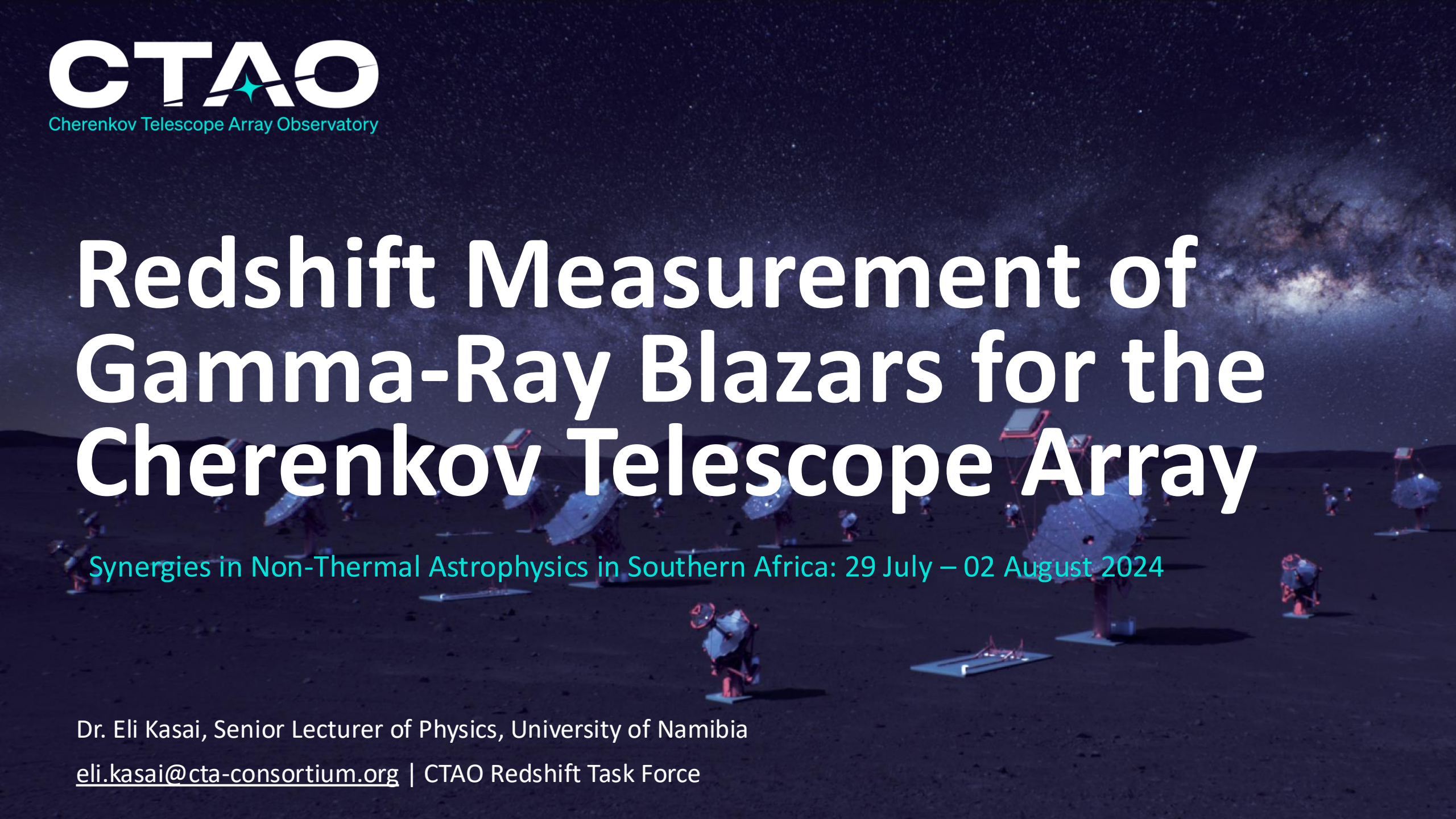


CTAO
Cherenkov Telescope Array Observatory

# Redshift Measurement of Gamma-Ray Blazars for the Cherenkov Telescope Array

Synergies in Non-Thermal Astrophysics in Southern Africa: 29 July – 02 August 2024

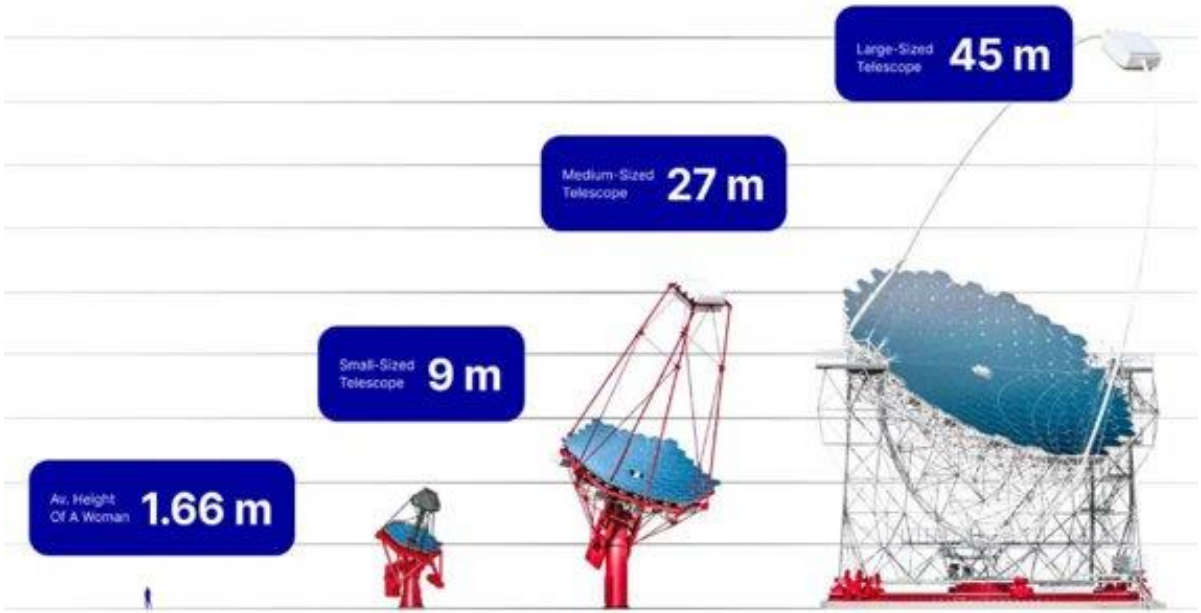
Dr. Eli Kasai, Senior Lecturer of Physics, University of Namibia

eli.kasai@cta-consortium.org | CTAO Redshift Task Force

# OUTLINE

- Overview of CTAO
- Overview of z-Task Force
- Sample selection and observing strategy
- z-measurement and est. of total blazar emission
- Why blazar redshift measurements for CTAO
- Summary

# Brief overview of CTAO




- The world's largest ground-based observatory for gamma-ray astronomy at VHE

| Parameter | SSTs | MSTs | LSTs |
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| Count | 37 | 23 | 4 |
| Diameter (m) | 4-6 | 12 | 23 |
| Energy range (TeV) | 5 - 300 | 0.15 - 5 | 0.02 - 0.15 |

**Source: https://www.ctao.org/emission-to-discovery/telescopes/**

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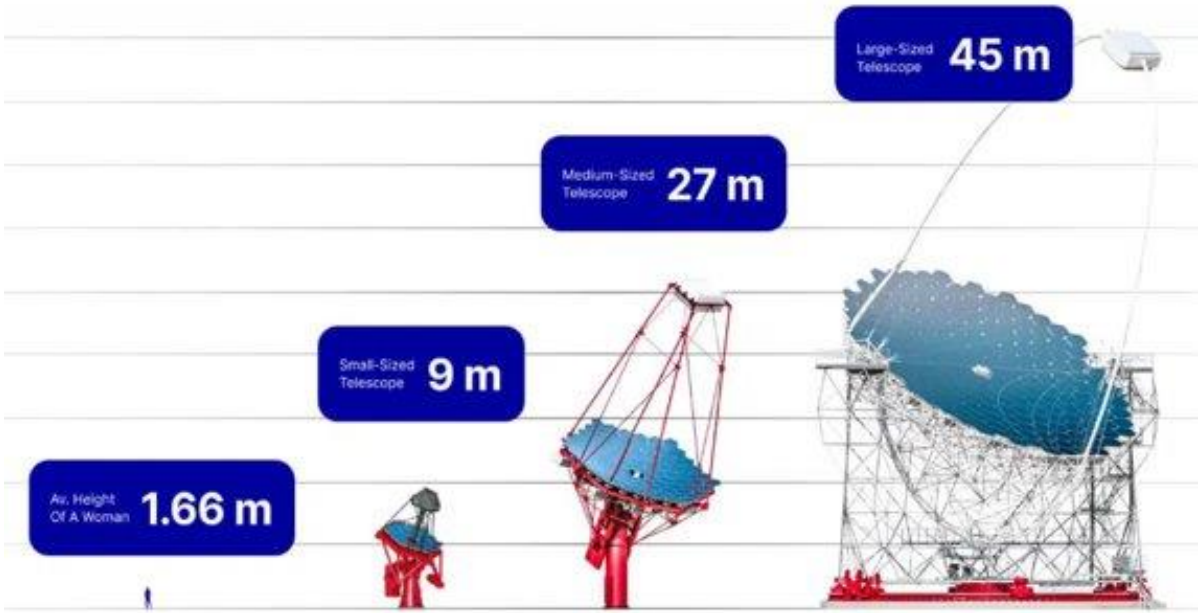


