Observations of Complex Organic Molecules

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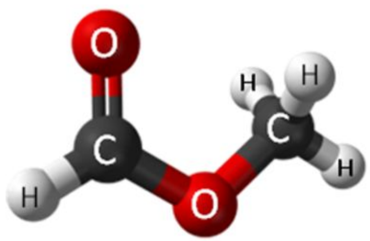
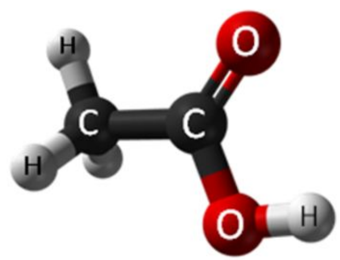
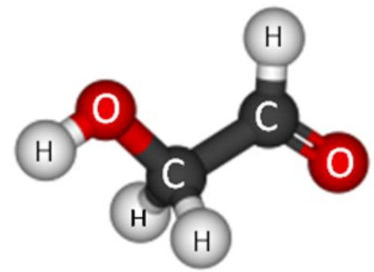


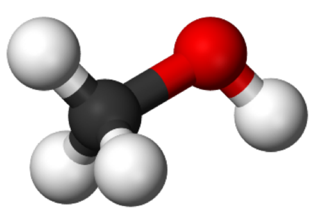
Methyl formate



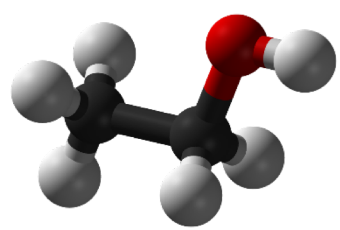
Acetic acid



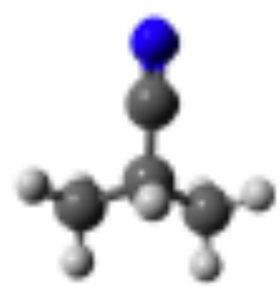
Glycolaldehyde



Methanol



Ethanol



***iso*-Propyl Cyanide**

Interstellar and Circumstellar Molecules

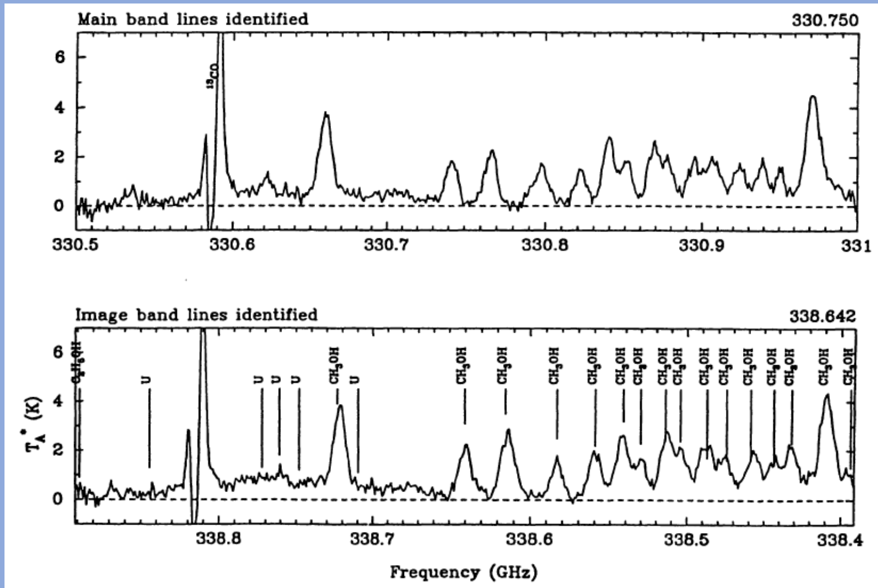
2-atom		3-atom		4-atom		5-atom	6-atom	7-atom	8-atom	9-atom	10-atom
H2	**ArH+**	**H3+**	SiCN	CH3	CNCN	CH4	CH3OH	CH3NH2	HCOOCH3	(CH3)2O	(CH3)2CO
CO	**CO+**	CH2	SiNC	NH3		CH2NH	CH3SH	**CH3CCH**	**CH3C3N**	C2H5OH	**CH3C5N**
CS	**NS+**	NH2	c-SiC2	**H3O+**		**H2CCC**	C2H4	CH3CHO	HC6H	C2H5CN	CH3CH2CHO
CN	NS	H2O	SiCSi	H2CO		c-C3H2	CH3CN	c-CH2OCH2	**C7H**	**CH3C4H**	(CH2OH)2
C2	O2	H2S	AlOH	H2CS		CH2CN	CH3NC	CH2CHCN	HOCH2CHO	**C8H**	CH3OCH2OH
CH	N2(?)	**CCH**	AlNC	c-C3H		NH2CN	HC2CHO	**HC5N**	CH3COOH	**HC7N**	CH3CHCH2O
CH+	**HCl+**	**HCN**	NaCl	**l-C3H**		CH2CO	NH2CHO	**C6H**	H2CCCHCN	CH3CONH2	***11-atom***
HF	AlO	HNC	FeCN	C2H2		HCOOH	**HC3NH+**	CH2CHOH	**H2C6**	CH3CHCH2	**HC9N**
CF+	**AlF**	HCO	KCN	**HCNH+**		**C4H**	**H2CCCC**	**C6H-**	CH2CHCHO	**C8H-**	**CH3C6H**
SiO	HS	**HCO+**	**CCN**	H2CN		**HC3N**	**C5H**	CH3NCO	NH2CH2CN	C2H5SH	CH25OCHO
SiS	NaCl	**HOC+**	**CCP**	HCCN		HCCNC	**HC4H**	**HC5O**	CH3CHNH	**HC7O**	CH3COOCH3
SiC	FeO(?)	**N2H+**	HCP	HNCO		HNCCC	HC4N		CH3SiH3	CH3NHCHO(?)	***12-atom***
SiN	SiH(?)	HNO	HS2	HOCN		**H2COH+**	c-C3H2O				C6H6
NH	**NO+(?)**	**HCS+**	HCS	HCNO		**C4H-**	CH2CNH				C3H7CN
NO		**C3**	HSC	HNCS		SiH4	**C5N-**				C2H5OCH3
SO		**C2O**		HSCN		**C5**	**C5N**				***> 12-atom***
SO+		**C2S**		**C3N**		**SiC4**	**C5S**				C60
CP		SO2		**C3O**		CNCHO	SiH3CN				C70
PO		N2O		**C3S**		CH3O					**C60+**
PN		CO2		**C3N-**		**NH3D+**					c-C6H5CN
HCl		**H2O+**		**HCO2+**		**NCCNH+**					
KCl		**H2Cl+**		PH3		**H2NCO+(?)**					
AlCl		OCS		c-SiC3		CH3Cl					
OH		MgNC		HOOH							
OH+		MgCN		**l-C3H+**							
SH+		NaCN		HCCO							
CN-		HO2		HMgNC							

