Black hole X-ray binaries: the missing PeVatrons?

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with Francesca Calore
and S. Markoff, M. Lucchini, C. Ceccobello, K. Chatterjee, A. Cooper, D. Gaggero, P. De La Torre Luque, M. Petropoulou

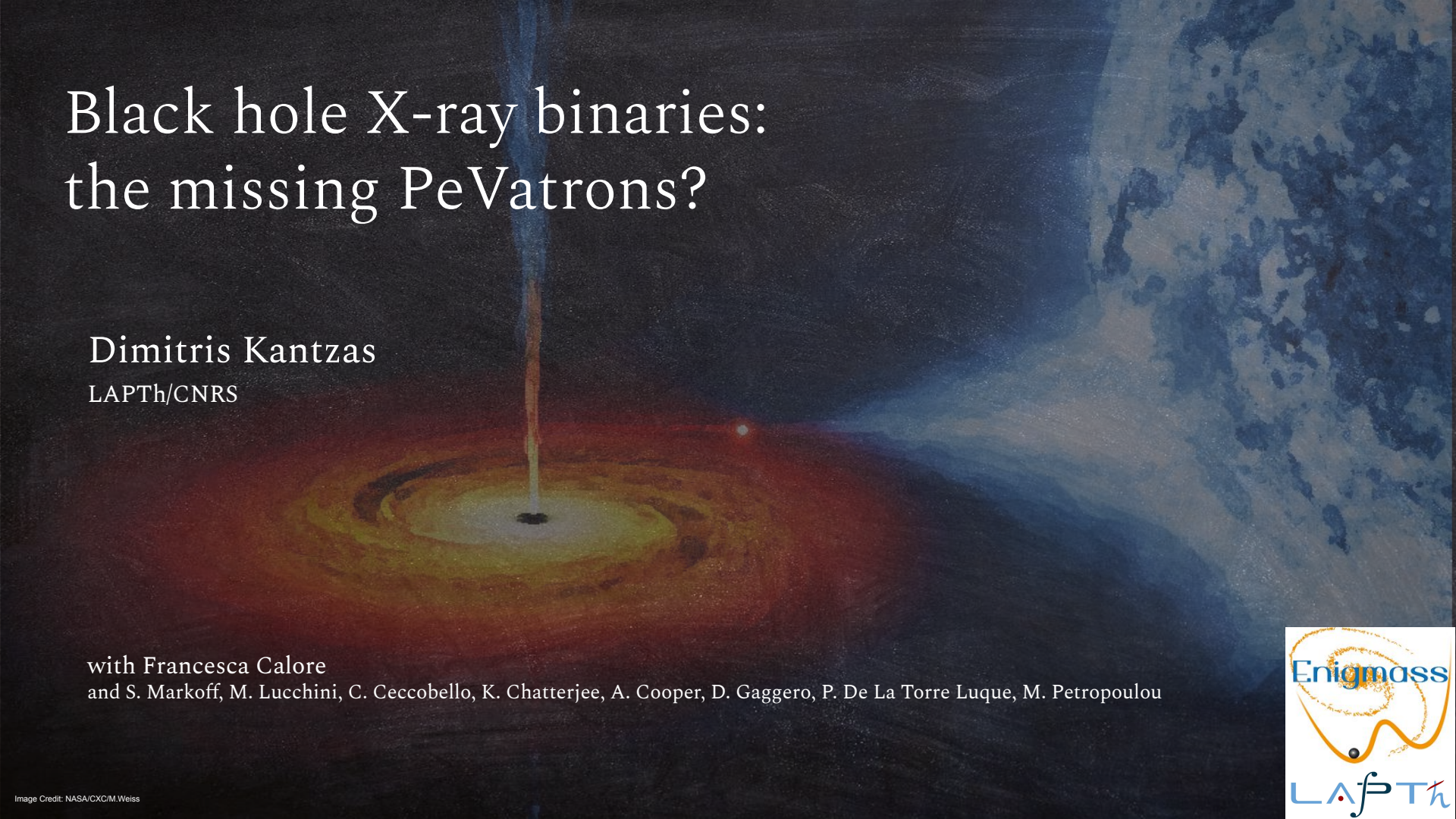
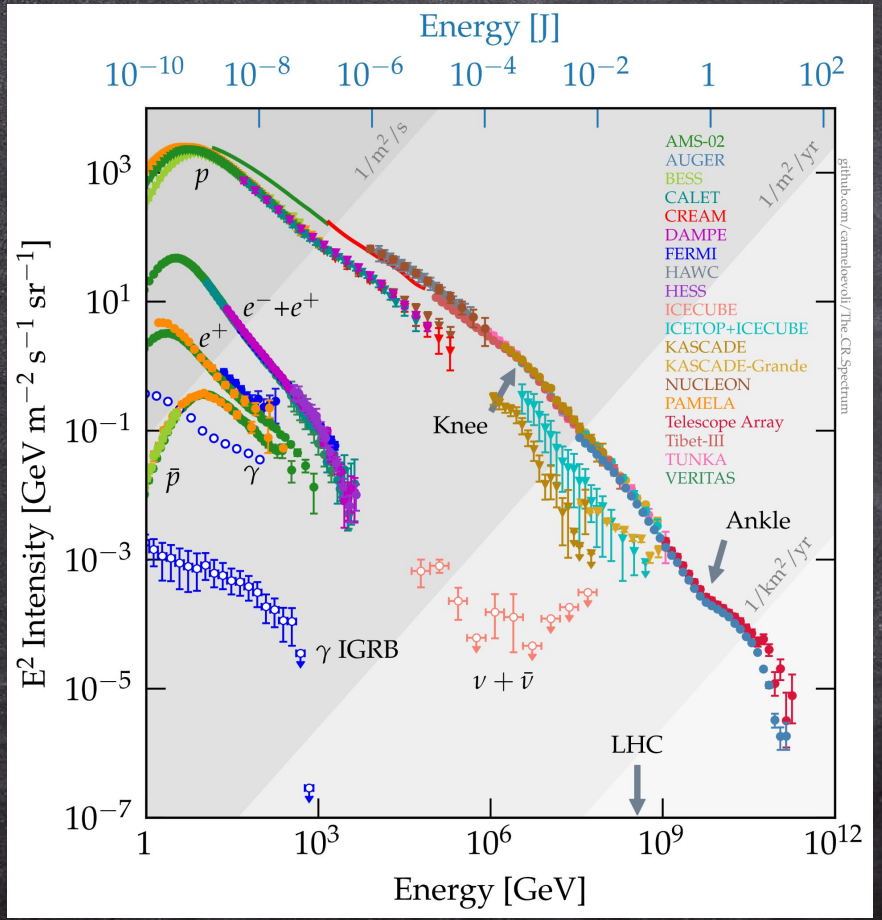


Image Credit: NASA/CXC/M.Weiss

Cosmic-ray sources

Galactic: up to **PeV**/knee

Extragalactic: ~ankle



Indirect cosmic-ray detection

$\pi^0 \rightarrow 2\gamma$

$p + p/\gamma \rightarrow p + \alpha\pi^0 + \beta(\pi^+ + \pi^-)$

PeVatron identification (mostly PWNe)!

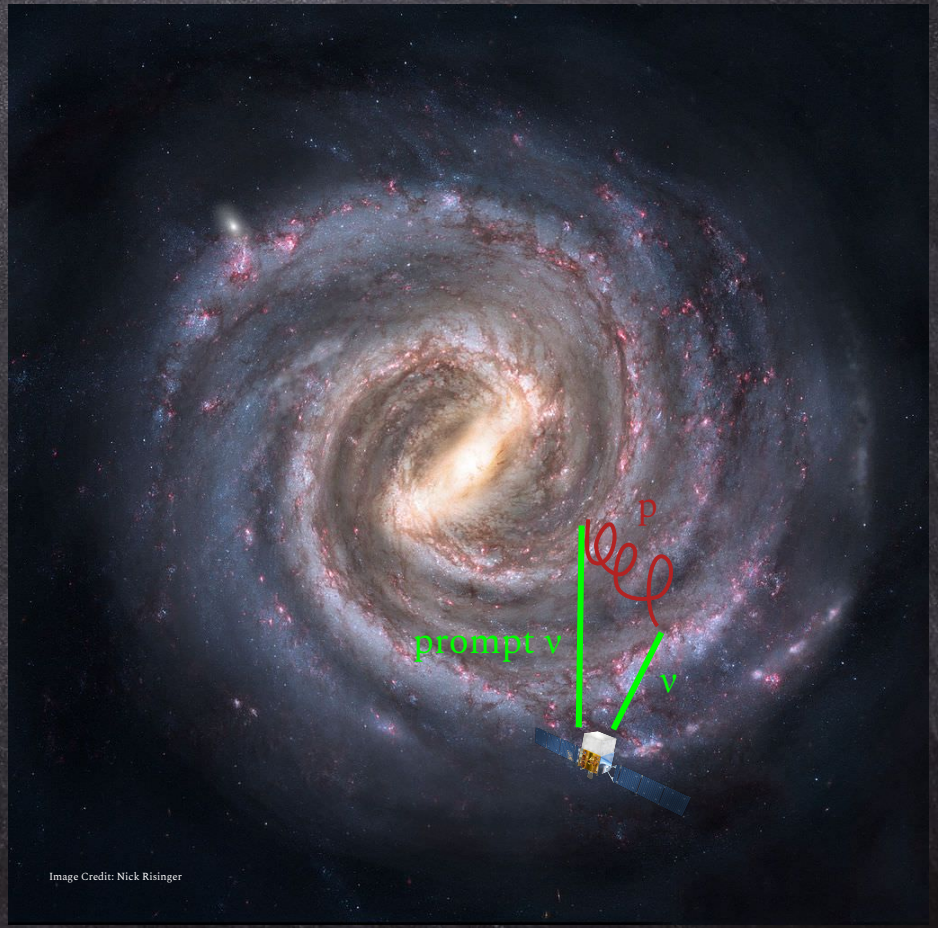
Indirect cosmic-ray detection

$\pi^0 \rightarrow 2\gamma$

$p + p/\gamma \rightarrow p + \alpha\pi^0 + \beta(\pi^+ + \pi^-)$

$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$

$\mu^{\pm} \rightarrow e^{\pm} + \nu_e + \nu_{\mu}$



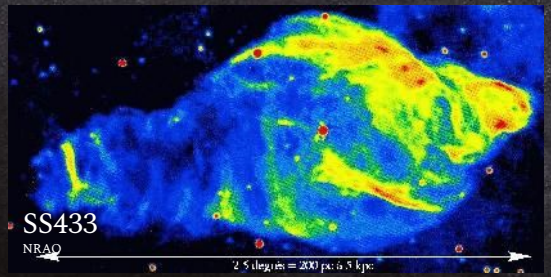
Small scale astrophysical jets

Black hole X-ray binaries (BHXBs)

