Mapping the Milky Way in Sub-millimeter Wavelengths Emission Lines

Masumichi Seta

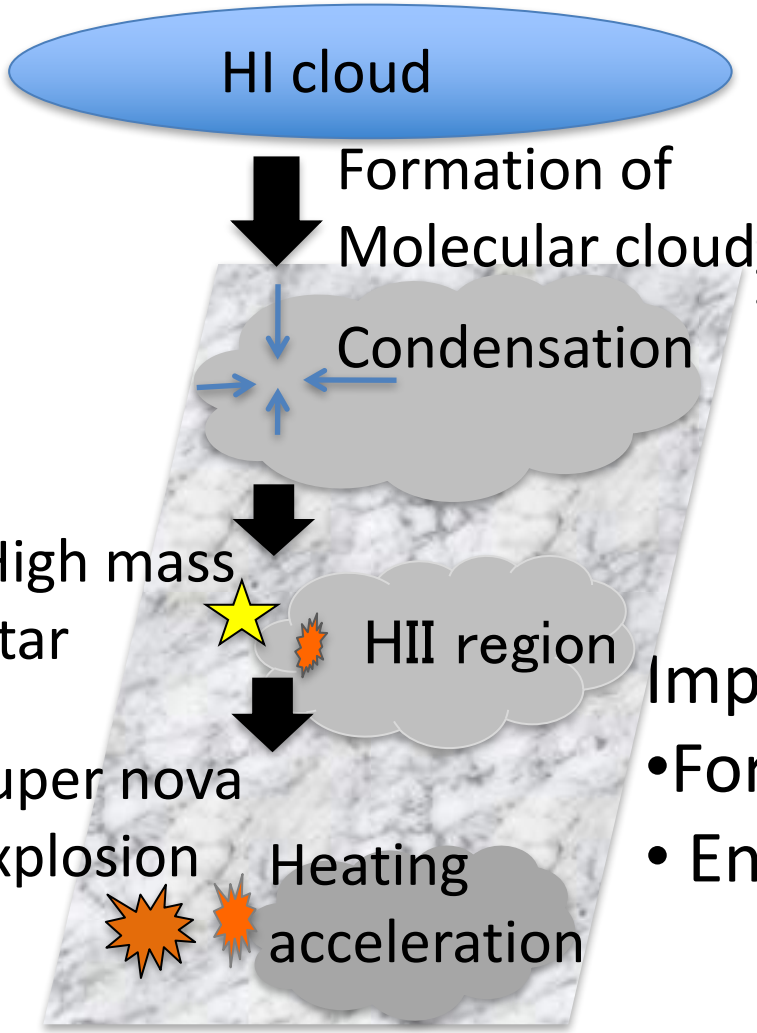
（KwanseiGakuin Univ.）

Contents

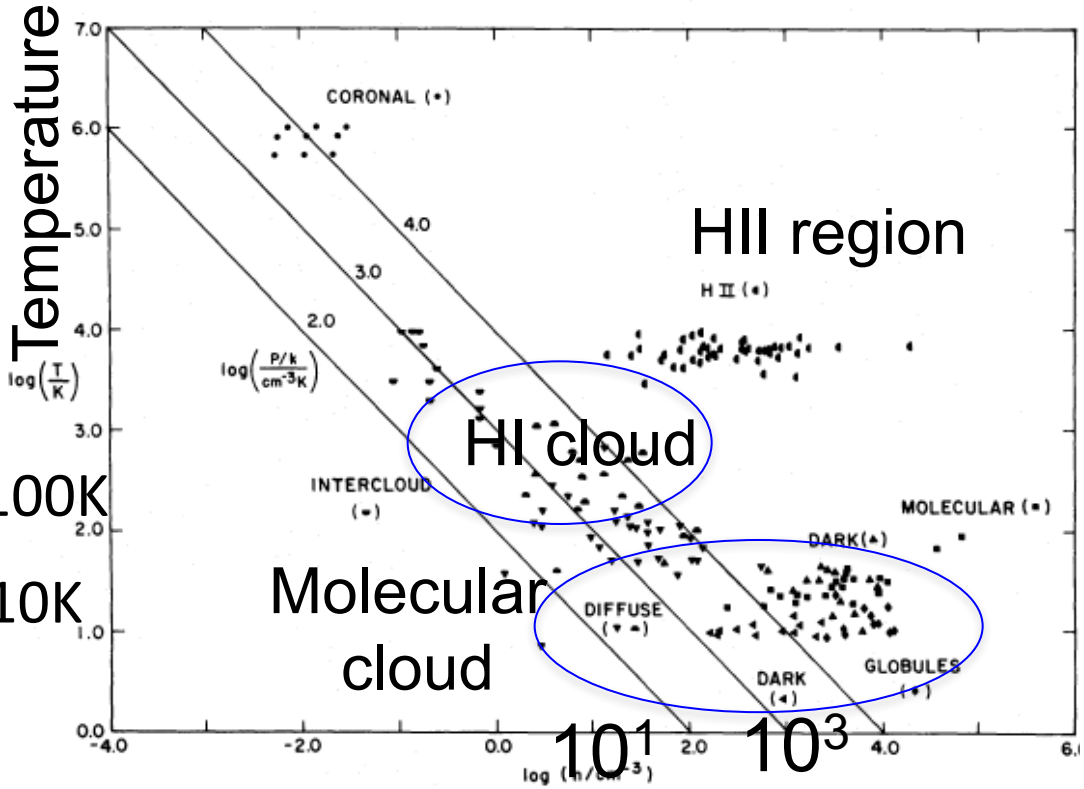
- Molecular cloud
- Survey observations of the Milky Way
- Emission lines in sub-mm wavelengths
- Astronomy from Antarctica

Molecular cloud (MC)

- Inter Stellar Medium
  Gas+Dust
- Classification on ISM



(Myers 1978)



Importance of molecular cloud

- Forming stars
- Energy source of Active Galactic Nuclei

Formation and evolution of
MC is a hot research topic

Probe for Observing Molecular Cloud

- No emission from main constituent H_2
  - Thermal emission from dust grains
  - Emission lines of molecule and atom
- What is good probe?

Abundance

[He]/[H]～ 0.1

[O]/[H] ～5×10^{-4}

[C]/[H] ～3×10^{-4}

UV・cosmic ray change state

Ionization of H_2 >13.6 eV

Ionization of C > 11.3eV

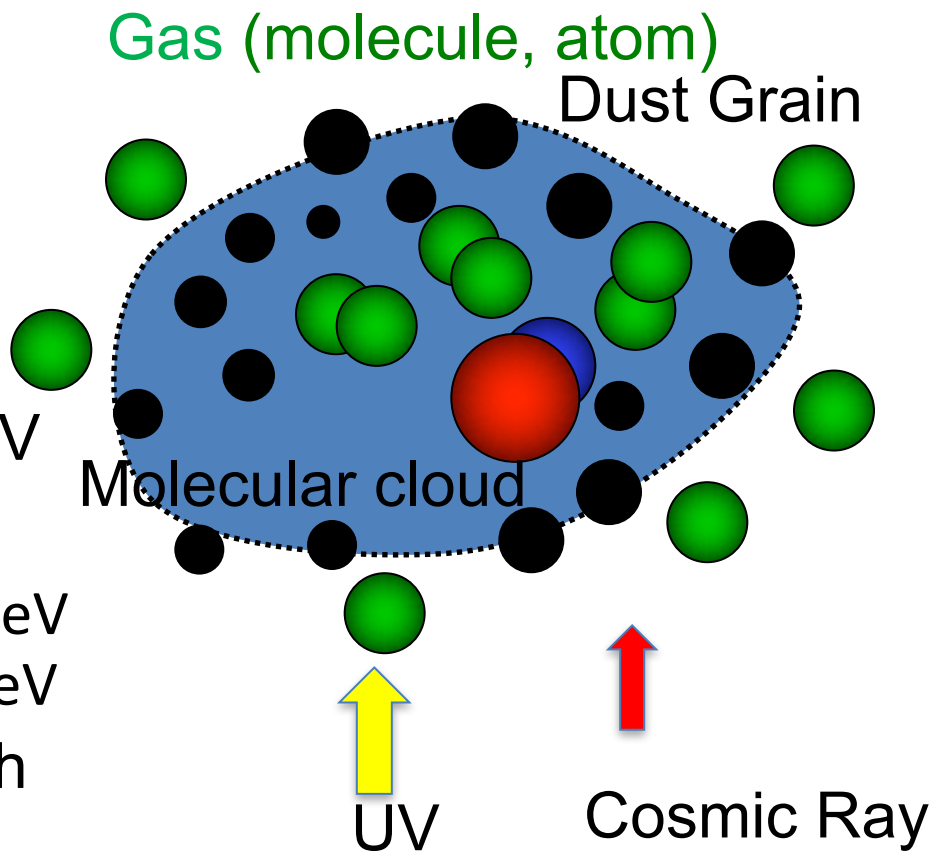
Dissociation of H2 >14.7 eV

Dissociation of CO >11.1eV

Critical density n optical depth

CO *J*=1-0 n～1×10^3/cc

CO *J*=4-3 n～4×10^4/cc



CO has been used. Atomic carbon may be good probe.

