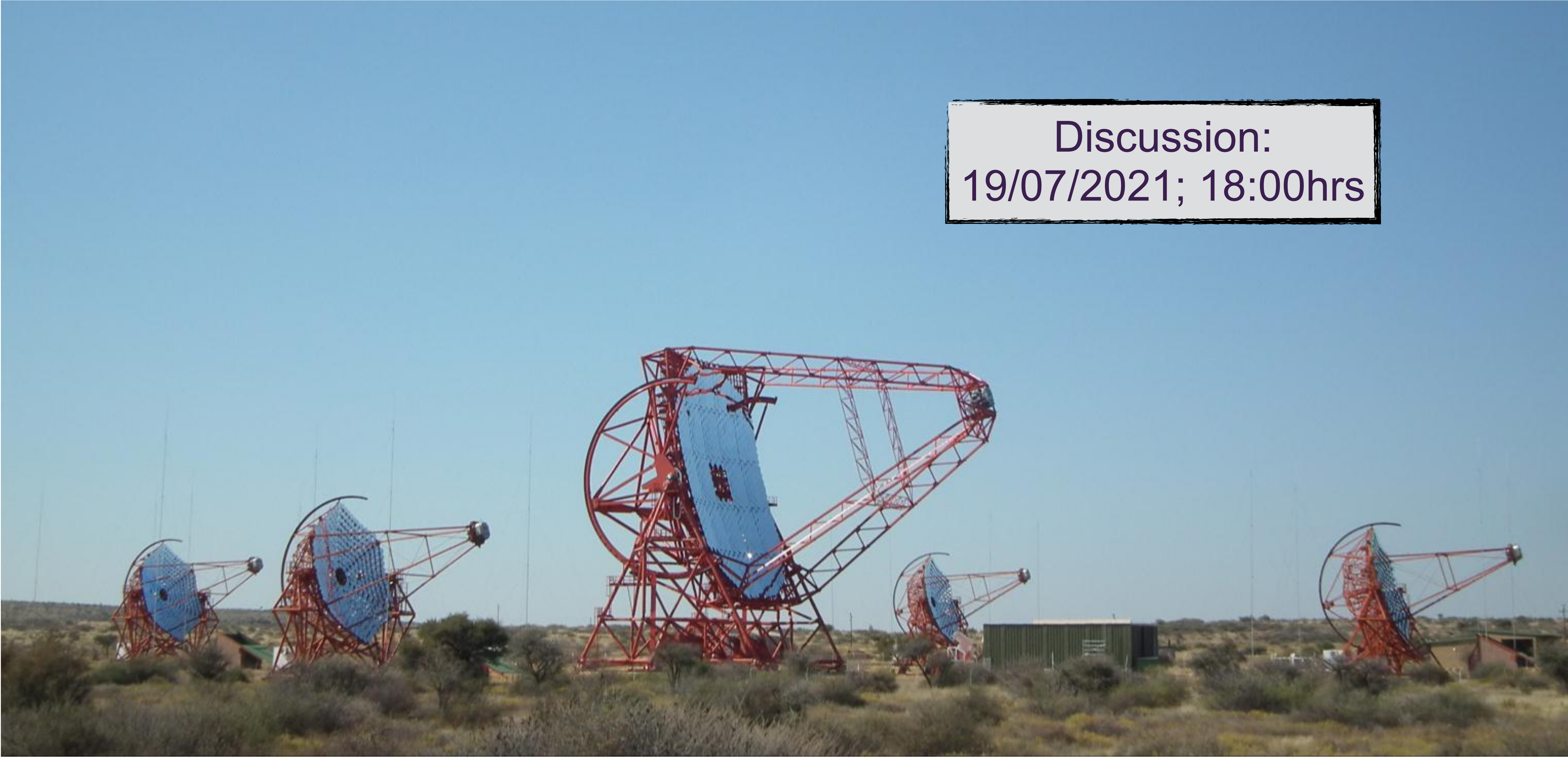

Search for enhanced TeV gamma ray emission from Giant Molecular Clouds with H.E.S.S

