Gamma-rays *from* Neutron Star *(and other)* Mergers

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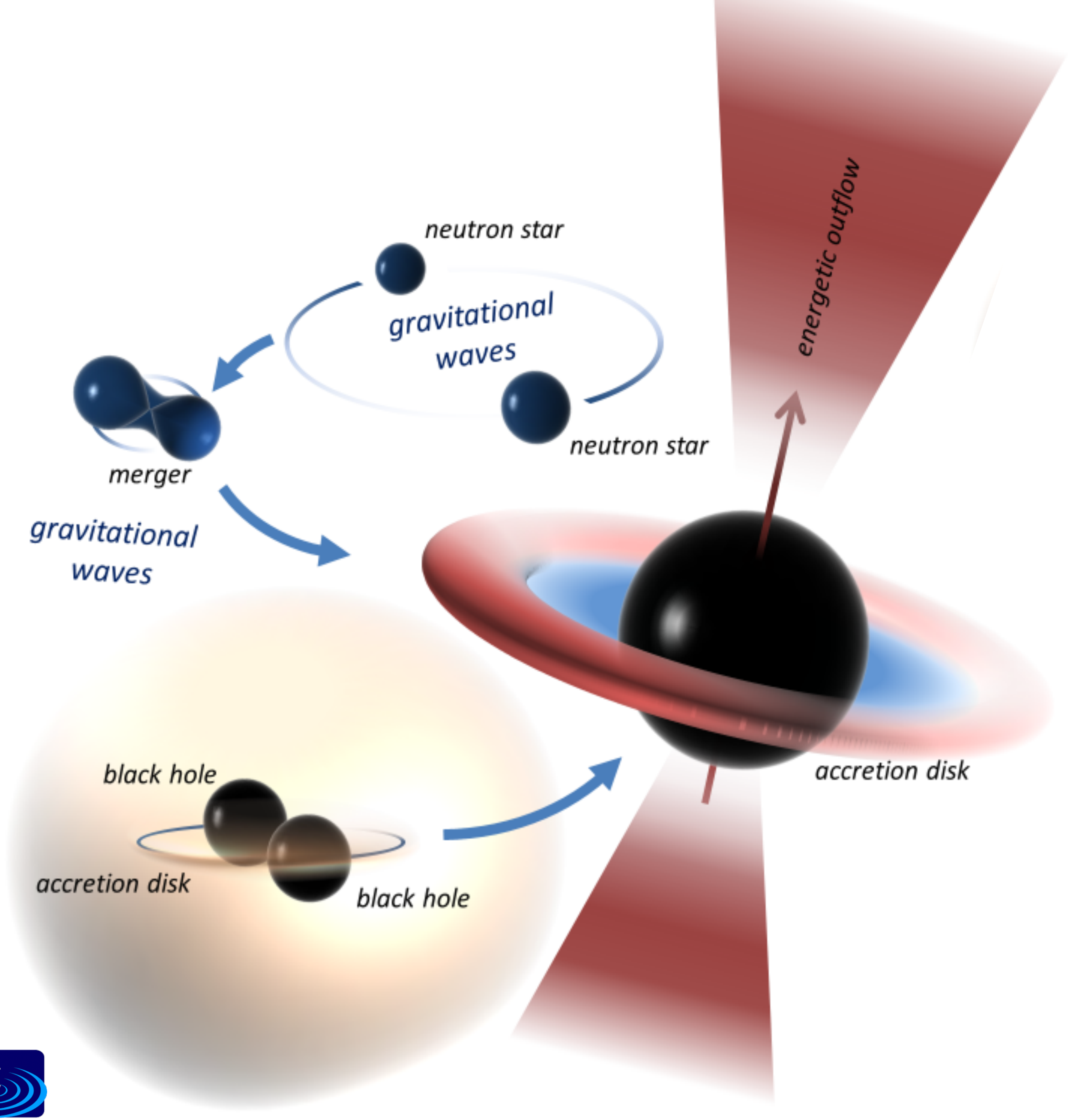
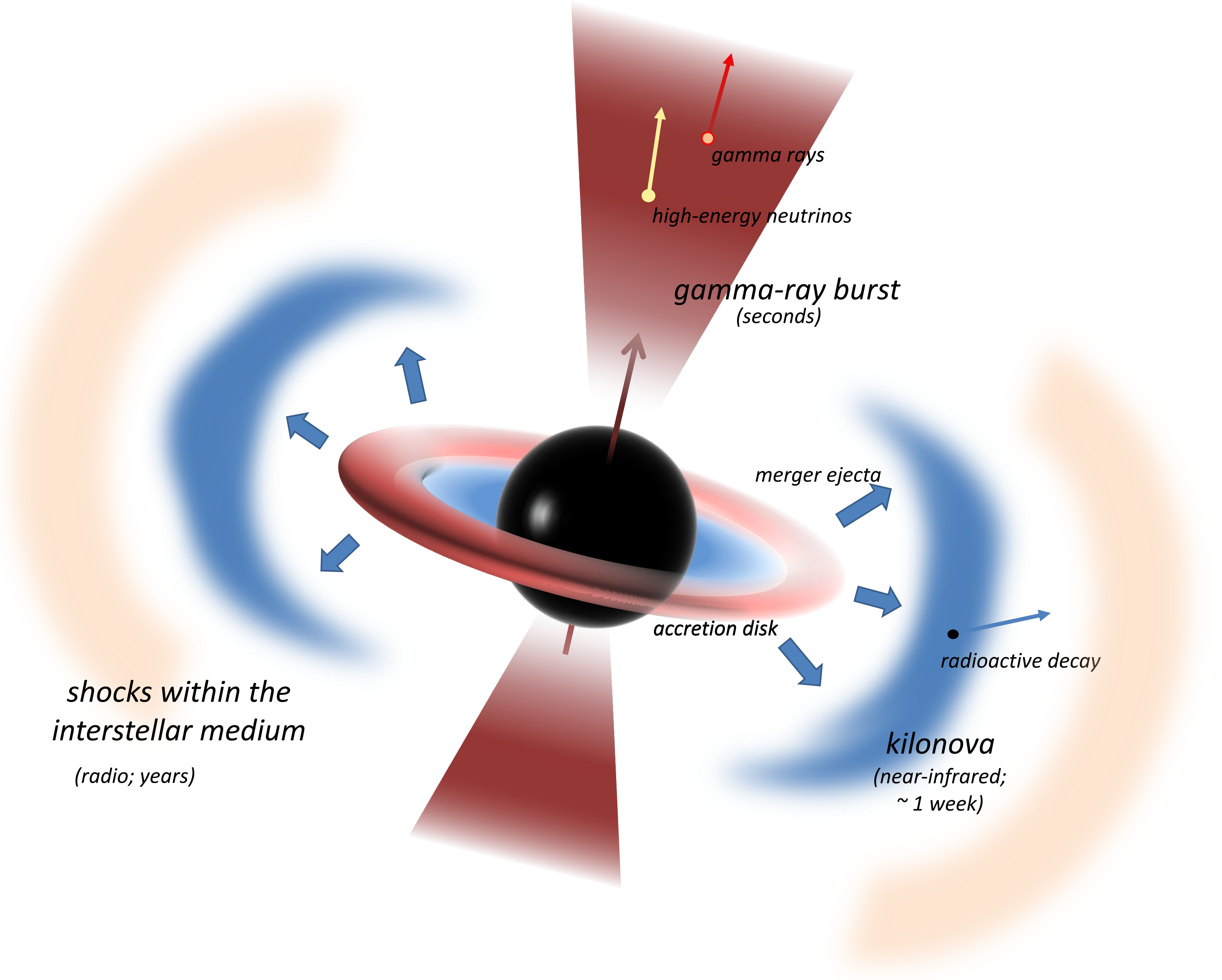


