銀河中心領域の高温プラズマの観測

高階電離鉄輝線の起源（100万年？の活動）

GC South/North プラズマ（10万年の活動）

鶴 剛 (Kyoto University)

on behalf of the Suzaku GC team.

20131114_ALMA_GC2013_v2.key

銀河中心領域の拡散Ｘ線の概観

Observation of the GC region with Suzaku

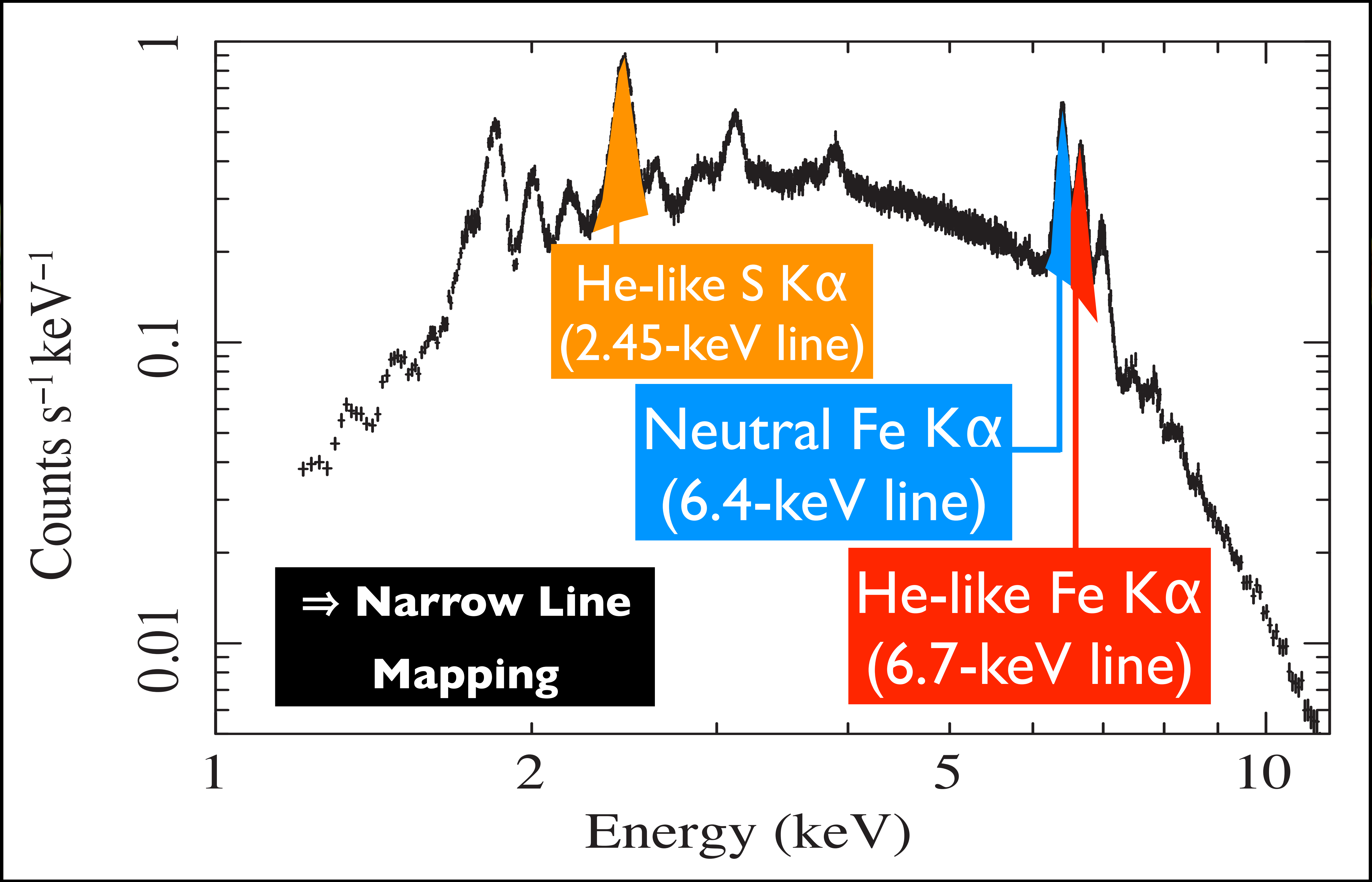
Suzaku is the best observatory to observe "diffuse" emission from the Galactic center region.

High Spectral Resolution,
Large Collecting Area,
Low and Stable Non-X-ray Background

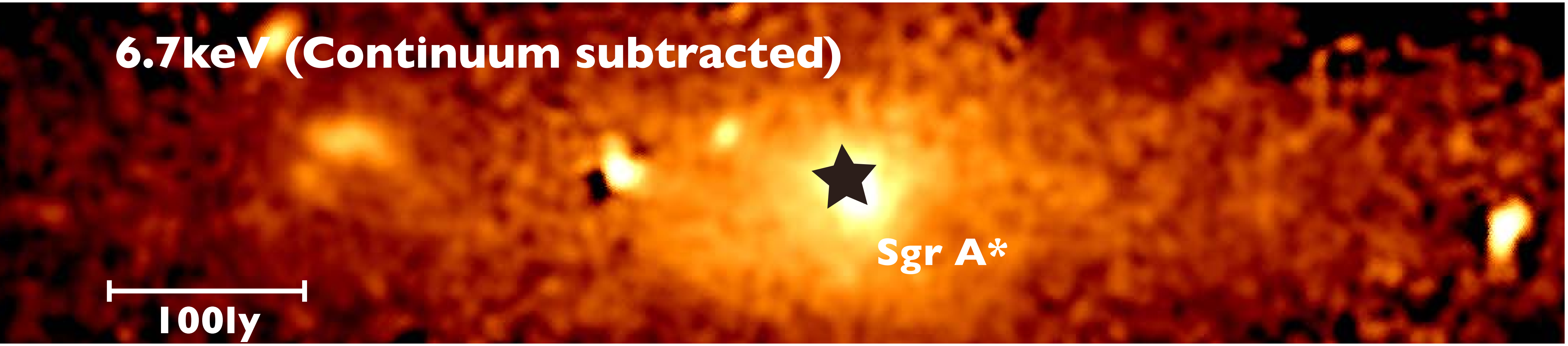
204pointings, 5.96Msec
SWG, AO, LP, KP x2 (|l|<3.5°, |b|<5°)

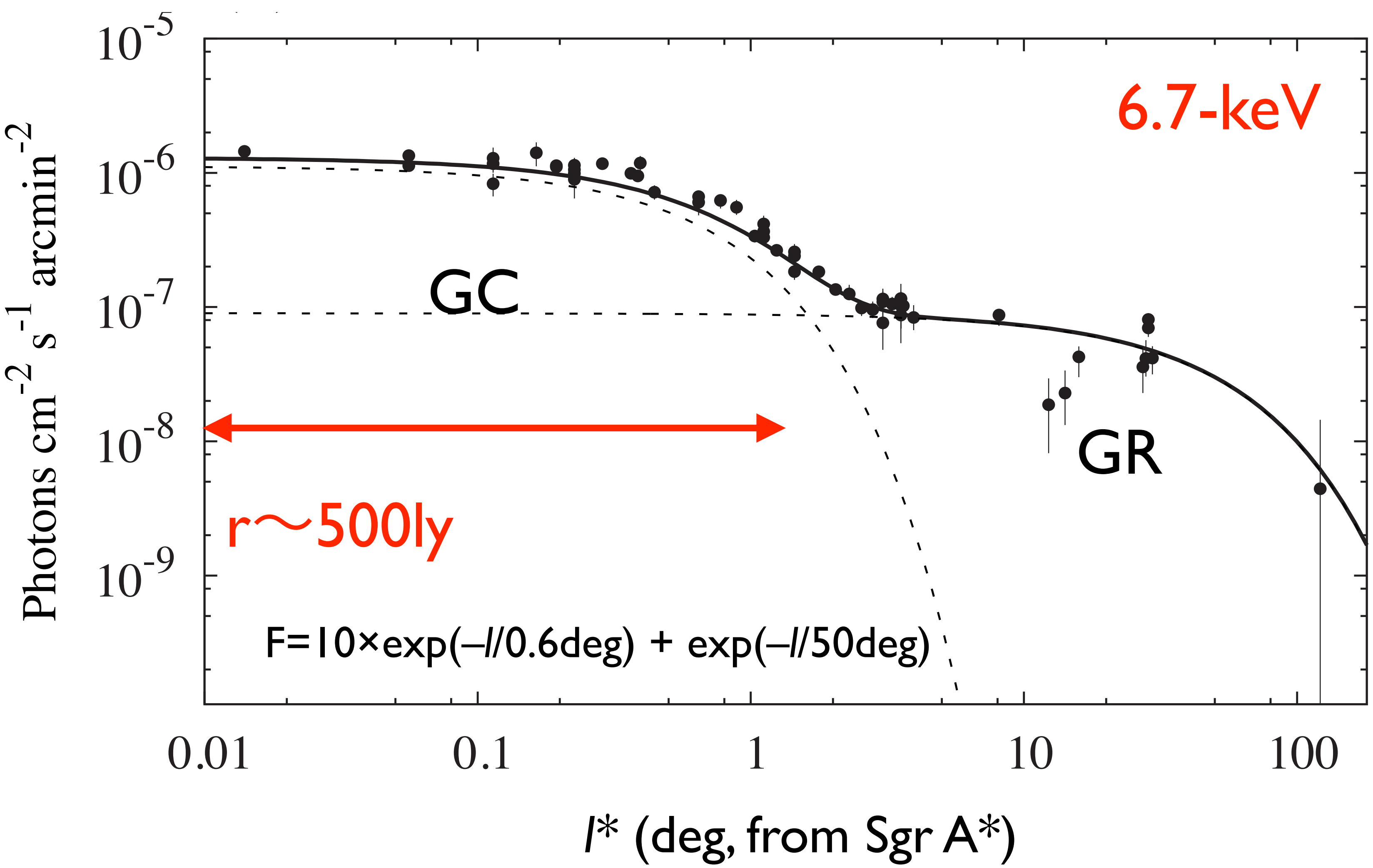
36 refereed papers,
7 Doctor Theses.

Suzaku Spectrum of the GC region



6.7-keV Line Image (He-like Fe Kα)

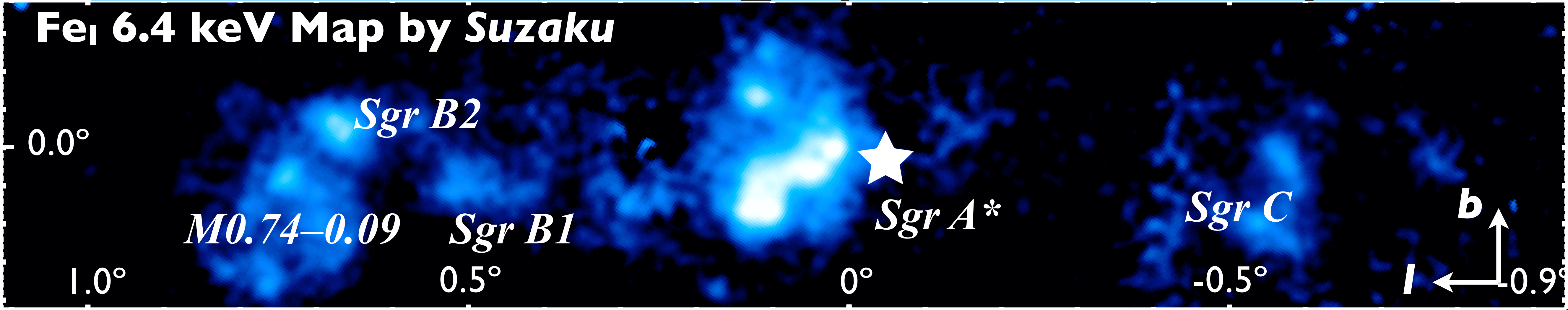


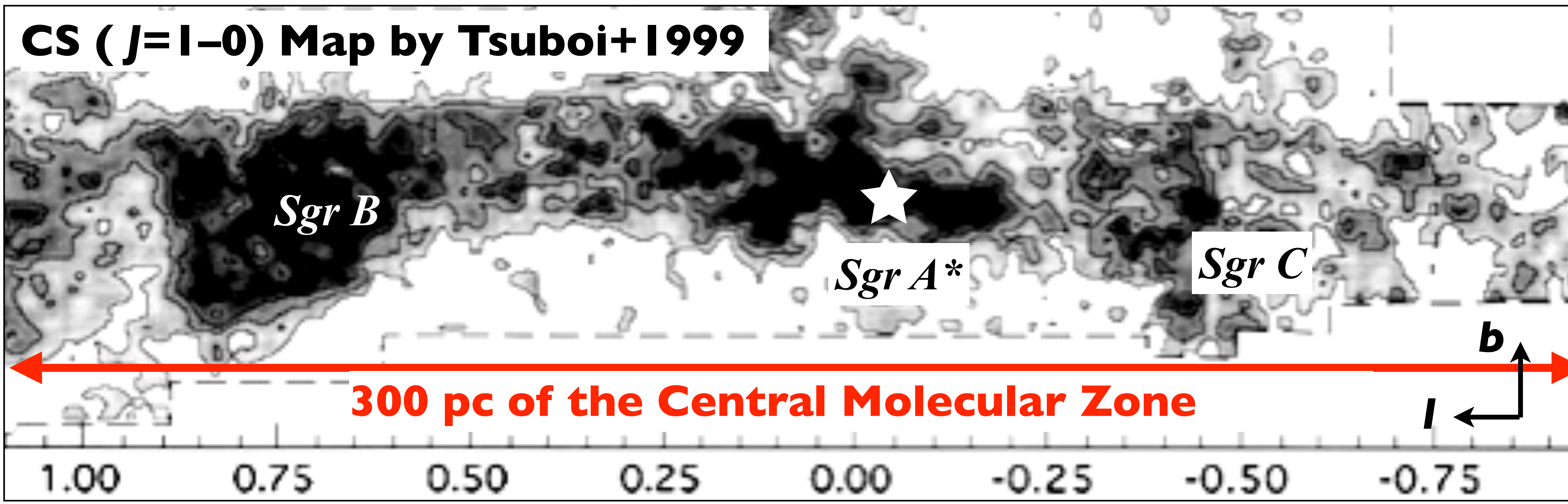


Uchiyama+11, +12

- Thermal Plasmas smoothly distribute in the GC region.
- The origin is still under debate.
  - Truly diffuse plasma filling in the GC region.
  - Or, collection of faint unresolved point sources.

