AP Librae's unusual SED — VHE emission from an extended jet?

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Abstract

AP Librae is classified as an LBL. Hence, the detection of VHE gamma radiation from this source reveals an unusually broad inverse Compton component spanning over 10 orders of magnitude in energy. This cannot be explained by a one-zone leptonic model. Furthermore, an extended X-ray jet was discovered with a clear inverse Compton origin. *These observations may point to the extended jet as the origin of the VHE emission*.

Extended X-ray jet [5]

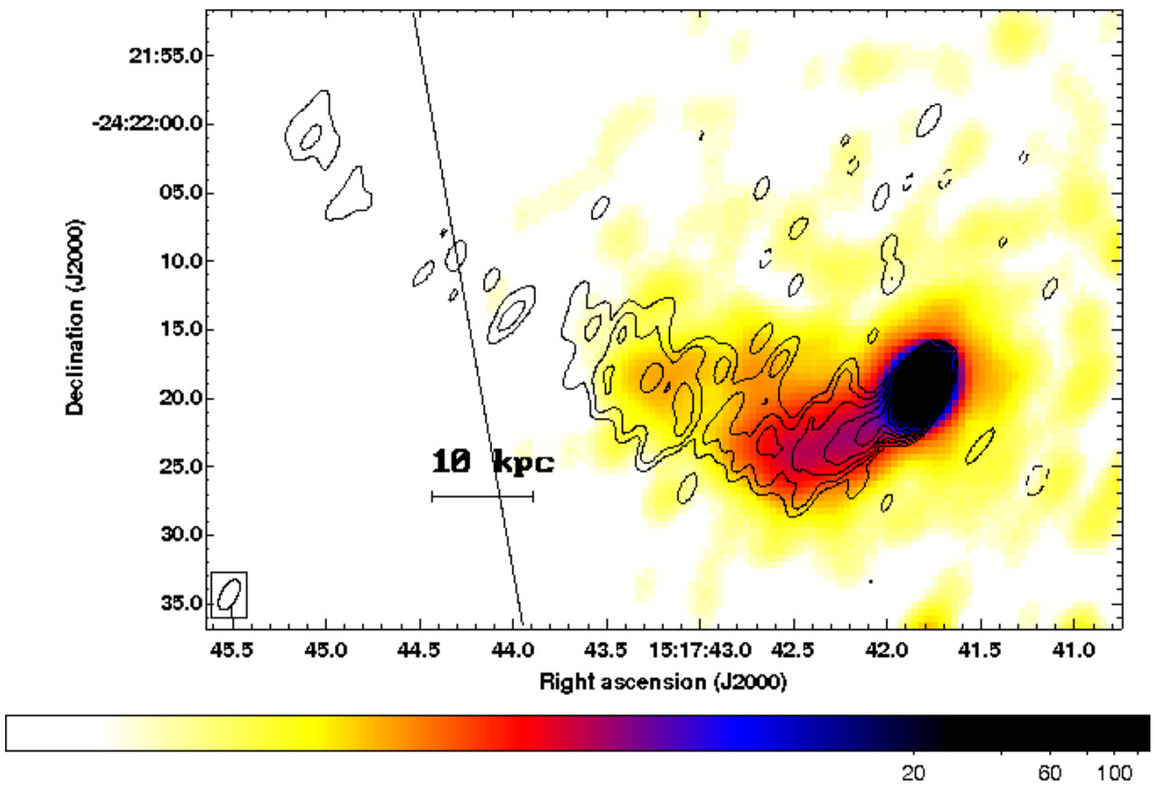

Figure 1 : Smoothed X-ray count map ($0.2 - 8$keV) of Chandra/ACIS observations and VLA radio contour plot (A+B configuration, 1.36GHz).