Relativistic jets

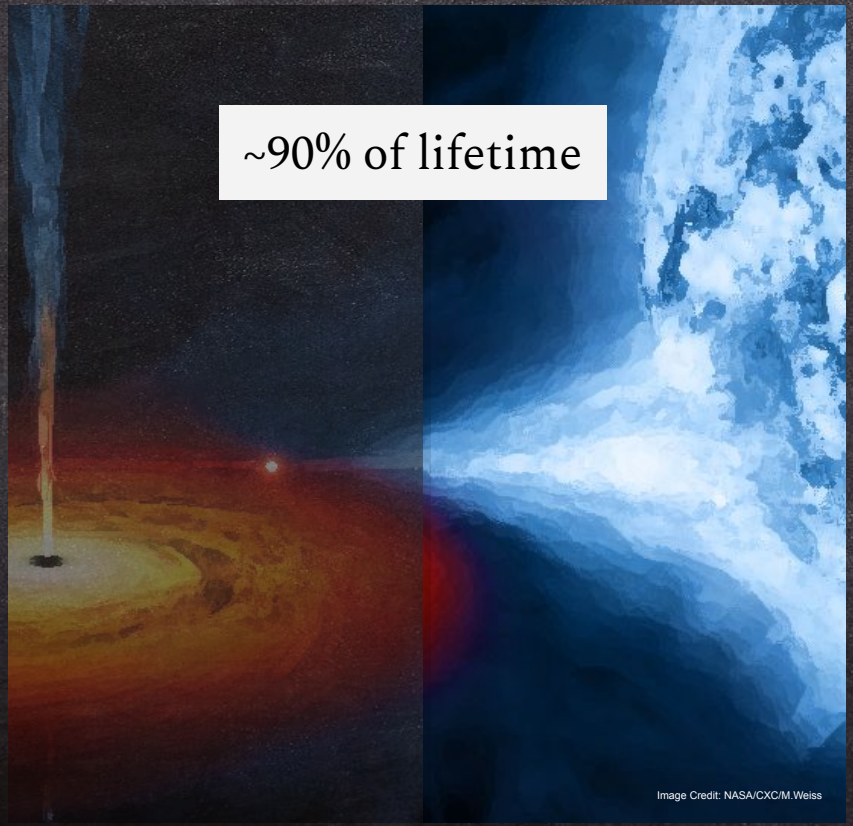
Strong magnetic field

Efficient particle acceleration

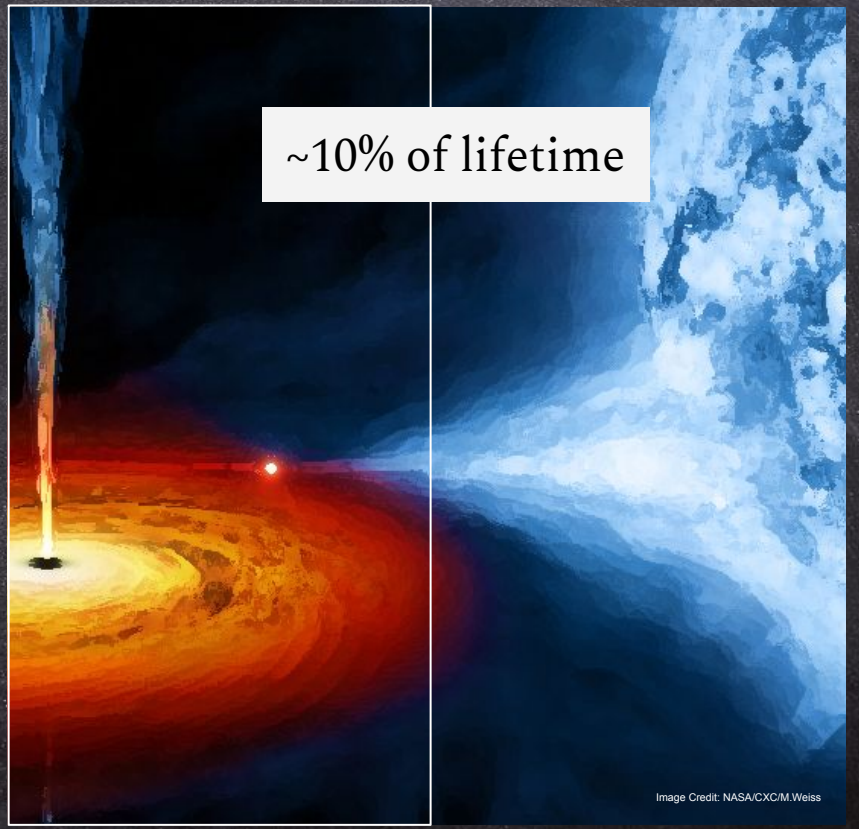


Between quiescence and outburst

quiescence

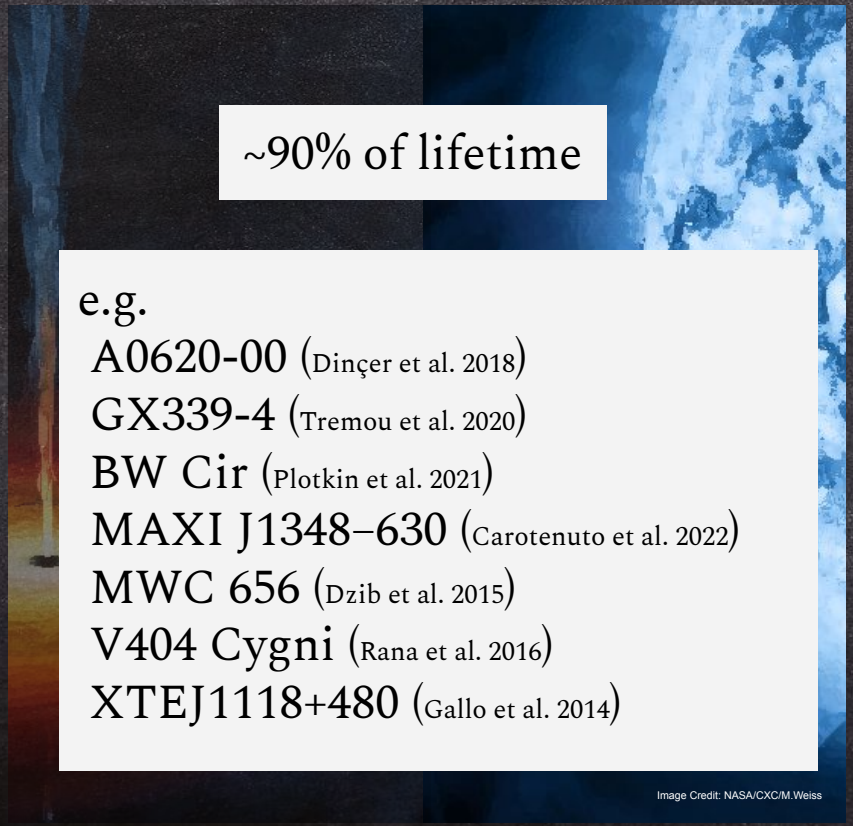


outburst

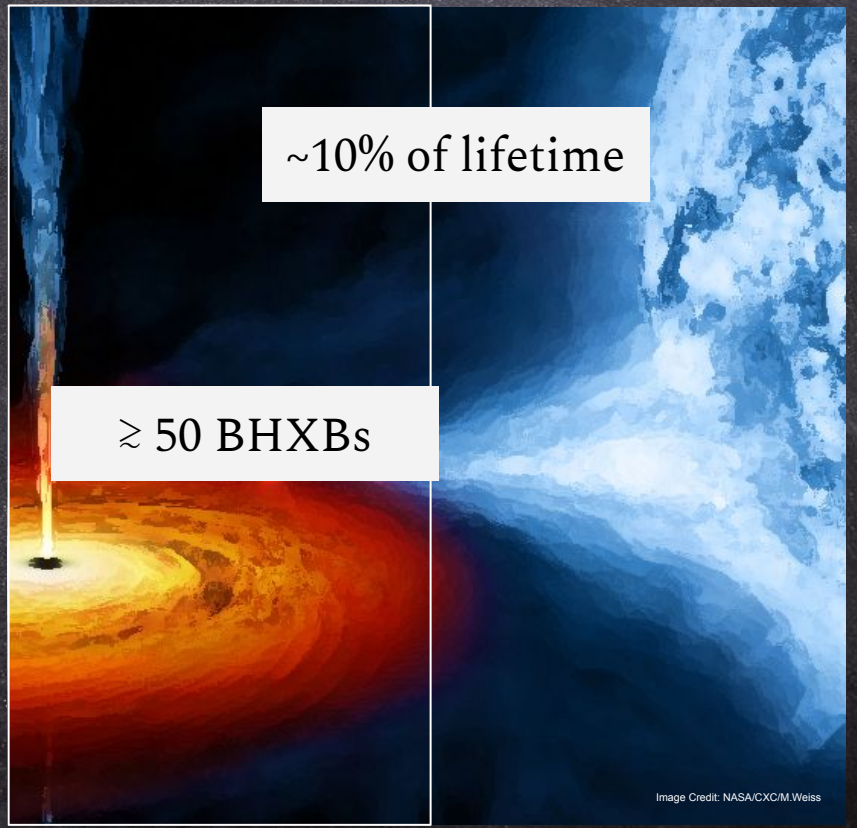


Between quiescence and outburst

quiescence



outburst



Between quiescence and outburst

quiescence

~90% of lifetime

e.g.
- A0620-00 (Dinçer et al. 2018)
- GX339-4 (Tremou et al. 2020)
- BW Cir (Plotkin et al. 2021)
- MAXI J1348−630 (Carotenuto et al. 2022)
- MWC 656 (Dzib et al. 2015)
- V404 Cygni (Rana et al. 2016)
- XTEJ1118+480 (Gallo et al. 2014)

Image Credit: NASA/CXC/M.Weiss

outburst

~10% of lifetime

≳ 50 BHXBs

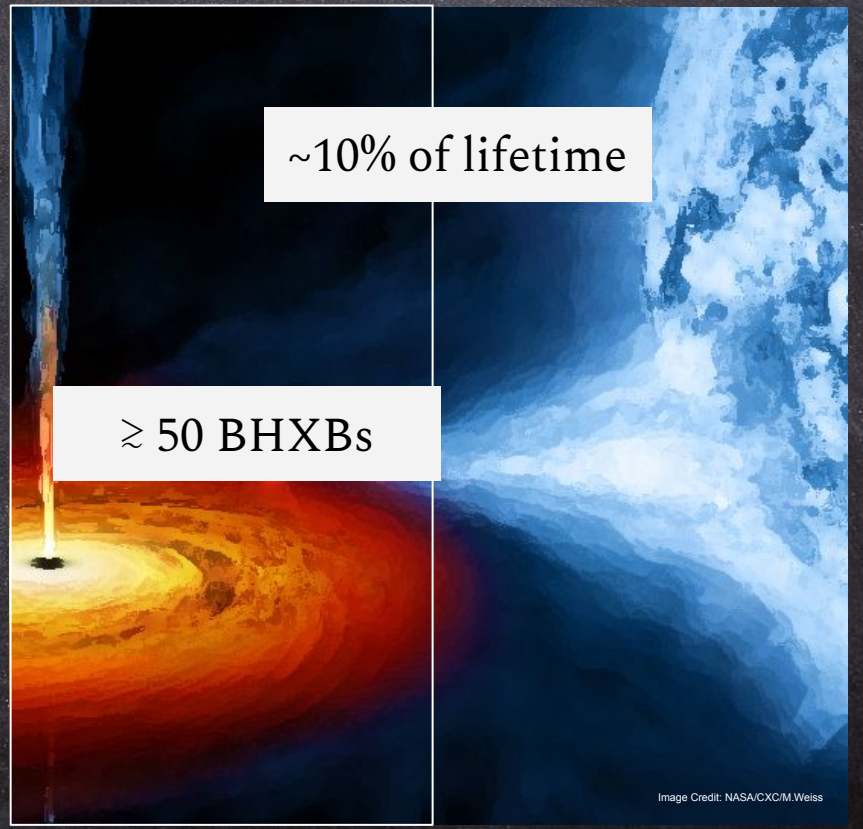
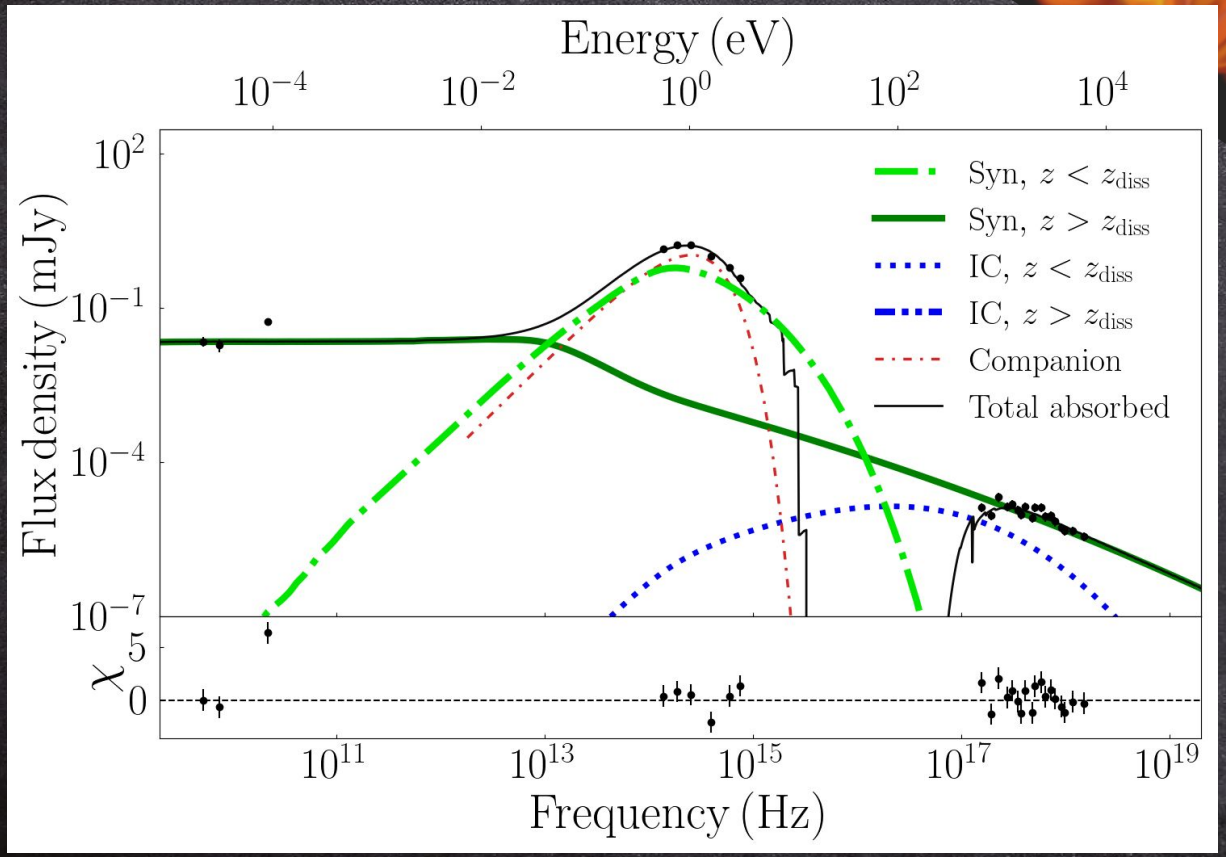