Neutron star mergers are prime multi-messenger sources

- Merger → gravitational waves
- Accreting black hole → relativistic outflow → high-energy emission (γ-rays, neutrinos)
- Slow ejecta (tidal disruption of NS, disk winds) → optical /NIR emission (kilonova) → interaction with circum-megger medium → radio flare (years)



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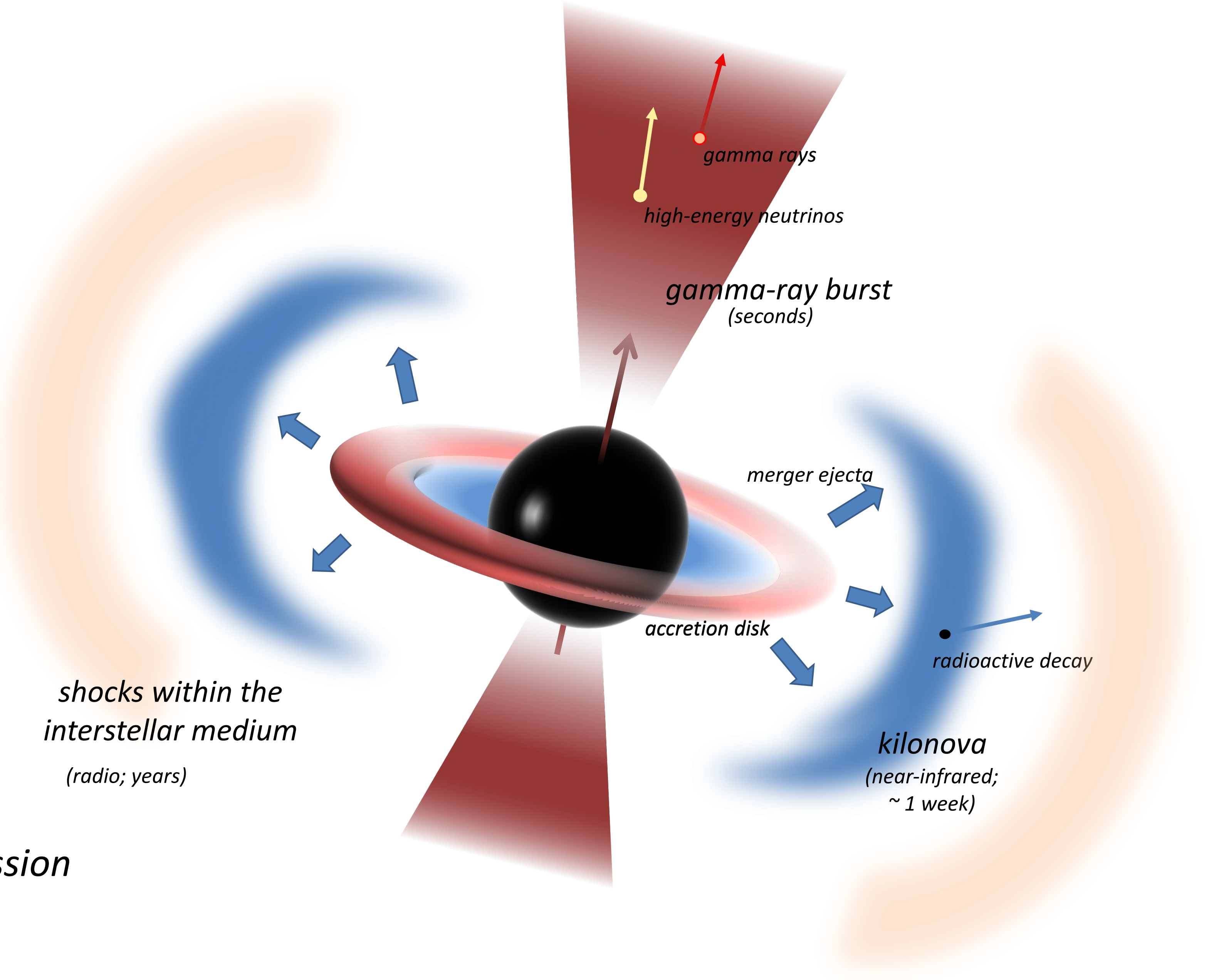
✓ *Impacts high-energy emission*

