15 June, 2017
Elusive AGN in the next era@George Mason University

Mm/submm energy diagnostics in the ALMA era

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Astrochemistry as a tool for Astrophysics

- Feedback = Astrophysical processes
  ⇄ **Astrochemistry**

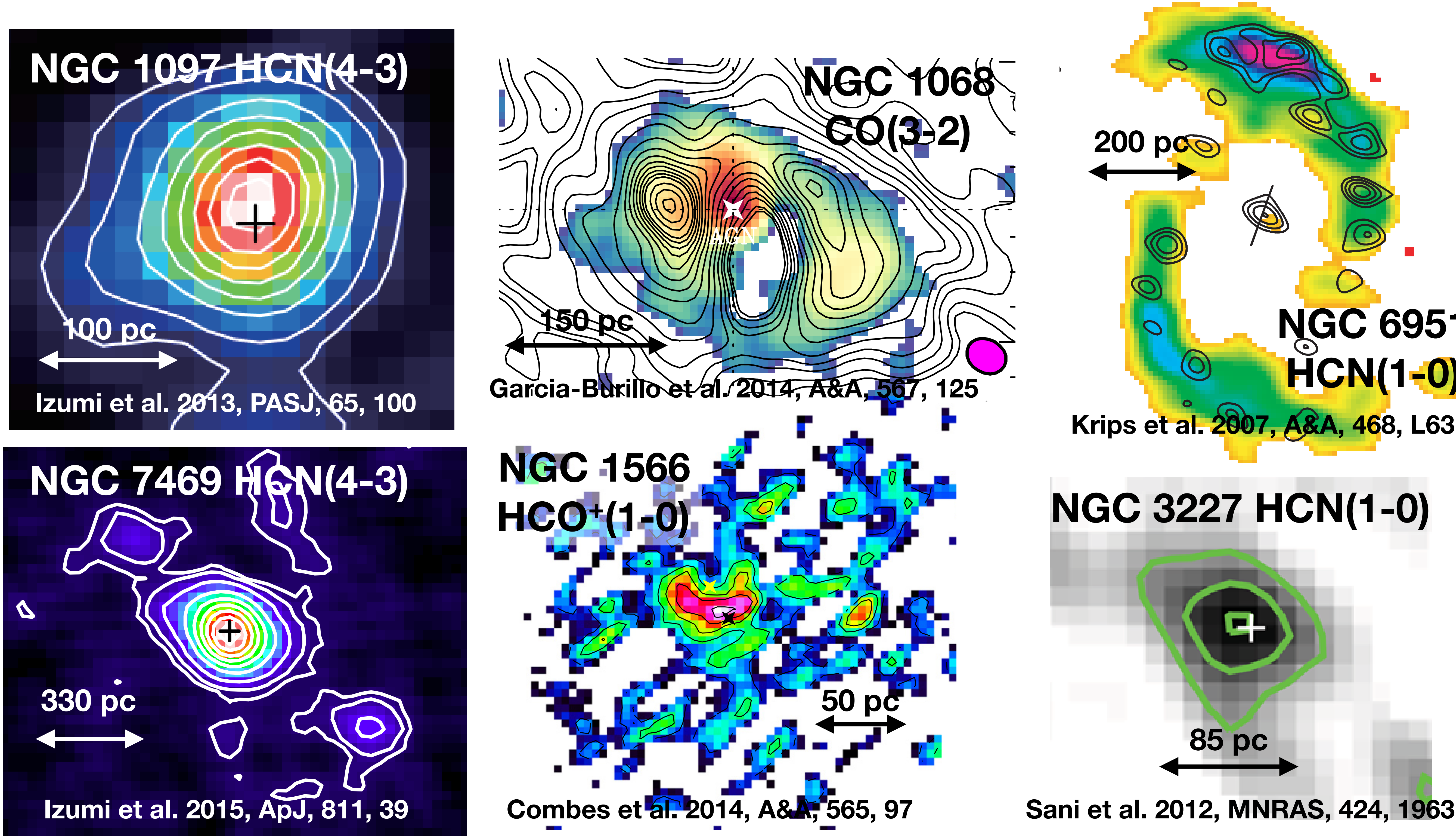
- Different physical/heating processes (AGN, starburst) will produce different signature on the ISM

- **PDR**, **XDR**, **MDR**…
  → ***Chemical feedback***

- Application: mm/submm spectroscopy can be a powerful tool to identify a *dust-obscured* energy source

★
Arp220 / NASA, ESA, and C.Wilson

Circumnuclear Disk (CND)