Image Credit: NASA/CXC/M.Weiss

A0620-00 in quiescence



20 TeV max proton

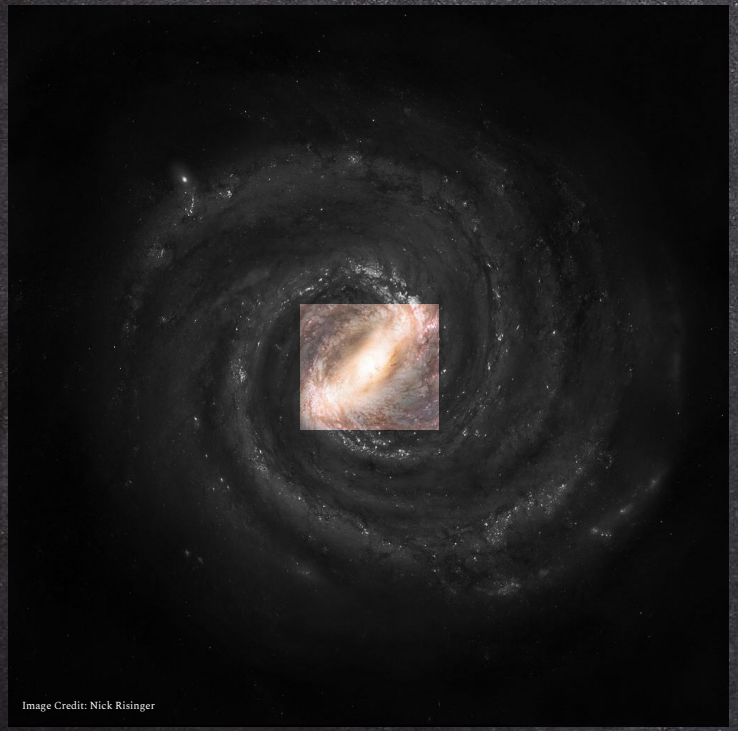
energy at $z_{diss} = 73R_g$

No Fermi/CTA detection

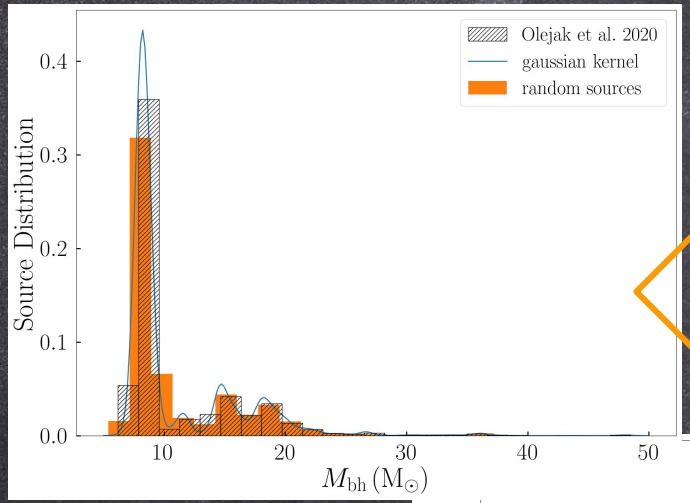
D. Kantzas et al. submitted (MW data from Dinçer et al. 2018)

see also Galo et al. 2006, Connors et al. 2017, dePolo et al. 2022

Population of BHXBs: bulge

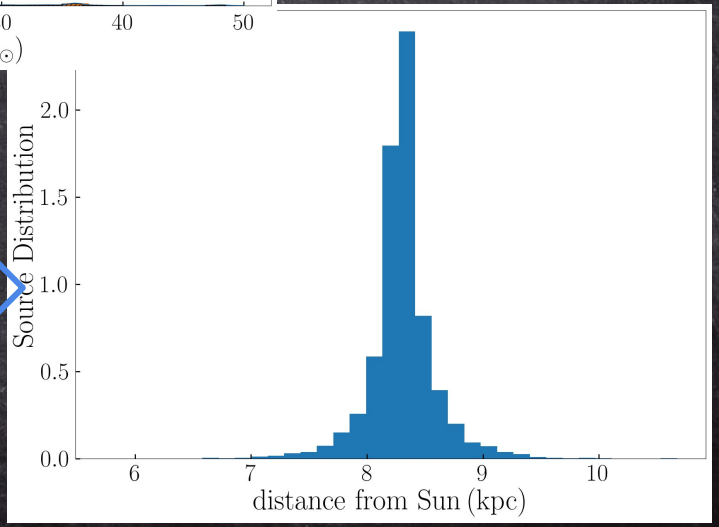


10.000 sources following a 3D Boxy Bulge distribution (Cao et al. 2013)



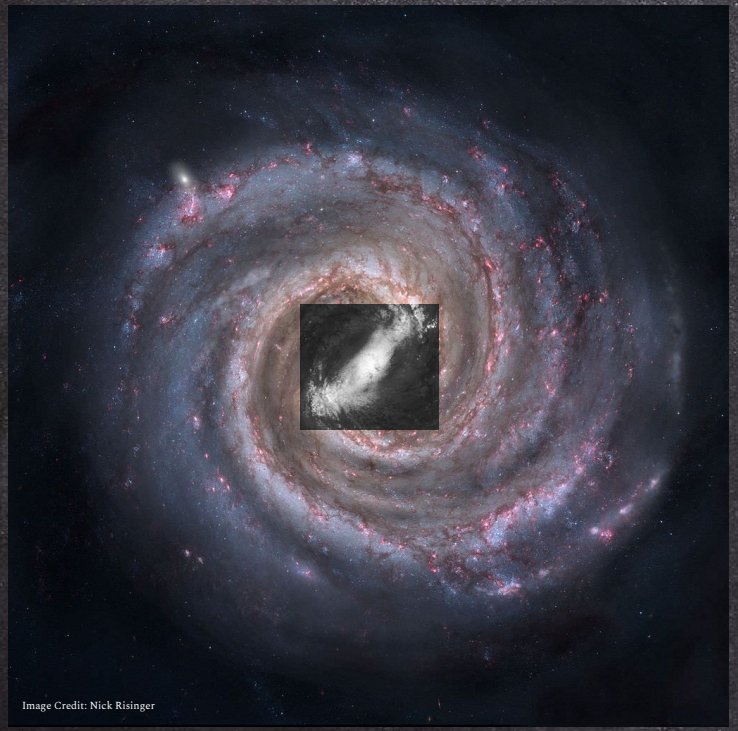
Black hole masses
based on Olejak et al. 2020

Black hole distances

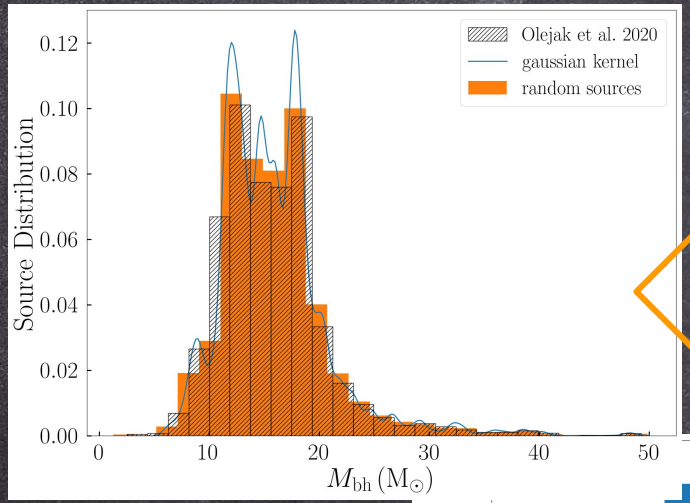


D. Kantzas et al. submitted

Population of BHXBs: disc



120.000 sources following a 2D Lorimer distribution (Lorimer et al. 2006)



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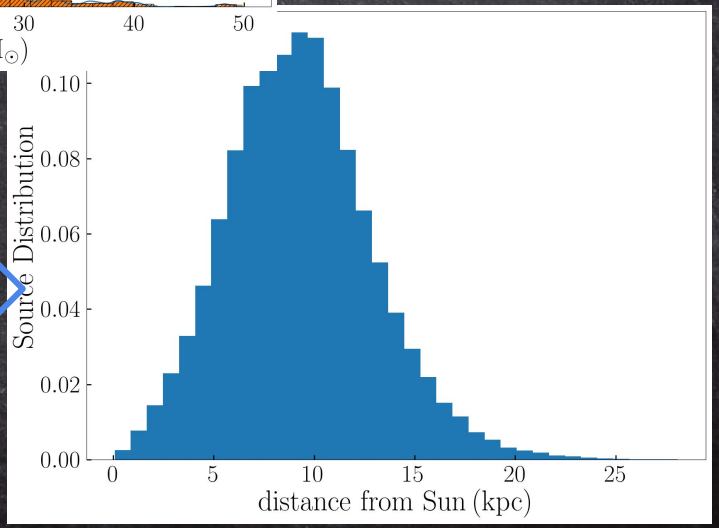
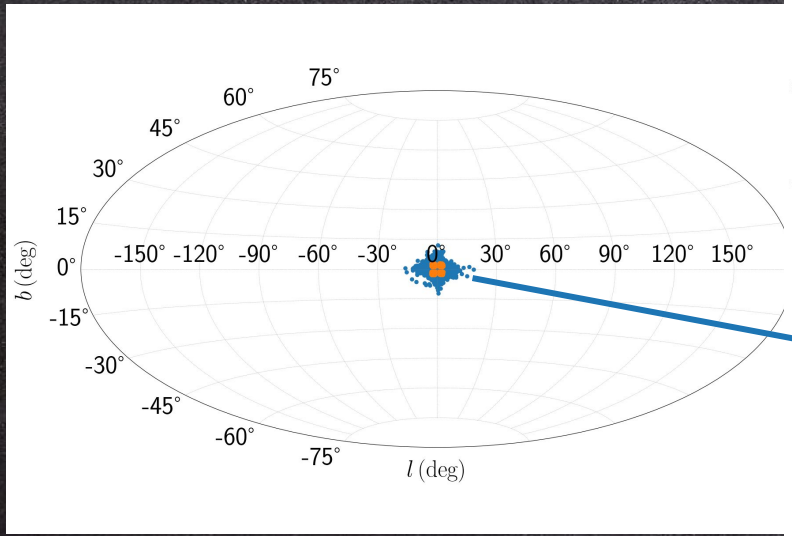
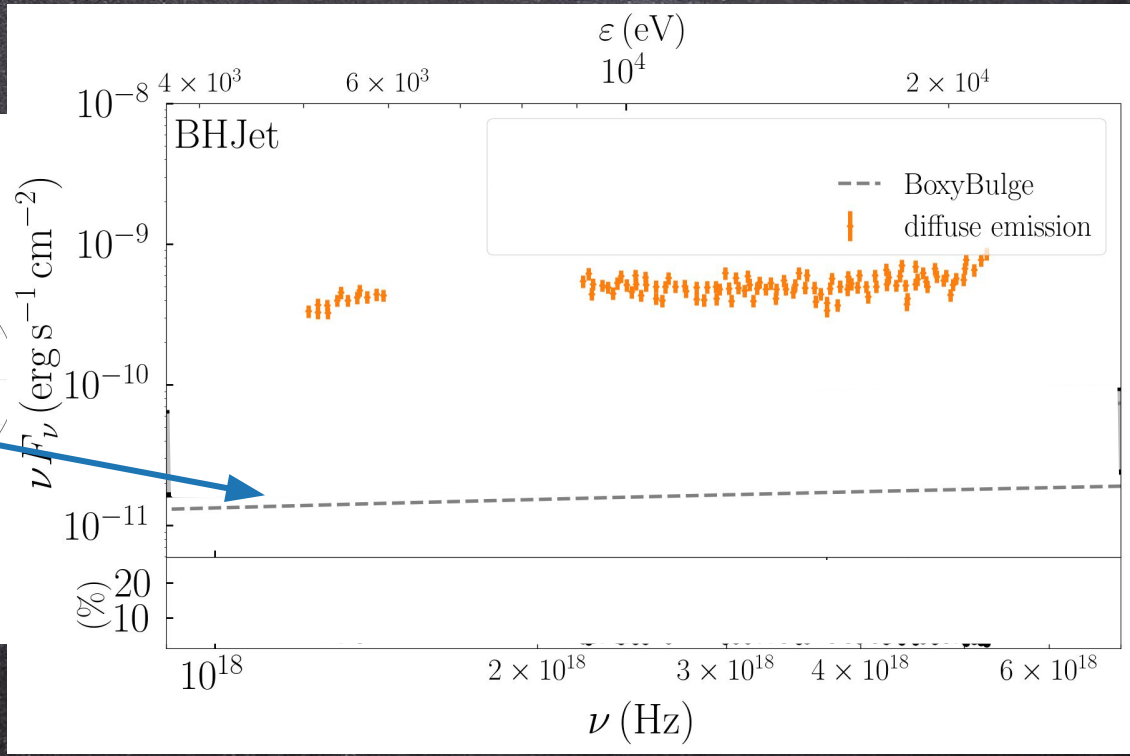


