A Chandra and ALMA Study of X-ray-irradiated Gas in the Central ~100 pc of the Circinus Galaxy
&
A Science Prospect in the XRISM Era

(Kawamuro+19a)

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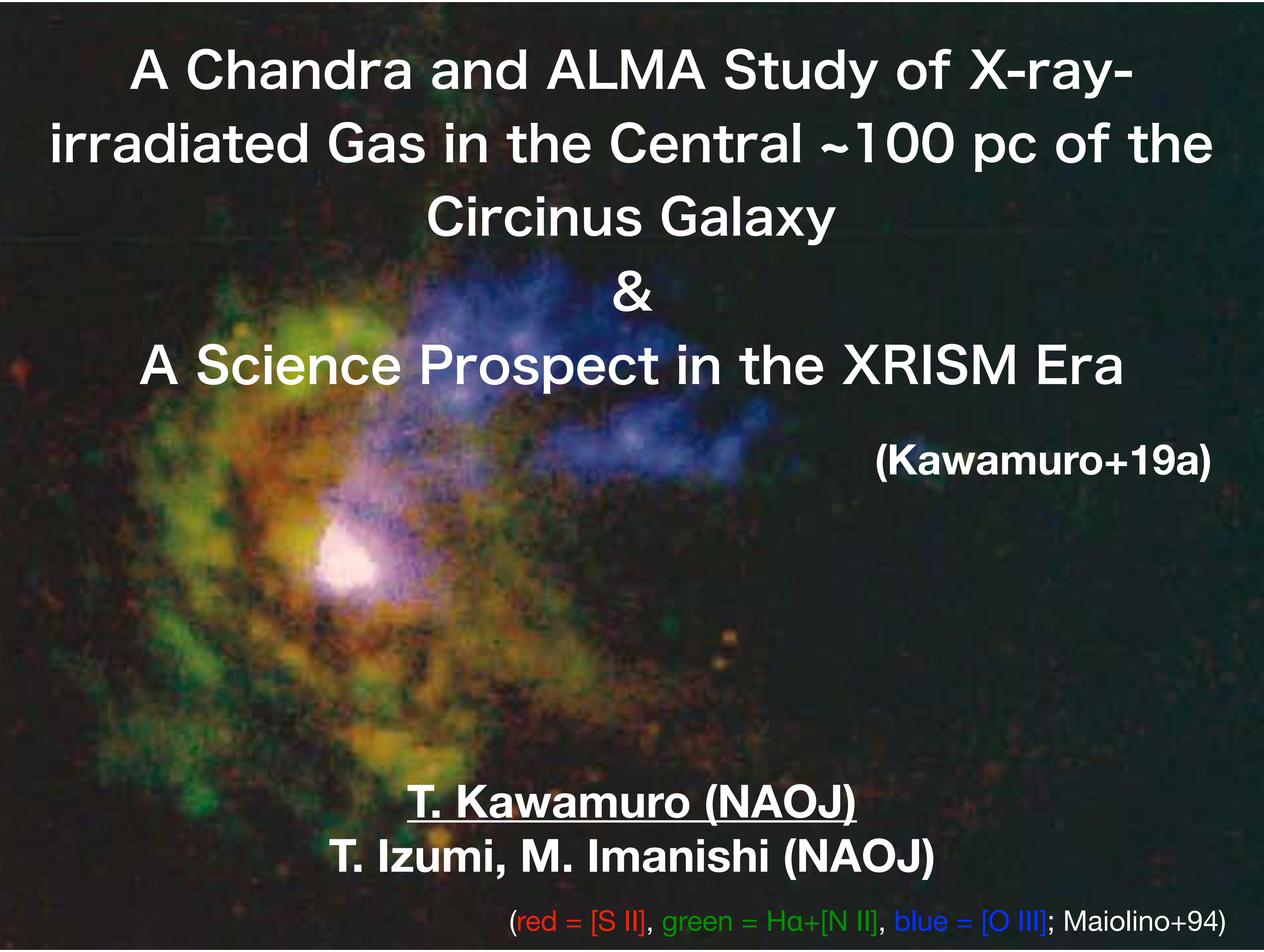
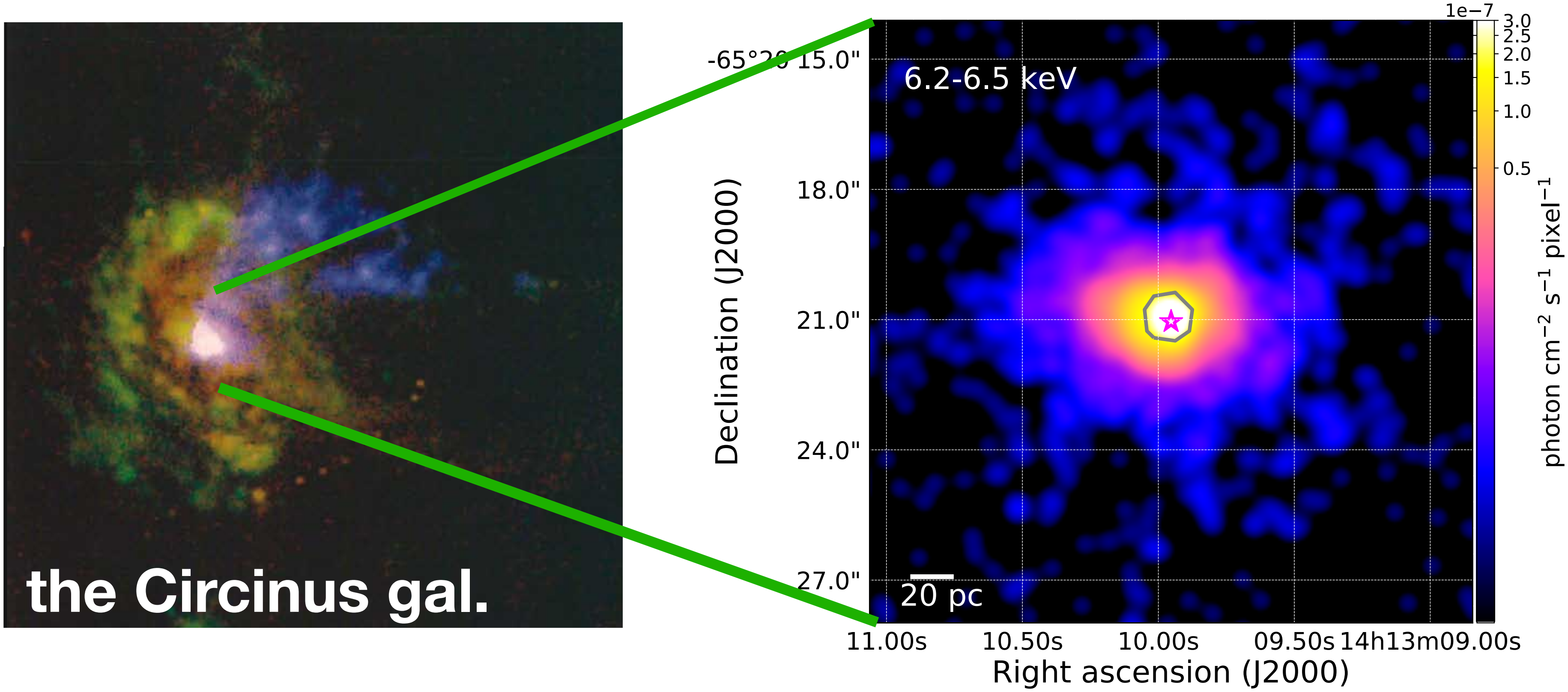


(red = [S II], green = Hα+[N II], blue = [O III]; Maiolino+94)

Spatially-extended Fe emission

- **Motivation: Understanding of co-evolution b/w galaxies and SMBHs**
- **AGNs basically emit X-rays, and therefore X-ray irradiation of the ISM is an un-avoidable effect on host galaxies.**
- **X-ray-irradiated regions can be traced by Fe-Kα emission at 6.4 keV.**