Typical spatial scale: ~100 pc

Molecular Energy Diagnostics
- to find elusive AGNs -

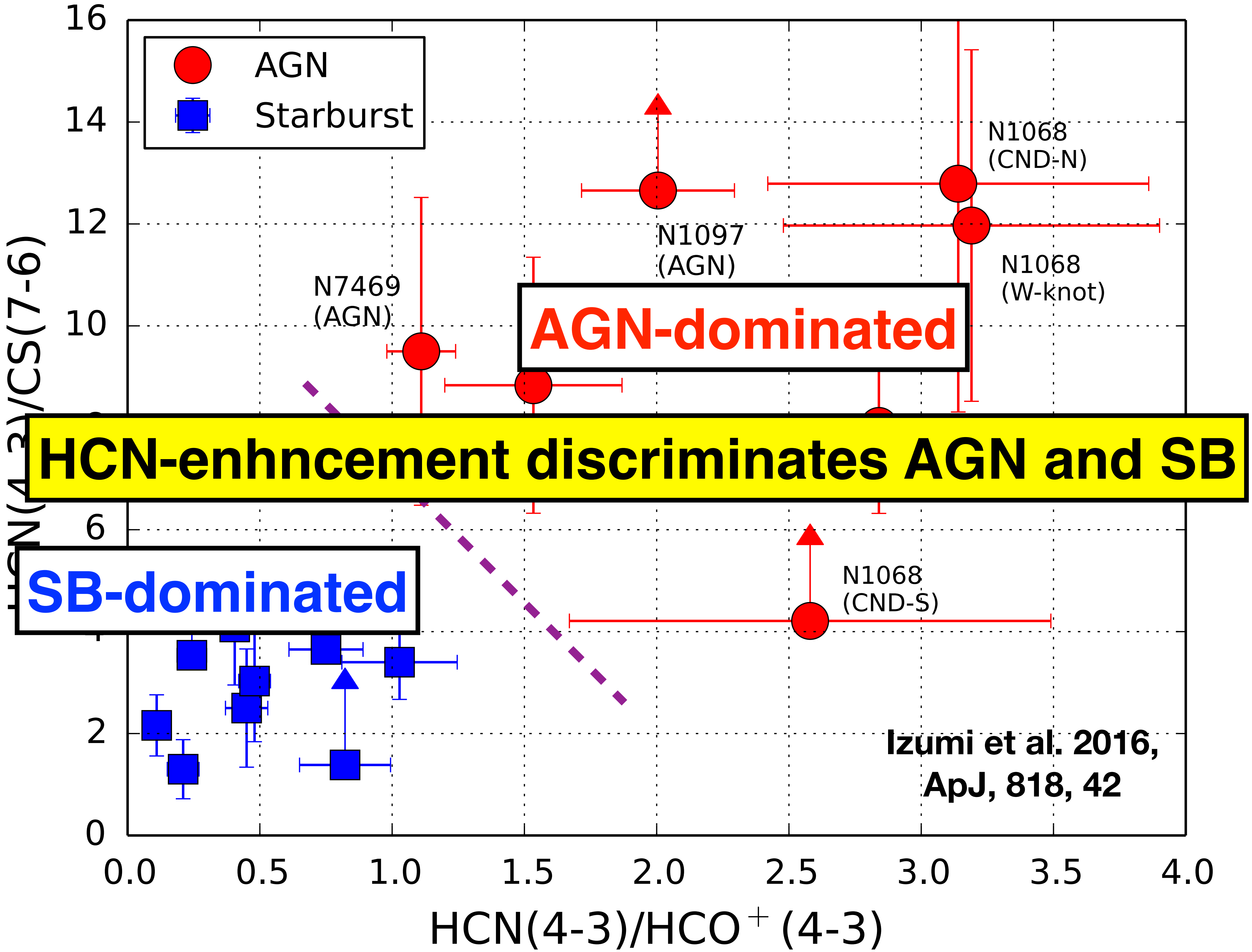
Submm HCN-diagram: ALMA Band 7 lines

[CI](1-0)/CO(1-0) diagnostic:
new method under initial investigation

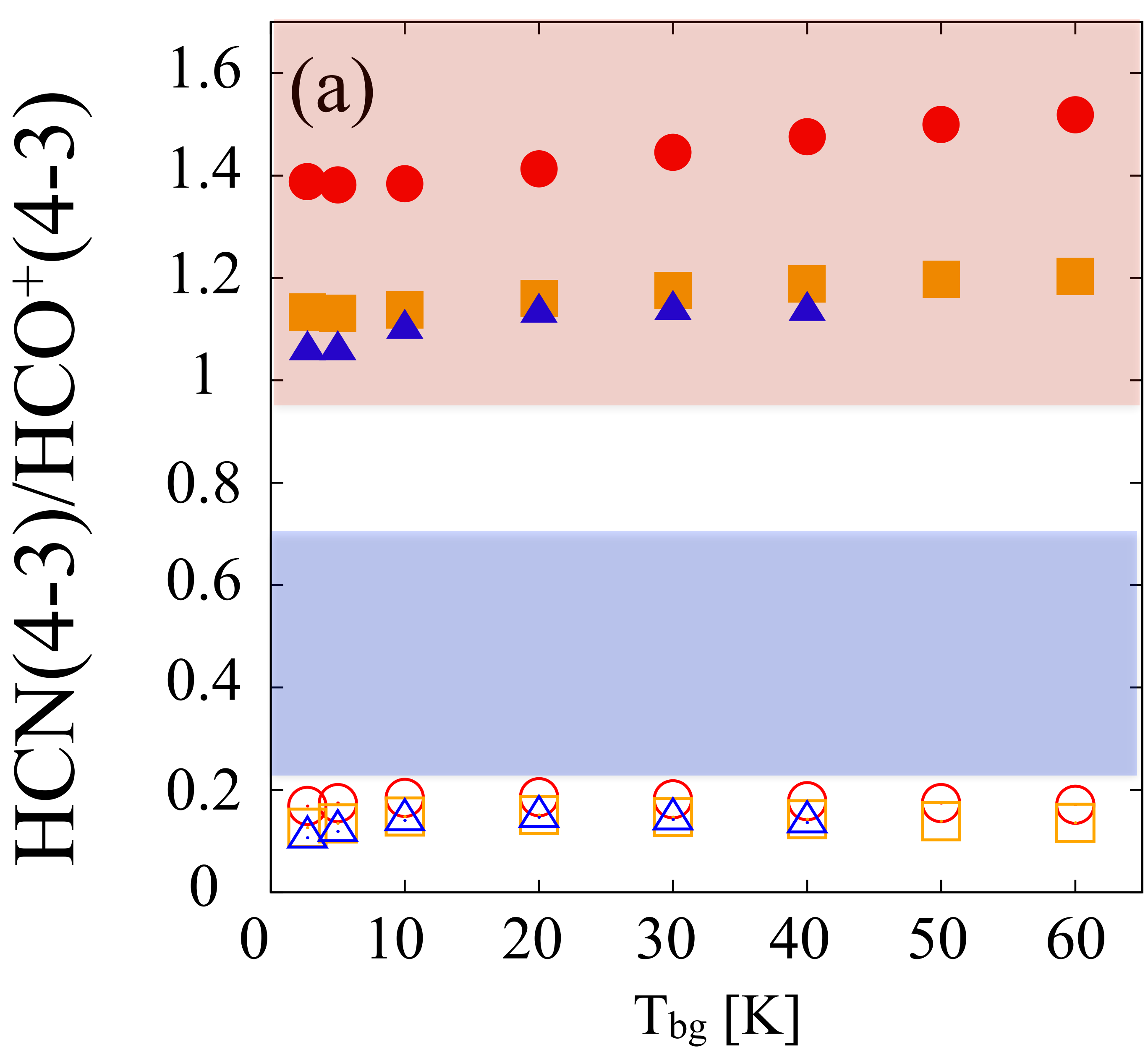
→ I will show new ALMA data obtained recently

1. Submm-HCN Diagram:

Toward the submm-version of the BPT-diagram?



Non-LTE radiative transfer modeling of emission lines

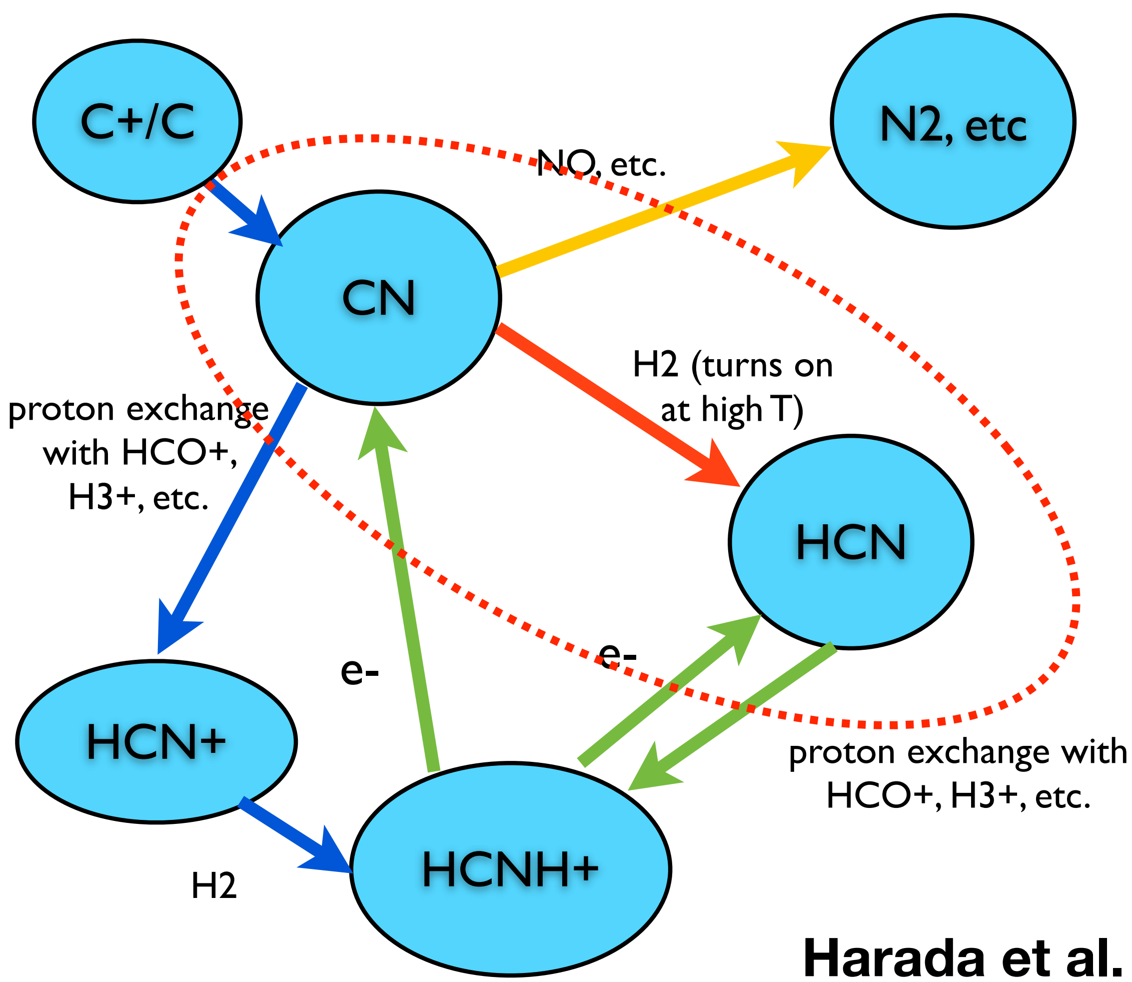


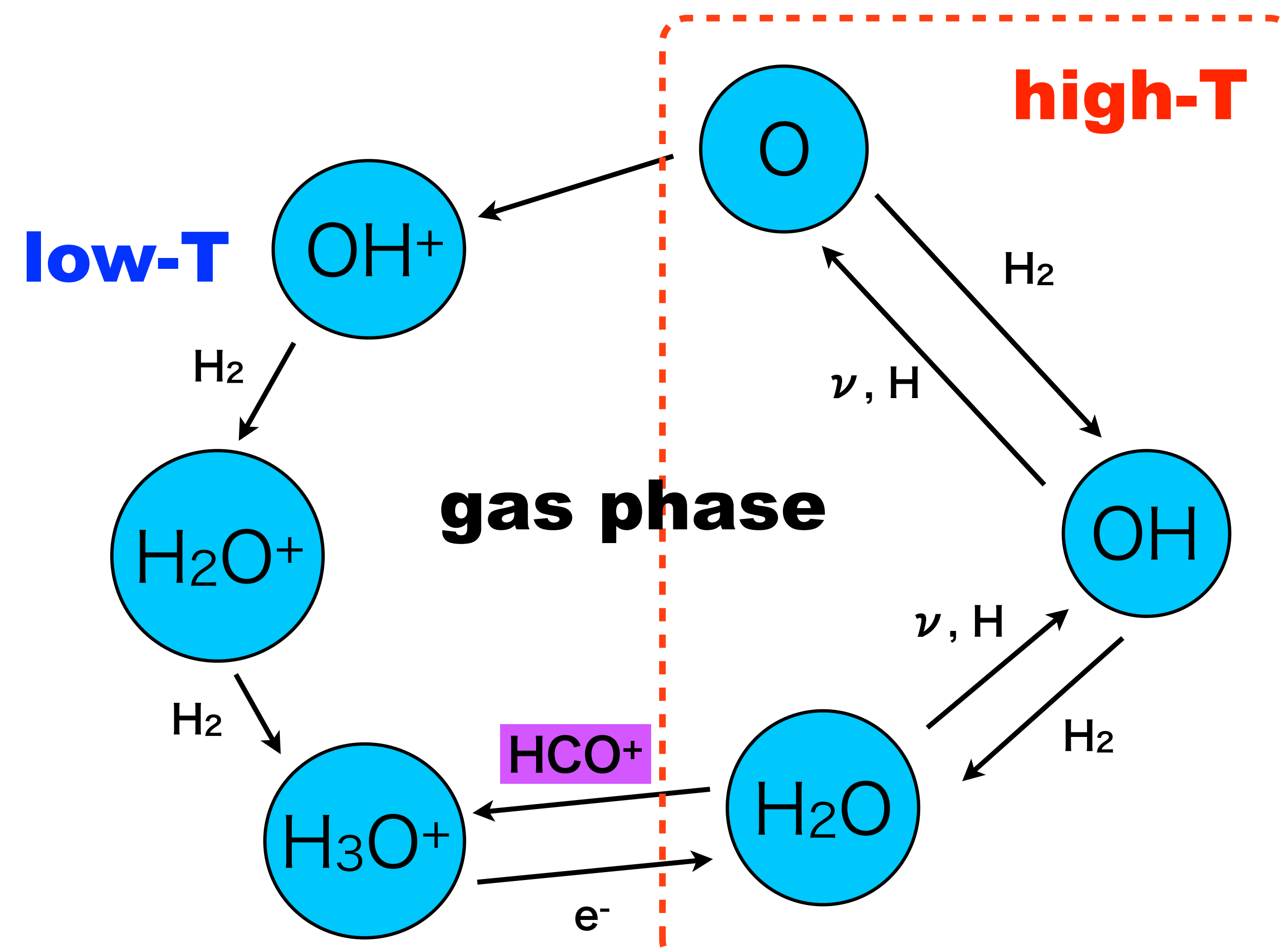
Izumi et al. 2016, ApJ, 818, 42

- HCN(4-3)/HCO$^+$(4-3)
  ※ T_b unit
- n_{H2} = 10^5 cm^{-3}; T_{kin} = **50K**, **100K**, **200K**
- **Filled** symbols
  → X(HCN)/X(HCO$^+$) = **10**
- **Open** symbols
  → X(HCN)/X(HCO$^+$) = **1**
- The abundance of HCN is **enhanced in AGNs** w.r.t. SB galaxies

