Observational X-ray Astronomy II

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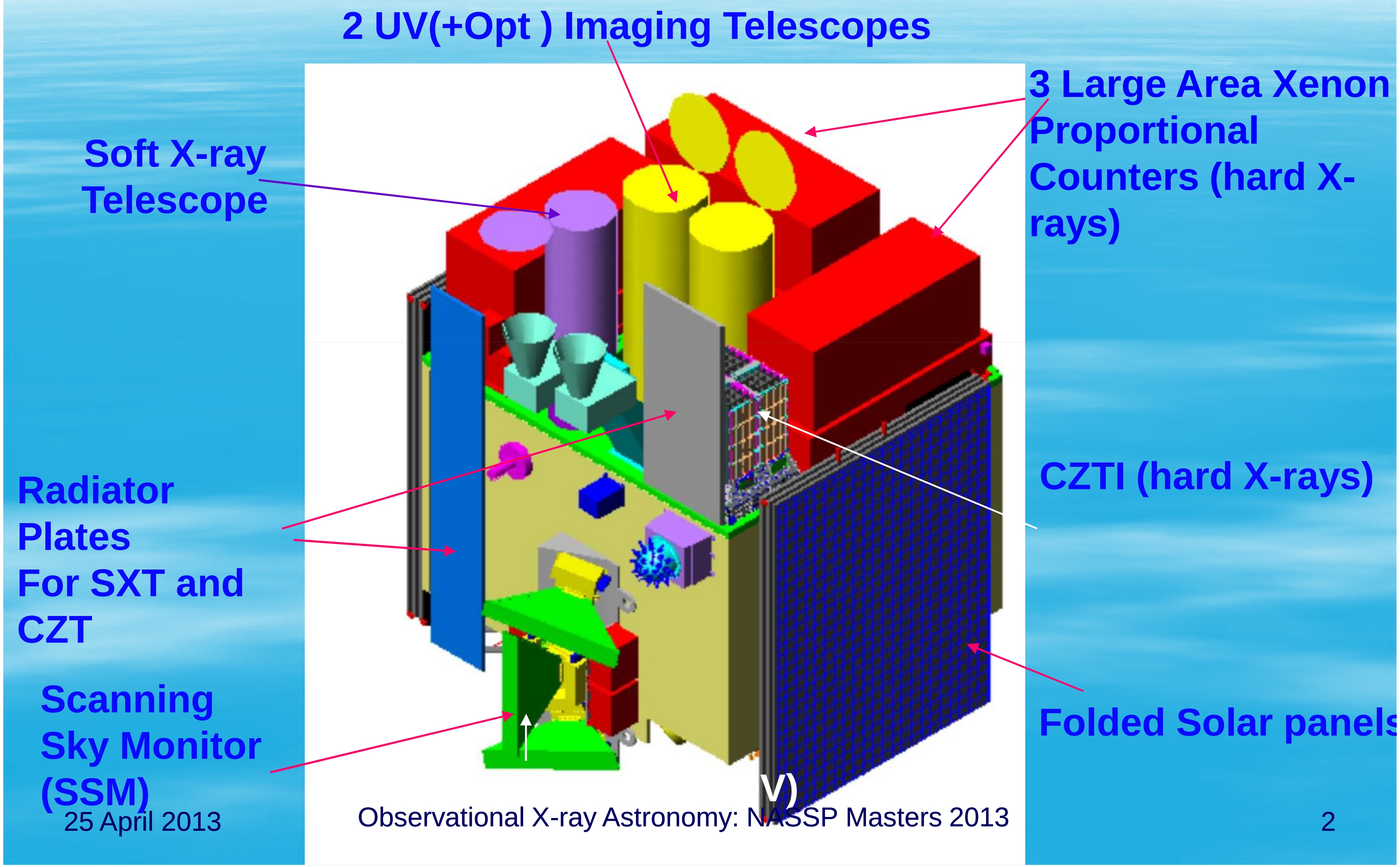
SAAO

ASTROSAT: India's first major astronomy satellite

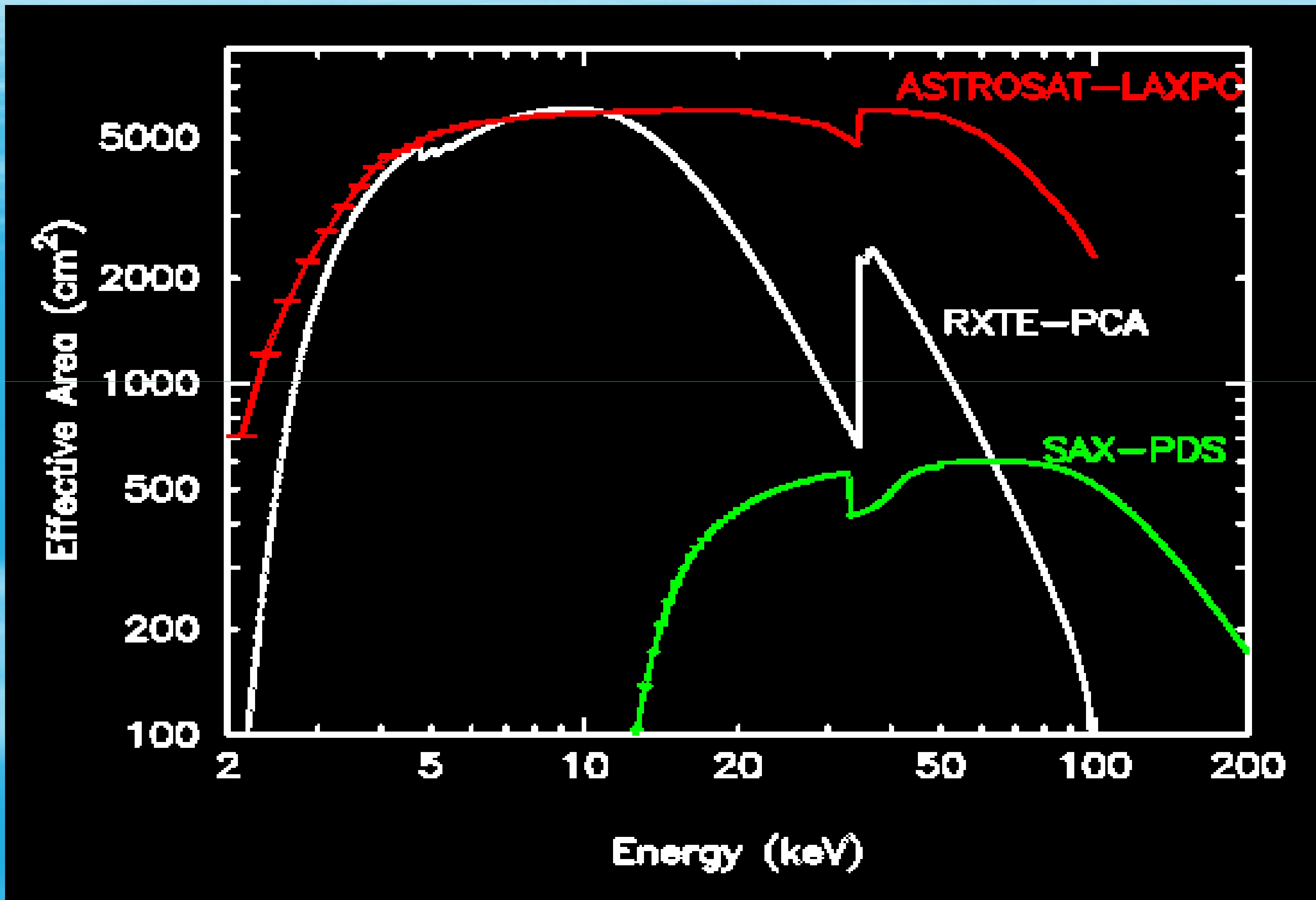


ASTROSAT – Key Strengths

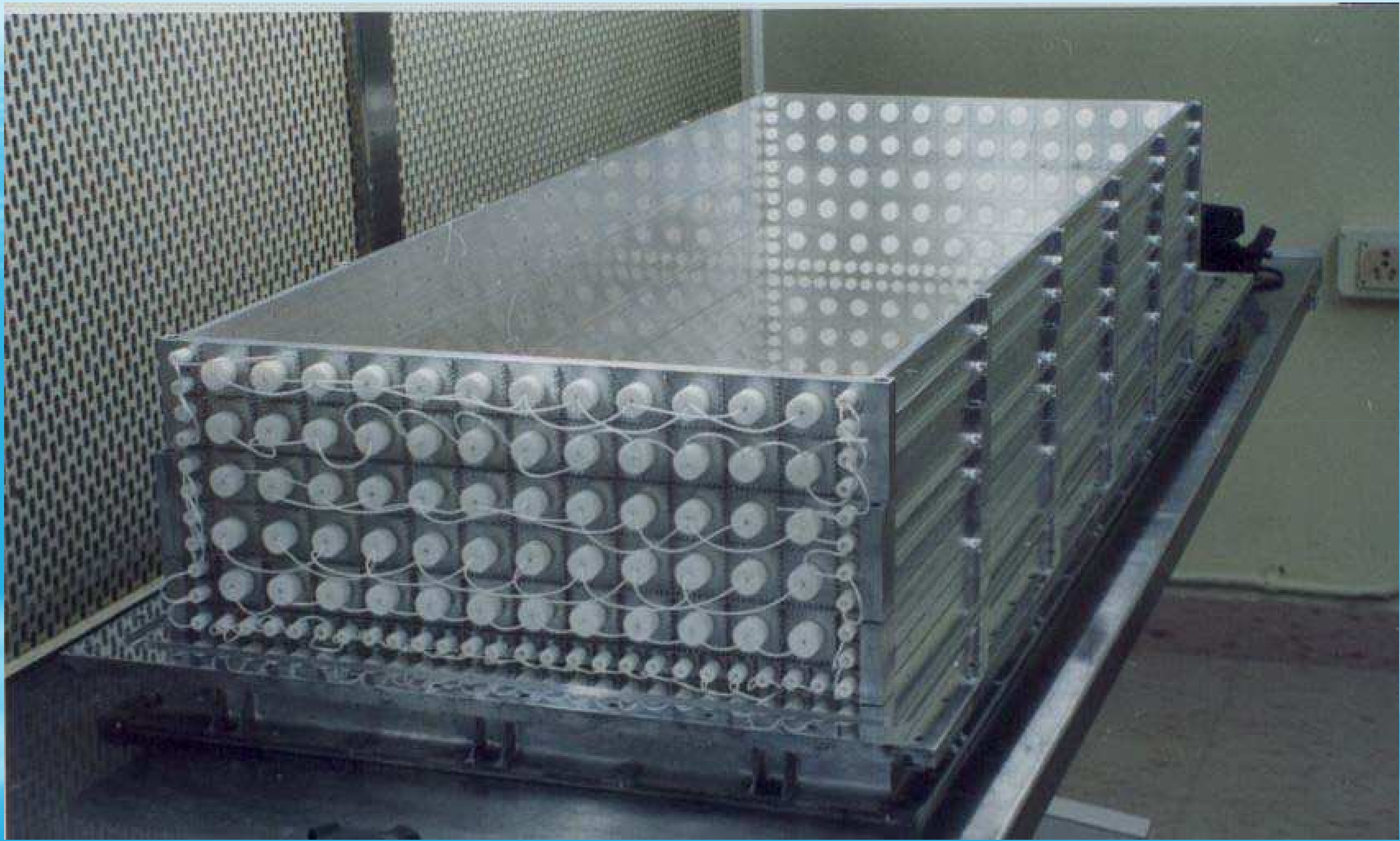
- **Simultaneous UV to hard X-ray continuum (pure continuum) measurements**
- **Multiwavelength observation capability with coaligned instruments.**
- **Large X-ray bandwidth, better hard X-ray sensitivity with low background**
- **UV imaging capability better than GALEX**
- **Transient detector via SSM**
- **High sensitivity to hard X-rays to ~150 keV**

Satellite: 1.55 tons; 650 kms, 8 deg inclination. 3 gyros and 2 star trackers for attitude control by reaction wheel system with a magnetic torquer. Launch in ~mid 2014.

