How can LLAMA help us understand MICROQUASARS

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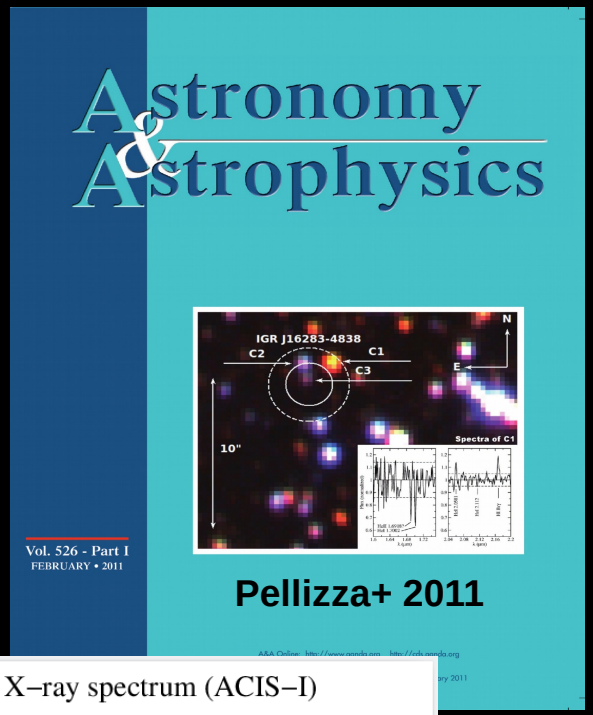
Image: CEA - France

Microquasars

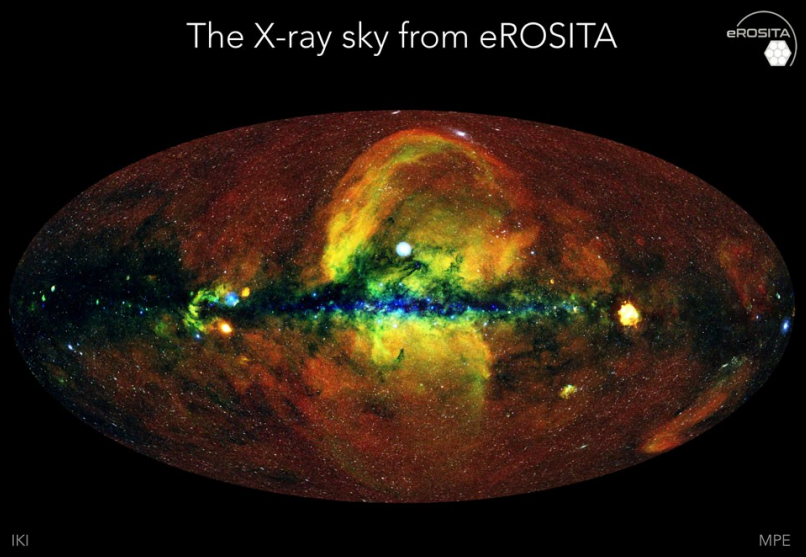
Observational point of view

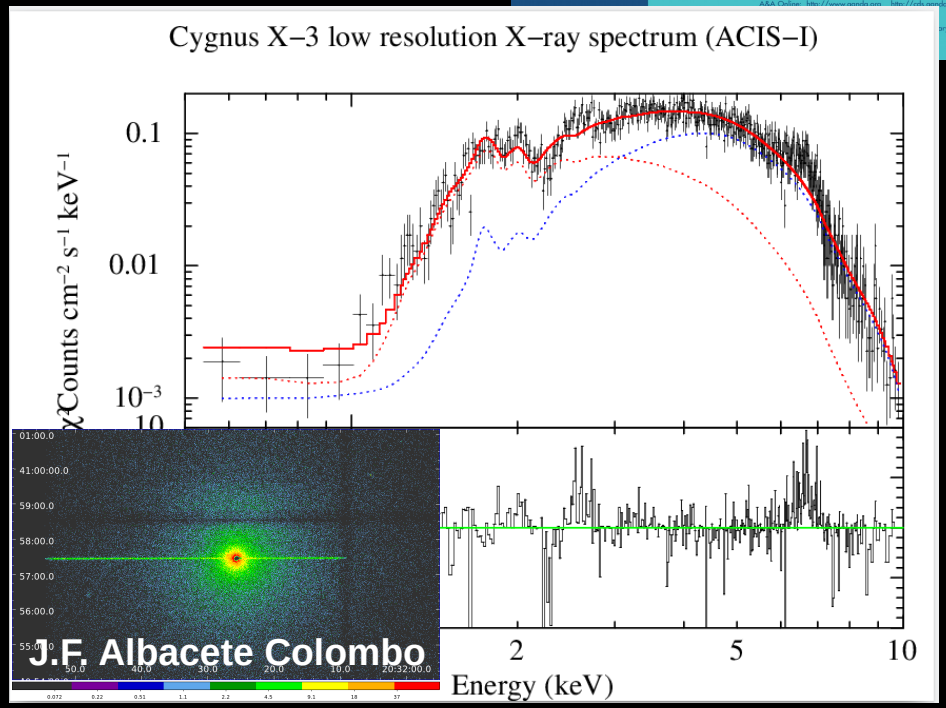
X-ray binaries (XRBs)

stellar X-ray sources
L ~ $10^{36\text{-}40}$ erg/s, ε ~ keV
optical/IR counterparts
orbital motion / periods measured



