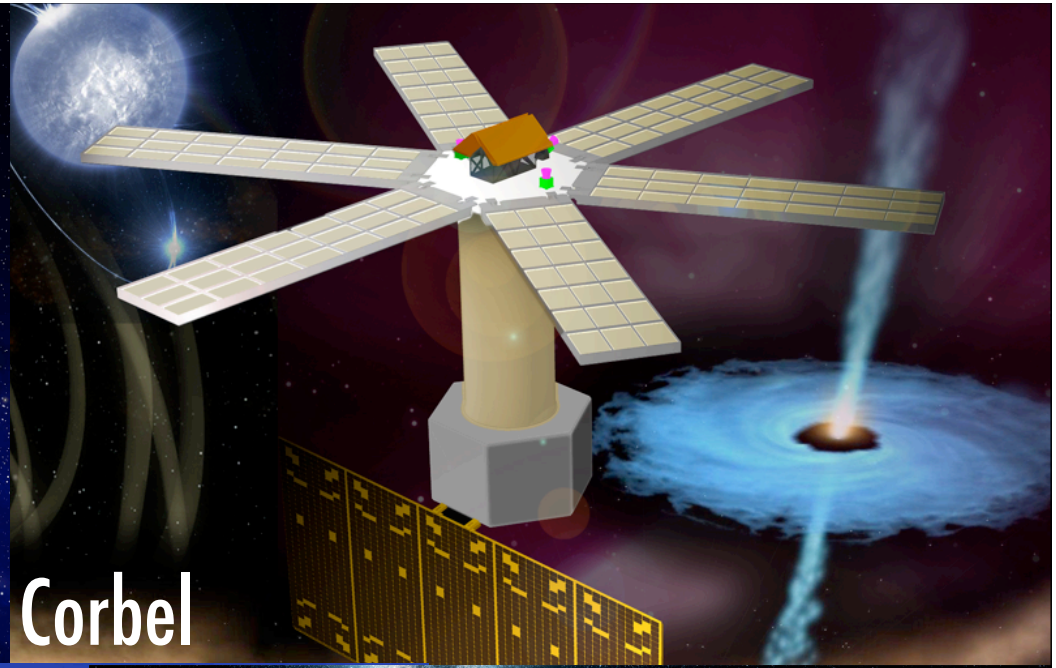


Stéphane Corbel

Univ. Paris Diderot & CEA/IRFU/SAp & IUF

X-ray astronomy synergies with radio/mm

Outline

- New facilities in the radio and millimeter domains
  - The **ALMA** array and its context
  - The **SKA** array and its precursors/pathfinders
- Scientific synergies with the X-ray domains: few examples

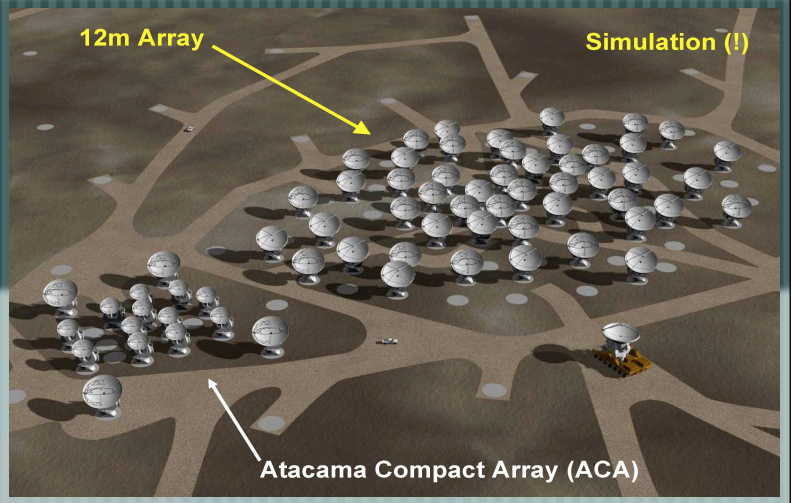
  Synergy: Two or more agents working together to produce a result not obtainable by any of the agents independently (wikipedia)
- Conclusions

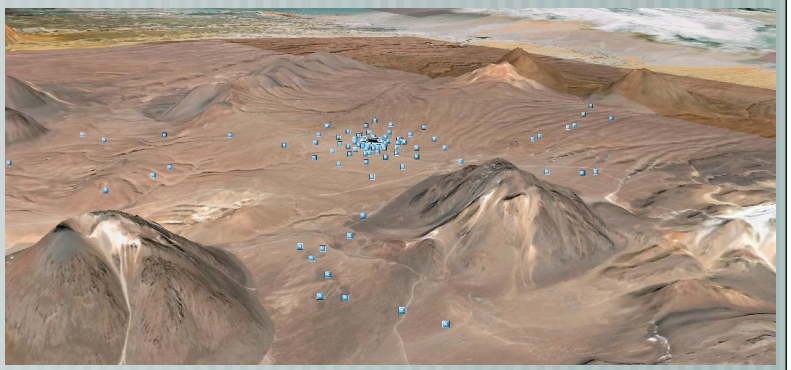
The ALMA array

- ALMA: a world partnership to deliver a transformational millimeter/sub-millimeter interferometer
- Collaboration between North America (US, Canada, Taiwan), Europe (ESO), East Asia (Japan,Taiwan) and Chile
- Site in Chile at 5000m
- 66 antennas: 7 to 12 m.

