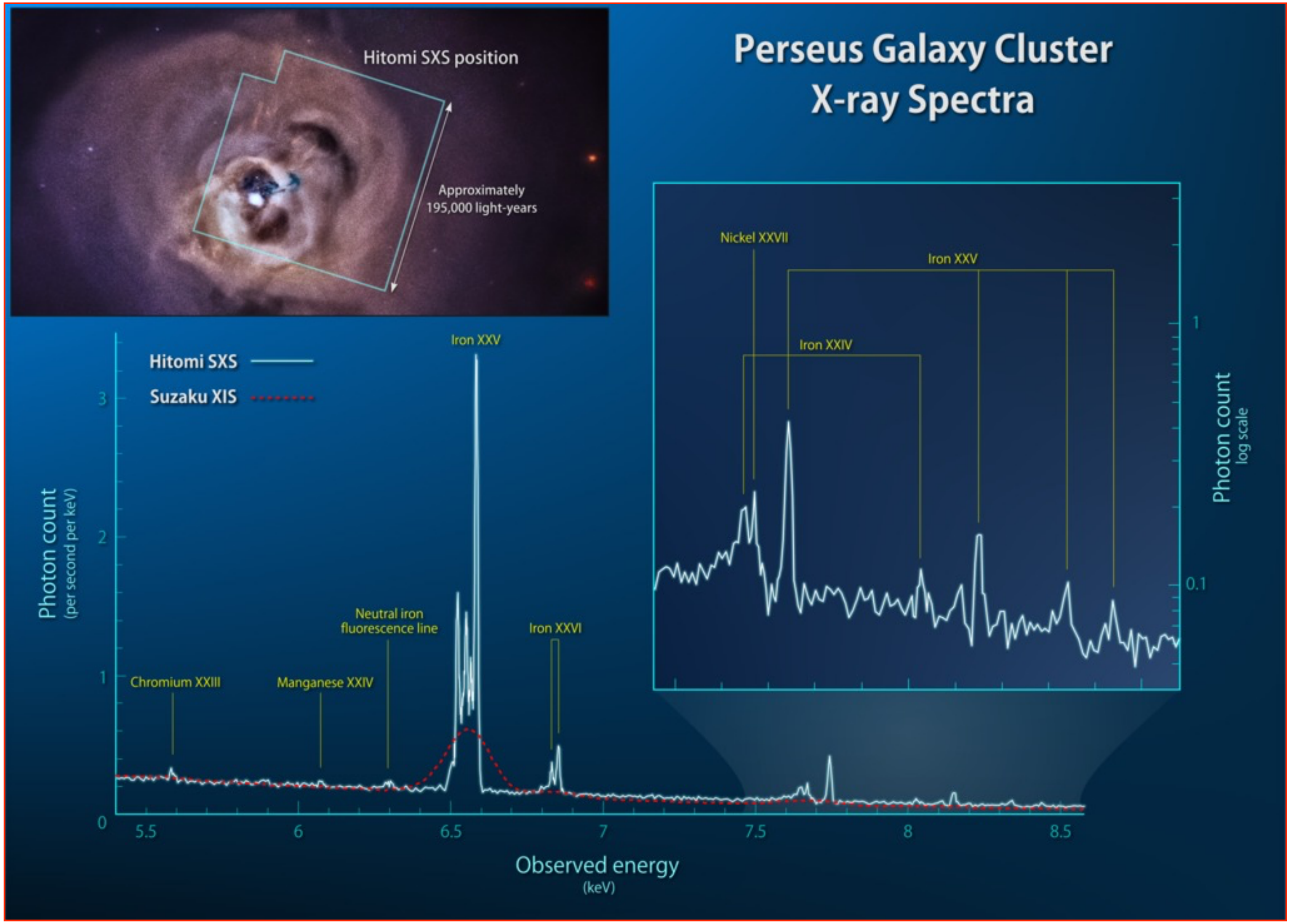
Astrofisica Nucleare e Subnucleare
Accretion power in astrophysics

