Microphysics in gamma ray bursts central engine

Agnieszka Janiuk

Center for Theoretical Physics
Polish Academy of Sciences
Warsaw

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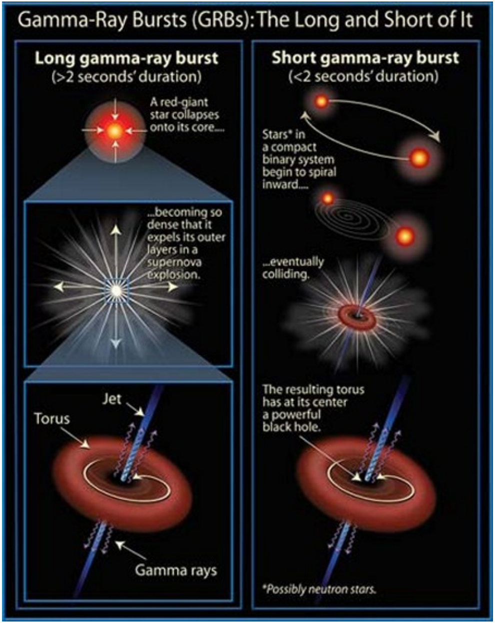
- In GRBs, about 10^{51} ergs is released in 1 second. This is about 10^{18} of the luminosity of our Sun.
- Huge energy released at the source can be explained only by accretion onto compact object and viscous dissipation of its gravitational potential energy
- Accretion power $\sim GM\dot{M}/R$

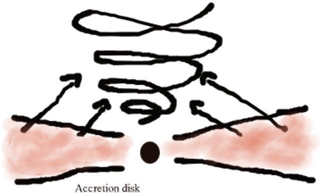
Gamma ray bursts: long and short



Accretion models

- Central engine hidden from observations. We need to build models.
- Accretion model requires to satisfy the basic equations
  - Continuity equation
  - Energy equation
  - Conservation of momentum (radial transport, rotation)
- Equation of state. Simplest case: ideal gas
- Dissipation of energy. Simplest case: α-disk (Shakura & Sunyaev 1973). Mimics the agular momentum transport by MHD turbulences
- Dynamics. Simplest case: stationary.
- Radiation (neutrino) transport. Simplest case: diffusion.

- Hyperaccretion: rates of 0.01-10 $M_\odot/s$
- EOS is not ideal, plasma composed of n, p, e^+, e^-
- Chemical and pressure balance required by nuclear reactions. Arbitrary degeneracy of species
- Charge neutrality condition
- Neutrino absorption & scattering



Popham et al. 1999; Di Matteo et al. 2002; Kohri et al. 2002, 2005; Chen & Beloborodov 2007; Reynoso et al. 2006; Janiuk et al. 2004; Janiuk, Yuan, Perna & Di Matteo 2007; Janiuk & Yuan 2010; Janiuk et al. 2013, 2017; Lei et al. 2009; Liang et al. 2015;

HARM code: High Accuracy Relativistic Magnetohydrodynamics (Gammie et al. 2003). The code provides solver for continuity and energy-momentum conservation equations in GR:

$$\nabla_\mu(\rho u^\mu) = 0 \qquad \nabla_\mu T^{\mu\nu} = 0$$

Energy tensor contains electromagnetic and gas parts:

$$T^{\mu\nu} = T^{\mu\nu}_{\rm gas} + T^{\mu\nu}_{EM}$$

$$T^{\mu\nu}_{gas} = \rho h u^\mu u^\nu + p g^{\mu\nu} = (\rho + u + p) u^\mu u^\nu + p g^{\mu\nu}$$

$$T^{\mu\nu}_{EM} = b^2 u^\mu u^\nu + \frac{1}{2} b^2 g^{\mu\nu} - b^\mu b^\nu; \quad b^\mu = u_\nu {}^*F^{\mu\nu}$$

with equation of state. For ideal gas

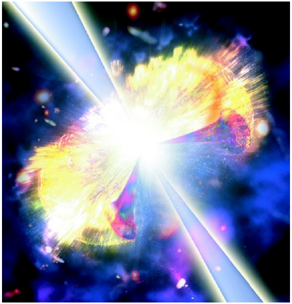
$$p = K\rho^\gamma = (\gamma - 1) u$$

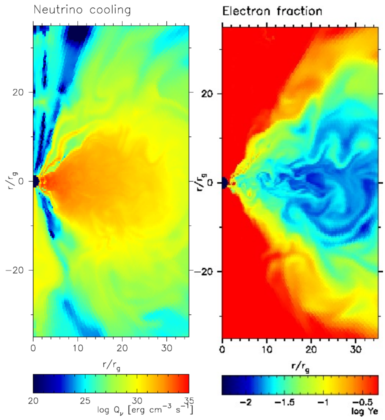
Energy extraction from rotating black hole. Magnetic fields, neutrinos?

