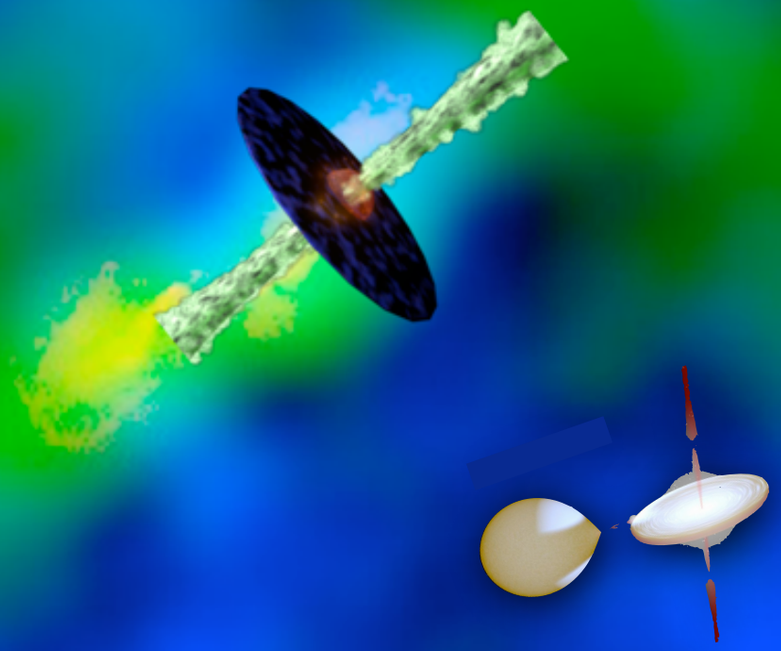
PARTICLE ACCELERATION IN JETS:
New insights Offered by CTA (+ MW)



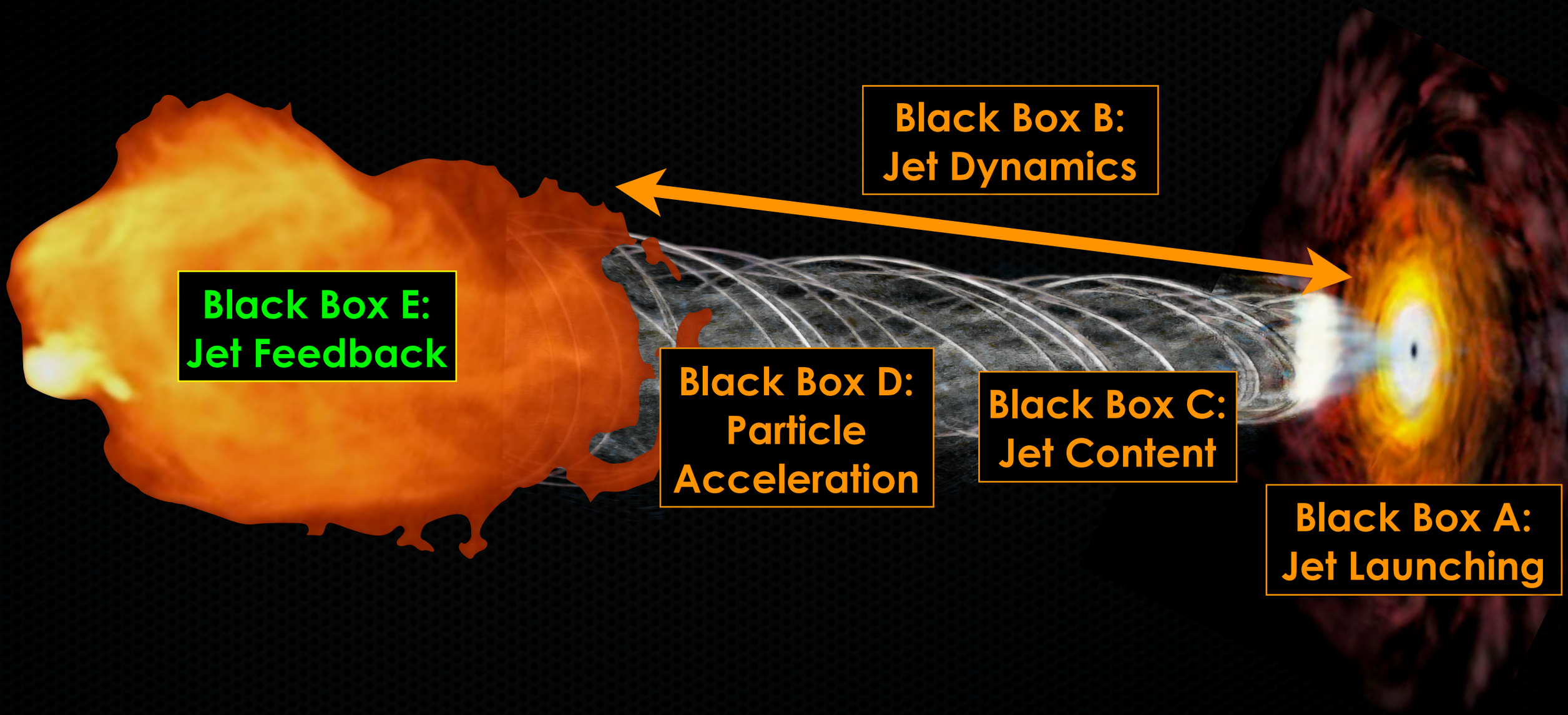
Sera Markoff (API, University of Amsterdam)

[Main collaborators: S.Corbel, J.Dexter, C. Ceccobello, R.Connors, S.Dibi, S.Drappeau, H.Falcke, R.Fender, P.C.Fragile, E.Gallo, S.Heinz, D.Meier, M.Middleton, J.Miller-Jones, M.Nowak, R.Plotkin, P.Polko, D.Russell, G.Sivakoff (+JACPOT), J.Wilms]

Jet studies embody several research priorities for EU/NL

- ★ **Origin of Cosmic Rays (CRs):** *One of the lead priorities for European and Dutch Astroparticle strategic plans*
- ★ **Physics of compact objects:** *E.g., how do black holes (BHs) and associated accretion flows/jets work? Coupling of plasma physics (magnetized) and strong gravity*
- ★ **Galaxy Evolution:** *The same BH jets that accelerate CRs play a significant role in altering their surroundings, suppressing galaxy growth*
- ★ **Transients:** *Galactic jets can be *transient* sources of CRs*
- ★ **CTA:** *If a jet accelerates CRs to TeV energies, you can get TeV γ-rays too!*

The current situation: too many black boxes



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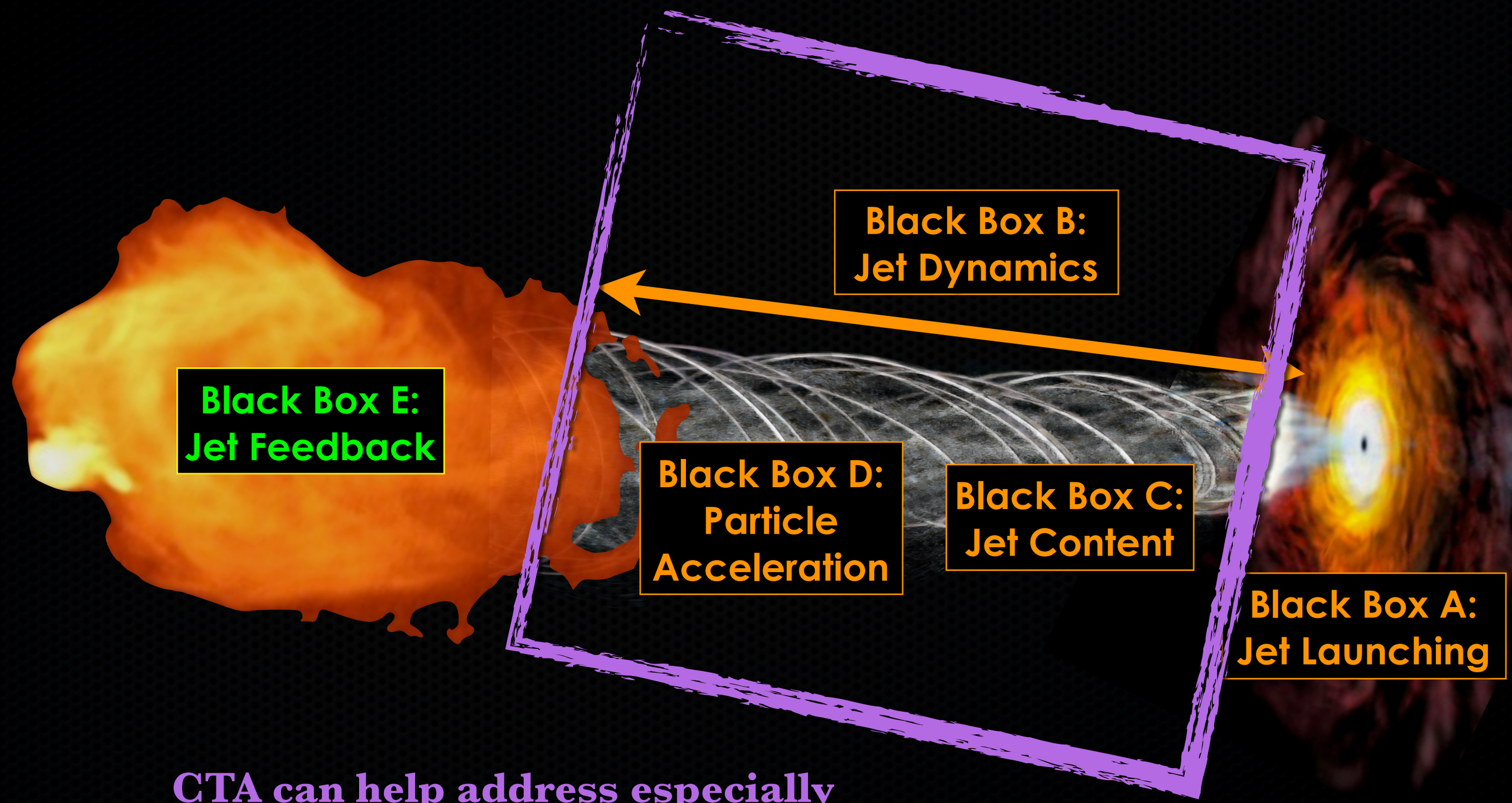
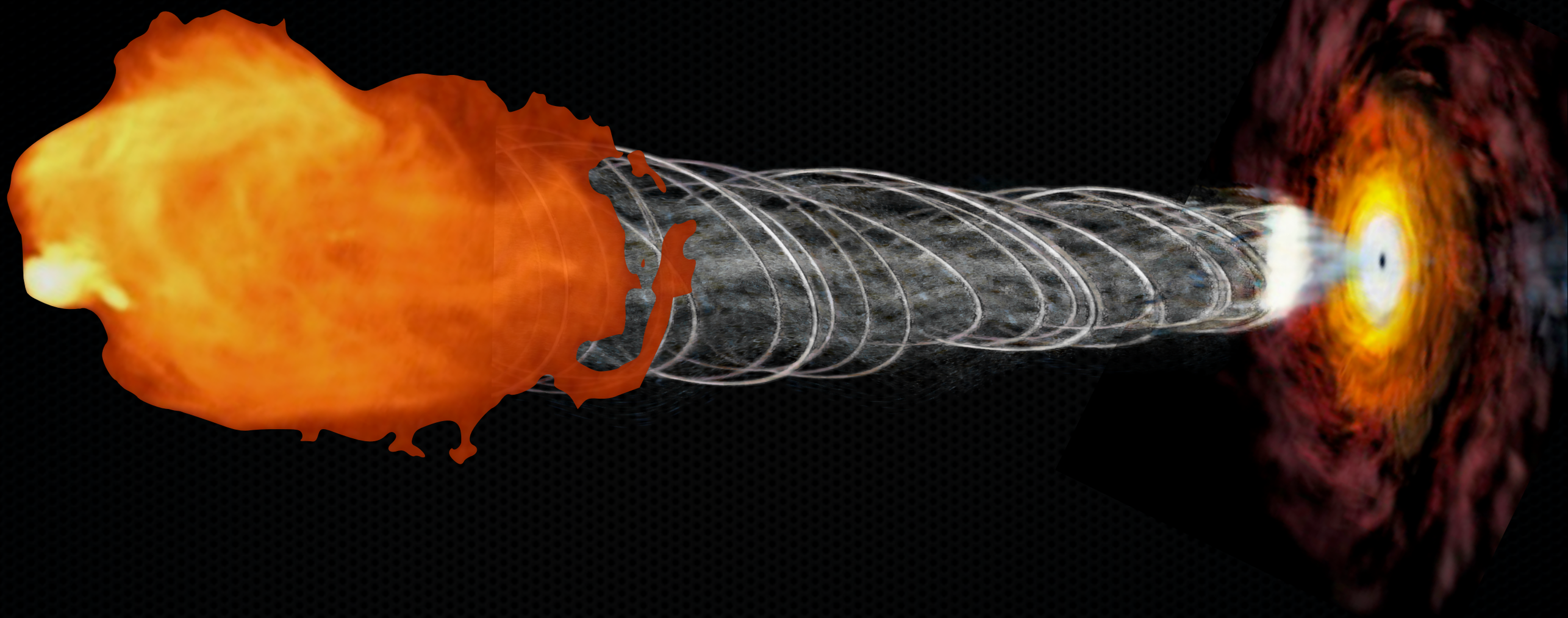


CTA can help address especially these core questions

TeV gamma-rays are tracers of acceleration



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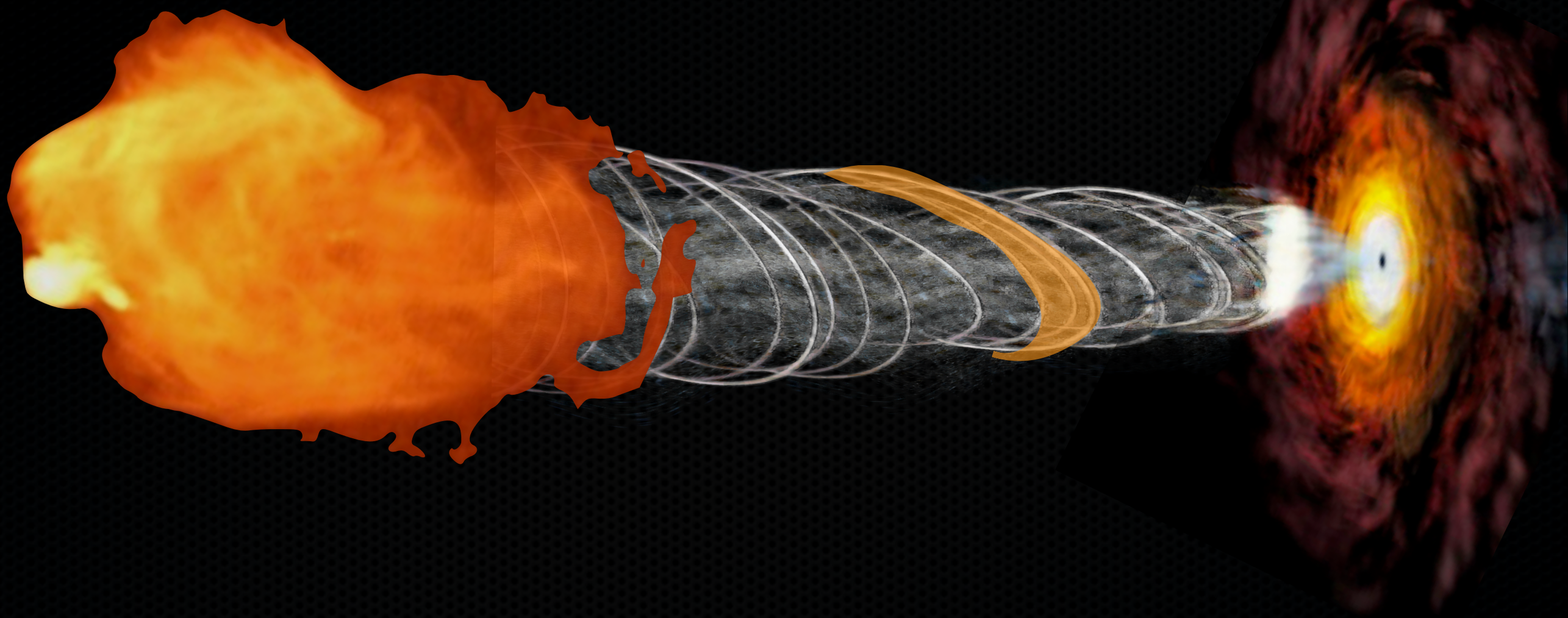

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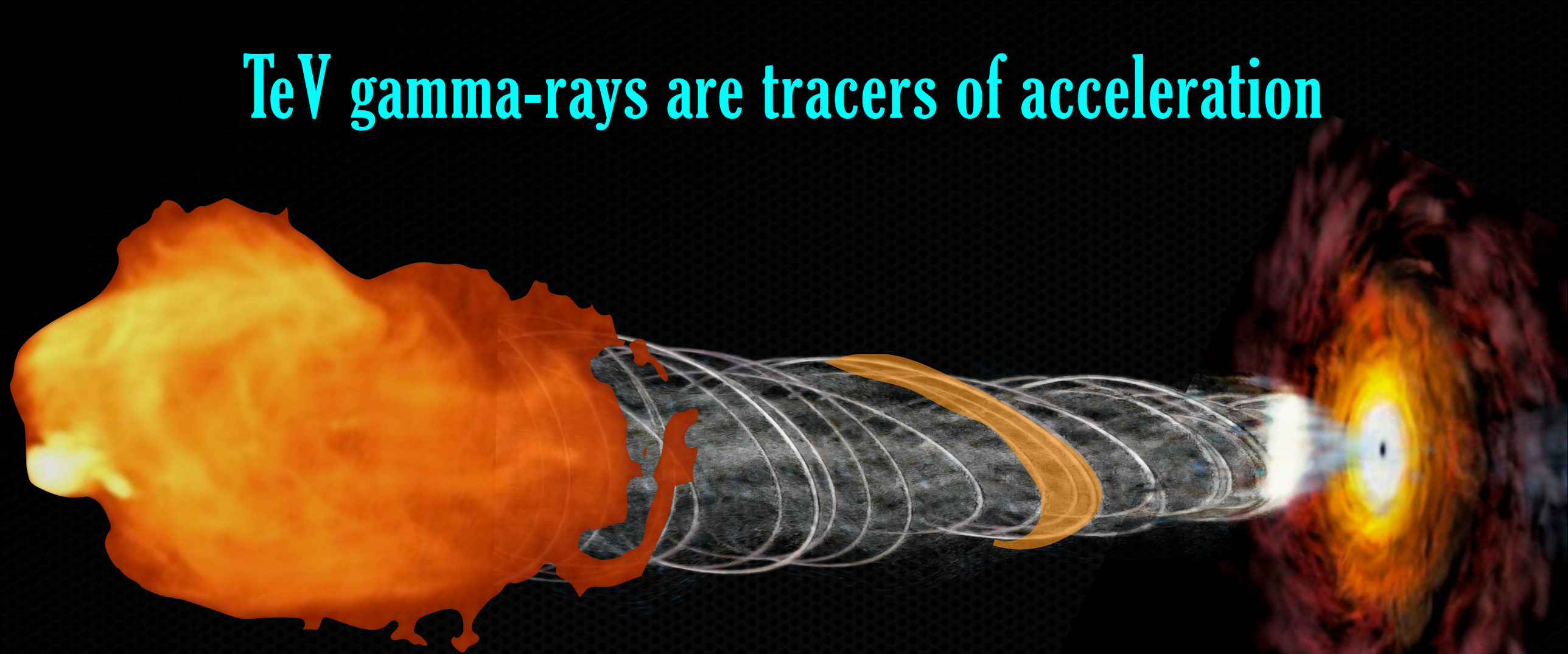

Particles (e+e- pairs and/or e-p/ions) + B field (or ∇V) + shock (or turbulence, or waves)

= accelerated particles (CRs: e+e-,p's, ions)

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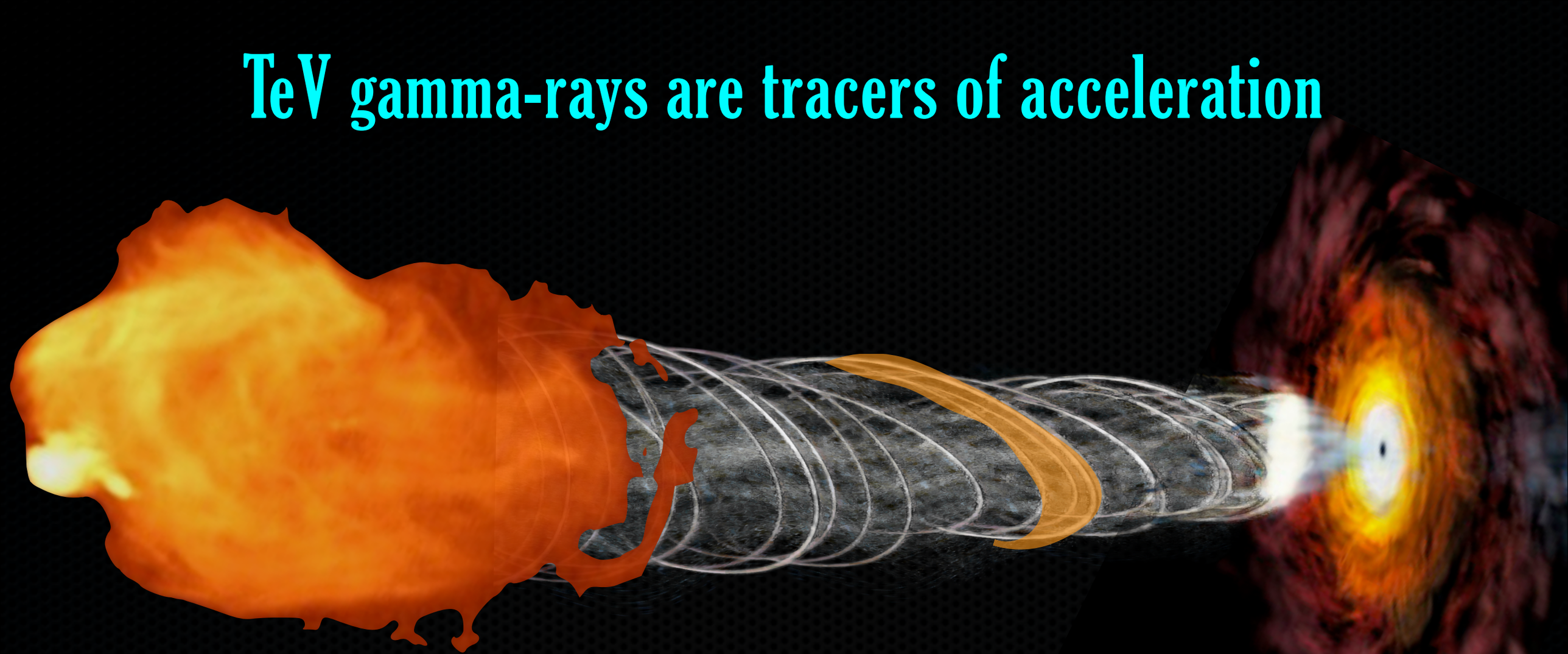

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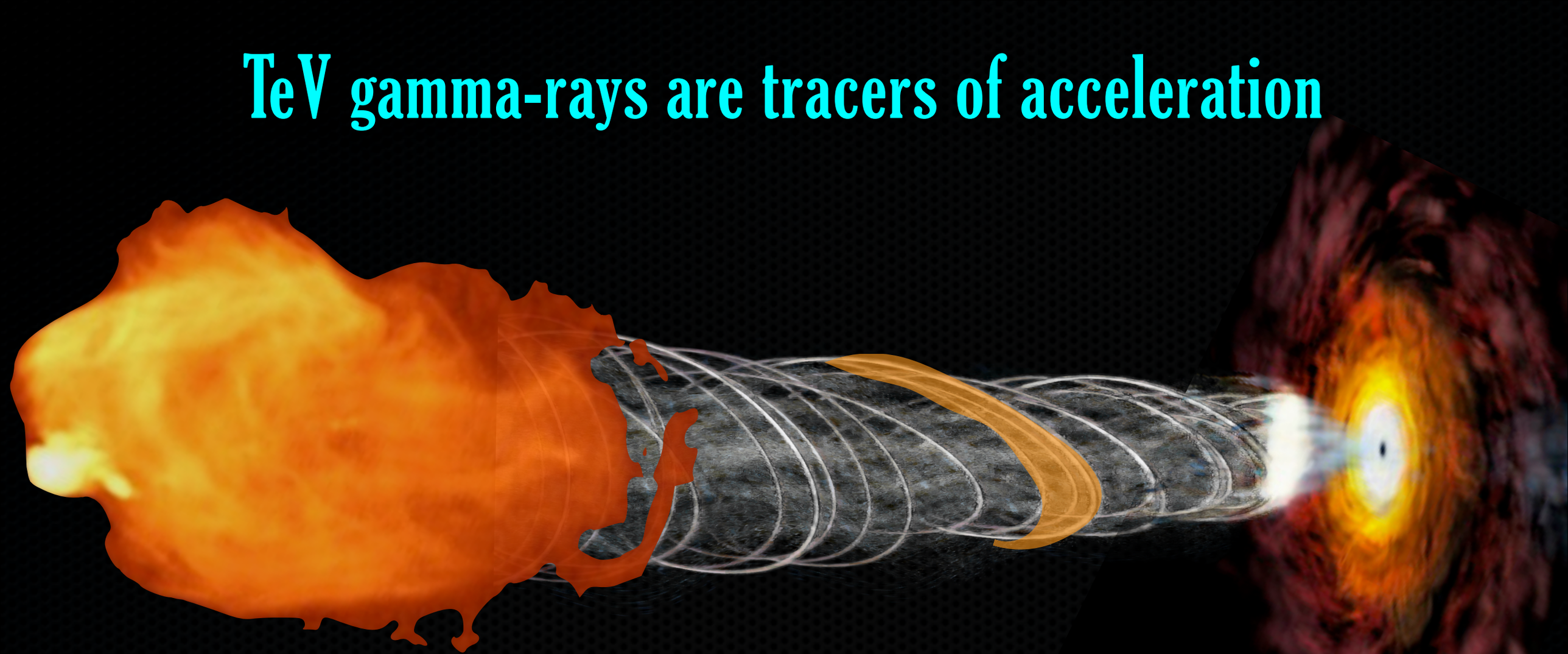

