

The background of the slide is a vibrant, swirling visualization of a neutron star-black hole merger. It features a central black hole with a dark event horizon, surrounded by glowing blue and white accretion disks. To the left, a bright blue neutron star is shown in the process of merging with the black hole. The surrounding space is filled with colorful, swirling patterns of red, orange, and yellow, representing the intense gravitational fields and the release of energy during the merger. The overall effect is a dynamic and energetic representation of this cosmic event.

Neutron Star – Black Hole Mergers

E.Schubert, 07925151

Course: Binary and multiple star systems

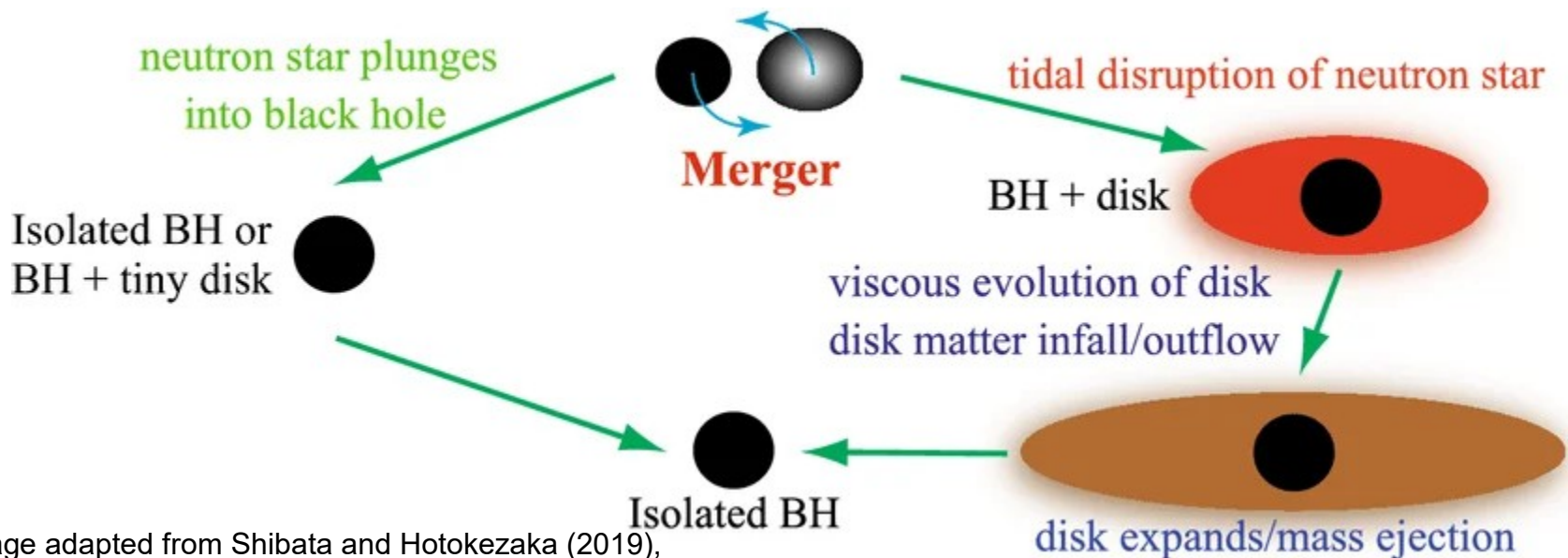
Introduction

- Binary system: neutron star + black hole
- Strong gravitational wave sources
- Possible electromagnetic counterparts
- Key probe for strong-field gravity

Artist's illustration of the merger of a black hole with a neutron star. [Carl Knox, OzGrav ARC Centre of Excellence]

