Violent Universe Explored by Japanese X-ray Satellites

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Asia Academic Seminar

CPS 8th International School of Planetary Science

September 30, 2011 at Awaji

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 Msolar H → He

M < 3 Msolar H → He → C/O----------------------White dwarf

3 Msolar < M < 8 Msolar C → O → Ne → Mg

Ty I SN ----------------------Scatter all mass

8 Msolar < M < 30 Msolar Si → Fe/Ni

Ty II SN ----------------------Neutron stars

30 Msolar < M -----------------------------------**Black holes**

(2) Evolution of Supernovae

Gravitational ε of collapsed star --> Neutrino (99%)

--> Kinetic E (1 %)

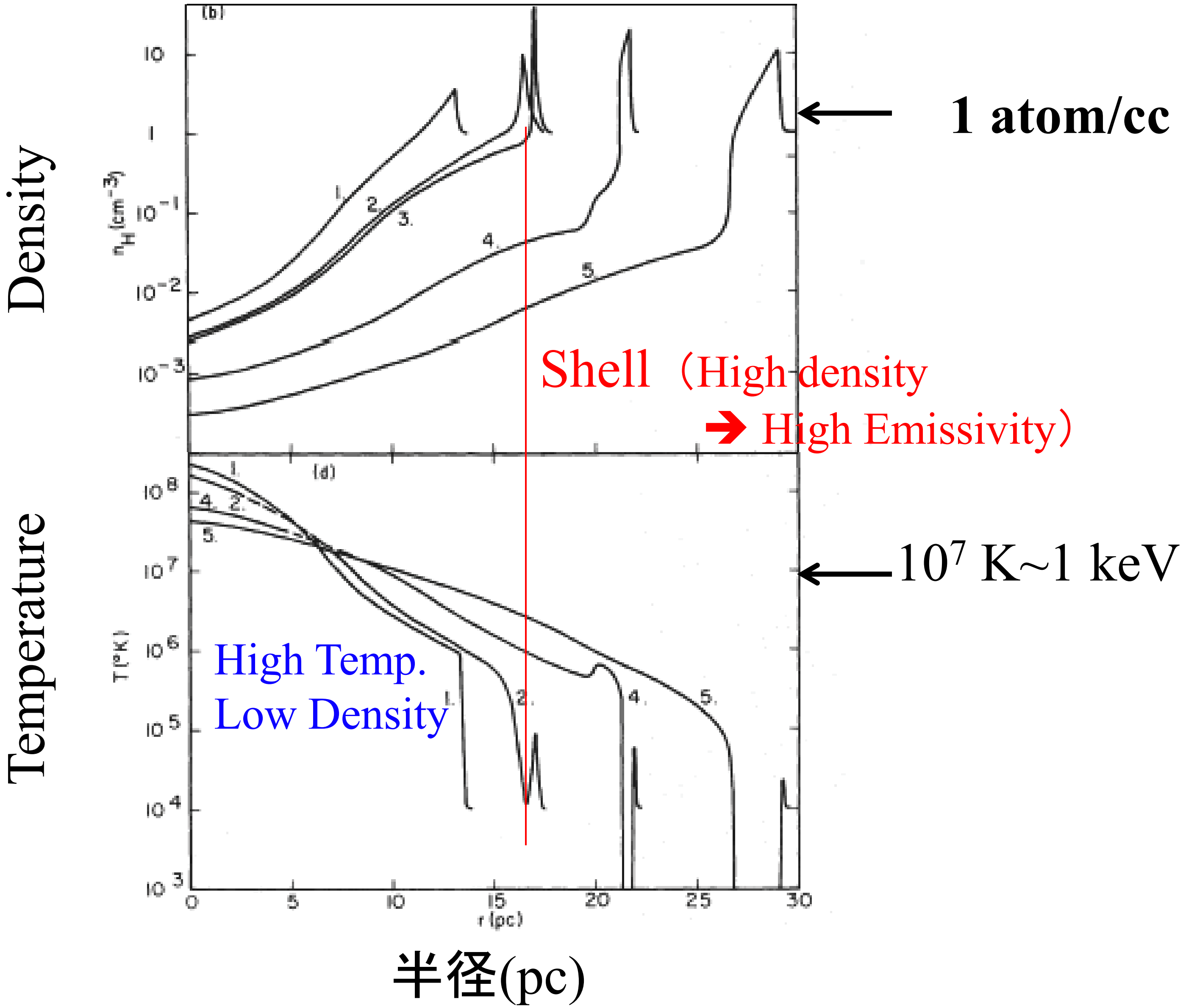
Shock wave enhances density, reduces speed

Kinetic ε ---> Thermal ε

Sweep-up surrounding gas --> Shell

High density --> **X-rays** ($\propto T^{1/2} n^2$)

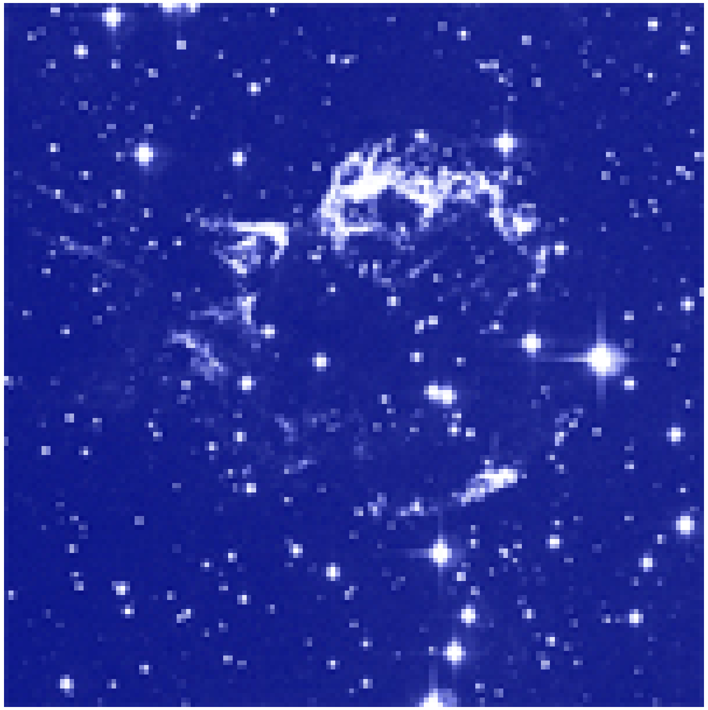
Effective cooling by X-rays when $T \sim 10^6$ K



Density
Temperature
(b)
(d)
n_H (cm^{-3})
T (°K)
r (pc)
1 atom/cc
10^7 K~1 keV
Shell（High density
➔ High Emissivity）
High Temp.
Low Density
半径(pc)

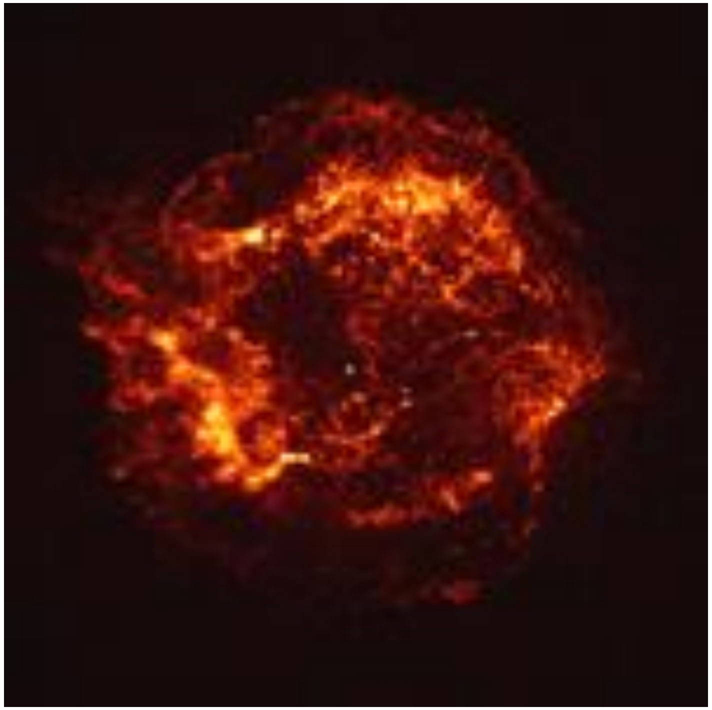
Cas-A (1680 AD)

Visible



10 light year

X-rays



5×10^7 K

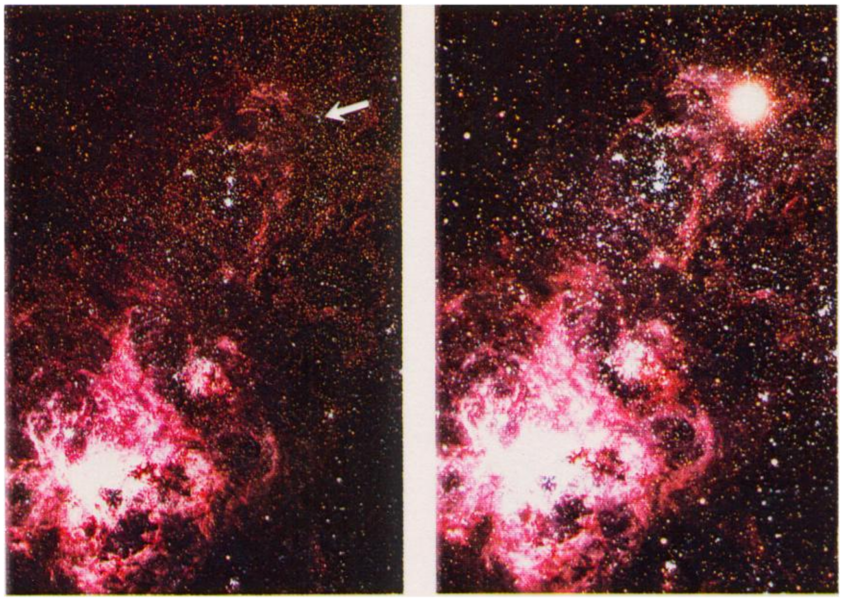
Photograph courtesy NASA/ESA/Hubble Heritage Team

Record of Supernovae

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

SN1987A

Anglo-Austrian Observatory

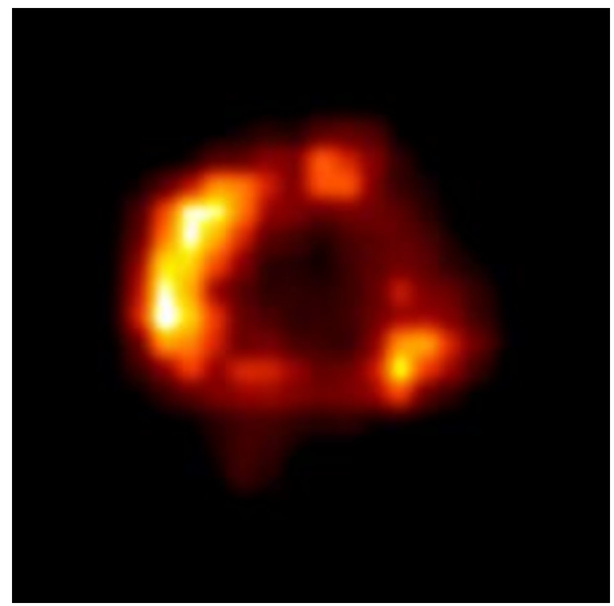


Before After

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

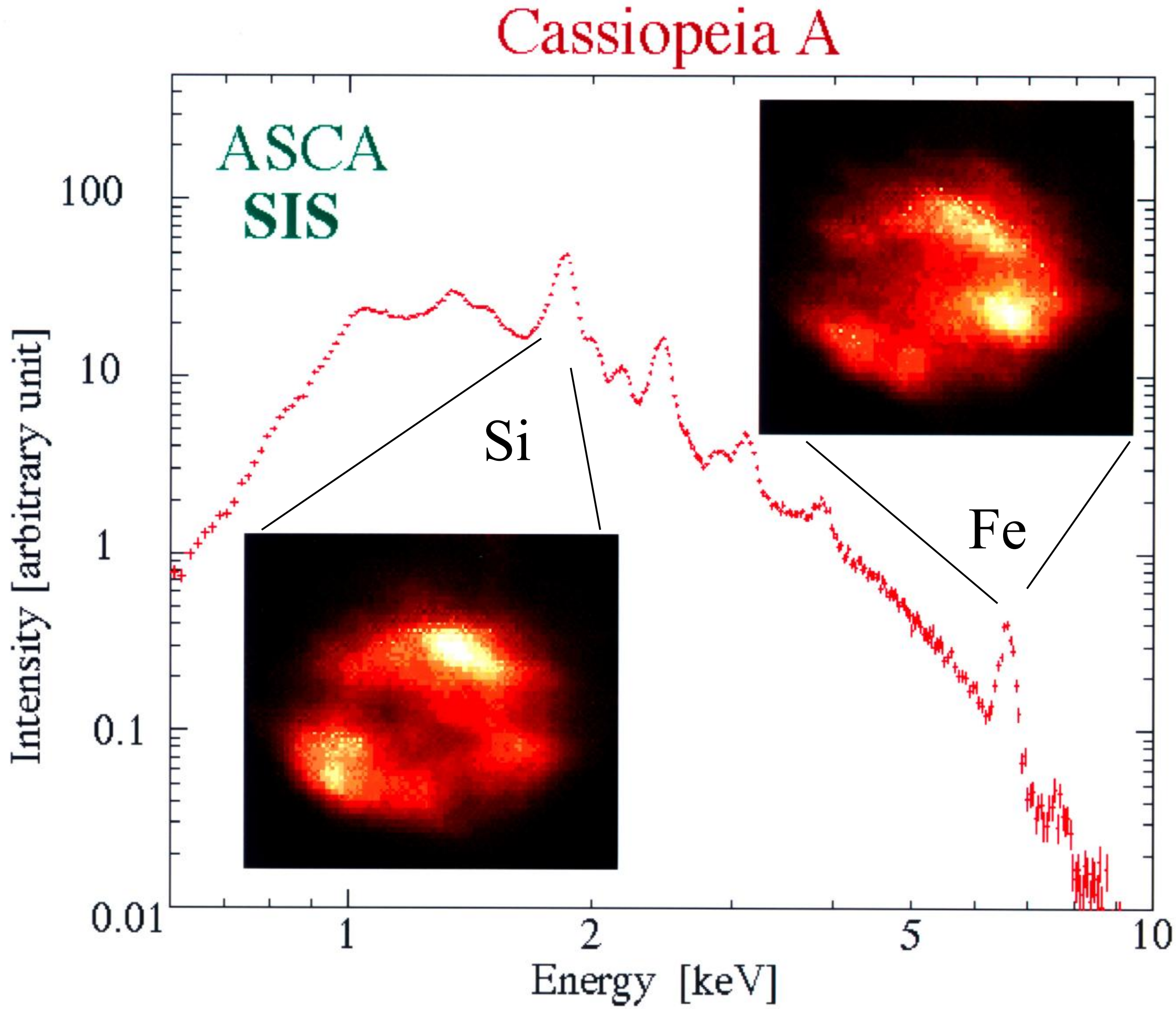
Cas A X-ray Spectra

Thermal Brems
+
Emission lines

Different dist. of elements

↓

Non-uniform explosion



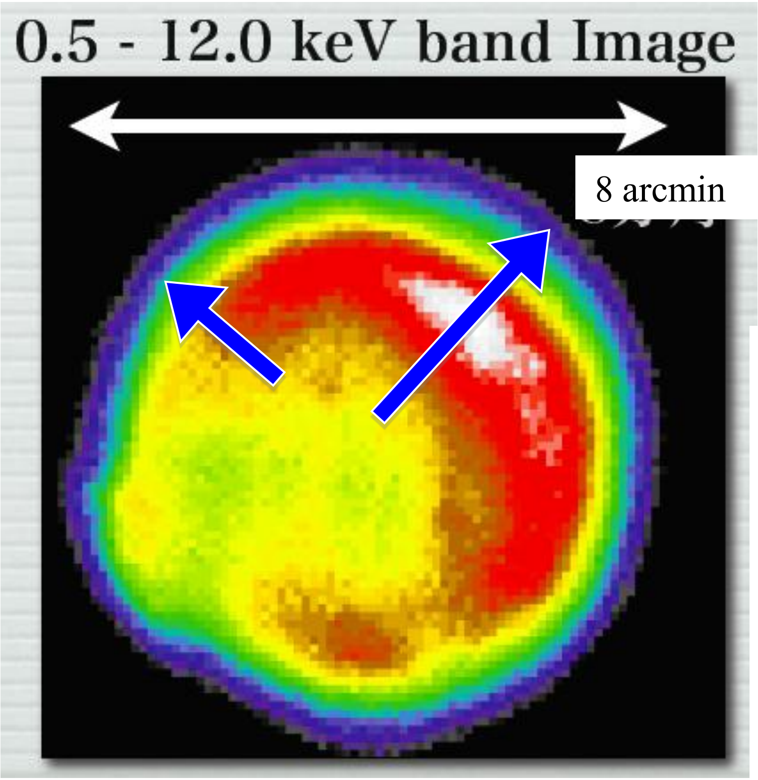
http://www.u.phys.nagoya-u.ac.jp/r_e/r_e3_4.html

