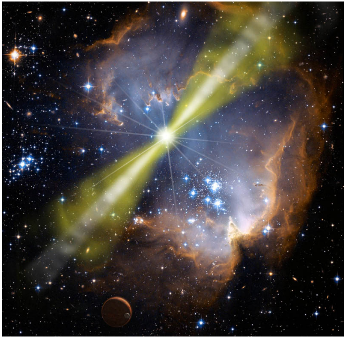
The study of magnetic black hole accretion disk as the central engine of gamma-ray burst

Cui-Ying Song

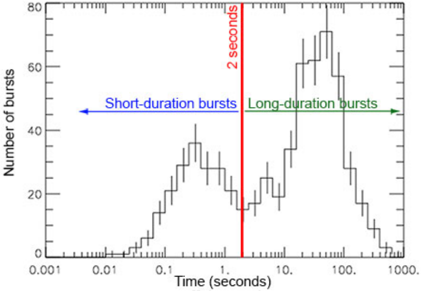
Xiamen University
Monash University

July 7, 2020

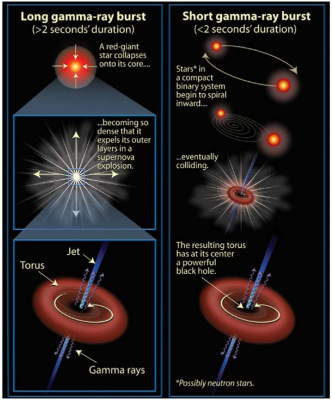


Credit: NASA

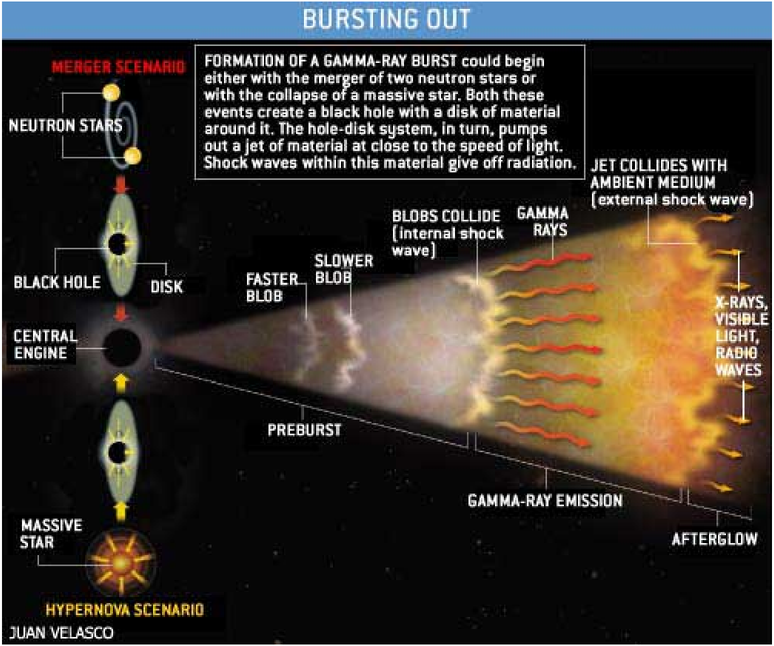
Gamma-ray bursts (GRBs) are extremely energetic transient events.



Credit: NASA



Credits: NASA and A. Feild (STScI)


BURSTING OUT
MERGER SCENARIO
NEUTRON STARS
FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
JET COLLIDES WITH AMBIENT MEDIUM (external shock wave)
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
SLOWER BLOB
FASTER BLOB
BLACK HOLE
DISK
CENTRAL ENGINE
X-RAYS, VISIBLE LIGHT, RADIO WAVES
PREBURST
GAMMA-RAY EMISSION
AFTERGLOW
MASSIVE STAR
HYPERNOVA SCENARIO
JUAN VELASCO

Credit: NASA

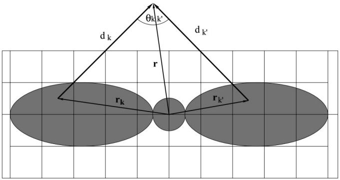
Background

What power the GRB jet?

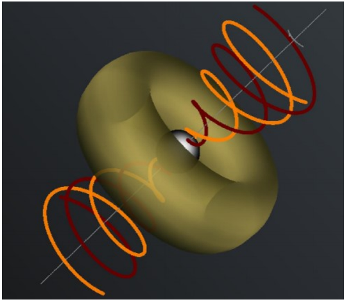
Background

What power the GRB jet?