Large Area Xenon Proportional Counter (LAXPC): Effective Area

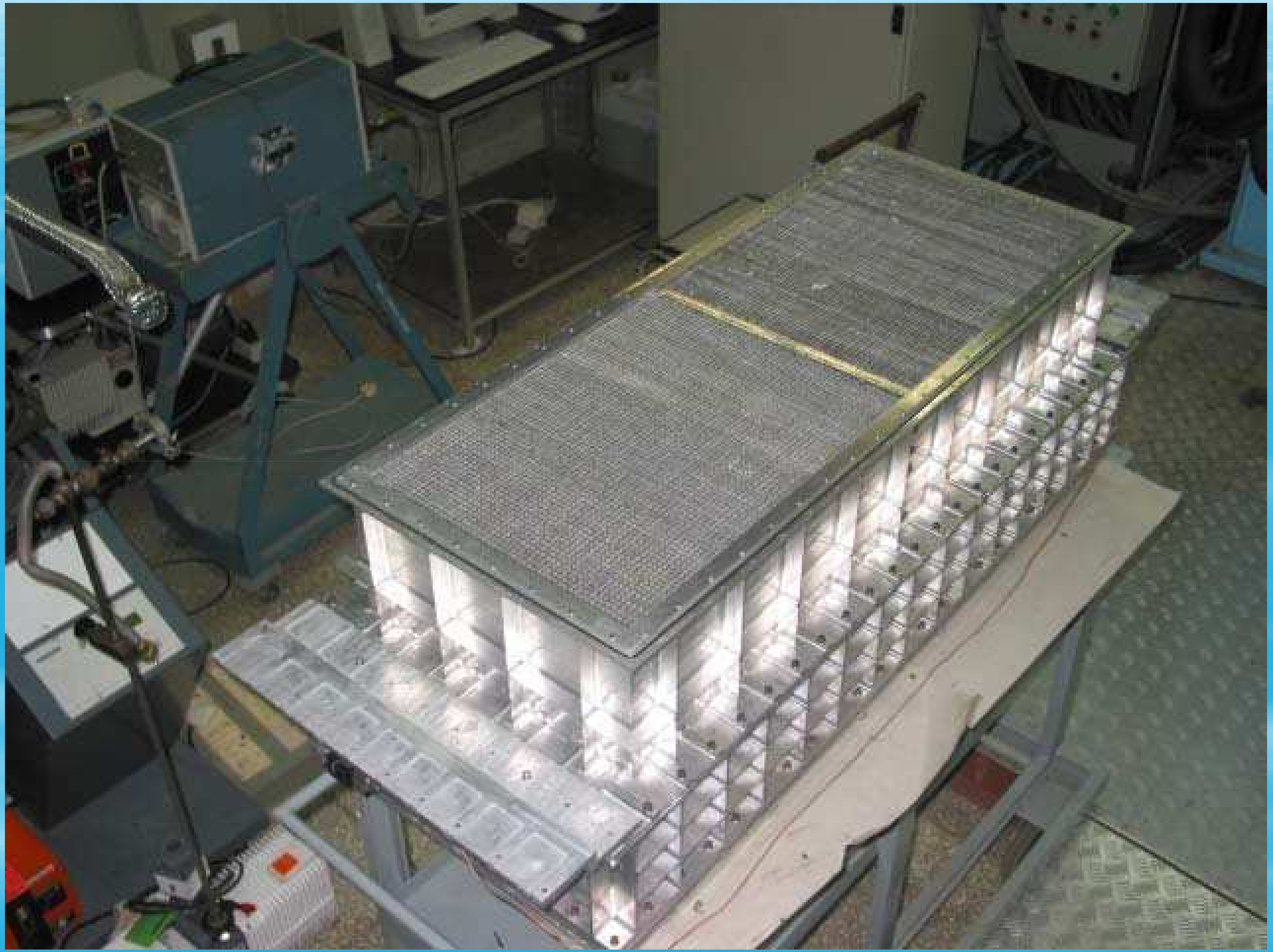


LAXPC



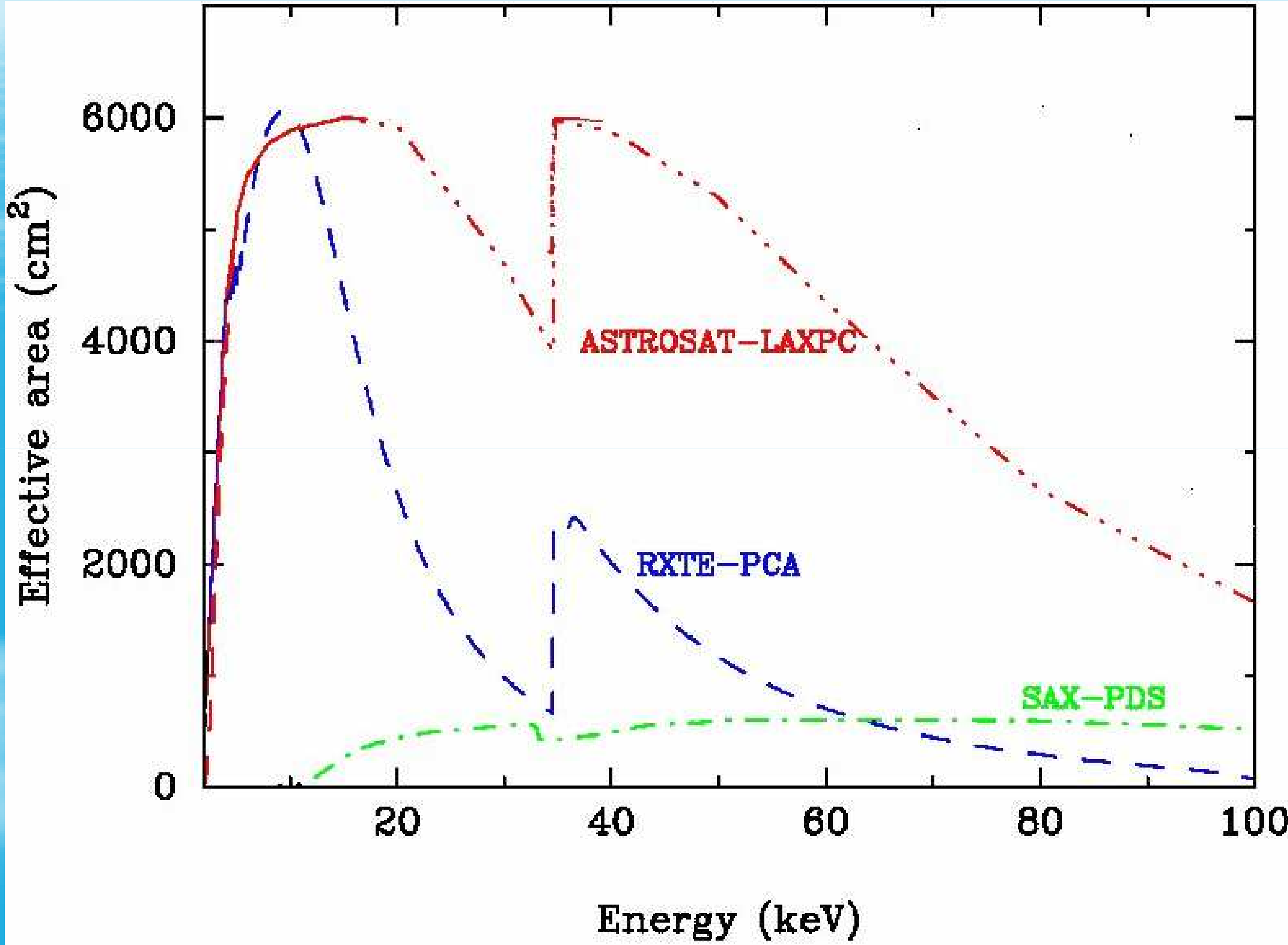
LAXPC X-ray detecting anode assembly with veto layer on 3 sides mounted on the back plate.

LAXPC

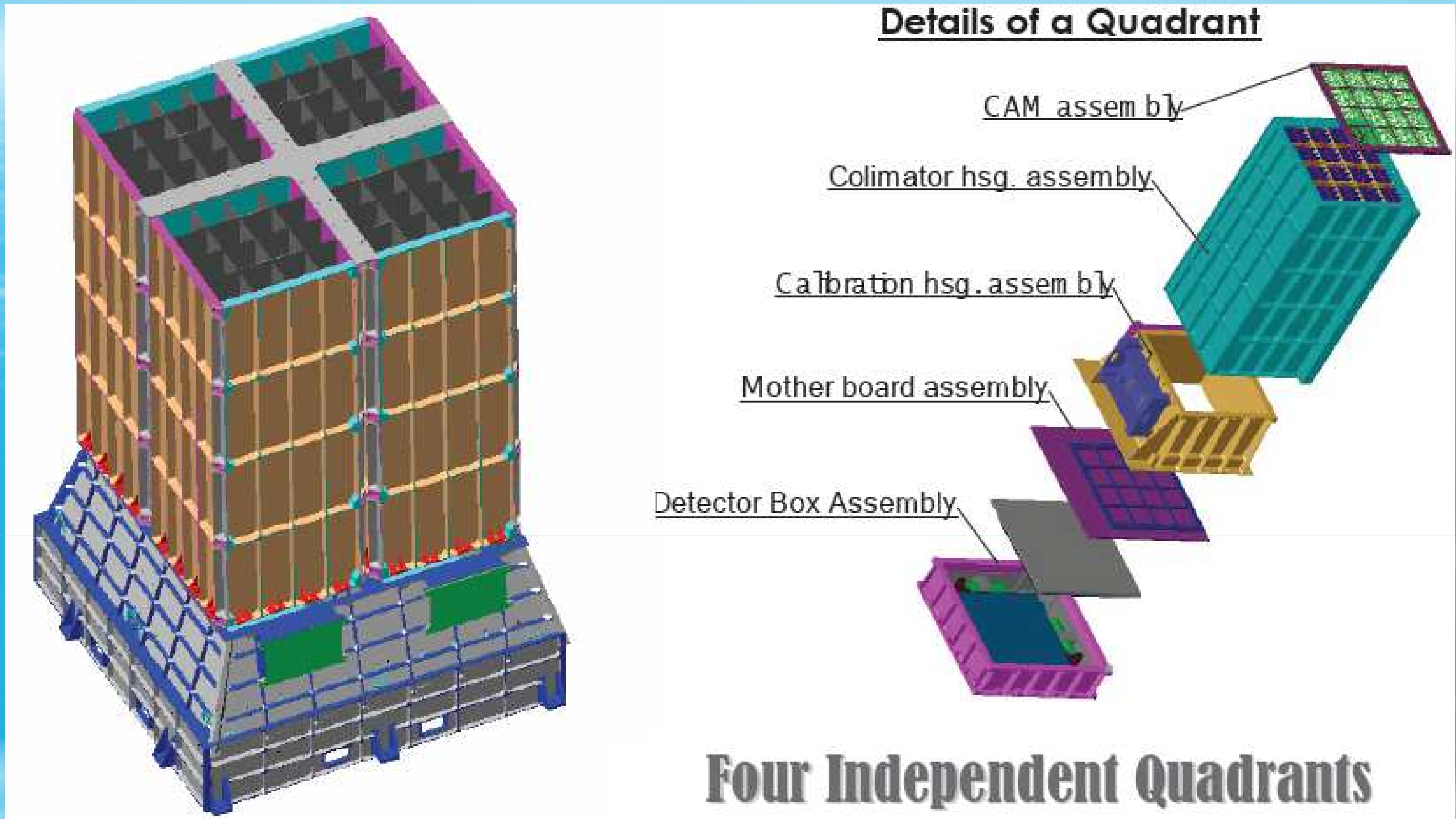


LAXPC unit with FOV Collimator installed
1°x 1°FoV;   8 – 20% energy resolution

LAXPC: Effective Area



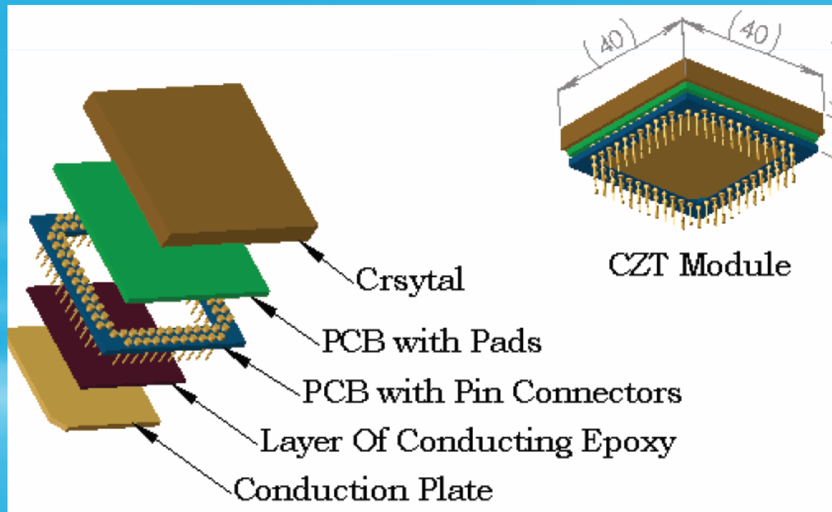
CZT (Cadmium Zinc Telluride) Imager



Targeting X-ray Spectroscopy
Good resolution (<5% at 60 keV)
Low background and accurate estimation
Emssion line studies (cyclotron lines)

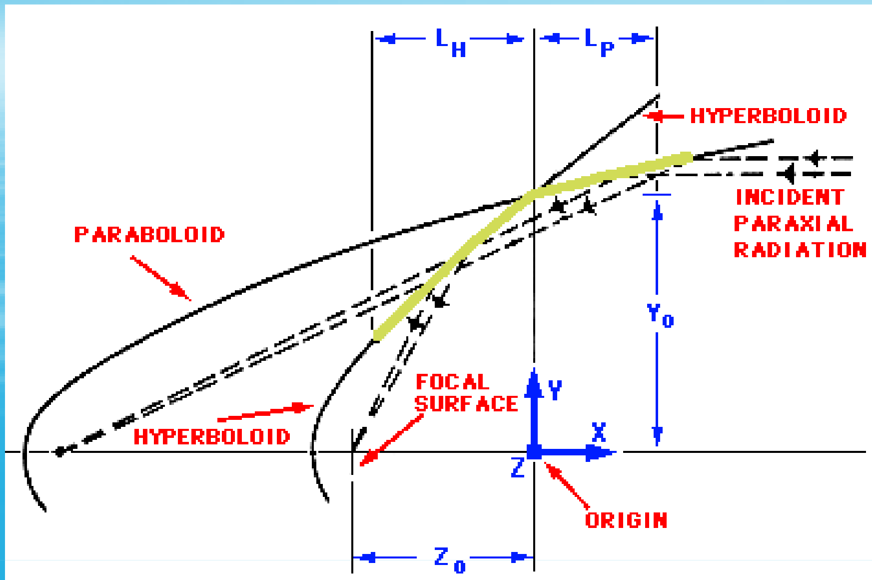
CZT (Cadmium Zinc Telluride) Imager

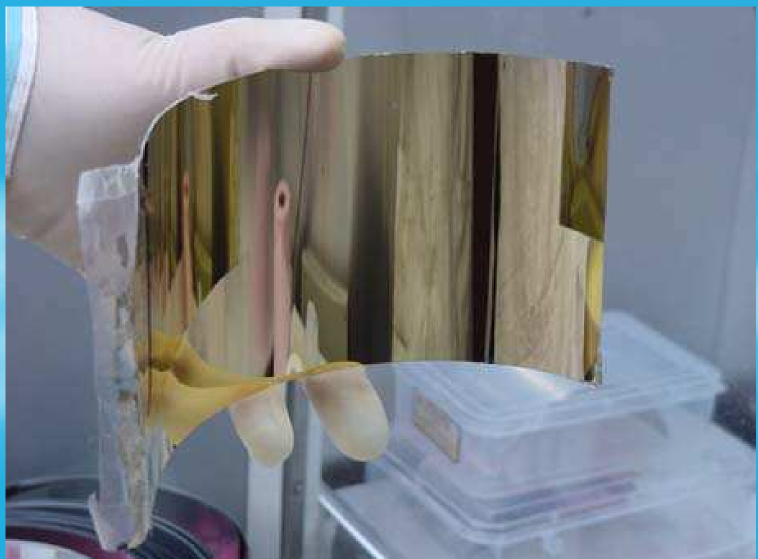
Imaging method: **Coded Aperture Mask (CAM)**
Field of View: **17°x 17° (>100 keV)**
5° x 5° (25 –100 keV)
1° x 1° (5 –25 keV)
Angular resolution: **8'**
Energy resolution: **< 5% @ 100 keV**
Energy range: **10 –100 keV; up to 1 MeV**
Sensitivity: **0.5 mCrab(5σ; 10^4 s)**

