Suzaku/XMM/Chandra study of Fe K line complex in the nuclear region of NGC253

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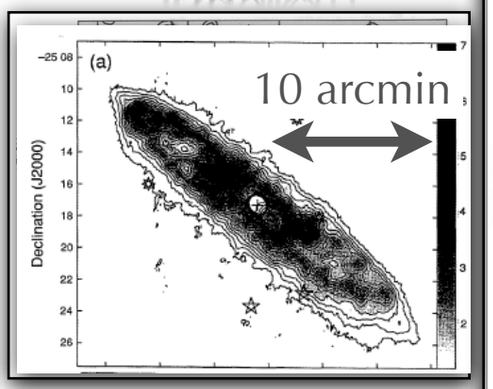
1. NGC253

Starburst phenomenon is important in the chemical enrichment of intergalactic space
Starburst galaxies show us real-time production of elements

NGC253 is a bright, nearby edge-on starburst galaxy
well examined in radio to gamma-ray ranges
We studied NGC 253 to understand metal enrichment process in galaxies

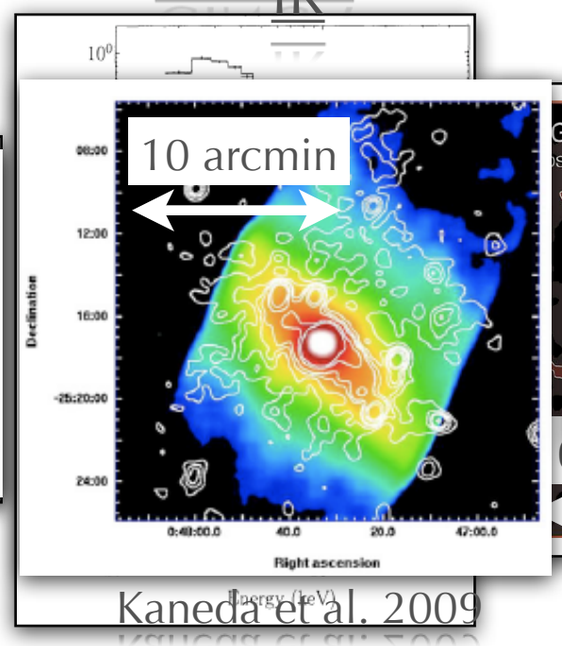
Radio



Koribalski et al. 1995

G. Tabbiano 1988

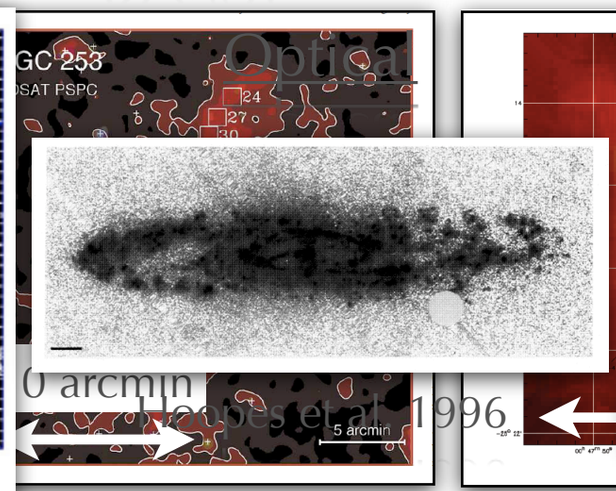
GINGA
IR



Kaneda et al. 2009

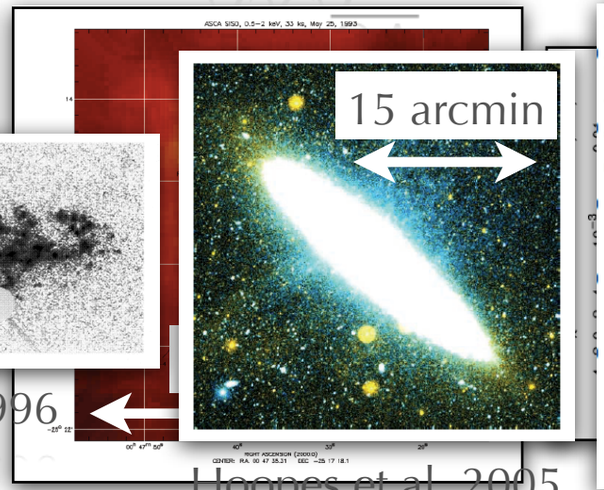
Ohashi et al. 1990

ROSAT
Optical



Pietsch et al. 2000

ASCA
UV

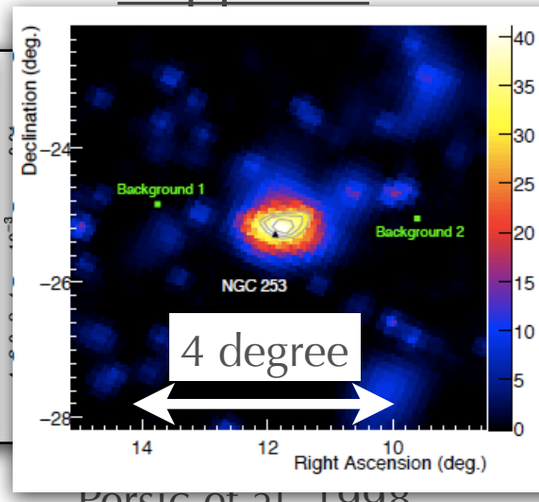


Hoopes et al. 1996

Hoopes et al. 2005

http://heasarc.nasa.gov/docs/rosat/gallery/ptak/

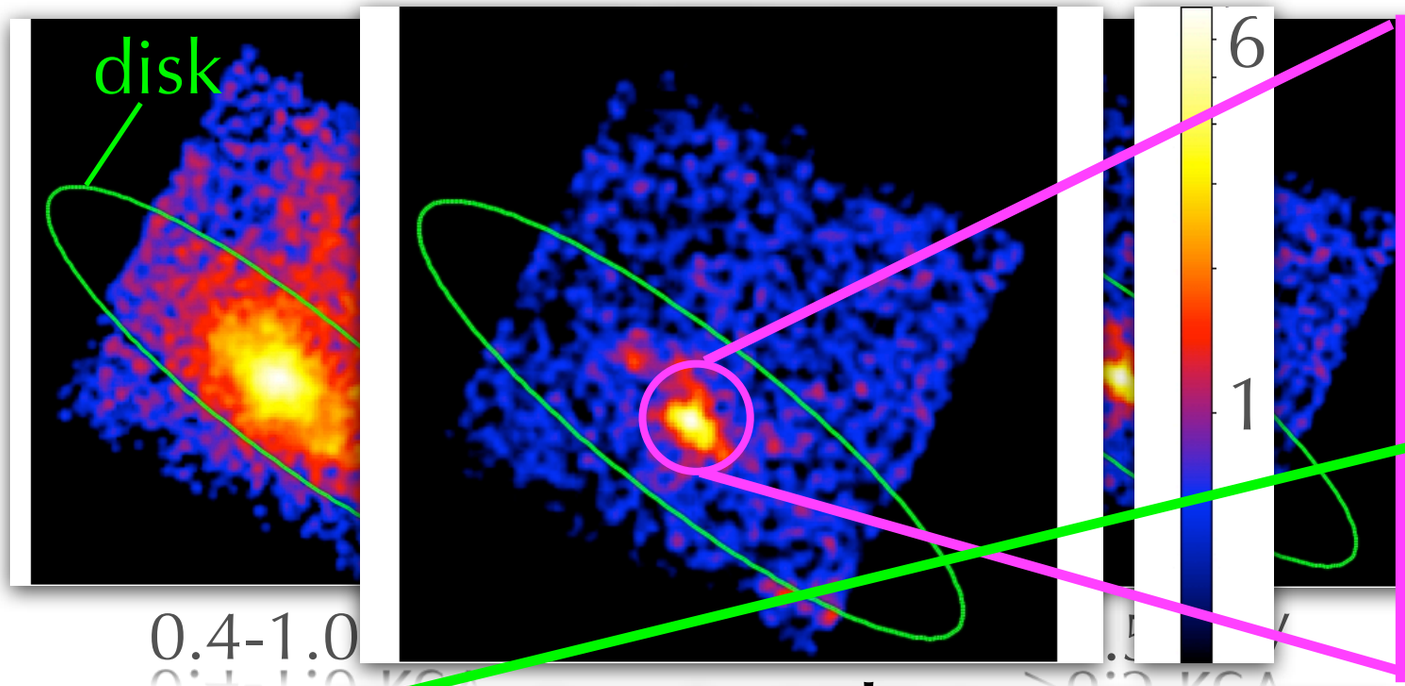
Gamma-ray
