Spatially resolved study of the CO selective dissociation in the Oph-A region

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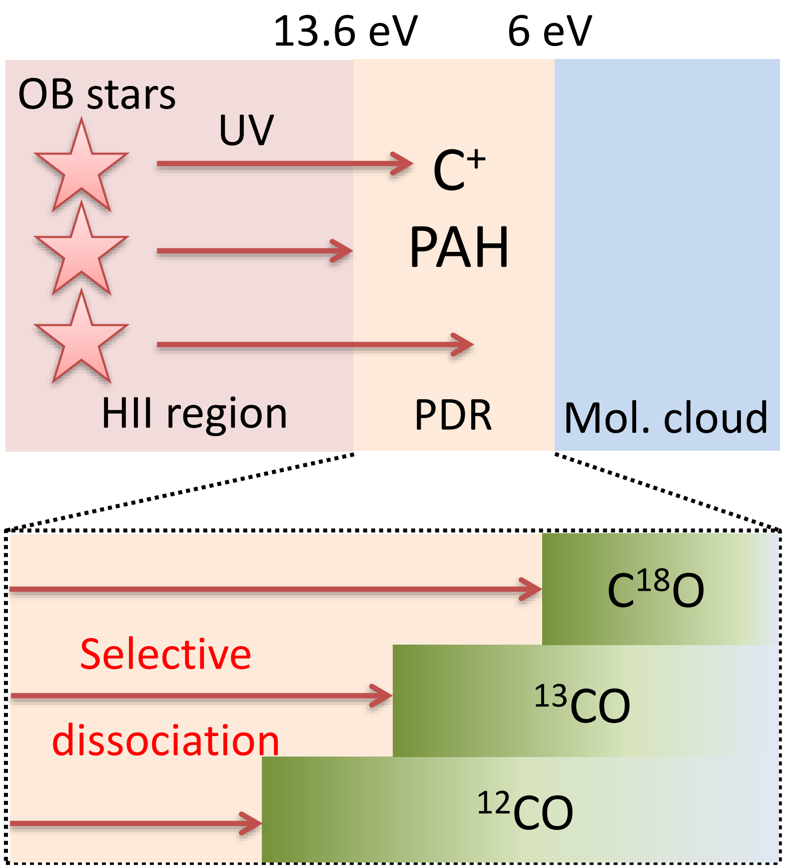
CO selective dissociation in PDR

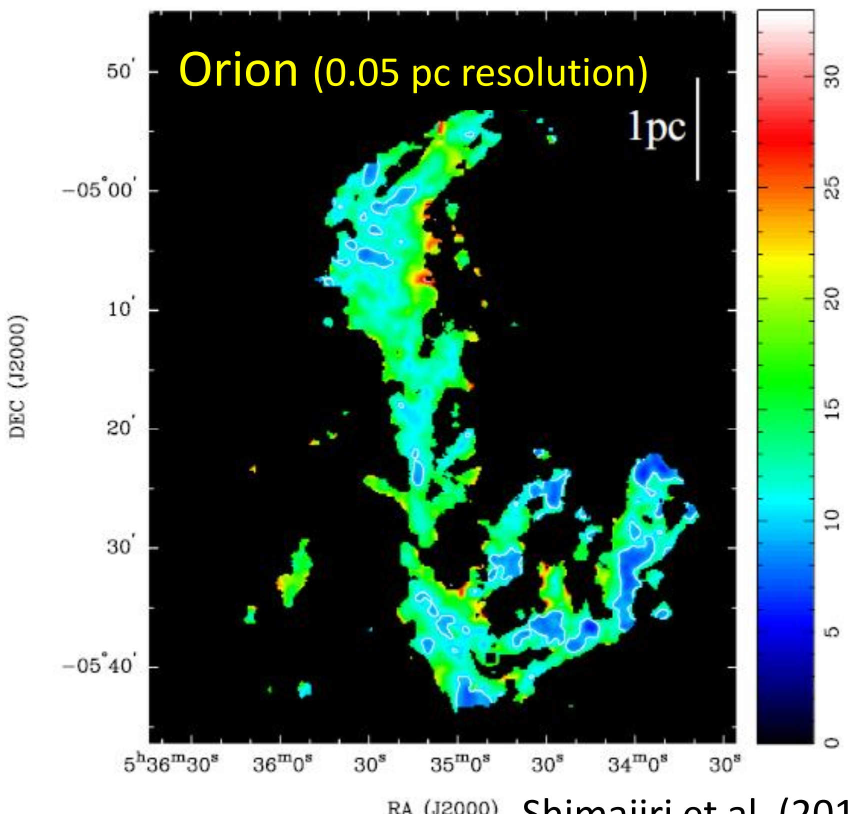
- PDR: Heating & chemistry are regulated by FUV (6-13.6 eV) photons (Hollenbach & Tielens 1999)
- Dissociation energy of CO: 11 eV
- CO may have layered structures due to the selective dissociation.
- Key mechanism is self shielding:
  - FUV photons to dissociate ^{12}CO is used and stopped at the surface of PDRs.
  - FUV photons to dissociate $C^{18}O$ reaches up to deep inside.

