

The background of the slide is a photograph of the Cherenkov Telescope Array (CTA) observatory. It shows several large, dish-shaped telescopes with blue and white hexagonal mirrors, mounted on metal frameworks. They are situated on a grassy, hilly mountain ridge under a clear blue sky. The telescopes are of various sizes, with the largest one in the foreground center-left.

CTAO

CONSORTIUM

Redshift Determination of Blazars for the Cherenkov Telescope Array Observatory

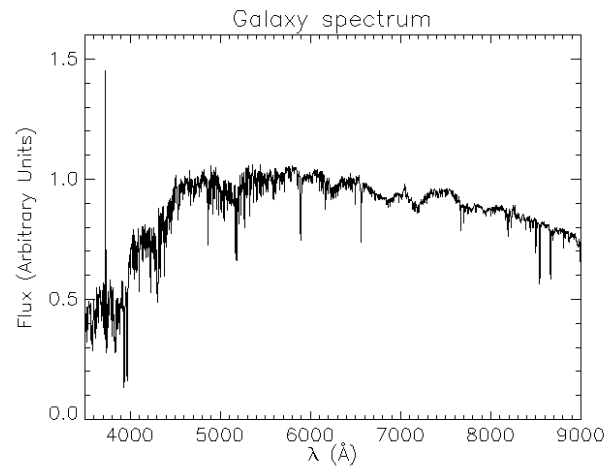
Paolo Goldoni for the Redshift Determination Group

Illuminating the Active Universe Garching 14/09/2026

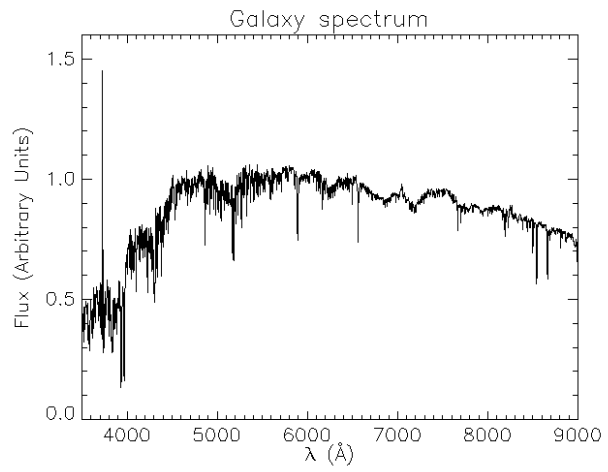
Dr. Paolo Goldoni, APC/IRFU Researcher
paolo.goldoni@cta-observatory.org

BL Lac optical spectrum

BL Lac optical spectrum

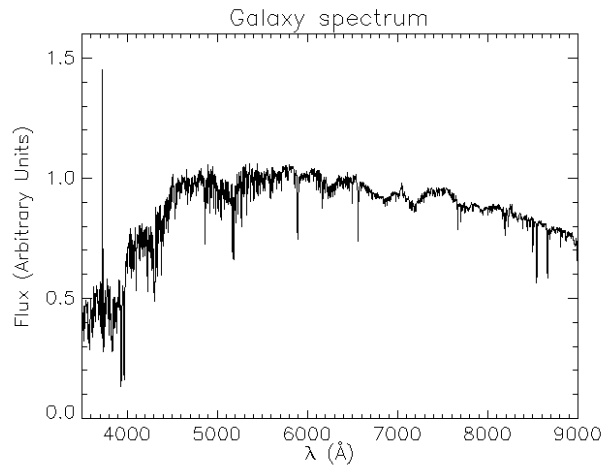


BL Lac optical spectrum

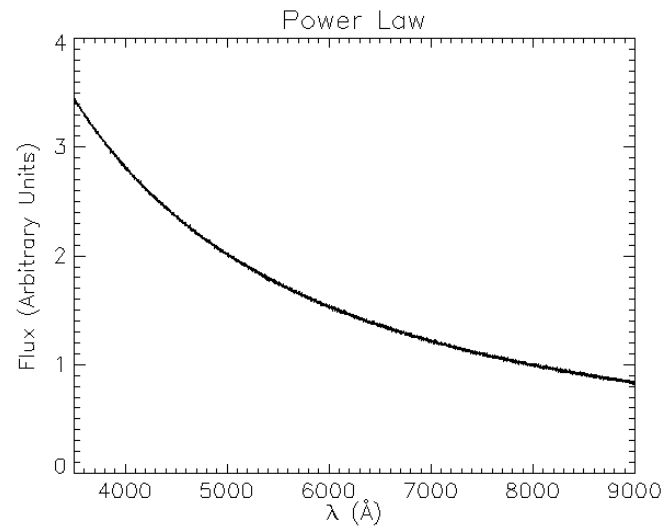


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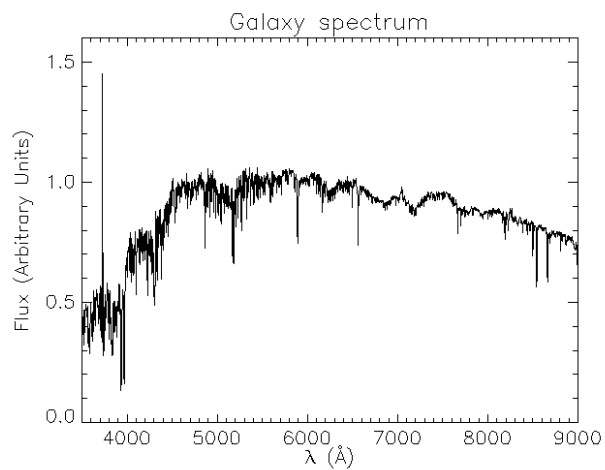
BL Lac optical spectrum



+

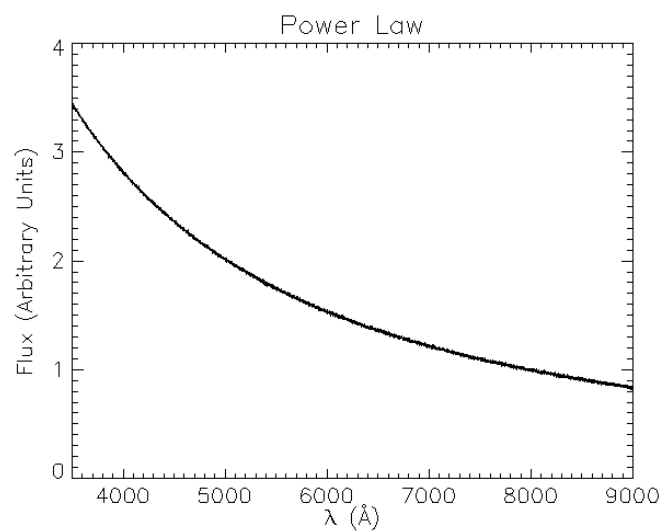


BL Lac optical spectrum

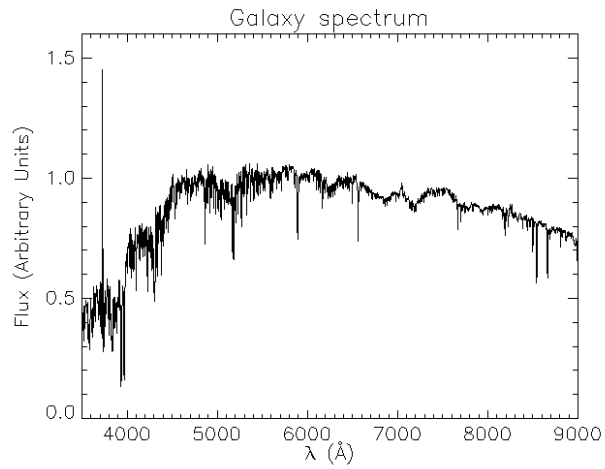


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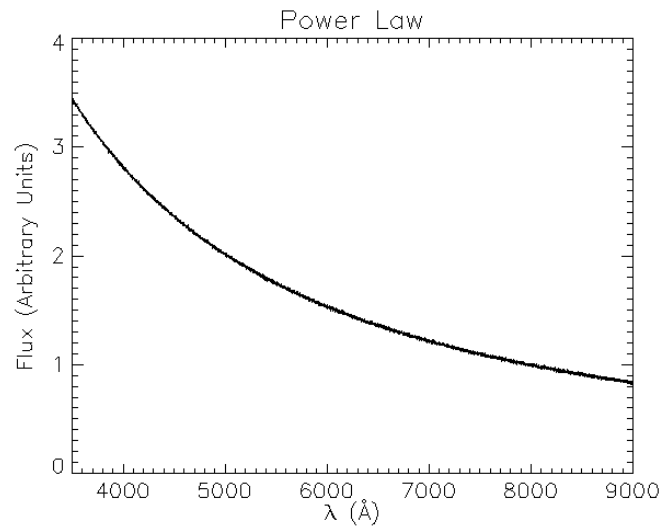
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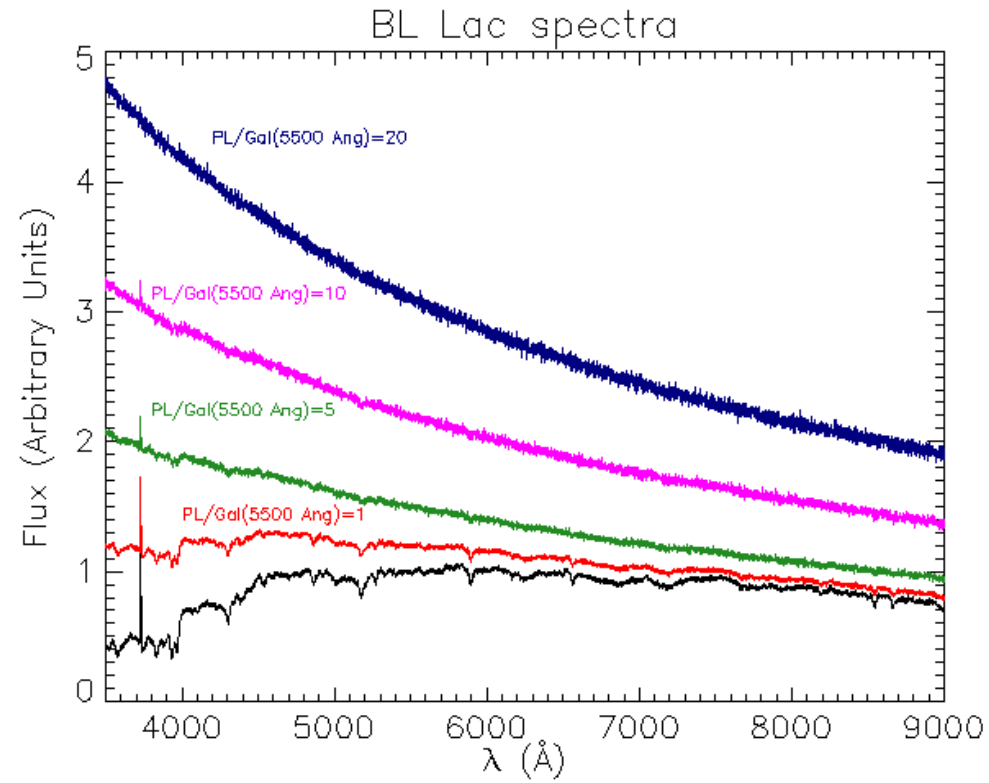
BL Lac optical spectrum



