Gamma ray emission from hot accretion flows

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Any detection of radiation above 100 MeV from accreting black holes by default considered as a signature of jet emission, although other sites of the production of high energy radiation possible, e.g.:

- BH magnetosphere (Neronov & Aharonian 2007)
- E-m cascades in the radiation field of the disc (Sitarek & Bednarek 2010)
- **Hadronic emission from hot accretion flows (Mahadevan+ 1997, Oka & Manmoto 2003, NXS 2013)**

Tenuous, two-temperature flows (usually referred to as ADAF/RIAFs – misleading terms if direct heating of electrons taken into account) - the most developed and widely accepted model for BH systems observed at luminosities below ~0.01 L_{Edd}

The key property of the model: $T_p >> T_e$ → proton pressure supports geometrically thick flow → low density (needed for inefficient proton-electron coupling and low opt. thickness)

Proton energies above the threshold for pion production:

$$pp \rightarrow \pi^0 + pp$$
$$\downarrow$$
$$2\gamma$$

$$pp \rightarrow \pi^{\pm} + \ldots$$
$$\downarrow$$
$$e^{\pm} + \ldots$$

The model aimed at precise modeling of spectra produced in optically thin, two-temperature accretion flows (for details see Xie, Niedźwiecki, Zdziarski, Yuan 2010; Niedźwiecki, Xie, Zdziarski 2012; Niedźwiecki, Xie, Stępnik 2013):

- a fully GR description of both the radiative processes and the flow structure
- exact (Monte Carlo) treatment of *global* Comptonization effect
- description of hadronic processes (charged and neutral pion production in proton-proton interactions and effects due to products of their decay)

Poorly understood MHD processes parametrized by:

$\beta = P_{gas}/(P_{gas}+P_{mag})$ [MHD simulations support β ≈ 0.9, e.g. Machida+ 2004; we find that β ≈ 0.5 is preferred for hard states in BHBs]

δ – fraction of accretion power directly heating electrons [δ≈0.5 required for hard state in Cyg X-1; while δ<0.1 for low luminosity radiogalaxies]

α–viscosity assumed [supported by MHD simulations, e.g. Ohsuga+ 2009]

GR parameters:

$$R_g = \frac{GM}{c^2} \qquad a = \frac{J}{cMR_g}$$

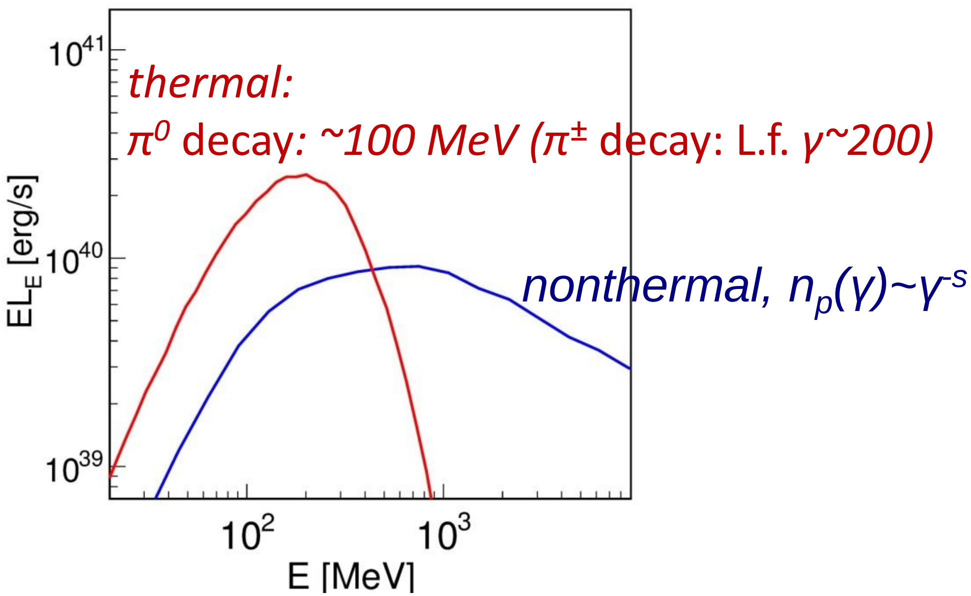
M – BH mass, J - BH angular momentum

$$\dot{m} = \frac{\dot{M}c^2}{L_{Edd}}$$

Distribution function of proton energies

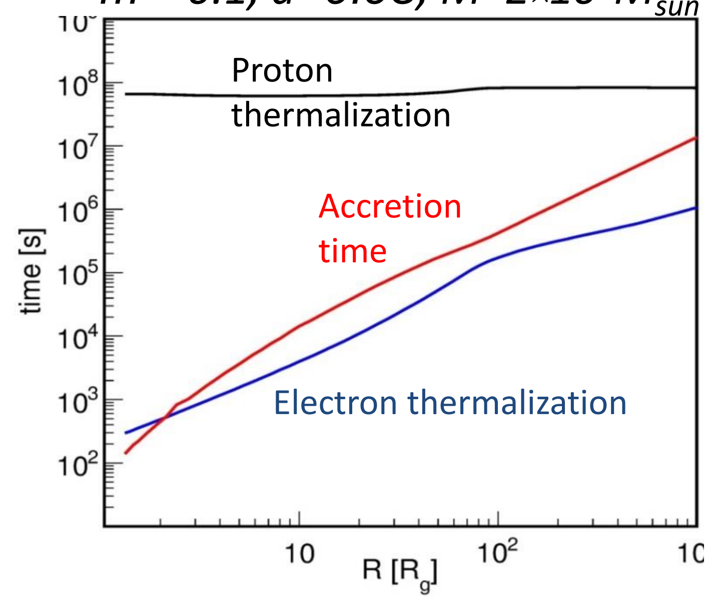
fully determined by uncertain heating mechanism: heating by MHD turbulence (Quataert & Gruzinov 1999)?, reconnection (Bisnovatyi-Kogan & Lovelace 1997)?, …?

Evidence for relativistic acceleration (the presence of a non-thermal component in the electron distribution: detections of the MeV tails in the hard states of BHBs; the shape of the radio spectrum of Sgr A*) which for protons may result even in an entirely nonthermal distribution