✓ *Informative of high-energy emission*



GW170817: structured jet

<u>Observational surprises:</u>

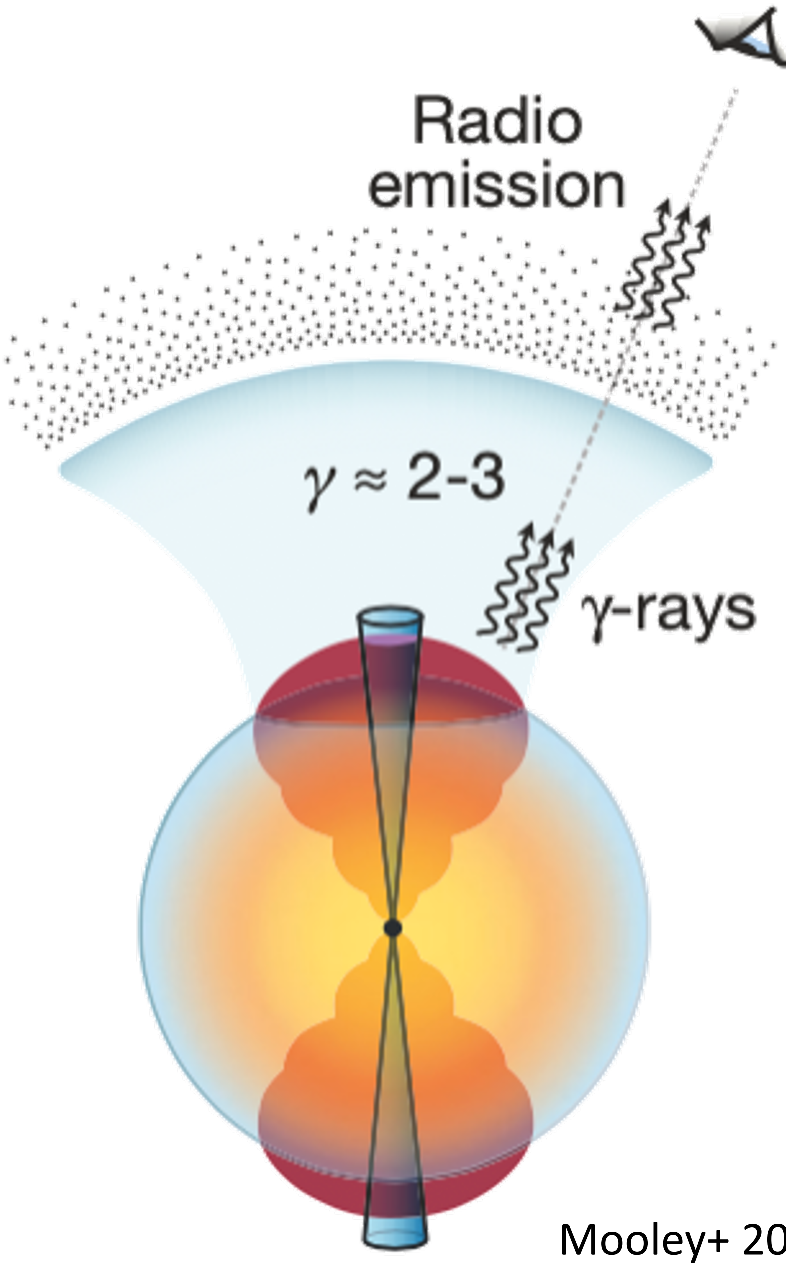
- GRB observed already for first gravitational wave detection.
- Nearby (40 Mpc vs previous closest > 250 Mpc).
- GRB 10^4 weaker than previous short GRBs.
- Delayed afterglow (X-ray, radio observed days after merger).

<u>What we learned:</u>

- Large observing angle ($\theta_{obs} \sim 20°$).
- Off-axis ($\theta_{obs} \gg \theta_{jet}$).
- Structured γ-ray emission.

<u>Questions:</u>

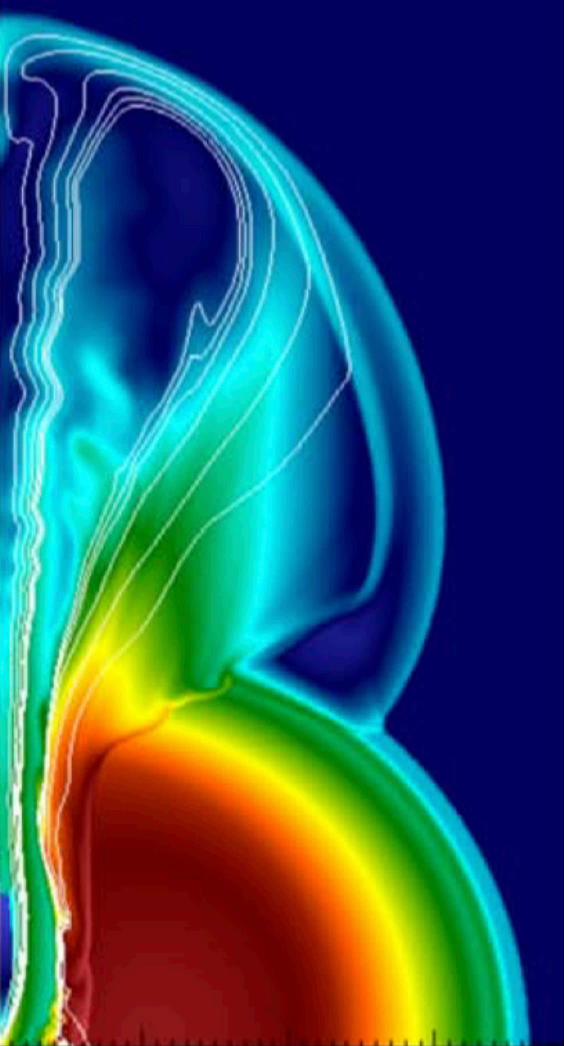
- Structure:
  - *Intrinsic structure of the outflow?*
  - *Interaction with the slower ejecta?*
- Is GW170817 typical? What fraction of GW detections will have GRB counterparts?