Multi-waveband observations

X-ray observation by Suzaku

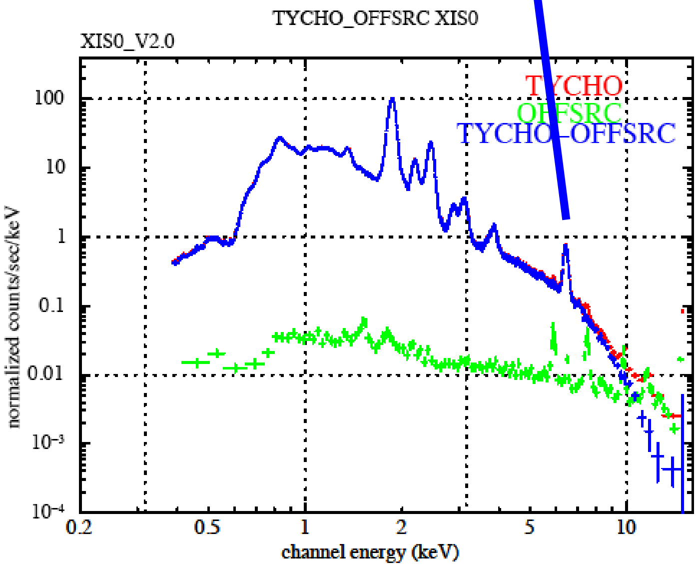
Left:
Slow
0.15"/year
Expansion
(Chandra)

Tycho SNR with Suzaku



Right:
Fast
0.45"/year
Expansion
(Chandra)

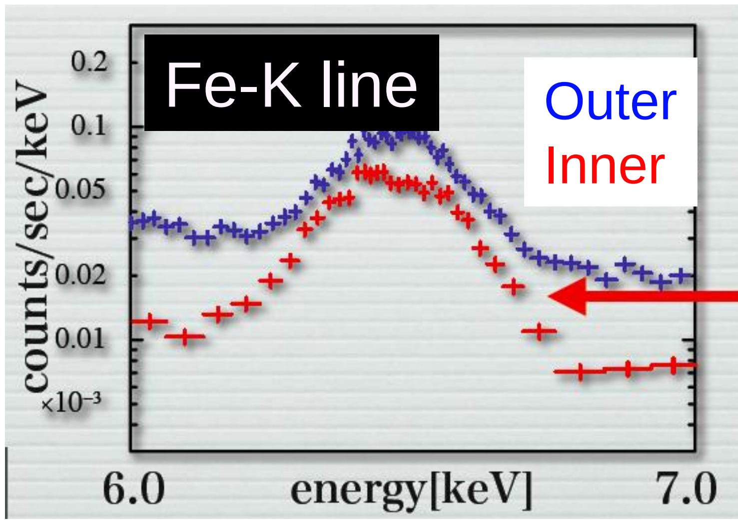
Fe rich shell

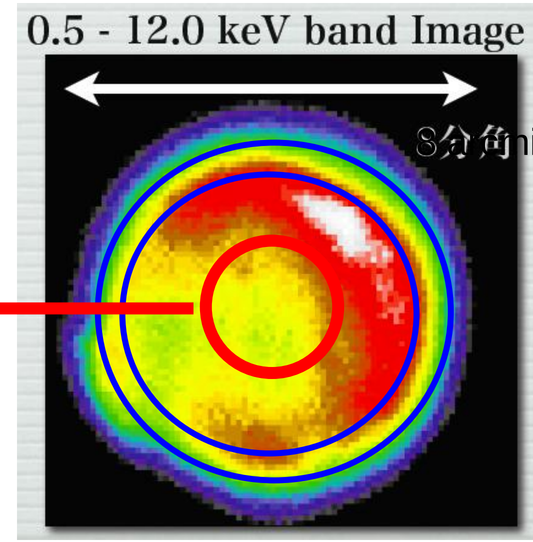


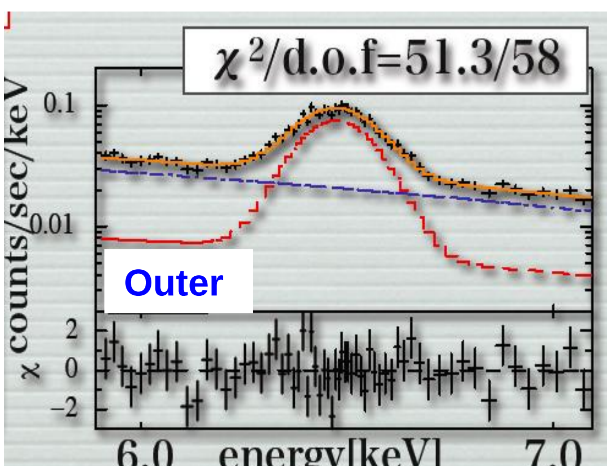
Tycho SNR

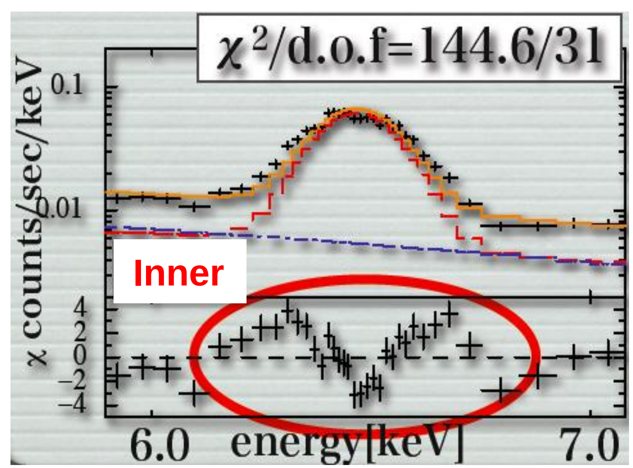
Discovered by Tycho Brahe in 1572

Tycho SNR with Suzaku









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

Furuzawa et al.

Tycho SNR

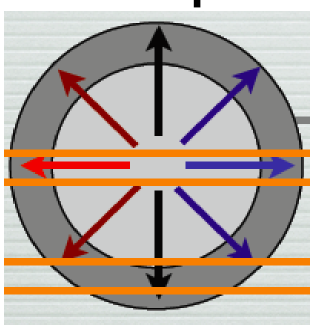
Expanding shell at 2000-3000km/s

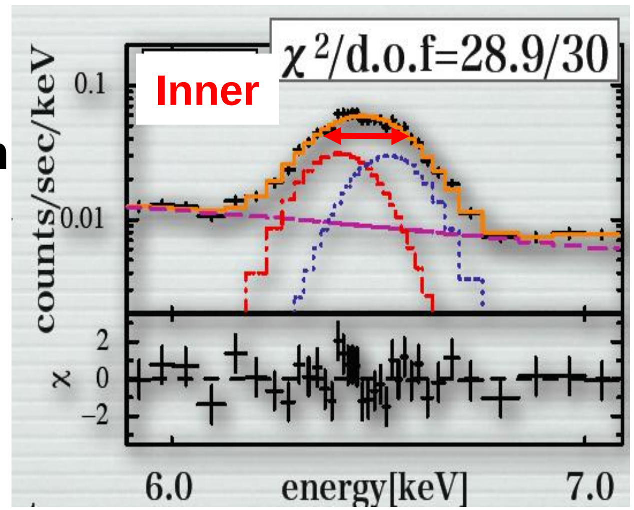
(3) Dynamics of SNR

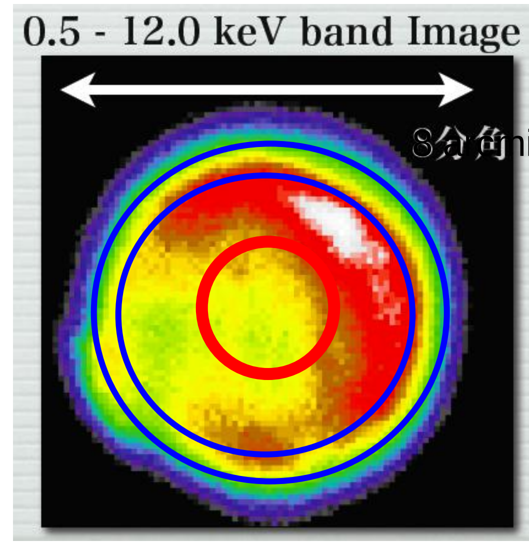
Tycho SNR with Suzaku

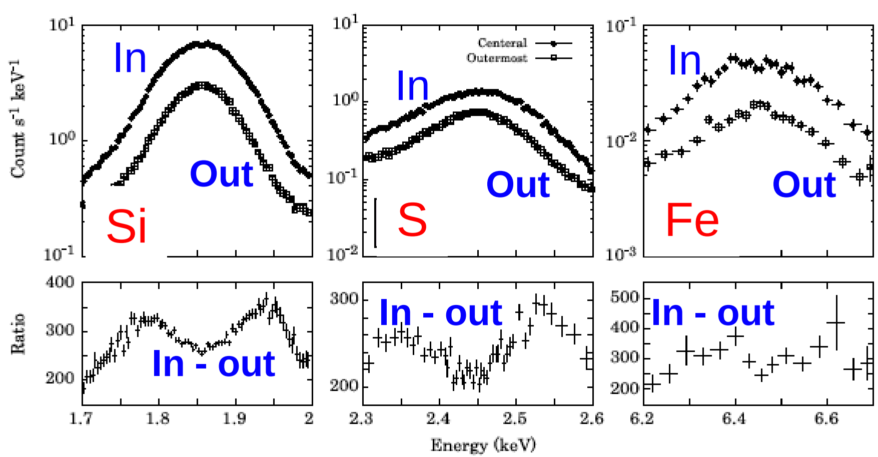
ΔV_{Fe} ~ 3000 km/s

Radial expansion







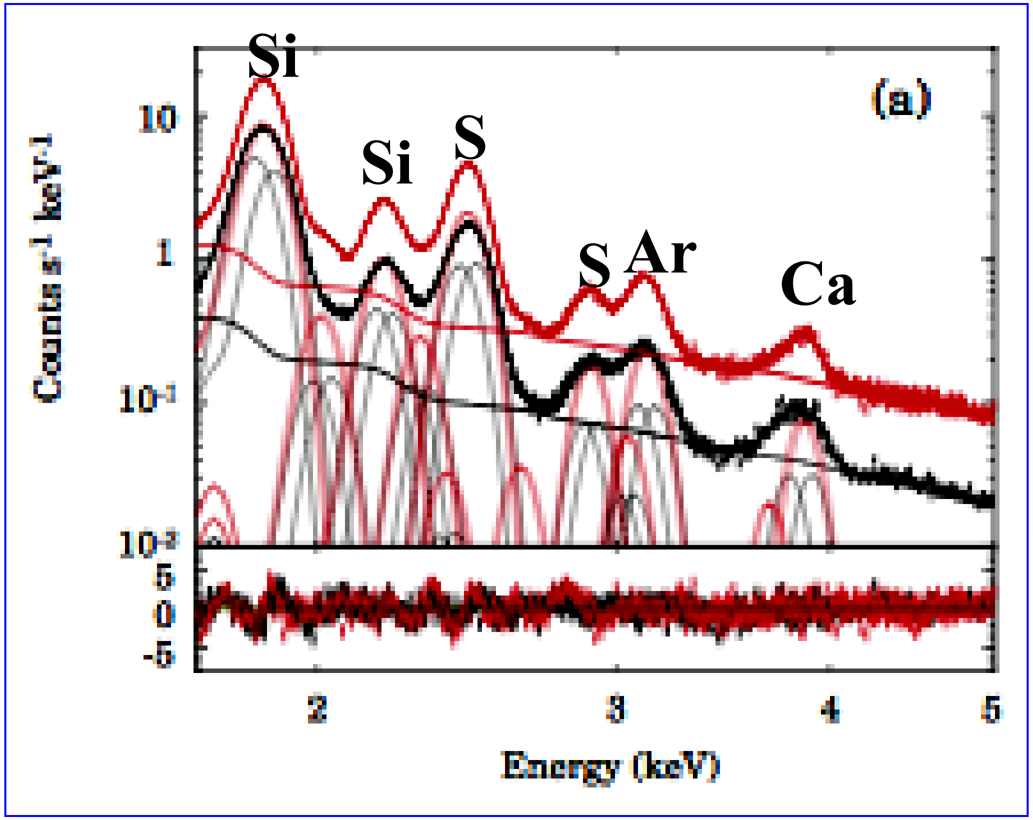


Furuzawa et al.

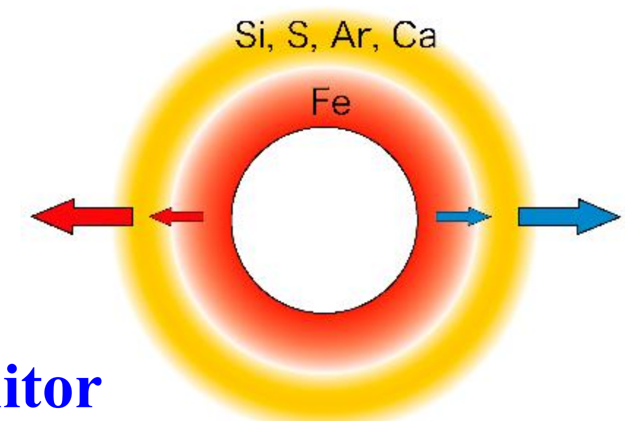
Furuzawa,2009:ApJ...693L..61F

Tycho SNR

Expanding shell at 2000-3000km/s



	$v_{\perp 1}$ (km s^{-1})	v_{exp} (km s^{-1})
Si Heα	3540 ± 20	4730^{+30}_{-20}
Si Heβ	3480^{+90}_{-100}	4700 ± 100
S Heα	3490 ± 40	4660 ± 50
Ar Heα	3600 ± 100	4800 ± 200
Fe Kα	2900 ± 200	4000 ± 300



Extend internal structure of progenitor

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

Furuzawa et al.