204 molecules

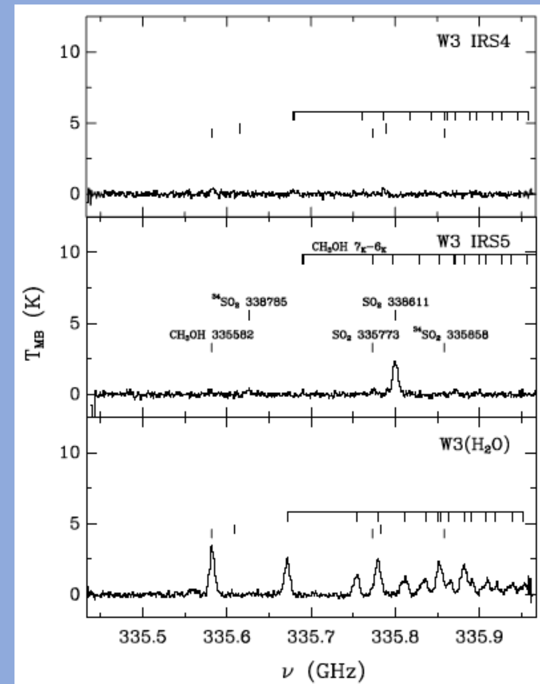
Complex Organic Molecules

2-atom		*3-atom*		*4-atom*		*5-atom*	*6-atom*	*7-atom*	*8-atom*	*9-atom*	*10-atom*
							CH3OH	CH3NH2	HCOOCH3	(CH3)2O	(CH3)2CO
							CH3SH			C2H5OH	
								CH3CHO		C2H5CN	CH3CH2CHO
							CH3CN	c-CH2OCH2			(CH2OH)2
							CH3NC	CH2CHCN	HOCH2CHO		CH3OCH2OH
							HC2CHO		CH3COOH		CH3CHCH2O
							NH2CHO			CH3CONH2	*11-atom*
								CH2CHOH		CH3CHCH2	
									CH2CHCHO		
								CH3NCO	NH2CH2CN	C2H5SH	CH25OCHO
									CH3CHNH		CH3COOCH3
									CH3SiH3	CH3NHCHO(?)	*12-atom*
							c-C3H2O				C6H6
							CH2CNH				C3H7CN
											C2H5OCH3
											> 12-atom
							SiH3CN				

40 molecules



G34.3+0.15 – JCMT 330-360 GHz
338 lines, inc. 70 U-lines
35 species plus 19 isotopomers
Macdonald et al. 1996



W3 – JCMT
334-365 GHz
14 species plus 24 isotopomers
Helmich & van Dishoeck 1997

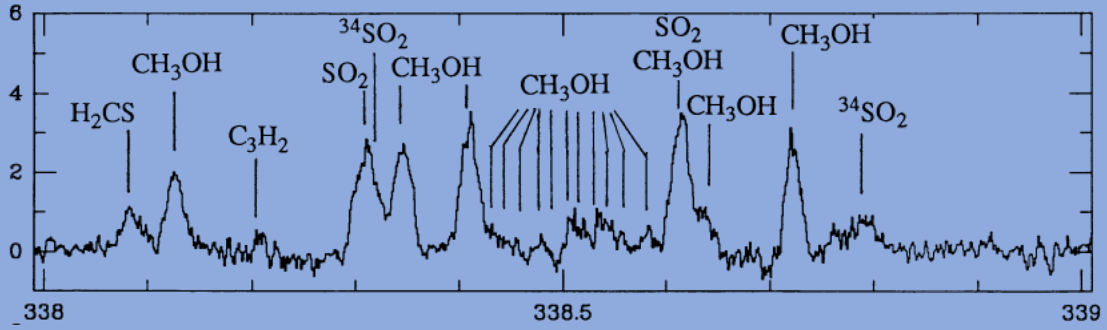
Rotational diagram analysis – Rotational temperatures, column densities

