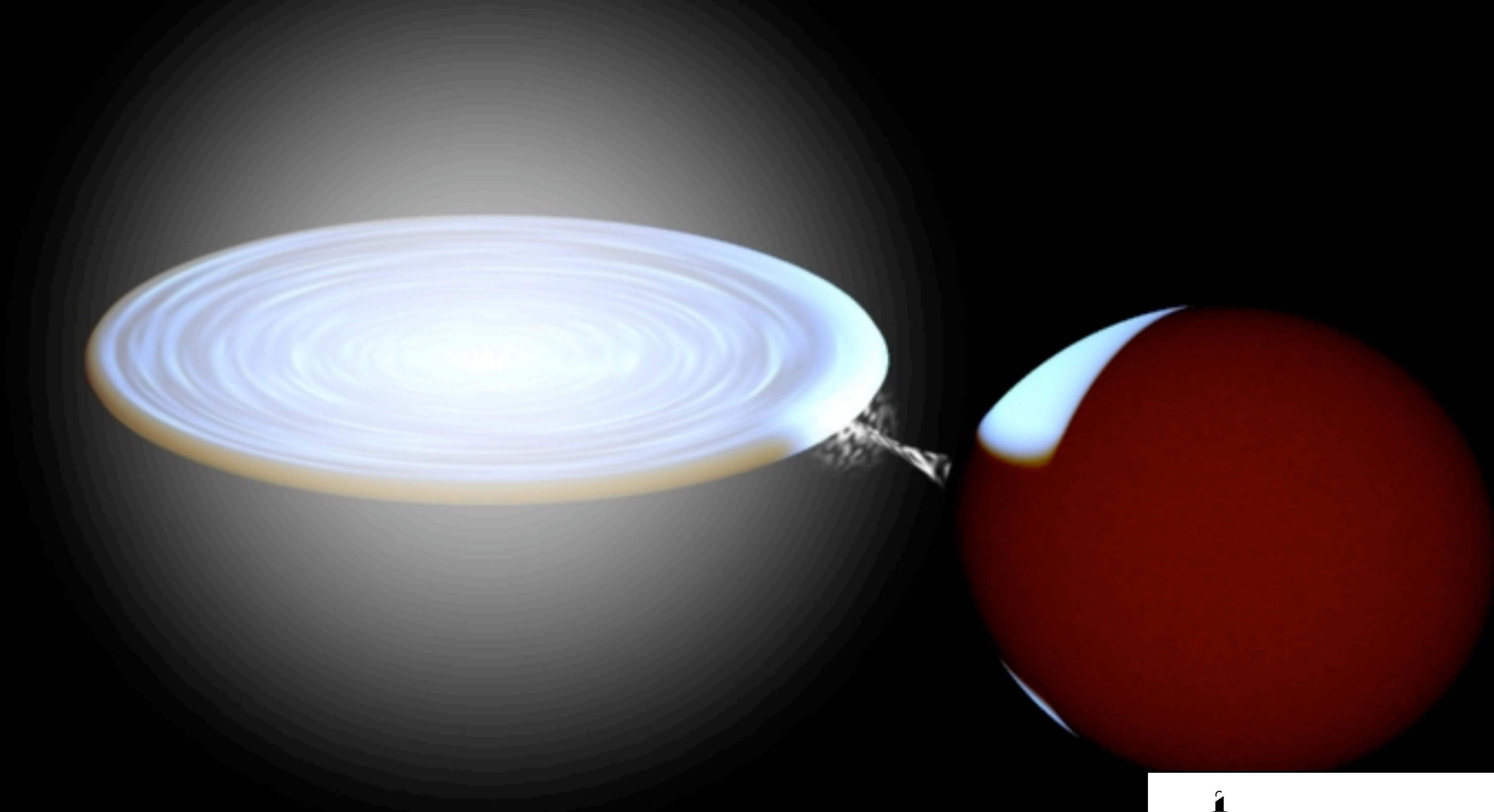
Accretion in Neutron Star/Black Hole Systems



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Overall Outline

Lecture 1: X-ray binary overview
Lecture 2: Spectral energy distributions
Lecture 3: Lightcurves
Lecture 4: Spectra
Lecture 5: Rapid variability

Focus

- Characteristics generic to both black hole and neutron star systems
- Observations of disks more than jets
- Emphasis on UV, optical & IR rather than X-ray/gamma-ray/radio
- More LMXBs than HMXBs

Lecture 1 Outline

Accretion modes and classification of X-ray binaries

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Multiwavelength capabilities for X-ray binaries

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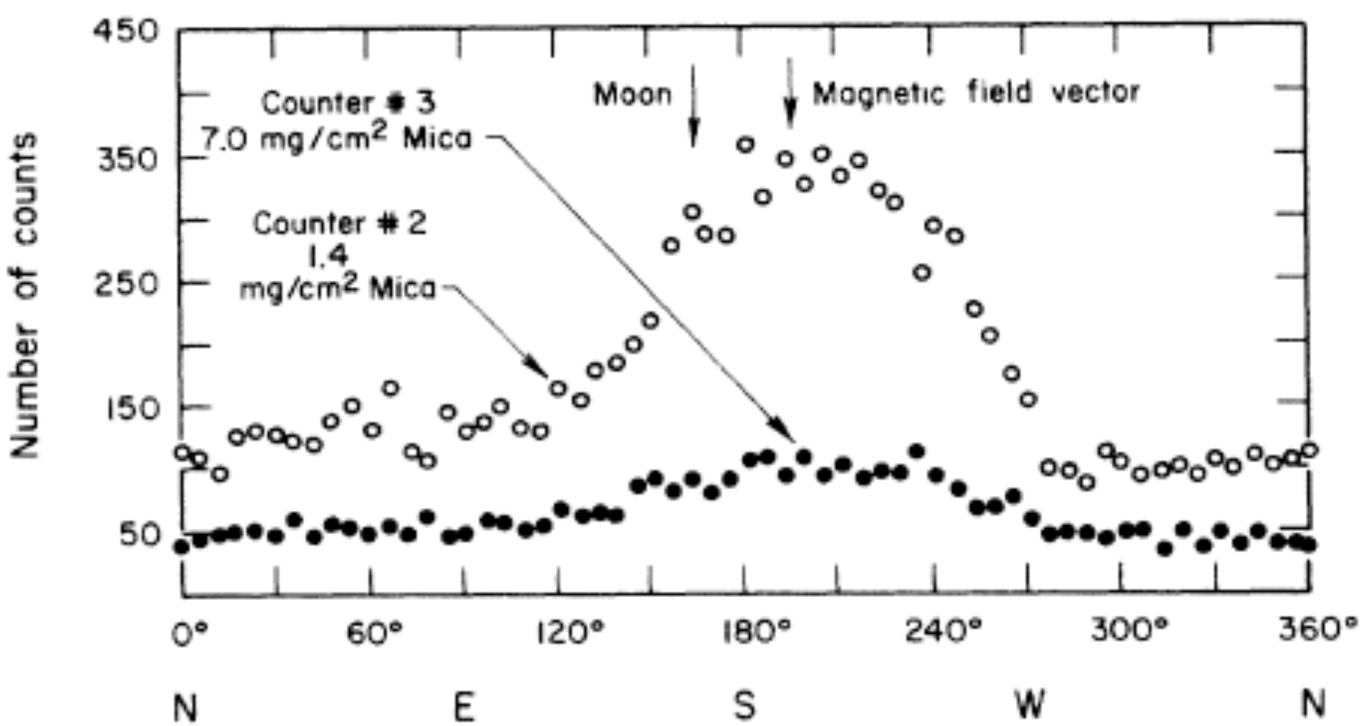
Transient and quasi-transient behavior in low-mass X-ray transients

X-ray Binaries

1962: Discovery of Sco X-1 in X-rays (Giacconi et al., PRL, 9, 11)
1966: Identification of optical counterpart (Sandage et al., ApJ, 146, 316)
1968: Detection of radio emission (Andrew & Purton, Nat, 218, 855)



Sco X-1, from Giacconi et al. (1962, PRL, 9, 11)

X-ray Binary Taxonomy

Companion mass

- High mass
- Low mass
- Intermediate mass

Accretion mode

- Roche lobe overflow
- Wind capture
- Eccentric orbit

Compact object type

- Black hole
- Neutron star

Activity

- Persistent
- Transient
- Quasi-persistent

Classification by Donor Mass

High mass X-ray binary (HMXB)

- Donor typically O or B type, $>10M_\odot$
- Young systems
- Accrete by capture of donor wind, Roche lobe overflow, or interaction with circumstellar disk
- Liu et al. (2006, A&A, 455, 1165) HMXB catalog lists 114

Low mass X-ray binary (LMXB)

- Donor is usually late type $< 1.5M_\odot$
- Can be much older systems
- Usually Roche lobe overflow
- Liu et al. (2007, A&A, 469, 807) LMXB catalog lists 187

