Identifying TeV Blazar Sources Using WISE Color-Color Data

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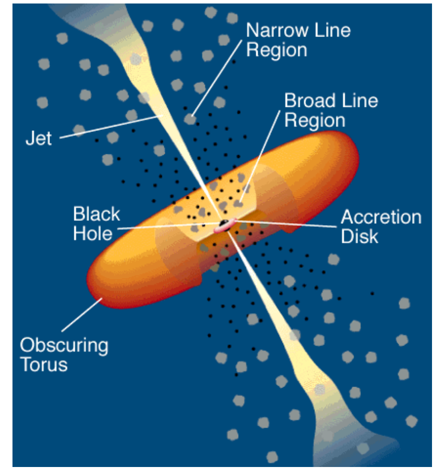
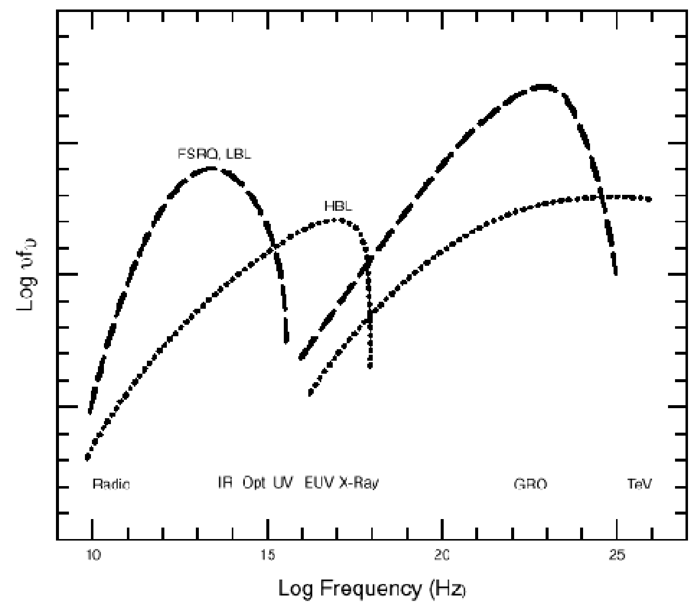
Reference:
"Identification of the Infrared Non-Thermal Emission in Blazars"
Massaro F., D'Abrusco R., Ajello M., Grindlay J. E., Smith H. A., 2011b, ApJ, 740, L48
http://adsabs.harvard.edu/abs/2011ApJ...740L..48M

Blazars

- Blazars are thought to be AGN that are viewed with the jet along the line of sight (very bright)
- Only non-thermal emission is seen
  - Emission from jet is non-thermal
  - Beamed jet emission outshines all other emission
  - Emission & absorption lines are typically not seen
- Two types: BL Lacertae and Flat Spectrum Radio Quasar (FSRQ)
- BL Lacs further subdivided:
  - LBL: low-frequency-peaked BL Lac
  - HBL: high-frequency-peaked BL Lac
  - TBL: TeV-detected BL Lac (suggested)

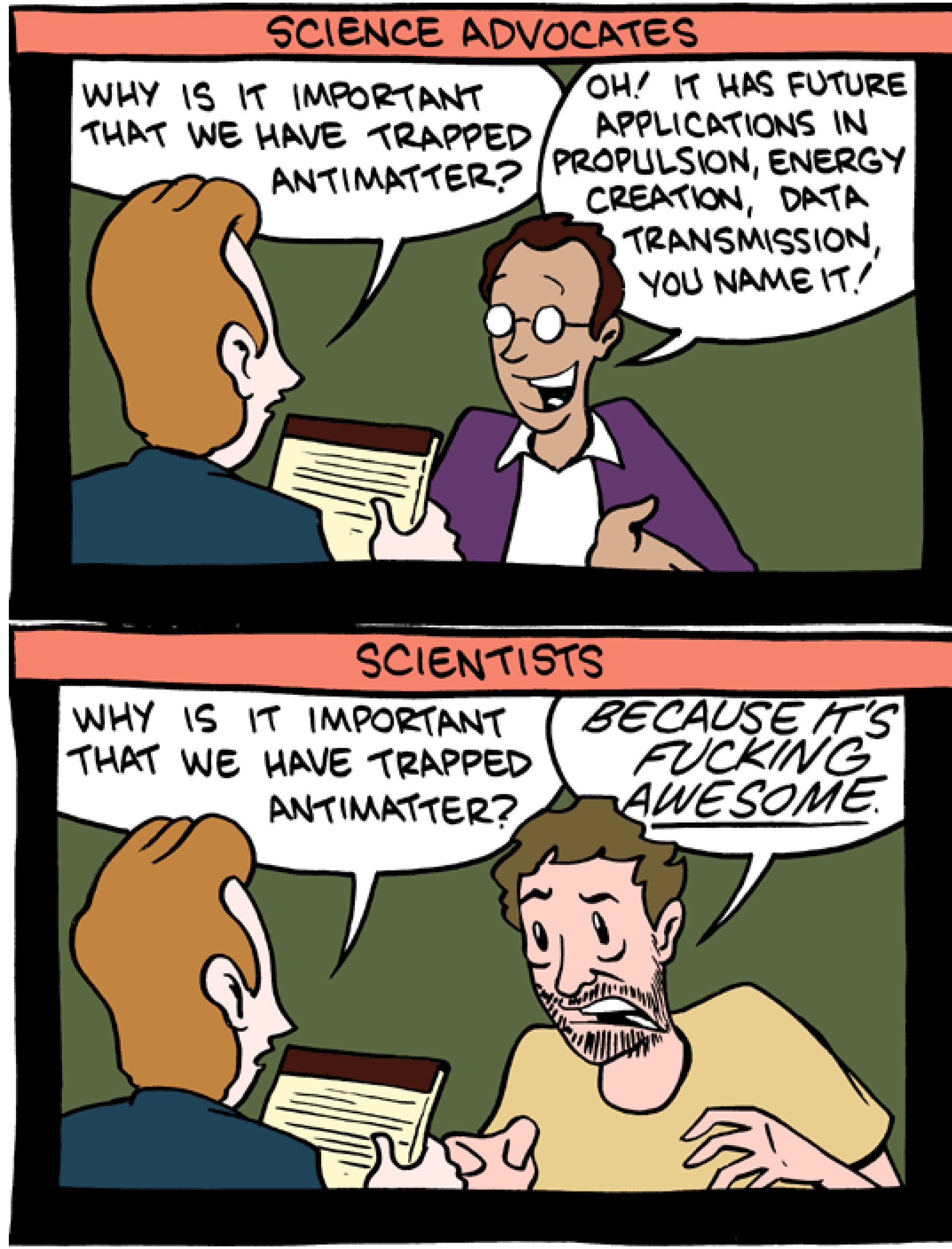


NASA HEASARC



Urry (1998)

Motivation



SCIENCE ADVOCATES
WHY IS IT IMPORTANT THAT WE HAVE TRAPPED ANTIMATTER?
OH! IT HAS FUTURE APPLICATIONS IN PROPULSION, ENERGY CREATION, DATA TRANSMISSION, YOU NAME IT!
SCIENTISTS
WHY IS IT IMPORTANT THAT WE HAVE TRAPPED ANTIMATTER?
BECAUSE IT'S FUCKING AWESOME.