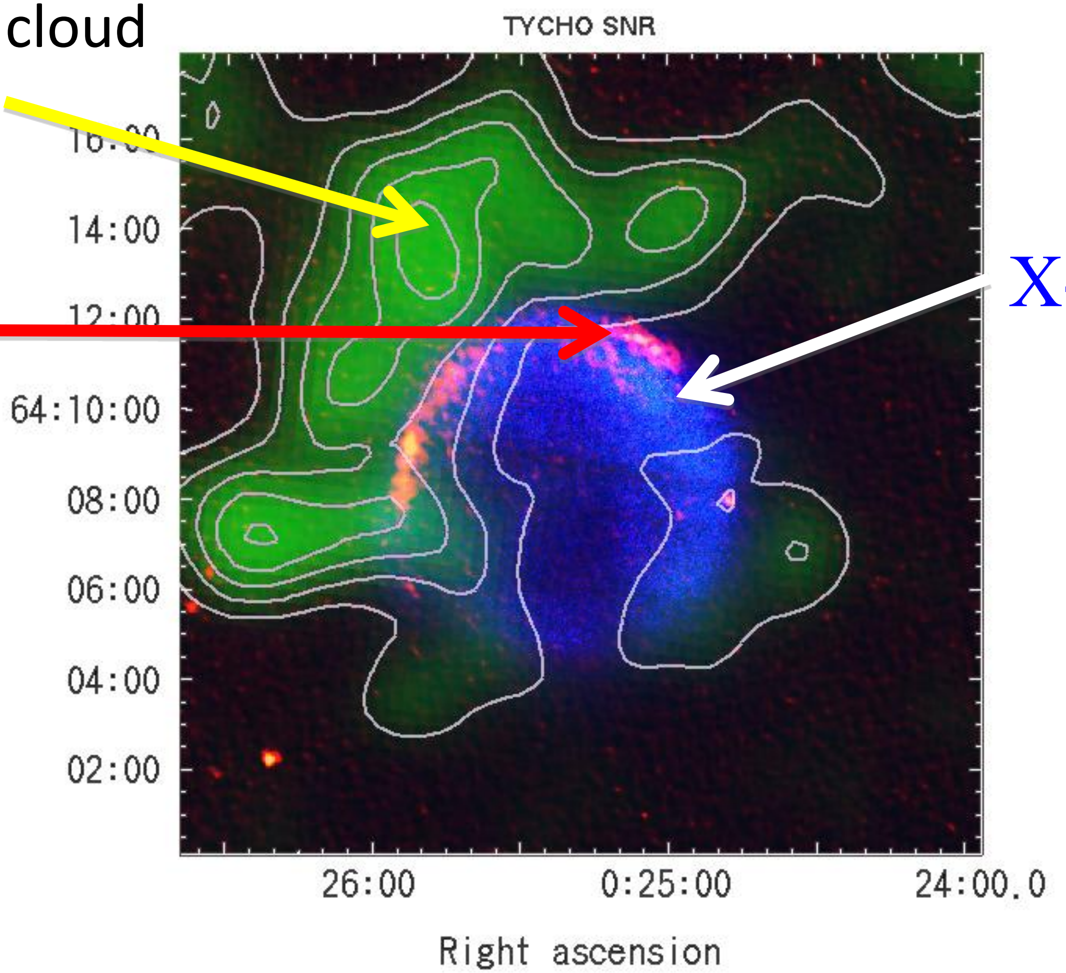
Tycho SNR

Multi-waveband observations

Molecular cloud
Radio(CO)

Infrared
(Akari)
Dust

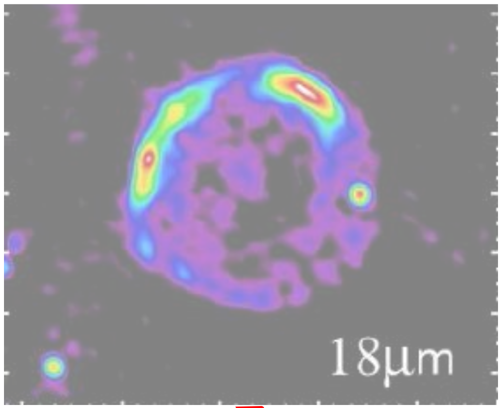
X-ray (SUZAKU)
Plasma

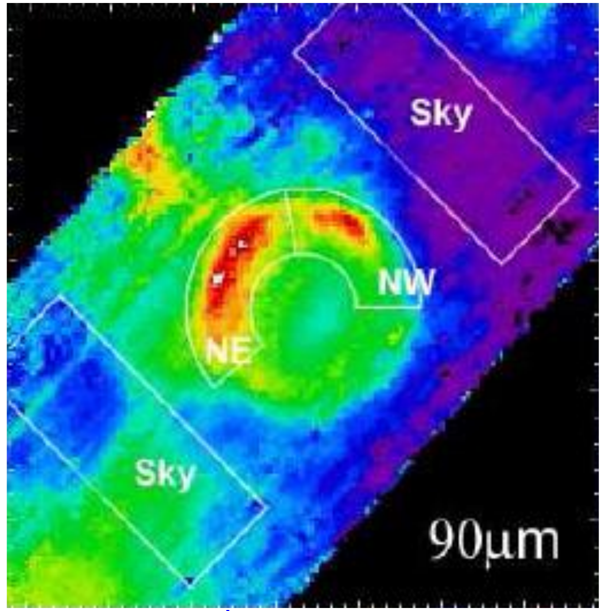


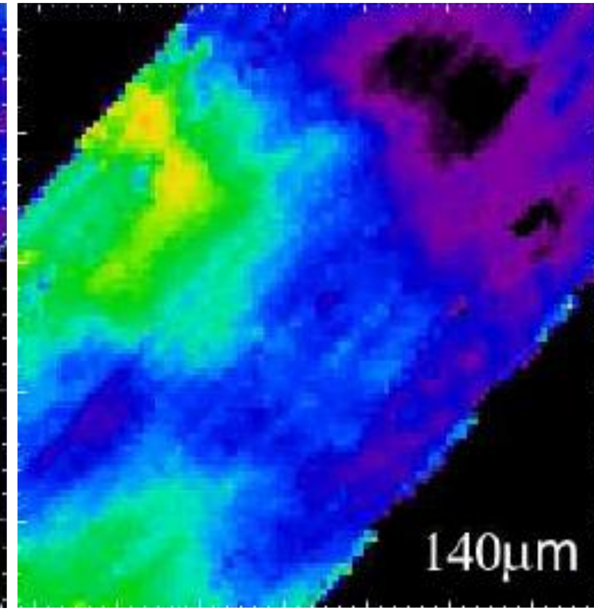
By Ishihara

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

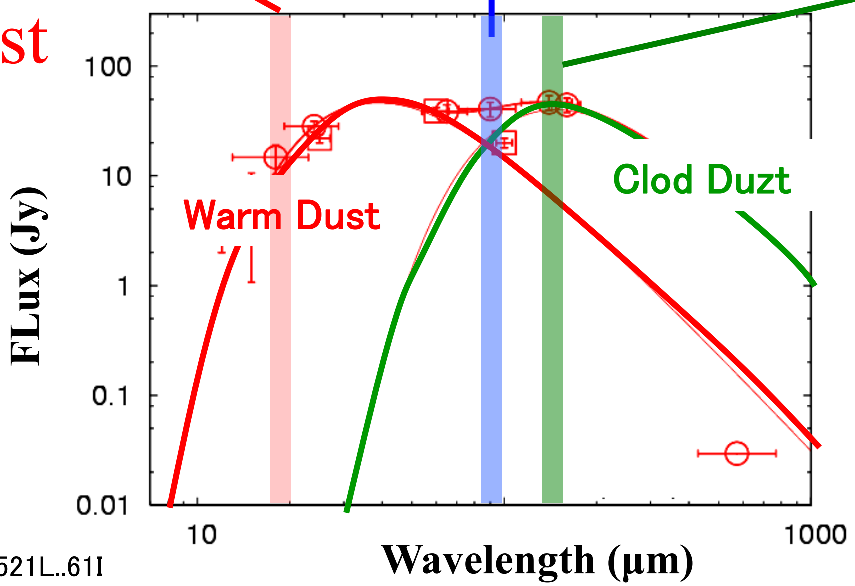
Infrared images by Akari







Right:
Warm Dust
(~100K)

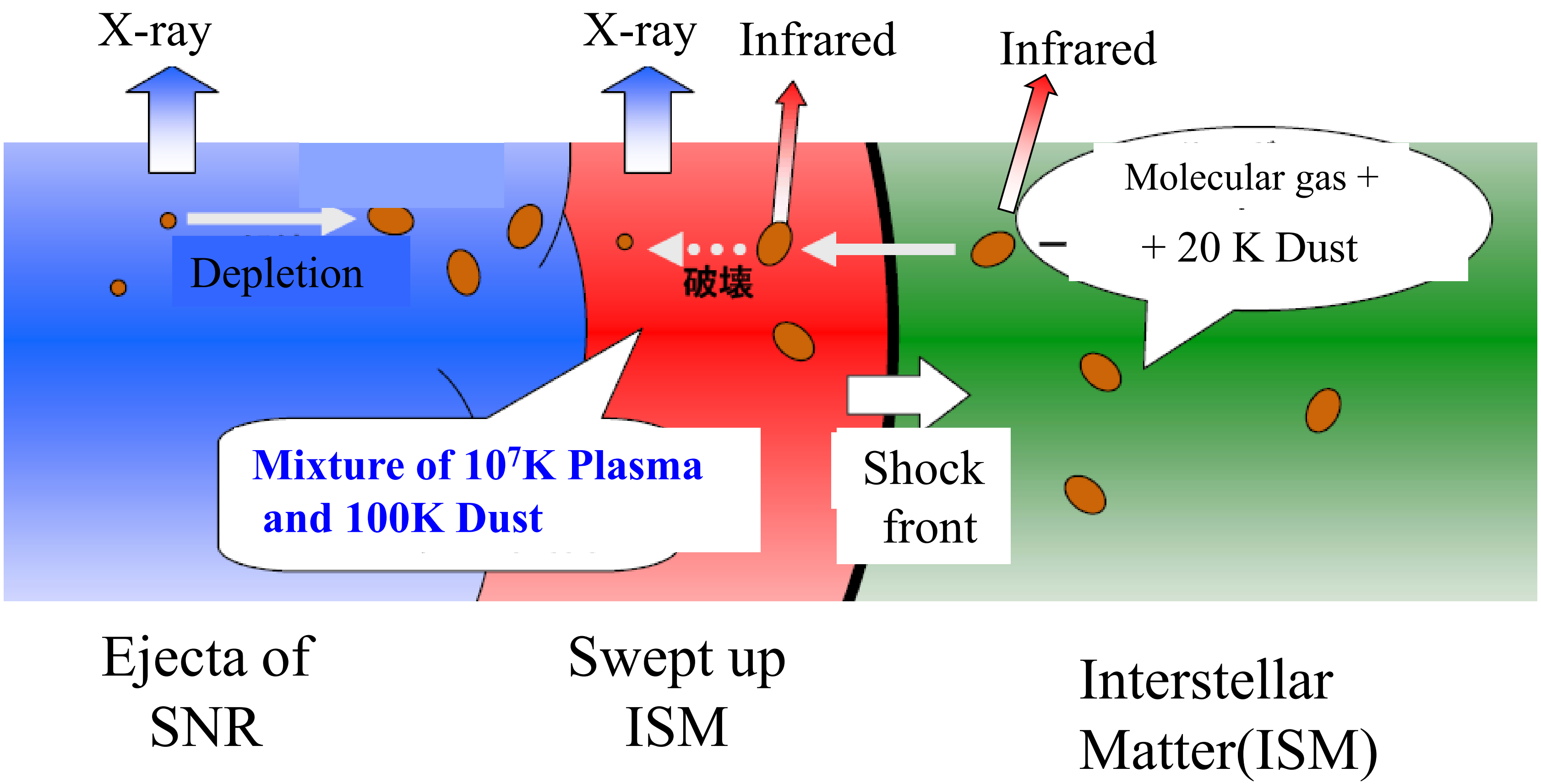


Left:
Clod Dust
(~20K)

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

Multi-waveband observations

Schematic View of the shell region

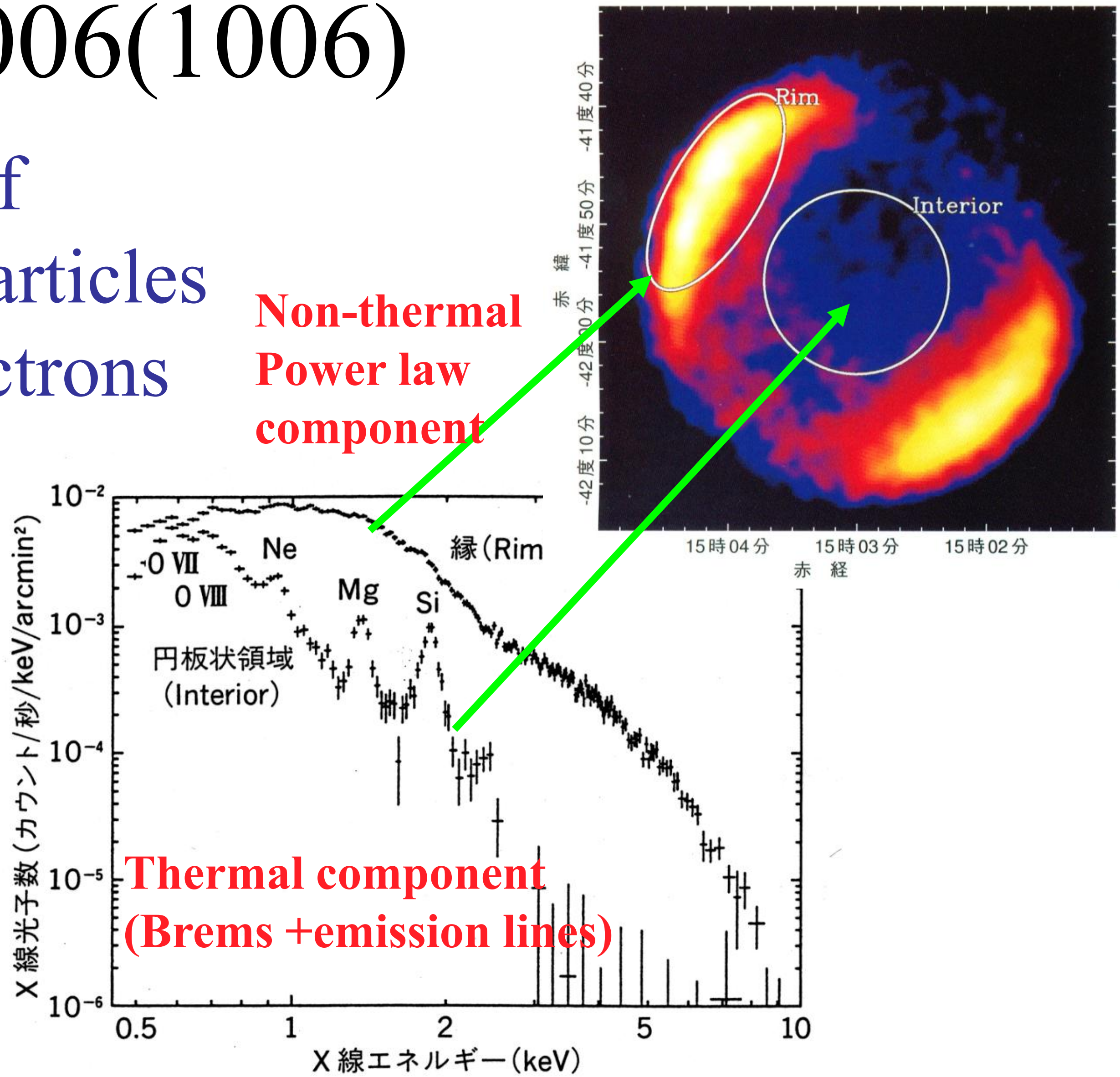


SN1006(1006)

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

↓

Production of
Cosmic rays
(protons)?



(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. X-ray binaries

(1) Mass Accretion from Companion Stars

Figure 12. Artist's conception of Cyg X–1. Illustration of L. Cohen.

II-4 : Active Galactic Nuclei(AGN)

Active galactic nuclei (AGN)

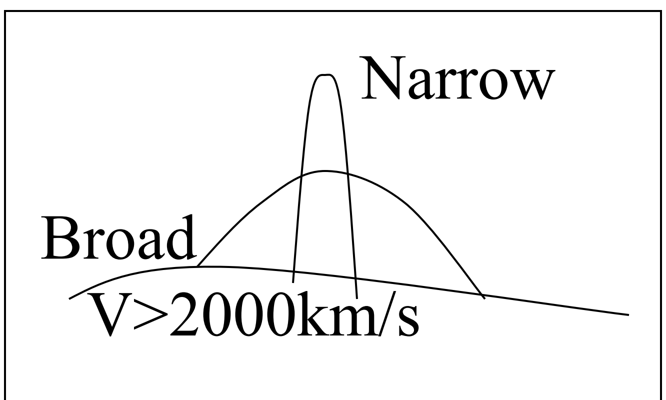
10^{11}

Bright nucleus > total radiation of stars

Emission lines instead of absorption lines

Ionization source!

Stellar emission



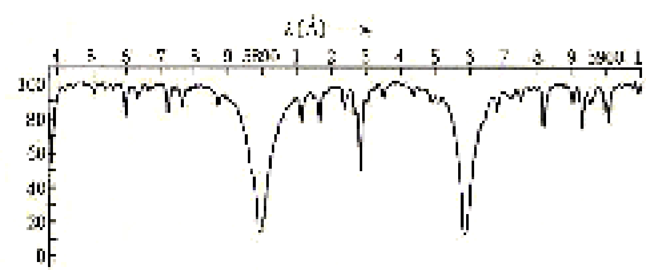


図 18.1 マイクロフォトメーター記録図
太陽スペクトル中のNa D線

Optical images of galaxies

AGN

Eliptical galaxies

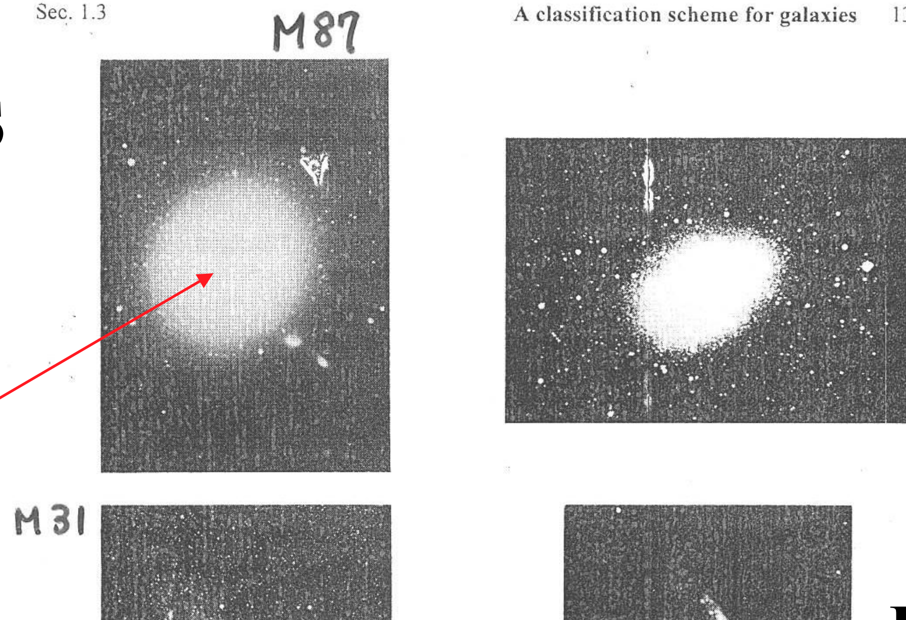


Fig. 1.2. Examples of galaxy types. Left to right, top: M87 (E0), NGC147 (dwarf E5); centre, M31 (Sb), NGC1365 (SBb–note the prominent bar); bottom, NGC2997 (Sc) and NGC4321 [M100] (Sc). The photographs are from the Anglo Australian Telescope apart from NGC147 and M31 which are from the Hale Observatories.

