First X-ray Detection from a Bow Shock Region of a Runaway Star, BD+43 3654, with Suzaku

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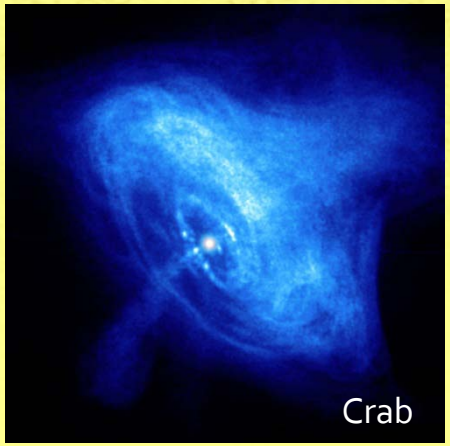
Non thermal Universe in our Galaxy

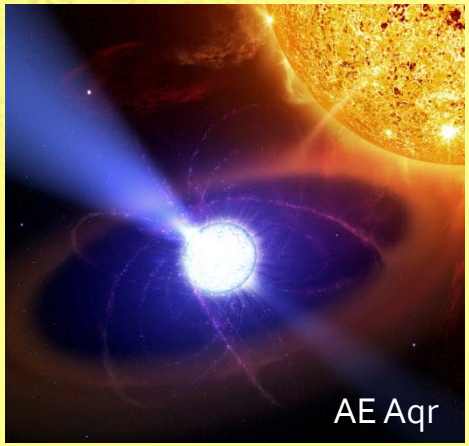
Many astrophysical objects show non-thermal phenomena.

Neutron Stars



- Rotating magnet
- Pulsar Wind nebula
- Pulsar in GeV & PWN in TeV

White Dwarfs?

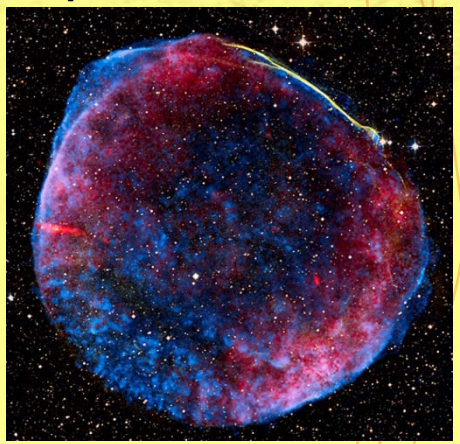


- Rotating magnet
- Hints by Suzaku (Terada + 07, 10)

Globular Cluster?

- Diffuse X-ray towards runaway direction (Okada+07, Yuasa+09)
- TeV detection with H.E.S.S. (Abramsowski+ 11)

Supernova Remnants



- Shock acceleration X-ray & TeV emission
- Feedback to thermal plasma, over ionized (Yamaguchi+09, Ozawa+09)

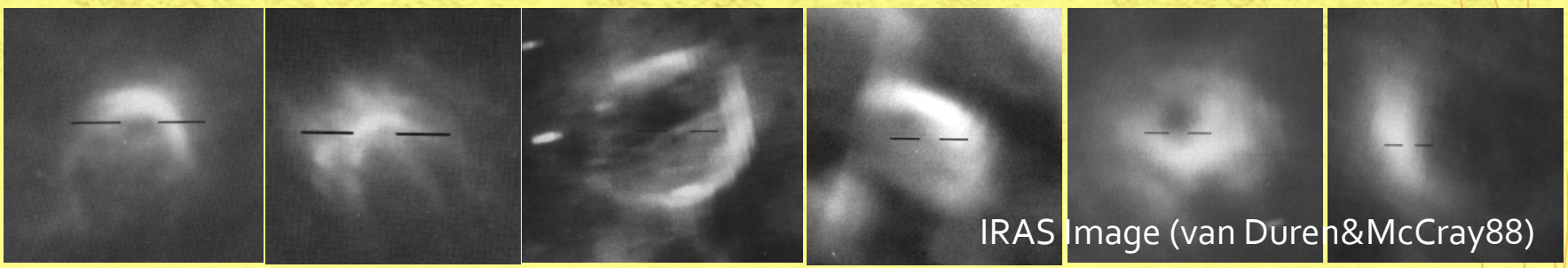
Size

Any other NEW particle acceleration site?

