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*"Per aspera ad astra..."*

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## Introduction to the stars in high energy

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Let your imagination soar. By sitting on the old rocker looking at the sky with couple of good old whiskey you can easily start thinking about the universe. You are looking at a heck of a different kinds of cosmic objects, but suddenly you see almost only the stars. Almost all the shiny dots on the sky are stars and these stars are only the closest ones. Yes, you can see few other galaxies by naked eye<sup>1</sup>, but none of the exotic cosmic objects you are imaging about. They are too faint to be observed easily, because they are not only far, far away, but they also usually shine on different wavelengths, not visible by human eye.

Think about distances in the universe. One of the most accurate explanation is that from: Adams (1979) *"Space," it says, "is big. Really big. You just won't believe how vastly, hugely, mindbogglingly big it is. I mean, you may think it's a long way down the road to the chemist's, but that's just peanuts to space..."*

Consider this, sometimes you want to study processes in these extreme, very faint objects, but they are too faint and too far in the universe. You are looking for "laboratory" with similar processes, but located much closer to the observer. The X-ray binary stars can be this kind of laboratories.

There is, of course, many interesting phenomena which could be studied in X-ray binaries or in non-binary X-ray stars. Several of them are mentioned in the motivation section.

I am mentioning many interesting things in this work, but the main effort is taken to study post shock region in the Intermediate Polars (IPs).

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<sup>1</sup>M31 and M33 in extremely good conditions on northern hemisphere and Magellanic clouds on southern one

## 1.1 Motivation

We can easily find many reasons why to study stars in the high energy bands. We can consider the direct and the most common scientific applications like observations of the supernovae, black holes & neutron stars in X-ray binaries. But for the education purposes I prefer several others, very nice examples closer to topic of this work.

- **Relativistic jet phenomena:** like it was proposed by Mirabel (2002) that universal mechanism should be at work in all the relativistic jet sources in the universe. Better understanding of sources including: microblazars, AGNs and gamma-ray burst will help to gain more comprehensive understanding of these phenomena. Microblazars can play role of “space laboratories”, where interesting processes last on different timescales as is the case with AGNs or GRBs.

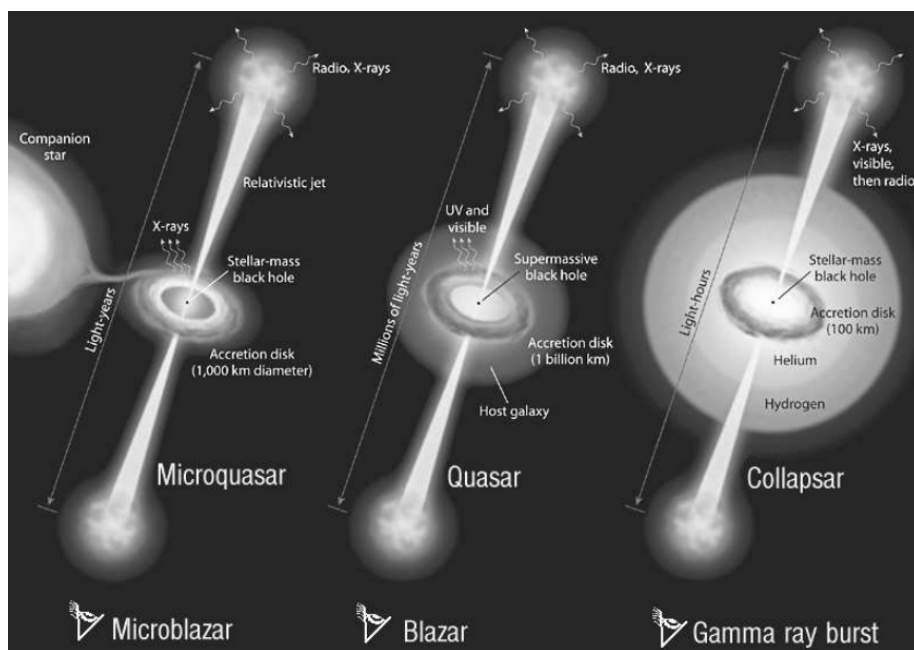


Figure 1.1: NOT in scale diagram, showing current ideas of micro-quasars, AGNs and gamma-ray bursts as space objects driven by same, universal mechanism Mirabel (2002).

