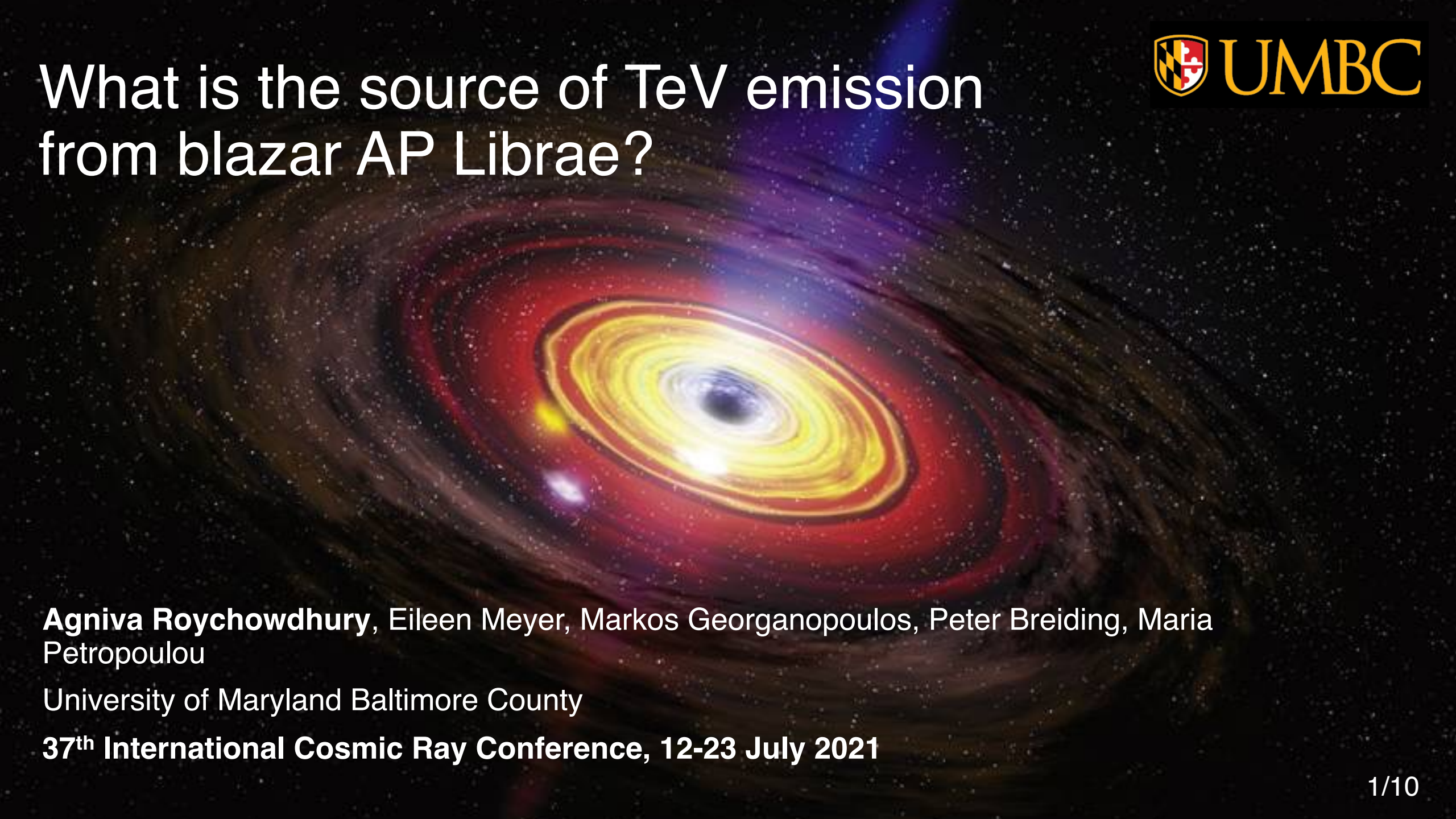
What is the source of TeV emission from blazar AP Librae?



