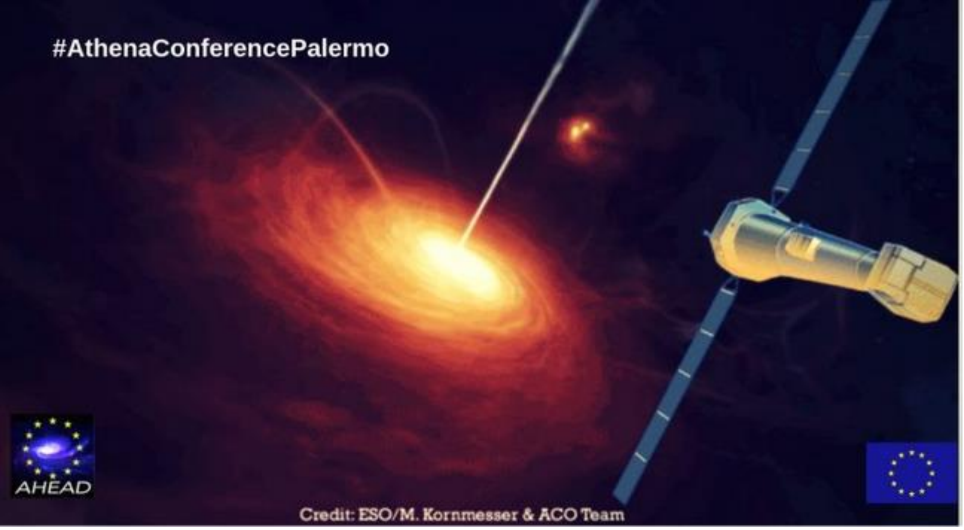

Accretion and ejection mechanisms in active galactic nuclei: the Athena and SKA synergy

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INAF

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Marcello Giroletti, Lorena Hernandez-Garcia, Ari Laor, Anna Lia Longinotti, Ian McHardy,
Raffaella Morganti, Rodrigo Nemmen, Miguel Perez-Torres, Luigi Piro, Francesco Tombesi, Phil Uttley

accretion disc

jet

wind

OPEN QUESTIONS

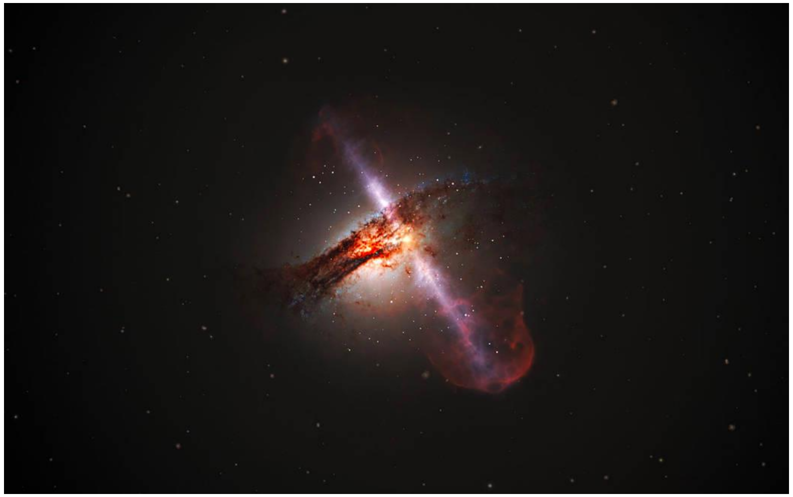
How are jets and winds formed?

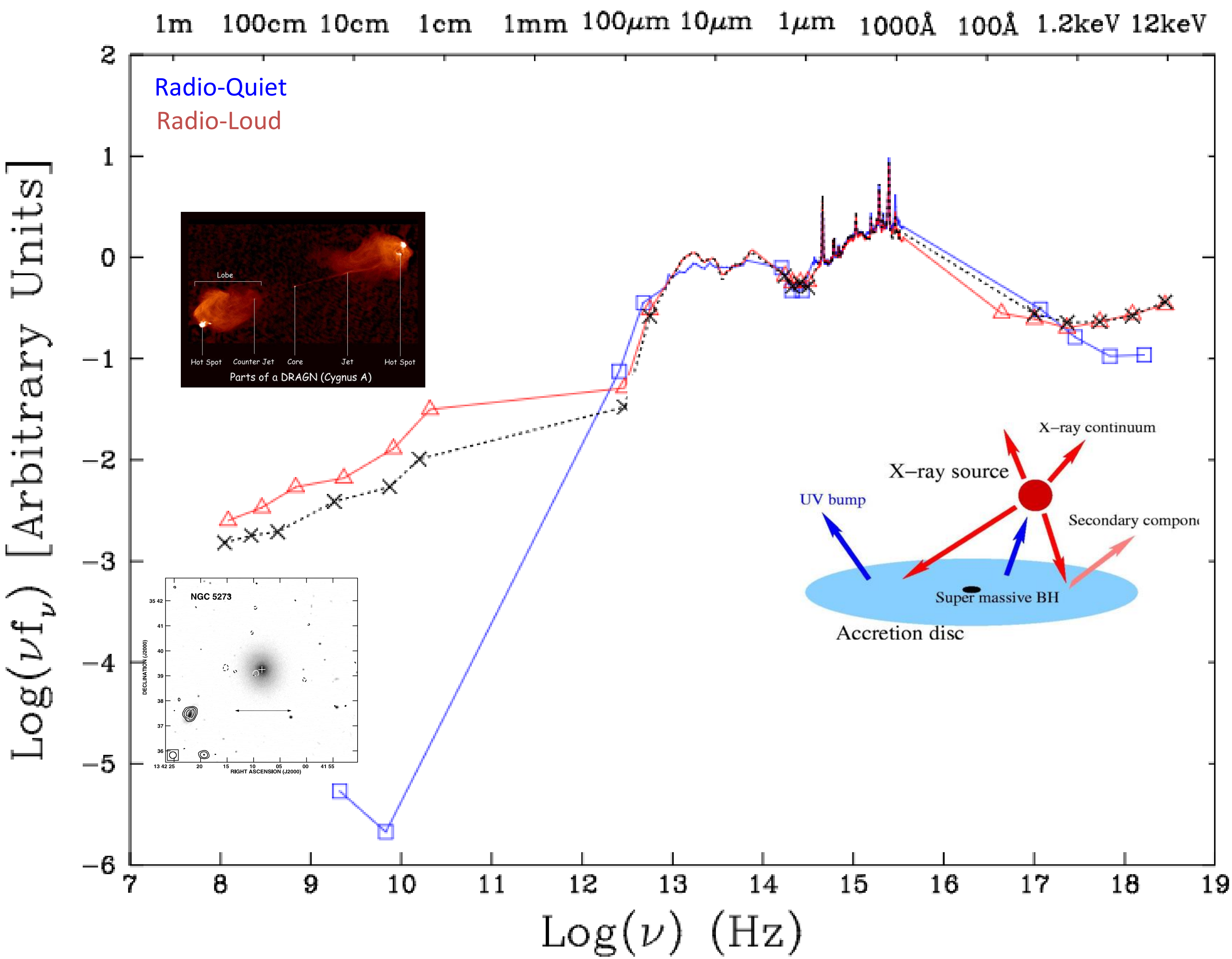
Are they present only in a small fraction of the AGN population?

Are the jet and the wind connected to the accretion flow and how?

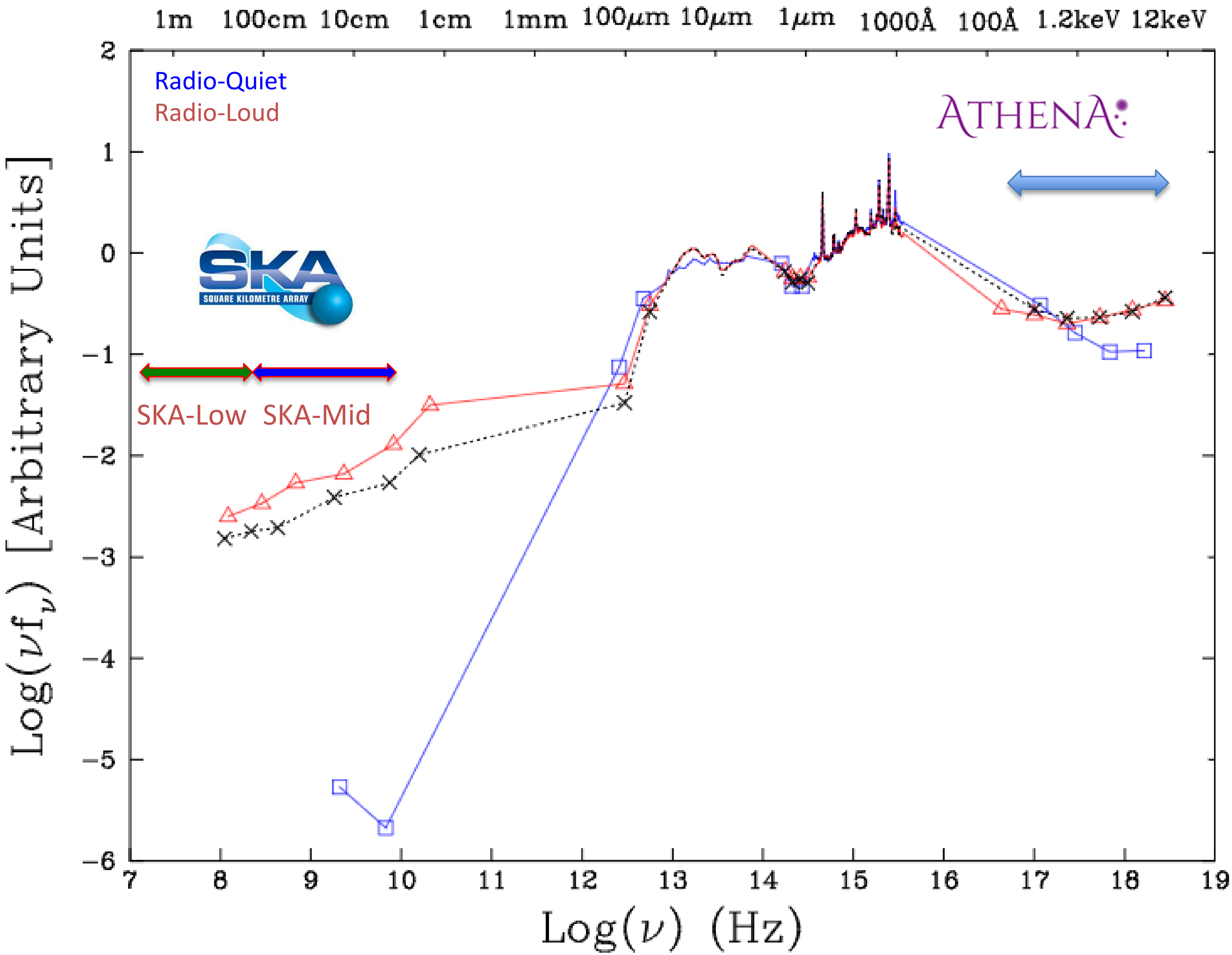
Which is the activity duty cycle in AGN?

How is the jet and wind feedback acting in galaxies?



