Prebiotic Molecules in Planet / Star Forming Regions

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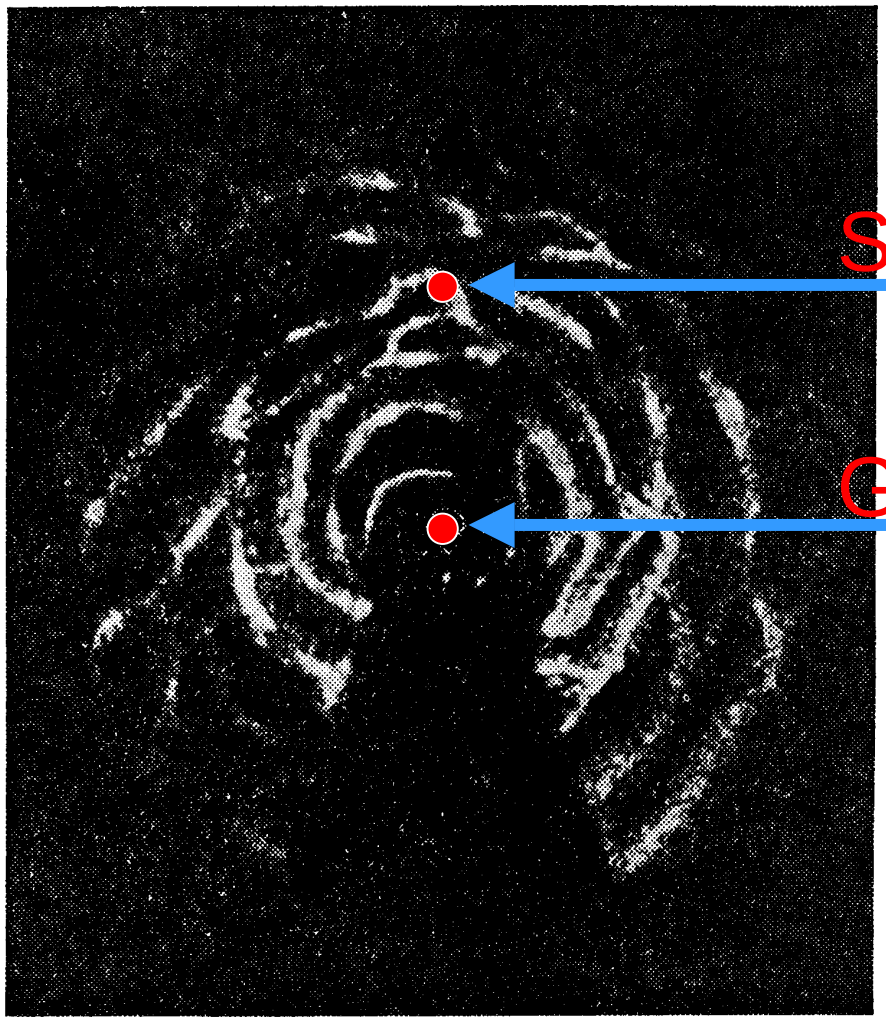
Overview of My Talk

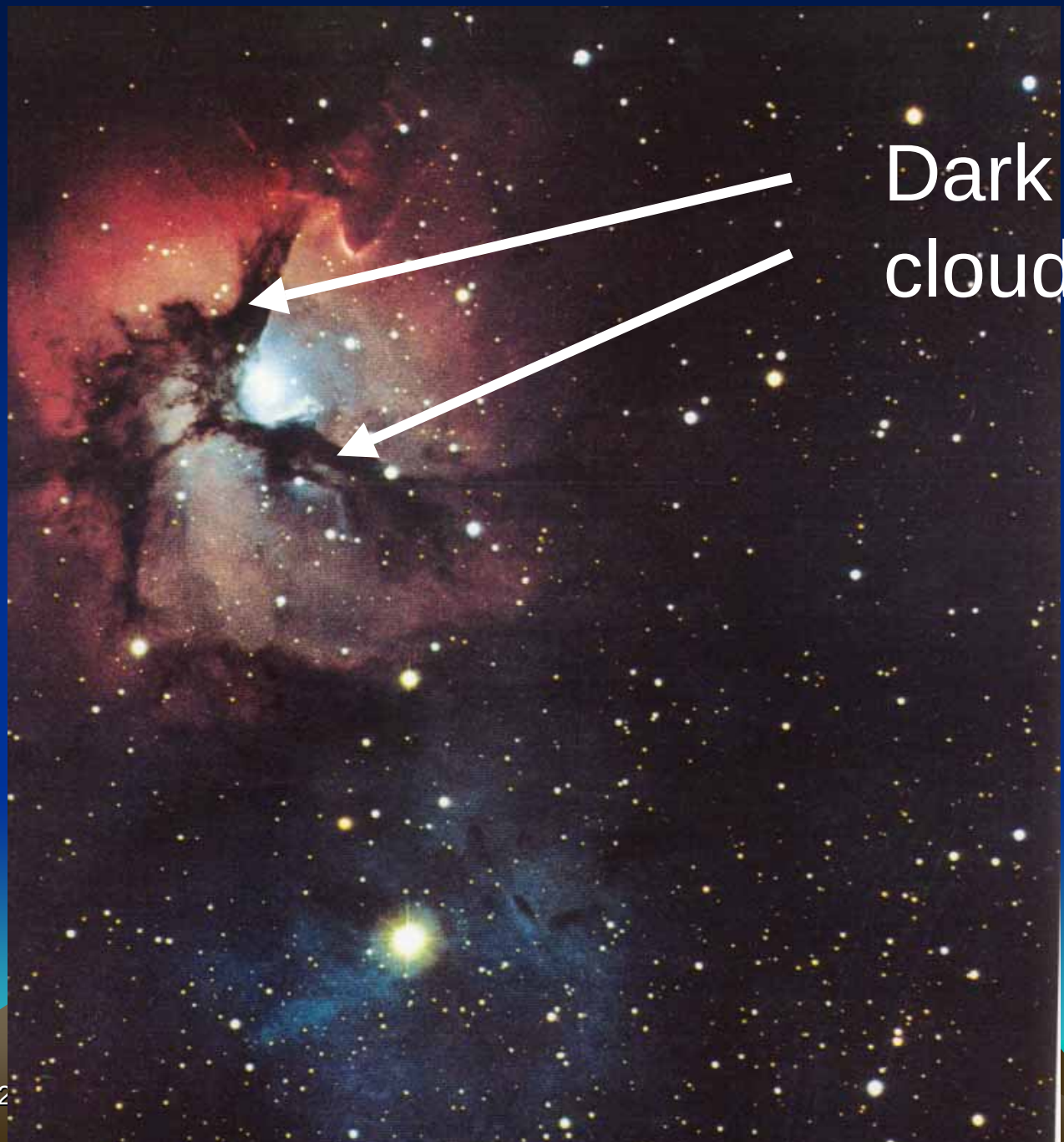
- Interstellar Molecules
- Interstellar Organic Molecules
- Recent Observations of Prebiotic Molecules
- Glycine – the first amino acid ??
- Possible Formation Mechanism of Glycine
- Possible link to life
- Future prospects

Our Galaxy is a Spiral

HI observations revealed hidden spiral structure !



8.5 kpc


Dark molecular cloud

Interstellar Gas

Rarefied Gas between Stars

density：10^{-3}〜10^{10} H/cc

temperature：10^{6}〜10K

Dense Interstellar Gas :