Classical "Plane parallel"

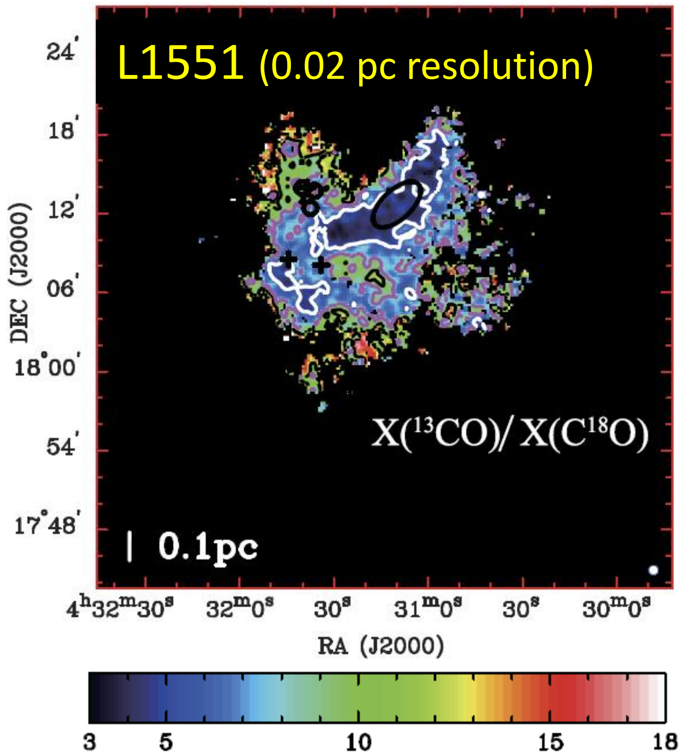


Observations of X(^{13}CO)/X(C^{18}O)

- Large-scale (~0.1 pc) variations of X(^{13}CO)/X(C^{18}O) have been observed for nearby molecular clouds with NRO45m (15” beam).
- Direct detection of CO layered structures has not been achieved.



Shimajiri et al. (2014)



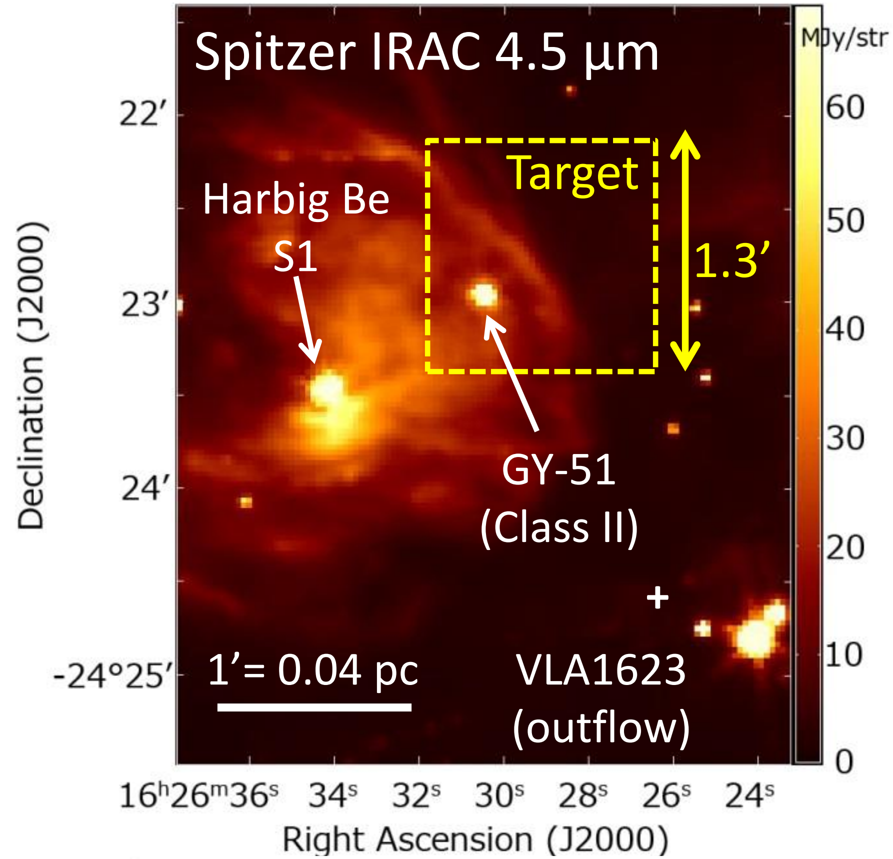
Lin et al. (2016)