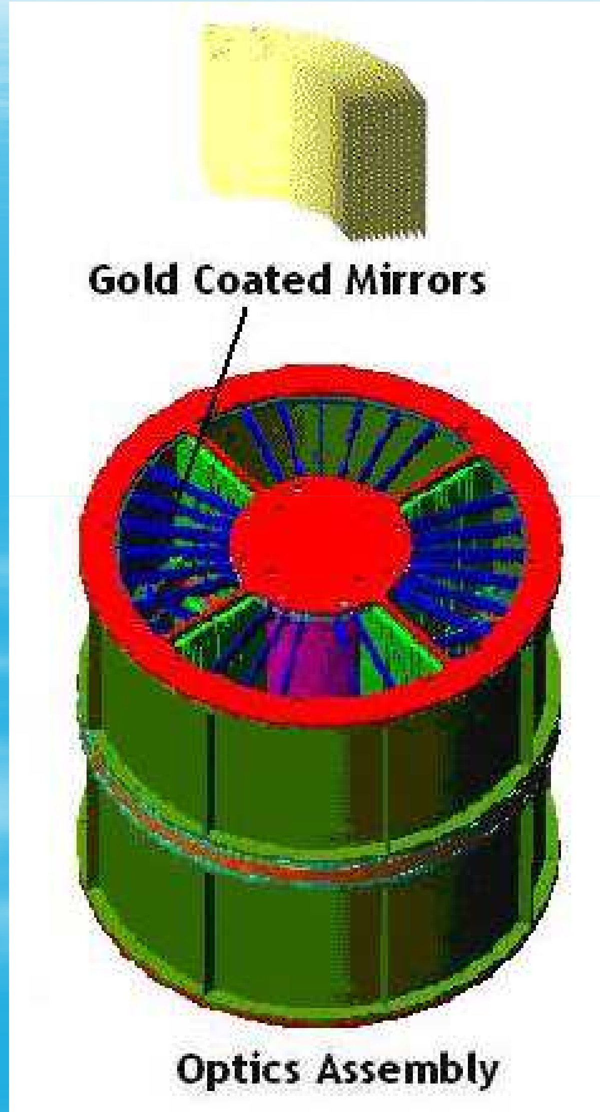


Detector size: **32 cm x 32 cm**
Area: **1024 cm^2**
Pixels: **128 x 128 (16384)**
Pixel size: **2.5 mm x 2.5 mm (5 mm thick)**
Read-out: **ASIC based (128 chips of 128 channels)**

Soft X-ray Telescope: SXT







Soft X-ray Telescope: SXT

SXT Characteristics

Focal Length : 2.0 metres

Mirrors: Conical shells of Al (0.2 mm thick) + epoxy (20-50 microns thick) + Au (1400 Angstroms thick) foils of length 100 mm

Telescope PSF (min- max values) :

1.5 – 2.5 arcmin (σ) ;

3.5 – 7.0 arcmin (FWHM)

Detector : E2V CCD-22 (Frame-Store)

Detector Format : 600 x 600 pixels

CCD Readout Modes : Photon counting,

Imaging, Timing

Field of view : 41.3 x 41.3 arcmin

Pixel Scale : 4.13 arcsec/pixel

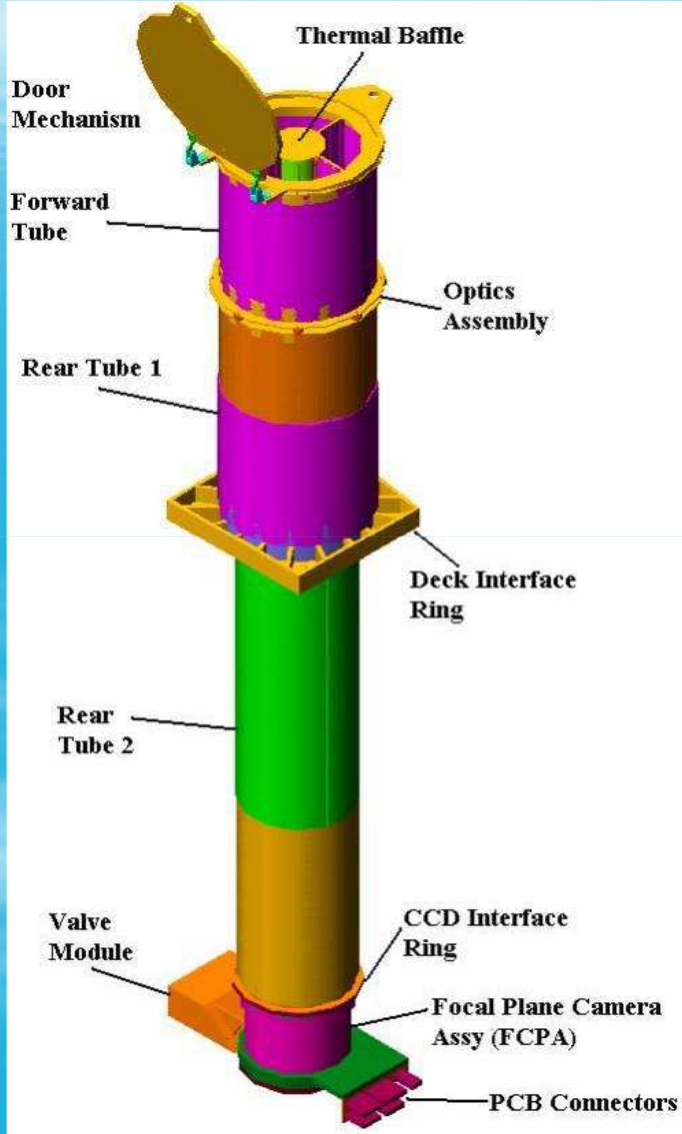
Energy Range : 0.3 – 8.0 keV 2% - 5% E res

Effective Area : 200 cm^2 @ 1.5 keV

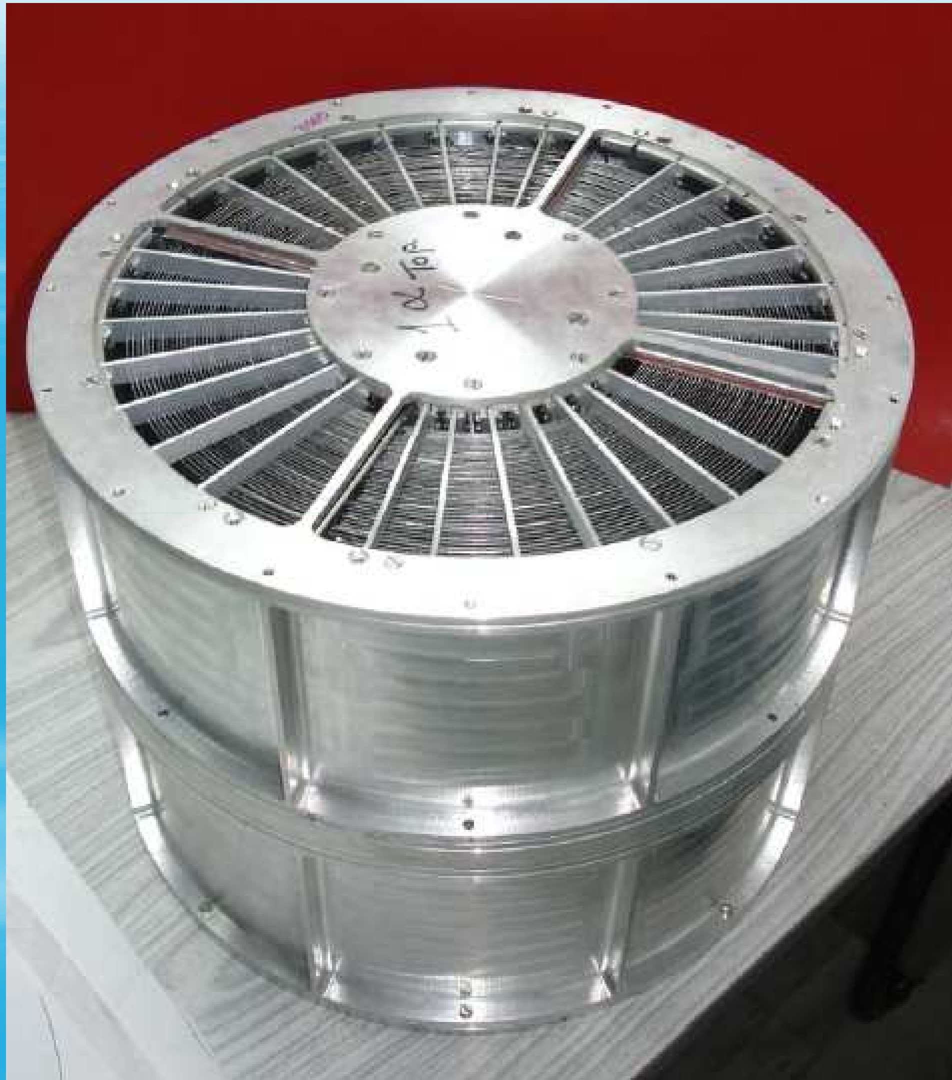
20 cm^2 @ 6.5 keV

Sensitivity : < 10 μCrab (1.5 cps/milliCrab)