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- CTAO will be ~10 times more sensitive than existing instruments

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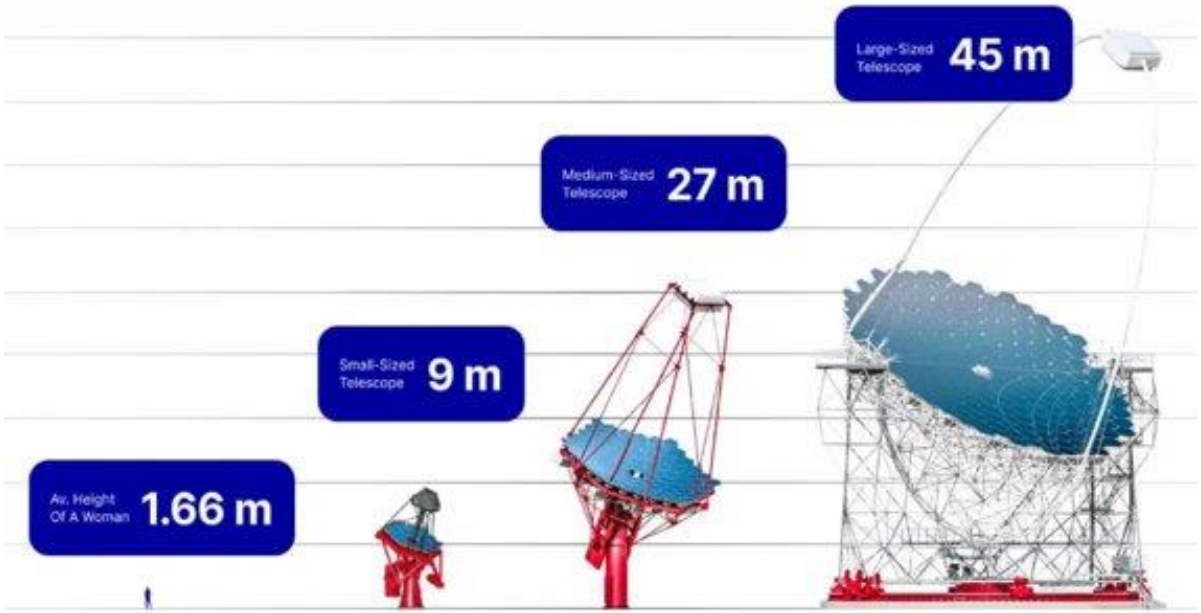


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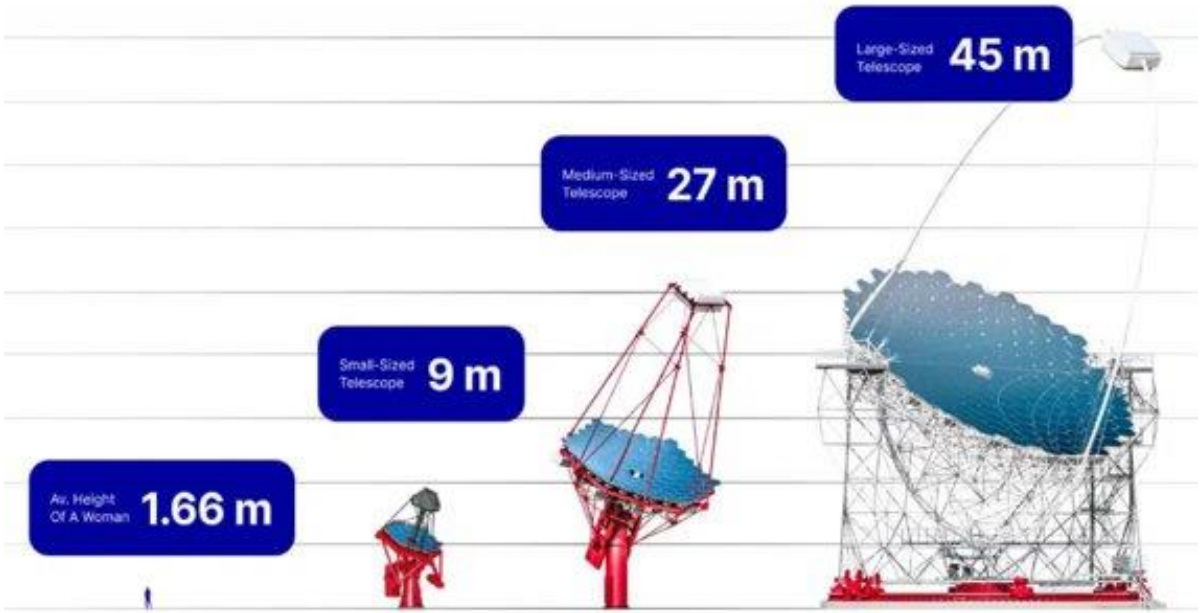


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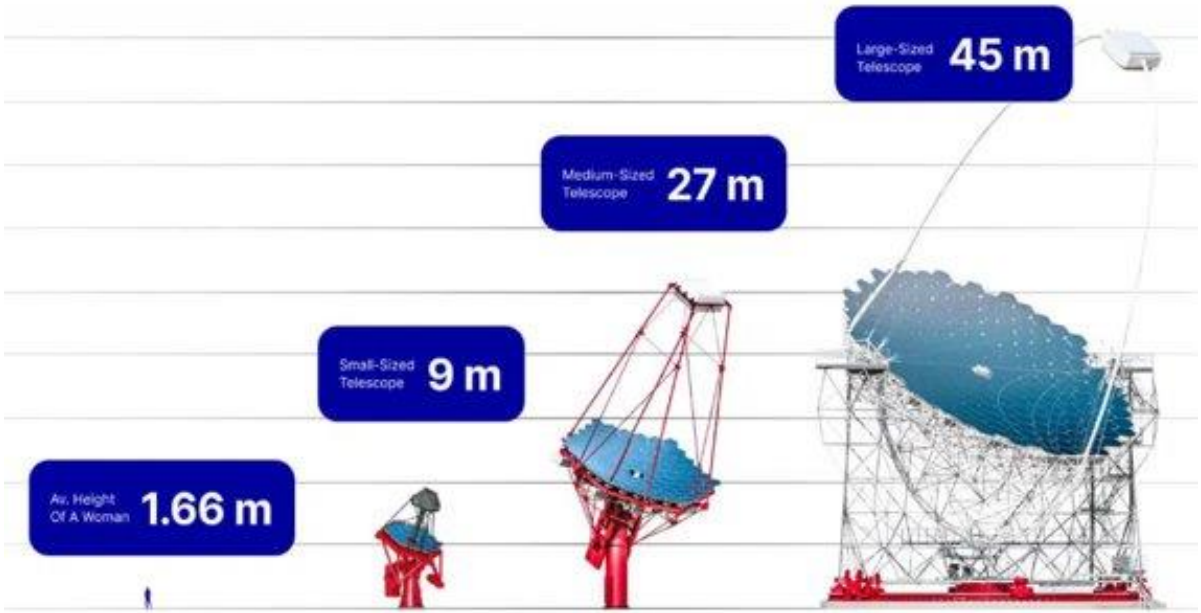


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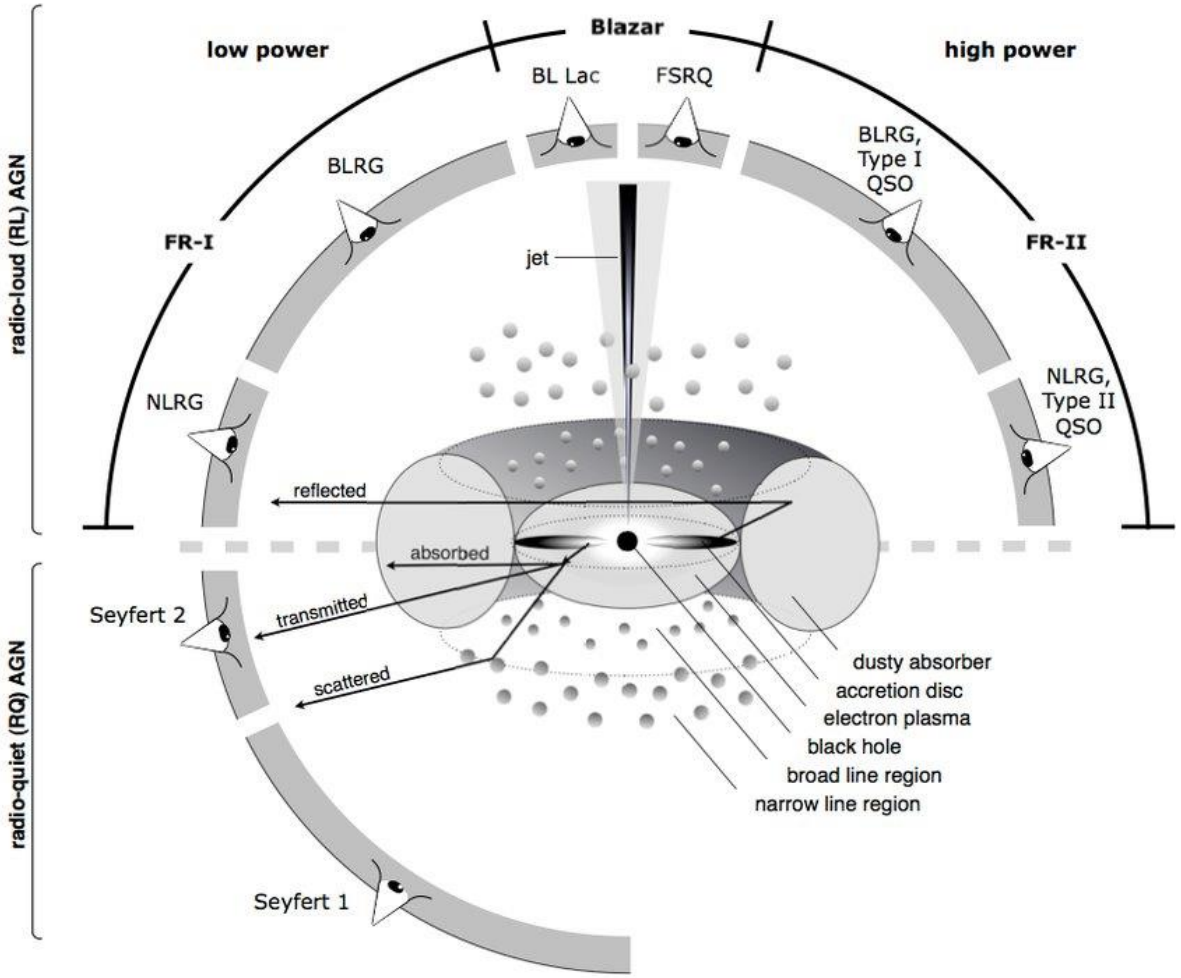
- Sites:
  - North: La Palma
  - South: Paranal Obs.

