אוניברסיטת תל-אביב
TEL AVIV UNIVERSITY
School of Physics and Astronomy

Modeling the central engine of relativistic jets - application to GRBs outflows

Noemie Globus & Amir Levinson

A. Levinson and N. Globus, ApJ 770, 159 (2013)
N. Globus and A. Levinson, Phys. Rev. D, 88, 084046 (2013)

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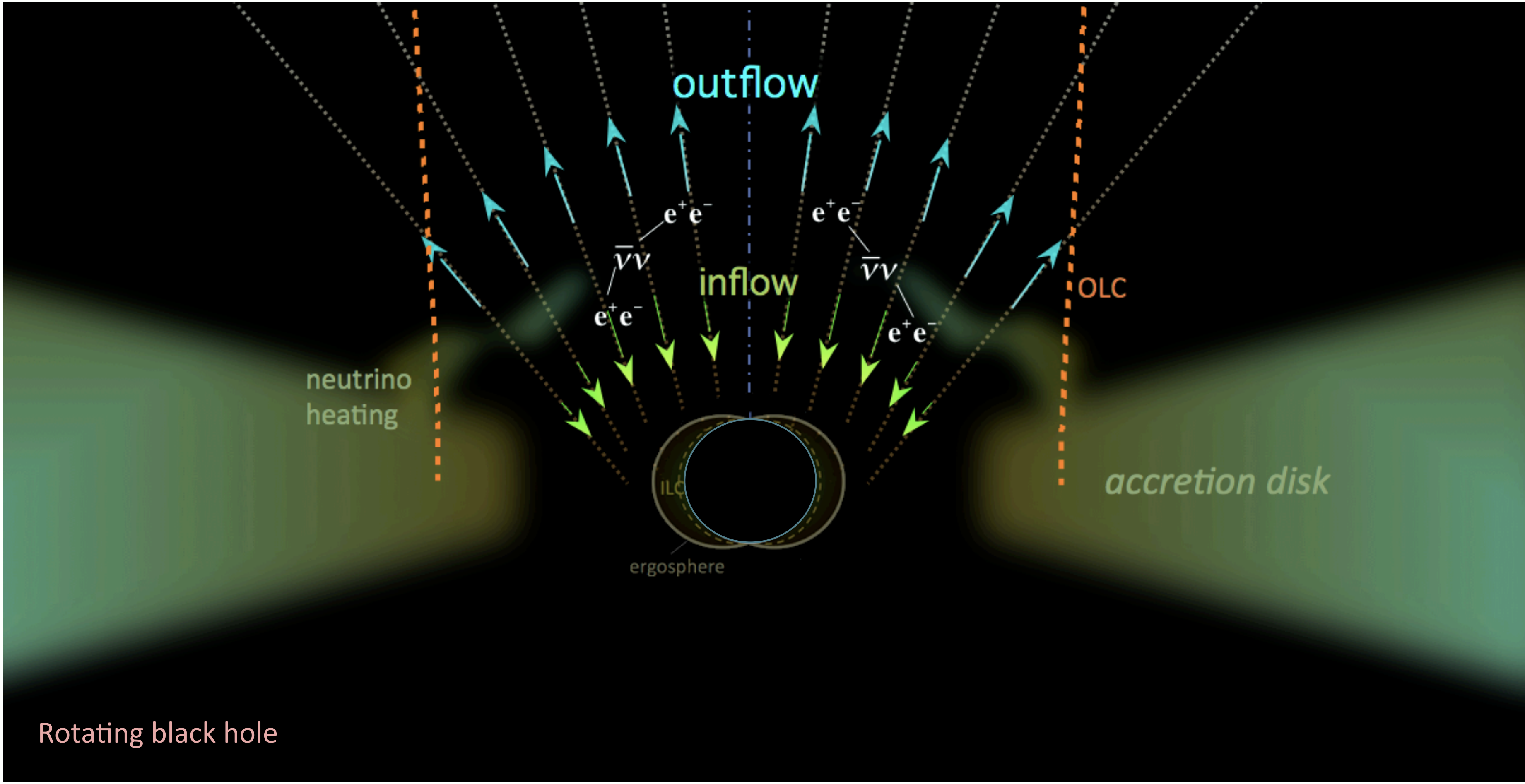
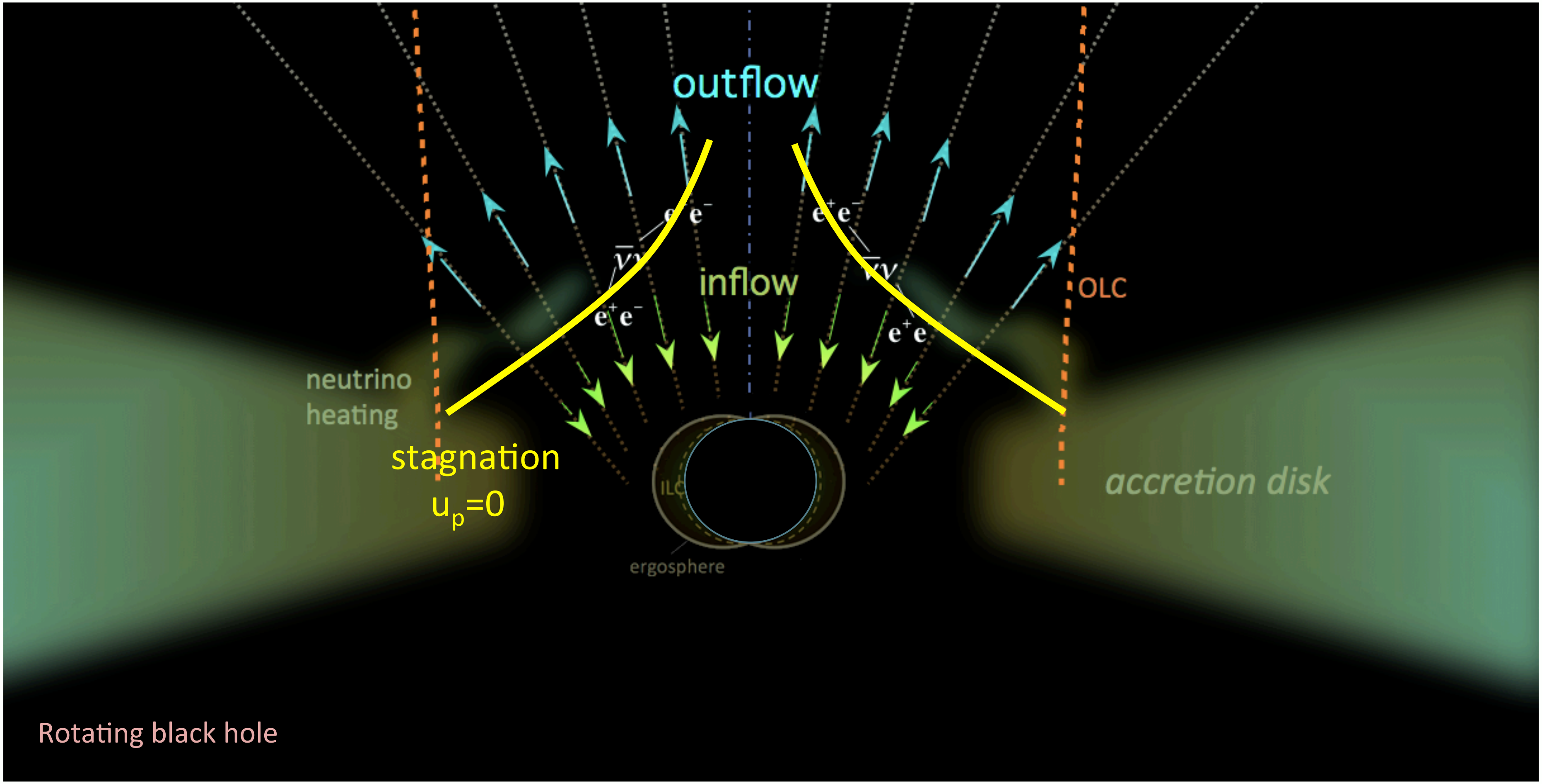
The double flow structure of a black hole magnetosphere



