Black-hole X-ray binaries in the new era of multi-messenger astronomy

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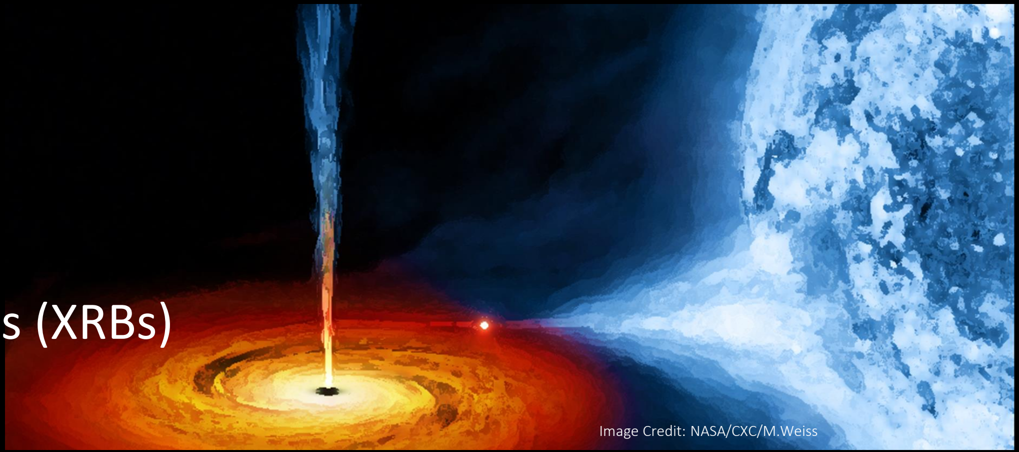
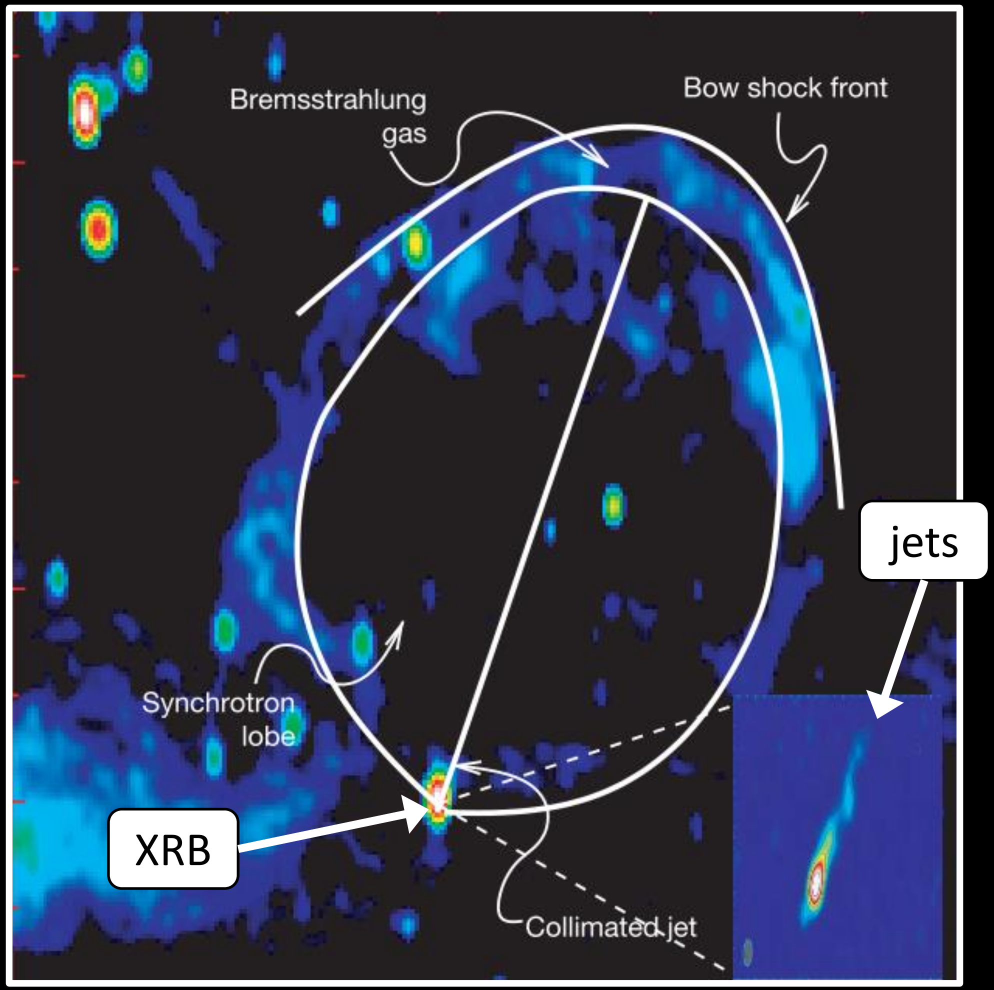
Image Credit: NASA/CXC/M.Weiss

Stellar Black Holes and Jets



- X-ray Binaries (XRBs)
- Launch (mildly) relativistic jets during outbursts
- Affect their medium

Westerbork radio image of Cygnus X-1



Gallo et al. 2005
see also Snell et al. 2015,
Miller-Jones et al. 2021

Why to study XRB/Jets?

Understand:

- Fundamental physics (e.g. accretion, strong gravity)
- Nature of XRBs (merger progenitors)
- Galactic cosmic-ray sources

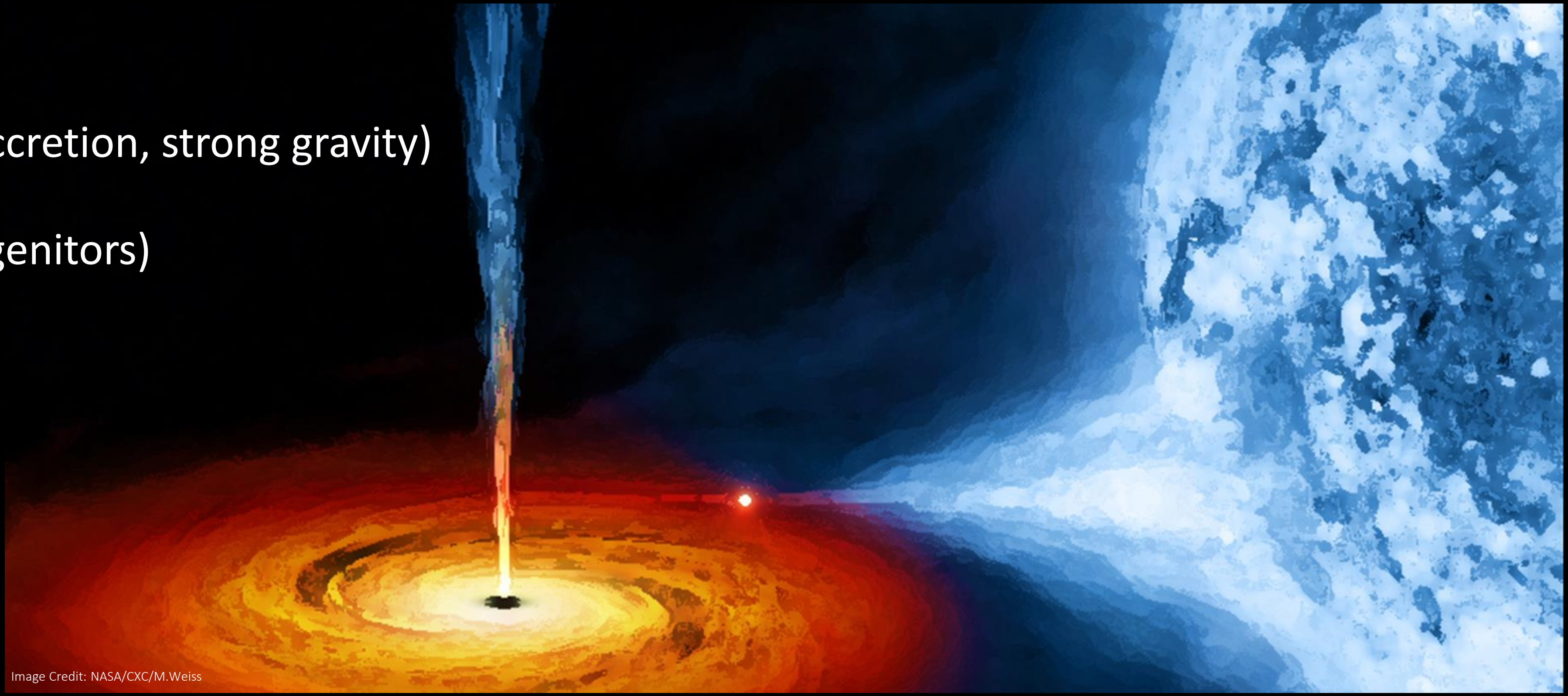
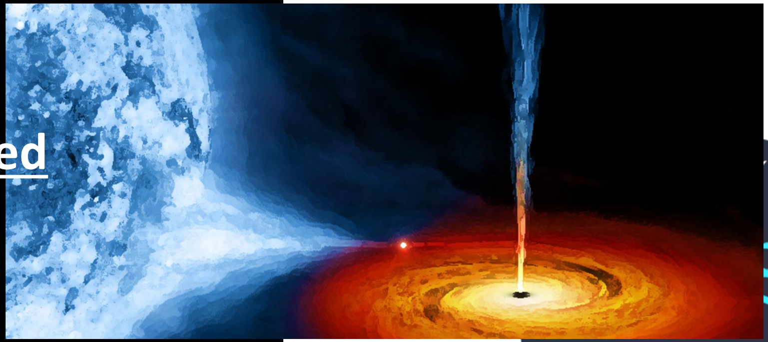