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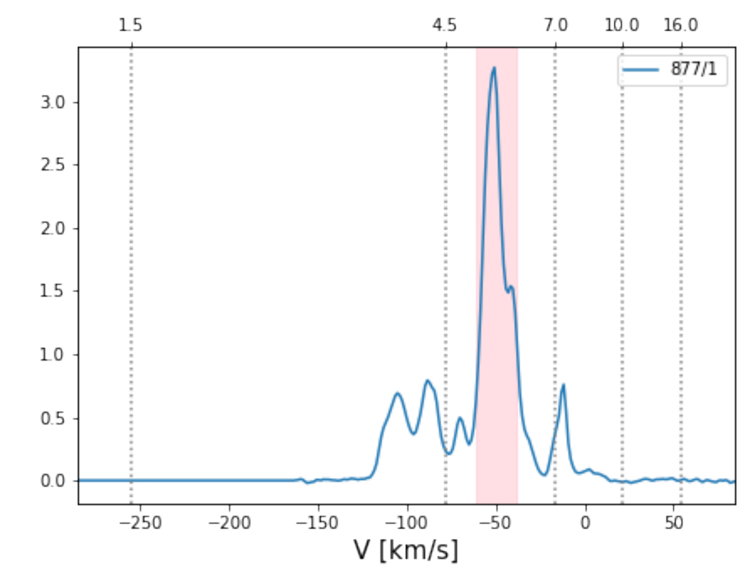
Molecular clouds as cosmic ray barometers

- Direct cosmic ray measurements (eg: AMS-02, DAMPE)
  - Flux/spectrum in the vicinity of the solar system - “local spectrum”
  - Is it representative of the cosmic ray distribution in our galaxy?
- Probing passive molecular clouds directly
  - Trace the distribution of CR at different spatial points
- Gamma ray production in Molecular clouds:
  - Dominant: Pion decay from proton-proton interactions



CO velocity peaks in the direction of cloud 877; [from the data of Dame et al, 2001]

CR proton spectrum reported by local measurements

$$F_\gamma(E_\gamma) = 1.25 \times 10^{19} A \xi_N \int dE_p \frac{d\sigma}{dE_\gamma} F_p(E_p) \; (A = M_5/d^2_{kpc}, M_5 = M/M_{Sun})$$

The total p–p inelastic cross section (Kafexhiu et al. 2014)

See #151 Peron et al.

