

Diagnostics of magnetospheric activity in stellar and supermassive BHs

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Outline

- Theoretical and observational motivation
- Steady gap solutions: structure and emission
- Can steady gap exist?

Motivation

- Theoretical: what is the plasma production mechanism in BZ outflows?
- Spark gaps produce HE emission (seen in pulsars, speculated in BHs)

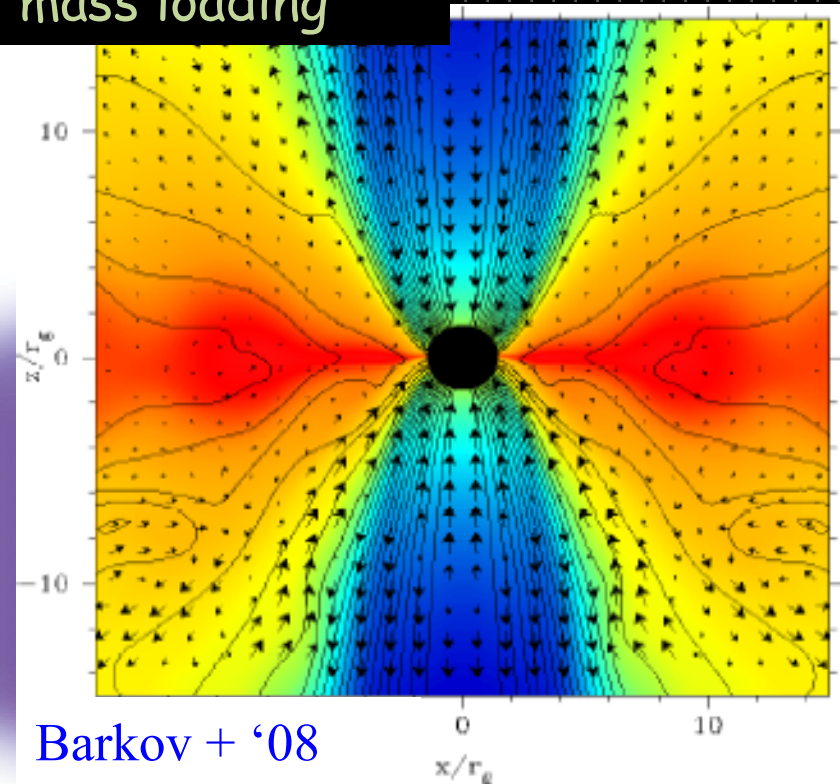
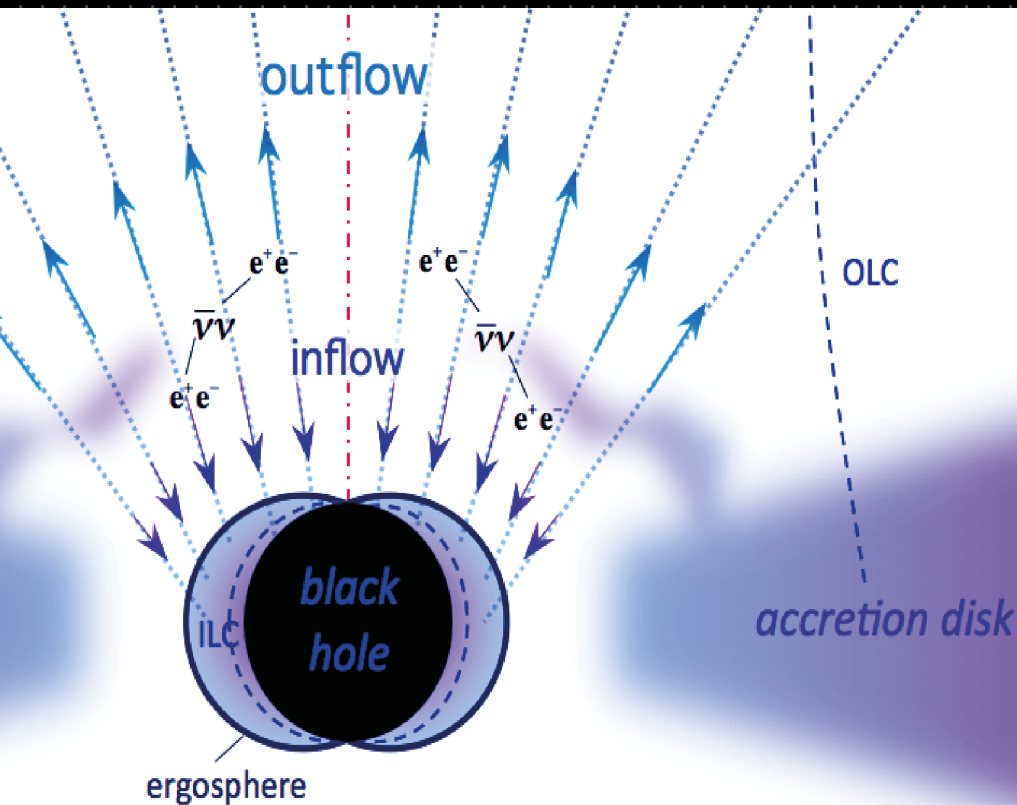
Plasma injection in the magnetosphere

- plasma source between inner and outer Alfven surfaces
- escape time \approx few r_g/c

$\gamma\gamma \rightarrow e^\pm$ in AGNs

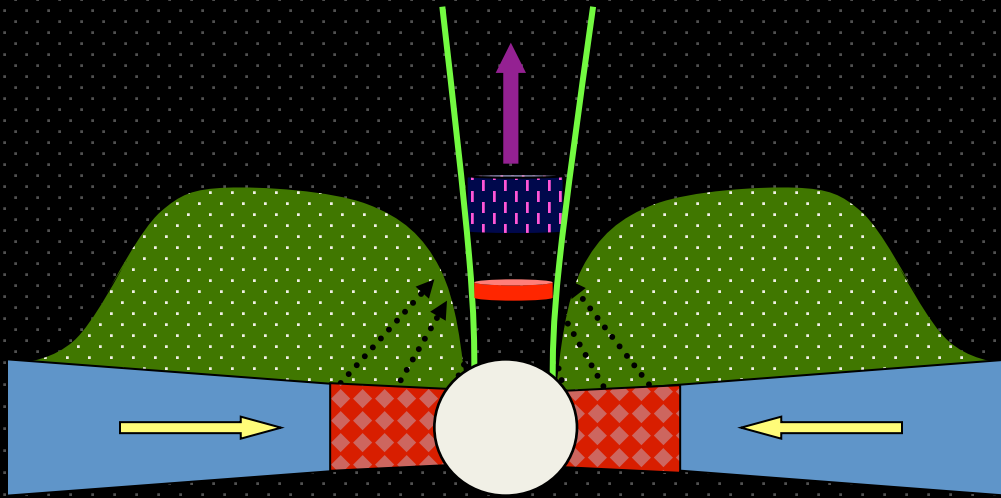
$\nu\nu \rightarrow e^\pm$ in GRBs

mass loading



Barkov + '08

How to produce the required charge density?

