The Physics of Particle Acceleration Probed with Hard X-rays

~ importance of the energy band above 10 keV ~

K. Max Makishima

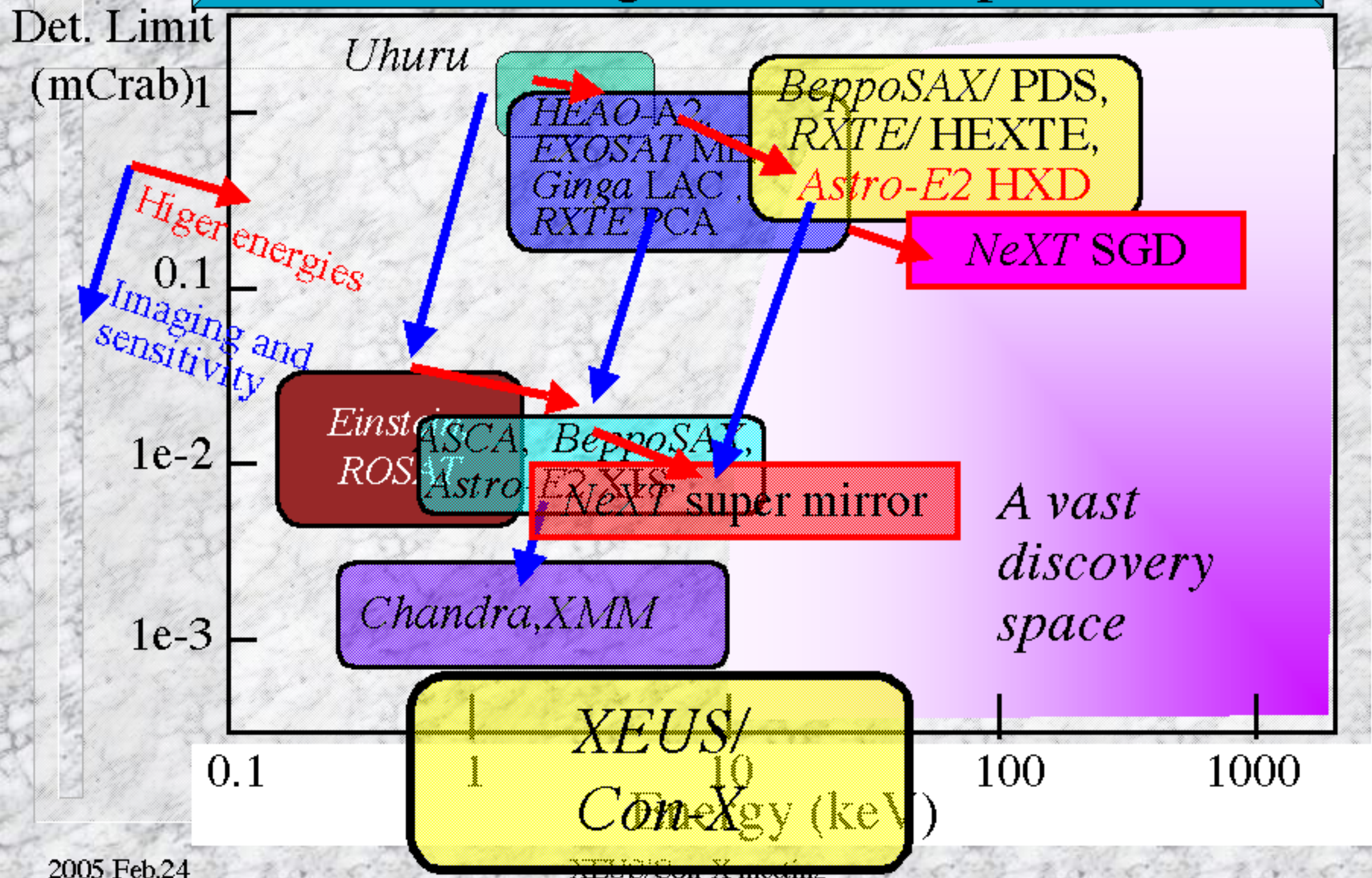
Department of Physics, The University of Tokyo

and

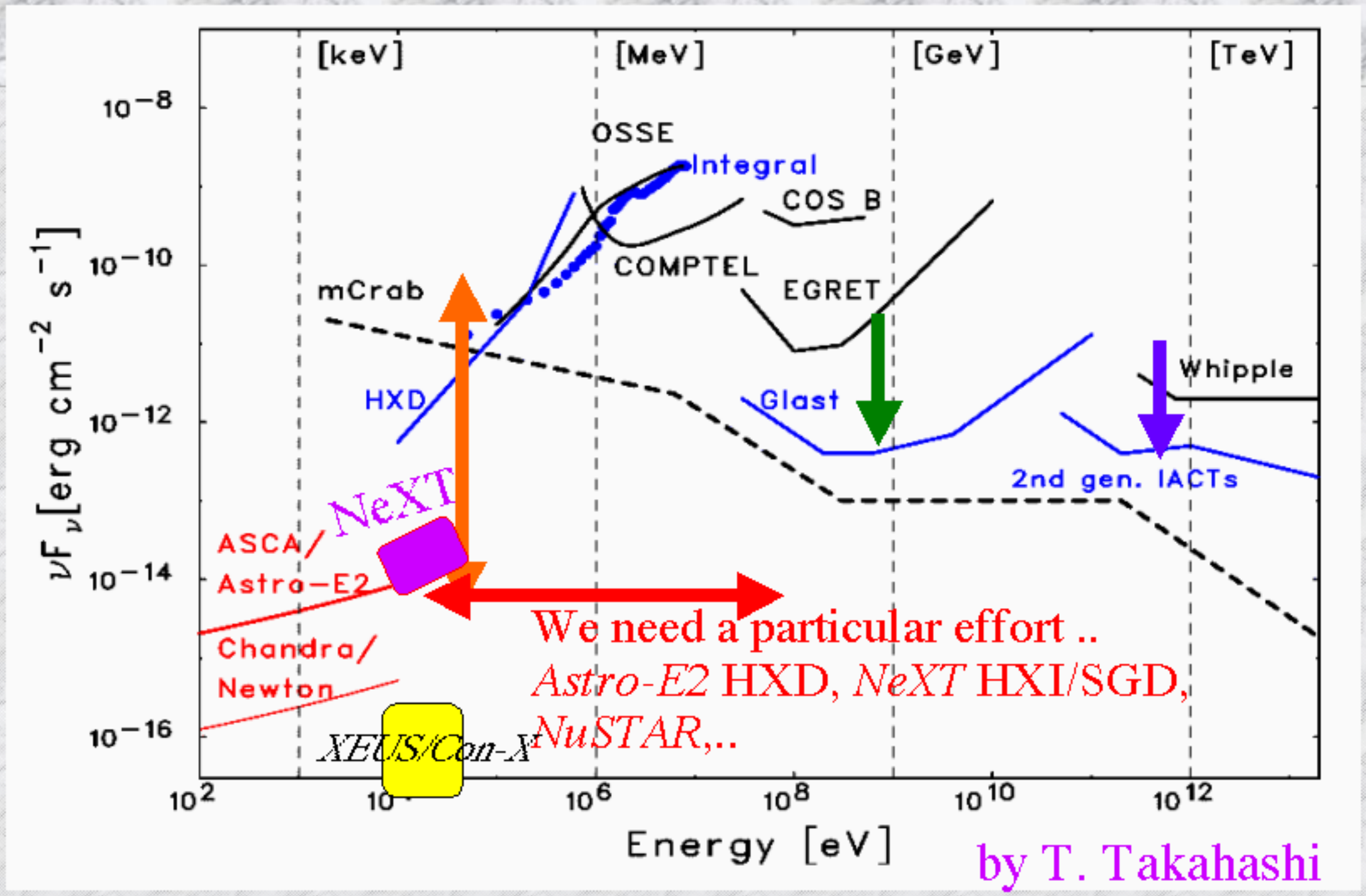
Cosmic Radiation Laboratory,
The Institute of Physical and Chemical Research