Pellizza+ 2011





Microquasars

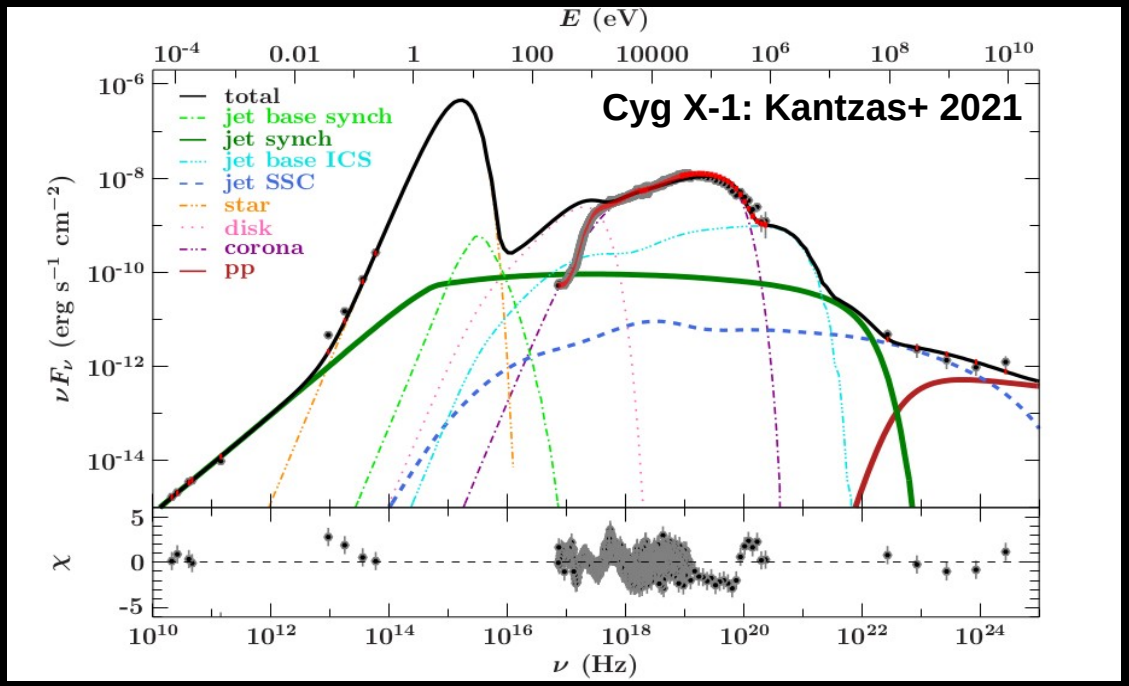
Microquasars

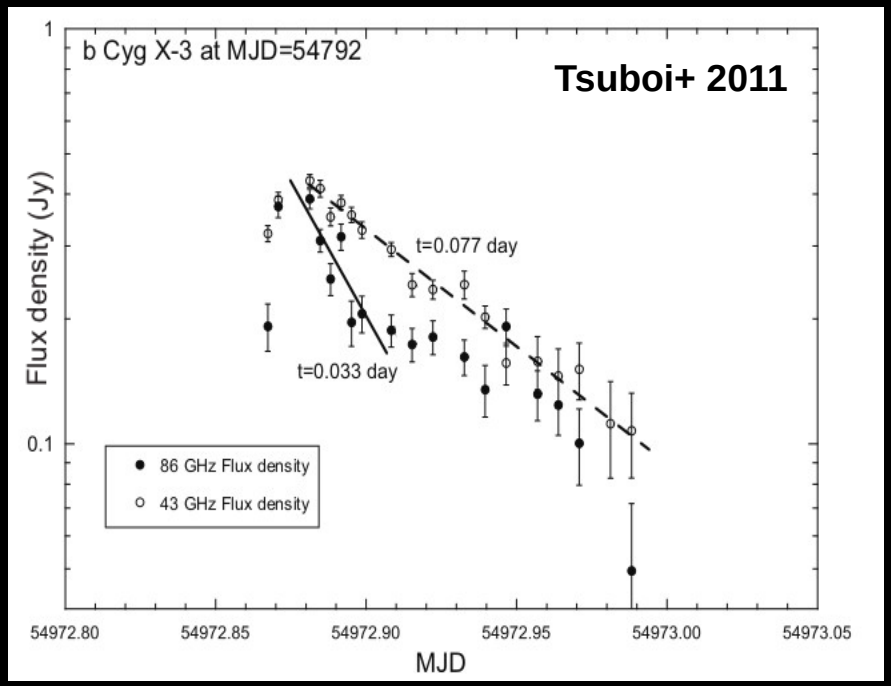
- XRBs displaying two-sided radio lobes
- collimated outflows (jets)
- non-thermal emission across the EM spectrum
- variability / flaring activity