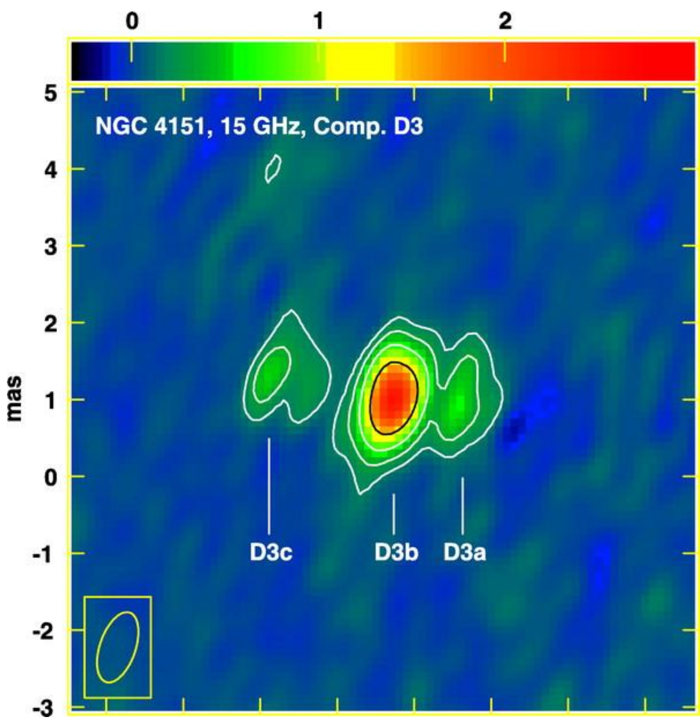


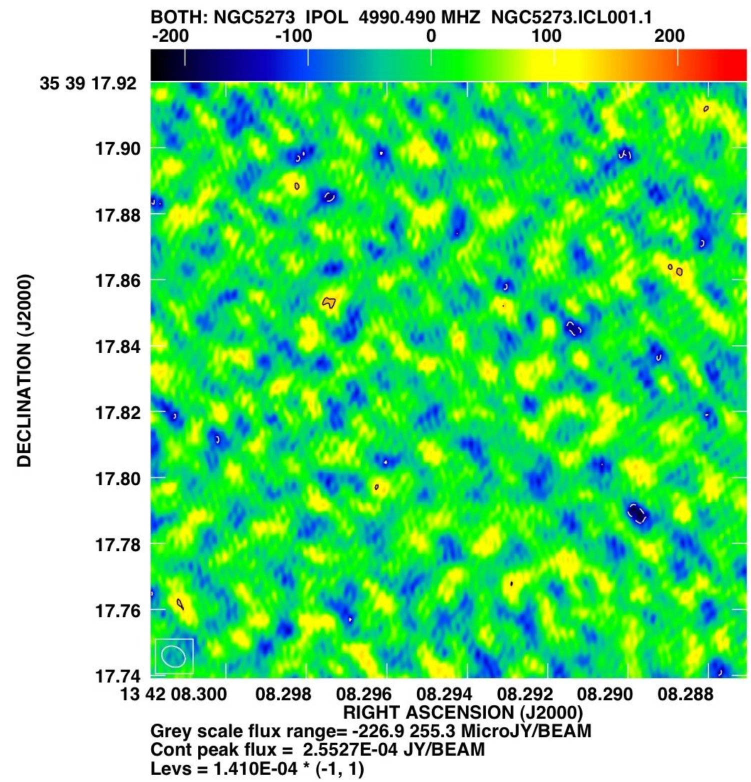
Shang et al. (2011)



Shang et al. (2011)

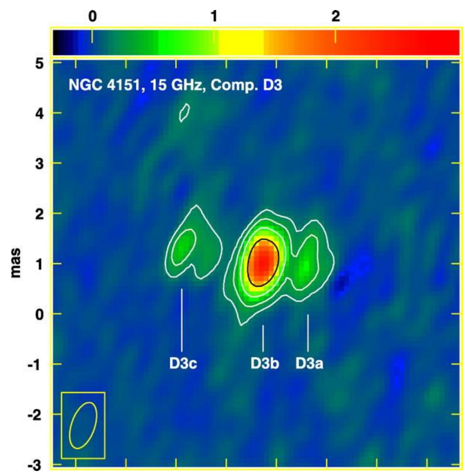
THE DOMINANT SKA POPULATION: RADIO FAINT AGN

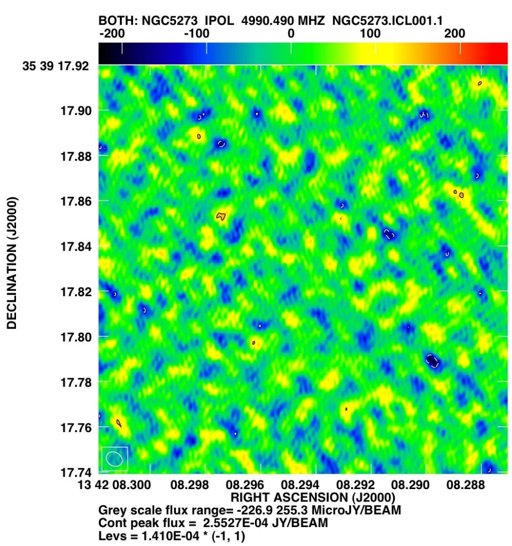


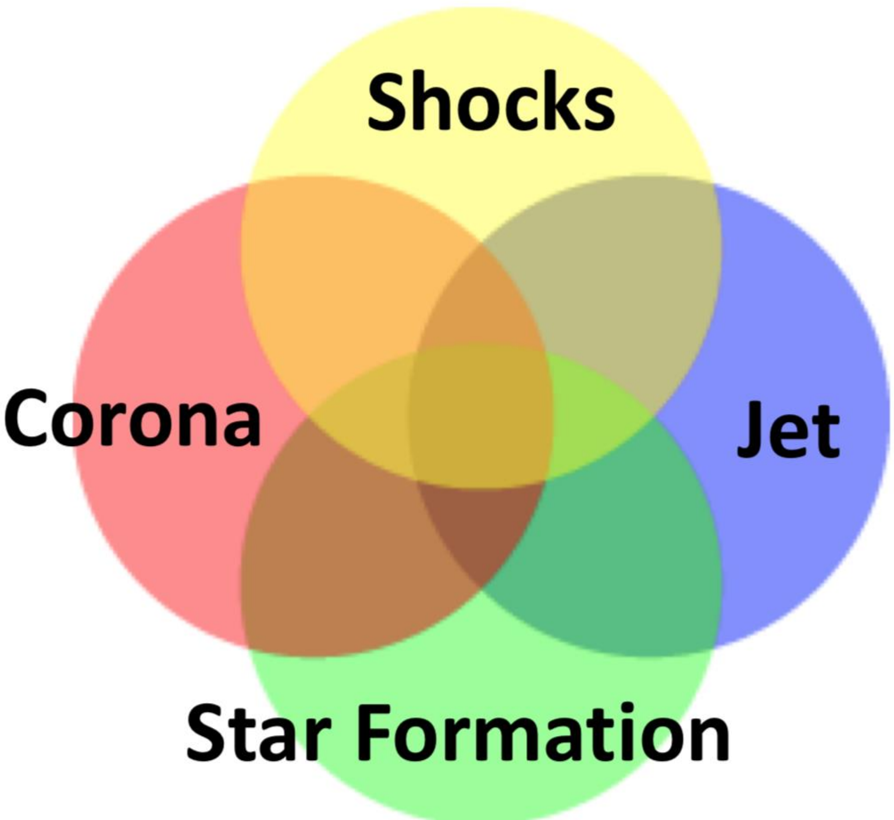


Ulvestad et al. 2001, Nagar et al. 2002, Giroletti & Panessa 2009, Panessa & Giroletti 2013, Bontempi et al. 2012)

THE DOMINANT SKA POPULATION: RADIO FAINT AGN

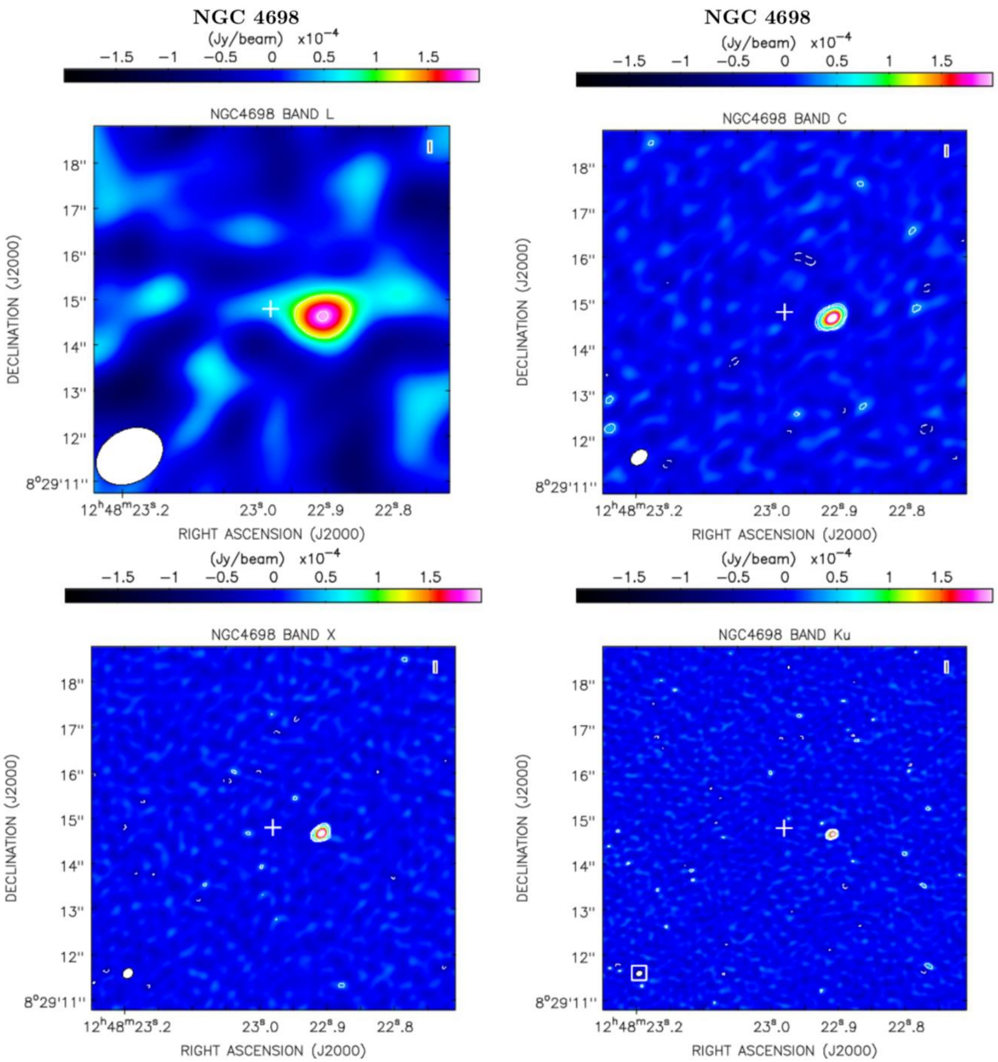






Amy Kimball's courtesy

THE SKA ON LLAGN



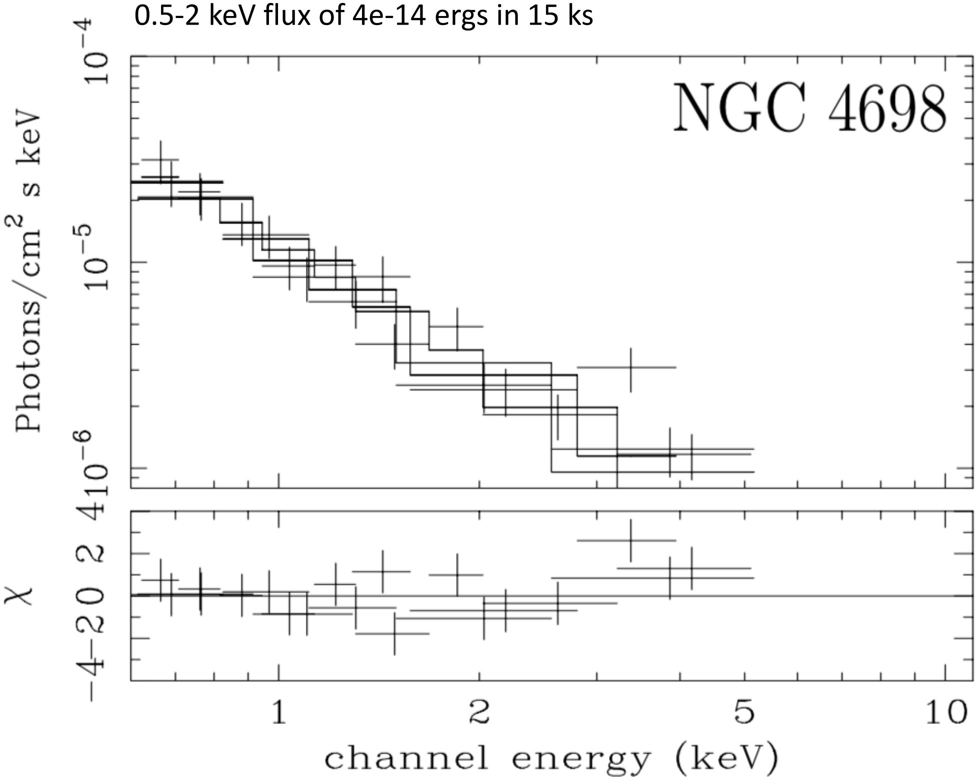
→ ~300 microJy/beam at 5 GHz
in 7 mins observation with JVLA