History of Mapping the Milky Way

Bell Lab7m ^{13}CO 1-0 (Stark+ IAU Stmp. 1987)

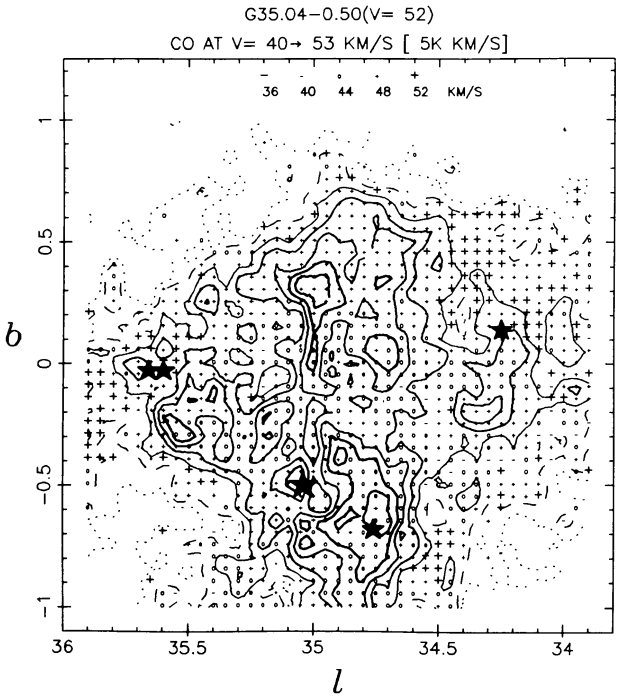
Masschusetts-Stony Brook

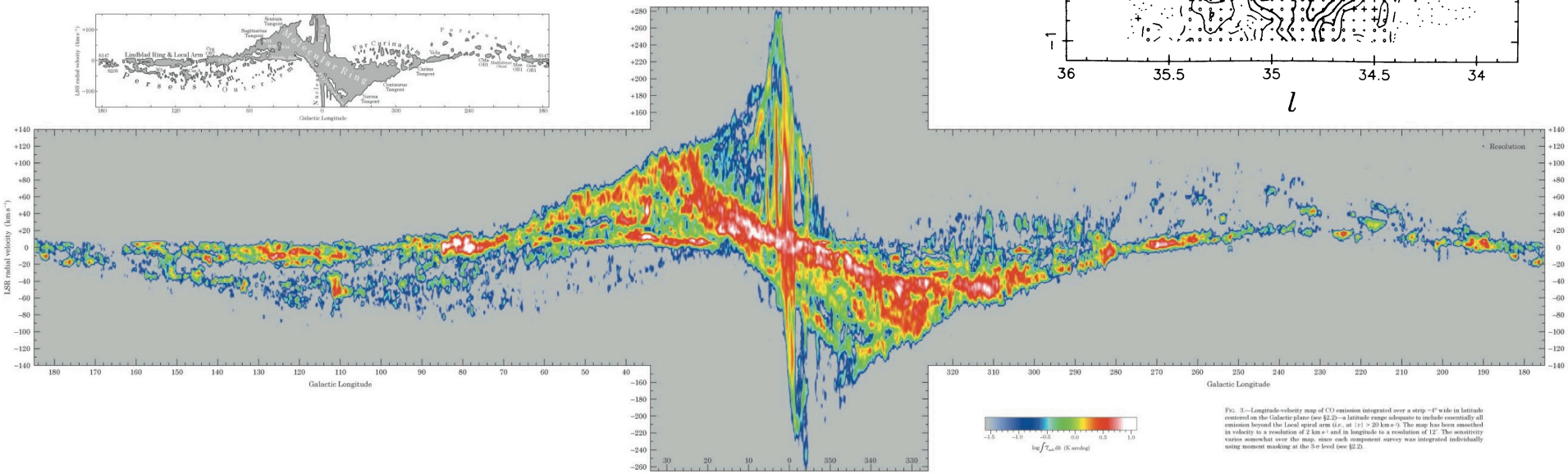
FCRAO 14m ^{12}CO 1-0 45” 3’grid

(Sanders+ApJS 1986, Scoville+,ApJS 1987)

CfA 1.2m ^{12}CO 1-0 9’ 4deg <full beam

(Dame+ ApJ 1987, 2001)





MC exists in the form of GMC (40pc、10^5Mo)

Concentrated in a ring between 4<r<8 kpc from the Galactic center

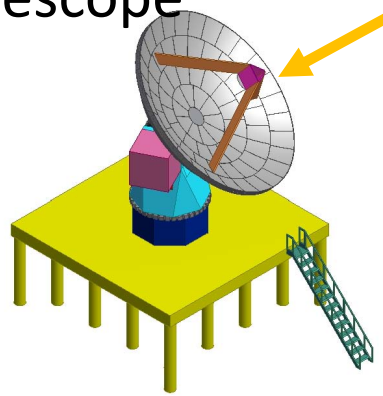
Velocity of Molecular Cloud

Doppler Shift

Velocity

MC

Radio Telescope

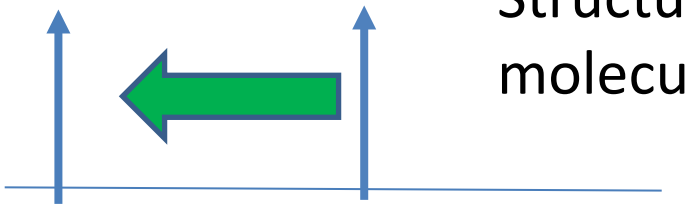


Relative motion

→Shift in Frequency

($f_0 \rightarrow f_d$)

Rest frequency f_0 : Structure of molecule&Atom

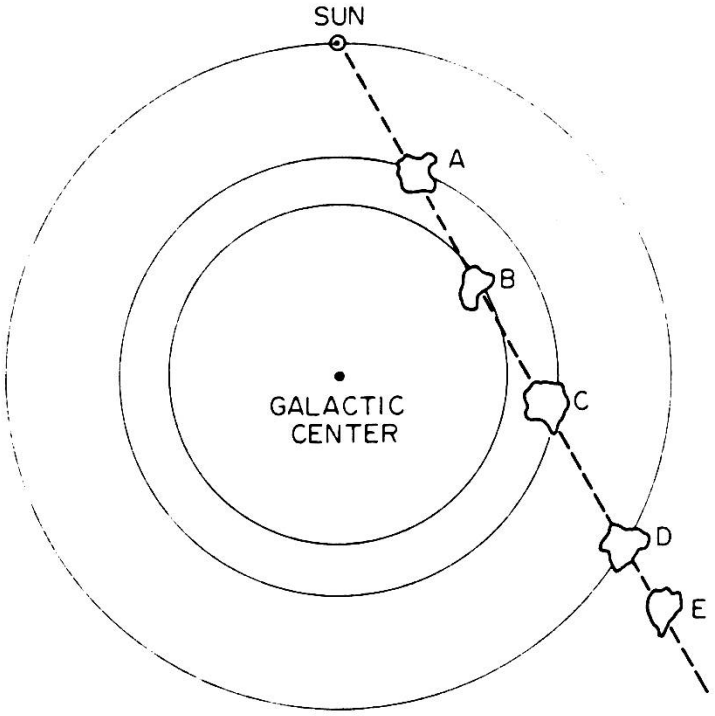


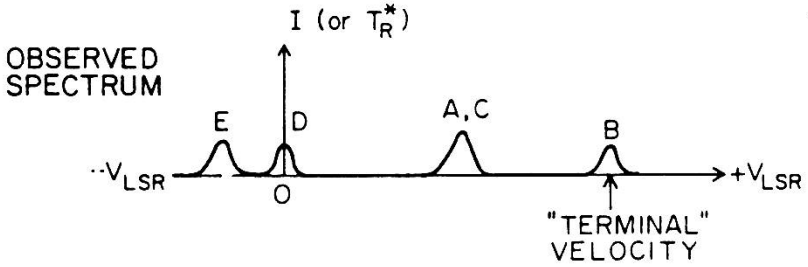
f_d f_0 Frequency

Δf→Velocity of MC

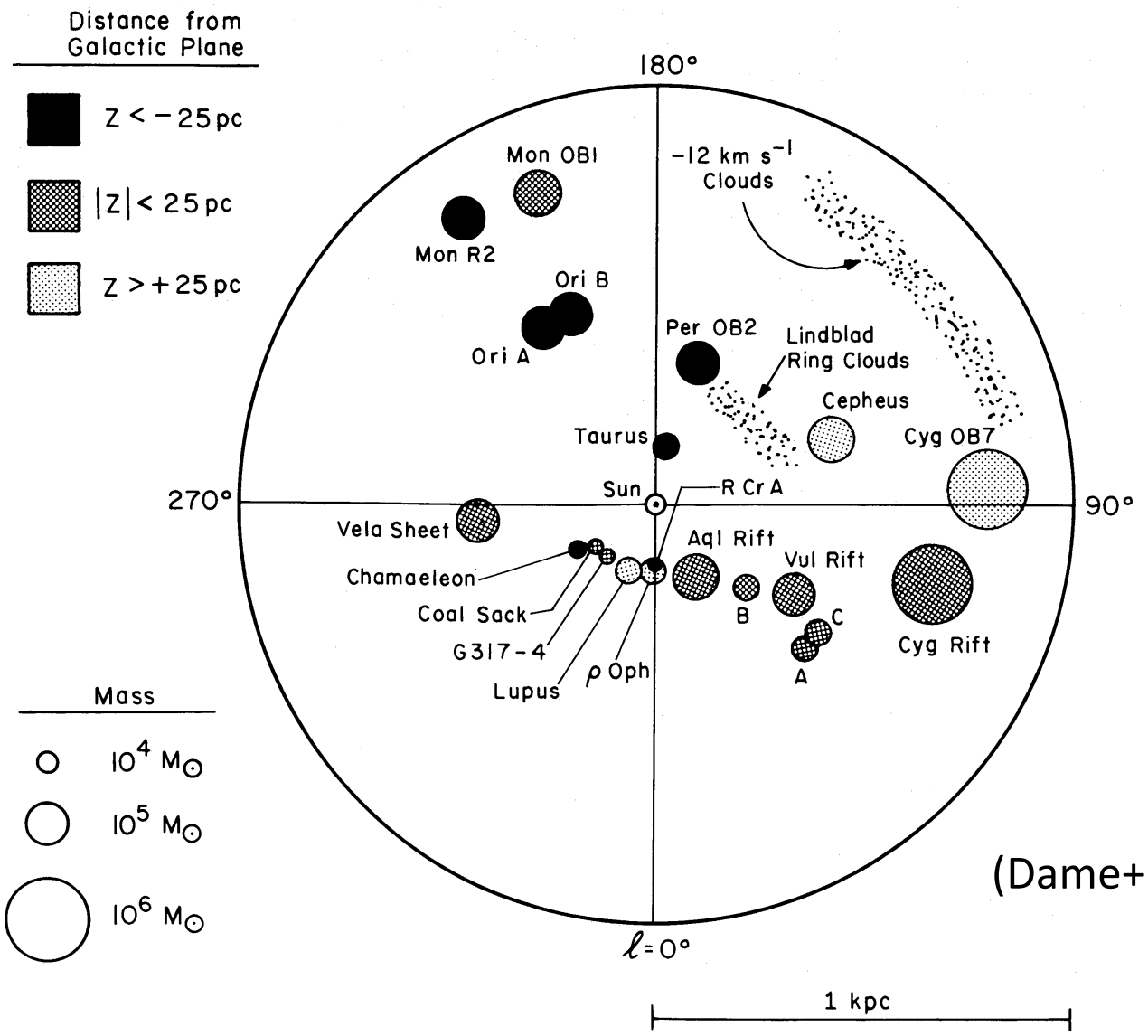
Distance to MC

Galactic rotation





Molecular Cloud around Sun



(Dame+ 1987)