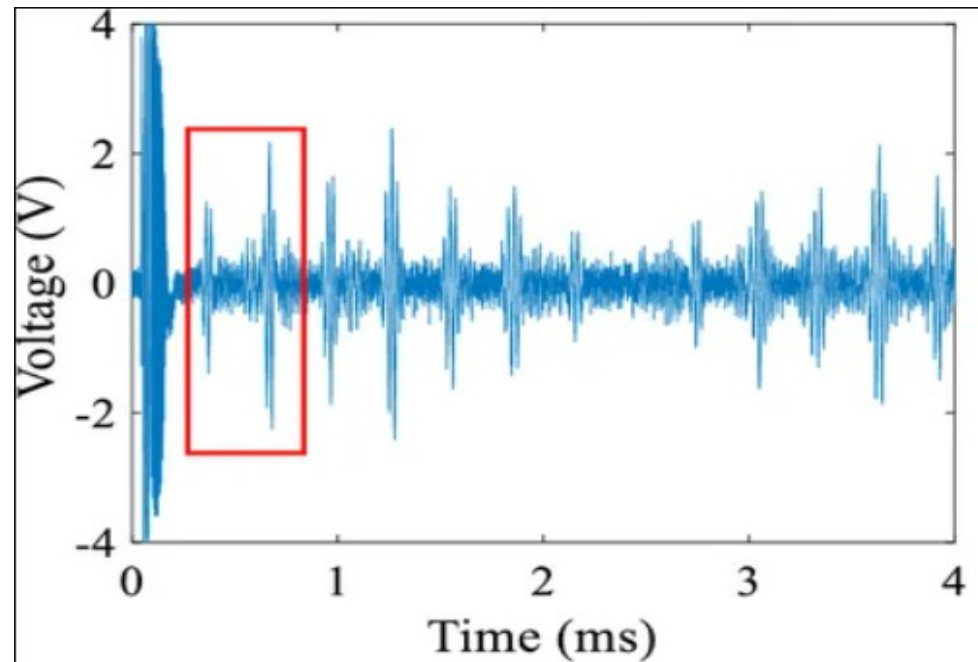
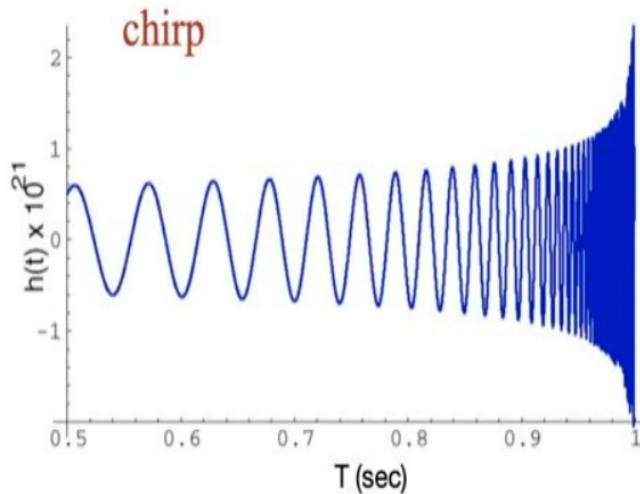
Formation Channels

- Isolated binary stellar evolution
- Dynamical formation in dense clusters
- Supernova kicks influence survival
- Mass transfer alters orbital evolution



Gravitational Wave Inspiral

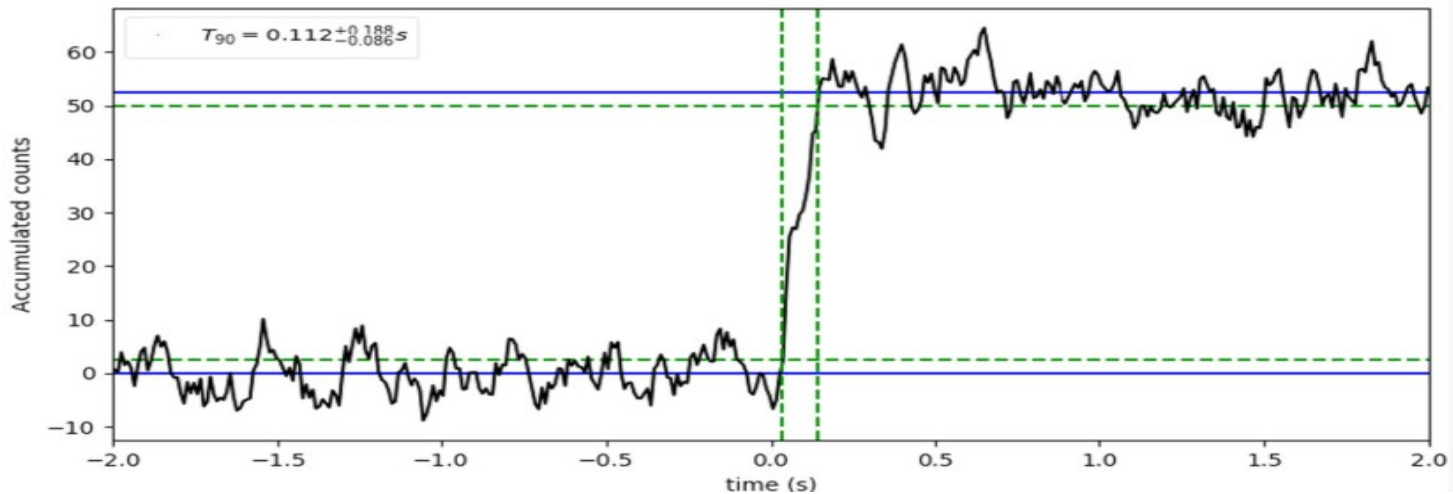
- Energy loss via gravitational radiation
- Orbital decay over time
- Chirp signal: $f \uparrow$ and amplitude \uparrow
- Final merger produces peak strain



