Prospects on High Energy Astrophysics

Tadayuki Takahashi
ISAS/JAXA

高橋忠幸

宇宙開発研究機構／宇宙科学研究本部

自己紹介をかねて

素粒子実験出身者が宇宙にたどり着くまで

- 1987 : KEK-PS / PEP4-TPC / TRISTAN-TOPAZ
- 1987 :SN1987A
- 1988-1991: ガンマ線大気球実験（ブラジル）
- 1993 : ガンマ線大気球実験（三陸）
- 1995 : 本郷から宇宙研へ
  (硬X線・ガンマ線検出器HXDをAstro-Eに搭載するために）
- 2000 :Astro-E 打ち上げ（打ち上げロケットの失敗）
- 2005 :Astro-E2 打ち上げ

Outline

- JAXAについて
- 最近の日本の科学衛星
- X線天文衛星
- すざくと非熱的超新星残骸
- GLAST と宇宙背景放射
- 次期高エネルギー天文衛星 NeXT

JAXA

Three Japanese organizations were merged as the Japan Aerospace Exploration Agency (JAXA) on October, 2003.

Through the merger of ISAS, NAL, and NASDA, JAXA now promotes all space development, from basic research to development and utilization.

ISAS	Academic Research Graduate School Education
NAL	Aerospace Technology
NASDA	Rockets/Satellites following Japanese Policy

Strategy

Step-by-step but challengingly progressive strategy

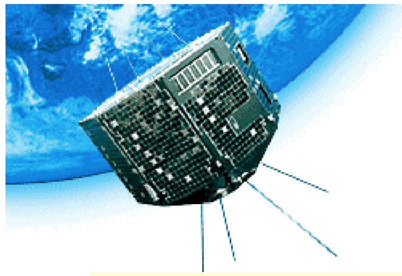
Example: X-ray astronomy satellites

Small but beautiful

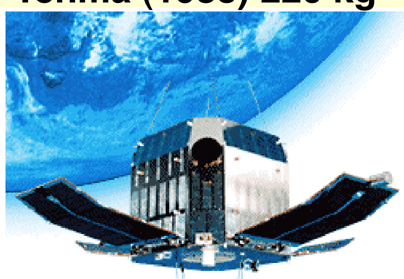
Aiming at new results with unique, original mission instruments

International Collaboration

Hakucho (1979) 90kg



Tenma (1983) 220 kg



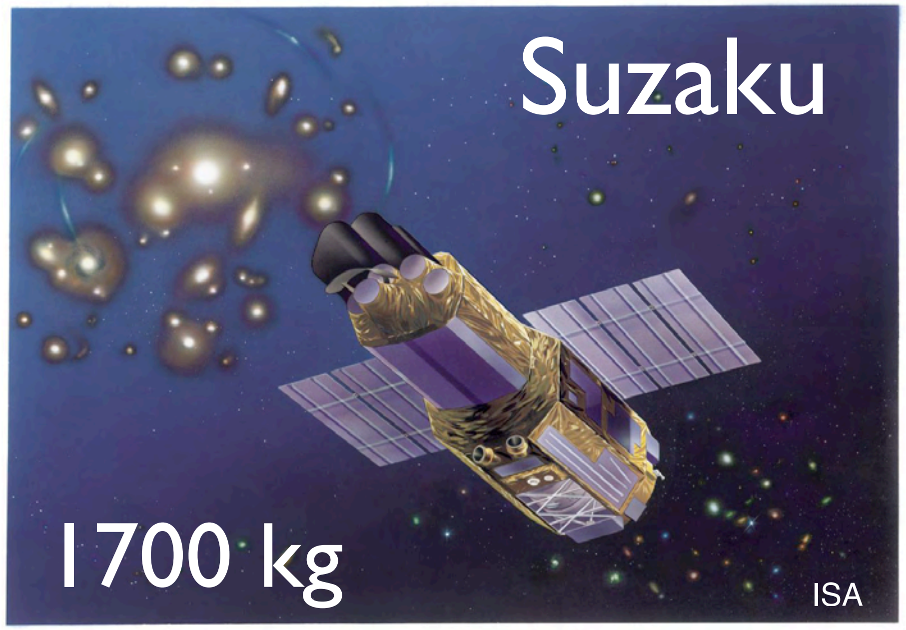
Ginga (1987) 430 kg

with UK/USA

ASCA (1993) 420 kg

with USA

Japan-US international Mission



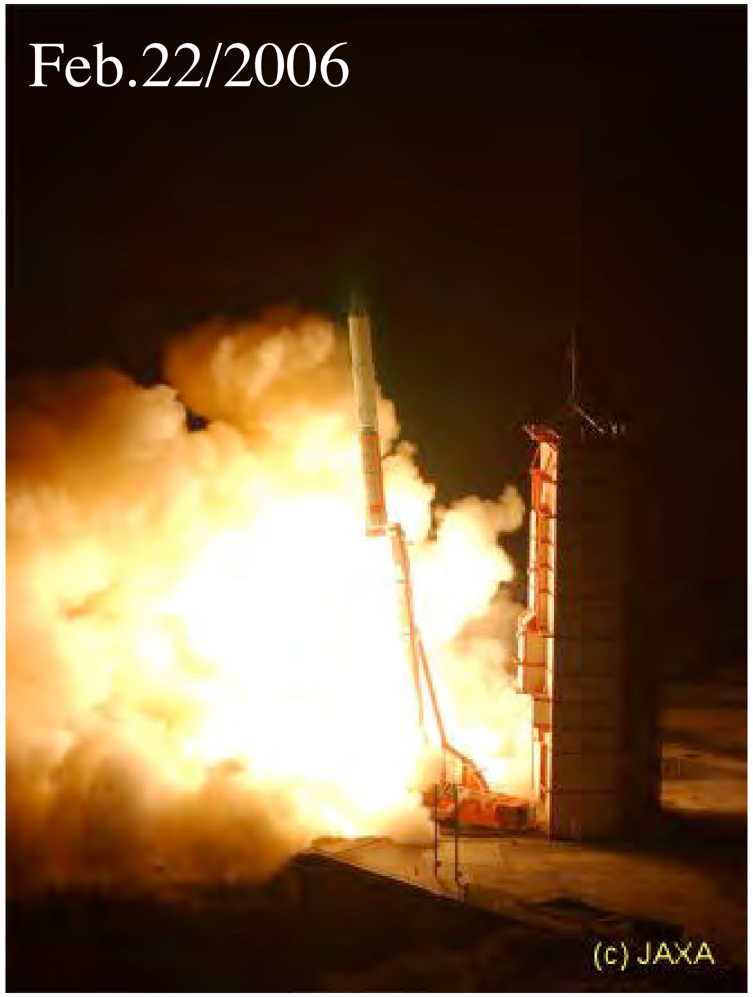
M3

M-V

To understand the universe
- From the Big Bang to Ourselves -

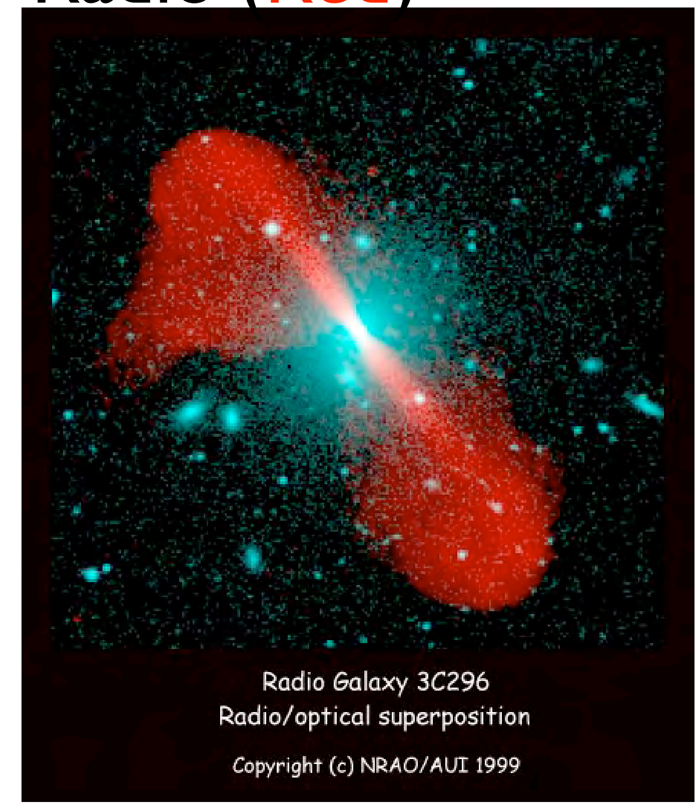
Birth & Evolution of Galaxies
(Infrared : Low Temperature, Less Extinction, High Redshift)

AKARI (Astro-F) , the second space mission for infrared astronomy in Japan. It aims for an all-sky survey with much better sensitivity, spatial resolution and wider wavelength coverage than IRAS.

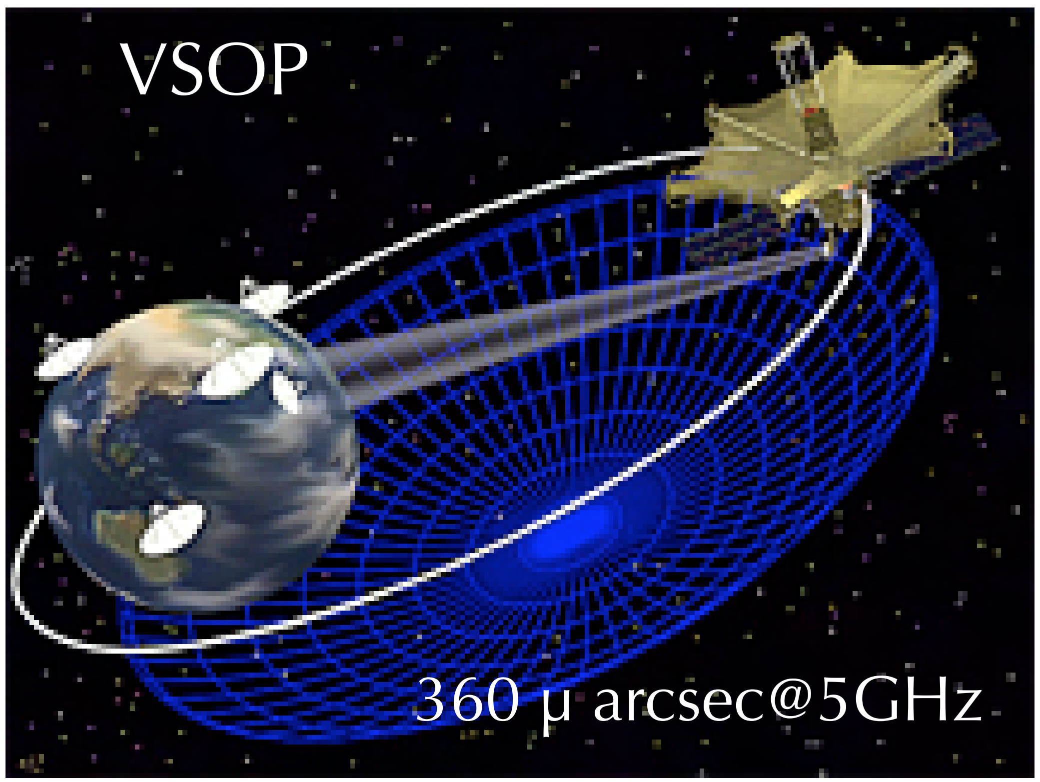


To understand the universe
- From the Big Bang to Ourselves -

Optical (Green)
vs
Radio (Red)



High resolution imaging by
Space VLBI (relativistic jets)



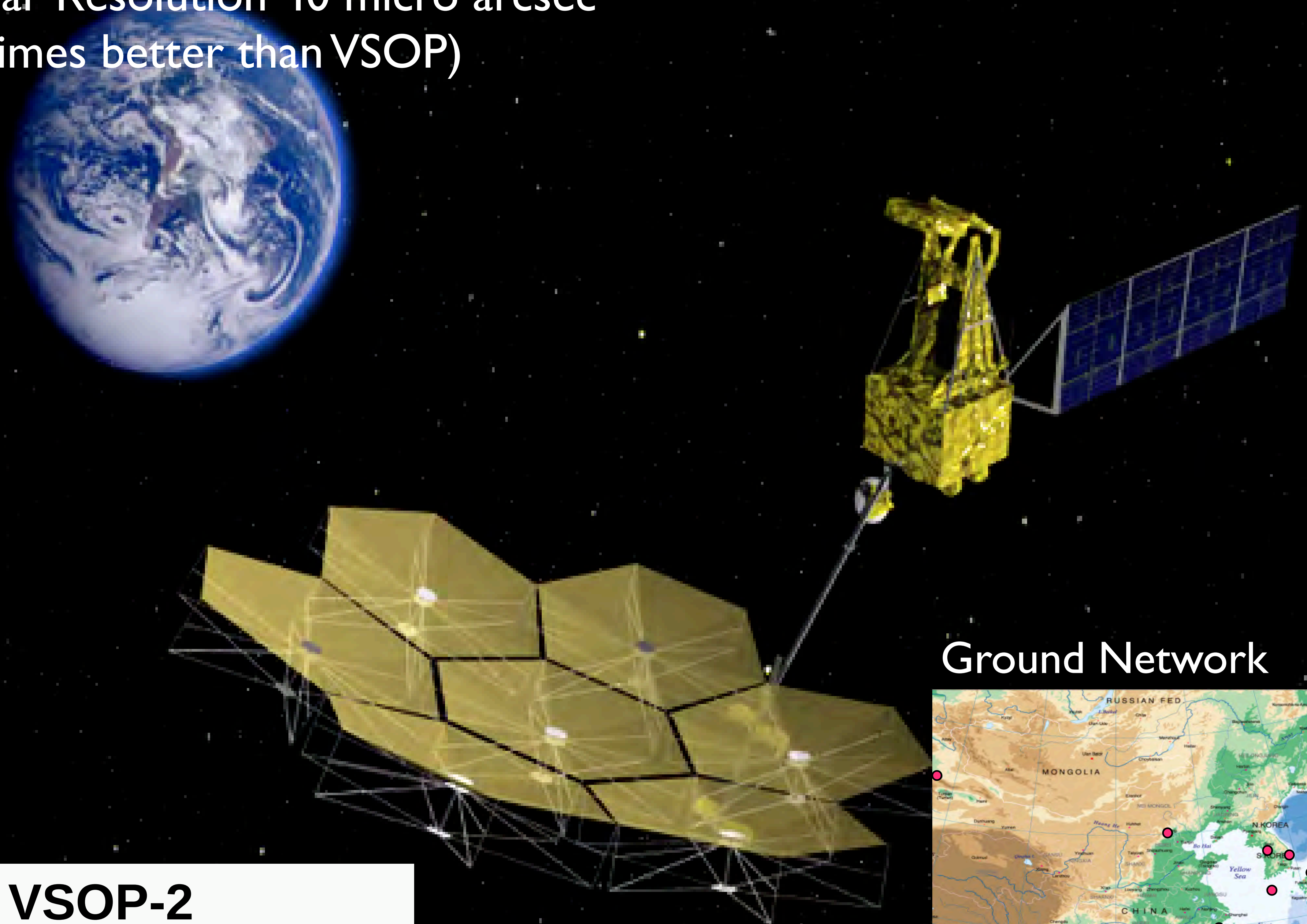
Synchrotron Radio
-> Trace
Distibution of
High Energy Electrons

M87 Jet by Hubble Telescope

VSOP2ではこの中を
さらに分解する

VSOP2(ASTRO-G, 2011)

Angular Resolution 40 micro arcsec
(10 times better than VSOP)

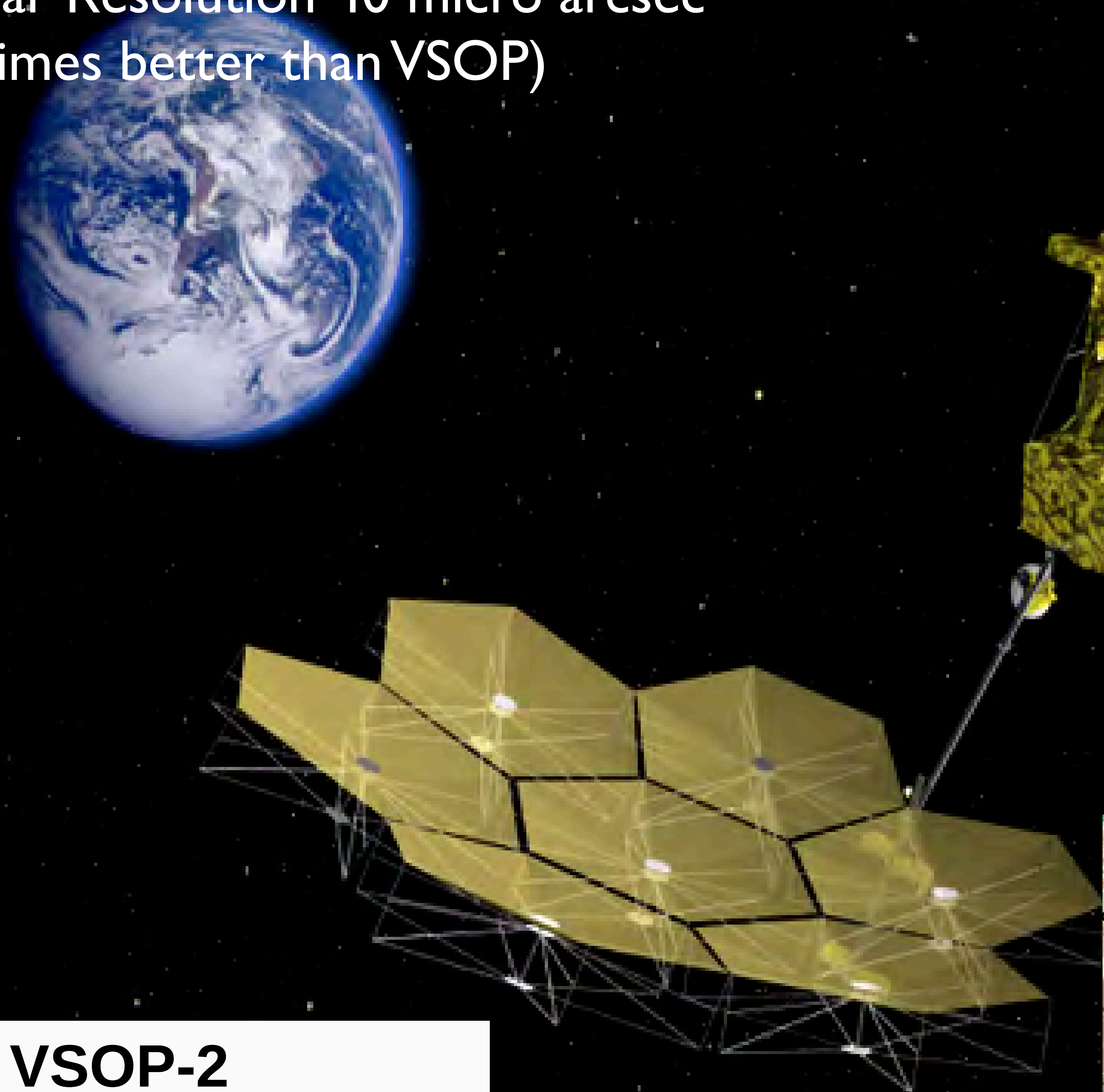


Ground Network

VSOP-2
(selected as the 26'th scientific satellite)

VSOP2

Angular Resolution 40 micro arcsec
(10 times better than VSOP)



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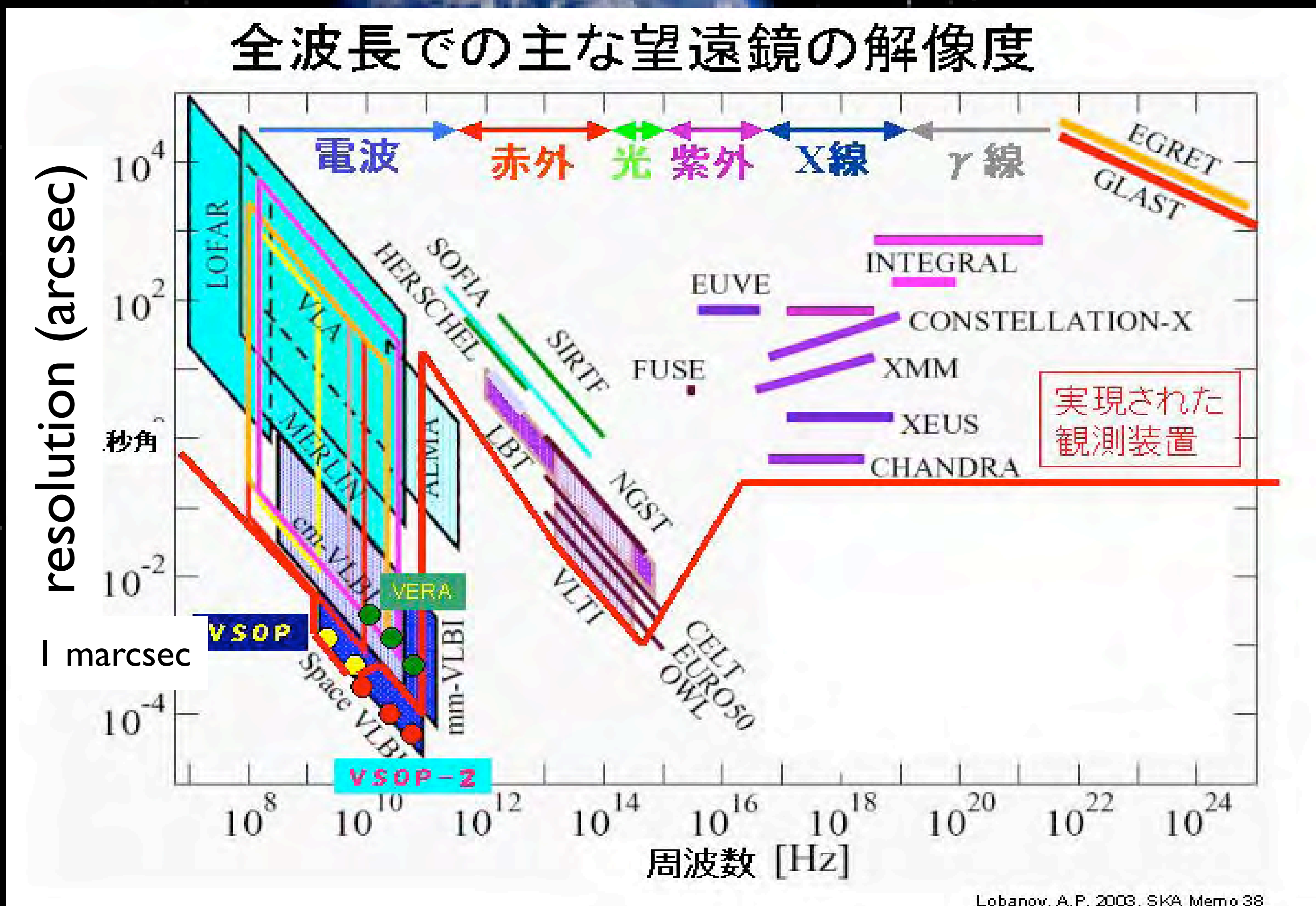

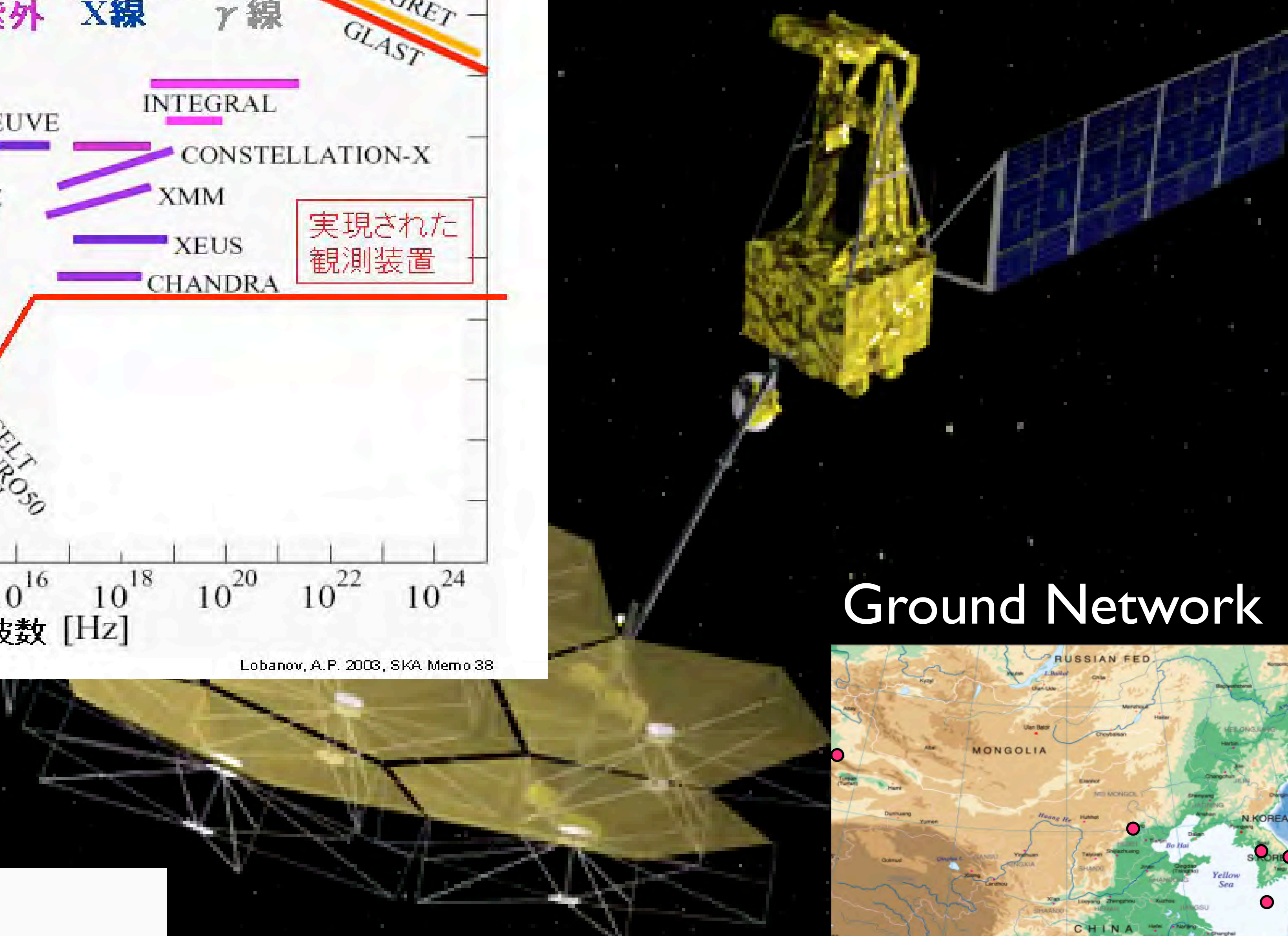

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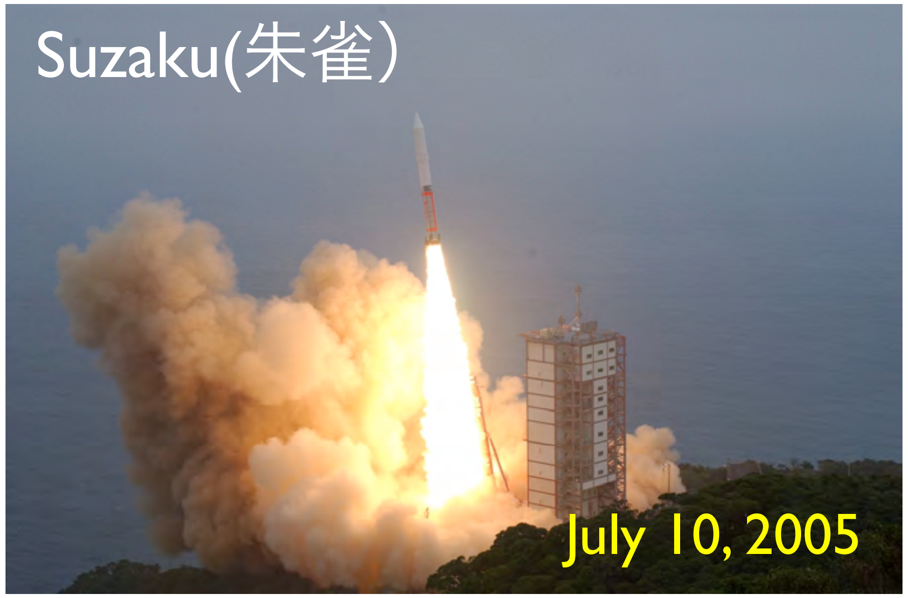
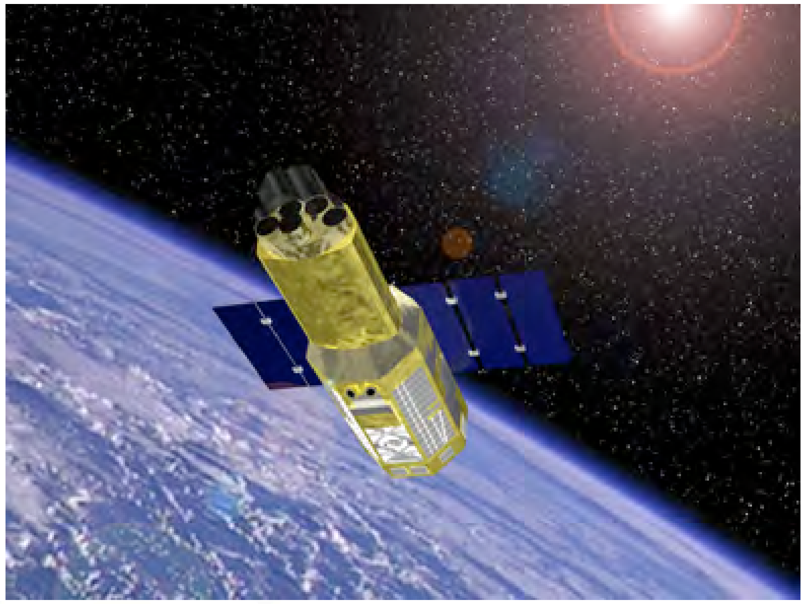
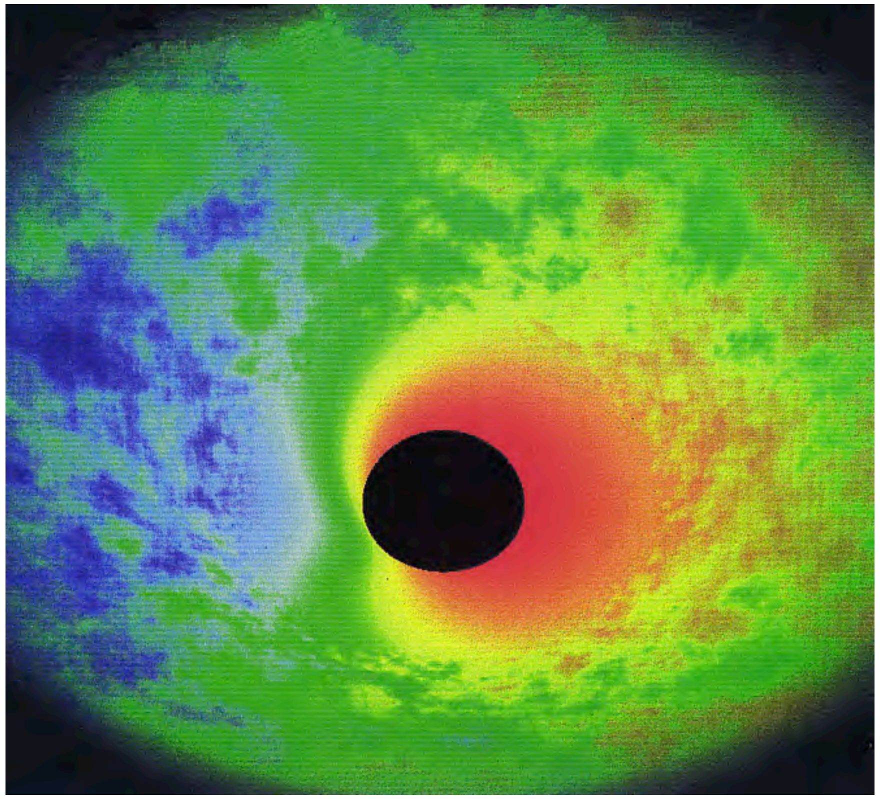
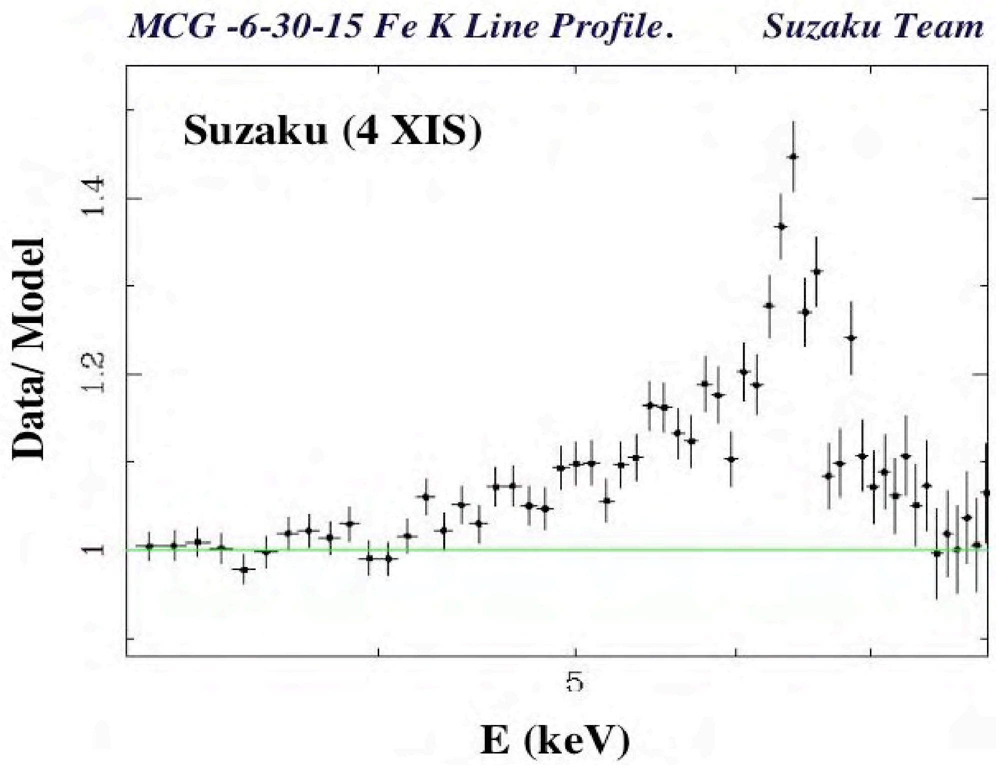


X-ray/Gamma-ray
Best probe to study Extreme Universe.
Can be done only in space



X-ray emission from close to the event horizon provides a powerful probe





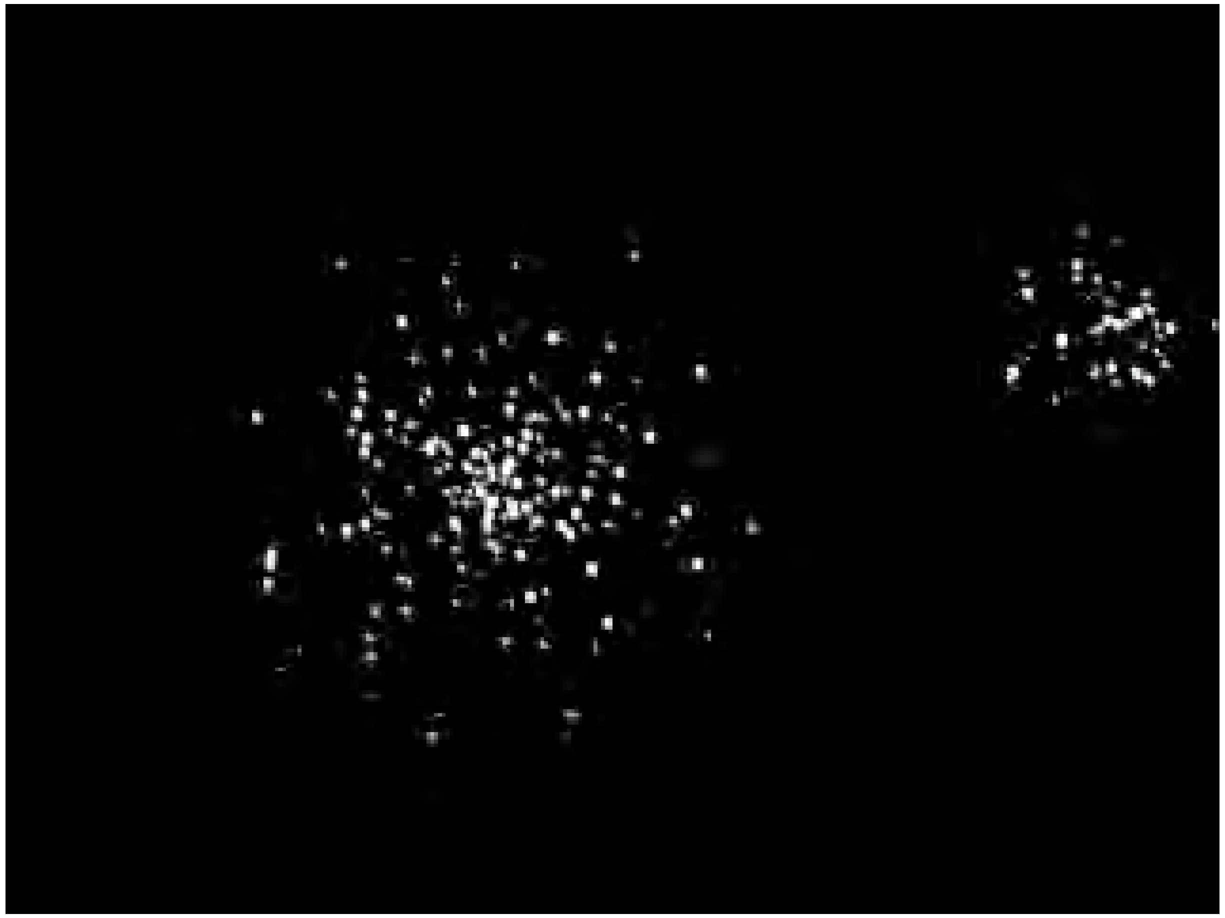
Broad Iron line interpreted as due to gravitational redshift toward the black hole (First discovered by ASCA)

From the edge of a black hole to the collision of largest celestial objects

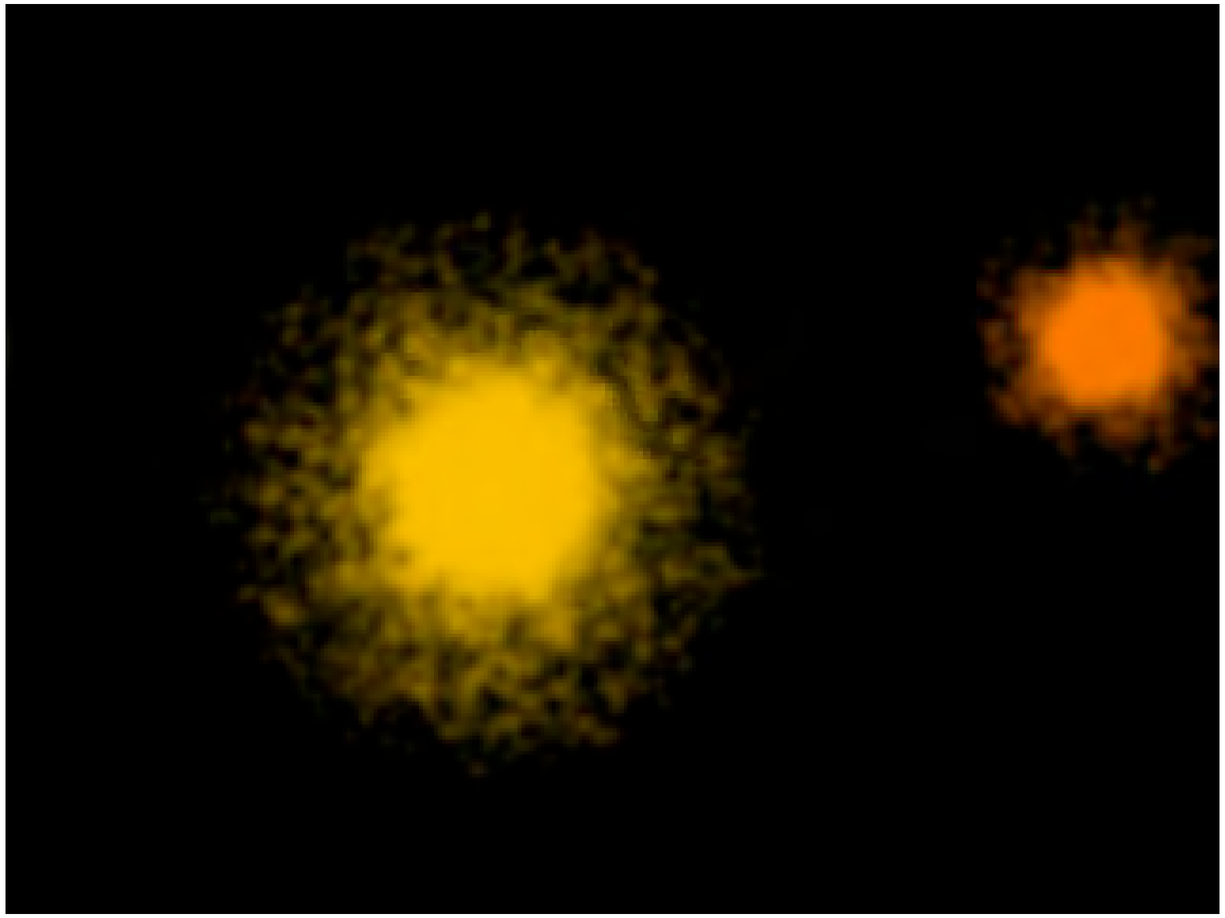
Study of the structure of the universe:

Cluster of galaxies : Largest celestial object
(self gravitating energy 10^64 erg, hundreds of galaxies)

Cluster merging (optical)



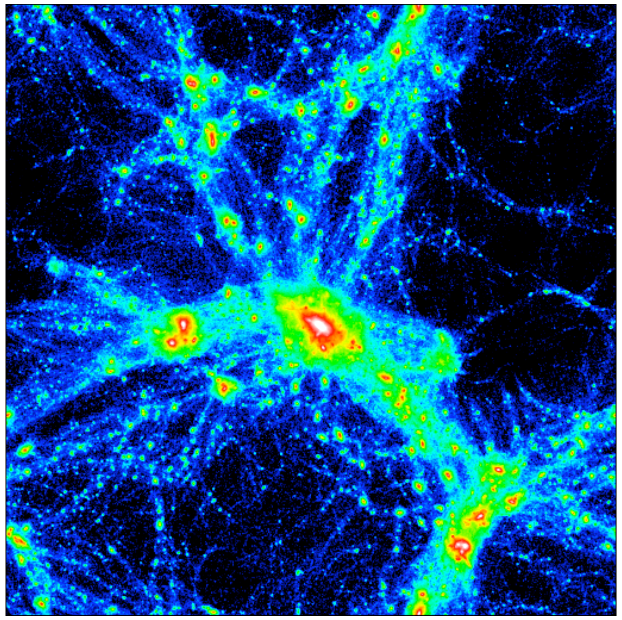
Cluster merging (X-ray)



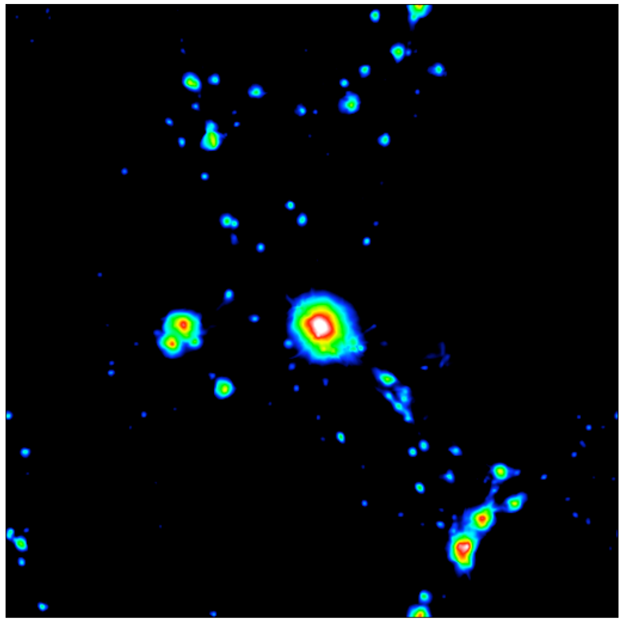
(Takizawa, ApJ, 2000, vol. 532, 183)

Galaxy Clusters as Cosmological Tools

Dark Matter

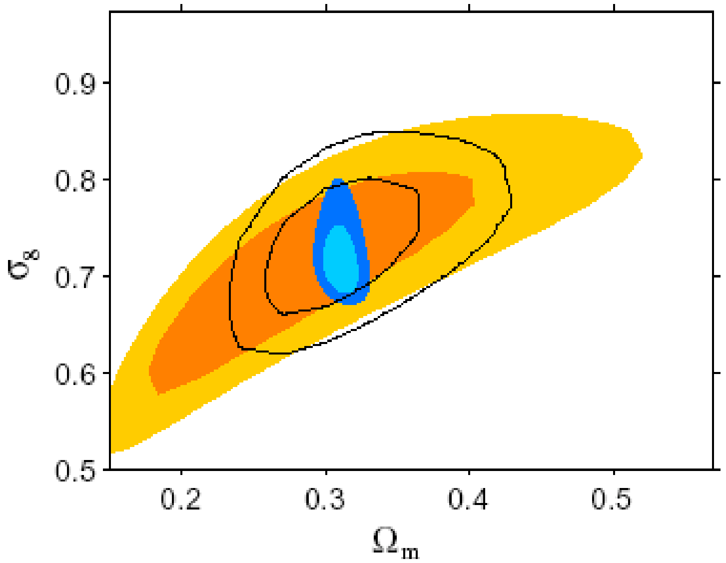


Hot Gas



X-ray emission is an excellent tracer of dark matter over a wide range of masses and redshift

Evolution of massive clusters with redshift is very sensitive to Cosmological parameters



The sources are luminous and relatively bright X-ray sources, easily found in wide field surveys

Provides precise Cosmological parameters, e.g. contours in the Ω_m and σ_8 space from Allen et al (2003):

- ROSAT+Chandra z<0.5 luminosity function (blue)
- Galaxy counts plus WMAP1 (black)
- WMAP1 alone (yellow orange)

The ~0.75 value of σ_8 recently confirmed with WMAP3

Galaxy Clusters as Cosmological Tools

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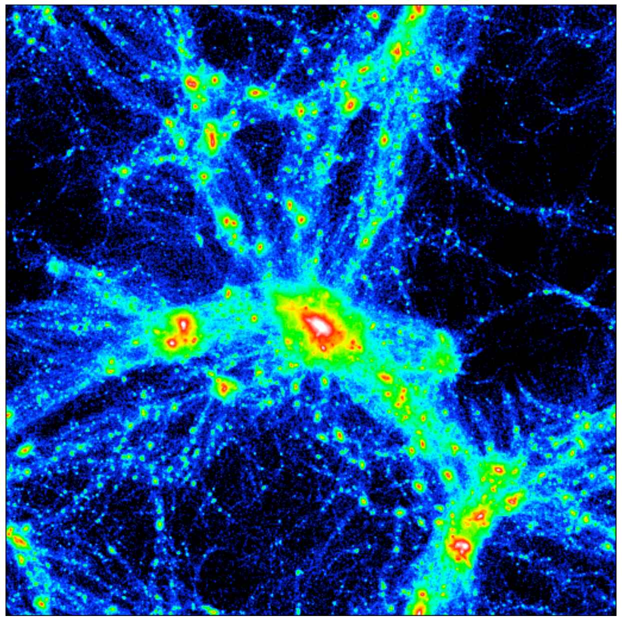