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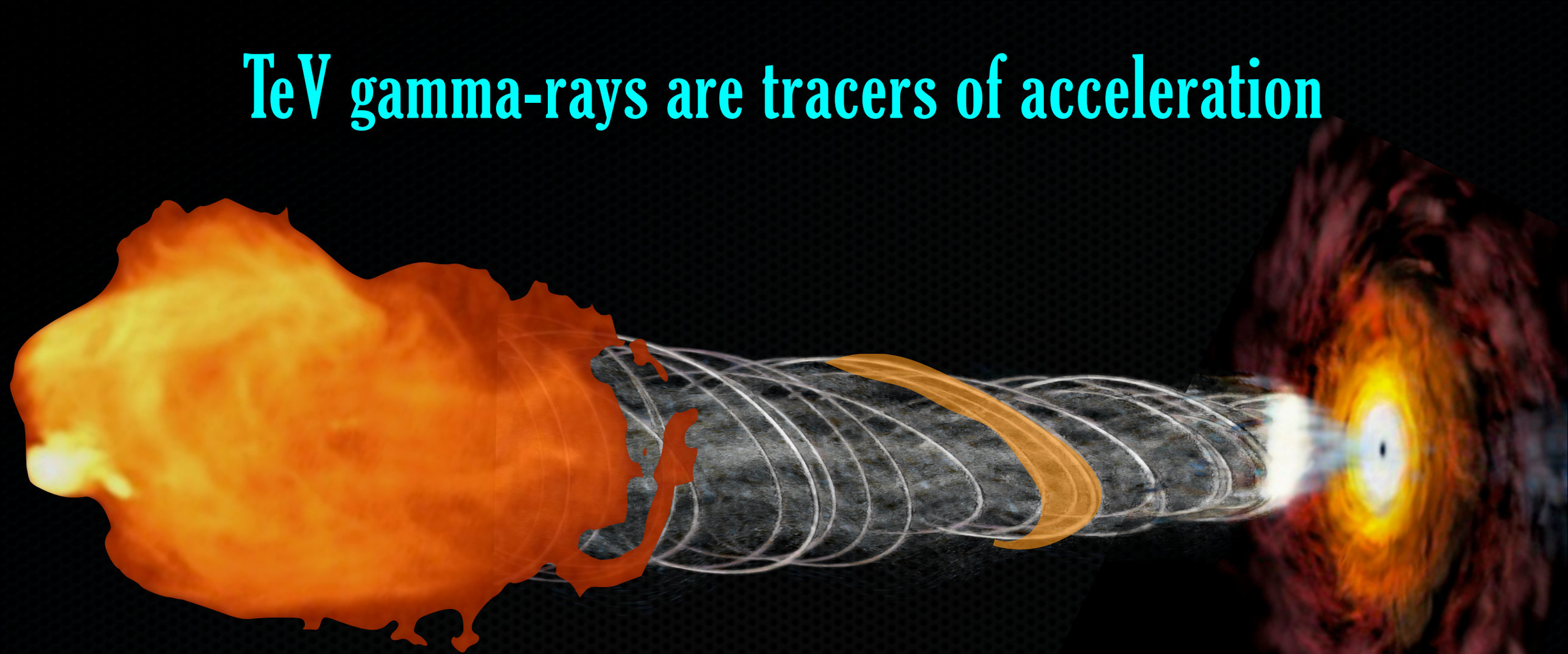

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+ CRs ➠ π_0's

+ CMBR/EBL γ's ➠ π_0's, IC

What CTA offers

- ★ **CTA on its own will be very interesting for jet studies**
  - ➠ **Characterize TeV spectrum/variability, identify the sources able to accelerate CRs to the highest energies**
  - ➠ **For Galactic jets, identify states associated with sporadic CR acceleration**
  - ➠ **Survey mode: populations and potentially serendipitous new states dominated by γ-rays**
- ★ **CTA together with MW facilities (radio through GeV)**
  - ➠ **key constraints on plasma/particle acceleration coupling properties in jets, particularly in Galactic jets (X-ray Binaries—XRBs)**

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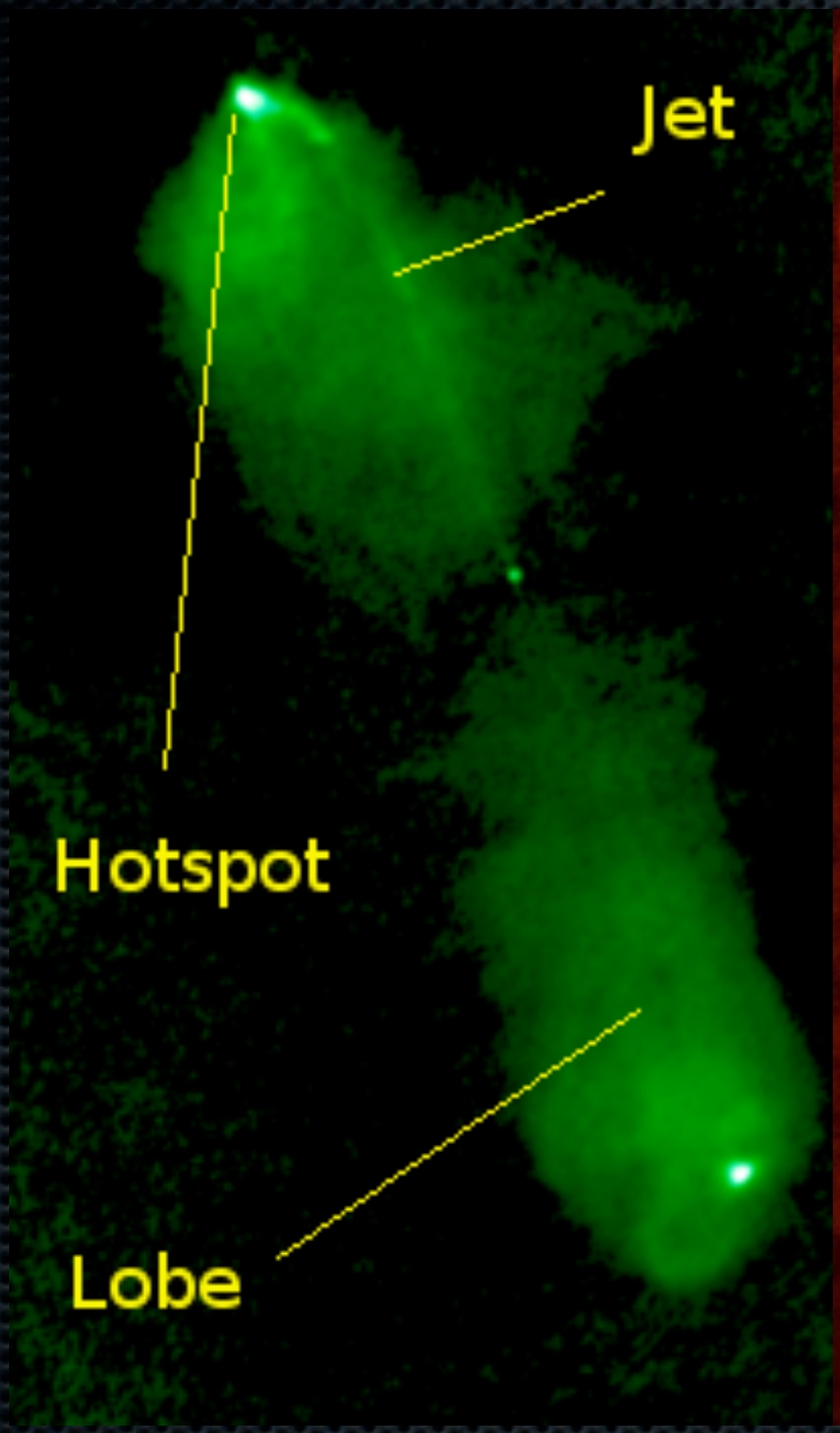
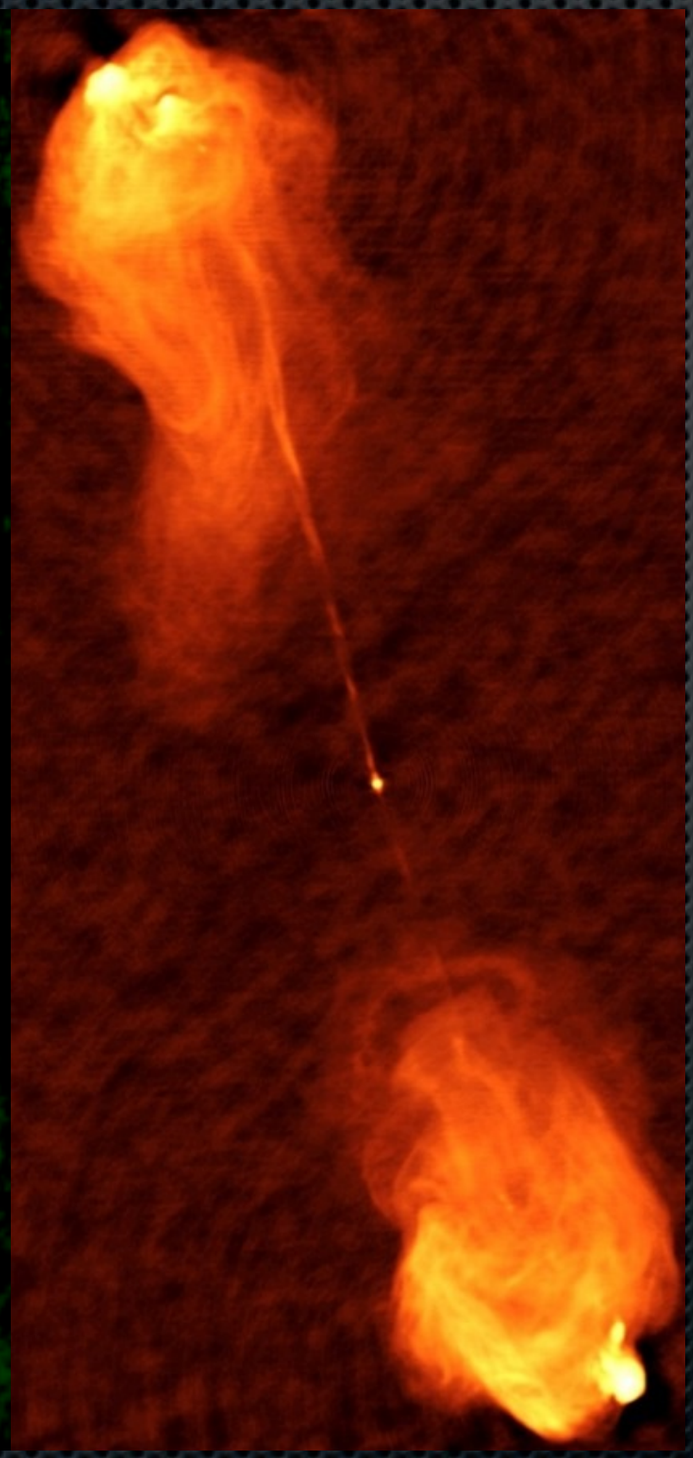
- **Expertise on dynamic observing, MW triggering (giving/receiving), data handling, observatory**
  - **particularly for XRBs, new insights from radio/X-ray monitoring are paving the way for triggered TeV runs**
  - **User Group, data handling groups: can help test fake data sets, use for model predictions in astro software**

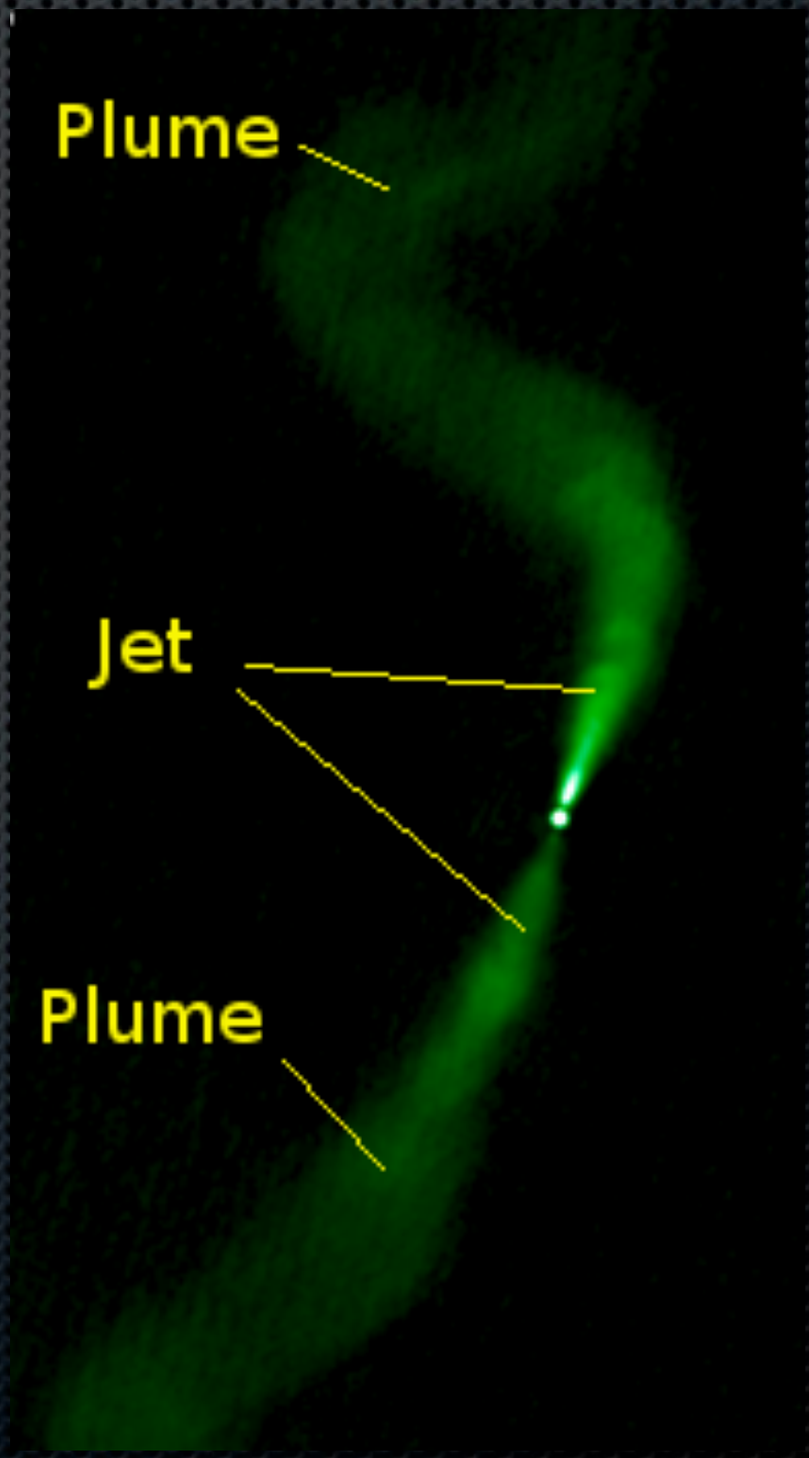
Two kinds of Radio Galaxies (AGN): FRI vs FRII

FRII

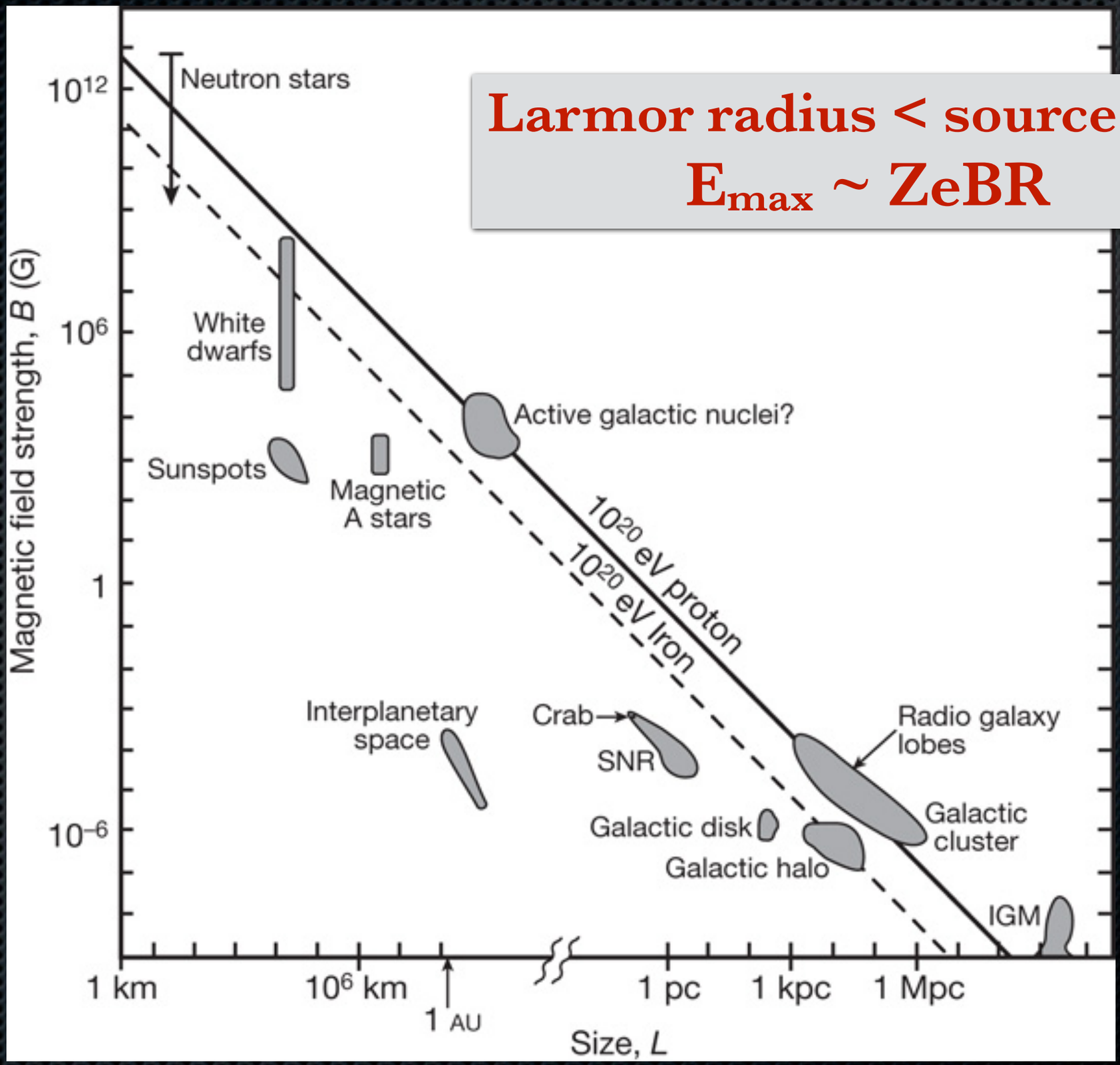




FRI



Hillas Diagram: estimates of CR accelerator sites



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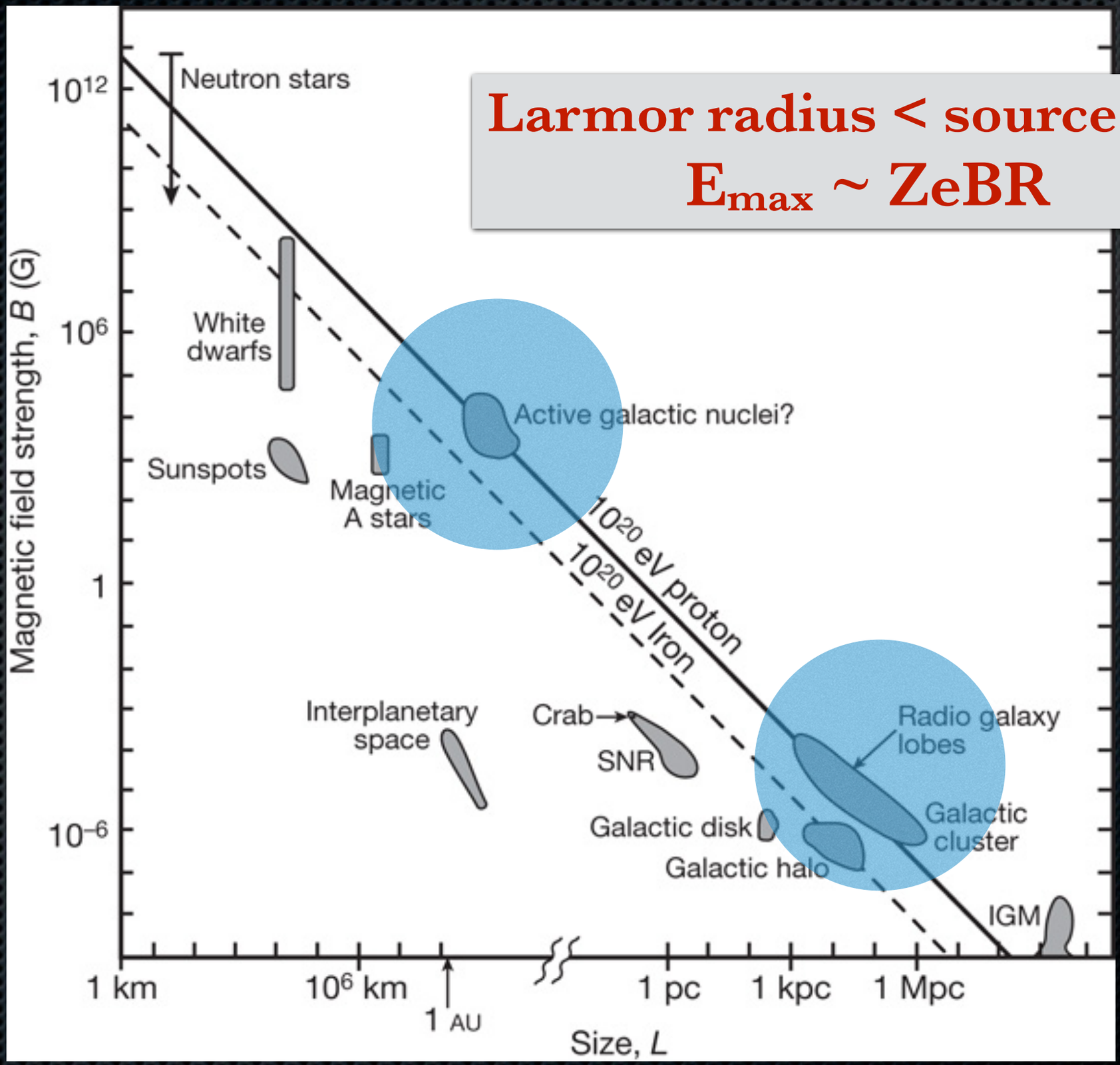

