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Accretion physics in the Small Magellanic Cloud (SMC)

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Frank Haberl (MPE)

Dave Buckley & Matt Schurch (SAAO & UCT)

Structure of presentation

- **Introduction to the SMC**
- **Results so far from our X-ray and optical work**
- **Implications for XRB population and SFR in the Magellanic Clouds**
- **Conclusions**

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History of the Magellanic Clouds

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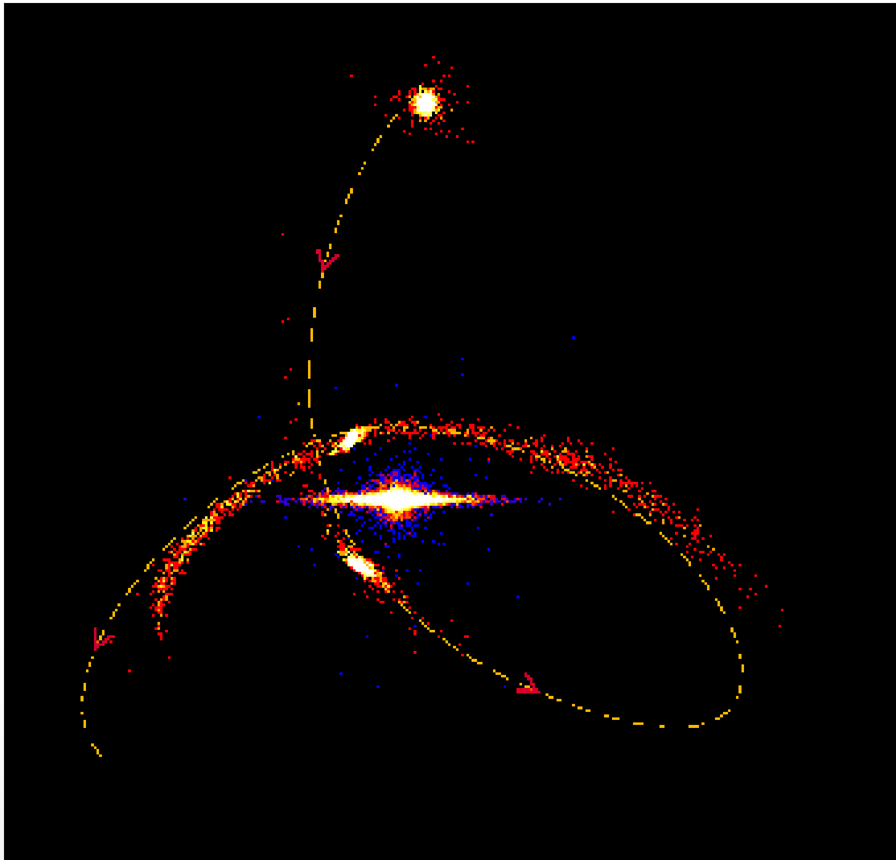
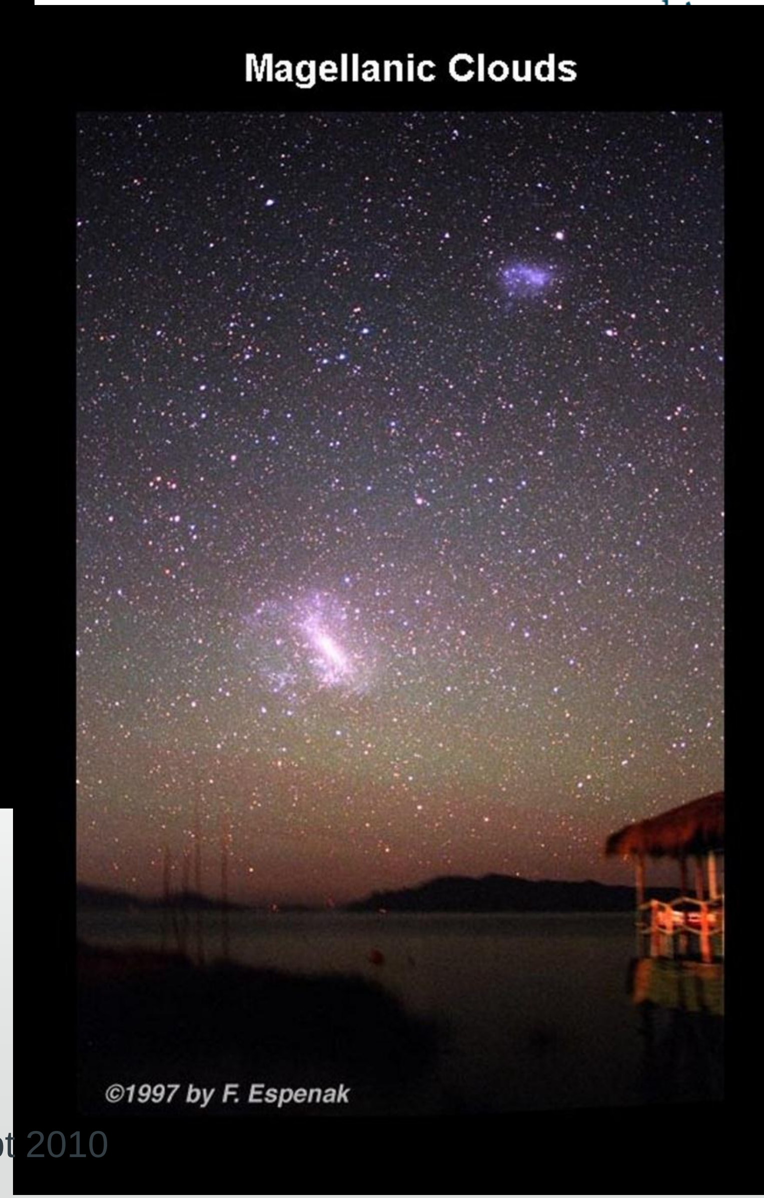
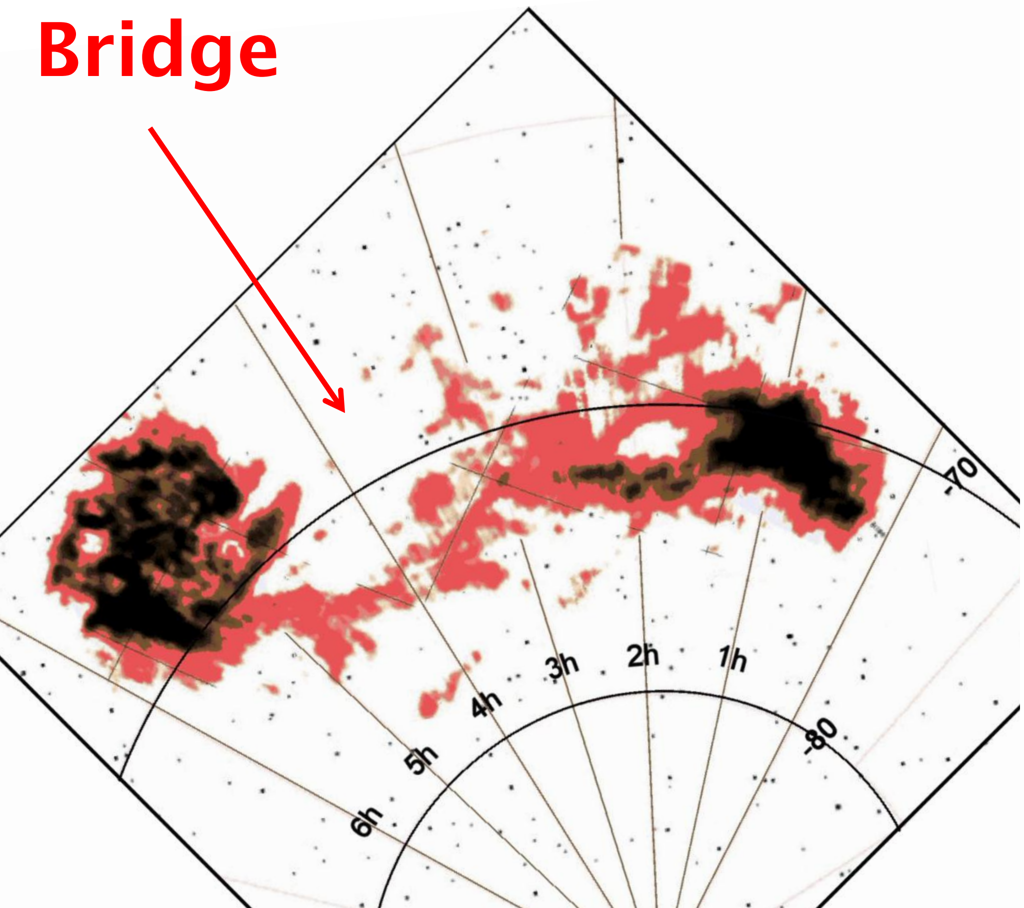


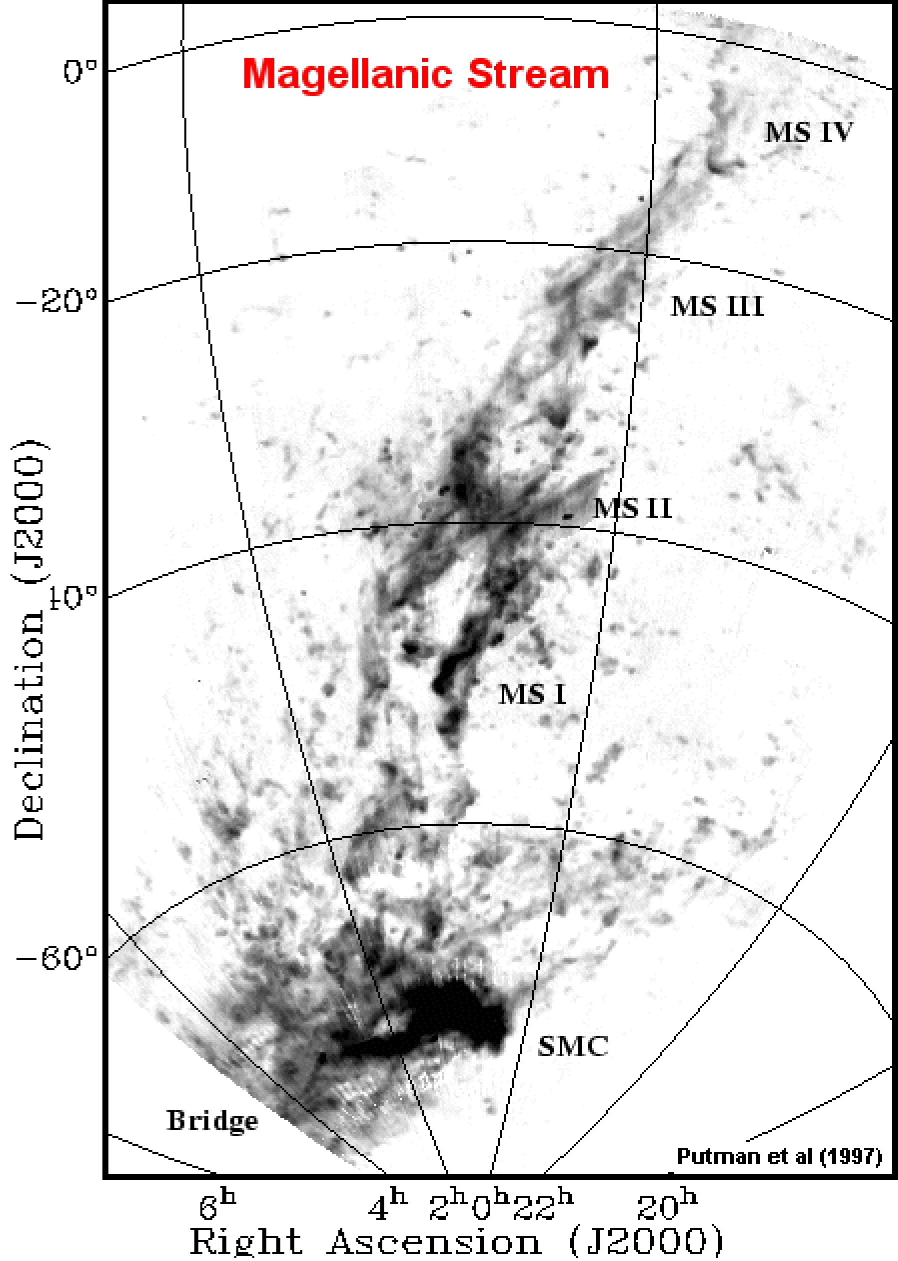


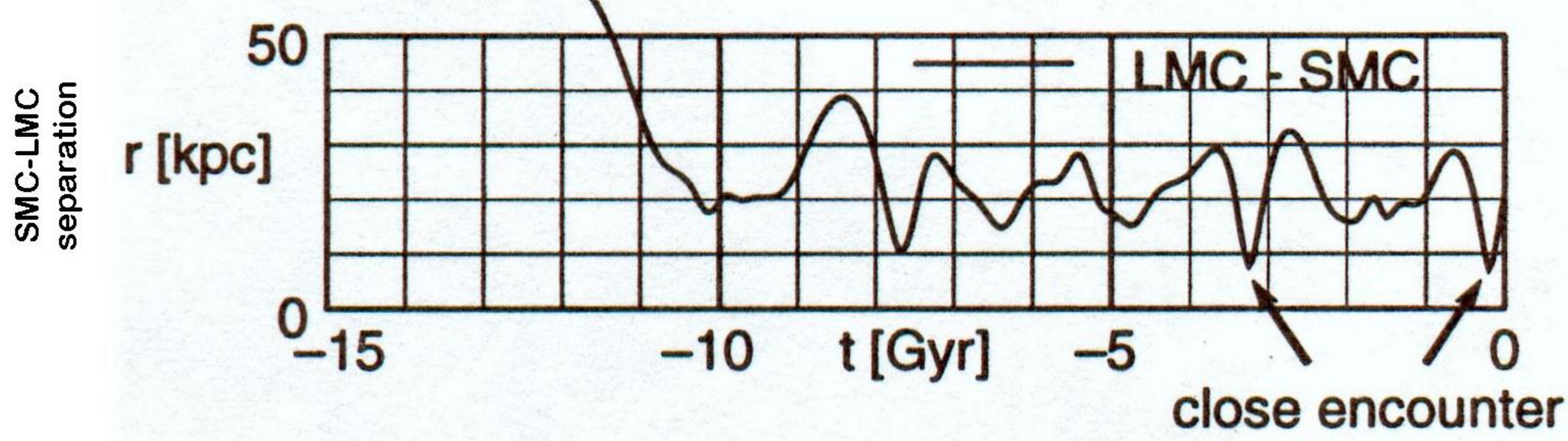
Traditionally believed to have been captured several Gyrs ago, orbital period ~1Gyr.

Bridges & Streams

Bridge







Sawa et al (1999) IAU Symp 190, 499.