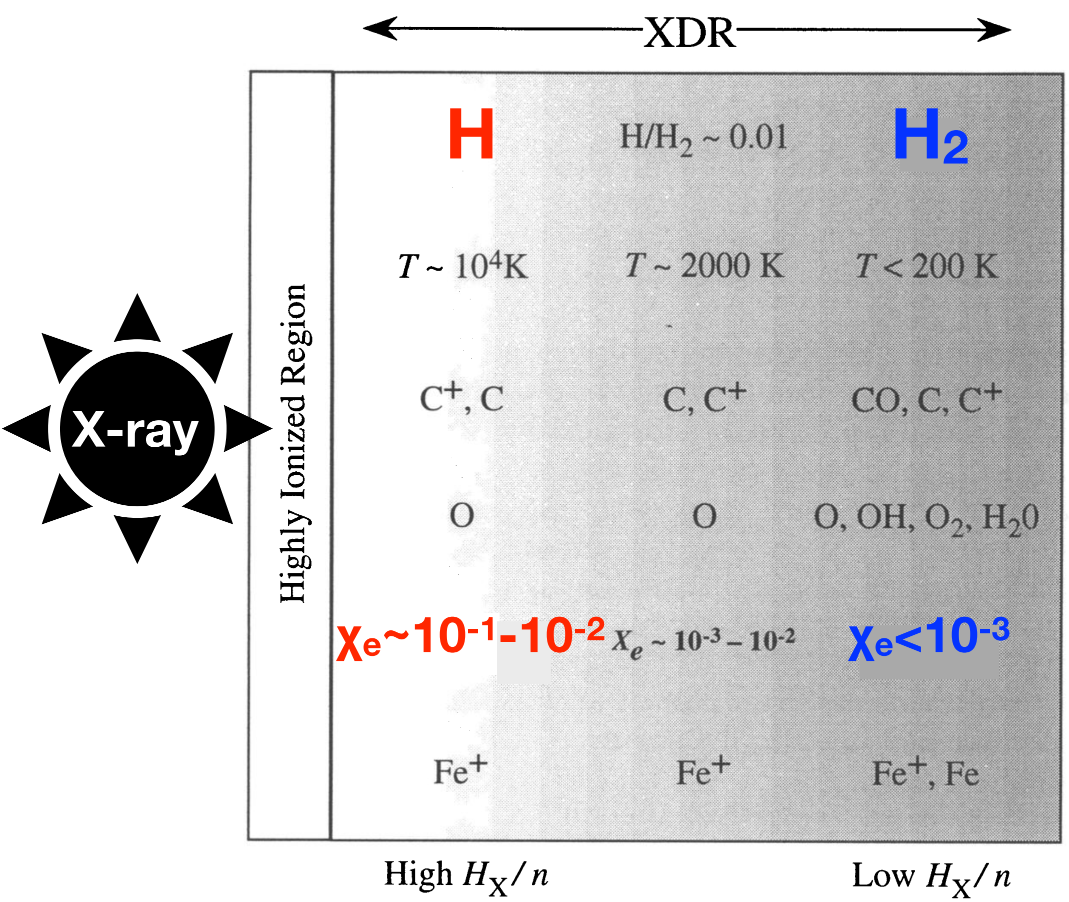


⇒ Study of the Fe-Kα emission would give us insights into an AGN feedback

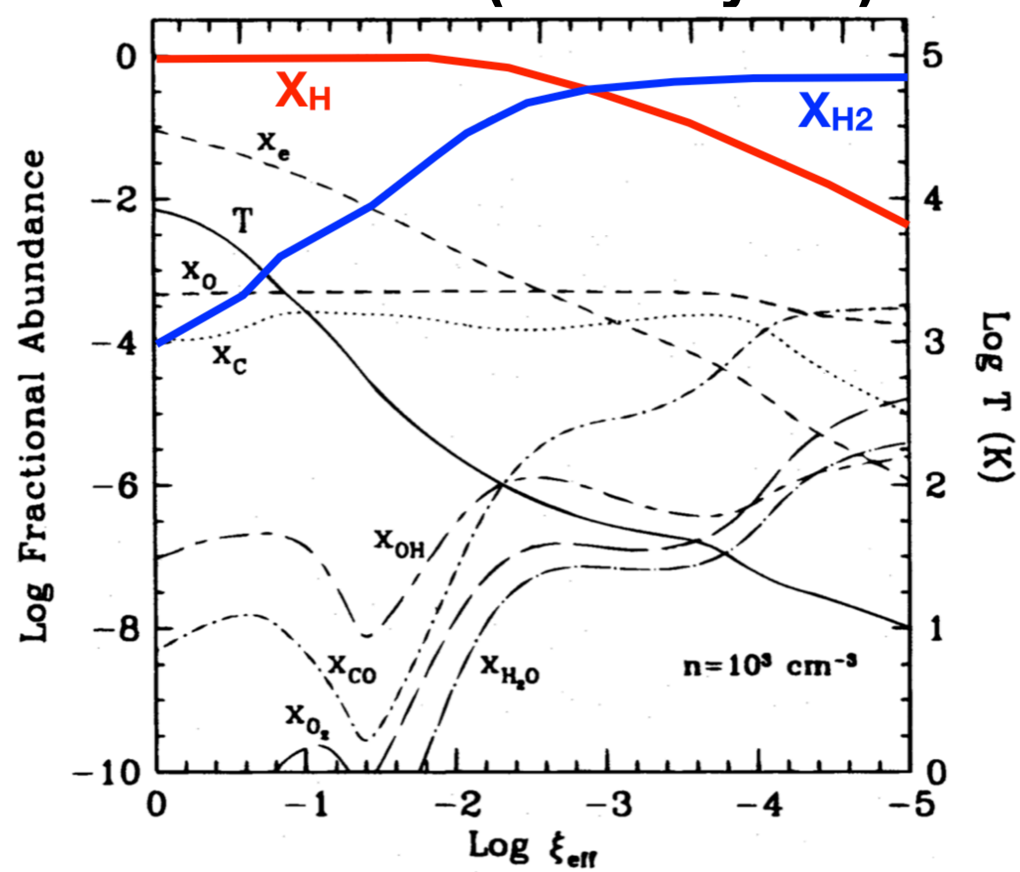
X-ray Irradiation of the ISM

- X-ray irradiation causes a change of the chemical composition. → *X-ray Dominated Region (XDR)*
- In the vicinity of an X-ray src, molecular dissociation is expected.

$$\xi_{eff} = L_X / R^2 n_{H2} N^{1.1}_{att}$$



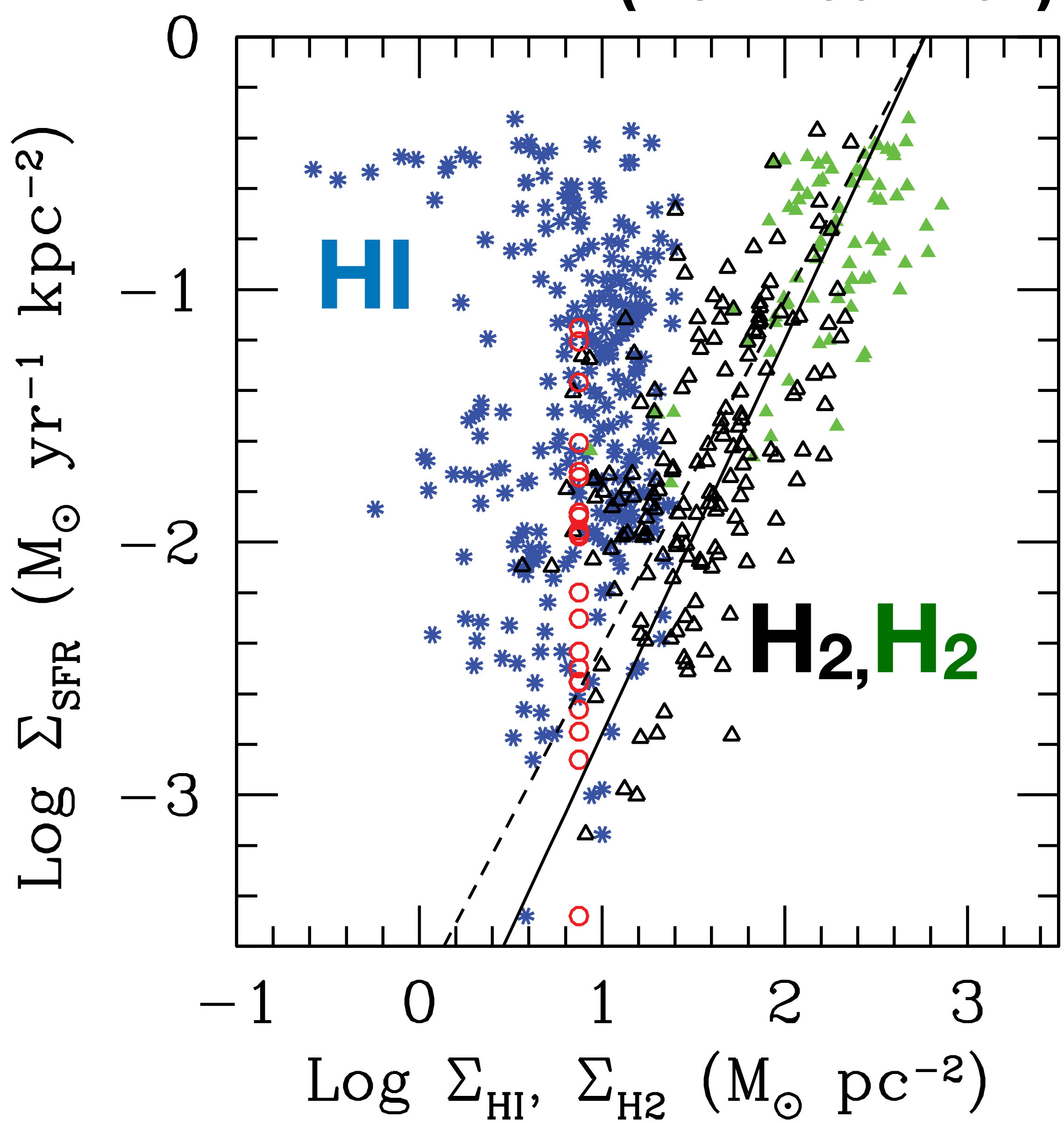
(Maloney+96)