Timescales in a hot flow

$\dot{m}$ = 0.1, a=0.95, M=2×$10^8 M_{sun}$

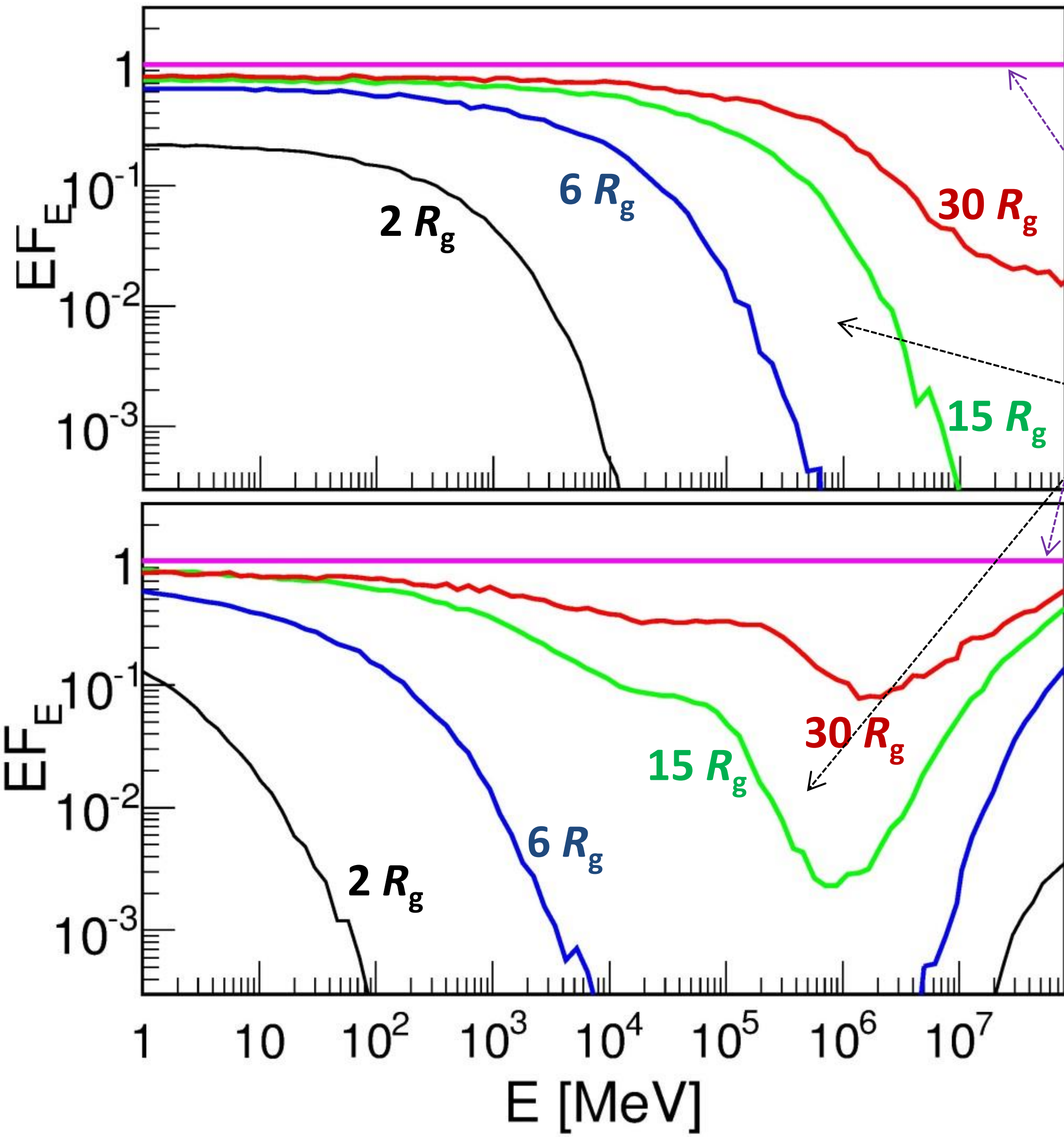


We consider two limiting cases:

- Thermal distribution (establishes a lower limit for the magnitude of hadronic component)
- Power-law distribution (total available energy provided to a fraction of p. with accel. index s)

Rest-frame hadronic emission computed following Dermer (1986)

