Revising the TeV emission of microquasars; the case of Cygnus X-1

Dimitrios Kantzas
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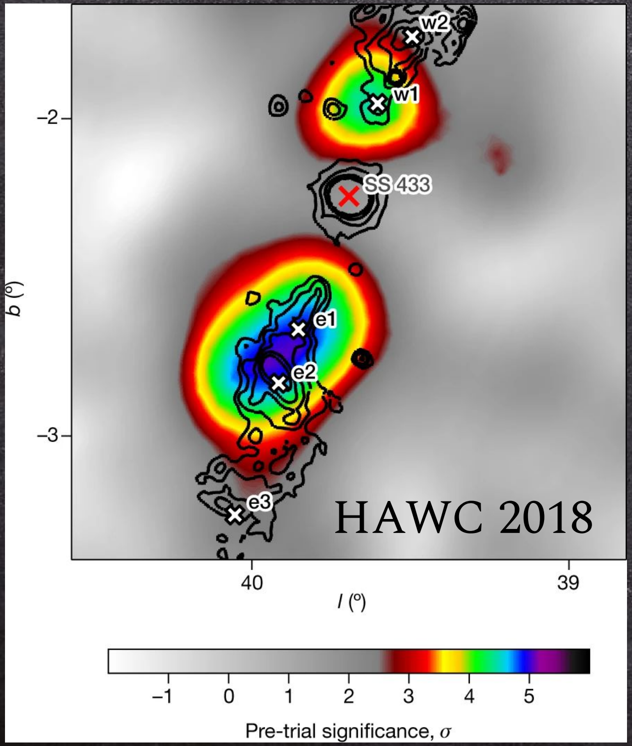
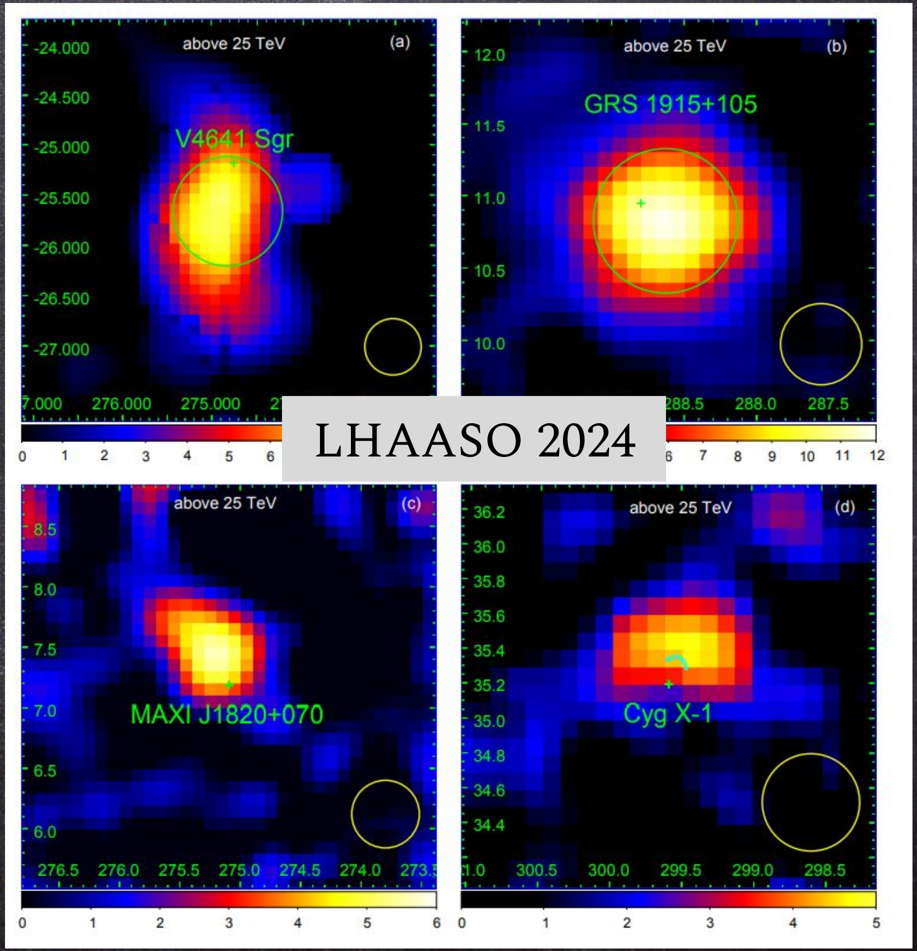
with
Francesca Calore, Marco Chianese, Sera Markoff, Matteo Lucchini, Chiara Ceccobello, Koushik Chatterjee, Alex Cooper, Daniele Gaggero, Pedro De La Torre Luque, Maria Petropoulou & CHOCBOX collaboration

Black hole X-ray binaries in TeV γ-rays

above 25 TeV

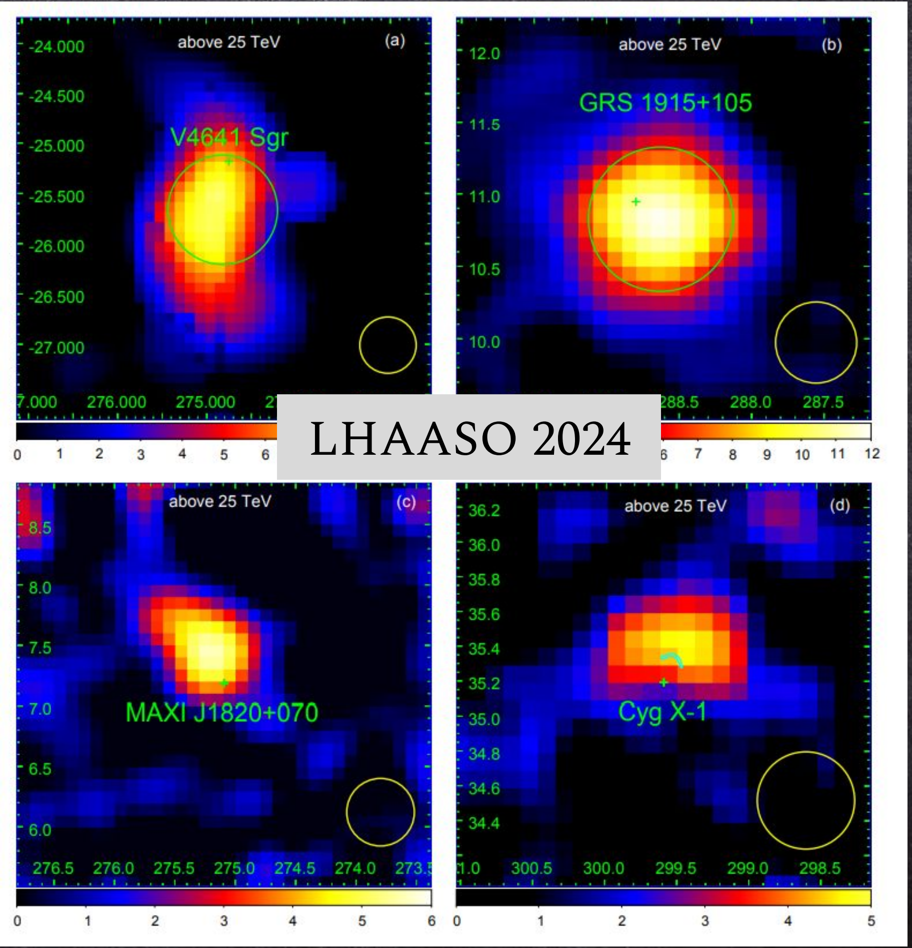




BHXBs are cosmic ray accelerators !?