(a) Original GW signal

Energy Emission

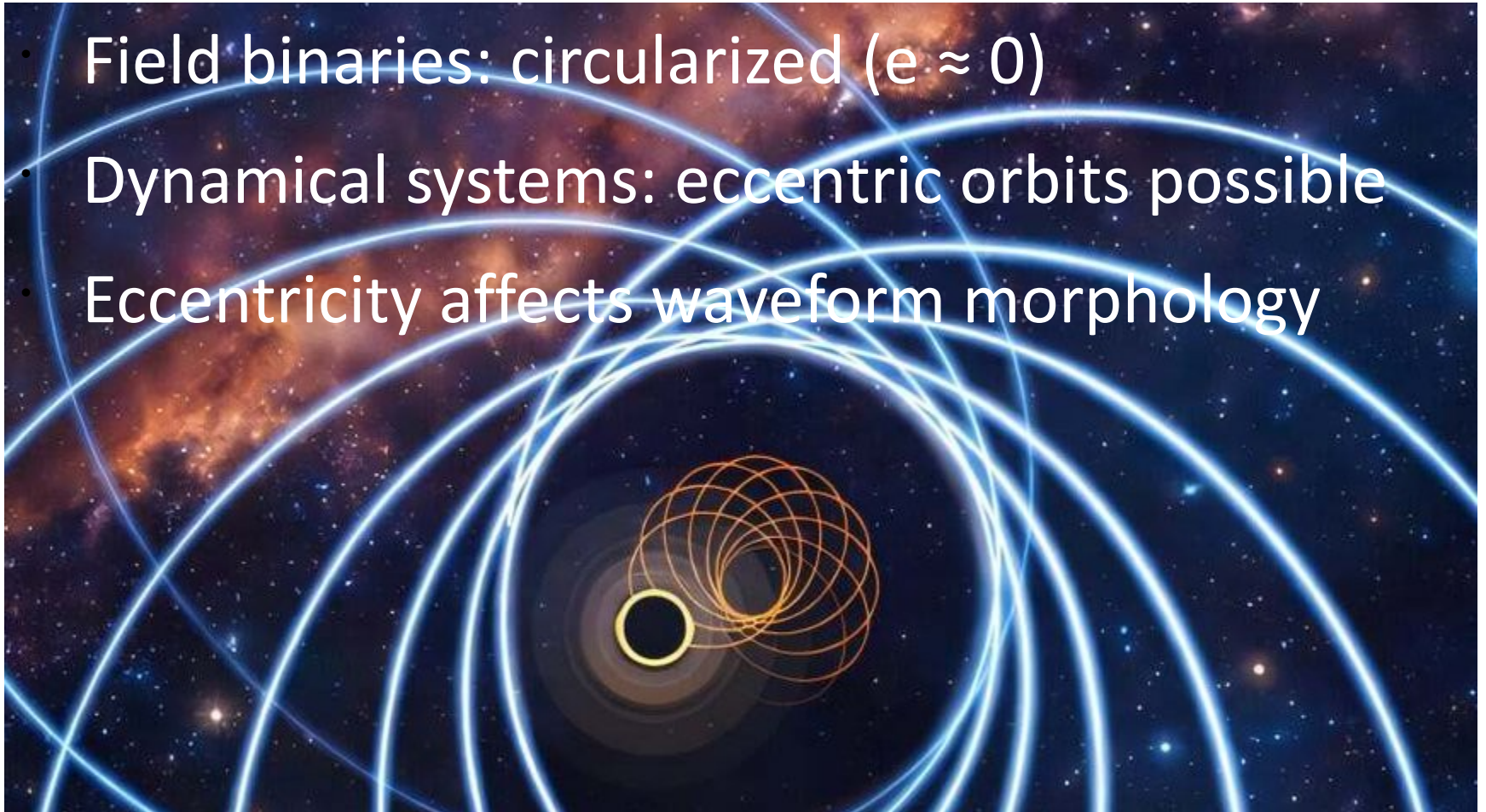
- Total energy $\sim 10^{53}$ erg
- Dominant: gravitational waves
- Subdominant: neutrinos
- Minor fraction: electromagnetic emission



