

Are icy worlds in our Solar system habitable?

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Outline:

- 1. Our goal
- 2. Introduction of Callisto
- 3. Observations
- 4. Approaches to find chemical composition
- 5. Results
- 6. Discussions
- 7. Summary



Using ALMA data to study chemical composition of Callisto to discuss whether they are habitable.



lo Europa Ganymede



Introduction (Callisto):



1. Alternative name: Jupiter IV 2. Orbital distance to Jupiter: 1.88×10^{6} km 3. Mean radius: 2410.3 km (0.378 Earths) 4. Mass: 1.076×10^{23} kg (0.018 Earths) 5. Mean density: 1.834 g/cm³ 6. Surface pressure: 7.4019×10^{-12} atm 7. Atmosphere: CO₂ & O₂

Observations:

- Atacama Large Millimetre/Submillimeter Array(ALMA)
- Frequency: 344.760 GHz~347.345 GHz, band 7
- Integration time: 206 seconds
- Callisto was observed as a bandpass calibrator
- Number of antennae: 21

Approaches to identify molecular transitions on the atmosphere of Callisto:

1. From spectral lines to molecular database

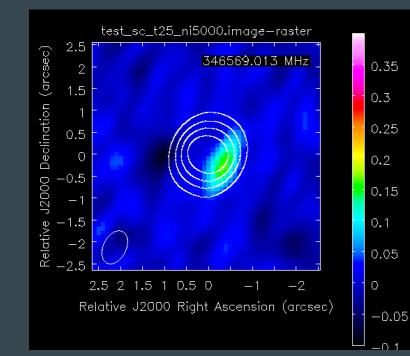
2. From molecular database to spectral lines

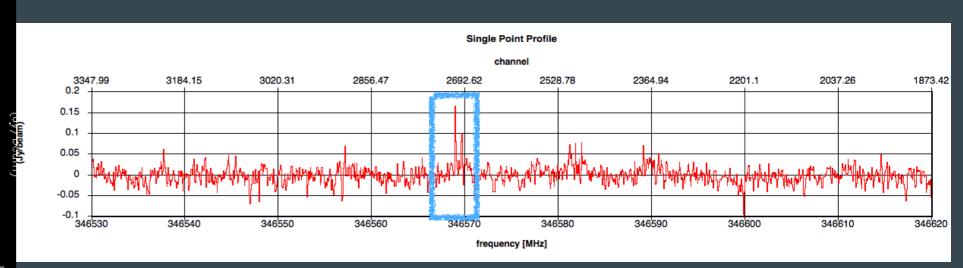
Approaches to identify molecular transitions on the atmosphere of Callisto:

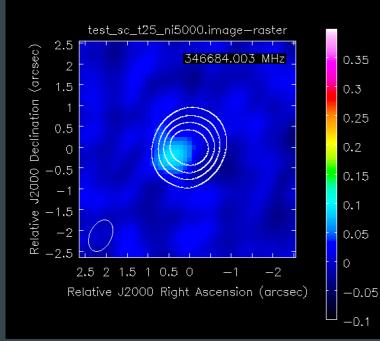
1. From spectral lines to molecular database

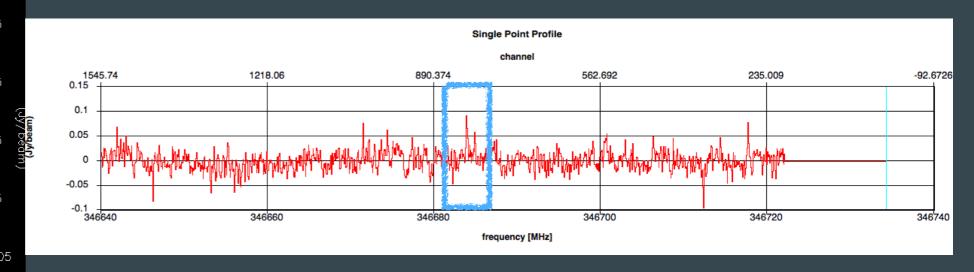
2. From molecular database to spectral lines

there are 22 candidate lines in spw0 (347111~347345 MHz) 19 candidate lines in spw1 (344760~344994 MHz) 16 candidate lines in spw2 (346550~346734 MHz) 21 candidate lines in spw3 (345735~345969 MHz)