1. Some Historical Overview

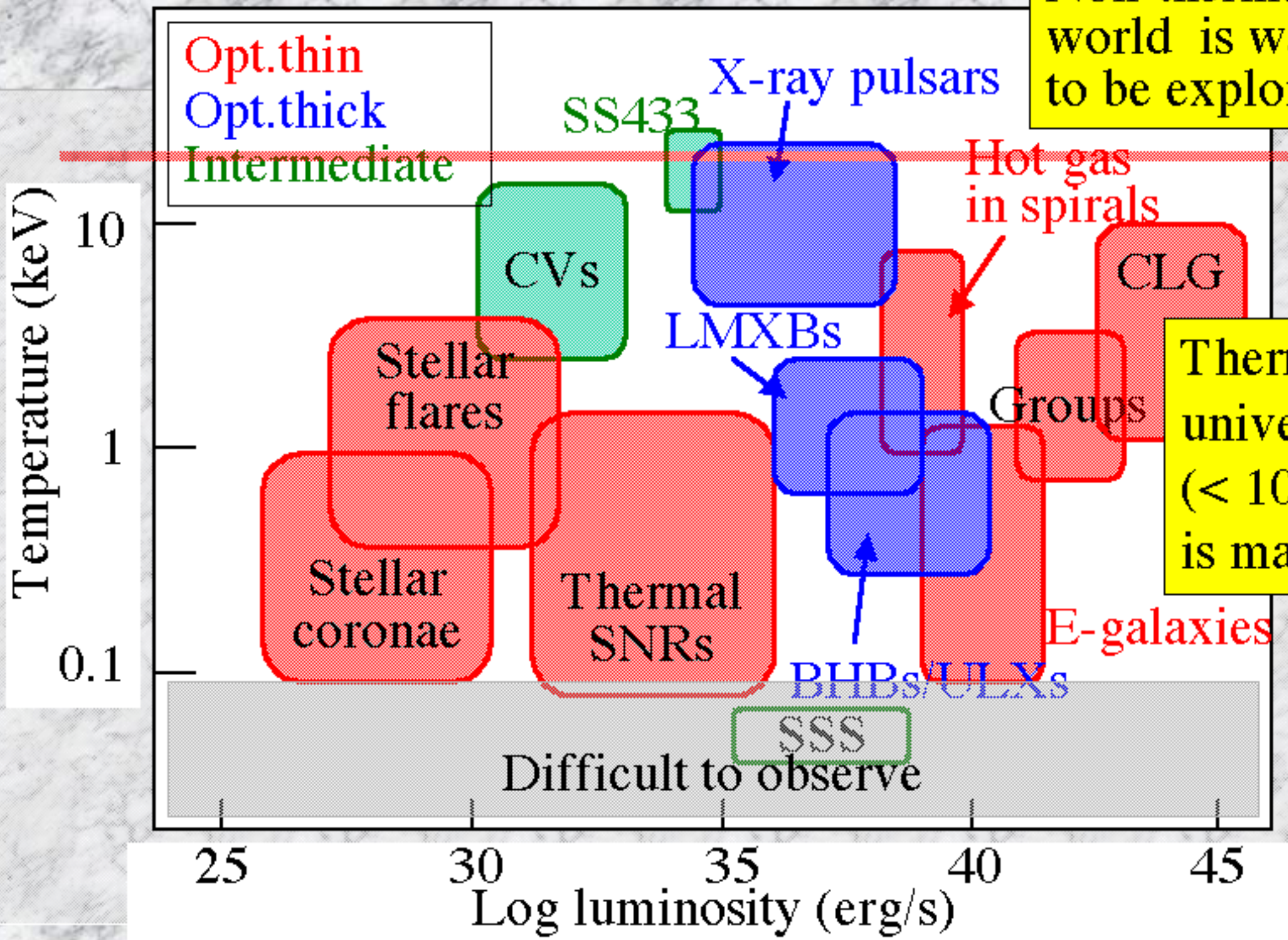
1a. Evolving Mission Capabilities



1b. A huge sensitivity gap across 10 keV



1c. The "hot universe" below ~10 keV

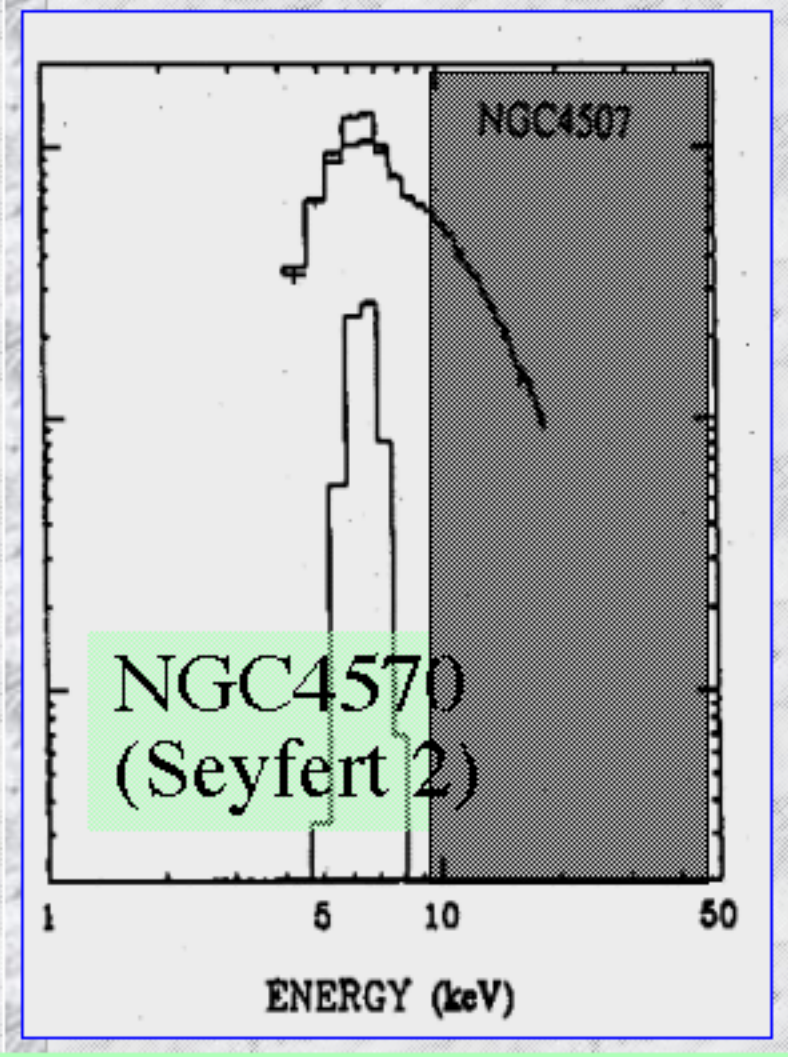


Non-thermal world is waiting to be explored.

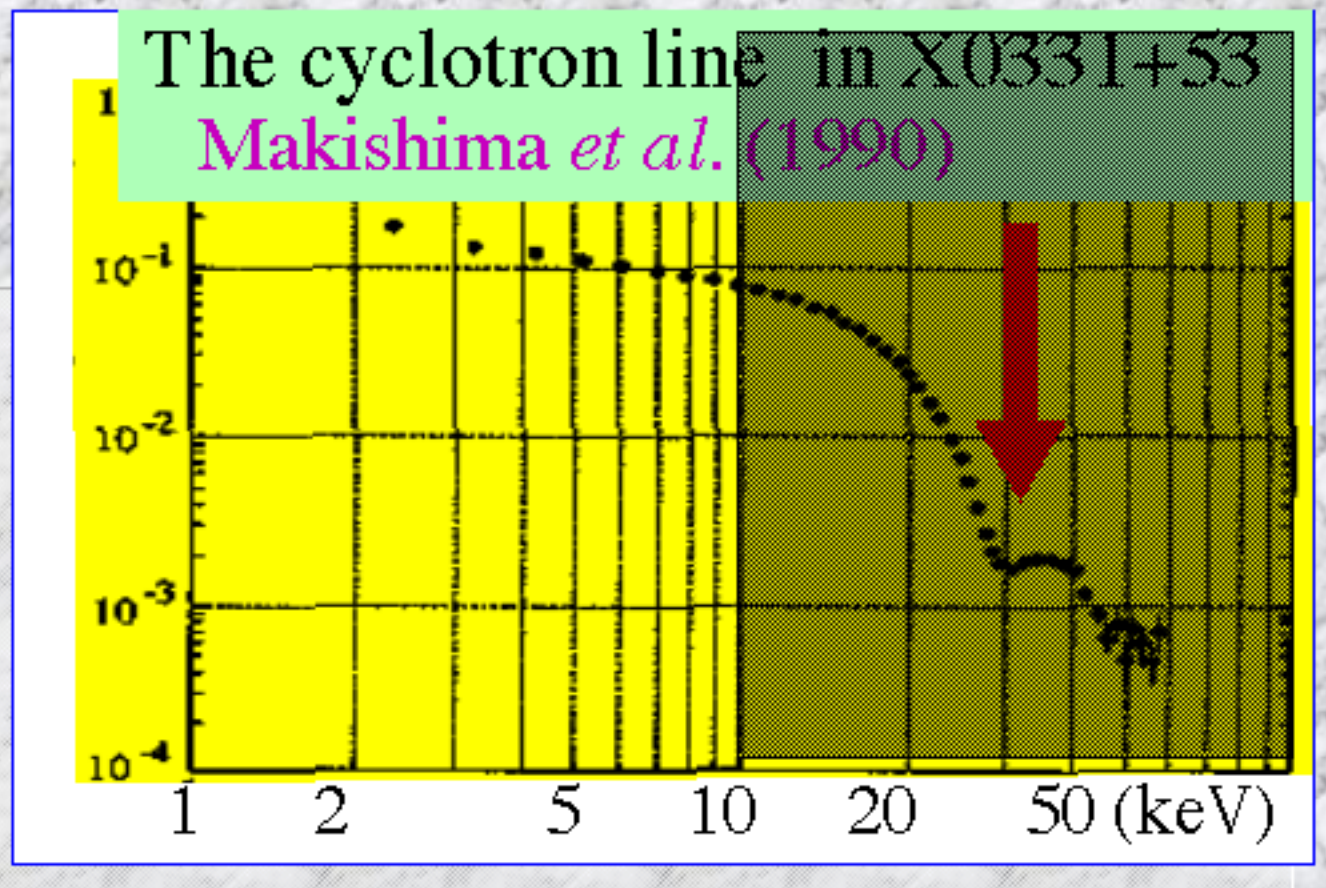
Thermal universe (< 10 keV) is matured.