Blazar Jet Physics

- Beamed emission in blazar jets originally proposed as a solution to high radio brightness temperature (Blandford and Königl 1979)
- Emission is thought to come from relativistic blobs of material and possibly strong shock fronts
- Blazars exhibit rapid variability on timescales as short as ~1 hour (Gaidos et al. 1992)
- Best observations of jets come from radio interferometry
- Need a large variety of targets, preferably nearby, to gain insight into jet physics

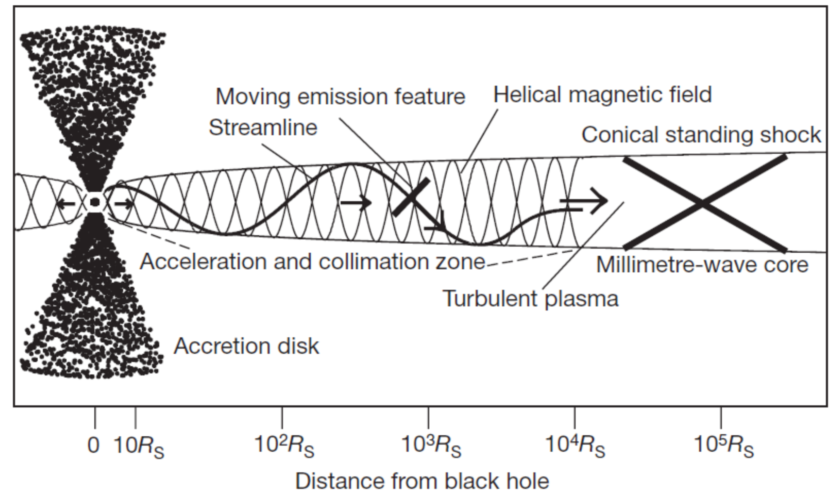


Figure 3 | Proposed model for the inner jet of BL Lac. A shock propagates down the jet along a spiral streamline. The first flare occurs during the last 240° twist of the streamline before the flow straightens and becomes turbulent. The passage of the feature through the millimetre-wave core stimulates the second flare. A logarithmic scale of distance from the black hole, shown in terms of the Schwarzschild radius (R_S), is used to illustrate phenomena on various scales.

Marscher et al. (2008)

Absorption of TeV Gamma-Rays

- Gamma-rays can interact with each other:

$$\sigma_{\gamma\gamma}(E,\epsilon,\phi) = \frac{1}{8}\,(1-\beta^2)\times\left[2\beta(\beta^2-2)+(3-\beta^4)\ln\frac{1+\beta}{1-\beta}\right]\ barns,$$

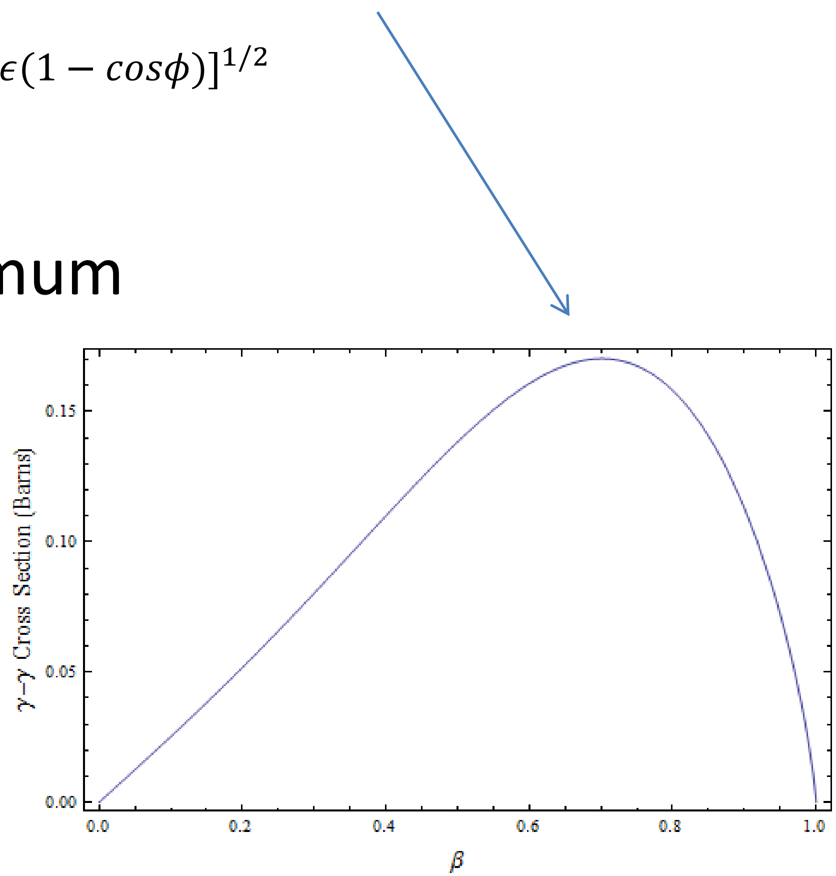
$$\beta(E,\epsilon,\phi) \equiv [1-2m_e^2/E\epsilon(1-cos\phi)]^{1/2}$$

(Heitler 1960)

