Exploring an Early Stage of Protostellar Evolution with Complex Organic Molecules

Complex Molecules in Space
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Introduction

Complex organic molecules

(ex; $HCOOCH_3$, CH_3OCH_3, and C_2H_5CN)

Hot core

- High temperature (T ≳100 K)
- High density (n ≳10^6 cm^{-3})

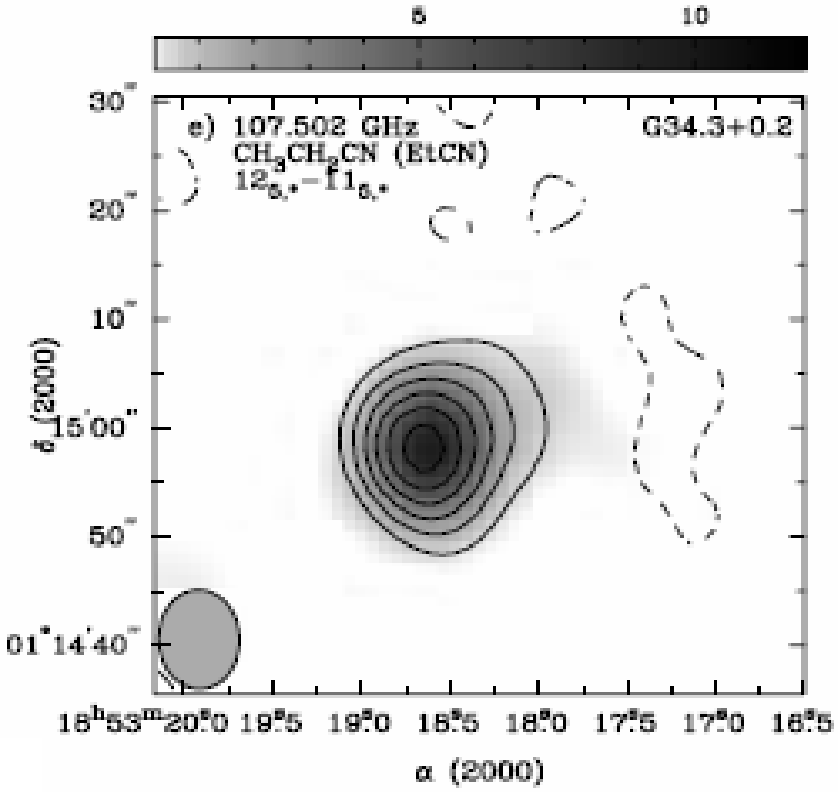
Low-mass star forming regions

★ IRAS16293 - 2444, Cazaux et al. 2003

★ NGC1333 IRAS4A, Bottinelli. et al. 2004

★ NGC1333 IRAS2A, Jørgensen et al. 2005

★ NGC1333 IRAS4B, N. Sakai et al. 2006



C_2H_5CN toward G34.3+0.15
(Remijan A. et al. 2003)

Bottinelli. et al. 2006

Behaviors of complex organic molecules

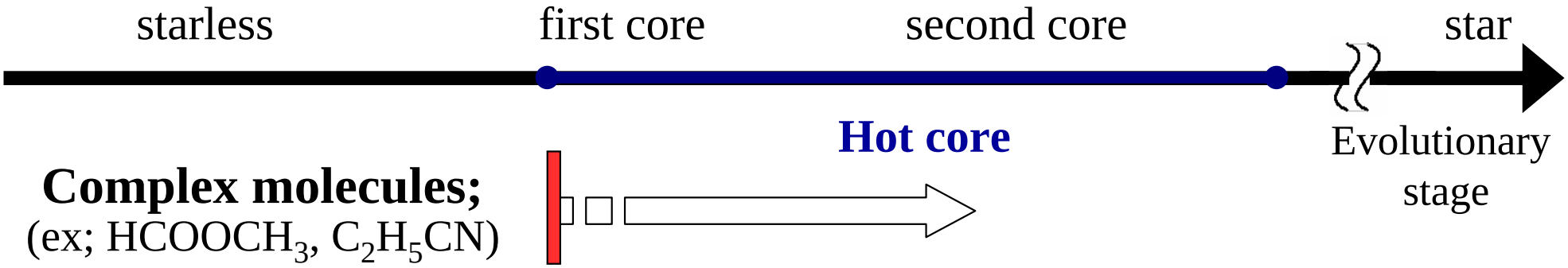
Model

Molecular depletion onto cold grains

Newly formed stars heat up the grains.