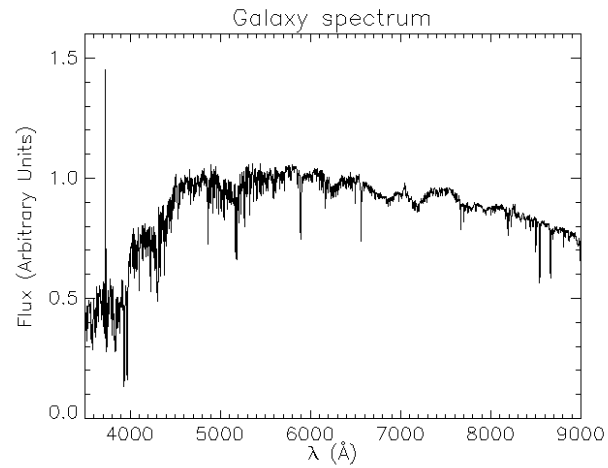
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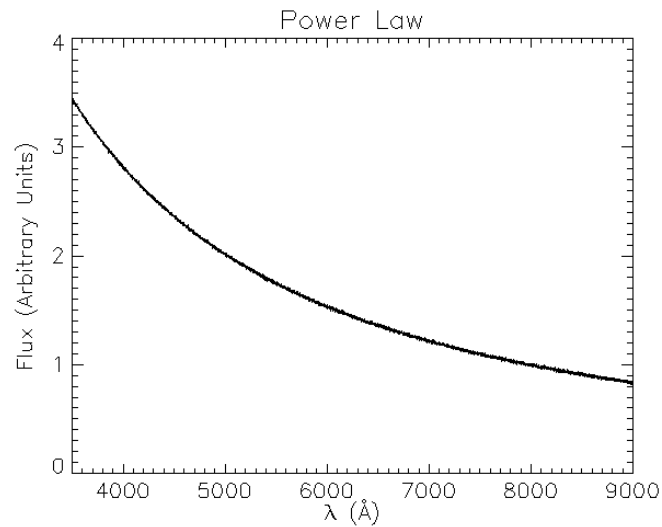
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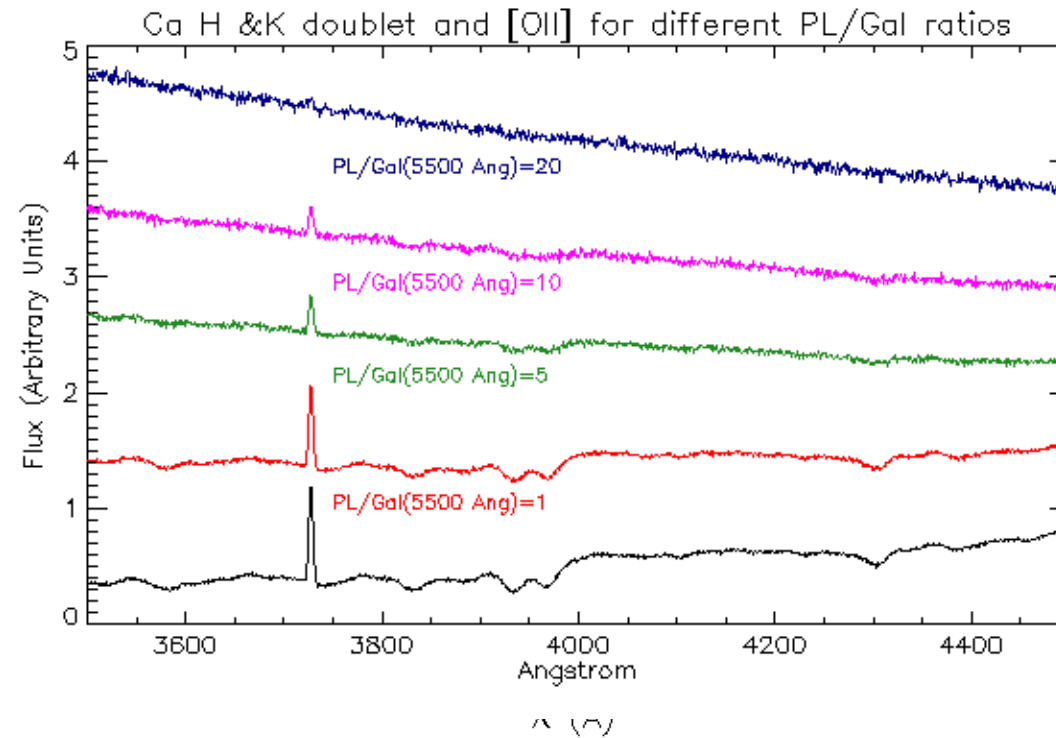
BL Lac optical spectrum



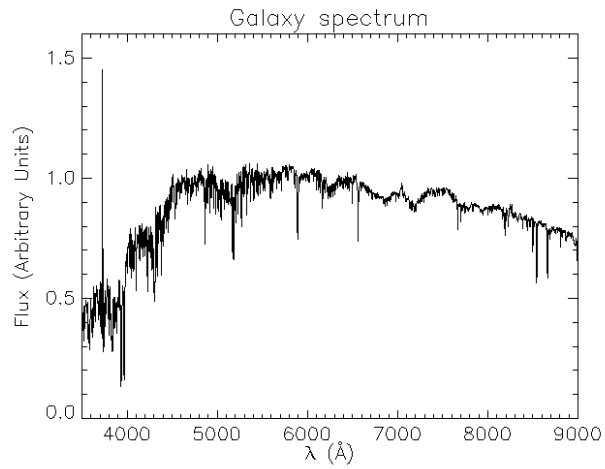
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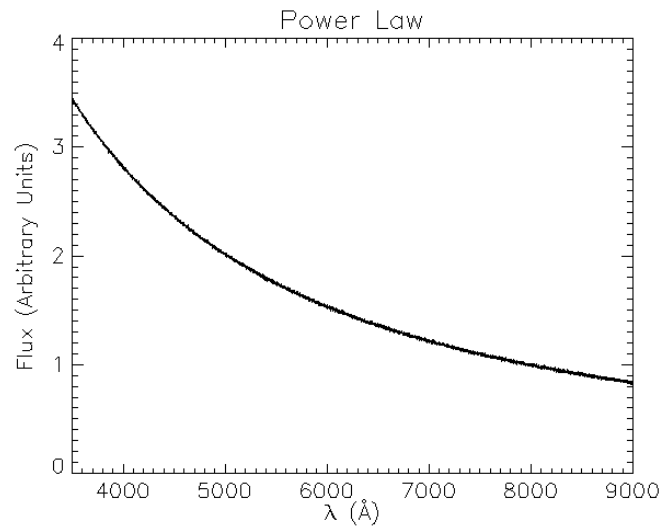
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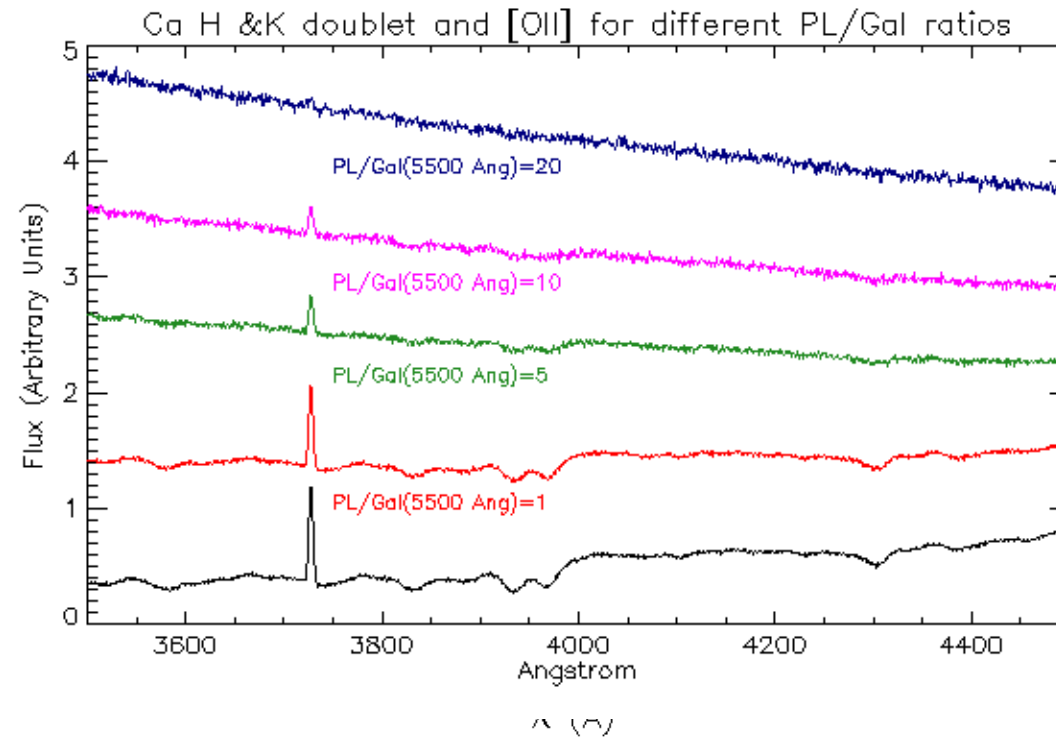
BL Lac optical spectrum