Atoms → Molecules

→ Molecular Cloud

Physical Condition of Molecular Clouds

T ー 10 ～ several 100 K

ρ ー 10^3～10^8 H_2/cm^3

Mean Free Time ～ 1 year

for T = 10 K & $\rho = 10^5$ H_2/cm^3

Radio Telescope detected most of Molecules

- Some 125 molecules in total
- 1963 OH was discovered

  NH_3, H_2O, H_2CO, ・・・, CO

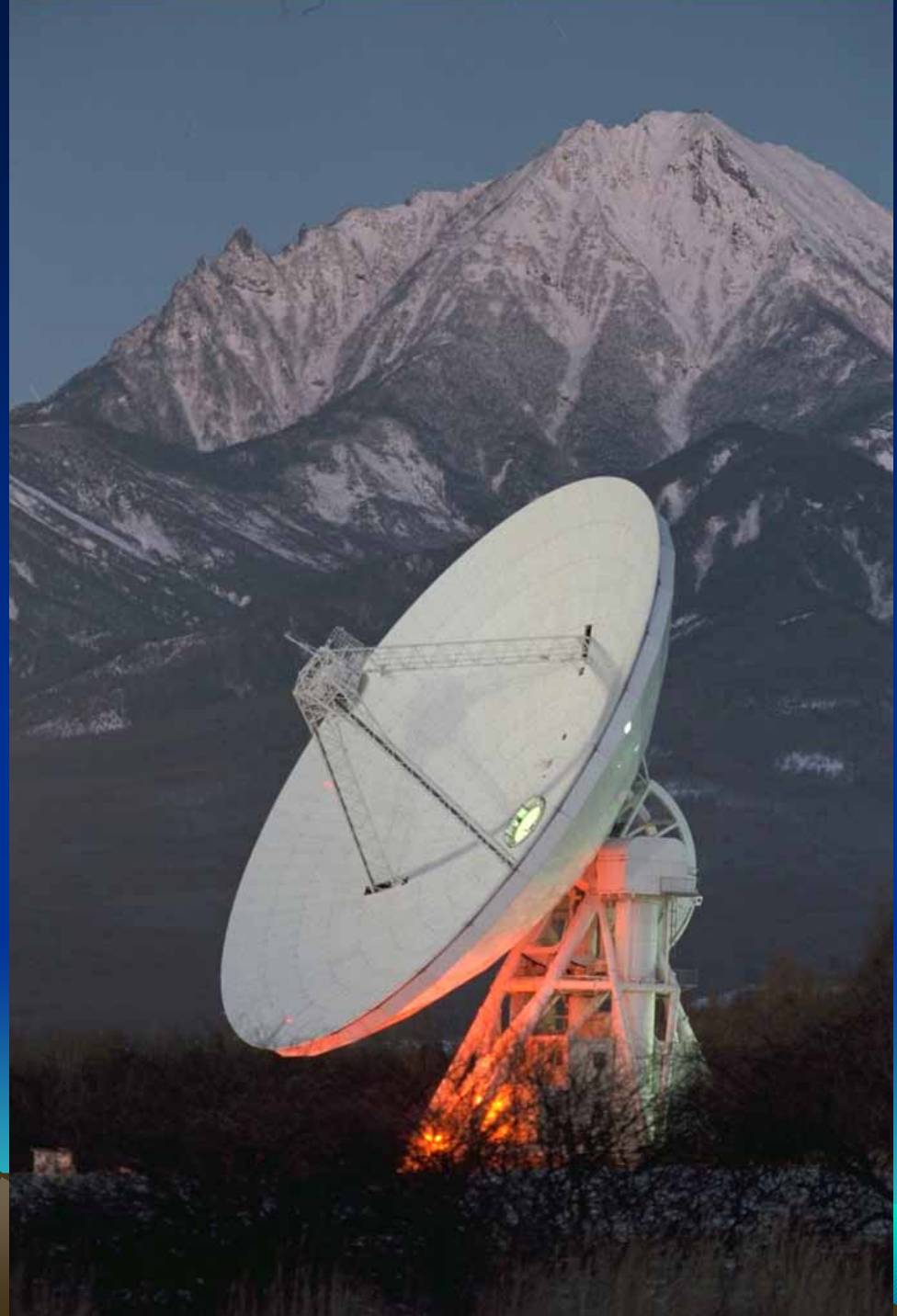
- Japanese Radio Astronomy Group

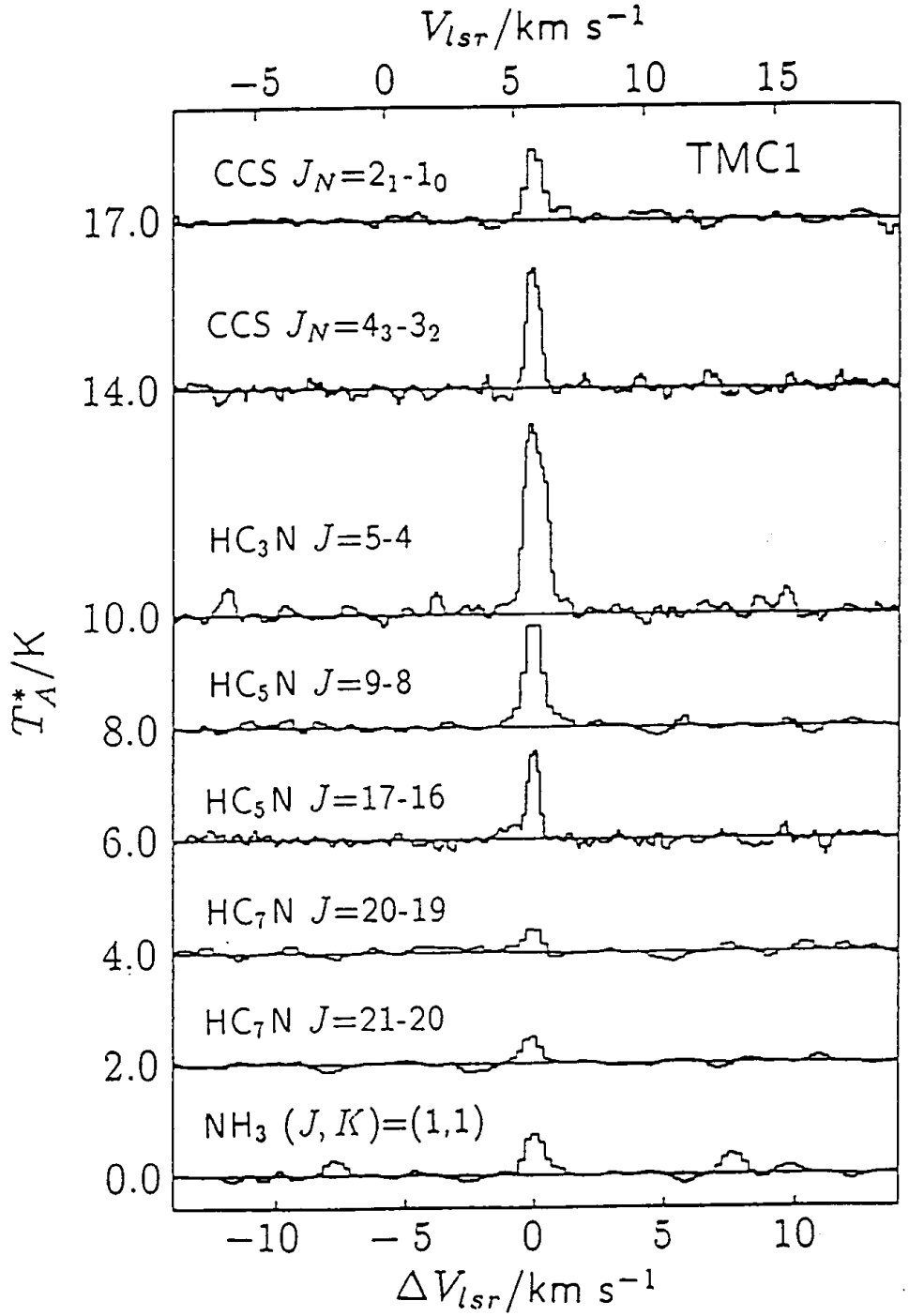
  CH_3NH_2, C_6H, C_2O, C_2S, SiC_4 etc.

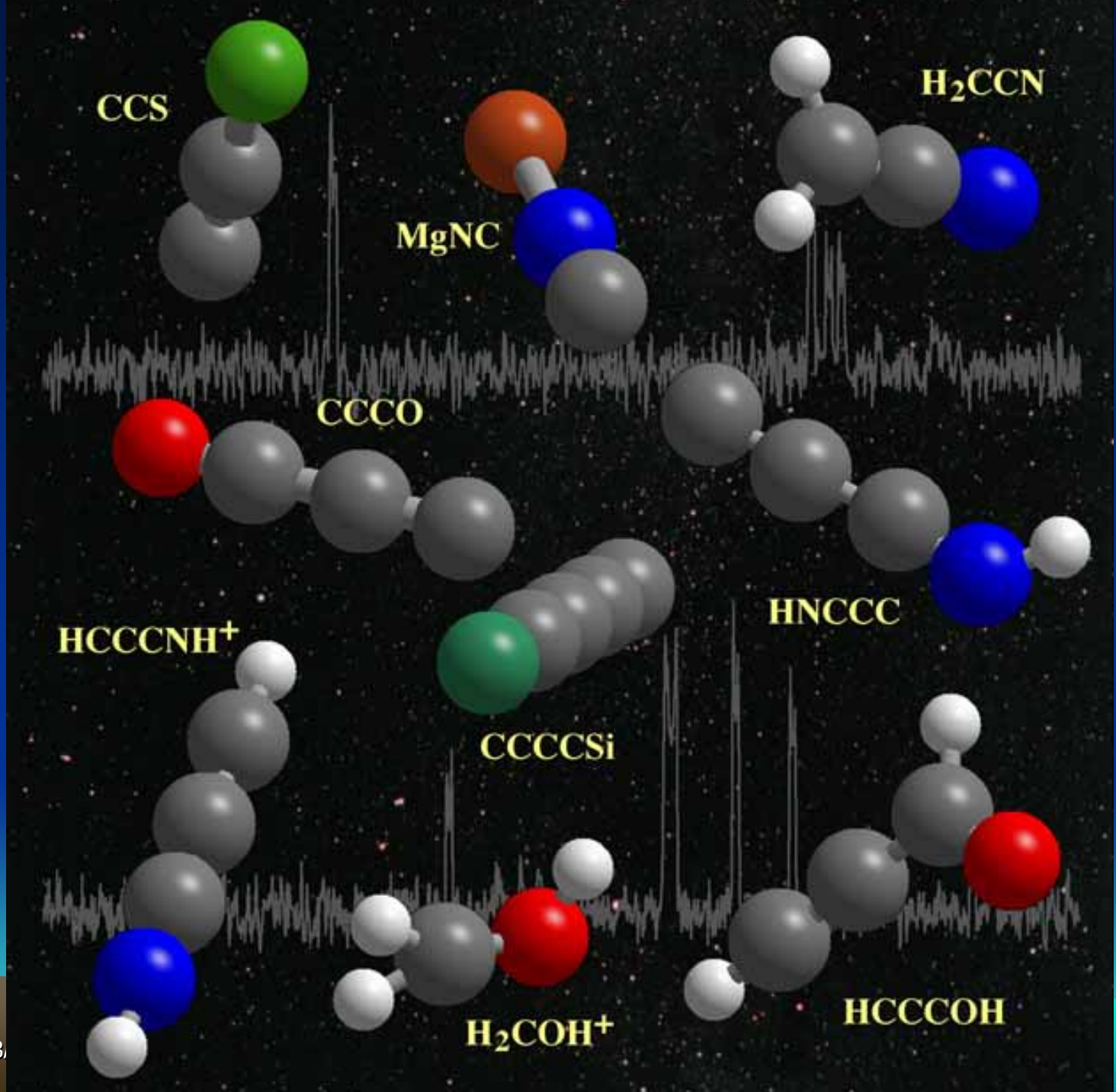
  17 molecules

Nobeyama Radio Observatory

45m Radio Telescope




V_{lsr}/km s^{-1}
−5
0
5
10
15
TMC1
CCS J_N=2$_1$-1$_0$
17.0
CCS J_N=4$_3$-3$_2$
14.0
HC$_3$N J=5-4
10.0
HC$_5$N J=9-8
8.0
HC$_5$N J=17-16
6.0
HC$_7$N J=20-19
4.0
HC$_7$N J=21-20
2.0
NH$_3$ (J, K)=(1,1)
0.0
T_A^*/K
−10
−5
0
5
10
ΔV_{lsr}/km s^{-1}


CCS
MgNC
H2CCN
CCCO
HNCCC
HCCCNH+
CCCCSi
H2COH+
HCCCOH

Classification of Molecules

- Simple Molecules

  H_2, CO, H_2O, CO_2, NH_3, etc.
- Molecular Ions

  H_3^+, HCO^+, H_3O^+, HCO_2^+, etc.
- Radicals

  C_nH, C_nO, C_nS (n=1,2,・・・), etc.
- Ring Molecules

  c-C_3H_2, c-SiC_2, c-C_3H, c-C_2H_4O, etc.
- Stable Molecules

  H_2CO, HCOOH, CH_3OH, C_2H_5OH, etc.