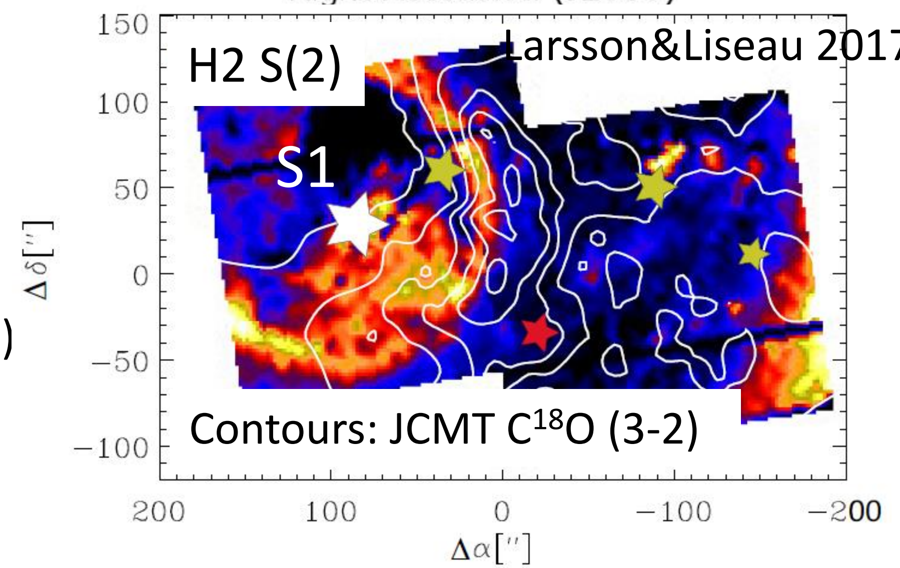
Ophiuchus A

- Closest PDR (d = 120 pc) illuminated by a Harbig Be star
  - Orion: 390 pc
  - L1551: 160 pc
- Ideal plane-parallel PDR
  - Clear shell structures in Spitzer 4.5 µm, H_2, [OI]
- FUV intensity at the shell:

  $G_0 = (3\text{-}4) \times 10^3$ (Shimajiri et al. 2017)
- Av = 20 mag behind the shell

  (2MASS extinction map)





Observation with ALMA

- ALMA cycle 2 (PI. F. Nakamura)
- Line transitions:

  ^{12}CO (2-1), ^{13}CO(2-1), $C^{18}O$(2-1)