The accumulated light curve for GBM-190816 shows the duration of the gamma-ray burst, roughly 0.1 seconds. [Adapted from Yang et al. 2020]

Orbital Eccentricity

- Field binaries: circularized ($e \approx 0$)
- Dynamical systems: eccentric orbits possible
- Eccentricity affects waveform morphology



Spin Effects

- Dimensionless spin $\chi = cS / (GM^2)$
- Spin-orbit coupling causes precession
- Modifies gravitational waveform
- Affects merger dynamics

Tidal Disruption

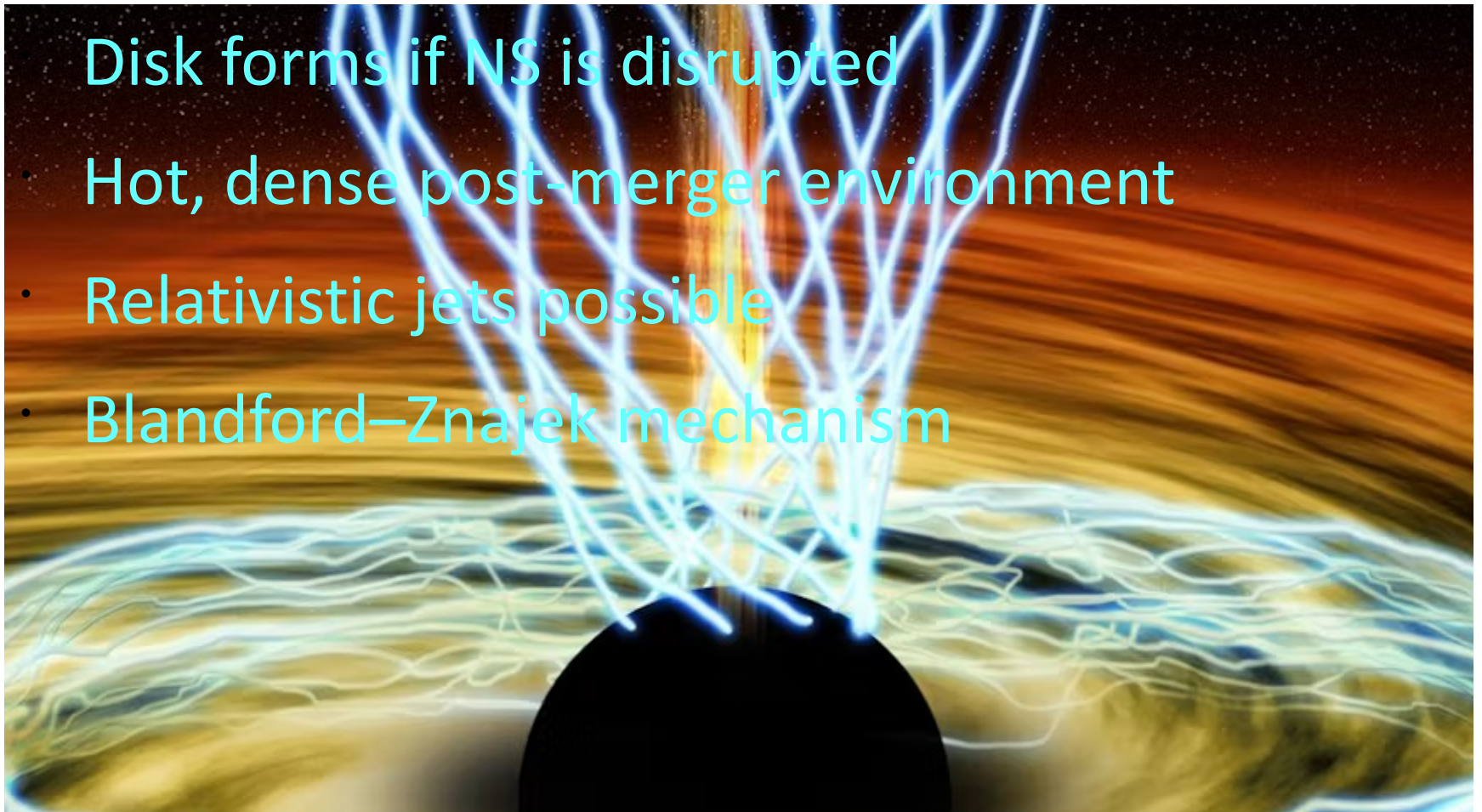
- Depends on BH mass and spin
- NS radius is critical parameter
- Outcome: disruption or direct plunge
- Determines EM counterpart formation



