Search for new TeV sources from our MWL and spectroscopic survey

UNIVERSITÀ DEGLI STUDI DI PALERMO

INAF

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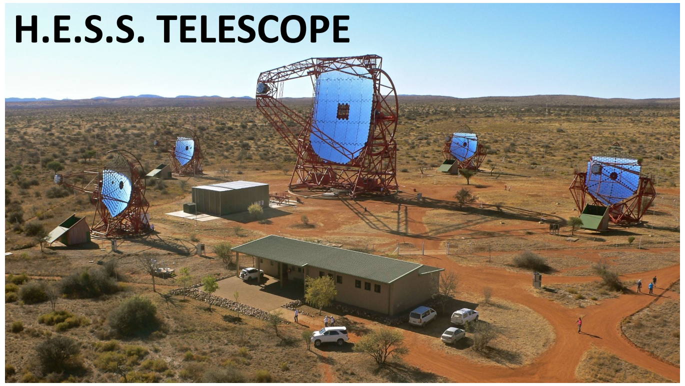
IASF
Istituto di Astrofisica Spaziale e Fisica cosmica
Palermo

Rome, AVENGe 29-31 May 2023

HE & VHE facilities

Space Observatory

20 MeV - 300 GeV (LAT)



Imaging Atmospheric Cherenkov Telescopes (IACT)

10s GeV - 10s TeV

Beyond IACT limit {
1. Water Cherenkov observatory
2. Indirect information also follows from neutrino detections in the PeV region

Future: CTA will improve the sensitivity in TeV range

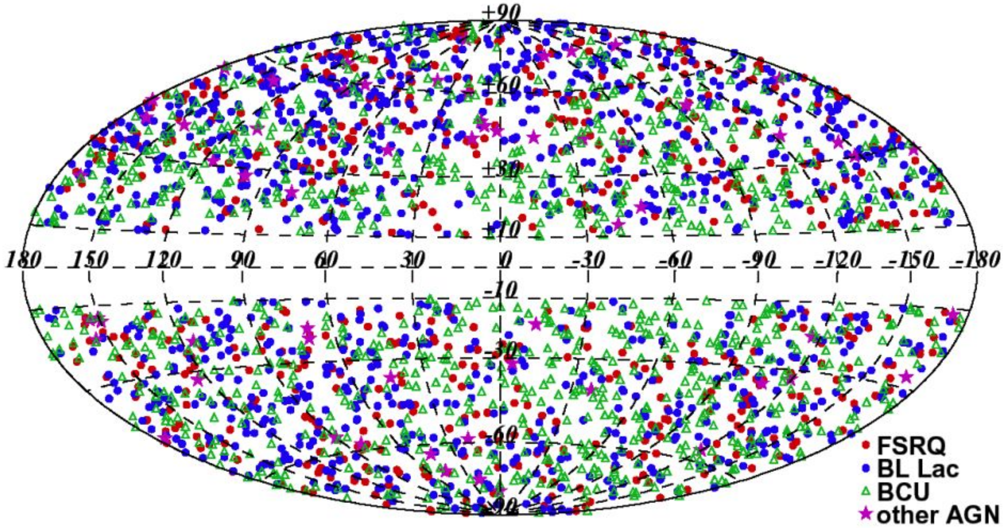
Extragalactic gamma-ray sky

1. Intrinsic spectral shape
2. Fermi all sky monitor

} # HE sources known > # VHE sources known

Blazar are the largest (~ 60%) γ-ray extragalactic population

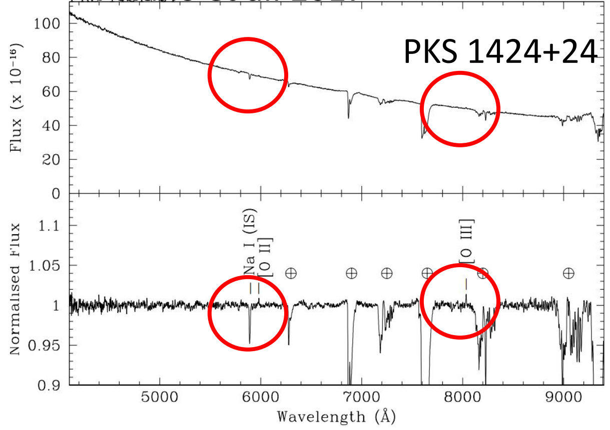
- Last Fermi catalog: 4FGL-DR3 (12 years of observations)