Runaway star from a OB association

Focus on runaway stars as another candidate of non-thermal emitter.

1) Fast runaway velocities at a few hundred km/s creating Bow shock structures

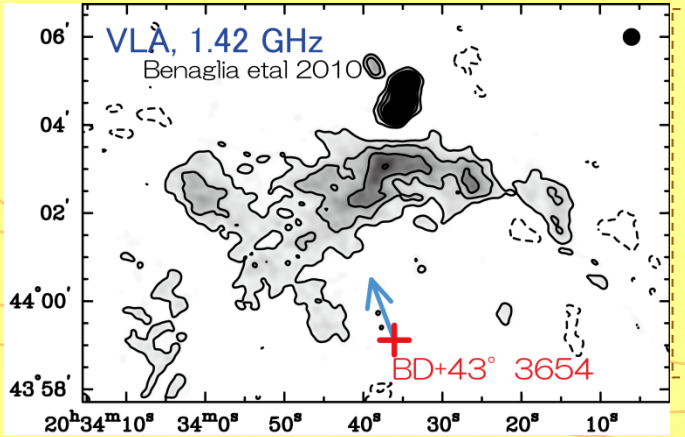


2) Very fast stellar wind at a few thousand km/s (Narjiva+04)

Comparable in magnitude to that of SNR!

Bow shock stands where the ram pressure of ISM equals to that of stellar wind.

3) Synchrotron radio emission has been discovered at the bow shock region (Benaglia+10)



- **First discovery** of Synchrotron emission
  - ✓VLA, 1.42 GHz & 4.86 GHz
- Runaway member, BD+43° 3654
  - ✓ Cygnus OB2 association (most massive one.)
  - ✓ d = 1.4 kpc, 70M_{sun}, 1.6M years, type O4 If
  - ✓ runaway at 400 km/s, stellar wind at 2300 km/s

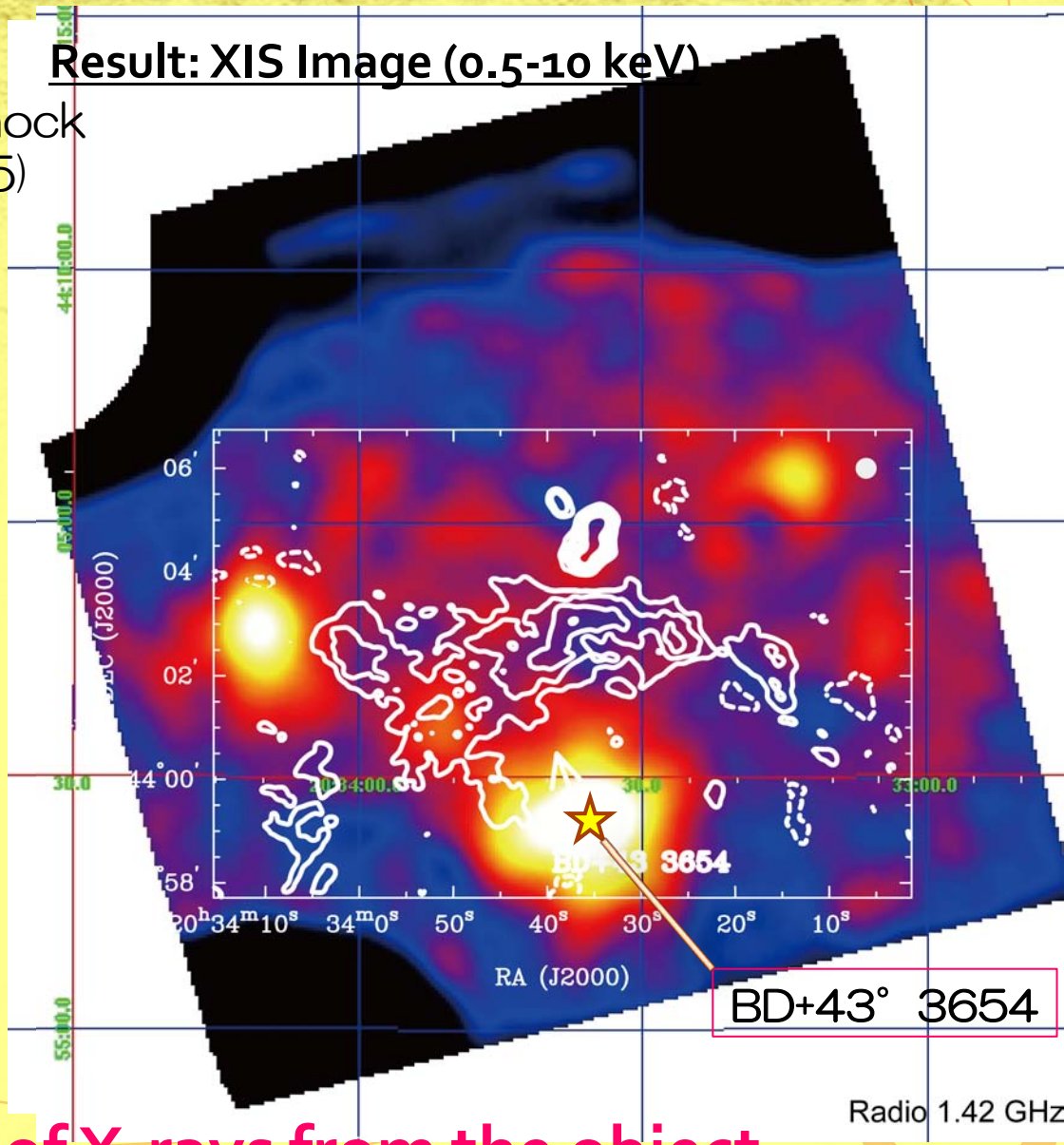
New candidate!