High Gas Temperature Chemistry

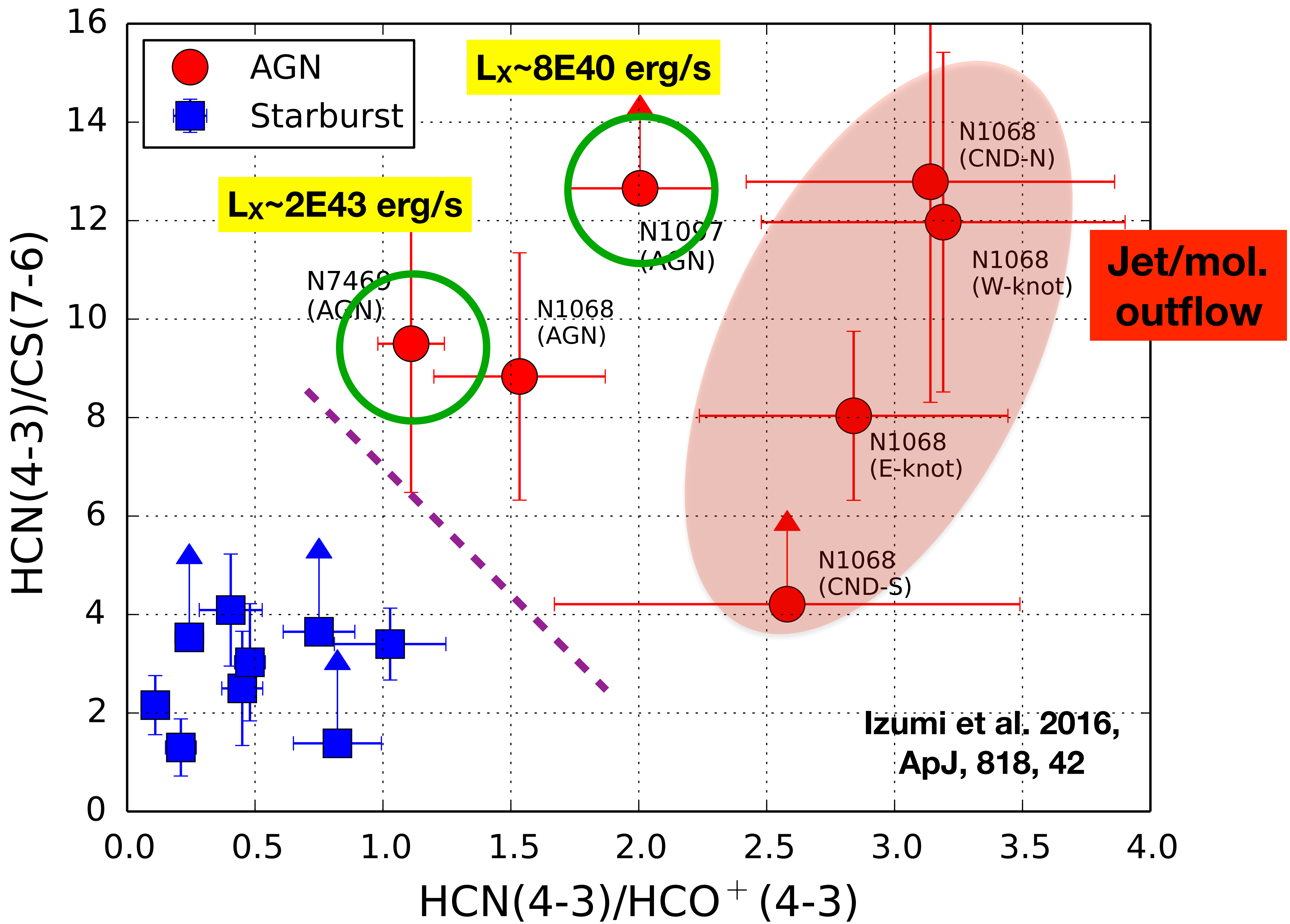
- <u>Neutral-neutral reactions</u> are enhanced at **T > 300K**
- Efficient formation of HCN (e.g., $CN + H_2 \rightarrow HCN + H$)
- Efficient destruction of HCO^+ (e.g., $HCO^+ + H_2O \rightarrow H_3O^+ + CO$)





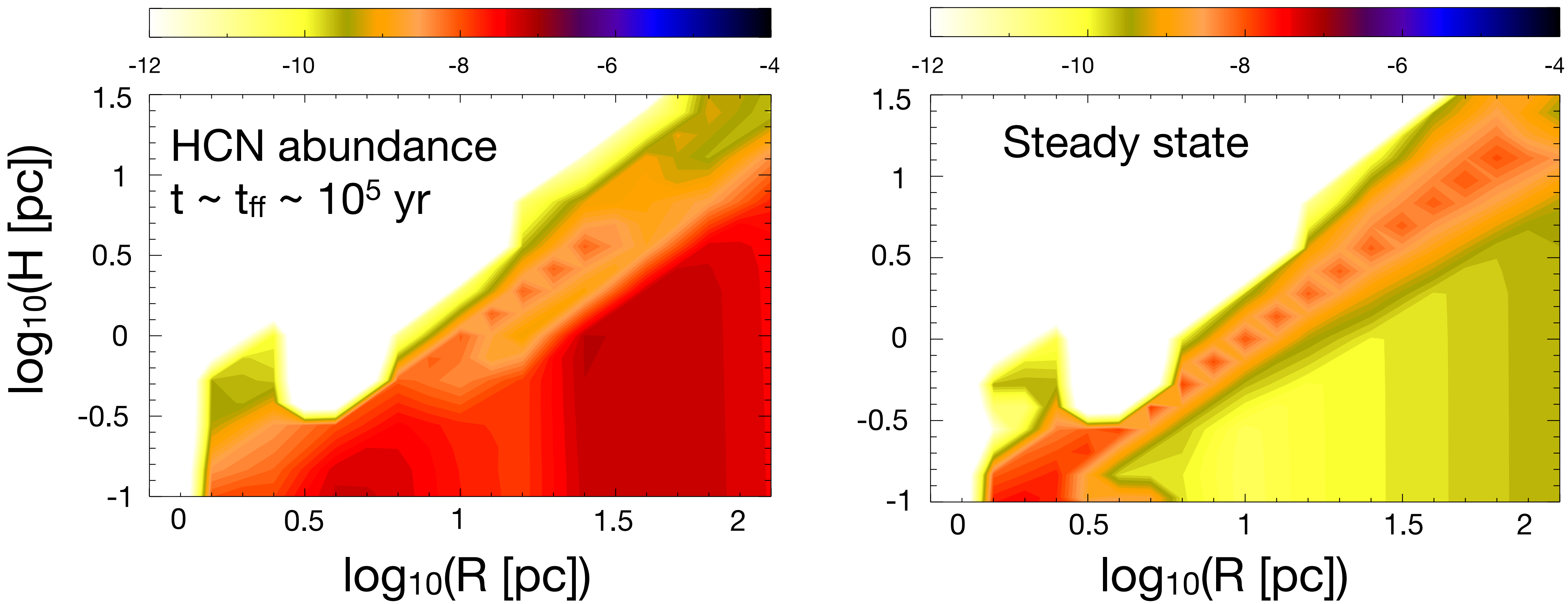
Harada et al. 2010, ApJ, 721,1570

Origin of the high temperature?



Time dependence of HCN abundance?