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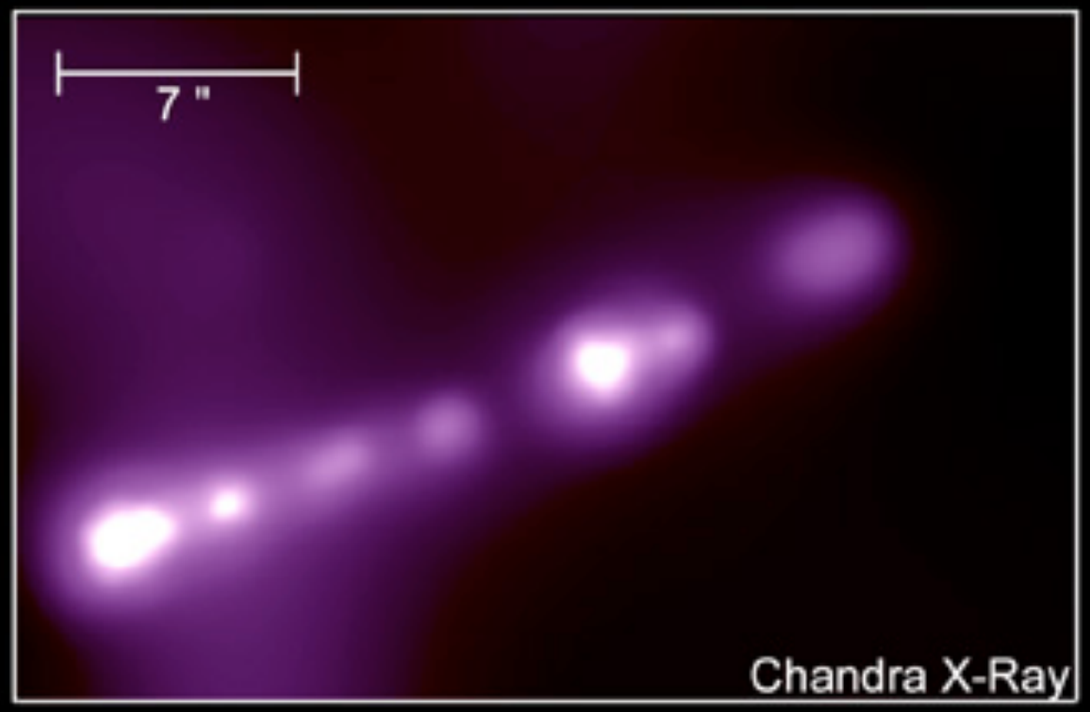
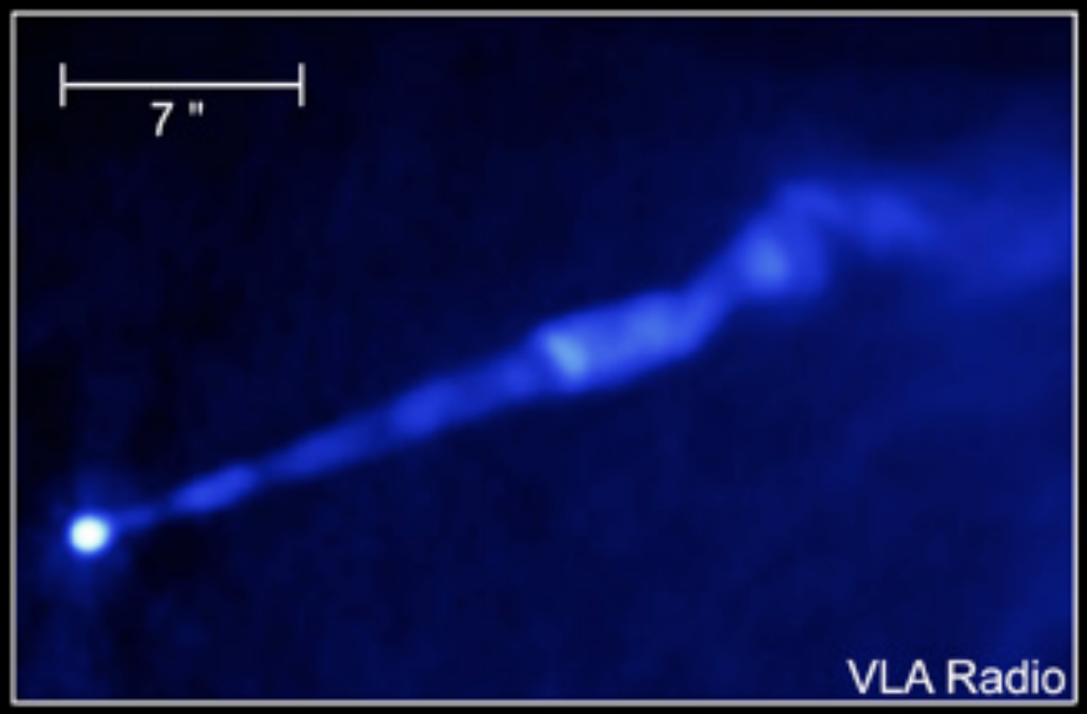
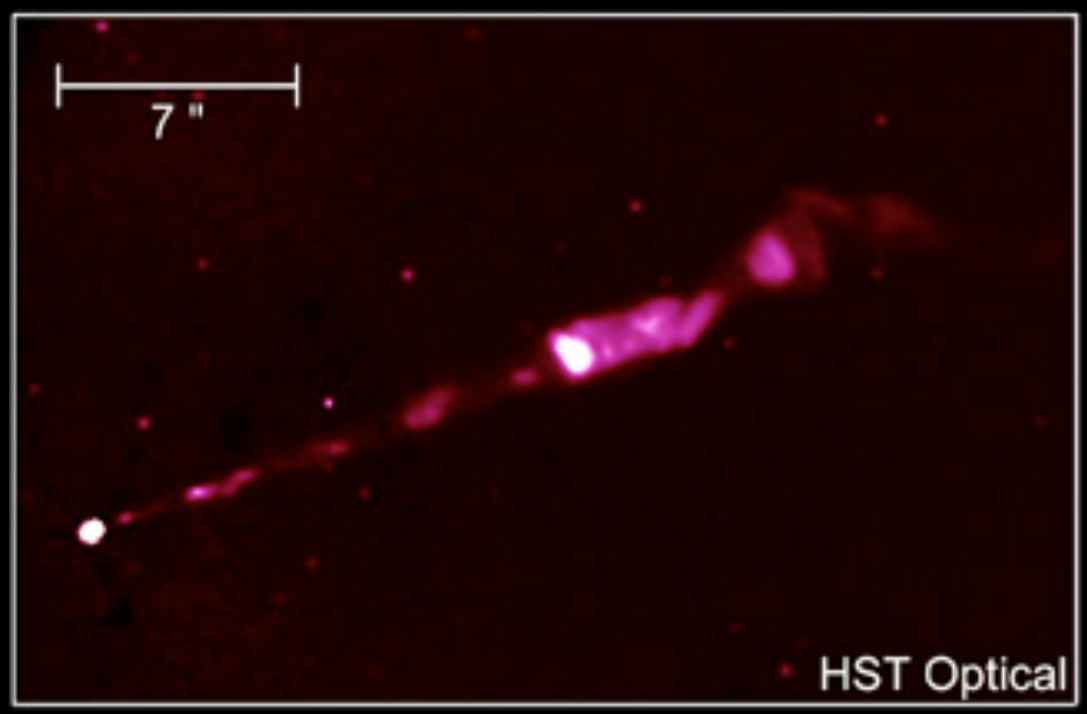
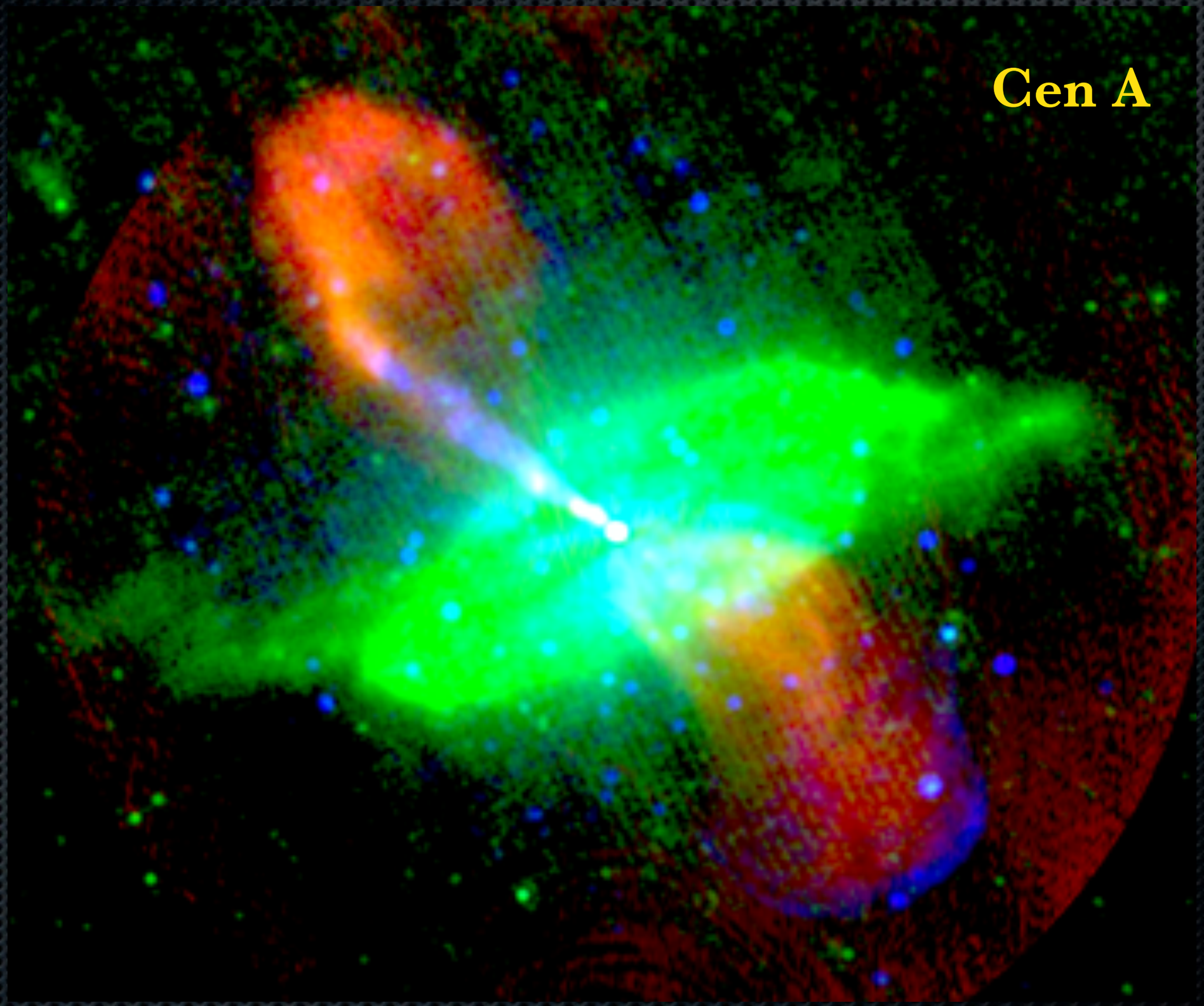


M87





Surprise: FRI's/Blazars are the GeV/TeV γ-ray sources!



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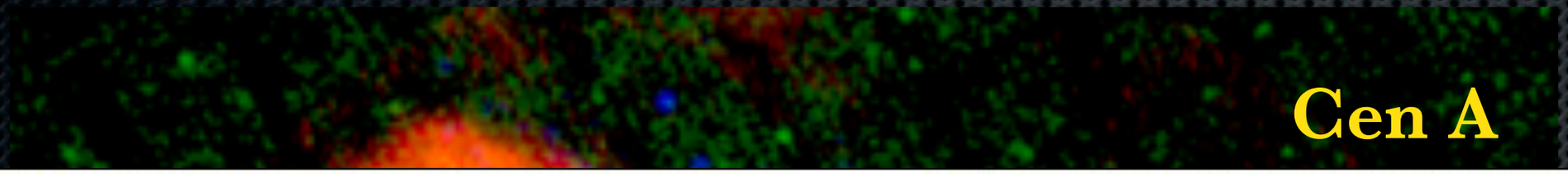
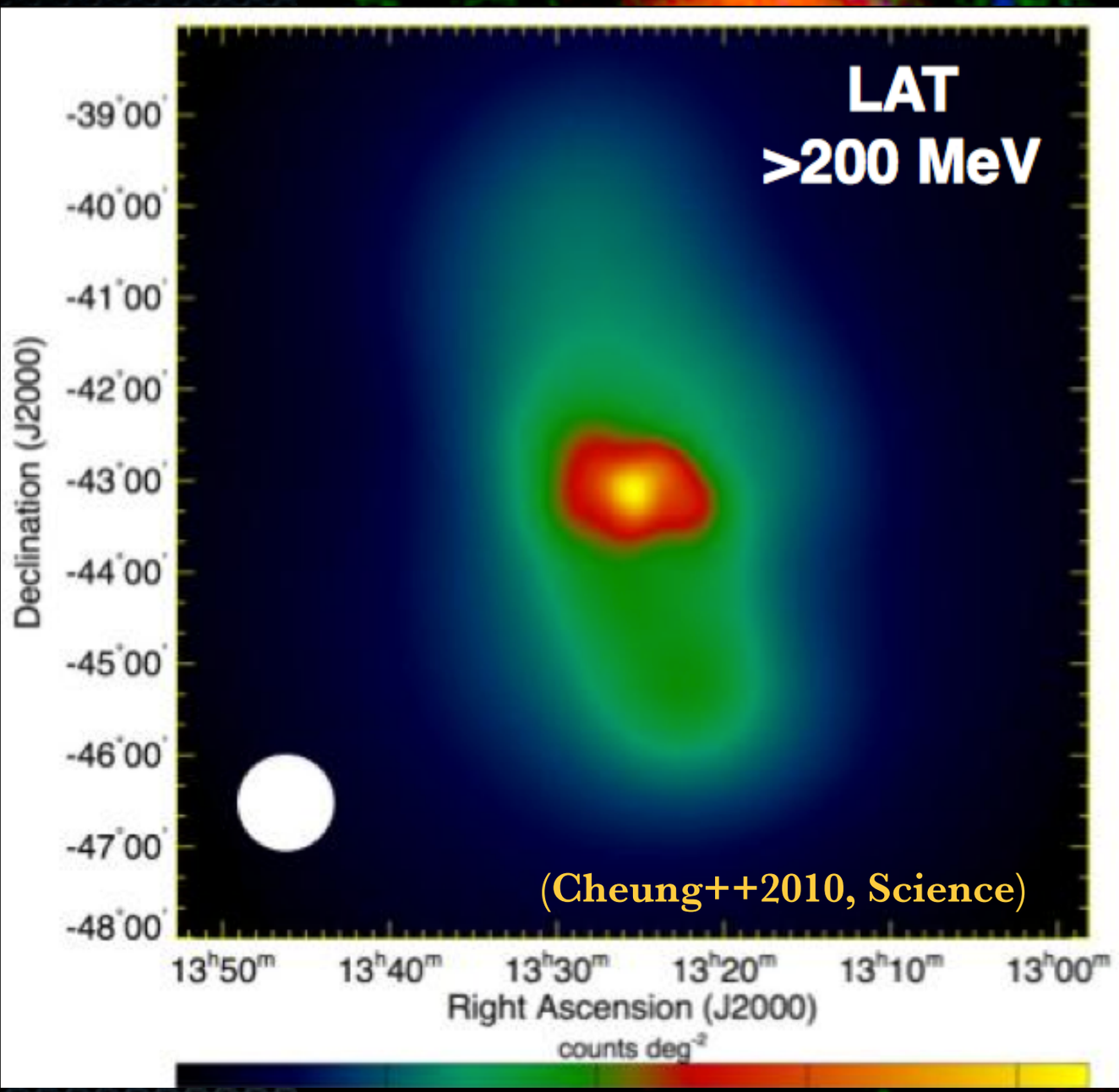
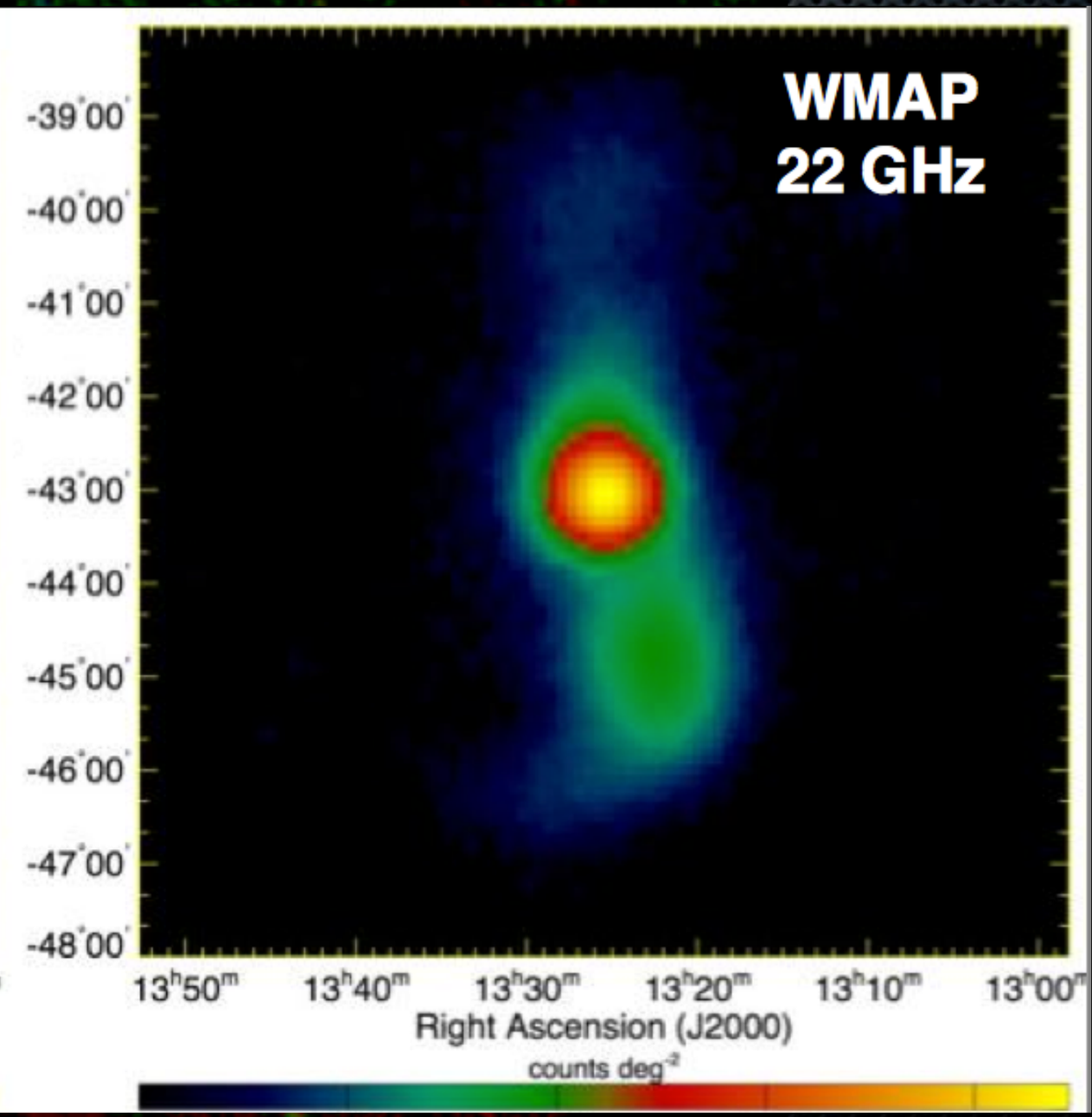
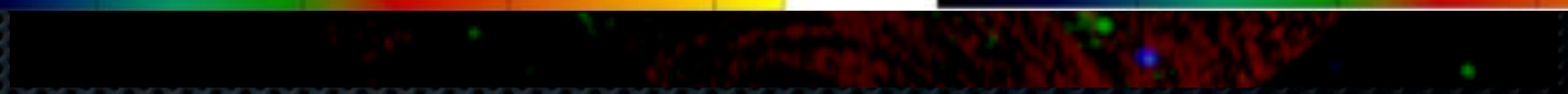


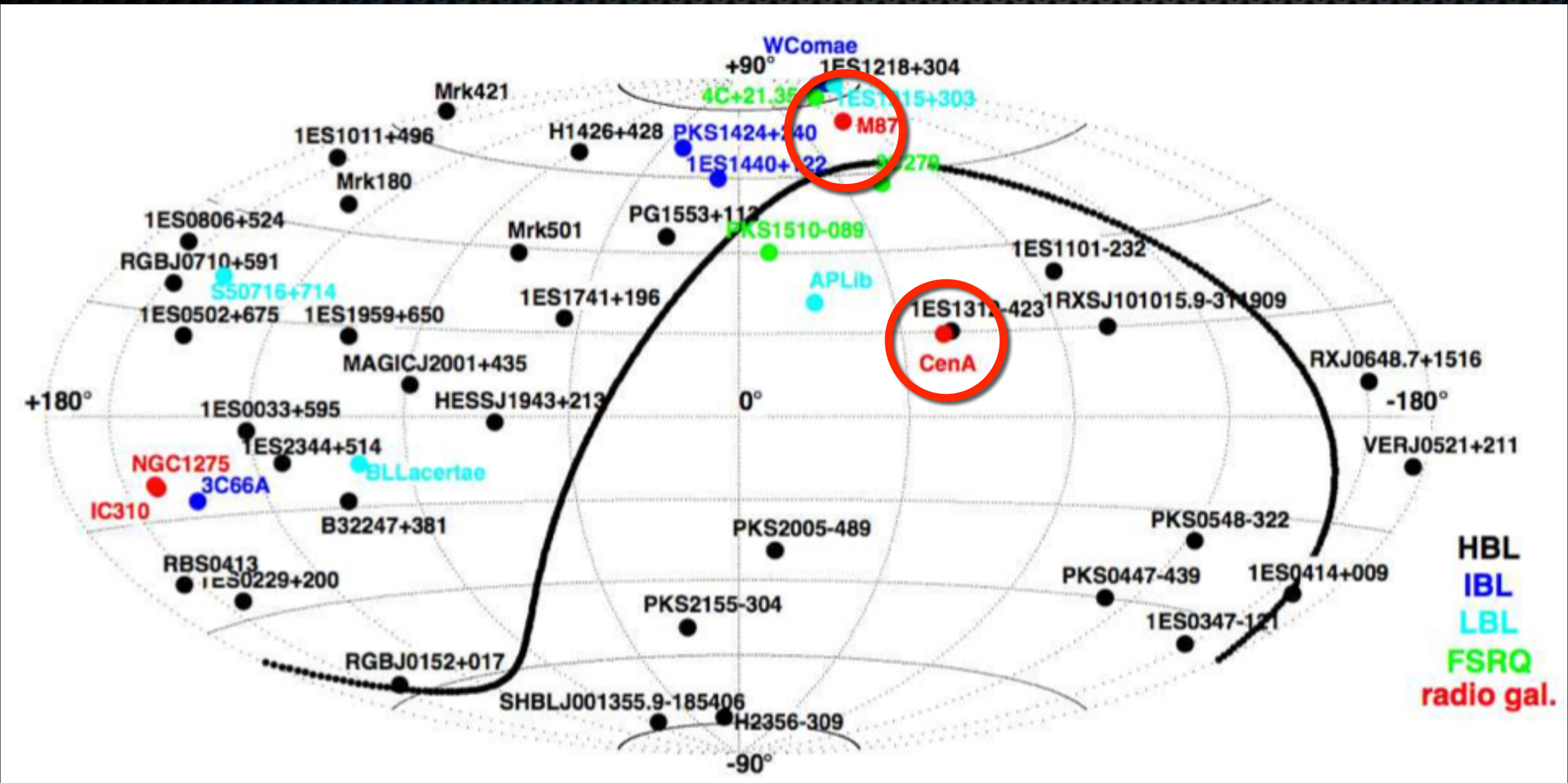


(Cheung++2010, Science)





All the TeV-detected AGN are more FRI-like (low-luminosity, steady-jet dominated "state" of AGN)



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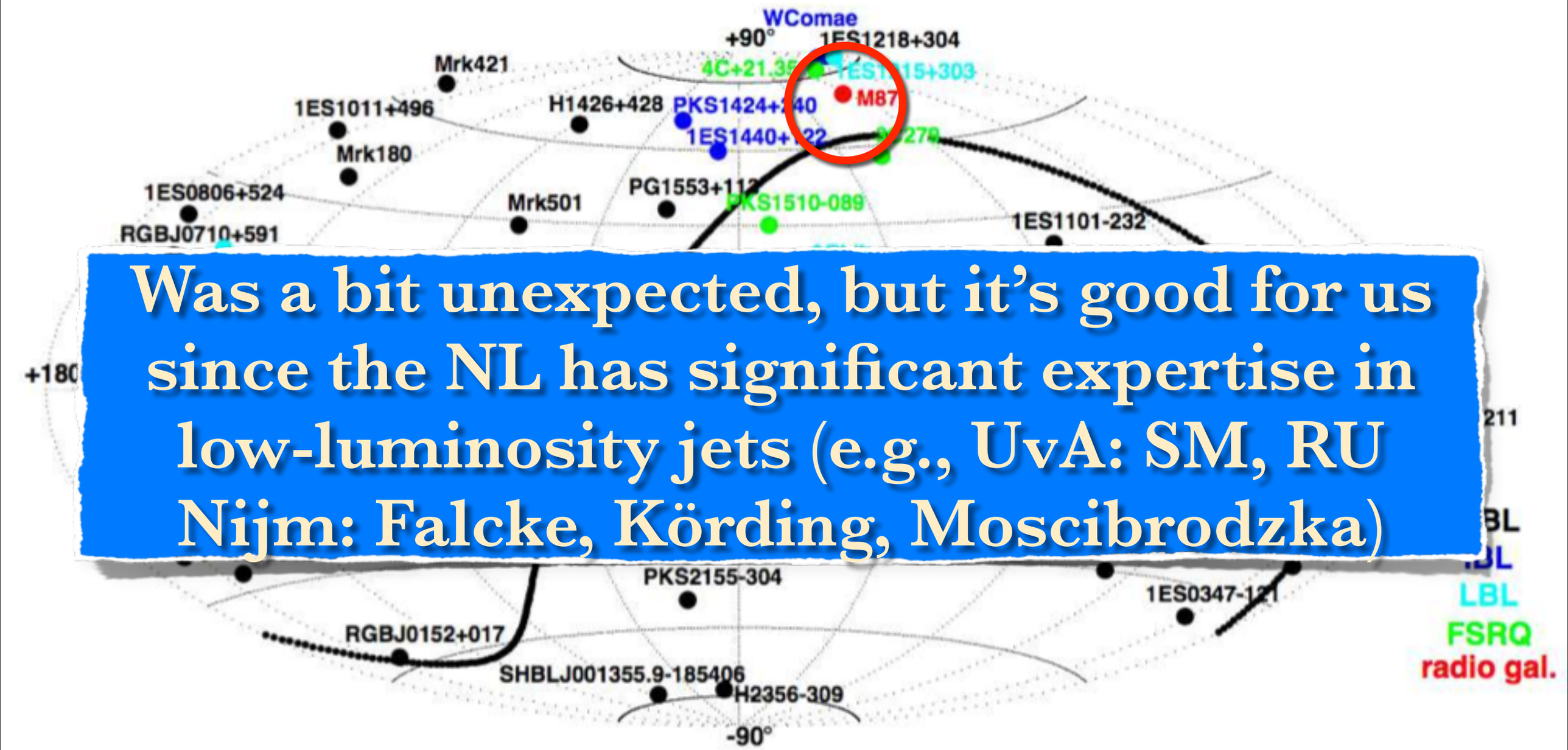

Was a bit unexpected, but it's good for us since the NL has significant expertise in low-luminosity jets (e.g., UvA: SM, RU Nijm: Falcke, Körding, Moscibrodzka)