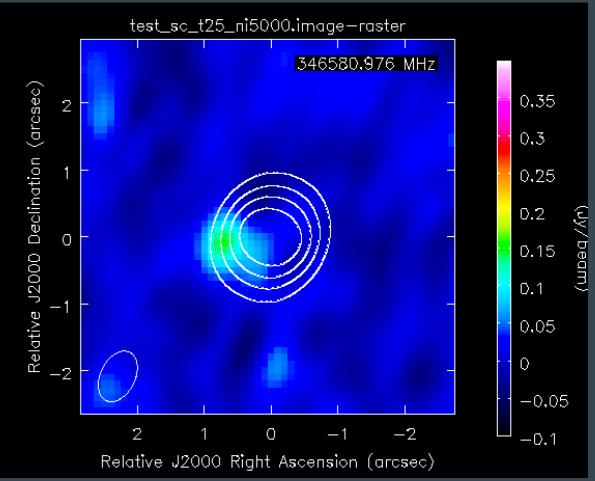


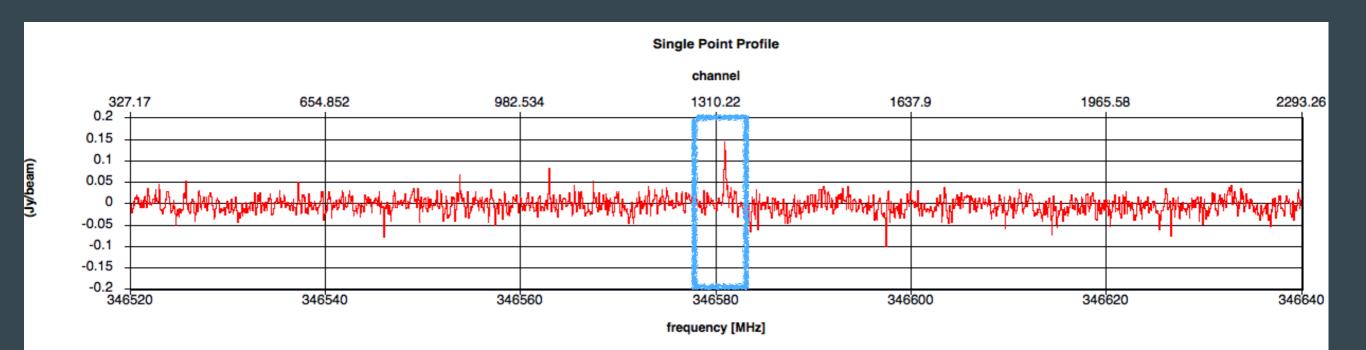




Selection criteria:

- 1. Intensity of the spectral features should be at least 3 sigmas.
- 2. Emission features should occur on Callisto disk.
- 3. There should not be strong noise peaks around Callisto.





However, Doppler shift should be considered...

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Jet Propulsion Laboratory California Institute of Technology

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Ephemeris / WWW_USER Tue Jul 26 02:20:49 2016 Pasadena, USA / Horizons												

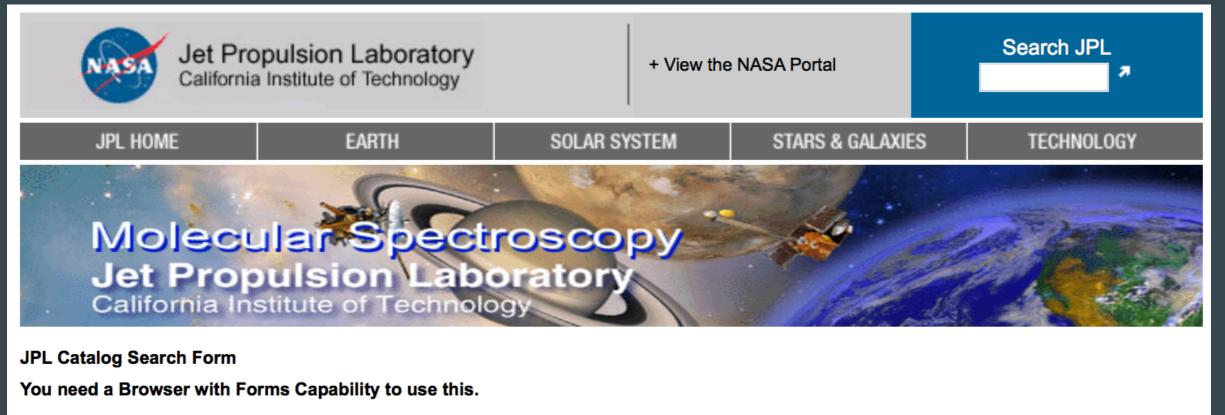
Target body name: Callist	o (504)	{source:	jup310}									
Center body name: Earth (399)	{source:	DE431mx}									
Center-site name: GEOCENT	RIC											
*****	*****	******	********	*******	******	*******	*******	*******	********	*******		
Date_(UT)_HR:MN	r	rdot	delta		S-0-T /r		-		GlxLon	GlxLat		
******	****	*****										
2012-Oct-17 09:33 5	.052722997643 -1	1.1149049 4.37408	152108482 -2	0.9213458 1	.28.3039 /L	8.9096	n.a.	n.a. 1	79.996304 -	-12.615693		

$$\Delta v = v_{sky} - v_{rest} \qquad ----(1)$$
$$\Delta v = \left(-\frac{v}{c}\right) v_{sky} \qquad ---(2)$$