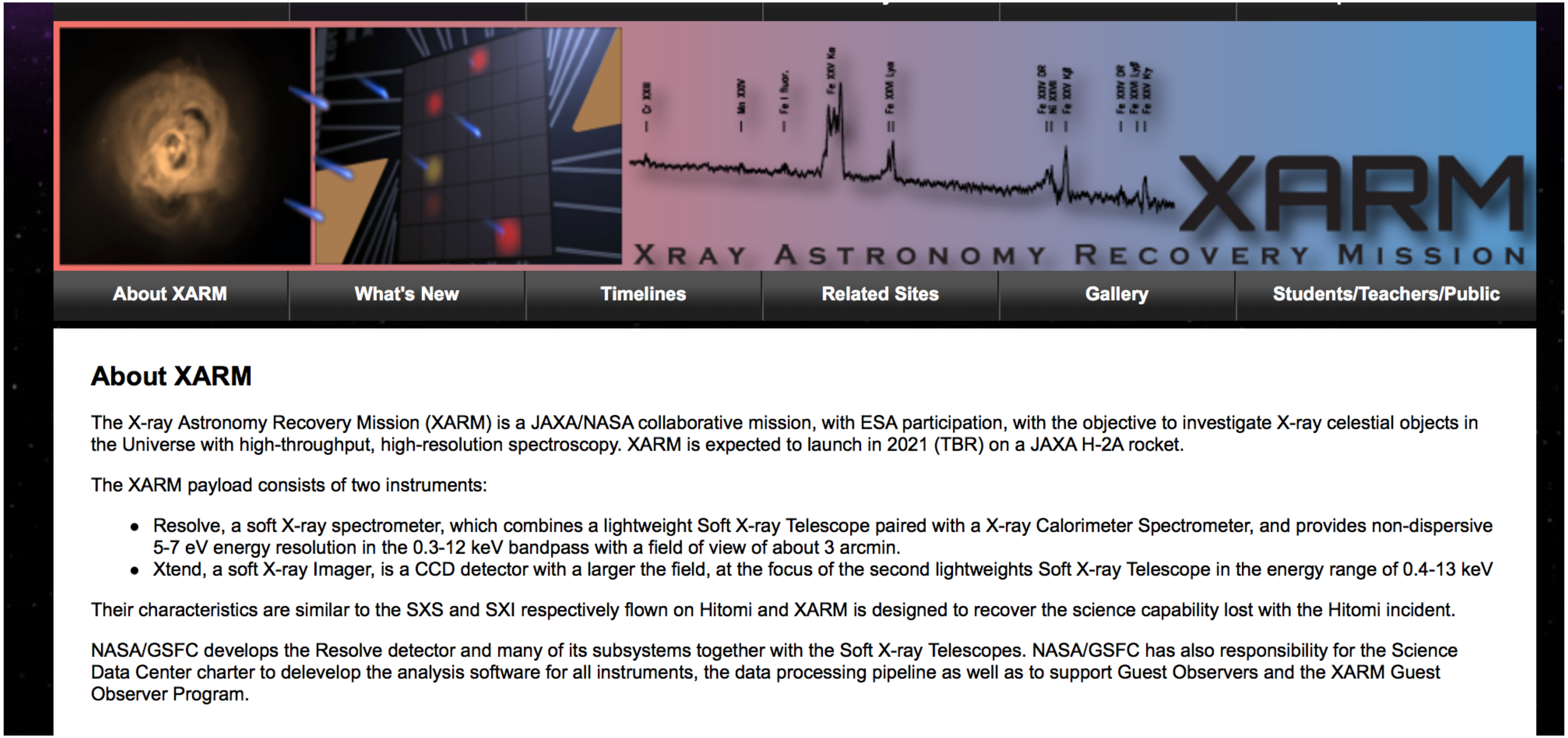
Astro-H – Hitomi

http://astro-h.isas.jaxa.jp/en/

Astro-H results



XARM



About XARM

The X-ray Astronomy Recovery Mission (XARM) is a JAXA/NASA collaborative mission, with ESA participation, with the objective to investigate X-ray celestial objects in the Universe with high-throughput, high-resolution spectroscopy. XARM is expected to launch in 2021 (TBR) on a JAXA H-2A rocket.