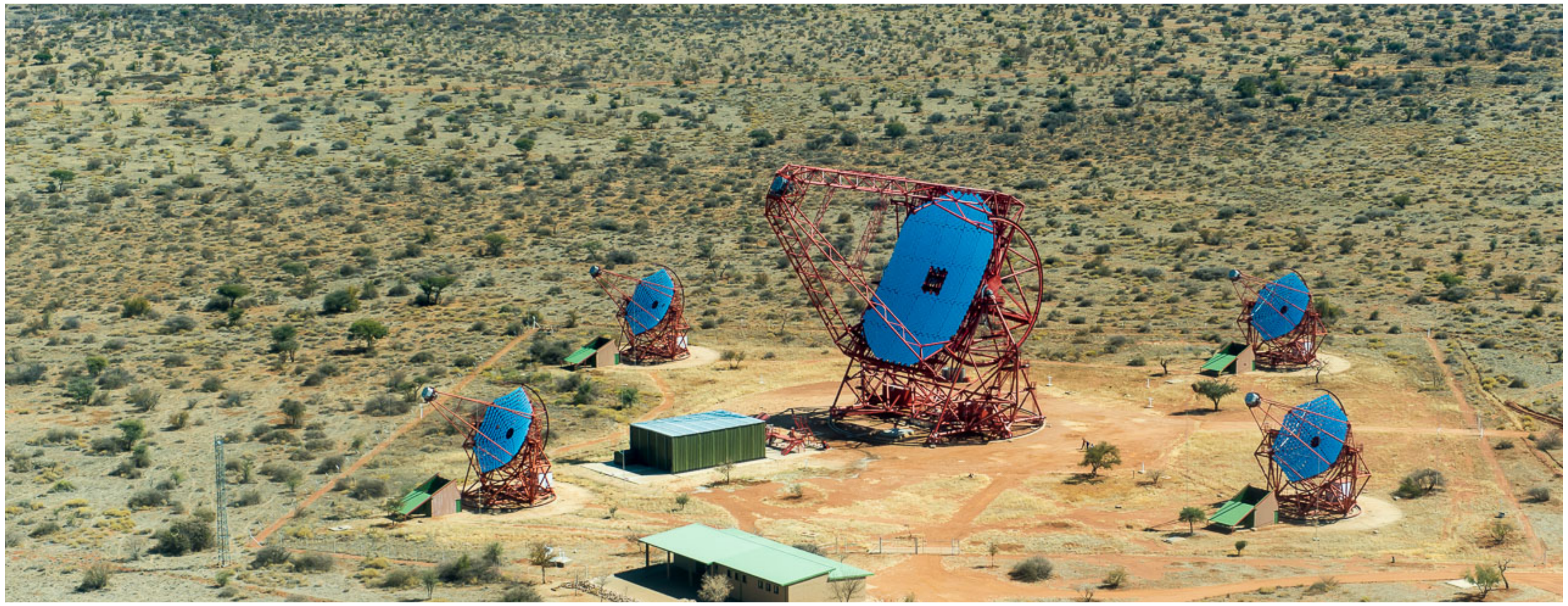
Results from Fermi-LAT and HAWC

- Multiple studies with Fermi-LAT reveal differences from the local spectrum
  - up to ~4 times higher density and harder spectrum, e.g. in a 1.5-4.5 kpc ring (Acero et al. 2016)
  - Deviations in the regions of specific clouds; eg 4-6 kpc ring (eg: Aharonian et al, 2020), Gould Belt (eg: Baghmanyan et al, 2021) , etc
- Upper limits (consistent with the local emission) published by HAWC for high latitude clouds
- **Q: Does the observed flux hardening continue at TeV energies?**

H.E.S.S.

The H.E.S.S. Telescope Array

- An array of 5 Imaging Atmospheric Cherenkov Telescopes (IACTs)
- Located in Khomas highlands, Namibia; operational since 2003
- Array design:
  - four 12m diameter telescopes (CT1-CT4) at the corners of 120m sided square;
  - Central telescope (CT5; 28m) added in 2012.
- This work uses data from
  - CT1-CT4; taken during 2004-2019; Field of View: 5°



Challenges with IACT

- Ideal case
  - Standard analysis of extracting spectrum/morphology in the direction of the cloud
- The emission from the cloud is comparable to the level of the surrounding diffuse emission
  - Find an efficient means of separating the large scale emission and the emission from the cloud
  - Subtract the hadronic background
  - Reject the emission from the known sources
  - ➡ Standard techniques like ring background/reflected background starts to fail
- ✓ Need a full 3D likelihood analysis

