EXTRAGALACTIC SOURCE POPULATION STUDIES AT VERY HIGH ENERGIES IN THE CHERENKOV TELESCOPE ARRAY ERA

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THE CHERENKOV TELESCOPE ARRAY

- The next generation of VHE gamma-ray detectors
- 4 decades of energy range: $\sim 20 \text{ GeV} \rightarrow \sim 300 \text{ TeV}$
- Layout of IACTs of 3 different sizes
- Full sky coverage: two sites, one in each hemisphere
CTA will greatly outperform current generation of IACTs
• Surveys the whole sky every 3 hours

• Recently released the 3FHL catalog

  • Out of 7 years of Pass 8 data

  • 1556 sources above 10 GeV (1231 extragalactic)

  • Only 72 of these sources detected by current IACTs. **What about CTA?**
- CTA will greatly outperform current generation of IACTs

**3FHL**

![Graph showing differential flux sensitivity vs. energy](image-url)
CTA will greatly outperform current generation of IACTs
Given the low energy threshold of CTA (~20 GeV), the 3FHL is the best available sample of persistent sources detectable by CTA.

79% of extragalactic sources (1231), 43% of these with known redshift (526).

The main two problems to extrapolate their spectra to VHE:

- 57% of unknown redshift → unknown EBL absorption
- Unknown intrinsic spectrum above ~60 – 100 GeV (limited by Fermi-LAT effective area)
SOURCE VHE EXTRAPOLATIONS

- To handle the unknown redshift of 57% of 3FHL extragalactic sources
  - We do not know their redshift, but we know their class

From the extragalactic sources with known redshift

![Graph showing normalized bin content for different redshift ranges for BL Lacs, FSRQs, and BCUs.]
SOURCE VHE EXTRAPOLATIONS

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From the extragalactic sources with known redshift

We assign a random redshift following each class distribution of known redshifts

- We assign a random redshift following each class distribution of known redshifts
To handle the unknown spectrum above ~60 – 100 GeV

- We fit spectra with different functions + EBL attenuation (Dominguez 2011)
  - Power-law + EBL attenuation
  - Power-law with exp. cutoff at \( 1/(1+z) \) TeV + EBL attenuation
  - Broken Power-law + EBL attenuation (if \( \Gamma > 2 \rightarrow \Gamma = 2.5 \) above \( 100/(1+z) \) GeV)
  - Log-Parabola + EBL attenuation
• To handle the unknown spectrum above ~60 – 100 GeV

  - We fit spectra with different functions + EBL attenuation (Dominguez 2011)

Using naima: https://github.com/zblz/naima
For handling the unknown spectrum above ~60–100 GeV:

- We fit spectra with different functions + EBL attenuation (Dominguez 2011)

**Bright source**

**Faint source**

Using naima: [https://github.com/zblz/naima](https://github.com/zblz/naima)
• Internal CTA performance IRFs were used to estimate source detectability

• Three different software packages were tested, providing consistent estimations
  
  • CTAmacros: https://github.com/cta-observatory/ctamacros
  
  • Gammapy: https://github.com/gammapy/gammapy
  
  • GAEtools: http://eprints.ucm.es/35143/
DETECTABILITY COMPUTATION

- Internal CTA performance IRFs were used to estimate source detectability

- Three different software packages were tested, providing consistent estimations

- Only sources culminating at less than 50 deg away from zenith at each site were considered (using IRFs at 20 and 40 deg)

- A source is detectable if $S > 5\sigma$ (off-to-on source exposure ratio of 5), excess > 10 and 5 times larger than 1% of the background
• Extragalactic source population accessible to CTA:

<table>
<thead>
<tr>
<th></th>
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Detectable sources by CTA
Detected by current IACTs
### ACCESSIBLE EXTRAGAL. POPULATION

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<td>BL Lacs</td>
<td>136 (39)</td>
<td>243 (43)</td>
<td>138 (27)</td>
<td>223 (30)</td>
<td>208 (50)</td>
<td>344 (53)</td>
</tr>
<tr>
<td>FSRQs</td>
<td>6 (3)</td>
<td>9 (4)</td>
<td>6 (3)</td>
<td>10 (3)</td>
<td>7 (3)</td>
<td>13 (4)</td>
</tr>
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<td>Blazar of uncertain type</td>
<td>43 (2)</td>
<td>80 (2)</td>
<td>62 (2)</td>
<td>94 (2)</td>
<td>79 (3)</td>
<td>129 (3)</td>
</tr>
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<td>Radio galaxy</td>
<td>4 (3)</td>
<td>6 (3)</td>
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<td>7 (5)</td>
<td>9 (5)</td>
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<td>Non-blazar active galaxy</td>
<td>1 (0)</td>
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<td>Star Burst Galaxies</td>
<td>0 (0)</td>
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• Extragalactic source population accessible to CTA:

CTA (Full Array, ≥ 5σ, 5 h)

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PLExp. 1 TeV

5 h obs. time
• Extragalactic source population accessible to CTA:

CTA (Full Array, $>5\sigma$, 20 h)

- PLExp. 1 TeV
- 20 h obs. time
ACCESSIBLE EXTRAGAL. POPULATION

- Detectable sources vs redshift

- Population of sources at large redshift, even in steady state, under conservative extrapolation schemes
CONCLUSIONS

- This kind of studies show the potential of future CTA Key Science Projects and dedicated proposals

- CTA will dramatically increase the number of detectable blazars in their steady state, measuring their spectra over 4 decades in energy, in a wide range of redshifts (\(z \sim 1.5\), not considering flaring states)

- Not only the study of AGN physics, also fundamental science topics will benefit from the detection of these sources (EBL, LIV, ALPs, IGMF...)

- CTA might be able to access new populations of EHBLs, not detectable by Fermi-LAT (BZCAT)
ACCESSIBLE EXTRAGAL. POPULATION

• CTA easily detects 3FHL hardest sources

• Could there be a fainter/harder population of EHBLs, not detected by Fermi-LAT?
BLAZARS NOT DETECTED BY LAT?

- There might be a hidden population of EHBLs
  - Nearly 50% of BZCAT BL Lacs not detected by Fermi-LAT
  - EHBLs are faint in the HEs, and would not be detectable by LAT
  - They are faint objects, but CTA may be able to detect a significant fraction