# Brief overview of CTAO: What are Blazars?




*Credit:* Beckmann and Shrader 2012

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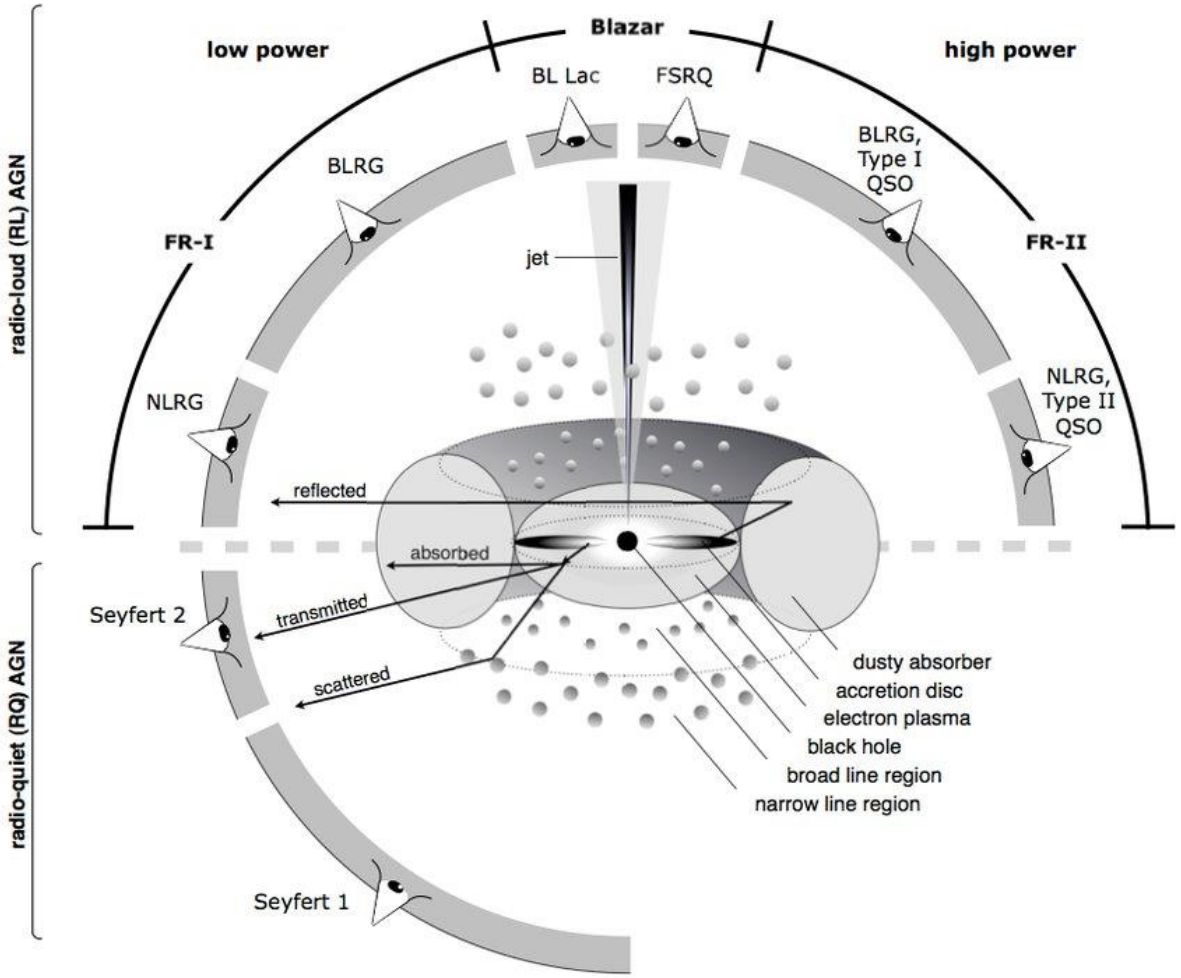


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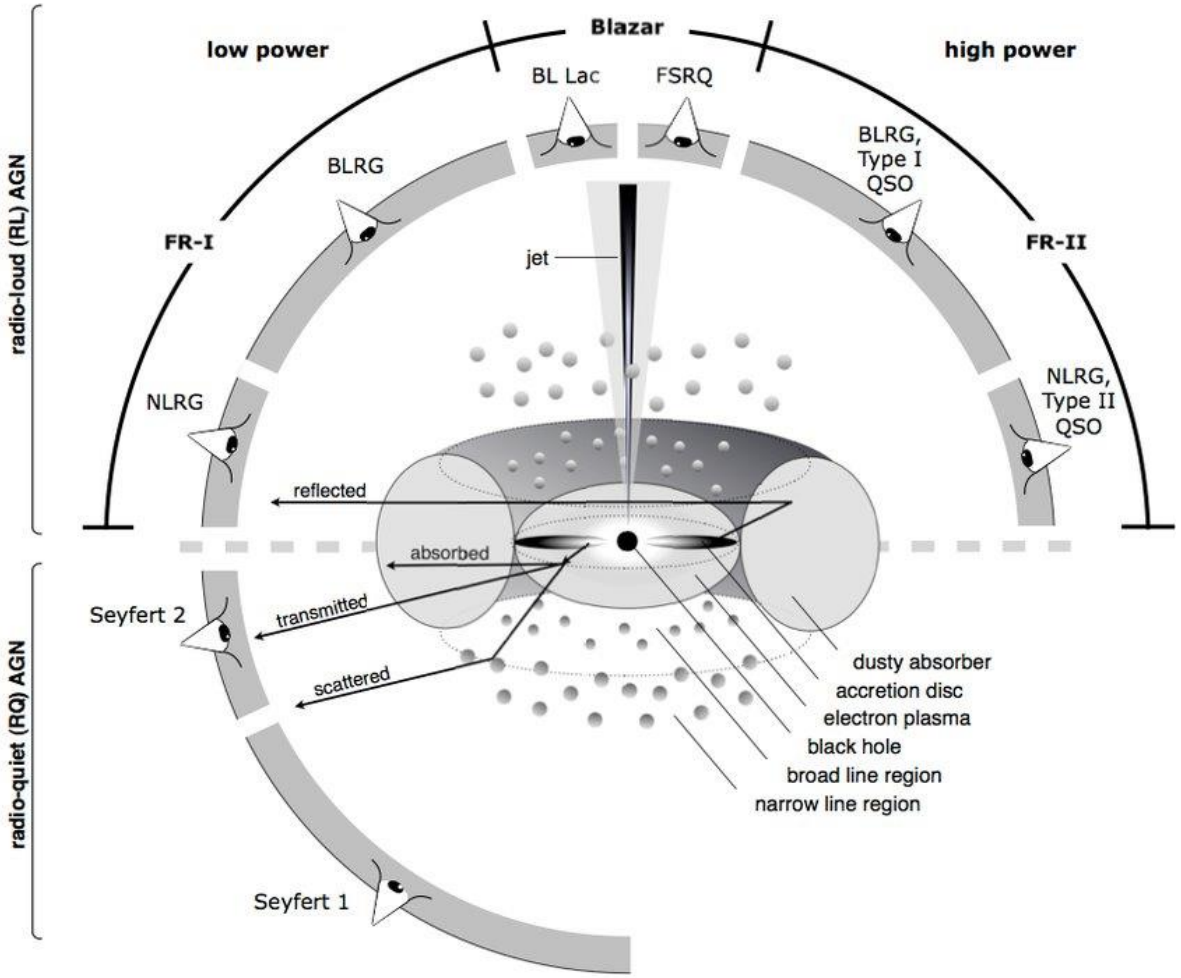