No surprise because it was predicted from

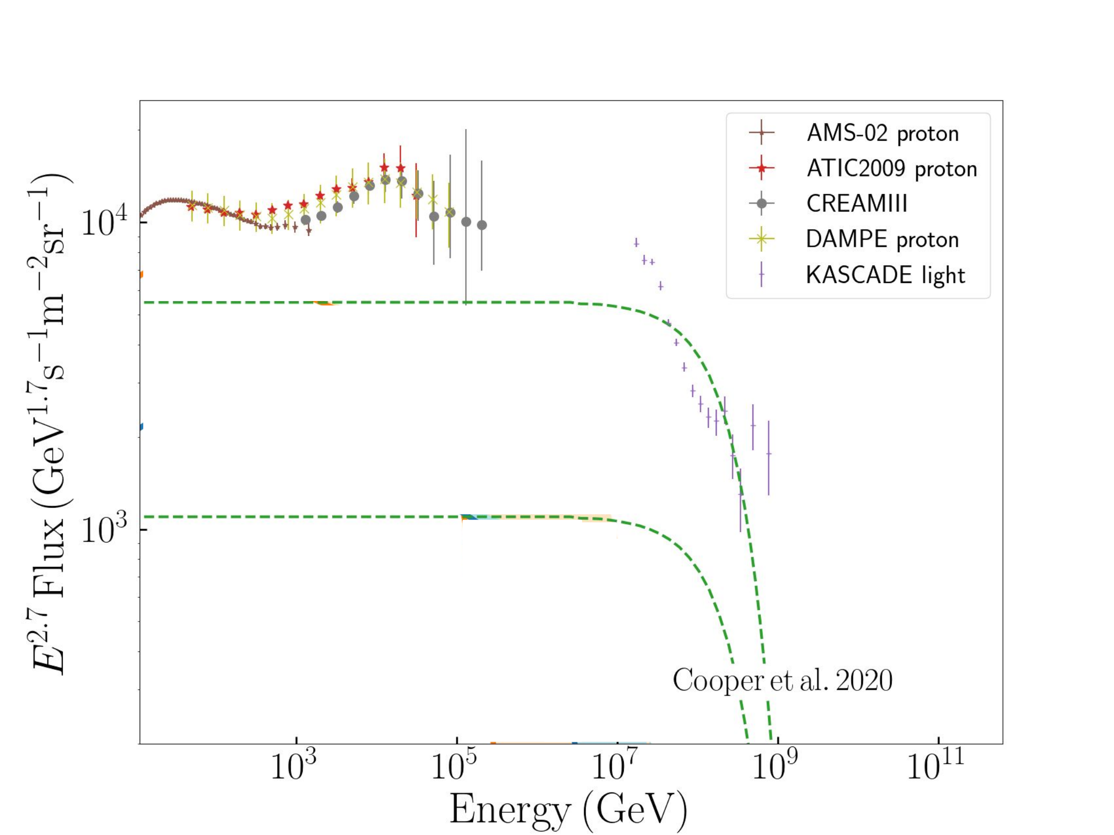
- Population analysis
- Spectral modelling



LHAASO 2024

Contribution of BHXBs to the CR proton spectrum

... in the hard state



See also
Levinson & Waxman 2001
Romero et al. 2003
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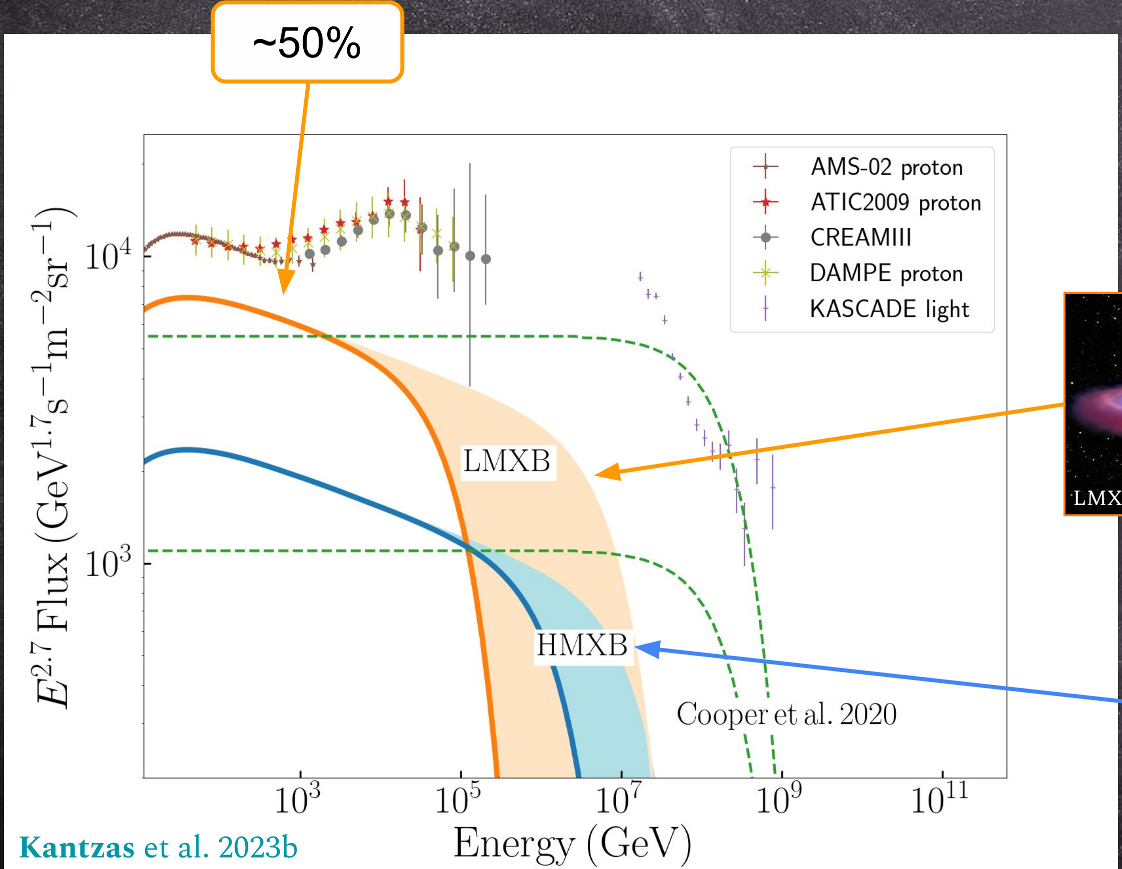

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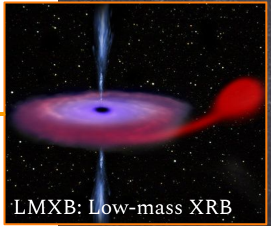

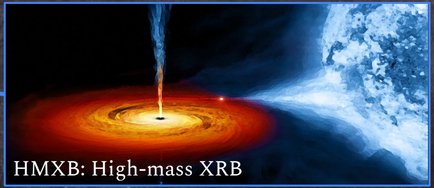

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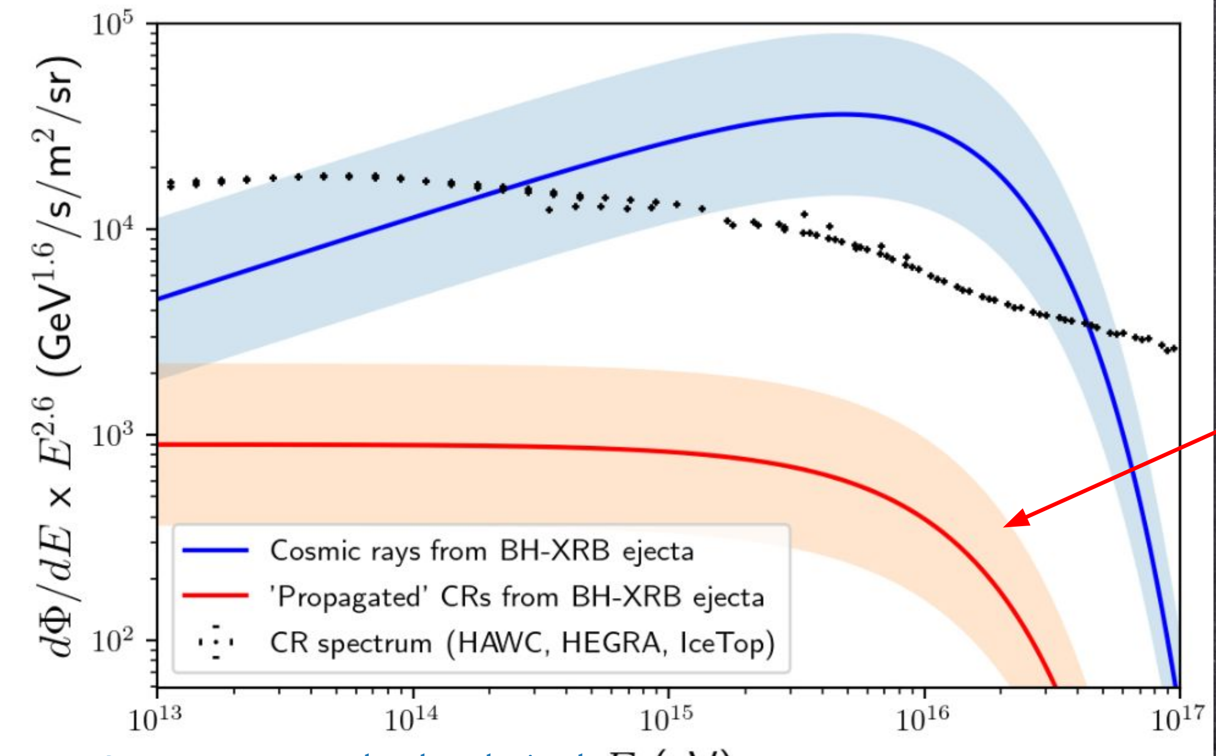
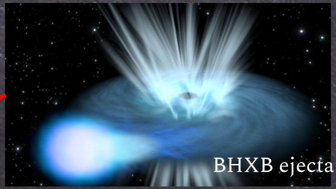
Contribution of BHXBs to the CR proton spectrum