Gamma-ray opacity of hot accretion flows

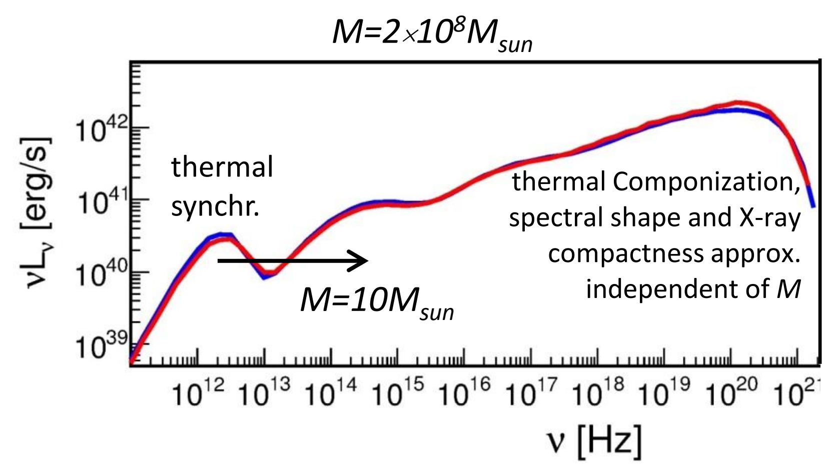


0.0005L_Edd
2×10^8M_sun

Intrinsic, rest-frame spectrum

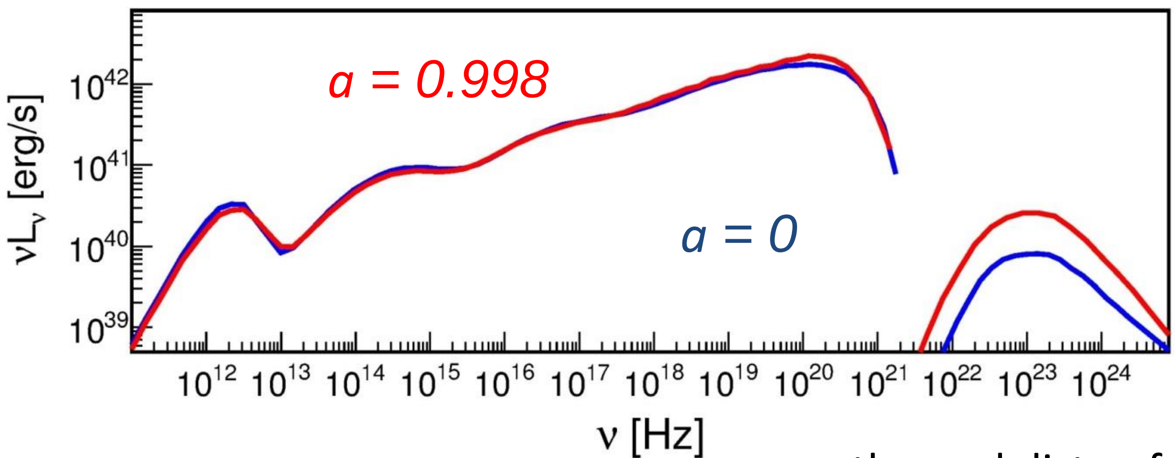
The spectra, affected by GR transfer and γγ absorption, observed from a source located at R = 2, 6, 15, 30 R_g

0.01L_Edd
10M_sun



In BHBs TeV emission from the vicinity of a BH can be observed even from luminous flows at ~0.01 L_{Edd}
In AGNs such emission can be observed only from strongly underluminous systems below ~10^{-6} L_{Edd}

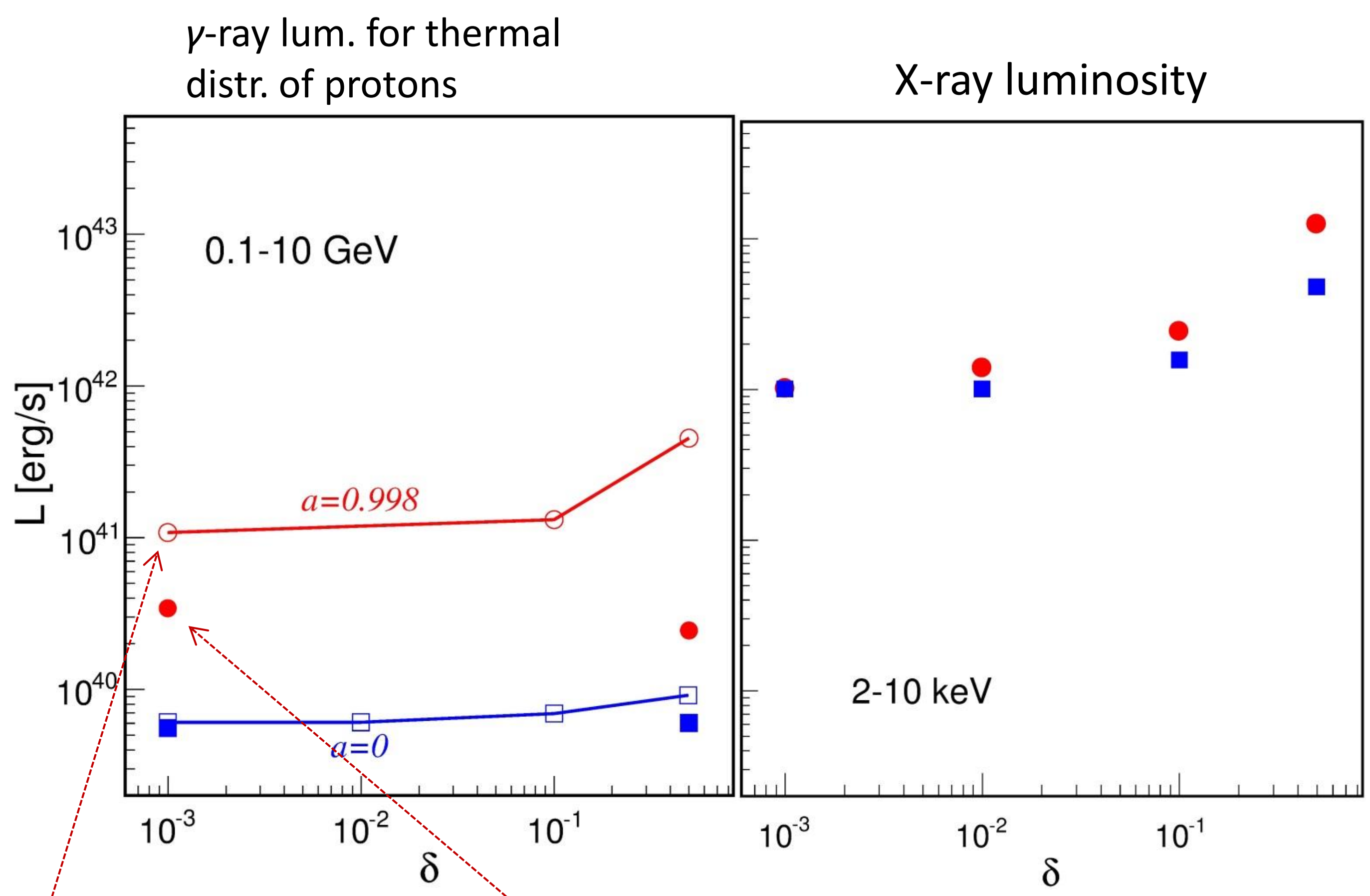
$\dot{m} = 0.1,\ \beta = 0.9,\ \delta = 0.001,\ M=2\times10^8 M_{sun}$