ALMA overview

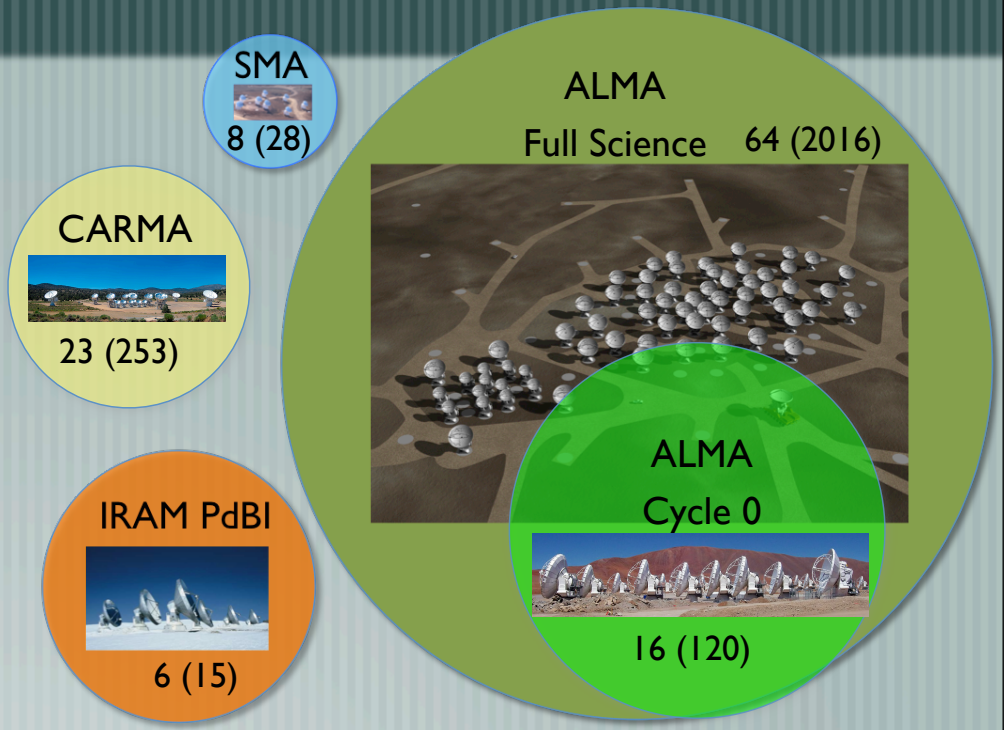
- Baselines up to 15 km (15 mas @300 GHz) and FOV ~21'' @ 300 GHz
- Sensitive and precise imaging from 84 to 950 GHz (10 bands)
- Low noise receivers + wide band–> high sensitivity
- Full polarisation + Flexible correlator
- Open access, but highly competitive



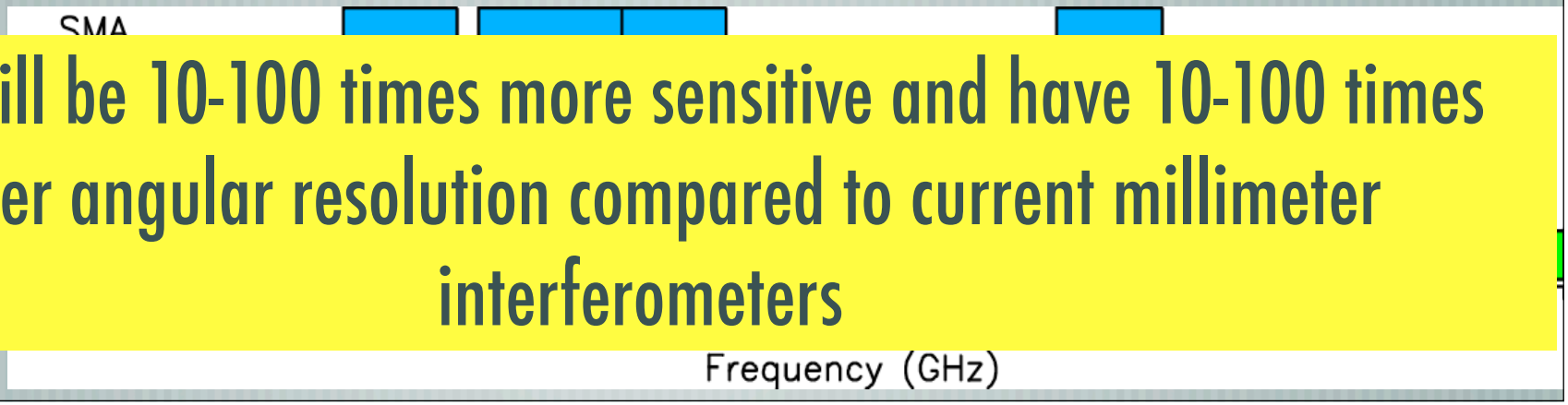


ALMA in the mm context

- Collecting area : Surf. + # of Antennas (# of baselines)
- Sensitivity goes as collecting area
- Image fidelity goes as # of baselines



ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution compared to current millimeter interferometers



The SKA telescope

SKA: basic parameters

- A collecting area of 1 km^2. Increased in sensitivity x 50
- Frequencies: 70 MHz – 10 GHz (SKA1) ➠ 25 GHz (SKA2) λ: 4 m to 1 cm
- Field of View: from 200 deg^2 at 70 MHz to few deg^2 at 1.4 GHz (21 cm).
- Large FOV + Independent beams ➠ increased survey speed (10^4 to 10^6 faster than today)
- Angular resolution better than 0.01 arcsec. Stations up to 200 km, with possibly 3 extended arms up several 1000 km
- Multiple precursors now being built around the world

How does **SKA1** baseline redefine state-of-art?

		JVLA	MeerKAT	SKA1-mid	ASKAP	SKA1-survey	LOFAR	SKA1-low
Aeff/Tsys	m^2/K	265	321	1630	65	391	61	1000
FoV	deg^2	0.25	0.86	0.49	30	18	14	27
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	1.76×10^4	8.86×10^4	1.30×10^6	1.27×10^5	2.75×10^6	5.21×10^4	2.70×10^7
Resolution	arcsec	1.4 - 44	11	0.22	7	0.9	5	11

A_{eff}/T_{sys}: 6.2xJVLA 6.0xASKAP 16xLOFAR

Survey Speed: 74x 22x 520x

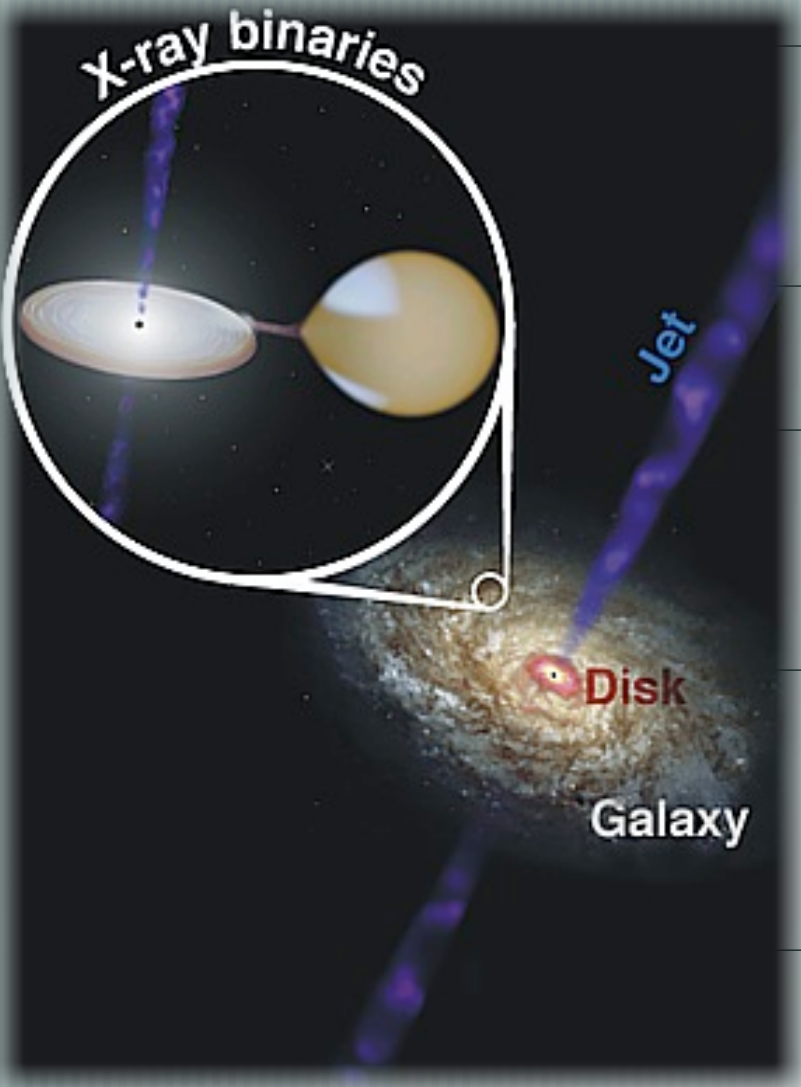
The radio to mm **summary** facts

- A **quasi continuous frequency coverage** from a few tens of MHz to almost 1 THz (4 to 5 decades) + Polarisation capab. + Spectroscopy
- From a very **small FOV** (ALMA) to **very large FOV** (SKA), typically much larger than a standard X-ray satellite
- **High sensitivity** coupled with **high resolution** imaging (typically in proportion, much better than anything possible in X-ray)
- A French community in construction for the SKA ! It happens now ....

