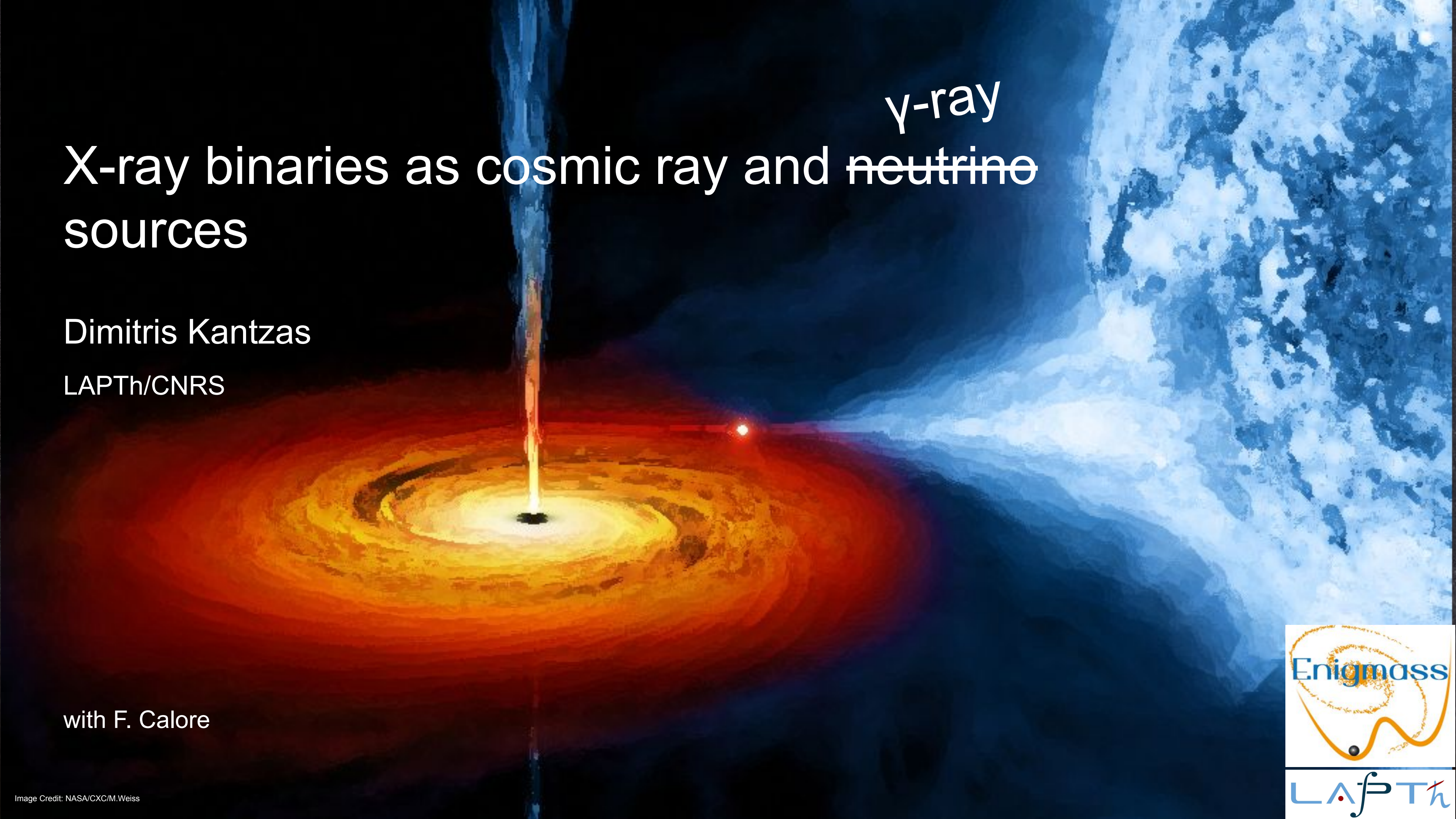


X-ray binaries as cosmic ray and ~~neutrino~~ γ-ray sources

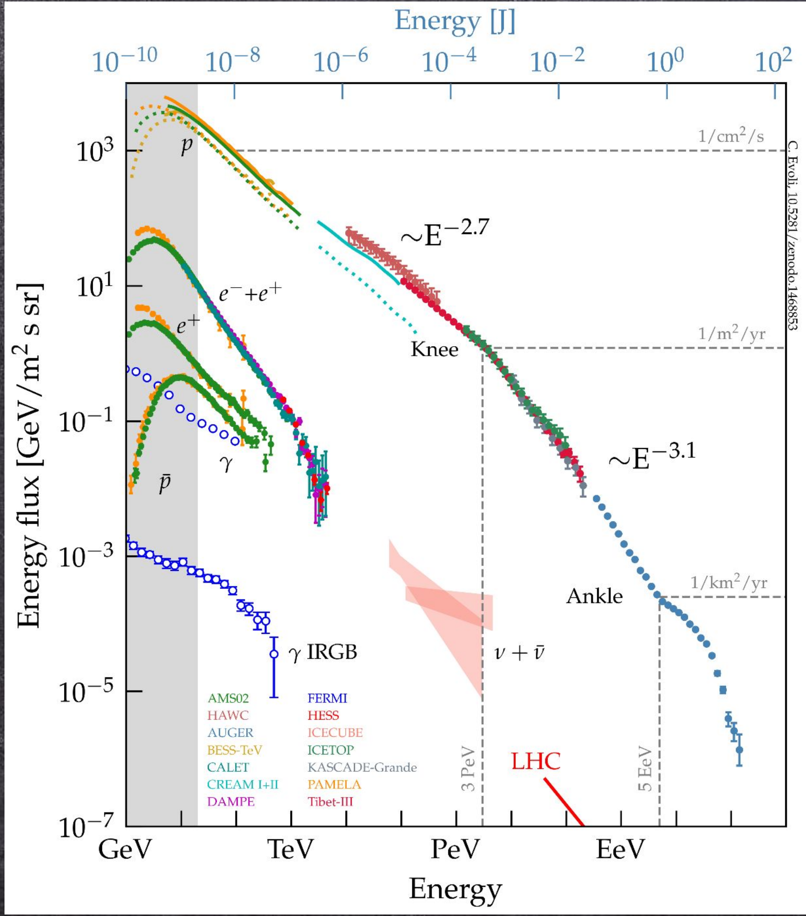
Dimitris Kantzas

LAPTh/CNRS

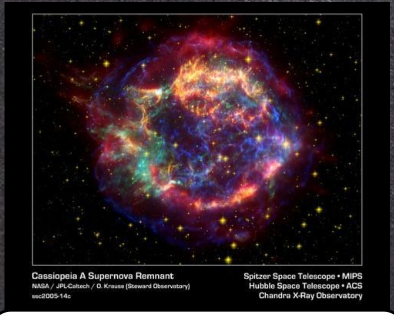
with F. Calore

Image Credit: NASA/CXC/M.Weiss

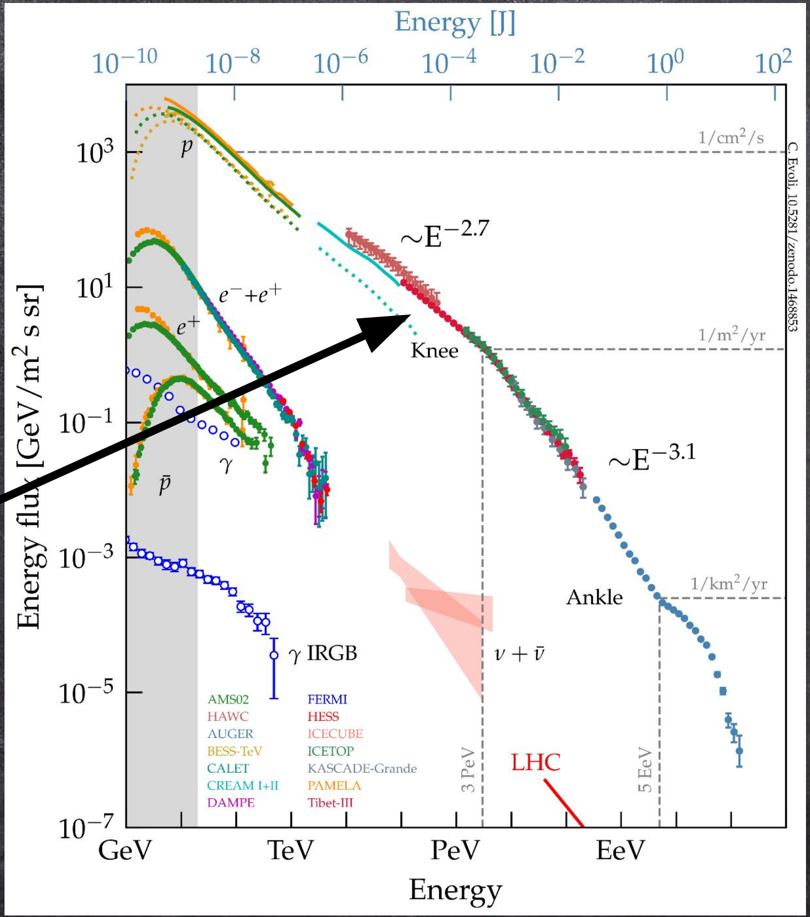
Cosmic-ray sources?



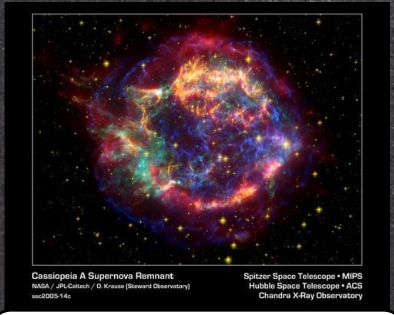
Cosmic-ray sources?



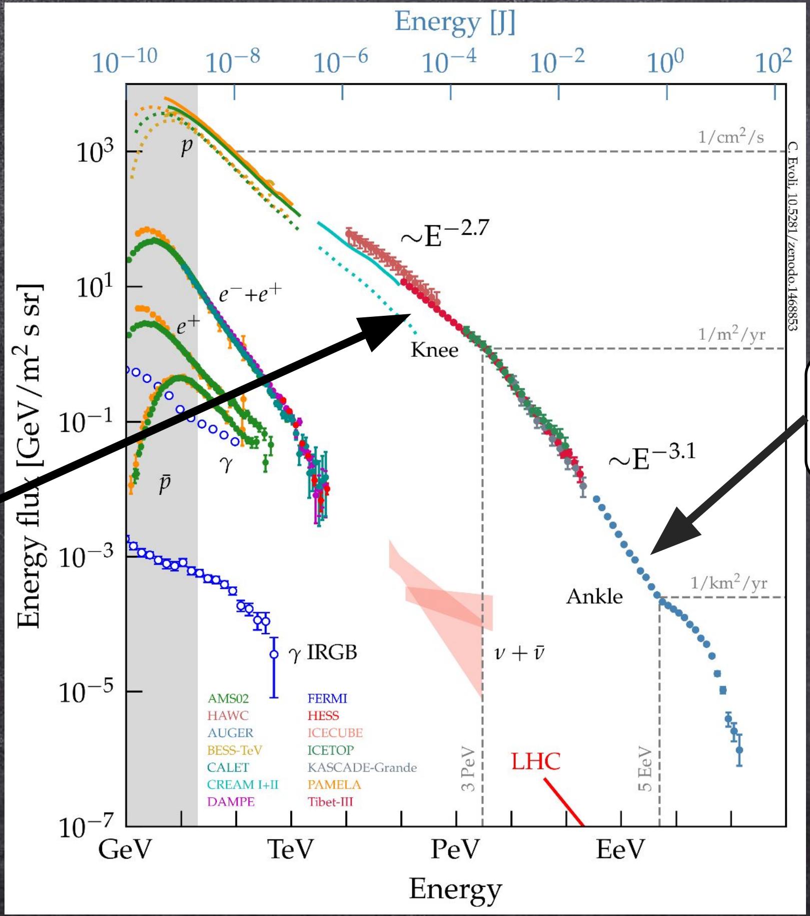
Galactic: SNe/SNRs?



Cosmic-ray sources?



Galactic: SNe/SNRs?



Extragalactic: AGN, star-forming galaxies?

Indirect cosmic-ray detection

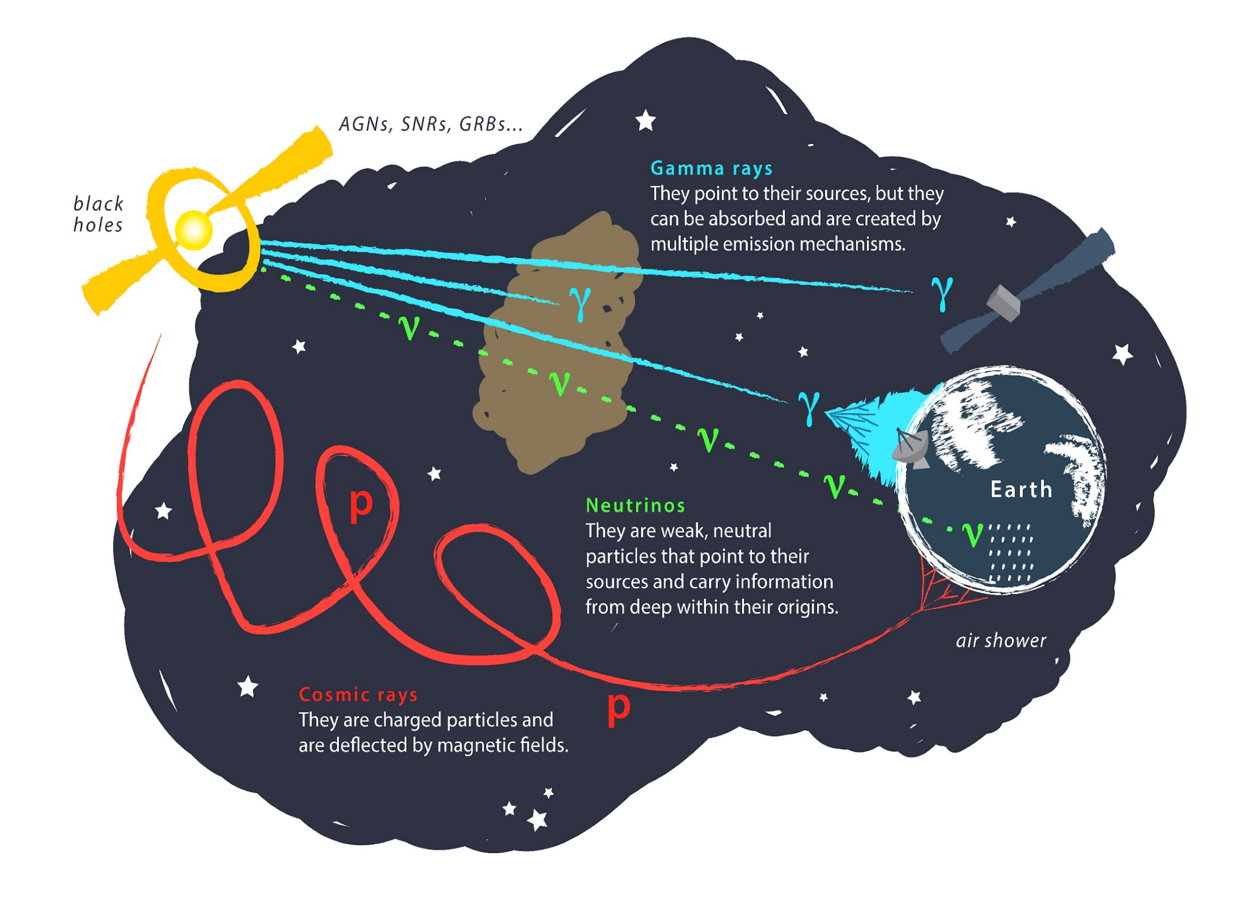
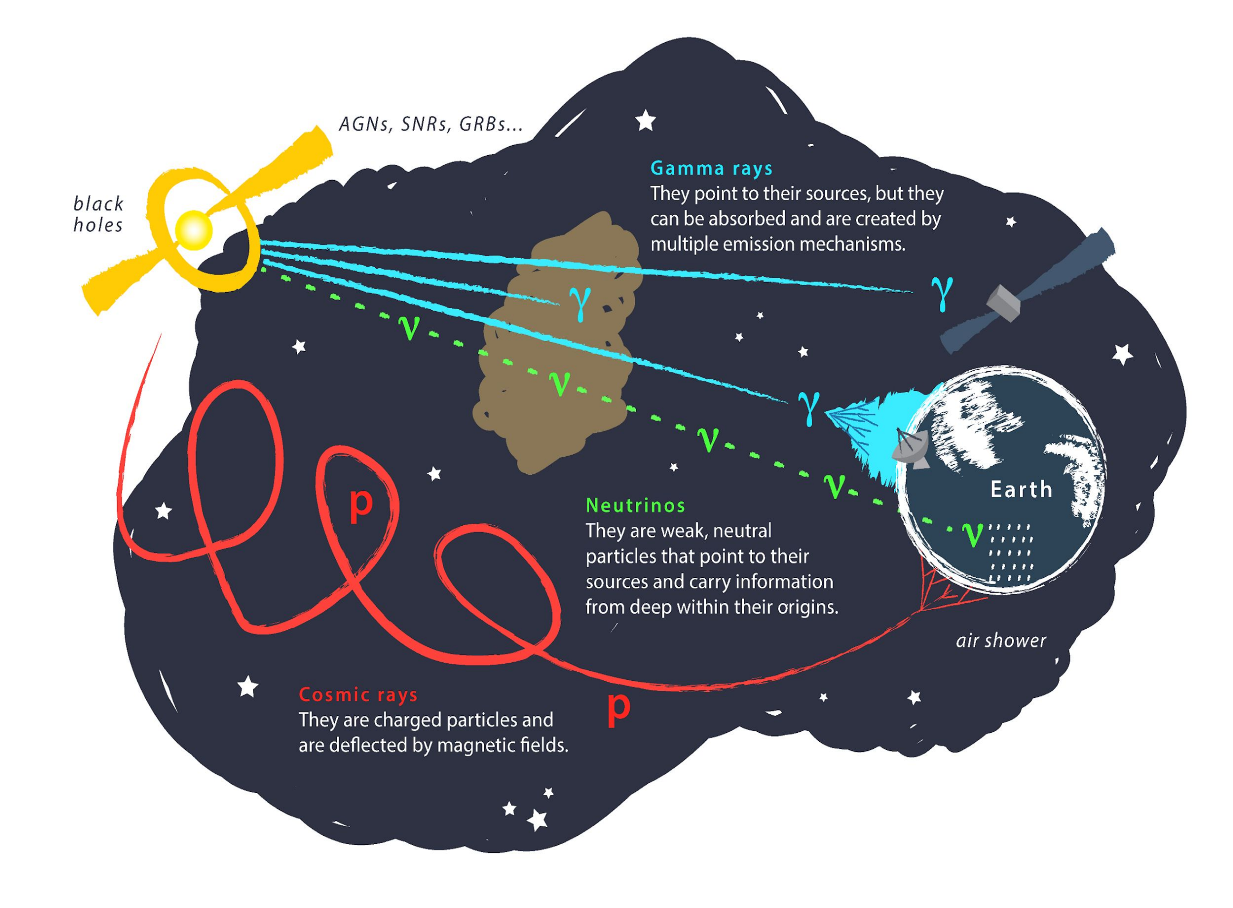


