Compact Galactic X-ray Sources

Joachim Trümper, MPE EXOSAT Reunion at ESAC Madrid, 24 - 26 May 2018

STATE OF TAXABLE PARTY.



EXOSAT Science Overview

I found 1036 refereed EXOSAT papers in the ADS with a total of 32807 citations. 52 papers have more than 100 citations.

21 of them are dealing with compact galactic sources – Black Holes, Neutron Stars or White Dwarfs in binary systems, as well as Isolated Neutron Stars and White Dwarfs.

21 EXOSAT-Papers on Galactic Compact Objects having more than 100 ADS-Citations Hasinger, van der Klis 1989: Timing and Spectra (QPOs) in LMXBs, 725 citations Done, Mulchaey, Mushotsky, Arnaud 1992: Cygnus X-1 Accretion disk, 255 White, Stella, Parmar 1988: Accretion disk Spectra in X-Ray Binaries 249 Stella, Priedhorsky, White 1987: 685 sec orbital Period from 4U1820-30 in NGC 6624, 231 Van der Klis, Jansen, van Paradijs, Lewin, van den Heuvel, Trümper, Sztajno, QPO in GX5-1, 214 Parmar, White, Giommi, Gottwald 1986: 3.8 hour Periodic Dips in LMXB EXO 0748-676, 206 Belloni, Hasinger 1990: Variability in the Noise Properties of Cyg X-1, 197 White, Peacock, Hasinger, Mason, Manzo, Taylor, Branduardi-Raymont 1986: Iron K line emission from LMXBs, 186 Shafter, Szkody Thorstensen 1986: Dwarf Nova SW Ursae Majoris- A new Cataclysmic Variable, 174 Rosen, Mason, Cordova 1988: The Magnetic CV EX Hya, 139 Belloni, Hasinger 1990: An Atlas of Aperiodic Variability in HXMB, 134 Parmar, White, Stella, Izzo, Ferri 1989: The Transient 42 Second X-ray Pulsar EXO 2030+375, 129 Trümper, Kahabka, Ögelman, Pietsch, Voges 1986: 35 Day Cycle of Her X-1 is due to Neutron Star Precession, 121 Watson, King, Osborne 1985: X-ray Pulse Period of Old Nova GK Per, 121 Mendez, van der Klis 1997: "Intermediate State" of GX 339-4, 109 Schulz, Hasinger, Trümper 1989: Color-Color Diagrams for LMXBs, 108 Barstow, Fleming, Diamond, Finley, Koester, ... 1993: Composition and structure of White Dwarf Atmospheres, 106 Kuulkers, van der Klis, Dotani, ..., van Paradijs, Lewin 1994: Spectral and Correlated Timing Behaviour of GX 5-1, 104 Vennes, Pelletier, Fontaine, Wesemael 1988: Helium in Hot White Warf Atmospheres, 103 White, Peacock, Taylor 1985: Broad IronLine Emission from Scorpius X-1, 101 Stella, White, Davelaar, Parmar, Blissett, van der Klis 1985: 4.4 Second Pulsations from the X-ray Transient V0332+53, 101

Missing: Papers on type I X-ray bursts

Gottwald, Haberl, Parmar & White 1986, EXO 0748-676, 98

Tennant, Fabian & Shafer 1986, 4U/MXB 1636 – 53, 92

Trümper, van Paradijs, Sztajno, Lewin, Pietsch, Krautter, Stollman, van der Klis 1985, 4U/MXB 1636 – 53, 63

1. The discovery of high frequency QPO's

Intensity-dependent quasi-periodic oscillations in the X-ray flux of GX5-1

van der Klis, Jansen, van Paradijs, Lewin, van den Heuvel, Trümper, Sztajno, 1985, 214



Quasi-periodic oscillations in the X-ray flux of Cyg X-2 Hasinger, Langmeier, Sztajno, Trümper,

Lewin, White 1986, 75

50

60

Two patterns of correlated X-ray timing and spectral behaviour in low mass X-ray binaries Hasinger & van der Klis, 1989, 725



Two patterns of correlated X-ray timing and spectral behaviour in low mass X-ray binaries (A review of QPOs) Hasinger & van der Klis, 1989



Citations/Publication Year for 1989A&A...225...79H 44 Unrefereed Refereed 40 Total citations: 725 36 Total refereed: 639 32 28 24 725 citations $\mathbf{20}$ 16 12 8 1990 2002 2006 1994 1998 2010 2014 2018 **Publication** Year

This paper is an evergreen!

Two happy postdocs

2. The famous Black Hole binary Cygnus X-1



An ionized accretion disk in

Cygnus X-1





The sharp Iron K line is part of the photon spectrum reflected by the accretion disk

3. Strong time variability of LMXB's The discovery of 3.8 hour periodic intensity dips and eclipses from the low-mass X-ray binary EXO 0748-676 Parmar, White, Giommi & Gottwald, 1986, 206 1-10 keV ME counts /s දු COUNTS/s 0.97 0.0 0.03 50 PHASE ֈՆլ^{൜ռվ}Ն COUNTS/s 35 35 10 15 20 HRS 5 0 1985 FEBRUARY 15 ~n_[.~n] Dips, bursts and eclipses 0.980 0.016 0.984 0.020 PHASE

Well resolved eclipses!