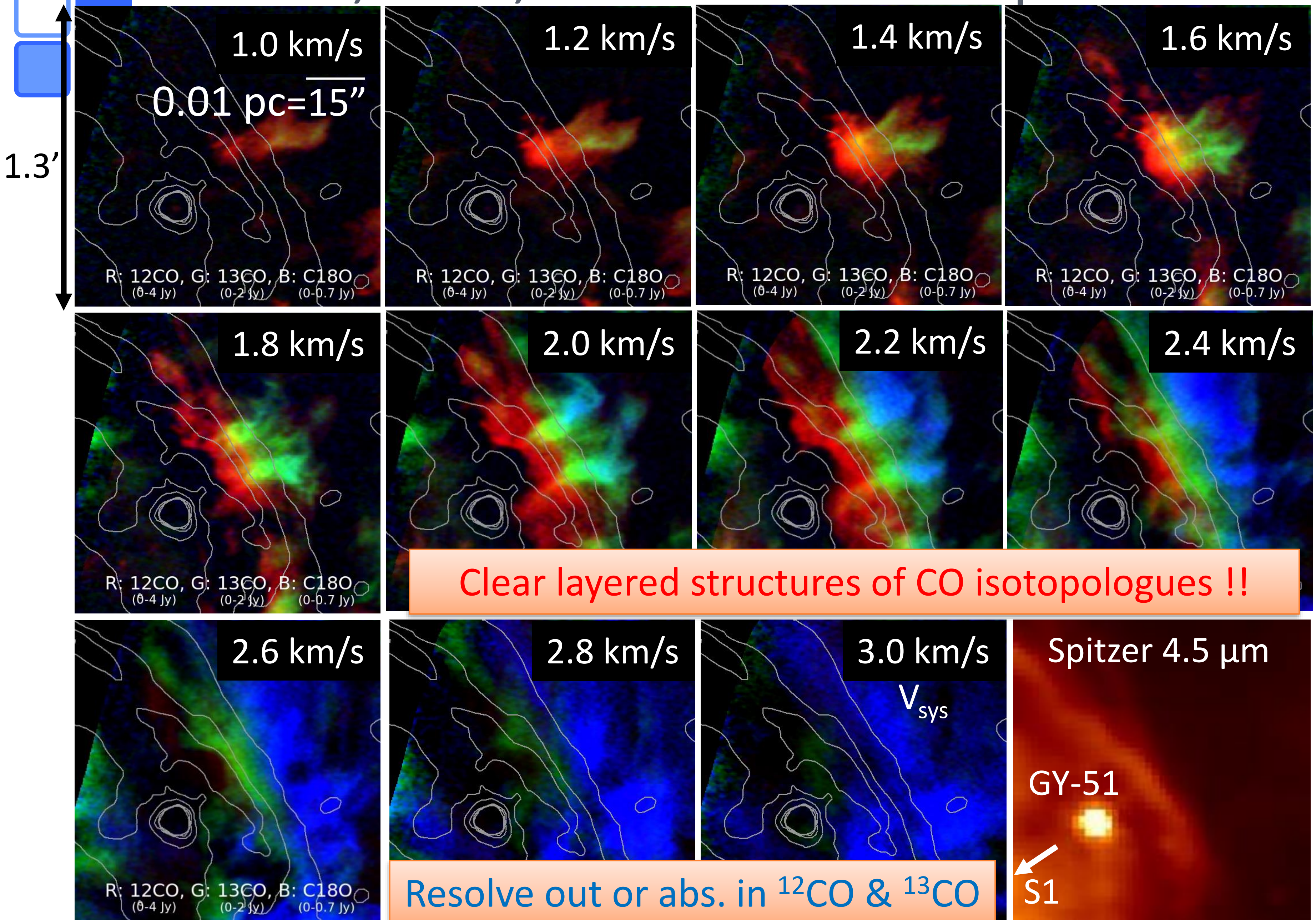
- Array configuration:

  12m array + 7m array (No TP data)

- Beam size: 0.94”x1.4”= 0.001 pc = 180 AU
  - 20 times higher resolution than those of previous singledish observations for Orion and L1551
- 1σ noise level: 44 mJy/beam (Δv=0.2 km/s)

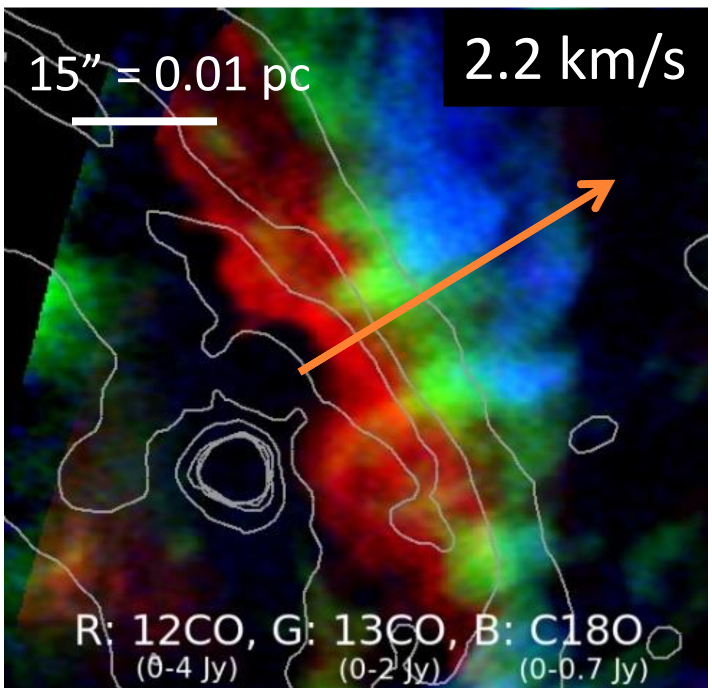
^{12}CO, ^{13}CO, $C^{18}O$ channel maps

