A Multi-Wavelength Blazar Campaign

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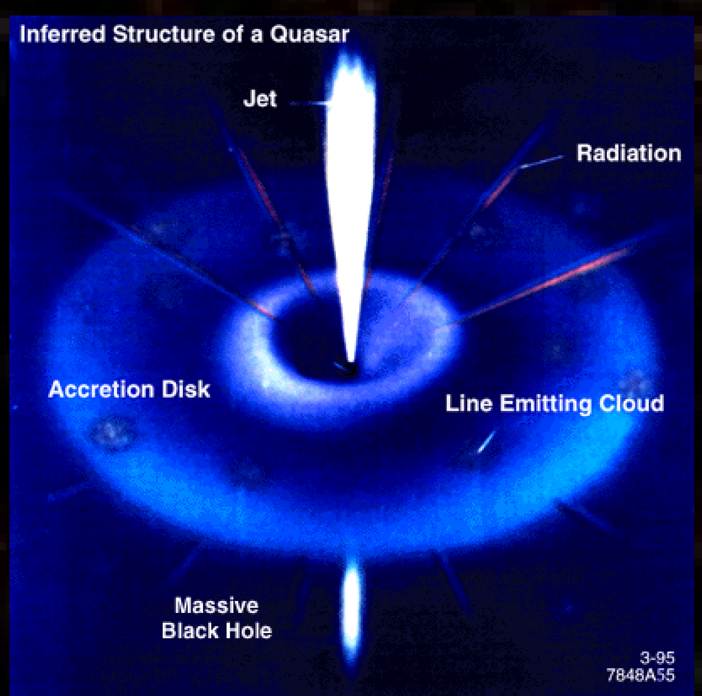

Figure 1
A diagram of an active galactic nucleus (AGN). A blazar is an AGN seen with the jets along our line of sight. Image courtesy of http://wwwmagic.mppmu.mpg.de/introduction/AGN_art.jpg

Background

Blazars are a subclass of active galactic nuclei (AGN). AGN are galaxies with a black hole at the center that are actively accreting matter. Figure 1 shows an artist's conception of an AGN as well as the relevant parts. Blazars are AGN that we happen to be looking at down the jet axis. Blazars are compact, highly variable sources. A subclass of blazars are objects known as BL Lacs, or BL Lacertae objects. These are blazars with intrinsically weak radio emission. All of our chosen sources fall into the category of being BL Lacs. BL Lacs have a characteristic two hump spectral energy distribution (SED). High frequency peaked BL Lacs (HBLs) have a synchrotron hump that peaks in the UV/X-ray and low frequency peaked BL Lacs (LBLs) have a synchrotron hump that peaks in the Infrared/Optical. All of our sources are also HBLs. HBLs are neutrino point source candidates. As can be seen from Figure 2, the SED of Markarian 421, there are two very distinct energy humps. It is generally agreed upon that the low energy component of this SED is synchrotron emission from relativistic electrons. (Mücke A., et al. 2003) The mechanism responsible for the high energy hump is still in dispute. There are both leptonic models and hadronic models for the source of these high energy X-rays and gamma rays. In leptonic models there is no neutrino production, but in hadronic models including the Synchrotron Proton Blazar Model proposed by Mücke A., et al. 2003, and the hadronic Synchrotron Mirror Model proposed by Reimer A., et al. 2005 gamma ray production by pion photoproduction would also lead to neutrino production through the decay of charged pions, and muons. These decays would result in the production of both electron and muon neutrinos. The major difference between leptonic and hadronic models is that in leptonic models, sometimes known as synchrotron-self Compton (SSC) models, the gamma ray emission is correlated with the X-ray flares. There is one very clear example of an "orphan" TeV flare, that is a gamma ray flare with no corresponding X-ray flare, from the source 1ES 1959+650. This orphan flare was observed on June 4, 2002 approximately fifteen days after an initial TeV flare that was correlated with X-ray emission. Krawczynski et al. 2004 Several hadronic models use the presence of protons to explain this orphan flare. Protons then create charged and neutral pions, which would result in both high energy gamma rays and neutrinos. These hadronic models could be confirmed by the detection of neutrinos by IceCube in the right time window and from the right direction as a TeV flare.