The XARM payload consists of two instruments:

- Resolve, a soft X-ray spectrometer, which combines a lightweight Soft X-ray Telescope paired with a X-ray Calorimeter Spectrometer, and provides non-dispersive 5-7 eV energy resolution in the 0.3-12 keV bandpass with a field of view of about 3 arcmin.
- Xtend, a soft X-ray Imager, is a CCD detector with a larger the field, at the focus of the second lightweights Soft X-ray Telescope in the energy range of 0.4-13 keV

Their characteristics are similar to the SXS and SXI respectively flown on Hitomi and XARM is designed to recover the science capability lost with the Hitomi incident.

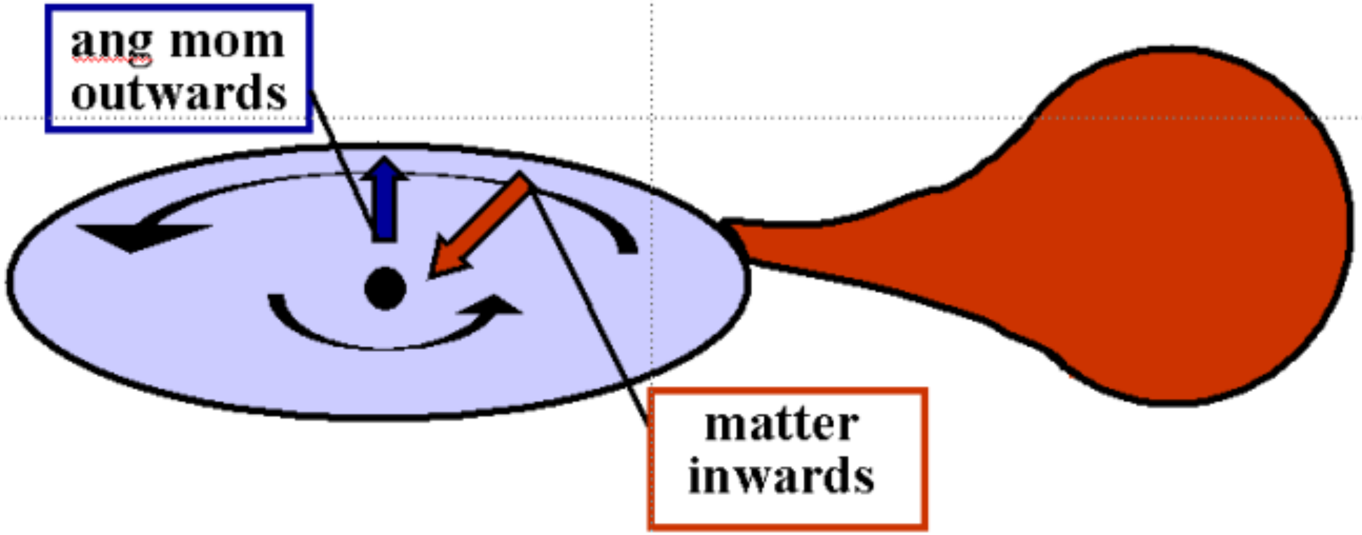
NASA/GSFC develops the Resolve detector and many of its subsystems together with the Soft X-ray Telescopes. NASA/GSFC has also responsibility for the Science Data Center charter to delevelop the analysis software for all instruments, the data processing pipeline as well as to support Guest Observers and the XARM Guest Observer Program.

