

# To explore the solar system

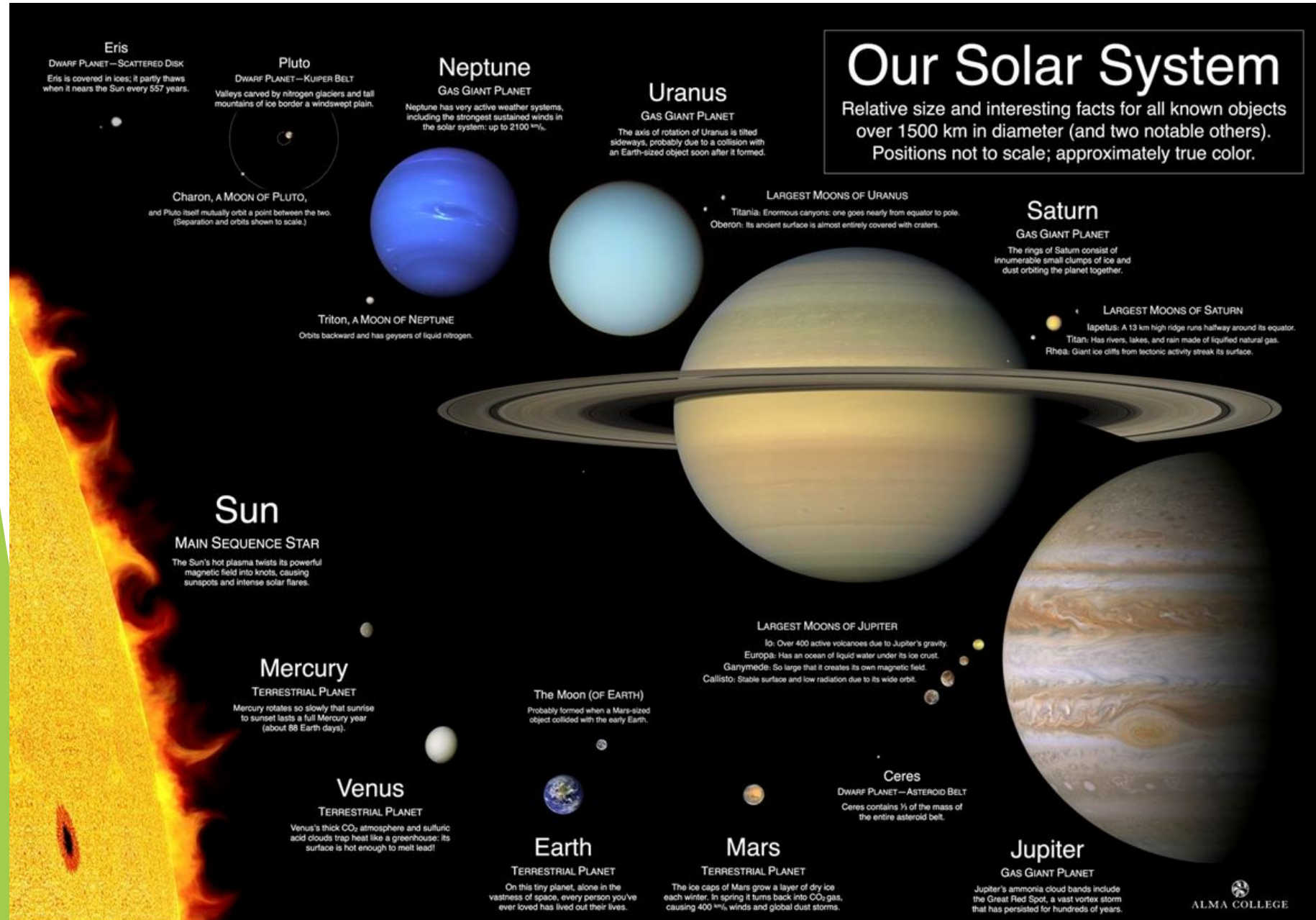
## — A case study of Callisto

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# Introduction: solar system

- The solar system formed about 4.6 billion years ago.



# Introduction: Callisto

- Callisto is the fourth Galilean moon orbits around Jupiter.
- Callisto formed at the same time as the solar system.
- The size of Callisto compared with other Galilean moons:



# Introduction: Callisto

- Mass:  $1.07 \times 10^{23}$  kg (0.018 earth mass)
- Mean radius: 2410.3 km (0.378 Earth radius)
- Mean density:  $1.83 \text{ g/cm}^3$  (mixture of ices and rocks)



NASA

# Introduction: Callisto

- Exosphere:  
Carbon dioxide is revealed by Galileo spacecraft, and molecular oxygen is revealed by Hubble space telescope.
- Solid surface:  
water ice, carbon dioxide, silicates, and organic compounds
- Interior structure:  
Callisto may have subsurface oceans of liquid water.