The mantle species are released into the gas phase.

(ex; H_2CO, CH_3OH)



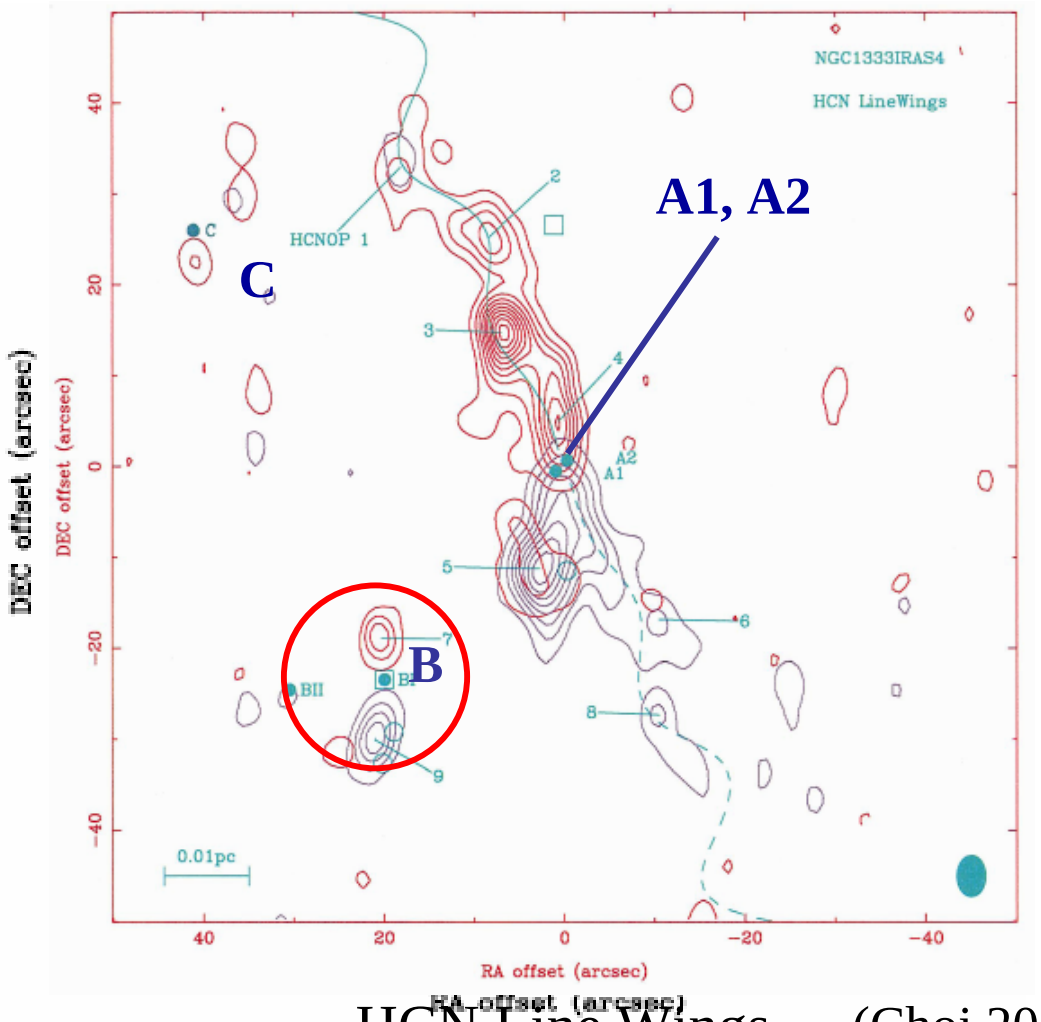
× Evaporation ○

Observation

- **When appear and disappear ?** **NGC1333 IRAS 4B**
- **Exist in all class 0 protostars ?** **L1527**

Low mass star forming regions

NGC1333 IRAS4



HCN Line Wings (Choi 2001 BIMA)

NGC1333 IRAS 4B

Distance : ~ 220 pc (*Perseus*)