Image Credit: NASA/CXC/M.Weiss

A sky full of PeVatrons

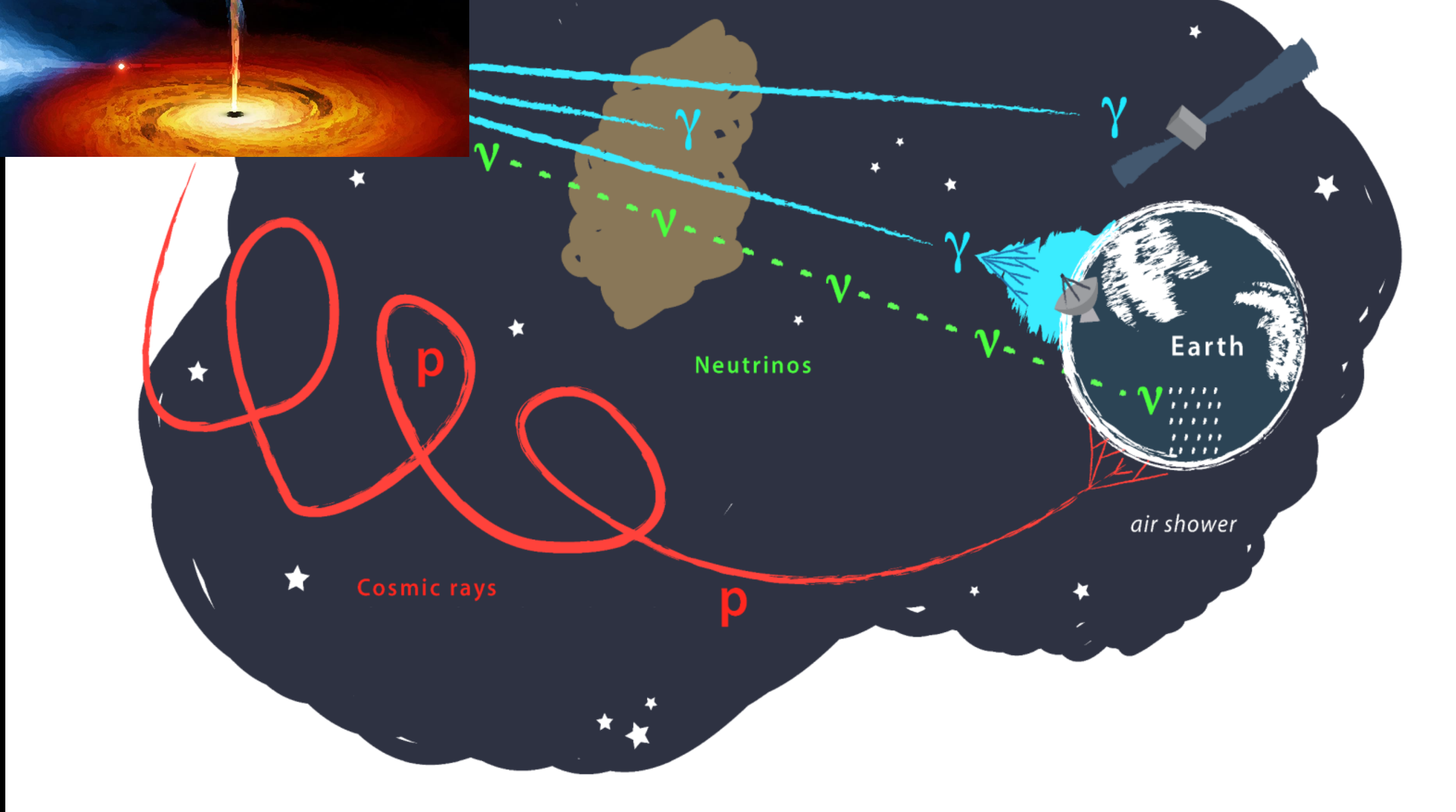
TeV and PeV γ-rays detected from **<u>unidentified</u>** sources!!



See **Tibet** and **LHAASO** experiments (Phys. Rev. Lett. 126, 141101 and Nature 594, p33–36, 2021, respectively)

Can XRBs be CR sources?

Heinz & Sunyaev 2002; Fender, Maccarone & van Kesteren 2005; Cooper et al. 2020



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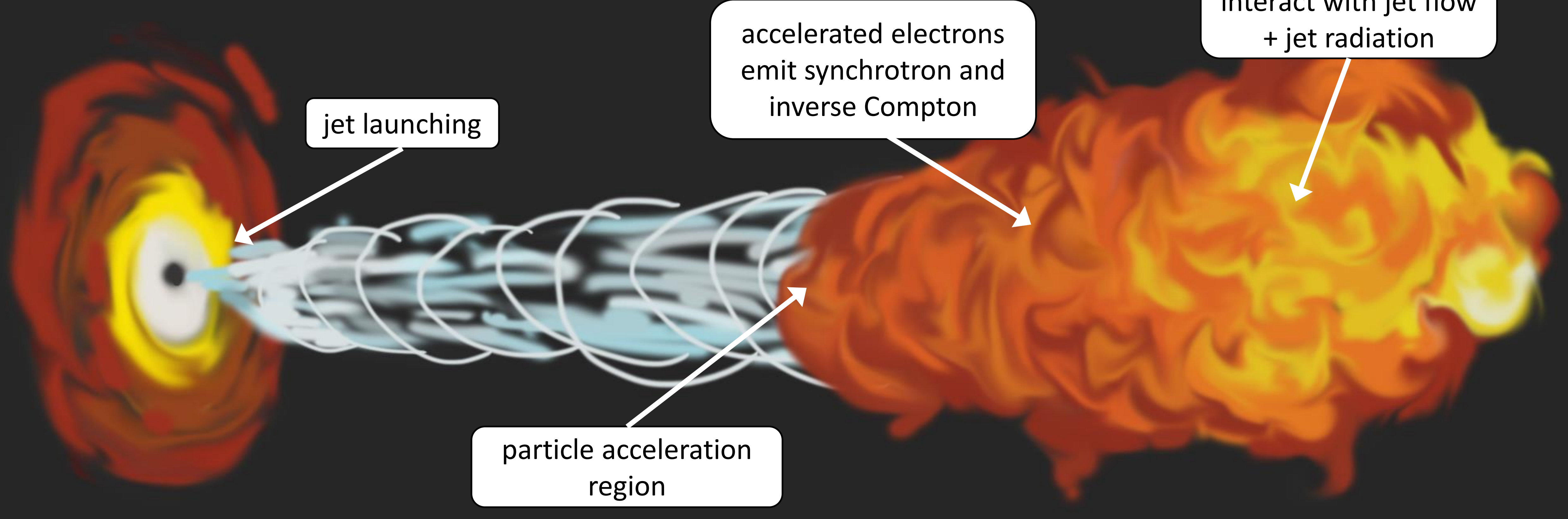
My PhD: hadronic interactions in a multizone jet model