AGN detected by Fermi

First neutrino source is a blazar (TXS0506+056, z=0.3365) → Blazars are possible neutrino emitters

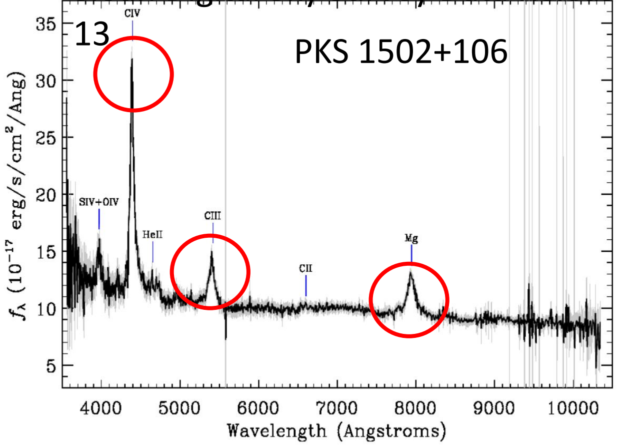
Paiano et al. 2017



BL Lac objects (BLL)

Emission lines weak or absent

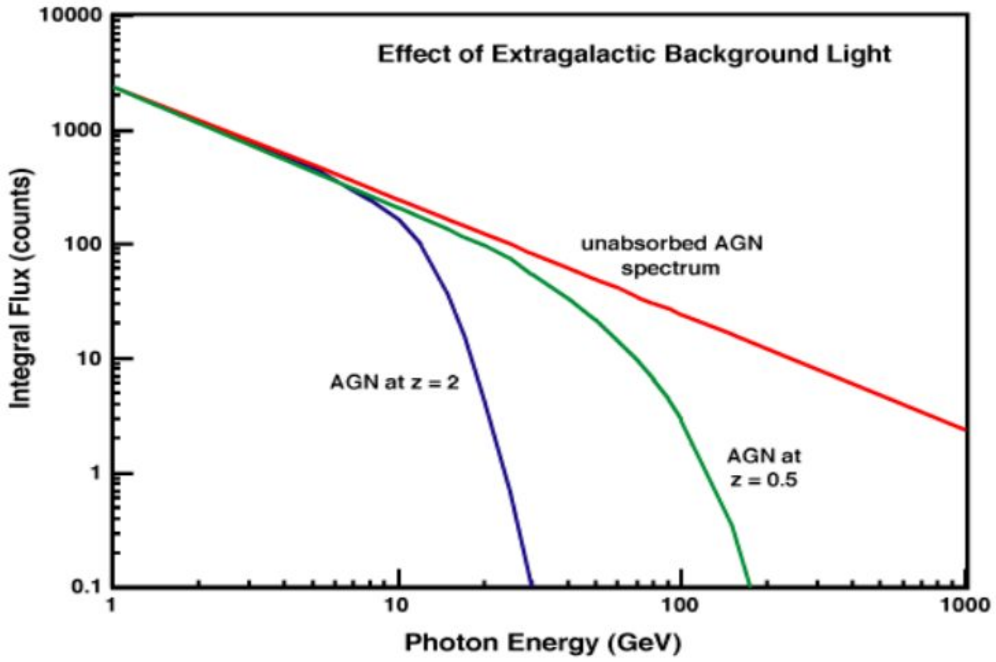
Sloan Digital Sky Survey Data Release 13



Flat Spectrum Radio Quasars (FSRQs)

Dominated by broad emission lines

VHE spectrum and Extragalactic Background Light (EBL) effect



- EBL → **Above a few GeV**, for objects at $z \gtrsim$ **0.1**, the **Universe** starts becoming **opaque** → pairs production
- To study **the intrinsic VHE spectrum** it is necessary to correct for the EBL absorption
- Absorption depends strongly on the **redshift**

Problem : for many BLL the redshift is unknown (> 50%)

Optical spectroscopy of extragalactic gamma-ray sources

We are carrying out an extensive and on-going spectroscopic campaign of blazars with optical telescopes of 8-10m class (GTC, VLT, SALT, LBT)