High Resolution Galactic Plane Survey

FOREST Unbiased Galactic plane Imaging survey with Nobeyama 45m telescope(FUGIN

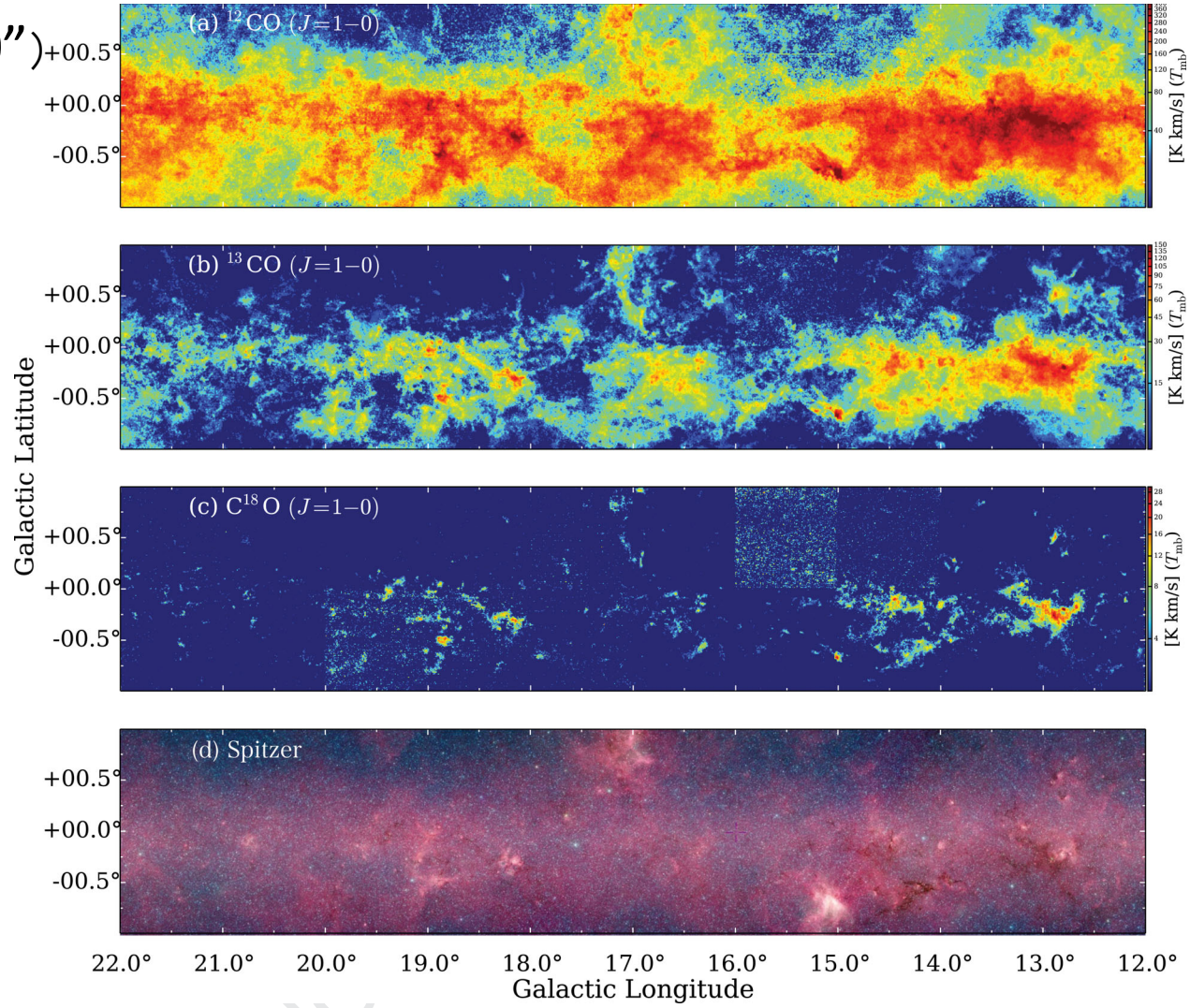
(Umemoto+ Publ 17

(resolution 20”)

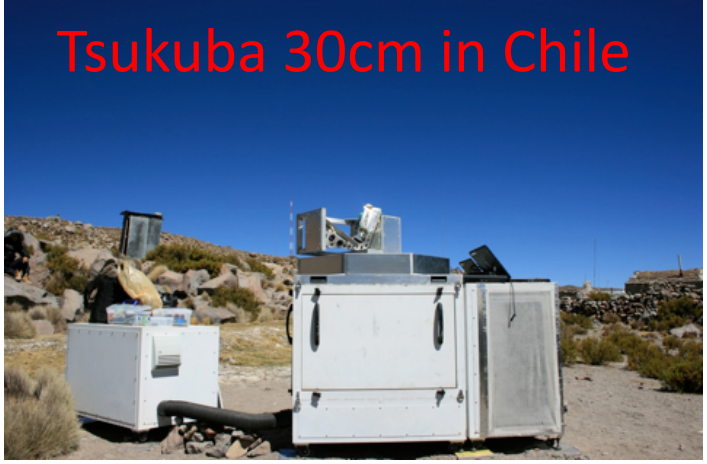
^{12}CO 1-0

^{13}CO 1-0

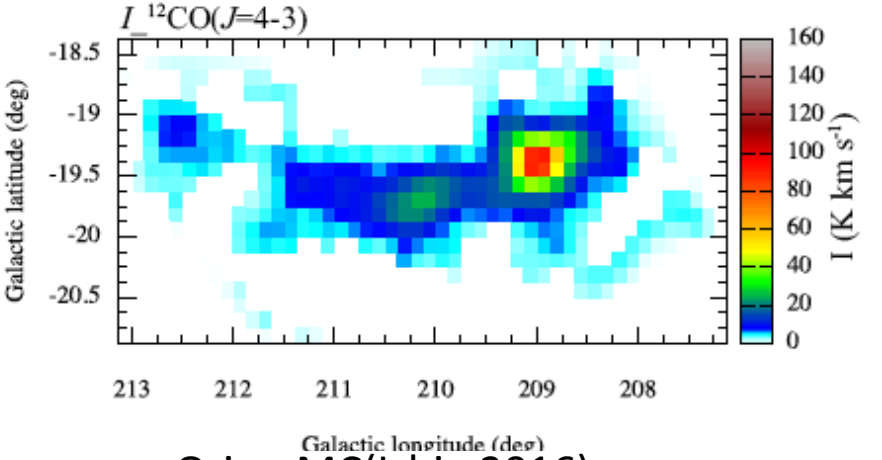
C^{18}O 1-0



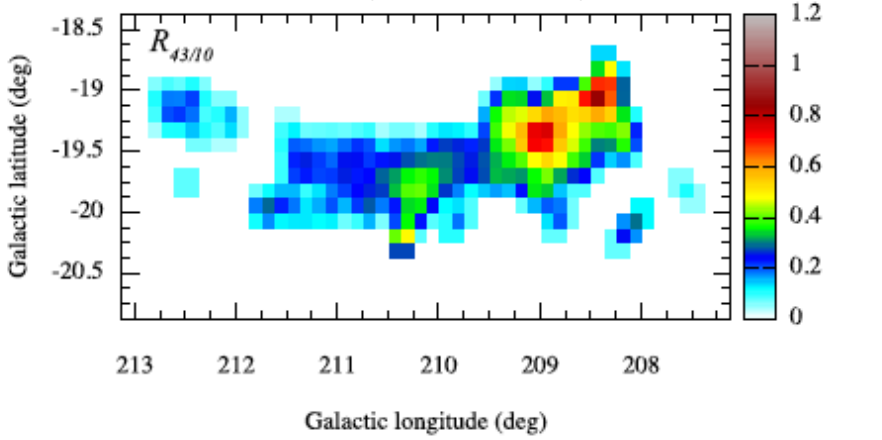
Advances in the Survey Obs.