Suzaku observation of BD+41 3654

Suzaku Observation

Object: BD+43° 3654 Bow shock
(RA,DEC)= (308.41667, 44.05)
(*l*, *b*) = (82.469, 2.35)
Position: XIS nominal
Date: 4 - 6 April, 2011
Exposure: 100 ksec
XIS: no window, no burst
HXD: nominal operation

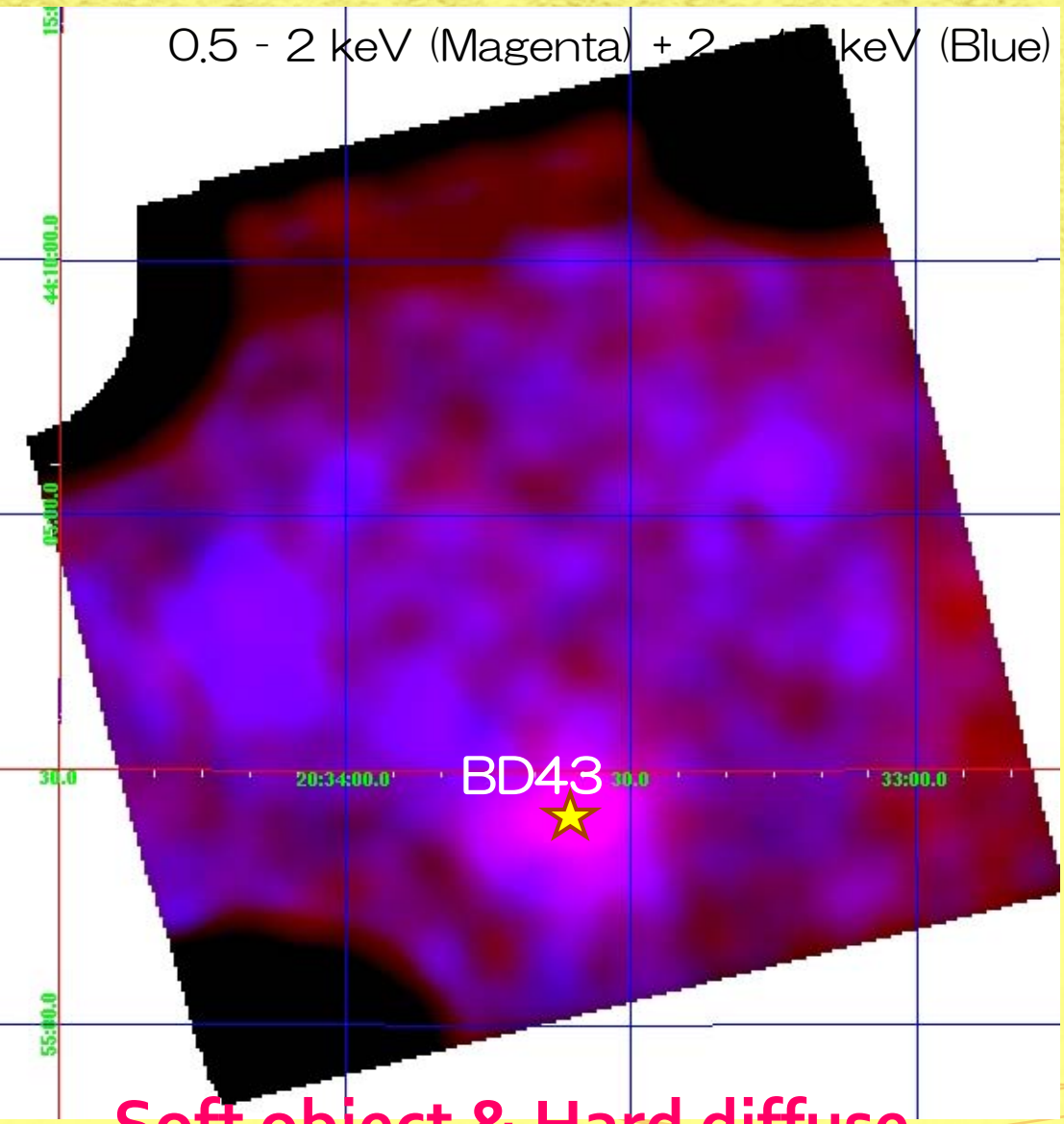
Result: XIS Image (0.5-10 keV)