Image Credit: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

Indirect cosmic-ray detection

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



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Indirect cosmic-ray detection

$$\pi^0 \rightarrow 2\gamma$$

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

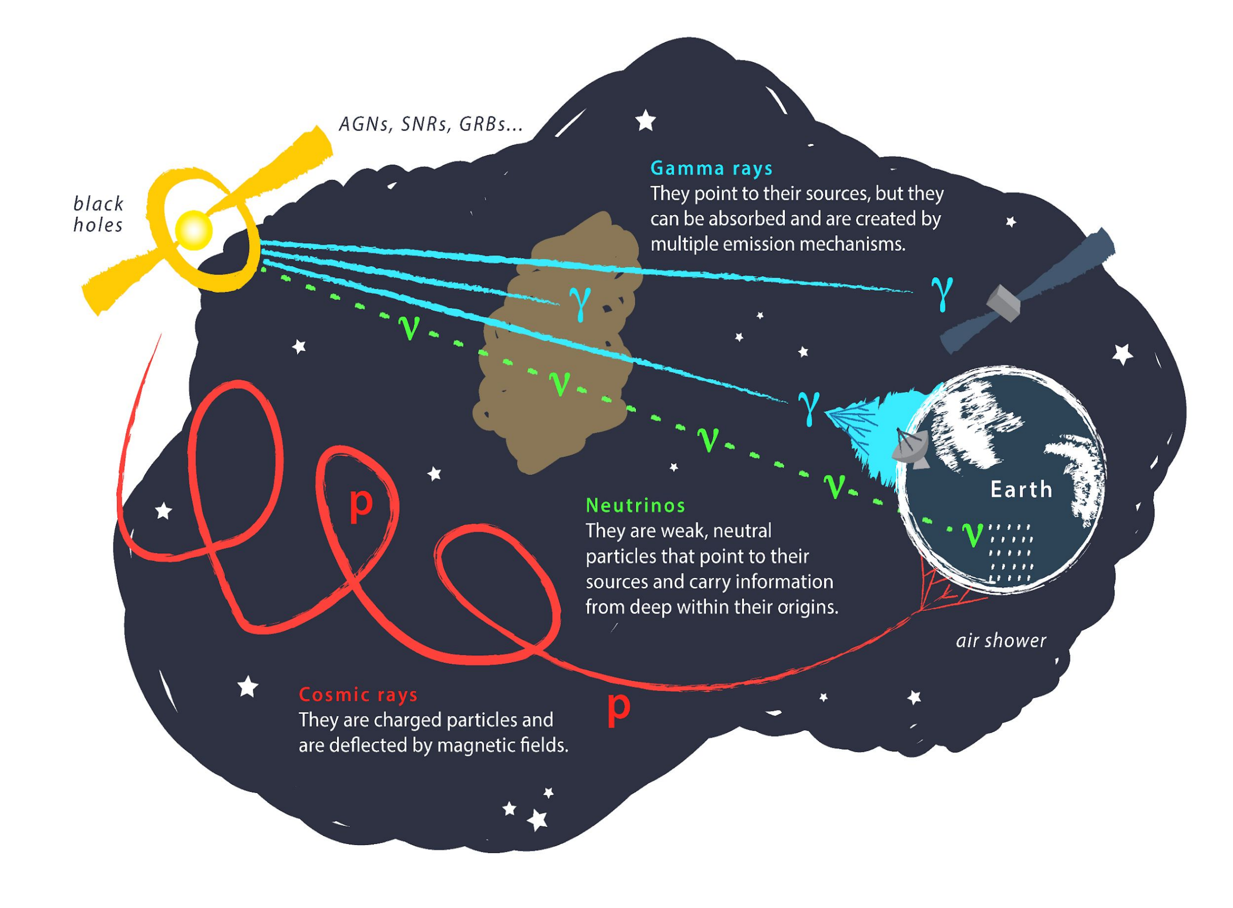


Image Credit: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

Indirect cosmic-ray detection

$$\pi^0 \rightarrow 2\gamma$$

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

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

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

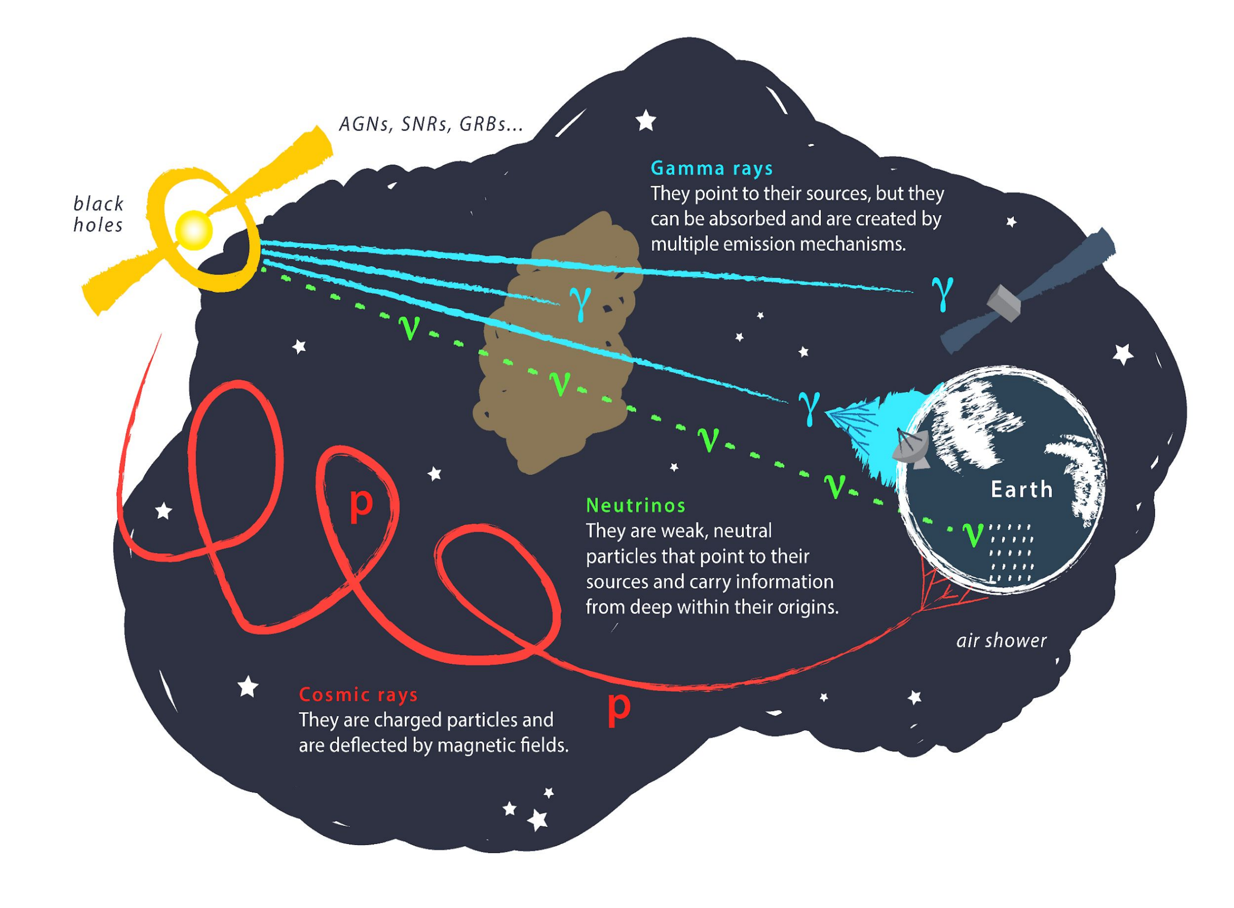
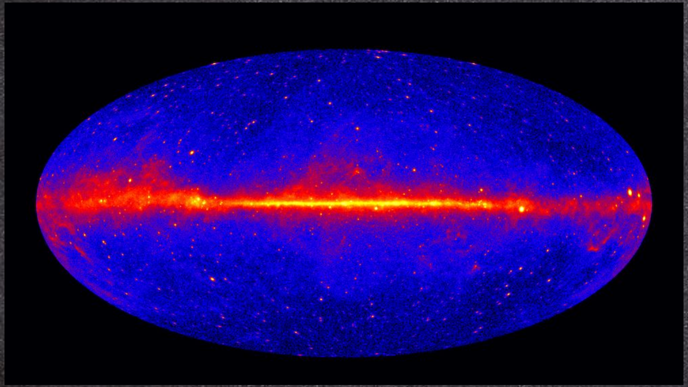


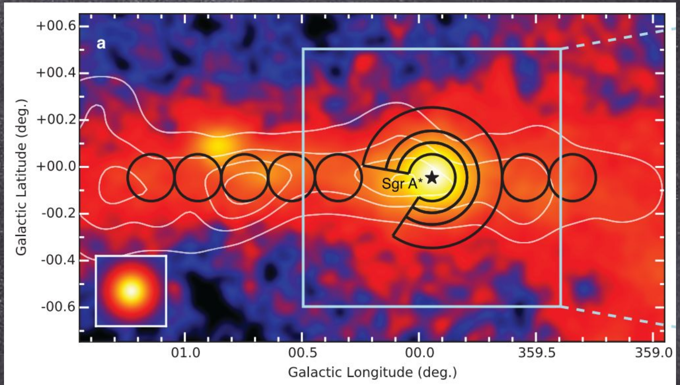
Image Credit: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

γ-ray emission …



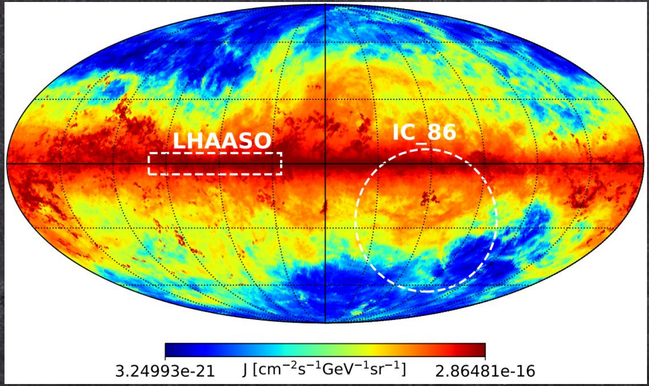
from Fermi/*LAT* (GeV) …

Ackermann et al. 2012



… to HESS (TeV) …

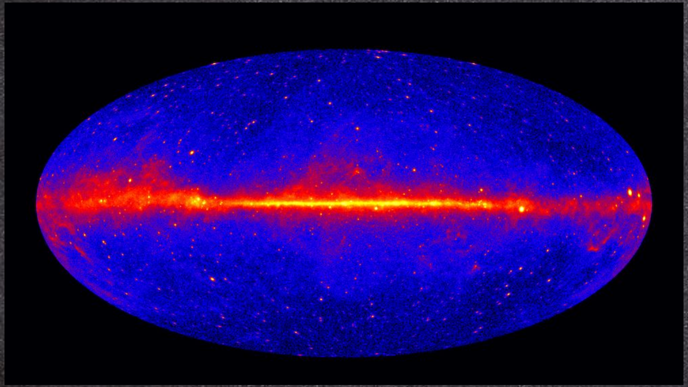
Aharonian et al. 2016



and recently by Thibet ASγ & LHAASO (PeV)

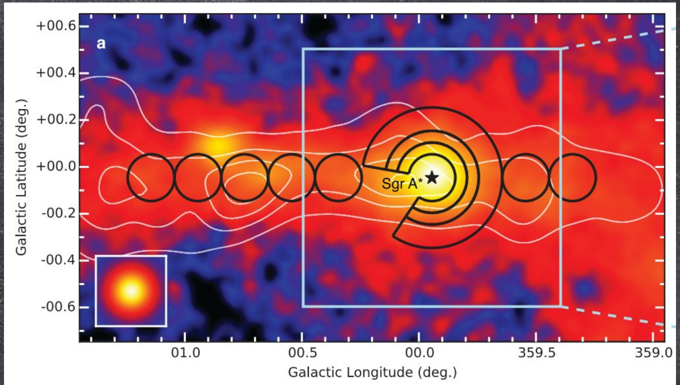
Amenomori et al. 2021, De La Torre Luque et al. 2022

γ-ray emission …



from Fermi/*LAT* (GeV) …

Ackermann et al. 2012



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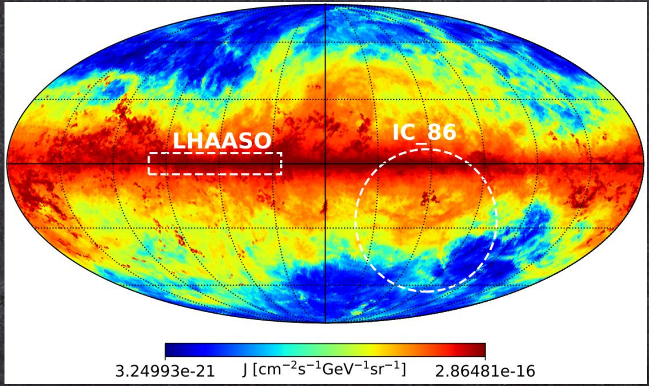


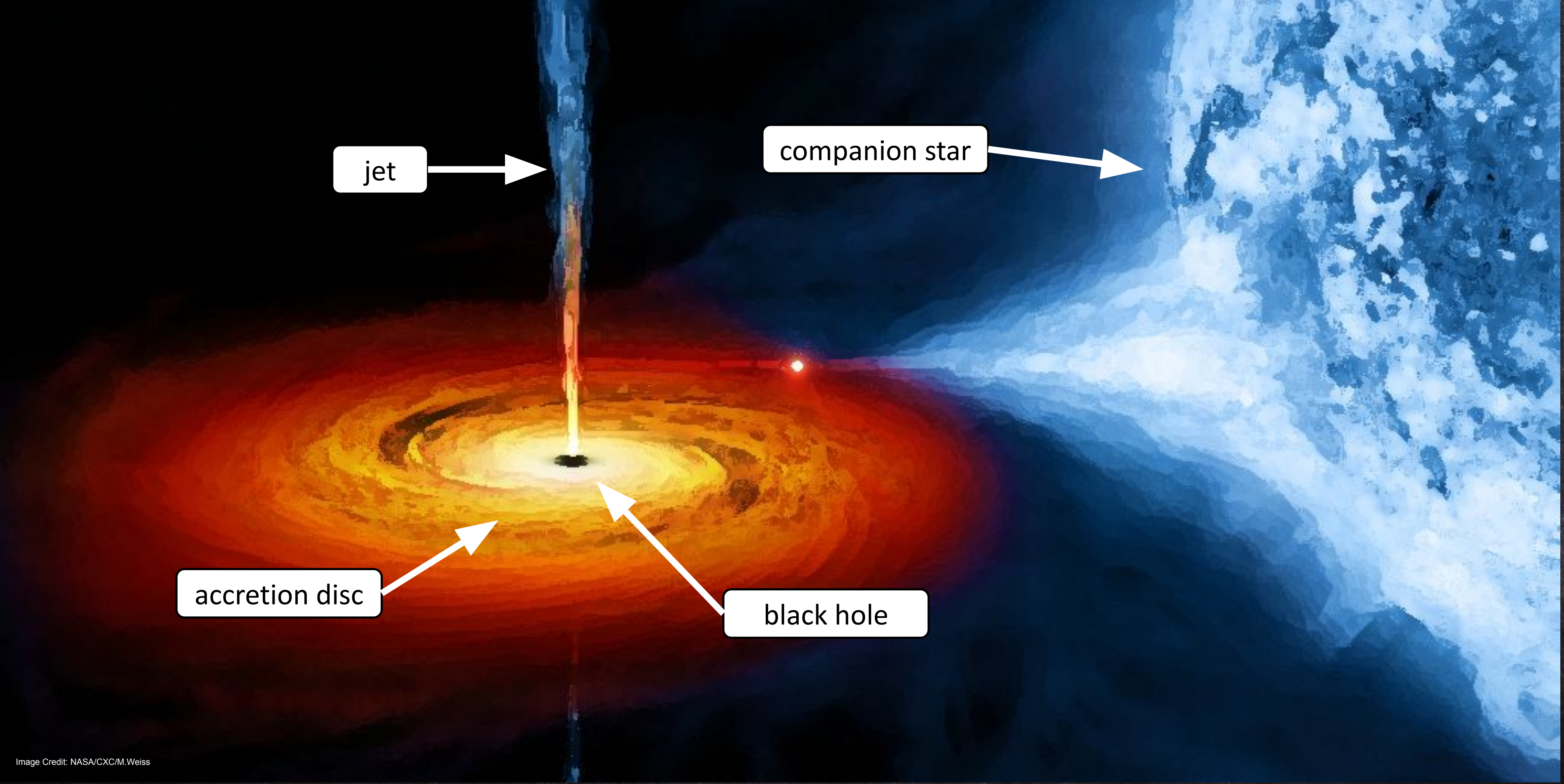
and recently by Thibet ASγ & LHAASO (PeV)

Amenomori et al. 2021, De La Torre Luque et al. 2022

Diffuse emission or point sources?