200 million years ago
in a galaxy not so far away ……

Gardiner & Noguchi (1996)

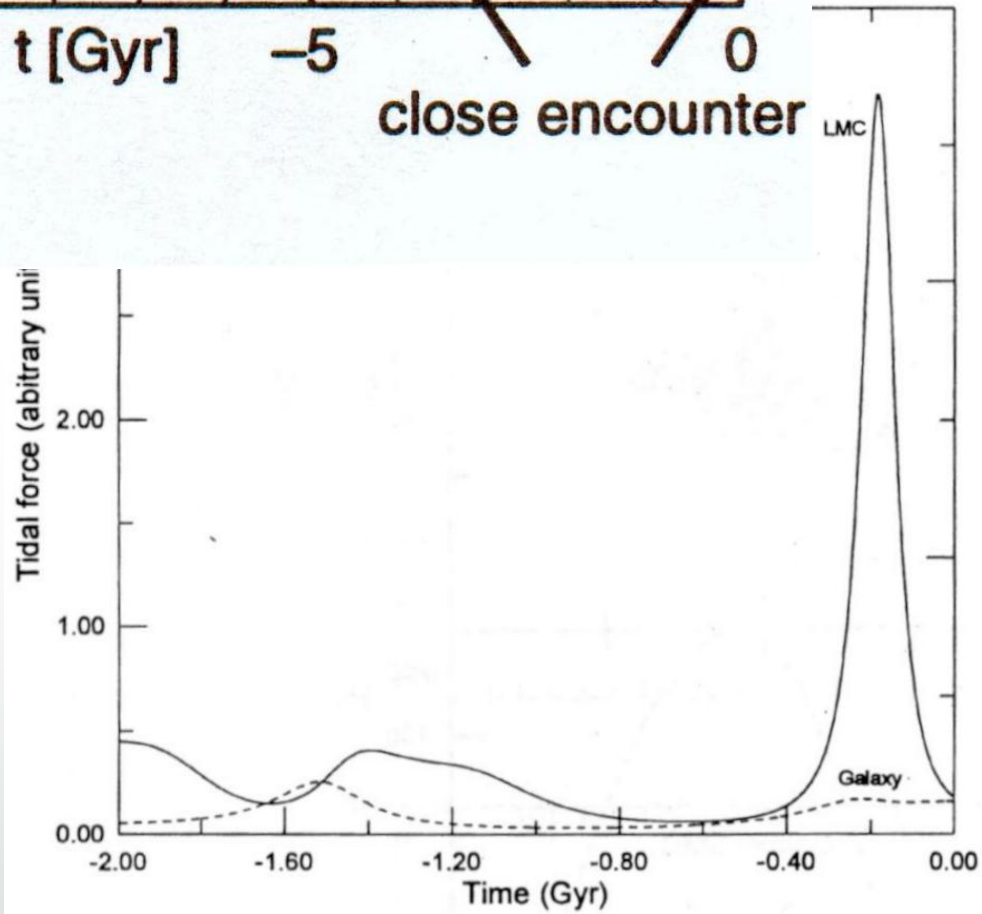


Figure 4. The tidal force exerted on the SMC by the Galaxy and the LMC as a function of time. The tidal force was calculated from the double derivative of the Galaxy and LMC potentials at the position of the SMC

New HST data results…..

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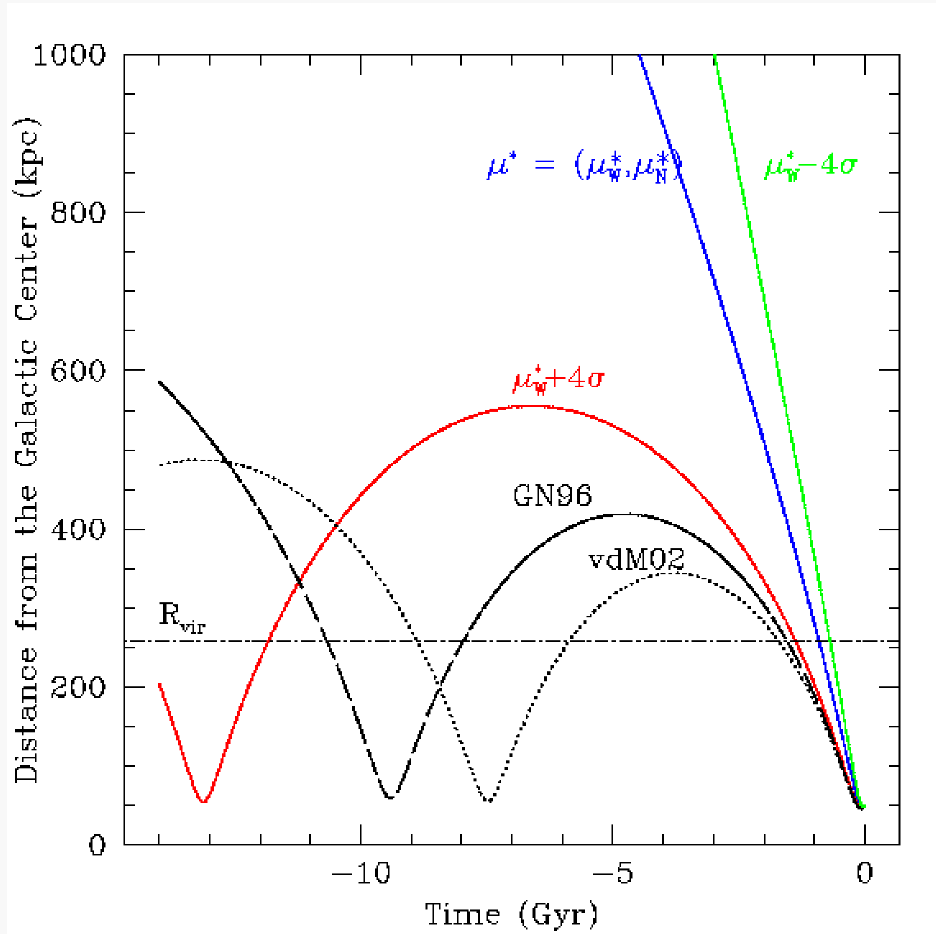
Kallivayalil et al 2006



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X-ray monitoring using RXTE

RXTE Observations of the SMC "weather"

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- **For ~10 years we have been getting an observation per week on at least one position in the SMC, sometimes 2-3 positions.**
- **A typical observation detects 0-3 active pulsars.**
- **We carry out a power spectral analysis searching for pulse periods (known & unknown).**

10 years of weekly observations of the SMC with RXTE

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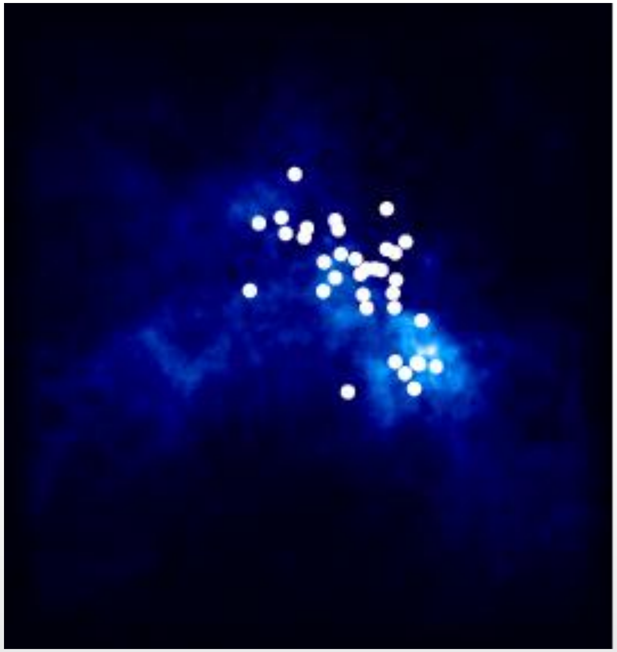

Movie produced by Vanessa McBride

Crete October 2010

Be/X-ray binary X-ray activity cycles

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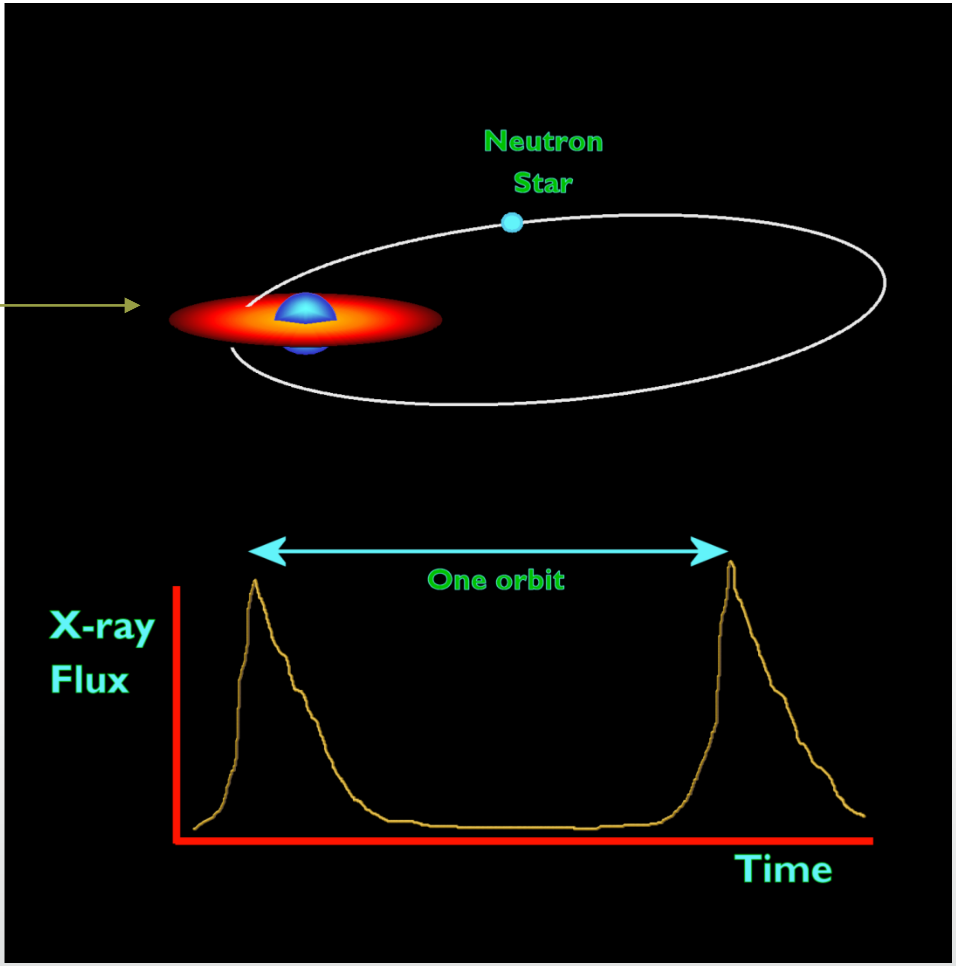
B0e-B2e

III-V

star



ACTIVITY CYCLES

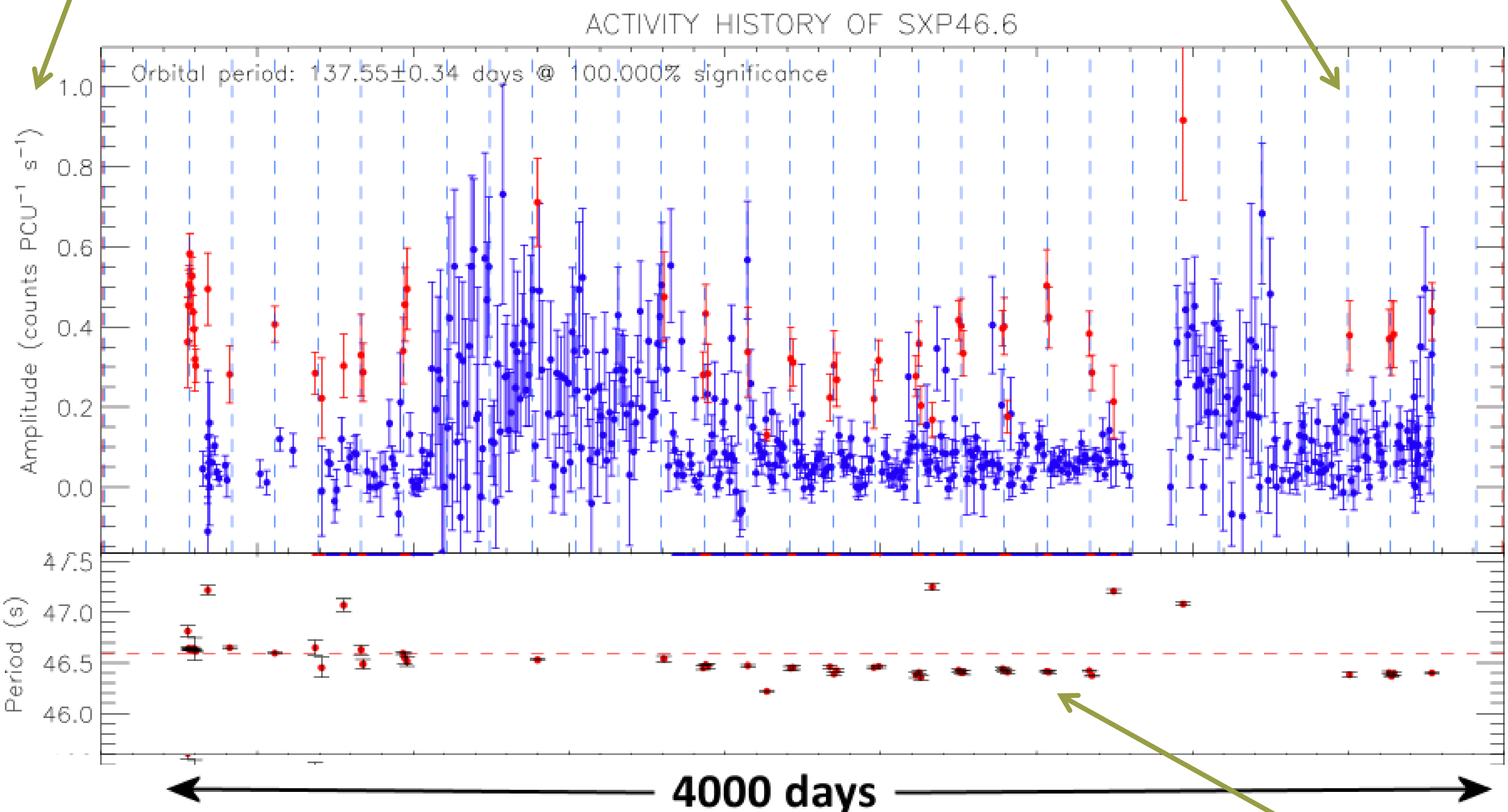
Type I : outbursts once per orbit

Type II : Unpredictable giant outbursts.

