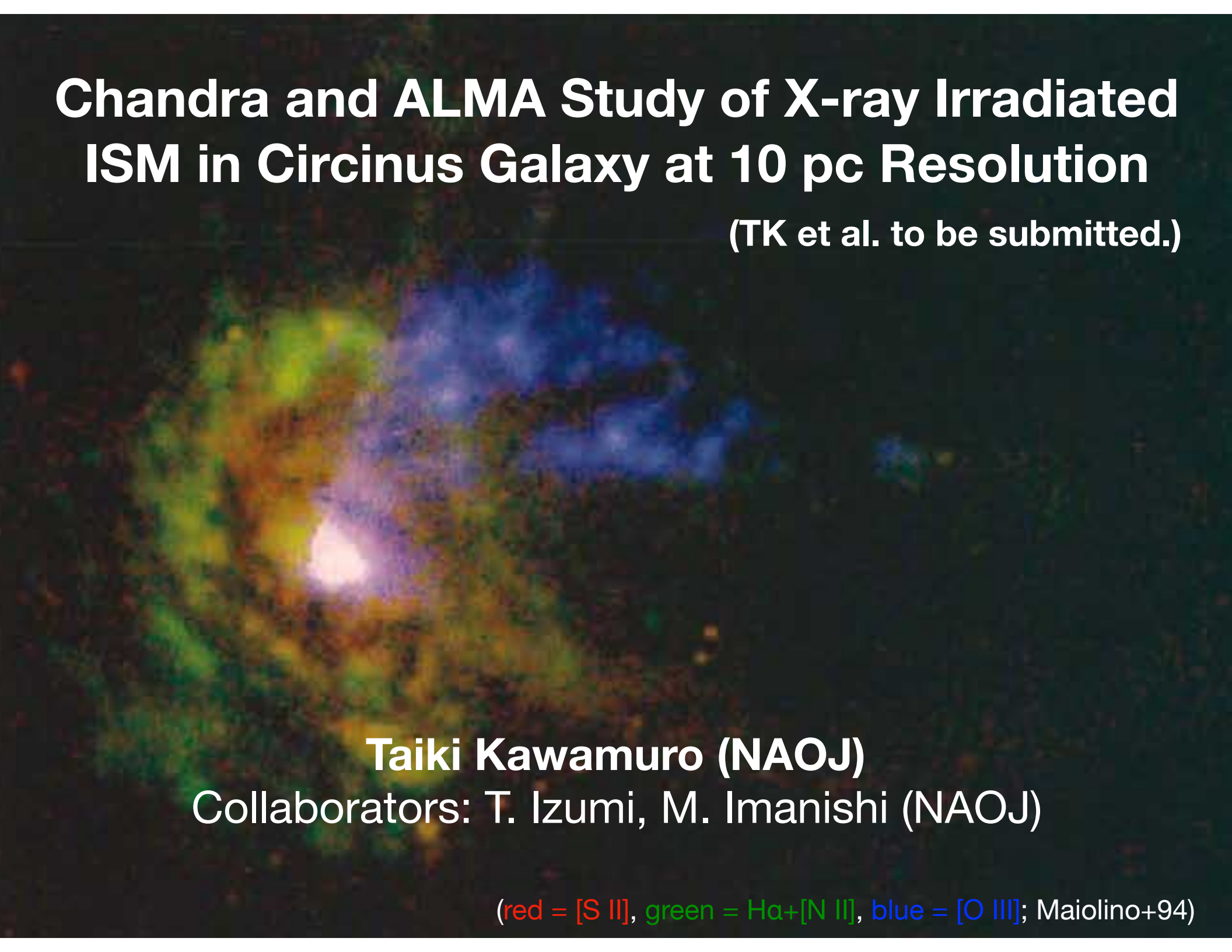
Chandra and ALMA Study of X-ray Irradiated ISM in Circinus Galaxy at 10 pc Resolution

(TK et al. to be submitted.)



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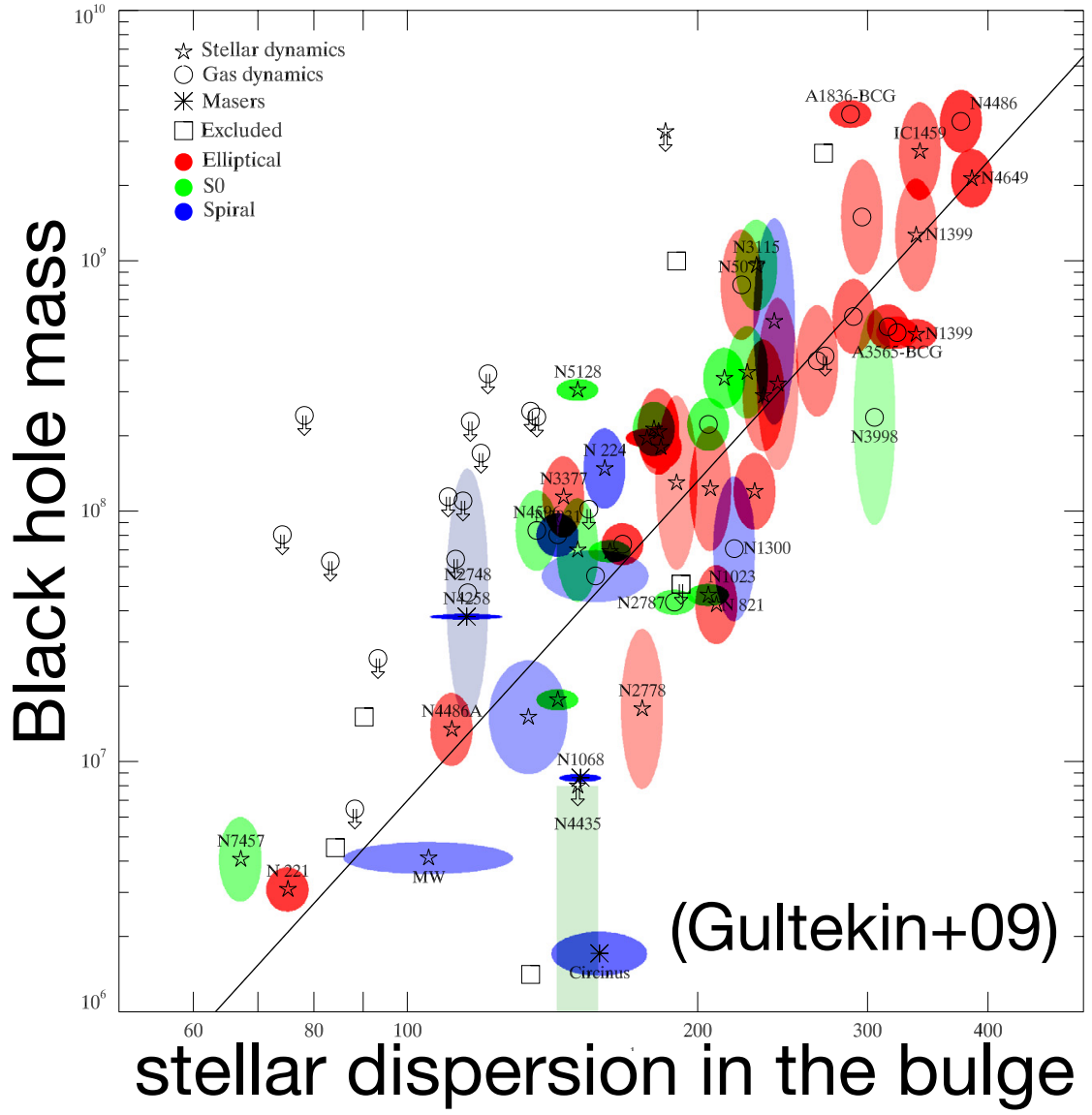
Collaborators: T. Izumi, M. Imanishi (NAOJ)

