SCHEDA INAF
BLazars in the Early Universe
(BLEU)

A. Caccianiga (INAF-OABrera)

Audizioni schede INAF

19/05/2022

Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 8

Struttura	Nfte	N0	TI 22	TI 23	TI 24	TD 22	TD 23	TD 24	Nex	Extra
O.A. BRERA	5	0	1.30	1.30	1.30	0.20	0.20	0.20	0	0.00
Totali	5	0	**1.30**	**1.30**	**1.30**	**0.20**	**0.20**	**0.20**	0	**0.00**

16. Personale Associato INAF coinvolto

Numero di partecipanti Associati INAF: 4

#	Struttura	TI 22	TI 23	TI 24	TD 22	TD 23	TD 24	Extra
1	Università di Bologna	0.10	0.10	0.10	0	0	0	0.00
2	Univ. Insubria	0	0	0	0.50	0.20	0.10	0.00
3	Universita' dell'Insubria	0	0	0	0.90	1.00	1.00	0.00
4	IRA BOLOGNA	0	0	0	0.00	0.00	0.00	0.00
	Totali	**0.10**	**0.10**	**0.10**	**1.40**	**1.20**	**1.10**	**0.00**

Tot FTE (2022/2024): 3+2.8+2.7=**8.5**

15. Personale INAF coinvolto

#	Nome	E-mail	Struttura	TI	Qualifica	Ruolo nel Progetto	FTE Accertate (2022/23/24)	FTE Presunte (2022/23/24)	Ext
1	alessandro.caccianiga	alessandro.caccianiga@inaf.it	O.A. BRERA	Y	RICERCATORE	Analisi dati e interpretazione	[0.6, 0.6, 0.6]	[0.0, 0.0, 0.0]	0.0
2	alberto.moretti	alberto.moretti@inaf.it	O.A. BRERA	Y	RICERCATORE	Analisi dati e interpretazione	[0.4, 0.4, 0.4]	[0.0, 0.0, 0.0]	0.0
3	tullia.sbarrato	tullia.sbarrato@inaf.it	O.A. BRERA	N	RICERCATORE	Analisi dati e interpretazione	[0.2, 0.2, 0.2]	[0.0, 0.0, 0.0]	0.0
4	paola.severgnini	paola.severgnini@inaf.it	O.A. BRERA	Y	RICERCATORE	Analisi dati e interpretazione	[0.1, 0.1, 0.1]	[0.0, 0.0, 0.0]	0.0
			BRERA		RICERCA	interpretazione			
6	fabrizio.tavecchio	fabrizio.tavecchio@inaf.it	O.A. BRERA	Y	PRIMO RICERCATORE	Analisi dati e Interpretazione	[0, 0, 0]	[0.1, 0.1, 0.1]	0.0
7	gianpiero.tagliaferri	gianpiero.tagliaferri@inaf.it	O.A. BRERA	Y	DIRIGENTE DI RICERCA	Analisi dati e Interpretazione	[0, 0, 0]	[0.0, 0.0, 0.0]	0.0
8	gabriele.ghisellini	gabriele.ghisellini@inaf.it	O.A. BRERA	Y	DIRIGENTE DI RICERCA	Analisi dati e Interpretazione	[0, 0, 0]	[0.0, 0.0, 0.0]	0.0

16. Personale Associato INAF coinvolto

#	Nome	E-mail	Struttura	TI	Qualifica	Ruolo nel Progetto	FTE Accertate (2022/23/24)	FTE Presunte (2022/23/24)	Extra
1	daniele.dallacasa	ddallaca@ira.inaf.it	Università di Bologna	Y	professore associato	Radio data	[0.1, 0.1, 0.1]	[0.0, 0.0, 0.0]	0.0
2	silvia.belladitta	silvia.belladitta@inaf.it	Univ. Insubria	N	Assegnista	Analisi dati e interpretazione	[0.5, 0.2, 0.1]	[0.0, 0.0, 0.0]	0.0
3	luca.ighina	luca.ighina@inaf.it	Universita' dell'Insubria	N	Studente Dottorato	Analisi dati e interpretazione	[0.9, 1.0, 1.0]	[0.0, 0.0, 0.0]	0.0
4	cristiana.spingola	spingola@ira.inaf.it	IRA BOLOGNA	N	AdR Postdoc	Radio data	[0, 0, 0]	[0.1, 0.1, 0.1]	0.0

+ students from University Milano-Bicocca:

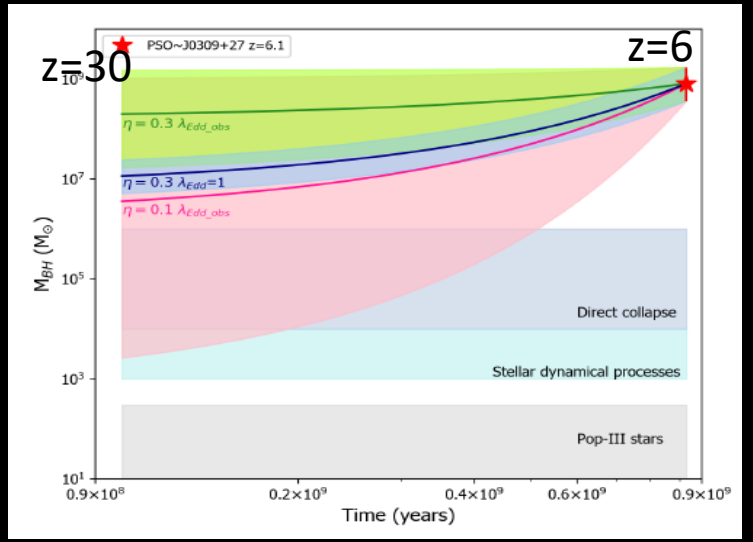
Alessandro Diana
Riccardo Brivio
Giulia Papini
Alessandro Bucci

+ external collaborations:

N. Seymour
G. Drouart
J. Broderick
(ICRAR, Australia)

RELATIVISTIC JETS AT HIGH REDSHIFTS

- ROLE IN THE ACCRETION PROCESS: do they affect the growth of the SMBH?
- IMPACT ON THE HOST GALAXY (feedback)



From Belladitta+20, phD thesis

POTENTIAL ISSUES:

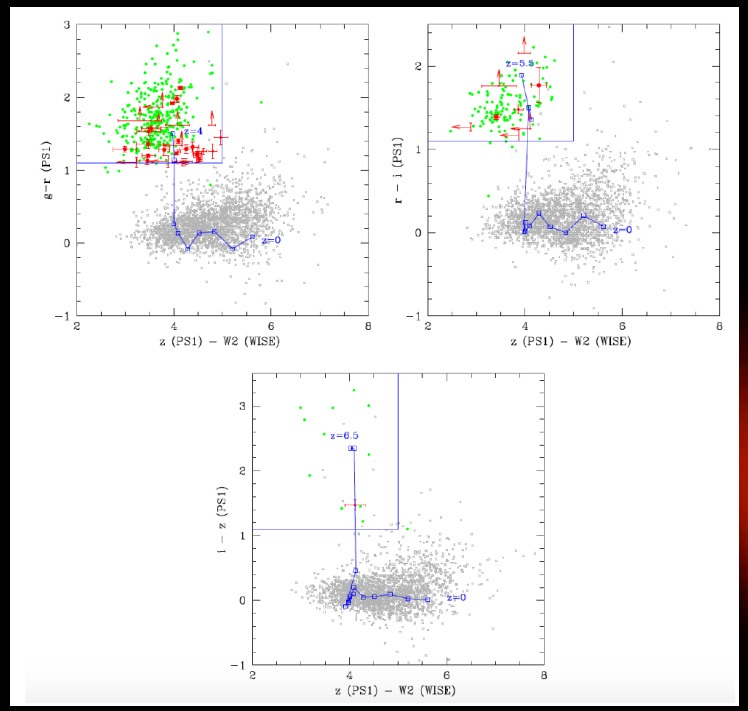
- OBSCURATION (*e.g Vito+18, Ghisellini&Sbarrato16; Zeimann+11; McGreer+06*)
- STRONG ANISOTROPY OF THE JET EMISSION

→ ORIENTED JETS (BLAZARS) CAN BE A SOLUTION (→ total population ~$2\Gamma^2$)