Mirabel+ 1992

~25 Galactic + 5 Extragalactic MQs known

www.aim.univ-paris7/CHATY/Microquasars/microquasars.html





Microquasar model

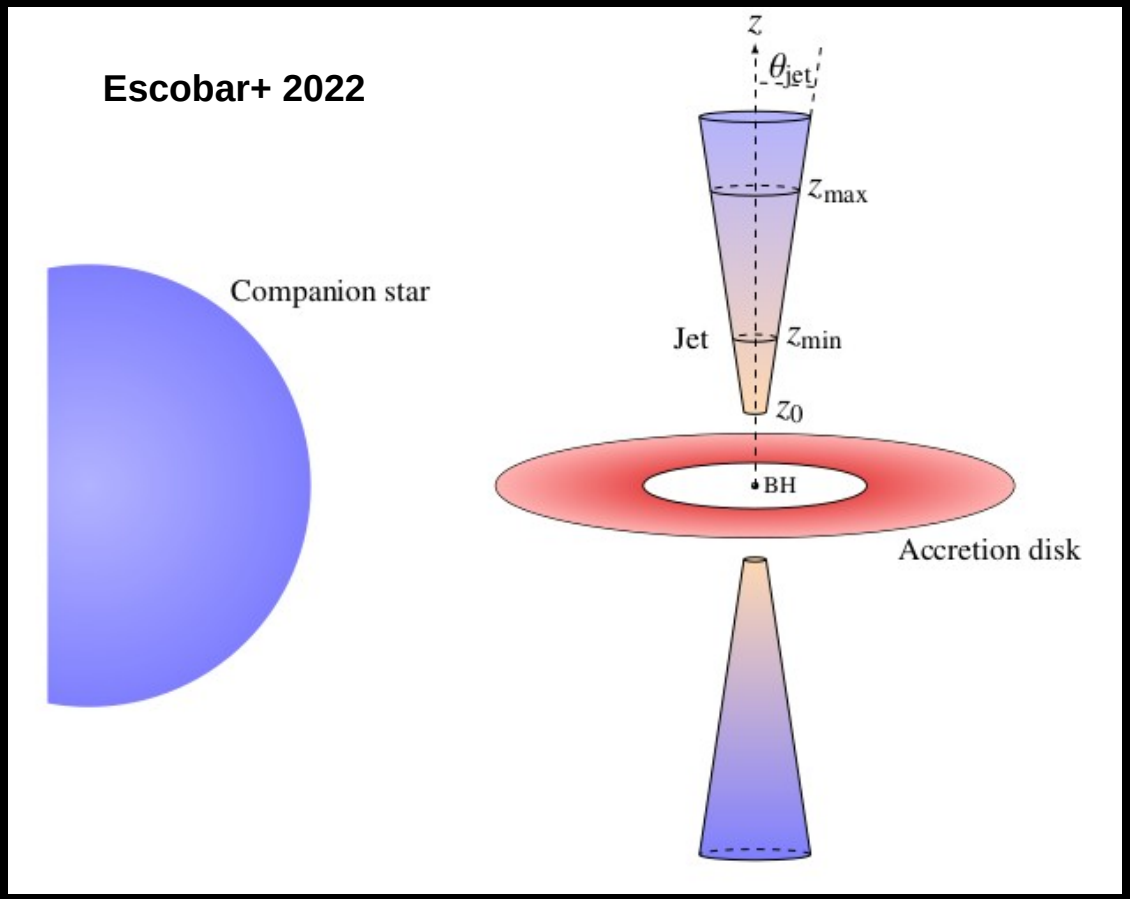
Accreting binary systems producing jets

compact object (BH / NS)
non-collapsed companion

accretion disk (T ~ MK)