nonthermal distr. of protons, s=2.6

Dependence on BH spin

discussed already by Shapiro, Lightman & Eardley 1976



Open symbols: neglect, filled: take into acount γγ absorption

$\dot{m} = 0.1$, $\beta=0.9$, $M=2\times10^{8}M_{sun}$

Dependence on BH spin

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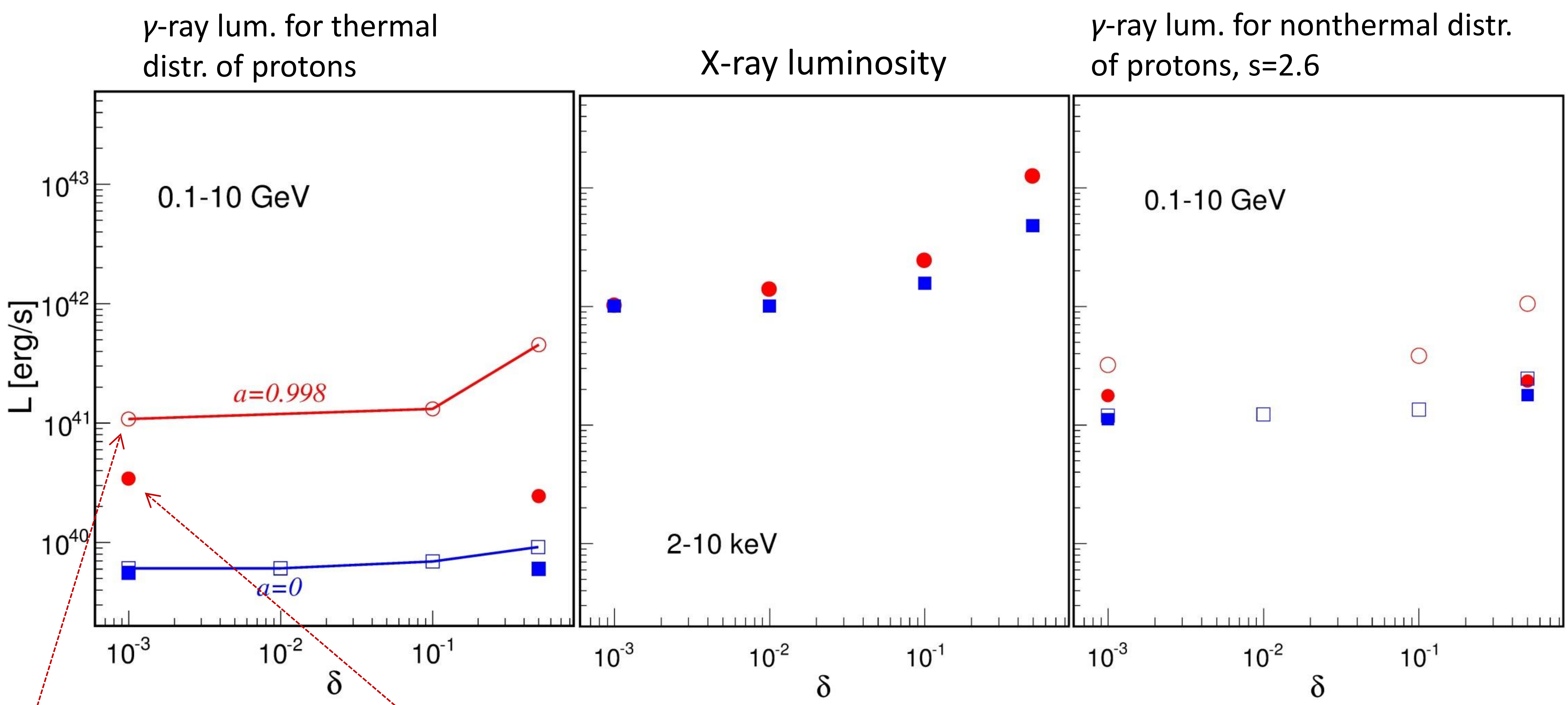