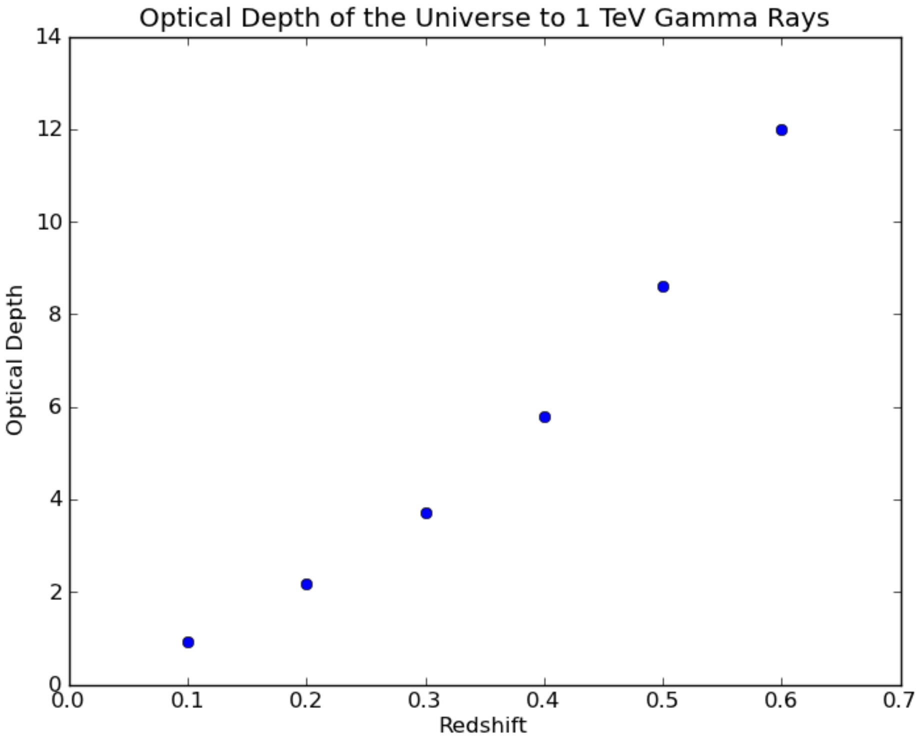
- For 1 TeV gamma-rays, maximum cross-section occurs when

$$\epsilon_{IR} \sim \frac{2(mc^2)^2}{E_\gamma} = 0.5\left(\frac{1\ TeV}{E_\gamma}\right)\ eV$$

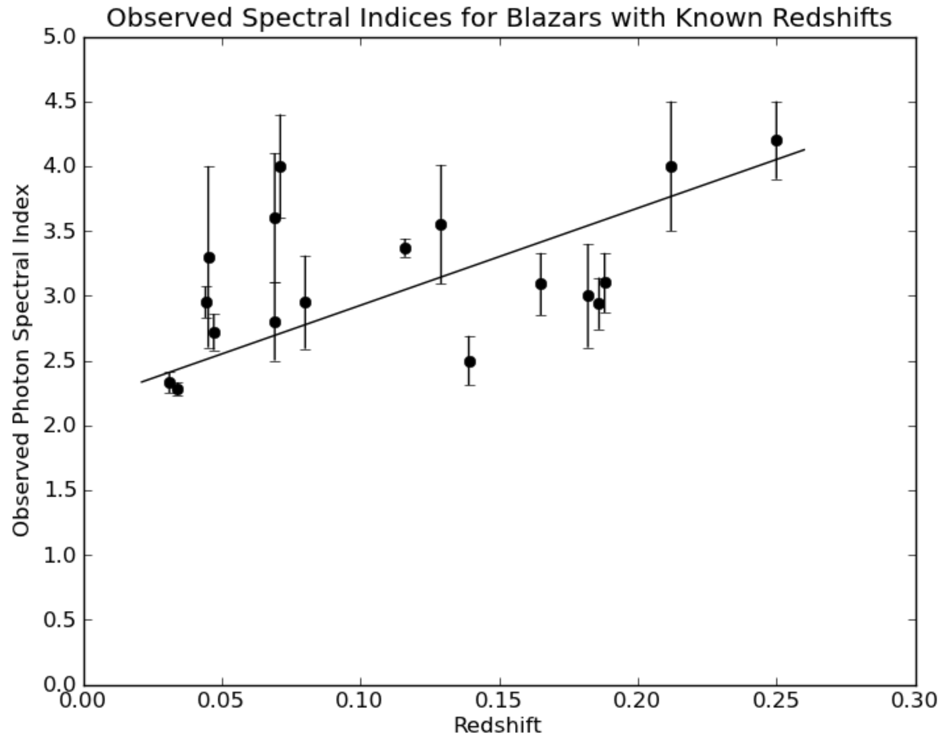
$$\lambda_{IR} = \frac{hc}{\epsilon_{IR}} = \frac{1.24\ eV\cdot\mu m}{\epsilon_{IR}}$$



Absorption of TeV Gamma-Rays

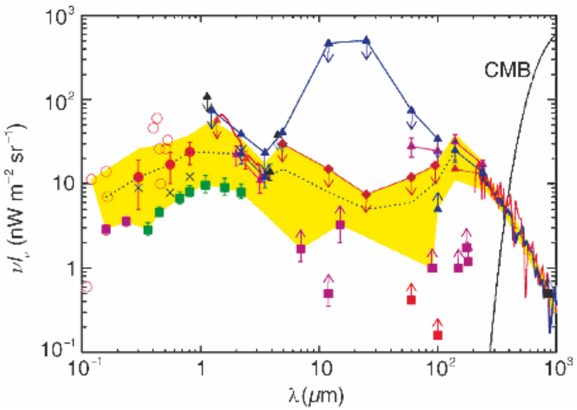


Stecker, De Jager, and Salamon (1992)

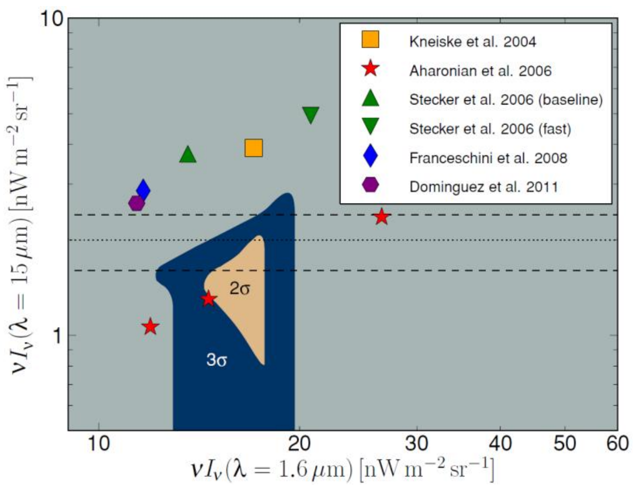


De Angelis et al. (2009)

Extragalactic Background Light



Plot of EBL intensity vs. wavelength. The EBL is thought to be double peaked at ~1 μm and ~100 μm.

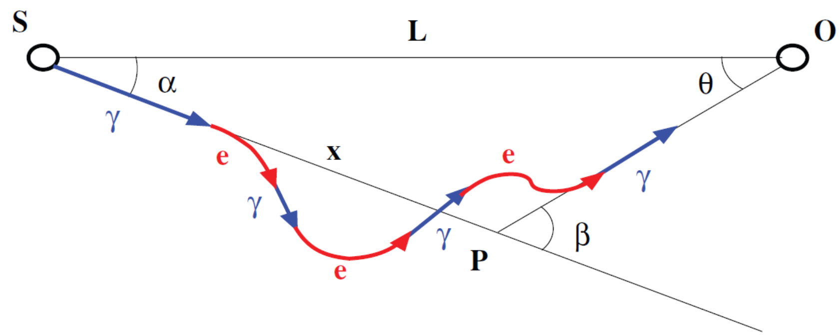


Plot showing 2σ and 3σ confidence regions obtained by Orr, Krennrich, and Dwek, with comparison to popular models of the EBL by several other authors. Dotted lines show integrated EBL intensity from Hopwood et al. (2011), with 1σ errors.