- **Galactic ridge X-ray emission (GRXE):** various physical processes contribute to brightness of GRXE in different bands, but several studies in 3-20 keV provide evidence that diffuse X-ray radiation originates from huge number of stellar X-ray sources, mostly coronally active stars and white dwarf X-ray binaries. In particular for the energies over 20 keV to 200 keV is

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spectrum very similar to spectrum of magnetic white dwarf binaries – e.g. Intermediate polars (IP) and polars (P). Krivonos et al. (2007)

- **White dwarfs masses in Intermediate Polars (IP):** as was proposed in Rothschild et al. (1981), the temperature of the post shock region (PSR) depends on WD mass. Therefore the X-ray spectrum can be used for WD mass determination Suleimanov et al. (2005). The WD mass estimations in cataclysmic stars is in general complicated. Usually the curve of radiation velocities can be used, but it is quite hard to construct and because of . Therefore X-ray spectrum method is very attractive for several reasons. This work is dedicated to this topic.

## 1.2 Aim of this work

Because of the general topic of this work is necessary to specify the aim of it. To cover the whole topic stars in high energies, is far behind capacity of master thesis. I decide to aim on Cataclysmic variable stars (CVs).

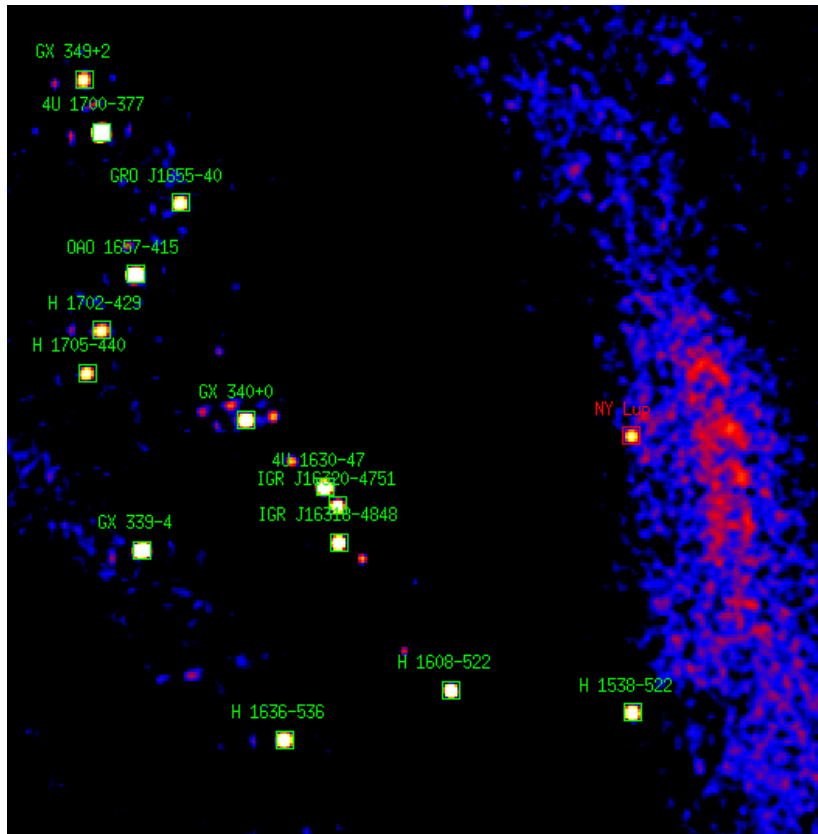


Figure 1.2: NY Lup region

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## 1.3 Observations

Cataclysmic Variable stars (CVs) have been, in fact, observed as early as ancient times. In historical records of many civilizations we can find references for various astronomical events. Mostly they are about temporary objects: planets, Moon and Sun. However several are about comets and new stars. Rightly, these new stars are in many cases novae and supernovae. In China, the records date back to 1500 AD.