Synergies with the X-ray domain

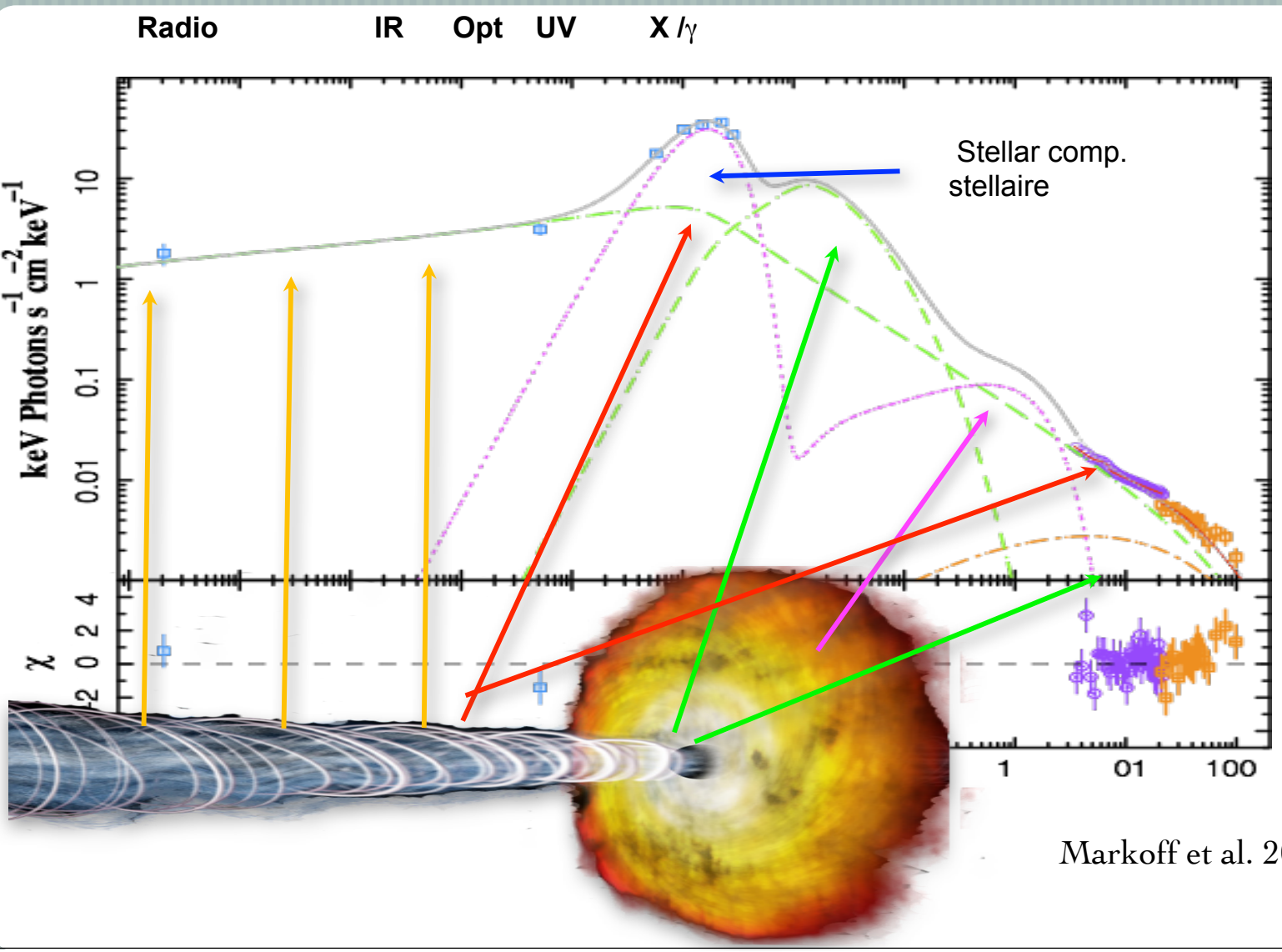
Some examples

X-ray binaries and AGNs



- Accretion: the most efficient source of energy in the Universe
- Jets : feedback, BH growth regulation...
- X-ray binaries: probing accretion/ ejection coupling
- Multi-physics ⇒ Multi-λ + Multi-messengers (not yet) + Muti-timescales
- Coupling e- in radio and HE for a large range of targets !