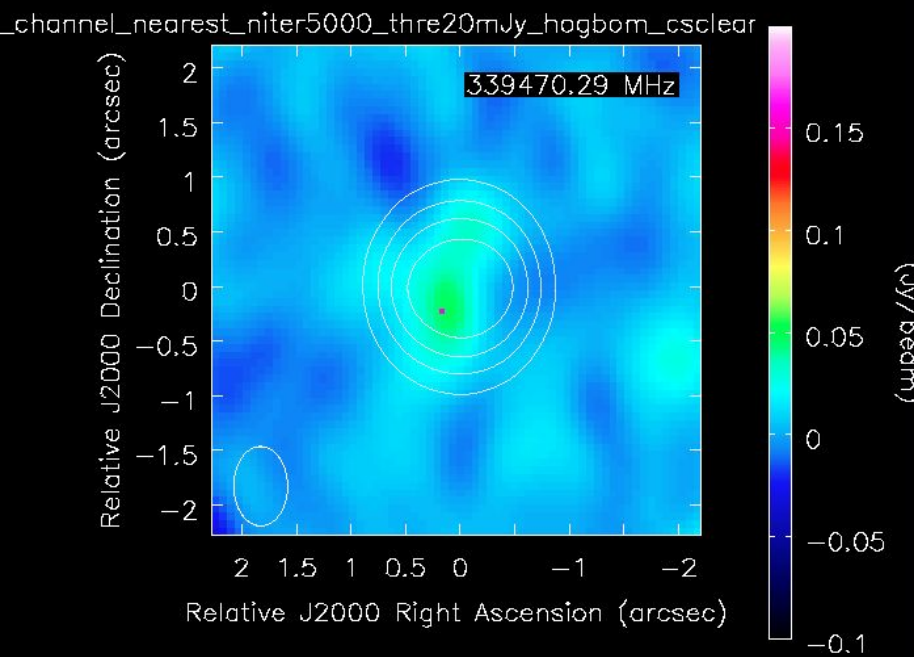
# Observations

- The observational data are taken from ALMA (Atacama Large Millimeter/submillimeter Array) that is the largest ground-based astronomical facilities in the world.
- ALMA is an interferometer array in Chile and it used 23 antennas to observe Callisto in our data (band 7) .
- Callisto was observed on 23-Oct-2012.
- Total integration time: 206.64 seconds

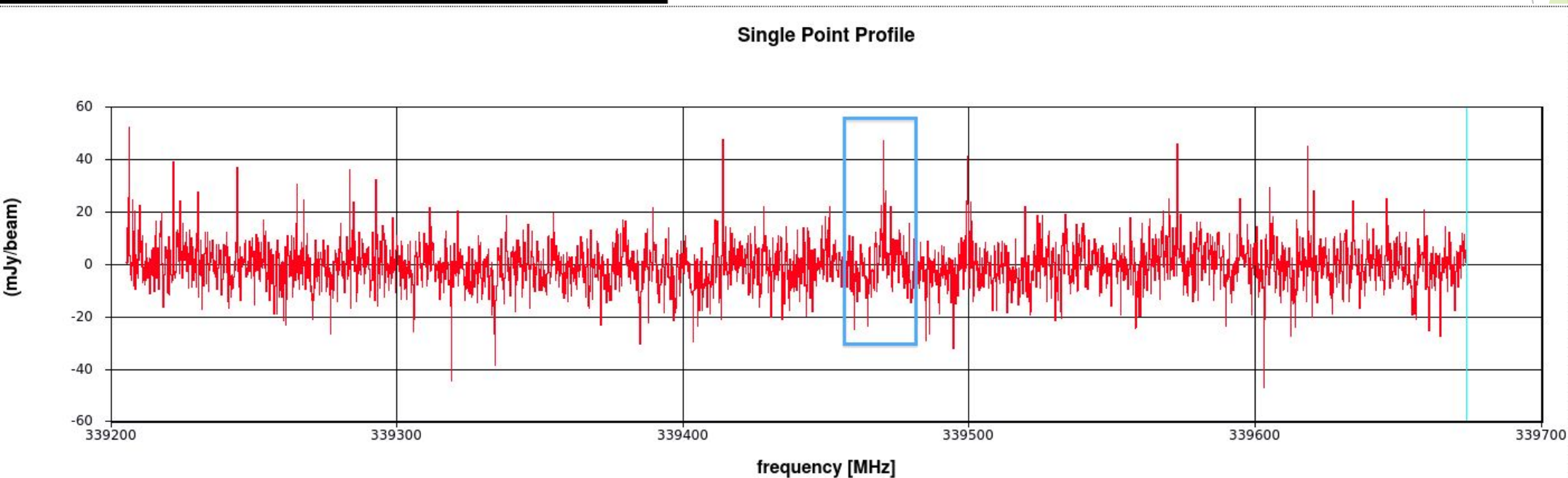




# Observations — Spectrum

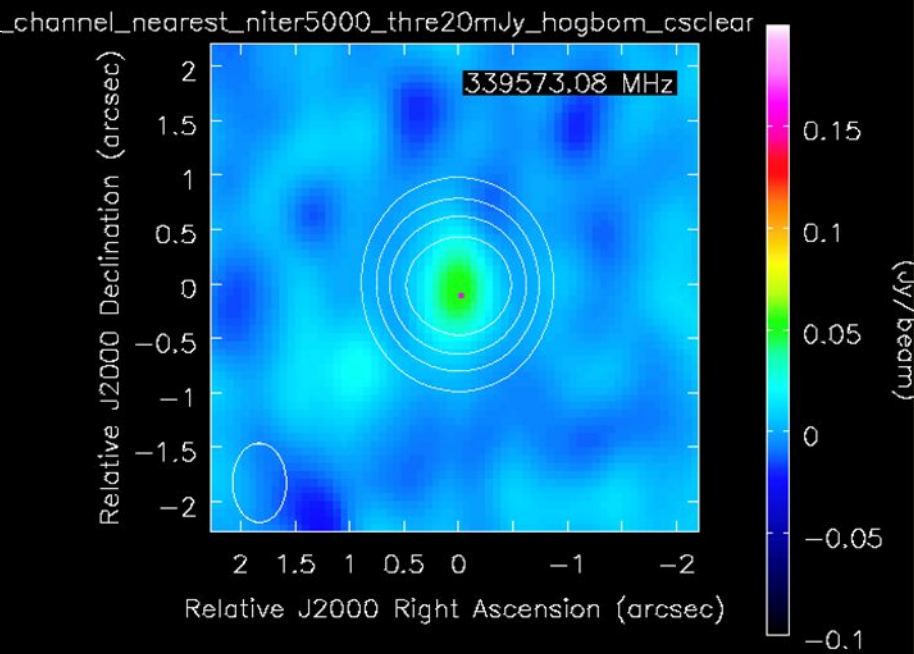


- spectral line s1
- sky frequency: 339470.290 MHz
- rms: 8.8mJy/beam
- S/N: 5.4  $\sigma$