First works (all from Brera) used Swift-BAT selected blazars (z~2-3.5)(*Ghisellini+10,MNRAS,405,387;* Volonteri+11,MNRAS,416,21) or SDSS DR7/FIRST z>4 blazars (e.g. Sbarrato+13,MNRAS,433,21; Sbarrato+15, MNRAS,446,24; Sbarrato+22,A&A) → interesting results on evolution and obscuration (e.g. *Ghisellini&Sbarrato16,MNRAS,461,L21*)

SELECTION STRATEGY

WIDE ANGLE RADIO +OPTICAL SURVEYS (MIR SURVEYS ALSO USEFUL)



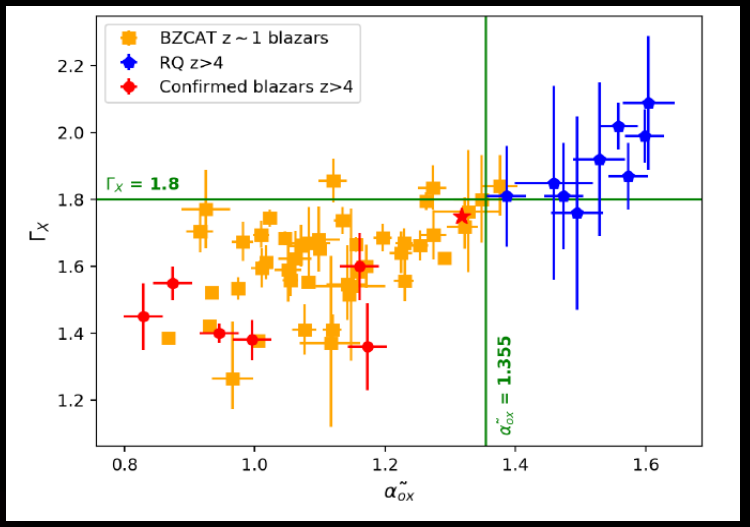
PHOTOMETRIC CANDIDATES SELECTION (DROP-OUT TECHNIQUE)

(Caccianiga et al. 2019, MNRAS, 484, 204)

SPECTROSCOPIC FOLLOW-UP to confirm the high-z nature

X-RAY FOLLOW-UP to confirm the blazar nature

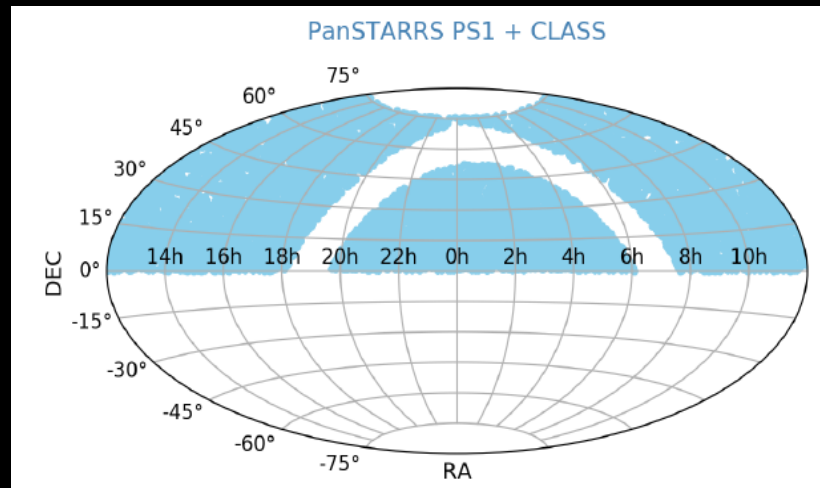
X-ray slope

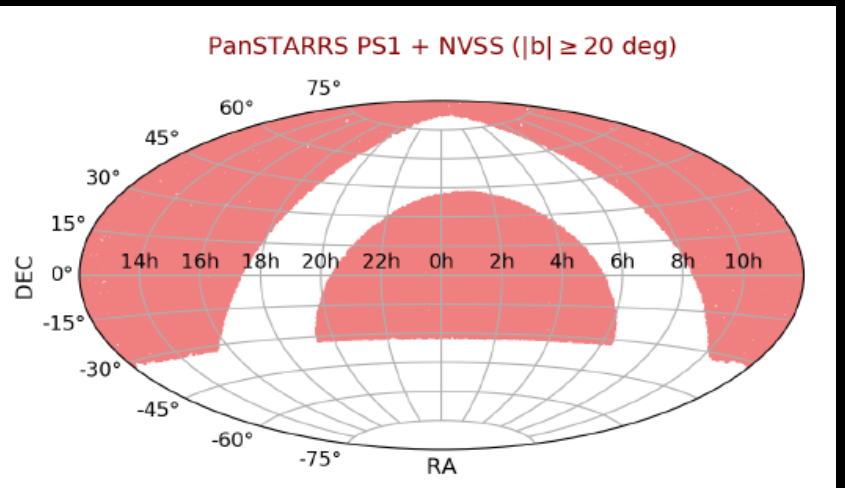


X-ray-to-UV luminosity ratio

(Ighina et al. 2019, MNRAS, 489, 27)

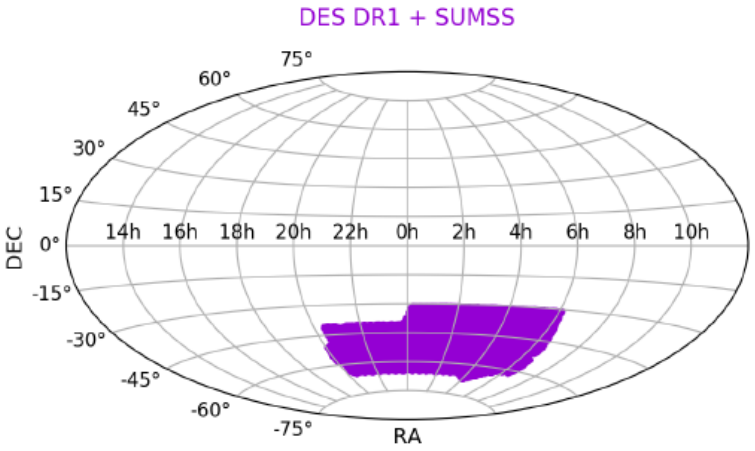
S(5GHz)>30mJy
mag<21.5

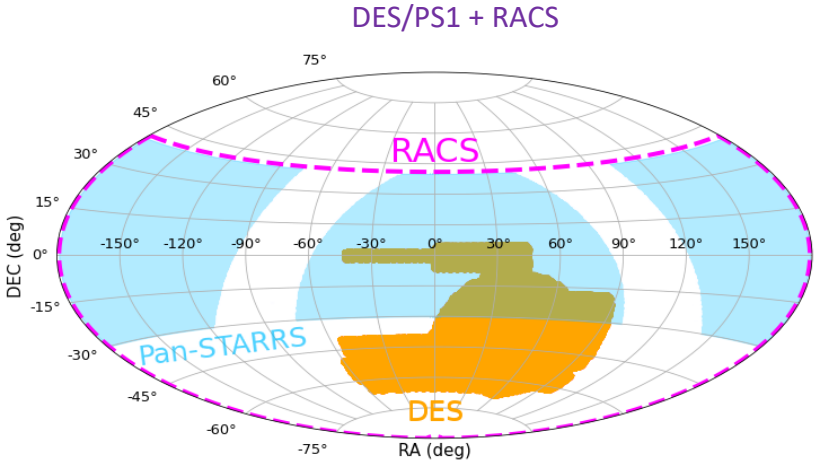




S(1.4GHz)>10mJy
mag<21.5

S(0.8GHz)>30mJy
mag<21.5





S(0.9GHz)>1mJy
mag<21.5

Since ~2015 we obtained:

~180h at optical telescopes (LBT/TNG/NTT/VLT) for photometric/spectroscopic follow up