1 count/pcu/s
~ 0.4 x 10^{37} erg/s

Dashed vertical lines indicate proposed binary period

and Astronomy



Long term pulsar spin-up

Frequency searching

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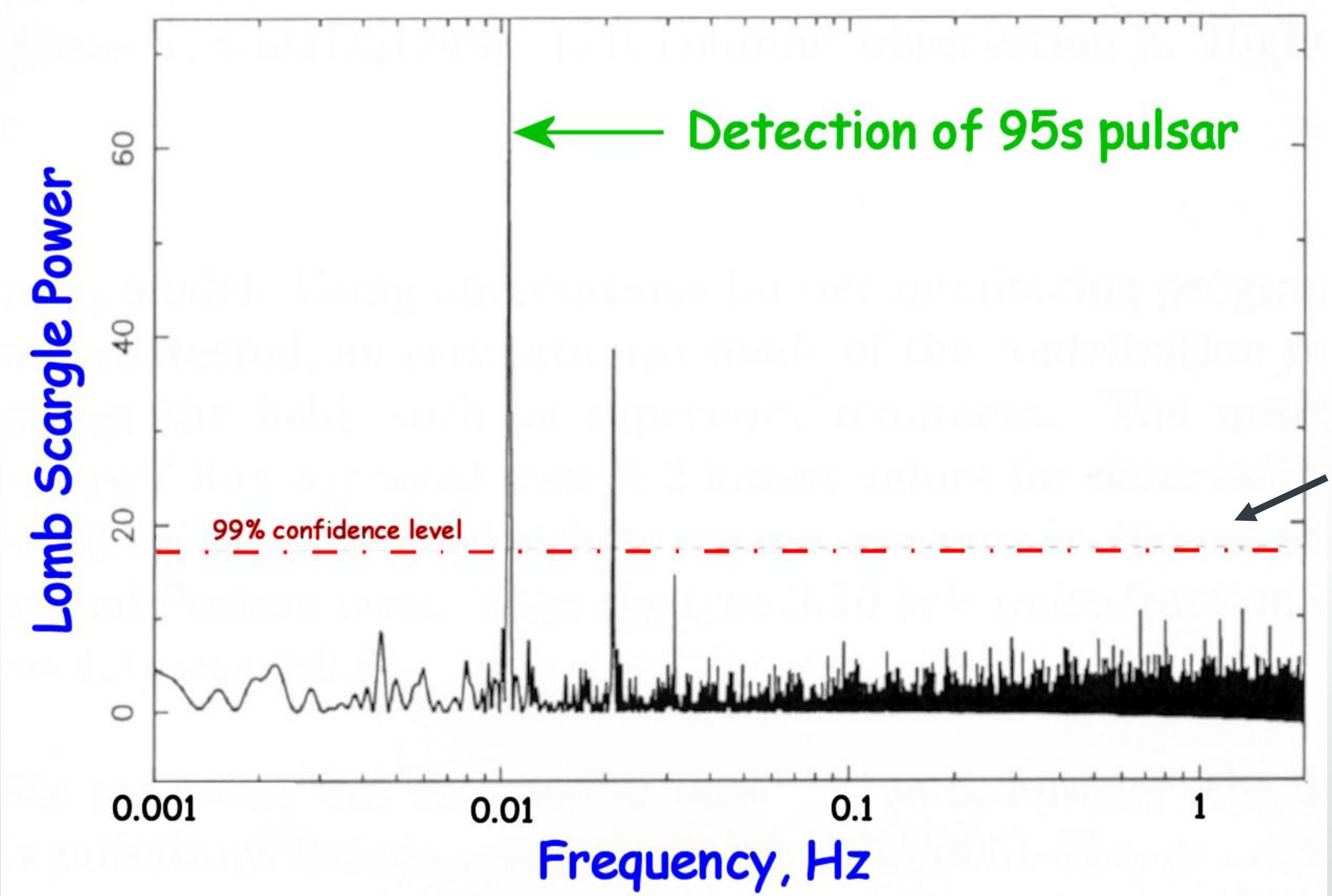
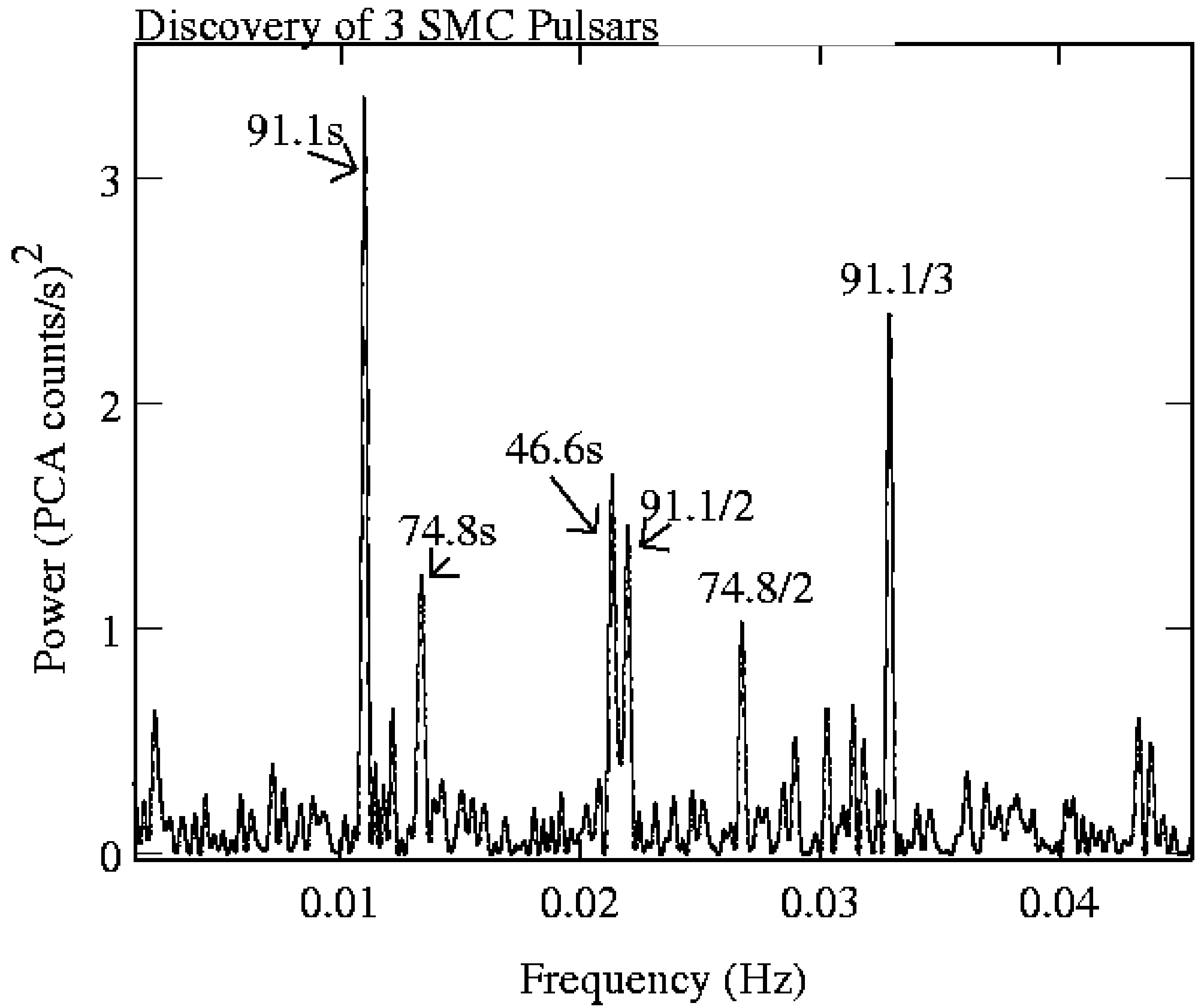


Established from Monte Carlo simulations



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On a really good day .....

How many HMXBs in the SMC?

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- If you simply use the mass ratio to the Milky Way, and an estimate of the B/Be star ratio, then the number of HMXBs could only be a few.

- More sophisticated estimates, based upon the SFR of the SMC (0.04-0.4 Mo/yr) predict 6-40 HMXBs with Lx > 10^{35} erg/s (*Shtykovskiy & Gilfanov, 2005*).

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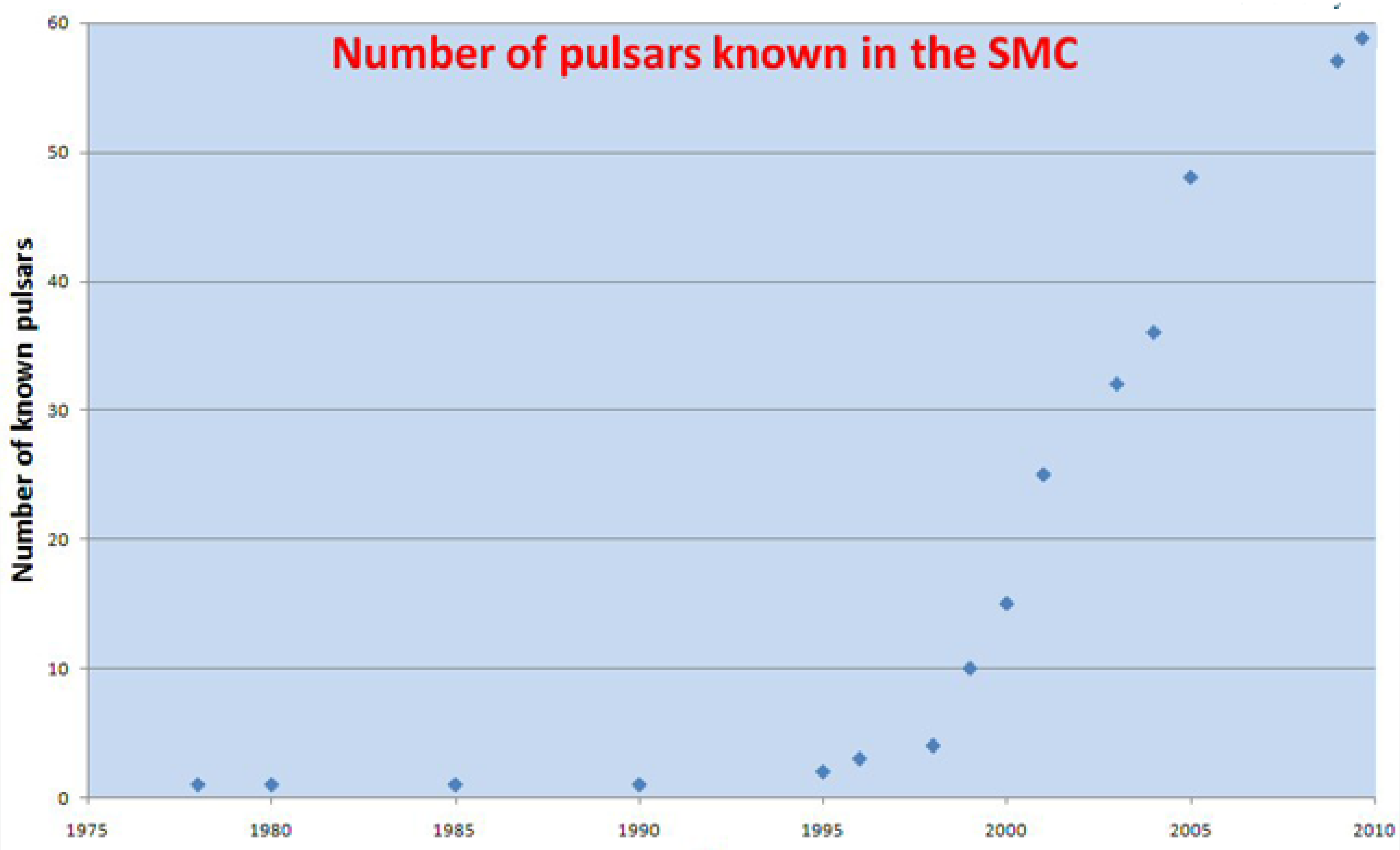

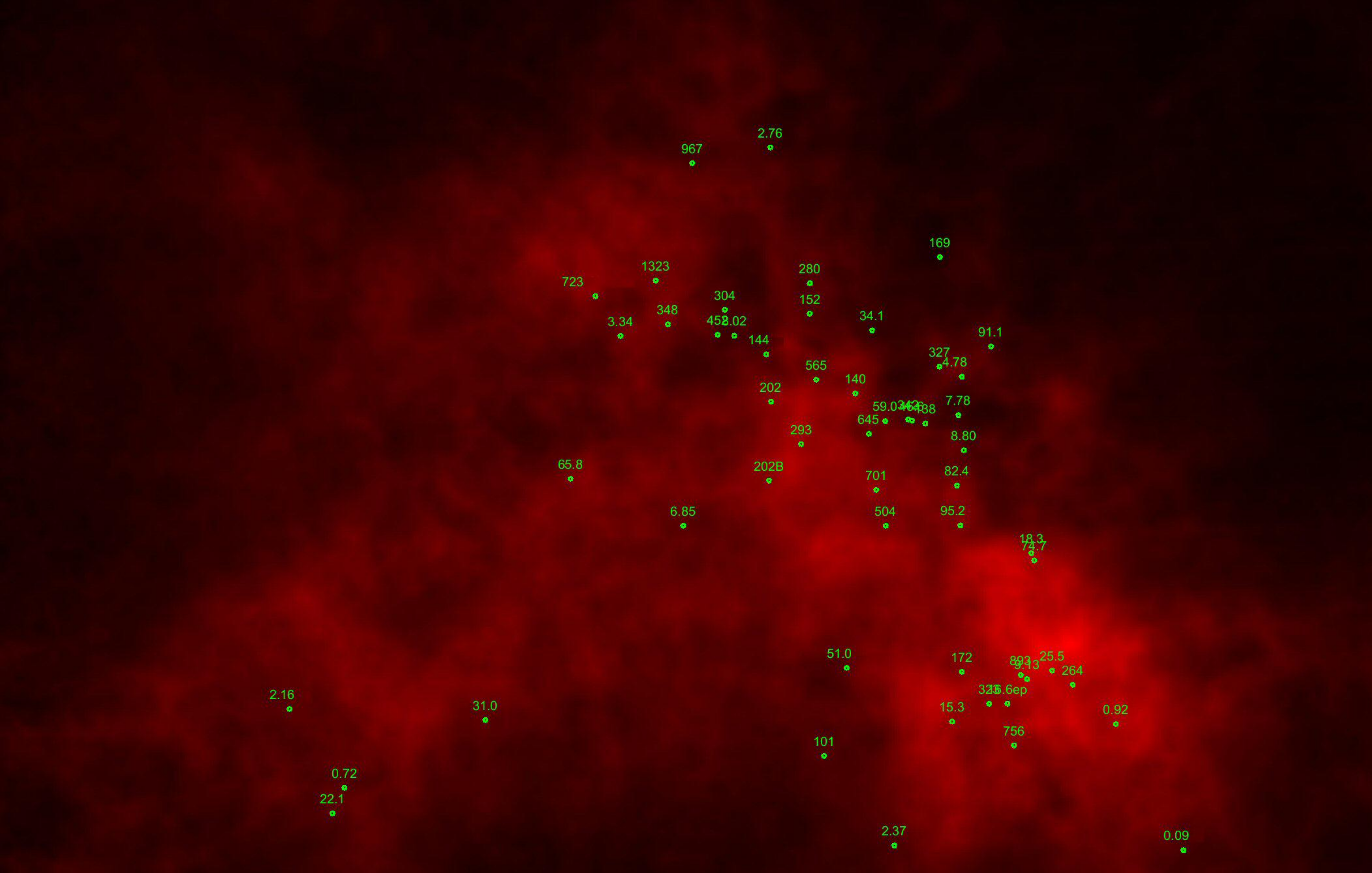

All at similar distances, similar extinctions and in similar environmental circumstances