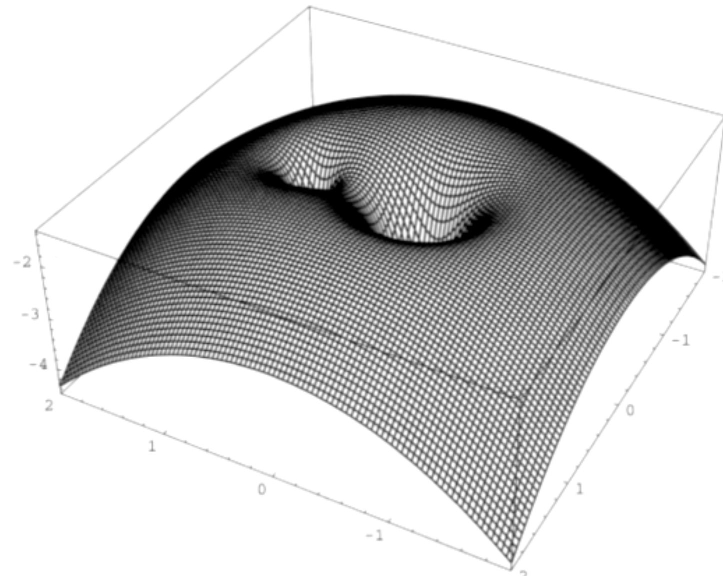
Intermediate mass X-ray binary (IMXB)

- A or F type donor stars
- May be progenitors of some LMXBs

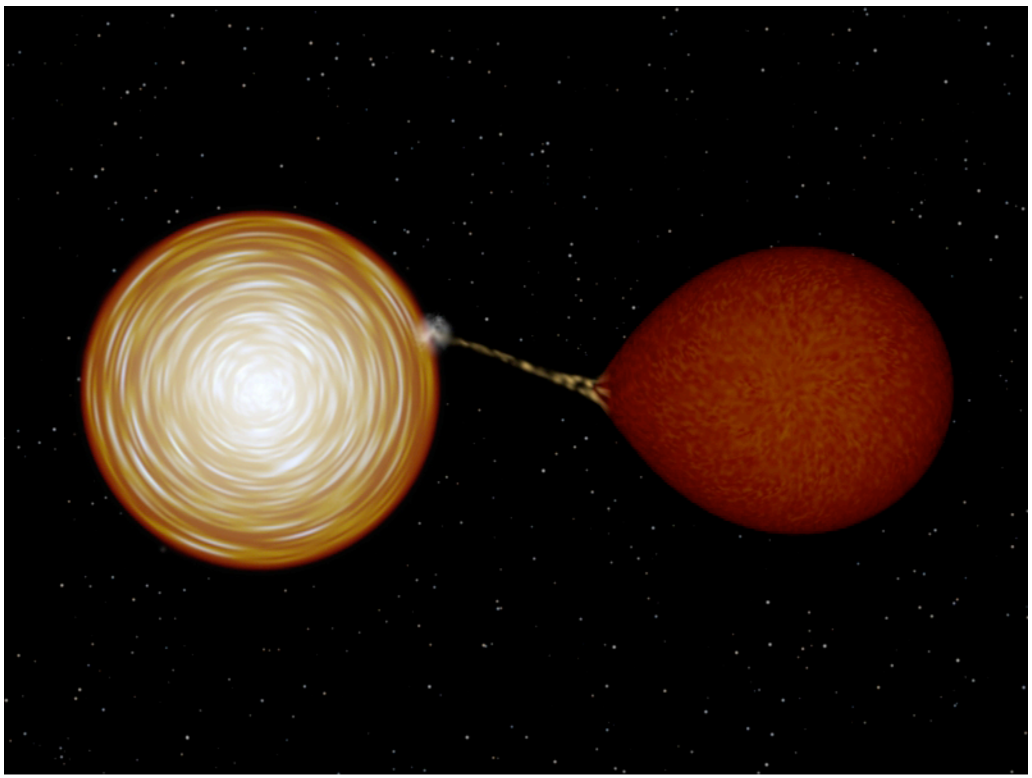
Roche Lobe Overflow Systems

Sample

- Almost all LMXBs and IMXBs
- Small fraction of HMXBs



From Frank et al., 2002, Accretion Power in Astrophysics



'Classic' Persistent LMXBs

Giant donors

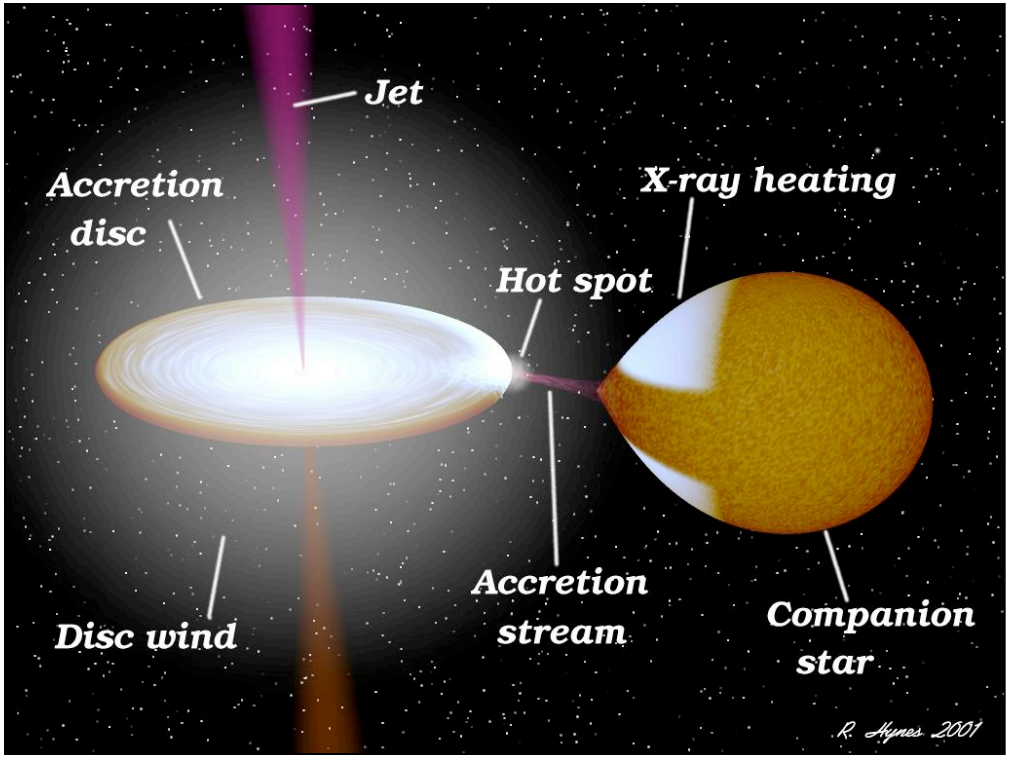
- E.g Cyg X-2 (9.8 d)

Main sequence donors

- E.g 4U 1636-536 (3.8 hr)

White dwarf donors (ultracompacts)

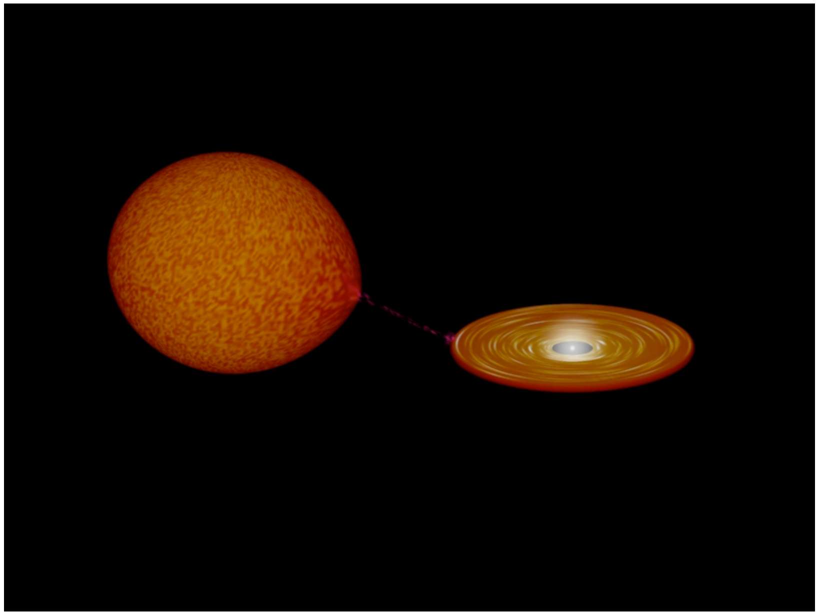
- E.g 4U 1820-303 (11 min)



Soft X-ray Transients (SXTs)

A.K.A. Black Hole X-ray Transients (BHXRTs)

- High incidence of black hole accretor



Quiescence

- Dynamical studies of donor ⇒ black hole mass
- Very low luminosity black hole accretion flows

