The II National Workshop of SKA science and technology

SQUARE KILOMETRE ARRAY Italy

Athena and SKA synergy: AGN physics

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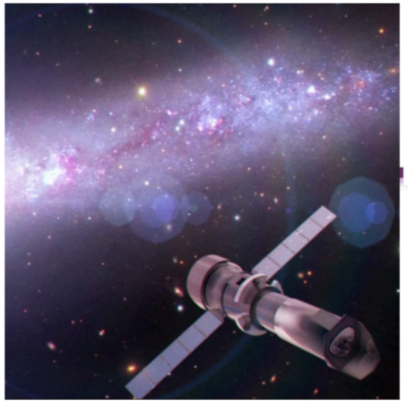
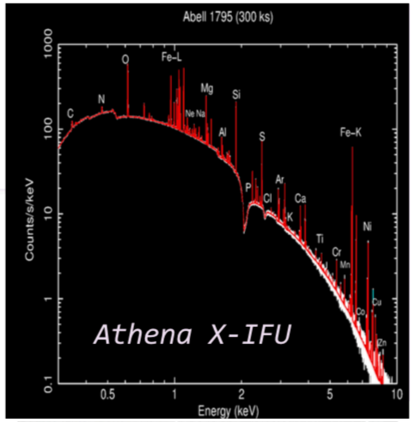
GRAL GAMMA RADIO ASTROPHYSICAL LAB

ATHENA

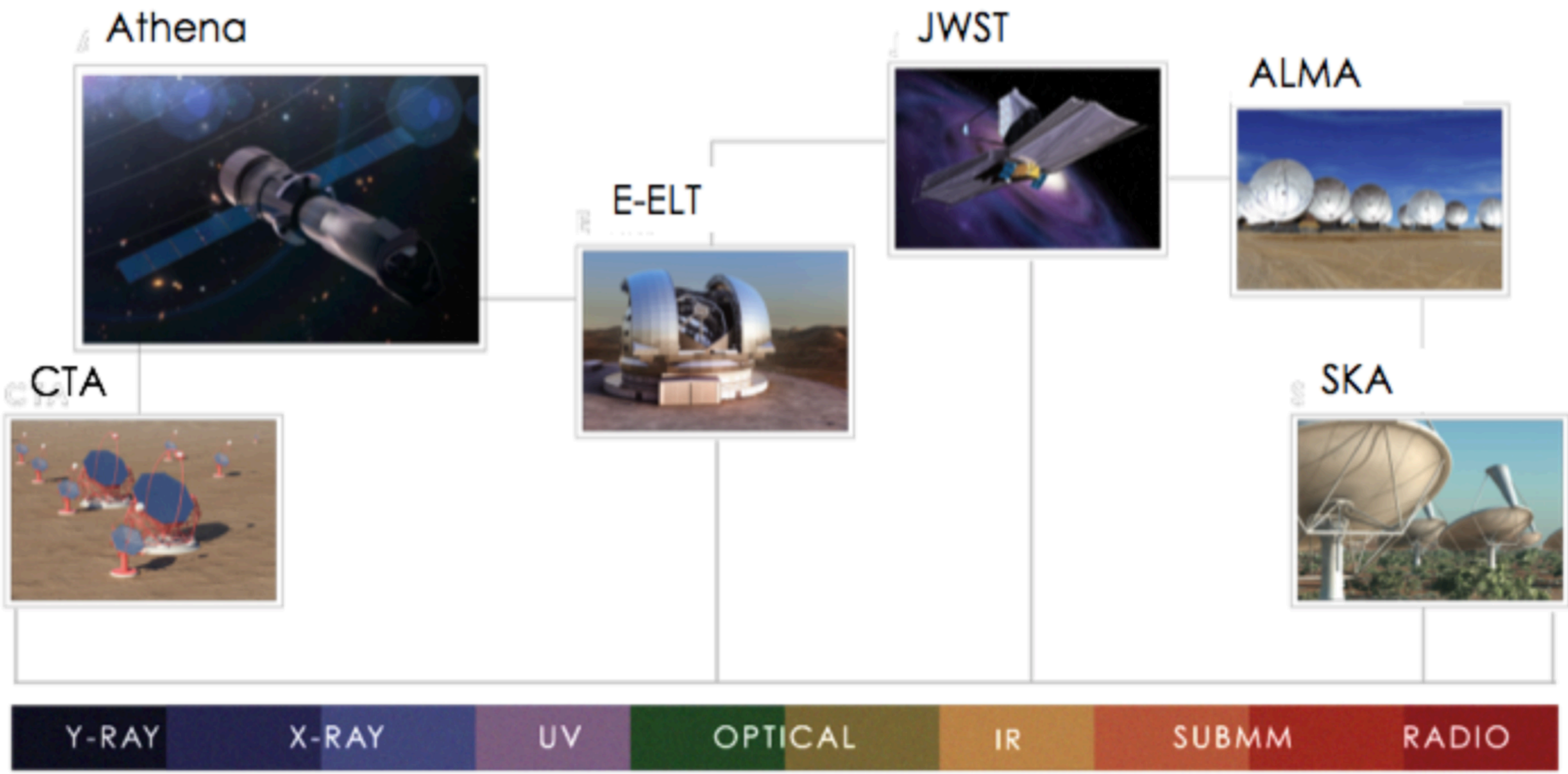
The Advanced Telescope for High Energy Astrophysics:
Scientific Activities in the Study Phase





- Launch uncertain but currently expected **~2030/31**

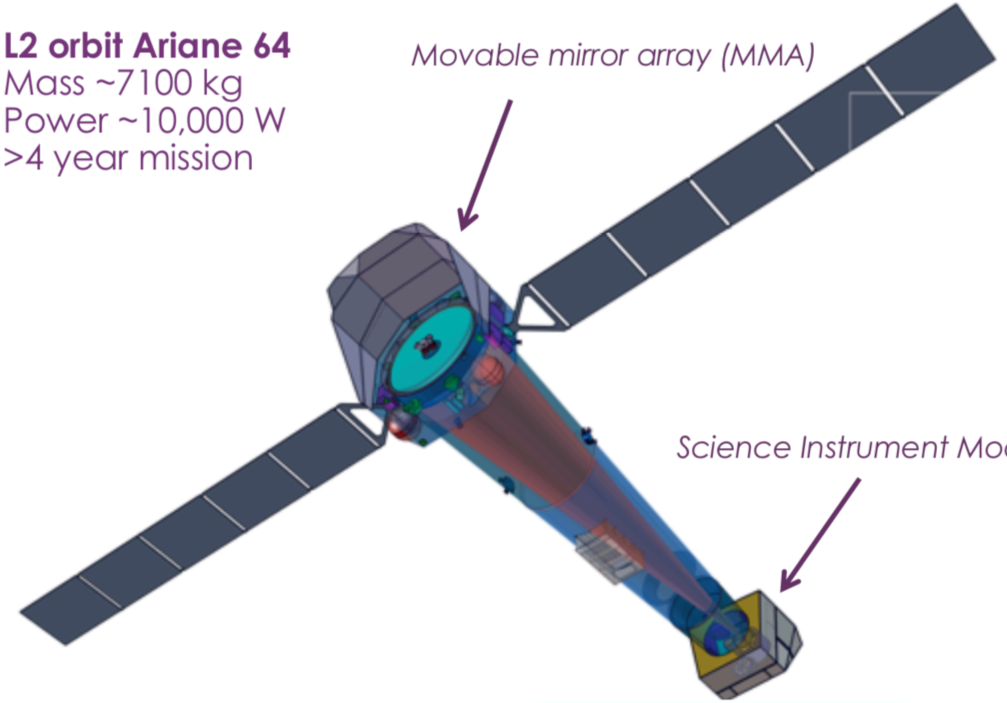
see Paul Nandra contribution to the 2018 Athena meeting


Athena
JWST
ALMA
E-ELT
CTA
SKA
Y-RAY
X-RAY
UV
OPTICAL
IR
SUBMM
RADIO

The Athena Observatory

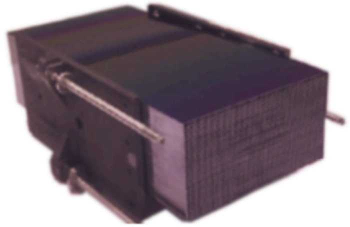
L2 orbit Ariane 64
Mass ~7100 kg
Power ~10,000 W
>4 year mission

Movable mirror array (MMA)

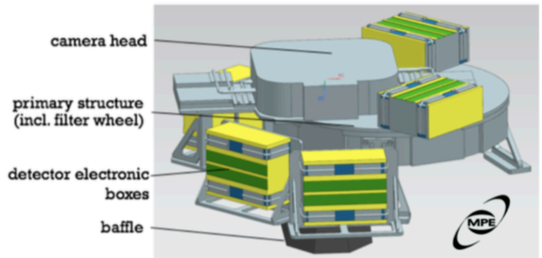


Science Instrument Module (SIM)

Willingale et al, 2013
Bavdaz et al. 2016,2018



Silicon Pore Optics:
1.4 m^2 (goal 2 m^2)@ 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}

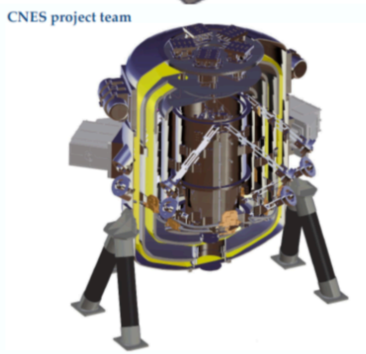


Wide Field Imager:
Si DEPFET-based detector
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

Meidinger et al. 2016, 2018, SPIE

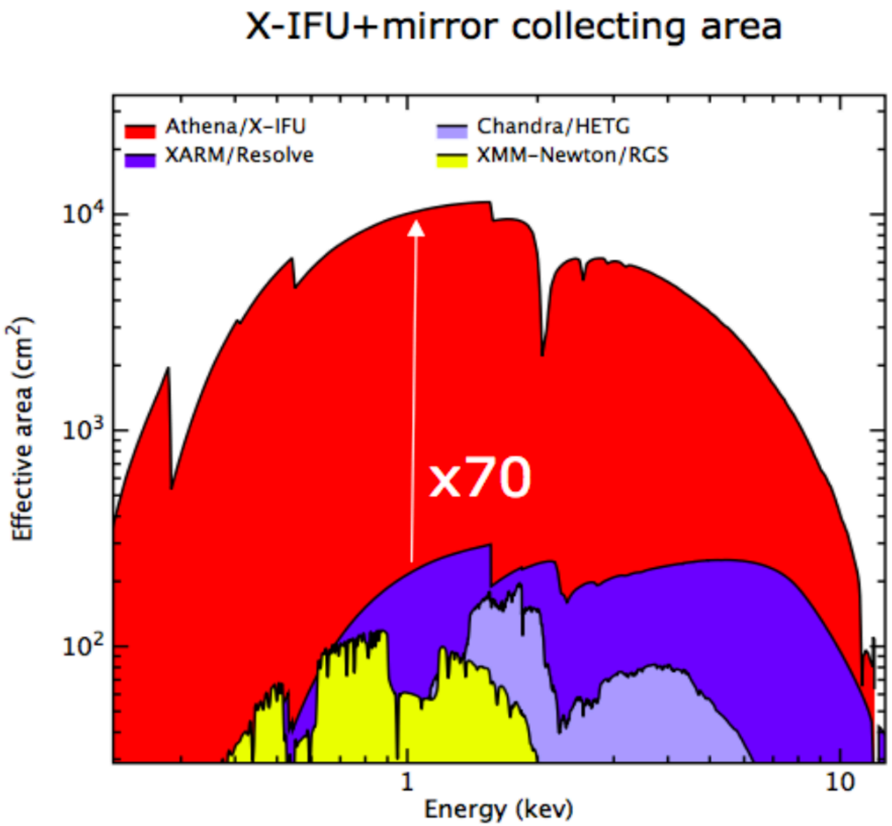
X-ray Integral Field Unit:
TES-based calorimeter
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

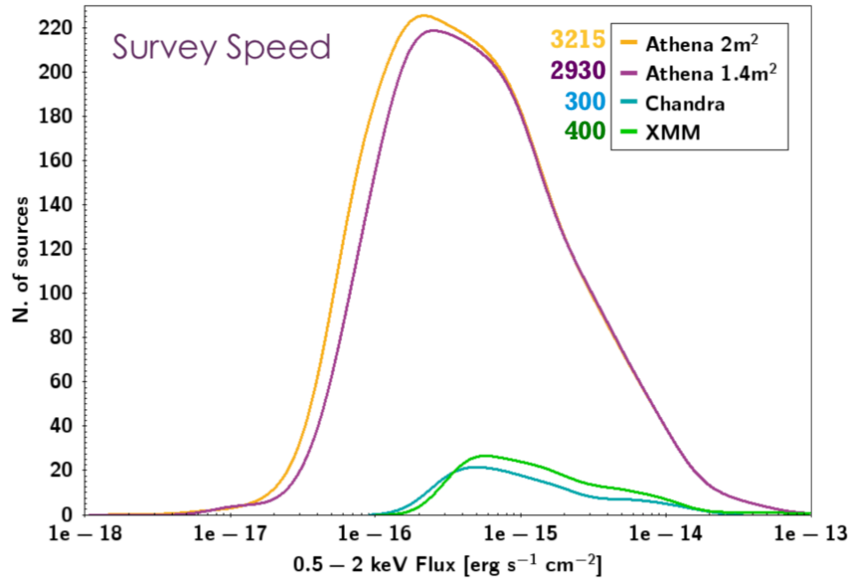
Barret et al., 2016, 2018 SPIE



Athena: a revolutionary observatory

Athena has vastly improved capabilities compared to current or planned facilities, and will provide **transformational** science on virtually all areas of astrophysics