... from ejecta

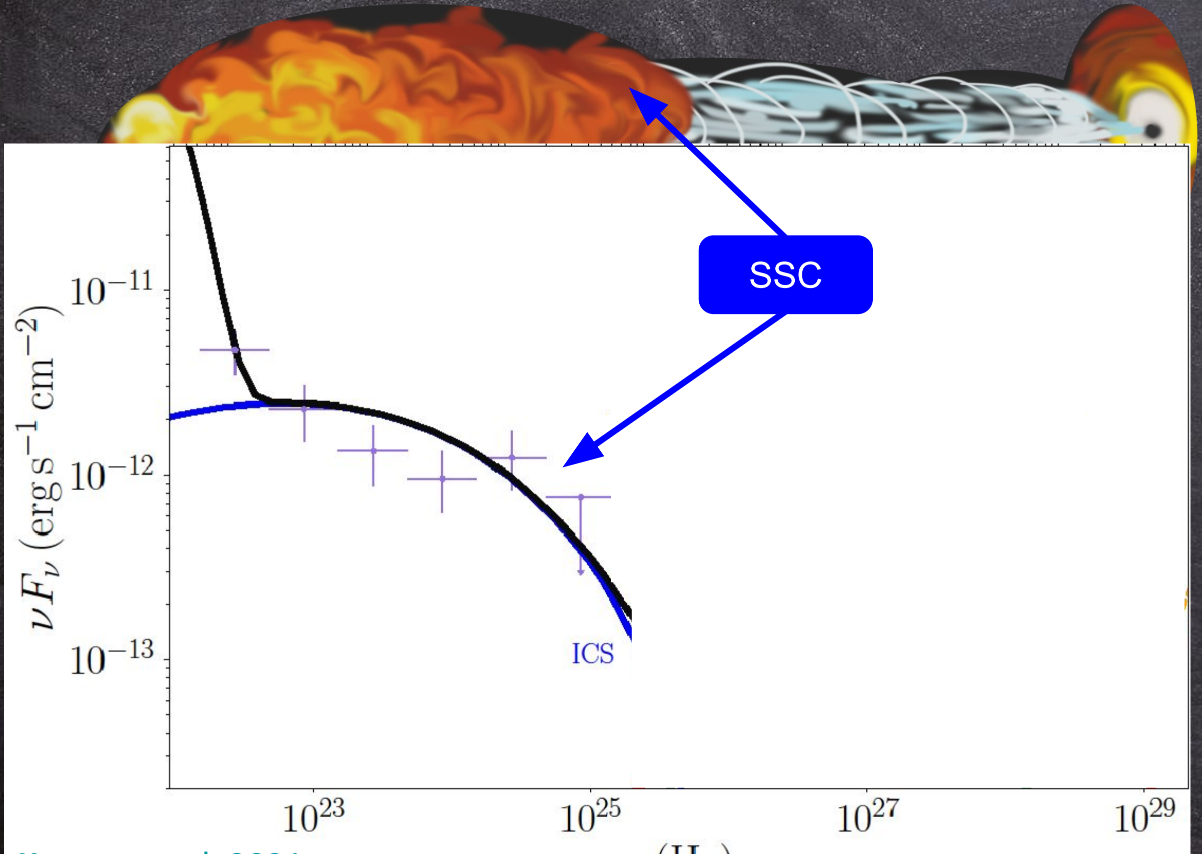


Bacon, Cooper, **Kantzas** et al. to be submitted



See also
Kantzas et al. 2024
for quiescence

Multiwavelength constraints from **Cygnus X-1**



Kantzas et al. 2021

... before LHAASO

- Hard particle spectra (p=1.7)

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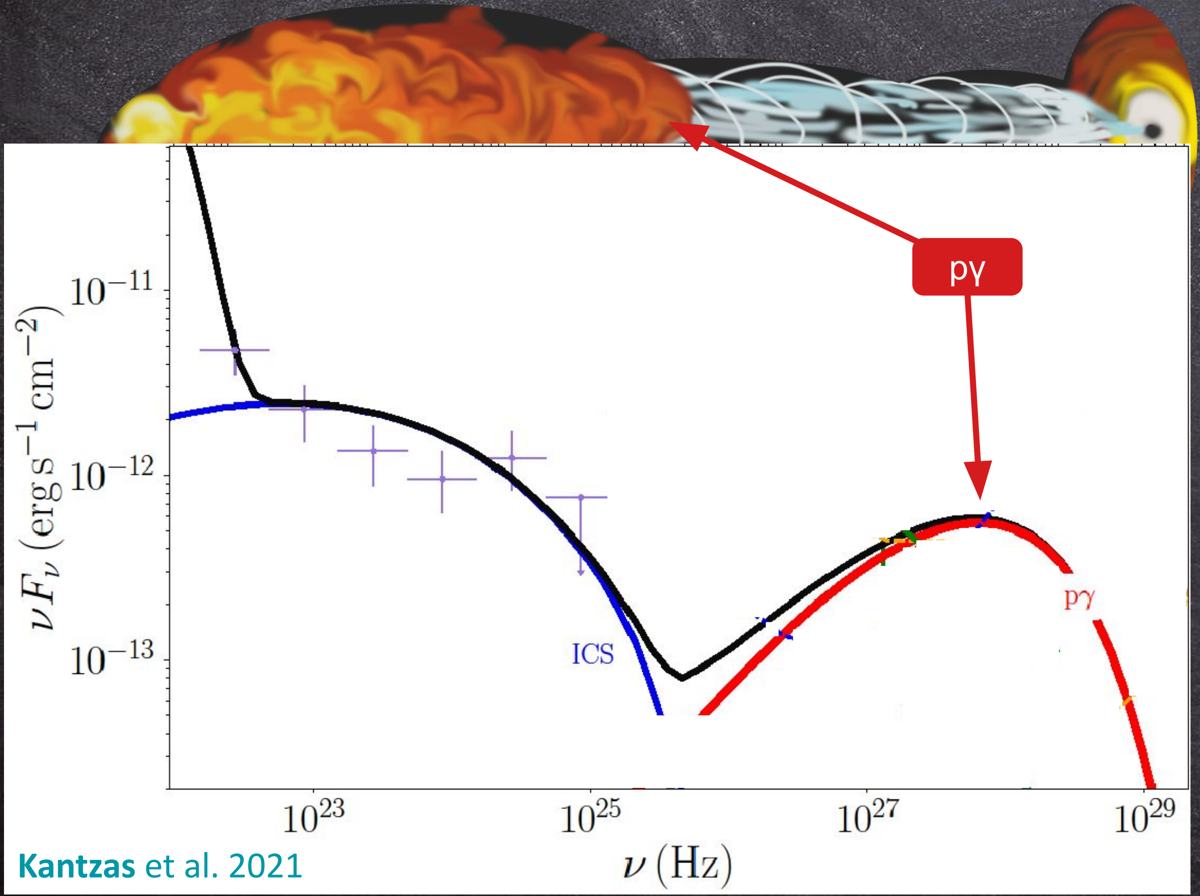

Kantzas et al. 2021

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- both leptonic and hadronic contribution