- X-ray and radio morphology perfectly consistent: a "kpc-core" + extended jet feature ("kpc-jet")
- X-ray spectral slope implies inverse Compton origin
- Extrapolation intersects Fermi spectrum at the break

VHE detection with H.E.S.S. [3]

- Inverse Compton (IC) component covers more than 10 orders of magnitude in energy
- Synchrotron component cuts off far below X-rays
- Electrons responsible for synchrotron cannot account for VHE
- $\Rightarrow$ AP Librae cannot be modeled with a one-zone model

X-ray core spectrum [5]

- Swift/BAT point in straight continuation of the Chandra spectrum ($\nu F_\nu \propto \nu^{0.4}$)
- Swift/BAT is a 105-months average and not influenced by potential flares
- The steepness of the X-ray spectrum severely constraints γ_1 to $> 10^2$ due to curvature in the SSC spectrum
- $\Rightarrow$ Synchrotron spectrum cannot be modeled by a single zone

MOJAVE observations [7]

- "kpc-core" resolved with VLBA at 15GHz into a steady "Component 0" and several moving knots ("pc-jet")
- "Component 0" flux marked with open diamond in spectrum
- Total MOJAVE flux ("Component 0" + knots) fits perfectly with other radio data
- $\Rightarrow$ Larger structure than "one-zone" responsible for most of radio data
- Superluminal motion ($\beta_{app,max} = 6.4$) restricts $\theta_{obs} = 2^\circ$ for $\Gamma_b = 10$

References

[1] Böttcher, M., et al., 2013, ApJ 768, 54
[2] Cassaro, P., et al., 1999, A&AS 139, 601
[3] H.E.S.S. collaboration, et al., 2015, A&A 573, A31
[4] Hervet, O., et al., 2015, A&A, accepted, arXiv:1503.01377
[5] Kaufmann, S., et al., 2013, ApJ 776, 68
[6] Kühr, H., et al., 1981, A&AS 45, 367
[7] Lister, M.L., et al., 2013, AJ 146, 120