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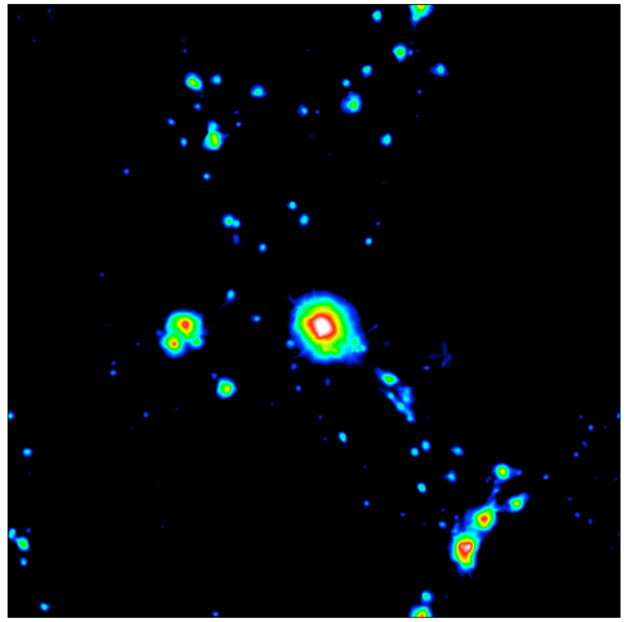

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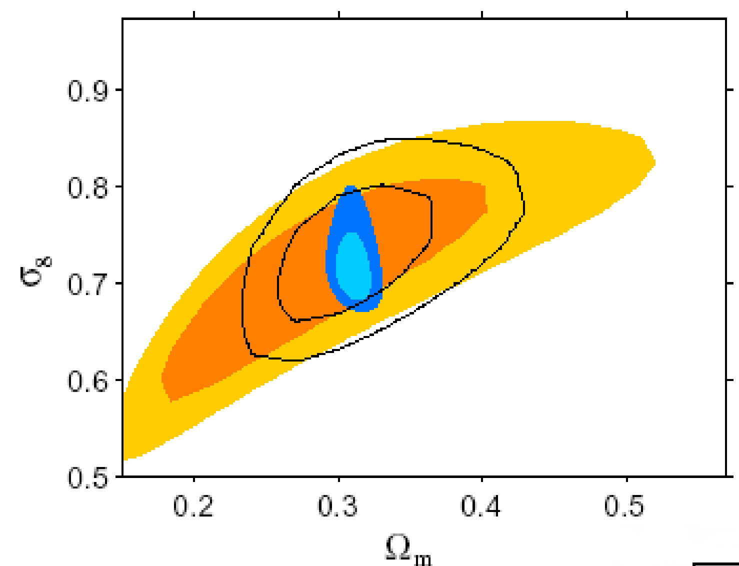

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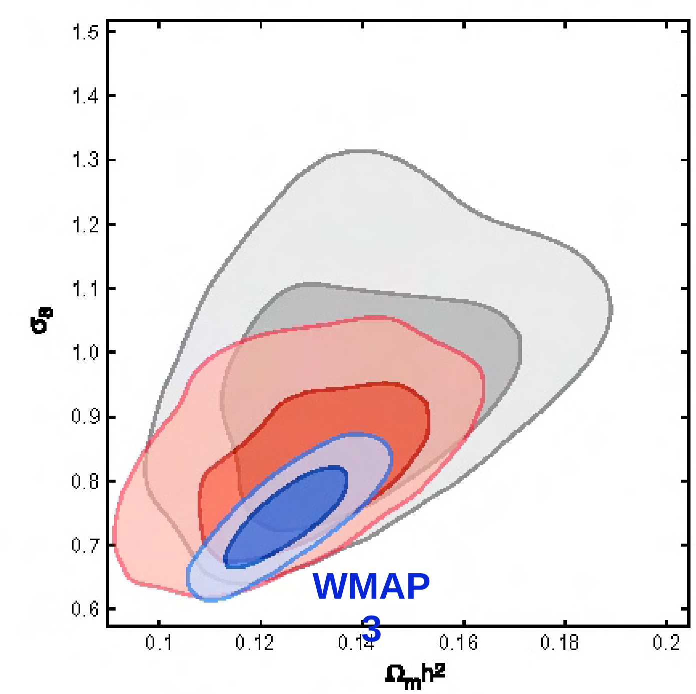
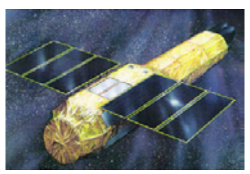


NASA X-ray Astronomy Roadmap + NeXT (Japan)

Chandra

Suzaku

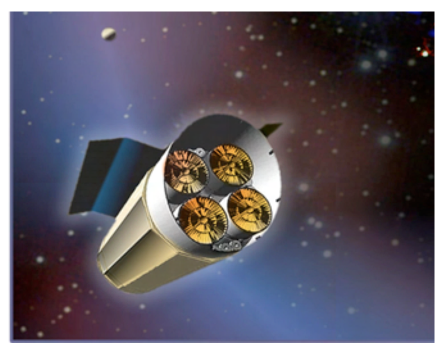


XMM-Newton

0.1-0.3 m^2
0.5-90 arc sec

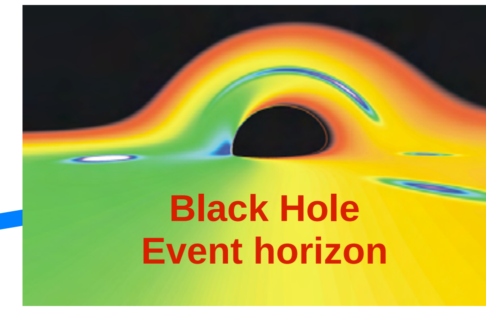
Constellation-X

20-100 times increased sensitivity for spectroscopy



1.5 m^2
5-15 arc sec

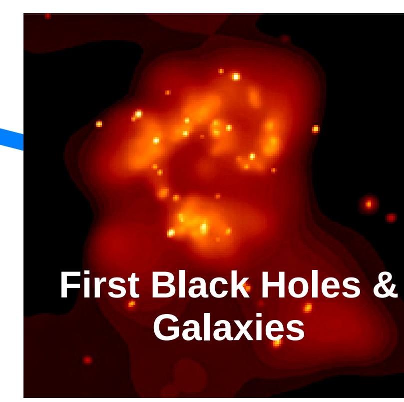
Black Hole Evolution
Test of GR
Dark Matter/Energy
Cycles of Matter & Energy



Black Hole Imager

10 Million times finer imaging

0.1-1.0 m^2
0.1 micro arc sec



Generation-X

1000 times deeper X-ray imaging

50-150 m^2
0.1-1 arc sec

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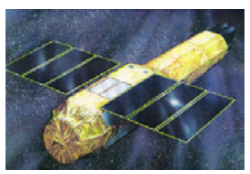
Chandra

Suzaku



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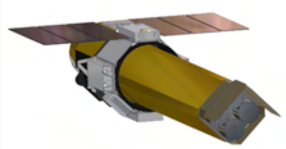

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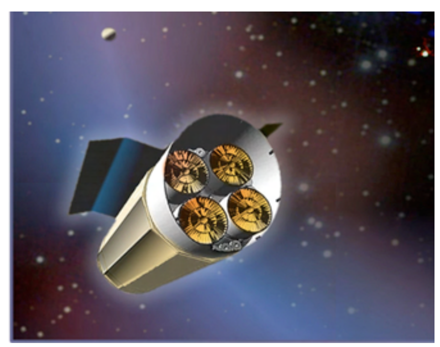

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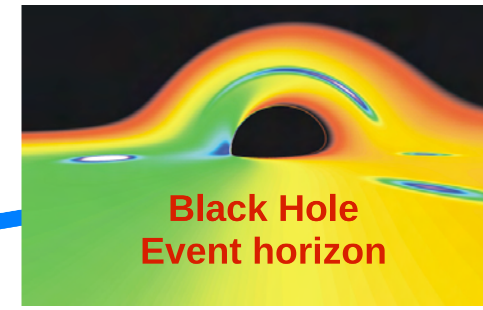

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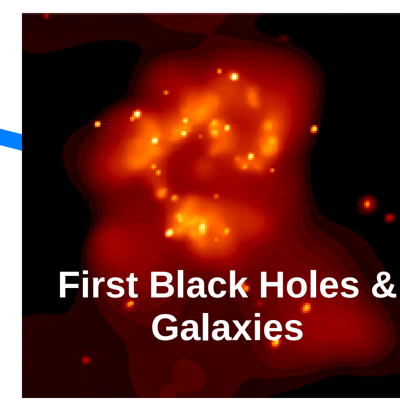

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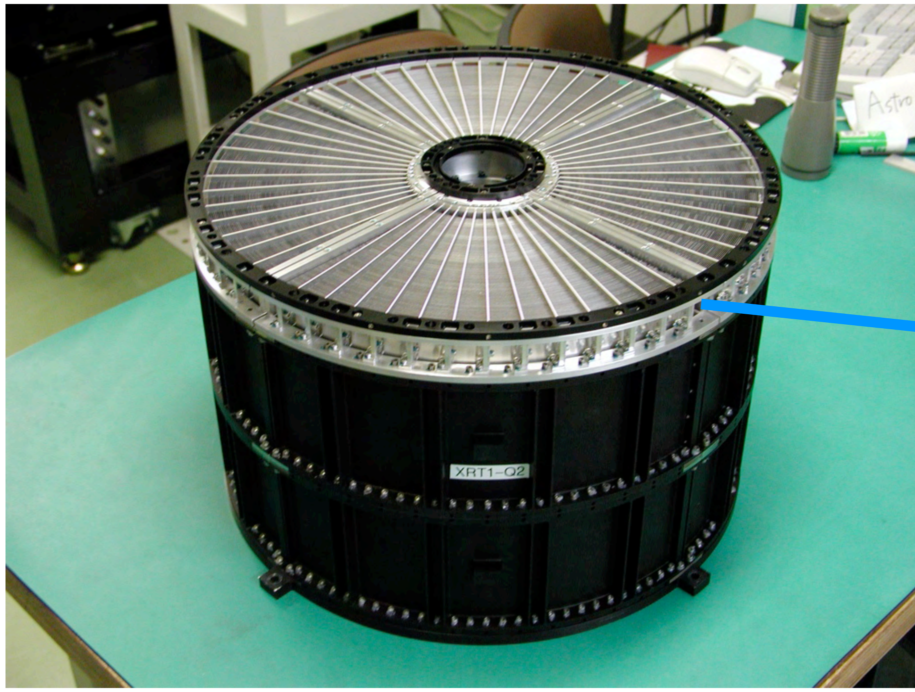
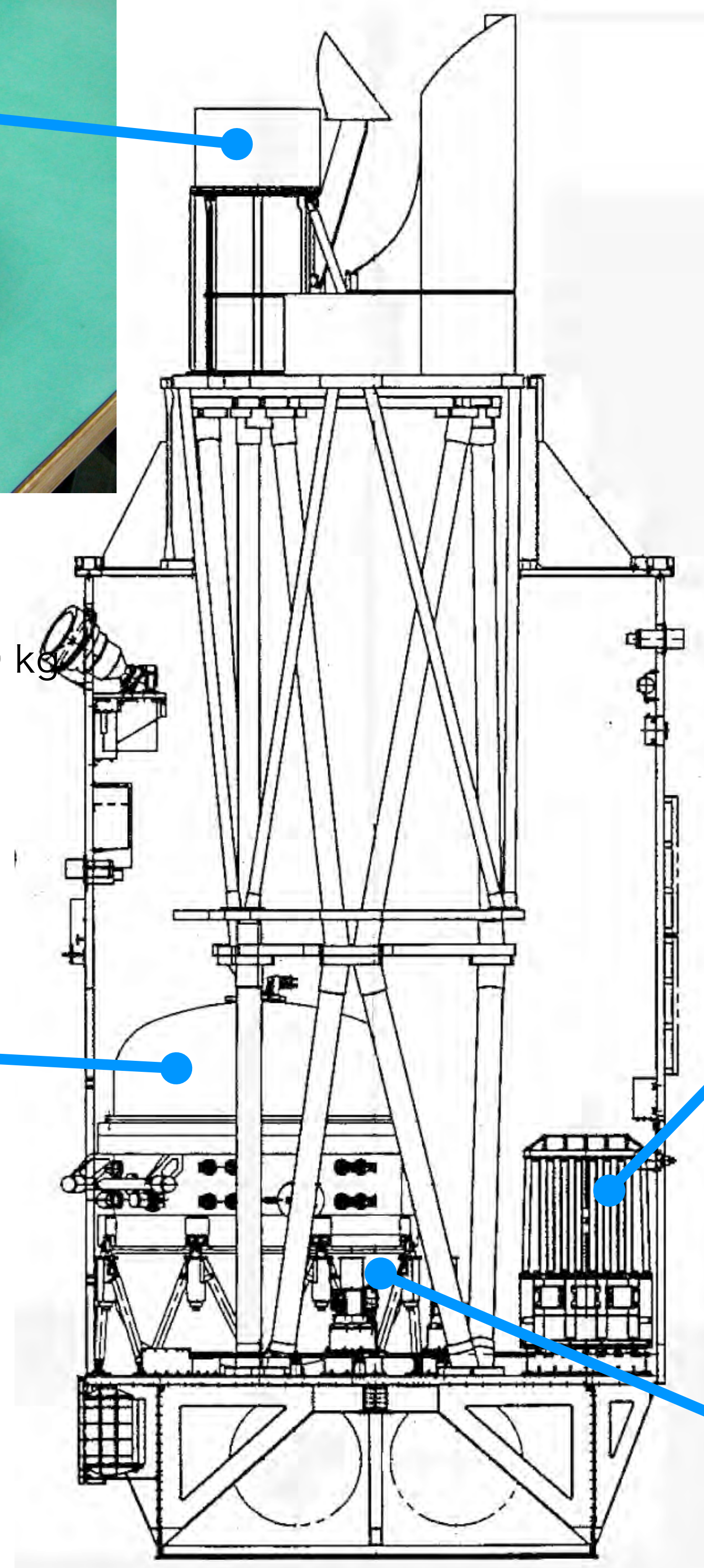
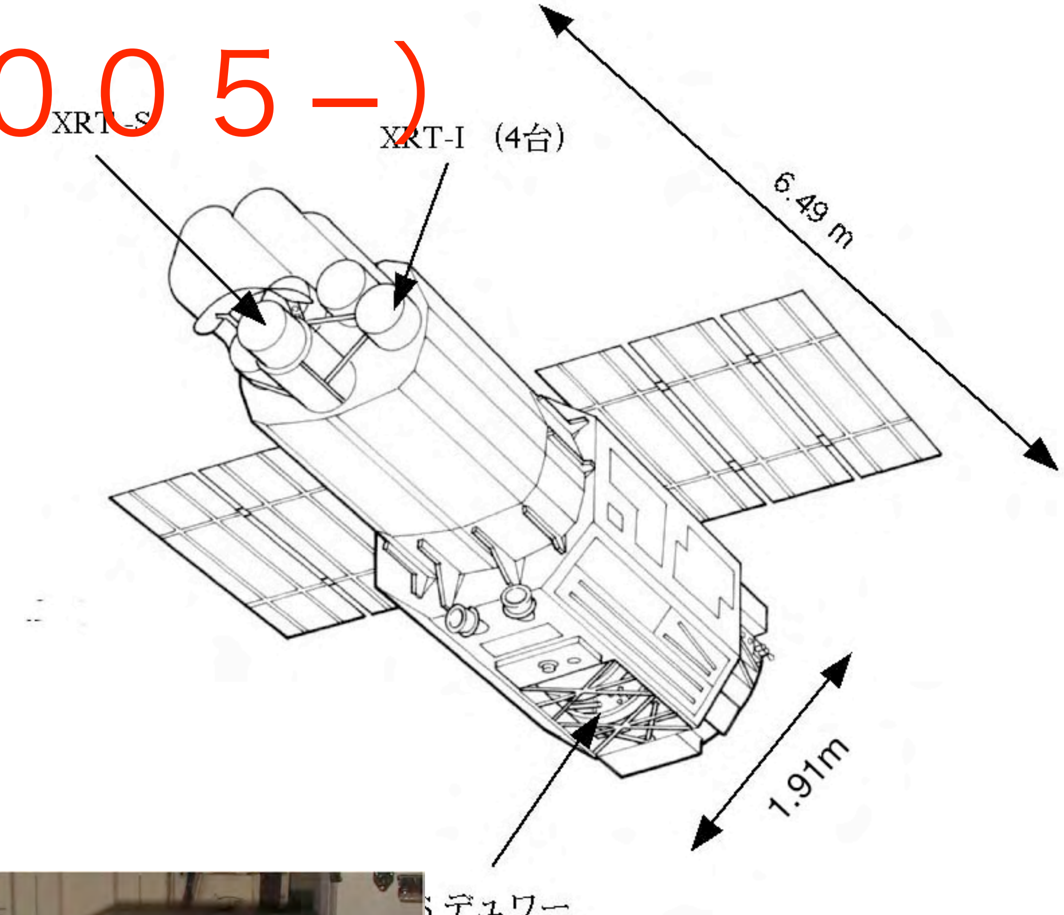
すざく（２００５−）

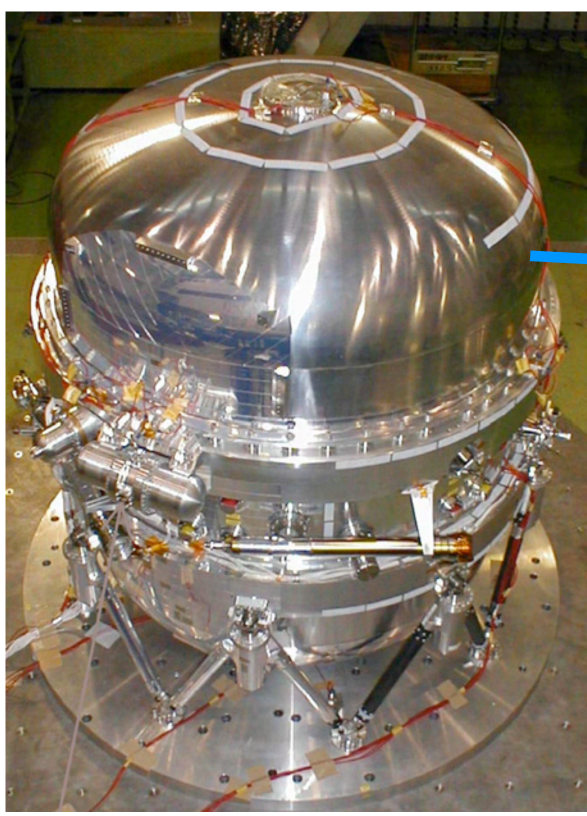


XRT (5 units)
NASA/GSFC-Nagoya-ISAS/JAXA

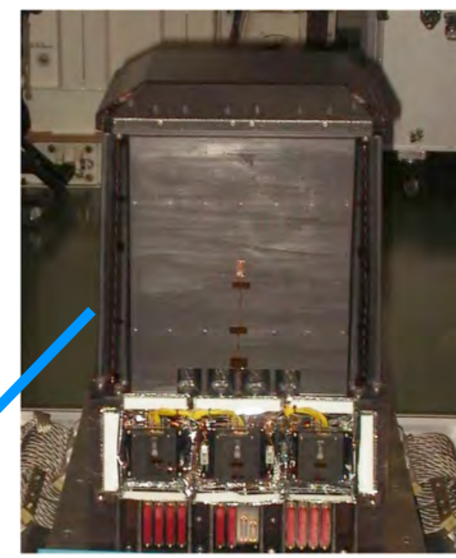
Chandra 1500 kg
XMM 440 kg
Suzaku 20 kg







XRS
NASA/GSFC-Wisconsin-ISAS/JAXA-TMU



HXD
Tokyo-ISAS/JAXA-Riken-Saitama-Hiroshima-Kanazawa-Aoyama

XIS (4 units)
MIT-Kyoto-Osaka -ISAS/JAXA

1700kg

Note: Chandra 4800 kg/Newton 3800 kg)

Tragedy

July 10: Valve 6 (He gas bent) was opened

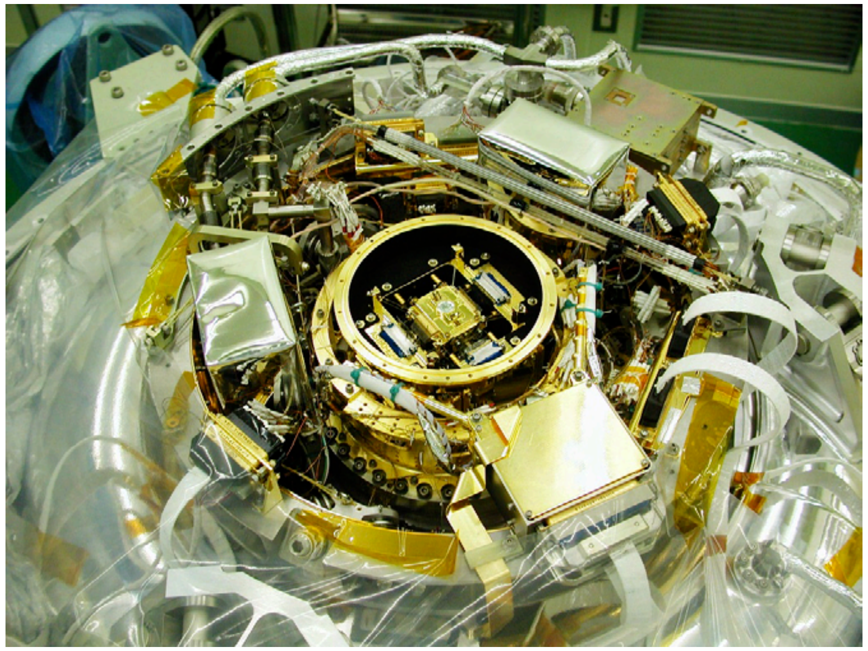
July 25: Valve 12 (main shell evacuation valve) was opened

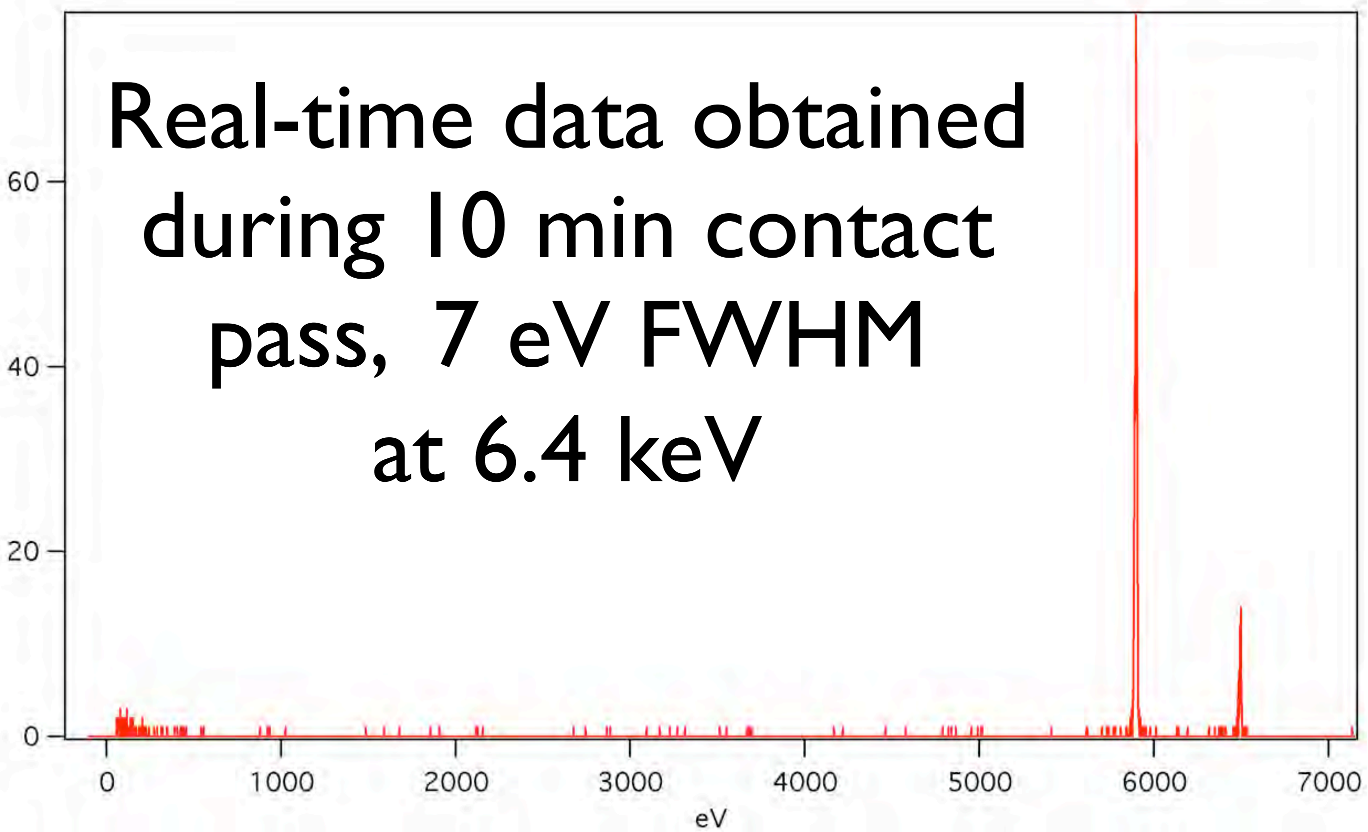
July 29: First temperature spikes were seen, indicating helium gas (almost certainly vented from the tank) got to parts of the XRS that it shouldn't have gotten into.

Aug 5: 7 eV resolution confirmed fo most of pixels.

Aug. 8: All Liquid He was lost (during several hours)

XRS





Cause of the failure is under investigation by JAXA and NASA.

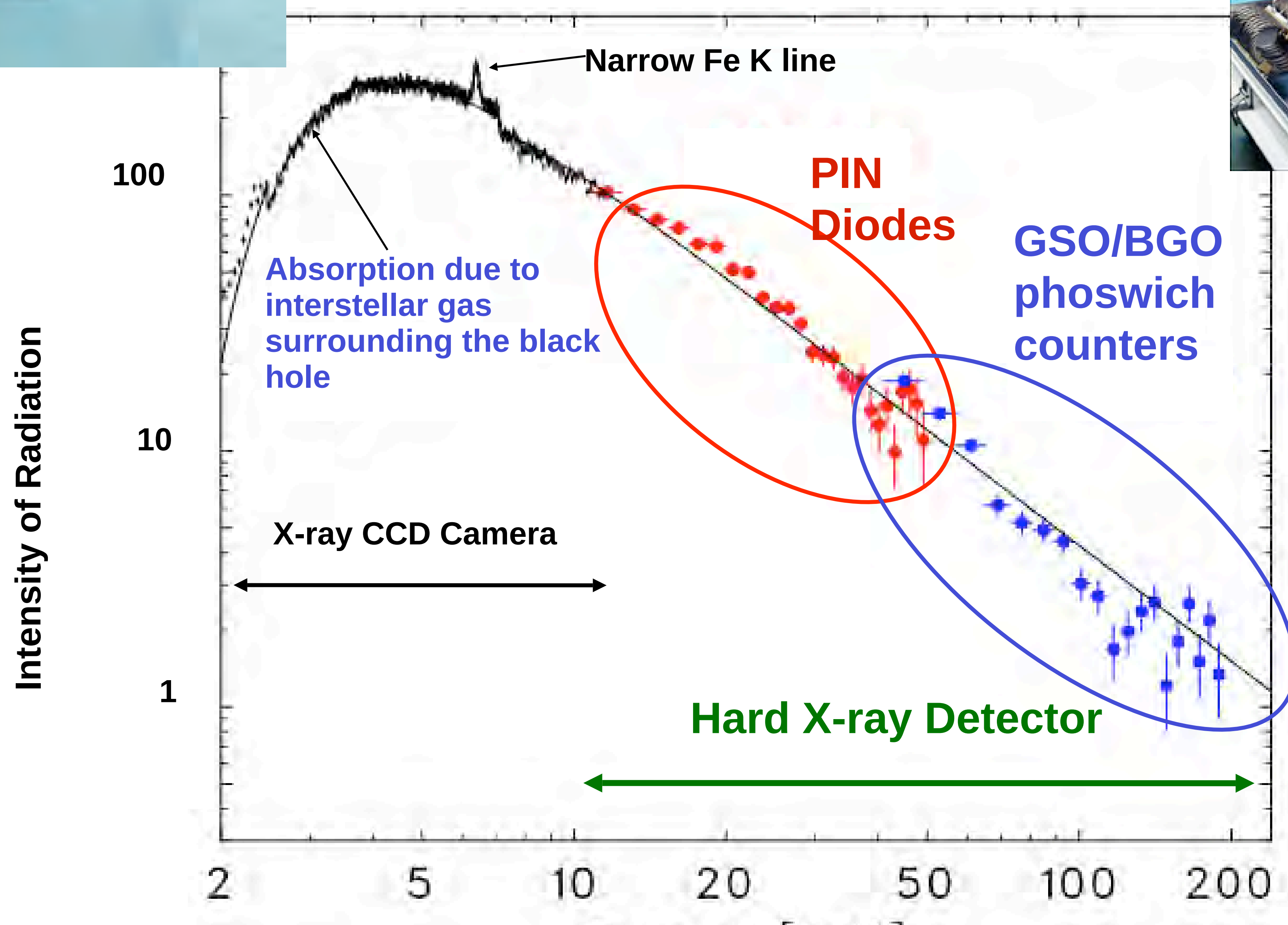
http://suzaku.gsfc.nasa.gov/docs/astroe_lc/news/xrsend.html

Power of Suzaku

Wide band observation of non-thermal sources

Connection between THERMAL and non-THERMAL

Cen A Observation



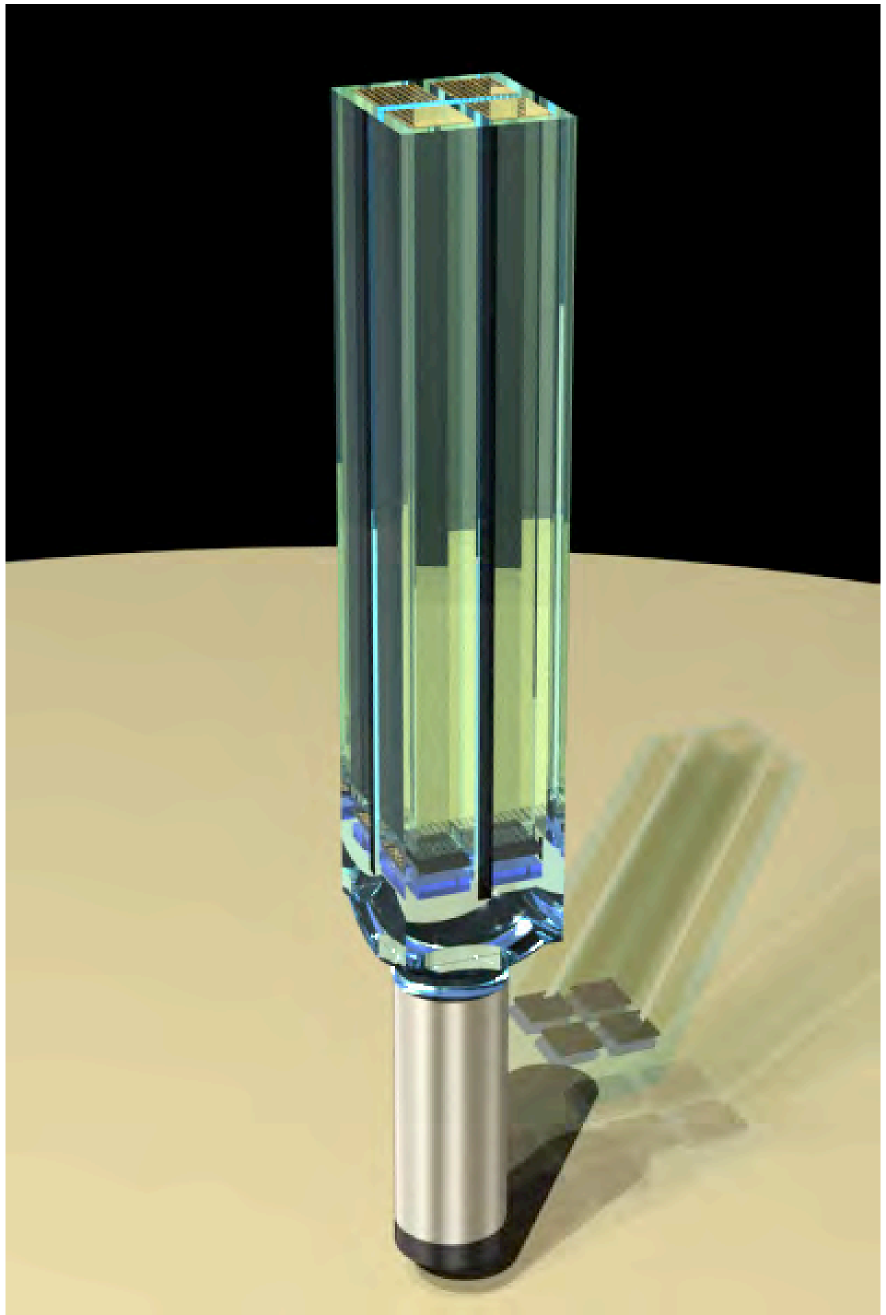
preliminary

Suzaku Team

HXD (Hard X-ray Detector)

Very Difficult : if you need comparable sensitivity with X-rays

- Japan's answer for the "high sensitivity Gamma-ray" detector.
- Low Background Well-type Shield
- Si-PIN (8-50 keV)
  160 cm2 @ 10 keV
- GSO Scintillator (50 - 600 keV)
  330 cm2 @ 100 keV
- Thick BGO Shield
  (av. 4 cm thick : GRB!)



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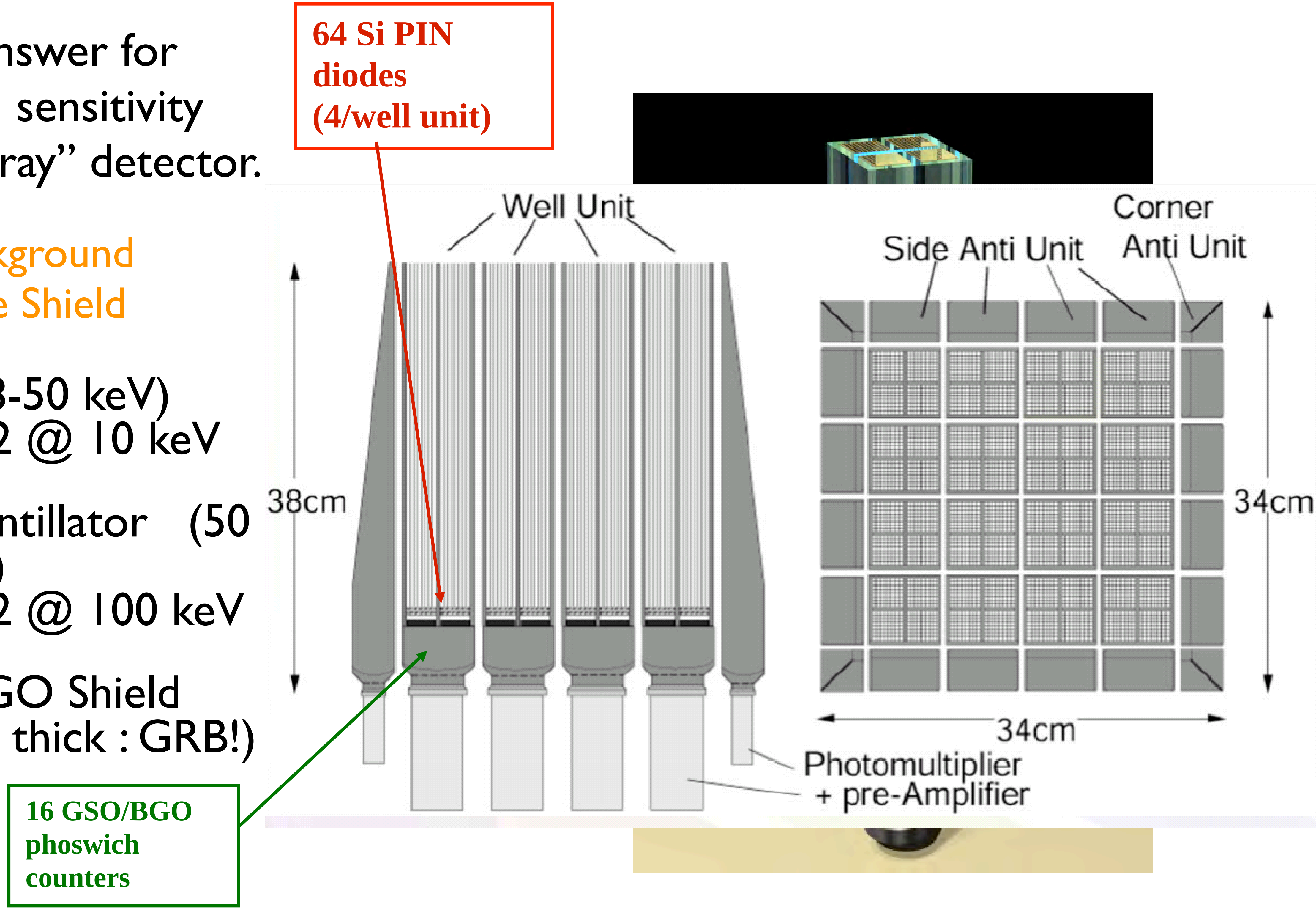
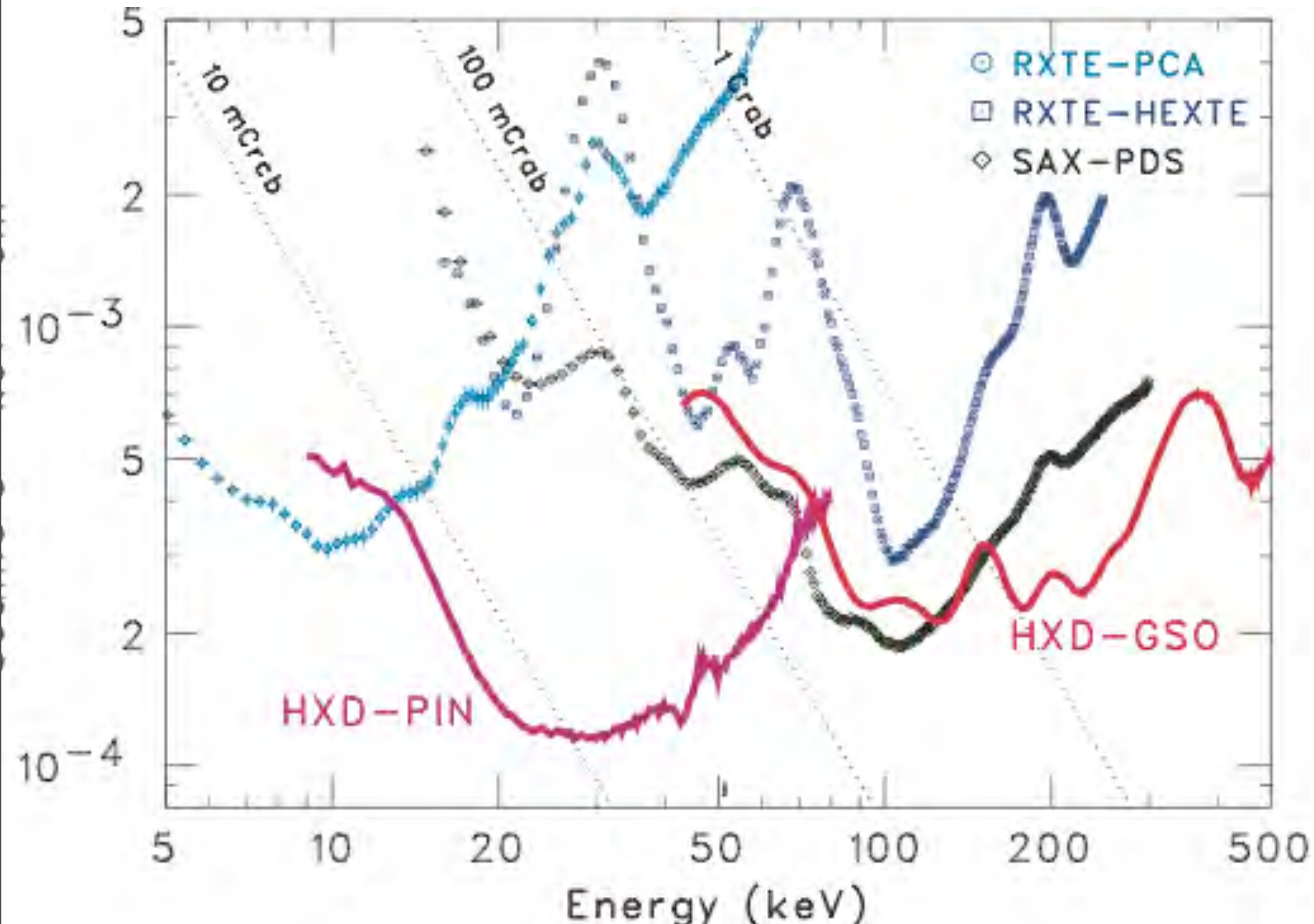


Wide-band spectroscopy with Suzaku

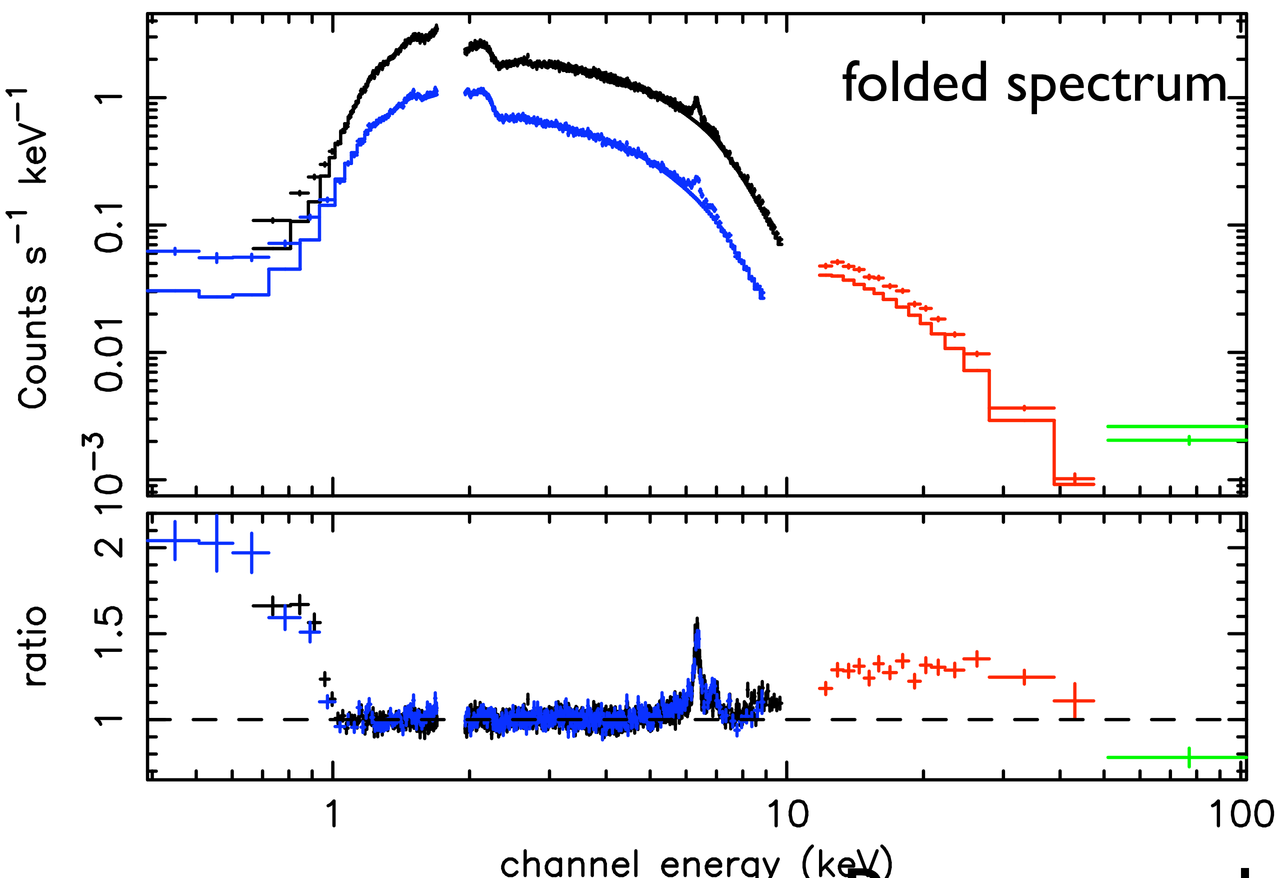
Xray CCD(XIS) : 0.3 keV - 12 keV
Hard X-ray Detector (HXD) : 10 keV - 600 keV

Allow us to constrain the shape of hard X-ray spectrum

Low Background
Hard X-ray Detector



MCG-5-23-16



Reeves et al. 06

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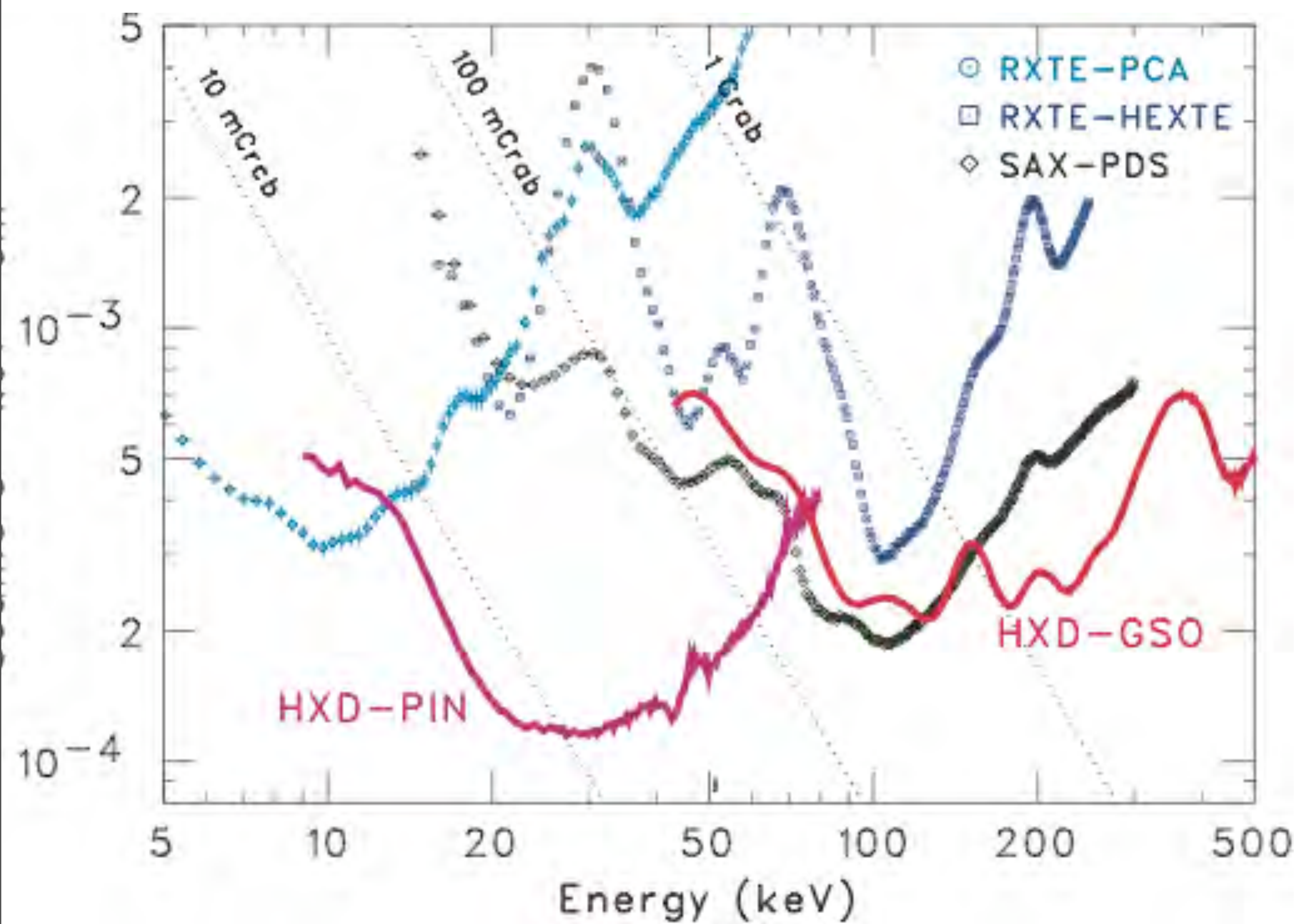

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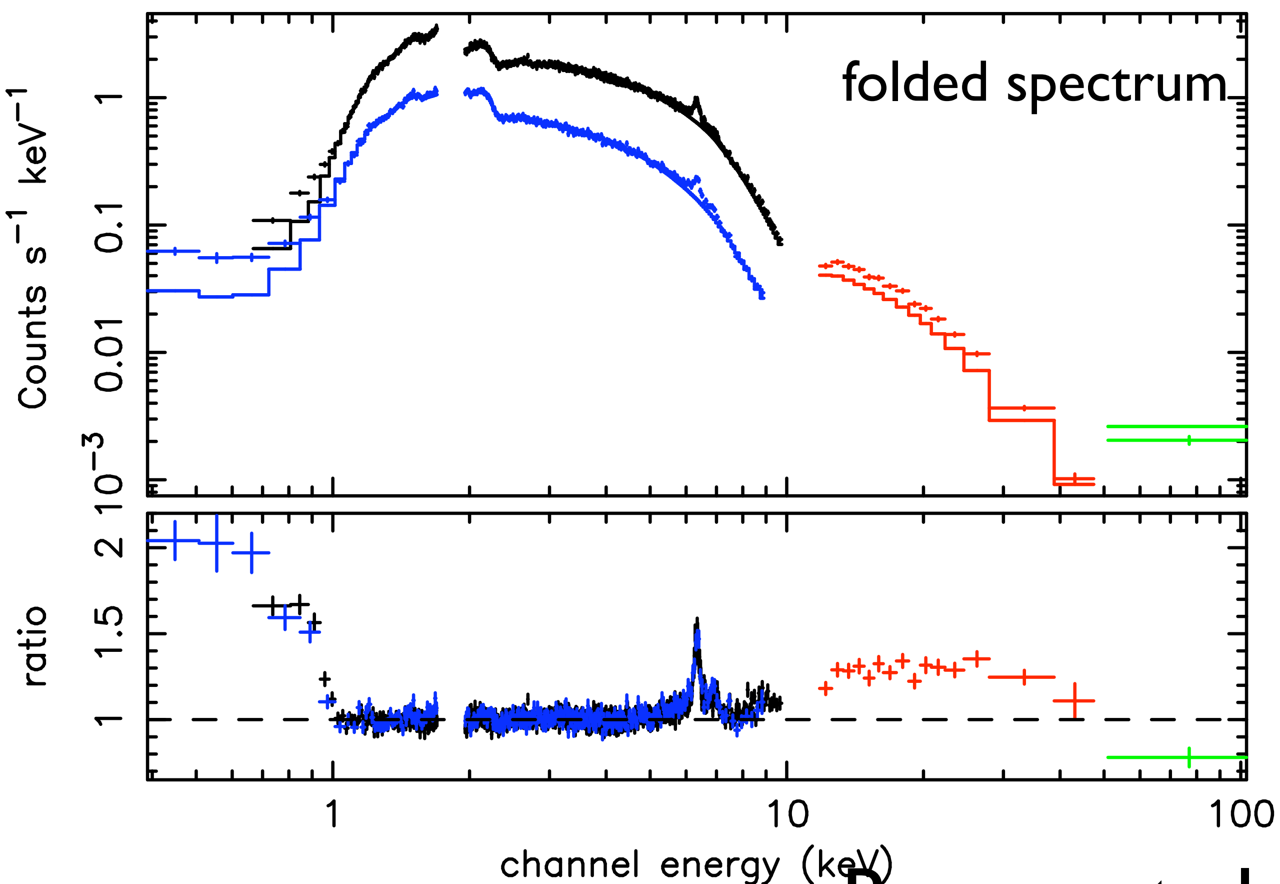


Reeves et al. 06

Suzaku/Swift/Integral should help to understand the nature of XRB, But.....