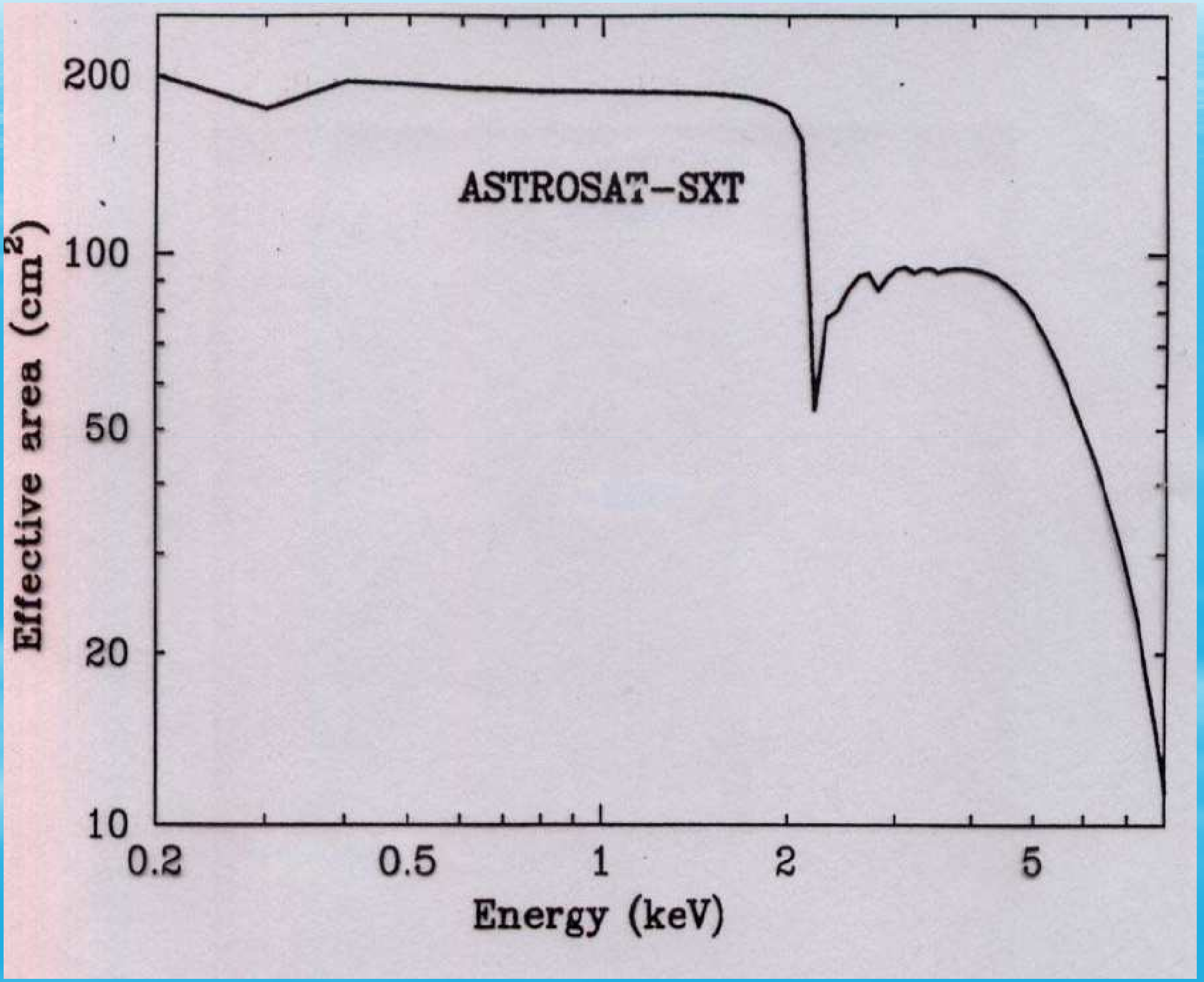
Position Accuracy : 30 arcsecs



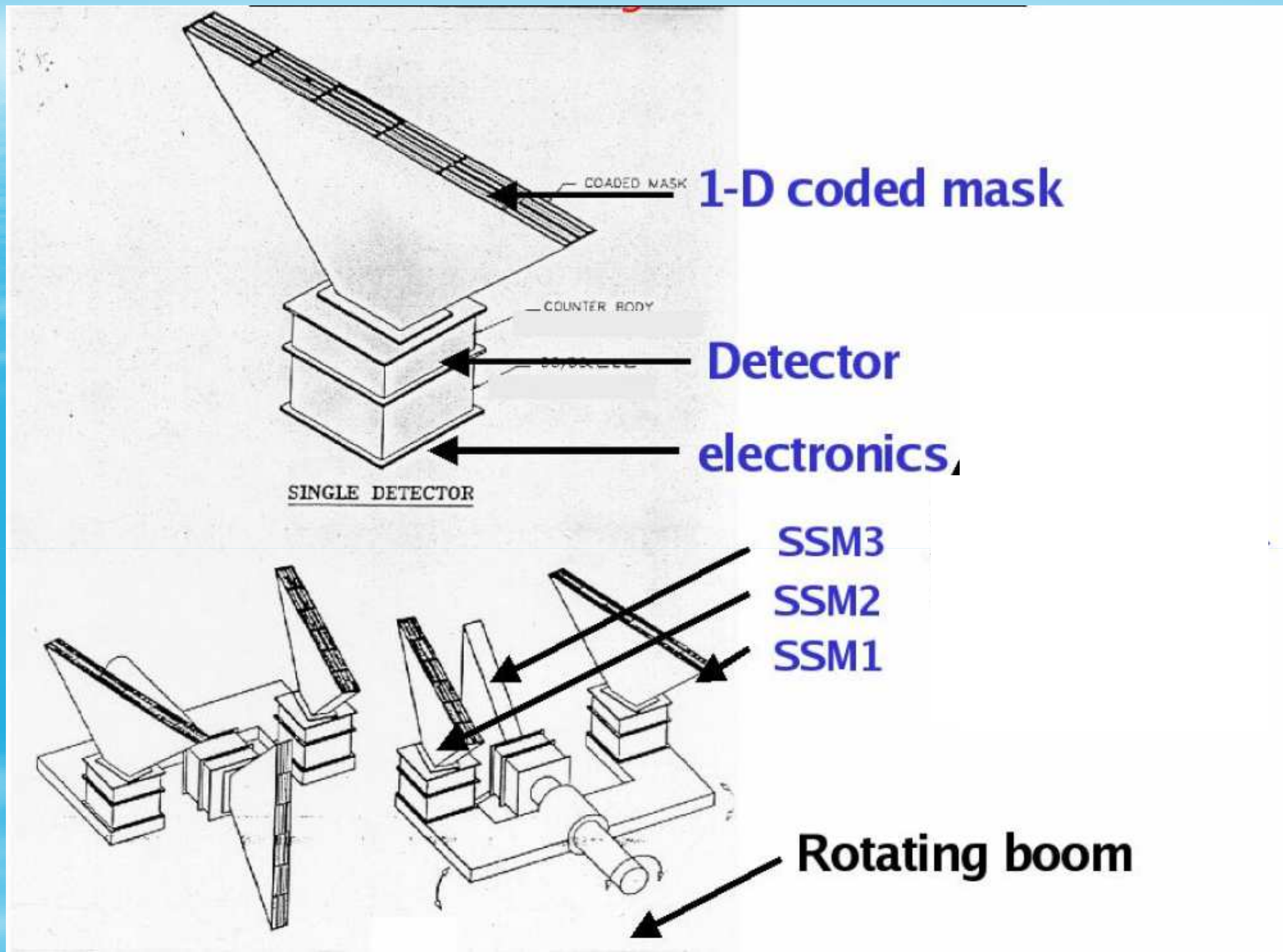
Soft X-ray Telescope: SXT



Soft X-ray Telescope: SXT



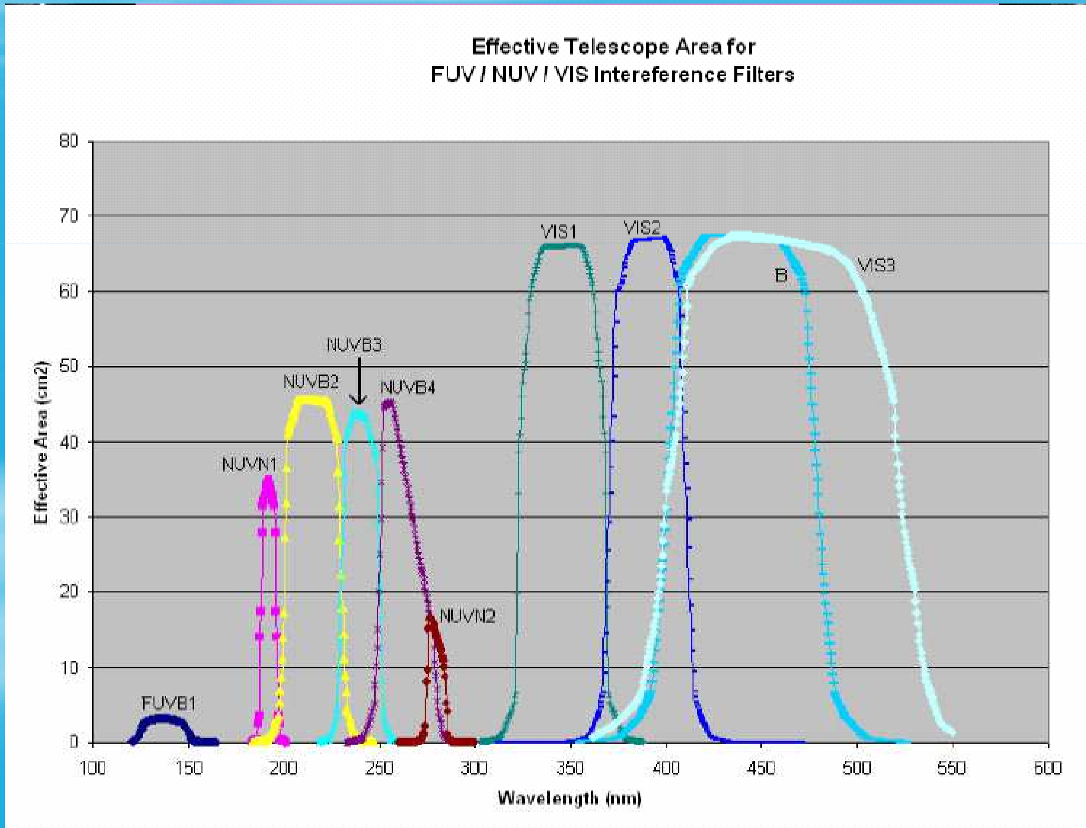
Scanning Sky Monitor (SSM)

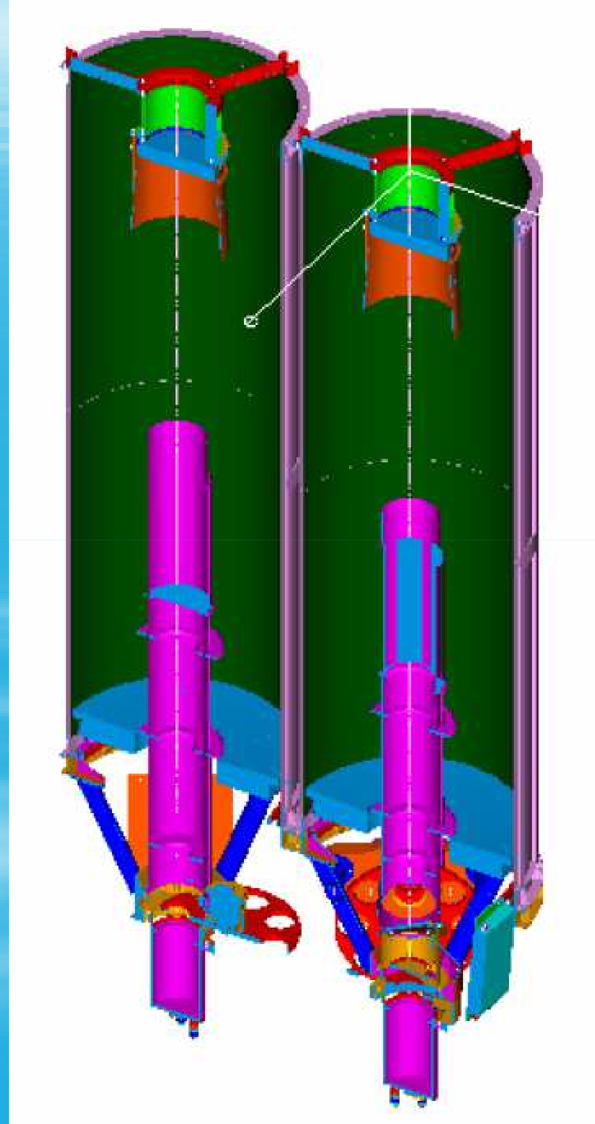


Targeting transient detection
Covers ~2π steradians
1-D coded aperture masks of 10 x 90 deg FoV

Ultraviolet Imaging Telescopes (UVIT)

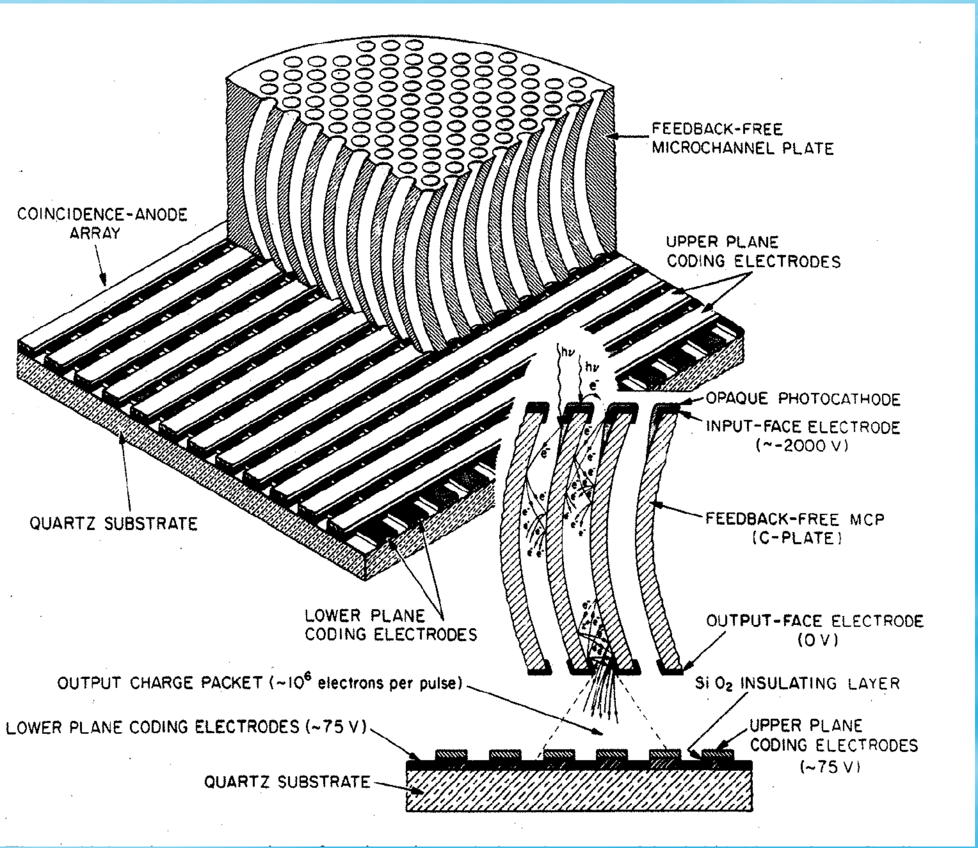
2 x 0.38m optical-UV telescopes: 120 – 650nm
Imaging and R ~ 100 spectroscopy
~1” resolution
Down to ~5ms time resolution

