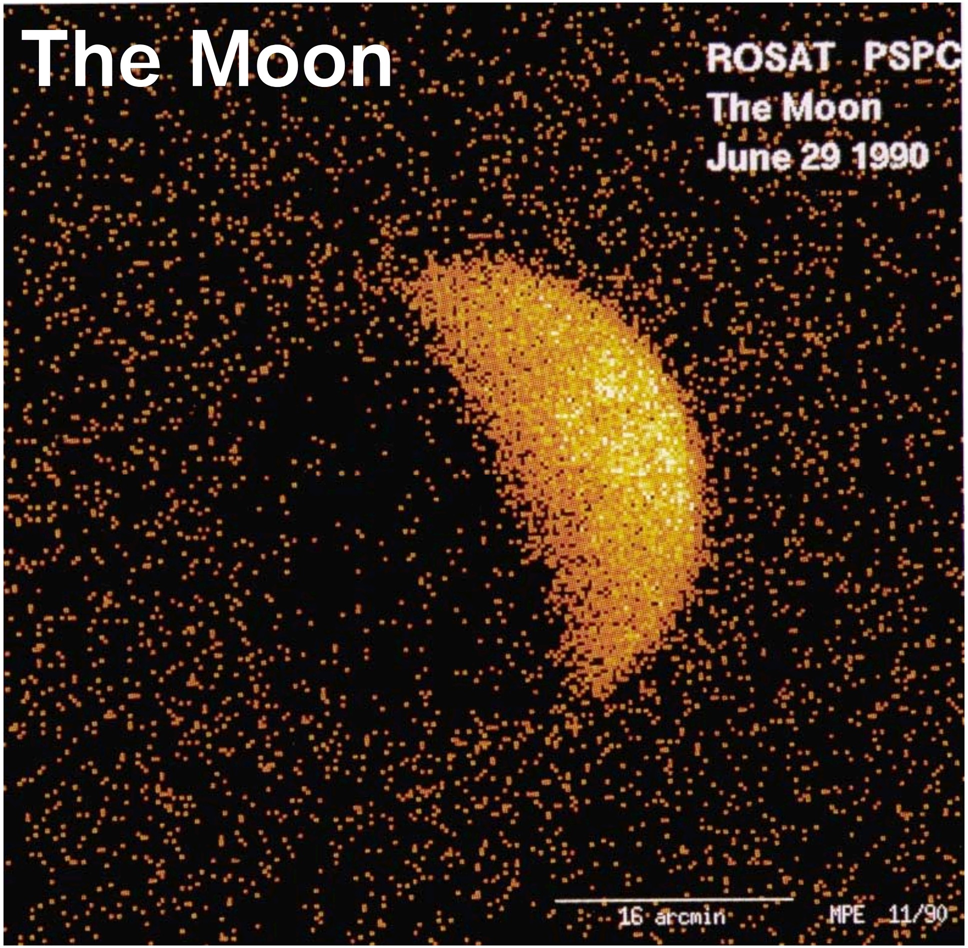
スターバースト二嘶とNeXT衛星

鶴 剛@京大物理

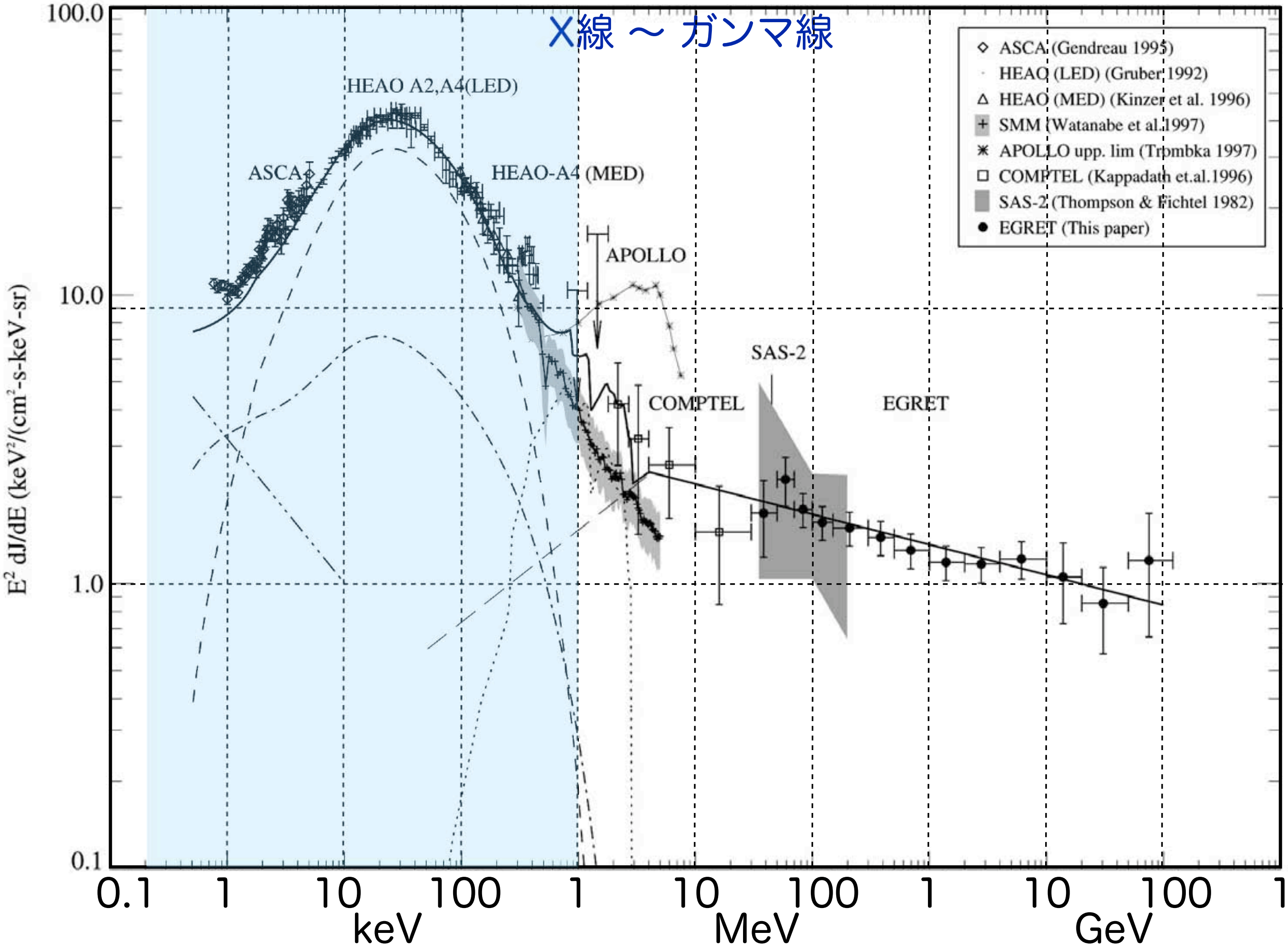
- Cosmic X-ray Background と 巨大ブラックホール
- M82の中質量ブラックホール
- NGC253のTeVガンマ線ハローとMeVガンマ線の起源
- NeXT衛星

Cosmic X-ray Back Ground (1)



Extra Galactic 起源の一様なX線放射

Cosmic X-ray Back Ground (2)

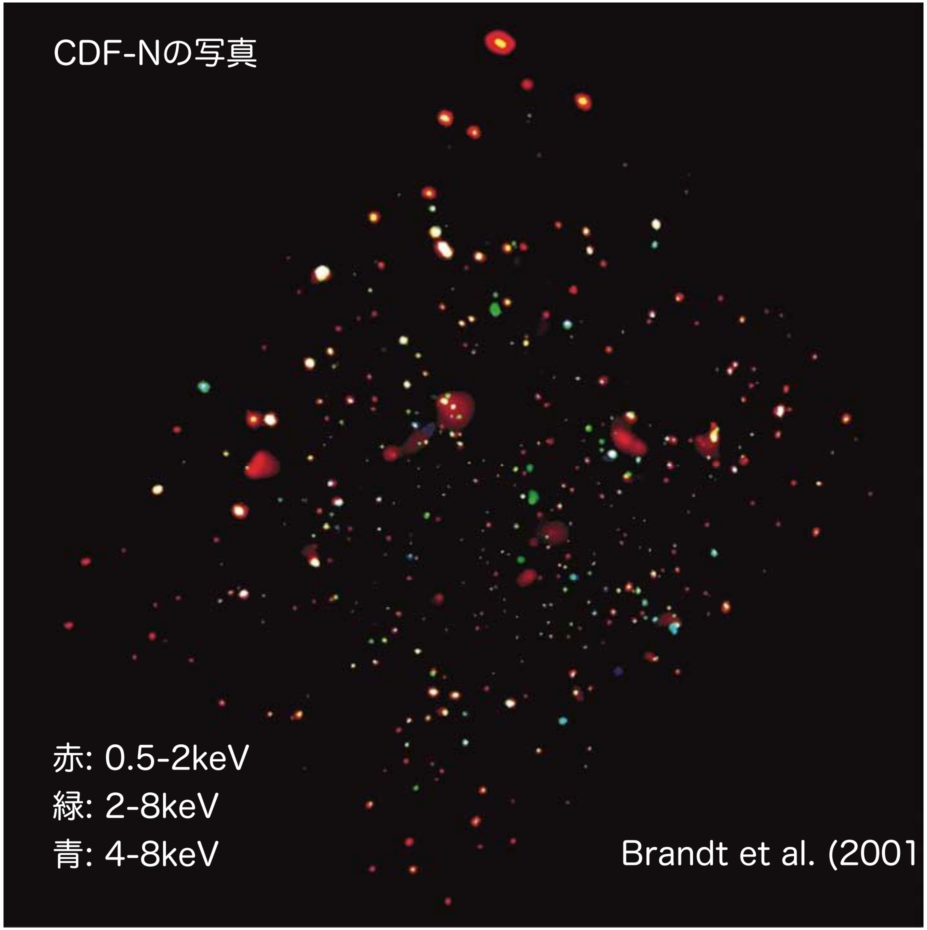


Sreekumar et al. (1998)

kT=40keV熱制動輻射、CMB揺らぎ無し→点源の足しあわせ

(ガンマ線バックグラウンド = Blazar の足しあわせ ?)

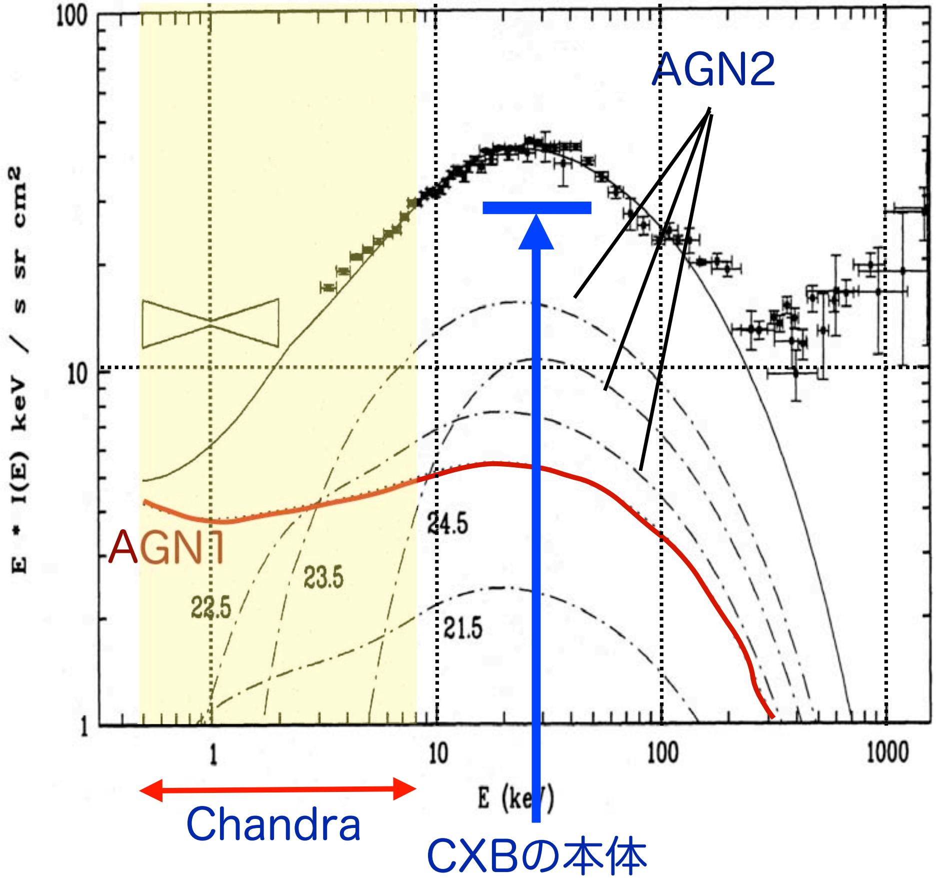
Chandra Deep Field North (CDF-N)



- 領域
  - HDF-Nを中心とする18'x22'
- 検出限界、検出したX線源の数
  - Exposure = 1.4Ms (16.2days)
  - 3×10^{-17} ergs/s/cm^2 (0.5-2keV)@1Ms
  - 2×10^{-16} ergs/s/cm^2 (2-8keV)@1Ms
  - CDF-Nトータル = 430個,
  - 多波長観測領域 = 120〜140個
- CXBエネルギーの分解
  - <2keV : 90%,　>2keV : 80%
  - むしろ全エネルギー測定の不定性

0.5-8keVはほとんど分解

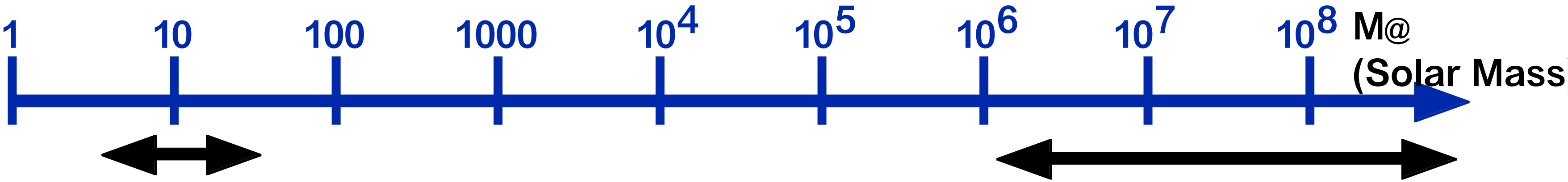
2型AGNの必要性とCXBの「本体」



- 2種類のAGN
  - 1型AGN: 吸収を受けていない Γ=1.7
  - 2型AGN: 吸収を受けている
- CXBのスペクトル
  - kT=40keVの熱制動輻射
  - X線で明るい1型では説明できない。
- CXBの理解の現状
  - Chandraなどによる個数カウント
  - 明るい2型AGN数個を0.5-100keVで観測
  - 両方を合体させて、適当な進化モデルを入れてCXBを説明できた、ことになっている。
  - CXBの本体はまだ分かっていない。

CXBの本体を説明する極めて強い吸収を受けたX線源は?

Two Types of Black Hole in the Universe

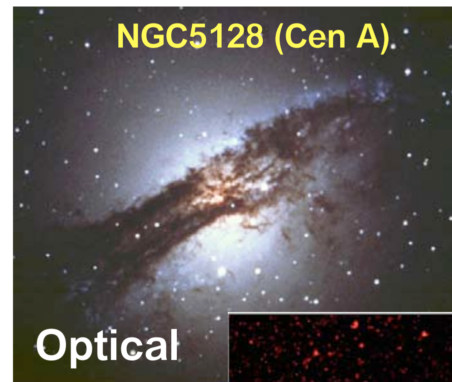


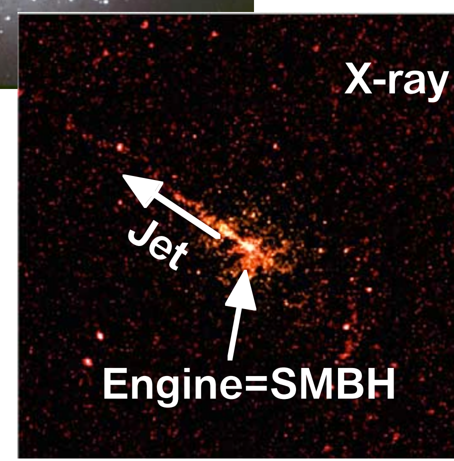
Stellar Black Hole
eg. Cyg X-1

Super Massive Black Hole
at the Center of Galaxy

Observed as Active Galactic Nuclei (AGN/QSO)

Born from Supernova due to Gravitational Collapse of Massive Star

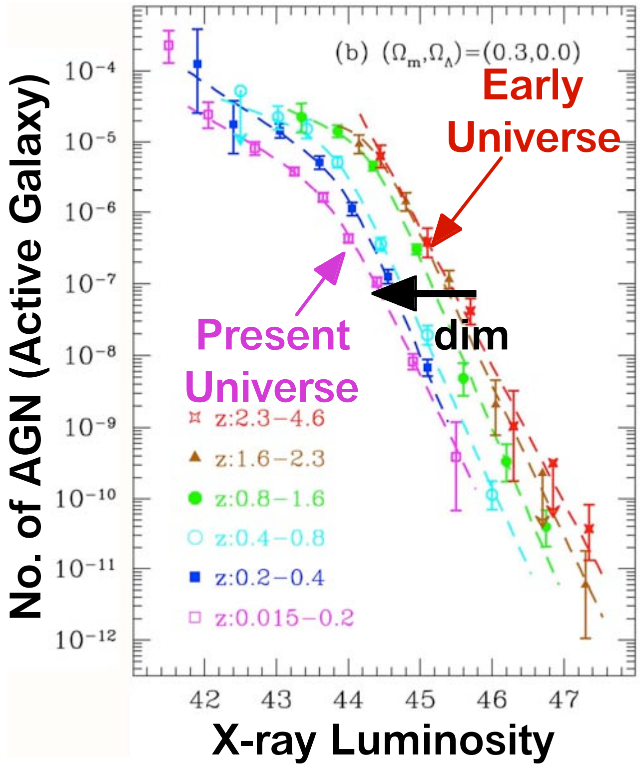




Born from What ?

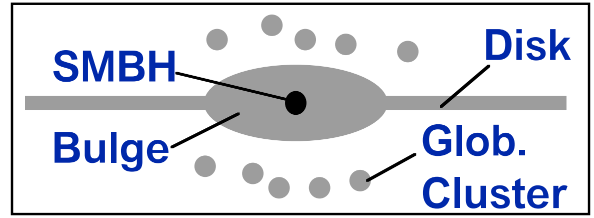
SMBH and Evolution of the Universe and Galaxy

$z=5 \Rightarrow z=0$

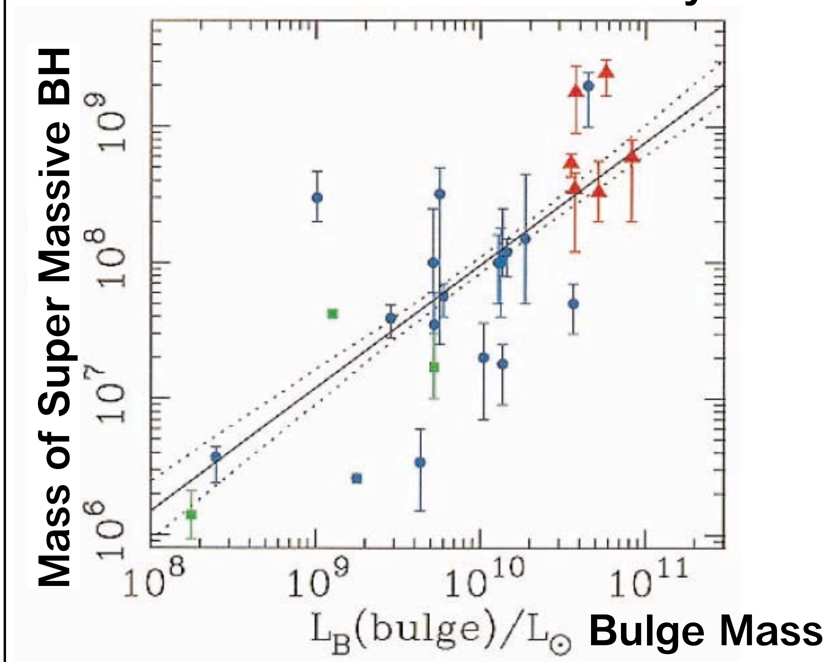


SMBH was Very Active in Early Universe, but is Inactive at Present

$z=0$



Schematic View of Galaxy



$M_{SMBH} \propto M_{Bulge}$

Evolution of Activity of Super Massive Black Hole

Origin of the SMBH connects with the Galaxy Formation.

What is the Origin of Super Massive Black Hole ?

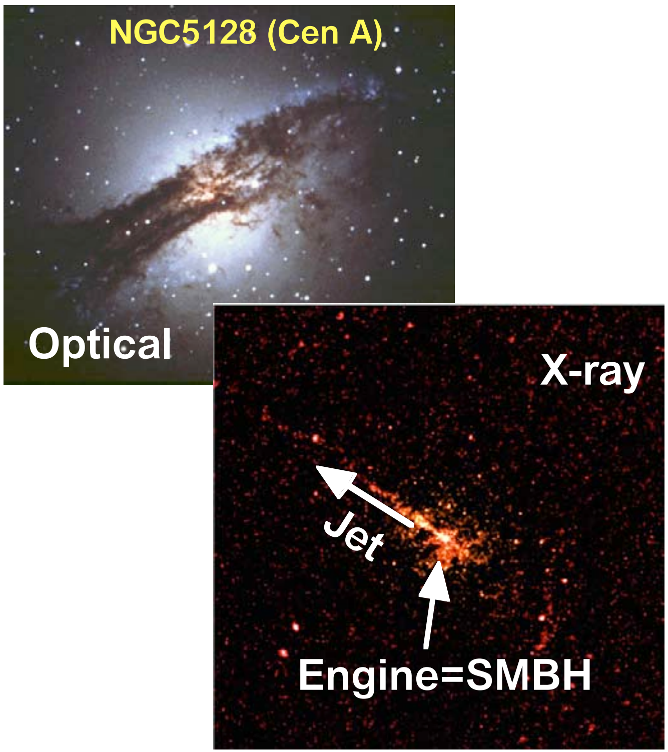
1 — 10 — 100 — 1000 — 10^4 — 10^5 — 10^6 — 10^7 — 10^8 M@ (Solar Mass)

Stellar Black Hole
eg. Cyg X-1

?

Super Massive Black Hole at the Center of Galaxy

Observed as Active Galactic Nuclei (AGN/QSO)



Search for Baby of the Super Massive Black Hole in Young Galaxy !