Detection by Infrared Sat. (ISO)

- CO_2
- HF
- C_6H_6 (Benzene)
- C_4H_2 (Diacetylene)
- C_6H_2 (Triacetylene)


esa

Formation Mechanism in Gas

High energy Cosmic Rays (CR) ignites the following reactions:

$He + CR \rightarrow He^+ + e + CR$

$He^+ + H_2 \rightarrow He + H_2^+ + e$

$H_2 + H_2^+ \rightarrow H_3^+ + H$

$H_3^+ + CO \rightarrow HCO^+ + H_2$

Mechanism in Gas phase

$H_3^+ + O \rightarrow OH^+ + H_2$

$OH^+ + H_2 \rightarrow OH_2^+ + H$

$OH_2^+ + H_2 \rightarrow OH_3^+ + H$

$OH_3^+ + e \rightarrow H_2O + H$

Ion-Molecule Reactions

Mechanism to form Organic species

- Dust surface acts as a catalyst

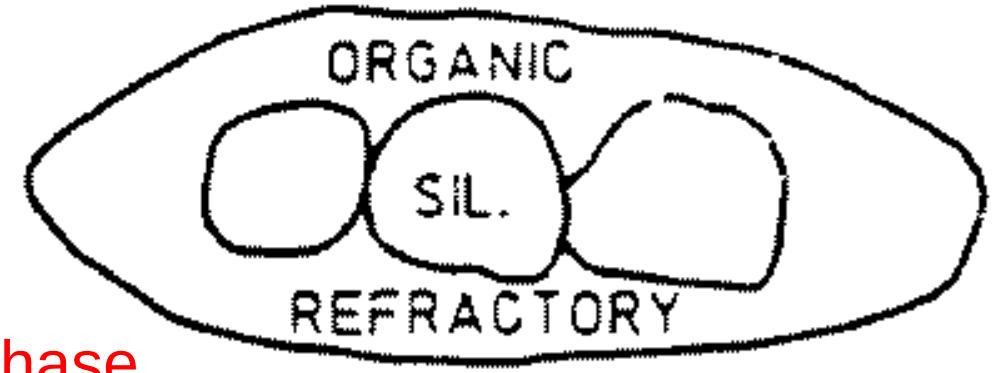
  →Molecules are adsorbed into dust, and react into larger species

  →From simple species to complex ones

Alcohols (CH_3OH, C_2H_5OH)

Acetic acid (CH_3COOH)

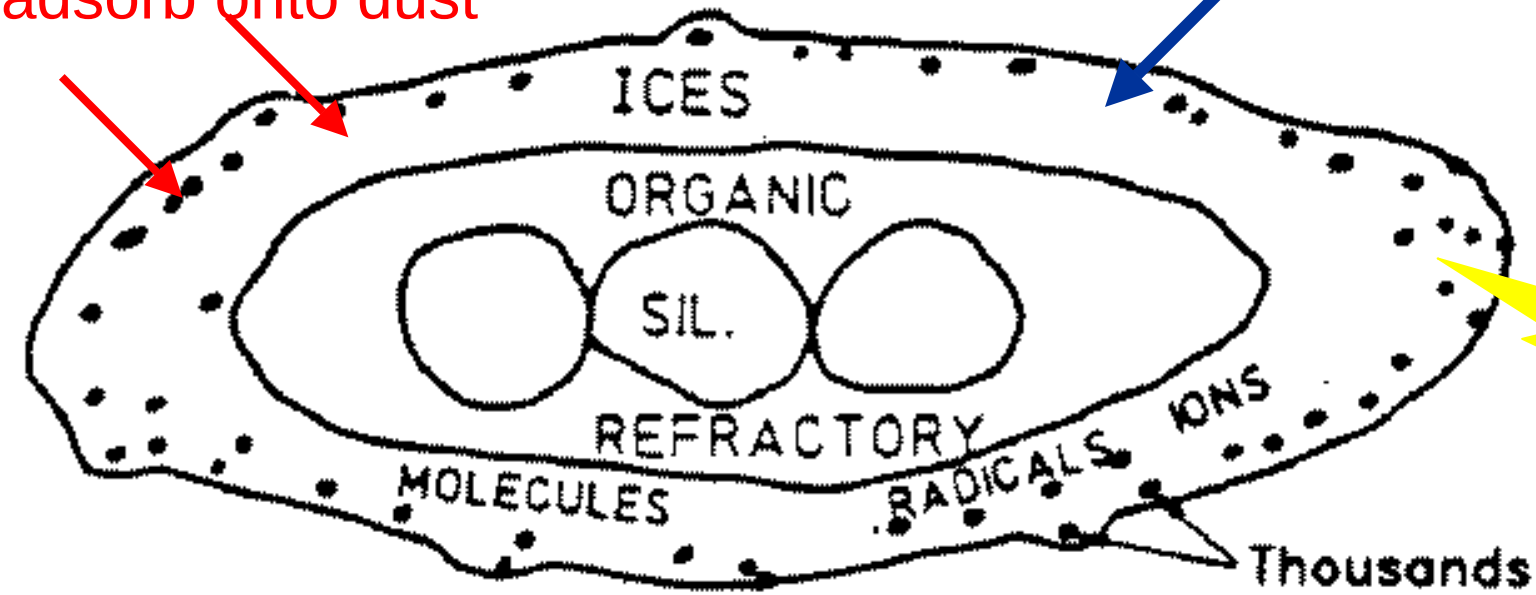
etc



DIFFUSE CLOUD GRAIN.

Gas phase molecules adsorb onto dust

Ice Mantle



UV light

Thousands of ≤0.01μm particles/ large molecules

PRECOMETARY GRAIN

Molecules with -NH_2, -COOH

- NH_2, NH_2CHO, NH_2CN, NH_2CH_3
- HCOOH, CH_3COOH

These molecules are very less abundant, and are observed only toward hot molecular cores.

Hot Molecular Cores

- Dense ($n(H_2) \sim 10^{7\text{-}8}$ cm^{-3})
- Hot ($T_k \sim 100 – 200$ K)
- Stars are formed inside

- UV photons from stars heat dust particles, and evaporate large molecules formed on the dust mantle.

Prebiotic Molecules

- Organic, large molecules

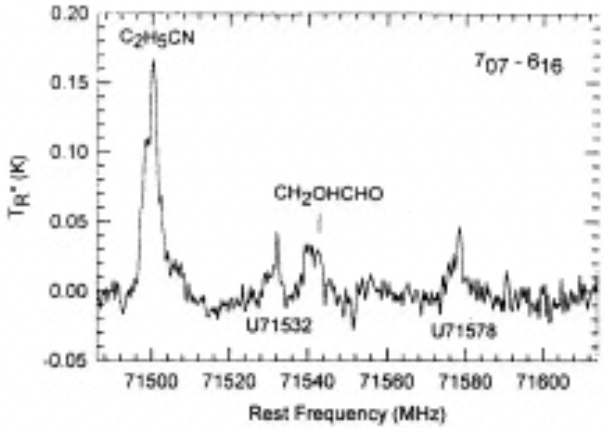
→ they are expected to exist in hot molecular cores

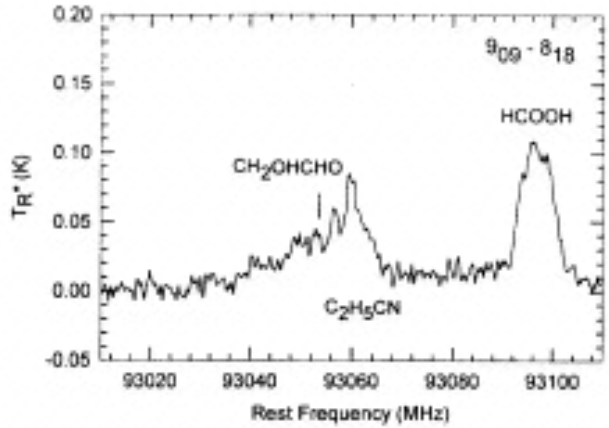
Glycol-aldehyde

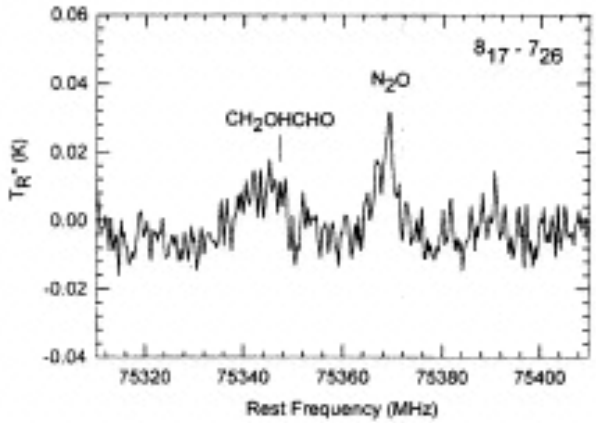
the simplest Sugar

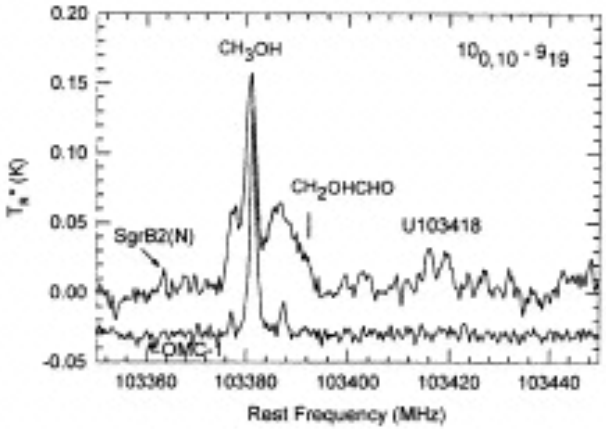
$C_2H_4O_2$

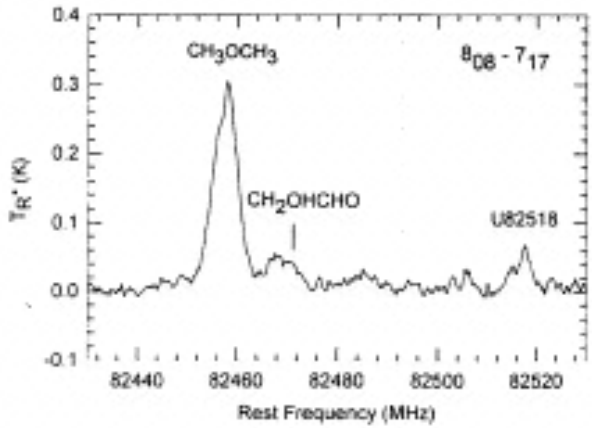
detected in 2000 toward SgrB2(N)

