First-Epoch VLBA Imaging of 20 New TeV Blazars

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Introduction and Background

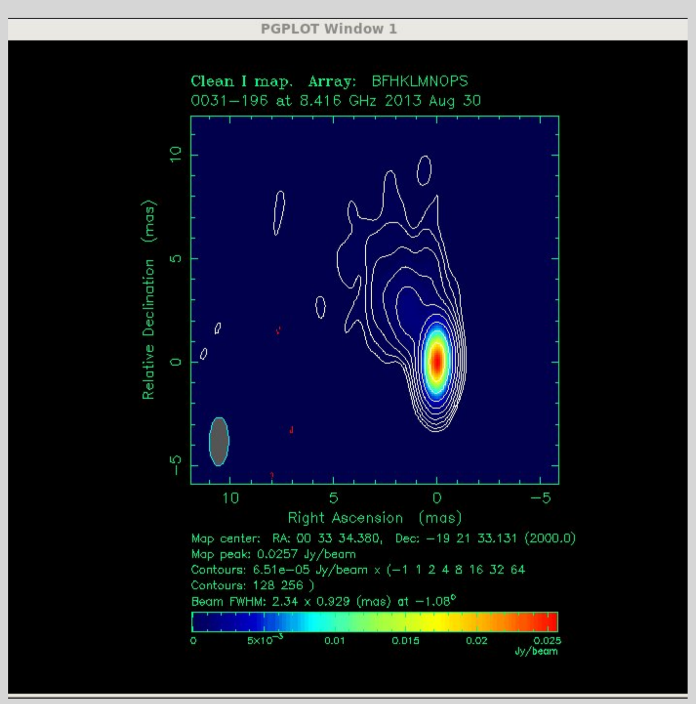
The current generation of ground-based TeV telescopes has now detected 56 blazars (tevcat.uchicago.edu). Most of these (45 of 56) belong to the class of high-frequency peaked BL Lac objects (HBLs), with synchrotron and inverse Compton spectra peaking in X-rays and high-energy gamma-rays, respectively. These TeV HBLs display remarkable variability in their gamma-ray emission on time scales of minutes (e.g., Aharonian et al. 2007), suggesting extremely high Lorentz factors of about 50 in their relativistic jets (e.g., Begelman et al. 2008).

The only way to image these jets directly on the parsec-scale is in the radio with VLBI. Most HBLs are relatively faint in the radio, so they are not well represented in other VLBI monitoring projects. We have taken advantage of both the rapidly growing TeV blazar source list and the upgraded sensitivity of the VLBA to significantly expand of our earlier work on the parsec-scale structure of TeV blazars. We have previously reported multi-epoch VLBI results for 11 TeV blazars (Tiet et al. 2012, Piner et al. 2010), and in this poster we present our first-epoch VLBI observations of 20 new TeV blazars discovered during the years 2006 to 2013, a number of which had never before been imaged with VLBI.