D. Kantzas et al. submitted

Prompt emission detected by NuSTAR

Boxy bulge sources

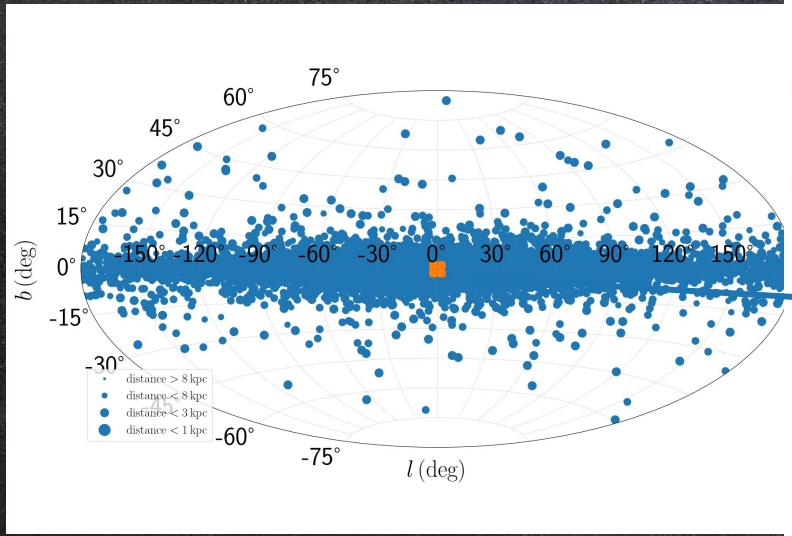


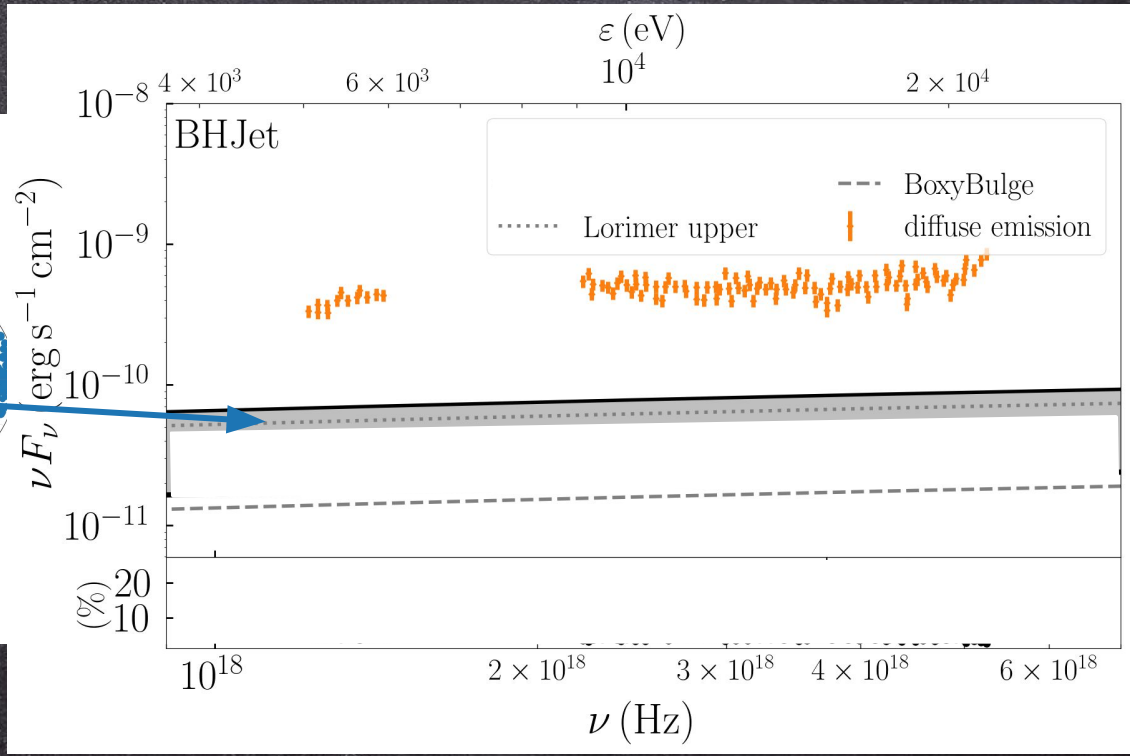


D. Kantzas et al. submitted
NuSTAR data from Perez et al. 2019

Prompt emission detected by NuSTAR

Disc sources





D. Kantzas et al. submitted
NuSTAR data from Perez et al. 2019

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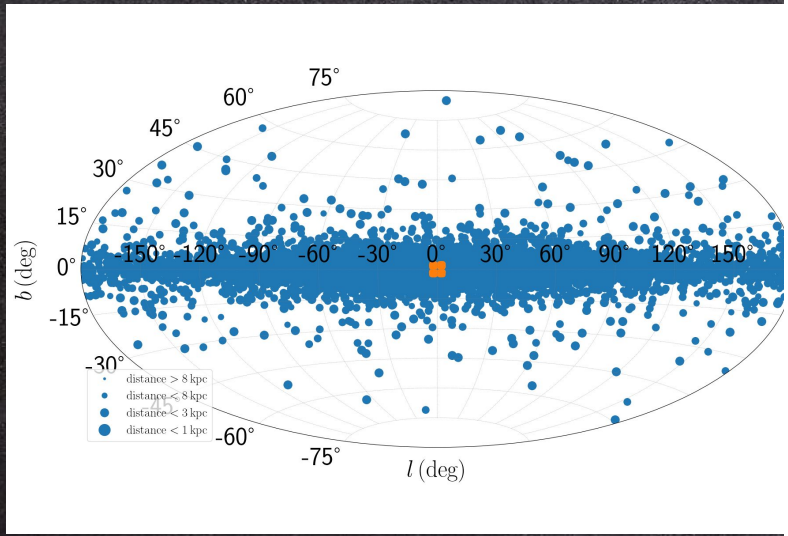
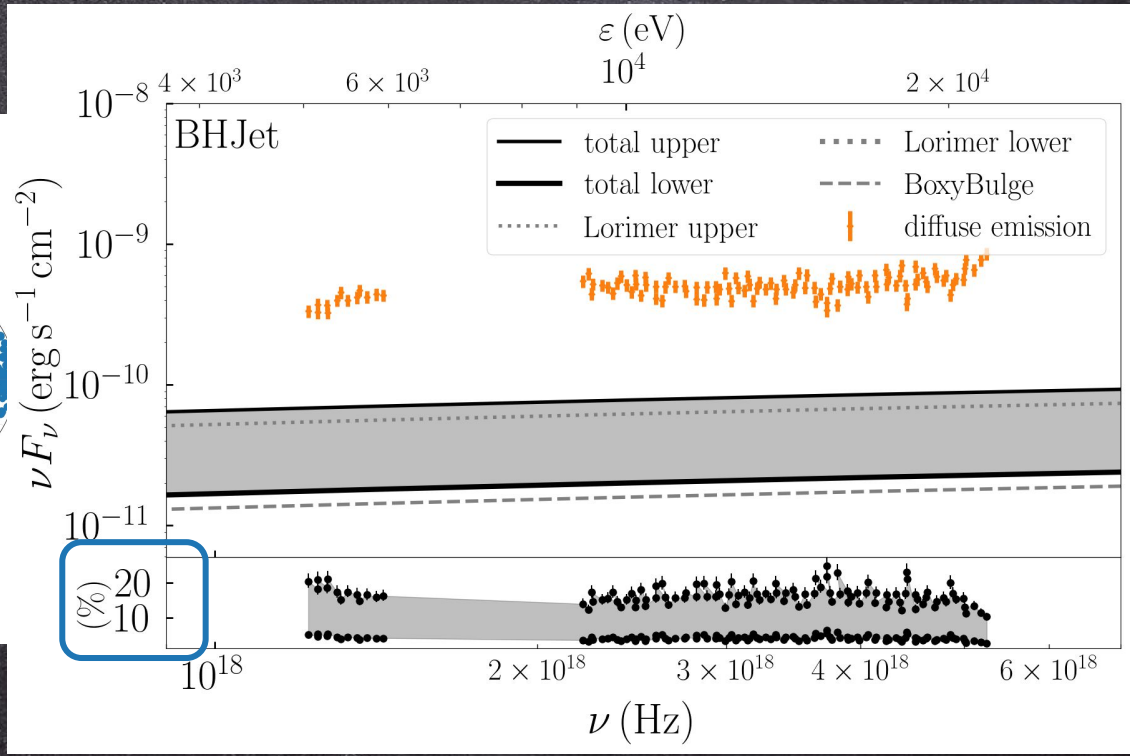
Disc sources



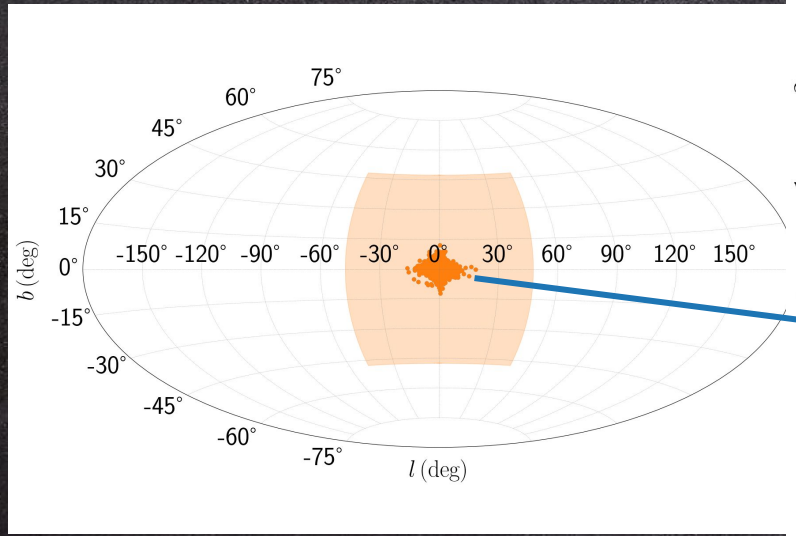
D. Kantzas et al. submitted
NuSTAR data from Perez et al. 2019

