The Impact of Suzaku on the Knowledge of Cataclysmic Variables

The Golden Age of CVs and Related Objects, 2011.09.14

Dai Takei
Rikkyo University
Harvard-Smithsonian Center for Astrophysics
Acknowledgement

- Suzaku managers and operation members
- Hayakawa Satio foundation (travel grant)
- My Ph.D. thesis advisers ...
  - Shunji Kitamoto (Rikkyo University)
  - Masahiro Tsujimoto (JAXA/ISAS)
  - Jan-Uwe Ness (ESA/ESAC)
  - Jeremy J. Drake (Harvard CfA)

and all concerned ...

Vorrei ringraziare gli organizzatori per avermi dato la possibilita` di parlare
I would like to thank the organizers for giving me a chance to talk
Scope & Goal

- **Scope**: observational results in X-rays
  - An emphasis on Suzaku results
  - Results in other wavelengths are not included
- **Goal**: to convey three ideas
  - Various fields are covered with Suzaku
    Magnetized CVs, Dwarf Novae, Classical Novae, etc.
  - Great impacts on the knowledge of CVs
    Non-thermal processes with high energy emission
  - ASTRO-H has important roles in future
    Further improvement of X-ray instruments
Talk Plan

1. Suzaku X-ray Mission
2. Review of Suzaku Results
3. Suzaku Impact on CVs
4. Future Outlook

Further reading:
- Suzaku Home Page
Talk Plan

1. Suzaku X-ray Mission  ~ 3 min
2. Review of Suzaku Results  ~ 6 min
3. Suzaku Impact on CVs  ~ 8 min
4. Future Outlook  ~ 6 min

Further reading:
• Suzaku Home Page
1-1. What is Suzaku ...?
1-1. What is Suzaku ...?
1-2. Suzaku X-ray Satellite

- Japan-US joint mission
- Launched on July 10, 2005
- Low-Earth orbit ...
  - altitude \( \sim 570 \text{ km} \)
  - orbital period \( \sim 96 \text{ min} \)
1-2. Suzaku X-ray Satellite

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XRS</td>
<td>Disable</td>
</tr>
<tr>
<td>XIS</td>
<td>(0,1,2,3)</td>
</tr>
<tr>
<td>HXD</td>
<td>(PIN,GSO)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>XIS</th>
<th>HXD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandpass</td>
<td>62.0 ~ 1.0 Å</td>
<td>0.8 ~ 0.02 Å</td>
</tr>
<tr>
<td>Spatial Res.</td>
<td>2 arcmin. (HPD)</td>
<td>N/A</td>
</tr>
<tr>
<td>Energy Res.</td>
<td>130 eV @ 6 keV</td>
<td>4.0 keV (PIN)</td>
</tr>
<tr>
<td>Timing Res.</td>
<td>8 sec</td>
<td>61 μsec</td>
</tr>
</tbody>
</table>

1-3. Advantages of Suzaku

- Wide-band X-ray observations with ...
  - high effective areas
  - medium energy resolutions
  - low background levels

Diagnoses of emission line spectra
Studies of high energy phenomena

...> Let’s take a look!
2. Review of Suzaku Results

1. Magnetic CVs (Polar, IP)
2. Dwarf Novae
3. Classical Novae

Three Ph.D. and 16 papers were produced. Two of them were issued in press releases.
2-1. Magnetic CVs

• Ph.D. Thesis
  - Takayuki Yuasa, 2011
    Suzaku Studies of White Dwarf Stars
    and the Galactic X-ray Background Emission

• Refereed Papers
  - Hayashi et al. 2011, PASJ
  - Yuasa et al. 2010, A&A
  - Scaringi et al. 2010, MNRAS
  - Nobukawa et al. 2009, PASJ
  - Terada et al. 2008, PASJ
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Systematic studies were conducted on magnetic CVs.
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Next Talk

Main Topic (1)
2-2. Dwarf Novae (DNe)

- **Ph.D. Thesis**
  - Shunsaku Okada, 2008
  An Observational Study on the Nature of the Boundary Layer Plasma in the Non-Magnetic Cataclysmic Variable SS Cygni