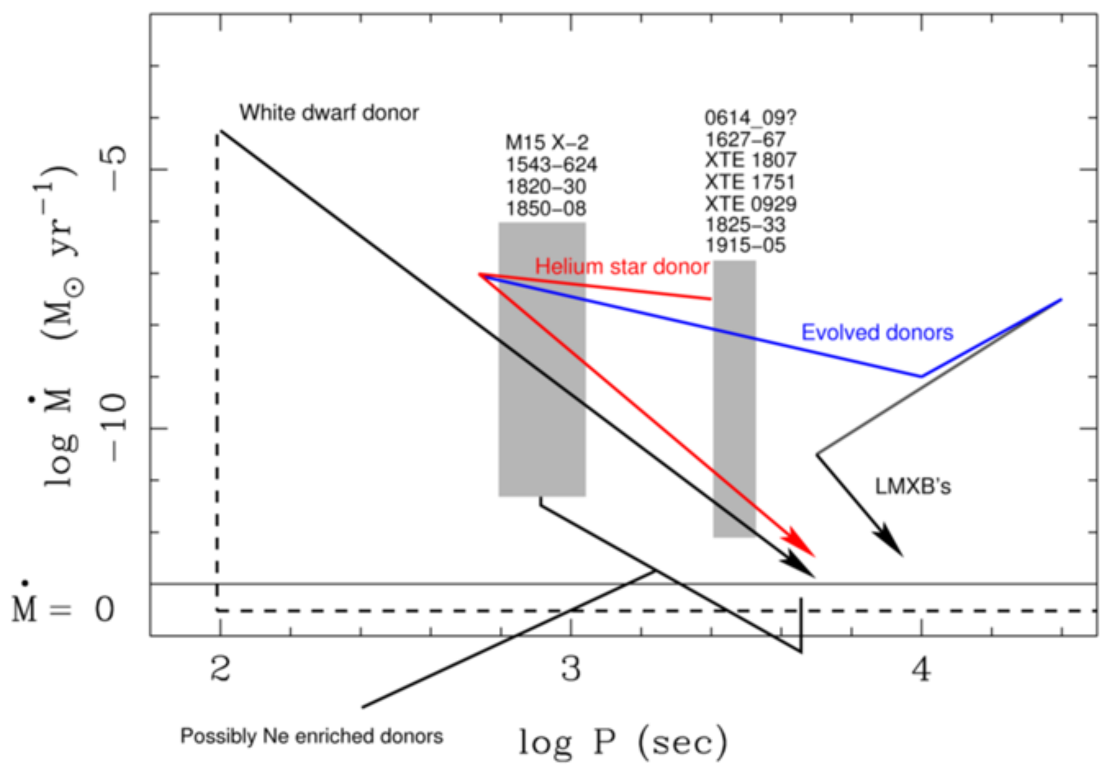
Ultracompact X-ray Binaries (UCXBs)

Short orbital periods

- 11 min (4U 1820-30) to 50 Min (4U 1916-05)

Hydrogen deficient donors

- White dwarfs
- Helium stars

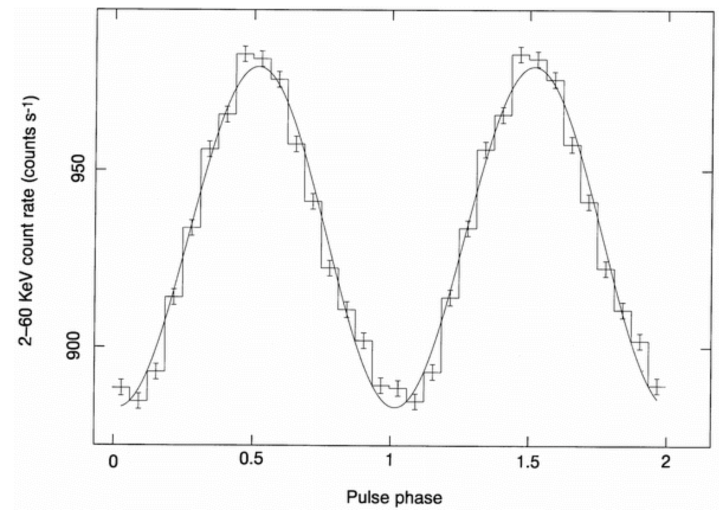


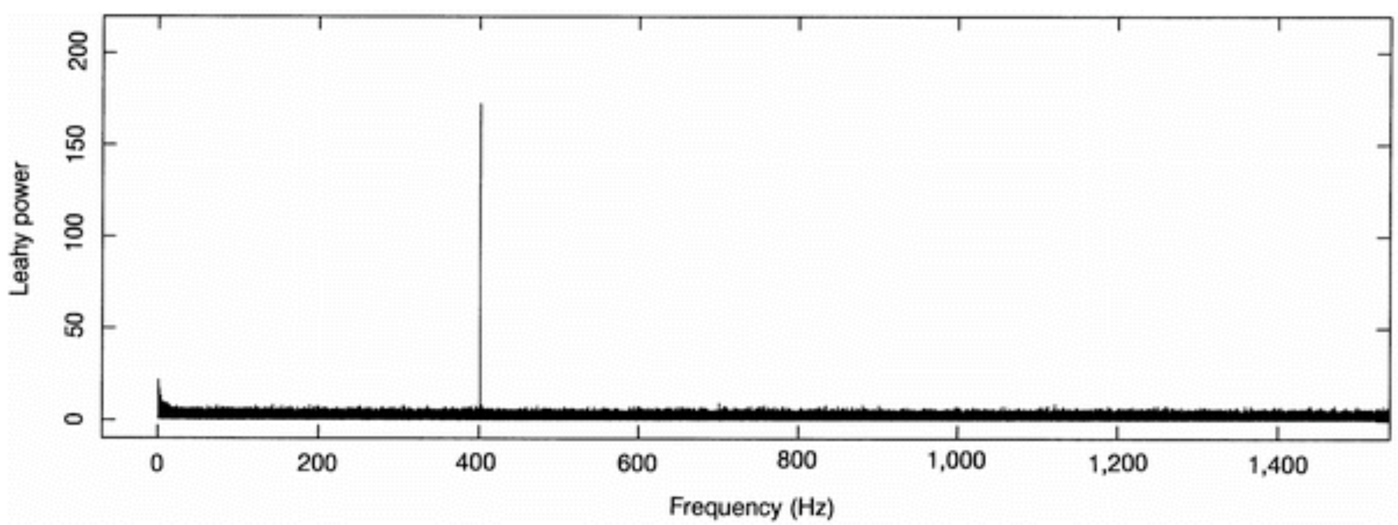
From Nelemans (2008, arXiv:0711.0602)

Accreting Millisecond Pulsars (MSPs)

Important missing link

- LMXB → accreting MSP → radio MSP
- Short periods, some are UCXBs
- First discovery in 1998



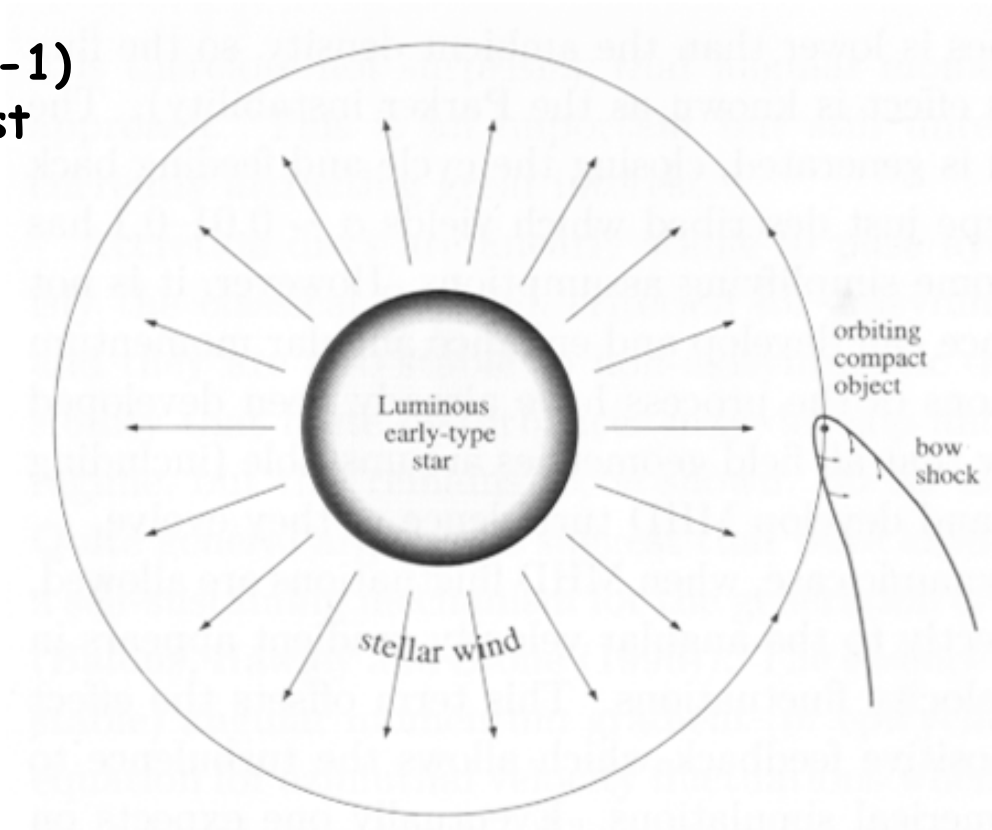


Figures show SAX J1808.4-3658 from Wijnands & van der Klis, (1998, Nat, 394, 344)