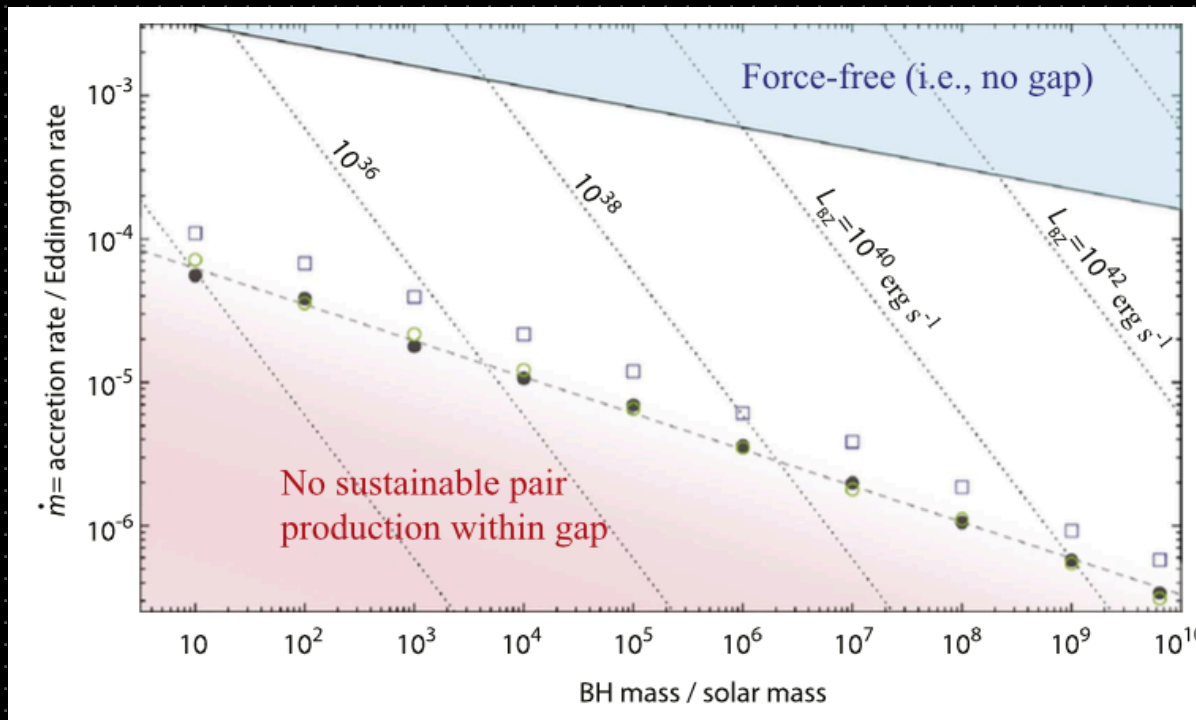


- Protons from RIAF ?
- Protons from n decay ?
- e^\pm from $\gamma\gamma$ annihilation ?
- Other source ?

- Protons have to cross magnetic field lines. Diffusion length over accretion time extremely small.
- instabilities or field reversals. But intermittent spark gaps may still form.

Direct pair injection

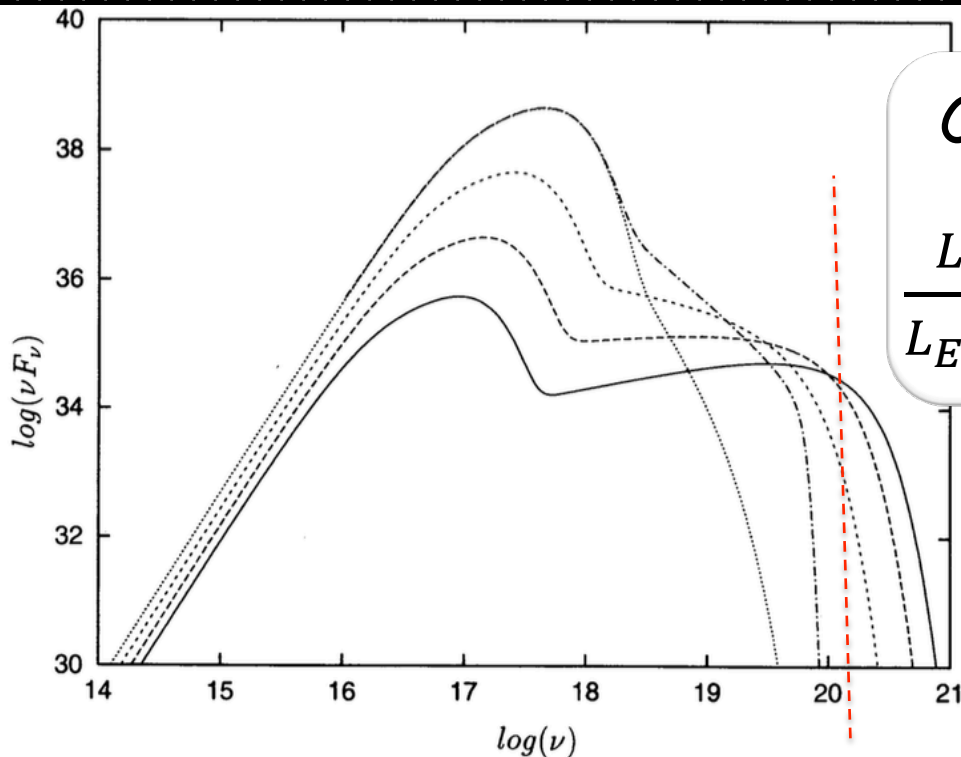
- Low accretion rates (RIAF): AC may be hot enough to produce gamma-rays above threshold (Levinson + Rieger 11, Hirotani + 16)



Conditions for gap formation (From Hirotani+ 16)

Direct pair injection

- Intermediate accretion rates: Disk is cold, but corona may scatter photons to MeV energies.