II

Starburst Galaxy

Discovery and Observation of Intermediate Massive Black Hole

Takeshi Go Tsuru (Kyoto Univ.) 鶴 剛 (京大物理)

X-ray

T.G.Tsuru (Kyoto Univ.), H. Matsumoto(Osaka Univ., MIT CSR)

Radio

S. Matsushita (Harvard-Smithonian CfA), R. Kawabe (NAOJ)

Infrared

T.Harashima (Kyoto Univ., Minolta), T.Maihara,

F.Iwamuro (Kyoto Univ.), N.Kobayashi, T.Usuda (NAOJ Hawaii),

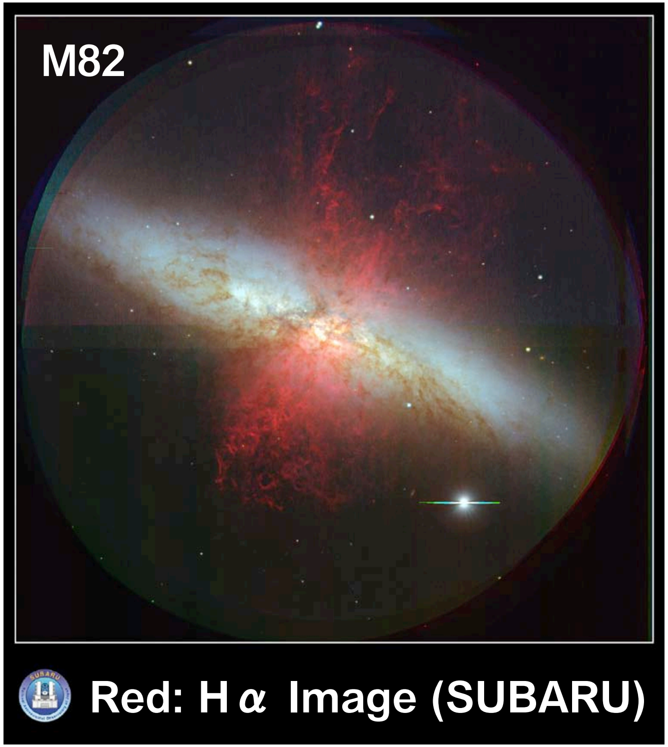
M.Goto (Hawaii Univ. IfA)

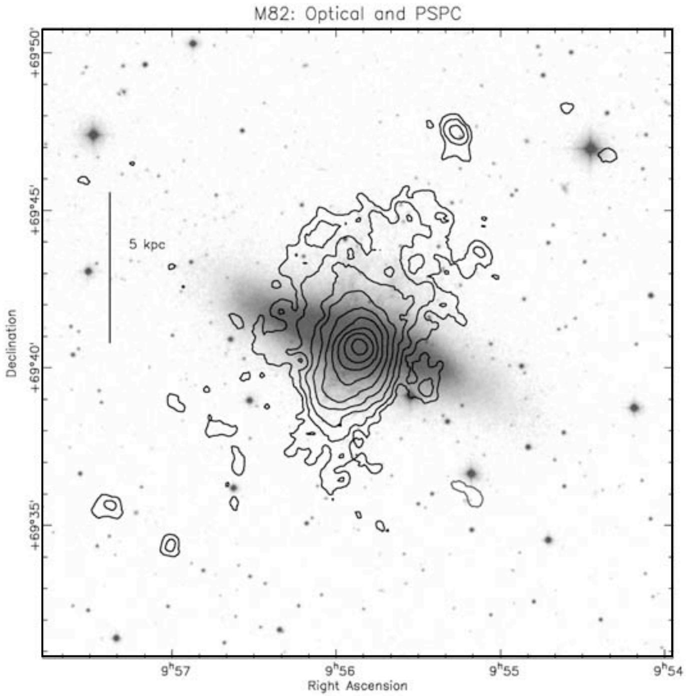
Theory

T.Ebisuzaki(Riken), J.Makino. H.Umeda, K.Nomoto(Univ. of Tokyo)

Starburst Galaxy

- Burst Star Formation is Occuring.
- M82: Star Formation Rate = 10^4×Our galaxy
- Very High Supernova Rate
- Burst Formation of Stellar Black Hole
- Interstellar Matter is Heated uo
- Formation of Galactic Wind



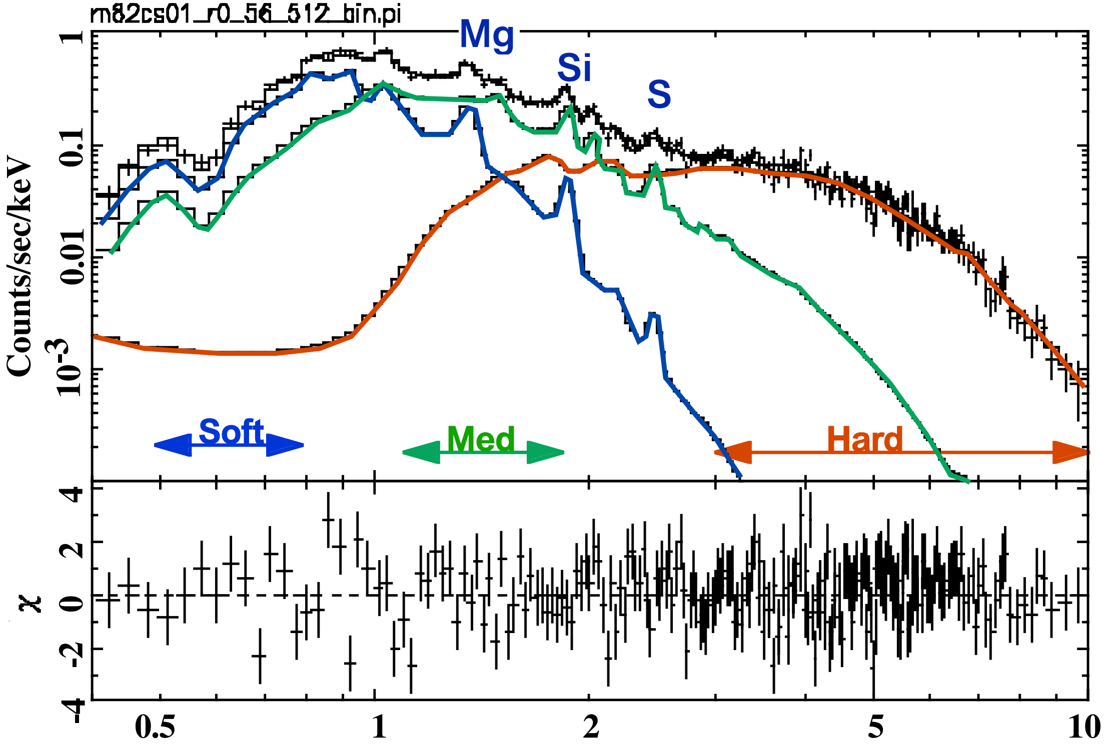


Prototype of Young Galaxy in Early Universe

Observation of M82 with X-ray, IR, Radio

M82 Spectrum (SIS and GIS Simultaneous Fitting)

$Abs_{Whole} \times (RS_{Soft} + RS_{Med} + Abs_{Hard} \times RS_{Hard})$



red χ^2=1.197

Ptak et al. (1997), Tsuru et al. (1997)

Abs_{Whole}: 3.0(+0.5,-0.4)×10^{21} cm^{-2} (>Galactic)

RS_{Soft}: 0.32(+0.04, -0.03) keV

RS_{Med}: 0.95(+0.09, -0.08) keV

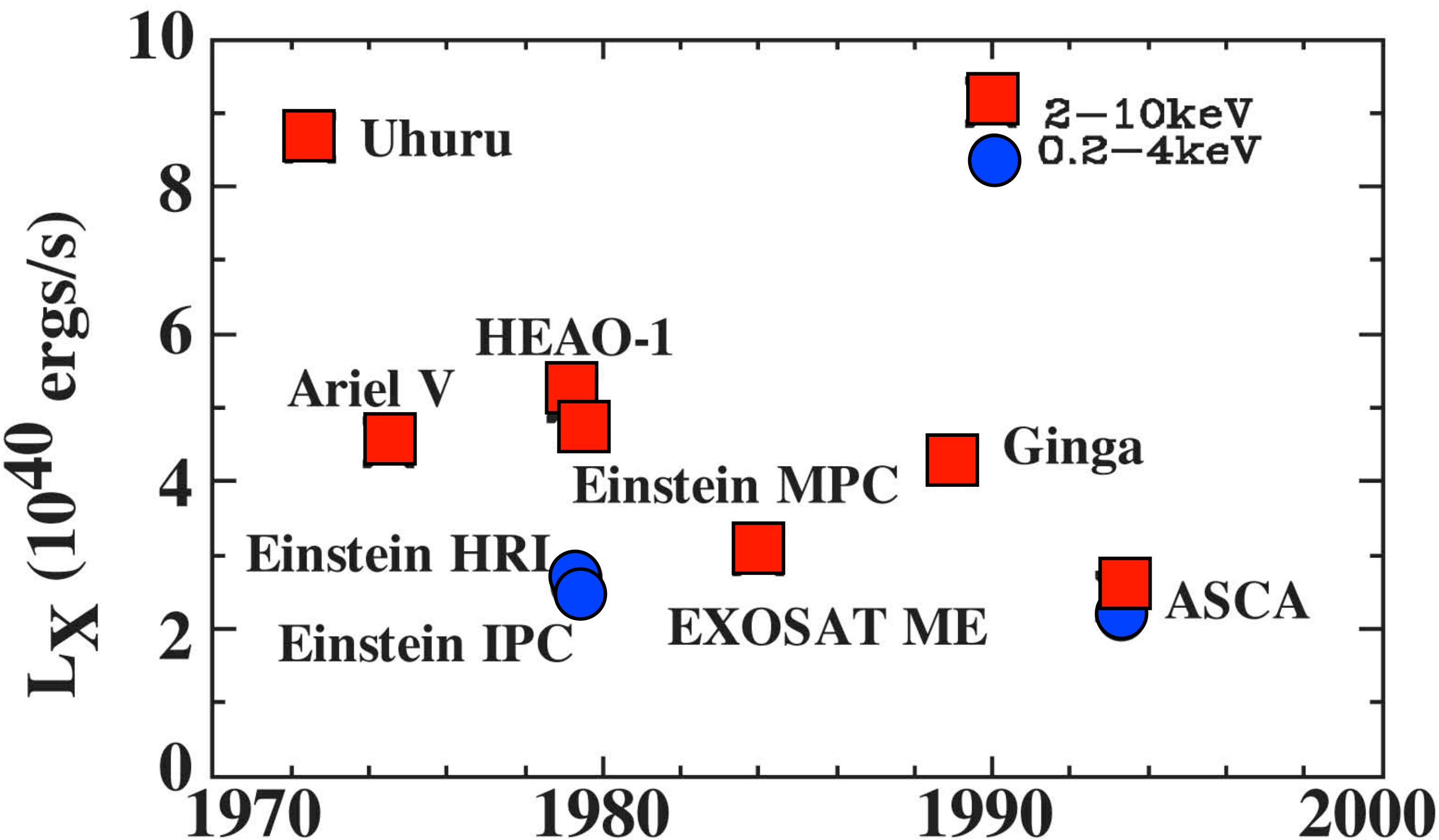
RS_{Hard}: 13.8(+3.8, -2.6)keV

Abs_{Hard}: 1.9(+0.43, -0.41)×10^{22}cm

⇓

Image of Each Component

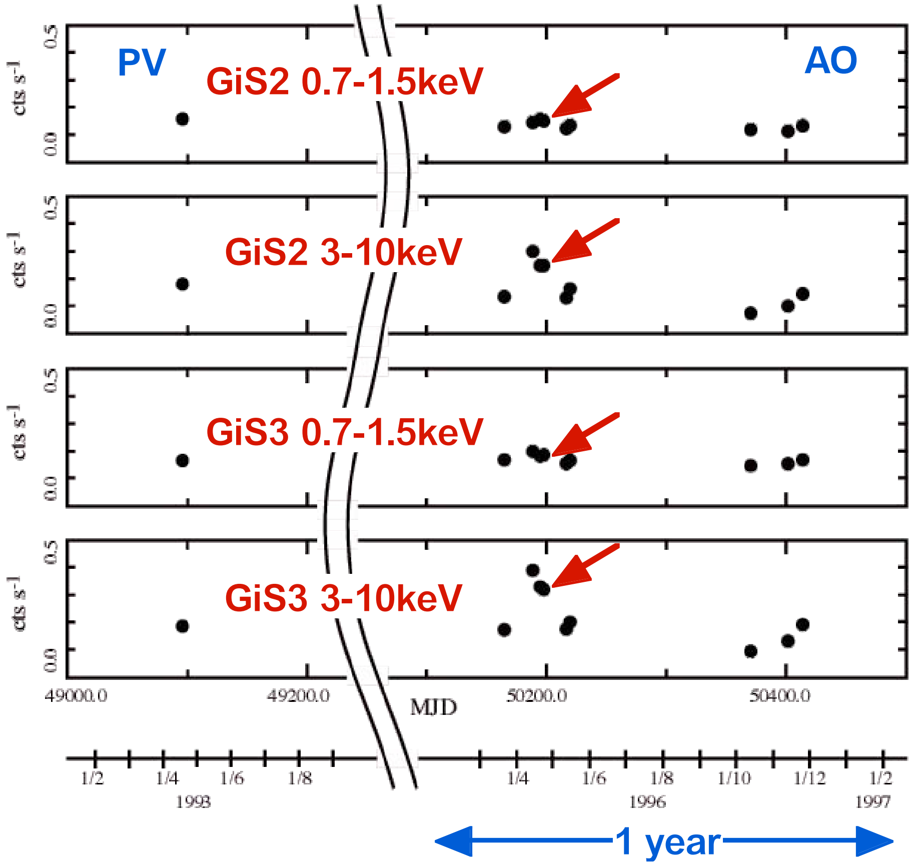
Long Term Variability



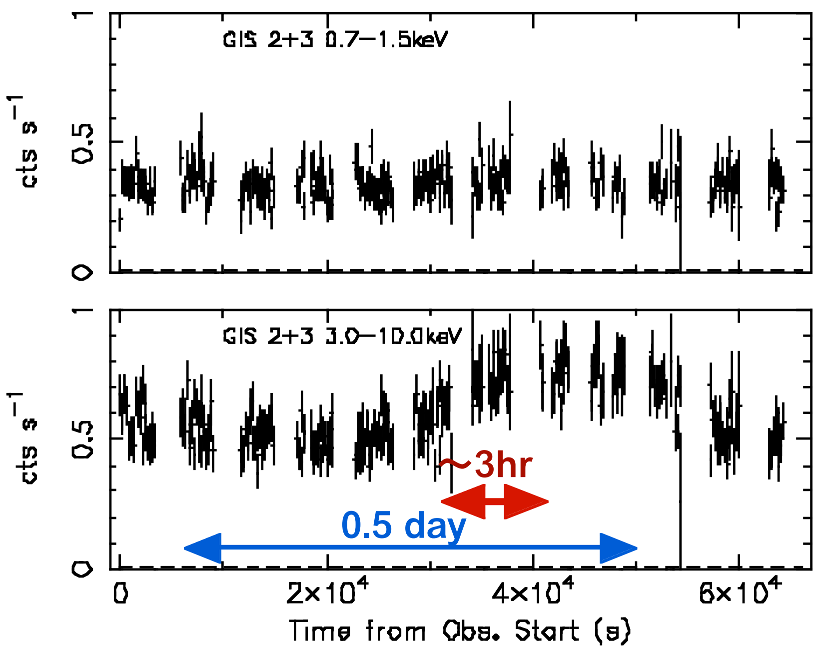
- The compilation of the data through Uhuru and ASCA shows a significant variability in the 2-10keV band.

Tsuru et al. (1996)
ASCA meeting in Waseda

Light Curves



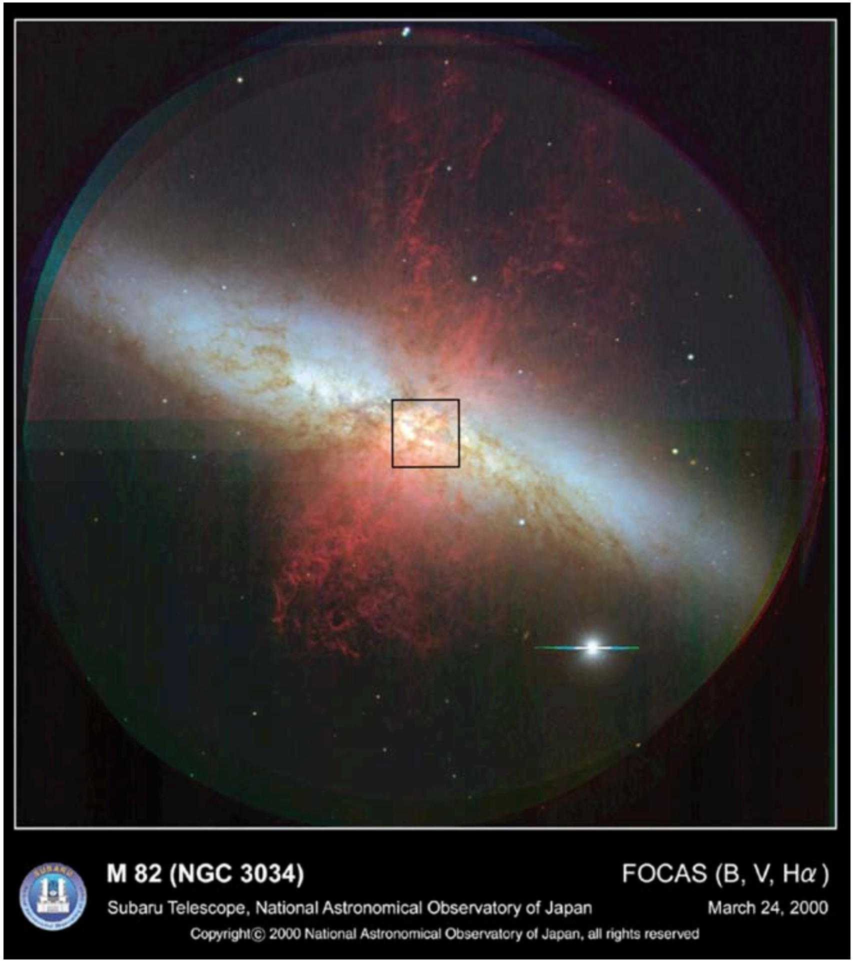
Short Time Variability in the obs. marked with " "

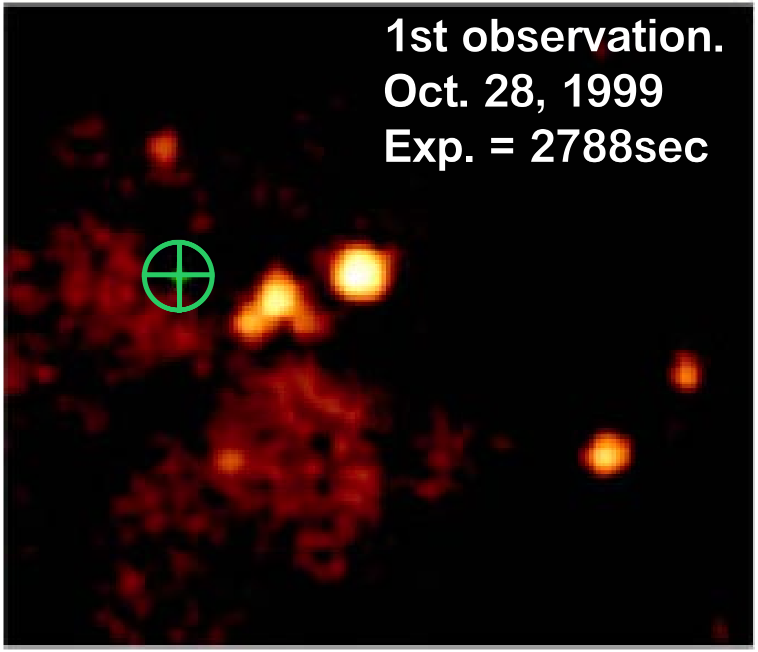


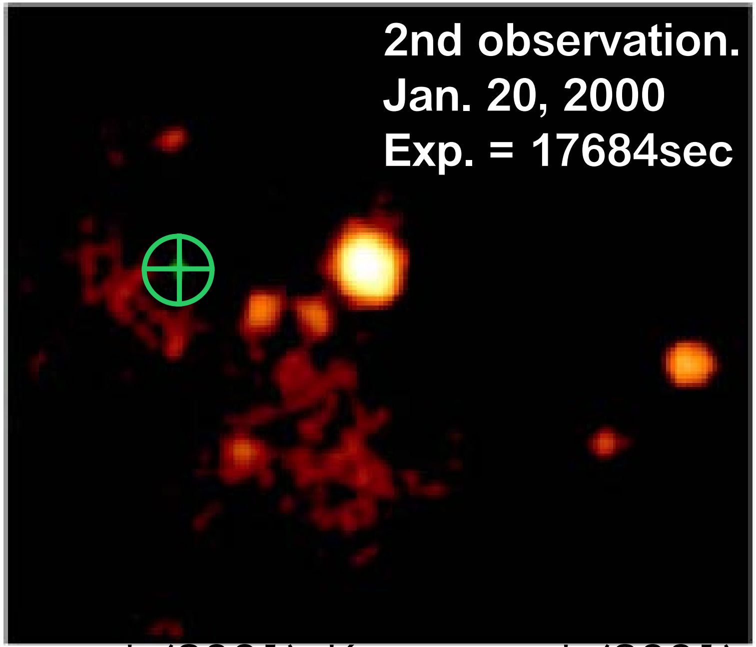
3hr Time Variability with 10^{41}ergs/s
→ Direct Evidence for the X-ray Luminous Black Hole

Matsumoto and Tsuru (1999), Ptak and Griffiths (1999)

Obs. with Chandra HRC (1)







Time variable sources

No Source at the center.

Matsumoto et al. (2001), Kaaret et al. (2001)

Nature of M82 X-1

- Time Variability ~ 3hr

  → X-ray Luminous Black Hole

- Luminosity ~ 1×10^{41} ergs/s → $M_{BH} > 700 M_{@}$

  → Not Stellar Black Hole

- The BH is 170pc away from the dynamical center

  → $M_{BH} < 10^{7} M_{@}$. Otherwise the position of the BH should have been the dynamical center

  Condition of the dynamical friction → $M_{BH} < 10^{6} M_{@}$

  → Not Super Massive Black Hole

$700 M_{@} < M_{BH} < 10^{6} \sim 10^{7} M_{@}$

Off Center Position

New type of Black Hole

"Intermediate Massive Black Hole"

QPO

Strohmayer et al. (2003) reported;

- QPO in M82 X-1 was detected with XMM.
- f_{QPO} = 54.3±0.9mHz
- Assuming $f_{QPO} \propto 1/M_{BH}$, the BH mass of M82 X-1 is estimated to be ∼100-300$M_{@}$.
- Consistent with the M_{BH} derived from the X-ray luminosity.