Need large exclusion regions - difficult due to the small FoV

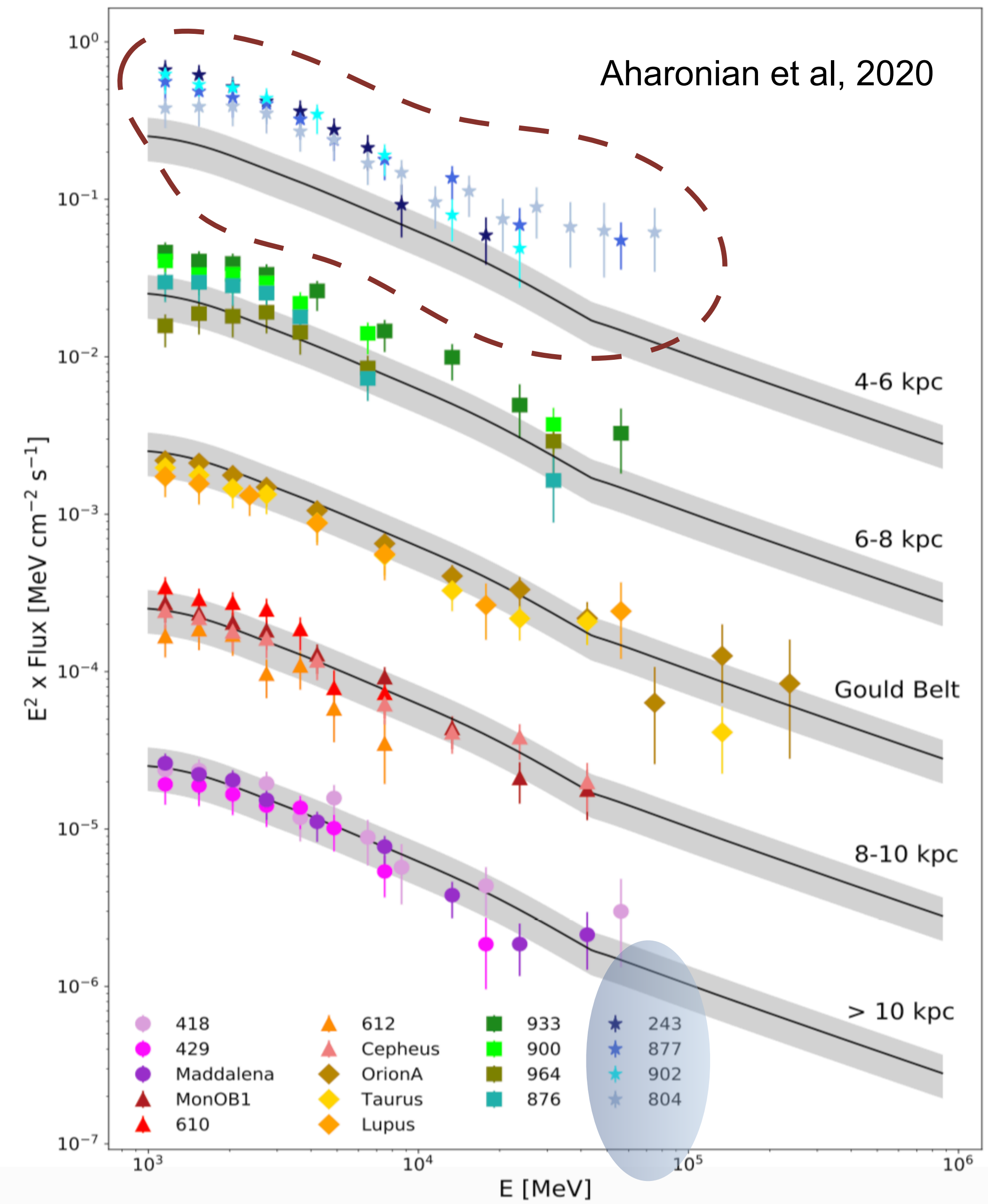
H.E.S.S.

A **Python** package for gamma-ray astronomy

See #1019 Donath et al.