Solving the transport equation

$$\frac{\partial N(E,t,z)}{\partial t} + \frac{\partial(\Gamma_{\rm jet} v_{\rm jet} N(E,t,z))}{\partial z} + \frac{\partial(b(E,t,z)N(E,t,z))}{\partial E} - \frac{\partial}{\partial E}\left[\frac{E^2}{(a+2)\,t_{\rm acc}}\frac{\partial N(E,t,z)}{\partial E}\right] + \frac{N(E,t,z)}{T_{\rm dec}(E)} + \frac{N(E,t,z)}{T_{\rm esc}(E)} = Q(E,t,z)$$

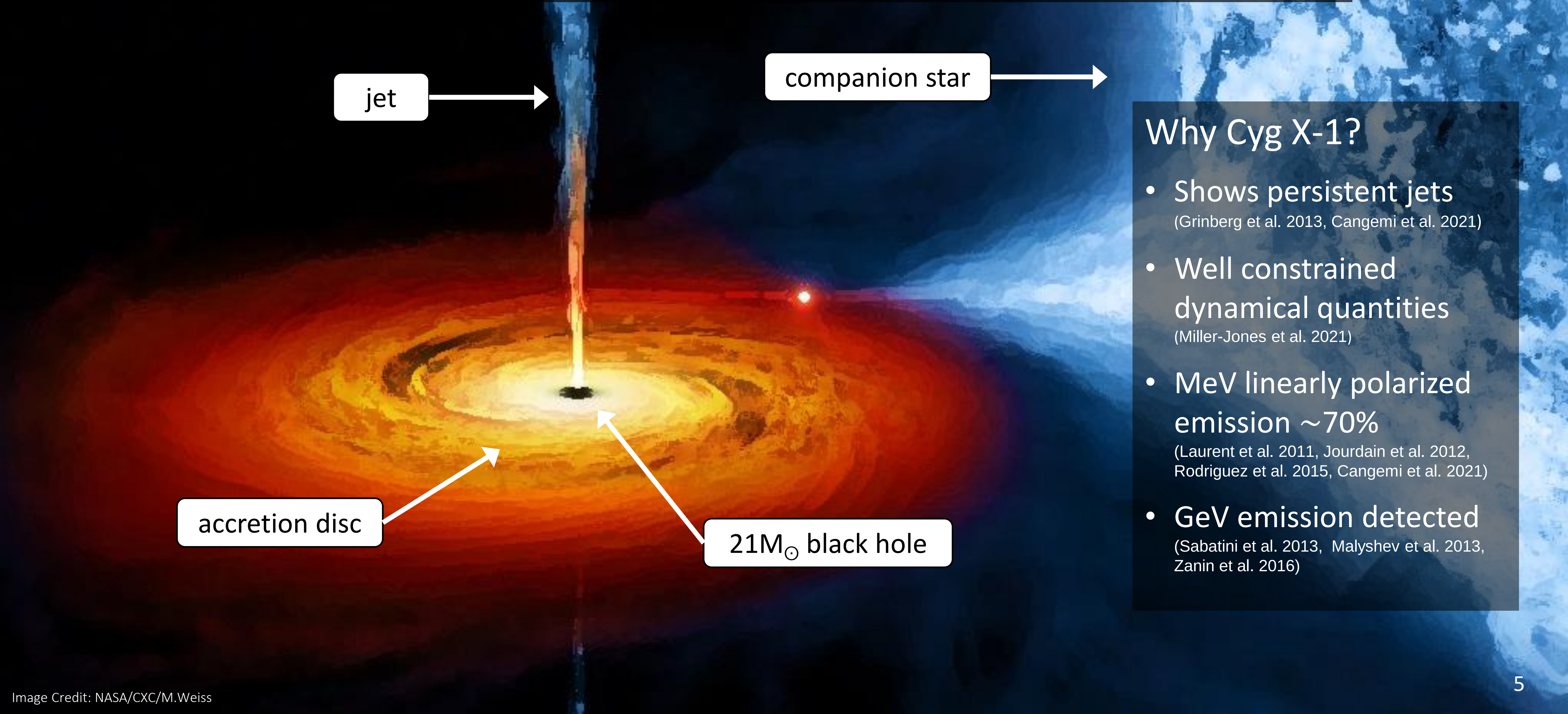
for each jet segment

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;
Kantzas et al. 2021

Image Credits: T. Revolta

High-mass black-hole X-ray binaries (HMXBs)