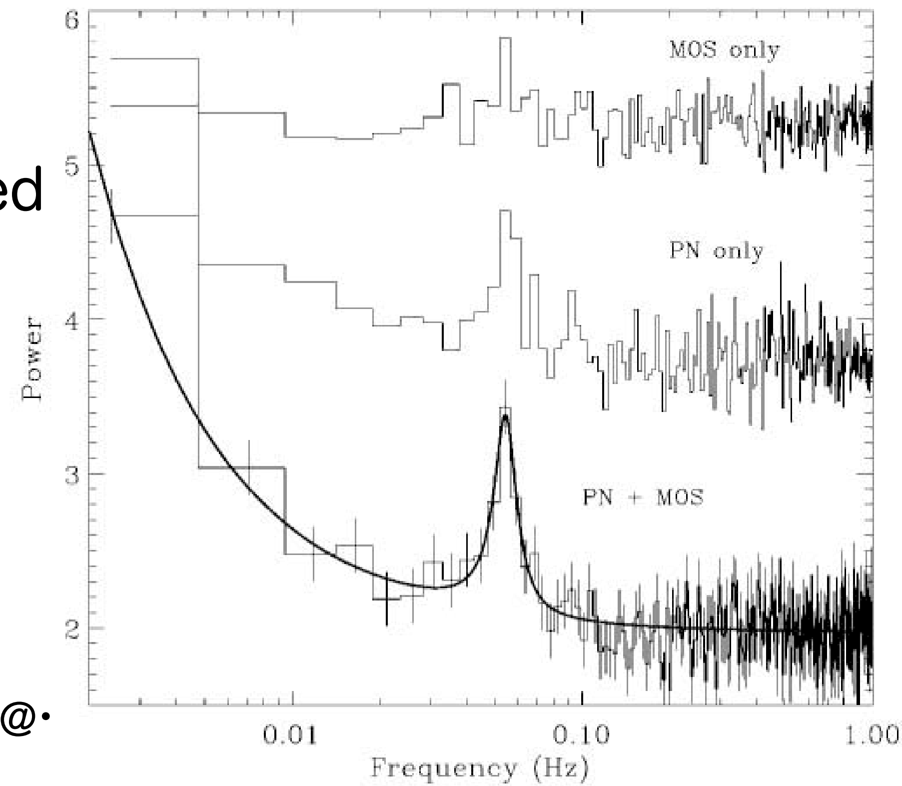
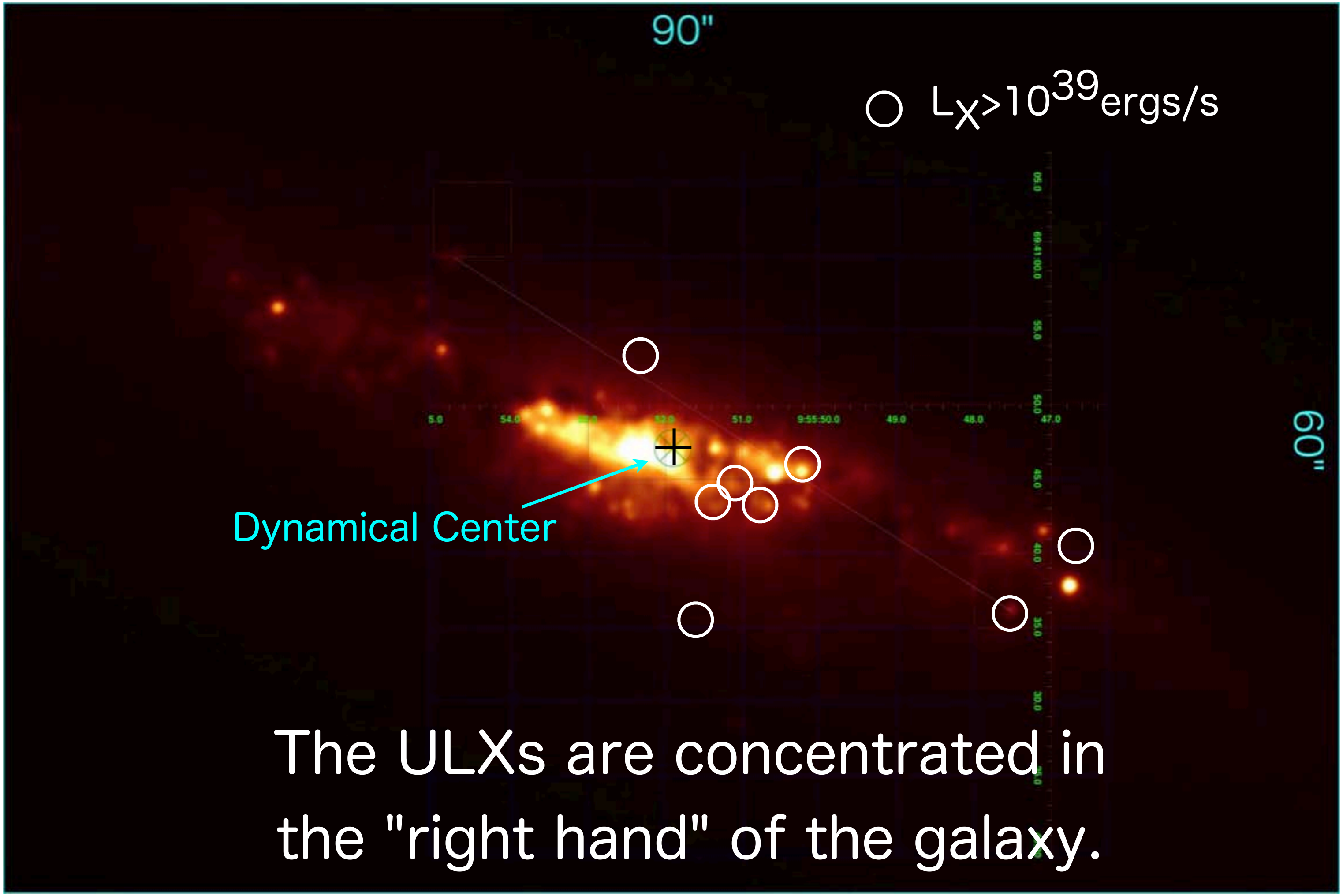


FIG. 1.—Power spectrum of the EPIC > 2 keV data from M82 X-1. The Nyquist frequency is 1 Hz. The frequency resolution is 4.7 mHz. The Poisson level has not been subtracted. Shown are the power spectra from the combined PN+MOS data (*bottom*), the PN only (*middle*), and the MOS only (*top*). The best-fitting power-law+Lorentzian model is shown as the thick solid curve (*bottom*).

Subaru K'-band



Harashima et al. in prep.

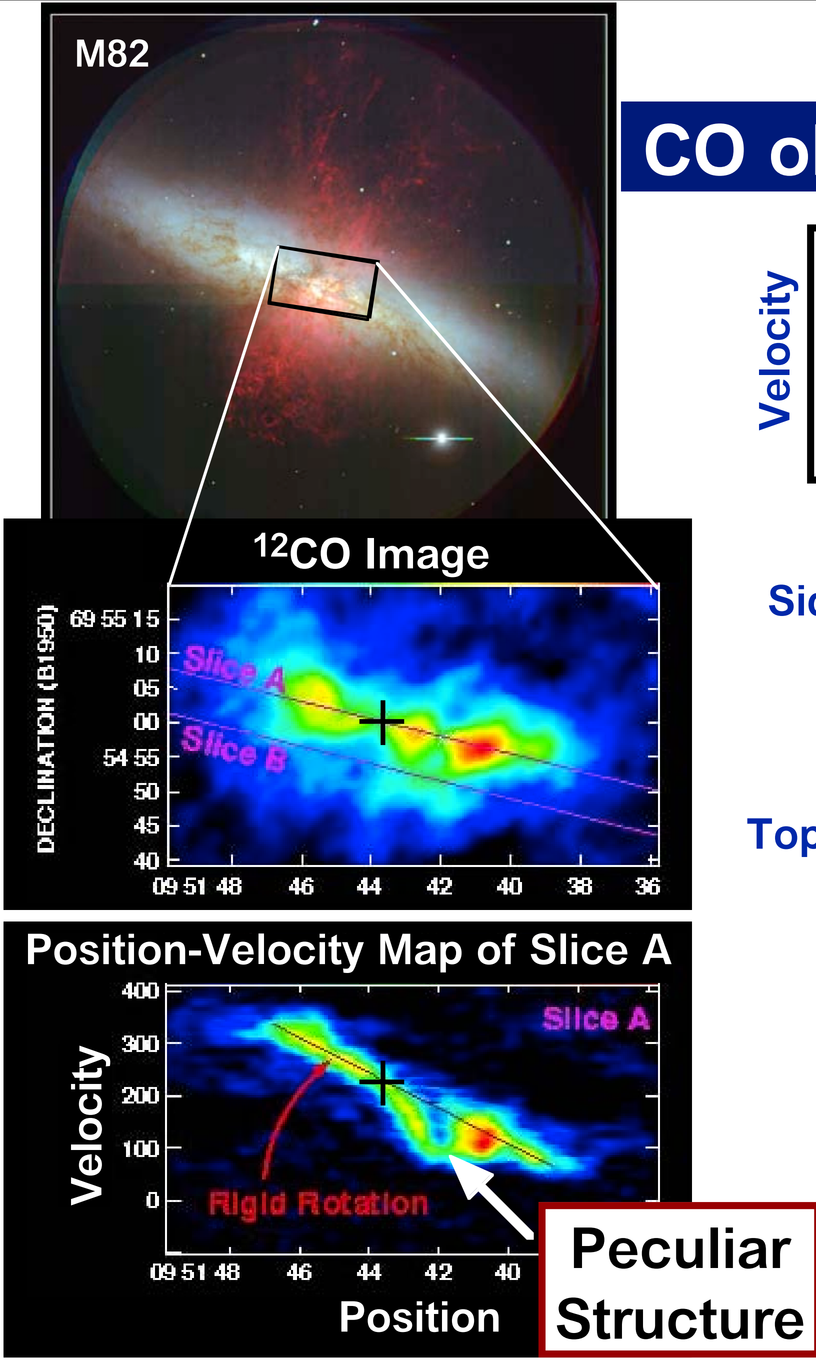
Nobeyama Millimeter Array (野辺山ミリ波干渉計)

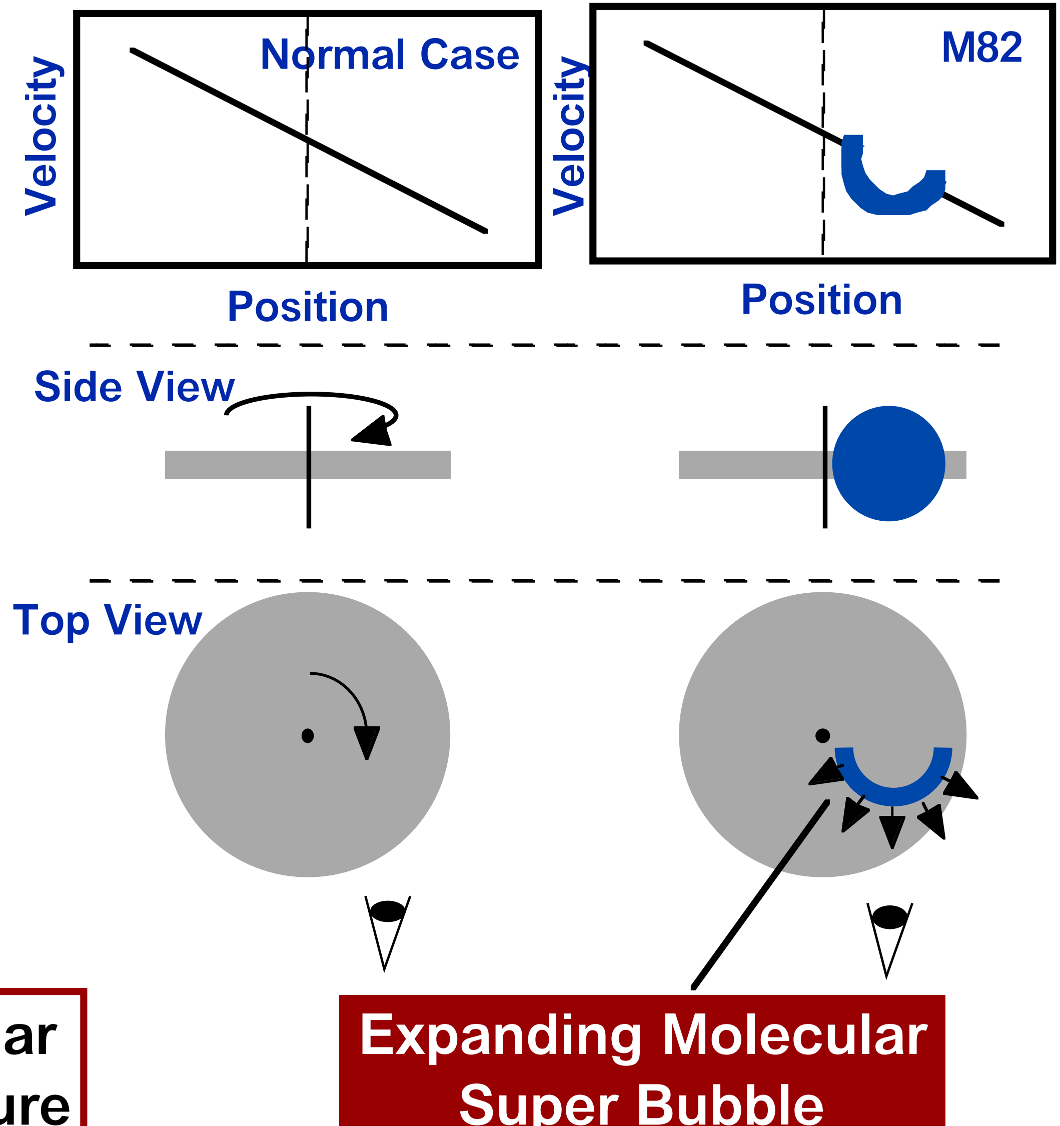
- Interferometer with 10m ANT × 6 at Nobeyama, JAPAN
- Imaging and Spectroscopy of Molecular Cloud

Matsushita et al. (2000)

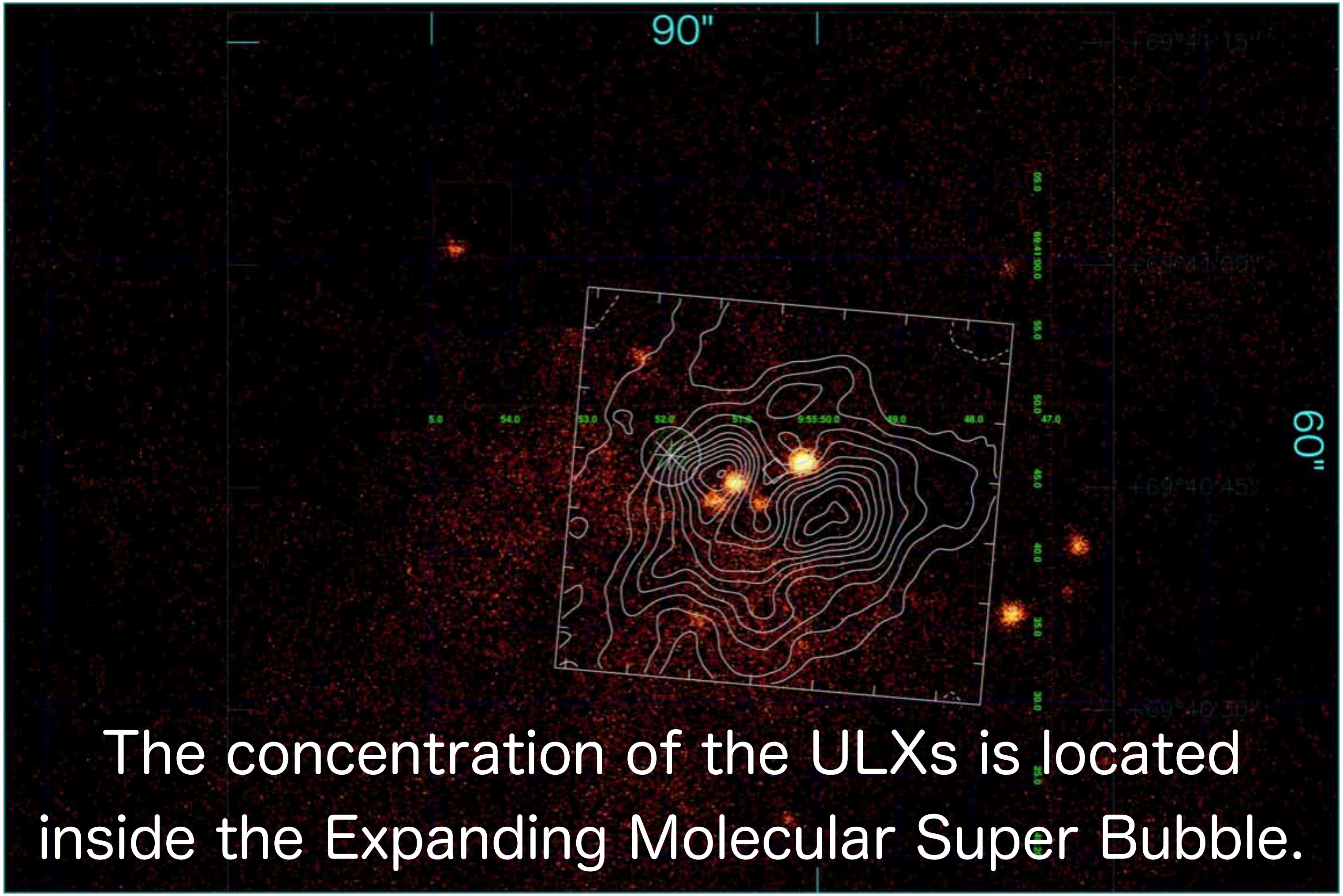
Matsushita et al. (2000)

CO observation of M82 with NMA





CO and X-ray



The concentration of the ULXs is located inside the Expanding Molecular Super Bubble.

The Expanding Molecular Super Bubble

- The existance of the Expanding Molecular Super Bubble suggests a recent starburst activity with the energy of

  $E_{kin} = 1\times10^{55}$ergs ∼ 10^{4}SNe

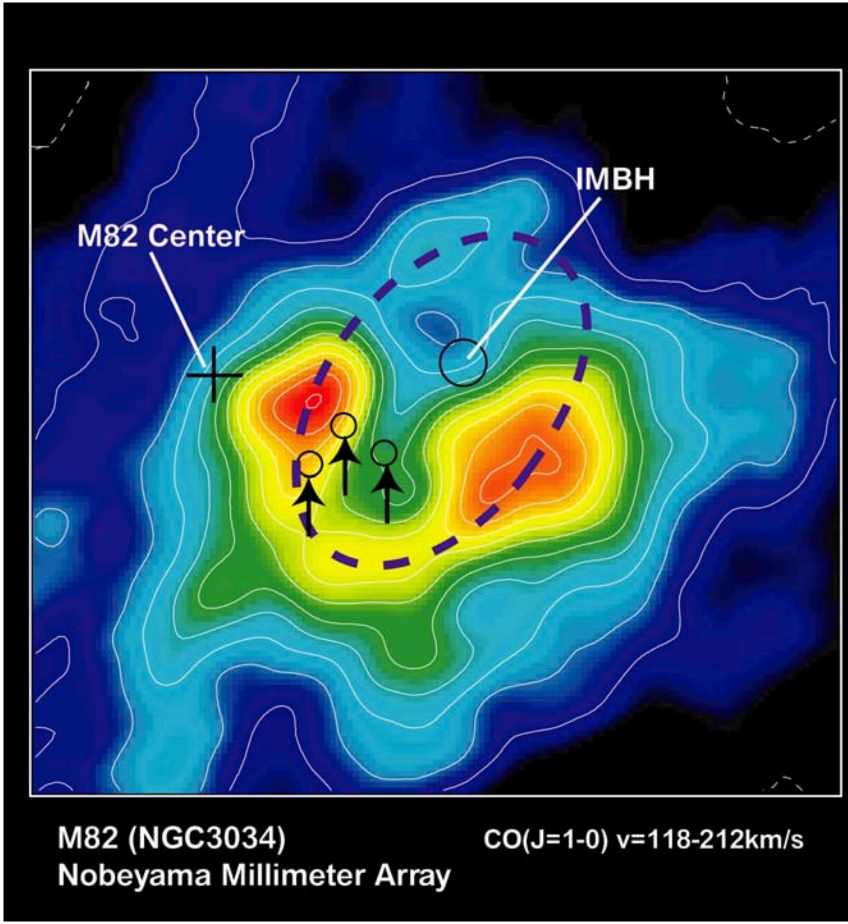
- Age of the EMSB is estimated from

  Age ∼ R(210pc)/V(100km/s) ∼ 10^{6}yr.

- Age of the star clusters in the EMSB

  NIR spectrum suggests ∼1×10^{7}yr

-
-
- The ULXs and X-1 were born (or at least activated) by the starburst activity, which occured ∼10^{6}-10^{7} years ago at the galactic off-center.

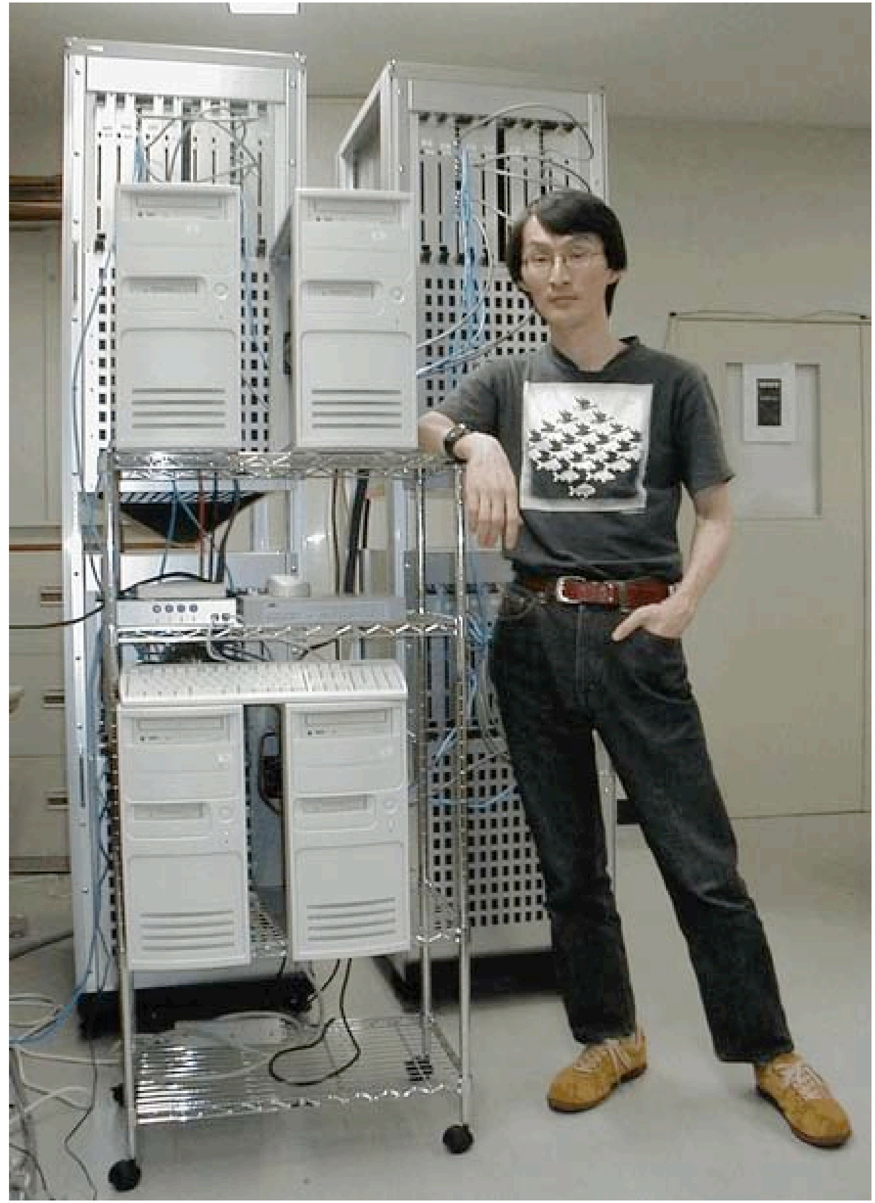


Matsushita et al. (2000)

