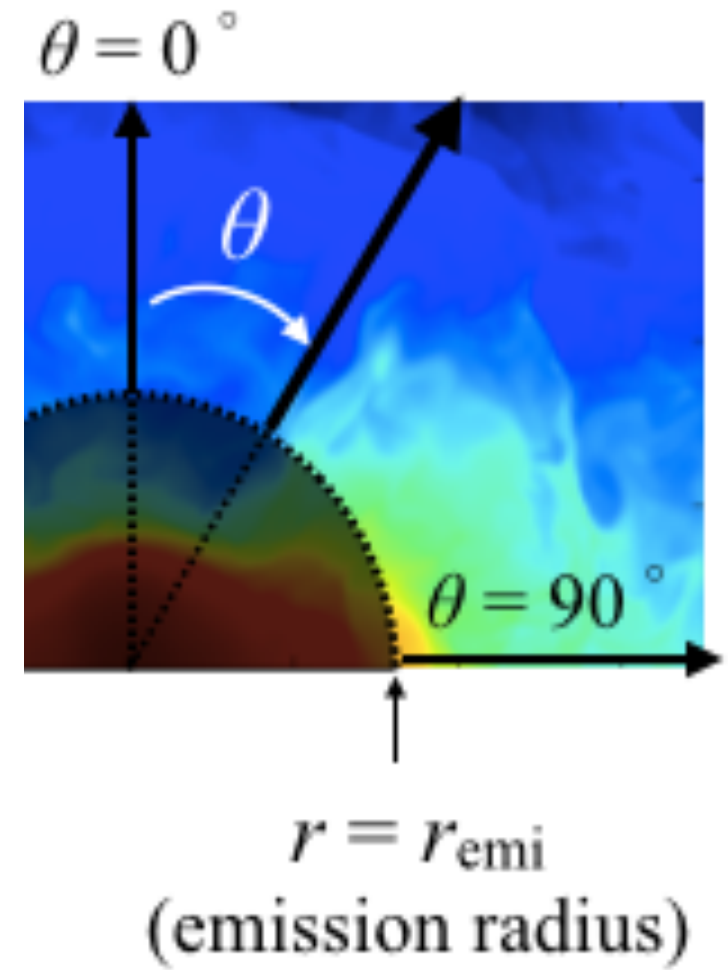
Column density of ejected matter

We calculate the φ-averaged column density (at $r > r_{\rm emi}$) for several polar angles (θ)



Column density evolution (r_{emi} = 30km)