With the aim of…

- **Study the nature of the optical counterparts**
  - Analysis of the optical spectrum
    - Describe of continuum
    - Search for emission/absorption lines
- **Determine the redshift**
  - Intrinsic parameters e.g. L, Lline
  - Useful for modeling the ν emissions
  - Nucleus-to-host ratio
  - Estimate of the SMBH mass
- **Search for good targets for future IACTs**
  - Extrapolation of the HE spectrum to VHE band

Optical spectroscopy of extragalactic gamma-ray sources

We are carrying out an extensive and on-going spectroscopic campaign of blazars with optical telescopes of 8-10m class (GTC, VLT, SALT, LBT)

- More than 300 spectra with High S/N (>100 - 1000) Spectral range 3600 Å - 9000 Å
- For about 85% we provide a redshift from the em/abs lines
- For remaining we can set stringent lower limit
- Our spectra (and of other groups) are in our online database: **https://web.oapd.inaf.it/zbllac/**

Optical spectroscopy of extragalactic gamma-ray sources

Different blazar samples

TeV sources

3FHL TeV candidates

Neutrino candidate blazars

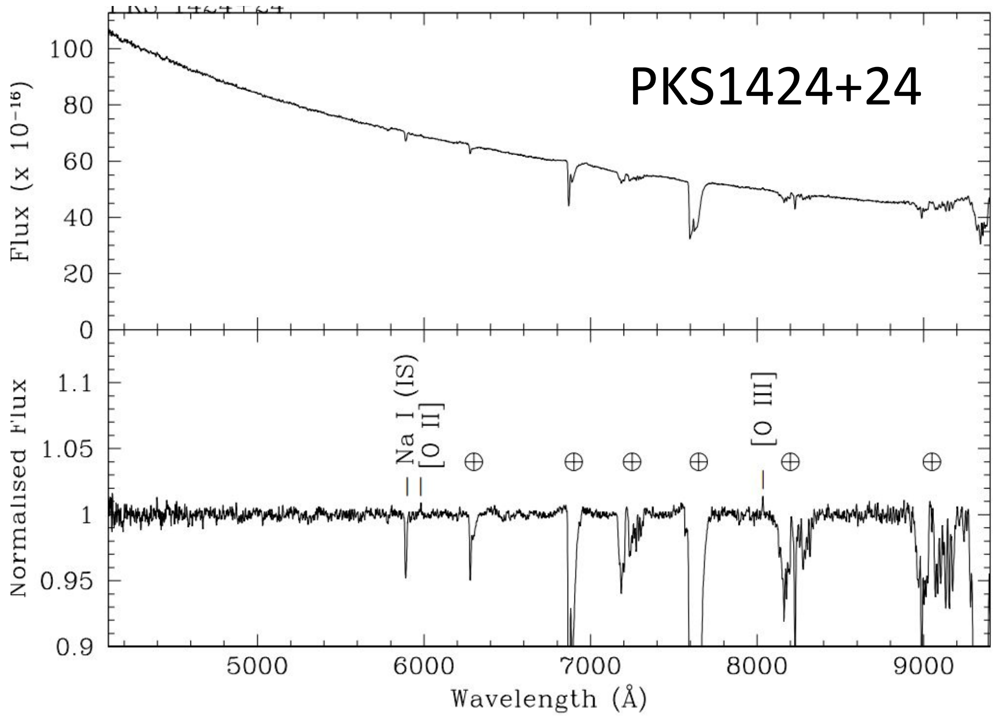
4FGL-DR3 UGS

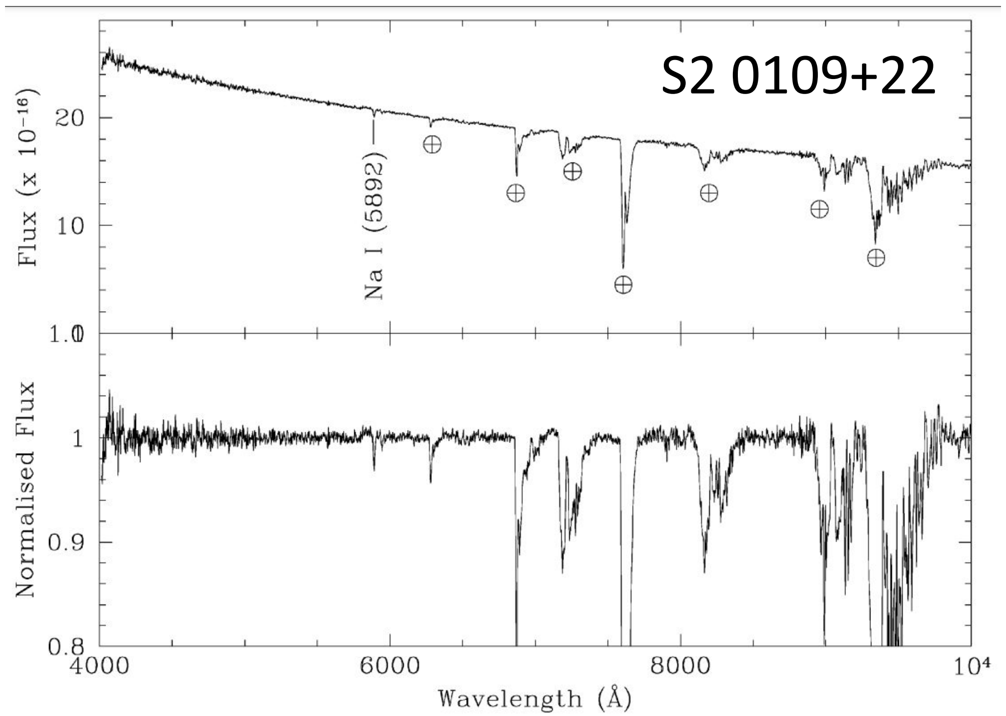
Optical spectroscopy of extragalactic gamma-ray sources

TeV sources 3FHL TeV candidates Neutrino candidate blazars 4FGL-DR3 UGS

22 BL Lac objects (and candidates) detected in the **VHE**

- **New redshift** for PKS1424+240 (z=0.604) : **the farthest BLL detected in the TeV**