Radiative transfer calculations – densities, temperature, abundance

CLOUD STRUCTURES

Sgr B2 Line Surveys

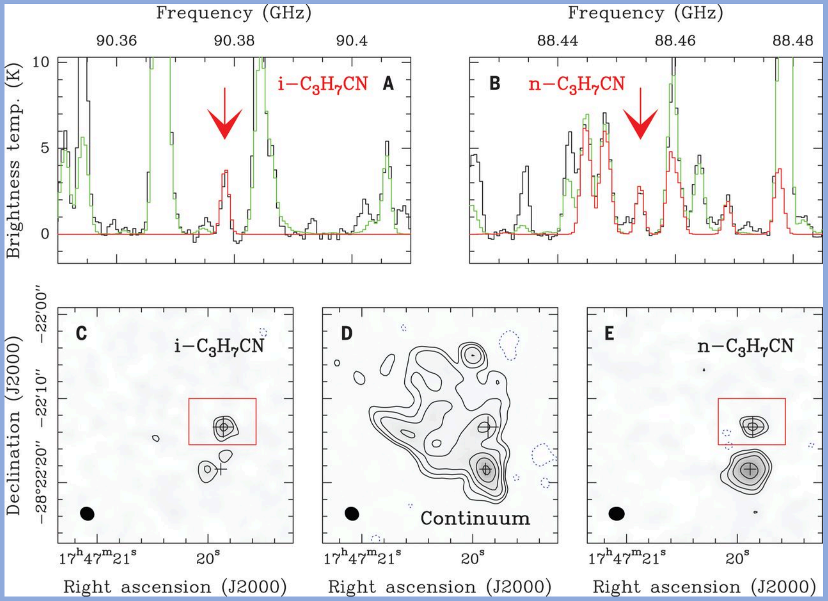
1986 – Bell Labs – Cummins et al – 100GHz, 450 lines, 39 species
1989, 1991 – NRAO – Turner – 100 Ghz, 700 lines, 36 species
1991 – CSO – Sutton et al – Sgr B2(M) – 330-355 GHz, 128 lines, 22 species

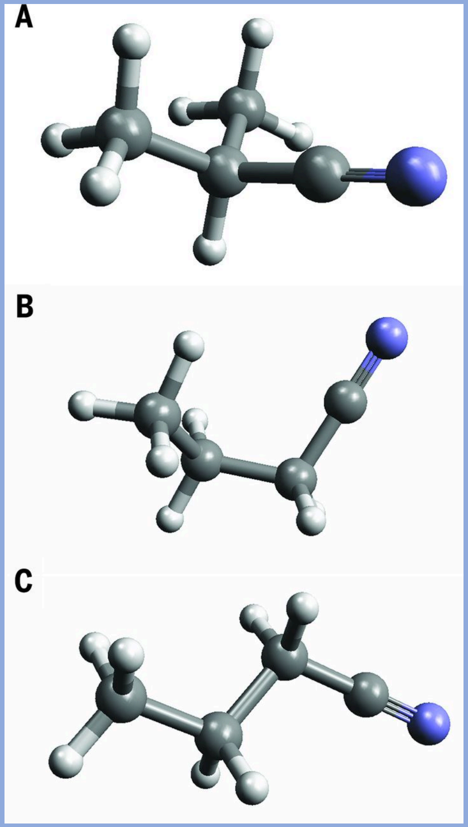


1998 – SEST – Numellin et al – N, M, NW – 218-264 GHz, 1730, 660, 110 lines
2013 – IRAM – Belloche et al – N, M – 80-116 GHz, 3700, 950 lines, including many COMs: amino acetonitrile NH2CH2COOH, n-propyl cyanide, C3H7CN, ethyl formate C2H5OCHO,
56, 46 species detected
30, 50% of all lies are U-lines

Sgr B2 Line Surveys

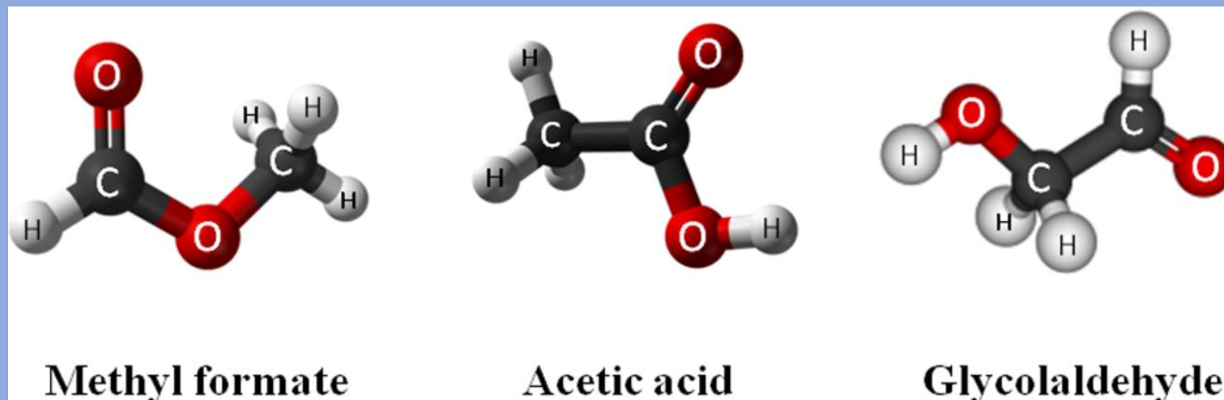
2014 – ALMA – Belloche et al – iso-propyl cyanide