Many records are saved from medieval time, for example positions of *Nova Vulpecula 1670* and *Nova Cygni 1600* (now known as P Cygni) in Hevelius maps.

With progress of astronomical photography in late 19th century started era of continuous observations and with development of first photo-multipliers in the mid-1940s CVs were begun attractive targets because of their big variability in different time scales.

It is suitable to mention, that AAVSO has light curve of SS Cyg from 1896 up to date.

### 1.3.1 Optical and IR observations

The very first visual observation was followed by photographic photometry and then spectroscopy, followed by photo-multiplier photometry since mid-1940s. The binary nature of all the CVs was confirmed. The flickering was discovered and was assumed that it is somehow connected to stars duplicity Walker (1957), Warner (1995).

Statistical studies by Luyten and Hughes in mid-1960th showed, that novae remnants have  $M_V \approx 4$  and dwarf novae at quiescence have  $M_V \approx 7.5$ . They concluded that the hot primary star in CVs must be WD or hot subdwarf Warner (1995).

The most important contribution of optical astronomy to this work is the discovery of large and variable circular polarization in several CVs. This helped to identify magnetic CVs, which were later divided into two categories, polars and intermediate polars.

There are more important discoveries in optical and IR bands in CVs subject. In case of interest the Warner (1995) is proper book.

### 1.3.2 X-ray observations

The very first CV detected in X-rays was the EX Hya observed by Uhuru X-ray space mission. Uhuru works in 2.0 – 6.0 keV and in spite of its poor sensitivity the well-known 4U catalogue was created Forman et al. (1978) from its observations.

The NASA's HEAO<sup>2</sup> program follows with three space missions. As the X-ray detectors technology evolves, the number of detected CVs grown linearly. EXOSAT provided long and uninterrupted data of many CVs during his operation from May 1983 until April 1986. Similar results were obtained from Soviet mission Kvant 1 and Japan's Ginga. The high hopes were entered into ROSAT

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<sup>2</sup>High Energy Astronomy Observatory, The HEAO 2 was also known as The Einstein Observatory

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which provides all-sky survey in the 0.1 – 2.0 keV but expected huge number of new CVs was not discovered.

The situation slightly changes with RXTE<sup>3</sup> which after years on orbit provides good data for several articles about WD masses Suleimanov et al. (2005). The data from RXTE are used in new articles even  $\sim 15$  years after its launch Butters et al. (2011).

Several others missions were launched in last ten years period. Few of them carried several detectors where one was sensitive in X-rays, like SUZAKU/XIS and Swift/XRT. But for the X-ray astronomy was been the year of 1999 the most important ever. The two major big observatories was launched on the Earth's orbit. The Chandra X-ray Observatory onboard STS-93 space shuttle Columbia on July and the XMM-Newton launched onboard ESA's Ariane 5 rocket.

That was the beginning of the X-ray astronomy's golden era. During last decade the combination of Chandra and XMM provides enormous data archives which will be useful for astronomers for another decades.

Sadly, there will not be such big observatory in X-rays for several decades. Only bigger space mission is Japan's ASTRO-H with several X-ray and gamma ray detectors on-board to cover broad high energy bands. The future of big ESA & NASA space mission Athena (formerly: Constellation-X, XEUS, IXO) is questionable because of budget cuts in both space agencies.

Fortunately, there are several data archives with open data for anybody interested. This is big challenge mainly for young astronomers, who are not in any big space mission program but want to do science. In this case, they don't need any special hardware, even modern laptops are powerful enough.

### 1.3.3 Gamma ray observations

In last millennium several space mission observed few CVs in bands from tents of keV to TeV.<sup>4</sup> The biggest breakthrough came with ESA's INTEGRAL space mission which was able with its sensitivity and large field of view observed many CVs. Mostly intermediate polars. Only  $\sim 2\%$  of all CVs are actually magnetic ones, but those ones are only visible in gamma rays. INTEGRAL/IBIS was been used to determine white dwarf masses by Landi et al. (2009).