Harada et al. 2013, ApJ, 765, 108

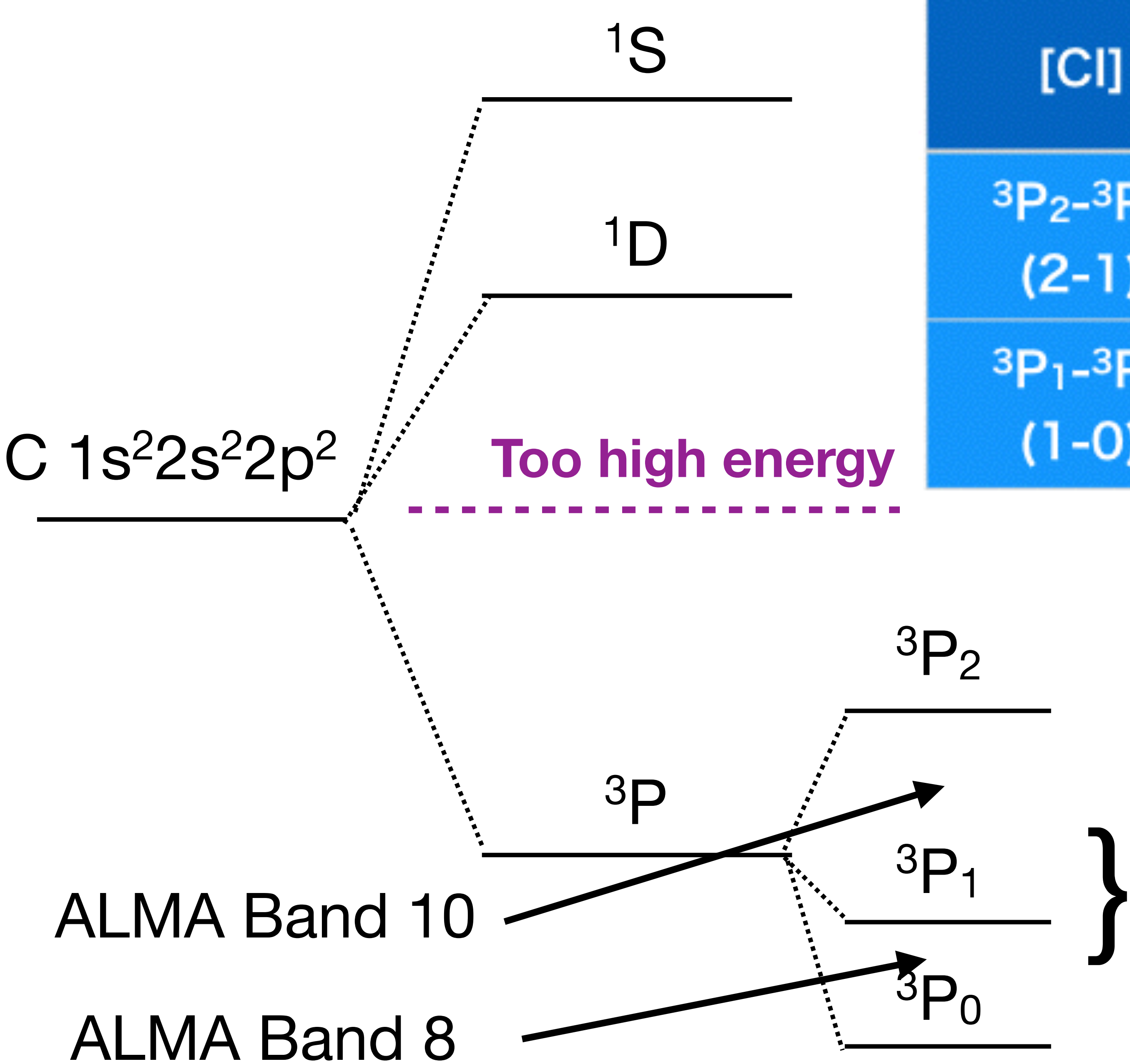


- We might select AGNs recently caused "**mechanical feedback**" by **jet/outflow**.
  → We can explain the time-dependent chemistry as well, **since shocks reset the chemistry**

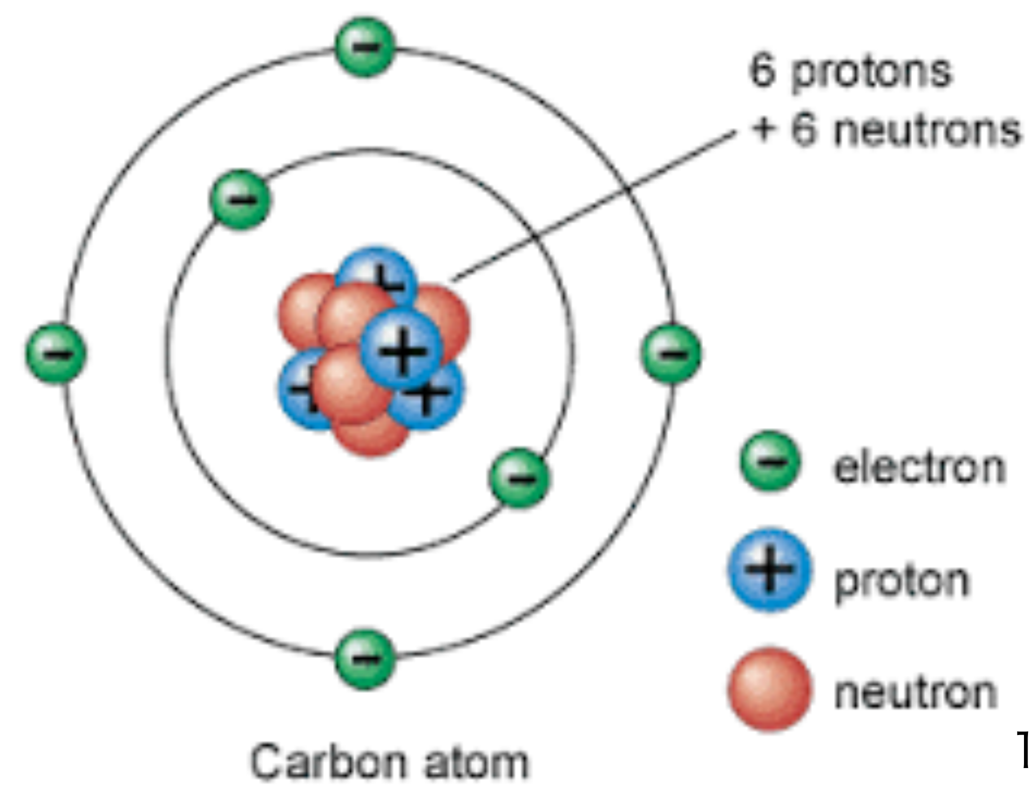
Brief Summary 1

- **AGN vs SB diagnostics** by using enhanced HCN intensity (w.r.t HCO^+ and CS) in AGNs (@ALMA Band 7)
- **Abundance variation of HCN** is responsible for the enhancement
- High-temperature neutral-neutral reactions can be natural explanation
  - maybe, this method is sensitive to AGNs recently caused mechanical feedback (jet/outflow)

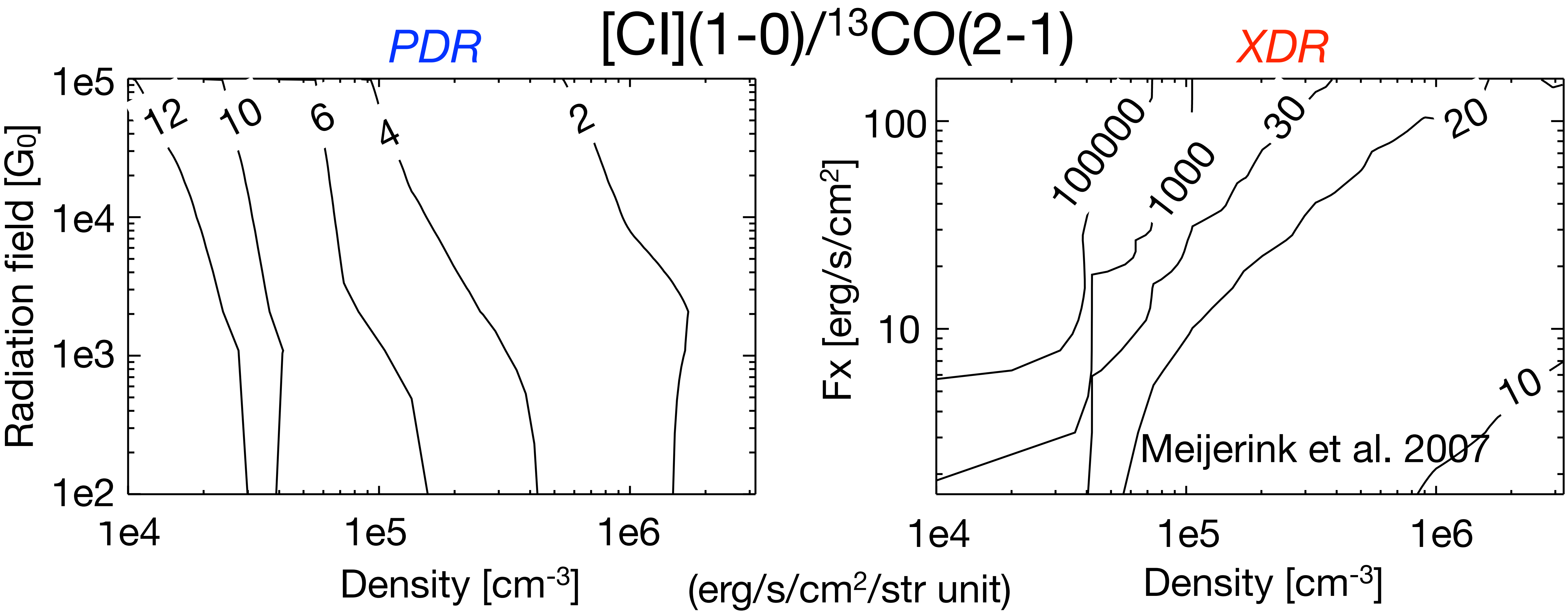
2. A new method in the ALMA era
- C^0/CO ratio -



[CI]	ν_{rest} [GHz]	n_{cr}@50K [cm-3]	E_u [K]
$^3P_2$-$^3P_1$ (2-1)	809.34	3000	62.5
$^3P_1$-$^3P_0$ (1-0)	492.16	500	23.6