XRB populations

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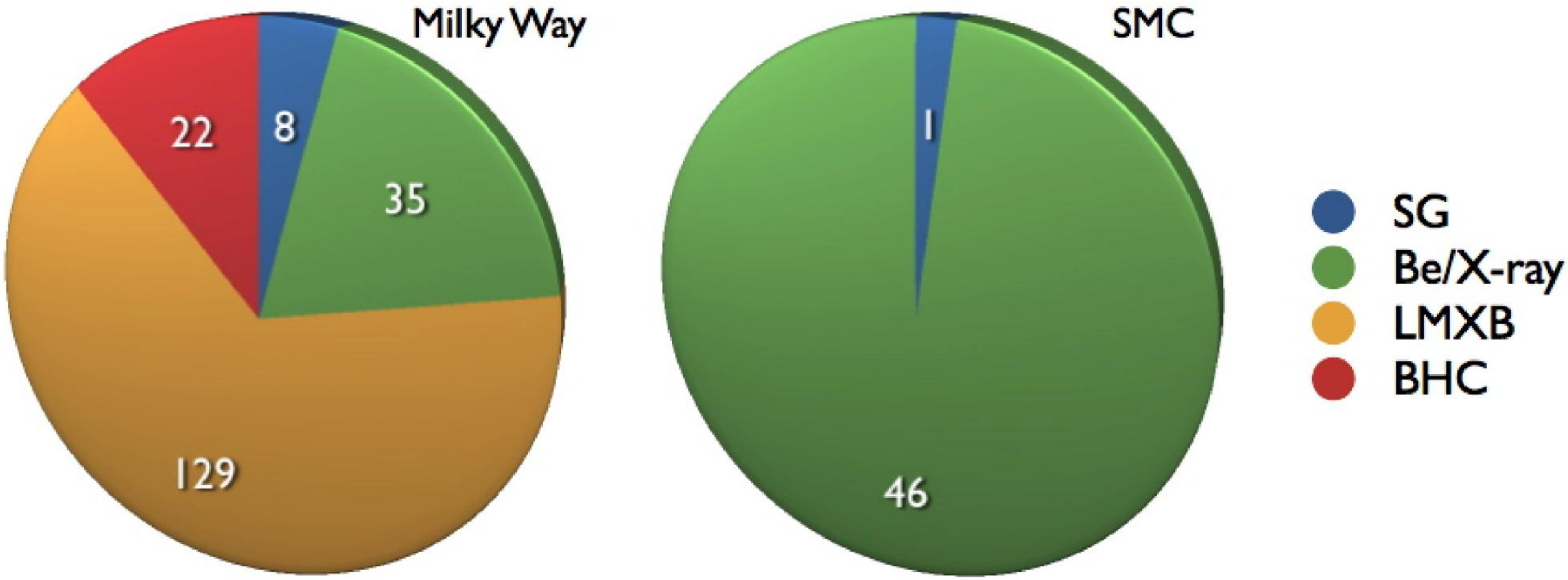

Where are the Supergiant and BH systems in the SMC?

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Optical observations

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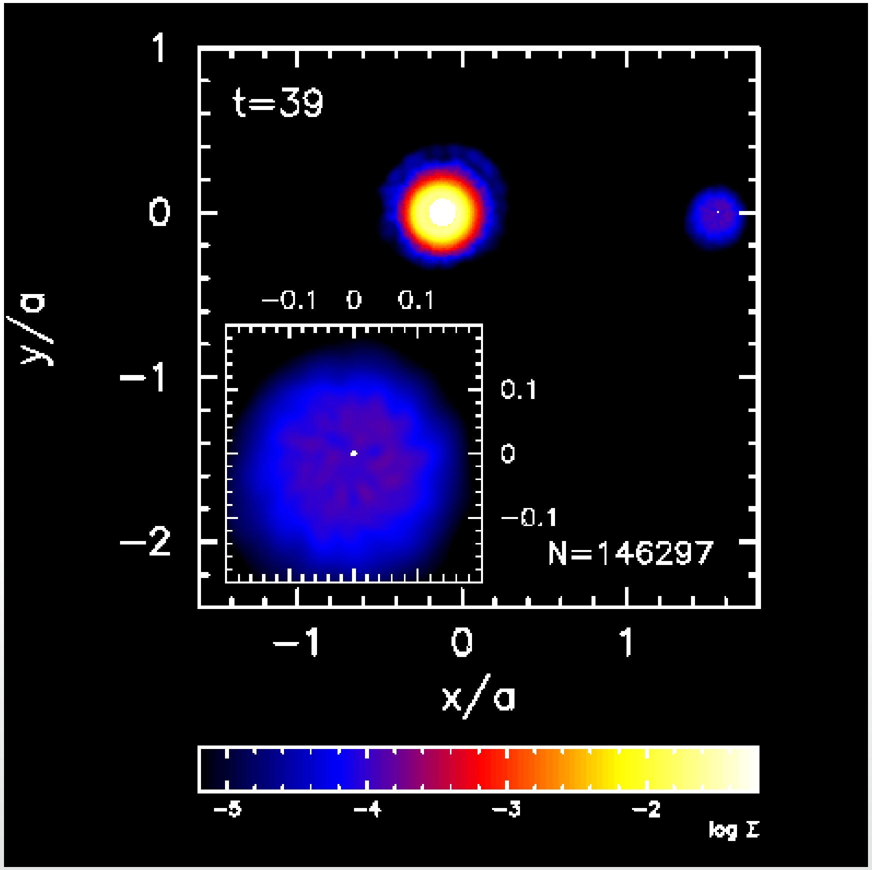
Simulations

•SPH simulations of viscous decretion disks by Okazaki & Negueruela (2001).

•They demonstrated that the eccentricity of the orbit was crucial in predicting the types of mass-transfer events that might occur.

•For low eccentricities, stable disks could form in low resonant states.

•For high eccentricities the disk would be disrupted every orbit as in this simulation.



Simulation from Okazaki's web page

Optical data

- We have ~40 optically identified systems. So this represents by far the largest homogeneous population of X-ray binaries in any galaxy – including the Milky Way.
- OGLE & MACHO lightcurves for >10 years – confirming counterparts, identifying binary periods, looking for correlated optical/X-ray flaring etc
- Follow-up spectroscopy (SALT, SAAO 1.9m AAT & ESO) – establishing spectral classes, circumstellar disk status and links into binary evolution

SXP18.3 – 8 years in the life of an 18d binary

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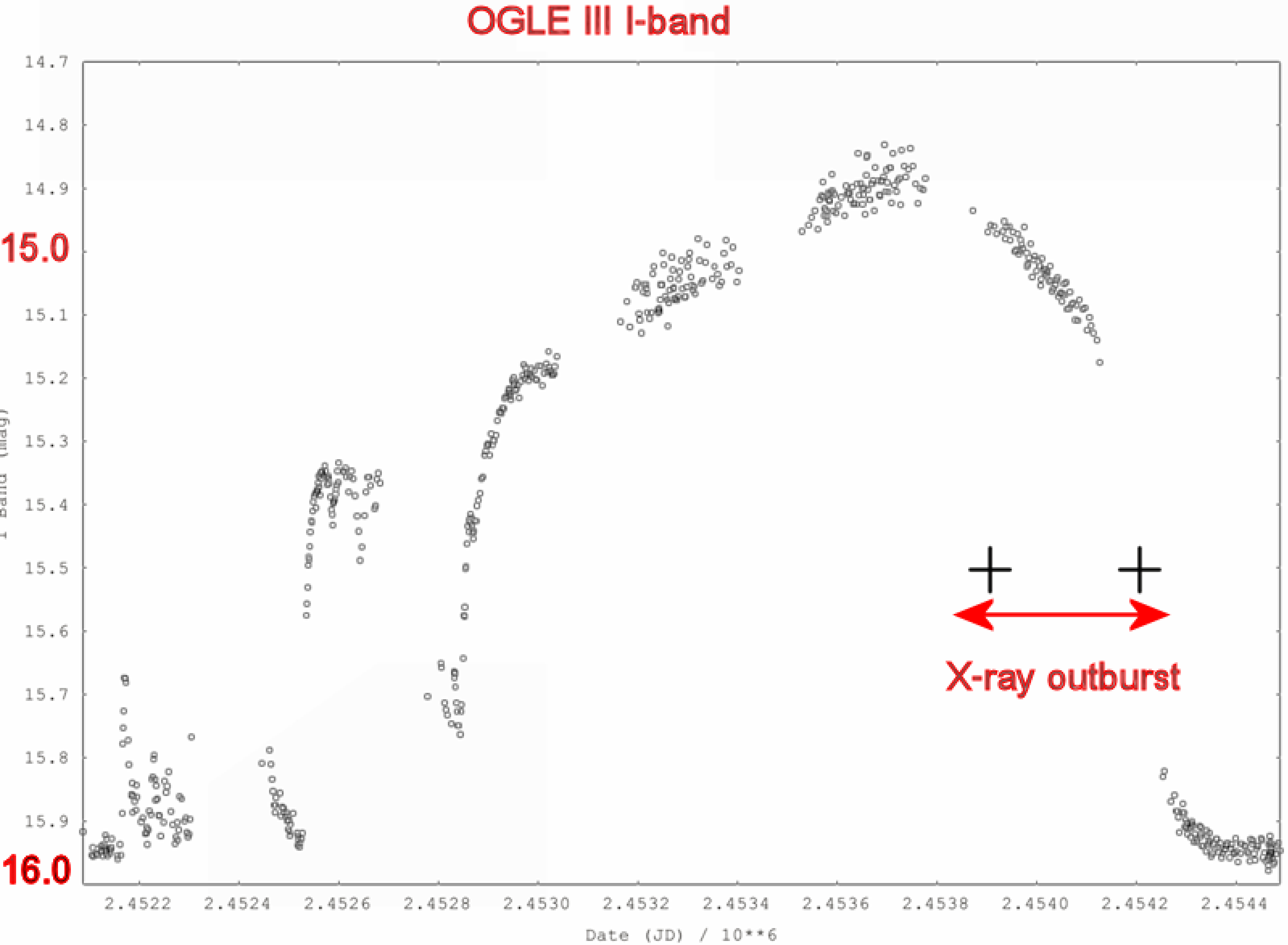

Optical counterpart identified by Eger & Haberl (2008)

Schurch et al, 2009

SXP756 – optical outbursts every 394 days seen in OGLE data

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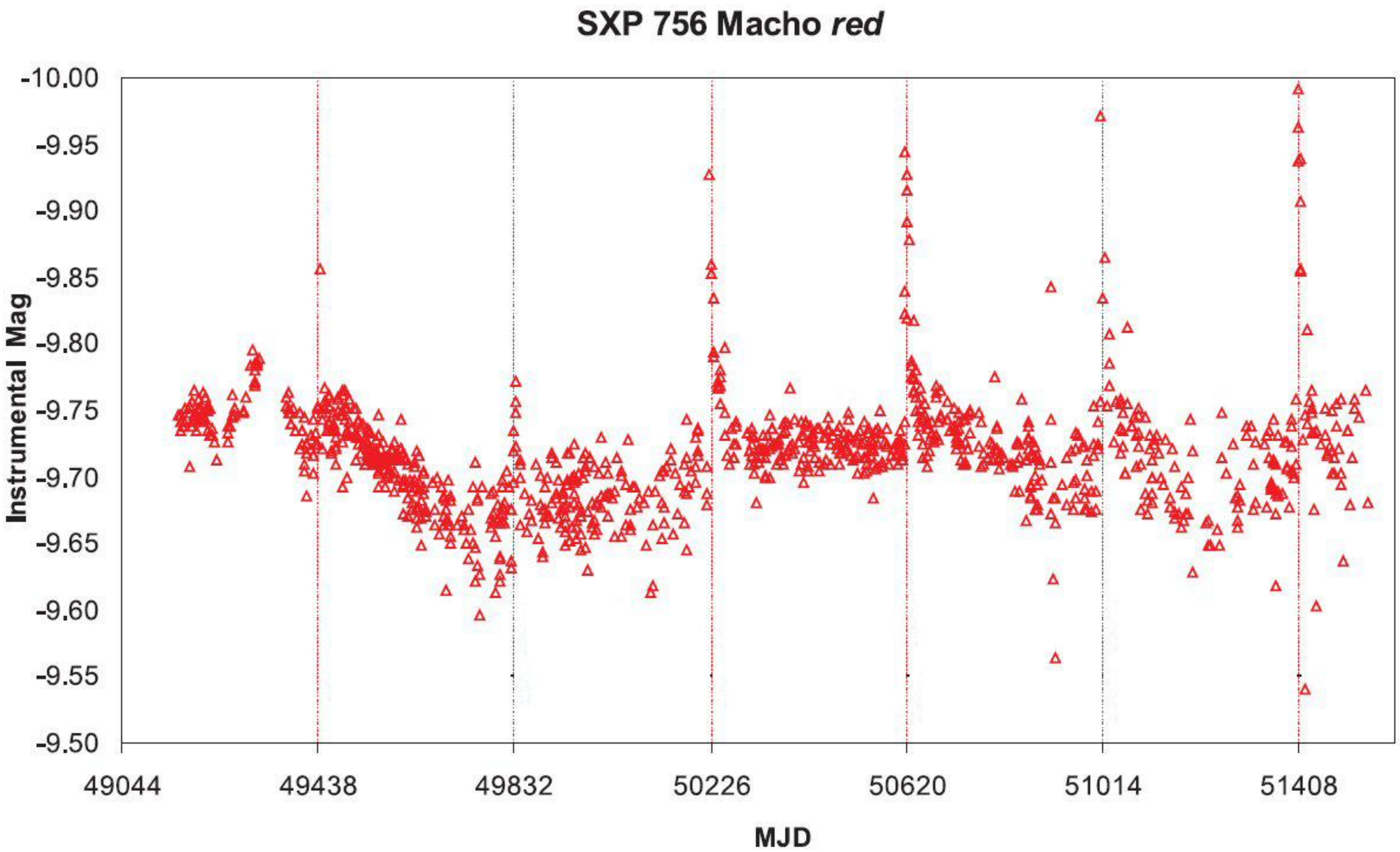

Coe & Edge 2004

SXP756 – optical data folded at the binary period of 394d.