Wind Fed Systems

Sample

- Some HMXBs with supergiant companions (32% of Liu HMXB Catalog)
- Both persistent (e.g. Vela X-1) and transient (supergiant fast X-ray transients)
- Symbiotic X-ray binaries (e.g. GX 1+4)



From Frank et al., 2002, Accretion Power in Astrophysics

Persistent Systems with Supergiant Donors

Black hole accretor

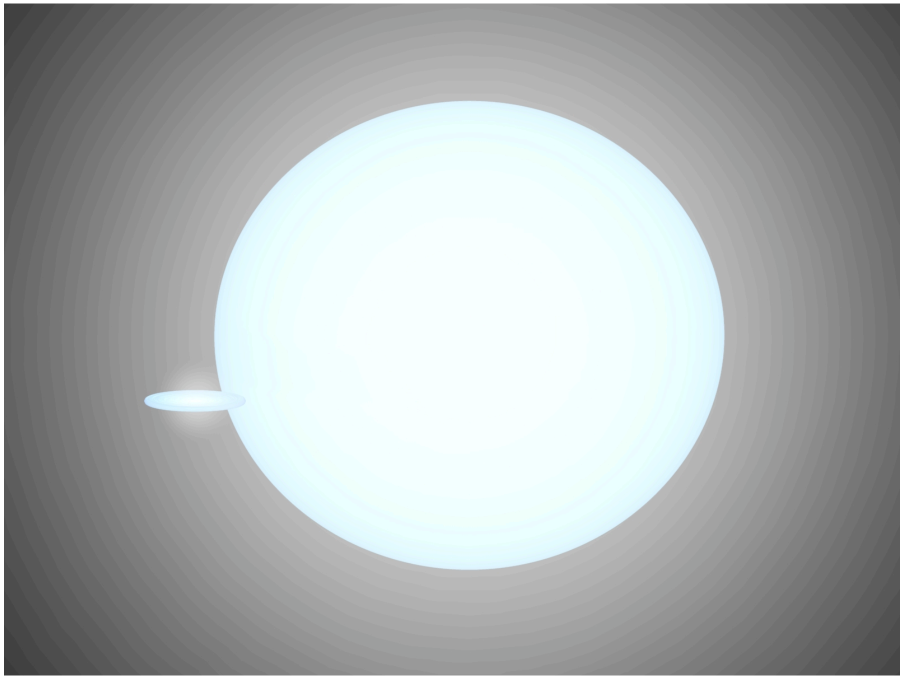
- Cyg X-1

Neutron star accretor

- Often pulsars
- Vela X-1
- Cen X-3

Close binaries

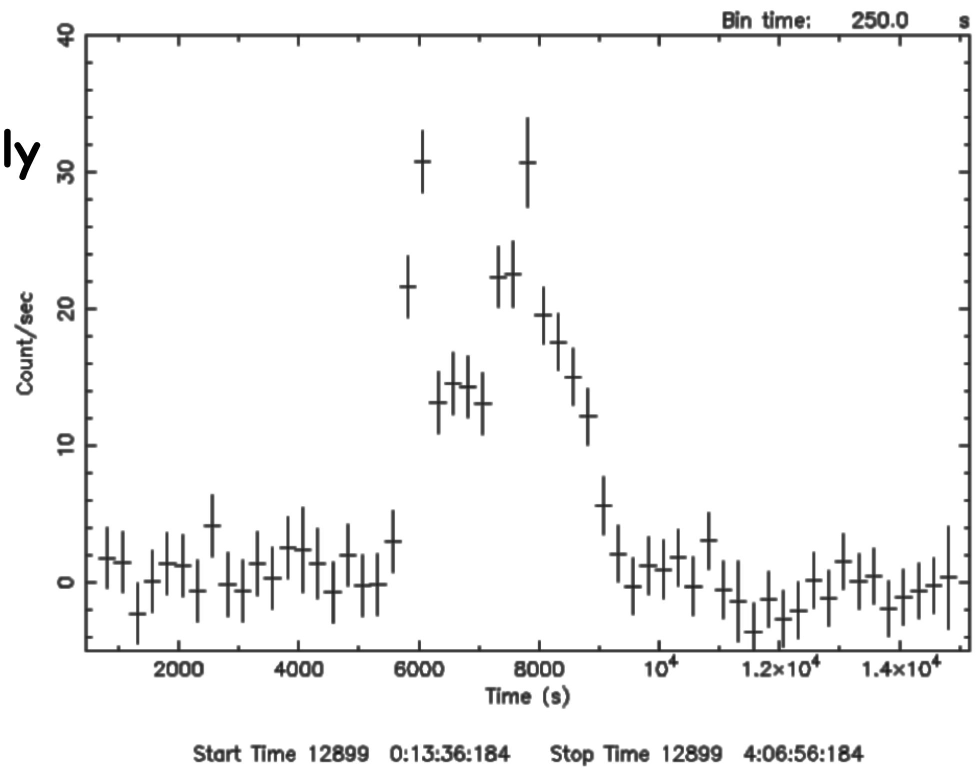
- < 15 day orbit
- Little eccentricity



Supergiant Fast X-ray Transients (SFXTs)

Recent discovery

- Outburst duration hours to days
- Supergiant donors
- Accretion from clumpy winds
- Larger orbits than persistent sources
- Periodic outbursts may imply eccentric orbits

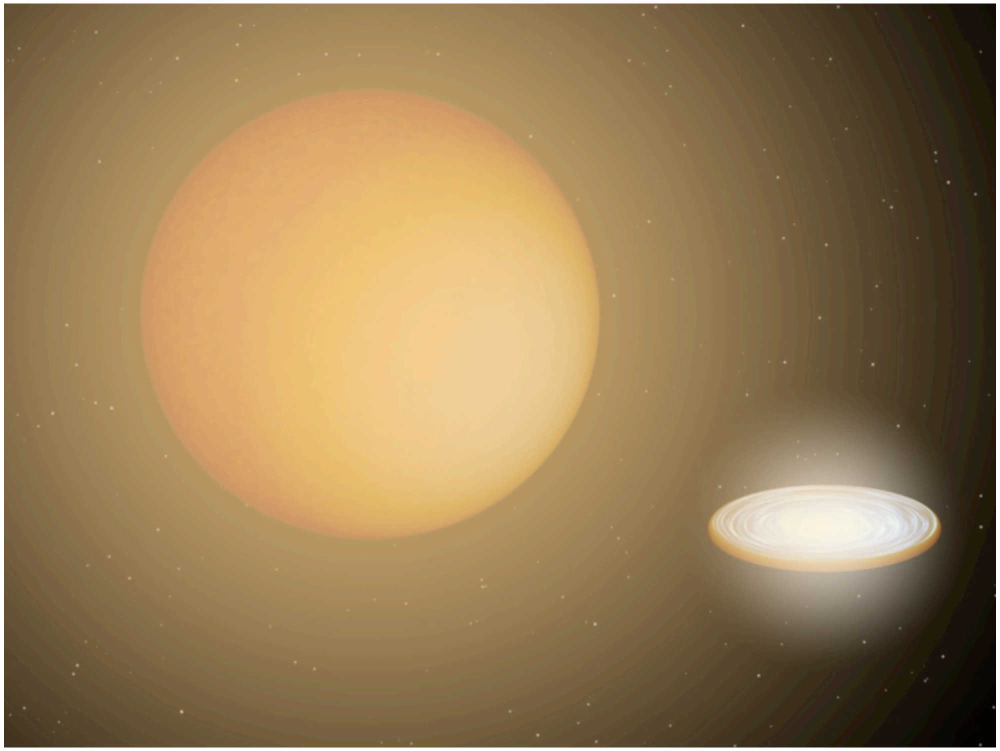


IGR J17544-2619 from Sguerra et al. (2006, ApJ, 646, 452)

Symbiotic X-ray Binaries

M giant donor

- Many symbiotic systems with white dwarfs
- Rarer sample with neutron star accretor (~5 strong candidates)
- GX 1+4 is best known
- See Corbet et al. (2008, ApJ,675, 1424) for recent summary



Eccentric Systems

Sample

- HMXBs with Be companion and circumstellar disk (60% of Liu HMXB Catalog)
- Cir X-1 (HMXB or IMXB)
- Possibly also supergiant fast X-ray transients (SFXTs)