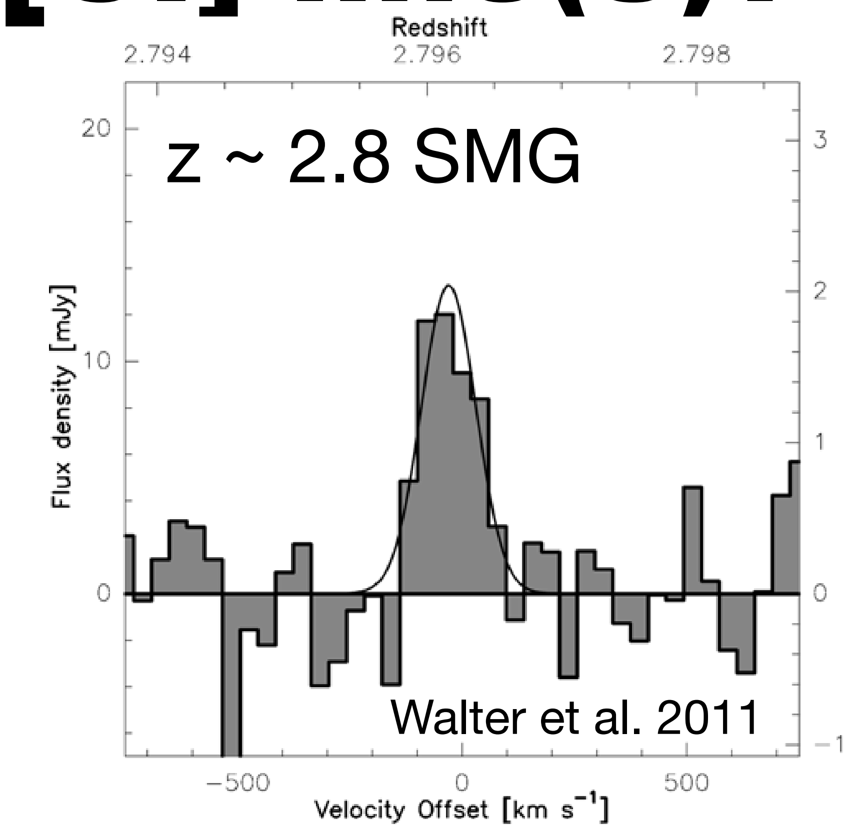
Idea: X-ray dissociation: CO → C^0

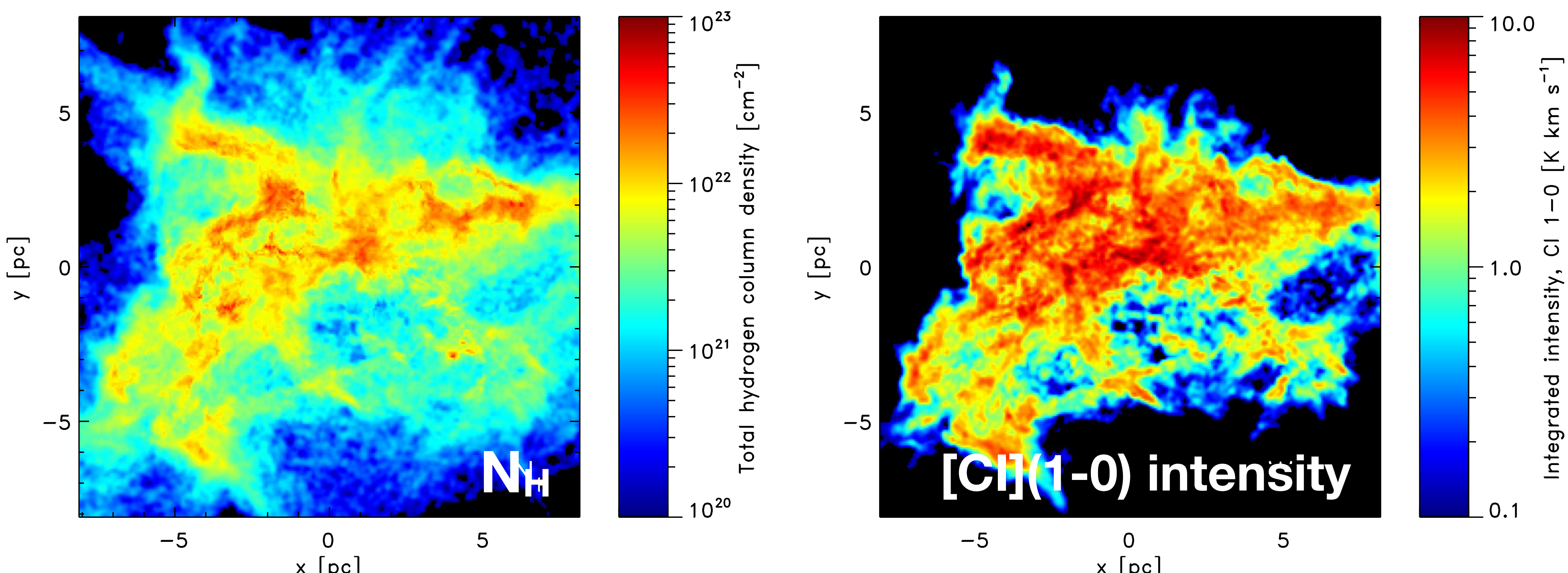


- We can easily expect much more efficient CO dissociation in XDRs than in PDRs. → Efficient formation of C^0
- Underlying physics/chemistry is rather simple!

Why submm people like [CI] line(s)?

- Easy to solve **line excitation**
  → There are only two transitions
- Good tracer of **molecular mass**!!
- We can observe them in **high-z** objects (z ~ 5)

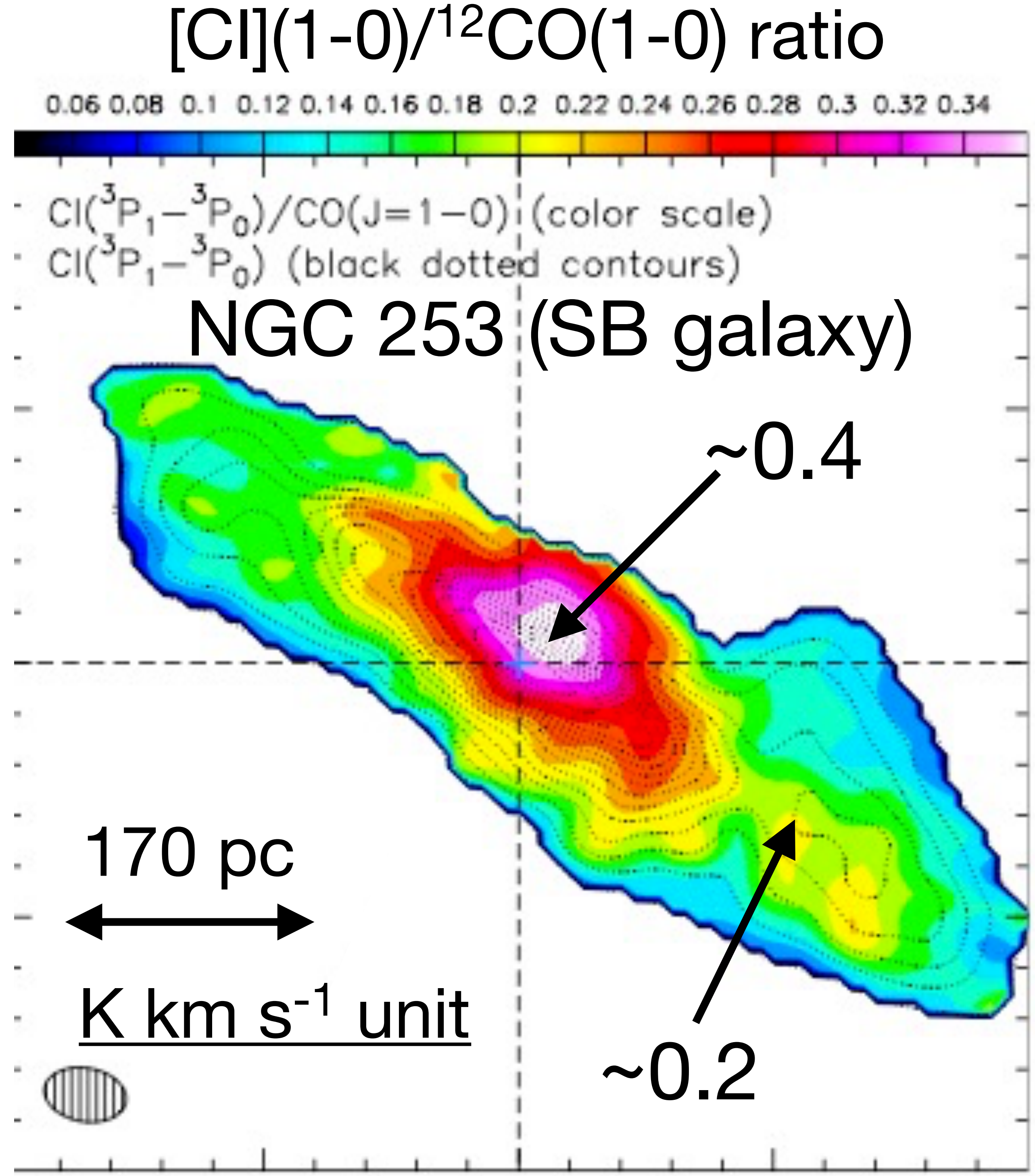




Glover et al. (2015)

Current status of [CI] observation

- There is only ONE spatially resolved extragalactic [CI](1-0) measurement
  → NGC 253 (Krips et al. 2016)
- This indicates that [CI] line is really a new tool for extragalactic (but rather nearby) studies.
- [CI](1-0)/CO(1-0) ratio ~ 0.4 at the center (T_B unit)