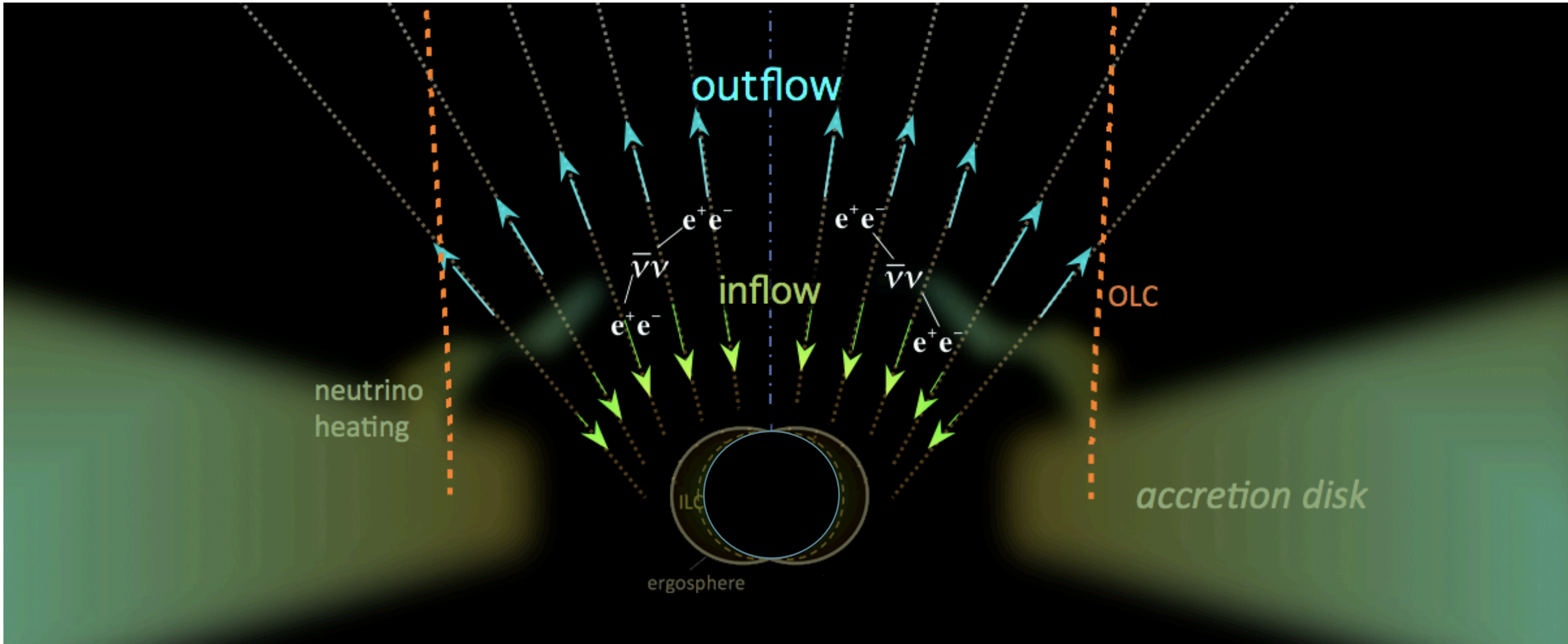
GRBs: energy deposition by $\nu\nu \rightarrow e^- e^+$

The double flow structure of a black hole magnetosphere



The position of the stagnation surface depends on the **energy injection** rate (Levinson & Globus 2013)