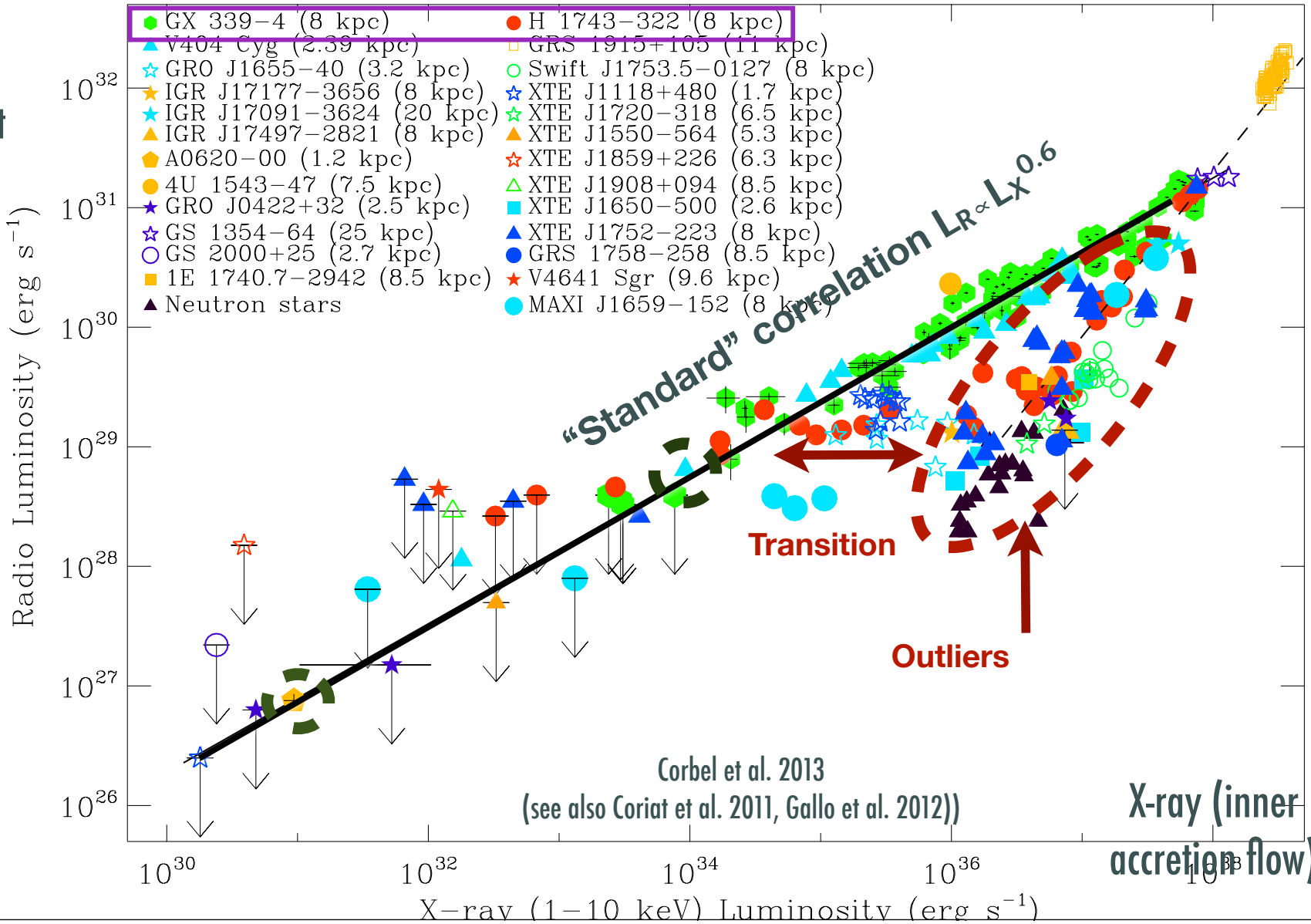
Broadband Spectral Energy Distribution



Markoff et al. 2005

Radio X-ray correlation

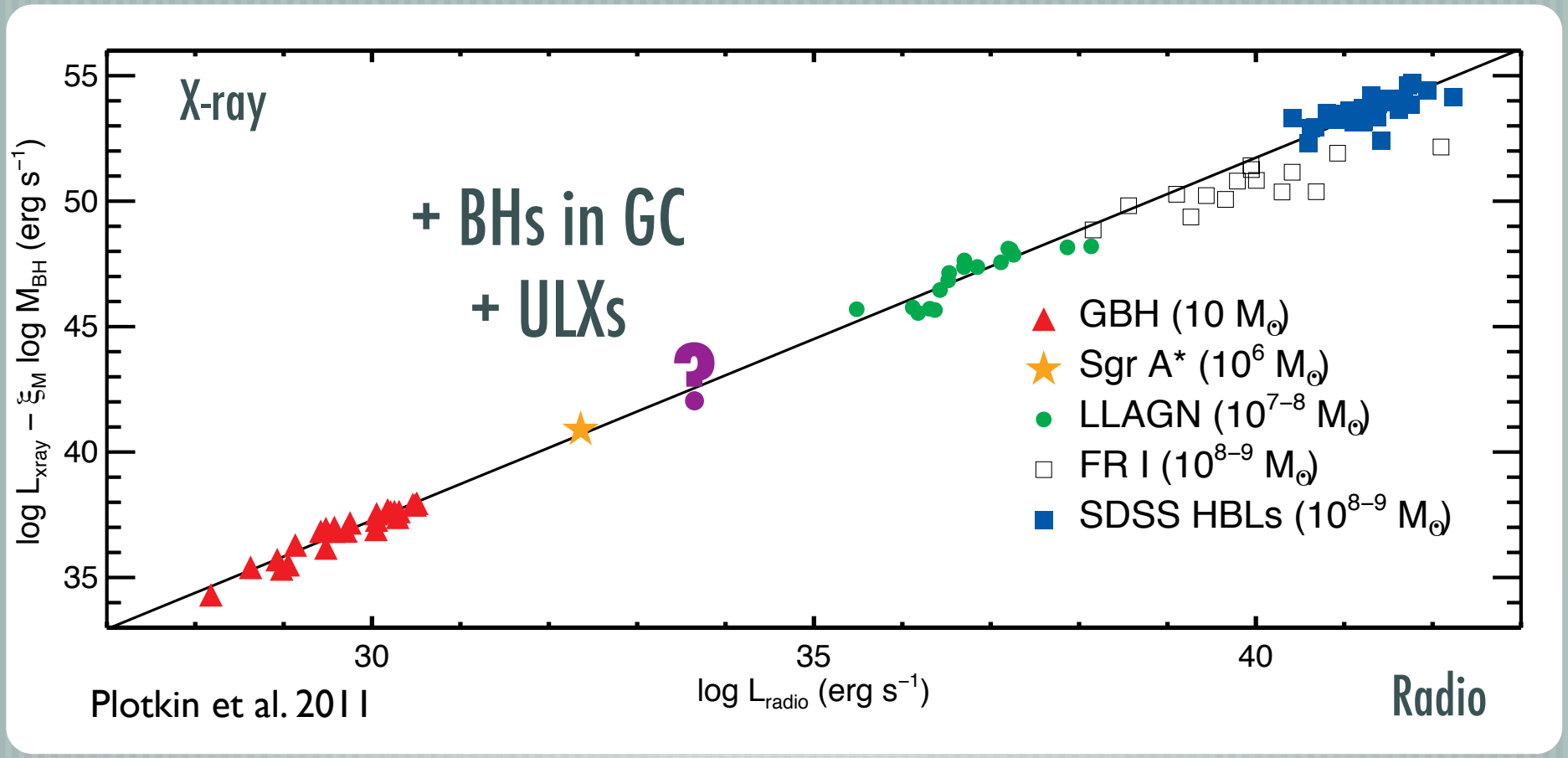
Radio (compact jets)



Corbel et al. 2013
(see also Coriat et al. 2011, Gallo et al. 2012))

X-ray (inner accretion flow)

The fundamenal plane of BH activity



Universality of scaling laws (same physics ?) along mass scale ?

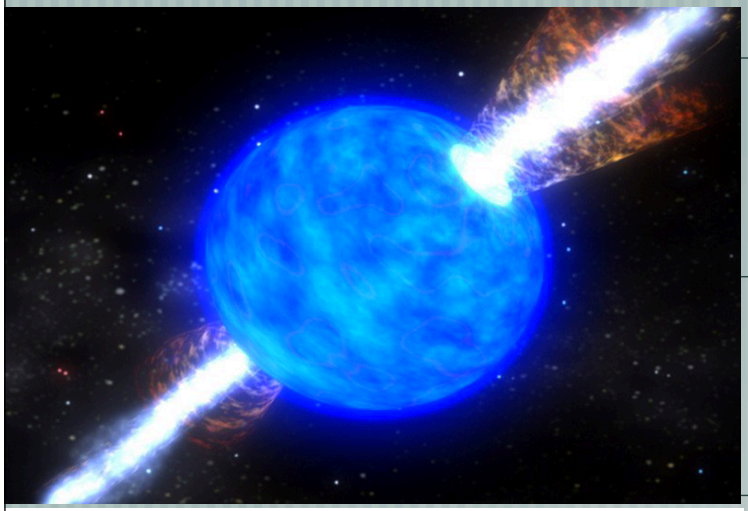