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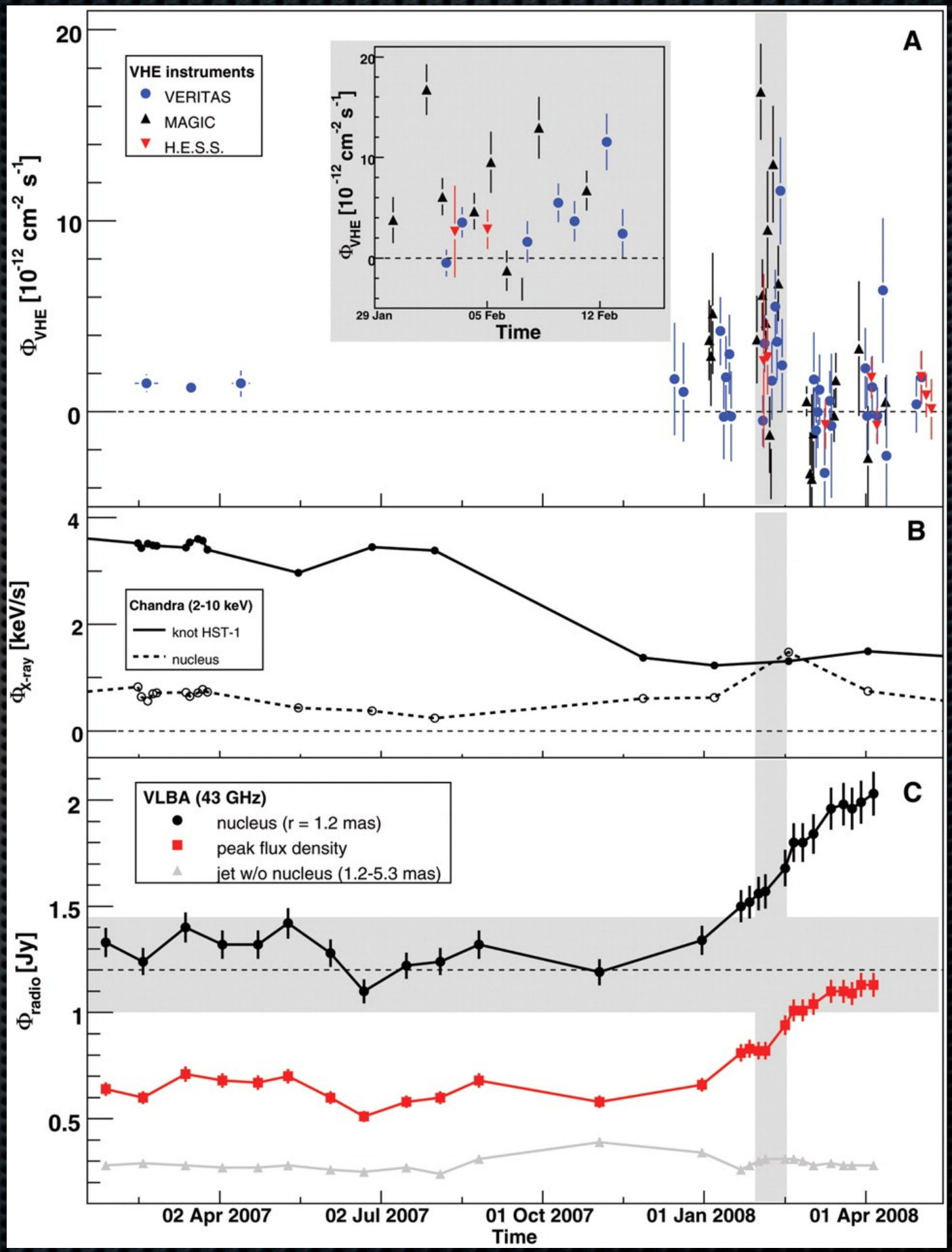
Extreme TeV Variability found in M87

- ★ Causality: emission region ≤ $5\delta R_S$ ➠ rules out DM annil, CR with IGM, knots. Leaves just regions interior to jet, "mini-jets"
- ★ Precision VLBA localized radio to the core/nucleus, very hard to understand how TeV photons would escape pair production
- ★ Challenges to models, "minijets" a good candidate, flux tubes within the jet

(Veritas, HESS, MAGIC, VLBA 2008, Science)



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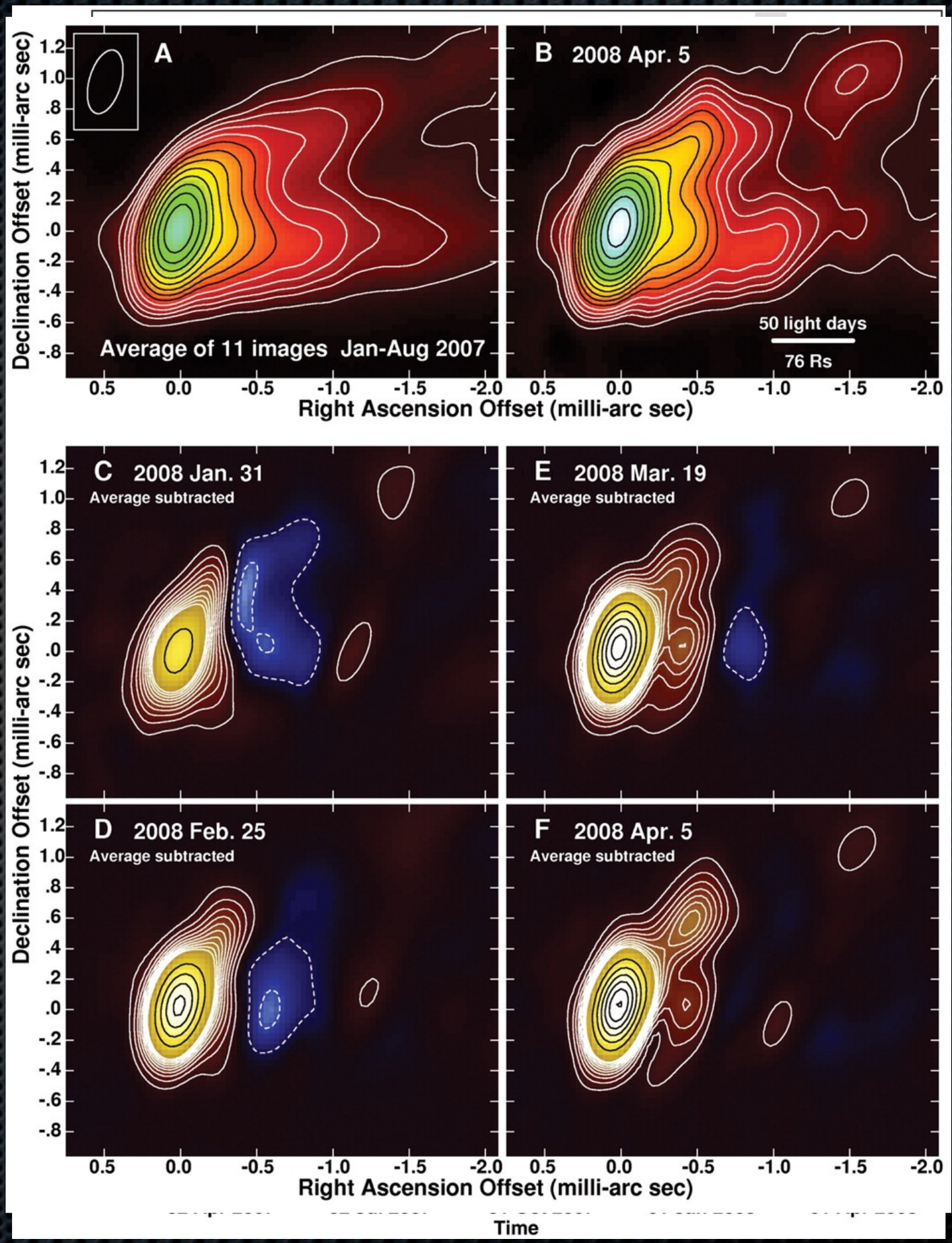
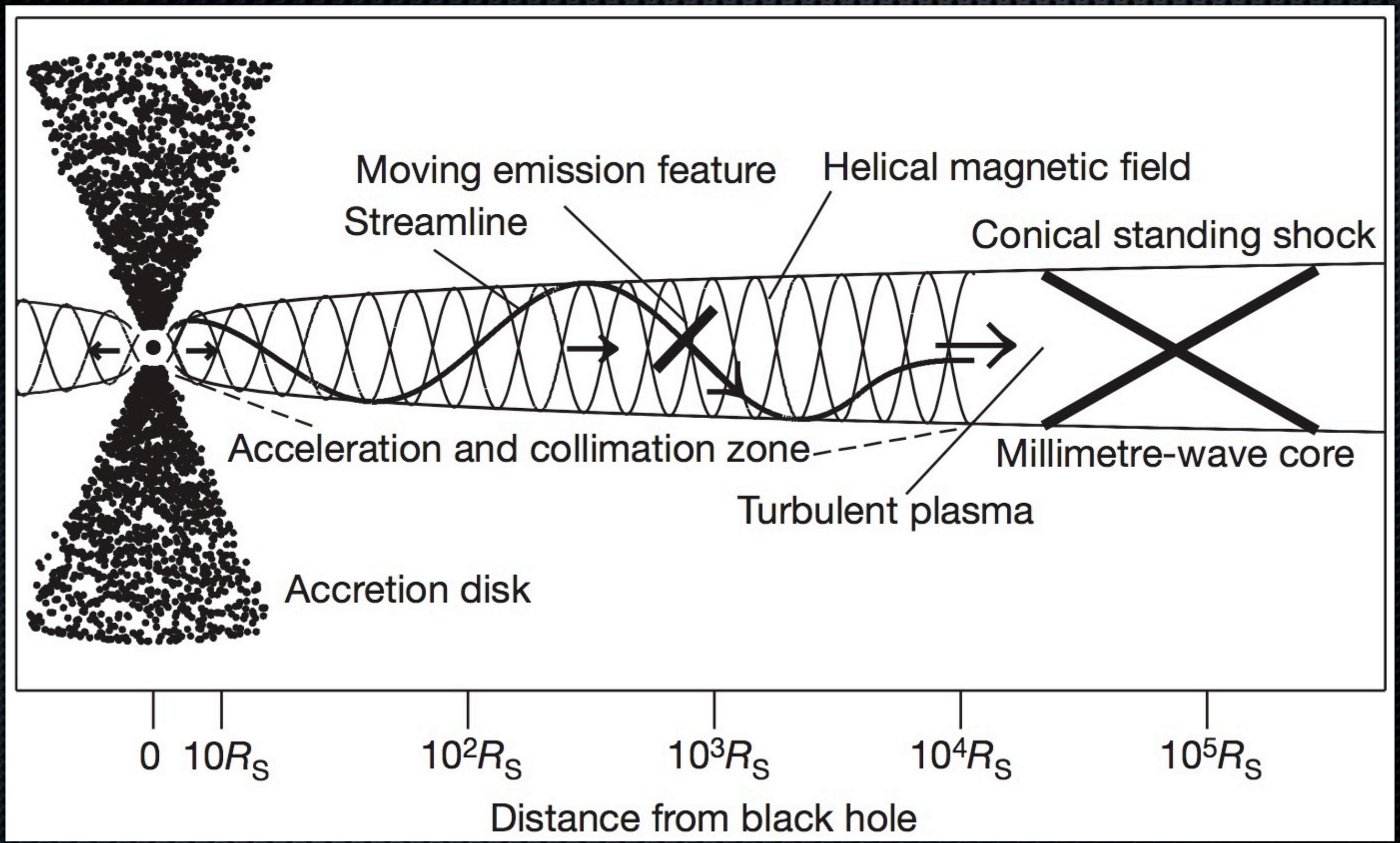


BL Lac "paradigm" (Marscher et al. 2008)



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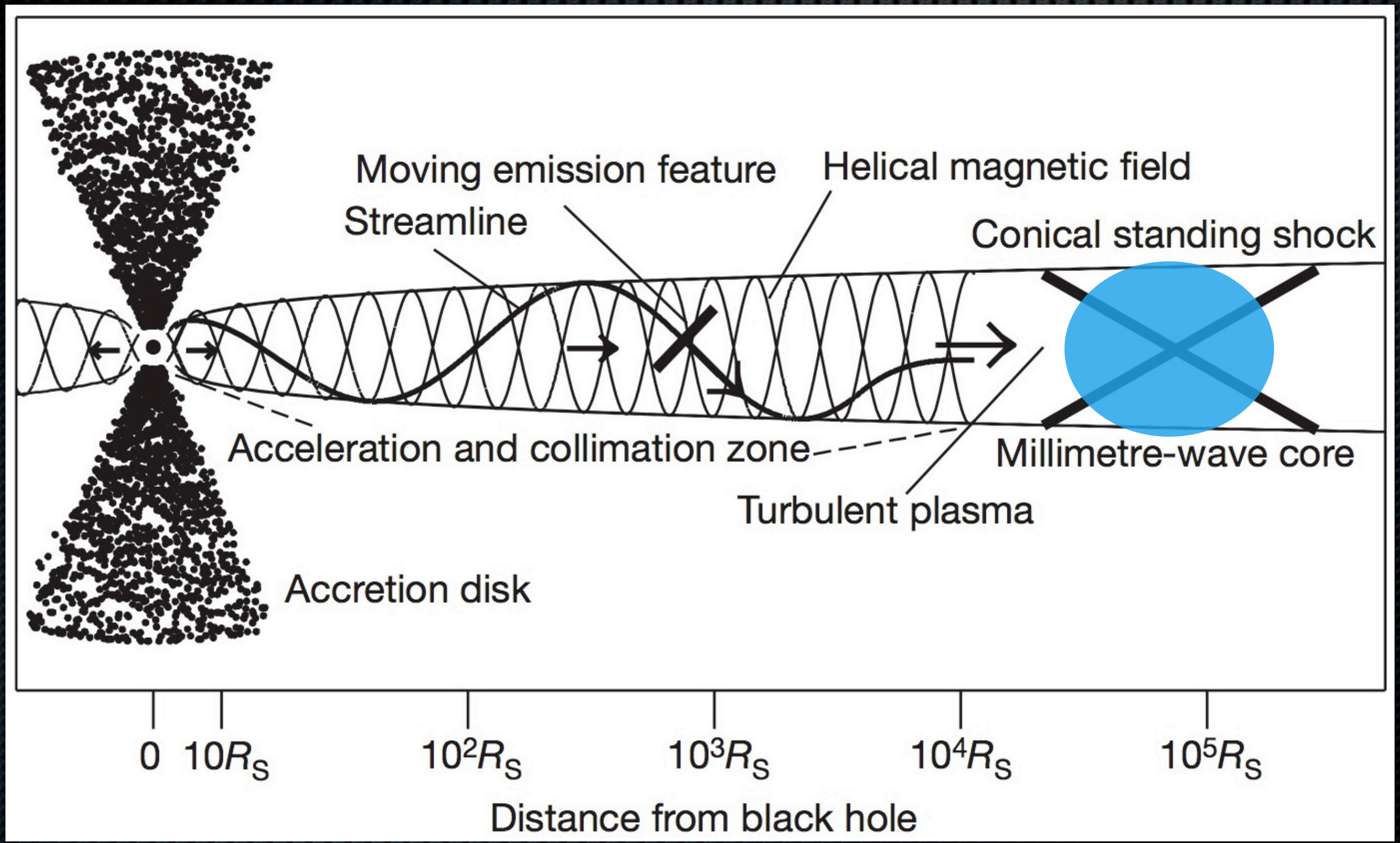
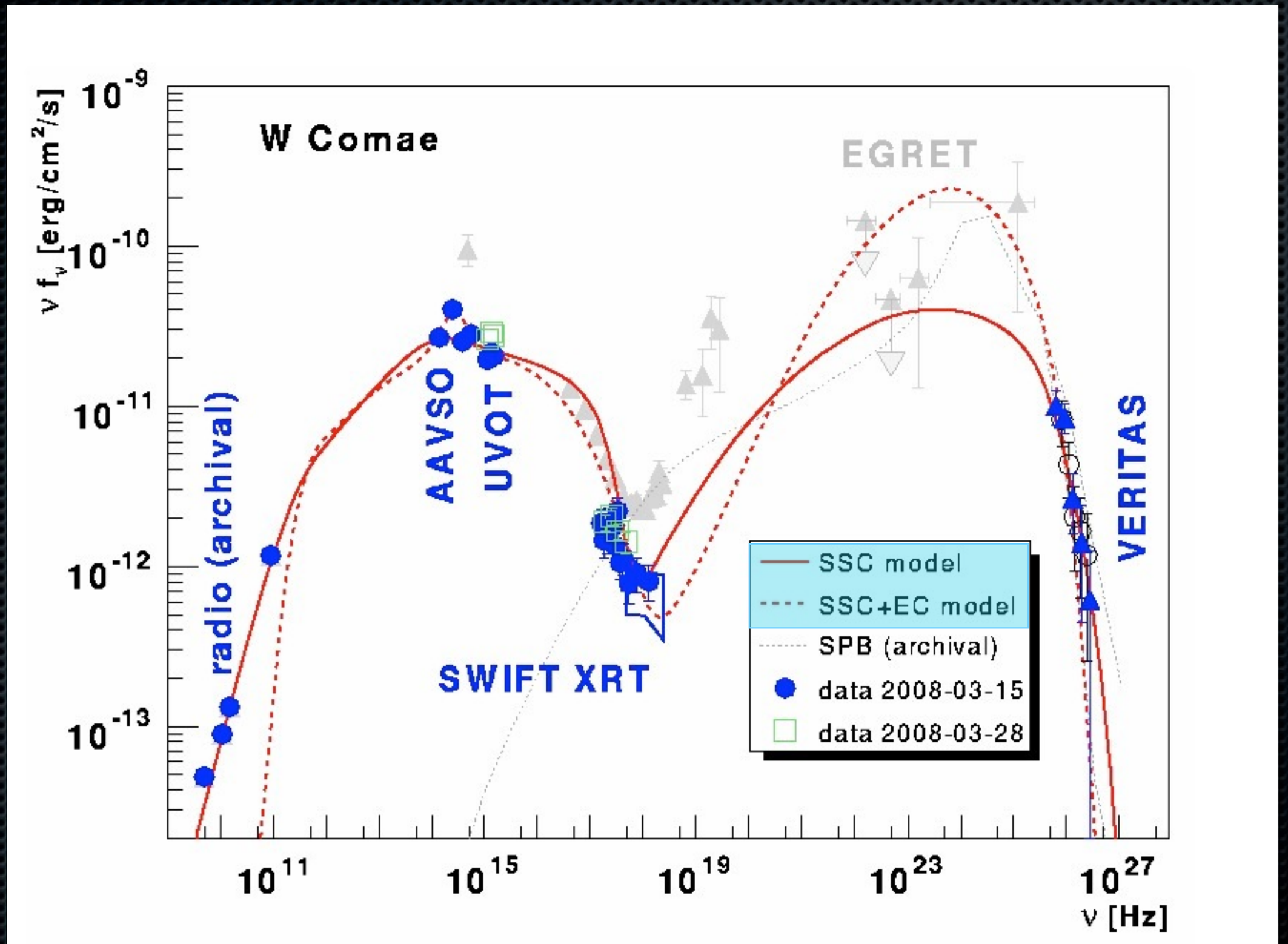


Single zone modelling is the current standard



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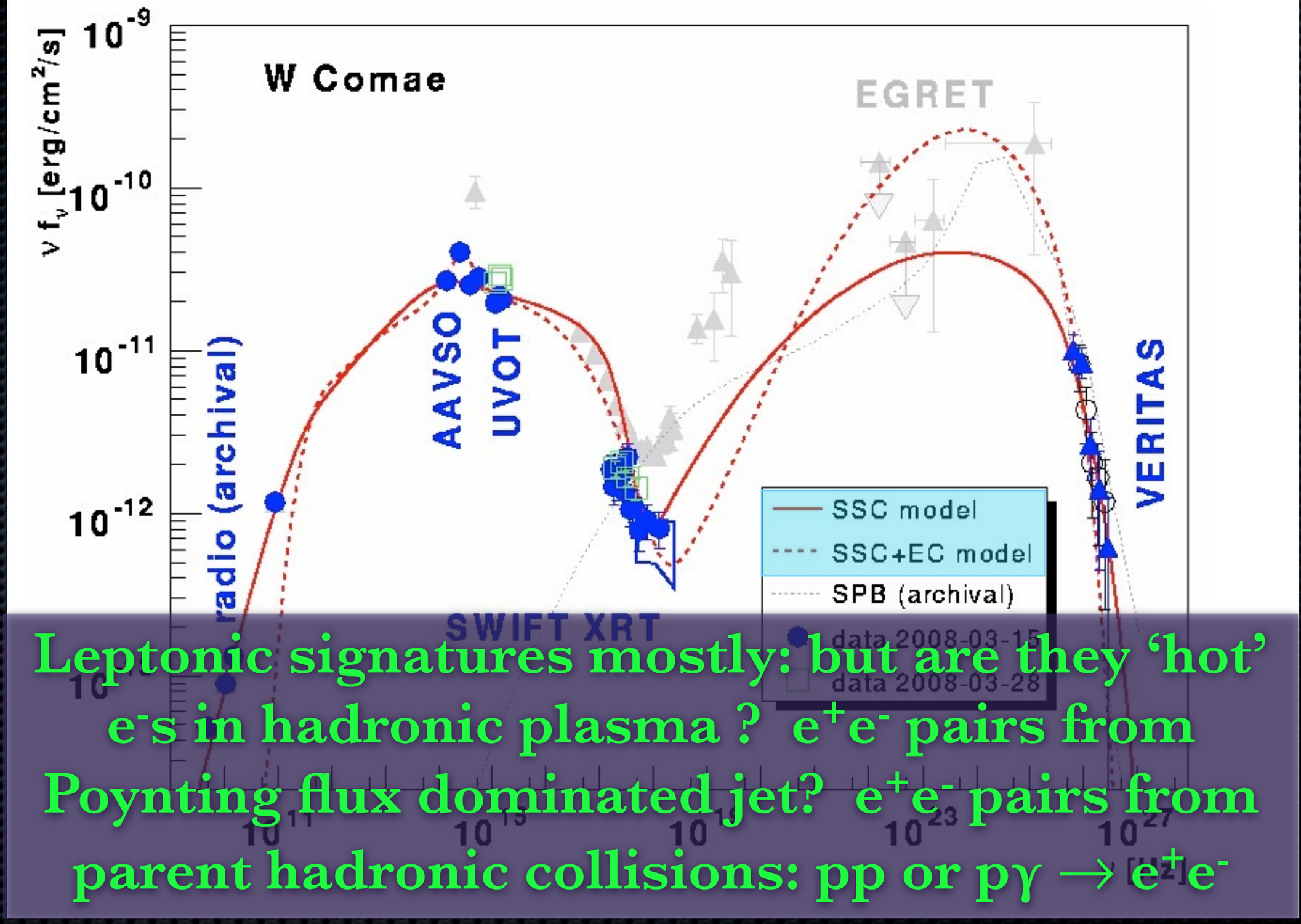
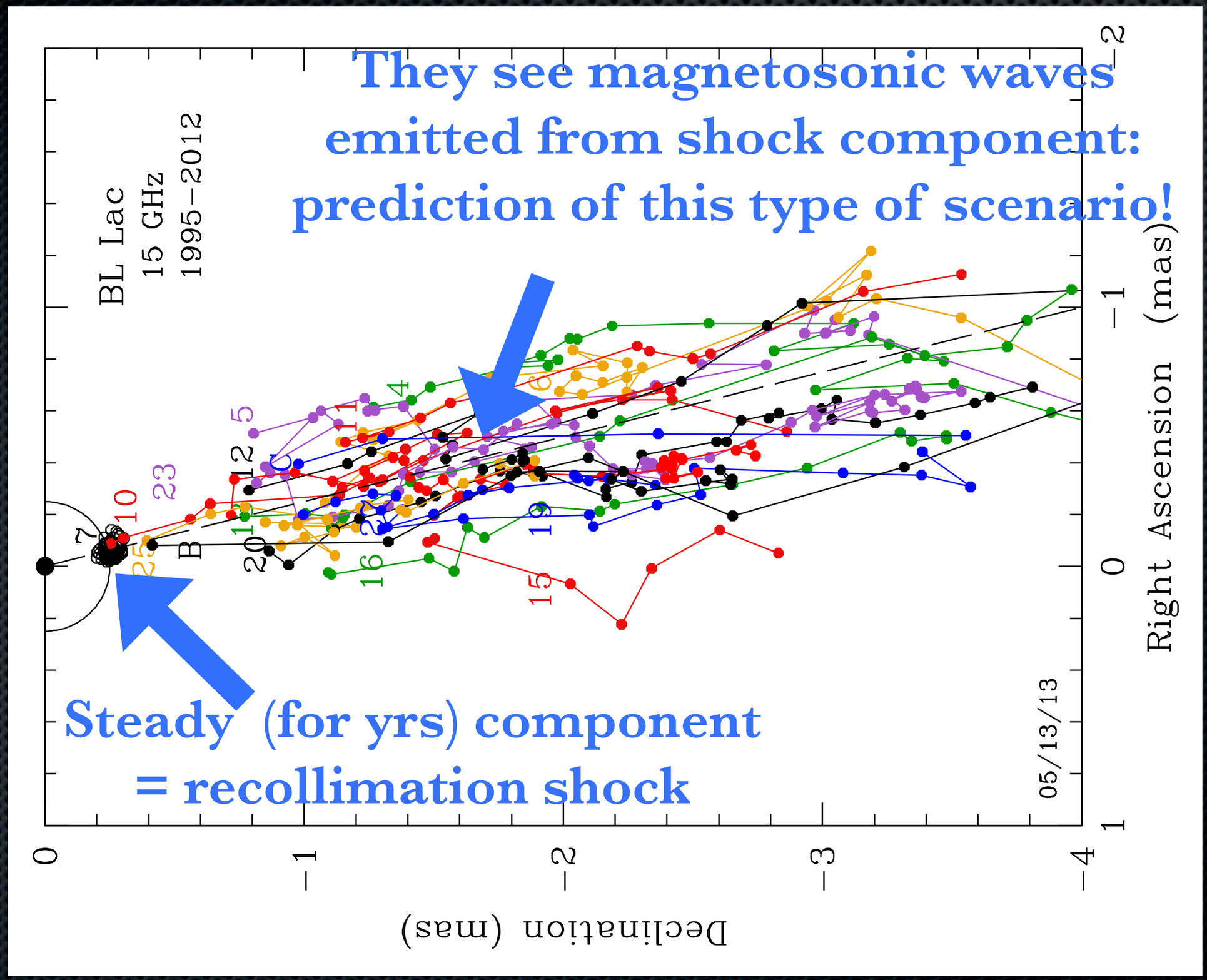