- Extragalactic Background Light (EBL) is thought to be the second most dominant cosmological radiation field after the CMB
- Thought to have a bimodal distribution
  - 1 μm component thought to be from star formation and AGN accretion
  - 100 μm component re-radiated from dust
- EBL intensity is difficult to measure directly
  - Must subtract foreground thermal radiation from detector & telescope
  - Must subtract contribution from dust in the solar system and Milky Way
- TeV-emitting blazars provide a good tool for measuring EBL; requires distant blazars (z > 0.1) with hard spectra (out to multi-TeV)

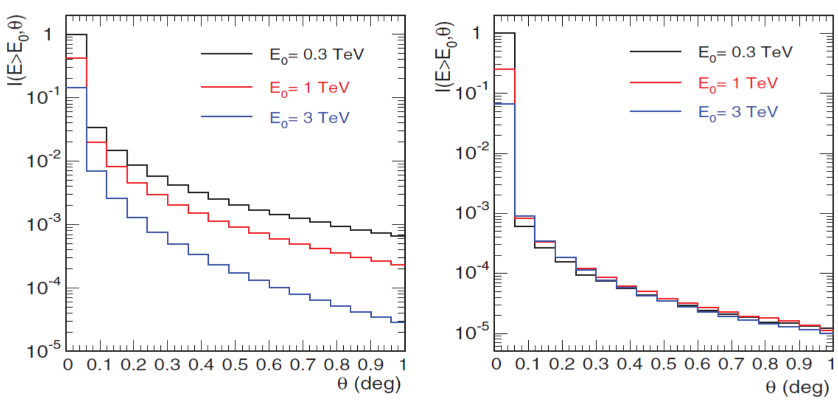
Extragalactic Magnetic Fields

- Hard γ-rays are thought to create electron-positron pairs as they travel between the source and observer
- The electron positron pairs can be deflected by the extragalactic magnetic field (EGMF)



Schematic of scattering gamma-ray and electron-positron cascade off of EGMF, creating a halo with opening angle θ

- If the EGMF happens to have a magnetic field strength within 10^{-16} – 10^{-10} G, EGMF strength may be inferred from presence of a “blazar halo”
- Requires nearby blazars that are very luminous at high energies

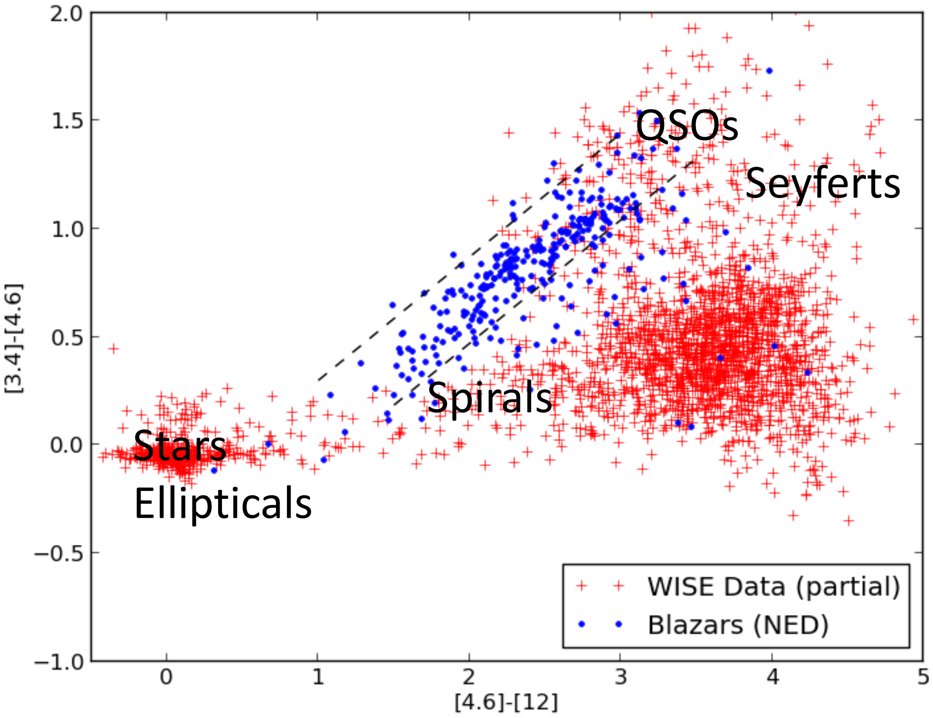


Integral intensity vs. halo opening angle for a uniform EGMF. Left figure: $B = 10^{-12}$ G. Right Figure: $B = 10^{-10}$ G.