https://heasarc.gsfc.nasa.gov/docs/xarm/about/

Galactic Sources

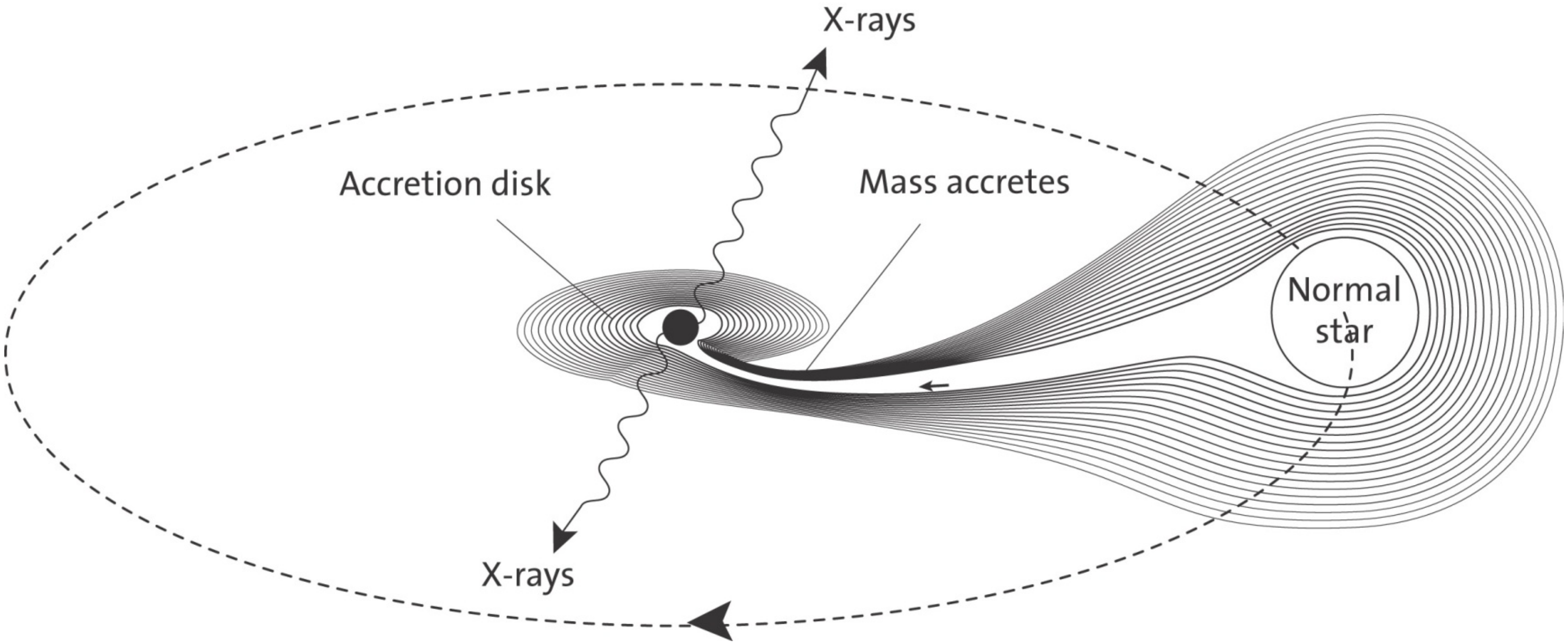
Accretion disk formation

Matter circulates around the compact object:

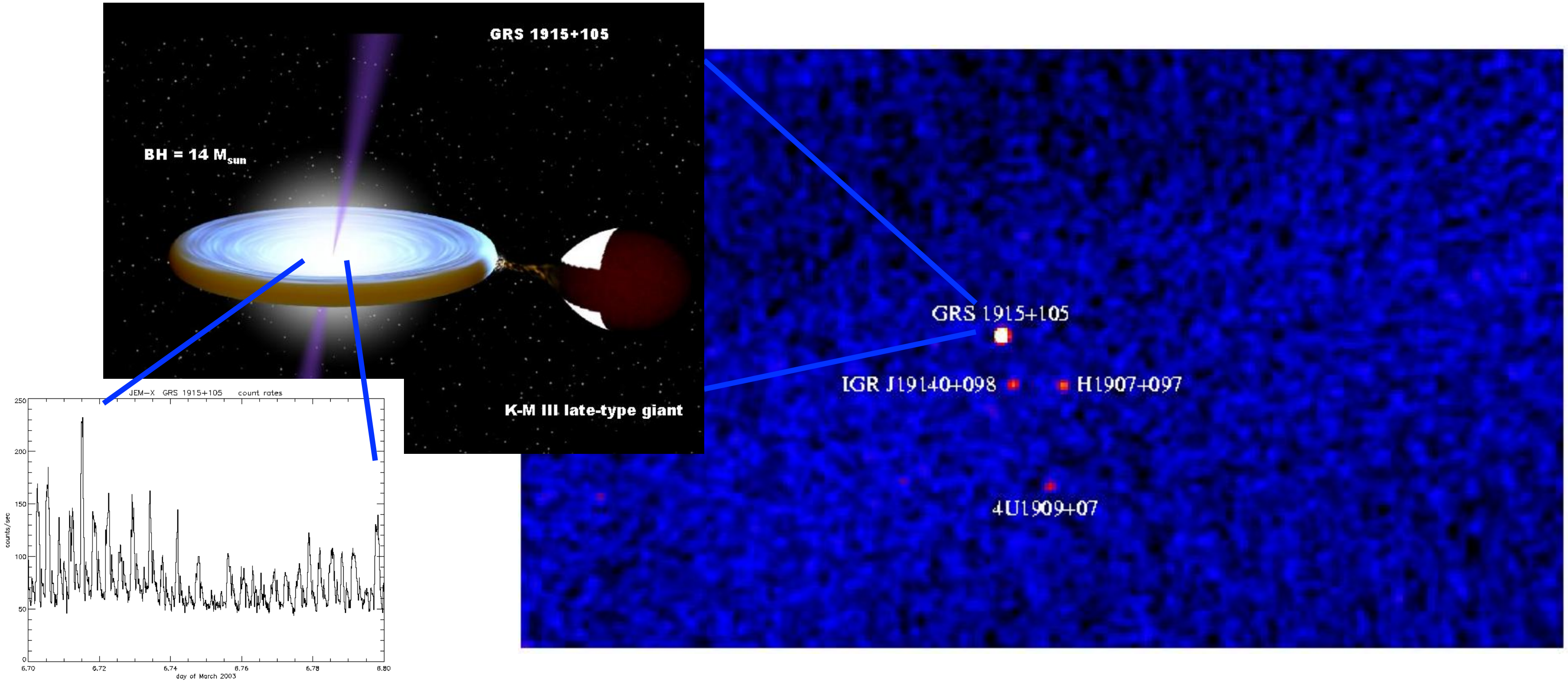


Galactic Sources

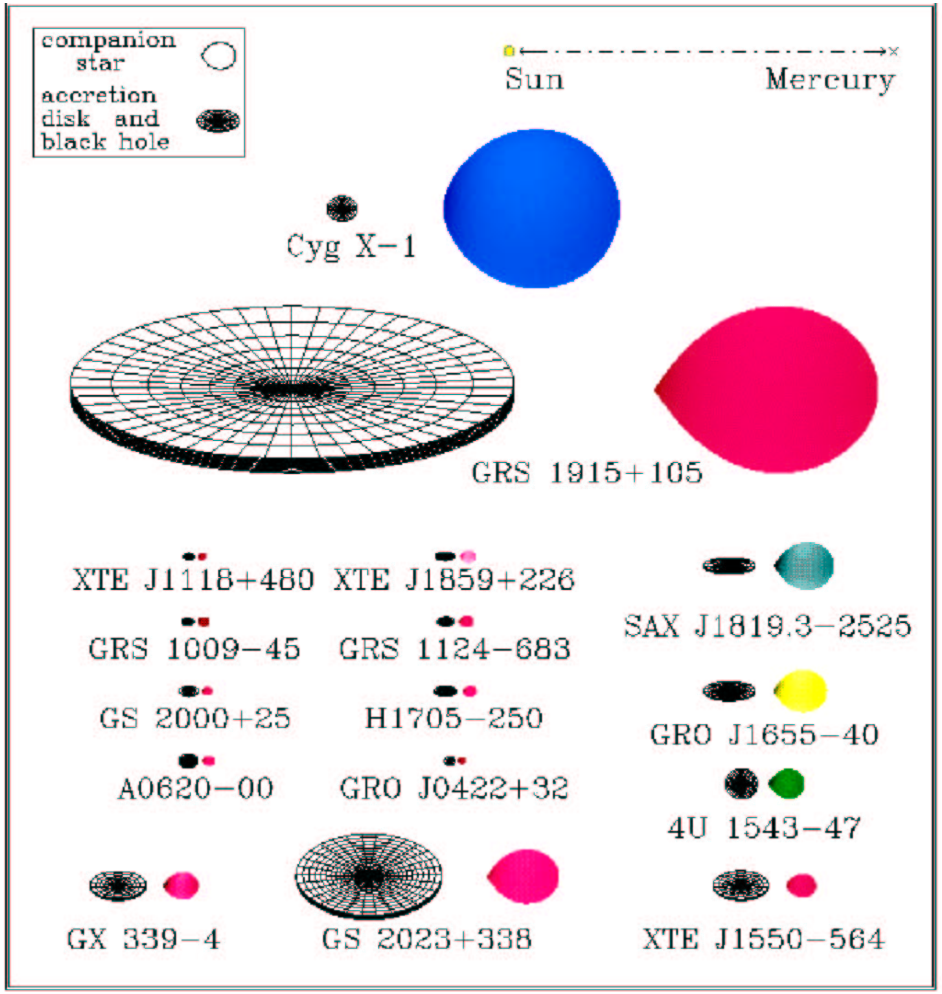
- Nobel Prize 2002:
  - Riccardo Giacconi “for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources”