The double flow structure of a black hole magnetosphere



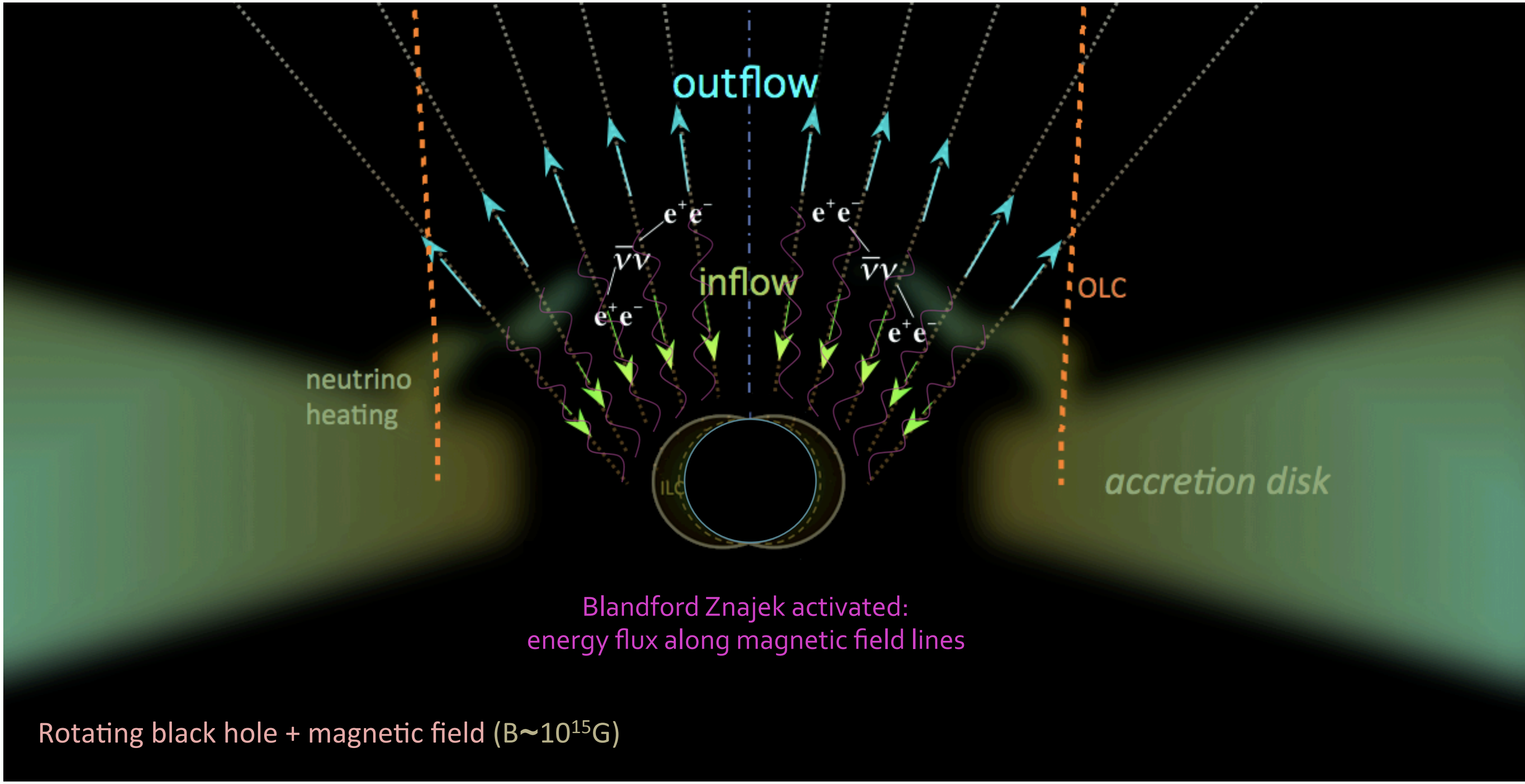
Rotating black hole

$$\dot{E}_{\nu\bar{\nu}} \approx 1.1\times 10^{52}\, x_{\rm ms}^{-4.8} \left(\frac{M}{3M_\odot}\right)^{-3/2} \left\{ \begin{array}{ll} 0 & \dot{M} < \dot{M}_{\rm ign} \\ \dot{m}^{9/4} & \dot{M}_{\rm ign} < \dot{M} < \dot{M}_{\rm trap} \\ \dot{m}_{\rm trap}^{9/4} & \dot{M} > \dot{M}_{\rm trap} \end{array} \right\} \text{erg s}^{-1}$$

Zalamea & Beloborodov 2011

GRBs: energy deposition by νν → e-e+

The double flow structure of a black hole magnetosphere



Conditions Takahashi+ 1990 **1)** $\omega_H > \Omega_F > 0$ **2)** Alfvén surface of the inflow inside the ergoregion **3) Loading ?**

Loaded GRMHD flows

Levinson, 2006; Globus & Levinson, 2013

- stationary + axi-symmetric MHD
- mass and energy injection included
  source terms: particle q_n; energy-momentum q^{α}
- split-monopole geometry invoked

Stream function (magnetic flux) : $\Psi(r,\theta)$ (assumed)

Constants of motion along a given streamline ($q_n = q^{\alpha} = 0$)

- angular velocity: Ω (a free parameter)
- particle flux per unit B flux: η
- specific energy (per baryon): ε
- specific angular momentum : L
- specific entropy : s

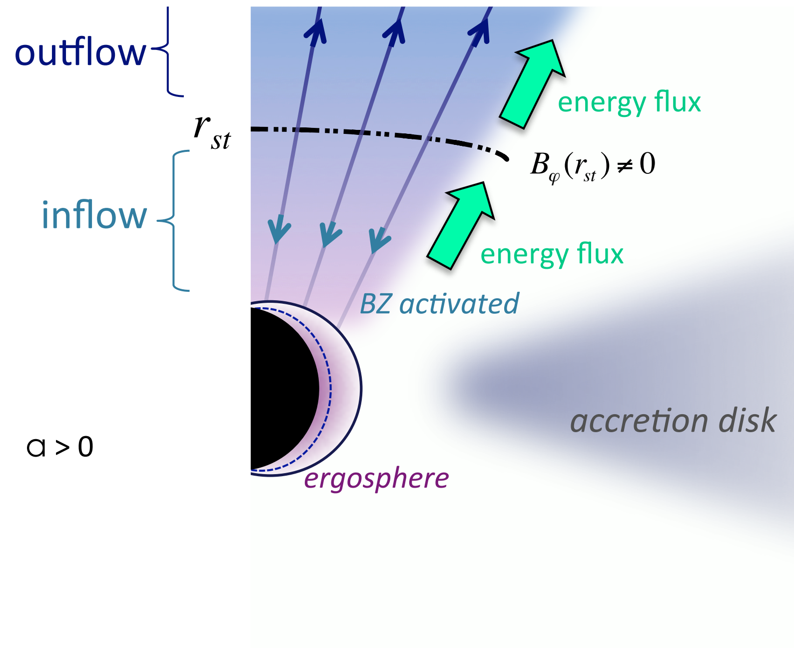
TYPE I

powered by black hole

energy flux on horizon: $\varepsilon^r \propto \eta\varepsilon$

(inflow: $\eta < 0$)