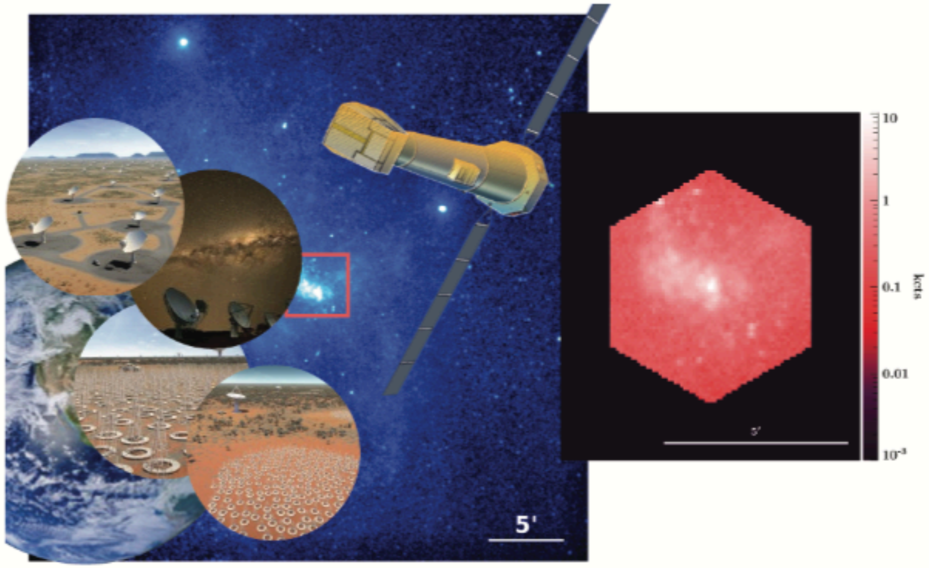


Deep survey capability into the dark ages and epoch of reionization

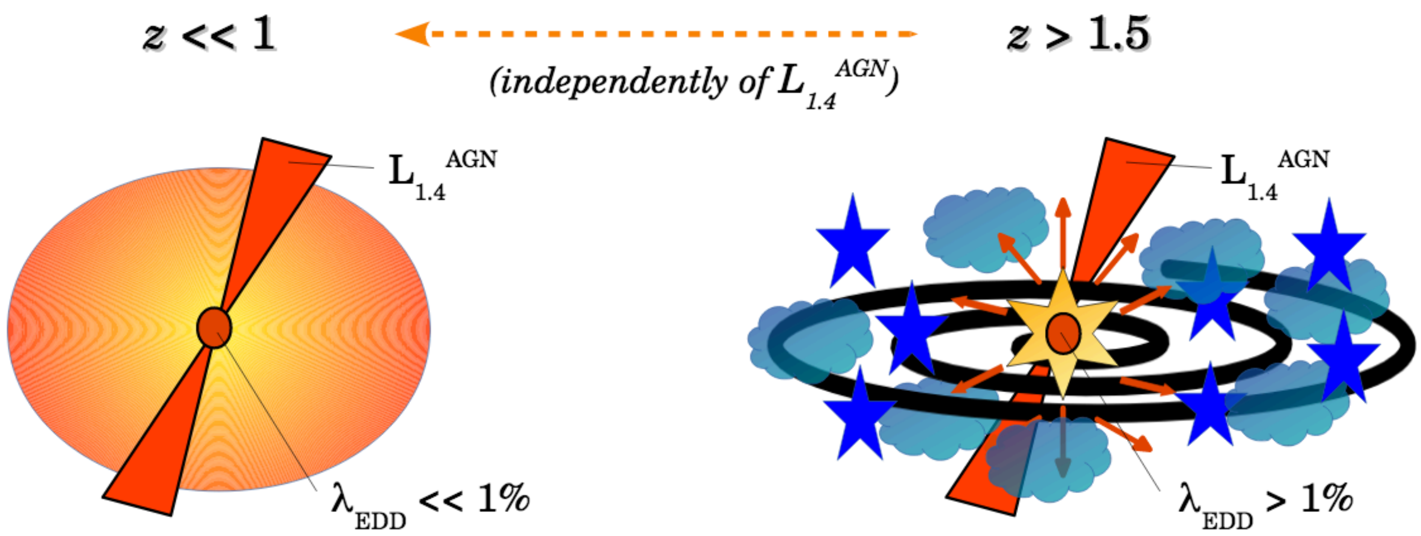
Chair: R. Cassano

SKA-Athena Synergy White Paper

SKA-Athena Synergy Team



THE SKA – ATHENA SYNERGY ON AGN



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

Delvecchio et al. (2018)

→ Evolution of accretion/ejection activity from low to high z

AGN PHYSICS and FEEDBACK MAIN PLAYERs:

Maiolino et al. 2017 - Image credit: ESO / M. Kornmesser

- Accretion disc
- Wind
- Jet
- Star-formation

→ Radio and X-rays emitters!

OPEN QUESTIONS

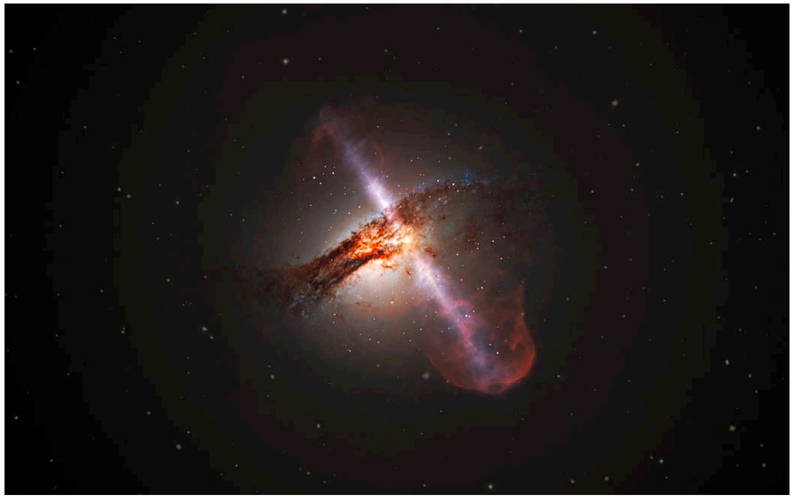
How are jets and winds formed?

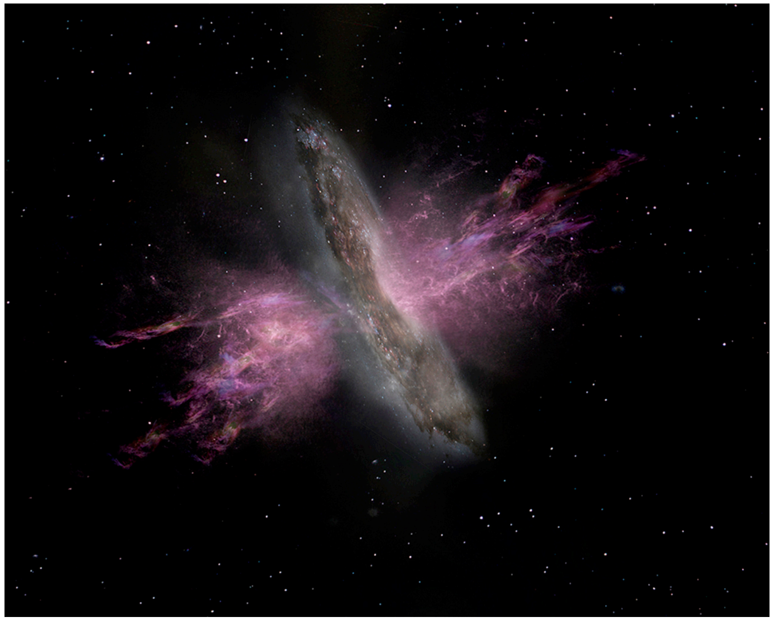
How are the jet and the wind connected to the accretion flow?

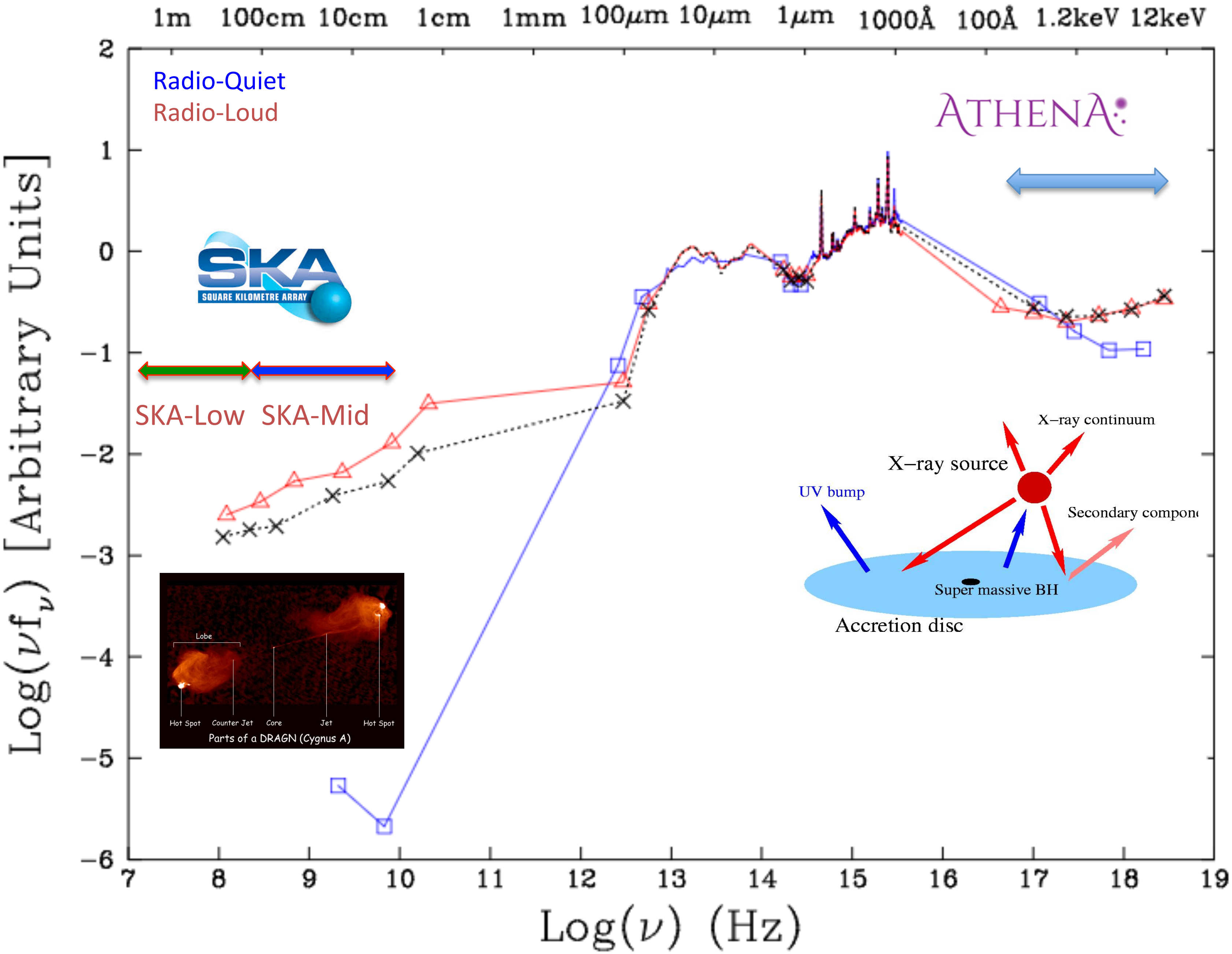
Do accreting objects share the same accretion/ejection physics?

Which is the activity duty cycle in AGN?

How is the jet and wind feedback acting in galaxies?