~560ks for X-ray (Swift-XRT/Chandra) follow up

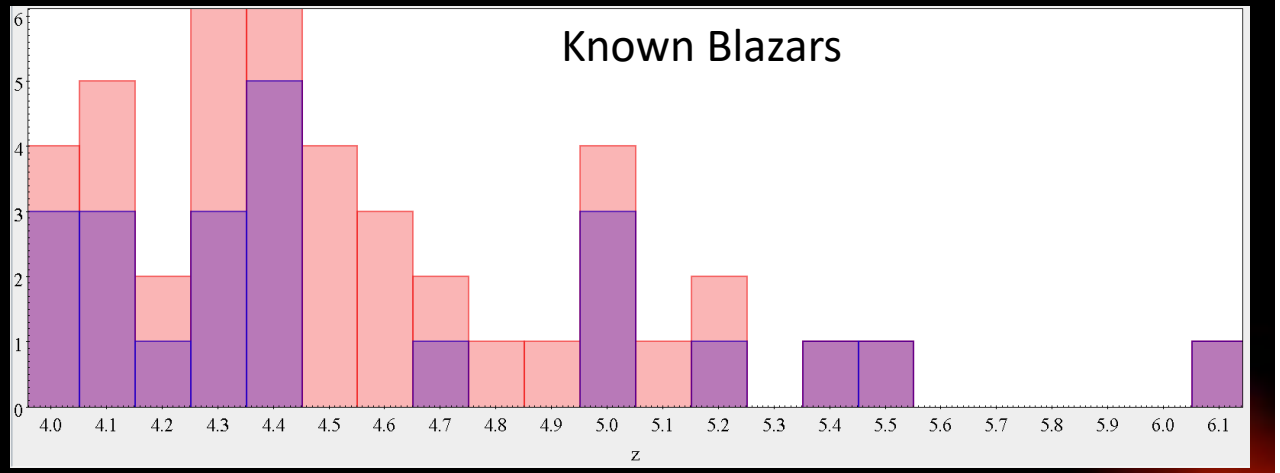
~130h for radio (EVN/VLBA/VLA) follow-up

ACCEPTED PROPOSALS (since 2015)

TELESCOPE	PI	Title	Time	Status
		2015/2016		
TNG-LRS	A.Moretti	Looking for quasars in the first Gyr after the Big Bang	4h	Completed
TNG-LRS	A.Caccianiga	Finding one to count a hundred: search for the highest z blazars	4h	Completed
Swift-XRT	A.Caccianiga	An X-ray survey of high-z blazars	85ks	Published
		2017/2018		
TNG-LRS	A. Moretti	Looking for quasars in the first Gyr after the Big Bang	35h	Completed
VLT-FORS2	A. Moretti	Probing the dust reddened and radio loud Quasar population at high z	1.2h	Completed
EVN	A.Caccianiga	A VLBI survey of high redshift blazars candidates	24h	Analysis in prog.
Swift-XRT	A.Caccianiga	An X-ray survey of high-z blazars	70ks	Published
NTT-EFOSC2	A.Moretti	Looking for Radio Loud Quasars in the first Giga-year of the Universe	5n	Published
VLT-FORS2	A.Moretti	Probing the dust reddened radio loud Quasar population at high z	2h	Completed
LBT-MODS	A.Caccianiga	Finding one to count a hundred: searching for high-z blazars	17h	Published
LBT-LUCI	A.Moretti	Spectrum of ULAS1008+01, a highly probable candidate QSO at z∼6.5	1h	Completed
Swift-XRT	A.Caccianiga	An X-ray survey of high-z blazars	70ks	Published
Swift-XRT	A.Caccianiga	GB6J1648+4603: a blazar at z=5.4	22ks	Published
EVN	A.Caccianiga	A VLBI survey of high redshift blazars candidates	10h	Analysis in prog.
LBT-MODS	A.Moretti	Probing the dust reddened radio loud Quasar population at high z.	17h	Completed
VLT-XSHOOTER	A.Moretti	Measuring the mass of one of the most powerful radio loud QSO at z=5	1.3h	Published

TELESCOPE	PI	Title	Time	Status
		2019/2020		
LBT-LUCI	S. Belladitta	PSOJ030947.49+271757.31	3h	Published
LBT-MODS	S. Belladitta	Looking for blazars at the end of re-ionization era	18h	Completed
Swift-XRT	S. Belladitta	Testing the orientation of high redshift radio-loud AGN with Swift-XRT	120ks	Published
Chandra	A.Moretti	Chandra observations of PSO0309+27	25ks	Published
VLA	S..Belladitta	Studying the radio properties of the first blazar at z>6	1.2h	Publihsed
EVN	C. Spingola	The parsec-scale view of the most distant blazar at z = 6.1	24h	Analysis in prog.
LOFAR	C. Spingola	The low and ultra-low frequency emission of the first blazar at z>6	16h	Pending
VLBA	C. Spingola	The sharpest view of the first blazar at z>6	6h	Publihsed
Chandra	A.Moretti	An high red-shift QSO jet interacting with the CMB	100ks	Published
		2021		
ATCA	L..Ighina	High-frequency Radio Properties of three New z>6 Jetted QSOs	24h	Pending
GMRT	L..Ighina	Low-frequency Radio Properties of Three New z>6 Jetted QSOs	14h	Pending
VLBA	S. Belladitta	The sharpest view of a young radio source in the early Universe	12h	Analysis in prog.
LBT	S. Belladitta	Searching for galaxy over-densities in the field of z>6 radio-loud quasars	8h	Analysis in prog.
GEMINI-s	L..Ighina	Spectroscopic confirmation of two z>6 Radio-Loud Quasar candidates	3.9h	Paper in prep.
TNG-NICS	S. Belladitta	Near-infrared photometric observations of the highest redshift blazar	2h	Completed
Chandra	L.Ighina	UNCOVERING THE X-RAY PROPERTIES OF A Z∼6.5 RADIO-POWERFUL QUASAR	70ks	Paper in prep.

RESULTS..



We increased by ~50% the number of blazars with z>4 and the number of RL QSO at z>6

12 papers in refereed journals in the last 4 years (→ 3papers/y)

1 2022MNRAS.511.5436D 2022/04 cited: 2
The evolution of the heaviest supermassive black holes in jetted AGNs
Diana, A.; Caccianiga, A.; Ighina, L. *and 3 more*

2 2022A&A...660A..74B 2022/04 cited: 2
Central engine of the highest redshift blazar
Belladitta, S.; Caccianiga, A.; Diana, A. *and 8 more*

3 2022arXiv220308142I 2022/03 cited: 2
Constraining the Radio Properties of the z=6.44 QSO VIK J2318−3113
Ighina, Luca; Leung, James K.; Broderick, Jess W. *and 19 more*

4 2022A&A...659A..93I 2022/03 cited: 4
Direct observation of an extended X-ray jet at z = 6.1
Ighina, L.; Moretti, A.; Tavecchio, F. *and 6 more*

5 2021ApJ...920...15M 2021/10 cited: 2
Minute-timescale Variability in the X-ray Emission of the Highest Redshift Blazar
Moretti, Alberto; Ghisellini, Gabriele; Caccianiga, Alessandro *and 6 more*

6 2021MNRAS.505.4120I 2021/08 cited: 4
The impact of the CMB on the evolution of high-z blazars
Ighina, L.; Caccianiga, A.; Moretti, A. *and 3 more*

7 2021A&A...647L..11I 2021/03 cited: 14
Radio detection of VIK J2318−3113, the most distant radio-loud quasar (z = 6.44)
Ighina, L.; Belladitta, S.; Caccianiga, A. *and 4 more*

8 2020A&A...643L..12S 2020/11 cited: 20
Parsec-scale properties of the radio brightest jetted AGN at z > 6
Spingola, C.; Dallacasa, D.; Belladitta, S. *and 4 more*