Hubble Space Telescope

Mass estimation of nuclei

Nuclear gas motion

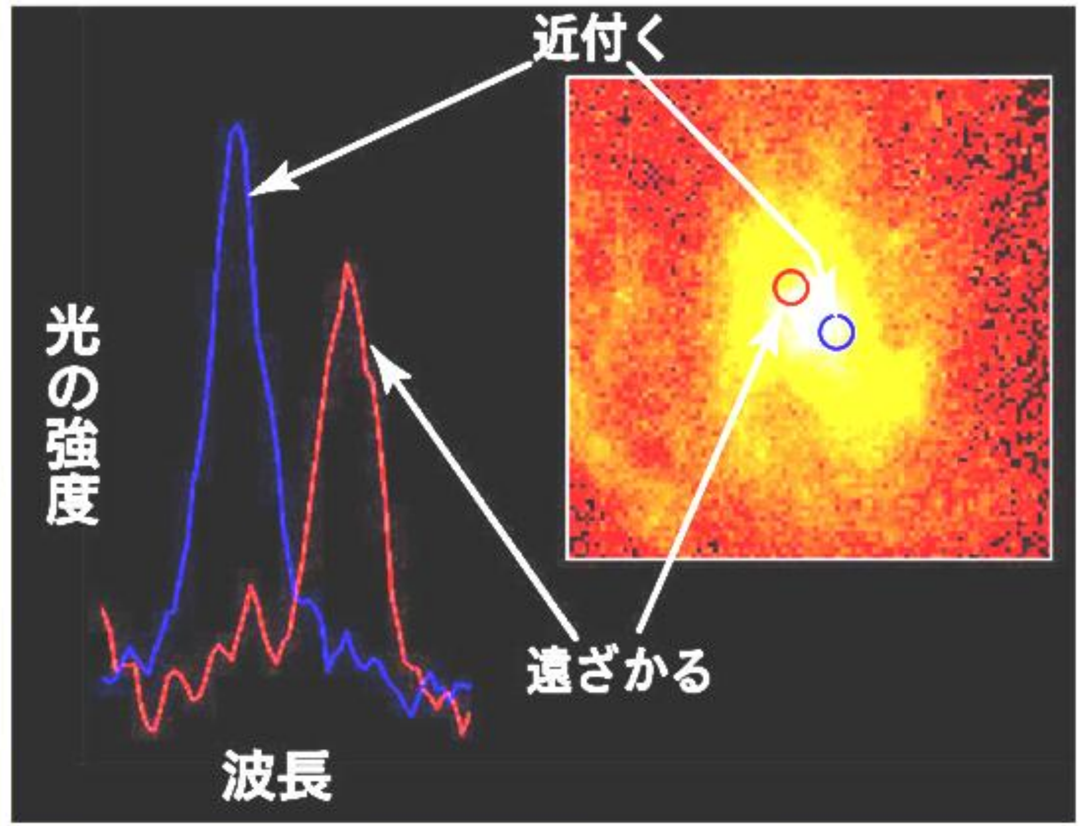
$v^2/r = GM/r^2$

v=500km/s、

Radius: r=18pc

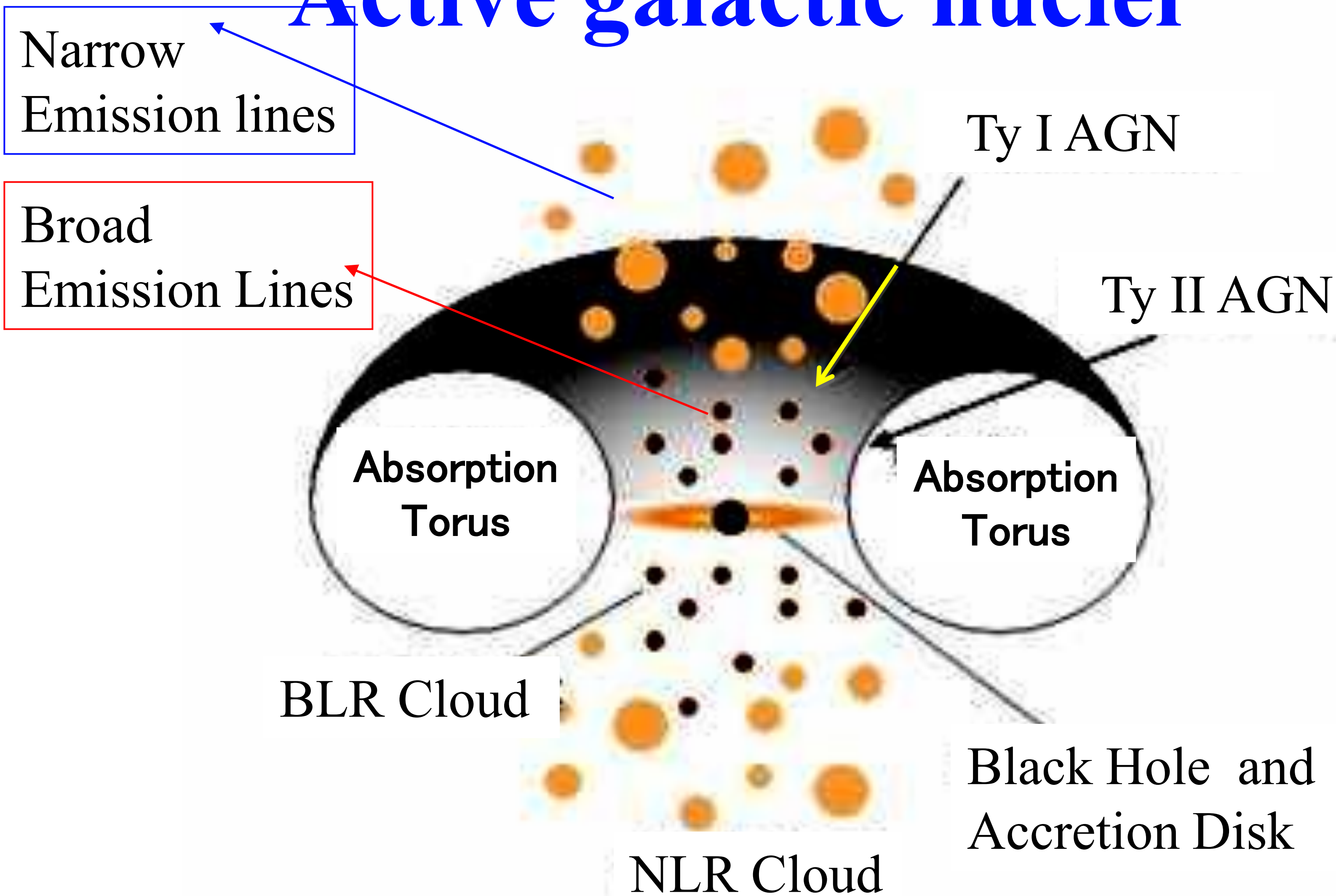
M＞ 10^9 Msolar

Blue shift <-- Approaching



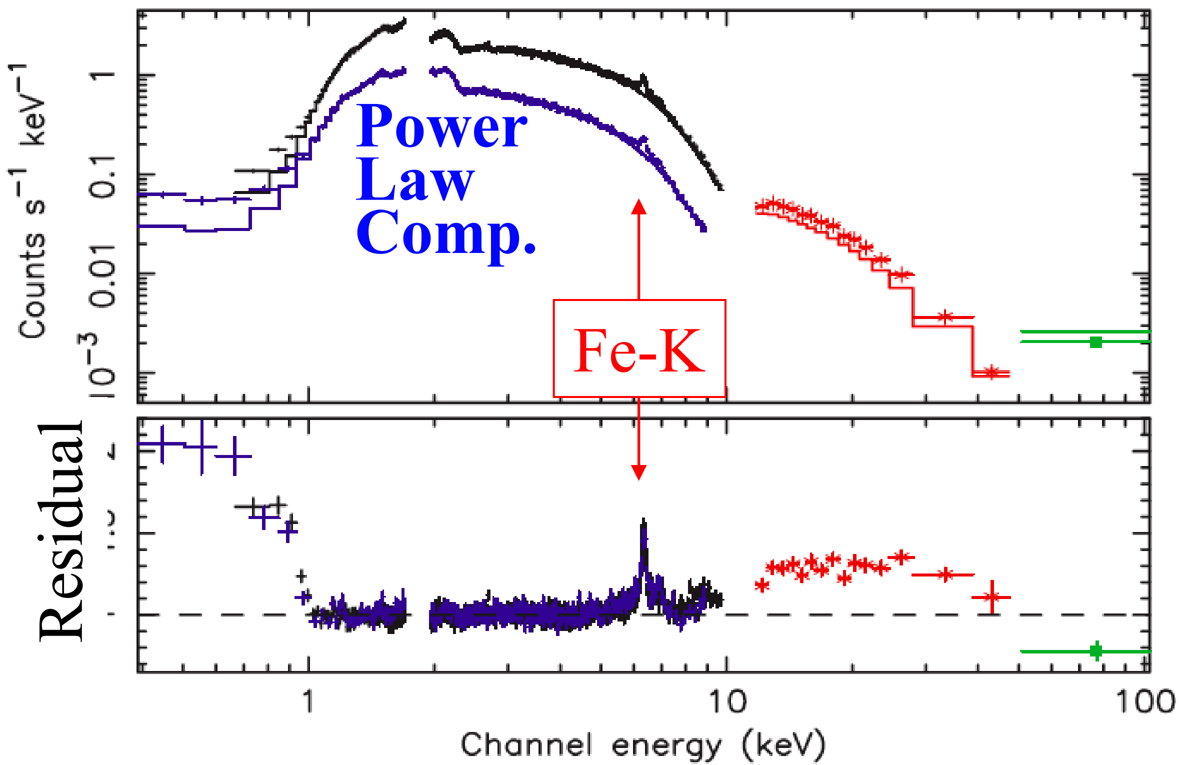
Red shift <-- Reseeding

Active galactic nuclei

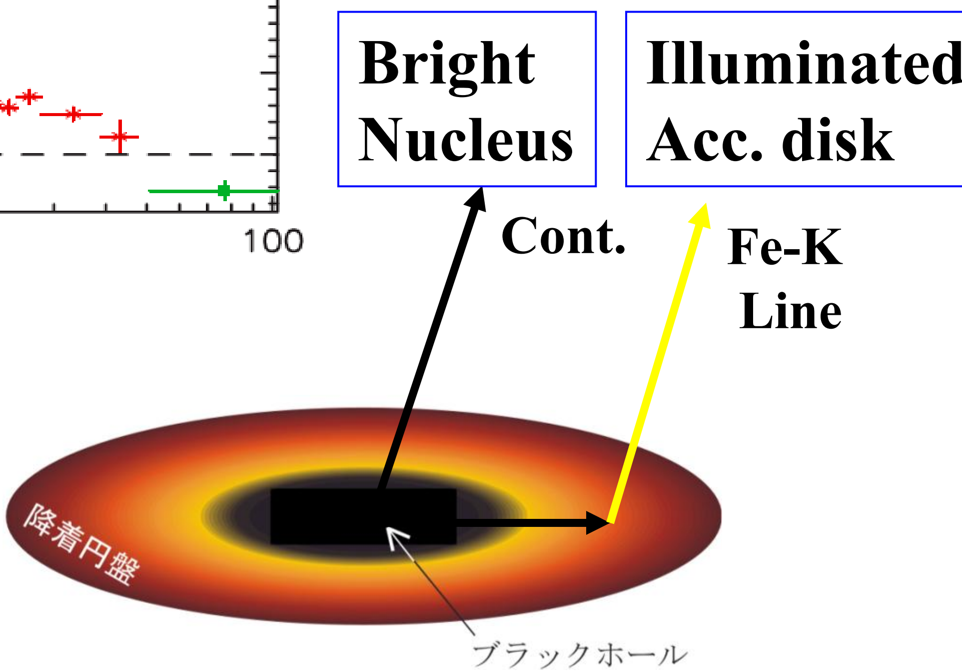


http://www.astro.isas.ac.jp/xjapan/asca/3/agn/

X-rays from AGN



Strong X-ray Source

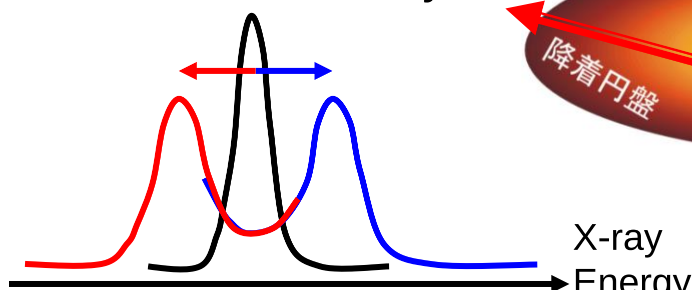


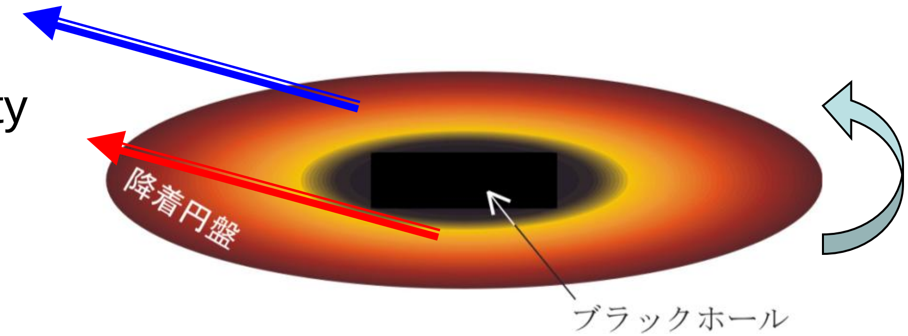
James N, Reeves et al, 2007, Publ. Astron. Soc.Japan, 59, 301

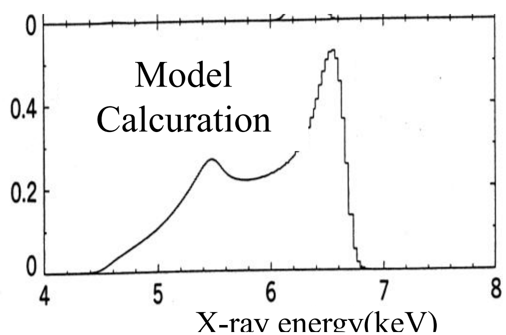
Fabian et al, 1989, Mon. Not. R. astr. Soc, 238, 729