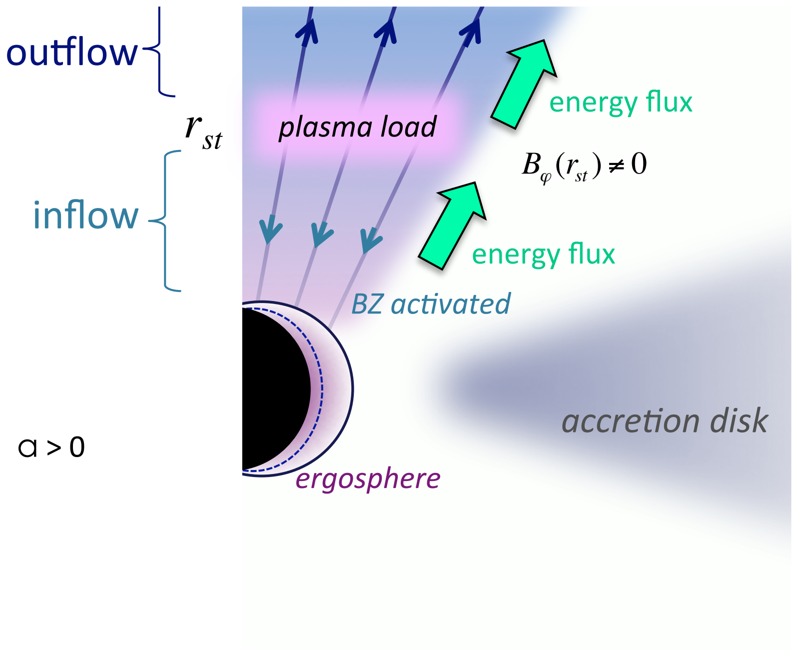
$\varepsilon_H < 0 \;\Rightarrow\; \varepsilon^r > 0$ (extraction)



TYPE II

powered by external source

TYPE I
powered by black hole



TYPE II
powered by external source

Loaded GRMHD flows

Levinson, 2006; Globus & Levinson, 2013

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Loading :

Energy deposition

$$\frac{1}{\sqrt{-g}}\partial_r\left(\sqrt{-g}\,\varepsilon^r\right) = -q_t$$

$\varepsilon^r = \rho u^r \varepsilon$ energy flux

$$q_t(r) = q_{t0}\delta(r - r_{st})$$

adiabatic (ε is conserved)

$$q_t(r) = f(r)$$ (ε not cst)

Particle deposition

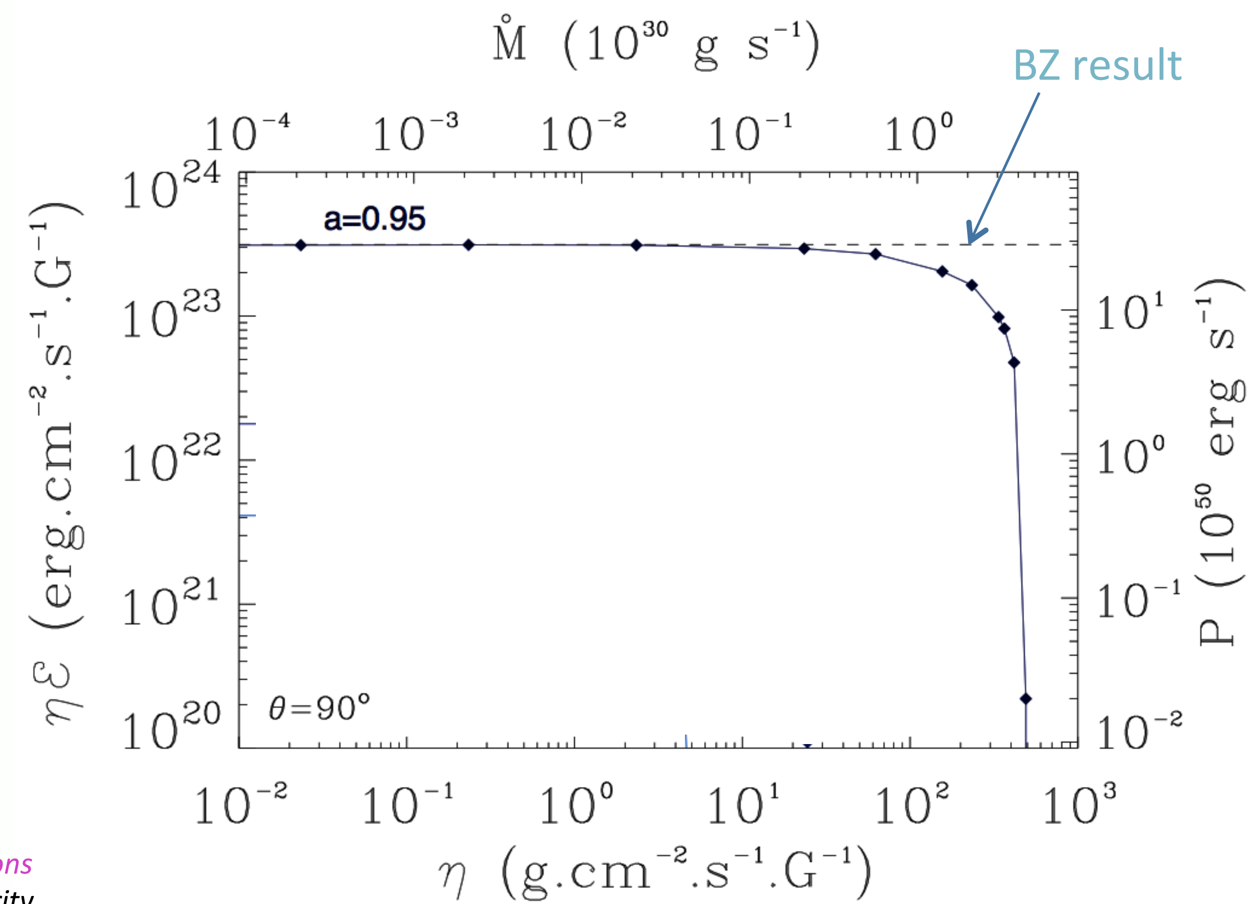
$$q_n(r) = q_{n0}\delta(r - r_{st})$$ (η is conserved along field lines)