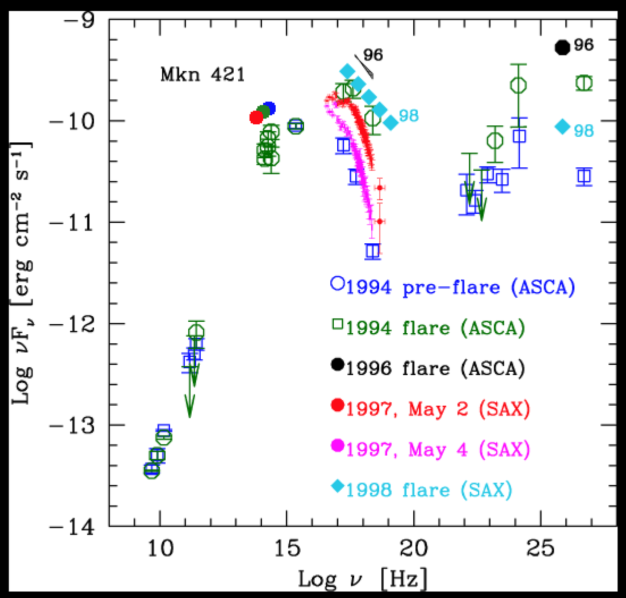

Figure 2
The spectral energy distribution (SED) of Markarian 421 reproduced from Guetta D., et al. 2004. The red, blue, and green data points are representative of the data collected during the summer of 2007. They agree well with the rest of the SED.