the study-case of **Cygnus X–1**

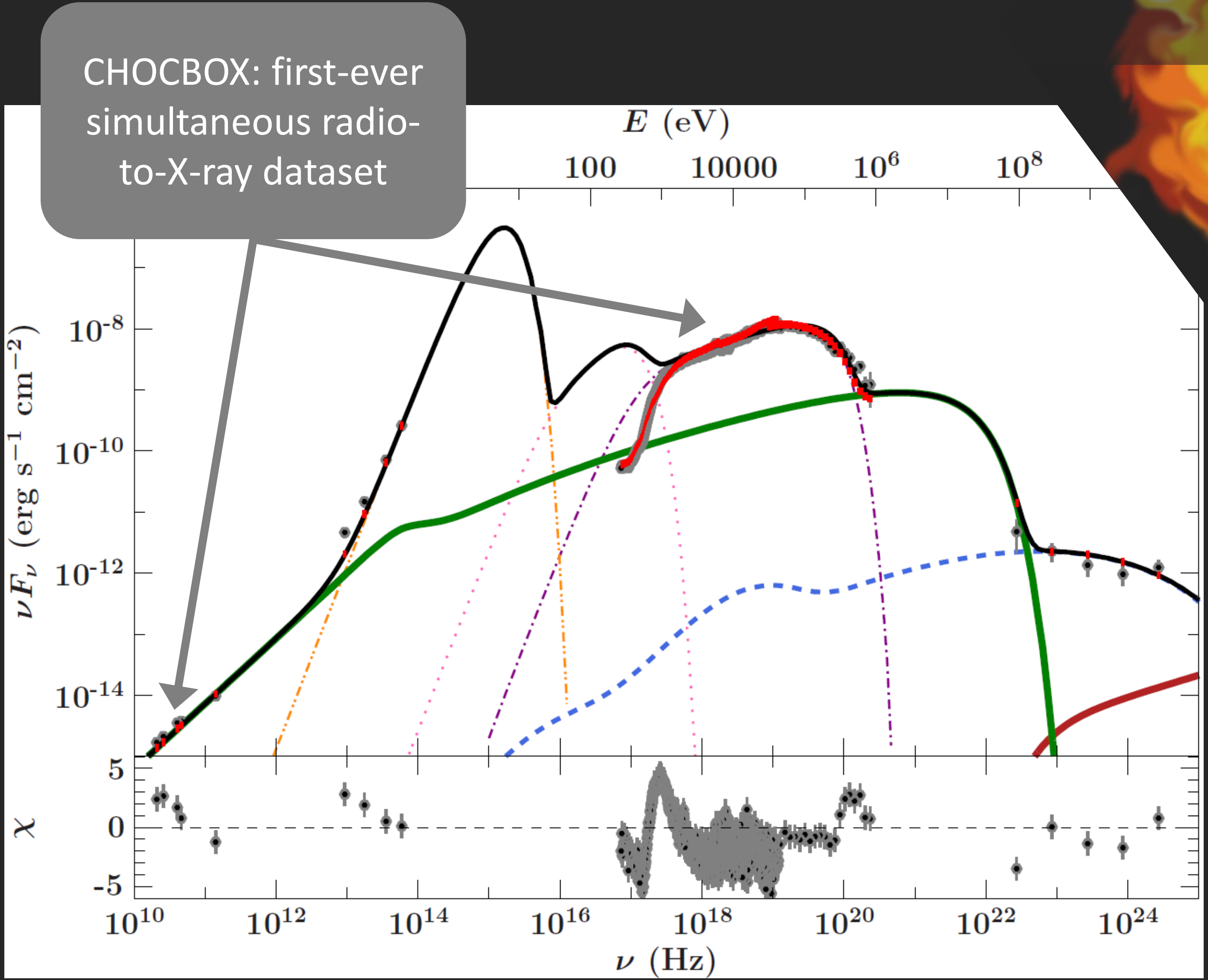


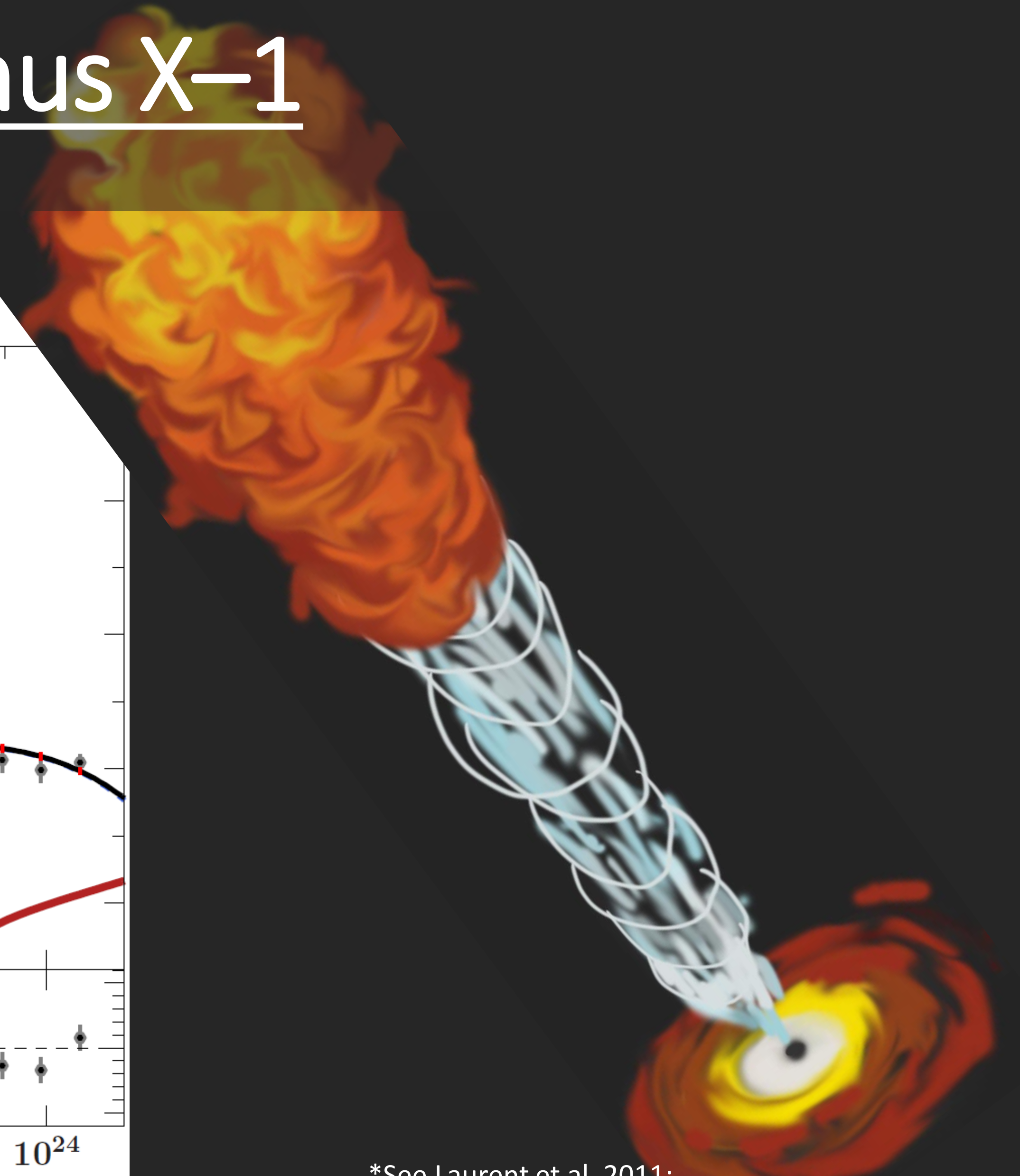
Why Cyg X-1?

- Shows persistent jets
  (Grinberg et al. 2013, Cangemi et al. 2021)
- Well constrained dynamical quantities
  (Miller-Jones et al. 2021)
- MeV linearly polarized emission ~70%
  (Laurent et al. 2011, Jourdain et al. 2012, Rodriguez et al. 2015, Cangemi et al. 2021)
- GeV emission detected
  (Sabatini et al. 2013, Malyshev et al. 2013, Zanin et al. 2016)

Image Credit: NASA/CXC/M.Weiss

Radio-to-GeV spectrum of Cygnus X–1





*See Laurent et al. 2011;
Jourdain et al. 2012;
Rodriguez et al. 2015;
Cangemi et al. 2021