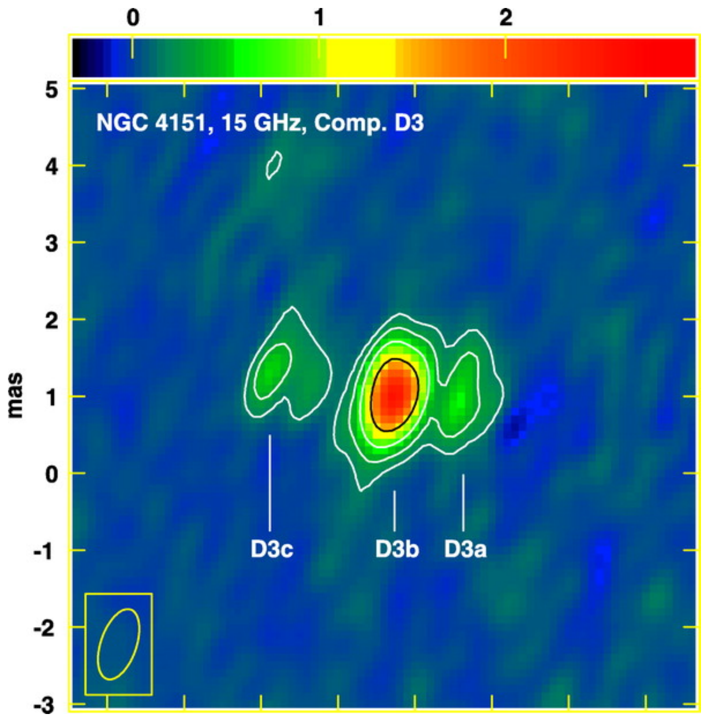


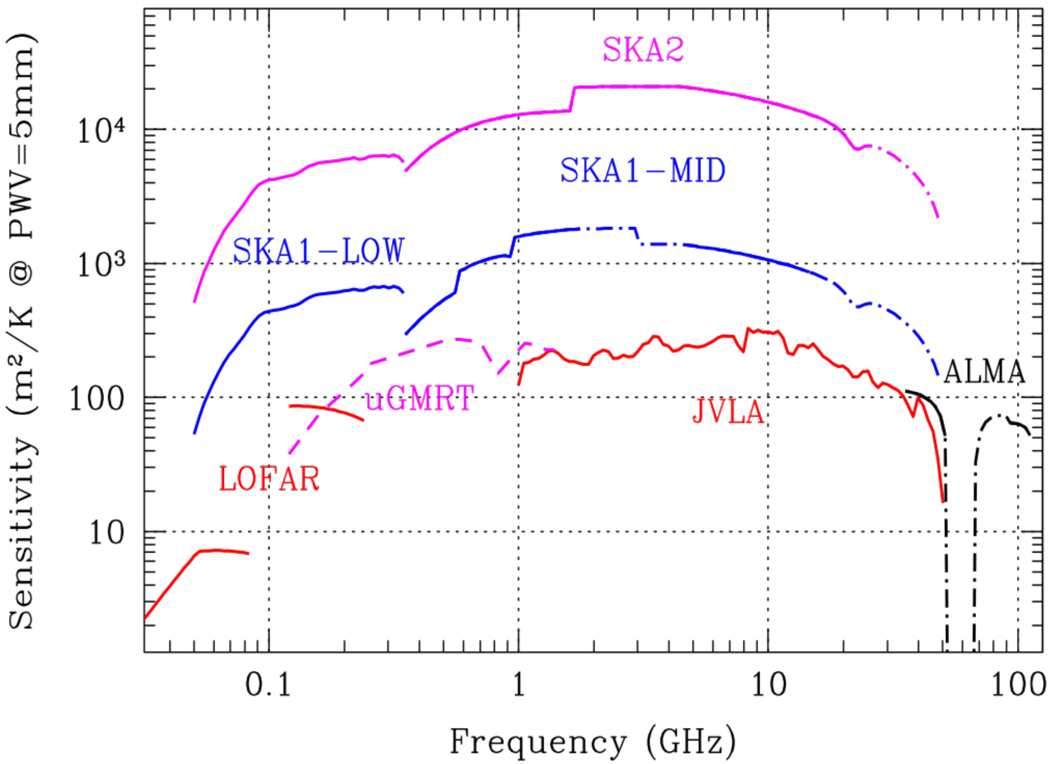


Shang et al. (2011)

ONE of THE DOMINANT SKA POPULATION:

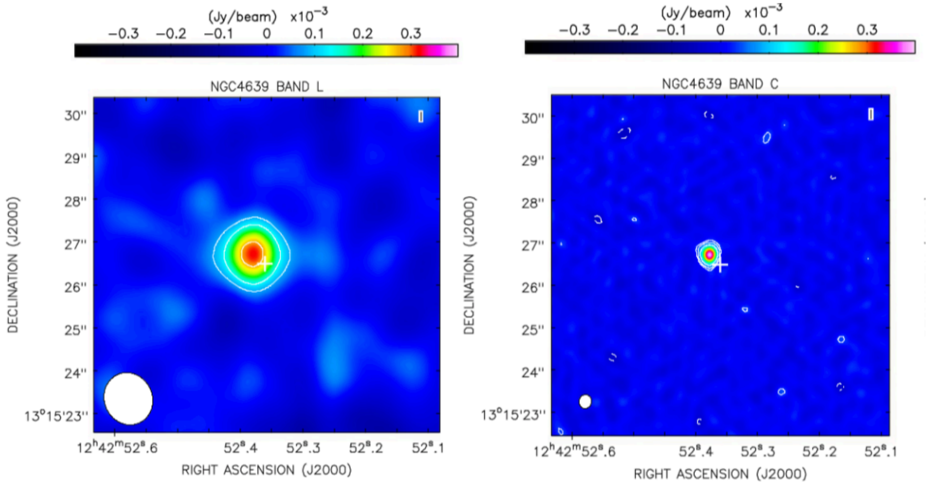
RADIO FAINT AGN



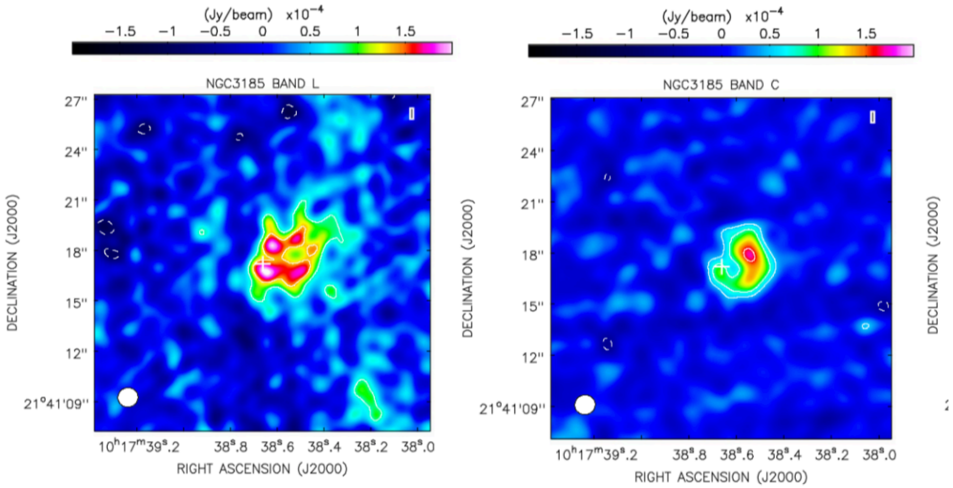


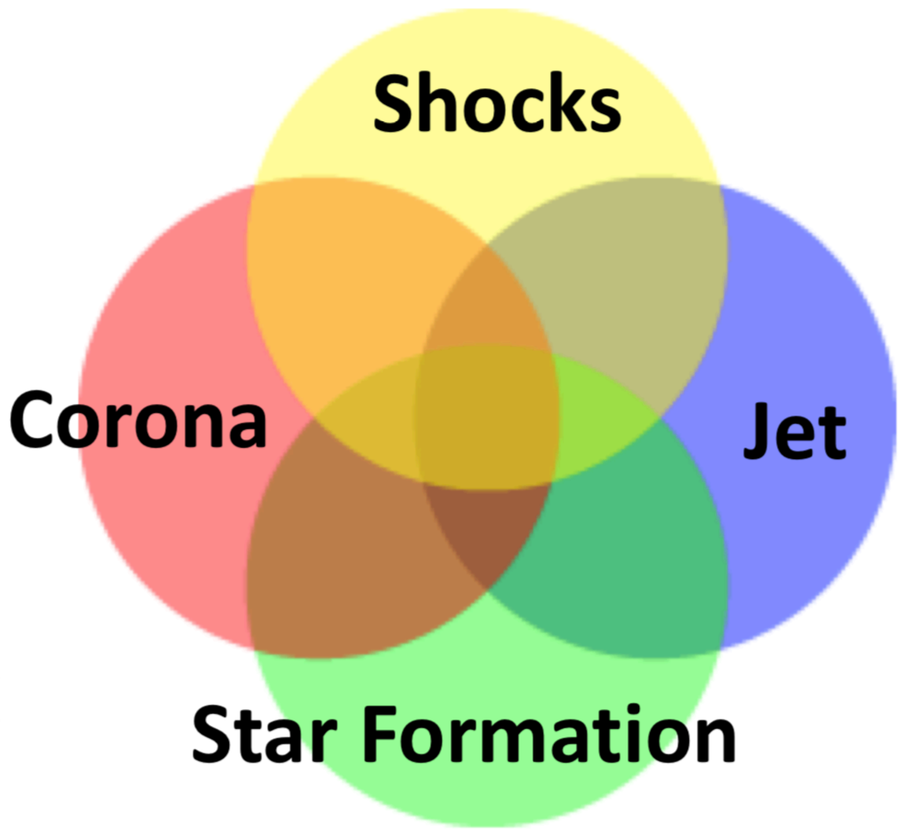
→ Full SKA will detect nanoJy sources

SKA POPULATION: RADIO FAINT AGN



Chiaraluce et al. in prep. (PhD@IAPS)

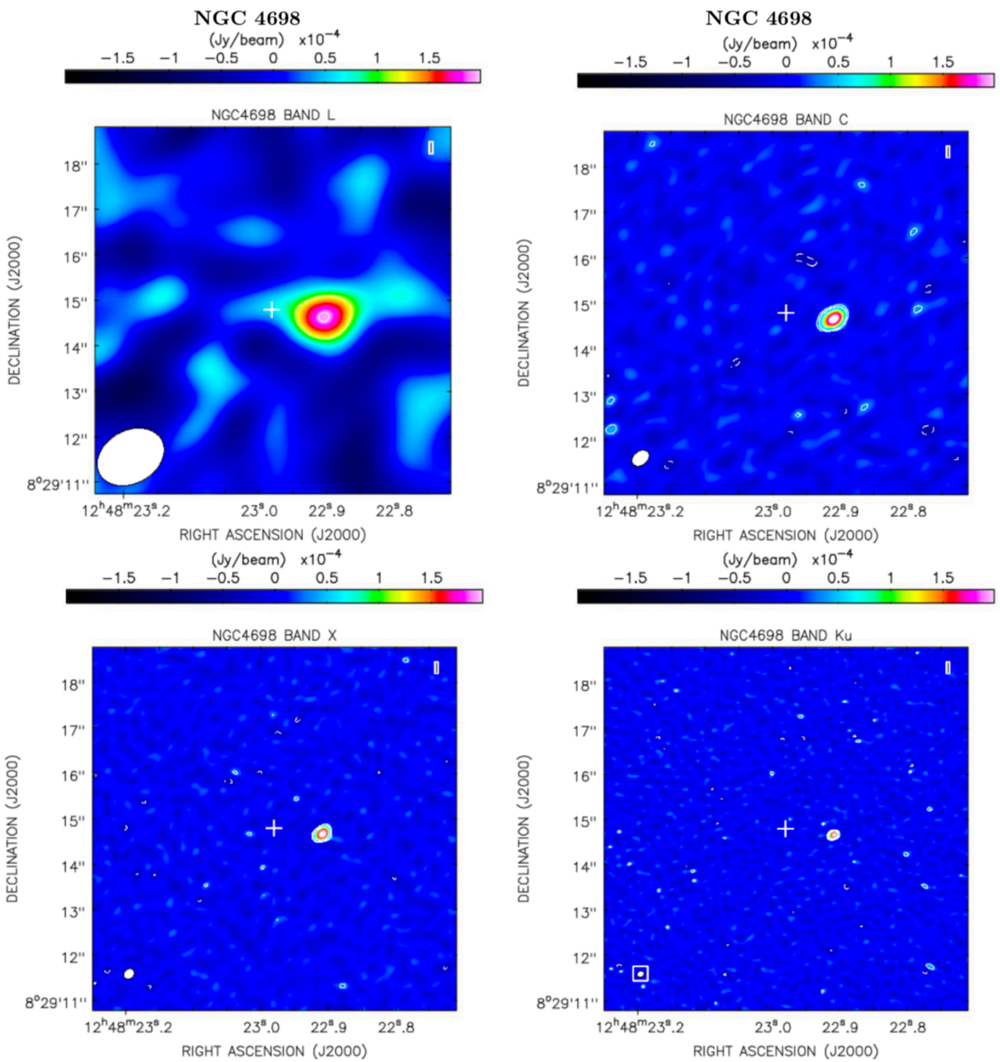




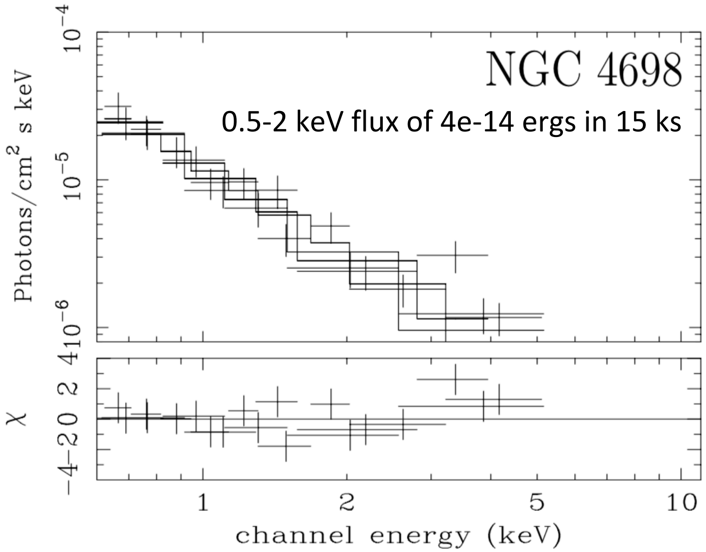
Amy Kimball's courtesy

Giroletti & Panessa 2009, Bontempi et al. 2012, Panessa & Giroletti 2013, Baldi et al. 2018, Panessa et al. submitted