- For 7 cases **we can not validate the previous redshift** (as 3C66A, S2 0109+22, VERJ0521+211)





Paiano et al. 2021

Optical spectroscopy of extragalactic gamma-ray sources

TeV sources **3FHL TeV candidates** Neutrino candidate blazars 4FGL-DR3 UGS

55 Hard Fermi-LAT sources (detected above > 10 GeV with Fermi) labelled as **BLL/BCU TeV candidates**, with photon index < 2.5 and **unknown z**

- They are all **BLL**
- **26** objects **with firm redshift** on the basis of detected emission/absorption lines
- For **5** sources spectroscopic z **lower limit** from MgII intervening absorption
- Prediction of **TeV emission extrapolating** the Fermi spectral fit (see later)

Paiano et al. 2021,2023
Padovani et al. 2022

Optical spectroscopy of extragalactic gamma-ray sources

TeV sources | 3FHL TeV candidates | **Neutrino candidate blazars** | 4FGL-DR3 UGS

SIN project (Spectra of Icecube Neutrino)

50 neutrino candidate blazars from Giommi et al. 2020 + a dozen of blazars from new alerts and from the updated IC alert track catalog (Abbasi+2023)

- Almost all of targets are classified as BLL
- 80% objects with firm redshift
- Estimates of [OII] and [OIII] luminosities and M_{BH}
- Several objects classified as masquerading BLL
- Subsequent papers with MWL studies and modelling using lepto-hadronic models to estimate the expected neutrino emission

Paiano 2017,2019,
Ulgiati et al. (in prep)

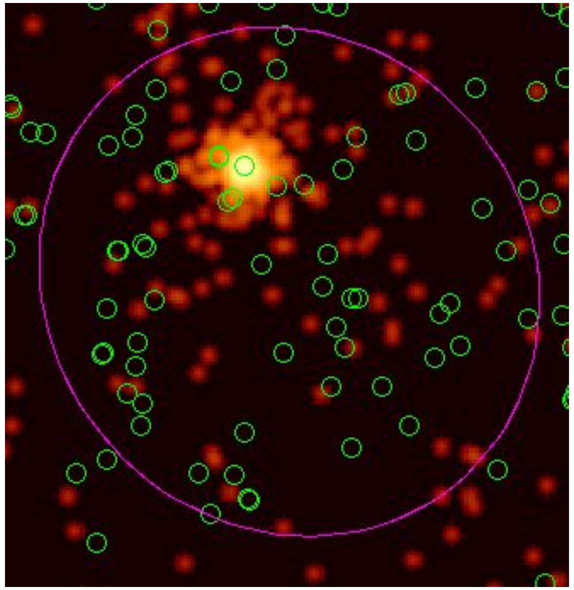
Optical spectroscopy of extragalactic gamma-ray sources