Doppler Effect

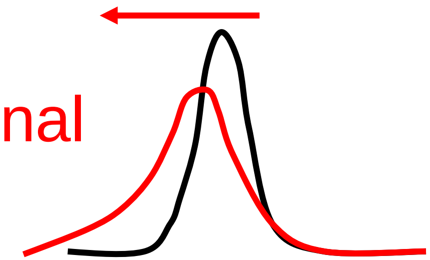
Relativistic Orbital Velocity



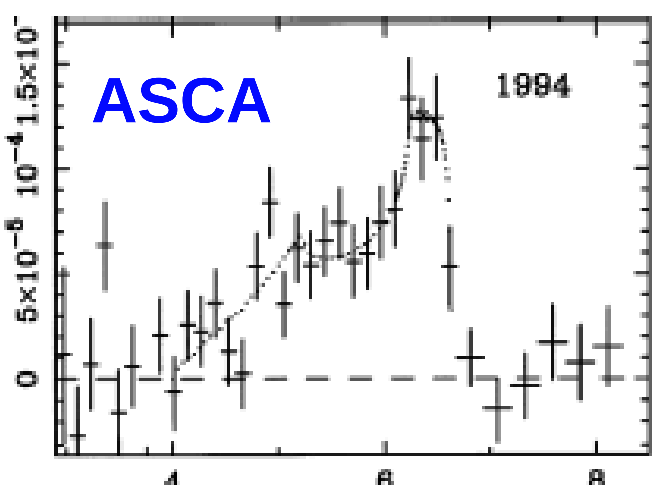


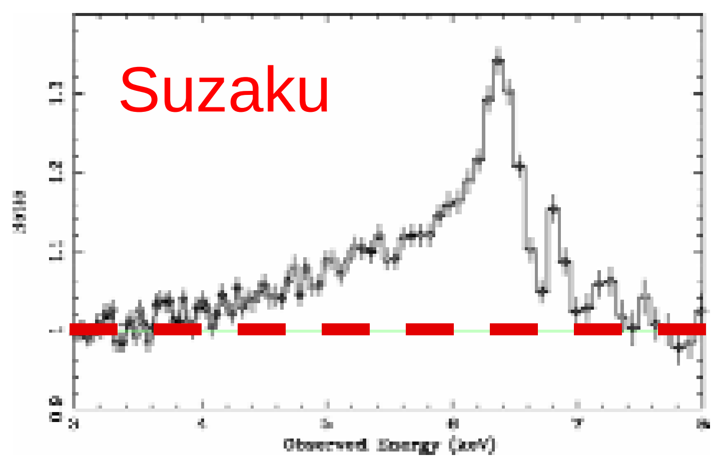


Gravitational Red Shift



MCG-6-30-15 $v = (1 - r_g/r)^{1/2}\, v_{em}$





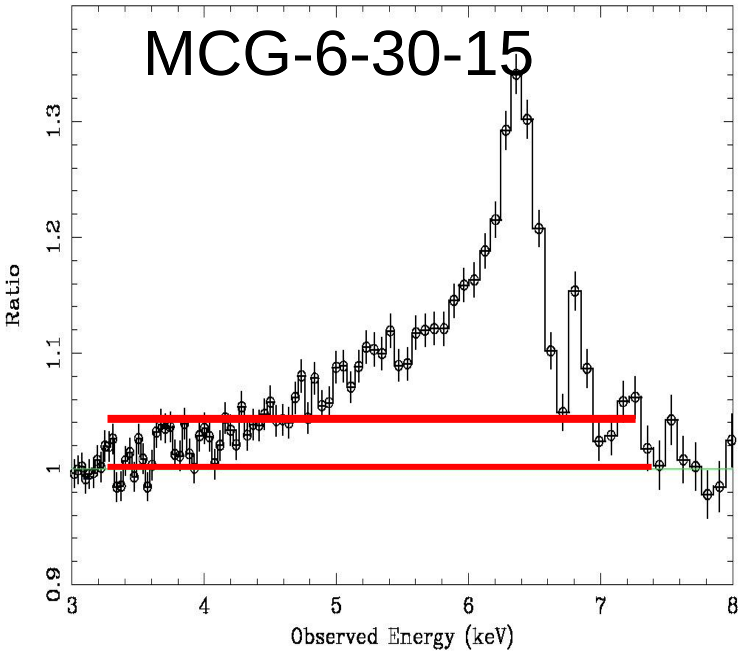
Tanaka,Y et al, 1995, Natur., 375, 659

Miniutti, H et al, 2007, Progress of Theoretical Physics Supplement, 169, 260

How small the inner most radius could be?

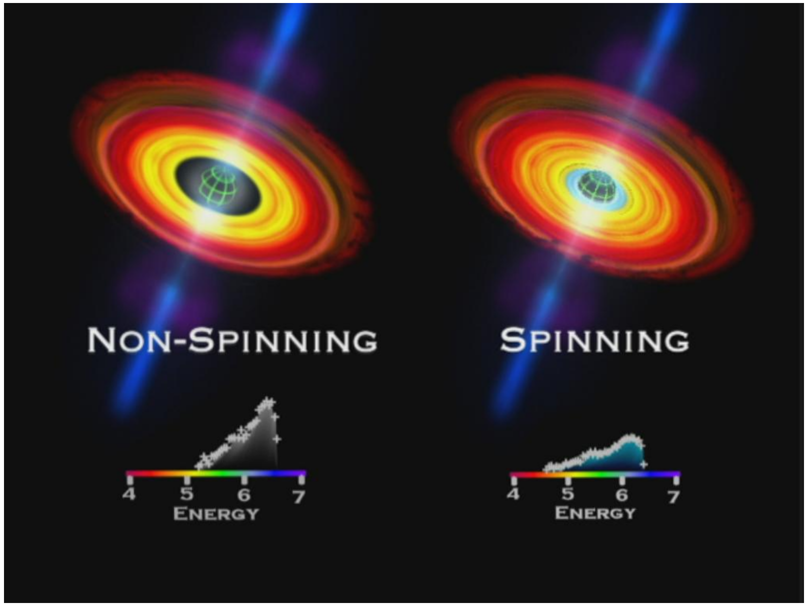
How large red shift could be?

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



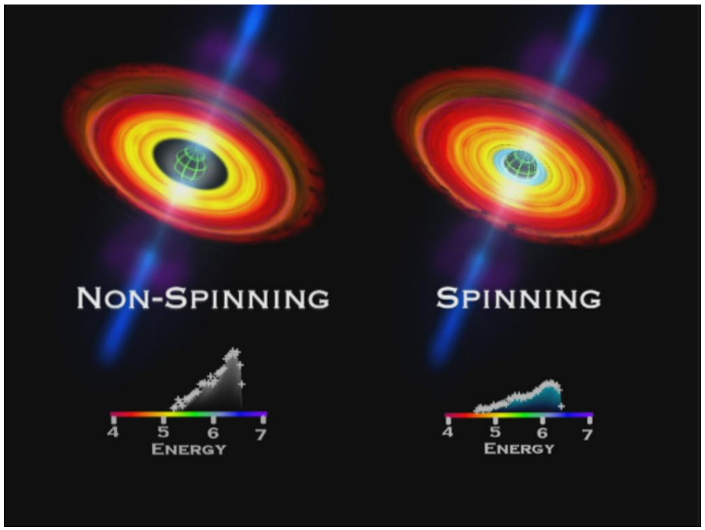
Continuum level affects the red shift

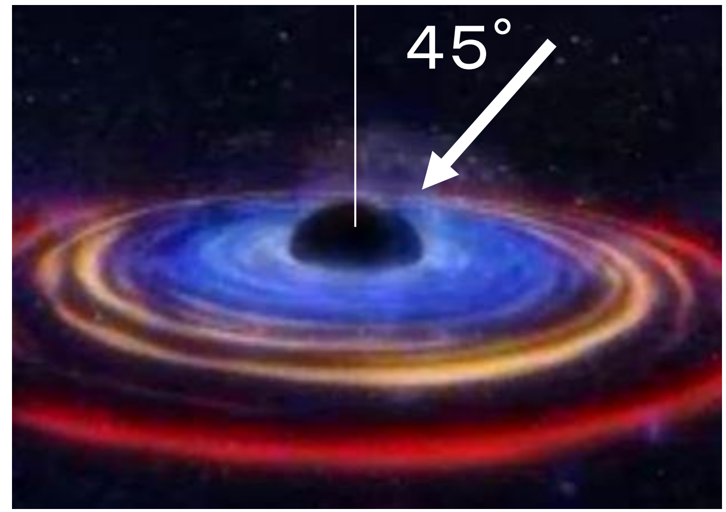
ESA

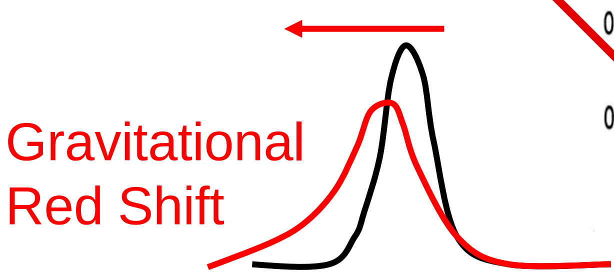


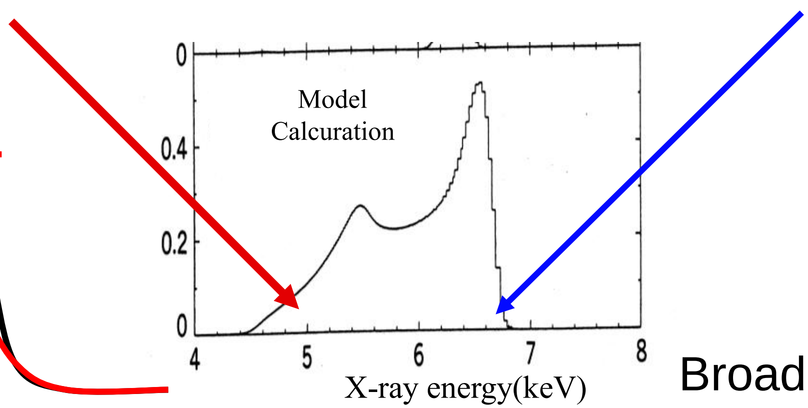
Red shift to 5keV is sure--> but Rotating Kerr BH is not clear yet

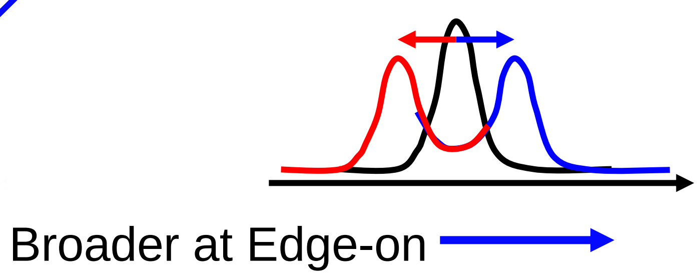
Structure of the BH vicinity Determined by Suzaku