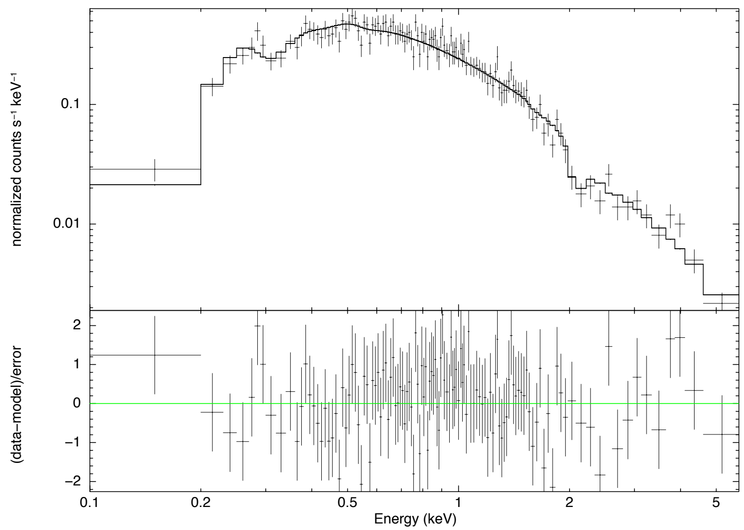
The SKA-Athena synergy on LLAGN



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

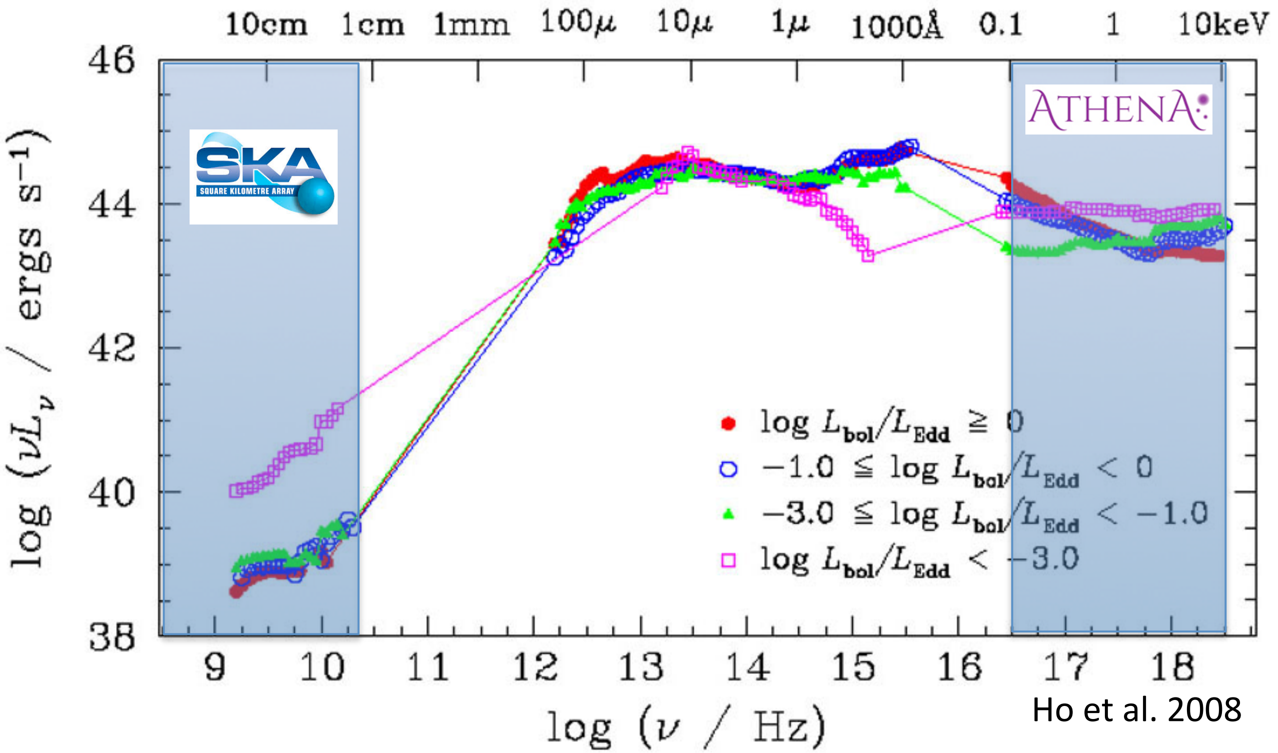


Athena simulation T_{exp} = 8 ks



courtesy of Hernandez-Garcia

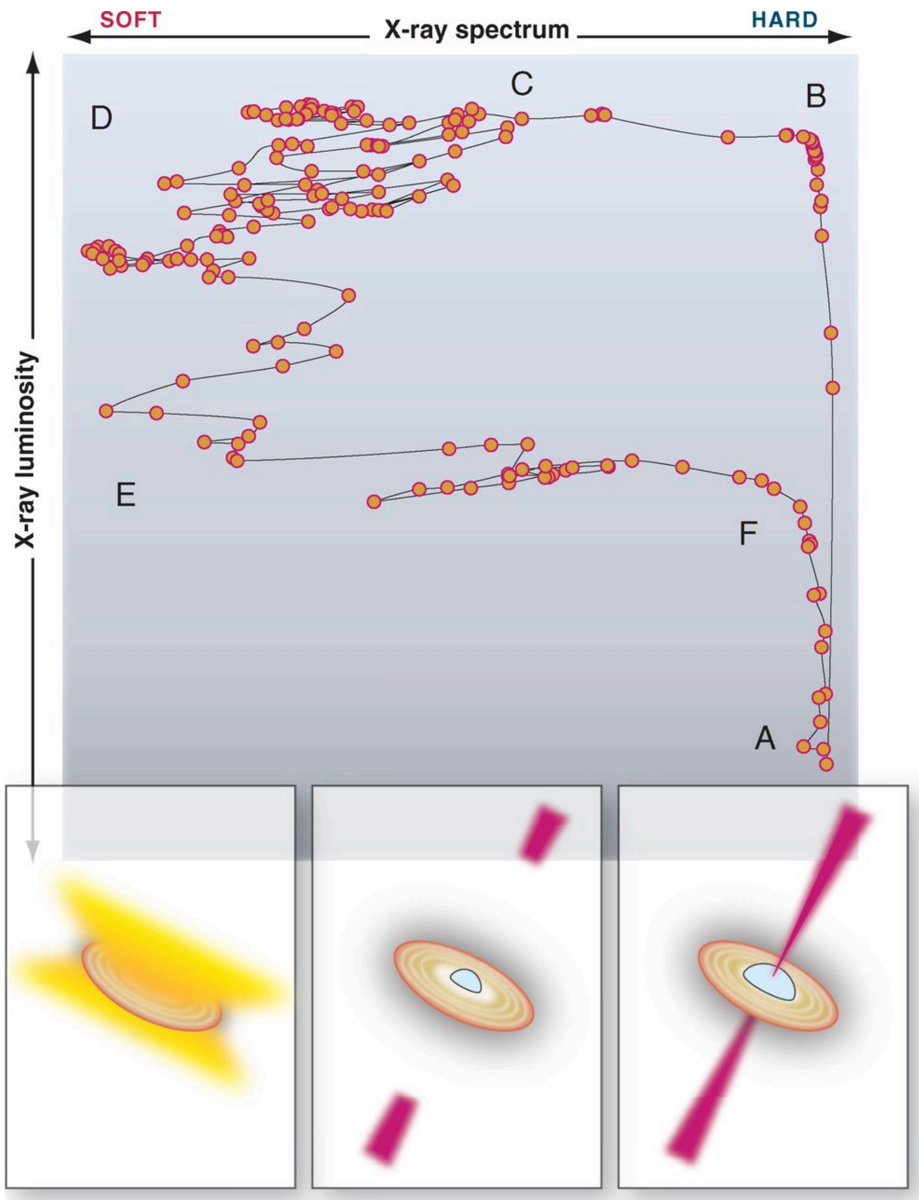
THE SKA – ATHENA SYNERGY ON AGN



Ho et al. 2008

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

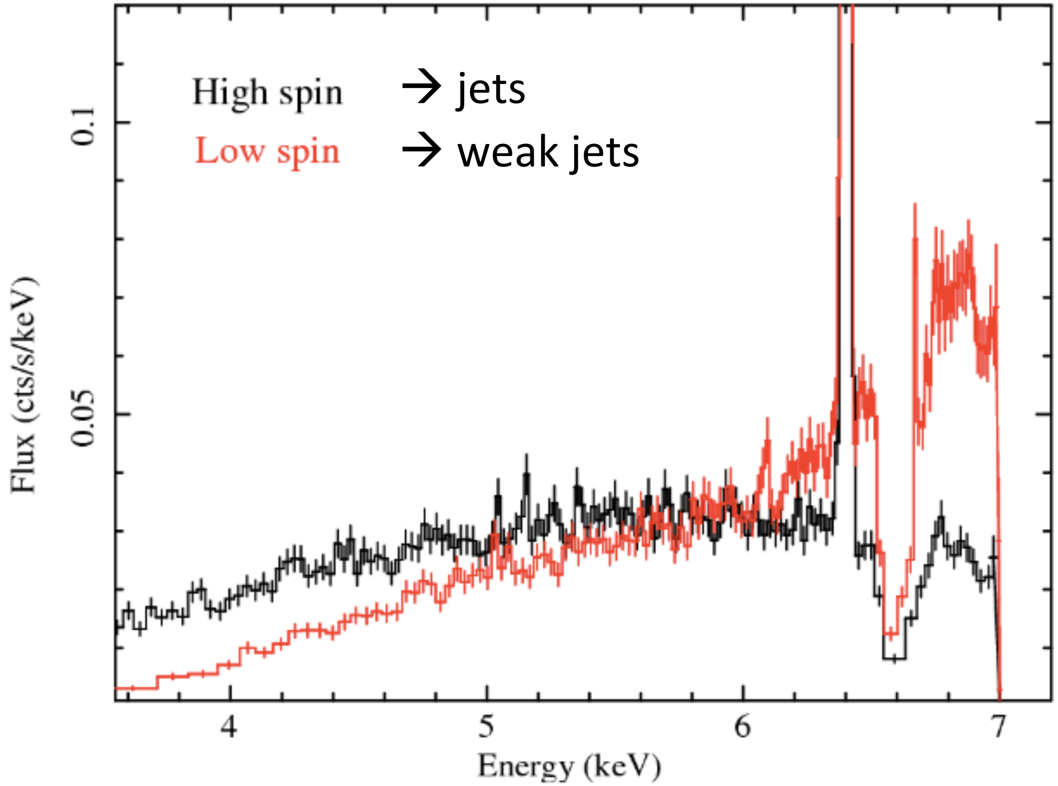
AGN and XRBs accretion/ejection physics



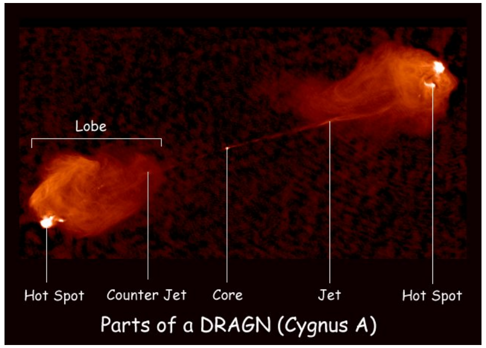
Fender & Belloni 2012

JET DEPENDENCE on SPIN

Jet energy can come from the rotational energy of a black hole
Blandford & Znajek (1977)



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)

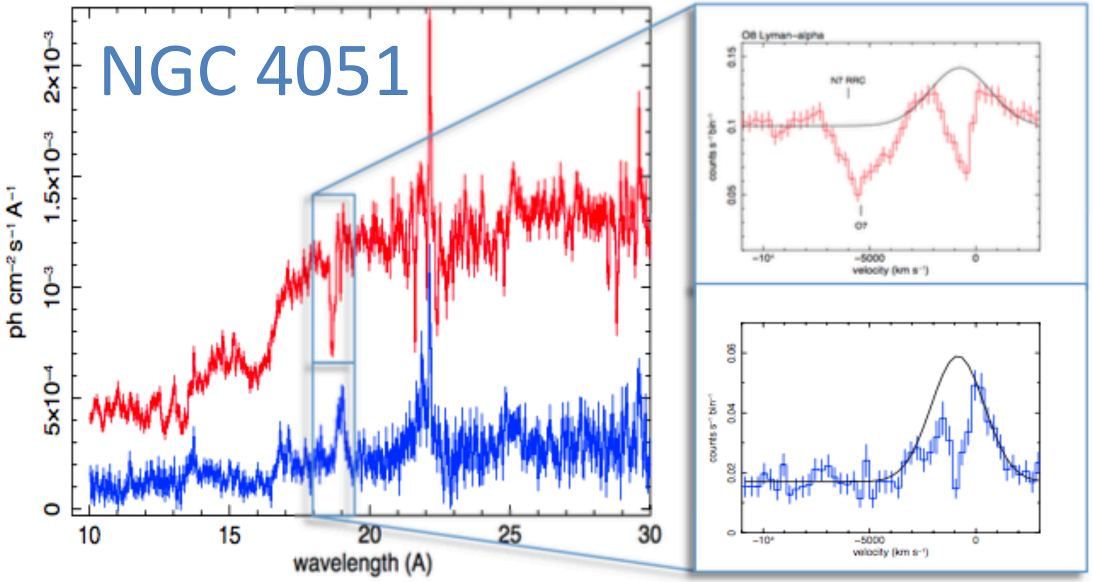
- ✓ the spin paradigm for jet power is still awaiting broad observational support