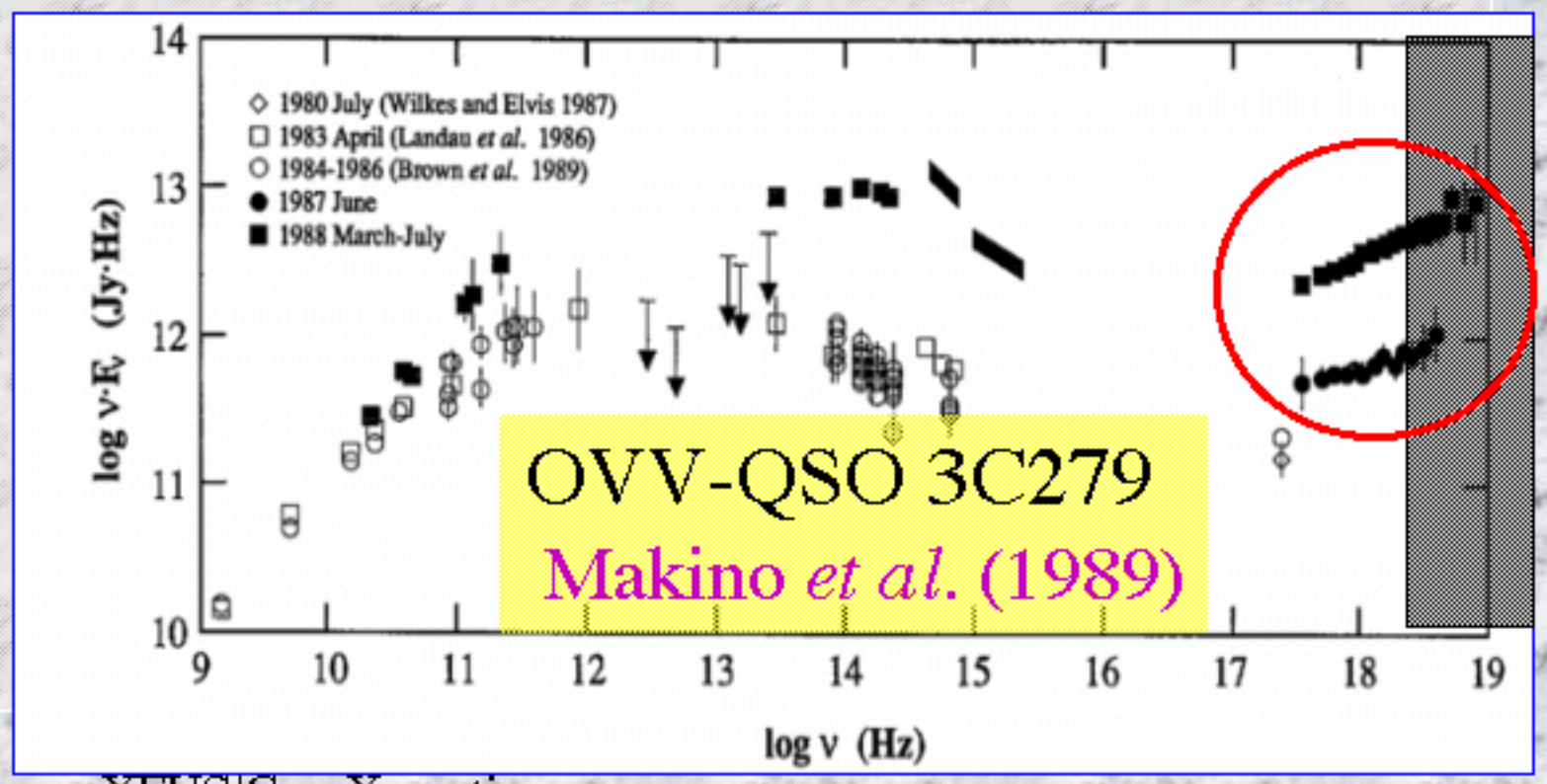
2. Glimpses of the Hard X-ray Universe

2*a*. Highlights from the *Ginga* LAC

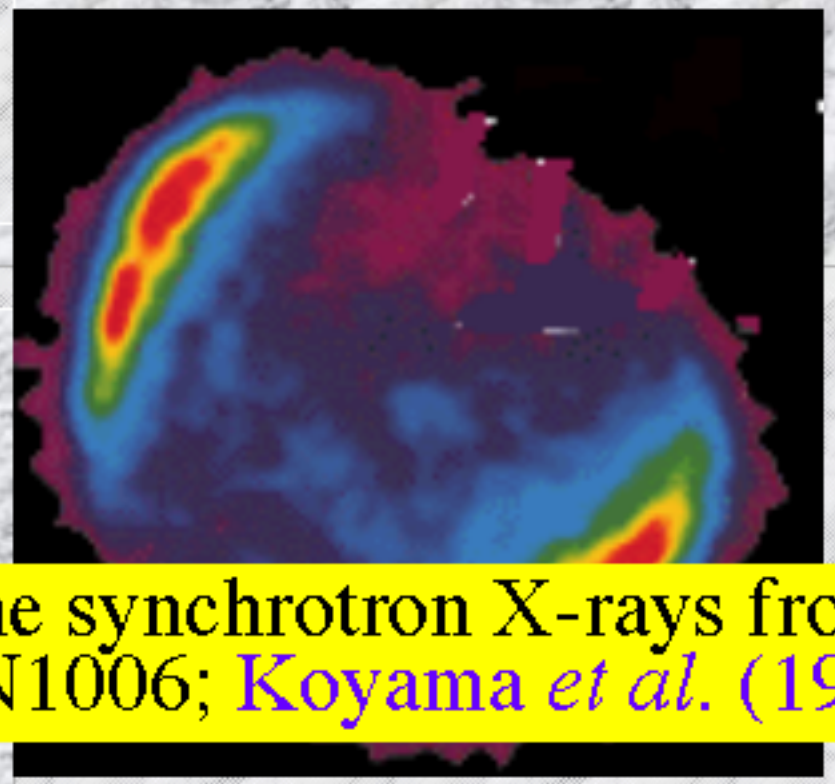


Awaki *et al.* (1991)
--> Comastri *et al.* (1995)

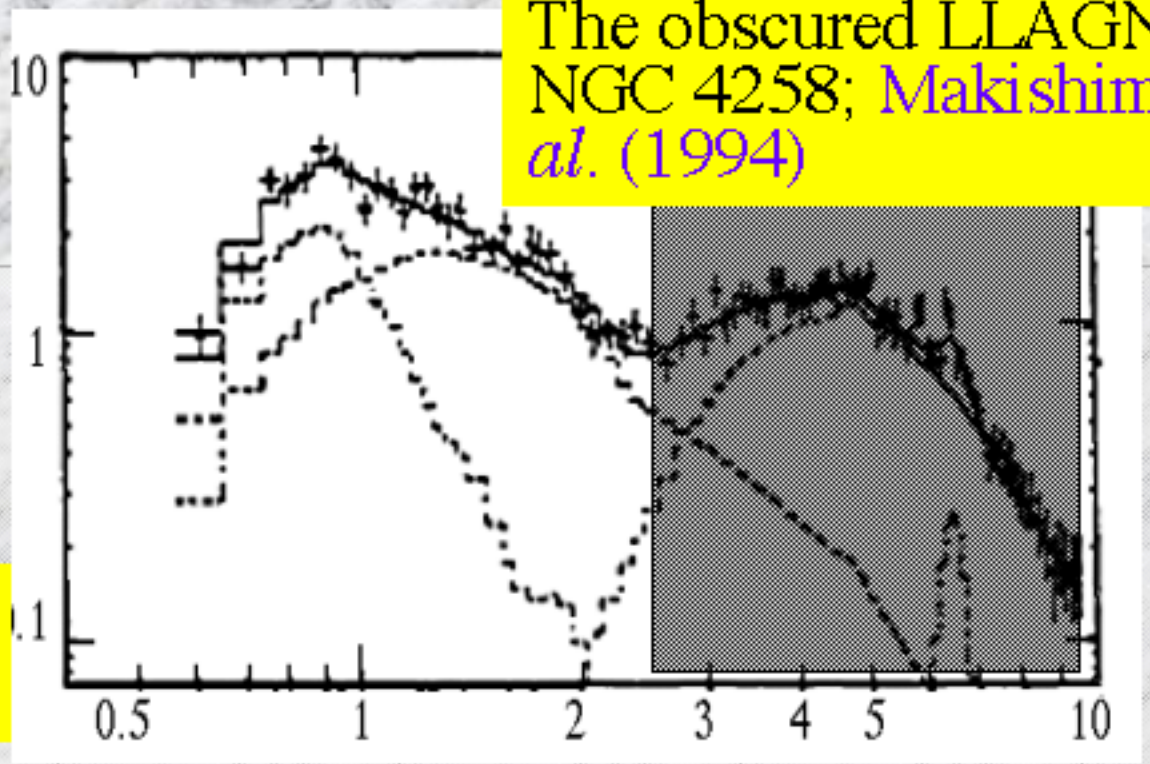




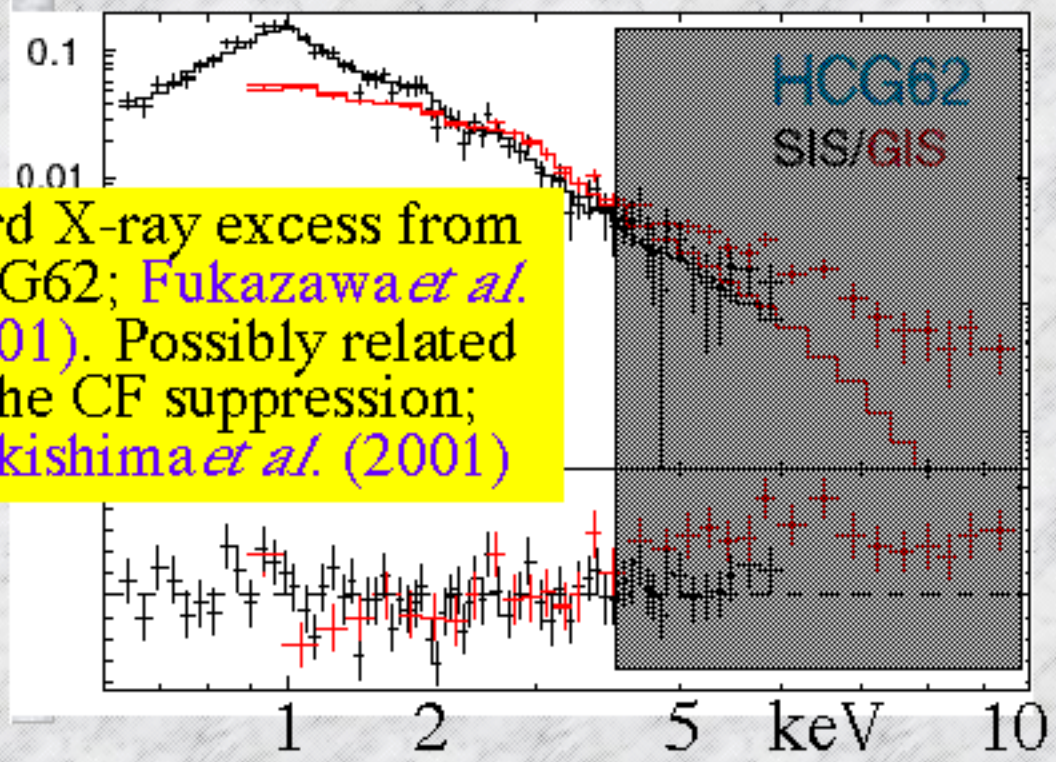
2*b*. Highlights from the *ASCA* GIS



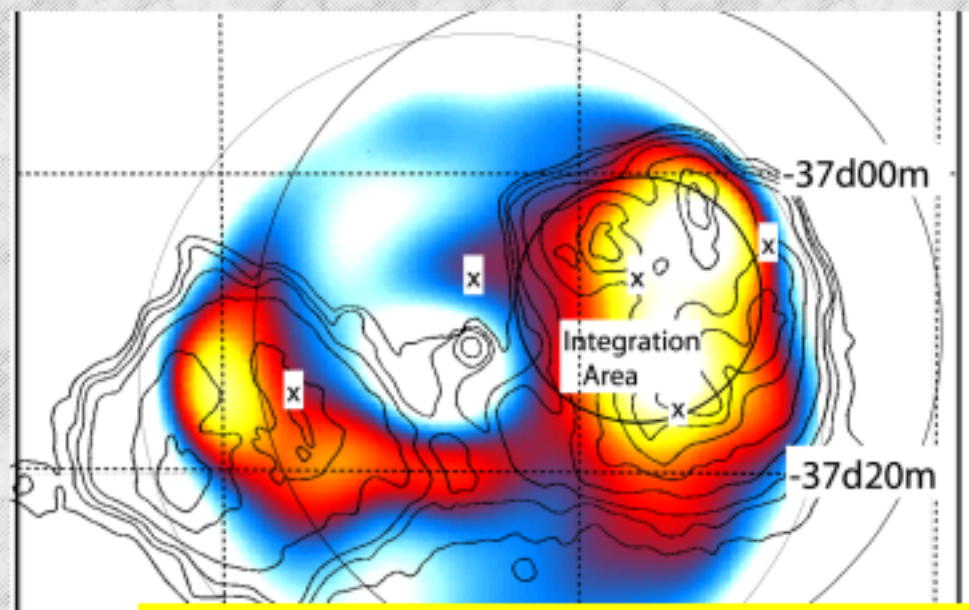
The synchrotron X-rays from SN1006; Koyama *et al.* (1995)



The obscured LLAGN in NGC 4258; Makishima *et al.* (1994)