Bepposax

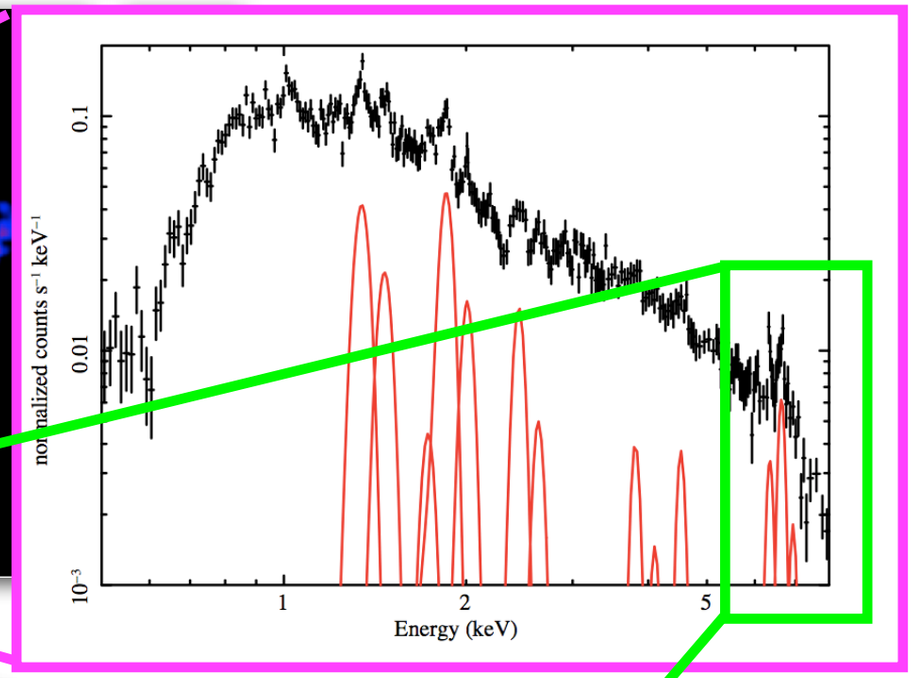


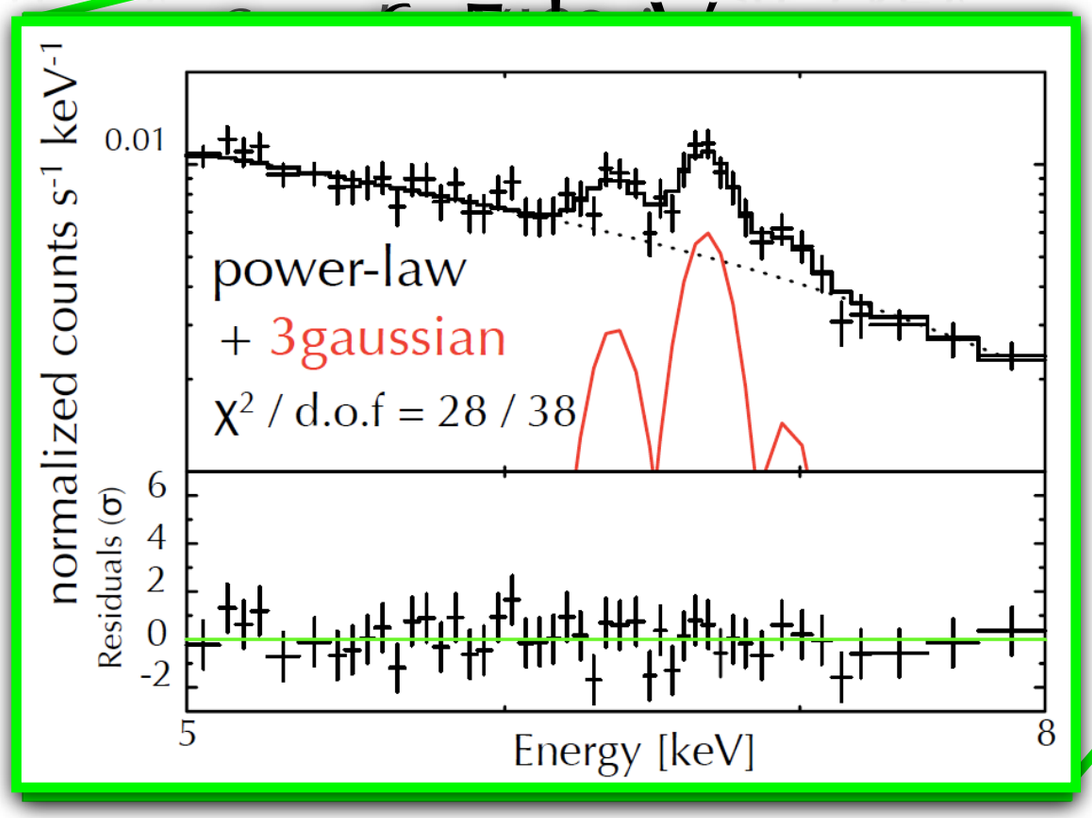
Persic et al. 1998

Abdo et al. 2010

2. Fe K lines in the nuclear region of NGC253 (1)



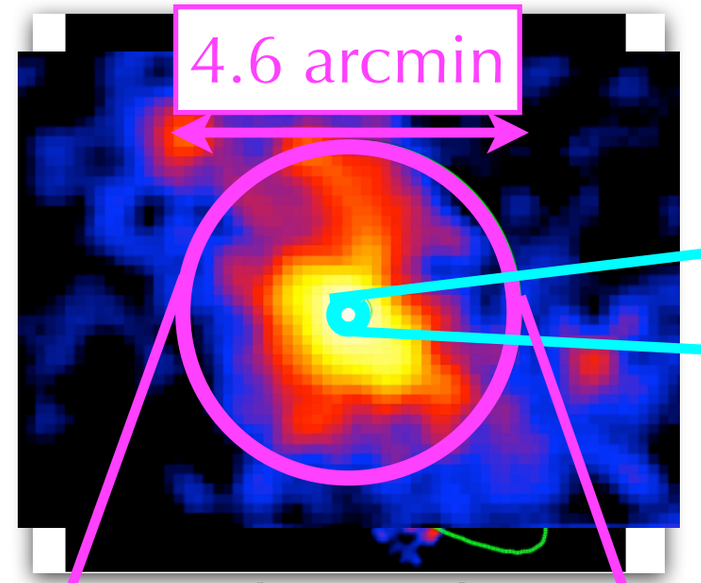




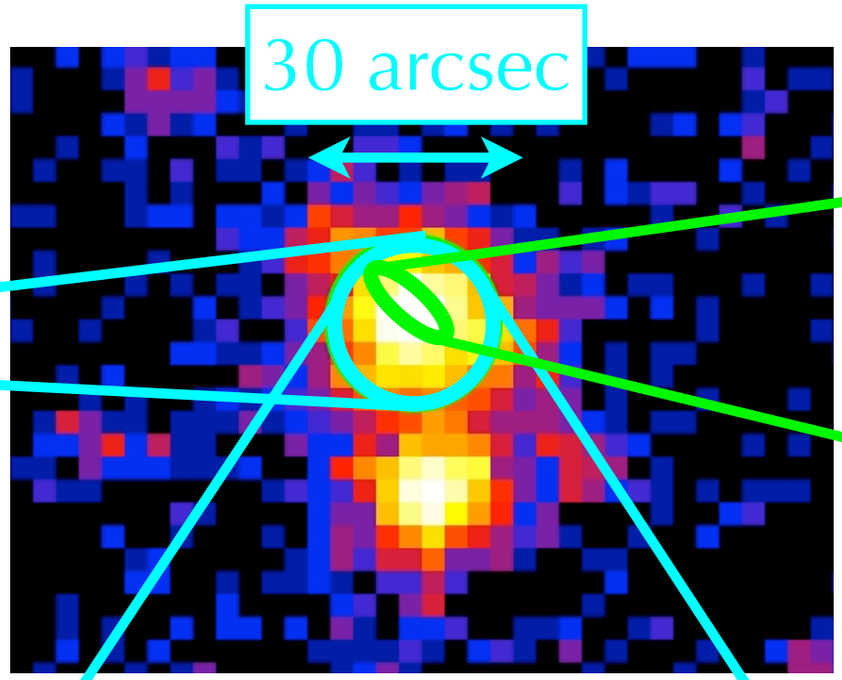
Suzaku XIS3 spectrum with 14 gaussians

We detected the Fe K complex line structure in the nuclear region of NGC253

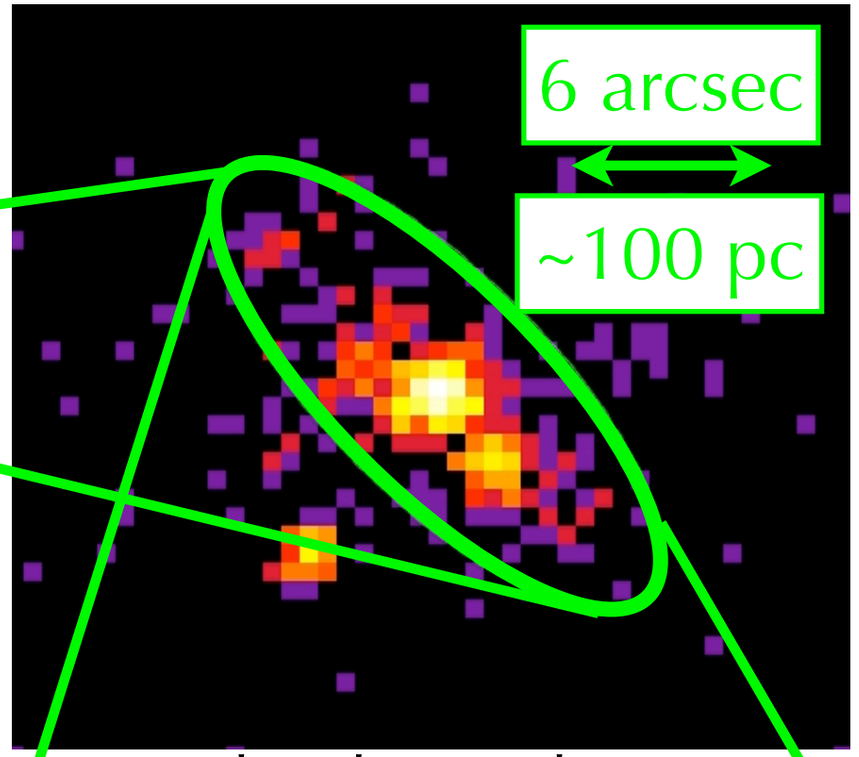
2. Fe K lines in the nuclear region of NGC253 (2)