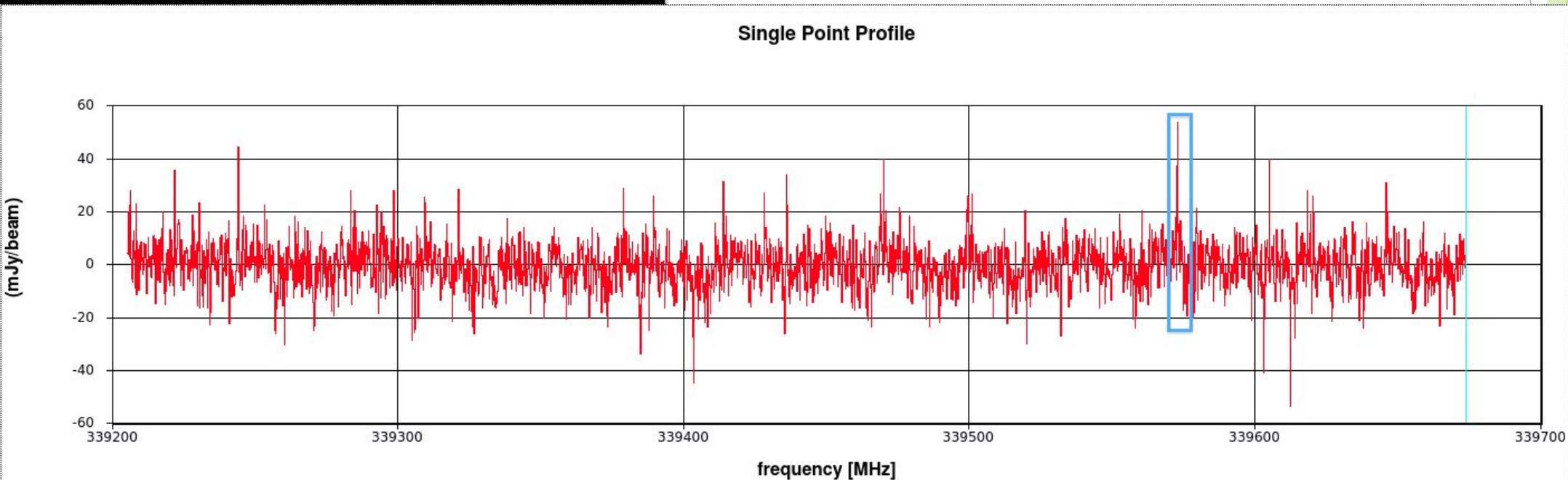




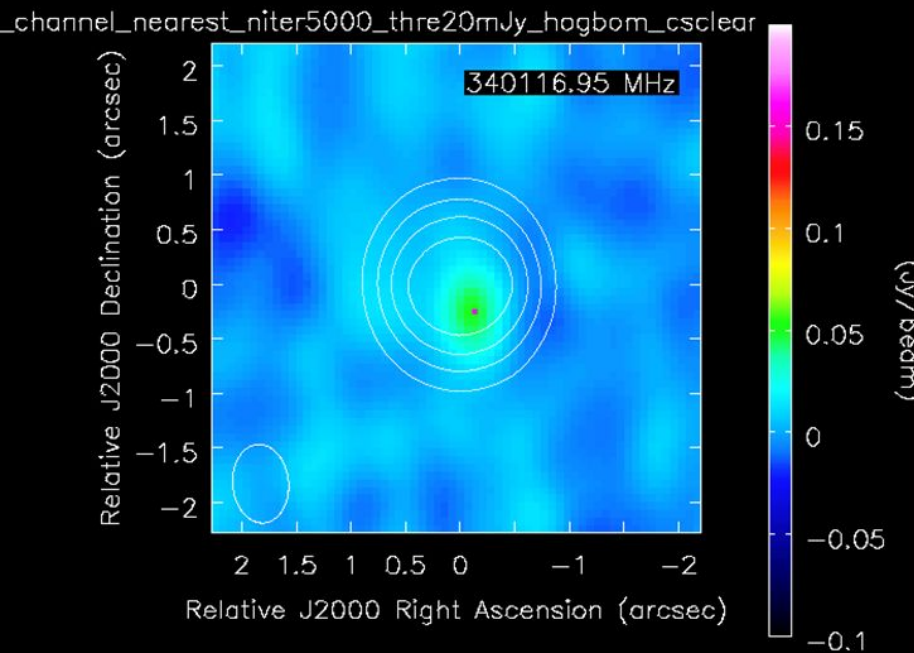
# Observations — Spectrum



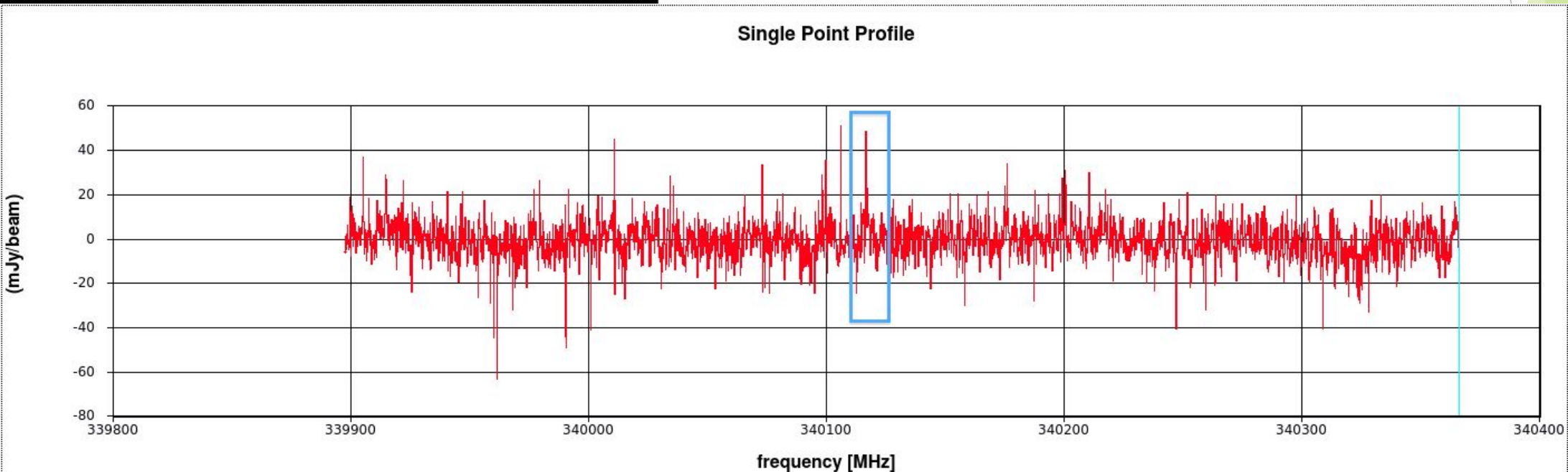
- spectral line s2
- sky frequency: 339573.080 MHz
- rms: 8.8mJy/beam