Clear detection of X-rays from the object.

Diffuse X-ray emission?

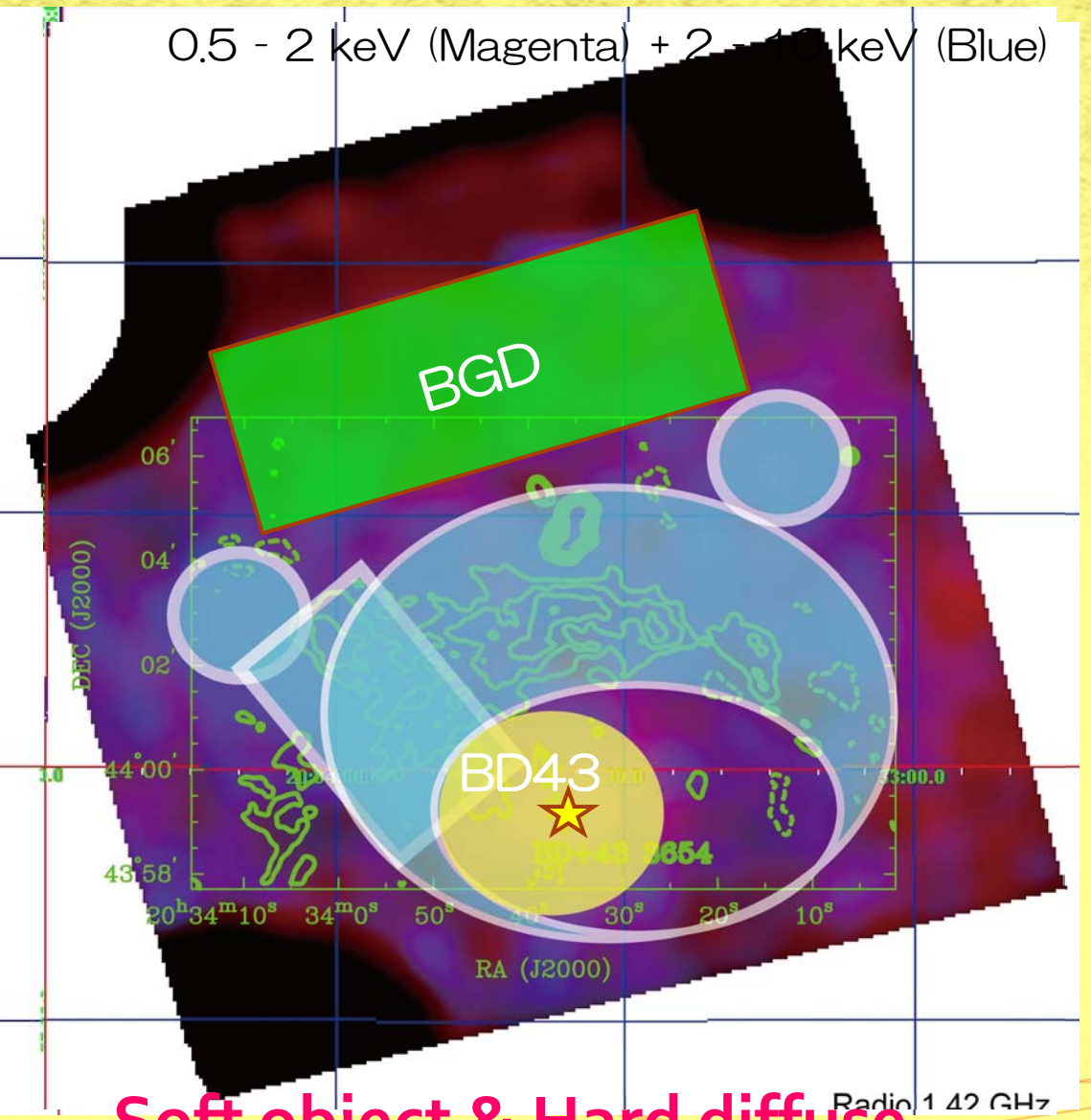
Energy Resolved Image (vignetting corrected)