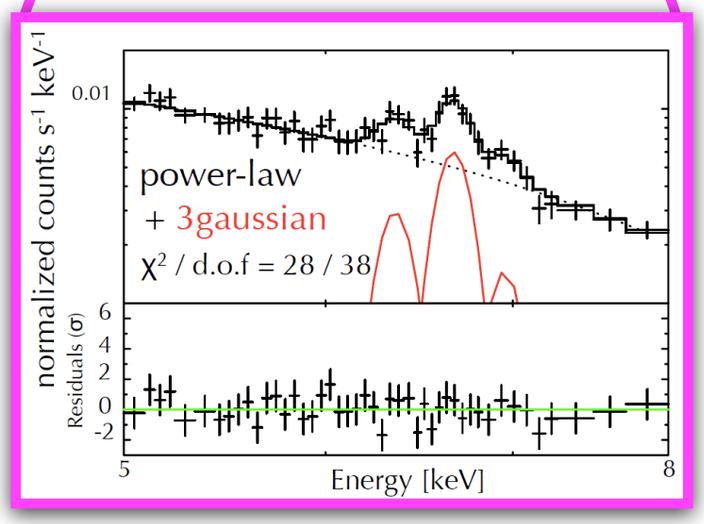
Suzaku (5-8 keV)

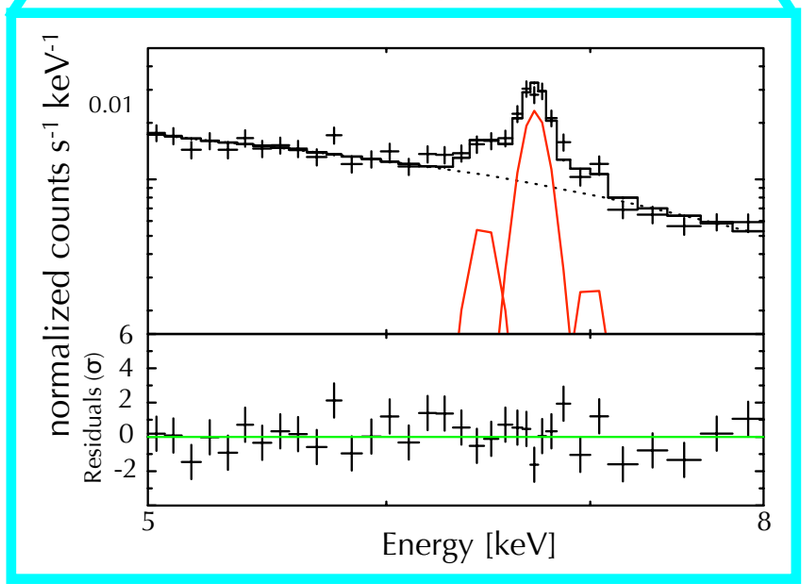


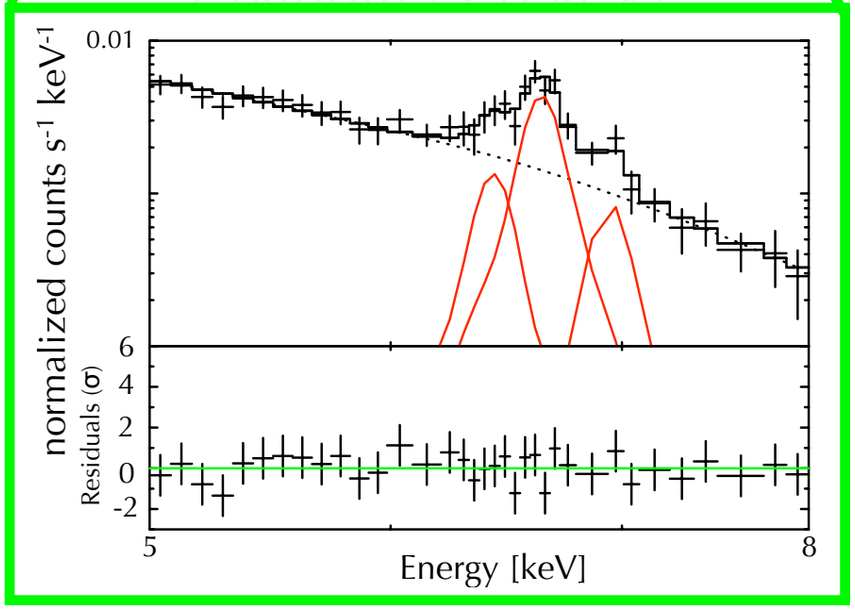
XMM (5-8 keV)



Chandra (5-8 keV)