Condition for gap formation

$$\frac{L_\gamma}{L_{Edd}} < 10^{-3} \left(\frac{B}{10^8 G} \right)^{1/2} \left(\frac{R_\gamma}{30 r_g} \right)^2$$

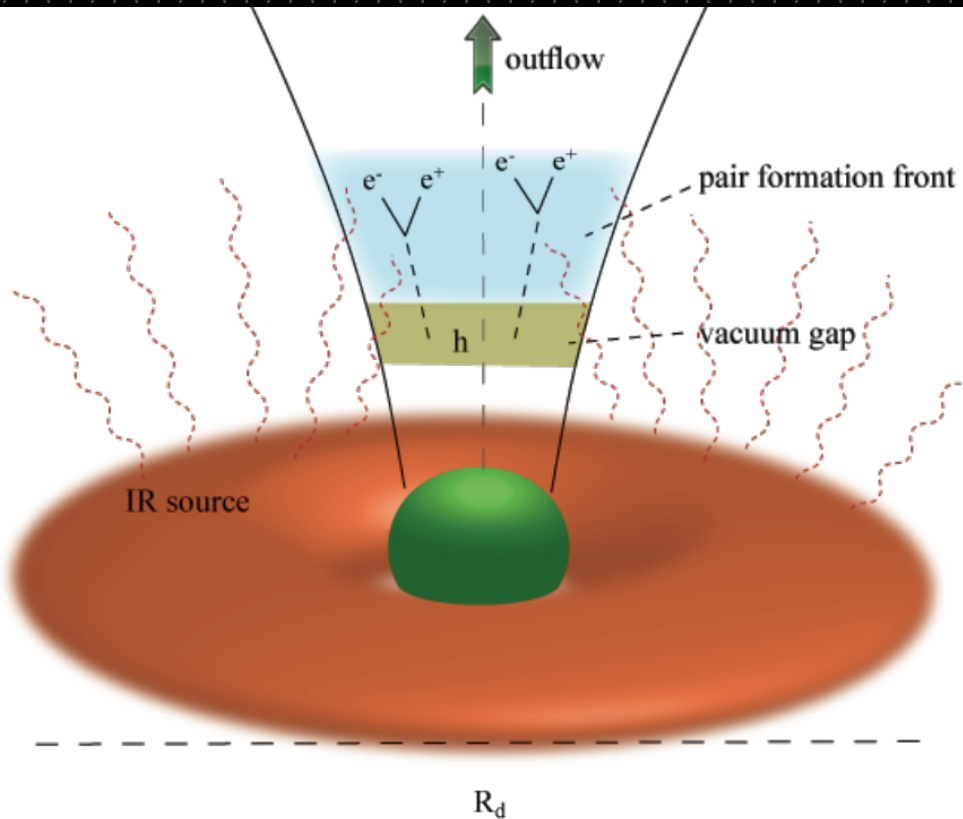
Stellar BH: $B \approx 10^8 G$

AGNs: $B \approx 10^4 G$

Model SED of a $5 M_\odot$ BH at different states
(from Chakrabarti + 95)

Activation of a spark gaps

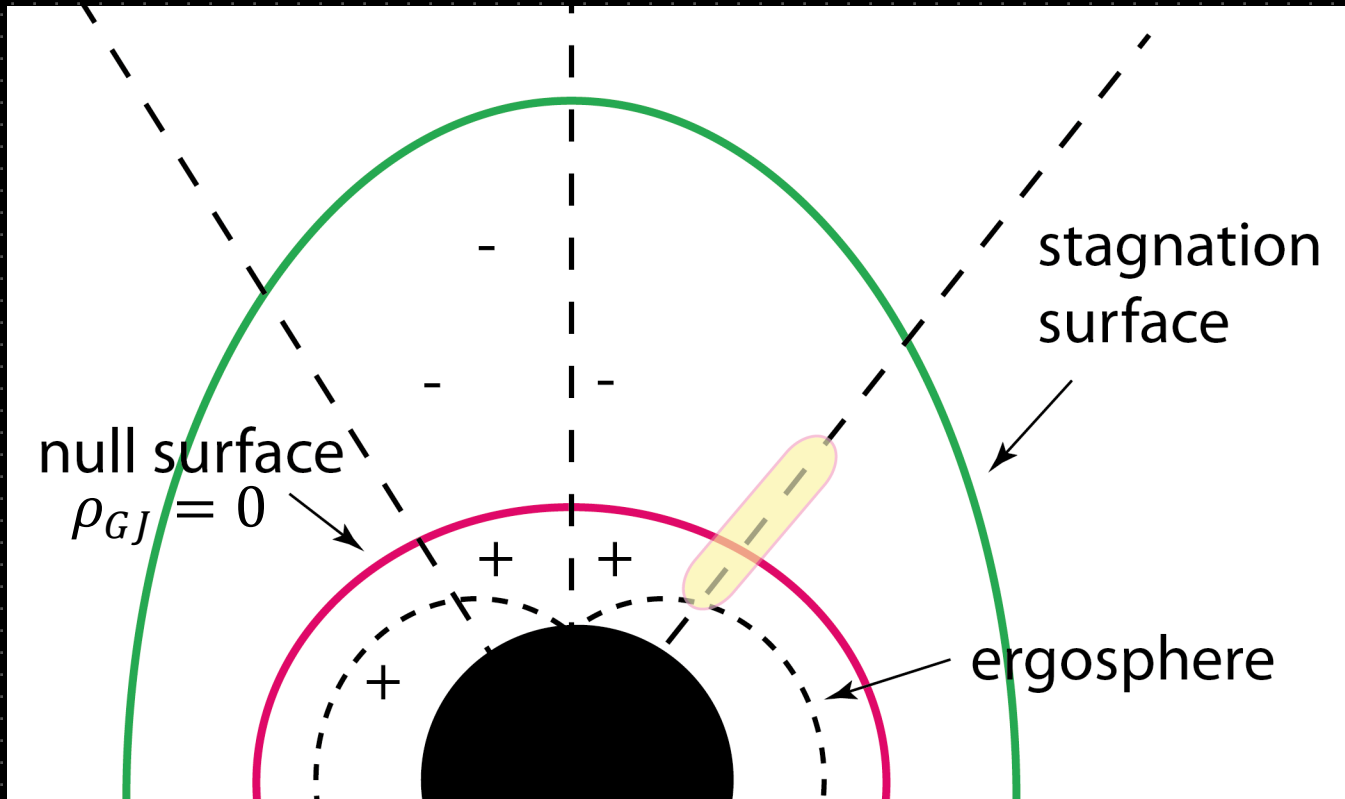
AL 00; Neronov + '07, AL + Rieger '11, Broderick + 15; Hirovani+ 16



- activated when $n < n_{GJ}$.
Expected in M87 when accretion rate $< 10^{-4}$ Edd.
- must be intermittent.
- particle acceleration to VHE by potential drop.