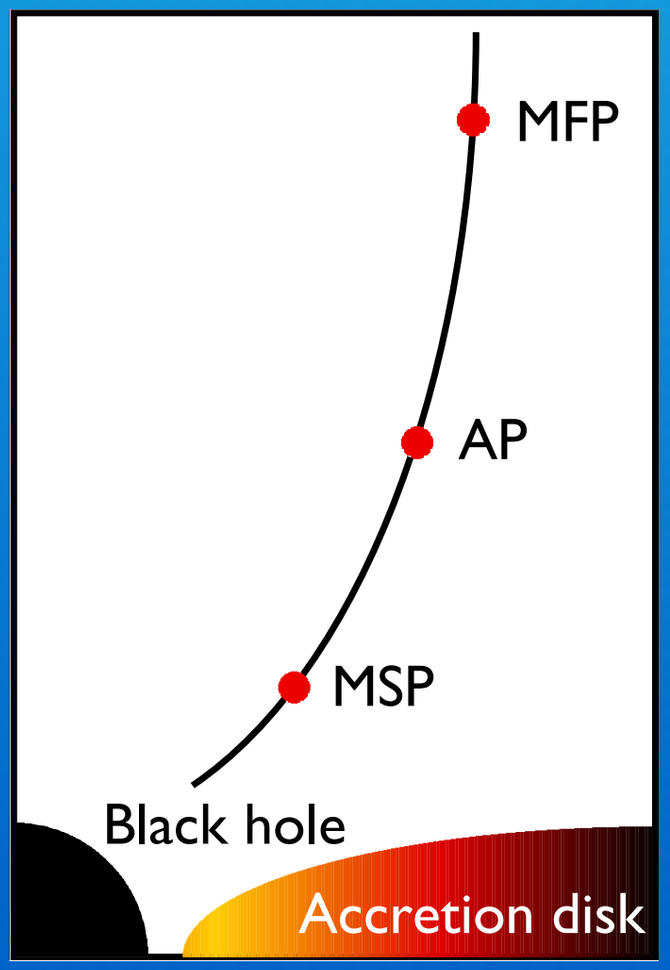
Leptonic signatures mostly: but are they 'hot' e^-s in hadronic plasma ? e^+e^- pairs from Poynting flux dominated jet? e^+e^- pairs from parent hadronic collisions: pp or $p\gamma \rightarrow e^+e^-$

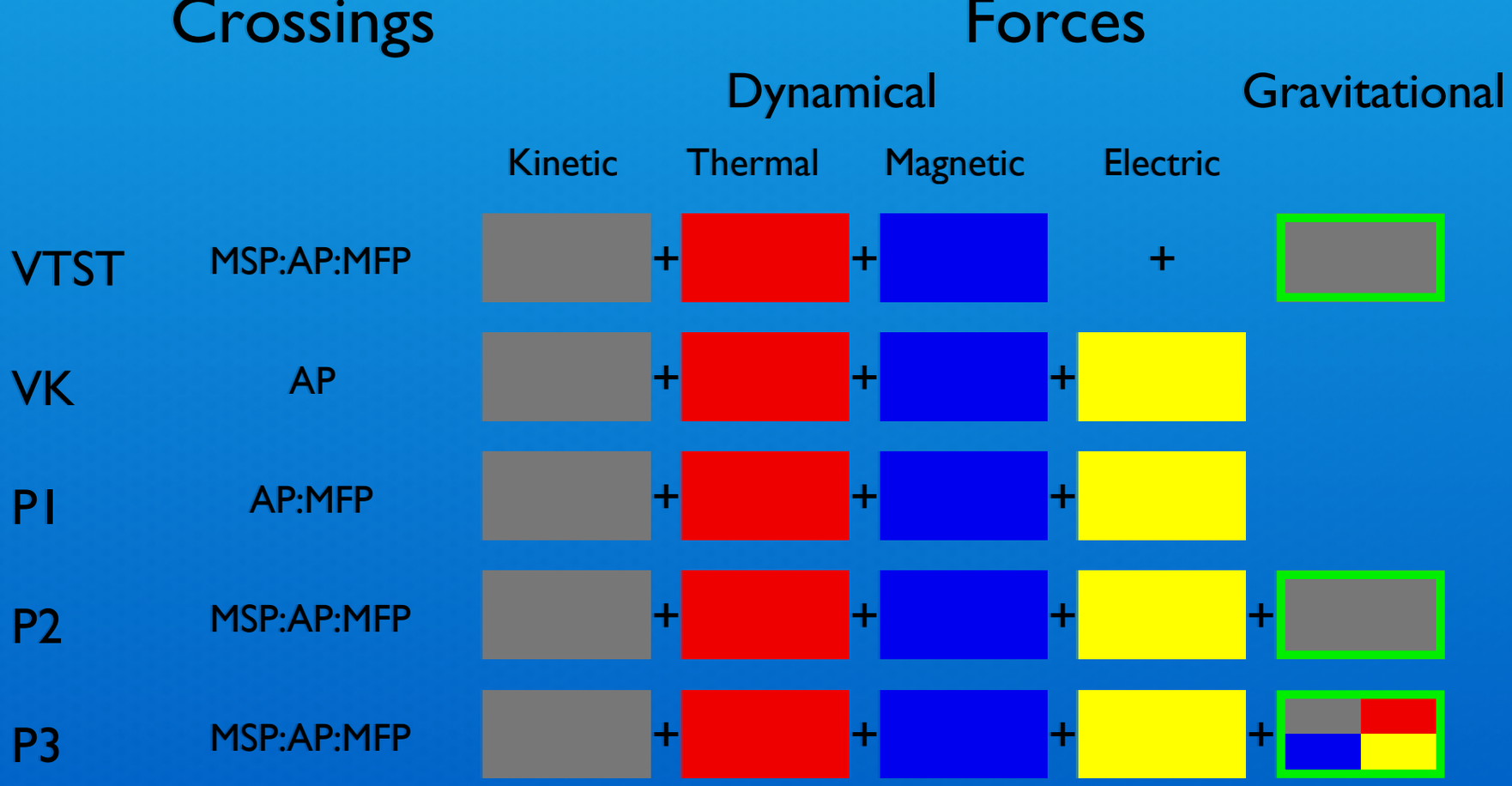
(Acciari et al. 2008, Böttcher et al. ++)

BL Lac itself (MOJAVE group, VLBI, in prep.)



New models: location of acceleration and jet dynamics linked explicitly to conditions in inner accretion flow (breaks degeneracies)





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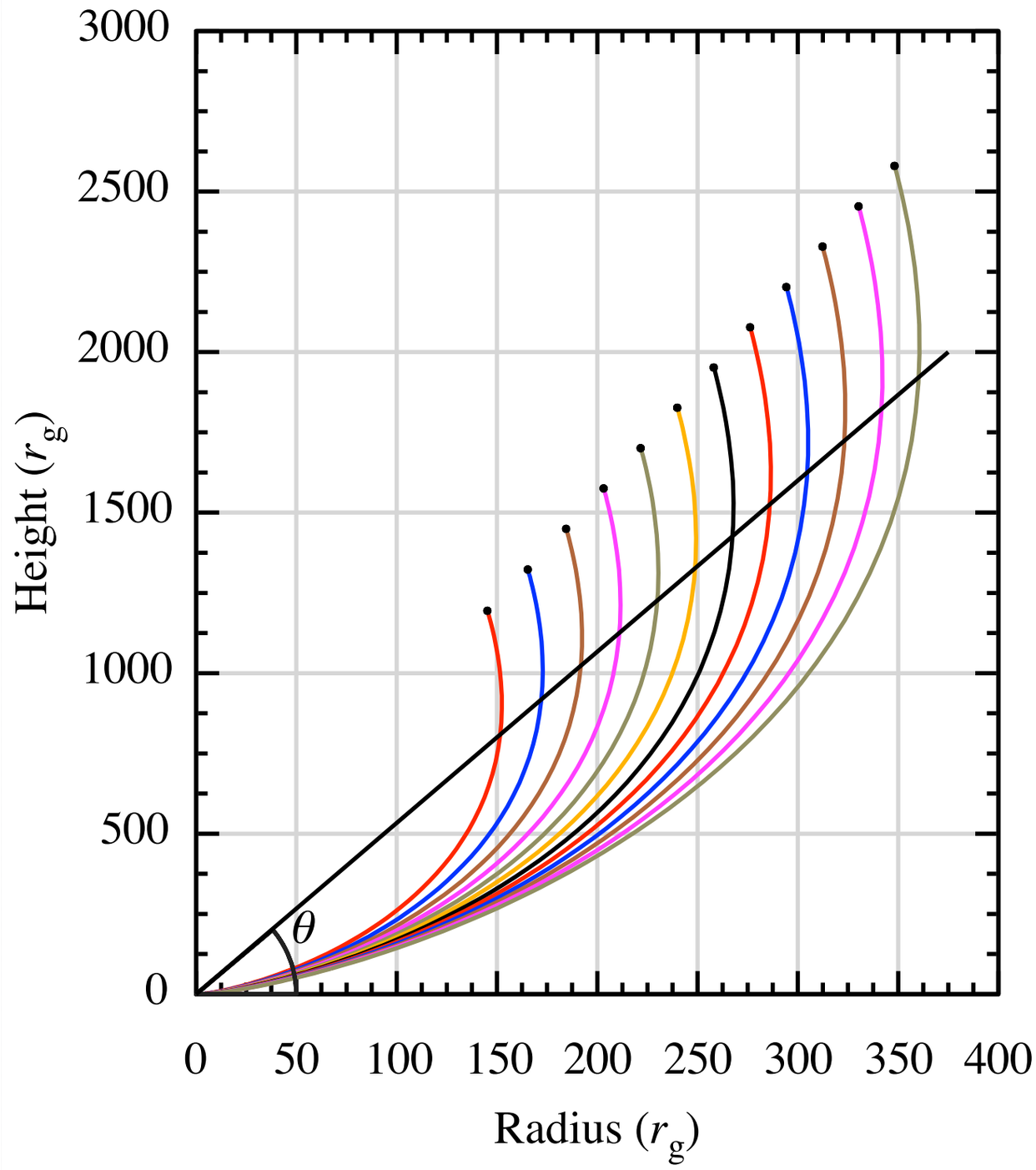

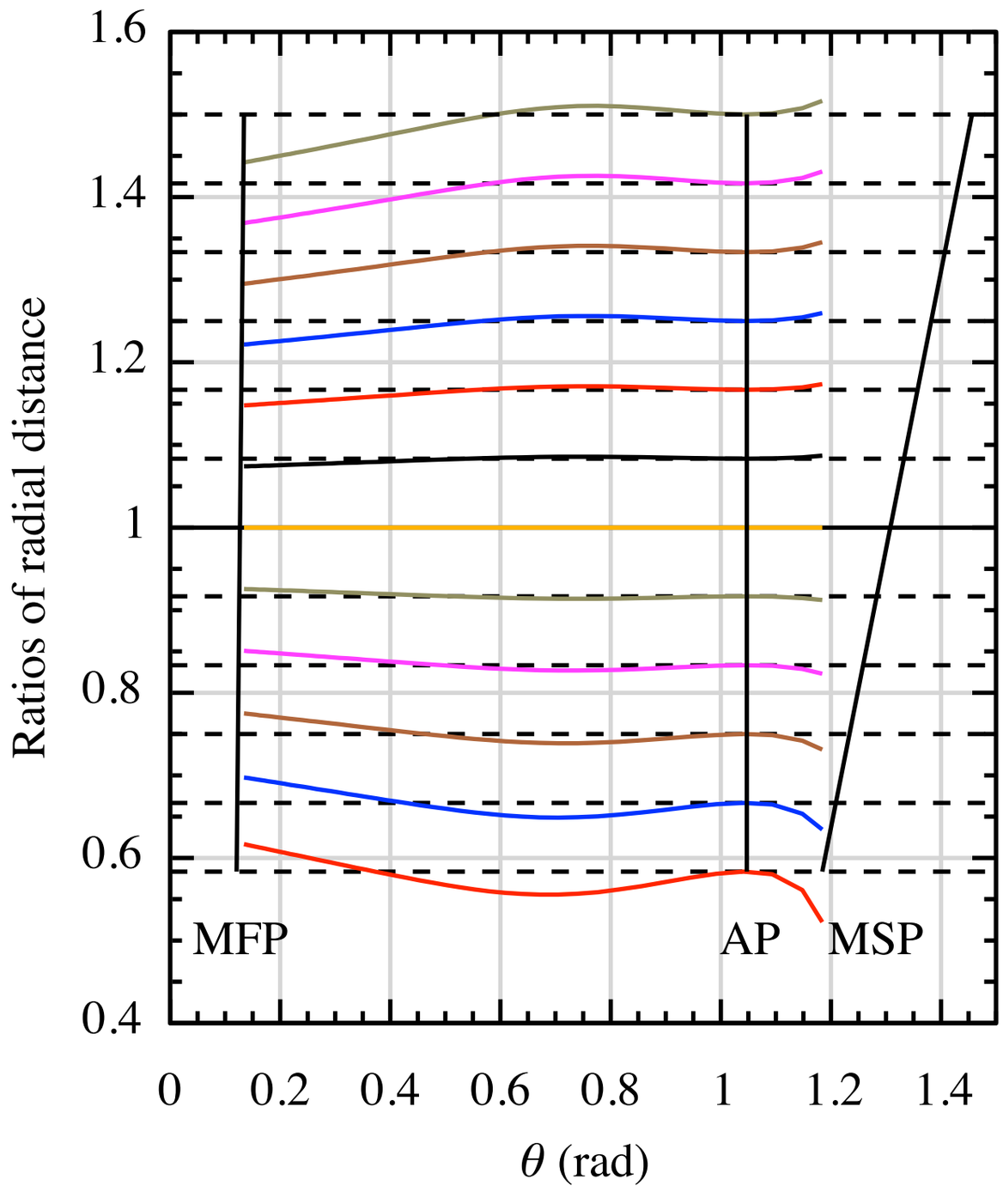

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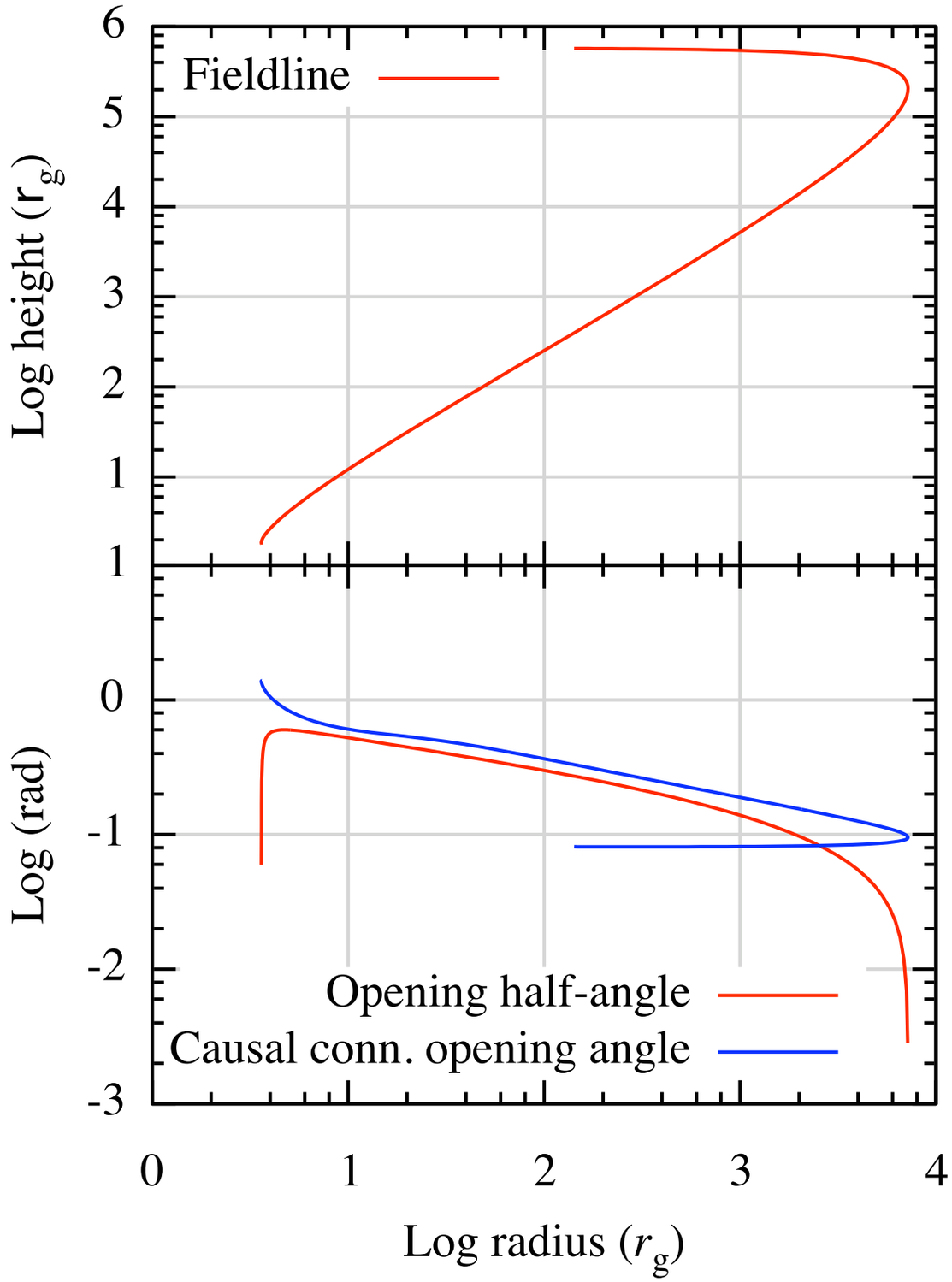

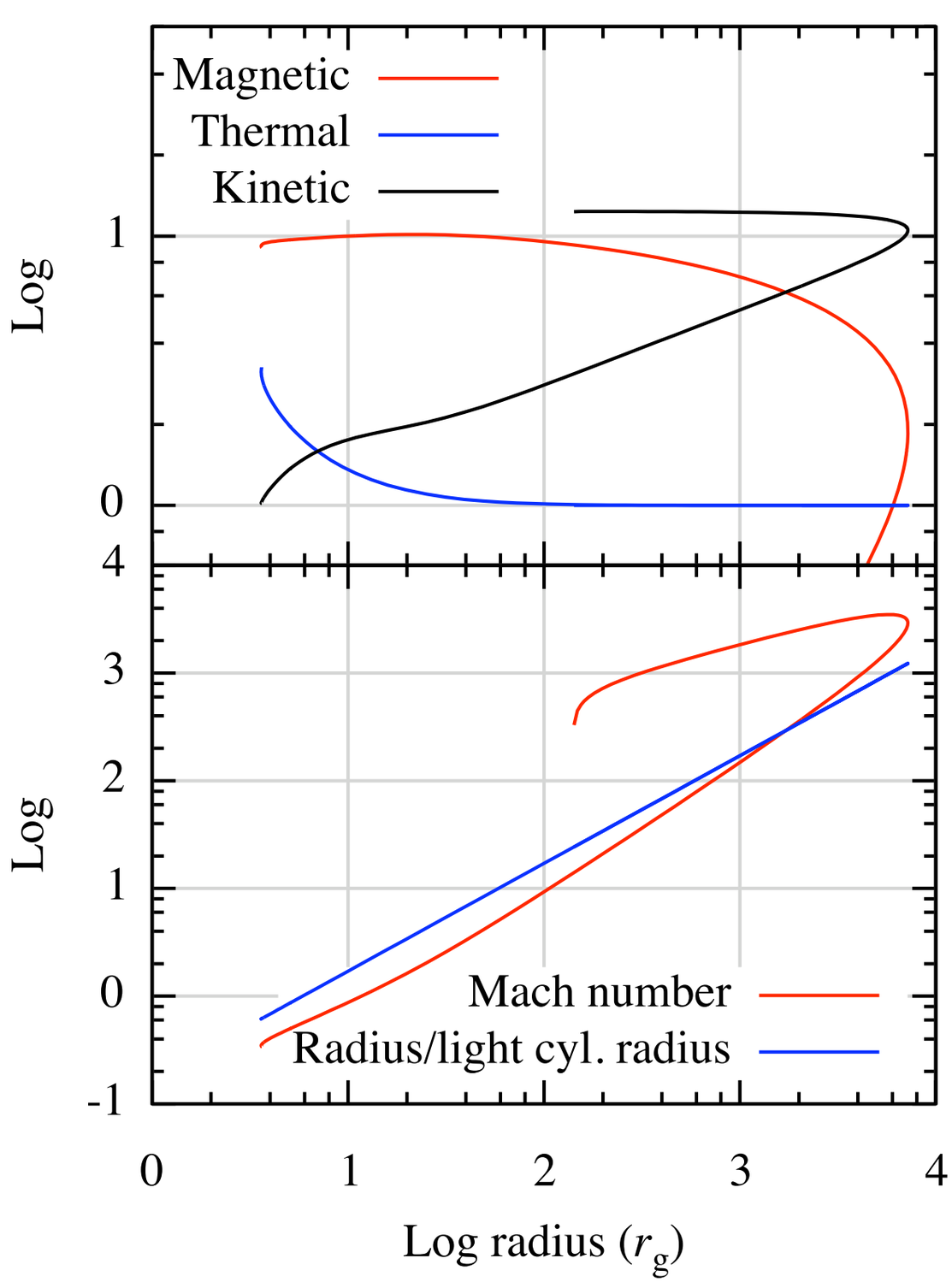

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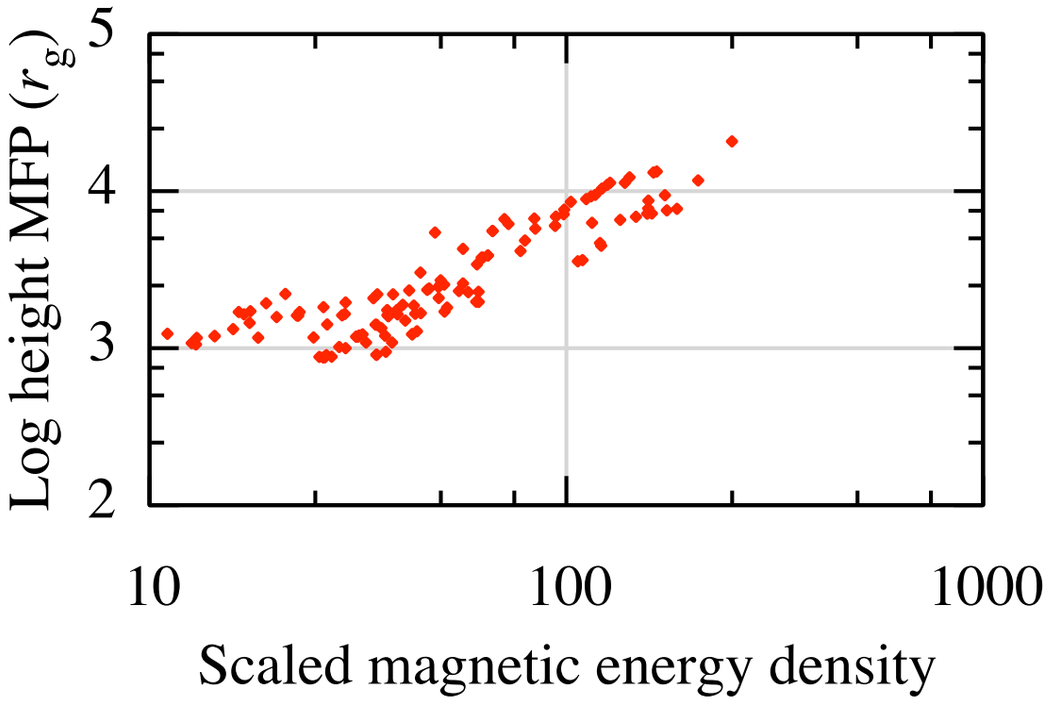