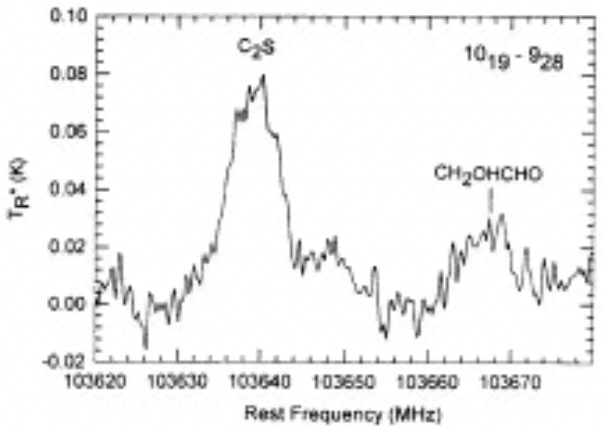


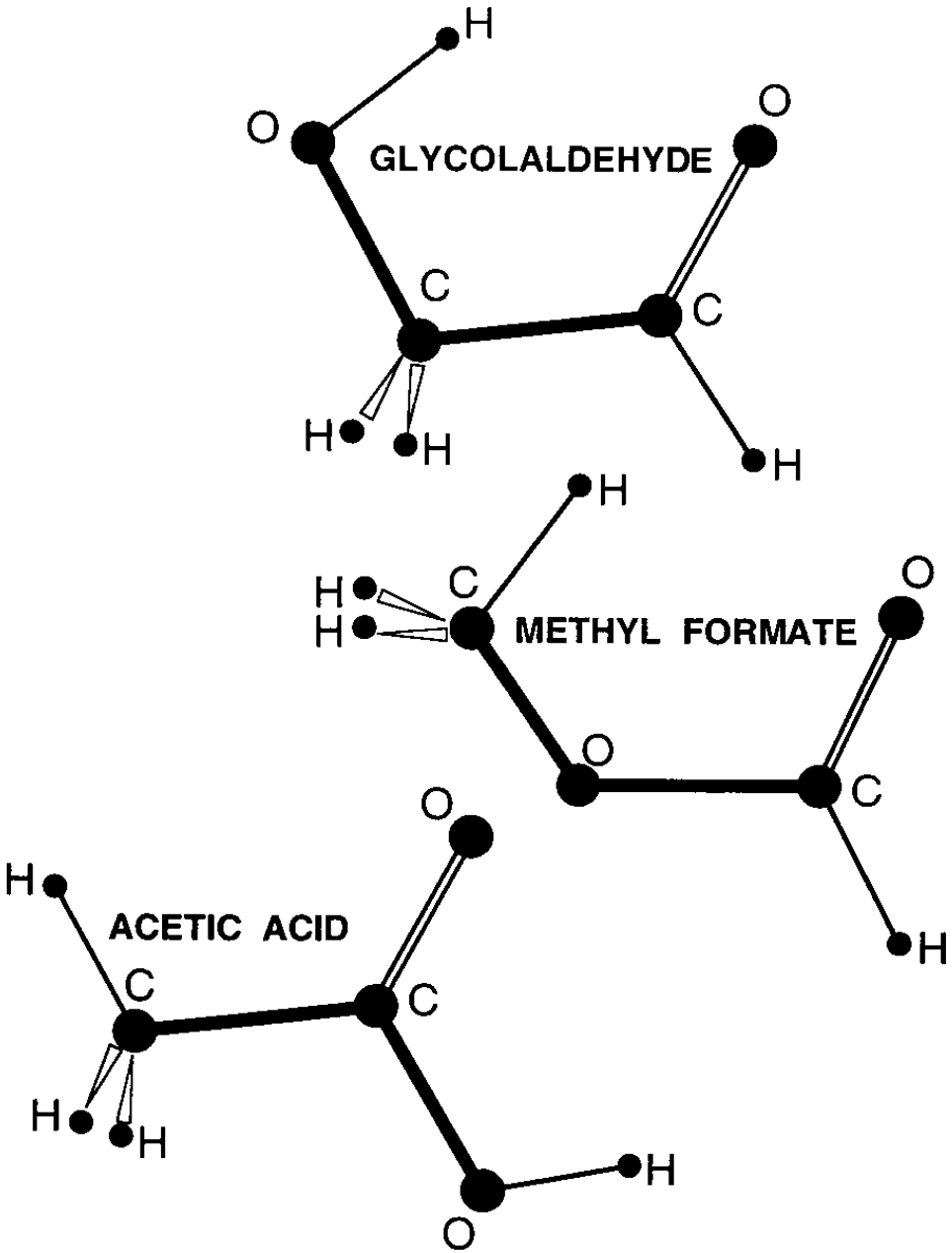












very abundant

much less abundant

Glycine : the simplest amino acid

- (α–)Amino acids : NH_2—R—COOH
- Glycine : R = CH_2
- Several conformers
  - Conformer I : smaller dipole moments
  - Conformer II : E=705 cm^{-1} & larger dipole moments

Detection of Glycine published in August 2003

?

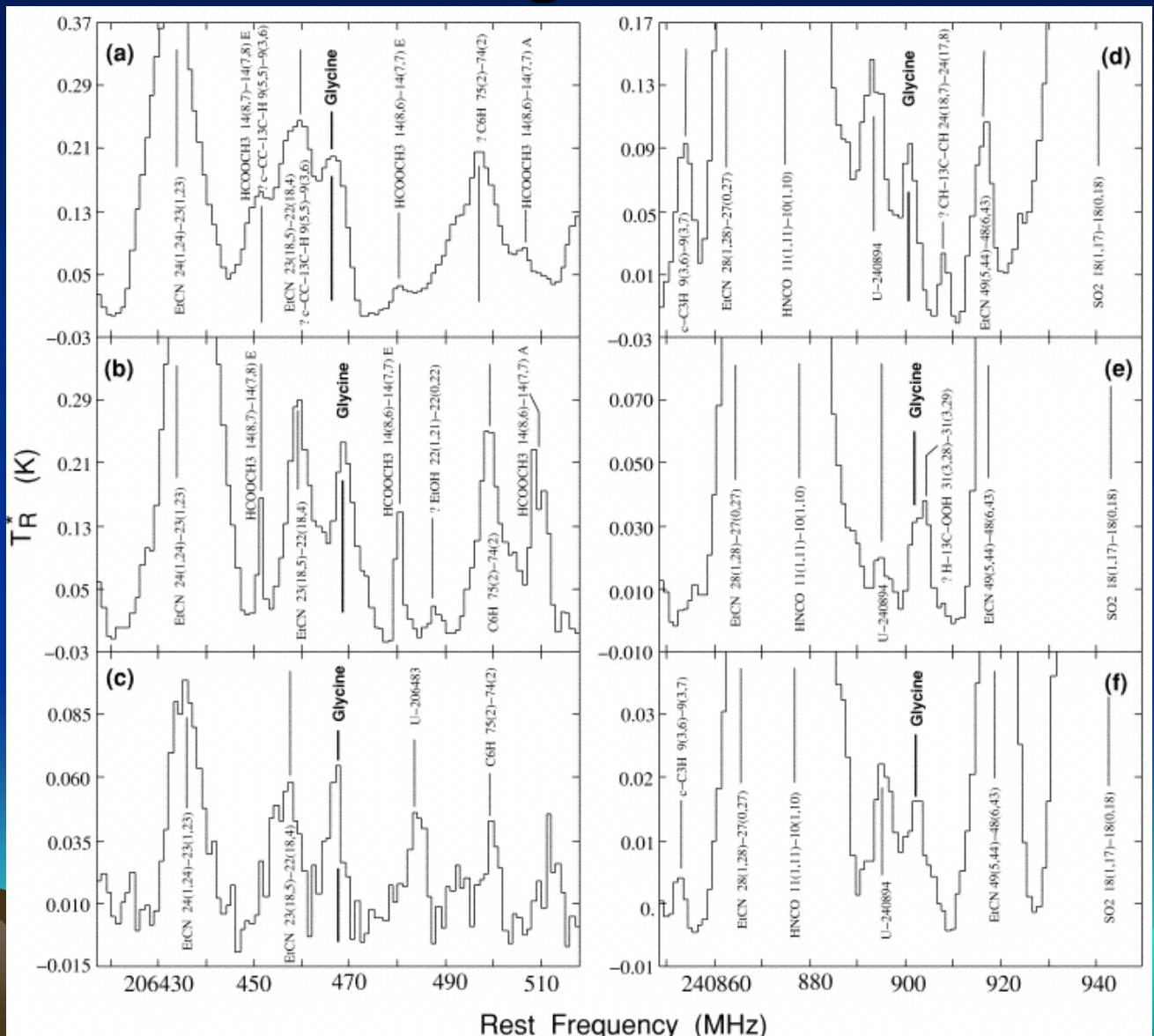
?

?

SgrB2(N)