- **Refereed Papers**
  - Byckling et al. 2010, MNRAS
  - Ishida et al. 2009, PASJ
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Detailed spectroscopy was conducted on Dwarf Novae

1. Phase-induced spectroscopy
2. Partial eclipse
3. Luminosity classification, etc...

X-ray (thin-thermal) (fluorescence)

WD

Boundary Layer

Accretion Disk
2-3. Classical Novae (CNe)

- **Ph.D. Thesis**
  - Dai Takei, 2011
    - An X-ray Study of Classical Novae

- **Refereed Papers**
  - Takei et al. 2011, PASJ
  - Takei and Ness 2010, AN
  - Takei 2010, Astronomical Herald
  - Tsujimoto et al. 2009, PASJ
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Systematic studies were conducted on Classical Novae

1. WD mass
2. Ejecta chemistry
3. Binary evolution, etc...
2-3. Classical Novae (CNe)

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**X-ray observation of CNe**
(e.g., V2491 Cyg; Swift)

1. Surveys by amateur astronomers
2. X-ray monitoring with Swift
3. Deep spectroscopy with Suzaku

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Friday, 17:00
by Dr. Kim Page

- < Suzaku
- < XMM-Newton
2-3. Classical Novae (CNe)

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The golden age of CNe has arrived!!
3. Suzaku Impact on CVs

- Two press releases
  - Non-thermal pulses from AE Aqr (Magnetic CVs) *(Terada et al. 2008, PASJ, 60, 387)*

- What is the Suzaku impact ...?

CVs have potential to be non-thermal sources
3-1. WD Pulsars

- **Neutron Star (NS) pulsars vs. WD pulsars**
  - Particle acceleration occurs from NS pulsars
  - Synchrotron emission from magnetosphere
    (e.g., *Crab pulsar: Mori et al. 2004, ApJ*)
3-1. WD Pulsars

**Neutron Star Pulsars**

- Particle acceleration occurs from NS pulsars.
- Synchrotron emission from magnetosphere (e.g., Crab pulsar: Mori et al. 2004, ApJ).
- There should be WD pulsars...
- Suzaku discovered 33 sec pulses from AE Aqr.
- Synchrotron emission is a feasible origin (Terada et al. 2008, PASJ).

**Neutron star pulsar**
(X-ray image of Crab pulsar)

- Spin msec ~ sec
- Radiation
- Magnetic field ~10^{12-13} Gauss
- Size ~ 10 km
- Induced electric potential ~10^{16-18} Volts
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<table>
<thead>
<tr>
<th>Dynamo in bicycle</th>
<th>Neutron Star</th>
<th>White Dwarf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin ~ a few sec</td>
<td>Spin msec ~ sec</td>
<td>Spin sec ~ hr</td>
</tr>
<tr>
<td>Magnetic field ~10^{23} Gauss</td>
<td>Magnetic field ~10^{12-13} Gauss</td>
<td>Magnetic field ~10^{-5-7} Gauss</td>
</tr>
<tr>
<td>Size ~ a few cm</td>
<td>Size ~ 10 km</td>
<td>Size ~ 10000 km</td>
</tr>
<tr>
<td>Induced electric potential ~a few Volts</td>
<td>Induced electric potential ~10^{16-18} Volts</td>
<td>Induced electric potential ~10^{14-16} Volts</td>
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X-ray pulses from AE Aqr (Terada et al. 2008, PASJ)
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First discovery of non-thermal X-ray pulses
WDs have potential as particle accelerators
3-2. Hard X-rays from CNe

- **Annihilation signatures from CNe**
  - CNe produce radioactive isotopes
    (e.g., Clayton and Hoyle 1974, ApJL)
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  - A model was proposed to explain the result (Suzuki and Shigeyama 2010, ApJL)