Spectrum and Fit

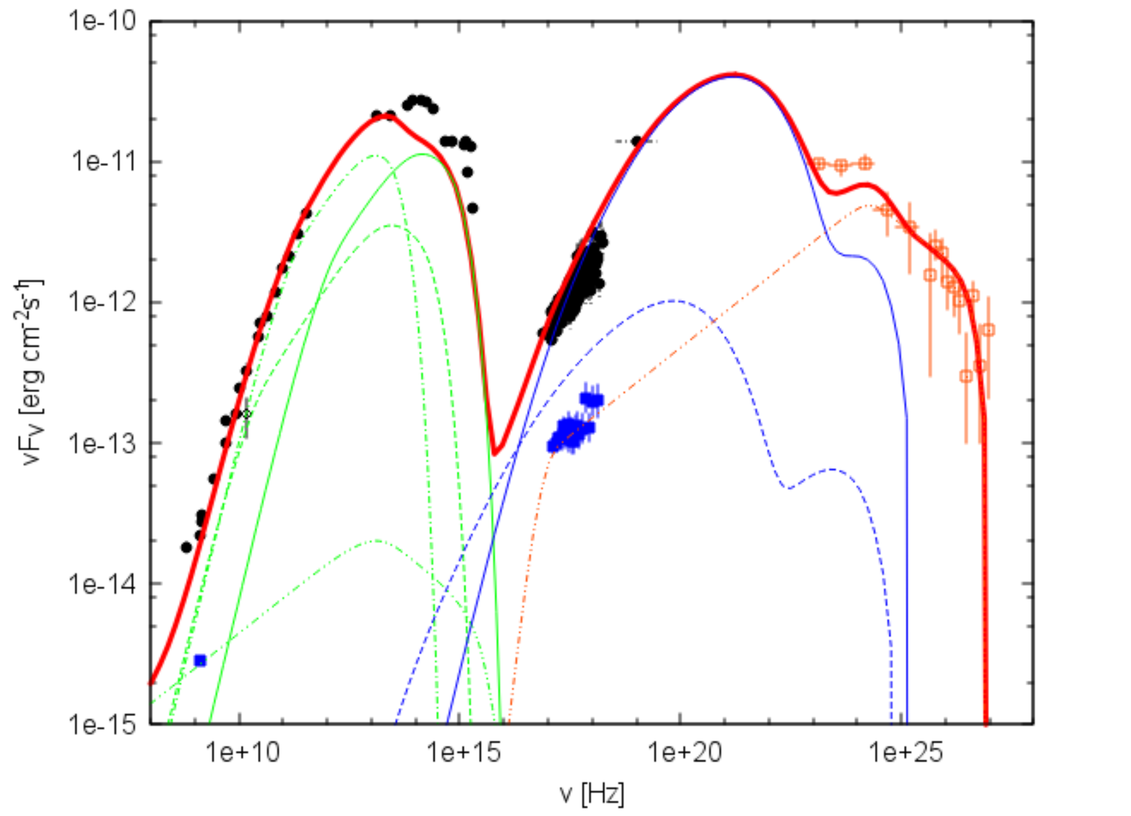

Figure 2 : The spectrum of AP Librae. Black data points: Radio: [6], [2], MOJAVE [7], PLANCK; IR: 2MASS, WISE; optical: ATOM [5]; UV: Swift-UVOT; X-ray: [5], Swift/BAT. Black open diamond: MOJAVE ("Component 0") [7]. Blue filled squares: Radio: [2]; X-rays: [5]. Red open squares: [3]. Color code of fitting lines: synchrotron (green), SSC (blue), IC/CMB (red), sum of all components (thick red).

- General parameters:
  - Bulk Lorentz factor: $\Gamma_b = 10$, Observation angle: $\theta_{obs} = 2^\circ$
- "Component 0-A" (solid lines):
  - $\gamma_1 = 2 \times 10^2$, $\gamma_b = 2.4 \times 10^3$, $\gamma_2 = 8 \times 10^3$
  - $s_1 = 2.0$, $s_2 = 3.0$
  - $n_{el} = 6.86 \times 10^3$cm^{-3}, $B = 0.2$G, $R = 1 \times 10^{15}$cm
- "Component 0-B" (dashed lines):
  - $\gamma_1 = 3 \times 10^1$, $\gamma_b = 1 \times 10^3$, $\gamma_2 = 4 \times 10^3$
  - $s_1 = 2.0$, $s_2 = 3.0$
  - $n_{el} = 4.39 \times 10^3$cm^{-3}, $B = 0.2$G, $R = 2 \times 10^{15}$cm
- "pc-jet" (dash-dotted lines):
  - $\gamma_1 = 5 \times 10^2$, $\gamma_b = 7.8 \times 10^3$, $\gamma_2 = 1 \times 10^4$
  - $s_1 = 2.0$, $s_2 = 3.0$
  - $n_{el} = 3.66 \times 10^{-7}$cm^{-3}, $B = 5$mG
  - Jet length (projected): 10pc
- "kpc-jet" (dash-double-dotted lines):
  - $\gamma_1 = 6 \times 10^1$, $\gamma_b = 3.3 \times 10^5$, $\gamma_2 = 5 \times 10^6$
  - $s_1 = 2.5$, $s_2 = 3.5$
  - $n_{el} = 1.45 \times 10^{-10}$cm^{-3}, $B = 2.2\mu$G
  - Jet length (projected): 10kpc, Observation angle: 4°

Model

- Using the self-consistent leptonic one-zone code of [1]
- Self-consistency demands electron spectral break $\Delta s = 1$
- Extended jets modeled as combination of many non-interacting, but self-similar "one-zones"
- For clarity, no accretion disk and galactic spectrum added (IC/BLR may explain missing flux at GeV energies)

Results

- "Component 0" requires at least two zones due to difficulties with X-rays
- PLANCK spectrum explained by "pc-jet", which produces no significant IC flux
- Unlike [4], core cannot account for VHE emission
- **VHE emission may be due to extended jet**
- However, kpc-jet parameters poorly constrained

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