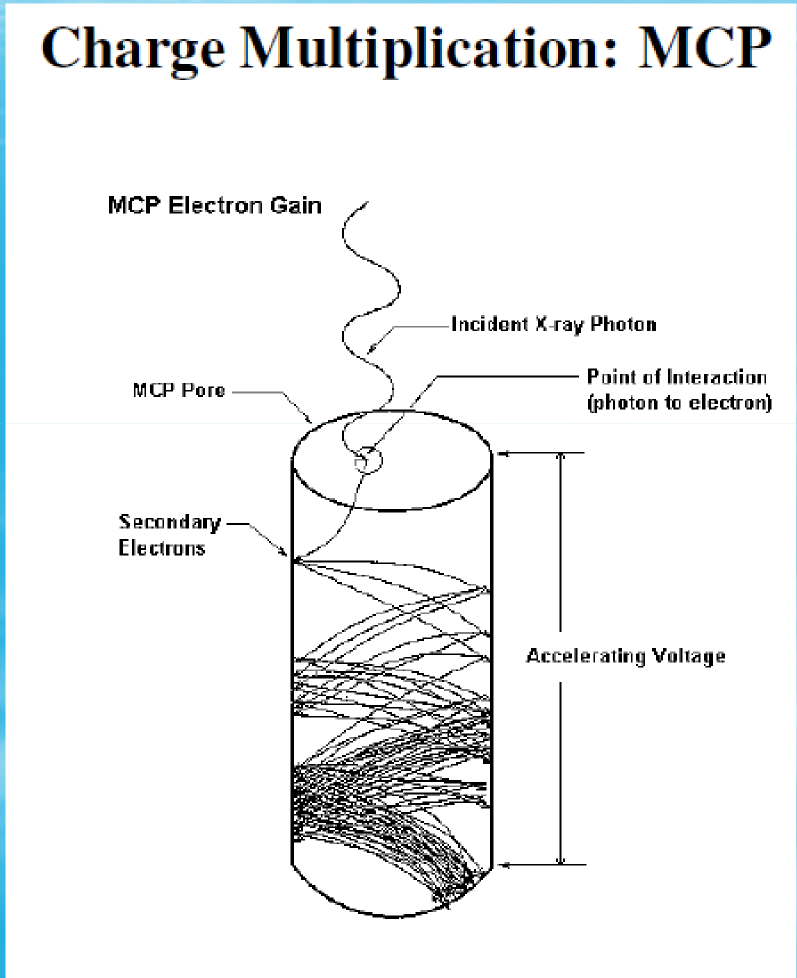




Ultraviolet Imaging Telescopes

Detector system based on Micro Channel Plate array plus CMOS detector





Ultraviolet Imaging Telescopes

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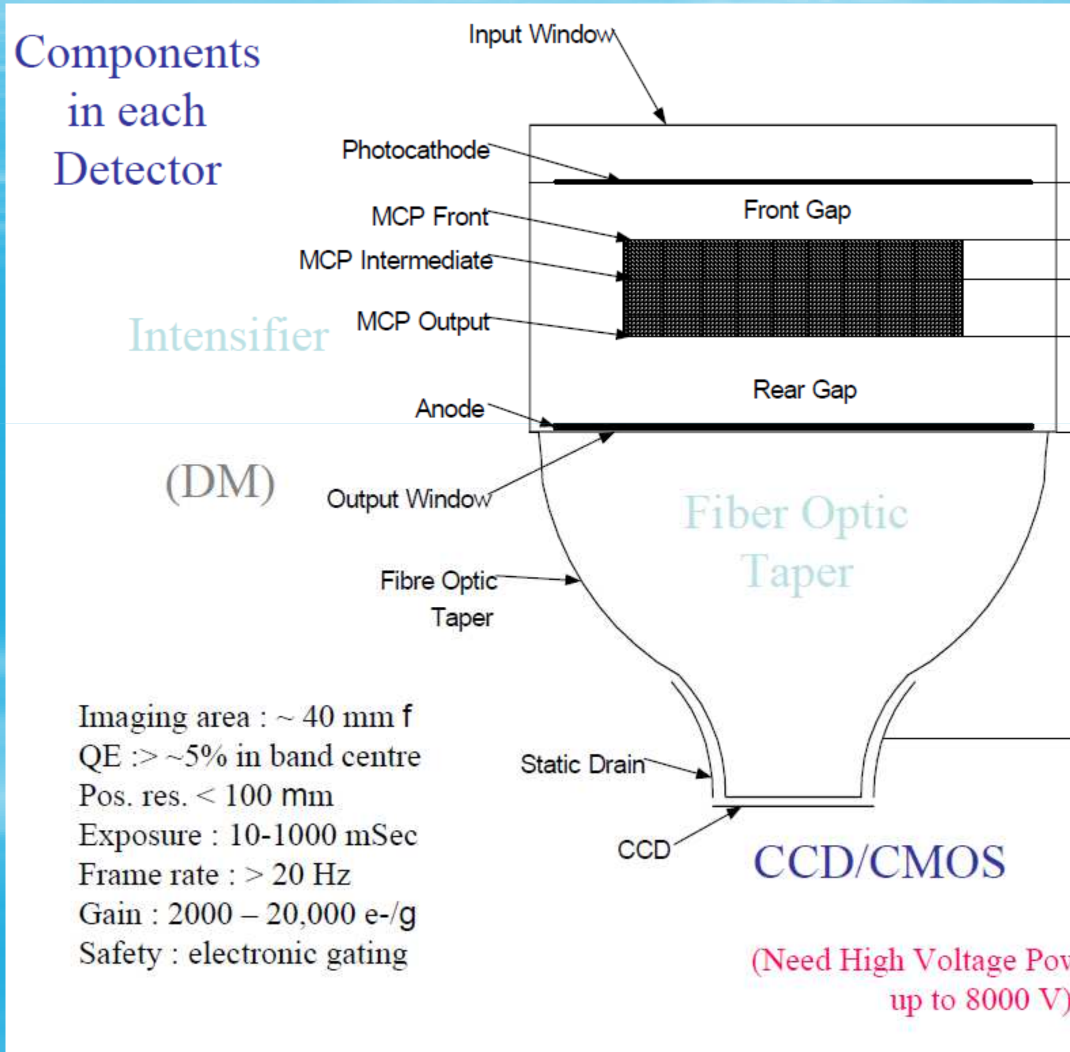


Imaging area : ~ 40 mm f
QE :> ~5% in band centre
Pos. res. < 100 mm
Exposure : 10-1000 mSec
Frame rate : > 20 Hz
Gain : 2000 – 20,000 e-/g
Safety : electronic gating

Brightest X-ray and UV Sources

- **Galactic Sources :**

Compact Stars in Accreting X-ray Binaries :

Bright X-ray and UV sources , especially the White Dwarfs (single as well as in binary) are bright UV objects .

Neutron Stars (~ 250) { Both have high luminosity in X-rays

Black Holes (~ 30) { and are also visible in UV

White dwarfs (~ 100) $L_x \sim 10^{32} - 10^{34}$ ergs per sec , $L_{UV} \sim 10^{31-33}$ ergs per sec

Rotation powered Pulsars (Isolated Neutron Stars)

Supernova Remnants :

About 200 SNRs in our galaxy .

Shock heated gas ($T \sim 10^5 - 10^7$) emits UV and X-rays

Hot Stars and Stellar Coronae :

Young early type Stars have $T > 10^4$ K and radiate energy mostly in UV.

Single and Binary starStars have hot chromosphere, transition region and coronae radiating UV and X-rays

Extragalactic Sources :

AGNs (Quasars, BL Lacs , Seyfert Galaxies) :

Powered by massive (10^7- 10^9 $M_\odot$) accreting Black Holes in their nuclei

Accretion Disks Around BHs emit UV and X-rays . There is excess UV from AGNs (called UV Bump)

Star Burst Galaxies : Nurseries of hot young stars , bright UV , X-ray emitters.

Cluster of Galaxies :

Thermal emission $L_x \sim 10^{44} \sim 10^{46}$ ergs per sec

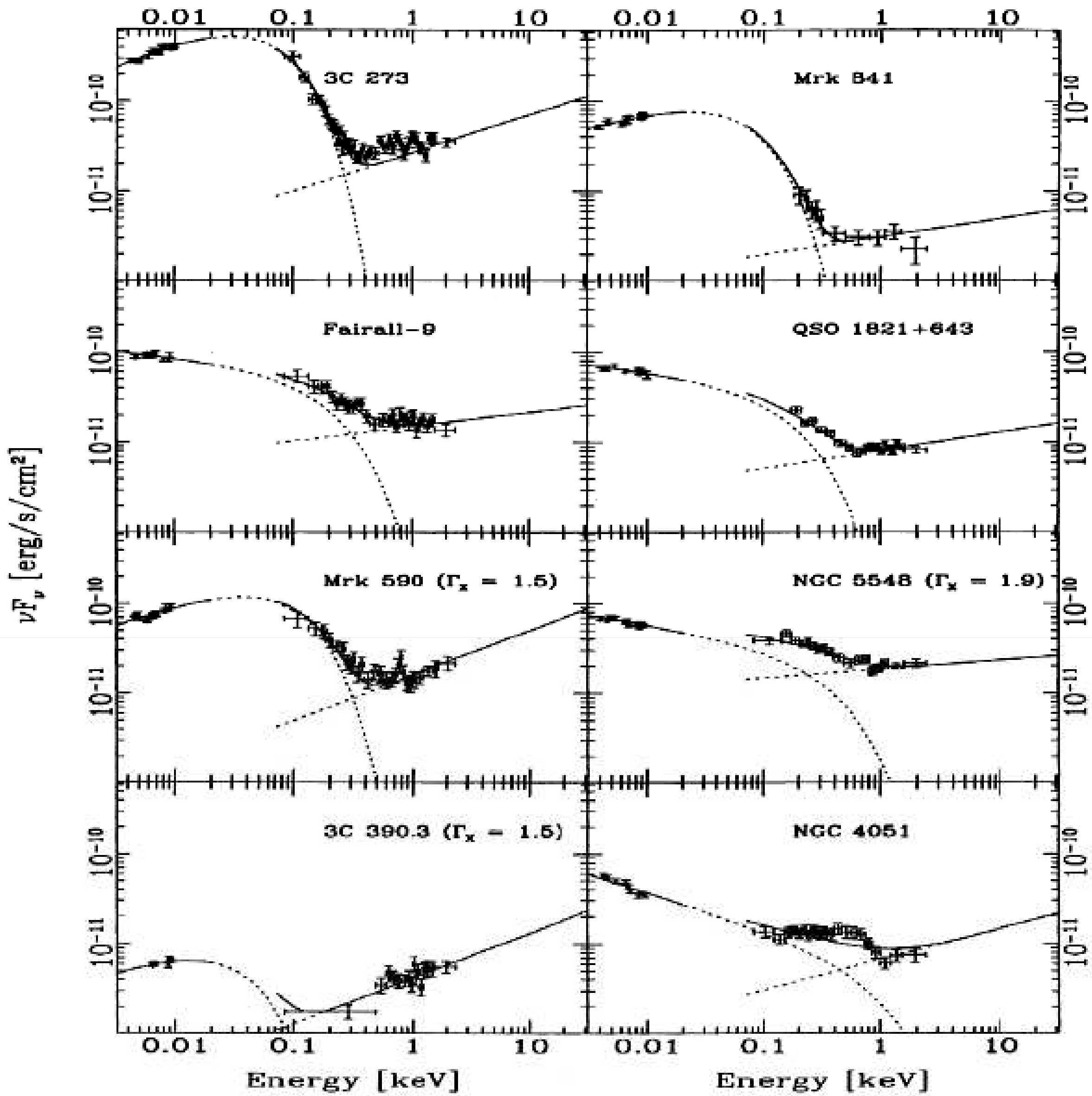


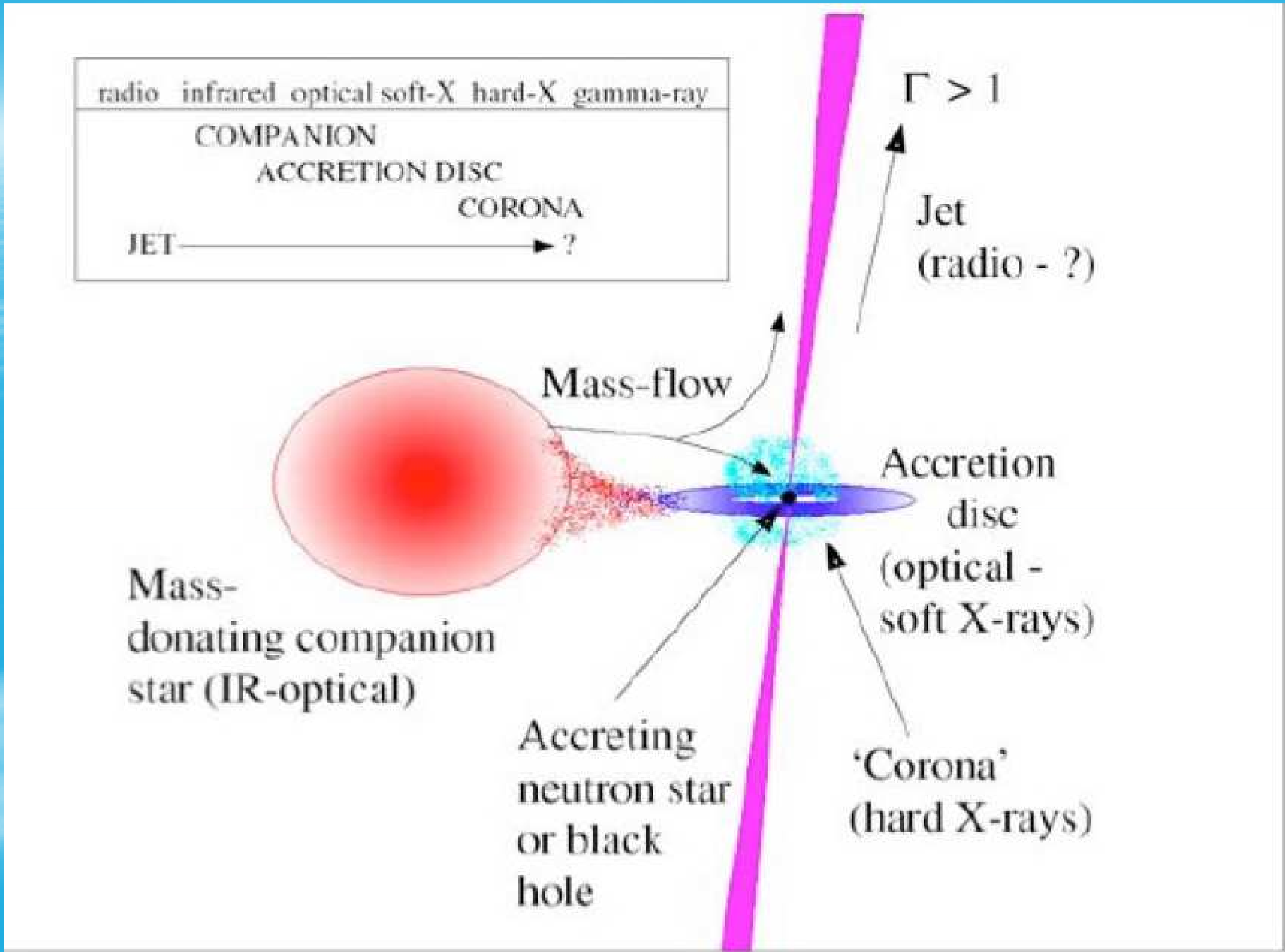
Fig. 2a. Multiwaveband spectra and best fit description A

Multiwavelength Spectra of AGNs with IUE,Rosat and Ginga (Walter et al. 1993)

X-ray Binaries

Why are XRBs important?