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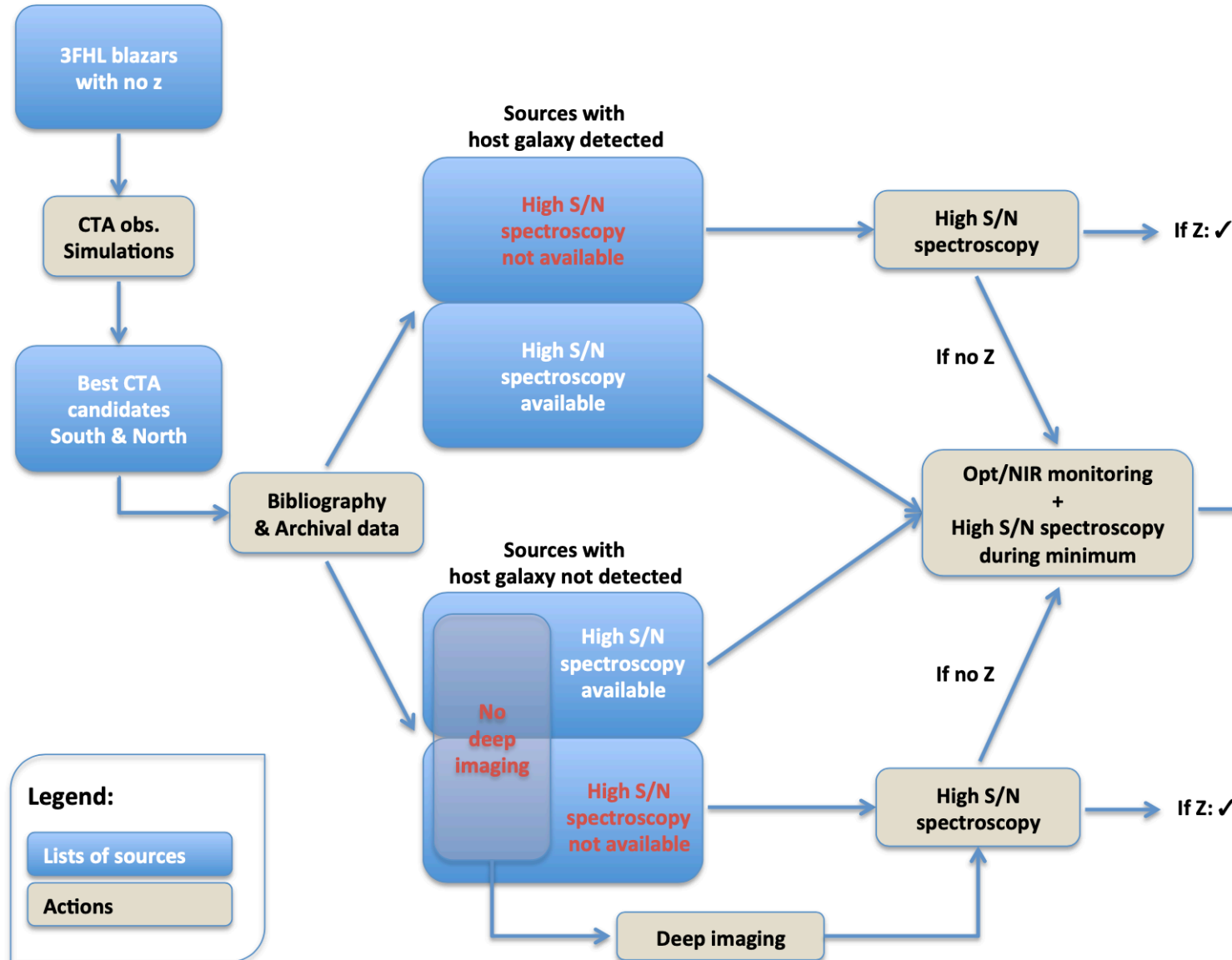
Power law is strongly variable (1-2 magnitudes) on several years

Goal of the Task force

- Blazars (BL Lacs) are the main extragalactic targets of CTAO, their redshifts are difficult to measure because the jet hides the features of the host galaxy. Uncertain results are found in the literature
- Organize within the CTAO consortium the effort to determine redshifts of Blazars that are CTAO candidates
- Simulations using the 3FHL hard spectrum Fermi-LAT catalogs to pick the most promising candidates without redshift for CTAO observations¹ assuming $z=0.3$
==> 165 3FHL sources without z detectable in <30 hrs
- Proposals to Observatories in both hemispheres: spectroscopic and imaging observations

1) Note that Fermi catalogs give average flux, so we used a conservative estimation for the flux.

- Blazars (BL Lac) are difficult to measure because of the lack of literature
- Organize with simulations and archival data to find candidates
- Simulations used to find candidates without spectroscopy ==> 165 3FHL sources
- Proposals to OATs



are difficult to
be found in the
sources that are CTAO
promising
observations

1) Note that Fermi c

- Strategy: Deep spectroscopic and imaging observations to measure or constrain the redshift. All observations are carefully planned, the data analysed thoroughly and the results published in detail.

- Spectroscopy (VLT, Keck, SALT, Lick) :
 - 1) obtain one high S/N (> 100), resolution > 1000 spectrum,
 - 2) if unsuccessful perform low state observations of the same quality when the source is fainter.
When one target already has a high S/N observation by other authors, go to step 2) directly
 - Redshift measurement (errors few $\times 10^{-4}$)
 - Lower limits from detection of absorption systems (identification of high redshift objects)
 - Estimation of host galaxy properties

- Deep spectroscopic and imaging observations to measure or constrain the redshift. All the observations are carefully planned, the data analysed thoroughly and the results published in detail.
- Imaging (NOT, SOAR): observations to a depth 25 mag/arcsec², When one target already has deep imaging from other authors, we skip it.
 - Statistical redshift estimation (errors ~0.05-0.1)
 - Measure of the host galaxy properties
 - Study of the environment (cluster ?)

- Monitoring (REM, TJO): Follow up of sources already observed in spectroscopy to detect low states (note that public monitoring results complement our results)
- Results of all of these observations may be needed to clinch the redshift
- Database to organise the information on the sources (observations, also from literature, simulations, counterparts, public spectra, light curves,...)
- Accessible to members of the group, we are still uploading data. The database will become public when the next (and final for this sample) spectroscopic paper is accepted.

Telescopes and Instruments

Spectroscopy

VLT(ESO) (8.2 m mirror)

FORS 28 targets

Keck (10 m mirror)

ESI 15 targets

SALT (11.2 m mirror)

RSS 27 targets

NTT(ESO) (3.5 m mirror)

EFOSC2 18 targets

Shane (Lick) (3.5 m mirror)

KAST 31 targets

GTC 10m mirror

OSIRIS 1 target (DDT)

Imaging

NOT (2.5m mirror)

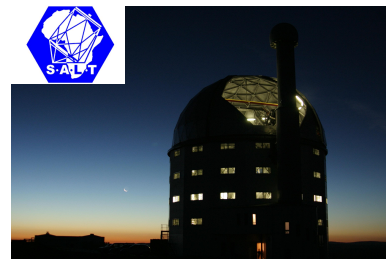
ALFOSC 17 targets

SOAR (4.1 m mirror)

SAM 6 targets

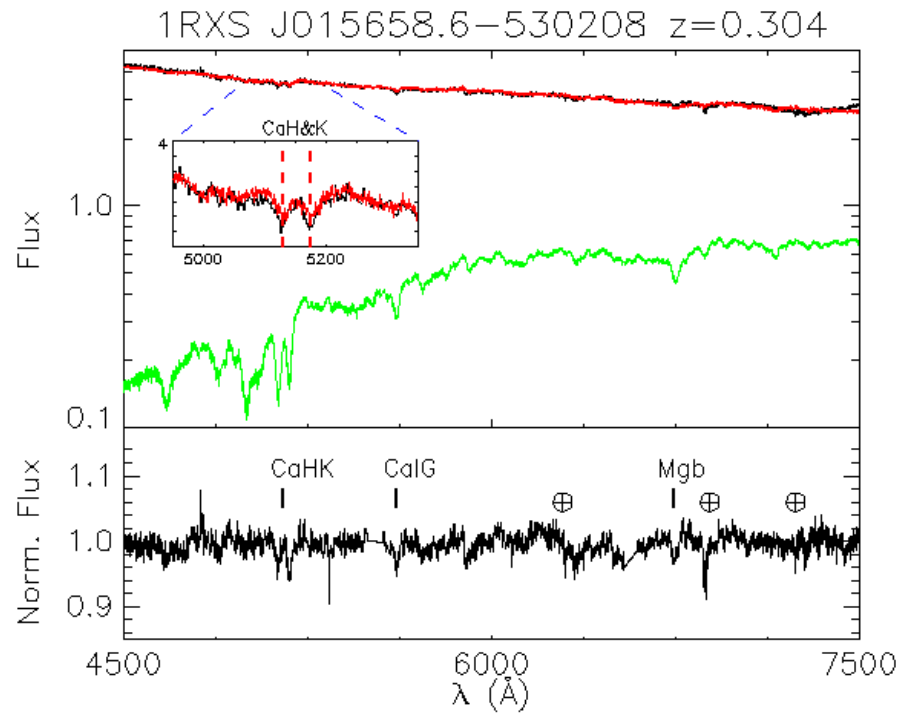
Gemini (8 m mirror)