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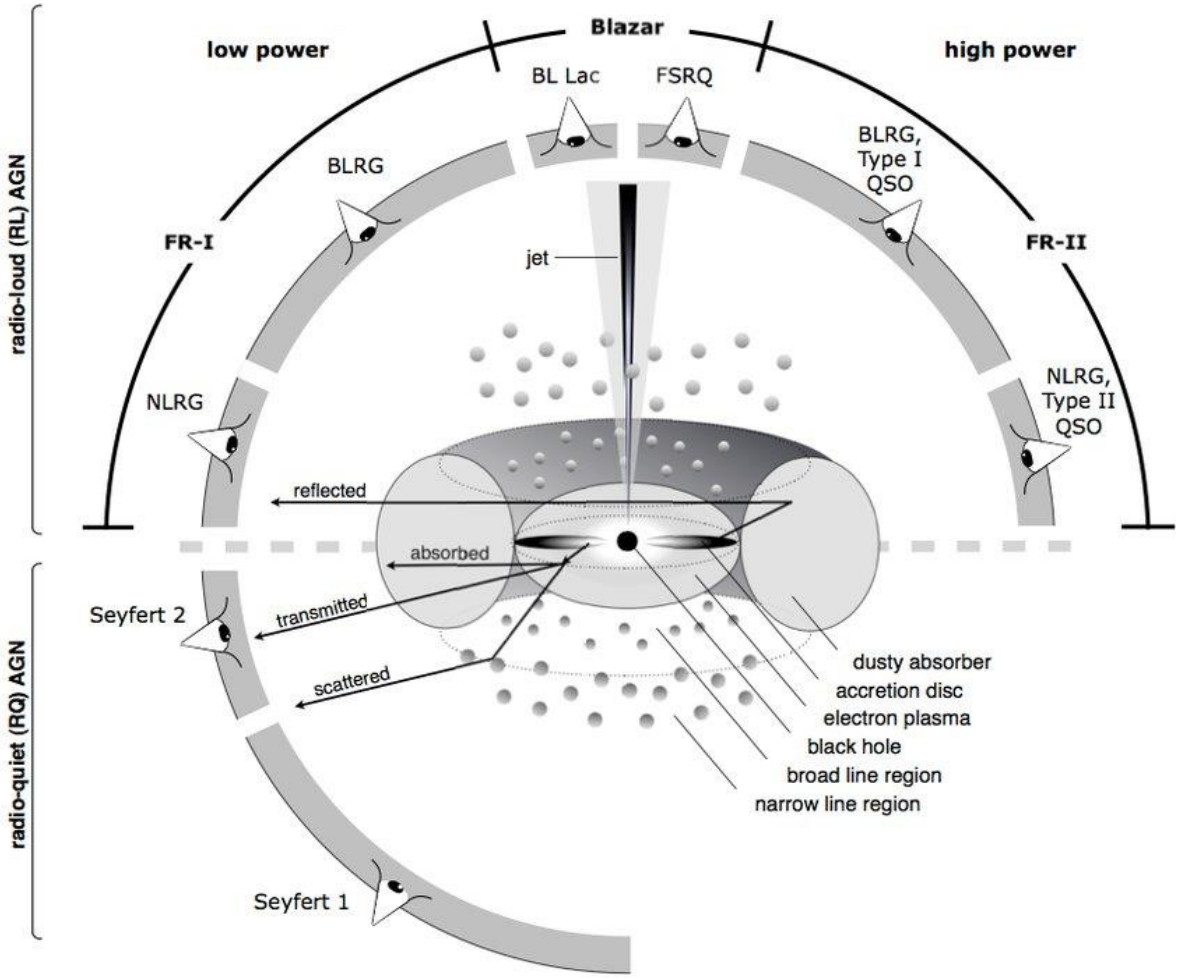


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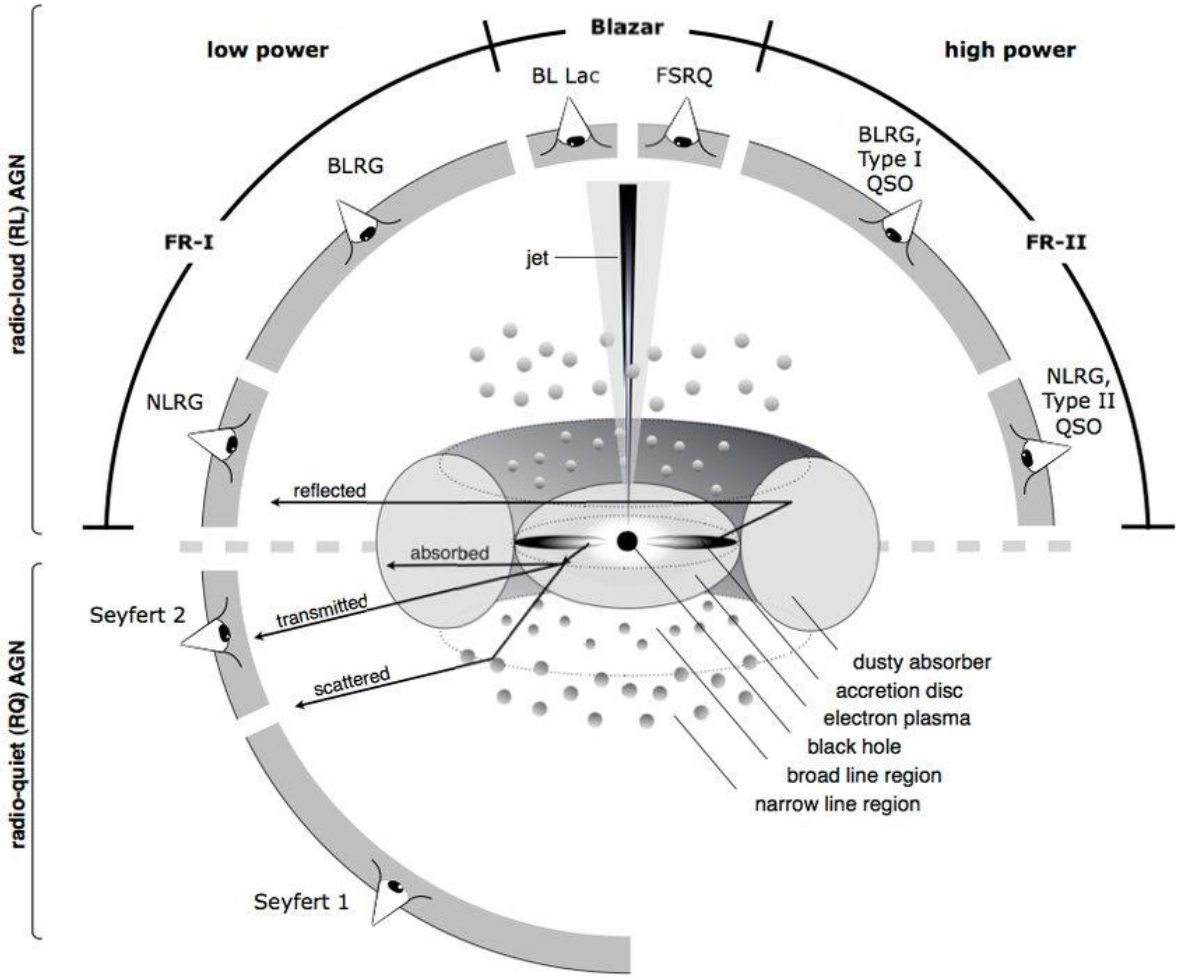


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- Possess powerful relativistic jets aligned near the LOS of an observer
- Radiation is dominated by non-thermal emission
- Strongly polarized in the radio and optical regimes
- Radiation observed to vary across all frequencies on timescales of years, months, days and minutes