Astrophysical origin or beyond the Standard Model physics?

Stellar-mass black holes with jets



Stellar-mass black holes with jets

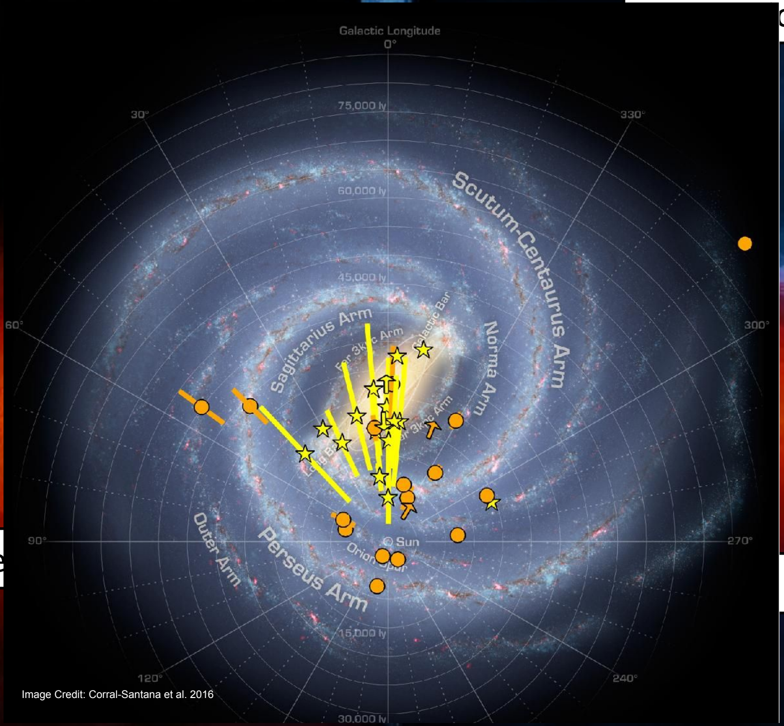


Image Credit: Corral-Santana et al. 2016

- distributed in the Milky Way (~50 detected)
- both persistent and transient
- strong magnetic fields
- accelerate particles to high energies
- emit in γ-rays

Image Credit: NASA/CXC/M.Weiss

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

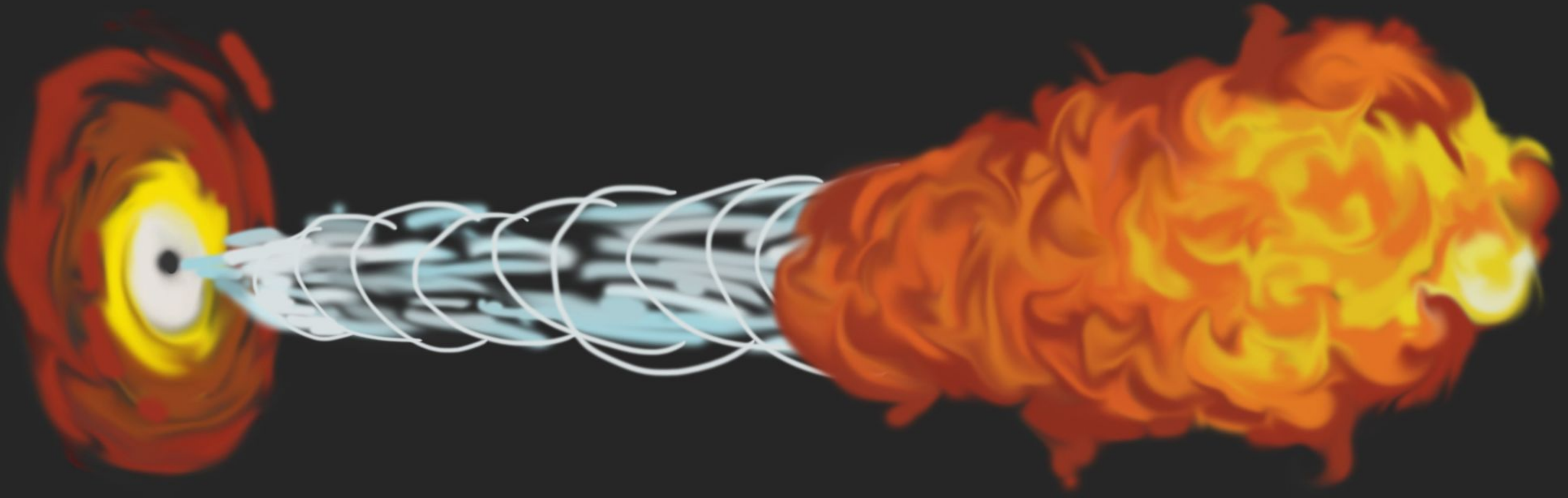
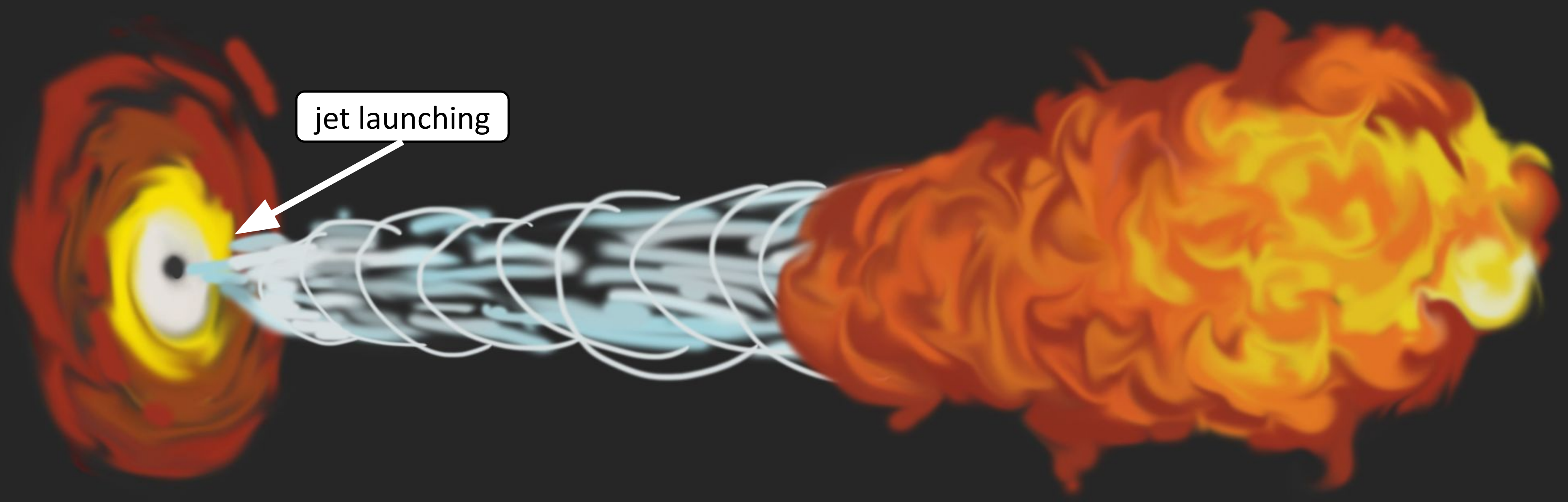


Image Credit: T. Revolta

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



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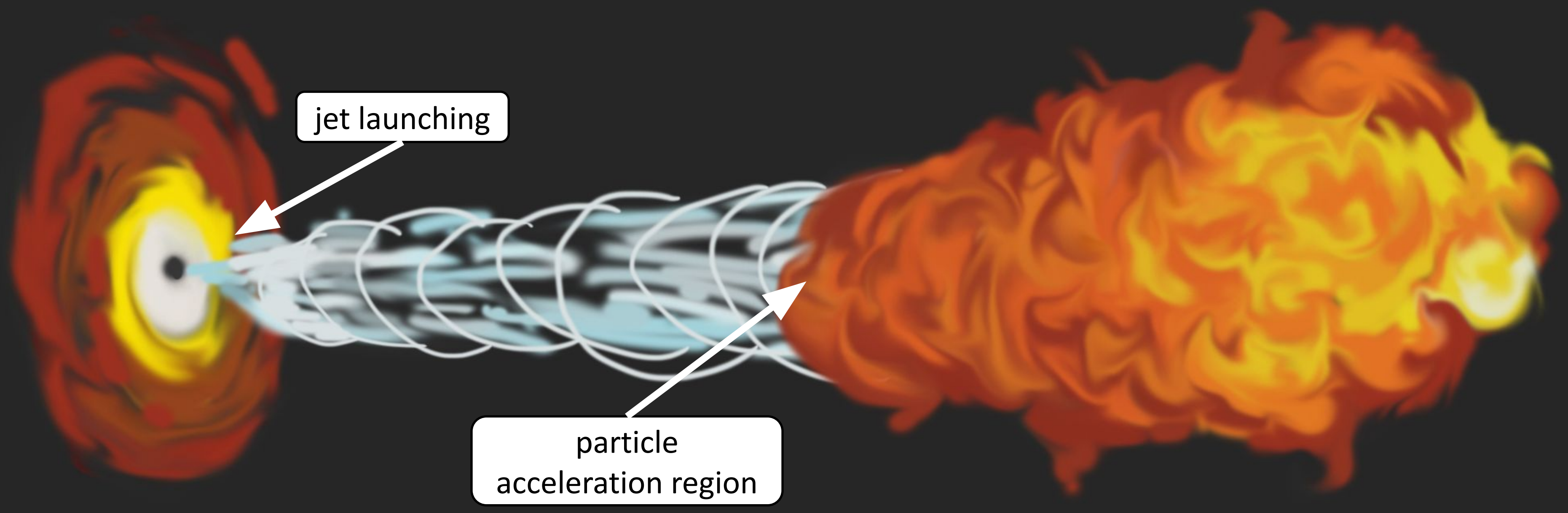

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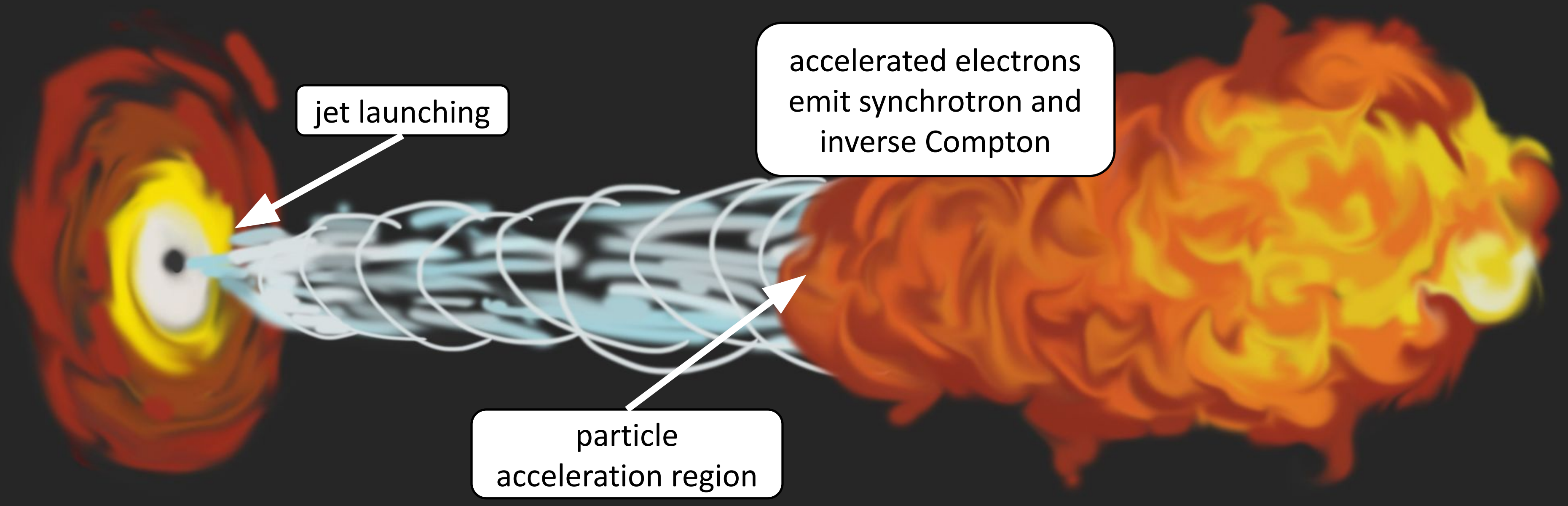
A multi-zone, *jet model* with hadronic interactions



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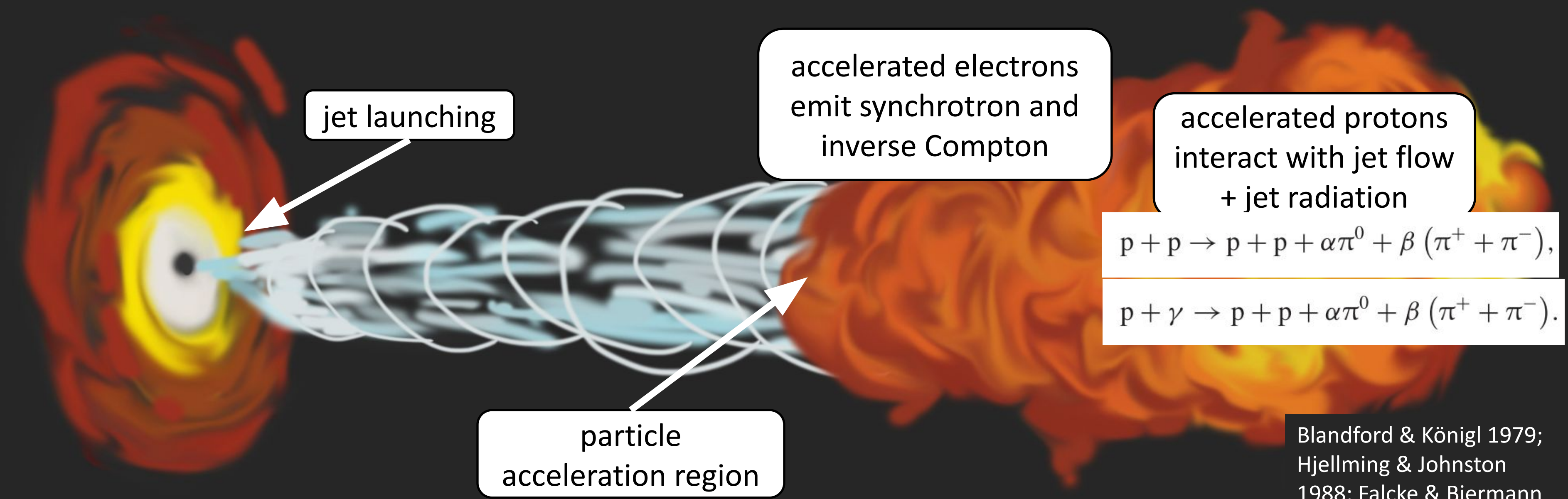
A multi-zone, *jet model* with hadronic interactions