 $\Delta \nu$: shifted frequency V : velocity

for example:

Freq (sky): 346580.976 MHz Freq (rest): 346556.997 MHz



See **README** for output format.

What is the minimum frequency?	346.540

What is the **maximum** frequency? 346.570

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? -500

	All
	1001 H-atom
	2001 D-atom
	3001 HD
	4001 H2D+
What molecules should be included ? (use mouse control click to select multiple values)	7001 Li-6-H

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

To reset the form, press this button: Reset .

take 346580.976 MHz (sky freq) as an example:

	44006 DNCO					
346555.3361	0.0366 -5.0983	3	92.4976 33	44006 30417	01716	16 01616
346556.1689	0.0353 -2.6133	3	92.4975 37	44006 30417	01718	16 01617
346556.1706	0.0353 -2.6389	3	92.4976 35	44006 30417	01717	16 01616
346556.1717	0.0353 -2.6645	3	92.4975 33	44006 30417	01716	16 01615
346556.9570	0.0365 -5.0983	3	92.4975 35	44006 30417	01717	16 01617
	46004 C2H5OH					
346550.6162	0.0147 -7.4278	3	752.7514 95	46004140447	938 1	461037 1
346552.5552	0.0093 -6.7288	3	633.4758 87	46004140443	835 1	43 736 1
	46006 NO2					
346558.0681	0.0143 -6.1981	3	107.4564 30	46006 33514	2121515	15 1151516
	47002 HC-13-00H	I				
346558.4520	0.0500 -2.7909	3	88.5244 31	-47002 30315	213	14 212
	48007 O3-2v2					
346553.5307	0.2497 -7.7715	3	2071.1536 71	48007140435	729 2	36 630 2
	48011 CH3OOH					
346558.4144	7.2242 -5.4326	3	535.6029138	48011140434	1223 1	341124 4
346558.6272	7.2265 -5.4326	3	535.6030138	48011140434	1222 2	341123 5
346558.7624	7.2248 -5.4326	3	535.6029138	48011140434	1223 0	341123 3
346558.7661	7.2248 -5.4326	3	535.6029138	48011140434	1222 0	341124 3
	49005 НОЗ					
346554.3318	0.7462 -5.9359	3	48.1212 25	49005 32511	3 91212	12 0121313
346554.3683	0.7463 -5.9707	3	48.1212 23	49005 32511	3 91211	12 0121312

take 346580.976 MHz (sky freq) as an example:

	44006 DNCO			
346555.3361	0.0366 -5.0983	3	92.4976 33	44006 30417 01716 16 01616
346556.1689	0.0353 -2.6133	3	92.4975 37	44006 30417 01718 16 01617
346556.1706	0.0353 -2.6389	3	92.4976 35	44006 30417 01717 16 01616
346556.1717	0.0353 -2.6645	3	92.4975 33	44006 30417 01716 16 01615
346556.9570	0.0365 -5.0983	3	92.4975 35	44006 30417 01717 16 01617
	46004 C2H5OH			
346550.6162	0.0147 -7.4278	3	752.7514 95	46004140447 938 1 461037 1
346552.5552	0.0093 -6.7288	3	633.4758 87	46004140443 835 1 43 736 1
	46006 NO2			
346558.0681	0.0143 -6.1981	3	107.4564 30	46006 33514 2121515 15 1151516
	47002 HC-13-00H	Η		
346558.4520	0.0500 - 2.7909	3	88.5244	
	48007 O3-2v2			
346553.5307	48007 03-2v2 0.2497 -7.7715	3	2071.1536	rest freq: 346556.997 MHz
346553.5307		3	2071.1536	rest freq: 346556.997 MHz
346553.5307 346558.4144	0.2497 -7.7715		2071.1536 535.60291	rest freq: 346556.997 MHz
	0.2497 -7.7715 48011 CH3OOH	3		rest freq: 346556.997 MHz
346558.4144	0.2497 -7.7715 48011 CH3OOH 7.2242 -5.4326	3 3	535.60291	
346558.4144 346558.6272 346558.7624	0.2497 -7.7715 48011 CH3OOH 7.2242 -5.4326 7.2265 -5.4326 7.2248 -5.4326	3 3 3	535.60291 535.6030138 535.6029138	480111404341222 2 341123 5
346558.4144 346558.6272 346558.7624	0.2497 -7.7715 48011 CH3OOH 7.2242 -5.4326 7.2265 -5.4326 7.2248 -5.4326	3 3 3	535.60291 535.6030138 535.6029138	480111404341222 2 341123 5 480111404341223 0 341123 3
346558.4144 346558.6272 346558.7624 346558.7661	0.2497 -7.7715 48011 CH3OOH 7.2242 -5.4326 7.2265 -5.4326 7.2248 -5.4326 7.2248 -5.4326 7.2248 -5.4326 49005 HO3	3 3 3 3	535.60291 535.6030138 535.6029138 535.6029138	480111404341222 2 341123 5 480111404341223 0 341123 3