# Overview of CTAO Redshift Task Force: Telescopes









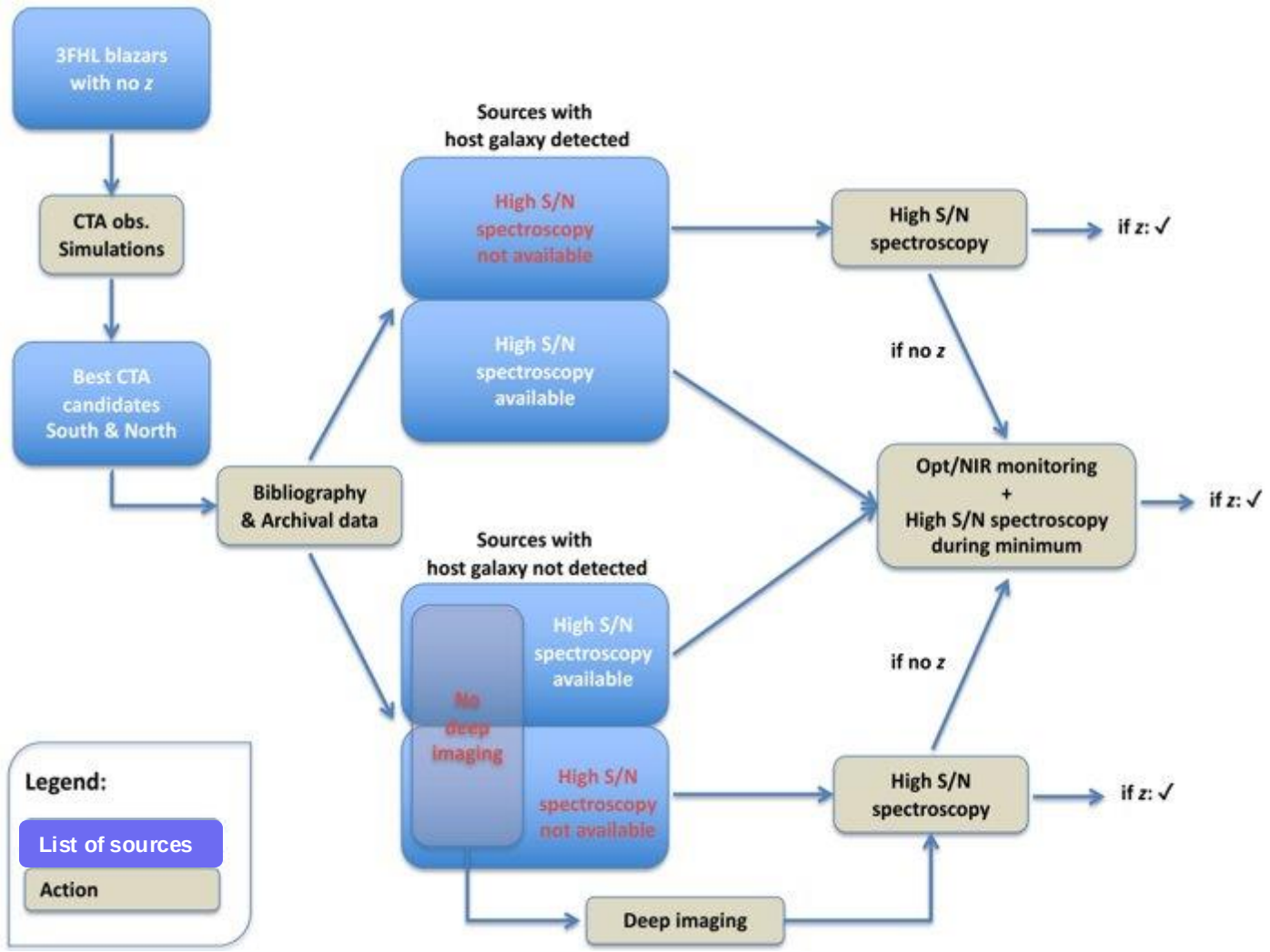



# Overview of CTAO Redshift Task Force: Observations

| Telescope | Diameter (m) | Instrument | λ coverage (Å) /Filter (CW (Å)) | λ / Δλ / FWHM (Å) | Targets observed |
|---|---|---|---|---|---|
| SALT | 11 | RSS | 4500 – 7500 | ~ 1000 | 38 |
| GTC | 10.4 | OSIRIS | 3650 – 10000 | 300 – 2500 | 1 (DDT) |
| KECK-II | 10 | ESI | 3900 – 10000 | ~ 10000 | 29 |
| ESO/VLT | 8.2 | FORS2 | 3300 – 11000 | 260 – 1600 | 39 |
| ESO/NTT | 3.5 | EFOSC2 | 3860 – 8070 | ~ 500 | 18 |
| SHANE-3m | 3.0 | KAST double (B) | 3500 – 5600 | ~ 1000 | 42 |
| SHANE-3m | 3.0 | KAST double (R) | 5400 – 8000 | ~ 1500 | |
| GEMINI | 8.0 | GMOS | i (7481) | 886 | 2 |
| SOAR | 4.1 | SAM | i (7481) | 886 | 6 |
| NOT | 2.5 | ALFOSC | i (7481) | 886 | 17 |
| LESEDI | 1.0 | Sibonise | R (6470) | 1090 | 44 |
| TJO | 0.8 | MEIA | R (6470) | 1090 | 30 |
| REM | 0.6 | REMIR/ROSS | r, H (6231, 16500) | 842, 2000 | 44 |

# Sample selection and observing strategy

***Fermi*-LAT sources**




**Flowchart from *Kasai et al. 2023b***

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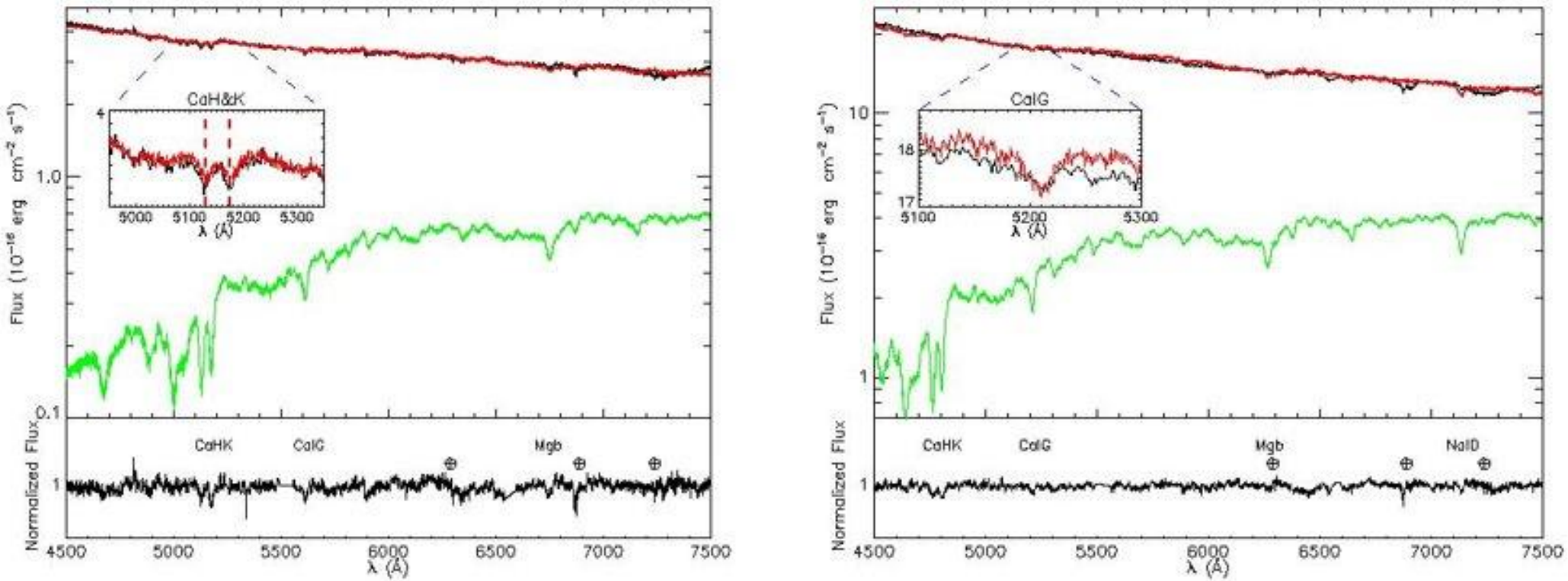
- We also search for emission lines such as [O II], [O III], Hα and [N II]
- To measure the redshift convincingly, we require a minimum of two different features yielding the same *redshift* value
- To estimate the total emission of the blazar, we model the spectrum using a power law and elliptical galaxy templates

# Some results

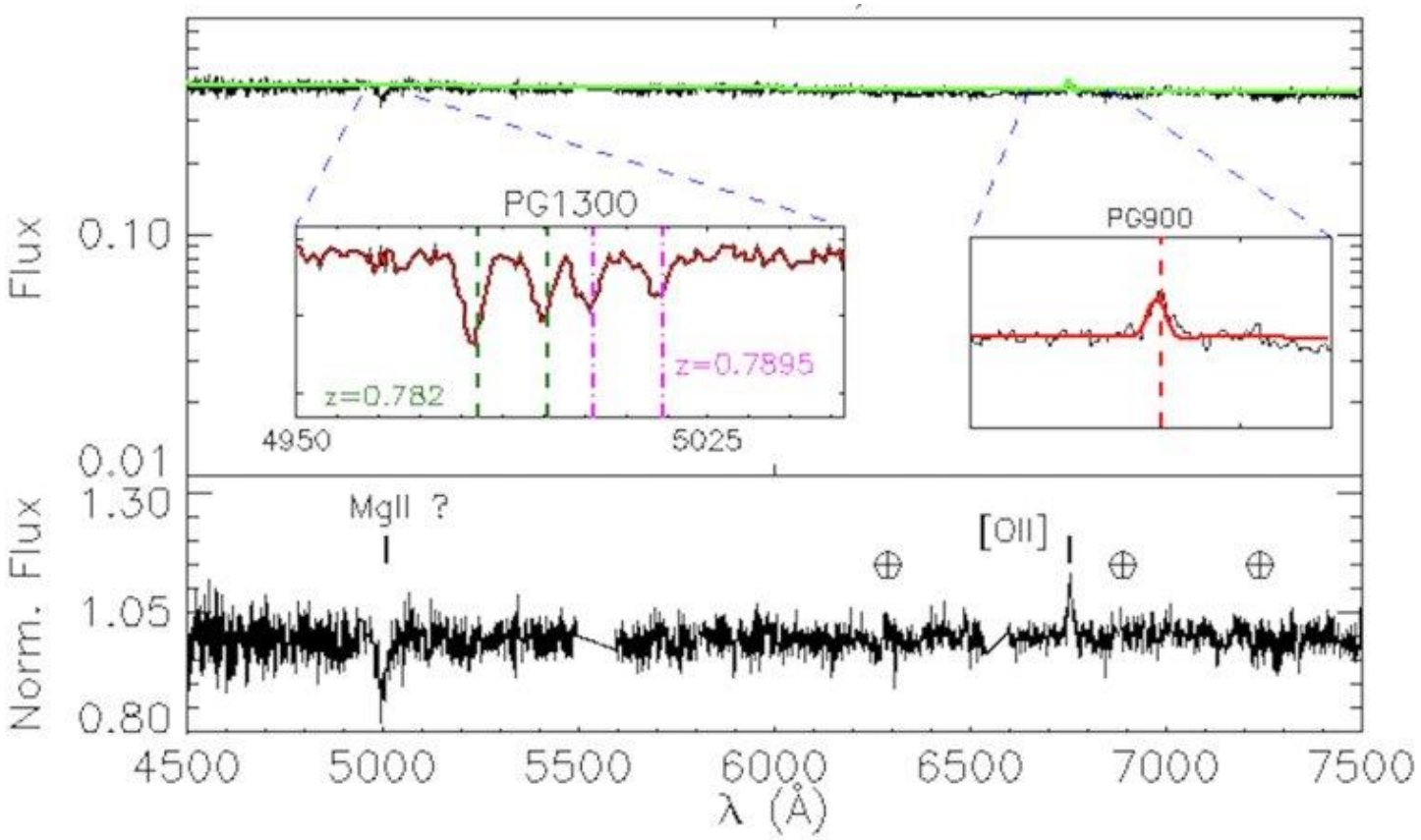
$z = 0.3043 \pm 0.0004$ | $z = 0.2110 \pm 0.0002$




