The Galactic TeV sky: sources or diffuse emission?

Kathrin Egberts, Constantin Steppa, Karol Peters
University of Potsdam

Introduction

Galactic diffuse emission at TeV energies is characterised by small fluxes, which challenge its measurements.

Recent measurements seem to indicate a difference between imaging atmospheric Cherenkov telescopes (IACTs) and air-shower particle detectors (ASPDs): while IACTs see a *source-dominated* Galactic Plane, ASPDs see *predominantly diffuse emission*.

Besides probing different parts of the Milky Way, this discrepancy could be a consequence of the individual biases of the instruments, based on their strengths and weaknesses.

Abstract

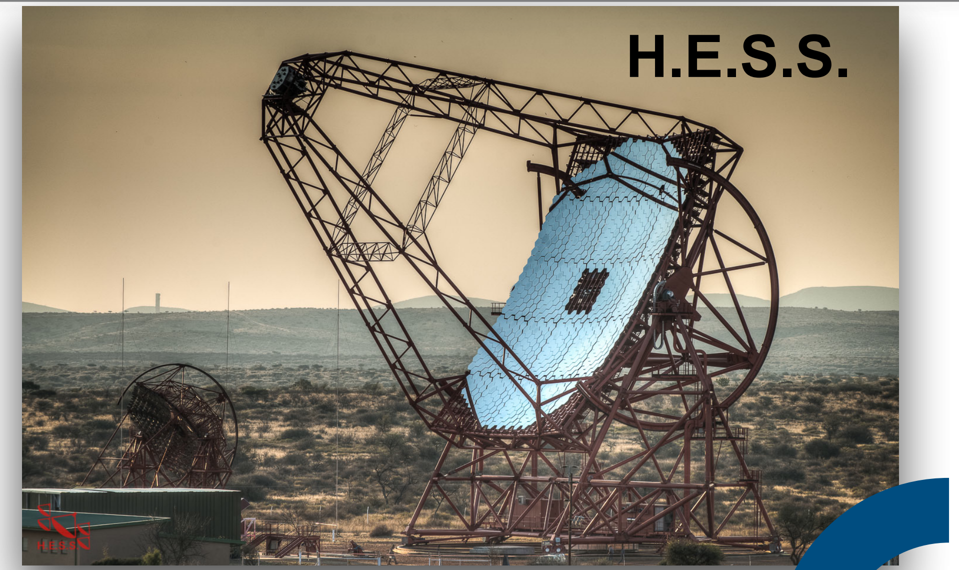
Gamma-ray observations have recently shifted the focus to higher and higher energies, with capable ground-based instruments enabling measurements in the TeV to PeV domain. While a clear prevalence of diffuse emission is observed in the GeV sky, energy-dependent cosmic-ray transport suggests a reversal of this hierarchy at higher energies. Measurements, however, are at strife regarding this question. While imaging atmospheric Cherenkov telescopes (IACTs) see a source-dominated Galactic plane, air-shower particle detectors (ASPDs) report a dominance of diffuse emission. Reconciling these claims requires a closer look at the involved instrument limitations: IACTs have a small field of view, resulting in poorer performance for large-scale emission due to the applied background subtraction technique. ASPDs have reduced resolution capabilities, resulting in unresolved sources contributing to the measurable diffuse emission signal.