Analysis

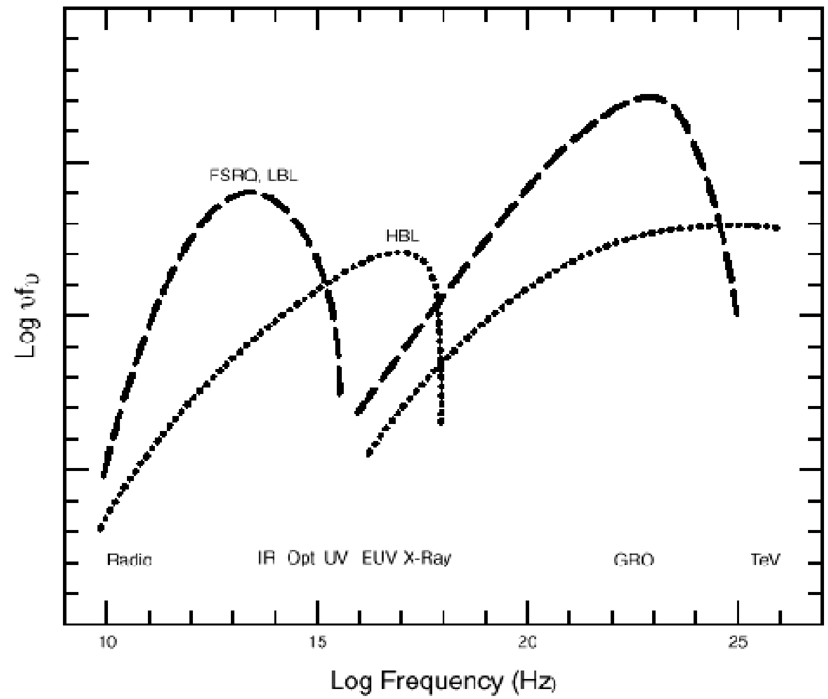
WISE color-color diagram

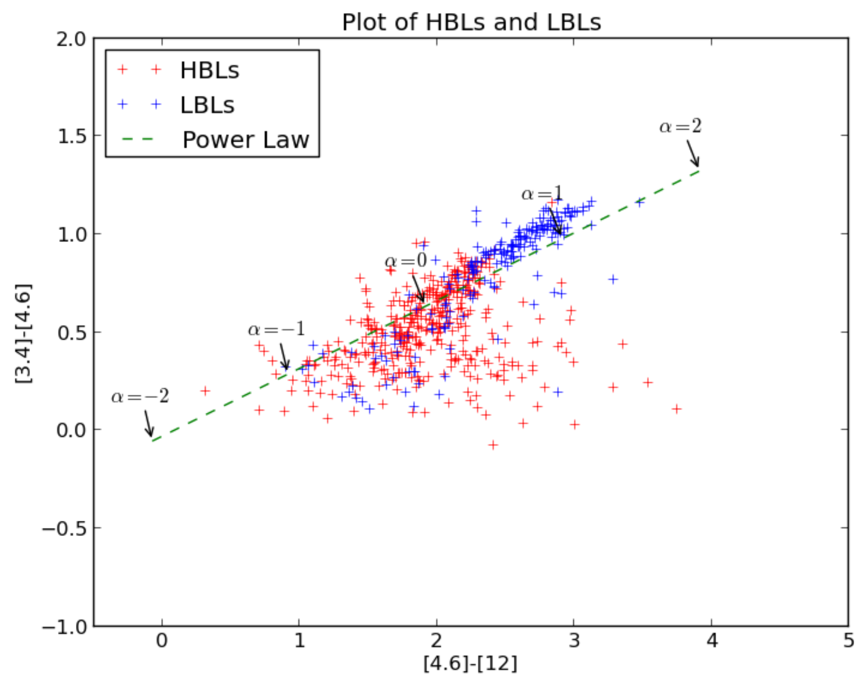
- Shows location of different classes of objects.
- Red '+' corresponds to objects found within a randomly selected 4 deg^2 area of the sky in WISE.
- One sees that the blazars (blue) lie in a strip that is separated from the other classes of objects.
- Call this region the WISE Blazar Strip (WBS).
- It will be shown that the existence of the WBS seems to arise from the fact that blazars typically exhibit nonthermal emission.
- Stars, galaxies, quasars, and other sources typically exhibit thermal emission with emission lines and have a spectral energy distribution that follows a blackbody spectrum.



Why lie along a strip?

- Spectral energy distributions (SEDs) of blazars seem to follow a power law in the IR (Bersanelli 1992).
- Synchrotron emission for lower peak, inverse-Compton scattering for higher peak.
- The power-law spectrum takes the form:
$$S_\nu \propto \nu^{-\alpha}$$
- And from the relation of flux to apparent magnitude, one finds:
- $$m_\nu - m_{\nu'} = \alpha\ 2.5\ \log_{10}\left(\frac{\lambda'}{\lambda}\right) - 2.5\ \log_{10}\left(\frac{S_{\nu,0}}{S_{\nu',0}}\right)$$
  - ν, ν' are the frequency bands
  - λ, λ' are the corresponding wavelengths
  - $S_{\nu,0}, S_{\nu',0}$ are the corresponding zeropoint magnitude fluxes.
- $[3.4] - [4.6] = 0.636 + 0.344\ \alpha$
- $[4.6] - [12]\ = 1.923 + 1.000\ \alpha$
- Different values of α correspond to different colors on the diagram.
- On can see that sources within the WBS are in agreement with the line given by the power law, thus confirming the nonthermal origin of the spectrum.



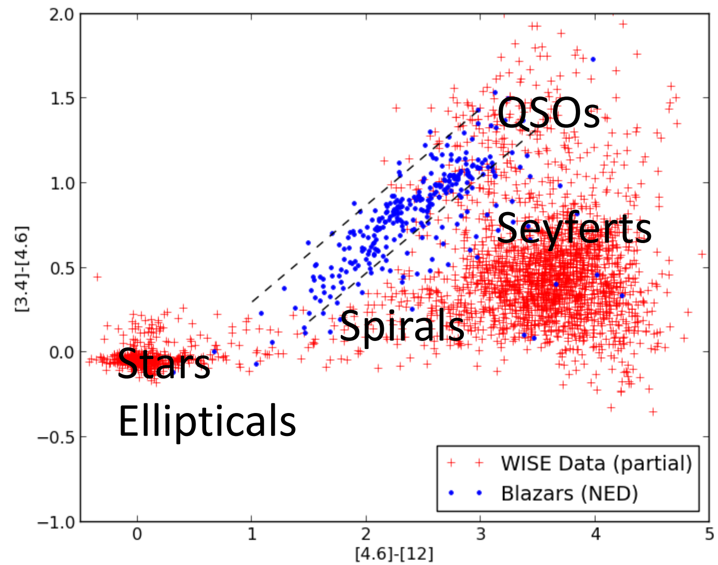


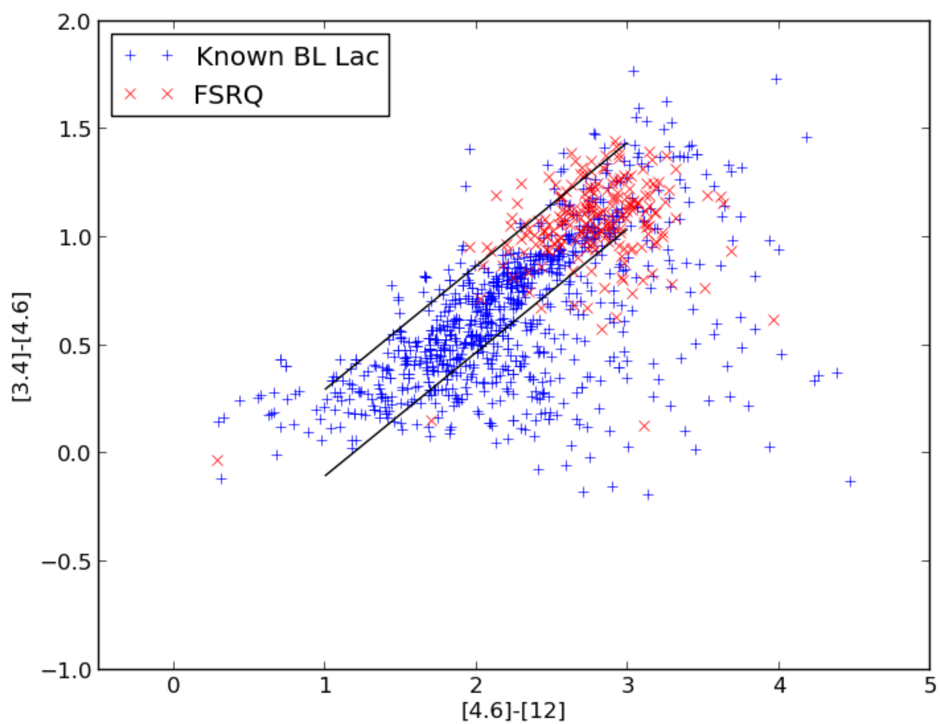
Combined Data from HEASARC-ROXA, ROMA-BZCAT, NED, TeVCat