corona

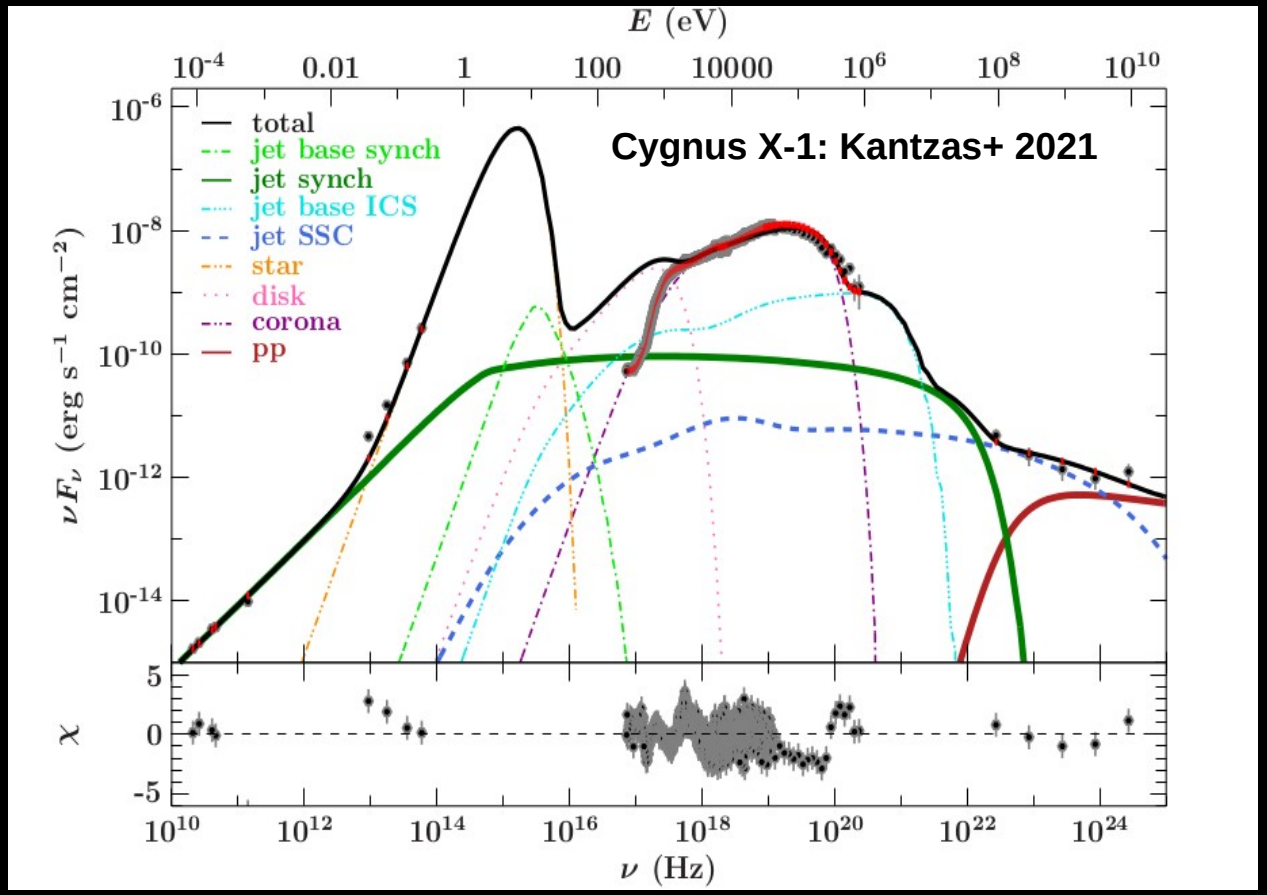
collimated relativistic jets



Microquasar models

Broadband SED modelling

compact object (BH / NS)
non-collapsed companion
    IR / optical / UV
accretion disk
    soft X-rays
corona
    hard X-rays (ICS)
jets
    NT: radio - gamma
    IC, synchrotron, pp, etc.
    relativistic particles



Microquasar models

Broadband SED modelling

Problems
- many free parameters
- poorly constrained
- degeneracies

Key to improve models
- Precise SED measurements
- Full spectral coverage

Table 1. Jet parameters for the fiducial model. **Escobar+ 2022**

Parameter	Symbol	Value	Units
Jet luminosity	L_{jet}	10^{38}	$erg\,s^{-1}$
Jet-base half-opening angle†	θ_{jet}	2	deg
Bulk Lorentz factor	Γ	1.25	
Relativistic power fraction	q_{rel}	0.1	
Proton-electron power ratio	a	39	
Jet launching distance	z_0	1.1×10^8	cm
Base of acceleration region	z_a	2.8×10^8	cm
Top of acceleration region	z_t	1.9×10^{12}	cm
End of emission region‡	z_{max}	1.9×10^{12}	cm
Acceleration efficiency	η	1.5×10^{-2}	
Magnetic power-law index	m	1.9	
Injection spectral index	p	2.4	
Geometric index	α	1	
Convection index	δ	-	

Microquasars: open problems

Physics of strong gravitational fields

Space-time curvature - BH mass / spin

Relativistic plasma physics

Jet launching mechanism (MHD vs. GR)
Jet composition (leptonic vs. lepto-hadronic)
Jet power and collimation
Particle acceleration mechanisms

Cosmic rays

MQs as sources of CRs (Heinz+2002, Escobar+ 2022)

Evolution of galaxies

Energy feedback into the ISM (Artale+ 2015)

Early Universe

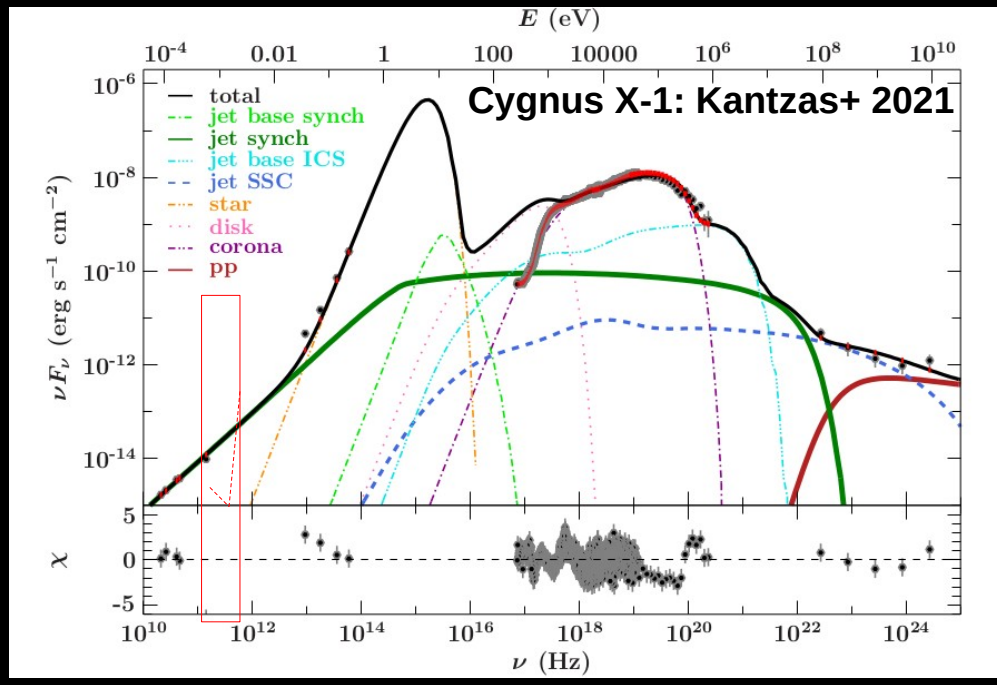
Ionization / heating of the IGM (Mirabel+ 2011, Tueros+ 2014, Douna+ 2018)