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

Galaxy and Black Hole Co-evolution

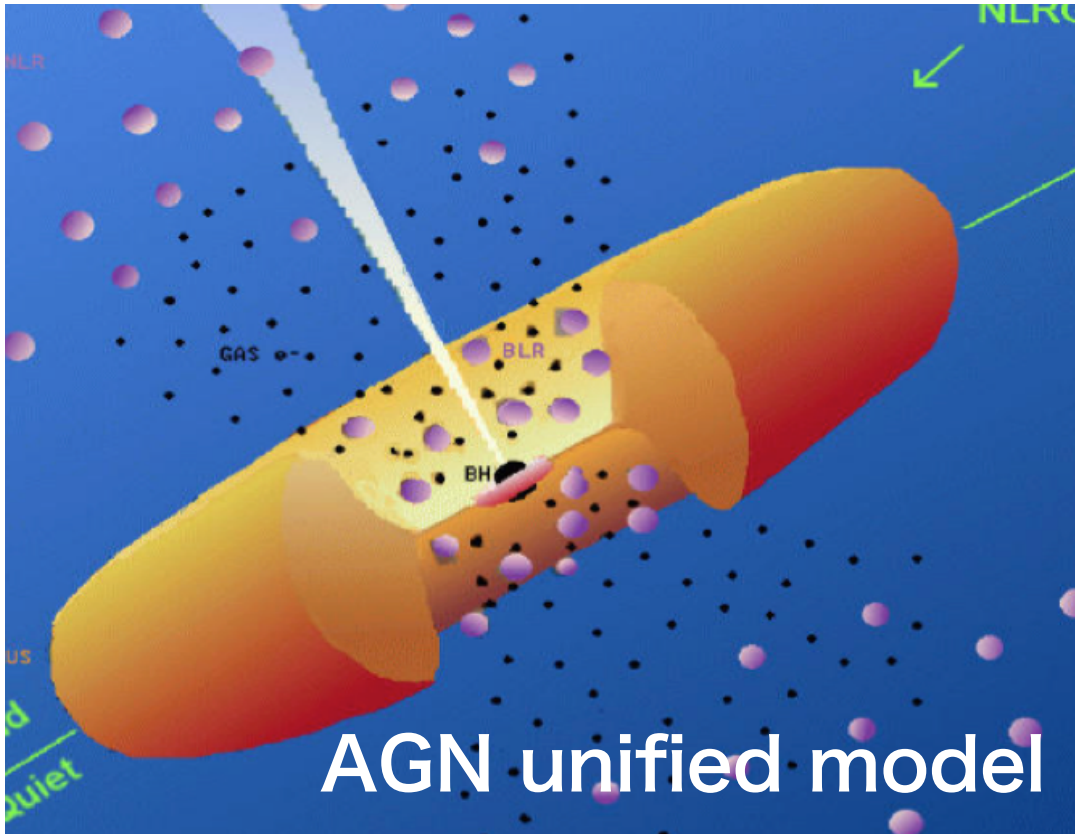
- **Tight correlation between the massive black hole (MBH) and host gal. properties.**
  → ***the co-evolution***



Galaxy and Black Hole Co-evolution

- **Tight correlation between the massive black hole (MBH) and host gal. properties.**
  → *the co-evolution*

- **AGN may be a key object.**
  ✓ SMBH growth
  ✓ High energy output (i.e., AGN feedback)



Galaxy and Black Hole Co-evolution

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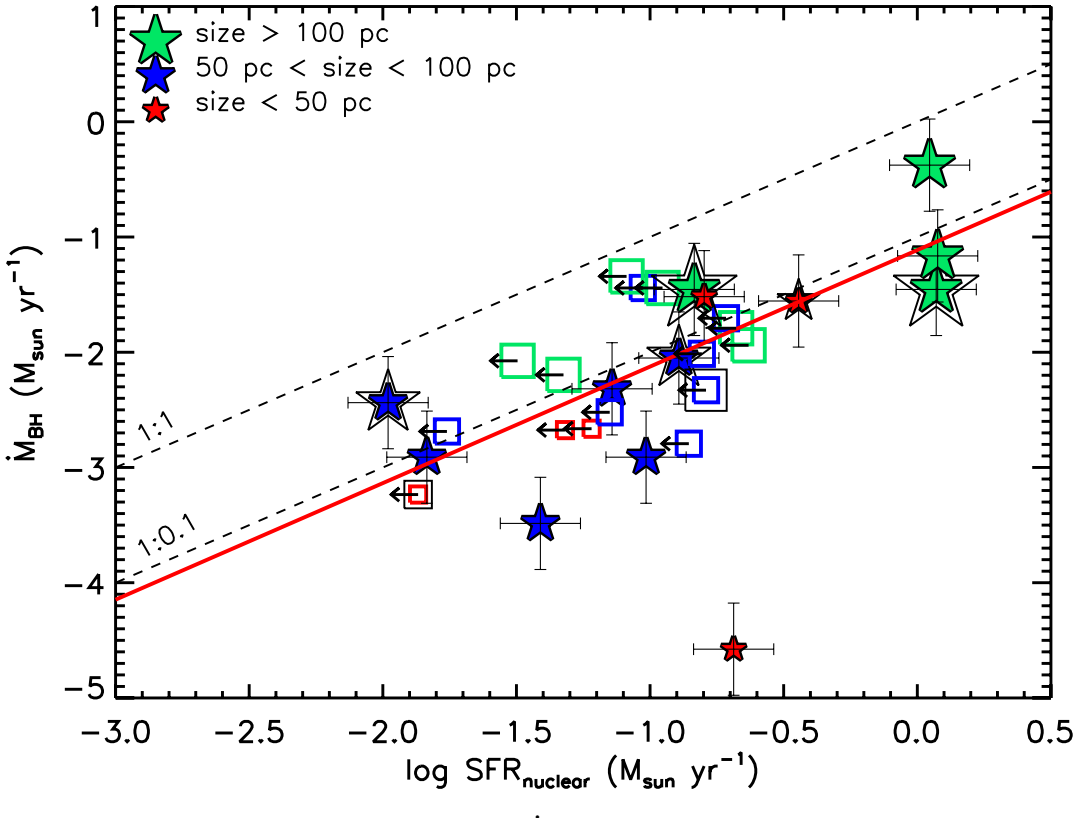
  → *the co-evolution*

