Suzaku Observations of Accreting White Dwarf Binaries

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Outline

• Magnetic CVs
  ➢ First discovery of article acceleration from the white dwarf in AE Aquarii. (Terada)
  ➢ Intermediate Polars with soft X-ray emission. (Mukai)

• Dwarf Novae
  ➢ Hard X-ray emission site of SS Cyg in outburst. (Ishida)
  ➢ Distance-limited unbiased survey for the luminosity function. (Mukai)

• New type of symbiotic star SS73 17. (Smith)
• Serendipitous super-soft source Suzaku J0105-72 in SMC. (D. Takei)
The Intermediate Polar AE Aquarii

- **IP**: Asynchronous rotator, $P_{\text{spin}}$ ~$0.1P_{\text{orb}}$.
- **AE Aqr**
  - $B \approx 10^{5-6}$ G.
  - Fastest rotator, $P_{\text{spin}}$ = 33.08 sec, ~35% of the break-up speed (Patterson 1979; Casares et al 1996). $\Rightarrow V \approx 6 \times 10^{14}$ eV.
  - Steady spin down (de Jager 1994, M"{o}nache 2006): loss rate $\approx 5 \times 10^{33}$ ergs s$^{-1}$.

\[ V \approx \left| \frac{e}{c} \times \frac{r}{B} \right| \cdot \frac{2\pi e R_{\text{WD}}^2 B}{cP} \]
Suzaku Observations of AE Aqr

- 2005 Nov. 70/49ks (XIS/HXD)
  2006 Oct. 53/42ks (XIS/HXD)
- Epoch-folding analysis $\Rightarrow \chi^2$
  peak at
  $P_{\text{XIS}} = 33.0769 \pm 0.0001$ sec
  $P_{\text{PIN}} = 33.076 \pm 0.005$ sec
  consistent with the rotational period (Mauche 2006).
- The peak is sharper for PIN.
New pulsating component in the PIN band

- Pulse profile is sinusoidal below ~4 keV.
- Above 10 keV (PIN), a separate spiky pulse appears, which is also visible in the XIS 4-10 keV band.
- Relative phase-shift of ~1 sec could be due to premature XIS timing calibration.

_Terada et al. (2008)_
Suzaku Spectra

- XIS spectra in the 1.5-10 keV band can be fit with two-temperature mekal model with \( kT = 0.5 \) and 3 keV, as before (Choi et al. 1999).

- The PIN flux cannot be explained by the thermal model.

- If power law, \( \Gamma = 1.1 \pm 0.6 \), in the range of NS pulsars (Gotthelf 2002).
• $L_{\text{HX}} = 5.3 \times 10^{29}$ ergs s$^{-1}$ (0.09% of the spin-down energy).
• Likely to be synchrotron emission (curveture radiation, non-thermal bremsstrahlung, inverse Compton radiation are considered).
Observations of Soft Intermediate Polars

• IPs are the hardest ($kT \approx 30$keV) and the most luminous ($L_{\text{hard}} \approx 10^{32-34}$ergs s$^{-1}$) X-ray sources among all CVs.

• Although $L_{\text{soft}} \approx L_{\text{hard}}$ is expected as the shock is low, no IP showed any detectable soft component until 10 years ago.

• Recently a few IPs are found to have soft blackbody emission, but with higher $kT_{\text{bb}} \approx 90$-100eV (de Martino et al. 2004). ⇒ Suzaku BI-CCD.

• These soft IPs are good targets of Suzaku in that
  ➢ High sensitivity and a wide band (0.2-50keV).
  ➢ Good energy resolution to resolve emission lines.
Observations of two Soft IPs

- Observations of two IPs which are reported to have a soft blackbody component.
- Preliminary analysis indicates multi-phase plasma, reflection from the white dwarf surface, ionized absorber, as well as the blackbody component.

Mukai et al. Poster A28
The dwarf nova SS Cygni

- Optical outburst in every ~50d, $\Delta m_V \sim 4$.
- Outburst is due to the thermal instability in an outer disk (Osaki 1996), where disc viscosity increases associated with hydrogen ionization.

Wheatley, Mauche & Mattei (2003)
BL/Inner Disc Behaviour

  - AAVSO: Outer accretion disc
  - EUVE: Inner accretion disc (optically thick BL)
  - RXTE: Optically thin BL (2-15keV).
- Optically thin to thick transition of BL is detected.
- Optically thin hard X-ray flux never disappears.
- Hard X-ray emission site in outburst has not been identified.

Wheatley, Mauche & Mattei (2003)
Suzaku Observation of SS Cyg

- Observation in Quiescence: 2005 Nov. 2 /40ksec
- Observation in Outburst (ToO): 2005 Nov.18 /60ksec
• Unlike $E > 0.4\text{keV}$, $E < 0.4\text{keV}$ declines monotonically.
  ⇒ Dominated by emission from the optically thick BL.
XIS Spectra

- H/He-like K$_\alpha$ lines from O to Fe in outburst.
- Soft disc blackbody component below 0.3 keV.
Time-resolve spectra of the soft component

- Segmented into three spectra with equal counts for the soft component.
- Intensity declines below 0.3 keV.
Disk BB fit

- $N_H = 5.0^{+2.9}_{-1.5} \times 10^{19} \text{cm}^{-2}$, (interstellar $\equiv 3.5 \times 10^{19} \text{cm}^{-2}$; Mauche et al. (1988))

- Innermost radius is consistent with the $1.2M_\odot$ white dwarf radius.
  - $\Delta R_{\text{in}} \approx 1000 \text{km}$ due to $N_H$ uncertainty.
  - The disc can be interpreted as reaching the WD surface in outburst.