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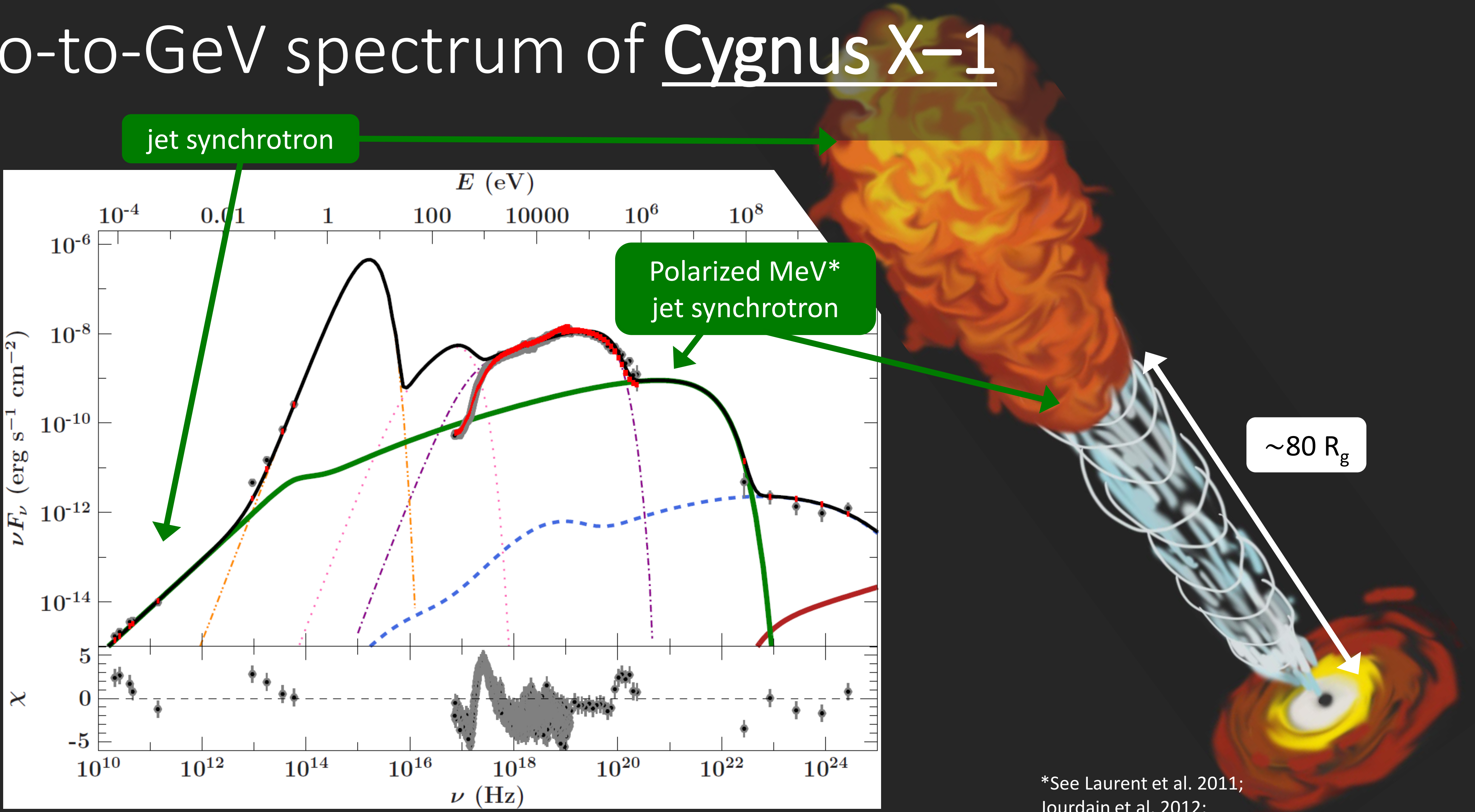
IR, hard X-rays & GeV γ-rays from Rahoui et al. 2011; Cangemi et al. 2021 & Zanin et al. 2017

Radio-to-GeV spectrum of Cygnus X–1



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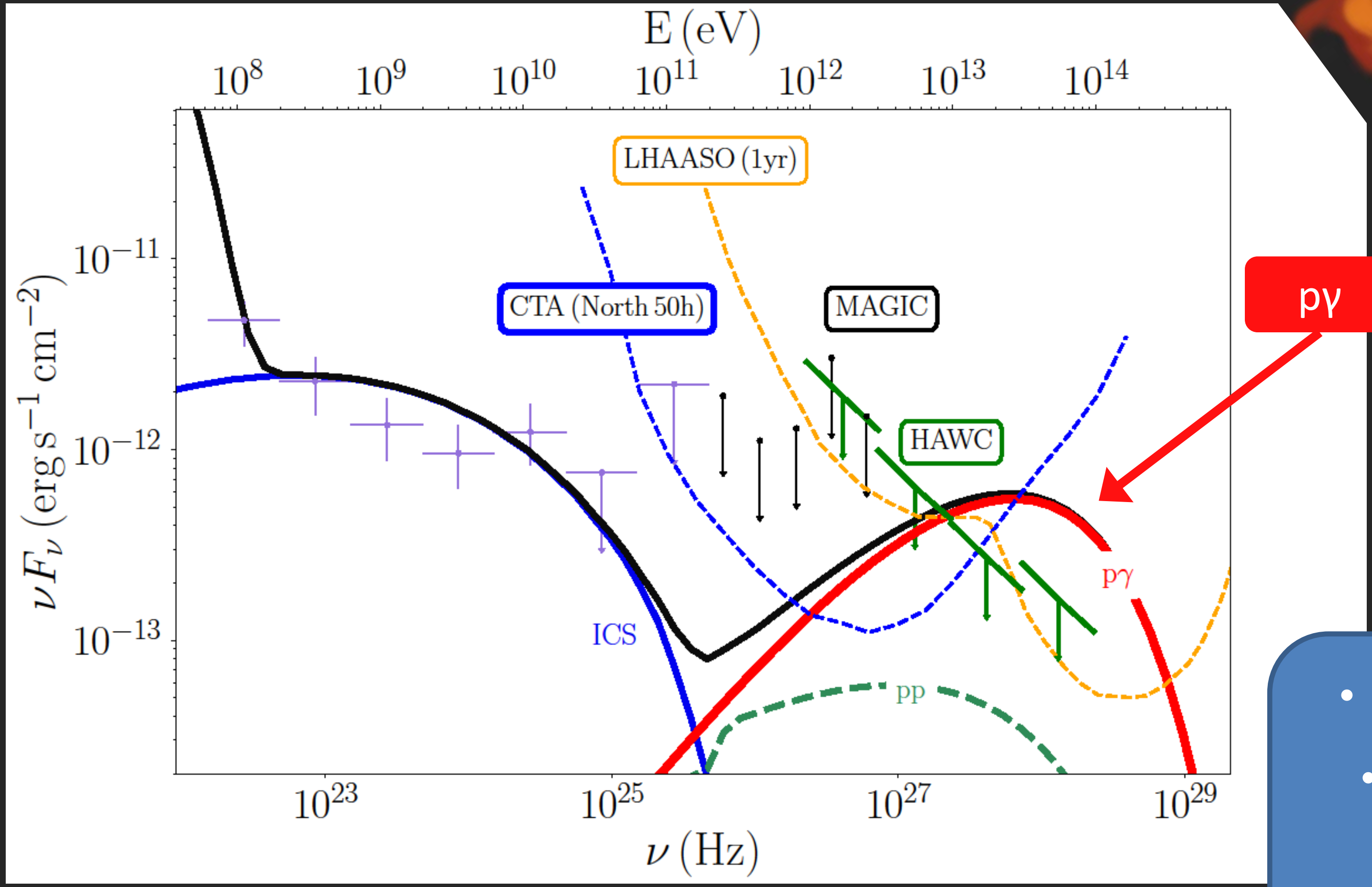
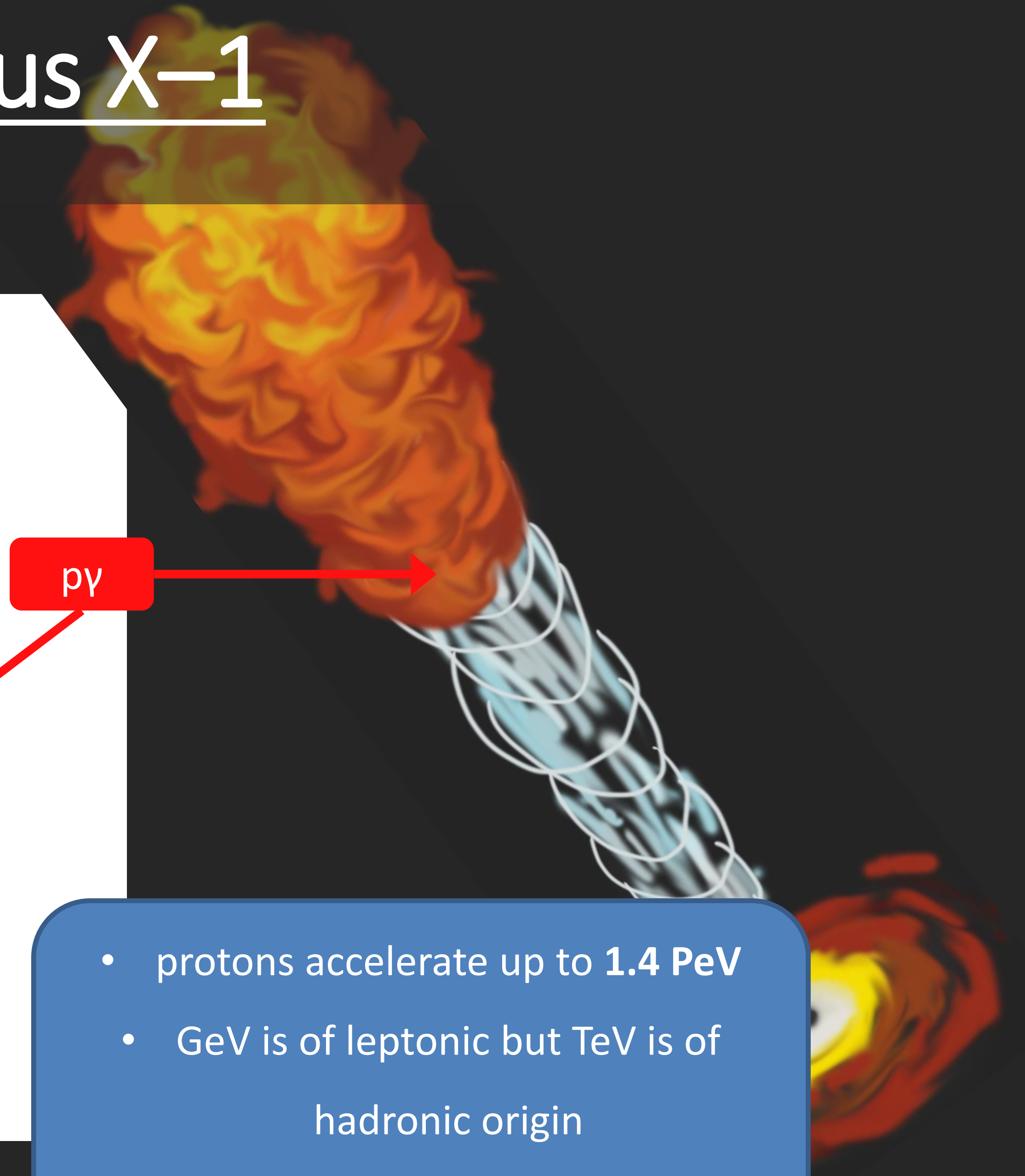
GeV-to-TeV spectrum of Cygnus X–1