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$\dot{m}$ = 0.1, β=0.9, $M=2\times10^8 M_{sun}$

Dependence on BH spin

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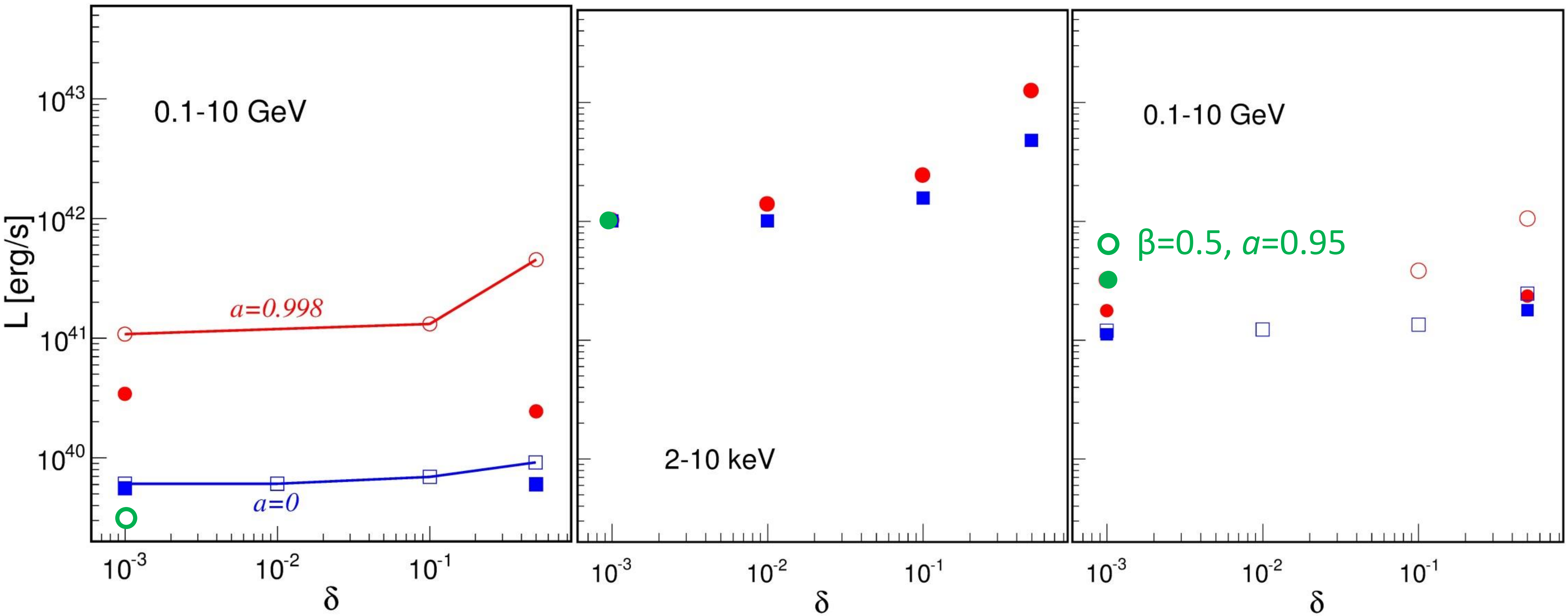
γ-ray lum. for thermal distr. of protons