(Chiaraluce et al. in preparation)

→ Full SKA will detect nanoJy sources

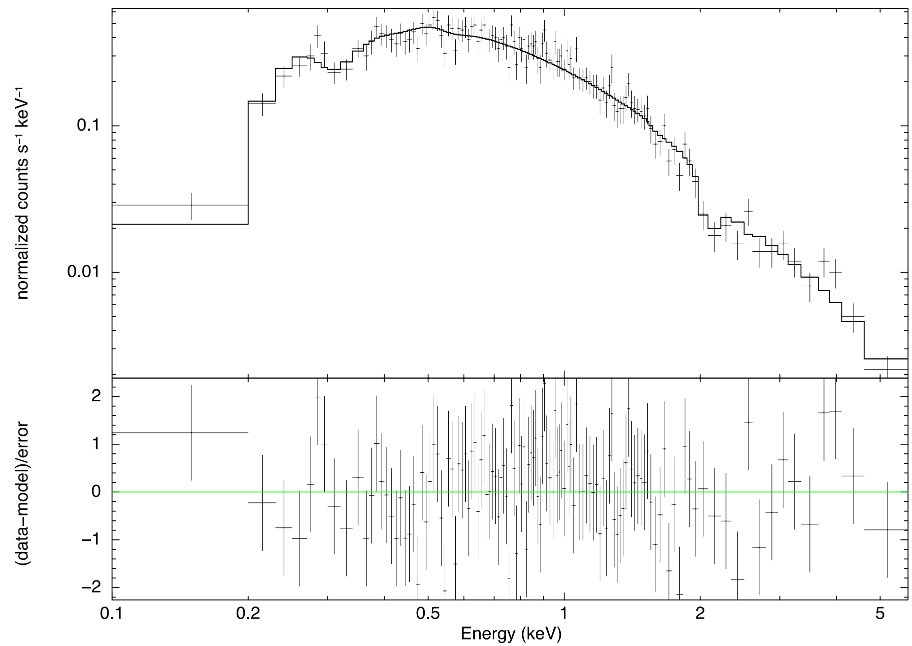
THE SKA – ATHENA SYNERGY ON LLAGN

0.5-2 keV flux of 4e-14 ergs in 15 ks

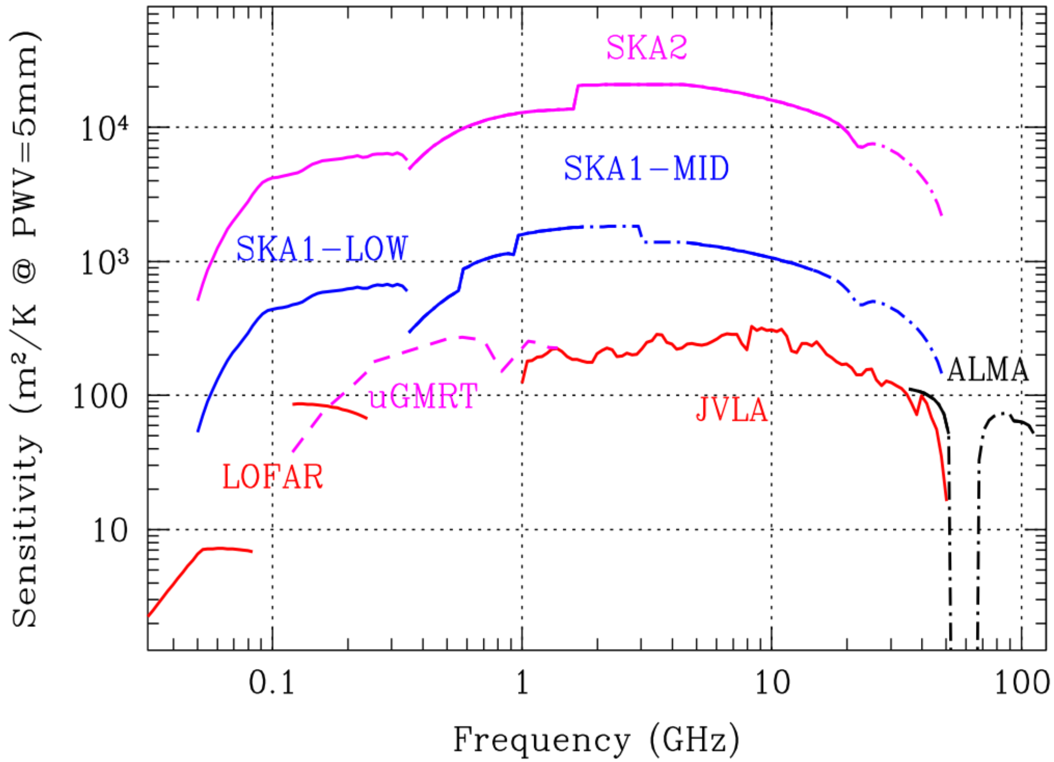


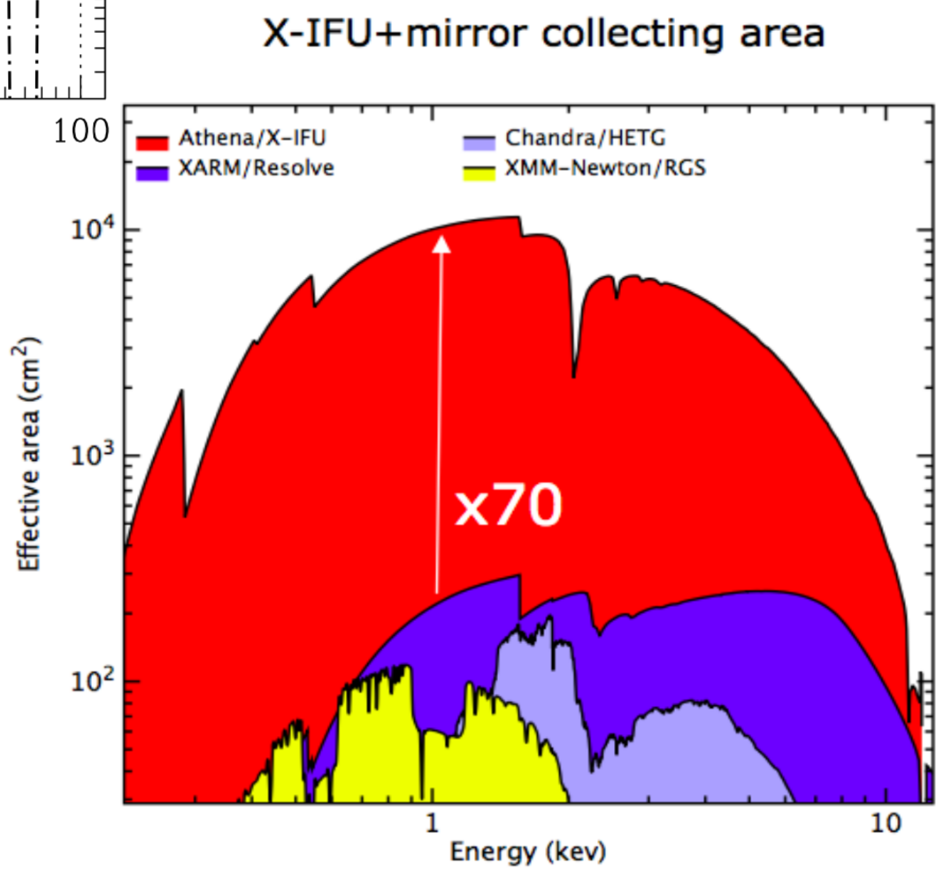
Cappi et al. (2006)

Athena simulation T_{exp} = 8 ks

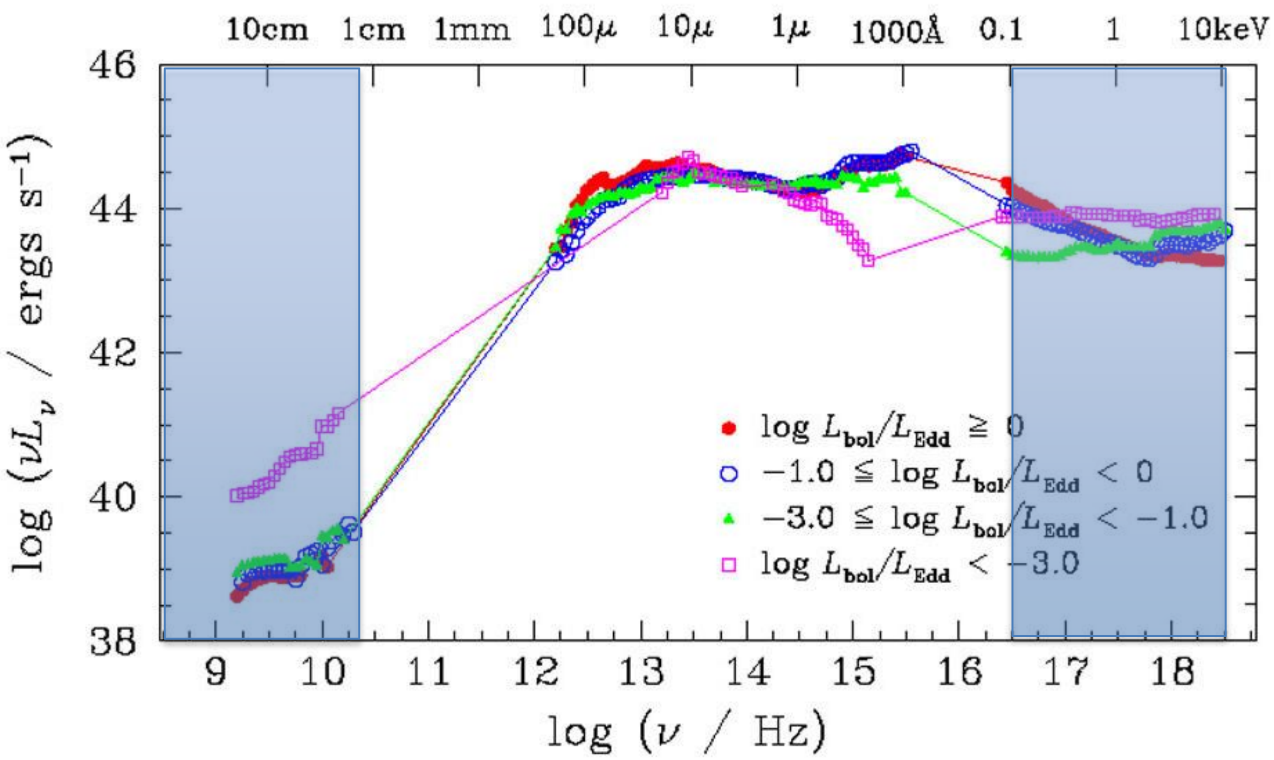


courtesy of Hernandez-Garcia


SKA2
SKA1−MID
SKA1−LOW
ALMA
uGMRT
JVLA
LOFAR
Sensitivity (m²/K @ PWV=5mm)
Frequency (GHz)
0.1
1
10
100
10
100
10³
10⁴


X-IFU+mirror collecting area
Athena/X-IFU
XARM/Resolve
Chandra/HETG
XMM-Newton/RGS
x70
Effective area (cm²)
Energy (kev)
1
10
10²
10³
10⁴