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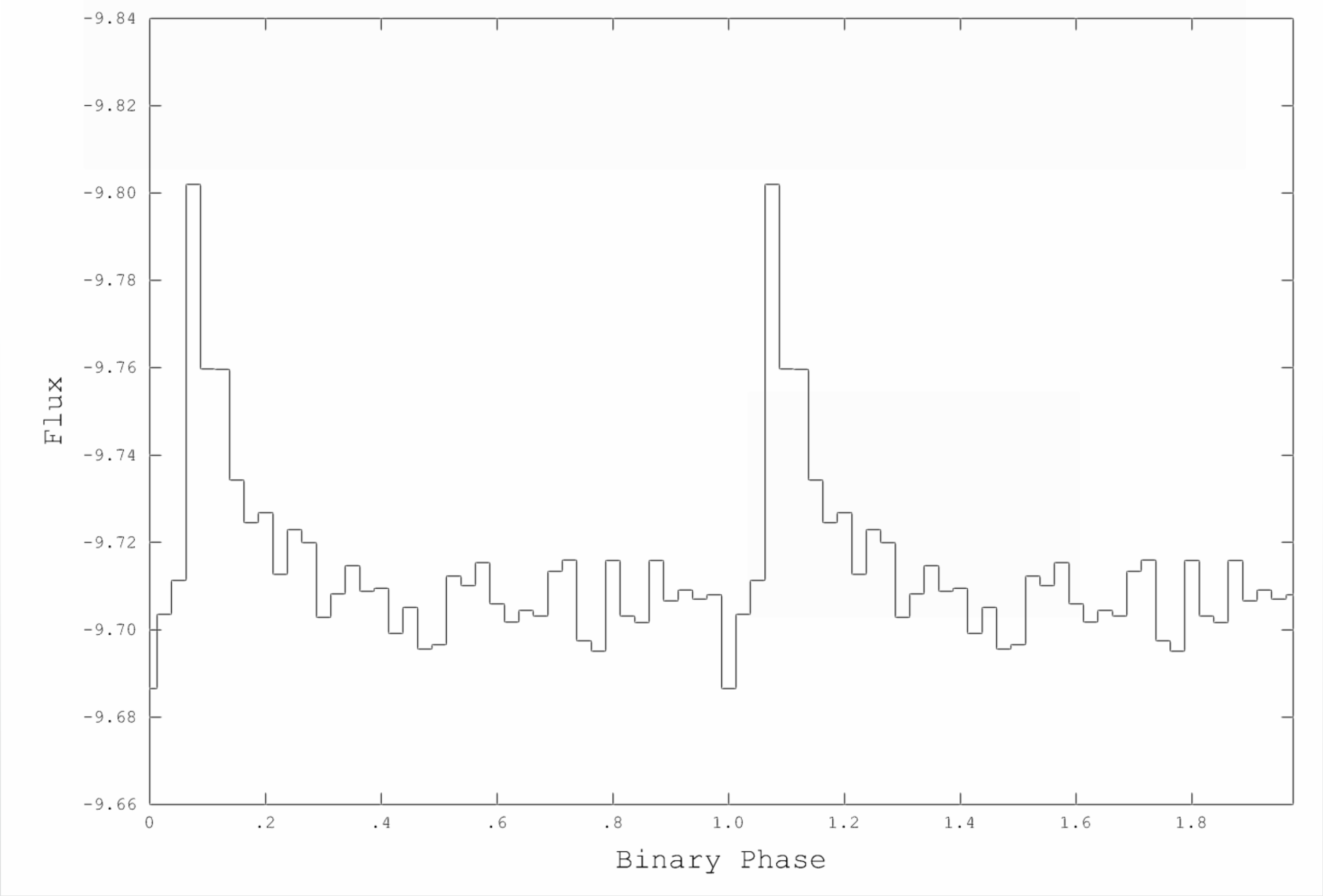
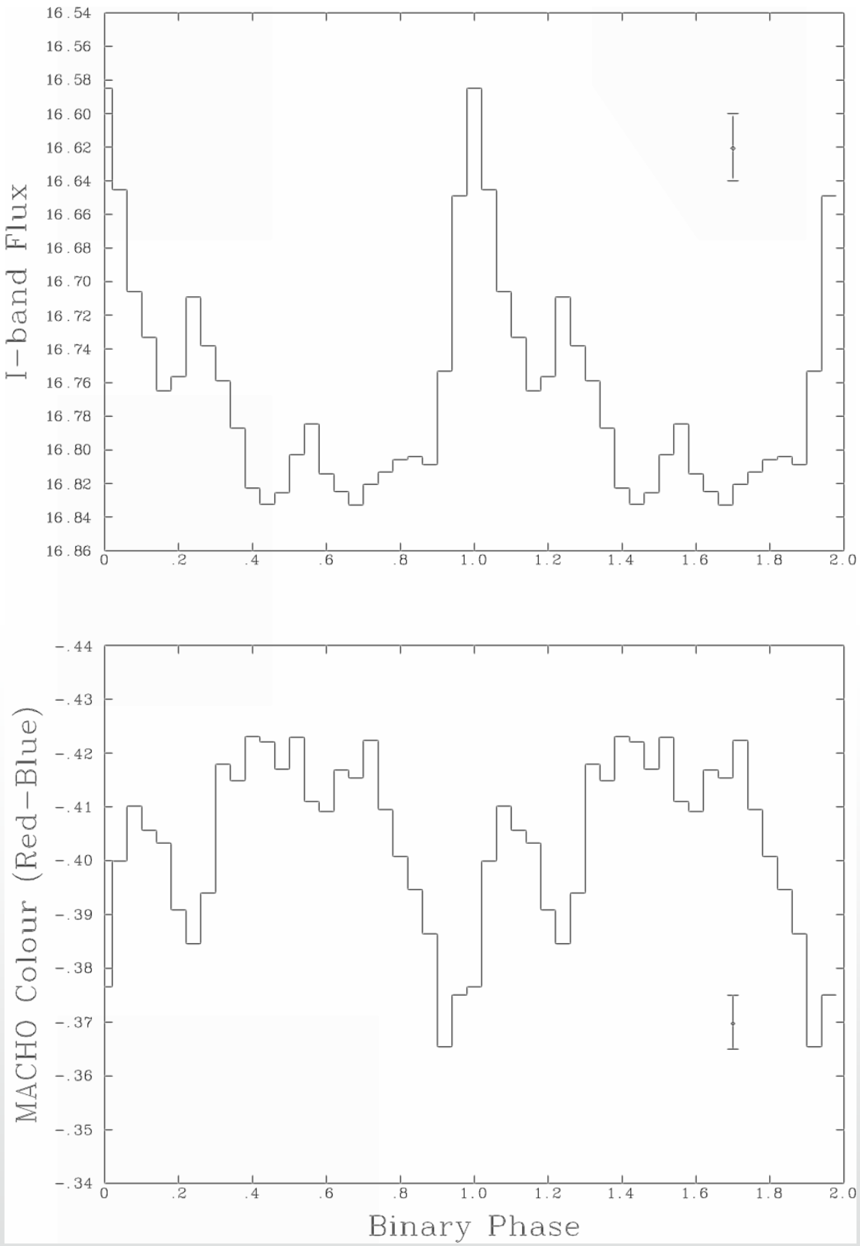
Coe & Edge 2004



SXP327

Coe et al 2008



Crete October 2010

Strong correlated colour effects when folded at binary period of 46d.

n.b. the double peaked structure.

SXP46.6 optical & X-ray outbursts every 138d

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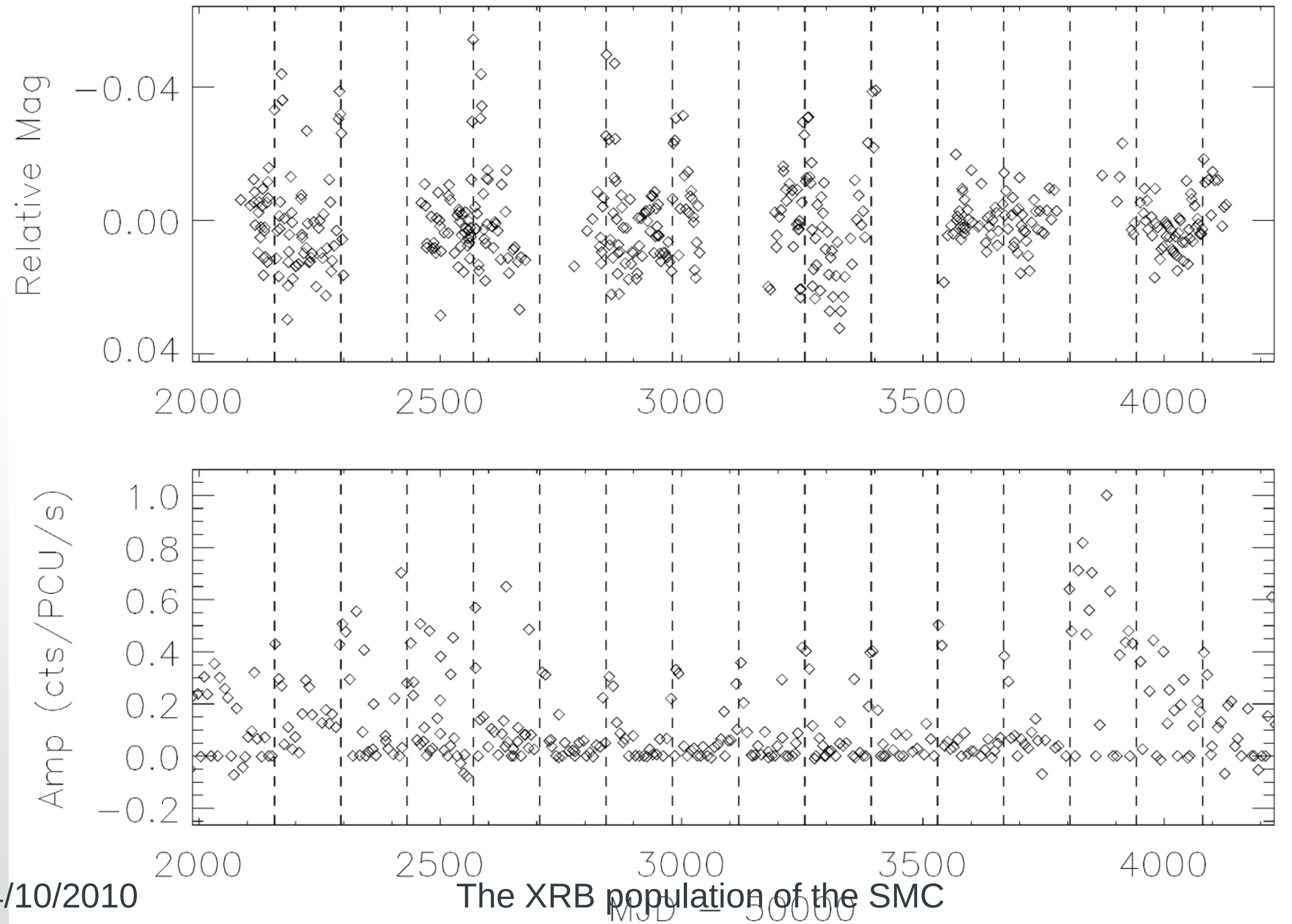
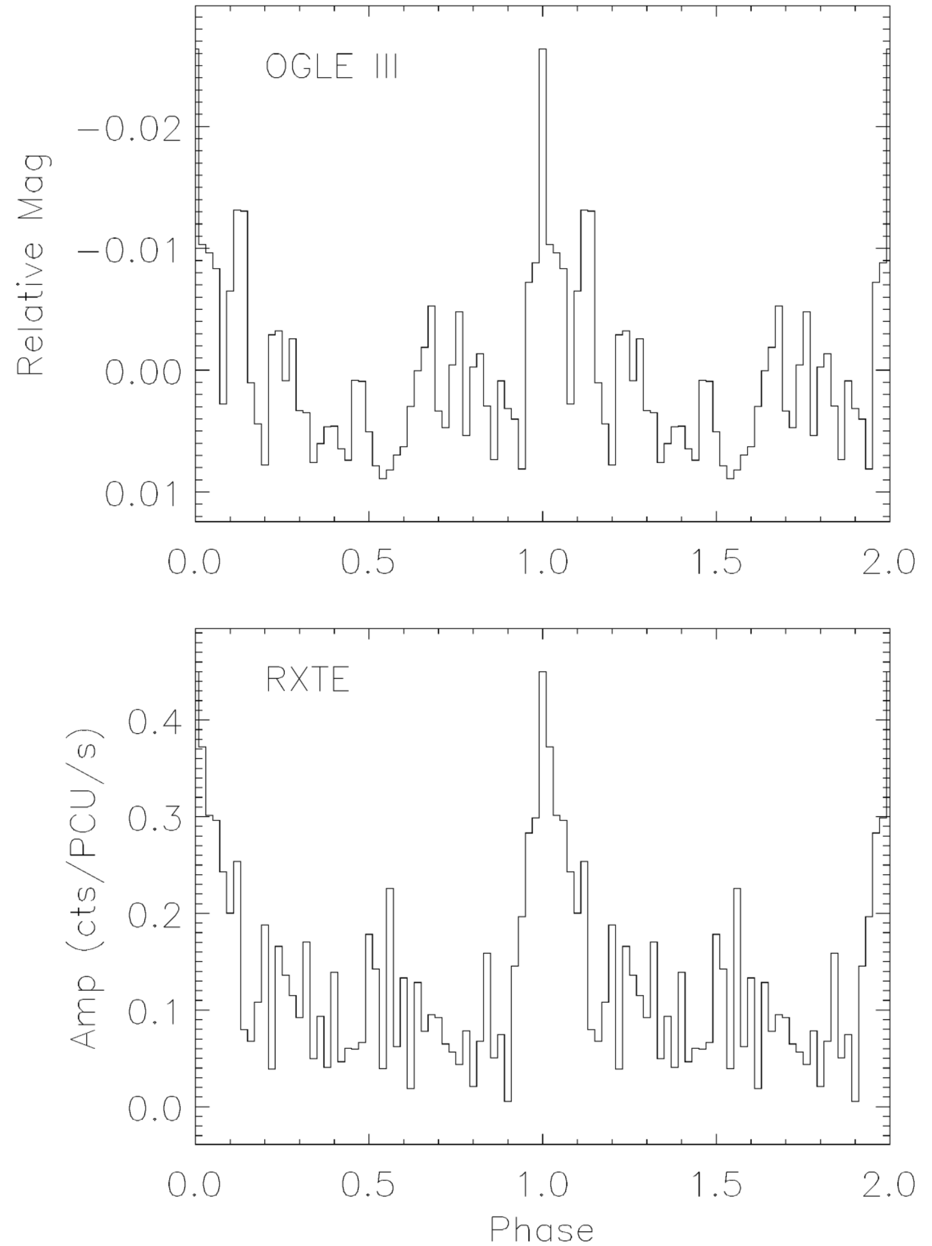


Optical (OGLE)

X-ray (RXTE)