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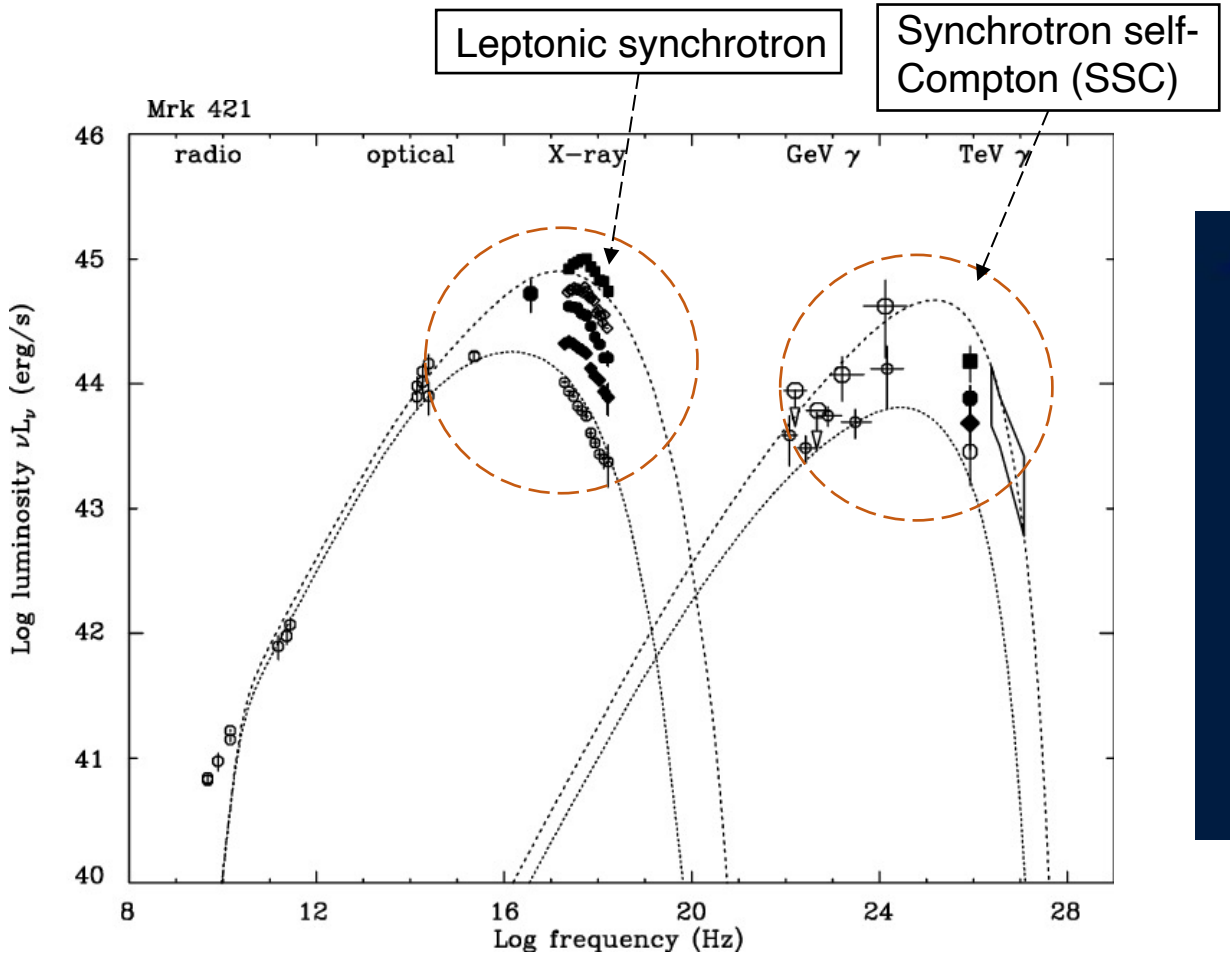
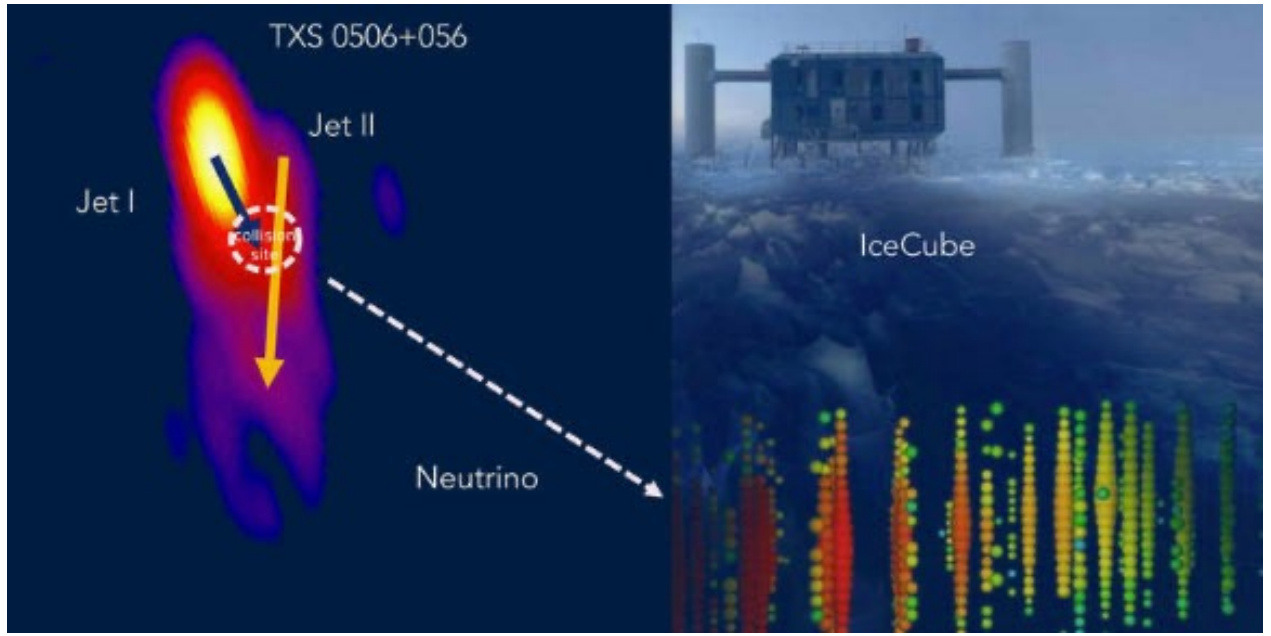
Blazars, neutrinos and cosmic rays