TYPE I

Loaded MHD flows in Kerr geometry

Example : cold adiabatic case

Globus & Levinson, 2013



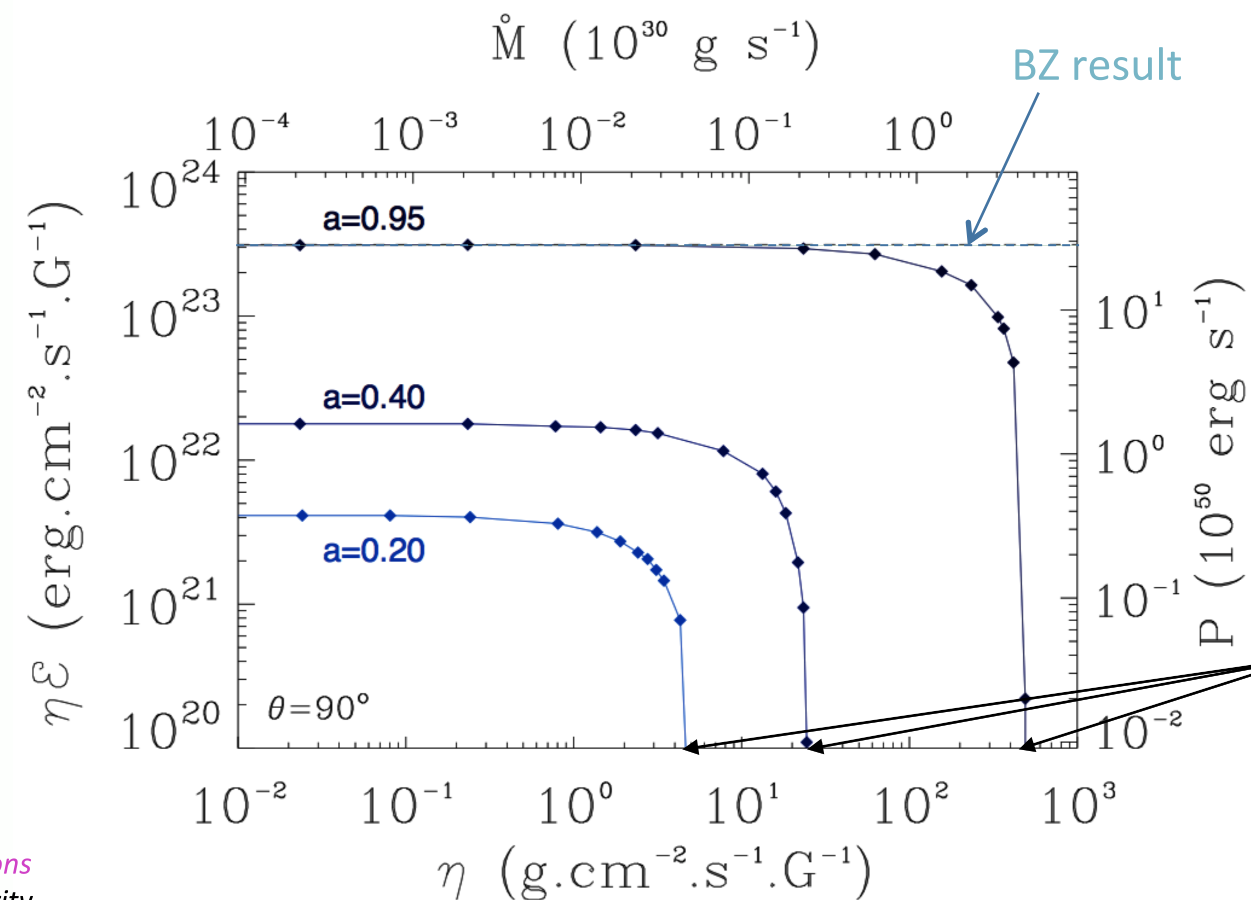
Assumptions
stationnarity
axisymmetry
ideal MHD
Split monopole geometry

each diamond = an inflow solution that crosses all the MHD critical points *and for which rotational energy is extracted from the BH*

TYPE I

Loaded MHD flows in Kerr geometry

Example : cold adiabatic case



critical loading:

for $\eta > \eta_c$

BZ is shut-down !