A 3D FoV likelihood analysis

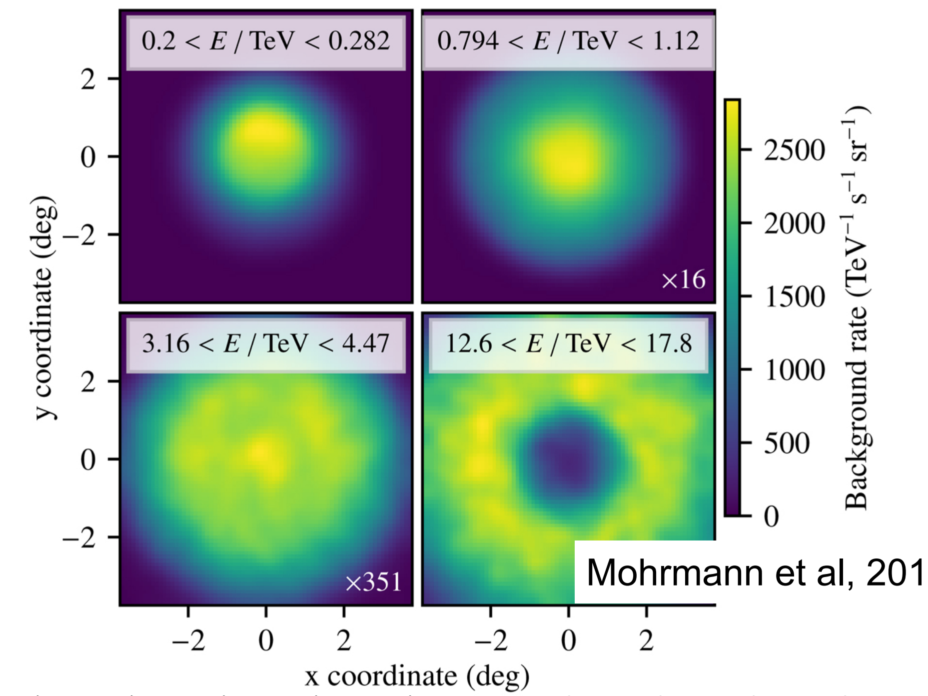
- Implement a 3D likelihood analysis to probe for such emission from molecular clouds: using gammapy-v0.18
- Simultaneous modelling of the
  - Hadronic background: using background models for the entire field of view (FoV)
  - The large scale emission surrounding the cloud
  - The emission from the cloud
  - Known sources in the field masked during the fit
- Significance of each component computed by means of likelihood ratio tests
- Applied technique on Cloud 877 from Rice et al, 2016
  - Known to show excess emission at GeV energies
  - Mass: $(13 \pm 4)\ 10^5\ M_{\odot}$
  - Position: $(l,b) = (333.46\ -0.31)$
  - Distance = 3.4 ± 0.4 kpc ; galactocentric = 5.5 kpc