We can evaluate the radial energy flux, as the power of the Blandford-Znajek process:

$$\dot{E} \equiv 2\pi \int_0^\pi d\theta \sqrt{-g} F_E$$

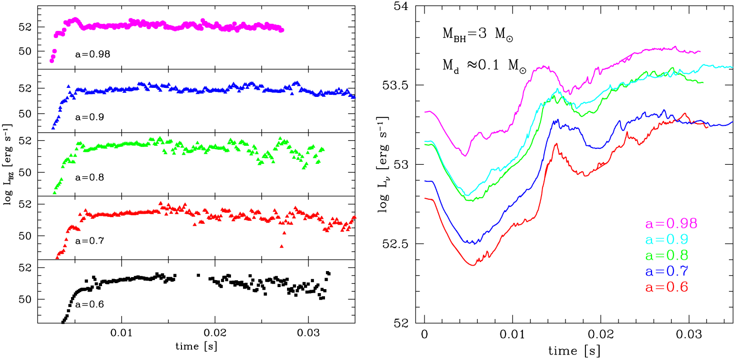
where $F_E \equiv -T^r_t$.
This can be subdivided into a matter $F_E^{(MA)}$ and electromagnetic $F_E^{(EM)}$ part, although in the force-free limit the matter part vanishes (McKinney & Gammie 2004).
This power is then used to accelerate the jets.



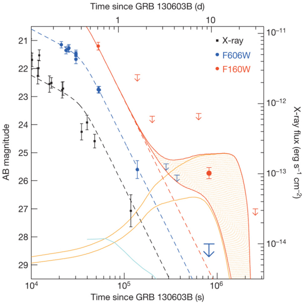


- Neutrino emissivities and electron fraction computed from the balance of nuclear reactions
- MHD evolution followed with the nuclear pressure as a function of density and temperature, EOS update at every time-step (Janiuk A., 2017, ApJ, 837, 39)
- Example parameters: black hole mass $M = 3M_{\odot}$ and spin $a = 0.9$, disk mass $M_d = 0.1M_{\odot}$, initial $\beta = P_{gas}/P_{mag} = 50$

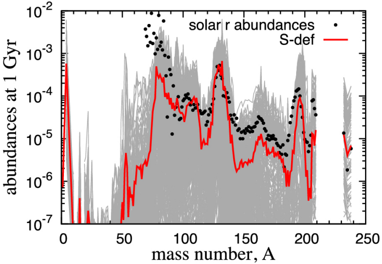
Blandford-Znajek vs. neutrino power: jets

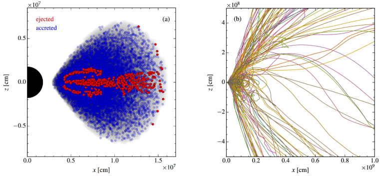


- Optical and near-Infrared emission, powered by radioactive decay of r-process nuclei
- Dynamical ejecta from compact binary mergers, $M_{\rm ej} \sim 0.01 M_{\odot}$, can emit about $10^{40} - 10^{41}$ erg/s in a timescale of 1 week
- Subsequent accretion can provide bluer emission, if it is not absorbed by precedent ejecta
- Kilonova candidates can be distinguished from supernova by faster time evolution, fainter absolute magnitudes, and redder colors (Tanaka M., 2016)



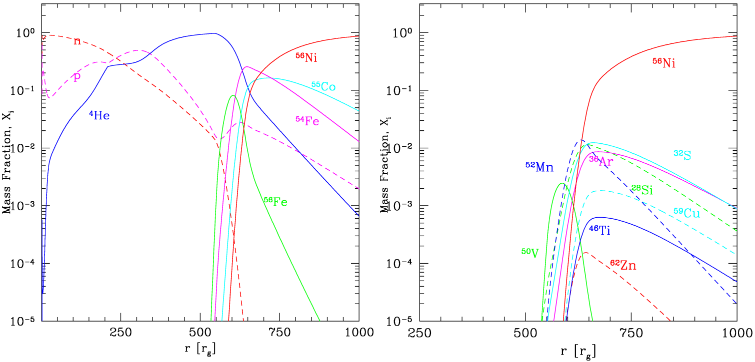
GRB 130603B afterglow. The excess NIR flux corresponds to absolute magnitude $M(J) \sim 15.35$ mag at $\sim$ 7d after the burst, consistent with the kilonova behaviour. Cyan curve shows predicted r-process kilonova optical emission (Tanvir N., et al, 2013)





