Iron K-shell line: a probe of low energy cosmic rays in SNRs Katsuji Koyama (Kyoto University) & Tamotsu Sato (ISAS)

- Non thermal power-law X-rays from SN1006 (ASCA: Koyama+1995). TeV gamma Rays (H.E.S.S.: Acero+2010)
- → High Energy Cosmic Ray(HECR)~10¹²⁻¹³
- Narrow filaments are expanding with a speed of ~4000 km/s (Katsuda+2009)







SNR Shell is a High Energy Particle (HECR) Accelerator. Q: Where is an injector (Low Energy Particle: LECRs) ? So far, no hint of LECRs has been found from SNRs. I report the first hint of LECRs in SNRs, which is Fe I-Ka line at 6.4 keV.

Fe K-shell line from the thermal hot plasma (HP) of SNRs: Energy vs Flux (Yamaguchi+2014).
Red :la SNR, Black:CC-SNR.
No 6.4 keV (FeI-Ka) line was found in the HP of CC-SNRs.

But, we discovered 6.4 keV line from CC-SNRs in the Scutum Arm.



(1) CC-SNR, Kes79

Left: Soft X-ray map. Out side of the dotted region is the background , inside is the source region.

- Right: Source spectrum (blue), and the background spectrum
- (red). Solid lines are the best-fit models

(bremsstrahlung plus Gaussian lines)

The Kes 79 spectrum shows clear 6.4 keV lines.



The X-ray image of Kes 79 in the 6.2–6.5 keV band (6.4 keV line)

- + CCO is central compact object (\rightarrow CC SNR) Cyan circle is radio shell Magenta contours are the ¹³CO (J=1 \rightarrow 0) line emission.
- Correlation of the 6.4-keV line to a molecular cloud (MC) → 6.4 keV line comes from MC (not from HP)



(2) Another CC SNR, W44

- Left: The 6.2–6.5 keV band (6.4 keV line) image.
- Green lines : the source regions.
- Right: The 2-10 GeV band image (Fermi LAT) overlaid on the Radio contour (Green).
- Good correlation of the 6.4 keV line to the GeV Emission



(3) The other is Kes78
Down: The 6.2–6.5 keV band image . Cyan contours are the 1.4 GHz emission.
Right : The X-ray spectra of Source Region



6.4 keV (Fel-Ka) line



Clear Excess of the 6.4 keV line

The observed spectra of CC-SNRs in the 6.4 keV line band are too poor to judge the origin of the 6.4 keV line, LECR proton or electron (LECRp or LECRe) ?

A hint is obtained from the Galactic ridge emission=Origin is mainly point sources (Cataclysmic Variables).

The 6.4 keV excesses are found at I~2-4 deg and I~-20 deg.



Left: X-ray spectra extracted from the east (red) and west (black) sides.

Right: X-ray spectrum of the excess emission in the east. The red line is the best-fit power law plus a Gaussian line (6.4keV) model .



EW of the 6.4 keV line as a function of particle or photon index.

- The thin red, blue and green belts are simulated EWs by protons, electrons and X-rays.
- The best-fit regions are shown by the hatched region.



\rightarrow Then

Proton (LECRp) origin is most likely.

Since the spectrum is similar to those of CC-SNRs, LECRp is more likely.

- In Kes 79, the observed 6.4 keV flux is 3.0×10^{-6} cm⁻² s⁻¹ and N_H of the MC is ~ 10^{22} cm⁻².
- Then the proton energy density is estimated to be
- ~ $10^2 \, eV$ /cc , ~100 times larger than in the ISM of ~1 eV/cc .

The other CC SNRs are more or less similar to Kes 79.

Conclusion

We have found 6.4 keV lines from 3 CC-SNRs in the Scutum arm, and proposed that the 6.4 keV line is a good (unique) tool to search for the LECRs.

Thank you for your attention !