- S/N: 6.1  $\sigma$



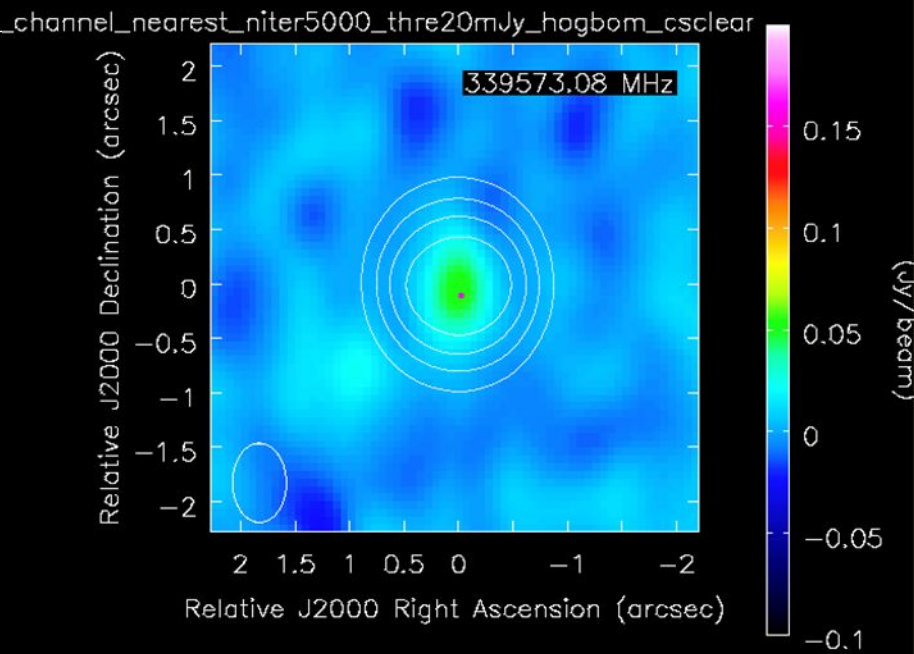
# Observations — Spectrum



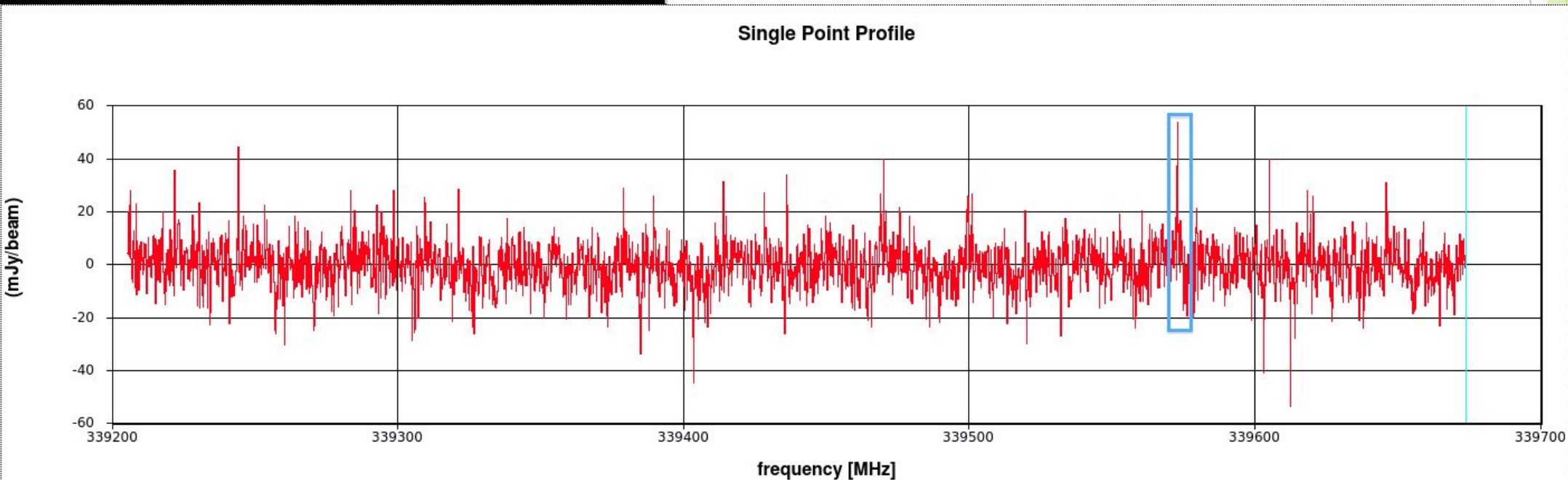
- spectral line s3
- sky frequency: 340116.950 MHz
- rms: 8.9 mJy/beam
- S/N:  $5.6 \sigma$