GRAPE 重力多体計算機「グレープ」

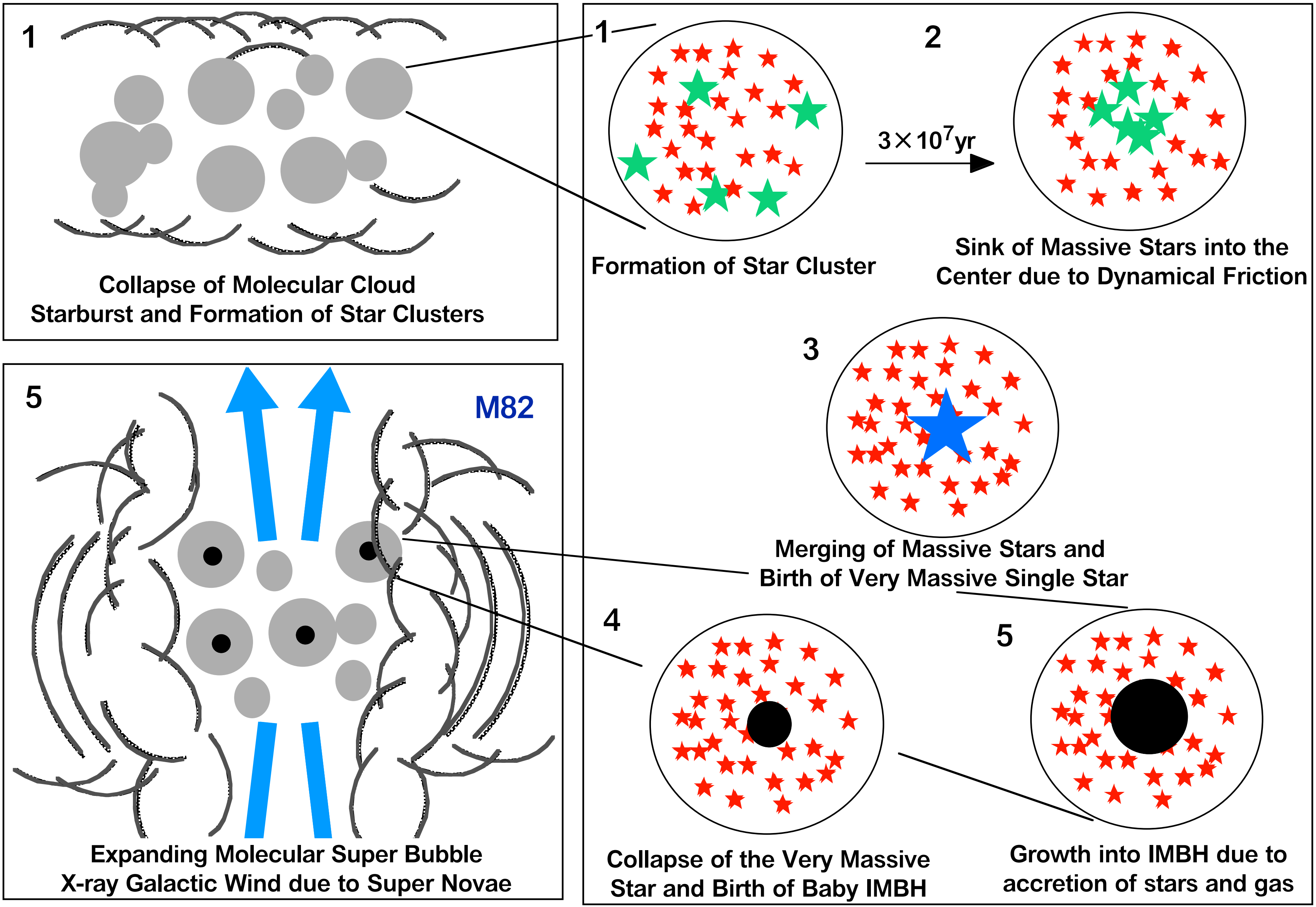
Formation Scenario of IMBH and SMBH based on N-body Simulation

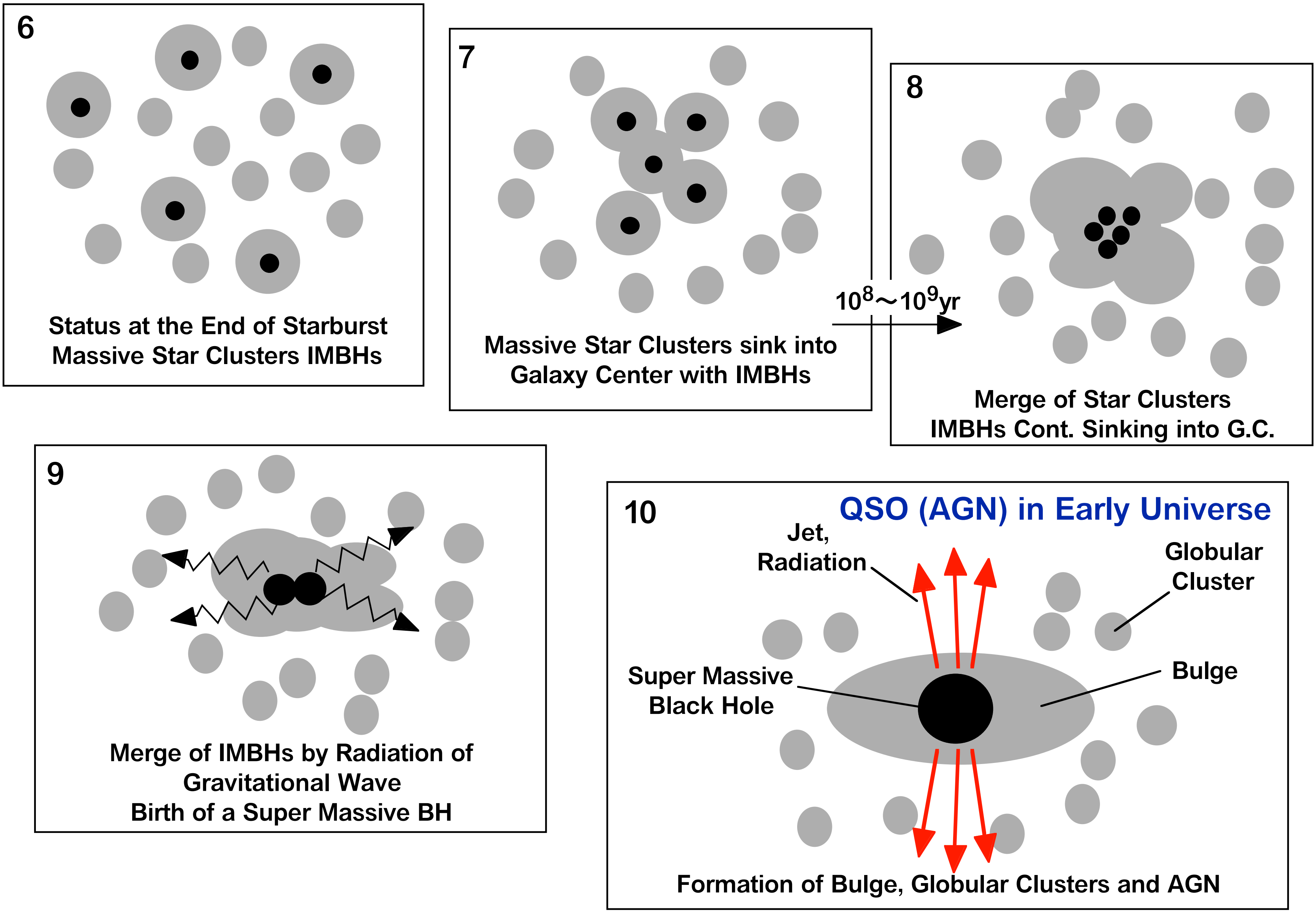
- Special Purpose Computer designed for Gravitational N-body Simulation
- GRAPE-6 reaches 100Tflops
- (Our study is based on the simulation done by GRAPE-4 with 1 Tflops)

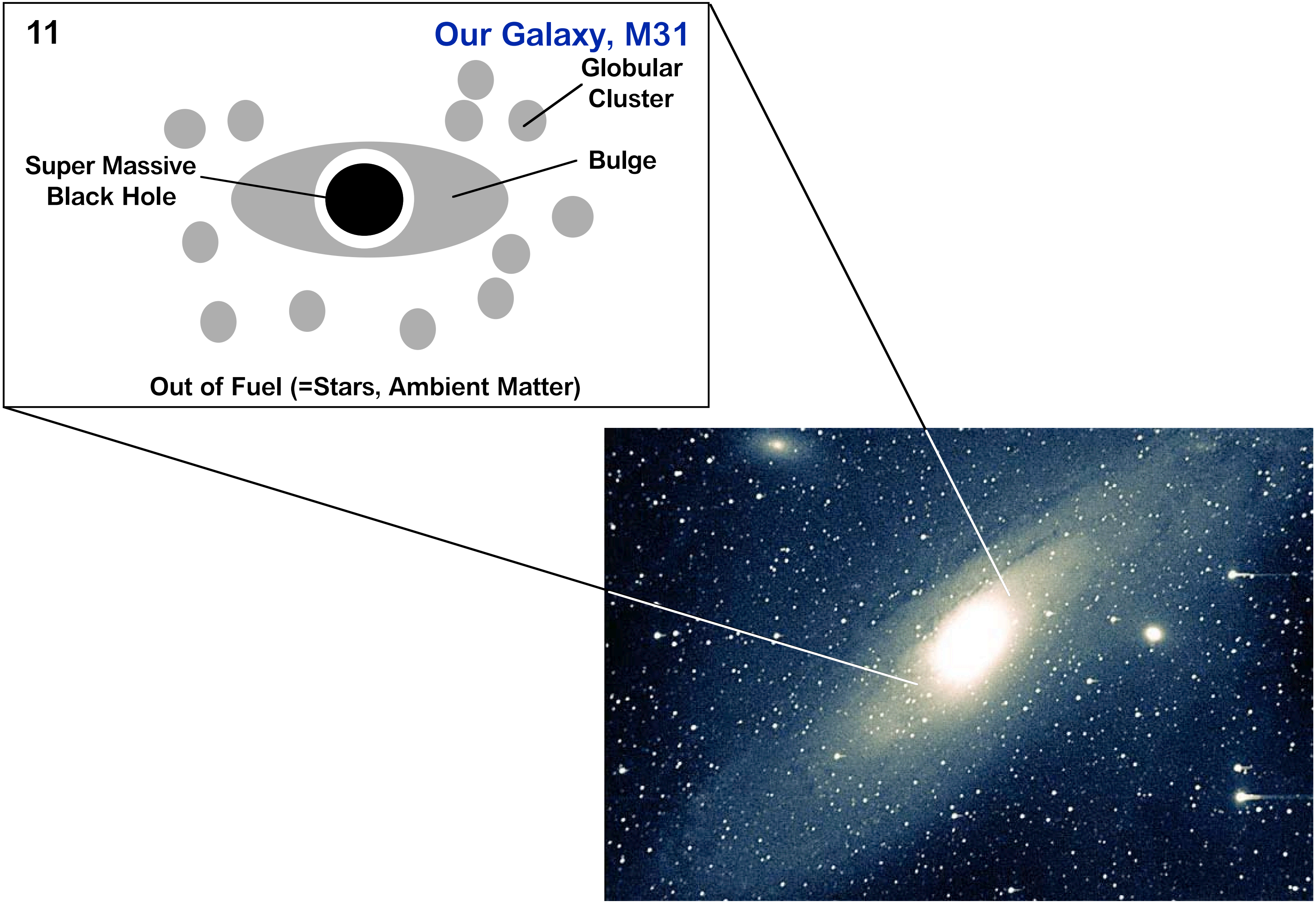


GRAPE-6 and Prof. Makino (Univ. of Tokyo), the leader of the GRAPE project.

Ebisuzaki et al. (2001)


1
Collapse of Molecular Cloud
Starburst and Formation of Star Clusters
1
Formation of Star Cluster
2
3×10^7yr
Sink of Massive Stars into the
Center due to Dynamical Friction
3
Merging of Massive Stars and
Birth of Very Massive Single Star
5
M82
Expanding Molecular Super Bubble
X-ray Galactic Wind due to Super Novae
4
Collapse of the Very Massive
Star and Birth of Baby IMBH
5
Growth into IMBH due to
accretion of stars and gas


6
Status at the End of Starburst
Massive Star Clusters IMBHs
7
Massive Star Clusters sink into
Galaxy Center with IMBHs
$10^8 \sim 10^9$yr
8
Merge of Star Clusters
IMBHs Cont. Sinking into G.C.
9
Merge of IMBHs by Radiation of
Gravitational Wave
Birth of a Super Massive BH
10
QSO (AGN) in Early Universe
Jet,
Radiation
Globular
Cluster
Super Massive
Black Hole
Bulge
Formation of Bulge, Globular Clusters and AGN


11
Our Galaxy, M31
Globular Cluster
Super Massive Black Hole
Bulge
Out of Fuel (=Stars, Ambient Matter)

Galactic TeV Gamma-Ray Halo of the Nearby Starburst Galaxy NGC253

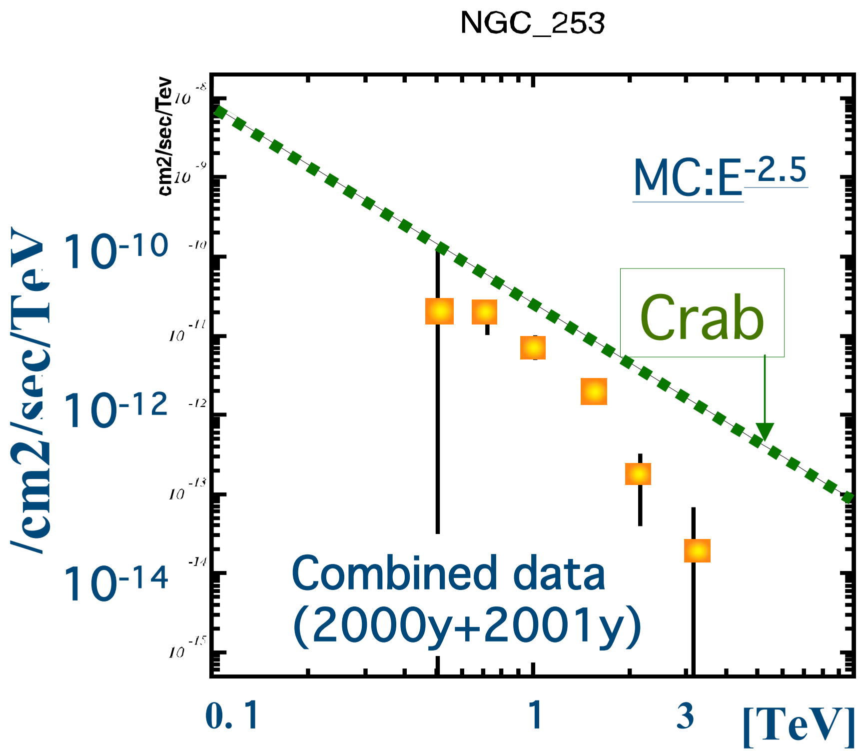
C.Itoh (Ibaraki Univ.), R.Enomoto (ICRR, Univ. of Tokyo), S.Yanagita,
T.Yoshida (Ibaraki Univ.), T.G.Tsuru (Kyoto Univ.)

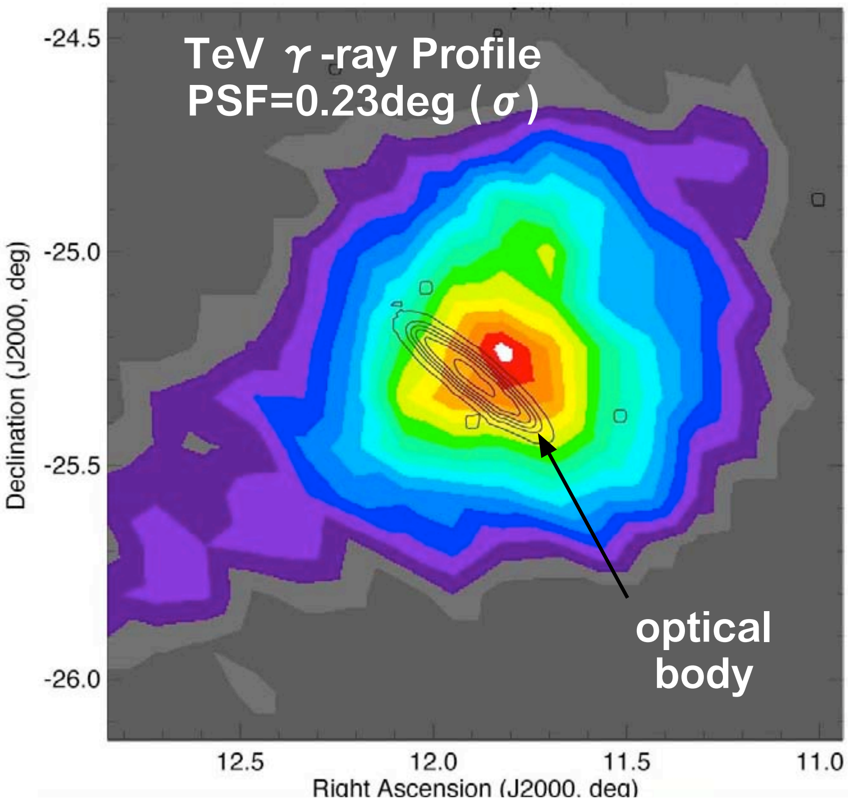
Outline

- □ TeV γ-ray emission from NGC253
- □ Multiwave-length Spectrum
- □ Possible Cosmic Ray Acceleration in the Halo
- □ Future Prospect

Itoh and CANGAROO corroboration, A&Ap Lett 396, L1 (2002)
Discovery of TeV γ-ray from NGC253
Itoh, Enomoto, Yanagita, Yoshida, Tsuru, ApJL 584, L65 (2003)
Multiwave-length spectrum and the origin of TeV γ-ray

Observation with CANGAROO (Itoh et al. 2002)





Detected in the both of observation of 2000 and 2001.

Emission is Extended ∼0.3deg(σ)=42'(FWHM)=32kpc(FWHM) @ 2.6Mpc

Disk major axis size∼18'(Full)=13.6kpc, X-ray halo size∼20'(Full)=15kpc

Radio

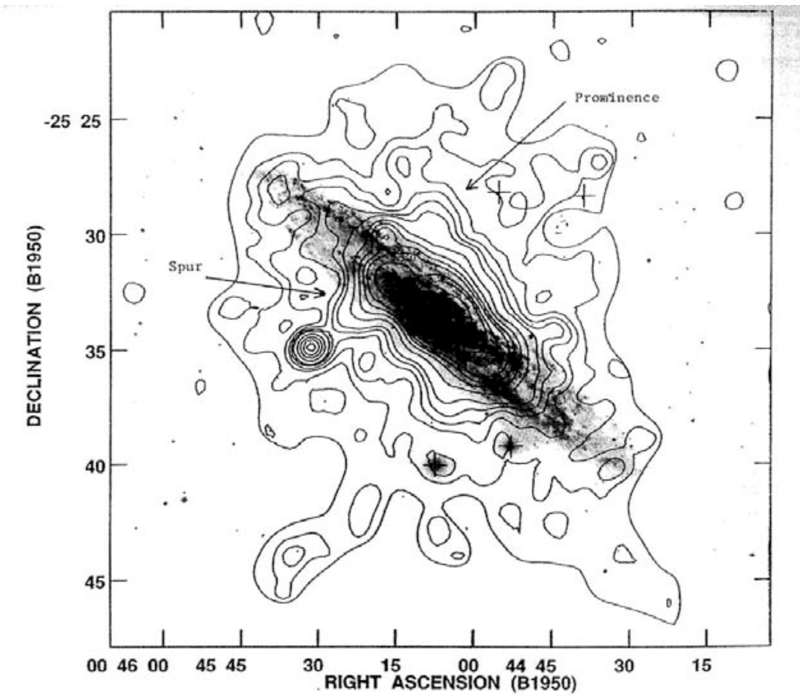


FIG. 2.—The same optical image as Fig. 1. The contours are now of total intensity from NGC 253 at 0.33 GHz with a resolution (FWHM) of 60". The off-source RMS is 3 mJy beam^{-1}, and the peak surface brightness is 4.12 Jy beam^{-1}. Contour levels are −12, 12, 24, 36, 48, 60, 90, 120, 150, 180, 240, 300, 600, 1200, and 2400 mJy beam^{-1} (excluding the outer most contour). The outermost contour is for an image convolved to 120" resolution. The level for this contour is 24 mJy beam^{-1}, or 3 times the off-source rms at this resolution.

Carilli et al. ApJL 399, L59 (1992)

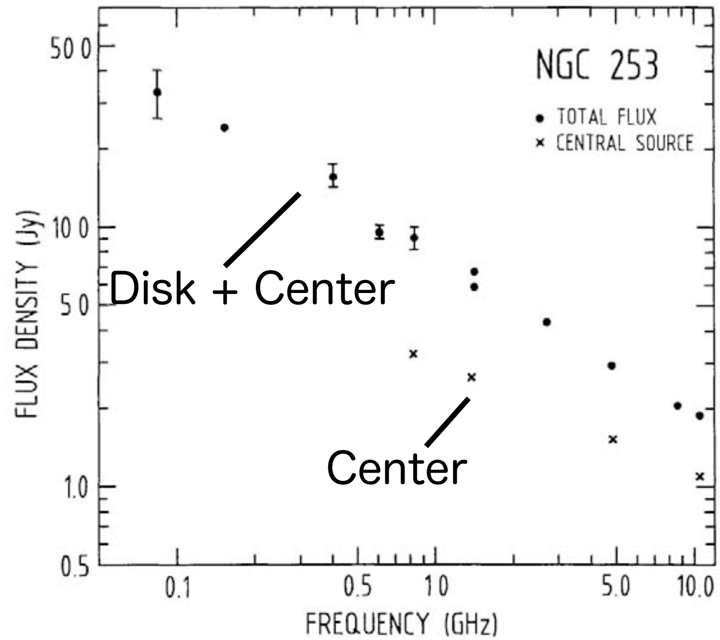
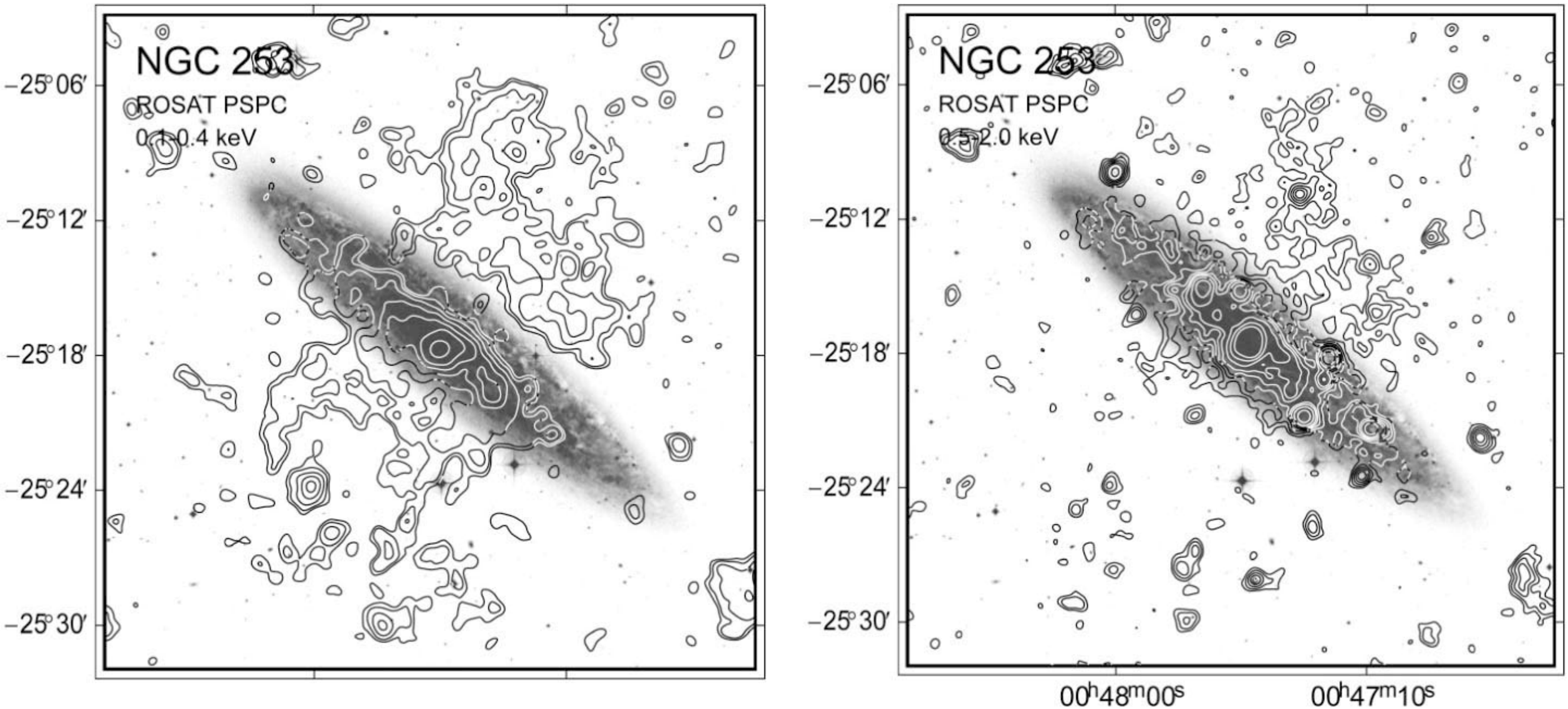


