Violent Universe Explored by Japanese X-ray Satellites

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**Lecture Plan**

**September 30, 10:45-12:00**

**II. High energy phenomena**

2. Supernova remnants (SNR)
3. Neutron stars and blackholes
4. Active Galactic Nuclei(AGN)
5. Cluster of galaxies and Cosmology
II-2 : Supernova remnants (SNR)
Supernova Remnants (SNR)

(1) Evolution of main sequence stars

M < 0.5 M_{solar} \quad H \rightarrow He

M < 3 M_{solar} \quad H \rightarrow He \rightarrow C/O

\quad \text{----------------------------------------White dwarf}

3 M_{solar} < M < 8 M_{solar} \quad C \rightarrow O \rightarrow Ne \rightarrow Mg

\quad \text{Ty I SN} \quad \text{-------------------------Scatter all mass}

8 M_{solar} < M < 30 M_{solar} \quad Si \rightarrow Fe/Ni

\quad \text{Ty II SN} \quad \text{------------------------Neutron stars}

30 M_{solar} < M \quad \text{----------------------------------Black holes}
(2) Evolution of Supernovae

Gravitational $\varepsilon$ of collapsed star $\rightarrow$ Neutrino (99%)
$\rightarrow$ Kinetic $E$ (1 %)

Shock wave enhances density, reduces speed
Kinetic $\varepsilon$ $\rightarrow$ Thermal $\varepsilon$

Sweep-up surrounding gas $\rightarrow$ Shell
High density $\rightarrow$ X-rays ($\propto T^{1/2} n^2$)

Effective cooling by X-rays when $T \sim 10^6$ K
Temperature

Density

半径 (pc)

Shell （High density ➔ High Emissivity）

High Temp.
Low Density

1 atom/cc

10^7 K ~ 1 keV
Cas-A (1680 AD)

Visible

X-rays

10 light year

5 x 10^7 K

Photograph courtesy NASA/ESA/Hubble Heritage Team
## Record of Supernovae

<table>
<thead>
<tr>
<th>Year(AD)</th>
<th>Constellation</th>
<th>Name of objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>Centaurus</td>
<td>G314.4-2.3</td>
</tr>
<tr>
<td>386</td>
<td>Sagittarius</td>
<td>G11.2-0.3</td>
</tr>
<tr>
<td>1006</td>
<td>Lupus</td>
<td>SN1006</td>
</tr>
<tr>
<td>1054</td>
<td>Taurus</td>
<td>Crab Nebula</td>
</tr>
<tr>
<td>1181</td>
<td>Cassiopeia</td>
<td>3C58</td>
</tr>
<tr>
<td>1572</td>
<td>Cassiopeia</td>
<td>Tycho</td>
</tr>
<tr>
<td>1604</td>
<td>Ophiuchus</td>
<td>Kepler</td>
</tr>
<tr>
<td>1680</td>
<td>Cassiopeia</td>
<td>Cas A</td>
</tr>
<tr>
<td>1987</td>
<td>LMC</td>
<td>1987A</td>
</tr>
</tbody>
</table>
SN1987A

Before

After

Visible

Half year later Ginga discovered X-rays from --> Projenitor hit by shock wave

Expanding Ring observed by Hubble

X-ray image by Chandra Jan. 2000
Cas A X-ray Spectra

Thermal Brems + Emission lines

Different dist. of elements

Non-uniform explosion

http://www.u.phys.nagoya-u.ac.jp/r_e/r_e3_4.html
Multi-waveband observations

X-ray observation by Suzaku

Left: Slow 0.15”/year Expansion (Chandra)

Right: Fast 0.45”/year Expansion (Chandra)