# Observations — Spectrum



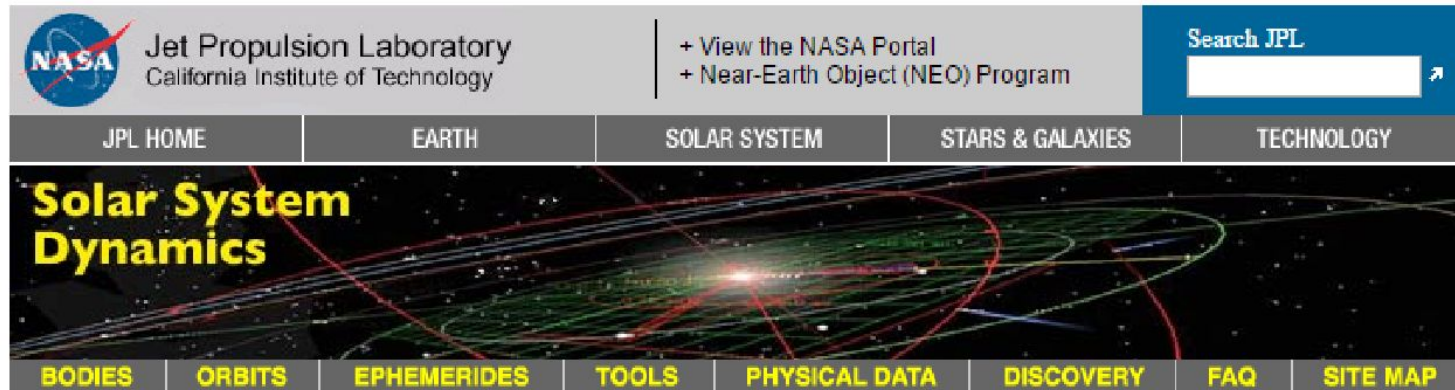
- spectral line s2
- sky frequency: 339573.080 MHz
- rms: 8.8mJy/beam
- S/N: 6.1  $\sigma$





# Observations

- Doppler shift need to be considered.



## HORIZONS Web-Interface

This tool provides a web-based *limited* interface to JPL's [HORIZONS system](#) which can be used to generate ephemerides for solar-system bodies. Full access to [HORIZONS features](#) is available via the primary [telnet interface](#). [HORIZONS system news](#) shows recent changes and improvements. A [web-interface tutorial](#) is available to assist new users.