ATHENA

SKA SQUARE KILOMETRE ARRAY

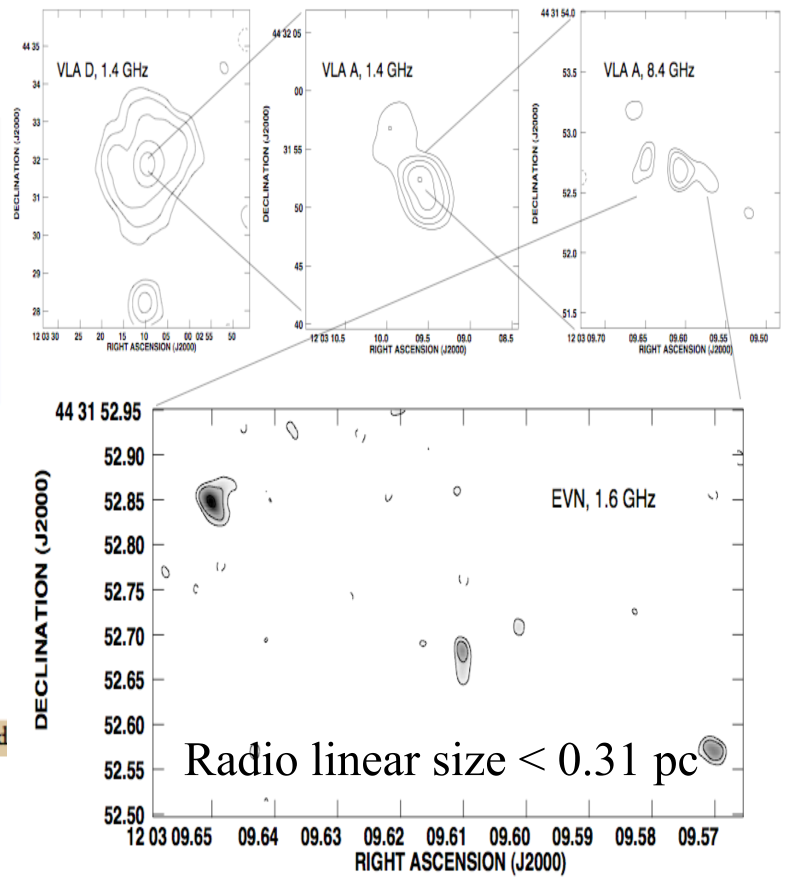
→ statistically relevant correlation to probe the spin paradigm

WINDS in NON JETTED AGN



(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)

Giroletti & Panessa 2009



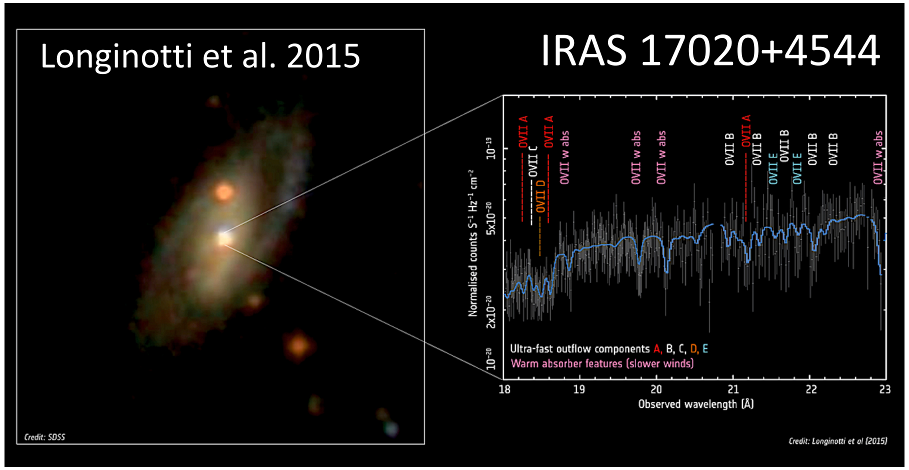
ATHENA → outflows with a wide range of velocities and ionization parameter

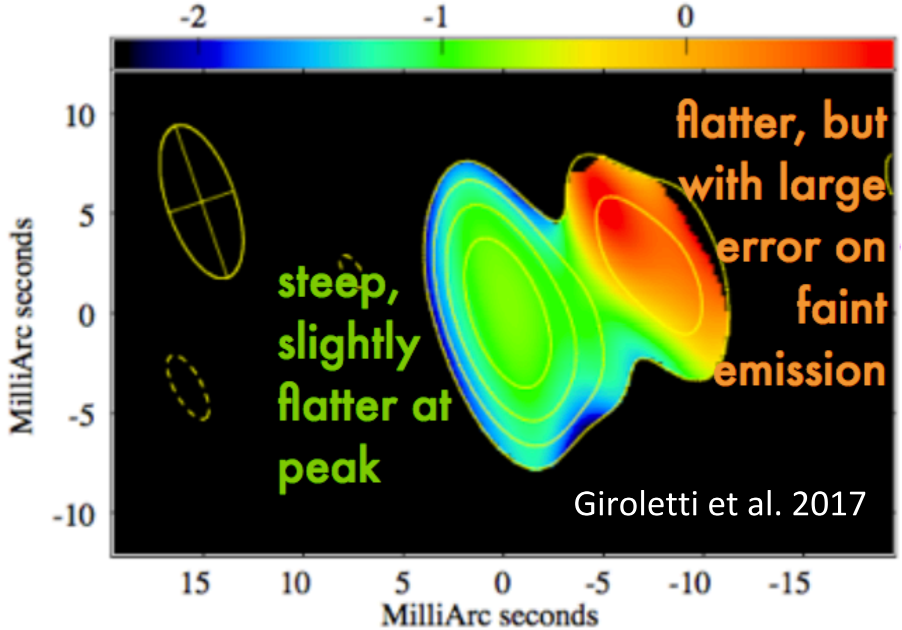
SKA SQUARE KILOMETRE ARRAY → derive physical parameters to contrain outflow models

SKA - Very Long Baseline Inteferometry!!!

JET AND OUTFLOW COEXISTENCE

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



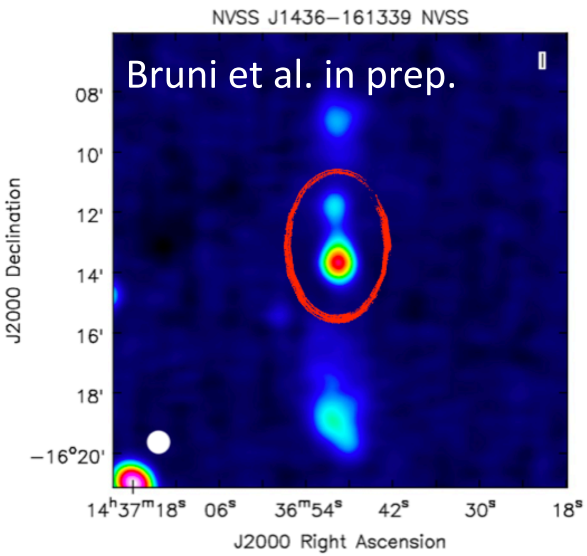


ATHENA → detect a large number of outflows in jetted AGN, determining their physical parameters

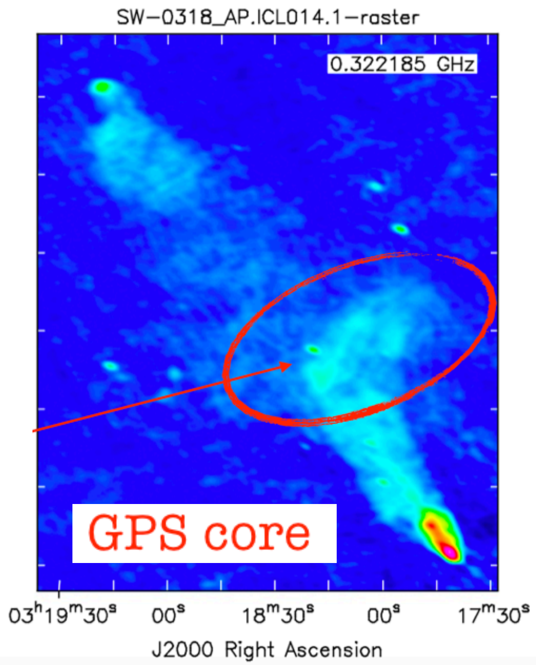
SKA → determine the occurrence of radio jets and their properties over a wide range of powers, morphologies and spatial scales

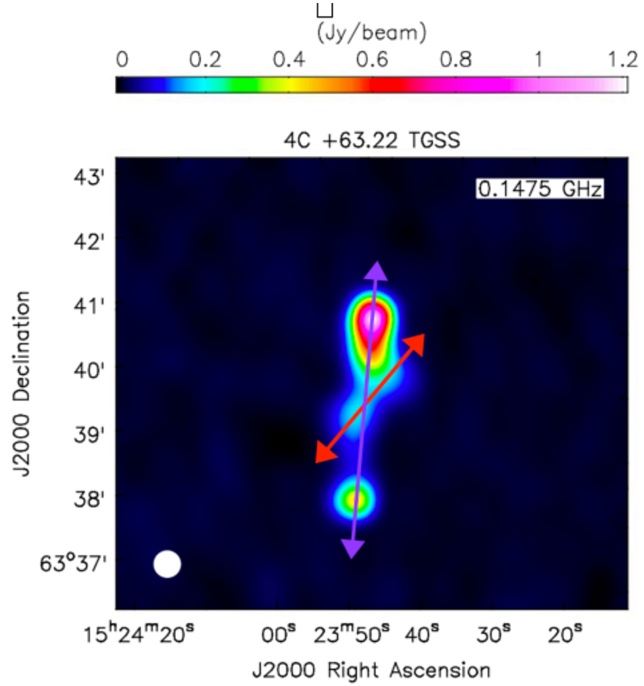
estimate the outflow and jet kinetic power → feedback

AGN RESTARTING ACTIVITY



Double-double radio-sources





X-shaped radio-sources

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

→ estimate the present epoch activity of the source

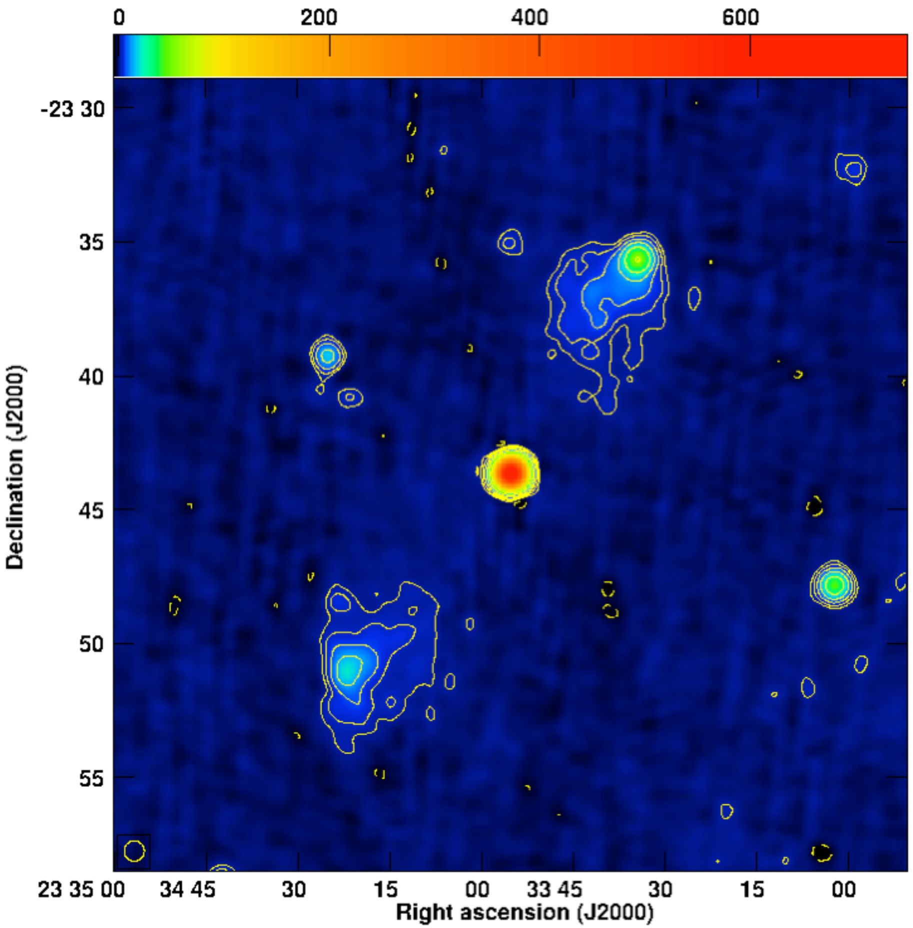
estimate the duty cycle of activity in galaxies

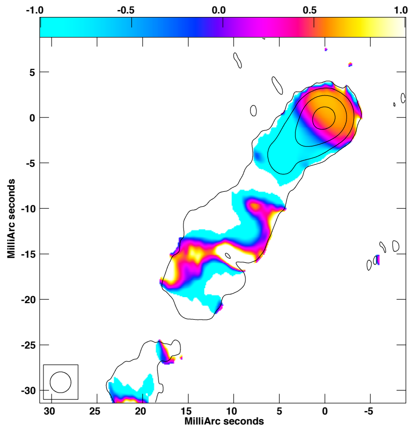
Molina et al. 2014, 2015, Bassani et al. 2016, Hernandez-Garcia et al. 2017, Ursini et al. 2018, Bruni et al. submitted

Thank you!