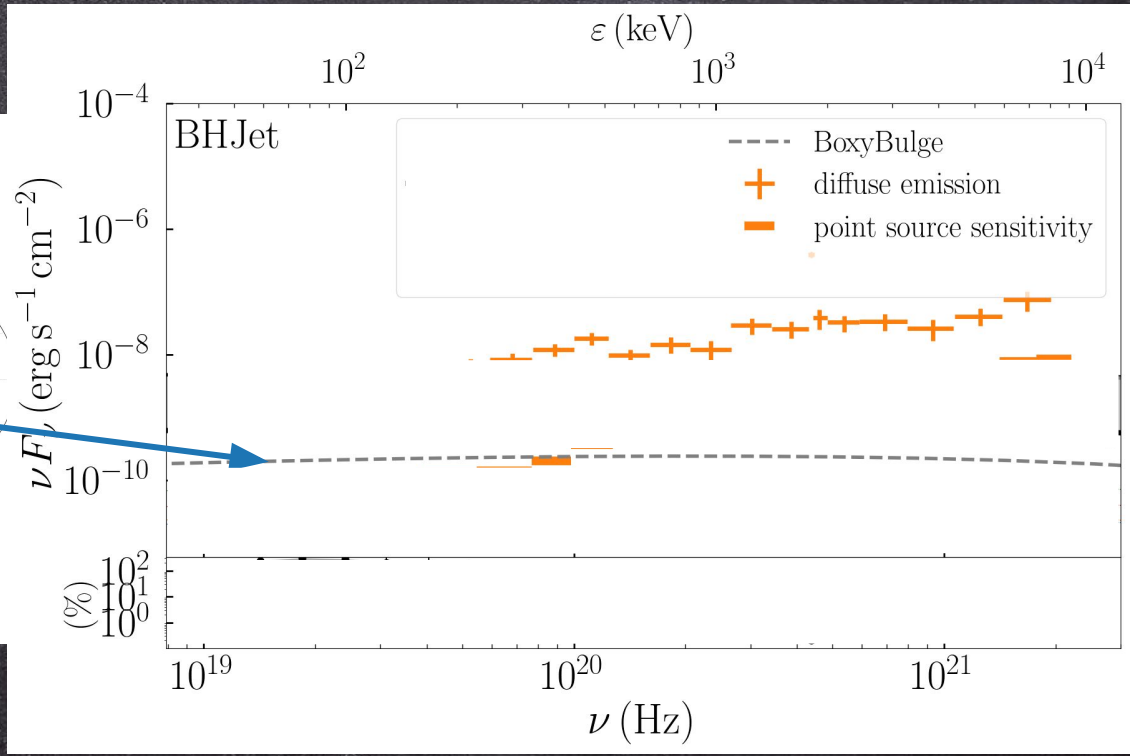


~10% contribution of BHXBs to the Galactic keV diffuse emission

Prompt emission detected by INTEGRAL

Boxy bulge sources

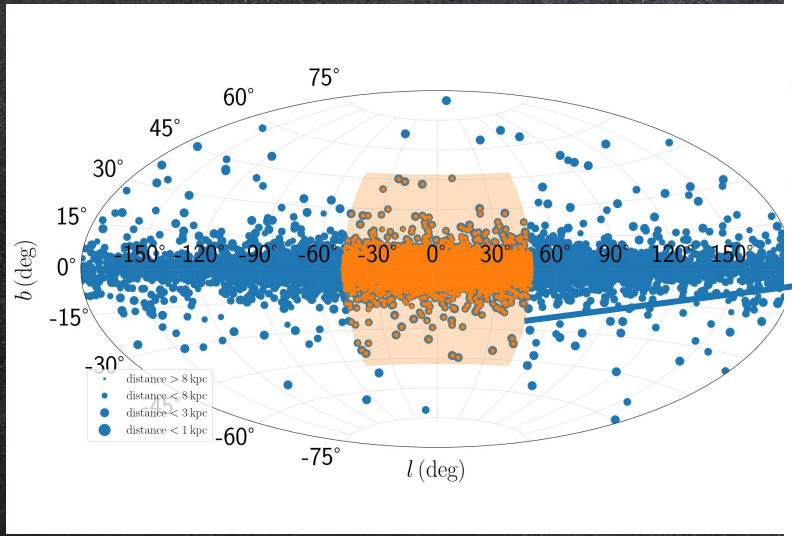


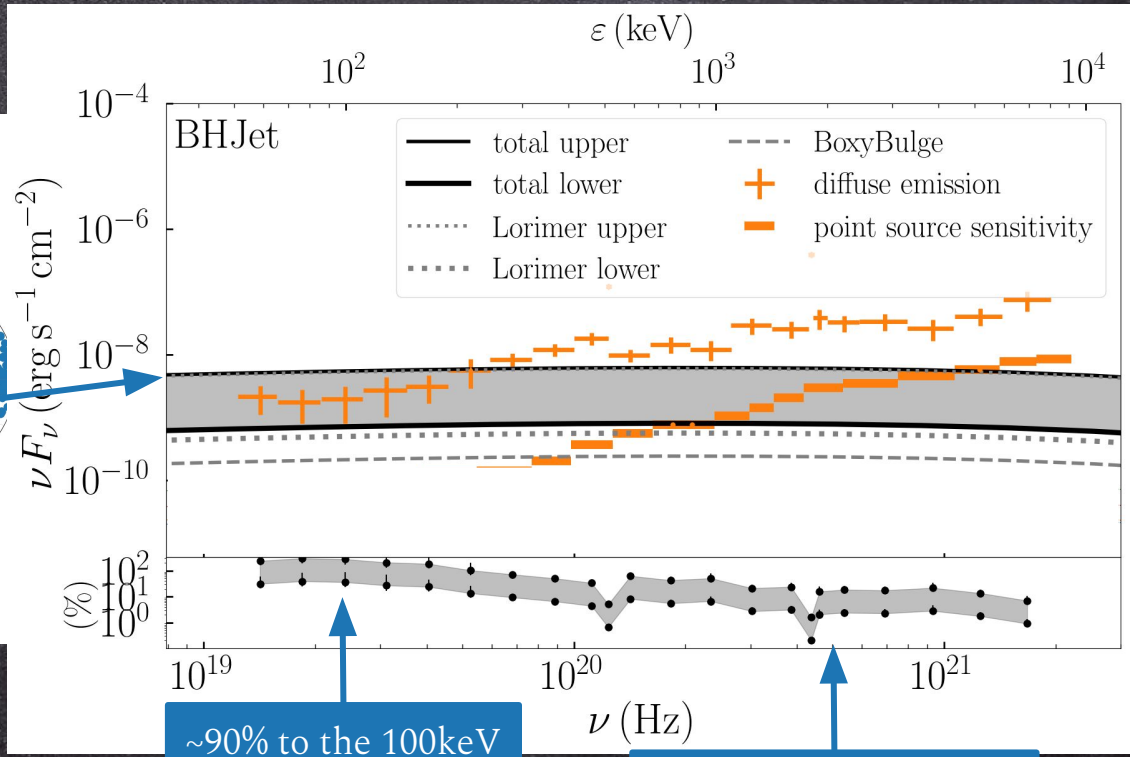


D. Kantzas et al. submitted
INTEGRAL data from Berteaud et al. 2019 and sensitivity from Roques et al. 2003

Prompt emission detected by INTEGRAL

Disc sources





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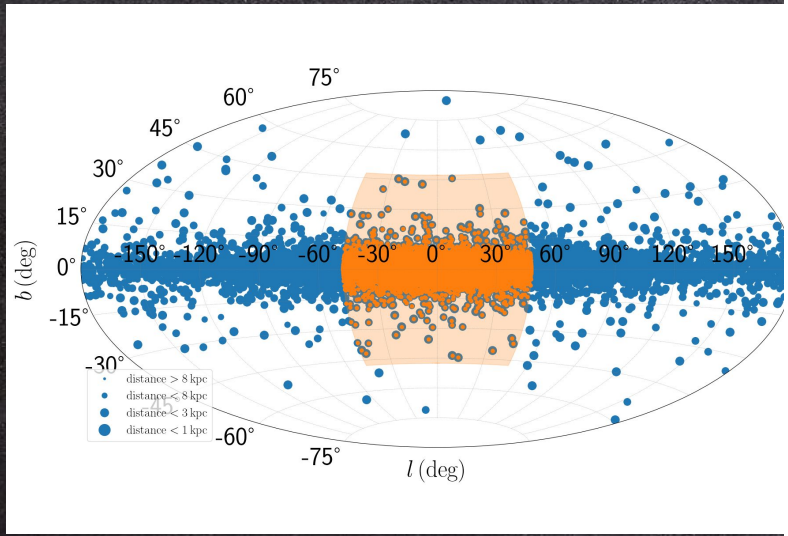
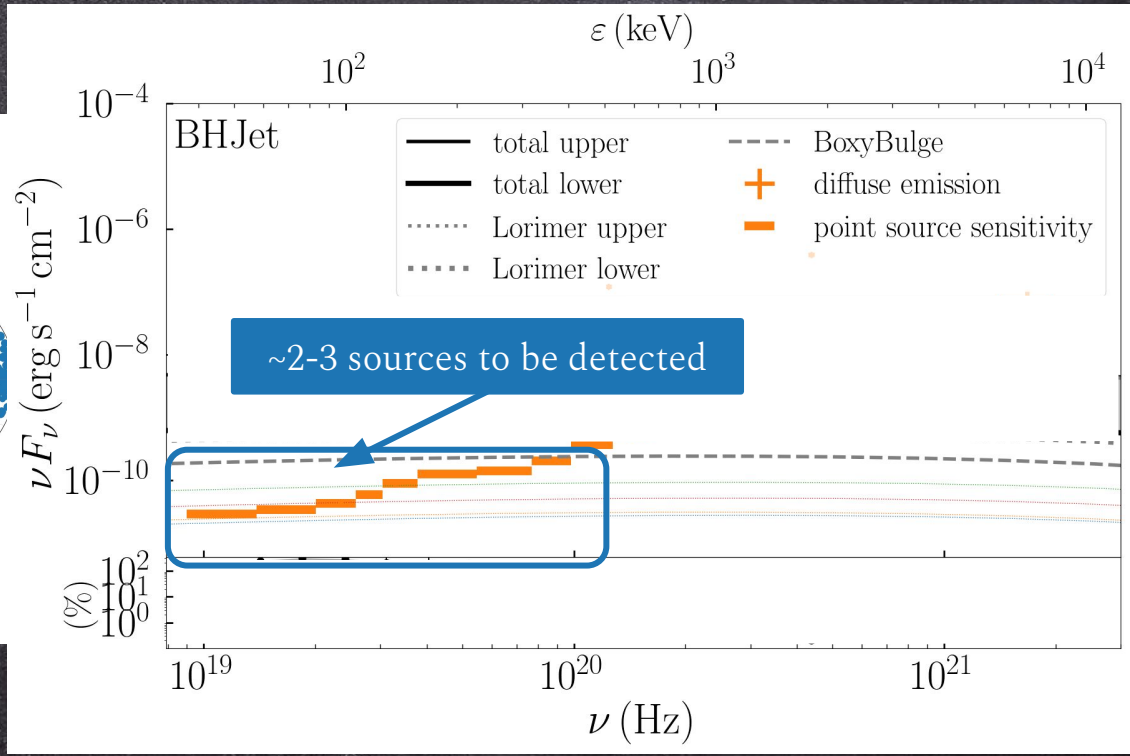
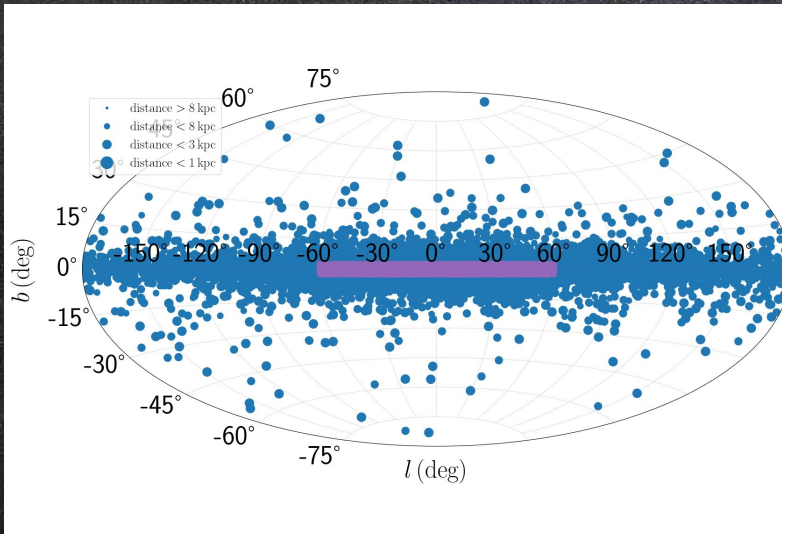


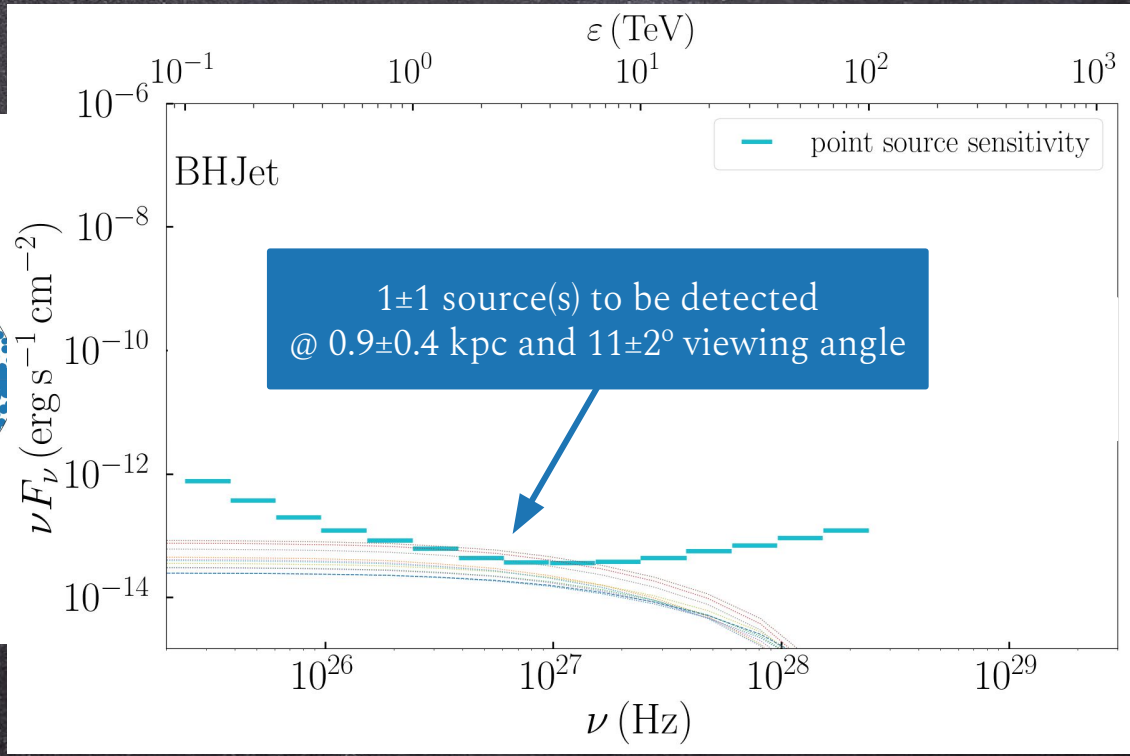


D. Kantzas et al. submitted
INTEGRAL data from Berteaud et al. 2019 and sensitivity from Roques et al. 2003

Prompt emission detected by CTA

Disc sources



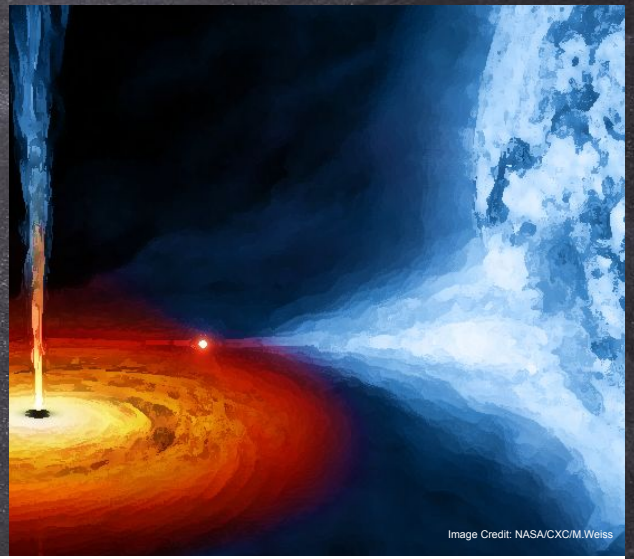


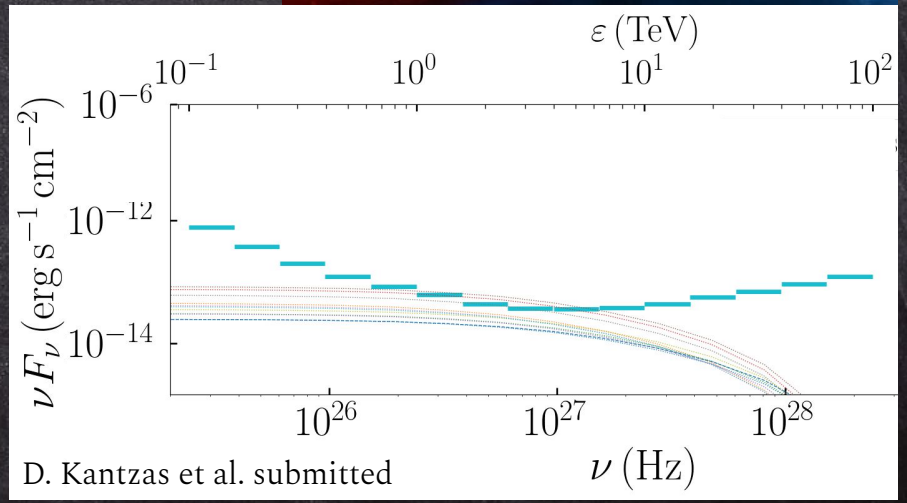
D. Kantzas et al. submitted
CTA point source sensitivity from Eckner et al. 2023