Two others space missions have on-board detectors similar to INTEGRAL/IBIS with their sensitivity and coverage: the NASA's Swift/BAT and Japan's Suzaku/XRT. Both are widely used to study white dwarf masses in IPs Brunschweiler et al. (2009), Yuasa et al. (2010).

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<sup>3</sup>Rossi X-ray Timing Explorer

<sup>4</sup>The most studied CV from this era is AE Aqr (Meintjes 1990; Bowden et al. 1991)



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## White Dwarfs

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## Cataclysmic variable stars

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### **3.1 Non magnetic cataclysmic variables**

### **3.2 Magnetic cataclysmic variables**

#### **3.2.1 Polars**

#### **3.2.2 Intermediate polars**

### **3.3 Galactic population of cataclysmic variables**

### **3.4 Others important creatures**

### **3.5 GXRE**

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## Masses of white dwarfs in intermediate polars

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### 4.1 Breaking radiation

#### 4.1.1 Bremsstrahlung

$$a_{\parallel} = \dot{v}_x = -\frac{eE_x}{m_e} \frac{\gamma Z_e^2 v t}{4\pi\epsilon_0 m_e \left[ b^2 + (\gamma v t)^2 \right]^{2/3}} \quad (4.1)$$

#### 4.1.2 Thermal bremsstrahlung

### 4.2 Synchrotron radiation

### 4.3 Post shock region

### 4.4 WD mass estimations methods

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## Data analysis

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### 5.1 INTEGRAL

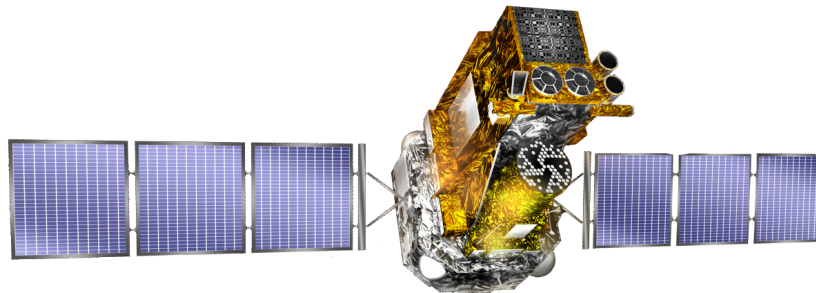


Figure 5.1: INTEGRAL

### 5.2 XMM-Newton

### 5.3 Results

### 5.4 Discussion

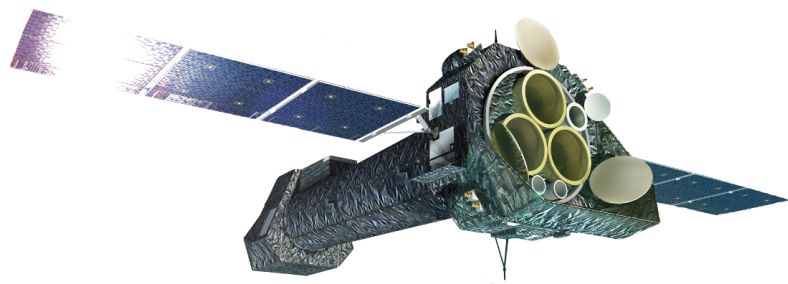


Figure 5.2: XMM-Newton

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## Conclusions

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## **Appendix**

this will be the appendix

Table 1: Estimated WD masses from previous reports ...

System	Suzaku	Swift	RXTE	RXTE	RXTE	Ginga	ASCA	This work
	XIS+HXD	BAT	PCA+HEXTE	PCA	LAC	SIS	XMM & Integral	
	$M_{WD}$	$M_{WD}$	$M_{WD}$	$M_{WD}$	$M_{WD}$	$M_{WD}$	$M_{WD}$	$M_{WD}$
FO Aqr								
XY Ari								
MU Cam								
BG CMi								
V709 Cas								
TV Col								
TX Col								
YY Dra								
PQ Gem								
EX Hya								
NY Lup								
V2400 Oph								
AO Psc								
V1223 Sgr								
RX J2133								
IGR J17303								