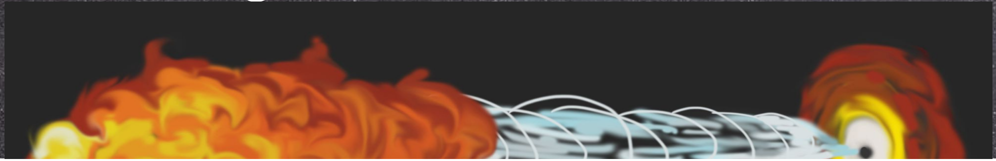
$$\mathrm{p} + \mathrm{p} \rightarrow \mathrm{p} + \mathrm{p} + \alpha\pi^0 + \beta\left(\pi^+ + \pi^-\right),$$

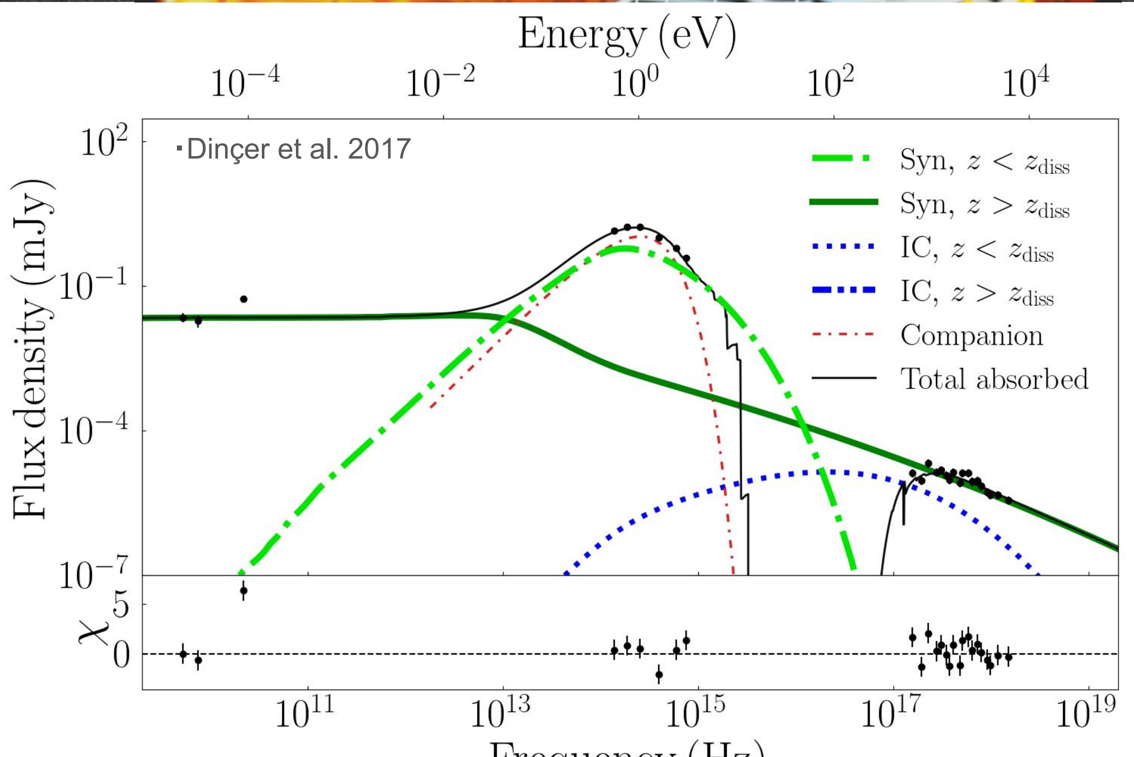
$$\mathrm{p} + \gamma \rightarrow \mathrm{p} + \mathrm{p} + \alpha\pi^0 + \beta\left(\pi^+ + \pi^-\right).$$

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

Multiwavelength constraints from A0620–00





Kantzas et al. in prep

quiescent black-hole X-ray binary (qBH-XRB)

M_{bh}: 6.61 $M_{\odot}$

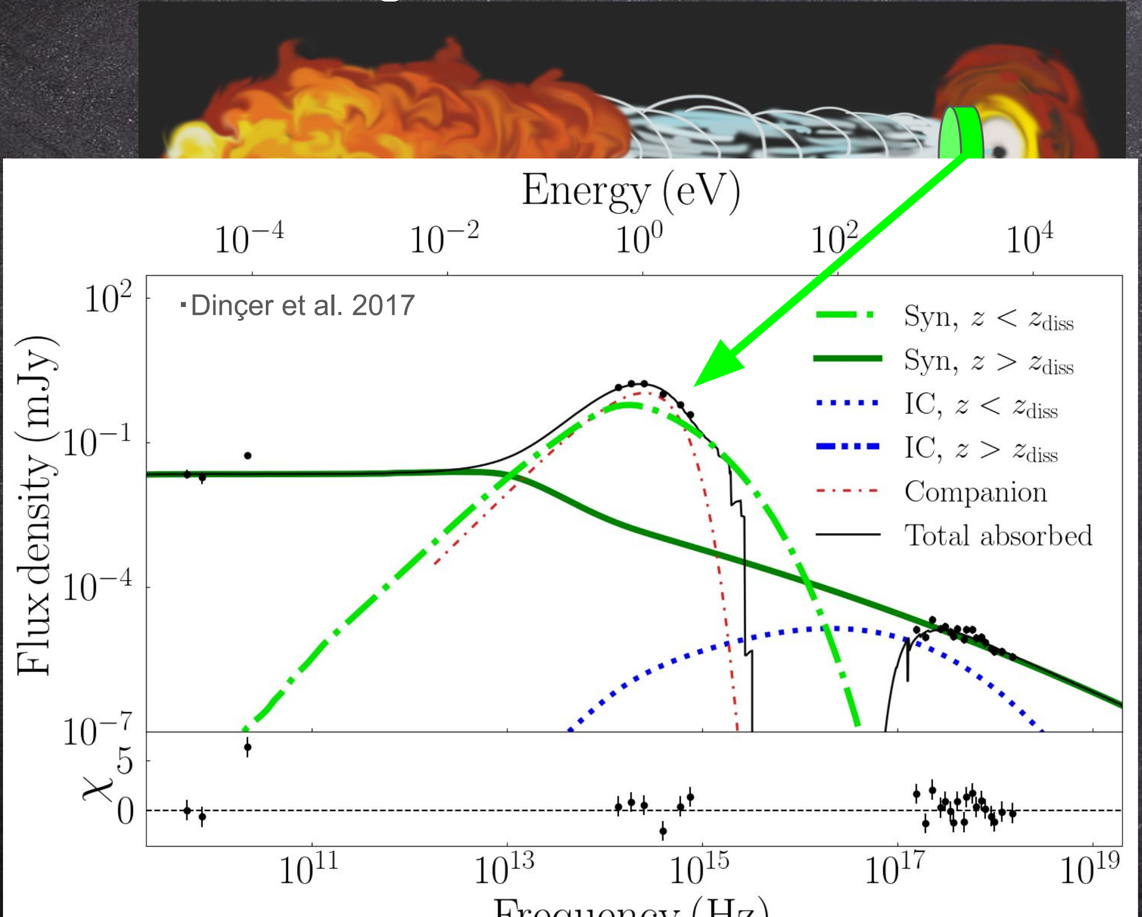
distance: 1.1 kpc

inclination: 51 deg

jet power: 10^{-5} Edd*

*Eddington luminosity: ~10^{38} erg/s ($M_{bh}/M_{\odot}$)

Multiwavelength constraints from A0620–00



Kantzas et al. in prep

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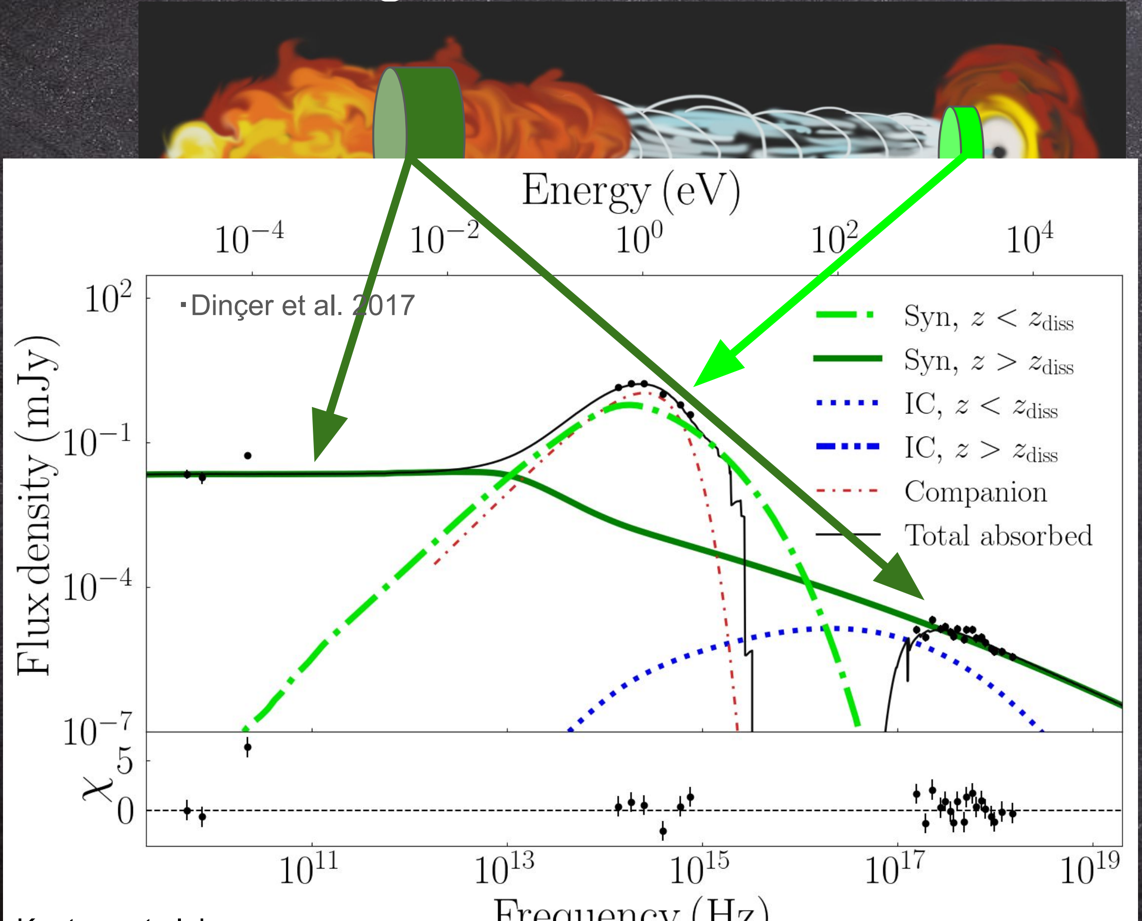

Kantzas et al. in prep

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M_{bh}: 6.61 $M_\odot$

distance: 1.1 kpc

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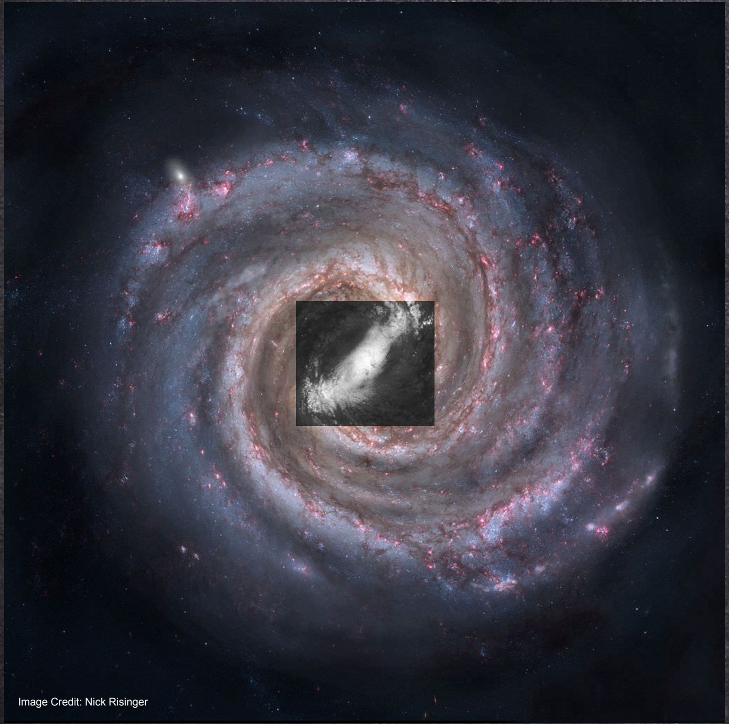
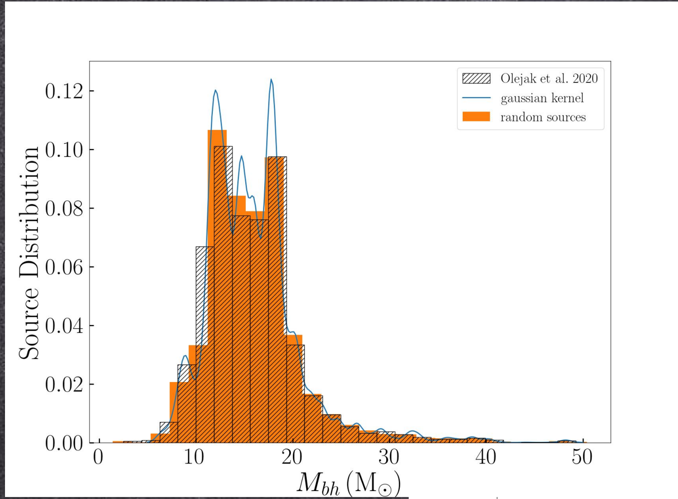
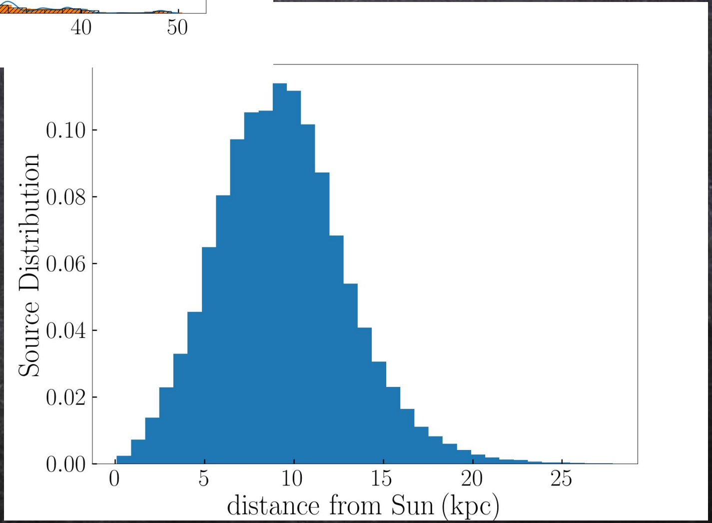
Population of BH-XRBs: disc





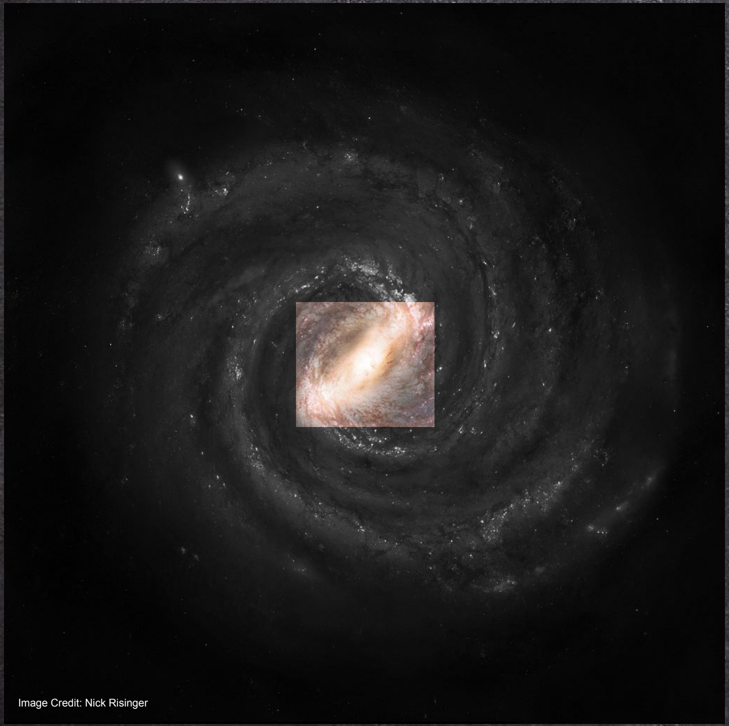
Black hole masses
based on Olejak et al. 2020