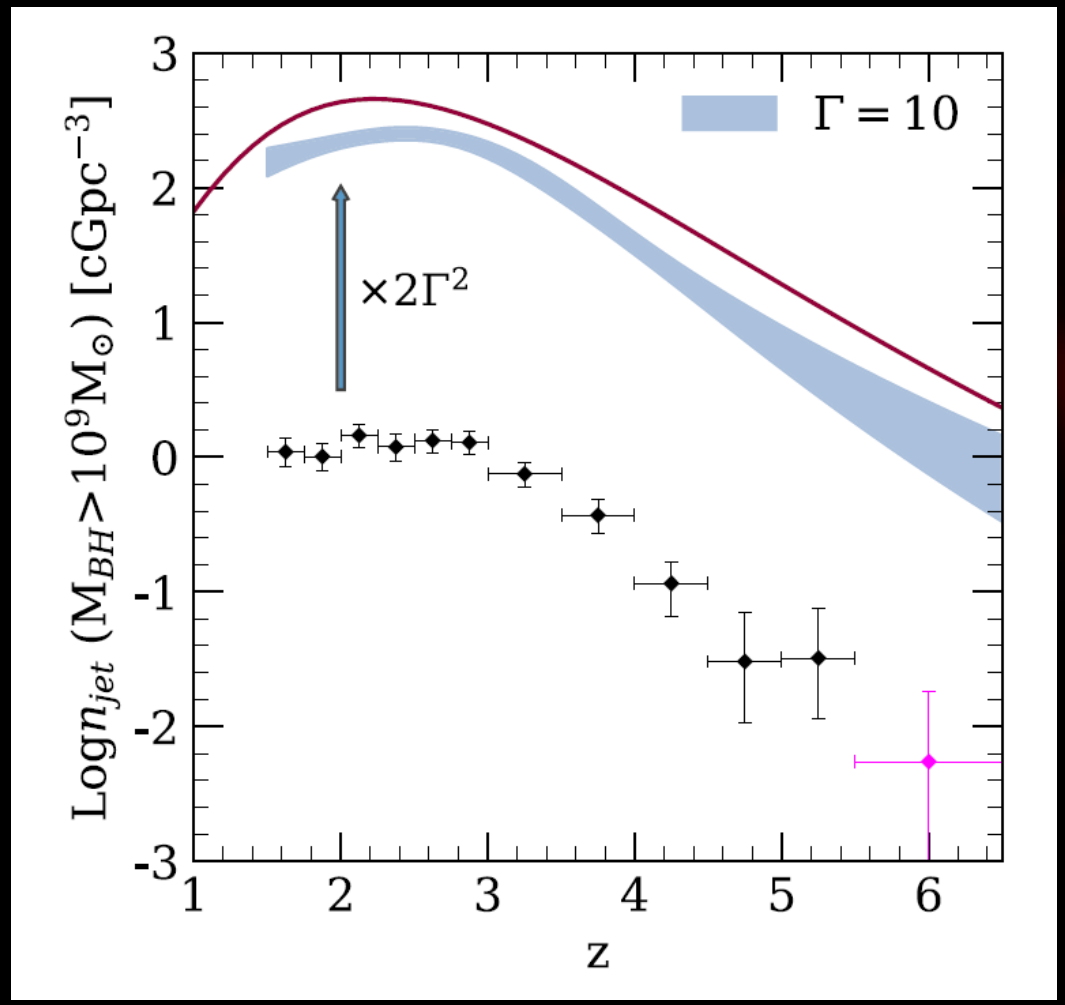
9 2020A&A...635L...7B 2020/03 cited: 34
The first blazar observed at z > 6
Belladitta, S.; Moretti, A.; Caccianiga, A. *and 9 more*

10 2019MNRAS.489.2732I 2019/10 cited: 19
X-ray properties of z > 4 blazars
Ighina, L.; Caccianiga, A.; Moretti, A. *and 4 more*

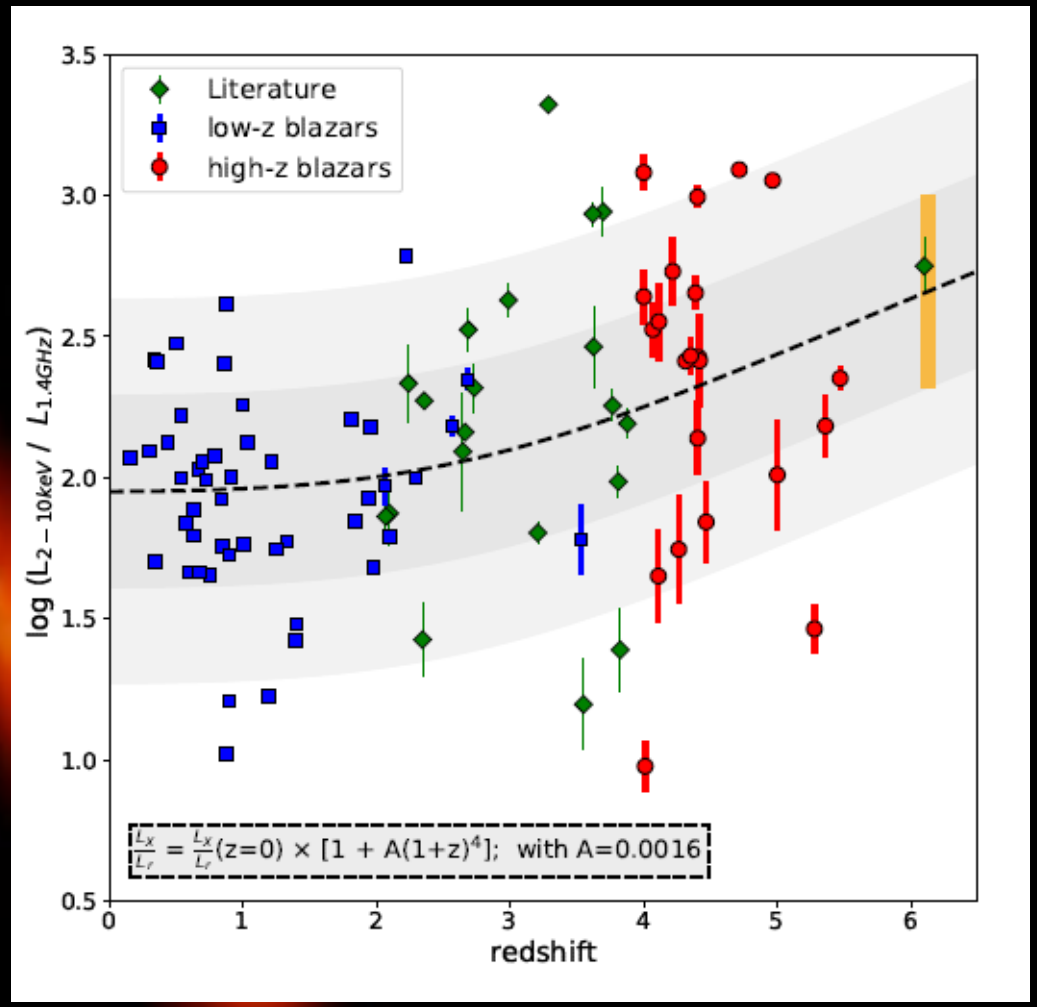
11 2019A&A...629A..68B 2019/09 cited: 6
An extremely X-ray weak blazar at z = 5
Belladitta, S.; Moretti, A.; Caccianiga, A. *and 5 more*

12 2019MNRAS.484..204C 2019/03 cited: 19
The space density of z > 4 blazars
Caccianiga, A.; Moretti, A.; Belladitta, S. *and 9 more*