Spectra of 1RXS J015658.6-530208 (left) and 1RXS J020922.2-522920 (right), observed during November and December of 2019, respectively. Goldoni et al. A&A, 650, 106 (2021)

# Some results

PMN J2321-6438, $z$ = 0.8126 ± 0.0002

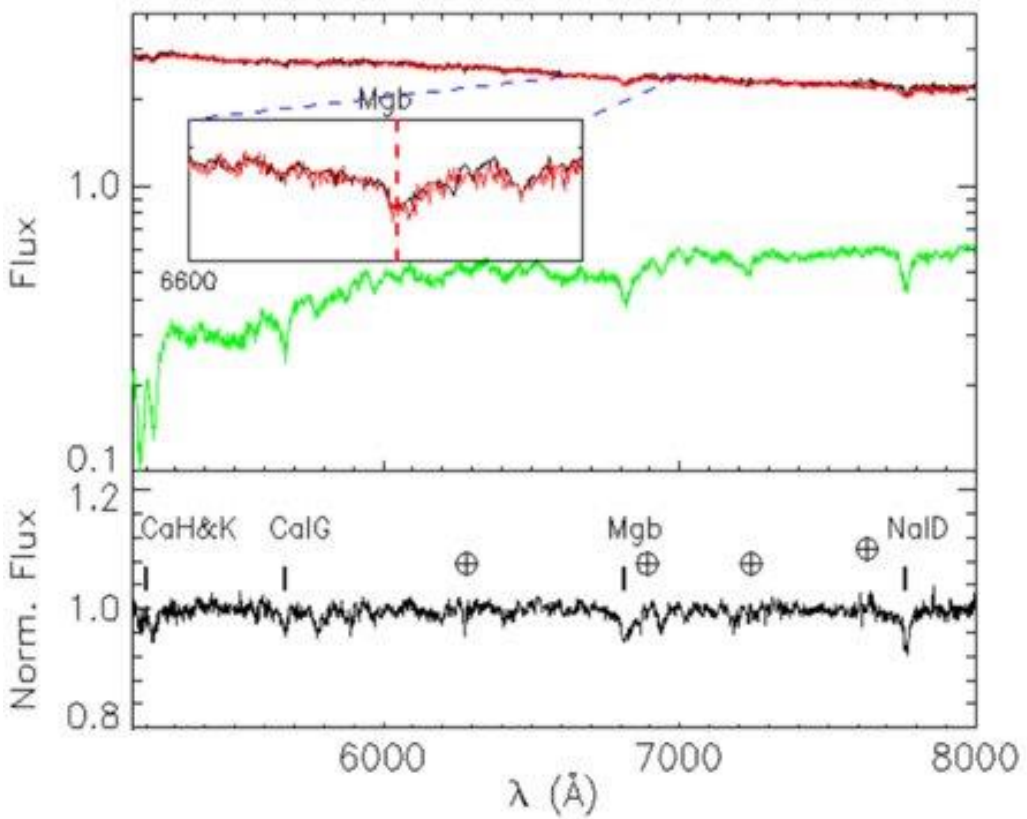


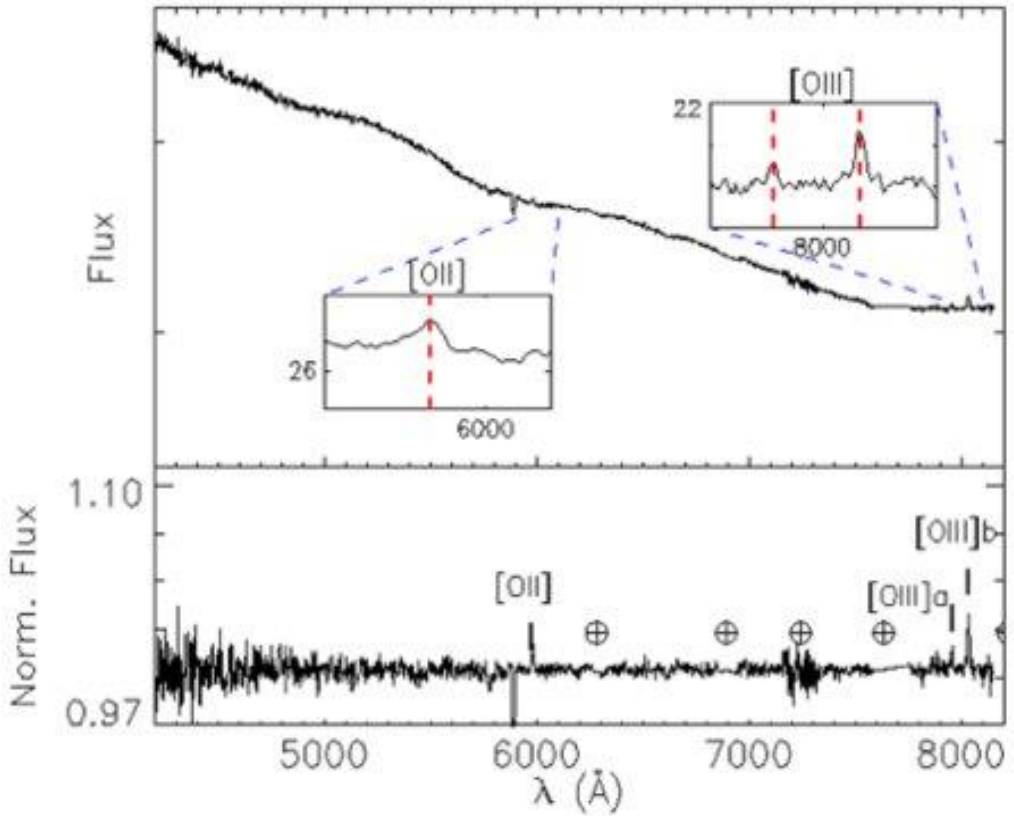

Spectra of PMN J2321-6438, observed during September and October of 2020, respectively. Kasai et al. MNRAS, 518, 2675 (2023)

- PG0900: [OII] of [OII] feature
- Interpretation:
  - $z$ ~ 0.812 if [OII]
  - $z$ ~ 0.349 if [OIII]
- Broad absorption feature at 5000 Å, not consistent with above interpretation
- Broad feature consistent with Mg II feature at $z$ ~ 0.79
- PG1300 observation to verify

# Some results

$z = 0.3171 \pm 0.0002$ | $z = 0.6045 \pm 0.0002$




Spectra of SUMMS J1130.5-780105 (left) and PKS 1424+240 (right), observed during January 2021, March 2022, and during April 2022, respectively. D'Ammando et al. A&A, 683, 222 (2024)

# Key results of spectroscopic papers I, II & III

| Item | Paper I | Paper II | Paper III |
|---|---|---|---|
| Authors & publisher details | Goldoni *et al*. A&A, 650, 106 (2021) | Kasai *et al*. MNRAS, 518, 2675 (2023) | D'Ammando *et al*. A&A, 683, 222 (2024) |
| Redshifts measured | 11(12)/19 | 14(15)/25 | 12(13)/24 |
| Measured redshift range | $0.1116 < z < 0.482$ | $0.0838 < z < 0.8125$ | $0.2223 < z < 0.7018$ |
| Lower limits (LL) | 0.449, 0.868, (0.618) | 0.3821, 0.6293 | 0.6185, 0.6347 |
| Median redshift | 0.21 (0.23 incl. LL) | 0.37 (0.38 incl. LL) | 0.39 (>0.42 incl. LL) |
| Host galaxy $M_R$ | -22.6 ± 0.4 | -22.6 ± 1.0 | -22.9 ± 0.6 |
| Combined median redshift: $z_m = 0.30$ | | | |