McGowan et al 2007



McGowan
et al 2007

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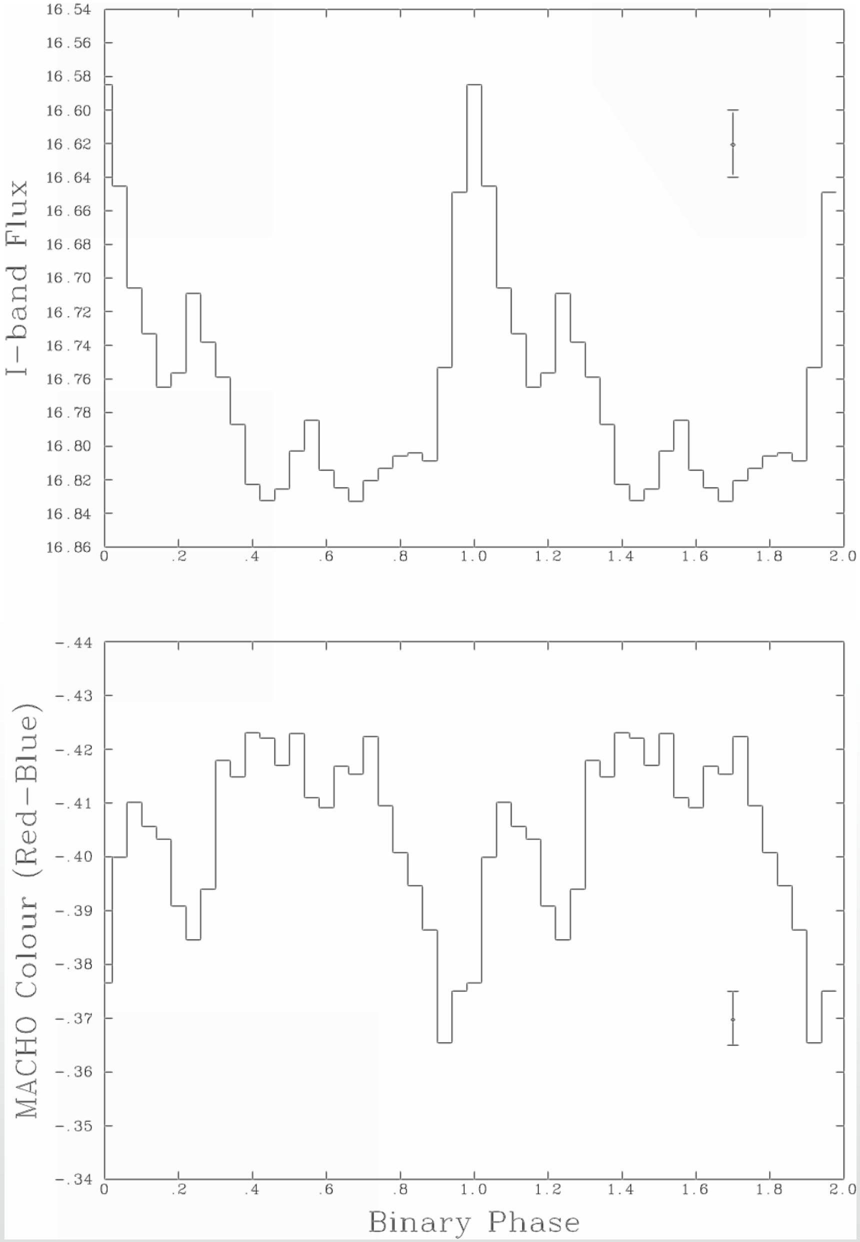
SXP 46.6

Correlated optical & X-ray outburst profiles folded at binary period of 138d.

SXP327

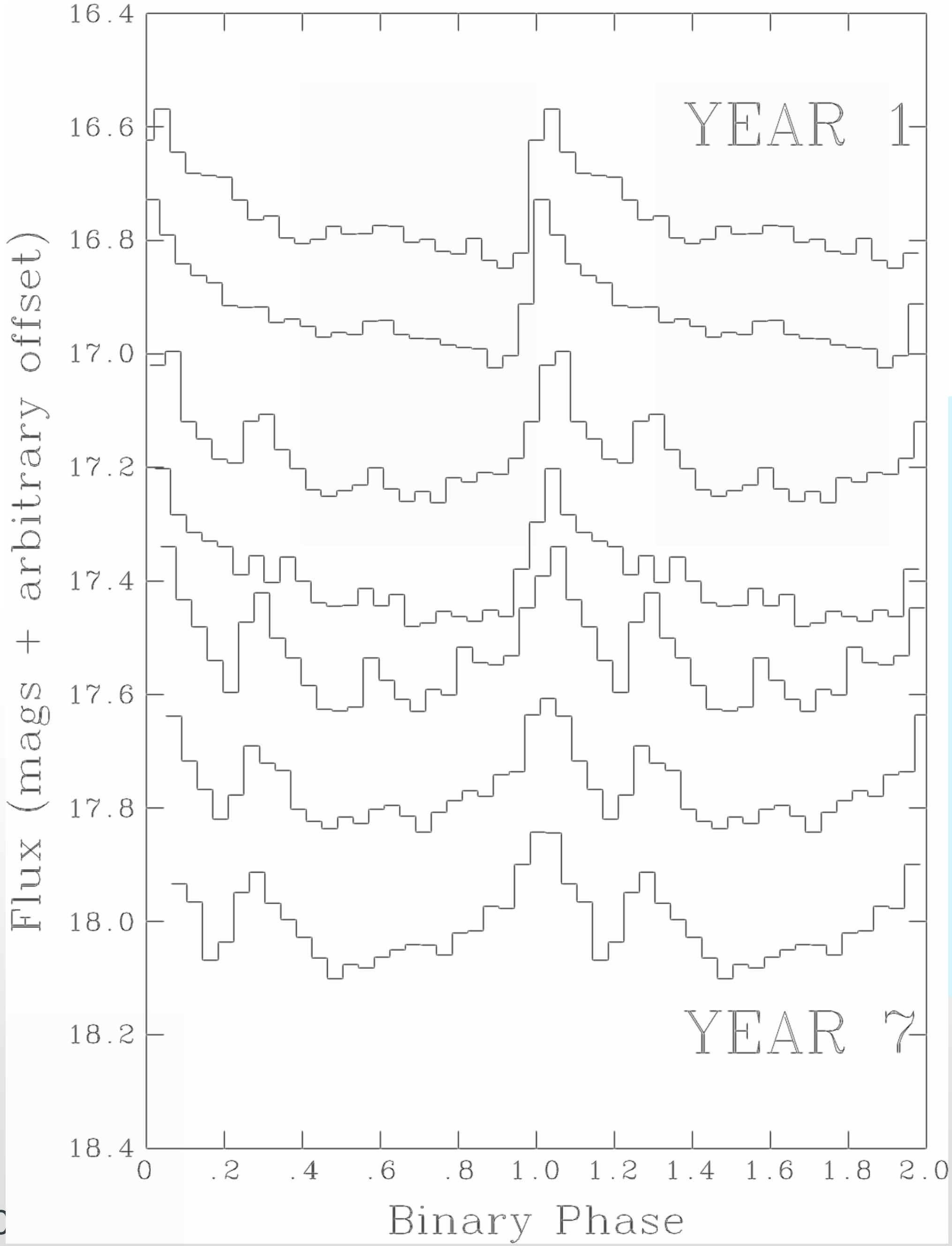


Coe et al 2008

Strong correlated colour effects when folded at binary period of 46d.

n.b. the double peaked structure.

SXP327



Coe et al 2008

Annual variation in the binary profile of the optical photometry obtained from folding the OGLE III data.

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Accretion physics at work.....

Coe, McBride & Corbet (2010)

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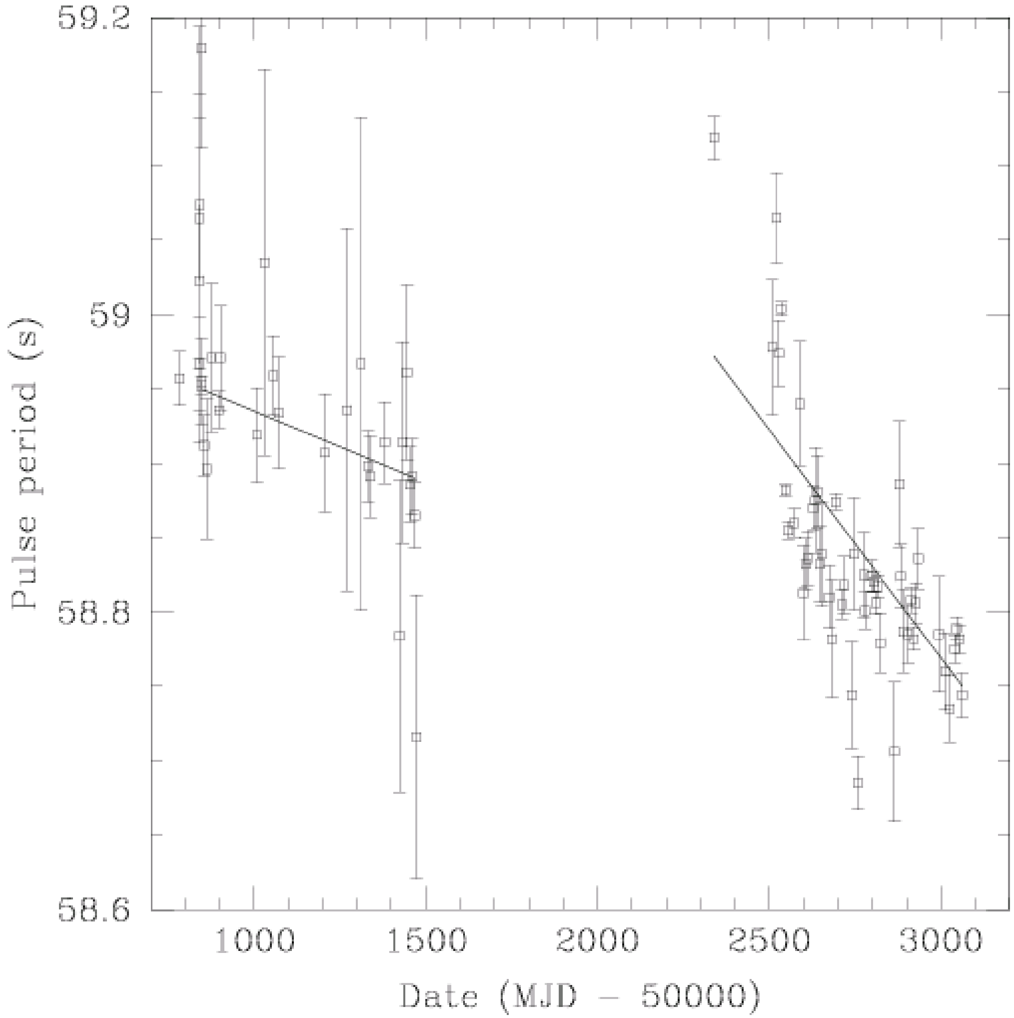

An example of the spin period changes seen in one system, SXP59.0. The straight lines show the chi-sq best fit to each data set. The fit gives us $\dot{P}$

$\dot{P}$ is normally negative (i.e. spin-up) but there are exceptions.

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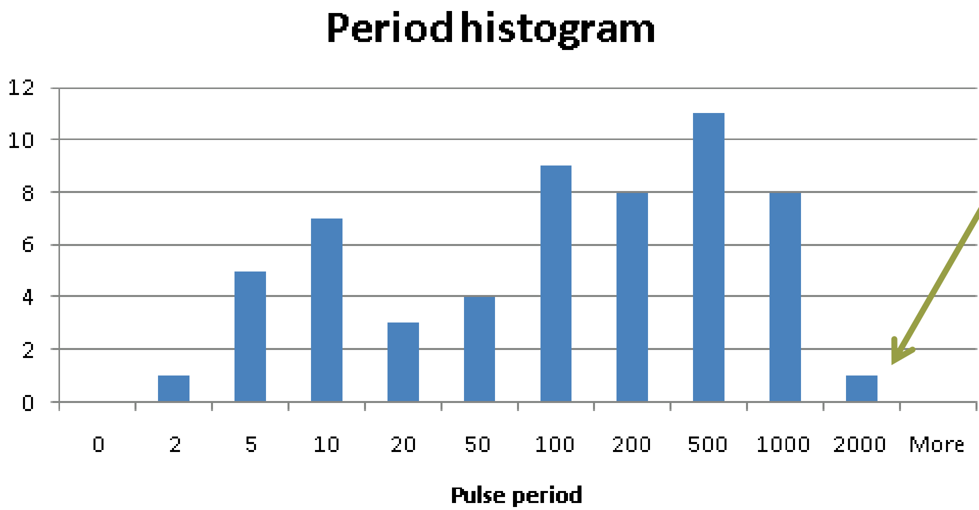
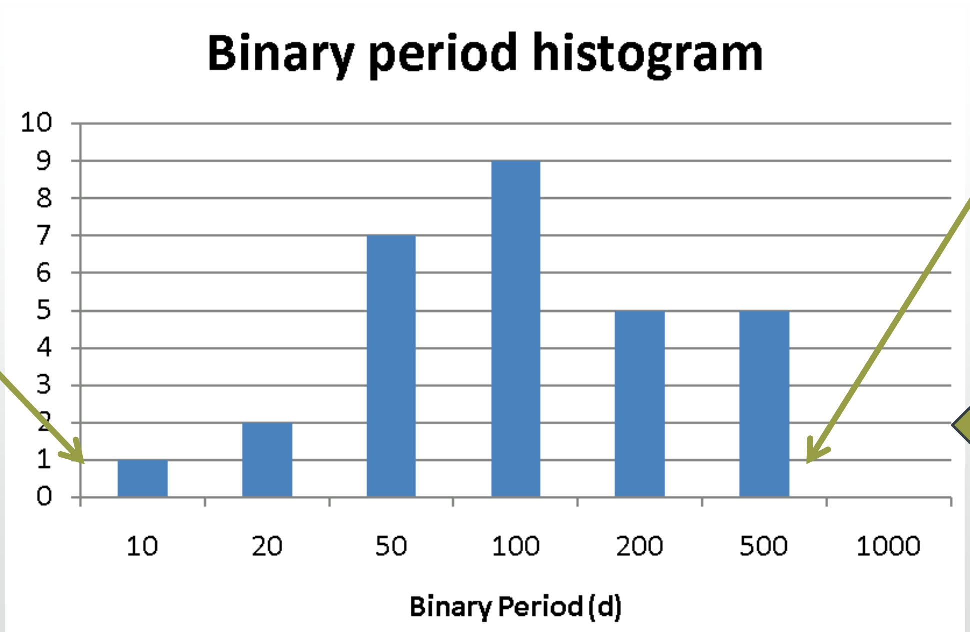


Observational limits

From X-ray observations



Observational limits

Observational limits

From X-ray and optical (OGLE) observations

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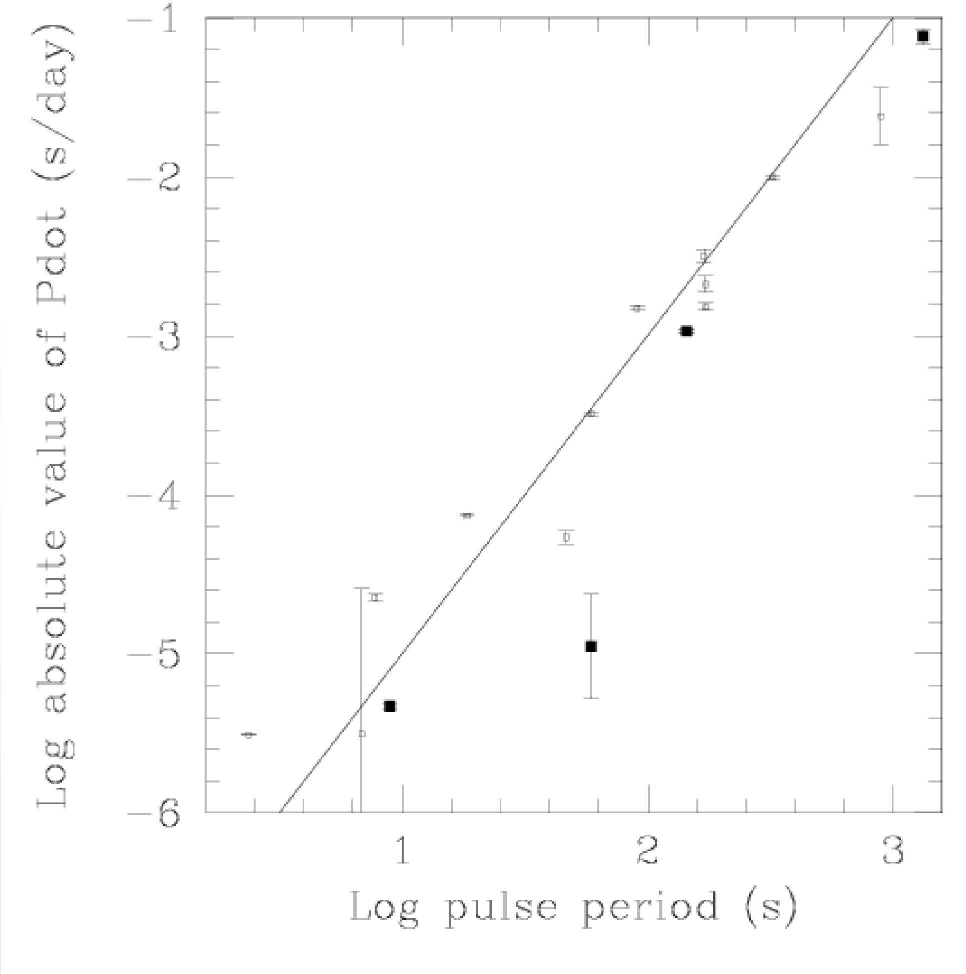
The observed relationship between equilibrium spin period and the rate of spin change during an outburst:

The four points marked with a solid squares have positive P_{dot} values (spin down), the rest are negative (spin up). This suggests that torque-reversal does not change the basic accretion physics.



