H.E.S.S. Observations & VLT Spectroscopy of PG 1553+113

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Abstract

Very-high-energy (VHE; >100 GeV) γ-ray observations of PG 1553+113 were made with the High Energy Stereoscopic System (H.E.S.S.) in 2005 and 2006. A strong VHE signal, ~10σ excess, is measured during the ~25 hours of observations. The integral flux observed is ~3.3% of the Crab Nebula flux above 300 GeV. The time-average energy spectrum measured from ~200 GeV to ~600 GeV is characterized by a very steep power law (photon index of $\Gamma=4.43\pm0.37_{stat}\pm0.10_{syst}$). There is no evidence for any temporal flux or spectral variations within the VHE data. H.E.S.S. results during simultaneous Suzaku X-ray observations are also presented. To determine the redshift of PG 1553+113, near-infrared spectroscopy was performed in March 2006 with SINFONI, an integral field spectrometer of the ESO Very Large Telescope (VLT) in Chile. Unfortunately the redshift is still unknown as no absorption of emission lines are found in the near-infrared spectrum.

Introduction

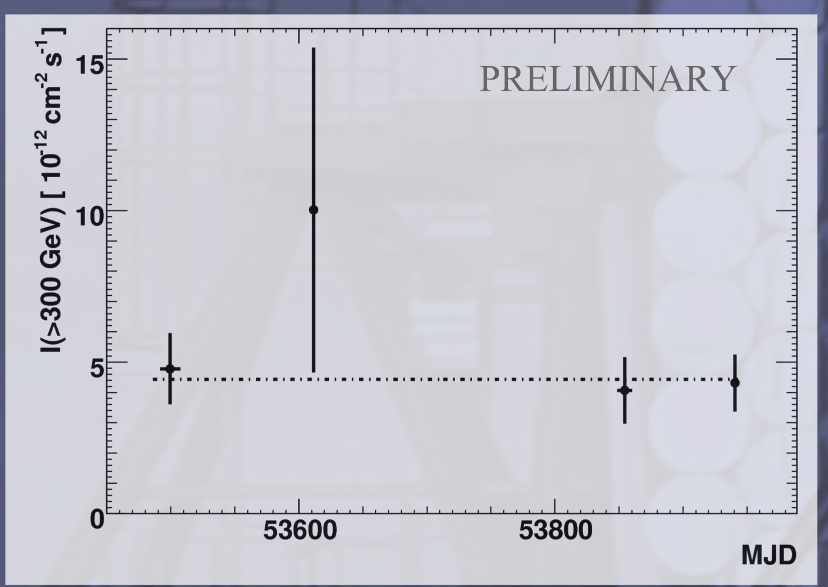
The H.E.S.S. experiment [7], an array of four imaging atmospheric-Cherenkov telescopes located in Namibia, uses stereoscopic observations of γ-ray induced air showers to search for astrophysical γ-ray emission from AGN at VHE energies. The sensitivity of H.E.S.S. (5σ in 25 hours for a 1% Crab Nebula flux source at 20° zenith angle) has enabled the detection of VHE emission from 10 AGN, including PG 1553+113 [1].

PG 1553+113 is a high-frequency peaked BL Lac and should possess a double-humped broad-band spectral energy distribution (SED) typical of blazars. Although it is well-studied from radio to X-ray energies, the high-energy bump of its SED is only measured [1,4] at VHE energies and the errors on the observed VHE quantities are relatively large. Further complicating the interpretation of the SED are the potentially strong effects of the redshift and energy-dependent absorption of VHE photons on the Extragalactic Background Light (EBL). These effects are difficult to account for as the redshift of PG 1553+113 is unknown, despite many measurement campaigns, and only weakly-constraining limits, ranging from z>0.09 to z<0.74, have been determined. Reliable modeling of PG 1553+113 requires improved VHE measurements, simultaneous observations at lower energies, and a redshift determination.

VHE Monitoring of PG 1553+113

Evidence for VHE γ-ray emission from PG 1553+113 was discovered [1] by H.E.S.S. during observations in 2005. It was re-observed in 2006 to increase the event statistics measured from the object, improve the VHE spectrum, and to monitor for potential VHE flaring behavior. A total of 17.2 hours of good-quality observations were performed, increasing the total data set to 24.8 hours. A point-like γ-ray excess is detected from PG 1553+113 in both 2005 and 2006. The observed VHE flux is constant on all time scales.