Fig. 3. The radio spectrum of the total emission (●) and of the peak flux of the central source (×). The latter are obtained from 71″ × 71″ maps at 1.46, 4.9, and 10.7 GHz and from a 92″ × 38″ (p.a. = 0°) map at 0.84 GHz

Hummel et al. A&A 137, 138 (1984)

- Faraday rotation and depolarization
  - Bar (disk) B(turb)=17μG (n_e=0.1-3 cm^{-3})
  - Halo B(turb)=6μG (ne=0.02 cm^{-3}), $B_{||}$=-2μG

ROSAT



ROSAT PSPC (0.1-0.4keV) ROSAT PSPC (0.5-2.0keV)

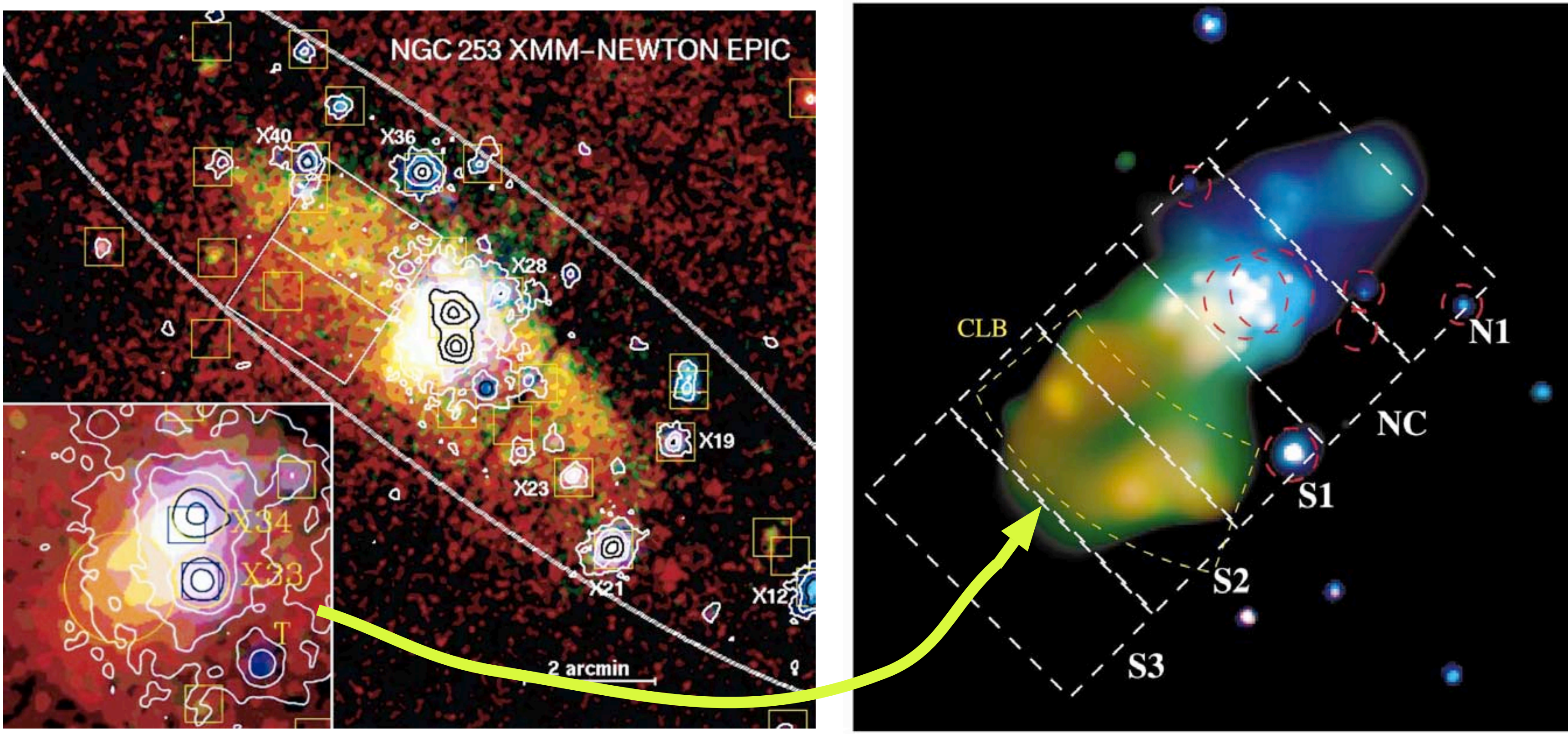
Pietsch et al. A&A 360, 24 (2000)

X-ray Emission = Center & Plume + Disk + Halo

"Rim brightening" in the halo.

"Jet like feature" along the minor axis.

XMM/CXO Image



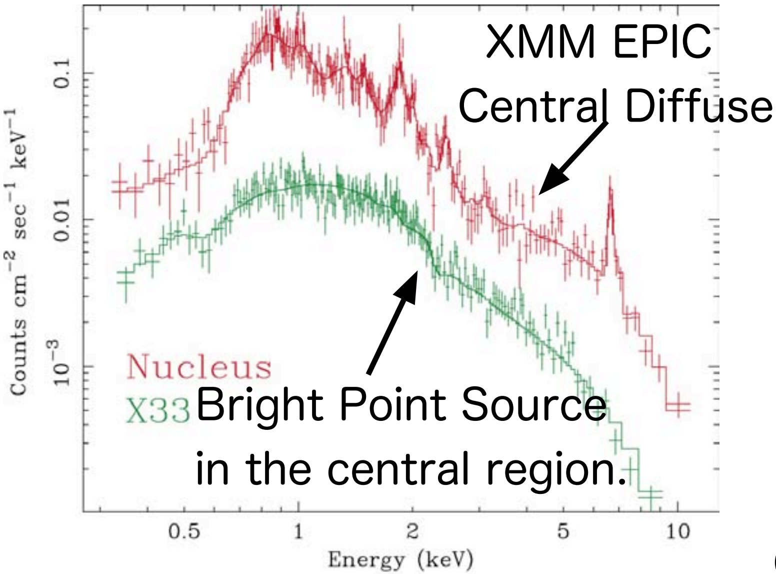
XMM-Newton
(R,G,B)=(0.2-0.5, 0.5-0.9, 0.9-2.0)
Contour=2-10keV

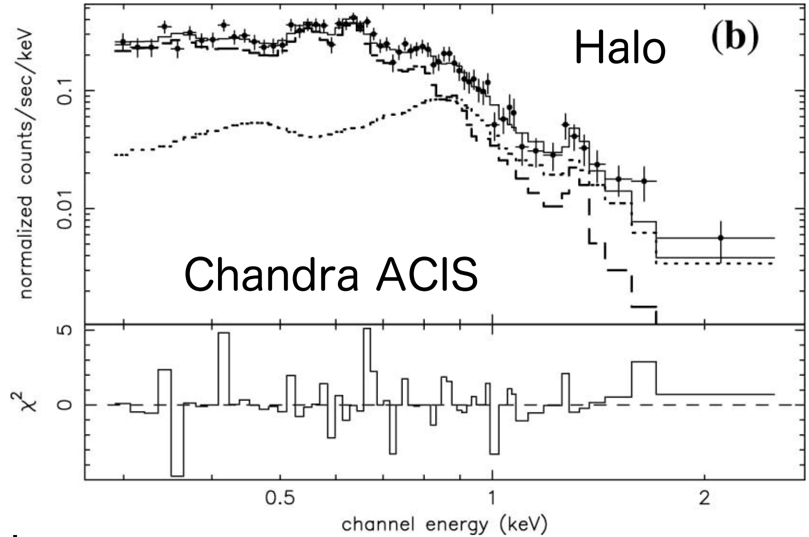
Pietsch et al. A&A 365, L174 (2001)

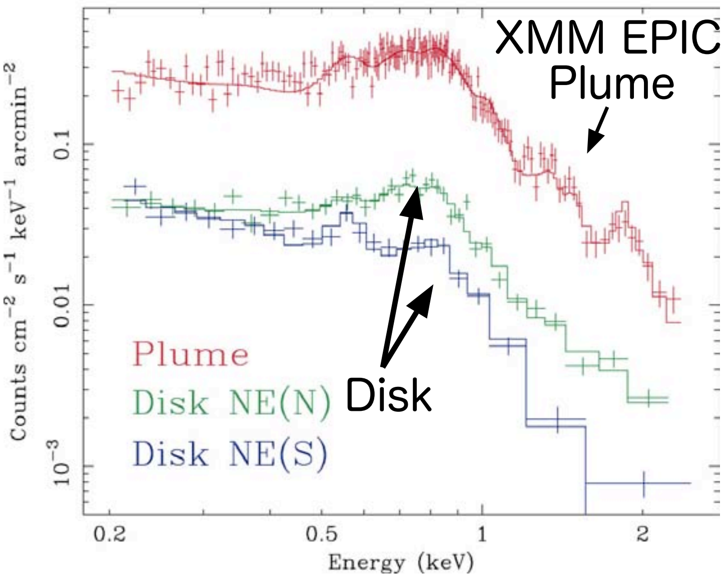
Chandra
Plume Region
(R,G,B)=(0.3-0.6, 0.6-1.1, 1.1-2.0)

Strickland et al. AJ 120, 2965 (2000)

X-ray Spectrum of Each Component







Center

- □ kT =0.6, 0.9, 6keV, nH=10^{22}cm^{-2}
- □ Fe 6.7keV

Plume, Disk, Halo

- □ kT=0.2keV, 0.5-0.7keV (CXO)
- □ Solar (XMM), Low Abundance(CXO)
- □ Disk : Halo : Plume = 1 : 1 : 0.15

Emission lines in the halo and disk

→ Thermal Emission dominates.

→ Upper limit on the Non-Thermal.

Pietsch et al. A&A 365, L174 (2001); Strickland et al. ApJ 568, 689 (2002)

BeppoSAX PDS, OSSE, EGRET

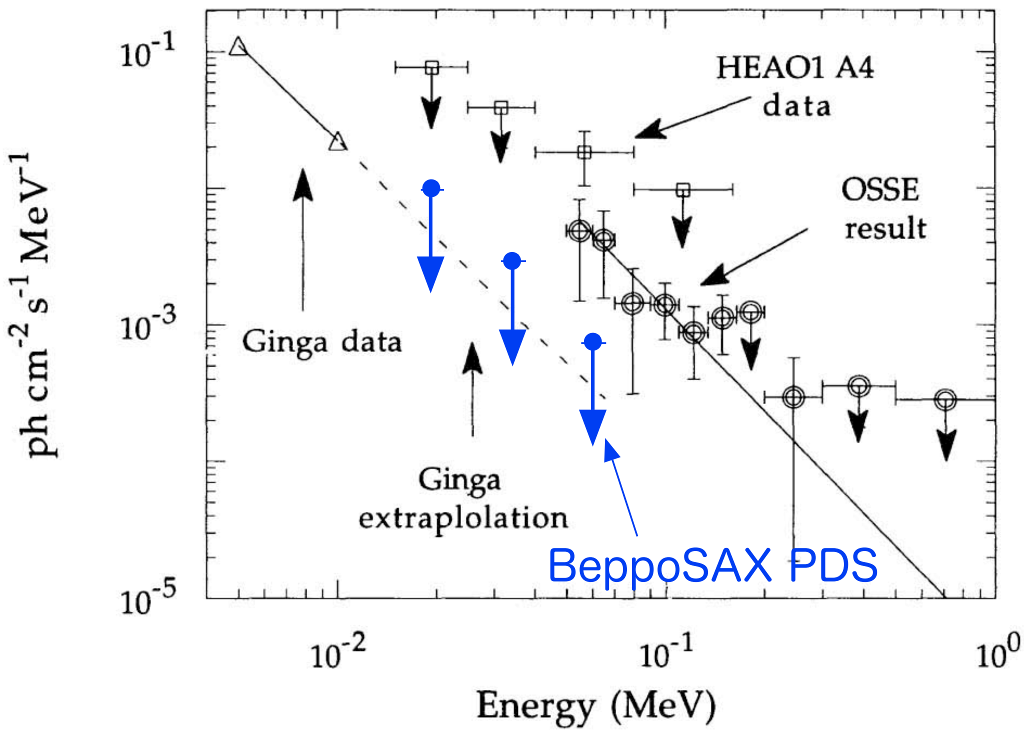
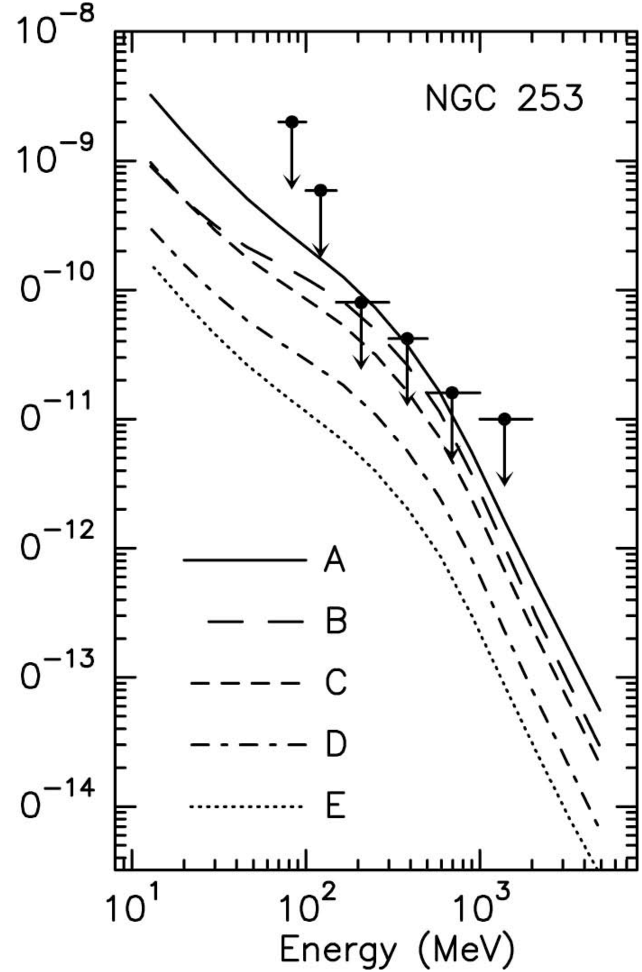


FIG. 1.—Derived photon fluxes for NGC 253. The *Ginga* X-ray points and their extrapolation to higher energies are also shown. *HEAO* A4 data and upper limits are also displayed for comparison.



EGRET

BeppoSAX : Cappi et al. A&A 350, 777 (1999)

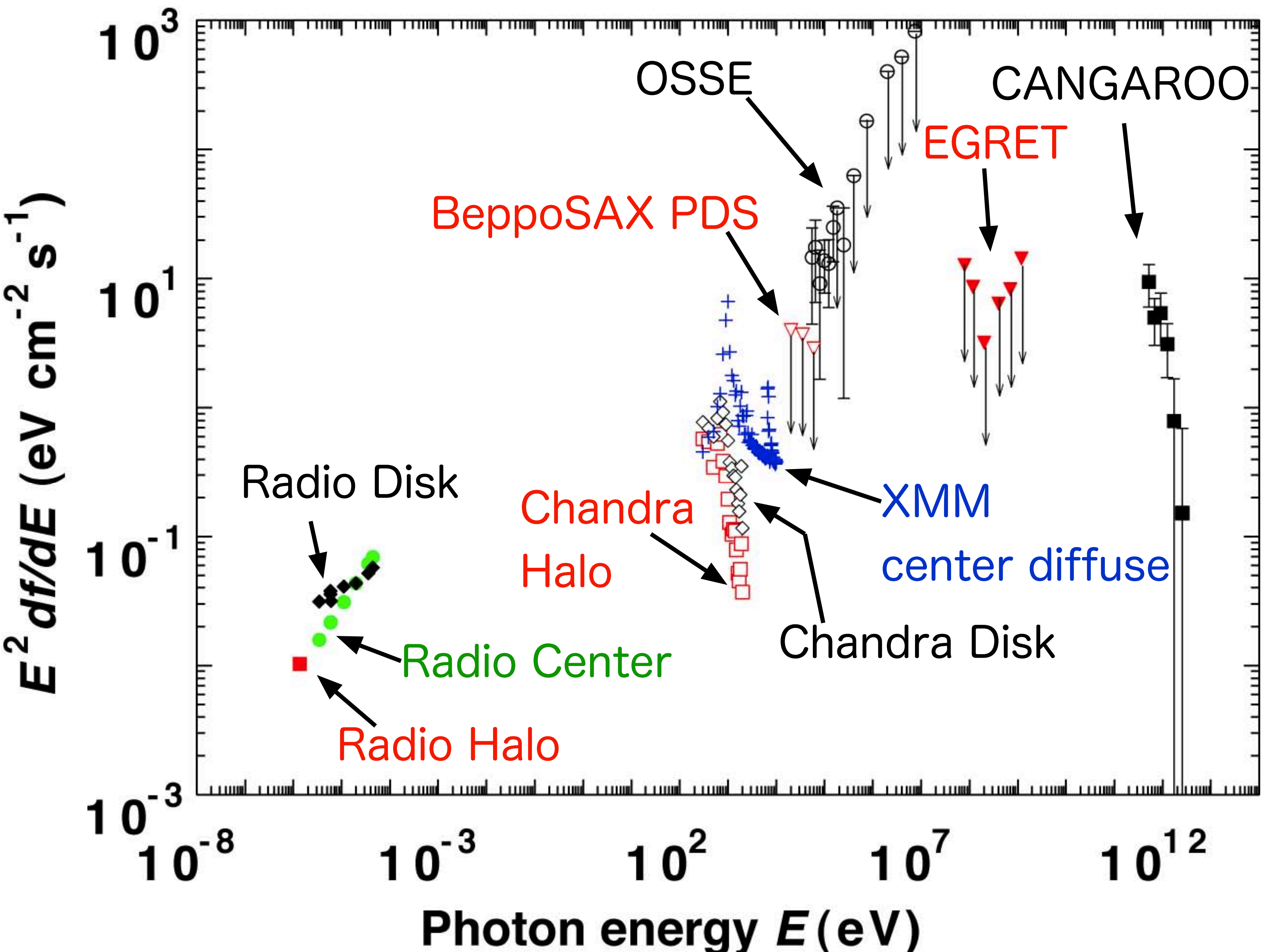
Ginga : Ohashi et al. ApJ 365, 180 (1990)

HEAO1 A4: Gruber and MacDonald (1993)

OSSE: Bhattacharya et al. ApJ 437, 173 (1994)

EGRET: Blom et al. ApJ 516, 744 (1999)

Multiwavelengths Spectrum of NGC253



Spectral Model

Synchrotron + π^0 decay

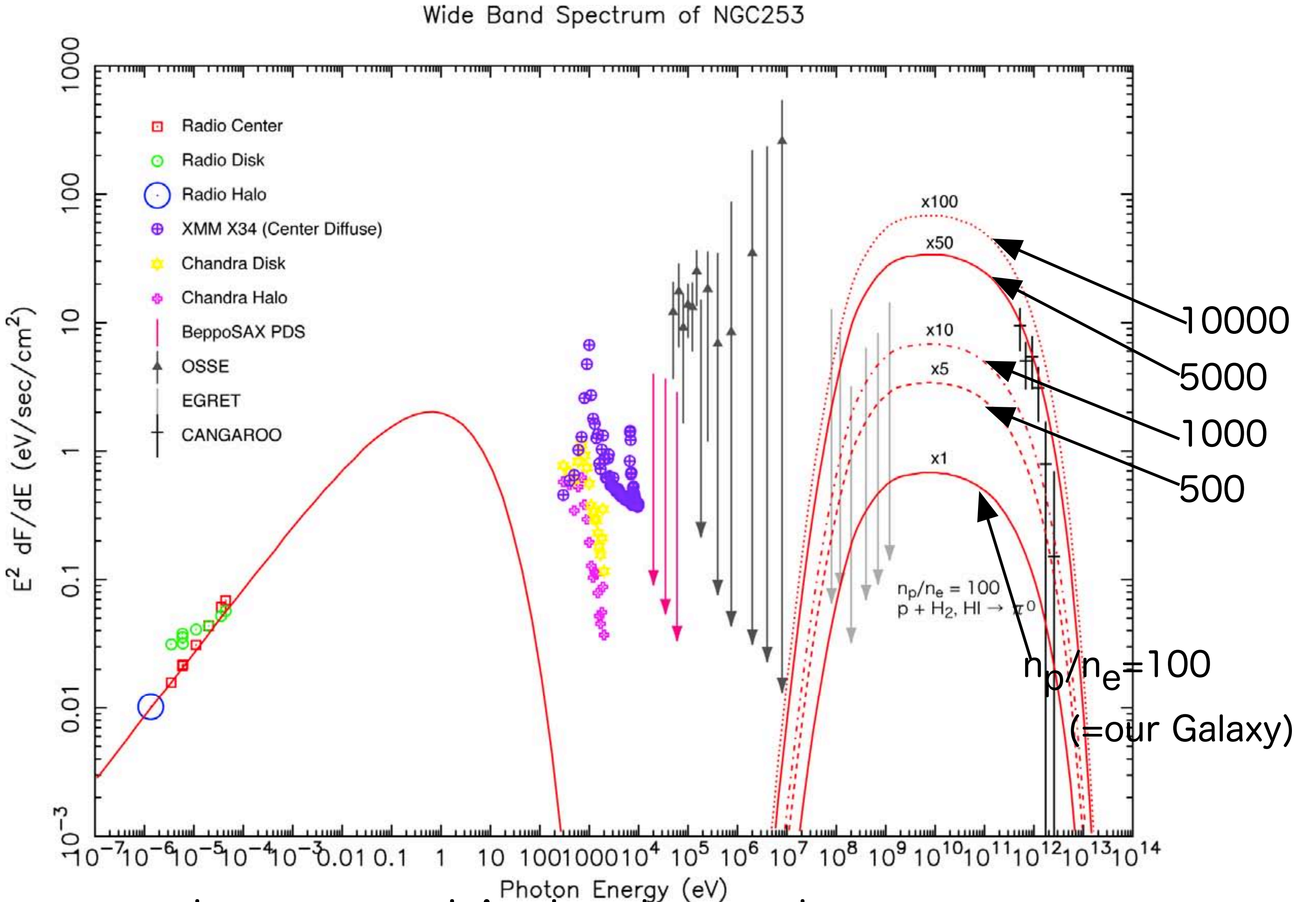
- □ High energy electron + B → Synchrotron
- □ High energy proton + ambient gas (H_2, H_I, H_{II}, X-ray plasma) $\to \pi^0 \to 2\gamma$

Synchrotron + Inverse Compton

- □ High energy electron + B → Synchrotron
- □ High energy electron + Soft Photon → Inv. Compton

Soft photons consist of CMB, FIR from starburst region, star light.