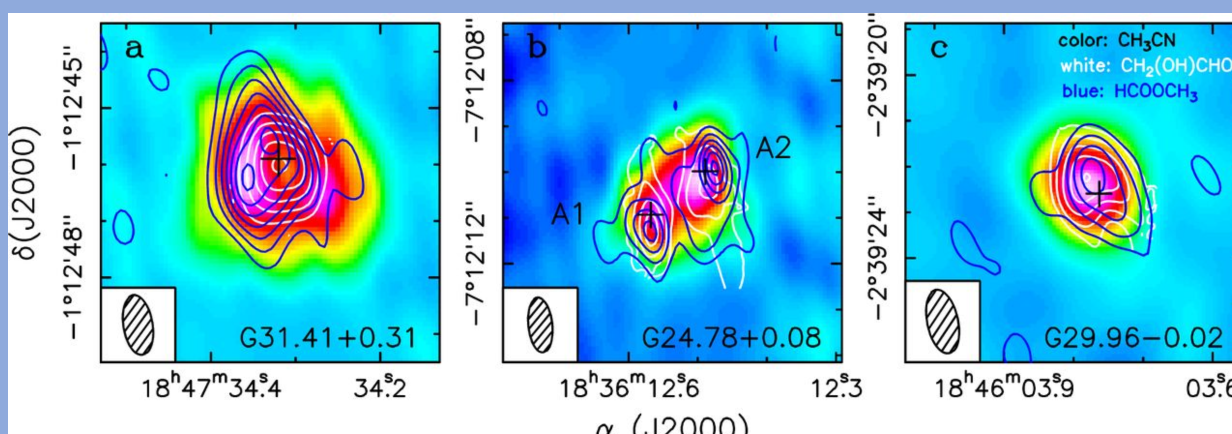


Identify new molecules by fitting LTE calculated spectra of **ALL** identified molecules

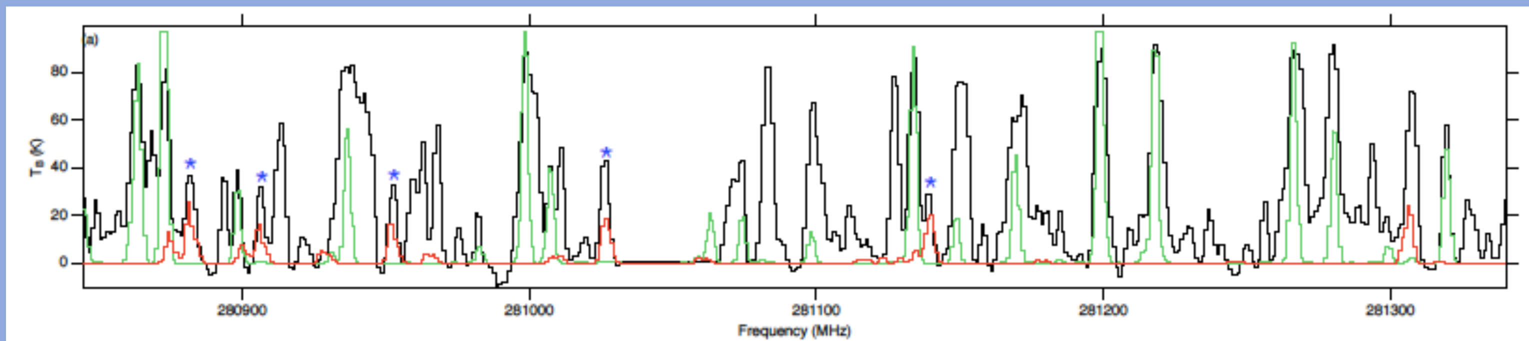
COMs in Hot Molecular Cores



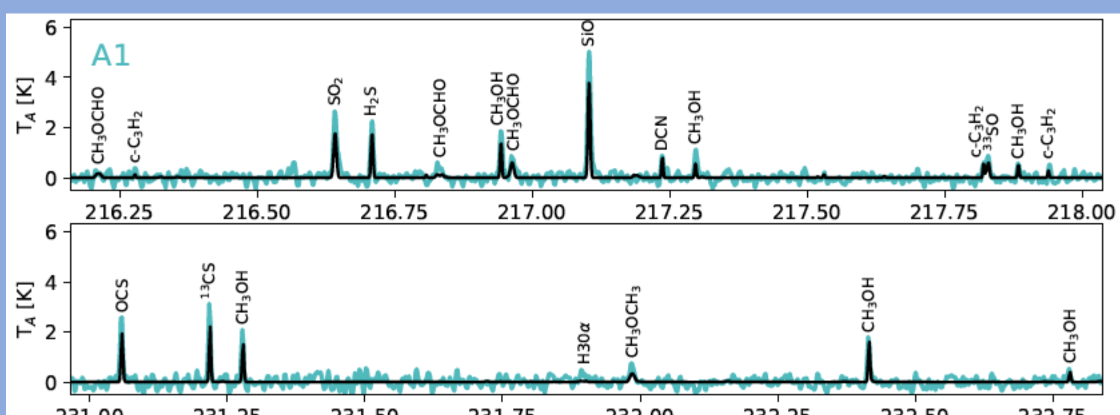
PdBI Maps: Methyl formate (blue), glycolaldehyde (white), CH_3CN (colours) Calcutt et al. 2014 MNRAS, 443, 3157