2 targets

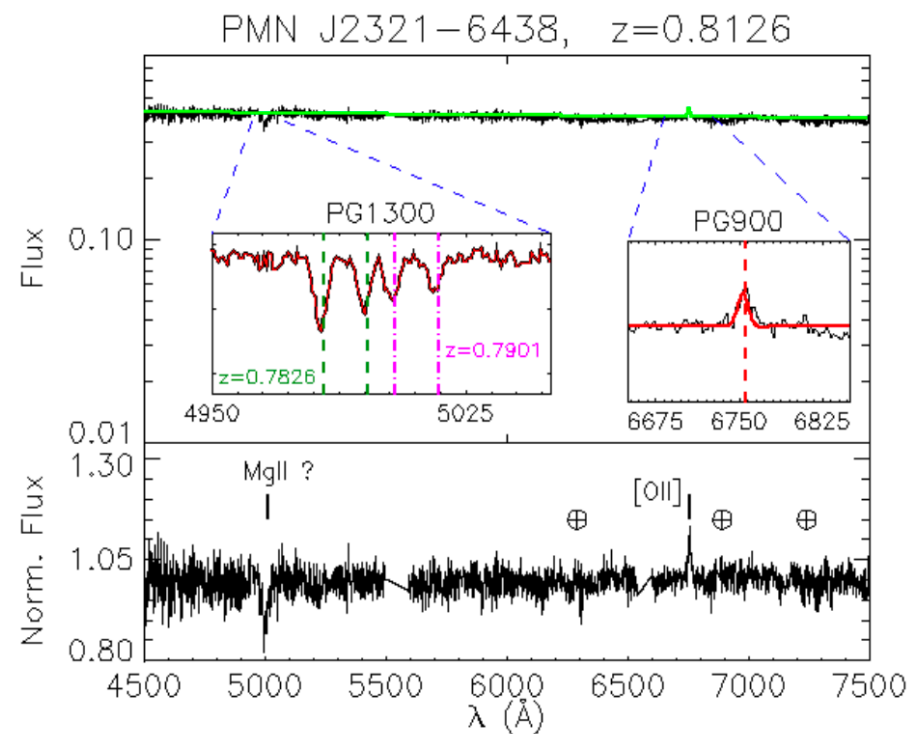
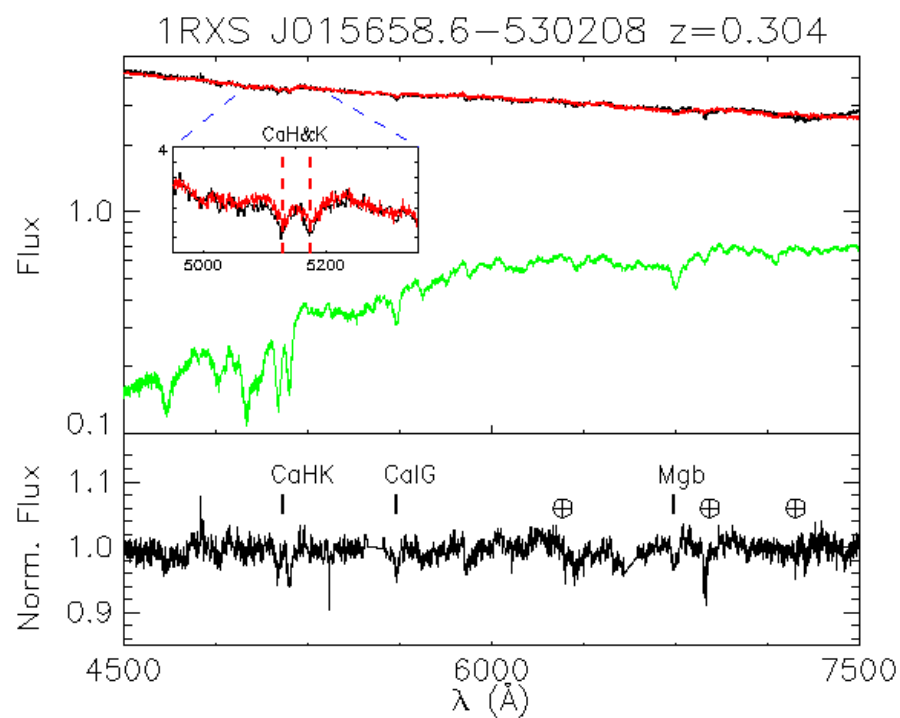


Example spectra

Example spectra

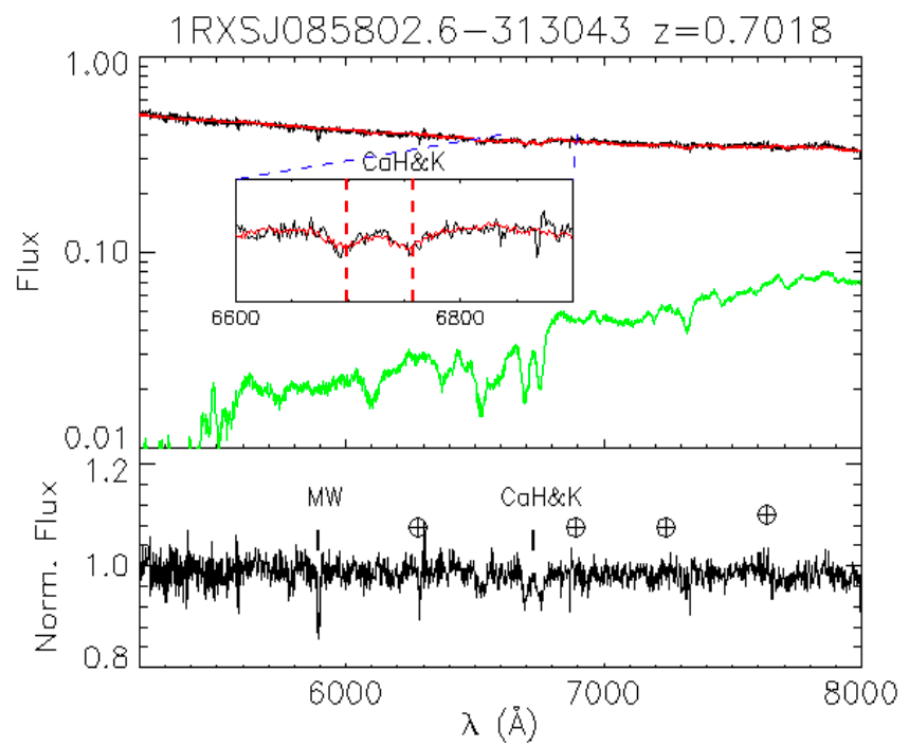


Example spectra

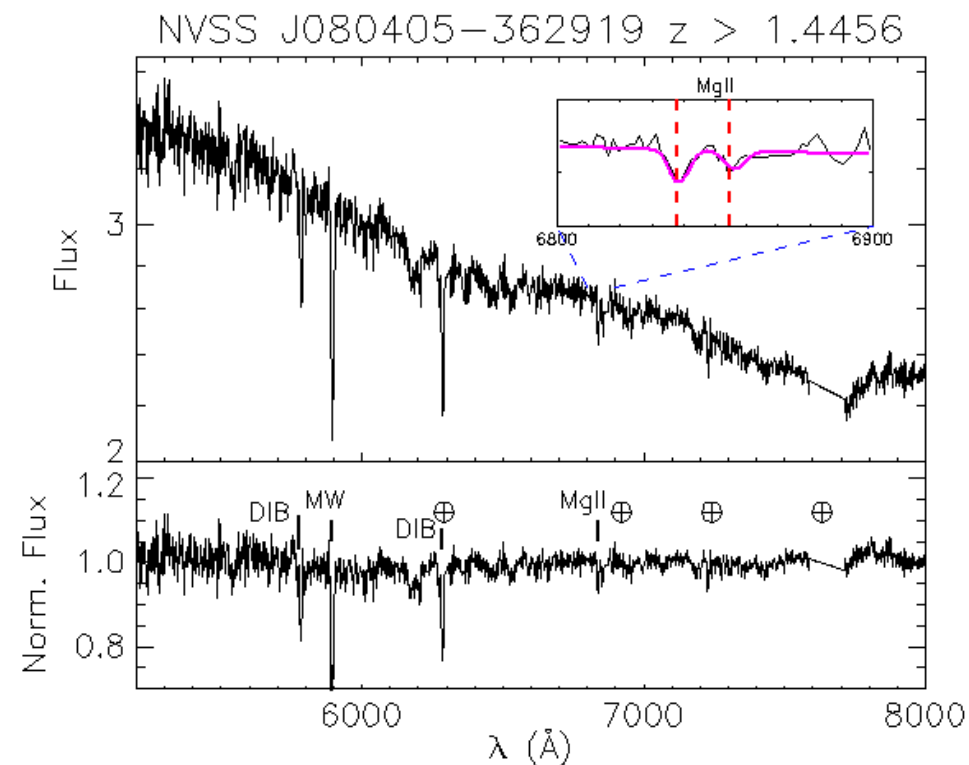
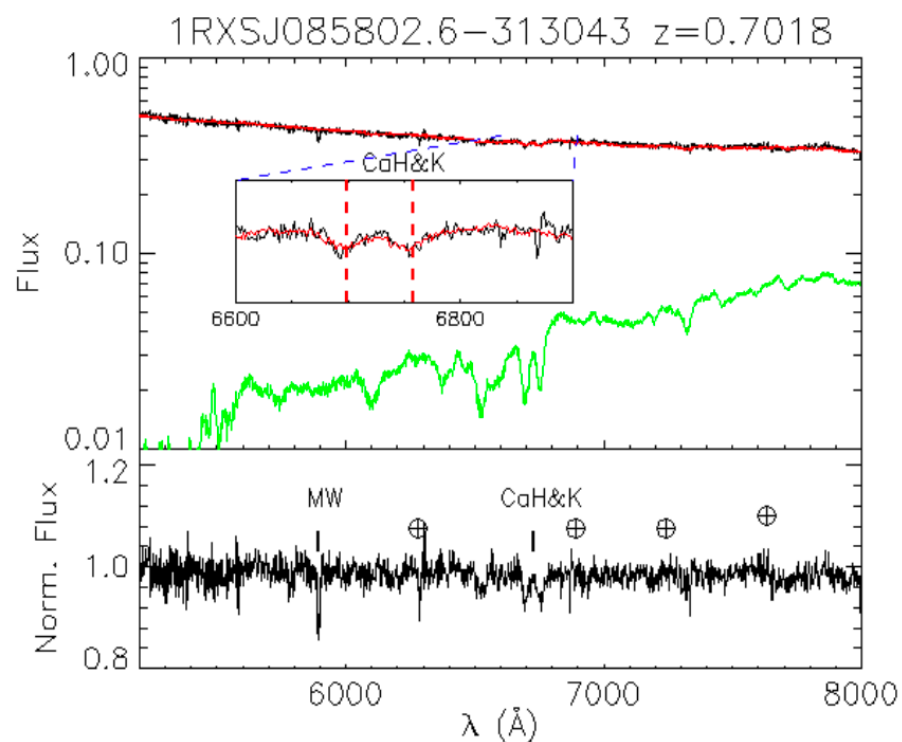