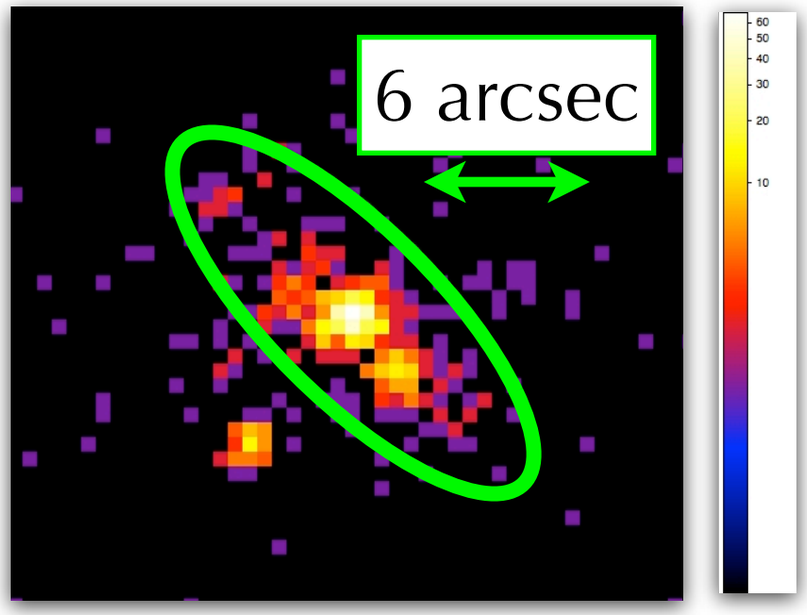




Hard emission was originated from only ~60 arcsec^2 region

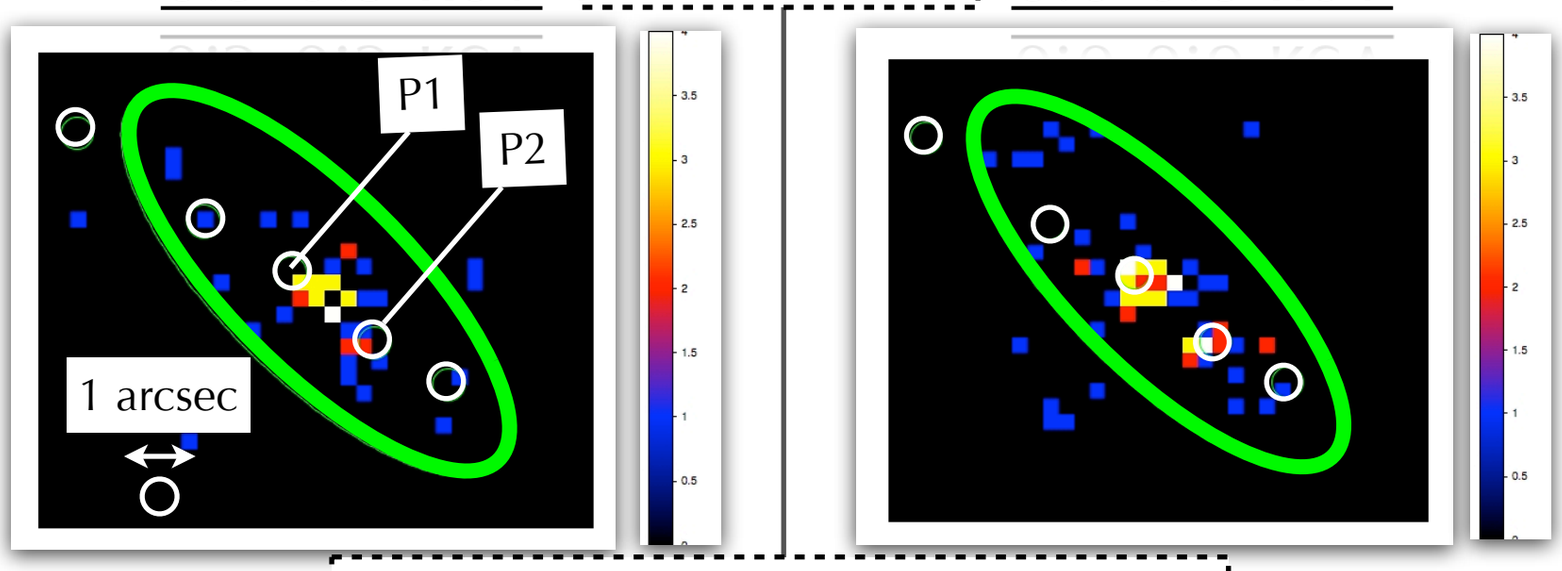
2. Fe K lines in the nuclear region of NGC253 (3)

hereafter we analyzed the Chandra data

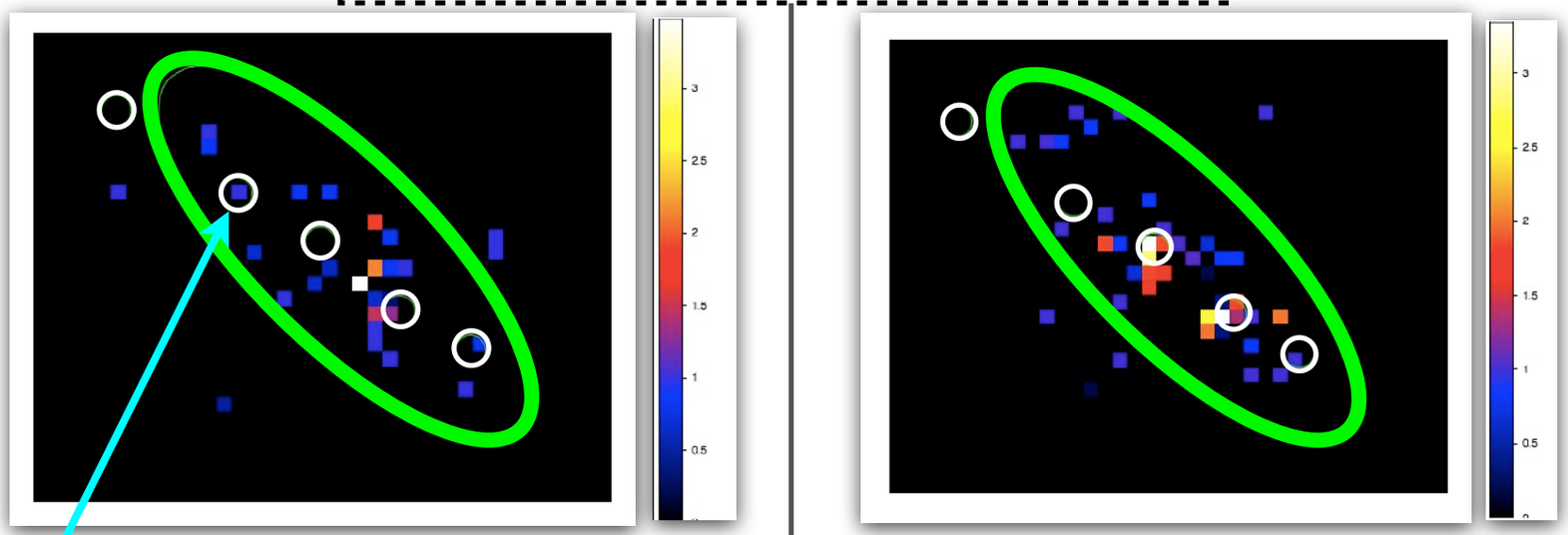


Chandra (5-8 keV)