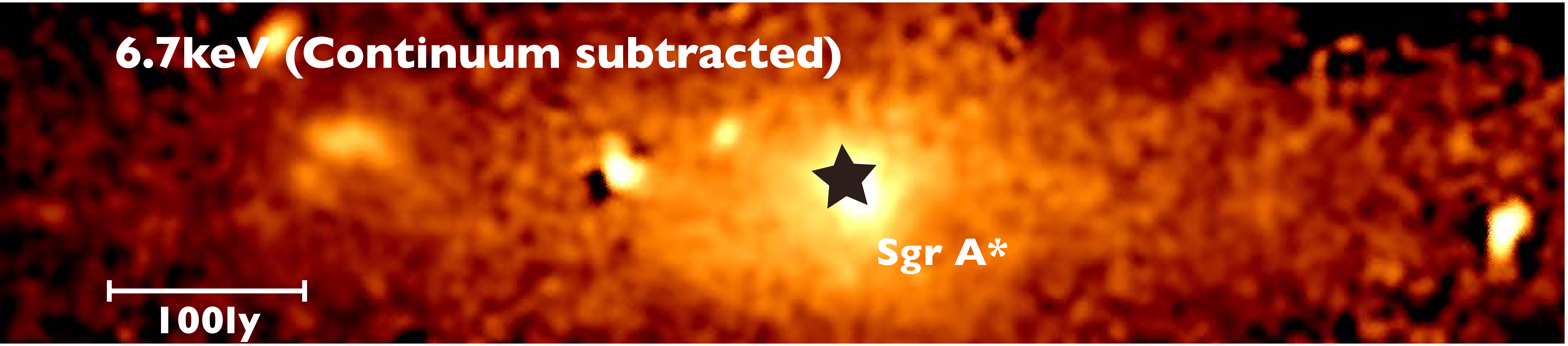
6.4-keV Line Image (Neutral Fe Kα)

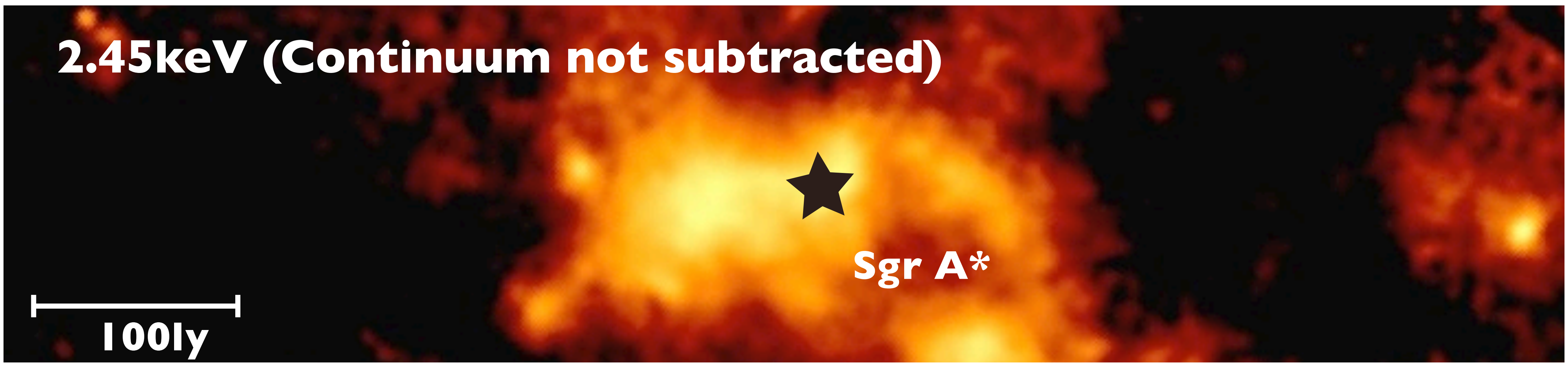


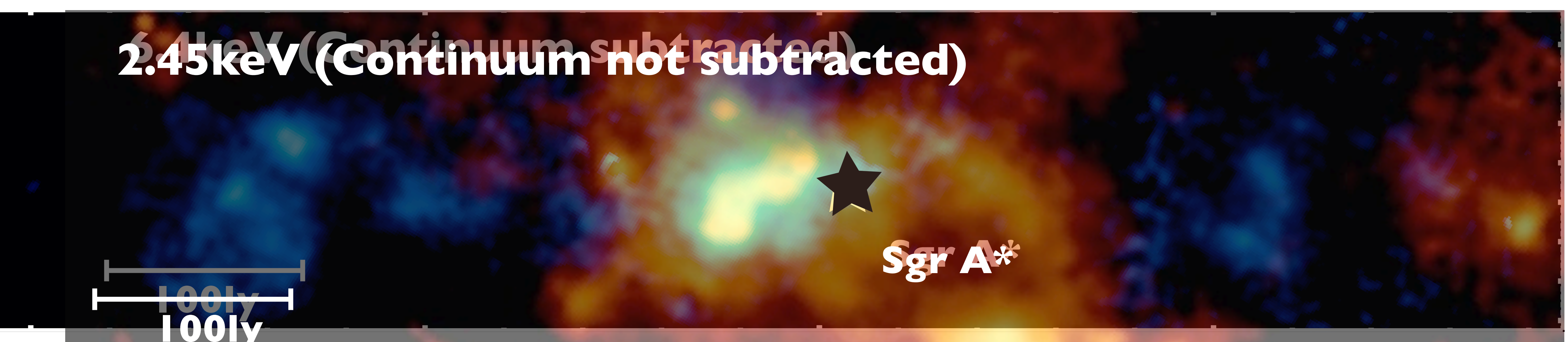


- 6.4-keV line generally traces the distribution of the molecular clouds.
- 6.4-keV fluorescence line is emitted from MC.

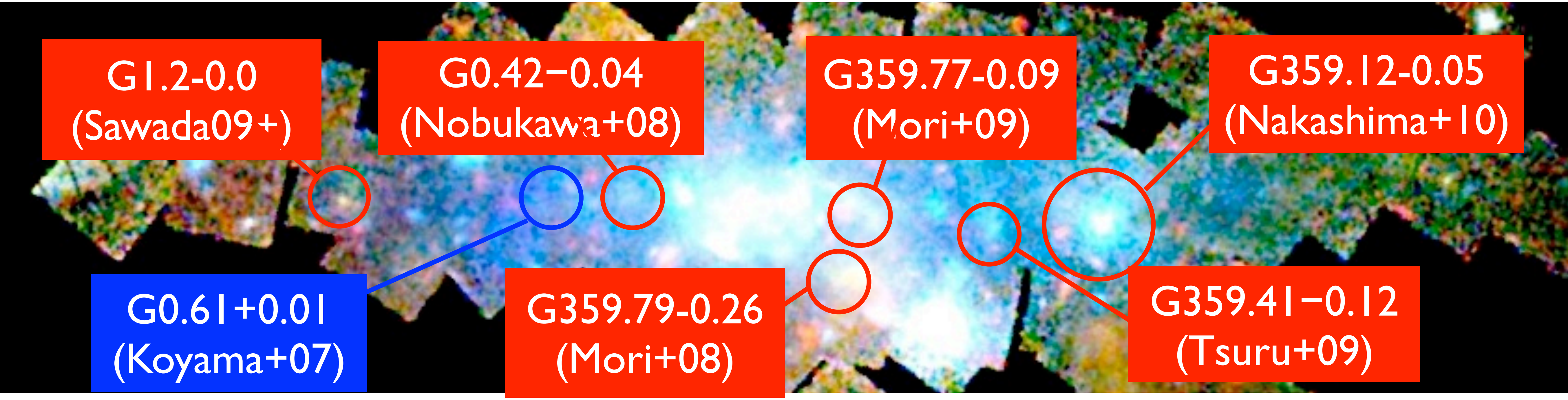
What is the ionizing particles ? Electrons or X-rays ?


6.7keV (Continuum subtracted)
Sgr A*
100ly

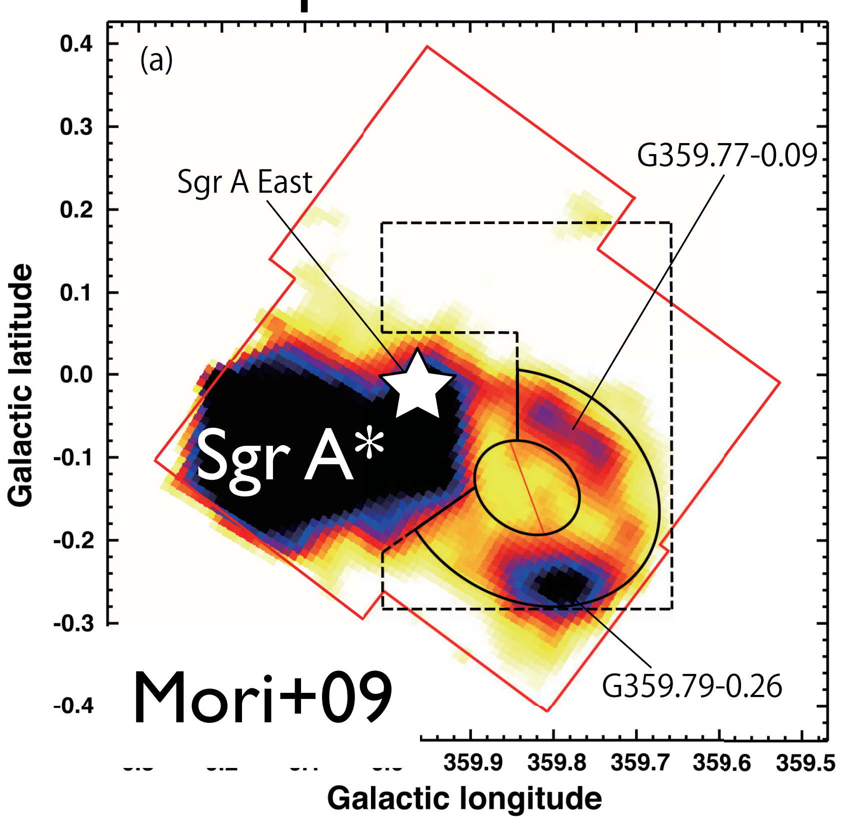

2.45keV (Continuum not subtracted)
Sgr A*
100ly


2.45keV (Continuum not subtracted)
Sgr A*
100ly

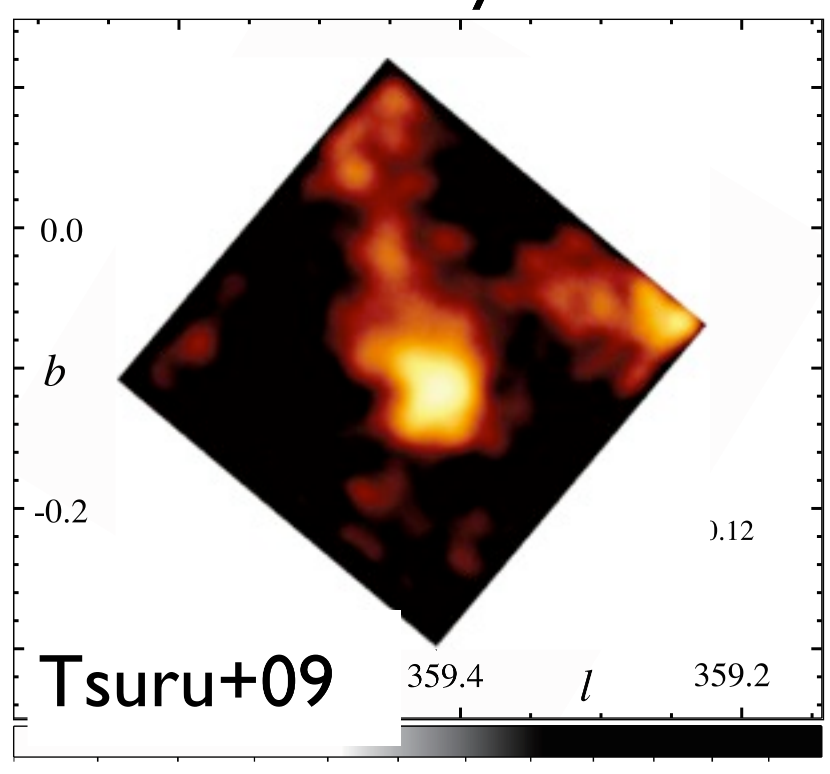
I. Discovery of SNR candidates



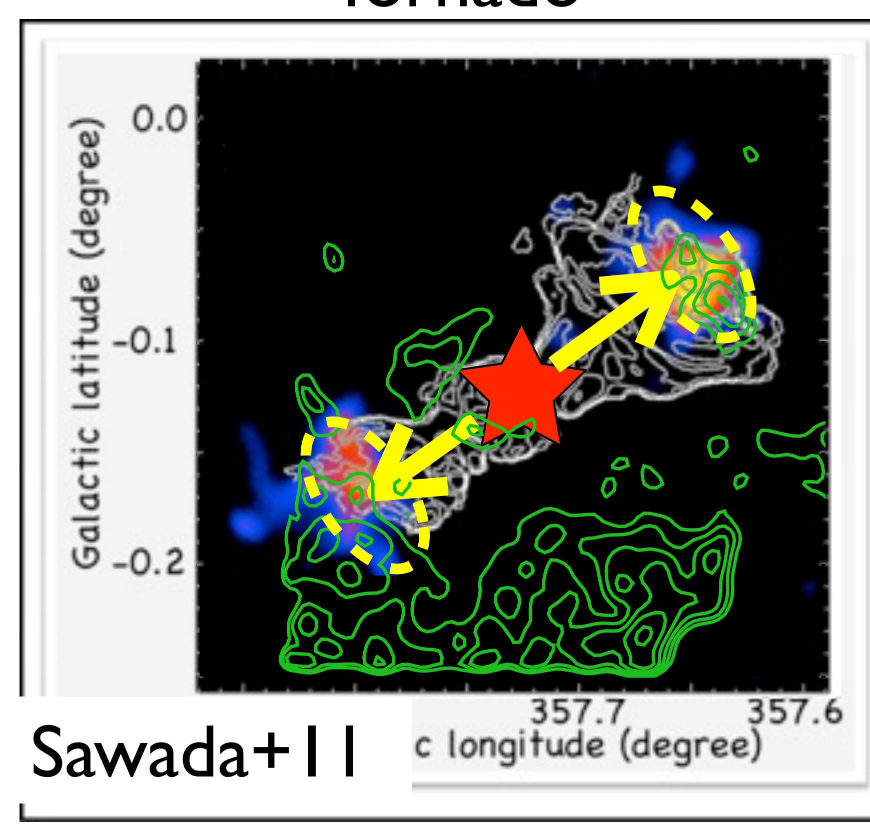
Super Bubble



“Chimney”



Tornado



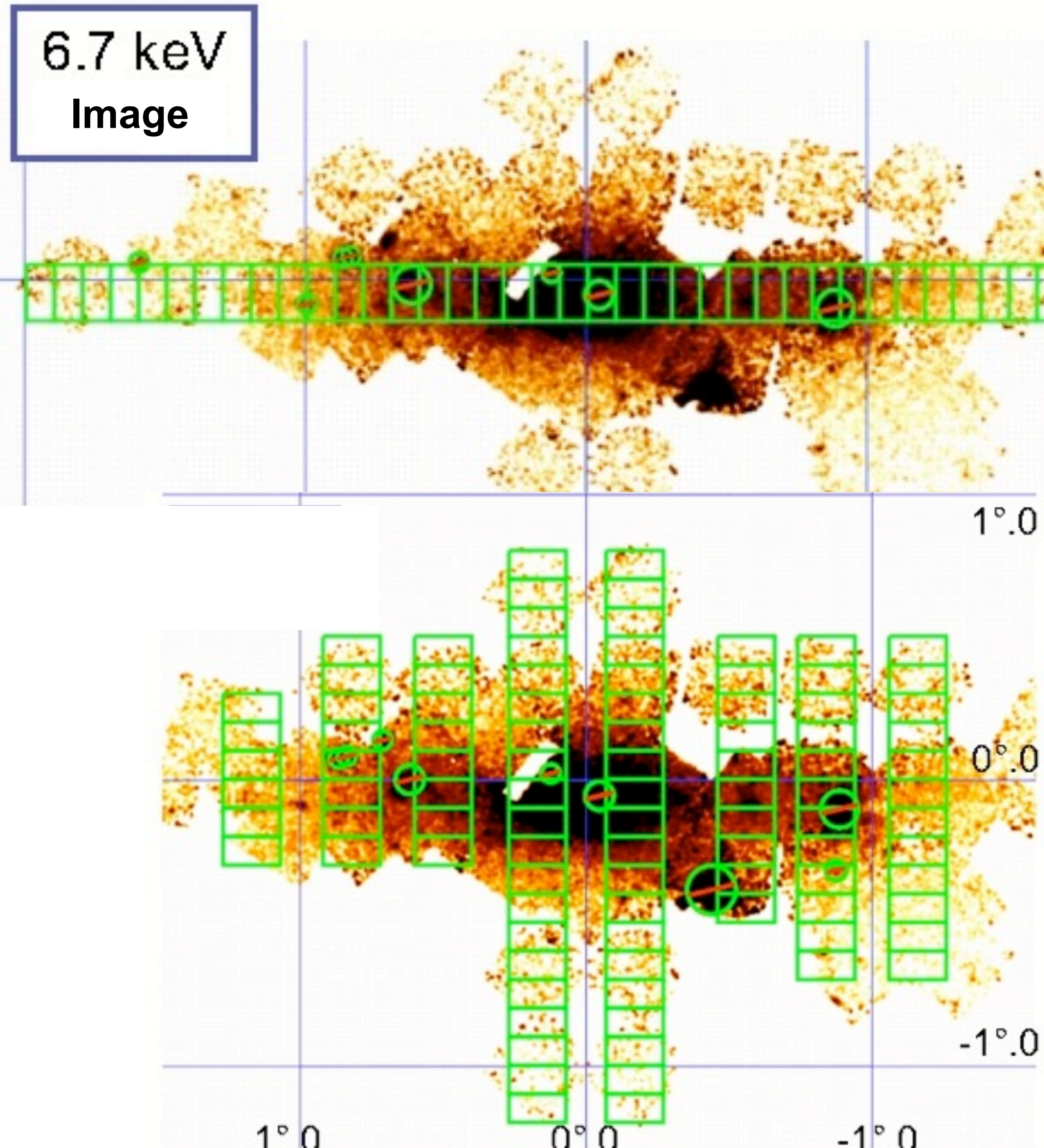
高階電離鉄輝線の起源：100万年？の活動

〜点源寄せ集め or 真に拡がる？〜

Uchiyama et al. (2011) PASJ 63, S903

Uchiyama FY2009 Doctor Thesis, Kyoto Univ.