HXD　日本で独自に開発された

高感度 硬X線・ガンマ線検出器

数10keVから数100keVで高感度の検出器を作るのは非常に難しい（コンプトン散乱の領域）

・井戸型アクティブシールド

・GSO/BGO シンチレータ

・大面積シリコンPIN検出器

・「ぎんが」「あすか」の経験

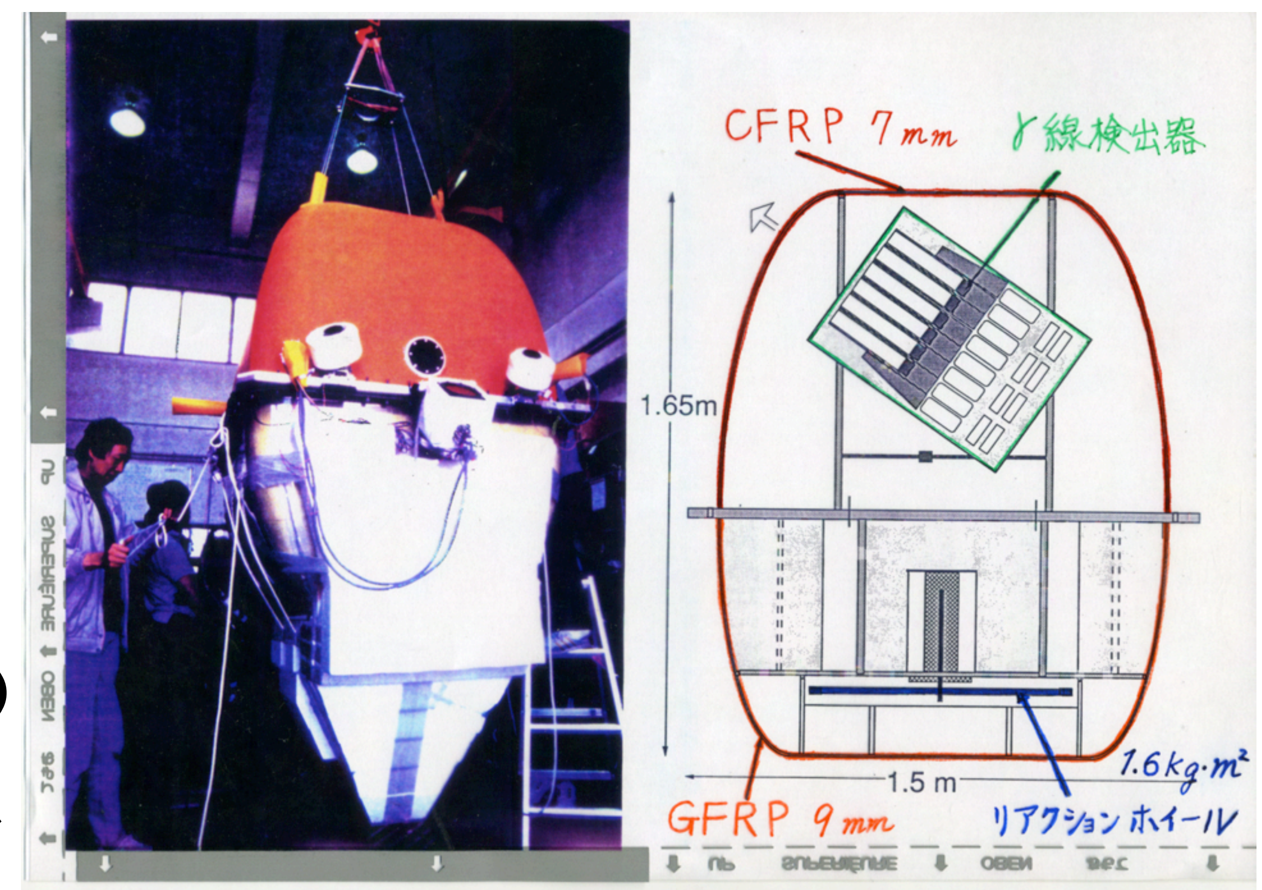
ブラジルにおける気球実験 (1988―91)

釜江、高橋、郡司、田村、宮崎、
関本、山崎、平山、星野、能町
ISAS 気球グループ

三陸における気球実験(1993)

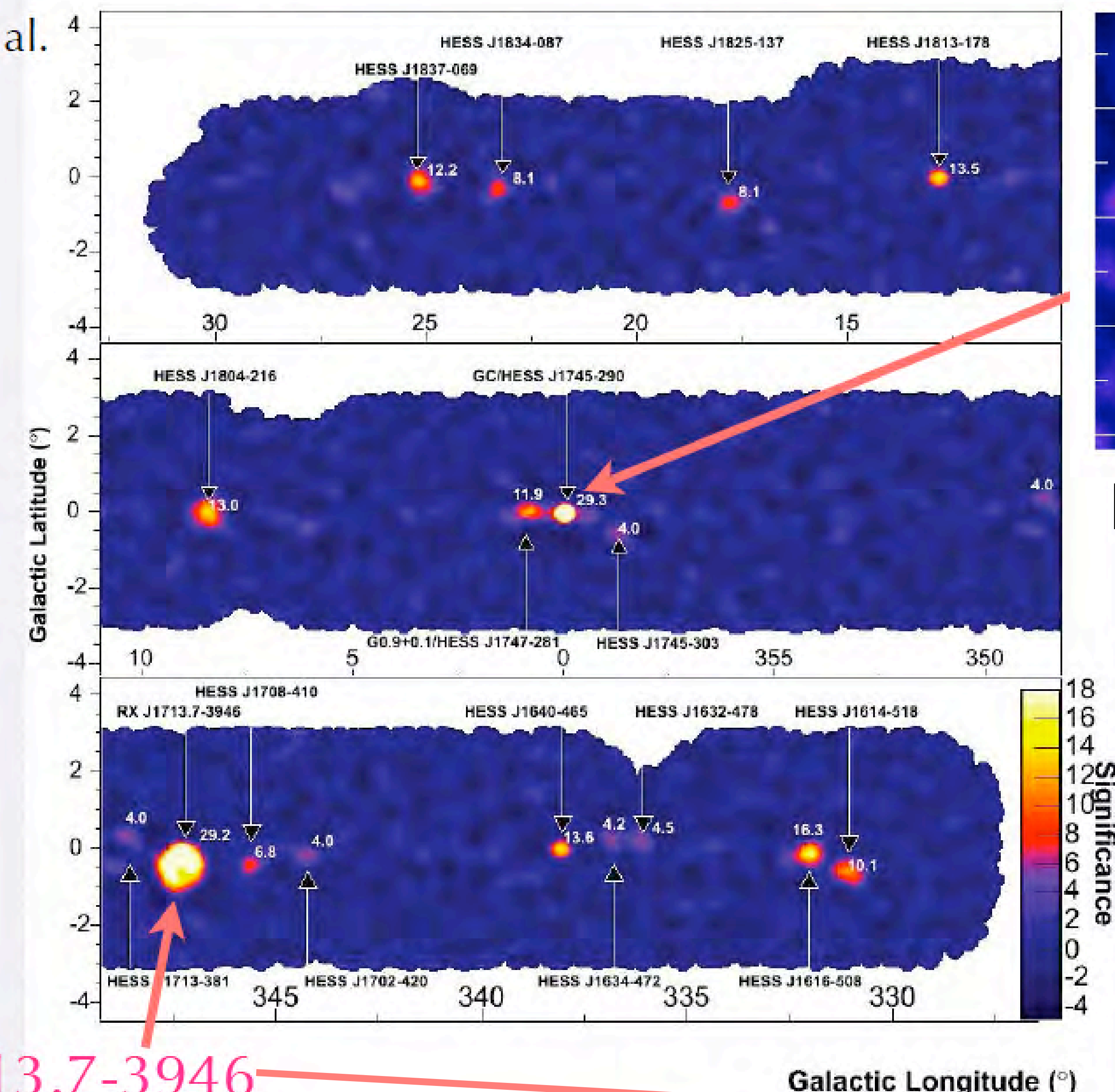
釜江、高橋、関本、平山、窪、斉藤、
鈴木、能町、ISAS 気球グループ

ブラジルで７回
三陸で２回



Hard X should have a connection with TeV gamma ray from Accelerators

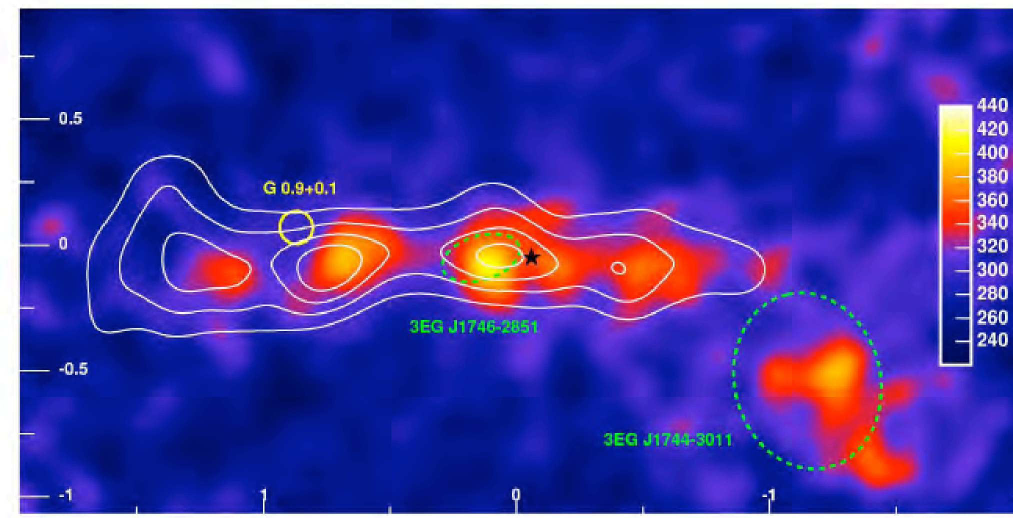
(Aharonian et al. 2005)



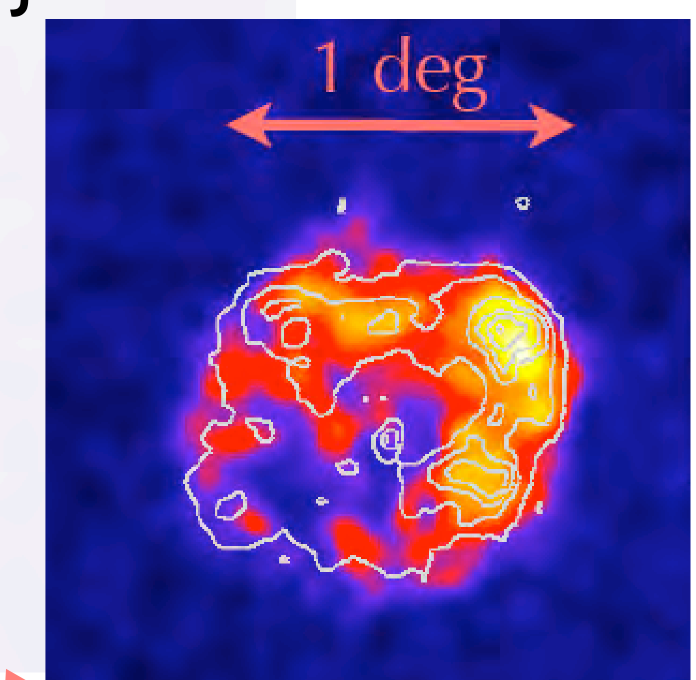
RX J1713.7-3946

TeV SNR (proton accelerator)

TeV Diffuse near GC

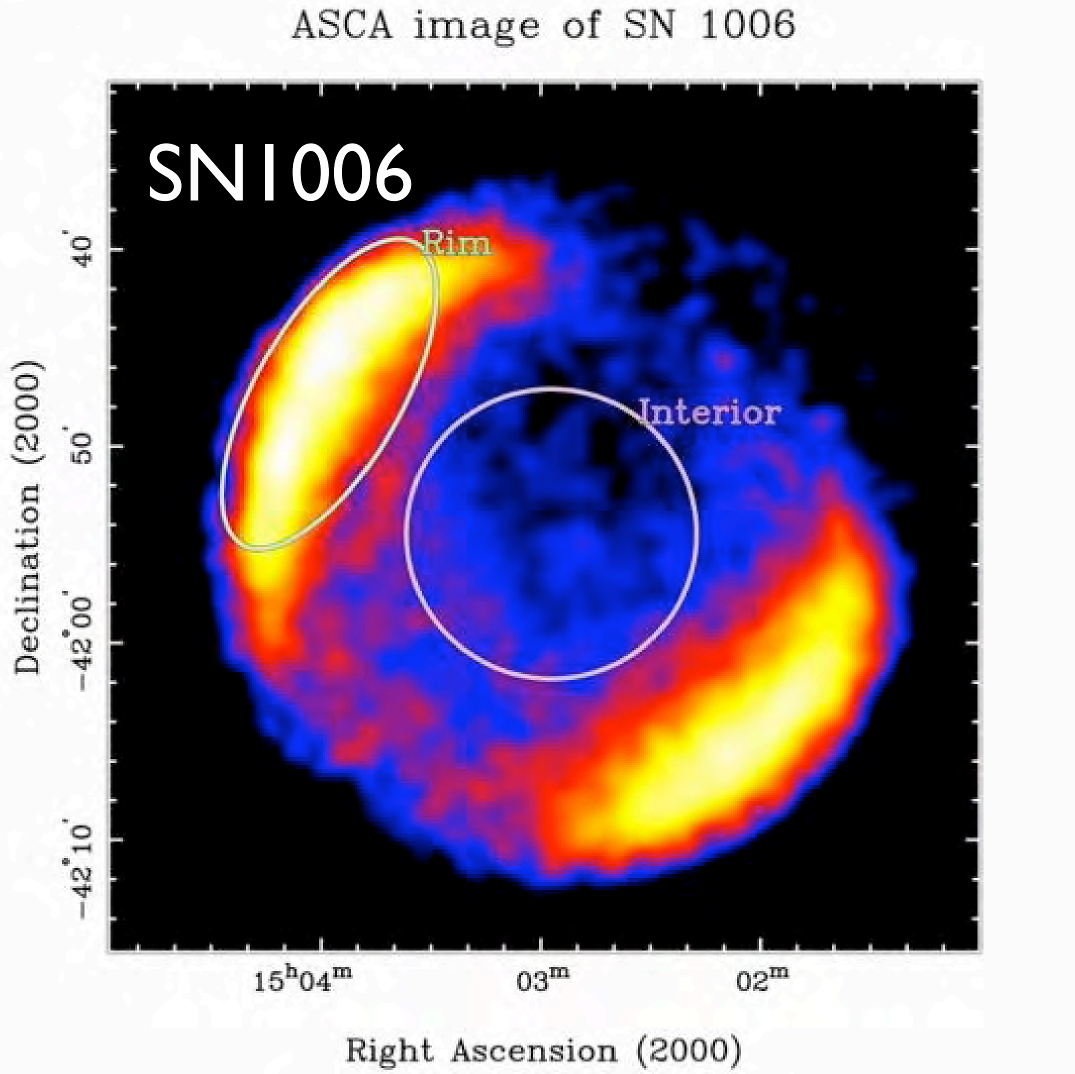


RXJ 1713.7-3946



TeV Image/X-ray Contour

Supernova Remnants as the site of Cosmic-ray Acceleration



- ASCA discoveries of X-ray synchrotron emission from SN1006 (Koyama et al. 1995)

$$h\nu_{\rm synch} = 5.3\ E^2_{100\,\rm TeV} B_{10\,\mu\rm G}\quad [\rm keV]$$

→ Existence of

high energy electrons with energy up to 10 - 100 TeV.

【Maximum Energy $(t_{acc} = t_{age})$】

$$E_{max} = \frac{3}{20}\frac{1}{\eta}\left(\frac{V_s}{c}\right) eBR$$

$$= 460 \times \frac{1}{\eta}\left(\frac{V_s}{10^4\ \rm km/s}\right)\left(\frac{B}{10\mu G}\right)\left(\frac{R}{10\ \rm pc}\right)\ \textbf{TeV}$$

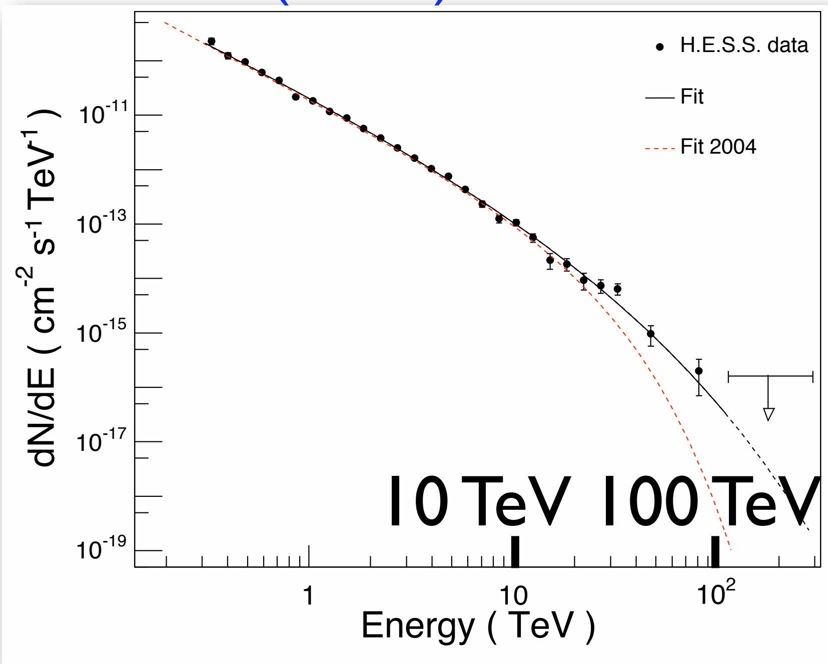
Diffusive Shock Acceleration

maximum energy = Velocity x B filed x Region size

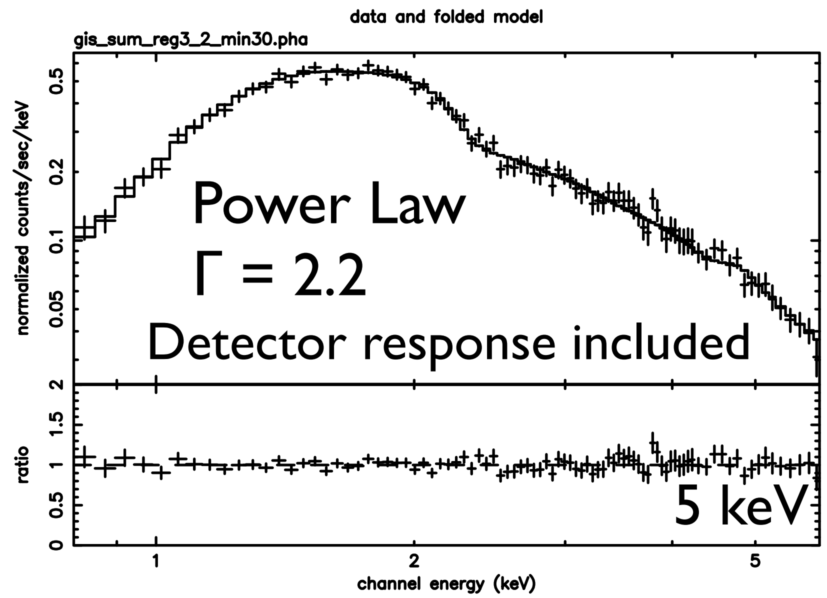
RX J1713.7-3946

Brightest Non-thermal X-ray/TeV SNR, probably at D=1kpc and age ~ 1000yrs.

H.E.S.S. (2006)



ASCA



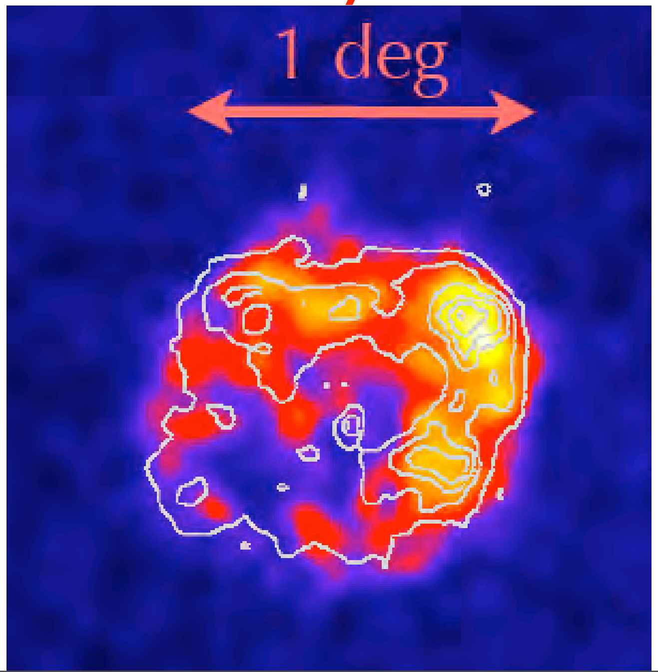
Uchiyama 2003

Hard Power-law Spectrum with Γ = 2.2 up to 5 keV, synchrotron dominated

Q1. Ecut (Maximum Energy)?

Q2. How can we explain it?

TeV Image vs
ASCA X-ray Contour



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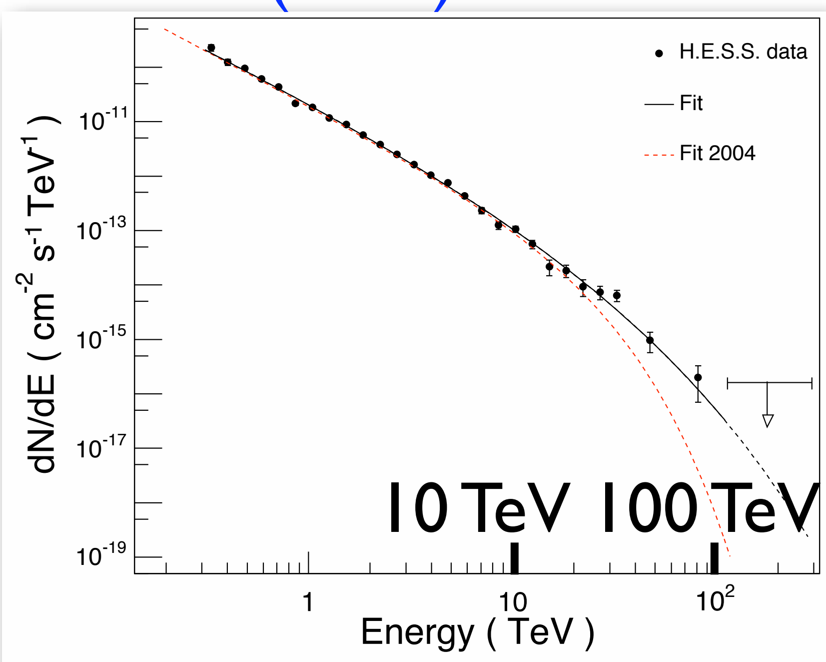
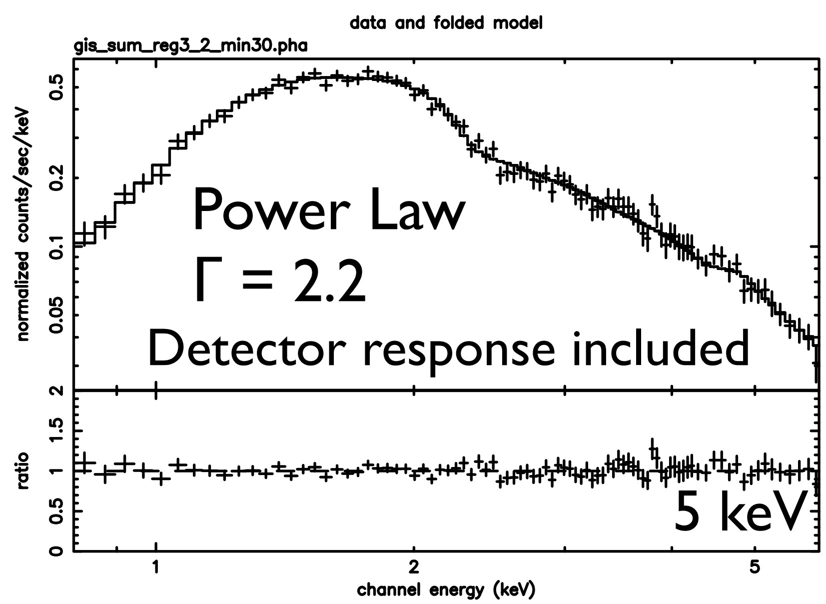


ASCA



Uchiyama 2003

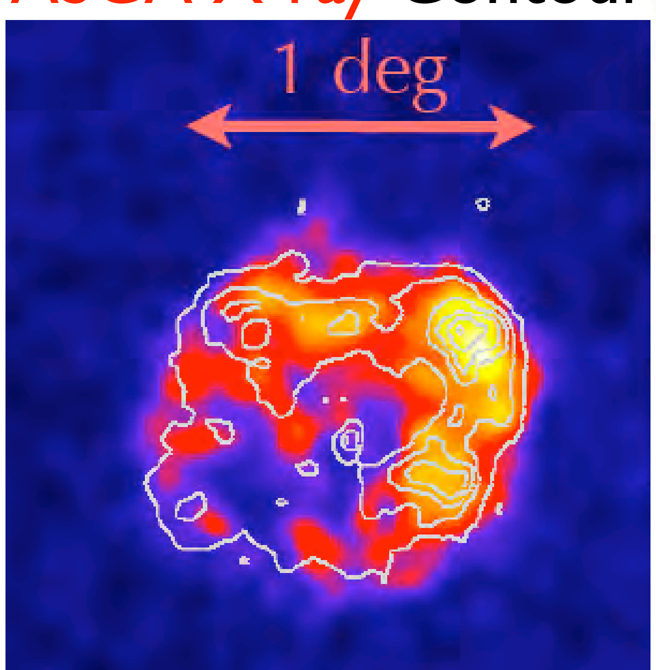
Hard Power-law Spectrum with Γ = 2.2 up to 5 keV, synchrotron dominated

Q1. Ecut (Maximum Energy)?

Q2. How can we explain it?

synchrotron cooling

TeV Image vs ASCA X-ray Contour



【Loss limited maximum energy ($t_{acc} = t_{sync}$) 】

$$E_{max} = 67 \times \left(\frac{B}{10\mu G}\right)^{-\frac{1}{2}} \left(\frac{V_s}{2000\ \mathrm{km/s}}\right) \eta^{-\frac{1}{2}}\ \mathrm{TeV}$$

If Cutoff > 10 keV, very high Vs is required.

【Synchrotron cutoff】

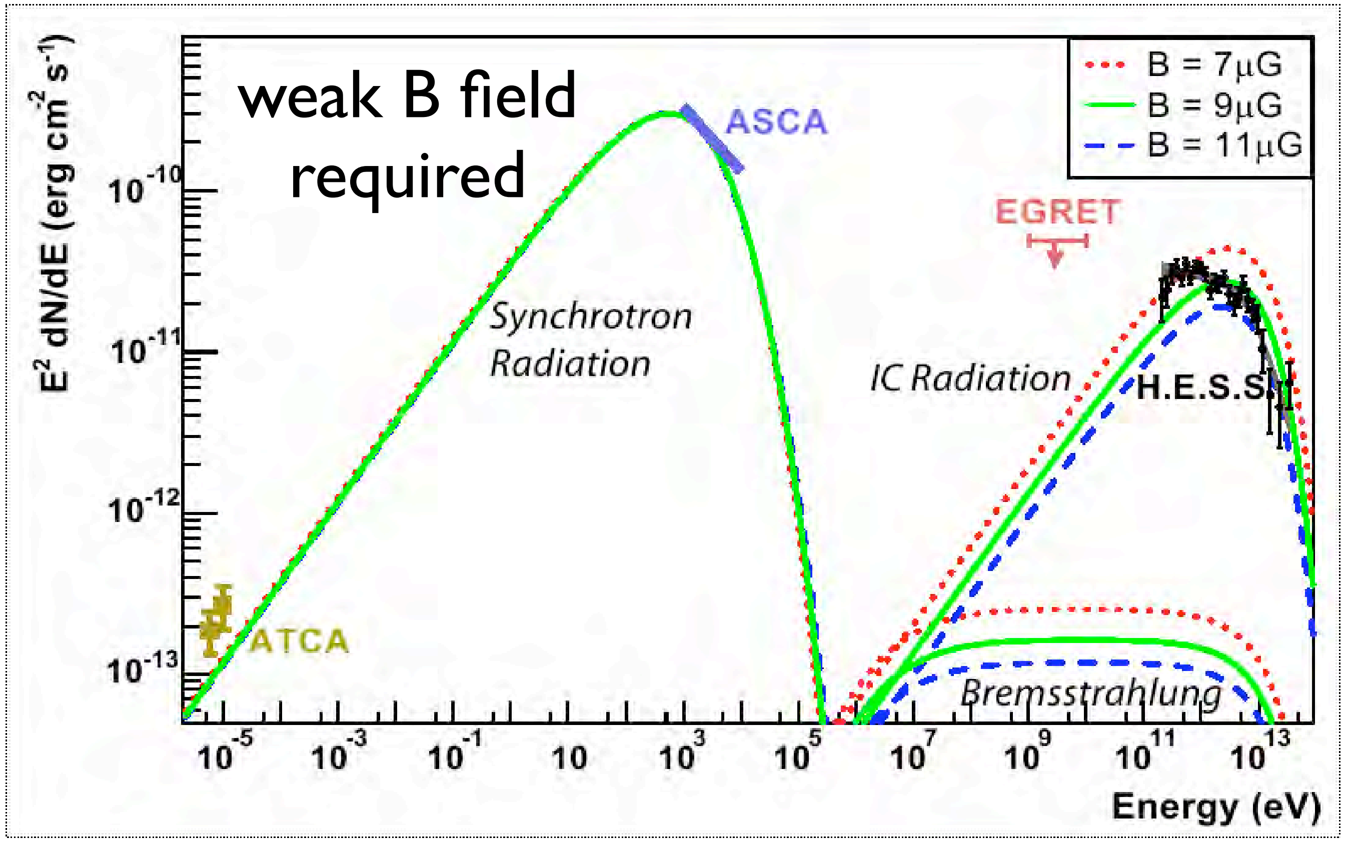
$$\epsilon_0 = 2.0 \times \left(\frac{V}{2000\mathrm{km/s}}\right)^2 \times \eta^{-1} keV$$

independent of B

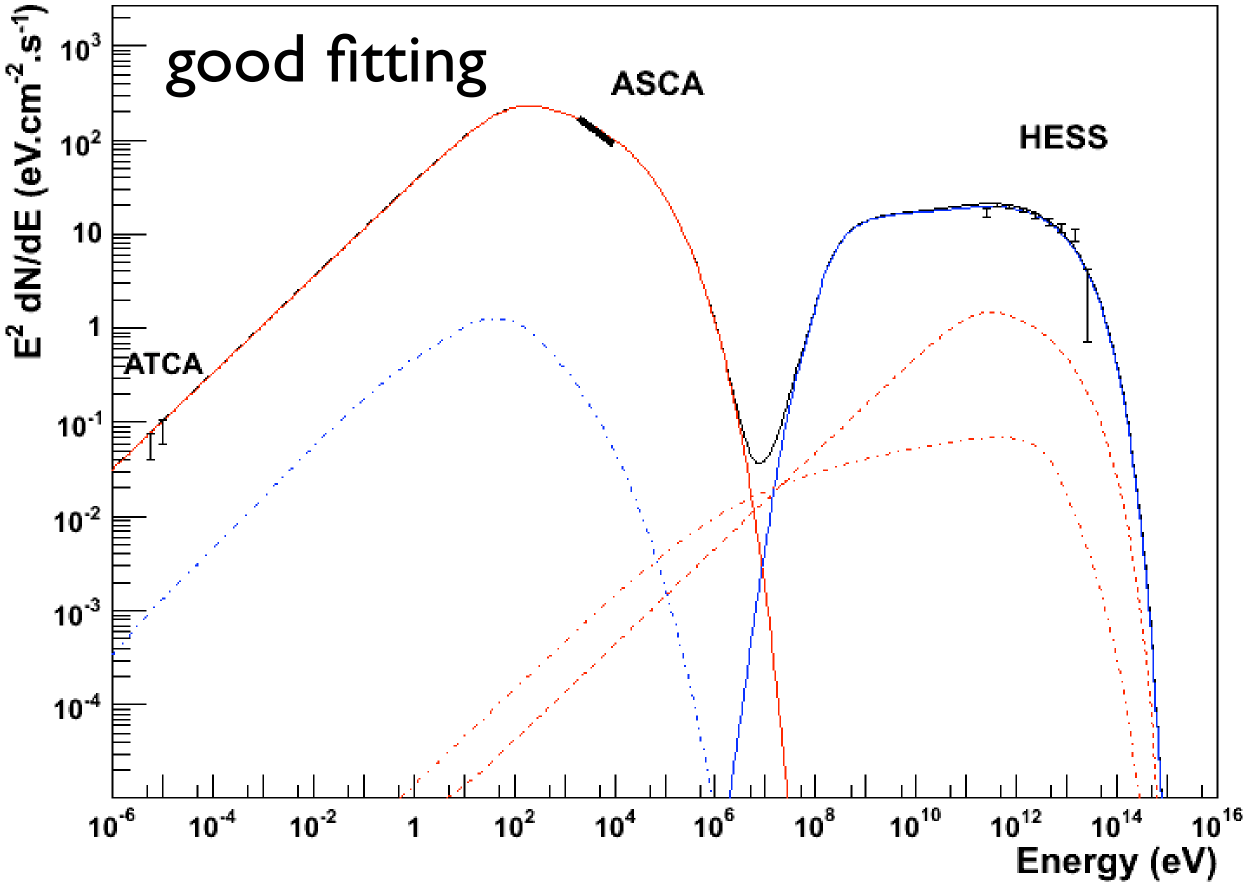
Multi Wave Length Spectrum

We need to explain the origin of X-ray and TeV, in a consistent manner.

Electronic scenario



Hadronic scenario



D=1kpc
age = 1000 yrs
n = 1 cm^3

Injection of electrons, p=2
E<100 TeV

Injection of protons, p=2
E<120 TeV

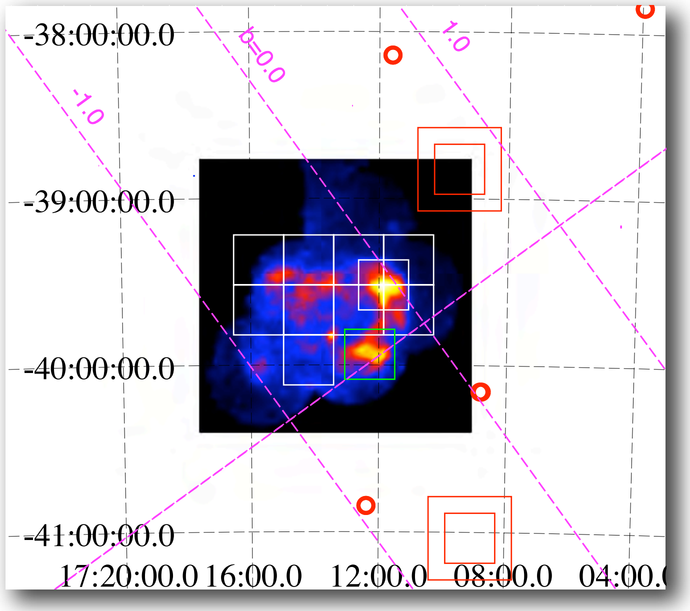
By Dieter Horns,
M. Lemoine-Goumard

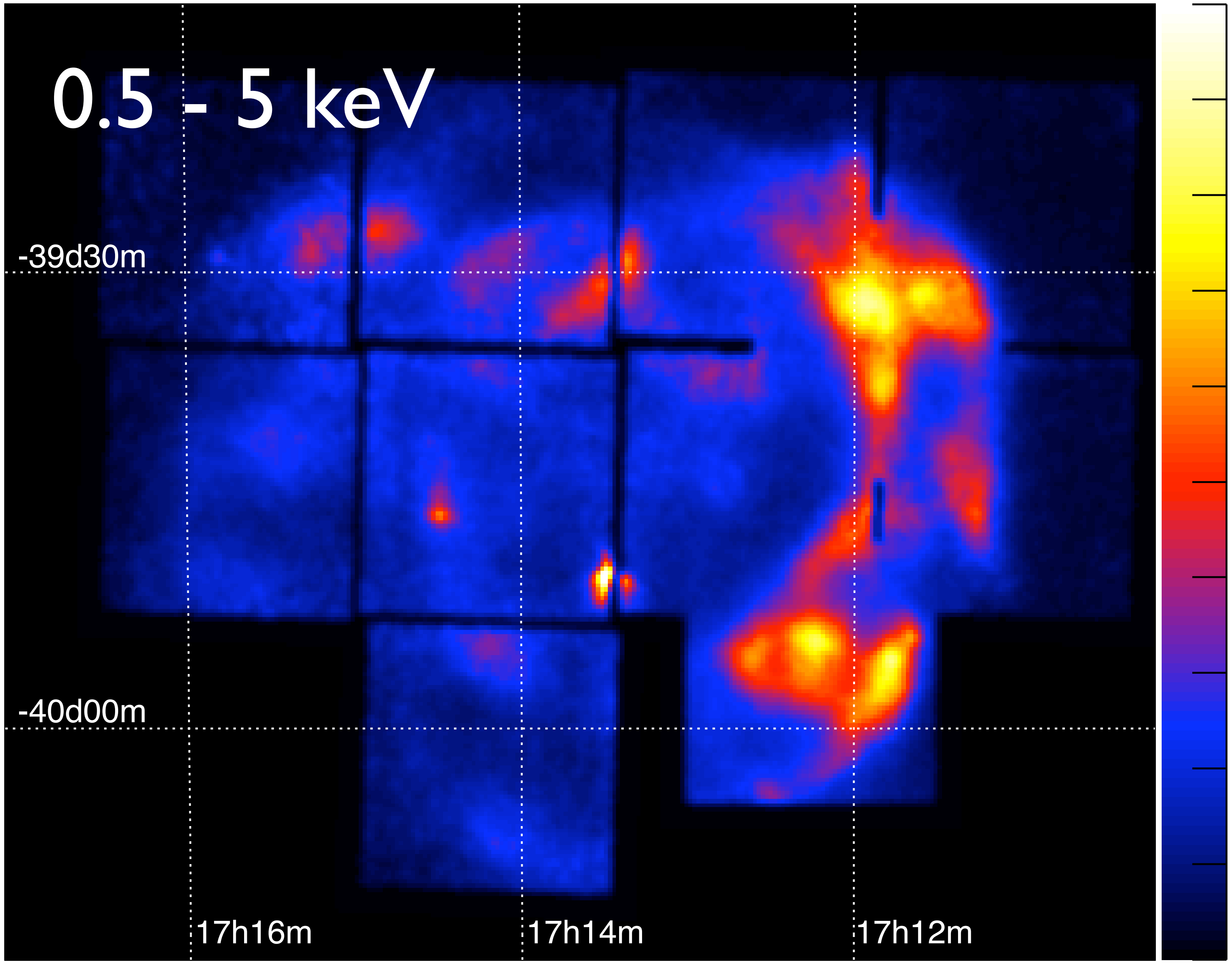
Hard X-ray data should give strong constraints

Mapping Observation of RX J1713-3946

AO1 (PI T.Takahashi, completed in Sep. 2006)