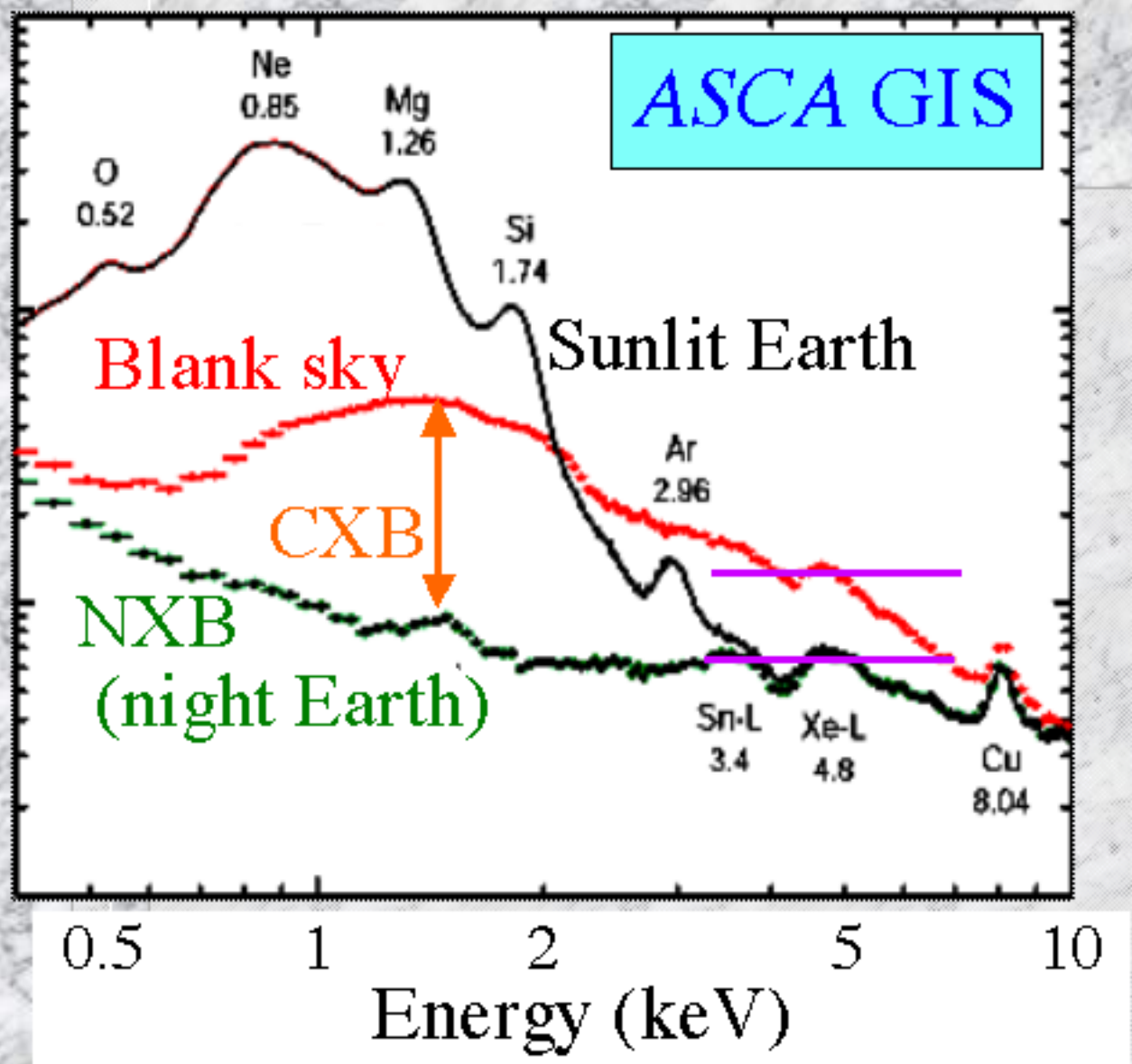


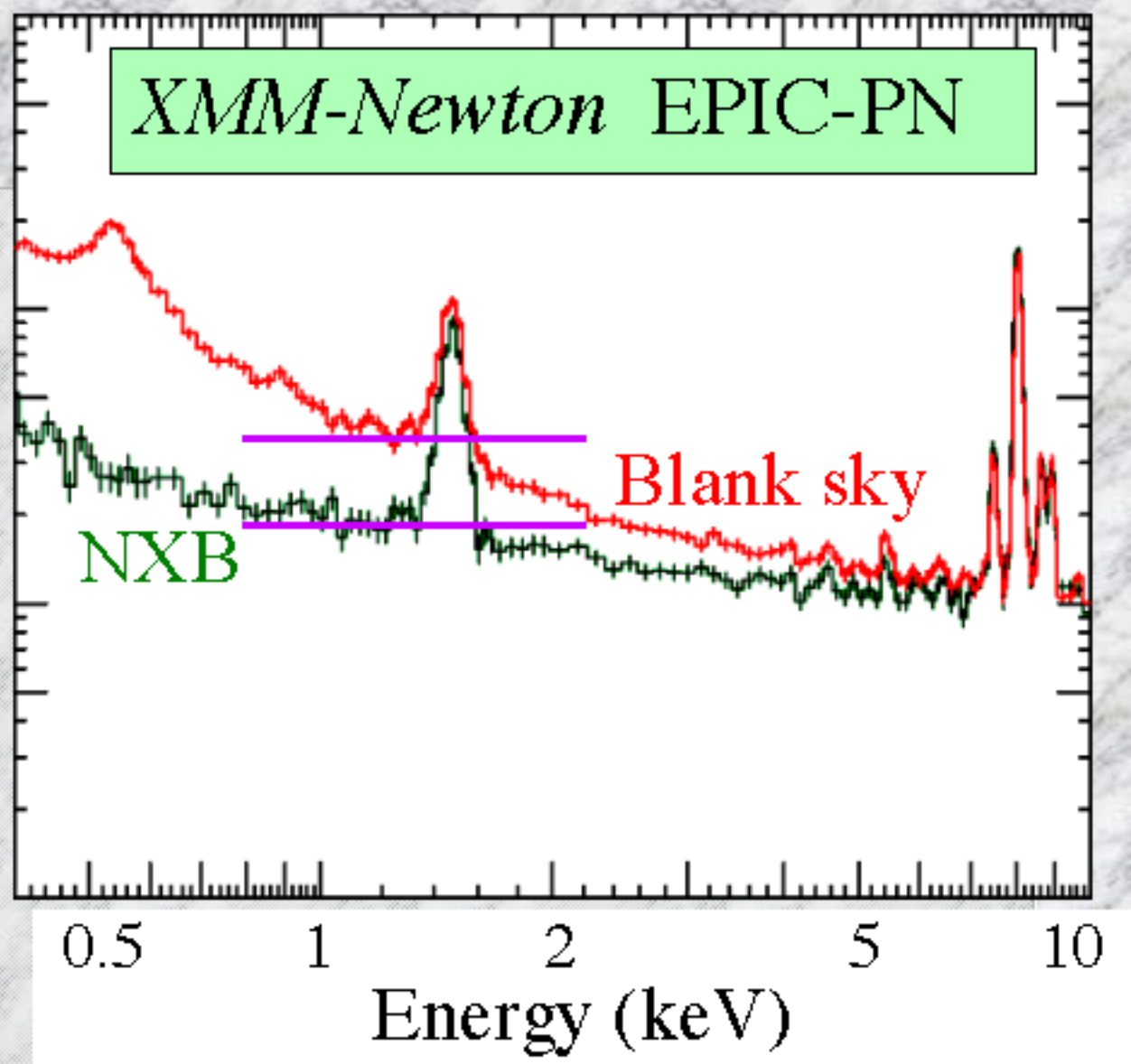
Hard X-ray excess from HCG62; Fukazawa *et al.* (2001). Possibly related to the CF suppression; Makishima *et al.* (2001)



The first IC X-rays detected from lobes of Fornax A; Kaneda *et al.* (1995) , Tashiro *et al.* (2001)