Example spectra

Example spectra



Example spectra



Spectroscopy results

- Of the 165 targets, ninety spectra have been published. We still have 17 spectra to publish (paper in prep). Considering also other groups observations, there are 8 objects with no high SN spectrum (+ 3 with medium SN spectrum).==> sample >90 % observed

Spectroscopy:

Goldoni et al. 2021 A&A, 650, 106

Kasai et al. 2023 MNRAS, 528, 2675

D'Ammando et al. 2024 A&A, 683, 222

Goldoni et al. 2024 A&A Letters, 691, 5

Rajput et al. 2025, A&A, 704, 190

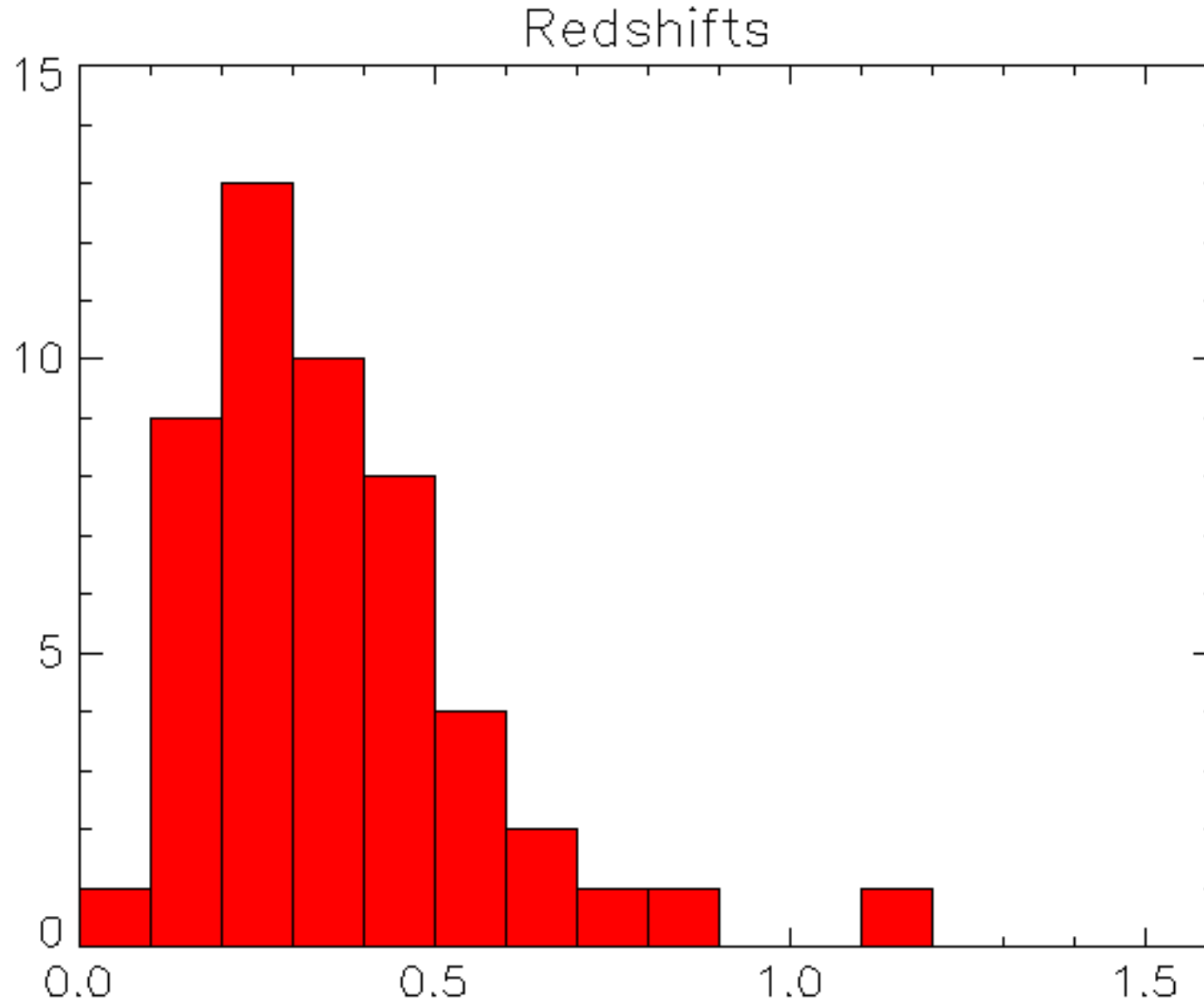
Hervet et al. In preparation

Spectroscopy			
Published	Redshifts	LL	zmed
90	49(+1*) * uncertain	8	0.32 0.36 with LL

- The value of the median redshift of the sample becomes higher when lower limits are included

- Of the 165 t (paper in prep spectrum (+ 3

Spectroscopy:
 Goldoni et al. 2021
 Kasai et al. 2023 M
 D'Ammando et al.
 Goldoni et al. 2024
 Rajput et al. 2025,
 Hervet et al. In pre



to publish
 h no high SN

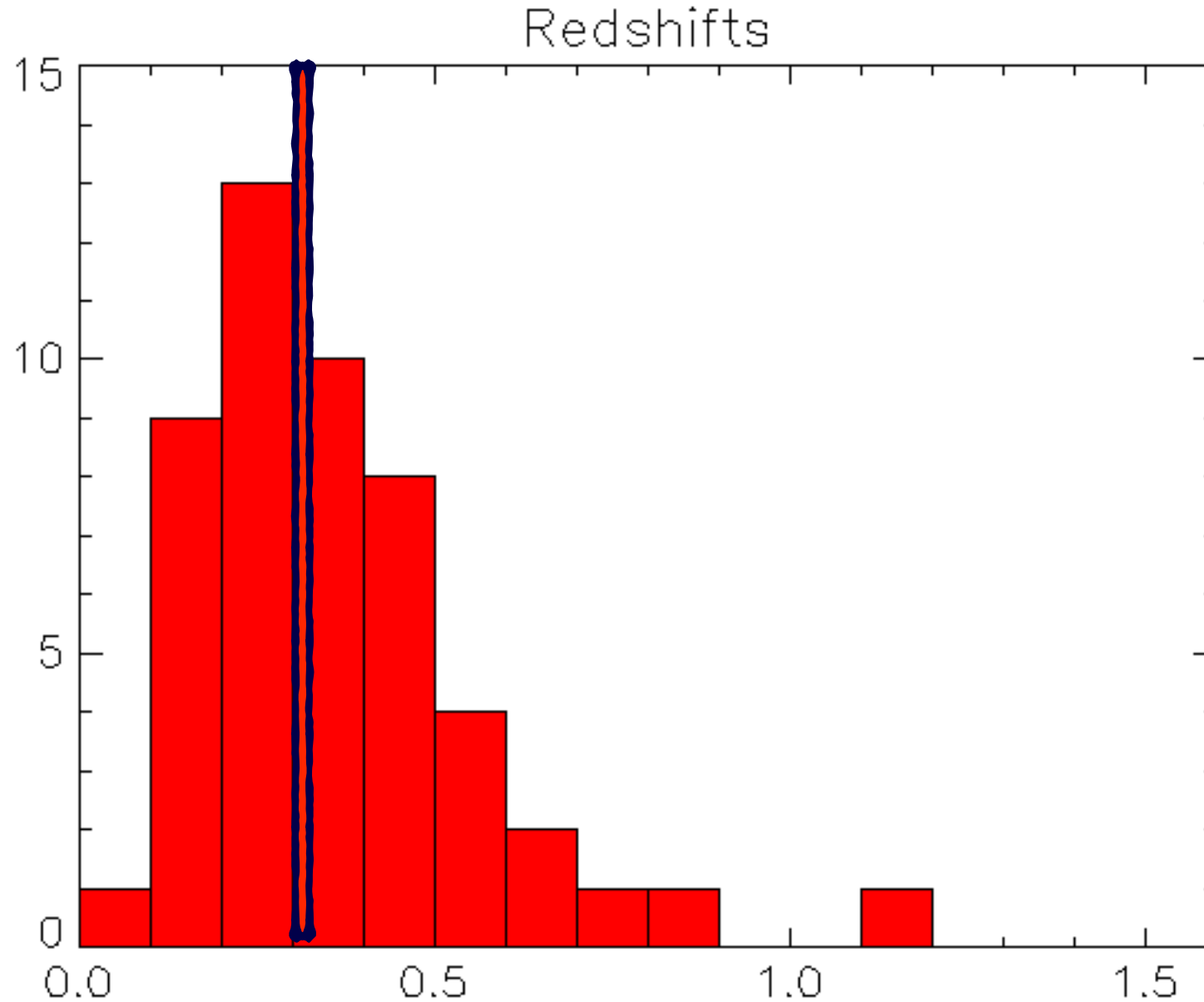
zmed
0.32
0.36 with LL

- The value o

s are included

- Of the 165 t (paper in prep spectrum (+ 3

Spectroscopy:
 Goldoni et al. 2021
 Kasai et al. 2023 M
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 Goldoni et al. 2024
 Rajput et al. 2025,
 Hervet et al. In pre