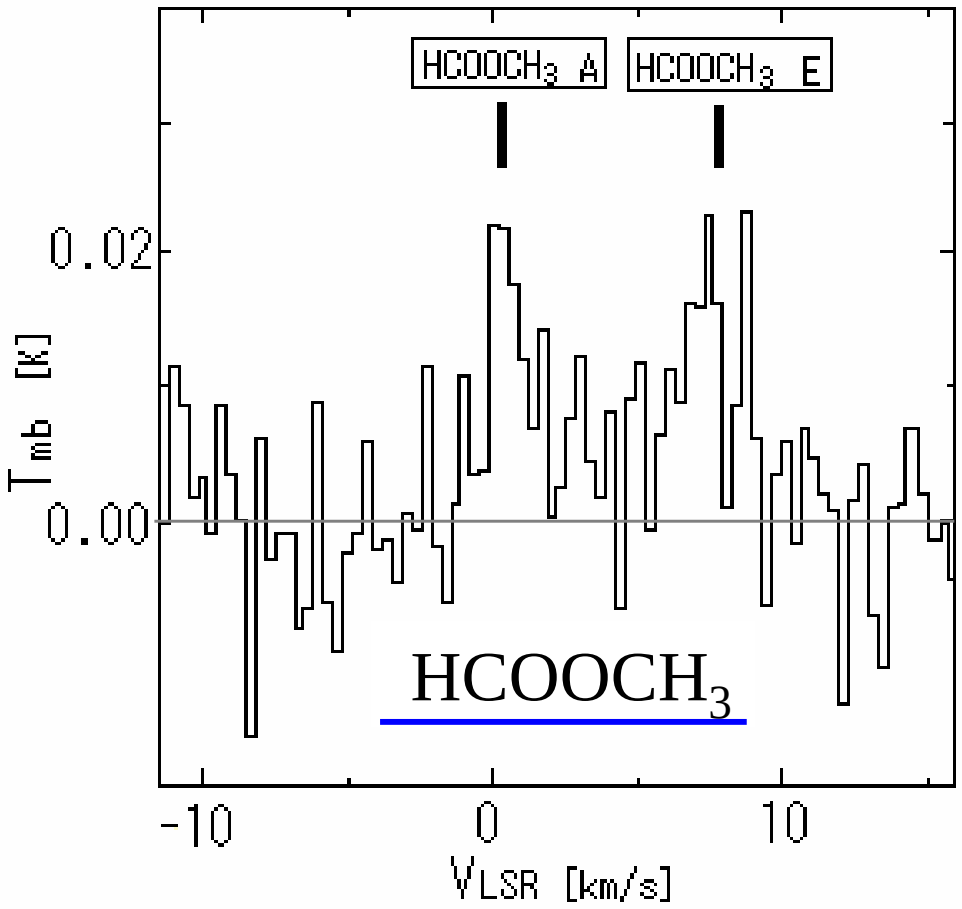
Mass (dust) : ~ 0.4 $M_{\odot}$
(cf : IRAS 4A : ~ 0.9 $M_{\odot}$)

Class 0 protostar

Extremely young ; ~ a few 100 yr (Choi 2001)

NGC1333 IRAS 4B

(rms : 3.6 mK)



v_0 ; 89.3146 GHz, $HCOOCH_3$ **E**

NRO45 m, Nami Sakai et al. ,
Publ. Astron. Soc. Japan 58, L15-L18, 2006

Exist even in the early stage of protostellar evolution.

- Column density

(Source size : 1", T_{rot} : 50 - 200 K)

N : (3 - 16) ×10^{15} cm^{-2}

- Fractional abundance

(N_{H_2} = 3.0×10^{23} cm^{-2}, Jørgensen et al. 2002)

f : (1 - 5) ×10^{-8}

Summaryl

Object	L^{a}_{bol}	Distance[a]	Dynamical age	N / 10^{15} [cm^{-2}]	f / 10^{-8}
I 16293-2422[b]	$27L_{\odot}$	160 pc (*Oph.*)	(Multiple)	9.8[b]	2.3[b]
N1333 I 4**A**[c]	$6L_{\odot}$	220 pc (*Per.*)	6500 yr	58[c]	3.6[c]
N1333 I 2**A**[d]	$16L_{\odot}$	220 pc (*Per.*)	-	-	-
N1333 I 4**B**[e]	$6L_{\odot}$	220 pc (*Per.*)	a few 100 yr	≥ 3-16	≥ 1-5
L1527	$2L_{\odot}$	140 pc (*Tau.*)	15000 yr	≤ 0.35	≤ 1