Structure of inner magnetosphere

- Stagnation surface: separates plasma inflow/outflow
- null surface: GJ density vanishes (owing to frame-dragging)



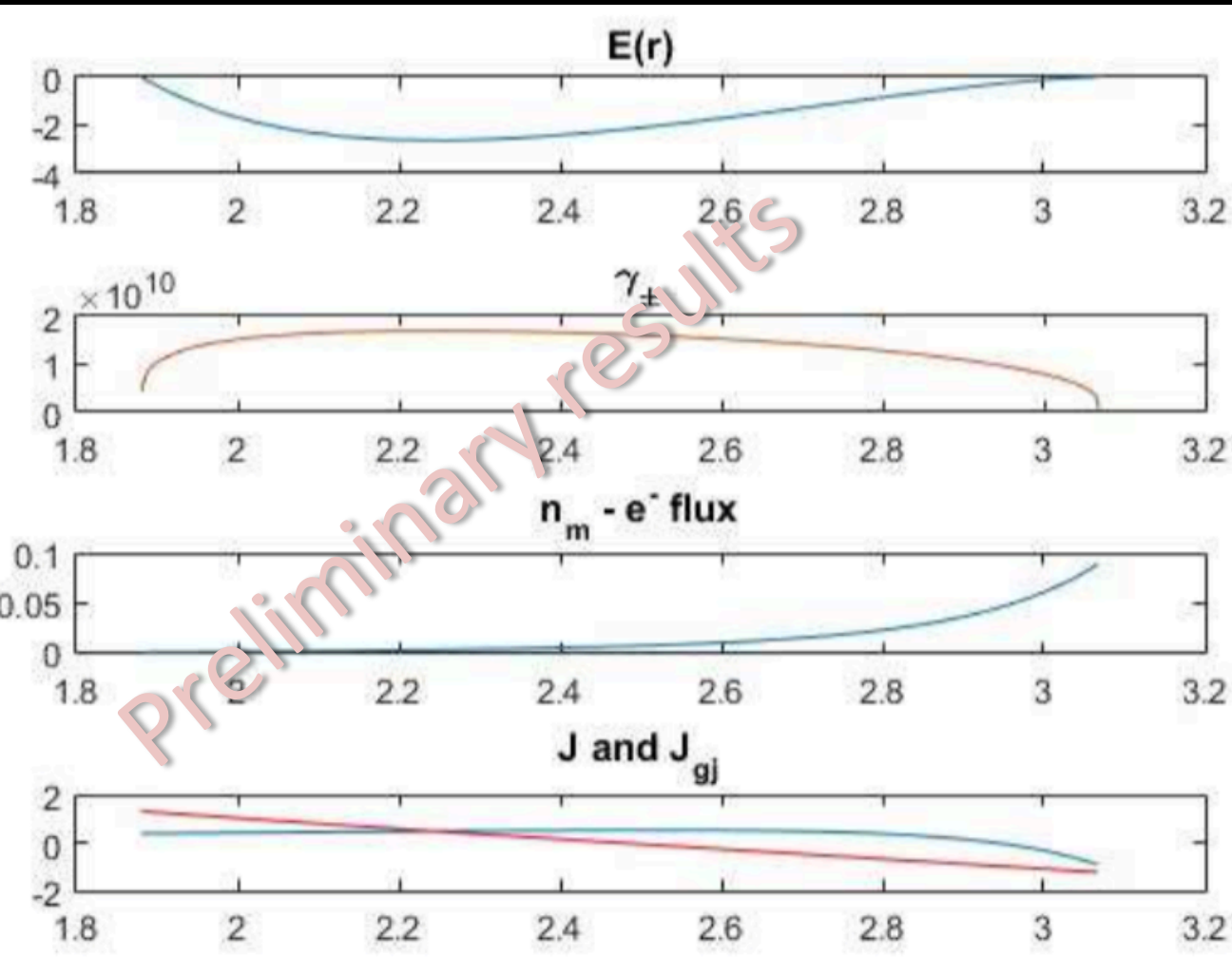
Steady gap

Characterized by global current

- invoke B field geometry + properties of seed photon source,
- solve
$$\partial_{\mu} \left(\frac{\sqrt{-g}}{\alpha^2} F_t^{\mu} \right) = 4\pi \sqrt{-g} (\rho_e - \rho_{GJ})$$
 - +Eq of motion for pairs
 - + radiative transfer (with IC and curvature sources)
 - + pair production (continuity Eq)
- iterate until all boundary conditions are met.