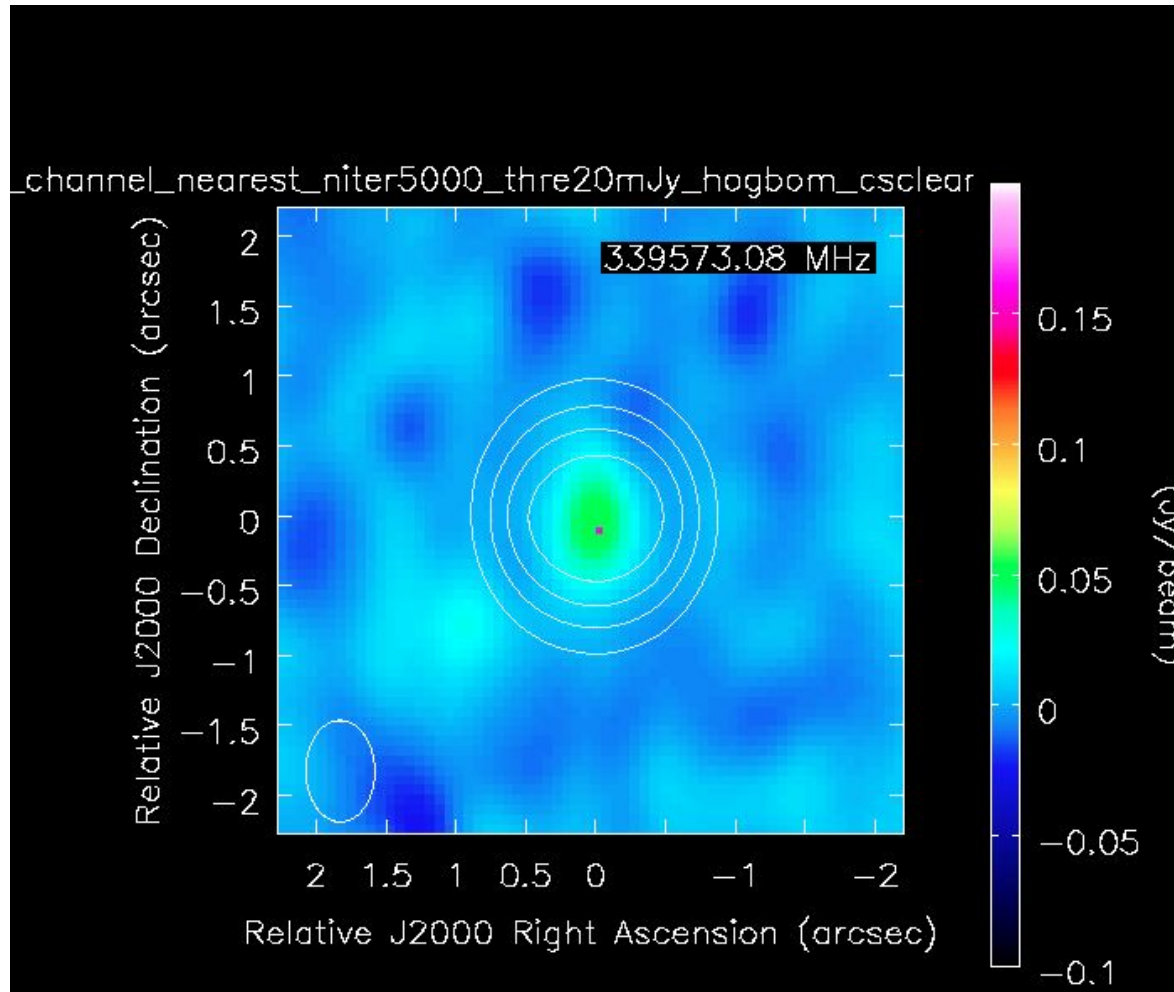
### Current Settings

Ephemeris Type [\[change\]](#) : OBSERVER  
Target Body [\[change\]](#) : Callisto (JIV) [504]  
Observer Location [\[change\]](#) : Atacama Large mm/sub-mm Array (ALMA) Center of Array [-7] ( 292°14'43.1"E, 23°01'45.0"S, 5079.71 m )  
Time Span [\[change\]](#) : Start=2012-10-23, Stop=2012-10-24, Step=1 m  
Table Settings [\[change\]](#) : defaults  
Display/Output [\[change\]](#) : default (formatted HTML)

Date__(UT)__HR:MN	R.A.__(ICRF/J2000.0)_DEC	APmag	S-brt	delta	deldot	S-O-T /r	S-T-O
2012-Oct-23 07:12	04 58 26.11 +21 50 29.1	5.95	6.63	4.28666981991501	-24.9207826	134.3610 /L	8.1285
2012-Oct-23 07:13	04 58 26.09 +21 50 29.1	5.95	6.63	4.28665982534677	-24.9174479	134.3618 /L	8.1284
2012-Oct-23 07:14	04 58 26.07 +21 50 29.0	5.95	6.63	4.28664983211620	-24.9141125	134.3626 /L	8.1283
2012-Oct-23 07:15	04 58 26.05 +21 50 29.0	5.95	6.63	4.28663984022360	-24.9107763	134.3634 /L	8.1282



# Observations



Sky frequency: 339573.080 MHz

Doppler effect:  $\Delta f = f_{\text{sky}} - f_{\text{rest}}$

$$\Delta f = (-v/c) f_{\text{sky}}$$

$f_{\text{sky}}$ : sky frequency

$f_{\text{rest}}$ : rest frequency


$v$ : velocity of the receiver relative to the source

$c$ : speed of light

Rest frequency: 339544.854 MHz

# To identify spectral lines

- To search candidates from Jet Propulsion Laboratory.

**Jet Propulsion Laboratory**  
California Institute of Technology

[+ View the NASA Portal](#)

Search JPL

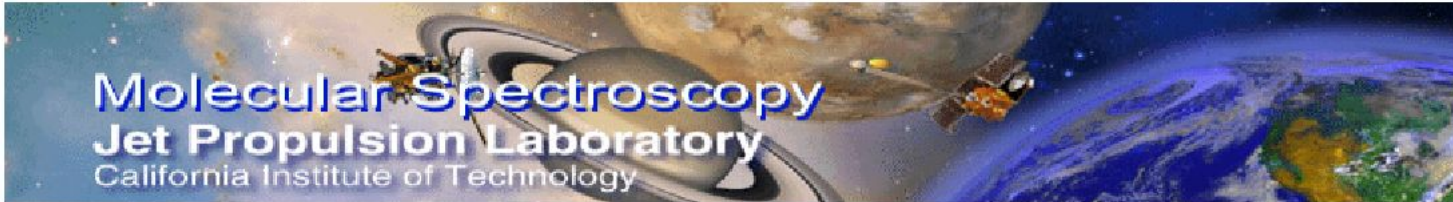
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SOLAR SYSTEM

STARS & GALAXIES

TECHNOLOGY

**Molecular Spectroscopy**  
**Jet Propulsion Laboratory**  
California Institute of Technology

### JPL Catalog Search Form

You need a Browser with Forms Capability to use this.

See [README](#) for output format.

What is the minimum frequency ?

What is the maximum frequency ?

The frequency units can be ☒ GHz or ☐ wavenumbers. If GHz is checked, the format of the output will be in standard catalog form (with MHz units). If wavenumber is checked, the frequency and error fields of the output will be in wavenumbers.

What is the common log of the minimum strength in catalog units ?

