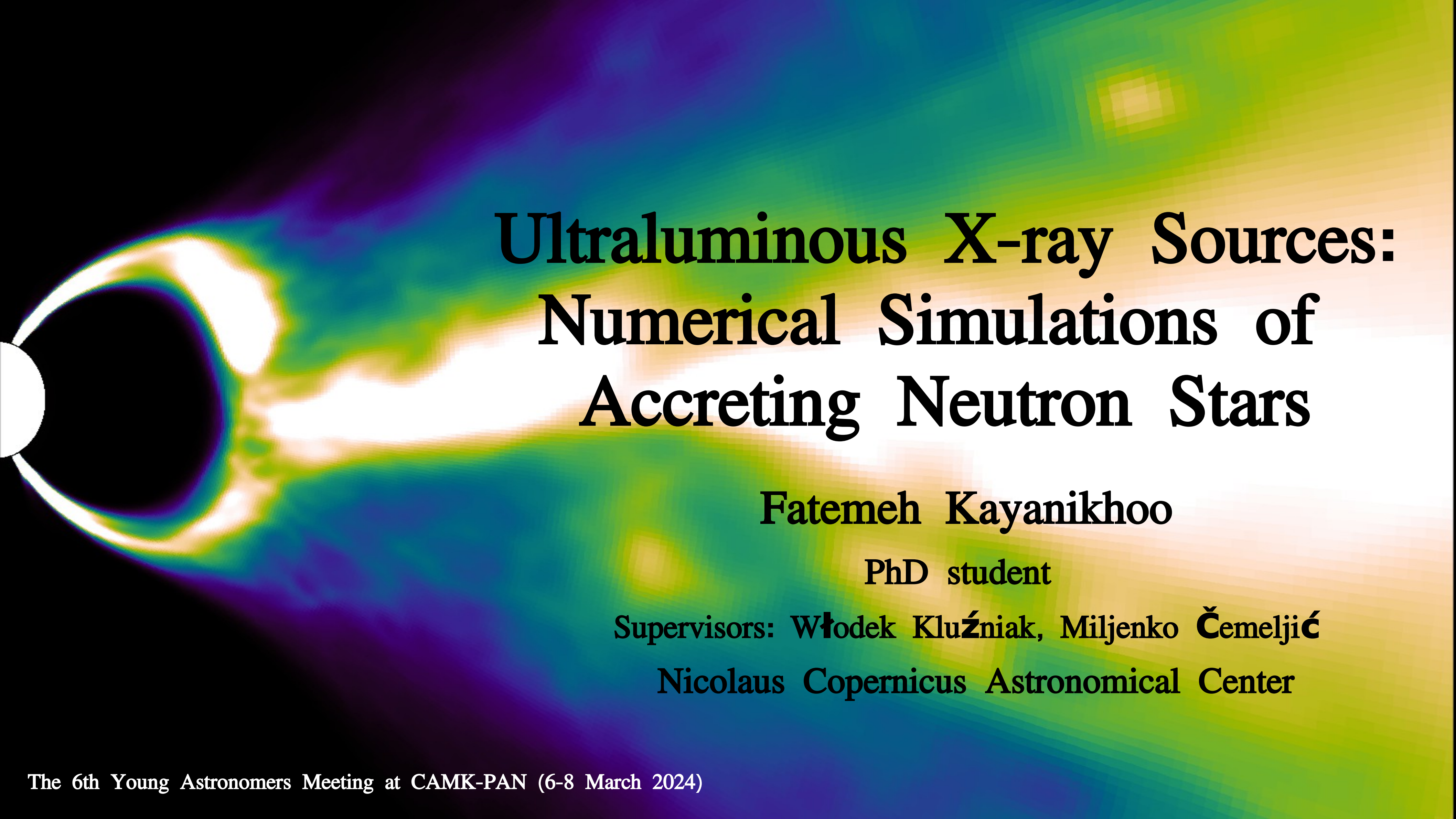

Ultraluminous X-ray Sources: Numerical Simulations of Accreting Neutron Stars

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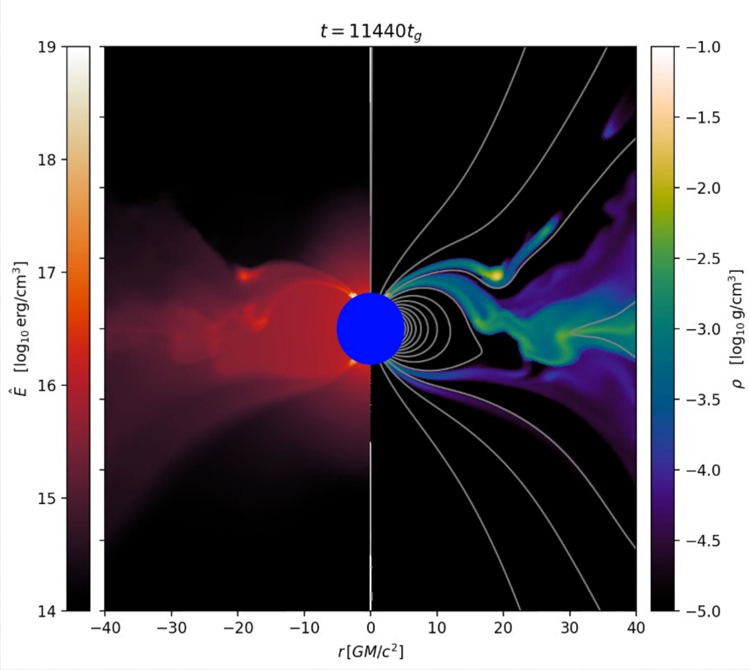
Outlines

- About our research group
- What are Ultraluminous X-ray Sources (ULXs)?
- Numerical simulations
- Some results
- Summary

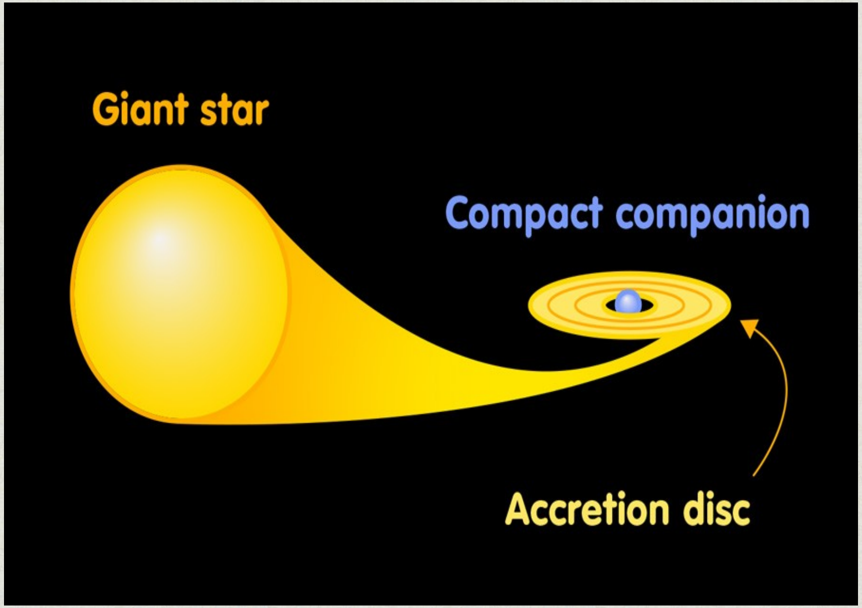
About our research group

- Study Ultraluminous X-ray Sources (ULXs)
- Numerical simulations of accretion disc onto compact objects
  - Magnetized neutron stars
  - Black holes
- Numerical simulations of pulsar planet aurora
- Neked singularity simulations



Accretion disk

- In a binary star system, an accretion disk forms when material from one star (Donor star) transfers onto a compact companion (such as a white dwarf, neutron star, or black hole) known as the accretor.
- Material accumulates around the object and forms a disk.
- The basic mechanics in an accretion disk involve the transfer of angular momentum outward and the material inward.
- Accretion disks in binary star systems are important for understanding the evolution of individual stars, and also for studying phenomena such as X-ray emission.



What are Ultraluminous X-ray Sources?

- ULXs have been observed to emit X-rays at luminosities exceeding the luminosity expected from stellar mass compact objects.
- The first observation of ULXs: 1980s during X-ray surveys conducted by the Einstein Observatory and the ROSAT satellite.
- Early systematic X–ray surveys found significant numbers of these objects.

✓ Fabbiano, 1989: reported 16 sources with $L > 10^{39}$ erg/s.