to publish
 h no high SN

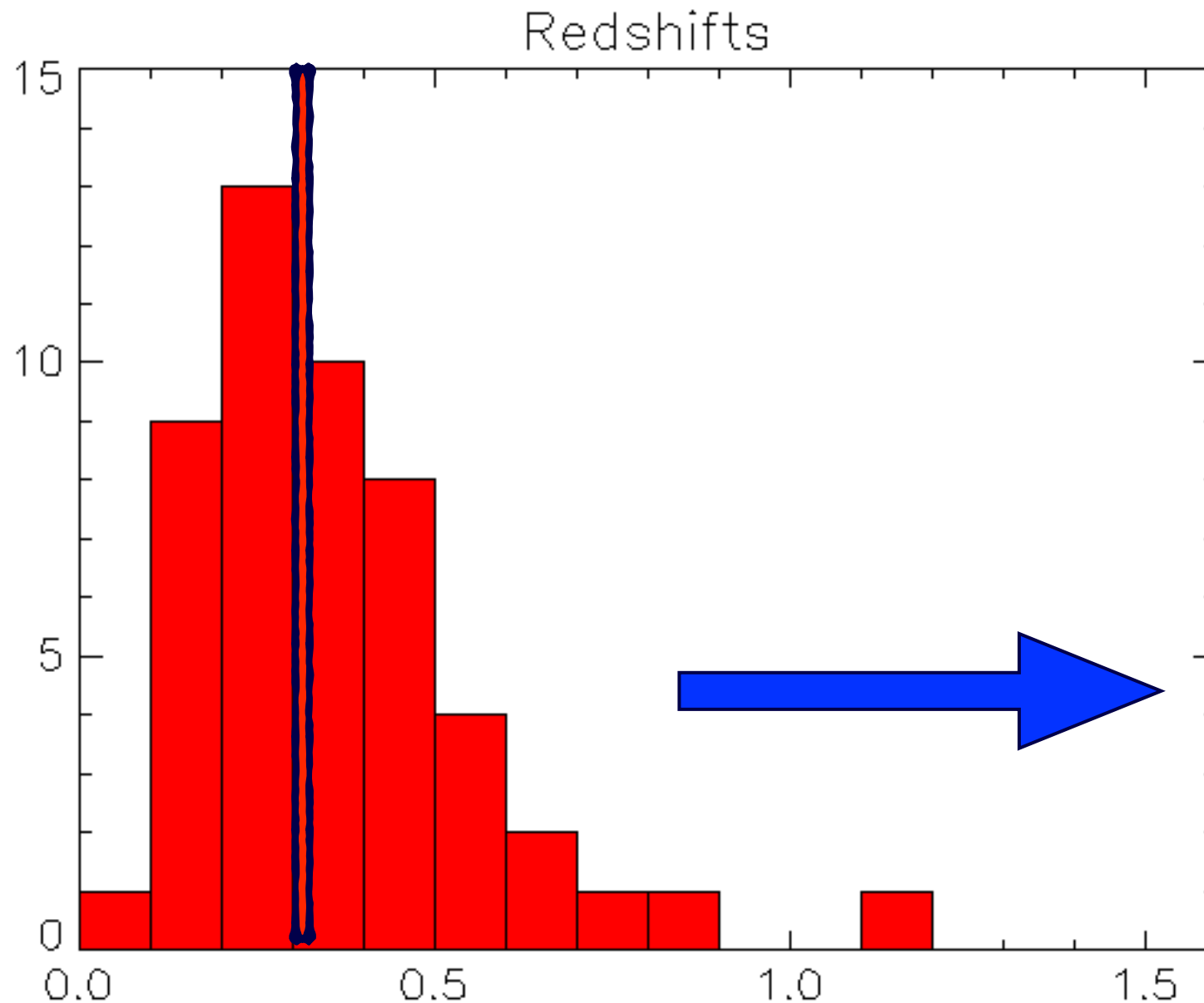
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 Hervet et al. In pre



to publish
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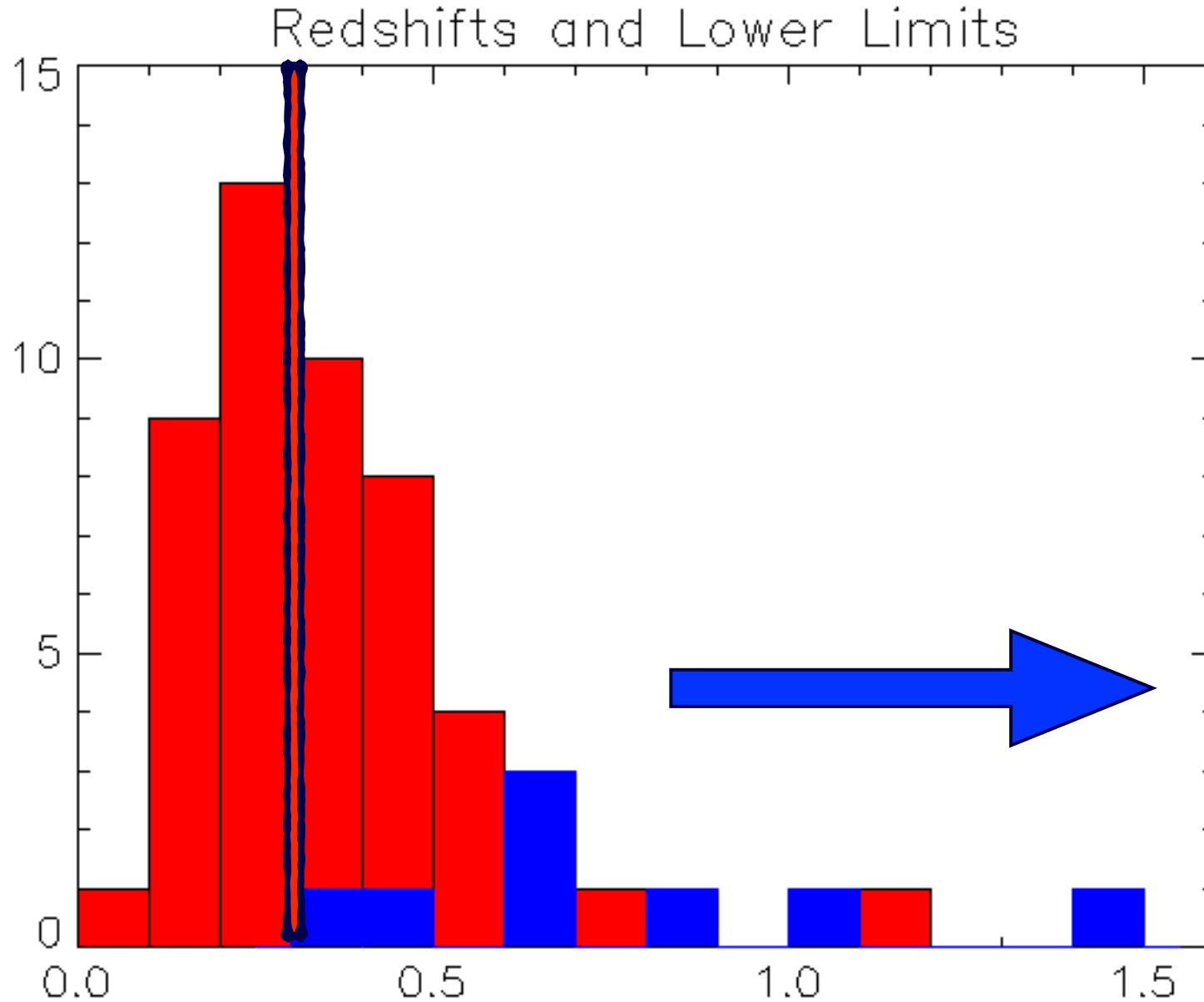
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Goldoni et al. 2024
Rajput et al. 2025,
Hervet et al. In pre