~1596 objects

- Used given positions in above catalogs to find corresponding sources in WISE.
- We used a 2.4" radius for the position cone when searching WISE.
- Choice of radius came from combination of 1" error in ROMA-BZCAT positions and 1.4" error in fourth WISE band.
- Excluded multiple cross matches.
- Plot shows only those points that contain one source within the 2.4" cone.
- Minimum S/N of 7 in at least one band.

- Flat-spectrum radio quasars (FSRQs) lie closer to the normal quasars and Seyfert galaxies.
- BL Lacs lie mostly in the WBS and tend to overlap only with FSRQs in a certain region.



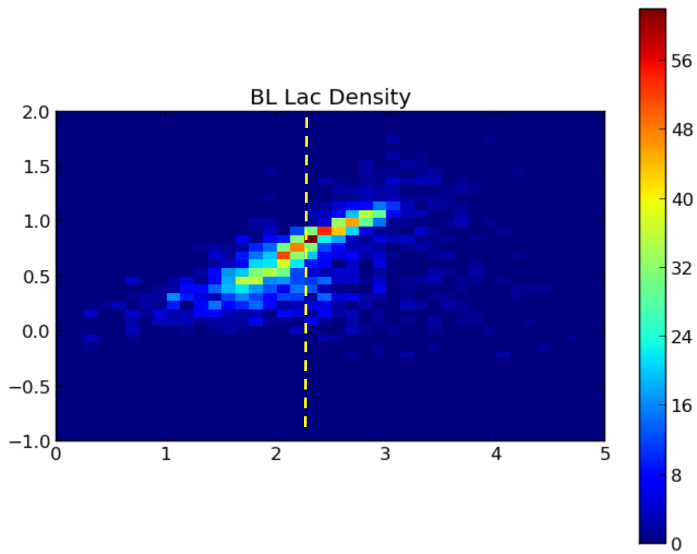


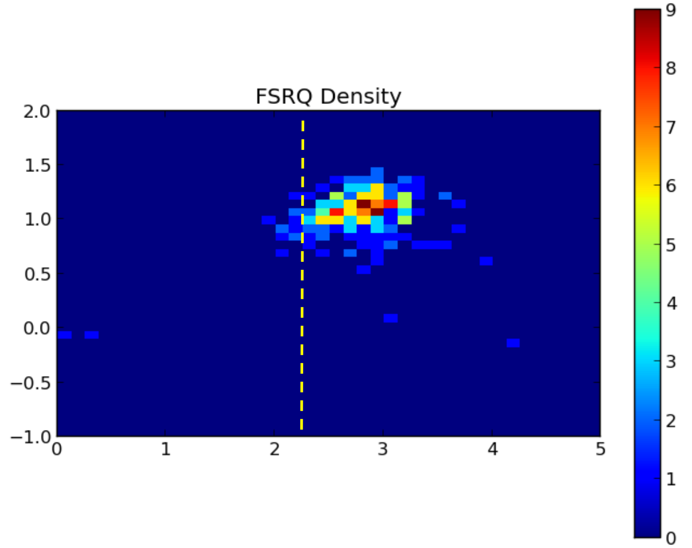
Separation of BL Lacs and FSRQs

- FSRQs cluster in a region near the QSOs
- BL Lacs spread along the WBS
- Dashed line represents approximate cutoff for FSRQ region.

Can possibly be used to classify object as BL Lac or FSRQ.

However, overlap of some BL Lacs with FSRQs can cause problems with using this classification method.