OrionKL

W51e$_1$/e$_2$



Abundances of Glycine (?) in Orion KL

- Kuan et al. (2003) – NRAO 12m

  4.4×10^{14} cm^{-2}

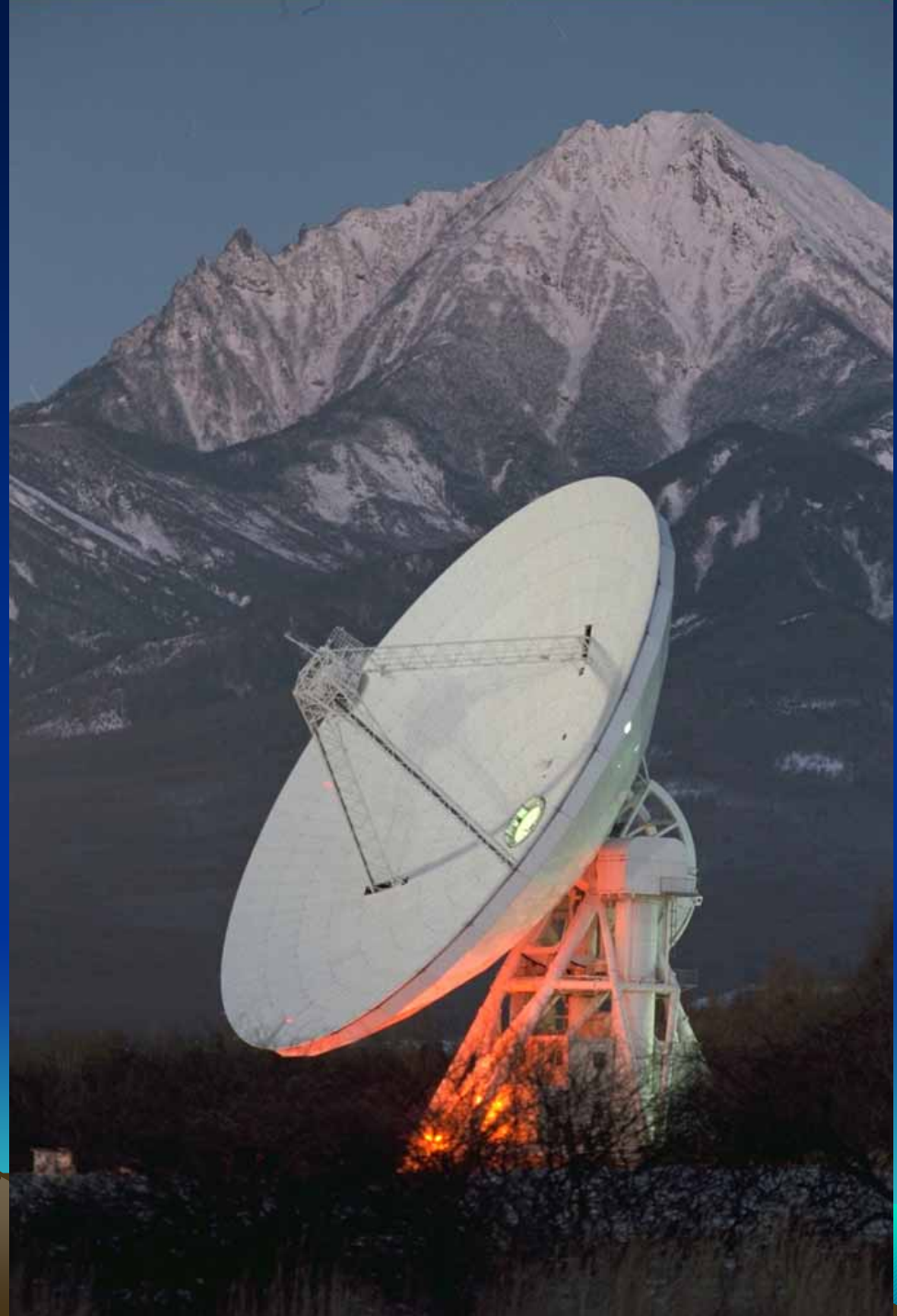
- Hollis et al. (2003) – VLA (interferometer)

  $< 1.2 \times 10^{12}$ cm^{-2}

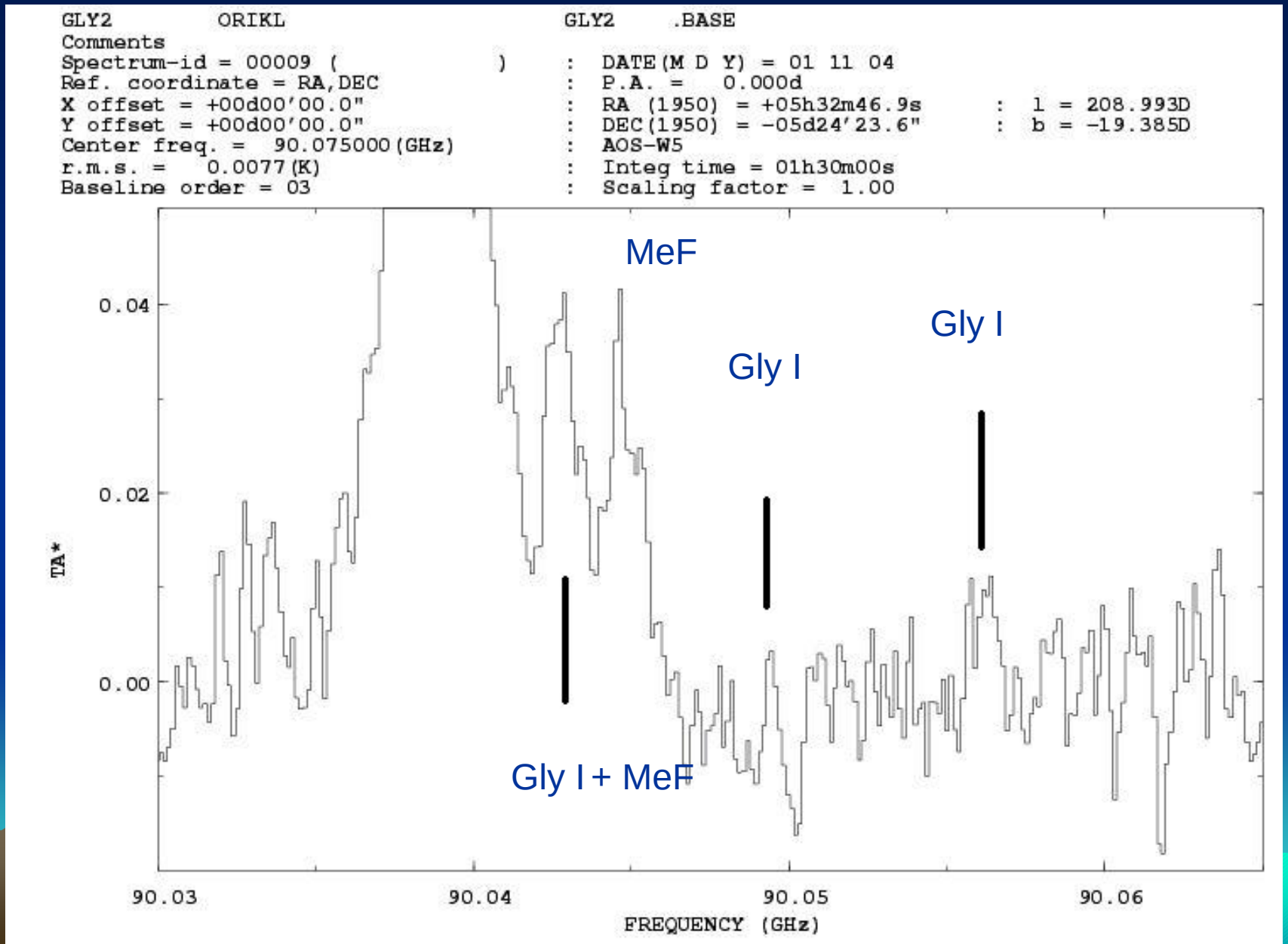
THIS IS SO PUZZLING !!!!

Nobeyama Radio Observatory

45m Radio Telescope



Glycine ? by the 45m telescope

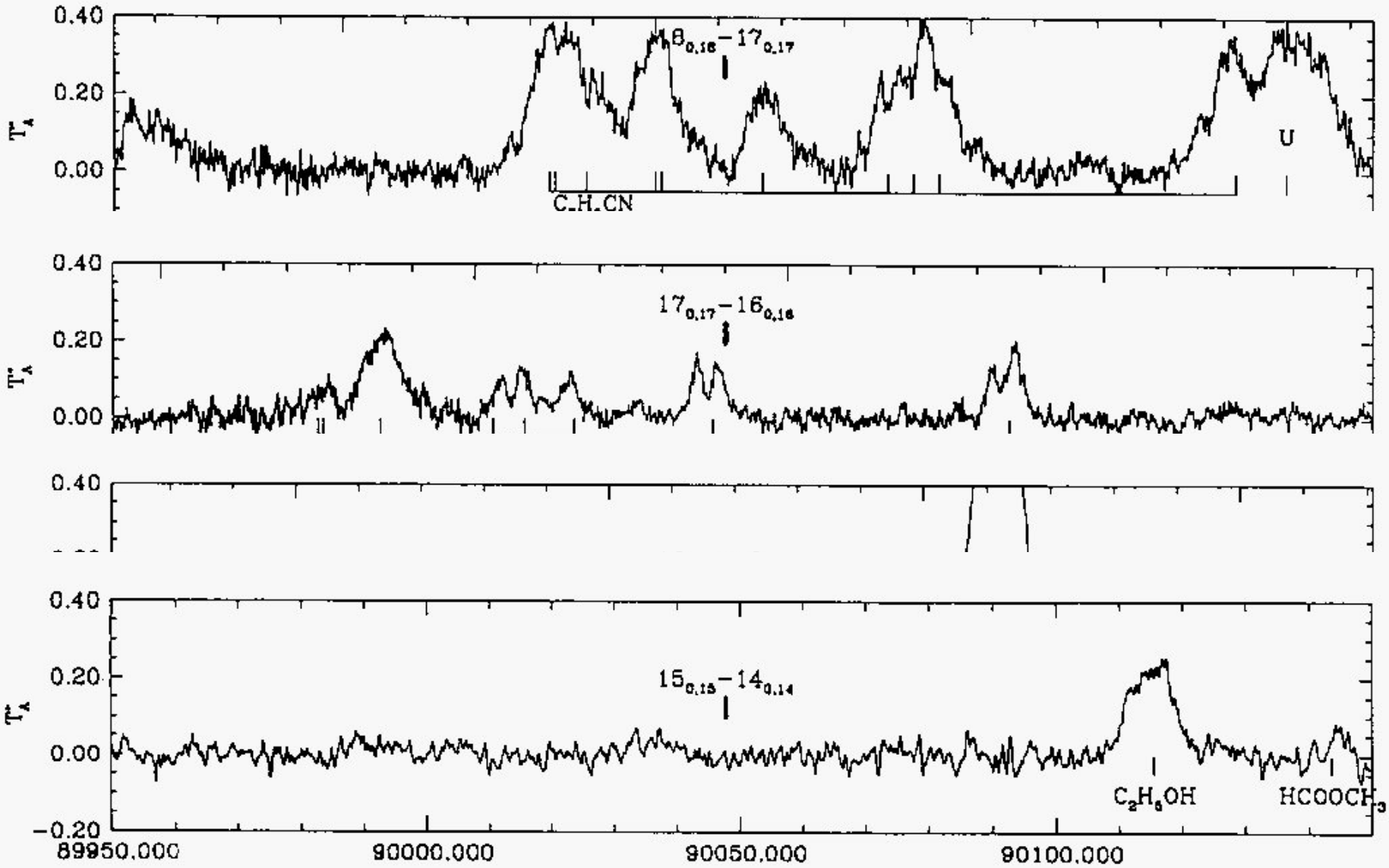


Abundance of Glycine ?

- transition : 15(1,15) – 14(0,14)
- excitation temp : 100 K (assumed)
- LTE condition & optically thin

- $N_{total} \sim 1.5 \times 10^{14}$ cm^{-2}
- This value is regarded as maximum.