SF and Phases of Gas

- **Why do we care about the mol. gas dissociation?**
- **The positive correlation b/w Σmol and ΣSFR suggests a causal link b/w mol gas and the ability to form stars.**
- **A naive expectation is that X-ray emission can suppress SF by dissociating molecules.**

(Kennicutt+07)



An Observational Test in the Circinus Galaxy

What we have done is to reveal an XDR around an AGN

Target: the Circinus galaxy

- D = 4.2 Mpc (1" ~ 20 pc).
- A Compton-thick AGN host.
  → Good for detecting faint, extended emission.

Obs.: Chandra & ALMA

- high spatial res. (< 1").
- high penetrating power of X-ray & submm/mm.
  → Good to study the dense nuclear region with the least bias.
- high S/N data.

ObsID	Obs. date (UT)	Grating	Exp. (ksec)
(1)	(2)	(3)	(4)
12823	2010/12/17	NO	147
12824	2010/12/24	NO	38
62877	2000/06/16	YES	48
4770	2004/06/02	YES	48
4771	2004/11/28	YES	52

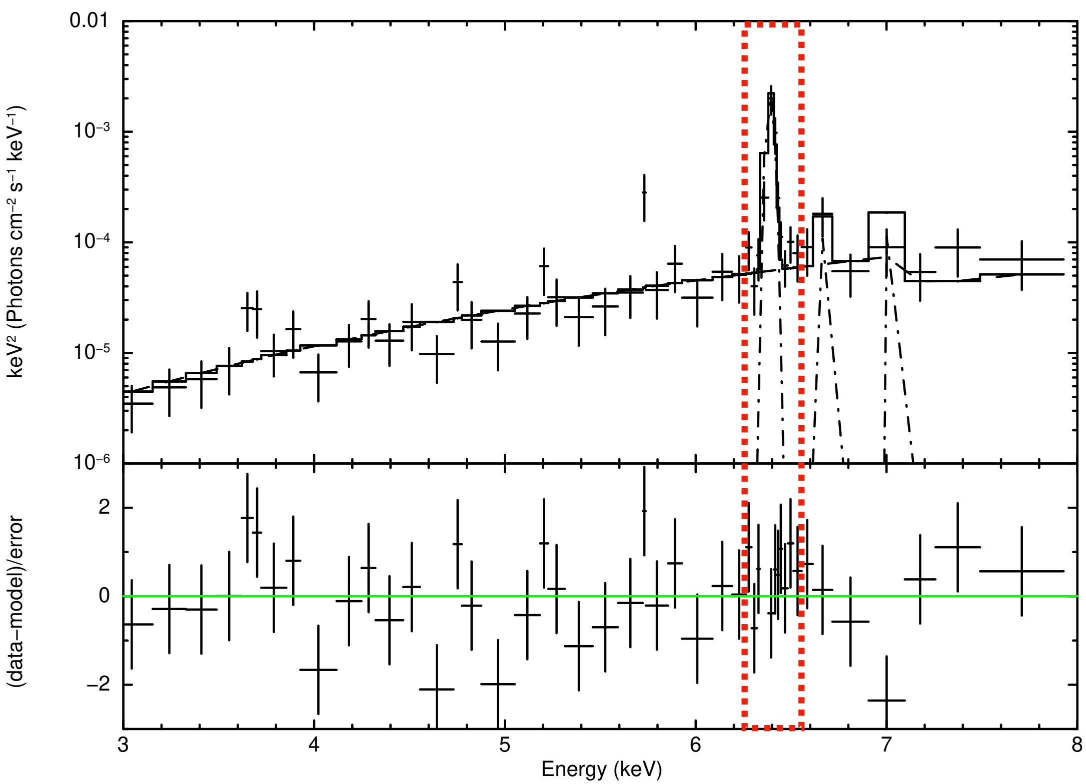
Project code	Obs. date (UT)	Molecules	Exp. (min)
(1)	(2)	(3)	(4)
#2015.1.01286.S (PI: F. Costagliola)	2015/12/31	$HCO^+(J=4–3)$ $HCN(J=4–3)$ $CO(J=3–2)$	3
#2015.1.01286.S (PI: F. Costagliola)	2015/12/31	$HCO^+(J=3–2)$ $HCN(J=3–2)$	5
#2016.1.01613.S (PI: T. Izumi)	2016/11/24	$HCO^+(J=4–3)$	125

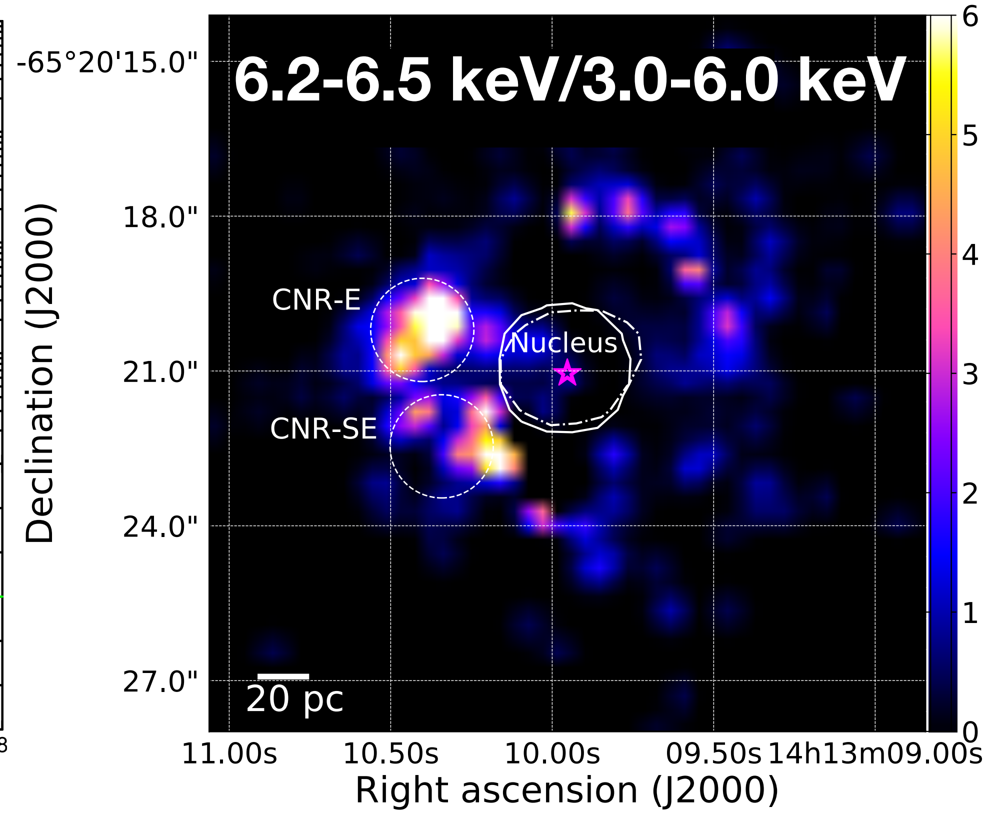
Fluorescent Iron-Kα Line as a Probe

- **The iron-Kα line probes X-ray-irradiated regions.**

  (τ~1 for the X-ray w/ the edge energy when log N_{H}/cm^{-2} ~ 23.9)