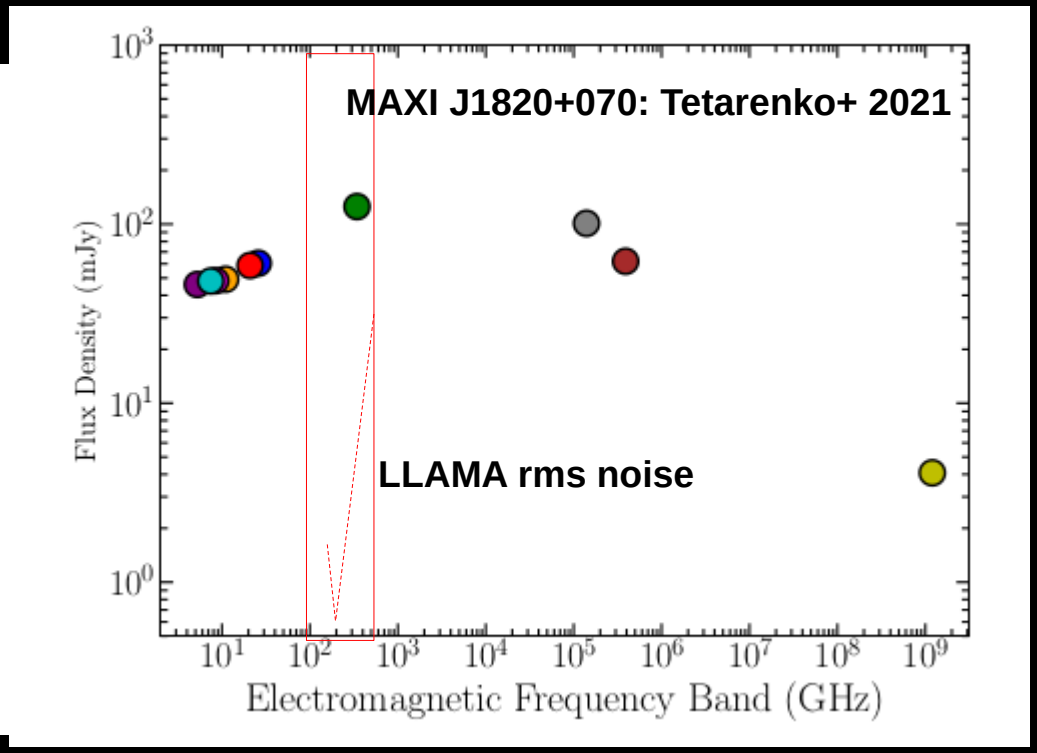
LLAMA: observing time availability

Observations in mm/sub-mm bands

- Scarce (SS 433, Cyg X-1, Cyg X-3, MAXI J1820+070)
- Single band

LLAMA: enlarge the sample, coordinated multi-λ observations

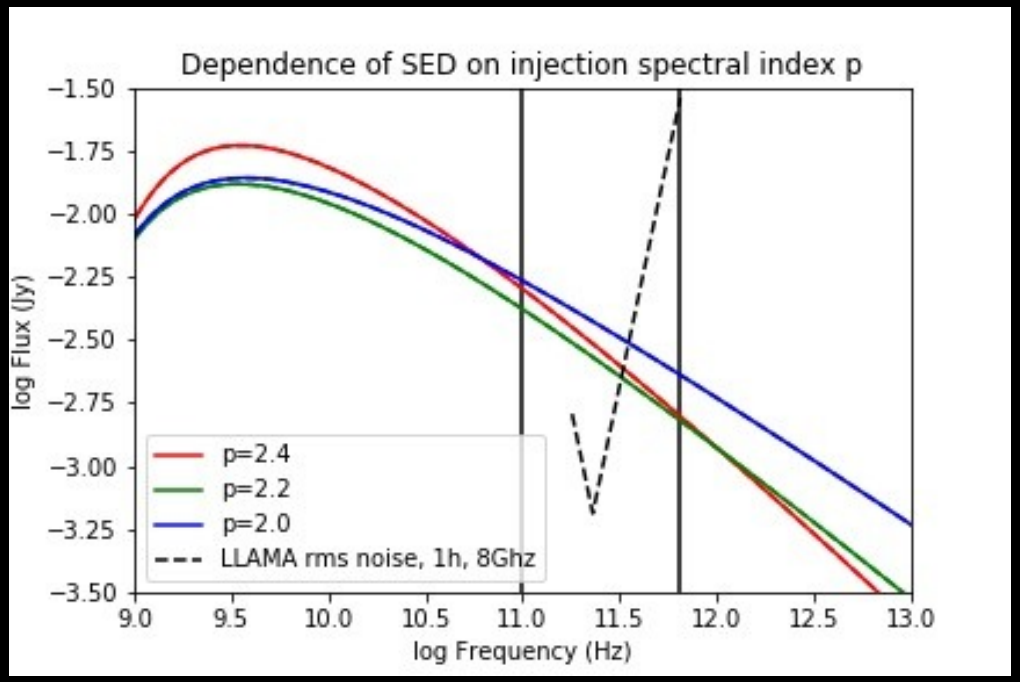