Assumptions

stationnarity

axisymmetry

ideal MHD

Split monopole geometry

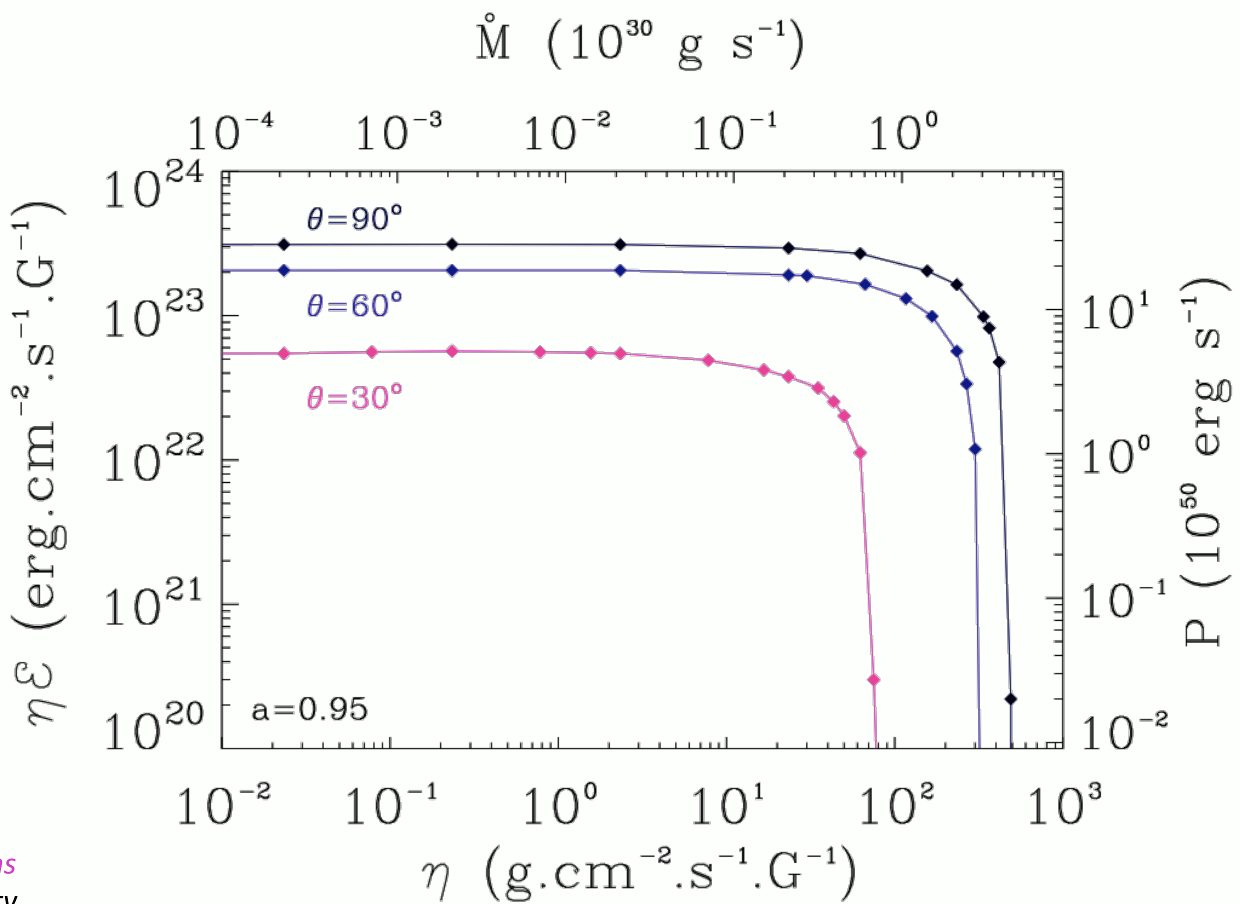
spin dependance

$$\eta_c \propto \frac{a^2}{1+\sqrt{1-a^2}}$$

TYPE I

Loaded MHD flows in Kerr geometry

Example : cold adiabatic case



Assumptions

stationnarity

axisymmetry

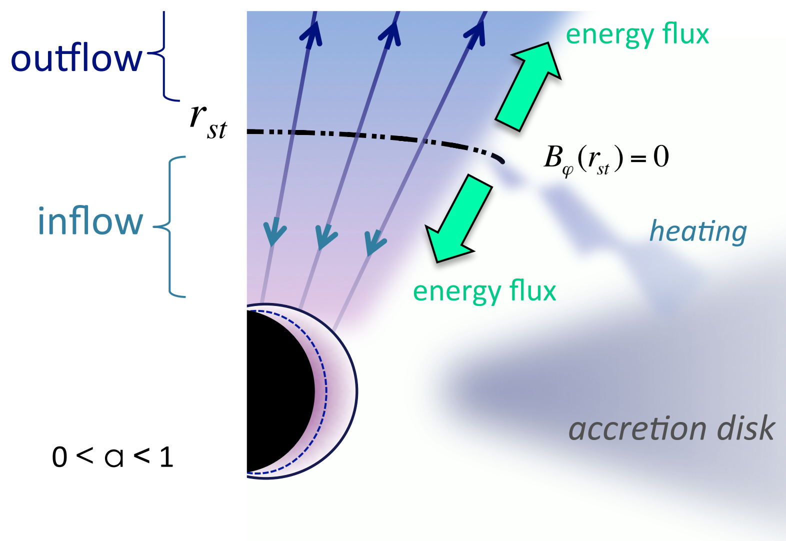
ideal MHD

Split monopole geometry

angular dependance $\eta_c \propto \sin^2\theta$

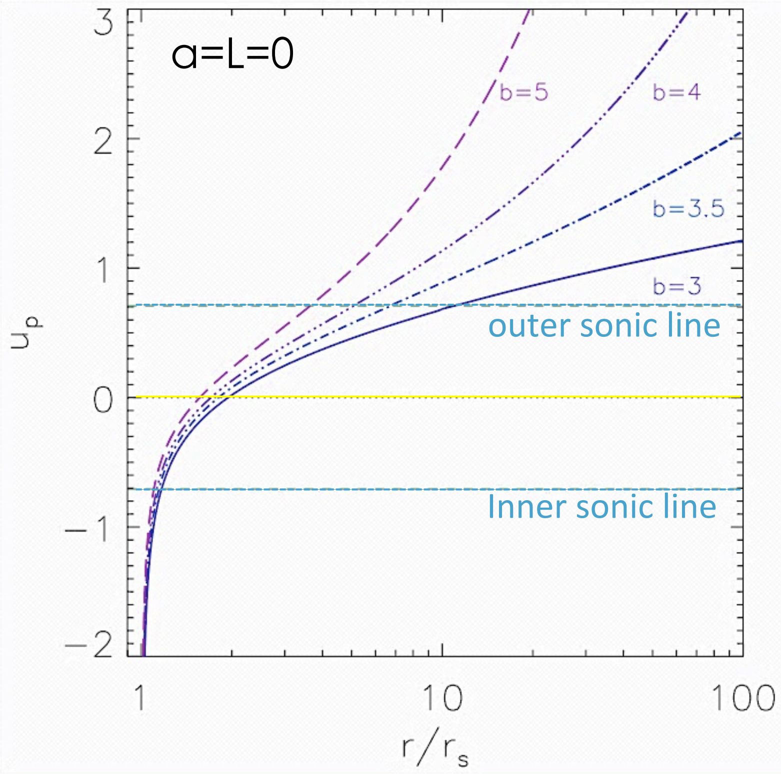
TYPE I
powered by black hole

TYPE II
powered by external source



TYPE II Double transonic flow in Schwarzschild geometry

Levinson & Globus, 2013



solutions with a realistic energy injection profile : $-q_t(r) = \dot{Q}_0 r^{-b}$