Krips et al. (2016)

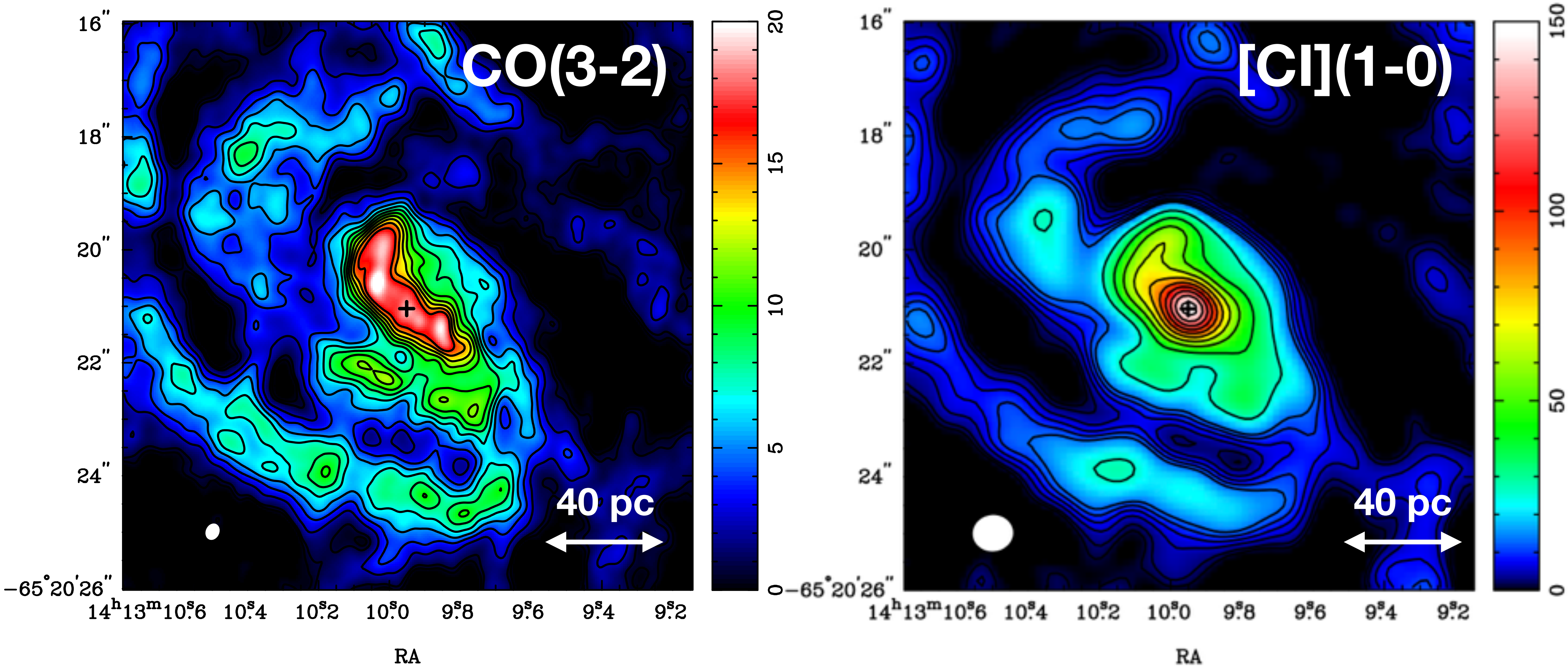
Our ALMA Cycle 4 Study: Circinus galaxy (AGN)

- The nearest (4.2 Mpc) type-2 Seyfert
  → high spatial resolution (~20 pc/arcsec)
- $L_{2\text{-}10keV} = 4 \times 10^{42}$ erg/s (Marinucci et al. 2012) → Strong XDR may extend to ~20-30 pc (Schleigher et al. 2010)
- Our objective: compare **[CI](1-0)/CO(1-0)** ratio with NGC 253 (Starburst)

Line	Band	θ (pc x pc)	1σ (mJy/beam)	dV (km/s)	$t_{on\text{-}source}$ (hr)
[CI](1-0)	8	13 x 12	7.5	2.8	1.2
CO(3-2)	7	5.7 x 4.5	1.8	3.4	3.9