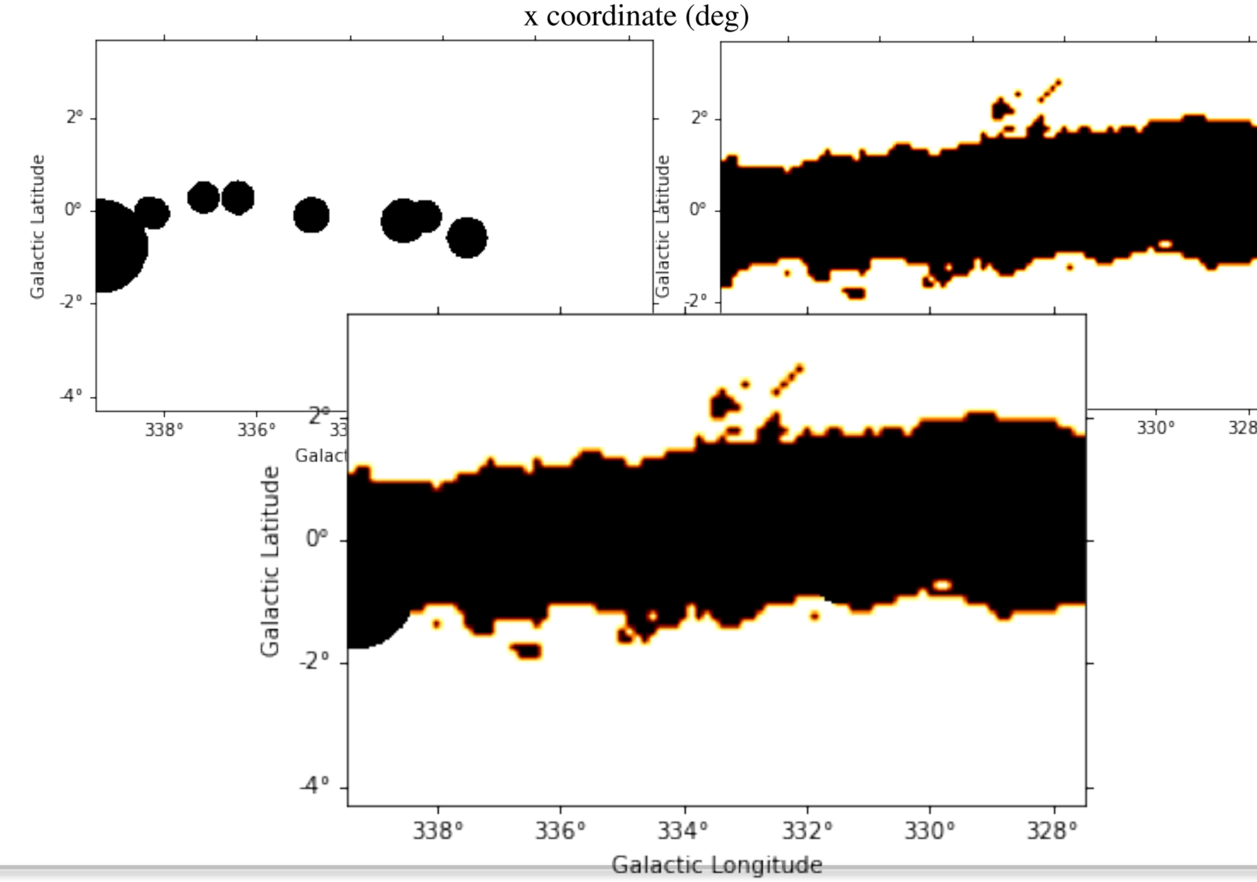


H.E.S.S.

1. The hadronic background

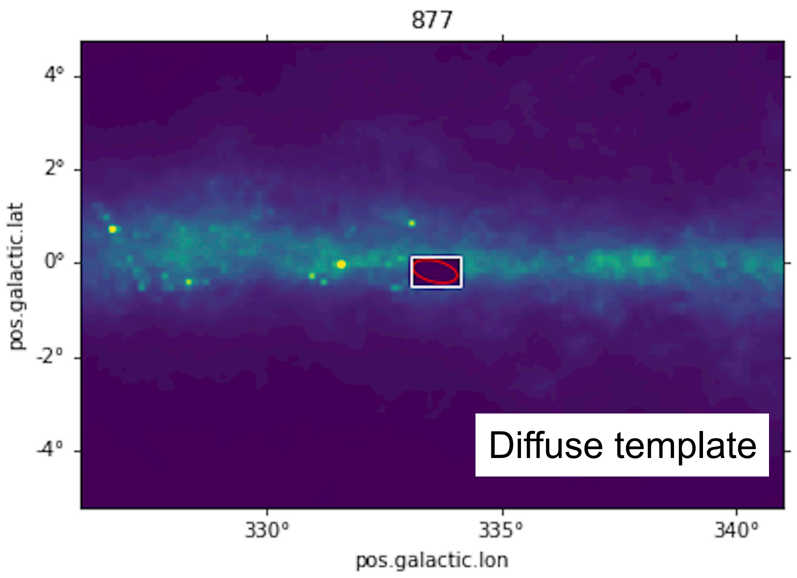
- Energy dependent background models constructed from mostly empty fields (Mohrmann et al, 2019)
- Necessary to fit the background models on a run-by-run basis
- Exclusion region chosen based upon Planck dust maps: exclude the dense gas, i.e., all pixels with a column density above 2* 10^{22} cm^{-2}
- Exclude the known sources