(All class 0 sources)

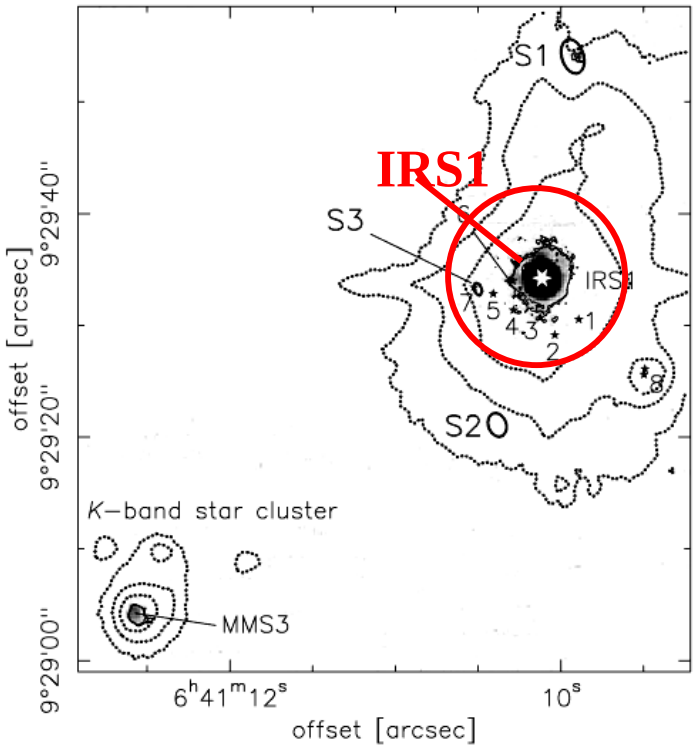
Complex species appear only in very early stage ?

([a] Maret et al.2004, [b] Cazaux et al.2003, [c] Bottinelli. et al.2004, [d] Jørgensen et al.2005, [e] Sakai et al. 2006)