THE REACTIVATING NUCLEUS OF PBC J2333.9-2343

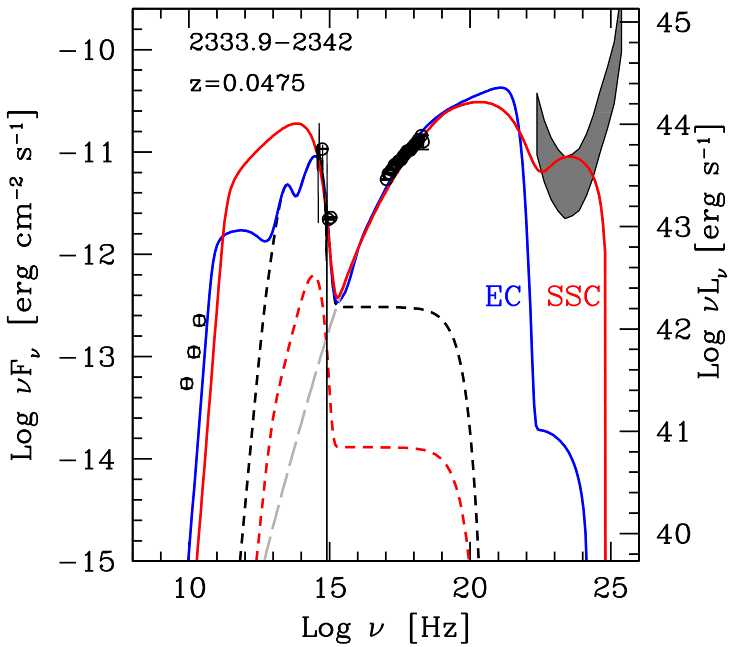
from giant radio galaxy to blazar!





→ small angle!

↑

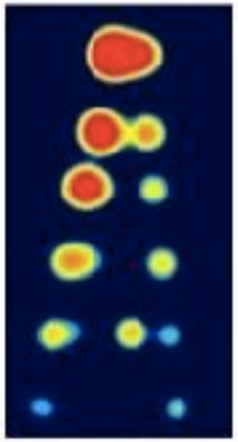


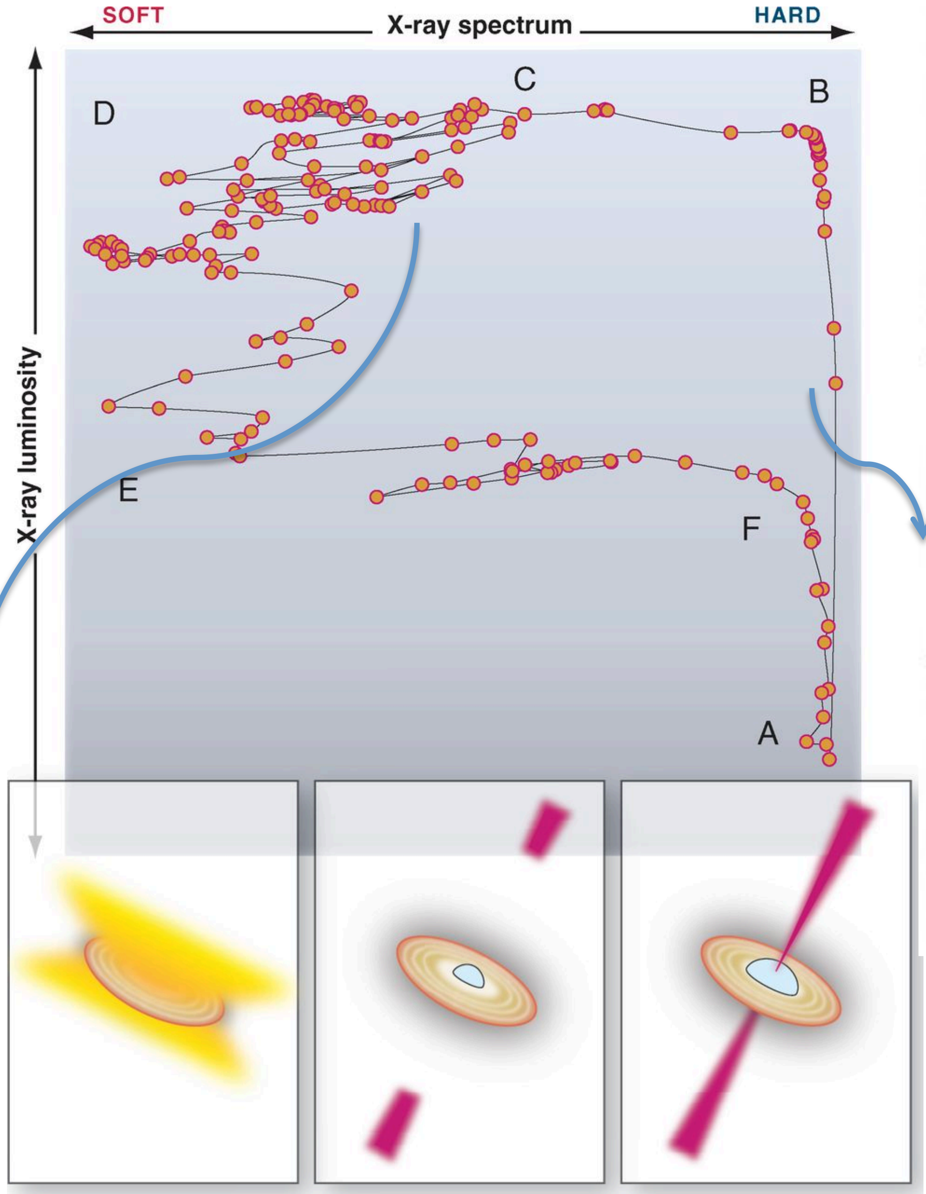
Hernandez-Garcia et al. 2017

X-RAY BINARIES in OUTBURST (weeks time scales)

Thermal dom.
(high/soft)

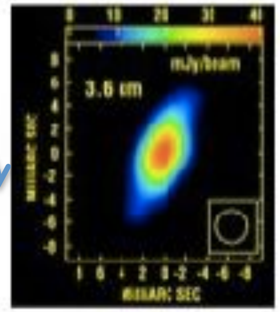
Large-scale (100s A.U.) transient optically thin relativistic jets





(Low/)hard

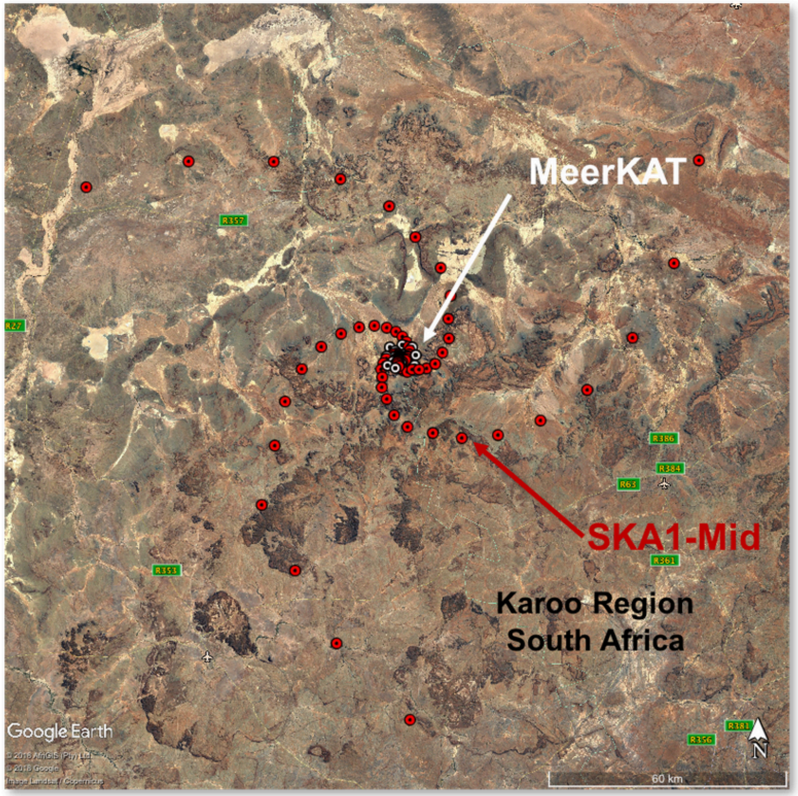
Persistent flat-spectrum compact (milliJy) radio source resolved into jet >0.01L_Edd jet~10 A.U.



Quiescence

Persistent flat-spectrum compact unresolved (microJy) radio source

Fender & Belloni 2012

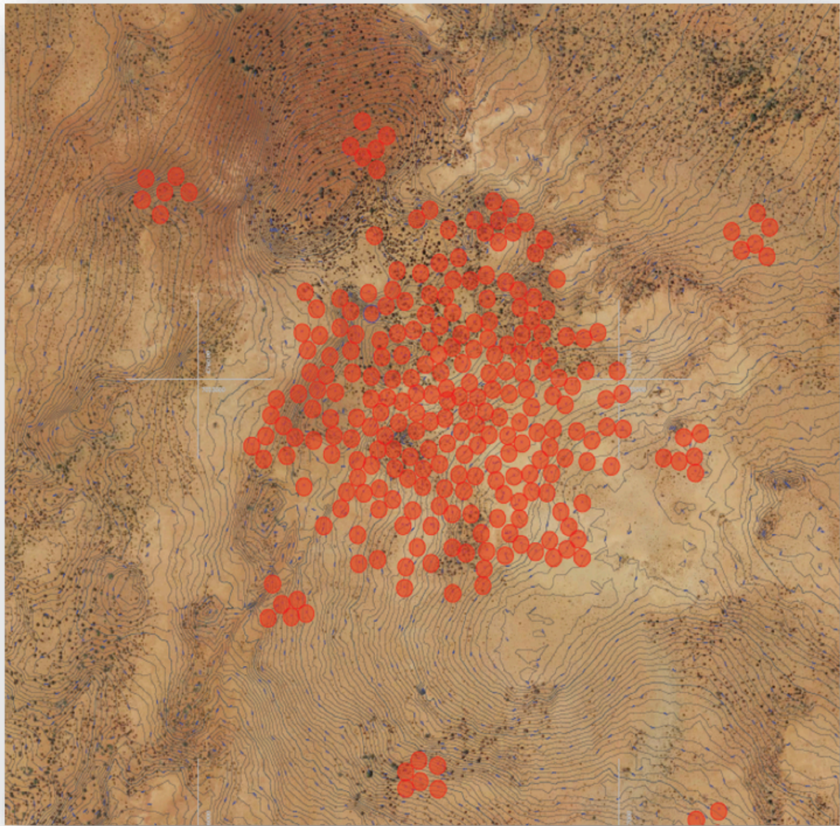


SKA1 Mid Layout

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.

SKA SQUARE KILOMETRE ARRAY

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

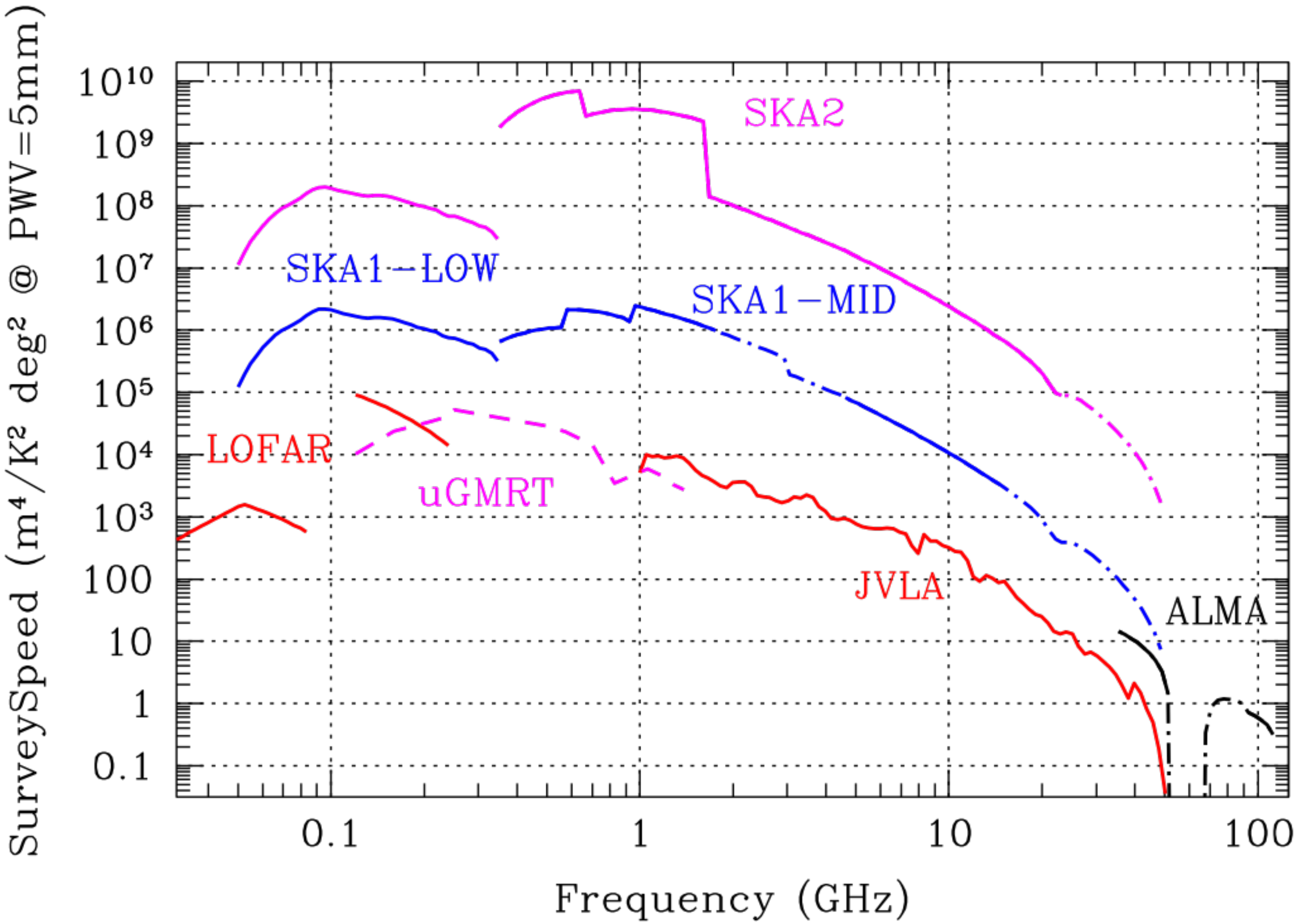
- ✓ Study of the jet launching and acceleration zone in nearby AGN
- ✓ Systematic measurement of the brightness temperatures, slopes and morphologies in complete samples of radio sources
- ✓ Investigate flaring coronal and jet activity and its correlation with X-ray activity