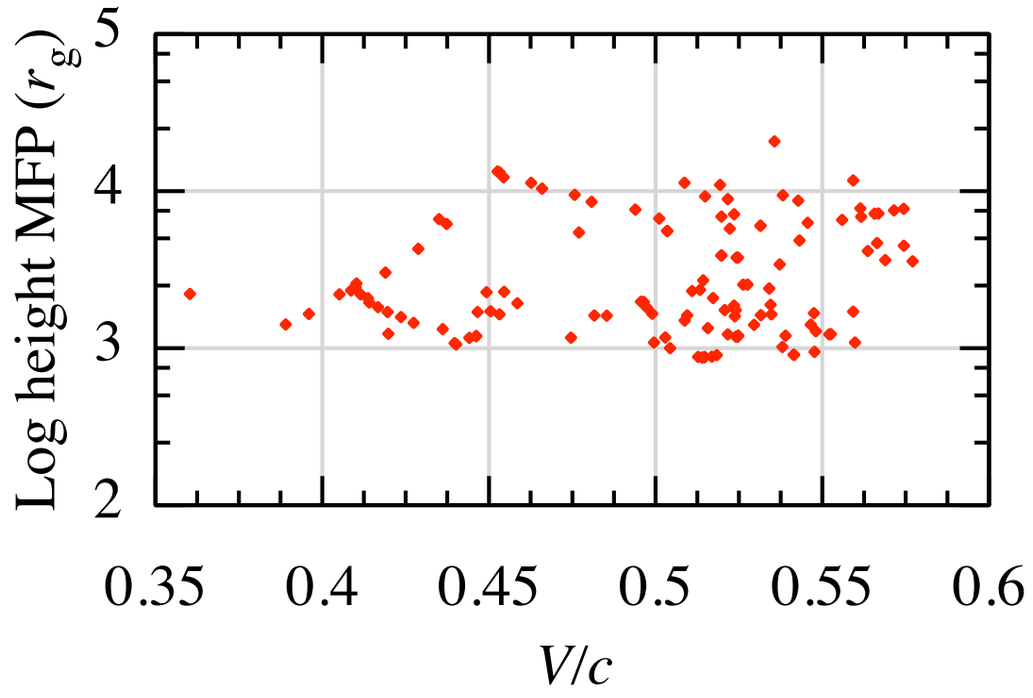

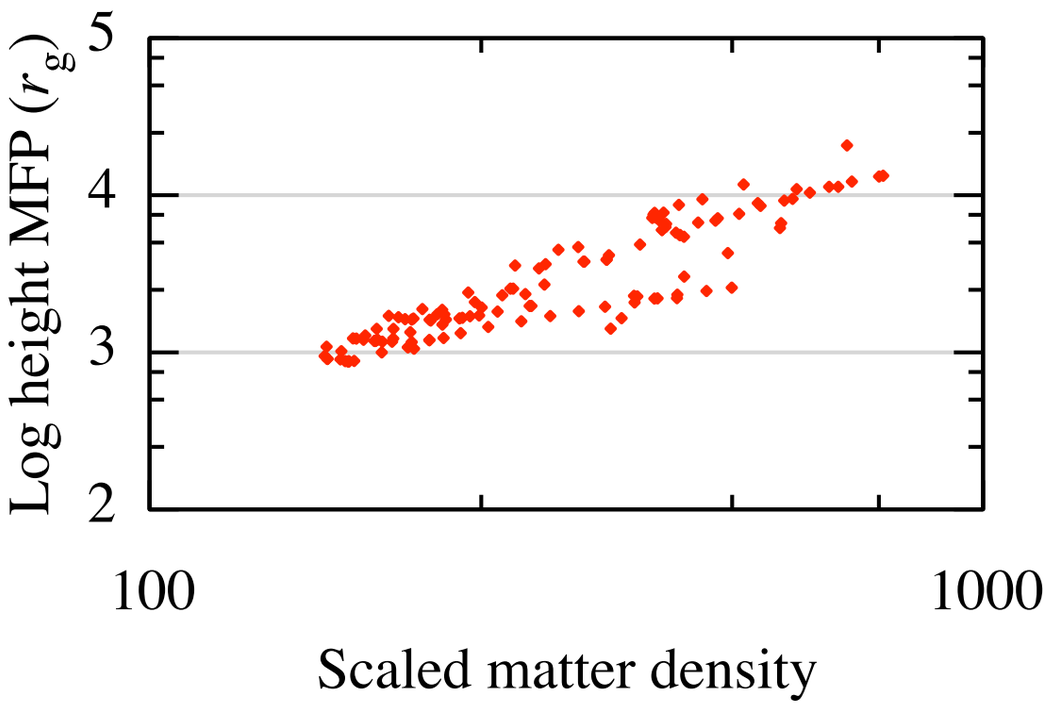

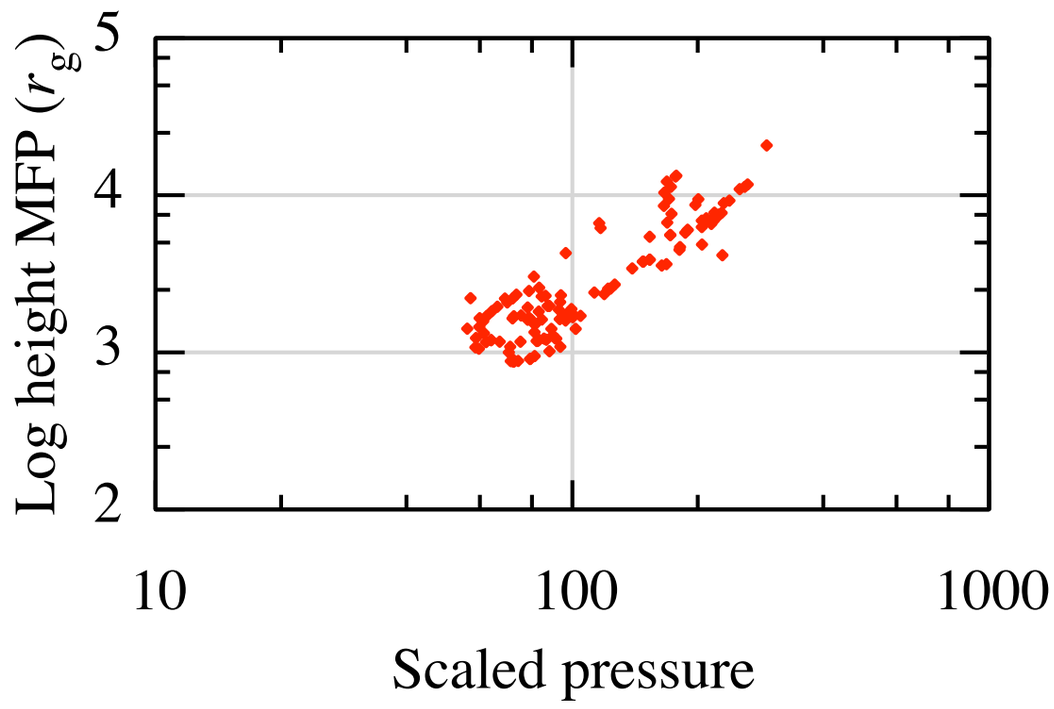

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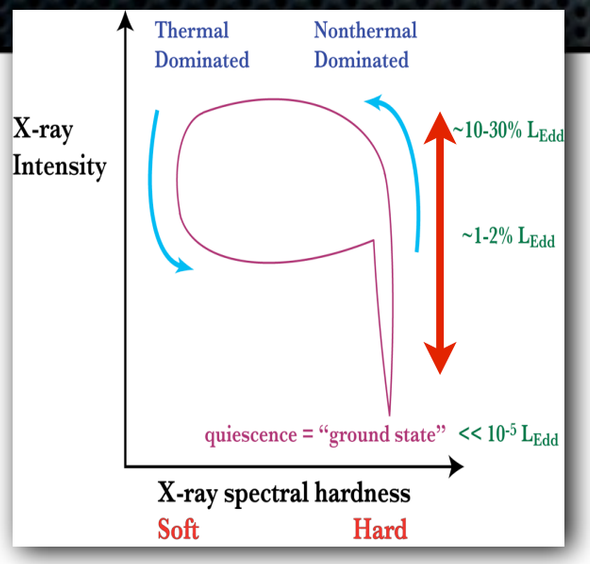
Accretion disk

M_{BH} ~ $10^{7\text{-}10}$ $M_\odot$
$10^{4\text{-}6}$ yrs!

M_{BH} ~ 10 $M_\odot$
1 day

Mass/power scalings (XRB ⇔ FRI/BL Lac)
The "Fundamental Plane" of BH accretion



(SM ea. 2003; Heinz & Sunyaev 2003; Merloni, Heinz & diMatteo 2003; Falcke, Körding, SM 2004; SM 2005; Körding et al. 2006; Plotkin, SM, Kelly, Körding & Anderson 2012)

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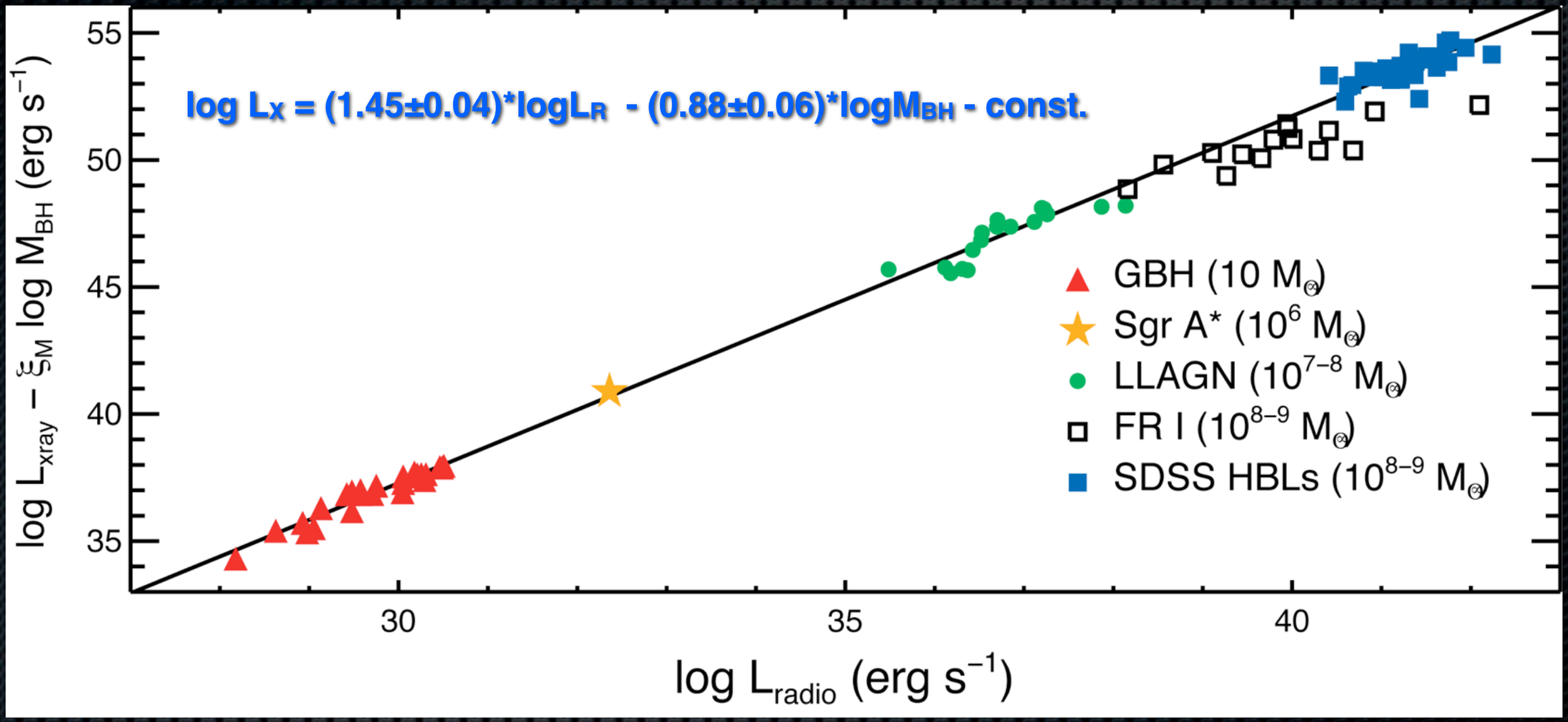
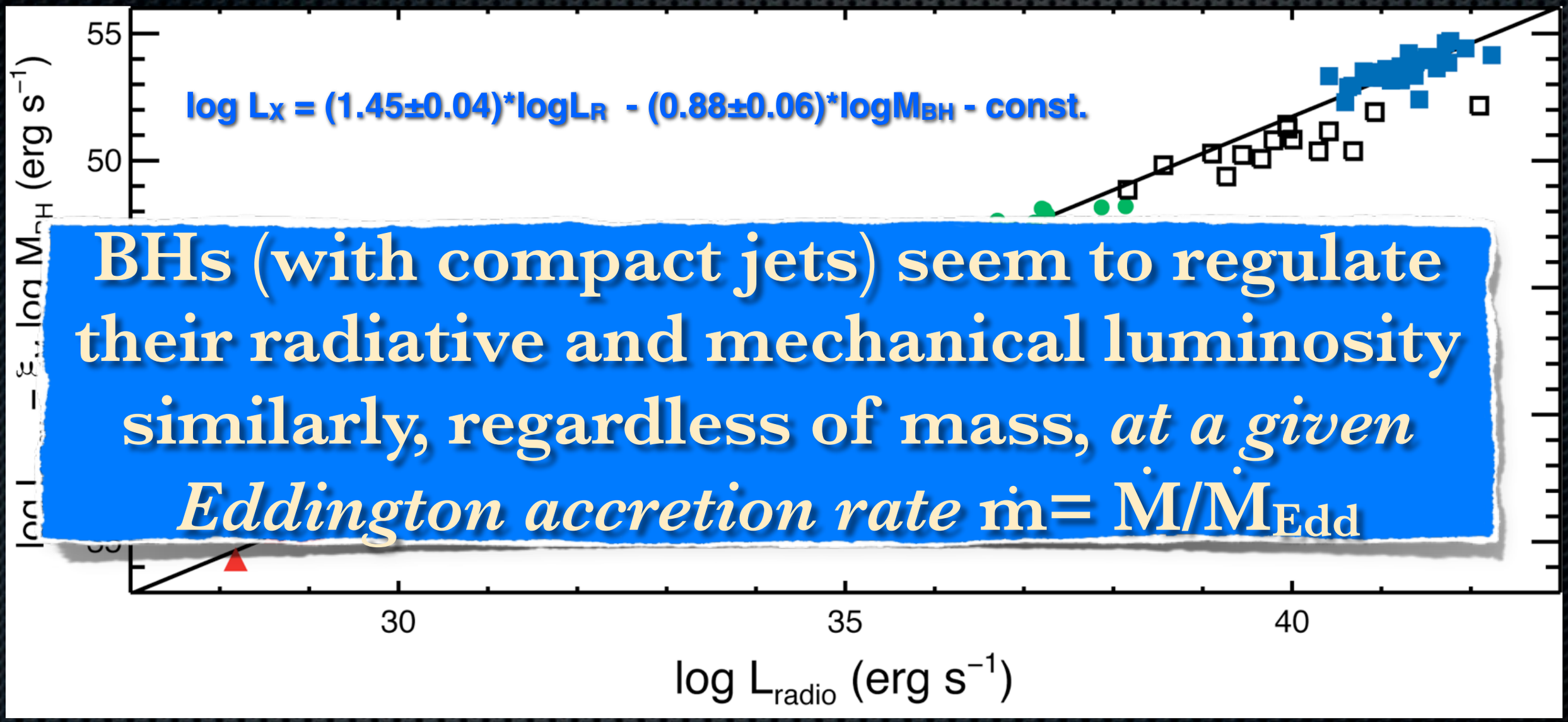


(SM ea. 2003; Heinz & Sunyaev 2003; Merloni, Heinz & diMatteo 2003; Falcke, Körding, SM 2004; SM 2005; Körding et al. 2006; Plotkin, SM, Kelly, Körding & Anderson 2012)

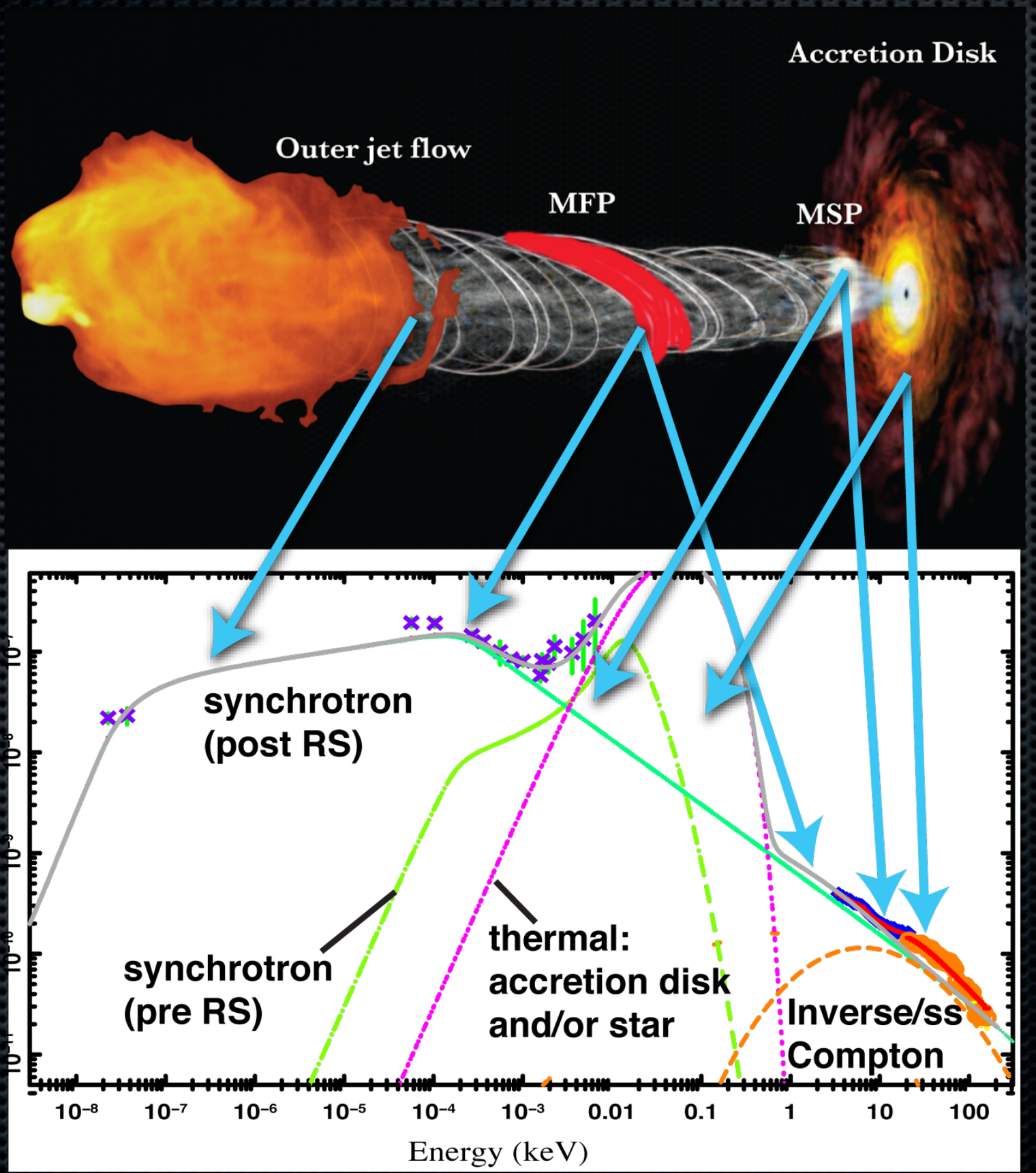
Mass/power scalings (XRB ⇔ FRI/BL Lac)
The "Fundamental Plane" of BH accretion



BHs (with compact jets) seem to regulate their radiative and mechanical luminosity similarly, regardless of mass, *at a given Eddington accretion rate* $\dot{m} = \dot{M}/\dot{M}_{Edd}$

(SM ea. 2003; Heinz & Sunyaev 2003; Merloni, Heinz & diMatteo 2003; Falcke, Körding, SM 2004; SM 2005; Körding et al. 2006; Plotkin, SM, Kelly, Körding & Anderson 2012)

Schematic of "BL Lac" like state in XRBs



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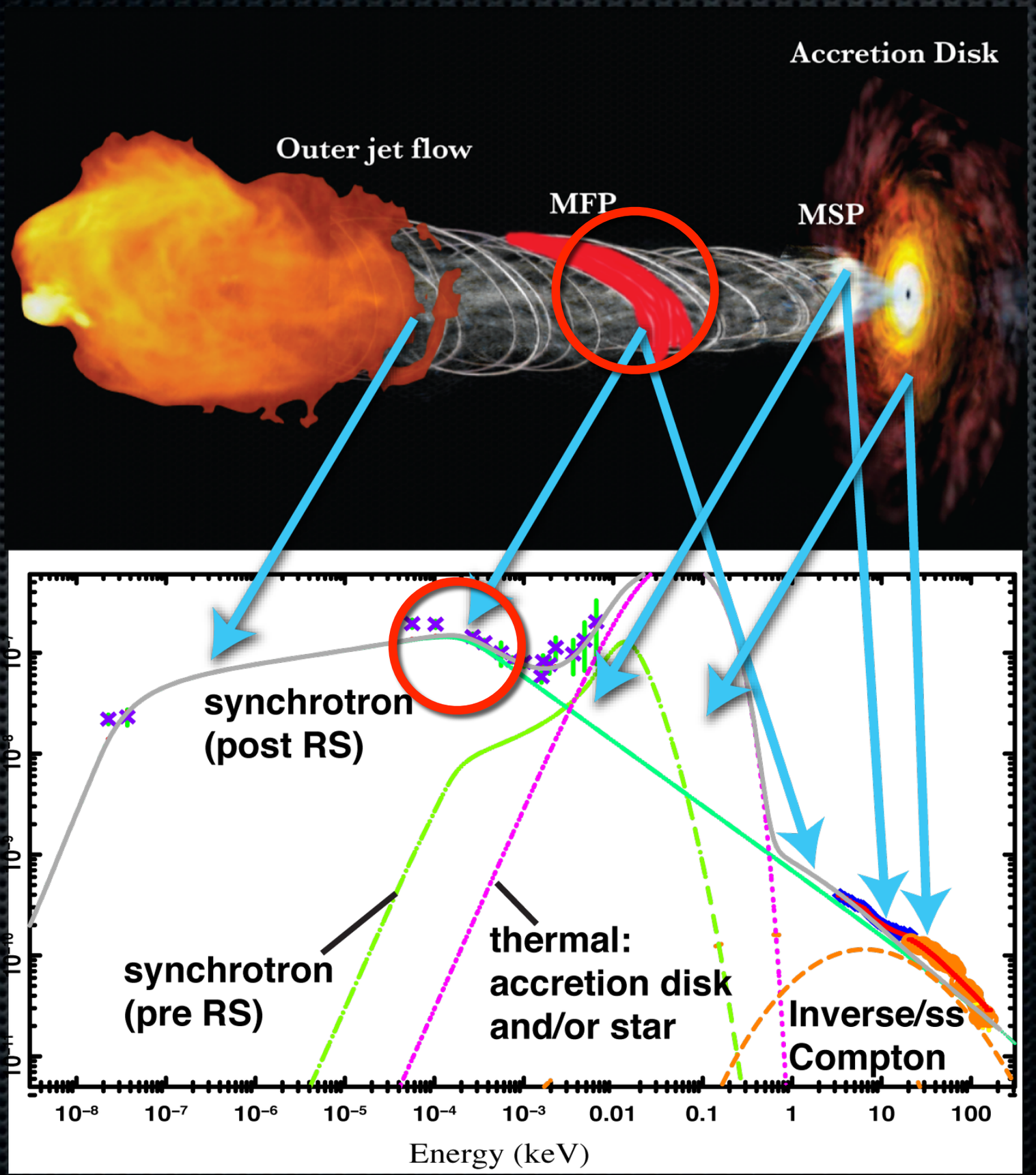
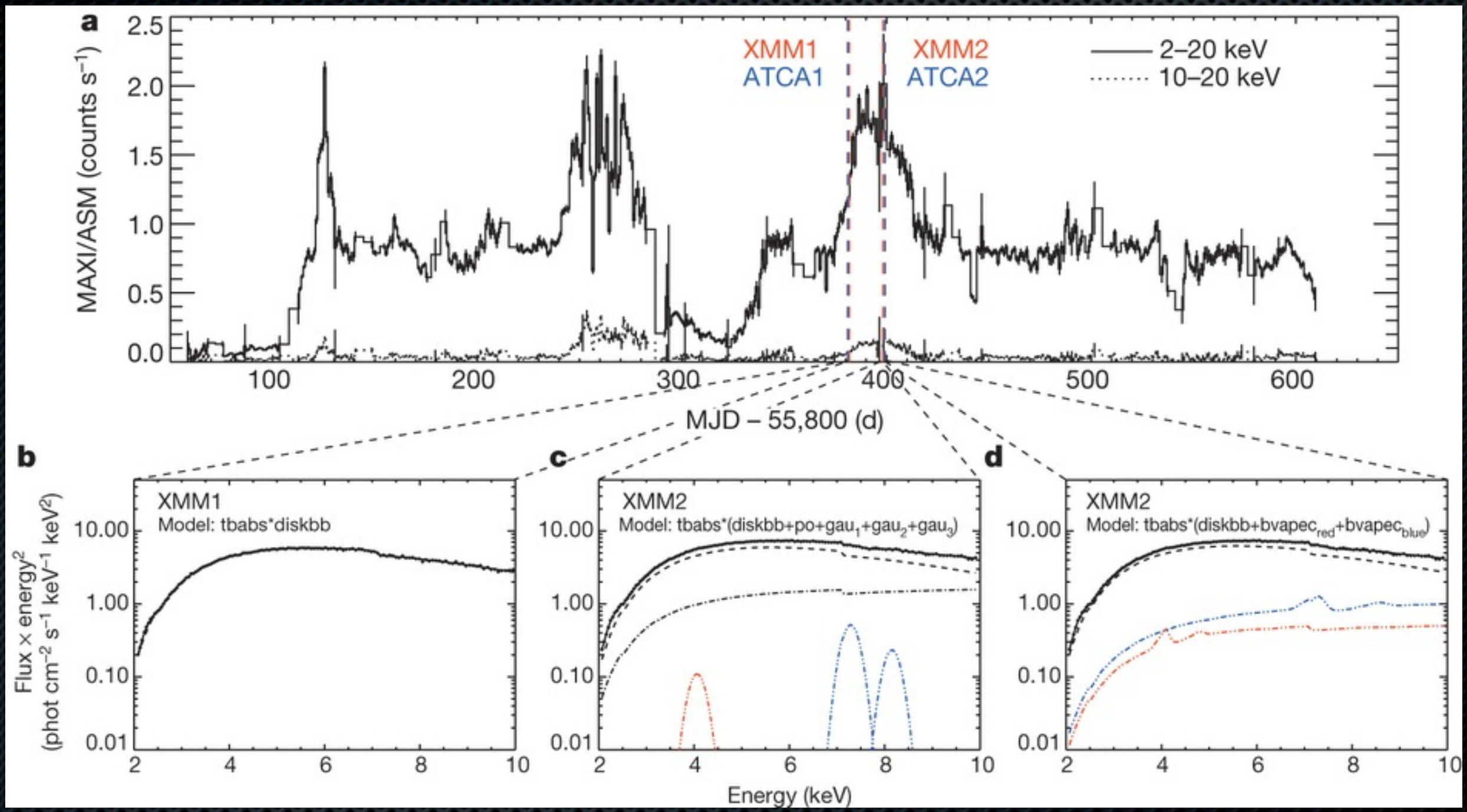
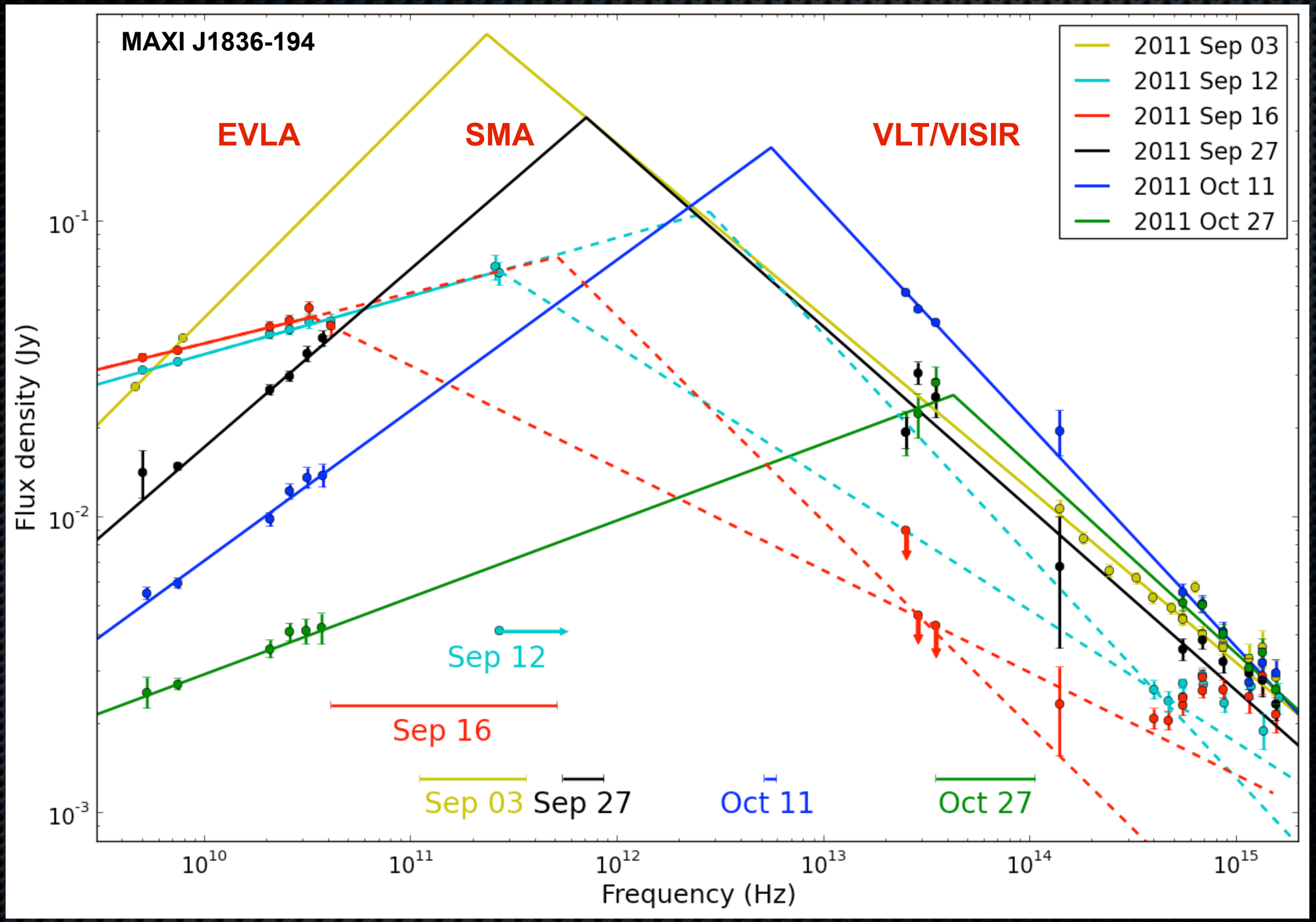