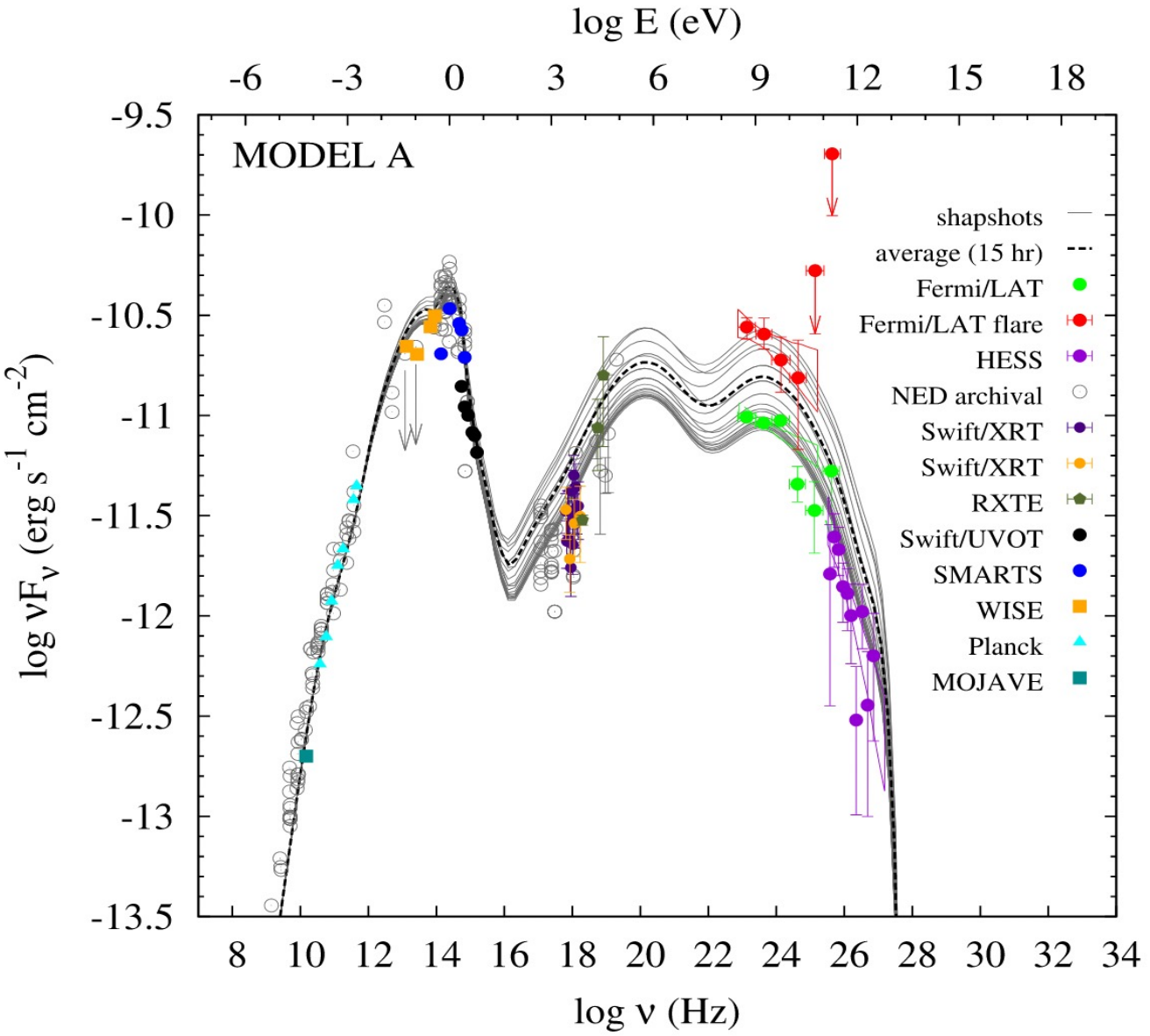
Archetypal blazar Markarian 421



TXS 0506+056: source of neutrinos → particle acceleration to millions of TeV?