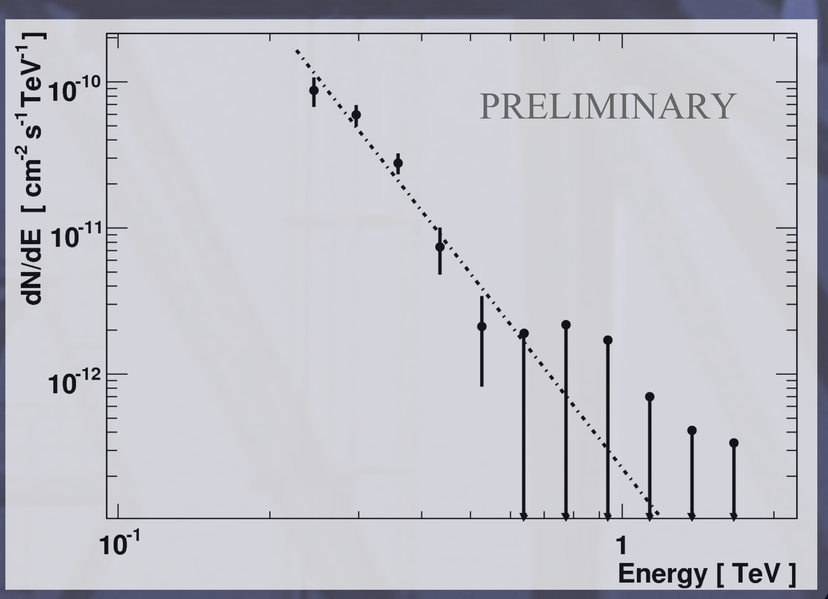
Epoch	T [h]	Excess	Signif. [σ]	I(>300 GeV) [10^{-12} cm^{-2} s^{-1}]
2005	7.6	248	6.0	$5.43\pm1.23_{stat}$
2006	17.2	537	8.3	$4.21\pm0.72_{stat}$
Total	24.8	785	10.2	$4.55\pm0.62_{stat}$



RIGHT: The flux (>300 GeV) measured by H.E.S.S. from PG 1553+113 in monthly bins. The x-errors reflect the observation dates. The 2005 values are ~3 times higher than previously published [1] as all fluxes are corrected [3, see below] for degradation in the absolute optical efficiency of the H.E.S.S. system. Only the statistical errors are shown.

VHE Spectrum of PG 1553+113

The time-average photon spectrum is well fit by a power-law function (photon index $\Gamma=4.43\pm0.37_{stat}$) from 224-585 GeV. There are no significant spectral features (e.g. a cut-off or break). The photon index agrees well with the MAGIC measurement [4], $\Gamma=4.21\pm0.25_{stat}$, at slightly lower energies.



RIGHT: The VHE spectrum measured by H.E.S.S. from PG 1553+113 in 2005-2006. Only the statistical errors are shown. The upper limits are at the 99% confidence level [6].

Remarks on the Scientific Quantities

The H.E.S.S. standard analysis [3,5] is used for all results presented here. For all integral fluxes a power-law spectrum with the measured photon index $\Gamma=4.43$ is assumed. Using a different Γ (i.e. $4.0 < \Gamma < 5.0$) has less than a ~10% effect. The systematic error is 20% for all flux quantities and 0.1 for the photon index. For the spectrum and flux determination the energy of each event event is corrected [3] for the absolute optical efficiency of the system using efficiencies determined from simulated and observed muons. This correction eliminates any potential long-term variations in the absolute energy scale of the HESS analysis due to a changing optical throughput. The correction affects the flux of soft spectrum sources much more strongly than hard spectrum objects.