Suzaku





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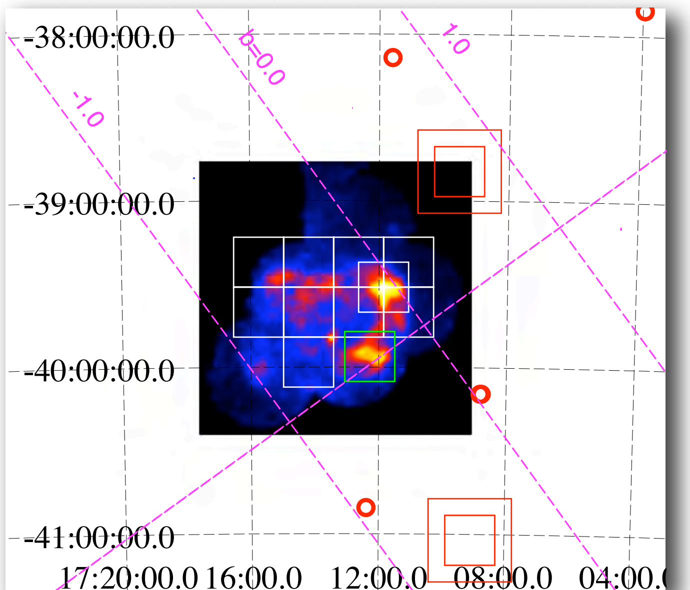
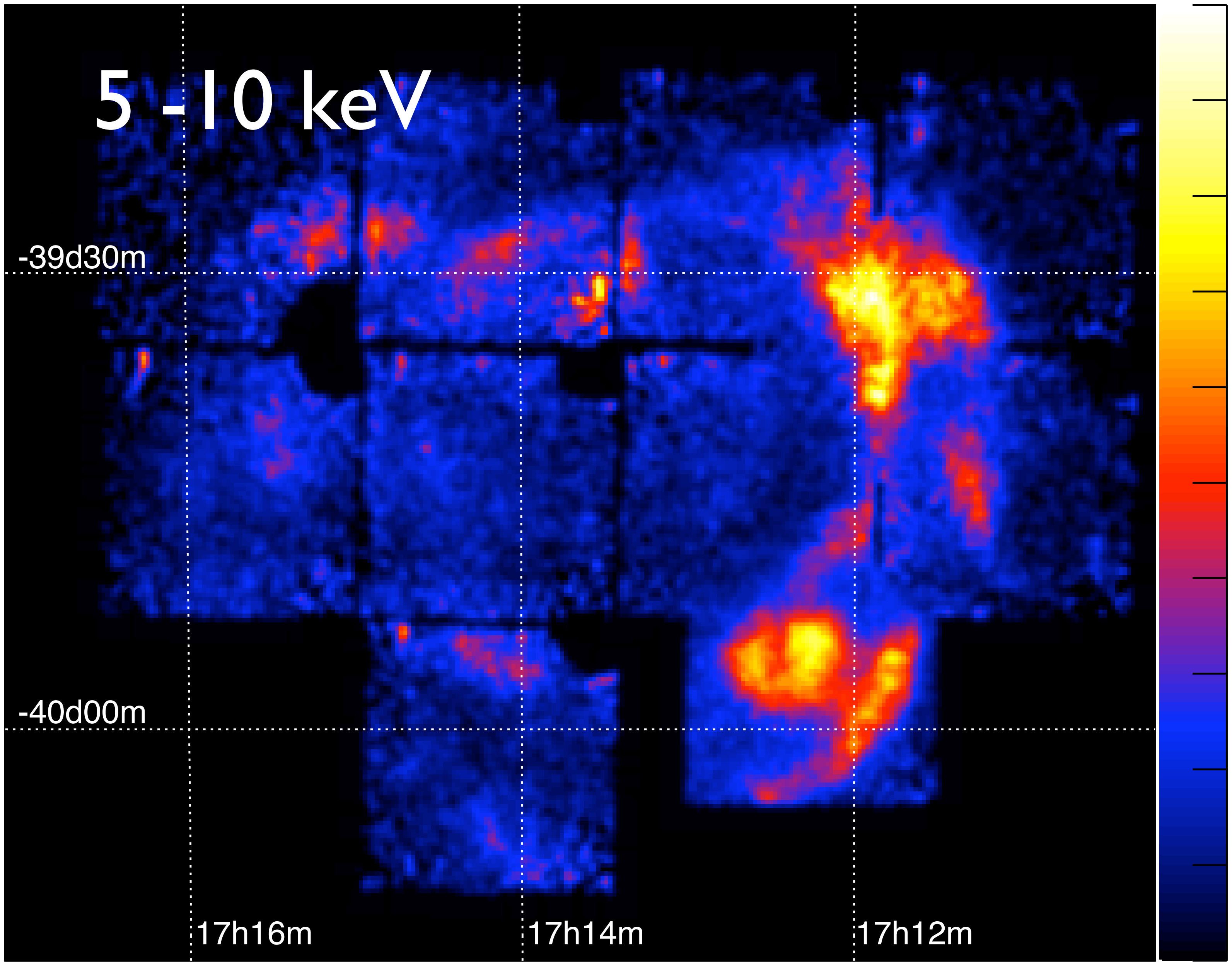
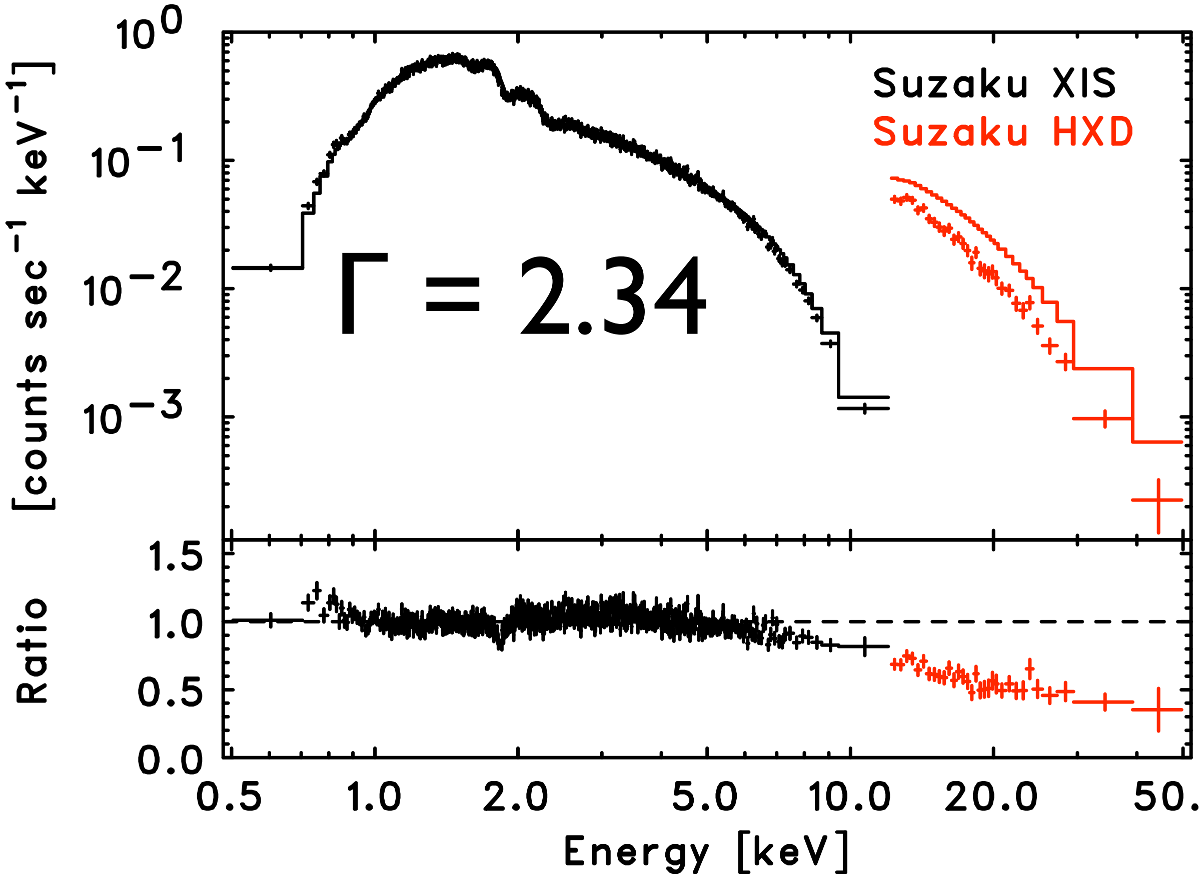
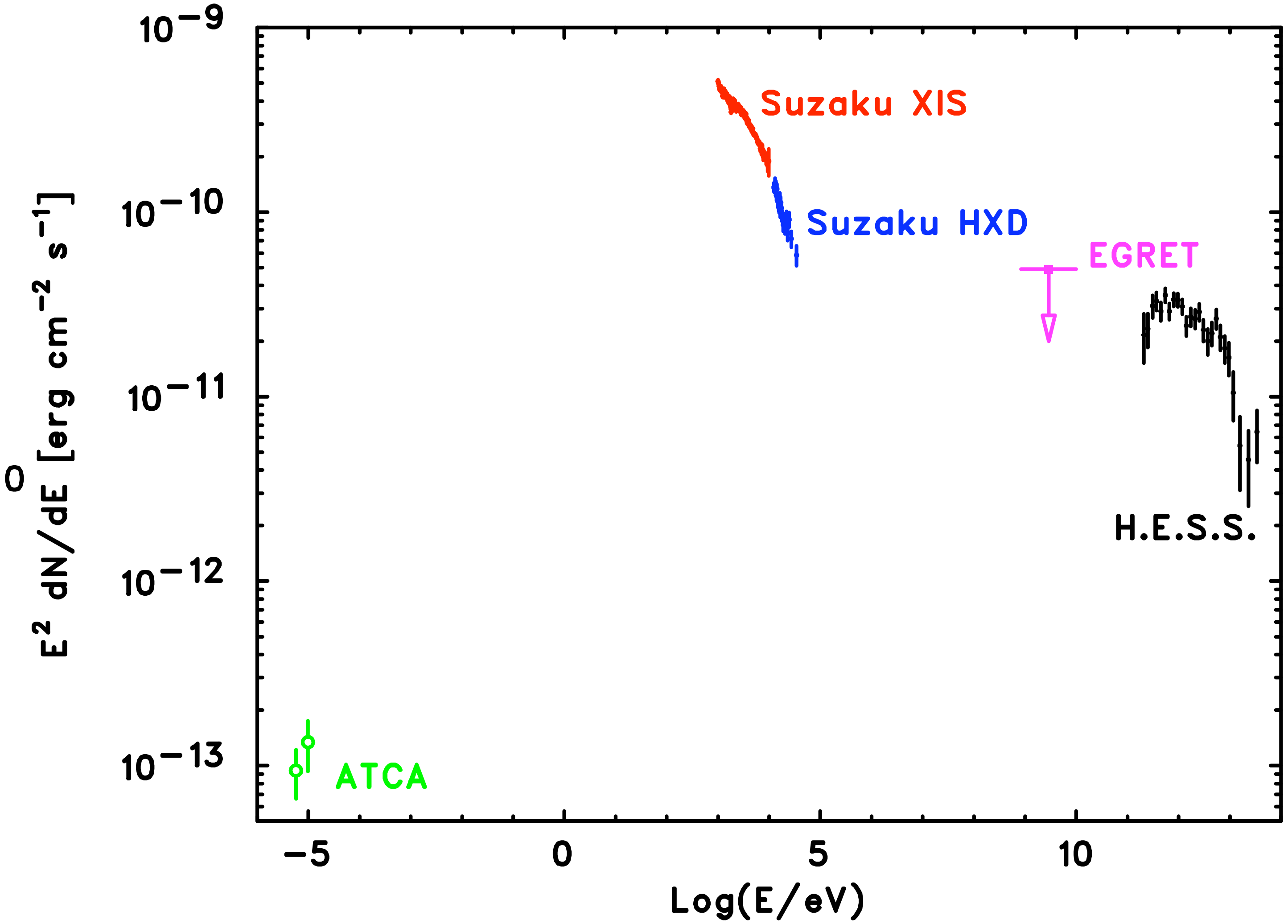




Suzaku Broad-band Spectrum (240 ks)

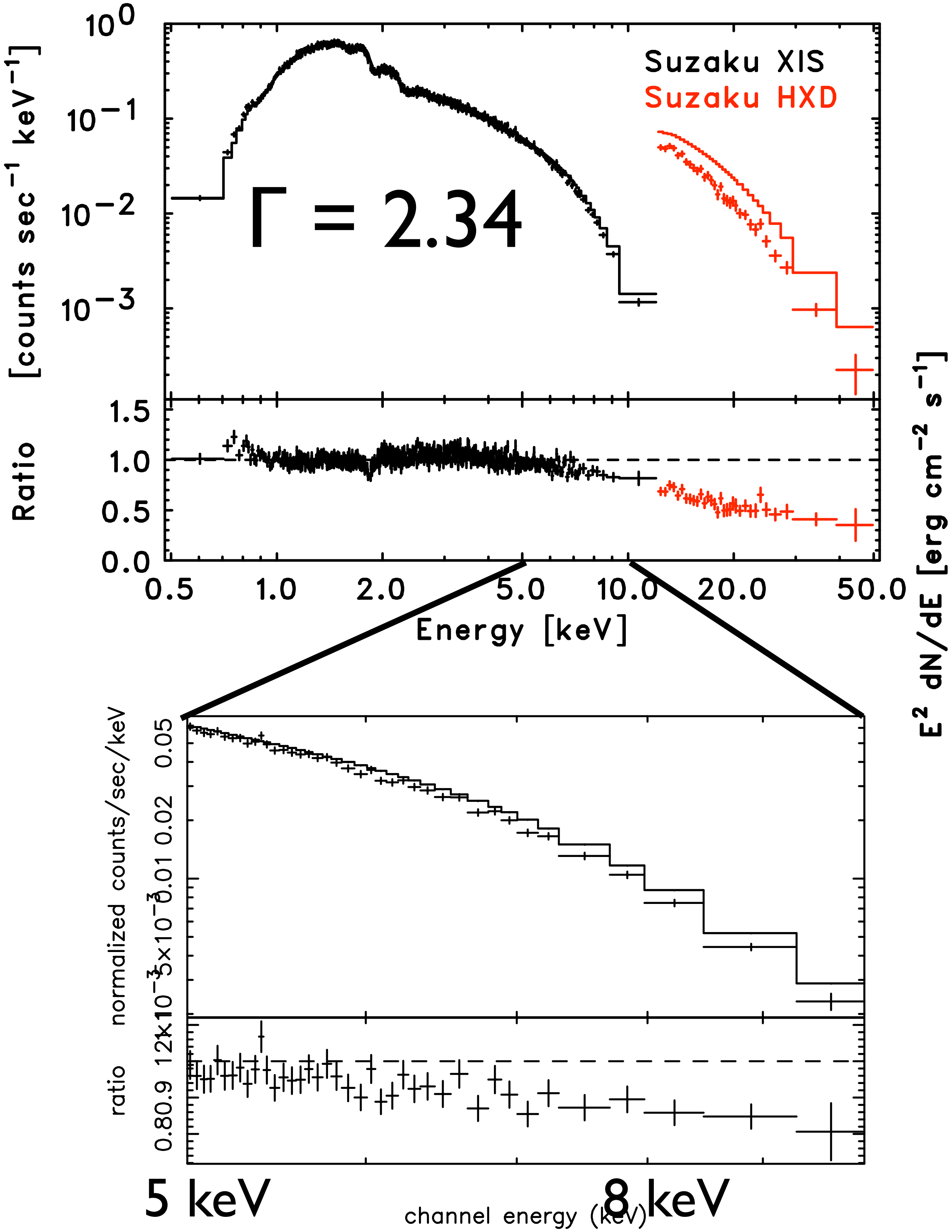


keV and TeV spectra

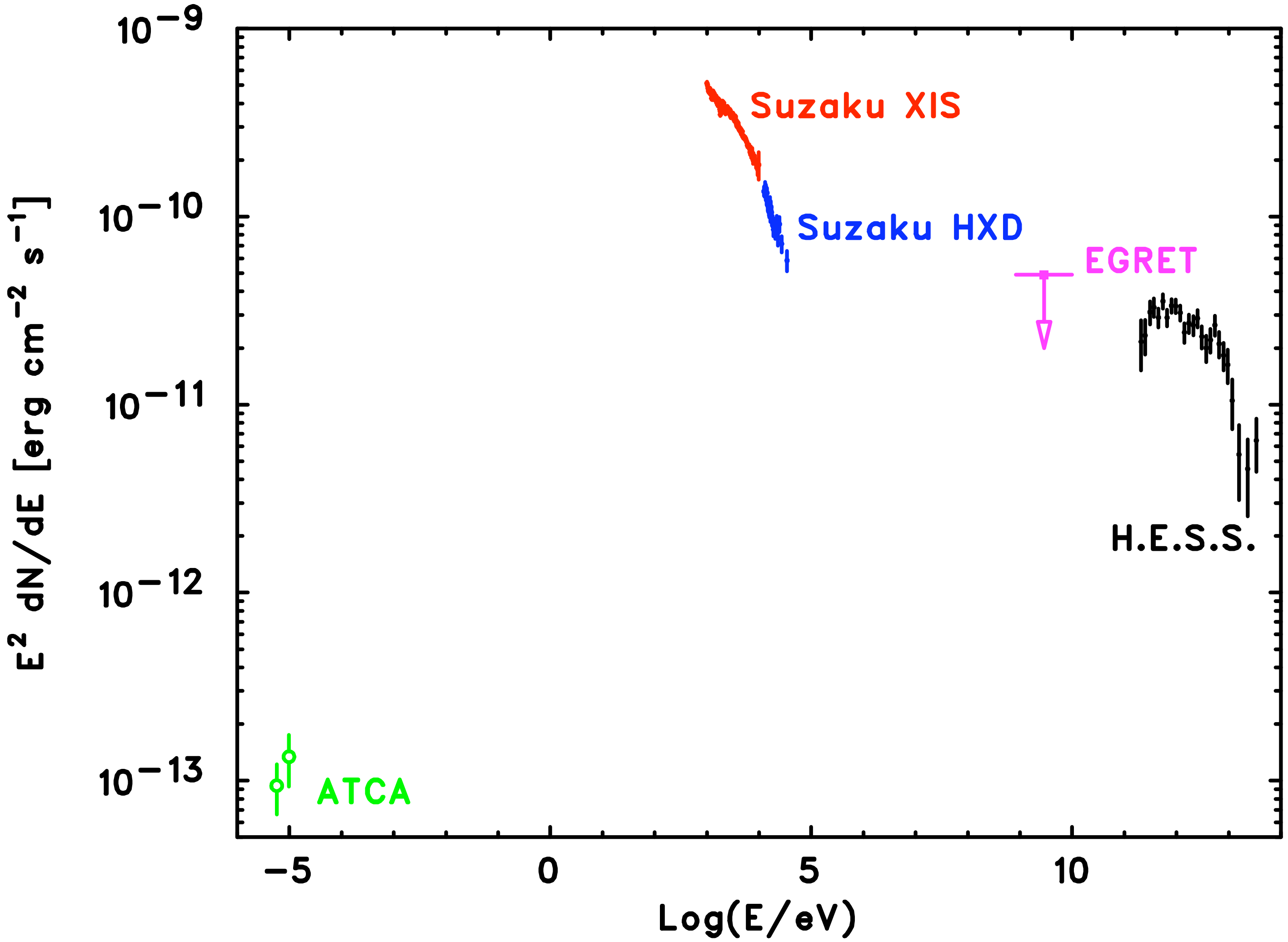


preliminary (AO1)

Suzaku Broad-band Spectrum (240 ks)

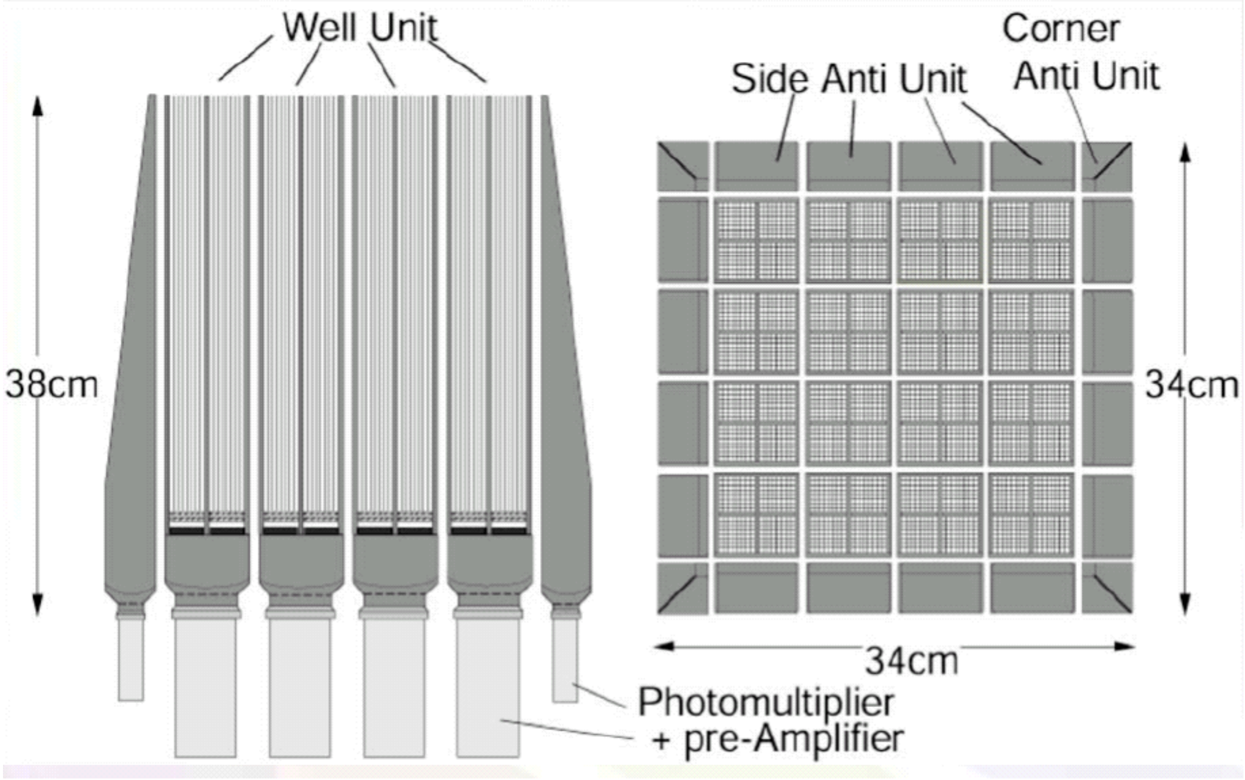


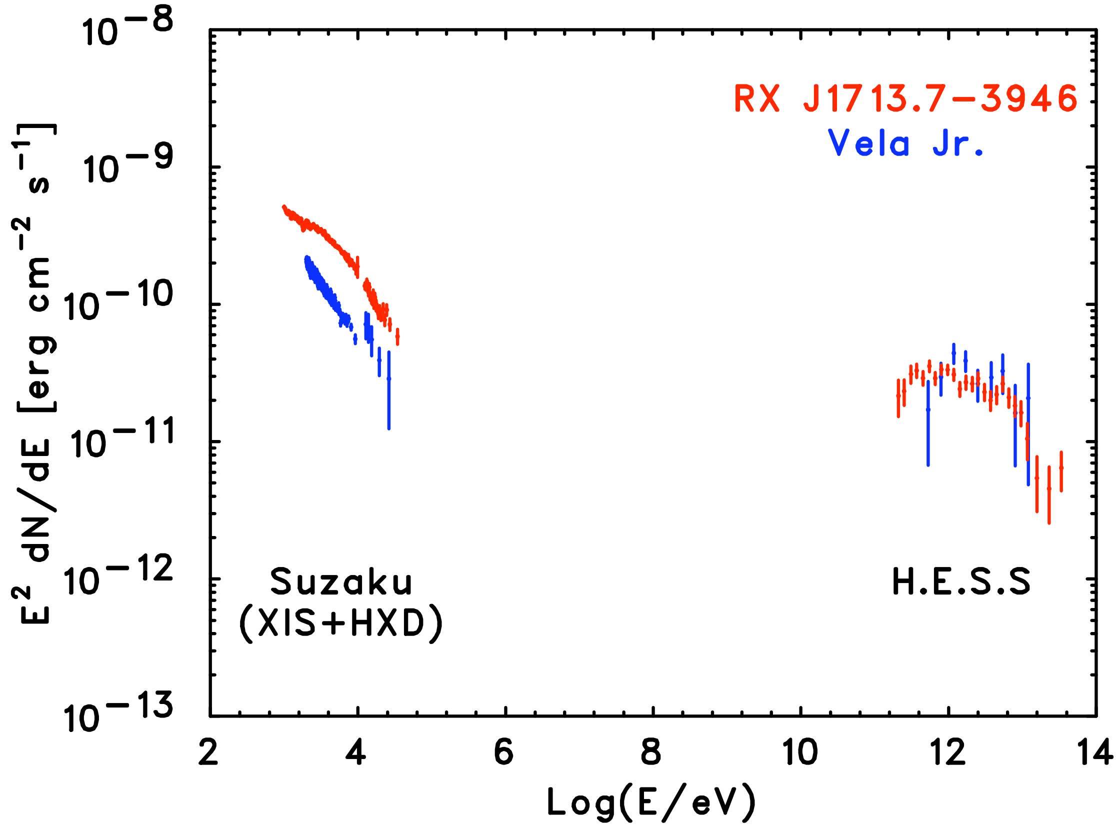
keV and TeV spectra



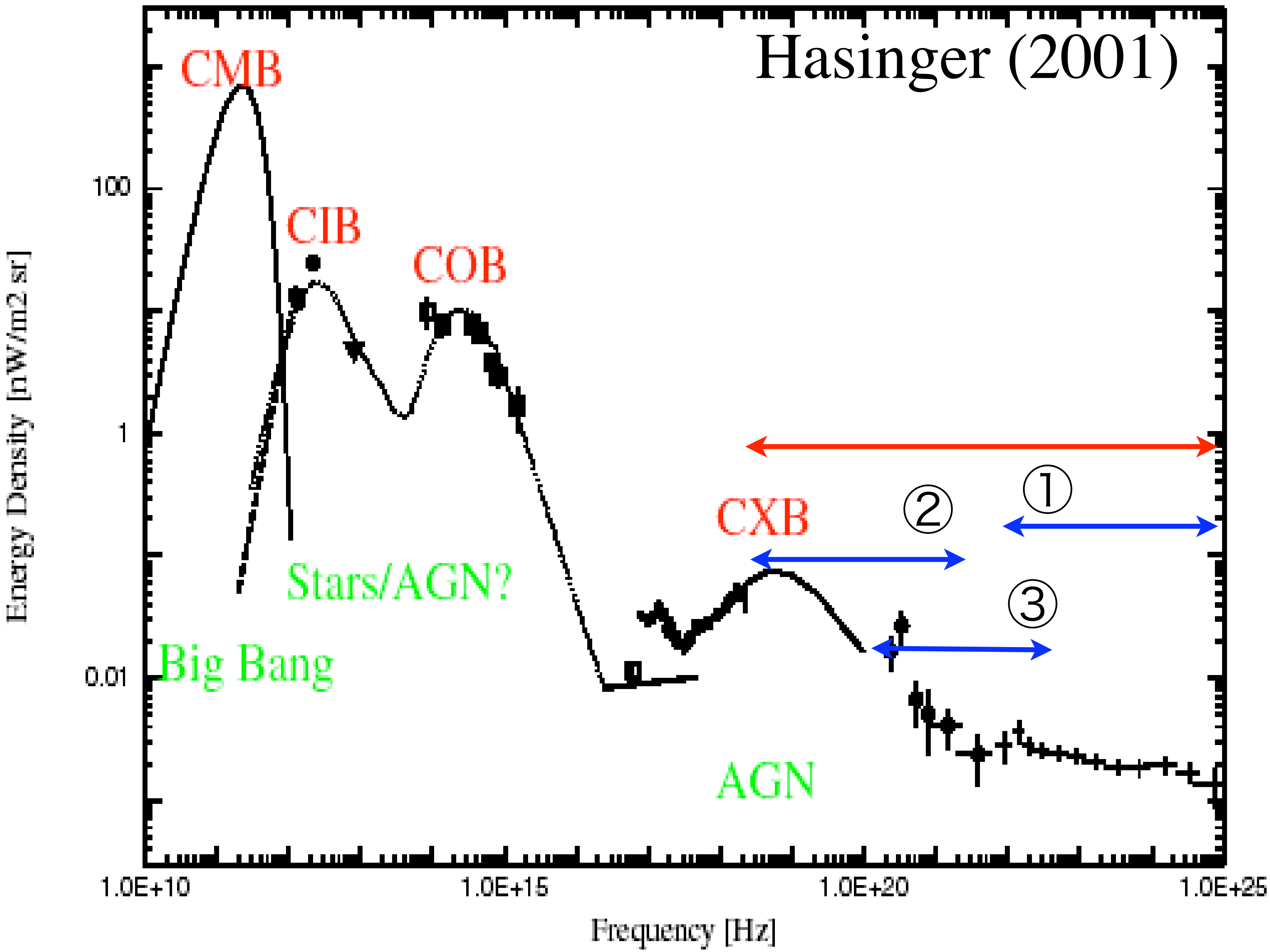
preliminary (AO1)

- Power of Suzaku
  - Low background property for both the XIS and the HXD
  - Small FOV of the HXD/PIN
- **RX J1713-3946**
  - Clear Detection up to 50 keV. First Mapping above 10 keV.
  - HXD-PIN data suggests harder X-ray spectrum at fainter region, indicating higher Emax, higher acceleration efficiency
  - New data for the keV-TeV correlation
- **Vela Jr.**
  - Another bright TeV source
  - Detected above 10 keV for the first time.





Radiation Backgrounds

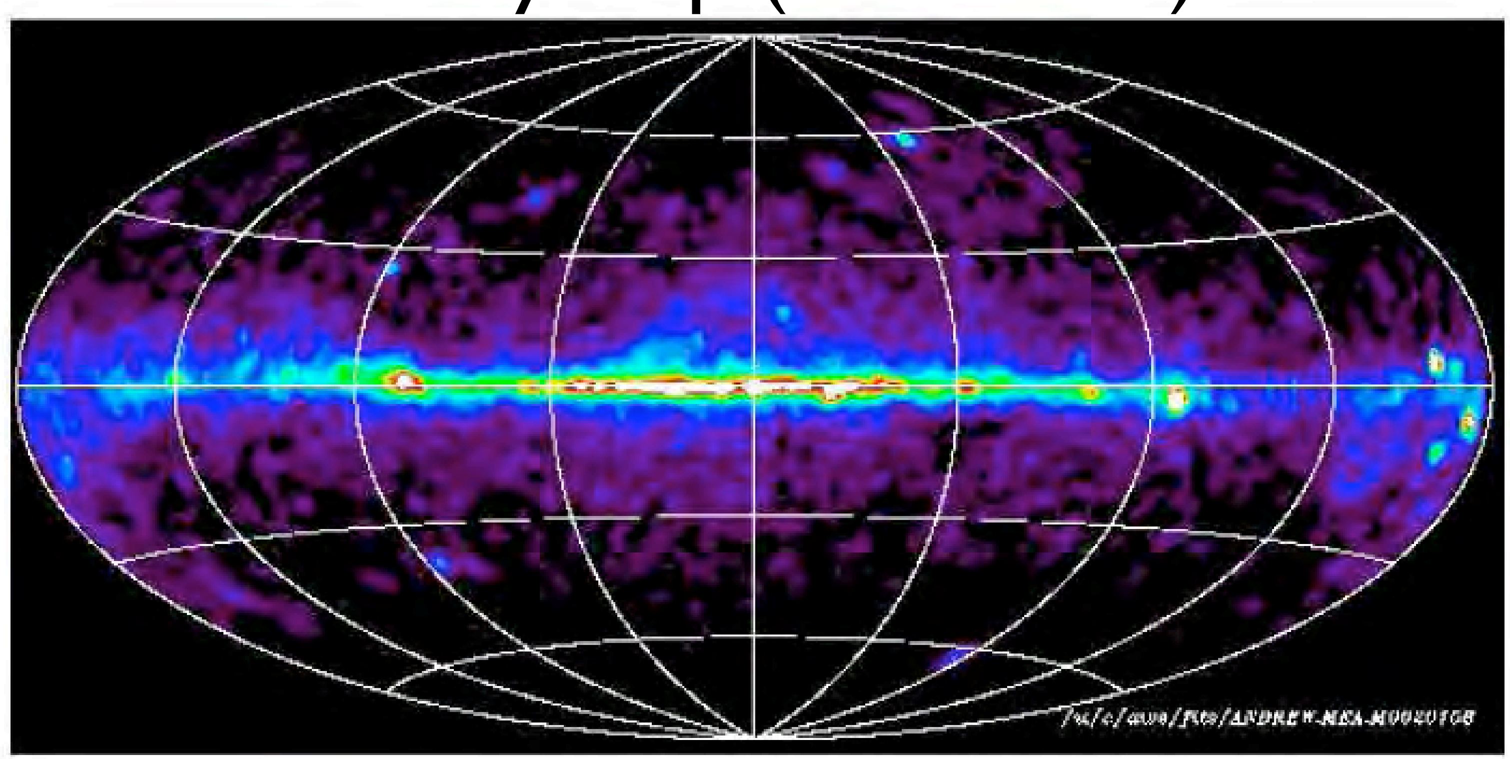


Extragalactic diffuse γ-ray emission (EGB)

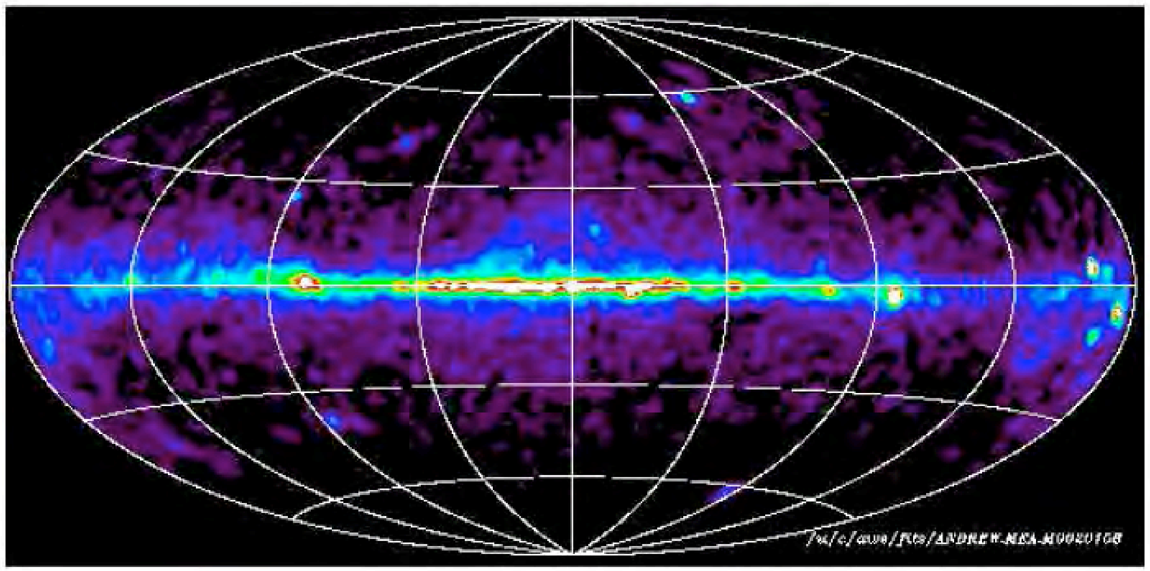
- The EGB is the component of the diffuse emission which is most difficult to determine.
- It is not correct to assume that the isotropic component is wholly extragalactic.

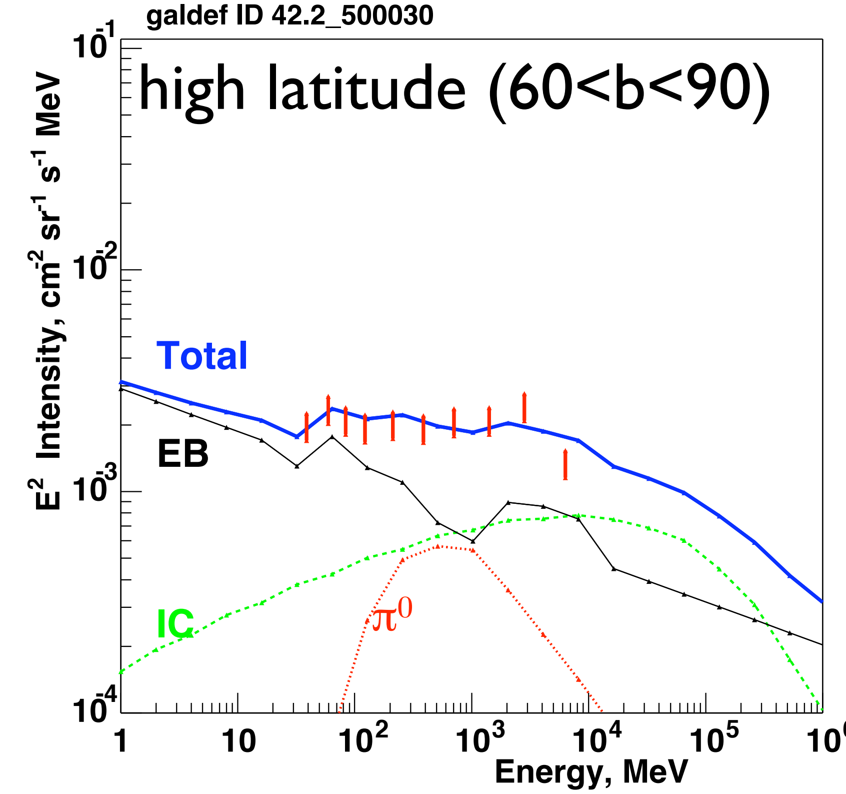
(Moskalenko, Strong, Reimer, 2004)

EGRET All-Sky Map (>100 MeV)

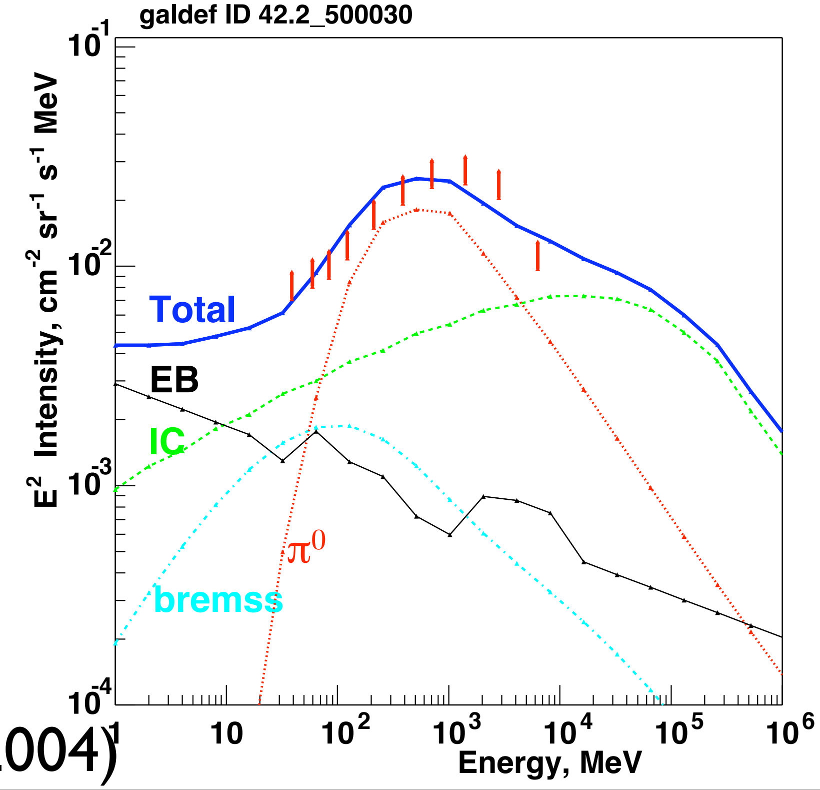


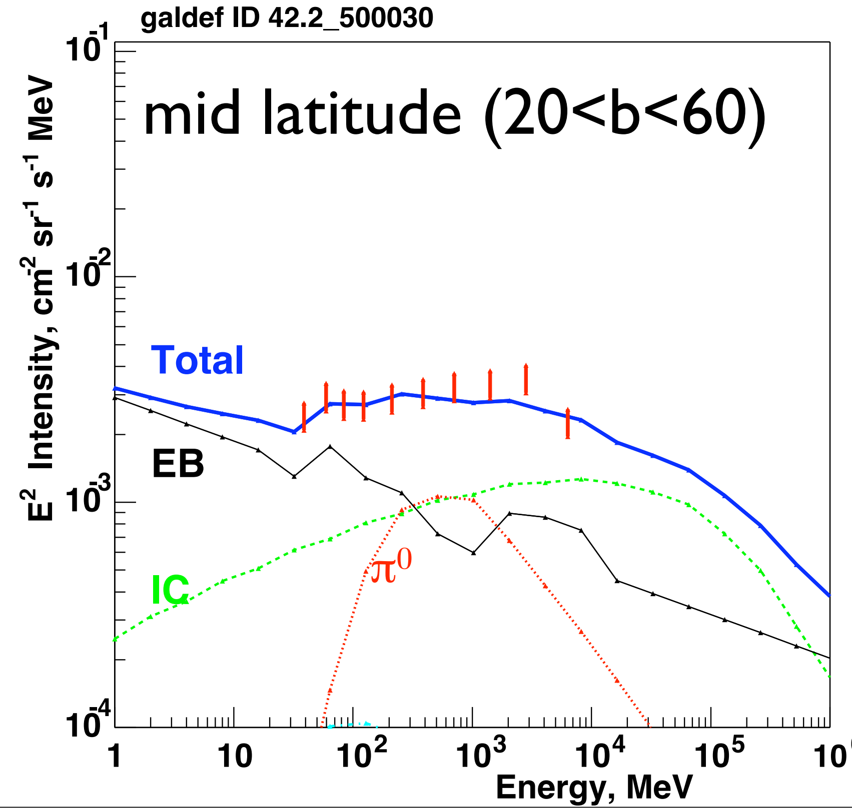
EGB measued by EGRET





The Galactic plane
excluding the inner galaxy

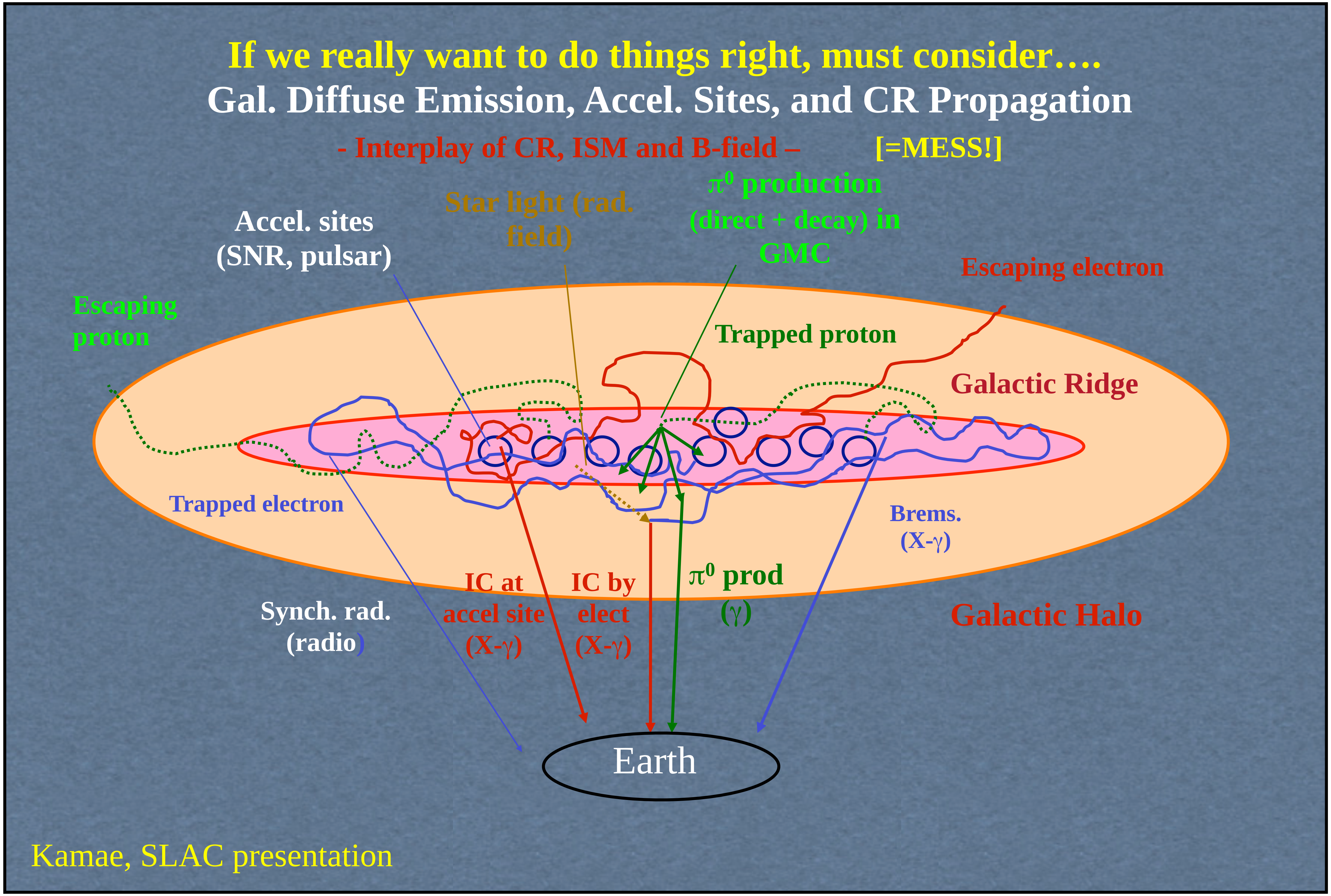




Inverse Compton Component due to the electron population in the halo is comparable to the extragalactic.

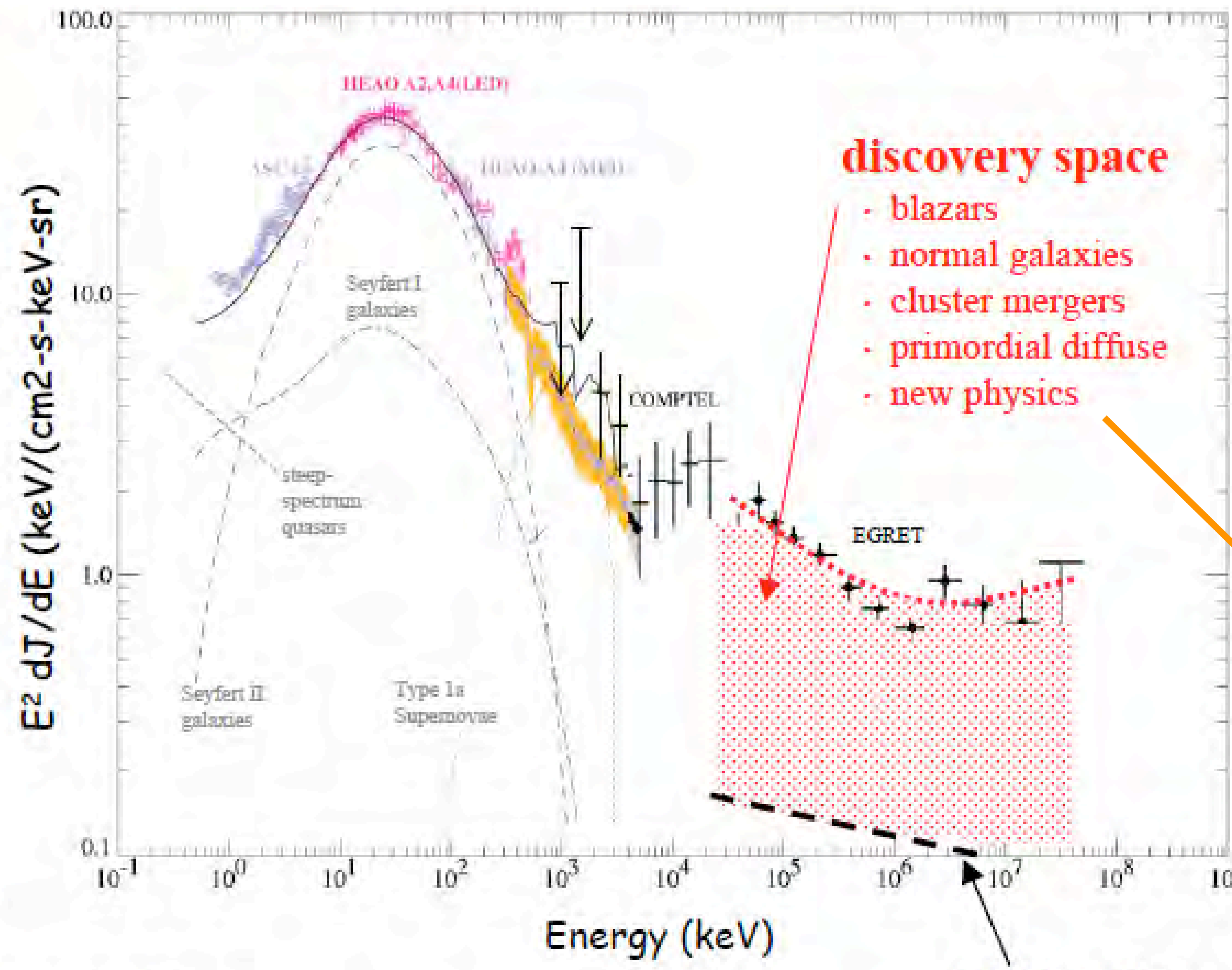
(Strong, Moskalenko, Reimer, 2004)

Galactic Diffuse Emission Model:



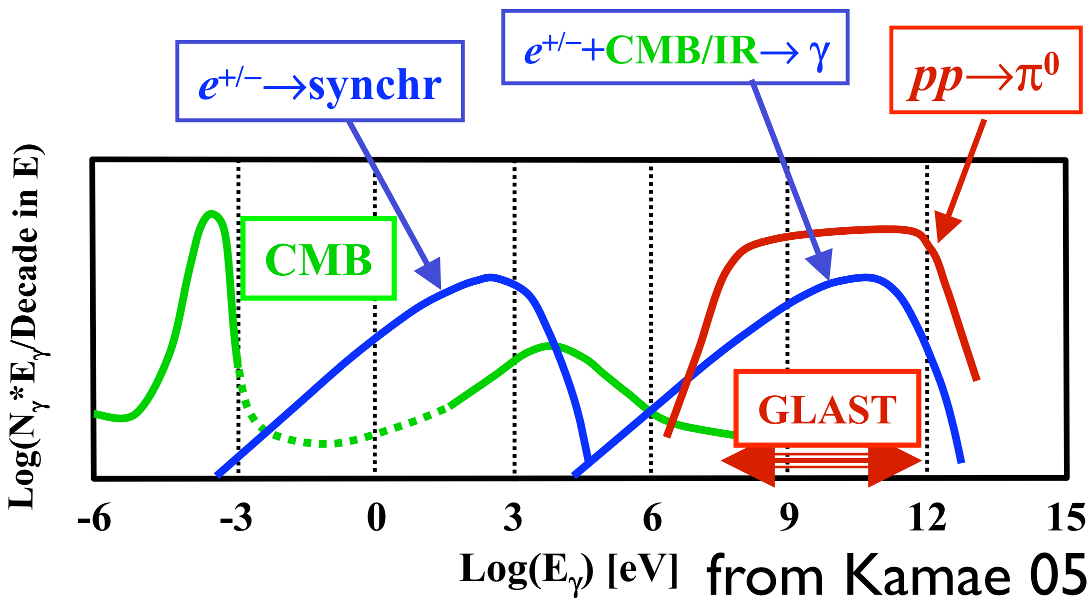
Extragalactic Diffuse γ-ray Emission

If reliably determined,
it can be used in many ways.