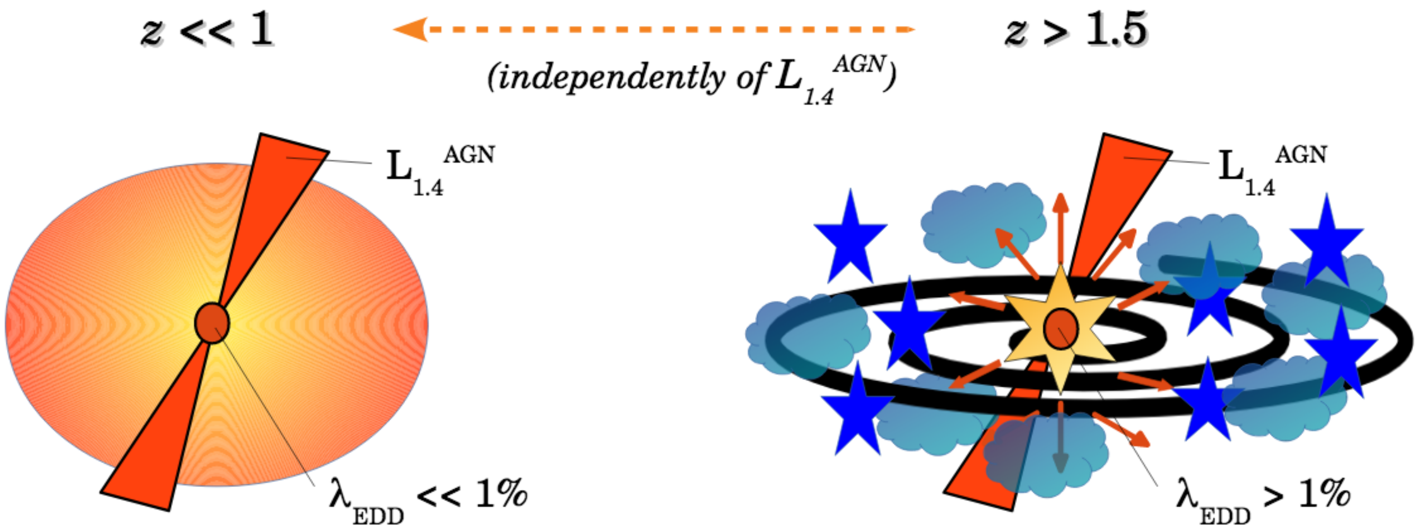
THE SKA – ATHENA SYNERGY ON AGN



Ho et al. 2008

Explore SEDs of AGN from a very large range of Eddington ratios
→ test accretion regime transitions and jet production

THE SKA – ATHENA SYNERGY ON AGN



Red and passive galaxy	RADIO (AND NON) AGN HOST	Blue and highly star-forming galaxy
Weakly accreting SMBH (λ_{EDD} << 1%)	RADIO AGN	Highly accreting SMBH (λ_{EDD} > 1%)

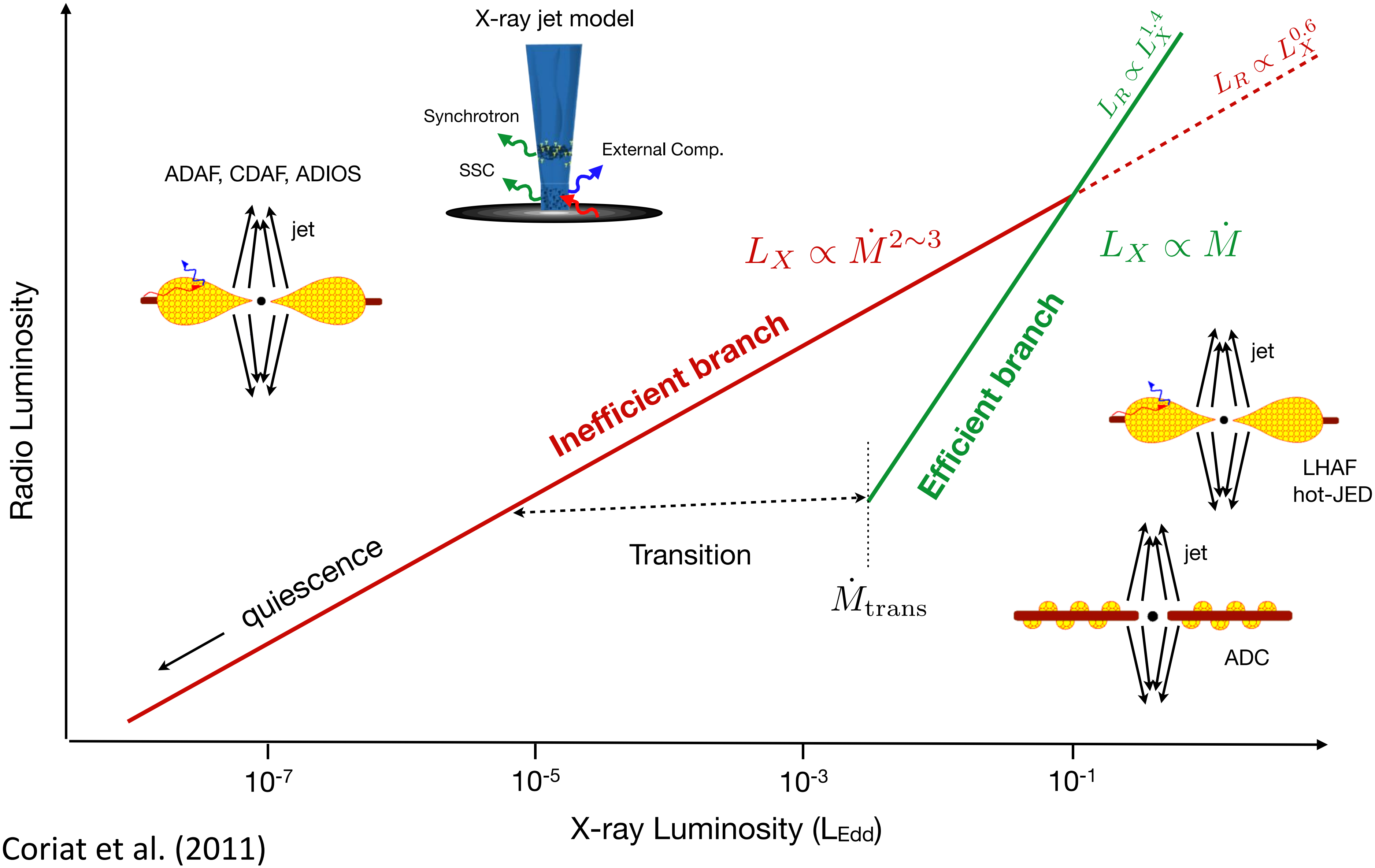
Delvecchio et al. (2018)

ATHENA

SKA SQUARE KILOMETRE ARRAY

→ Evolution of accretoion/ejection activity at high-z

ACCRETION/EJECTION COUPLING

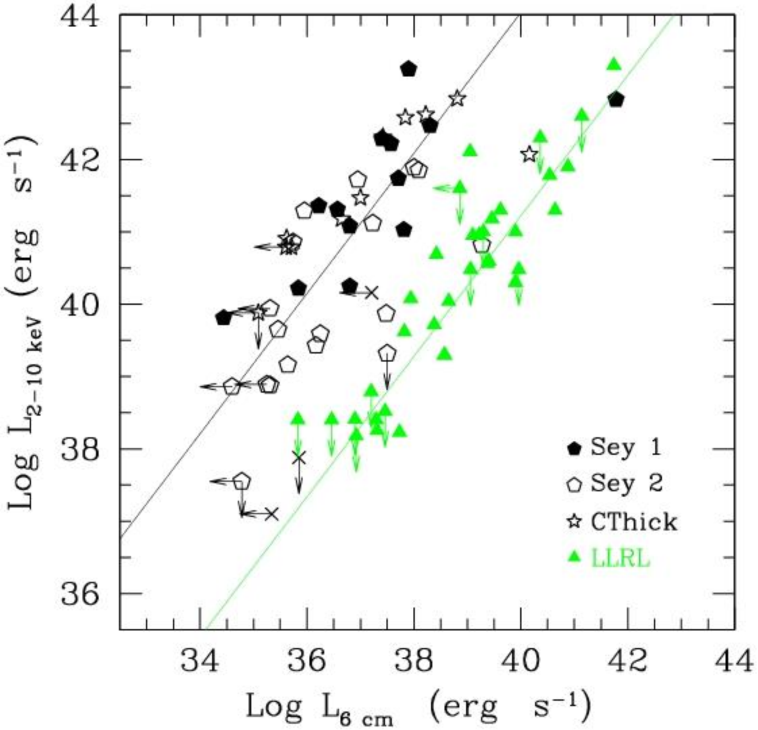


Coriat et al. (2011)

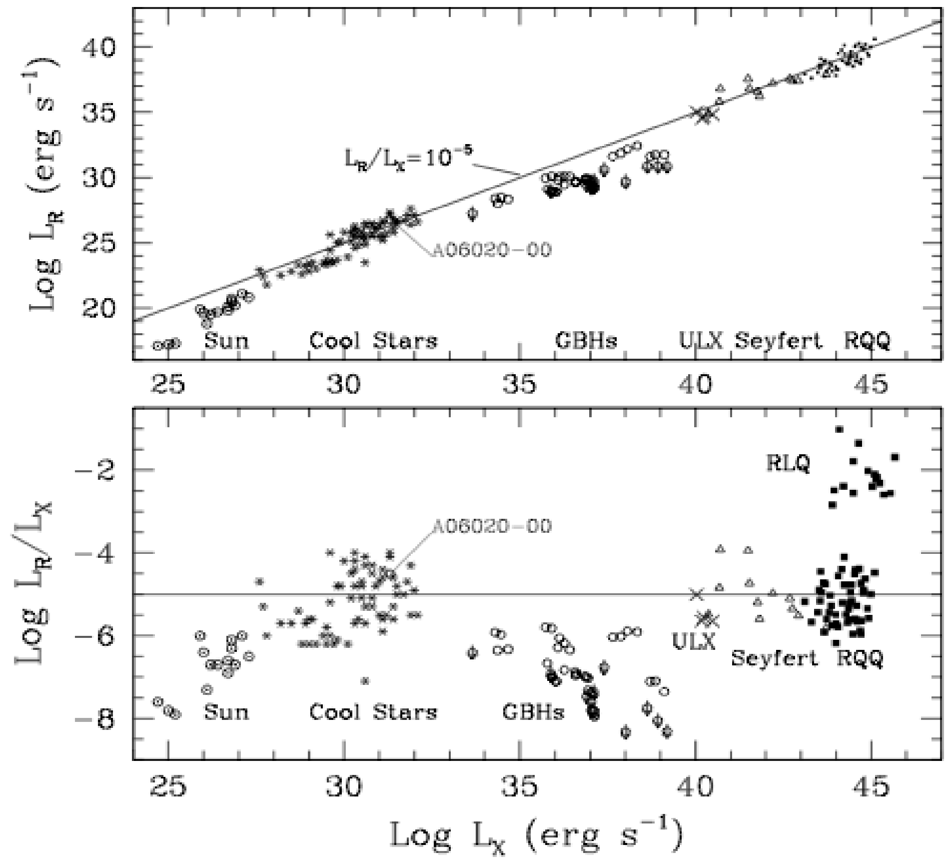
Hannikainen et al. (1998), Corbel et al. (2003), Gallo, Fender & Pooley (2003)

ACCRETION/EJECTION COUPLING

Panessa et al. (2007)



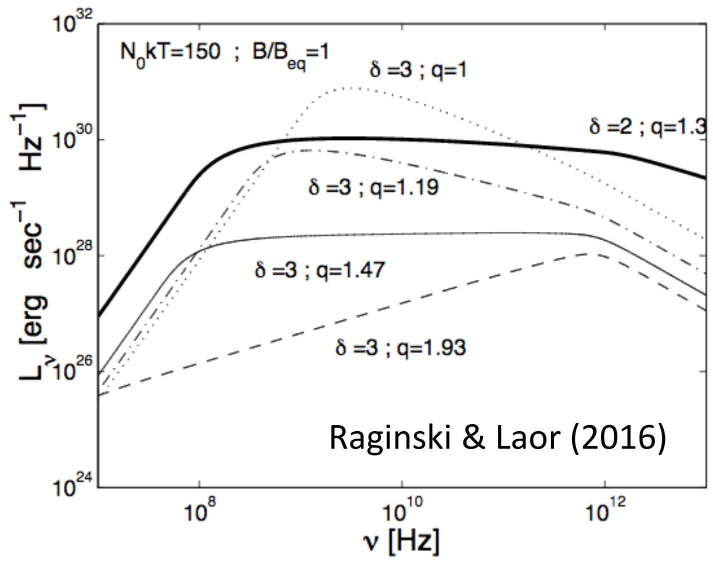
Laor & Behar 2008



Correlation from low luminosity AGN to bright AGN

→ hypothesis: RQ AGN lie on the same relation as Coronally Active stars and radio emission originates from coronal mass ejections