3. Fe-K Lines (6.7, 6.9 keV) Distributions



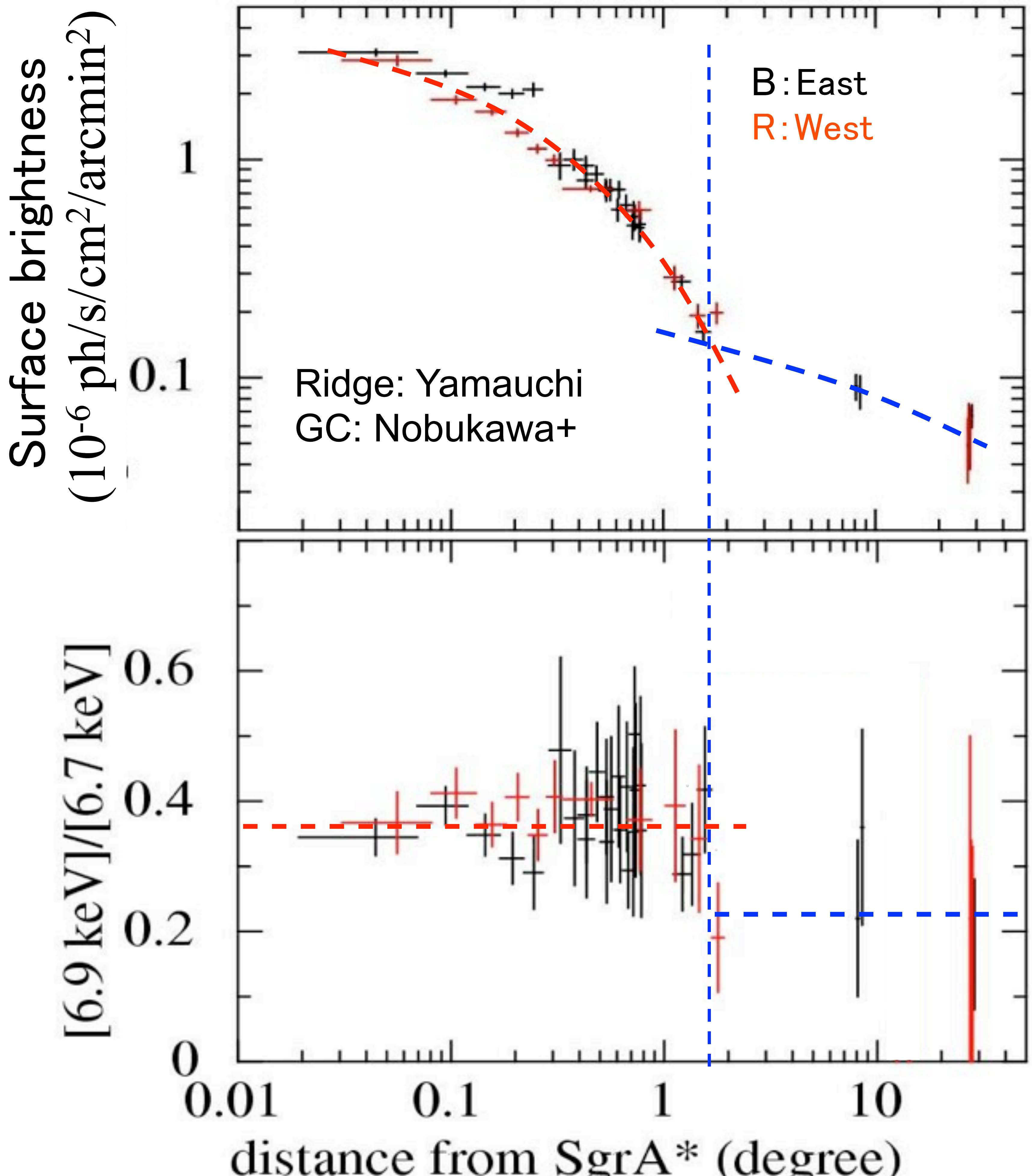
Truly Diffuse or Point Sources ?

Divided into small areas and made spectra, fit the individual spectrum with a power-law + Gaussians.

Fluxes (*F*)

$F_{6.7}$: 6.7 keV line

$F_{6.9}$: 6.95 keV line

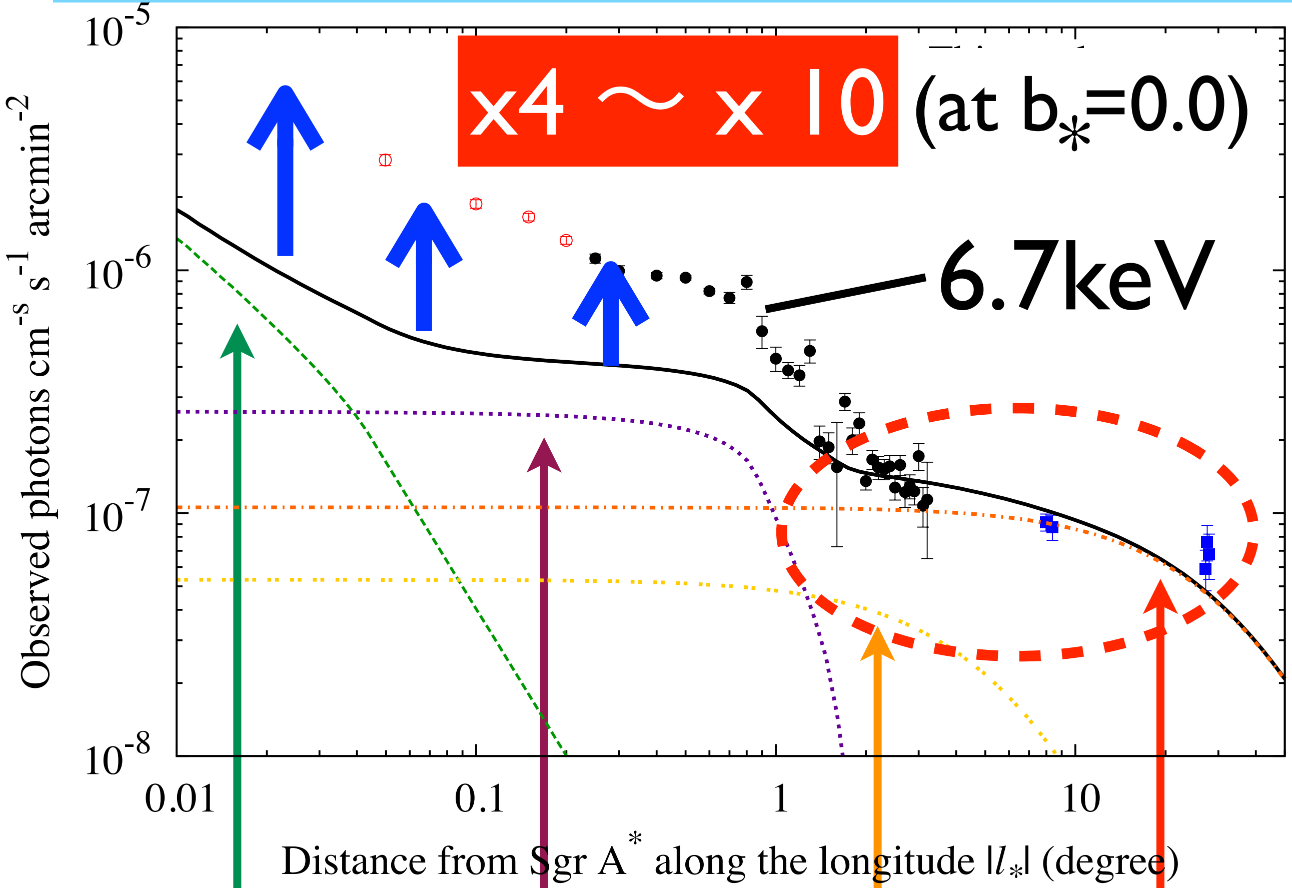


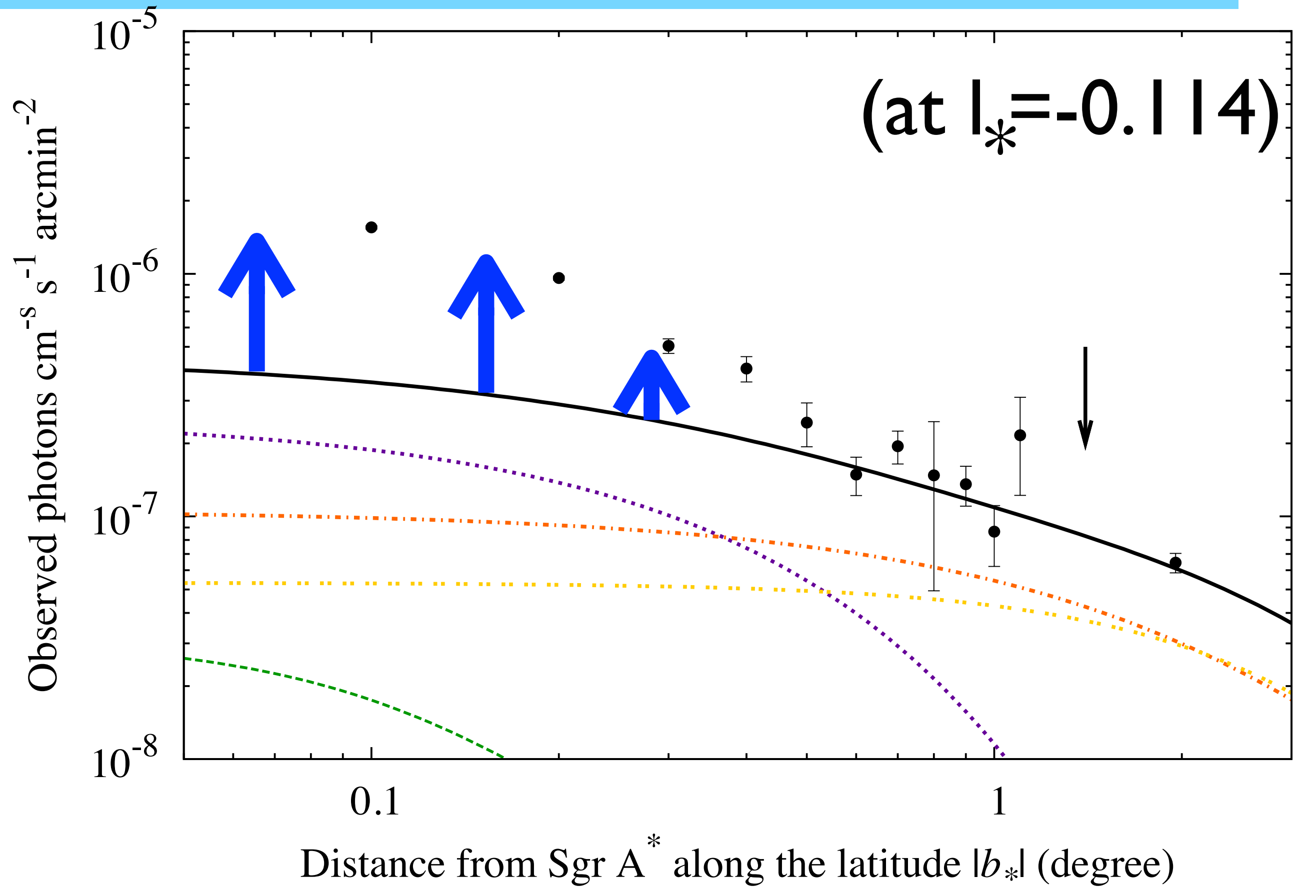
- The border between GC and GR is located at l = 1〜2deg.

- The temperature of GC would be higher than GR.

Nobukawa, Hyodo+, Yamauchi+09

6.7keV Line Profile vs Stellar Mass Distribution





Nuclear stellar cluster

Nuclear stellar disk

Galactic bulge

Galactic disk

Nuclear bulge

A new population of point sources with a strong 6.7keV line.