- **6.2-6.5 keV/3.0-6.0 keV ratios**
  → an proxy of the EW (Fe-Kα)

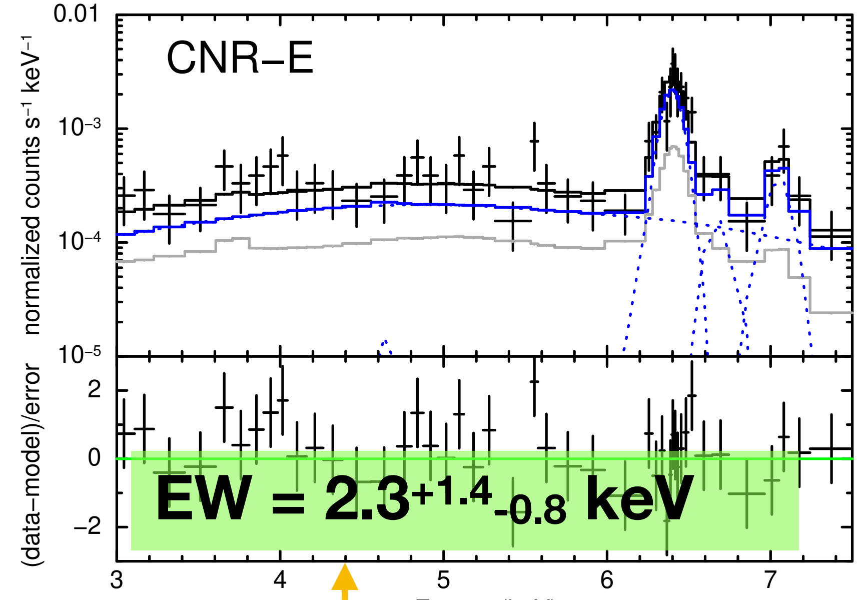


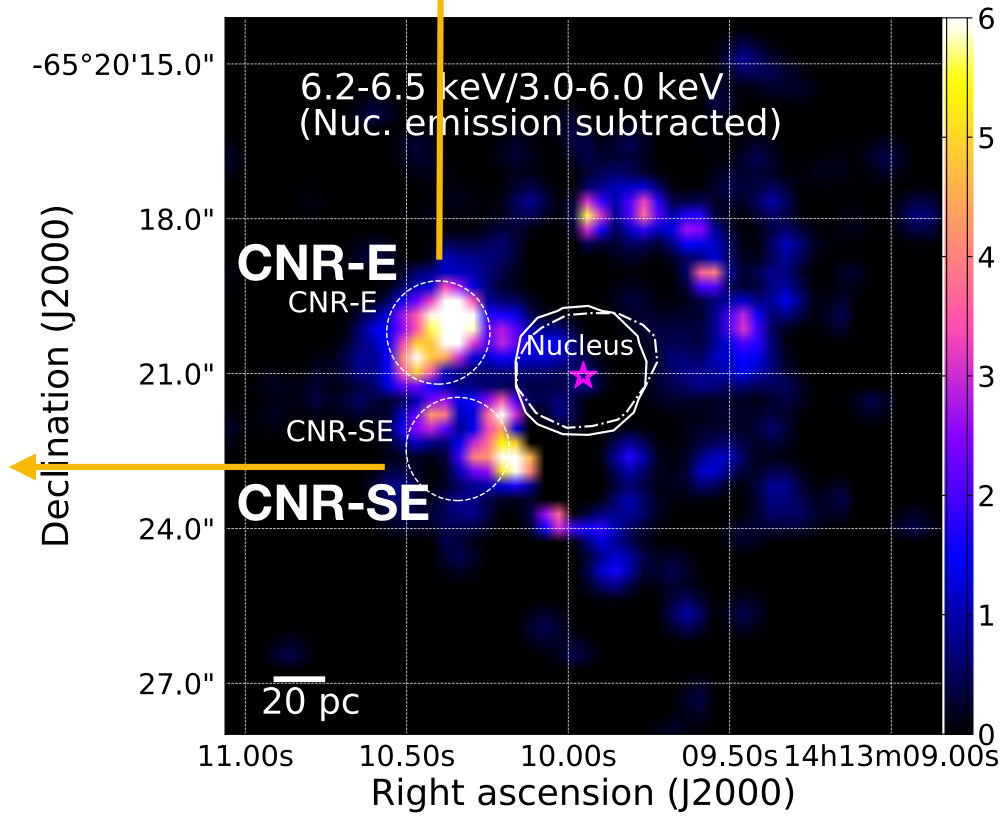


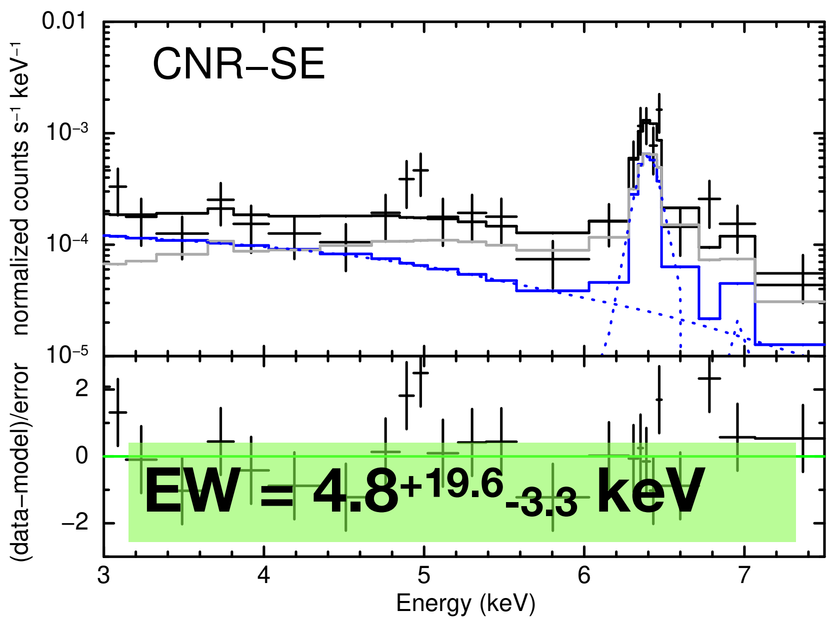
X-ray Irradiation

- **Multiple regions w/ bright Kα emission**

- **high EWs (> 1 keV) are consistent w/ being irradiated by an X-ray src.**

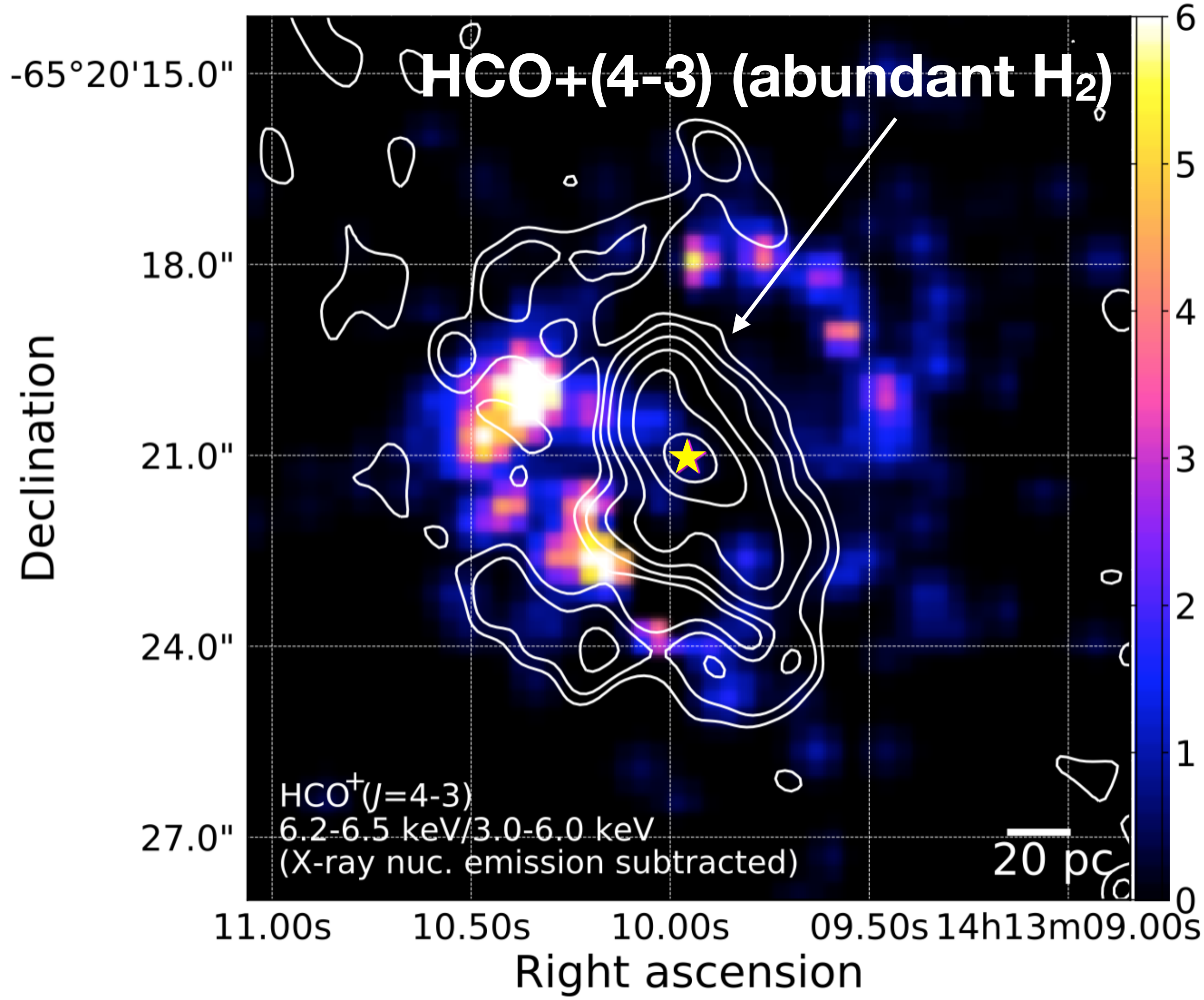






Spatial Anti-correlation b/w Mol. and Iron Line

- HCO+(4-3)
  → Molecular gas
  → high critical dens.
  = dense gas tracer
- Iron-Kα line
  → gas irrespective of atomic/mol. phases



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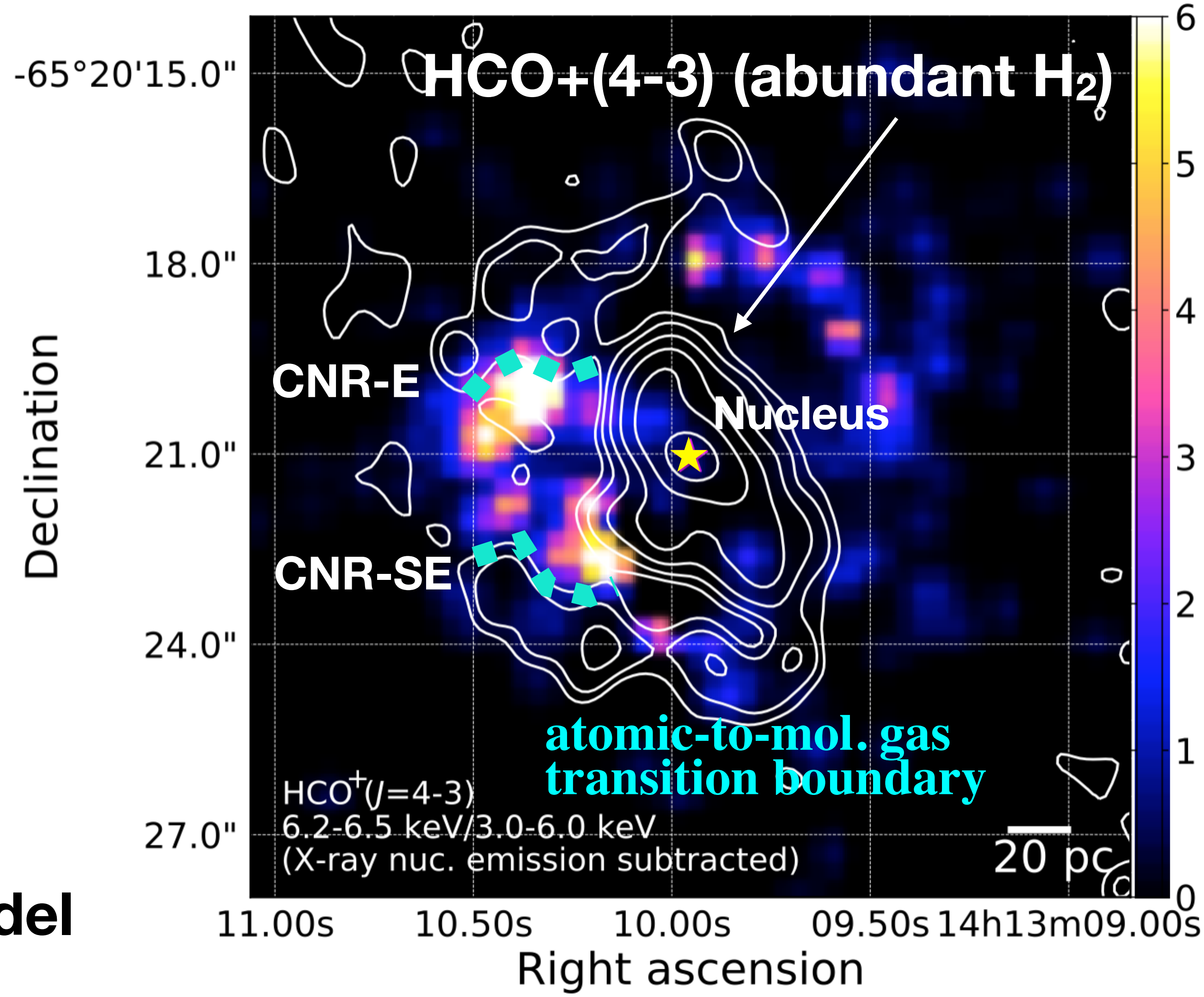
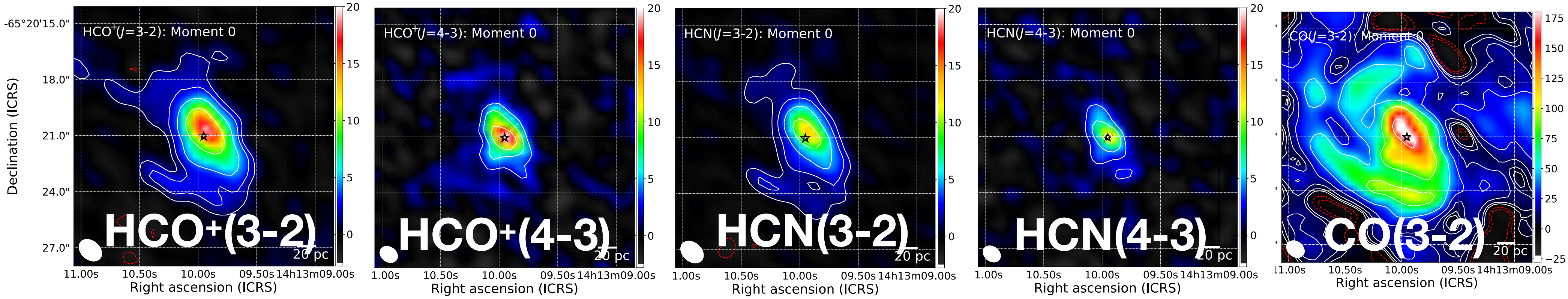
- HCO+(4-3)
  → Molecular gas
  → high critical dens.
  = dense gas tracer
- Iron-Kα line
  → gas irrespective of atomic/mol. phases
- Atomic-to-mol. transition boundaries ?
- Mol. dissociation ?
- Next is quantitative discussion w/ XDR model



$$\xi_{eff} = L_X / R^2 N_{att}^{1.1} n_{H2}$$

Physical State of the ISM

- **Multiple mol. line detections by ALMA**



- **Line ratios are compared w/ statistical equilibrium calculations involving collisional and radiative processes.**

(i.e., non-LTE code by van der Tak+07)

→ constrains on N_{H2}, n(H_2), T_k, [HCN]/[HCO^+]

	Nucleus	CNR-SE	CNR-E
log N_{H2} [cm^{-2}]	24.5 [25.0]	23.5 [24.5-25.0]	24.5 [20.0-25.0]
log n_{H2} [cm^{-3}]	**5.0 [4.5]**	**4.5 [3.0-4.0]**	**3.5 [3.0-5.0]**
T_k [K]	290 [190-400]	130 [80—400]	200 [50-330]
[HCN]/[HCO^+]	3 [-]	4 [2-5]	2 [3-4]

Is the X-ray emission powerful enough?