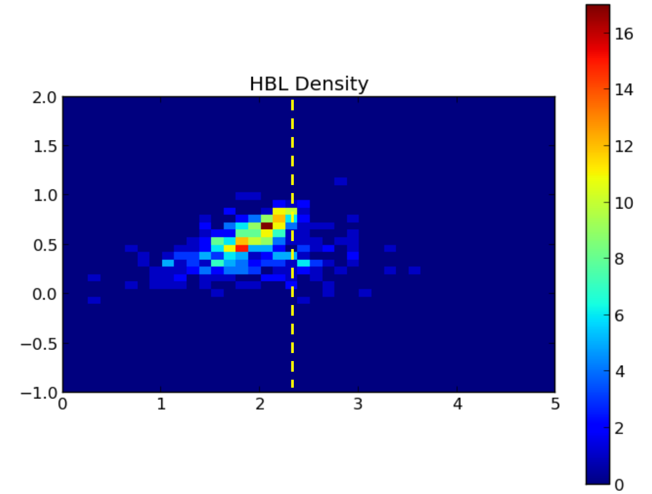


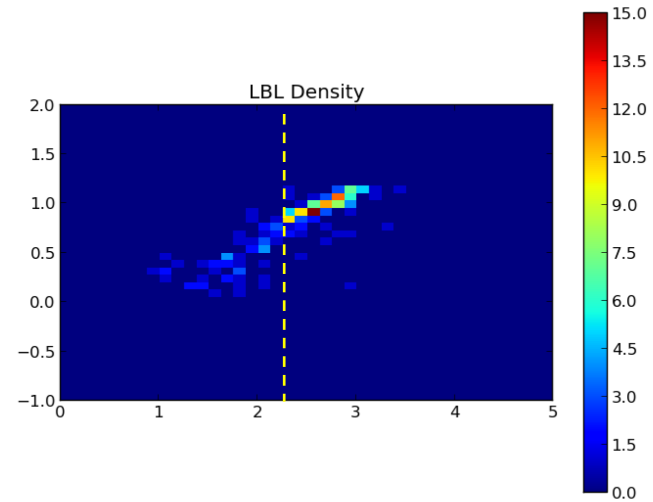
Separation of HBLs and LBLs

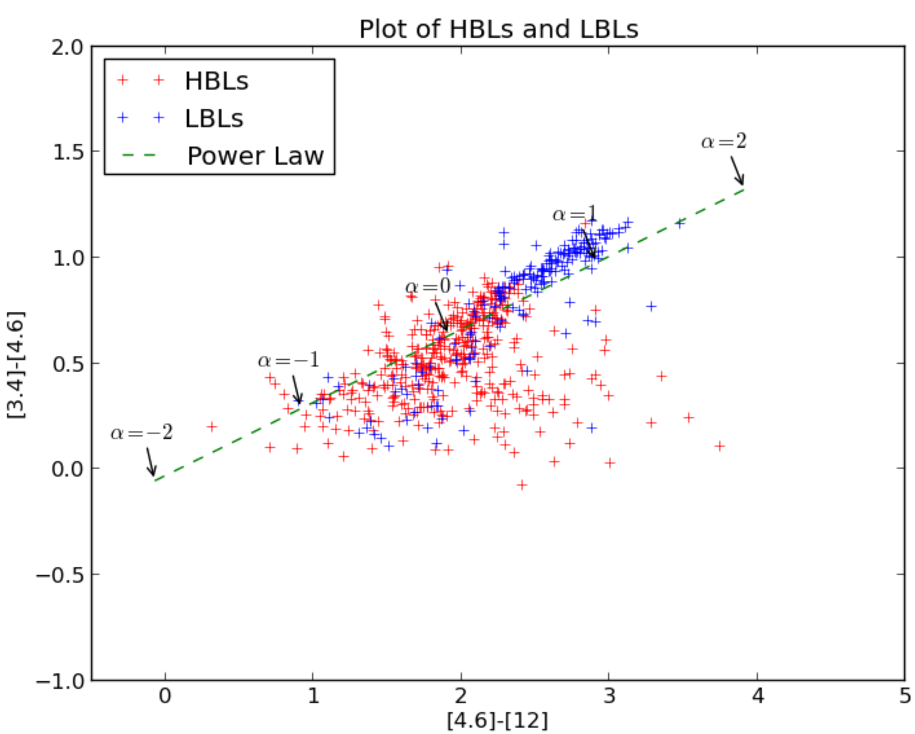
LBLs tend to overlap with FSRQs, making classification by use of color-color diagram alone impractical.

HBLs are well separated from other types of sources.

This could possibly be used to classify candidates as HBLs with some confidence.







TBLs in TeVCat

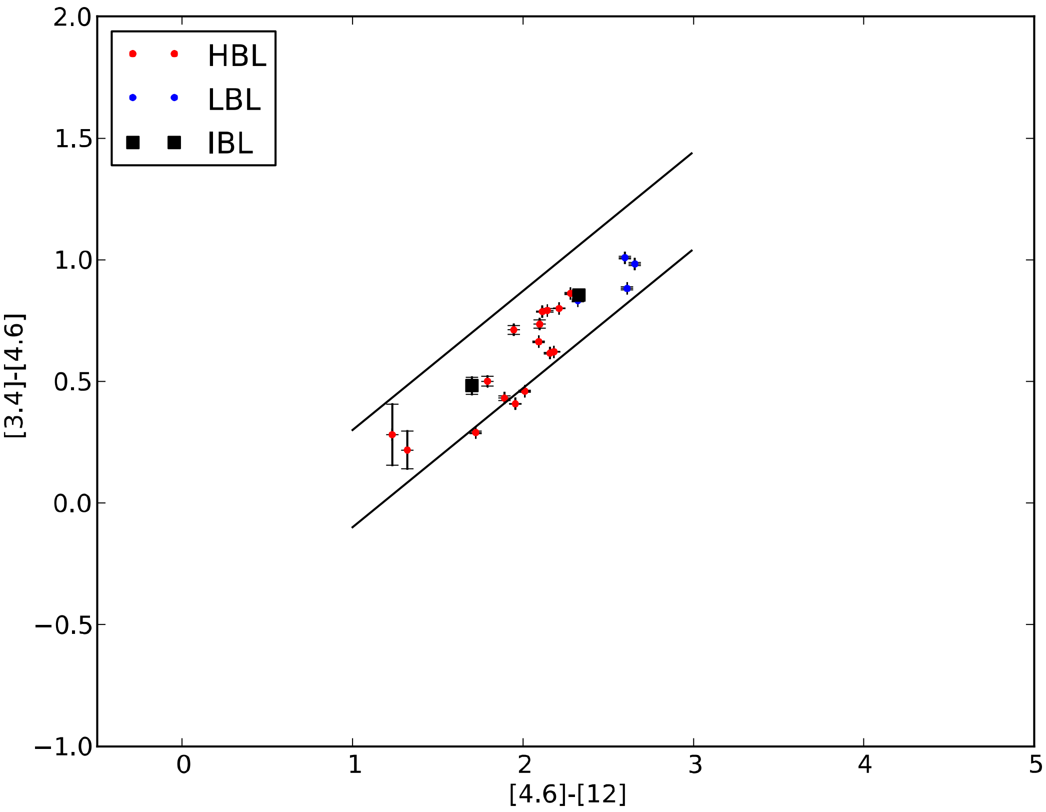
Using positions of all known BL Lacs in TeVCat (TeV source catalog), we plotted the corresponding WISE sources within a 2.4” cone.

Notice that HBLs detected as TeV sources fall within a distinct region of the WISE Blazar Strip.

- Classify these objects as TBLs (TeV BL Lacs)

This fact could be used to identify possible TeV candidates for future observation.

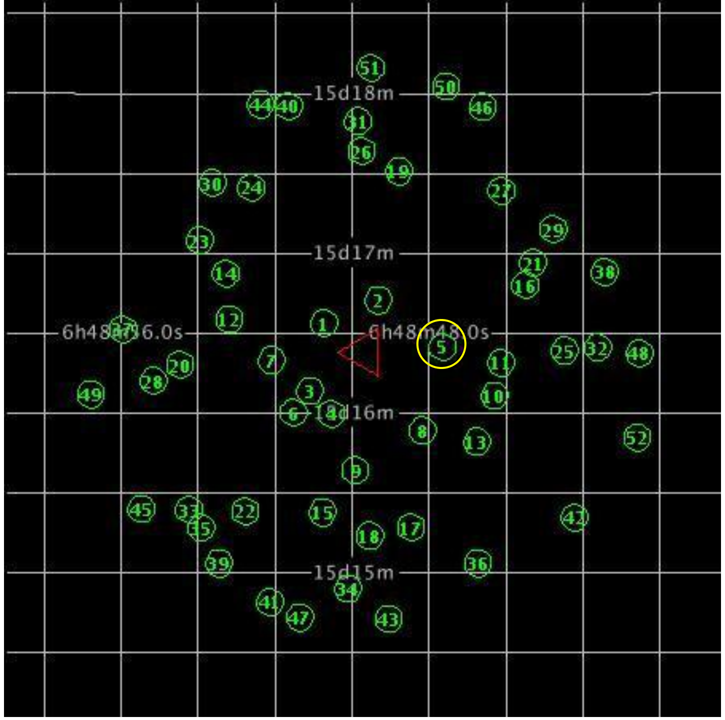
Also, newly detected TeV sources that have not yet been identified may have counterparts in the WISE catalog that allows them to be classified as TBLs or rule out the classification.