Take home message

Quiescent black hole X-ray binaries:

- may accelerate CRs @ ~20 TeV ~~PeVatron~~
- may contribute:
  - 1-20% @ keV, > 20% @ 100 keV,
  - ~a few % @ 1MeV
  - <1% @ GeV and TeV
  - <1% @ TeV neutrinos
- 1±1 to be detected by CTA

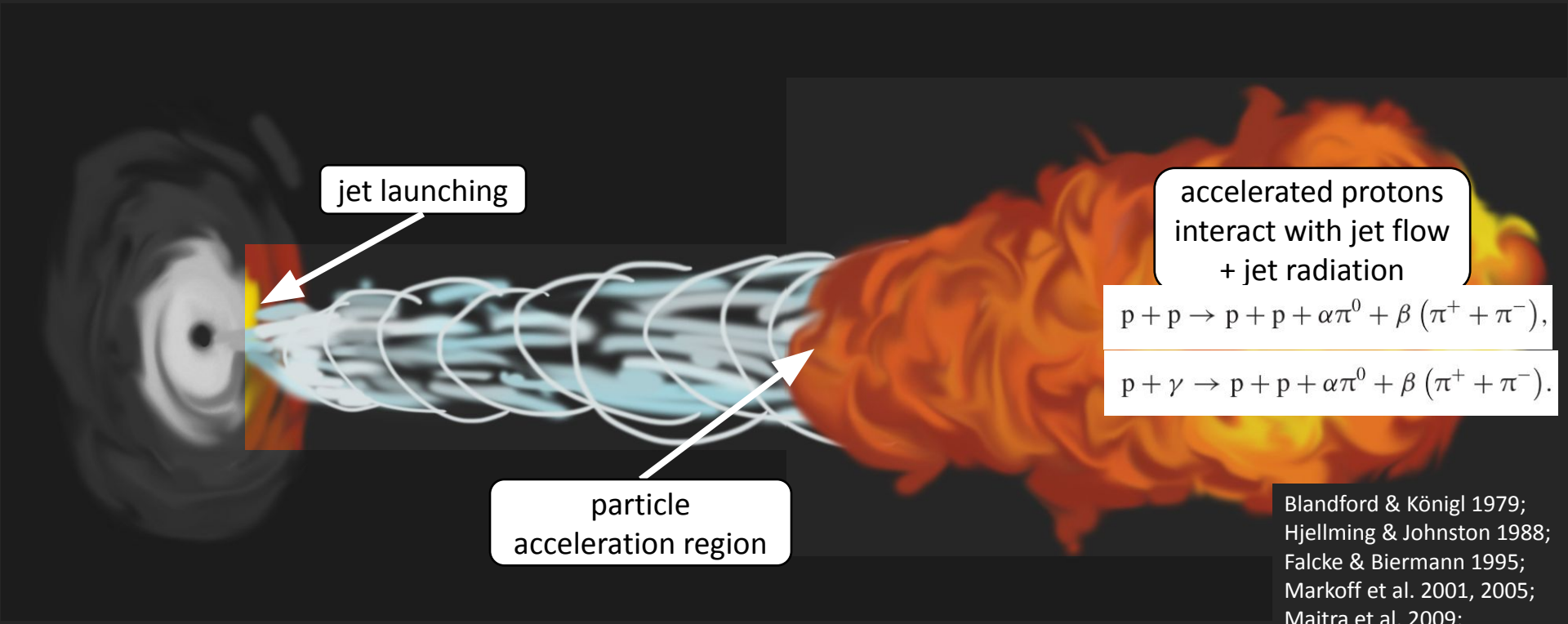




D. Kantzas et al. submitted

Backup slides

A multi-zone, *jet model* with hadronic interactions

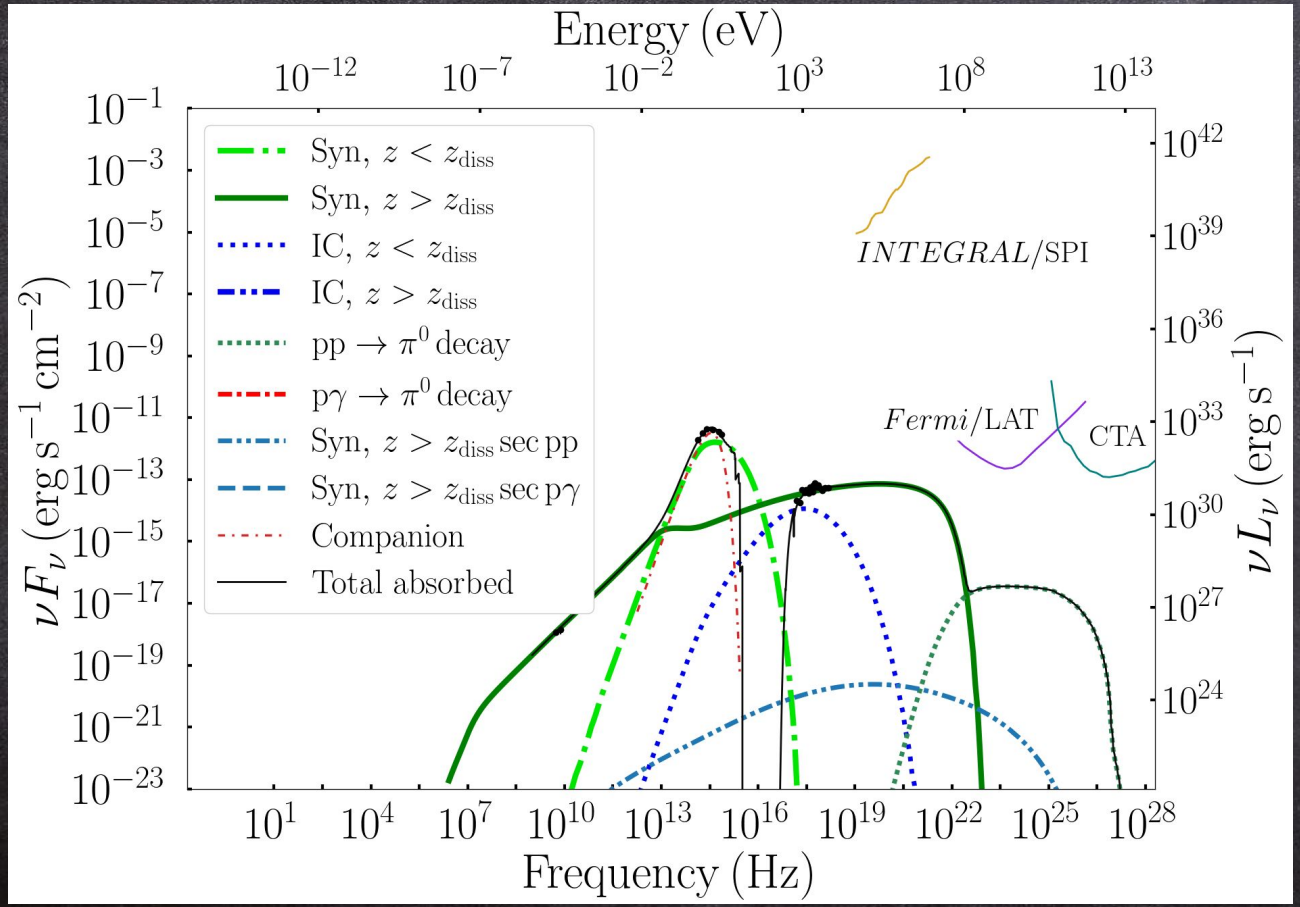


BHJet

Blandford & Königl 1979;
Hjellming & Johnston 1988;
Falcke & Biermann 1995;
Markoff et al. 2001, 2005;
Maitra et al. 2009;
Crumley et al. 2017;
Lucchini et al. 2019, 2022
Kantzas et al. 21, 22, 23a

Image Credit: T. Revolta

A0620-00 in quiescence

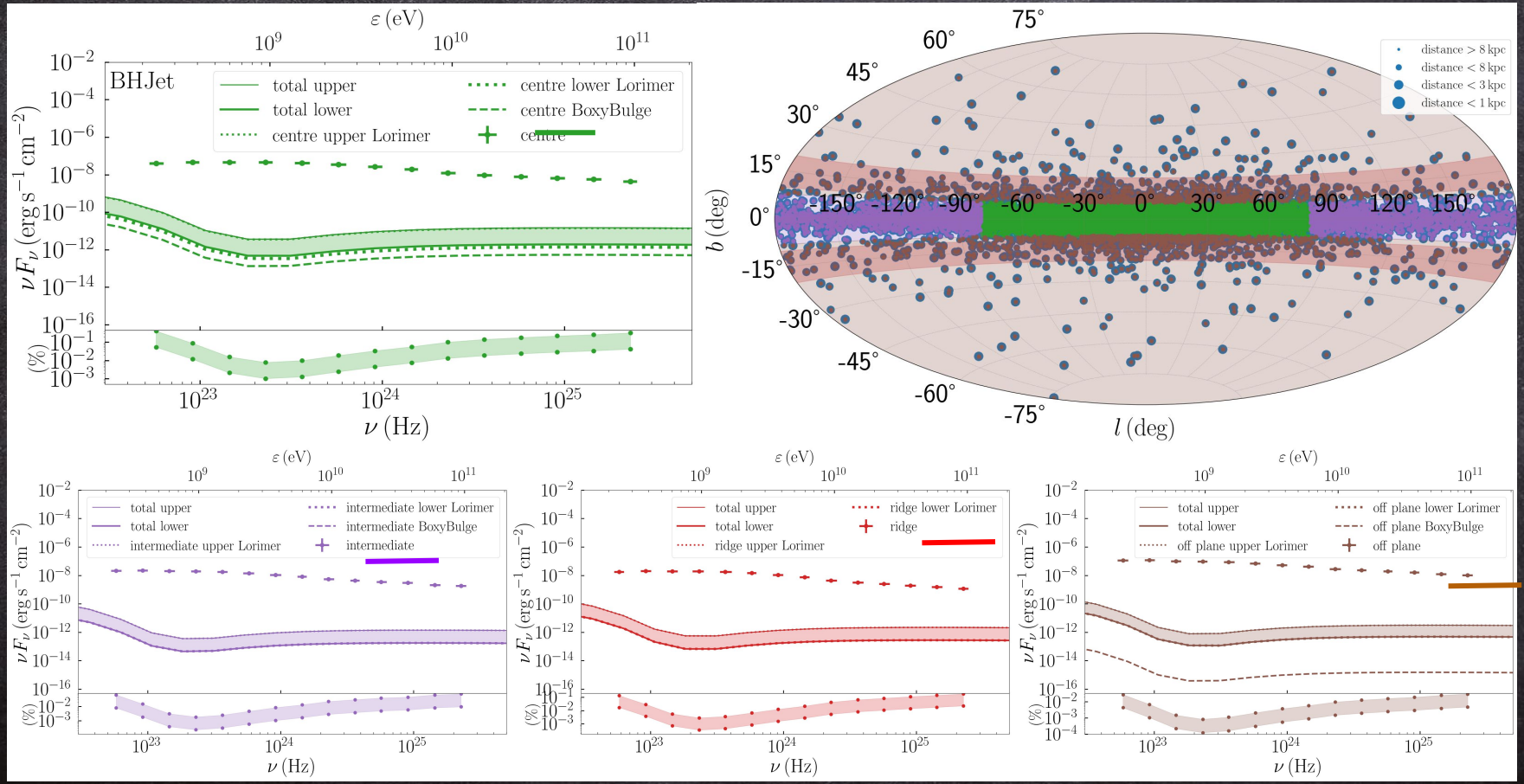


20 TeV max proton energy at $z_{diss}=73R_g$

No Fermi/CTA detection

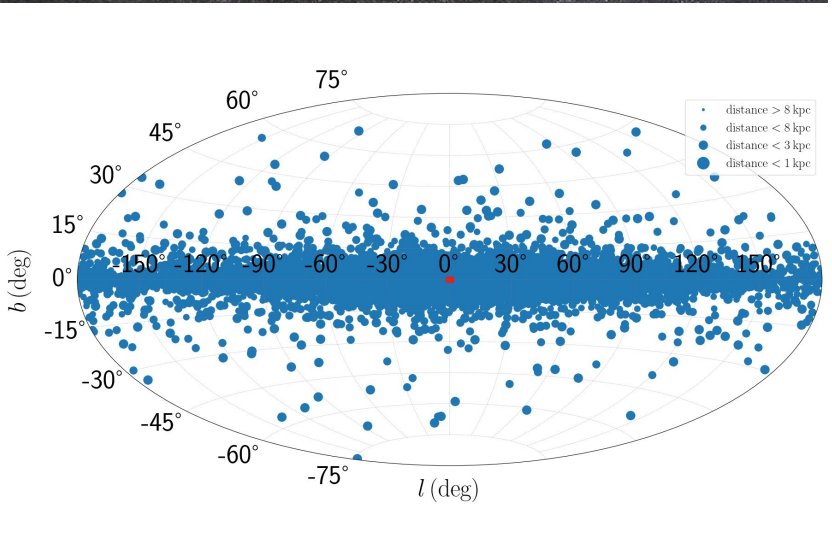
D. Kantzas et al. submitted (MW data from Dinçer et al. 2018)