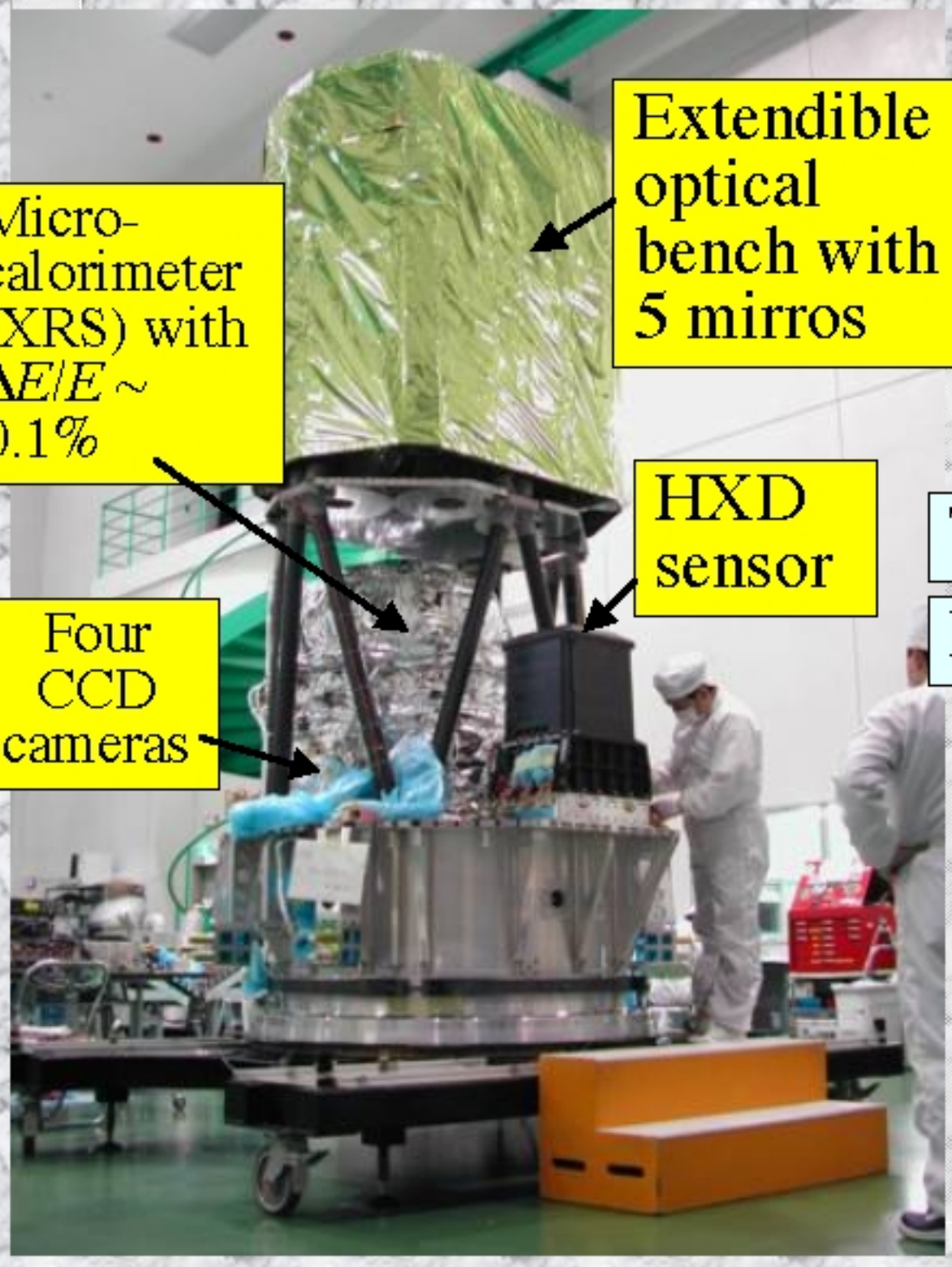
2c. The GIS onboard *ASCA*





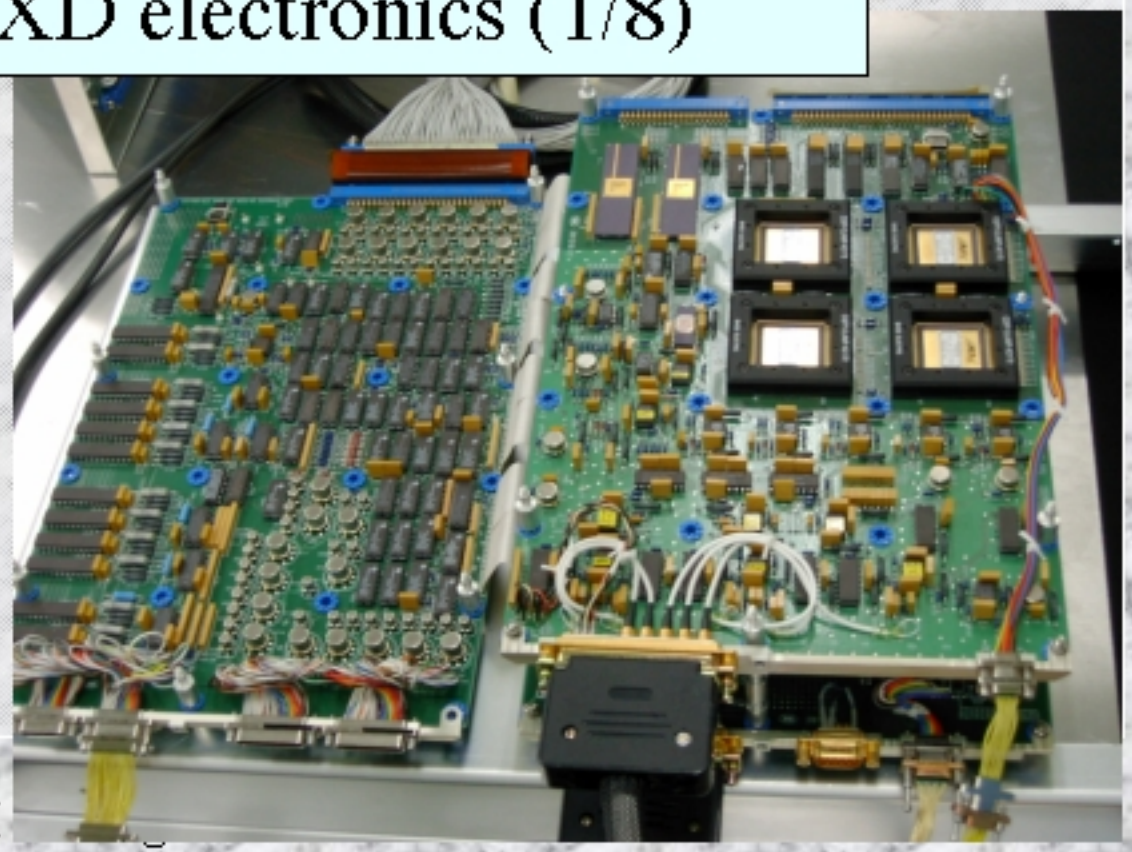
Our knowledge on diffuse hard X-ray sources is not much improved beyond what we discovered with the *ASCA* GIS.

2*d*. The HXD onboard *Astro-E2*



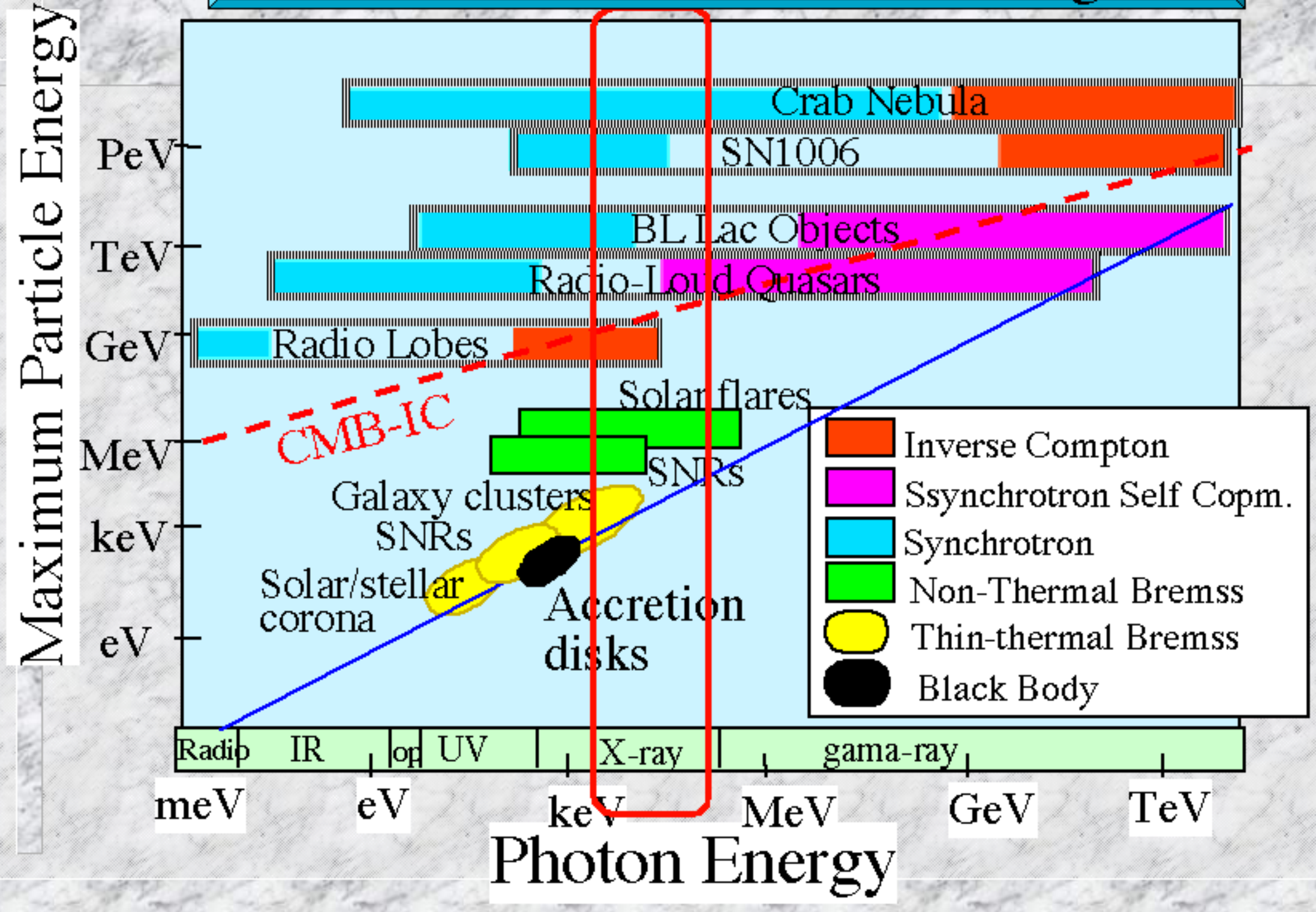
The HXD team photo (June 2004)

HXD electronics (1/8)