- protons accelerate up to **1.4 PeV**
- GeV is of leptonic but TeV is of hadronic origin
- TeV is of jet origin

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IR, hard X-rays & GeV γ-rays from Rahoui et al. 2011; Cangemi et al. 2021 & Zanin et al. 2017

Low mass black-hole X-ray binaries (LMXBs)

the study-case of **GX339–4**

Why GX339-4?

- Outbursts every 2–3yr for a few weeks (Tetarenko et al. 2016)
- Bright outburst in 2010 (Corbel et al. 2012)
- Distance ~8 kpc (Parker et al. 2016)

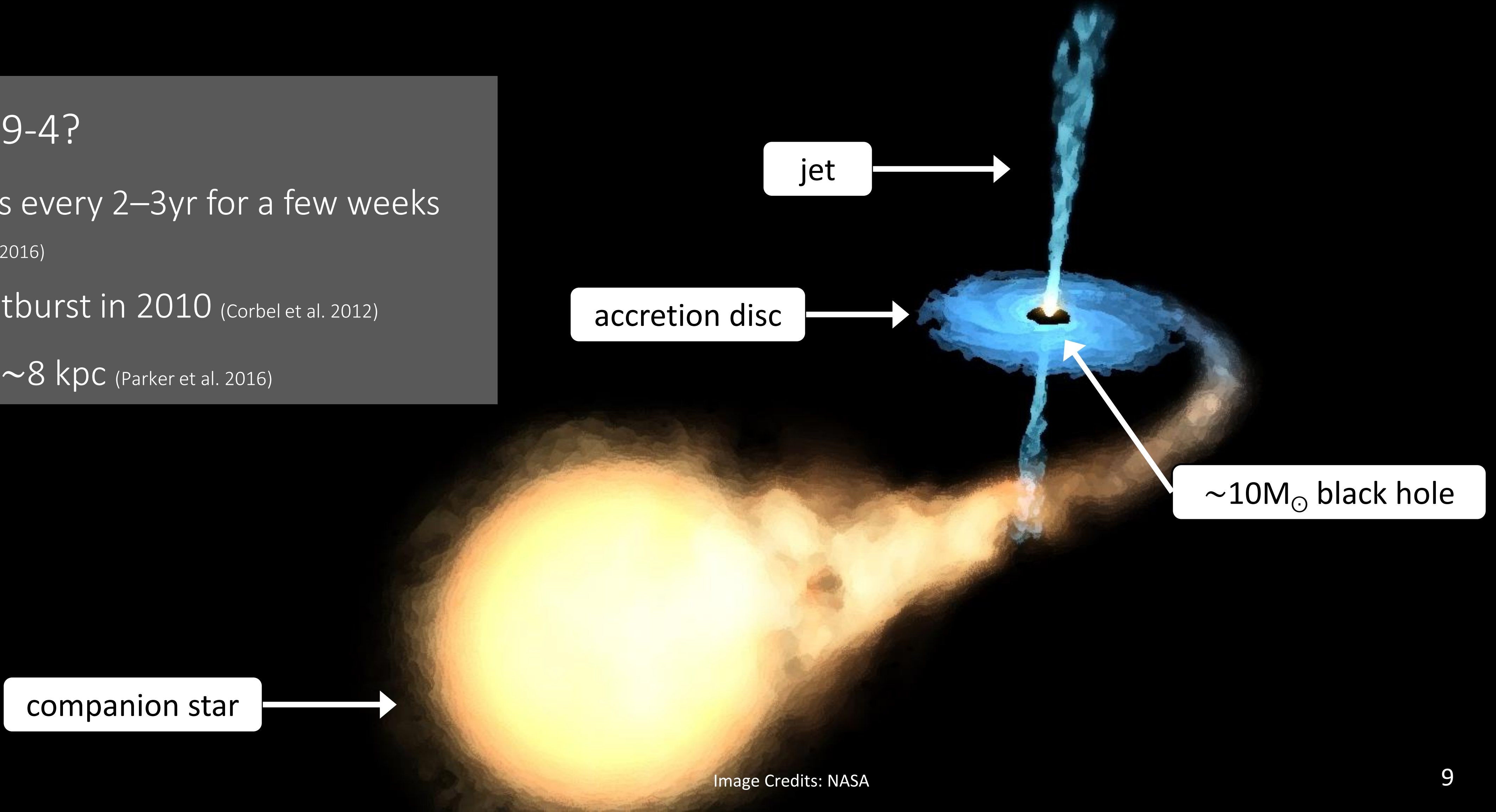
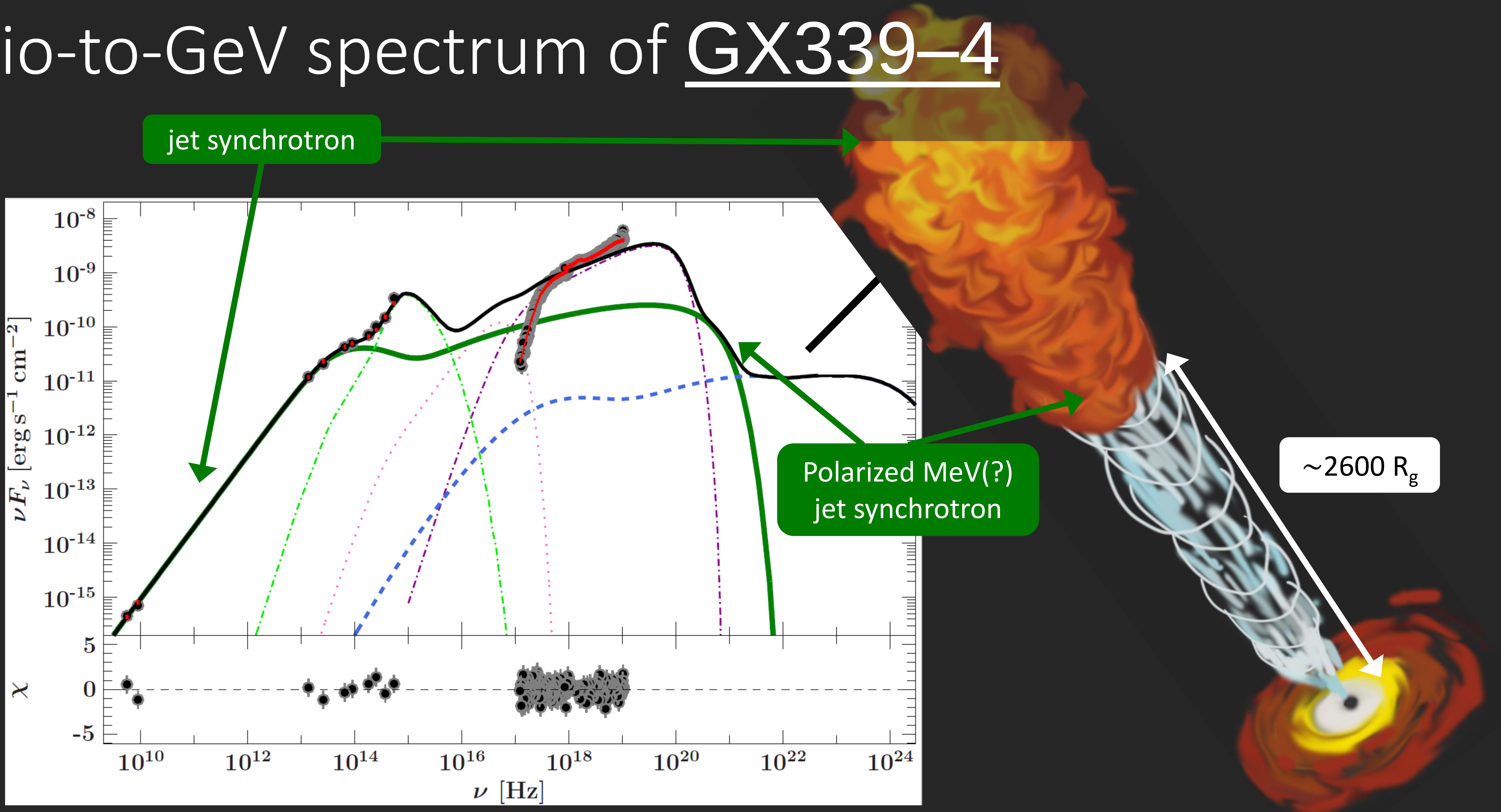