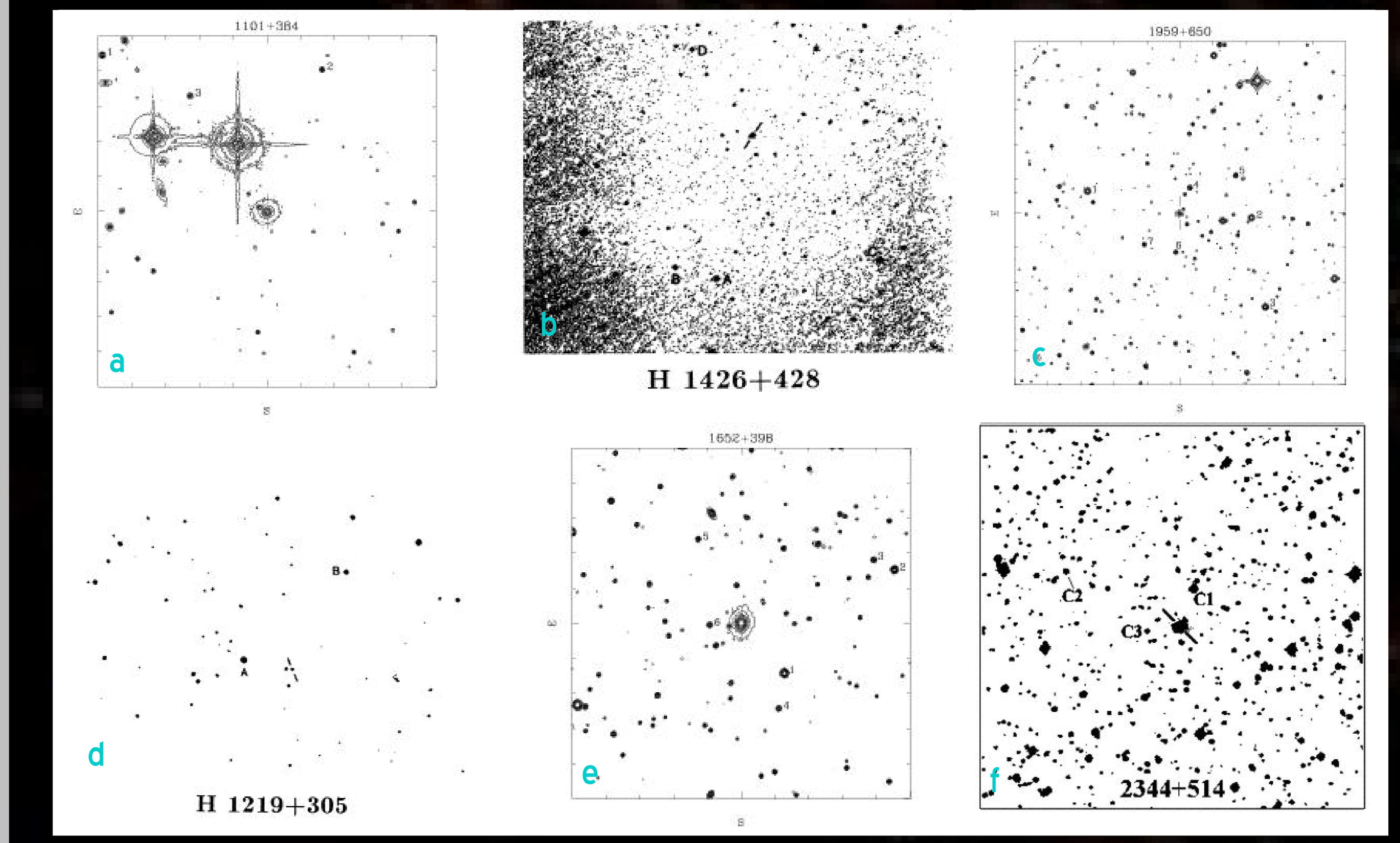

Figure 3
Our six sources are Markarian 421, H 1426+428, 1ES 1959+650, 1ES 1218+304, Markarian 501, and 1ES 2344+514, Figure 3 a-f respectively. Figure 3a, 3c, and 3e are reproduced from Villata M., et al. 1998. Figure 3b and 3d are reproduced from Smith P., Jannuzi B.T., & Elston R. 1991. Figure 3f is reproduced from Fiorucci M., Tosti G., & Rizzi N. 1998. Images of our six sources were taken almost nightly in the B and V Johnson filters and the R Cousins filter. Instrumental magnitudes and errors were extracted from the images using IRAF. Using the comparison star magnitudes published in the above papers, apparent magnitudes for the six sources were calculated from the instrumental magnitudes. Errors were calculated using the spread in the differences between the known magnitudes of the comparison stars and their instrumental magnitudes. If not enough comparison stars were available, due to saturation or bad columns, then the errors were propagated from the original errors extracted by IRAF. Fluxes were calculated from the apparent magnitudes using the zero point equations published in Sparke & Gallagher. Figure 4 shows the plots of these calculated fluxes versus time. The errors in the fluxes were calculated in a similar way.

Conclusions

These optical observations were taken of our six sources on an almost nightly basis from April 2006 to June 2006 and from February 2007 to July 2007 using the WIYN 0.9m telescope on Kitt Peak. Optical observations were also carried out in September and October of 2007 on the 0.9m and more optical observations are planned. There are X-ray data of these blazars being taken by RXTE and SWIFT. These blazars are also being observed in the TeV range by Whipple. Neutrino data from these blazars are available from IceCube. Figure 5 shows gamma ray and optical data for Markarian 421 over the same time period. Using this abundance of data, a time dependent analysis which incorporates all of the available bands is planned for the future. Such an analysis will be able to correlate periods of higher and lower activity between the high energy and low energy humps of the SED of these objects. This analysis will also be able to determine whether there is a correlation between neutrino emission and high energy gamma ray emission. Whether or not such a correlation exists could rule out or lend weight to certain theoretical models for AGN.