HIGHLIGHTS 1: STATISTICAL ANALYSIS OF THE SAMPLES



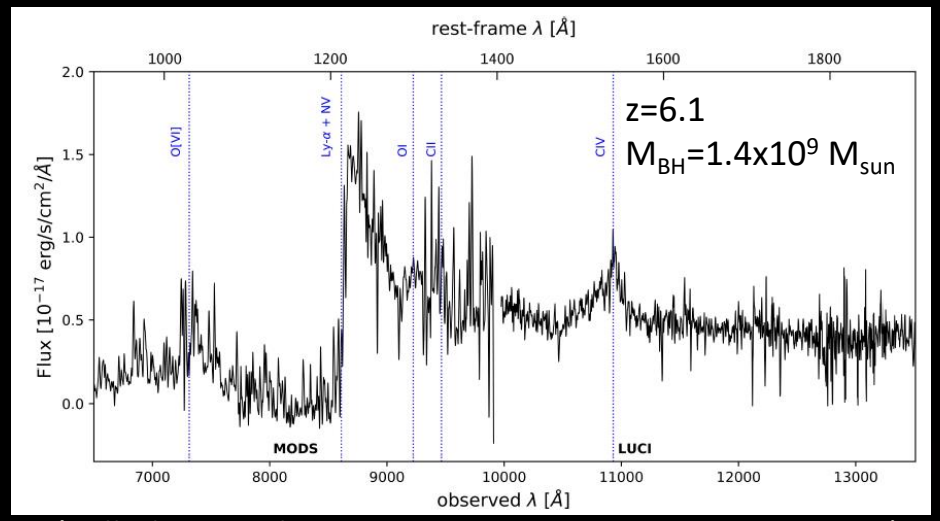
Diana et al. 2022, MNRAS, 511,5436



Ighina et al. 2021, MNRAS, 505,4120

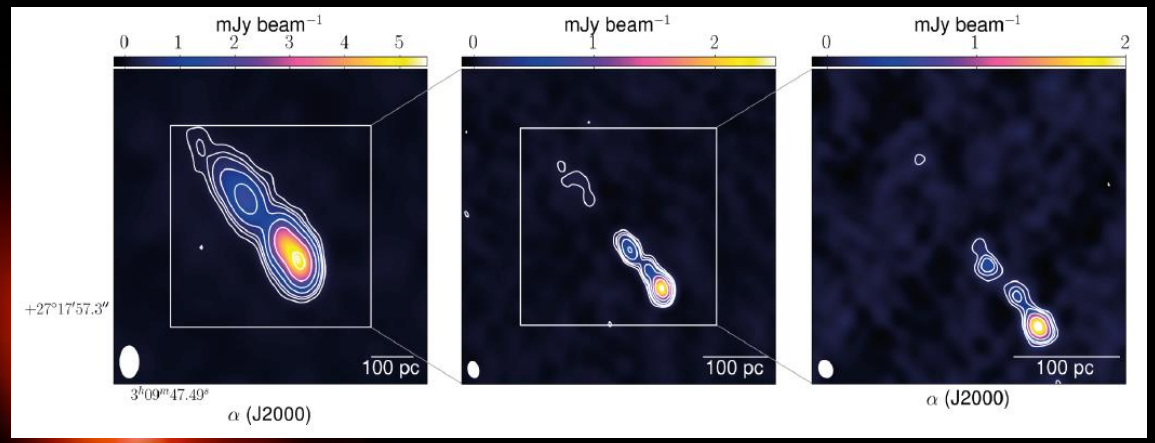
- Evolution of the most massive SMBH in jetted AGN is similar to those in RQ (but peak possibly at z~3 instead of 2.2)
- We do not confirm the z>4 peak observed with Swift-BAT sample → CMB may explain the discrepancy

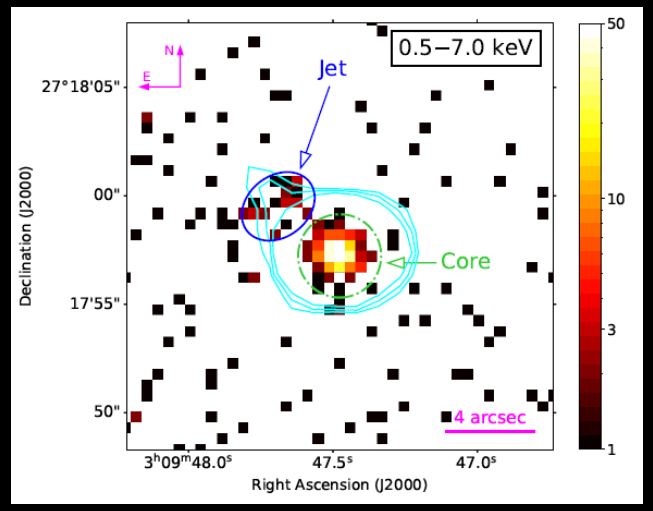
HIGHLIGHTS 2: J030947.49+271757.31 - the First blazar at z>6



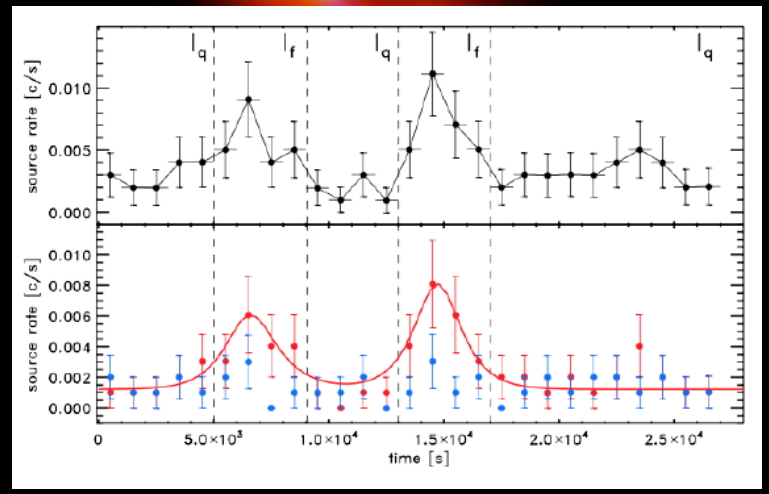
(Belladitta et al. 2020,A&A, 635,L7; 2022, A&A, 660, 74)

VLBA at 1.5GHz, 5GHz and 8.4GHz
(Spingola et al. 2020, A&A, 643, 12)



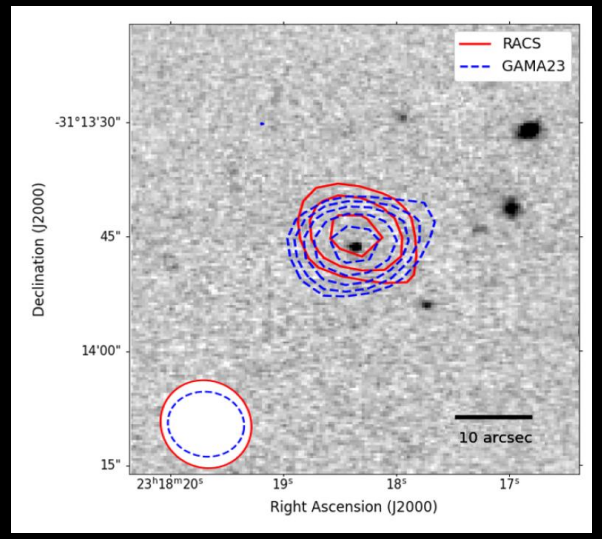


Chandra (128 ks)
(Ighina et al. 2022, A&A, 659, 93)

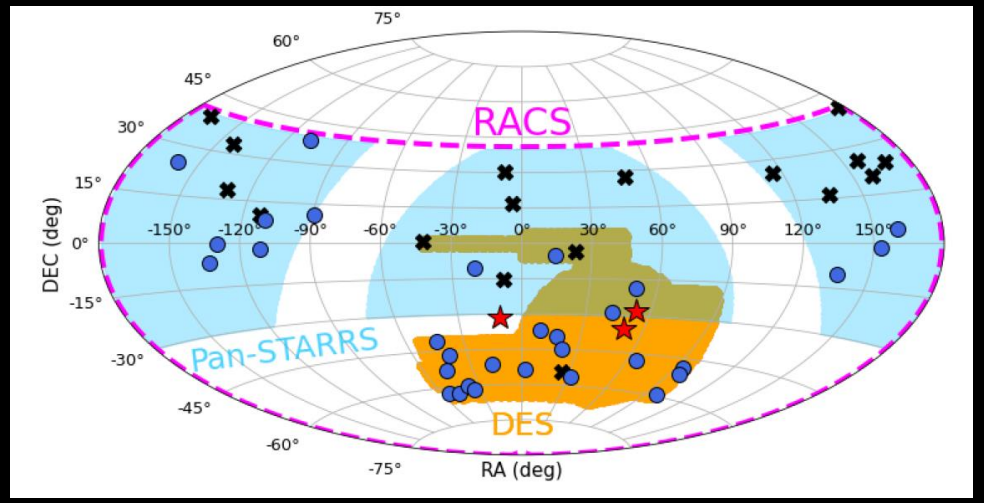


Variability in X-rays of the core:
bulk Comptonization?
Moretti et al. 2022, ApJ, 920, 15