THE SKA – ATHENA SYNERGY ON AGN



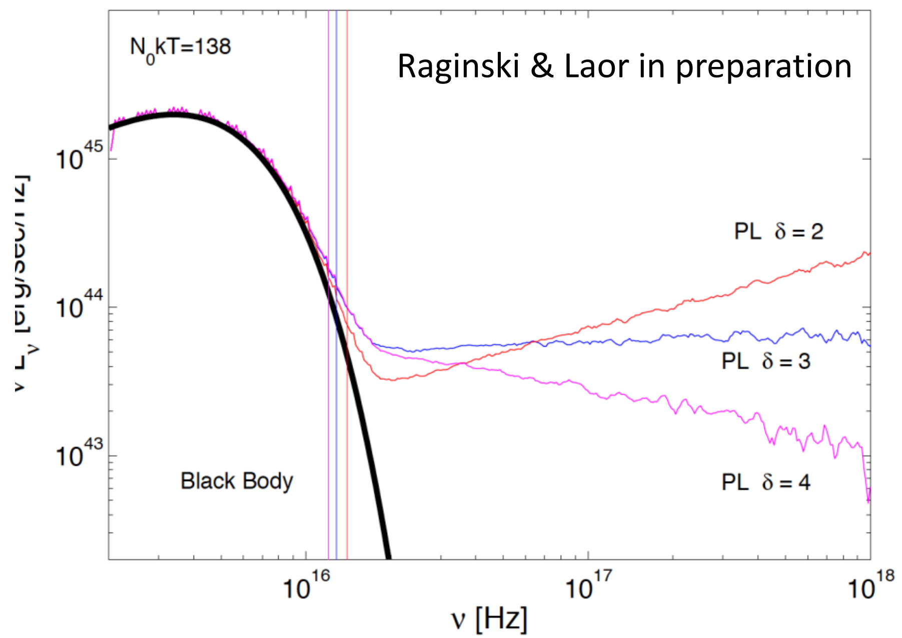


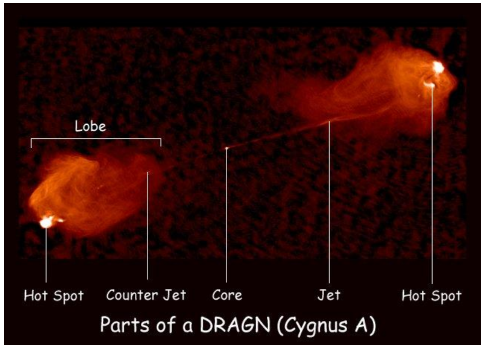
Figure 7: Emissions of three PL distributions. The vertical lines designate the turn-over frequency

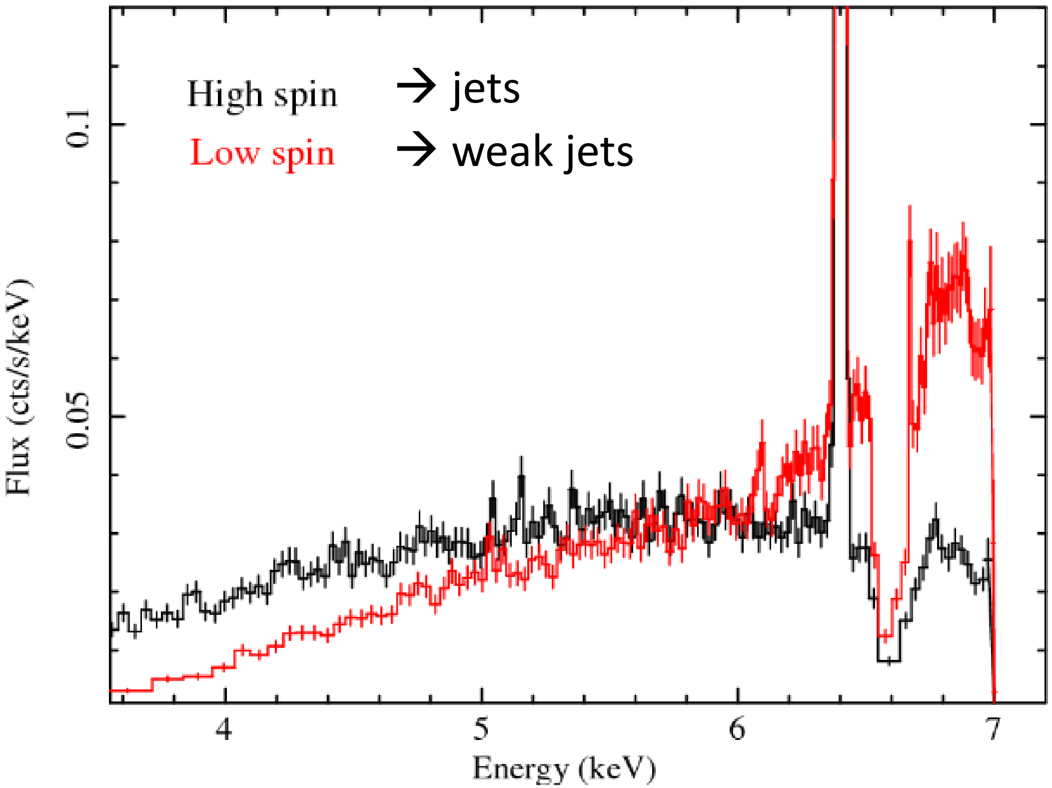
RADIO from synchrotron emission of power-law (PL) electrons in coronal models:

If X-rays are by comptonization from PL electrons
→ same radio and X-ray spectral slope

JET DEPENDENCE on SPIN

Jet energy can come from the rotational energy of a black hole:





Dovciak et al. Athena supporting paper

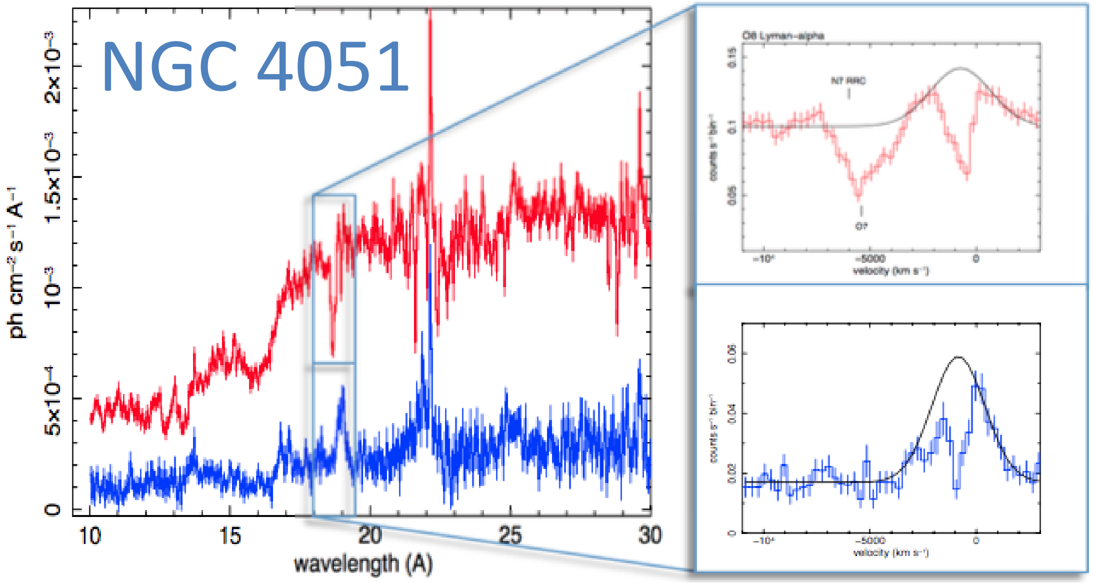
- ✓ In X-ray binaries moderate or no convincing correlation between the jet and a spin (Miller et al. 2009, Fender et al. 2010, Narayan et al. 2011)
- ✓ the spin paradigm for jet power is still awaiting broad observational support

ATHENA SKA SQUARE KILOMETRE ARRAY

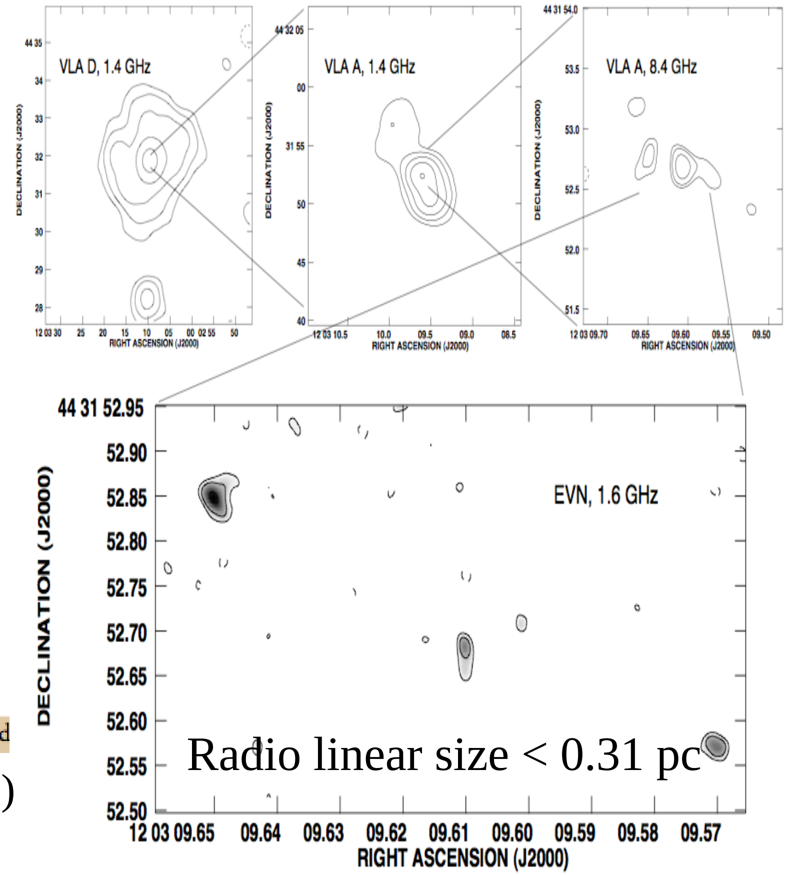
→ statistically relevant correlation to probe the spin paradigm

WINDS in NON JETTED AGN

Giroletti & Panessa 2009



(Left) Athena+ simulated (~1 ks) soft X-ray spectrum of the Seyfert 1 galaxy NGC 4051 expected from a shocked post-shock region of radius ~0.3 pc (Pounds and Vaughan 2011)

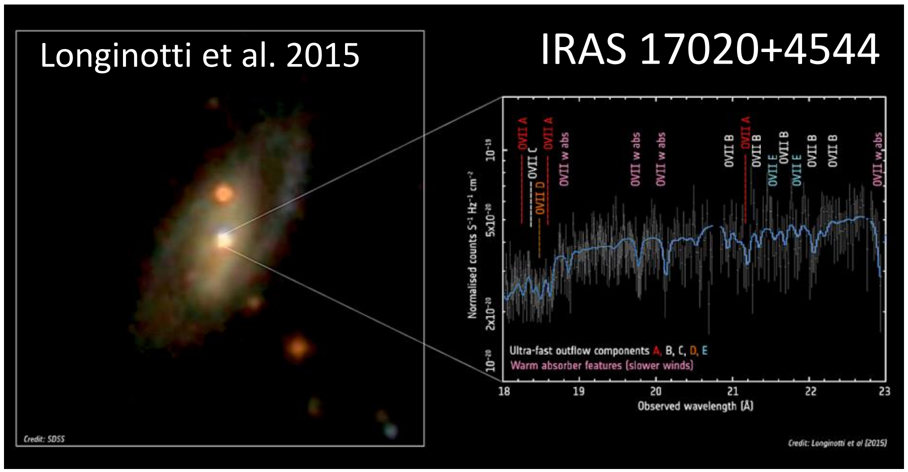


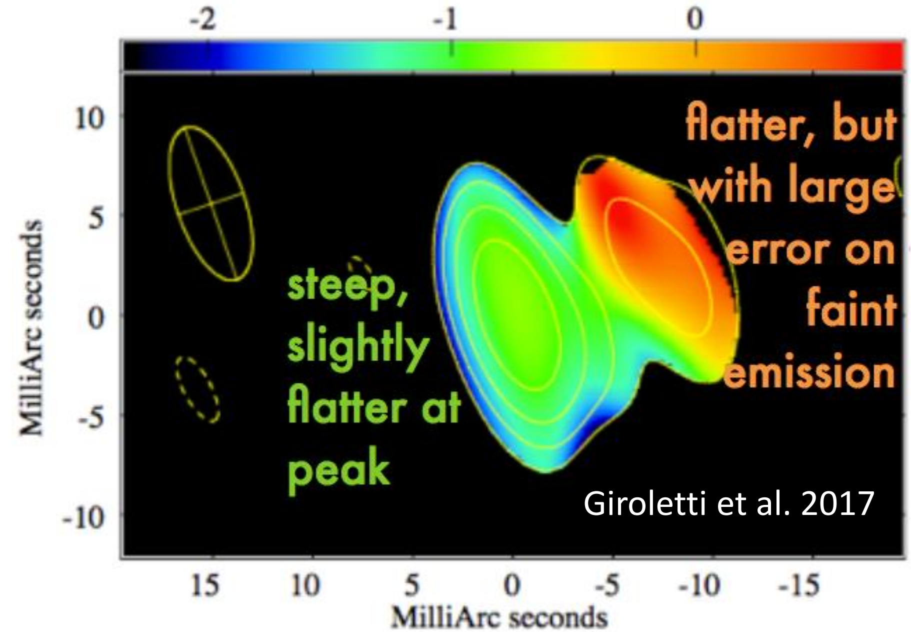
→ outflows with a wide range of velocities and ionization parameter