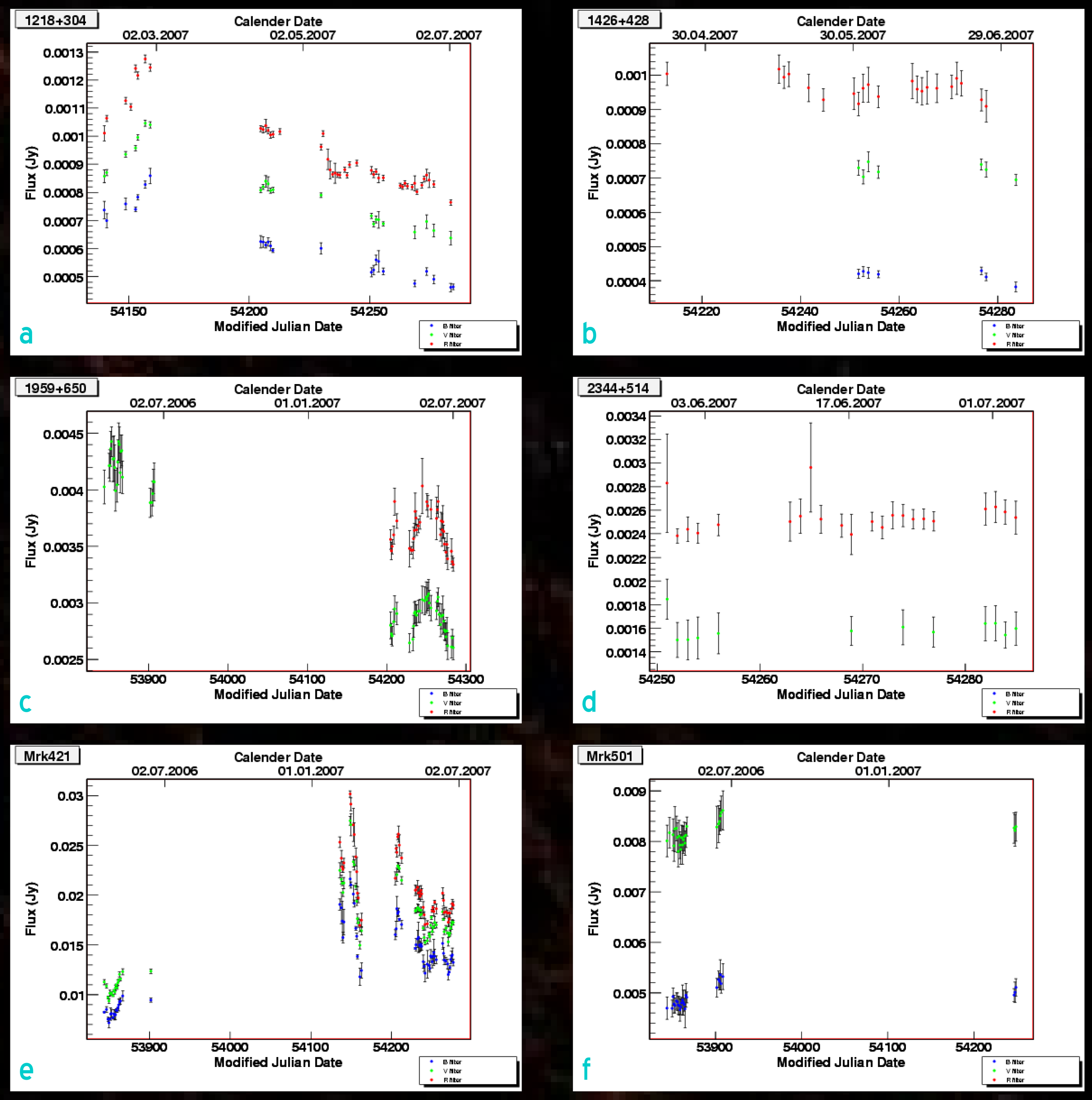

Figure 4
These plots are of fluxes of our six sources over time. Blazars can be variable on time scales of minutes or hours, but they often have periods of high and low activity that last for days or months.

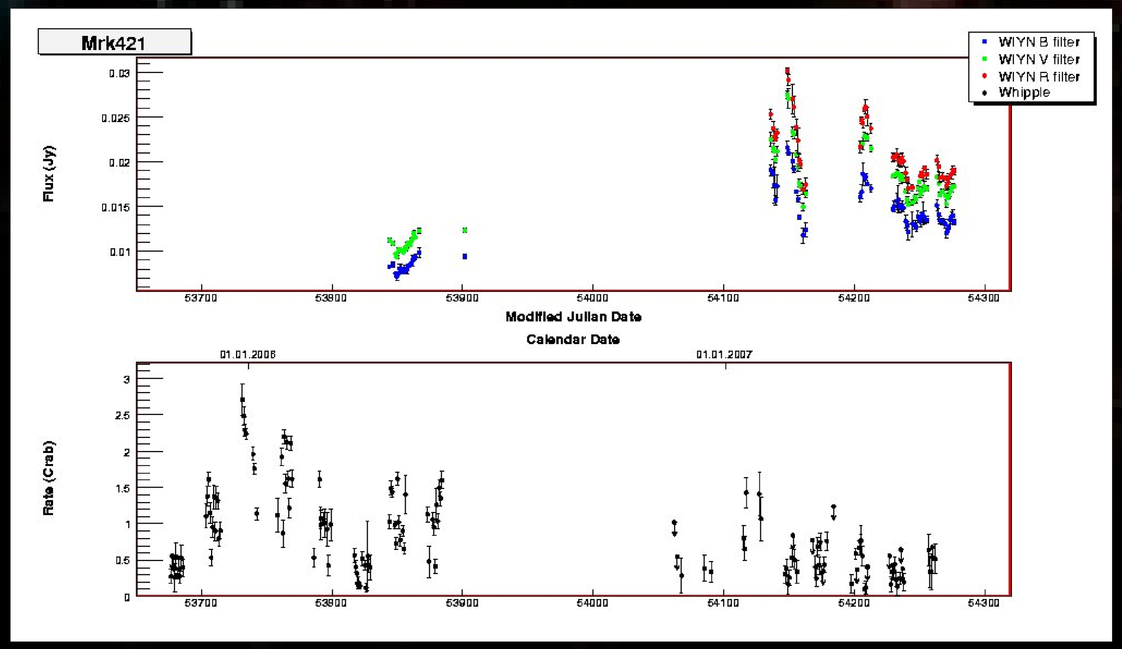

Figure 5
This is a plot of optical data from the WIYN 0.9m telescope on Kitt Peak and gamma ray data from the Whipple 10m telescope on Mount Hopkins from November 2005 through July 2007. These data points will be analyzed for a potential time correlation.

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