GLAST Baseline Background Limit

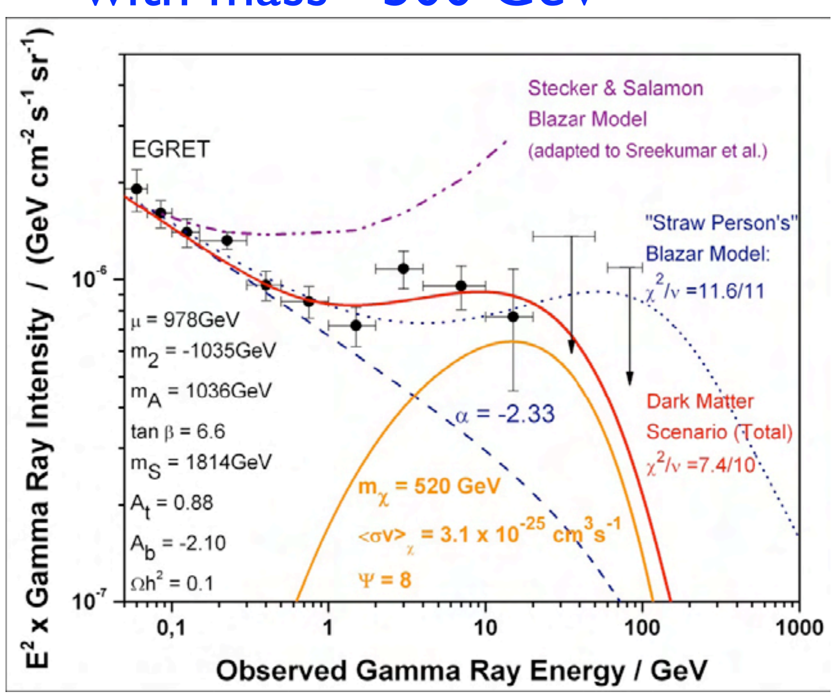
Emission from established process



from Kamae 05

Or follow the scenario that
attracts particle physicists

Annihilation of DM particles
with mass ~500 GeV



Elasser & Mannheim 04

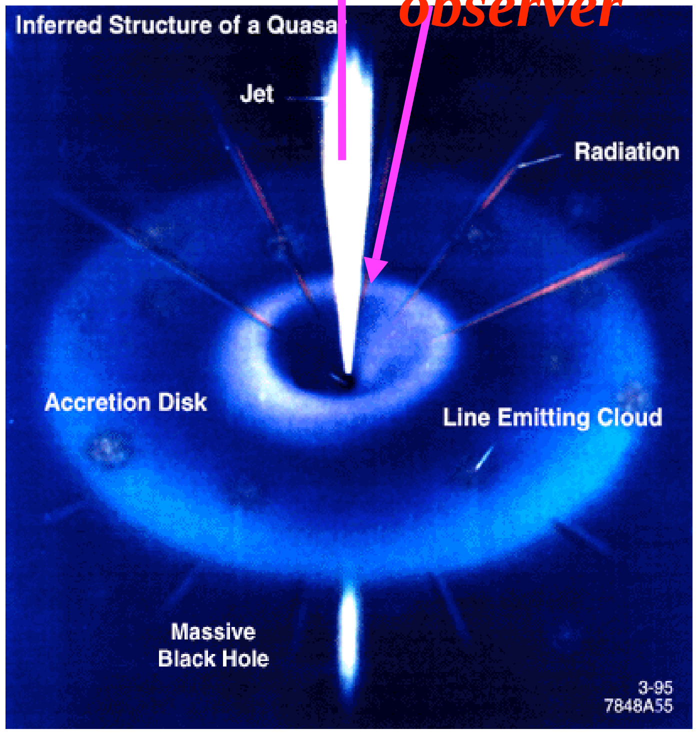
γ-ray emitting AGN

Blazars are the dominant population of extragalactic point sources at
• Gamma-ray
• TeV
(but not in X-rays and Optical)

produced in relativistic jets pointing close to the line of sight

$\Gamma_{BLK} \sim 10$

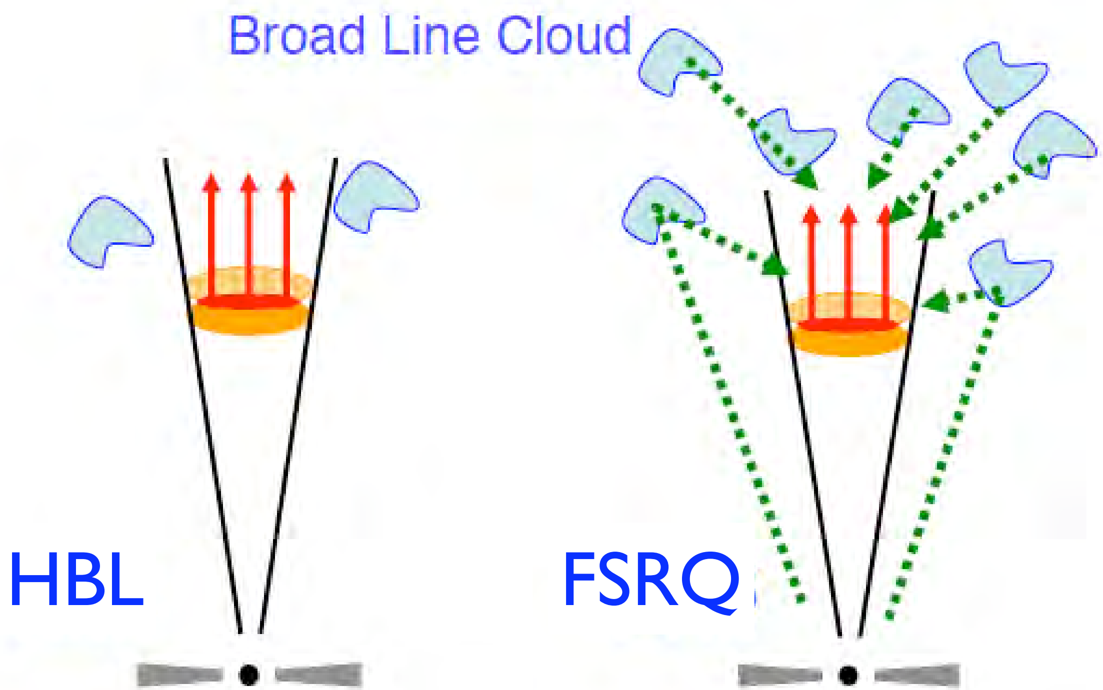
observer



AGN
• Non-thermal Spectrum
• Highly variable at all frequencies
• Highly polarized
• Radio core dominance
• Superluminal Motion

FSRQ & BL Lacs

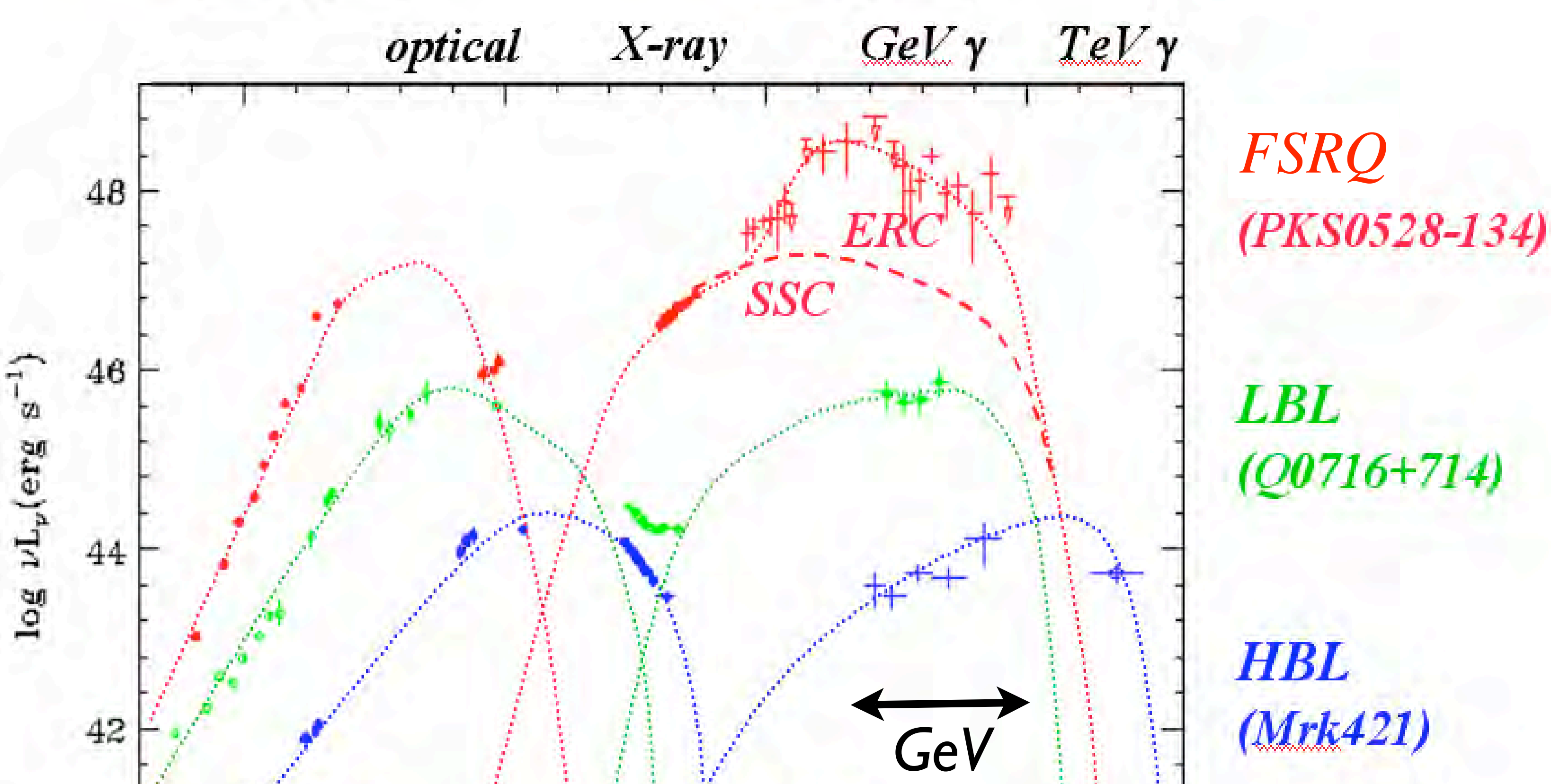
Environment of Blazar Jets



Comptonization of

1. Synchrotron Photon
2. External Photon

γ-ray emission is related to the environment



Kataoka, TT et al.
(ASCA/COMPTEL/EGRET
Simultaneous Observations)

Flat Spectrum Radio Loud QSO
(FSRQ)

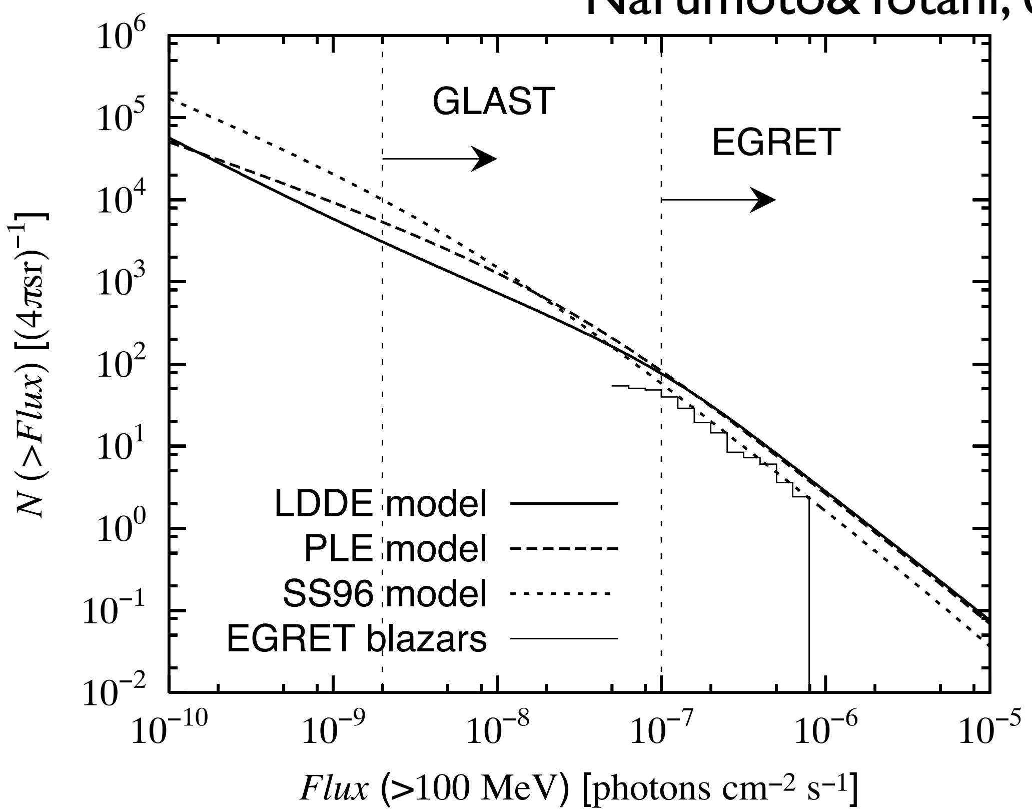
Before EGRET, nobody expected FSRQ emits huge amount of γ-rays
(External Radiation Compton)

Population Studies

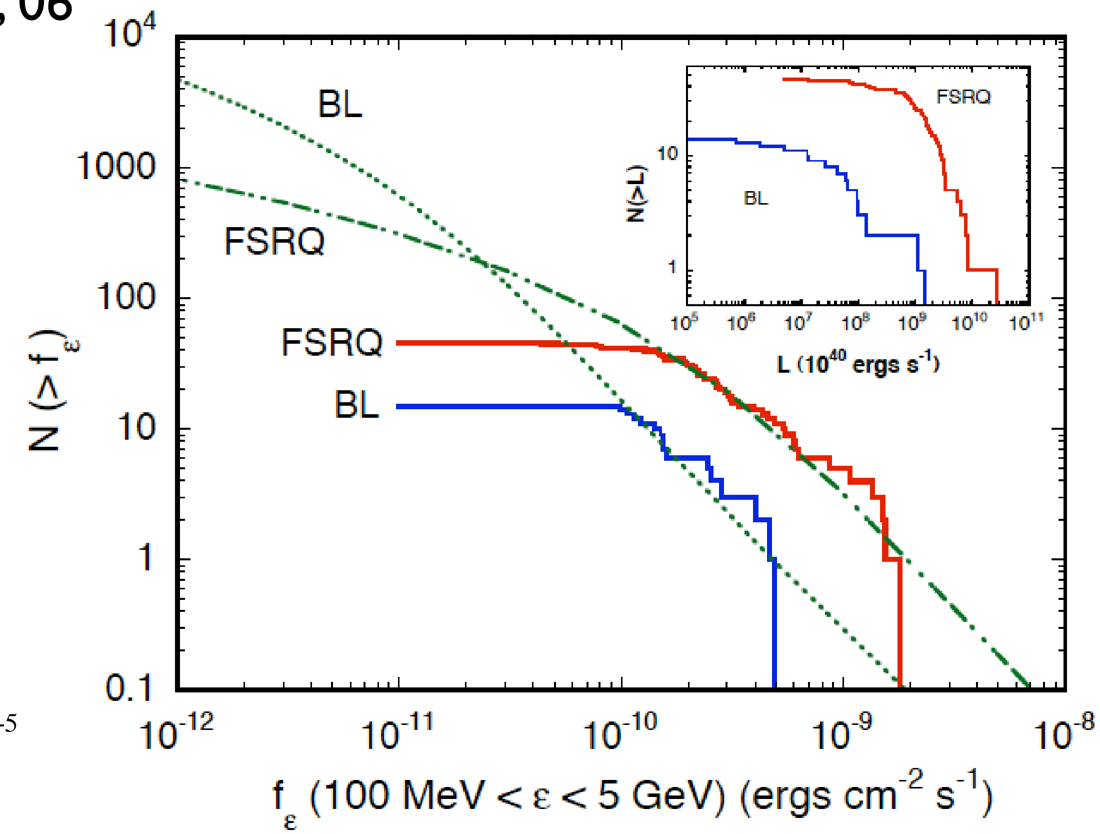
- It is important to determine whether the number of unresolved blazars are enough to account for all of the EGB.
- How the "Blazar γ-ray Luminosity Function" looks like.

Current situation (model/prediction)

Narumoto&Totani, 06



Dermer, 06



The era of GLAST

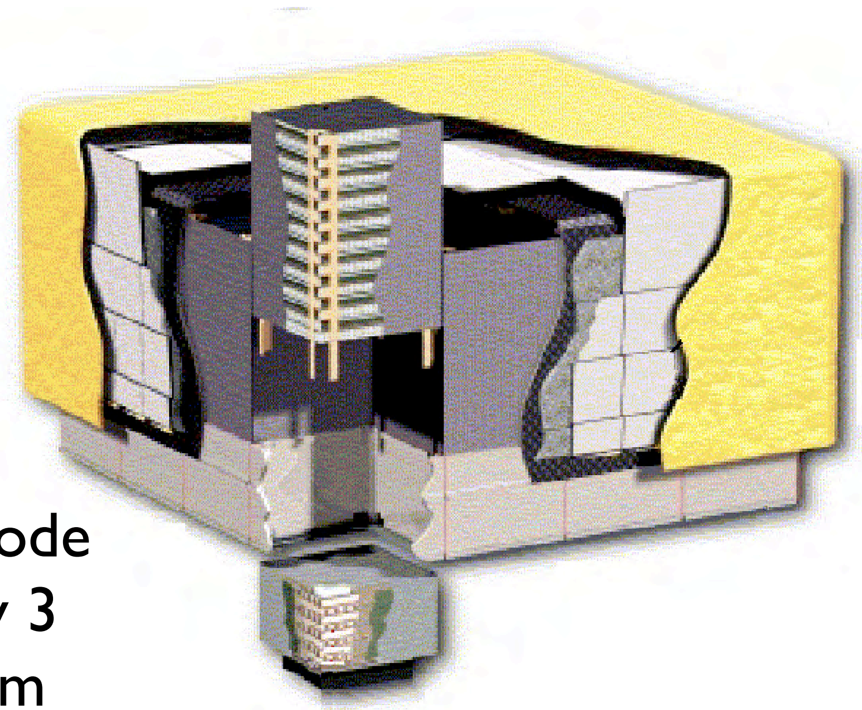
Large International Collaboration

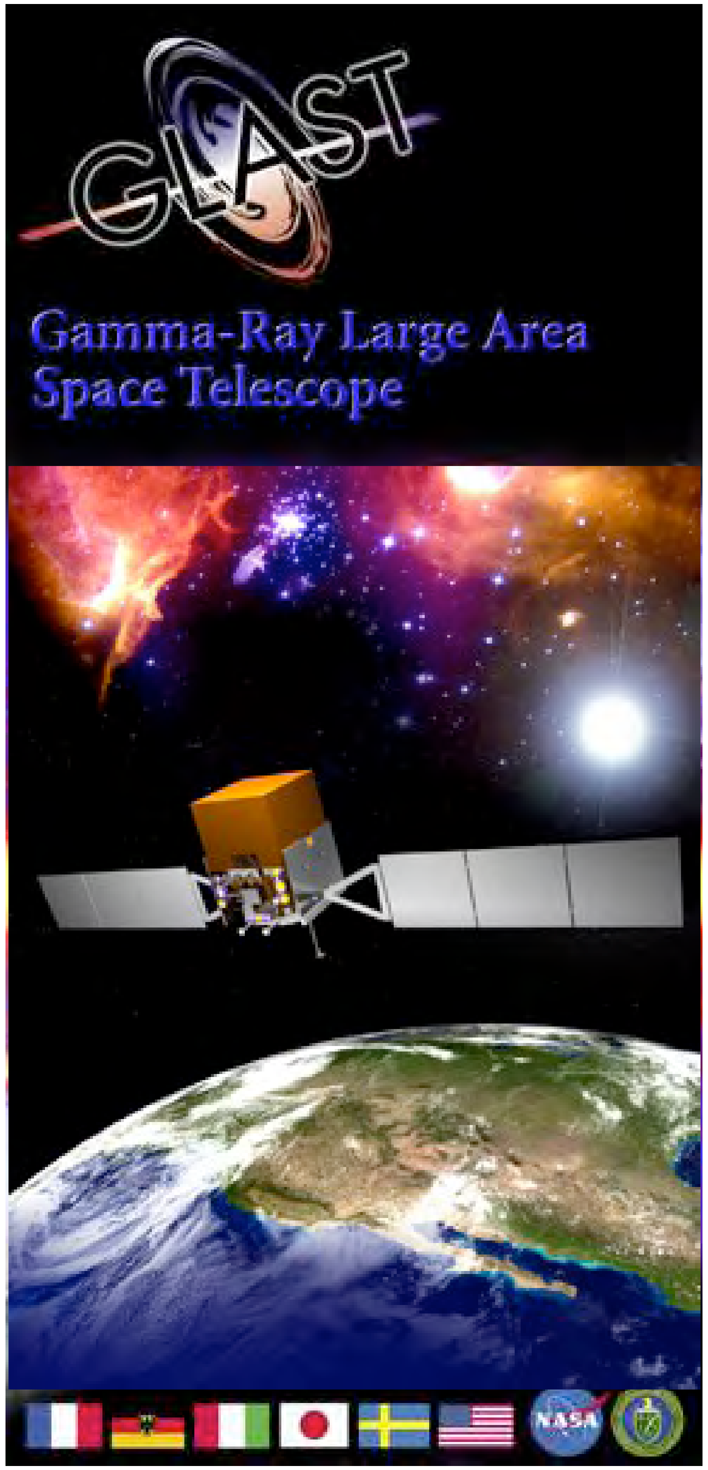
Astro physicist + Partcile physiscist

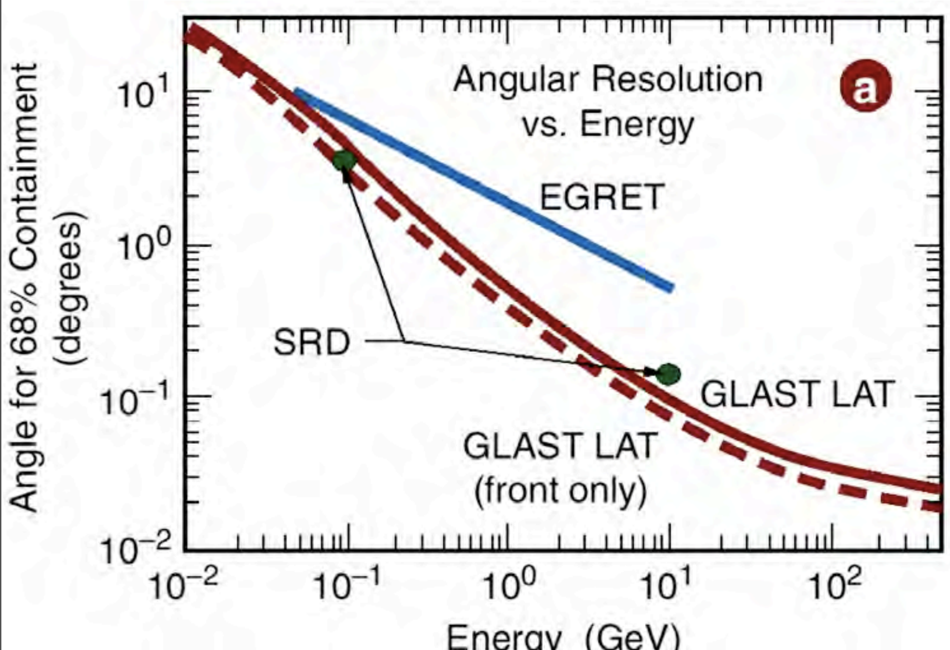
- Modular pair-conversion telescope
  80 m^2 silicon Microstrips,
  8.8 x 10^5 readout channel

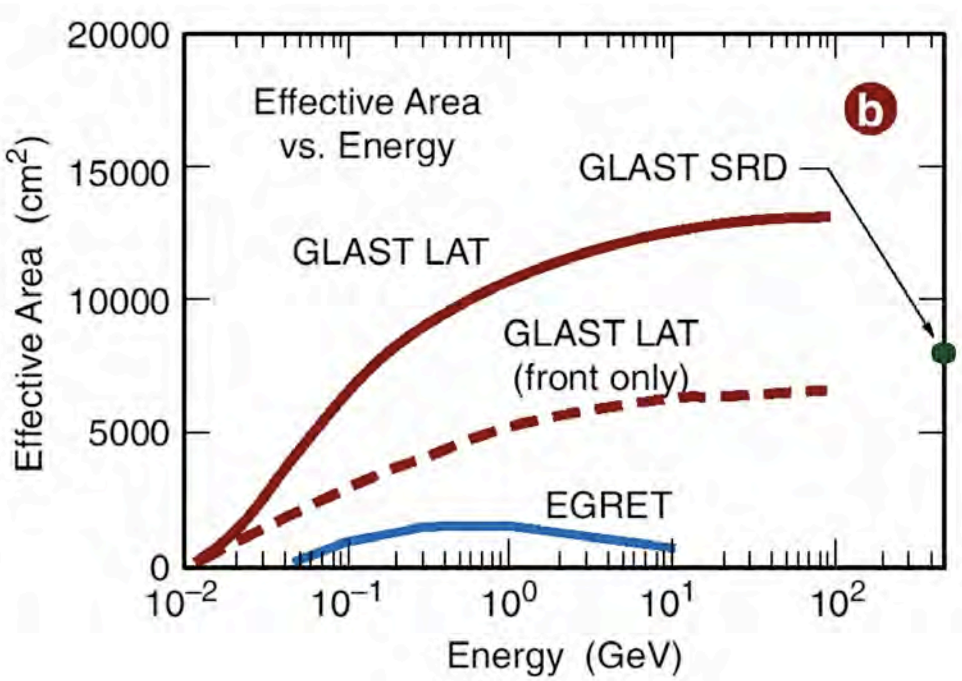
- FOV (2.4 sr; 20 % of the sky)

- All-sky coverage in survey mode (samples the entire sky every 3 hours with reasonably uniform exposure)



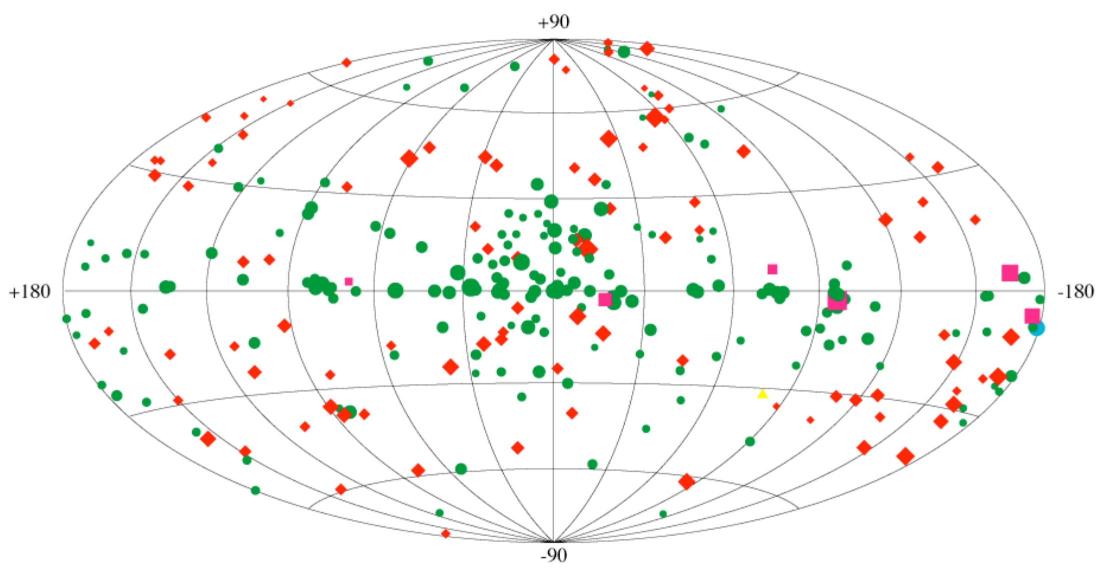


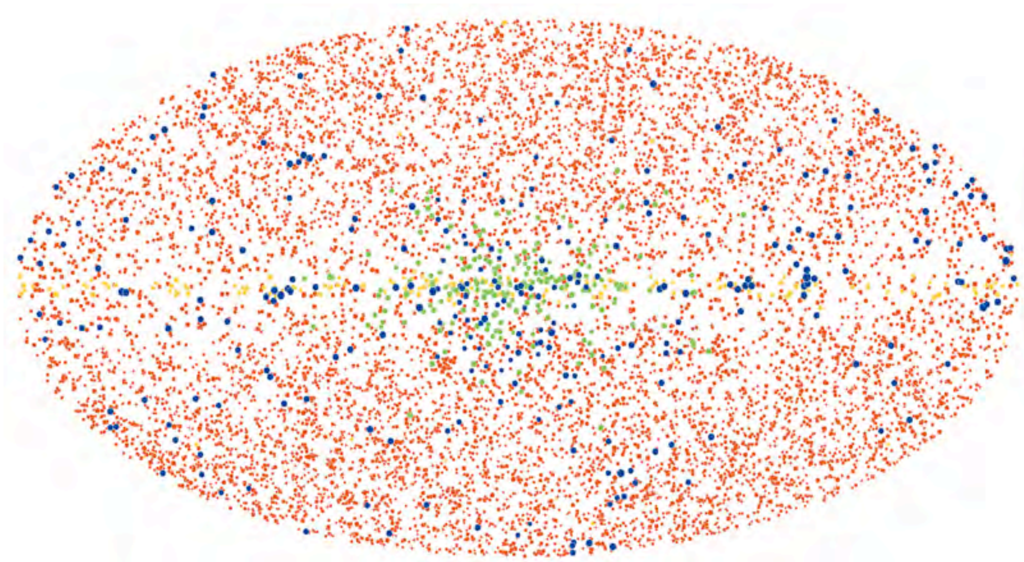




Population Studies

With >1000 Blazars, we can derive γ-ray luminosity function from observations (no assumption)

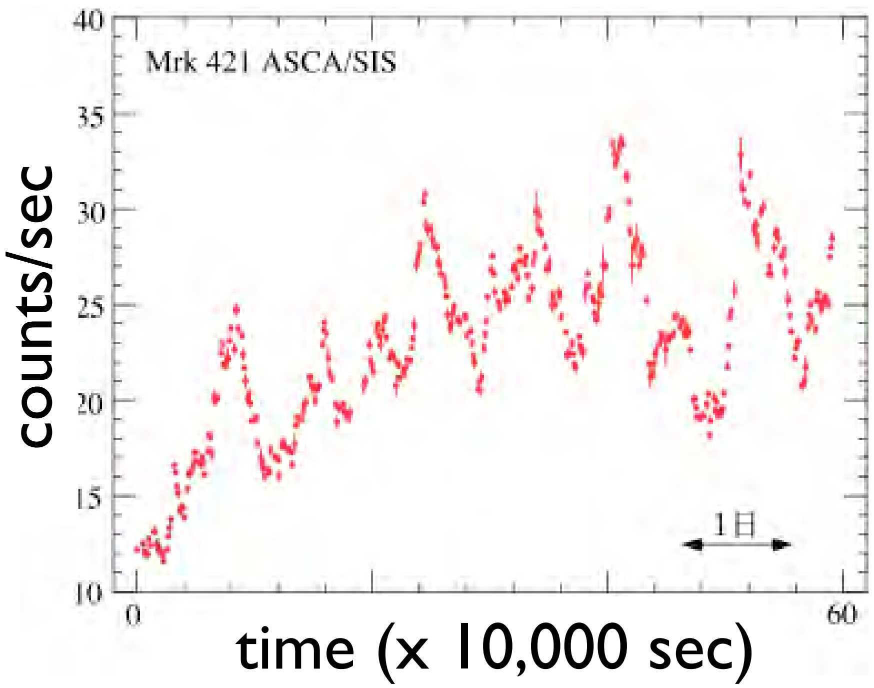




- Gamma-ray blazars should be closely related to galaxy evolution with Jets
- Question is "gamma-ray" properties of these galaxies ("quiet state" vs "flare" and...)

Multi-wavelength observation, essential.

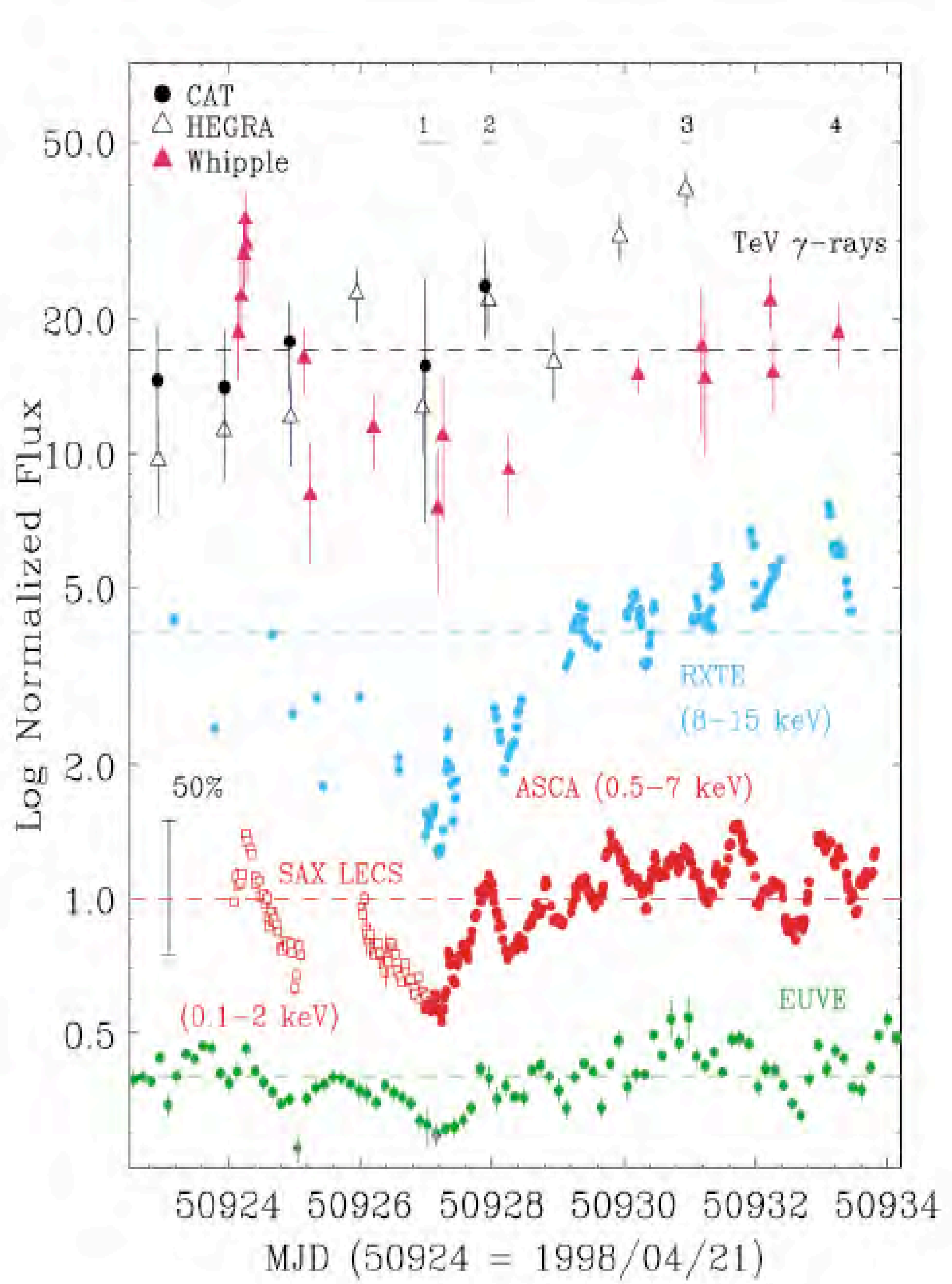
1. Non-thermal Spectrum
2. Time variablity



1day

Multi-wavelength observation, essential.

1. Non-thermal Spectrum
2. Time variablity



Takahashi+ 2000

Multi-wavelength observation, essential.

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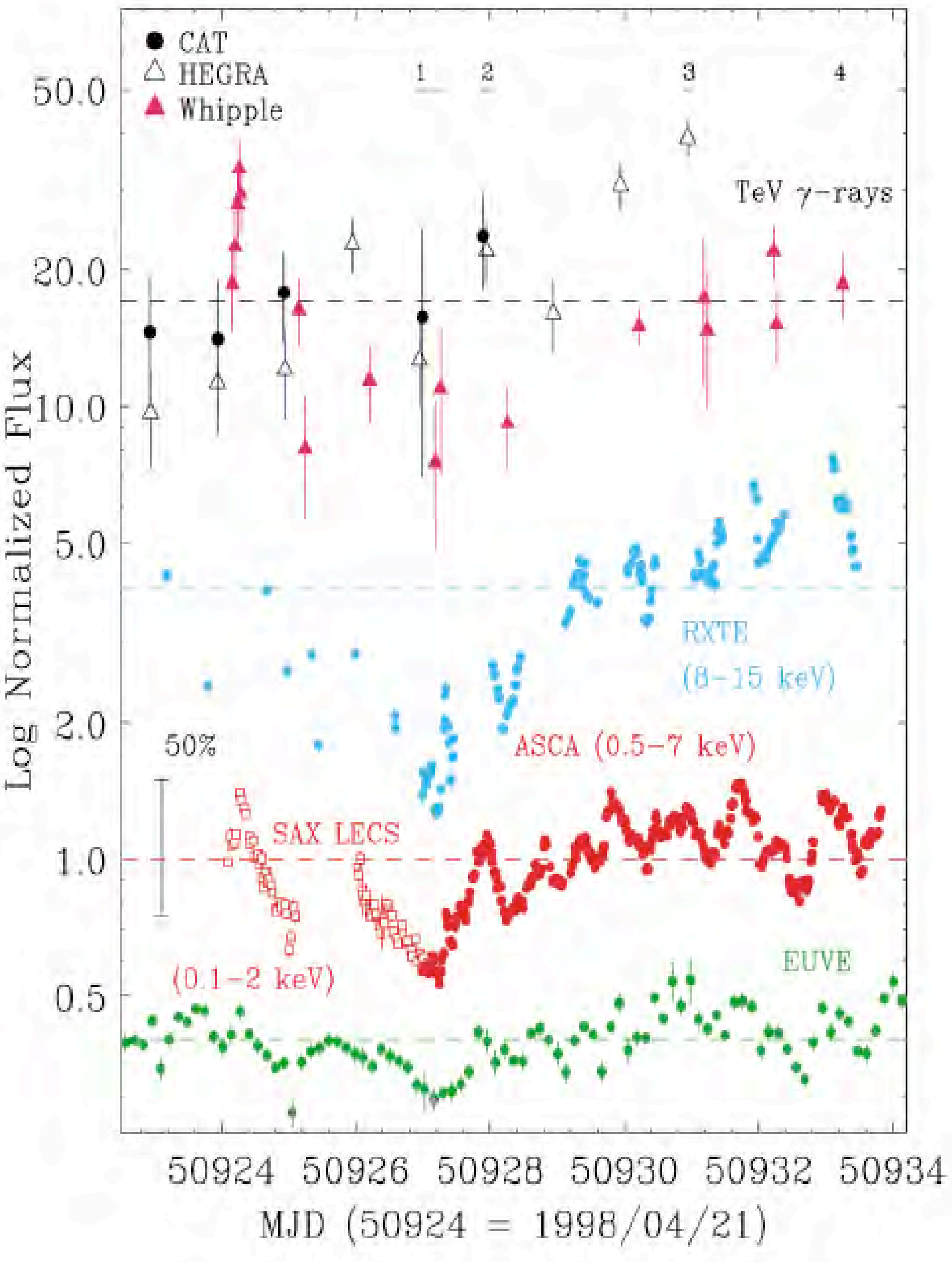
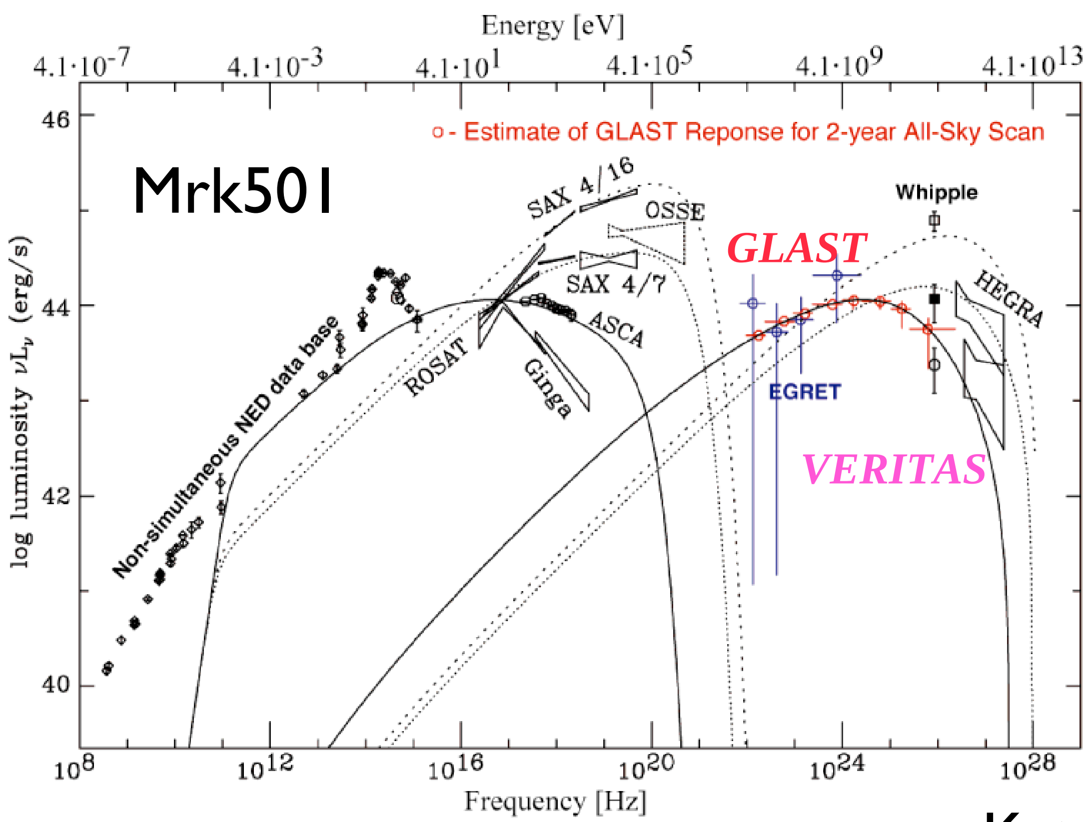
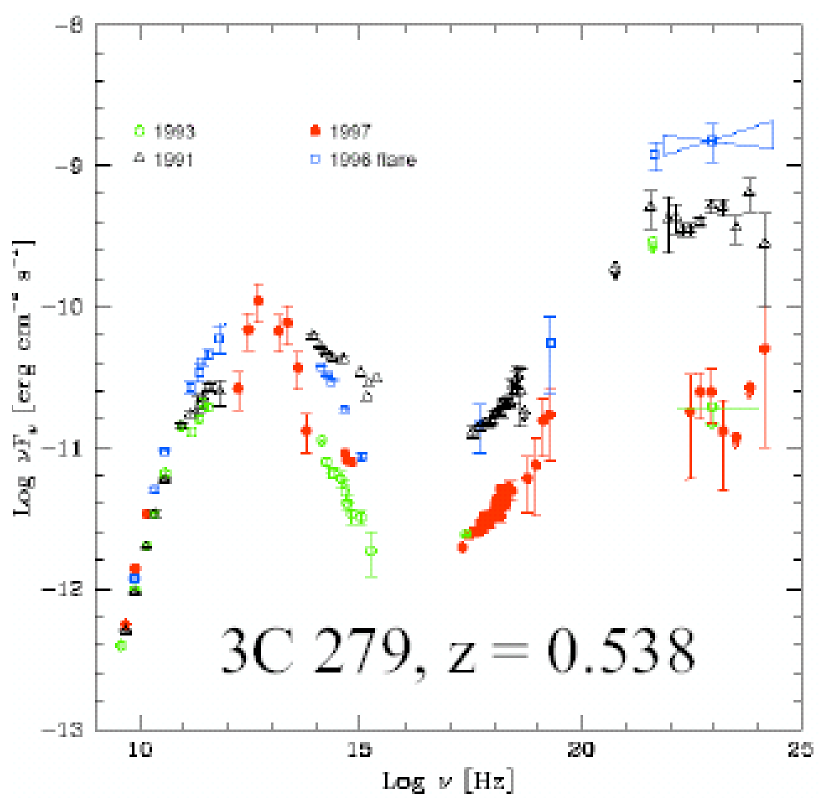


Takahashi+ 2000

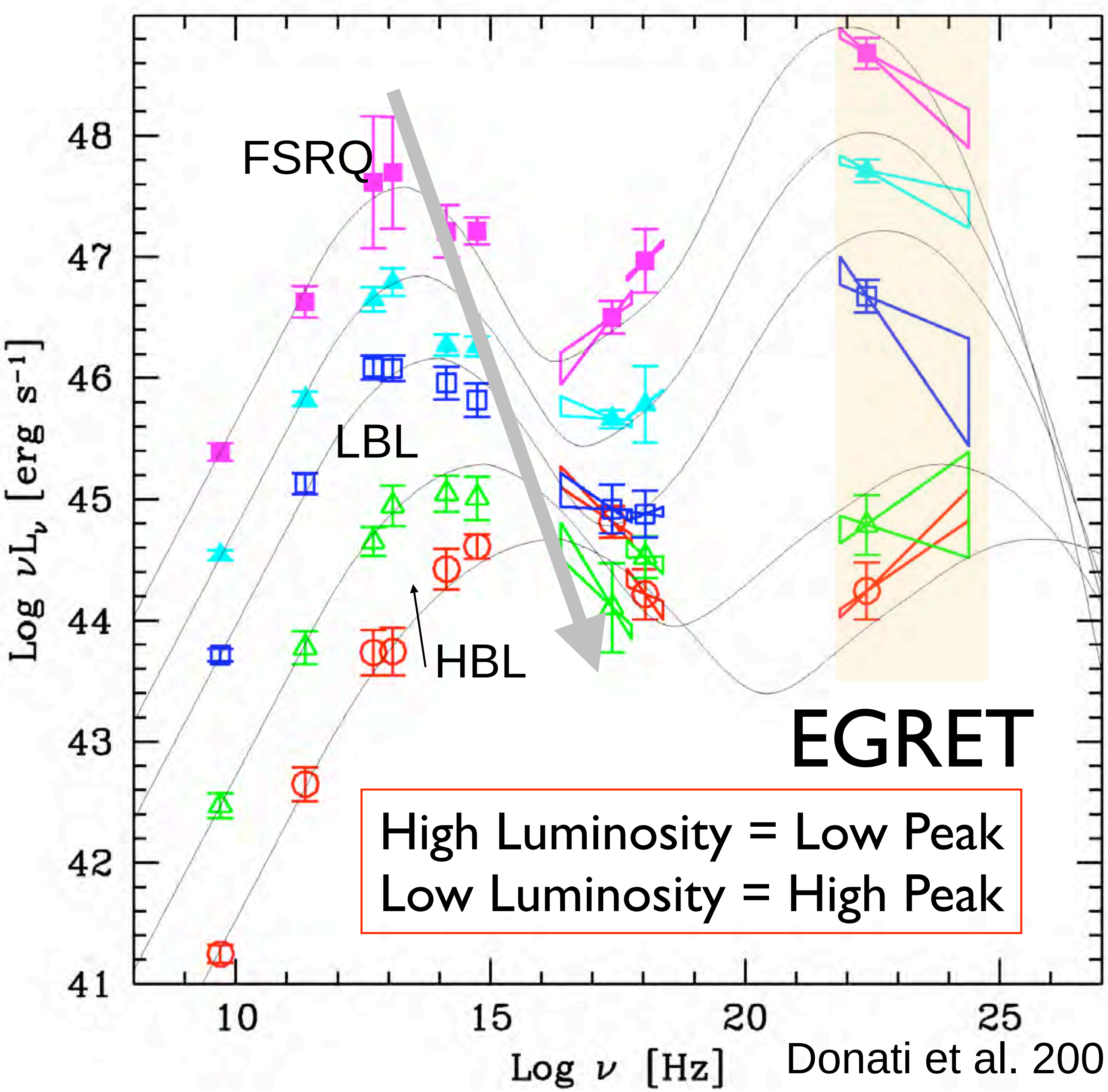


Kataoka, TT+



Do we really understand gamma-ray blazars?