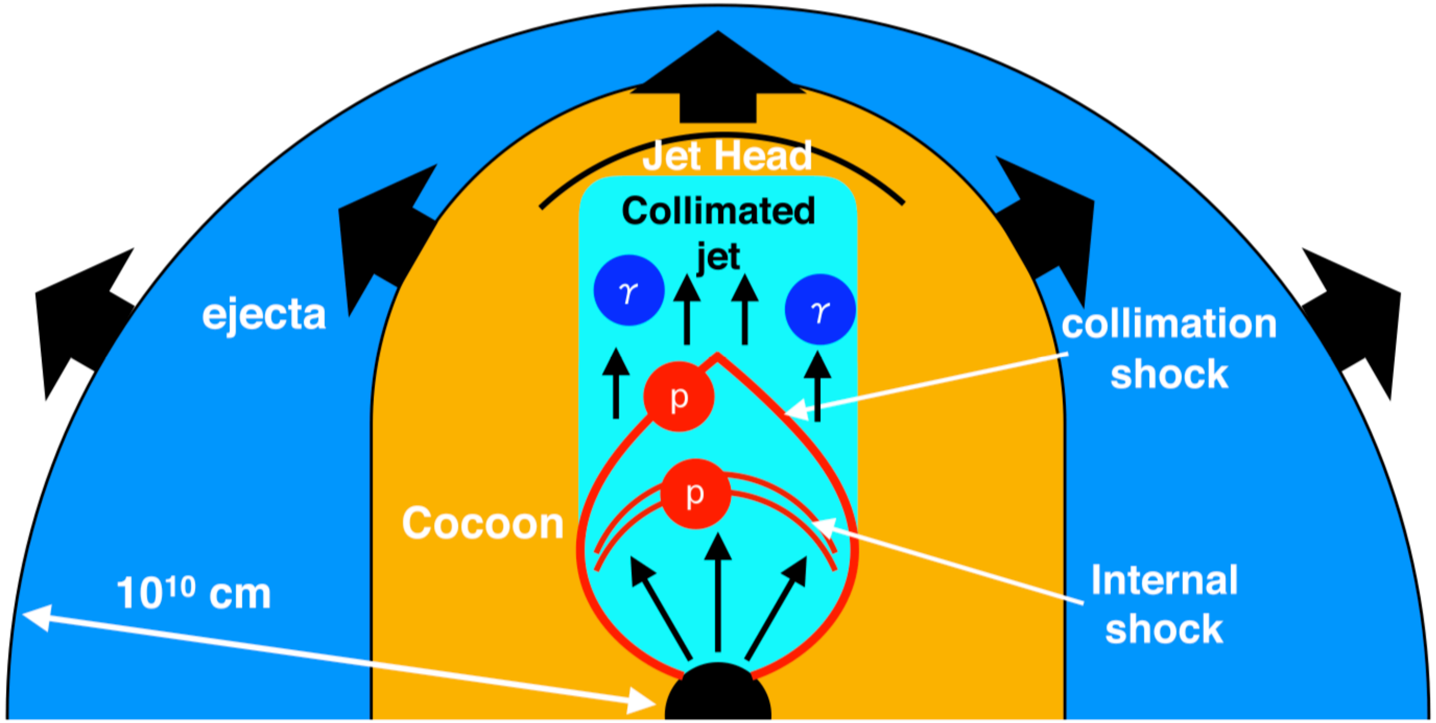
Mooley+ 2018

Interaction between relativistic jet and slow outflow

Geng+ 2019
Duffell+ 2018
Wu & MacFadyen 2018
Duffell+ 2018



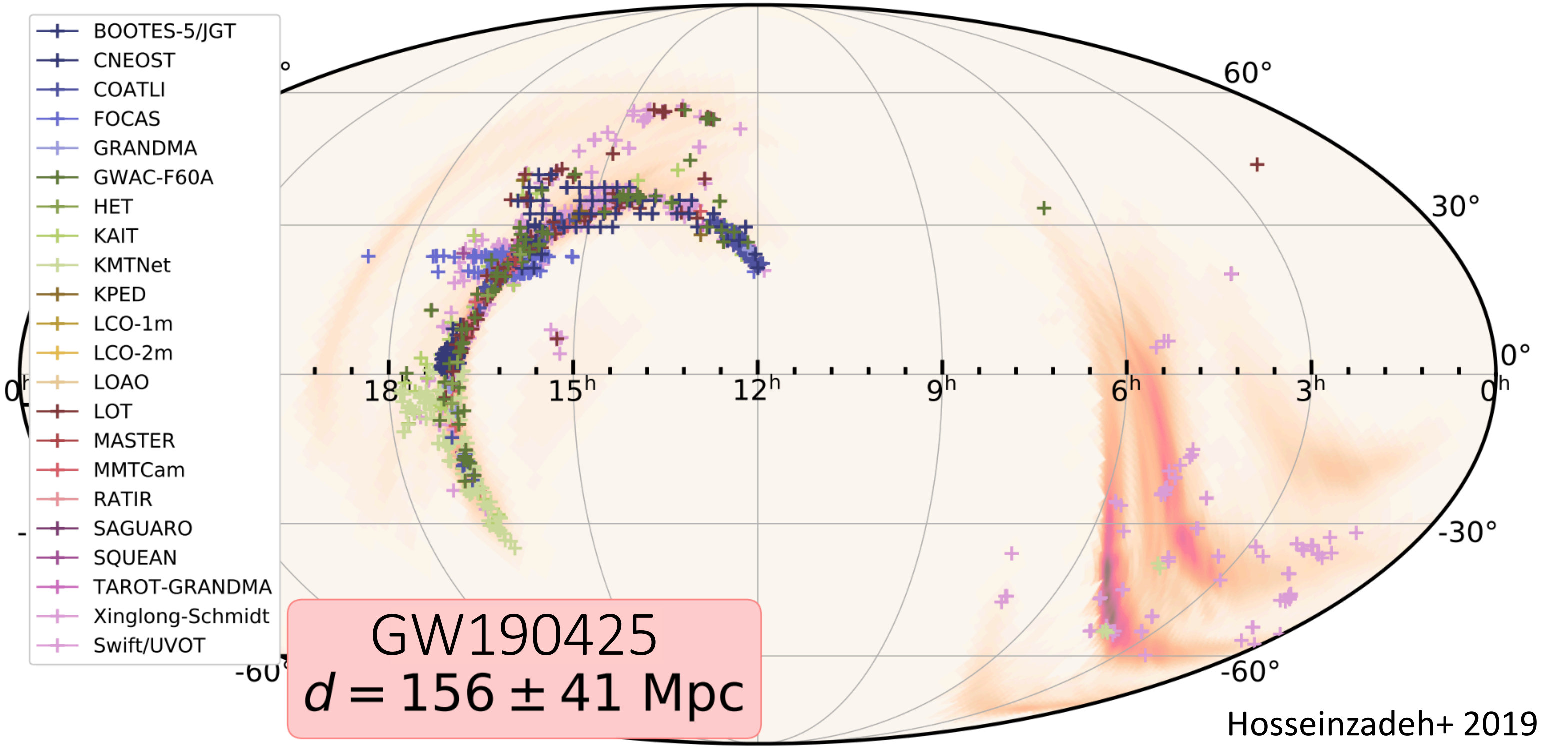
- Hydrodynamic simulations, radio afterglow: GW170817 likely had a successful jet (e.g. Duffell+ 2018, Beniamini+ 2018)
- Neutrino emission can probe what happens under the surface…