6.3-6.5 keV line band images 6.6-6.8 keV



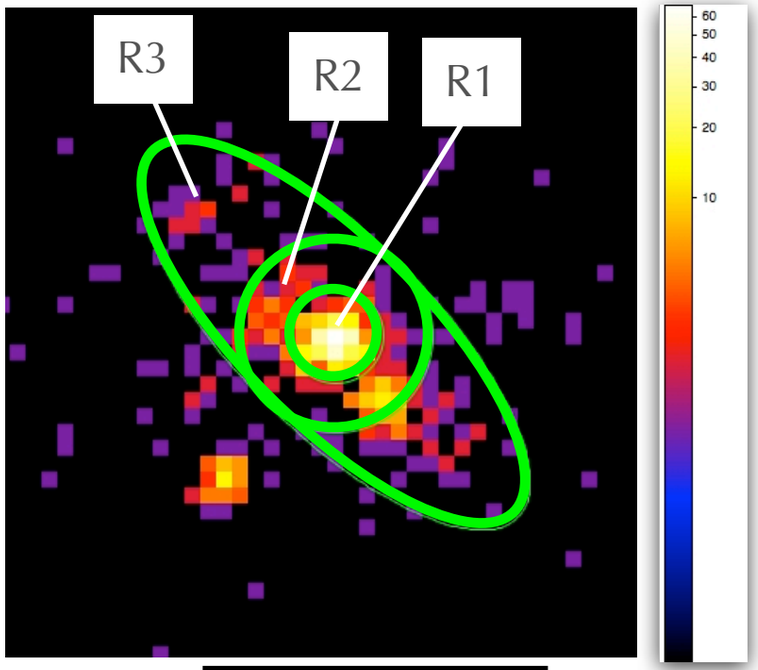
continuum subtracted (line only) images

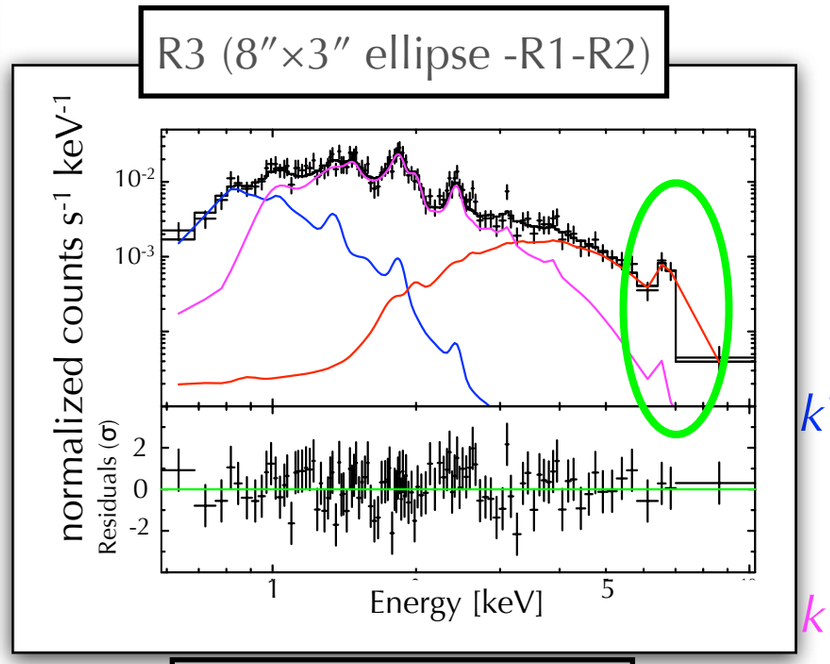


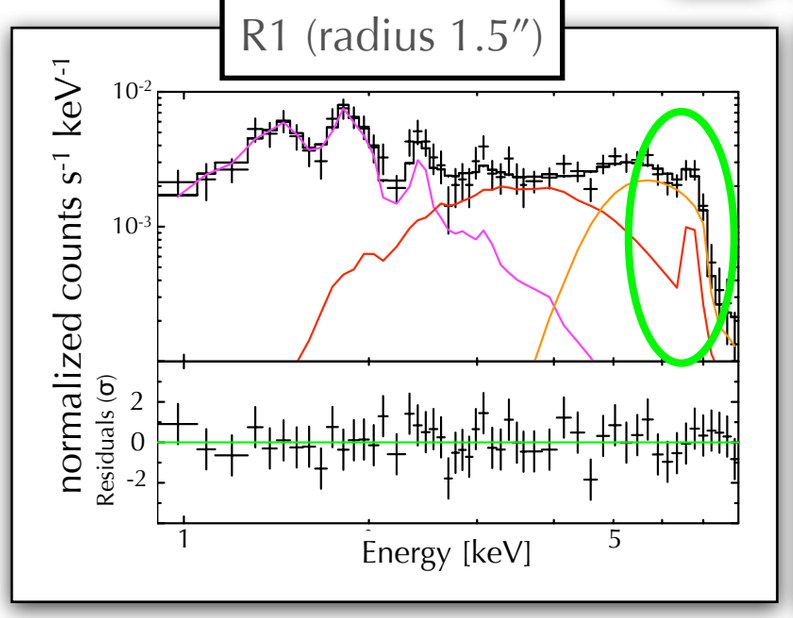
Peak positions in 1.3 mm radio (Sakamoto et al. 2010)
P1: galactic center, P2: most luminous mid-IR source