Galactic Sources

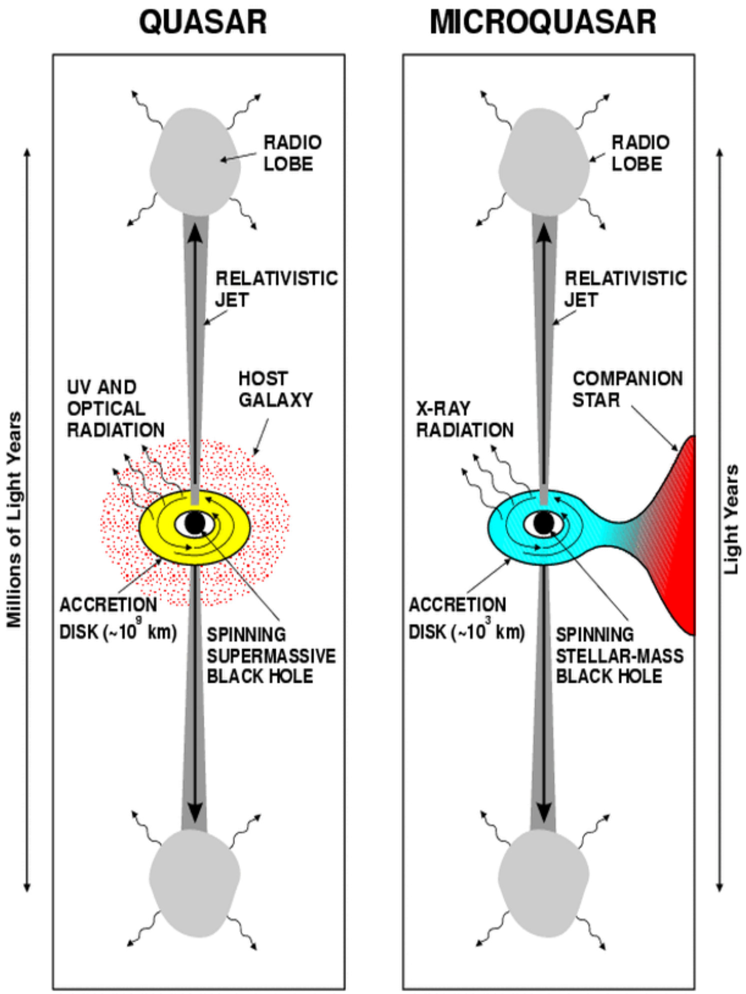


Galactic Sources

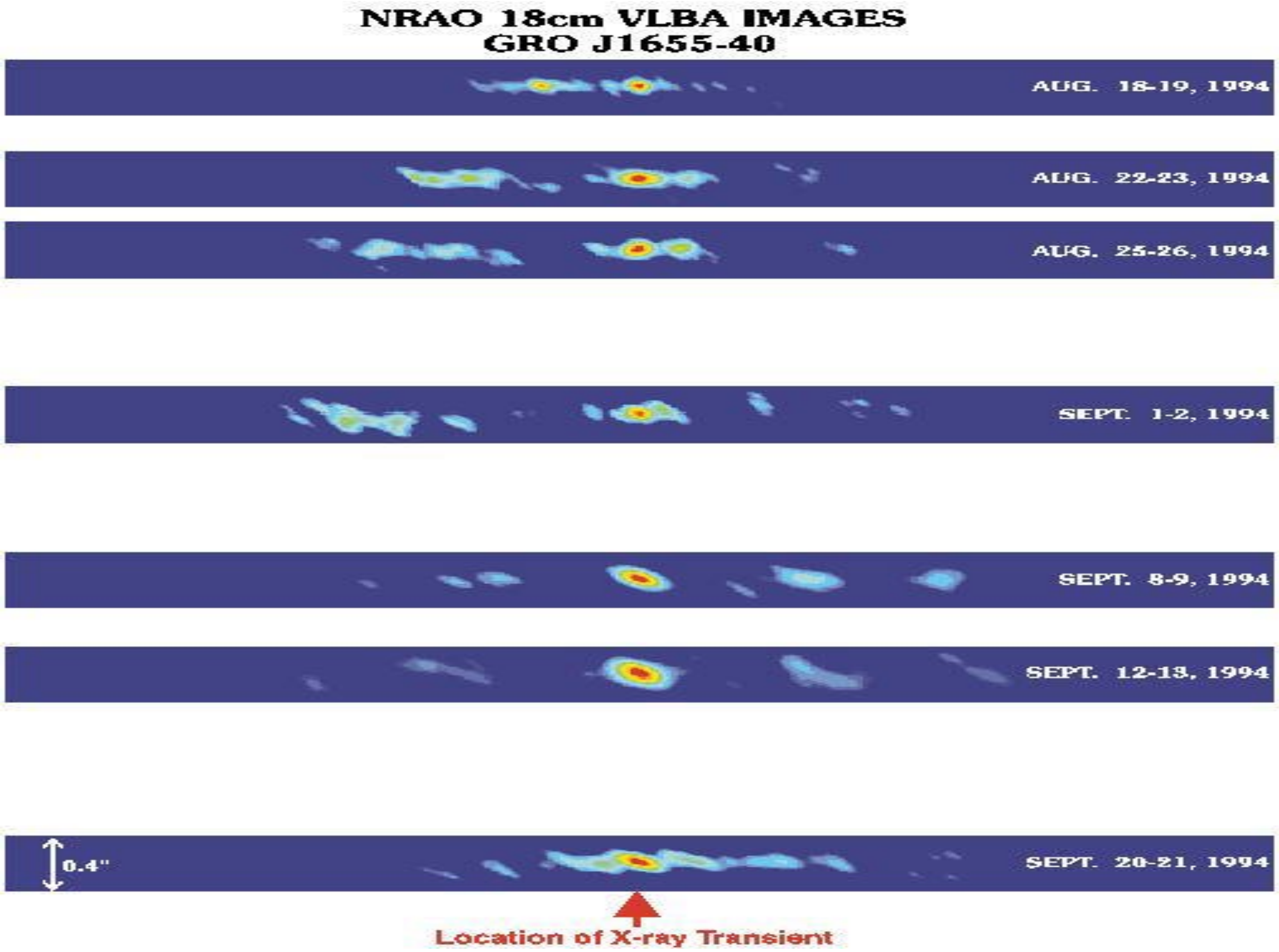


Credit: Jerome A. Orosz

Galactic Sources



Galactic Sources



Accretion Power

Accretion onto a compact object

- Principal mechanism for producing high-energy radiation
- Most efficient of energy production known in the Universe.

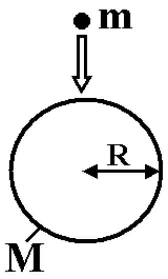
$$\boxed{E_{acc} = G\frac{Mm}{R}}$$

Gravitational potential energy released for body mass M and radius R when mass m accreted

Accretion Power

Example - neutron star

Accreting mass m=1kg onto a neutron star:



neutron star mass = 1 solar mass

R = 10 km

=> ~10^{16} m Joules,

ie approx 10^{16} Joules per kg of accreted matter - as electromagnetic radiation

Efficiency of accretion

- Compare this to nuclear fusion H => He releases ~ 0.007 mc^2 ~ 6 x 10^{14} m Joules - **20x smaller** (for ns)

$$E_{acc} = G\frac{Mm}{R}$$

So energy released proportional to M/R ie the more compact a body is, the more efficient accretion will be.