$\xi_{eff} = L_X / R^2 N^{\alpha}_{att} n_{H2}$

L_X ~ 1.3e+43 (1–100 keV)

(NuSTAR estimate by Arevalo+14)

R ~ 60 pc

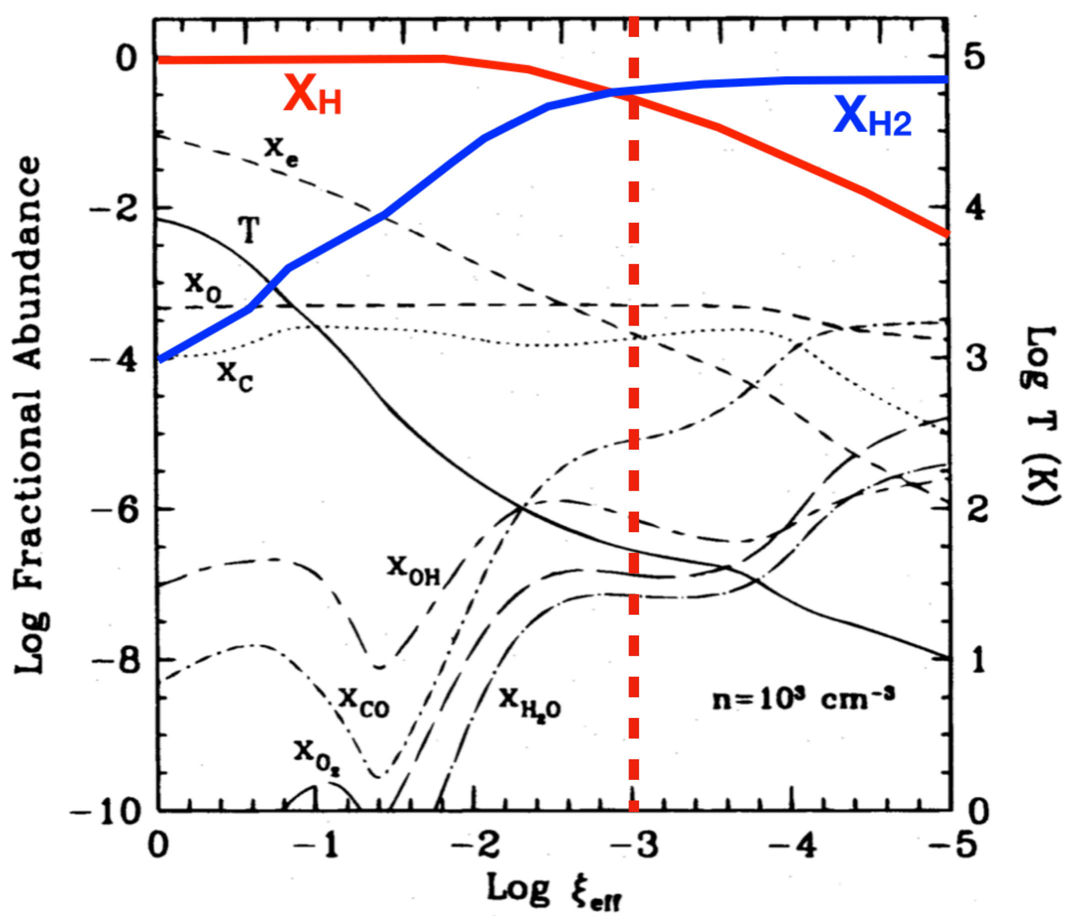
(spatial resolved map)

N_{att} ~ 1e+23.9 cm^{-2}

(τ~1 for the neutral iron)

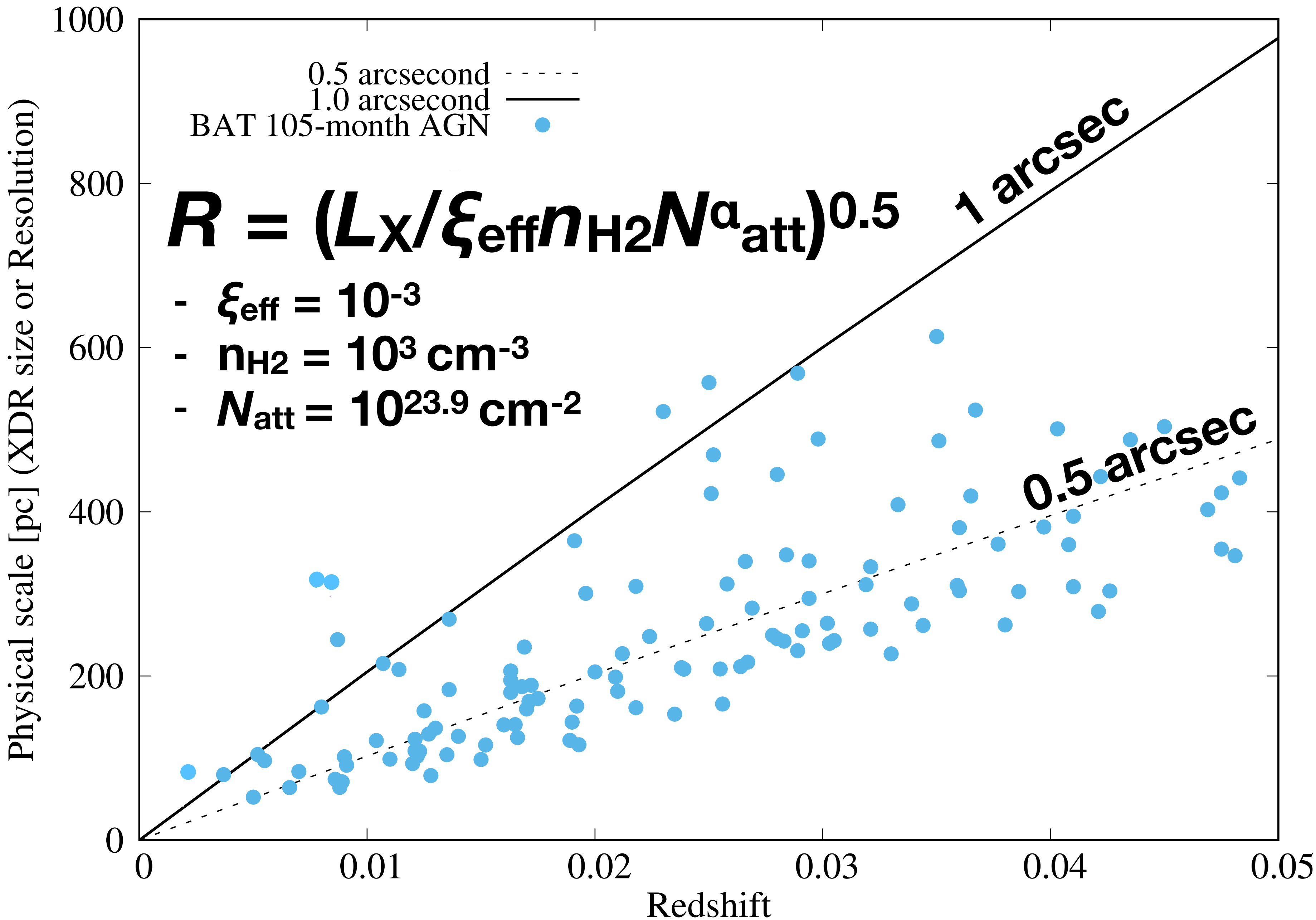
n_{H2} ~ 1e+3.0-5.0 cm^{-3}

(mol. line ratios fit by RADEX)