Massive star forming regions

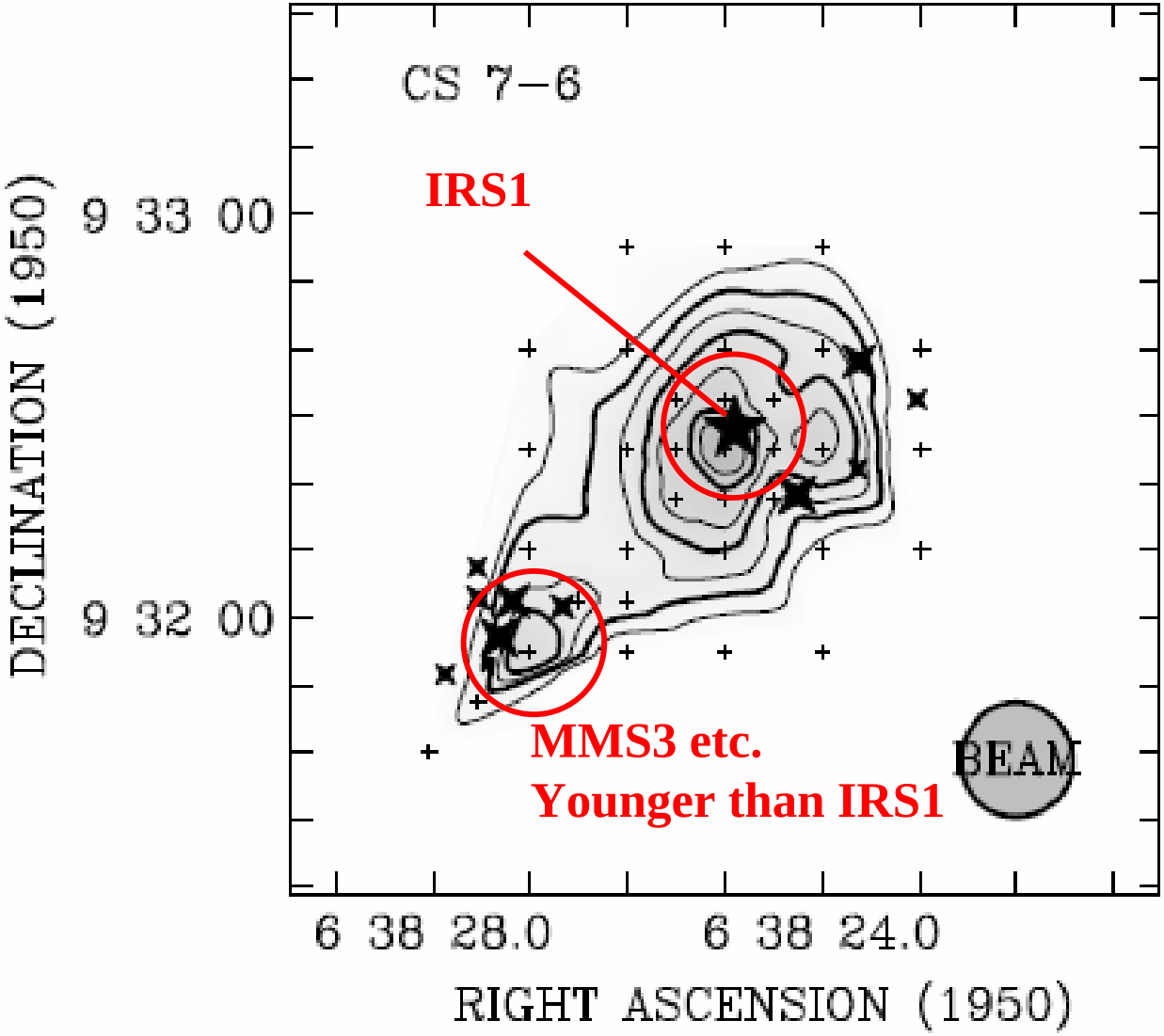
NGC2264

- Young Stellar Object
- Brightest IR source
- Luminosity ： 3500 $L_{\odot}$
- Distance ： 800 pc