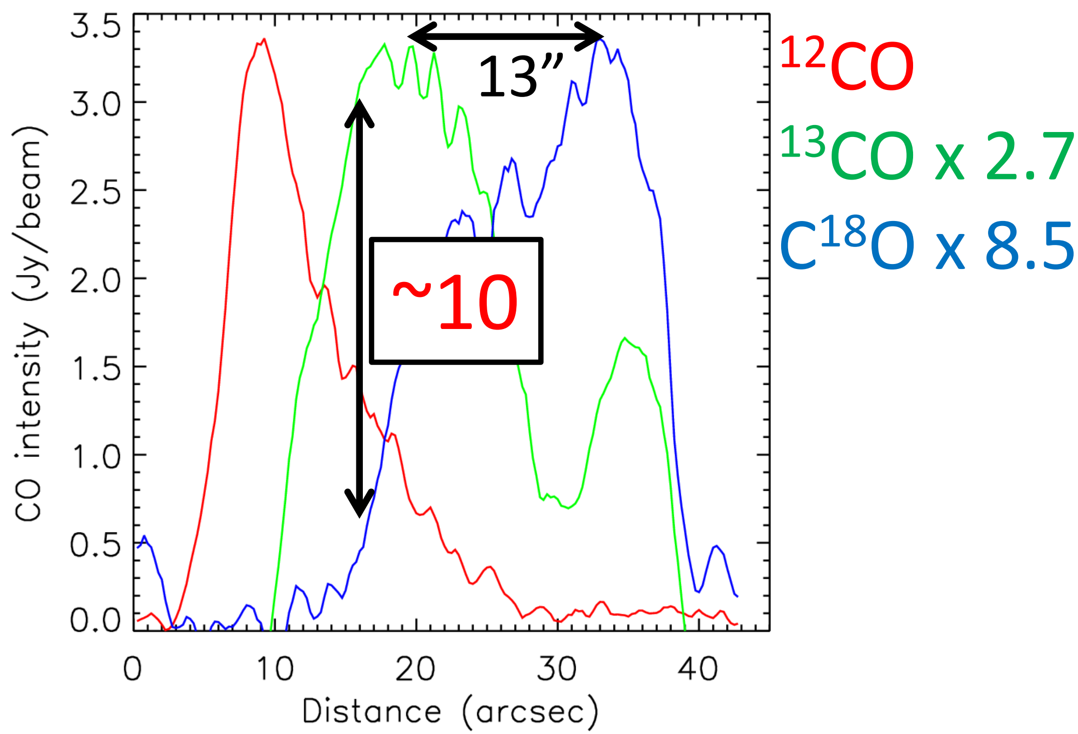
Contours : Spitzer 4.5μm



Separation between ^{13}CO and $C^{18}O$

- **Spatial separation: 10”-15”** < beam size of large singledish telescopes
  c.f. NRO45m, JCMT: 15”
  ⇒ Unique study with ALMA
- **$^{13}CO/C^{18}O$ intensity ratio >> 5** ⇔ RADEX calculation : 1.4-4.9
  - Av = 20 mag, $[^{13}CO]/[H_2]=1.7\times10^{-6}$, $[C^{18}O]/[H_2]=2.7\times10^{-8}$
  - T_{kin} = 10-80 K, $n_H = 10^2$-10^5 cm^{-3}, background = 2.7 K, ΔV= 1 km/s