TeV sources | 3FHL TeV candidates | Neutrino candidate blazars | **4FGL-DR3 UGS**

Unassociated Gamma-ray sources (UGS):
30% of the Fermi detections are missing a clear and obvious association and classification with astronomical objects

We focus our study on high latitude (|b|>10) sources (higher possibility to be extragalactic)

4FGLJ0026.1-0732



- **Uncertainty** on the γ-ray position→ **several arcminutes**;
- **Optical band allows to constrain the nature of sources → however a lot of sources within the Fermi error box**
- **MWL analysis**

Black box→ Swift /XRT sky map
Magenta ellipse → Fermi error box
Green circles → Optical sources

Paiano 2017,2019,
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Optical spectroscopy of extragalactic gamma-ray sources

TeV sources | 3FHL TeV candidates | Neutrino candidate blazars | **4FGL-DR3 UGS**

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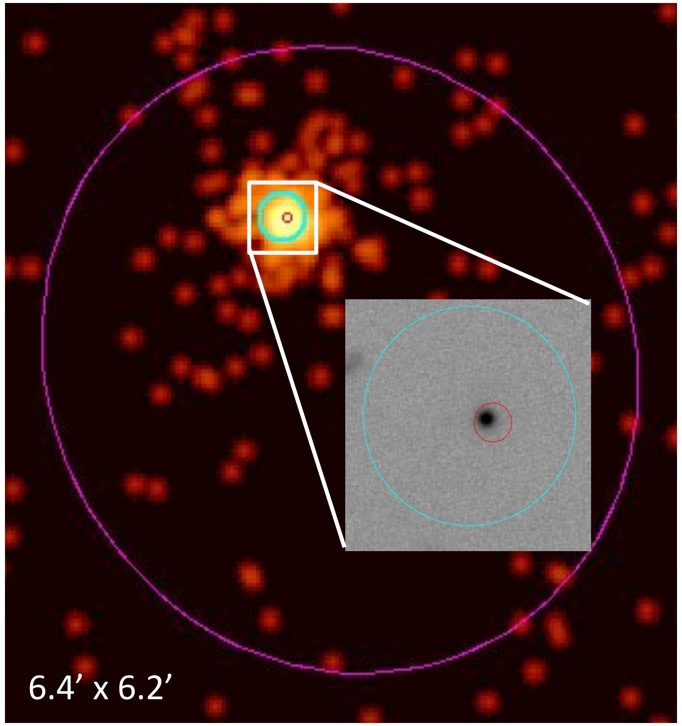


Black box→ Swift /XRT sky map
Magenta ellipse → Fermi error box
Green circles → Optical sources
Red circles → X-ray counterpart
Cyan circles → Radio counterpart
Black object → Optical counterpart

UGS → X-ray counterparts → Radio counterparts → Optical counterparts

First two works

- **48** 2FGL/3FGL UGS were **associated**
- **28** objects **with firm redshift** on the basis of detected emission/absorption lines
- **44** are **BLL**, **1 FSRQ**, **2** objects with **Sy2-like spectrum**, **1 NLSY1**