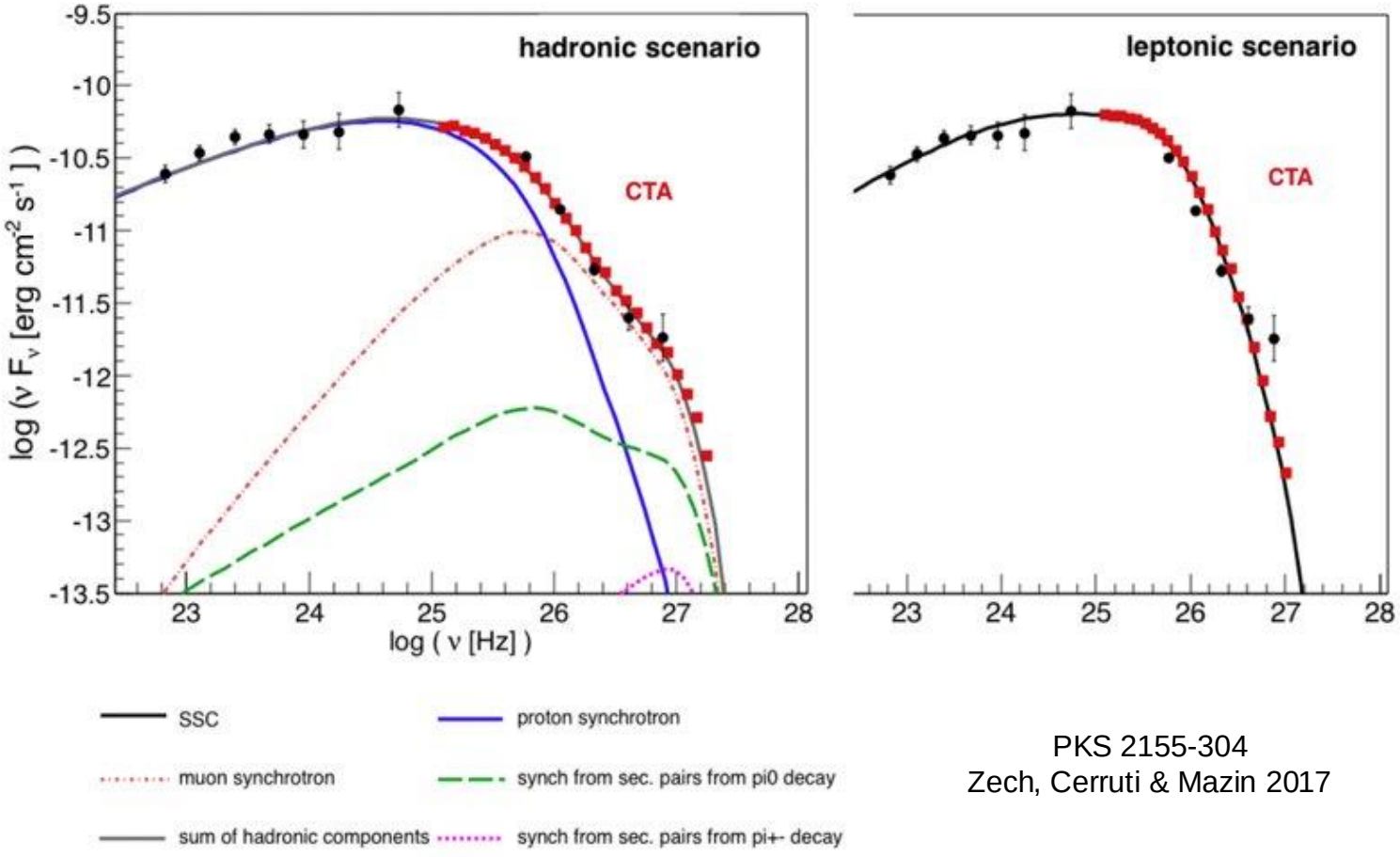
# Why blazar redshift measurements for CTAO?

The primary motivation is to

- **compile a special blazar sample with redshifts for the CTAO observations for/to**
  - gamma-ray emission modelling
  - VHE BL Lacs cosmological evolution studies
  - extragalactic background light (EBL) density studies
  - constrain the intergalactic magnetic field (IGMF)
  - constrain photo-axion coupling and Lorentz Invariance Violation (LIV) theories

# Why blazar redshift measurements for CTAO?

## Gamma-ray emission modelling




PKS 2155-304
Zech, Cerruti & Mazin 2017

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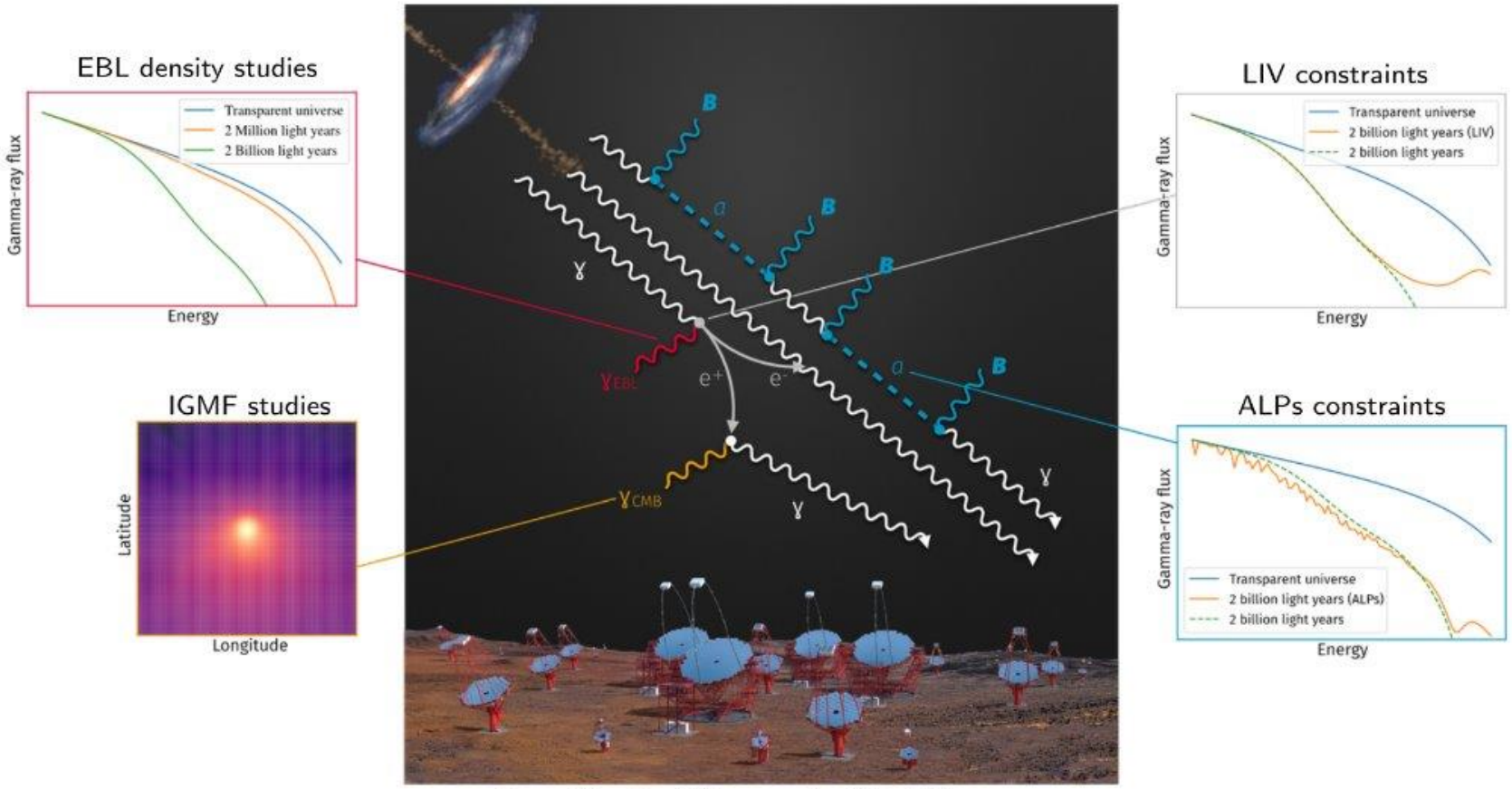
## EBL density & IGMF, LIV, ALP theory constraints




*Credit*: J. Biteau & M. Meyer

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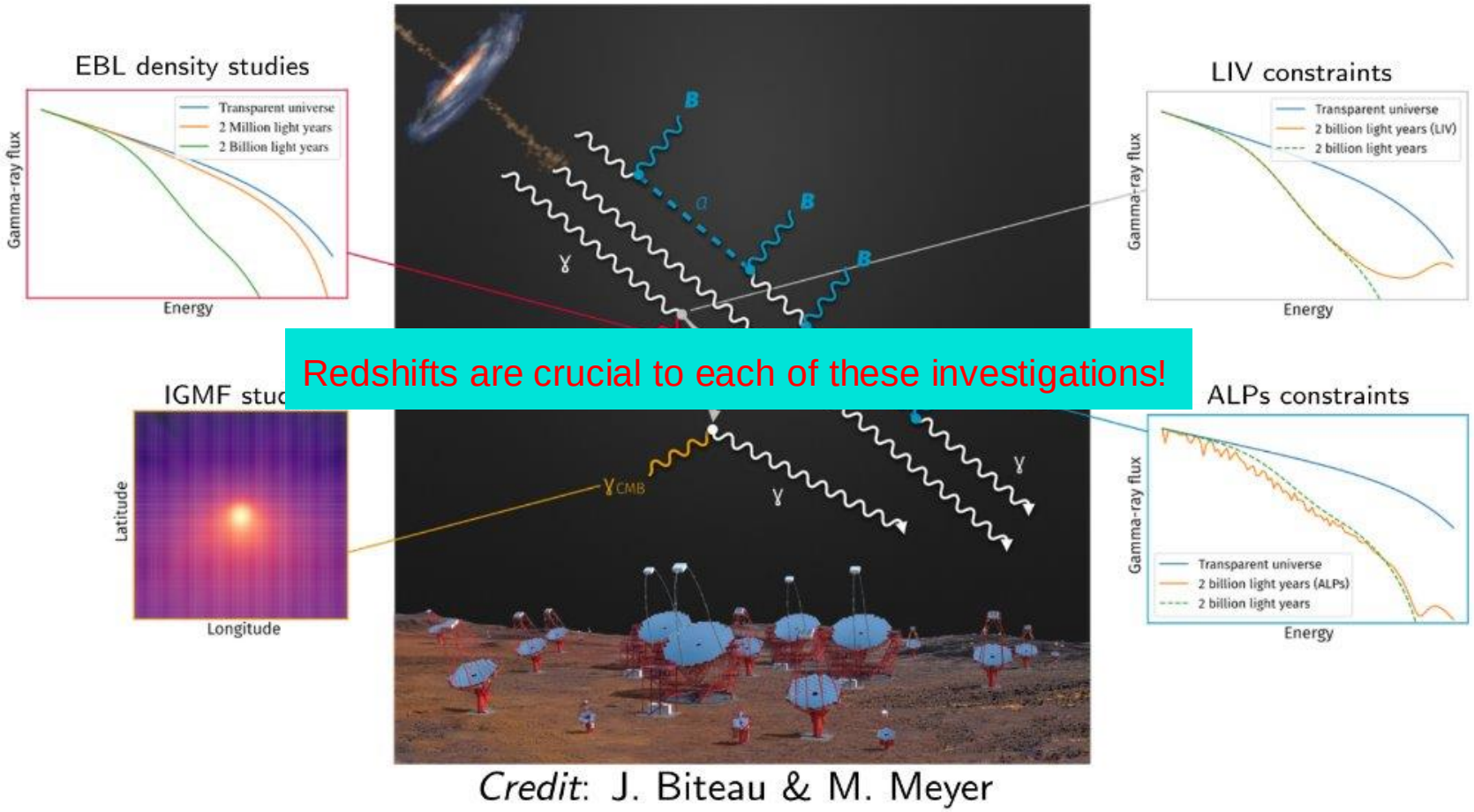