Glycine toward SgrB2(N)?



Abundances of Glycine in SgrB2

- Kuan et al. (2003)

  4.2×10^{14} cm^{-2}

- Ohishi & Ikeda (1997)

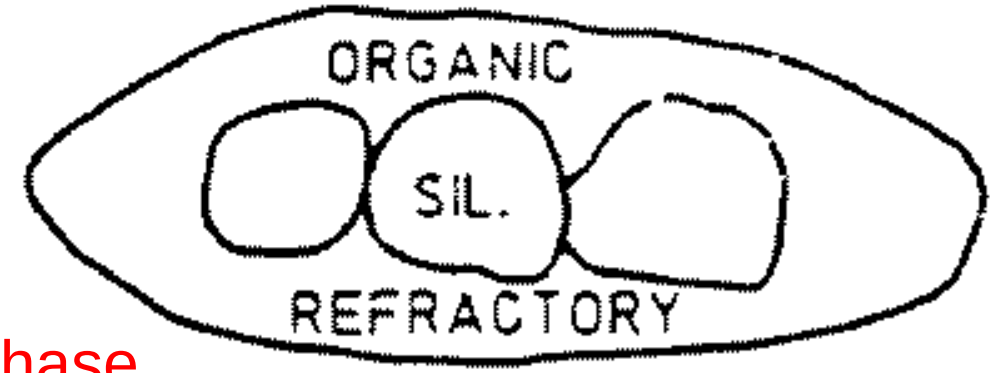
  $< 9 \times 10^{13}$ cm^{-2}

THIS IS ANOTHER PUZZLE !!!!

Is the Detection Secure ?

- The claim is not consistent with other sensitive observations.
  - N(SgrB2) ~ 100 x N(Ori) ~ 100 x N(W51)
- Why Ka=0, 1 lines are so few ??
- Astronomers are discussing.
- It is necessary to observe more intense lines (e.g. @ submillimeter-wave) by more sensitive telescopes.

- Overseas info : negative reports will appear soon.



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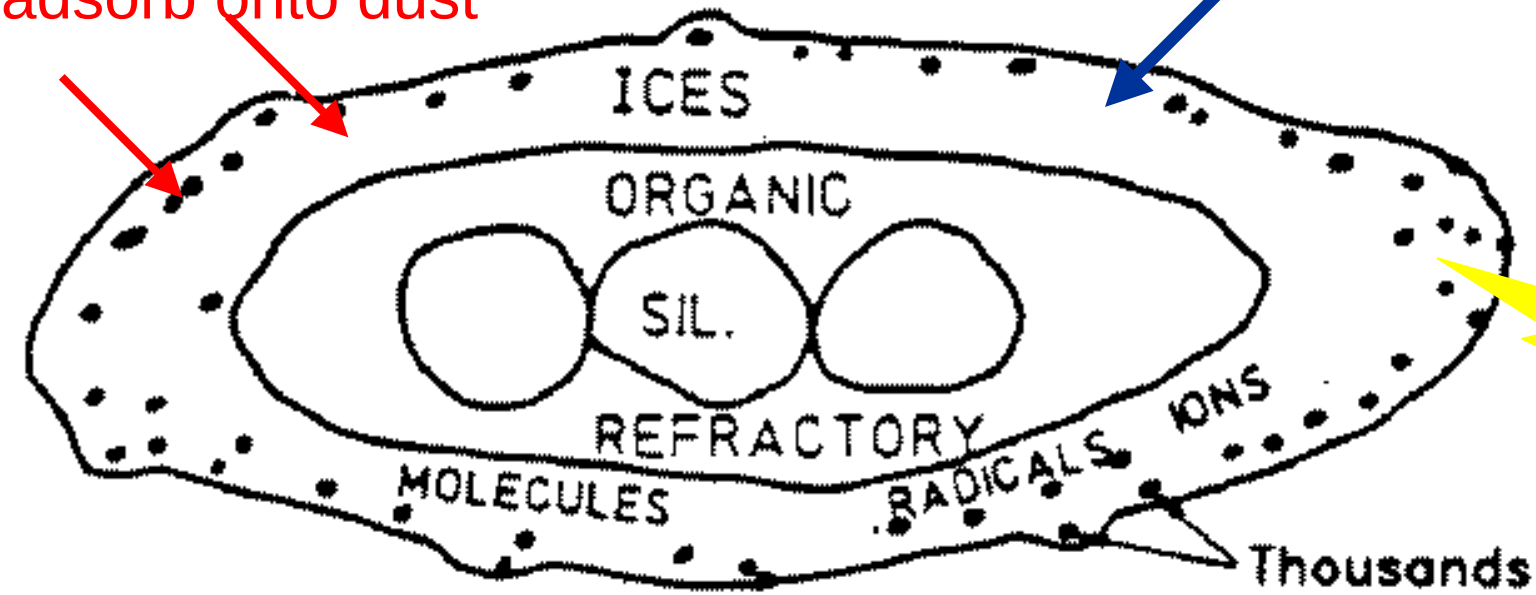


UV light

Thousands of ≤0.01μm particles/ large molecules

PRECOMETARY GRAIN

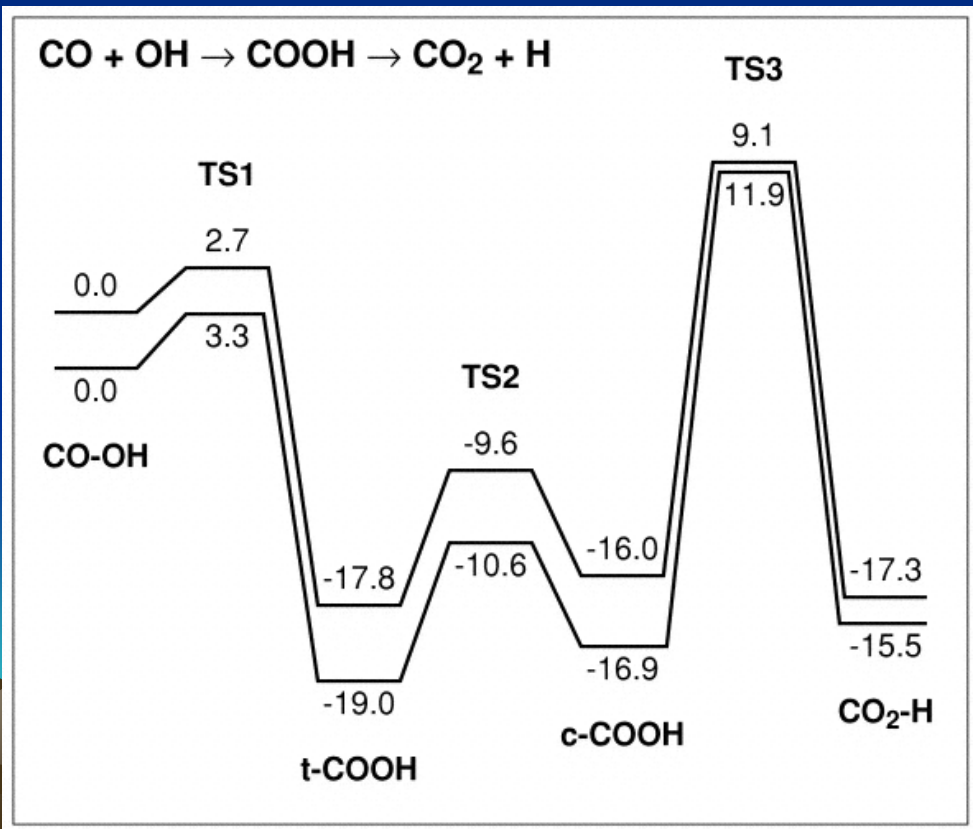
Glycine formation on Ice

- Bernstein et al. (2002)
- UV irradiation onto interstellar ice at 15 K
  - H_2O ice with 0.5-5 % NH_3, 5-10% CH_3OH, 0.5-5% HCN
- Amino acids were formed :

  glycine, alanine, serine, etc.
- These are racemic → not contamination
- Munos Caro et al. (2002) obtained similar results.

Proposed Formation Path (Quantum Chemical Calculations by Woon 2002)

- H_2O + hν (UV) → OH + H
- CO + OH → COOH



Formation Path (contd)