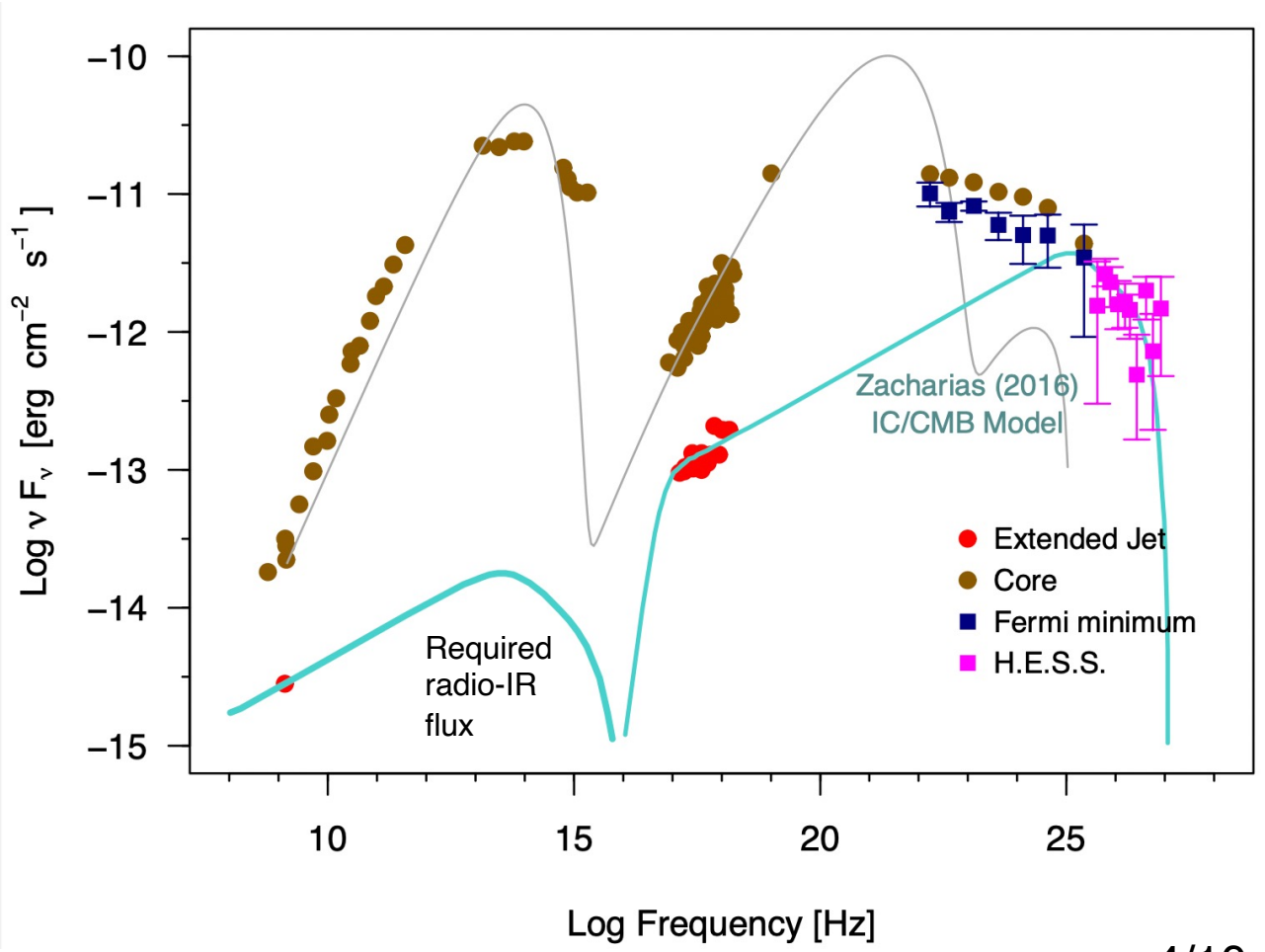
The unusual spectrum of AP Librae

- Spread through 20 decades in energy.
- Origin of VHE emission unknown: one-zone synchrotron self-Compton models not viable.
- Zacharias+, Sanchez+ 2016: inverse Compton scattering of Cosmic Microwave Background photons in the kpc-scale jet ("IC/CMB"): multi-TeV electrons, equipartition field and near Eddington jet power.
- Hervet+ 2015. pc-scale blob-in-a-jet model: leptonic radiation but super-Eddington jet powers dominated by protons.
- Petropoulou+ 2016. Photohadronic processes in the core: 10-100 times Eddington power, radiation dominated by 1000 TeV protons.



Goal of this work

- Different explanations considerably at variance.
- <u>Goal of this work:</u> test the predictions of the Zacharias +16 IC/CMB model.
- Analyzed radio (VLA/ALMA) to IR (HST) data for the extended jet.
- Analyzed 12 years of Fermi data of AP Librae.