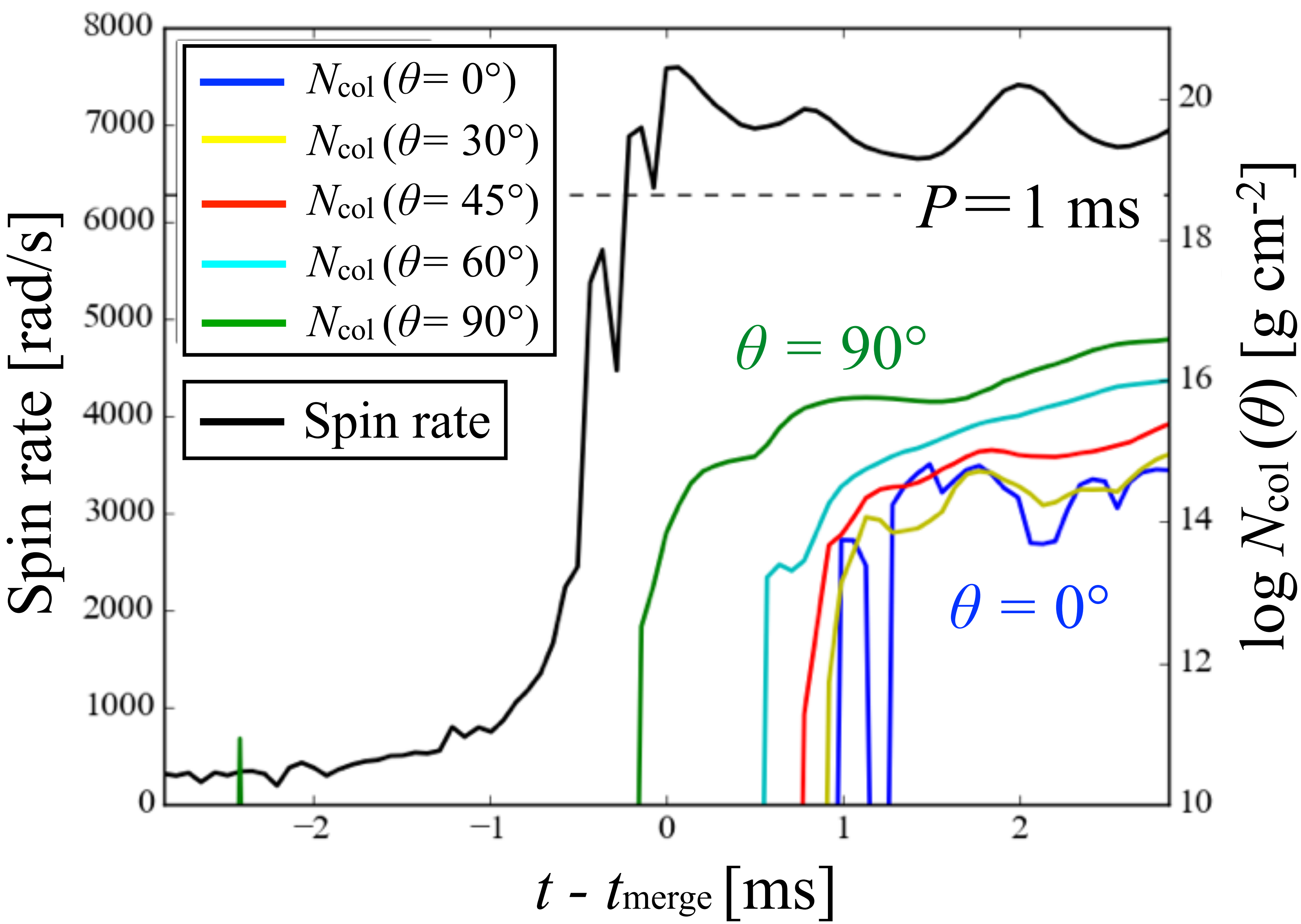


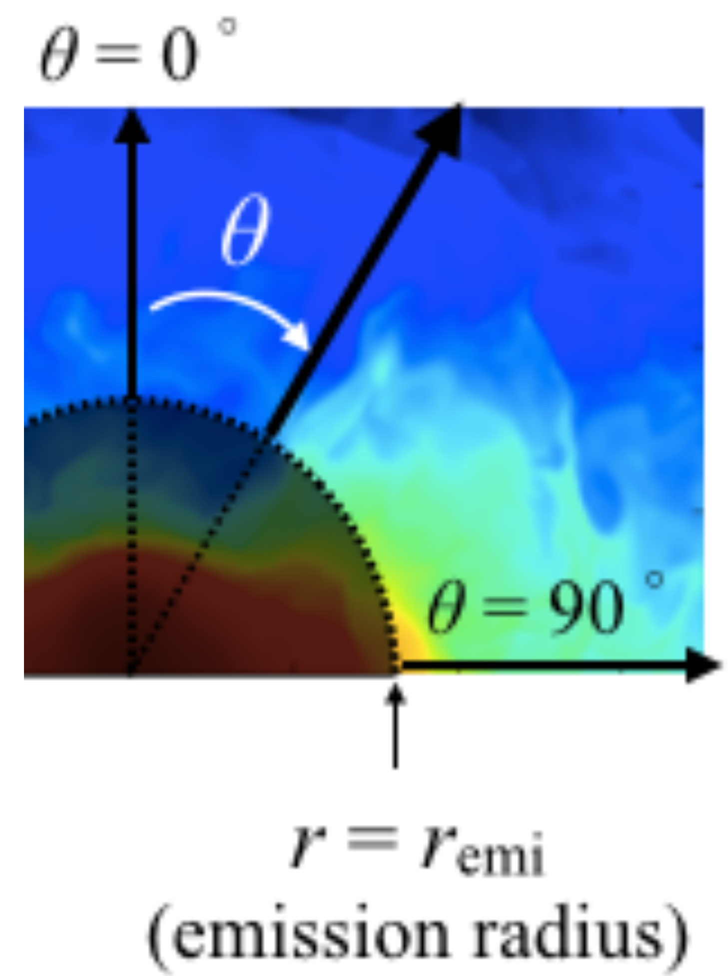


Polar cap size of MSP: $\boldsymbol{\theta_{\mathrm{cap}} \sim 26°}$