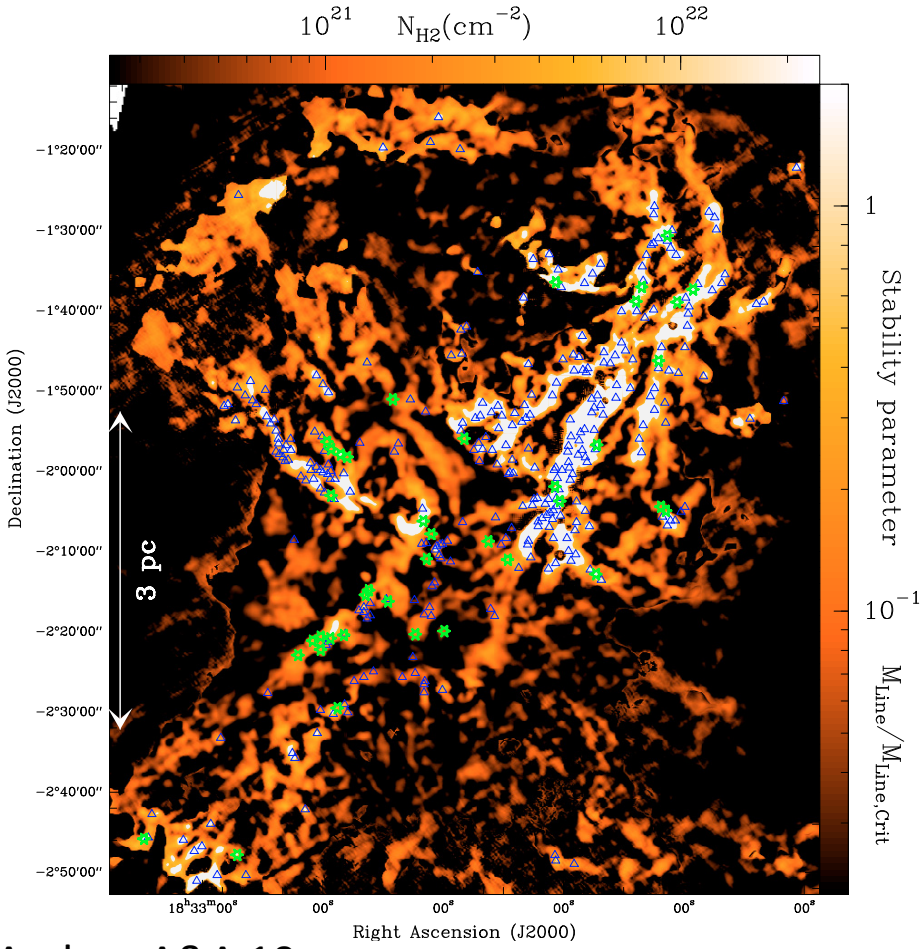
- Higher angular resolution
  - NRO 45m FUGIN
  - Nagoya Univ. NANTEN2 4m
- Higher frequency
  - Univ. Tokyo-NRO 60cm CO 2-1 9
  - Osaka Prefect. Univ. 1.8m 3'
    - ^{12}CO ^{13}CO C^{18}O 2-1
  - Univ. of Tsukuba 30cm 9'
    - CO 4-3 CI 9'
      - Intensity ratio (I 4-3/1-0)
      - →physical condition
  - Mt. Fuji 1.2m CO 4-3
  - JCMT 15m CO 3-2
    - (Dempsey+ ApJS 2013)

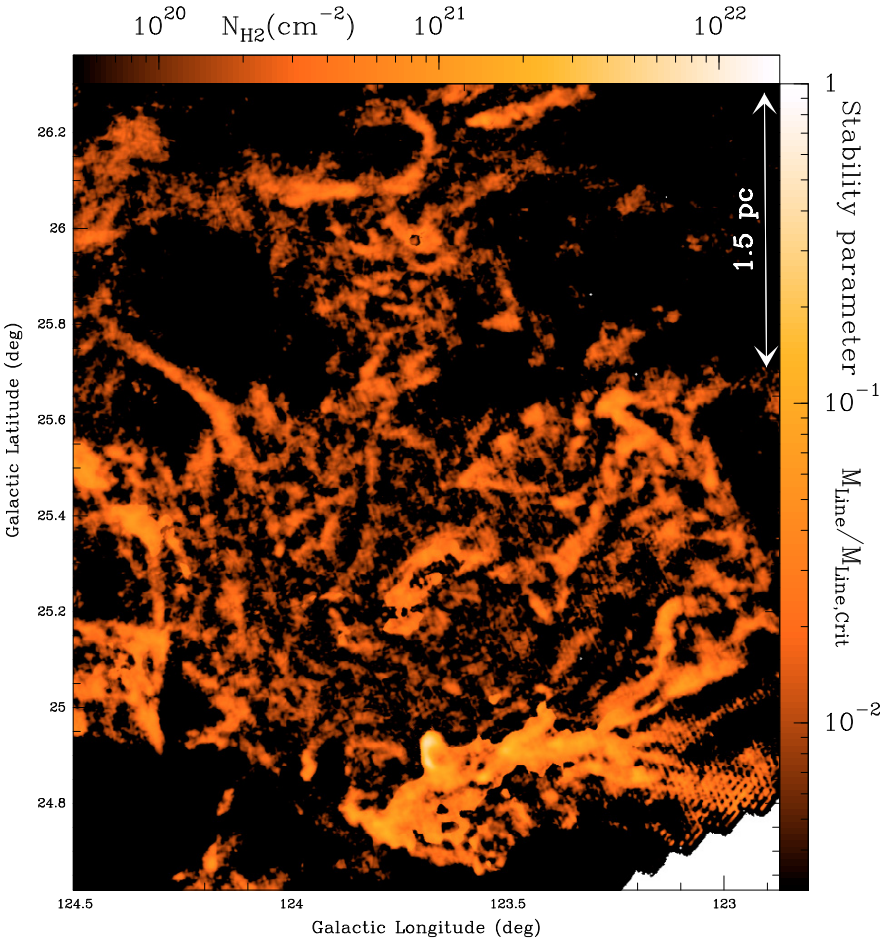


Orion MC(Ishi+ 2016)



Filamental structure of Dust





Andre+ A&A 10

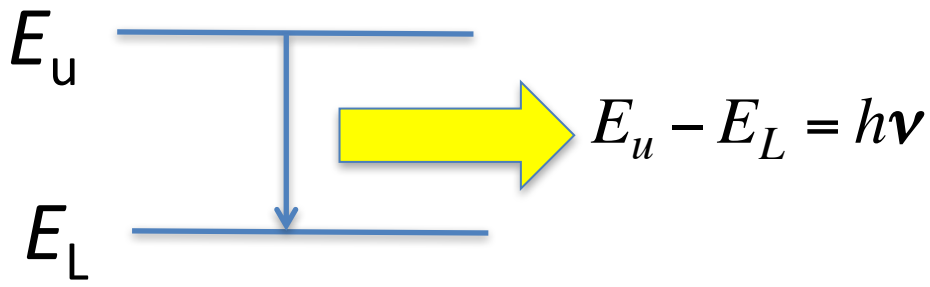
~0.1pc width

Colum density（Hershel SPIRE/PACS

70-500um

Emission Lines from Atom and Molecule

Change in internal energy

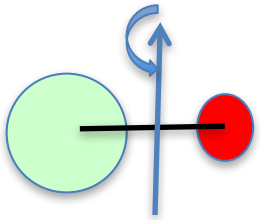


Energy States of molecule

$$E = E_{electron} + E_{vibration} + E_{rotation}$$

Rotational transition of CO

CO J=1-0 115GHz CO J=4-3 460GHz



Fine structure line of atomic carbon (CI)

Interaction between angular momentum of electron and spin

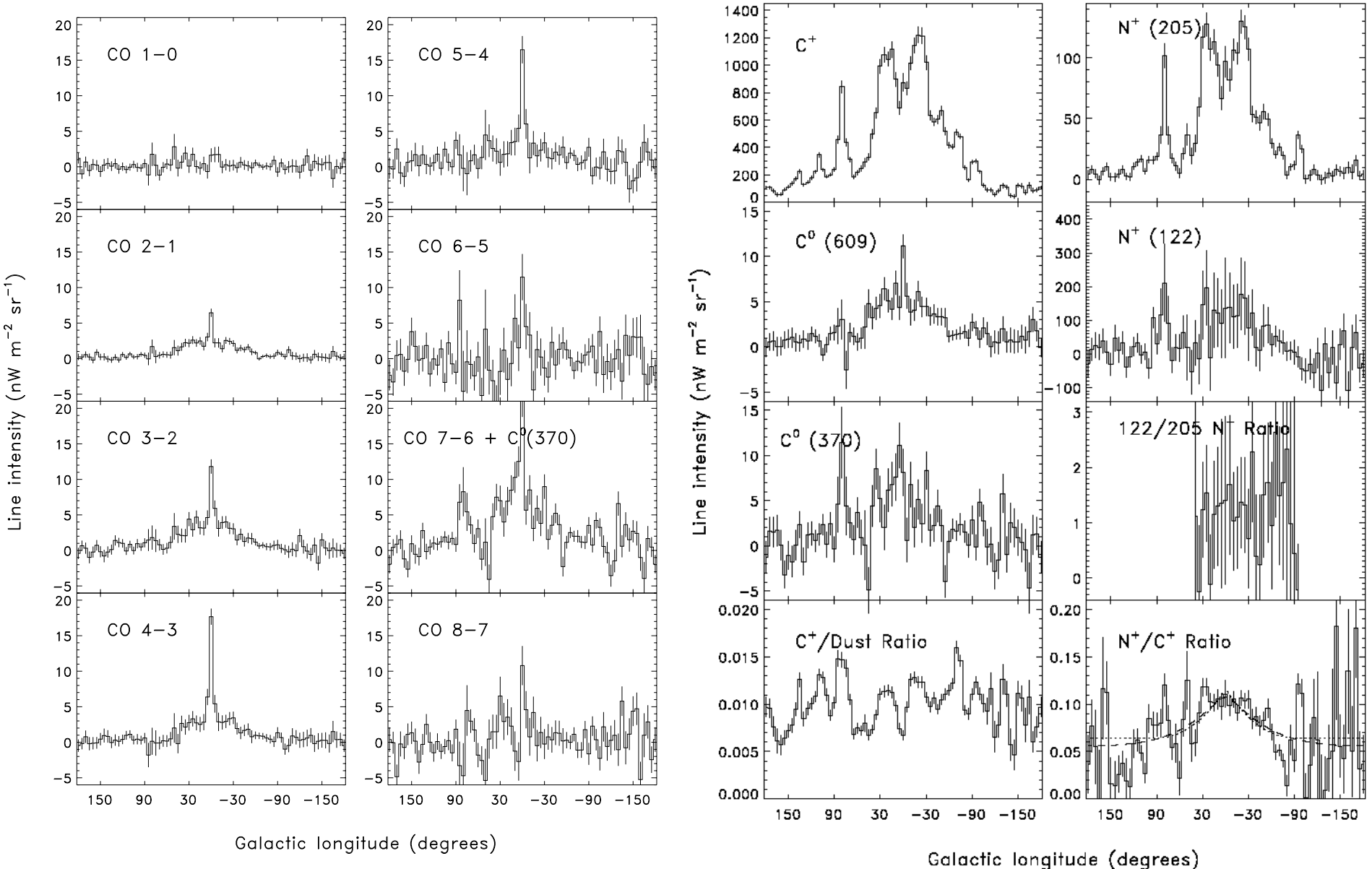
$^3P_2 - ^3P_1$ 809.34GHz (370um)