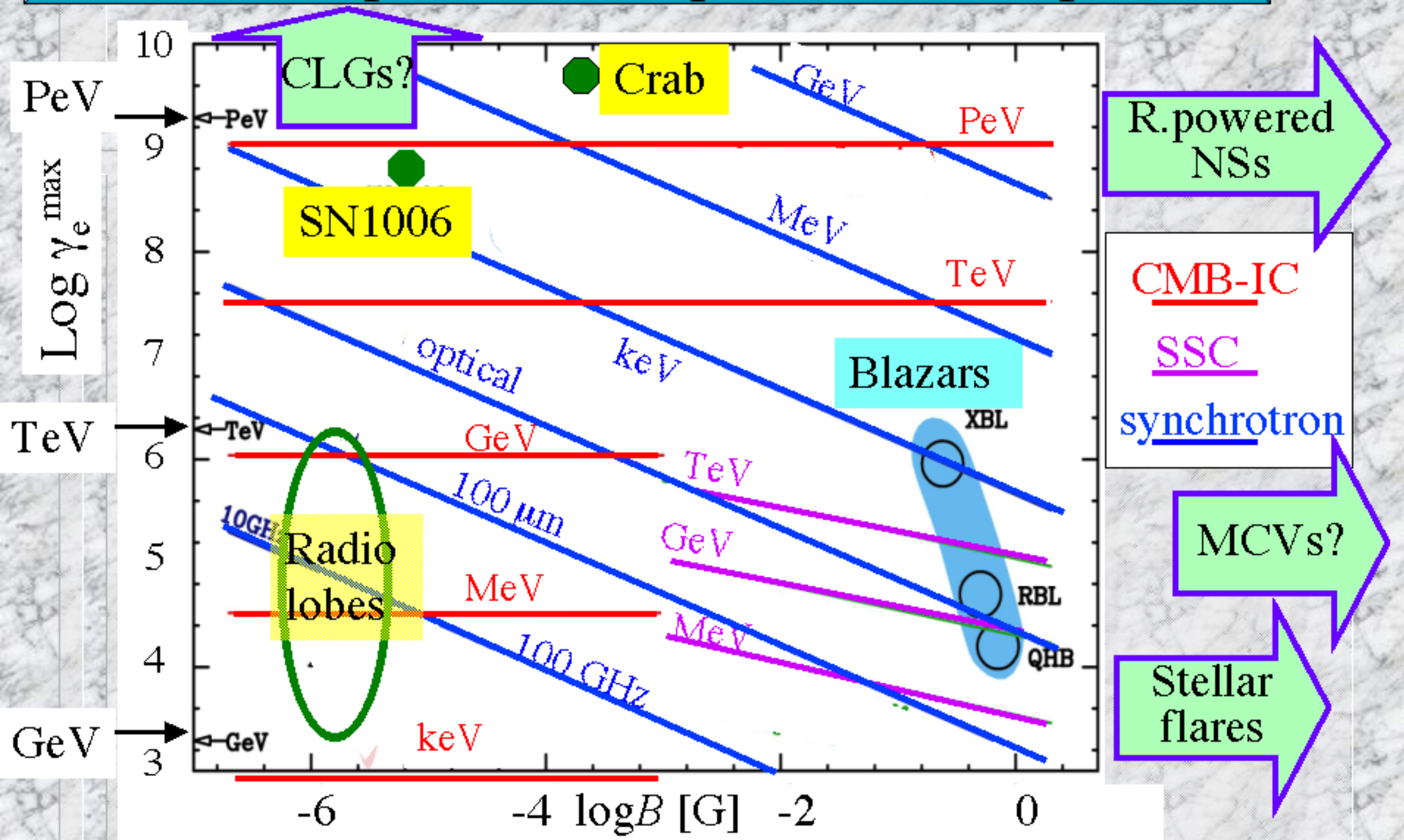


3. The Accelerating Universe

3a. Particle *vs*. radiation energies

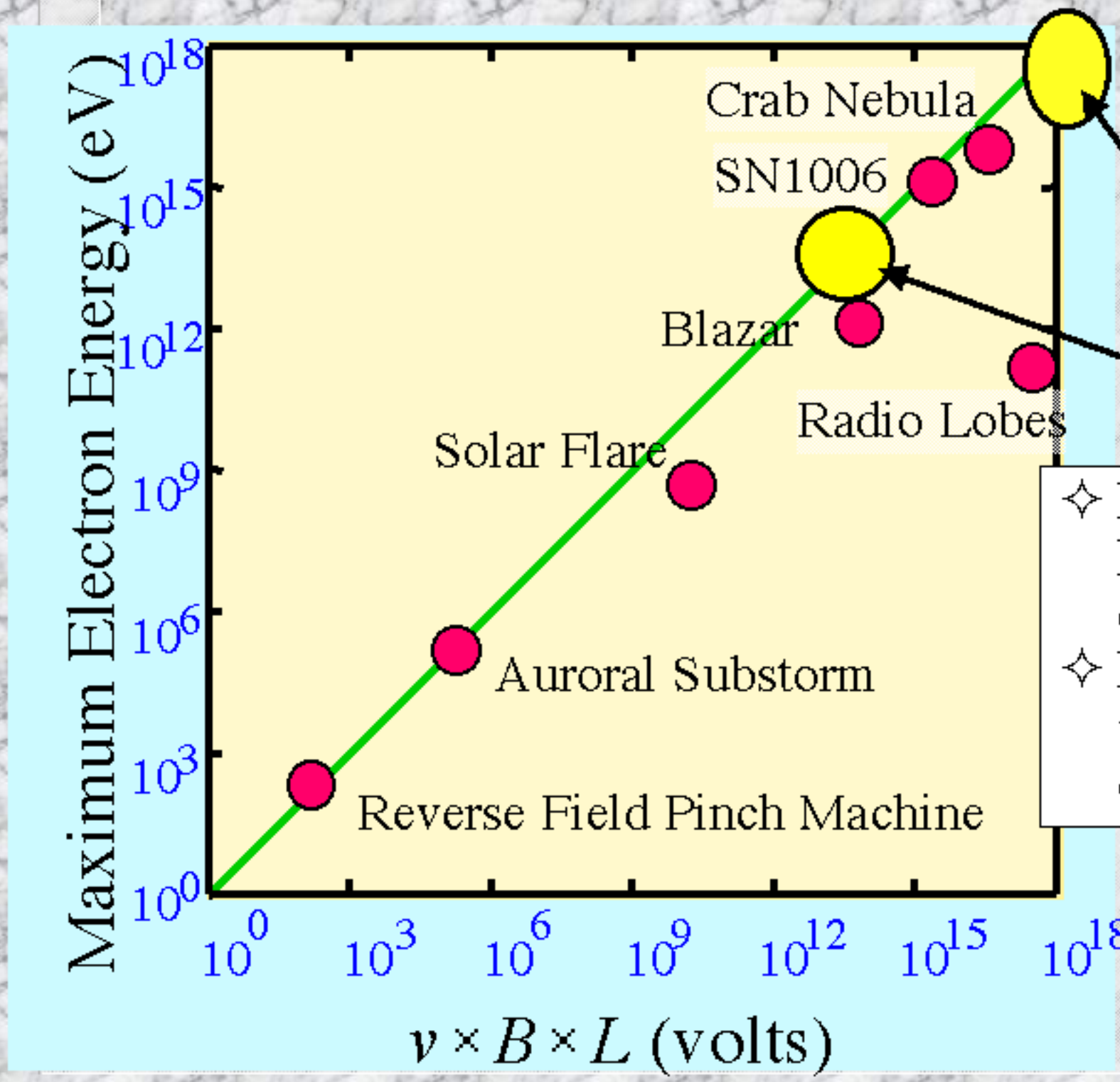


3b. A vast parameter space to be explored



Makishima, Kamae, & Takahashi

3c. An empirical scaling law



Hillas (1984)
Makishima (1999)

Clusters of galaxies?

Magnetized WDs?

- ✧ Diffusive shock process: a large B xL means a good confinement
- ✧ Direct electric acceleration: vBL is simply the inductive electric field,

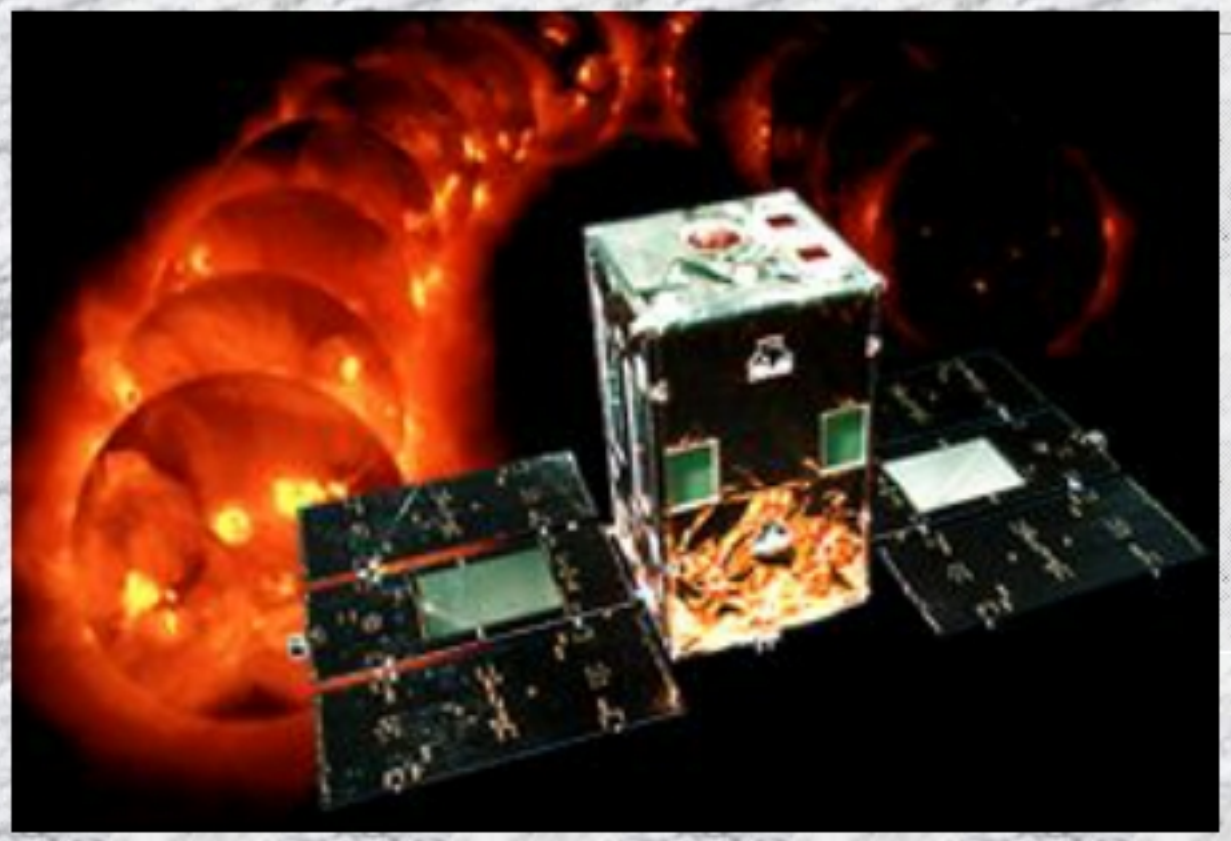
3d. A working hypothesis

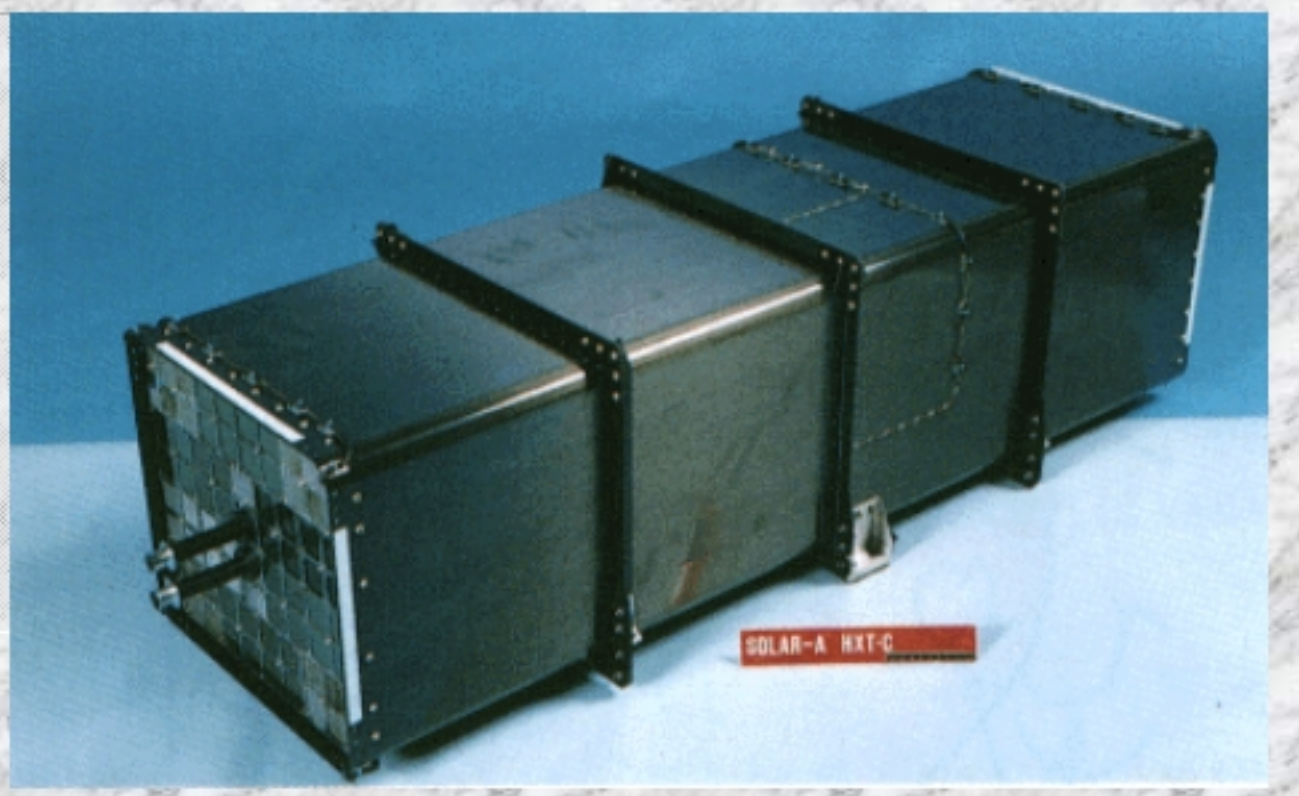
- Diffusive shock acceleration -- shell-like SNRs, blazars, jet-terminal lobes, GRB afterglows, starburst winds…
- Direct electromagnetic acceleration -- rotation-powered pulsars, solar/stellar flares, interplanetary phenomena, Crab-like SNRs, jet initiation, …
- Quasi-steady acceleration by celestial bodies moving in hot plasmas -- e.g. galaxies in a cluster or group; stars in a galaxy (Galactic ridge/bulge),..