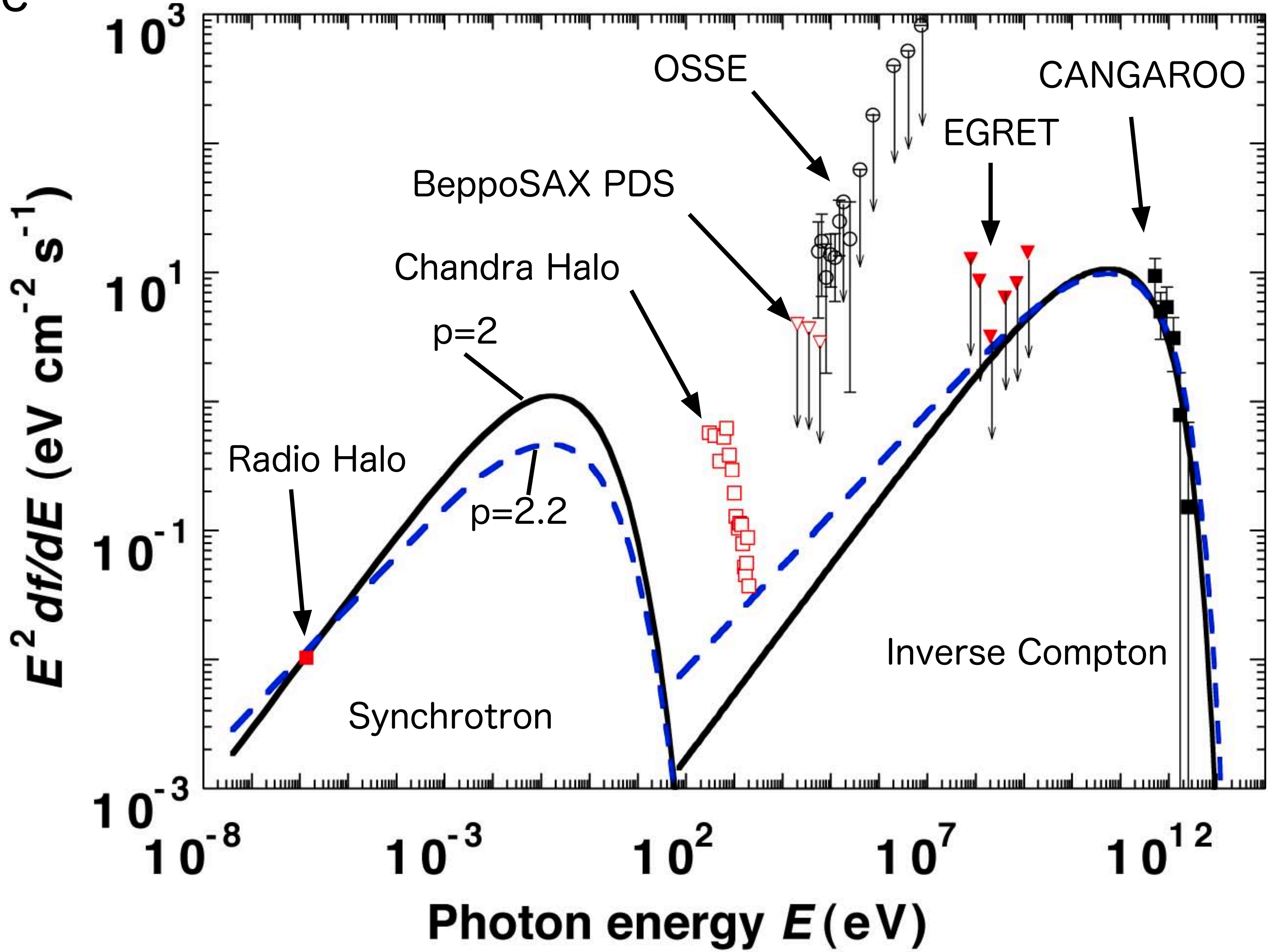
Synchrotron + π^0 decay



→ does not explain the observed spectrum

Sync. + IC in the Halo

$E_e(max)$=1.3～1.9TeV, B=2.5～1.7μG, FIR of NGC253



What is the Origin ?

TeV and Multiwave-length Observation

→ Evidence for the existence of high energy electrons in the starburst galaxy NGC253.

Where is the acceleration site ?

How about propagation ?

1. The acceleration is done in SNRs in the disk and/or galactic center. They propagate out to the halo or not.

2. (Re-)Acceleration itself is made in the halo.

Propagation out to the Halo

□ Acceleration in SNRs is effective.

□ Propagation of high energy electrons out to the halo due to the diffusion.

Diffusion length $R_L \sim 2(\kappa \cdot t_{cool})^{1/2}$ [cm]

diffusion coefficient $\kappa = 3\times10^{29}(E/GeV)^{0.6}$ [cm^2/sec]

Synch. + IC cooling time $t_{cool} = E_e/(P_{sync} + P_{IC})$

E_e = 1TeV diffuses up to R_L=9kpc before cooling due to B=2.9μG and the FIR of NGC253. ～ Size of the halo

↓

The high-energy electrons can not be confined in the disk or central region, but should be extended in the halo. This result supports the idea that TeV γ-rays come from the halo.

Shock Acceleration in the Halo

<u>Observational Results</u>

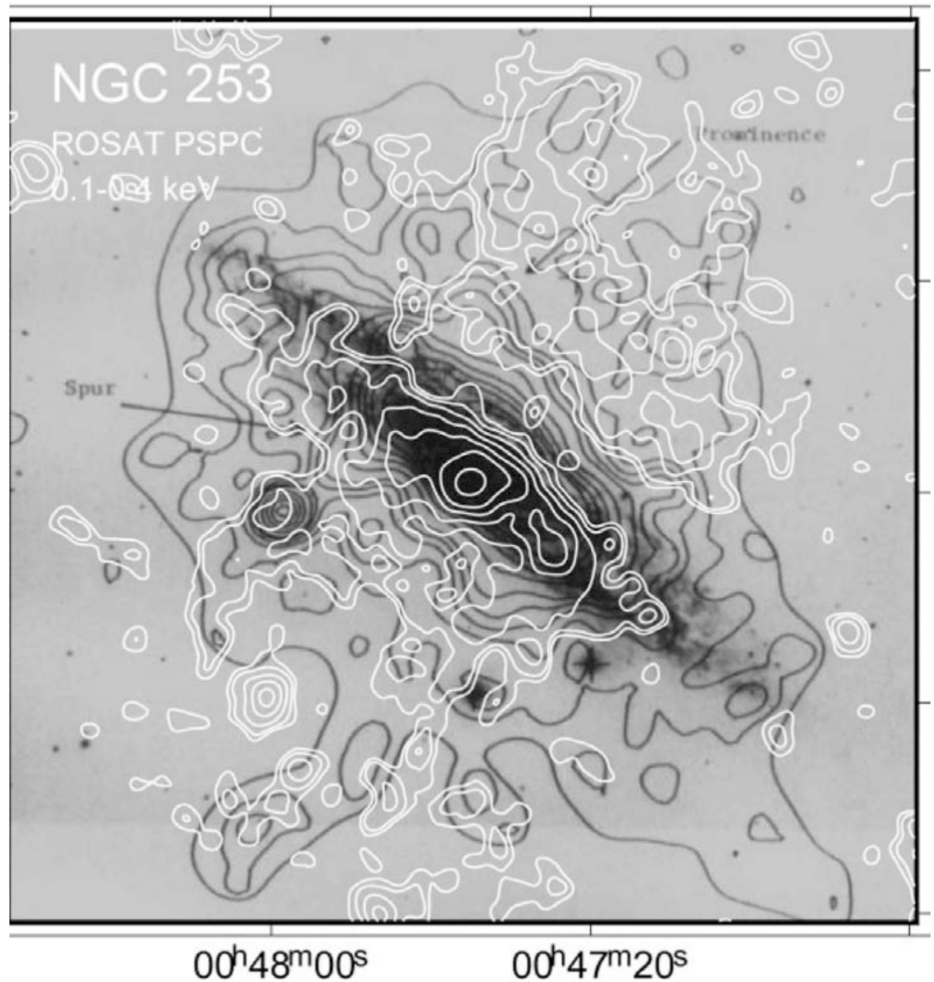
Soft X-ray halo is made due to the galactic wind.

The radio is from synchrotron emission of the high energy electron.

These two images match each other.

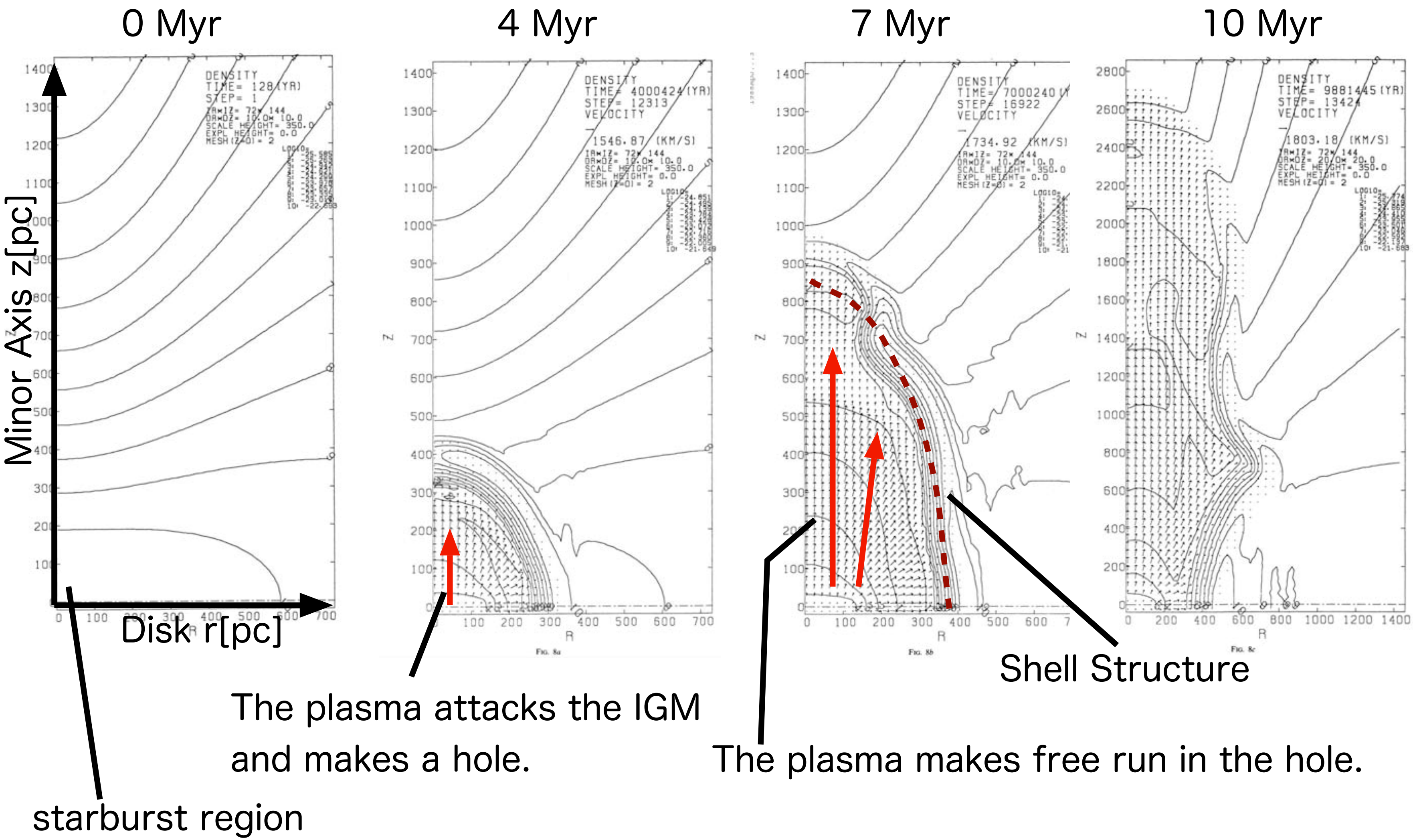
<u>Numerical simulations</u>

The simulations show that the galactic wind collides the IGM and forms shock wave.



Pietsch et al. A&A 360, 24 (2000)

Hydrodynamic Simulation (1)



Tomisaka, Ikeuchi ApJ 330, 695 (1988) : Model C

Hydrodynamic Simulation (4)

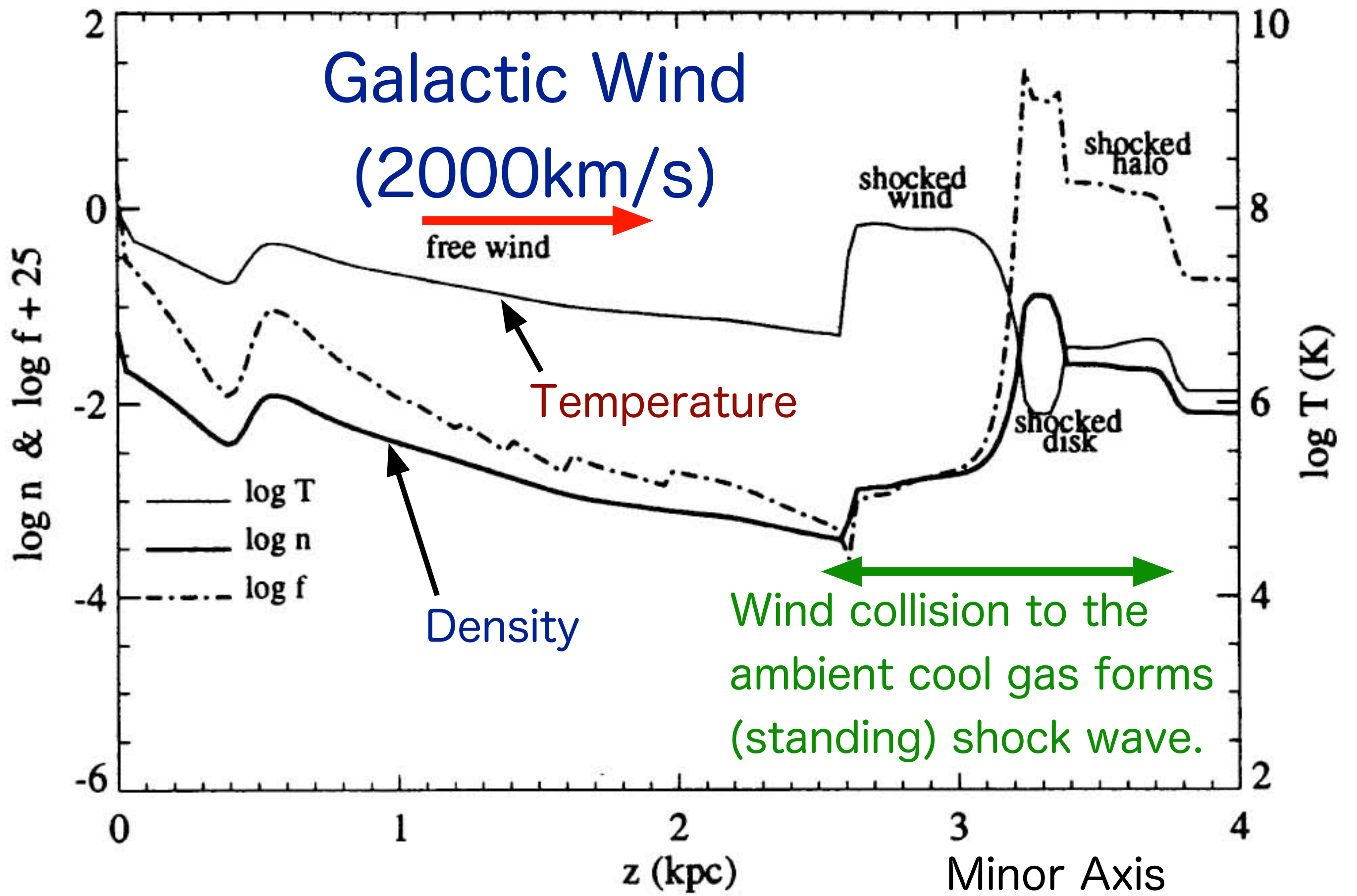


FIG. 5.—Temperature, density, and 0.1–2.2 keV X-ray emissivity profiles along the minor axis at 8.3 Myr in model A1. The units for density and X-ray emissivity are cm^{-3} and ergs cm^{-3} s^{-1}, respectively. The regions occupied by the free wind, shocked wind, shocked halo, and shocked disk material are indicated.

Suchkov et al. ApJ 430, 511 (1994) : Model A1 @ 8.3Myr

Electron Acceleration in the Halo

Shock Acceleration Parameters

- □ The speed of the galactic wind ～2000km/s.
- □ The starburst age of NGC253 $\sim 10^7$yr.
- □ Cooling due to FIR & CMB + Magnetic files
- □ Magnetic field : B(radio, halo)=6μG, B(this work)=1.7～2.5μG

Maximum Acceleration Energy in the Halo

- □ Maximum acceleration energy within the starburst time.

→ 3700TeV $(10/\xi)(V_S/2000\mathrm{km/s})^2(B/2\mu G)(\tau/10^7\mathrm{yr})$

- □ Maximum acceleration energy given by cooling = acceleration.

→ 8TeV$(U_B+U_{ph}/1.7\mathrm{eV/cm^3})^{-0.5}(V_S/2000\mathrm{km/s})(B/2\mu G)^{0.5}(10/\xi)^{0.5}$

↓

explains the observation (1.3～1.9TeV) well.

Total Energy of the Cosmic Ray

Total Cosmic Ray Energy

- □ Total electron energy = $5.9\times10^{54} \sim 2.4\times10^{55}$ergs
- □ Assuming our galaxy's value of $n_p/n_e \sim 100$
- □ Total CR energy = $5.9\times10^{56} \sim 2.4\times10^{57}$ergs ～100×Our Gal.

⇔ X-ray Halo in NGC253: $E_{Th}=6\times10^{55}$ergs, $E_{Kin}=5\times10^{56}$ergs

Energy Input by Starburst Activity

- □ SNe rate = 0.3SNe/yr, Age = 10^7yr
- □ Total Energy Input

$$= 3\times10^{56}\text{ergs}\ (f/0.1)\ (\text{SN rate}/0.3\text{SNe/yr})\ (\tau/10^7\text{yr})\ (E_{SN}/10^{51}\text{ergs})$$

↓

The starburst activity can supply the total energy of the cosmic rays.

Max. Acceleration Energy of Proton

(My own personal view)

Total and Maximum Energy of CR (proton).

- ☐ E_p(max) ~ 3700TeV in NGC253 ~ "knee" in our galaxy.
- ☐ E(total) ~10^{57}ergs in NGC253 ~ 100×E(total) in our galaxy.

Starburst Activity in Our Galaxy

- ☐ Plasmas with kT~10keV exist in the GC. ⇔ NGC253
- ☐ Mild starbursts in ~10^{7}yr (and ~10^{8}yr) with ~10^{55}ergs (obtained by MIR obs.) in the GC. ⇔ 3×10^{56}ergs in NGC253

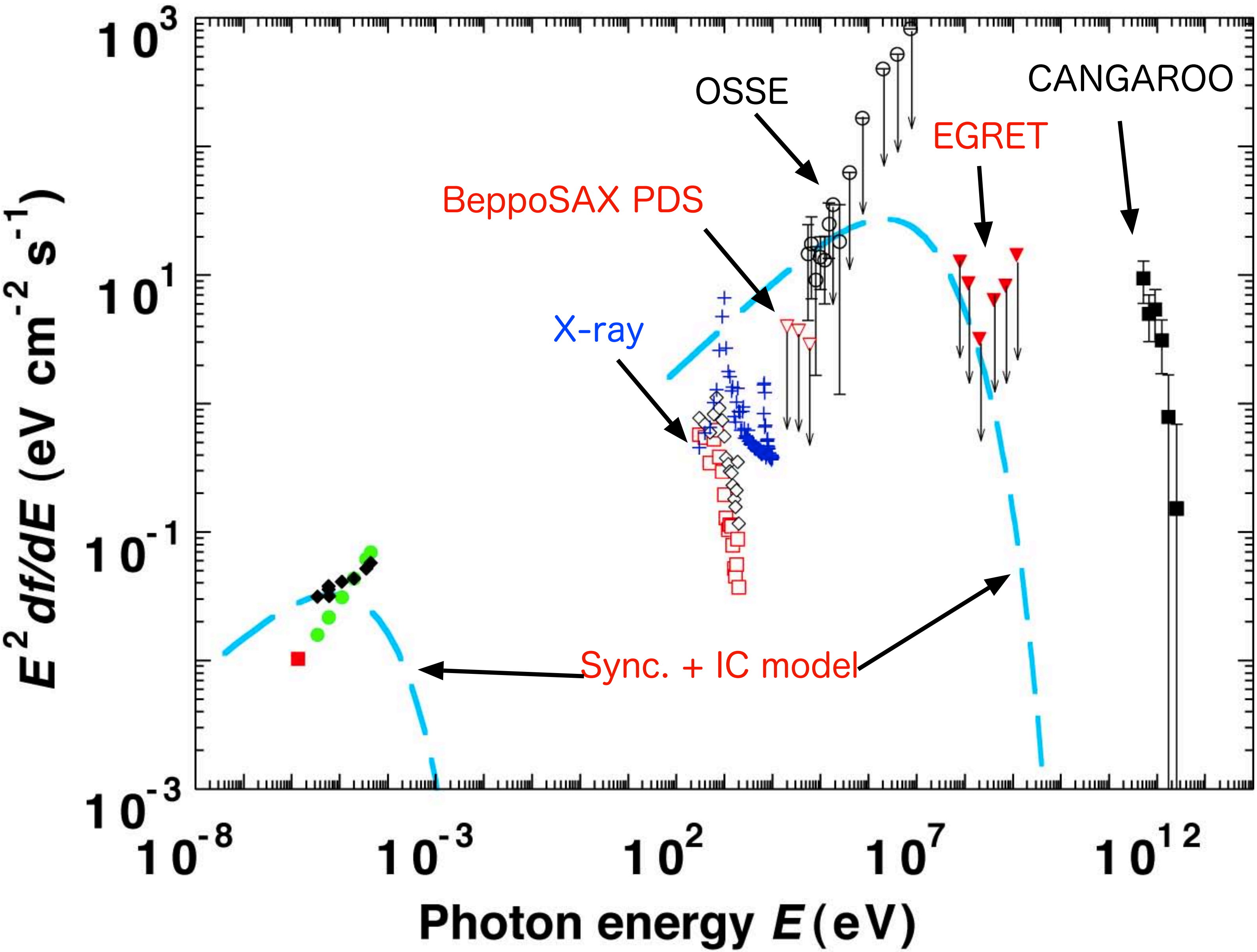
The scale of starbusrt is smaller than NGC253.
However, the physical status is very similar.

↓

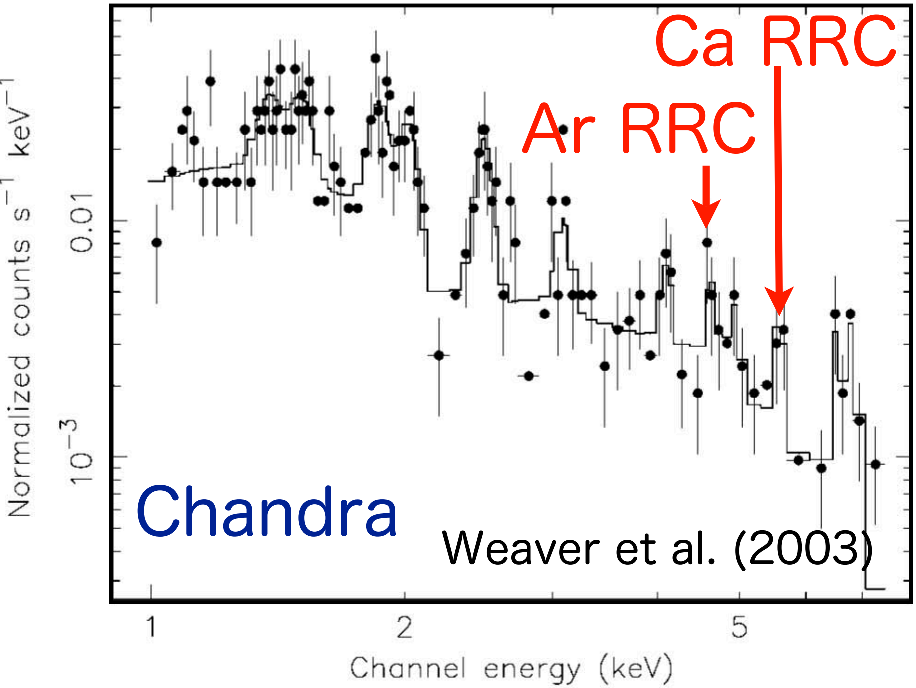
The Cosmic Rays in our Galaxy would be accelerated in the halo due to the starburst activity within ~ 10^{7}yr in our Galaxy !