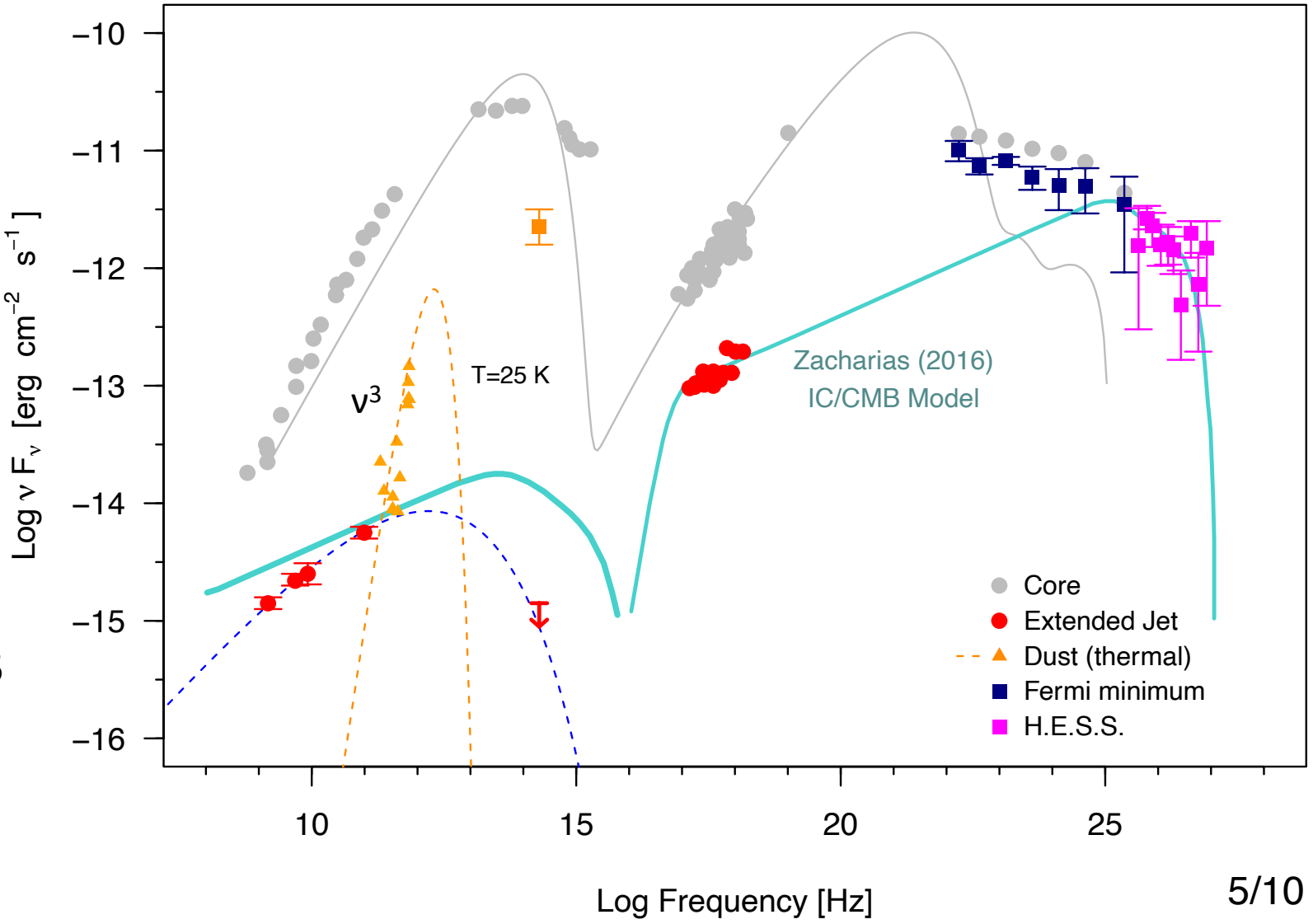


IC/CMB for TeV emission: not viable

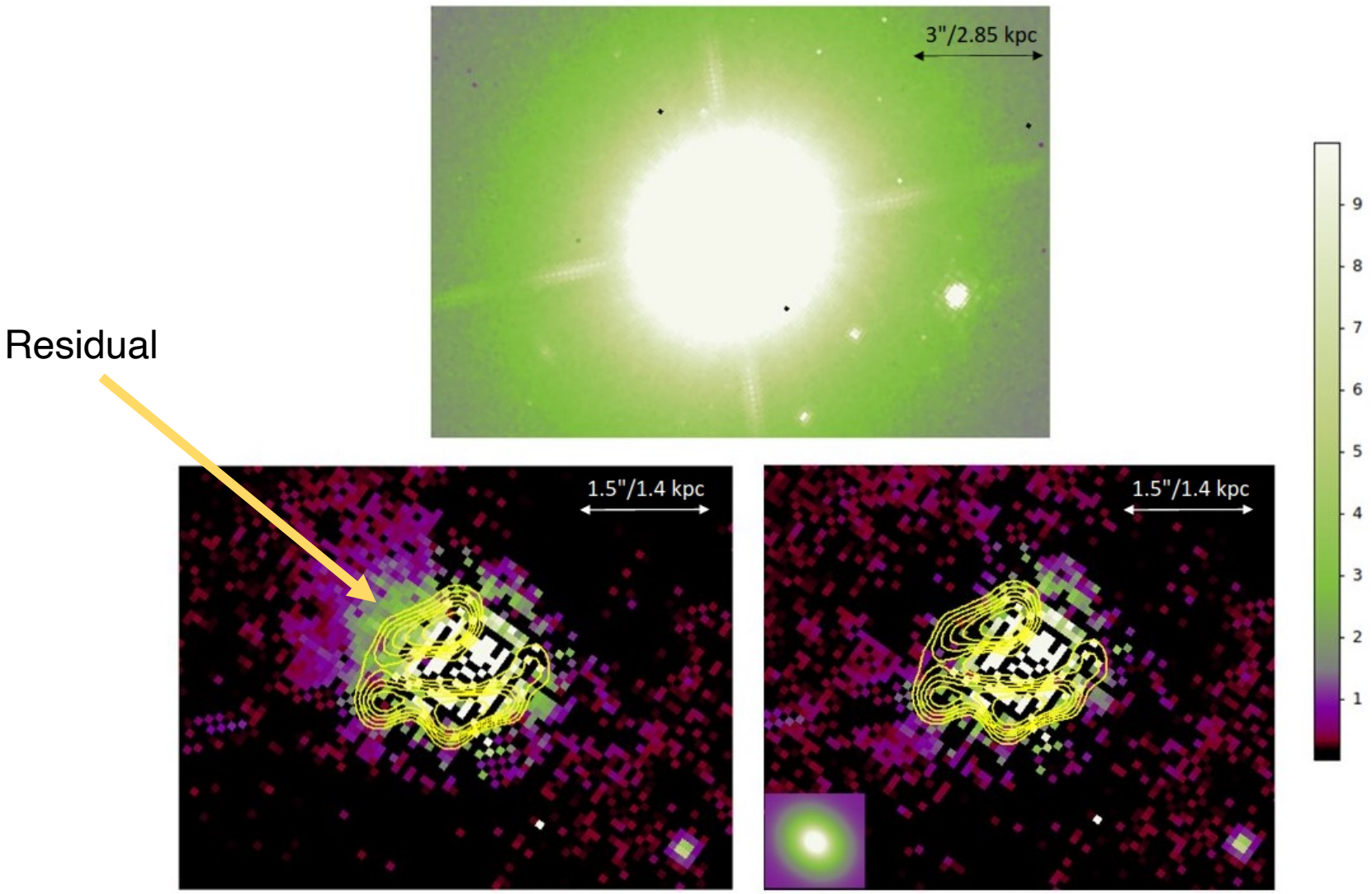
$$\frac{\nu_c}{\nu_s} = \frac{\nu_{\rm CMB}\delta^2\gamma^2}{eB\delta\gamma^2/[2\pi m_e c(1+z)]}$$