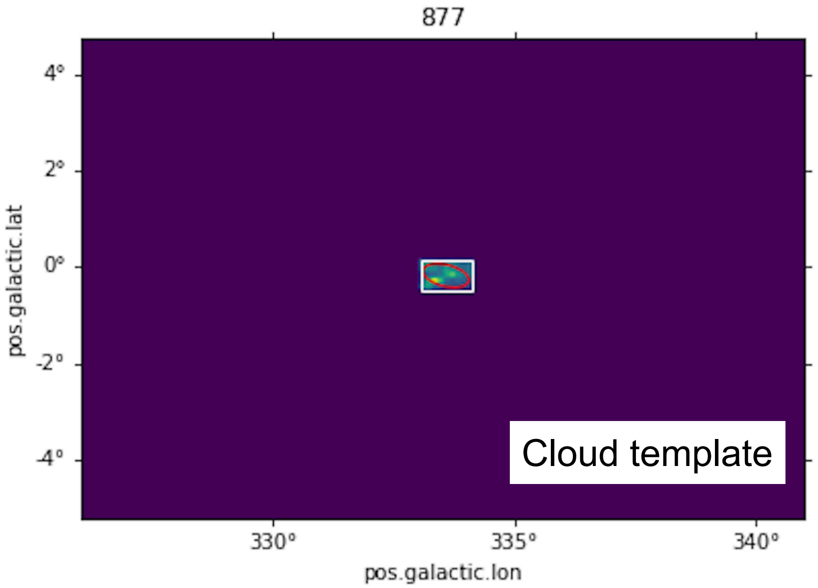




Separation of cloud from the diffuse emission

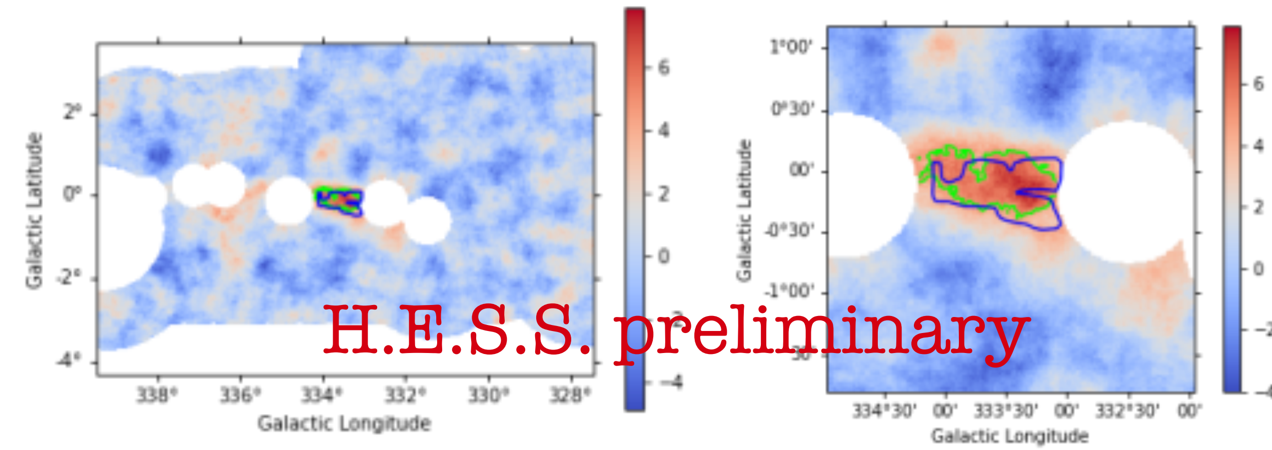
- Construct spatial templates for the pion decay emission
  - Use the dust 353 GHz opacity map from Planck
  - Tracer of both molecular and atomic hydrogen
  - Avoid the uncertainties related to the X_{CO} conversion factor and HI spin temperature
  - Traces the dark gas
- Realise a rectangular cutout for the cloud
  - Using catalog position/size from Rice et al, 2016
- Consider the rest as diffuse emission
  - The cloud template consists of the entire emission in the line of sight
  - Reasonable because the dominant contribution comes from cloud 877 (~60% of the gas column)
- Modelling the large scale component is necessary to avoid over-estimation of the hadronic background.



