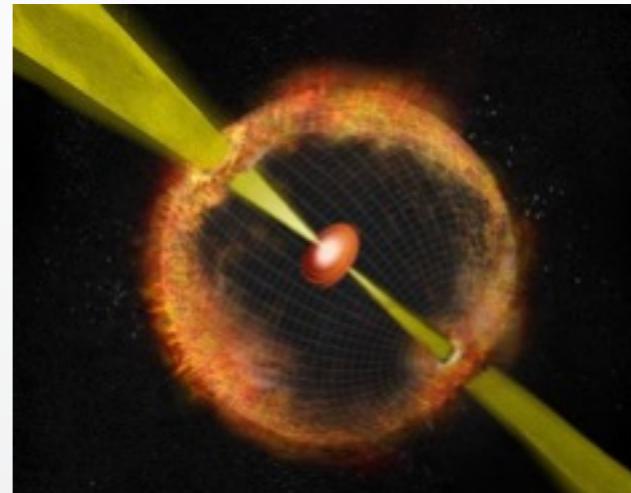


Modelling Black hole Emission

- Efforts and Results -

The many faces of Black Holes



- ◎ **Multi-scale (mass, length, time...)**
- ◎ **Multi-environnement**
- ◎ **Multi-component**
- ◎ **Multi-lambda**
- ◎ **Multi-messenger**
- ◎ **Still many similarities...**



Stakes

- **At the heart of international prospective exercices**

- ▶ ESA 2015-2025: “The hot and energetic universe/How do black holes grow and shape the Universe?”
- ▶ AstroNet: “Do we understand the extremes of the Universe?/How do BH accretion, jets and outflows operate?”

- **In France (highlighted french contributions) :**

- ▶ More than 20 persons (+postdoc, Phd)
- ▶ More than 6 institutes (IRAP, AIM/APC, IPAG, LUTH, OAS, LUPM...)

- **Black holes as astrophysical objects**

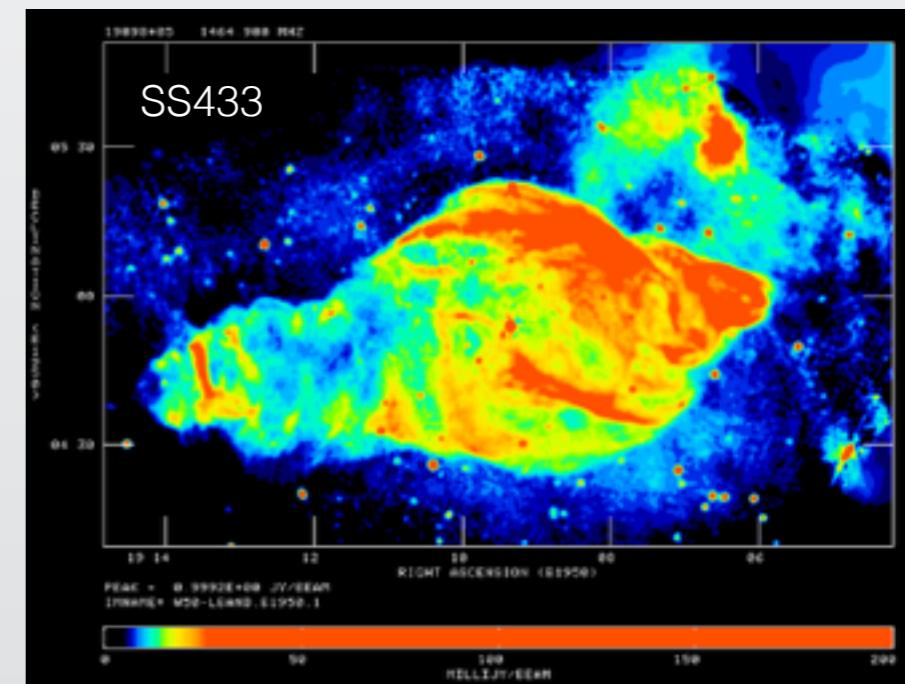
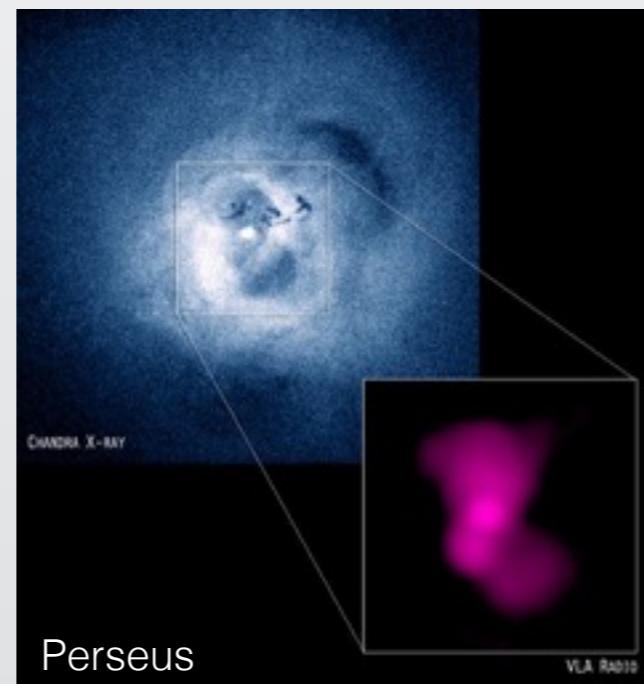
- ▶ Structure of accretion/ejection
- ▶ Formation/evolution

- **Impact on the environnement**

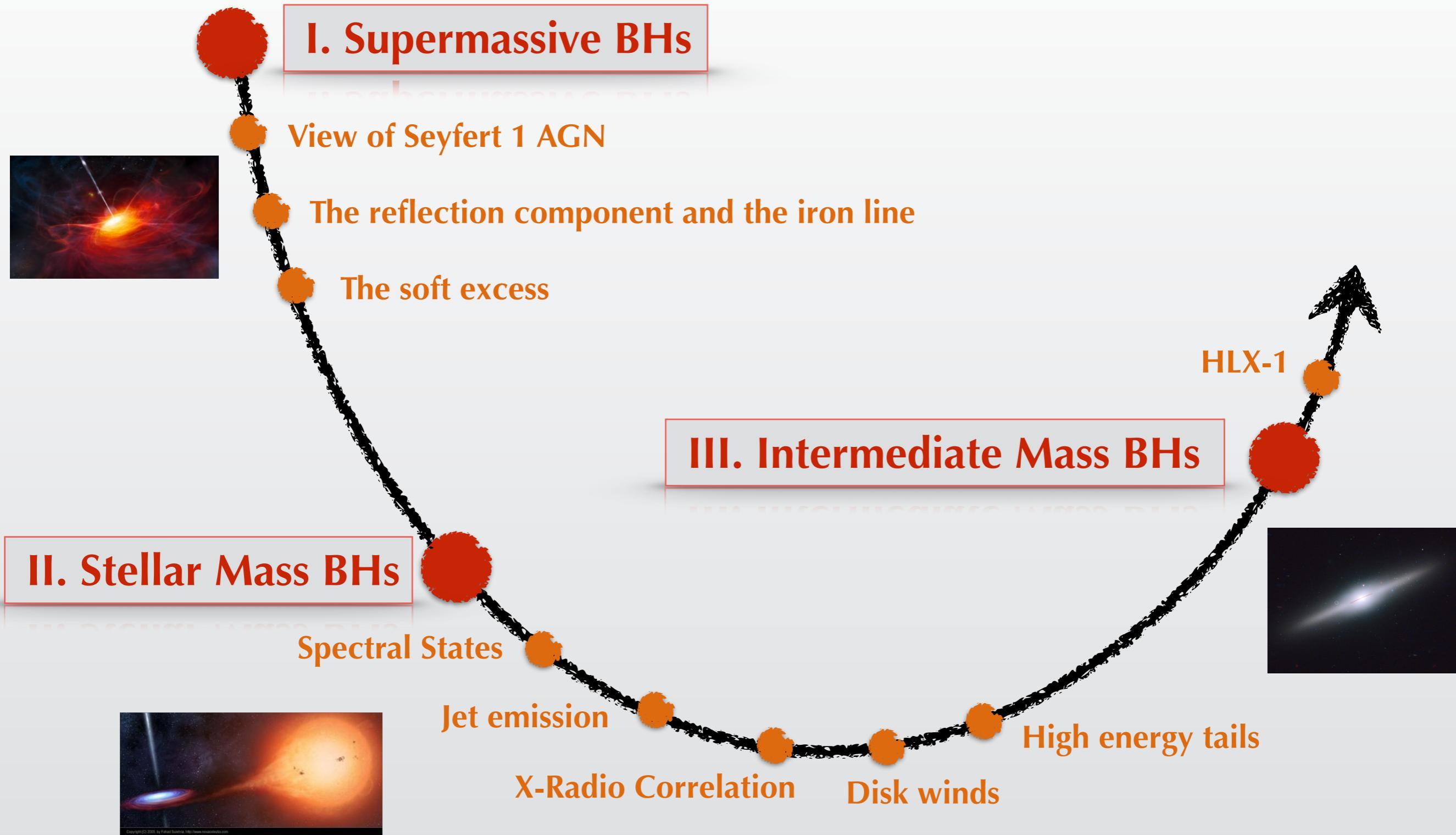
- ▶ Heating
- ▶ Ionisation
- ▶ Magnetism
- ▶ Cosmic Rays