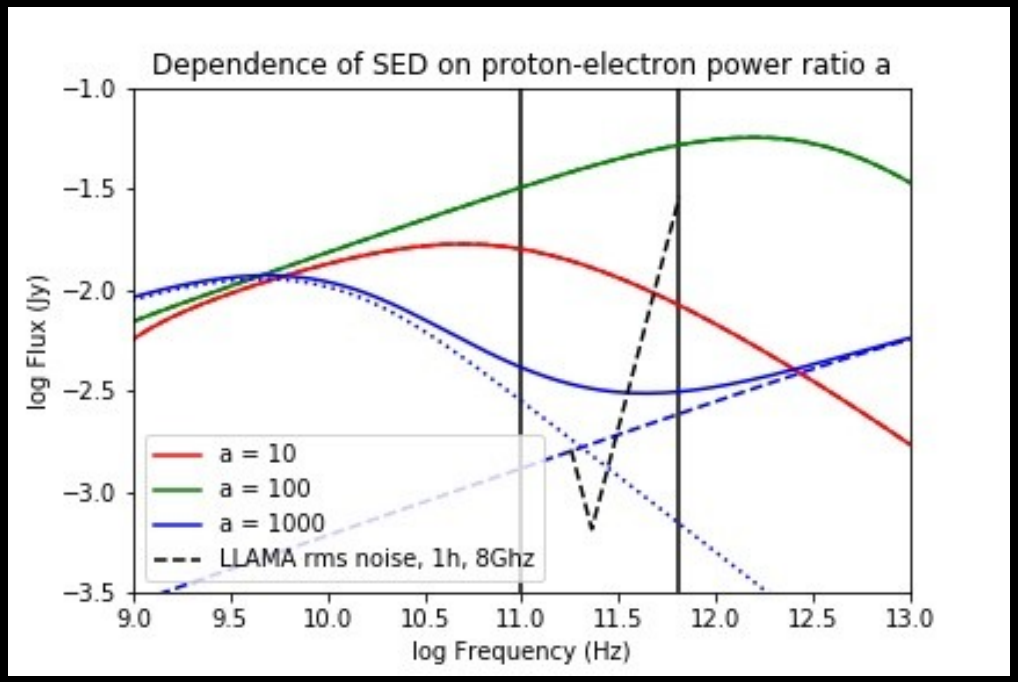


LLAMA: spectral coverage

LLAMA: take advantage of multi-band coverage

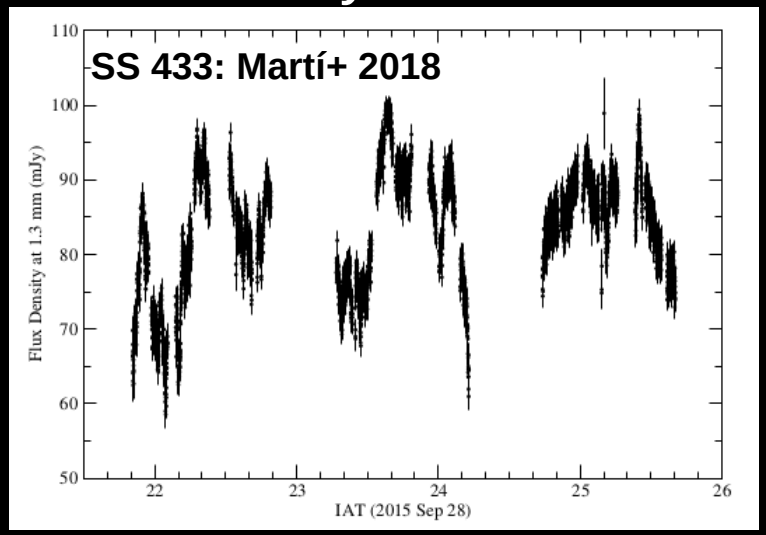
SED spectral index (at least 3 bands): less noisy than intra-band index
constrain parameters & break model degeneracies