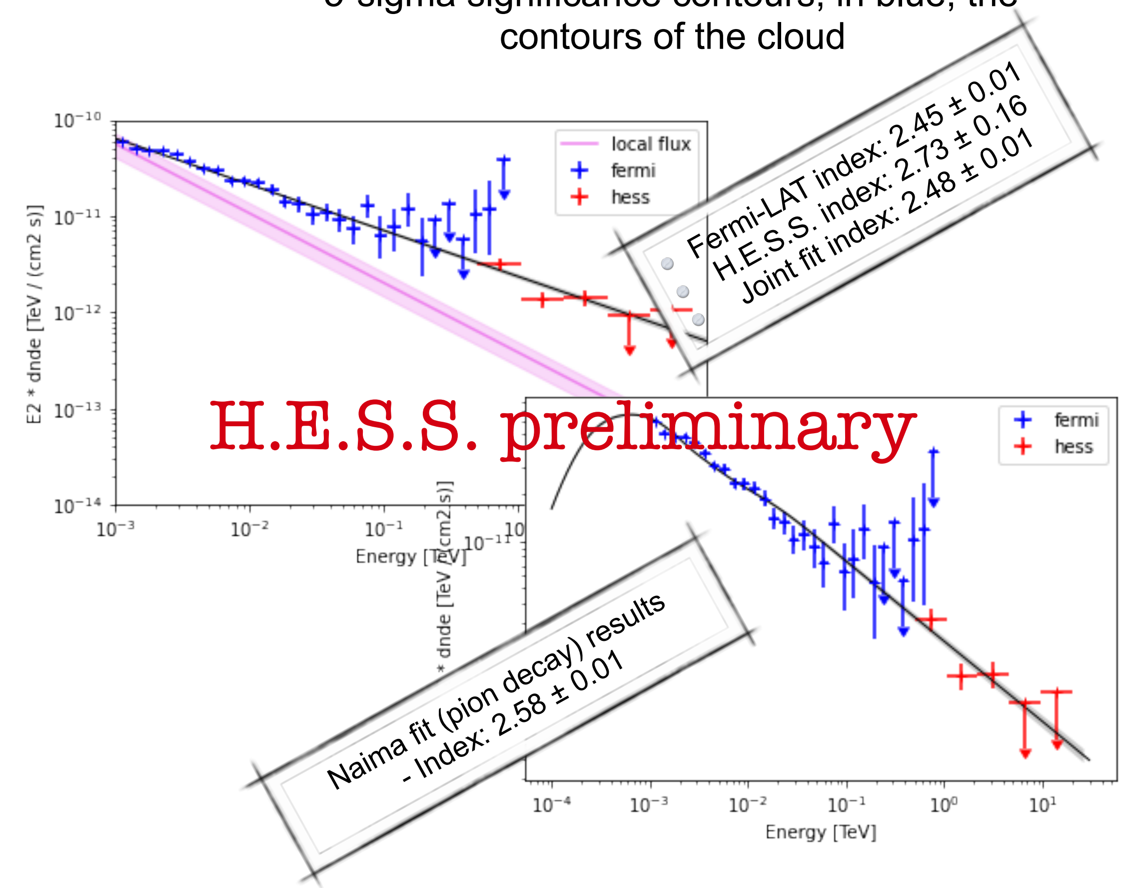


Results

- A significant excess in the direction of the cloud
- The gamma-ray contours trace the contours of the cloud
- Agrees well with the extrapolation of the Fermi flux to TeV energies
- Significant excess and hardening over the expected local emission
- Differential cosmic-ray proton number density inside the cloud ~ 1.5e-17/GeV/cm^3 at 1 TeV (~ 5 times the local density)



Significance maps of the 877 region. In green, the 5-sigma significance contours, in blue, the contours of the cloud



Conclusions

- A 3D FoV likelihood technique provides us with a powerful method to probe passive molecular clouds at TeV energies
- We detect significant emission from the direction of cloud #877
  - Follows the extrapolation of the Fermi-LAT spectrum
  - Shows significant excess emission above what is expected from AMS-02 and DAMPE measurements
- We can now probe multiple clouds at TeV energies across our galaxy
  - Does observed hardening at GeV energies continue till TeV energies?
- Detailed study with multiple clouds under progress!

Thanks for your attention!