$H + CH_2NH \rightarrow CH_2NH_2$

$CH_2NH_2 + COOH$

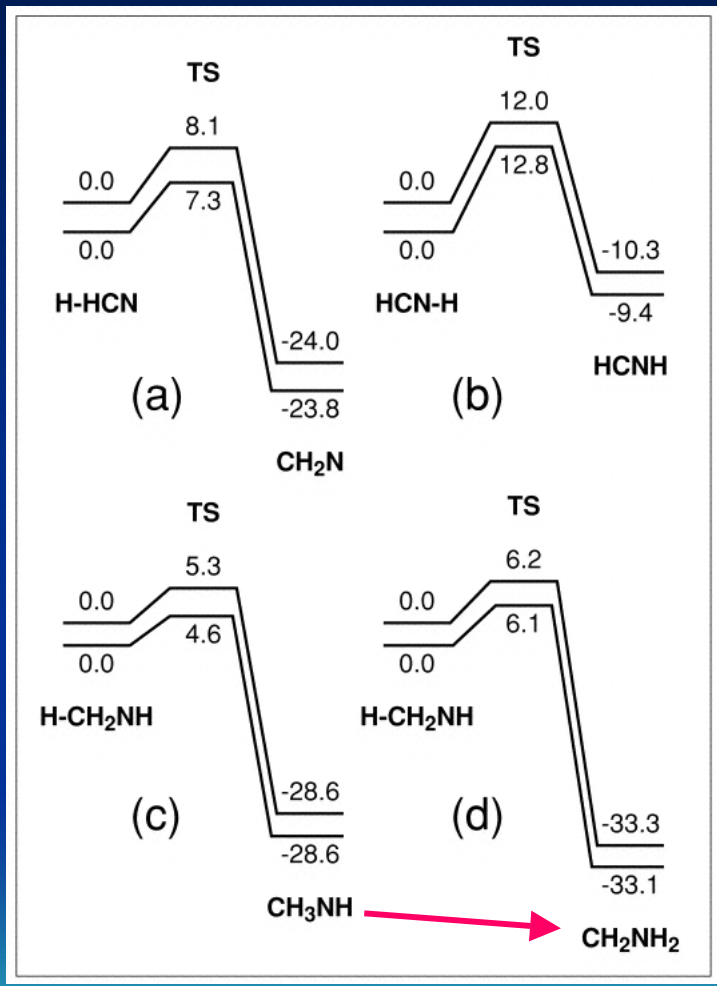
$\rightarrow NH_2CH_2COOH + \Delta E$

$NH_2CH_2COOH \rightarrow$

$NH_2CHCOOH$

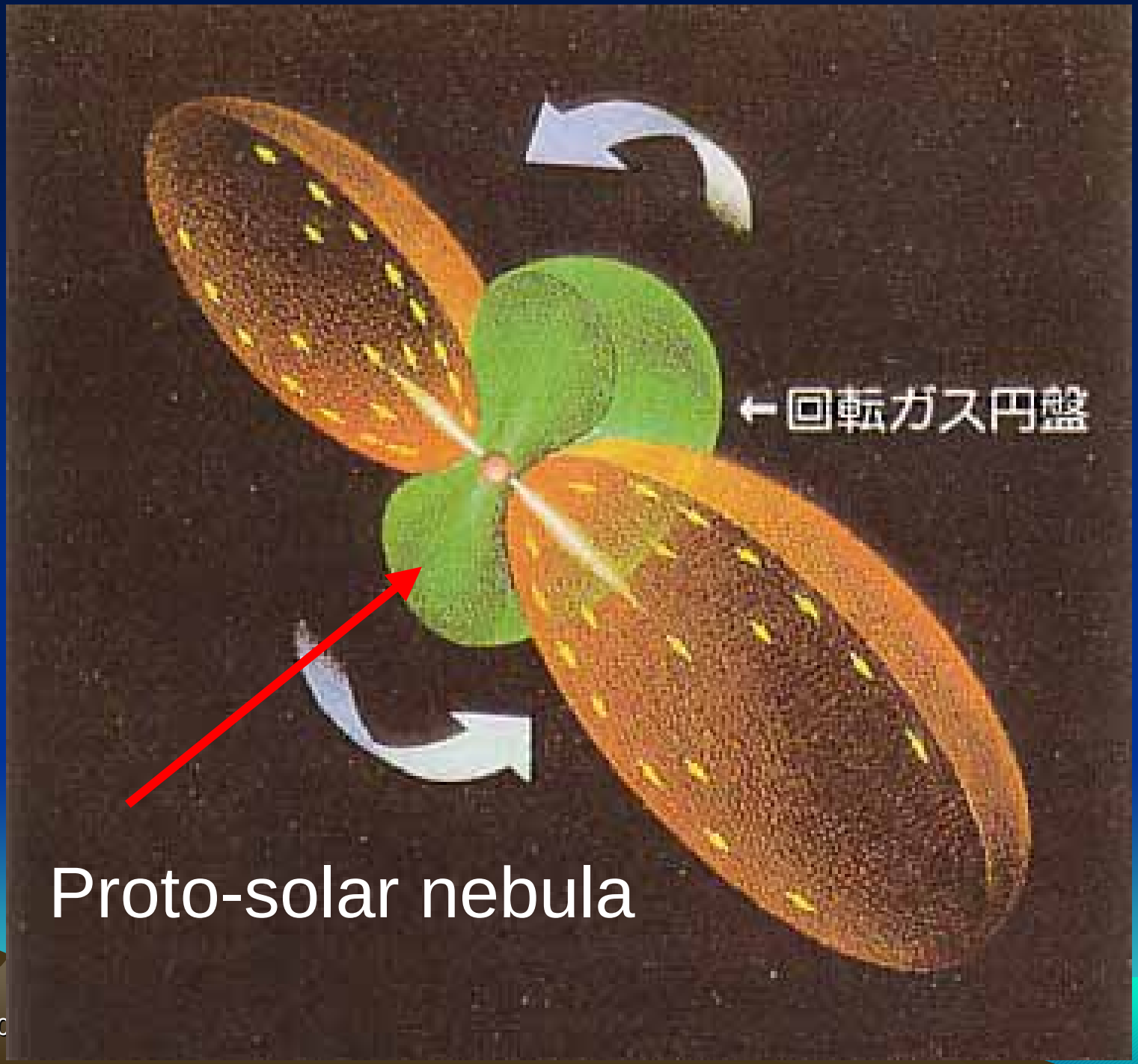
$NH_2CHCOOH + CH_3/CH_2OH$

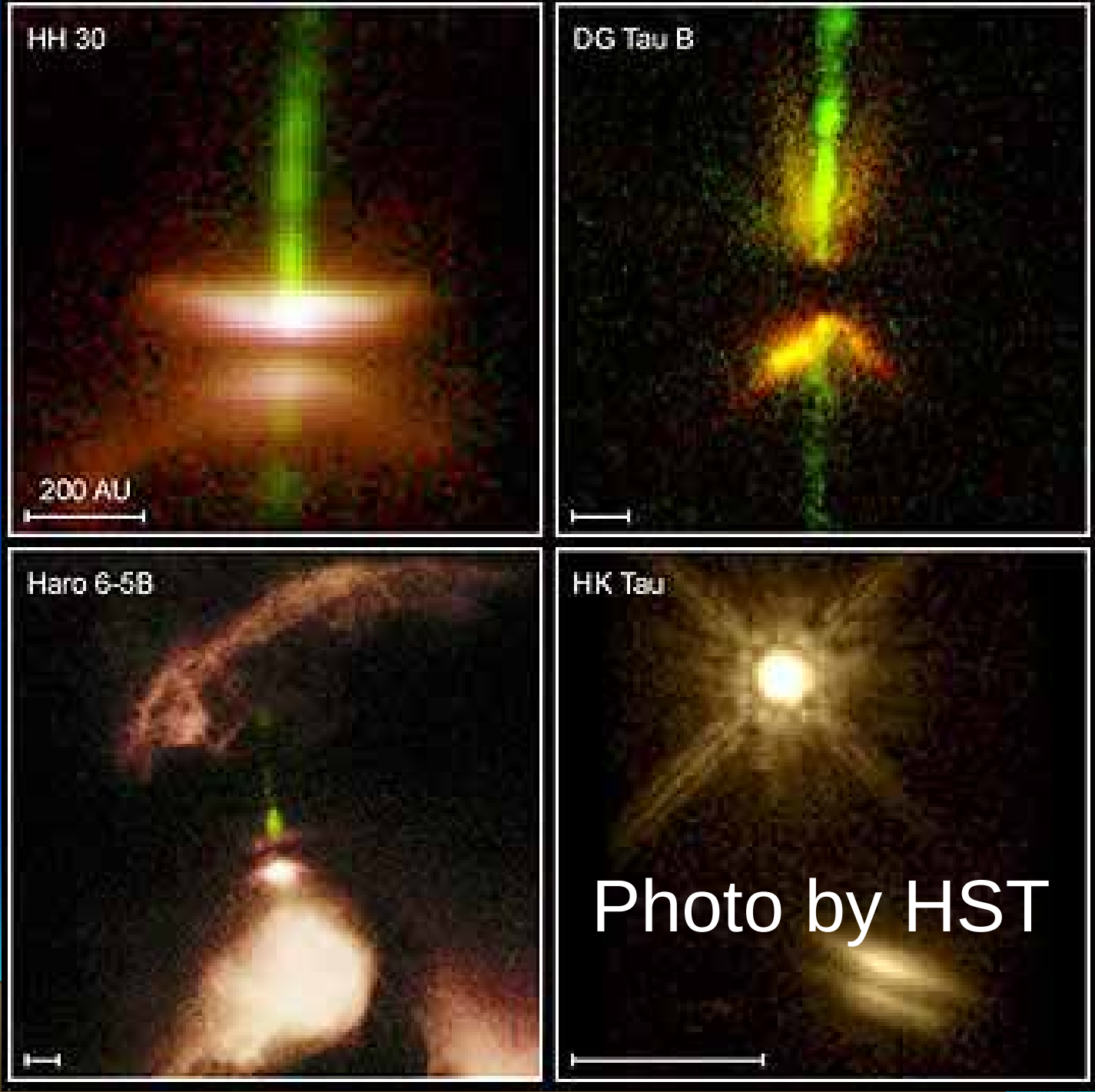
$\rightarrow$ alanine, serine



UV

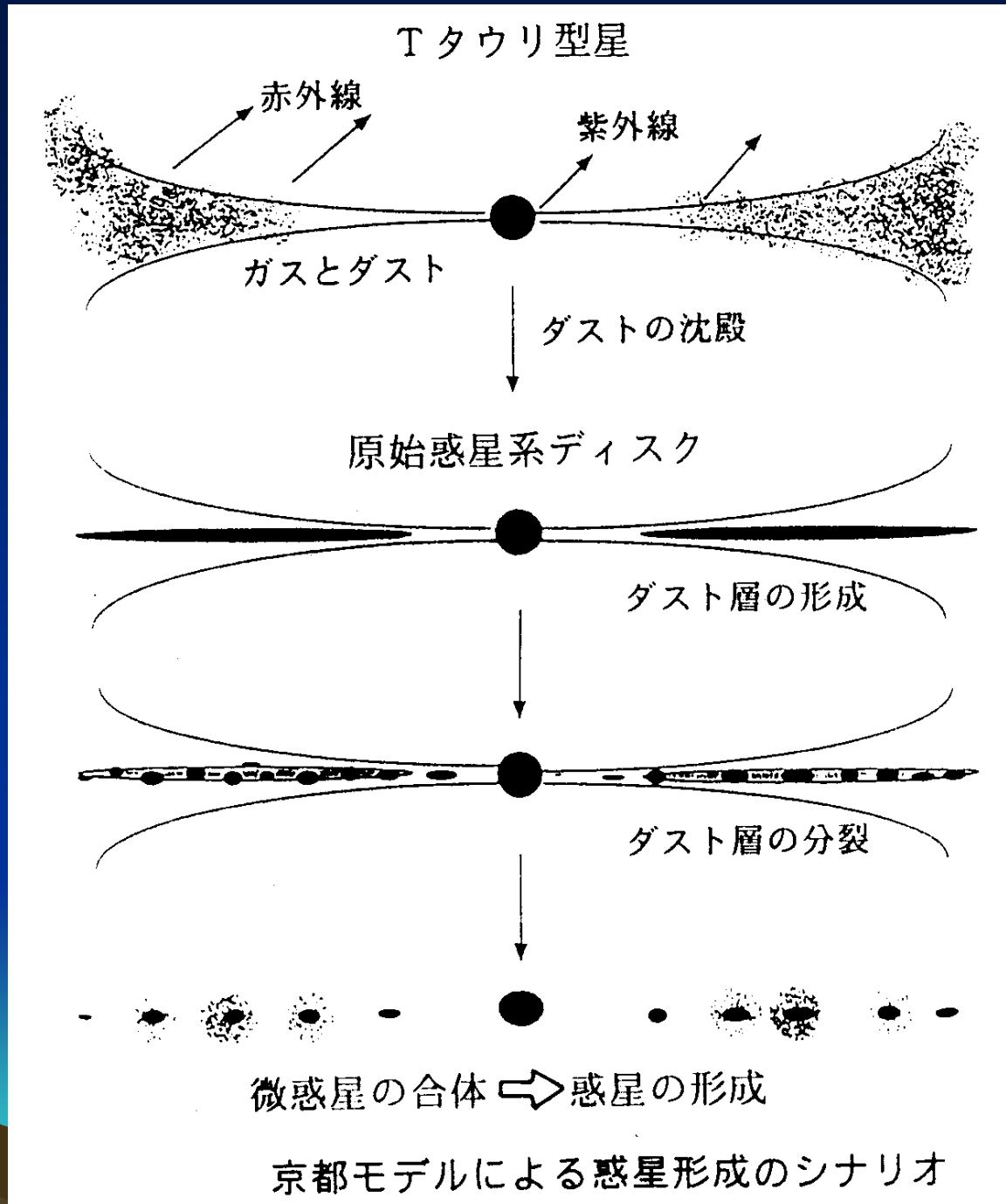
CH_3OH


←回転ガス円盤
Proto-solar nebula


HH 30
200 AU
DG Tau B
Haro 6-5B
HK Tau
Photo by HST

Kyoto Model

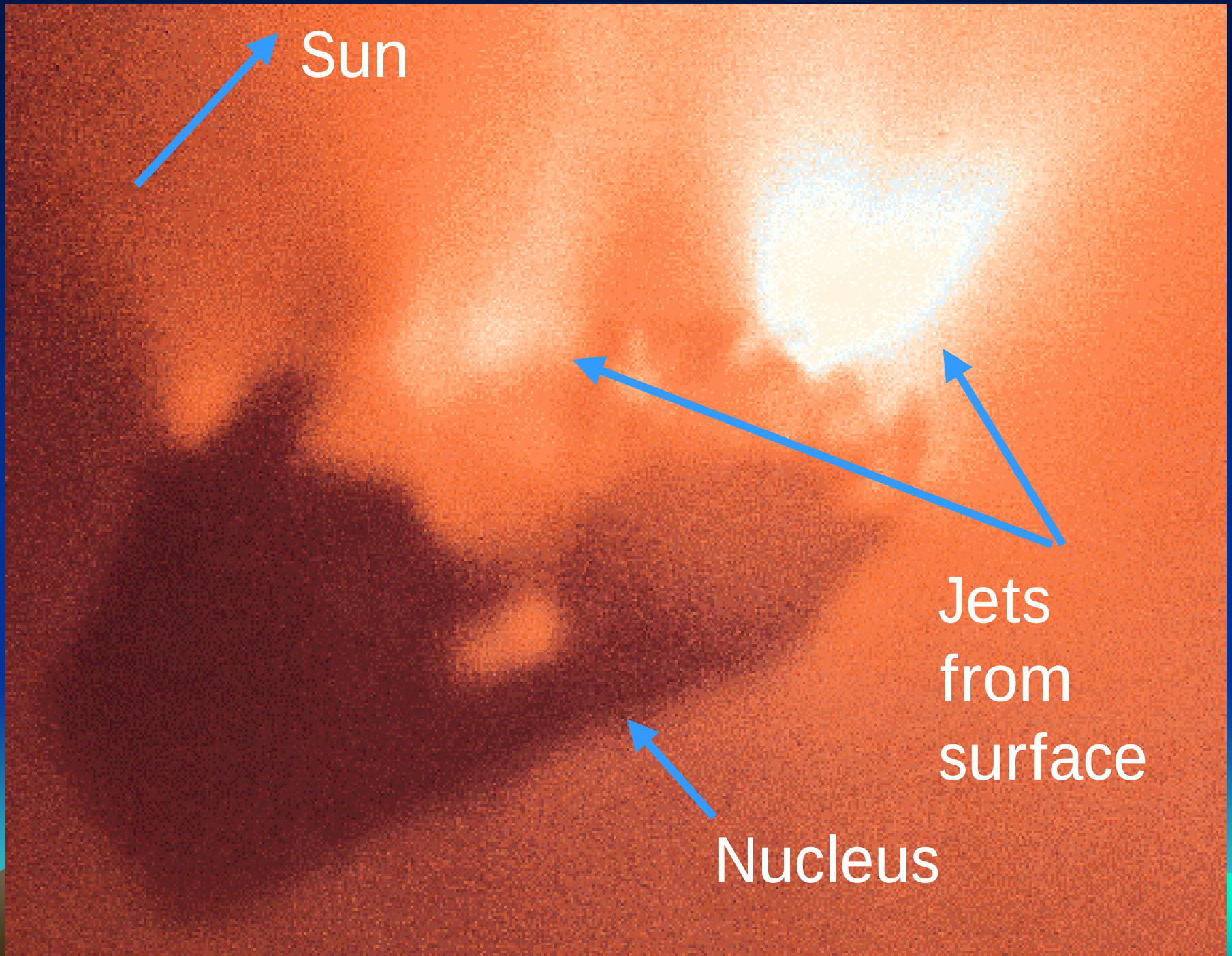
A standard model on the formation of solar systems



京都モデルによる惑星形成のシナリオ

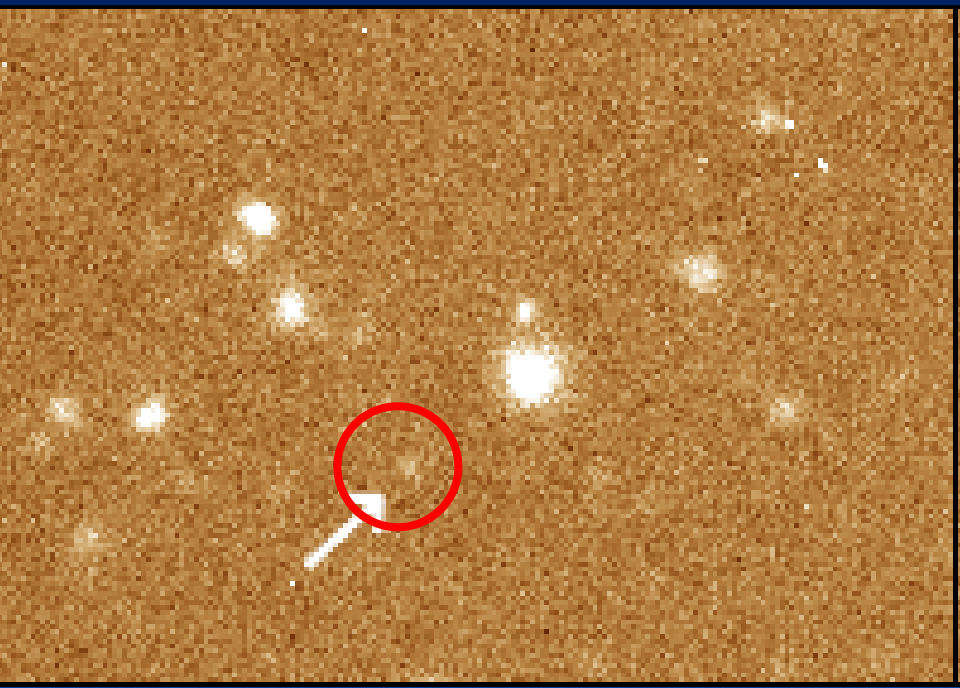
Comet Halley

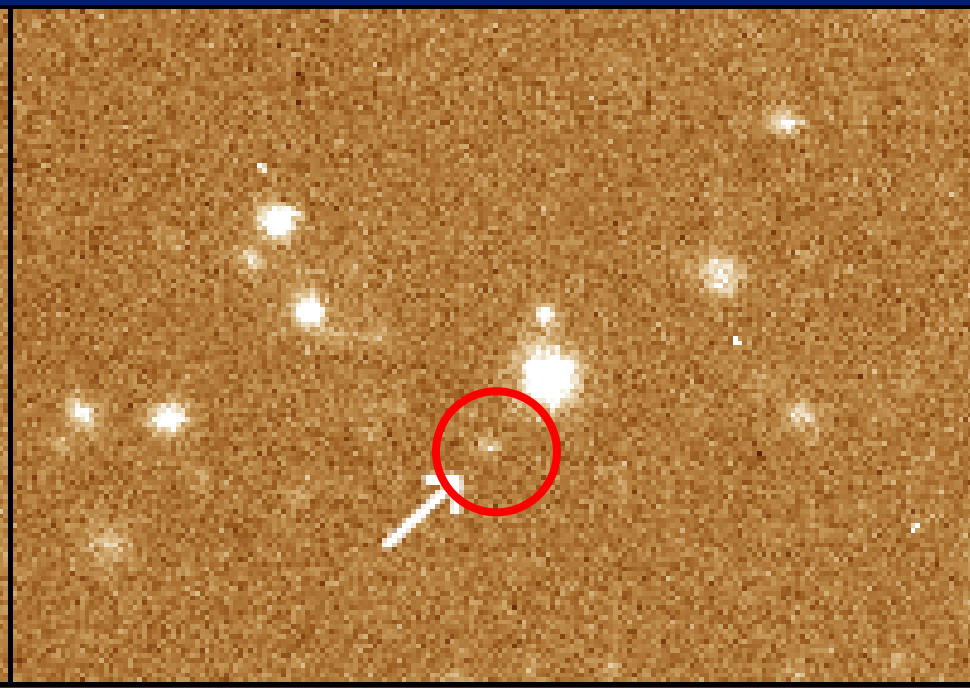
H_2O, CH_3OH etc were observed from comets


Sun
Jets
from
surface
Nucleus

Pluto and Charon

Edgeworth-Kuiper Belt Objects





Small icy objects

Can these molecules be brought into the Earth ?

- Stars are formed in molecular clouds where prebiotic molecules could be formed.
- Planets are also formed in proto-solar nebula around a protostar.
- Proto-solar nebula produced comets which are believed to contain molecular composition of molecular clouds.
- Comets collided into Earth to form ocean.

ALMA in Chile (sub-mm wave)

Summary

- Prebiotic molecules could be formed in interstellar molecular clouds.
- Sugar has been detected.
- Amino acid was reported, but has not yet been confirmed.
- ALMA and other next generation facilities may solve such issues.