Complex Chemistry – Hot IS Clouds



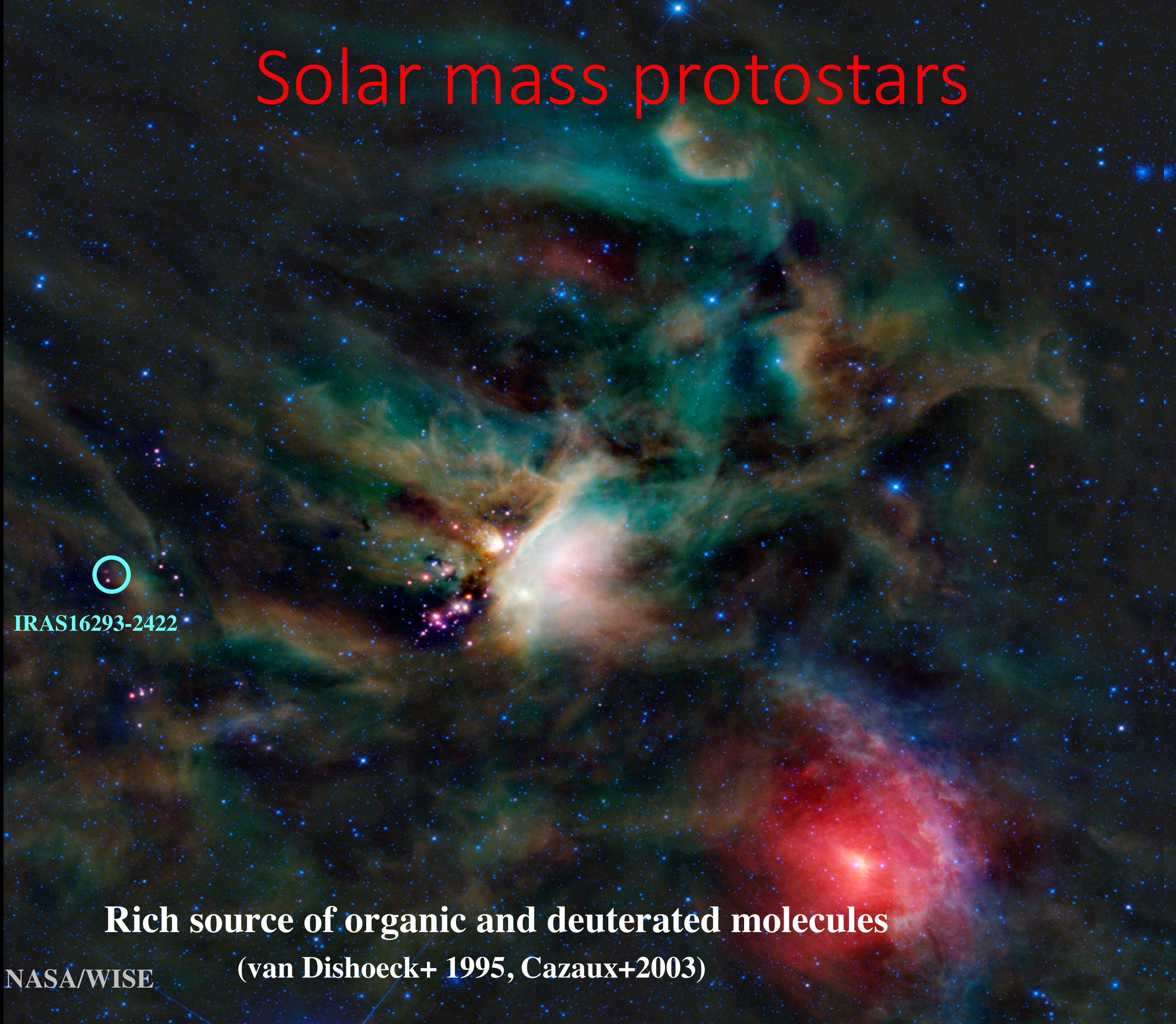
ALMA detection of methoxymethanol, CH_3OCH_2OH, in NGC 6334I MM1, T_{rot} = 200K
Formation: CH_3O + CH_2OH on ice
McGuire et al ApJL, 851, L46 (2017)



ALMA: COMs in the LMC
CH_3OH, CH_3OCHO, CH_3OCH_3
T_{rot} = 130K
Sewilo et al ApJ, 853, L19 (2018)