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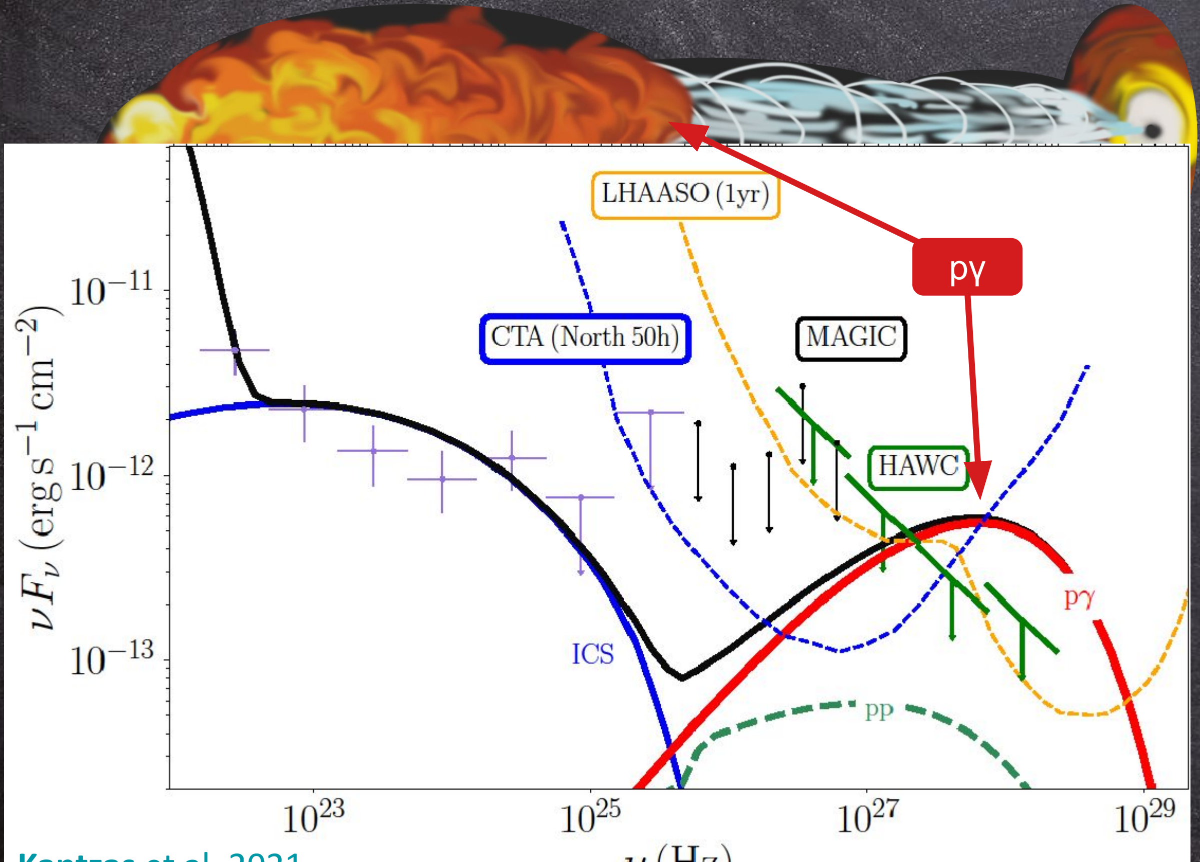

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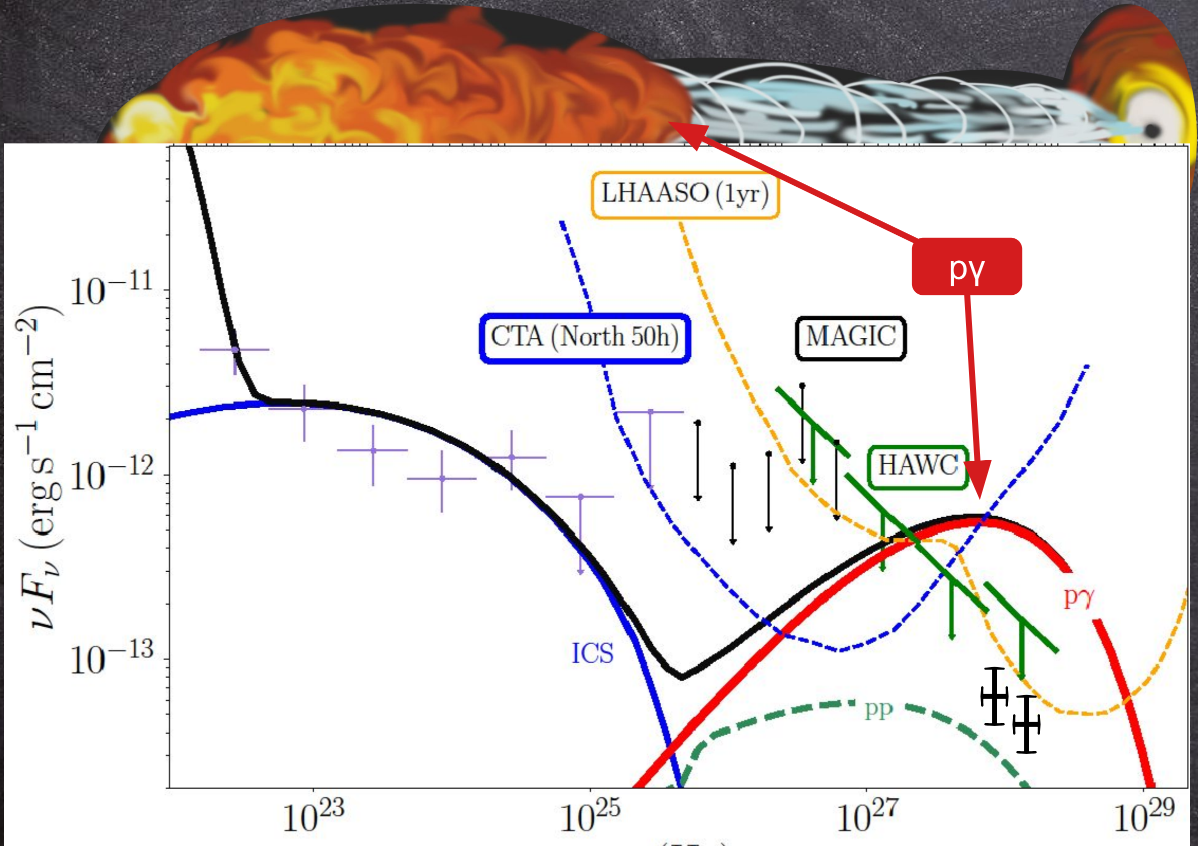

Kantzas et al. 2021

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LHAASO does detect it !!

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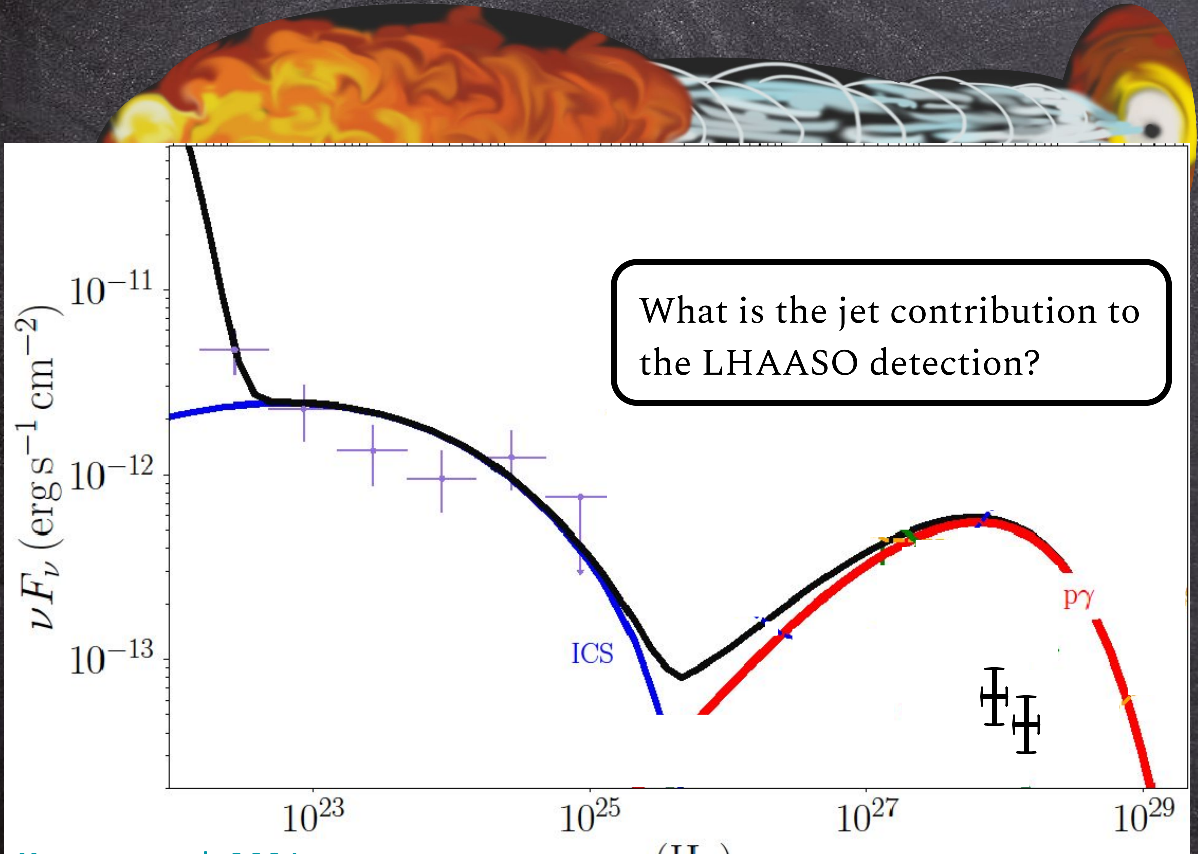