Accretion Disk & Jets

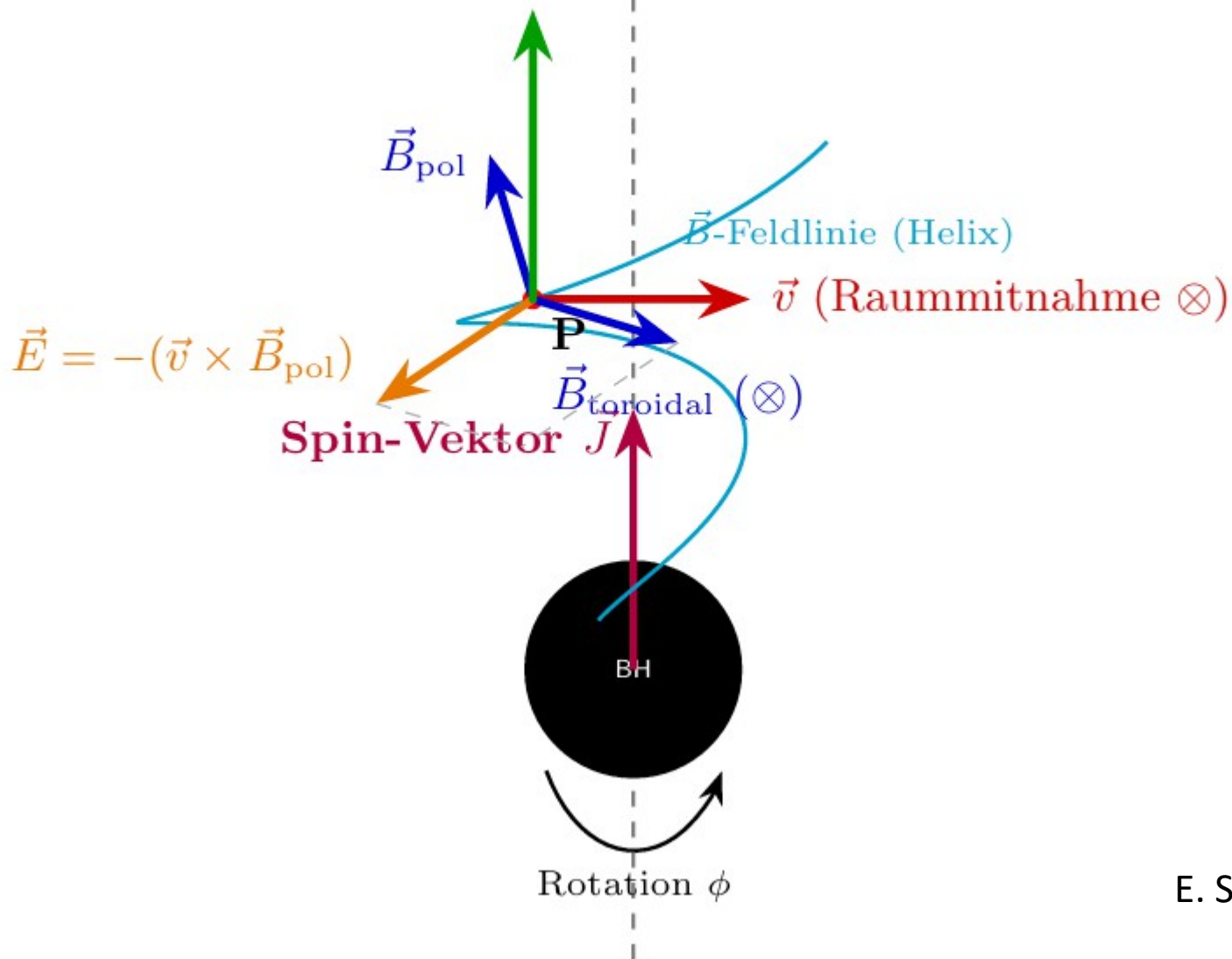
Disk forms if NS is disrupted

- Hot, dense post-merger environment
- Relativistic jets possible
- Blandford–Znajek mechanism