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
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
100
10
1
0.1
1
10
100

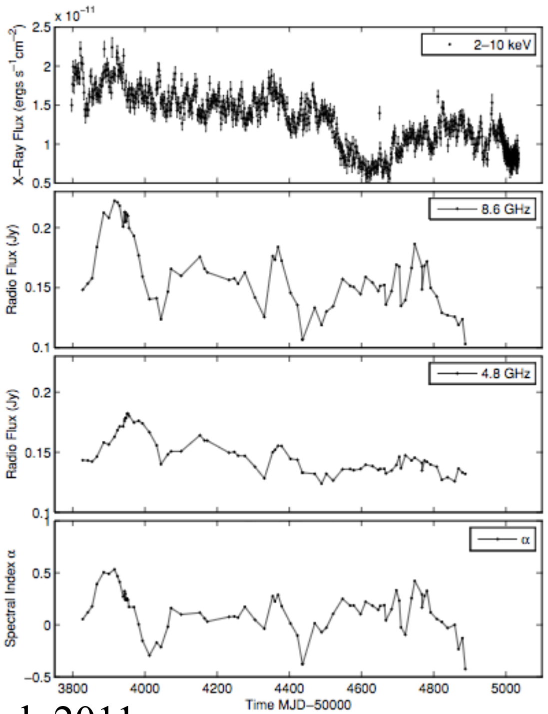
ANTICIPATED SKA1 HPC RE QUIREMENTS – May 2018

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_{Ipatch}
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

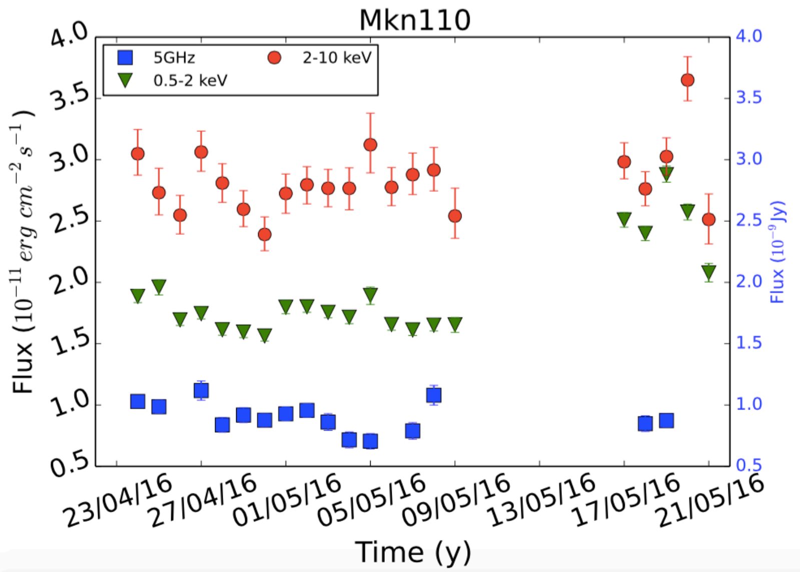
ν_{min} (GHz)	ν_c (GHz)	ν_{max} (GHz)	Sub-band	Band	σ_c (μJy/Bm)	θ'_{min} (")	θ_{min} (")	θ_{max} (")	θ'_{max} (")
0.050	**0.060**	**0.069**	Low sb1		163	16.4	23.5	1175	3290
0.069	**0.082**	**0.096**	Low sb2		47	11.9	17.0	850	2379
0.096	**0.114**	**0.132**	Low sb3		26	8.6	12.3	614	1719
0.132	**0.158**	**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:

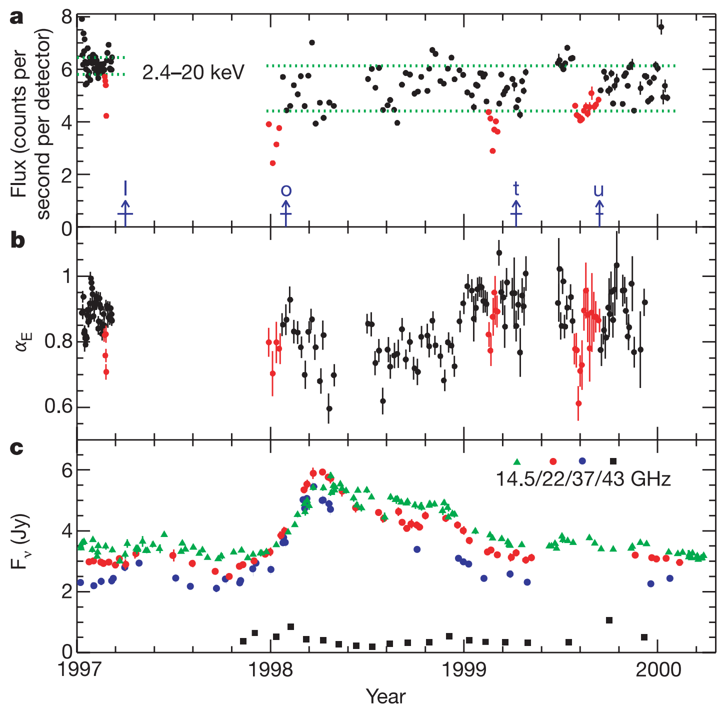
- ✓ disk instabilities propagate into the jet base
- ✓ coronal mass ejections
- ✓ comparison to XRBs

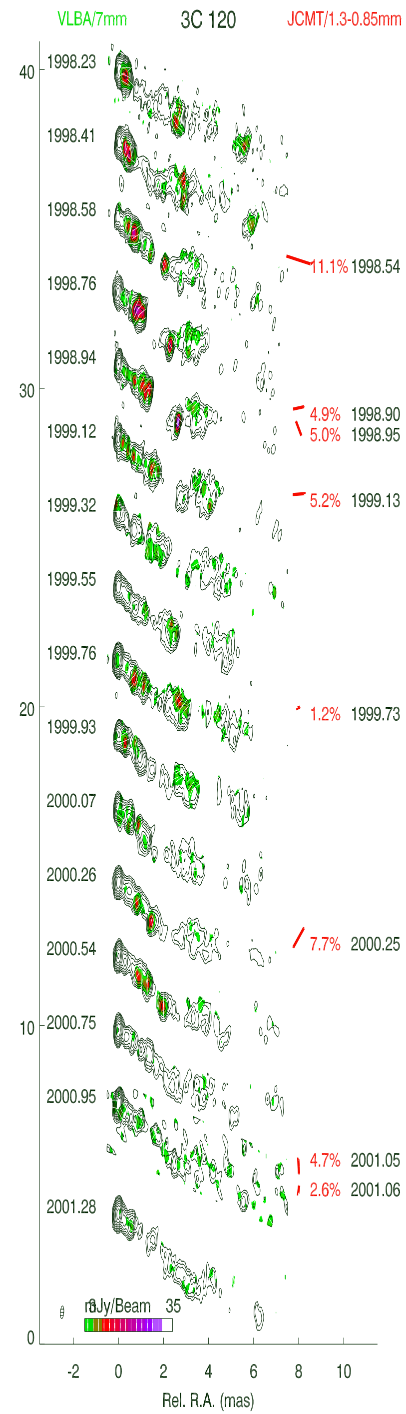
JET-DISK COUPLING in JETTED AGN

MONITORING VARIABILITY

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

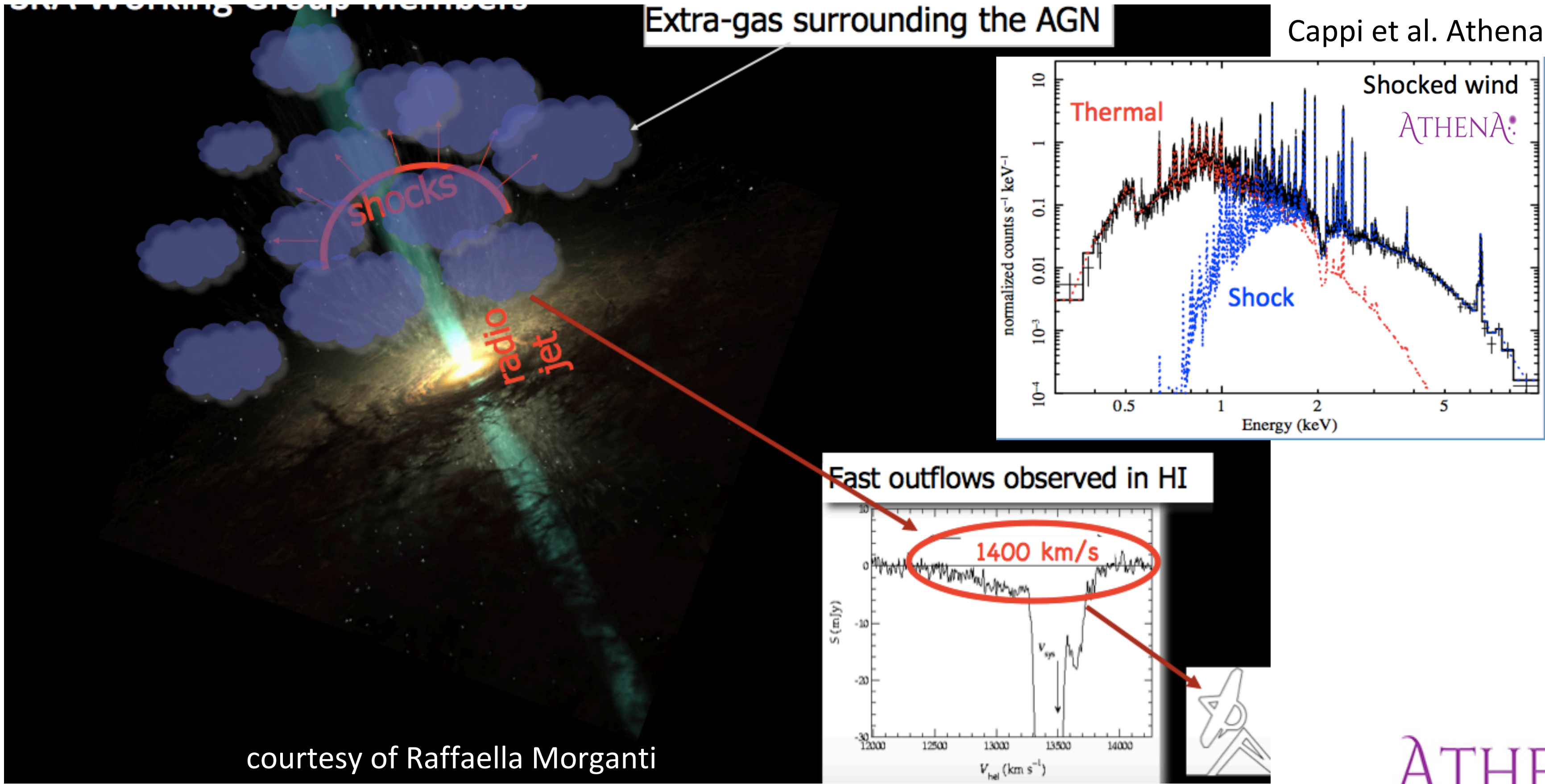
Marsher et al. 2002





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

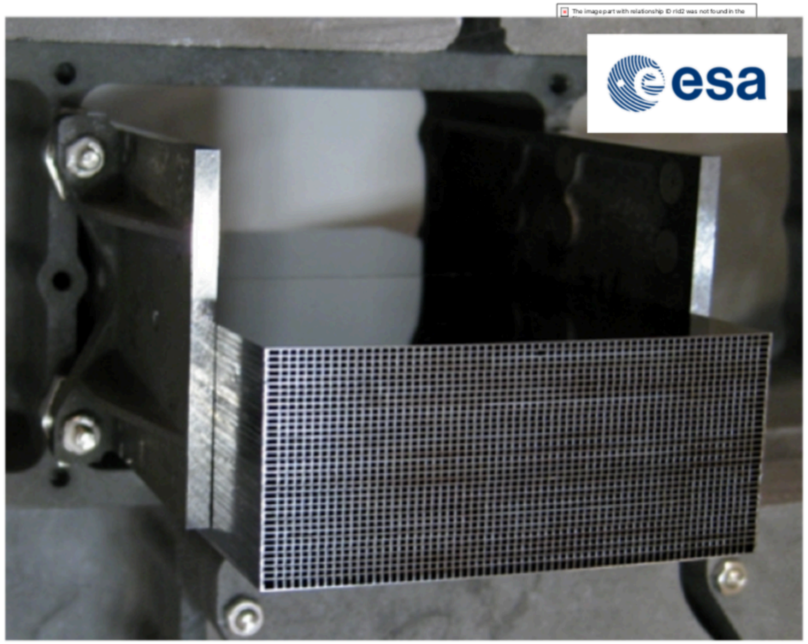
The combined spatial and spectral response of the X-IFU on Athena+ will allow to map the velocity field of the hot gas with uncertainties of ~20-30 km/s on scales down to few kpc in 40-50 nearby AGN/ULIRG/starburst galaxies