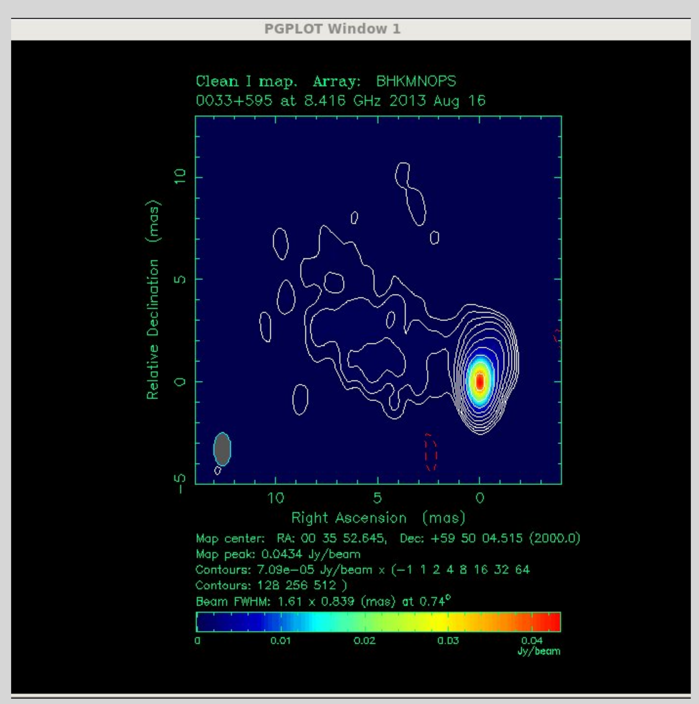
Observations

We observed these 20 new TeV blazars with the VLBA at 8 GHz between August and December 2013, as the first epoch in a new multi-epoch campaign which is ongoing throughout 2015. All observations used a 2 Gbps recording rate. The typical observing time per source was 2 hours, yielding a typical rms noise level of about 0.02 mJy per beam. Data were calibrated in AIPS, and imaged in Difmap. A selection of 10 of these images (chosen from among the brighter sources) is shown below. The complete set of 20 images has been published in Piner & Edwards (2014), and all of the images and calibrated data files are available at the project website.

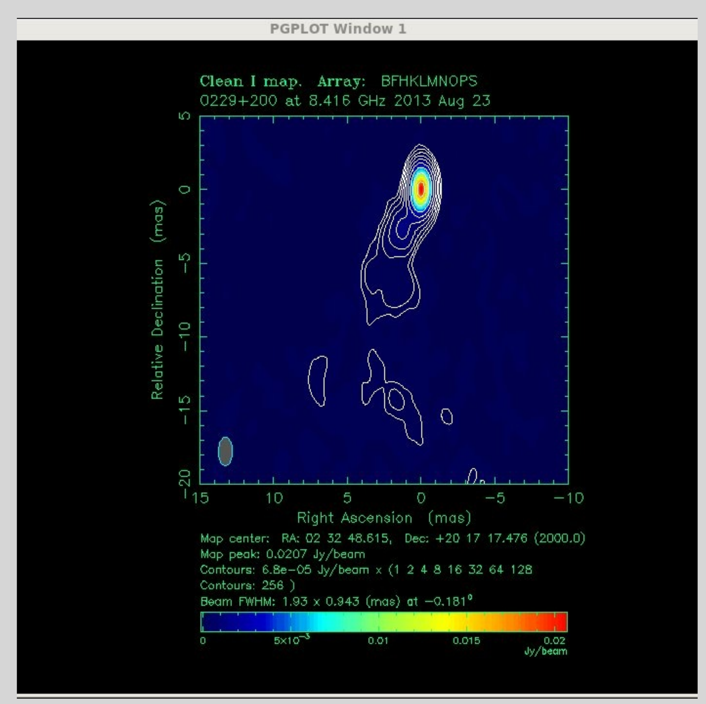
KUV 00311-1938 (*z*>0.5)



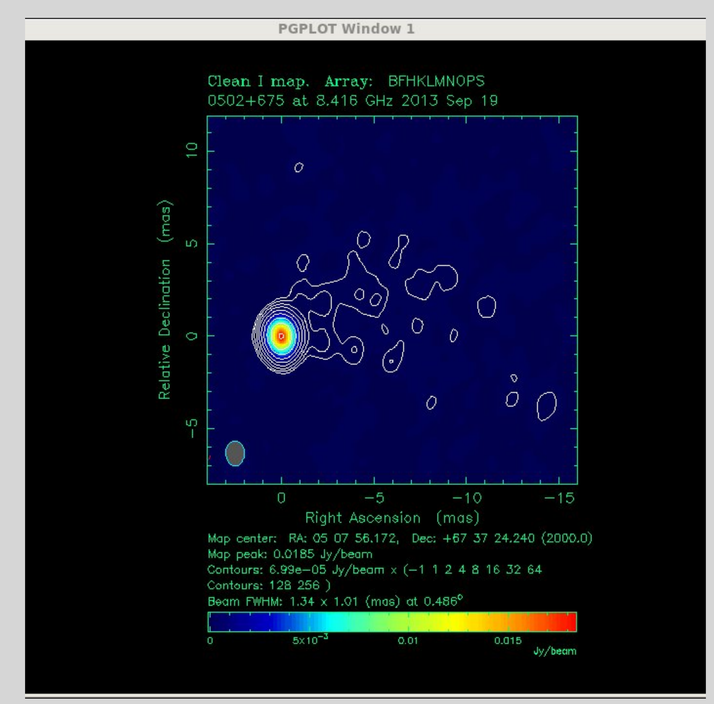
1ES 0033+595 (*z*>0.24)