	Nucleus	CNR-SE	CNR-E
log ξ_{eff}	< -4.0	-4.6~-2.6	-4.0~-2.5

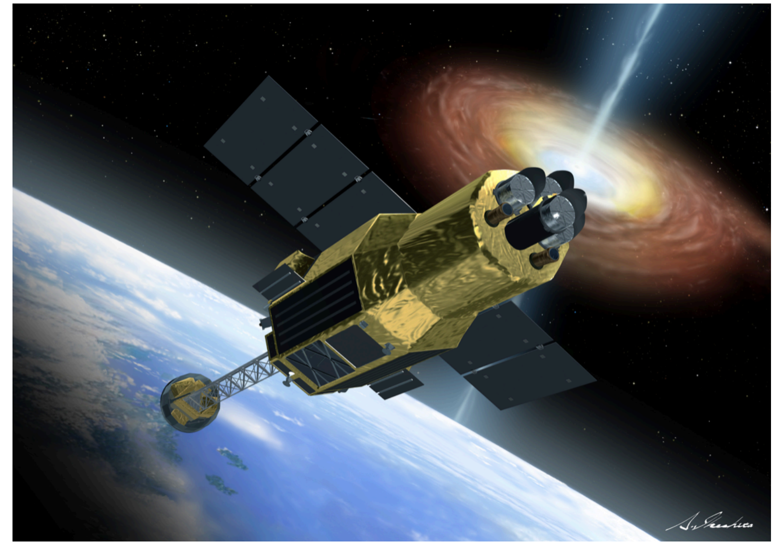
Towards a further XDR study

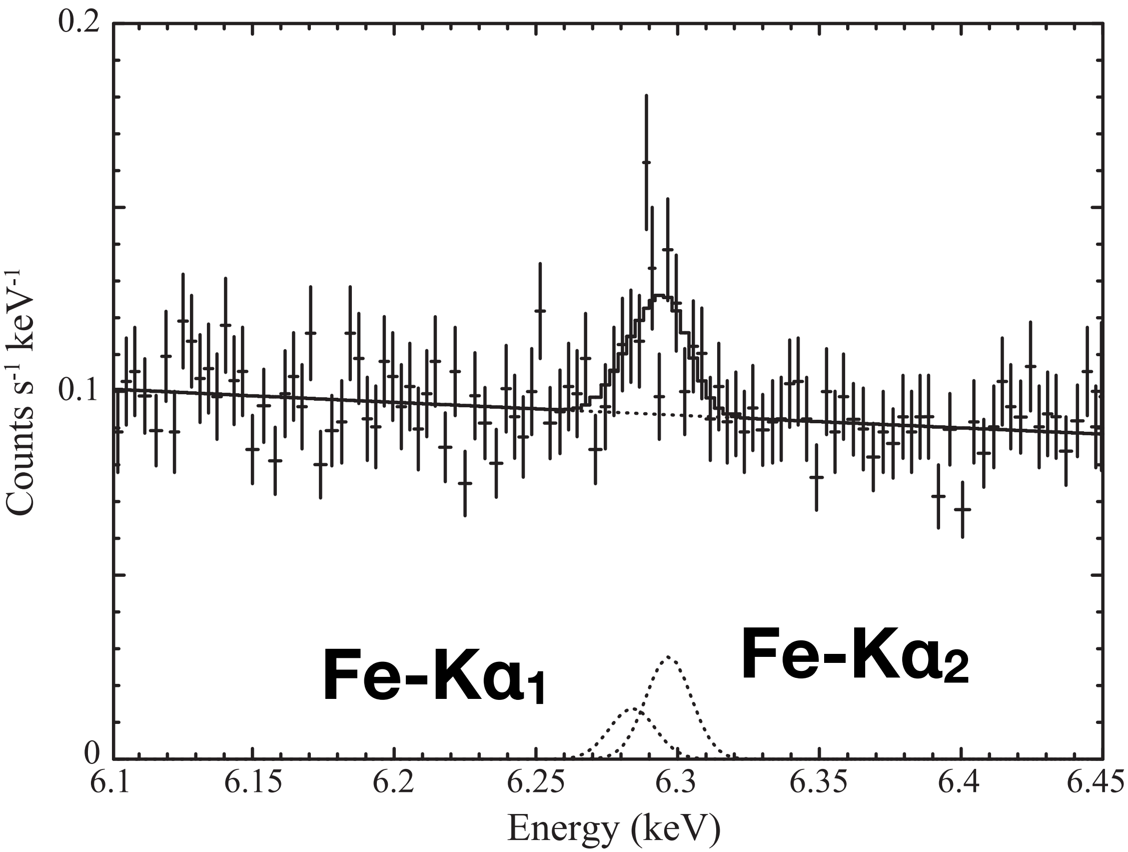


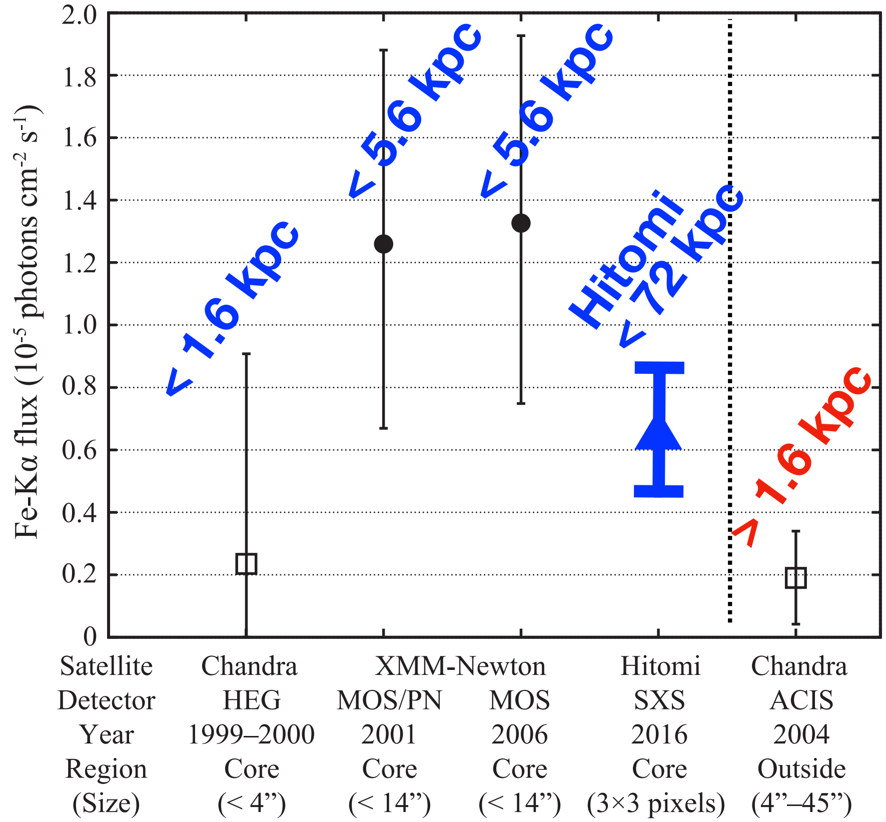
High-E resolution calorimeters

- *Hitomi* study of NGC 1275 constrained iron line emitting regions.
  - 1σ ~ 200-700 km/s => r > 1 pc
  - the help of CXO => r < 2 kpc