Tycho SNR with Suzaku

Fe rich shell
Tycho SNR

Discovered by Tycho Brahe in 1572

Fe-K line broadening

Multiple lines yield $\delta E \sim 40$ eV

Furuzawa et al., 2009: ApJ...693L..61F
Tycho SNR

Expanding shell at 2000-3000 km/s

$\Delta V_{Fe} \sim 3000$ km/s

Radial expansion

Tycho SNR with Suzaku

0.5 - 12.0 keV band Image

Furuzawa et al., 2009: ApJ...693L..61F

Furuzawa, 2009: ApJ...693L..61F
Tycho SNR

Expanding shell at 2000-3000 km/s

Extend internal structure of progenitor

Hayato et al., 2010: ApJ...725..894H

Furuzawa et al.
Tycho SNR

Multi-waveband observations

Molecular cloud
Radio(CO)

Infrared (Akari)

Dust

X-ray (SUZAKU) Plasma

Ishihara et al. 2010: A&A...521L..61I

By Ishihara
Infrared images by Akari

Left: Clod Dust (~20K)

Right: Warm Dust (~100K)

Ishihara et al. 2010: A&A...521L..61I
Multi-waveband observations

Schematic View of the shell region

Ejecta of SNR

Mixture of $10^7$K Plasma and 100K Dust

Depletion

Shock front

Swept up ISM

Interstellar Matter (ISM)

Molecular gas + 20 K Dust

X-ray

Infrared
SN1006(1006)

Acceleration of High energy particles $E > 10^{14}$ eV electrons

Production of Cosmic rays (protons)?

- Non-thermal Power law component
- Thermal component (Brems + emission lines)
(3) Products of Super novae

Hot plasmas --> Hot Inter-Stellar Medium (HISM)

Nuclear synthesis --> Pollution of ISM
  --> material for the next generation stars
  --> Contraction of B --> Acceleration of e⁻

Acceleration of high energy particles → Cosmic rays
  --> Supply of Energy and abundance to ISM

Dense core (Neutron stars, Black holes)
II-3: Neutron stars and blackholes
(1) Mass Accretion from Companion Stars
II-4 : Active Galactic Nuclei (AGN)
Active galactic nuclei (AGN)

Bright nucleus $> 10^{11}$ total radiation of stars

Emission lines instead of absorption lines

Ionization source!

Stellar emission

V$>2000$ km/s

Narrow

Broad
Optical images of galaxies

Eliptical galaxies

AGN

M 87

Hubble Space Telescope

Fig. 1.2. Examples of galaxy types. Left to right, top: M87 (E0), NGC147 (dwarf E3); centre, M31 (Sb), NGC1365 (SBB—note the prominent bar); bottom, NGC2997 (Sc) and NGC4521 [M100] (Sc). The photographs are from the Anglo Australian Telescope apart from NGC147 and M31 which are from the Hale Observatories.
Mass estimation of nuclei

Nuclear gas motion
\[ v^2/r = GM/r^2 \]
\( v=500\text{km/s} \)
Radius: \( r=18\text{pc} \)
\( M > 10^9 \text{Msolar} \)

**Blue shift** ← Approaching

**Red shift** ← Reseeding
Active galactic nuclei

Narrow Emission lines

Broad Emission Lines

Ty I AGN

Ty II AGN

Absorption Torus

BLR Cloud

NLR Cloud

Black Hole and Accretion Disk

X-rays from AGN

Power Law Comp.

Fe-K

Bright Nucleus

Illuminated Acc. disk

Cont.

Fe-K Line

Residual

Counts s^{-1} keV^{-1}

Channel energy (keV)

Doppler Effect

Relativistic Orbital Velocity

\[ v \approx (1 - \frac{r_g}{r})^{1/2} v_{em} \]

MCG-6-30-15

Gravitational Red Shift

\[ v \approx (1 - \frac{r_g}{r})^{1/2} v_{em} \]


Tanaka, Y et al, 1995, Natur., 375, 659

Miniutti, H et al, 2007, Progress of Theoretical Physics Supplement, 169, 260
How large red shift could be?