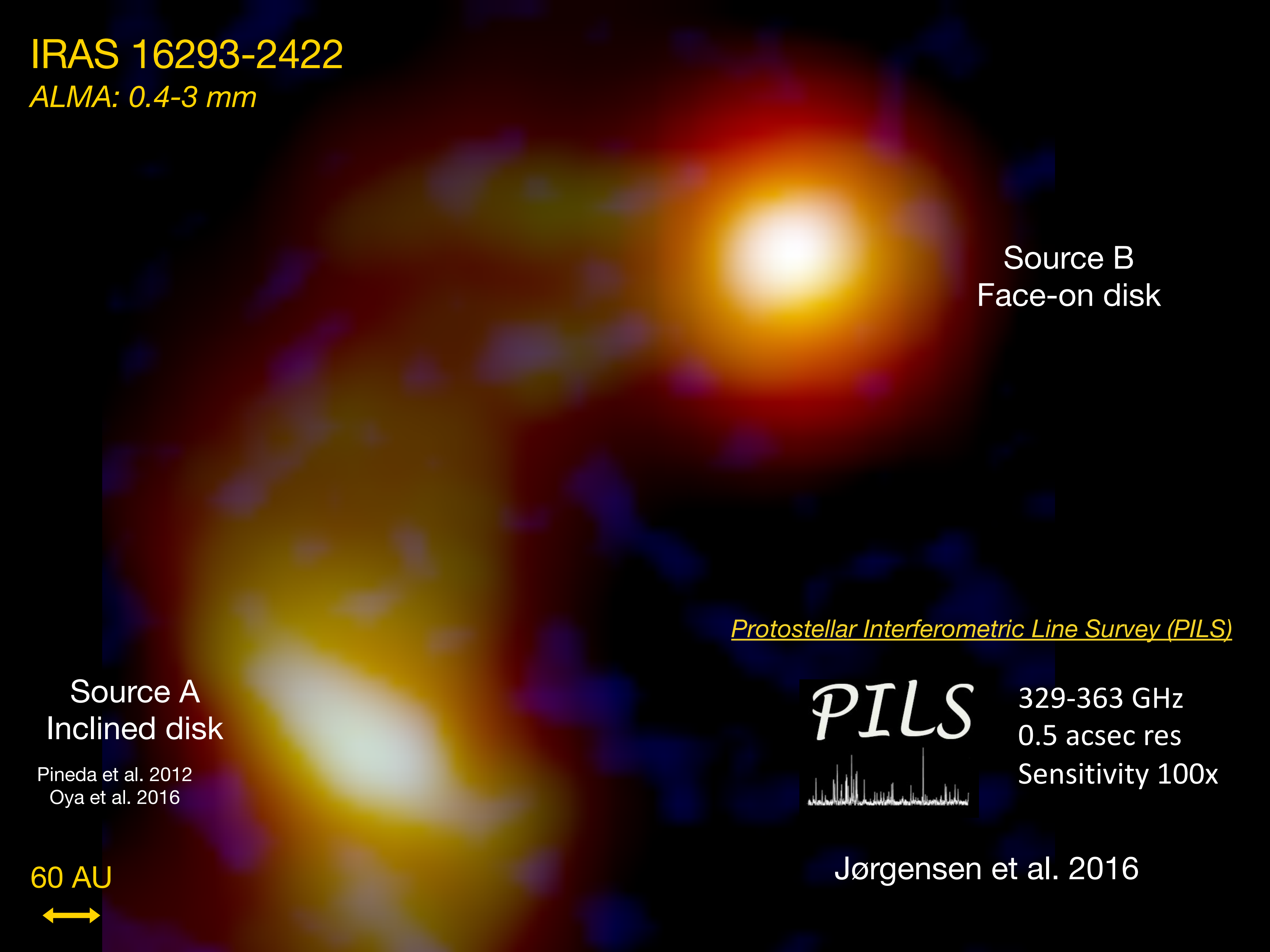
Solar mass protostars

Ophiuchus d=125 pc low-mass star-forming region

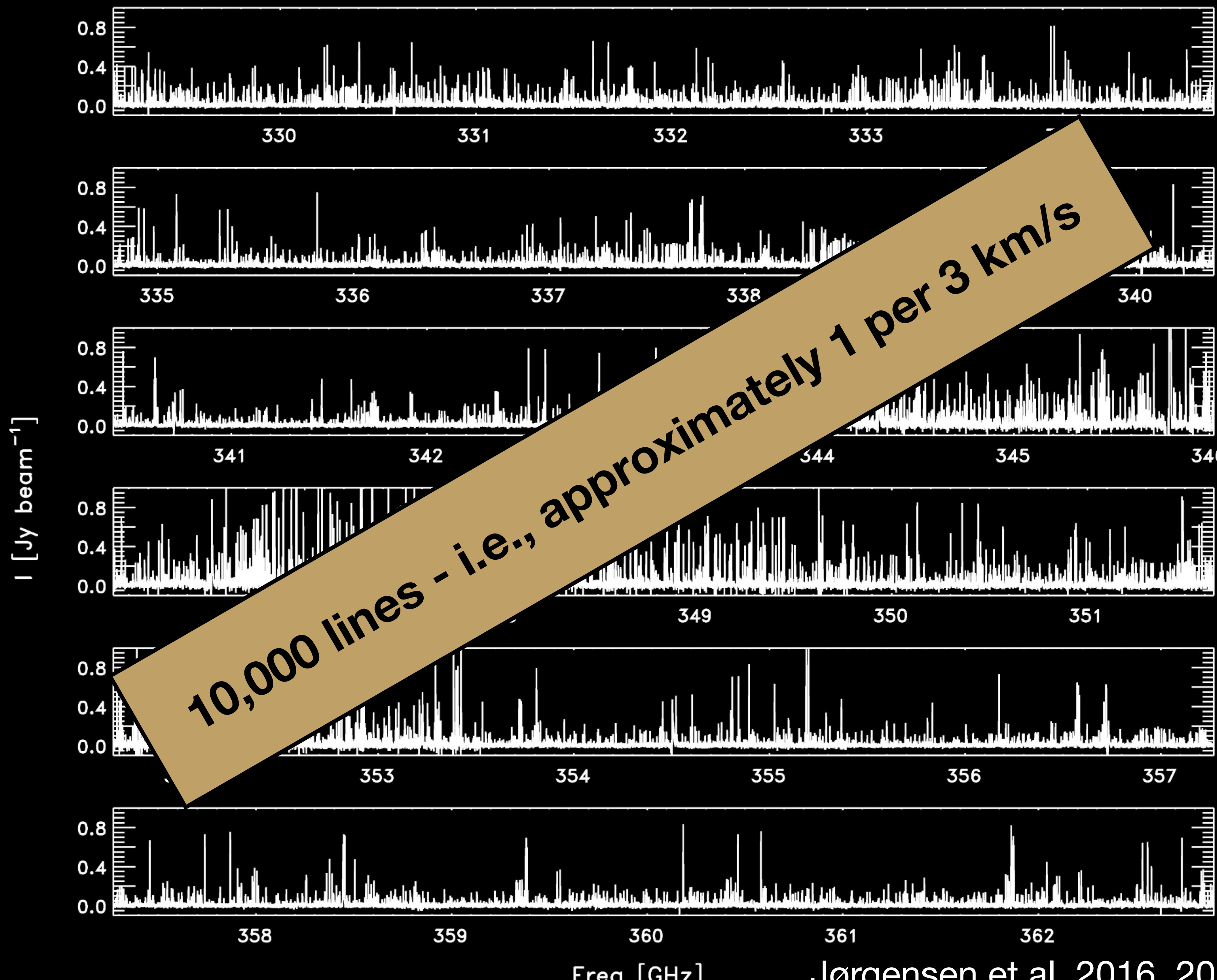


Rich source of organic and deuterated molecules

(van Dishoeck+ 1995, Cazaux+2003)


IRAS 16293-2422
ALMA: 0.4-3 mm
Source B
Face-on disk
Source A
Inclined disk
Pineda et al. 2012
Oya et al. 2016
60 AU
Protostellar Interferometric Line Survey (PILS)
PILS
329-363 GHz
0.5 acsec res
Sensitivity 100x
Jørgensen et al. 2016