GLAST together with present MW observatories
will give us an answer



Donati et al. 2001
(cf. Fossati el. 1998)

- Blazar Sequence
- Evolution

Do we really understand gamma-ray blazars?

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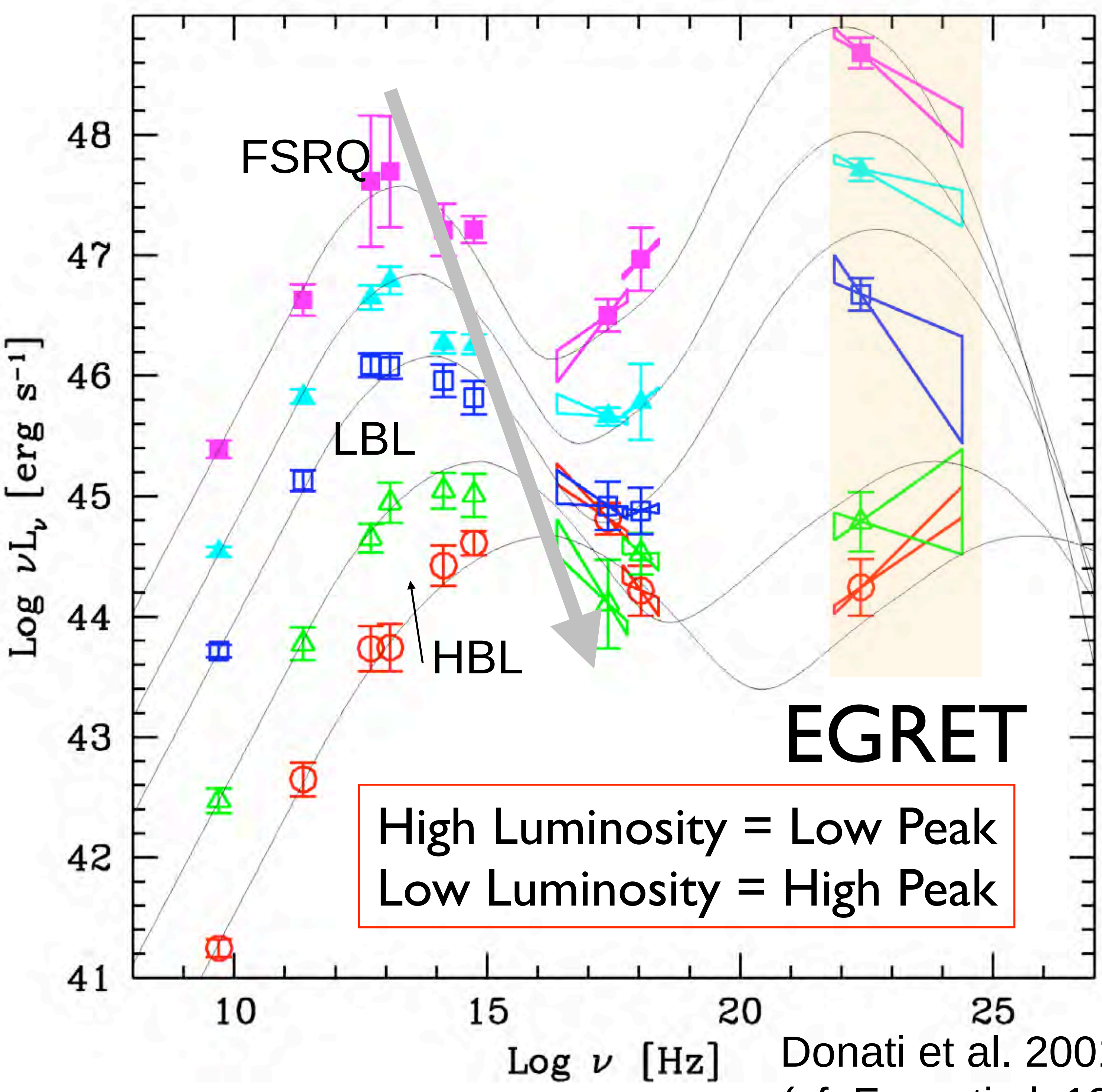

Donati et al. 2001
(cf. Fossati el. 1998)

- Blazar Sequence
- Evolution

Nieppola et al.2006

Sync Peak
Luminosity

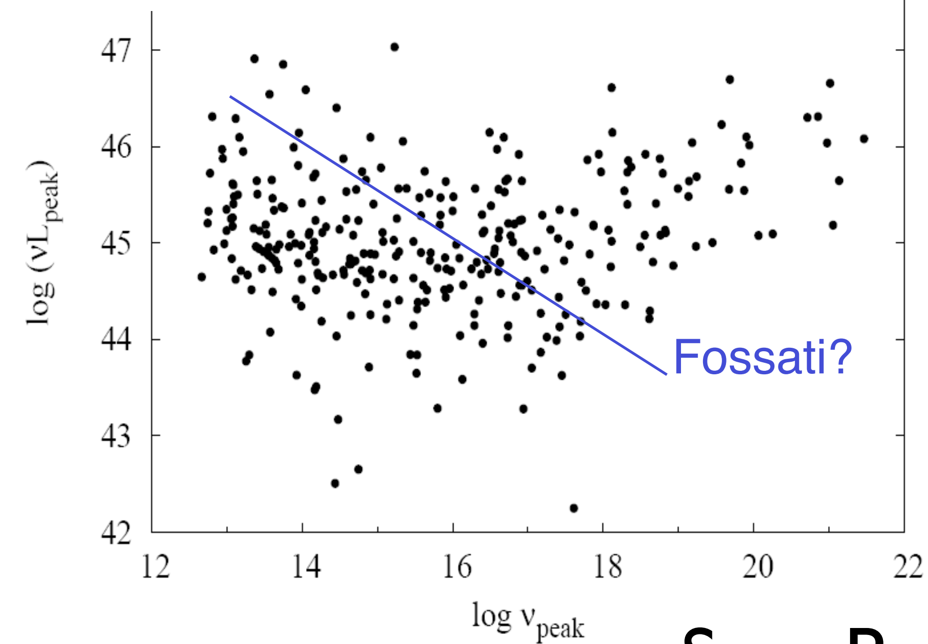

Fig. 6. Luminosity at the synchrotron peal
against synchrotron peak frequency.

Sync Peak
Freq.

Do we really understand gamma-ray blazars?

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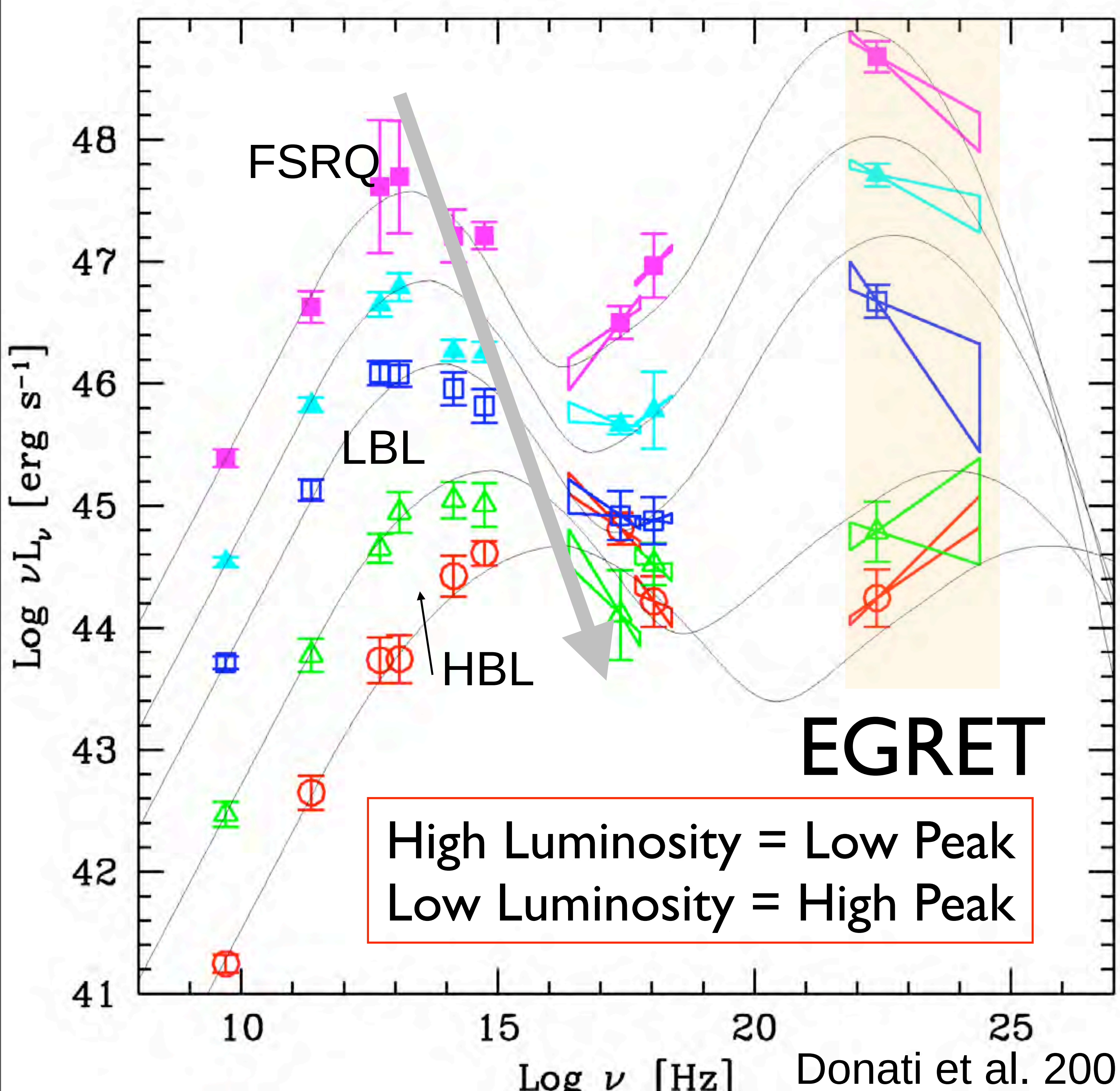

Donati et al. 2001
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Nieppola et al.2006

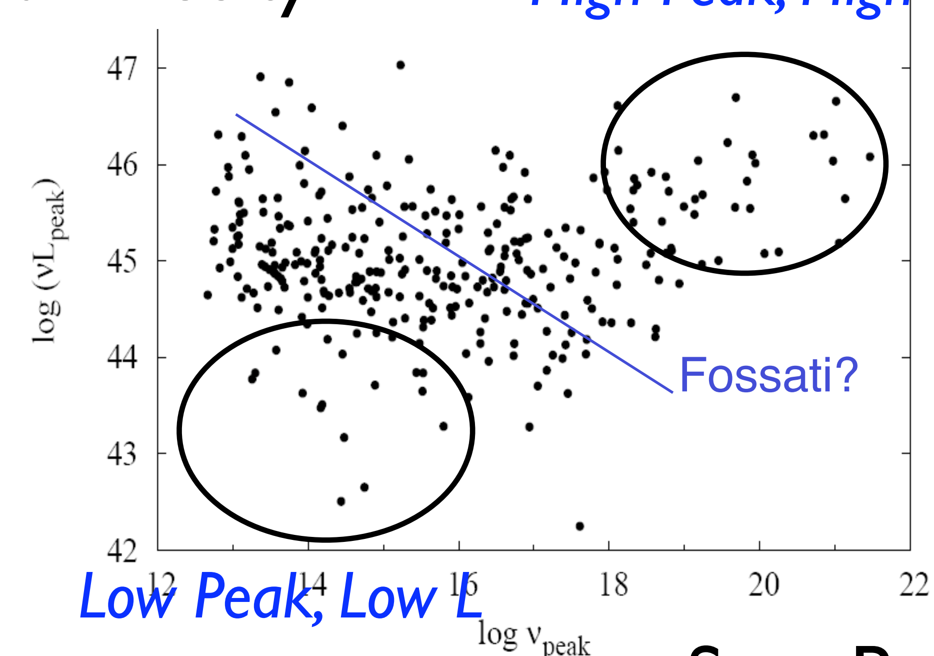
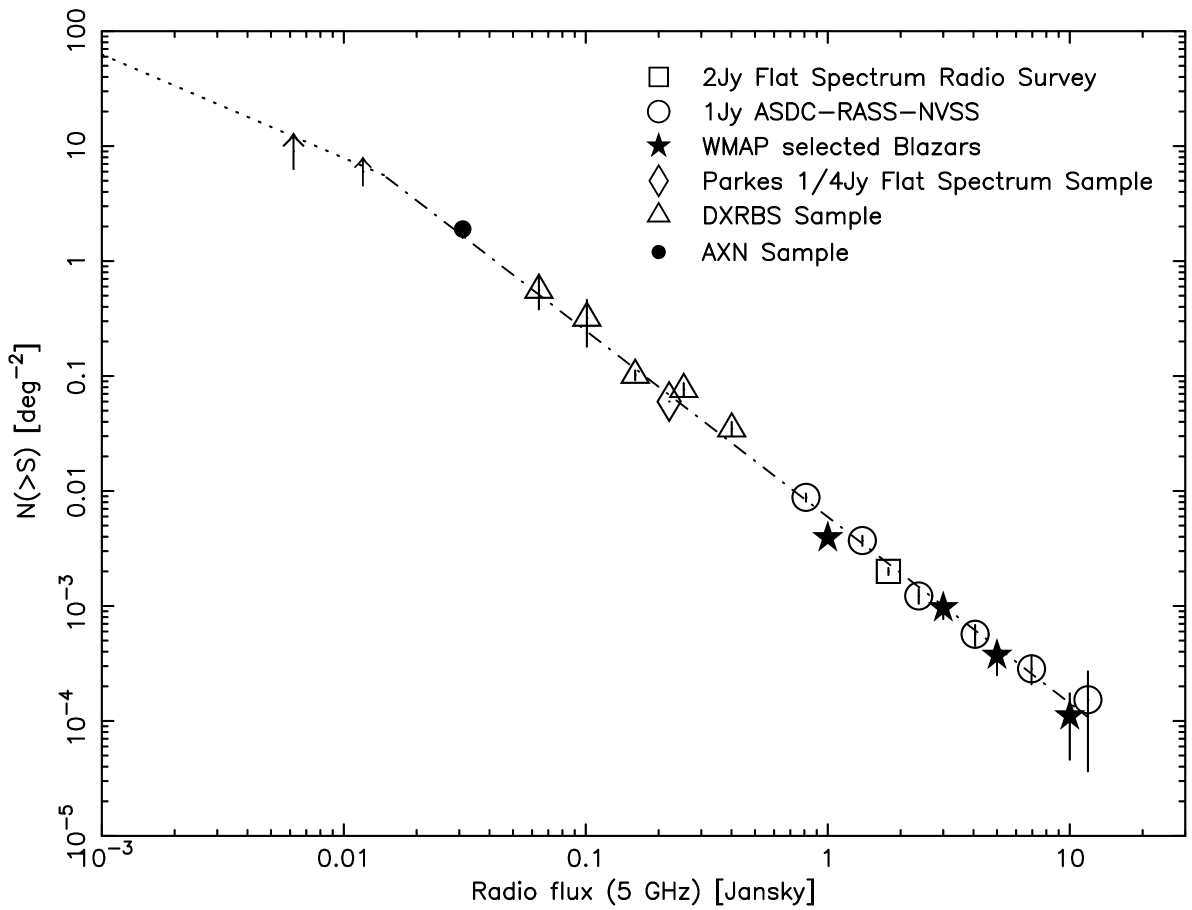


Fig. 6. Luminosity at the synchrotron peal against synchrotron peak frequency.

More blazar candidates

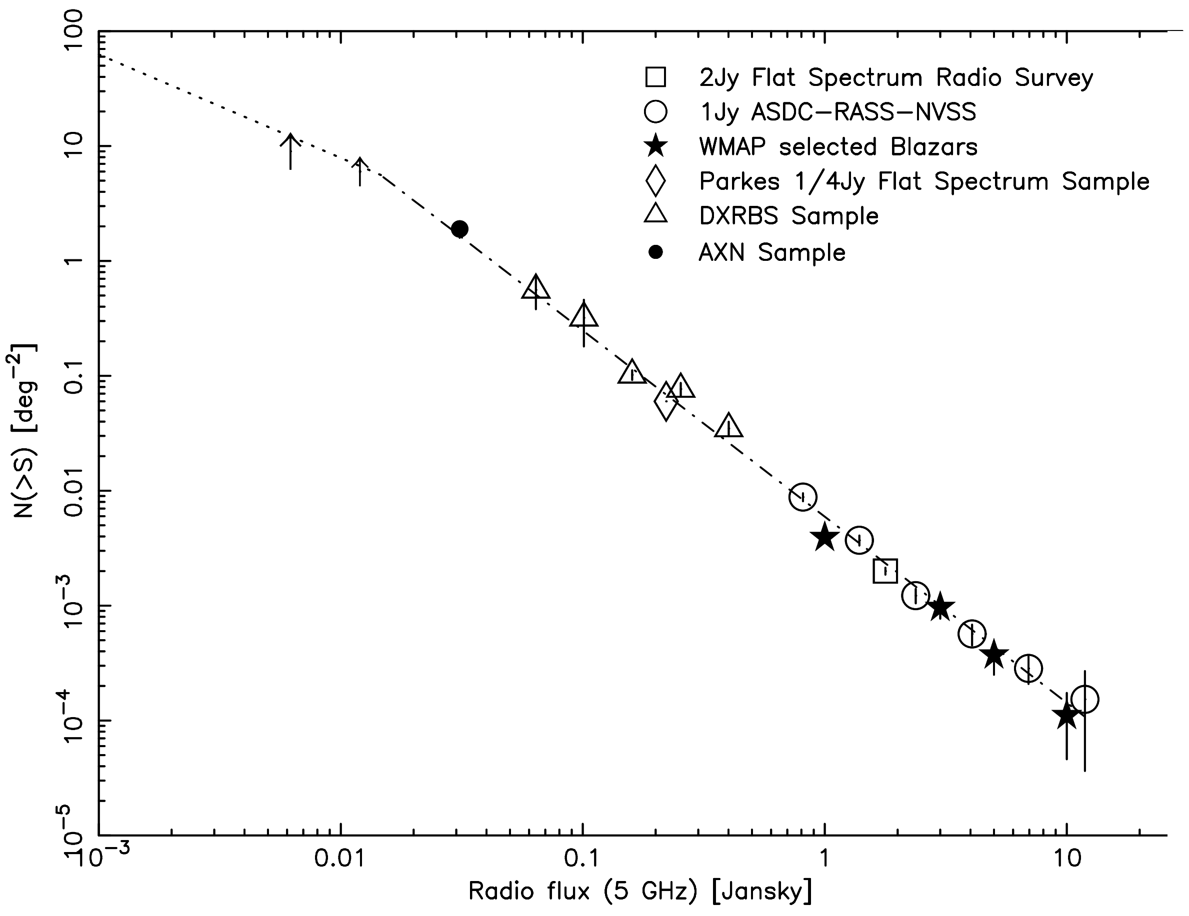
The deep blazar radio (5GHz) LogN-LogS by Giommi et al. (2006)



Once the Log N-LogS of a population of sources is known in a given energy band, it is possible to estimate their emission in other parts of spectrum

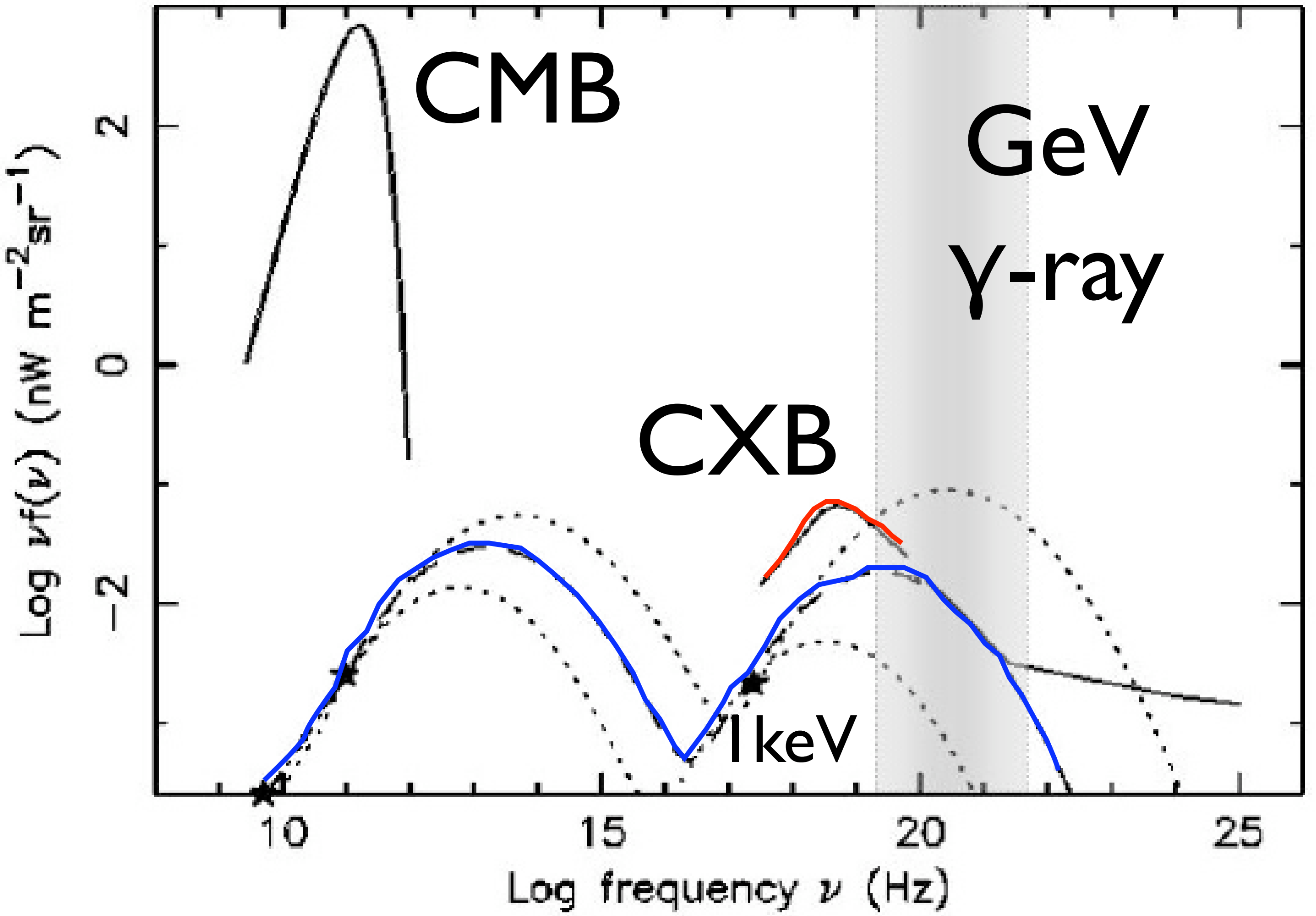
More blazar candidates

The deep blazar radio (5GHz) LogN-LogS by Giommi et al. (2006)



The contribution to GeV seems to be small (duty cycle?)

Blazars may be responsible for Hard-X/Soft γ



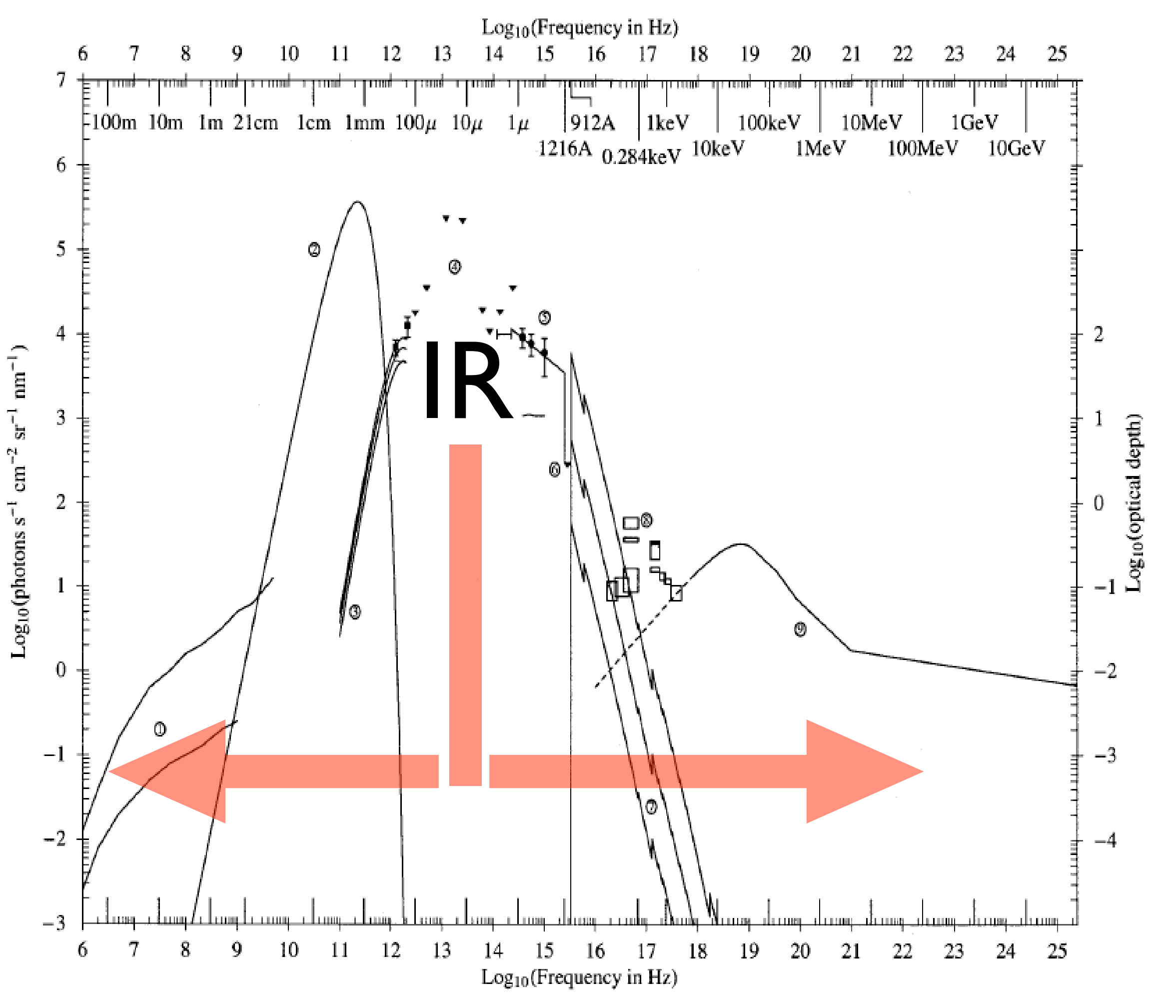
Once the Log N-LogS of a population of sources is known in a given energy band, it is possible to estimate their emission in other parts of spectrum

IR-Radio/IR-γray Connection

Thompson et al. 2006

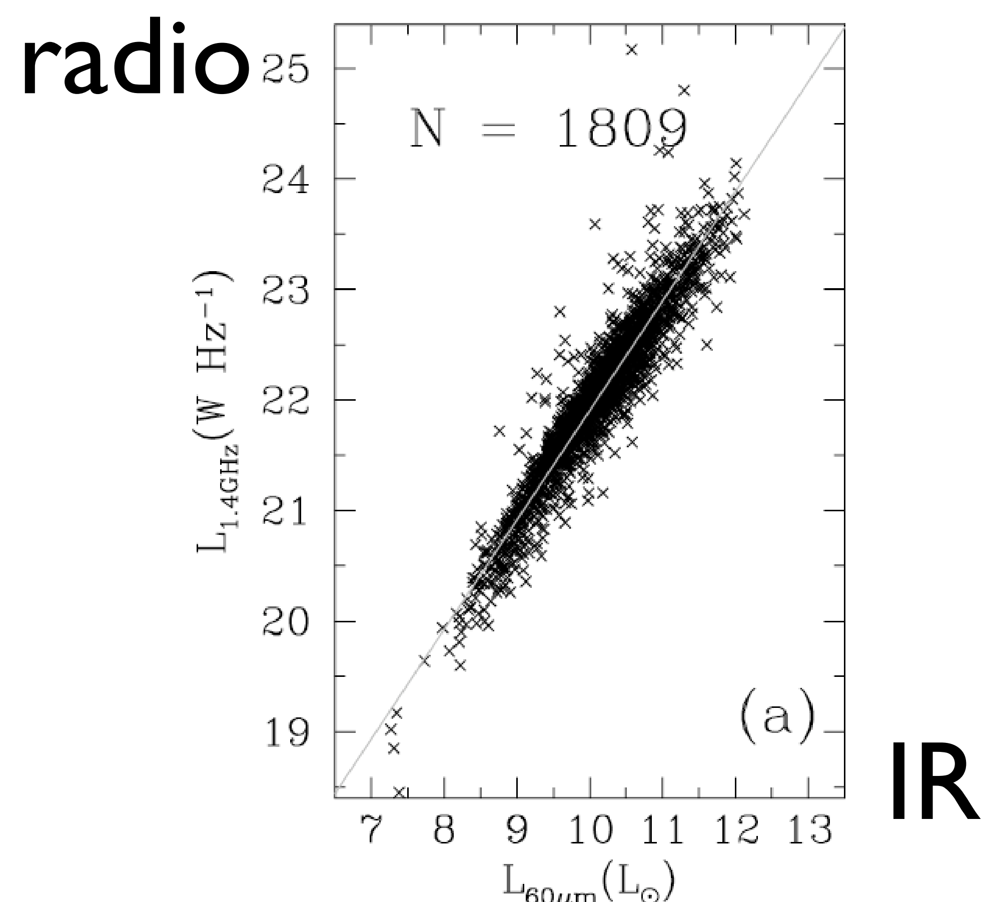
Assume that the star formation rate is related to the total IR luminosity

- Starburst galaxies can act as Cosmic-ray Calorimeters
  1. Star burst → Heating (High IR)
     → Acceleration of Cosmic ray in SNR
  2. electron → synchrotron → Radio emission
  3. pp interaction → π^0 → γ-ray



Henry 97

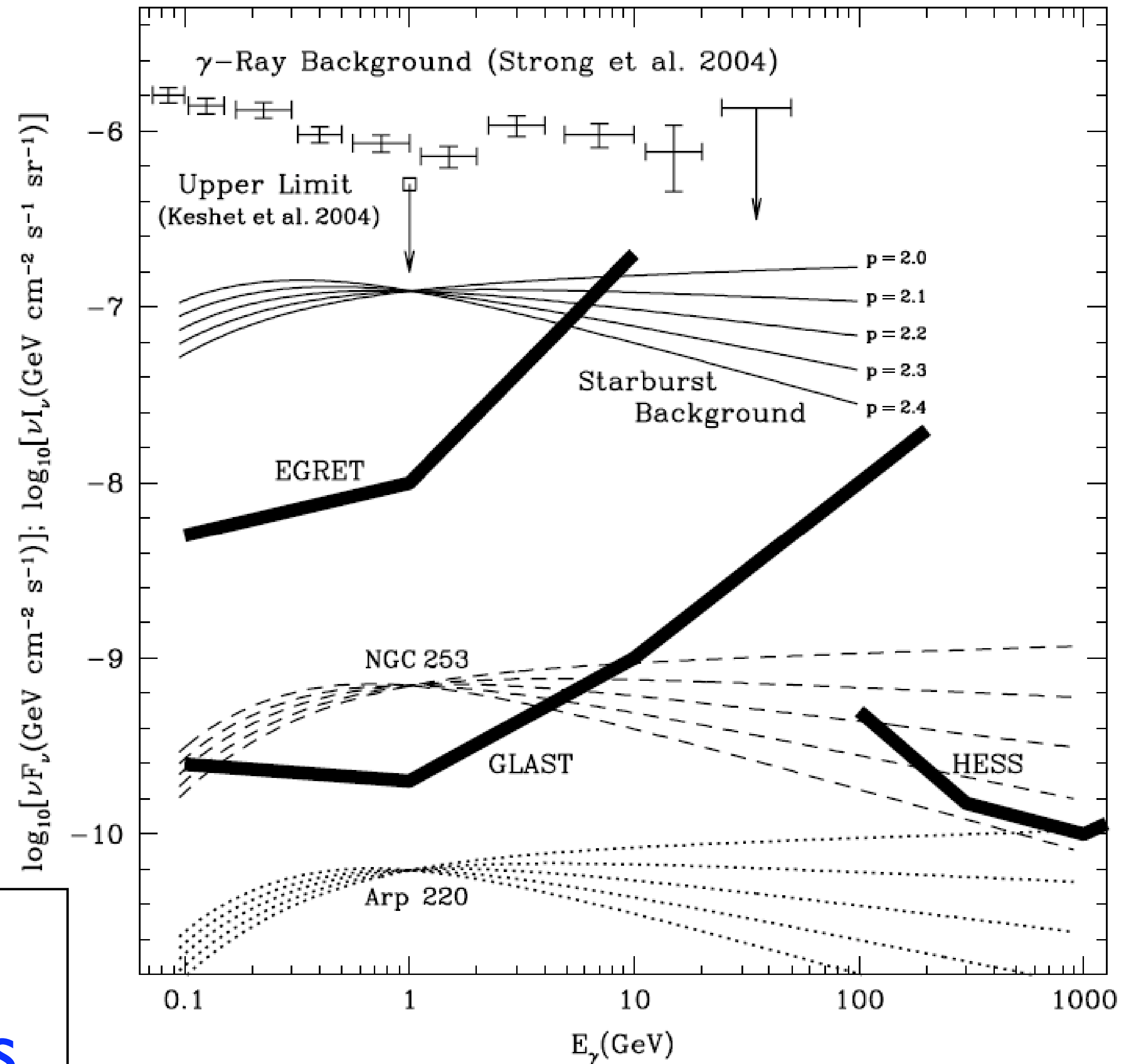
IRAS 2Jy sample



Yun et al. 2001

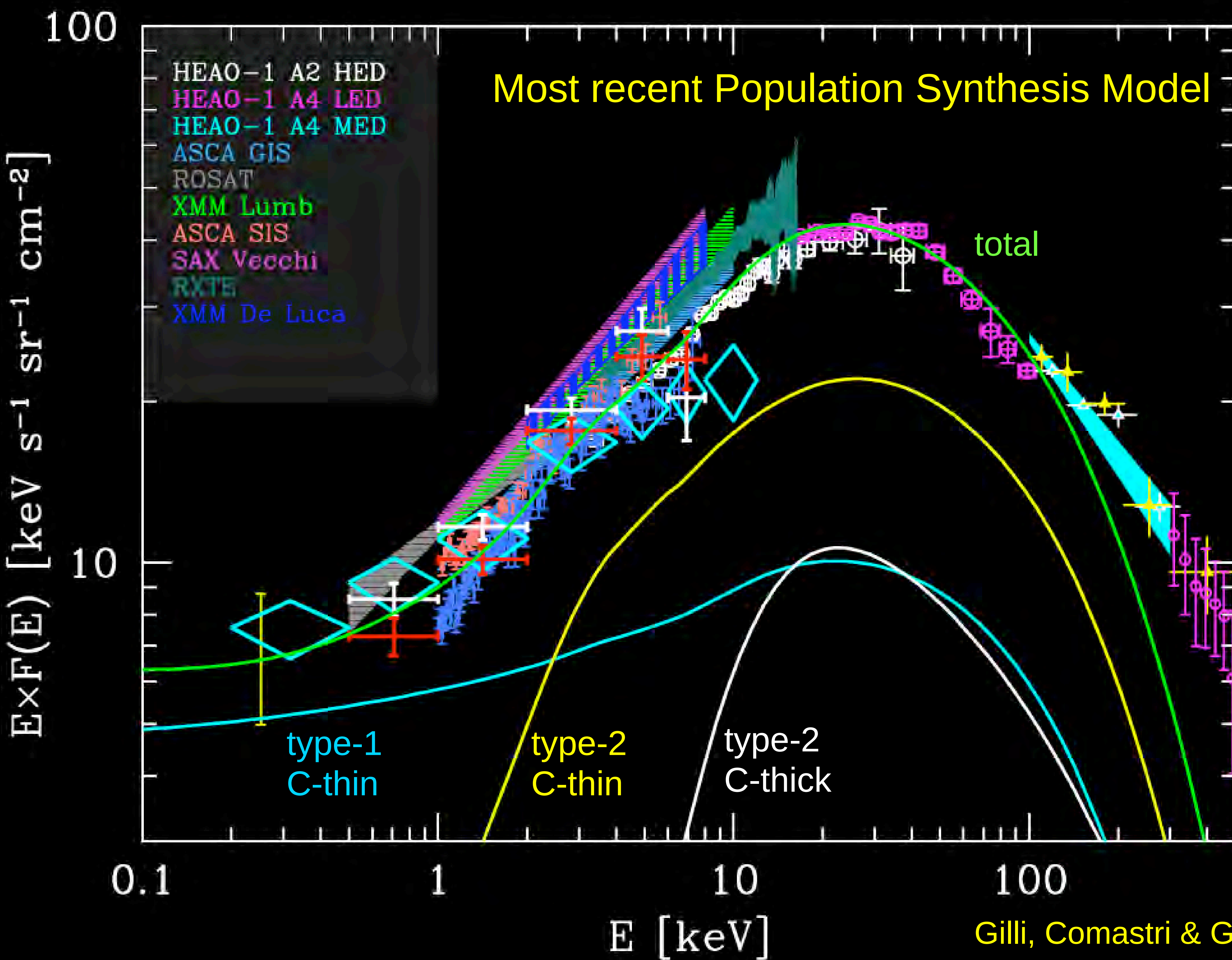
γ-rays from Proton Calorimeter

- It would be possible to explain 10% of contribution in γ-ray extragalactic diffuse.
- Prediction depends on
  - The star formation history of the universe
  - The redshift evolution of the starburst population



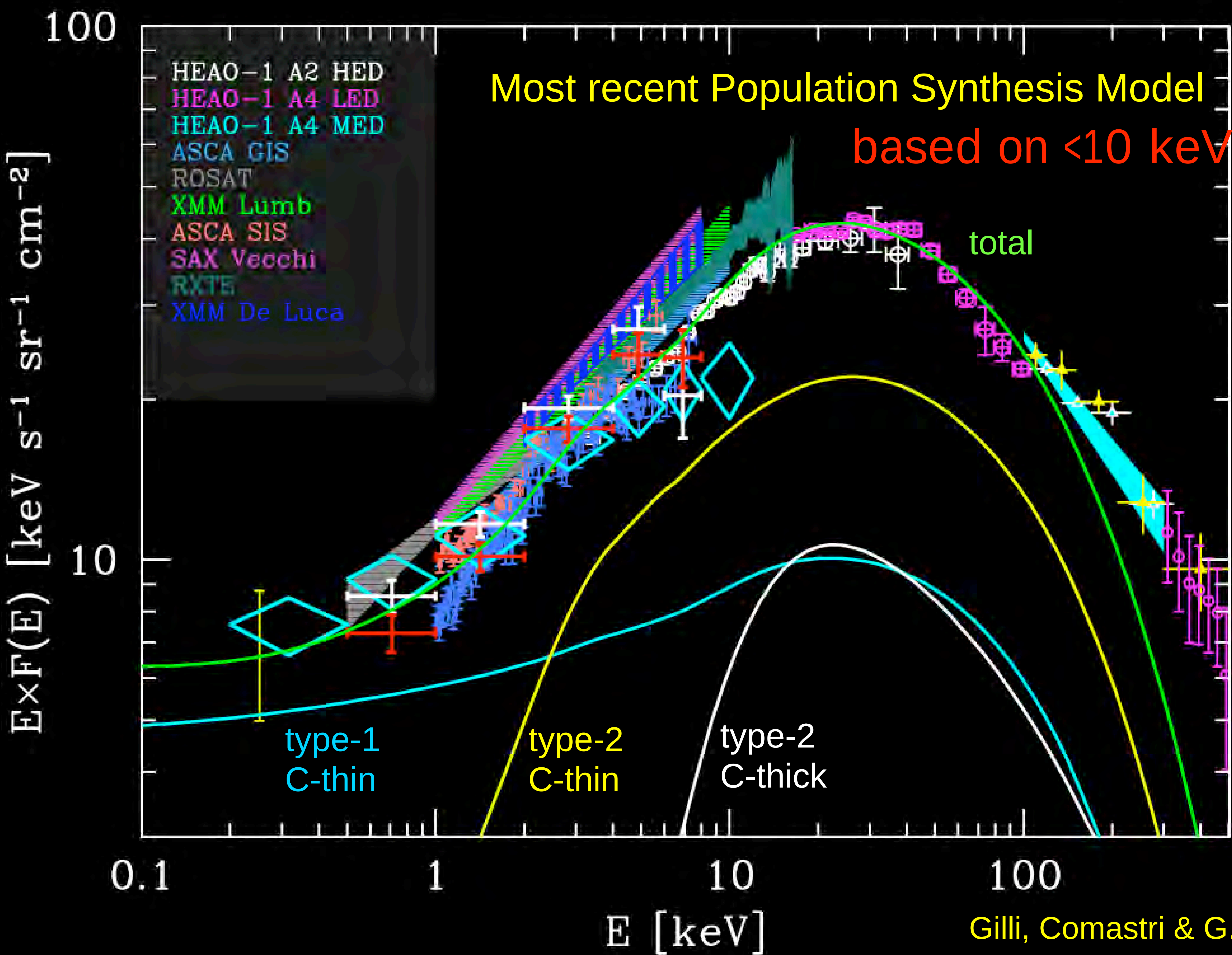
If GLAST detects γ-rays from starburst galaxies, we can discuss the connection between IR and γ-ray background.