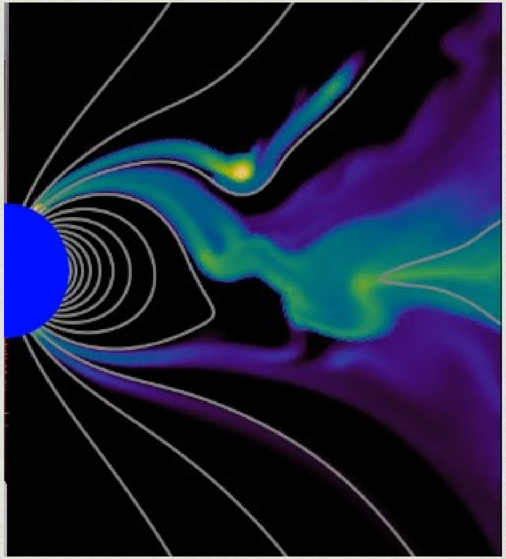
✓ Walton et al., 2022: More than about 1800 ULXs are known, including several with $L > 10^{41} - 10^{42}$ erg/s

What caused high X-ray luminosity?

- Intermediate Mass Black Holes (IMBH):
- $10^2\ M_{sun} < M < 10^4\ M_{sun}$
- Photon–bubble instability in accretion disc of typical black holes ($M < 10\ M_{sun}$)
- Magnetic field in neutron star accreting system

Neutron star

- Discovery of coherently pulsating ULXs (Bachetti et al. 2014) revived interest in ULXs.
- PULXs show the period of 1s to days.
- Hence some/many ULXs are neutron stars.
- Neutron stars are the end-states of massive stars whose cores exceed the 1.4 $M_\odot$ Chandrasekhar mass limit.
- Typical masses between 1 – 2 $M_\odot$ and typical radii between 10km.
- A crucial difference between neutron stars and black holes is that neutron stars have an intrinsic magnetic field and a surface.



- ✔ Observational data confirm that the magnetic field of neutron stars is on the order of $10^8 - 10^{15}$G at the surface.
- ✔ The magnetic field truncates the disc and the material is able to accrete onto the polar regions along the magnetic field lines, while radiation can escape from the sides of the column.

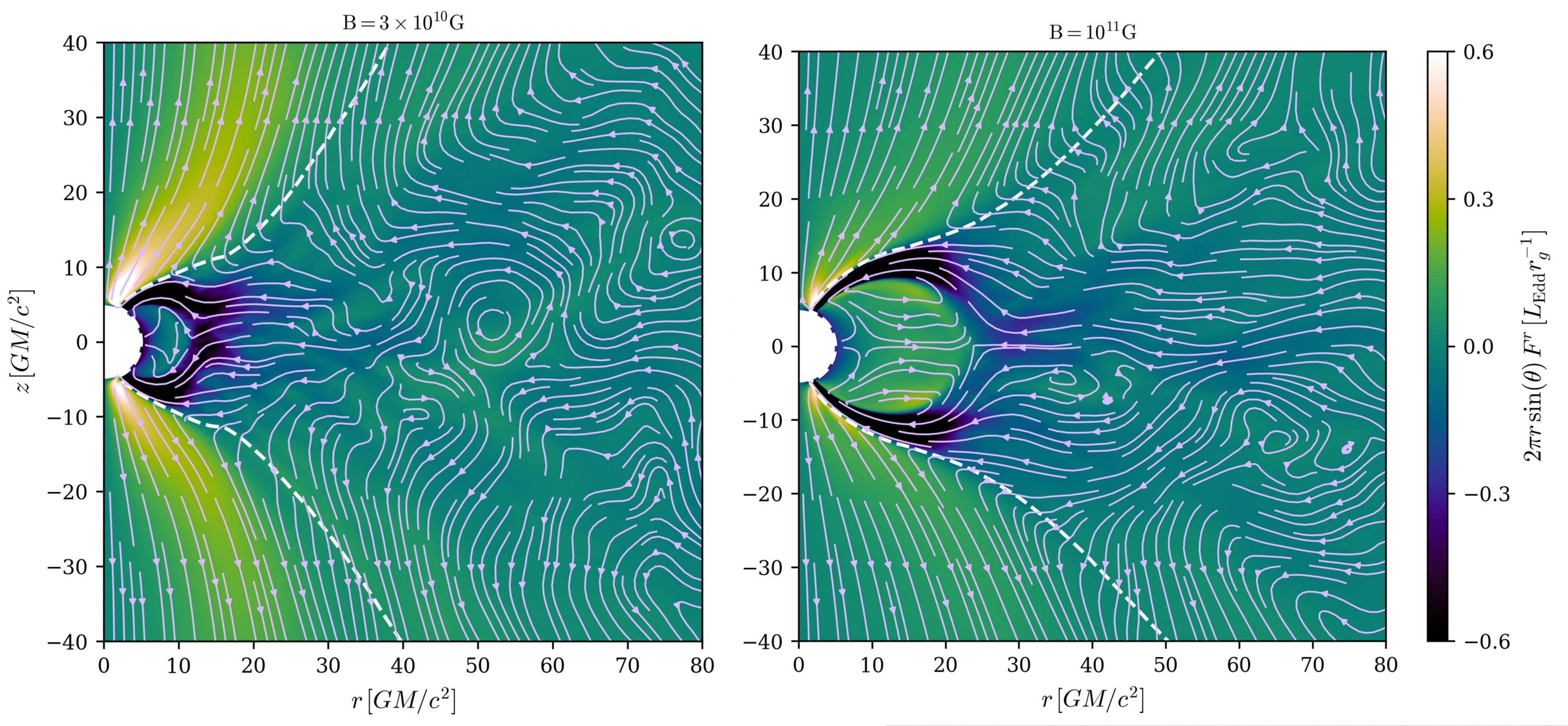
Why numerical simulations?