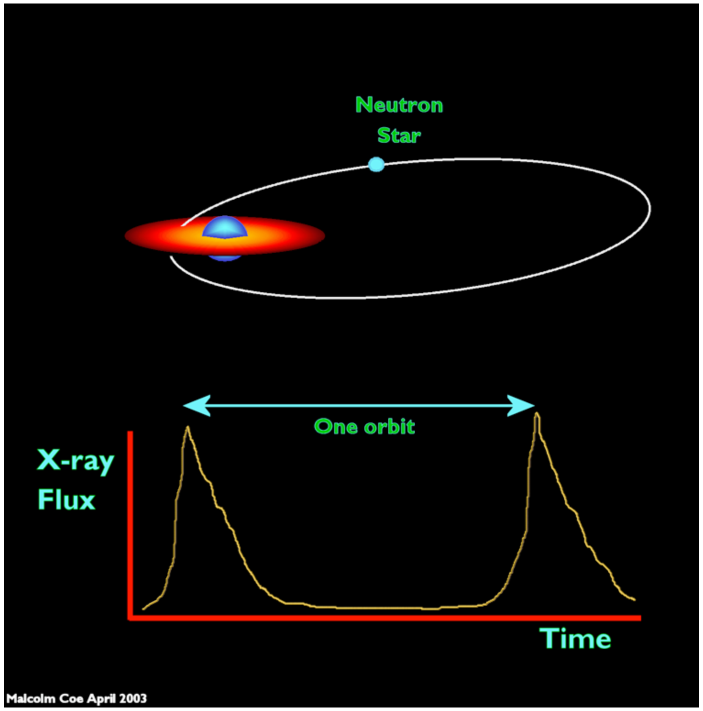
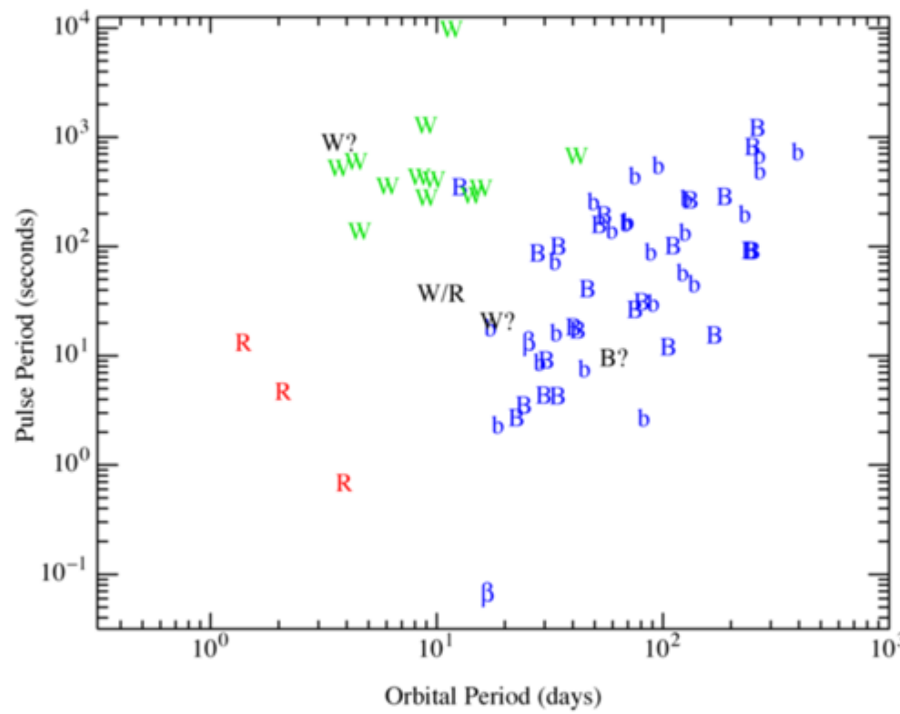


Image Credit: Malcolm Coe

Be X-ray Transients

Typically X-ray pulsars

- Pulse period correlated with orbital period
- Different location in P_{orb}-P_{spin} space ("Corbet diagram") from Roche lobe overflow (R) and wind accreting (W) systems



From Corbet et al. (2008, arXiv:0810.4915)

X-ray Binaries Across the Spectrum

Radio (Spatial-resolution)

- Jets and outflows
- Ground-based

IR

- Companion stars, jets
- Ground & space based (Spitzer)

Optical (Spectral-resolution)

- Disks and companion stars
- Ground based

UV

- Disks
- Space-based (HST, Swift)

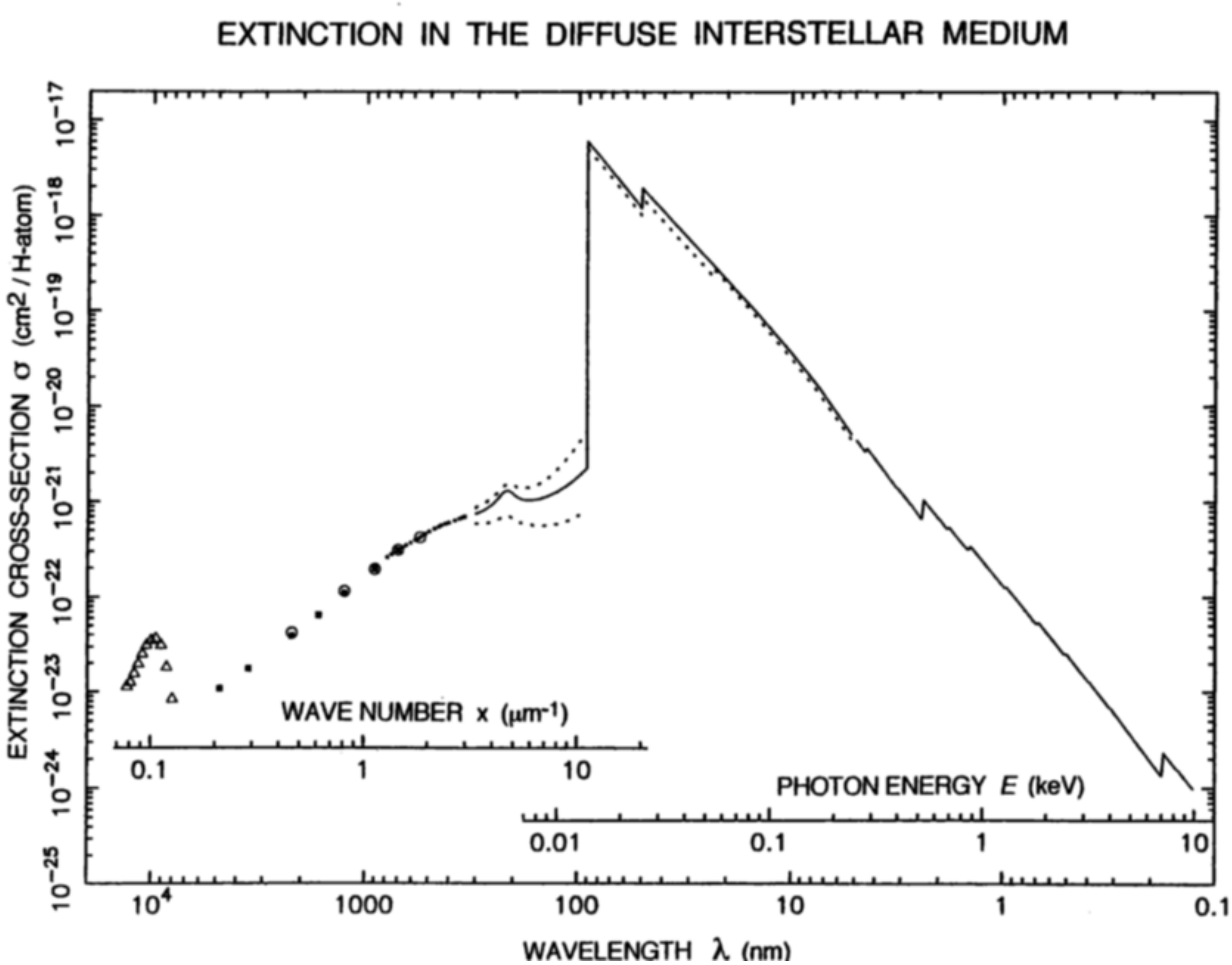
X-ray (Time-resolution)

- Disks, 'coronal' hot gas
- Space-based (RXTE, CXO, XMM, Suzaku, Swift)

Gamma-ray

- Hot gas
- Space-based (Integral, Fermi + RXTE, Suzaku)

Interstellar Extinction



From Ryter (1996, Ap&SS, 236, 285)