What molecules should be included ? (use mouse control click to select multiple values)

All

1001 H-atom

2001 D-atom

3001 HD

4001 H2D+

7001 Li-6-H

Response will be limited to 1000 lines. Press this button to submit the query:

To reset the form, press this button:



# To identify spectral lines

37002 C3H									
339540.3431839.2272	-4.2770	2	27.0947	11	370021325	5	0	1	6 5 6-1 0 6 5
42003 NH2CN									
339544.9830	0.0088	-2.1501	3	341.6674105	42003140417	512	0	16	511 0
339544.9830	0.0088	-2.1501	3	341.6674105	42003140417	513	0	16	512 0
46004 C2H5OH									
339544.0950	0.0500	-4.3164	3	52.3989	17	-460041404	8	7	1 2 8 6 2 2
339544.0950	0.0500	-4.3164	3	52.3989	17	-460041404	8	7	2 2 8 6 3 2
46011 DOCO+									
339534.7258	98.3990	-4.8934	3	1403.6907	35	46011 3031710	7	1610	6
339534.7258	98.3990	-4.8934	3	1403.6907	35	46011 3031710	8	1610	7
52009 CH3Cl-37									
339530.3239	0.0161	-4.5914	3	697.8120	56	52009 213131114		121113	
339531.0431	0.0166	-4.6252	3	697.8119	52	52009 213131113		121112	
339535.2245	0.0183	-4.5577	3	697.8114	60	52009 213131115		121114	
339535.9348	0.0188	-4.6590	3	697.8113	48	52009 213131112		121111	
53001 C2H3CN									
339547.1295	0.9222	-5.3050	3	667.8561	91	53001140544	441	245	44 342 245
339547.1322	0.9222	-5.3245	3	667.8561	87	53001140544	441	243	44 342 243
339547.1632	0.9222	-5.3149	3	667.8560	89	53001140544	441	244	44 342 244
55001 C2H5CN									
339544.3560	0.0500	-3.9303	3	404.4402	99	-55001 30349	842	49	743
57003 HCCCH2OD									
339530.0111999.9999	-5.3183	3	856.5739	77	570031404382810	0	3728	9	0
339530.0111999.9999	-5.3183	3	856.5739	77	570031404382811	0	3728	10	0
339537.3216999.9999	-5.4815	3	911.8266	77	5700314043829	9	1	3729	8
339537.3216999.9999	-5.4815	3	911.8266	77	570031404382910	1	3729	9	1
60003 CH3OCHO									
339548.4026	0.0090	-5.1865	3	484.5465150	600031404371325	3	371226	3	

rest frequency:  
339544.854MHz

- Selection criteria:

1. Integrated intensity can't be too low.
2. Frequencies can't be more or less than rest frequency by 2MHz(0.107km/s/channel).

# To identify spectral lines

- From database to spectral lines



## JPL Catalog Search Form

You need a Browser with Forms Capability to use this.

See [README](#) for output format.

What is the **minimum** frequency ? 339.2

What is the **maximum** frequency ? 339.7

The frequency units can be ☒ GHz or ☐ wavenumbers. If GHz is checked, the format of the output will be in standard catalog form (with MHz units). If wavenumber is checked, the frequency and error fields of the output will be in wavenumbers.

What is the common log of the **minimum** strength in catalog units ? -6

What molecules should be included ? (use mouse control click to select multiple values)

41010 CH3CN v8=1  
41011 K41-atom  
42001 CH3CN-15  
42002 CH2CO  
42003 NH2CN  
42004 CaD

Response will be limited to 1000 lines. Press this button to submit the query:

To reset the form, press this button:

- Frequency range:  
339.206 GHz to 339.674 GHz



# To identify spectral lines

42003 NH2CN

339238.0406	0.0055	-1.7988	3	179.3581105	42003140417	215	1	16	214	1	
339239.4169	0.0104	-2.7304	3	385.0814	35	42003140417	512	1	16	511	1
339239.4169	0.0104	-2.7304	3	385.0814	35	42003140417	513	1	16	512	1
339347.0172	0.0078	-2.0553	3	297.0513105	42003140417	414	1	16	413	1	
339347.0186	0.0078	-2.0553	3	297.0513105	42003140417	413	1	16	412	1	
339376.4504	0.0111	-2.8750	3	451.5164	35	42003140417	611	0	16	610	0
339376.4504	0.0111	-2.8750	3	451.5164	35	42003140417	612	0	16	611	0
339422.7962	0.0064	-2.3787	3	228.4772	35	42003140417	315	1	16	314	1
339423.4774	0.0064	-2.3787	3	228.4773	35	42003140417	314	1	16	313	1
339450.5912	0.0063	-1.7026	3	140.1788105	42003140417	017	1	16	016	1	
339544.9830	0.0088	-2.1501	3	341.6674105	42003140417	512	0	16	511	0	
339544.9830	0.0088	-2.1501	3	341.6674105	42003140417	513	0	16	512	0	
339692.1611	0.0070	-2.4243	3	251.5365	35	42003140417	414	0	16	413	0
339692.1632	0.0070	-2.4243	3	251.5365	35	42003140417	413	0	16	412	0