- Astrophysical systems often involve complex interactions of various physical processes such as gravity, radiation, hydrodynamics, and magnetic fields.
- Numerical simulations:
  - Allow scientists to study these interactions in detail.
  - Provide a platform to test theoretical models proposed to explain observed phenomena in the universe
  - Allow scientists to explore extreme environments including phenomena such as supernova explosions, black hole mergers, accretion disc and the behavior of matter under extreme gravitational conditions.

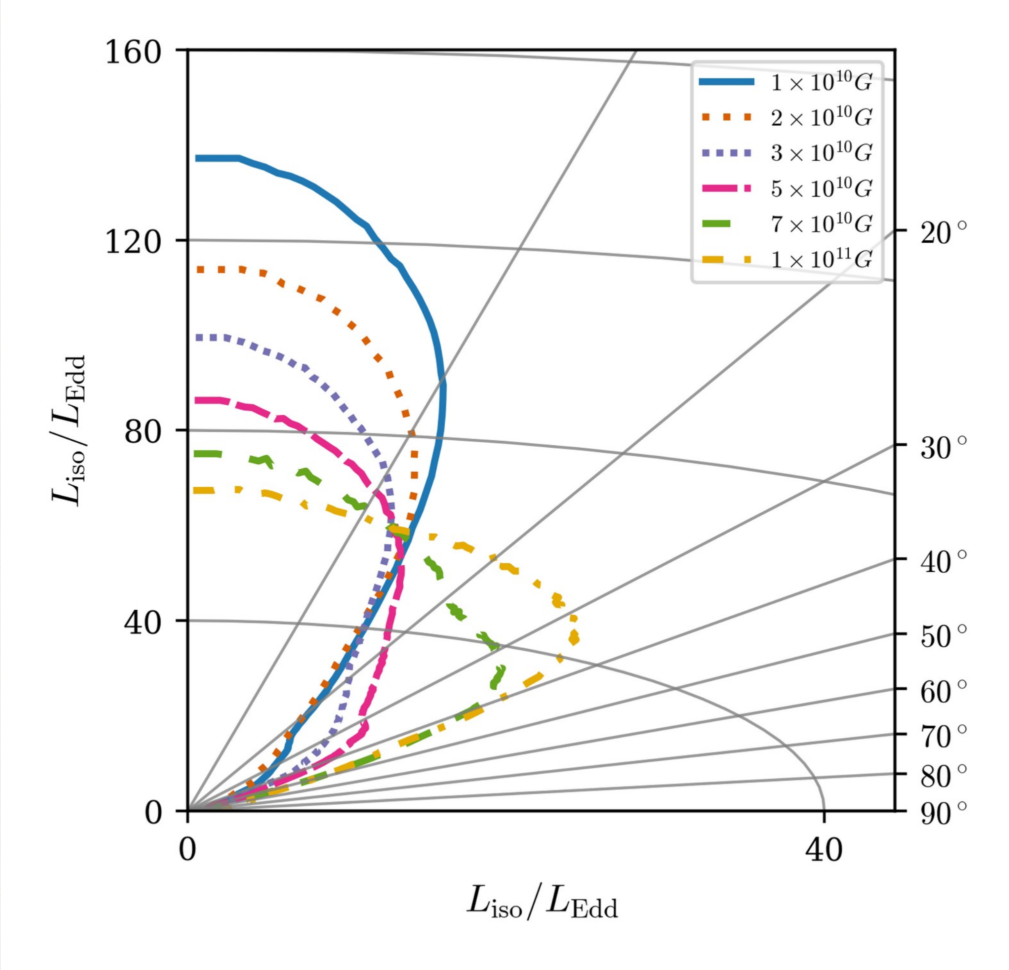
MHD Simulation Codes

- Newtonian Magnetohydrodynamic (MHD) code PLUTO
- General Relativistic Radiative Magnetohydrodynamic (GRRMHD) code Koral, is used to perform the simulations of accreting systems.
- The KORAL code is upstanding because it contains radiation transfer.
- MHD codes work base on conservation of quantities like mass, gas and radiation energy-momentum