Needs in term of X-rays ?

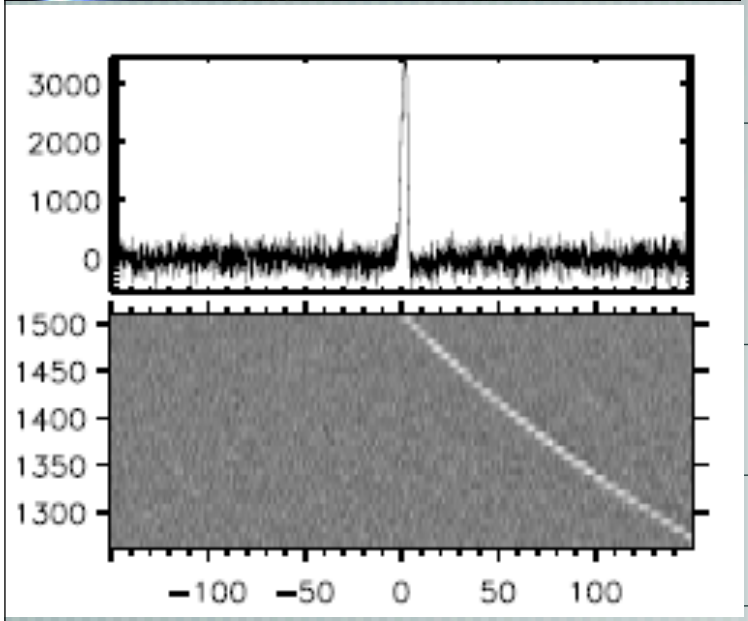
- Most of these new discoveries were driven initially by X-ray observations, and most particularly **X-ray All Sky Monitor** (RXTE/ASM, Swift/BAT...)
- But also great success of RXTE/PCA+HEXTE due to its extreme **flexibility** ⇒ allowing a great numbers of **ToO** (idem Swift/XRT), sampling XRB evol.
- Need **broadband coverage** in X-ray : a few 0.1 keV to few tens of keV !