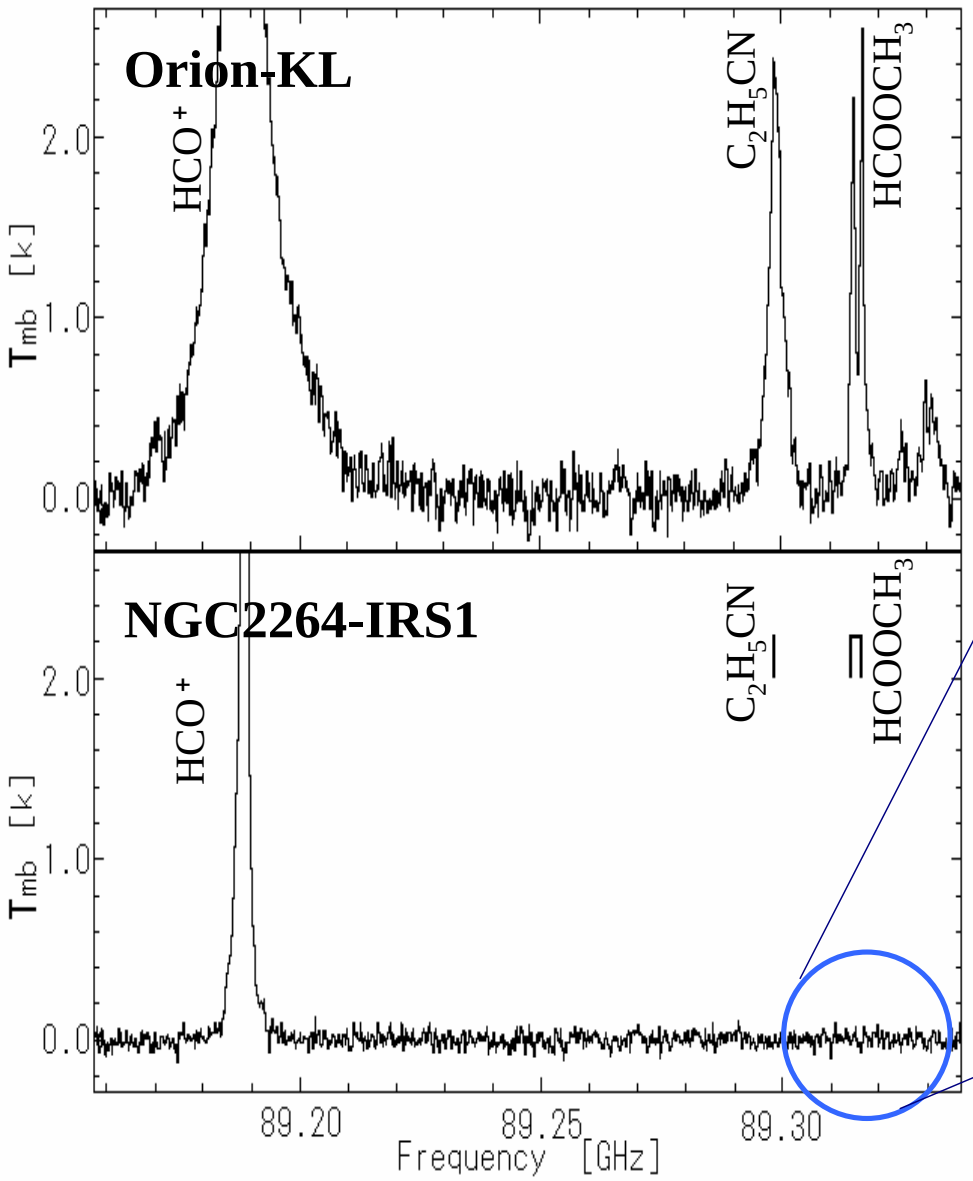
Grey-scale : 11.9μm Contour ： K - band

(Shreyer et al.2003)

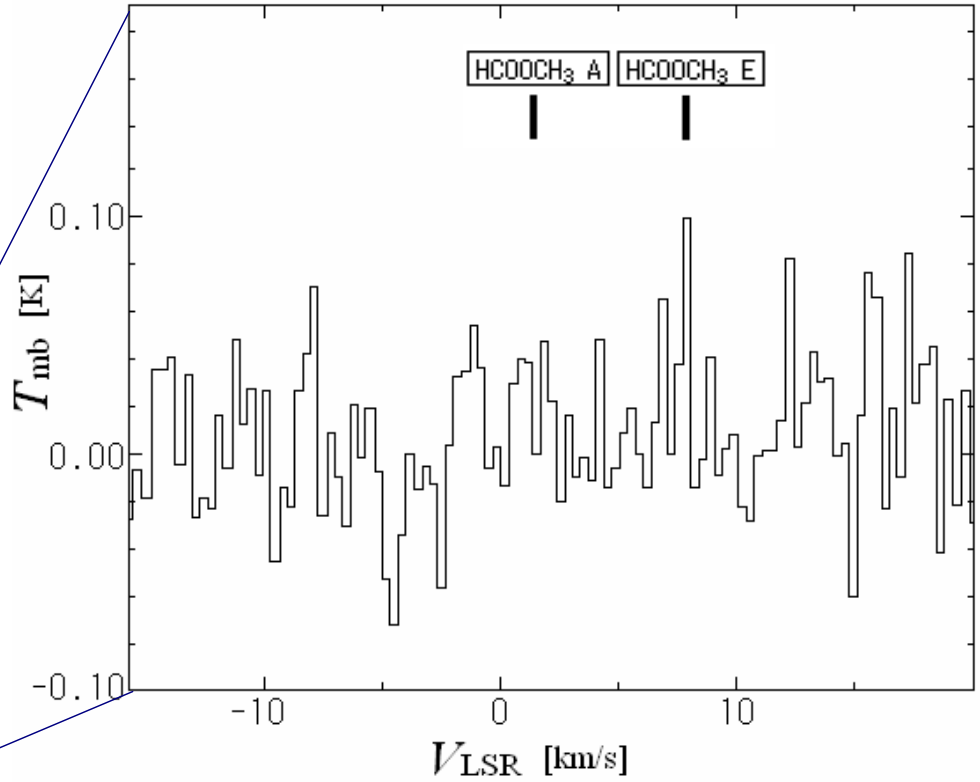


CS(7-6) (Shreyer et al.1997)