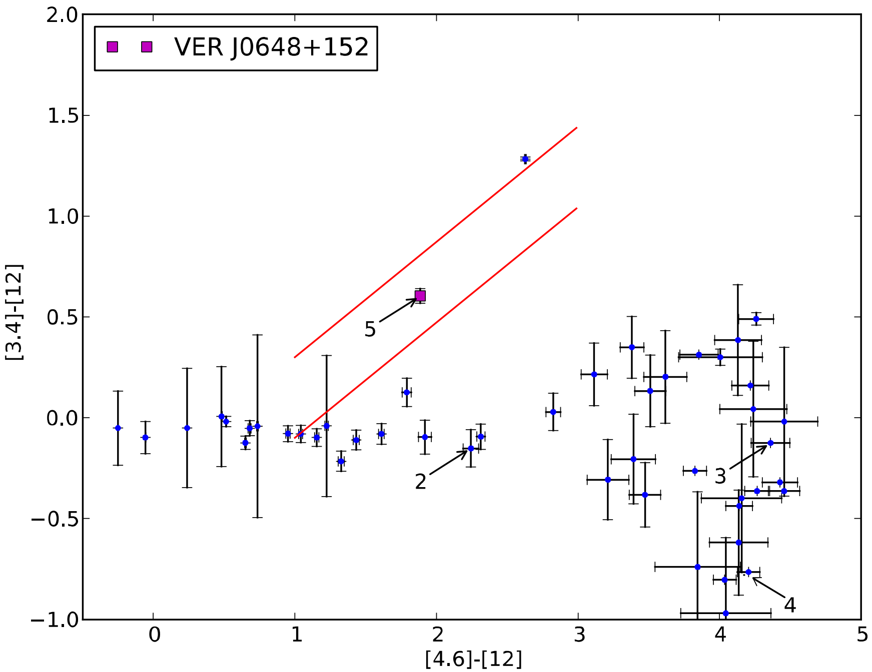


16 TBLs from a total of 22 sources.

Example: An Unidentified TeV Source

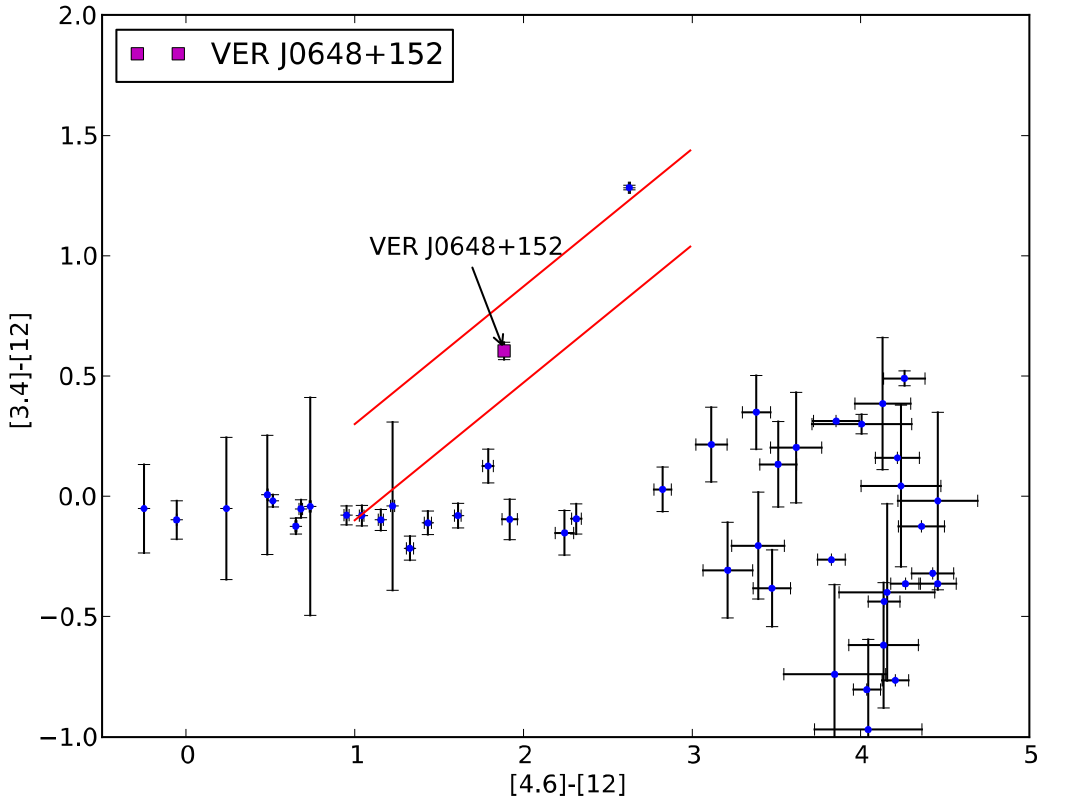
- *Fermi* detected a gamma-ray source, 1FGLJ0648.8+1516, within a positional circle of 108".
- First figure shows all WISE sources within this circle.
- Numbered according to distance from center of positional circle (1 being nearest ~18”)
- When plotting the WISE data on a color-color diagram, it is found that the 5th closest object is the only one that lies in the WBS and thus must be the WISE counterpart to the source observed by *Fermi*.
- Point 5 also corresponds to the position of the X-ray counterpart within the error box of *XMM-Newton* (7.2”) and the position reported by VERITAS for the TeV unidentified source VER J0648+152 (~50")
- Strongly supports blazar classification and TBL candidate.





So why was this useful?

- By placing all WISE sources over the color-color diagram, one could find unidentified sources in the WBS and could use these sources as blazar candidates for further observation.
- Provides diagnostic tool for blazar association.
  - Associate known blazars with WISE counterparts
- Classify unidentified TeV sources (as in previous slide)
- Identify new TeV candidates by location of WISE source in TBL region of the blazar strip.



Conclusions

- Blazar discovery surveys are important for doing interesting science; need blazars at a variety of redshifts, and usually prefer bright blazars with hard spectra
- WISE data is a useful tool for selecting blazars because their IR properties are only loosely related to their behavior at TeV energies
- When plotted on a color-color diagram, blazars tend to fall within a strip (WBS), well separated from other classes of objects
- Different classes of blazars tend to occupy different regions of the WBS, allowing selection of harder HBLs
- WISE data could be a useful tool in identifying unknown gamma-ray emitting sources from surveys à la *Fermi*

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