Black hole distances

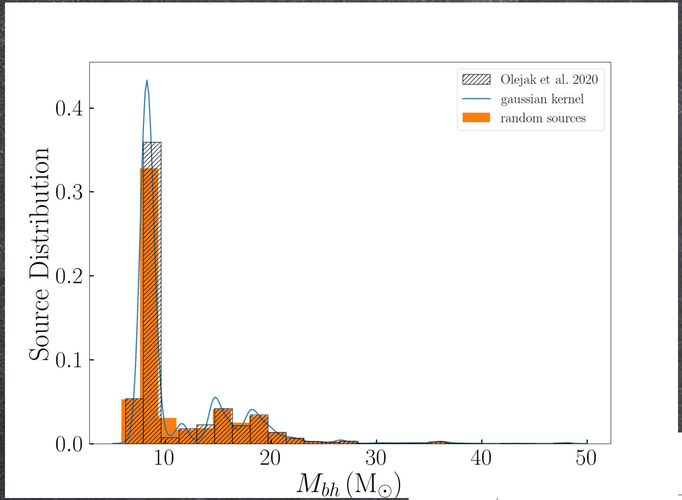


100.000 sources following a 2D Lorimer distribution (Lorimer et al. 2006)

Population of BH-XRBs: bulge



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



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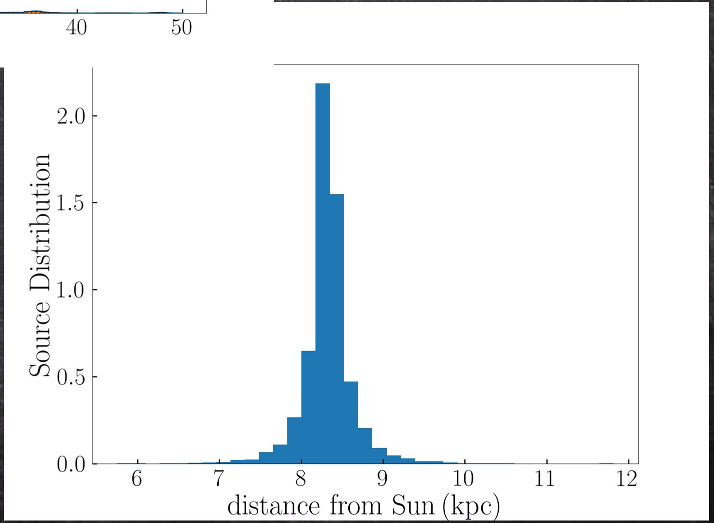

Population of BH-XRBs: diffuse and prompt emission

- CR propagation
  - contribution to the CR spectrum
  - contribution to the γ-ray spectrum
  - contribution to the neutrino spectrum

Population of BH-XRBs: diffuse and prompt emission

- CR propagation
  - contribution to the CR spectrum
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- prompt (intrinsic) emission
  - contribution to the γ-ray spectrum
  - contribution to the neutrino spectrum

Population of BH-XRBs: diffuse and prompt emission

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  - contribution to the CR spectrum
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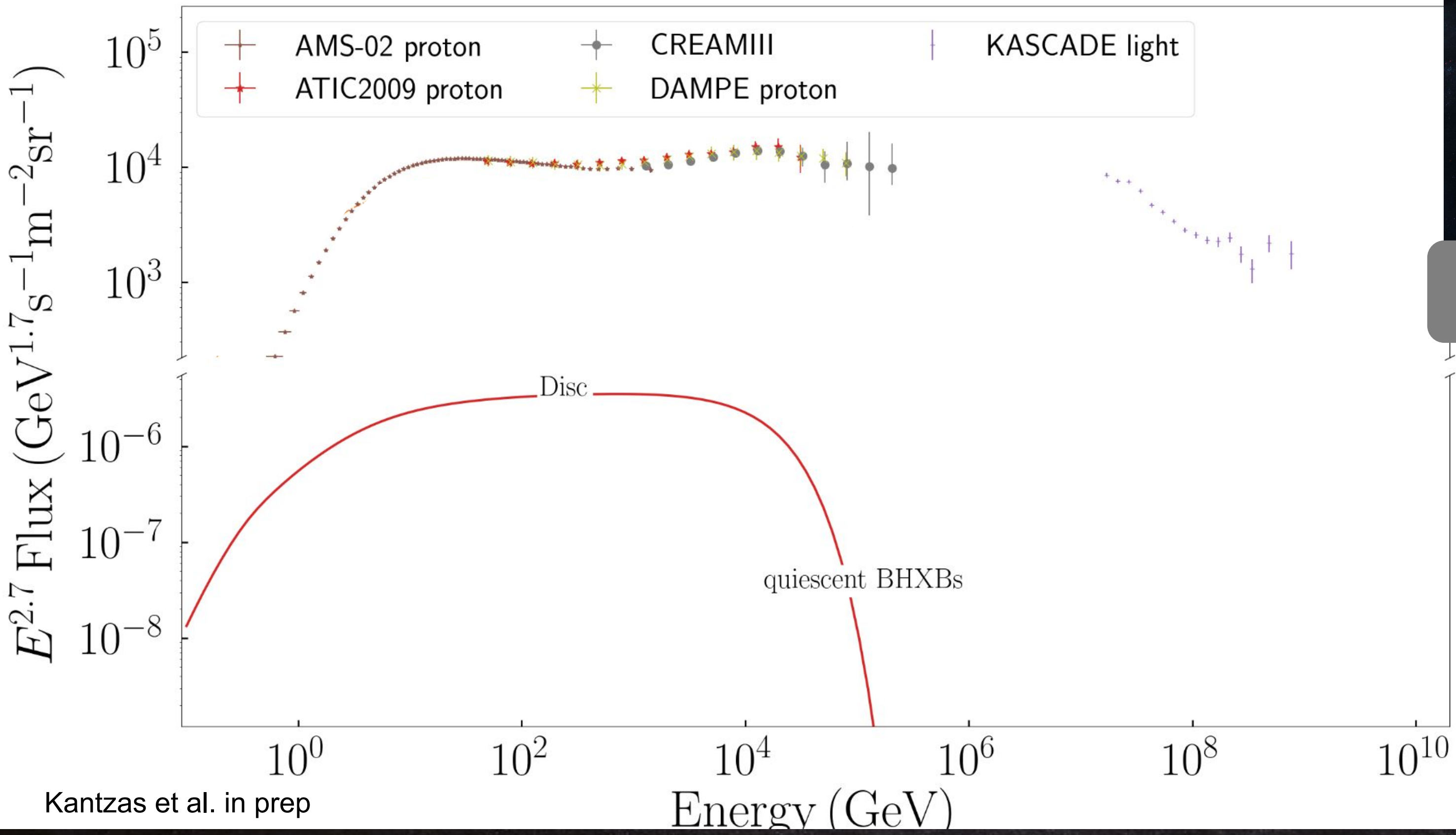
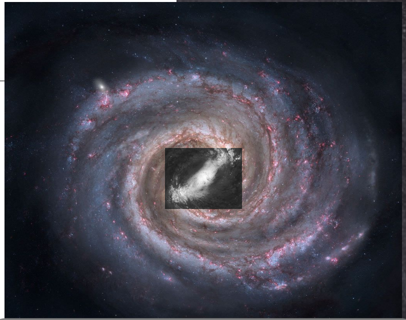
  - ~~contribution to the neutrino spectrum~~
- prompt (intrinsic) emission
  - contribution to the γ-ray spectrum
  - ~~contribution to the neutrino spectrum~~

Contribution of BH-XRBs to the CR proton spectrum



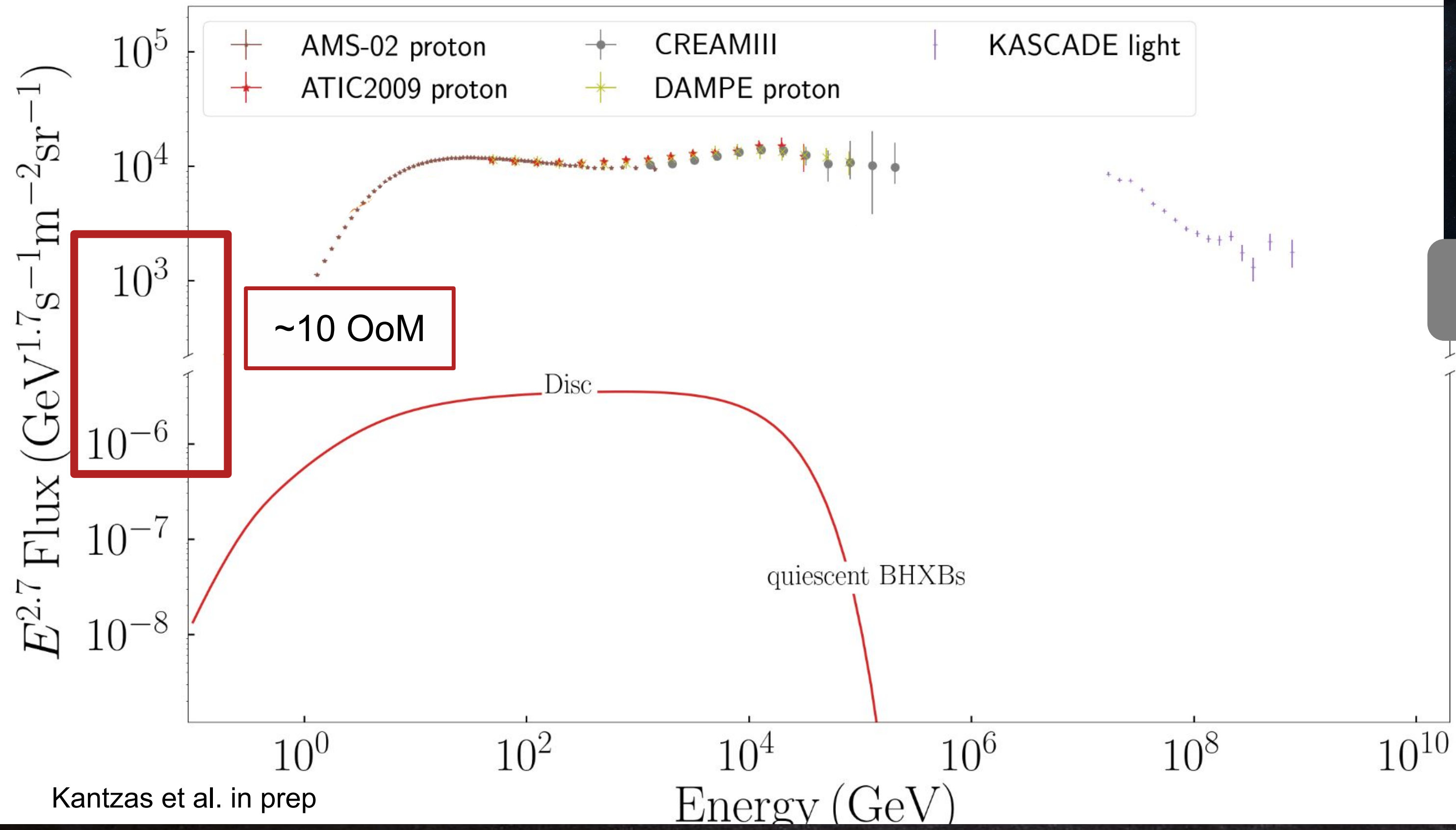
Kantzas et al. in prep



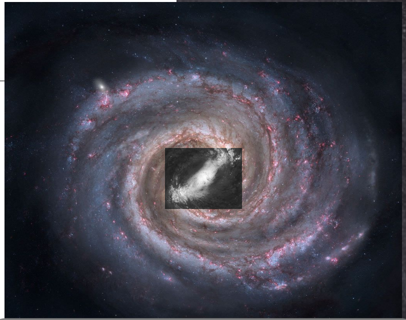
100.000 qBH-XRBs

Evoli et al. 2017, 2018

Contribution of BH-XRBs to the CR proton spectrum



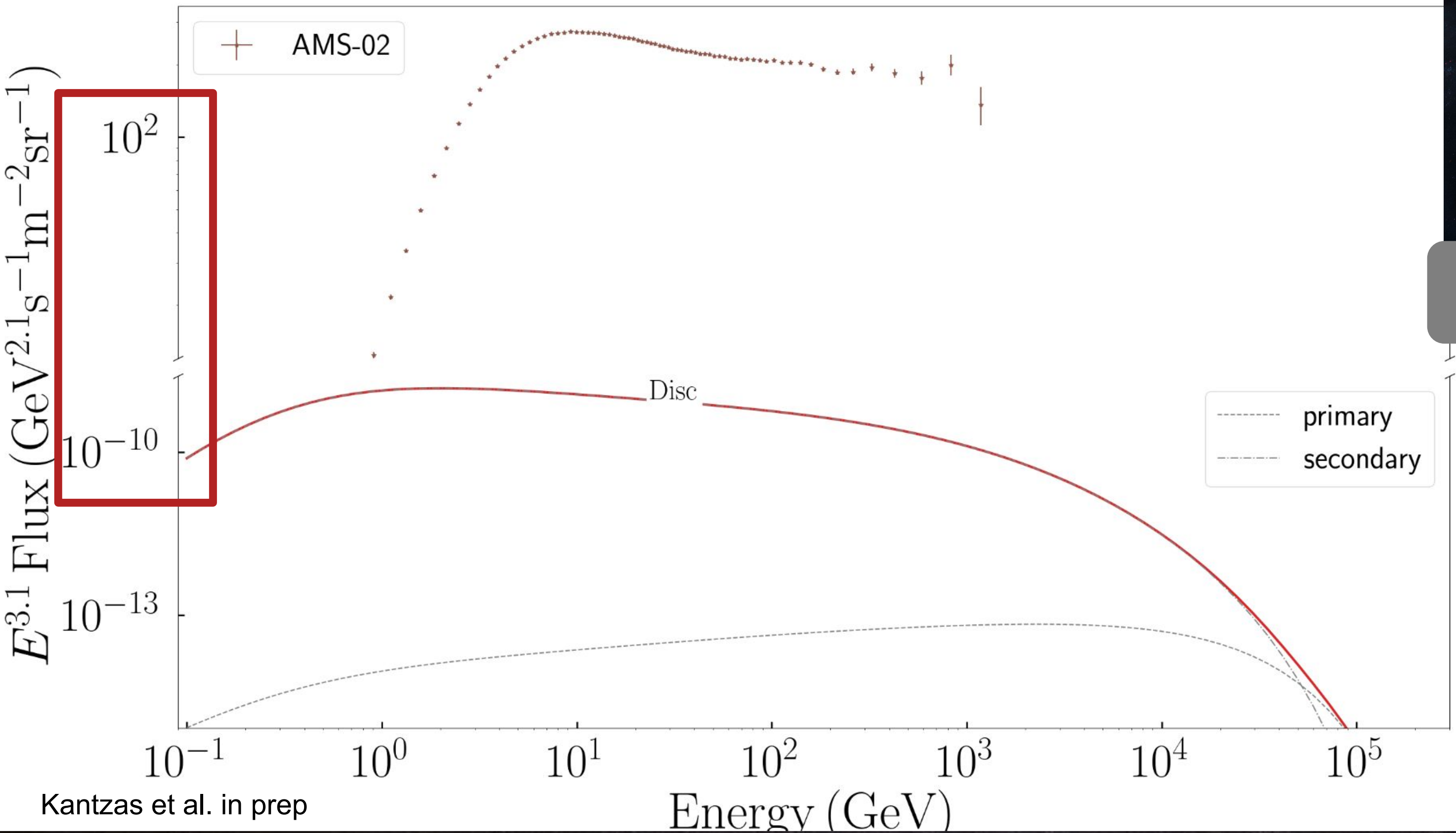
Kantzas et al. in prep



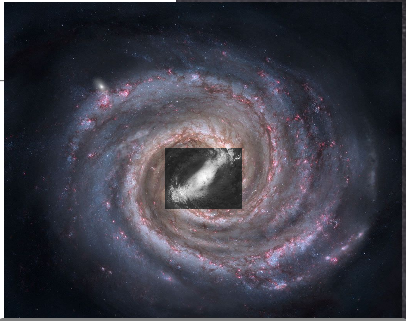
100.000 qBH-XRBs

Evoli et al. 2017, 2018

Contribution of BH-XRBs to the CR electron spectrum



Kantzas et al. in prep



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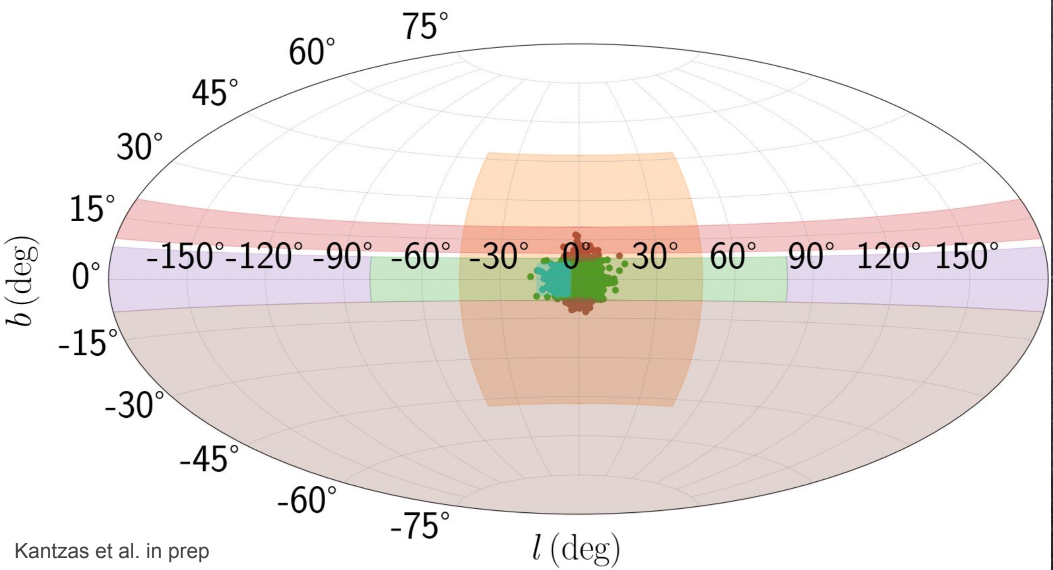
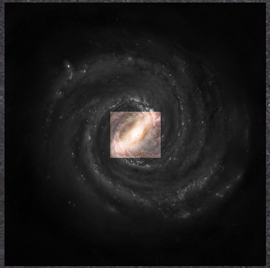
    - contribution to the γ-ray spectrum
    - contribution to the neutrino spectrum