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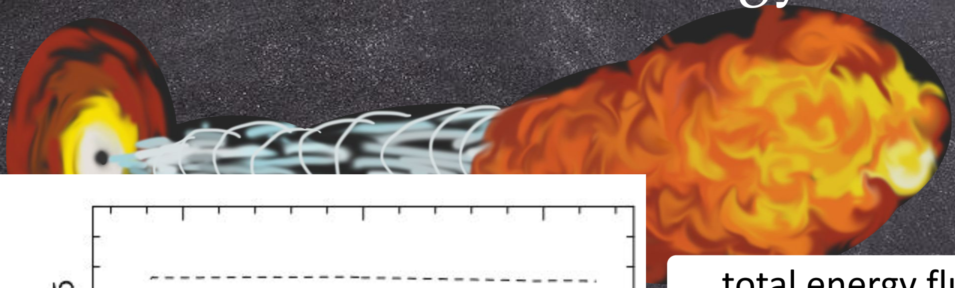
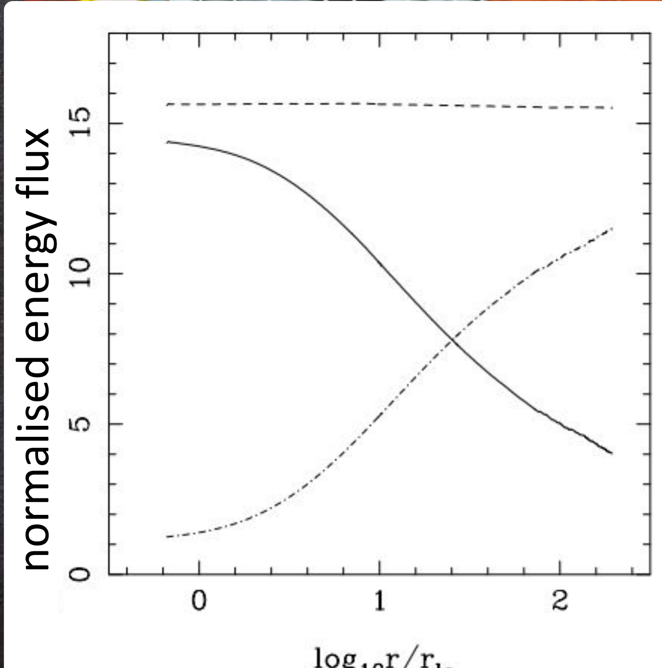
Jet acceleration and energy dissipation





Komissarov et al.

total energy flux/rest mass flux: $\mu=\gamma\,(\sigma+1)$

bulk Lorentz factor: γ

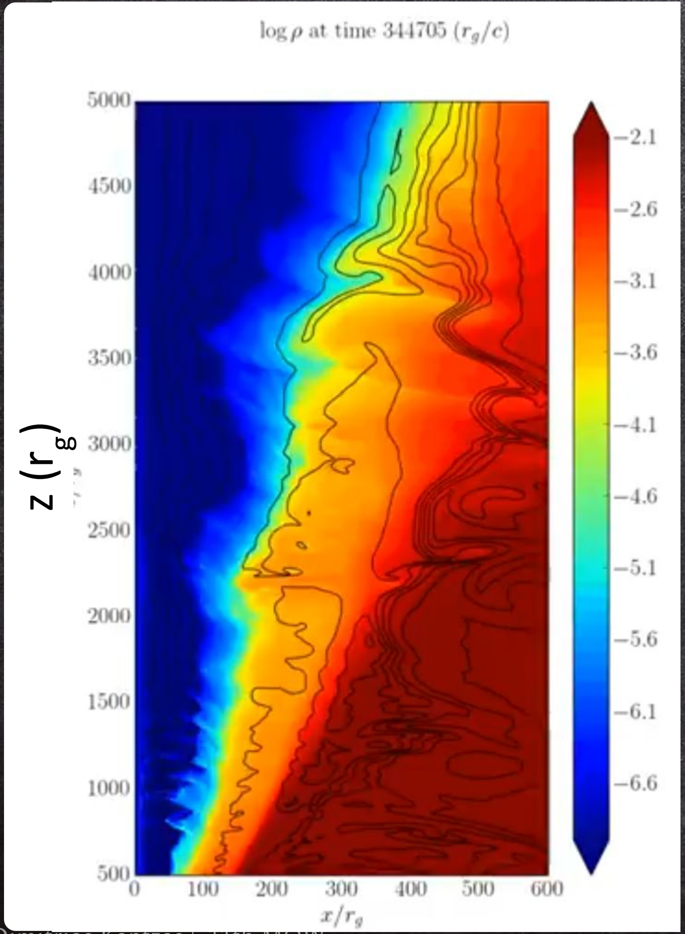
magnetisation: $\sigma=B^2/4\pi\rho c^2$

jet mass density

Magnetic energy dissipates to accelerate the jet & thermalize the particles

See also: Vlahakis et al. 2003, 2004, Beskin & Nokhrina 2006, McKinney et al. 2006, 2009, Komissarov et al. 2009, Tchekhovskoy et al. 2008, 2011, 2016

Mass loaded jets



General Relativity MagnetoHydroDynamic (GRMHD) simulations of Chatterjee et al. 2019; 6000 × 800 × 1 with *H-AMR* (Liska et al. 2018a,b,c)

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See also: Eichler 1993; Spruit et al. 1997; Begelman 1998; Giannios & Spruit 2006; Sironi et al. 2021

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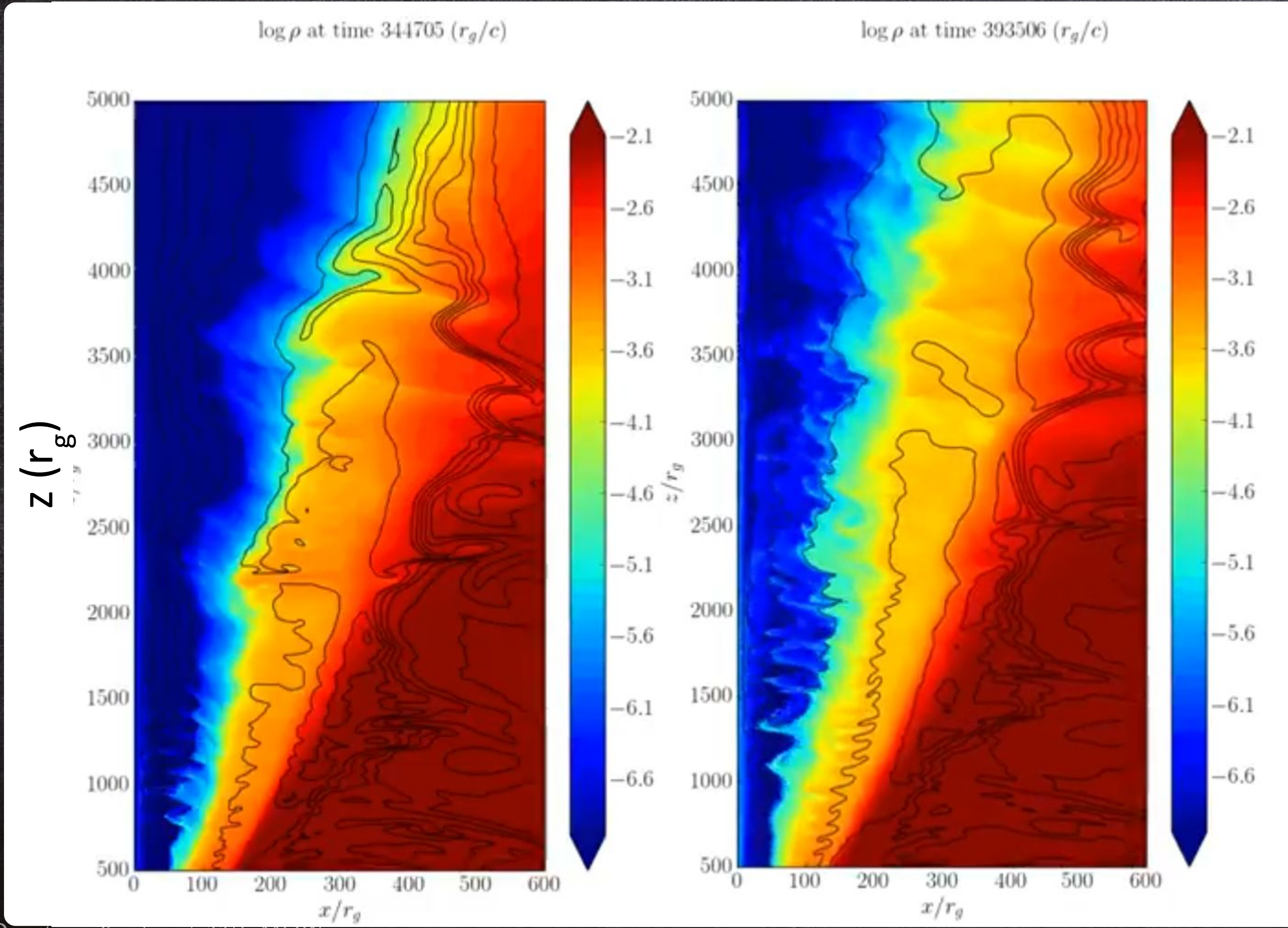