Acknowledgments & References

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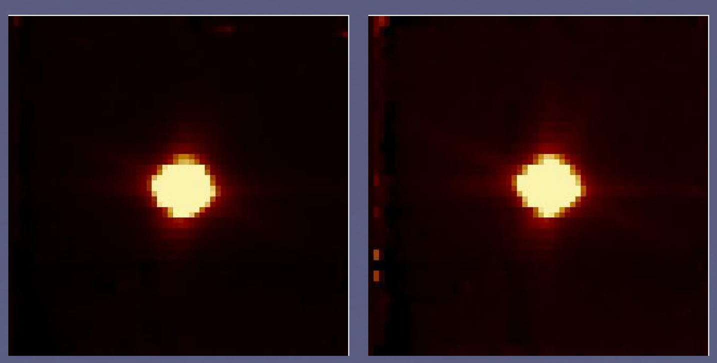
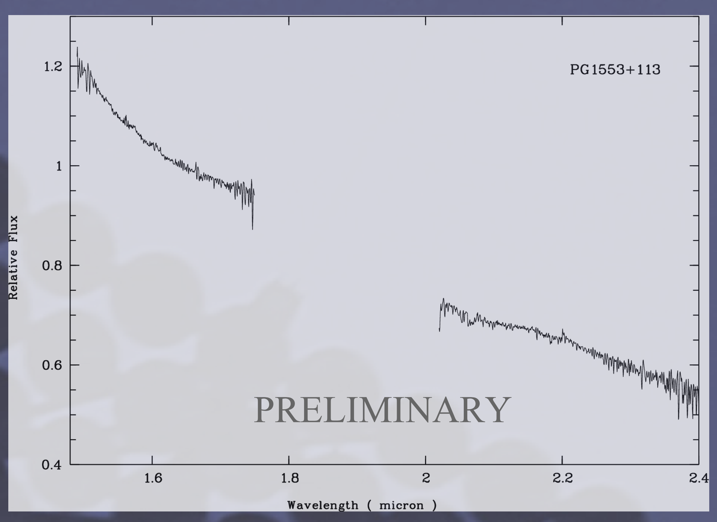
[1] Aharonian et al., A&A, 448, L19 (2006); [2] Aharonian et al., Nature, 440, 1018 (2006); [3] Aharonian et al., A&A, 457, 899 (2006); [4] Albert et al., ApJ, 654, L119 (2007); [5] W. Benbow, Proc. of Towards a Network of Atmospheric Cherenkov Detectors VII (Palaiseau), 163 (2005); [6] Feldman & Cousins, Phys Rev D, 57, 3873 (1998); [7] J. Hinton, New Astron Rev, 48, 331 (2004); [8] Primack et al., AIP Conf. Proc., 558, 463 (2001) [9] M. Punch, Proc. of Towards a Network of Atmospheric Cherenkov Detectors VII (Palaiseau), 509 (2005);

SINFONI Near-IR Spectroscopy

In an attempt to determine the redshift of PG 1553+113, via the detection of absorption features from the host galaxy or emission lines from the AGN, H+K (1.45-2.45 μm) spectroscopy was performed with SINFONI, an integral field spectrometer mounted at Yepun, Unit Telescope 4 of the ESO Very Large Telescope (VLT) in Chile. A total of 2.5 hours of observations were taken on March 9 & 15, 2006.



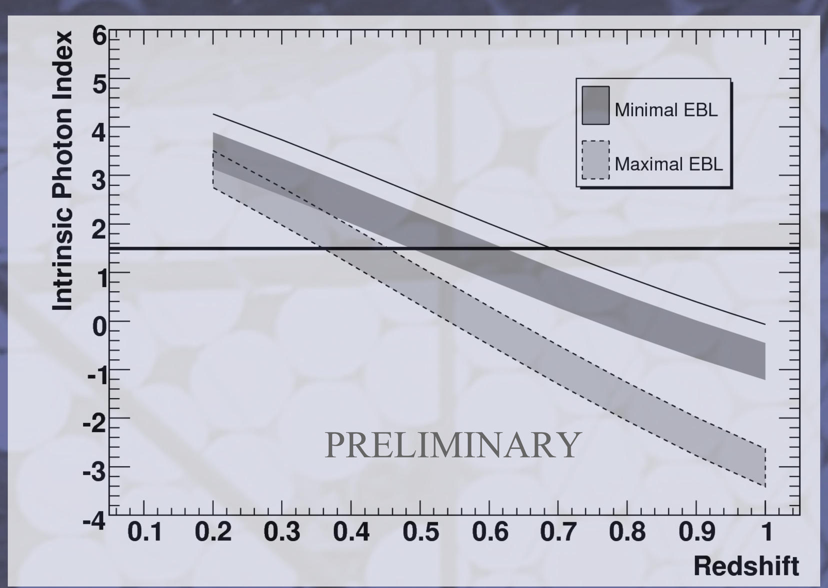
ABOVE: The H (left) and K (right) band images of PG 1553+113. The images are totally unresolved and the host galaxy is not detected.



BELOW: The normalized H and K band spectrum of PG 1553+113. The signal-to-noise reach is ~250 in the H-band and ~50 in the K-band. The lack of data between the H and K bands is due to highly-reduced atmospheric transmission. No redshift can be determined from the featureless spectrum. The measured flux is 12.7±1.3 mJy at 1.65 μm.