Rin could be as small as 3Rg
If BH is rotating, Rin could be < 3Rg
then red shift could be larger

Continuum level affects the red shift

Red shift to 5keV is sure --> but
Rotating Kerr BH is not clear yet
Structure of the BH vicinity
Determined by Suzaku

Gravitational Red Shift

Broader at Edge-on

Model Calculation

Energy

X-ray energy (keV)
X-ray Spectrum of the Galactic Center

Emission lines of Fe at different ionization state

- Neutral 6.4 keV
- He-like ion 6.7 keV
- H-like ion 6.9 keV

CCD Spectral Resolution

Sgr A*

6.7 keV Line mapping

Hot Plasma

6.4 keV Line Mapping

Reflection Nebulae

30 pc
Galactic Center Region

Molecular Cloud
Sgr B2

Galactic Plane

Sgr B2
Radio Arc
Sgr A*
Sgr C

Chandra X-ray Image of GC
Bright X-ray Source at Galactic Center?

Central Luminosity
350 years ago

Very bright
350 years ago!

Massive Black hole
was very active!

Murakami, H et al, 2003, Astron. Nachr, 324, 125
X-ray Front approaching to molecular clouds

K. Koyama

Koyama et al., 2008, Publ. Astron. Soc. Japan, 60, 201
II-5 : Cluster of galaxies and Cosmology
Structure of C. G.

Visible (Stars)  X-rays (Gas density$^2$)  Gas temp.

Fig. 7.2  R. Shibata et al., 2001, ApJ, 549, 228
Abundance Distribution

Concentration at cores
Nucleus-synthesis
Ty Ia/Ty II SNR
Scatter of galactic gases
Galactic wind
Ram pressure
Mass of C. G.

Galaxies (stars) $10^{11} \times 10^3 \, M_{\text{solar}}$

Intra-cluster gas

$V = 4\pi (16 \, \text{Mpc} \times \tan 2^\circ)^3 / 3 = 2 \times 10^{73}$

$V \times 0.001 / N_A / 2 \times 10^{33} \, g = 5.4 \times 10^{14} \, M_{\text{solar}}$

Dark matter $> 10^{15} \, M_{\text{solar}}$

Vilial mass (8 keV, 1000 km/s)

Lubin et al. 1996, ApJ...460...10
Lecture Plan

September 30, 9:00-10:15

I. Basic processes in High energy astronomy
   I-1: Why X-ray astronomy?
   I-2: Emission mechanisms
   I-3: Energy sources

II. High energy phenomena
   II-1: Stellar X-ray emission

September 30, 10:45-12:00

II-2: Supernova remnants (SNR)
II-3: Neutron stars and blackholes
II-4: Active Galactic Nuclei
II-5: Cluster of galaxies and Cosmology
X-ray Telescope
Astro-H satellite

Hard X-ray Telescope
12 m FL
Extension

Nagoya Univ.

Soft X-ray telescope
6 m FL
fixed bench

Calorimeter
High resolution spectrometer

Hard X-ray Imagers

Soft γ-ray Detector

2014~
X-ray Telescope

X-ray missions in 21\textsuperscript{st} Century

Current missions
- Chandra
- Newton

ISAS/JAXA missions
- Suzaku
- SUMIT
- InFOCµS
- HERO

Small Missions
- GLAST
- Hard X-ray Astronomy
- ASTROSAT
- ATHENA
- International X-ray Observatory
References

- [http://www.u.phys.nagoya-u.ac.jp/r_e/r_e3_4.html](http://www.u.phys.nagoya-u.ac.jp/r_e/r_e3_4.html)
- Ishihara et al., 2010, Origin of the dust emission from Tycho's SNR: A&A...521L..61I
- Tanaka et al, 1995, Gravitationally redshifted emission implying an accretion disc and massive black hole in the active galaxy MCG-6-30-15, Natur., 375, 659
- Ezawa et al., 1997, Discovery of a Large-Scale Abundance Gradient in the Cluster of Galaxies AWM 7 with ASCA: ApJ...490L..33E