- **Connex science:**

- ▶ General Relativity
- ▶ Particle acceleration

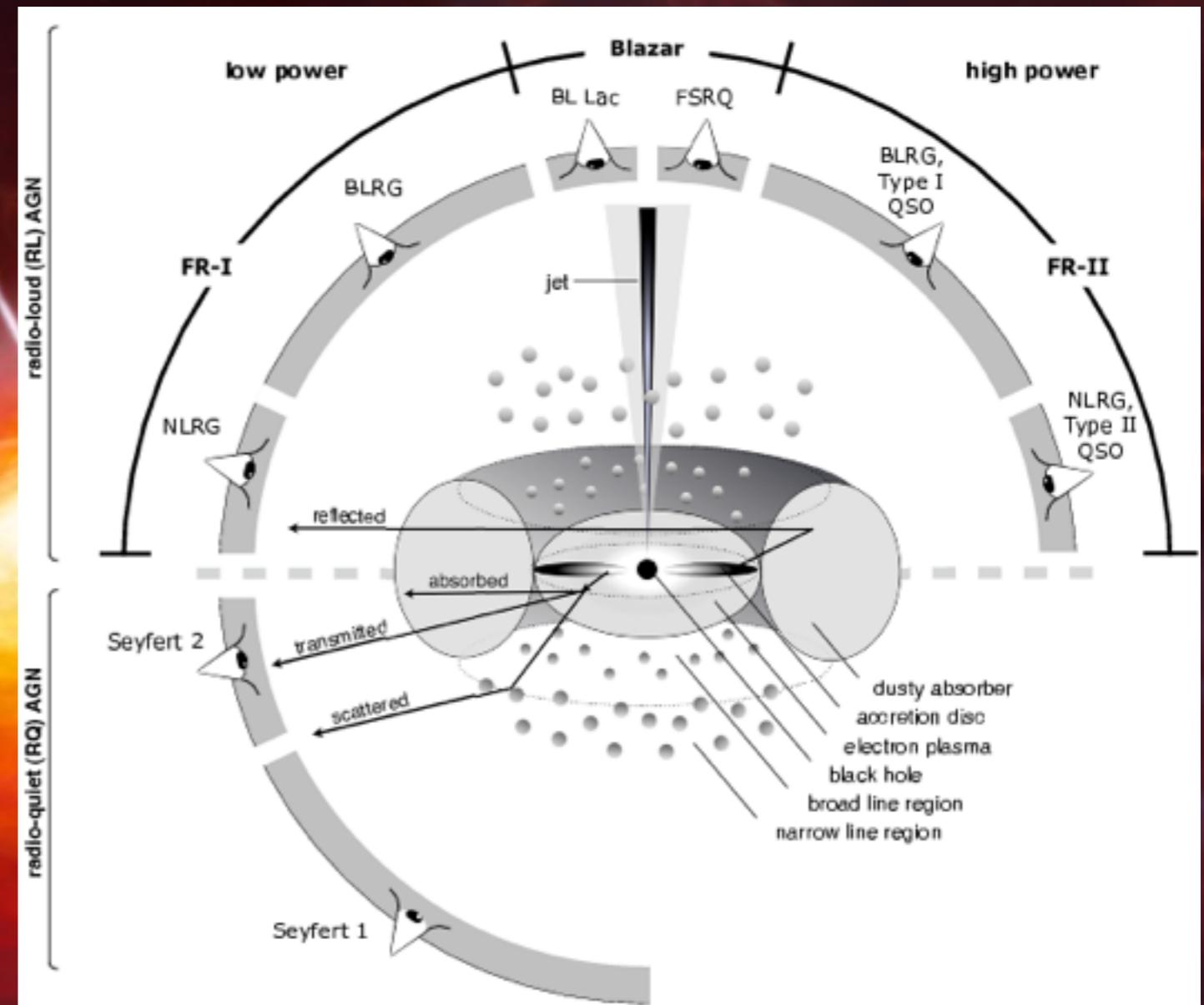


Outline



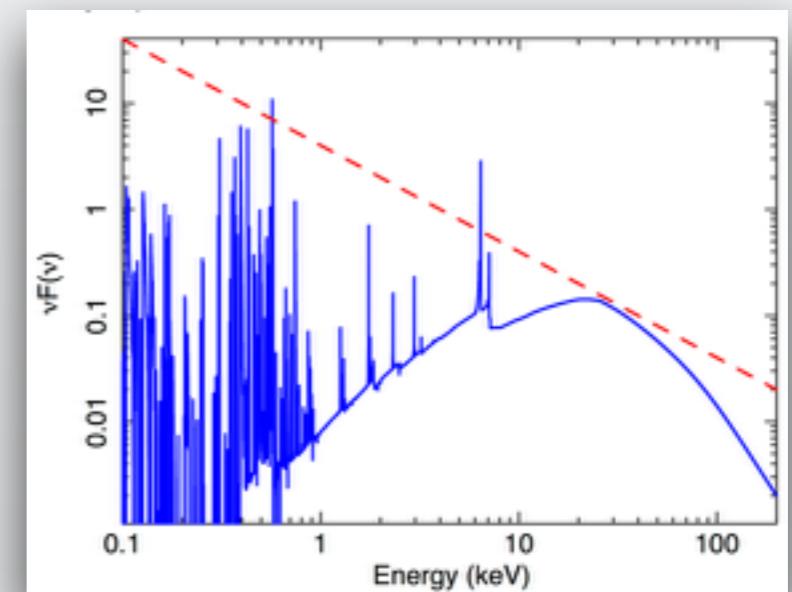
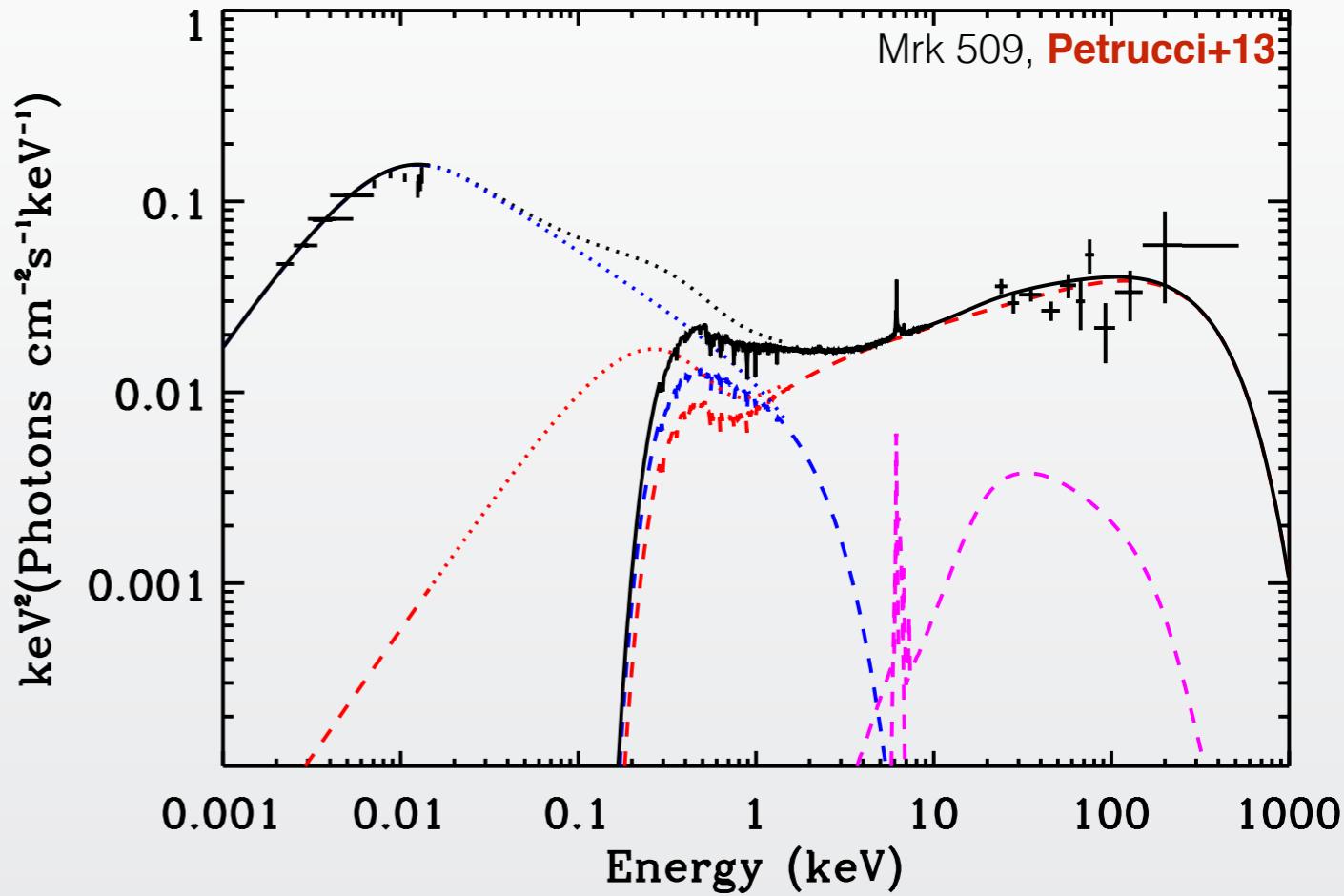
Supermassive Black Holes

- Mass: $10^6\text{-}10^{10} M_\odot$
- Rich environment
 - disc, jet, corona
 - absorbing/reflecting material, winds
 - soft excess
- Seyfert 1 probe the BH vicinity
 - Spectral components
 - Iron line and reflection component
 - Soft excess
- Past/present activity of SgA*



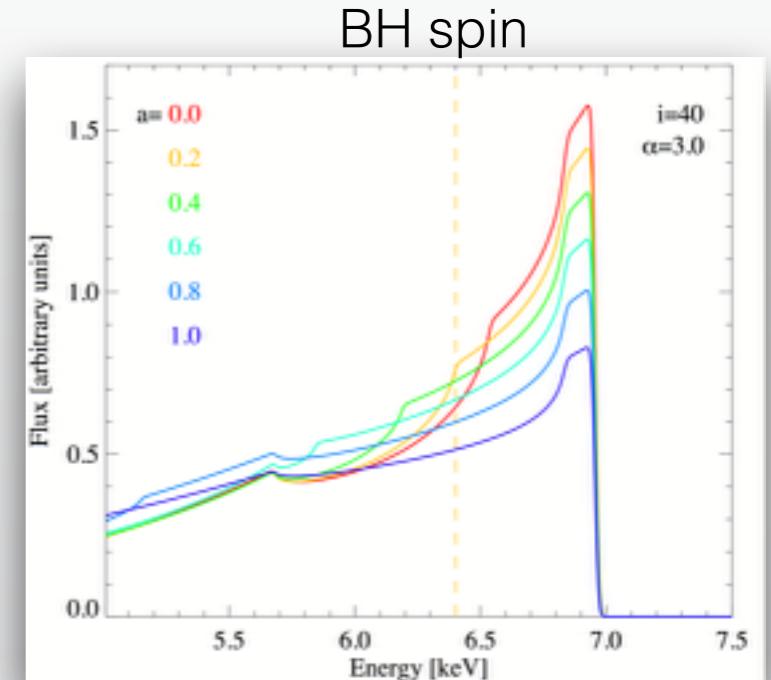
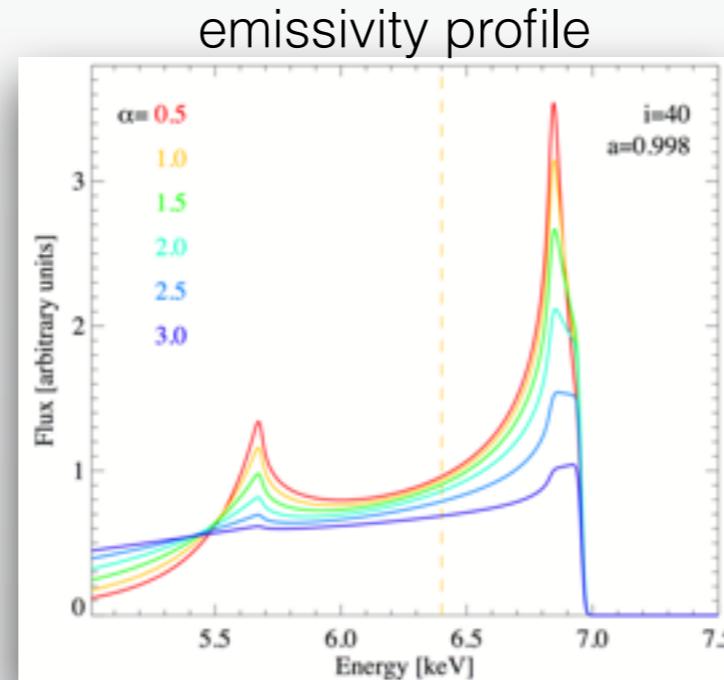
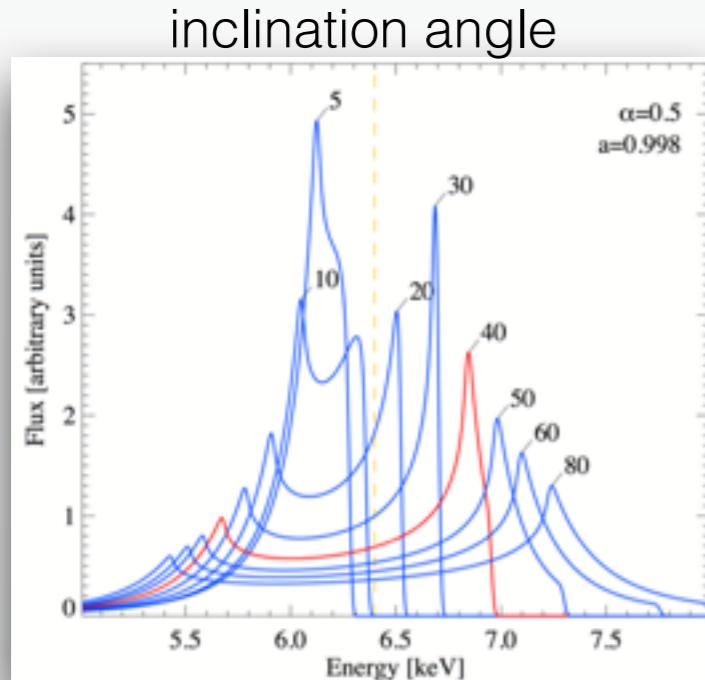
X-ray Spectrum

- **Black body**
 - ▶ Disc at ~ 10 eV
- **Hard power-law/Comptonisation**
 - ▶ Corona: $\tau < 1$, $T > 100$ keV
- **Inner reflection component**
 - ▶ Compton hump/shoulder
 - ▶ Broad lines (neutral Fe K α + ionised)
- **Outer reflection**
 - ▶ Narrow Fe-K α line
- **Multi-phase warm absorber + galactic absorption**
- **Soft excess < 1 keV**



Fe-line and BH spin

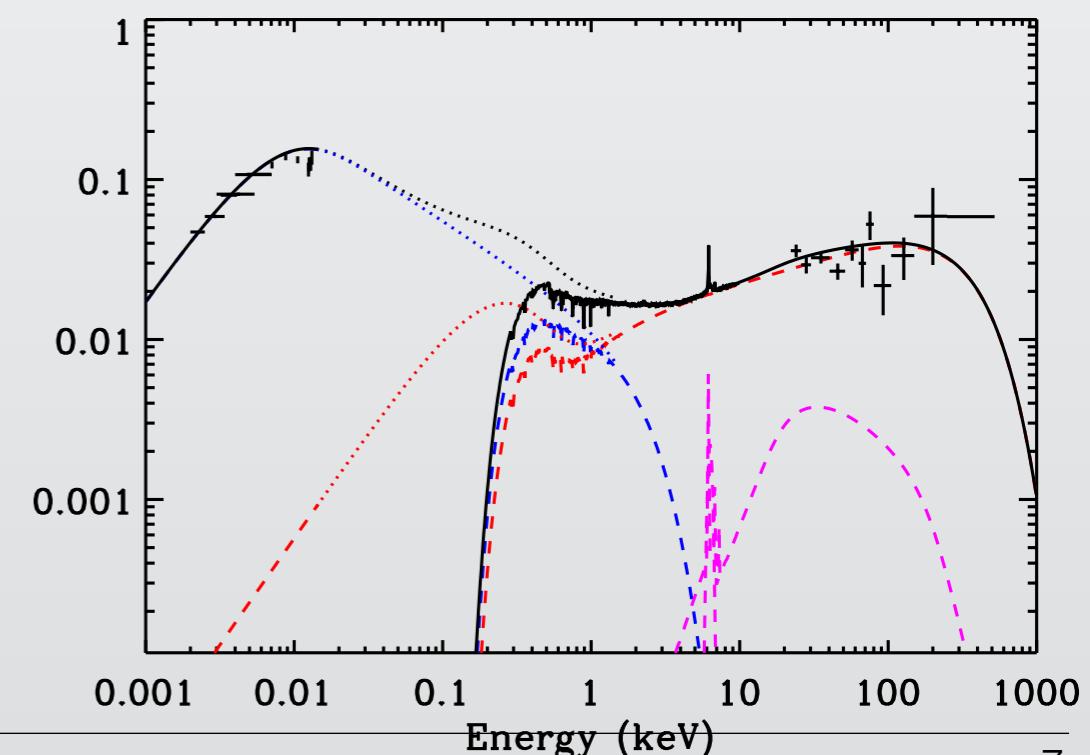
- ◎ Broad Fe-K α line interpreted as GR effects (Fabian+89)



- ▶ Assume $R_{\text{in}}=R_{\text{isco}}$
- ▶ Broad lines often suggest maximal spin ($a=1$), steep emissivity profiles ($q>4$)

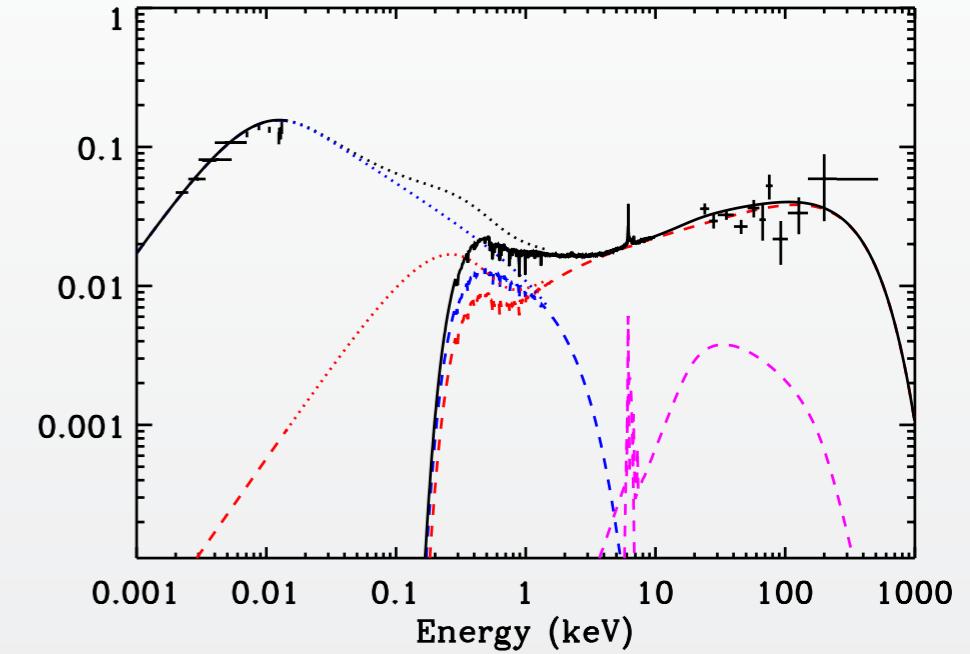
- ◎ Line shape very sensitive to the underlying continuum

- ▶ Warm absorber
- ▶ Reflection continuum at high-energy (10-100 keV)
- ▶ soft excess at low-energy (<1 keV)