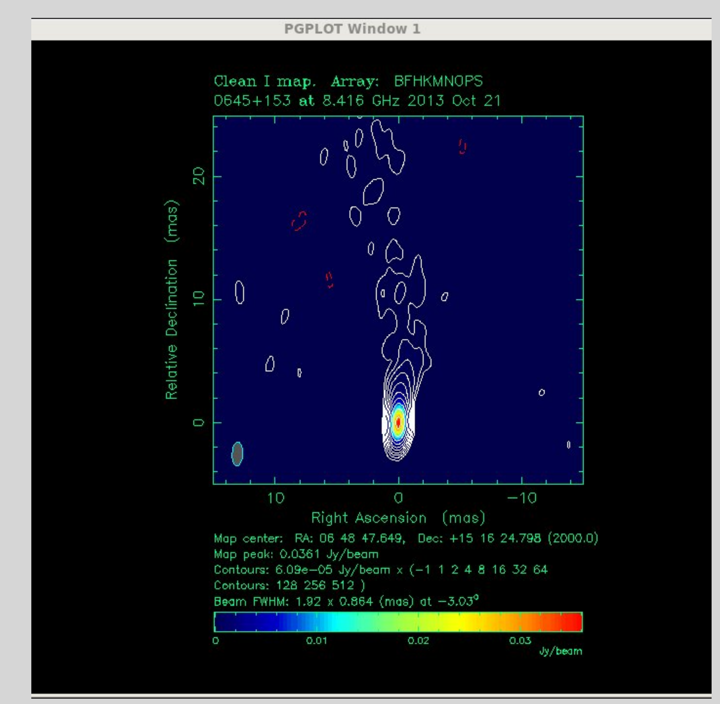
1ES 0229+200 (*z*=0.14)



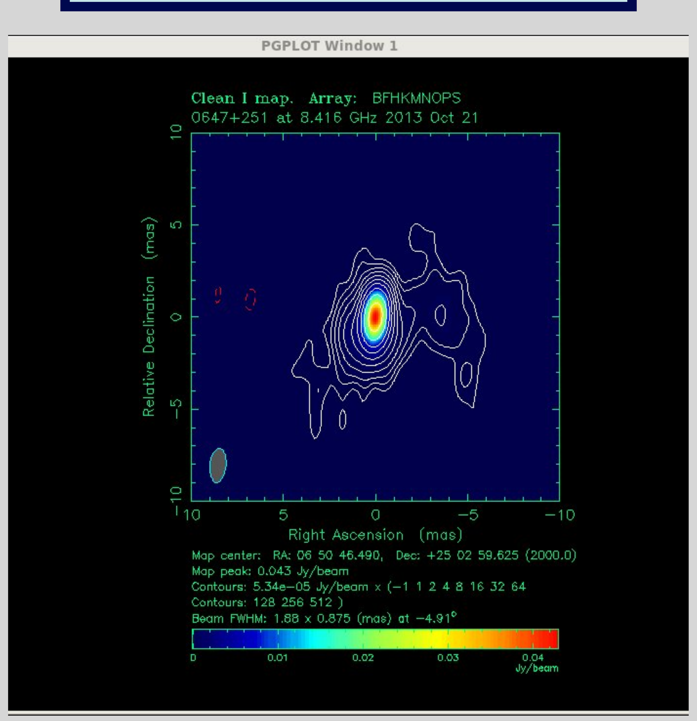
1ES 0502+675



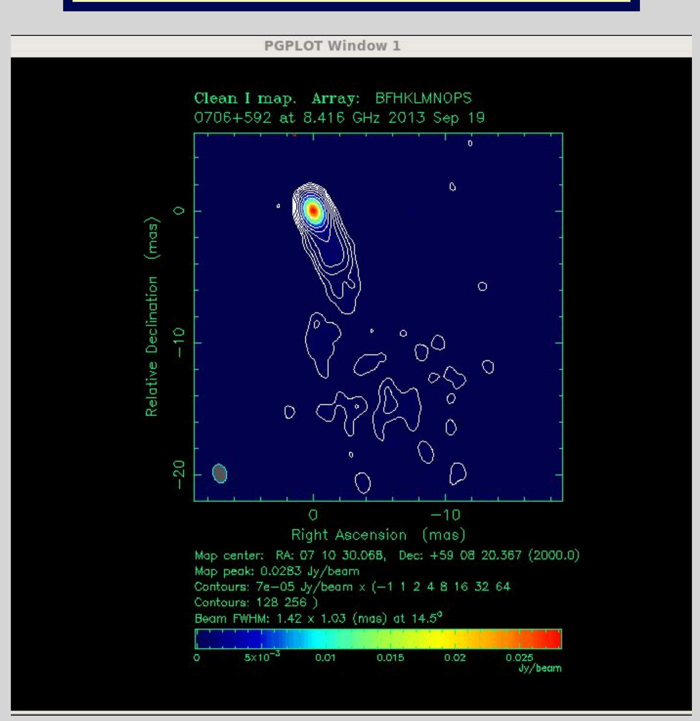
RX J0648.7+1516 (*z*=0.18)