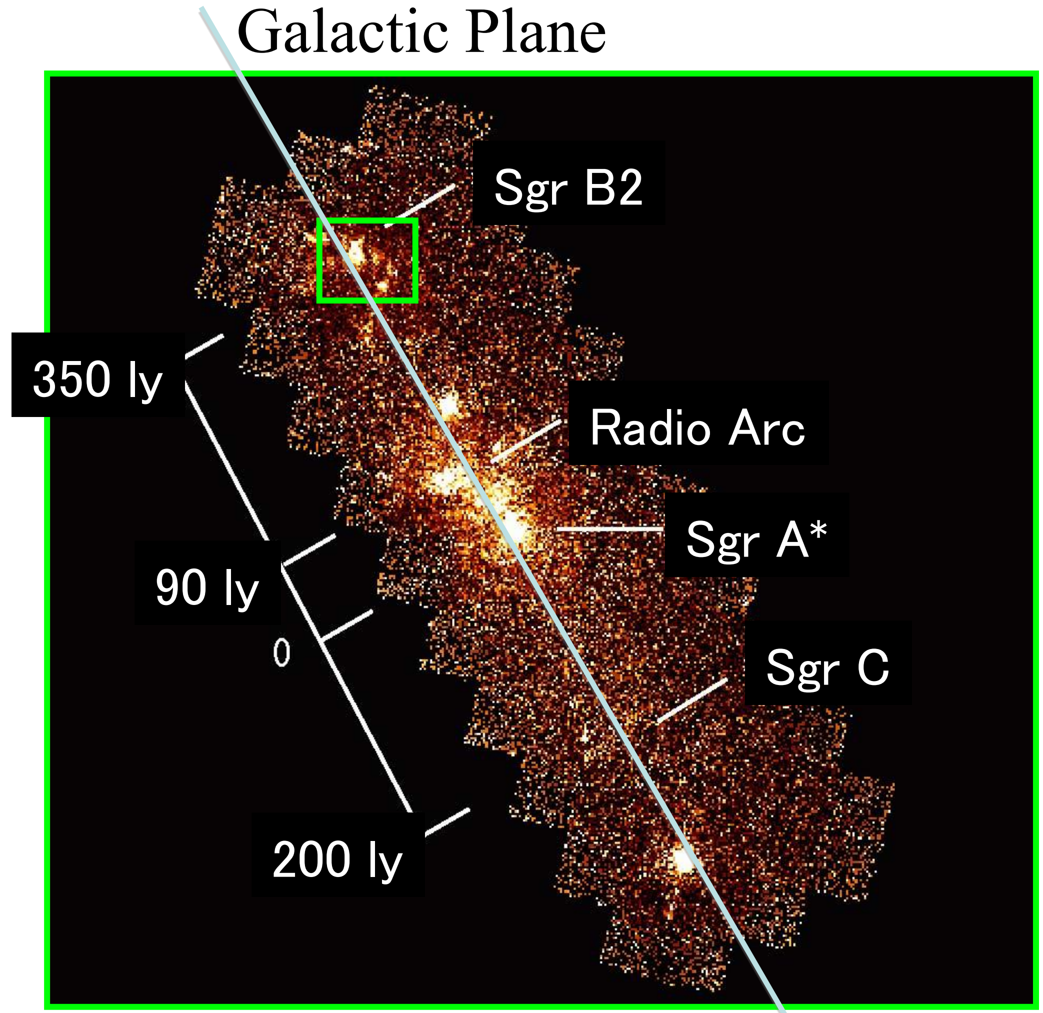






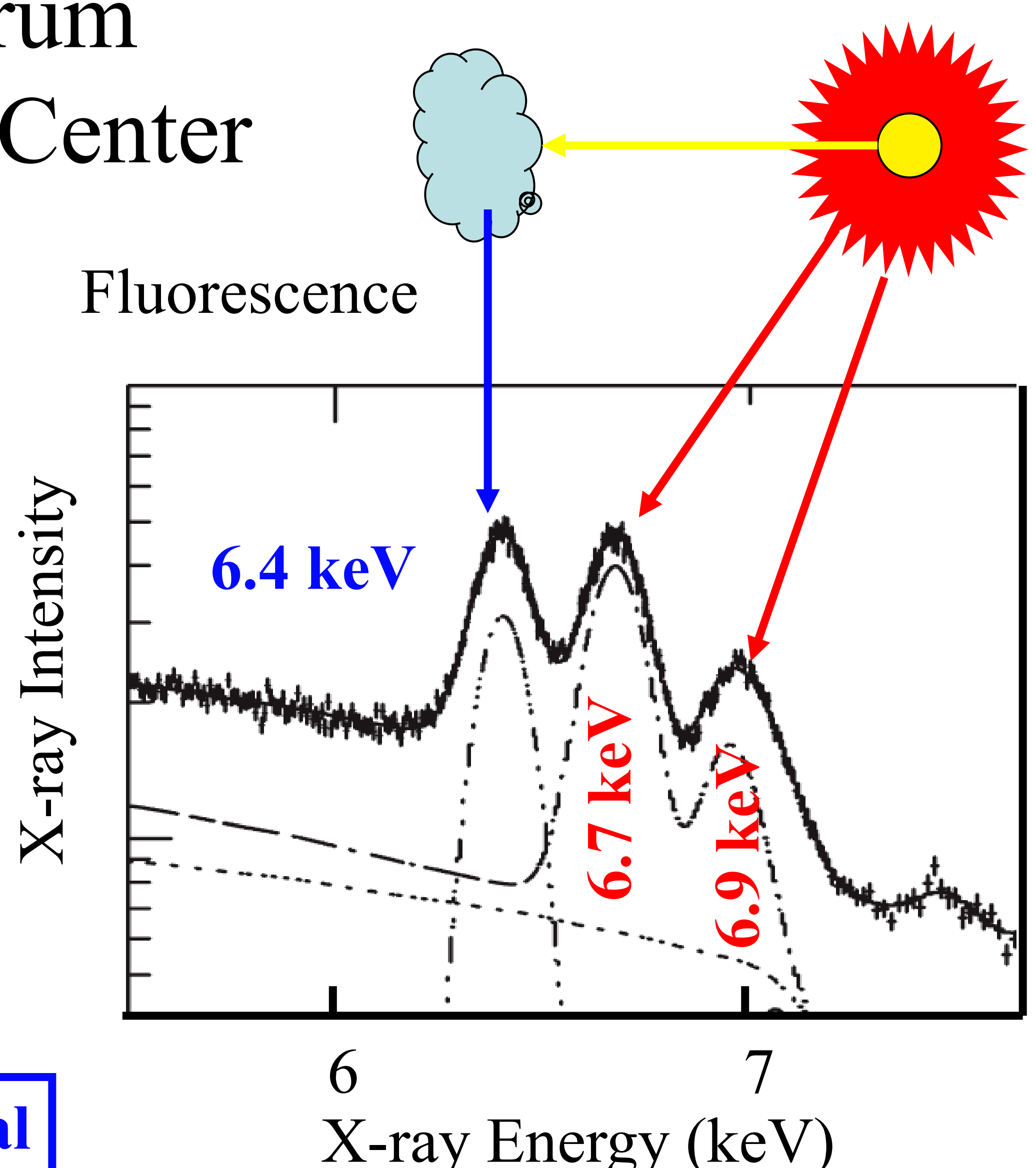


Galactic Center Region



Chandra X-ray Image of GC

X-ray Spectrum of the Galactic Center

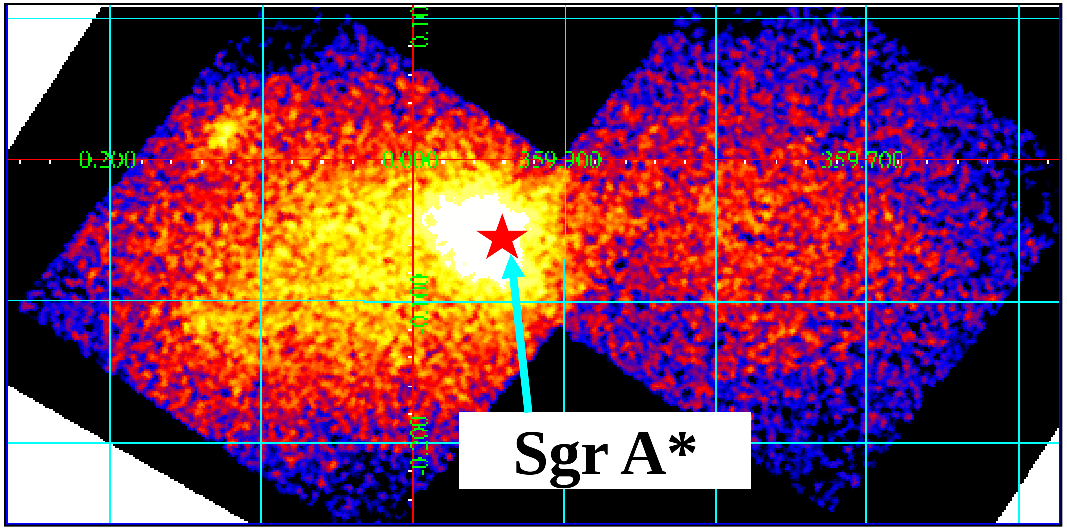


Emission lines of Fe at different ionization state

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

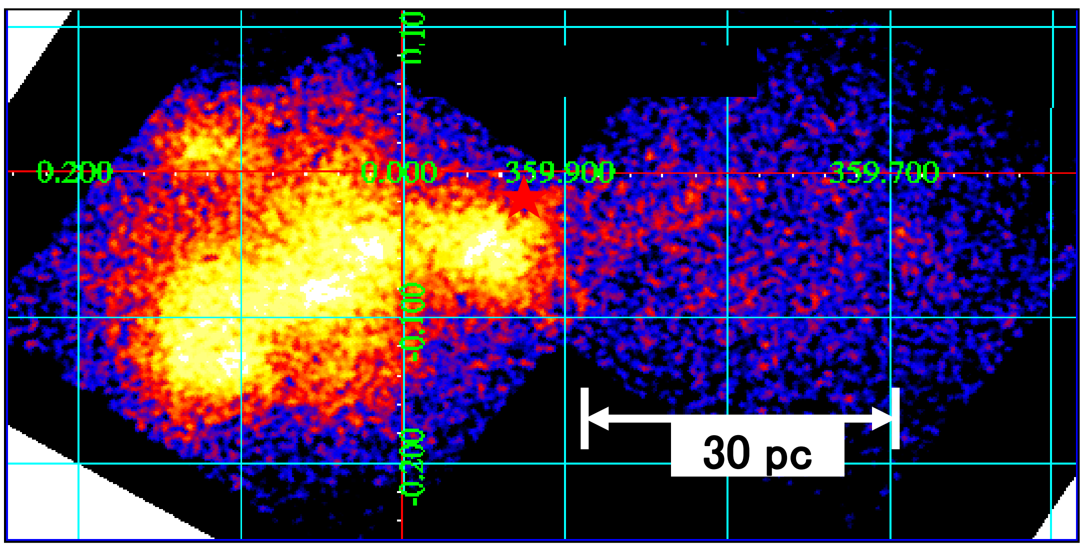
CCD Spectral Resolution

Koyama et al., 2007, Publ. Astron. Soc. Japan, 59, 245



6.7 keV
Line mapping

Hot Plasma



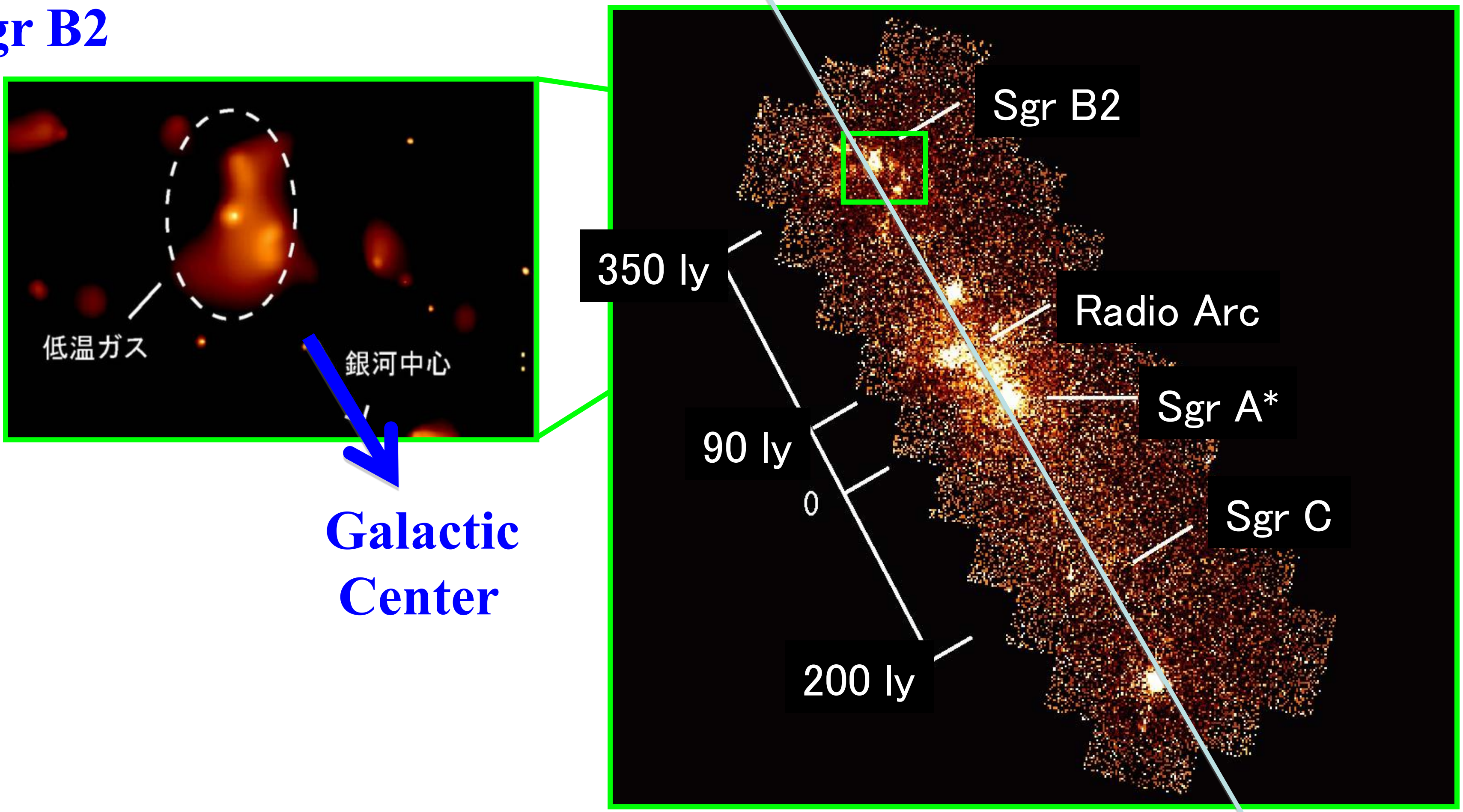
6.4 keV
Line Mapping

Reflection Nebulae

Galactic Center Region

Molecular Cloud
Sgr B2

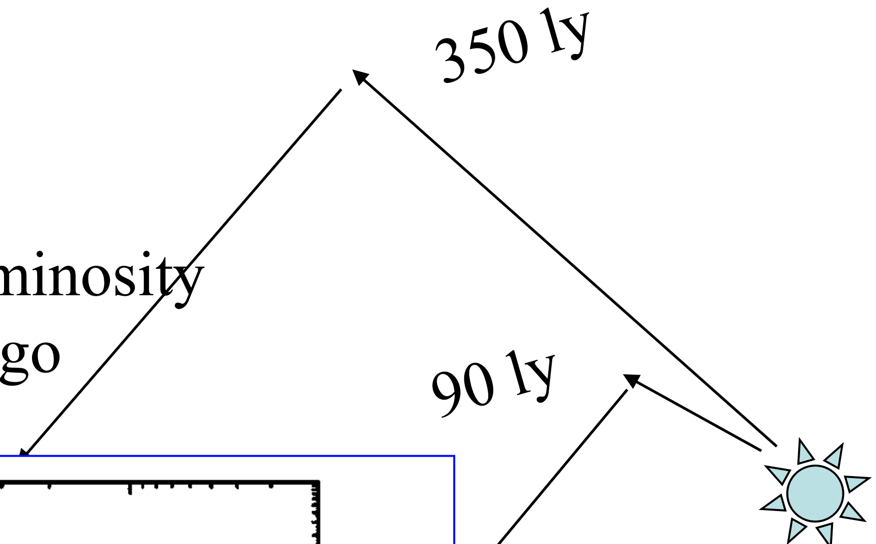
Galactic Plane



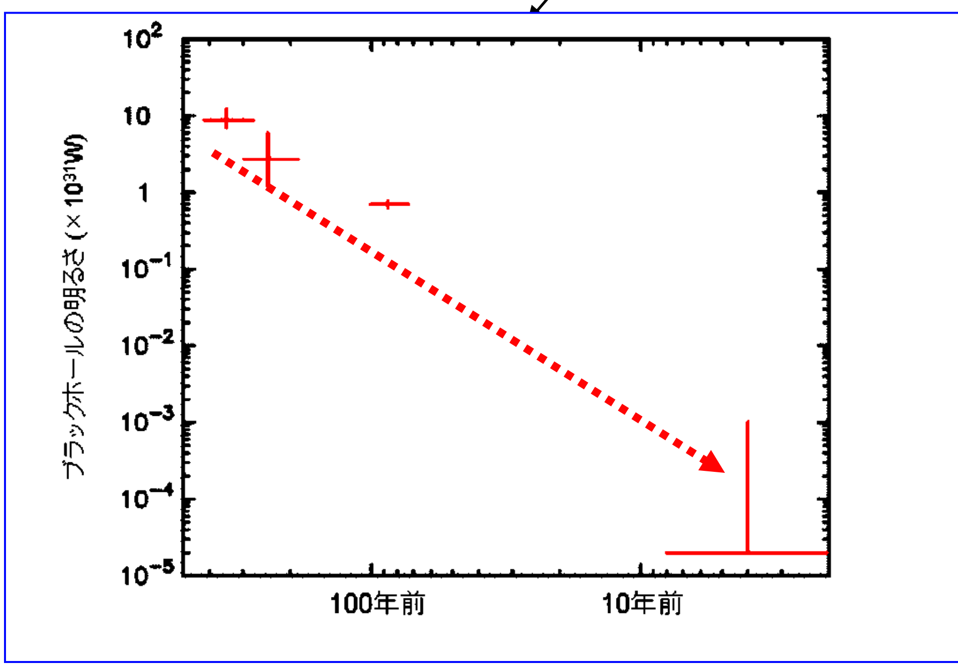
Galactic Center

Chandra X-ray Image of GC

Bright X-ray Source at Galactic Center?



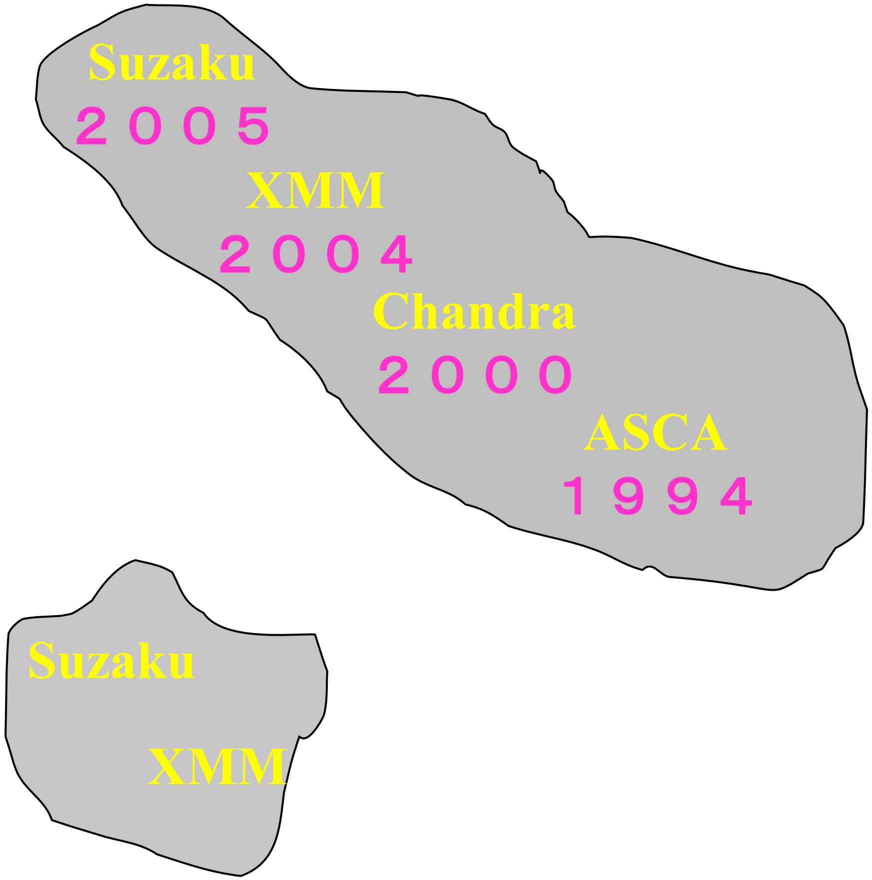
Central Luminosity
350 years ago

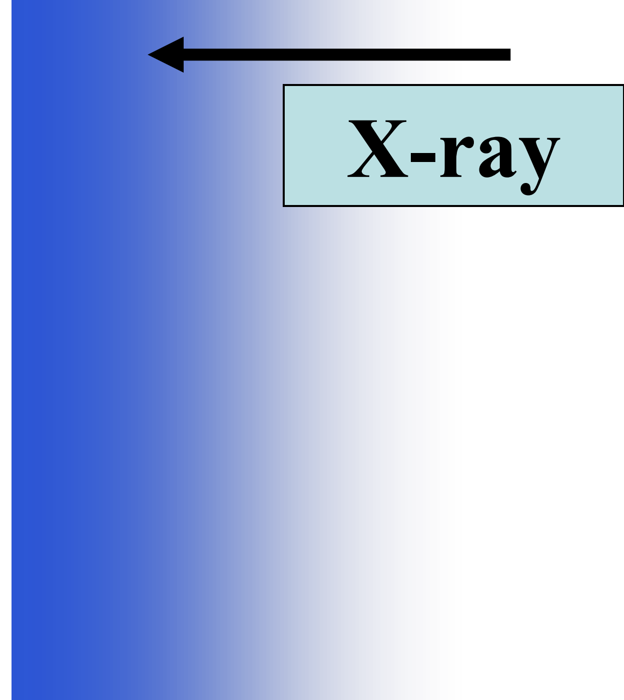


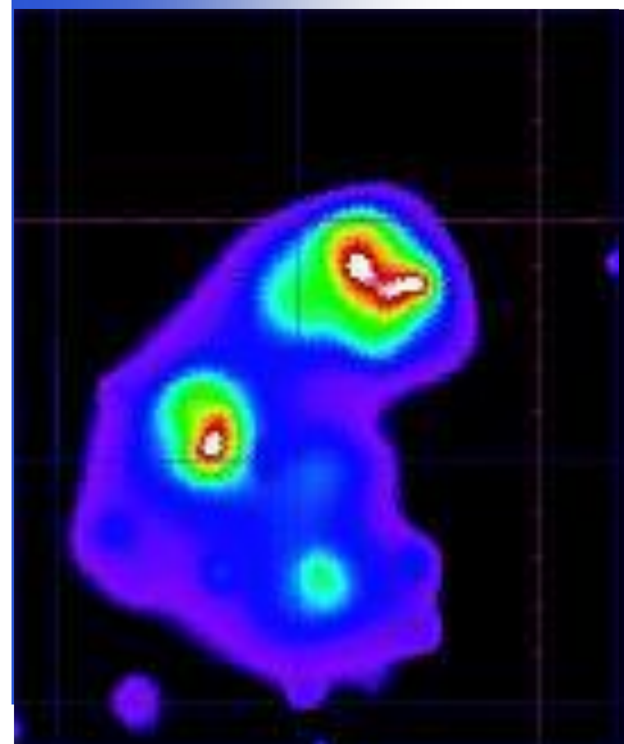
Very bright 350 years ago!