Approaches to identify molecular transitions on the atmosphere of Callisto:

1. From spectral lines to molecular database

2. From molecular database to spectral lines

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 ? 344

What is the maximum frequency? 348

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? -500

46002 Si-30-O	
46003 H2CS	
46004 C2H5OH	
46005 HCOOH	
46006 NO2	
46007 N2O-18	

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

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

To reset the form, press this button: Reset .

NO₂ transitions in frequency range 344-348 GHz

345191.9942 0.0591 -6.4889 3 1101.7250102 46006 33550 2485051 49 3474950 345196.8035 0.0590 -6.4972 3 1101.7207100 46006 33550 2485050 49 3474949 345198.5321 0.0587 -6.4954 3 1101.6884102 46006 33550 2485151 49 3475049 345602.4731 0.0588 -6.4777 3 1101.6914104 46006 33550 2485151 49 3475050 345662.4731 0.0123 -7.4613 3 107.4566 46006 33514 2121415 15 1151515 345753.9933 0.0252 -6.5615 3 1101.7700 44006 33548 444484 49 3474948 345774.6000 0.600 -5.0908 3 107.4586 28 -66006 33514 2121415 15 1151515 345753.9933 0.0252 -6.5615 3 1101.7270 6 -46006 33548 444484 49 3474949 345774.6600 0.600 -5.5193 <th></th> <th></th> <th>46006</th> <th>NO2</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>			46006	NO2								
345196.8035 0.0590 -6.4972 3 1101.7277100 46006 33550 2485050 49 3474949 345198.5321 0.0591 -6.5075 3 1101.7300 98 46006 33550 2485049 49 3474948 345597.7244 0.0587 -6.4954 3 1101.6858100 46006 33550 2485151 49 3475049 345602.4731 0.0585 -6.4874 3 1101.6814104 46006 33550 2485151 49 3475050 345611.8231 0.0588 -6.4777 3 107.4586 30 46006 33512 2121415 15 1151515 345662.24721 0.0123 -7.4677 3 107.4586 30 46006 33514 2121415 15 1151515 345662.24721 0.0123 -7.4677 3 107.4586 28 46006 33514 2121414 15 1151515 345771.0100 0.0600 -5.0695 3 107.4586 28 46006 33514 2121414 15 1151515 345753.9933 0.0252 -6.5615 3 1101.7300 94 46006 33514 2121414 15 1151515 345766.3200 0.0600 -5.0990 3 107.4686 28 -46006 33514 2121413 15 1151514 345776.600 0.0600 -6.5612 3 1101.7277 96 -46006 33548 444847 49 3474949 345774.6600 0.0600 -6.5612 3 1101.7250 98 -46006 33514 2121514 15 1151514 346420.5947 0.0198 -7.7046 3 107.4586 28 46006 33514 2121514 15 1151515 346630.925 0.0149 -6.1899 3 107.4586 28 46006 33514 2121514 15 1151515 3466400.925 0.0149 -6.1899 3 107.4586 28 46006 33514 2121515 15 1151515 346630.7300 0.0600 -6.55613 3 1101.6858 96 -46006 33548 444949 49 3475050 346531.7486 0.0263 -6.5329 3 1101.6858 96 -46006 33514 2121515 15 1151515 346650.0300 0.0600 -6.5568 3 1101.6858 96 -46006 33514 2121515 15 1151515 346650.0547 0.0138 -7.5683 3 107.4586 30 46006 33514 2121515 15 1151515 346650.0547 0.0143 -6.1981 3 107.4564 32 46006 33514 2121515 15 1151515 346650.0547 0.0143 -6.2392 3 107.4291 28 46006 33514 2121515 15 1151515 346650.0547 0.0180 -7.6633 3 107.4291 28 46006 33514 2121514 15 1151515 346650.0547 0.0180 -7.6633 3 107.4291 28 46006 33514 2121516 15 1151516 347380.1700 0.0600 -5.0563 3 107.4291 28 46006 33514 2121516 15 1151615 347380.2177 0.0160 -7.04940 3 107.4291 30 46006 33514 2121516 15 1151615 347380.2177 0.0160 -5.0563 3 107.4291 28 46006 33514 2121516 15 1151615 347380.2177 0.0159 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151615 347380.2017 0.0159 -7.4940 3 107.4314 30 -46006 33514 2121515 15 1151616 347809.0826 0		345101 0042			2	1101 7250102	46006	33550	2485051	10	3474950	