Kimura, Murase, Bartos, Ioka, Heng, Meszaros 2018

Is GW170817 typical?
Electromagnetic follow-up can be difficult

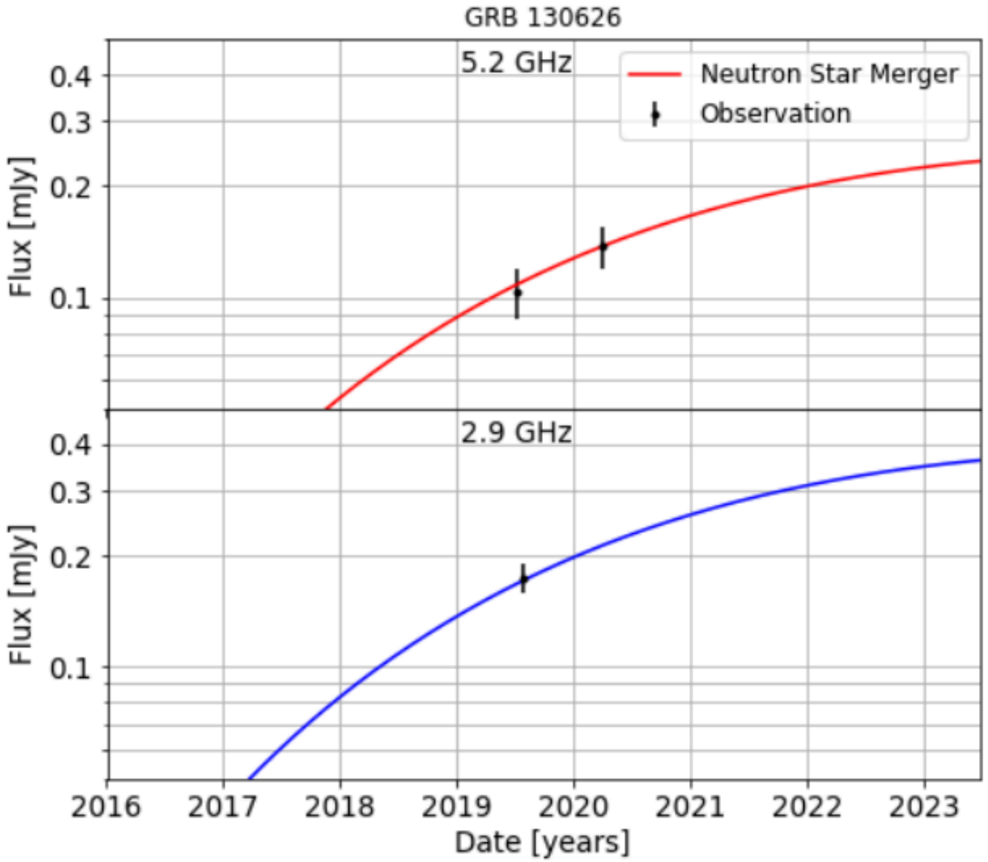
- We were spoiled by GW170817.
- No GRB / high-energy neutrino counterpart.
- Dozens of observatories, 100s of observations (>230 GCN circulars).
- Extensive observation campaign only covered ~50% of volume.
- Many false positives.
- Galaxy targeted searches --- < 1% covered.



Hosseinzadeh+ 2019

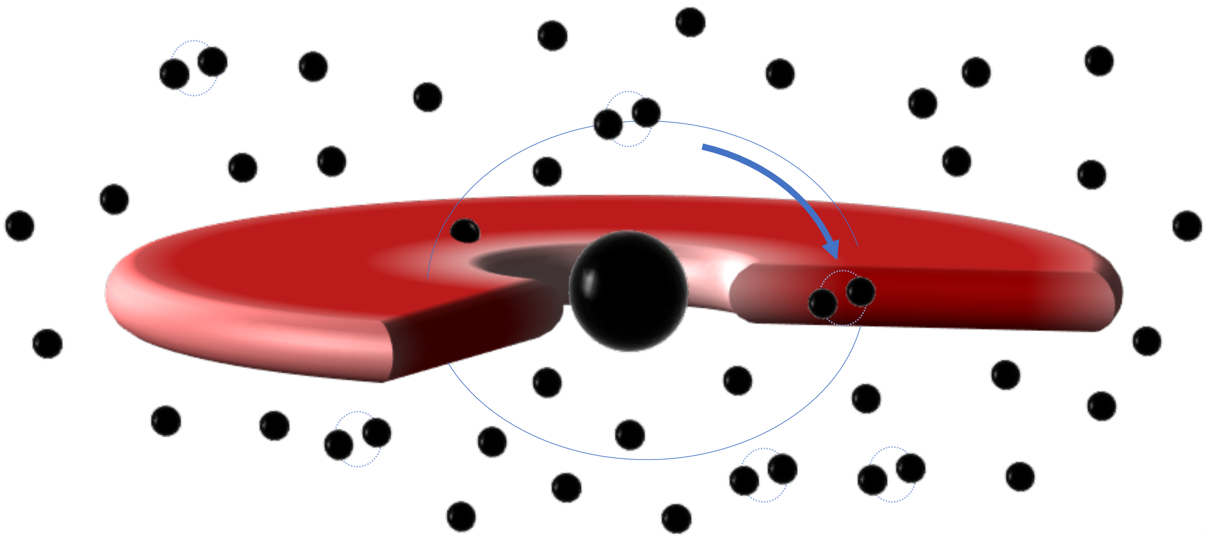
Missing nearby mergers?

- ✓ GRB170817A was only localized because of the gravitational wave detection.
- ✓ There could have been other nearby GRBs that we detected but didn't identify as nearby.
- ✓ We can use radio observations to "go back in time" and find the radio signature of nearby events.
- ✓ We used the Very Large Array to find out.