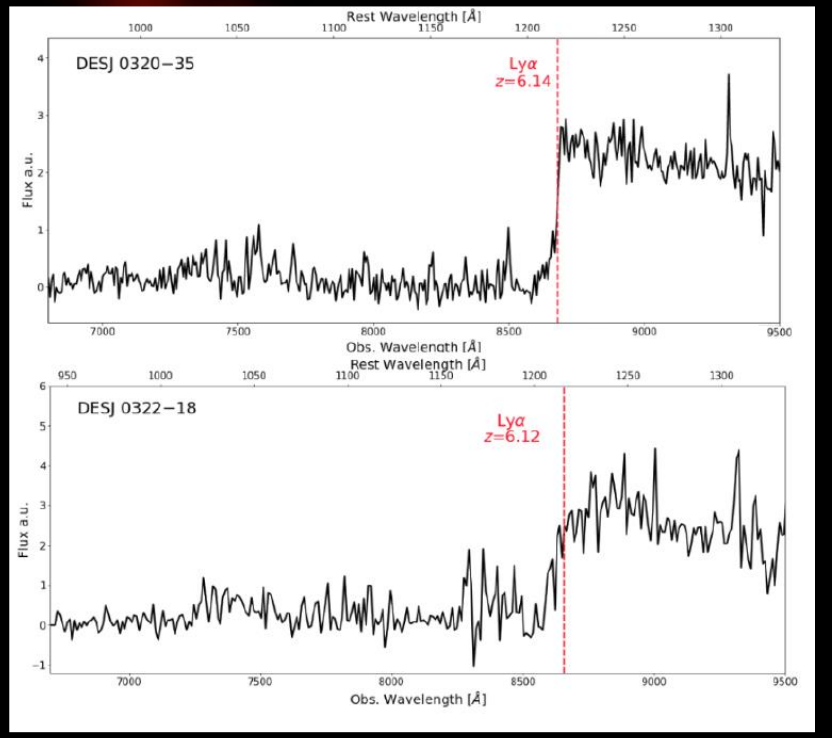
HIGHLIGHTS 3: new RL QSOs above z>6 from Rapid ASKAP Continuum Survey (RACS)



Radio detection of **z=6.44**, the **most distant RL QSO** (at least for a few months…)
Ighina et al. 2021, A&A, 647,L11; Ighina et al. 2022, A&A, in press



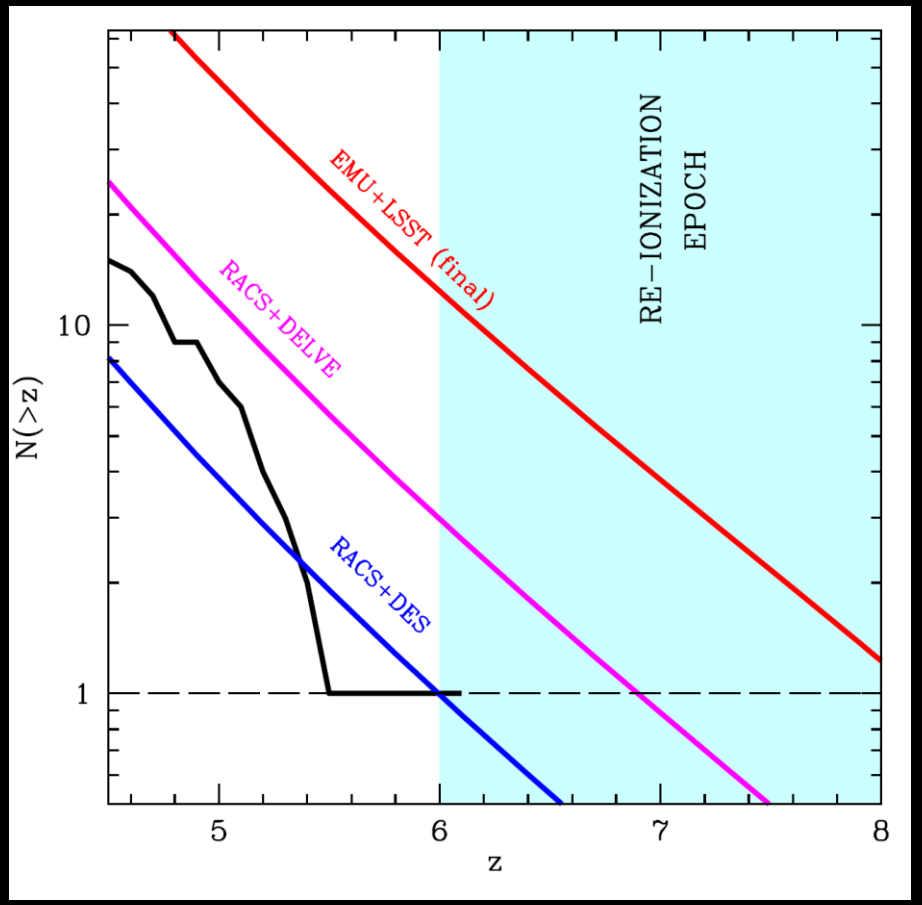
RACS+DES/PS1



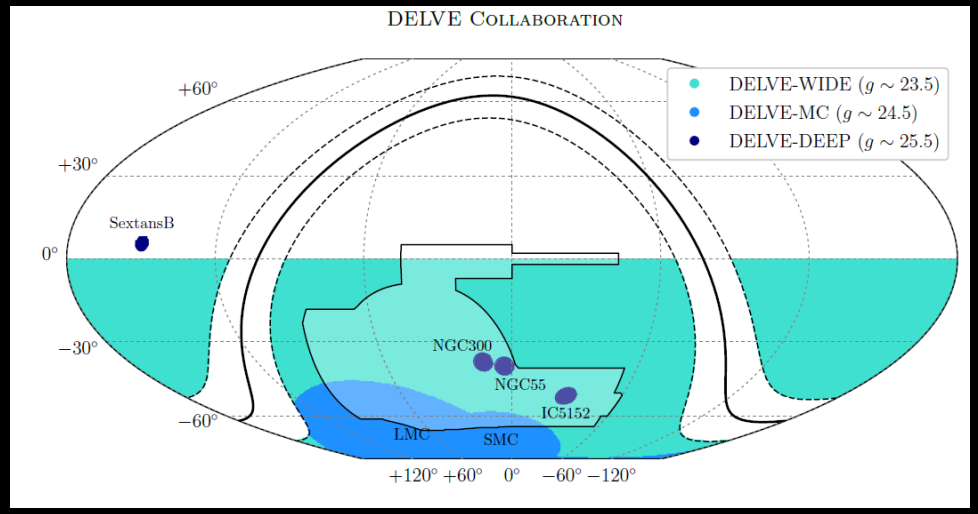
Ighina et al. in prep

2 New RL QSO at z>6 from RACS+DES (spectroscopy at GEMINI-south)

FUTURE 1 – MORE BLAZARS !