(Esquej+14)



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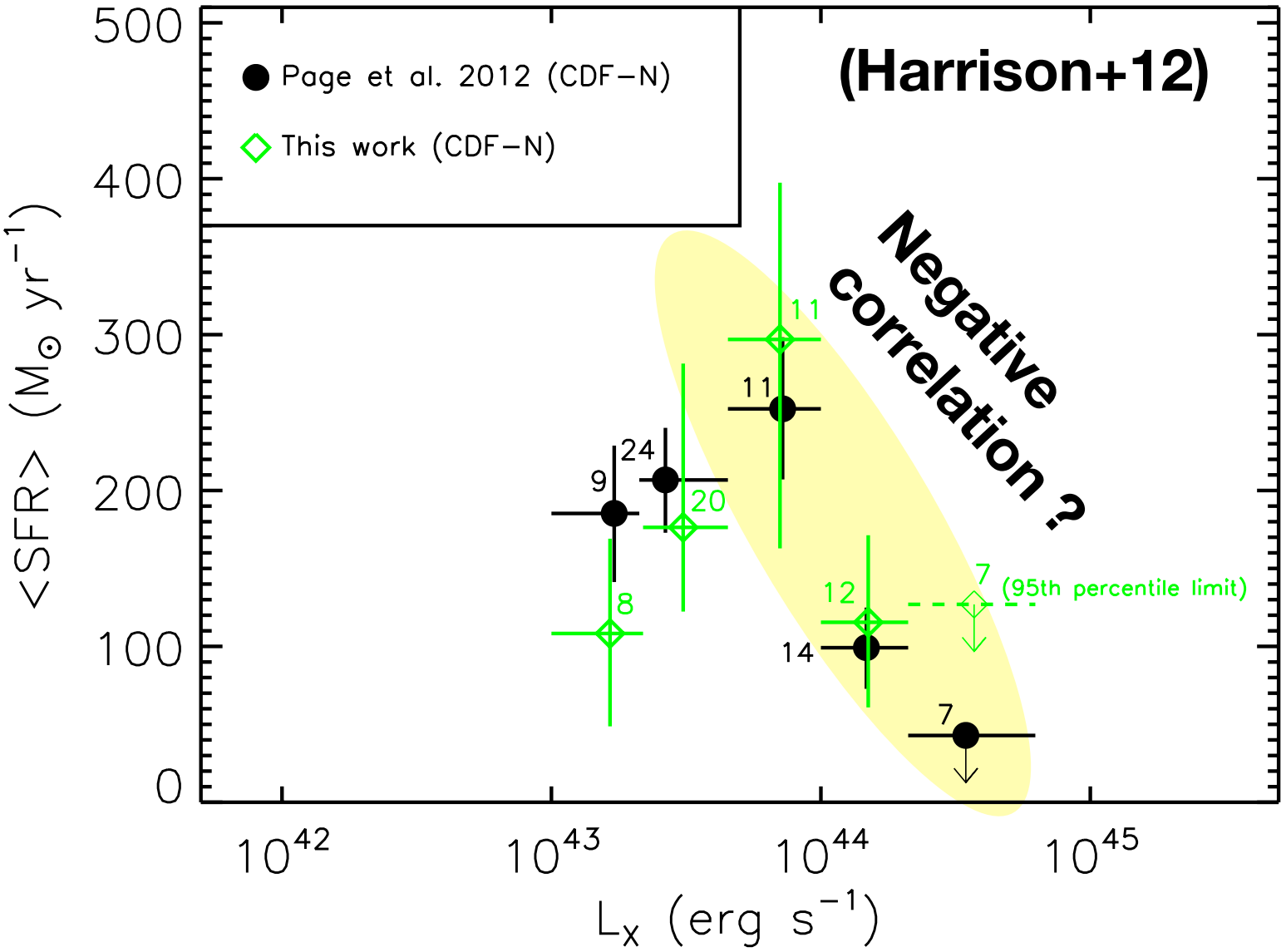
- **Starformation rate (SFR) and AGN mass accretion relation**
  (e.g., Imanishi+11, Matsuoka+15)

Starformation and AGN accretion power

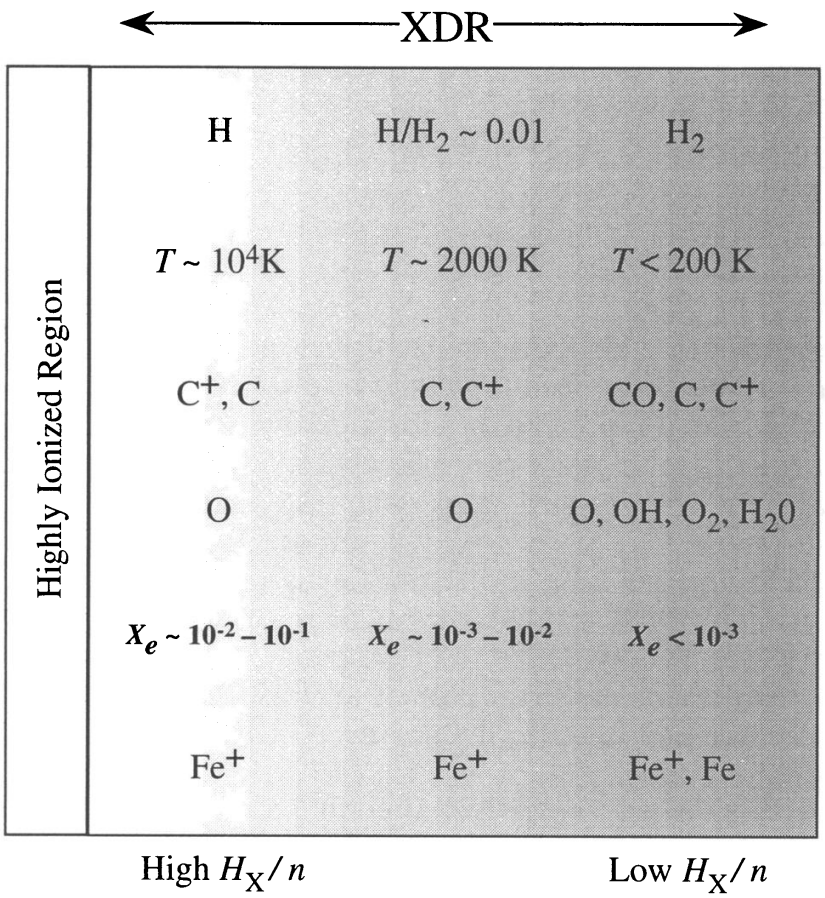
- **Suppressed SF in X-ray luminous AGN?**
  → AGN may have strong impacts on SF.