to publish
h no high SN

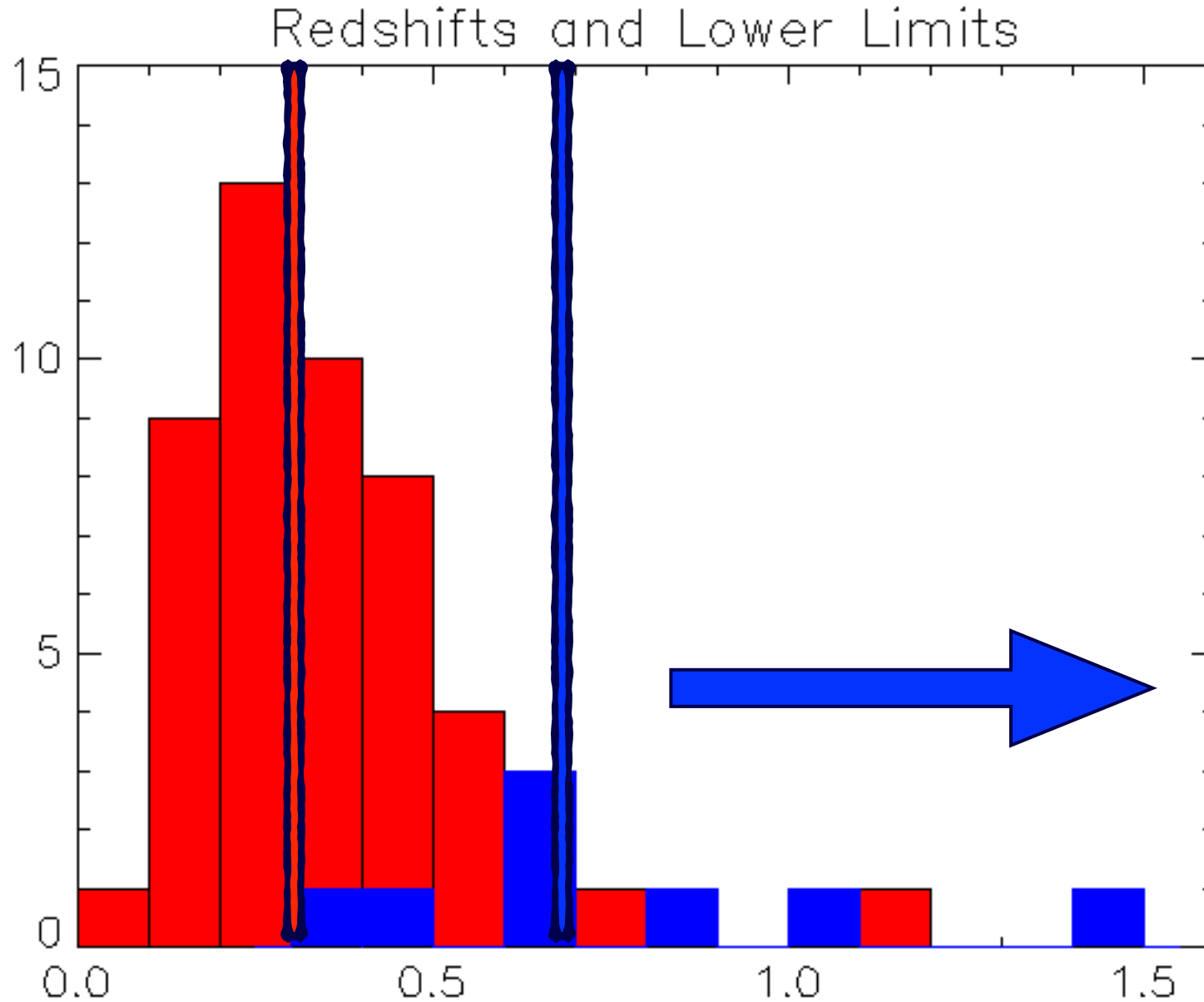
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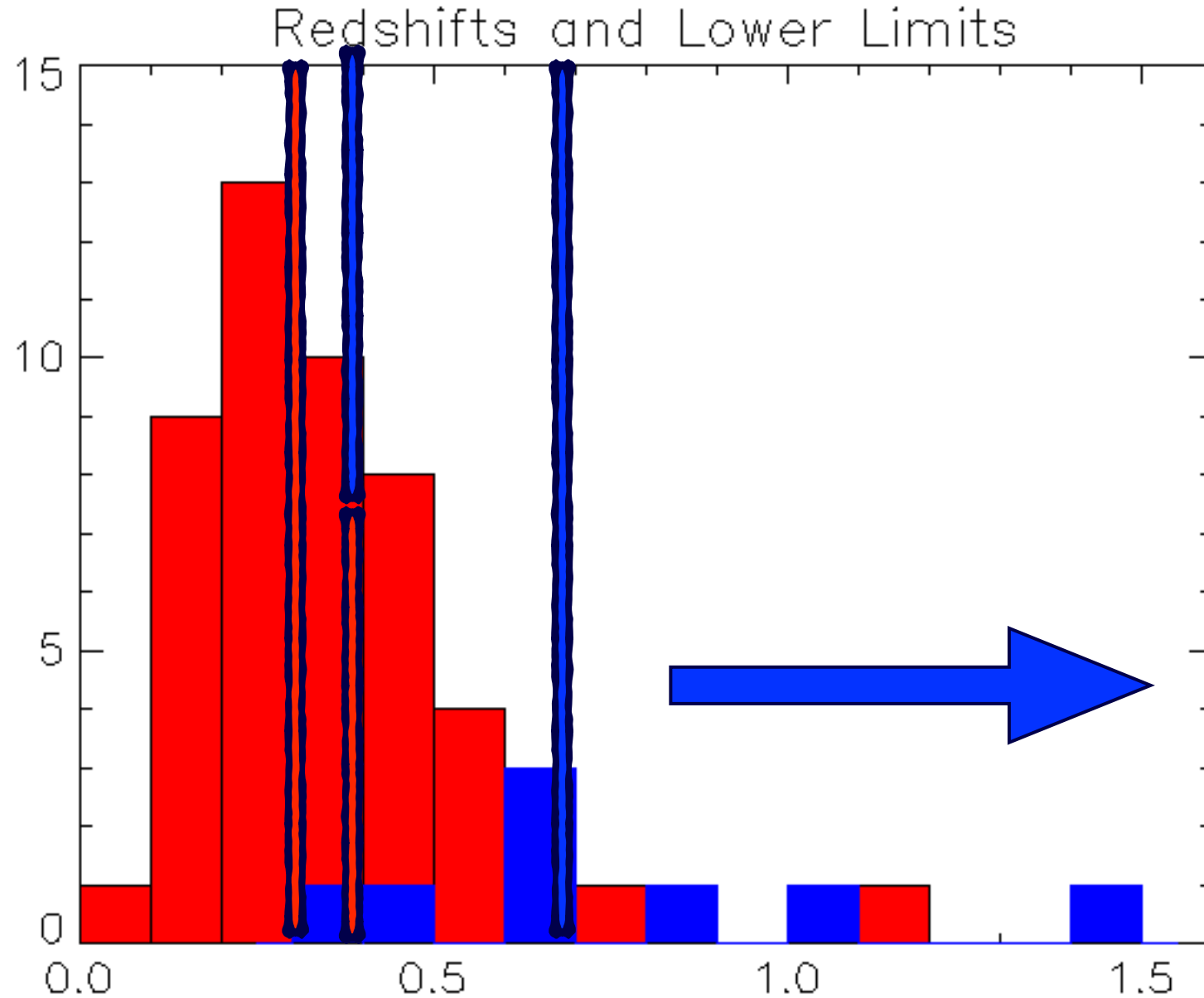
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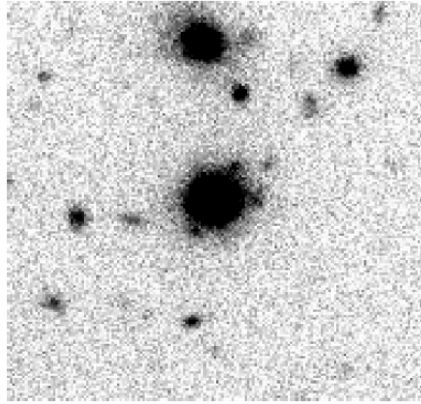
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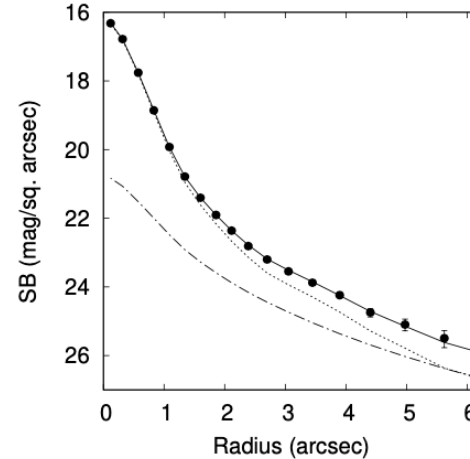
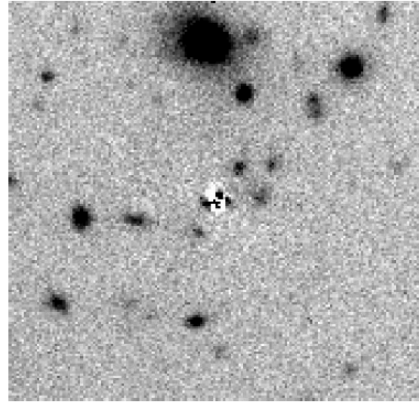
s are included

Imaging results

J0905.5+1357



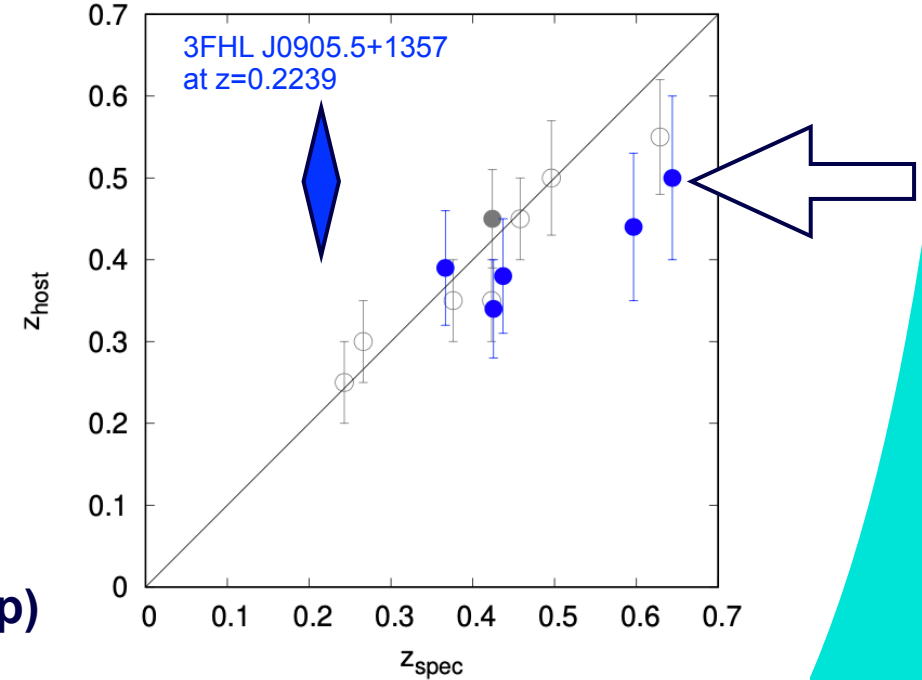
35''