Prompt emission from the Boxy Bulge qBH-XRBs

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



Prompt emission from the Boxy Bulge qBH-XRBs



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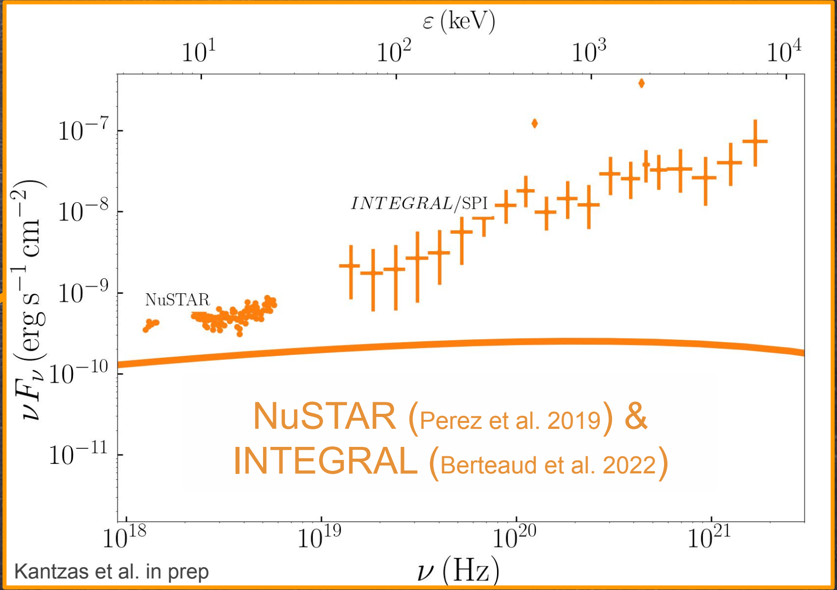
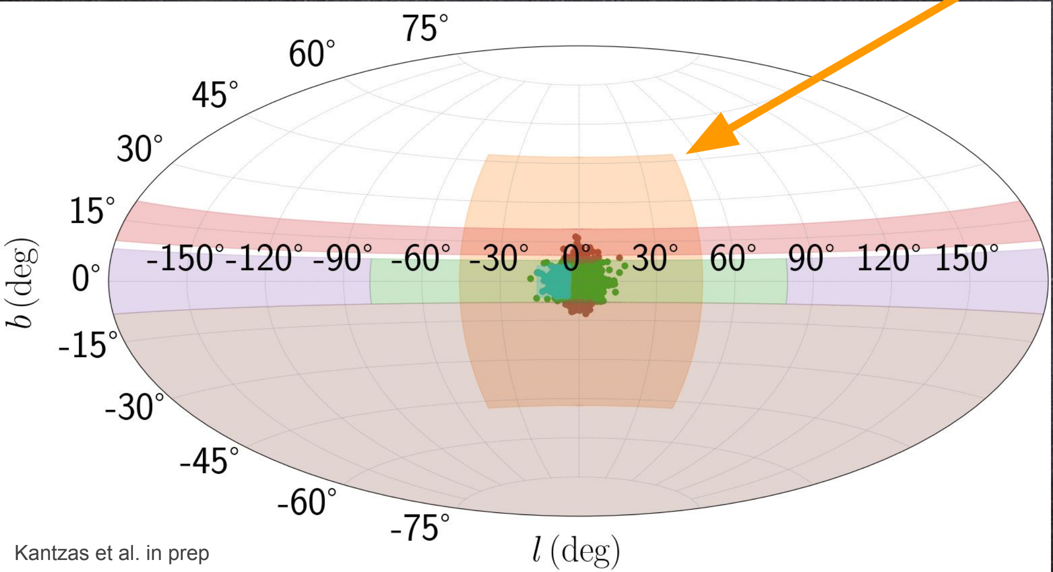
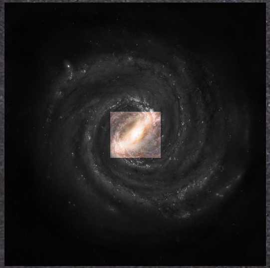




~20% in the 10keV regime

Prompt emission from the Boxy Bulge qBH-XRBs



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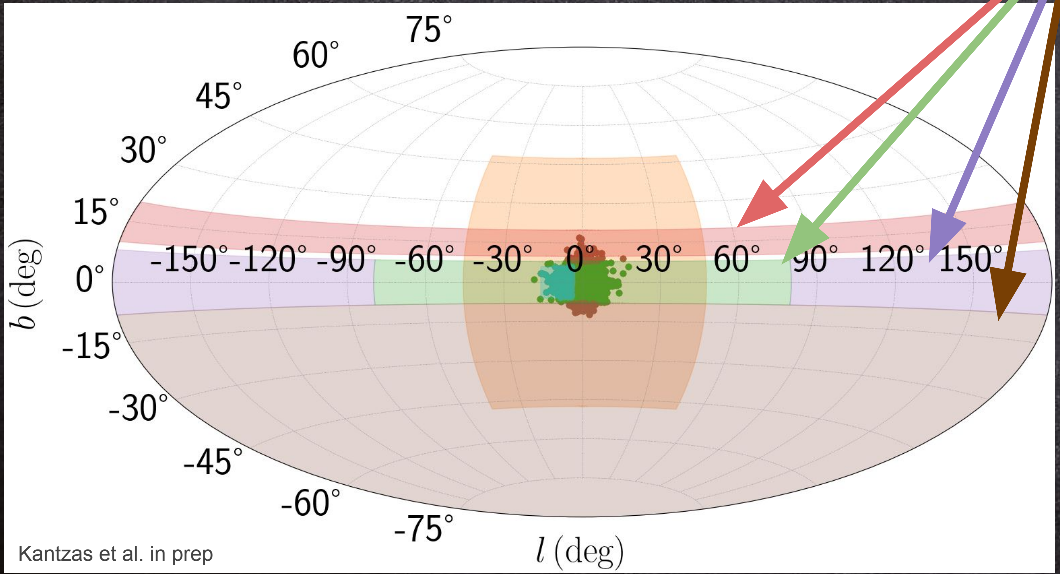
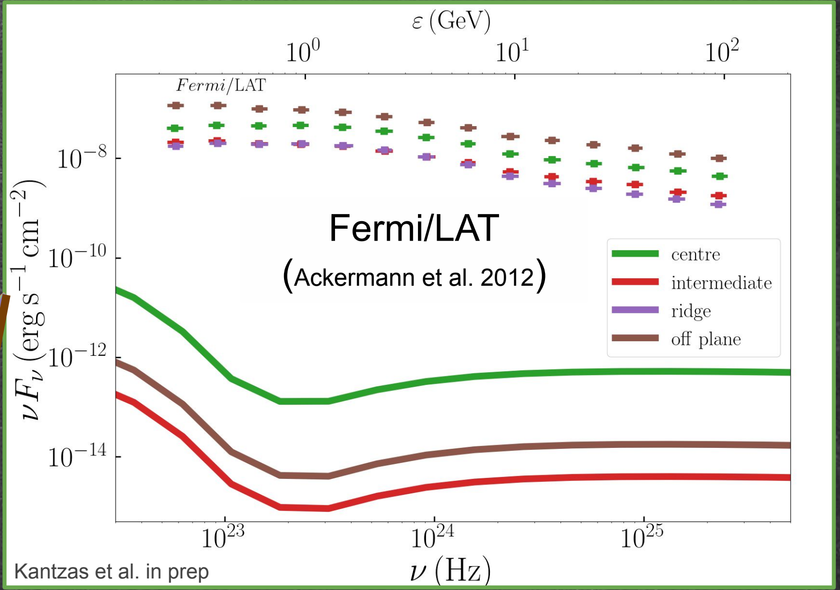
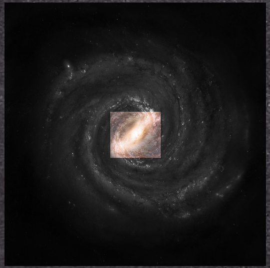




<0.01% in the GeV regime

Prompt emission from the Boxy Bulge qBH-XRBs



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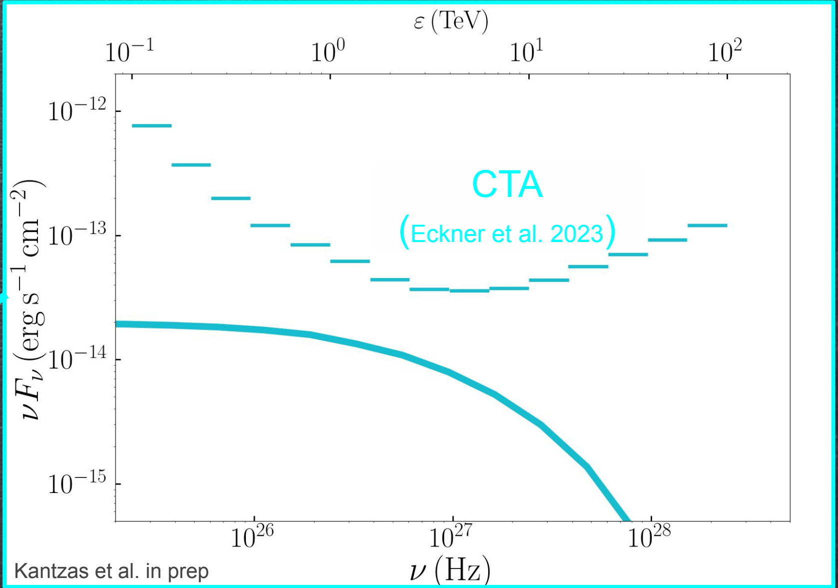
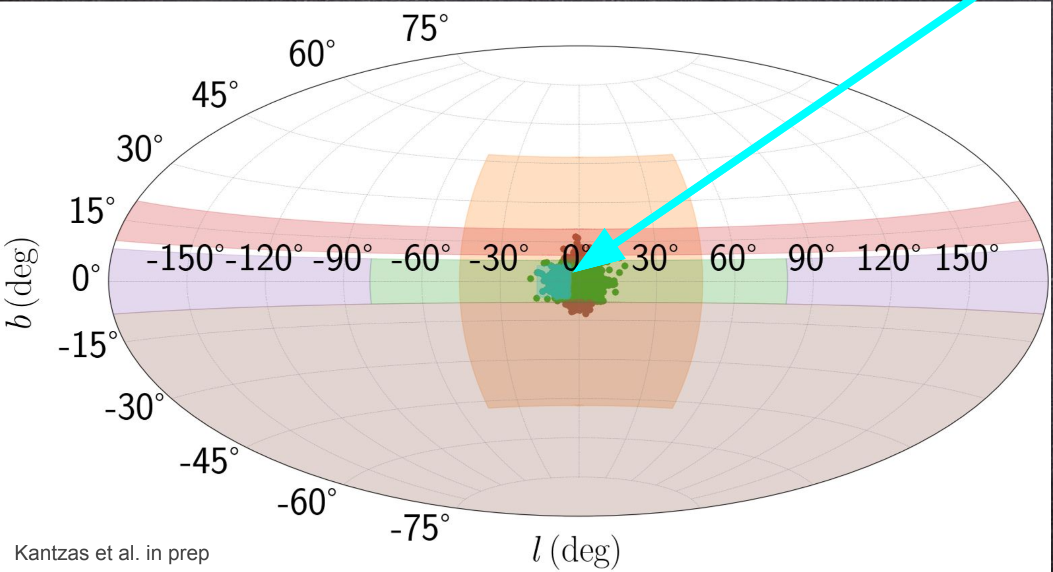
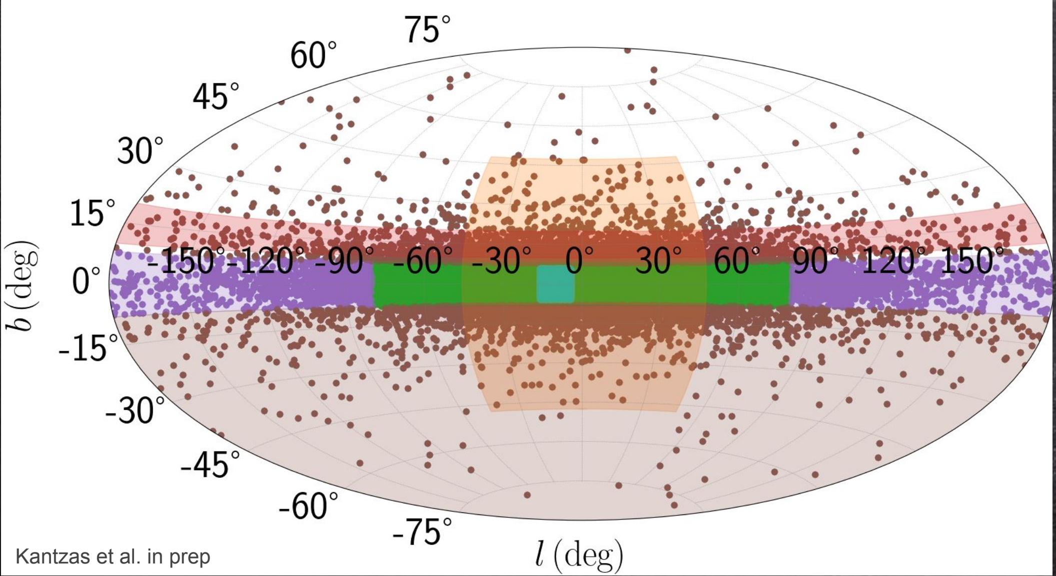




~20% in the TeV regime

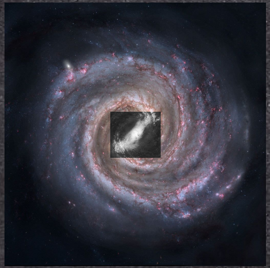
Prompt emission from the disc qBH-XRBs

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



Kantzas et al. in prep

Prompt emission from the disc qBH-XRBs



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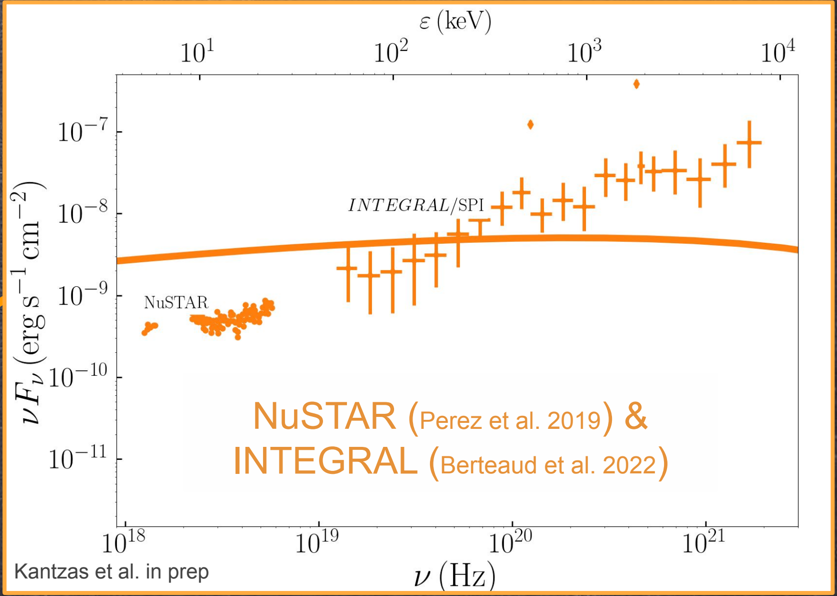
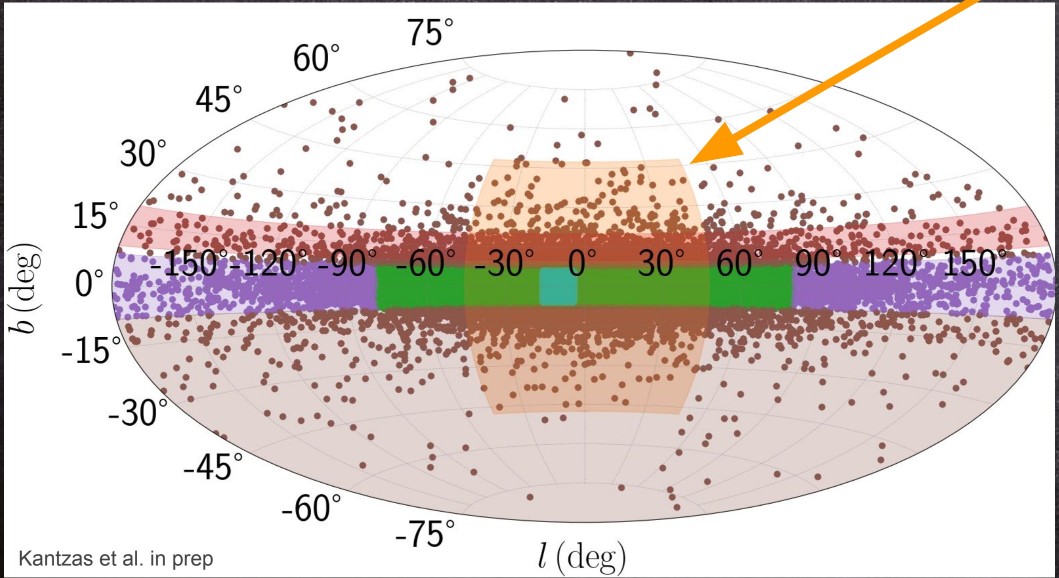
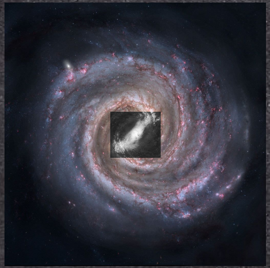