Soft Excess Models

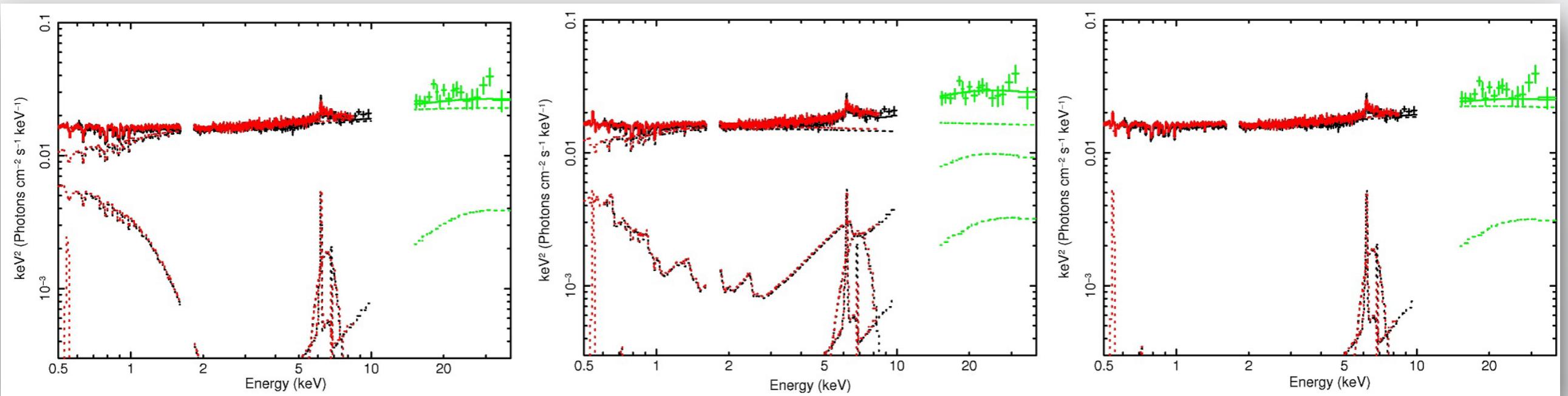
- ◎ **Partially covering absorption** (Inoue+03, Turner+08, Iso+16)
 - ▶ Relativistic outflow
- ◎ **Ionised, blurred reflection** (Crummy06+, Walton+13, Parker+14)
 - ▶ Many ionised Fe lines
- ◎ **Warm corona** (Porquet+04, Medhipour+11, Petrucci+13, Boissay+16)
 - ▶ Comptonisation in a lukewarm, thick corona



warm corona

ionised reflection

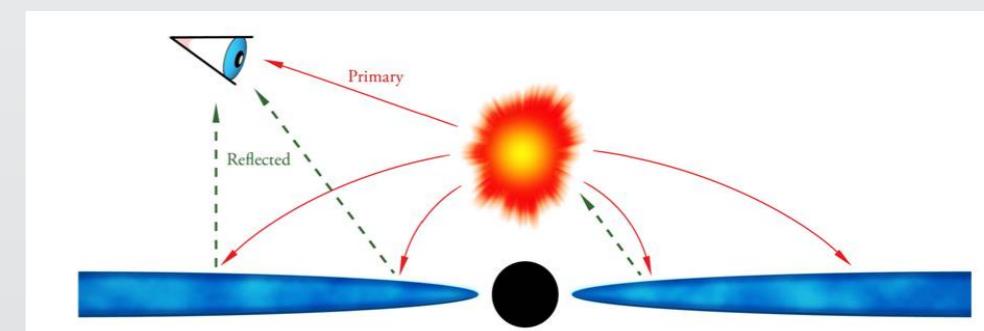
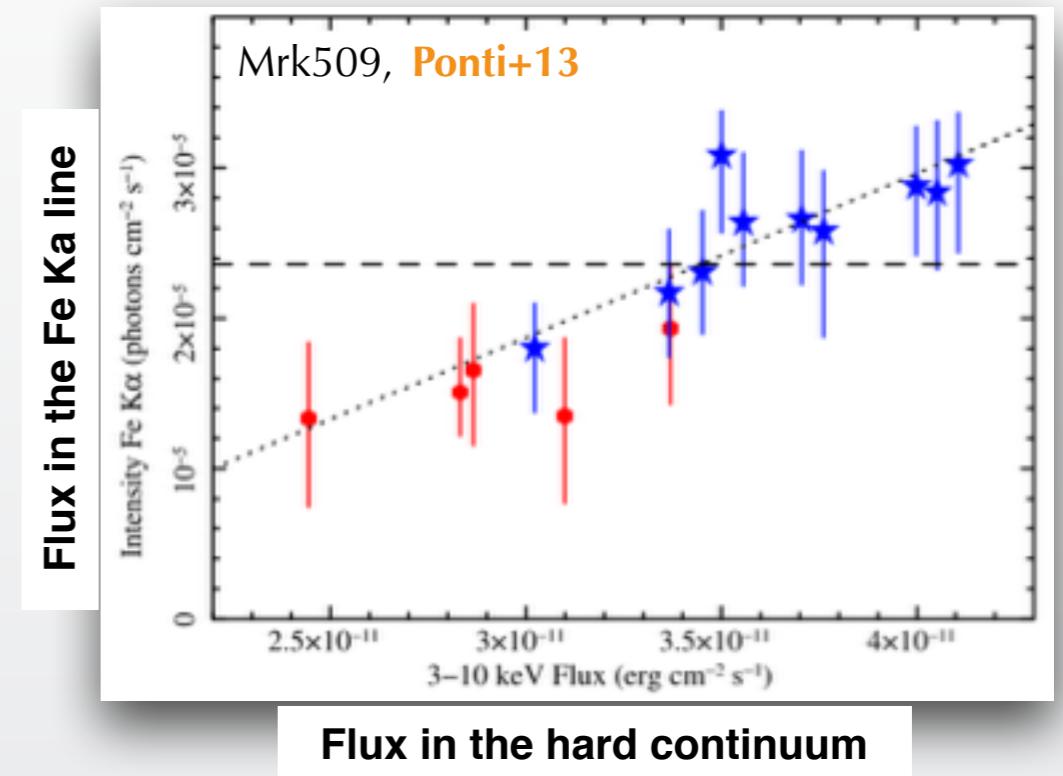
Partial absorption



Mrk 509, Cerutti+11

Recent studies

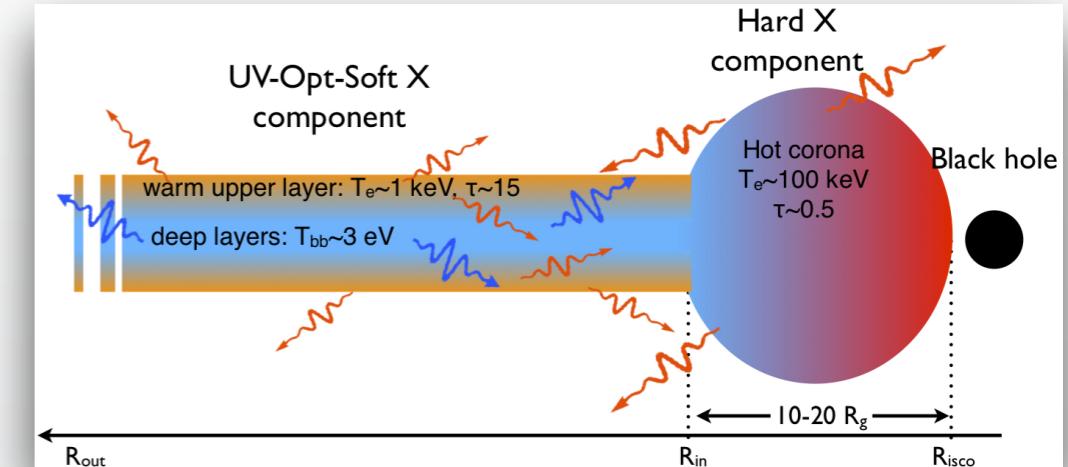
- More and more sophisticated reflection models
(Garcia+14, Dauser+14, XSPEC/KYNRLPLI:Dovciak+14)
- Broadband spectra + high resolution spectroscopy
 - Swift, XMM, Suzaku, NuStar, Integral
- Population studies (Patrick+11,12, Boissay+16)
- Time resolved spectroscopy
 - Correlations:
 - Reflection/Hard X-ray correlation (Ponti+13)
 - UV/Soft excess correlations (Mehdipour+11, Petrucci+13)
 - Lags => length scale
- Reverberation mapping (Fabian+09,13, DeMarco+12, Wilkins+16)
 - lags vs energy
 - Short variability: lags vs frequency



Recent studies

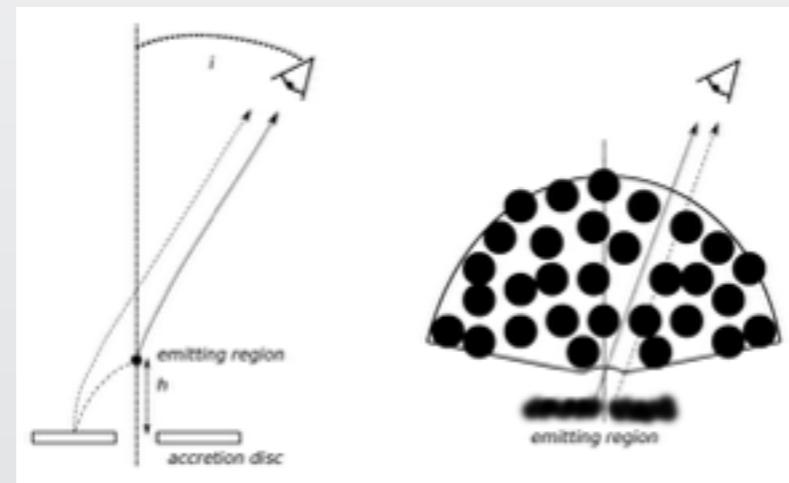
◦ Model for the warm corona (Rozanska+14,Belmont+15)

- Warm ($kT=1\text{ keV}$), thick ($\tau>10$) Corona + passive disk
- Upper layer of the accretion disk (Petrucci+13)?
- Detail radiation transfer modelling: OK if
 - Magnetically dominated
 - Energy dissipated mostly in the corona

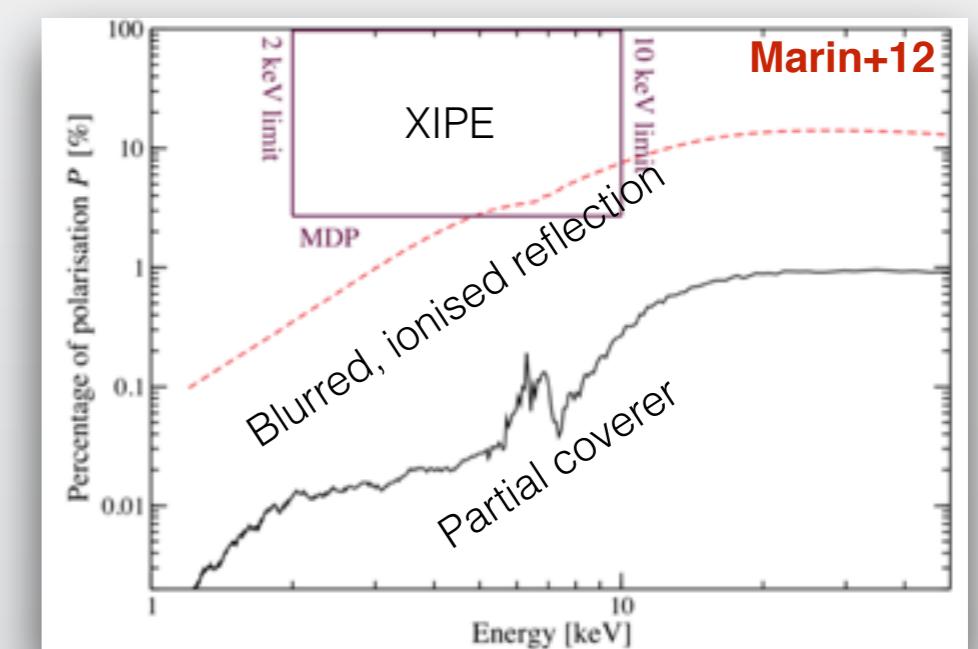


◦ Prediction for Polarisation (Goosmann+11,Marin+12,13)

- Monte-Carlo simulations to test soft excess models



- X-ray Imaging Polarimetry Explorer mission (XIPE)
 - preselection for M4 (2025)
 - Mirror focussing on gas pixel detectors (photo-e)



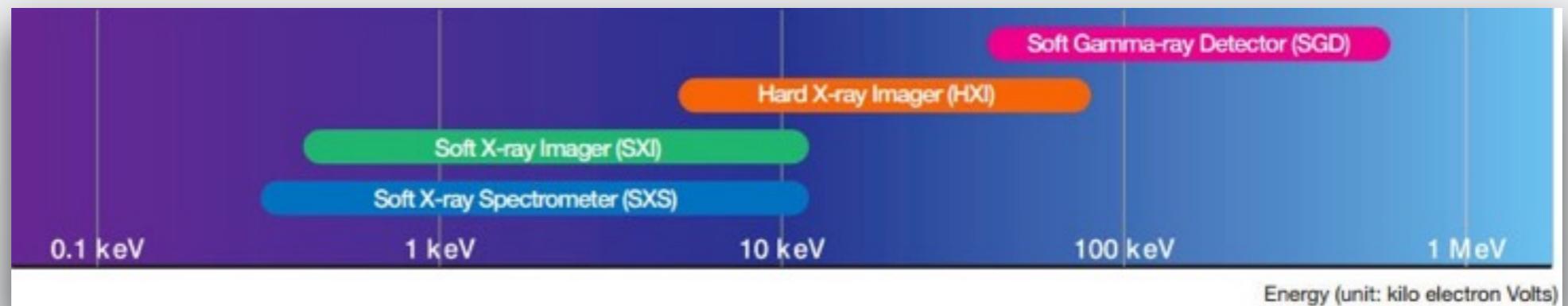
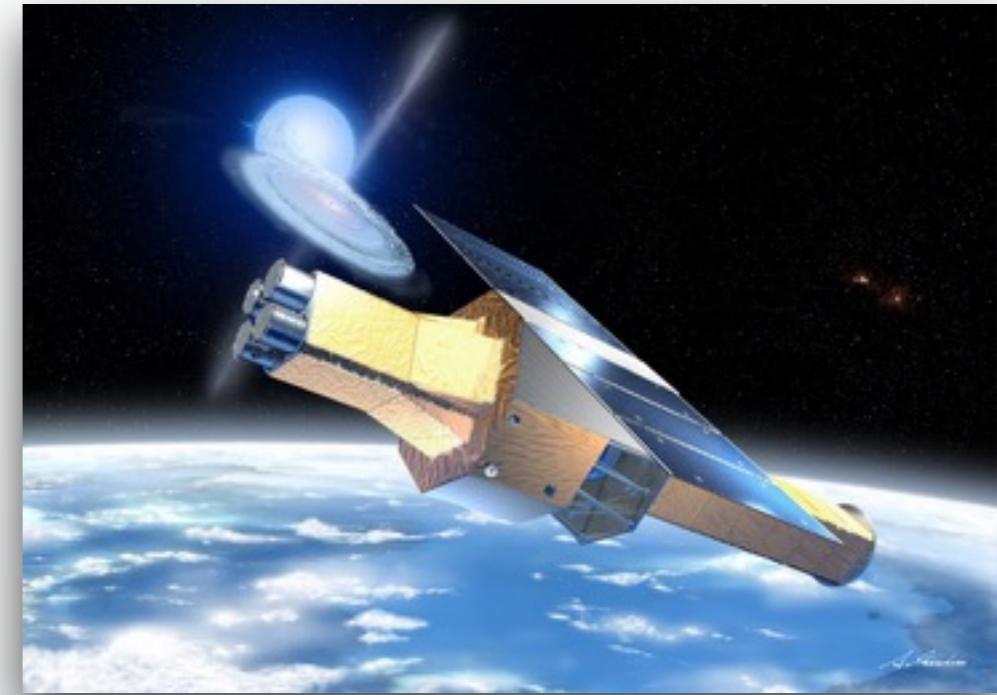
Hitomi (Astro-H)

- ◎ **Hitomi (Astro-H) launched on February 17th, 2016**

- Critical operation phase completed.
- On going verification phase.
- Last Saturday: Communication failure...