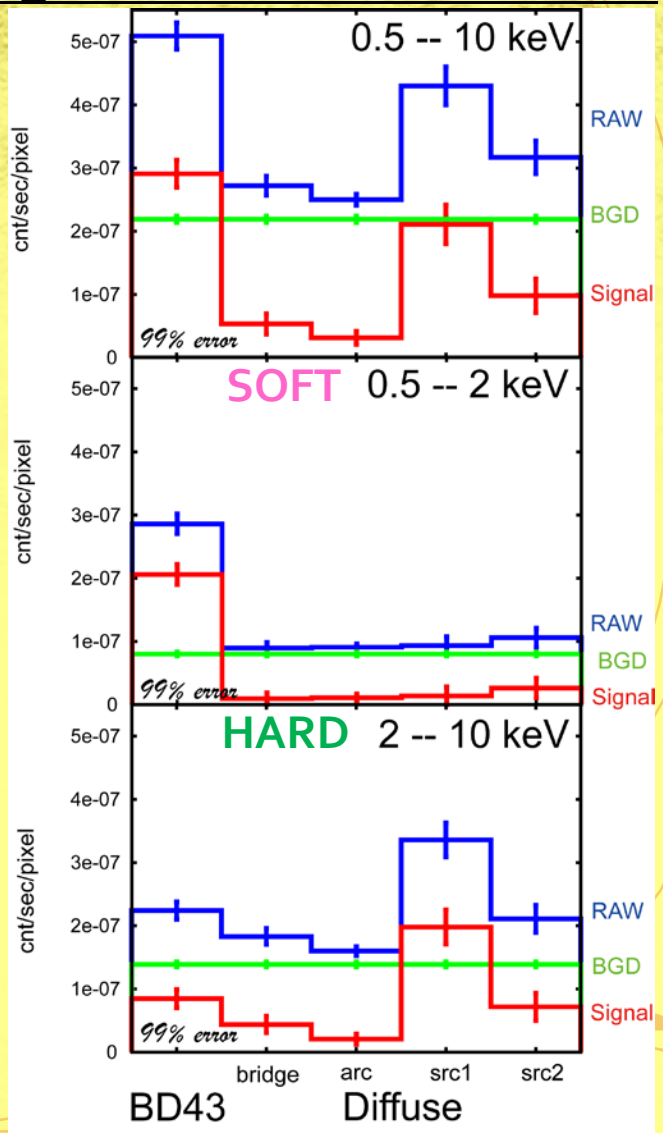
Soft object & Hard diffuse

Diffuse X-ray emission?