100% in the 10–100keV regime

100.000 with 10^{-5} Eddington luminosity

Prompt emission from the disc qBH-XRBs



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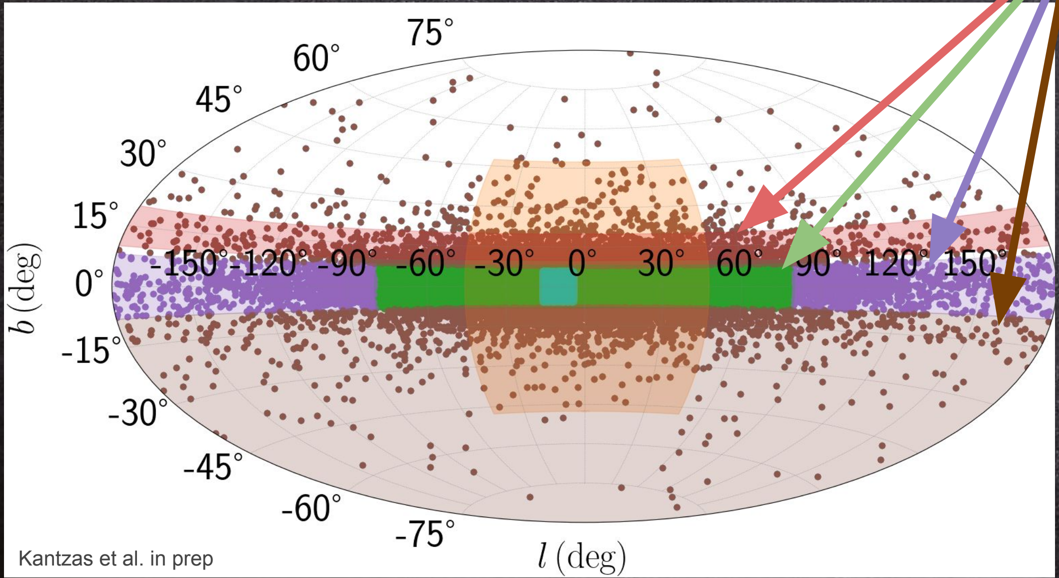
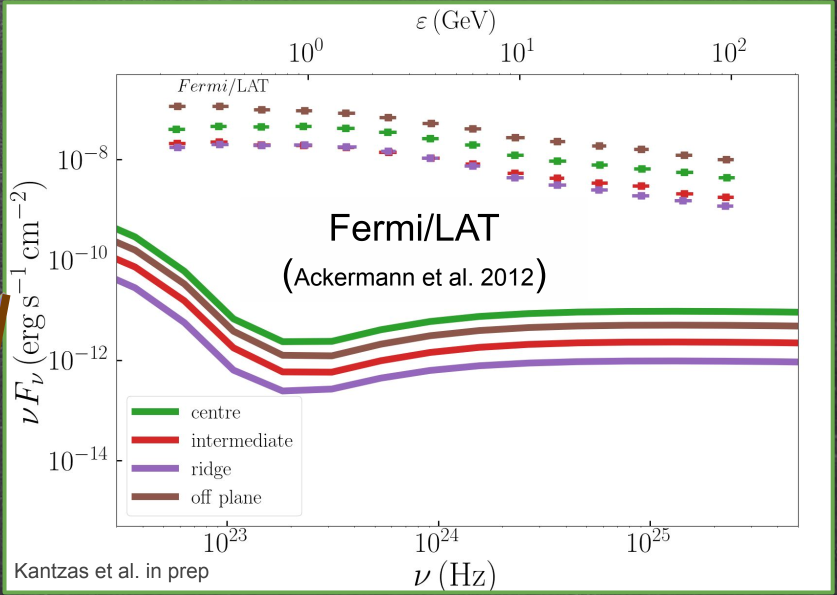
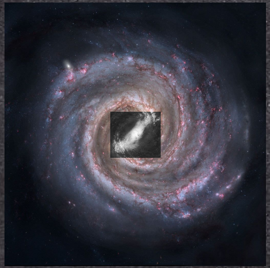


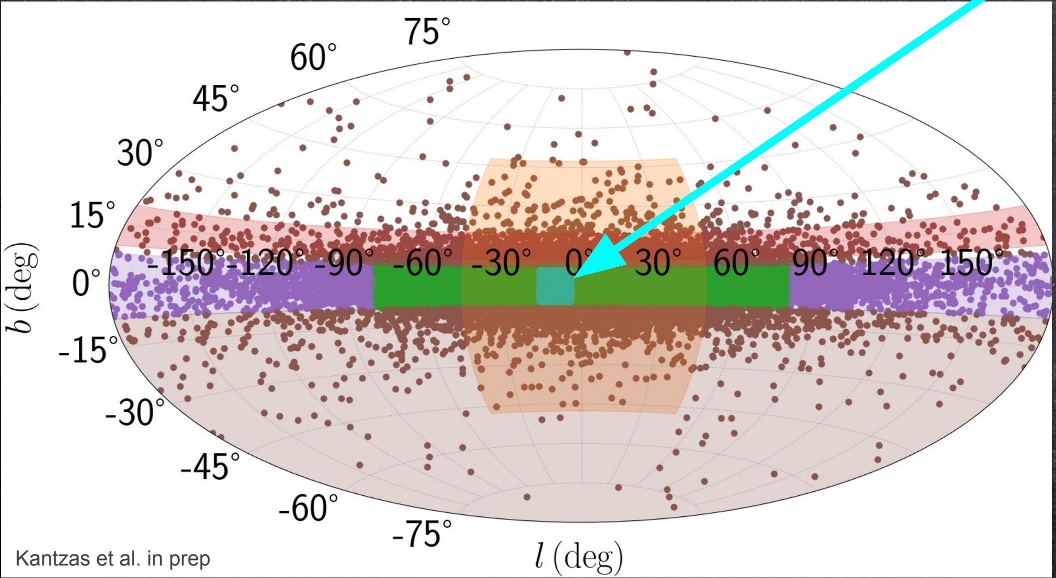


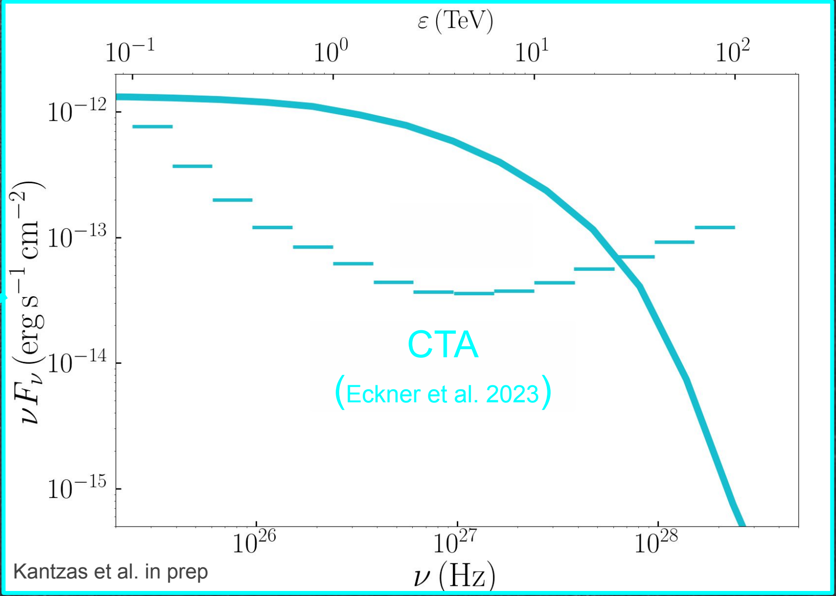
<0.01% in the GeV regime

Prompt emission from the disc qBH-XRBs



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





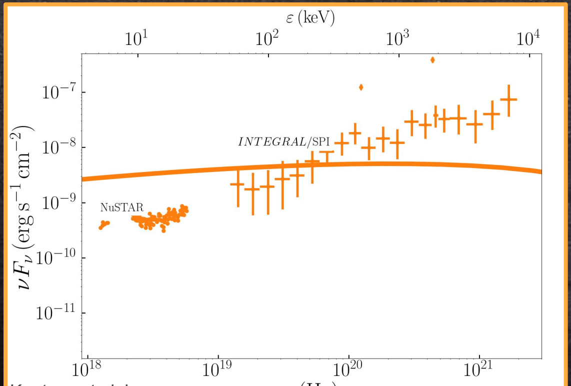
100% in the TeV regime

Population of BH-XRBs: diffuse and prompt emission

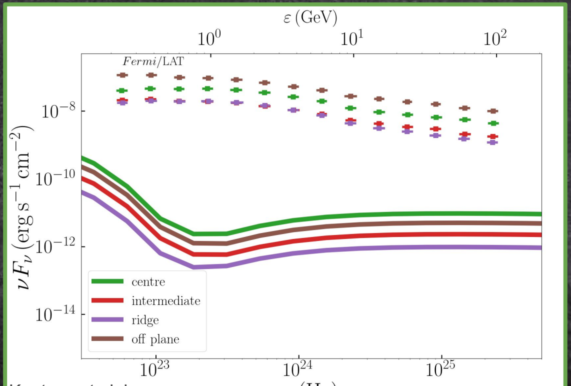
- CR propagation
  - contribution to the CR spectrum
  - contribution to the γ-ray spectrum
  - contribution to the neutrino spectrum
- prompt (intrinsic) emission
  - contribution to the γ-ray spectrum
  - contribution to the neutrino spectrum

Conclusions

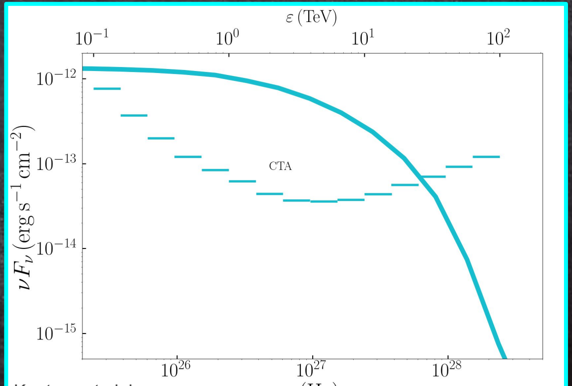
- quiescent black-hole XRBs may contribute:
  - ~0% to the CR proton spectrum
  - ~0% to the CR electron spectrum
  - with prompt emission:
    - up to ~ 100% to the X-ray spectrum (100.000 with 10^{-5} Eddington luminosity)
    - up to ~ 0.01% to the GeV γ-ray spectrum
    - up to ~ 100% to the TeV γ-ray spectrum



Kantzas et al. in prep



Kantzas et al. in prep

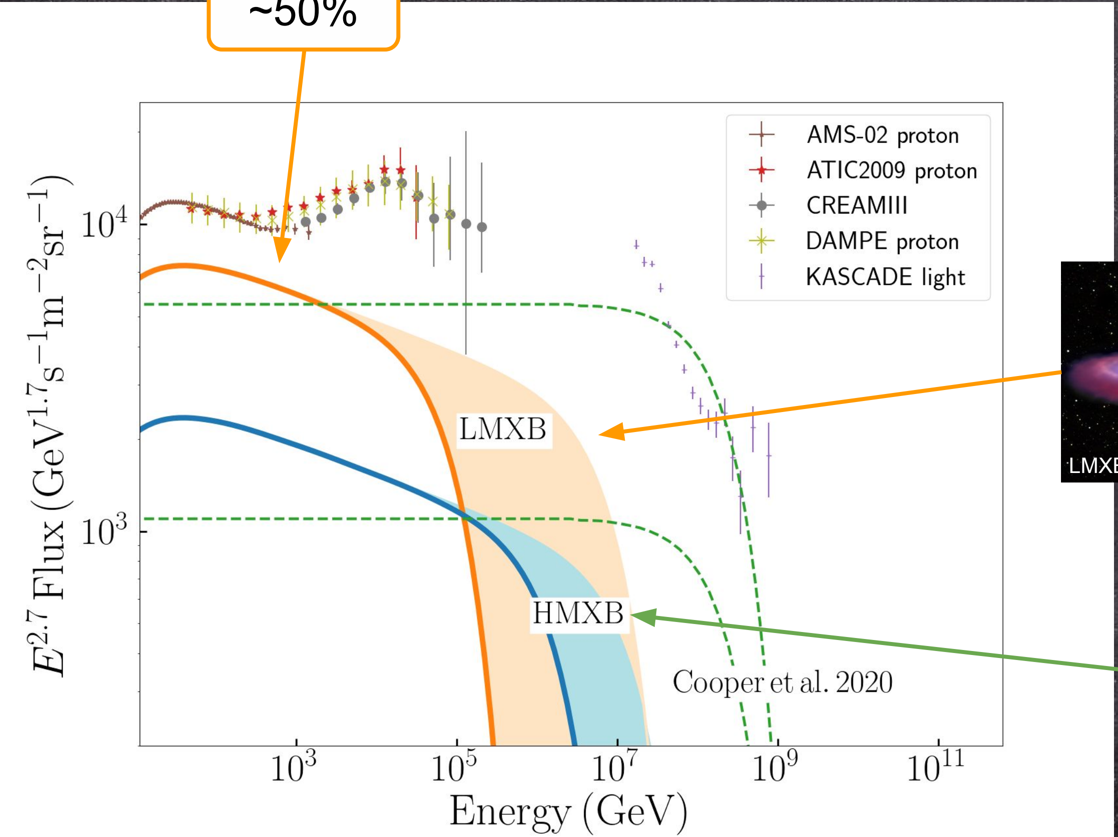


Kantzas et al. in prep

Extra Slides

Contribution of black hole XRBs to the CR proton spectrum

~50%



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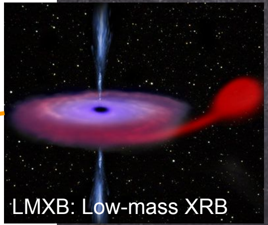
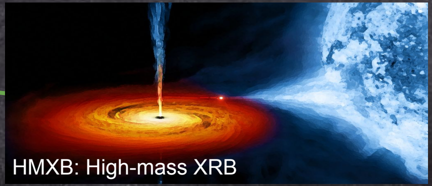
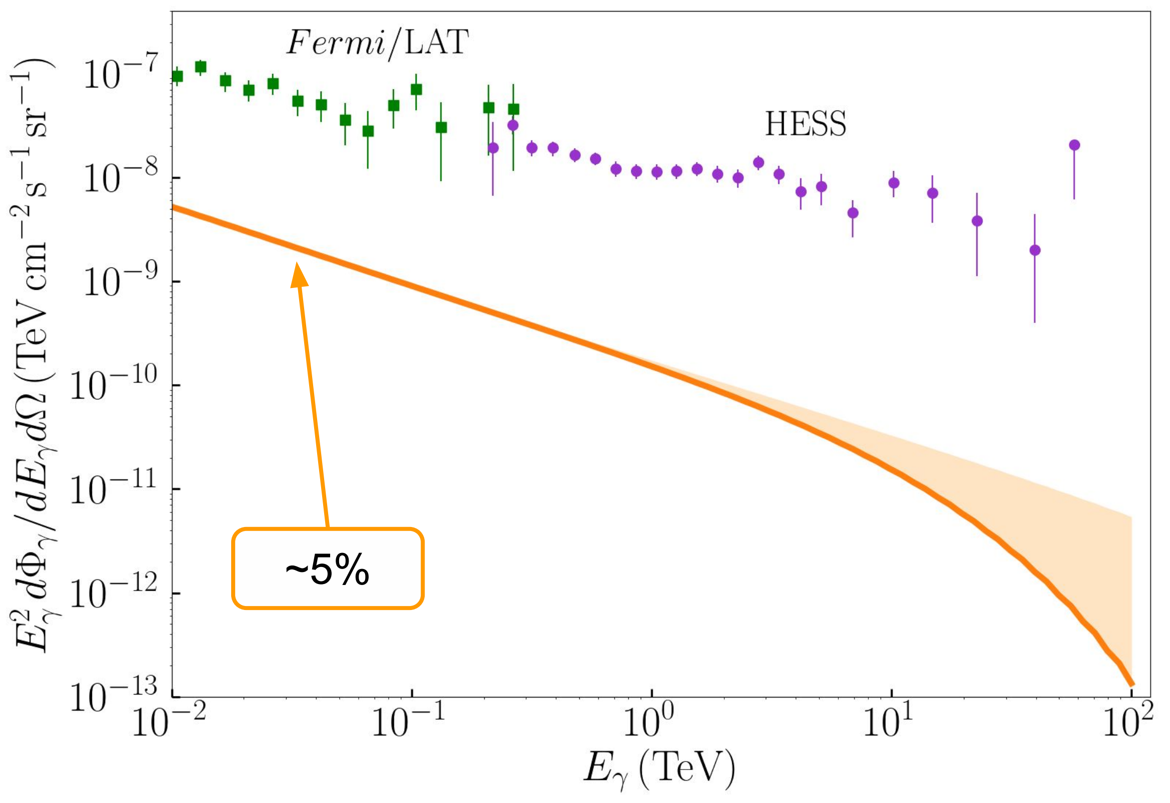
if **1000** black hole XRBs follow the same spatial distribution as Pulsars
(Lorimer et al. 2006)