$\begin{array}{c} 345198.5321 & 0.0591 - 6.5075 & 3 & 1101.7300 & 98 & 46006 & 33550 & 2485194 & 49 & 3474948 \\ 345597.7244 & 0.0587 & -6.4954 & 3 & 1101.6858100 & 46006 & 33550 & 2485151 & 49 & 3475049 \\ 345602.4731 & 0.0585 & -6.4874 & 3 & 1101.6814102 & 46006 & 33550 & 2485151 & 49 & 3475051 \\ 345611.8231 & 0.0588 & -6.4777 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121415 & 15 & 115515 \\ 345662.4421 & 0.0123 & -7.4677 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121415 & 15 & 115515 \\ 345666.2468 & 0.0170 & -7.4613 & 3 & 107.4605 & 28 & 46006 & 33514 & 2121415 & 15 & 115515 \\ 34573.9933 & 0.0252 & -6.5615 & 3 & 1101.7300 & 94 & 46006 & 33514 & 2121414 & 15 & 115515 \\ 34573.9933 & 0.0252 & -6.5615 & 3 & 1101.7277 & 96 & -46006 & 33548 & 4444847 & 49 & 3474948 \\ 345756.3200 & 0.0600 & -5.5910 & 3 & 107.4605 & 28 & 46006 & 33514 & 212141 & 15 & 115515 \\ 34657.3728 & 0.0198 & -7.7046 & 3 & 107.4605 & 28 & 46006 & 33514 & 2121514 & 15 & 115515 \\ 346460.0925 & 0.0149 & -6.1899 & 3 & 107.4314 & 30 & 46006 & 33514 & 2121514 & 15 & 115515 \\ 346530.7300 & 0.0600 & -6.5568 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 115515 \\ 346510.7300 & 0.0600 & -6.5568 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 115515 \\ 346530.7300 & 0.0600 & -6.5568 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121515 & 15 & 115515 \\ 346530.0547 & 0.0128 & -7.5808 & 3 & 107.4586 & 32 & 46006 & 33514 & 2121515 & 15 & 115515 \\ 346530.0547 & 0.0163 & -6.5302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 115515 \\ 346630.0547 & 0.0163 & -6.5302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 115515 \\ 346630.0547 & 0.0160 & -7.6633 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 115516 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 115516 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 115616 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121516 & 15 & 115616 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121516 & 15 & 1$												
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$\begin{array}{c} 345602.4731 \\ 345602.4731 \\ 0.0585 \\ -6.4874 \\ 3 \\ 1101.6914104 \\ 46006 \\ 33550 \\ 2485152 \\ 49 \\ 3475051 \\ 345642.4721 \\ 0.0123 \\ -7.4677 \\ 3 \\ 107.4586 \\ 30 \\ 46006 \\ 33514 \\ 2121414 \\ 15 \\ 115151 \\ 15 \\ 15 \\ 15 \\ 15 \\$												
$\begin{array}{c} 345611.8231 & 0.0588 & -6.4777 & 3 & 1101.6914104 & 46006 & 33550 & 2485152 & 49 & 3475051 \\ 345642.4721 & 0.0123 & -7.4677 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121415 & 15 & 1151515 \\ 345666.2468 & 0.0170 & -7.4613 & 3 & 107.4605 & 28 & 46006 & 33514 & 2121414 & 15 & 1151514 \\ 345710.0100 & 0.0600 & -5.0698 & 3 & 107.4564 & 30 & -46006 & 33514 & 2121414 & 15 & 1151516 \\ 345721.5500 & 0.0600 & -5.0898 & 3 & 107.4564 & 30 & -46006 & 33514 & 2121414 & 15 & 1151515 \\ 345753.9933 & 0.0252 & -6.5615 & 3 & 1101.7300 & 94 & 46006 & 33548 & 444484 & 49 & 3474948 \\ 345764.8400 & 0.0600 & -5.0900 & 3 & 107.4605 & 26 & -46006 & 33548 & 444484 & 49 & 3474948 \\ 345764.3200 & 0.0600 & -6.5512 & 3 & 1101.7270 & 98 & -46006 & 33548 & 444848 & 49 & 3474949 \\ 345774.6600 & 0.0600 & -6.5612 & 3 & 1101.7270 & 98 & -46006 & 33548 & 444848 & 49 & 3474950 \\ 346357.3728 & 0.0198 & -7.7046 & 3 & 107.4605 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346400.925 & 0.0149 & -6.1899 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346490.5947 & 0.0128 & -7.5808 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346510.7300 & 0.0600 & -6.5563 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346630.05947 & 0.0128 & -7.5808 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346630.0547 & 0.0163 & -6.2302 & 3 & 107.4564 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346630.0547 & 0.0180 & -7.6633 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.2017 & 0.0160 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151616 \\ 347308.2017 & 0.0126 & -7.4940 & 3 & 107.4314 & 30 & -46006 & 33514 & 2121515 & 15 & 1151616 \\ 347308.2017 & 0.0126 & -7.4940 & 3 & 107.4314 & 30 & -46006 & 33514 & 2121515 & 15 & 1151616 \\ 347308.2017 & 0.0159 & -7.4942 & 3 & 107.4314 & 30 & -46006 & 33514 & 2121515 & 15 & 1151616 \\ 347308.2017 & 0.0159 & -7.4942 & 3 & 107.4314 & 30 & 46006 & $												
$\begin{array}{c} 345642.4721 & 0.0123 & -7.4677 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121415 & 15 & 1151515 \\ 345666.2468 & 0.0170 & -7.4613 & 3 & 107.4505 & 28 & 46006 & 33514 & 2121414 & 15 & 1151514 \\ 345710.0100 & 0.0600 & -5.0605 & 3 & 107.4564 & 30 & -46006 & 33514 & 2121415 & 15 & 1151516 \\ 34573.9933 & 0.0252 & -6.5615 & 3 & 1101.7300 & 94 & 46006 & 33514 & 2121414 & 15 & 1151515 \\ 345764.8400 & 0.0600 & -5.0900 & 3 & 107.4605 & 26 & -46006 & 33514 & 2121413 & 15 & 1151514 \\ 345764.8400 & 0.0600 & -6.5591 & 3 & 1101.7277 & 96 & -46006 & 33548 & 4444847 & 49 & 3474949 \\ 345774.6600 & 0.0600 & -6.5591 & 3 & 1101.7277 & 96 & -46006 & 33548 & 444848 & 49 & 3474949 \\ 345774.6600 & 0.0600 & -6.5612 & 3 & 1101.7275 & 98 & -46006 & 33548 & 444848 & 49 & 3474949 \\ 345774.6600 & 0.0600 & -6.5612 & 3 & 1101.7275 & 98 & -46006 & 33514 & 2121514 & 15 & 1151515 \\ 346412.7036 & 0.0151 & -6.2397 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346490.5947 & 0.0128 & -7.7046 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346518.6100 & 0.0600 & -6.5513 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346518.6100 & 0.0600 & -6.5513 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346518.6100 & 0.0600 & -6.5513 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346588.0681 & 0.0143 & -6.1981 & 3 & 107.4564 & 30 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 346606.8089 & 0.0163 & -6.2302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4345 & 32 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.2017 & 0.0150 & -7.4940 & 3 & 107.4314 & 30 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.2017 & 0.0159 & -7.4940 & 3 & 107.4314 & 32 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.2017 & 0.0159 & -7.4940 & 3 & 107.4314 & 32 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.2017 & 0.0159 & -7.4940 & 3 & 107.4314 & 32 & 4$												