Rotationsachse (Jet-Zentrum)

$$\vec{S} = \frac{1}{\mu_0} (\vec{E} \times \vec{B}_{\text{toroidal}})$$



Kilonova

- r-process nucleosynthesis in ejecta
- Production of heavy elements
- Optical/IR transient
- Timescale: days to weeks

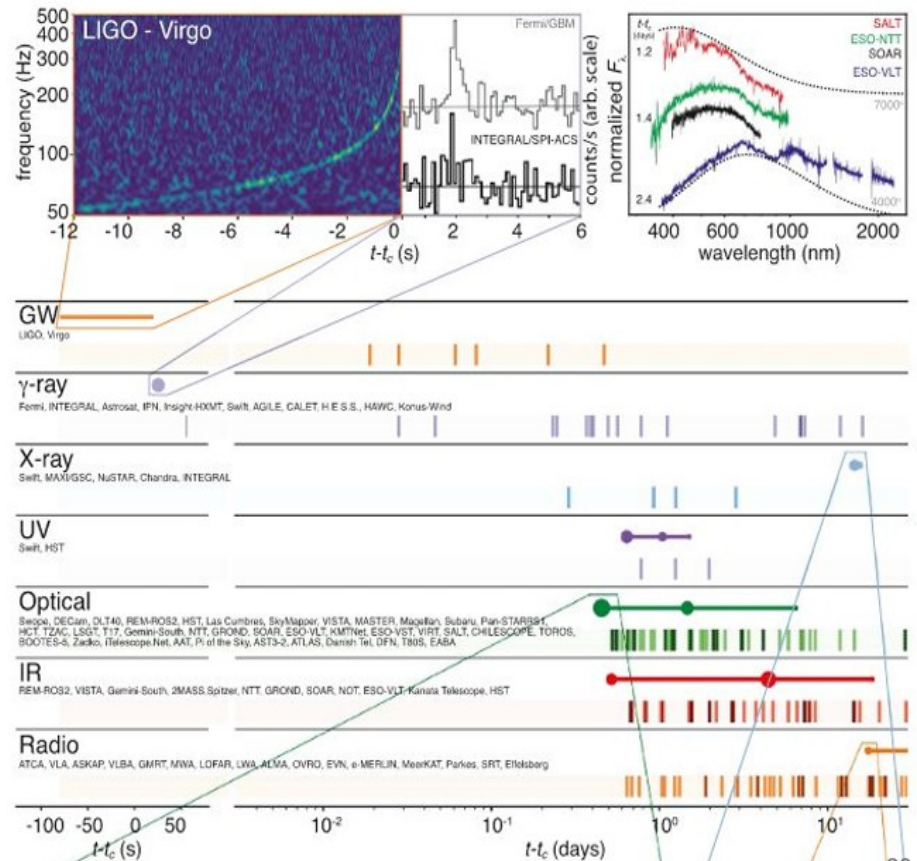
Observations



KAGRA, illustrated at top right, will join a network of gravitational-wave observatories that includes LIGO Hanford (top left), LIGO Livingston (bottom right), and Virgo (bottom left). Image credit: ICRR, Univ. of Tokyo/LIGO Lab/Caltech/MIT/Virgo Collaboration.

Multi-Messenger Astronomy

- Gravitational waves
- Electromagnetic signals
- Neutrinos (theoretical contribution)
- Full system characterization



Multi-messenger Observations of a Binary Neutron Star Merger, *The Astrophysical Journal Letters*, 848:L12(59pp), 2017 October 20

Conclusion

- NSBH mergers probe strong gravity
- Important for nuclear astrophysics
- Key source for multi-messenger astronomy
- Crucial for future GW detectors

A multimessenger model for neutron star-black hole mergers

<https://ui.adsabs.harvard.edu/abs/2023MNRAS.526.4585G/abstract>

Kollision auf unerwartet elliptischer Bahn

<https://www.spektrum.de/news/gravitationswellen-kollision-auf-unerwartet-elliptischer-bahn/2314228>

Kilonova in 3-D

<https://www.spektrum.de/news/neutronensterne-kilonova-in-3-d/2206790>

BLACK HOLE–NEUTRON STAR MERGERS AS CENTRAL ENGINES
OF GAMMA-RAY BURST, H.T. Janka

The Astrophysical Journal, 527:L39–L42, 1999 December 10