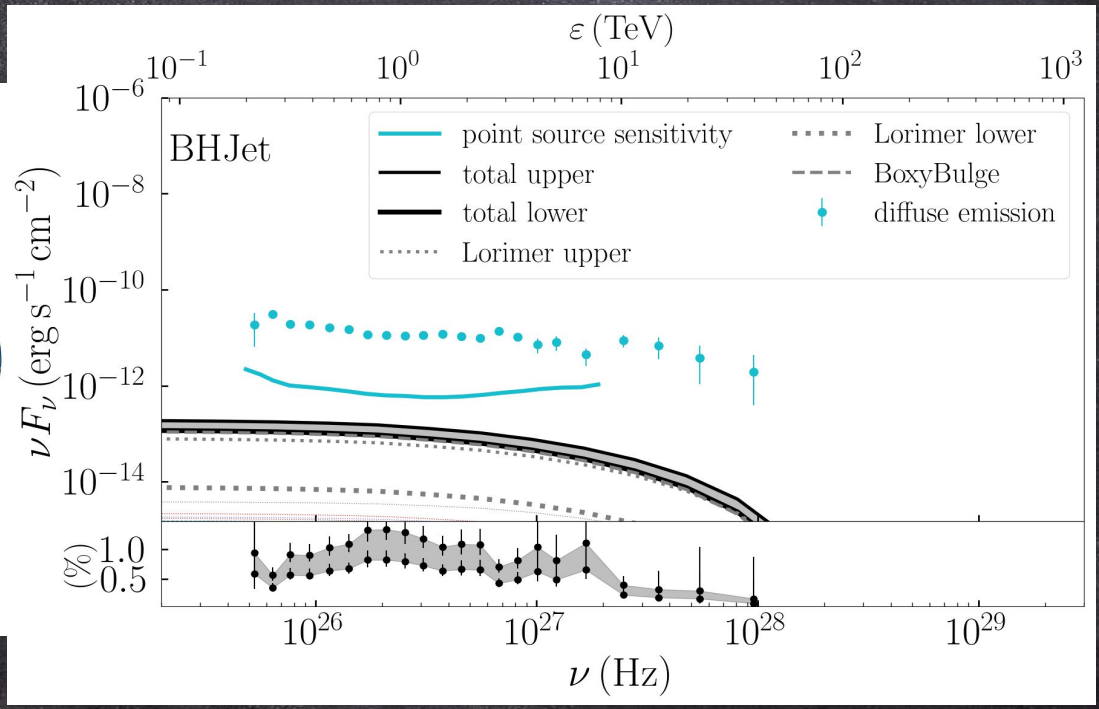
Prompt emission and Fermi/LAT



D. Kantzas et al. submitted (Fermi data and regions from Ackermann et al. 2012)

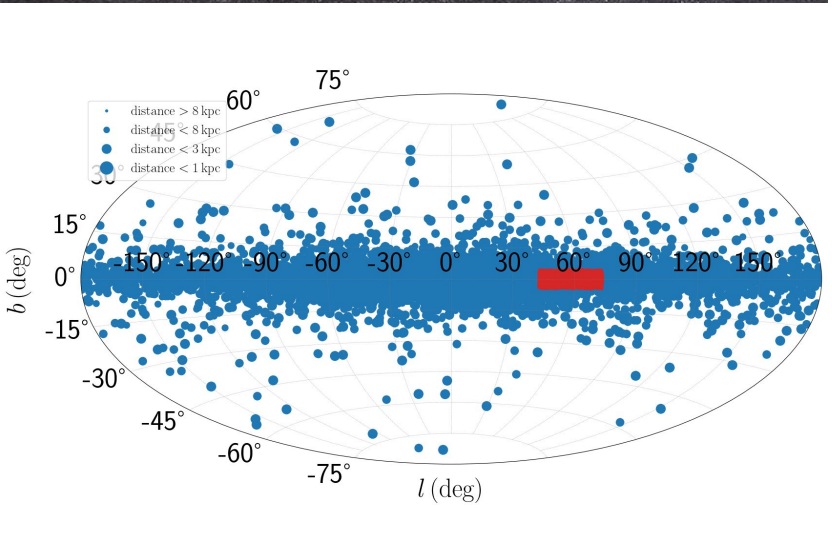
Prompt emission and IACTs (HESS)

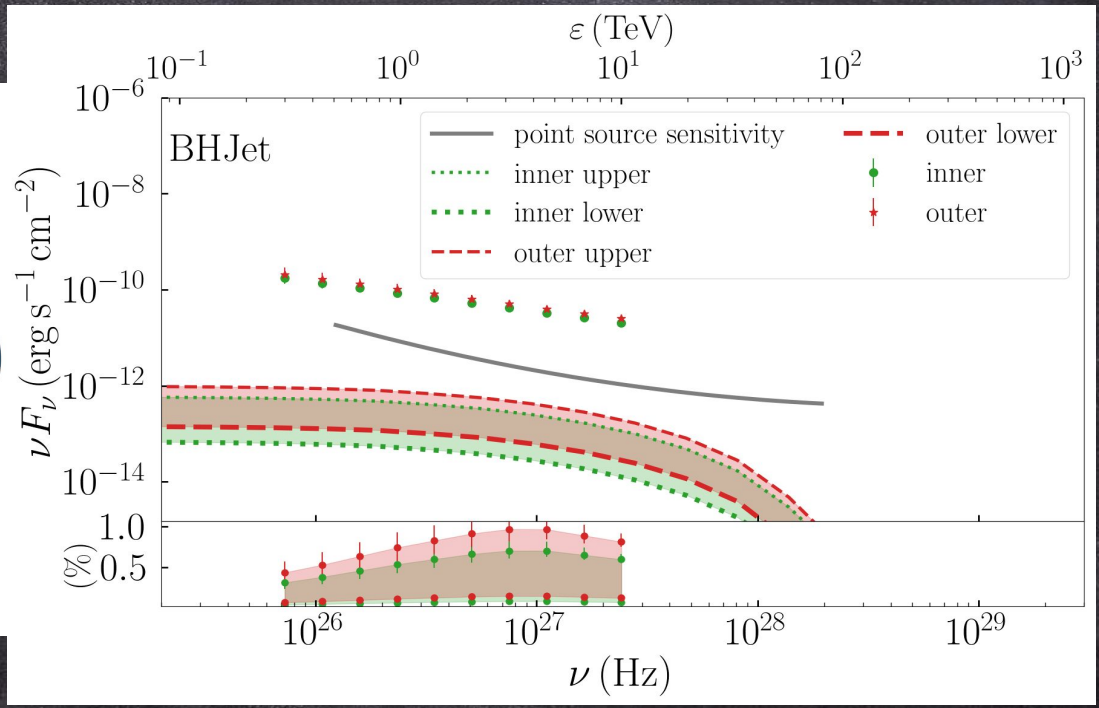




D. Kantzas et al. submitted (HESS data from HESS 2018)

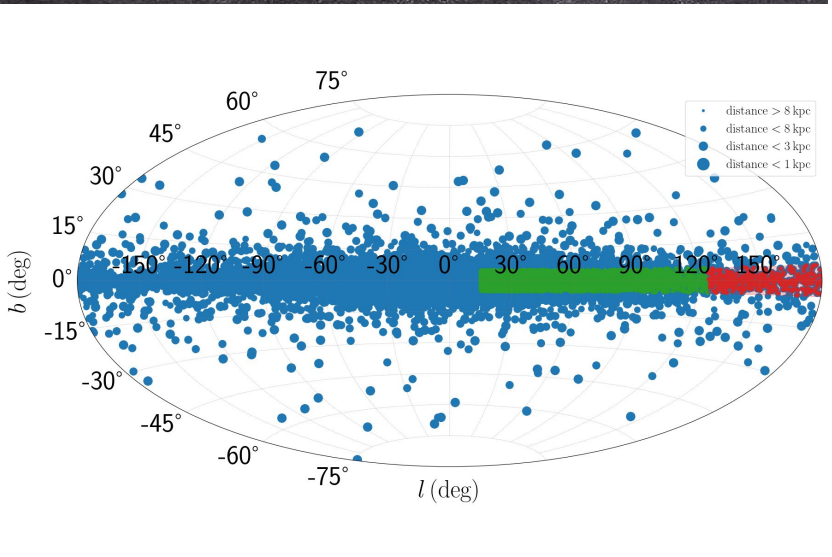
Prompt emission and IACTs (HAWC)

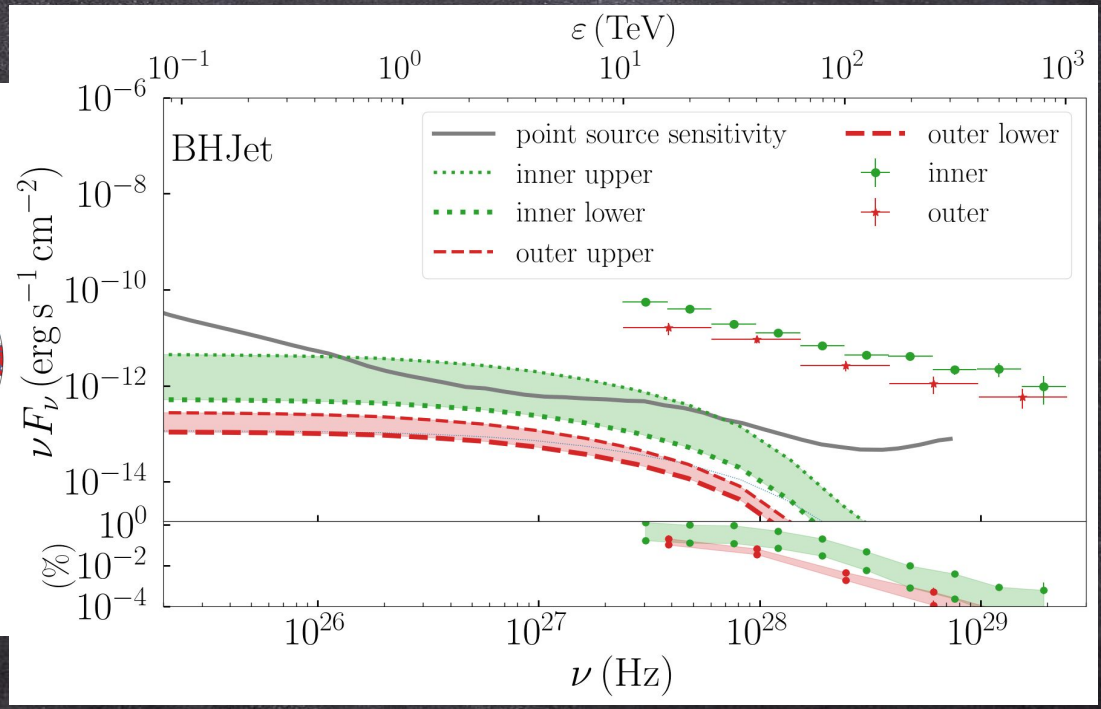




D. Kantzas et al. submitted (HAWC data from Alfaro et al. 2024)

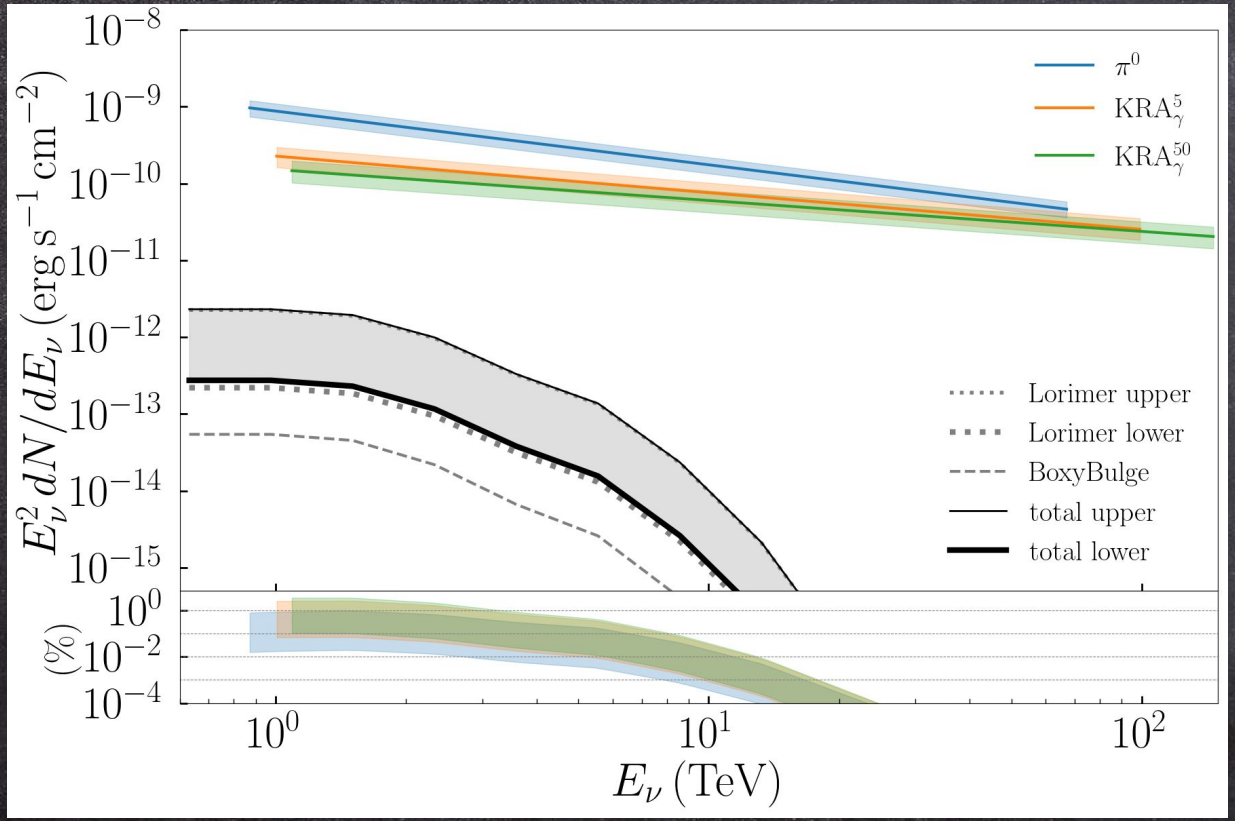
Prompt emission and IACTs (LHAASO)