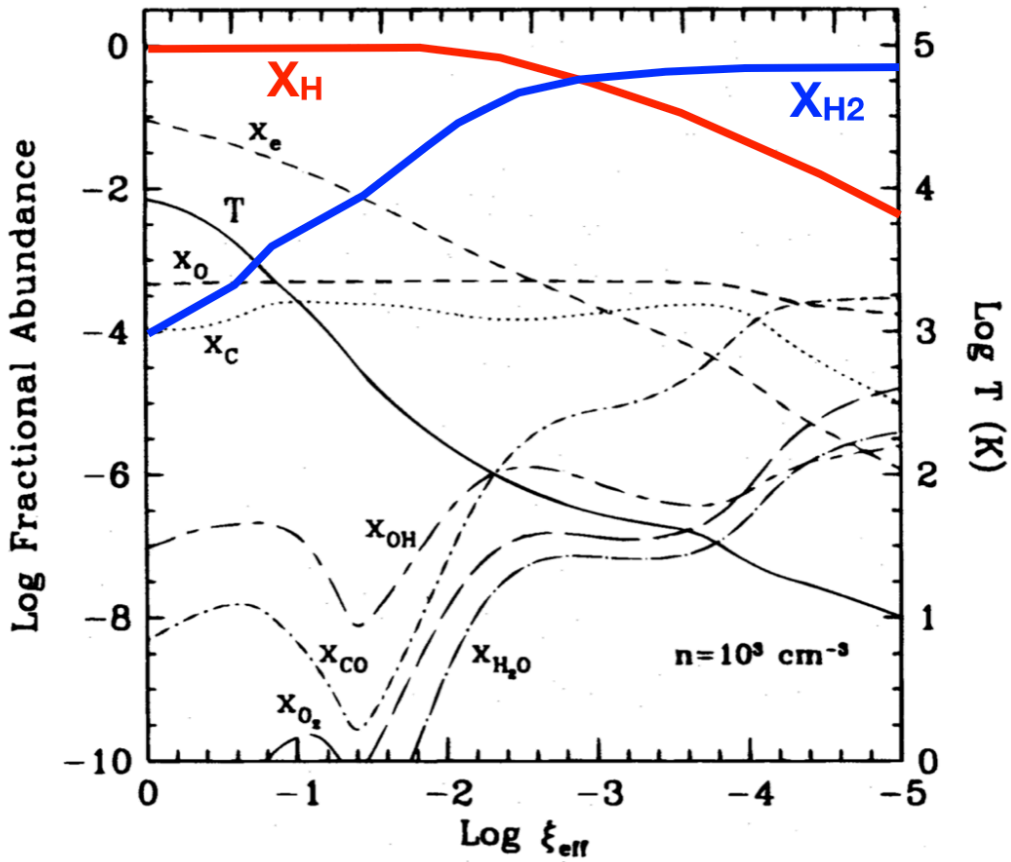
X-ray Dominated Region (XDR)

- **Strong penetrating power of X-rays largely heats the ISM, so called XDR**
- **X-ray producing photoelectrons dissociates molecules**

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

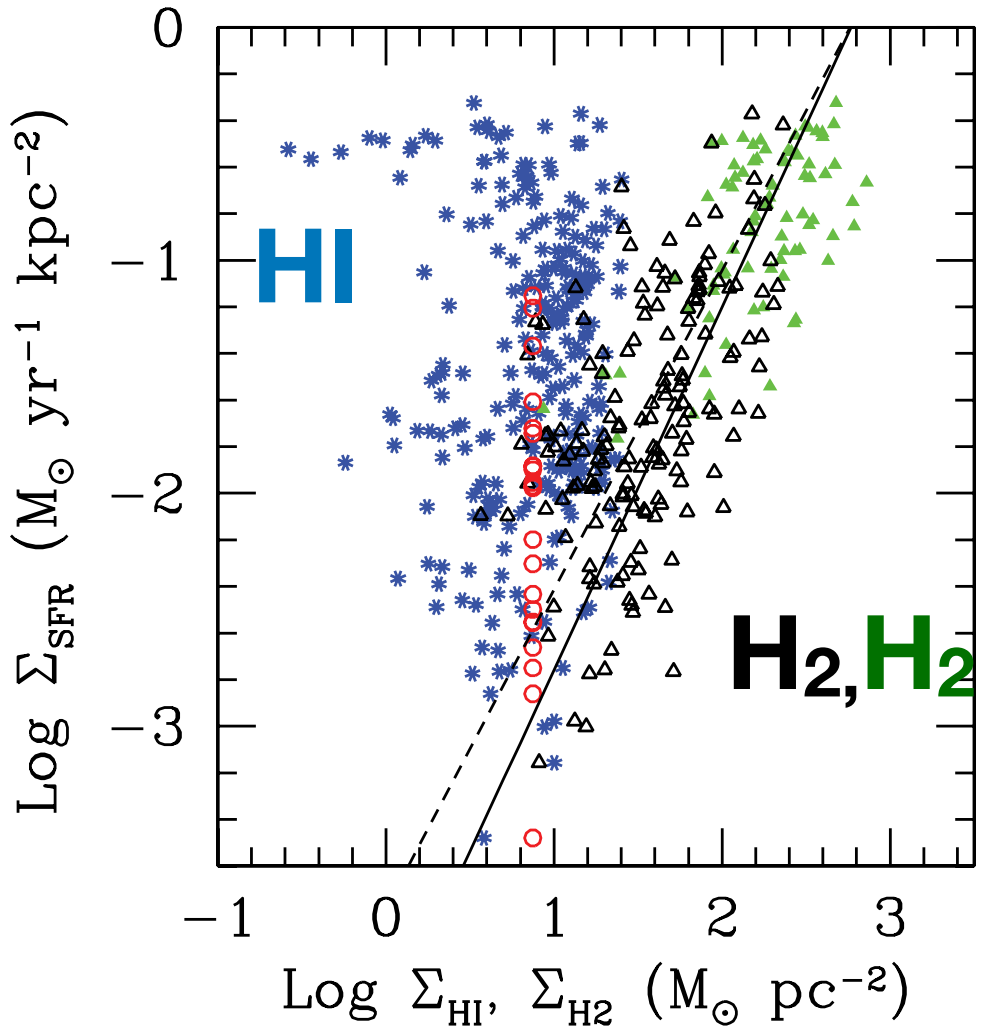


(Maloney+96)