$^3P_1 - ^3P_0$ 492.16GHz (609um)

CI in the Milky Way

MW survey by COBE(7°)

(Fixsexen+ 1999, Wright,et al. ApJ,1991)

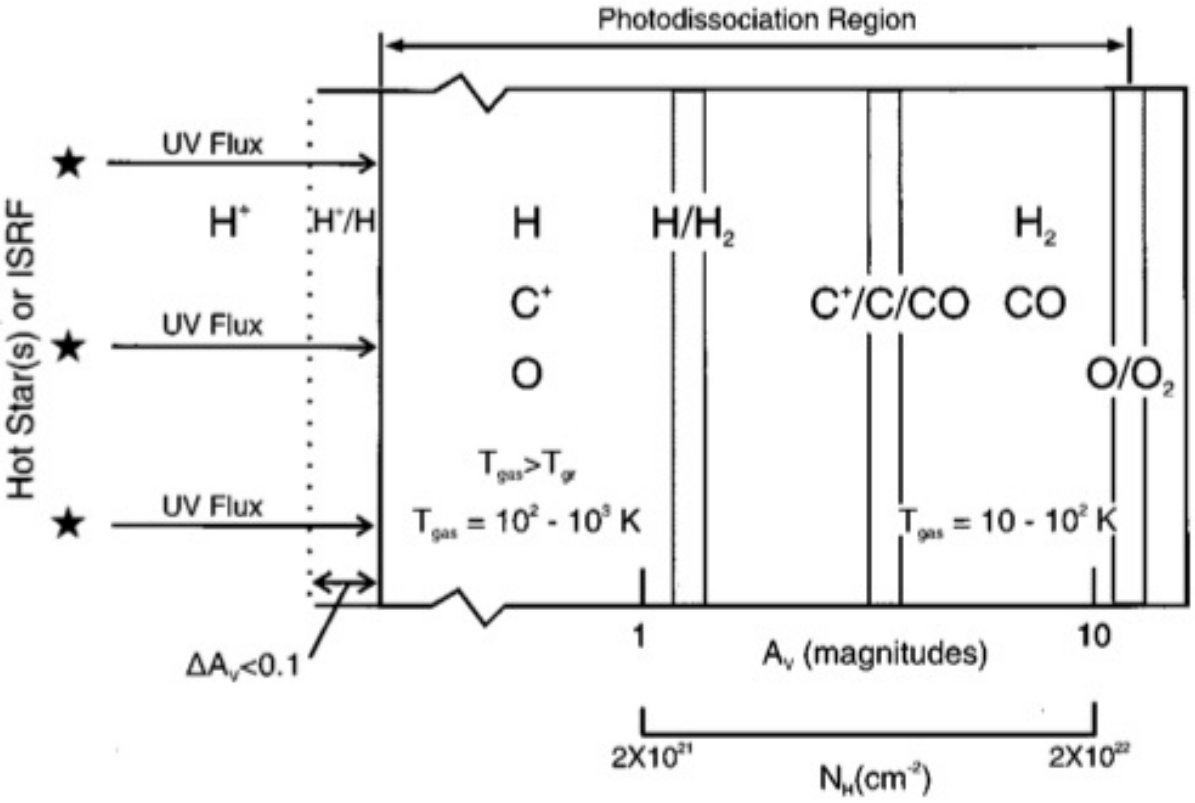


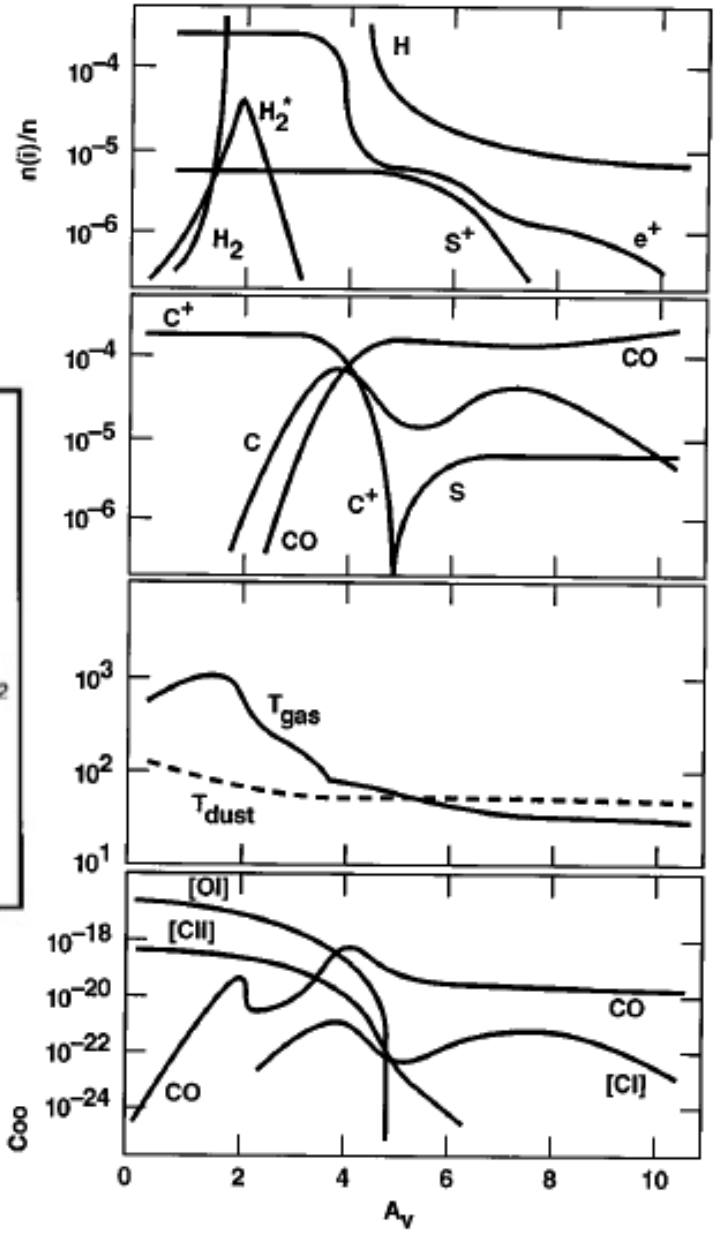
Atomic carbon (CI) is detected at PDR

Photo Dissociation Region(PDR)

Simulation

(Hollenbach & TienenRev. Mod. Phys.1999)