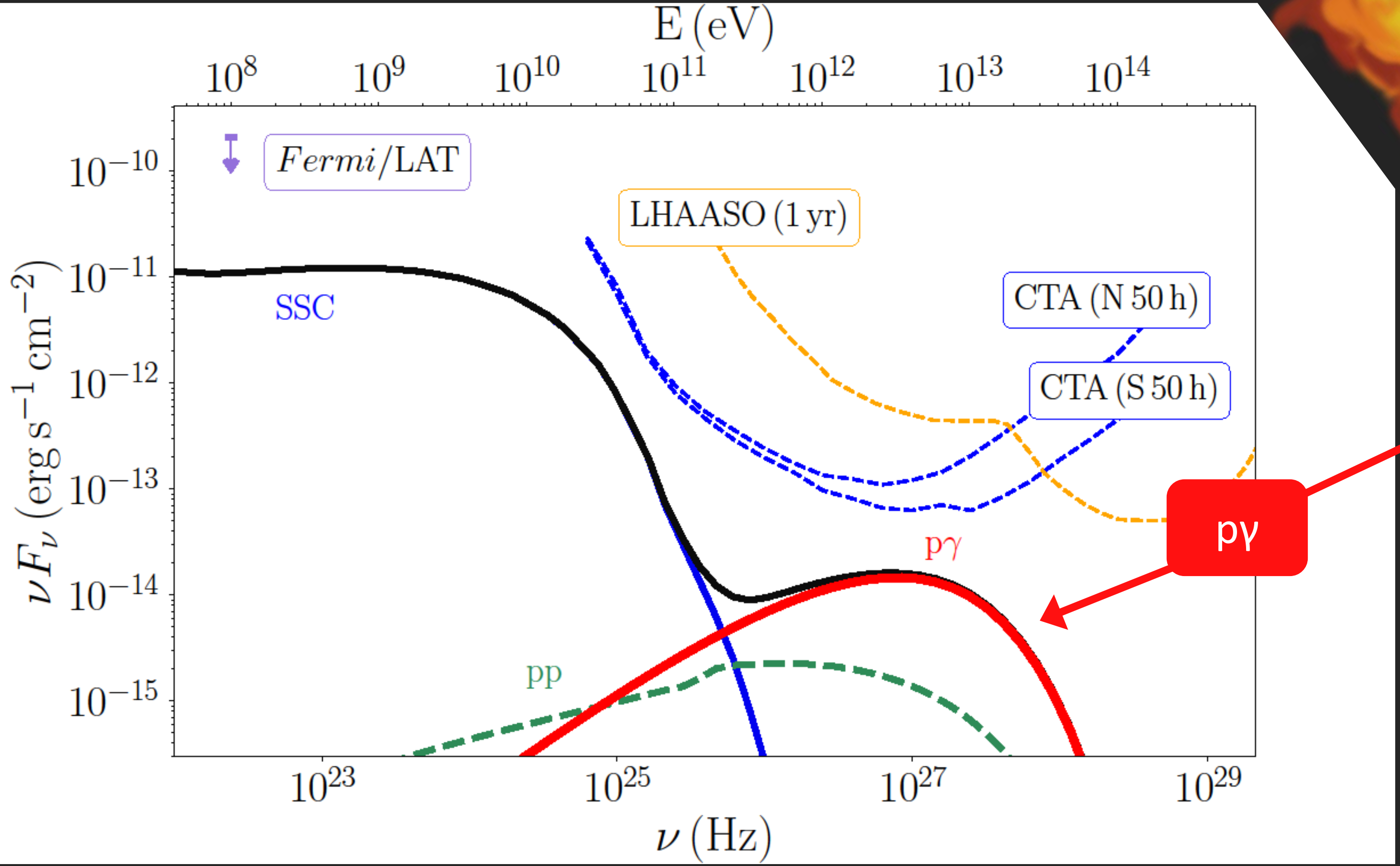
Image Credits: NASA

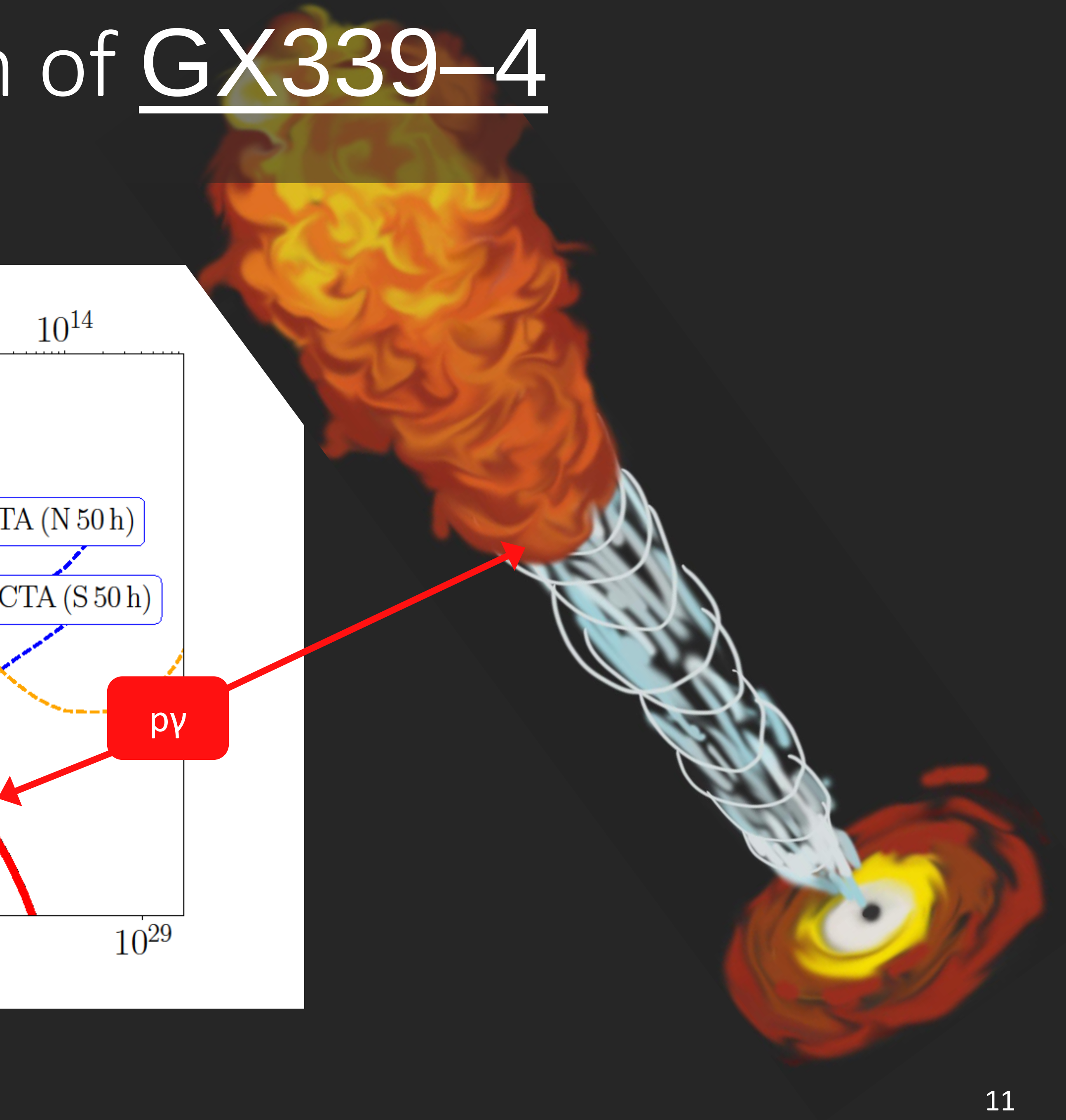
Radio-to-GeV spectrum of GX339–4



D. **Kantzas** et al. submitted

GeV-to-TeV γ-ray spectrum of GX339–4





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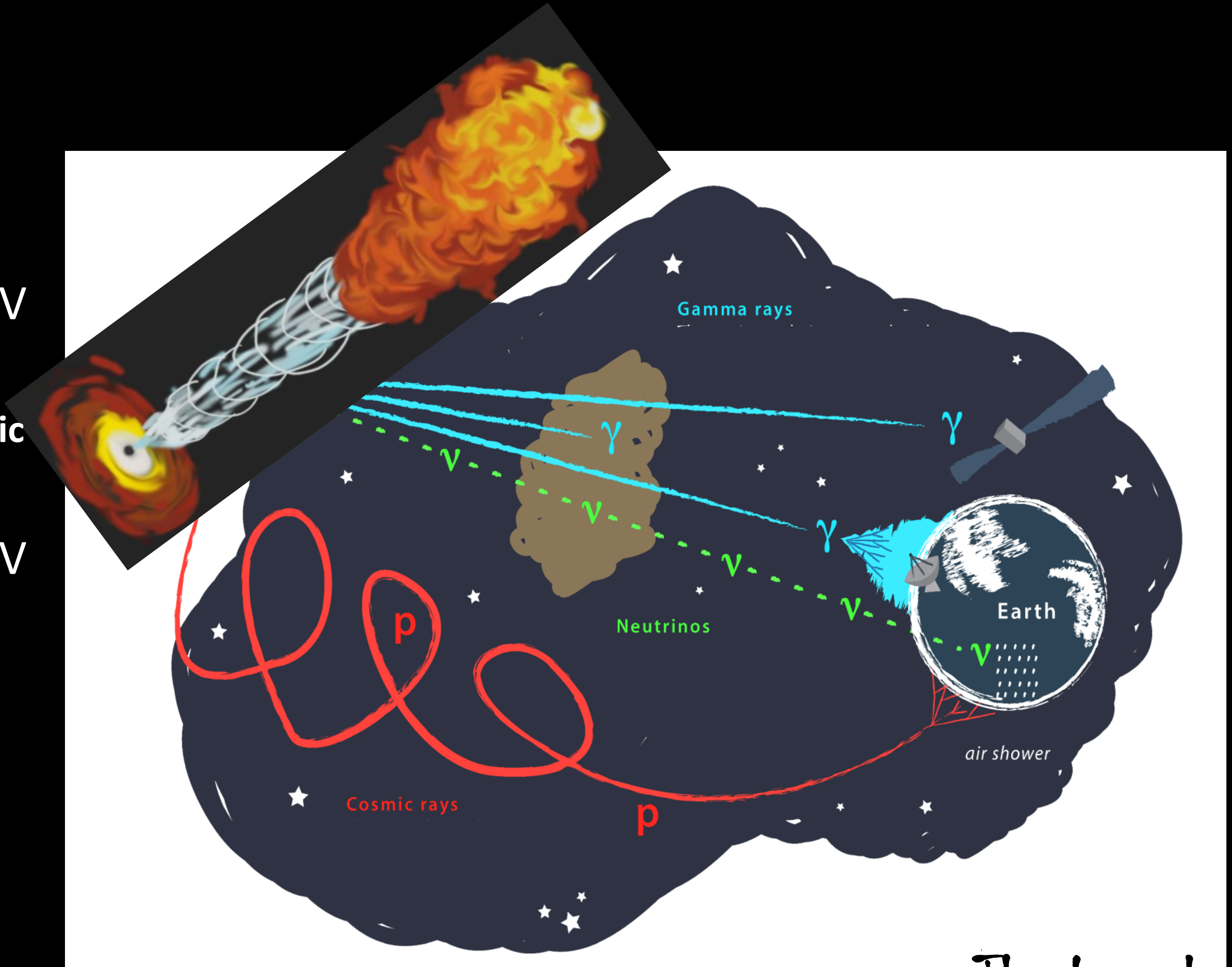
Take home message

Galactic Jets as PeV cosmic ray sources?

- Study mutliwavelength spectrum and predict TeV emission from **<u>high mass</u>** XRB **Cyg X-1**
    - **If CTA detects any TeV emission it can only be hadronic**
- Study mutliwavelength spectrum and predict TeV emission from **<u>low mass</u>** XRB **GX339-4**
    - **CTA will NOT be able to detect any TeV emission**

Time will show if BHs are connected to one of the biggest mysteries, that of CR sources!



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Thank you!