or

Truly diffuse plasma

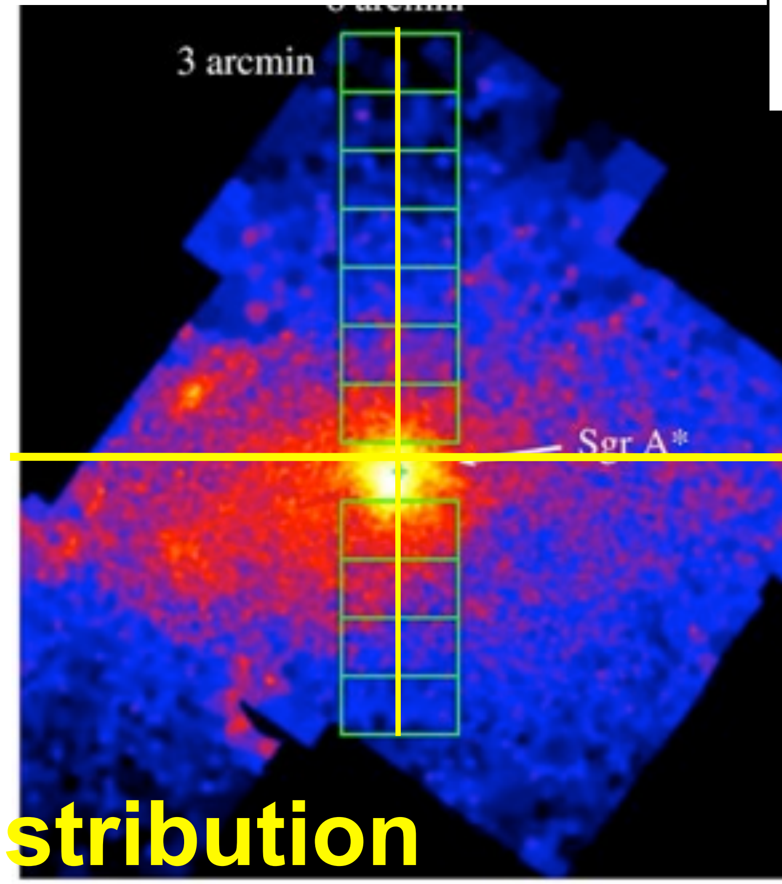
6.7keV Lines Excess at GC

Origin of 6.7keV line in GC is different from GR

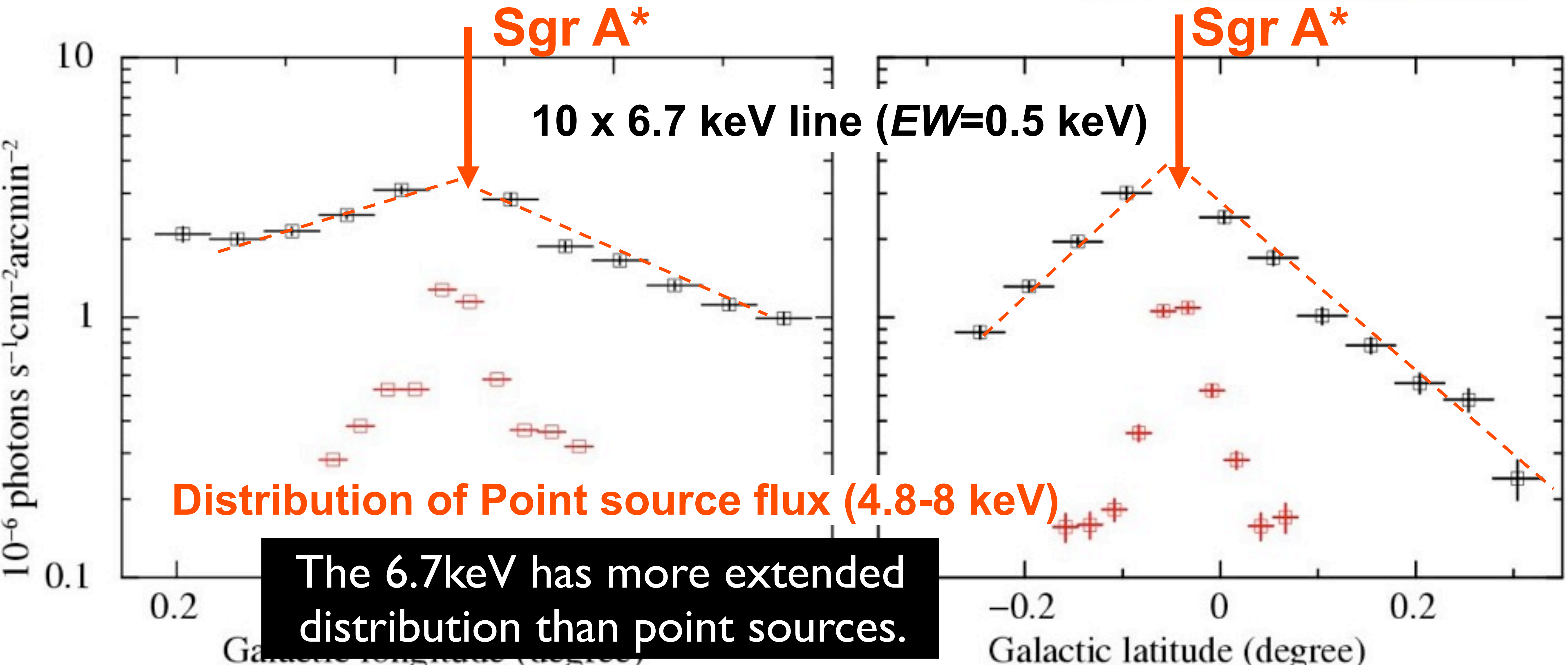
Uchiyama+11

The 6.7 keV line flux vs Integrated point source flux (Chandra deep exposure) Near GC (< 0.3 deg)

Nobukawa, Hyodo+



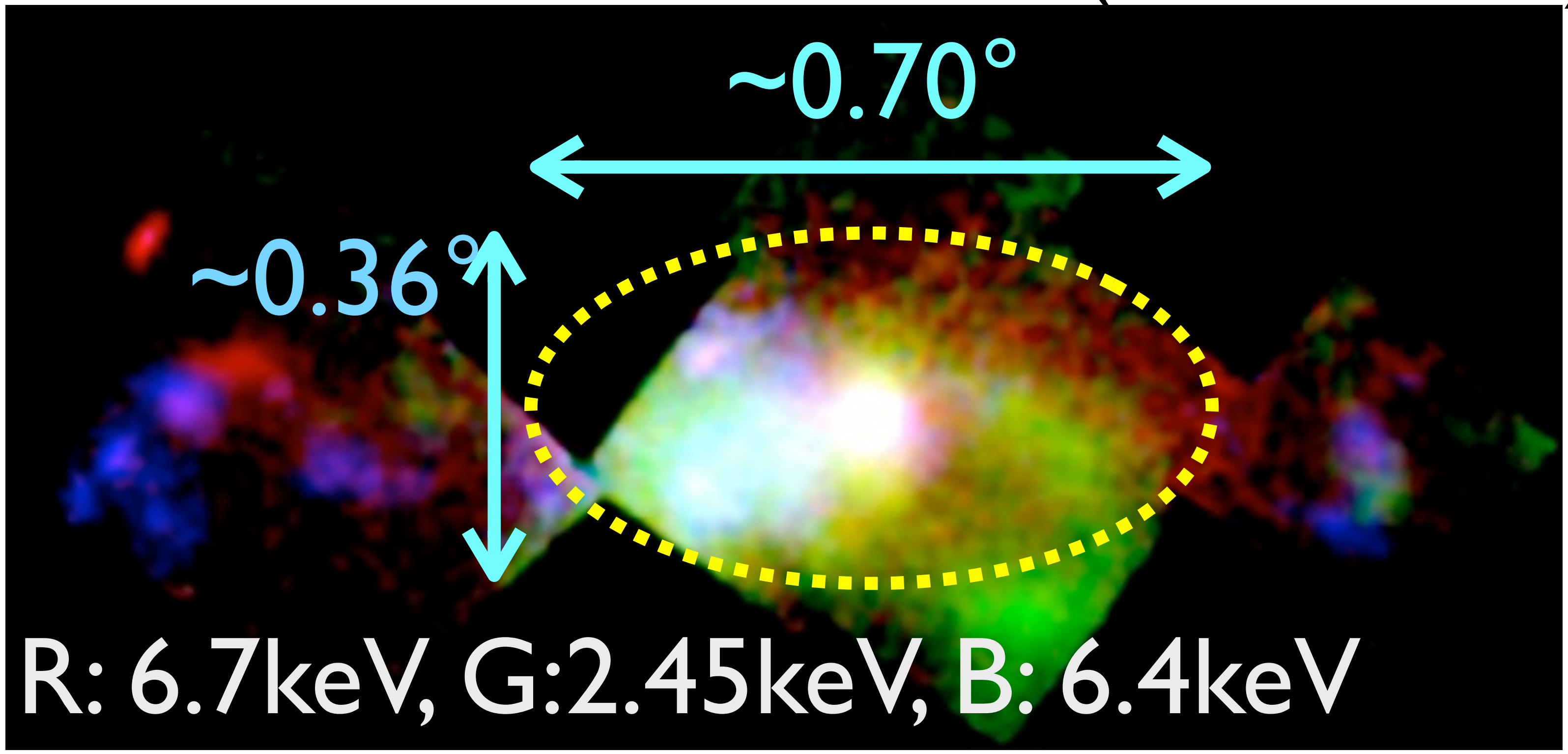
l-distribution *b*-distribution



Plasma Parameters in the Sgr A (assuming Z_{Fe}=1.2)

- Size ~ 50pc x 30pc
- $L_{2\text{-}10}$ ~ 2×10^{36}ergs/s
- n_{ave} ~ 0.1cm^{-3}
- n_{peak} ~ 0.4cm^{-3}
- E_{gas} ~ 3×10^{52}ergs

Tsuru+ (Suzaku2007)



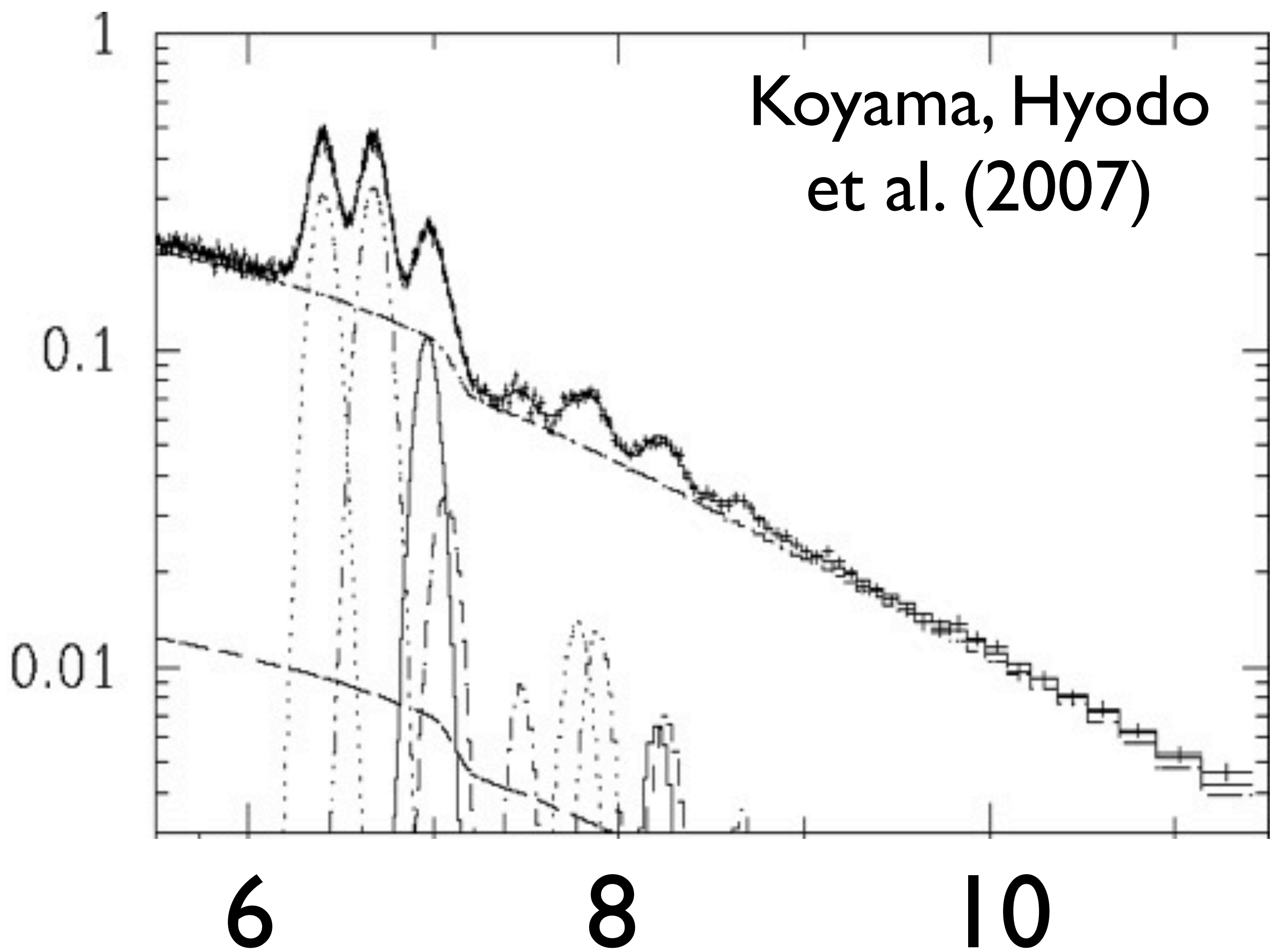
- Escape Time scale (latutude) τ_{esc} = Size/Cs = 2×10^{4}yr
- Heating Rate = E_{gas}/τ_{esc} ~ 5×10^{40}ergs/s ~ 10^{-3} SN yr^{-1}
- Much higher than the current activity of Sgr A* and ~10^{-5} SN yr^{-1} expected from the stellar mass in this region.
- Plasma is in the ionization equilibrium or not ?

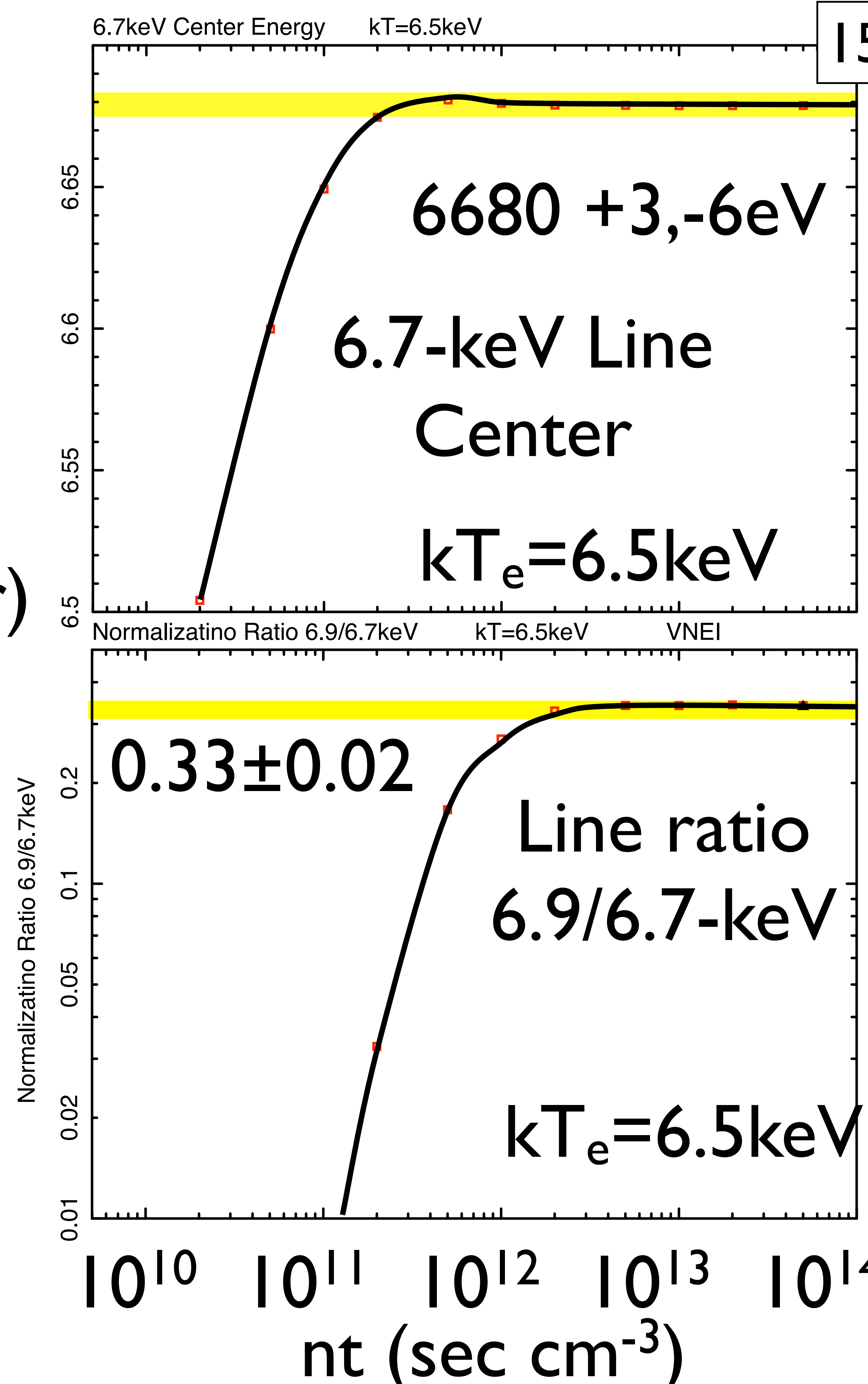
EI or NEI

Tsuru+ (Suzaku2007)

- Suzaku spectrum

  $n\tau_{ion} > 2\times10^{12}$ sec cm^{-3}
- >> $n\tau_{esc} \sim 1\times10^{11}$ sec cm^{-3}
- small escape (age > 6e+5yr)





Confinement by Magnetic Field ?

Tsuru+ (Suzaku2007)

(eg. Yamauchi+90, Koyama+96, Muno+04)

- Pressure
  - B = 0.1mG~1mG
  - $P_B/k = 10^6\text{-}10^8$ K/cm^3 ~ $P_{gas}/k = 2\times10^7$ K/cm^3

- The strength of the magnetic field can confine 6.7keV plasma.
- Slow diffusion → Makes the required heating rate lower.