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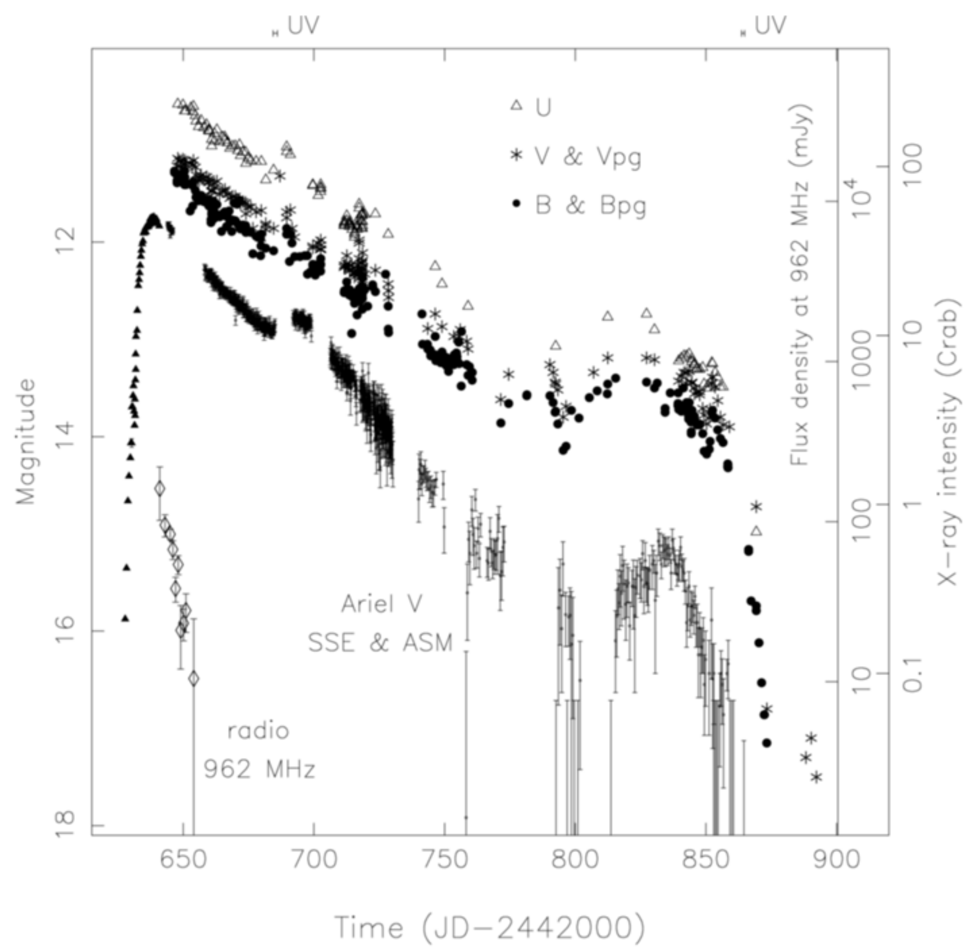
Prototypical Soft X-ray Transient (SXT)

- Outburst in 1975 (and 1917)
- 7.8 hr period
- 10 $M_\odot$ black hole

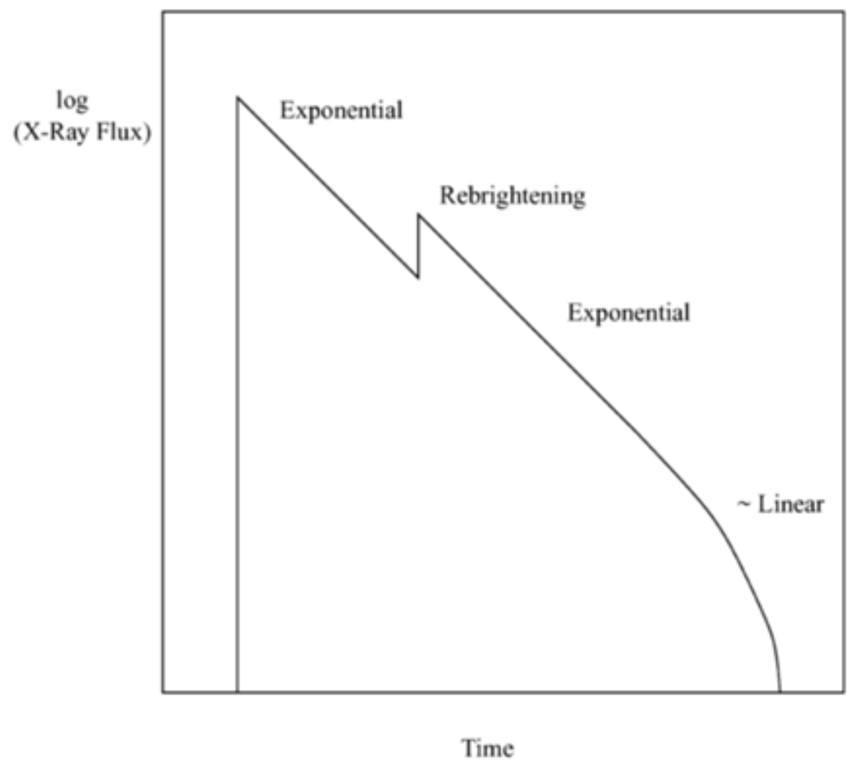


From Kuulkers et al. (1998, NewAR, 42, 1)

FRED Outbursts

Fast Rise Exponential Decay

- Accretion rate proportional to disk mass
- WHOLE disk maintained in hot state by irradiation
- Most of disc mass is accreted ⇒ long recurrence time

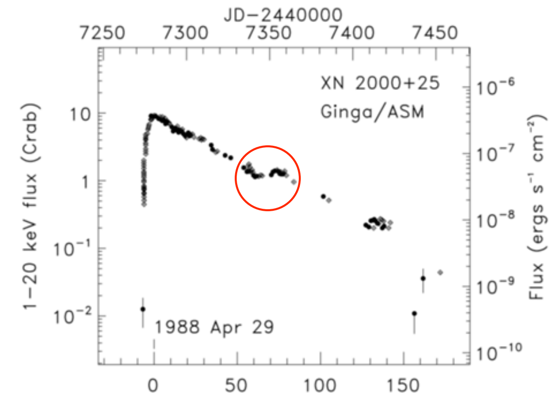


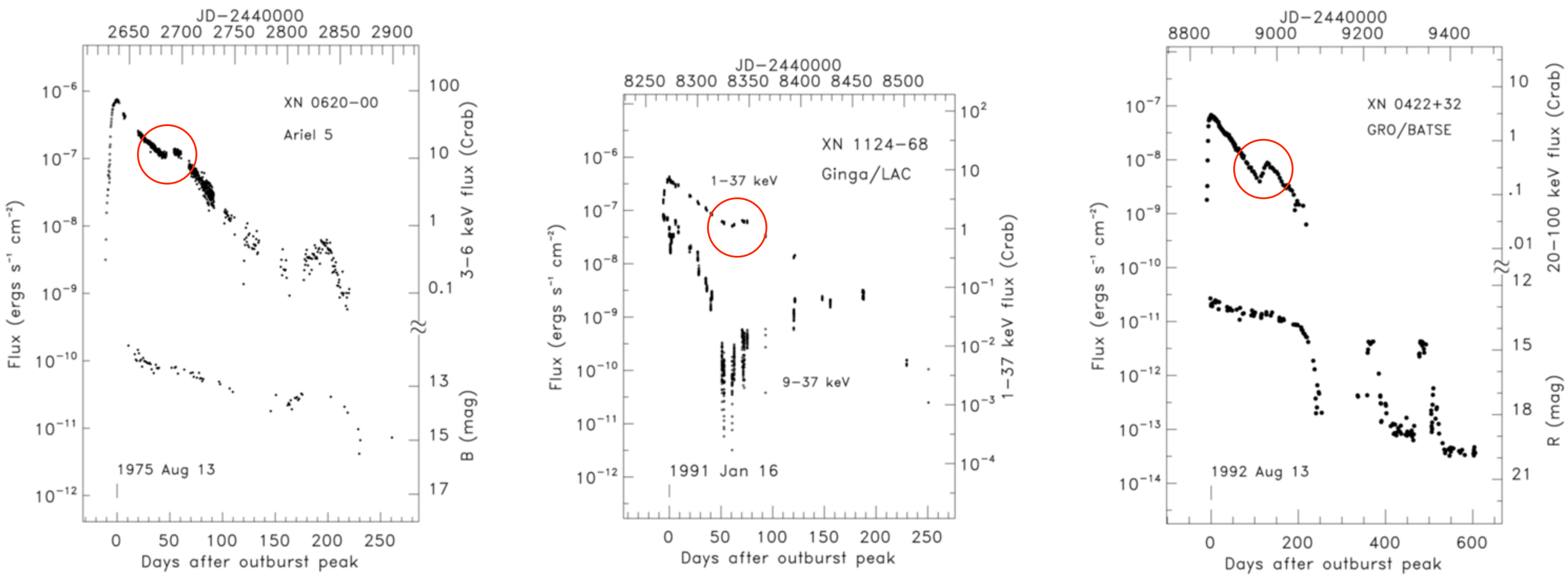
From Truss et al. (2002, MNRAS, 337, 1329)

Secondary Maxima / Rebrightenings / Glitches

Secondary maxima in FRED outbursts

- Ubiquitous
- Around 60 days after peak
- Present in optical as well as X-ray





From Chen et al. (1997, ApJ, 491, 312)

Explanations of Secondary Maxima

Augusteijn & van Paradijs (1993, A&A, 279, L13)

- Enhanced mass transfer from companion due to irradiation

King & Ritter (1998, MNRAS, 293, L42)

- Irradiation of cool outer disk increases active disk mass

Truss et al. (2002, MNRAS, 337, 1329)