NGC2264 IRS1



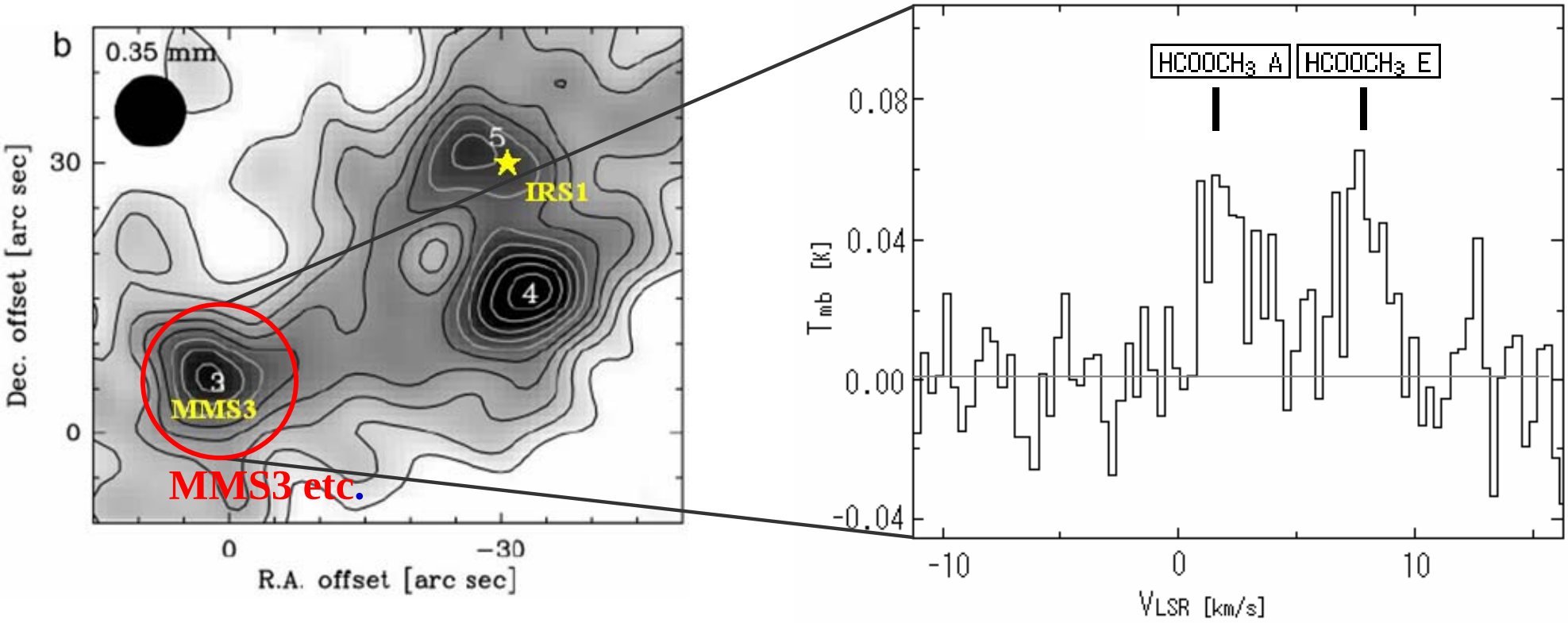
Complex species were not detected



v_0 ; 89.3146 GHz, $HCOOCH_3$ E

(N. Sakai et al. in preparation, NRO45 m)

NGC2264 MMS3



0.35 mm continuum
(Ward-Thompson et al. 2000)

ν_0 :89.3146 GHz, $HCOOCH_3$ E
(N. Sakai et al. in preparation, NRO 45 m)

$HCOOCH_3$ is detected toward MMS3 region

$HCOOCH_3$

- Column densities (N / 10^{15} cm^{-2}) (Source size : 5")