Atomic/molecular gas vs. SFR

- **Molecular gas seems to be a important parameter for SF.**



(Kennicutt+07)

- **AGN may suppress the SF by dissociating molecules**

  ⇒ ***Let's confirm the dissociation!***

CXO and ALMA obs. of Circinus galaxy

Investigation whether AGN has impacts on SF

→ **Detailed study using a nearby AGN host as a laboratory**

Circinus galaxy:

- D = 4.2 Mpc (i.e., 0”5 ~ 10 pc)
- host of Compton-thick AGN

Chandra & ALMA

- (sub-) arcsec resolution
- X-ray and submm/mm
  - → strong penetrating power to dust/(gas)
  - → suitable for studying nuclear dense regions
- high S/N data are available

CXO & ALMA archive data

Chandra
~ 300 ksec (!) archive data
ALMA
covers
multi-species
(CO, HCO+, HCN) emission
and
multi-transition
(J=4-3, J=3-2)
= 5 mol. lines

Chandra datalist

Obs. ID (1)	Start Obs. Date (UT) (2)	Exp. (ksec) (3)	Grating (4)
356	2000/03/14	20	NO
365	2000/03/14	1	NO
374	2000/06/15	6	YES
62877	2000/06/16	48	YES
4770	2004/06/02	48	YES
4771	2004/11/28	52	YES
12823	2010/12/17	147	NO
12824	2010/12/24	38	NO

NOTE— Columns: (1) Observation ID. (2) Observation start date. (3) Exposure after the data reduction. (4) Check on grating observation.

ALMA datalist

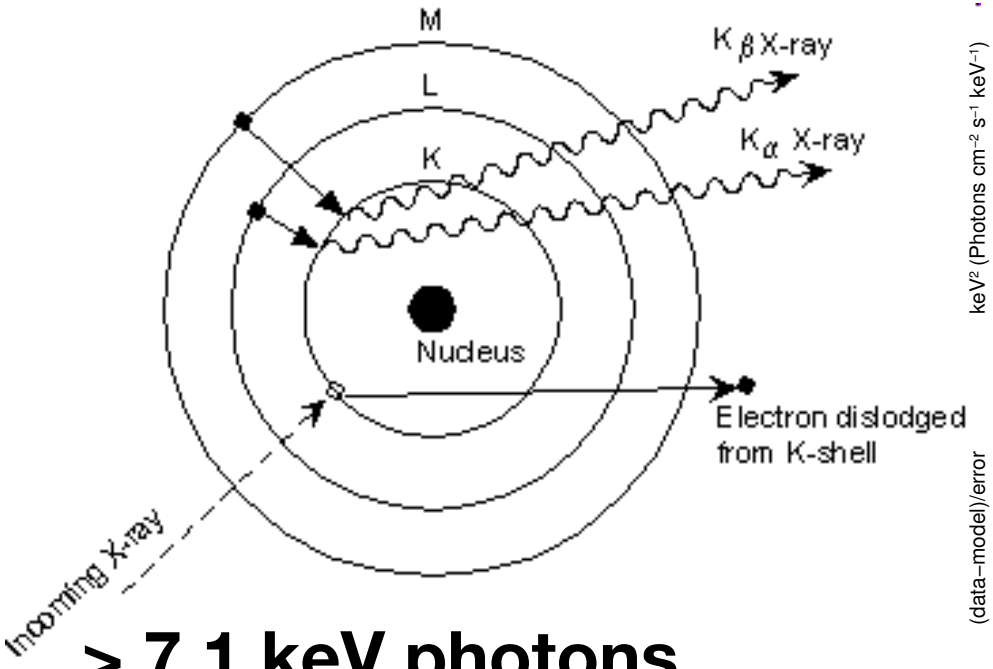
Tag (1)	Program Info. (2)	Obs. Date (3)	Exp. (4)	Molecules (5)
(a)	#2015.1.01286.S (PI: F. Costagliola)	2015/12/31	3	HCO^+(J=4–3), HCN(J=4–3), CO(J=3–2)
(a)	#2015.1.01286.S (PI: F. Costagliola)	2015/12/31	5	HCO^+(J=3–2), HCN(J=3–2)
(b)	#2016.1.01613.S (PI: T. Izumi)	2016/11/24	125	HCO^+(J=4–3)

What can we know from X-ray?

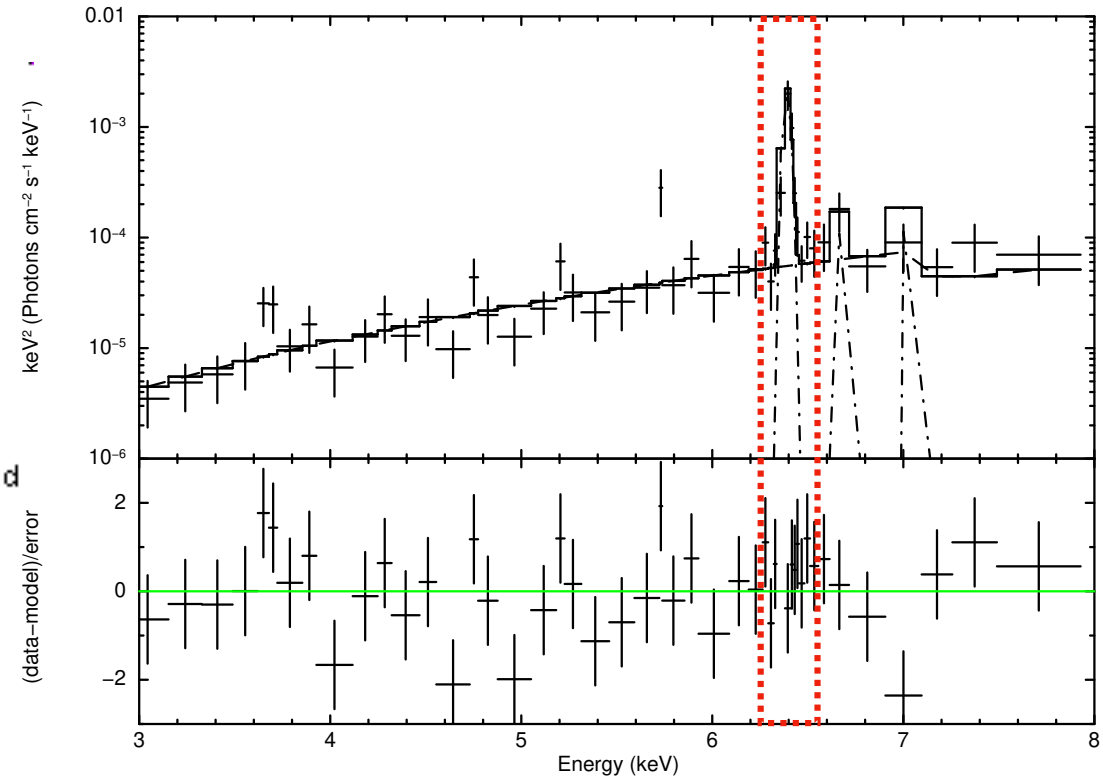
Iron-Kα fluorescent line is very important

- **τ~1 for log N_H ~ 23.9 cm^{-2}**
  - **⇒ probe of dense gas material**
- **6.4 keV emission**
  - **⇒ high penetrating power**

Suitable for nuclear region study !