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$\begin{array}{c} 345753.9933 & 0.0252 & -6.5615 & 3 & 1101.7300 & 94 & 46006 & 33548 & 444847 & 49 & 3474948 \\ 345754.8400 & 0.0600 & -5.0900 & 3 & 107.4605 & 26 & -46006 & 33514 & 2121413 & 15 & 1151514 \\ 345766.3200 & 0.0600 & -6.5591 & 3 & 1101.7277 & 96 & -46006 & 33548 & 444848 & 49 & 3474949 \\ 345774.6600 & 0.0600 & -6.5612 & 3 & 1101.7250 & 98 & -46006 & 33548 & 444848 & 49 & 3474949 \\ 345774.6600 & 0.0198 & -7.7046 & 3 & 107.4605 & 28 & 46006 & 33514 & 2121514 & 15 & 1151514 \\ 346412.7036 & 0.0151 & -6.2397 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346400.925 & 0.0149 & -6.1899 & 3 & 107.4314 & 30 & 46006 & 33514 & 2121515 & 15 & 1151616 \\ 346490.5947 & 0.0128 & -7.5808 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346510.7300 & 0.0600 & -6.5613 & 3 & 1101.6884 & 98 & -46006 & 33548 & 444949 & 49 & 3475050 \\ 346518.6100 & 0.0600 & -6.5688 & 3 & 1101.6914100 & 46006 & 33548 & 444950 & 49 & 3475051 \\ 346630.0547 & 0.0180 & -7.6633 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 346630.0547 & 0.0180 & -7.6633 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4345 & 32 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.2017 & 0.0159 & -7.4940 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347809.0826 & 0.0163 & -6.1647 & 3 & 252.3891 & 48 & 46006 & 33514 & 212354 & 24 & 0242424 \\ \end{array}$												
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$\begin{array}{c} 346412.7036 & 0.0151 - 6.2397 & 3 & 107.4586 & 28 & 46006 & 33514 & 2121514 & 15 & 1151515 \\ 346460.0925 & 0.0149 - 6.1899 & 3 & 107.4314 & 30 & 46006 & 33514 & 2121415 & 15 & 1151616 \\ 346490.5947 & 0.0128 - 7.5808 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346510.7300 & 0.0600 - 6.5613 & 3 & 1101.6884 & 98 & -46006 & 33548 & 444949 & 49 & 3475050 \\ 346518.6100 & 0.0600 & -6.5568 & 3 & 1101.6858 & 96 & -46006 & 33548 & 444948 & 49 & 3475051 \\ 346531.7486 & 0.0263 & -6.5329 & 3 & 1101.6914100 & 46006 & 33548 & 444950 & 49 & 3475051 \\ 346558.0681 & 0.0143 & -6.1981 & 3 & 107.4564 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346606.8089 & 0.0163 & -6.2302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 346630.0547 & 0.0180 & -7.6633 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4345 & 32 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347297.9100 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0633 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347380.2017 & 0.0126 & -7.4940 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347809.0826 & 0.0163 & -6.1647 & 3 & 252.3891 & 48 & 46006 & 33524 & 1232524 & 24 & 0242424 \end{array}$		345774.6600	0.0600	-6.5612	3	1101.7250 98	-46006	33548	4444849		the second s	
$\begin{array}{c} 346460.0925 & 0.0149 & -6.1899 & 3 & 107.4314 & 30 & 46006 & 33514 & 2121415 & 15 & 1151616 \\ 346490.5947 & 0.0128 & -7.5808 & 3 & 107.4586 & 30 & 46006 & 33514 & 2121515 & 15 & 1151515 \\ 346510.7300 & 0.0600 & -6.5613 & 3 & 1101.6884 & 98 & -46006 & 33548 & 444949 & 49 & 3475050 \\ 346518.6100 & 0.0600 & -6.5568 & 3 & 1101.6858 & 96 & -46006 & 33548 & 444948 & 49 & 3475049 \\ 346531.7486 & 0.0263 & -6.5329 & 3 & 1101.6914100 & 46006 & 33548 & 444950 & 49 & 3475051 \\ 346558.0681 & 0.0143 & -6.1981 & 3 & 107.4564 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346606.8089 & 0.0163 & -6.2302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 346630.0547 & 0.0180 & -7.6633 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347380.2017 & 0.0126 & -7.4940 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347809.0826 & 0.0163 & -6.1647 & 3 & 252.3891 & 48 & 46006 & 33524 & 1232524 & 24 & 0242424 \end{array}$		346357.3728	0.0198	-7.7046	3	107.4605 28	46006	33514	2121514	15	1151514	