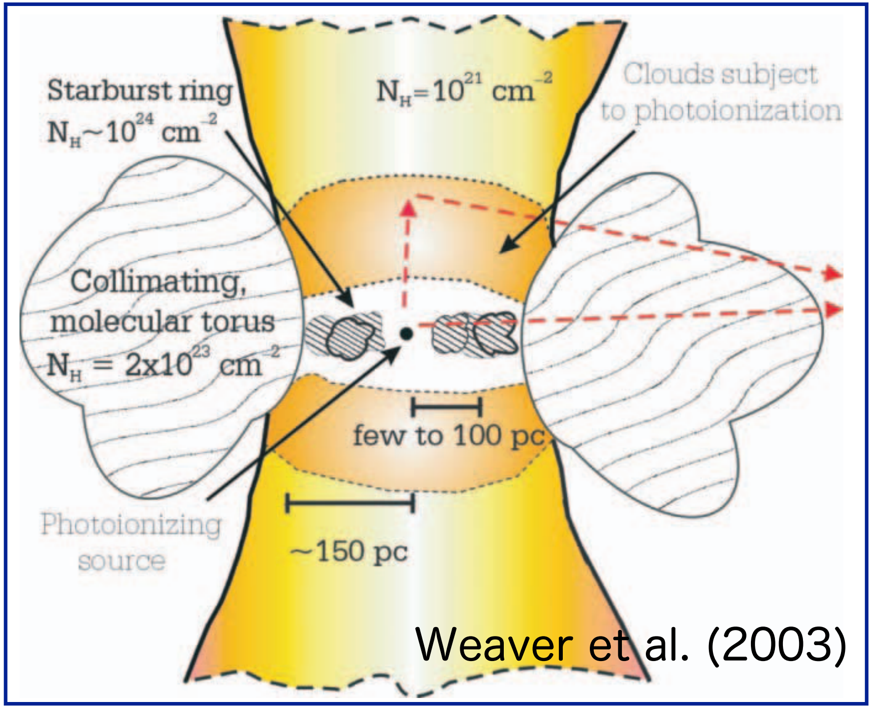
(eg. Jokpii and Morfill 1985)

What is origin of the MeV γ-ray ?



NGC253 photoionized plasma (?)



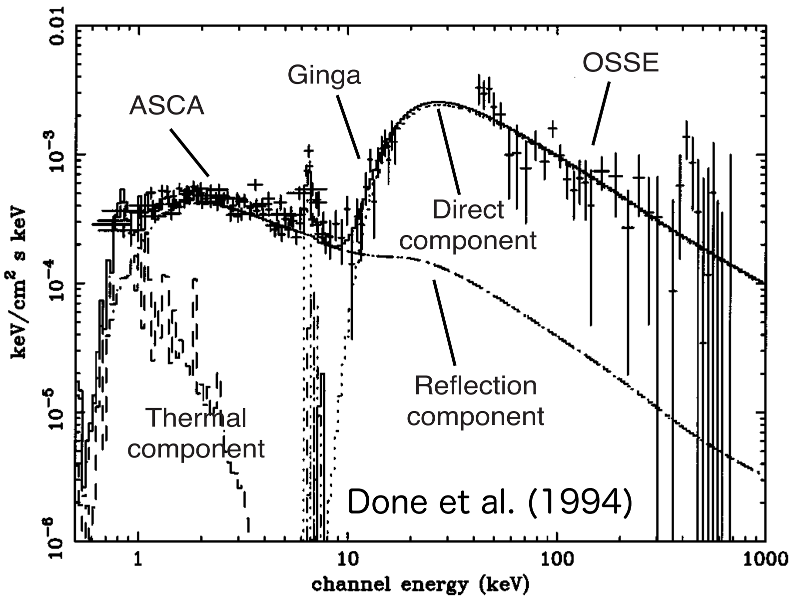


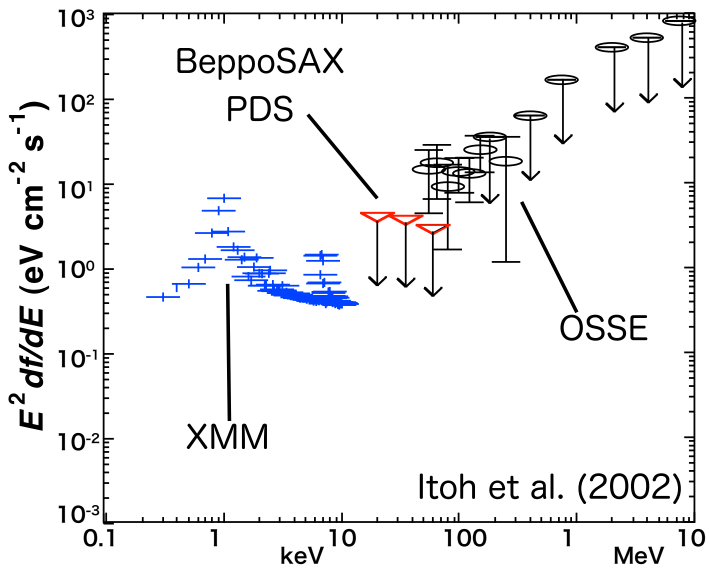
Radiative recombination continuum ?

Weaver et al. (2003) reports;

- X-ray spectrum at the NGC253 center shows the characteristic emission lines from photo-ionized plasma irradiated by strong X-rays.
- There is a strongly absorbed IMBH or LLAGN.

Absorbed IMBH or SMBH in NGC253

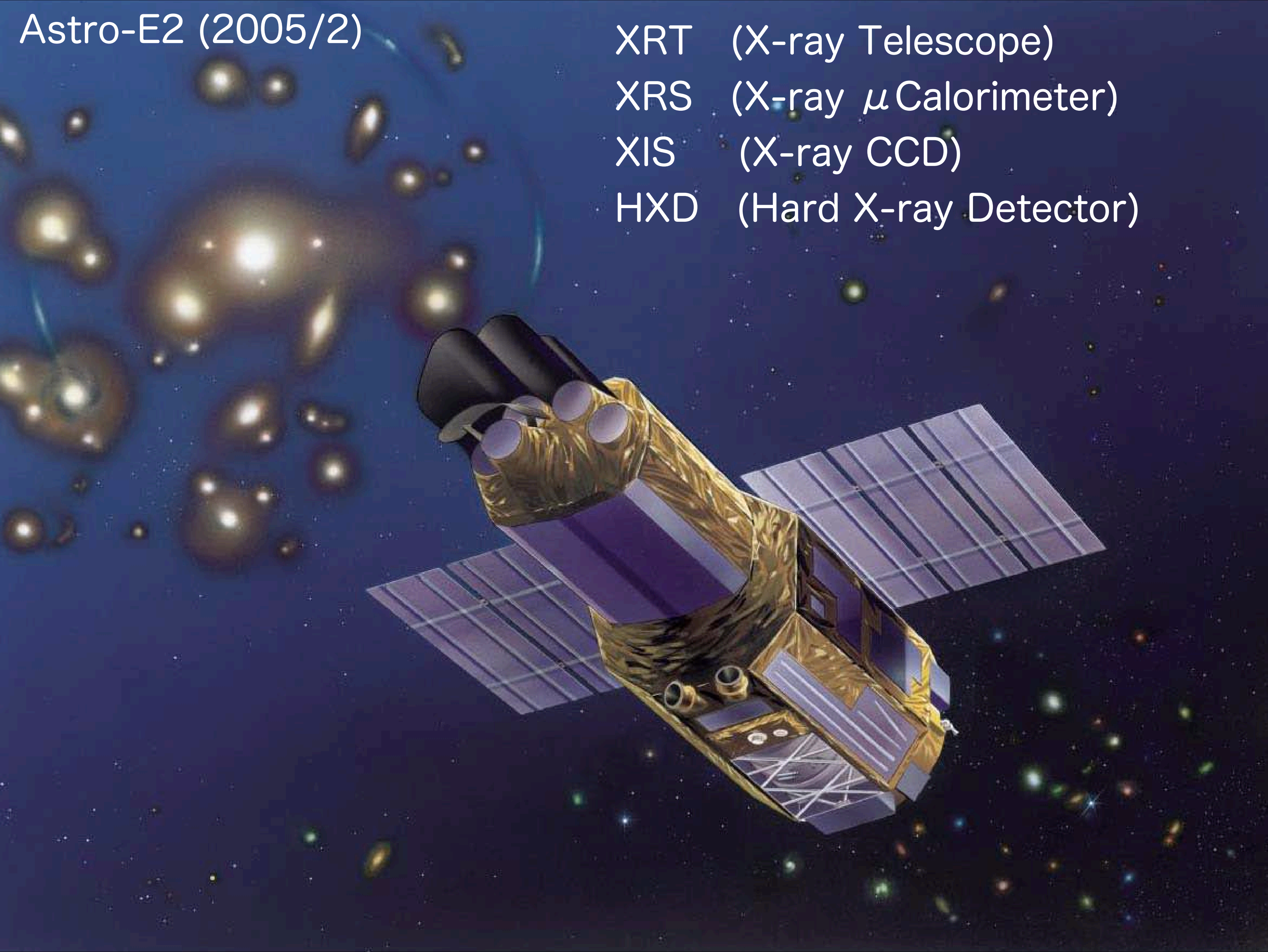




- Heavy absorption (~10^{24}cm^{-2}) as seen in NGC4945 solves the contradiction between X-ray and MeV (Done et al. 1994).
- Very Similar Spectrum is seen in NGC253.

⇩

- Is an absorbed IMBH or SMBH forming at the galactic center of NGC253 ?


Astro-E2 (2005/2)
XRT (X-ray Telescope)
XRS (X-ray μCalorimeter)
XIS (X-ray CCD)
HXD (Hard X-ray Detector)

NGC253 Non-Thermal Emission

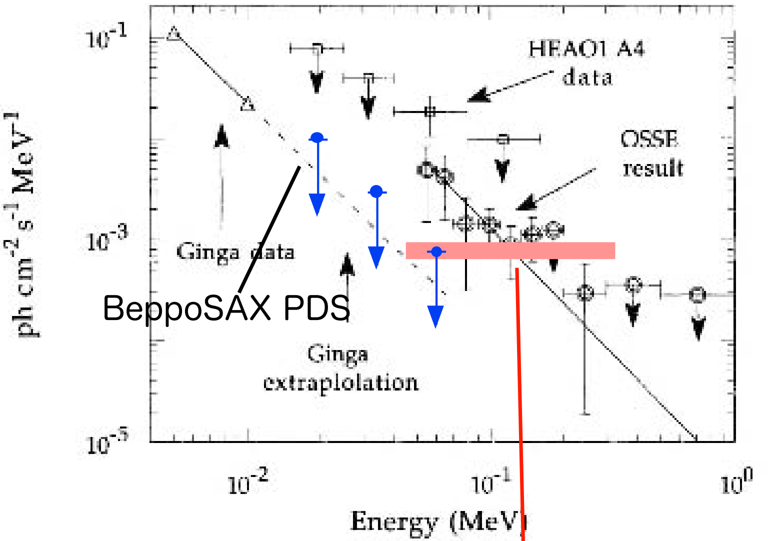
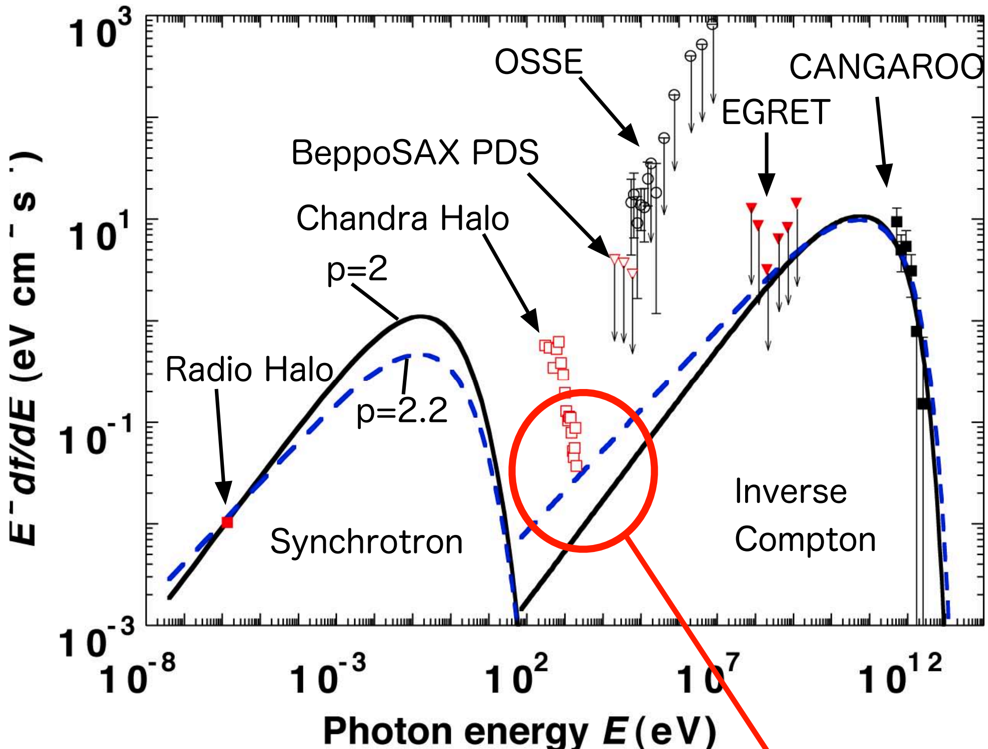


FIG. 1.—Derived photon fluxes for NGC 253. The *Ginga* X-ray points and their extrapolation to higher energies are also shown. *HEAO* A4 data and upper limits are also displayed for comparison.



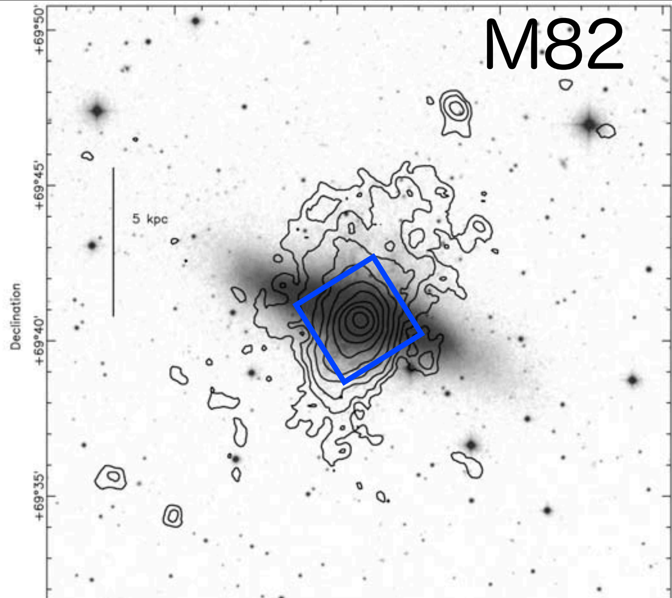
HXD Detection Limit

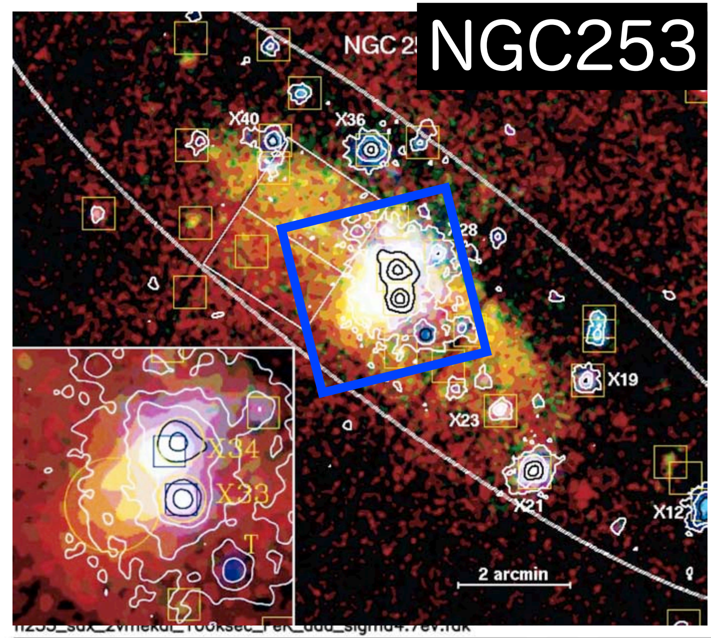
Confirm (or deny) OSSE result.

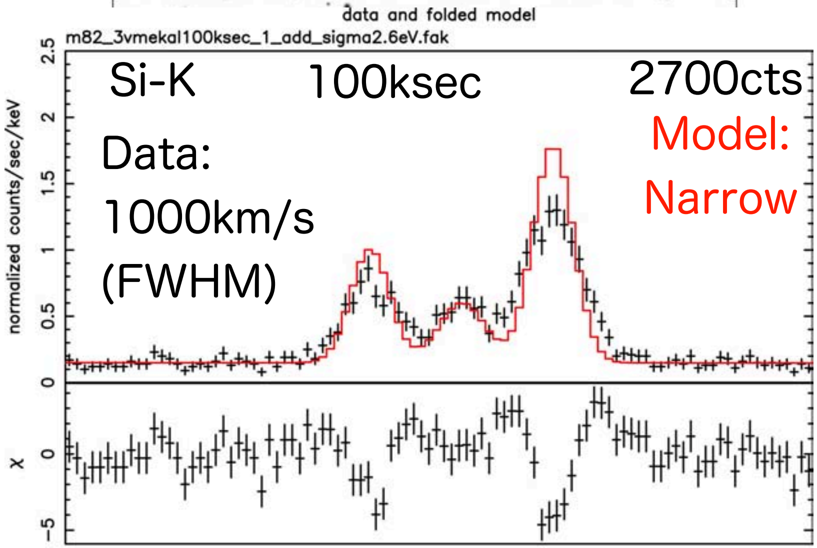
Non-Thermal (IC) Halo

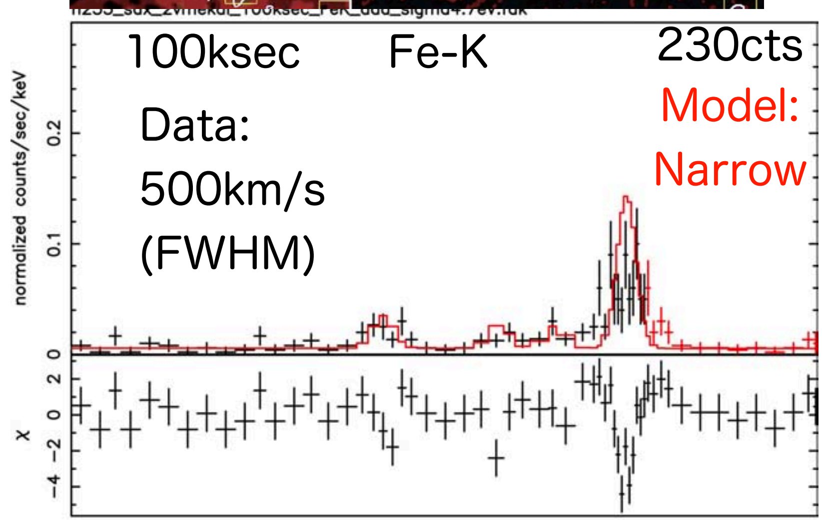
Search for the Sub-MeV γ-rays. (Is this the hidden photoionizing source ?)

Search for the IC halo in the X-ray band.



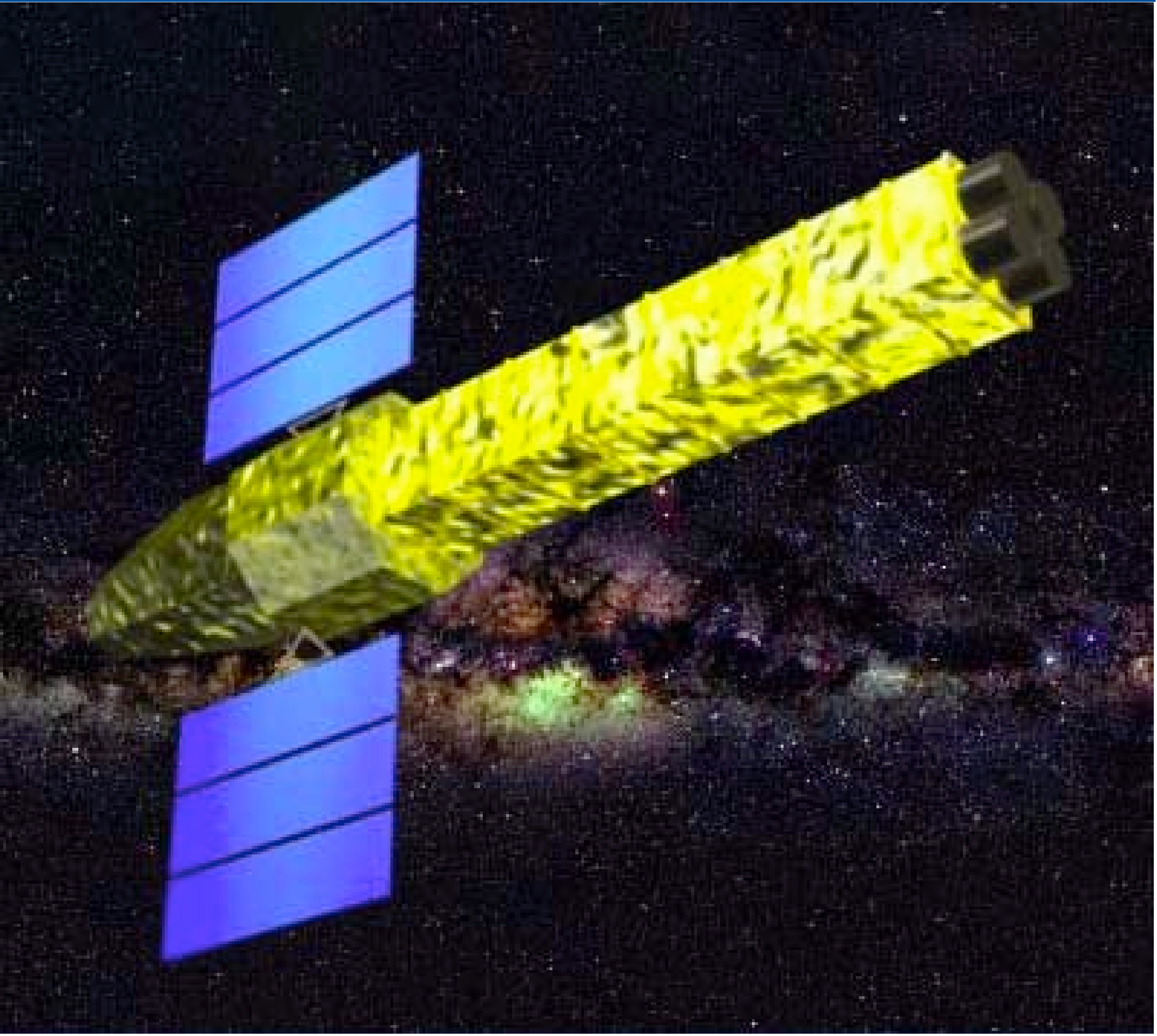






Detect the line broadening by turbulence > 600km/s for M82, > 300km/s for NGC253 (FWHM) at the 3σ confidence level. Try detection of line center shift due to the dopplar shift of the wind along the minor axis.