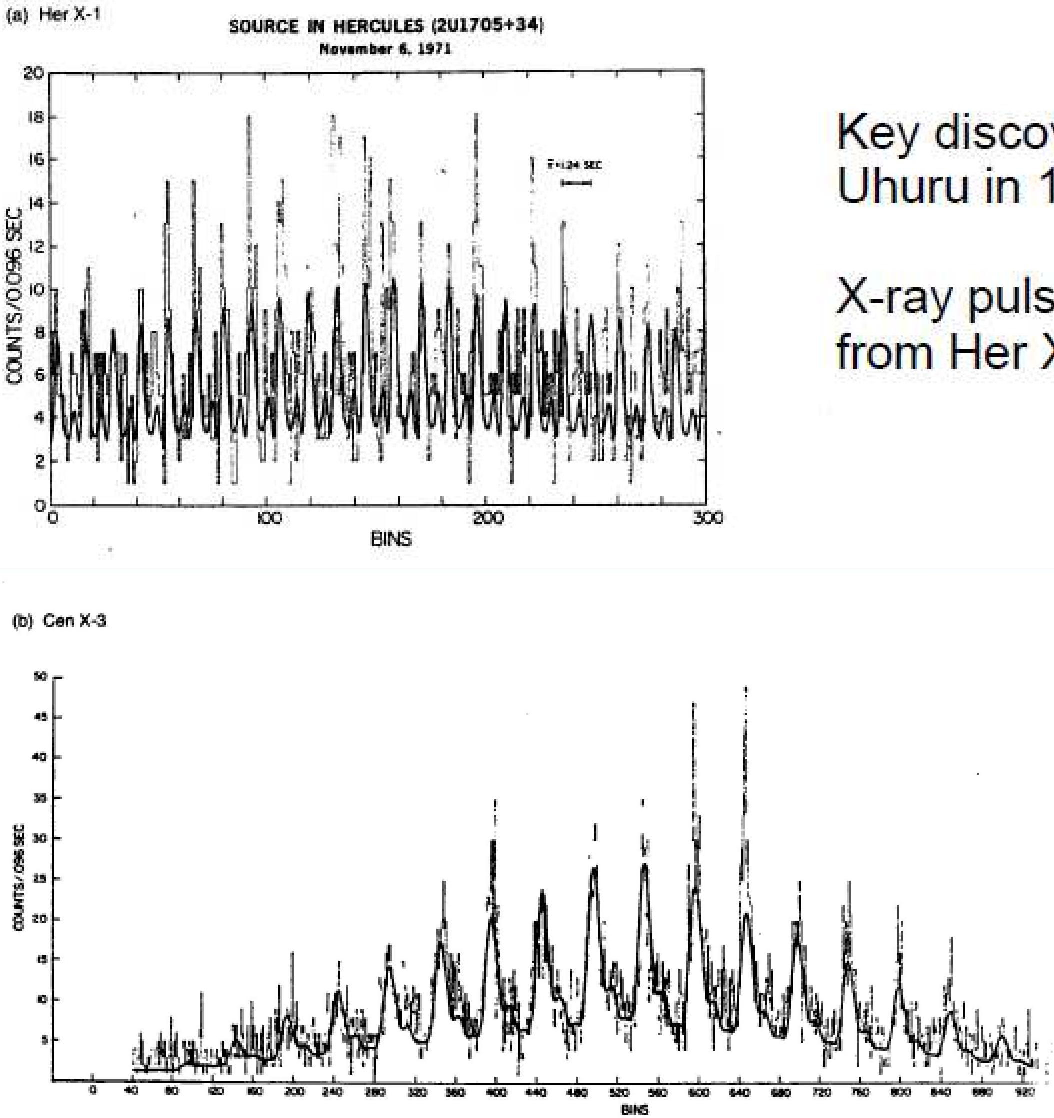
- access to exotic end-points of stellar evolution
- properties of accretion/accretion discs on accessible timescales
- galactic micro-scale analogues of AGN (e.g. micro-quasars, ULXs)
- probe physical processes close to NS surface or BH event horizon
- "controlled" environment where binary constrains volume of disc/mass-losing star
- binaries → opportunities for mass/size constraints or even accurate measurements, their fundamental properties
- *only* site where galactic BH mass measurements can be made


radio infrared optical soft-X hard-X gamma-ray
COMPANION
ACCRETION DISC
CORONA
JET ?
Γ > 1
Jet
(radio - ?)
Mass-flow
Accretion
disc
(optical -
soft X-rays)
Mass-
donating companion
star (IR-optical)
Accreting
neutron star
or black
hole
'Corona'
(hard X-rays)

Nature of the bright X-ray sources

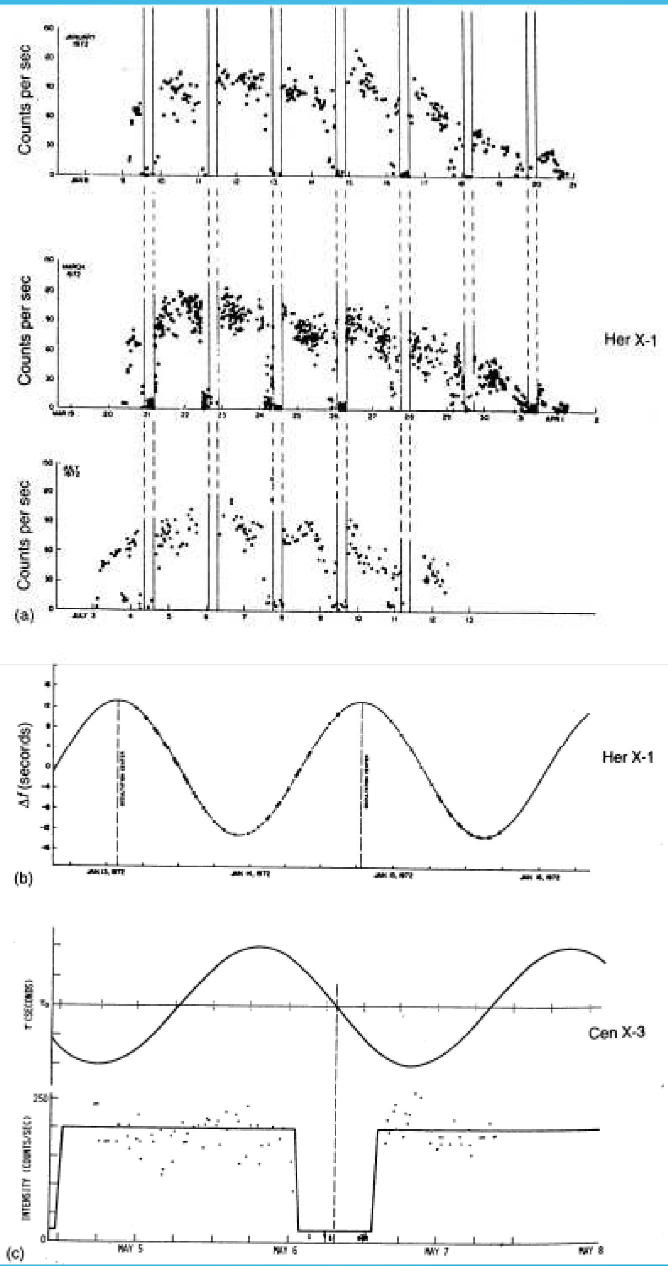
- Concentrated towards Galactic plane and Galactic centre
- Many highly variable on short timescales
  - therefore some must be distant (10 kpc) and high luminosity (10^{38} erg/s)
  - therefore compact
- Non-varying, extended sources are SNRs

➢ Energy from gravitational accretion



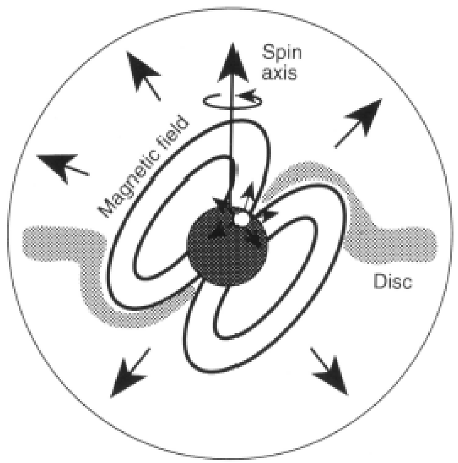
Key discovery was made by Uhuru in 1971

X-ray pulsations discovered from Her X-1 and Cen X-3

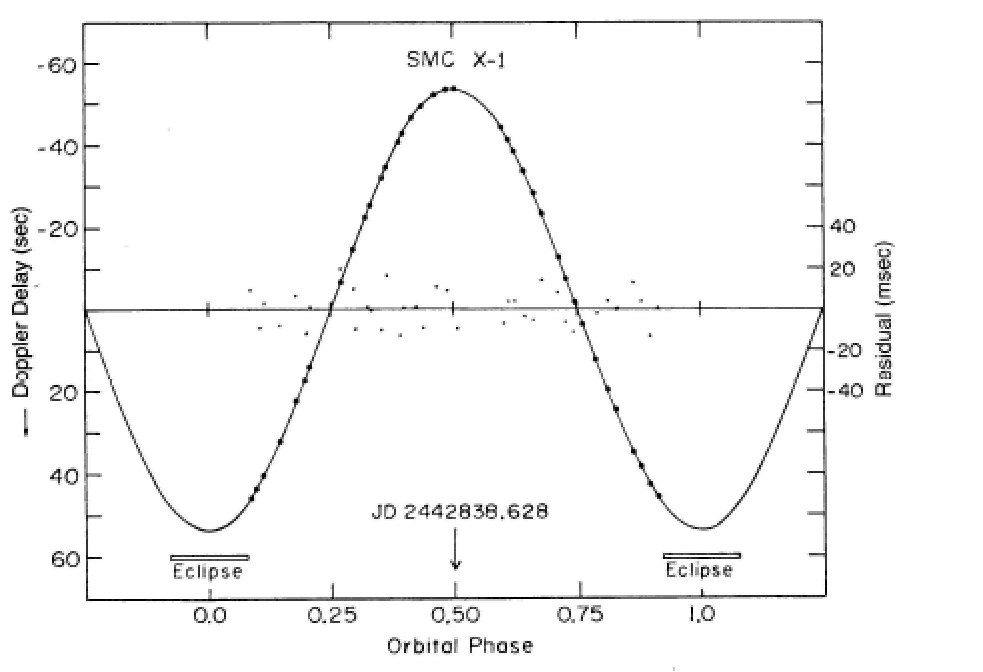


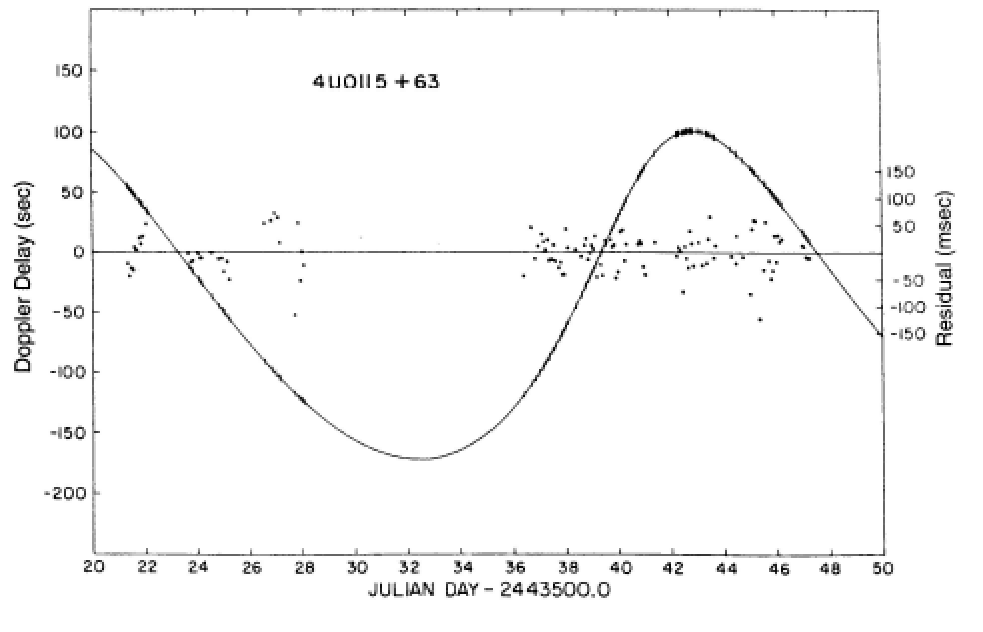
+ their binary nature was immediately apparent!