→ derive physical parameters to contrain outflow models

JET AND OUTFLOW COEXISTENCE

Ultra fast outflows in 27% of 26 Radio-Loud AGN sample (Tombesi et al. 2014)





ATHENA → detect a large number of outflows in jetted AGN, determining their physical parameters

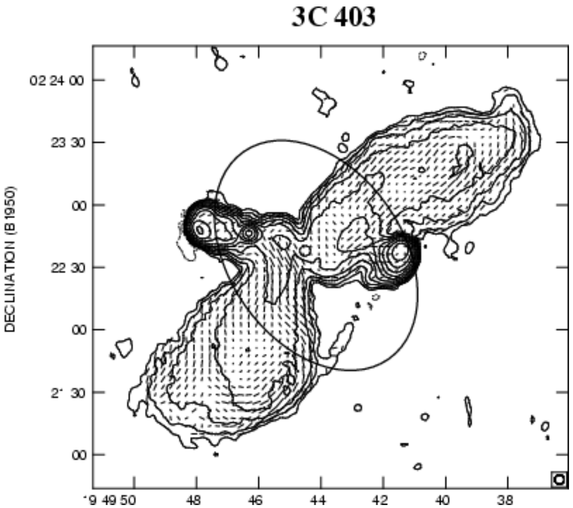
SKA SQUARE KILOMETRE ARRAY → determine the occurrence of radio jets and their properties over a wide range of powers, morphologies and spatial scales

estimate the outflow and jet kinetic power → feedback

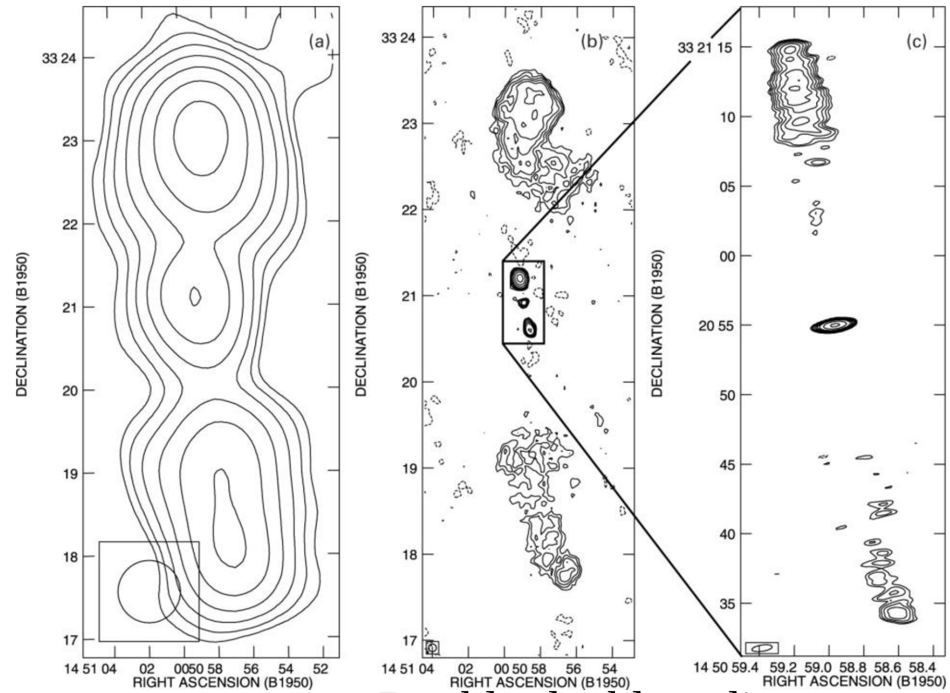
AGN RESTARTING ACTIVITY

Schoenmakers et al. 2000

Dennett-Thorpe et al. 2002



X-shaped radio-sources



Double-double radio-sources

→ discover a large number of new restarting activity sources (now rare!)

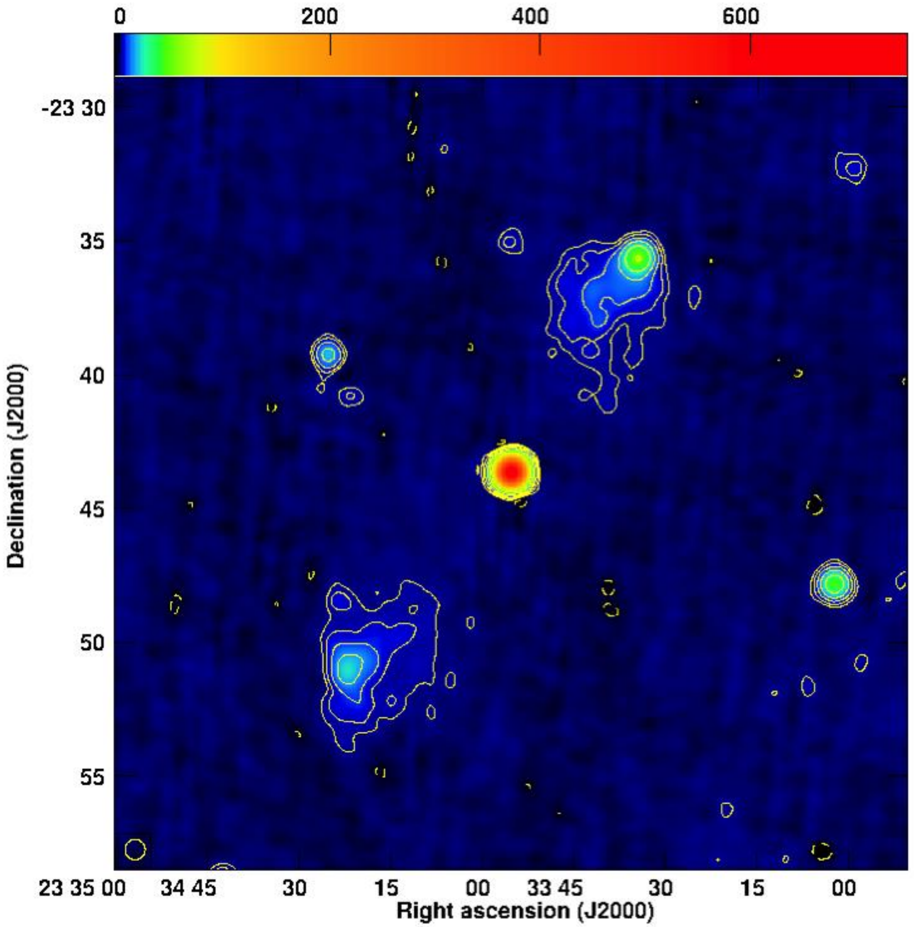
→ estimate the present epoch activity of the source

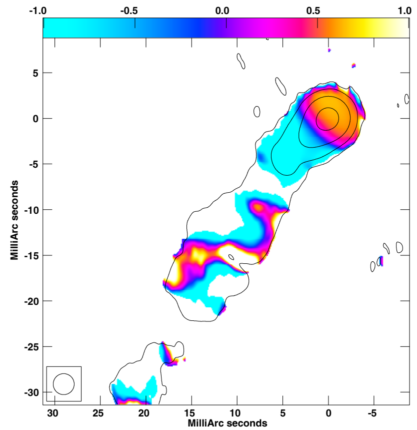
estimate the duty cycle of activity in galaxies

Thank you!

THE REACTIVATING NUCLEUS OF PBC J2333.9-2343

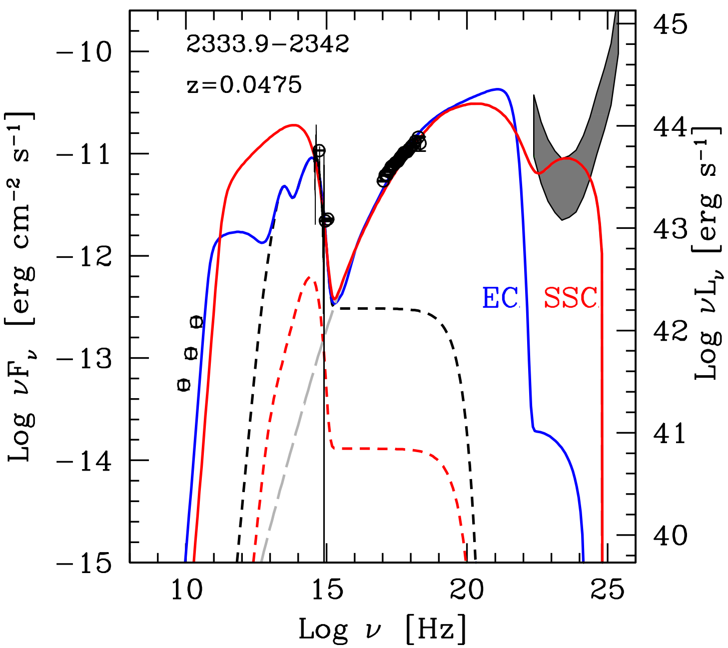
from giant radio galaxy to blazar!



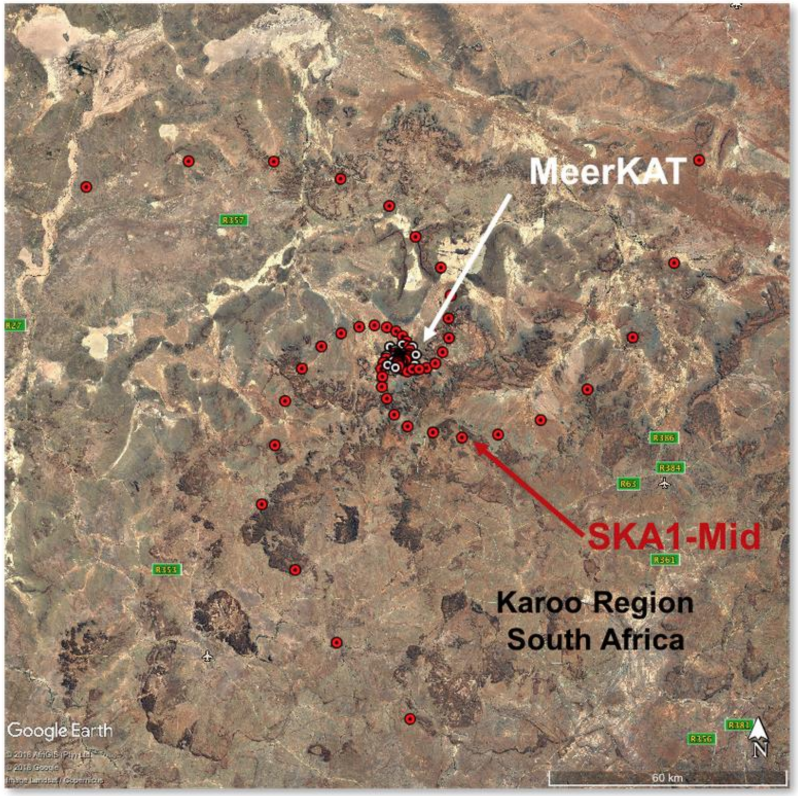


→ small angle!