- Growth of tidal instability in outer disk

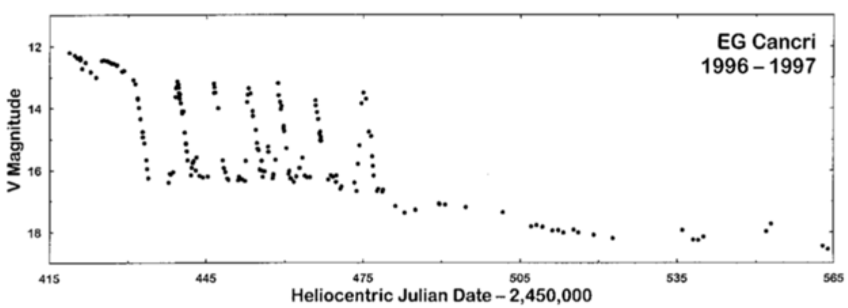
Mini Outbursts / Echo Outbursts / Reflares

Varied occurrences

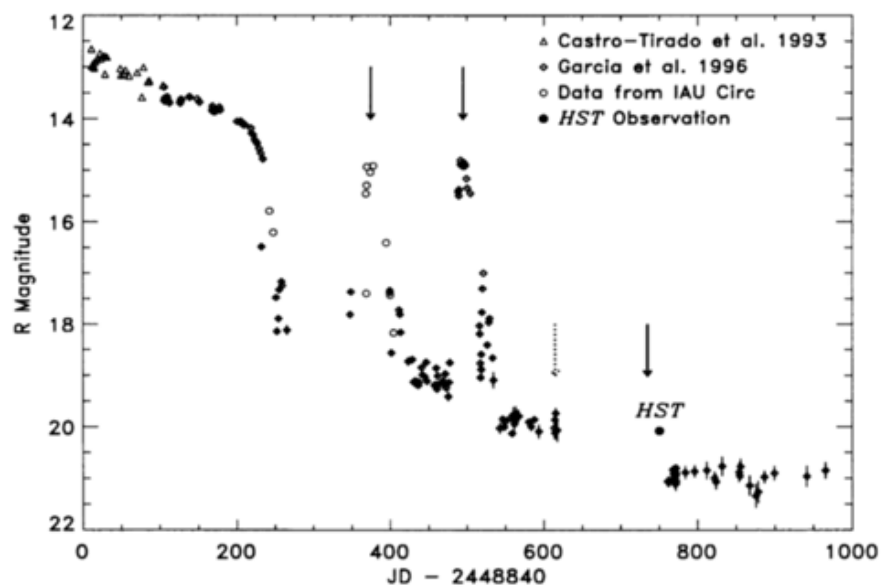
- LMXBs – GRO J0422+32, GRS 1009-45, XTE J1859+226
- SU UMa CVs – e.g. EG Cnc

Mechanism?

- Irradiation (Hameury, 2000, A&A, 353, 254)
- Viscosity decay (Osaki, 2001,A&A, 370, 488)
- Tidal effects (Hellier, 2001, PASP, 113, 469)



From Patterson et al. (1998, PASP, 110, 1290)

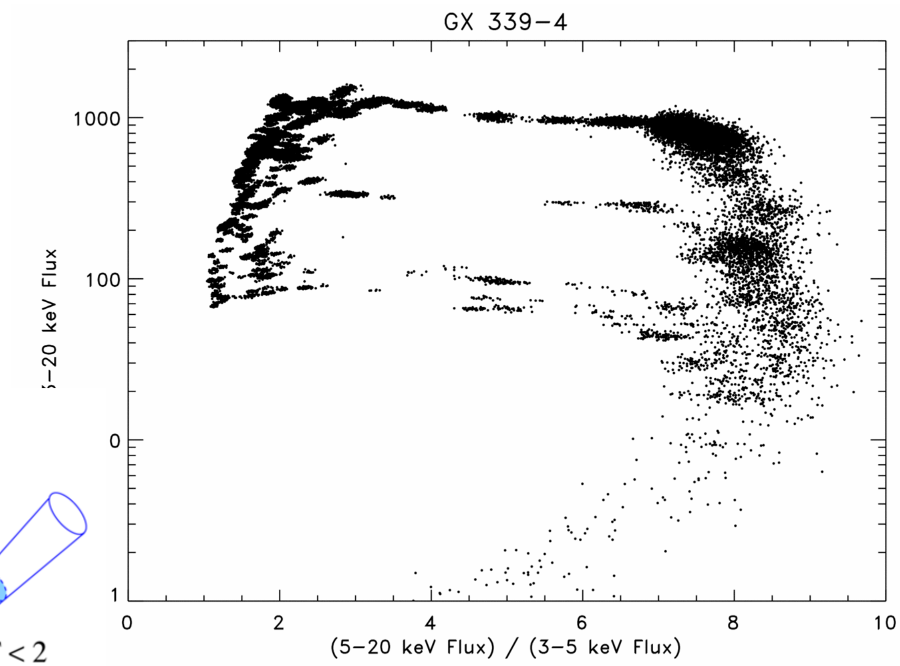


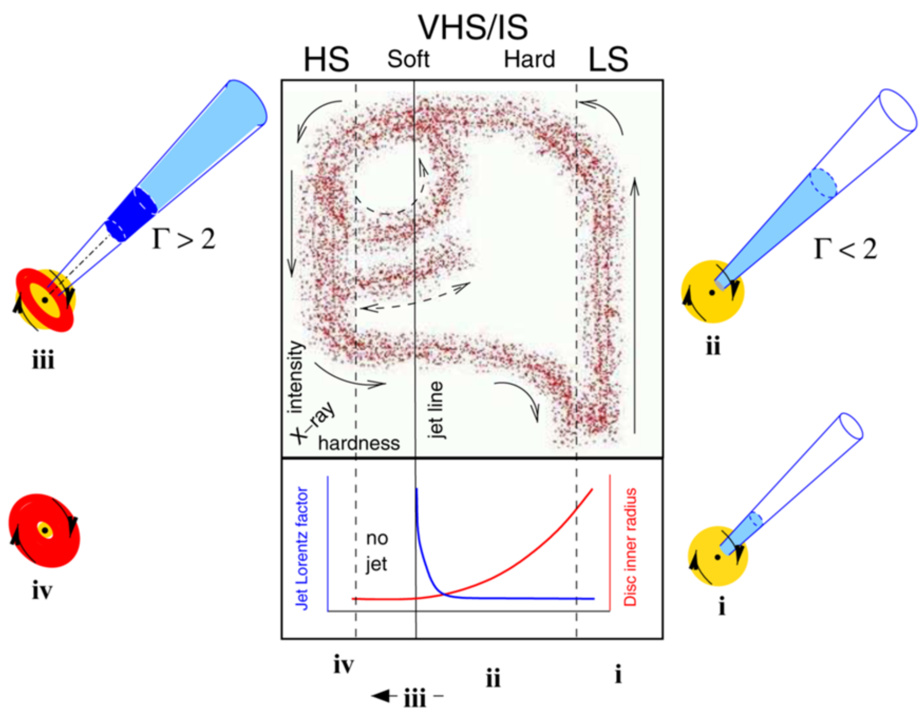
From Hynes et al. (1999, MNRAS, 303, 101)

Canonical Black Hole State Evolution

Hysteresis loop

- Hard rise, soft decay



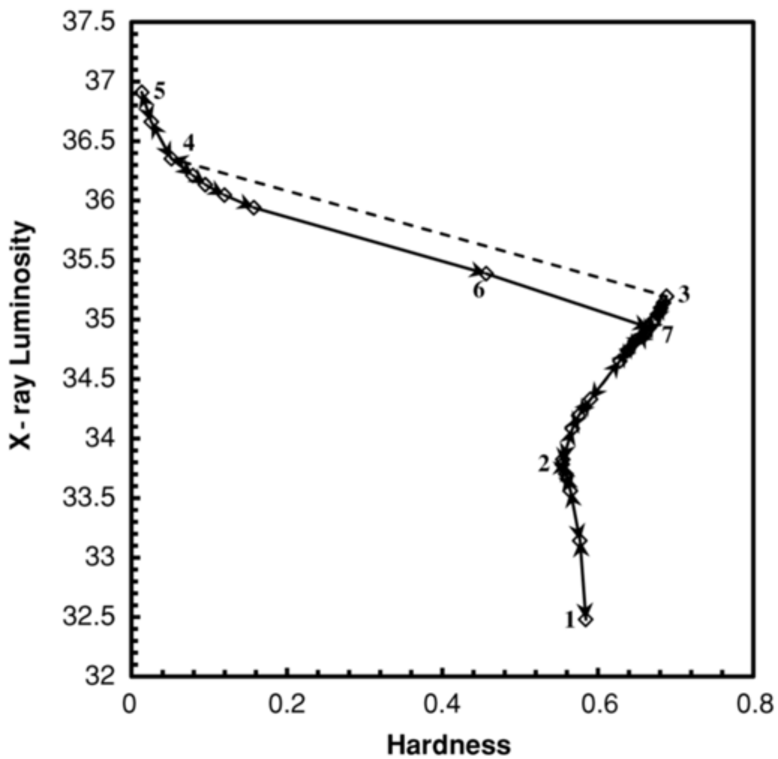


From Fender et al. (2004, MNRAS, 355, 1105)