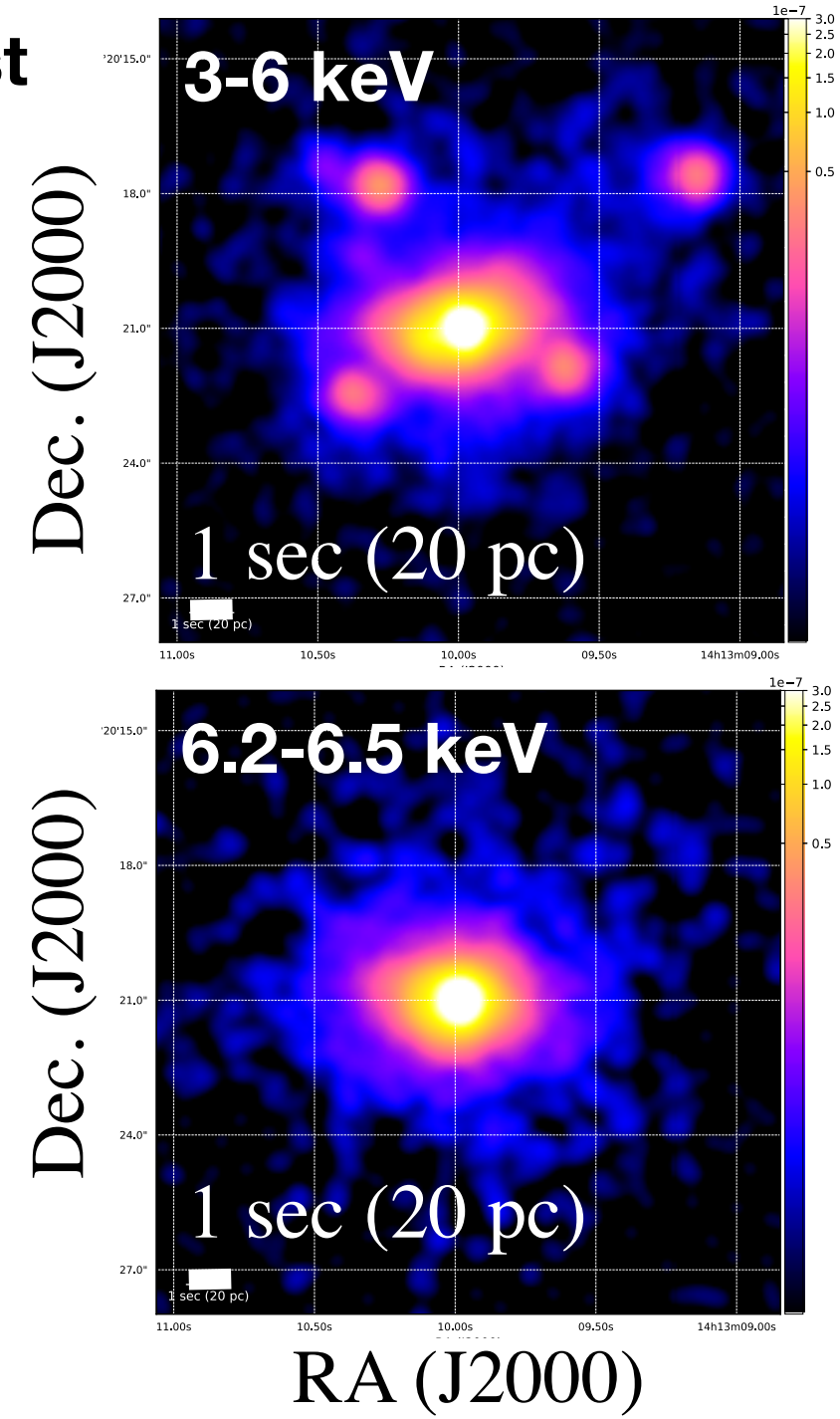


> 7.1 keV photons



X-ray emission maps

- **Chandra provides us with the most precise images at X-rays (~ 0.”5)**



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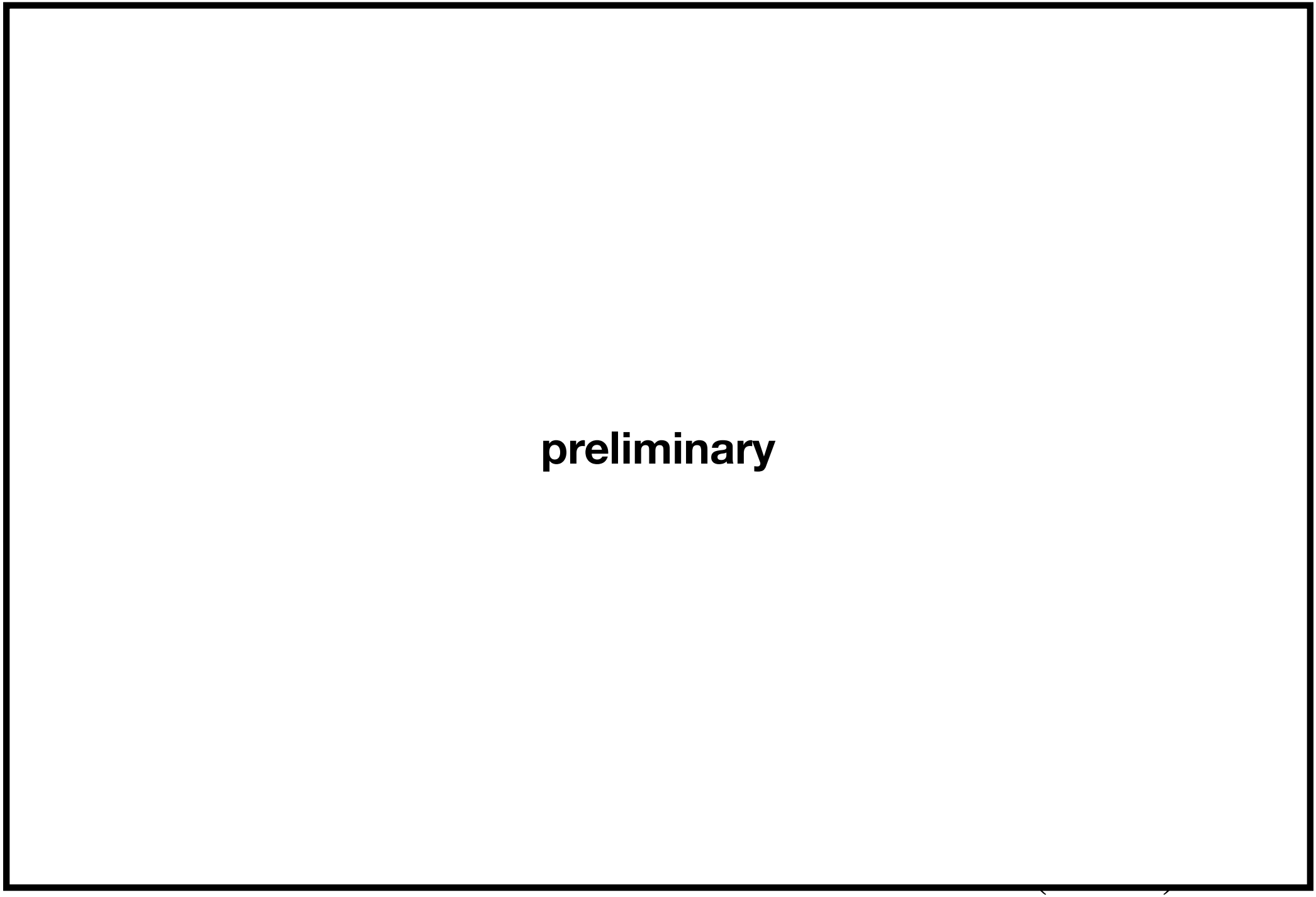
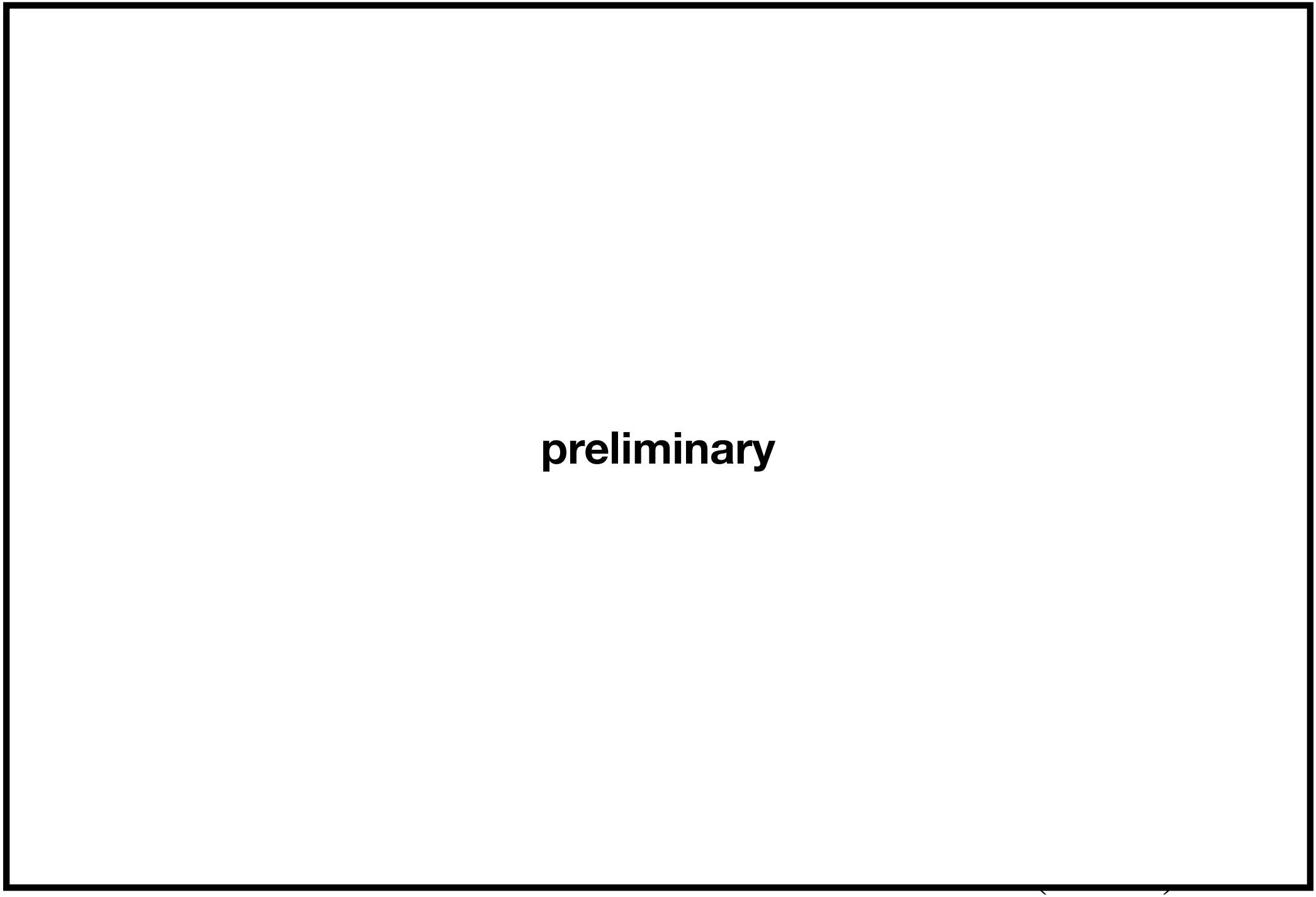


X-ray emission maps



Iron-Kα and Mol. gas emission lines

preliminary

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preliminary

Mol. line ratios fitting by RADEX non-LTE code

- **5 molecular lines → 10 line ratios**
- **4 free par. = NH2, n(H2), Tk, [HCN]/[HCO$^+$]**

	Nucleus	Cone	East_Limb	South_Limb
log N_{H2} [cm^{-2}]	24.0 [23.0-25.0]	25.0 [20–25.0]	23.5 [20.0-21.0,22.5–23.5]	22.0 [21.5-22.0]
log n_{H2} [cm^{-3}]	**5.5 [4.5-5.5]**	**3.0 [3.0-5.0]**	**4.5 [3.5-5.5]**	**6.0 [6.0]**
T_k [K]	380 [100–400]	390 [110-390]	40 [30-60]	30 [20-30]
[HCN]/ [HCO$^+$]	2 [2-4]	2 [2-3]	3 [3-4]	3 [-]
chi^2	1.15	0.24	0.58	3.33