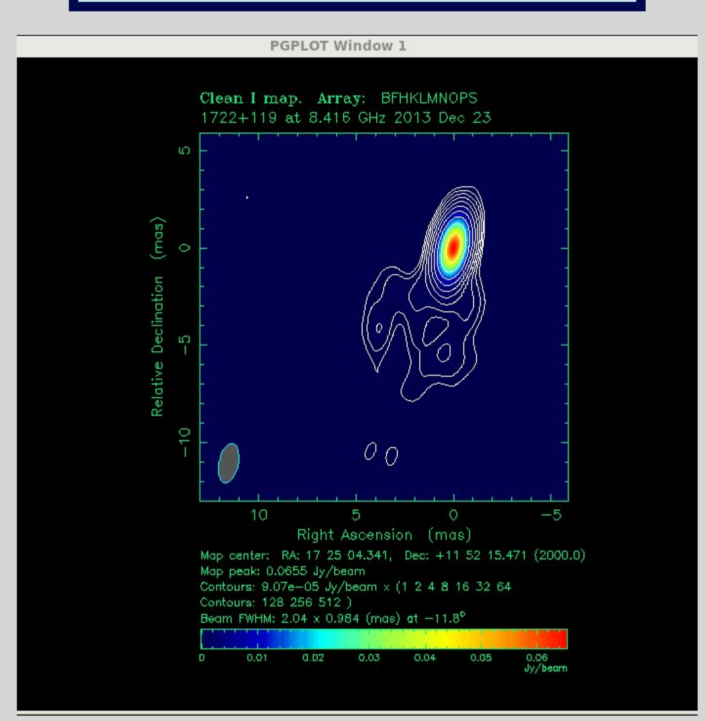
1ES 0647+250 (*z*=0.45)



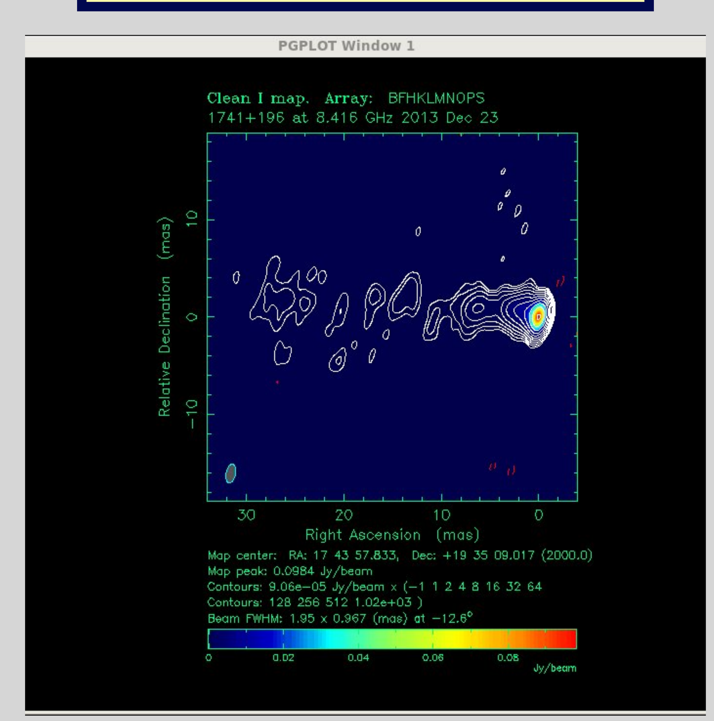
RGB J0710+591 (*z*=0.125)