no signal

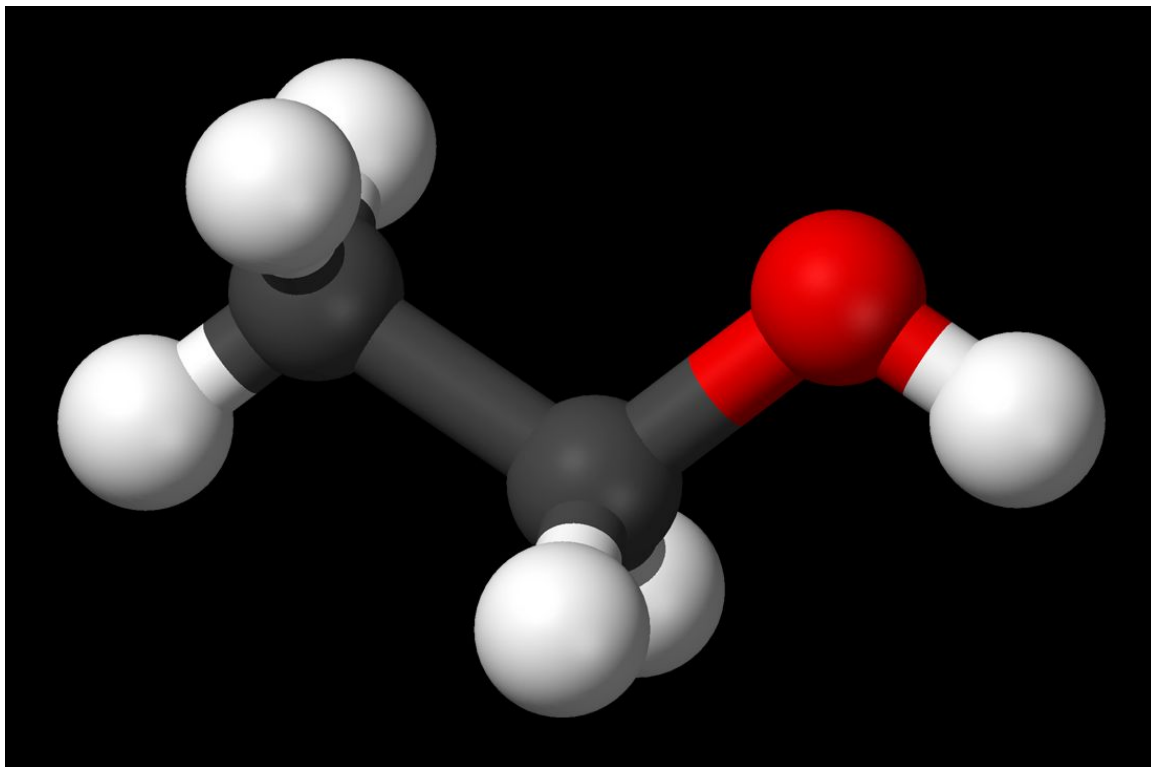
no signal

# Spectral line candidates

- 17 candidates for spw0 (NH<sub>2</sub>CN, C<sub>2</sub>H<sub>5</sub>OH , C<sub>2</sub>H<sub>5</sub>CN, etc.)
- 10 candidates for spw1 (CH<sub>3</sub>OCHO, C<sub>2</sub>H<sub>3</sub>CN, CH<sub>3</sub>CHO, etc.)
- 4 candidates for spw2 (HCOCH<sub>2</sub>OH, HNO<sub>3</sub>, Phenol , HSC)
- 11 candidates for spw3 (HO<sub>3</sub>, HOCl, C<sub>2</sub>H<sub>3</sub>CN, etc.)

# Spectral line candidates

- Ethanol



46004 C2H5OH

339201.6420 0.0500 -3.9171 3 84.5342 27 -46004140413 7 6 2 13 6 7 2  
339201.6420 0.0500 -3.9171 3 84.5342 27 -46004140413 7 7 2 13 6 8 2

339235.7497 0.0109 -3.6160 3 158.4519 41 46004140420 218 1 19 217 1

339282.5580 0.0044 -4.1782 3 111.1897 31 46004140415 412 0 14 312 1

339312.5700 0.0500 -3.9566 3 76.9355 25 -46004140412 7 5 2 12 6 6 2  
339312.5700 0.0500 -3.9566 3 76.9355 25 -46004140412 7 6 2 12 6 7 2

339398.4510 0.0500 -4.0081 3 69.9230 23 -46004140411 7 4 2 11 6 5 2  
339398.4510 0.0500 -4.0081 3 69.9230 23 -46004140411 7 5 2 11 6 6 2

339423.4340 0.0500 -3.5527 3 292.2965 65 -46004140432 131 2 32 032 2

339453.9700 0.0500 -3.9583 3 360.6054 71 -46004140435 233 2 35 134 2

339461.7880 0.0500 -3.6075 3 154.6536 41 -46004140420 219 1 19 218 1

339463.3090 0.0500 -4.0767 3 63.4963 21 -46004140410 7 3 2 10 6 4 2  
339463.3090 0.0500 -4.0767 3 63.4963 21 -46004140410 7 4 2 10 6 5 2

339510.7370 0.0500 -4.1720 3 57.6551 19 -460041404 9 7 2 2 9 6 3 2  
339510.7370 0.0500 -4.1720 3 57.6551 19 -460041404 9 7 3 2 9 6 4 2

339544.0950 0.0500 -4.3164 3 52.3989 17 -460041404 8 7 1 2 8 6 2 2  
339544.0950 0.0500 -4.3164 3 52.3989 17 -460041404 8 7 2 2 8 6 3 2

339566.3210 0.0500 -4.5829 3 47.7274 15 -460041404 7 7 0 2 7 6 1 2  
339566.3210 0.0500 -4.5829 3 47.7274 15 -460041404 7 7 1 2 7 6 2 2

339577.8590 0.0500 -3.8542 3 292.2966 65 -46004140432 231 2 32 132 2

Line E1

Line E2

Line E3

Line E4

Line E5

Line E6

Line E7

Line E8

Line E9

Line E10

Line E11

Line E12

Line E13

● Ethanol



# Summary

- Callisto is an important astronomical object because there may be organic compounds on its surface and Callisto may be habitable.
- We need more data to prove that there is ethanol in exosphere of Callisto.

# Implications

- Exosphere: chemical composition
- Cryovolcanos: a volcano that erupts ice-volcanic melt such as water, methane or ammonia.
- Subsurface oceans: molecules can provide evidence that Callisto have subsurface oceans.

The end