example

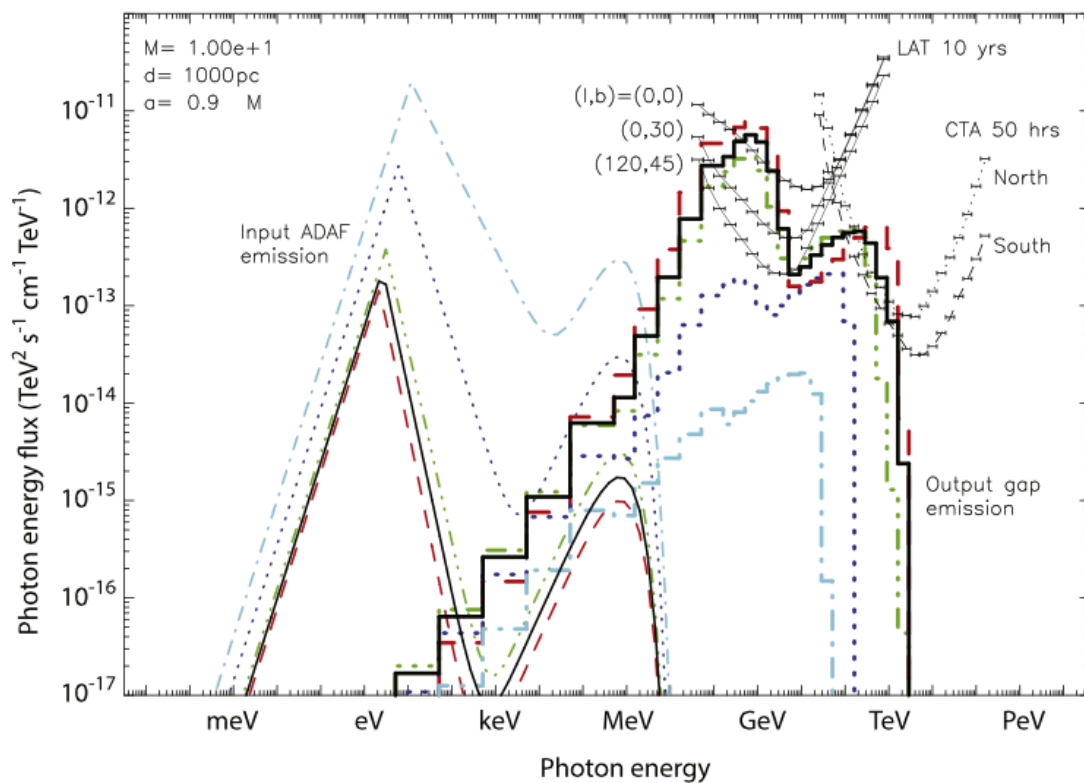
Levinson + Segev in prep



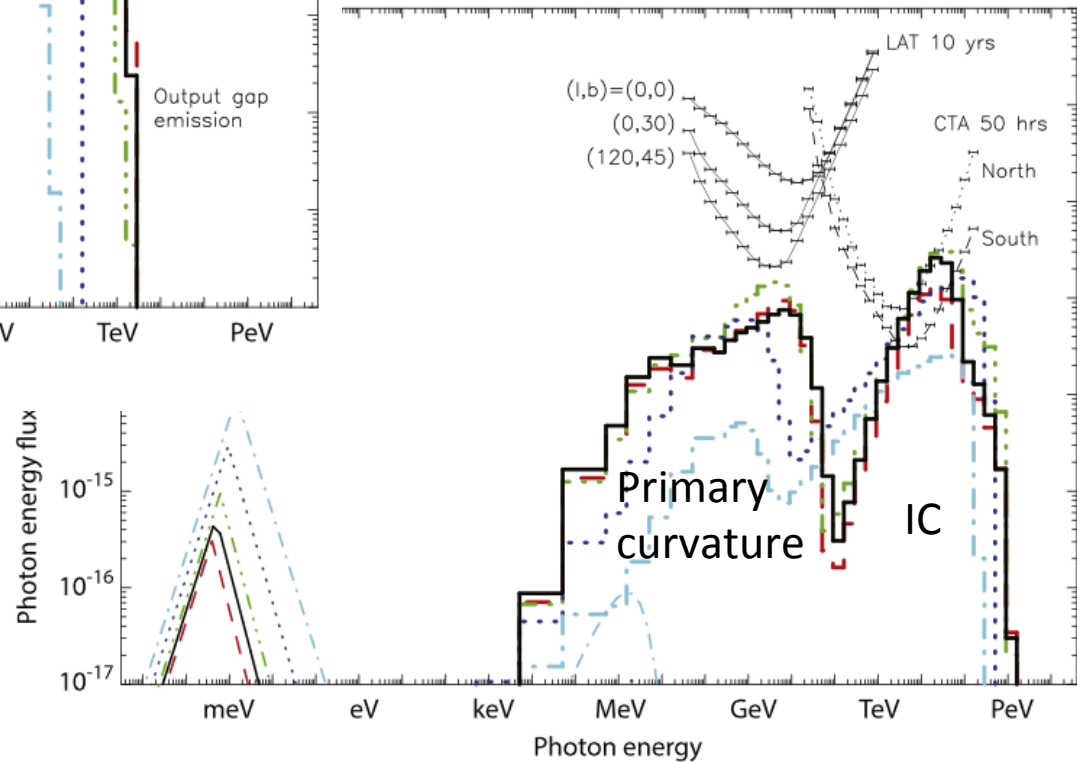
Gap location is fixed by magnetospheric current and disk luminosity

Stellar BH (M=10)

Gap spectra (Hirotani + 16)



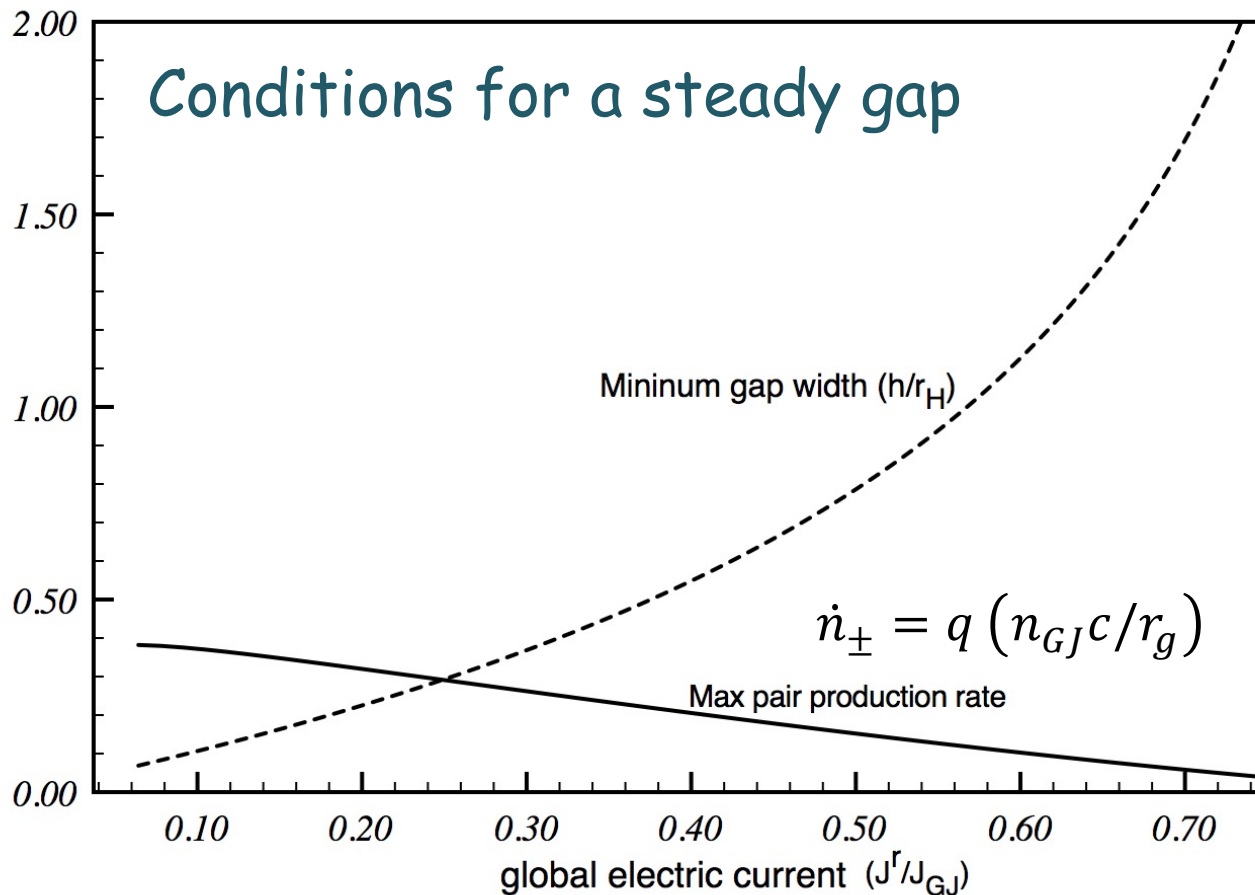
supermassive BH (M=10⁹)