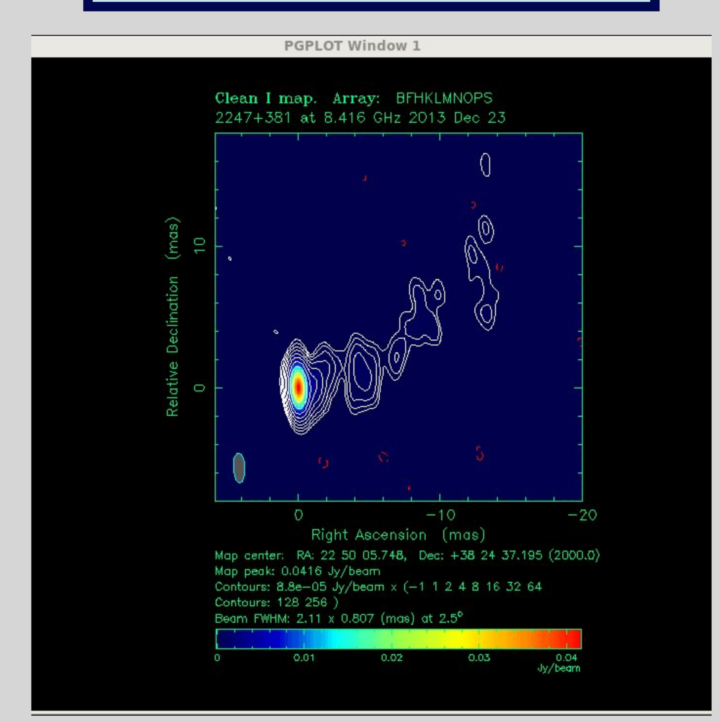
H 1722+519 (*z*>0.17)



1ES 1741+196 (*z*=0.08)



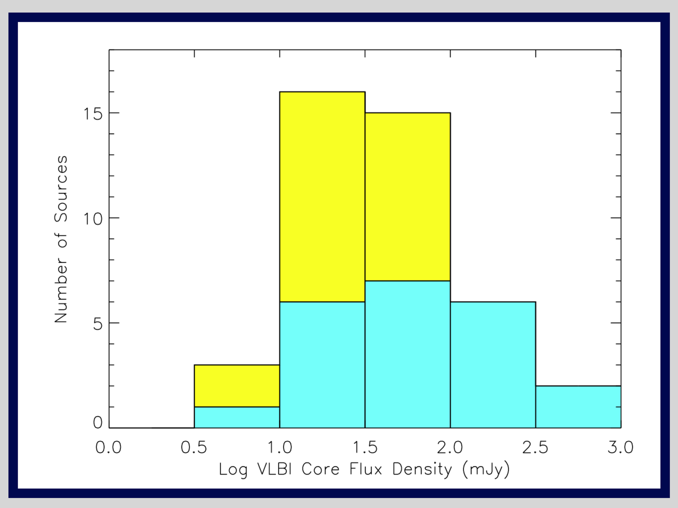
B3 2247+381 (*z*=0.12)