Connection from Thermal AGN to Non-thermal AGN



Gilli, Comastri & G.H., 2006

Connection from Thermal AGN to Non-thermal AGN



Gilli, Comastri & G.H., 2006

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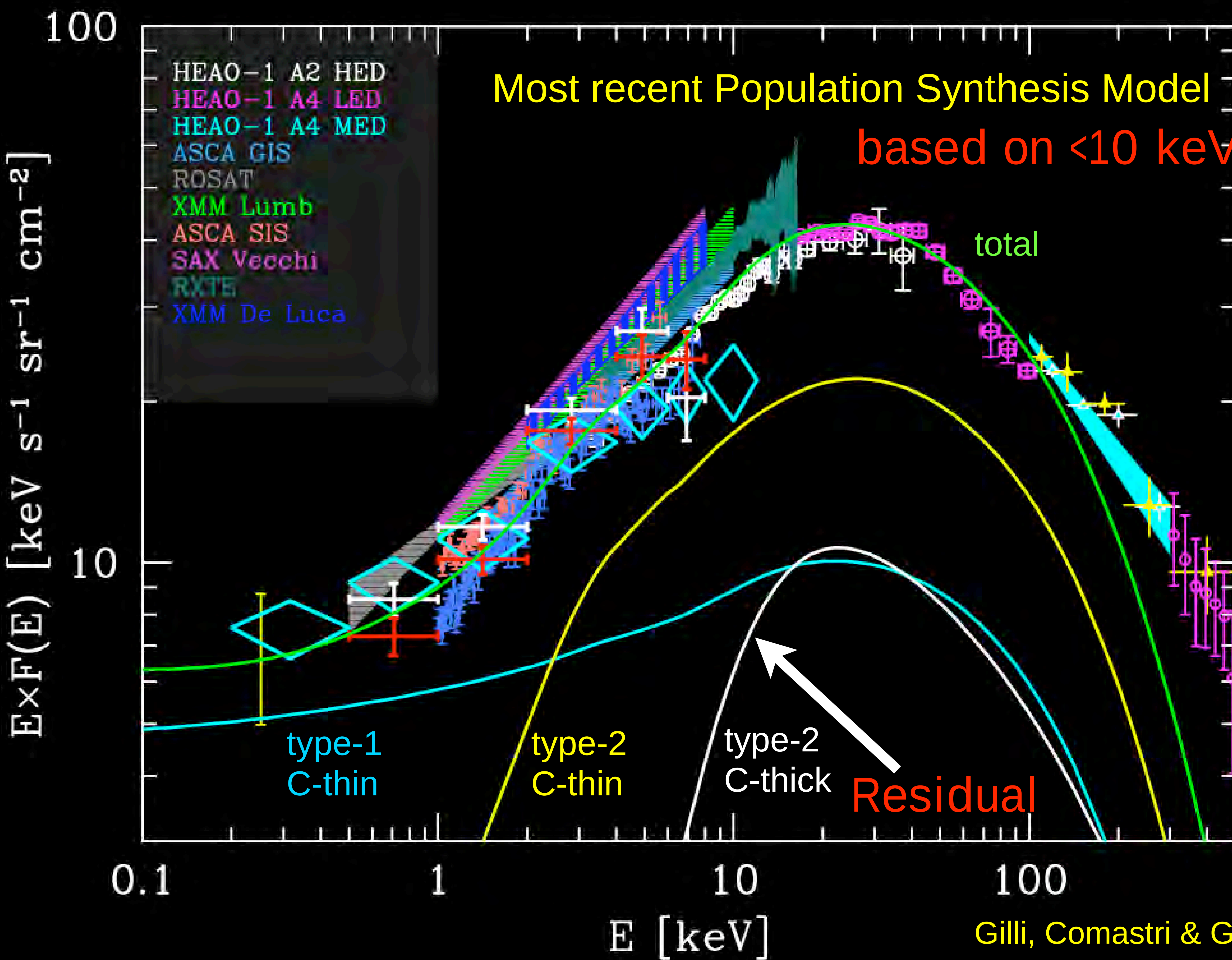
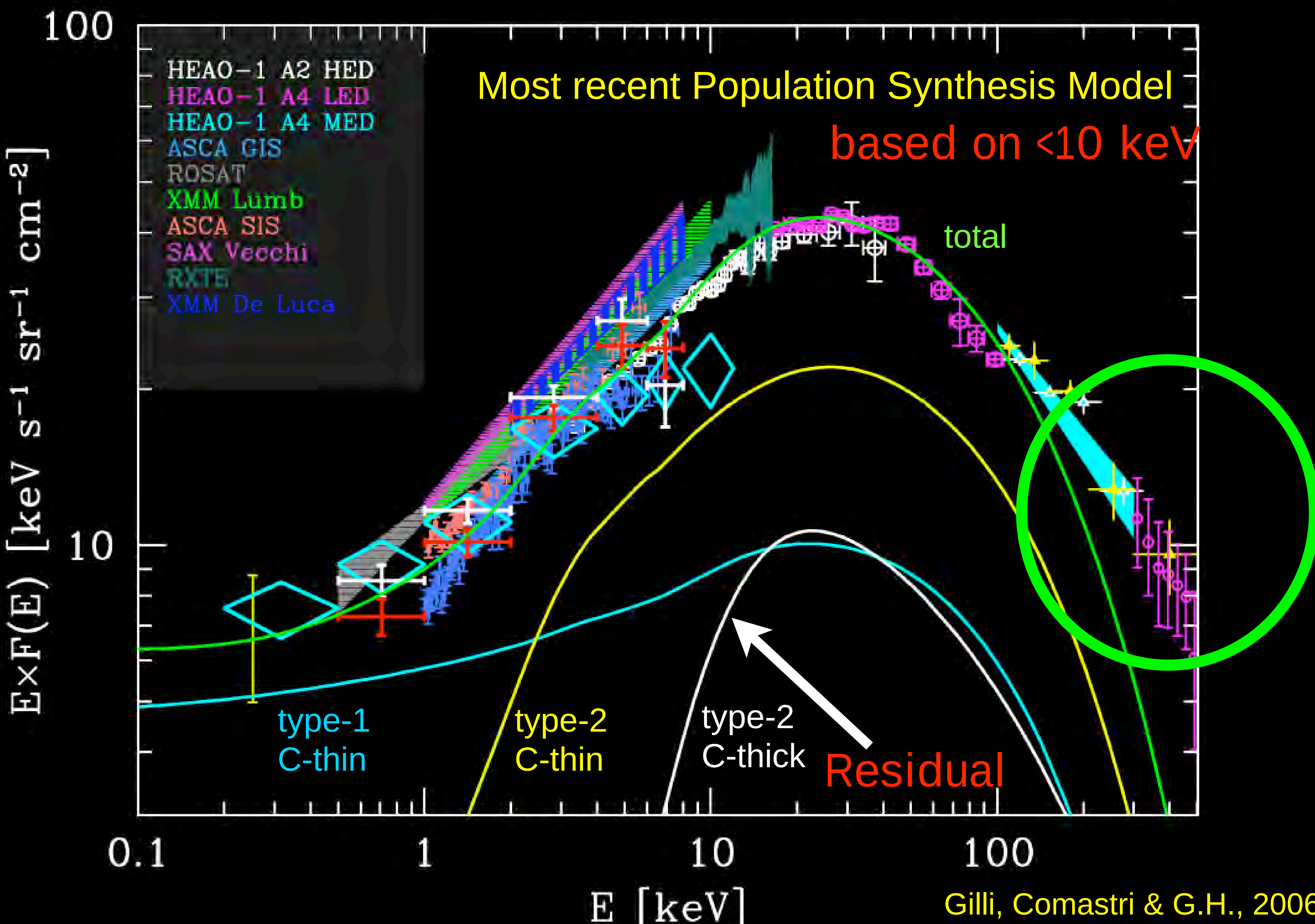


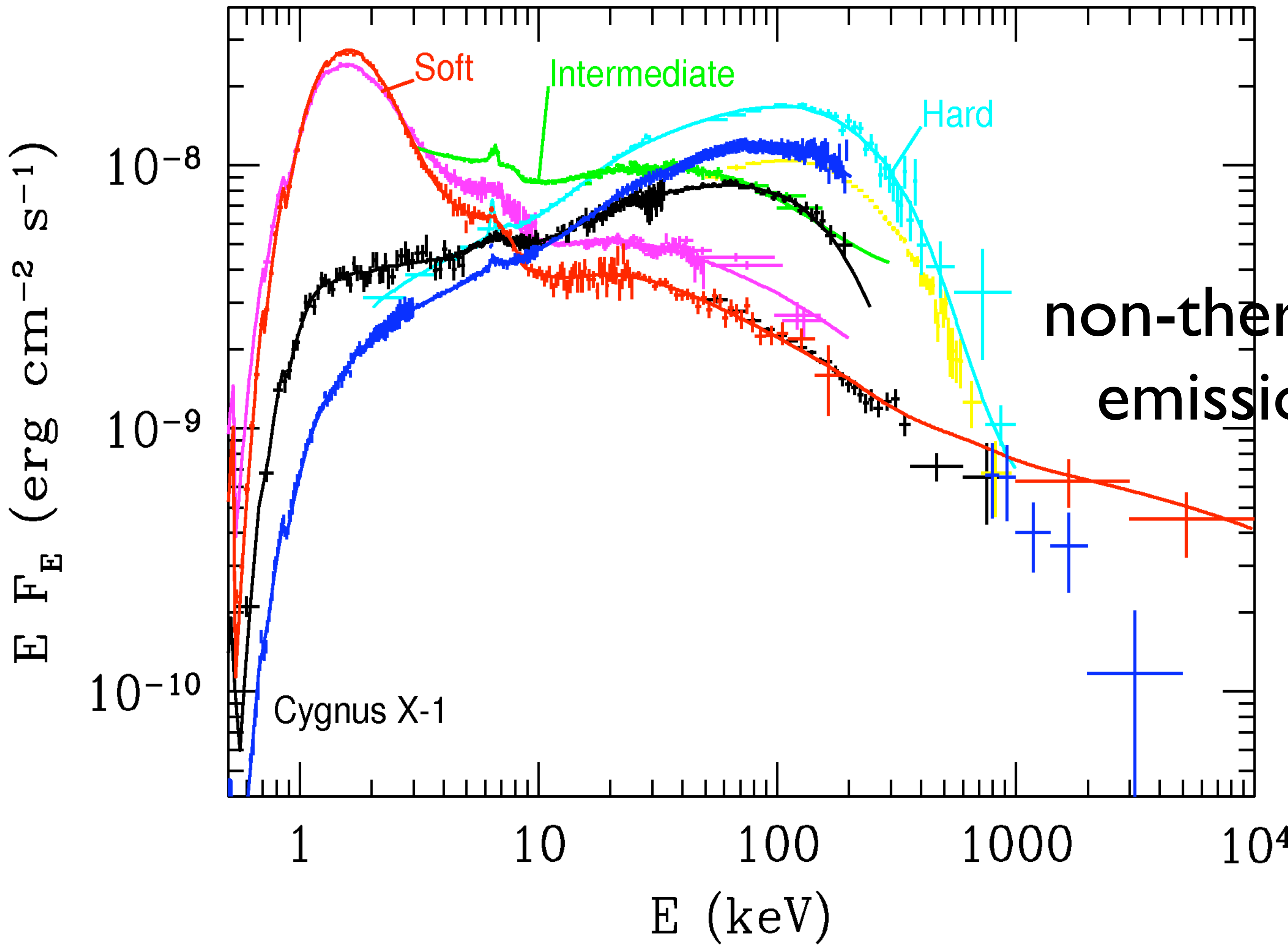
Gilli, Comastri & G.H., 2006

Connection from Thermal AGN to Non-thermal AGN



Gilli, Comastri & G.H., 2006

Black Hole Spectrum



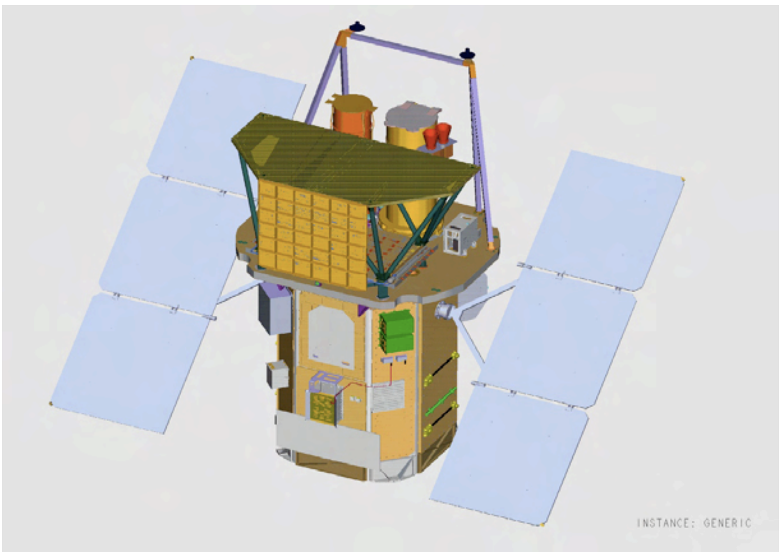
non-thermal emission

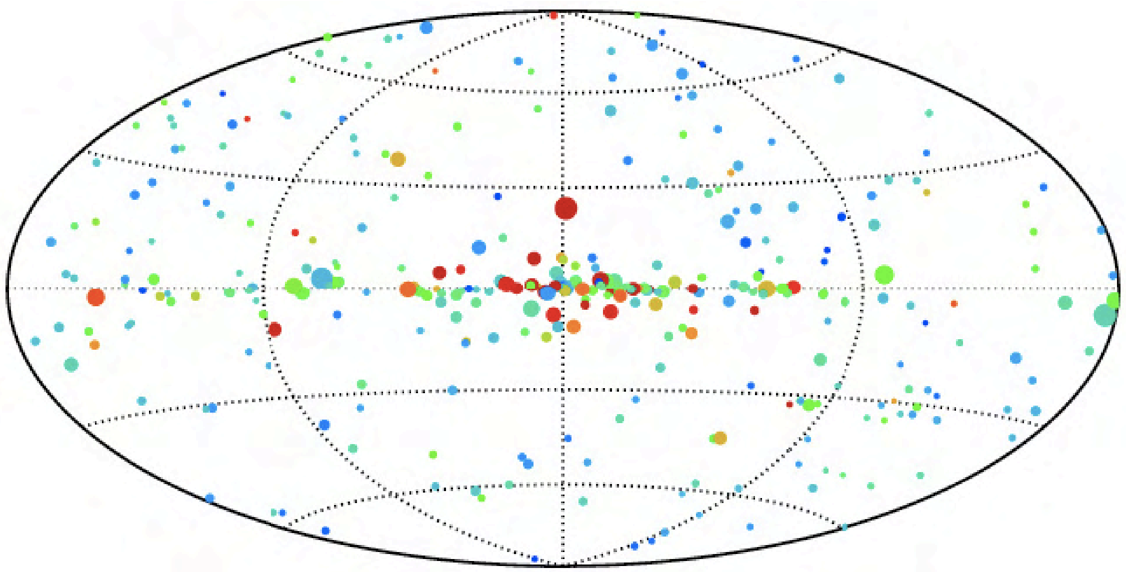
Swift Survey

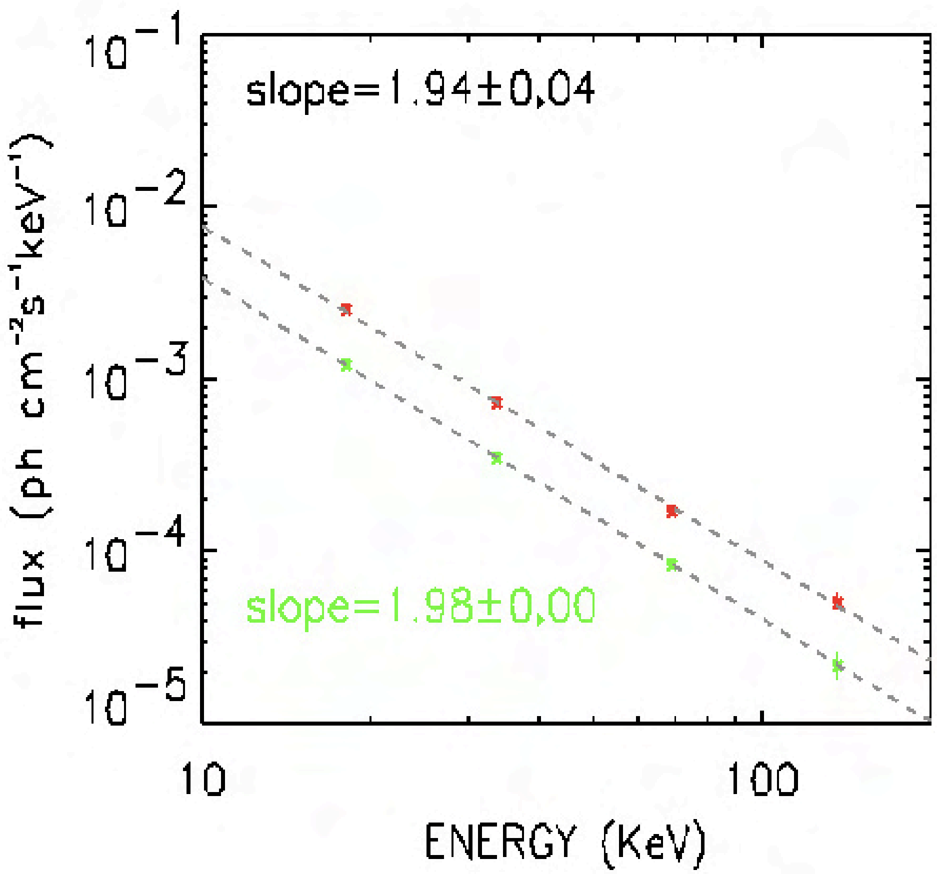
Significant contribution to the study of XRB
(together with INTEGRAL)

J. Tuller et al. 2006

Hard X-ray Sky (14-195 keV) by Swift



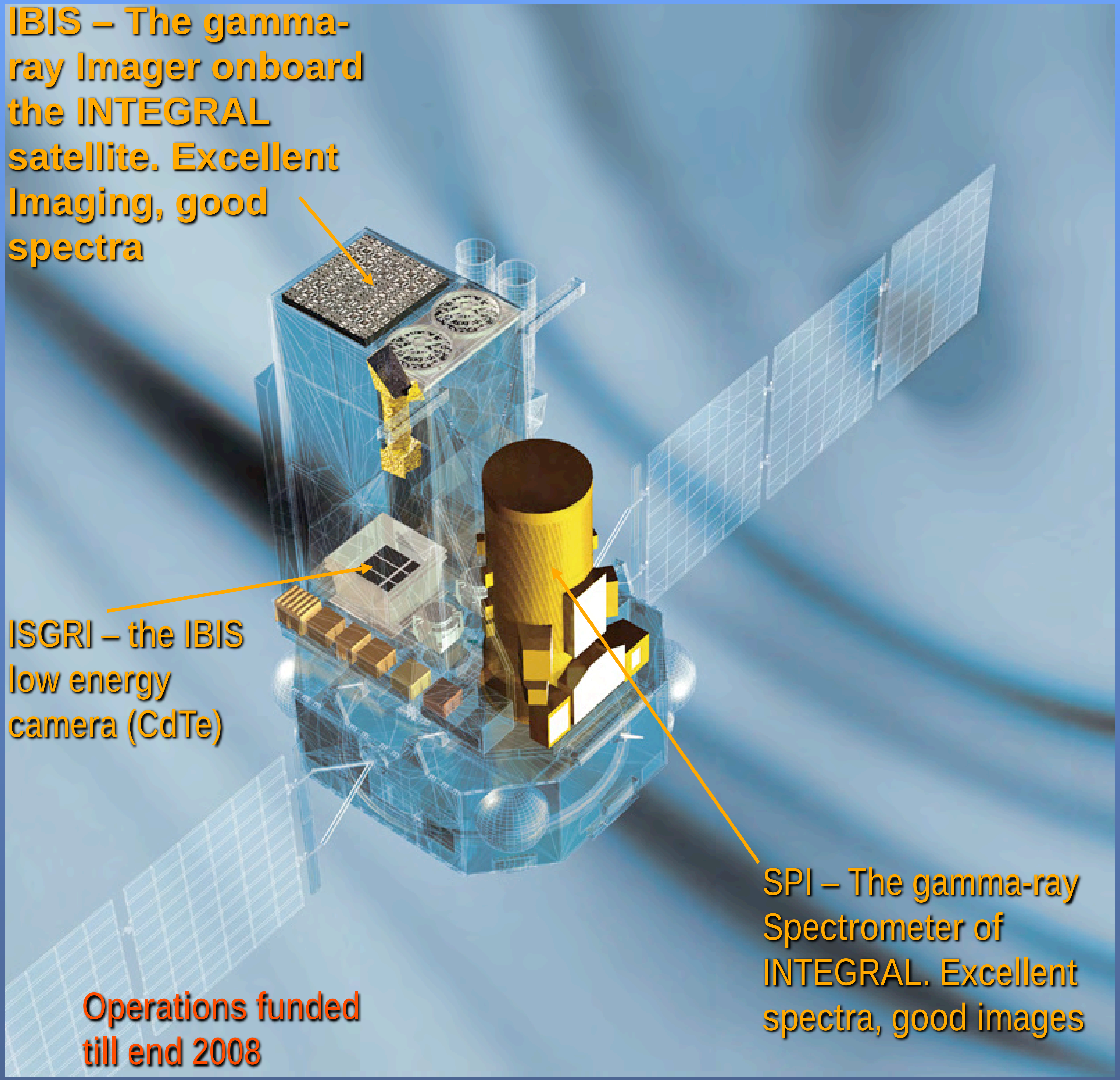




158 AGN detected so far (15 blazars)
No-evidence for a break below 200 keV
Same with brightest 36 AGN removed
Contrast with strong break at 40keV in CXB

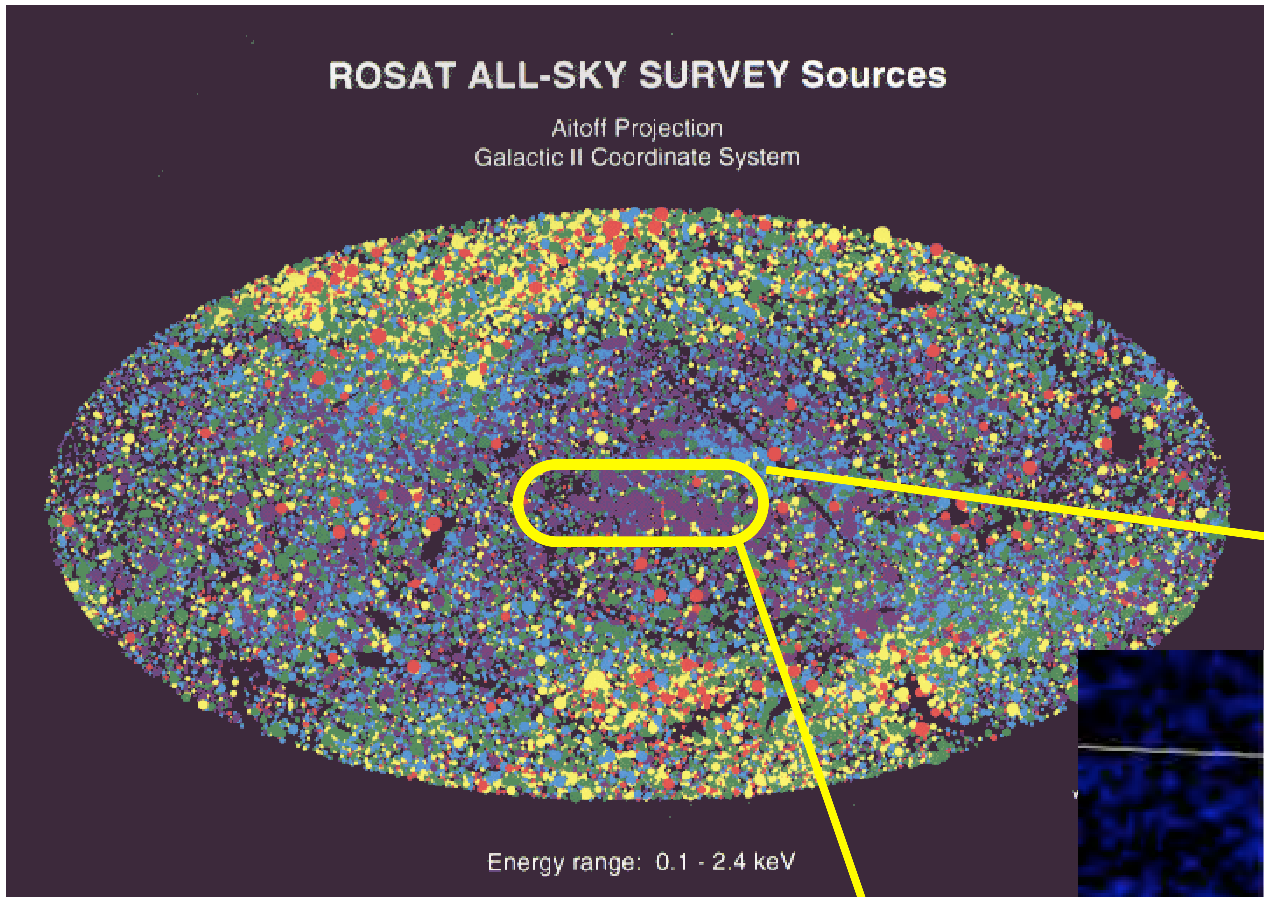
Resolve Background : 3-5 % level

INTEGRAL: a European gamma-ray observatory



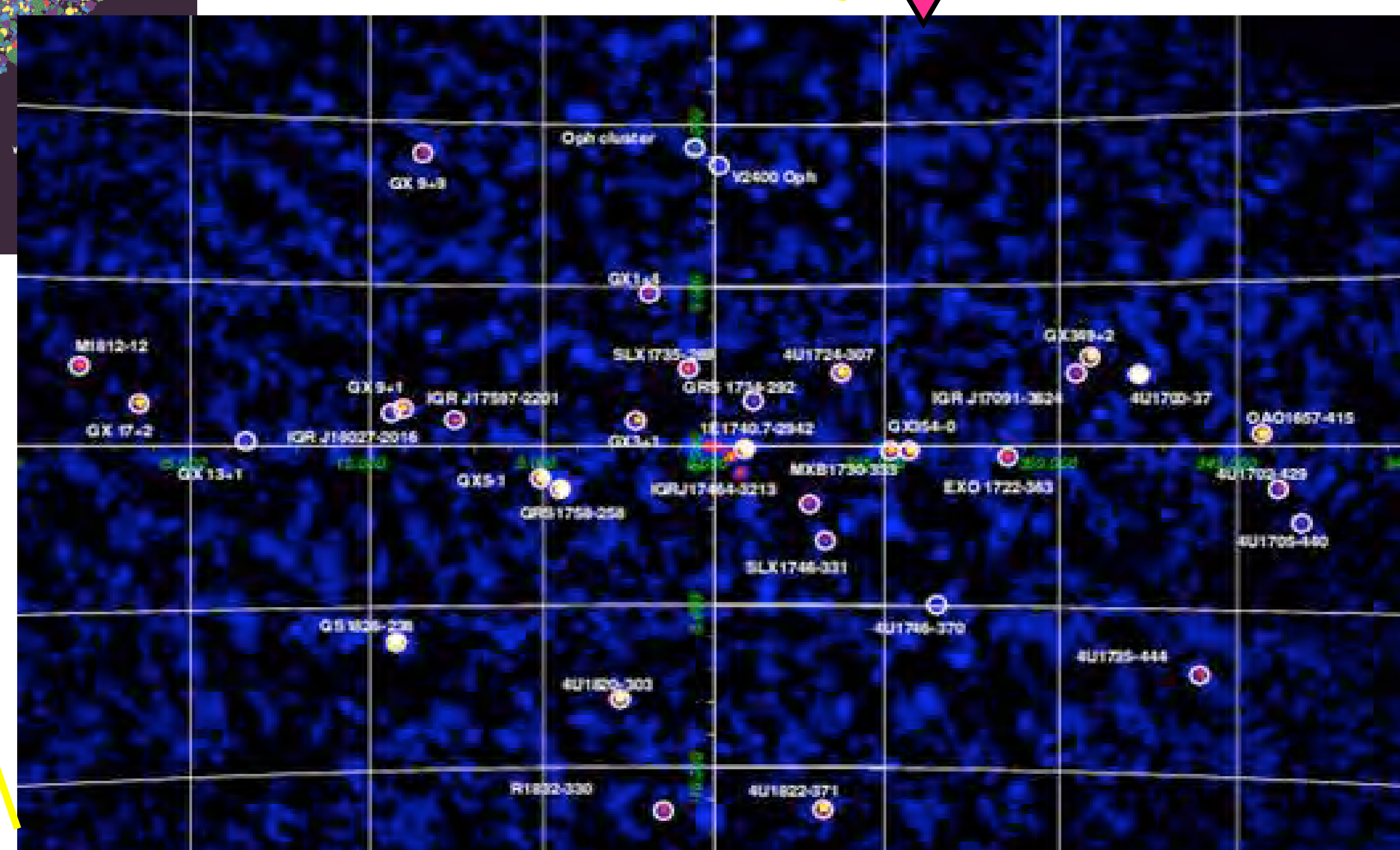
Launch: October 2002

Fact : Hard X-ray Astronomy is far behind the X-ray Astronomy



ROSAT All-sky survey

INTEGRAL ISGRI
galactic survey
20-40 keV



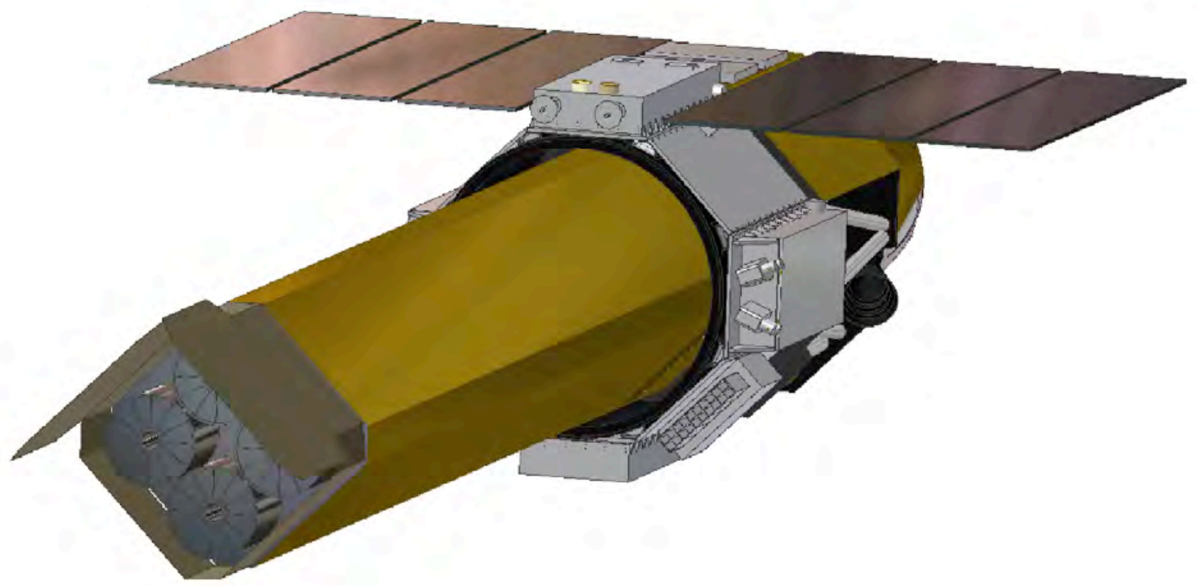
Sensitivity
X-ray : micro Crab
Hard X-ray : m Crab

Next generation X-ray Missions to study non-thermal universe

in near Future

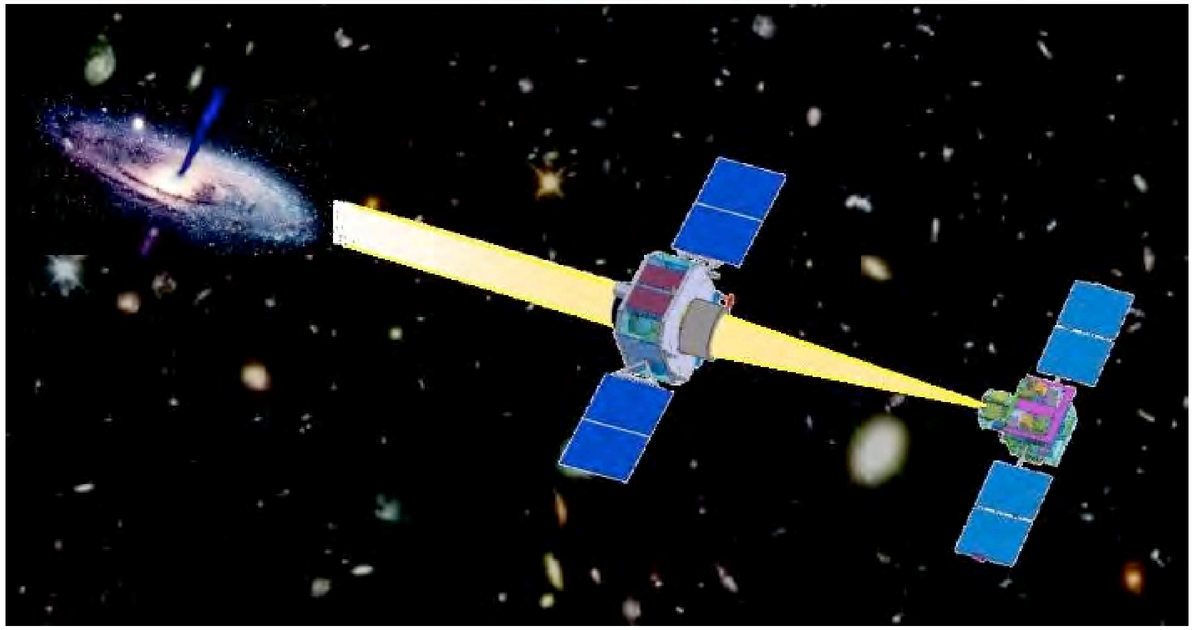
Direct Imaging at E=10-80 keV

NeXT Mission (Japan)



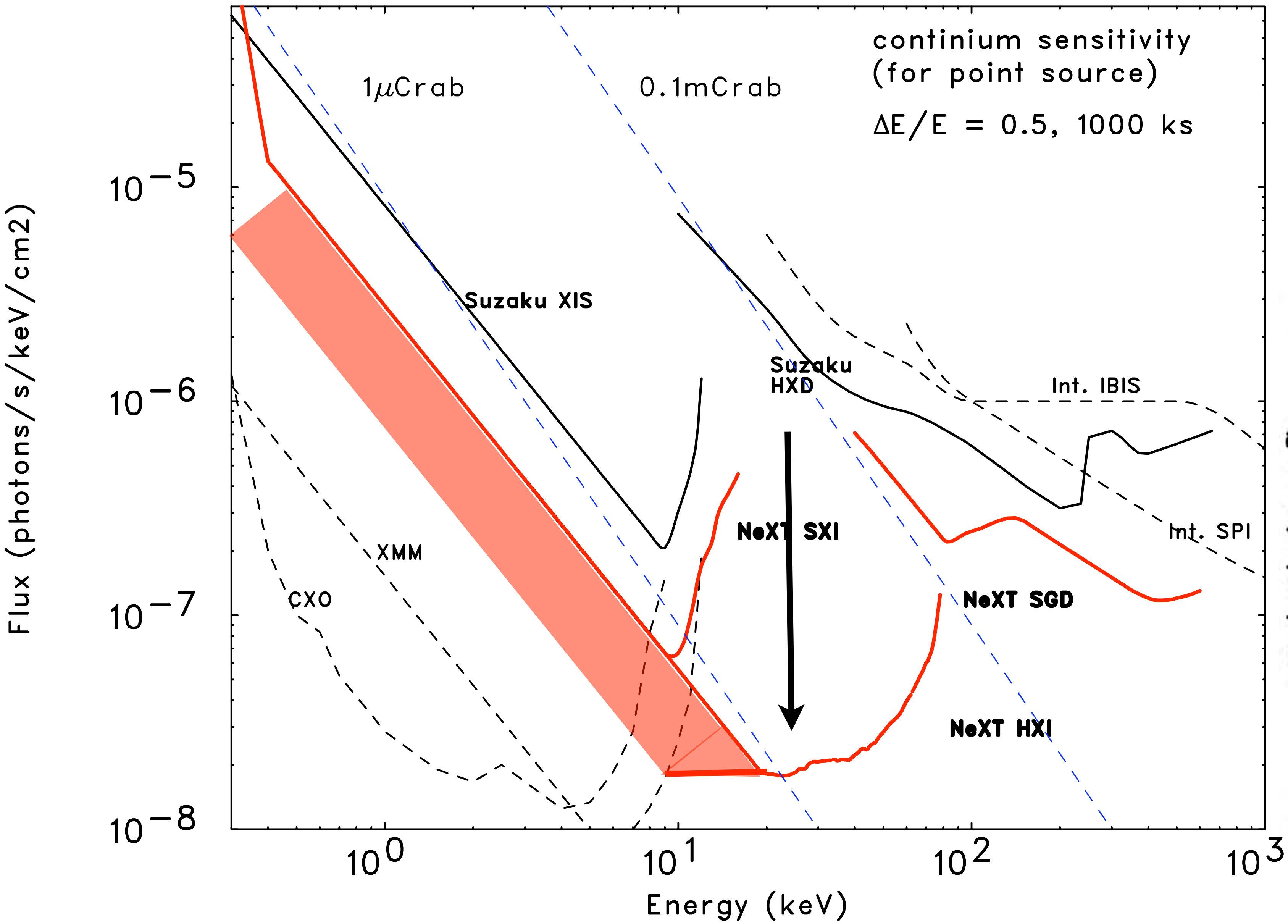
- Hard X-ray Imaging Observation (10 keV - 80 keV)
- Wide band observation (0.3 keV - 300 keV)
- High Resolution X-ray observation of Diffuse Sources

Simbol-X (Fr/It/G)

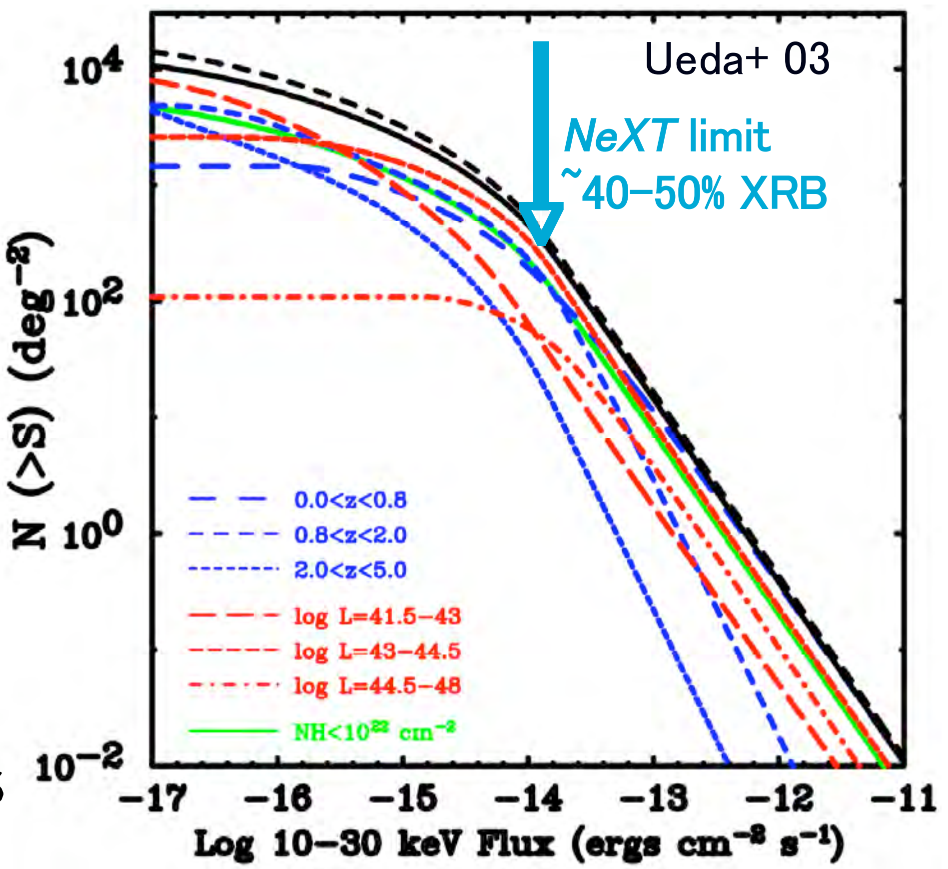


- Soft/Hard X-ray Imaging Observation (0.3 keV - 80 keV)
- Formation Flight

Two orders of magnitude improvement in 10-60 keV



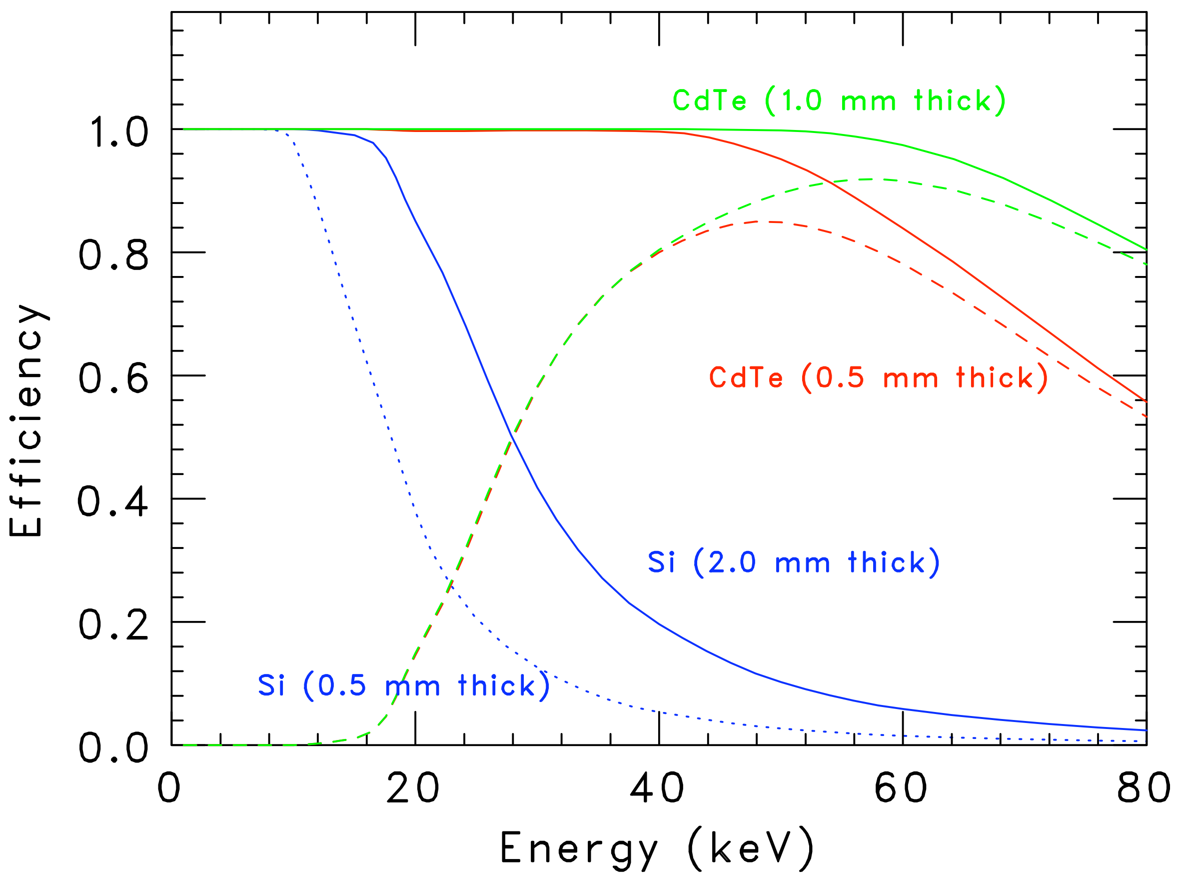
40-50% of Hard XRB will be resolved



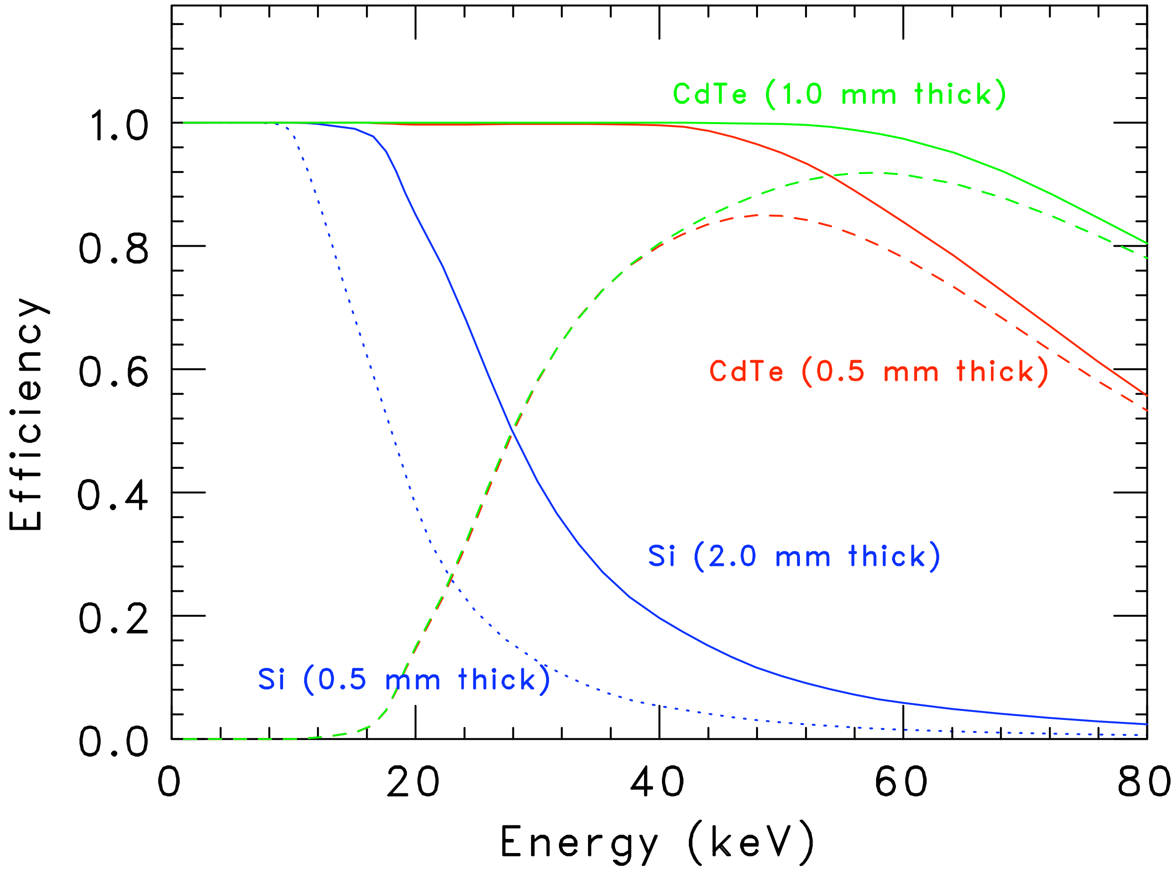
The fraction of Compton thick AGNs is predicted to be ~10% (Fx=1e-11) to ~25% (Fx=1e-16) (Ueda et al. 03)