The straight line (P_{dot} α P^2) is that predicted by Ghosh & Lamb (1979) for disk accretion.

How bright are the X-ray outbursts?

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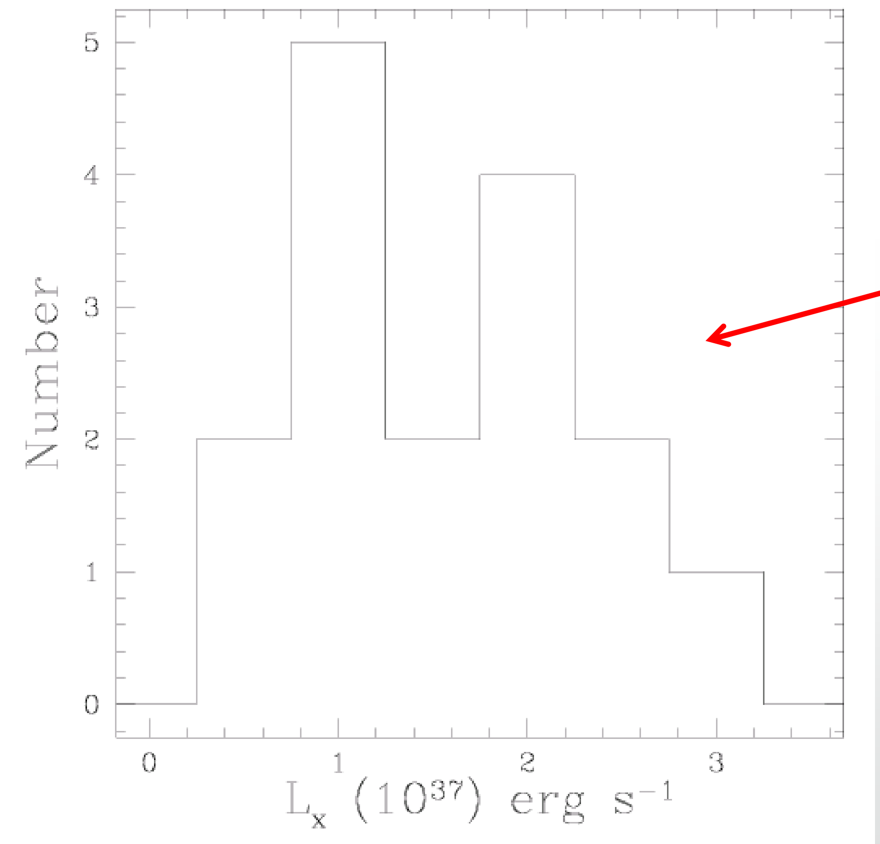

Luminosities typical of Type I outbursts (once per binary cycle).

Type II outbursts can be a factor of 10 brighter, but are much less common.

The relationship between the absolute values of the short (~couple of months) spin changes and the longer term changes (~10 years).

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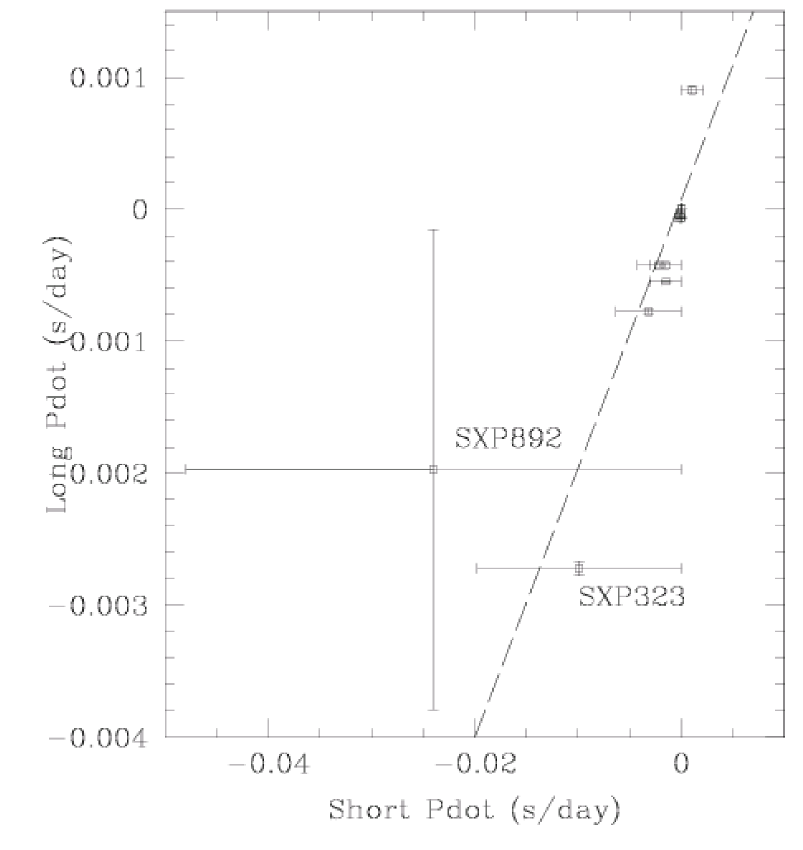

The dashed line shows the simple relationship:

Long P_{dot} = 0.2 x Short P_{dot}

This suggests that such accreting systems are only active for ~20% of the time.

The fundamental relationship between spin period change and X-ray luminosity

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- Accreting material generate torques on the magnetic field of the NS and alters the spin period.

- From Ghosh & Lamb (1979) and subsequently other authors e.g. FKR page 125:

Magnetic moment

Accretion torque function

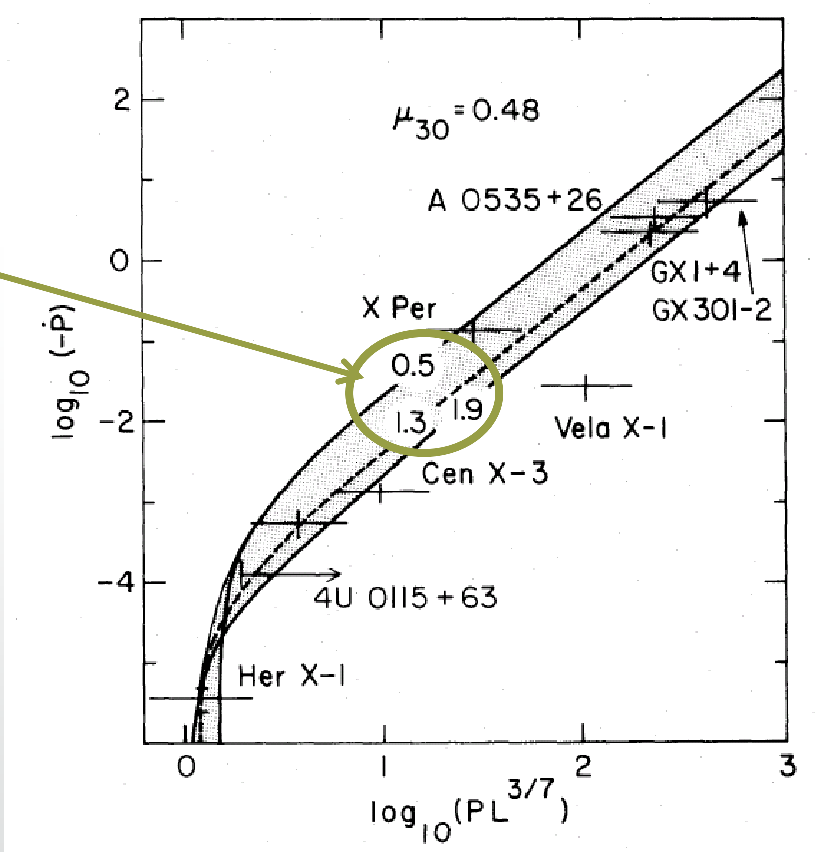
Function of mass and inertia of NS

$$-\dot{P} = 5.0 \times 10^{-5} \mu_{30}{}^{2/7} n(\omega_s) S_1(M) (P L_{37}{}^{3/7})^2 \text{ s yr}^{-1}$$

- **This predicts that a graph of log(P_{dot}) against log($PL^{3/7}$) should be a straight line**

Original figure from Ghosh & Lamb (1979) for galactic accreting pulsars

Possible NS masses in units of M_o



New version for twice as many SMC systems, again with NS magnetic moments of μ=0.48.

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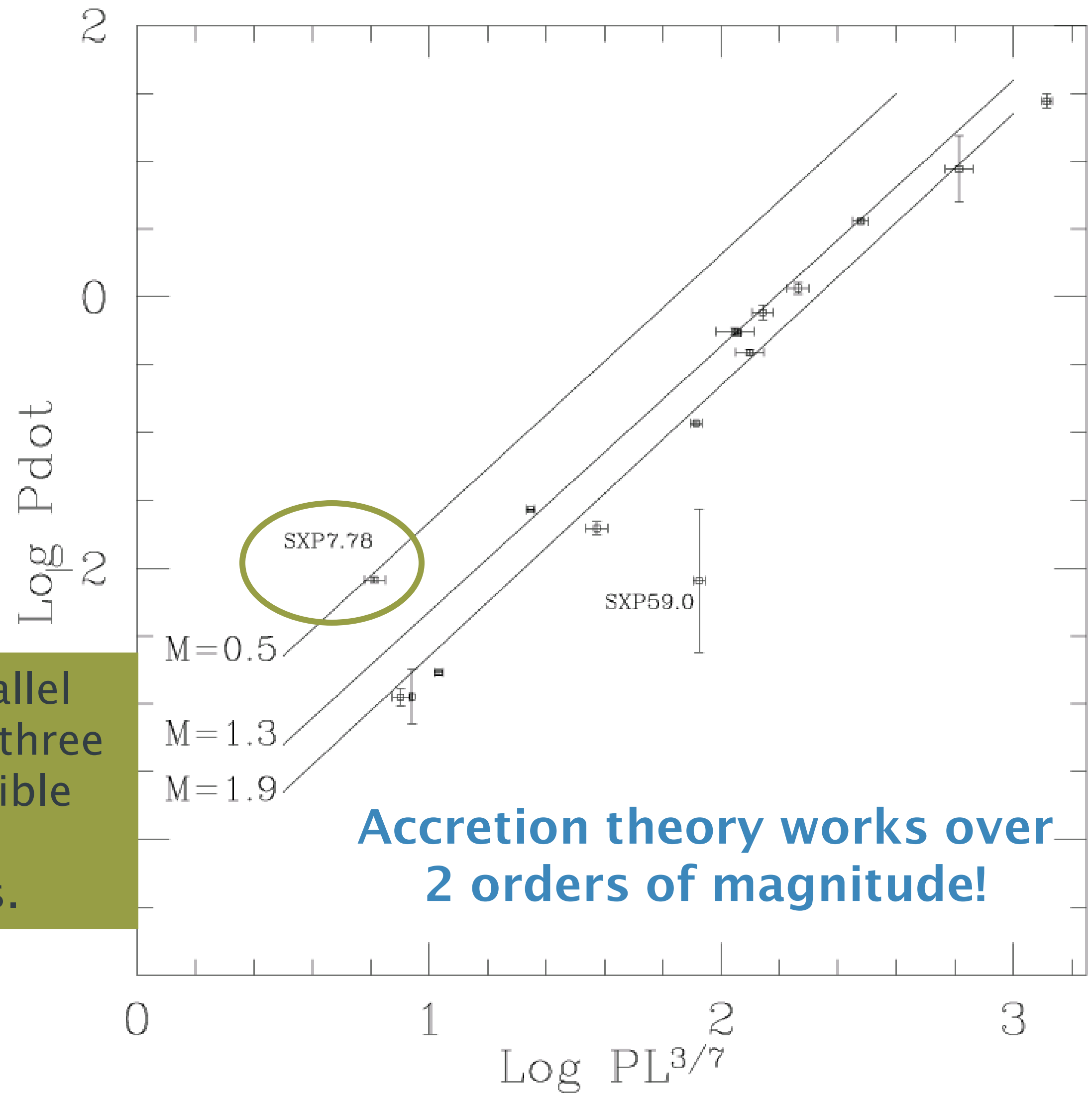

The three parallel lines represent three different possible neutron star masses.