Column density evolution (r_{emi} = 50km)

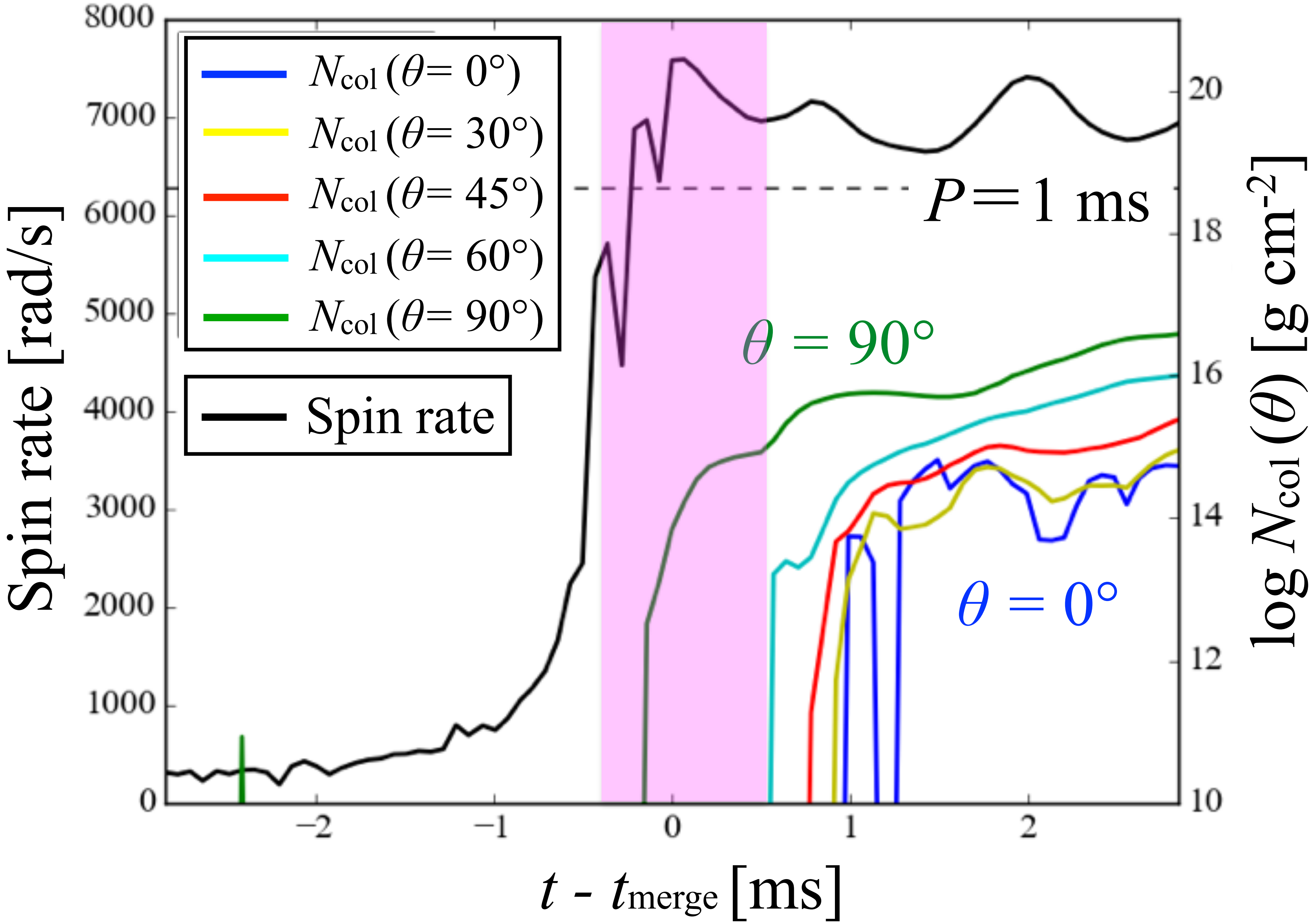
Light Cylinder radius of MSP : $R_L \sim 50\mathrm{km}\,(P/1\mathrm{ms})^{-1}$