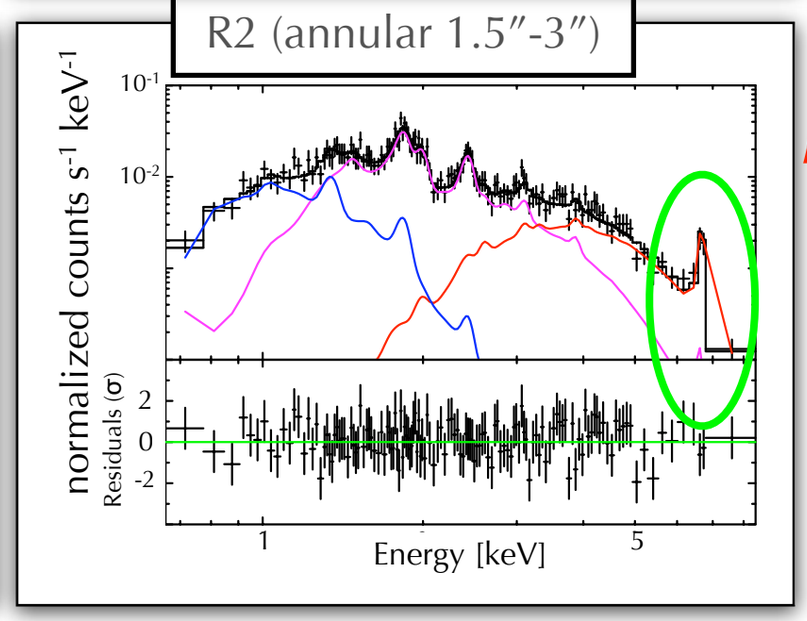
- neutral and He-like Fe K lines seem to have extended emission
- He-like Fe K line seems to be associated with molecular clouds

2. Fe K lines in the nuclear region of NGC253 (4)









fitting parameters

	R1	R2	R3
N_{H1} *		$1.3^{+0.2}_{-0.3}$	$0.7^{+0.3}_{-0.4}$
kT_1 [keV]		$0.31^{+0.35}_{-0.09}$	$0.33^{+0.25}_{-0.09}$
N_{H2} *	2.0 ± 0.2	3.0 ± 0.5	$1.9^{+0.4}_{-0.1}$
kT_2 [keV]	$1.0^{+0.2}_{-0.1}$	1.0 ± 0.1	$0.97^{+0.09}_{-0.08}$
N_{H3} *	$7.6^{+6.6}_{-2.9}$	$11.1^{+7.5}_{-5.5}$	$7.9^{+5.6}_{-2.6}$
kT_3 [keV]	$4.3^{+4.8}_{-3.5}$	$2.5^{+1.9}_{-0.9}$	$3.8^{+1.3}_{-1.6}$
N_H *	102^{+50}_{-36}		
Γ	$4.6^{+1.9}_{-2.2}$		
χ^2/d.o.f	29/43	93/129	86/98

* in the unit of [10^{22} cm^{-2}]

He-like Fe K line was found in all regions→ very extended

kT for 3 regions consistent →similar plasma structure

2. Fe K lines in the nuclear region of NGC253 (5)

Table: Summary of Fe K complex structure

		neutral	He-like	H-like	$L_{0.5\text{-}10.0\ keV}$ [10^{39}erg s^{-1}]	$E_{thermal}$‡ [erg]	Fe mass‡ [solar]
Suzaku (R = 2.3′)	center* [keV]	6.36±0.04	6.68±0.02	6.96±0.06			
	EW [eV]	92^{+32}_{-31}	233^{+43}_{-37}	74^{+44}_{-37}			
	flux†	$3.6^{+1.3}_{-1.1}$	$8.1^{+1.5}_{-1.3}$	$2.2^{+1.3}_{-1.1}$			
Chandra (R1+R2+R3) (16″×6″)	center* [keV]	$6.43^{+0.07}_{-0.05}$	6.64±0.02	$6.95^{+0.07}_{-0.08}$	$2.8^{+2.9}_{-0.5}$	$1.1^{+1.2}_{-0.5}$	86^{+149}_{-22}
	EW [eV]	138^{+92}_{-77}	832±181	242±171			
	flux†	$1.8^{+1.2}_{-1.0}$	6.9±1.5	1.7±1.2			

for high temp plasma

* Energy center at the rest frame
† Photon flux in the unit of 10^{-6} photons s^{-1} cm^{-2}
‡ Assuming the volume to be $(4\pi/3)*48*128^2$ [pc^3] as ellipsoid

3. Discussion of the origin of the Fe K complex line structure (1)

1. Point sources (CVs or active binaries) for neutral, He-like & H-like lines

→unlikely

Total luminosity of high temp plasma ($V_{R1+R2+R3}=(4\pi/3)*48*128**2$ [pc^3]) ~ 3×10^{39} [erg s^{-1}]

→required space density of CVs or active binaries ~ 2 [pc^{-3}] assuming L_X of SS Cyg in outburst period (Ishida et al. 2009) and Algol during flares (Favata et al. 1999)

→at least four or five orders of magnitude higher than Galactic plane (10^{-5} - 10^{-4} [pc^{-3}])

(e.g. Patterson 1998,Rogel et al. 2008)

2. SNRs for He-like & H-like lines

→possible

Total luminosity of high temp plasma ($V_{R1+R2+R3}=(4\pi/3)*24*128**2$ [pc^3]) ~ 3×10^{39} [erg s^{-1}]

→required total number of SNRs ~ 300 assuming the luminosity of Cas-A (ref. Chandra SNR Catalog)

Total thermal energy of high temp plasma ~ 1×10^{54} [erg] assuming the Cas-A case (Willingale et al. 2003)

→required total number of SNRs ~ 1000

Total Fe mass ~ 90 [$M_\odot$]

→required total number of Type II SNRs ~ 1100 assuming the solar abundance (Iwamoto et al. 1999)

→SN rate ~0.1-1 yr^{-1}(Radio Obs: ~0.1 SN rate)

3. Discussion of the oringin of the Fe K complex line structure (2)

3. Reflection from molecular clouds for neutral line

→possible

Line flux of the neutral Fe K line can be estimated as

$$I_{6.4\ keV} = \left(\frac{\Delta\Omega}{4\pi}\right)\epsilon \int_{7.1\ keV}^{\infty} n_{Fe}\cdot\sigma_{Fe}(E)\cdot F(E)\cdot dE \int ds$$

ε: fluorescent yield of the neutral Fe K, σ_{Fe}: photoelectric cross section
n_{Fe}: density of the molecular clouds, $F(E)$: X-ray source intensity