- ◎ **4 instruments**

- HXI: 5-80 keV
- SXS/SXI: 0.3-12 keV, $\Delta E=5$ eV
- SGD: 10-600 keV

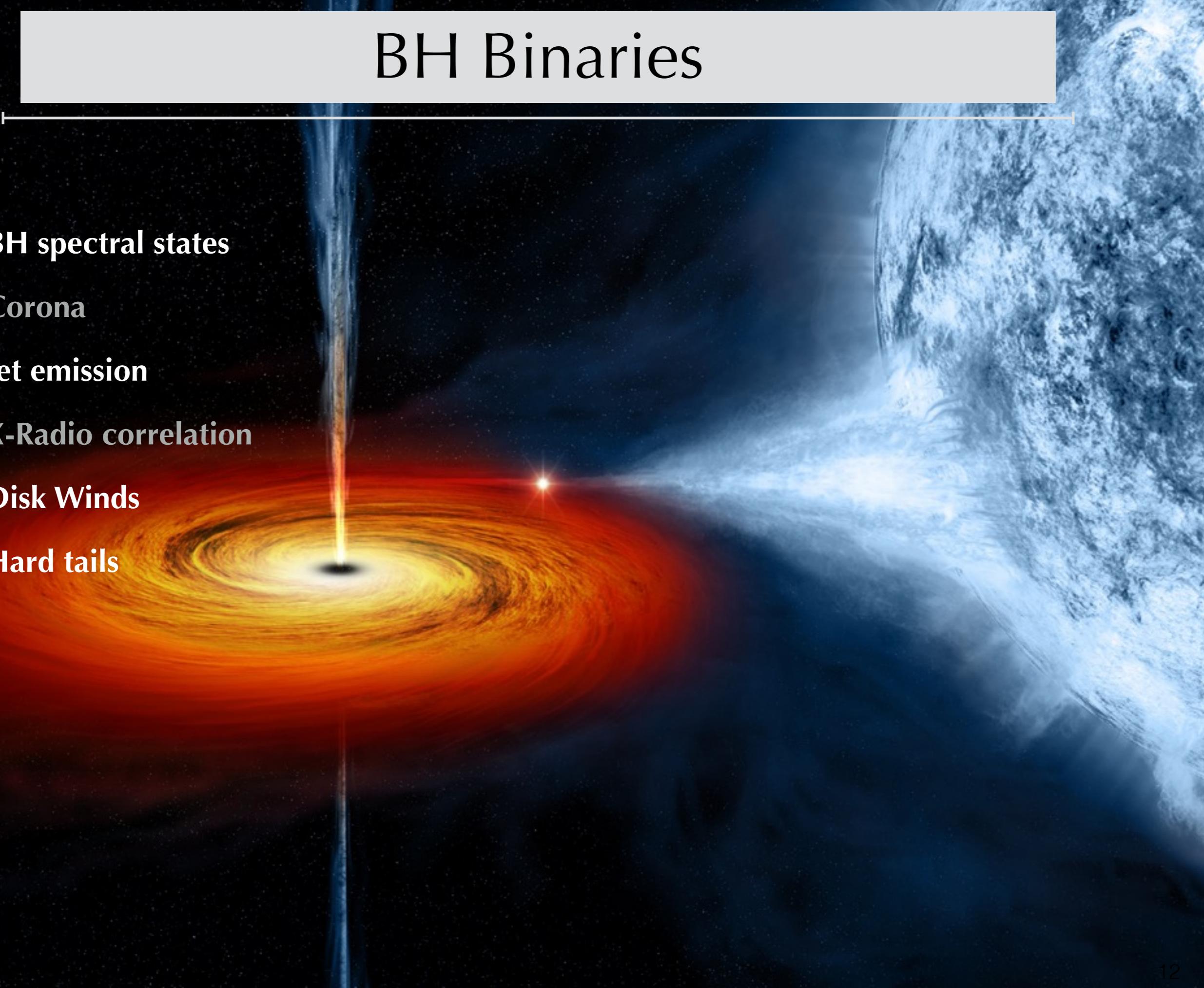


- ◎ **France:**

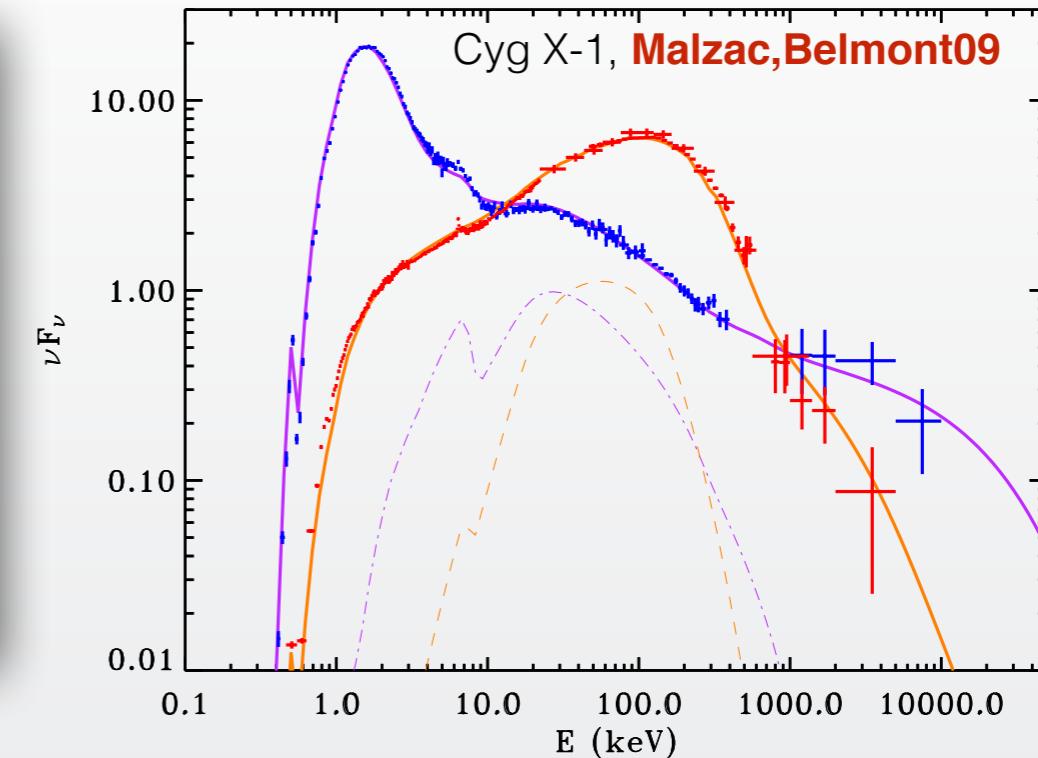
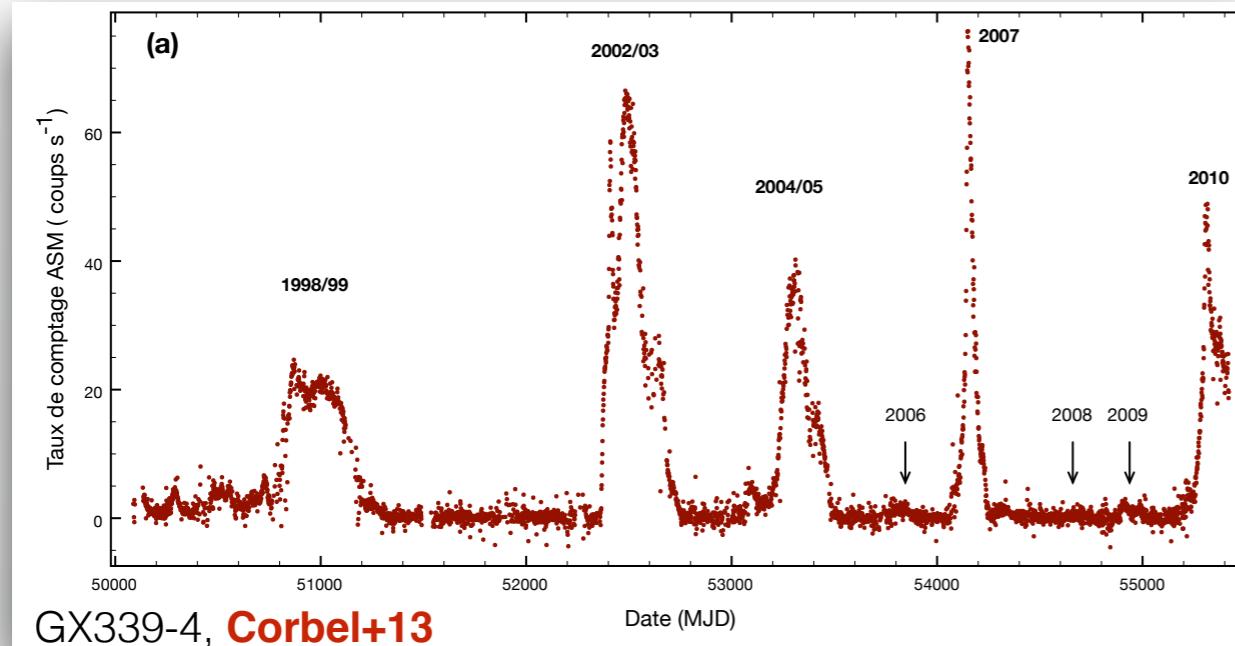
- Test of ASICS and CdTe detectors on HXI and SGD + calibration
- CEA/APC: P. Laurent, O. Limousin, A. Goldwurm
- Team-member time + 10% of observatory time for ESA

BH Binaries

- BH spectral states
- Corona
- Jet emission
- X-Radio correlation
- Disk Winds
- Hard tails