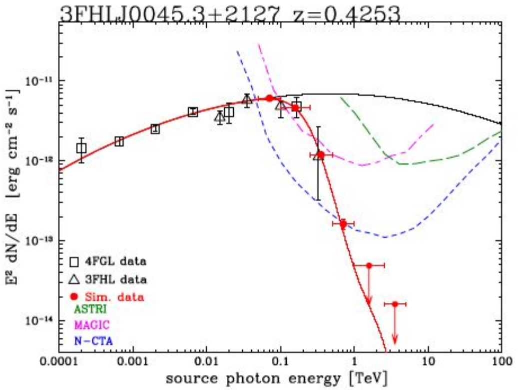
Current work

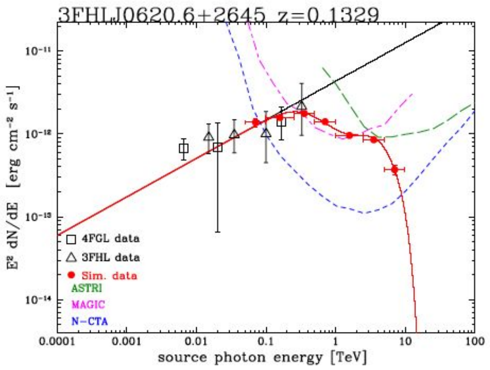
- **1125 UGS** → ~50% have X-ray Swift/XRT observations
- For ~**300 UGS,** we found **at least an X-ray counterpart**
- We obtained spectroscopy for the optical counterpart of ~**100 UGS**
- Reduction and analysis is on-going
- Some UGS are in the IC error box
- Preliminary results reveal new BLL but also some objects with broad lines.

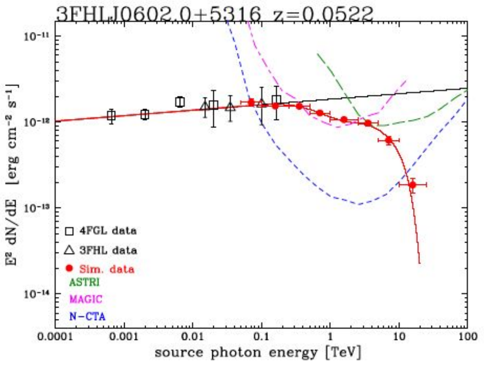
Prediction of TeV emission extrapolating the Fermi spectral fit

TeV detections require pointed observations of the duration of several hours

To direct and optimize the observational campaign with the IACT is a crucial task and it is important to select good targets on the basis of the **expected TeV flux**







Extrapolation of the HE Fermi spectral fit to VHE band

+

EBL absorption (depends on the redshift)

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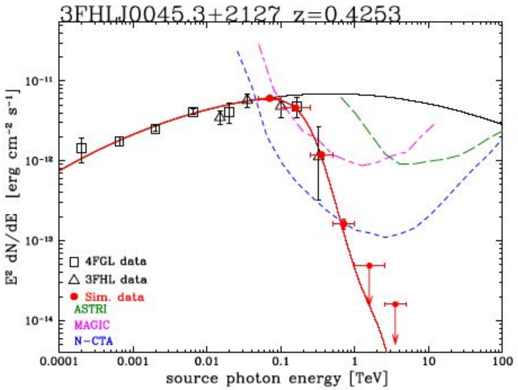

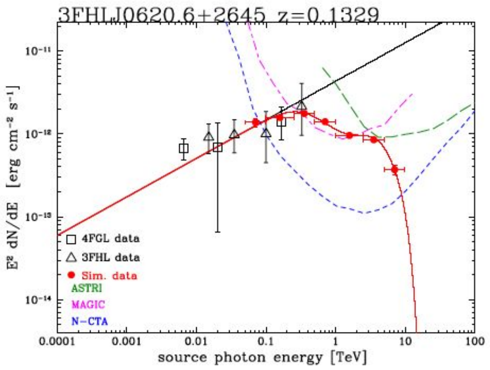

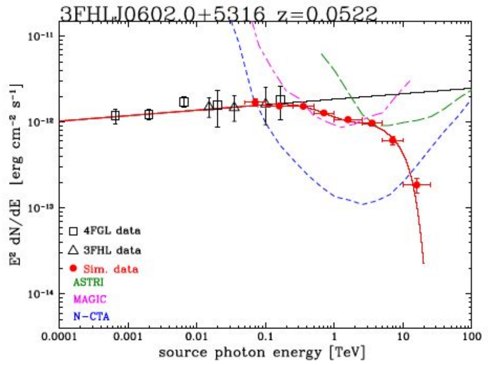

Extrapolation of the HE Fermi spectral fit to VHE band
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EBL absorption (depends on the redshift)

Our survey is treasure trove for good targets for CTA

It is important to work on this task, working together to improve the know-how and to take advantage of the CTA expertise