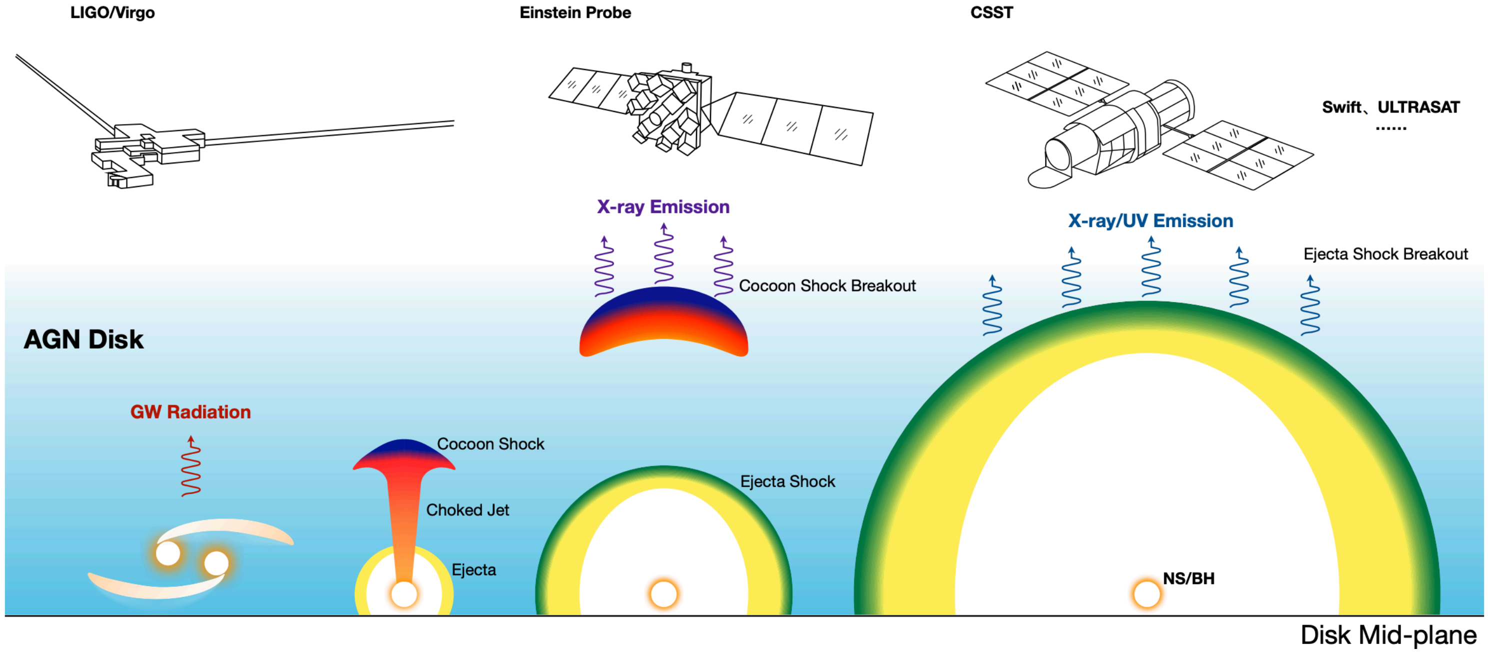


Bartos+ MNRAS 2018
Grandorf+ 2020

Binary mergers in Active Galactic Nuclei



- **Black hole mergers** can accrete in the dense environment and potentially produce energetic outflows.
- **Neutron star mergers** can also occur in the disk (McKernan+ 2019, Yang+ 2020) → special properties (Perna+ 2020, Zhu+ 2020).



1. Black holes align their orbit with disk
2. Migrate inward in disk
3. Gas capture → form binaries
4. Rapidly merge due to dynamical friction + binary-single interactions
5. Repeat (hierarchical mergers)

Bartos+ 2017, Stone+ 2017, McKernan+ 2020

Summary

- Exciting opportunities to learn about high-energy emission from neutron star mergers through multi-messenger observations.
- Sub-relativistic outflow: important role in high-energy emission structure and properties.
- There could be detected nearby neutron star mergers / GRBs we did not identify as such --- long-term radio follow-up may help.
- AGNs may host special short GRBs.
- Black hole mergers in AGNs --- possible multi-messenger source?

How to maximize multi-messenger science?

- Examine all observations/messengers simultaneously.
- There will be many gravitational wave detections – will need to learn what to target and when.
- Particular attention to special cases.