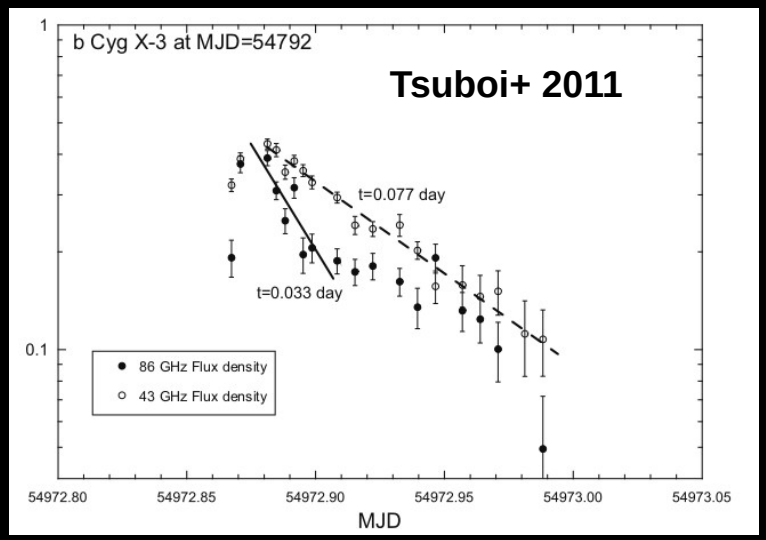


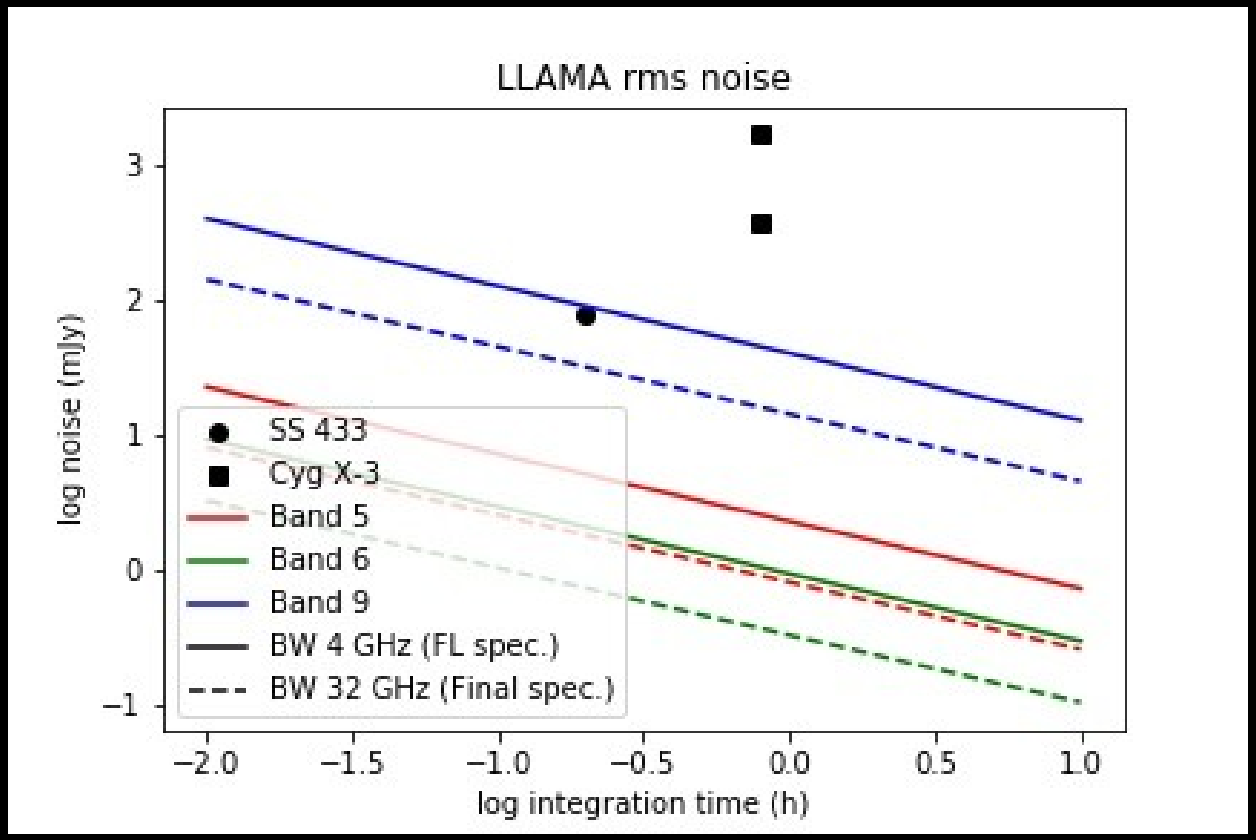


LLAMA: time-resolved observations

LLAMA: exploit time resolution and coverage to explore variability
variability / flares ~ time scales hours (need ToO / RRM)