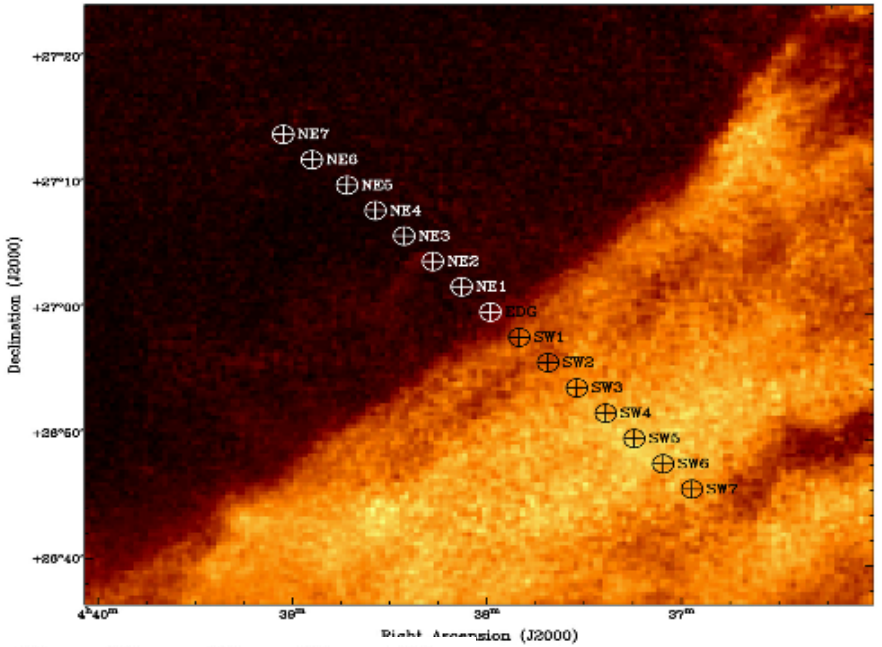


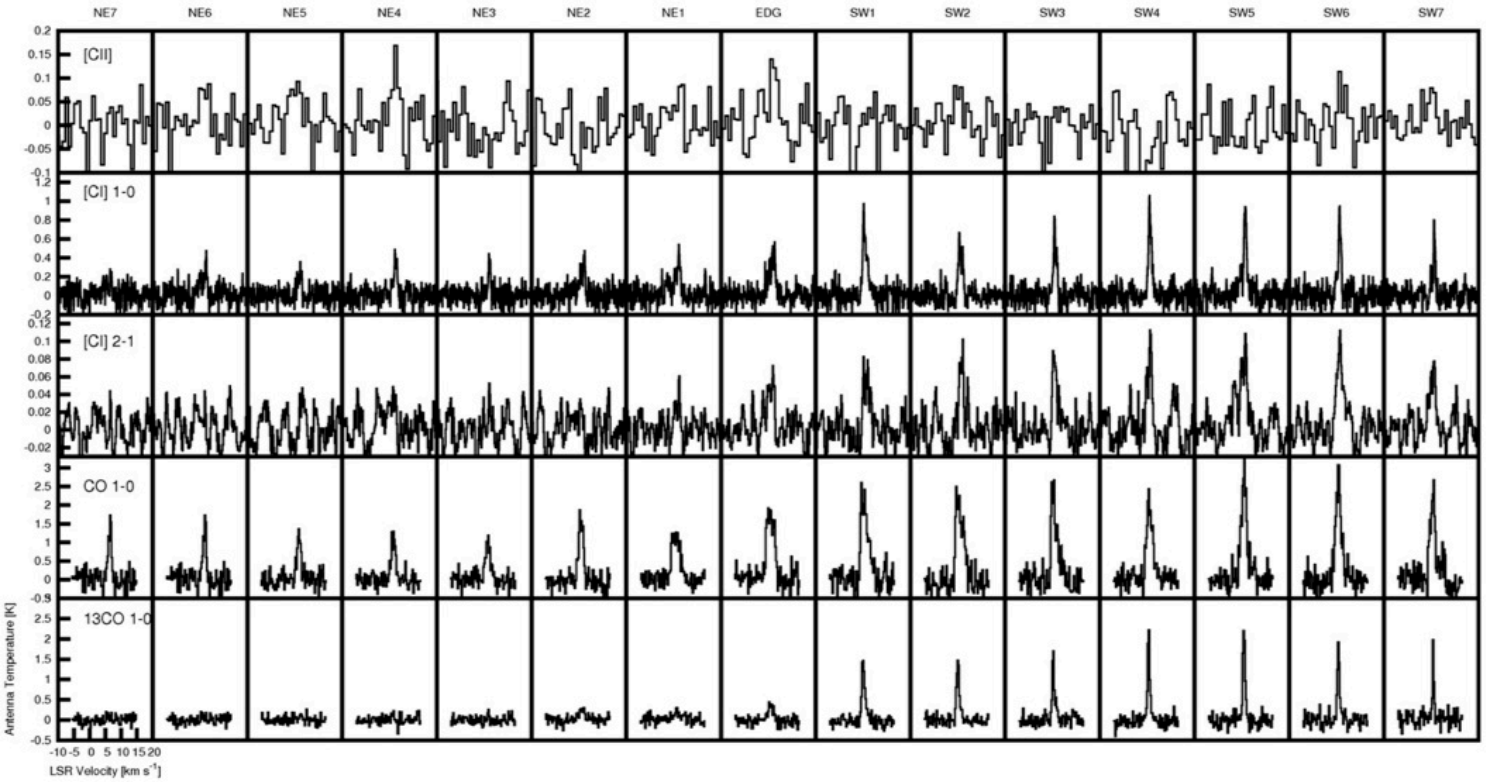
Observation of PDR

Taurus Molecular Cloud

(Orr, et al., ApJ, 2014)

PDR model well explains the results





CII 1.9THz

CI 492GHz

HIFI 44”@492GHz

CI 809GHz

^{12}CO 1-0

FCRAO14m 45”

^{13}CO 1-0

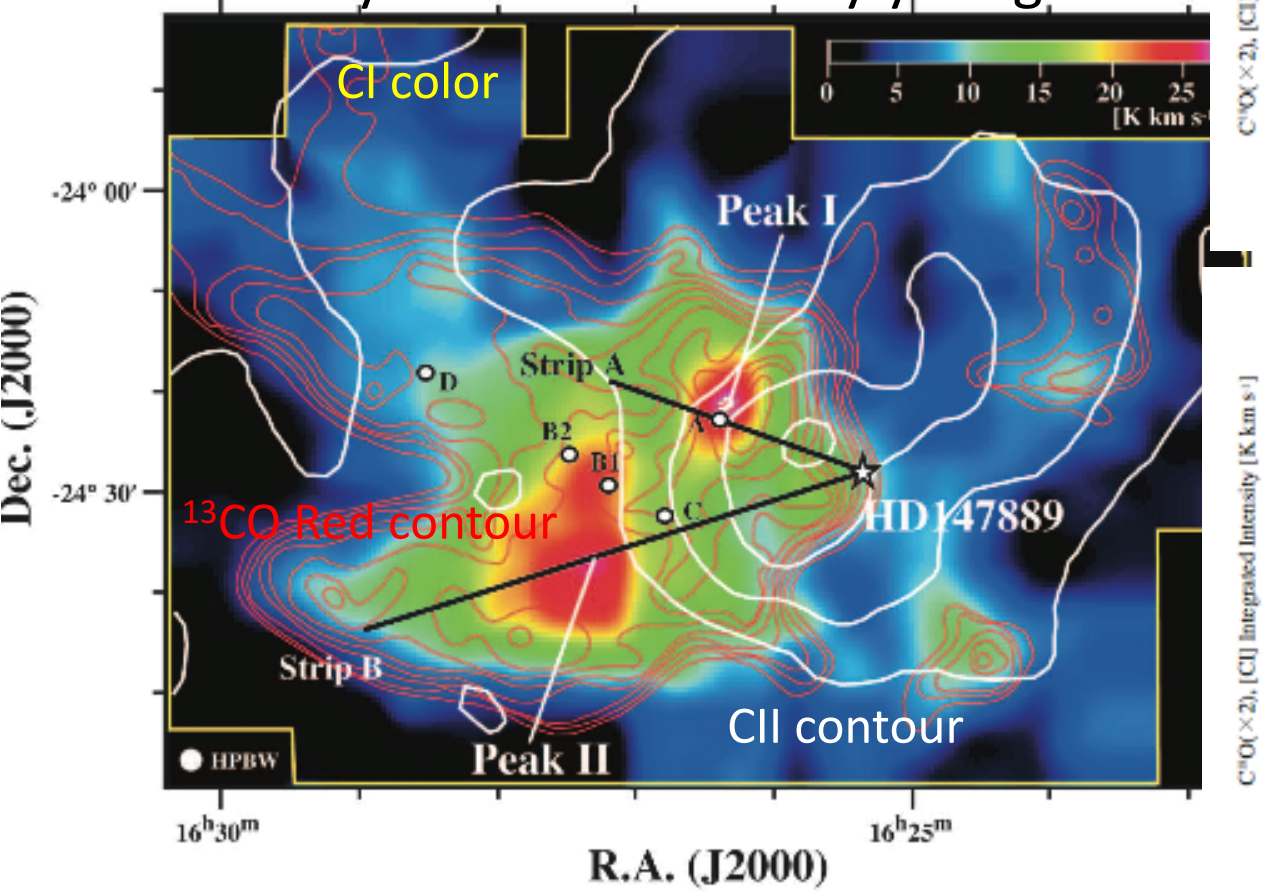
C I Peak behind CO

PDR in dark cloud L1688 Mt Fuji 1.2m

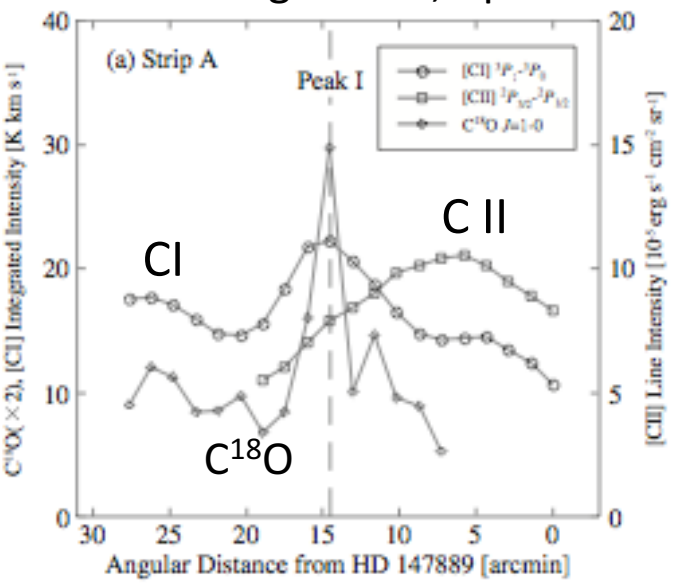
Distribution of CI is similar to that of ^{13}CO

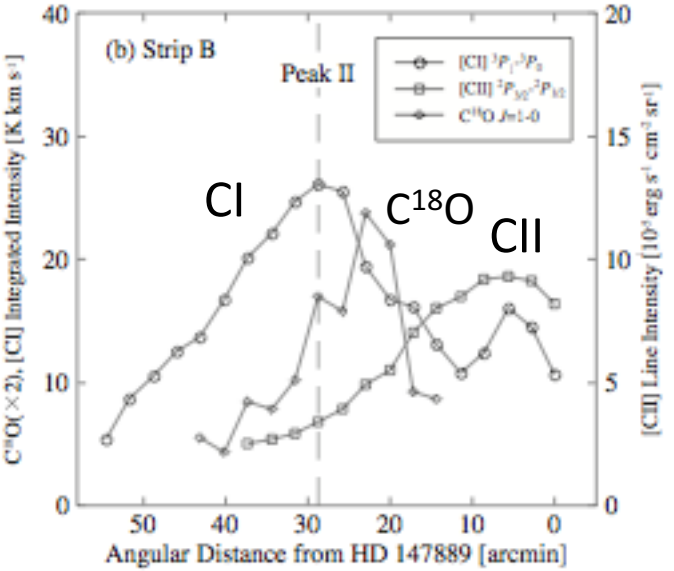
$C^{18}O$ core is closer to exciting star