- The spin-down of a neutron star (NS) with a millisecond rotation period and a strong magnetic field (millisecond magnetar)
- In the BH accretion systems: the neutrino annihilation or the Blandford–Znajek (BZ) mechanism

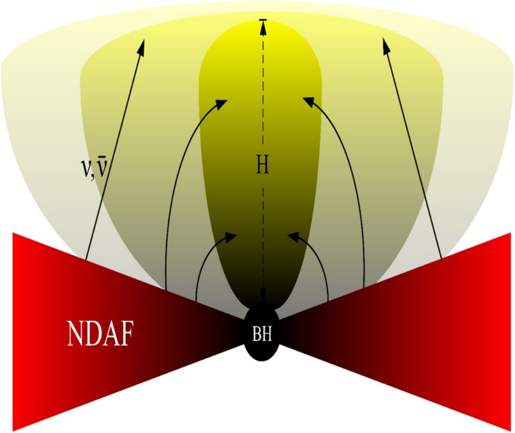


Rosswog et al. 2003



Nathanail et al. 2016

Neutrino-dominated Accretion Flow (NDAFs)

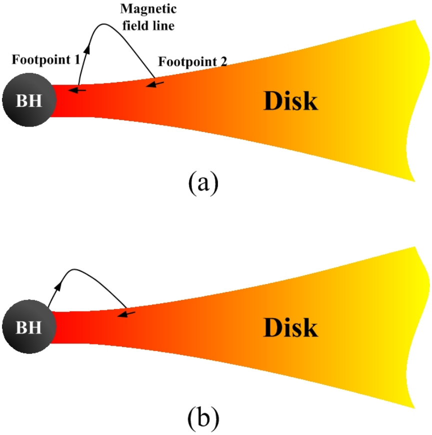


Liu et al. 2016

If the accretion rate is very high (0.001 – 10 $M_\odot\ s^{-1}$), the photons cannot escape from the accretion disk, and only neutrinos are emitted from the disk surface, named neutrino-dominated accretion Flow (NDAF).

$T \sim 10^{10} - 10^{11}$K,
$\rho \sim 10^{6} - 10^{13}$g cm^{-3}

NDAFs around stellar-mass black holes are plausible candidates for the central engine of GRBs.



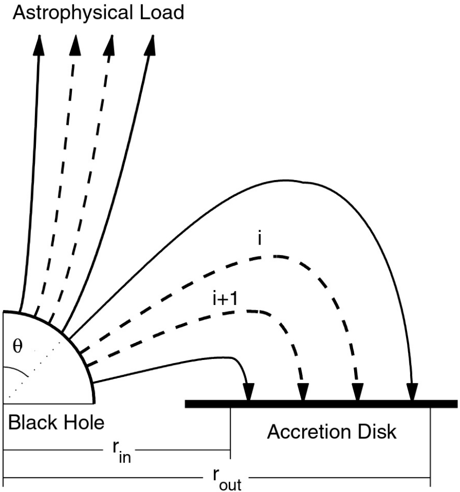
https://astro.xmu.edu.cn/ry/zrjs/lt.htm

MC mechanisms:

Closed magnetic field magnetic coupling (MC) between the inner disc and BH can transfer angular momentum and energy from the fast-rotating BH to the disc.

The neutrino luminosity and neutrino annihilation luminosity of NDAF are both efficiently enhanced by the MC process.

NDAFs: BZ + MC mechanisms

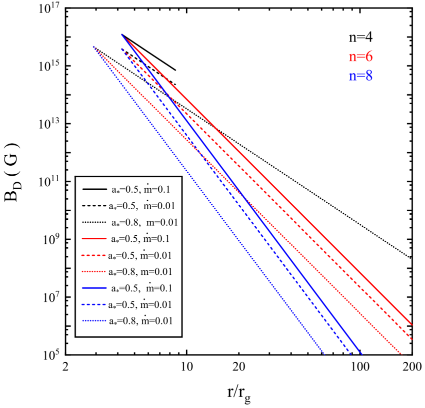


Ding-Xiong Wang et al. 2002

The BZ power:
$P_{\rm BZ} \propto a_*, \theta$

The MC power:
$P_{\rm MC} \propto a_*, \theta$

The radius profiles of the magnetic field strength on the disc



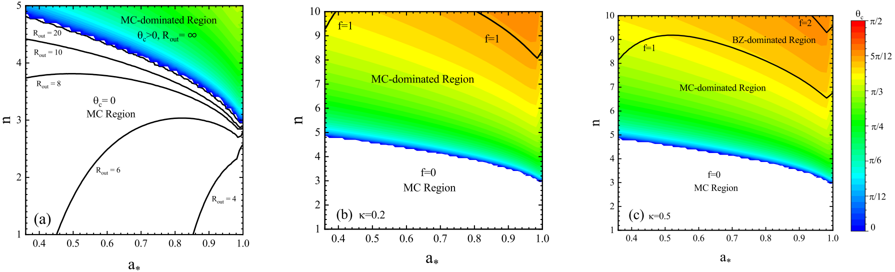
The magnetic field strength on the disc :