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<tr>
<th>Isotope</th>
<th>Lifetime</th>
<th>Novae</th>
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<tbody>
<tr>
<td>$^{13}$N</td>
<td>862 s</td>
<td>CO, ONe</td>
</tr>
<tr>
<td>$^{18}$F</td>
<td>158 m</td>
<td>CO, ONe</td>
</tr>
<tr>
<td>$^{7}$Be</td>
<td>77 d</td>
<td>CO</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>3.75 y</td>
<td>ONe</td>
</tr>
<tr>
<td>$^{26}$Al</td>
<td>$10^6$ y</td>
<td>ONe</td>
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- e.g., Hernanz et al. 2001
- Gomez-Gomar et al. 1998
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### Radioactive Isotope in CNe (proton-rich nuclei)

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### Nuclear Reactions

- $^{22}_{11}$Na
  - EC (10%)
  - $\beta^+$ (90%)
  - Internal Conversion
  - $^{22}_{10}$Ne $^*$
  - Annihilation

- $^{22}_{11}$Na: Neutron-deficient nuclei
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**X-ray Spectra of CNe (V2491 Cyg, Day 9)**

![X-ray Spectra Graph]

- Counts s⁻¹ keV⁻¹
- Energy (keV)
- Fe XXV Kα
- APEC
- Power-Law
- HXD (PIN)
- XIS (FI)
- XIS (BI)
- (APEC+Bremss)
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X-ray Spectra of CNe (V2491 Cyg, Day 9)

Power-law ($\Gamma = 0.1$)
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**Compton Degradation Model**

- $(^{22}\text{Na} > ^{22}\text{Ne})$
- $511$ KeV
- $1.27$ MeV

**Suzaku**

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First discovery of high energy phenomena
CNe have potential as non-thermal sources
CVs have potential to be non-thermal sources
4. Future Outlook

1. ASTRO-H (Japan-US X-ray mission)
2. Further studies of CVs
3. Are CVs origins of cosmic-rays ...?
4-1. ASTRO-H Mission

- Japan-US joint X-ray mission
- Satellite will be launched in 2014
- Advanced X-ray instruments
  - Telescope: HXT (Bragg-multilayer mirror)
  - SXT (Lightweight Wolter-I mirror)
  - Detector: SXS (Micro calorimeter)
  - SXI (Wide-field CCD array)
  - HXI (Si-CdTe imager)
  - SGD (Compton camera)
4-1. ASTRO-H Mission

X-ray Instruments onboard ASTRO-H

- SXS: HXT
- SXI: SXT
- HXI: SXS
- SGD: SXI

4-2. Further Studies of CVs

- **Survey of non-thermal emission**
  - HXI will provide hard X-ray images (>10 keV)
  - Study of synchrotron emission from CVs
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- **First discovery of annihilation lines**
  - SGD has potential to detect 511 keV photons
  - Study of annihilation processes on CNe

**ASTRO-H/HXI**
(shadow image; 28-33 keV)

Private communication with H. Odaka
4-2. Further Studies of CVs

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Compton Degrad. Model
(V2491 Cyg, $M_{\text{ejecta}} = 10^{-3} M_\odot$)

![Graph showing Compton Degradation Model]

ASTRO-H detection limit
(100 ksec)

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Research of particle acceleration in our Galaxy
Approach to positron factories in the Universe
4-3. Origins of Cosmic-Rays

- **Cosmic-ray electrons & positrons**
  - Excess was found by PAMERA (*Adriani*+ 2009)
  - New sites of particle accel., or dark matter?
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- Recent progress on CVs
  - AE Aqr (Suzaku; Terada+ 2008)
  - V2491 Cyg (Suzaku; Takei+ 2009)
  - V407 Cyg (Fermi; Abdo+ 2010)

Result of PAMERA (electron & positron excess)
4-3. Origins of Cosmic-Rays

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This Talk

Friday, 18:40

by Dr. Takashi Iijima
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CVs are important objects for cosmic-rays
The platinum age of CVs is coming soon !?
Summary

1. Suzaku made impacts on the CVs science
2. We found non-thermal X-rays from CNe
3. ASTRO-H will be bright, like these CVs

Grazie per la cortese attenzione !!
Please let me know if you are interested in this work.
dtakei@head.cfa.harvard.edu