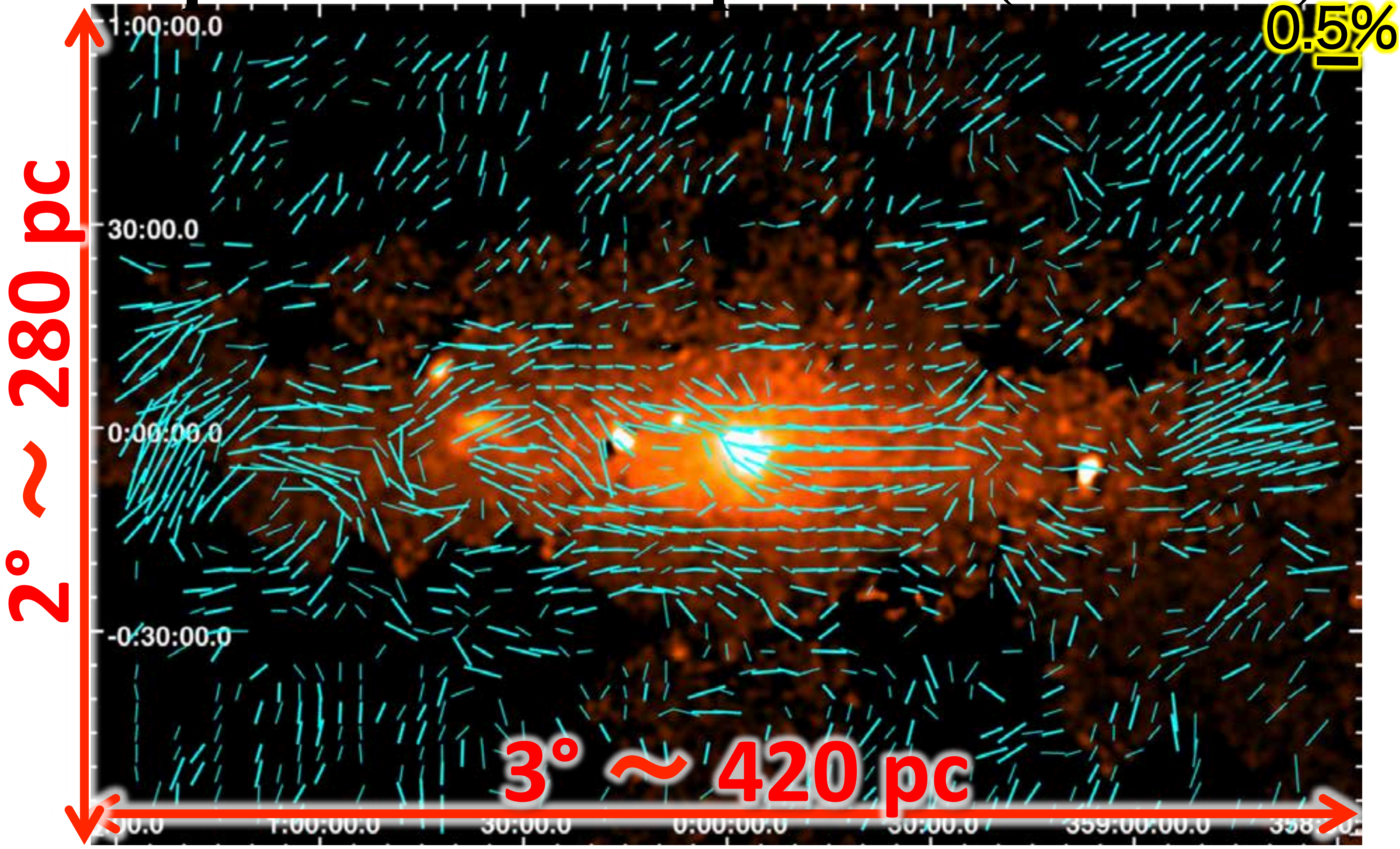
- But, the orientation of the mag. is vertical against the disk.
  → Easy to escape.

2007.12頃こんなことを考えていた...

→西山さん，長田さんに相談

Magnetic Field in the GC

Ks polarization map 3°×2° ($P/\delta P \geq 2$)



Nishiyama+13, ApJL, 769, 28

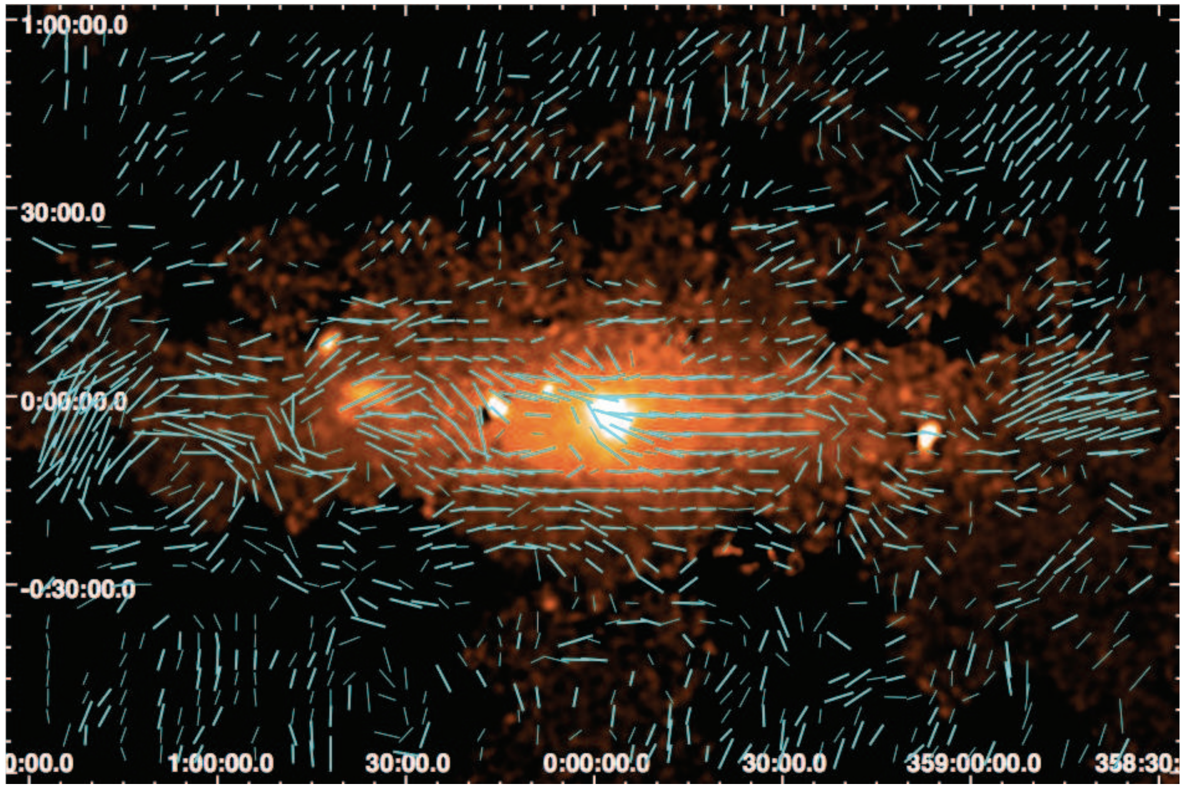


Fig. 5.— Polarimetry results covering 3°.0 × 2°.0 in the Galactic coordinate, together with an intensity map of 6.7 keV line emission (Nobukawa et al. 2012). The cyan vectors show the inferred magnetic field direction, and the lengths are proportional to polarization percentage. The vectors are averaged in a circle of 2′.4 radius with a 3′.0 grid, and plotted with thick bars (detected with more than 3σ) and thin bars (detected with 2 – 3σ).

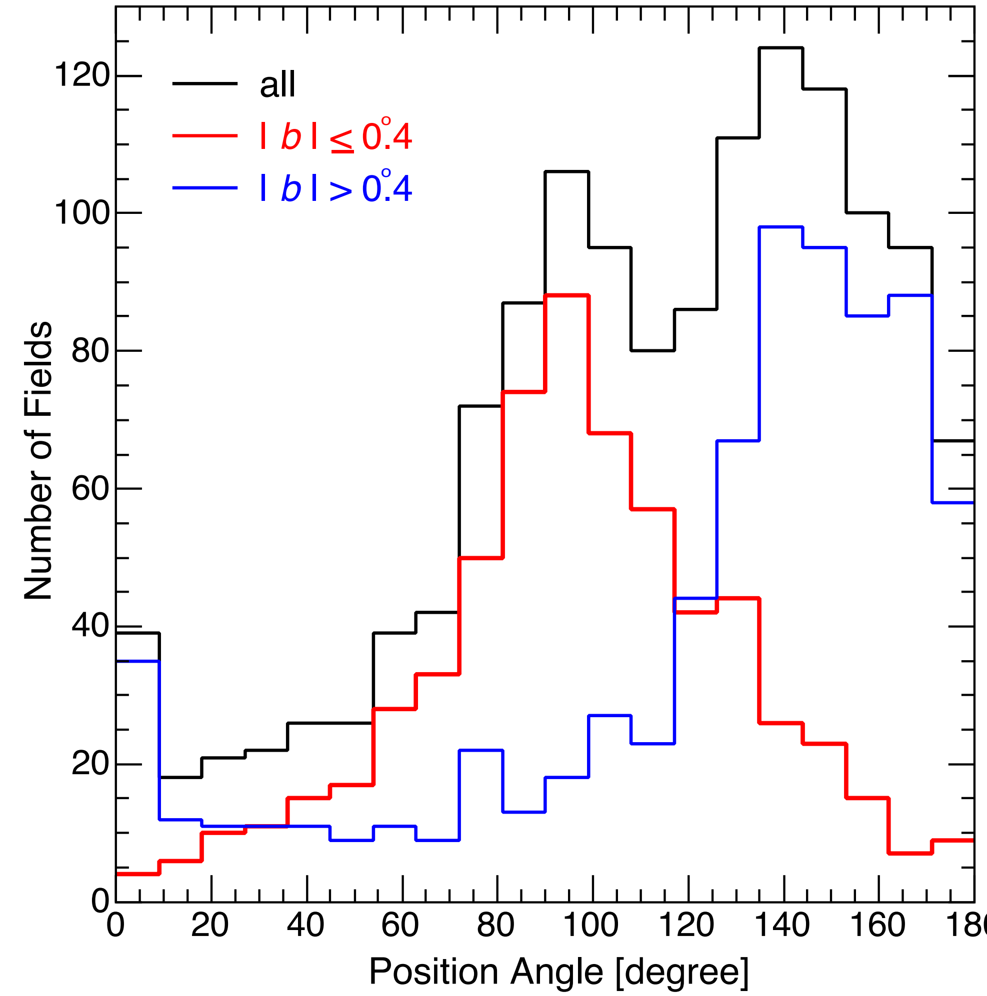


Fig. 6.— Histograms of the magnetic field direction at $| b | \leq$ 0°.4 (red), $| b | >$ 0°.4 (blue), and both (black). The red histogram has a clear peak at the direction almost parallel to the Galactic plane (90°), while the blue one has a peak at ∼ 150°, almost perpendicular to the plane.