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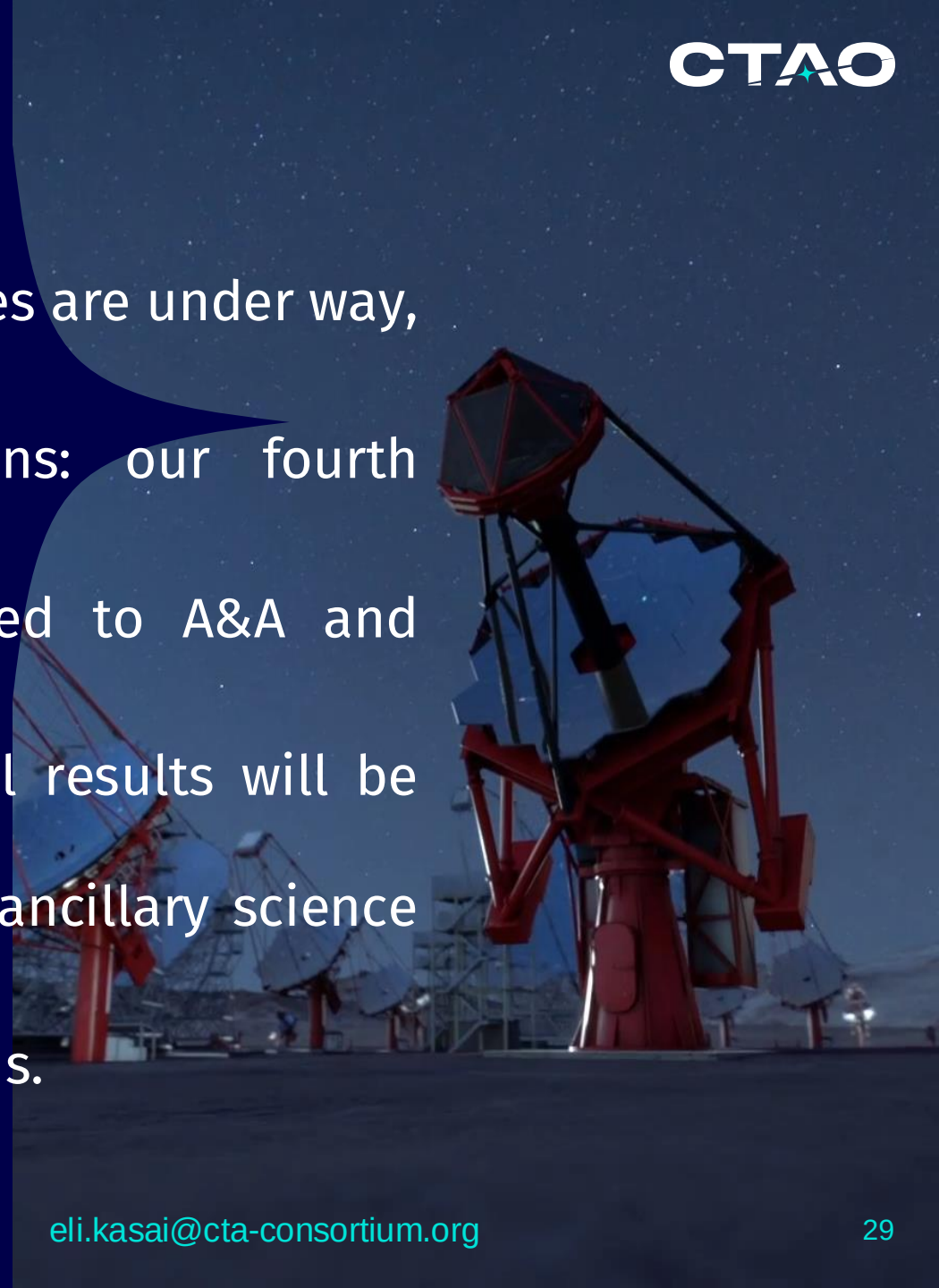
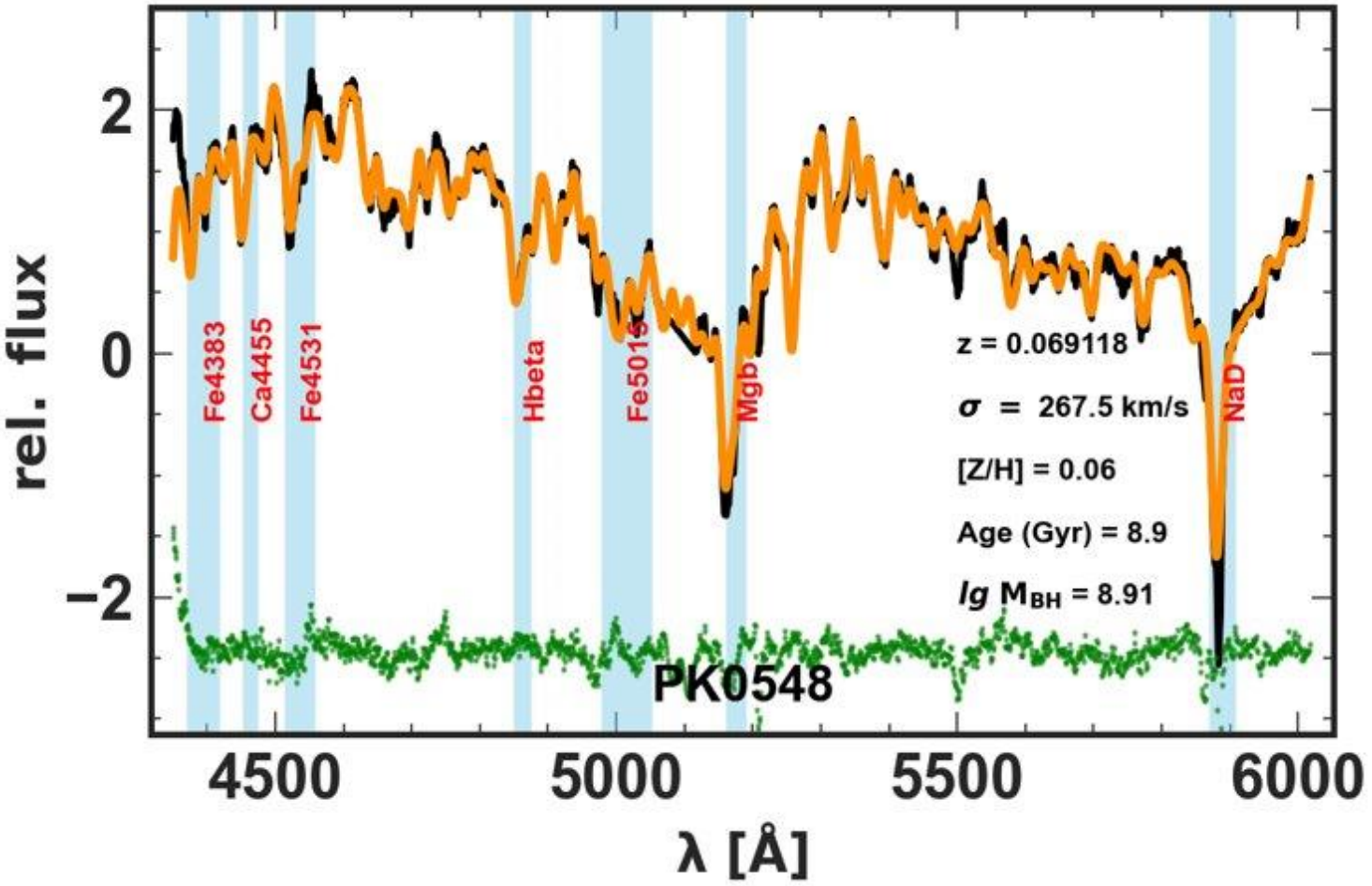
# Summary & future work

- New simulations of the blazar candidate sources are under way, which will increase our existing sample size.
- We continue observations and publications: our fourth spectroscopy paper is in preparation.
- Our first imaging paper has been submitted to A&A and reviewed the 1st time – resubmission in prep.
- A web database containing our observational results will be made public in the neaf-future.
- We have begun stellar population studies as ancillary science with some of our high S/N spectra.
- Feel free to contact me if you are keen to join us.



# Backup slide – SPS ancillary science: preliminary analysis of PKS 0548-322




***Credit:*** **Adebusola Alabi**