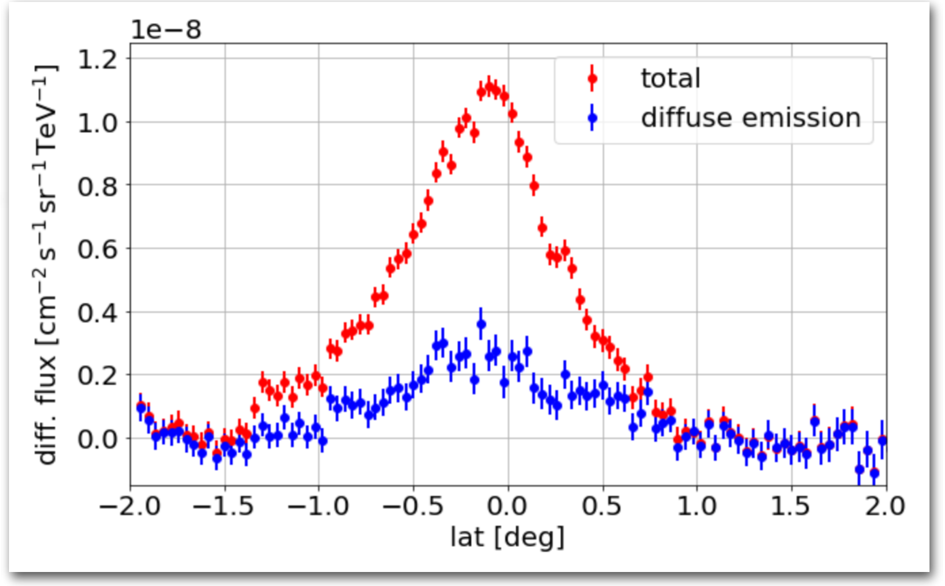
Here we shed light on this controversy by investigating the amount of unresolved sources in current TeV measurements in a population synthesis approach and discuss the unique capabilities for high-resolution diffuse-emission measurements with IACTs and their possibilities for overcoming their background limitations.

TeV Measurements

Imaging Atm. Cherenkov Telescopes

Small fields of view
Angular resolution of $\lesssim 0.1$ deg
Large instantaneous sensitivity

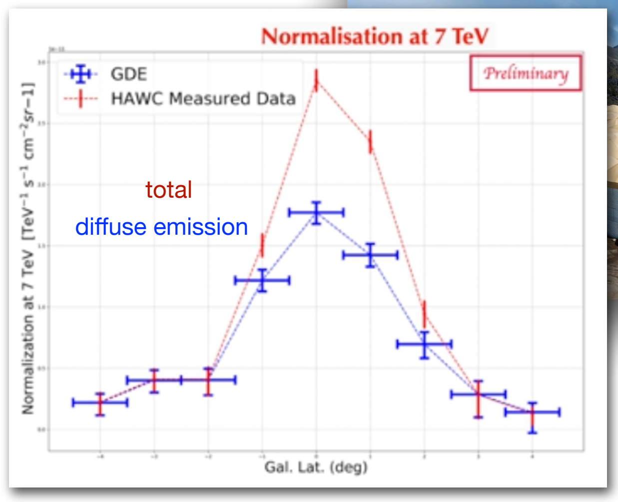




1 TeV diff. flux, $-75^\circ < l < 60^\circ$ (H.E.S.S. 2014)

Artificially reduced flux due to background subtraction (consequence of the small field of view)?

DO SOURCES OR DIFFUSE EMISSION DOMINATE THE GALACTIC PLANE?

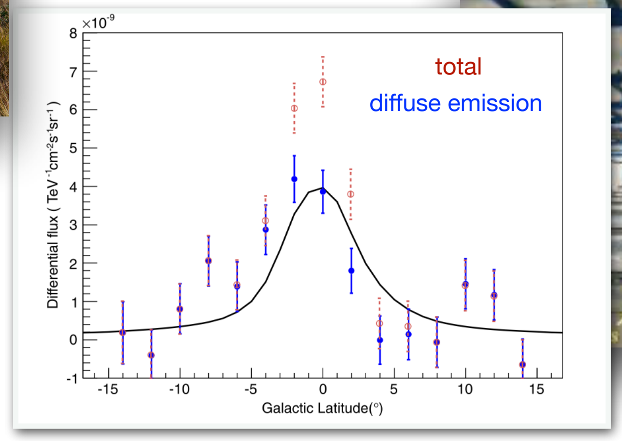


7 TeV diff. flux, $43^\circ < l < 73^\circ$ (Nayerboda et al. 2021)

Artificially increased flux due to unresolved sources (consequence of the poor ang. resolution/limited sensitivity)?