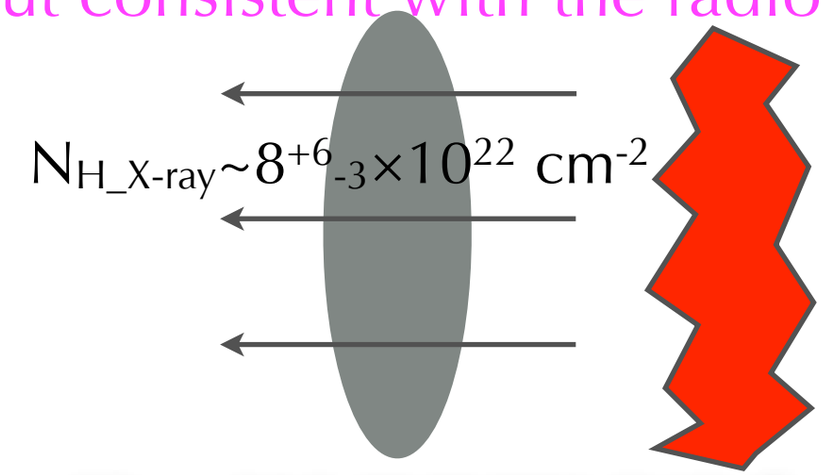
$F(E) \propto \exp(-E/k_BT)$ →

$$N_H = 2.9 \pm 1.0 \times 10^{23} \left(\frac{\Omega}{2\pi}\right)^{-1} \mathrm{cm}^{-2}$$

$$\int n_{Fe} ds = Z_{Fe} N_H = 4.7 \times 10^{-5} \times N_H \quad \epsilon = 0.34$$

$$\sigma_{Fe}(E) = E^{-2.58}\sigma_{Fe} = E^{-2.58} \times 6.0 \times 10^{-18}$$

→ Required column density of molecular clouds is ~3 times larger than the observed level, but consistent with the radio observation results



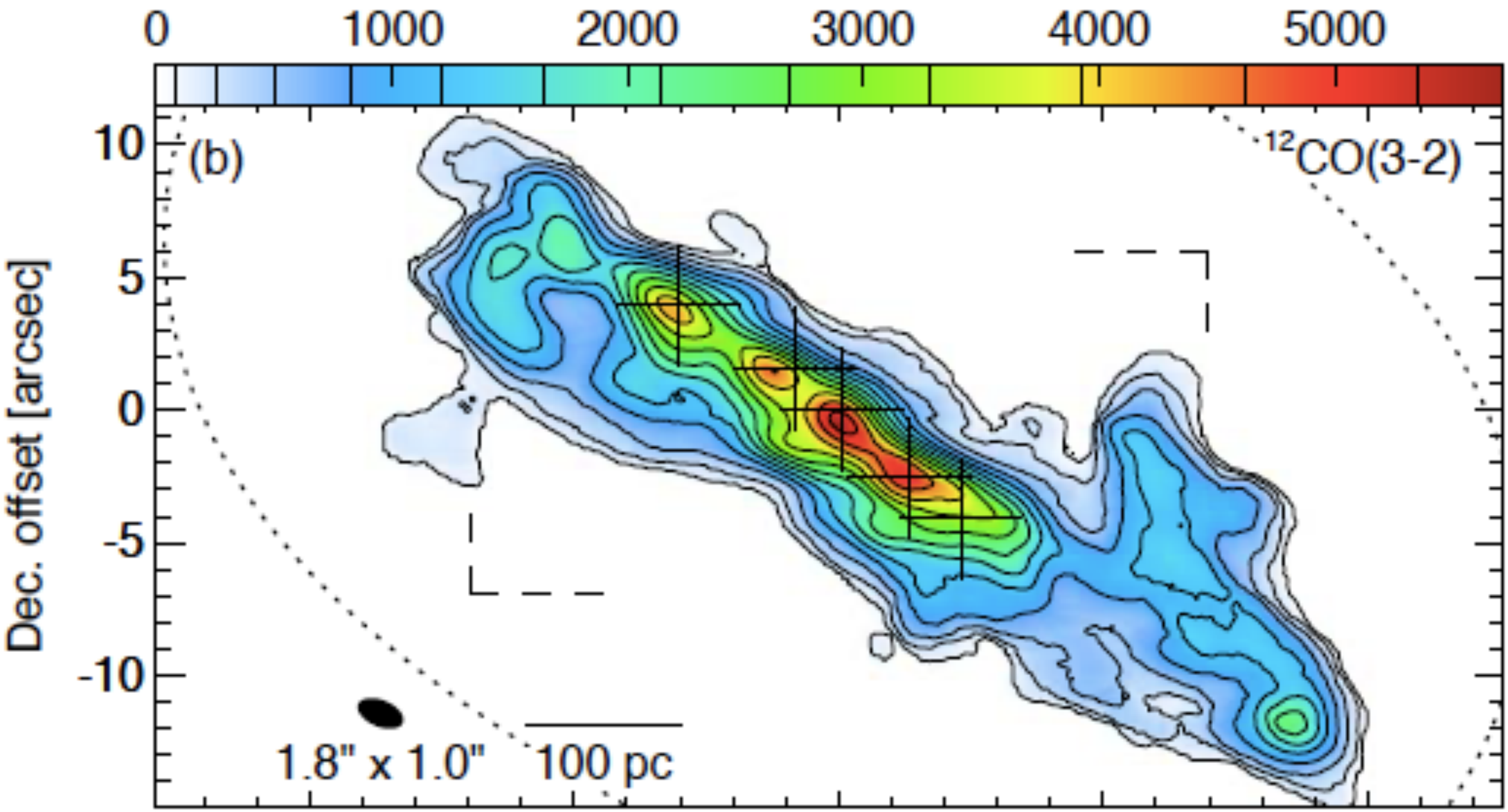
Summary

- Detected the 3 Fe K lines (neutral, He, H like) in the nuclear region of NGC253

- Extended nature (256 [pc] × 96 [pc]) revealed with Chandra

- Origin of Fe lines
  - (He-like & H-like) Fe K lines emitted by young SNRs associated with starburst activity
  - neutral Fe K line possibly from molecular clouds

see Mitsuishi et al. (in prep) in details


0
1000
2000
3000
4000
5000
10
5
0
-5
-10
(b)
^{12}CO(3-2)
Dec. offset [arcsec]
1.8" x 1.0"
100 pc