What's new in radio ?

- New radio facilities (but not ALMA) have huge FOV with rapid response + clever software + multiple fields + look-back mode + piggy-backing
- Towards **Radio All Sky Monitor !!** with good sensitivity
- **A new population of radio transients for X-ray observatories** (see next talk by Fréderic Daigne)

The Dynamic Radio Sky



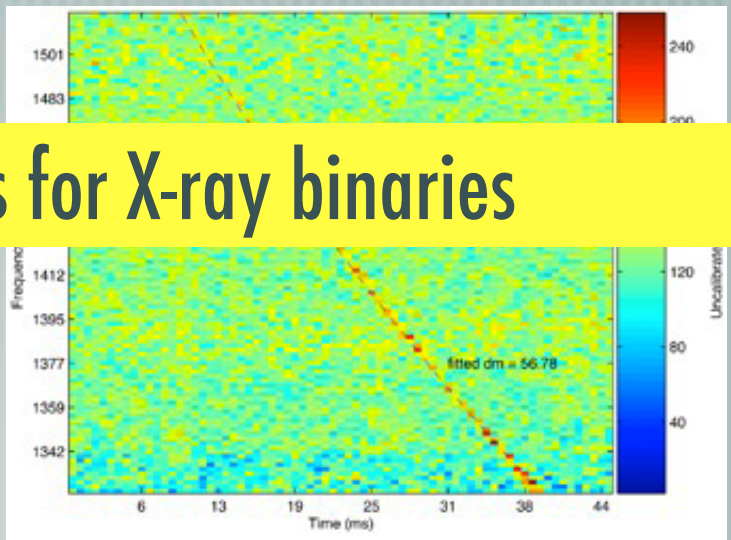


- Transient radio signals of any duration (ns to weeks)
- Neutron stars: Magnetars, Giant pulses, Short GRBs? Cosmic Radio Burst?
- GRBs: Afterglows, Prompt emission?
- Sub-stellar objects: Brown dwarfs, Extrasolar planets?
- Microquasars, BH collision at cosmological distance
- ETI
- The Unknown !!!! Remember the wise word of DR

Two flavours of transients

- Incoherent synchrotron emission (> 1s)
  - Relatively slow variability
  - Brightness temperature limited (10^{12} K)
  - Associated with all explosive events
  - Strong potential for MW astronomy
- Coherent emission (< 1s)
  - Relatively fast variability
  - High brightness temperature
  - Often highly polarised