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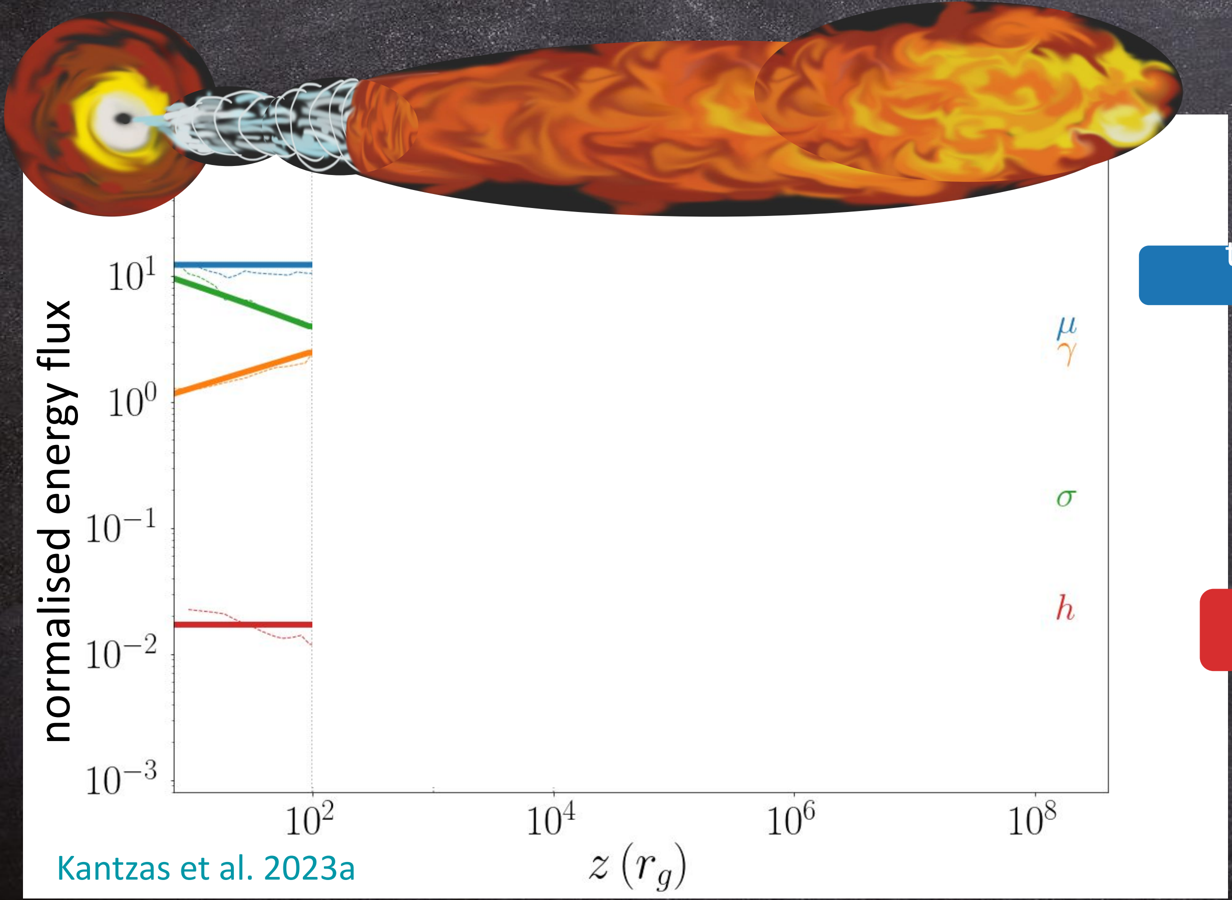
Mass loaded jets

… the analytical approach



Kantzas et al. 2023a

total energy flux/rest mass flux: $\mu=\gamma(\sigma+h+1)$

magnetisation: $\sigma=B^2/4\pi\rho c^2$

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specific enthalpy: $h=(U_{gas}+P_{gas})/\rho c^2$

jet mass density

Mass loaded jets

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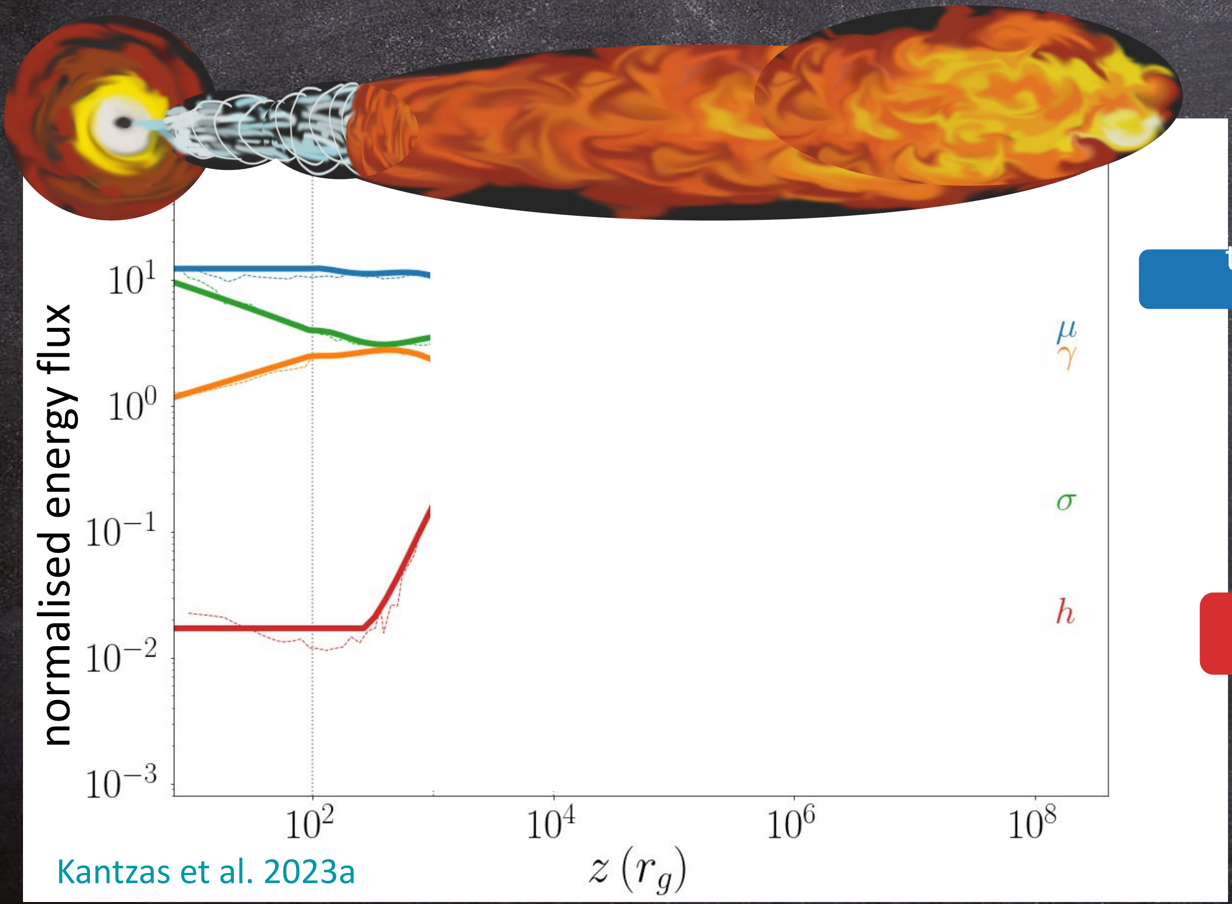