Note also the 35d cycle of Her X-1



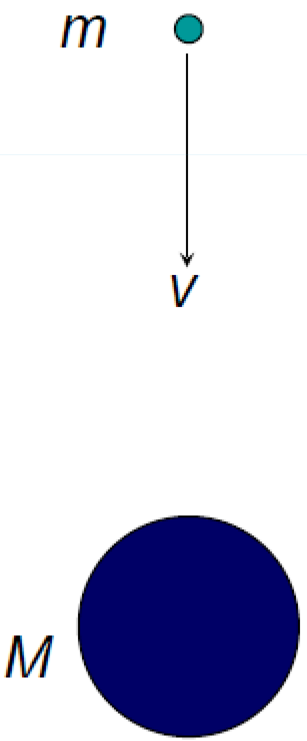
Orbital pulse time lags:





Both circular and eccentric orbit systems found

Accretion Energy



Accretion of mass *m* on star of mass *M*

Converts gravitational P.E.into K.E.

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

Energy liberated when particle strikes star's surface - comes to rest

cf. energy release as fraction of rest M energy

i.e. GM/rc^2 which depends only on *M*, *r*

Accretion Energy

'Efficiency' of conversion of rest mass energy simply depends on how compact the star is. Use Schwarzschild radius of star of mass M:

$$R_g = 2GM/c^2$$

Assume that all kinetic energy released

$$L = \frac{G \dot{m} M}{R} = \frac{1}{2} \dot{m} c^2 \frac{R_g}{R} = \epsilon \dot{m} c^2$$

For a white dwarf $\epsilon = 0.5 \times 4$ km /5000 km = 4×10^{-4}

neutron star $\epsilon = 0.5 \times 4$ km /10 km = 0.2

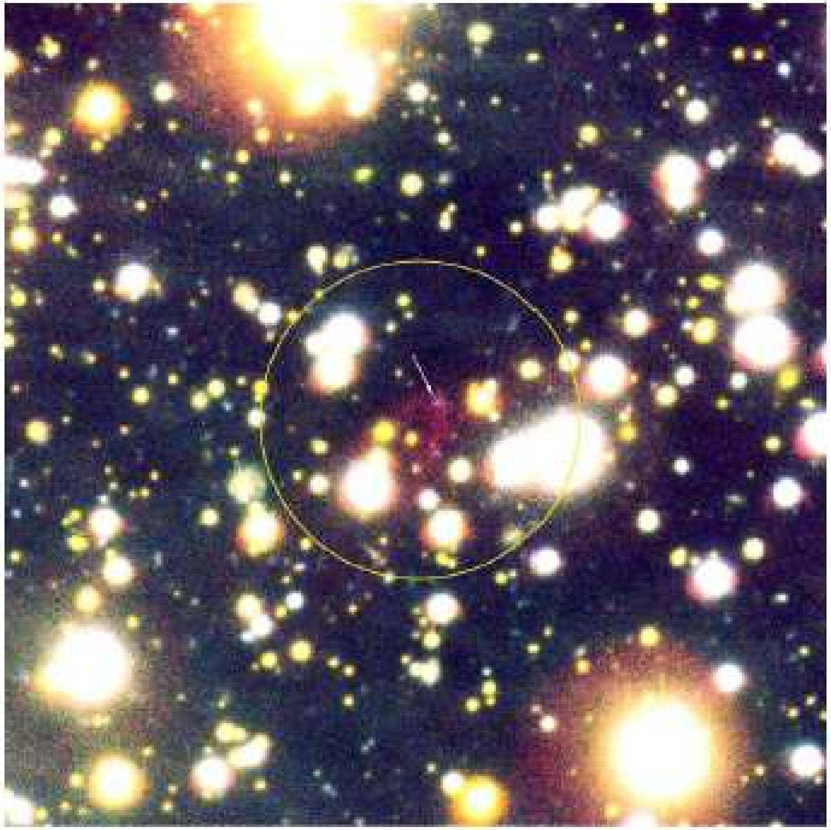
Nuclear burning $\epsilon = 0.01$

Source of accreting matter?

Interstellar Medium?

Not enough in most cases

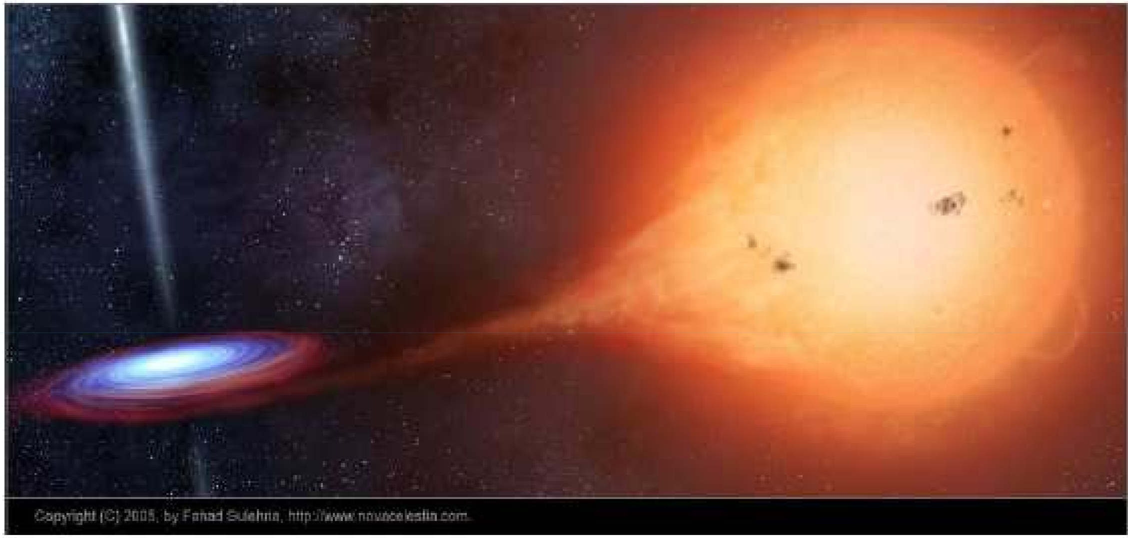
However, some isolated neutron stars may generate significant emission in this way



A Bowshock Nebula Near the Neutron Star RX J1856.5-3754 (Detail)

Binary Companion

Most of the bright variable Galactic X-ray sources are binaries

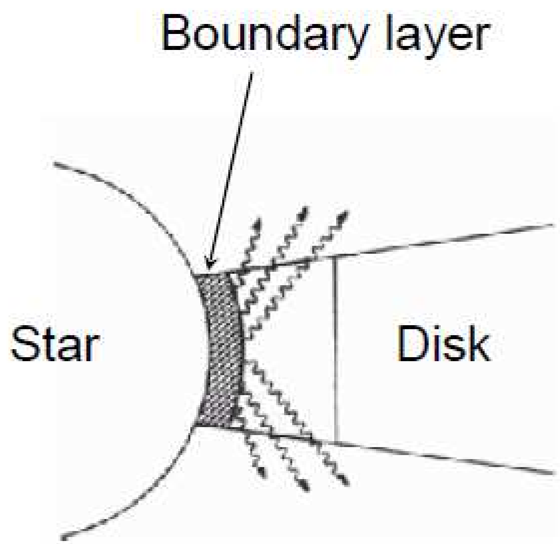


Binary companion provides accreting material either directly (as shown) or from a stellar wind or other ejecta

Binary signatures include eclipses, doppler shifts due to orbital motion etc.

Boundary Layer

- Half of accretion energy still bound up as orbital kinetic energy in innermost disk orbit (Virial Theorem)
- Shocks to make boundary layer which then radiates