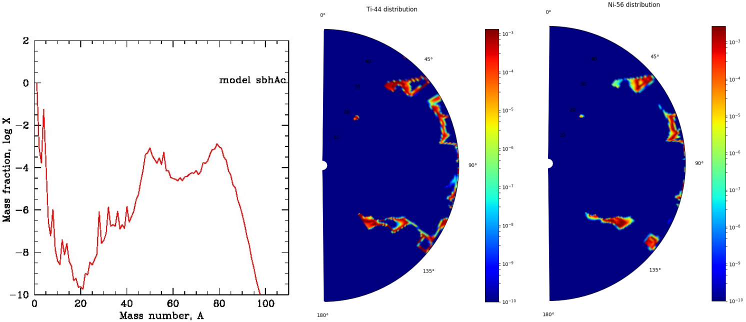
Simulations of the bh accretion of a remnant torus and r-process elements synthesized in the wind (Wu M.-R., et al. 2016, MNRAS).

Synthesis of heavy elements in accretion torus, 1D



Most abundant elements formed in the accretion torus in GRBs, $\dot{M} = 1.0 M_{\odot}/s$, $a = 0.9$ (1-D model of disk, Janiuk 2014, A&A, 568, 105)
We use the thermonuclear reaction network code (B.S. Meyer; *http://webnucleo.org*) to compute the nuclear statistical equilibria established for fusion reactions. The reaction data are taken from *JINA* reaclib online database

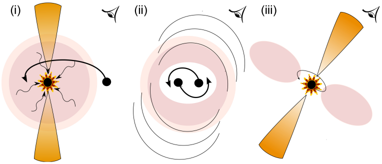
Synthesis of heavy elements in accretion torus, 2D



Left: Nuclear statistical equlibrium abundances. Volume integrated abundance distribution of elements synthesized in the accretion disk in 2D simulation. ($M_{\rm BH} = 3$, a=0.6, $M_{\rm torus} = 0.1$) (Janiuk A., 2017)

Right: Distribution of Titanium 44 and Nickel 56 within inner 50 Rg (K. Wojczuk & A Janiuk, in prep. 2017)

Gamma Ray Burst and Gravitational Wave

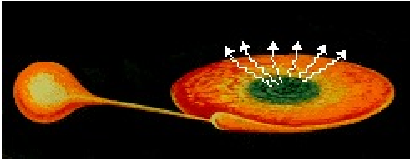


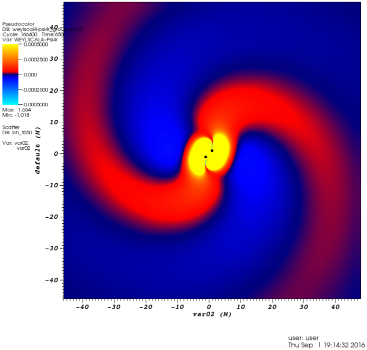
- Theoretical scenario proposed by Janiuk, Charzynski & Bejger (2013, A&A, 560, 25) for the GRB-GW coincidence
- Explored in the frame of putative detection of a weak GRB with GW150914 (AJ, M. Bejger, S. Charzynski, P. Sukova, 2017, New Astr. 51, 7)
- See also Loeb (2016); Perna et al. (2016); Woosley (2016), Zhang (2016)
- Binary induced core-collapse: Schwarzschild or Kerr companion black hole (e.g., Binsovatyi-Kogan 1970, Luminet & Marck 1985)

Summary

- Detailed description of microphysics in the GRB engine, torus and outflows, coupled with GR MHD evolution, gives reliable model of the event and constraints for physical parameters of the black hole (spin, mass)
- Observed signatures of radioactive decay of heavy species produced in GRB engines: faint emission in Ultraviolet/Optical/IR continuum (i.e. 'kilonova' or 'macronova'; Li & Paczynski 1998).
- Important in search for counterparts of GW signals: kilonovae offer an alternative, unbeamed electromagnetic signature
- For LIGO sources, mass and spin of BH constrained by waveform. The signal may be affected by the presence of surrounding matter (e.g. Fedrow et al. 2017)

GRBs, Microquasars, AGN, X-ray astronomy, gravitational waves, other...





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