$$\frac{L_c}{L_s} = \frac{32\pi U_{\rm CMB}(1+z)^4\delta^4}{3(B\delta)^2}$$

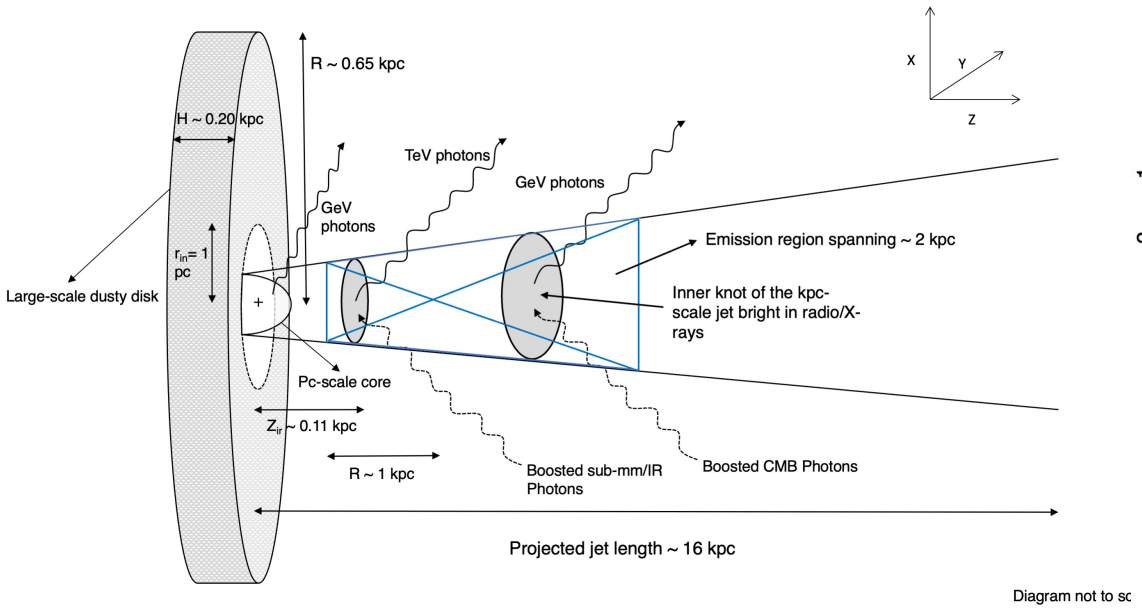
Georganopoulos+ (06), ApJL, 653, L5

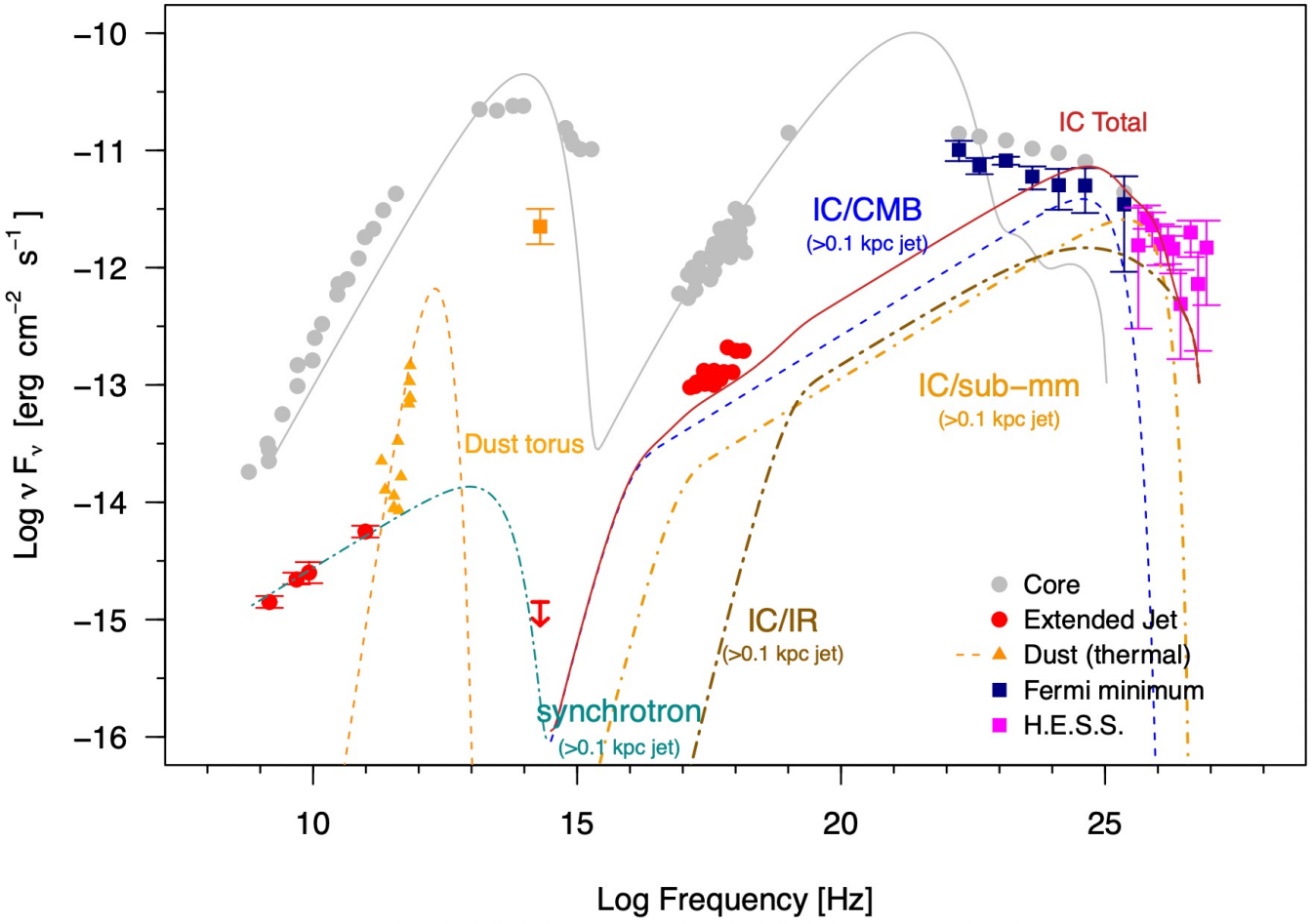


Observing the thermal excess using HST



>100 GeV emission: IC/CMB
TeV emission: IC/Dust



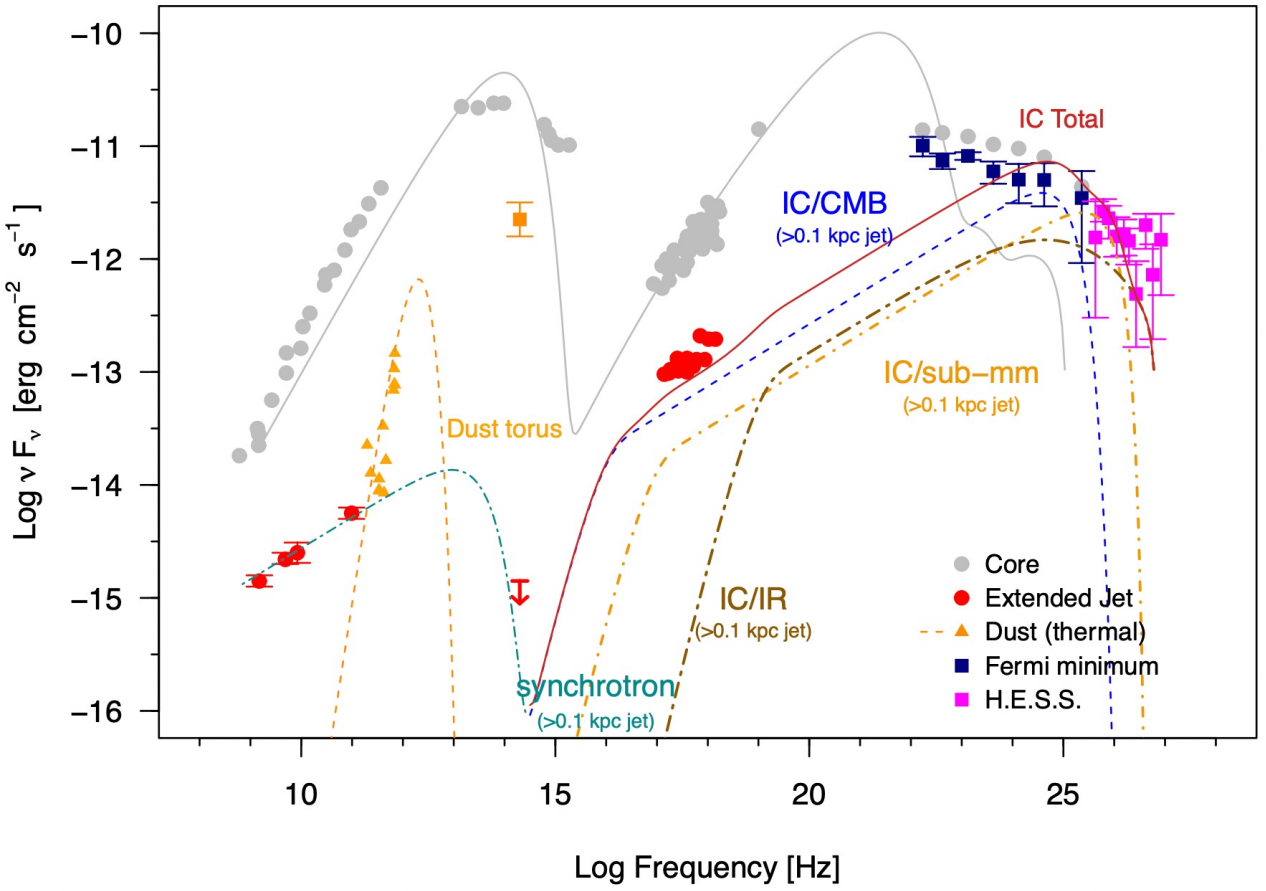