→ I need to convert CO(3-2) flux to CO(1-0) flux

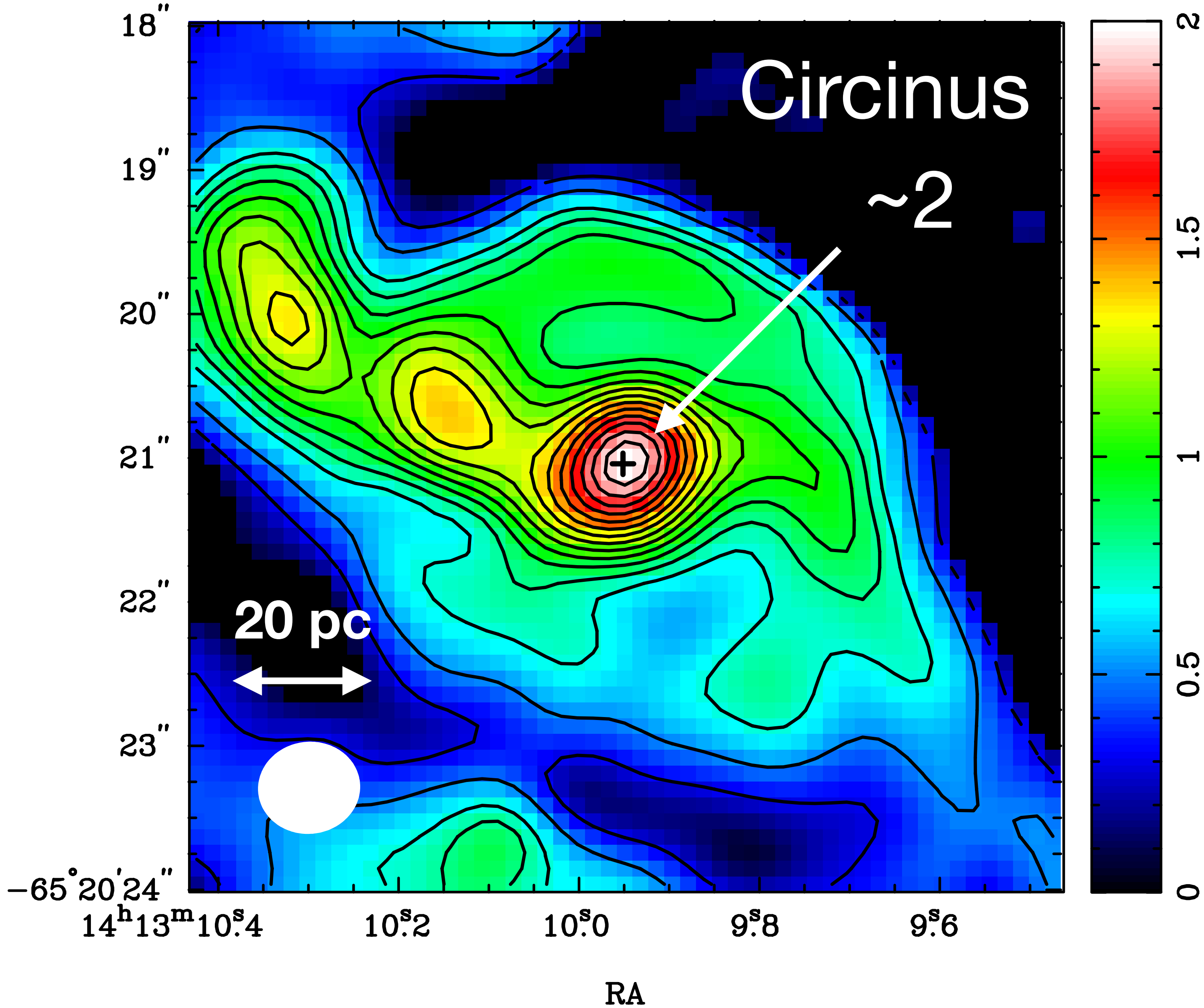
Spatial Distribution

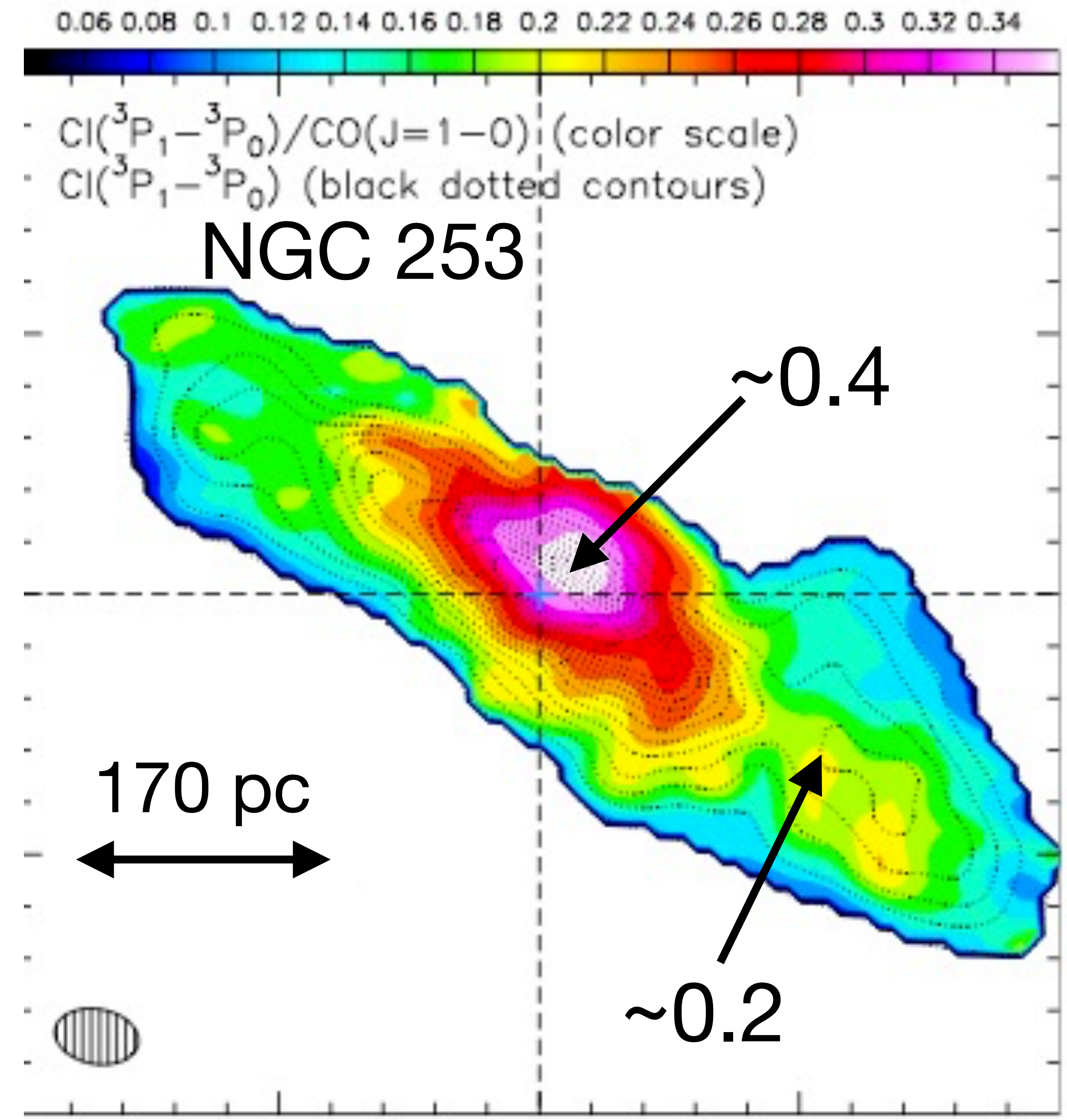


- Now you can see that [CI](1-0) is clearly concentrated toward the AGN position! → indicate the CO dissociation

- Then, measure [CI](1-0)/CO(1-0) ratio next → compare with NGC 253
  - (3-2)/(1-0) flux ratio ~ 25 @NGC 1068 (Viti et al. 2014) is assumed

[CI](1-0)/CO(1-0) diagnostic





- The ratio is **x5 higher** in Circinus (AGN) than in NGC 253 (Starburst).
  → support our claim that the ratio is enhanced in AGNs!
- We plan to expand the sample number to confirm this trend.

Brief Summary 2

- **[CI](1-0)/CO(1-0)** (or other transitions?) can be a new identifier of AGNs → Efficient CO dissociation to C^0 in XDRs
- We indeed found **x5 enhanced ratio** in Circinus (AGN) than in NGC 253 (SB): these are only two galaxies with spatially resolved [CI](1-0) measurements at this moment…
- We plan to expand the sample from next ALMA (cycle 6~?)

Summary

- **AGN vs SB diagnostics** by using enhanced HCN intensity (w.r.t HCO^+ and CS) in AGNs (@ALMA Band 7)
- **Abundance variation of HCN** is responsible for the enhancement
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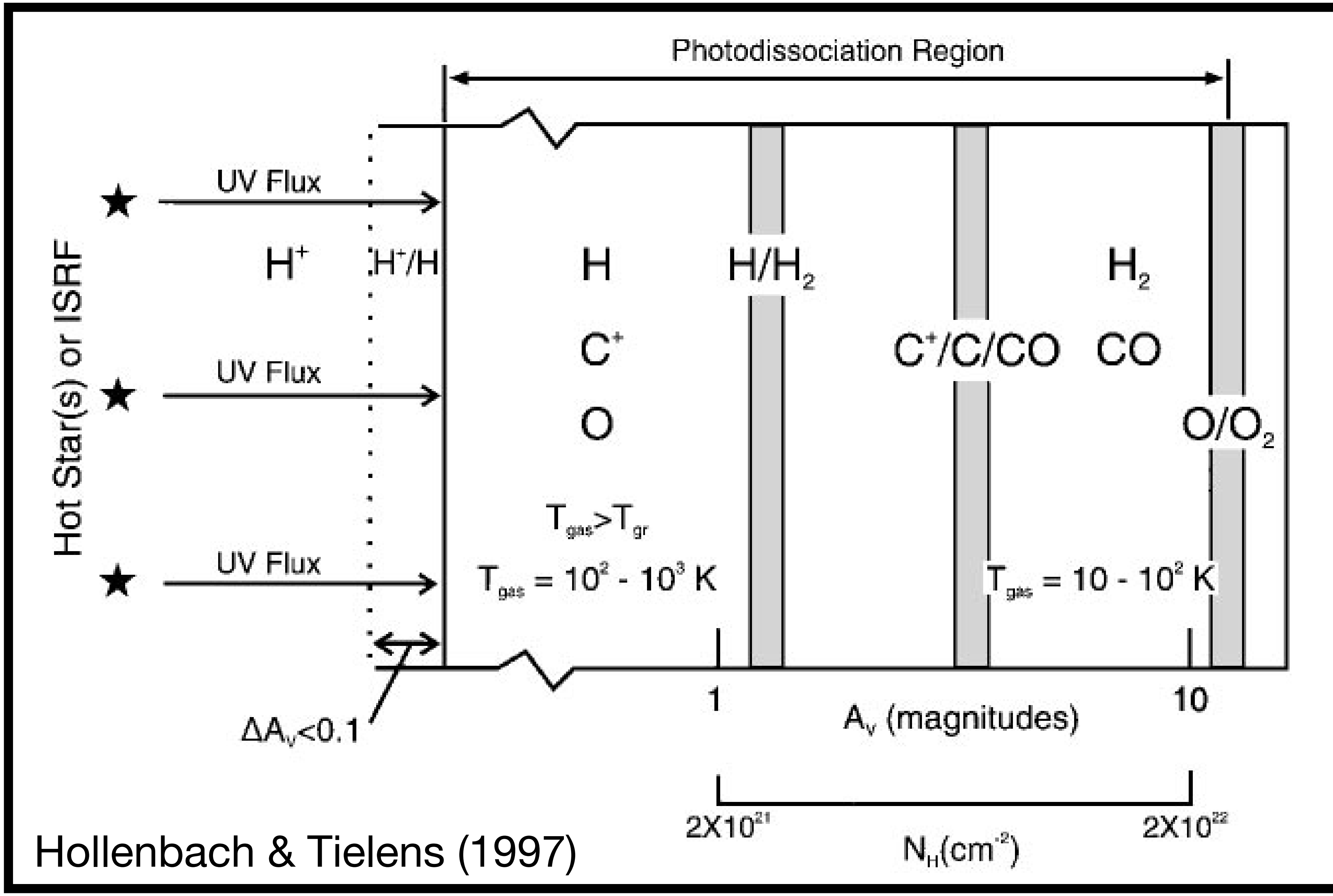
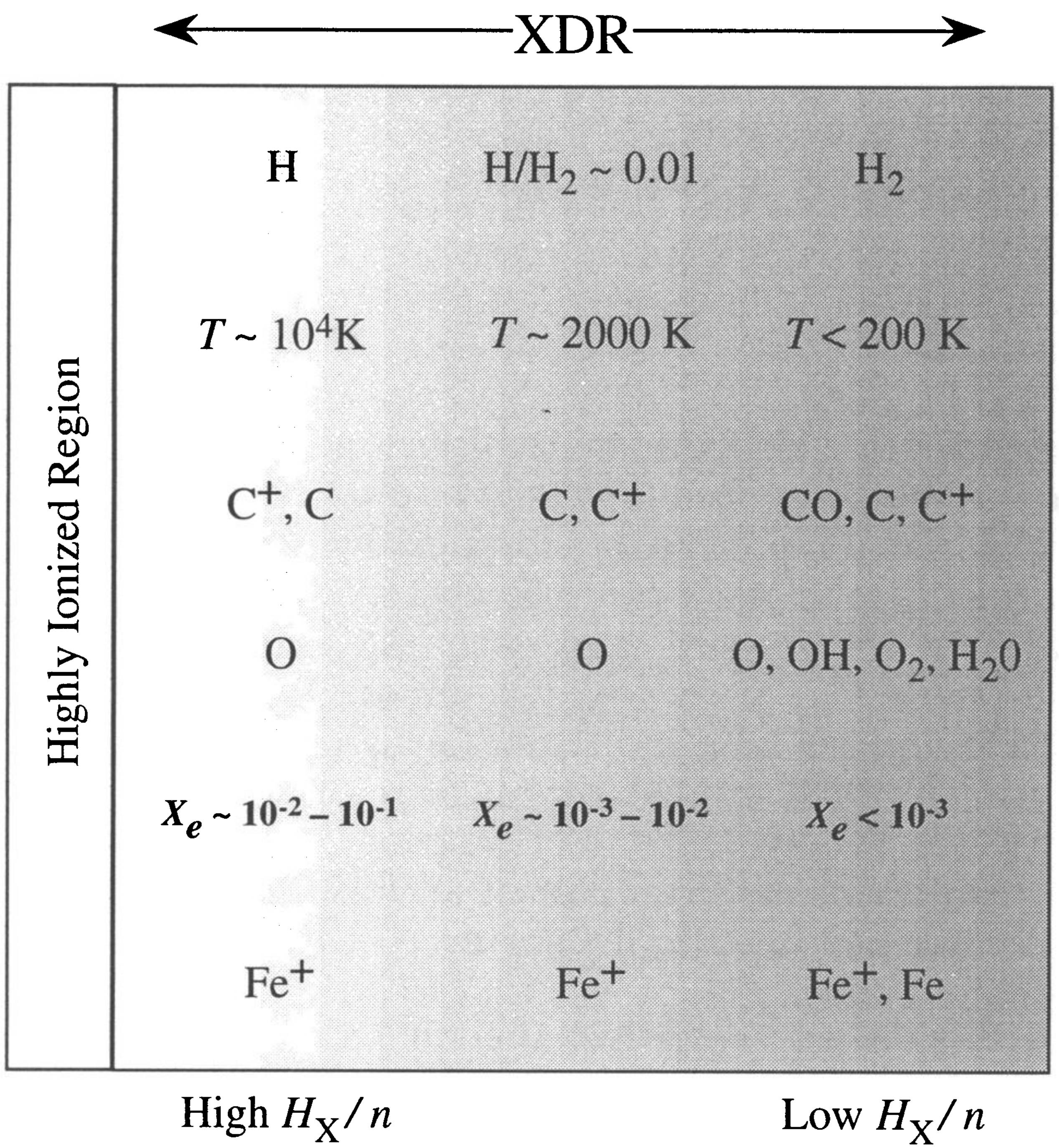
Backup