$\dot{Q}_0$: neutrino annihilation rates from Zalamea & Beloborodov 2011

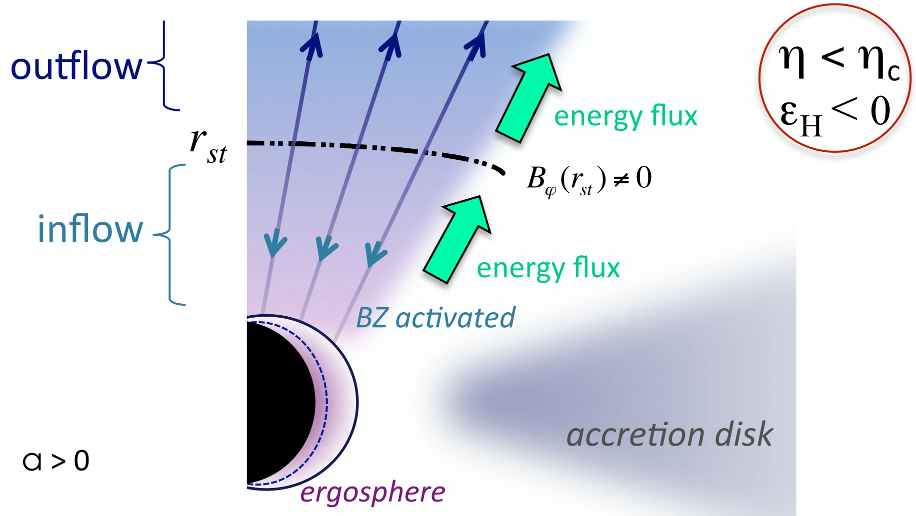
Sonic points

$$\sqrt{3}r_c^2(-q_{tc}) = \pm 4(r_c - 3m_H)p_c$$

- powered by neutrino source
- fraction of injected energy that emerges at infinity > 0.5
- high specific entropy

TYPE I

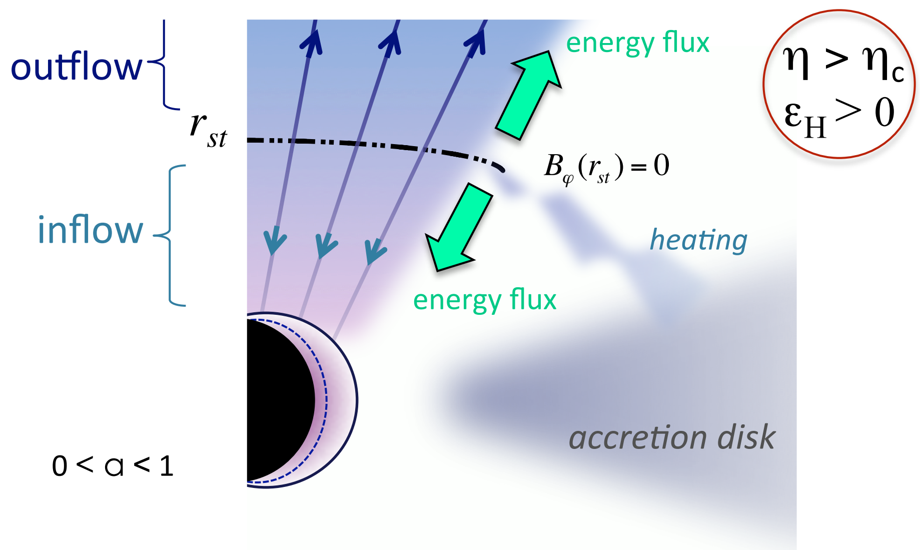
powered by black hole



Loading

TYPE II

powered by external source



To conclude…

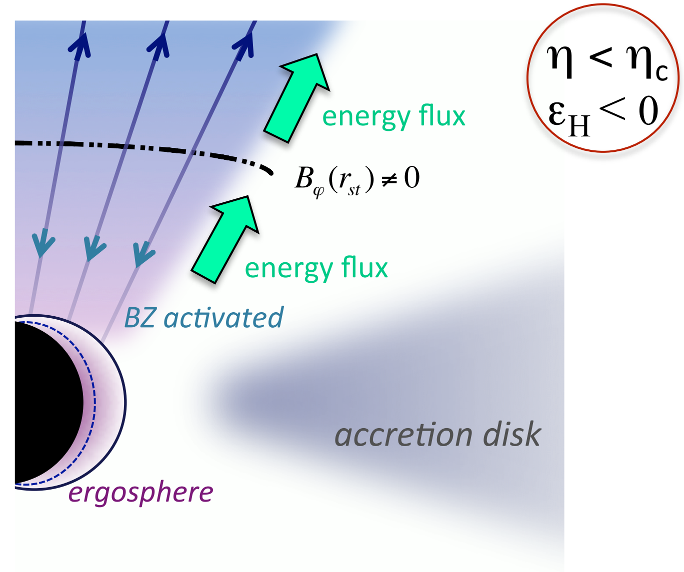
GRB case :

TYPE I

powered by black hole if

$$\dot{E}_{\nu\bar{\nu}} < P_{BZ}$$

$$\Rightarrow \quad \dot{m}_{acc} < 0.1 \left(\frac{M_H}{3M_\otimes}\right)^{-2/9} \left(\frac{\Psi_B}{10^{27}\ \mathrm{G\ cm}^2}\right)^{8/9} F(a)\ M_\otimes.s^{-1}$$