Energy Resolved Image (vignetting corrected)



Signal vs BGD in count rate

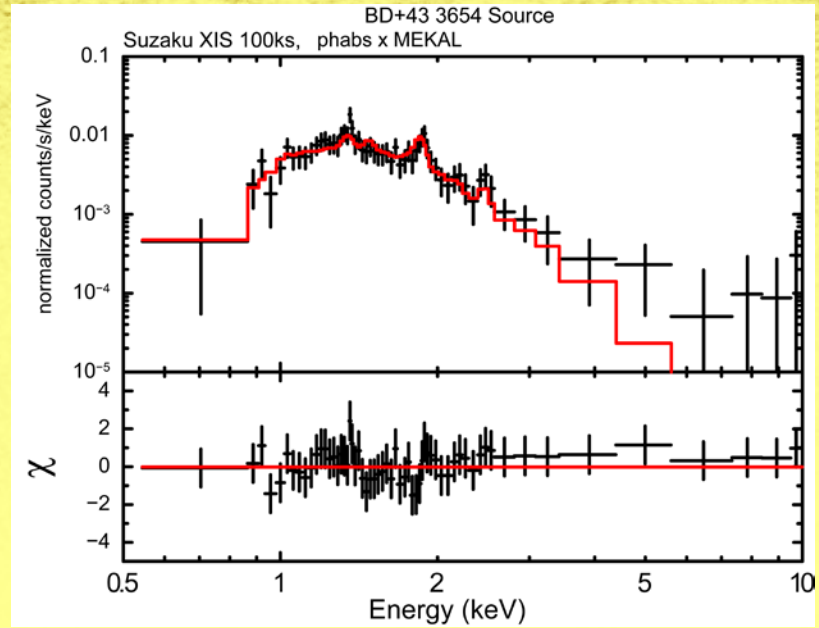


Soft object & Hard diffuse

Diffuse emission exists.

X-ray spectra with Suzaku

BD+43° 3654



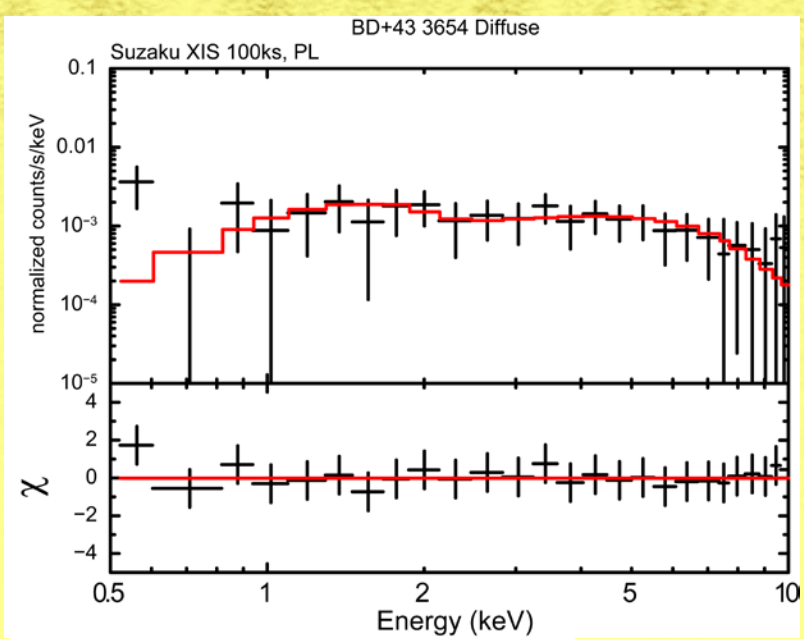
Single MEKAL

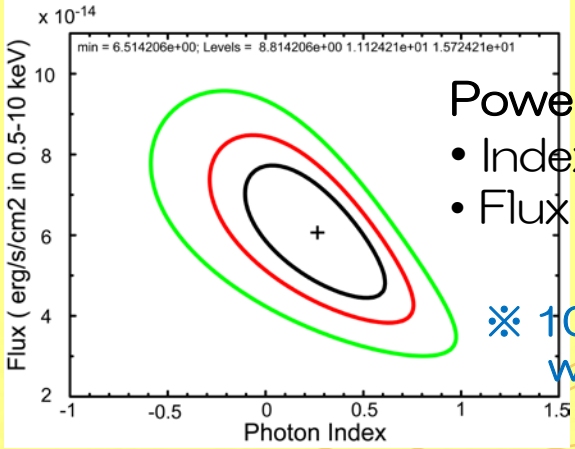
- n_H = 1.42±0.15 x 10^{22} cm^2
- kT = 0.62-0.06+0.09 keV
- Ab = 0.28 -0.12+0.28 solar
- Flux = 1.4 ±0.4 x 10^{31} erg/s @1.4kpc
- EM = 2.3 x 10^{55} cm^{-3}

※ 10^{53-55} cm^{-3} in Polar case

Bright Hot Plasma !