30-60 arcsec HPD

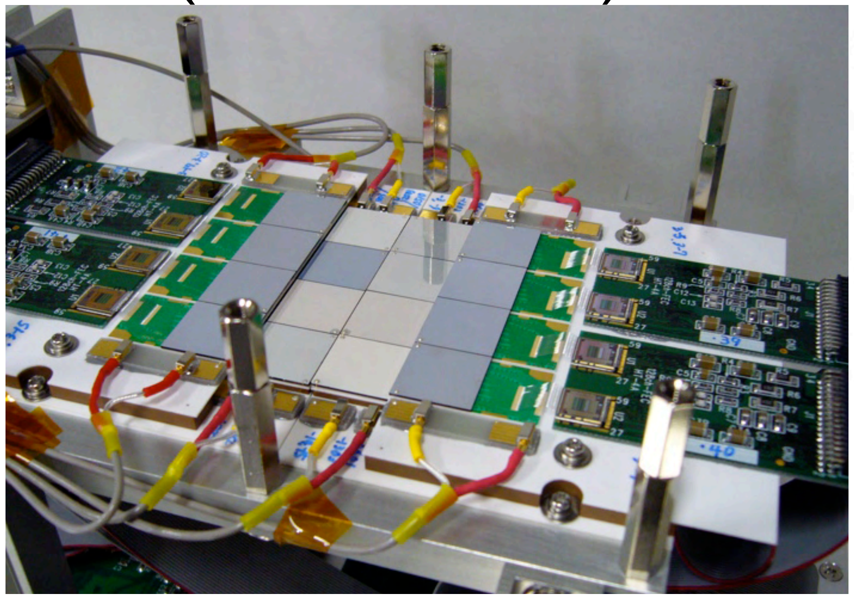
Detector Components



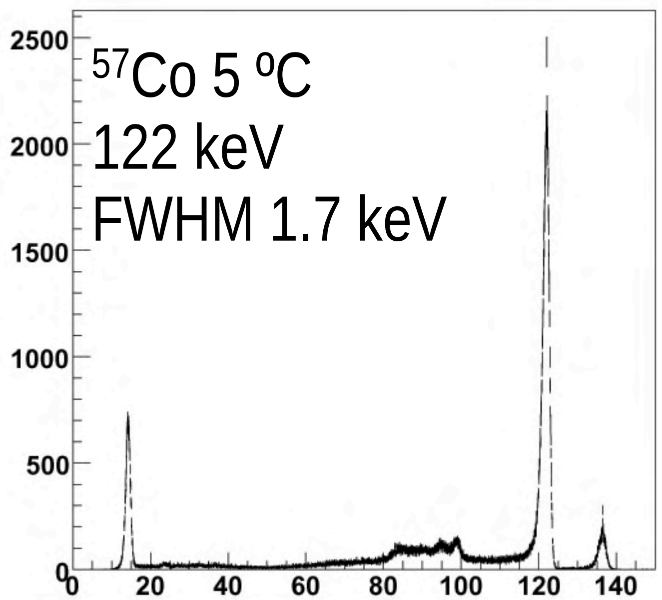
Detector Components



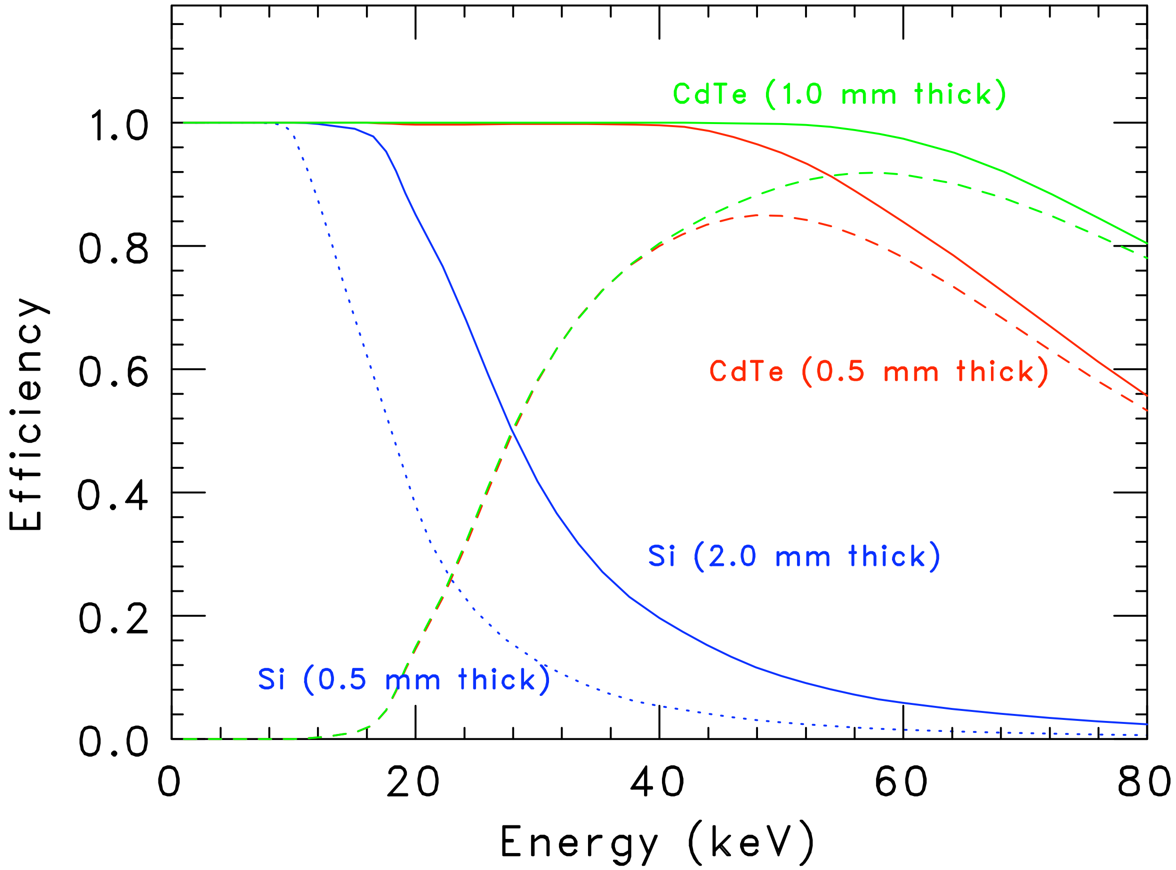
Large Area (4cm x 4cm) CdTe



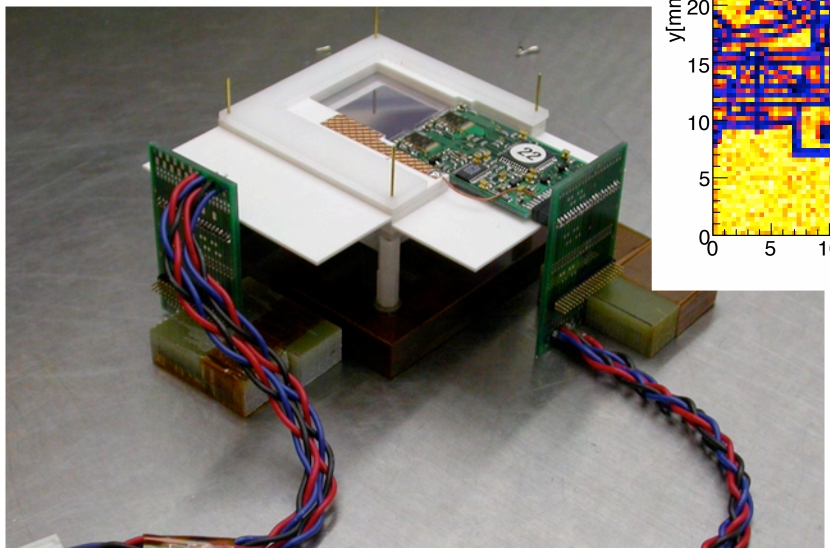
CdTe

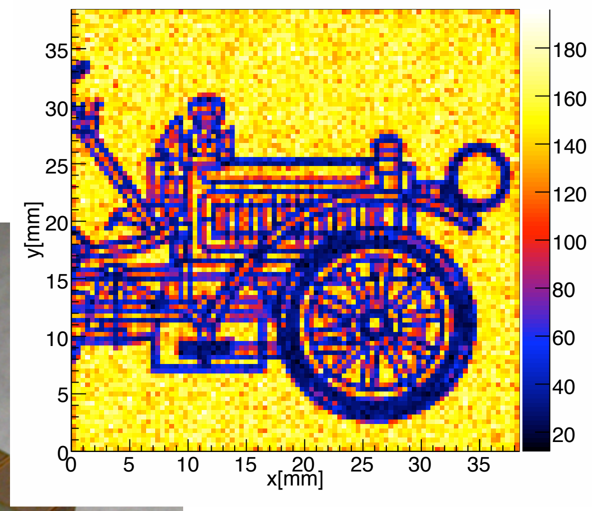


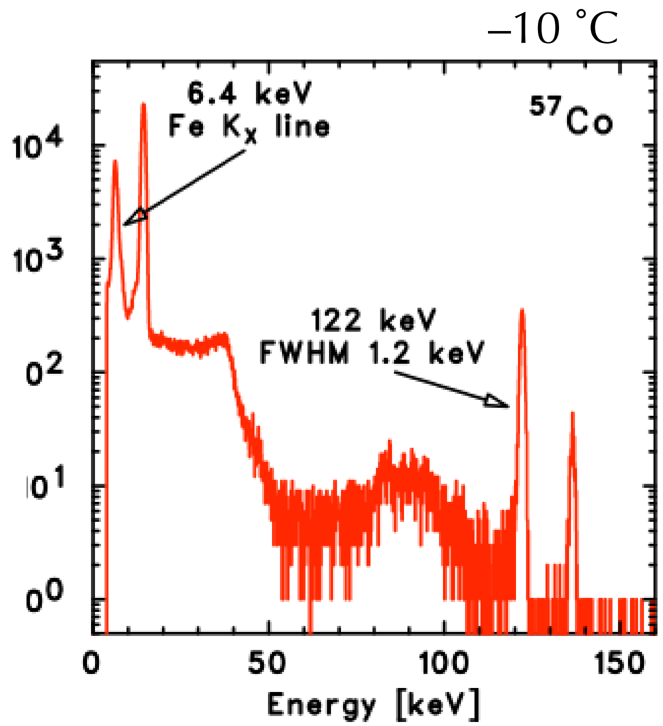
Detector Components



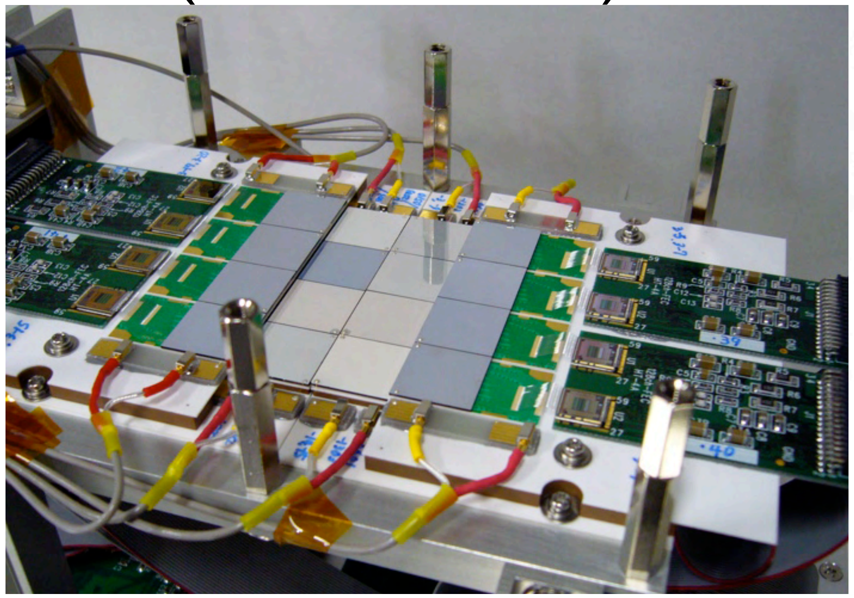
Si Microstrip
(4cm x 4cm)



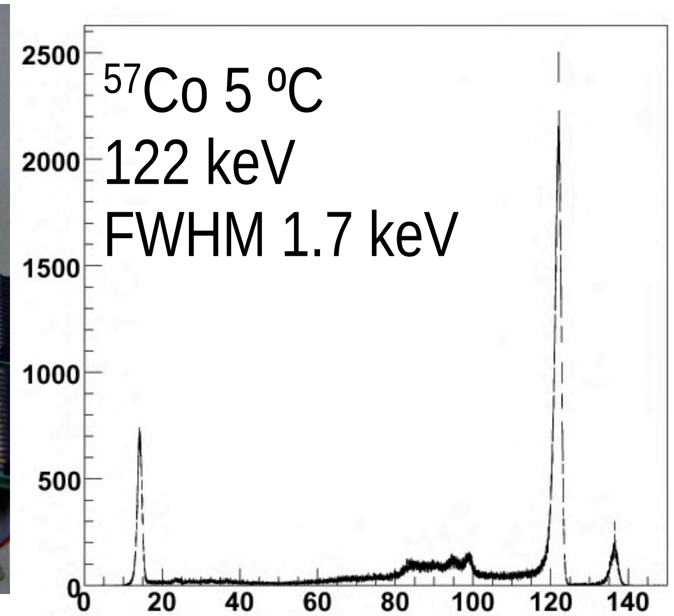




Large Area (4cm x 4cm) CdTe



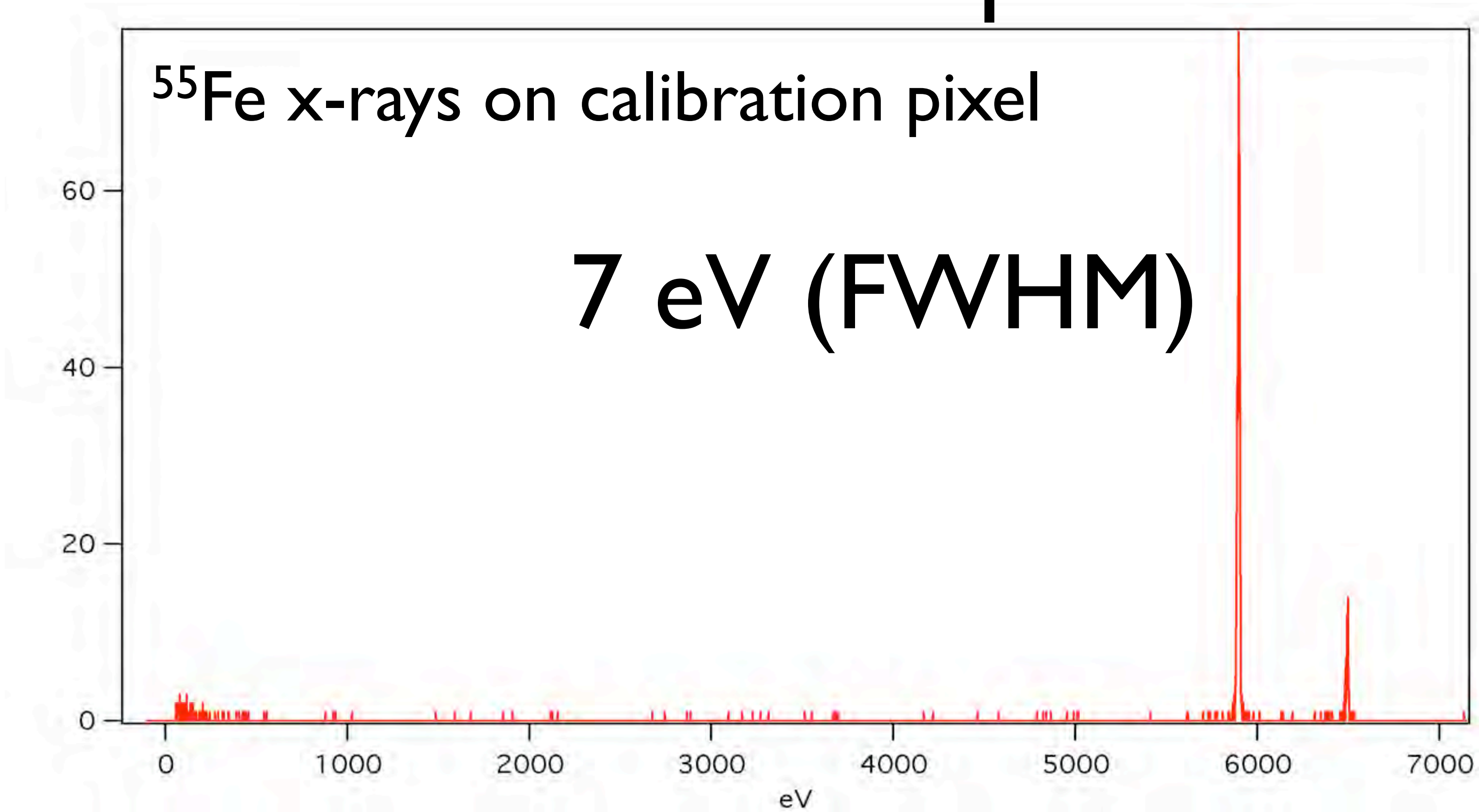
CdTe

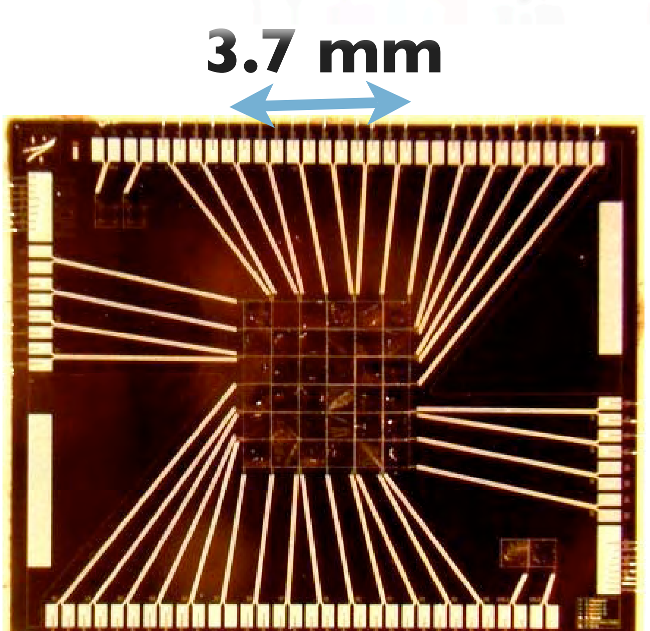


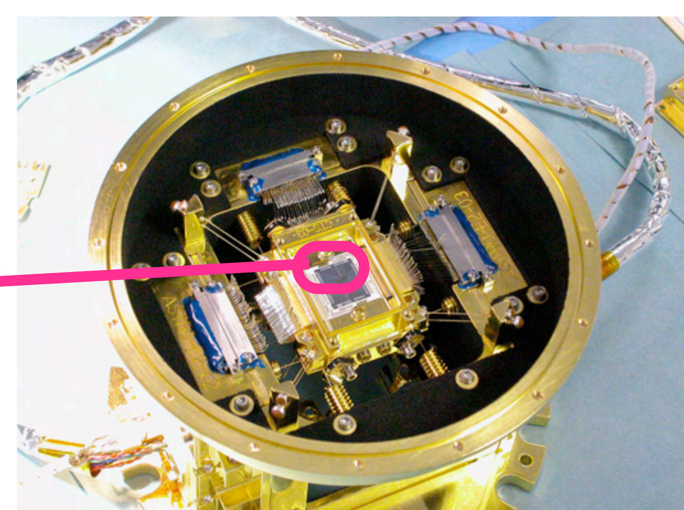
Si

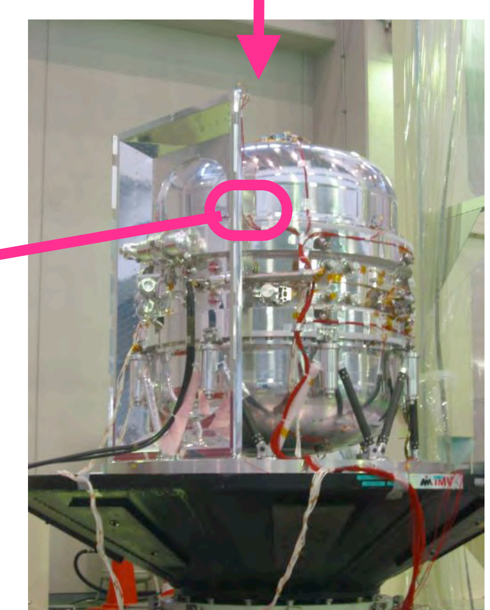
Soft X-ray Spectrometer (SXS)

What we should have operated



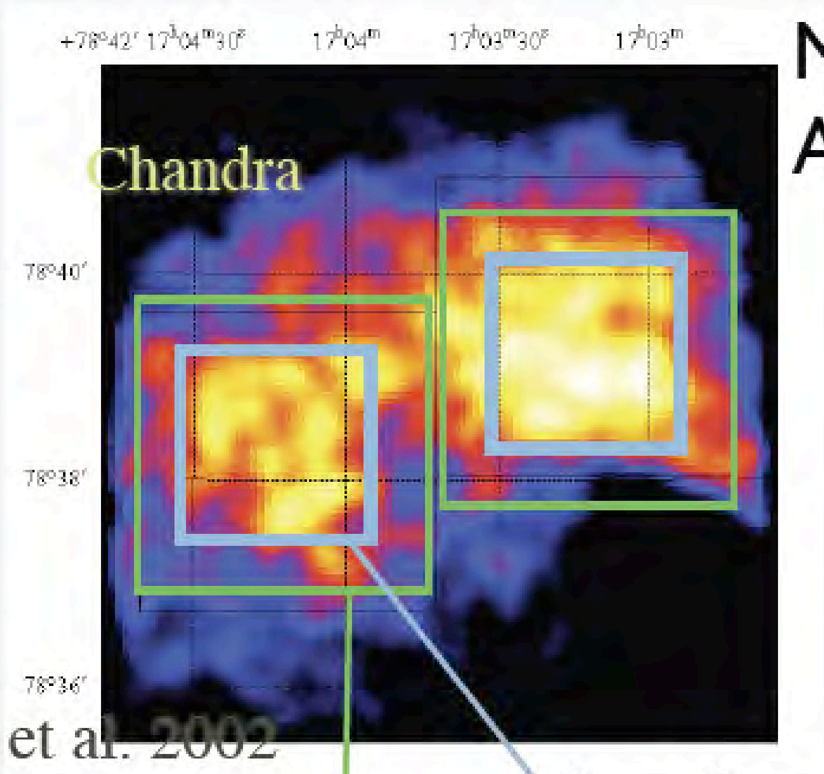






Mitsuda 物理学会

Gas dynamics: bulk motion, turbulence



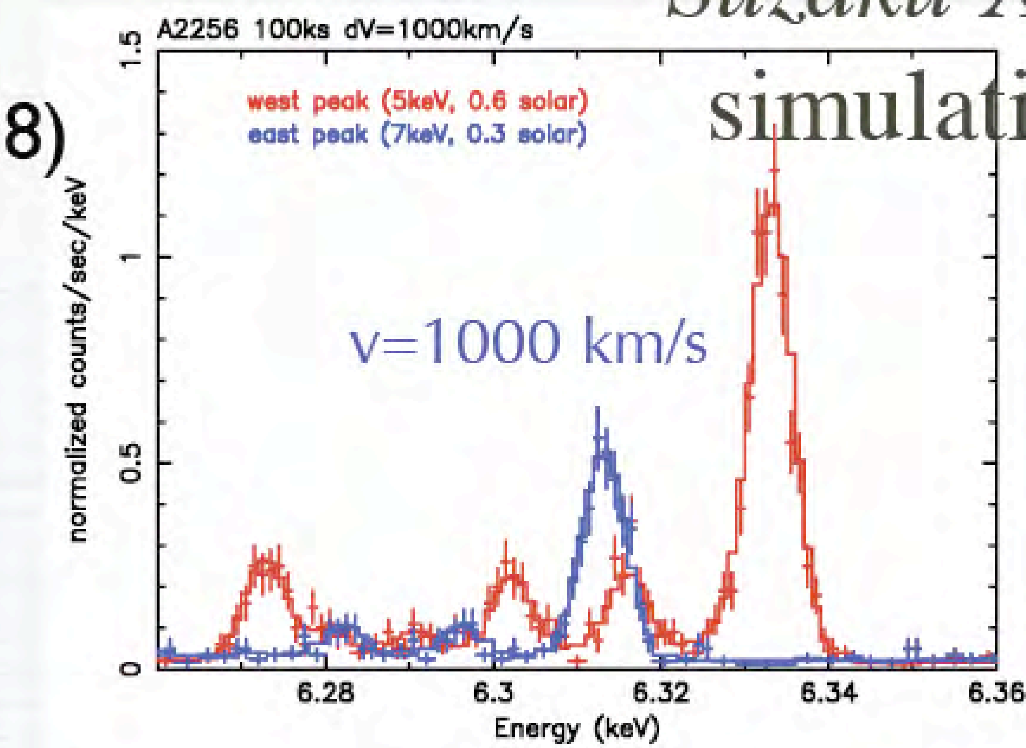
Sun et al. 2002

Merger,
A2256 (z = 0.058)

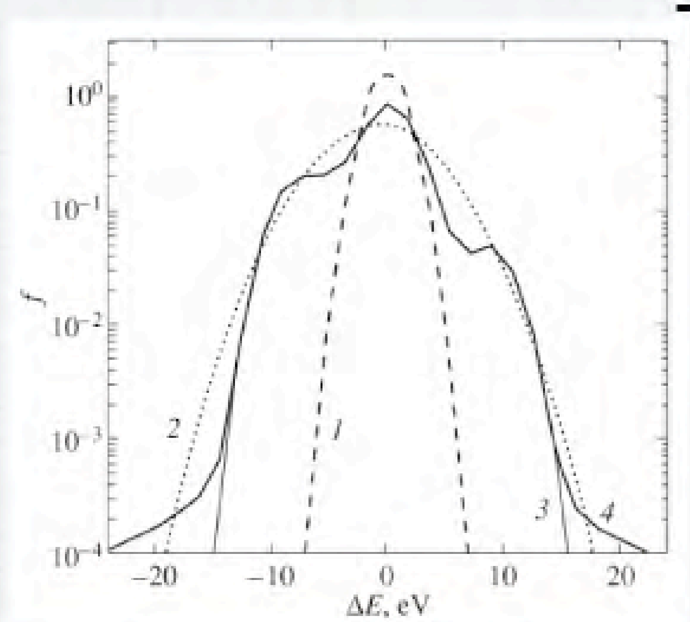
XRS FOV

baseline SXS FOV

Suzaku XRS simulation

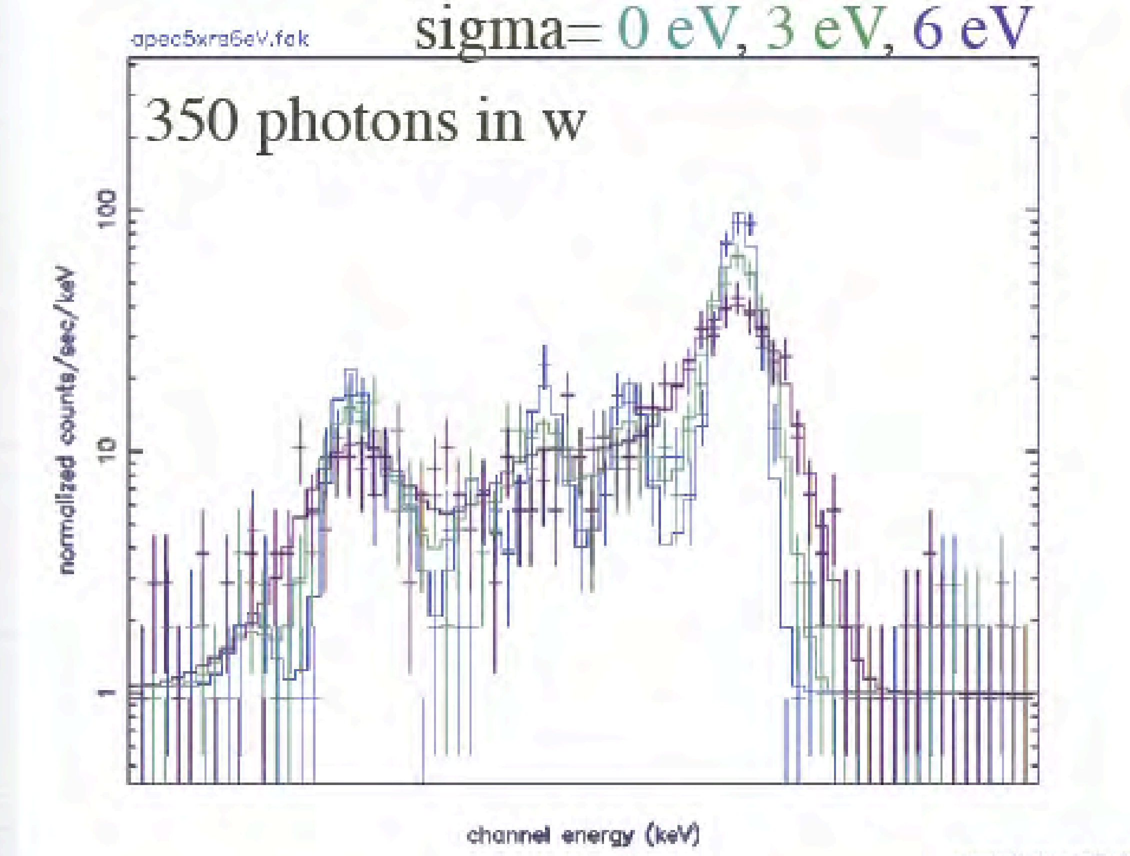


Turbulence



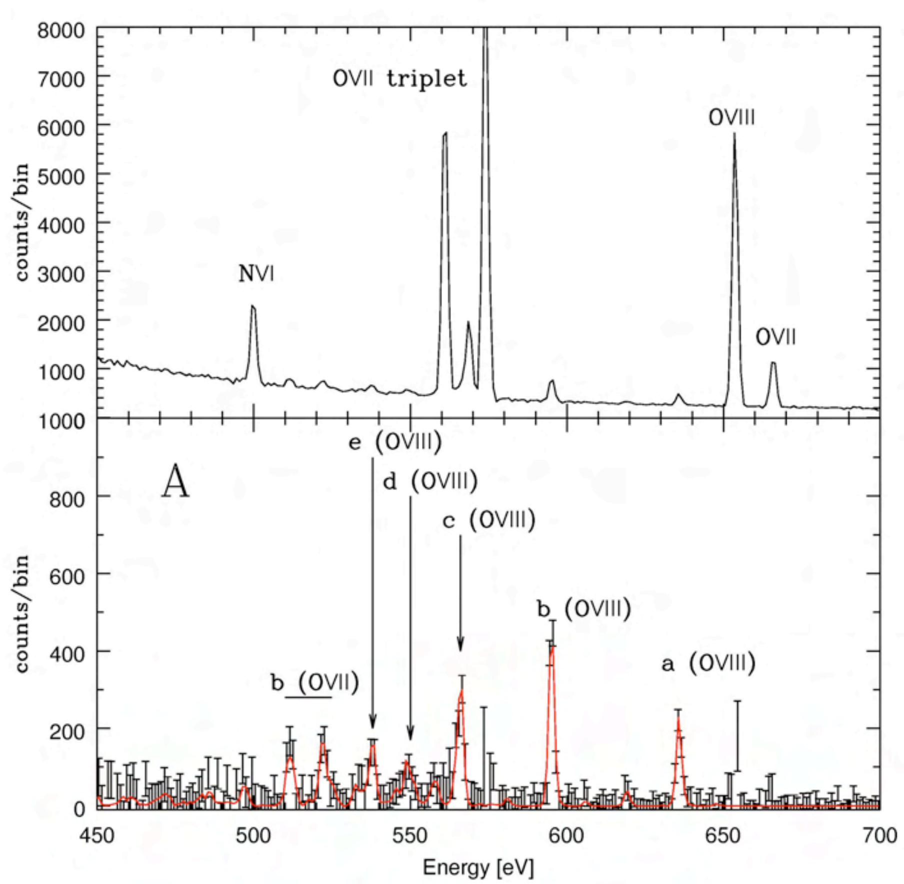
Inogamov and Sunyaev 2003

sigma= 0 eV, 3 eV, 6 eV

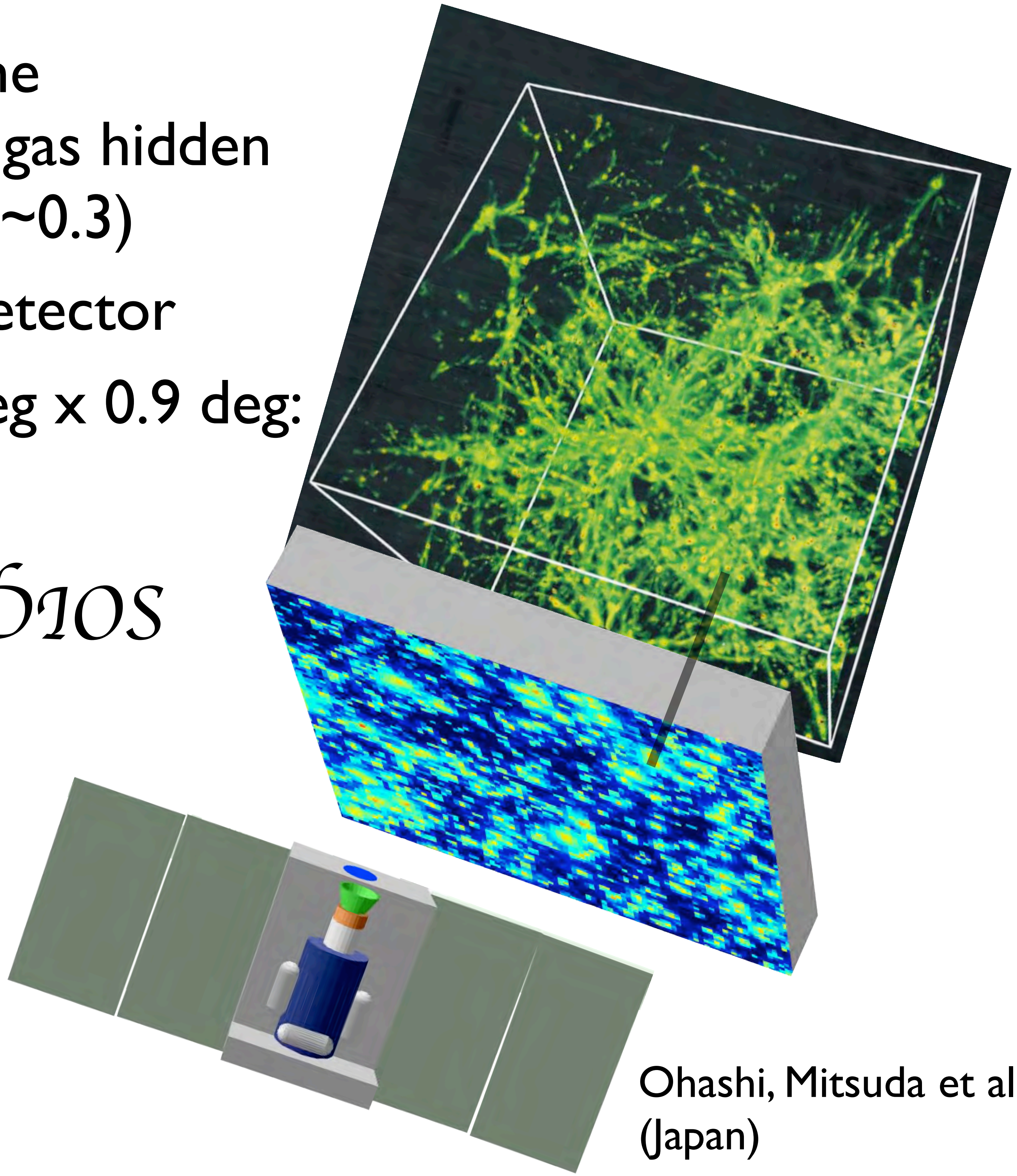


To Search for Missing baryon

- Detection of emission line (OVII, OVIII) from 10^6K gas hidden between galaxies (upto z~0.3)
- High Resolution (TES) detector
- Wide FOV mirror (0.9deg x 0.9 deg: Large SΩ)



DIOS

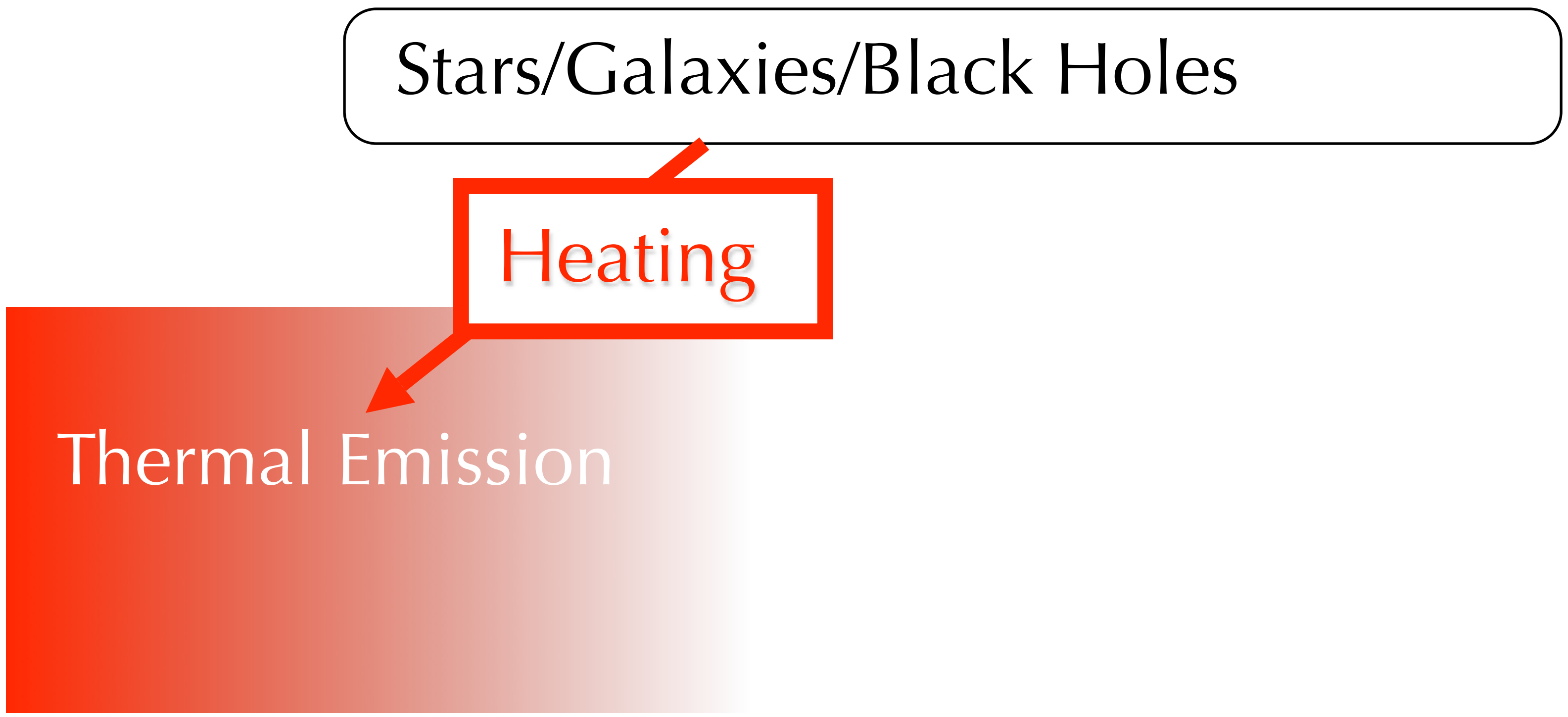


Ohashi, Mitsuda et al. (Japan)

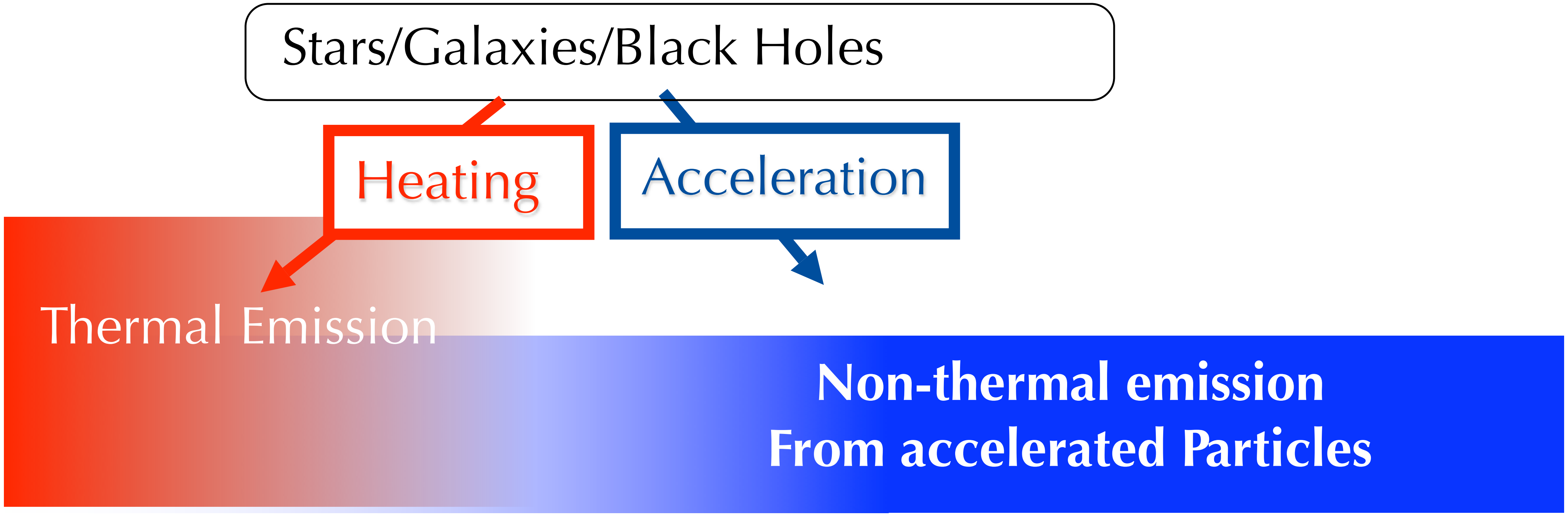
The entire extragalactic radiation

Stars/Galaxies/Black Holes

The entire extragalactic radiation



The entire extragalactic radiation



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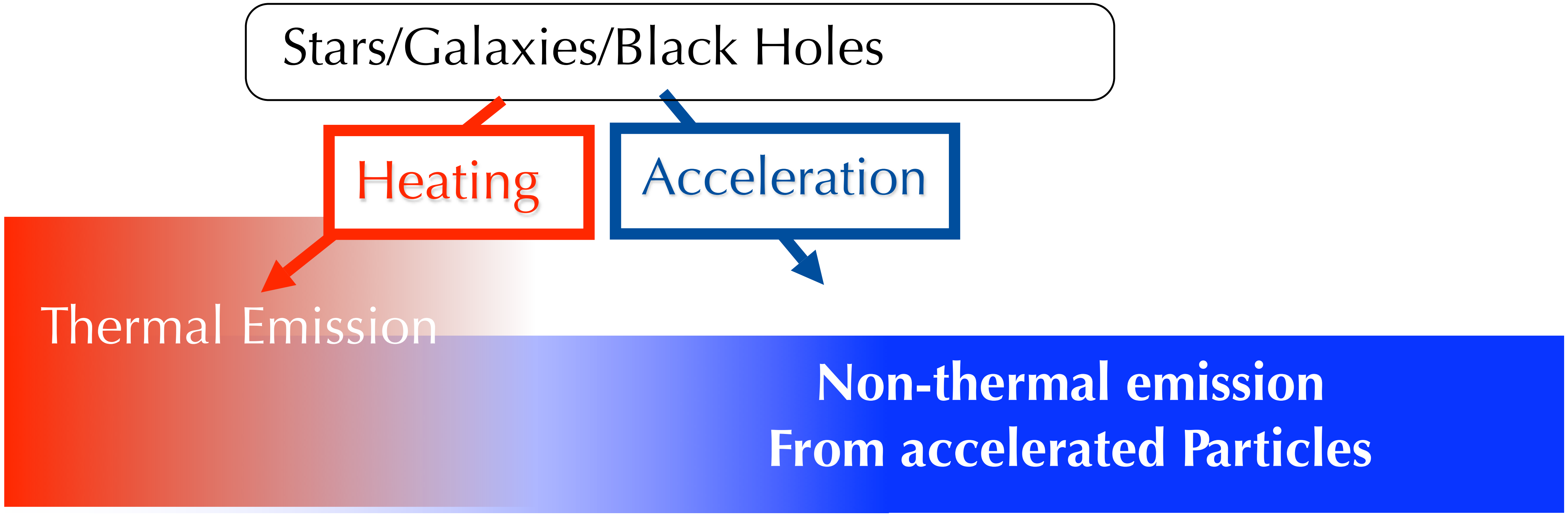


Cosmic Background Spectrum should tell us about the “Branching Ratio”

Star light → Absorption and Re-emission

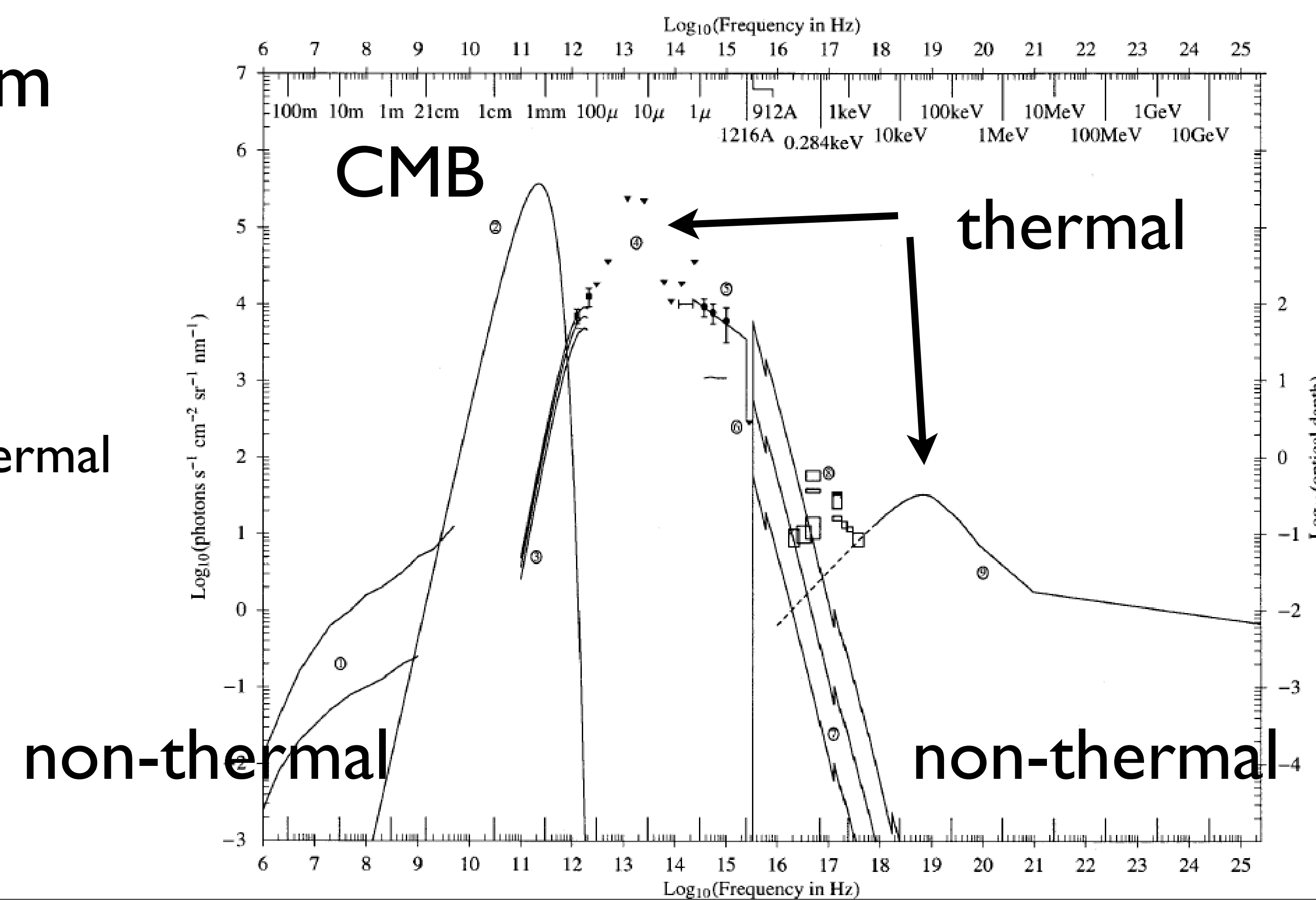
SN/SNR → Cosmic Ray Acceleration (non-thermal Radio/Gamma-ray)

Blackhole →

Thermal Emission from Hot Plasma

vs

Non-thermal emission from Jet



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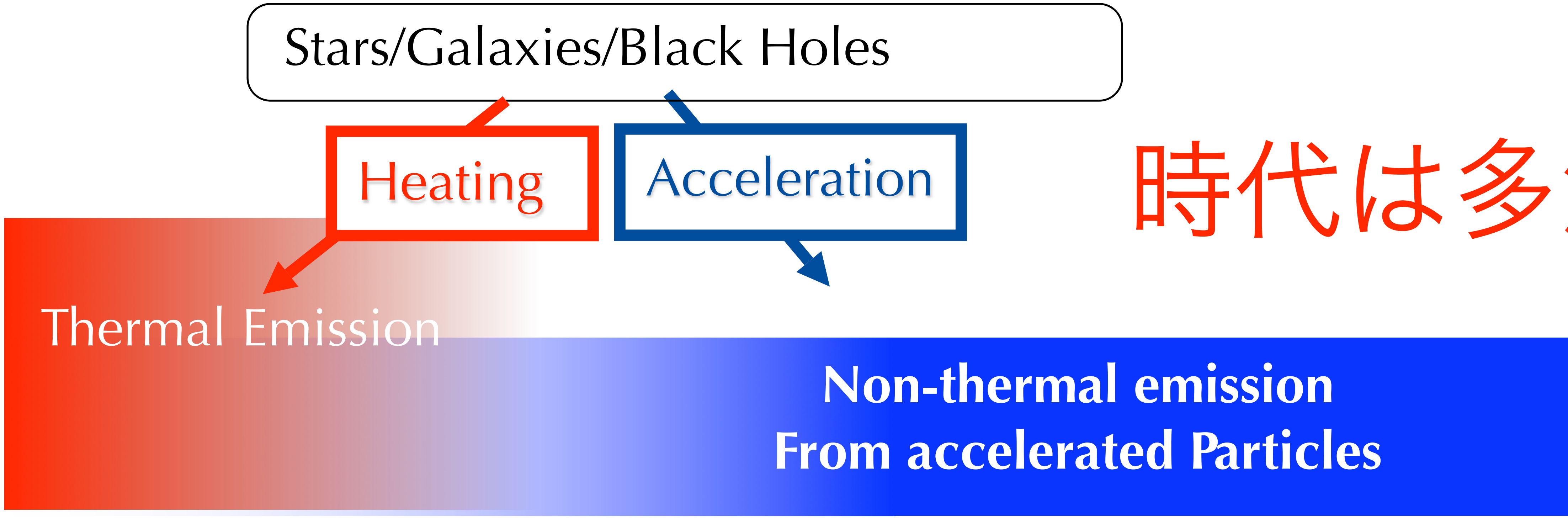

時代は多波長

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