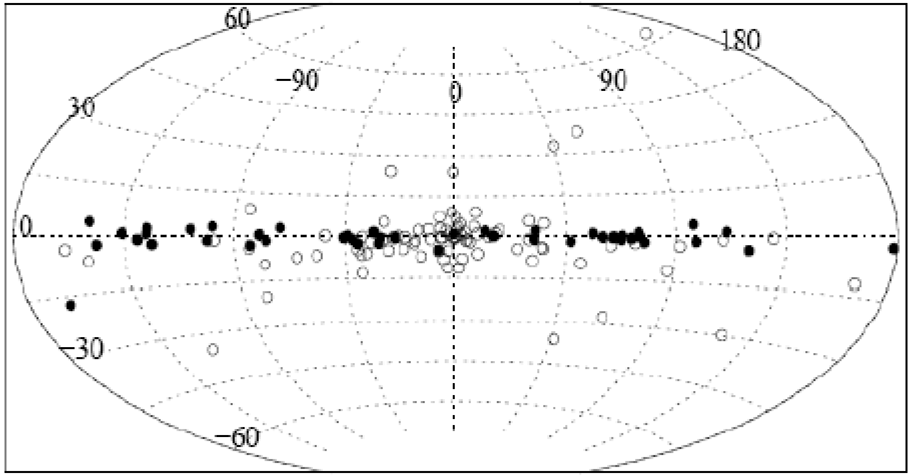


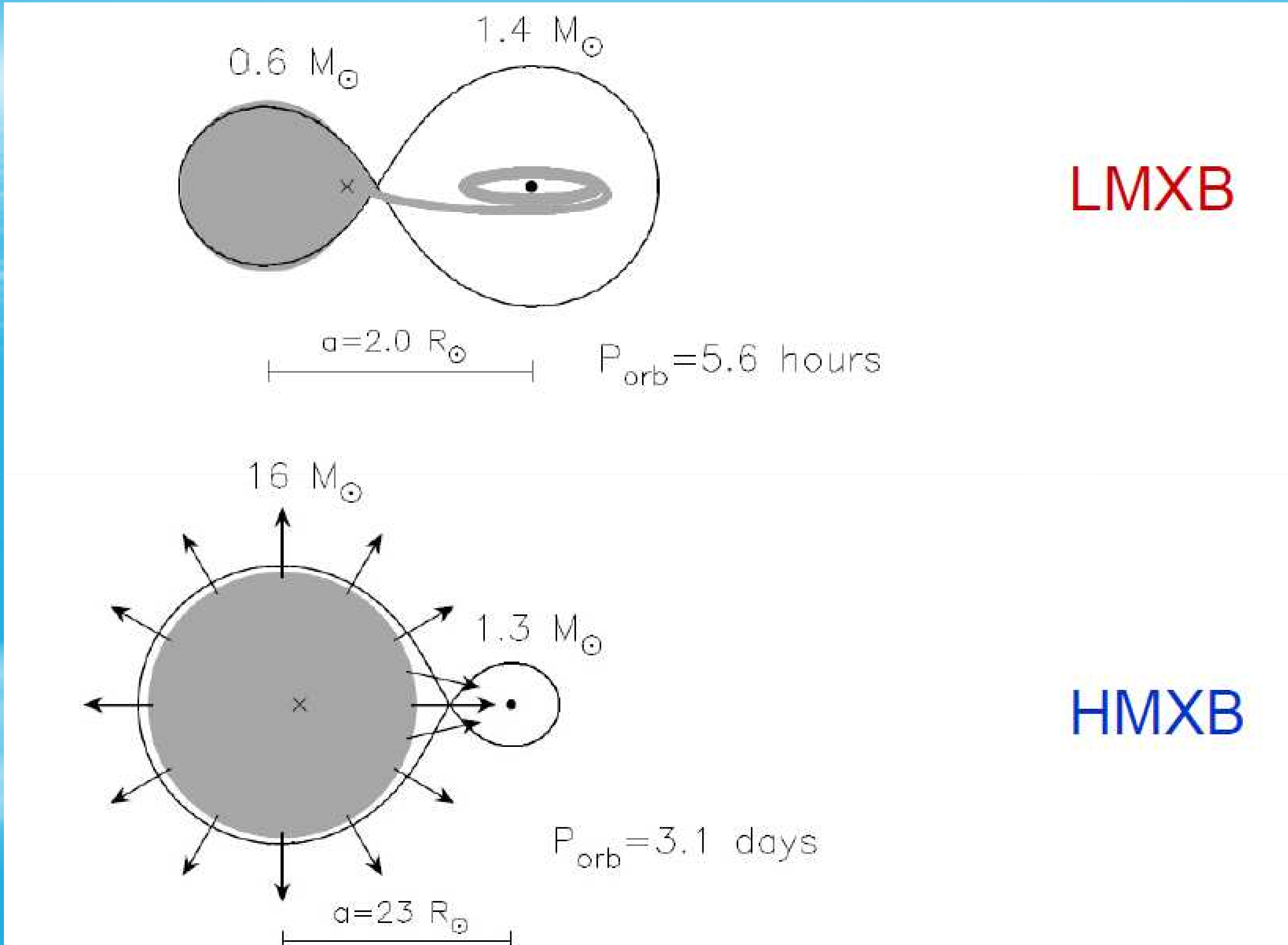
X-ray Binary Zoo

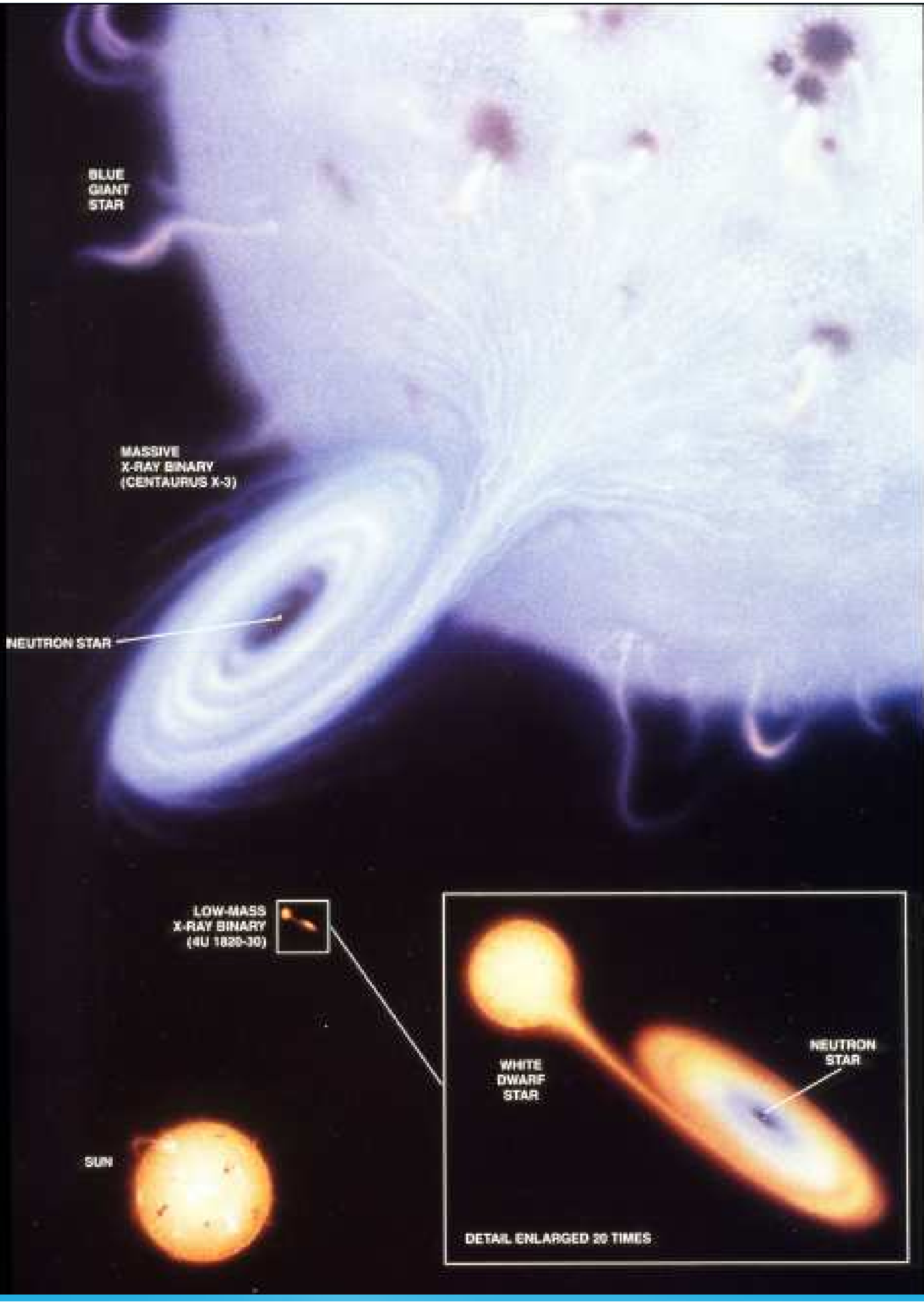
Basic division into high-mass and low-mass systems depending on nature of the companion star

High-mass, early-type (>5$M_\odot$) O-B
Low-mass, cool (<1$M_\odot$) K-M

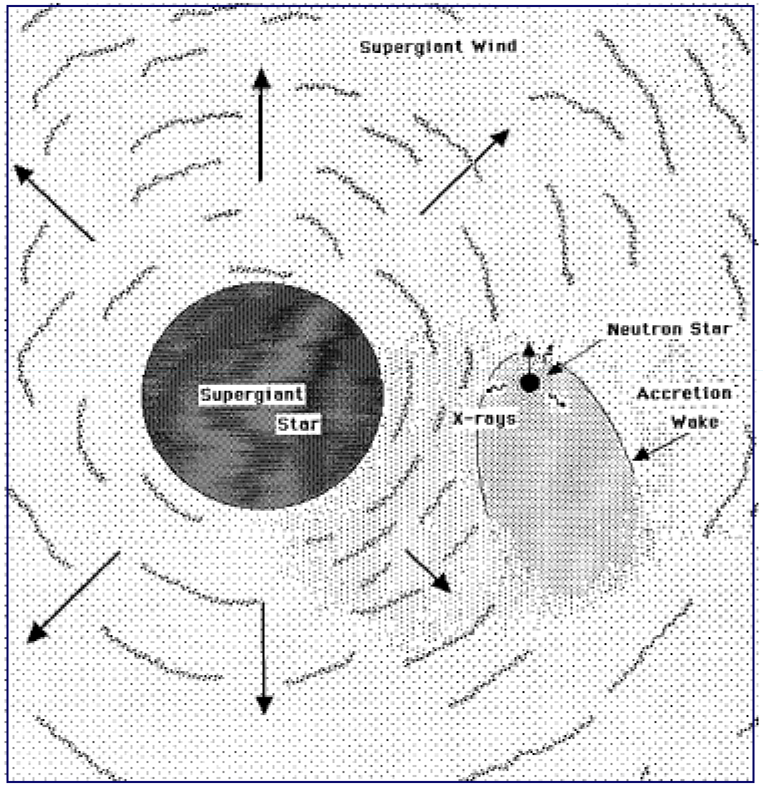
Energy generation mechanism in common, and both have accretion discs, but evolutionary history different



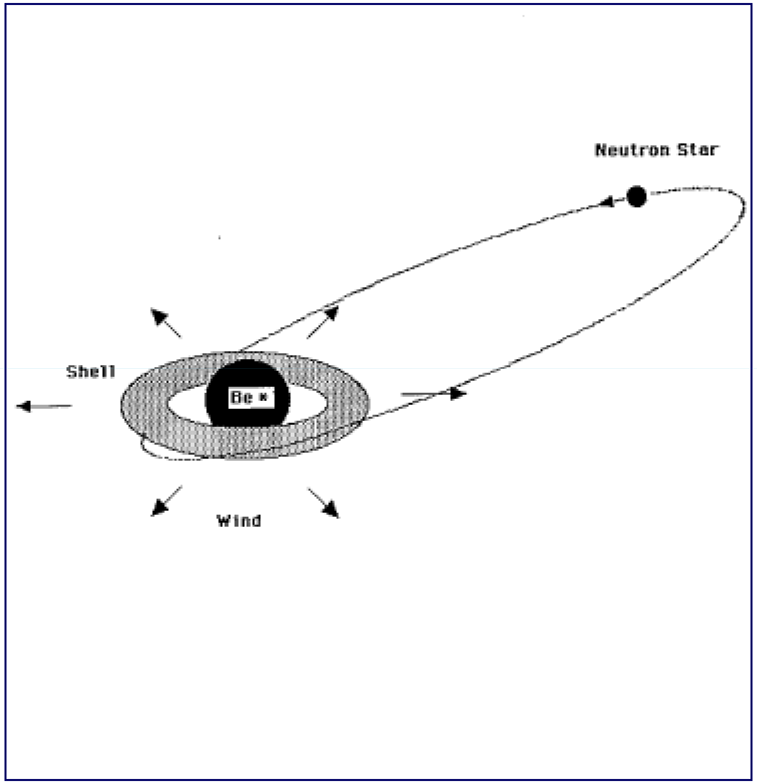

0.6 M⊙
1.4 M⊙
a=2.0 R⊙
P orb=5.6 hours
LMXB
16 M⊙
1.3 M⊙
P orb=3.1 days
a=23 R⊙
HMXB


BLUE
GIANT
STAR
MASSIVE
X-RAY BINARY
(CENTAURUS X-3)
NEUTRON STAR
LOW-MASS
X-RAY BINARY
(4U 1820-30)
WHITE
DWARF
STAR
NEUTRON
STAR
SUN
DETAIL ENLARGED 20 TIMES

High-mass X-ray binaries

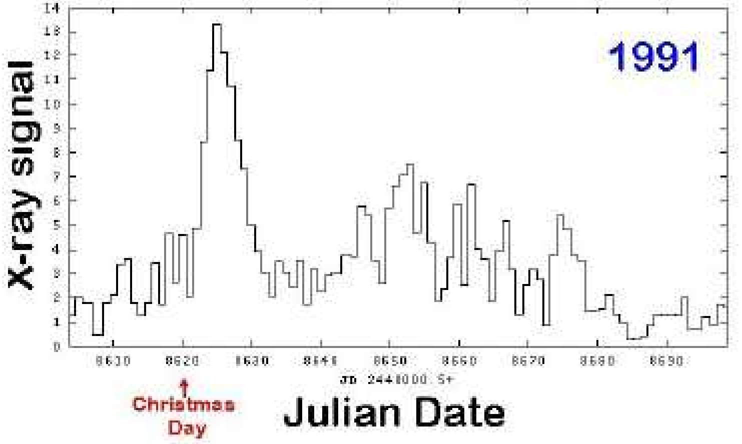


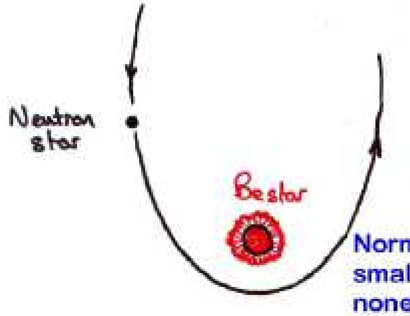
Supergiant companion



Be star companion

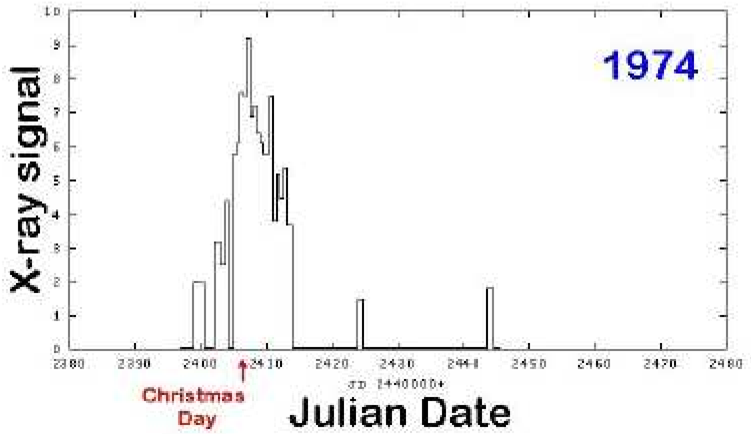
A1118-616 : two outbursts in 25 years

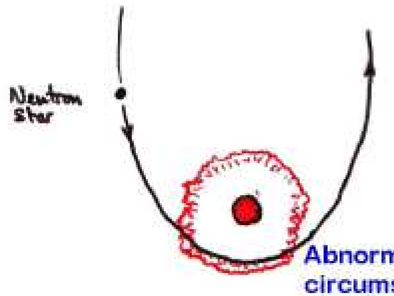




Normal situation:
small circumstellar disk
none/very little accretion
hence
negligible X-rays

Some time in late 1991 the Be star undergoes a substantial ejection of material:

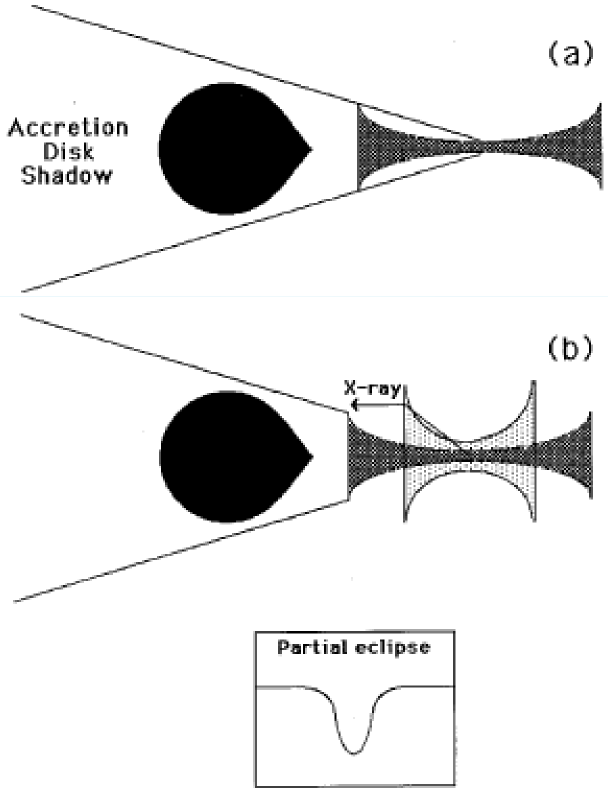




Abnormal situation:
circumstellar disk
doubled in size
plenty of fuel for accretion
hence
Massive X-ray outburst

Low-mass X-ray binaries (LMXBs)

- Companion is a low luminosity, low mass, late type (K,M) star
  - optical light dominated by reprocessed X-rays
- Accretion disks appear to be thick or have thick rims
  - selection against observing systems in the orbital plane
- wide variety of diagnostically useful phenomena
  - including orbital dips, bursts, quasi-periodic oscillations and evidence for scattering corona around the X-ray source



The End