Peak energy scales roughly as $M_{BH}^{1/4}$

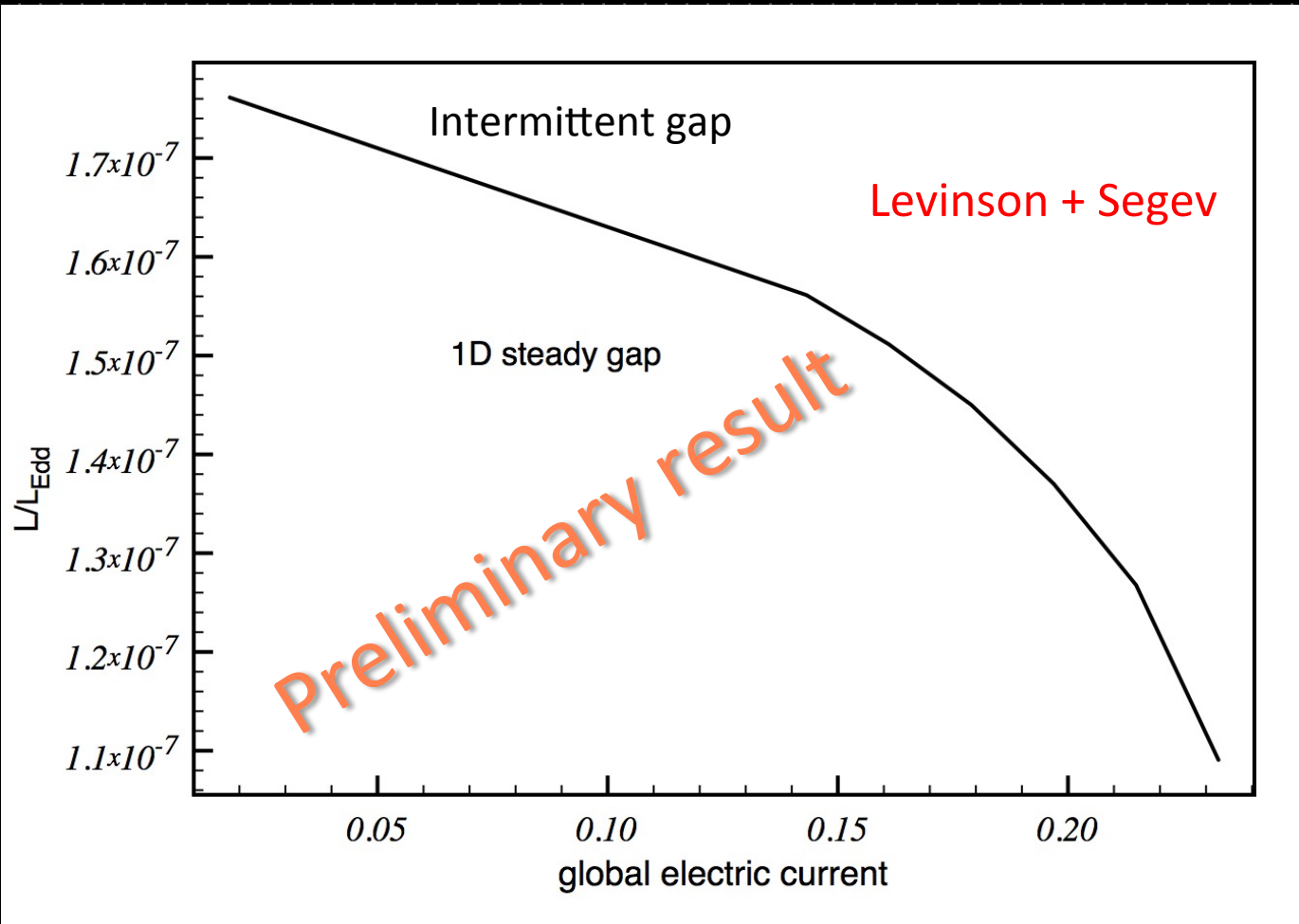
Inherent intermittency ?

If pp rate exceeds Max value, gap is intermittent



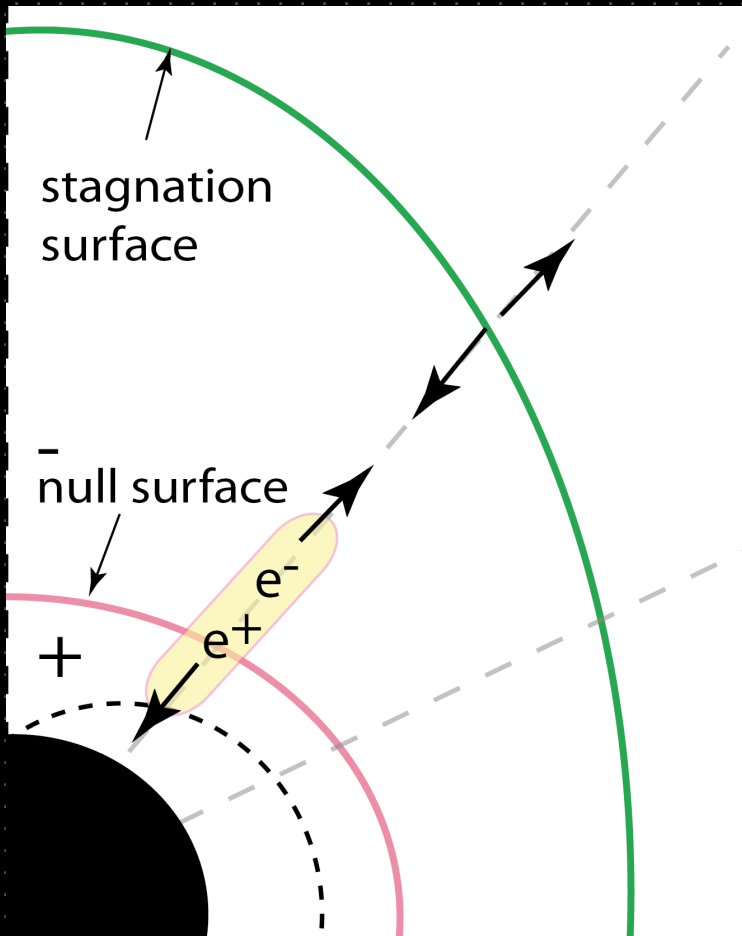
Inherent intermittency: 1. local condition