Evoli et al. 2017, 2018





Contribution of black hole XRBs to the γ-ray spectrum



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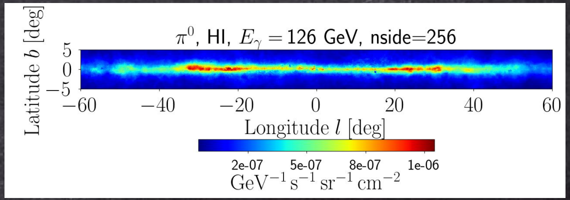
HERMES

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

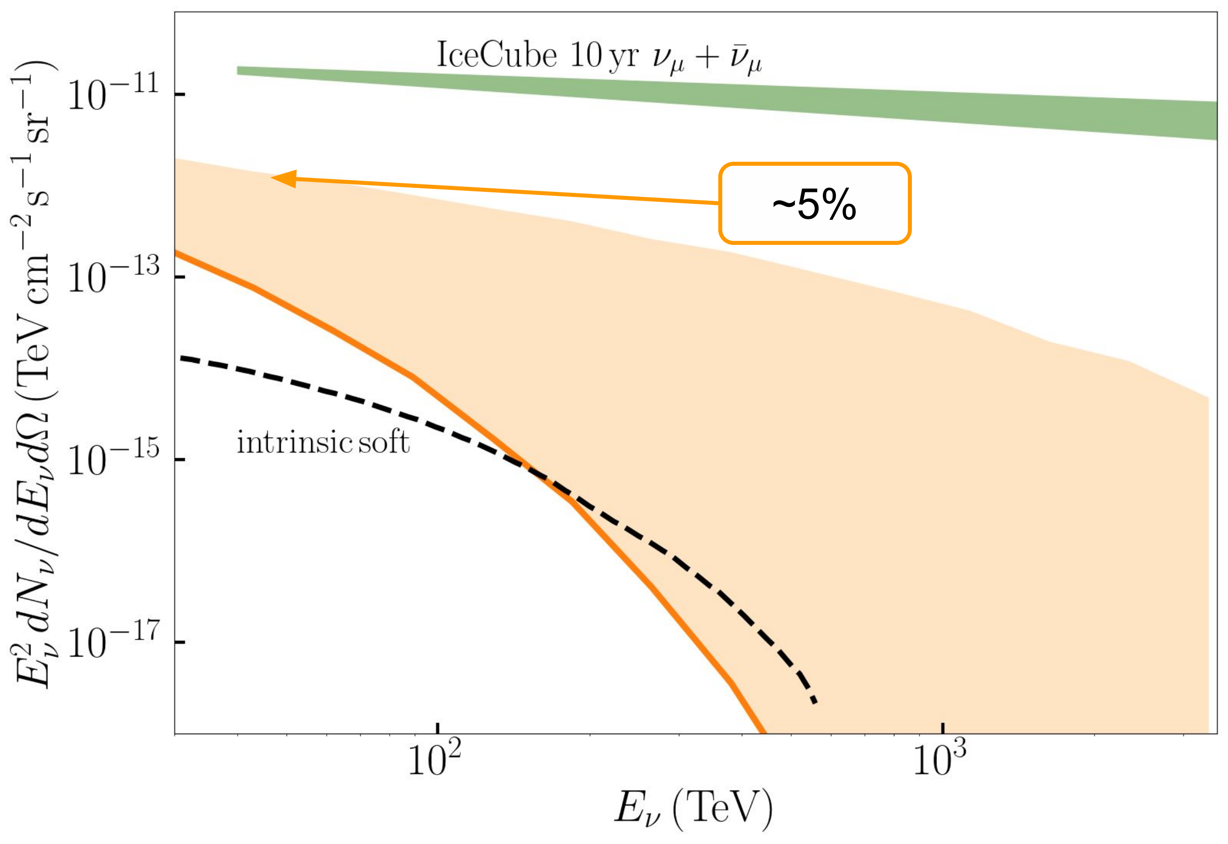
Dundovic et al. 2021

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

$$\pi^0 \rightarrow 2\gamma$$



Contribution of black hole XRBs to the neutrino spectrum



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HERMES

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

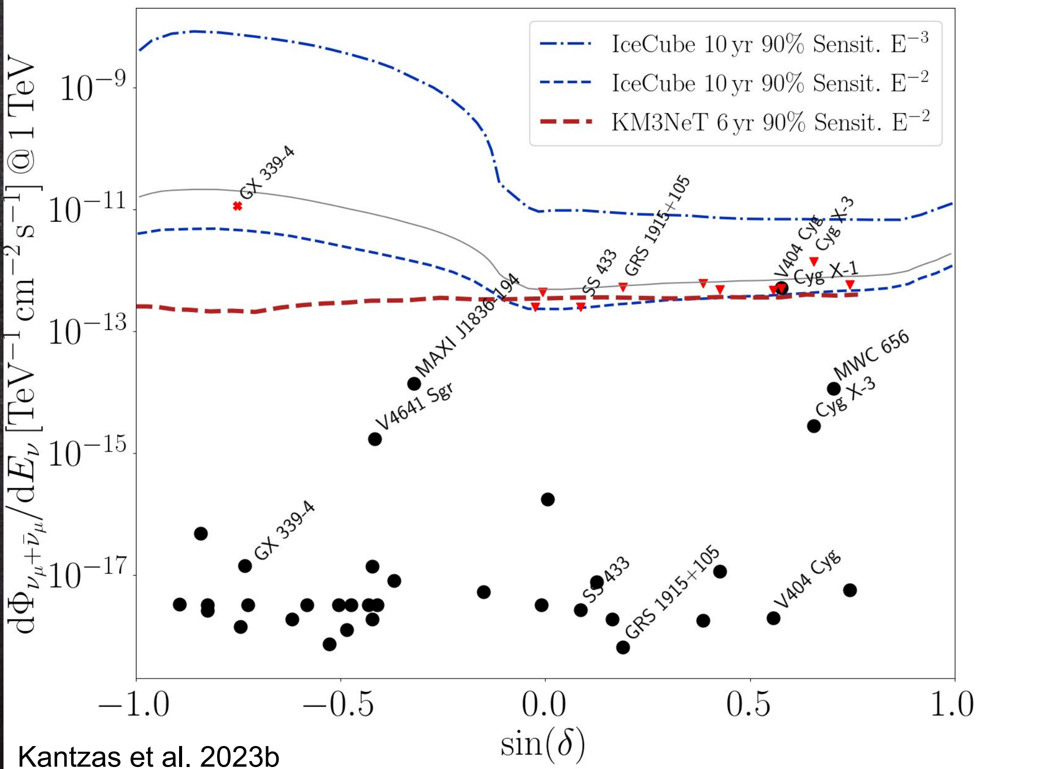
Dundovic et al. 2021

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

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

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

Contribution of black hole XRBs to the neutrino spectrum



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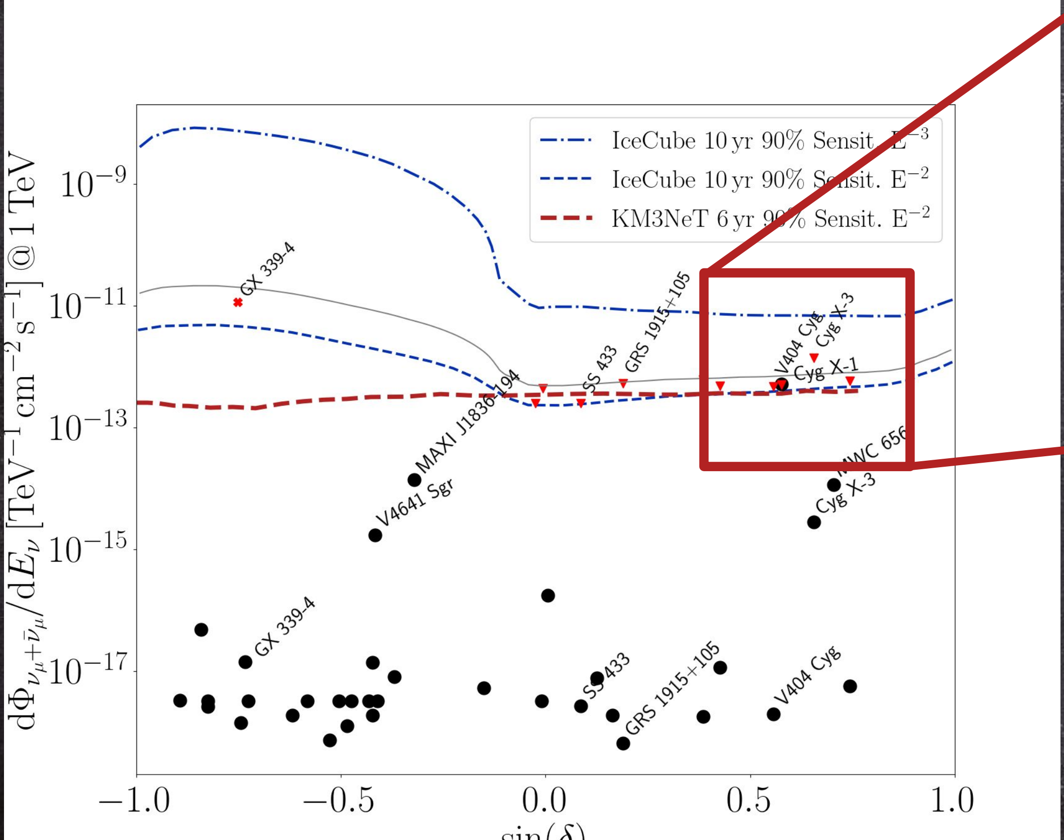
South | North

Contribution of black hole XRBs to the neutrino spectrum



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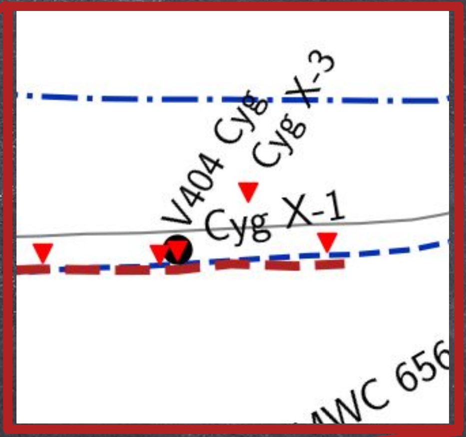
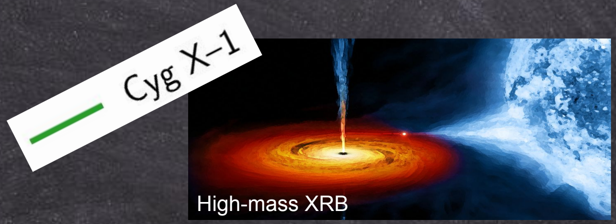
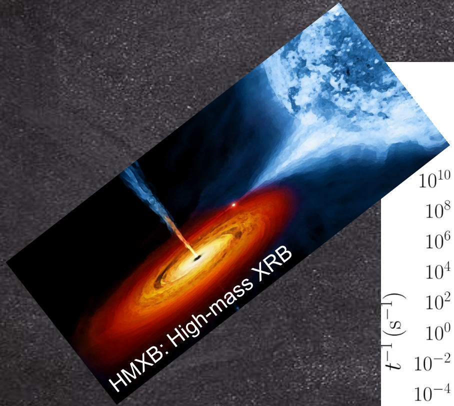


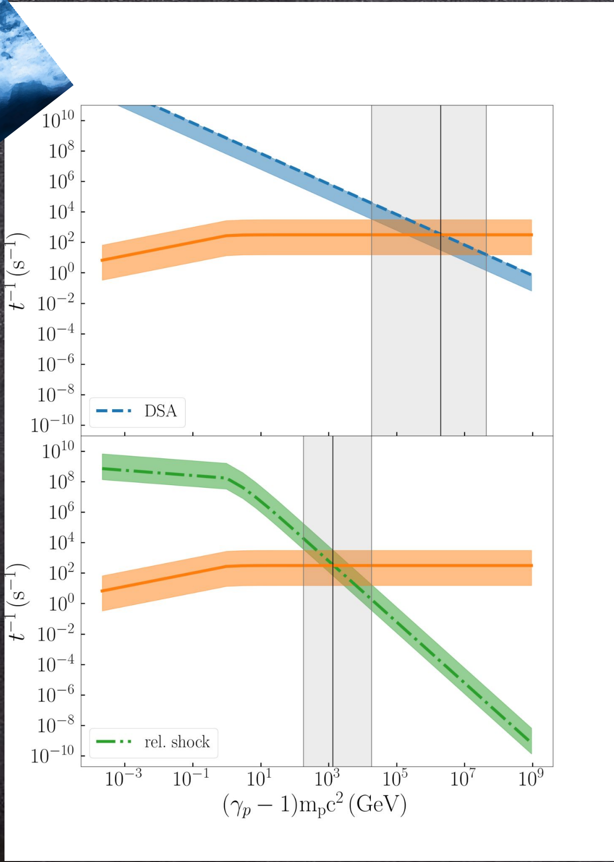


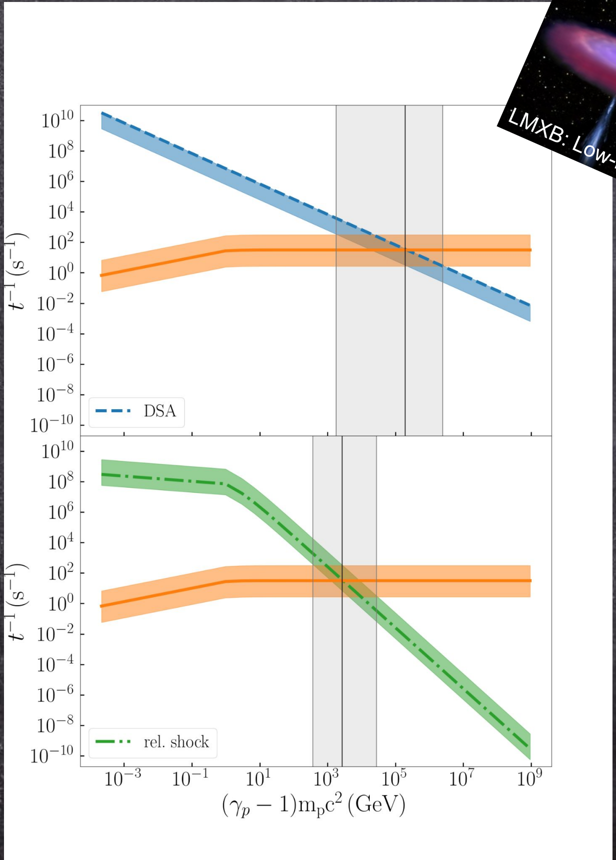
Potential Galactic neutrino emitter!!!

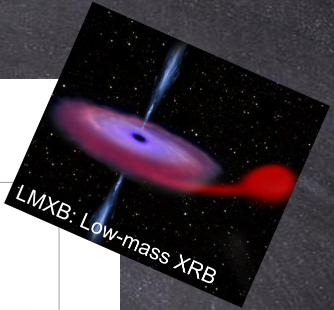
← South | North →

Particle acceleration uncertainties









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