3FHL J0905.5+1357 from spectroscopy (one line only)

$z=0.2239$ or $z=0.644$

Imaging strongly implies $z=0.644$ (host luminosity and galaxy group)



Imaging (Since 2016)

Observed	Published	Hosts
25	17	9

5 sources with host but no redshift

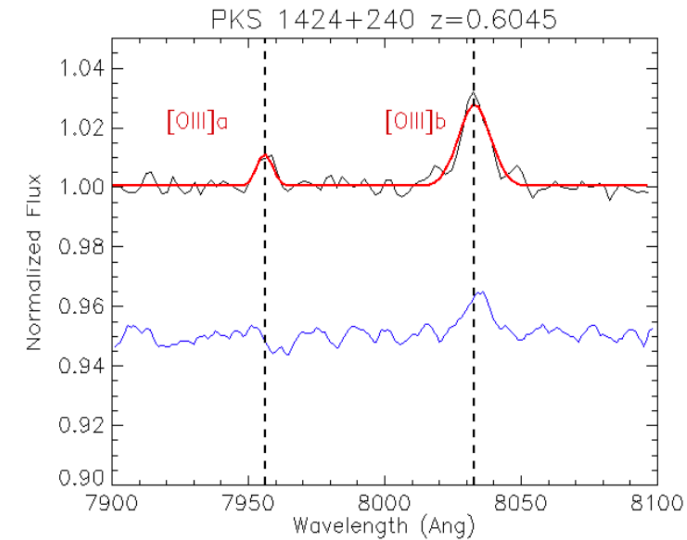
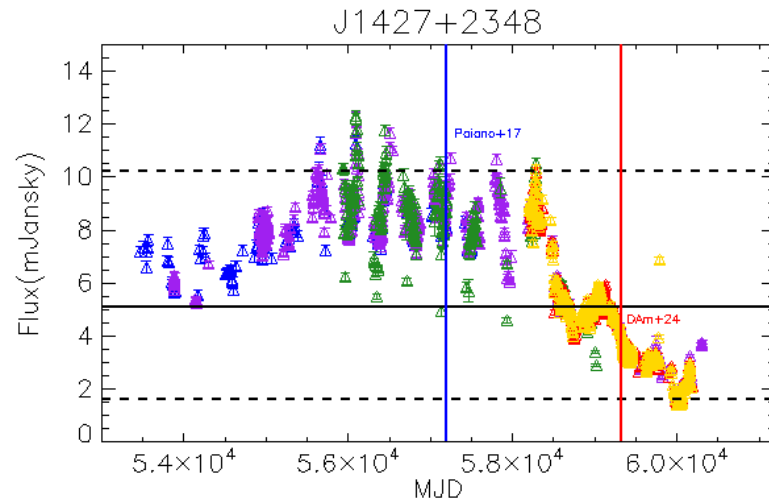
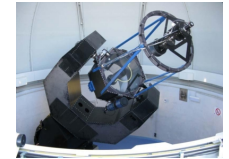
Nilsson et al. 2024 A&A

Still 63 targets (without redshift) to be observed. Lack of manpower.

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Monitoring and Low State observations - I

- If high S/N spectroscopy unsuccessful==> Spectroscopy in optical low state
- Optical follow-up of the sources (~ 70) TJO-REM
- Public optical light curves (ZTF, ATLAS,...)



PKS 1424+240 GTC OSIRIS $z = 0.6045$ (confirmation) DDT

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Monitoring and Low State observations - II

- We have shown that during optical low states redshift measurement is easier.
- Light curves are irregular and stochastic, optical low states are difficult to identify.
- Hamo+2025 ICRCconf E931 (and 2026 in prep.) developed an algorithm to identify high and low states in optical and gamma-ray light curves
- On a sample of gamma-ray blazars (ZTF) they identify approximately 0.5 low states per source per year
- Very promising (Vera Rubin observatory will start sending alerts soon !)
- ToO proposals (SOXS in the South, North ? TBD)

Bringing it all together: a Database

Reminder: a Web Database

- **Idea: gather and efficiently organize information (public and private) on the sources to allow identification of best targets and best observing time for imaging and spectroscopy**
- **The database has public and private sections:**
 - ✧ Redshifts or tentative redshift
 - ✧ Detectability with CTAO (simulation results)
 - ✧ Counterparts (position, magnitudes from different surveys)
 - ✧ Information gathered from optical observations
 - Spectra (public or private)
 - Light-Curves (public or private)
 - Imaging (public or private)
 - ✧ Proposals (private)

<https://vhe-redshifts.in2p3.fr>

ZTF light curves updated daily
(Thanks J. Hamo !)

Database - II

Main table

MainCTAO simulationsHostsSpectraLight CurvesProposals

FILTER THE SOURCES

This table contains the name and coordinates of each selected source, published information about its redshift when available, the name and coordinates of its counterpart, and the magnitudes obtained in the Pan-STARRS (DR2), DSS (USNO-B1.0), and Gaia (EDR3) surveys. The names of the counterparts are taken from the Fermi-LAT 4LAC-DR3 catalogue, and they were subsequently verified and replaced in a few cases as necessary. The coordinates of the counterparts are the optical ones when available (the Status column is then set to 1). Details on detectability by CTAO are provided in the "CTAO simulations" table.

Source	3FHL			Redshift			Counterpart				Magnitude			
	RA	DEC	Class	Value	Reference	Reliability	Name	Status	RA_ASSOC	DEC_ASSOC	Reference	Pan-STARRS	DSS	Gaia
3FHL J0015.7+5551	3.933663	55.864853	bl	0.218	Kasai et al. 2023	High	GB6 J0015+5551	1	3.91729	55.862409	Fermi 4LAC-DR3 (08 August 2022)	17.63	16.28	18.41
3FHL J0022.1-1855	5.525983	-18.917013	bl	>0.774	Shaw et al. 2013	Medium	1RXS J002209.2-185333	1	5.538621	-18.893019	Fermi 4LAC-DR3 (08 August 2022)	16.57	17.79	17.2
3FHL J0033.5-1921	8.392931	-19.357483	bl	>0.506	Pita et al. 2014	High	KUV 00311-1938	1	8.393251	-19.359203	Fermi 4LAC-DR3 (08 August 2022)	16.12	16.27	16.7
3FHL J0035.2+1514	8.817282	15.243119	bl				RX J0035.2+1515	1	8.81135	15.251154	Fermi 4LAC-DR3 (08 August 2022)	26.12	16.6	16.49
3FHL J0035.9+5950	8.978161	59.835045	bl	0.467	Paiano et al. 2017	Medium	1ES 0033+595	1	8.969355	59.834587	Fermi 4LAC-DR3 (08 August 2022)	18.14	17.15	17.74
3FHL J0045.3+2127	11.327788	21.463419	bl	0.425	Paiano et al. 2020	High	GB6 J0045+2127	1	11.330409	21.461111	Fermi 4LAC-DR3 (08 August 2022)	16.54	16.97	16.78
3FHL J0045.7+1217	11.439268	12.284432	bl	0.254	Kasai et al. 2023	High	GB6 J0045+1217	1	11.430585	12.286613	Fermi 4LAC-DR3 (08 August 2022)	16.95	17.15	17.65
3FHL J0051.2-6242	12.821679	-62.708385	bl				1RXS J005117.7-624154	1	12.819361	-62.701225	Fermi 4LAC-DR3 (08 August 2022)		16.82	16.26

<https://vhe-redshifts.in2p3.fr/>

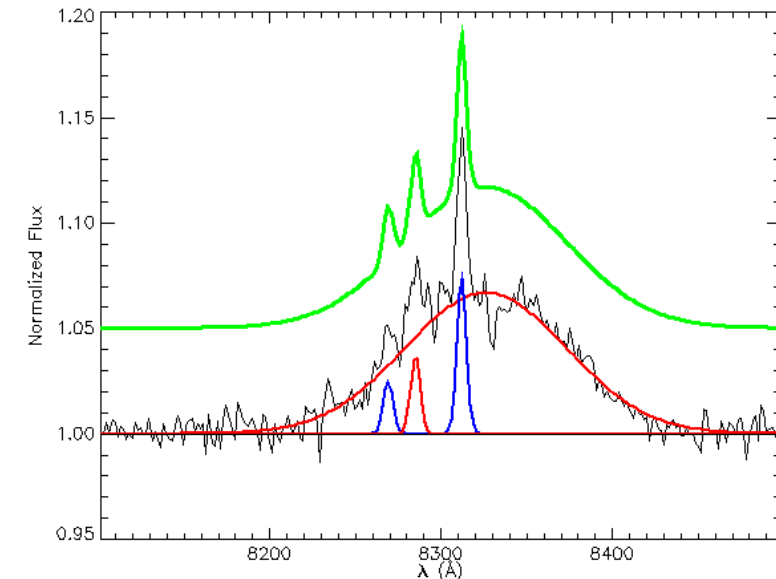
165 sources
89 published values,
57 from CTAO-RDG

Table continuously updated ✓

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Not only the redshift

- In addition to the redshift, our observations give information on the nature of the Blazar. These results support our proposals broadening our science case.
- PKS 0903-57: BLL ? (LSP) redshift $z=0.695$ (?) (one spectrum in 1990, weak emission lines)
- Our observations $z=0.2622$, FSRQ, Goldoni et al. 2024.
Offset between narrow and broad lines !
- Peculiar accretion ? Binary SMBHs ?
- New spectra taken in 2025
- Offset confirmed, stay tuned !



Near Future

- End publication of the spectra obtained ==> end 2026
- Database public ==> end 2026
- Search for low states ==> ToO observations of remaining sources
- Investigate the source properties
- Start observing fainter sources (new simulations) ??
- Contact us if interested !!!

Thank you

Backup