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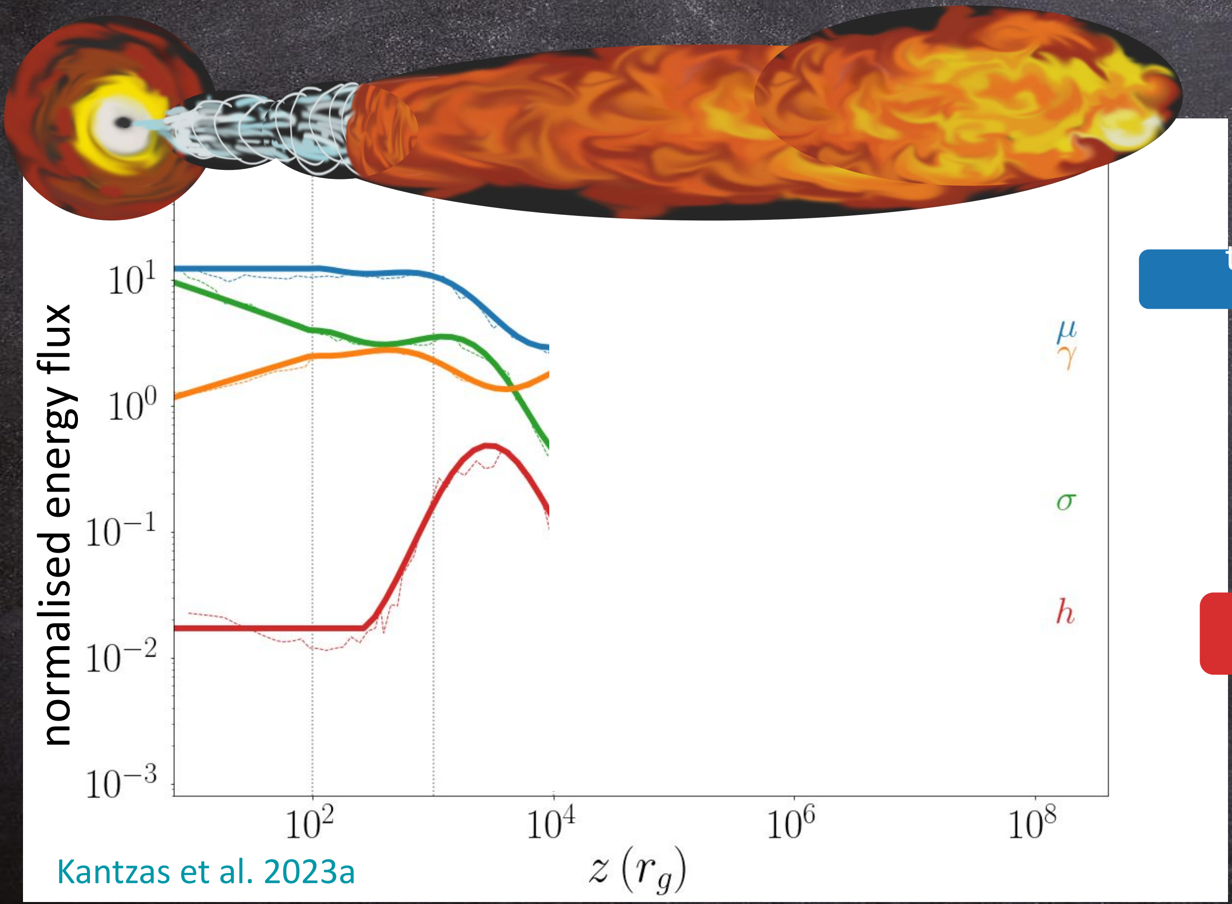

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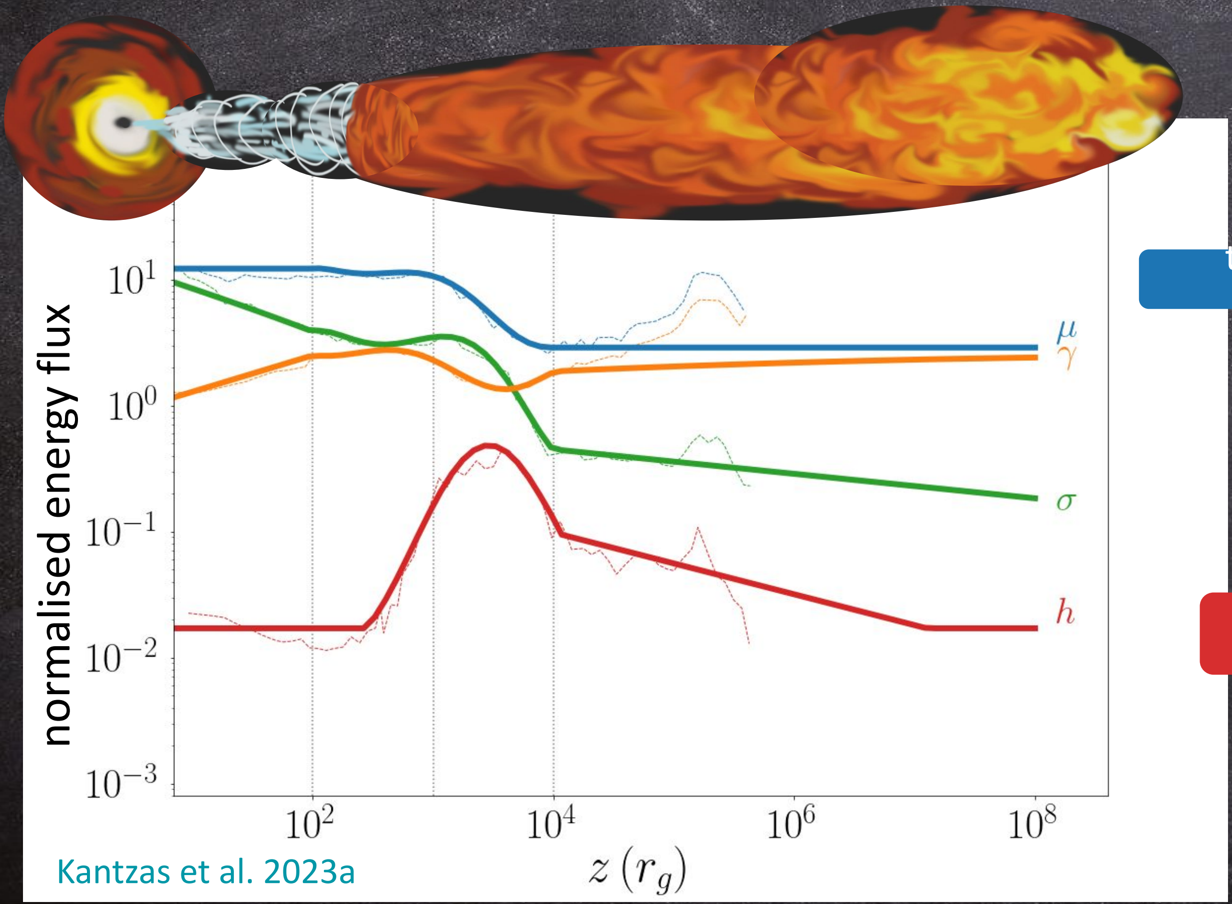

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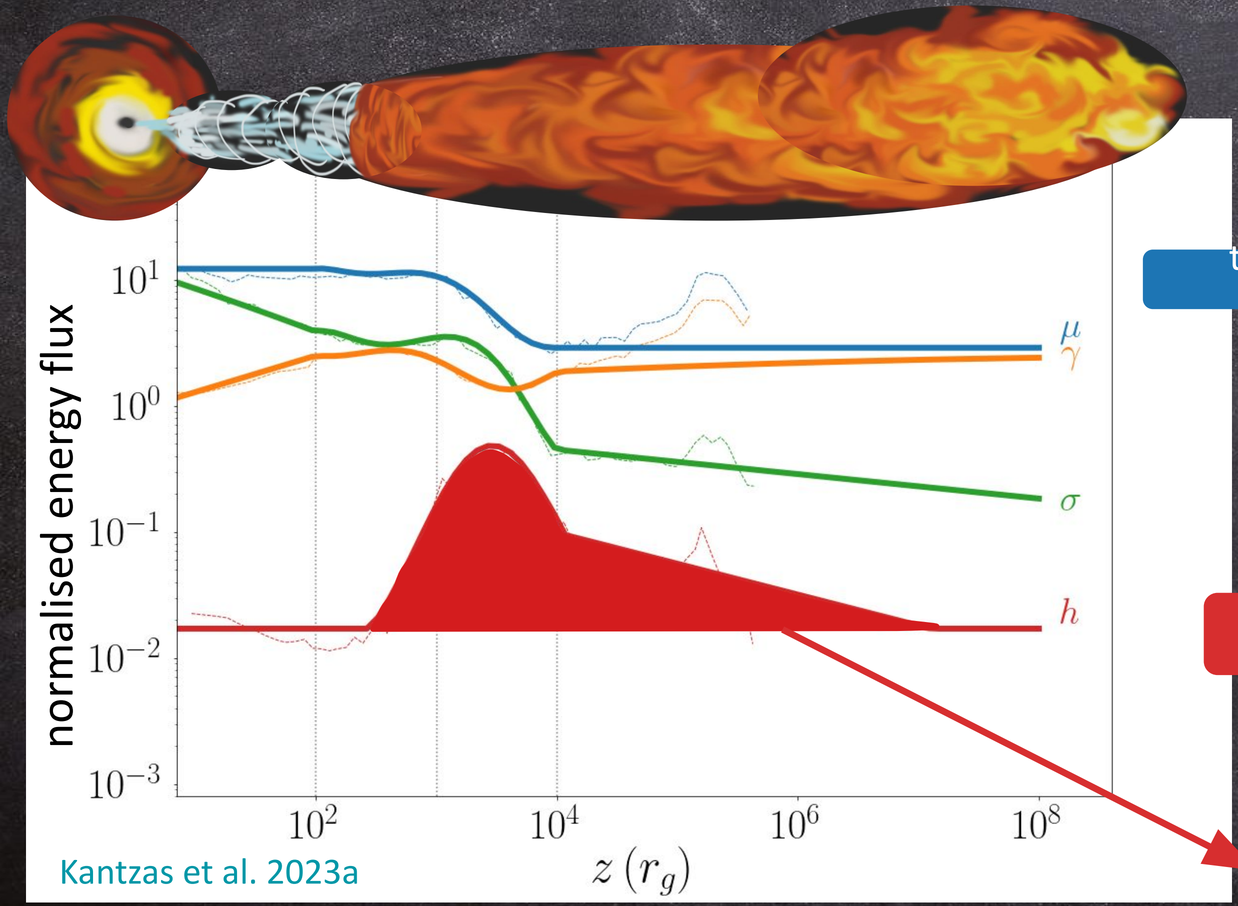