$M_{\text{BH}} = 10^9$ solar, $R_{\text{rad}} = 30 r_g$, power law spectrum

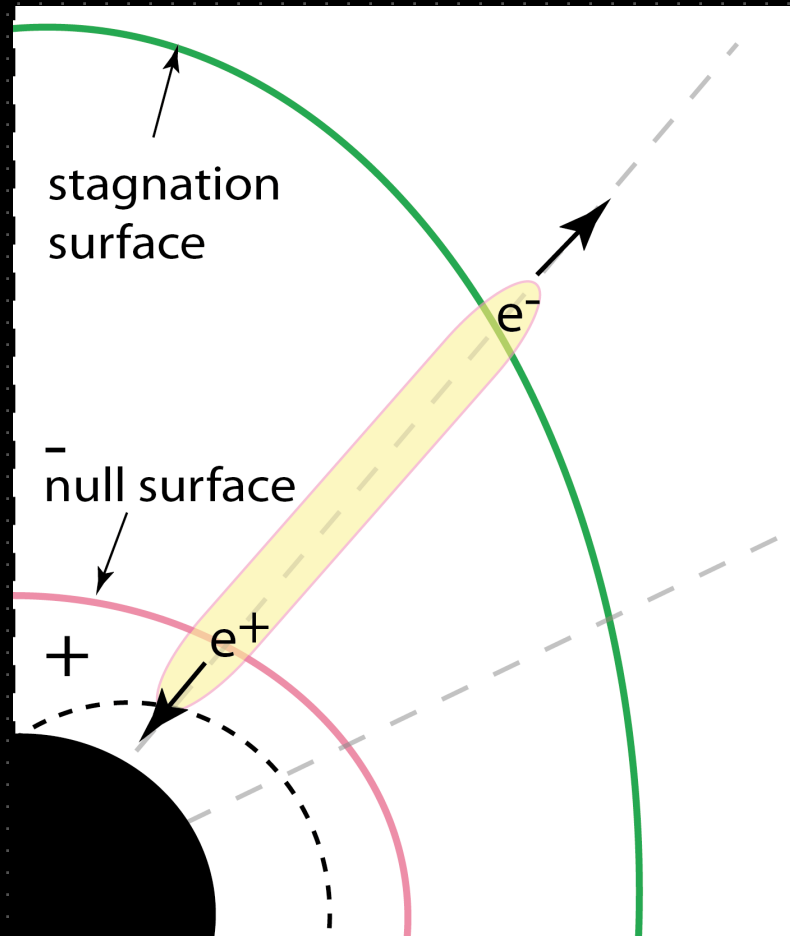


Inherent intermittency: 2. global condition

A steady gap must include the stagnation surface



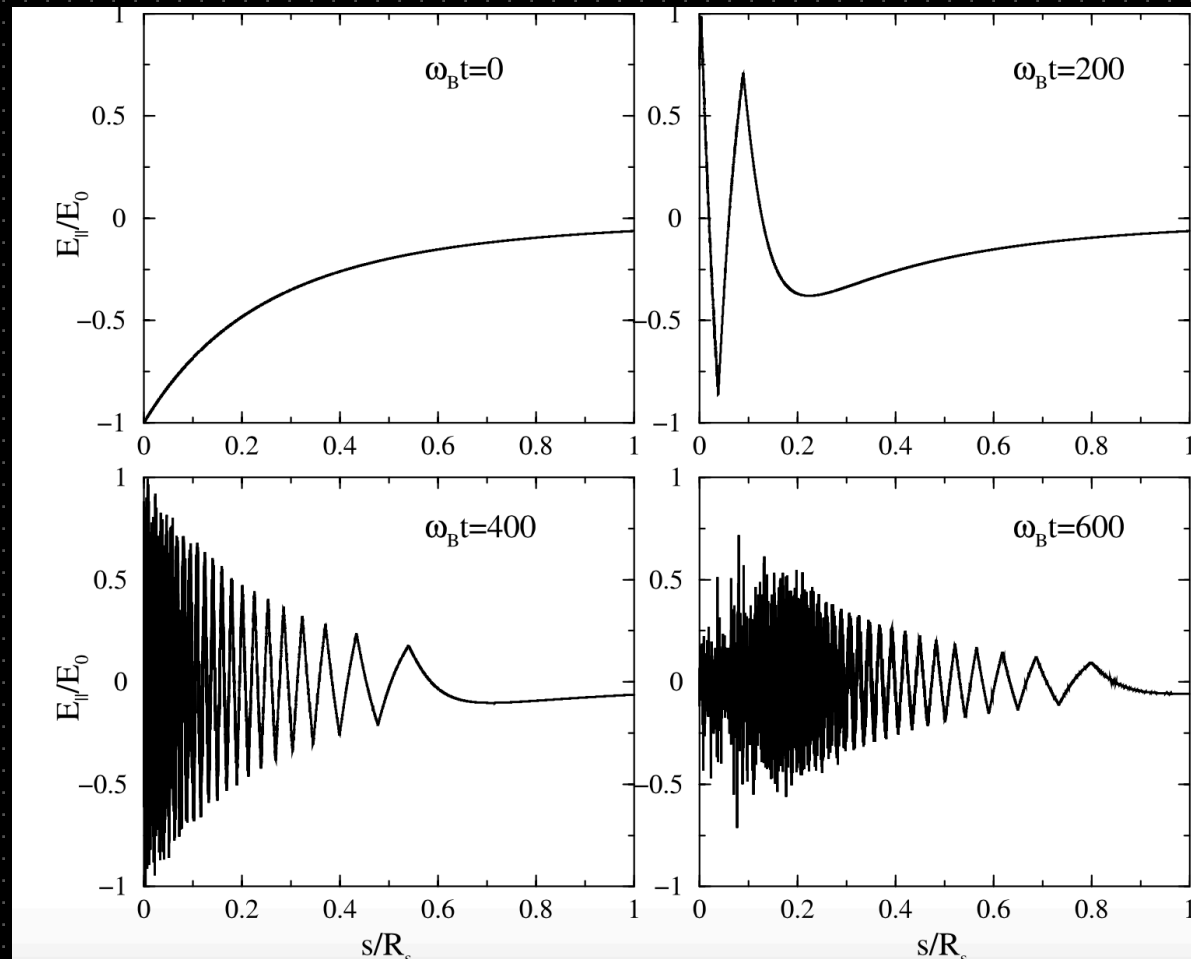
Inconsistent with MHD flow



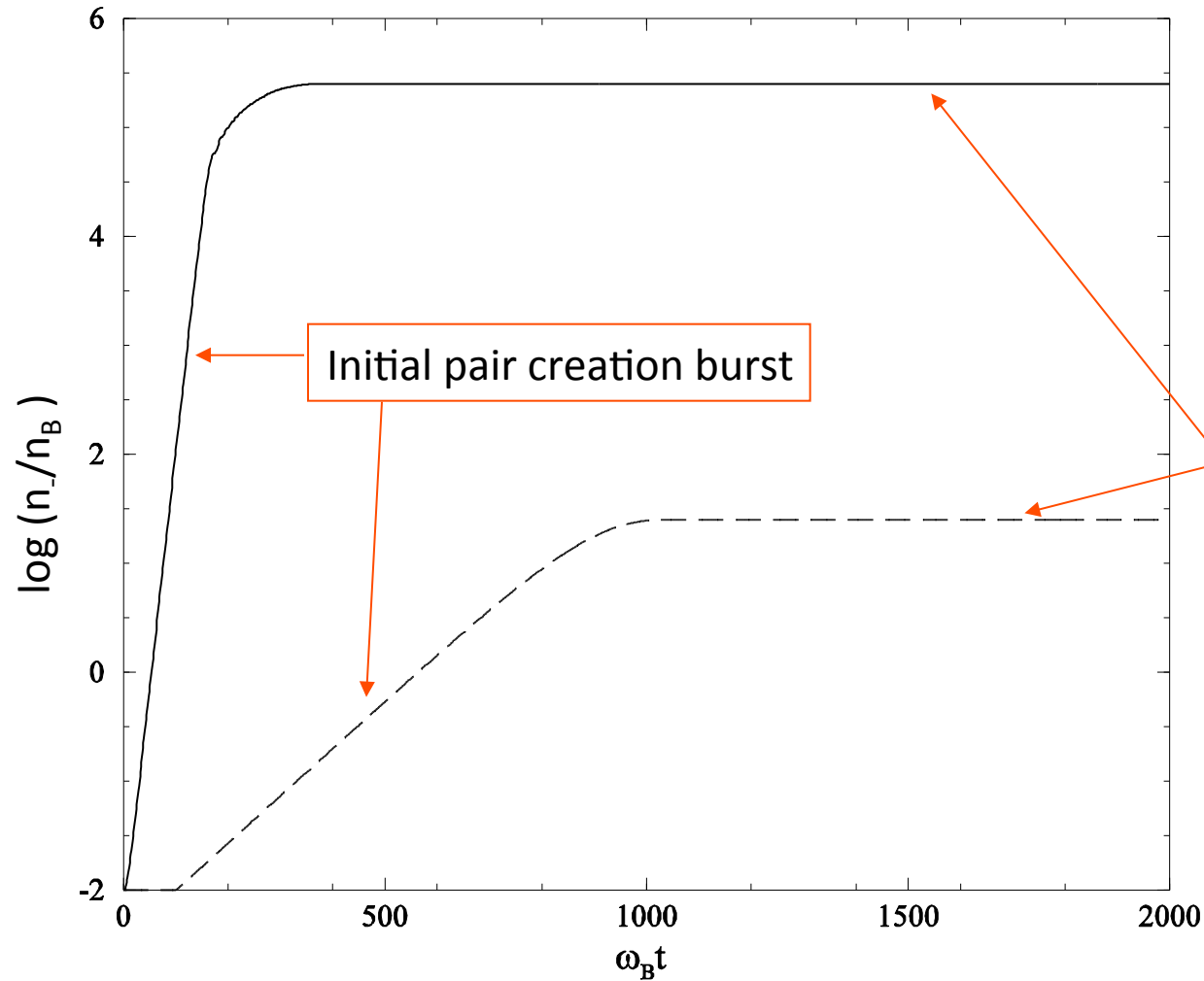
consistent with MHD flow

1D intermittent gap – analytic model

AL+ 2005



Evolution of pair density



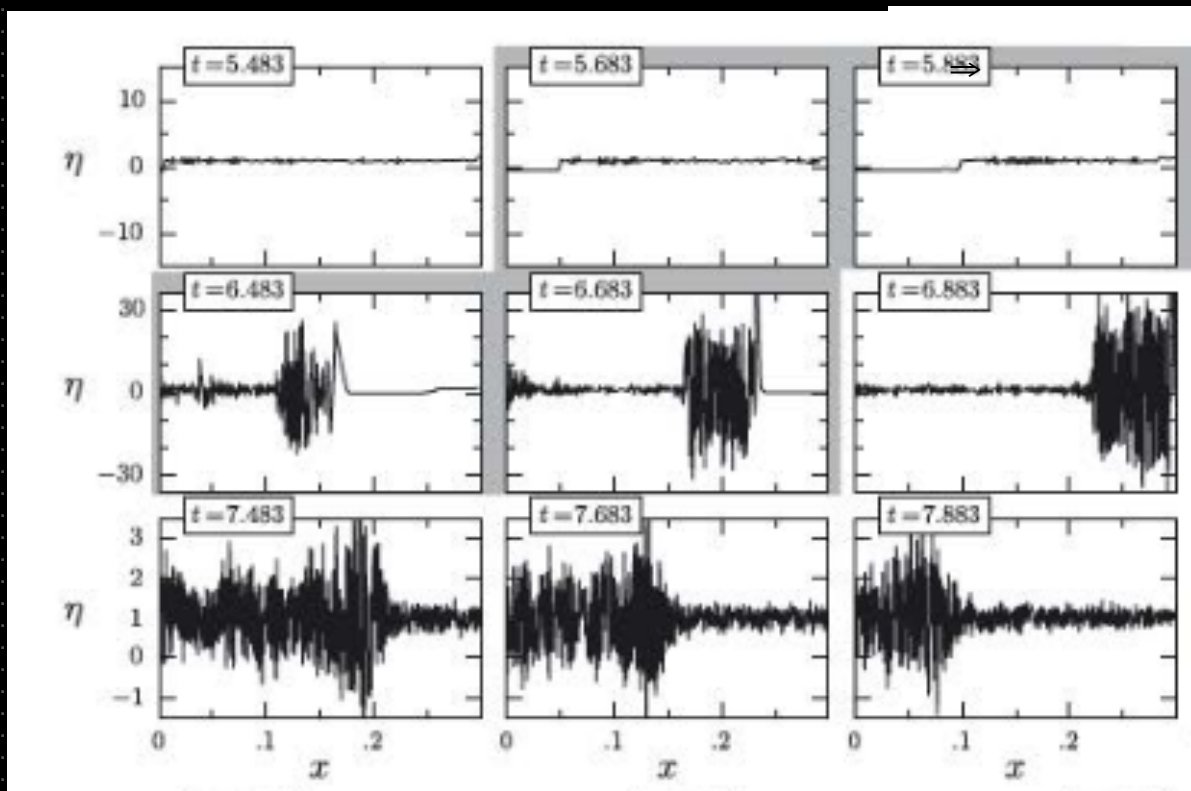
pair density saturates
when γ - velocity drops
below the threshold for
pair creation.

at saturation

$$n_{\pm} = \frac{E_0^2}{8\pi c^2 \gamma_{thr}}$$

Cyclic gap in pulsars – PIC simulations

Pair cascades in NS – Timokhin 2012



Conclusions

- spark gaps may form if survival time of coherent magnetic domains exceeds a few dynamical times. May be the production sites of variable VHE emission.
- gaps are inherently intermittent.
- PIC simulations can better probe gap dynamics and emission, and are underway