磁場は銀河面に平行→閉じ込められる可能性あり

Nishiyama+13, ApJL, 769, 28

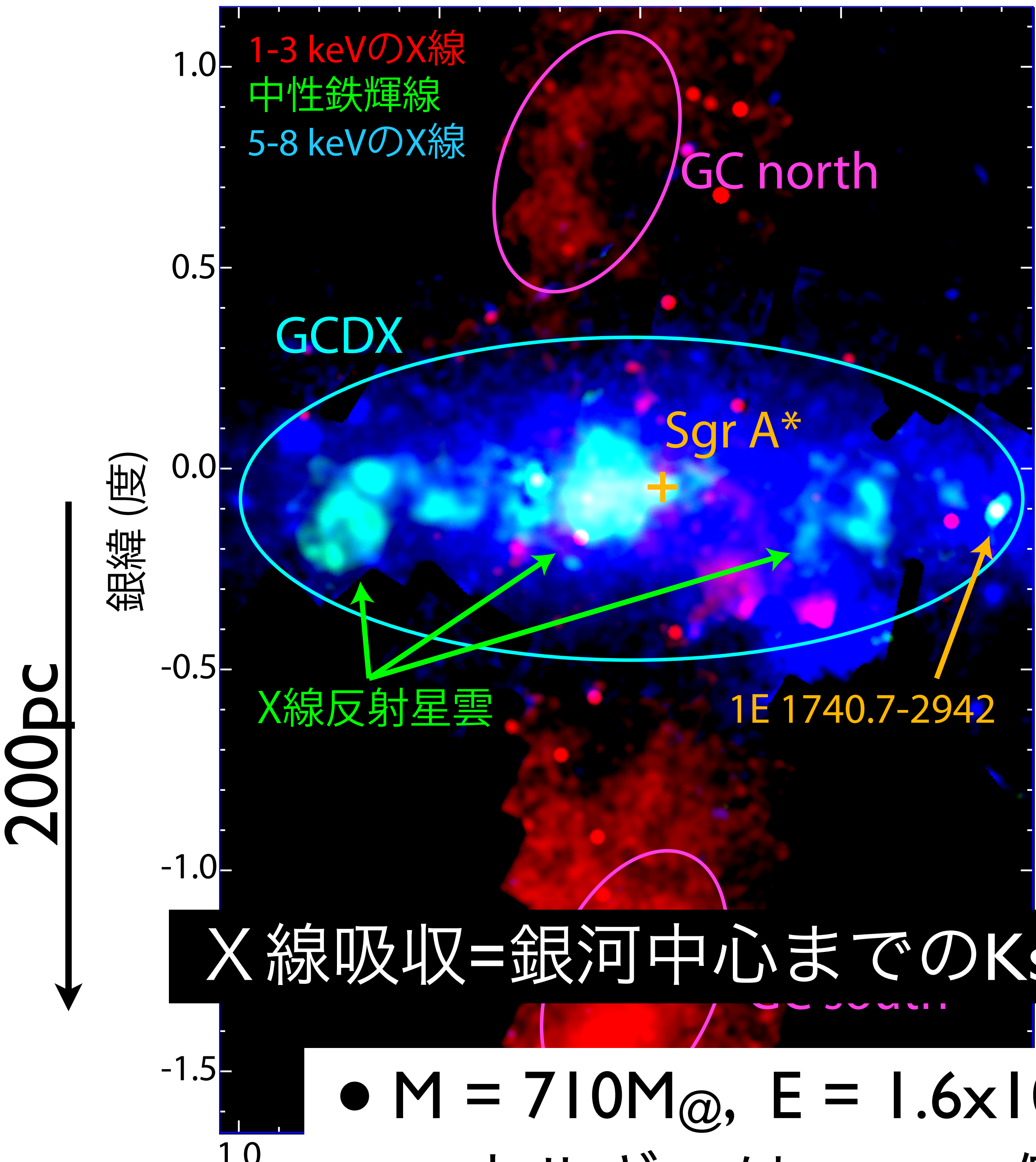
GC South Plasma : 10万年前の活動

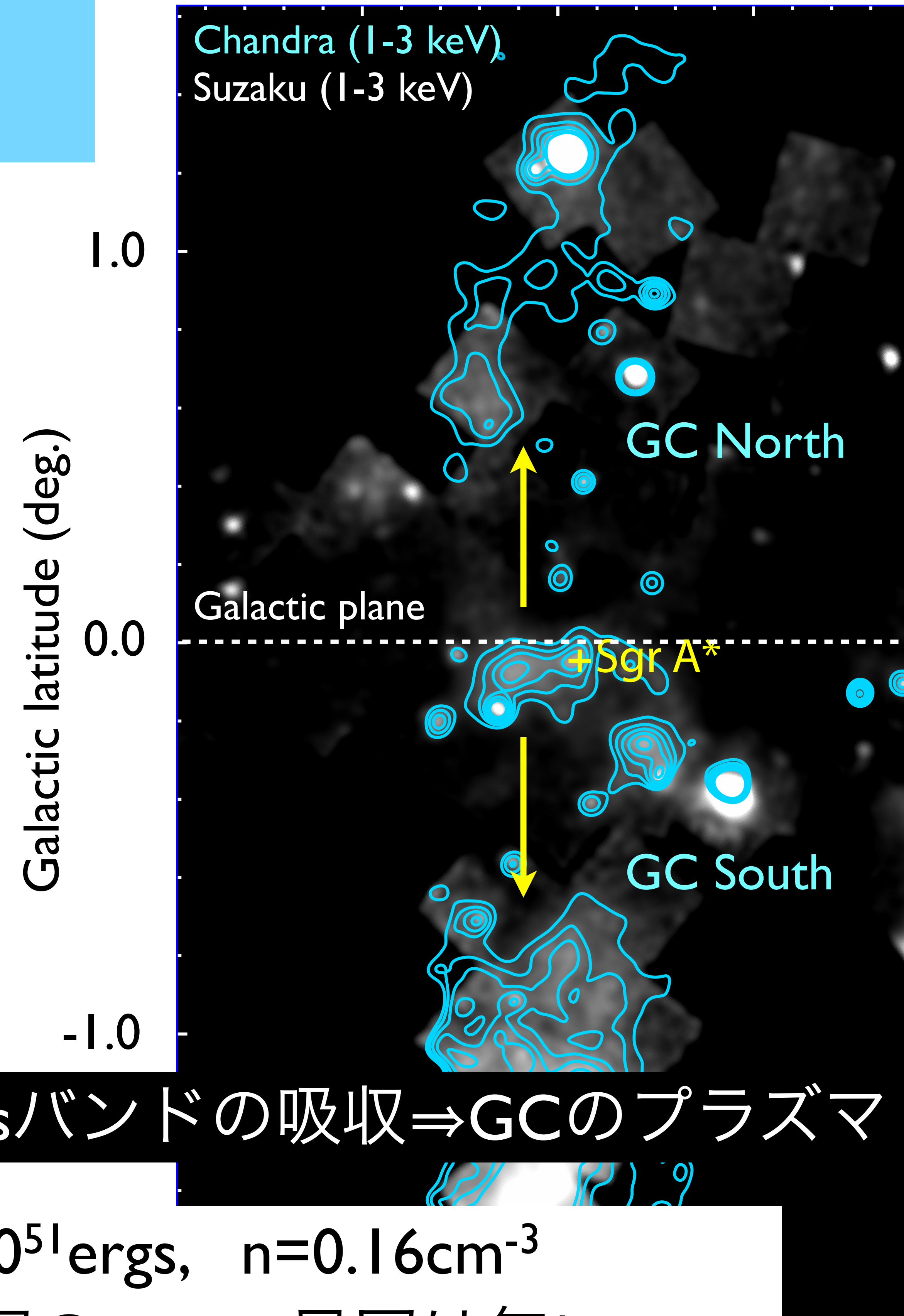
～再結合プラズマの発見～

Nakashima et al. 2013, ApJ, 773, 20

To be a part of Nakashima FY2013 Doctor Thesis, Kyoto Univ.

Bipolar X-ray emission from the GC



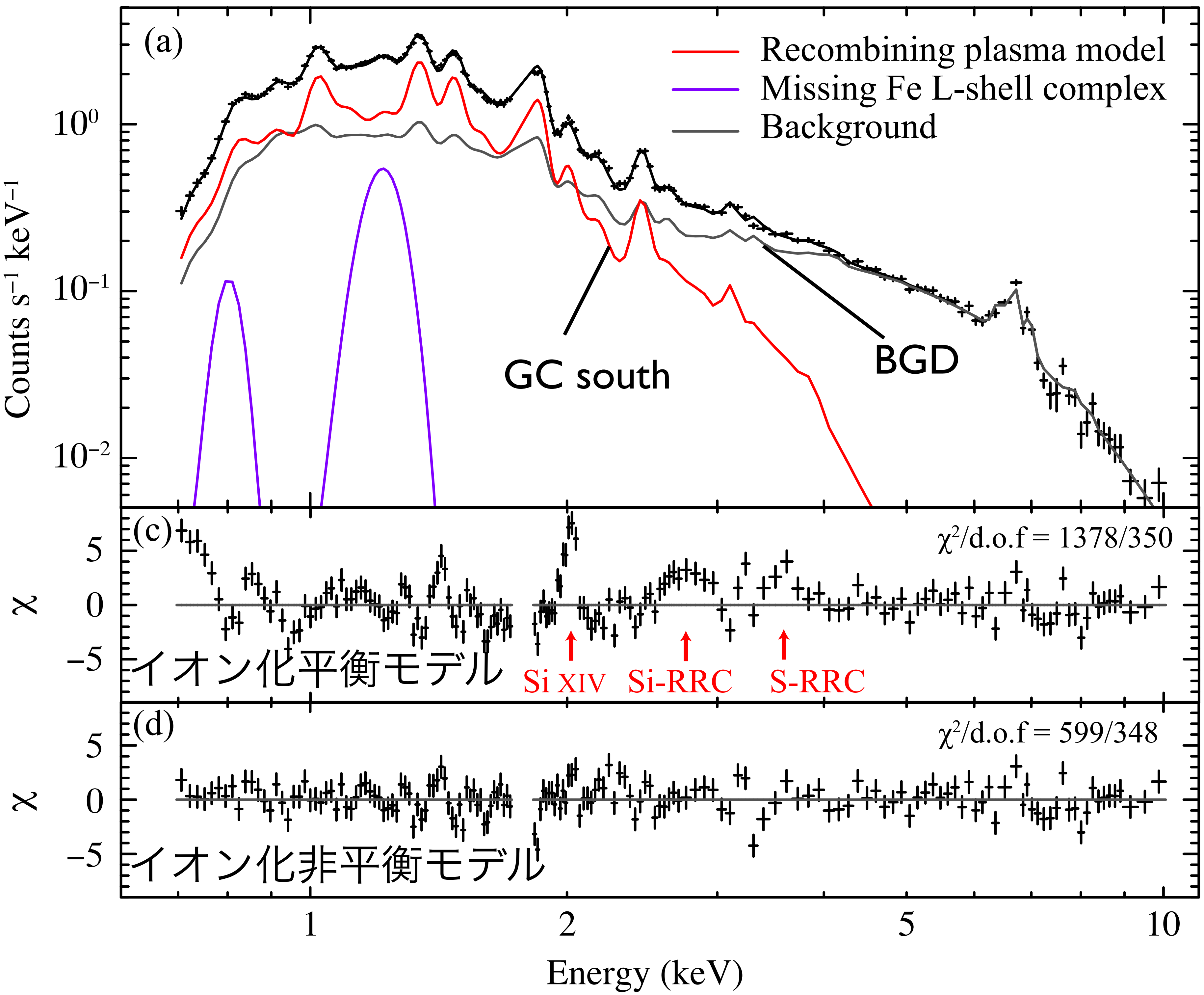


X線吸収=銀河中心までのKsバンドの吸収⇒GCのプラズマ

- M = 710M@, E = 1.6x10^{51}ergs, n=0.16cm^{-3}
- エネルギーは10~100個のSNR. 星団は無い.

⇒ 単一のSNR, Super Bubbleではない.

Recombining Plasma

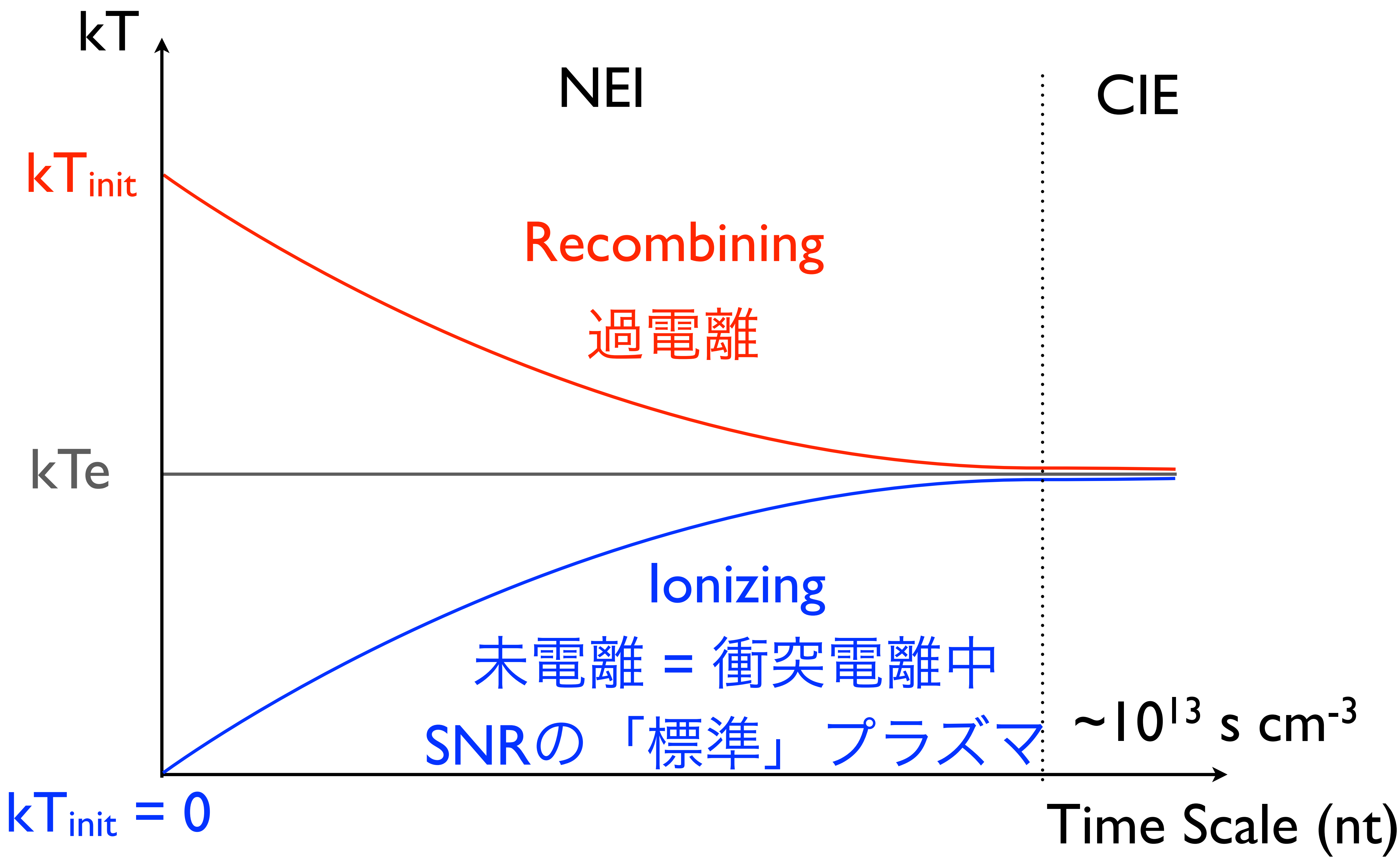


- 1成分イオン化平衡(1CIE)ではフィットできず.
- H-Si-Kαが強いだけ
  ⇒ 多温度CIEの可能性あり
- 再結合連続線 RRCは，CIEでは極めて弱い.
- イオン化非平衡