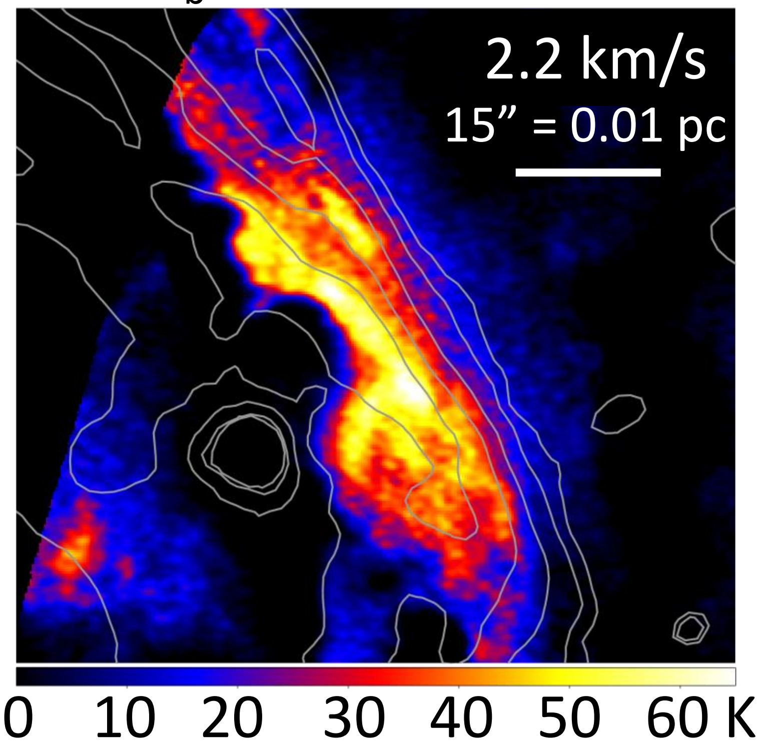




Bright CO heated by UV radiation

- ^{12}CO is very bright at the shell ~ 60 K

^{12}CO T_b map



- Gas Temperature:

  $T = 12.2 \times G_0^{1/5}$ (Hollenbach 1990)

- $G_0 \sim (3\text{-}4) \times 10^3$ at the shell (Shimajiri+17)