PDR and XDR



- Basically a simple **layered** structure driven by UV photons
- But in actual, interstellar turbulence mixes layers (e.g., Offner et al. 2014)

PDR and XDR

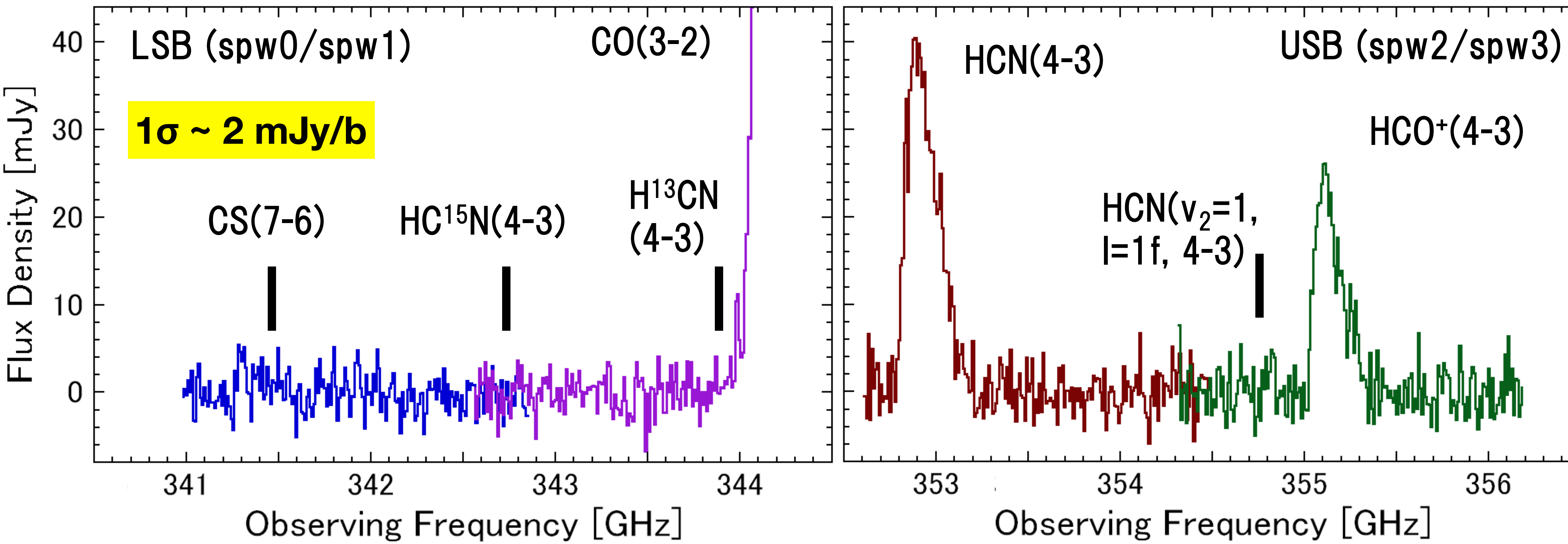


Maloney et al. (1996)

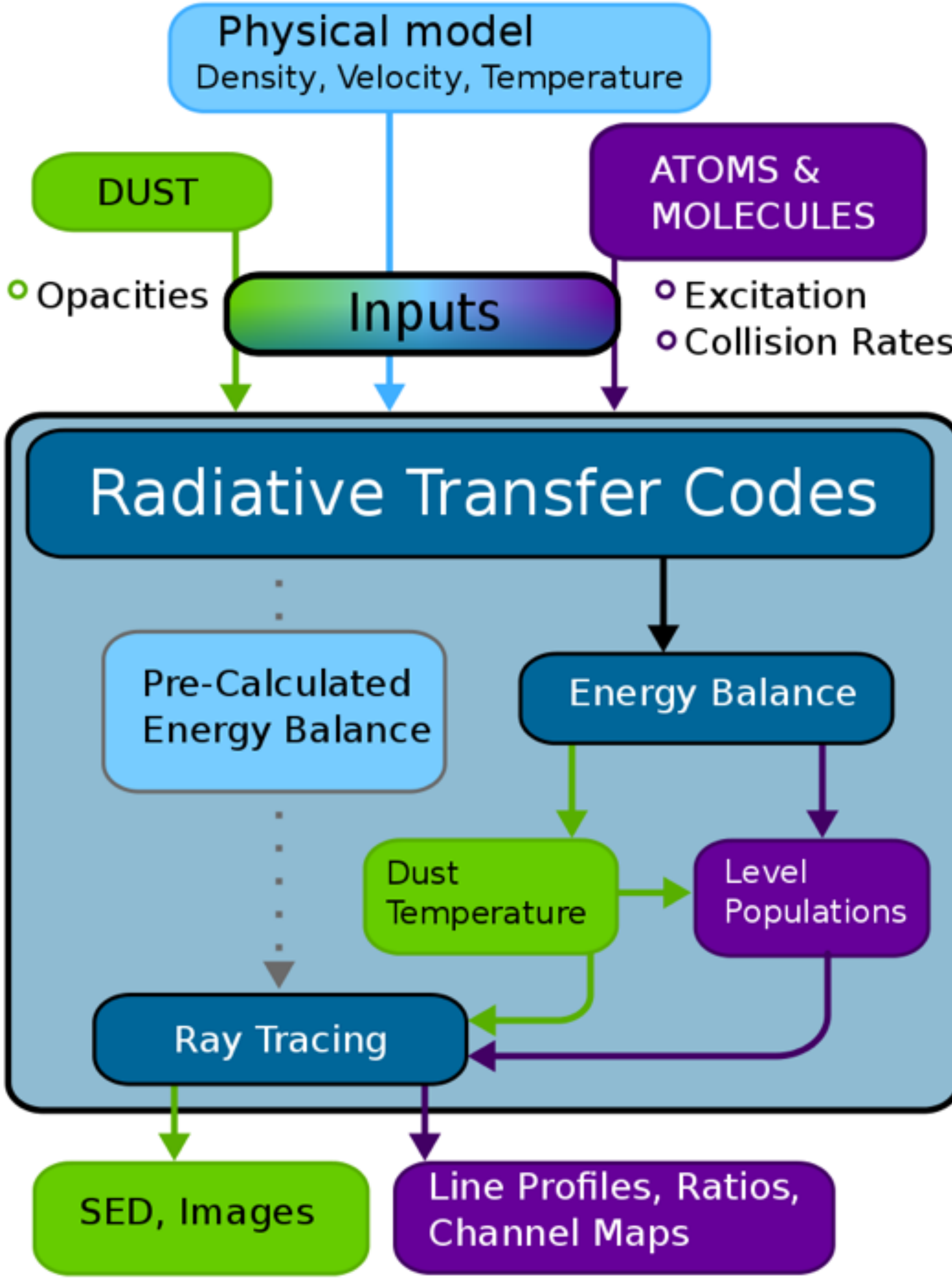
- Extends over a large volume → No layered structure
- Driven by X-ray photons (and yielded e.g., electrons)
- Much more efficient heating than in PDRs

Submm HCN-diagram: Case study in NGC 1097

- HCN(4-3)/HCO$^+$(4-3) > 1
- HCN(4-3)/CS(7-6) > 10
- Similarly high ratios in another AGN (NGC 1068)
- These high ratios are <u>not seen</u> in Starburst galaxies
  → **Watching the Feedback from AGNs? Key feature to identify AGNs?**



Izumi et al. 2013, PASJ, 65, 100



http://www.alma-allegro.nl/expertiseareas/science-modelling-tools/45

Non-LTE modeling of line radiative transfer

- We use a *RADEX* code
  - van der Tak et al. 2007, A&A, 468, 627
  - http://home.strw.leidenuniv.nl/~moldata/radex.html
- Statistical equilibrium:
  - Collisional process
  - Radiative process
  - Background radiation
- Optical depth is treated with an escape probability method
- Input parameters:
  n_{H2}, T_{kin}, T_{bg}, dV, N_{mol}
- We assume a spherical, uniform, single cloud for the modeling