- De-projected location of TeV emission (0.4-0.8 kpc) > 5 times width of the torus (0.1 kpc).
- Immune to γ-γ pair production opacity.
- TeV emission from pc-scale core can be ruled out ($\tau_{\gamma\gamma}$ >> 1 for the sub-pc jet, Blandford 1993).

Roychowdhury et al. (in prep)

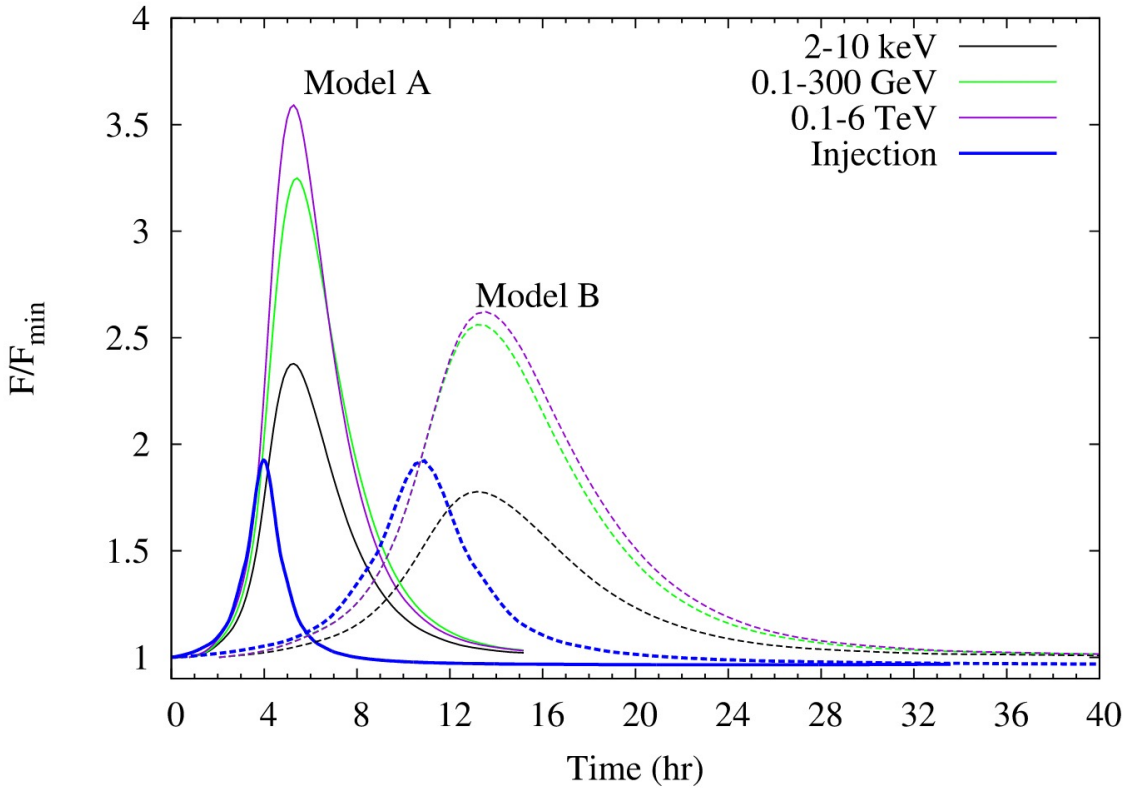
Where does our model stand?