Plus (new!): hadrons discovered in XRB jets!



(Diaz Trigo et al. 2013; Nature)

Simultaneous MW spectra ➠ jet break evolution



(D.Russell et al. 2013ab; T. Russell et al. 2014)

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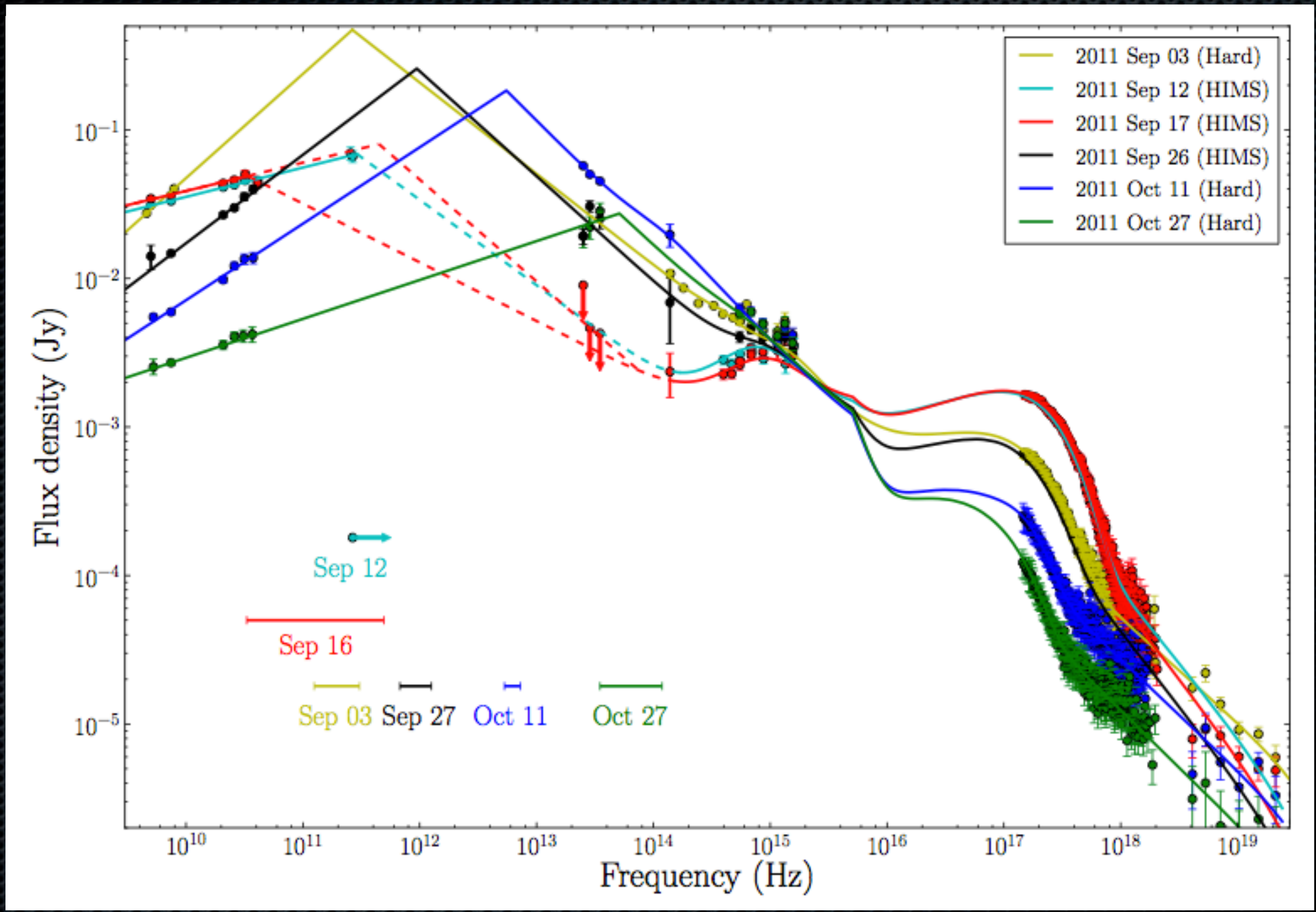

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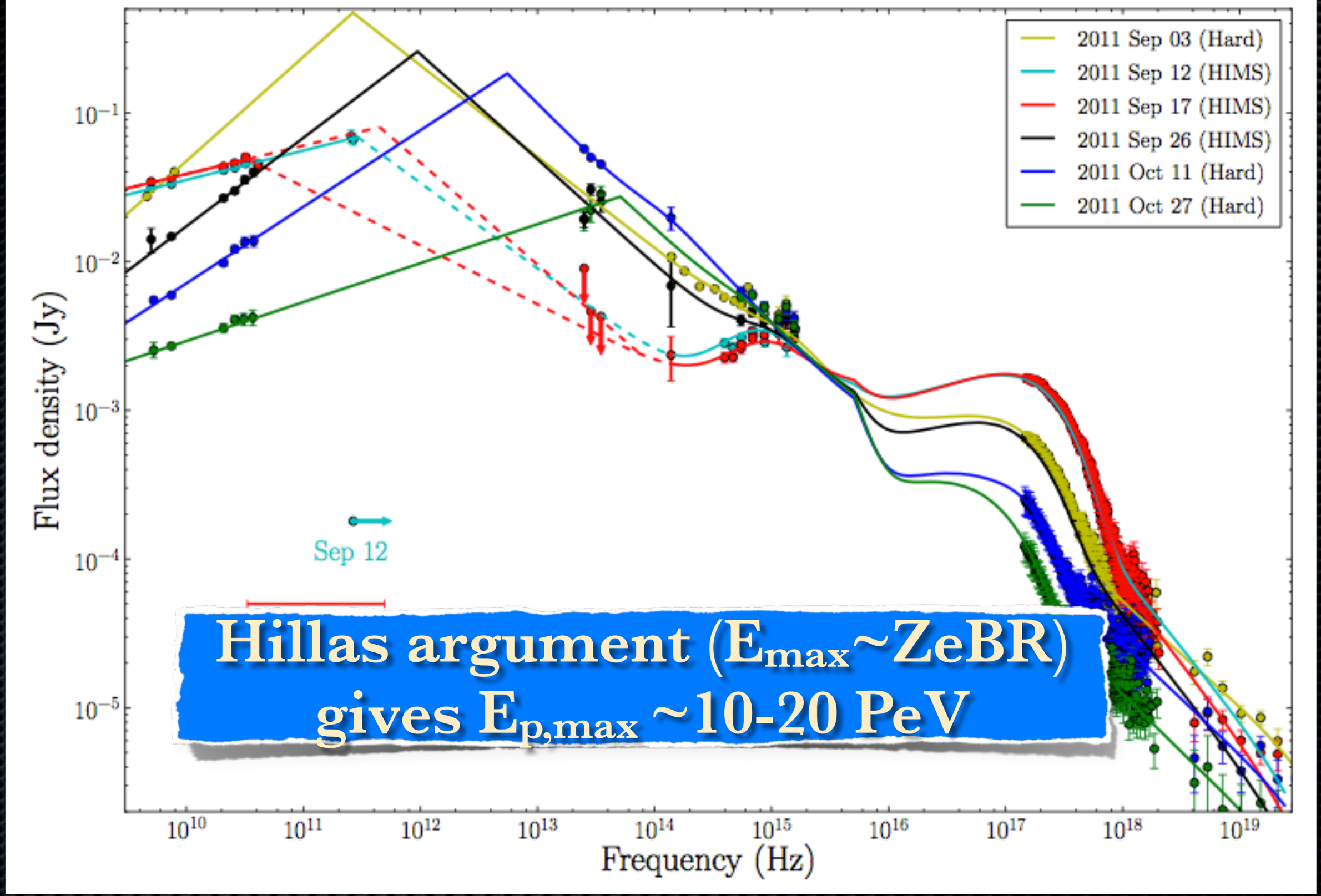

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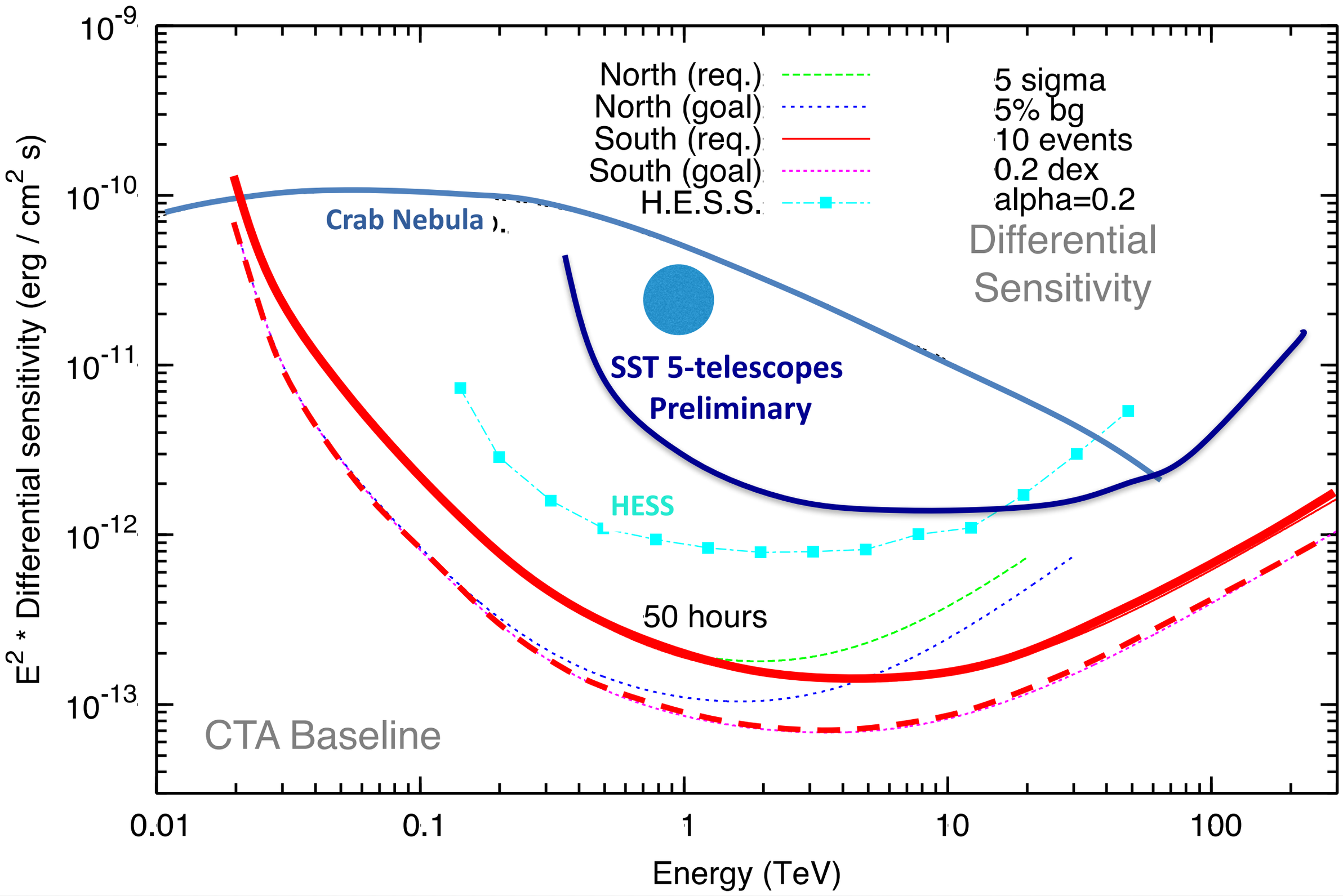
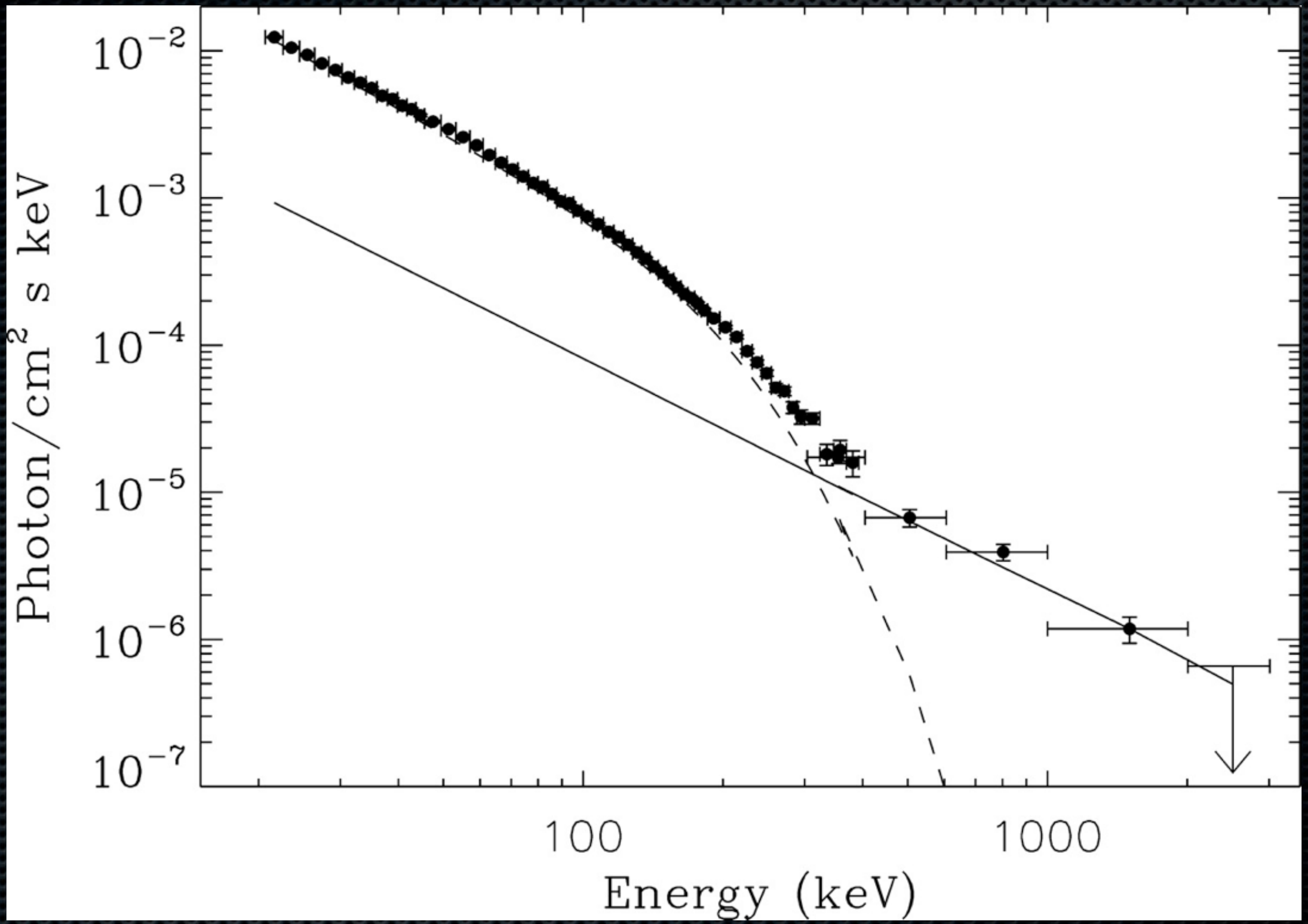
System Sensitivity



First forays into γ-ray detections of XRBs: Cyg X-1



(Laurent et al. 2011; Jourdain et al. 2012)

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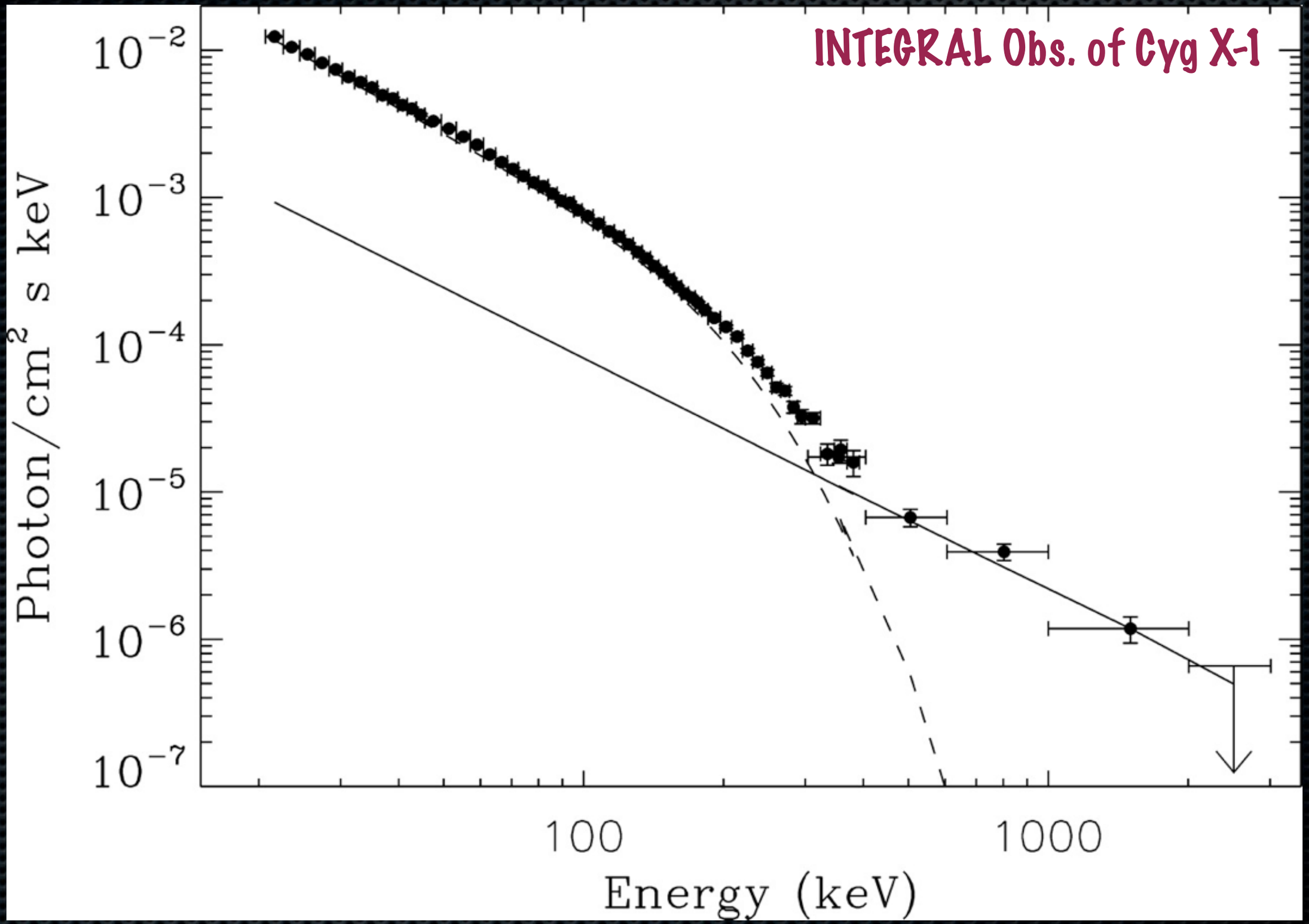

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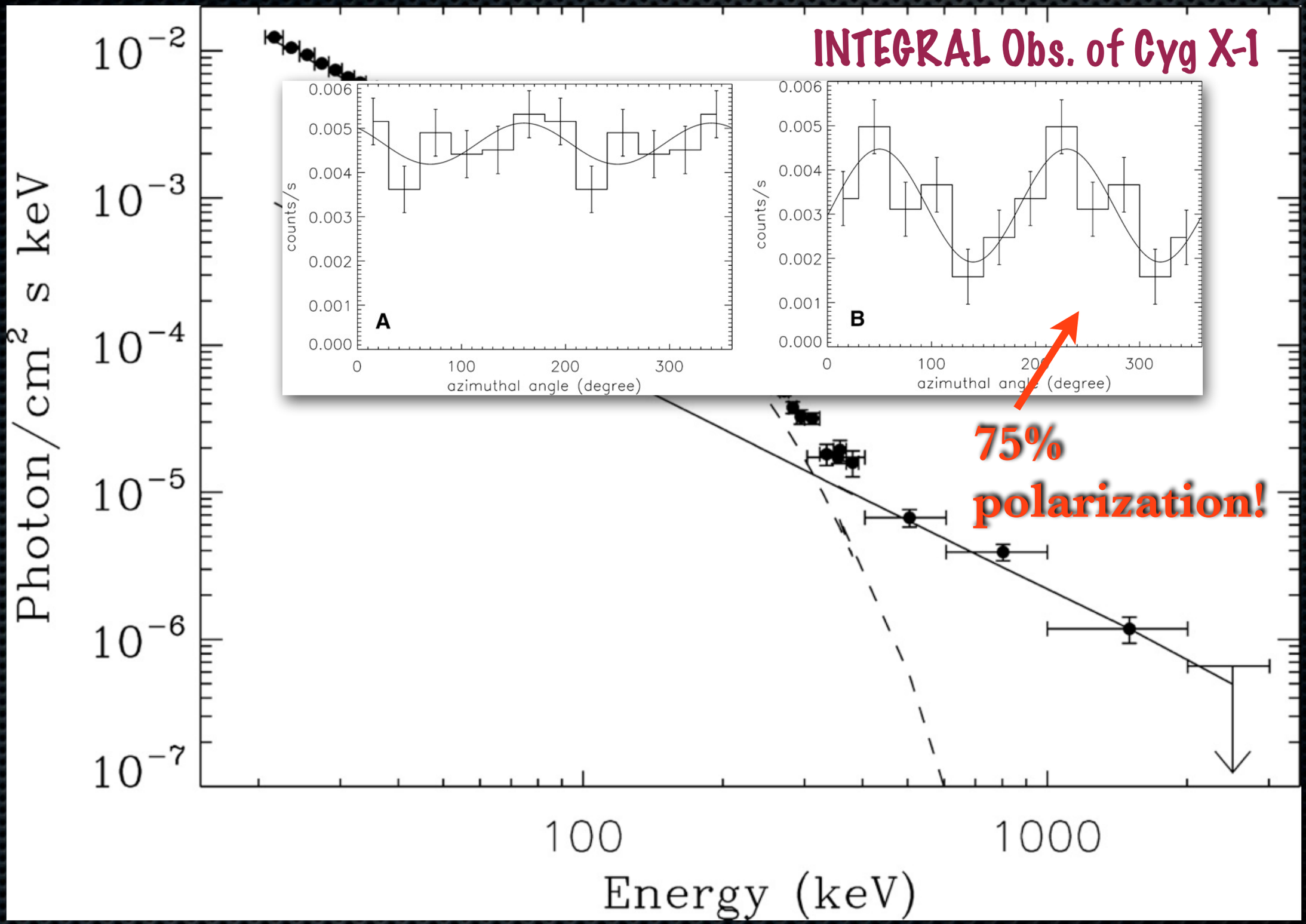