  The motion of the bodies is hydrodynamically trans-sonic (or subsonic), but super-Alfvenic in MHD sense leading to a significant EM dissipation.

4. Hard X-ray Imaging of Solar Flares

4a. The *Yohkoh* observatory (1991~2001)





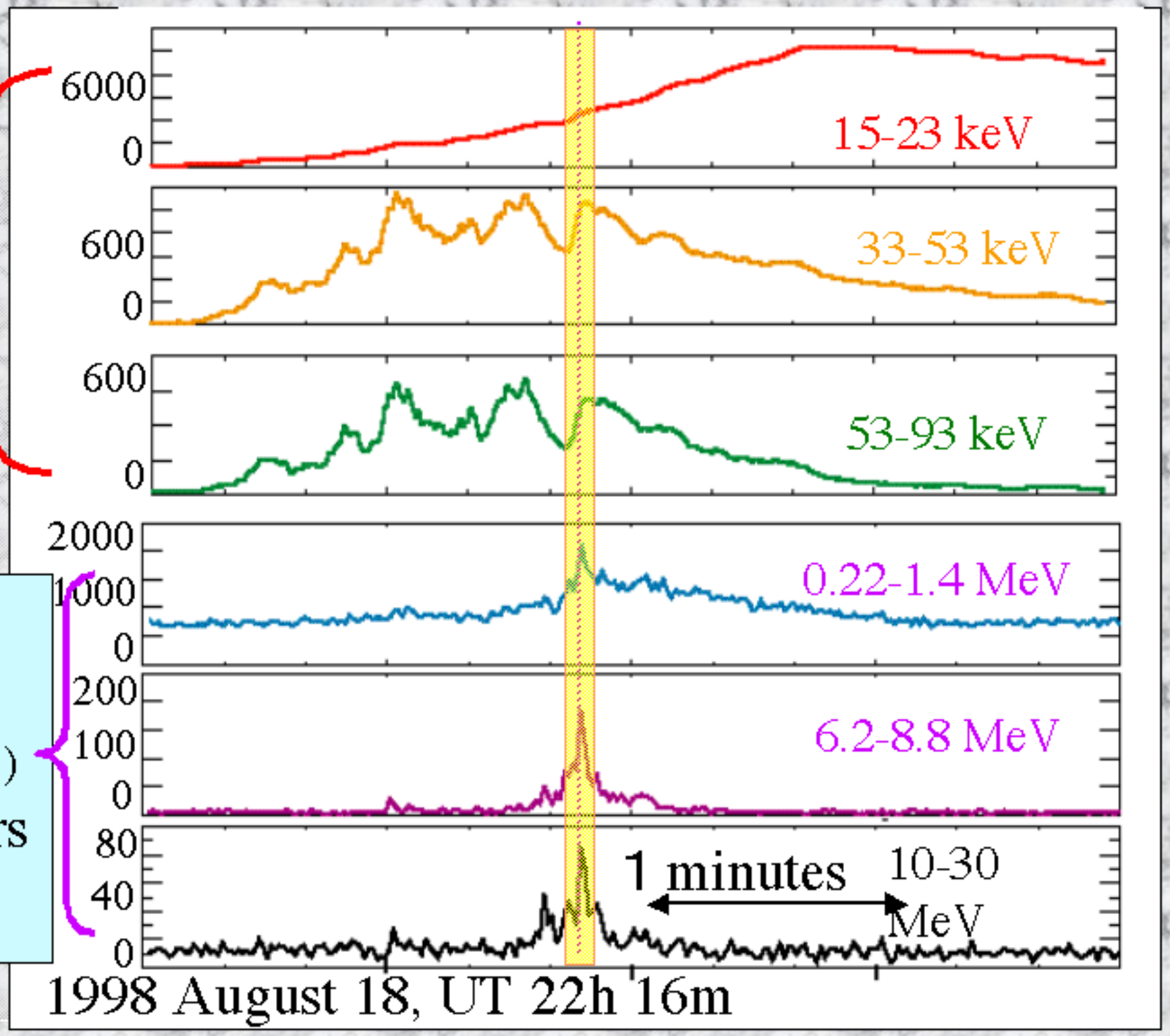
The Hard X-ray Telescope (Kosugi *et al.* 1991), using modulation collimators in Fourier-synthesis mode (Makishima+Oda 1978)

- 15-95 keV ; $\Delta\theta$=5" ; Δt=0.5 sec
- Observed more than 2700 flares over the whole mission life.

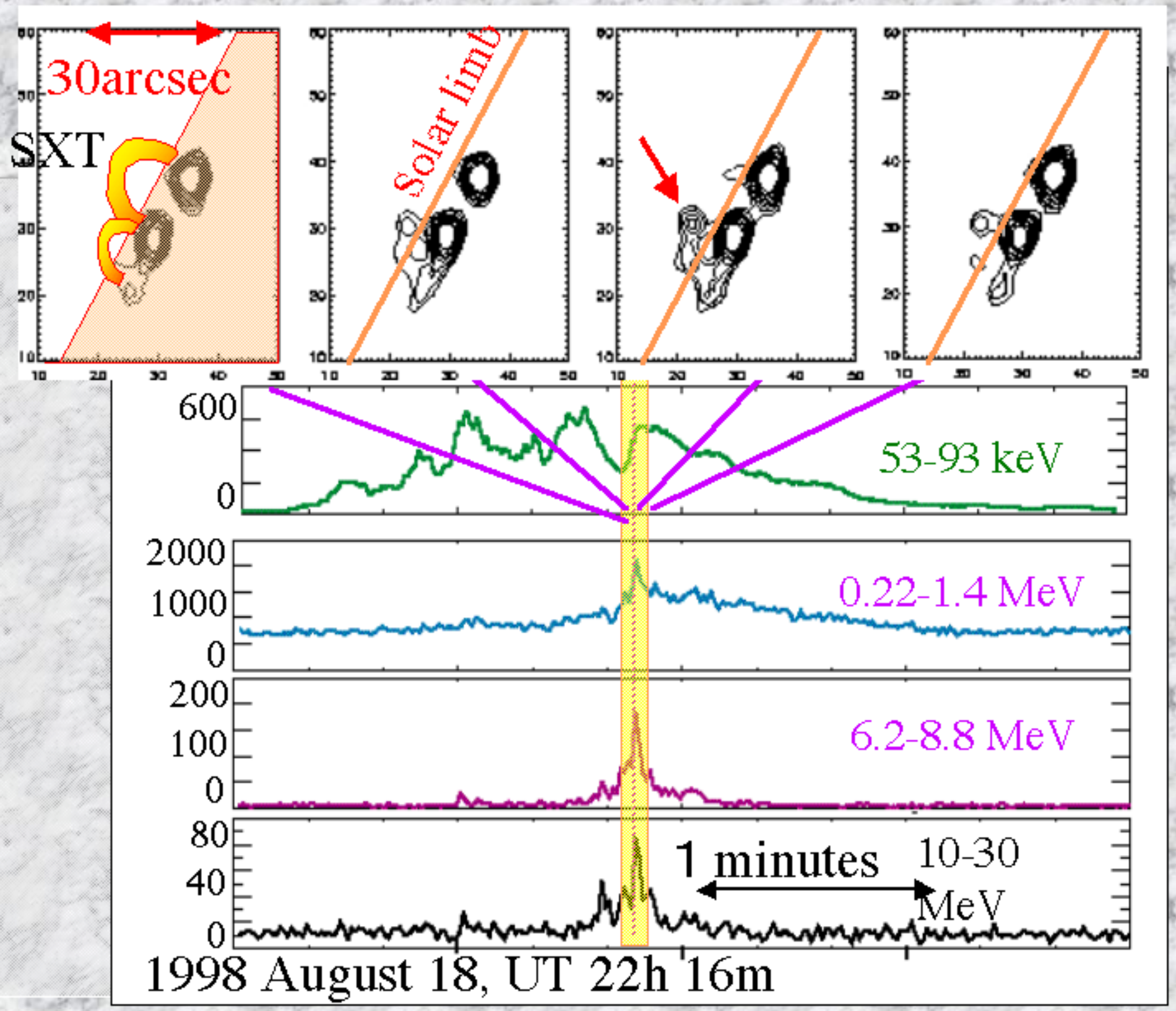
4b. The largest gamma-ray flare with *Yohkoh*

3 of the 4 channels of the HXT

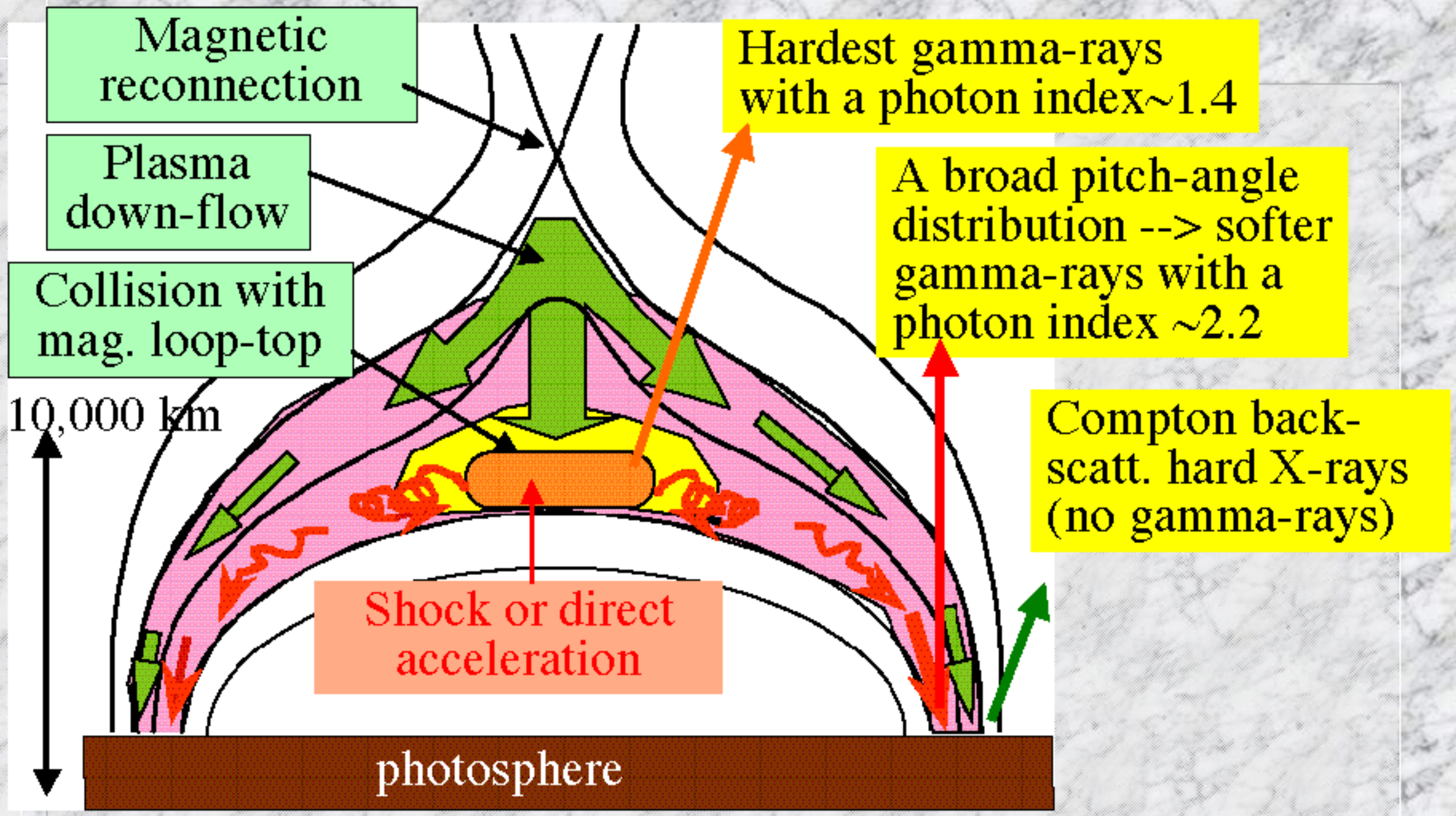
Gamma-ray Spectrometer
(Yoshimori *et al.* 1991)
- BGO scintillators
- 0.2 -100 MeV