$B_D \propto \dot{m}$

$B_D \propto r^{-n}$

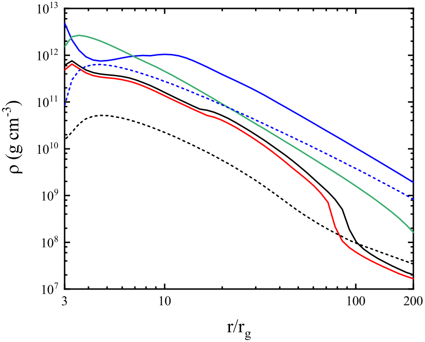
$B_D \propto 1/a_*$

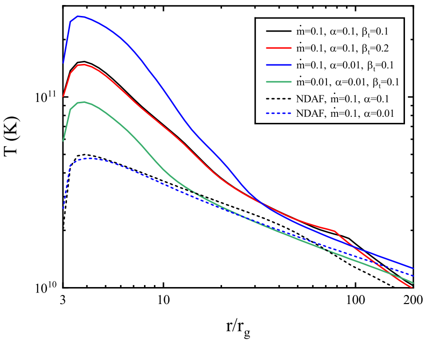
BZ and MC magnetic fields partition



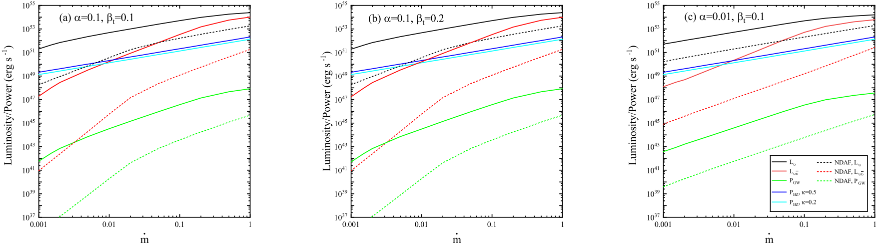
(a) The outer boundary of the MC region for different values of BH spin a_* and power-law index of the magnetic field n under the mapping relation constraint. (b) The values of θ_c and $f = P_{BZ}/P_{MC}$ vary with a_* and n for given $R_{out} = 200$, $\kappa = 0.2$. (c) Similar to (b) except for $\kappa = 0.5$. The vary of θ_c from 0 to $\pi/2$ are indicated by different color.

Radial profiles of density and temperature of MNDAF:



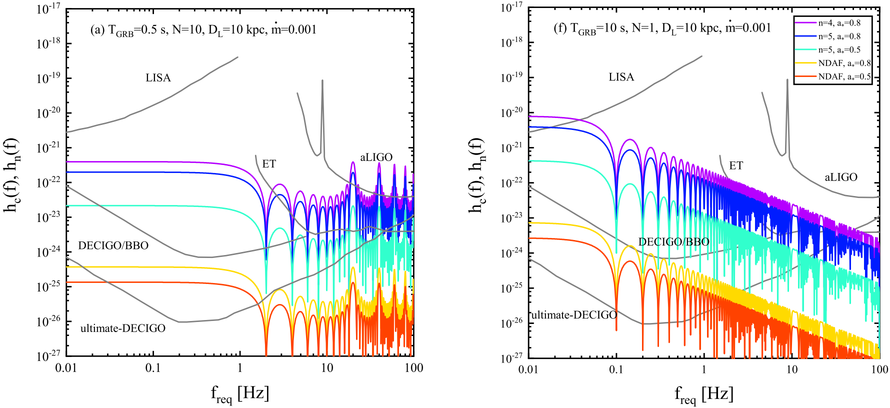


BZ vs Neutrino Annihilation

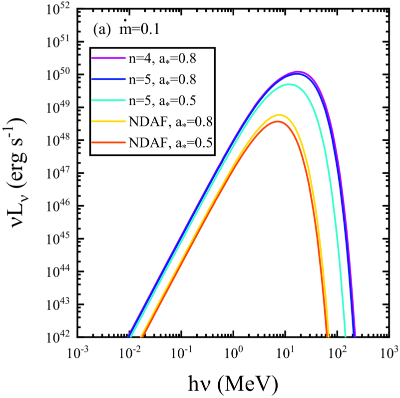


The BZ mechanism will compete with the neutrino annihilation luminosity to trigger jets under the different partitions of the two magnetic mechanisms.

Gravitational Waves from MNDAFs



If the MC process is dominant, then the gravitational waves originating from the anisotropic neutrino emission will be stronger.



The typical peak energy of neutrinos from MNDAFs is about two times higher than that from NDAFs.

Conclution

The BZ mechanism will compete with the neutrino annihilation luminosity to trigger jets under the different partitions of the two magnetic mechanisms.

The typical neutrino luminosity and annihilation luminosity of MNDAFs are definitely higher than those of NDAFs.

The typical peak energy of neutrino spectra of MNDAFs is higher than that of NDAFs, but similar to those of core-collapse supernovae.

Moreover, if the MC process is dominant, then the GWs originating from the anisotropic neutrino emission will be stronger particularly for discs with high accretion rates.

Thank you for attention!