# Ten years of H.E.S.S. I extra galactic observations revisited


**F. Brun[1*], D. Sanchez[2] and J. Chevalier[2]**
**for the H.E.S.S. collaboration**

[1]Centre d'Études Nucléaires de Bordeaux Gradignan - CNRS/IN2P3, France
[2]Laboratoire d'Annecy-le-Vieux de Physique des Particules – CNRS/IN2P3, France
* brun@cenbg.in2p3.fr


## Abstract


In the past decade, the H.E.S.S. (High Energy Stereoscopic System) experiment has significantly contributed to the field of VHE gamma-ray astronomy. In particular, during the first phase of the experiment from 2004 to 2013, the extra Galactic observation program led to the discovery of more than 20 sources of VHE gamma-rays. During this observation program, some regions of the sky were also observed without leading to a detection. About 6.5% of the sky was observed and it is now possible to re-analyse these data with the most up-to-date analysis techniques in an uniform way. This allows for population studies, variability studies, transient searches in the observed regions and robust comparison with the latest Fermi- LAT catalogs.

In this contribution, the re-analysis of these ~2700 hours of observation is presented, together with the data products that are intended to be released to the scientific community.

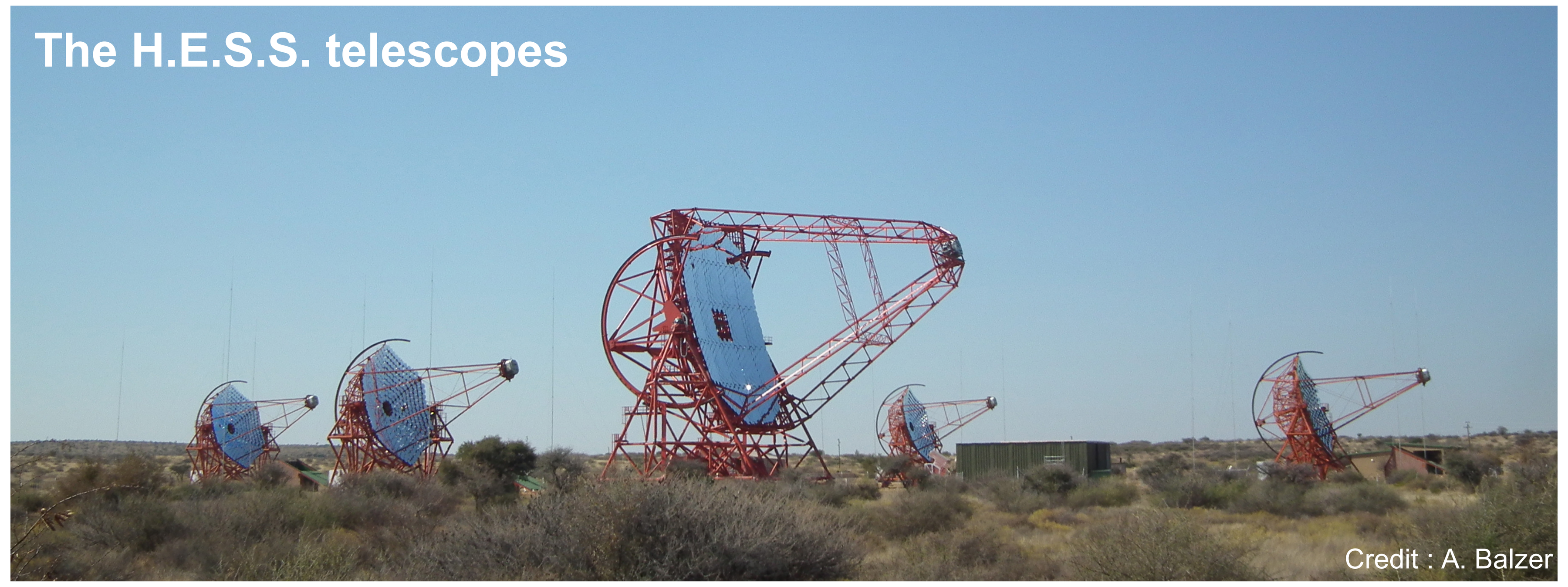




*FIG. 1 : The H.E.S.S. Telescopes. Located in Namibia, this array of Imaging Atmospheric Cherenkov Telescopes detects very-high energy gamma rays. In its first phase (2004 – 2012), the array had 4 telescopes. The fifth, largest, telescope was added in July 2012. The analysis presented here uses only data taken with the original array.*

## Data selection and analysis procedure

All H.E.S.S. data taken between January 2004 and January 2013 are selected for this analysis. The observation runs are then grouped in *RunsClusters* using the DBSCAN algorithm from the scikit-learn library [1]. After this step, some regions are removed from this study, such as the Galactic plane or the LMC. Each remaining *RunsCluster* defines a spatially independent region observed by H.E.S.S. The 123 selected RunsClusters are the results of ~ 6500 observation runs, corresponding to ~ 2700 hours of observation and covering ~6.5 % of the sky.