  $kT_Z > kT_e$
  で再現成功

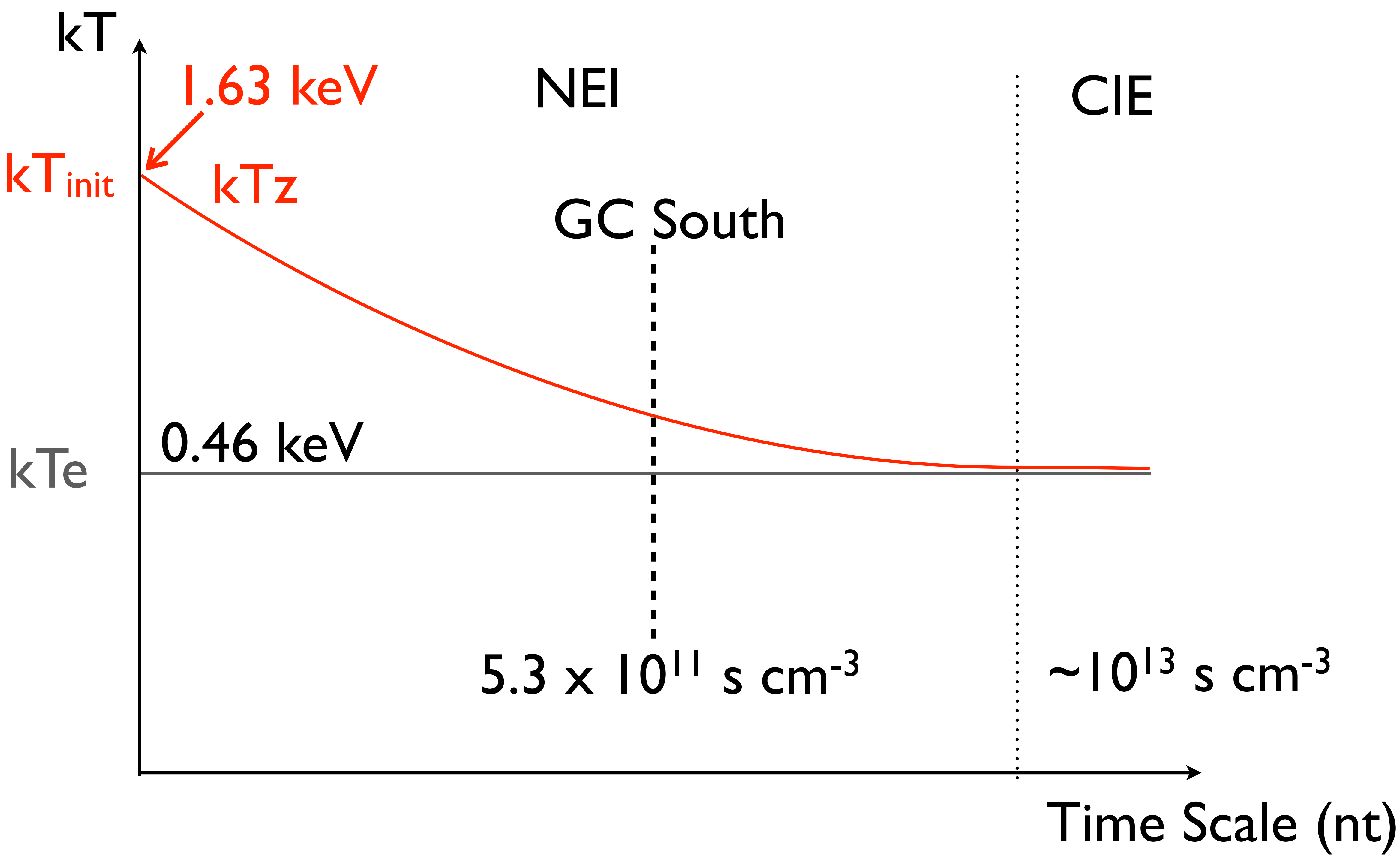
Recombining Plasma

Ionizing plasma v.s. Recombining plasma



Recombining Plasma

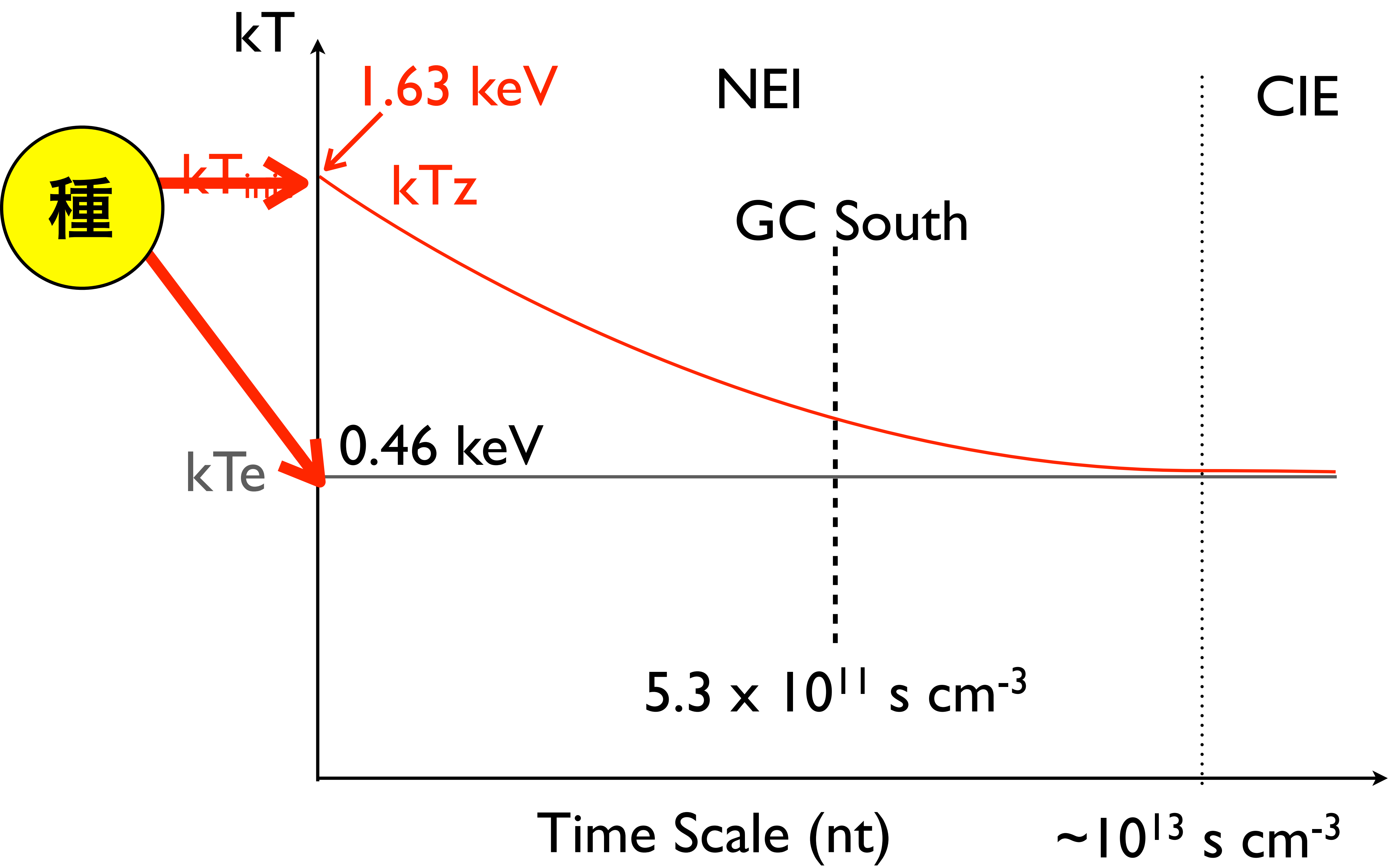
Ionizing plasma v.s. Recombining plasma



$\tau_{RP} = 1.1\times10^{5}$yr << $\tau_{cool} \sim 1\text{-}2\times10^{9}$yr

How to make Recombining Plasma

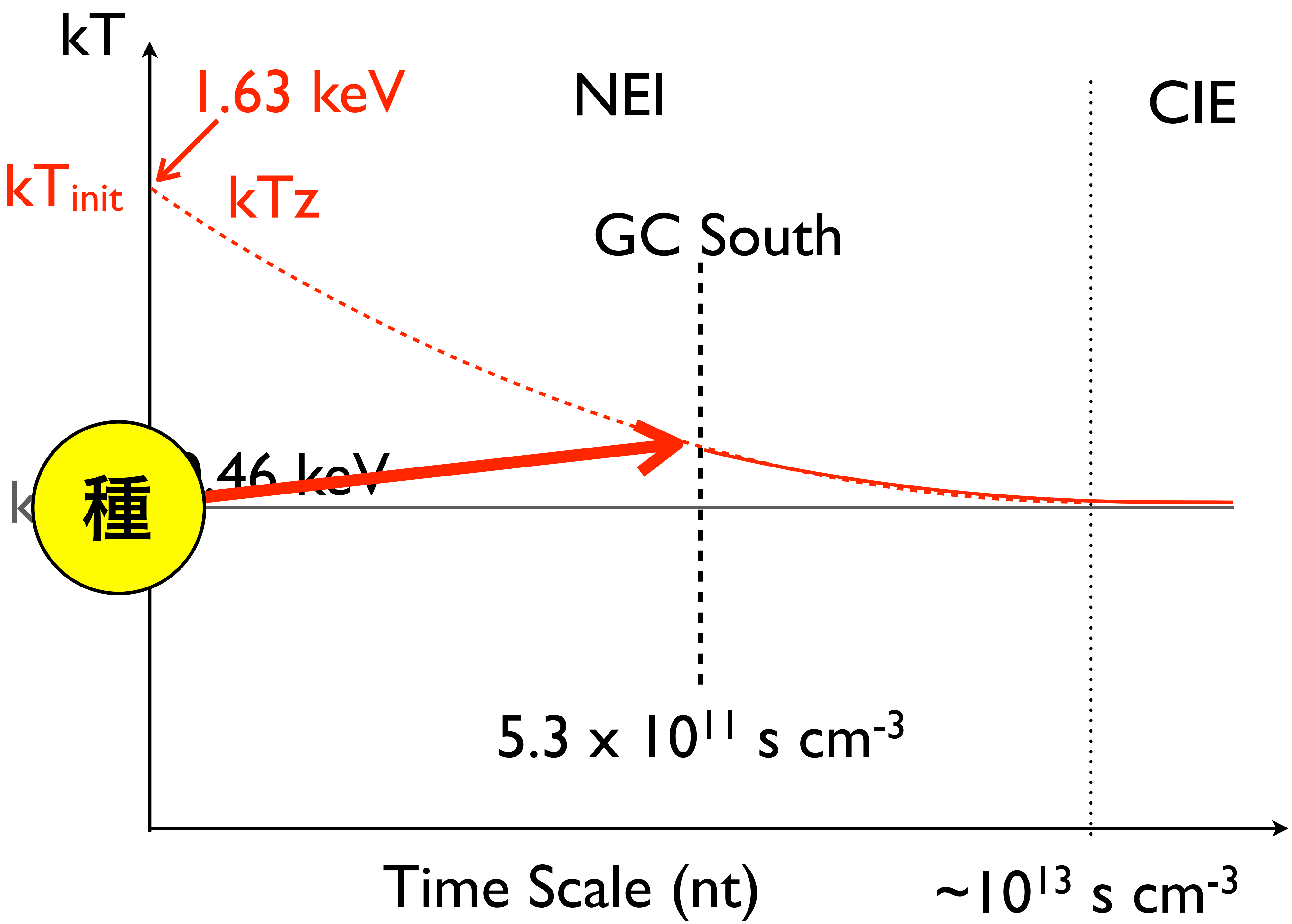
Ionizing plasma v.s. Recombining plasma



$\tau_{RP} = 1.1\times10^5$yr << $\tau_{cool} \sim 1\text{-}2\times10^9$yr

How to make Recombining Plasma

Ionizing plasma v.s. Recombining plasma



$\tau_{RP} = 1.1\times10^5\mathrm{yr} \ll \tau_{cool} \sim 1\text{-}2\times10^9\mathrm{yr}$

How to make Recombining Plasma

- 電子温度を下げる.
  - 断熱膨張により急激にkTeが下がった．その後ゆっくり再結合
  - 初期状態 kTinit = kTz = kTe = 1.63keV
  - $T \propto V^{(1-\gamma)}$, kTe=1.63→0.46keV
    ⇒ 体積が6倍に膨張（サイズ1.8倍）密度は $1cm^{-3}$ → $0.16cm^{-3}$.
  - (97 /1.8)kpc → 97kpc へ音速で膨張に必要な時間 ~ $8x10^4$yr
- イオン化温度を上げる.
  - σ(光電効果) ∝ z^5 ⇒ X線照射で重元素を選択的に電離
  - 初期状態 kTinit = kTz = kTe = 0.46keV
  - Sgr A*からのX線．L_X ~ $7.6x10^{43}$ergs/s
  - GC Plasma には，光電離 (RP)の痕跡がない． ⇒ ビーミング

Plasma Origin

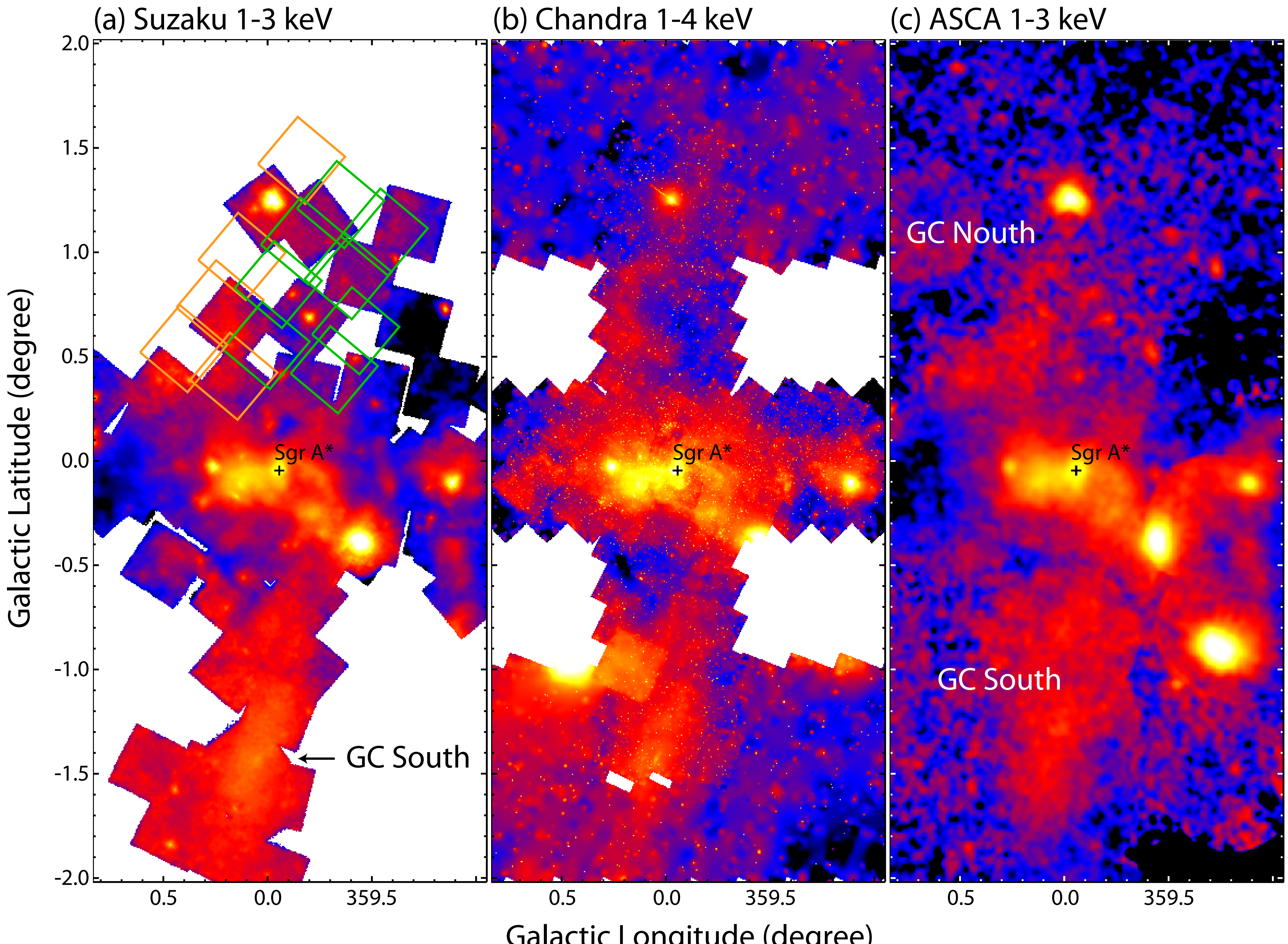
- 種プラズマの作り方
  - Starburst Activityに伴う銀河風
    - v=510km/s (Cs @ kTe=1.6keV) ⇒ GCから4×10^5yr
    - 10^5-10^7yr前にStarburst Activity (Matsunaga+11, Yusef-Zadeh+09)
  - Sgr A*からの(何らかの)エネルギー注入で冷たいガスが電離
    - 600~50yr前の活動 ⇒ $L_X \sim 1 \times 10^{39}$ergs/s
    - If これが ~10^5yr続いたと仮定 ⇒ $L_X \sim 10^{51}$ergs ~ E(GC south)

GC South North
～南があるなら北にも？～

Proposing as a key-project of Suzaku AO9

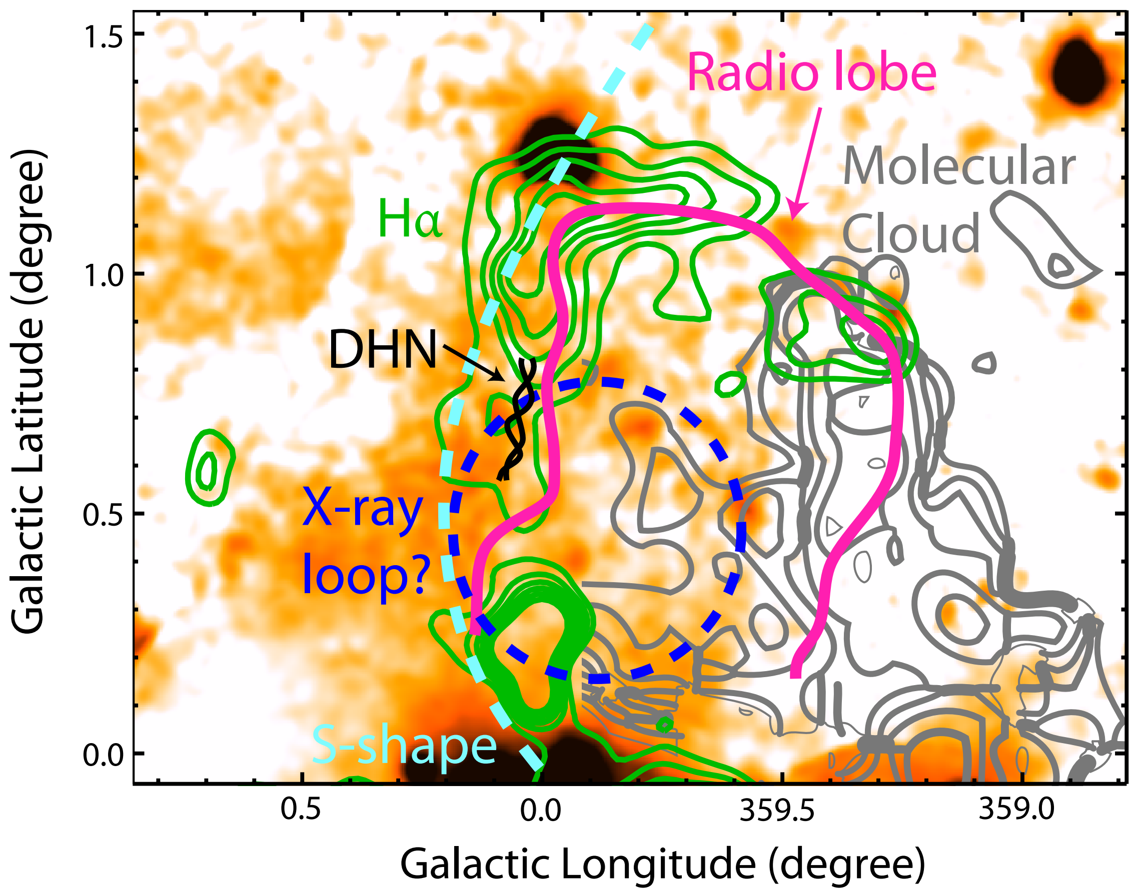
To be a part of Nakashima FY2013 Doctor Thesis, Kyoto Univ.