X-ray dominant region (XDR)

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

L_X ~ 1.3e+43 (1–100 keV)

(NuSTAR estimate by Arevalo+14)

R ~ 60 pc

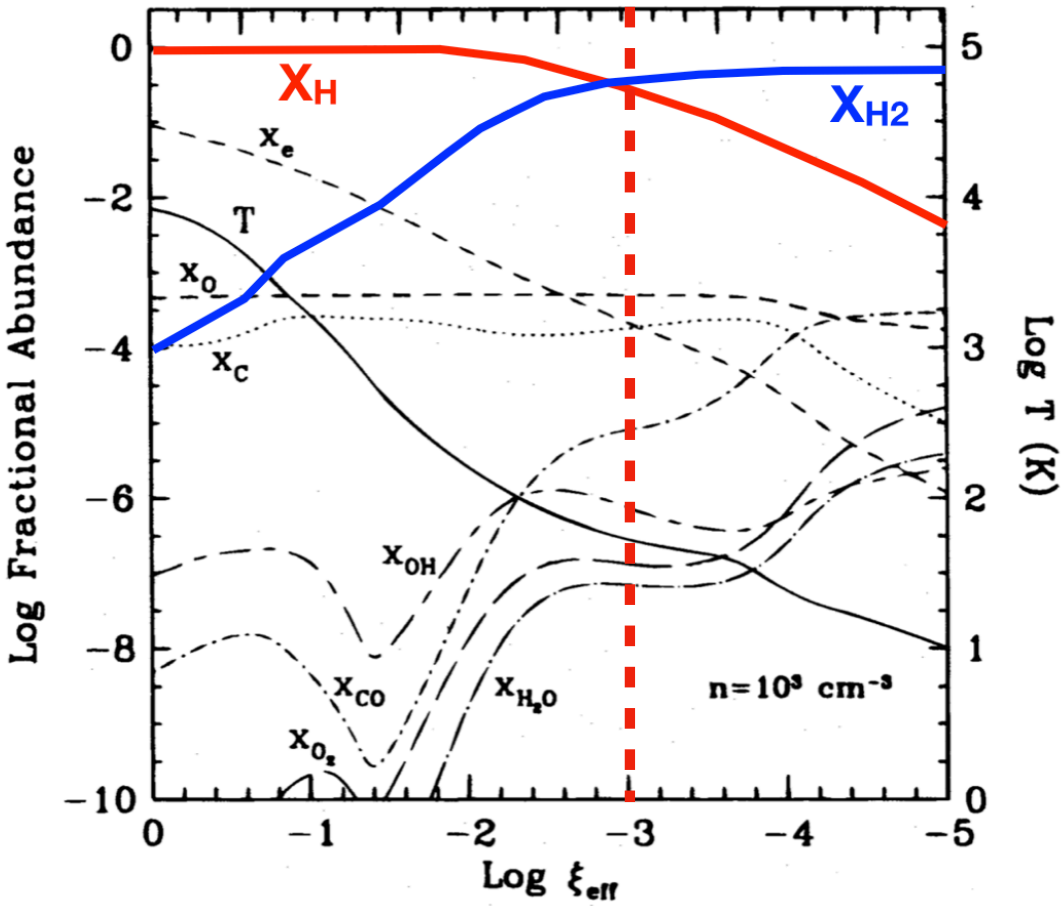
(spatial resolved map)

n_{H2} ~ 3.0-6.0 cm^{-3}

(mol. line ratios fit by RADEX)

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

(τ~1 for the neutral iron)



	Nucleus	Cone	East_Limb	South_Limb
log ξ_{eff}	-4.0~-5.0	-2.5~-4.5	-3.0~-5.0	-5.5

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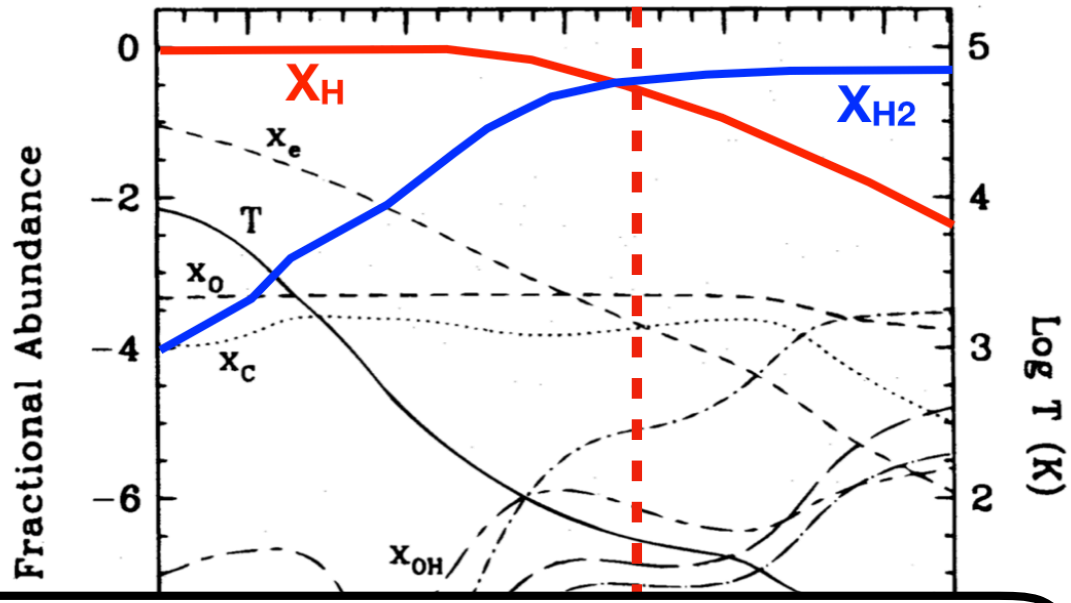

Our result supports that the X-ray radiation from the AGN can dissociate the molecule(, and the SF may be suppressed therein.)

	Nucleus	Cone	East_Limb	South_Limb
log ξ_{eff}	-4.0~-5.0	-2.5~-4.5	-3.0~-5.0	-5.5

Summary

- **Science BG: Physical connection between SF and AGN**

- **CXO & ALMA obs. of Circinus gal. at 10 pc resolution**
  → Study of X-ray heating effects on ISM

  - **Anti-spatial correlation b/w the dense molecular gas and iron line distribution.**

  - **From ξ_{eff}, we examined the XDR model to interpret the mol. deficit.**

  - **AGN X-ray can form the XDR and destructs molecule.**

- **<u>AGN may suppress the SF, if the molecular formation is critical for forming stars.</u>**