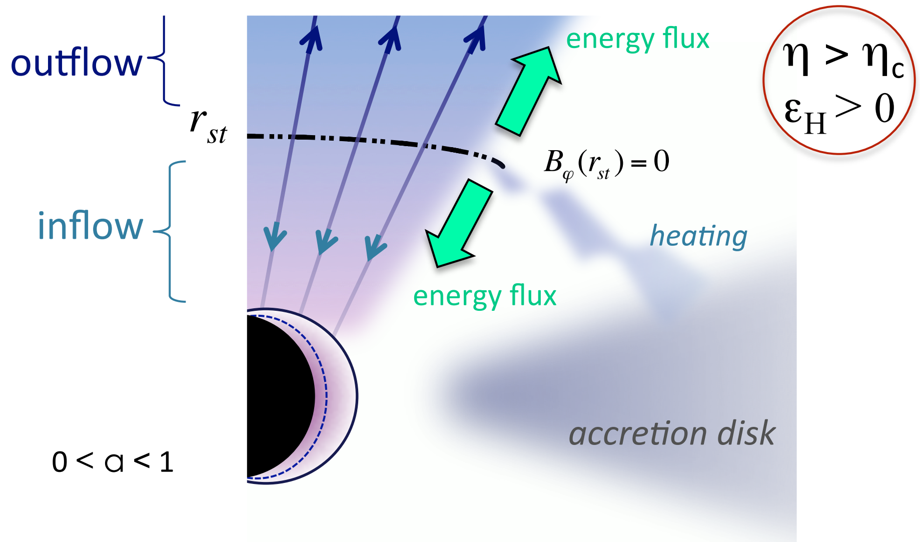
(both BZ and pressure driven jets currently under investigation)

Otherwise:

TYPE II

driven by neutrino annihilation

$\nu\nu \rightarrow$ e-e+



BACK-UP

Energy source for GRBs relativistic winds

...From the accretion disk ?

- Neutrino dominated accretion flows are candidates to be the central engine of GRB outflows.

⇒ Derivation of disk structure and neutrino annihilation rates: Popham et al. 1999, Zalamea & Beloborodov 2011 (calculations in the Kerr spacetime)

- Levinson, 2006 : **Loaded** (i.e. non adiabatic) relativistic MHD wind in the Schwarzschild spacetime.

...From the black hole polar region ? (this talk)

- Plasma injection in the magnetosphere : $\nu\nu \rightarrow e^+e^-$ in GRBs (the baryonic component from the disk can be neglected)

- The energy source is the rotational energy of the black hole

⇒ Pioneering work of Blandford & Znajek 1977

⇒ Many semi-analytic studies and numerical simulations support this scenario (Takahashi et al. 1990, Komissarov 2004, Barkov & Komissarov 2008..)

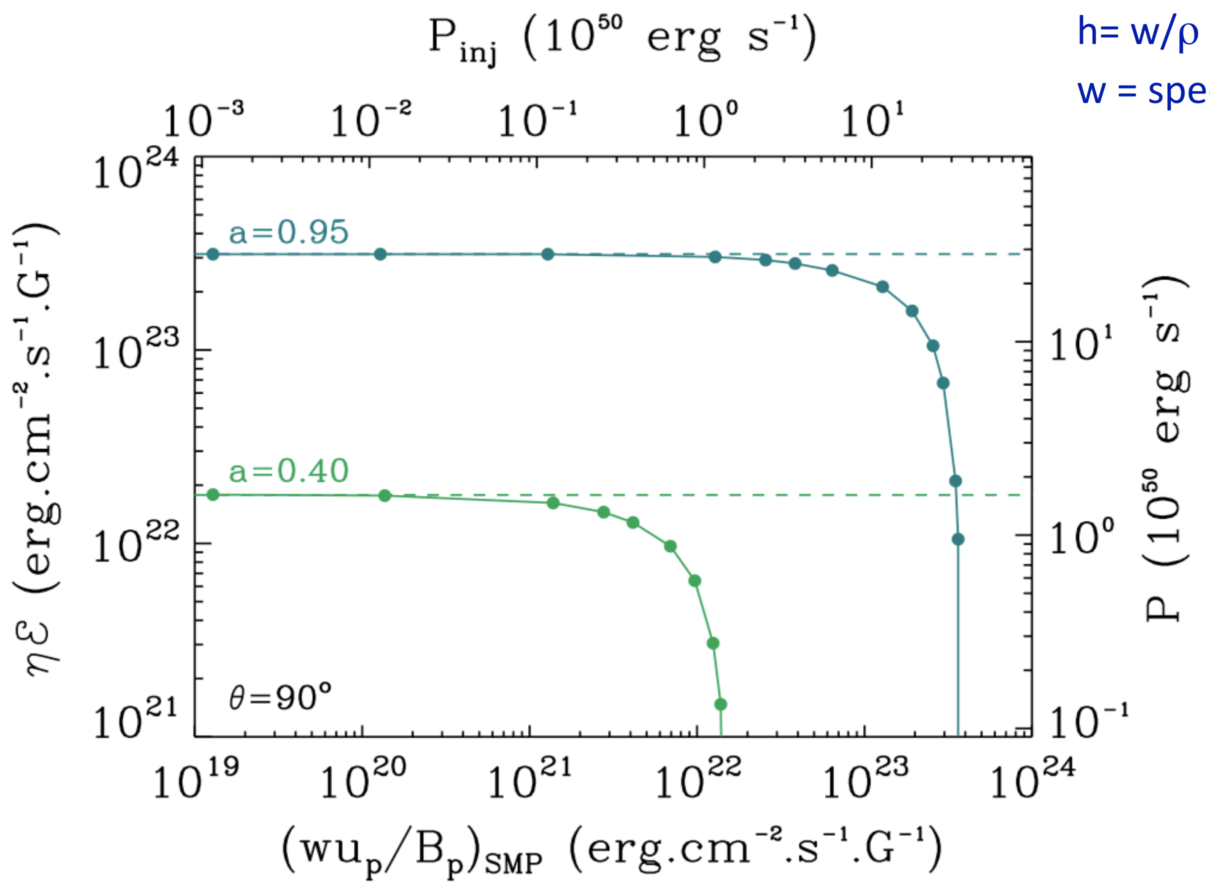
- The energy source is neutrino annihilation (neutrinos are emitted from the accretion disk)

⇒ Solutions for the **double-flow structure** in the Schwarzschild geometry : pressure-driven winds (Jaroszynski, 1996; Levinson & Globus 2013)

TYPE II

Loaded MHD flows in Kerr geometry

Example : hot case



$h = w/\rho \approx 4p/\rho >> 1$

w = specific enthalpy

Assumptions

stationnarity

axisymmetry

ideal MHD

Split monopole geometry