↑



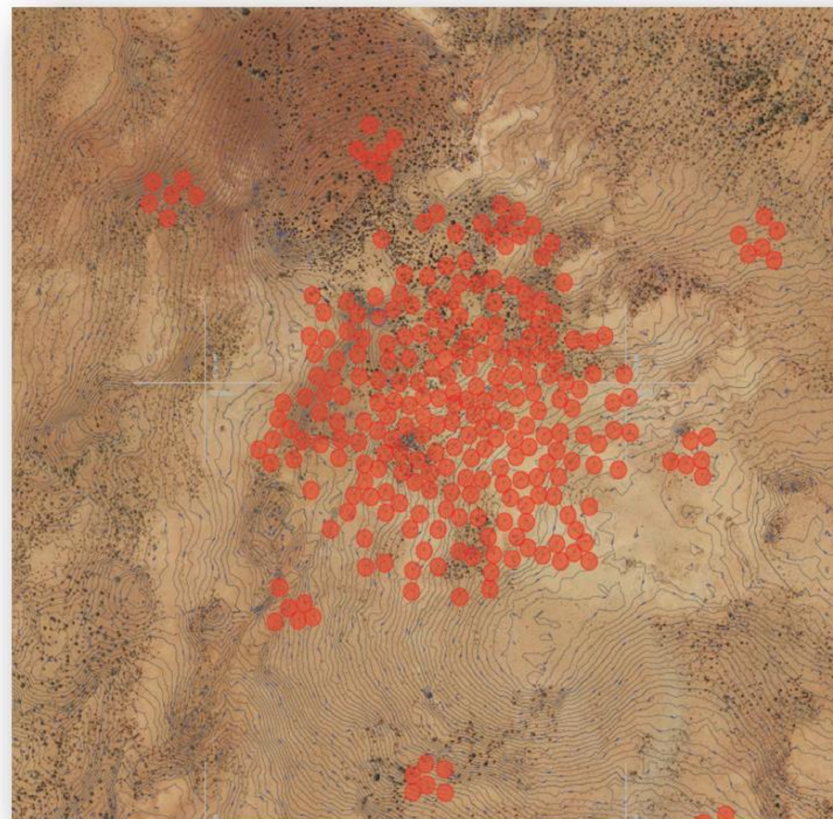
Hernandez-Garcia et al. 2017



SKA1 Mid Layout

SKA1-Mid will consist of 133 15m SKA dishes and 64 13.5m Meerkat dishes in the Karoo site in South Africa. The core comprises around 50% of the dishes, randomy distributed within 2 Km. There are 3 logarithmic spiral arms with a maximum baseline of 150 Km.

SKA1 Low will consist of 130,000 log-periodic dipole antennas, organised in 512 aperture array stations of 256 antennas each, in the Boolardy site in Western Australia. Around 50% of the stations are within 1 Km diameter core; the remaining ones are organised in clusters of 6 stations on three modifed spiral arms. The maximum baseline is 65 Km.



Band Definitions

(1): Part of the design baseline and deployed as a top priority
(2): Deployed as an upgrade path (to be confirmed)

Telescope	Band	Frequency Range (MHz)	Available Bandwidth (MHz)	Notes (MHz)
SKA1-LOW	N/A	50 – 350	300	(1)
SKA1-MID	1	350 – 1050	700	(1)
	2	950 – 1760	810	(1)
	3	1650 – 3050	1400	(2)
	4	2800 – 5180	2380	(2)
	5a	4600 – 8500	2 x 2500	(1)
	5b	8300 – 15300	2 x 2500	(1)
	5c	15000 – 24000	2 x 2500	(2)
	A	1600 – 5200	2500	(2)
	B	4600 – 24000	2 X 2500	(2)

THE DOMINANT SKA POPULATION: RADIO FAINT AGN

- SKA 1_mid (2019): survey between 1-3 GHz (100 km baseline)
  - In 1hr →1 microJy with 100 mas
  - 10^3 more LLAGN

Powerful tool to search for weak AGN

↓

Probe the kpc to pc scale properties of jets and AGN cores

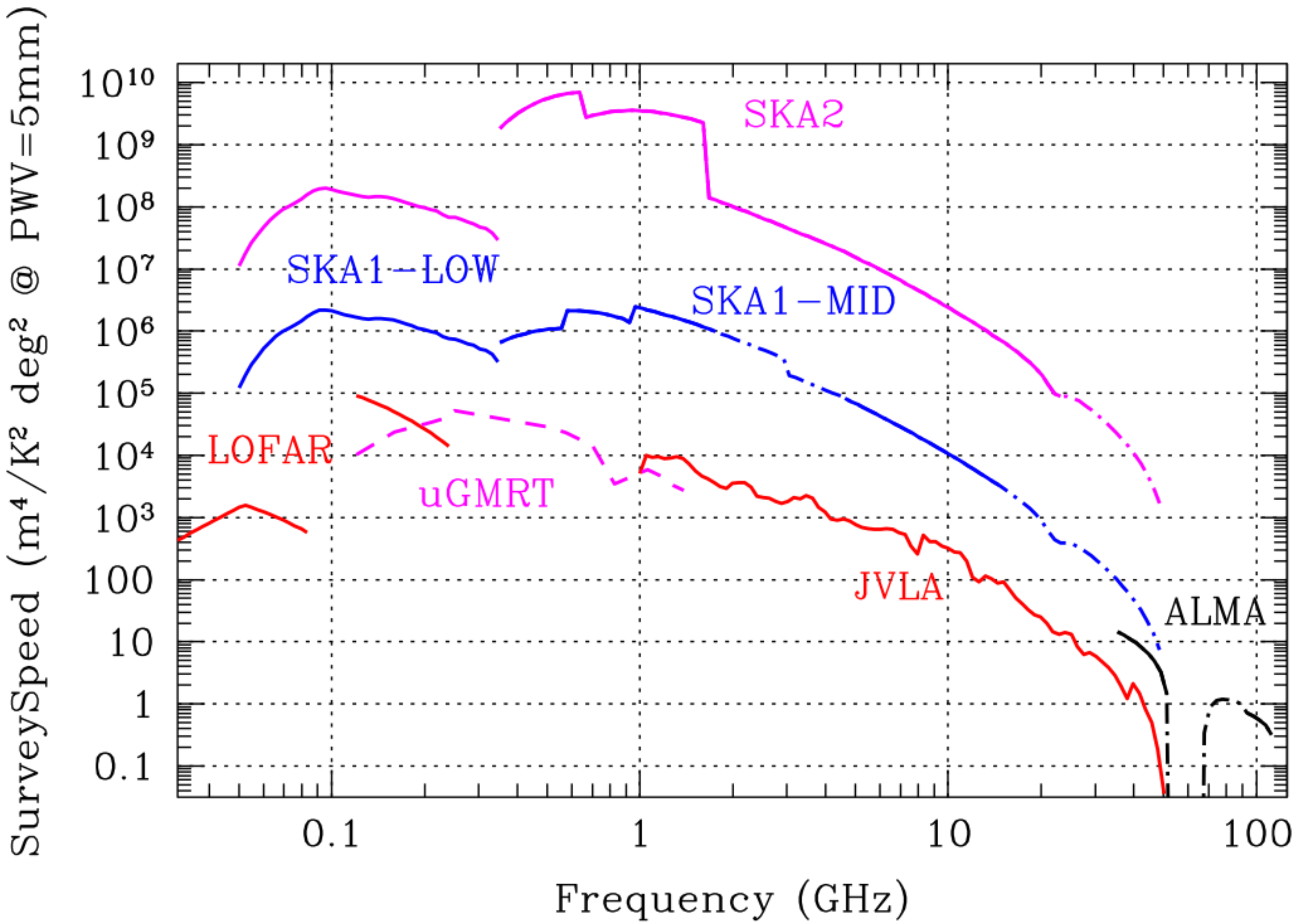
- ✓ Study of the jet launching and acceleration zone in nearby AGN
- ✓ Systematic measurement of the brightness temperatures, slopes and morphologies in complete samples of radio sources
- ✓ Investigate flaring coronal and jet activity and its correlation with X-ray activity

Predicted design & timeline for SKA2

The second phase of the SKA (SKA2) will follow after construction and deployment of SKA1.

The performance of the second phase of the SKA is likely to include:

- 4 x SKA1 sensitivity in the frequency range of 50 – 350 MHz
- 10 x SKA1 sensitivity in the frequency range of 350 MHz – 24 GHz (including deployment of all five frequency bands)
- 50% of the “natural” sensitivity of the facility over a wide range of beam size
- 20 x SKA1 Field-of-View in the frequency range of 350 MHz – 1.5 GHz
- 20 x SKA1 maximum angular resolution in the frequency range of 50 MHz – 24 GHz



SurveySpeed (m⁴/K² deg² @ PWV=5mm)
Frequency (GHz)
SKA2
SKA1−LOW
SKA1−MID
LOFAR
uGMRT
JVLA
ALMA
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
100
10
1
0.1
0.1
1
10
100

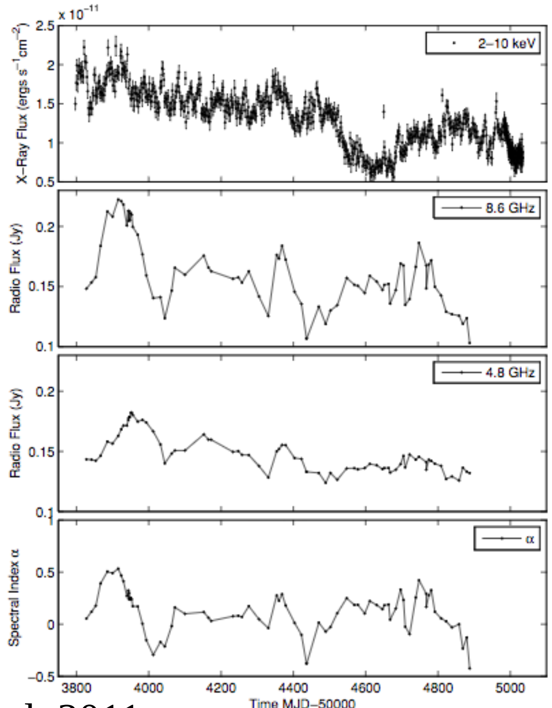
ANTICIPATED SKA1 HPC RE QUIREMENTS – May 2018

ν_{min} (GHz)	ν_c (GHz)	ν_{max} (GHz)	Sub-band	Band	N_{Ateam}	N_{Source}	S_{Max} (Jy)	S_{Min} (Jy)	$N_{SelfCal}$/ $N'_{SelfCal}$	N_{Maj}/ N'_{Maj}	N_{lpatch}
0.050	**0.060**	**0.069**	Low sb1		19	36820	68	14m	6/1	3/1	336
0.069	**0.082**	**0.096**	Low sb2		15	35270	32	3.9m	6/1	3/1	180
0.096	**0.114**	**0.132**	Low sb3		12	28390	14	1.4m	5/1	3/1	93
0.132	**0.158**	**0.183**	Low sb4		10	24760	6.3	0.7m	5/1	3/1	48
0.183	**0.218**	**0.253**	Low sb5		9	17050	2.8	0.5m	5/1	3/1	25
0.253	**0.302**	**0.350**	Low sb6		8	9602	1.3	0.5m	5/1	2/1	20
0.35	**0.41**	**0.48**	Mid sb1	B1	8	29860	2.0	0.3m	6/1	3/1	36
0.48	**0.56**	**0.65**	Mid sb2	B1	5	25140	0.9	0.1m	6/1	3/1	20
0.65	**0.77**	**0.89**	Mid sb3	B1	3	21530	0.4	60μ	5/1	3/1	20
0.89	**1.05**	**1.21**	Mid sb4	B2	2	18770	0.2	20μ	5/1	3/1	20
1.21	**1.43**	**1.65**	Mid sb5	B2	1	16290	90m	15μ	5/1	3/1	20
1.65	**1.95**	**2.25**	Mid sb6		0	11430	50m	9μ	5/1	3/1	20
2.25	**2.66**	**3.07**	Mid sb7		0	6660	31m	7μ	5/1	3/1	20
3.07	**3.63**	**4.18**	Mid sb8		0	3770	20m	6μ	5/1	3/1	20
4.18	**4.94**	**5.70**	Mid sb9	B5a	0	2087	13m	5μ	5/1	2/1	20
5.70	**6.74**	**7.78**	Mid sb10	B5a	0	1117	8m	4μ	4/1	2/1	20
7.78	**9.19**	**10.61**	Mid sb11	B5b	0	582	5m	4μ	4/1	2/1	20
10.61	**12.53**	**14.46**	Mid sb12	B5b	0	293	3m	3μ	4/1	2/1	20