- No space for hard X-ray emitter in the disc plane.
Chandra HETG observation in outburst

- Chandra observation of SS Cyg in outburst (Mukai et al. 2003; Mauche et al. 2005; Rana et al. 2006).
- Emission lines are all broad in outburst.
- H-like Kα lines are incompatible with a simple Gaussian profile (Okada, Nakamura, Ishida 2008).
Hard X-ray emission in outburst

• Line profiles can be fit by a diskline model ($R_{in} \sim 1000R_s$).
  ⇒ Hard X-ray emission region extends over the disc, like an accretion disc corona.

$\pm 5\%$ of $E_{line}$
Distance-limited survey of dwarf novae

- Non-magnetic CVs occupy more than 80% of all CVs.
- $N \approx 3 \times 10^{-5} \text{ pc}^{-3}$ (Schwope et al. 2002).
- Fainter in X-rays ($L_X < 10^{32} \text{ ergs s}^{-1}$) than mCVs.
- Dwarf novae are the majority.
- Potential constituents of the GRXE (Revnivtsev et al. 2006).
  ⇔ Truly diffuse emission (Ebisawa et al. 2005).
- It is important to know the luminosity function of DNe and their spectra in the range $L_X < 10^{30} \text{ ergs s}^{-1}$.
- The existing ensemble(s) (Mukai & Shiokawa 1993; Baskill et al. 2005) are not enough because they are weighted to higher luminosity sources.

⇒ Unbiased observations of DNe with $d < 200 \text{ pc}$ based on parallax measurements since AO-1 (lead by KM).
• In total 15 DNe are firmly known to be within 200pc based on the parallax measurements (Thorstensen and others).
• V893 Sco (AO-1) / SW UMa, VY Aqr (AO-2).
• $kT \approx 3–7$ keV if a single temperature mekal model is applied.
• $L_X \approx 1 \times 10^{30}–6 \times 10^{31}$ ergs s$^{-1}$.
Current luminosity function of DNe

- Three Suzaku-observed DNe together with GW Lib (XMM-Newton) significantly broaden the ASCA luminosity function which strongly peaks at $L_X = 10^{31} - 10^{32}$ ergs s$^{-1}$.
- In total $\approx 1000$ DNe are expected within 200pc.
- e-ROSITA survey (luminosity-weighted selection effect?).
Symbiotic Star

- Binary of a red giant star and a hot blue companion.
- A white dwarf accretes from the wind of the red giant.
- According to ROSAT results (Mürset et al. 1997),
  - SSS
  - Soft thin plasma $kT \approx 0.2\text{keV}$
  - With hard spectral component
- The hard source are relatively rare: CH Cyg (Ezuka et al. 1998), RT Cru (Masetti 2005), CI Cam (Ishida et al. 2004), T CrB (Trueller et al. 2005).

Luna et al. Poster A27

CH Cygni

Mukai et al. (2007)
SS73 17

• Discovered by INTEGRAL and Swift.
  ➢ IGRJ10109-5746 (Revnivtsev et al 2006)
  ➢ Swift J101103.3-574818 (Trueller et al 2005)
• A member of “highly-absorbed X-ray binaries” (Kuulkers 2005).
• Suzaku observation: 2006 June 5.
• The first symbiotic star that has hard X-ray component without significant soft X-ray emission.

Smith et al. (2008)

• Thin thermal spectra $kT \approx 9$keV
• Partial covering $CF \approx 92\%$
• $N_H \approx 2 \times 10^{23} \text{ H cm}^{-2}$
Discovery of a new super soft source in SMC

- E0102-72 (an SNR in SMC) is an XIS calibration source.
- Observed 16 times until 2007 March.
- An outbursting source is detected from one of these observations carried out on 2005 August 31.
- Detected only <2keV.
- No source was found in the error circle at a comparable brightness from Einstein, ROSAT, ASCA, Beppo-SAX, Chandra and XMM-Newton.
Spectra of Suzaku J0105-72

- Blackbody with $kT_{bb} \approx 72$eV
- $N_H \approx 4.9 \times 10^{20}$ H cm$^{-2}$, consistent with the value to SMC.
- $L_{bol} \approx 1 \times 10^{37}$ ergs s$^{-1}$ with $d = 60$ kpc.
- $R \approx 10^8$ cm $\Rightarrow$ White dwarf
- O\textsc{vii} K-edge at 0.74 keV ($\tau = 1.2$).
- All these characteristics are consistent with those of SSS.
The End
BI calibration with PKS2155-304

- The observation carried out on 2005 Nov. 30.
- Broken power law with $N_H = 1.7 \times 10^{20}$ H cm$^{-2}$ needs
  - Extra carbon edge at $E = 0.2842$ keV ($\tau = 0.88 \pm 0.05$)
  - Extra NH = $(8.2 \pm 0.7) \times 10^{19}$ H cm$^{-2}$.
- The band $E > 0.23$ keV can be used.