PILS survey: Full spectral survey of IRAS 16293–2422



Jørgensen et al. 2016, 2018

PILS – Deuterated COMs

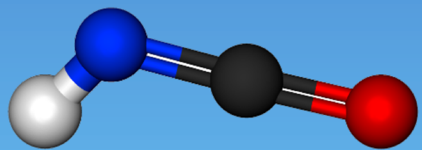
6-atom	7-atom	8-atom	9-atom
CH_2DOH	CH_3CDO	CH_2DOCHO	CH_2DOCH_3
CH_3OD		CH_3OCDO	CH_2DCH_2CN ?
CHD_2OH		CH_2OHCDO	CH_3CHDCN ?
CD_3OH		$CHDOHCHO$	CH_2DCH_2OH
CH_2DCN		CH_2ODCHO	CH_3CHDOH
$NHDCHO$			
NH_2CDO			

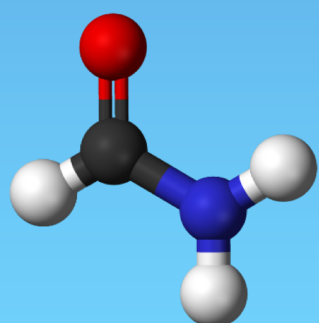
Recent detection of doubly-deuterated methyl formate CHD_2OCHO

$HDO/H_2O < 0.1\%$

Very high deuteration: groups of COMs?

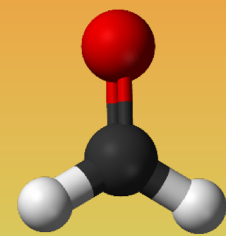
Isocyanic acid, formamide

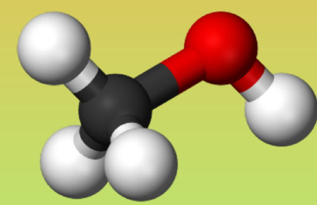


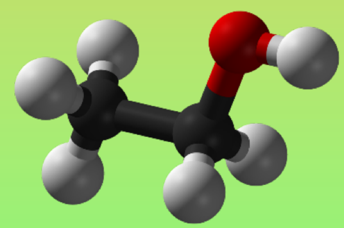


D/H ~ 1%

Formaldehyde, methanol, ethanol



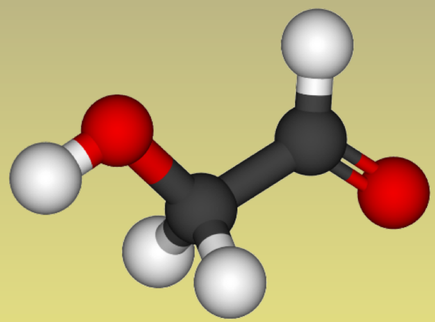


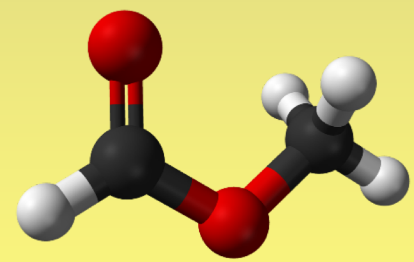


D/H ~ 2%

^{12}C:^{13}C ~ ISM

Glycolaldehyde, methyl formate





D/H ~ 5%

^{12}C:^{13}C ~ 0.5 × ISM

Jørgensen et al. 2018

COMs – Unexpected Consequences

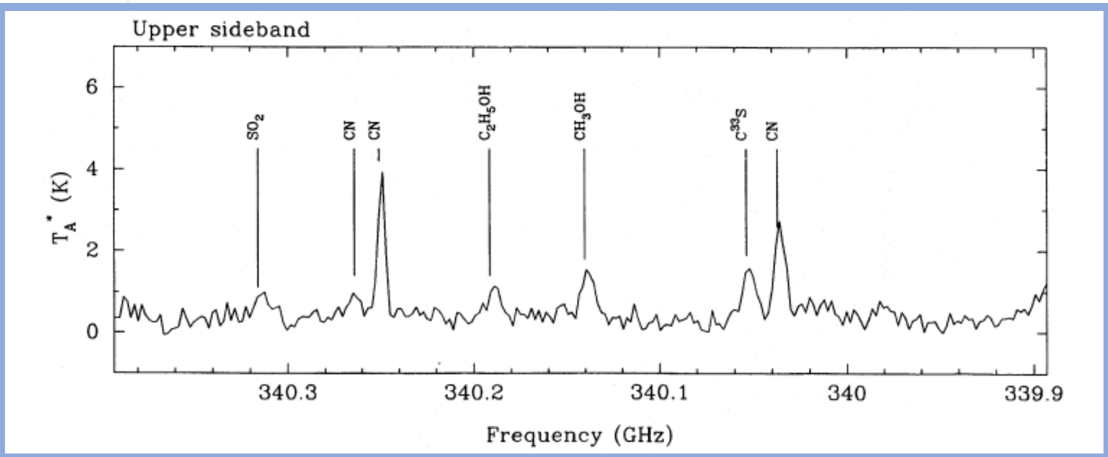
Mon. Not. R. Astron. Soc. **273**, 25–29 (1995)

The detection of hot ethanol in G34.3+0.15

T. J. Millar,[1] G. H. Macdonald[2] and R. J. Habing[2]

[1] *Department of Mathematics, UMIST, PO Box 88, Manchester M60 1QD*

[2] *Electronic Engineering Laboratories, The University of Kent at Canterbury, Canterbury, Kent CT2 7NT*



300,000 pints of beer a day for every person on Earth for next Billion years

The Sun, March 18 1995

Sun's the

Jamie . . . set up fondling

I planned TV grope

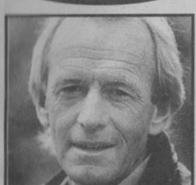
MOVIE star Jamie Lee Curtis has admitted she TOLD a comedian to grope her boob at a Hollywood awards bash.