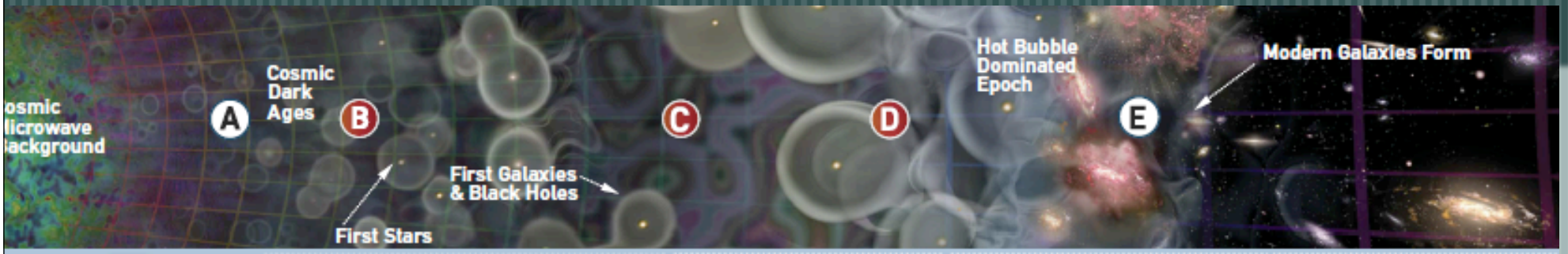
Detection: images



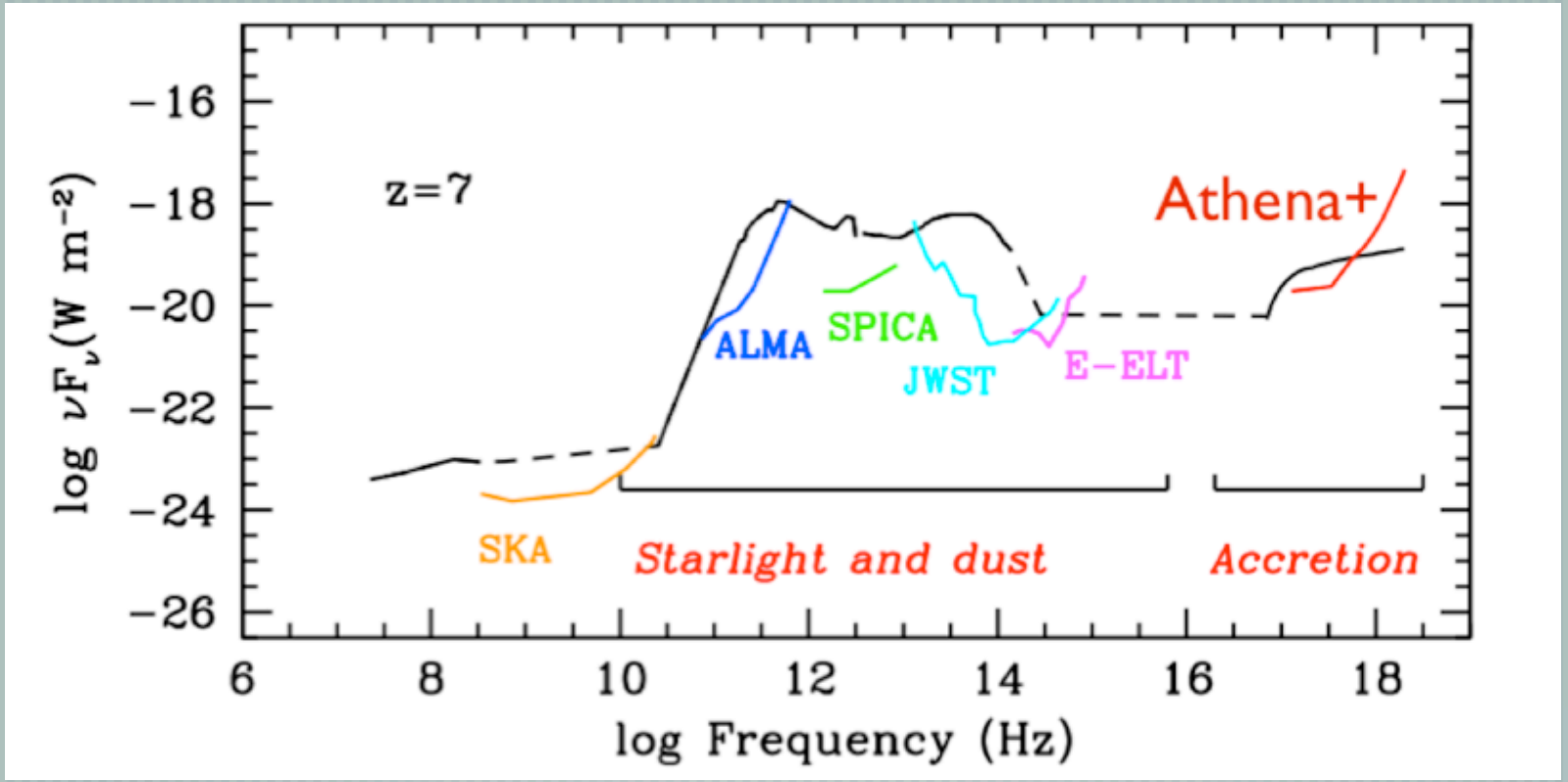
Detection: time series

In term of X-ray needs, similar as for X-ray binaries

High redshift Universe



- LOFAR, MWA...: first limits on HI around epoch of reinionisation
- A revolution coming with SKA with direct imaging
- ALMA + later JWST : first source at the origin of the reionisation
- X-rays: detecting fainter AGN at high redshift (z= 6-10) and tracing the growth of SMBHs (incl. absorbed AGNs)
- SVOM: High z GRB and associated physics (see talk by FD)



- To open up the high z Universe: high angular resolution needed (5″) in order not to be confusion limited and for identification at other l
- To increase survey speed, needed larger FOV also: Athena+ could be a factor 10 more efficient than Chandra
- Discussed this morning by Monique.

Conclusions

- Strong connection between radio at large and X-ray emission.
- **SKA** (Radio) and its precursors: high sensitivity, high angular and spectral resolution, large FOV **all in once** !
- **ALMA** (mm): dedicated sensitive pointed observations
- **X-rays**: two (exclusive ?) options :
  - Sensitive ASM, Flexibility, broad-band spectral coverage ⇒ e.g. SVOM, LOFT ?
  - Large area, high angular resolution, high spectral resol. , FOV ⇒ e.g. Athena+ ?
- In any-case, **strong synergies in many fields and** λ, but not sufficiently explored in radio, at least in France (current prospective).
- Mutual benefits for all communities.