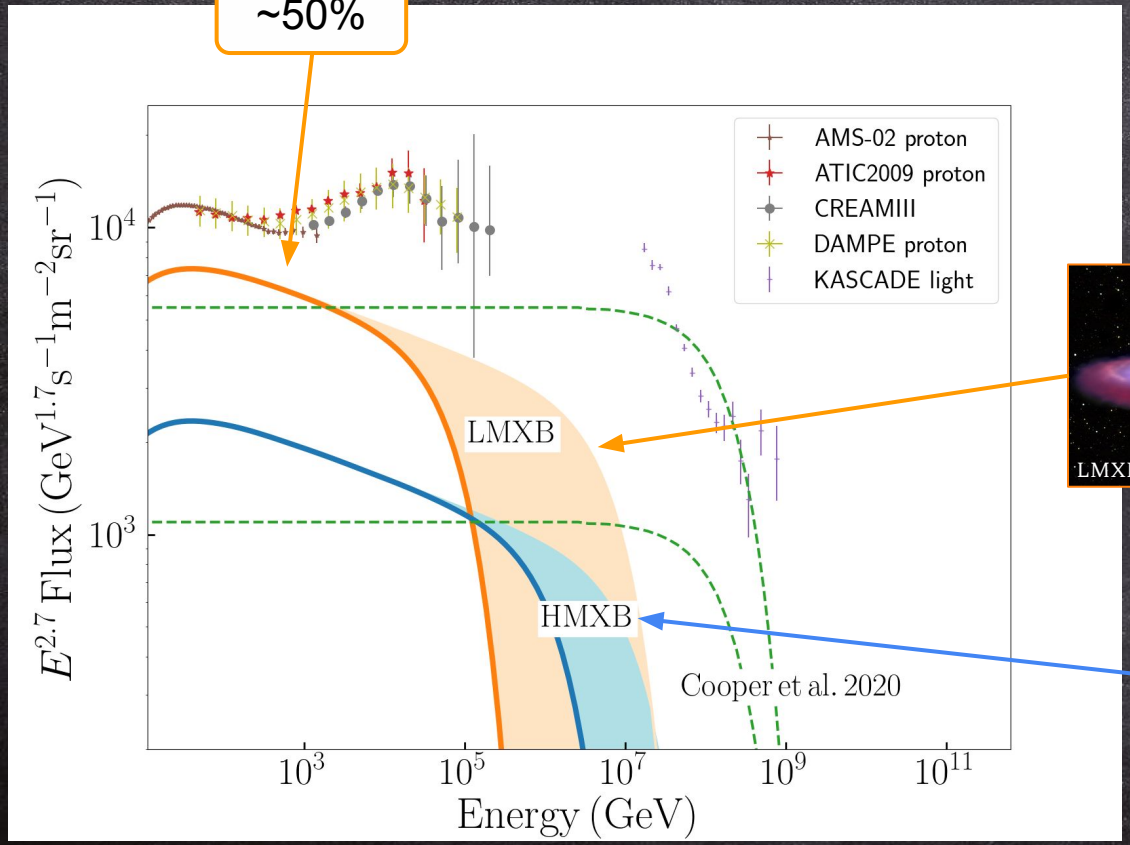
D. Kantzas et al. submitted (LHAASO data from from Cao et al. 2023)

Prompt neutrinos and IceCube diffuse emission



D. Kantzas et al. submitted (IceCube data from IceCube 2023)

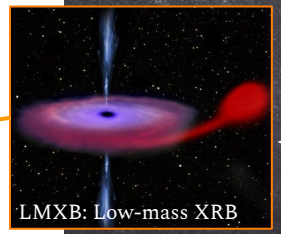
Contribution of black hole XRBs to the CR proton spectrum



Kantzas et al. 2023b

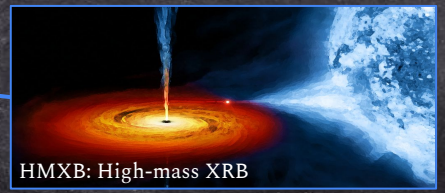
if **1000** black hole XRBs follow the same spatial distribution as Pulsars
(Lorimer et al. 2006)

Evoli et al. 2017, 2018

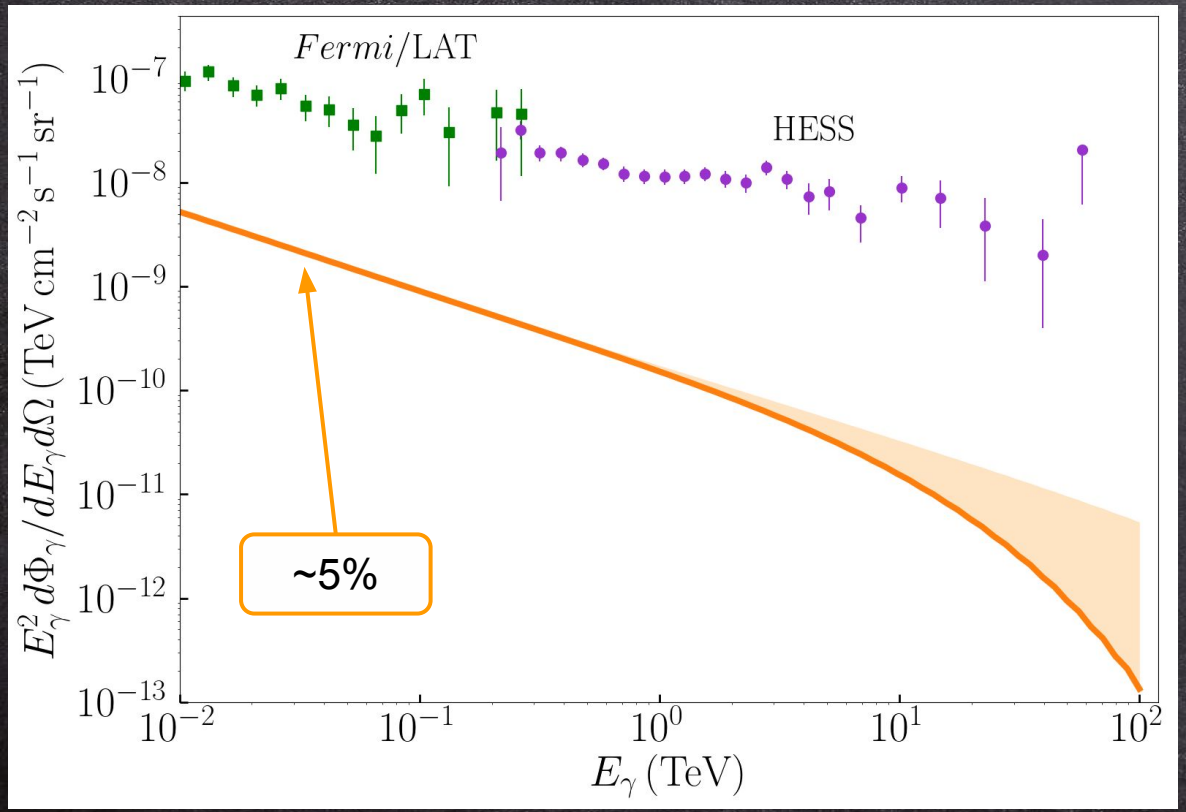


Kantzas et al. 2022

Kantzas et al. 2021



Contribution of black hole XRBs to the γ-ray spectrum



Kantzas et al. 2023b

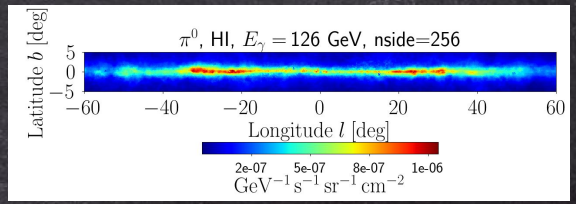
HERMES

High-**E**nergy **R**adiative **MES**sengers

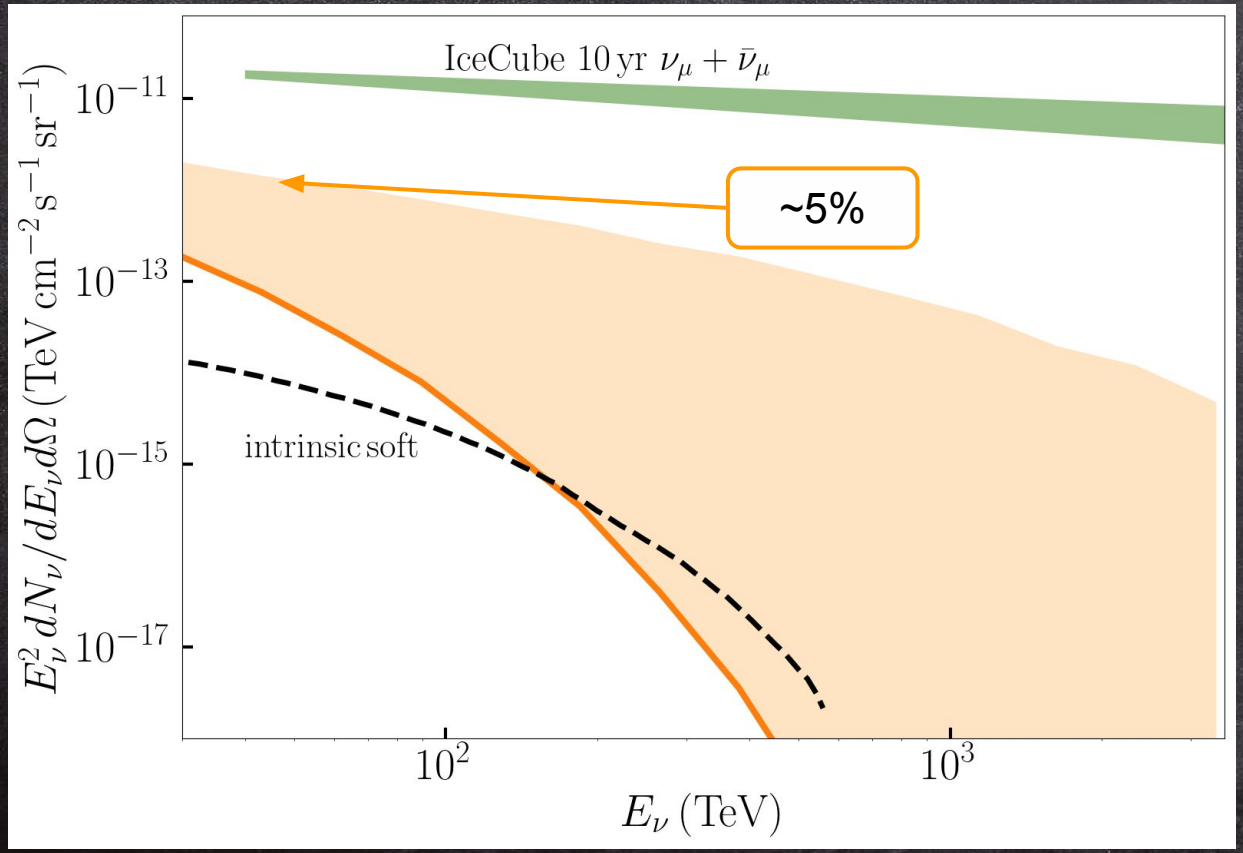
Dundovic et al. 2021

$p + p/\gamma \rightarrow p + \alpha\pi^0 + \beta(\pi^+ + \pi^-)$

$\pi^0 \rightarrow 2\gamma$



Contribution of black hole XRBs to the neutrino spectrum



Kantzas et al. 2023b

HERMES

High-**E**nergy **R**adiative **MES**sengers

Dundovic et al. 2021

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$\pi^\pm \rightarrow \mu^\pm + \nu_\mu$

$\mu^\pm \rightarrow e^\pm + \nu_e + \nu_\mu$