Accretion Power

Origin of accreted matter

- Given M/R, luminosity produced depends on accretion rate, $\dot{m}$.

$$L_{acc} = \frac{dE_{acc}}{dt} = \frac{GM}{R}\frac{dm}{dt} = \frac{GM\dot{m}}{R}$$

- Where does accreted matter come from? ISM? No - too small. Companion? Yes.

Accretion Power

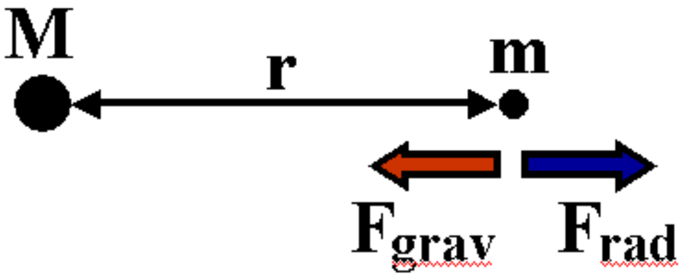
The Eddington Luminosity

- There is a limit to which luminosity can be produced by a given object, known as the Eddington luminosity.

- Effectively this is when the inward gravitational force on matter is balanced by the outward transfer of momentum by radiation.

Accretion Power

Eddington Luminosity



Accretion rate controlled by momentum transferred from radiation to mass

$$F_{grav} = G\frac{Mm}{r^2} \, Newton$$

Note that R is now negligible wrt r

Outgoing photons from M scatter material (electrons and protons) accreting.

Accretion Power

Scattering

L = accretion luminosity

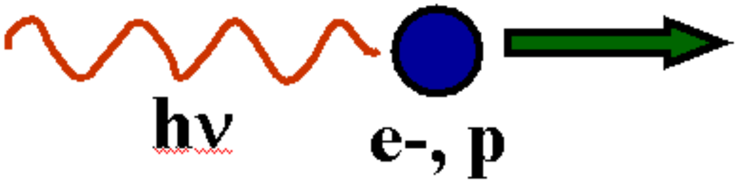
no. photons crossing at r per second $= \frac{L}{4\pi r^2}\frac{1}{h\nu}$ photons m^{-2} s^{-1}

Scattering cross-section will be Thomson cross-section σ_e; so no. scatterings per sec:

$$\frac{L\sigma_e}{4\pi r^2 h\upsilon}$$

Accretion Power

Momentum transferred from photon to particle:



$$\frac{h\nu}{c}$$

Momentum gained by particle per second = force exerted by photons on particles

$$\frac{L\sigma_e}{4\pi r^2 h\upsilon}\frac{h\nu}{c} = \frac{L\sigma_e}{4\pi r^2 c}\, Newton$$

Accretion Power

Eddington Limit

radiation pressure = gravitational pull

At this point accretion stops, effectively imposing a 'limit' on the luminosity of a given body.

$$\frac{L\sigma_e}{4\pi r^2 c} = G\frac{Mm}{r^2}$$

So the Eddington luminosity is:

$$\boxed{L = \frac{4\pi cGMm}{\sigma_e}}$$

Accretion Power

Assumptions made

- **Accretion flow steady + spherically symmetric:** eg. in supernovae, L_{Edd} exceeded by many orders of magnitude.
- **Material fully ionized and mostly hydrogen**: heavies cause problems and may reduce ionized fraction - but OK for X-ray sources

Accretion Power

Accretion energies

- In general, $\boxed{T_b \le T_{rad} \le T_{th}}$
- For a neutron star, $T_{th} \approx 5.4 \times 10^{11}\, K$
  $T_b \approx 2 \times 10^{7}\, K$
- assuming

$$L_{acc} \approx L_{Edd} = 1.3 \times 10^{31} \left(\frac{M}{M_{Sun}} \right) J / s$$

Accretion Power

Neutron star spectrum

- Thus expect photon energies in range:

$$\boxed{1keV \le h\nu \le 50MeV}$$

- similarly for a stellar mass black hole
- For white dwarf, $L_{acc} \sim 10^{26}$ J/s, $M \sim M_{Sun}$, $R = 5\text{x}10^{6}$m,

$$\boxed{6eV \le h\nu \le 100keV}$$

- => optical, UV, X-ray sources