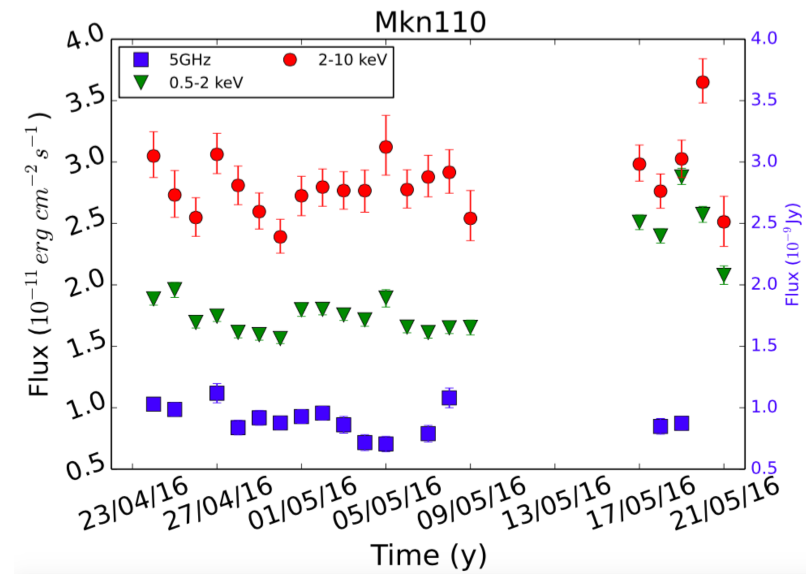
ν_{min} (GHz)	ν_c (GHz)	ν_{max} (GHz)	Sub-band	Band	σ_c (μJy/Bm)	θ'_{min} (“)	θ_{min} (“)	θ_{max} (“)	θ'_{max} (“)
0.050	**0.060**	**0.069**	Low sb1		163	16.4	23.5	1175	3290
0.069	**0.082**	**0.096**	Low sb2		47	11.9	17.0	850	2379
0.096	**0.114**	**0.132**	Low sb3		26	8.6	12.3	614	1719
0.132	**0.158**	**0.183**	Low sb4		18	6.2	8.9	444	1244
0.183	**0.218**	**0.253**	Low sb5		14	4.5	6.4	321	899
0.253	**0.302**	**0.350**	Low sb6		11	3.3	4.6	232	650
0.35	**0.41**	**0.48**	Mid sb1	B1	16.8	1.015	2.031	270.8	541.6
0.48	**0.56**	**0.65**	Mid sb2	B1	8.1	0.745	1.489	198.6	397.2
0.65	**0.77**	**0.89**	Mid sb3	B1	4.4	0.546	1.092	145.6	291.2
0.89	**1.05**	**1.21**	Mid sb4	B2	2.7	0.400	0.801	106.8	213.5
1.21	**1.43**	**1.65**	Mid sb5	B2	2.0	0.294	0.587	78.3	156.6
1.65	**1.95**	**2.25**	Mid sb6		1.6	0.215	0.431	57.4	114.9
2.25	**2.66**	**3.07**	Mid sb7		1.4	0.158	0.316	42.1	84.2
3.07	**3.63**	**4.18**	Mid sb8		1.6	0.116	0.232	30.9	61.8
4.18	**4.94**	**5.70**	Mid sb9	B5a	1.4	0.085	0.170	22.7	45.3
5.70	**6.74**	**7.78**	Mid sb10	B5a	1.3	0.062	0.125	16.6	33.2
7.78	**9.19**	**10.61**	Mid sb11	B5b	1.2	0.046	0.091	12.2	24.4
10.61	**12.53**	**14.46**	Mid sb12	B5b	1.2	0.034	0.067	8.9	17.9

JET-DISK COUPLING in AGN

MONITORING VARIABILITY



Bell et al. 2011



Panessa et al. in prep

X-ray and radio simultaneous monitoring at more frequencies, at different time scales, at higher sensitivities to constrain physical models:

- ✓ disk instabilities propagate into the jet base
- ✓ coronal mass ejections
- ✓ comparison to XRBs

ATHENA

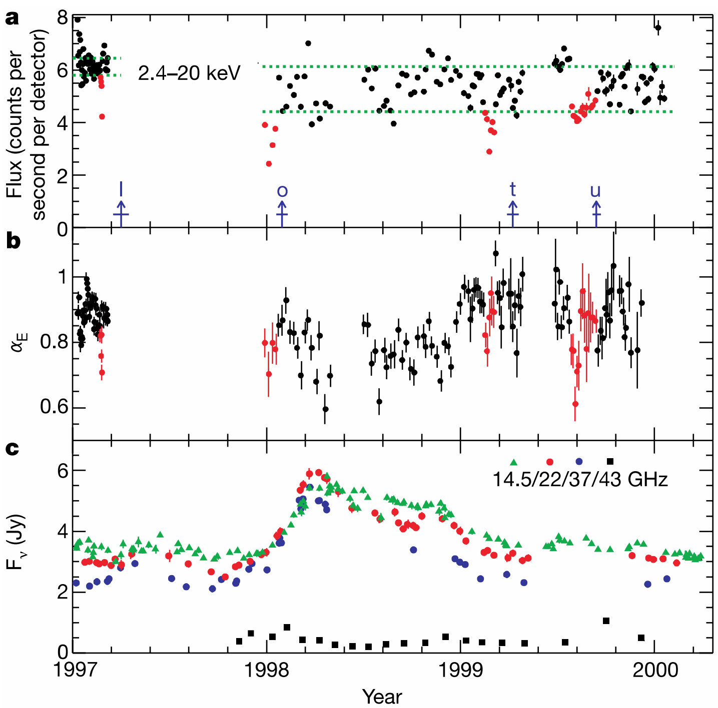
SKA SQUARE KILOMETRE ARRAY

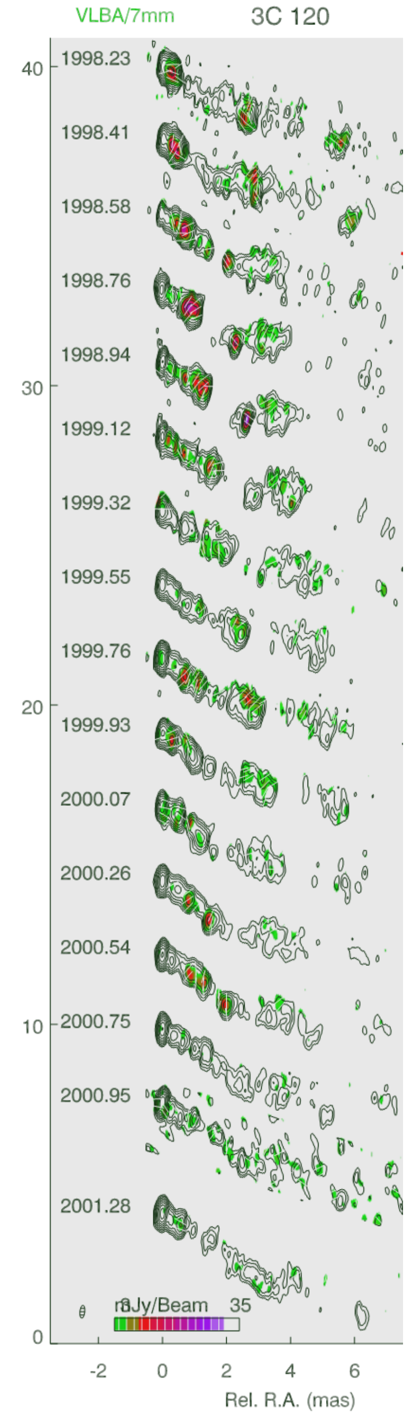
JET-DISK COUPLING in JETTED AGN

MONITORING VARIABILITY

FR I 3C120: Superluminal ejections follow X-ray dips
→ Similar to microquasar GRS 1915+105

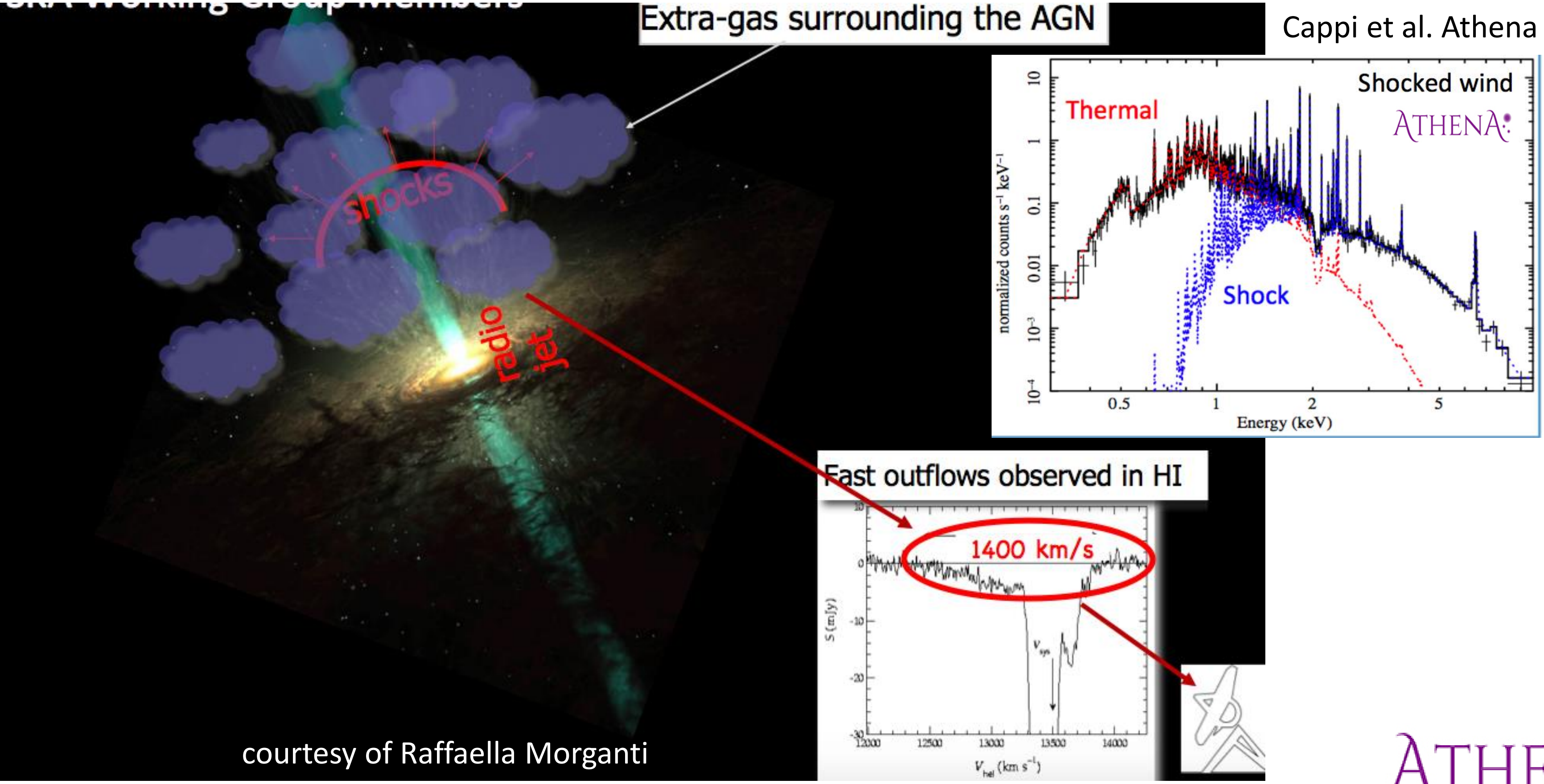
Marsher et al. 2002





TRACING RADIATION WINDS AND JET-DRIVEN OUTFLOWS WITH HI ABSORPTION

Cappi et al. Athena support



Tracer of the gas in the inner parts of the galaxy down to low-luminosity radio AGN (10 mJy at high z)

- *Tracer of circumnuclear disks*
- *Infalling gas ➔ feeding*
- *Outflowing gas ➔ feedback*

The combined spatial and spectral response of the X-IFU on Athena+ will allow to map the velocity field of the hot gas with uncertainties of ~20-30 km/s on scales down to few kpc in

40-50 nearby AGN/ULIRG/starburst galaxies