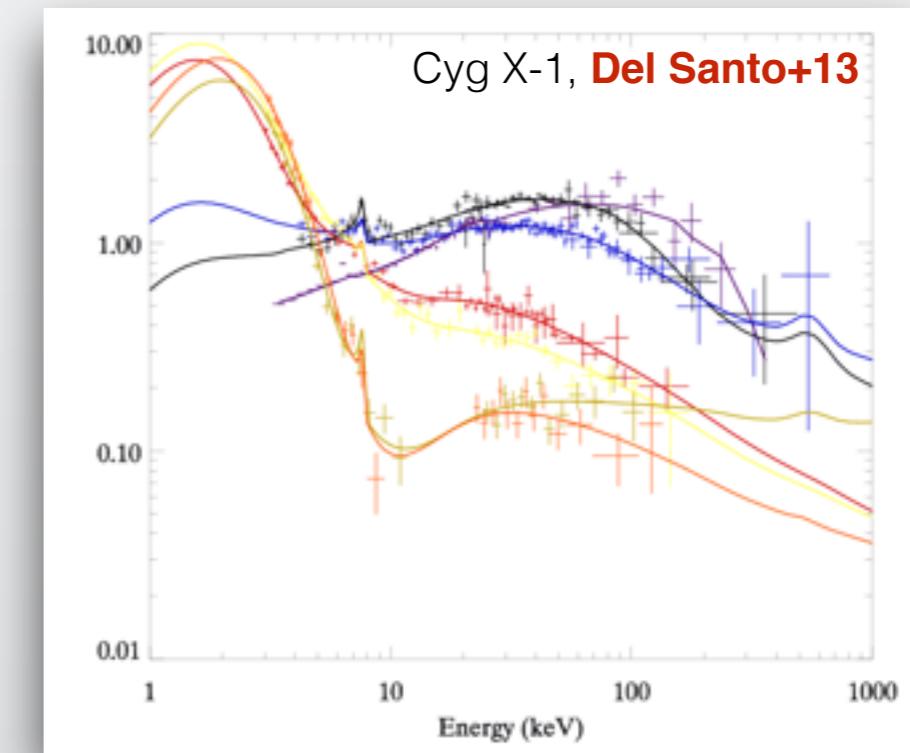
BHB Spectral States



- **Transient sources**
 - ▶ Accretion rate variations

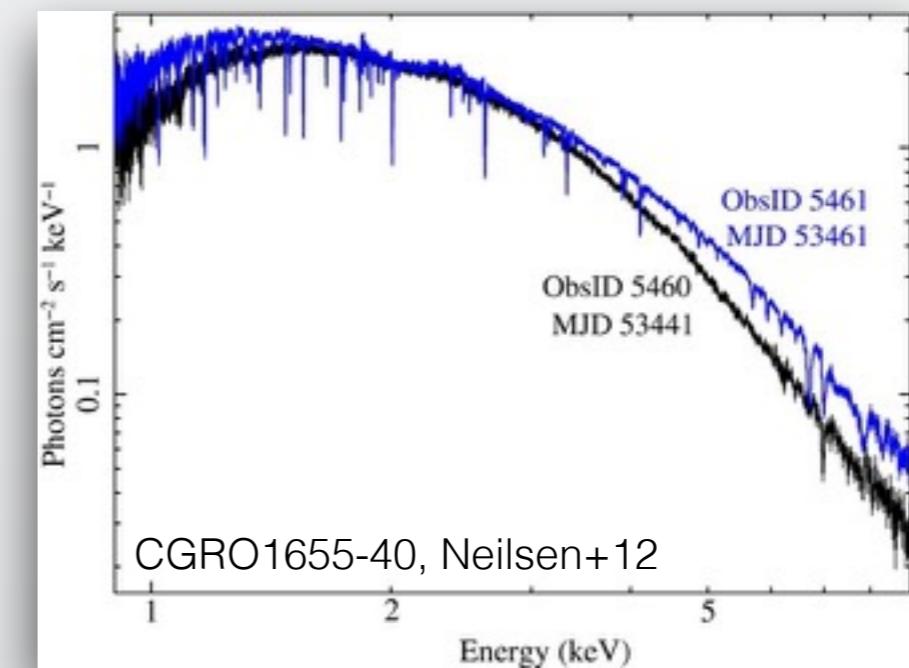
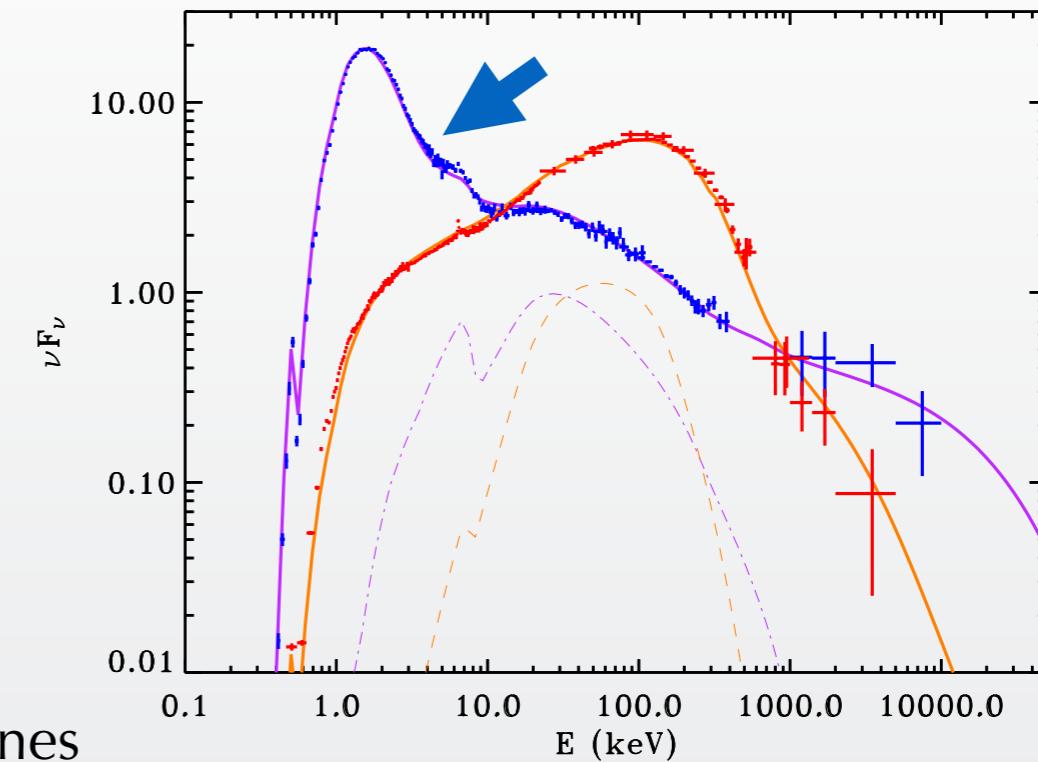
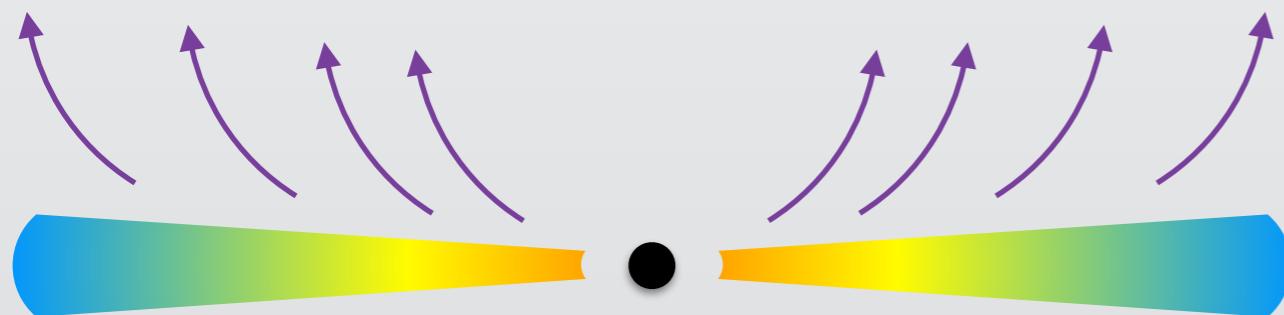
- **Dichotomy**
 - ▶ High/soft State
 - ▶ Low/hard State

- **Transitions**
 - ▶ Intermediate states
 - ▶ Hysteresis Cycle => HID



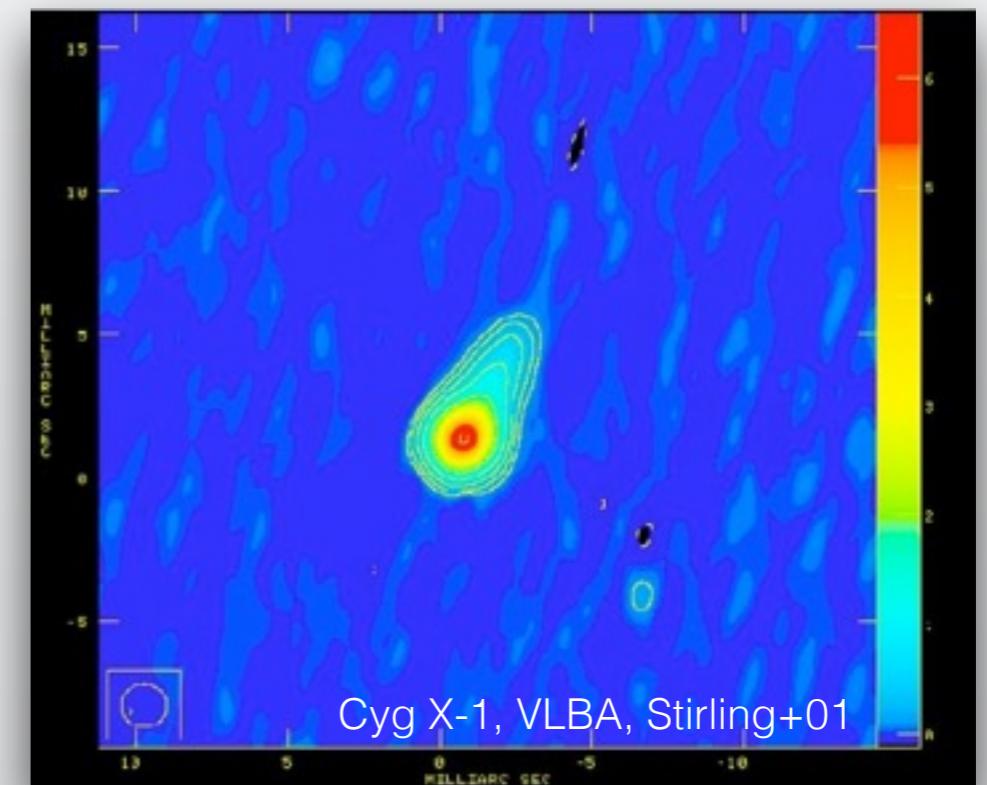
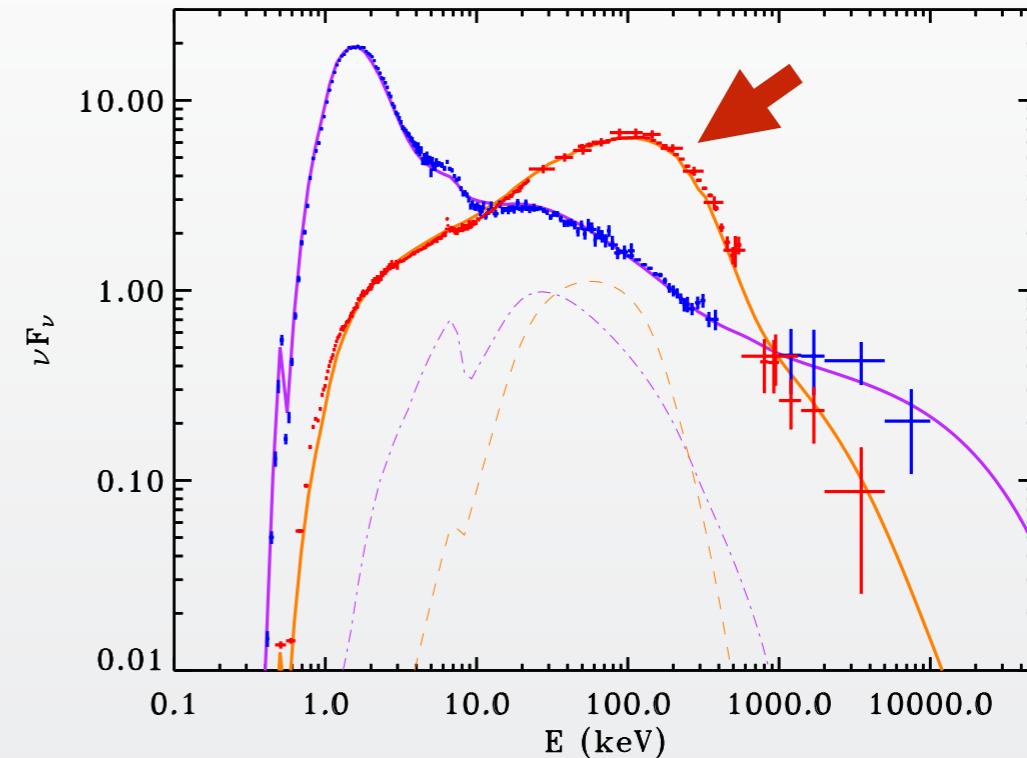
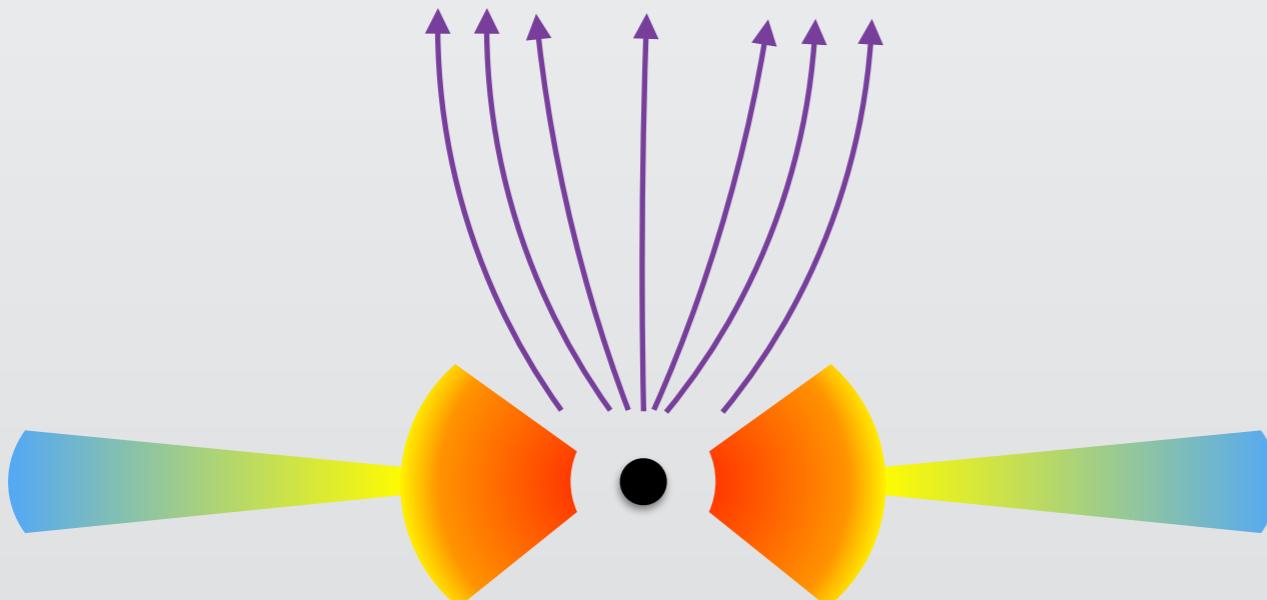
The High/Soft State

- **High accretion rate ($L > 0.01$ Ledd)**
- **BB disk 1 keV**
 - ▶ Alpha-disc model (Shakura,Sunyaev73)
- **Hard tail**
 - ▶ non-thermal comptonization => corona
- **Disk Winds (Diaz-Trigo+12, Ponti+12)**
 - ▶ Highly ionised Fe XXV/XXVI absorption lines
 - ▶ Strong mass outflow
 - ▶ Velocities 1000 km/s
 - ▶ Mostly equatorial



The Low/Hard State

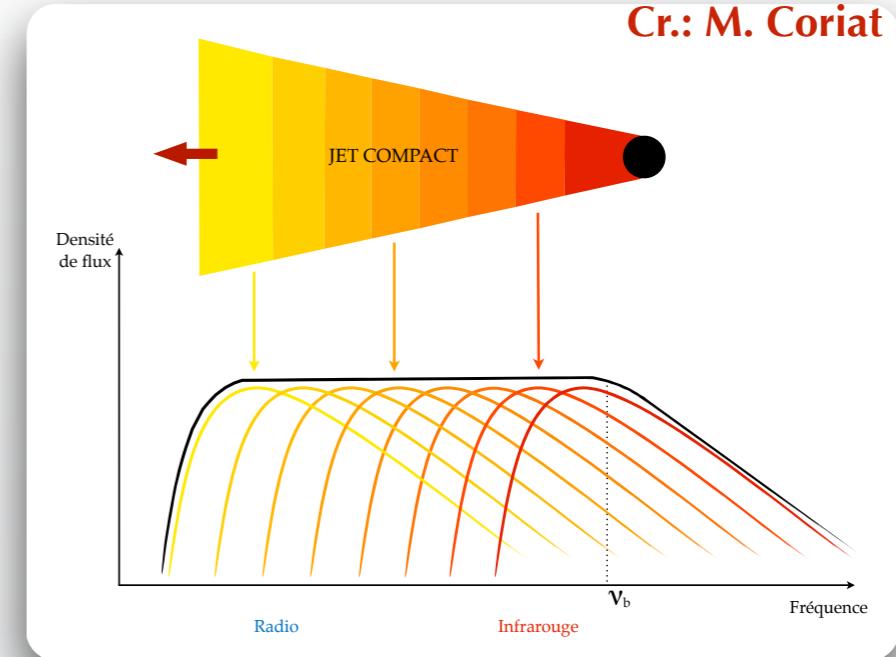
- **Low accretion rate ($L < 0.1 L_{\text{Edd}}$)**
- **Weak, low-T disc or no disc**
- **Cutoff power-law**
 - ▶ Thermal comptonisation
 - ▶ Corona ($kT=100 \text{ keV}$, $\tau=1$)
 - ▶ Radiatively inefficient flow
 - e.g. JED (Petrucci+08,10)
- **High energy tail ($>500 \text{ keV}$)**
- **Compact Jets**



Modelling the Jet emission

- **Flat radio spectrum** (Blandford,Koenig79)