Low density PDR or Chemically young core



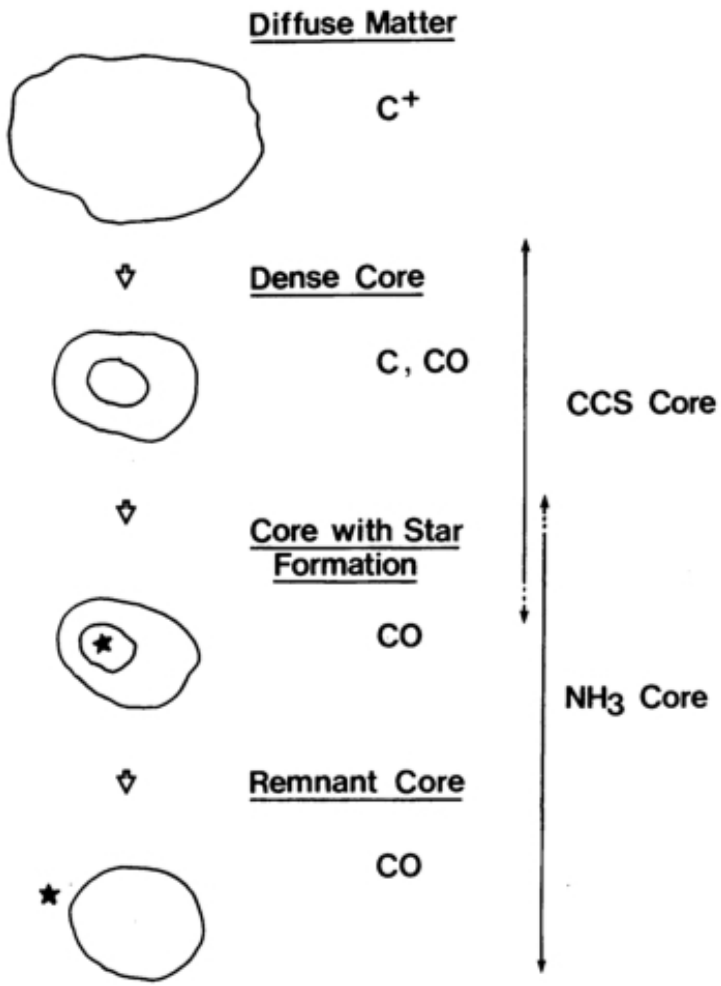
（Kamegai et al., ApJ 2003）

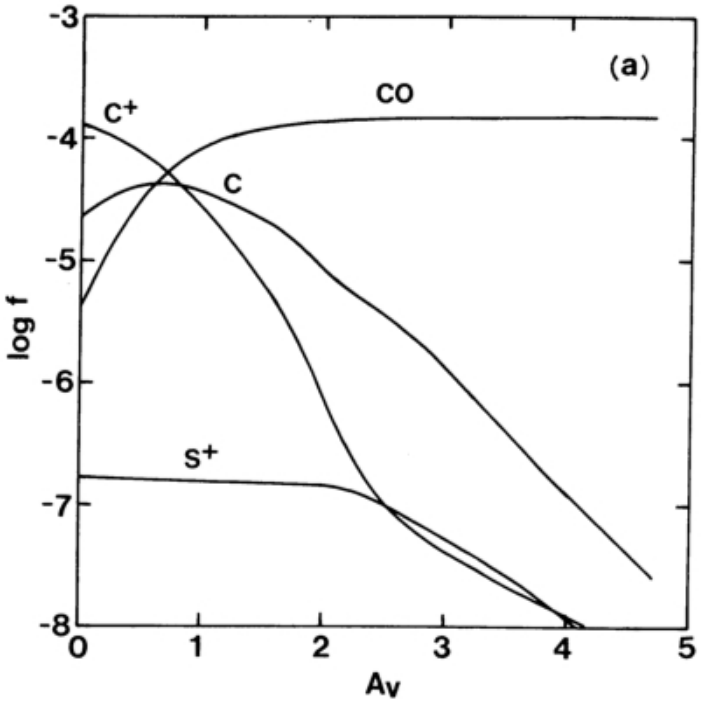


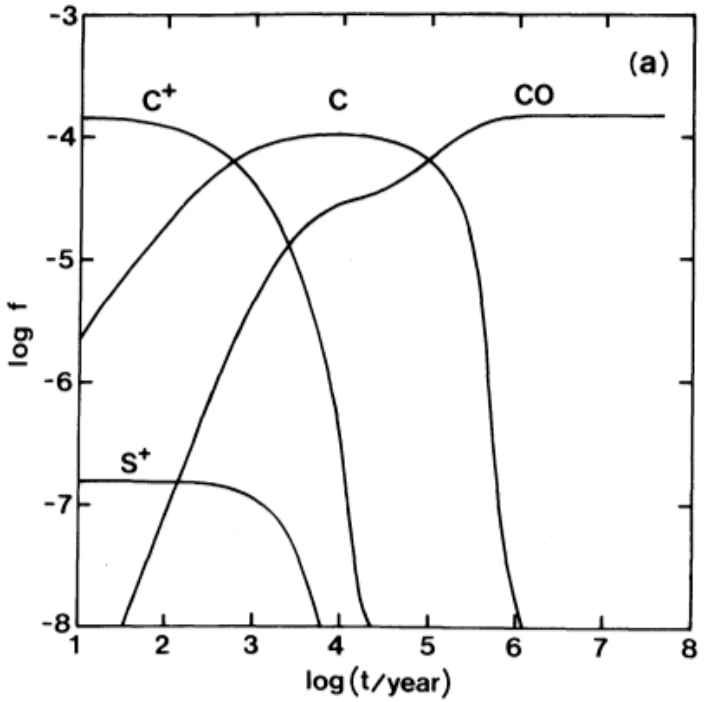


Chemical Evolution and CI

Chemical compositions change with time



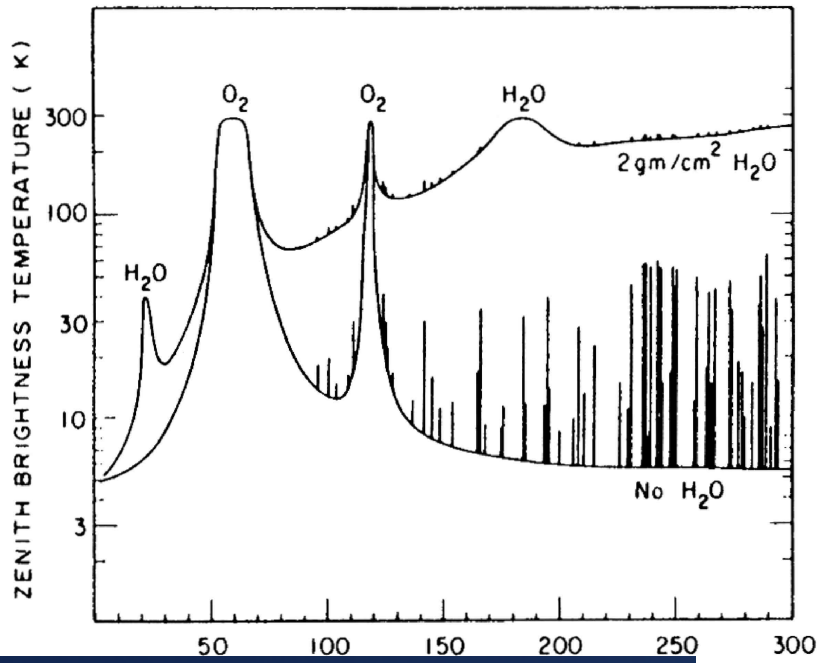




(Suzuki et al.,ApJ 1992)