Massive Black hole was very active!

Murakami, H et al, 2003, Astron. Nachr, 324, 125







X-ray Front approaching to molecular clouds

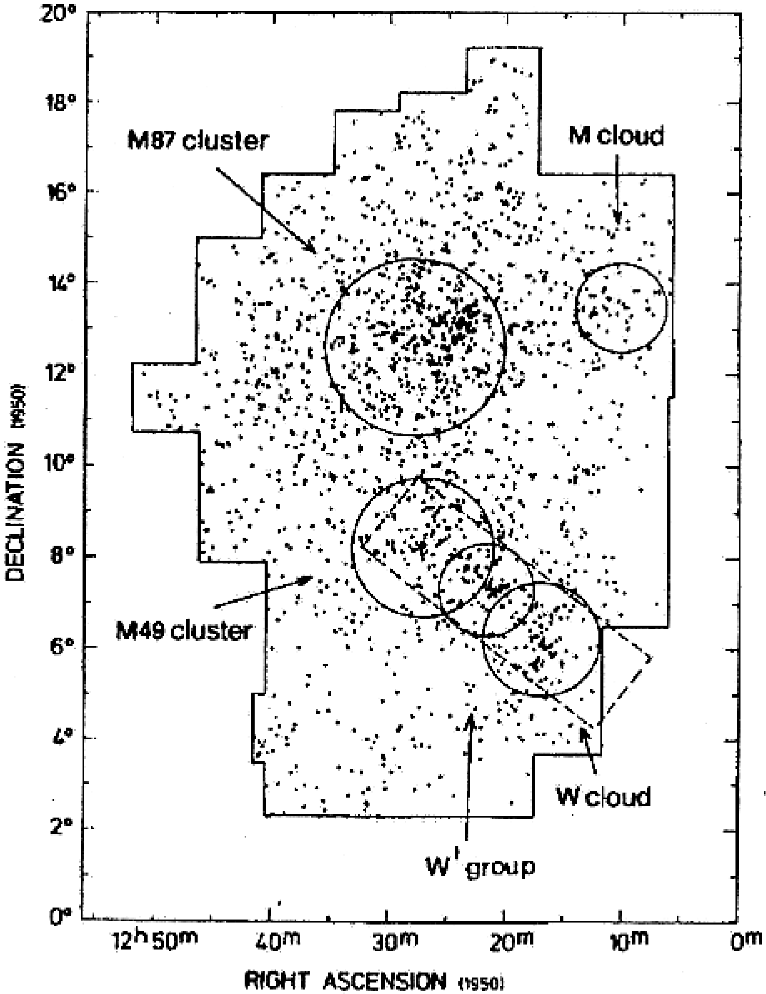
K. Koyama

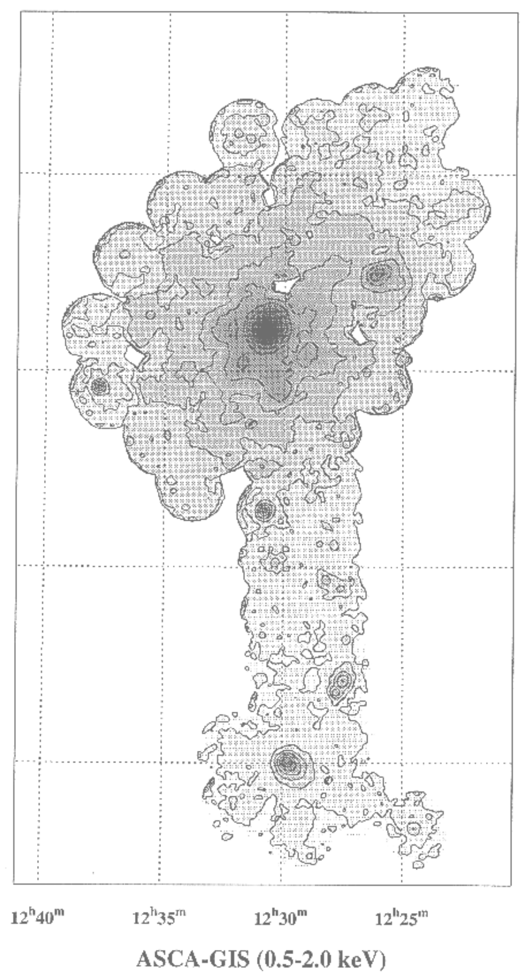
Koyama et al., 2008, Publ. Astron. Soc. Japan, 60, 201

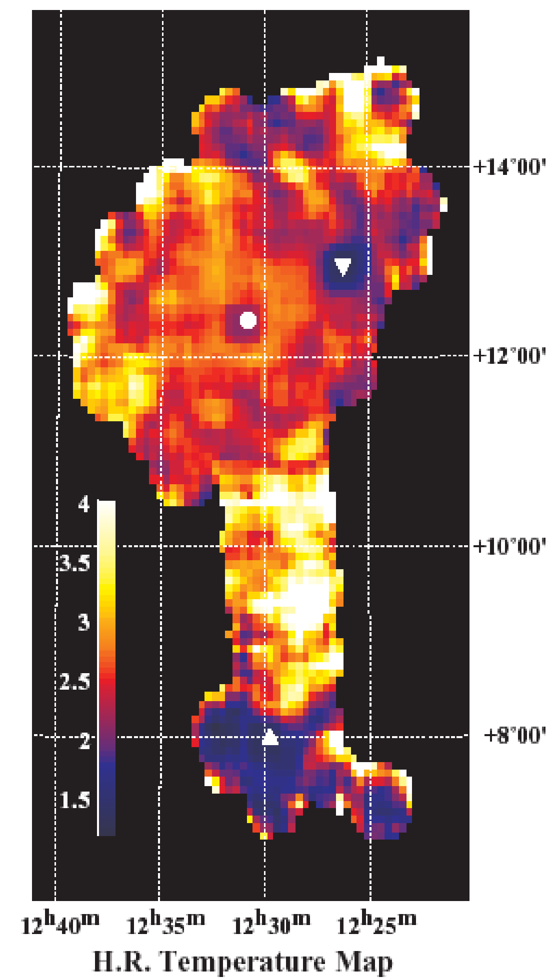
II-5 : Cluster of galaxies and Cosmology

Structure of C. G.

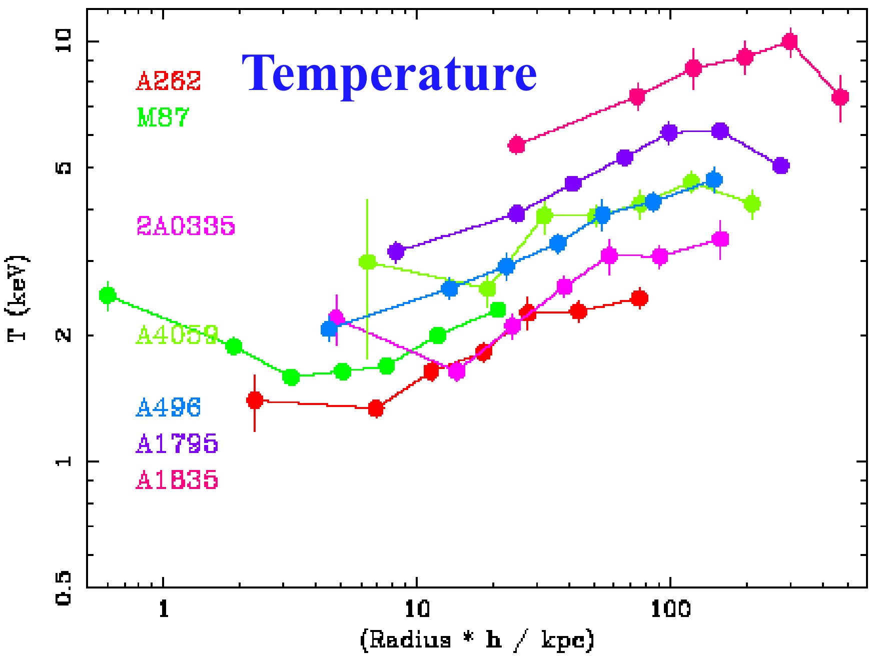
Visible (Stars) X-rays(Gas density^2) Gas temp.

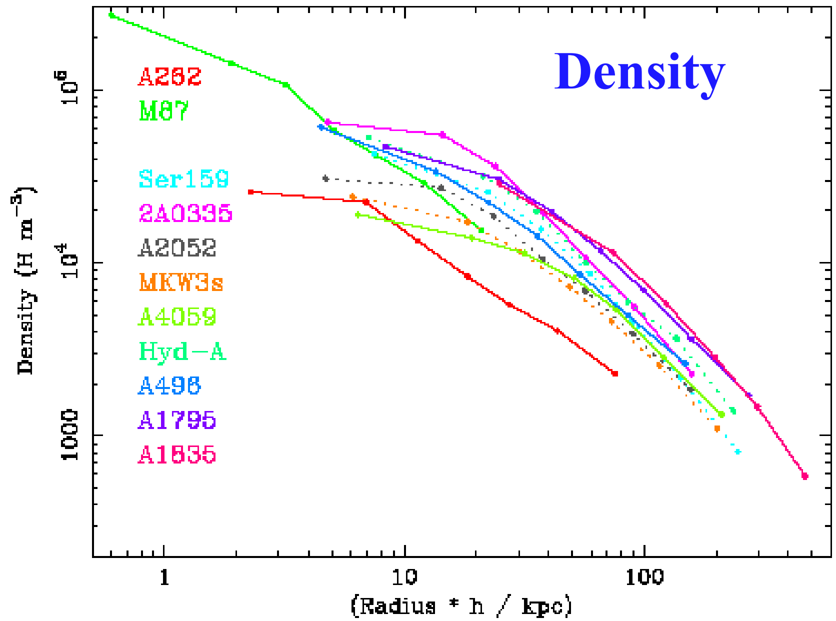


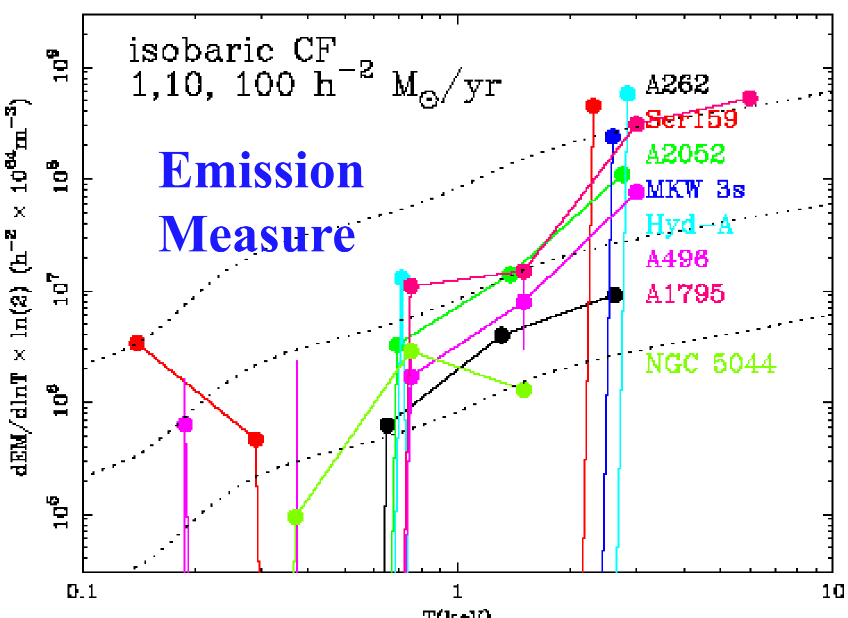


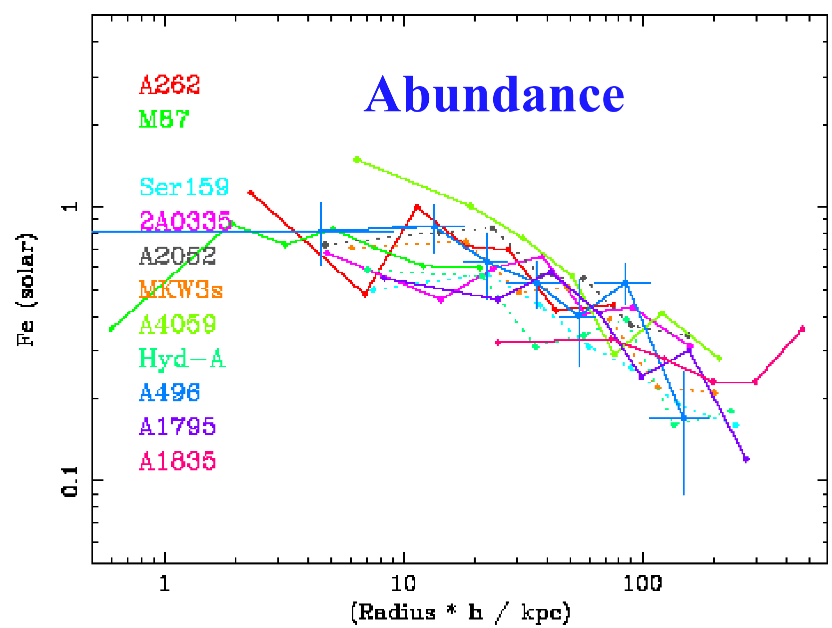


R. Shibata et al., 2001, *ApJ*, **549**, 228


Temperature
A262
M87
2A0335
A4059
A496
A1795
A1835
T (keV)
(Radius * h / kpc)


Density
A262
M87
Ser159
2A0335
A2052
MKW3s
A4059
Hyd-A
A496
A1795
A1835
Density (H m^{-3})
(Radius * h / kpc)


isobaric CF
1,10, 100 h^{-2} M$_{\odot}$/yr
Emission
Measure
A262
Ser159
A2052
MKW 3s
Hyd-A
A496
A1795
NGC 5044
dEM/dlnT × ln(2) (h^{-2} × 10^{64}m^{-3})
T(keV)


Abundance
A262
M87
Ser159
2A0335
A2052
MKW3s
A4059
Hyd-A
A496
A1795
A1835
Fe (solar)
(Radius * h / kpc)