The Intrinsic VHE Spectrum

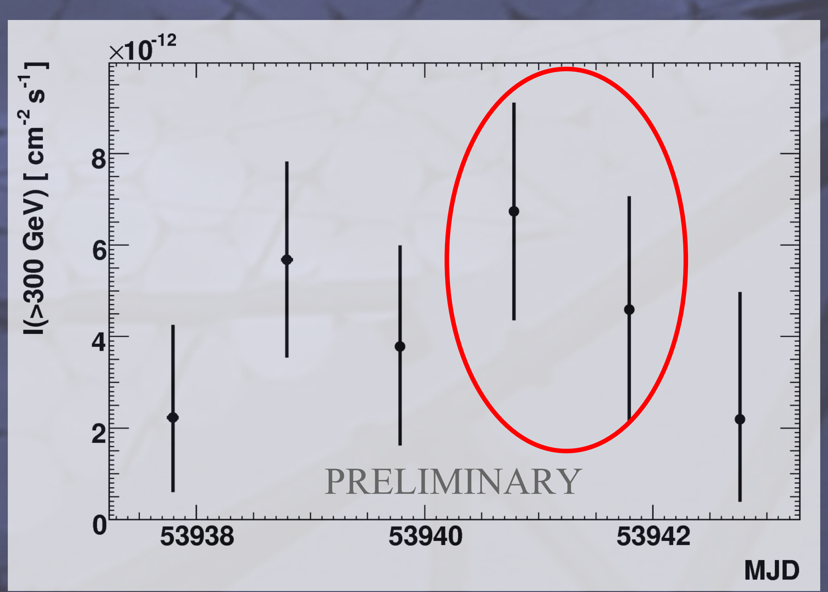
As the redshift of PG 1553+113 is likely z>0.2, the observed VHE spectrum should be strongly affected by VHE γ-ray absorption on the EBL. If the redshift were known the spectrum intrinsic to the source could be reconstructed assuming a model of the EBL density. However, the EBL SED is not well-determined. Using a "Maximal" EBL model at the level of the upper limits from [2] or a "Minimal" model near the EBL lower limits from galaxy counts can yield a significantly different intrinsic spectrum. The redshift of the AGN can be limited using assumptions for the intrinsic spectrum. Assuming the intrinsic photon index is not harder than $\Gamma_{int}=1.5$, a limit of z<0.69 is thus determined from a "Minimal" EBL model. The scaled models of [8] used here are described in [1].



Above: The photon index Γ_{int} determined from a power-law fit to the intrinsic spectrum of PG 1553+113 (i.e. the H.E.S.S. data de-absorbed with an EBL model) for a range of redshifts. The contours reflect the 1σ statistical uncertainty of the fits. The upper curve is the sum of Γ_{int} for the "Minimal" model and twice its statistical error.

Suzaku X-ray Observations

PG 1553+113 was continuously observed by the Suzaku X-ray satellite from 14:26^{UTC} on July 24, 2006 to 19:17^{UTC} on July 25, 2006. Ten H.E.S.S. runs (3.1 h) are simultaneous to these data, during which a 3.9σ excess of 101 γ-rays is detected. The average VHE flux is I(>300 GeV)=$5.8\pm1.7_{stat}$ x10^{-12} cm^{-2} s^{-1}.



RIGHT: The nightly flux measured from PG 1553+113 in July 2006. The points are located at the temporal midpoint of the data. Only the statistical errors are shown. The simultaneous H.E.S.S. data is circled.

Conclusions

With a ~25 hour data set that is ~3 times larger than previously published [1], the H.E.S.S. signal from PG 1553+113 is now highly significant (~10σ). Thus, the evidence for VHE emission previously reported is now clearly verified. However, the flux measured in 2005 is ~3 times higher than first reported due to an improved calibration of the absolute energy scale of H.E.S.S. The statistical error on the VHE photon index is now reduced from ~0.6 to ~0.4. Nevertheless, the error of 0.37 is still rather large. Barring a flaring episode, not yet seen in two years of observations, a considerably larger total exposure (~100 hours) would be required to significantly improve the spectral measurement. However, even a factor of a few increase in VHE flux would reduce the observation requirement considerably. Should such a VHE flare occur, not only will the error on the measured VHE spectrum be smaller, but the measured photon index may also be harder. Both effects would dramatically improve the redshift constraints and correspondingly the accuracy of the source modeling. As a result PG 1553+113 will continue to be monitored by H.E.S.S. In addition the extremely-soft observed spectrum ($\Gamma=4.43$) makes it an ideal target for the lower-energy-threshold H.E.S.S. Phase II [9].

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