$\Rightarrow T \sim 64\ (G_0/4\times10^3)^{1/5}$ K

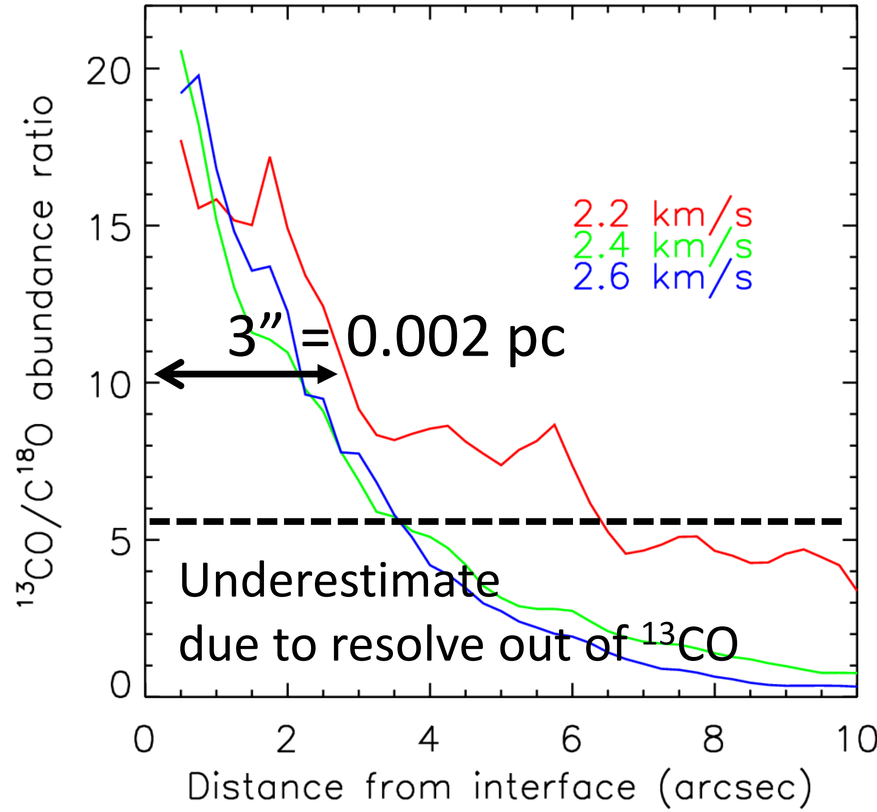
Supporting heating of CO by UV

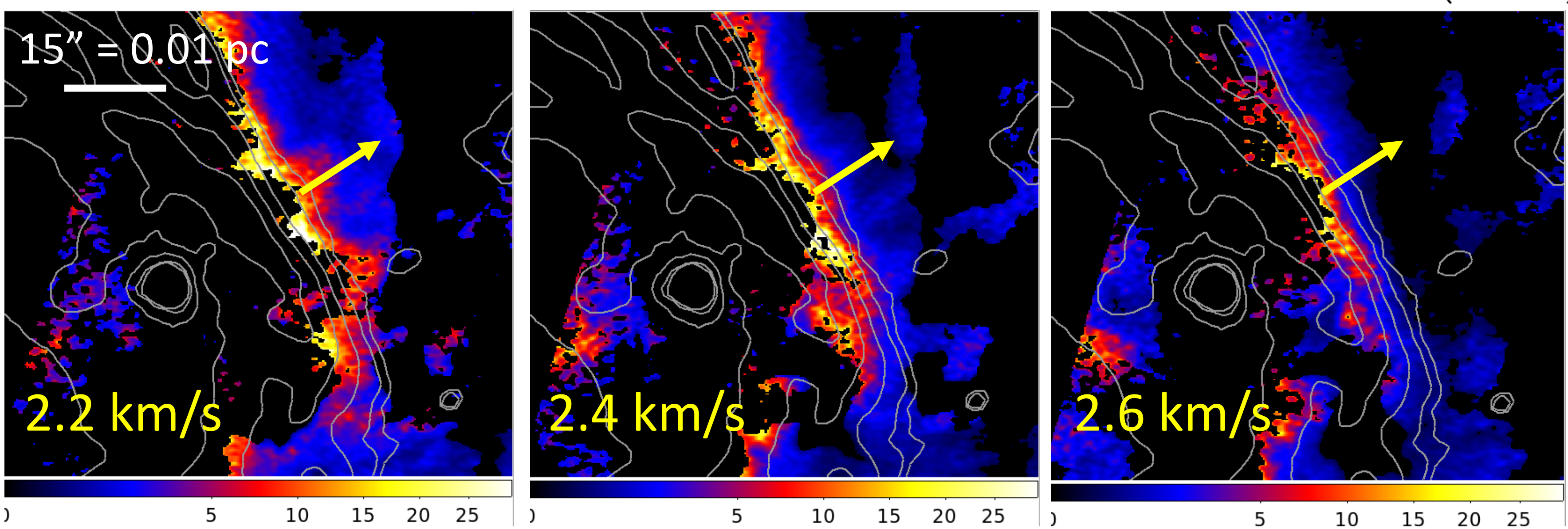
Variations of $X(^{13}CO)/X(C^{18}O)$

$N(^{13}CO)/N(H_2)$

- $X(^{13}CO)/X(C^{18}O) = N(^{13}CO)/ N(C^{18}O)$
- $^{12}CO \rightarrow T_{ex}$, ^{13}CO, $C^{18}O \rightarrow \tau$
- $^{13}CO/C^{18}O$ maps show clear gradient
- $X(^{13}CO)/X(C^{18}O) > 20$ > x4

⇔ $X(^{13}CO)/X(C^{18}O) = 5.5$ in the solar system





Messages from this study

- We for the first time directly investigate CO layers due to the selective dissociation.
- Direct effects to CO studies
  - We should pay attention to the large-scale UV environment. The CO column density estimated from $C^{18}O$ may be significantly underestimated. We need to use multiple lines.
- Astrochemical studies in PDRs
  - Abundance ratios are not uniform even in a small spatial scale. $^{12}C/^{13}C$ and $^{16}O/^{18}O$ ratios may drastically change. Such variations may affect isotopologue ratios of other molecules.
- TP observations are essential for nearby targets

Summary

- We have performed $^{12}CO(2-1)$, $^{13}CO(2-1)$, $C^{18}O$ (2-1) observations of Oph-A with ALMA.
- Layered structures of CO isotopologues are detected due to the selective dissociation.
- The spatial separation between the layers is 10”-15” (~0.01 pc), which is not detectable with any singledish telescopes.
- $X(^{13}CO)/X(C^{18}O)$ change from >20 to 5 in a small spatial scale (~3”=0.002pc).
- We should note that $^{12}CO/^{13}CO/C^{18}O$, $^{12}C/^{13}C$, $^{16}O/^{18}O$ ratios are not uniform even in a small region when we discuss column densities of various molecules in PDRs.