The HXT-H band images (every 1 sec)



4c. A proposed scenario for the particle acceleration in solar flares



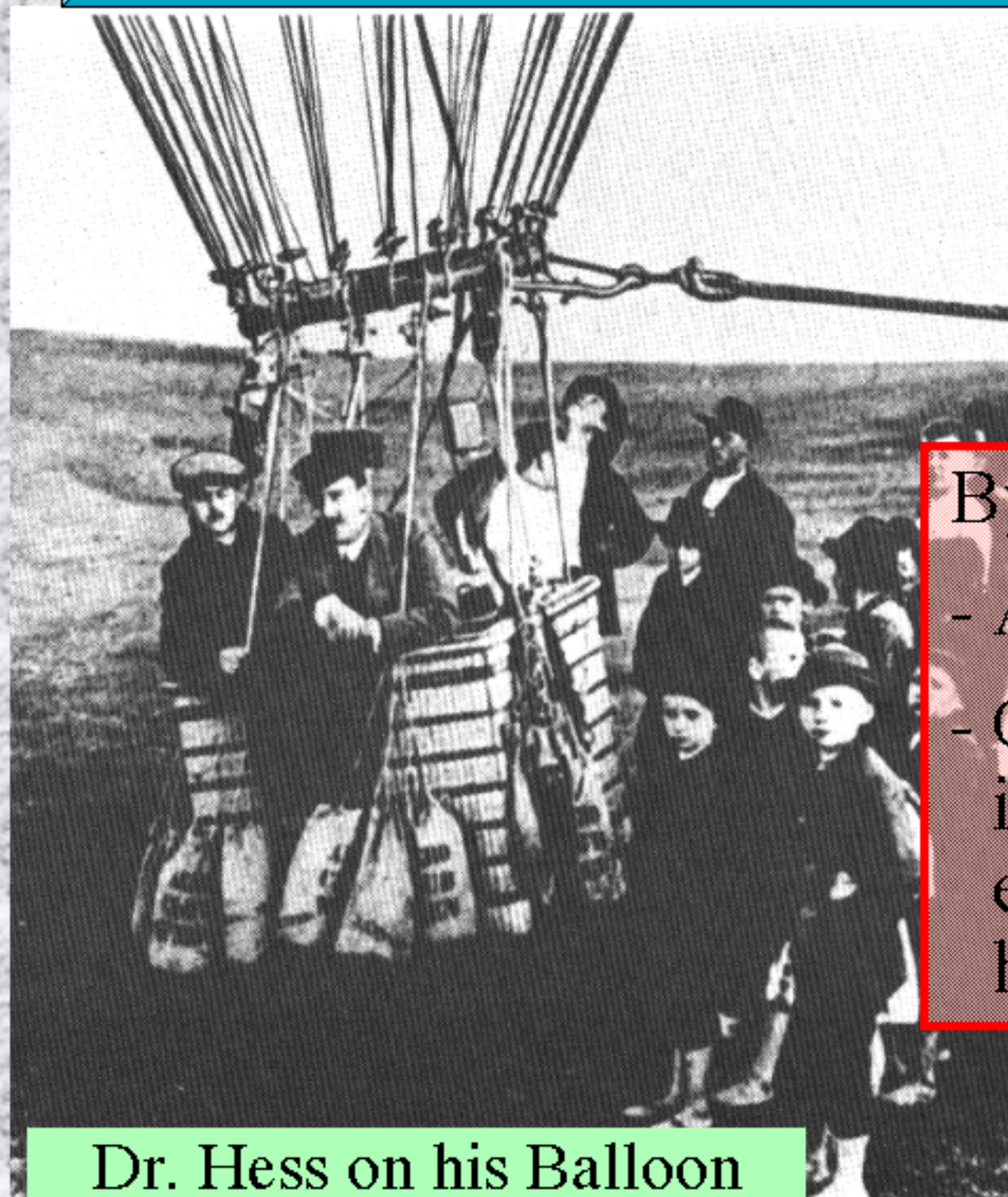
Matsumoto, Y., PhD Thesis (2003); Kotoku, J., PhD Thesis (2004); Matsumoto et al. PASJ (2005)

5. Scientific Goals in a Wider Scope

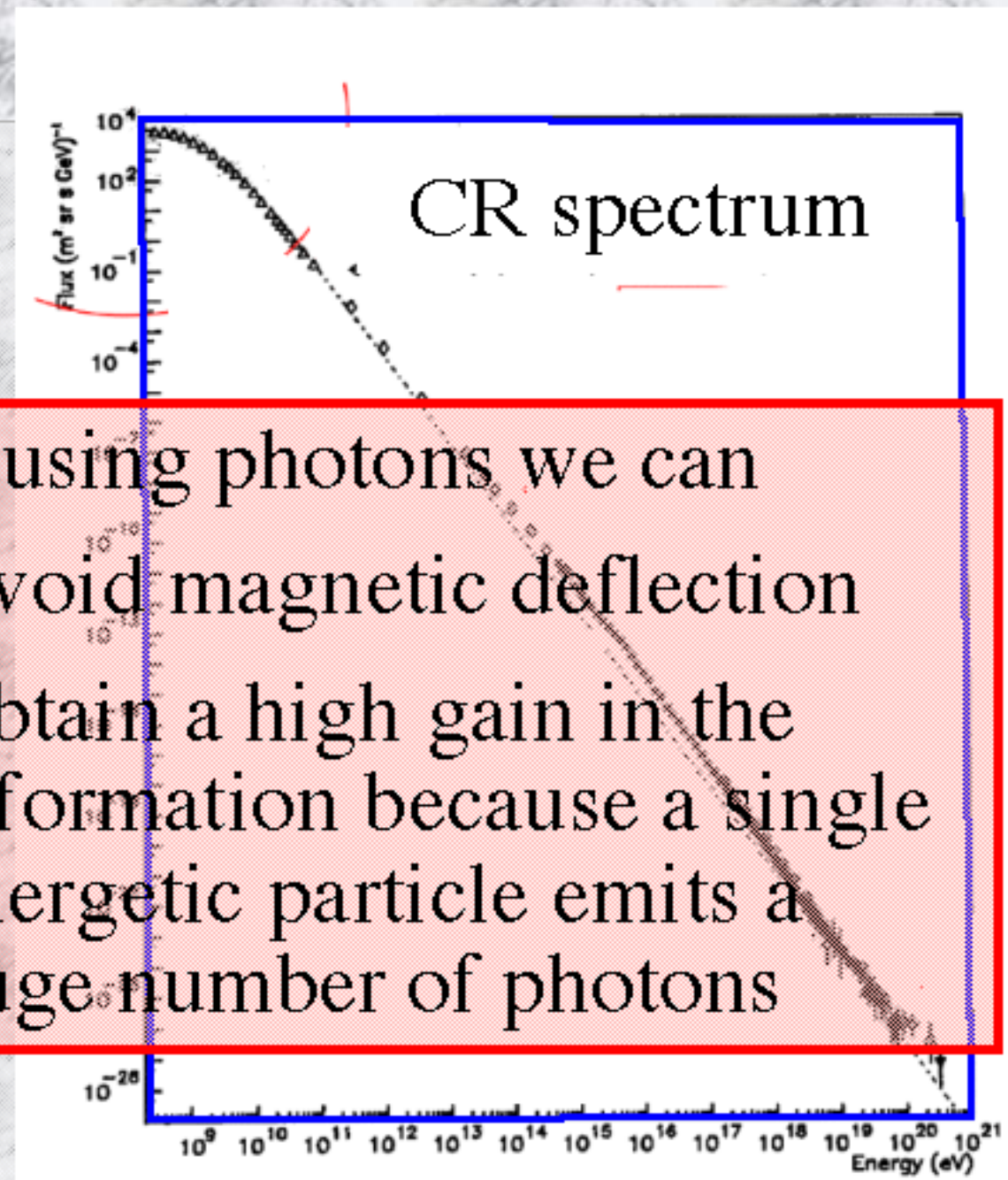
5a. The physics of particle acceleration

- What is the energy source and what is the overall energy budget? What determines heating/acceleration ratio?
- How? Diffusive shock; Direct-electric? Quasi-static?
- Thermal --> supra-thermal --> non-thermal (e.g., Galactic ridge XR, globular clusters, ..)
- Primary (bulk) acceleration and 2ndary acceleration.
- Is the particle vs. field equipartition realized or not?
- Are positive charges p^+ or e^+ ? Are e^-'s and p^+'s accelerated to same energies, or same γ, or?
- What fraction of the cosmic energy density is carried by relativistic particles? How about in the inter-galactic space?

5b. The century-long mystery of cosmic rays



Dr. Hess on his Balloon Gondola (1912)



By using photons we can

- Avoid magnetic deflection
- Obtain a high gain in the information because a single energetic particle emits a huge number of photons

5c. The physics of energy non-equipartition

- ✧Particle acceleration exemplifies "evolution away from equilibrium" and "energy non-equipartition", often seen in astrophysics. Other examples include stars and the universe itself.
- ✧Not known in other physical systems, but seen ubiquitously among biological systems.
- ✧To characterize the role of long-range interactions (gravitational and EM)
- ✧To clarify the significance of the proton-electron mass difference (broken symmetry)
- ✧To search for equation of motion which governs these evolving systems.

The hard X-ray universe is full of novel surprises that cannot be accessed via other means. An extension of the *XEUS/Con-X* energy band into higher energies would be highly desired.