NeXT計画

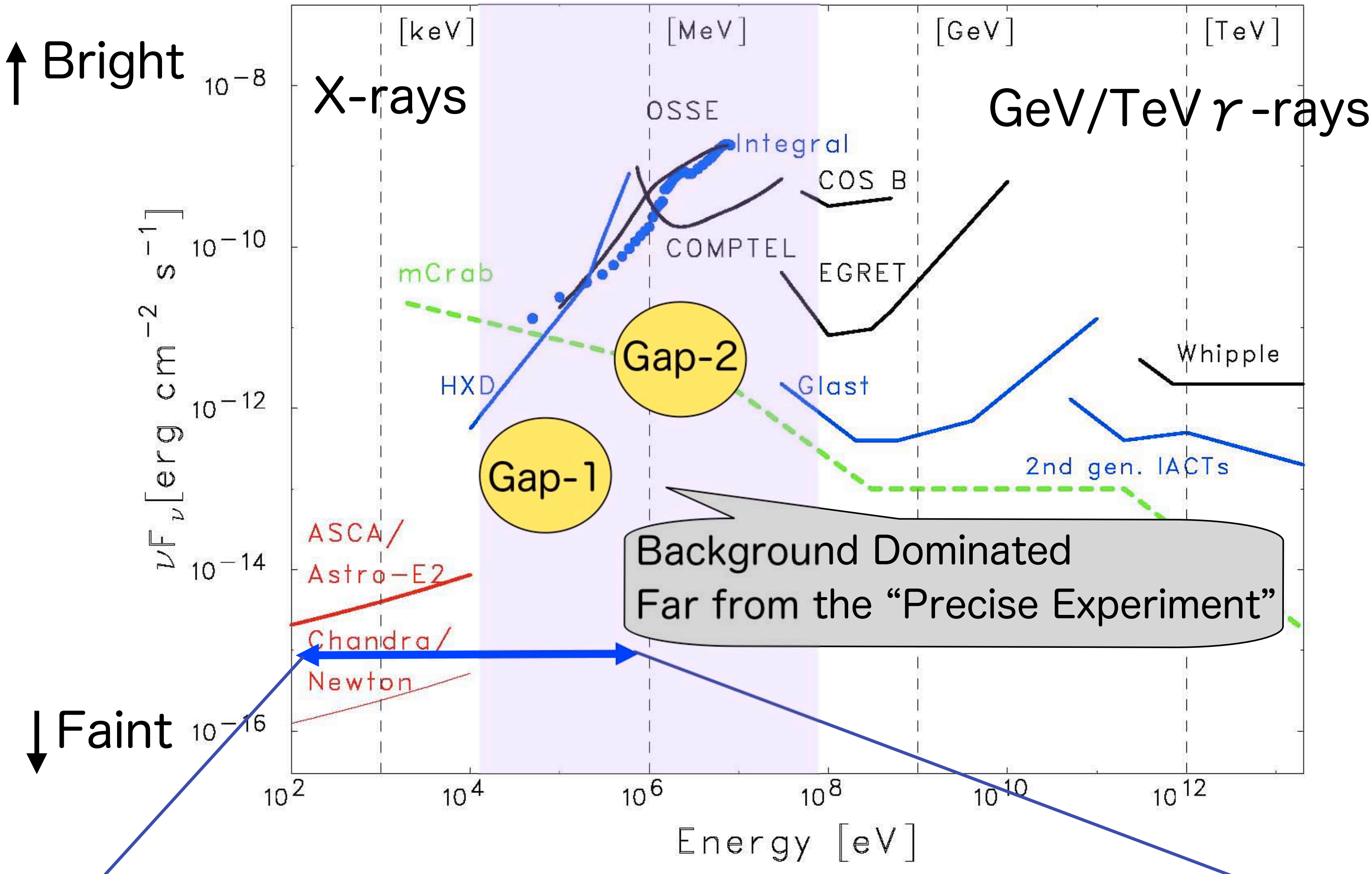


次期X線天文衛星
ワーキンググループ

2010年の打ち
上げをめざして

2004.1.8 宇宙科学シンポジウム

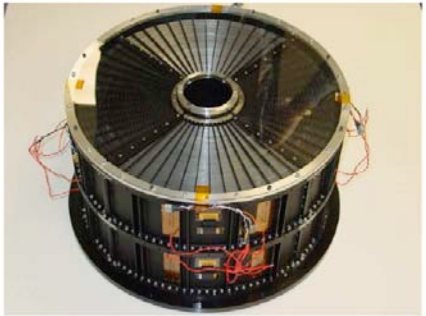
- The sensitivity gap -

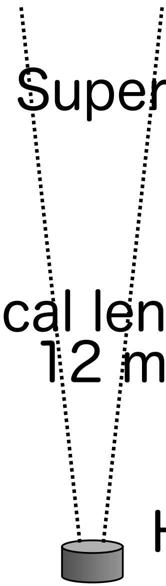


The NeXT (New X-ray Telescope) mission

(6th X-ray satellite in Japan, hope to be launched in 2010, with possible US participation)

NeXT衛星における硬X線撮像

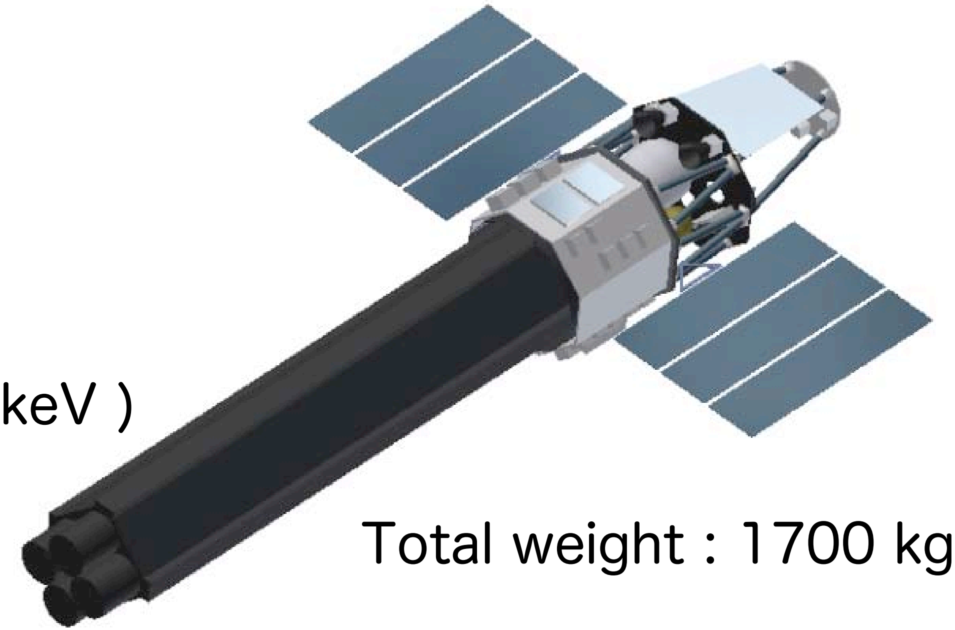




Super Mirror (0.5-80 keV)
30’’ HPD

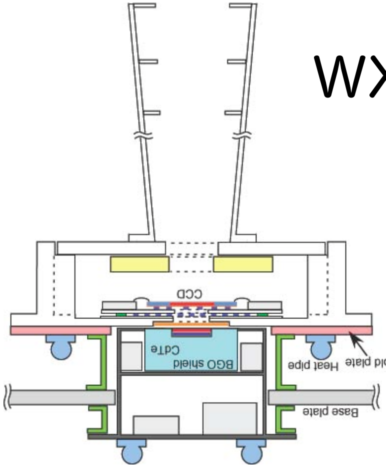
focal length
12 m

Hard X-ray Imager



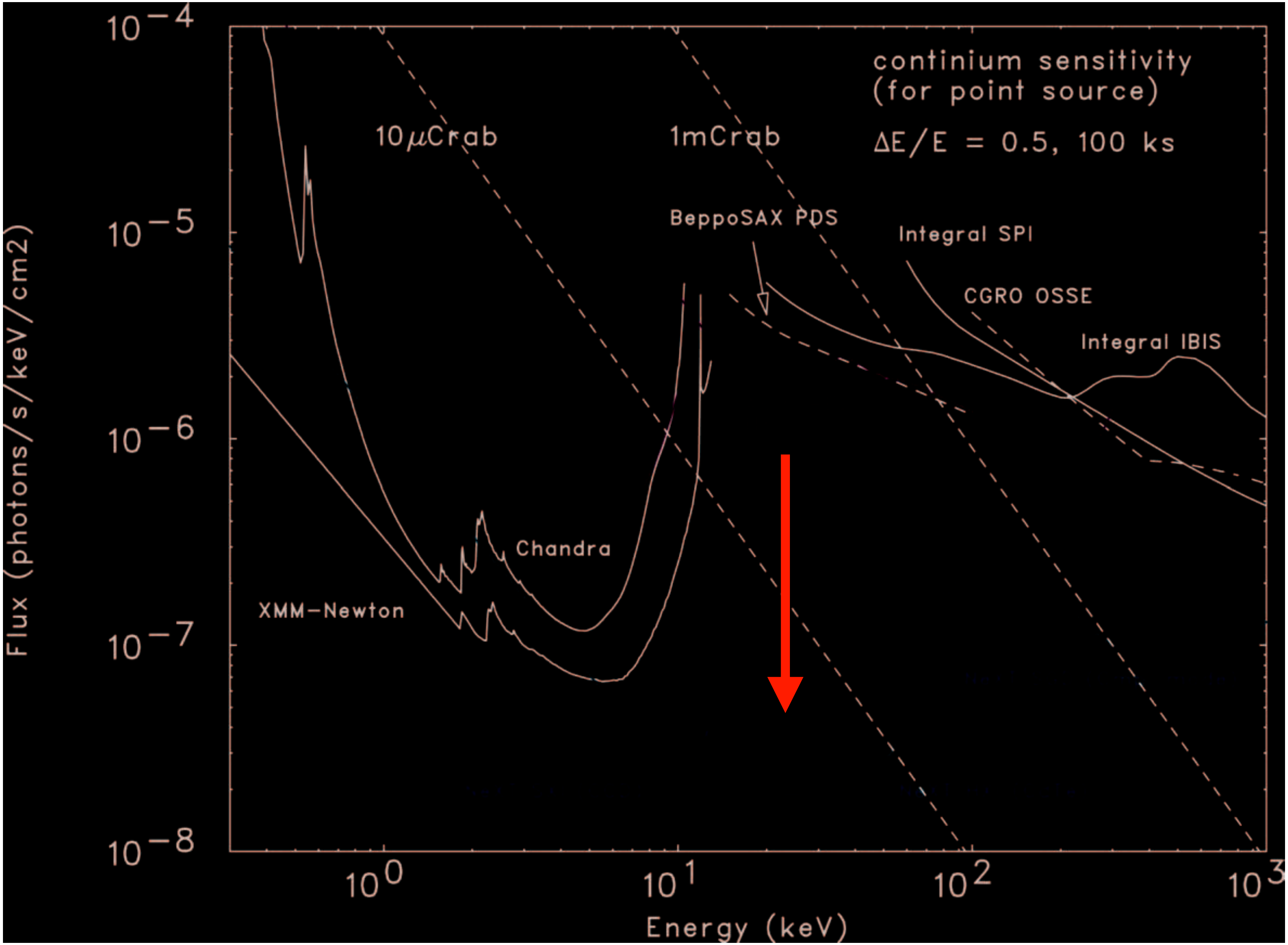
Total weight : 1700 kg

WXI

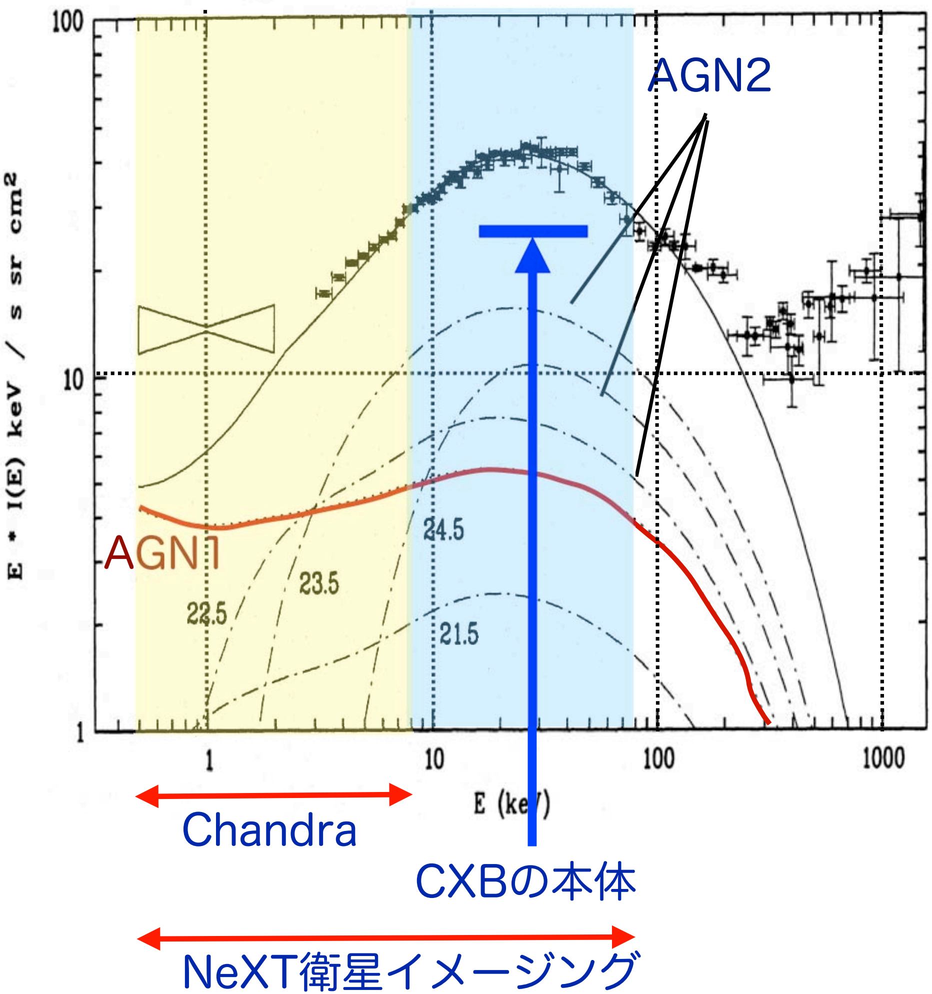


・イメージング
・小さな面積の検出器に集光することでバックグラウンドが劇的に低減される

感度


continium sensitivity
(for point source)
ΔE/E = 0.5, 100 ks
10μCrab
1mCrab
BeppoSAX PDS
Integral SPI
CGRO OSSE
Integral IBIS
Chandra
XMM−Newton
Flux (photons/s/keV/cm2)
Energy (keV)
10−4
10−5
10−6
10−7
10−8
100
101
102
103

2型AGNの必要性とCXBの「本体」

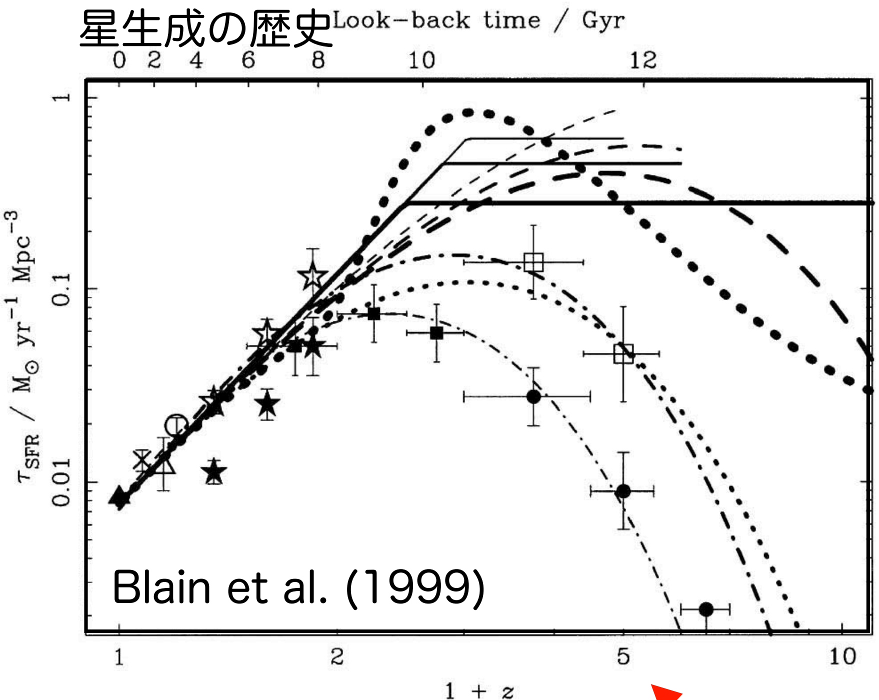


- 2種類のAGN
  - 1型AGN: 吸収を受けていないΓ=1.7
  - 2型AGN: 吸収を受けている
- CXBのスペクトル
  - kT=40keVの熱制動輻射
  - X線で明るい1型では説明できない。
- CXBの理解の現状
  - Chandraなどによる個数カウント
  - 明るい2型AGN数個を0.5-100keVで観測
  - 両方を合体させて、適当な進化モデルを入れてCXBを説明できた、ことになっている。
  - CXBの本体はまだ分かっていない。

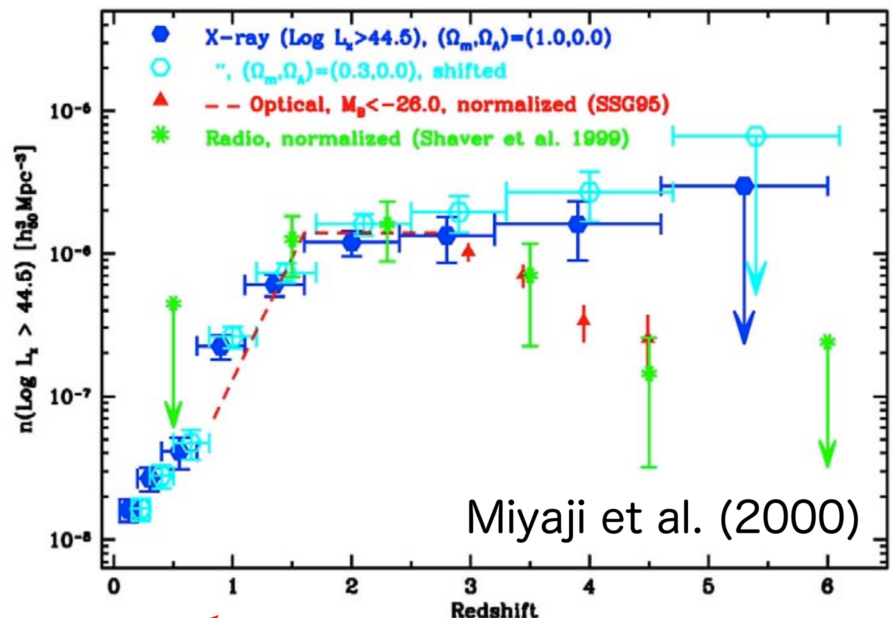
CXBの本体を説明する極めて強い吸収を受けたX線源の探査

星生成の歴史と巨大ブラックホール生成の歴史

星生成の歴史



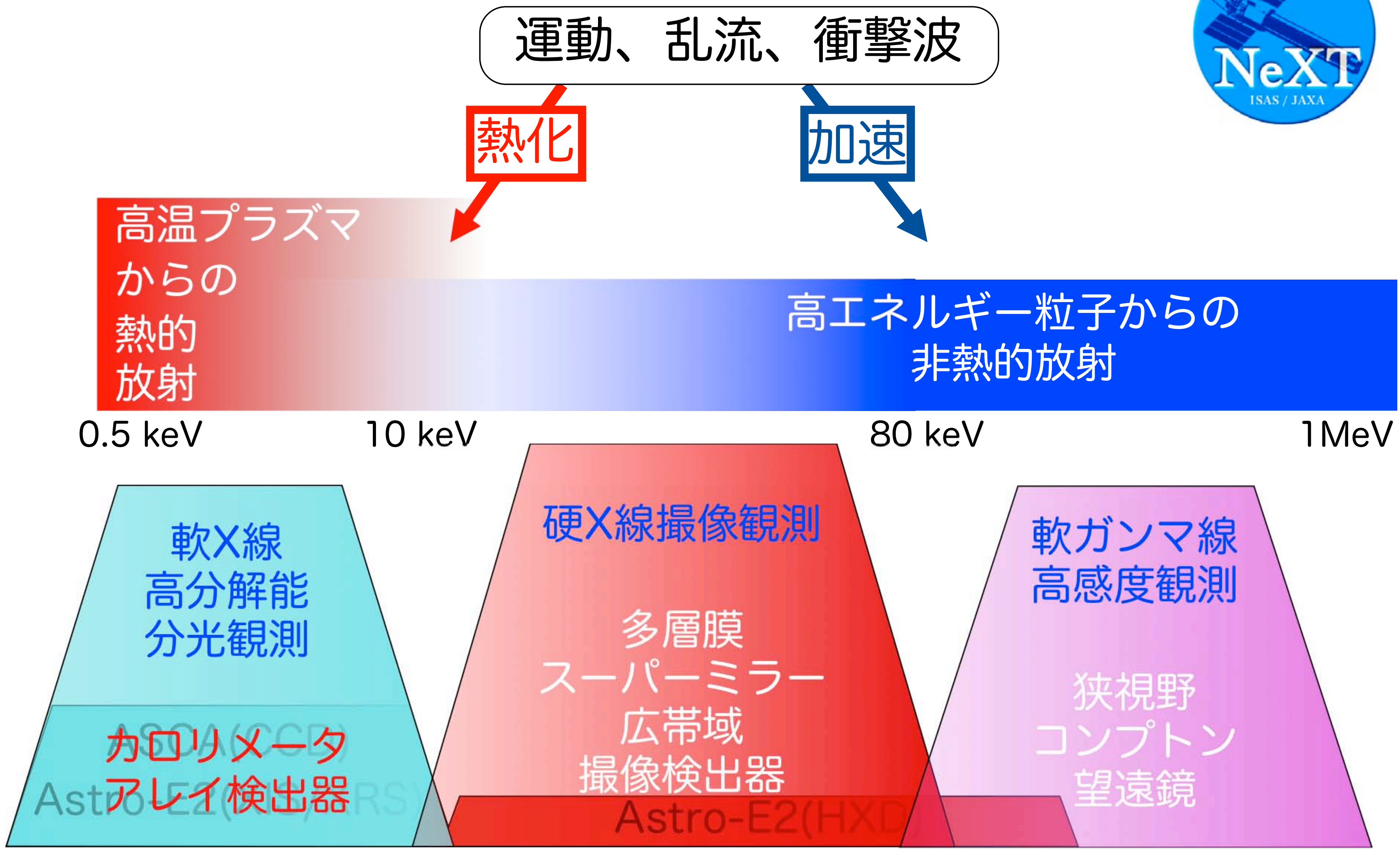
QSO = SMBH生成の歴史 (ROSAT)



強くカップル

- 巨大ブラックホールはいつどこでできたのか？
- スターバースト銀河中で誕生中の巨大ブラックホールの探査(鶴予想)

未踏の波長域に踏み出す



日本発の観測技術で、今、世界をリードする

NeXT衛星提案書から（2004）

- スターバーストの銀河風による宇宙線加速(鶴予想)

Observatories in Space -Road Map-