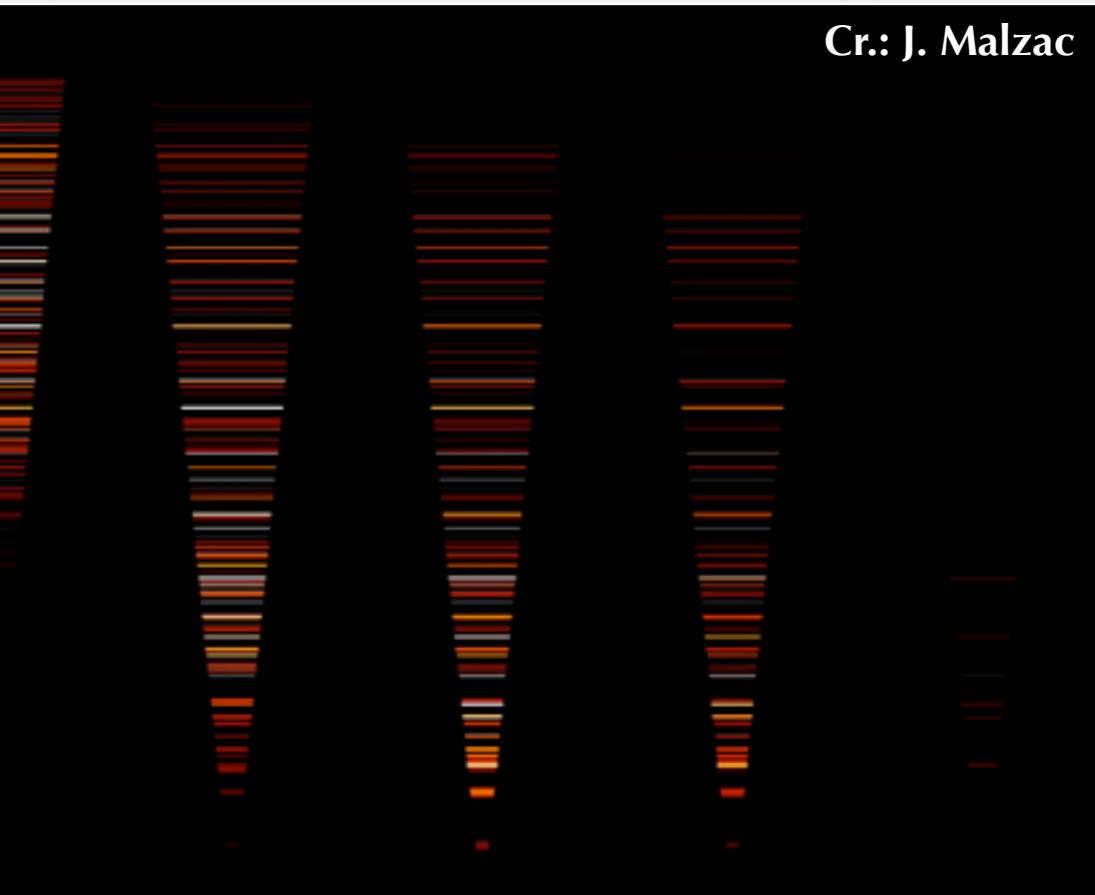
- Break in the mid-IR (Chaty+11,Rahoui+12)
- Non-thermal electrons
- Decreasing density only (uniform energy)



- **Adiabatic cooling => need for continuous acceleration**

- **Internal Shocks model** (GRB, Jamil+10, Malzac13,14)

- shell ejected with random velocities
- shocks => particle acceleration
- synchrotron emission



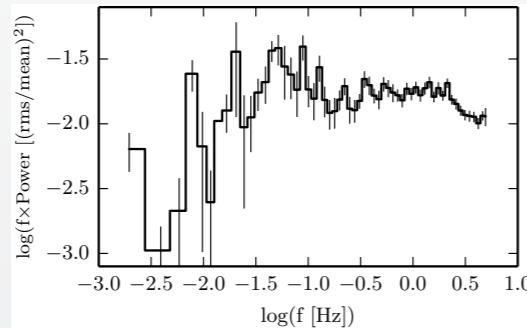
- **Photon spectrum depends on the shell statistics**

- Flicker noise ($1/f$) produces a flat photon spectrum

Modelling the Jet emission

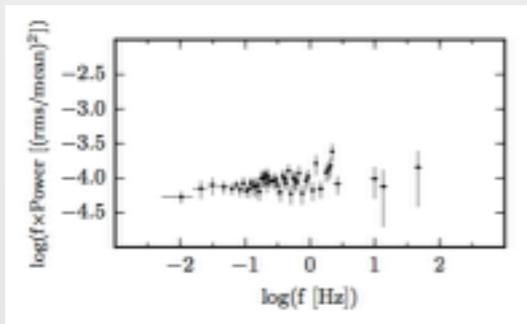
- Feeding the jet with observed disk (X-ray) fluctuations

- Hard state (Drappeau+15):



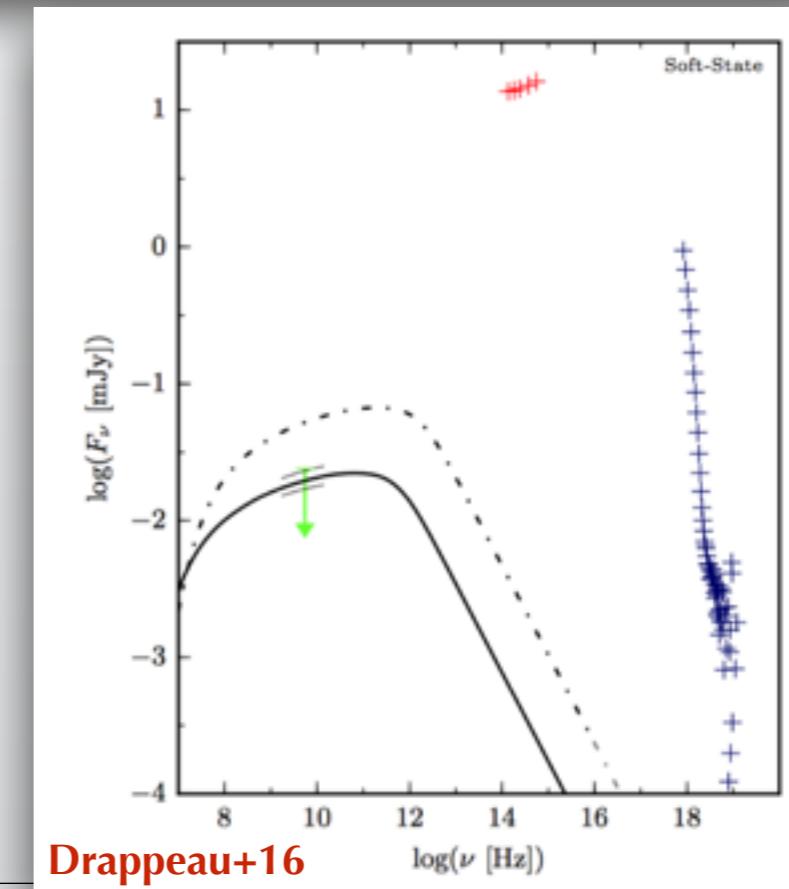
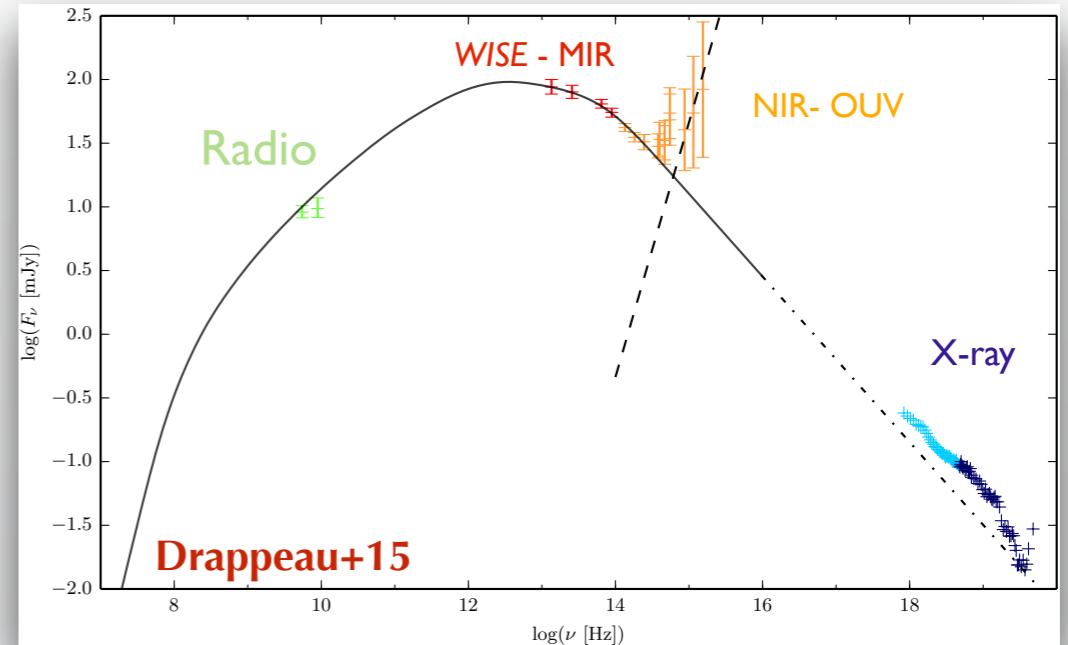
- Reproduces the spectrum
- Reproduces the variability

- Soft state (Drappeau+16, in prep.):



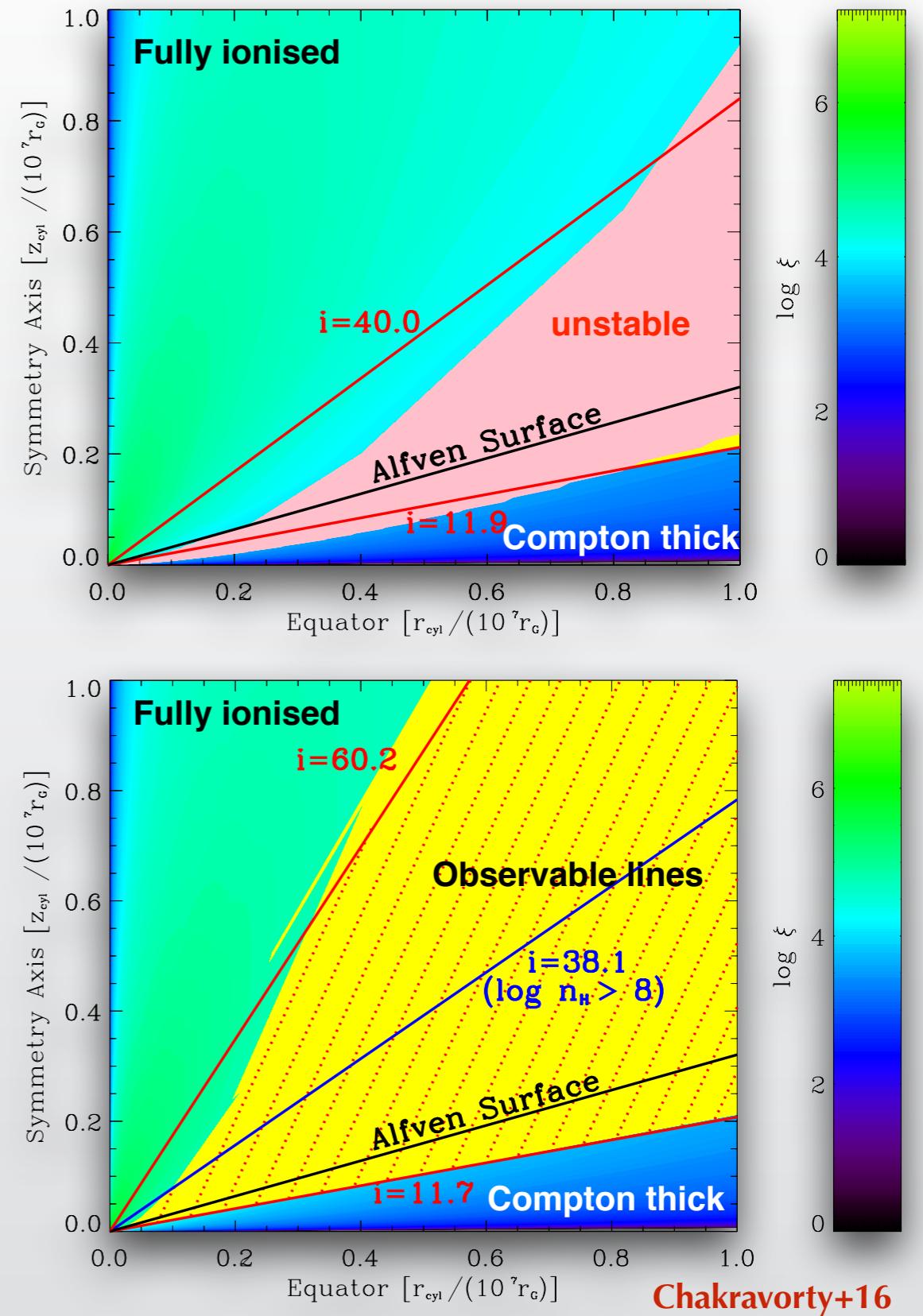
- Compatible with upper limits
- No/weak change in the kinetic jet power
- => Cold, dark jet?

- Towards a unified view...