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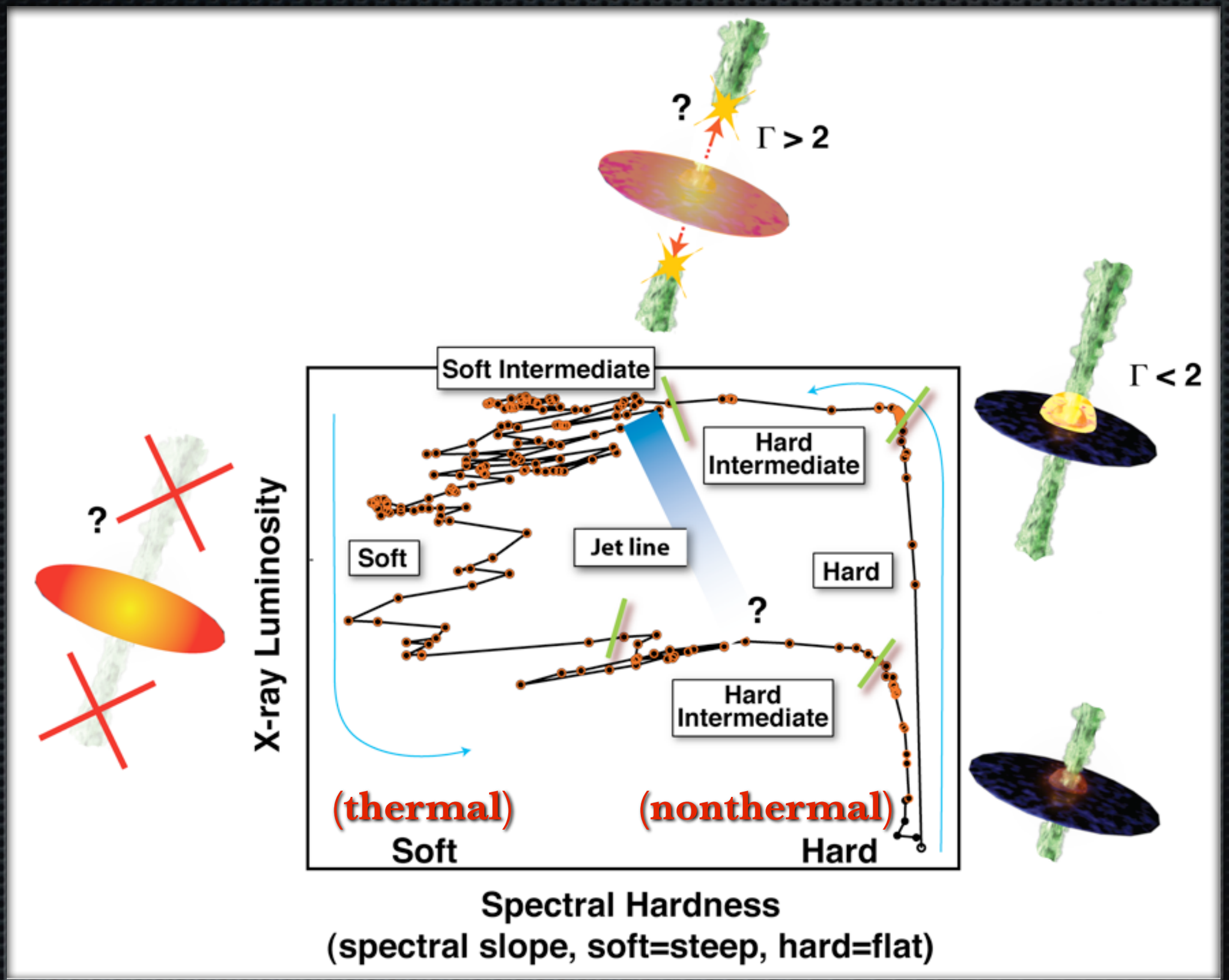
Time variable XRB behavior: The HID

Different forms of outflows: jets, winds or nothing



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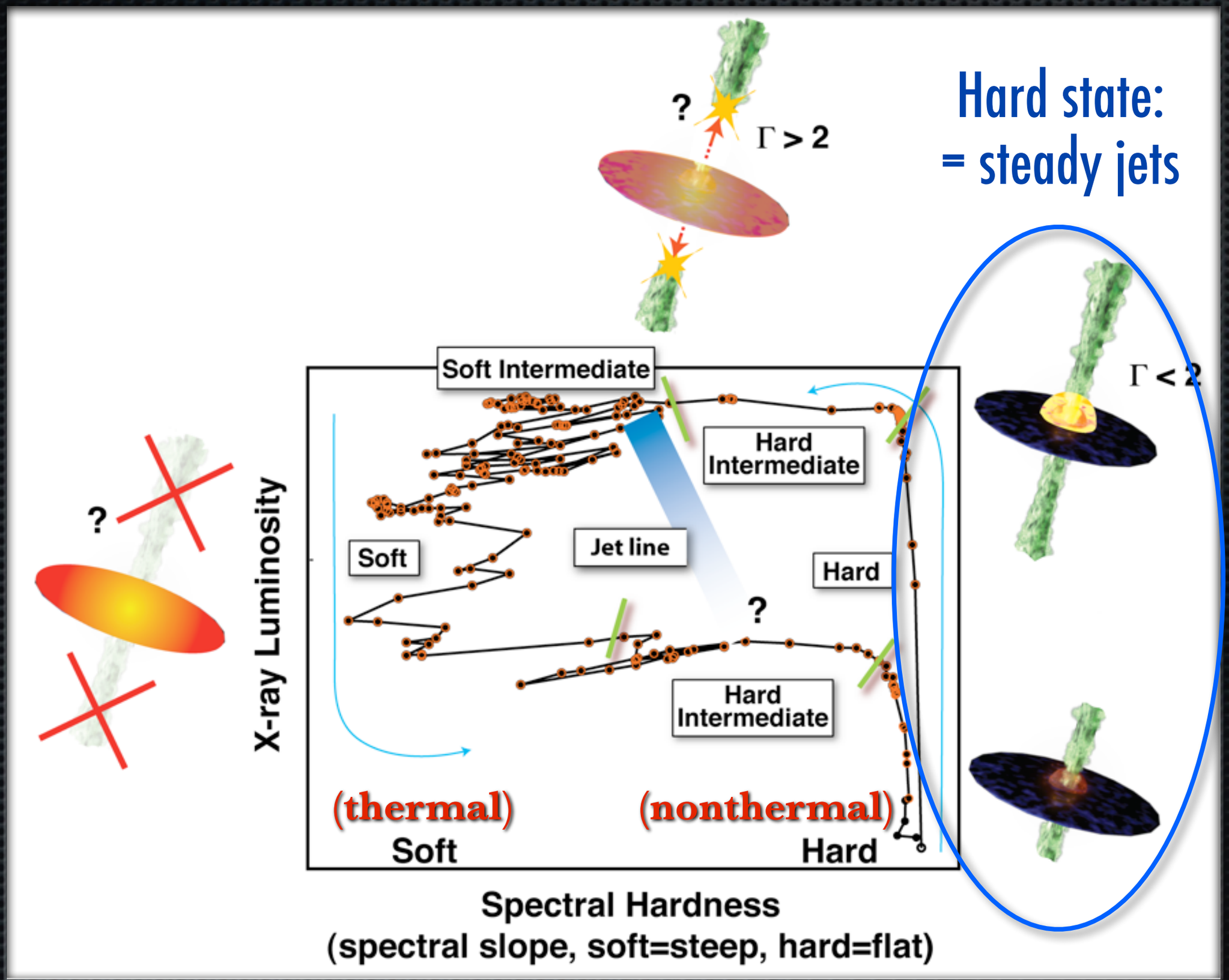

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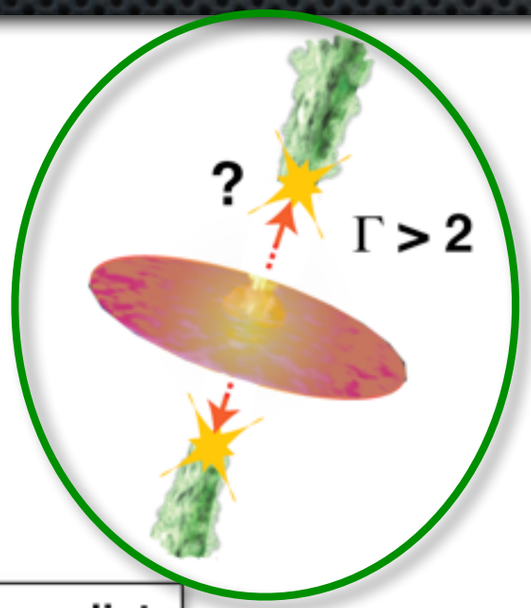
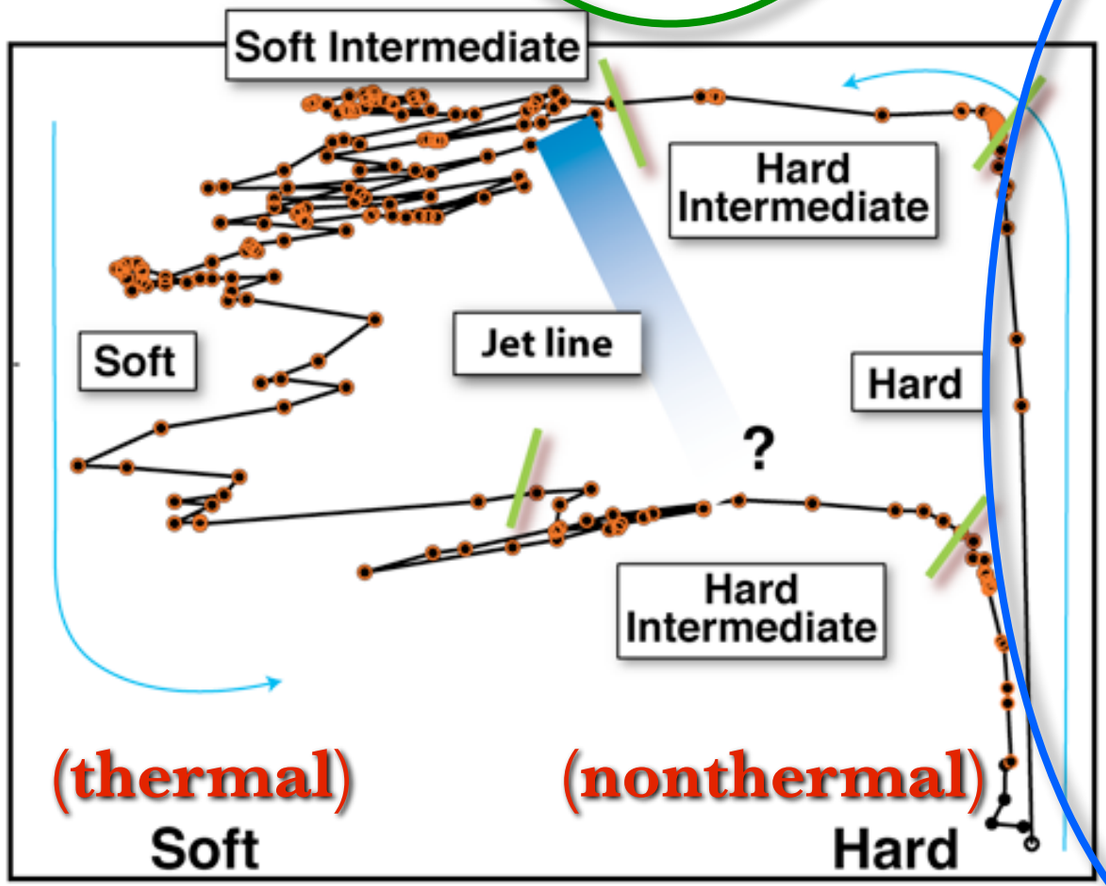
HIM/SIM transition
= ballistic jets



Hard state:
= steady jets



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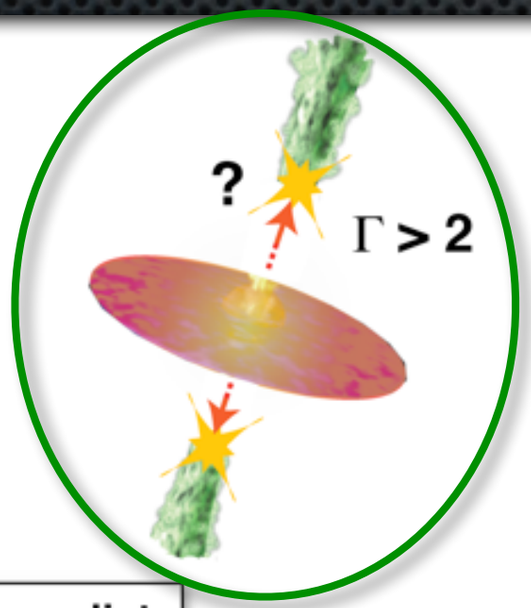
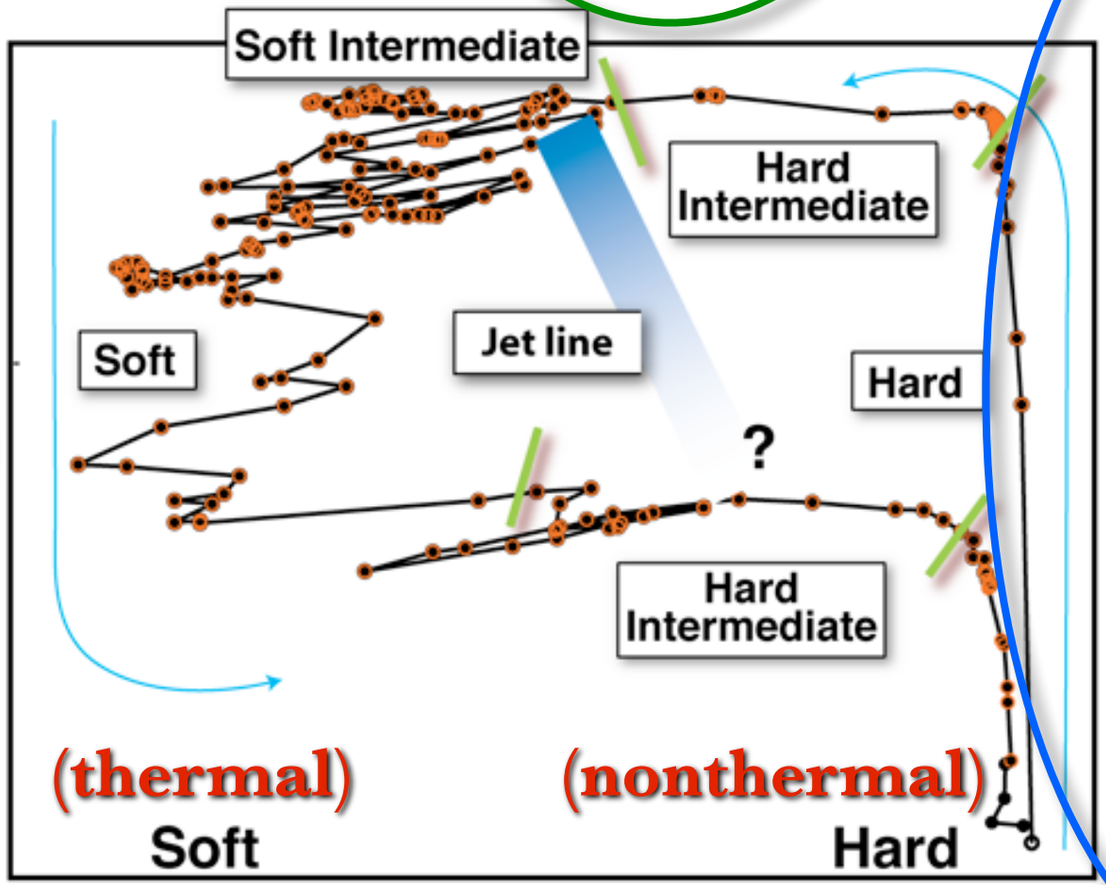
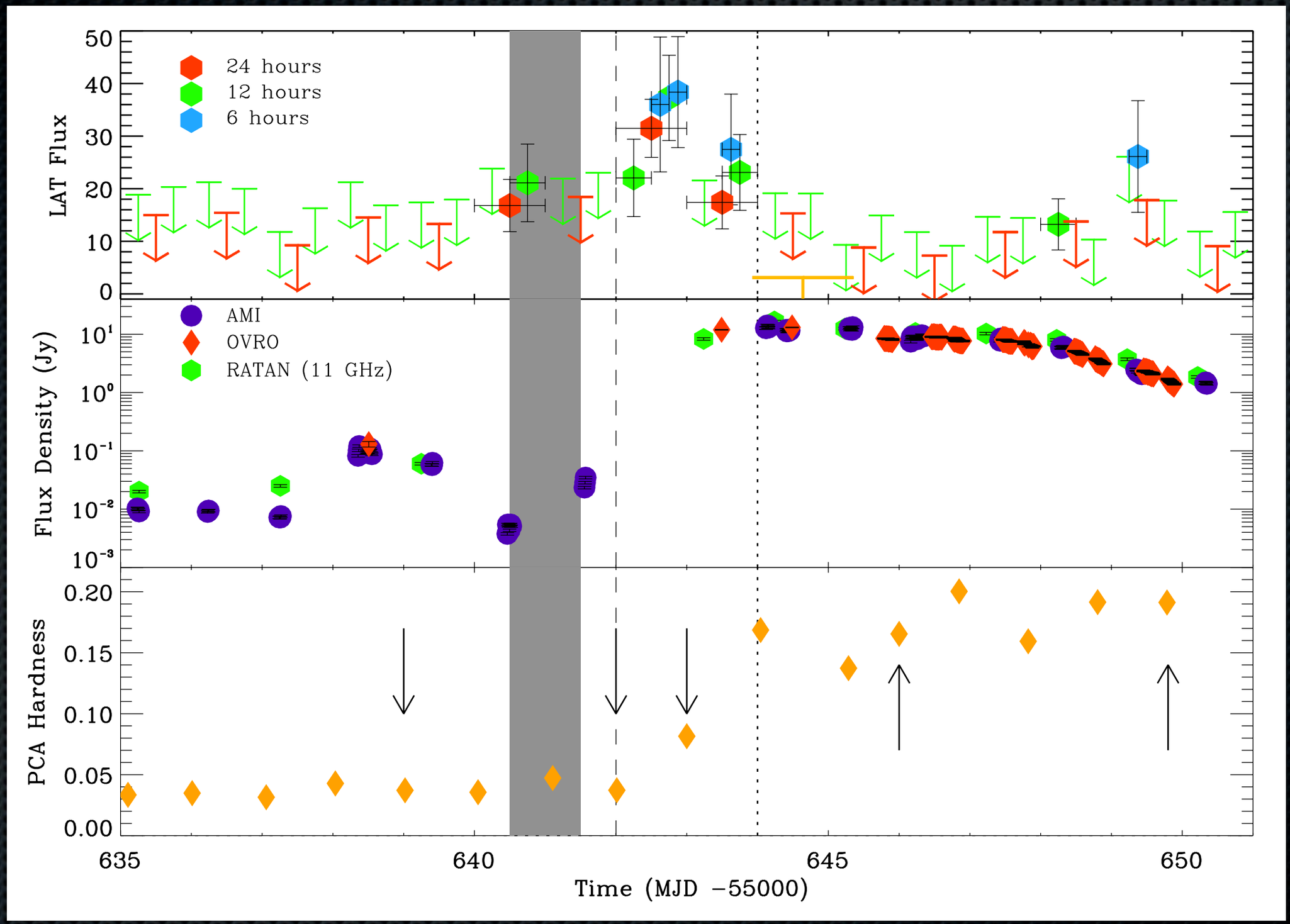


Hard state:
= steady jets

Soft state:
= no jets? winds

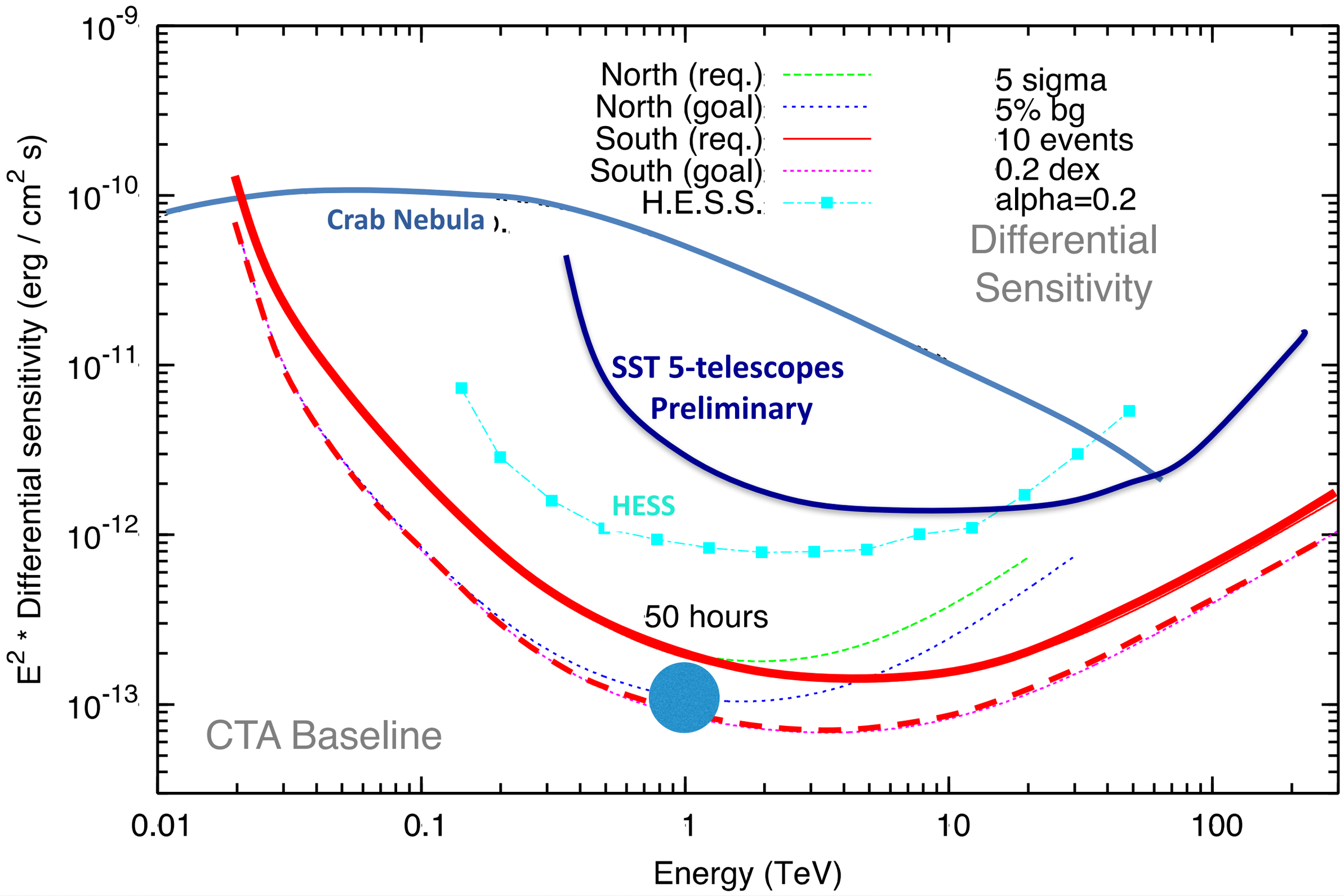


Cyg X-3: radio/GeV γ-ray flares (Fermi/AGILE)



(FERMI; Corbel et al. 2012)

System Sensitivity



Summary & Outlook

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- XRBs reveal the coupling between jet powering and particle acceleration: we see buildup from launch to onset of particle distribution, can localize acceleration regions ☛ key constraints for physical models, relevant to BL Lacs because of "Fundamental Plane"
- Potential for XRBs with CTA still not fully explored, particularly w/r/t multiwavelength monitoring and triggering: few γ-ray flares seen accidentally, need to start defining campaigns with HESS-2 as lead-up. We can get involved already by interfacing with HESS-2 Galactic folk!!
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- Outlook:
  - Improved models: implementing hadronic processes(S. Drappeau), new MHD+gravity jet flow solutions (C.Ceccobello)
  - Early Science: We should be thinking of how we can effectively engage the mini-array in transient studies, especially given upcoming "transient factories" coming online by 2016
  - Galactic populations: Eventually can use CTA survey results to characterise XRB contribution to Galactic CRs, effects on ISM, etc.