Radiation Flux

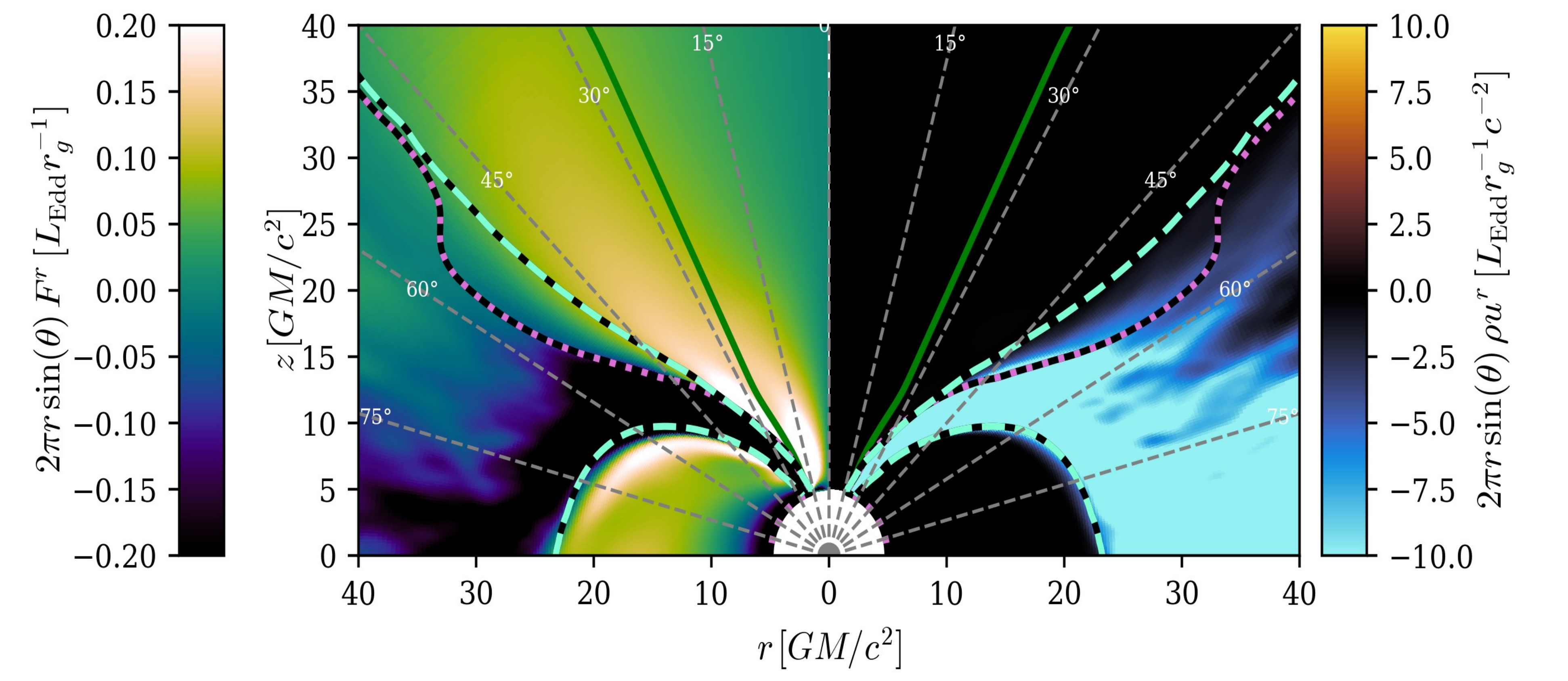


Apparent Luminosity



- Apparent luminosity (L_{iso}), might exceed the Eddington luminosity of neutron star by a large factor.
- Depends on viewing angel the luminosity changes with the magnetic field strength

Radiation Flux and Momentum density



- Depends on viewing angel the luminosity changes with the magnetic field strength

Summary

- Magnetic field of neutron star caused beaming
- The apparent luminosity, which varies depending on the viewing angle, can reach a peak value beyond 100 L_{edd}
- Stronger magnetic field results less beaming and lower luminosity
- Work in progress!