Project Status and Upcoming Milestones

- July 2015: Industrial Phase A study kickoff
- June 2016: Mission Consolidation Review (design choice)
- July 2016: Release of Instrument AO
- Dec 2017: End of Phase A
- Phase B1 2018-2019
- Mission Adoption ~2020 (Launch 2028)

Athena Mirror Progress

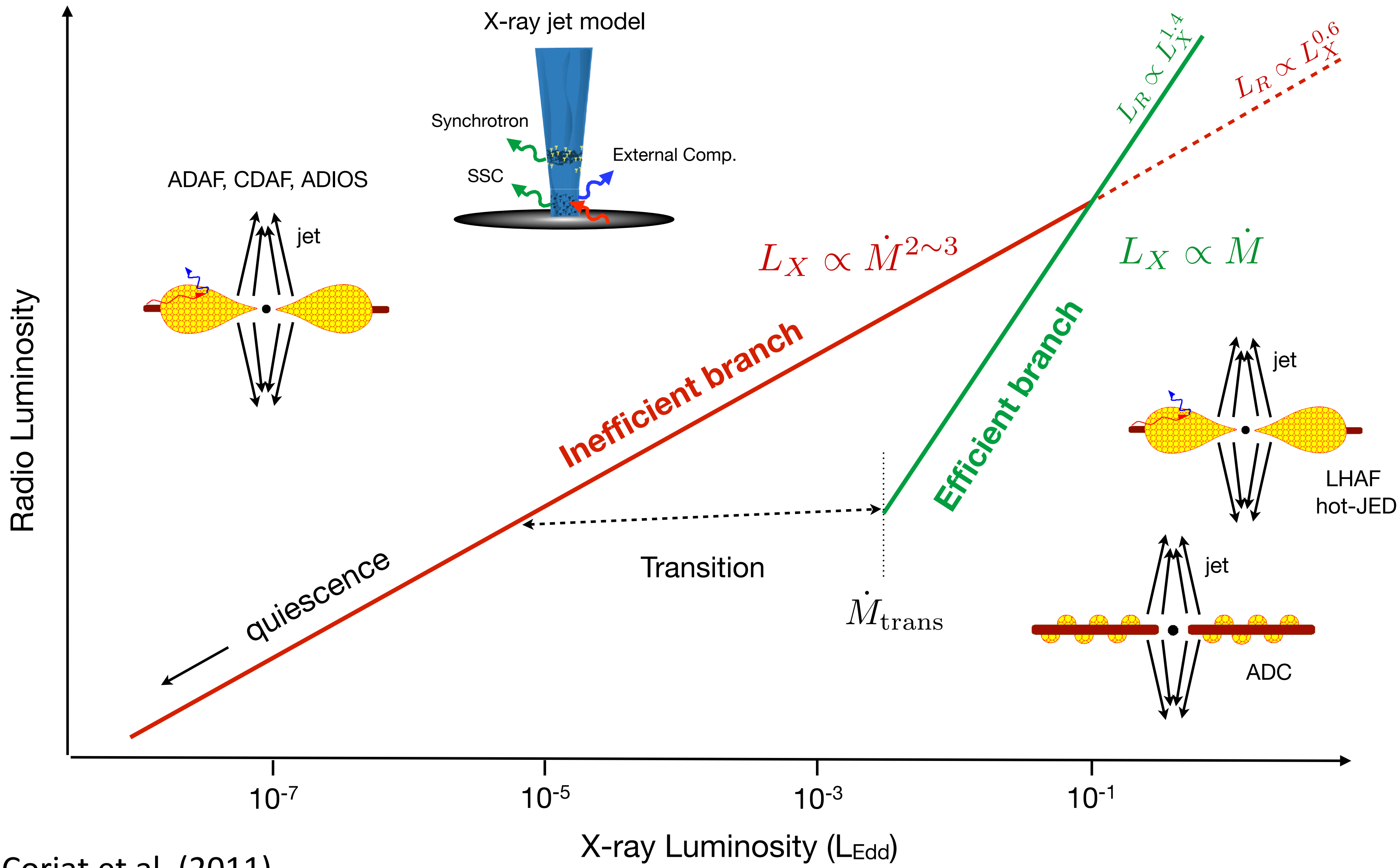
- **Optics requirements:**
  - 5" HEW on-axis, <10" @ 15' off-axis
  - >1.4 m^2 effective area @ 1 keV
- **Silicon Pore optics status:**
  - Best HEW performance (20m):
    - 12.8" HEW for 100% of area
    - 8.0" HEW for 70% area
    - 5.0" HEW for 10% of area
  - Change to 12m focal length: progressing rapidly, performance at MFR (and MAR) critical
  - ***Latest*** 12m results ~9" over 70% area, **5.4" HEW over 15%**
  - Other key issues: Rib pitch, Coatings, Stray Light baffling



Willingale et al 2013, arXiV: 1308.6785
Badaz et al. 2017, Proc. SPIE

Key issues becoming better understood?

ACCRETION/EJECTION COUPLING

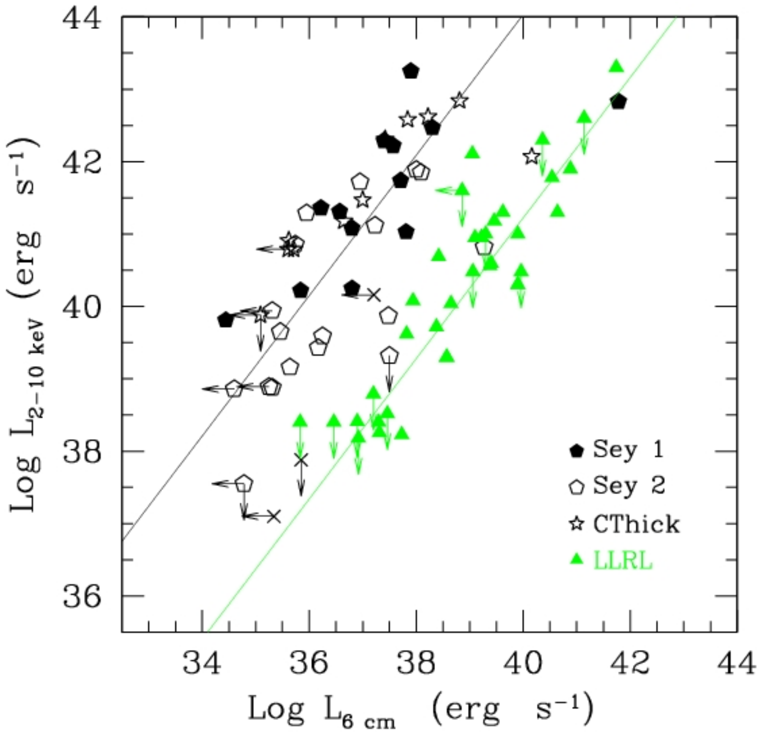


Coriat et al. (2011)

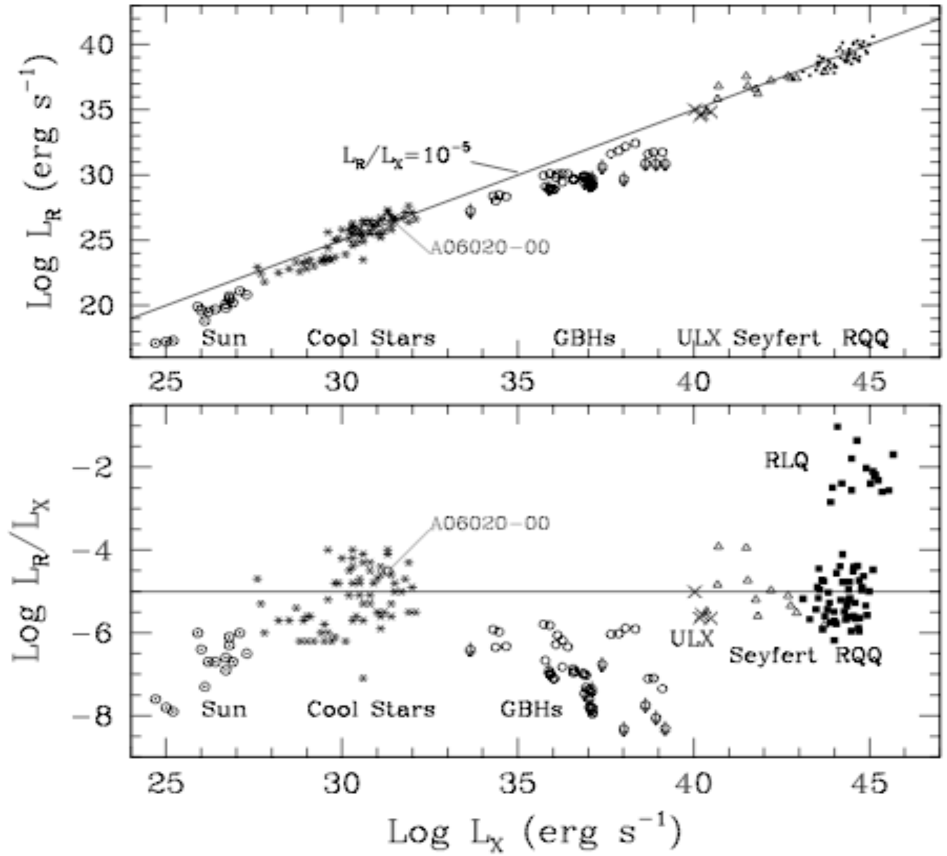
Hannikainen et al. (1998), Corbel et al. (2003), Gallo, Fender & Pooley (2003)

ACCRETION/EJECTION COUPLING

Panessa et al. (2007)

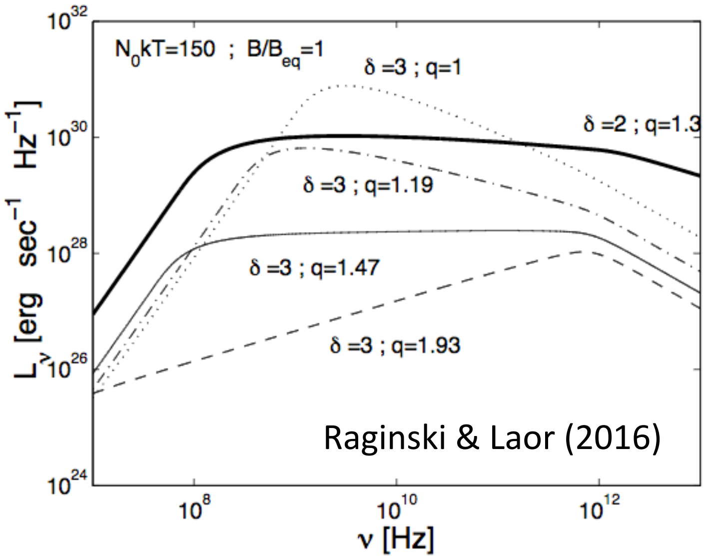


Laor & Behar 2008



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



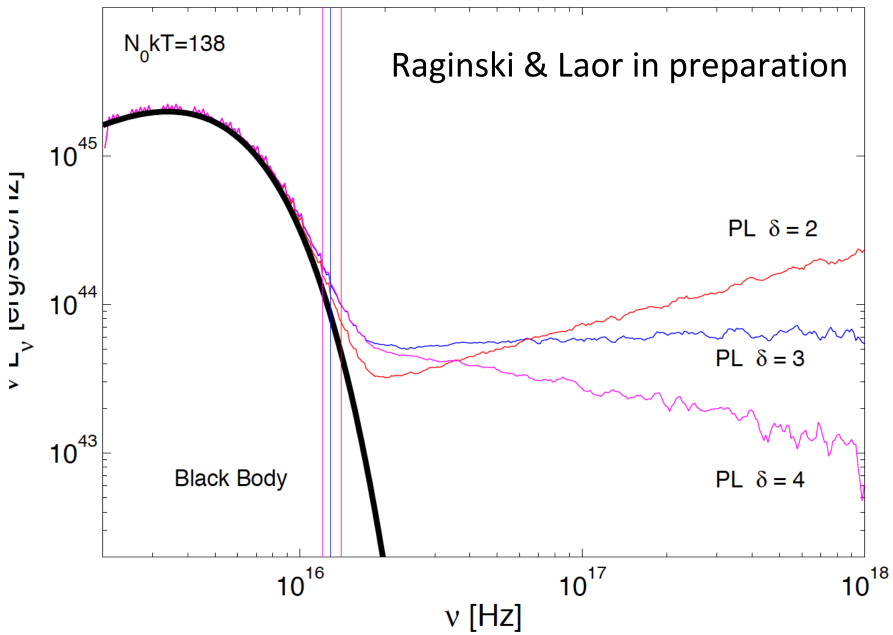


Figure 7: Emissions of three PL distributions. The vertical lines designate the turn-over frequency

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