→ torus ~ circum-nuclear disk





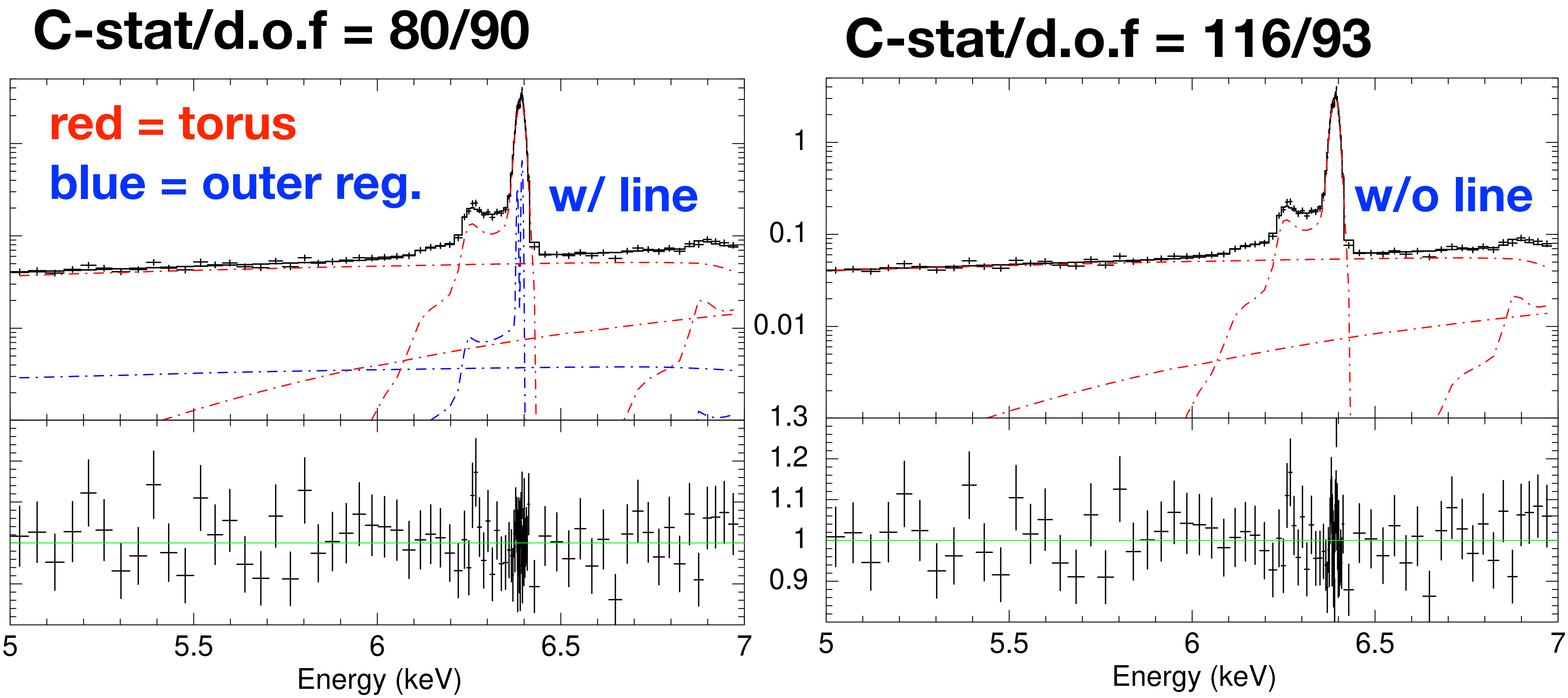


Disentanglement of iron lines w/ XRISM

XRISM (Astro-H) obs. simulation of a Circinus like spectrum

- a ratio of fluxes from a torus and an outer region is ~ 6%
- their velocity disp. (σ) are set to ~ 1000 km/s (from CXO) and ~ 20km/s (from ALMA)
- exposure = 100 ksec

We may detect iron lines ($K\alpha_1$, $K\alpha_2$) from an outer region.



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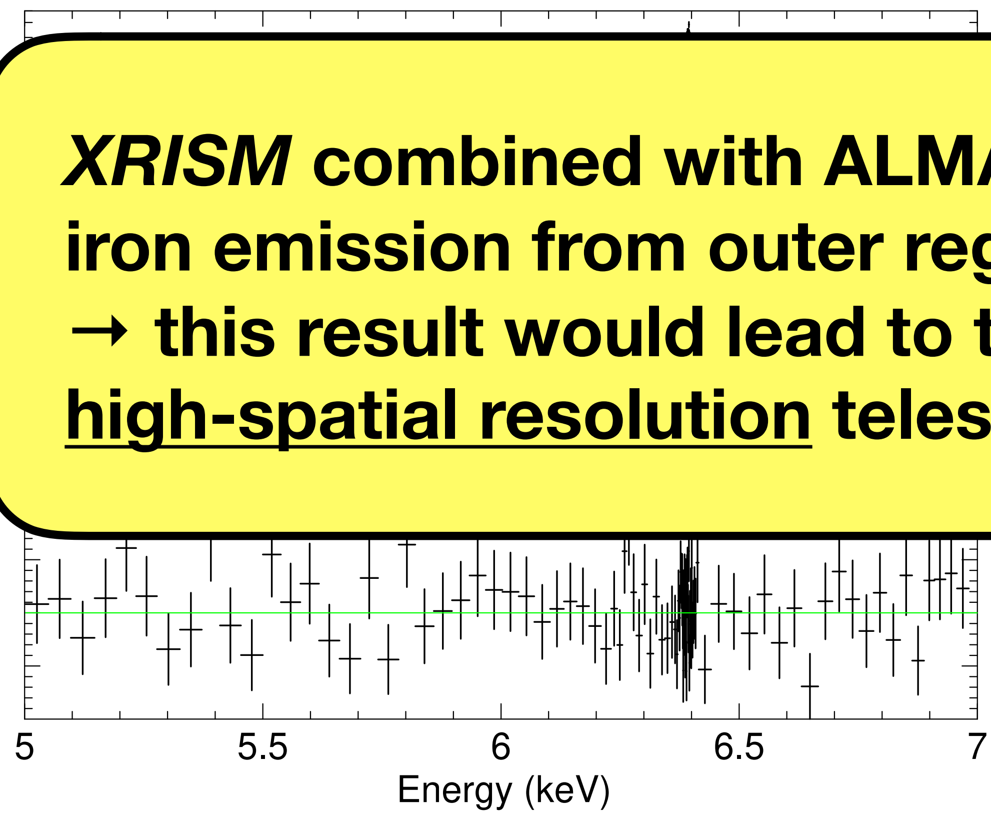
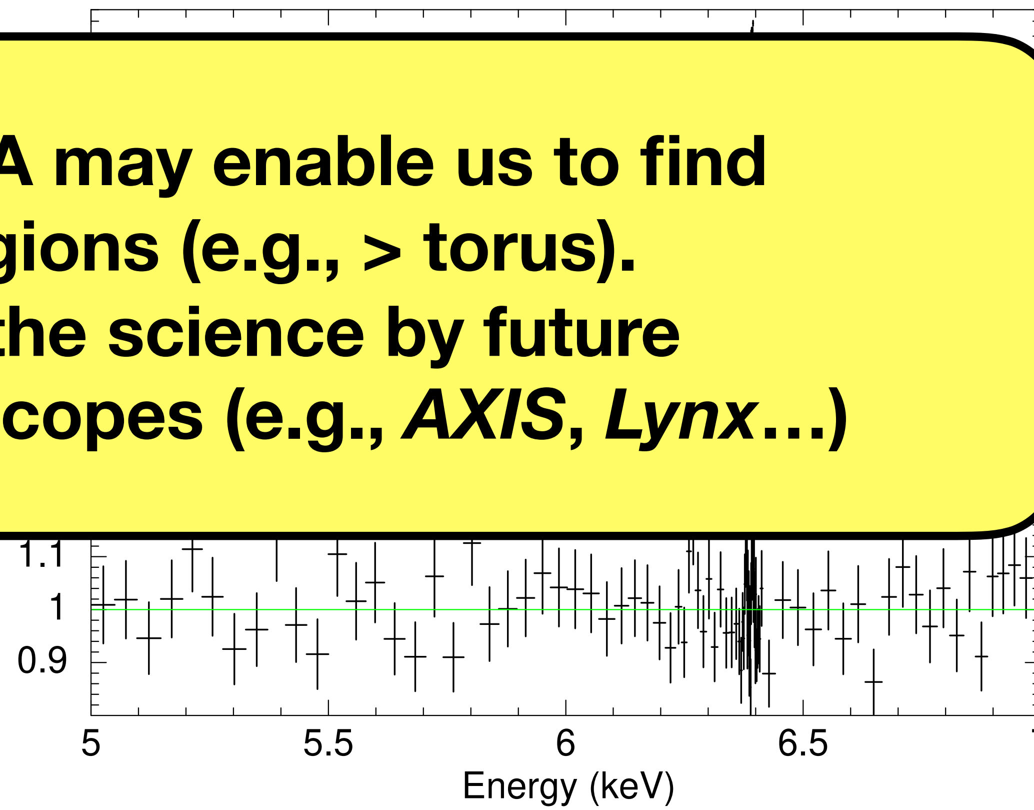
C-stat/d.o.f = 80/90

C-stat/d.o.f = 116/93

XRISM **combined with ALMA may enable us to find iron emission from outer regions (e.g., > torus).**
→ this result would lead to the science by future <u>high-spatial resolution</u> telescopes (e.g., *AXIS*, *Lynx*…)





Summary

- AGN usually emit X-rays, and therefore the X-ray irradiation is an un-avoidable effect on the host galaxy.

- Chandra and ALMA obs. have revealed the spatial anti-correlation b/w the molecular gas and iron-Kα line emission.

- Moderately high ionization parameters are consistent with molecules being dissociated by the X-ray emission.

- XRISM will also have potential to study the extended X-ray emission.
  → This result would lead to the future high spatial-resolution projects (e.g., AXIS, Lynx).