Air Shower Particle Detectors

Wide fields of view
Angular resolution of ~0.5 deg
Large duty cycle



600 GeV diff. flux, $25^\circ < l < 100^\circ$ (Bartoli et al. 2014)

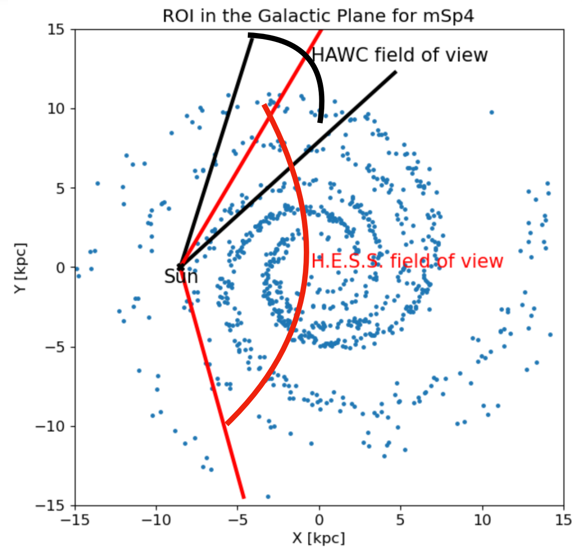
IACT Likelihood Analysis

An alternative method of determining the charged cosmic-ray background in the analysis of IACT data is a likelihood fitting in the two spatial and one energy dimension. Compared to the classical approach of measuring the background in the small field of view and subtract at the source position, this 3D fitting approach enables the recovery of structures larger than the field of view.

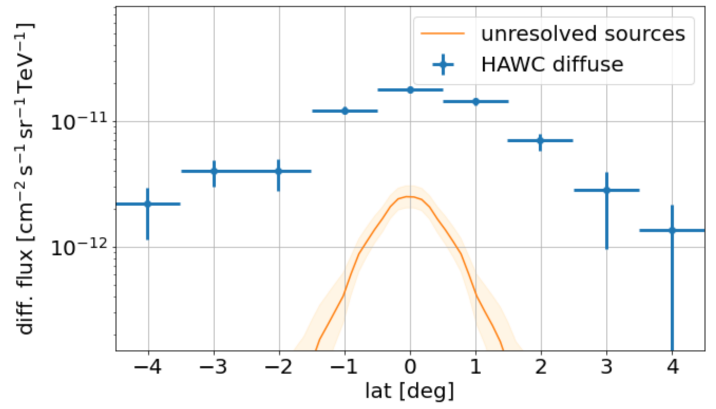
With large-scale diffuse emission being a small signal on top of a vastly dominating charged cosmic-ray background, the in-depth understanding of this background is crucial for a reliable measurement. With the development of run-wise simulations (Holler et al.) and their superior reflection of observation conditions, sufficiently precise background models are now within reach.

Unresolved Sources

We use population synthesis following the approach developed in Steppa & Egberts 2020 to simulate gamma-ray source populations and determine the sub-sample of detectable sources according to the instrument sensitivity and observation time for both H.E.S.S. and HAWC data. The model accurately predicts the latitude flux profile of the HAWC source catalog, verifying the chosen approach.



with HAWC sensitivity, angular resolution, and observation time of diffuse measurement



HAWC diffuse measurement (Nayerhoda et al. 2021)

unresolved sources: median with interquartile range of 3000 simulated populations

The study indicates that unresolved sources form at the Galactic equator a contribution of the order of 10% to the measurable diffuse emission. While this contribution is not large enough to explain the observed difference between IACT and ASPD measurements, it has to be noted that the source simulations *do not include the local arm*. Lying along the direction of the HAWC field of view, the inclusion of this feature has the potential to further increase the amount of unresolved sources in the HAWC diffuse-emission measurement.

References

H.E.S.S. Collaboration: Abramowski et al., PRD, 90, 12, id.122007, 2014
Bartoli et al., Astrophys. J., 806:20 (11pp), 2015
Nayerhoda et al. for the HAWC Collaboration, ICRC 2021
Steppa & Egberts, A&A 643, A137, 2020
Holler et al., Astropart. Phys., 123, 102491, 2020