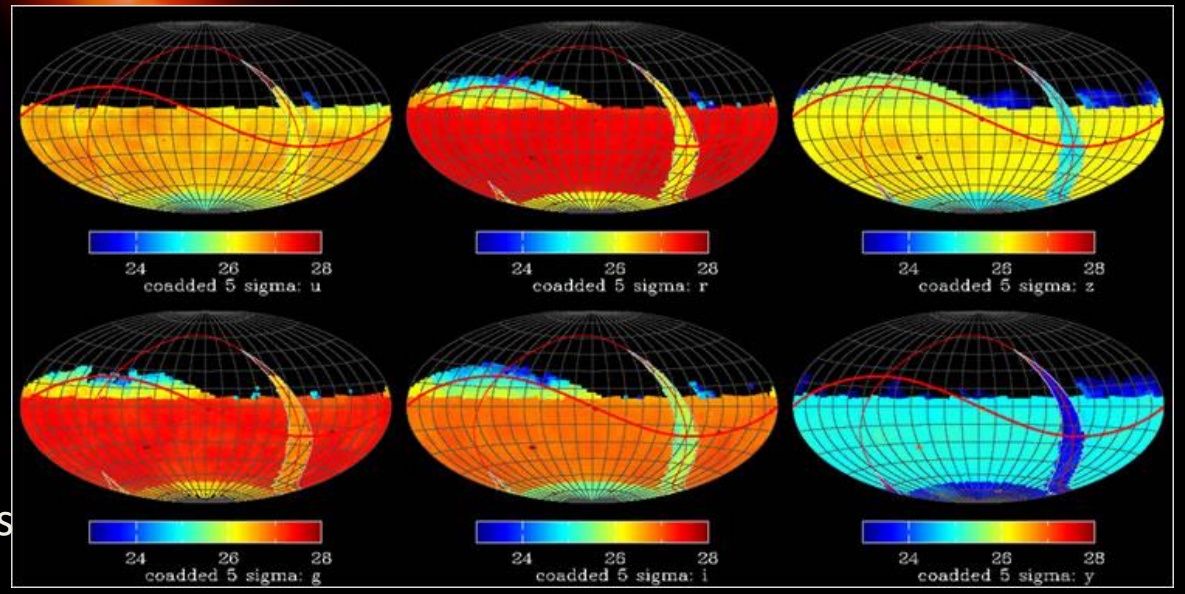


DELVE (DECam Local Volume Exploration survey) - 15000 deg2 in g,r,l,z; mag<23.5



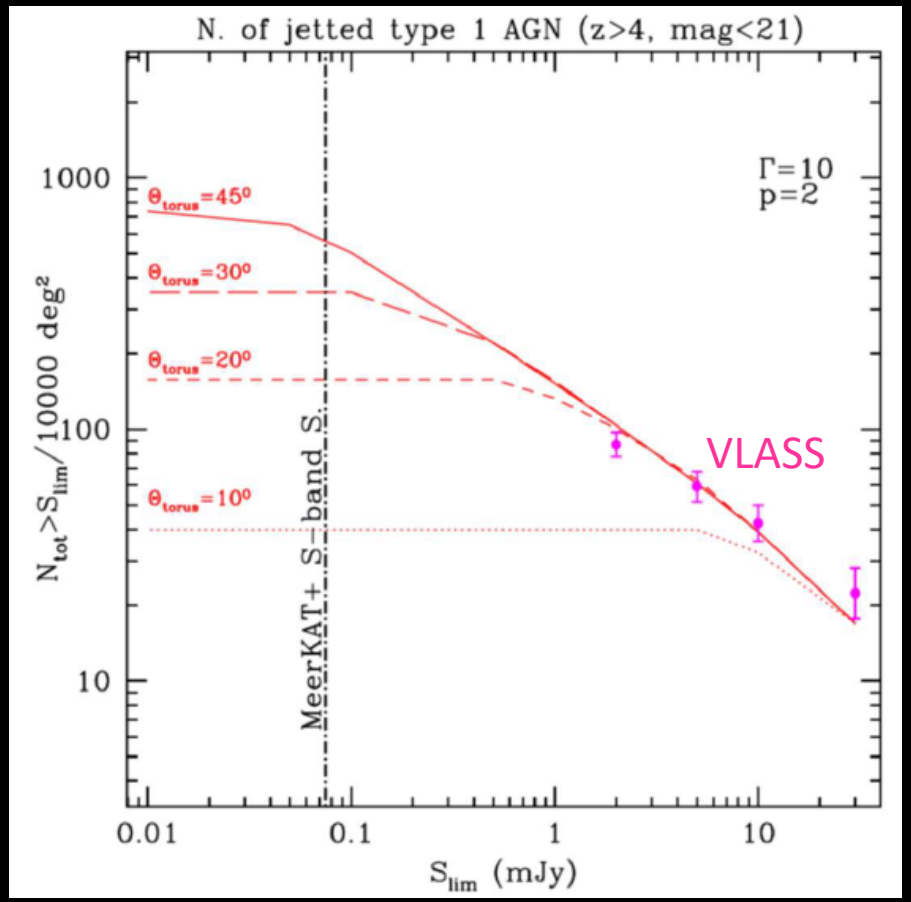
Vera Rubin Telescope (LSST)
mag<23 after 1 year
Mag<25-27 after 10 years

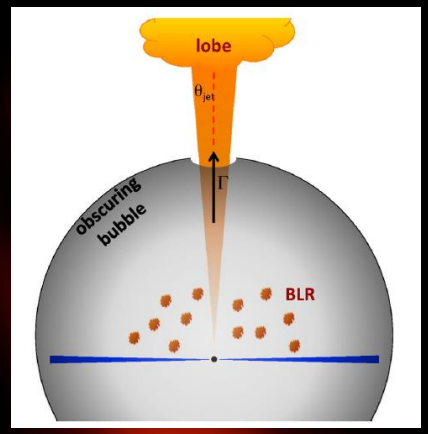
A. Moretti is a LSST data holder

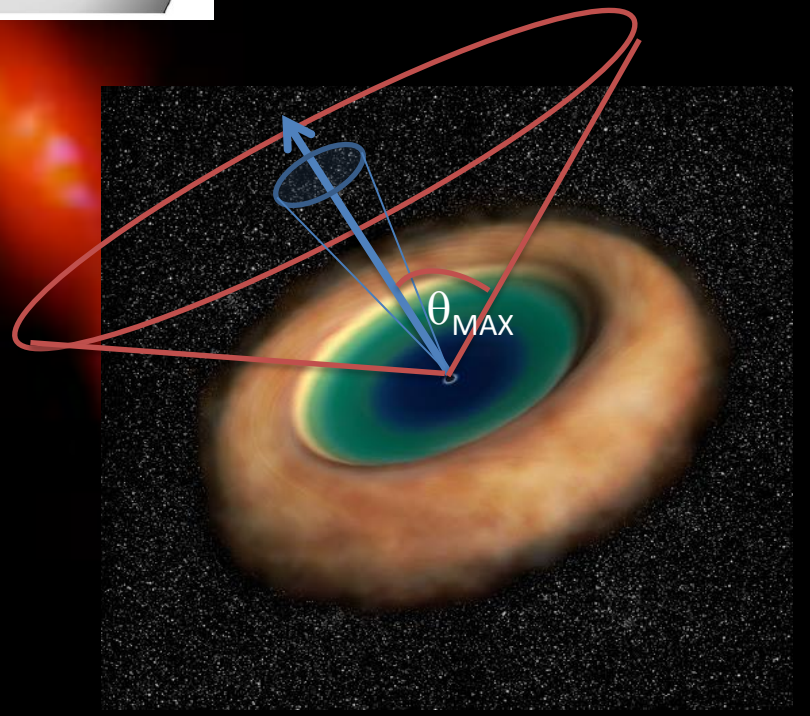


FUTURE 2: Mis-oriented sources. testing the obscuration…

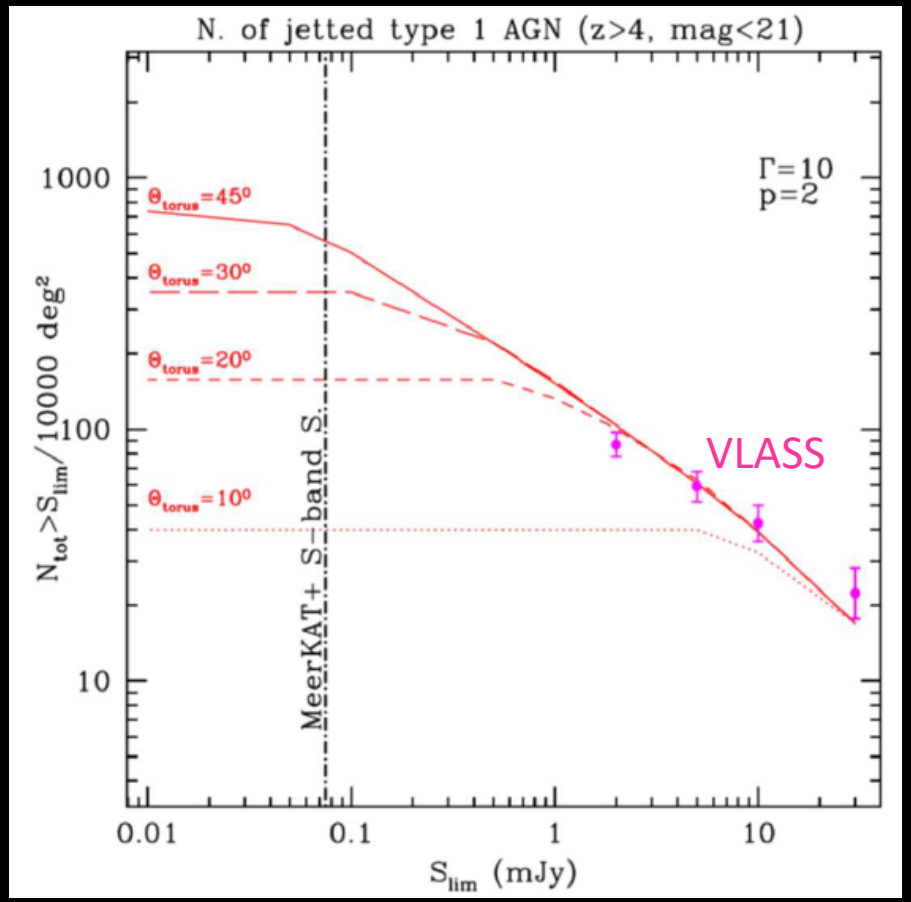
- In a radio flux limited survey for each blazar with flux F there must exist N mis-oriented. If not → obscuration (*Ghisellini&Sbarrato16,MNRAS,461,L21*)