The analysis of each *RunsCluster* is then performed using the Model Analysis [2] and a set of maps – significance, flux or upper limits – is derived. From these maps, values of interest can easily be retrieved. In this analysis, the flux-related products were derived assuming a Power-Law with a spectral index of 3. The results presented here have been cross-checked using an independent calibration and analysis chain.

## Released maps

For each *RunsCluster* identified on the all-sky map below, the following maps are computed : Significance, Flux, Flux Upper Limits and ON-OFF variability test. As an example, the RunsCluster presented here is the one towards the source Mrk 501.

**We intend to release the maps for all the RunsClusters in FITS format.**

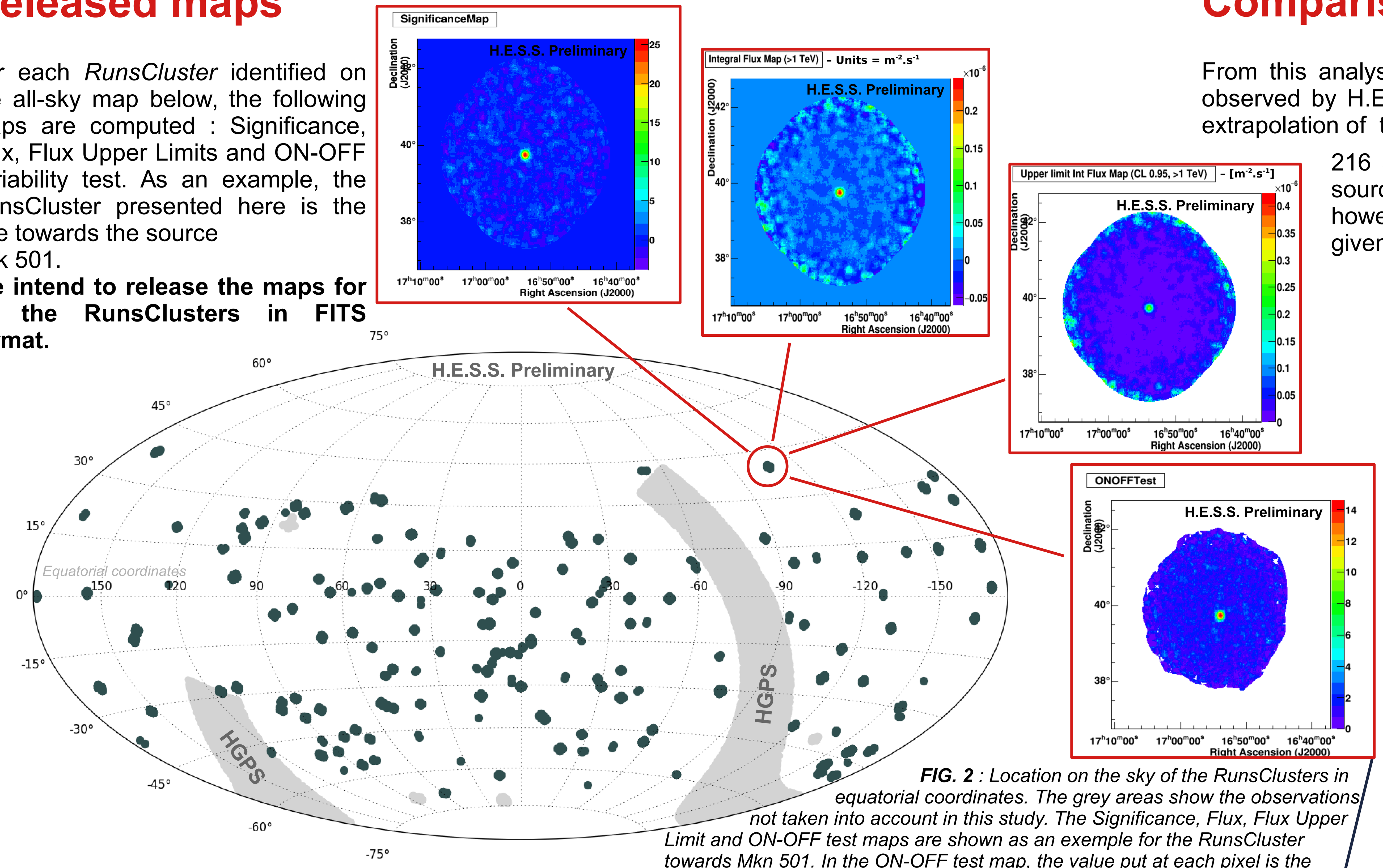
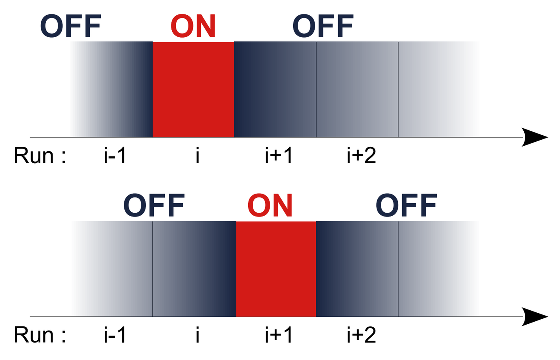