Disk Wind Emission

- Disk winds only observed in the soft state
 - blue-shifted absorption lines
- Can result from changes in
 - Ionising flux (Miller+12)
 - MHD properties of the outflow (Neilsen+11, 12)
- Recent results combining:
 - Self-similar MHD solutions for accretion-ejection (Ferreira+97, Casse+00, Ferreira04, 06)
 - Line diagnostic with Cloudy (Chakravorty+16):
- Hard-States:
 - Winds are thermo-unstable at the relevant ξ and cannot be observed
- Soft-States:
 - Winds can be observed at high inclination
 - Density/velocity constrain the flow properties:
 - Strong outflow
 - Additional dissipation in the disk upper layers



High Energy Tails

- MeV detection in the hard state of a few sources

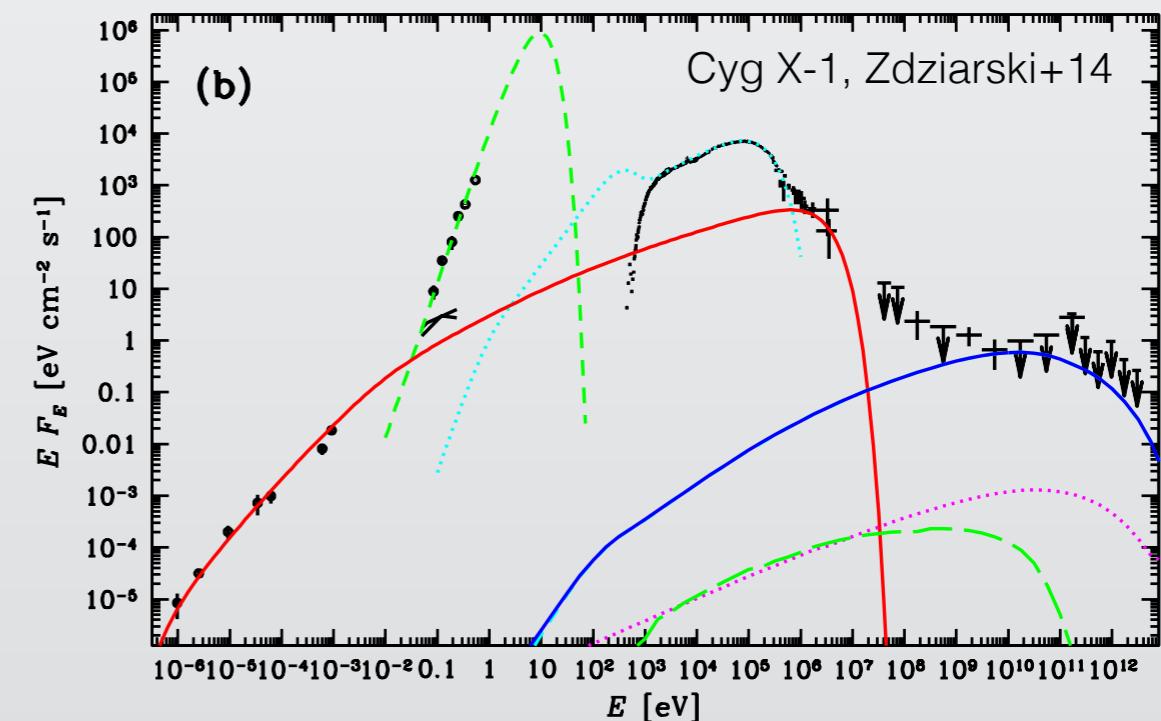
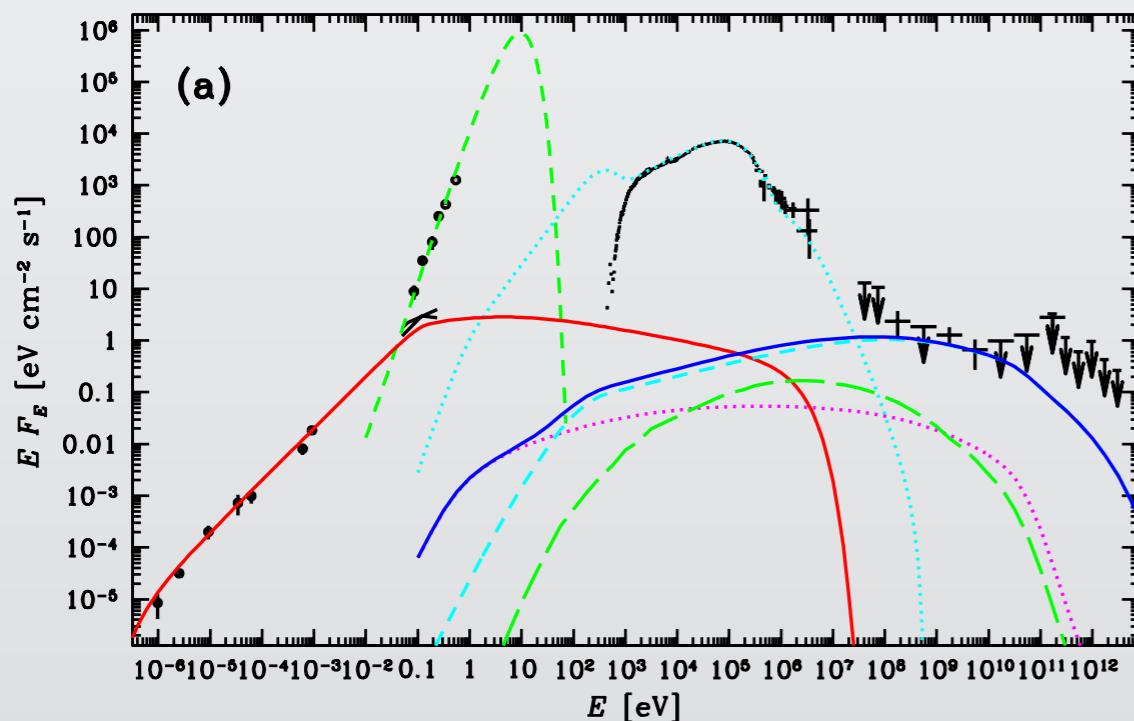
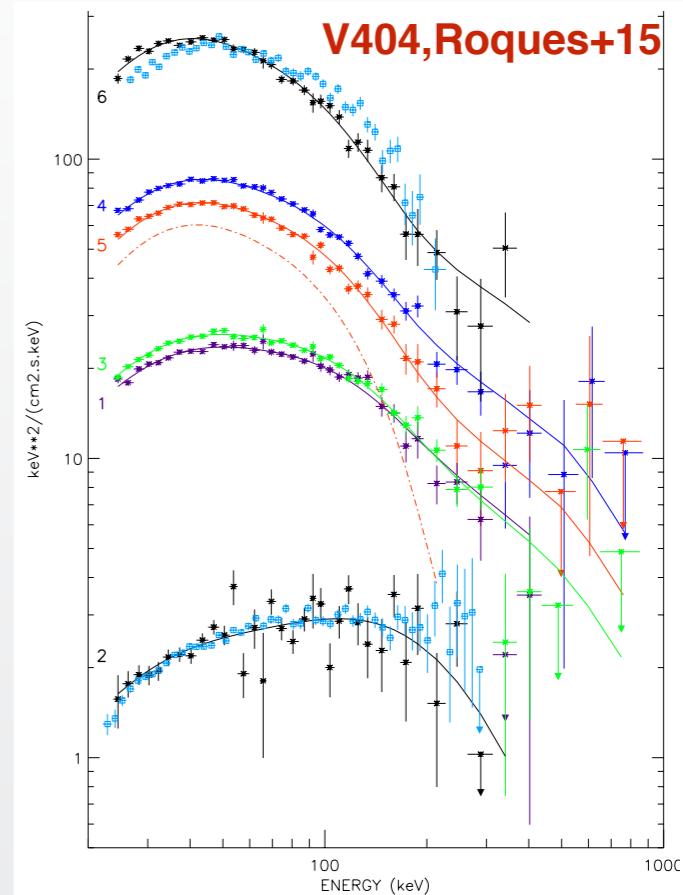
- e.g. GX339-4 (Droulans+10), Cyg X-1 (Del Santo+13, Roques+15)

- GeV detection of Cyg X-1 with Fermi (Malyshev+13, Bodaghee+13)

- Following Agile detection (Sabatini+10,13)
- In the hard state essentially

- Debated origin:

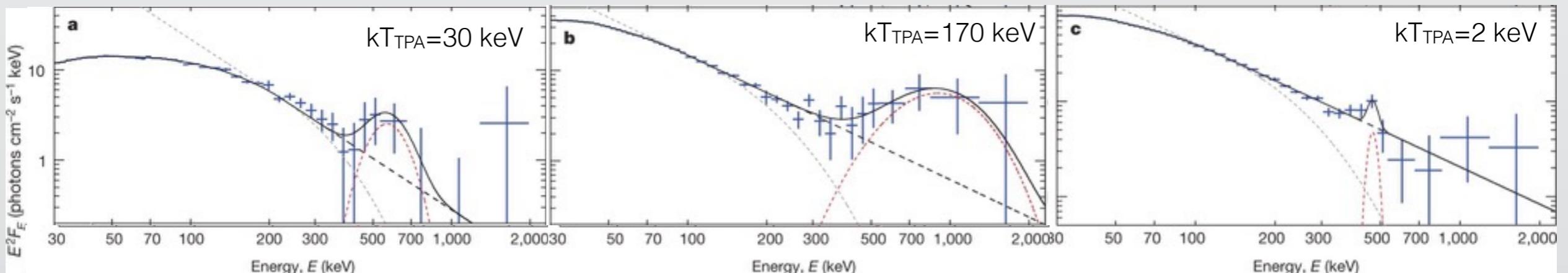
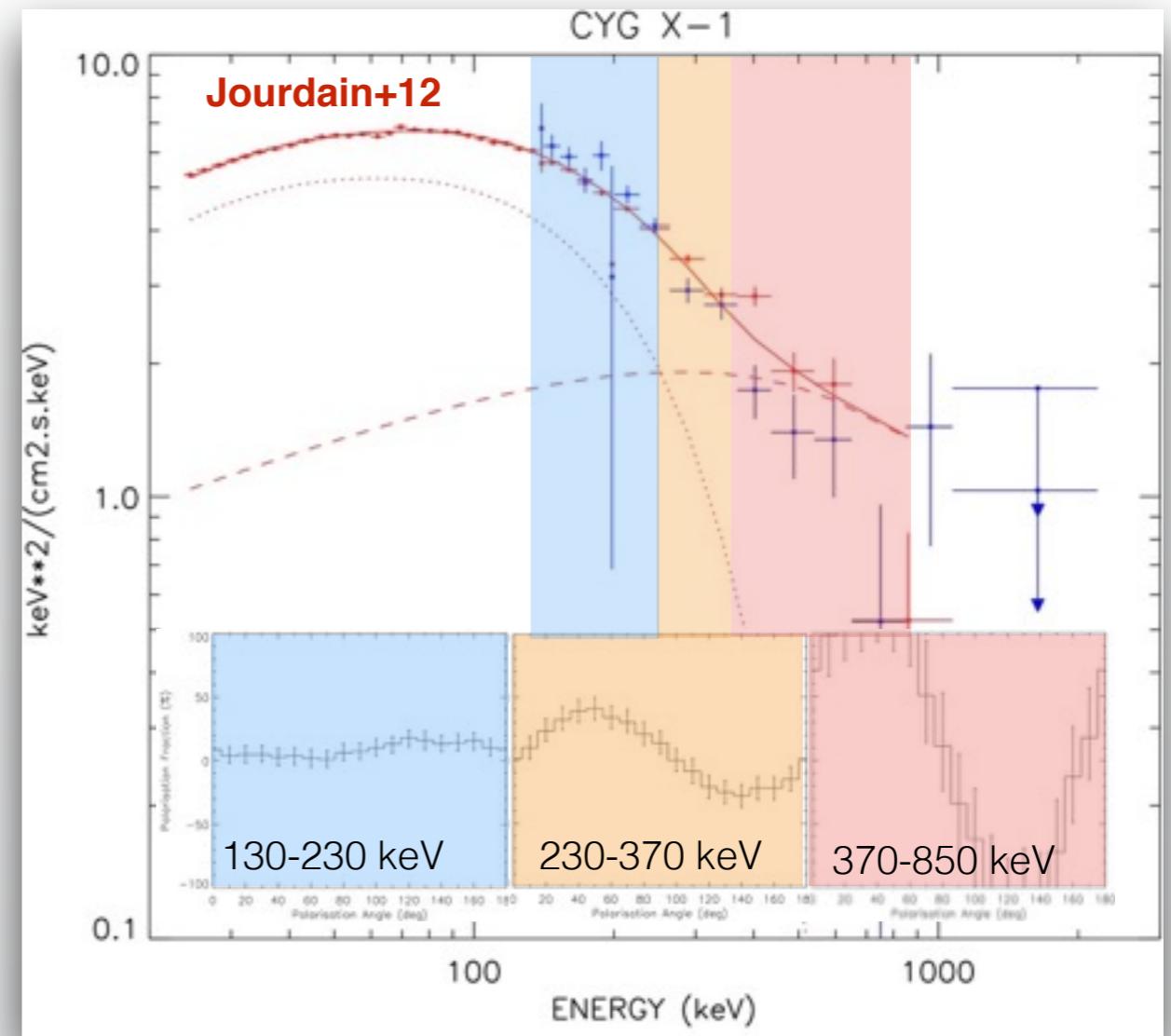
- Internal non-thermal particles aka “hybrid comptonisation” (Malzac+10, Droulans+10, Del Santo+13)
- Jet contribution (Markoff+)



The High Energy Tails

- **Polarisation of Cyg X-1 detected with Integral** (Laurent+11,Jourdain+12,Rodriguez+15)
 - Independent detections (IBIS/SPI)
 - Linear polarisation
 - Strong (70%)
 - Favours synchrotron contribution from the jet
 - Requires hard electron distributions ($p=1.5$)

- **Strong outburst of V404 Cygni** (Siegert +16,Roques+15,Roques+16)
 - Very luminous (up to 40Crab)
 - Rapid variability
 - Integral/SPI: annihilation line?

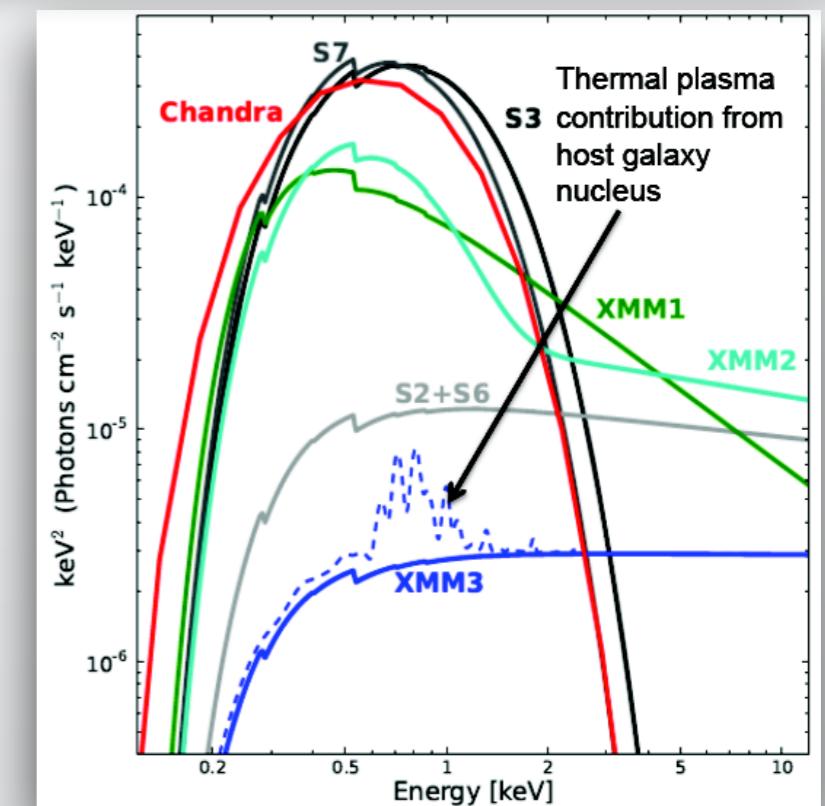
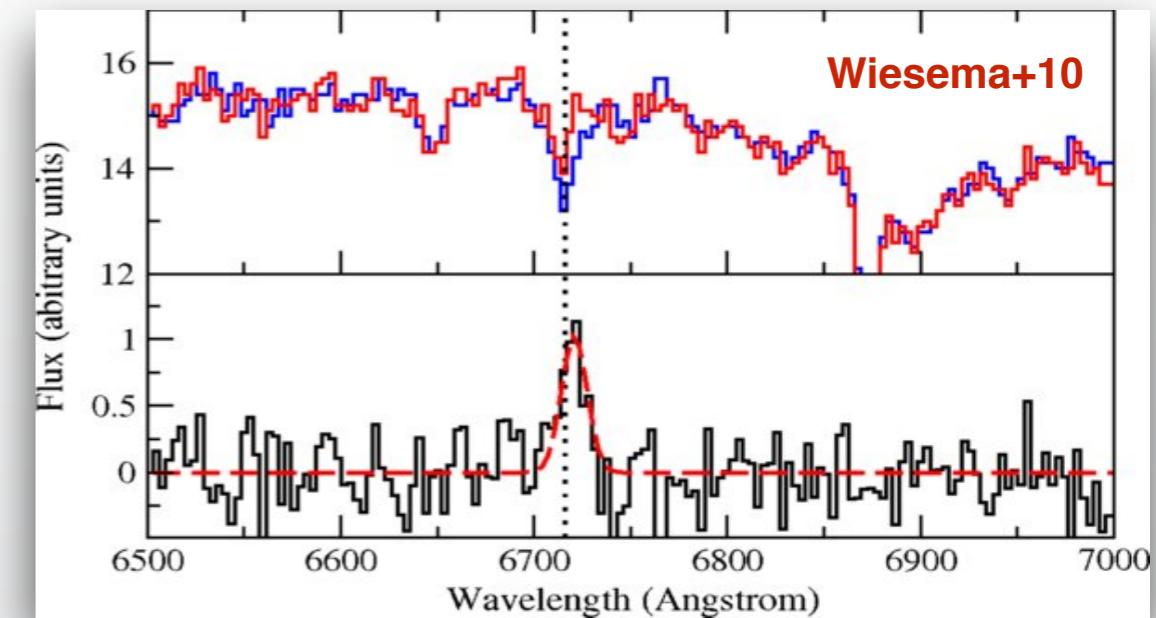