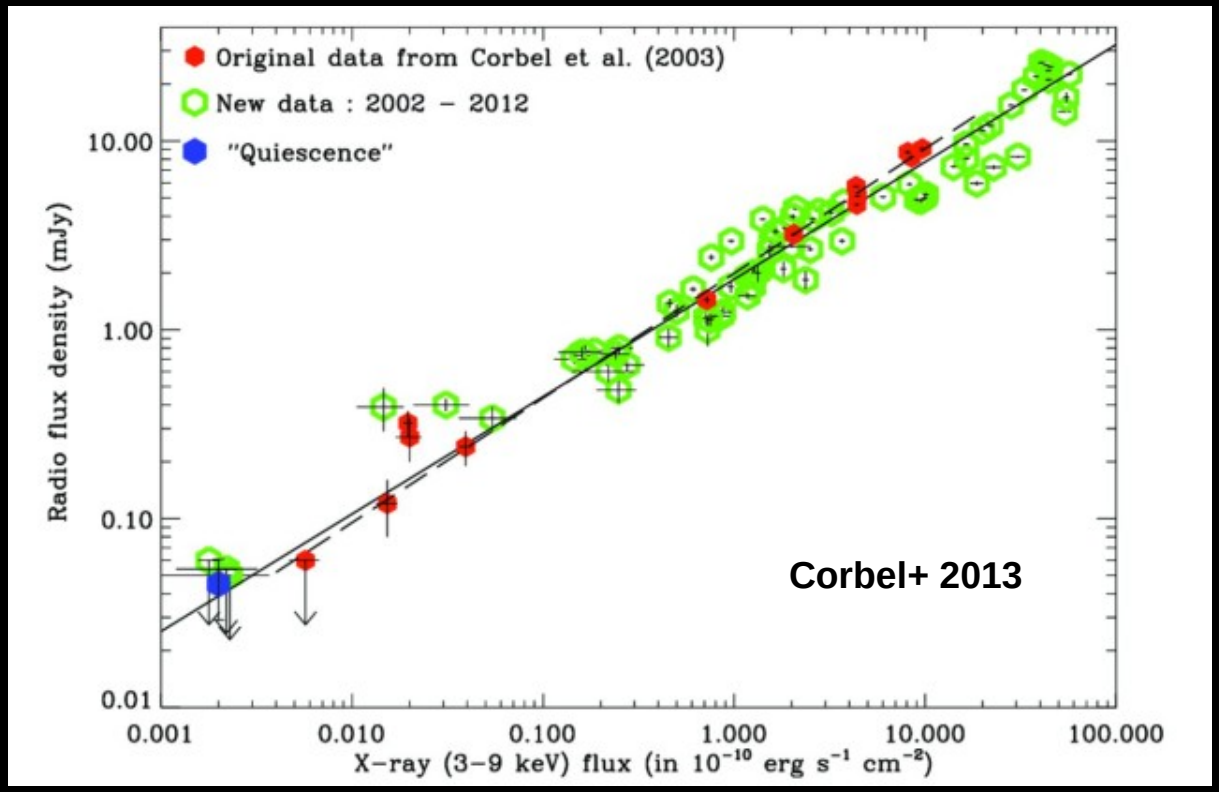




LLAMA: coordinated observations

LLAMA coordinated observations with other facilities
Explore correlations between different bands: e.g. X-mm?

X-cm correlation known
Describes the power share between inner disk and jet base



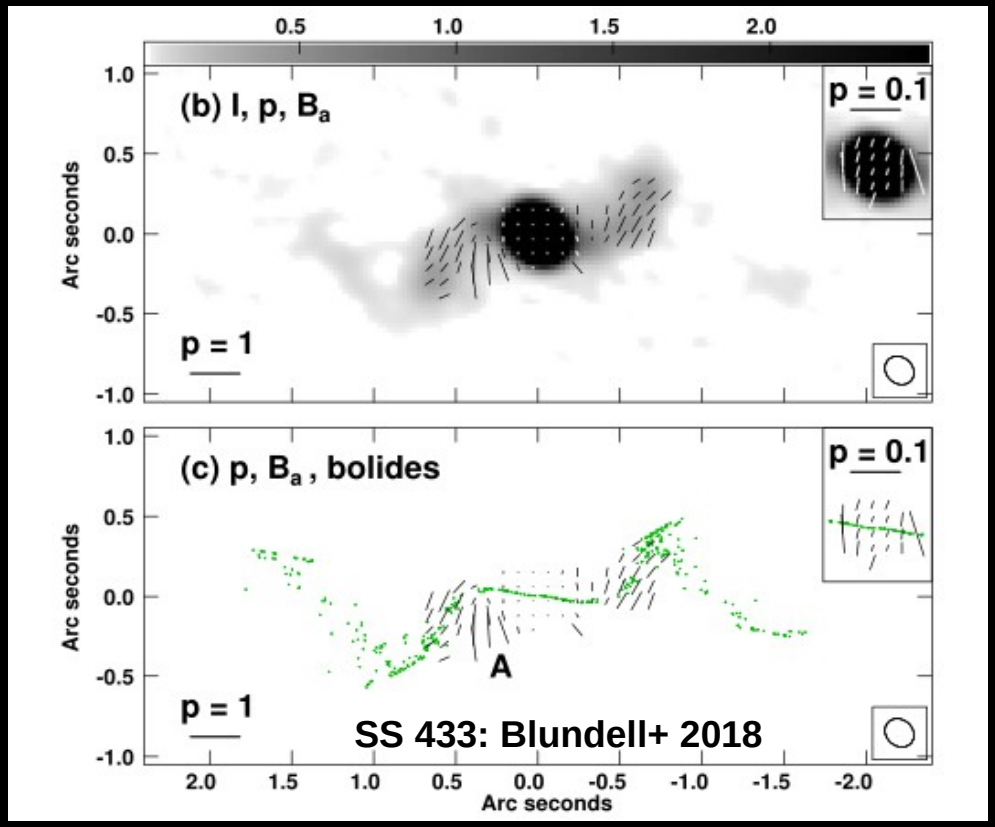
LLAMA: polarization observations

MQ jet emission is polarized (p ~ 0.5%, variable p?)

Related to orientation of ordered magnetic fields at the jet base

Faraday Rotation negligible @>100GHz (~λ^2)

Interesting to explore if LLAMA could reach this precision...



Summary

MQs are interesting targets, but mm observations are scarce

LLAMA could contribute to:

Improve population statistics:
MQ Survey (also XRB to discover new MQs);

Break model degeneracies and explore correlations:
Quasi-simultaneous observations at different mm bands,
Coordinated multiwavelength campaigns;

Understand MQ variability and flaring mechanisms:
Time-resolved observations,
Target of Opportunity / Rapid Response Modes;

Investigate jet magnetic fields (key for launching/collimation):
Polarization observations.