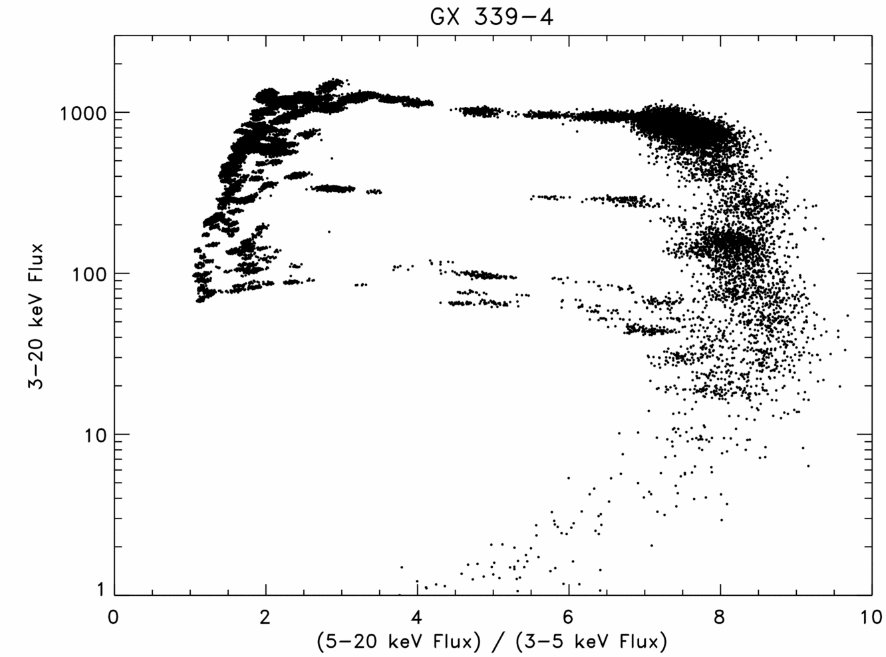
Modeling State Evolution

Hysteresis loop

- Some success using evaporation/recondensation model



From Bradley & Frank (2009, ApJ, 704, 25)



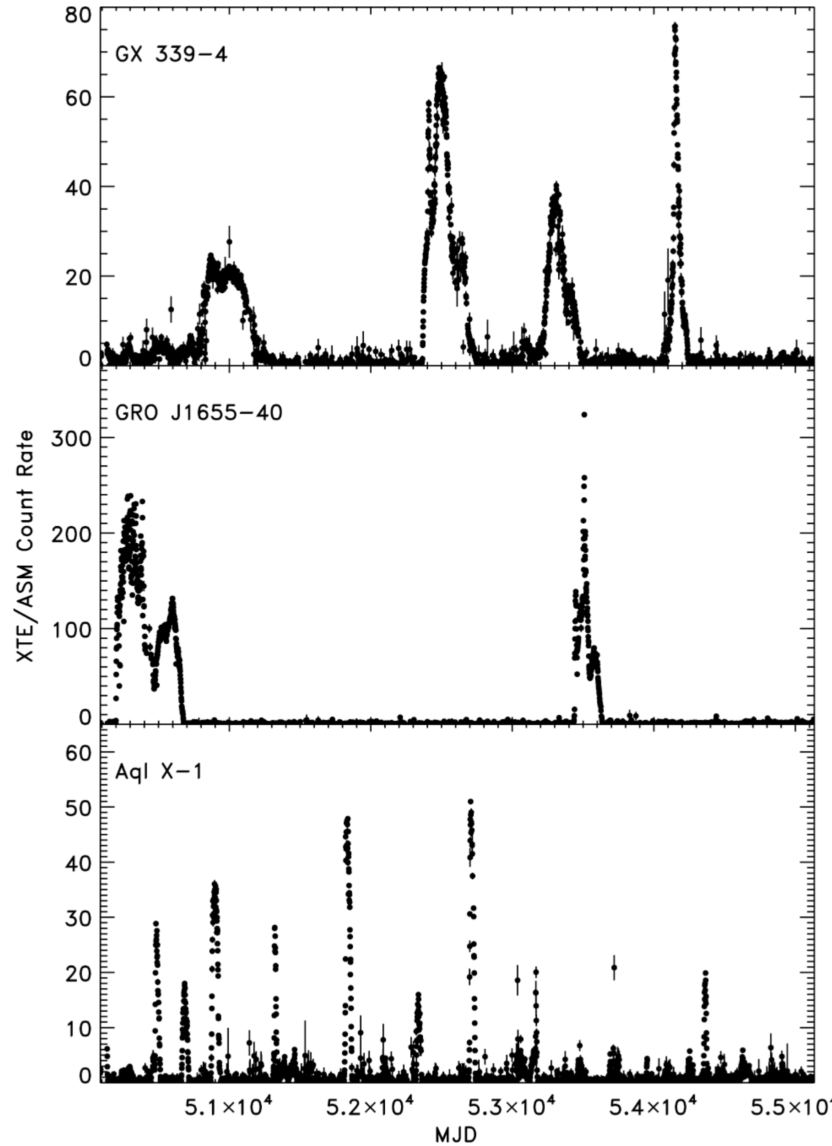
Recurrent Transients

Permanently outbursting systems

- Short recurrence time
- Aql X-1 (neutron star)
- GX 339-4 (black hole)

Temporary sequence of outbursts

- Follows extended quiescence
- GRO J1655-40
- XTE J1118+480



Quasi-Persistent Sources

Appear persistent for years

- Only observe a turn-on or turn-off
- How many ‘persistent’ sources are really only quasi-persistent?

Black holes

- GRS 1915+105 (1992 - present)

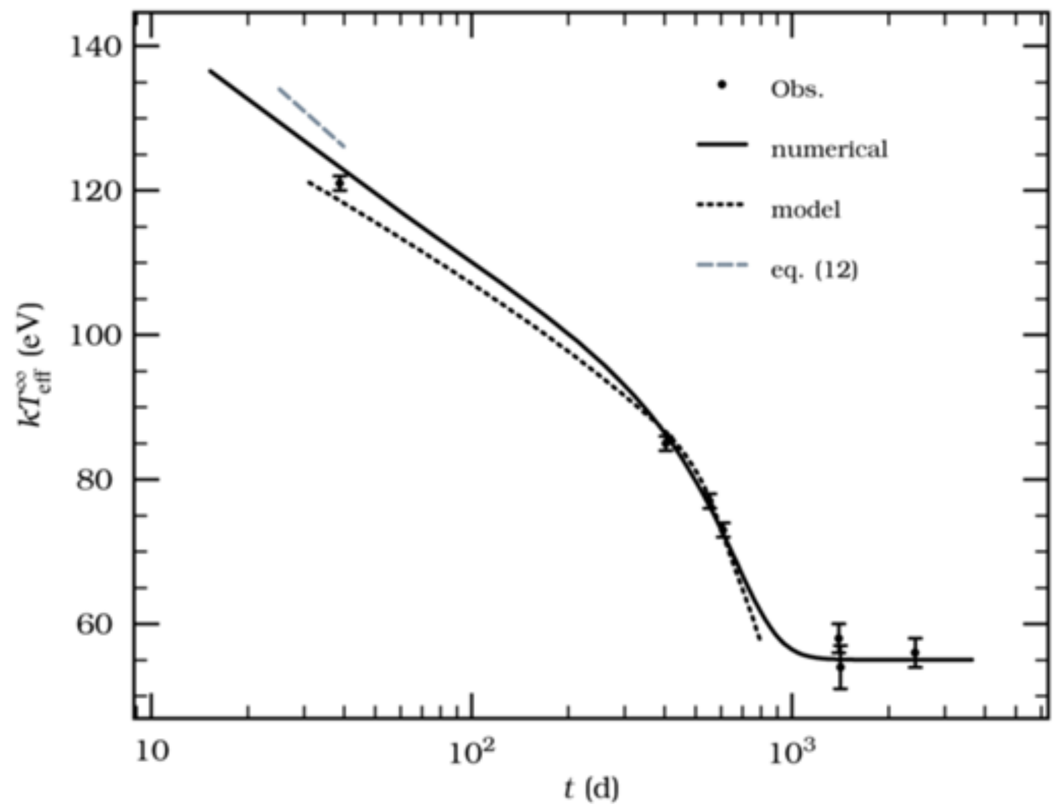
Neutron star systems

- 4U 2129+47 (? - 1983)
- EXO 0748-676 (1985 - 2008)
- KS 1731-260 (? – 2001)

Neutron Star Cooling

During outburst crust heated to above core temperature

- Cools by conduction to core
- Cooling curve tests internal structure



MXB 1659-29, from Brown & Cumming (2009, ApJ, 698, 1020)