Intermediate-Mass BH

- IMBH: $10^2 < M/M_\odot < 10^5$
- Interesting objects:
 - the missing link
 - formation scenario
 - role in globular clusters
 - role in cosmological ionisation
- HLX-1 first strong case for an IMBH (Farell+09, Nature)
 - If associated to the galaxy: $L = 10^{42} \text{ erg/s} = 10 L_{\text{Edd}} (M/500 M_\odot)^{-1}$
 - Debated distance...

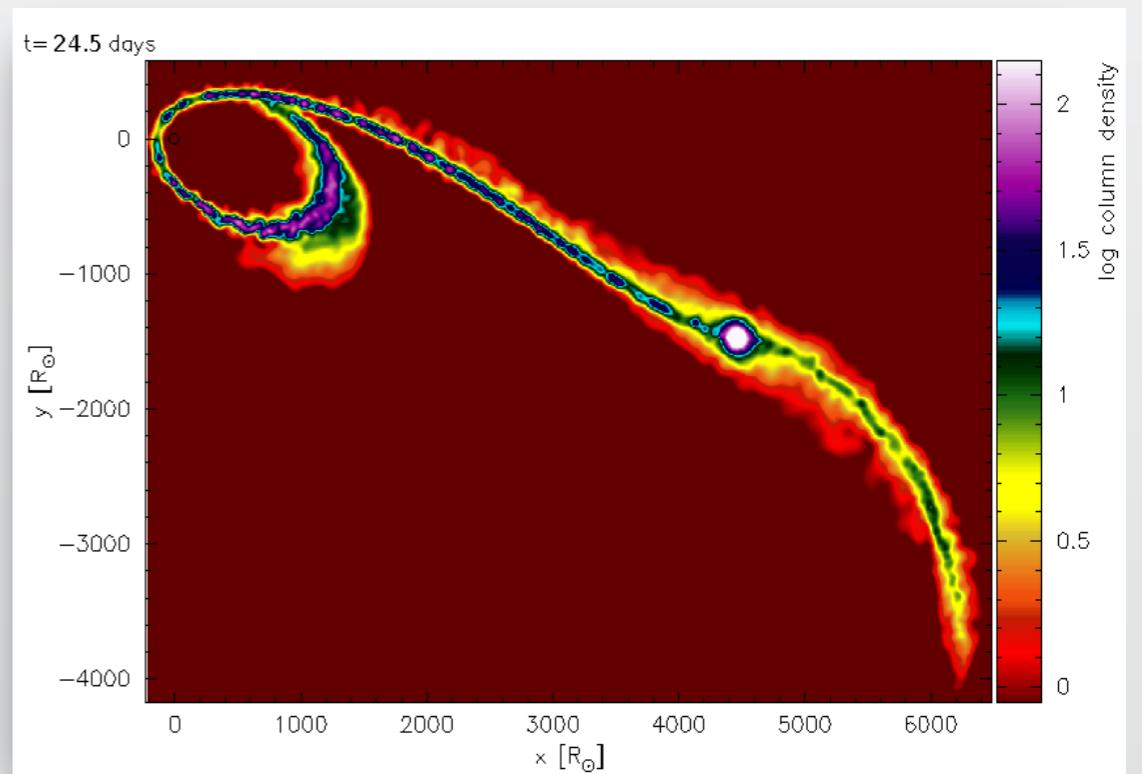
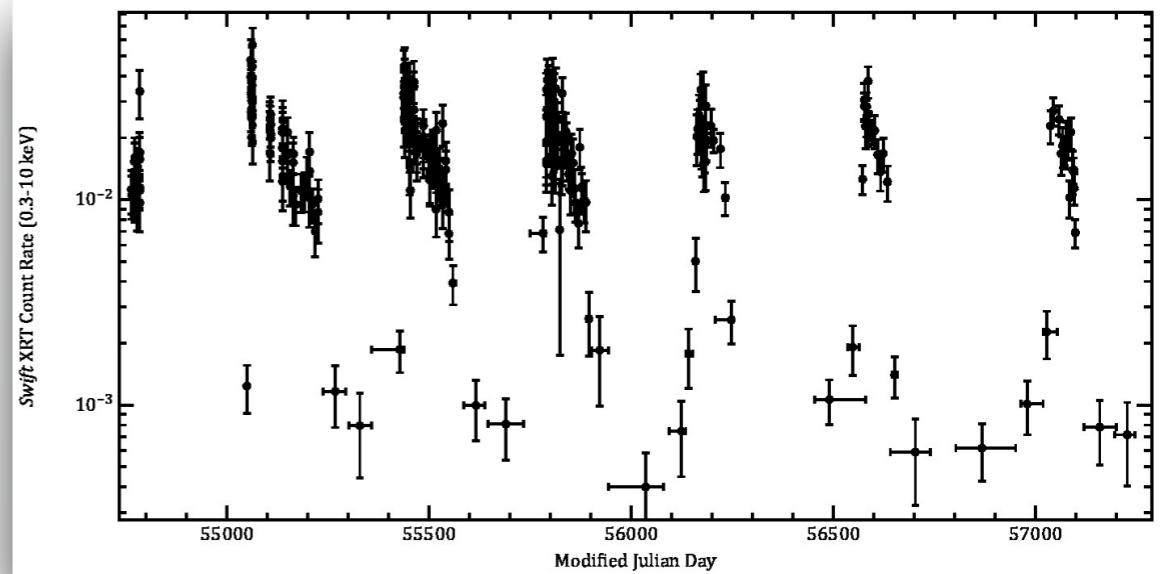
HLX-1

- ◎ Multi-Lambda follow-up: growing evidence for a IMBH
- ◎ H α line: redshift (Wiesema+10)
- ◎ Spectral states (Godet+09,11, Davis+11, Servillat +11, Straub14)
 - Hard/Soft transitions
 - Fits with relativistic disk models: $M=10^3-10^5 M_\odot$
- ◎ Radio flares (Webb+12):
 - As in galactic BH
 - Fundamental plane $\Rightarrow M=10^4-10^5 M_\odot$



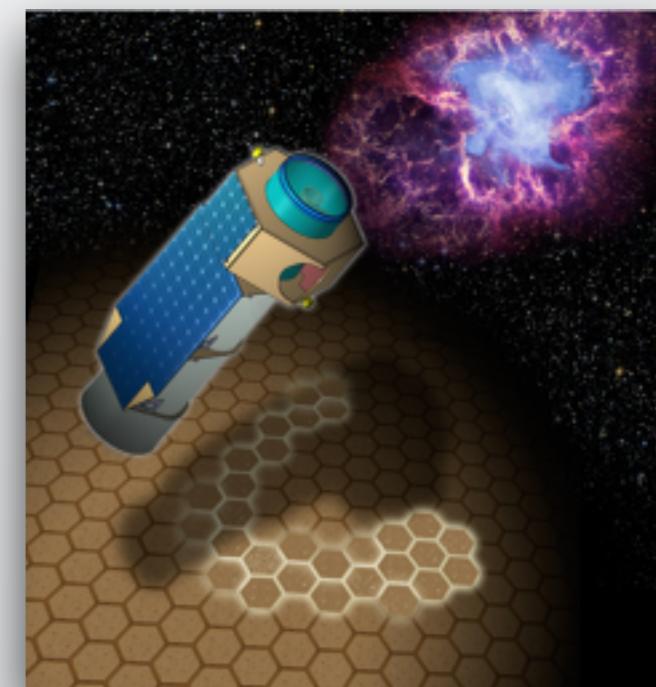
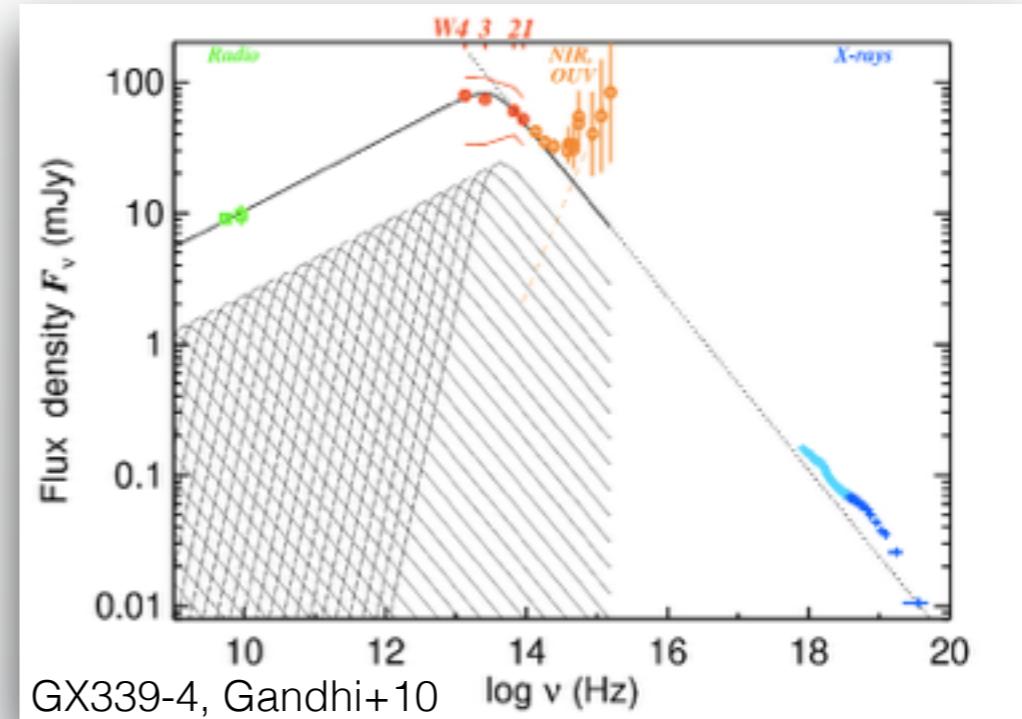
HLX-1

- **Constraints on its environment**
 - ▶ Globular cluster ([Farell+12, Webb+14](#))
- **Periodic light curve**
 - ▶ Companion star with eccentric orbit ([Lasota+11](#))
 - ▶ Evolution of amplitude & period
 - ▶ Due to tidal effects + mass transfer
 - ▶ Confirmed by SPH simulations for a near parabolic orbit ([Godet+14](#))
- **Next:**
 - ▶ HST, VLT, XMM, NuStar, Muse data being analysed
 - ▶ Search for other candidates
 - ▶ Search for low-mass SMBH in galaxies ([Graham+13](#))



Conclusion

- **Broad band observations**
 - e.g. IR: jet break in XRB
- **Simultaneous observations**
 - Strong variability
 - Correlations/Lags => Geometry
- **High resolution spectra**
 - Iron Line, Winds...
- **Polarisation:**
 - Many proposed missions:
NHXM, PHENIX, POLARX, GEMS, Hitomi...
 - XIPE



Hitomi Status

Communication failure of X-ray Astronomy Satellite “Hitomi” (ASTRO-H)

March 27, 2016 (JST)

National Research and Development Agency
Japan Aerospace Exploration Agency (JAXA)

The Japan Aerospace Exploration Agency (JAXA) found that communication with the X-ray Astronomy Satellite “Hitomi” (ASTRO-H), launched on February 17, 2016 (JST), failed from the start of its operation originally scheduled at 16:40, Saturday March 26 (JST). Up to now, JAXA has not been able to figure out the state of health of the satellite.

While the cause of communication failure is under investigation, JAXA received short signal from the satellite, and is working for recovery.

Under this circumstance, JAXA set up emergency headquarters, headed by the President, for recovery and investigation. The headquarters held its first meeting today, and has been working for recovery and the investigation of the cause. Updates will be announced as available, at the JAXA website.

Mar. 29, 2016 Updated

Current Status of Communication Anomaly of X-ray Astronomy Satellite “Hitomi” (ASTRO-H) (Mar. 29)

The Japan Aerospace Exploration Agency (JAXA) has been trying to communicate with the X-ray Astronomy Satellite “Hitomi” (ASTRO-H), using ground stations both in Japan and overseas.

By utilizing two opportunities of communicating with Hitomi, JAXA received signals from the satellite: the first time was at about 10:00 p.m. on 28 at the Uchinoura Ground Station, and the second one was at around 0:30 a.m. on 29 at the Santiago Tracking Station in Chile. JAXA has not been able to figure out the state of its health, as the time frames for receiving the signals were very short.

According to the U.S. Joint Space Operations Center (JSPOC), it is estimated that Hitomi separated to five pieces at about 10:42 a.m. In order to investigate the situation, JAXA is observing the objects, using a radar located at the Kamisaibara Space Guard Center (KSGC) and telescopes at the Bisei Space Guard Center (BSGC) owned by the Japan Space Forum. Up to now, the telescopes at BSGC detected two objects around the satellite’s original orbit, while the radar at KSGC identified one of them. It is confirmed that the signal received at the Santiago Tracking Station came from the orbital direction of the object identified at KSGC.

JAXA continues to investigate the relationship between the information announced by JSPOC and the communication anomaly.

JAXA will continue to do its best to recover communications with Hitomi and investigate the cause of the anomaly.