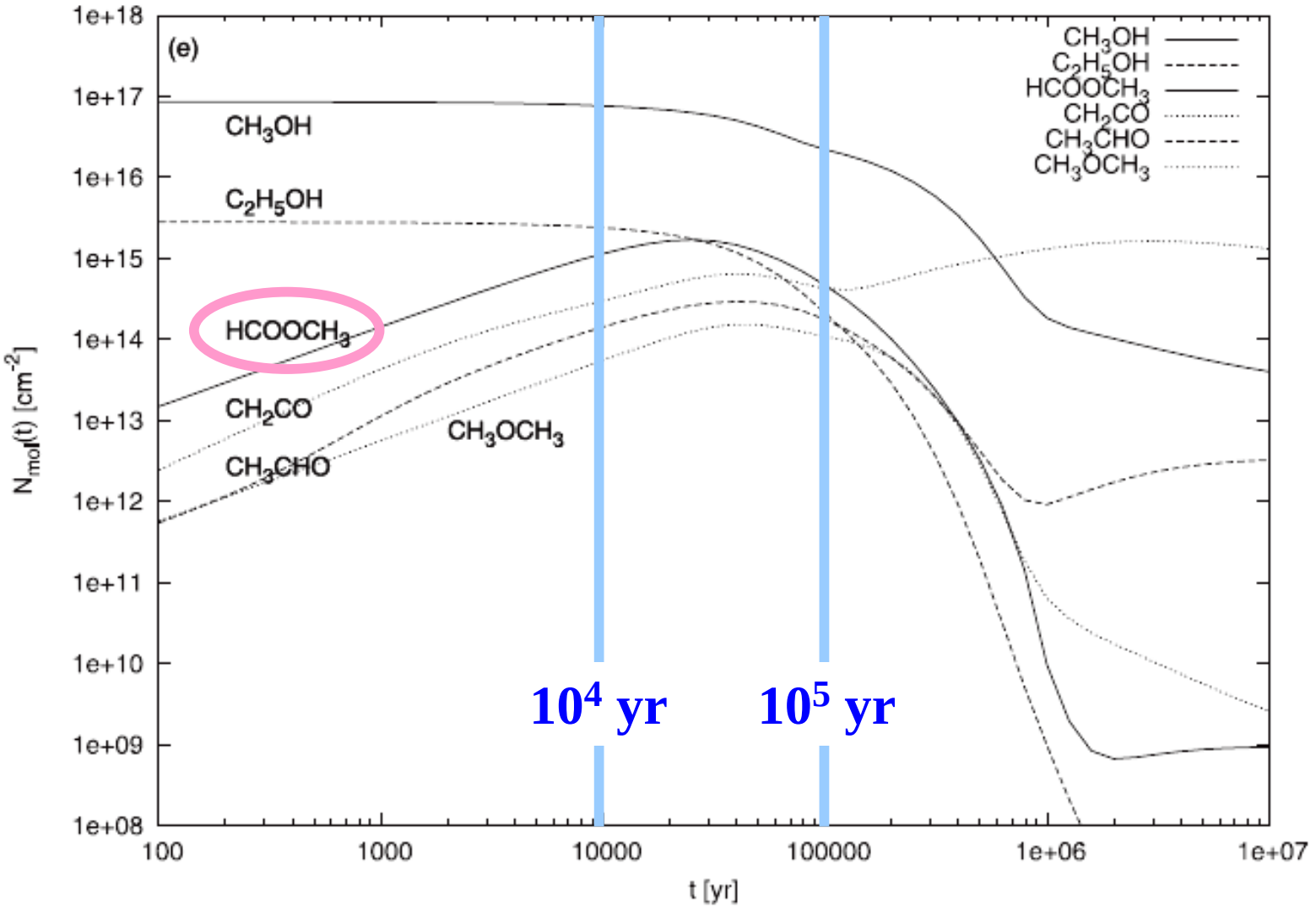
NGC2264 IRS1	:	**< 0.3 - 2**	(T_{rot} ; 50 - 250 K)	
NGC2264 MMS3	:	**2.8 - 22**	(T_{rot} ; 50 - 250 K)	
Orion KL	:	69.1	(T_{rot} ; 250 K)	(Remijan et al. 2003)

- Fractional abundances (F / 10^{-8})

NGC2264 IRS1	:	**< 0.05 - 0.4**	(N_{H_2} = 5.3×10^{23} cm^{-2})	(Peretto et al. 2006)
NGC2264 MMS3	:	**0.5 - 4.3**	(N_{H_2} = 5.1×10^{23} cm^{-2})	(Peretto et al. 2006)
Orion KL	:	14		(Remijan et al. 2003)

The time evolution of N [cm^{-2}] of some molecules

(Model for G34.3+0.15)



Evaporation of parent molecules (ex : CH_3OH) at t = 0.

(Nomura and Millar, 2004)

A potential tracer for exploring an early stage of protostellar evolution?

Summary ⅱ @ALMA

- When do the complex molecules appear and disappear ?

  (→Difference between $HCOOCH_3$ and C_2H_5CN (or CH_3OCH_3))

¡¡ Many observations !!

ex ; NGC1333 IRAS4B
Angular resolution ; 0.25”
Velocity resolution ; 1 km/s

Integration time for 5σdetection

4 min !!

(http://www.eso.org/projects/alma/science/bin/sensitivity.html)

- ★ Production process of complex organic molecules
- ★ Unique method to trace an early stage of protostellar evolution
- ★ Chemical evolution toward protoplanetary disks ?