3 ctd.: Strong time variability of LMXB's The discovery of 3.8 hour periodic intensity dips and eclipses from the transient low-mass X-ray binary EXO 0748-676 Parmar, White, Giommi & Gottwald



This paper is an evergreen as well!

3 ctd: Strong time variability of LMXB's The discovery of 3.8 hour periodic intensity dips and eclipses from the transient low-mass X-ray binary EXO 0748-676 Parmar, White, Giommi & Gottwald



This paper is an evergreen as well!

4. Iron K line spectroscopy with the GSPC

EXOSAT Observations of broad band

Iron K line emission from Scorpius X-1

White, Peacock, Parmar 1988, 249



A study of the continuum and iron K line emission from low mass X-ray binaries White, Peacock, Hasinger, Mason, Manzo, Taylor &



5. Can Neuton Stars precess?

EXOSAT observations of the 35 day cycle of Hercules X-1: Evidence for neutron star precession Trümper, Kahabka, Ögelman, Pietsch & Voges 1986, 121



This was an alternative to the occultation of the neutron star by an precessing accretion disk! Gerend & Boynton 1976, see also Schandl & Meyer 1994

Our paper led to a long discussion about the role of neutron star precession in Her X-1



Scott, Leahy Wilson, 2000: The 35 day evolution of the Her X-1 pulse profile: Evidence for a resolved inner disk occultation of the neutron star. The neutron star does not process

Staubert, Klochkov, Postnov, Shakura, Wilms, Rothschild 2009: Two ~ 35 day clocks in Her X-1: Evidence for neutron star free precession. The NS is the master clock, the precession of the disk precession is synchronized with it in a sloppy way.

Staubert, Klochkov, Vasco, Postnov, Shakura, Wilms, Rothschild 2013: Variable pulse profiles of Her X-1 repetition with the same irregular 35 day clock as the turn-ons. Serious problem for free precession of the neutron star.

a final answer is pending...

6. Helium in White Dwarf Atmospheres The presence of Helium in hot DA White Dwarfs: The role of radiative levitation and the case for stratified atmospheres

Vennes, Pelletier, Fontaine, Wesemael 1988, 103



The three curves correspond to the predicted Helium abundances supported by radiative forces of models with M = 0.4, 0.6 and 0.8 solar masses

Quite clearly, Helium levitation fails to explain the observations

More efficient additional mechanisms Diffusion? Opacity effects? ...



Later papers

ROSAT studies of the composition and structure of DA White Dwarf atmospheres

Barstow, Fleming, Diamond, Finley, Sansom, Rosen, Koester, Marsh, Holberg, Kidder 1993, A larger Sample of ROSAT WFC (XUV) and PSPC spectra + EXOSAT confirms the EXOSAT results for T < 40 000 K For T > 40 000 K additional trace **metals** are required!

Evidence for an external origin of heavy elements in hot DA White Dwarfs

Barstow, Barstow, Casewell, Holberg, Hubeny 2014

Fuse spectra of 89 DA White Dwarfs are used to measure metal abundances

"We propose that the supply of heavy elements is accreted from external sources rather being intrinsic to the star"

7. Type I X-ray bursters

The first burster was discovered with ANS (Grindlay et al. 1976) and extensively studied with SAS – 3 (e.g. Lewin et al. 1981)

The long observation times provided by EXOSAT allowed to study the burst activity over longer times

EXOSAT and optical observations of the X-ray burst source 4U/MXB 1636 – 53

Trümper, van Paradijs, Sztajno, Lewin, Pietsch, Krautter, Stollman, van der Klis, 1985, 63



Another aspect: The use of type I bursts to measure neutron star radii



These 8 bursts are not standard candles!

Large scattering of the blackbody radii!

This was confirmed by subsequent EXOSAT observations:

The bursting behaviour of EXO 0748-676 Gottwald, Haberl, Parmar & White 1986, 98

BURSTING BEHAVIOR OF EXO 0748-676 1985 February 18/19 To COUNTS 65 14:00 2:00 6:00 10:00 22:00 1985 April 8/9 1985 February 26 T's COUNTS

EXOSAT has shown that the Type I X-ray bursts are not good standard candles and do not give reliable neutron star radii (In contrast to a popular view which exists until now!)

0

22:00

2:00

6:00

65

9:00

13:00

17:00

Observations of type I bursts from Circinus X-1



X-Ray Missions – Number of refereed publications (ADS)



The data for the Einstein observatory were taken from the NASA HEASARC archive and those for Integral from the Erik Kuulkers list of ESA missions

Conclusion

EXOSAT's Large collection power, Spectroscopic capabilities, High time resolution and long uninterrupted observation times



revolutionized the field of compact galactic X-ray sources and paved the way for later missions

Thank you!