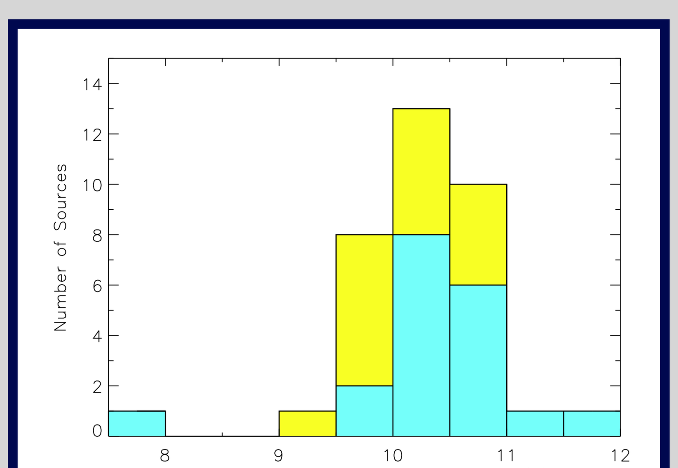


Results

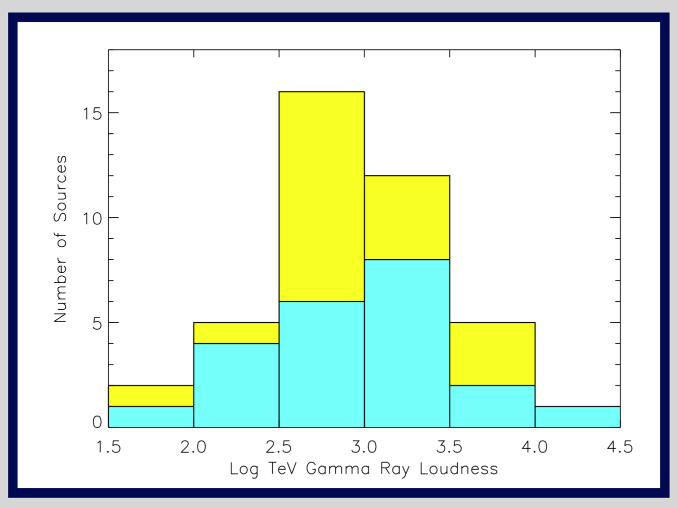
Many of the TeV HBLs show a collimated jet a few mas long (limb-brightened in a number of cases), followed by patchy, low surface brightness emission with a broad opening angle, similar to the morphology of Markarian 421 and Markarian 501. Core flux densities range from 7 to 95 mJy, with a median of 28 mJy. Brightness temperatures range from 3×10^{9} K to 5×10^{10} K, with a median of 2×10^{10} K; however, many of these are lower limits. We performed a detailed error analysis on the brightness temperatures to determine allowed ranges consistent with the measured visibilities (Piner & Edwards 2014). A brightness temperature of 2×10^{10} K is consistent with the data for all but one of the sources, and we conclude that this is a typical brightness temperature of a TeV HBL.

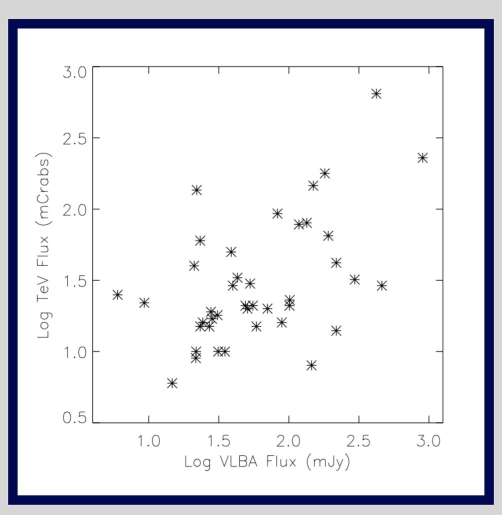
Combining the VLBI data with gamma-ray data from the literature, and removing any effects due to common redshift, we find a significant correlation between the VLBI and TeV flux density. Comparison with uncorrelated samples from Monte Carlo simulations using the method of Pavlidou et al. (2012) confirms a correlation, implying that the TeV and VLBI emission are not completely decoupled, despite their different beaming factors.





Core flux (42 sources) and brightness temperature (35 sources) of TeV HBLs. Sources from this work are in yellow.





Histogram of TeV loudness (ratio of TeV to VLBI flux), and scatter plot of VLBI flux versus TeV flux. Sources from this work are in yellow .

Discussion

Brightness temperatures of the TeV HBLs do not require large Doppler factors to bring them below the inverse Compton or equipartition limits. This agrees with our previous results on 11 TeV blazars that showed subluminal apparent speeds, implying only modest beaming factors. This contrasts with the high Lorentz factors invoked to explain the gamma-ray emission. This implies that the jets of the TeV HBLs are probably structured, with velocity structures either along the jet or transverse to the jet. Limb brightening in VLBI images of some TeV blazars (Piner et al. 2009, 2010) may also be evidence for transverse velocity structures. We are completing multi-epoch monitoring of these 20 sources; at least 4 epochs for each source are scheduled to be completed by the end of 2015. Apparent speeds should be available for these sources shortly after. All images and calibrated data files are available at the project website: www.whittier.edu/facultypages/gpiner/research/archive/archive.html.

References

Aharonian et al. 2007, ApJ, 664, L71; Begelman et al. 2008, MNRAS, 384, L19; Pavlidou et al. 2012, ApJ, 751, 149; Piner & Edwards 2014, ApJ,797, 25; Piner et al. 2009, ApJ, 690, L31; Piner et al. 2010, ApJ, 723, 1150; Tiet et al. 2012, arXiv:1205.2399