- Plausible explanation of TeV emission is IC/Dust in the >100 pc jet.
- Purely leptonic model: but requires continual acceleration through ~ 1 kpc in de-projected length.
- Uses the least number of model parameters compared to previous studies.
- Max electron energies ~ 100 GeV.
- Requires sub-Eddington jet luminosity (lower limit to total jet power).
- Magnetic field in the extended jet close to equipartition.



Possible future directions

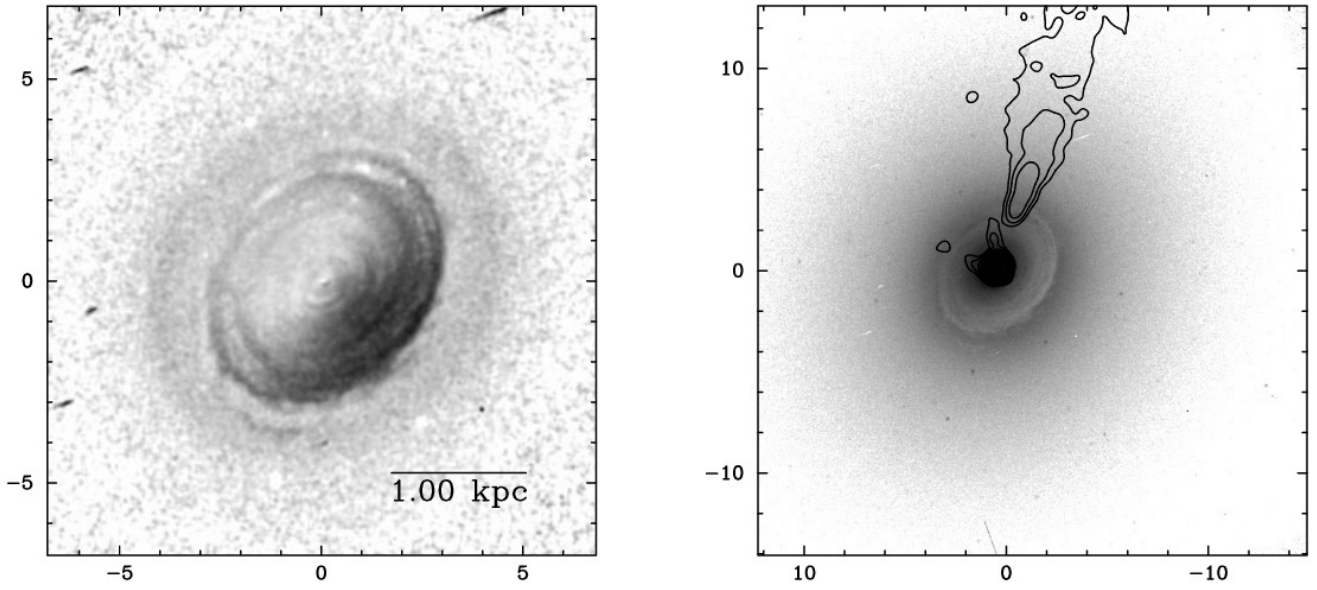
- IC/Dust (sub-mm to IR) in the sub-kpc jet is responsible for the TeV emission.
- IC/CMB is responsible for the GeV emission.
- Test(s): check variability in the >100 GeV band with upcoming Cherenkov Telescope Array (CTA).
- Constrain optical/IR synchrotron spectrum with deeper JWST observations.
- Re-observing with Fermi to further constrain GeV spectral shape.



Simulated light curves from photo-hadronic models (Petropoulou+ 2016): open to tests using Chandra, Fermi, CTA.

Global implications of a CND/sub-kpc torus in a BL Lac

- Kpc-scale CND/dust-lanes routinely observed in radio galaxies (e.g., de Koff+ 2000, ApJSS, 129, 33).
- BL Lacs – lineless or weak-lined spectrum, weak accretion and weak jets.
- No observational evidence of pc-scale tori in BL Lacs (Plotkin+ 2012).
- Are some BL Lacs in the strong accretion regime? (Keenan+ 2021)
- Follow up with deep spectral line observations using ALMA and JWST.



Radio Galaxy 3C 31.
Left: Absorption map; Right: HST image.
(de Koff+ 2000)