How about GC North ?

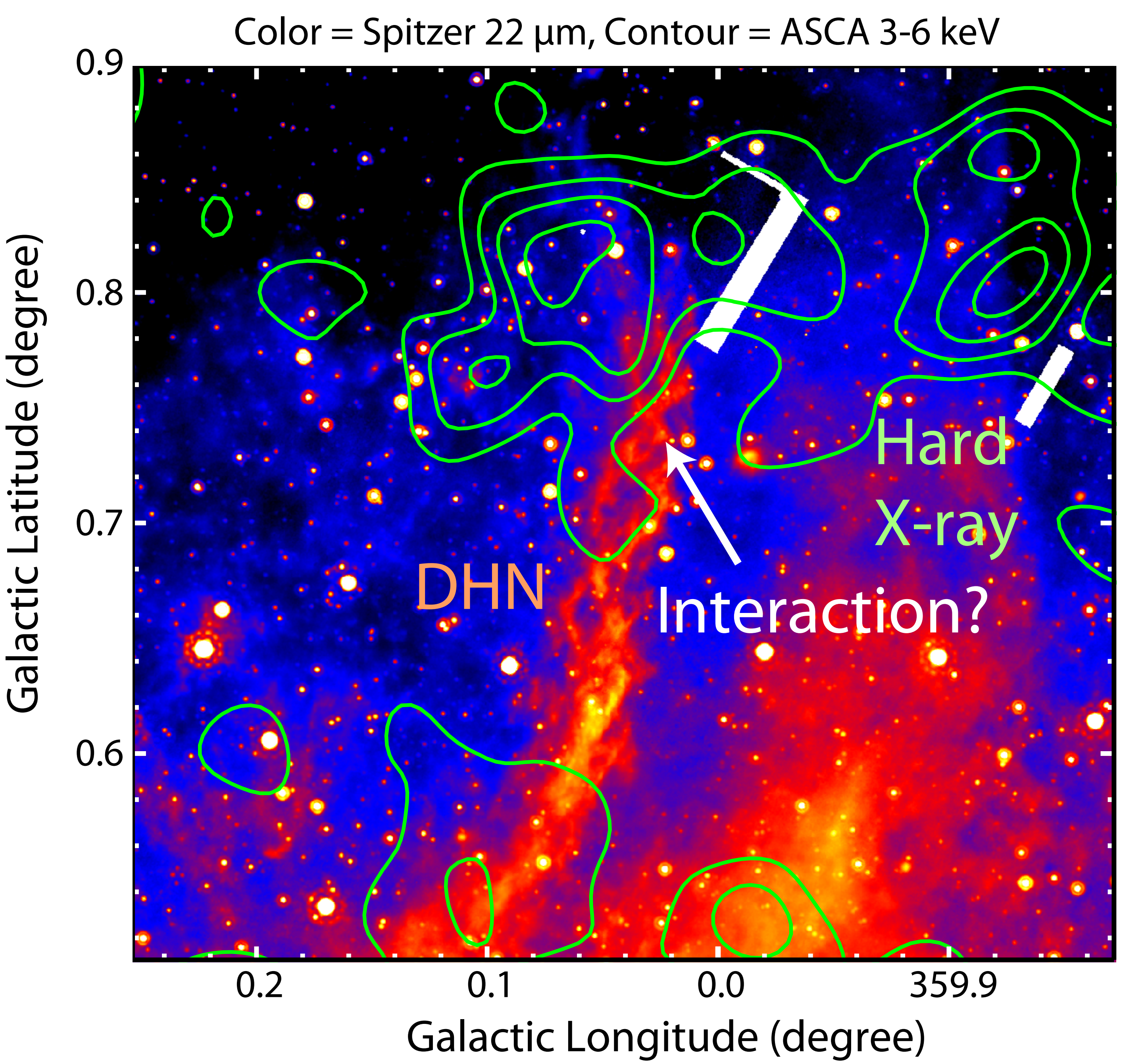


Tip of DHN

ASCA 1-3keV



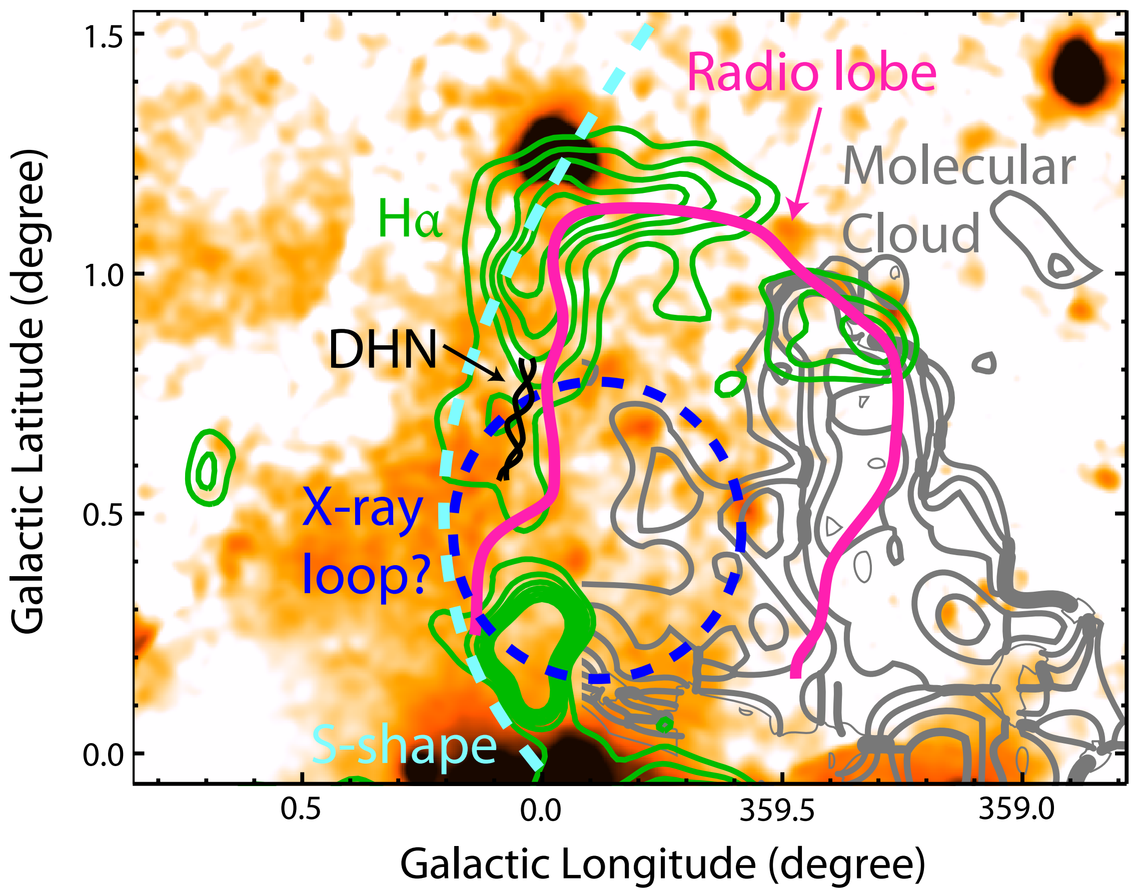
ASCA 3-6keV (Contour)

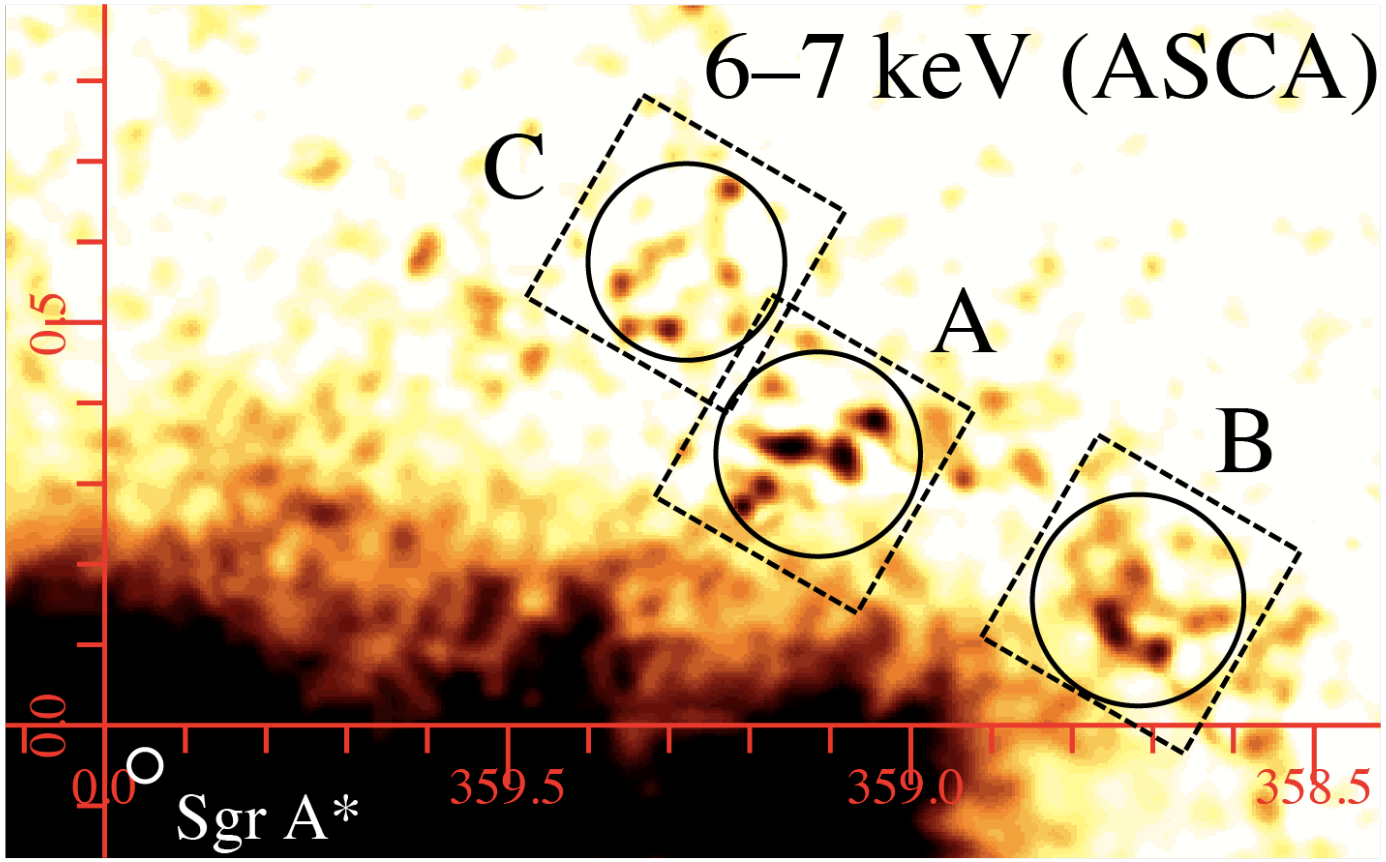


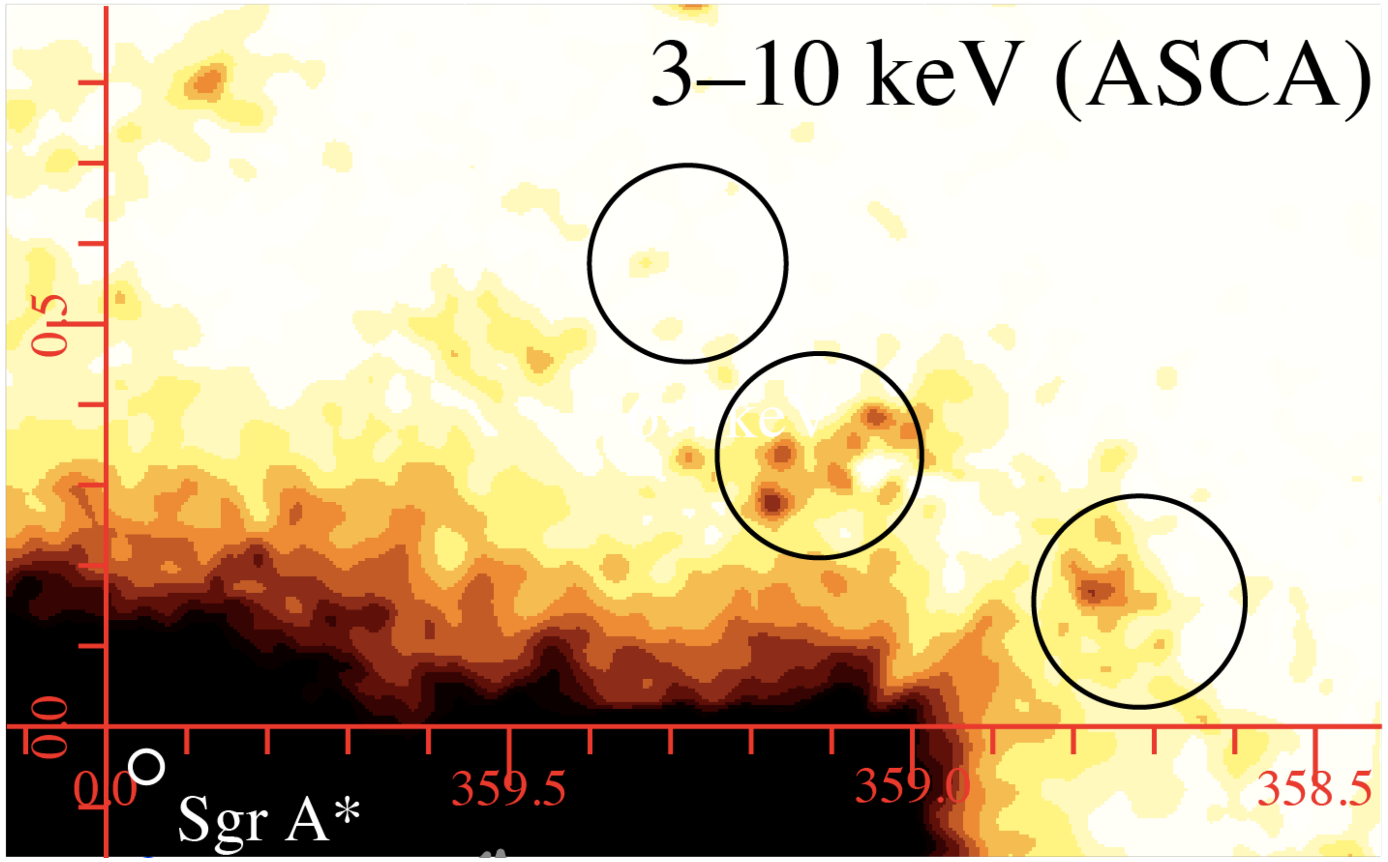
- Sgr A*の活動?
  - ジェット or アウトフロー?
- NSCからの磁気タワー?
  - 銀河面の高温プラズマの巻き上げ?

Fe-K line (6.4keV ?) from MC interacting Radio Lobe

ASCA 1-3keV







- New XRN ?
  - 従来 |b|<0.1度(15pc)
  - 初めての高銀緯(b=0.1-0.5°)
- Cosmic Rays (Electron or Proton) from Radio Lobe ?

Summary

- 高階電離鉄輝線の起源は，暗く鉄輝線の強い未知のX線天体種族．本質的に拡がったプラズマ．
- 本質的に拡がったプラズマの場合，磁場閉じ込め可能性あり．

- GCの南200pc (GC South)および北 (GC North)の領域に SNRの10~100個分のエネルギーを持つプラズマを発見した．
- GC Southは~10^5yr前に過電離状態になった再結合プラズマ．
- GC Northは様々な構造を持つ．

Thank you.