Diffuse Emission





Power Law

- Index = 0.27 -0.41 +0.37
- Flux = 1.4 ±0.9 x 10^{31} erg/s @1.4kpc

※ 10^{34} erg/s in SNR case where 10^{51} erg exists

Very Hard Emission.

Emission mechanism of the diffuse X-rays

Stellar Wind

- velocity 2300 km/s $= 2.3\times10^{8}$ cm/s >> $c_s = 3.7\times10^{6}$cm/s **(Shock)**
  → Shock heating up to $kT \leqq 10$ keV **(Hot Plasma)**
- Mass loss rate = 10^{-5} M_{sun} / year $= 6\times10^{20}$ g/s
  → Stellar wind has momentum energy E_{sw} up to 2×10^{37} erg/s !!
- Dynamical time scale = τ_{dyn} = 2pc/2300km/s = 3×10^{10} s

1) Thermal Origin

- Electron density $n = 6$ cm^{-3} [Benaglia+10]
  → Cooling time scale of bremsstrahlung: $\tau_{br} = 3\times10^{14}$ s @kT=5 keV >> τ_{dyn}

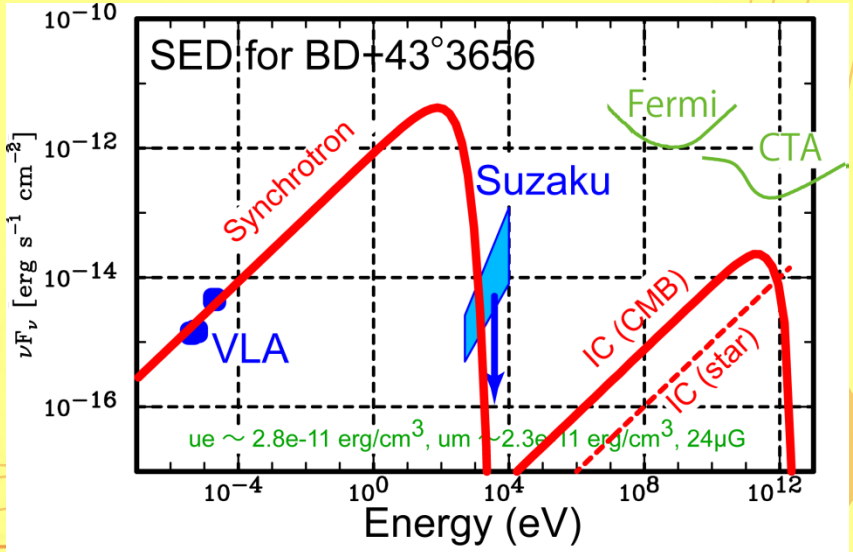
  Plasma Size ~ Bow shock size $V = 4.6$ pc^3 $= 1.4\times10^{56}$ cm^3
  →EM = $n^2V = 10^{59}\ \eta$ cm^{-3} (η is filling factor)
  →$L_{TH} = 6\times10^{34}\ \eta$ erg/s (if kT=5 keV, in 0.5–10 keV)
- Observation: $L_{OBS} = 1.4\times10^{31}$ erg/s (if all in thermal) → $\eta \leqq 0.02\%$

Law Conv. Eff. or Small filling factor

2) Non-Thermal Origin

- Assuming equi-partition between e & B.
  → electron energy $E_e \sim 1\times10^{45}$ erg,
  $B \sim$ 10–20 μG (**consistent with X-ray obs**)
- Cooling time $\tau_{syc} = 3\times10^{15}$ s >> τ_{dyn}
  → electron production rate (E_e/τ_{dyn})
  $\sim 5\times10^{35}$ erg/s (0.2 % of E_{sw})

Same Efficiency as that of SNR !



Summary

- Runaway star is one of new non-thermal cite.
- Suzaku observed a runaway star, BD+43° 3654, which has very fast stellar wind of 2300 km/s.
- Suzaku successfully detected the diffuse X-ray emission around the bow shock region.
- If the emission has non-thermal origin, acceleration efficiency of the runaway star is high as that of SNR.

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