X-ray luminosity

γ-ray lum. for nonthermal distr. of protons, s=2.6

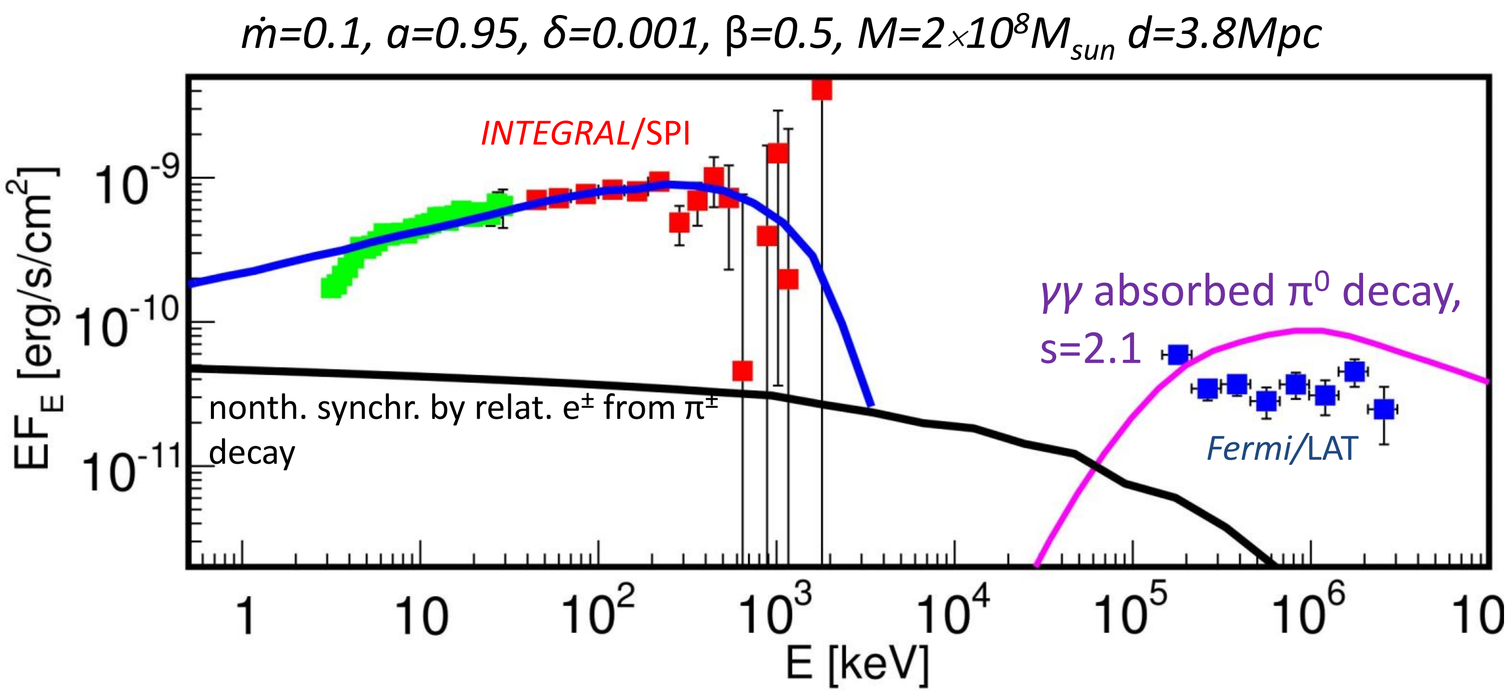


$\beta = P_{gas}/(P_{gas}+P_{mag})$

$\dot{m} = 0.1$, $\beta=0.9$, $M=2\times10^{8}M_{sun}$

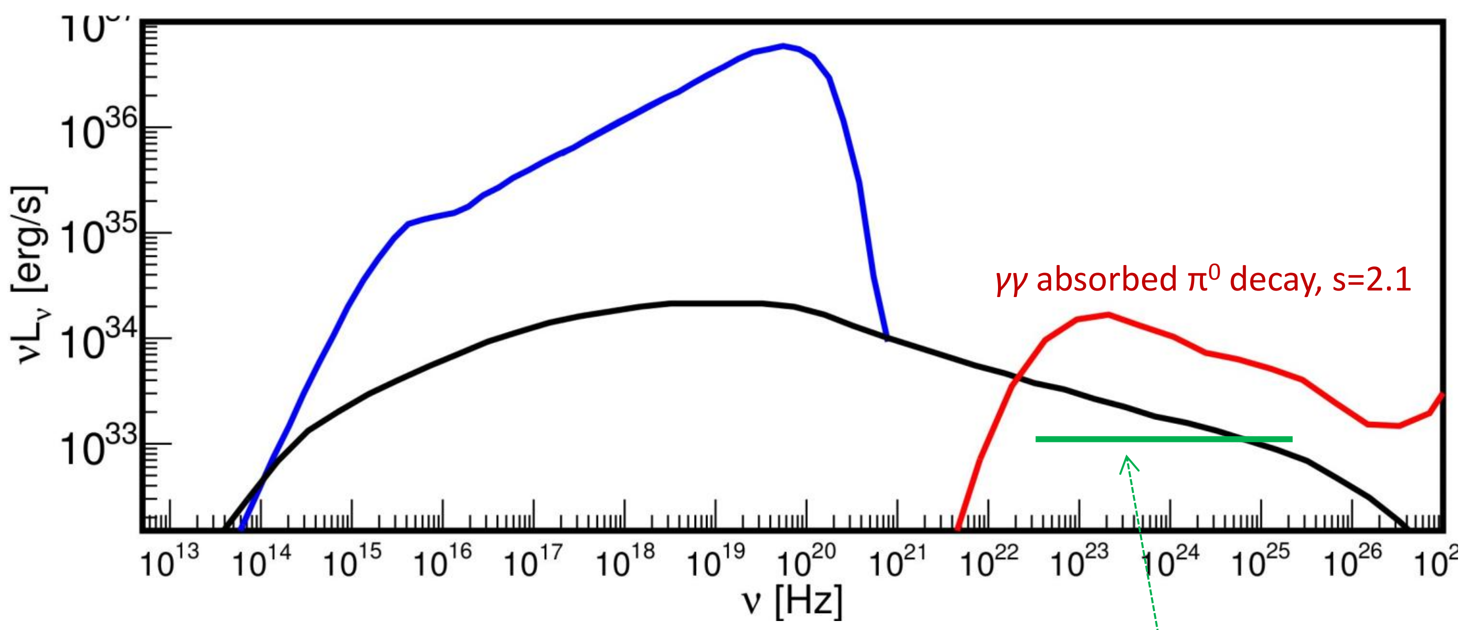
Centaurus A

SED dominated by
- jet (Chiaberge+; Abdo+,...)
- accretion flow (Evans+, Whysong & Antonucci, Meisenheimer+, Fukazawa, ...)



If the X-ray emission is produced by thermal Comptonization in a hot flow, π^0 decay photons should contribute significantly to the Fermi measurement, unless protons have a thermal distribution and either the BH rotates slowly or the magn. field is rather strong $\beta \approx 0.5$.

Model matching the X-ray luminosity and (approximately) the electron temperature in the hard state in Cyg X-1 – inconsistent with recent constraint from *Fermi* (and also from previous constraints from MAGIC if acceleration of protons to TeV energies assumed) unless protons have a thermal distribution and either the BH rotates slowly or the magn. field is rather strong β≈0.5.



Fermi constraint for the hard state in Cyg X-1, Malyshev+ (2013)

Summary

Hadronic processes in hot accretion flows lead to a substantial γ-ray emission, which may contribute significantly to the γ-ray fluxes measured from non-blazar systems; application to various objects in progress.

Comparison of the model prediction with observations can constrain the proton distribution function and, then, help to understand the heating mechanism in hot accretion flows.

If that problem is understood, the level of hadronic emission might be used to constrain the key parameters of the model: a, β, δ.

Hot flows around stellar BHs are mostly transparent to photons with energies above several TeV – may be an interesting target for CTA if episodic acceleration to very high energies occurs in the vicinity of BH horizon.