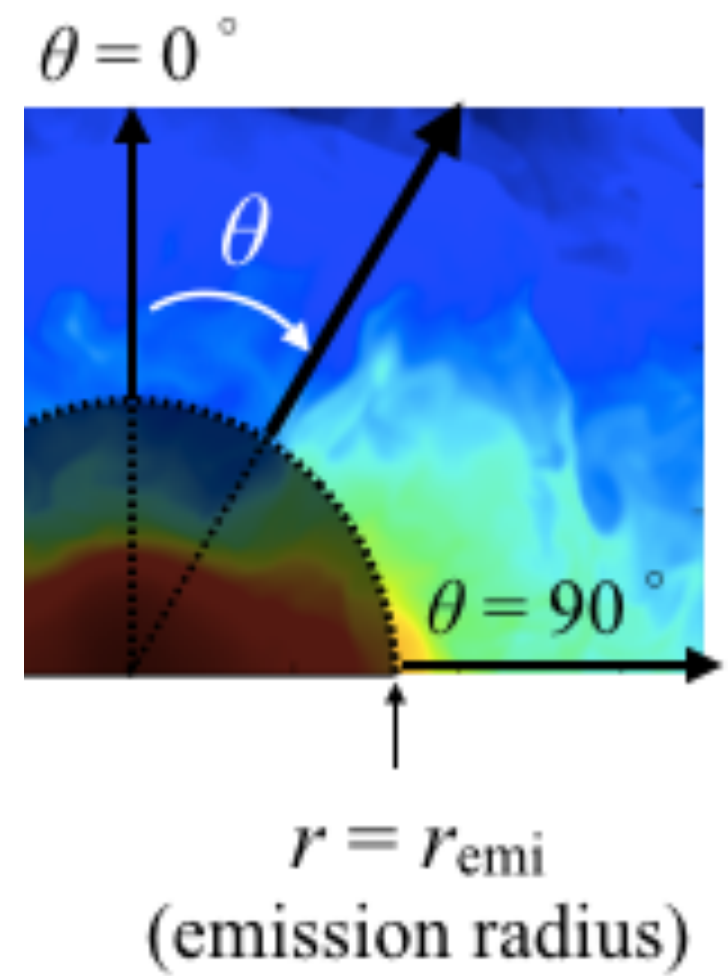




Column density evolution (r_{emi} = 50km)

An FRB could be produced here !





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Summary

- Optically thick dynamical ejecta (or "tidal tail") starts to expand after each NS starts to rotate rapidly (P ~1ms)

- Expansion is slower in the polar direction than in orbital plane

  → **Polar cap region right before merger is favored site for FRBs**

- **Given the radio emissions at about the light cylinder radius of msec pulsar (~ 50 km), they could be observable in all directions during ~ 1 ms after the spin rate becomes sufficiently large.**

- The duration of an FRB could be explained by the dynamical timescale of expanding ejecta :

$$\delta t \lesssim \frac{r_{\rm emi}}{V_{\rm ej}} \Rightarrow \delta t \lesssim 1.5\,{\rm ms}\left(\frac{r_{\rm emi}}{50{\rm km}}\right)\left(\frac{V_{\rm ej}}{0.1\,{\rm c}}\right)$$