Ezawa et al.,1997, ApJ...490L..33E

Abundance Distribution

Concentration at cores

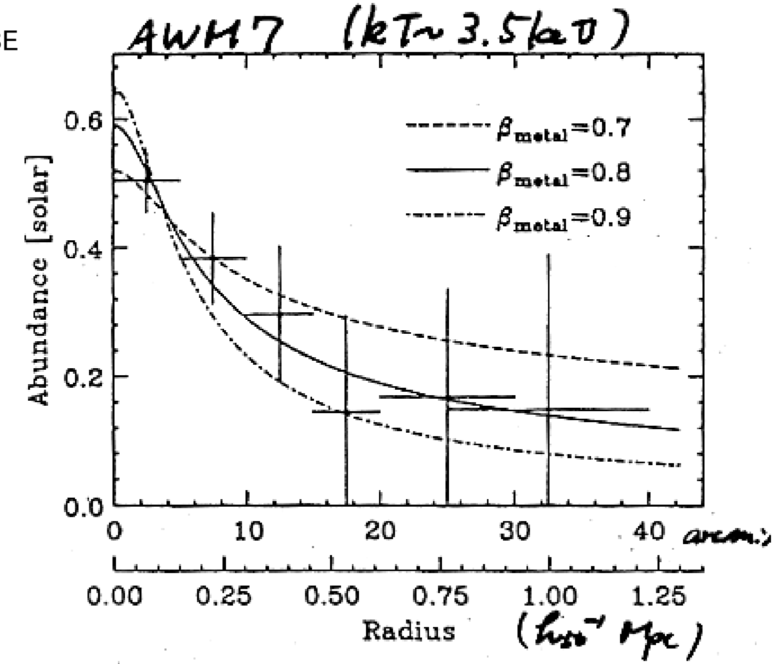
Nucleus-synthesis

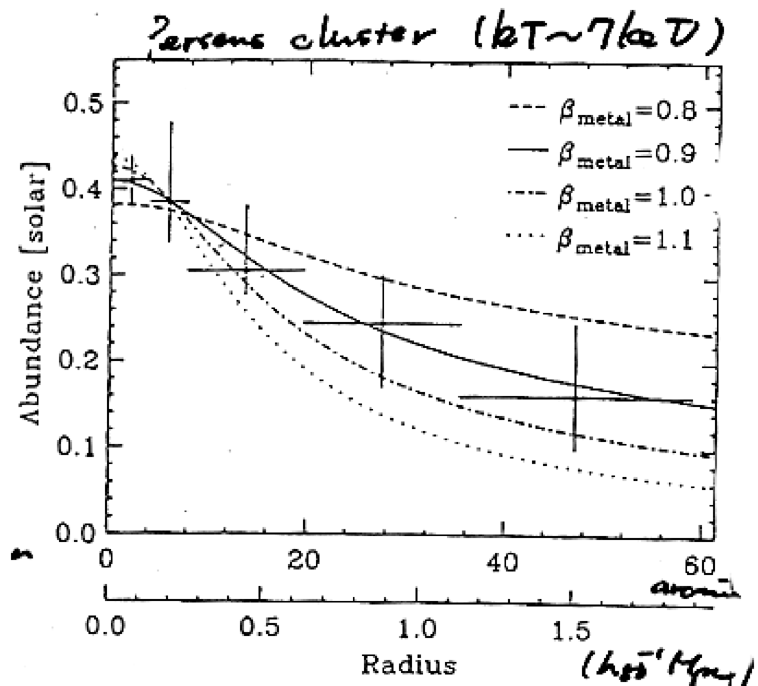
Ty Ia／Ty II SNR

Scatter of galactic gases

Galactic wind、

Ram pressure

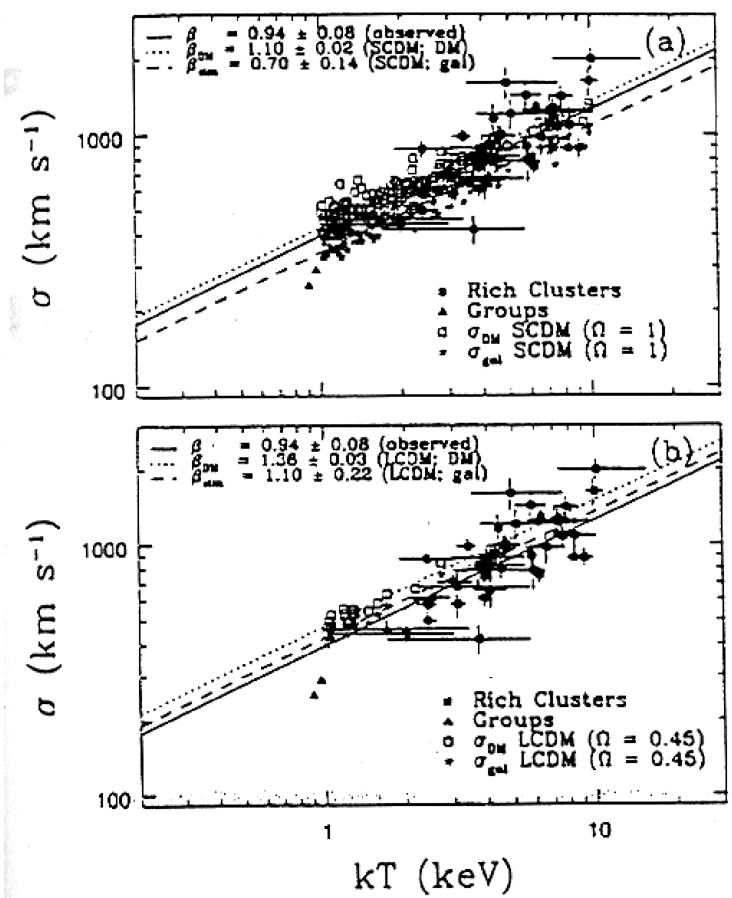


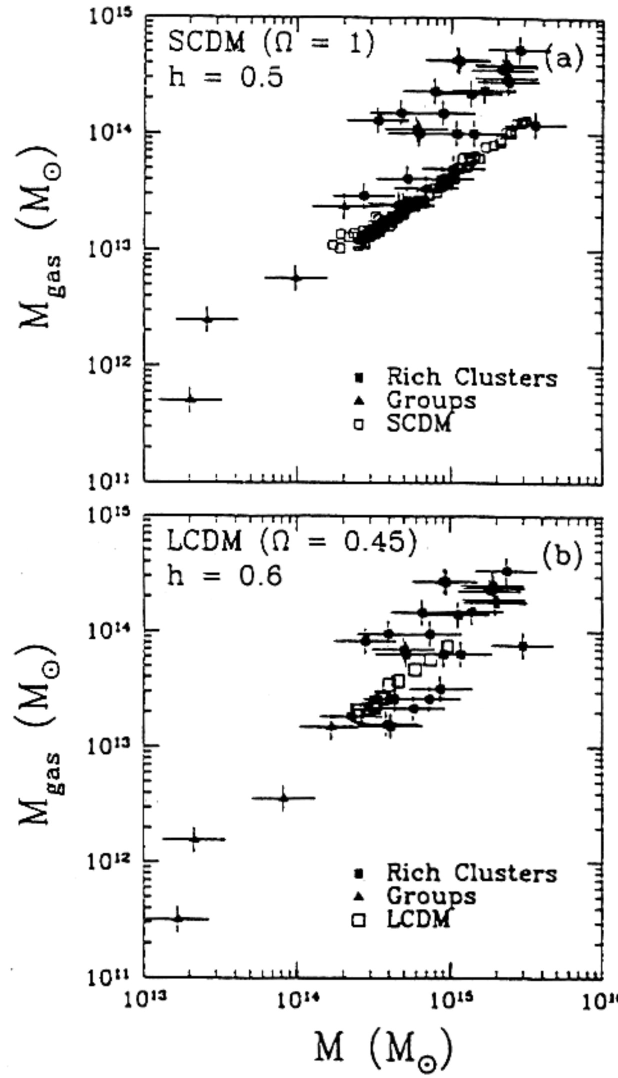


Mass of C. G.

Galaxies(stars) $10^{11} x 10^{3} M_{solar}$

Intra-cluster gas





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**

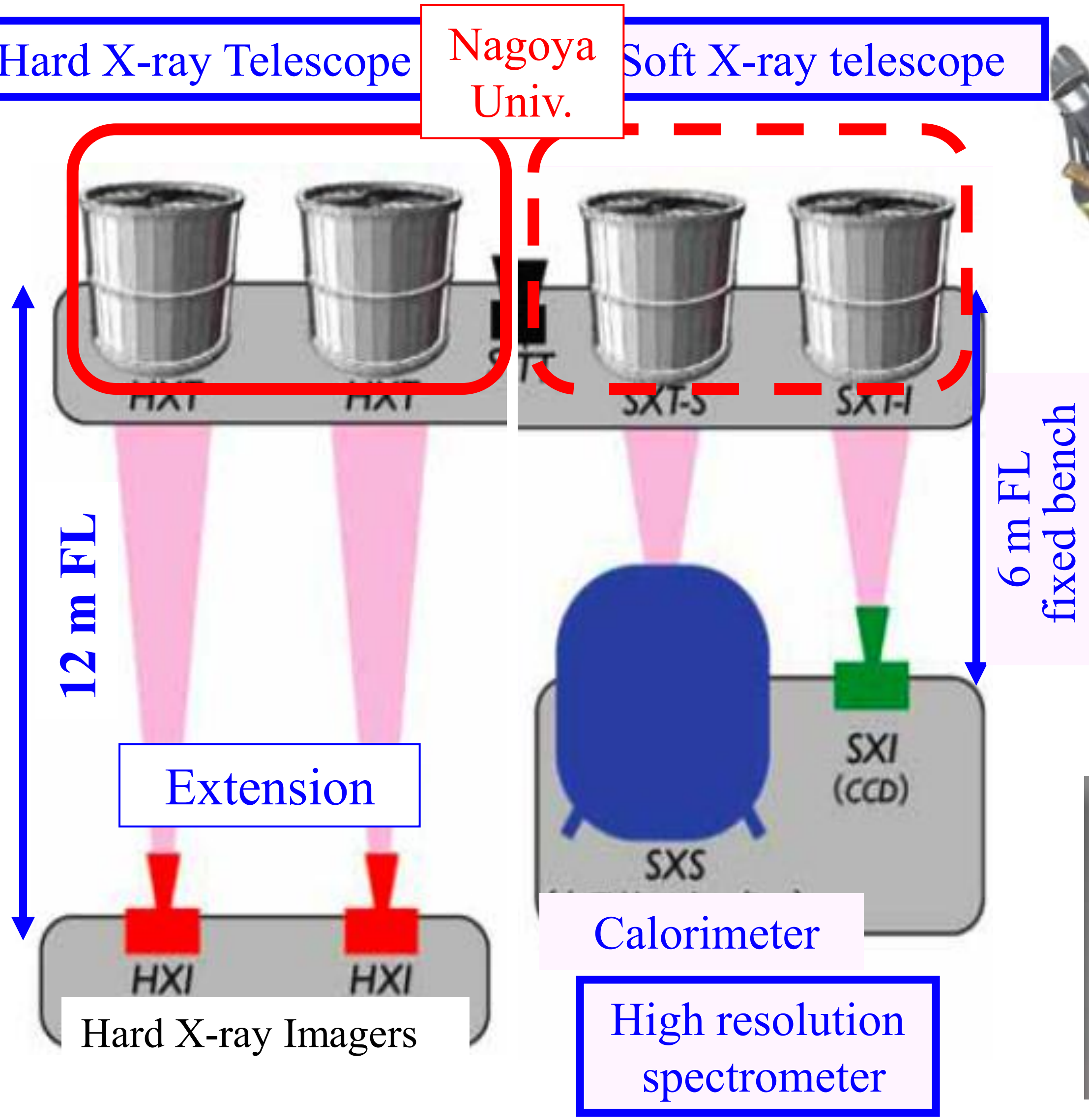
II. High energy phenomena
- **II-1: Stellar X-ray emission**

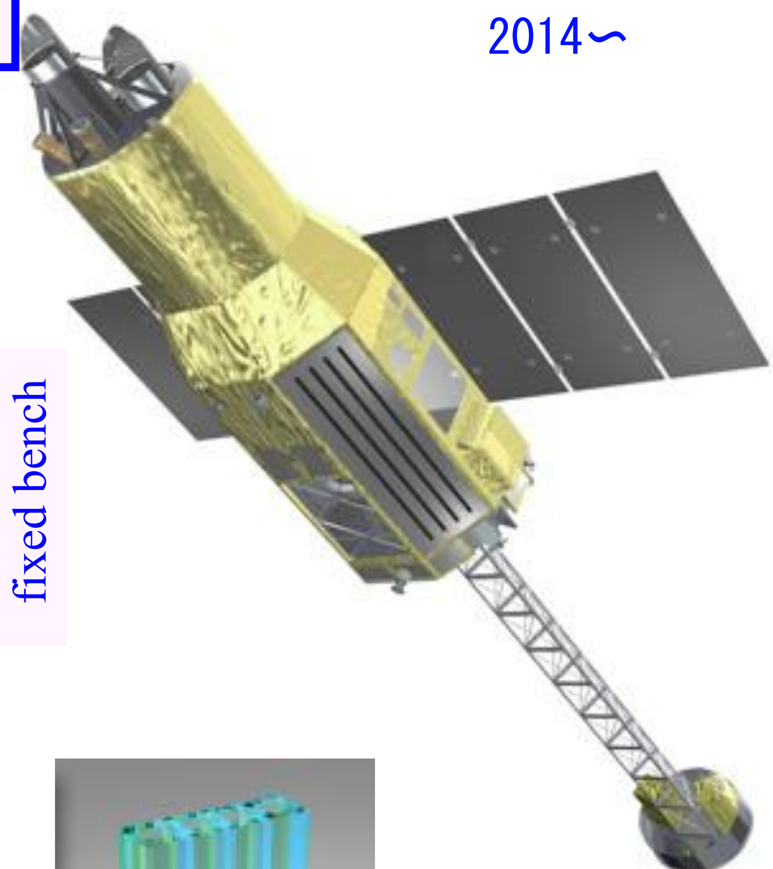
September 30, 10:45-12:00

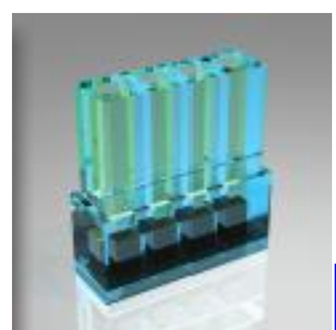
- **II-2: Supernova remnants (SNR)**
- **II-3: Neutron stars and blackholes**
- **II-4: Active Galactic Nuclei**
- **II-5: Cluster of galaxies and Cosmology**

X-ray Telescope

Astro-H satellite

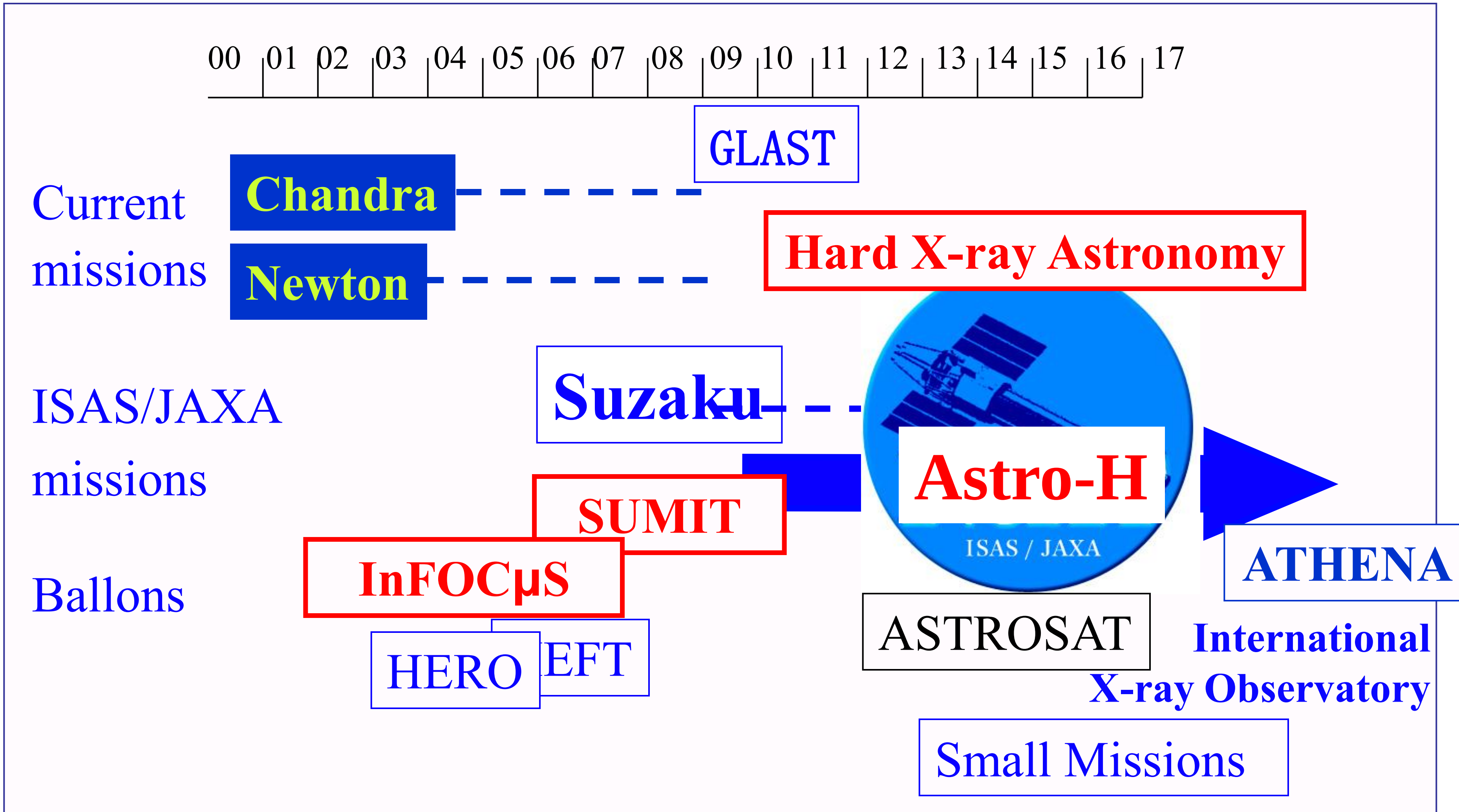






X-ray Telescope

X-ray missions in 21st Century



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