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proton energy

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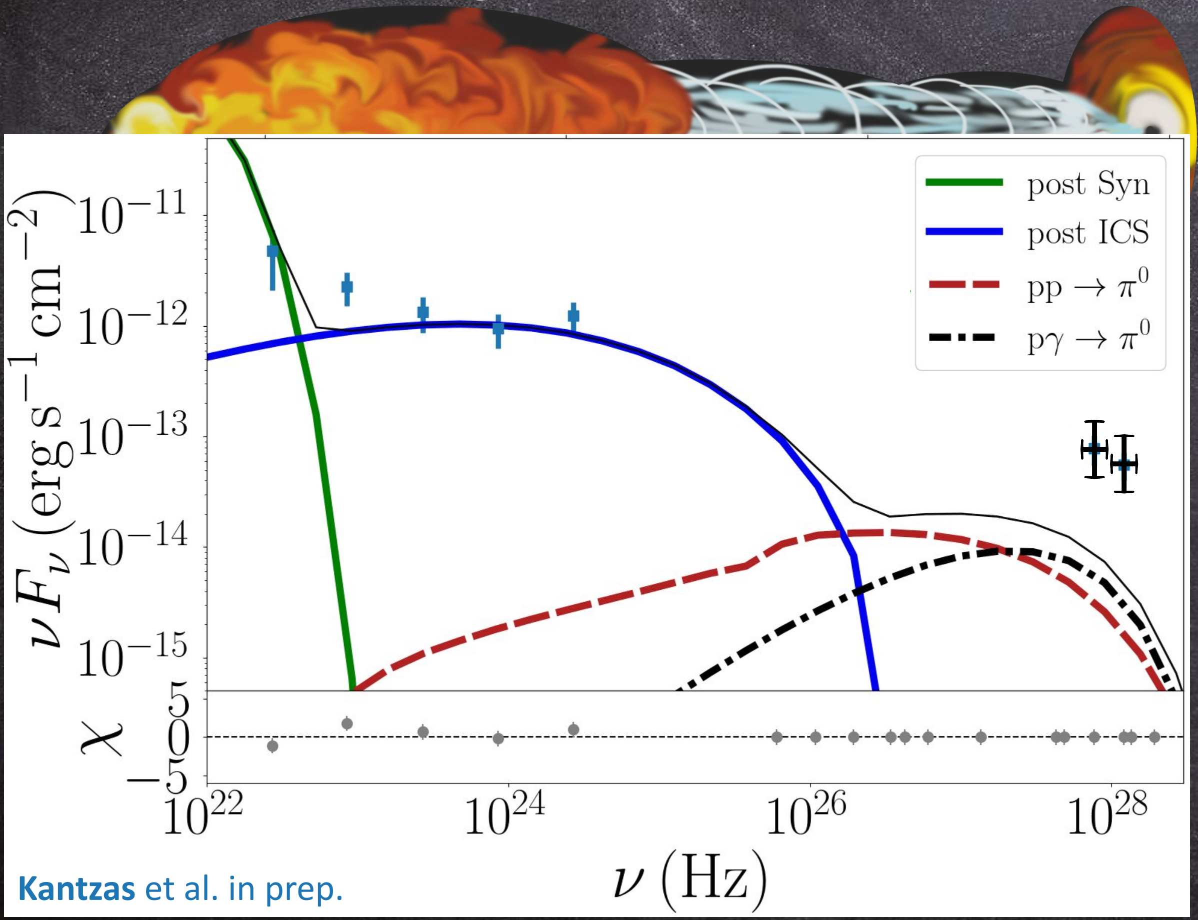
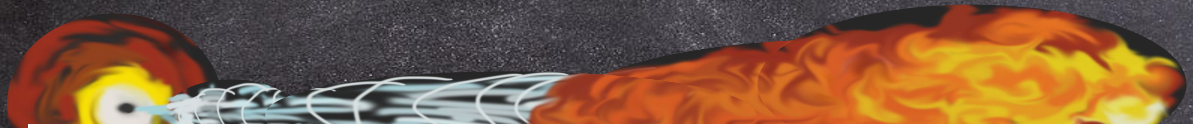
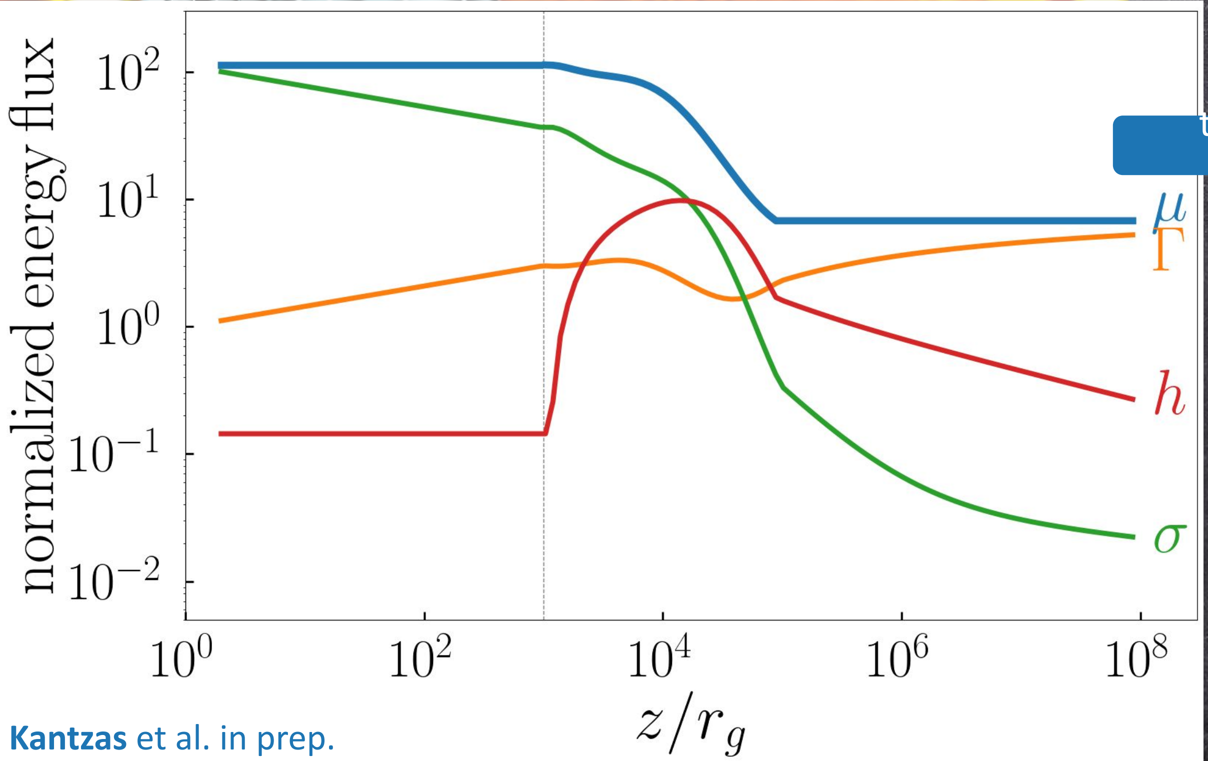


... after LHAASO

- Hard particle spectra (p=1.7)
- 10% hadronic contribution
- possible reacceleration
- mass loaded jets

Mass loaded jets of **Cygnus X–1**





Kantzas et al. in prep.

total energy flux/rest mass flux: μ=γ(σ+h+1)

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jet mass density

Take home messages

- BHXBs are CR accelerators ↔ γ-ray emitters
  - Theoretically predicted & observationally confirmed
- Mass-loading jets can explain the MW spectrum of Cygnus X-1
  - Reacceleration required to fully explain the TeV emission (work in progress)