The average mass of the neutron stars in the SMC sample is found to be 1.62±0.29 M_o

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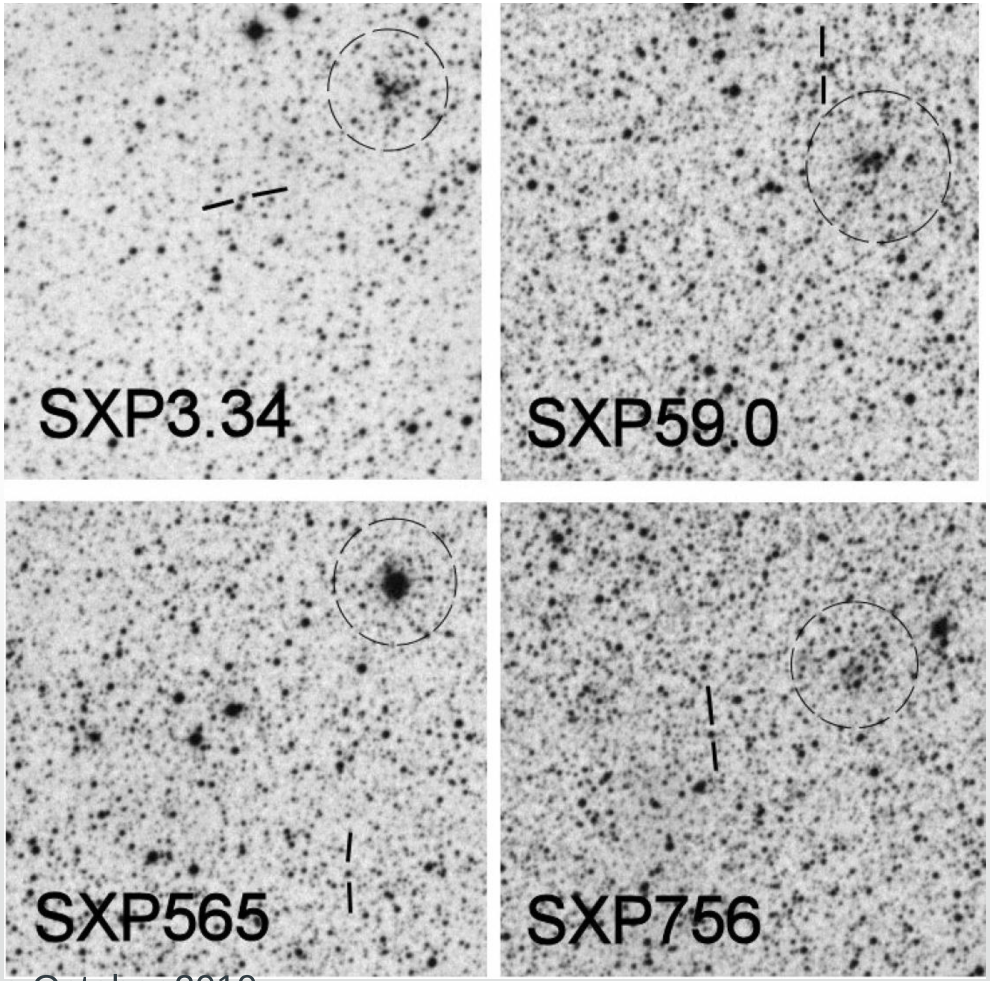
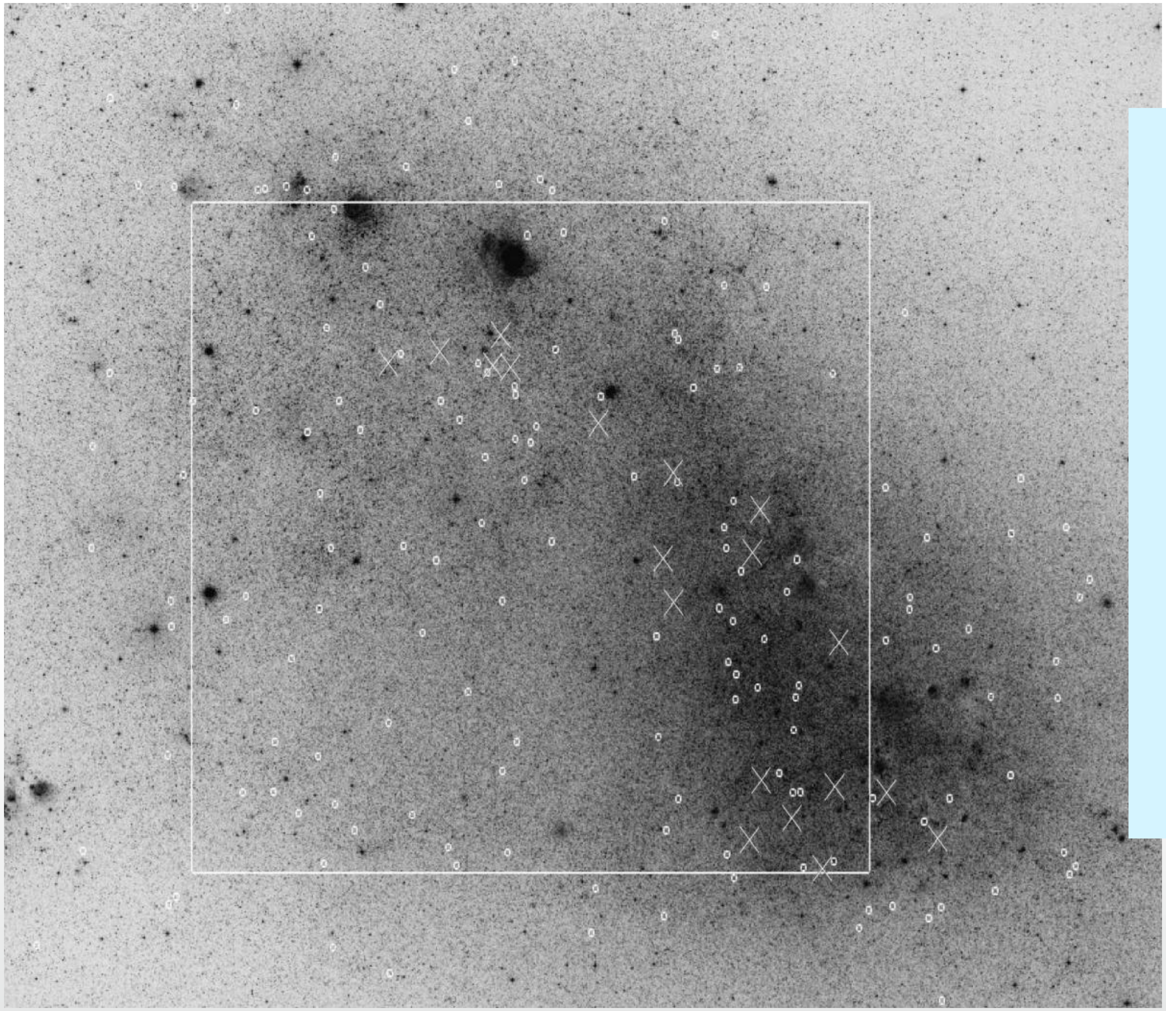
A record of SN kicks?

Originally Coe (2005) now updated with subsequently discovered sources

The fields around 4 Be/X-ray binary systems as a clue to HMXB evolution

- In each case we note the presence of a nearby cluster catalogued by Rafelski & Zaritsky (2004)
- But is the proximity just random, or are these the clusters in which the system was born?





Distribution of SXPs (shown as crosses) and Rafelski & Zaritsky (2004) clusters (shown as squares) in the SMC. The rectangular box indicates
the region used for the random sampling comparison

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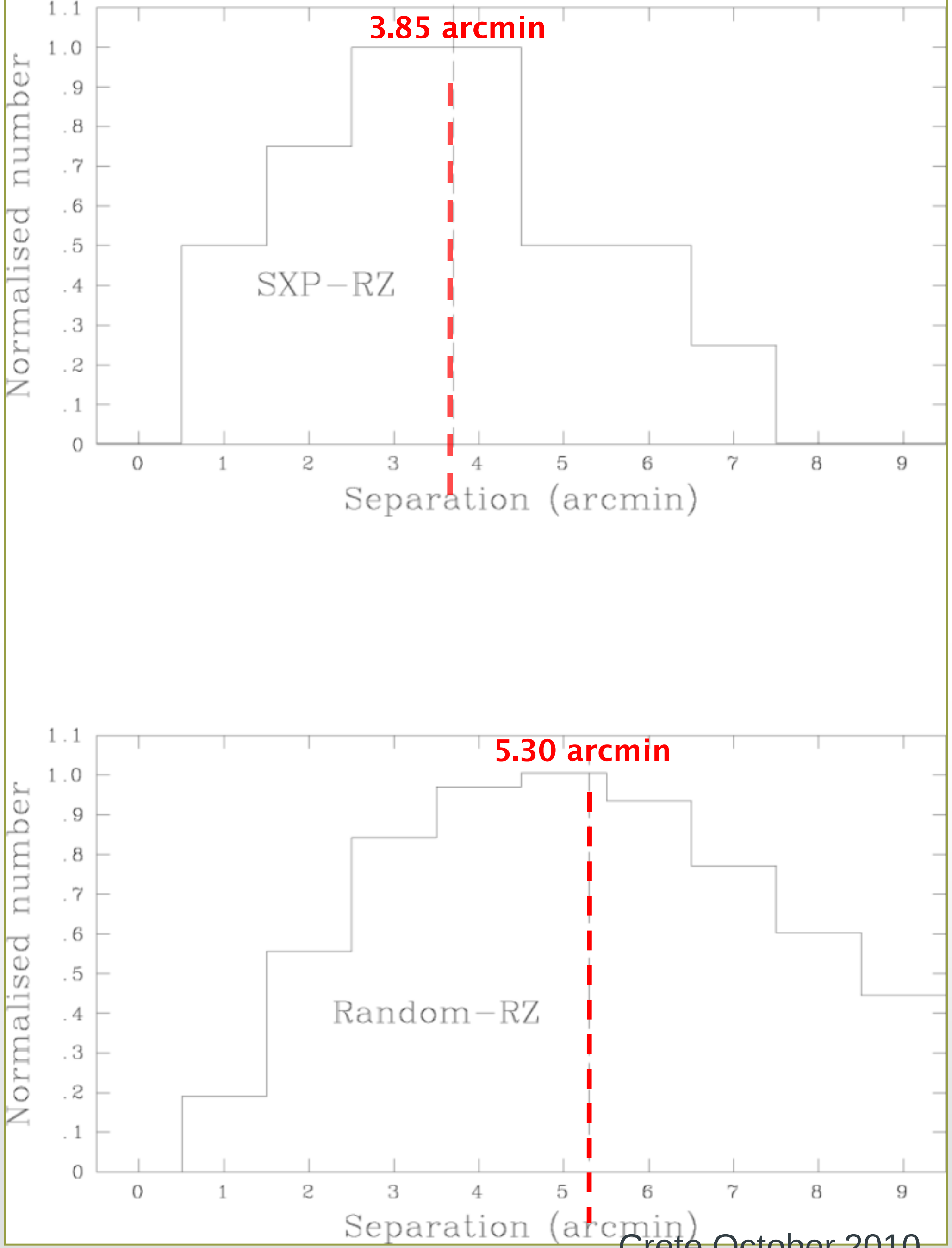

Upper panel : histogram of the distances between each SXP and its nearest neighbour RZ cluster.

Lower panel : histogram of the minimum distance between 100,000 random points and RZ clusters.

In each case the dotted vertical line shows the position of the mean of the distribution.

Coe 2008

Clustering implications

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- The K-S test gives a probability of 4% that the two distributions are the same, whereas the t-test gives a value of 2% that the means are the same.

- Using a value of 60 kpc for the distance to the SMC, and estimating the maximum possible lifetime of the companion Be star after the creation of the neutron star to be ~5 million years (Savonije & van den Heuvel , 1997) indicates a minimum average transverse velocity of the SXP systems is 16 km/s.

- van den Heuvel et al. (2000) interpreted the Hipparcos results for galactic HMXBs in terms of models for kick velocities, and obtained values around 15 km/s.

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Cluster ages

- the ages of the RZ clusters associated with the SXP sources are of significant interest. Using the extinction corrected ages presented in Table 2 of Rafelski & Zaritsky (2004) it is possible to determine the mean age to be 130±140 Myrs.
- this is very much at the young end of their cluster sample distribution. It therefore reinforces the suggestion that the clusters identified with the SXP sources are very likely to be the correct parent clusters for these objects.

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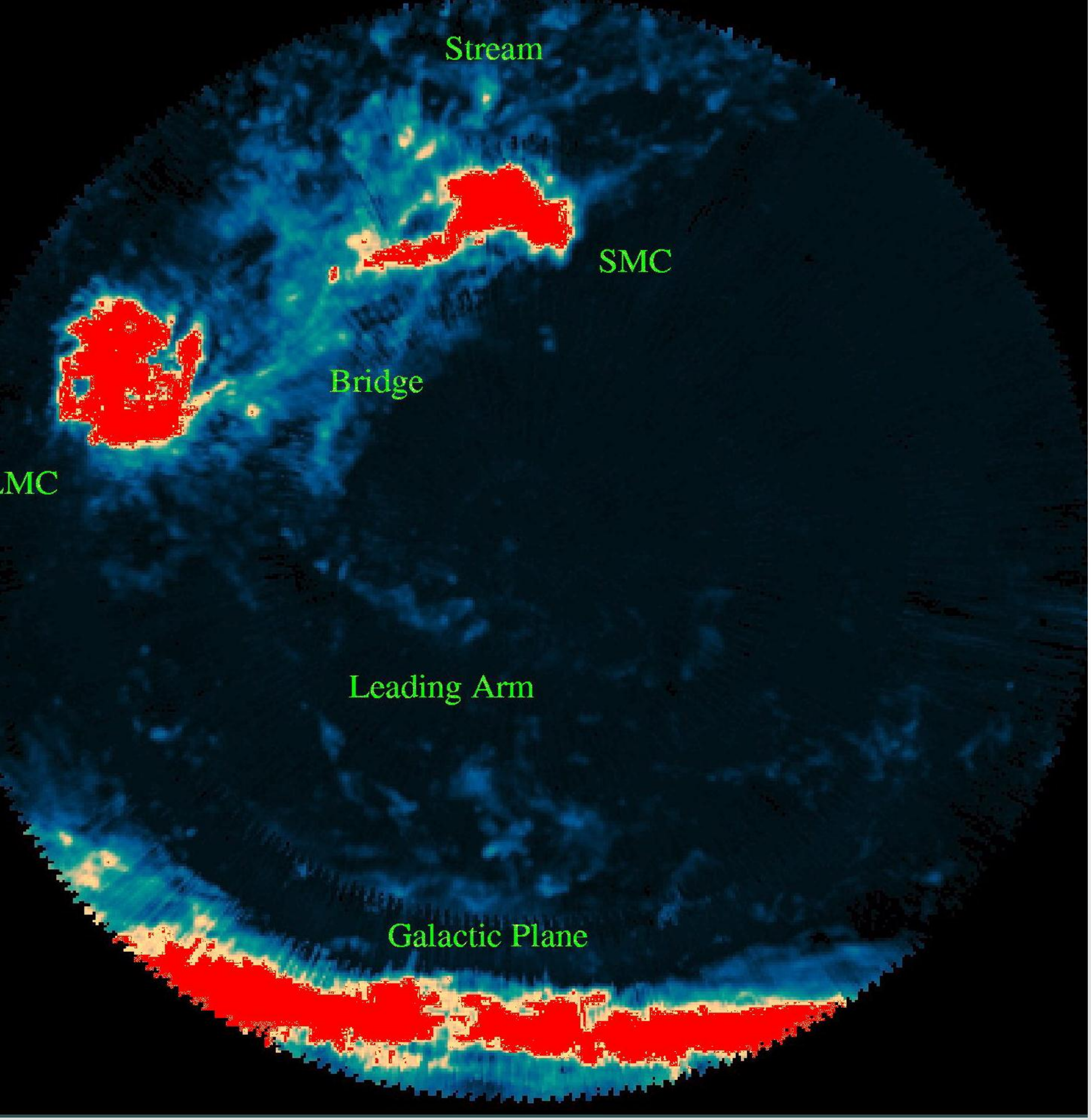
Conclusions:

In the SMC we have a beautifully homogeneous sample of HMXBs – same distance, same extinction.

The X-ray detected population is backed up with ~10 years daily optical monitoring.

Thus they represent an excellent opportunity to study accretion physics and the consequences of SFR in a different environment to the Milky Way



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- Any questions?