FUTURE 2: Mis-oriented sources. testing the obscuration…



Submitted a Letter or Interest for the MeerKAT+ S-band survey

Very little information publicly available (even to us)

- Targeted rms: 15 μJy/b
- Resolution: 1-2 asec
- All sky for: δ<-40°

➢ Full S band (1.75-3.5 GHz)
➢ Full Stokes parameters

Aiming at detecting:

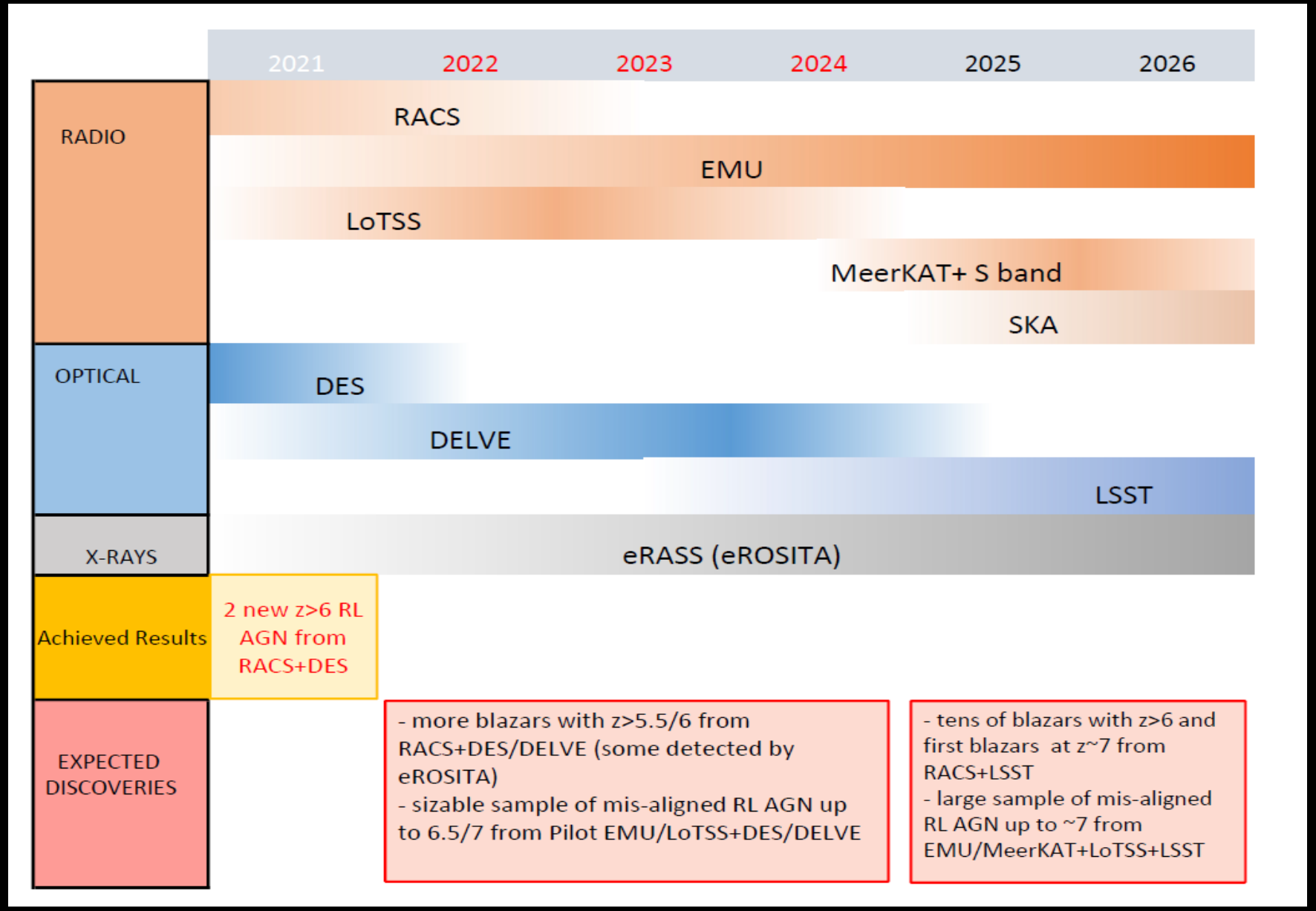
✓ ~10^7 sources above 5σ
✓ ~2x10^6 polarized sources (i.e. 25 sources/deg^2)

	low-z H I galaxy survey	S-Band Polarimetry	HI intensity mapping
survey tiers	1	1	1
sky coverage [deg^2]	1000	7368	5000
rms [μJy beam^{-1}]	550 line / ~ 10 cont	15	5
hours	2000	3000	2000
band	L-Band	S-Band	L-Band
total BW [MHz]	875	856 or 1750	875
spectral resolution	26 kHz	209 kHz	104 kHz
survey strategy	continuous area	continuous area	continuous area
data rates required	380/760 MB/s	115 MB/s	266 MB/s
archive storage requirements	2.7/5.4 PB	1.3 PB	2 PB
array configuration [prioritise]	4/84	84/64	64/84
required angular resolution [asec]	3/ 10 arcsec	1-2 arcsec	10 arcsec to 0.5 deg
need taper for MK+84 configuration	N/Y	N	N
special correlator modes	N (32k)	N (4K)	Y (8K; OTF)
Affected by bandwidth mismatch	N	N	Y
Affected by differing primary beams	N	N	Y
Advanced observing mode needed	N	N	Y (OTF)
Advanced calibration mode needed	N	N	Y (noise diode cycle)
Truncated survey plan	trade on sky area	trade on sky area	trade on sensitivity
Precursor to a SKA1-MID KSP	Y	N	Y

Table 2: Summary of the the three proposed MeerKAT+ Legacy Surveys.

(From T. Venturi presentation) INAF MeerKAT+ Day, December 16th, 2021

PROJECT TIMELINE



FUNDS & CRITICALITIES

- **2017** - Bando competitivo per l'assegnazione di Borse di Dottorato da parte di INAF

- **2016** - PRIN-INAF CTA/SKA (F.O. 1.05.01.88.03) - FORCaST project (Coordinator I. Prandoni): WP 2.2-
A new discovery window for SMBH at z>5

- **2017** - ASI contract "Attivita' di studio per la comunita' scientifica delle alte energie e fisica astroparticellare ASI/INAF n.2017-1-H.0 (F.O. 1.05.04.03.19 - **Quasars at High-Redshift: Physics and Cosmology** (Coordinator G. Risaliti): RU4 – OABrera

Tot ~ 8keuro (small left over that will be used for the incoming conferences)

Financial request (RSN4): QSO JETS IN THE EARLY UNIVERSE – P.I. A. MORETTI

Participants list

Name	E-mail	FTE 2022	FTE 2023
Alberto Moretti	alberto.moretti@inaf.it	0.3	0.3
Alessandro Caccianiga	alessandro.caccianiga@inaf.it	0.2	0.2
Silvia Belladitta	silvia.belladitta@inaf.it	0.2	0.2
Roberto Della Ceca	roberto.dellaceca@inaf.it	0.2	0.2
Luca Ighina	luca.ighina@inaf.it	0.5	0.5

Telescope	Program ID	Title	Accepted time	PI	Observation date	Data release
VLA	VLA/22A-305	*Characterising the kpc structure and emission of a powerful radio jet*	4h	Ighina	Apr-Sep 22	Oct 22
Chandra	704300 GO Cycle23	*Uncovering the X-ray properties of a z~6.5 Radio powerful Quasar*	70ks	Ighina	Apr 22	Apr 22
Gemini-S	DDT GS-2021-DD-112	*Spectroscopic confirmation of two z>6 Radio-Loud Quasar candidates*	3.9h	Ighina	Oct 21	Oct 21
ATCA	C3477 2022APR	*High-frequency Radio properties of three new z > 6 jetted QSOs*	36h	Ighina	Apr-Sept 22	Nov 22
GMRT	42_001 GO Cycle42	*Low-frequency Radio properties of three new z > 6 jetted QSOs*	14h	Ighina	Apr-Sept 22	Nov 22

Analytic budget description (numbers in Euro)

Item	Year 1 (*)
Data reduction	5000
Collaborations	8000
Conferences	10000
Hardware	3000
TOTAL	**26000**

(*) the budget is planned for 1year period, assuming the start in September 2022.