*FIG. 2 : Location on the sky of the RunsClusters in equatorial coordinates. The grey areas show the observations not taken into account in this study. The Significance, Flux, Flux Upper Limit and ON-OFF test maps are shown as an exemple for the RunsCluster towards Mkn 501. In the ON-OFF test map, the value put at each pixel is the maximum significance found over the observations considered in this pixel.*

## Variability search with the ON-OFF method

We can compute a set of maps for each observation. At any given position in the map and for each *RunsCluster* and each observation, we have the number of reconstructed gamma-like events together with an estimation of the detector's acceptance.
We have developed a method that uses these quantities to probe variability on the time-scale of the observations. This method is the analogous in the time domain to the standard ON-OFF method used to compute excess and significance maps [3].
This method computes the excess of gamma-rays at a given position and during a given observation with respect to all the other (excess-less) observations. The significance of the excess can then be computed from eq. 17 of the Li & Ma publication [4].

This method can therefore be used to blind-search variability across the observed field-of-views.




For N runs of observation and for a given position, the excess for each observation i is $N_{y,i} = N_{ON,i} - \alpha_i N_{OFF,i}$ where :
- $N_{ON,i}$ = number of events in run i
- $N_{OFF,i}$ = number of events in the N-1 other runs
- $\alpha_i$ = ratio of the acceptance integrated in the ON and OFF regions

*Note that the obtained significance must be corrected for the number of trials (number of time bins)*

## Comparisons with Fermi-LAT catalogs

From this analysis it can be derived how many Fermi-LAT sources have been observed by H.E.S.S. In addition, the Flux UL maps are useful to constrain the extrapolation of the flux observed with Fermi in the H.E.S.S. energy range.

216 3FGL [5] sources have been observed in this dataset. For 168 sources, the VHE extrapolation is not constraining. For 48 sources however, this extrapolation is constraining as in the two example SEDs given in the figure below :

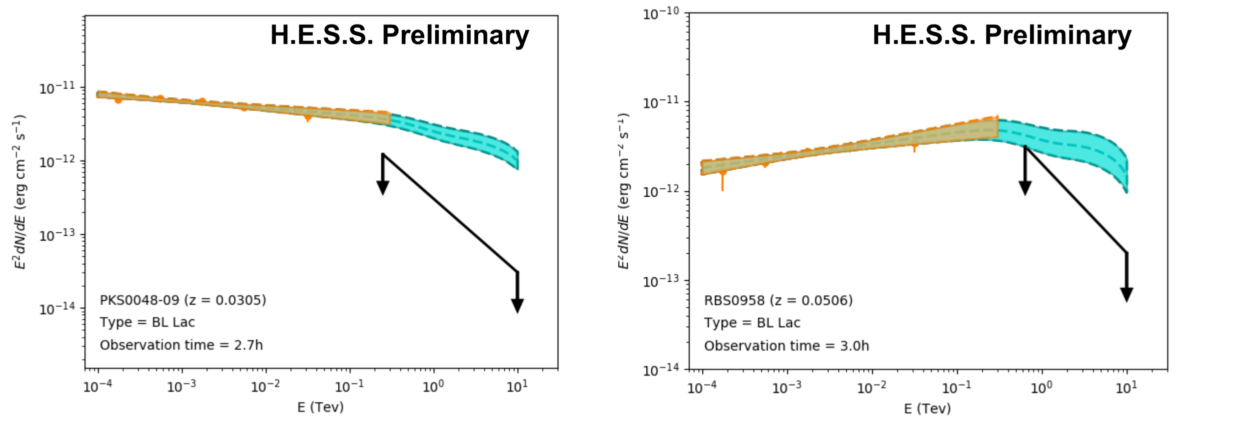



*FIG. 3 : Example SED of two 3FGL sources for which the H.E.S.S. upper limits (in black) are constraining. The 3FGL spectrum from 100 MeV to 100 GeV is shown in orange, the EBL absorbed extrapolation to 10 TeV is shown in blue.*

This study will be helpful to better understand the GeV-TeV connection of extra galactic sources. This will also be of particular interest to better prioritize the sources to observe in the future (see figure below).