Millions of TV viewers saw Jon Lovitz fondle her as she received a prize at the American Comedy Awards this month.

Jamie seemed shocked and retaliated by grabbing his groin.

Critics branded Lovitz "crude." But Jamie, 36, said: "I don't want Jon to take the heat. They asked us to do funny things. It was my idea."

biz for



Hogan . . . £2m movie role

Hogan's Flipped

CROCODILE Dundee star Paul Hogan is set to make a splash in a film version of Flipper.

CRATER BROWN ALE

Boffins find huge cloud of alcohol in space

ET foam home . . . how movie favourite would look enjoying a pint of outer-space ale

By DAVID WOODING, Spaced-Out Correspondent

STARGAZERS have found a boozers' paradise in outer space — a gigantic mass of pure alcohol.

They stumbled across a mystery cloud while peering through their telescopes at a distant constellation.

Now after months of research they have learned the mystery object is the final front-beer . . . enough alcohol to make **400 TRILLION, TRILLION** pints of beer.

That's 300,000 pints a day for every person on Earth for the next **BILLION** years. It would fill the world's oceans tens of thousands of times over.

Frozen

But star-trekkers who want to beam up for a quick one had better think again – the bar at the end of the Universe is 10,000 light years away – or 58,656,960,000,000,000 miles.

Last night, the three British astronomers who made the discovery were raising their glasses in a more down-to-Earth toast.

Geoff Macdonald and Rolf Habing, of the University of Kent and Tom Miller, of the University of Manchester Institute of Science and Technology, were the boffins who spotted the cloud.

They were looking through the powerful James Clerk Maxwell Telescope on Hawaii at a newly formed star called G34.3 in the constellation of Aquila. Further studies revealed that heat from the new star is producing alcohol faster than all the world's breweries and distilleries put together.

At minus 148°C the cloud is 'warm' by space standards – but the brew could be comfortably drunk without ice.

As Captain Kirk might say if he stumbled across the alcoholic haze: "Booze me up, Scotty."

Only one problem in outer space, though . . .

10 STOUT OF THIS WORLD DRINKS

1 Interstellar Artois
2 Carling Black Hole Label
3 Tennants Extra Terrestrial
4 Adnams Alien
5 Mars-tons Pedigree
6 Watneys Red Planet
7 Miller Lite Years
8 Rolling Rocket
9 Castlemoon XXXX
10 Red Spock Cider

Le Figaro, May 1995

Astronomie

ILS ONT DÉCOUVERT DE

A des milliers d'années-lumière, c'est un nuage dans l'espace. Et c'est la plus grande "cave" de l'univers : des milliards de milliards de litres d'alcool pur. Deux chercheurs viennent de découvrir cette chose stupéfiante.

PAR PATRICE LANOY

Vous pouvez imaginer une pile de quatre cent mille milliards de pintes de bière ? Cela ferait un joli mur, non ? De quoi boire pendant des milliers d'années pour tous les Terriens.

A l'évidence, Geof MacDonald, sujet de Sa Majesté et astronome à l'université du Kent, est ravi de son petit calcul. Pour ponctuer sa phrase, il vient d'ailleurs d'écoper d'un trait sa «*lady*» ambrée. Au *Loss O'Gowrie*, un très honorable pub, haut lieu des adorateurs de la *pure malt* de Manchester, nous avons sacrifié au culte, en compagnie de Tom Miller, chimiste et mathématicien à l'université locale. Le temps, pour les deux scientifiques, d'expliquer pourquoi leur trouvaille d'un gigantesque nuage d'alcool, flottant dans l'espace, à une distance d'environ 10 000 années-lumière de distance de notre planète (une année-lumière équivaut à 9 500 milliards de kilomètres) constitue une affaire de la plus intersidérale importance.

– *Cela ressemble à une plaisanterie, mais c'est très sérieux,* renchérit MacDonald, *c'est même une nouvelle étape de la cosmochimie.*

Ne fouillez pas des yeux la nuit du printemps. Si les chercheurs britanniques, en coopération avec une équipe de l'université de l'Ohio (Etats-Unis), ont déniché de l'alcool dans la constellation de l'Aigle (l'étoile principale en est Altaïr), le nuage, même gigantesque, restera invisible à vos yeux. C'est en analysant des ondes radio millimétriques, captées par une antenne située à 4 000 mètres d'altitude, sur les hauteurs volcaniques du Mauna Kea d'Hawaii (radiotélescope anglo-hollandais James Clerk Maxwell), que les chercheurs ont pu localiser cette étrange formation. Il se trouve que les ➔

PHOTOS : PASCAL GOETGUELUCK

A LA SANTÉ DU COSMOS !
Le Pr Geof MacDonald (à gauche, photo de gauche) a calculé le nombre de pintes de bière représenté par le nua d'alcool qu'il a découvert dans le cosmos, avec son ami le Pr Tom Miller (à droite). Un chiffre... astronomique. Ci-contre : ils nous montrent la constellation de l'Aigle (en blanc), où flotte ce gigantesque nuage.

Open Questions

- Physics of PPDs and Hot Cores/Corinos
- Results sensitive to physical model assumed

  Grain size distribution, porosity

  Gas and grain temperatures
- Accurate reaction rate coefficients

  Routes to COM formation in gas-phase (hot and cold)
- Accurate surface parameters (binding energies, diffusion energies, activation barriers, ice composition and morphology)
- Accurate description of surface (and bulk?) chemistry

  H atom addition/abstraction

  How complex is this chemistry?

  Deterministic vs. stochastic

  Thermal and non-thermal desorption mechanisms
- Conversion of laboratory rates to interstellar rates
- ALMA is a wonderful tool to probe PPDs, Hot Cores/Corinos but large COMs will be difficult to detect in PPDs