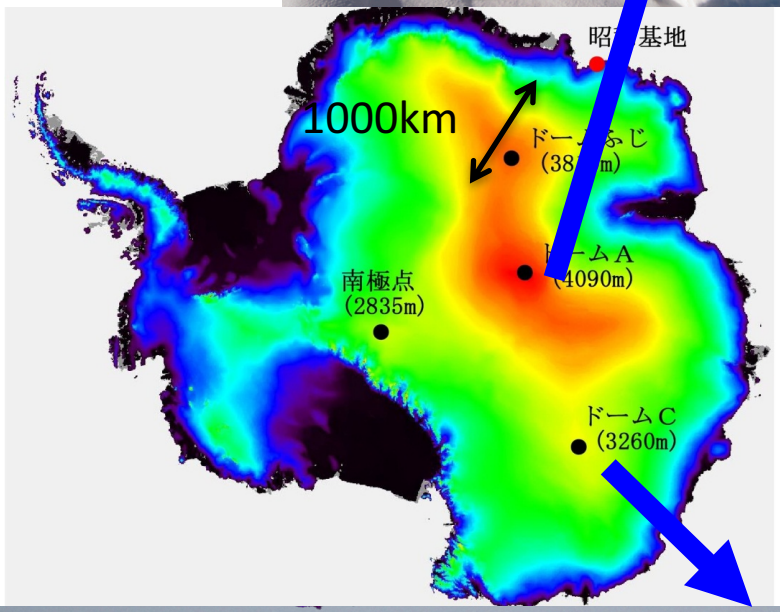
Sub-mm Observation is difficult

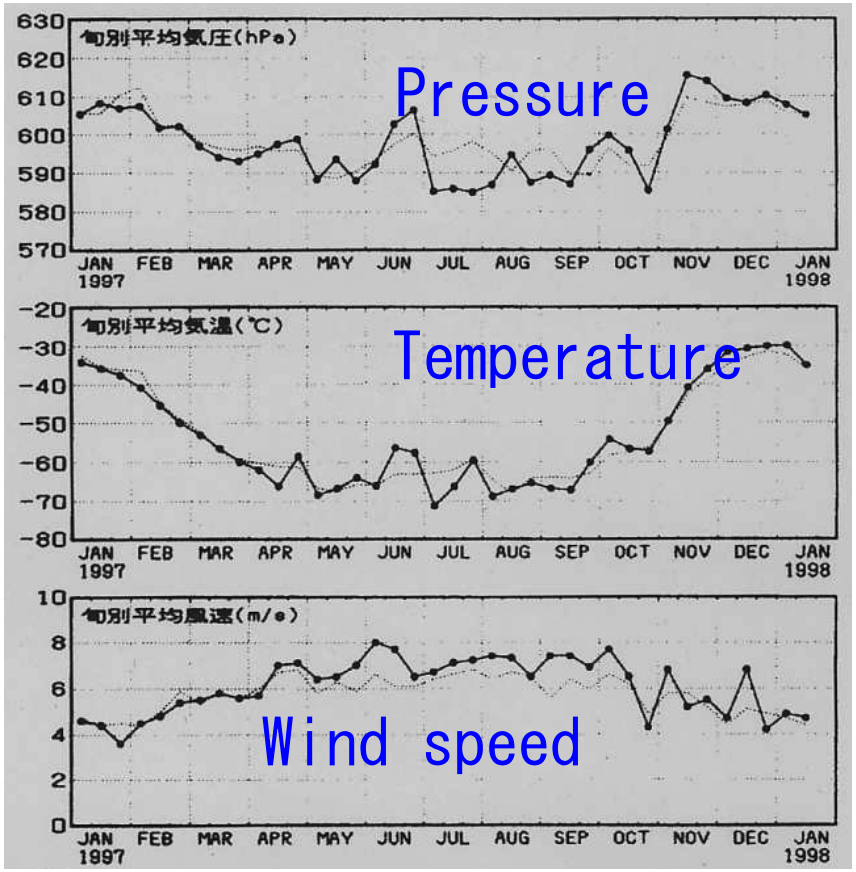
- No detector
  →THz detector is availab
    Camera MKIDS TES
    Heterodyne SIS, HEB
- Absorption by atmosphere
  (Water vapor & Oxygen)
  ↓
  ●High Altitude ,Dry site

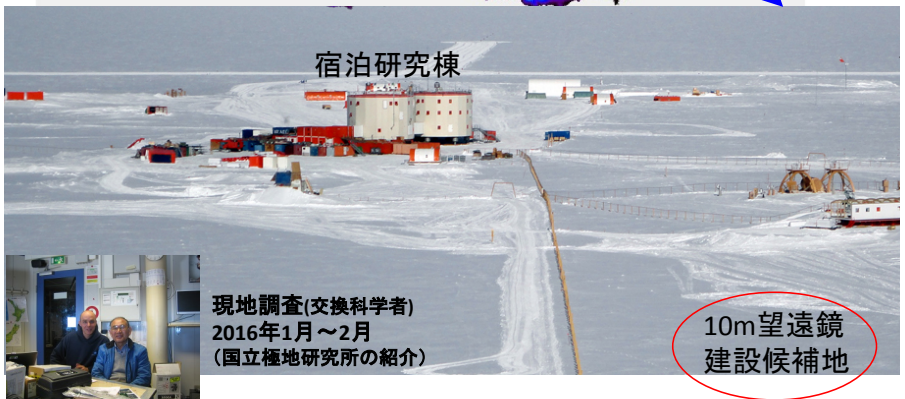


High Plateau in Antarctica

- **Best site for sub-mm Astronomy**
  - High altitude (3000m以上)
  - Low temp. (Min-80℃、Av-55℃)







10m Telescope in Antarctica

10m Reflector

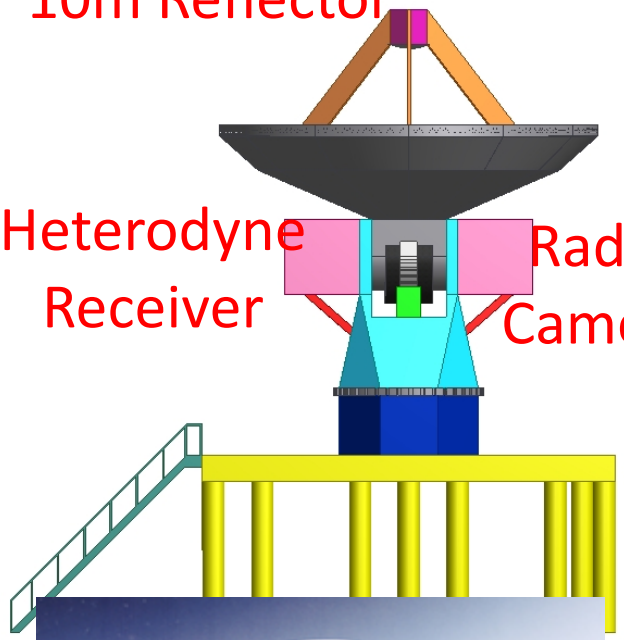
Heterodyne receiver

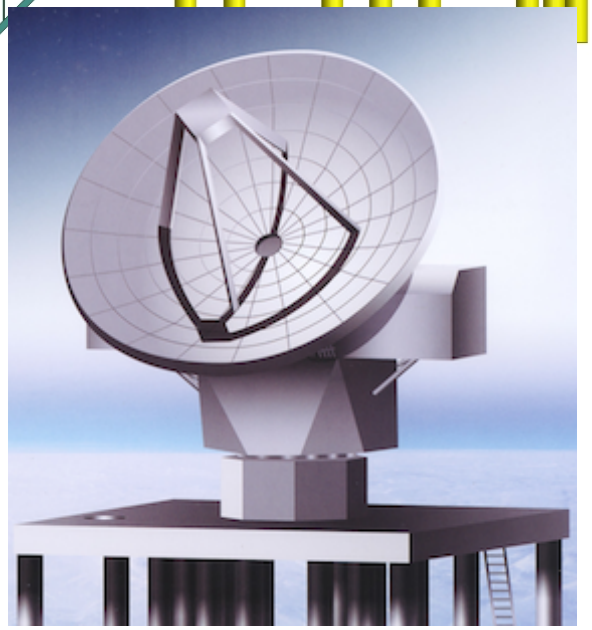
High frequency resolution

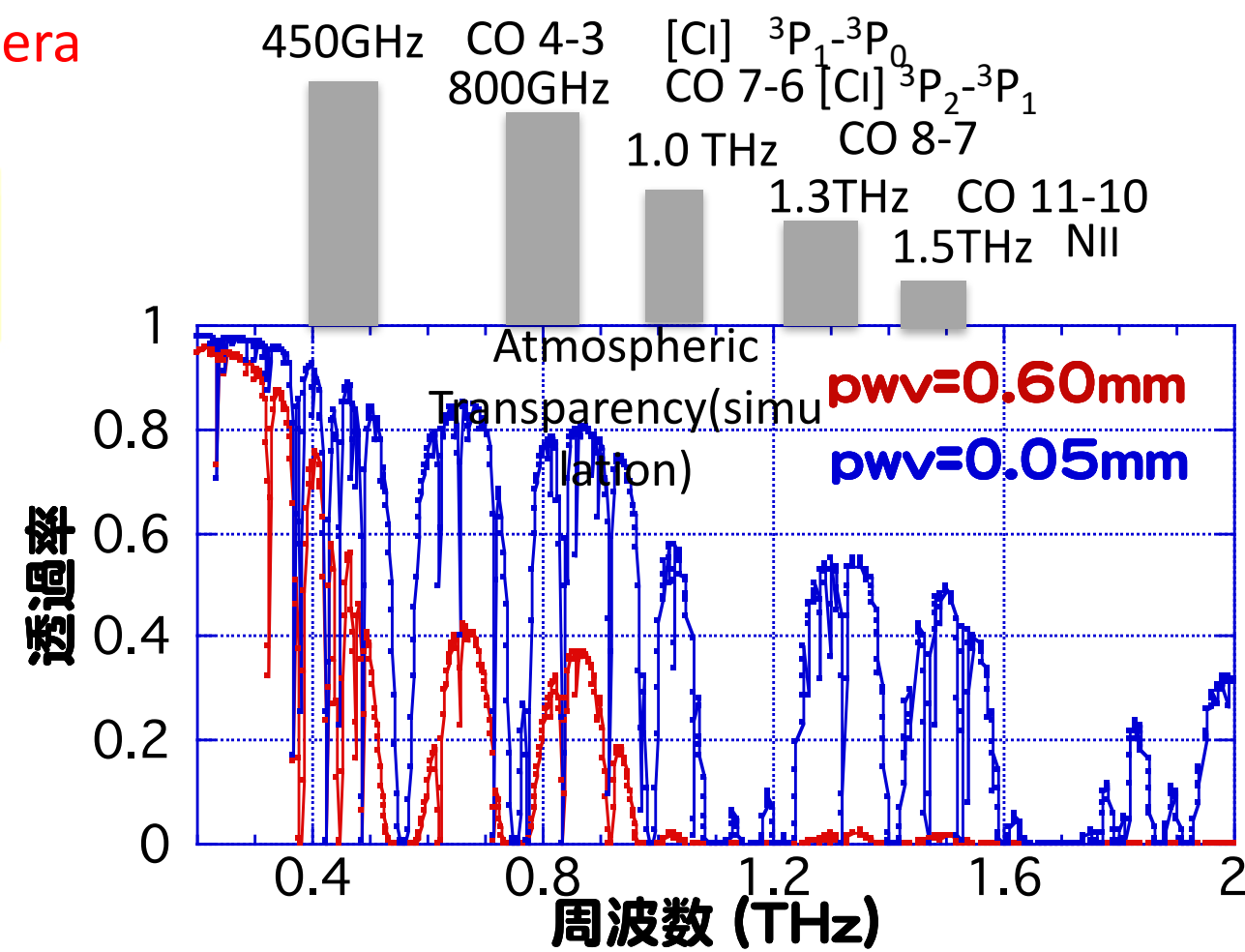
Heterodyne Receiver

Radio Camera

Observational band







Summary

- Molecular cloud is important
  - Energy source of Active Galactic Nuclei
  - Stars are born in Molecular cloud
- CI at 492 GHz & 809 GHz may be good probe for revealing formation and evolution of molecular cloud.
- Sub-mm Astronomy is difficult due to strong absorption of atmospheric water vapor.
- Antarctic plateau is best site on earth for Sub-mm Astronomy.
- We have plan to build 10m class telescope in Antarctica