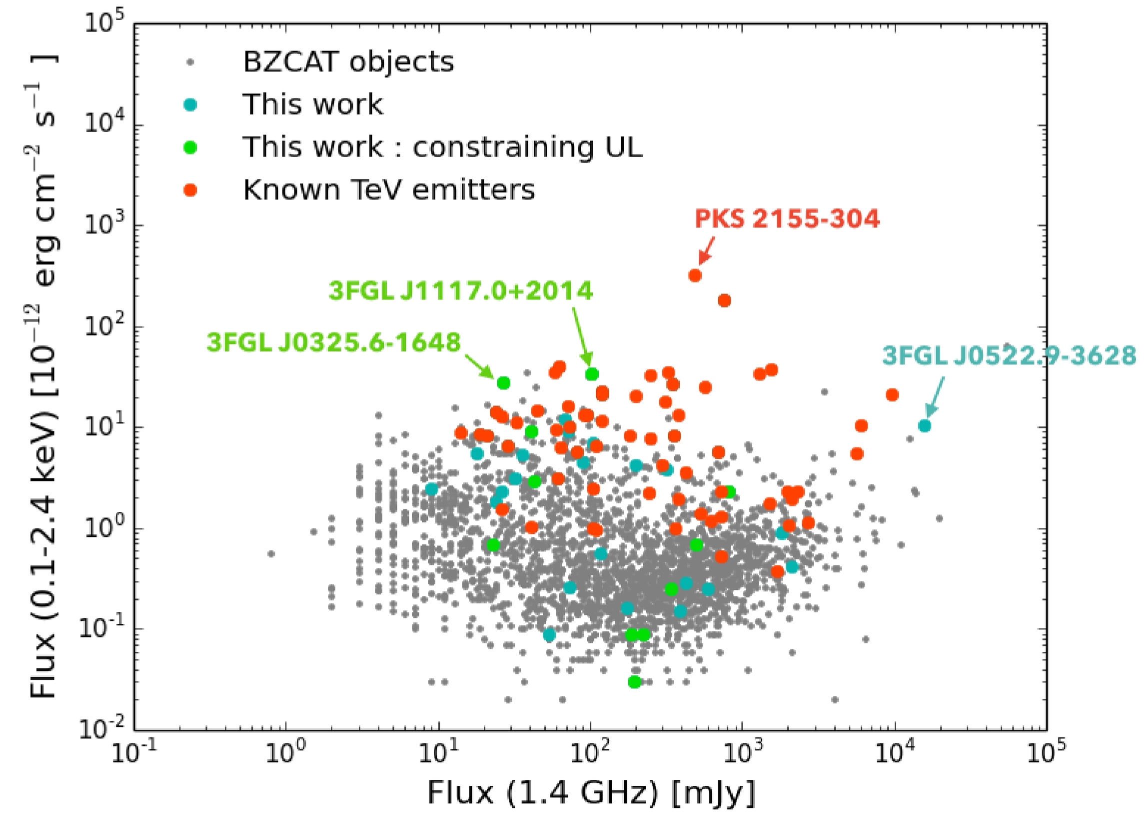



*FIG. 4 : X-ray vs. Radio Flux of the BZCAT objects. The known TeV emitters are shown in red, some of the most constraining H.E.S.S. UL are shown in green while the blue dots show example of non-constraining ULs. Figure taken from [6].*

## References


[1] http://scikit-learn.org [2] de Naurois & Rolland 2009
[3] Berge et al. 2006 [4] Li & Ma, 1983
[5] Fermi-LAT collaboration, 2015
[6] J. Chevalier, PhD Thesis, 2017



**Acknowledgements :** The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the German Research Foundation (DFG), the Alexander von Humboldt Foundation, the Deutsche Forschungsgemeinschaft, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Science and Technology Facilities Council (STFC), the IPNP of the Charles University, the Czech Science Foundation, the Polish National Science Centre, the South African Department of Science and Technology and National Research Foundation, the University of Namibia, the National Commission on Research, Science & Technology of Namibia (NCRST), the Innsbruck University, the Austrian Science Fund (FWF), and the Austrian Federal Ministry for Science, Research and Economy, the University of Adelaide and the Australian Research Council, the Japan Society for the Promotion of Science and by the University of Amsterdam. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment. This work benefited from services provided by the H.E.S.S. Virtual Organisation, supported by the national resource providers of the EGI Federation.


H.E.S.S.


**7th International Fermi Symposium – 15-20 October 2017 – Garmisch-Partenkirchen**