$\begin{array}{c} 346490.5947 0.0128 -7.5808 3 107.4586 30 46006 33514 2121515 15 1151515 \\ 346510.7300 0.0600 -6.5613 3 1101.6884 98 -46006 33548 444949 49 3475050 \\ 346518.6100 0.0600 -6.5568 3 1101.6858 96 -46006 33548 444948 49 3475049 \\ 346531.7486 0.0263 -6.5329 3 1101.6914100 46006 33514 2121515 15 1151516 \\ 346558.0681 0.0143 -6.1981 3 107.4564 30 46006 33514 2121515 15 1151615 \\ 346630.0547 0.0180 -7.6633 3 107.4291 28 46006 33514 2121516 15 1151615 \\ 347287.5200 0.0600 -4.9976 3 107.4291 28 -46006 33514 2121516 15 1151615 \\ 347308.1700 0.0600 -5.0563 3 107.4291 28 -46006 33514 2121515 15 1151615 \\ 347308.1700 0.0600 -5.0563 3 107.4291 28 -46006 33514 2121515 15 1151615 \\ 347308.1700 0.0600 -5.0563 3 107.4291 28 -46006 33514 2121515 15 1151615 \\ 347380.2017 0.0126 -7.4940 3 107.4314 30 -46006 33514 2121515 15 1151615 \\ 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424 \end{array}$		346412.7036	0.0151	-6.2397	3	107.4586 28	46006	33514	2121514	15	1151515	
$\begin{array}{c} 346510.7300 & 0.0600 & -6.5613 & 3 & 1101.6884 & 98 & -46006 & 33548 & 444949 & 49 & 3475050 \\ 346518.6100 & 0.0600 & -6.5568 & 3 & 1101.6858 & 96 & -46006 & 33548 & 444948 & 49 & 3475051 \\ 346531.7486 & 0.0263 & -6.5329 & 3 & 1101.6914100 & 46006 & 33548 & 444950 & 49 & 3475051 \\ 346558.0681 & 0.0143 & -6.1981 & 3 & 107.4564 & 30 & 46006 & 33514 & 2121515 & 15 & 1151516 \\ 346606.8089 & 0.0163 & -6.2302 & 3 & 107.4291 & 28 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 346630.0547 & 0.0180 & -7.6633 & 3 & 107.4564 & 32 & 46006 & 33514 & 2121516 & 15 & 1151615 \\ 347287.5200 & 0.0600 & -4.9976 & 3 & 107.4345 & 32 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347297.9100 & 0.0600 & -5.0836 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121516 & 15 & 1151615 \\ 347308.1700 & 0.0600 & -5.0563 & 3 & 107.4291 & 28 & -46006 & 33514 & 2121515 & 15 & 1151615 \\ 347380.2017 & 0.0126 & -7.4940 & 3 & 107.4291 & 30 & 46006 & 33514 & 2121515 & 15 & 1151615 \\ 347809.0826 & 0.0163 & -6.1647 & 3 & 252.3891 & 48 & 46006 & 33524 & 1232524 & 24 & 0242424 \end{array}$		346460.0925	0.0149	-6.1899	3	107.4314 30	46006	33514	2121415	15	1151616	
$\begin{array}{c} 346518.6100 \\ 346531.7486 \\ 0.0263 \\ -6.5329 \\ 3 \\ 101.6914100 \\ 46006 \\ 33548 \\ 4444948 \\ 49 \\ 3475051 \\ 346558.0681 \\ 0.0143 \\ -6.1981 \\ 3 \\ 107.4564 \\ 30 \\ 46006 \\ 33514 \\ 2121515 \\ 15 \\ 1151516 \\ 15 \\ 1151516 \\ 15 \\ 1151615 \\ 346630.0547 \\ 0.0180 \\ -7.6633 \\ 3 \\ 107.4291 \\ 28 \\ 46006 \\ 33514 \\ 2121516 \\ 15 \\ 1151617 \\ 347297.9100 \\ 0.0600 \\ -5.0836 \\ 3 \\ 107.4291 \\ 28 \\ -46006 \\ 33514 \\ 2121516 \\ 15 \\ 1151617 \\ 15 \\ 1151615 \\ 347308.1700 \\ 0.0600 \\ -5.0563 \\ 3 \\ 107.4291 \\ 28 \\ -46006 \\ 33514 \\ 2121516 \\ 15 \\ 1151615 \\ 15 \\ 1151615 \\ 347308.1700 \\ 0.0600 \\ -5.0563 \\ 3 \\ 107.4291 \\ 30 \\ 46006 \\ 33514 \\ 2121515 \\ 15 \\ 1151615 \\ 347308.2017 \\ 0.0159 \\ -7.4940 \\ 3 \\ 107.4314 \\ 32 \\ 46006 \\ 33514 \\ 2121515 \\ 15 \\ 1151615 \\ 347809.0826 \\ 0.0163 \\ -6.1647 \\ 3 \\ 252.3891 \\ 48 \\ 46006 \\ 33524 \\ 1232524 \\ 24 \\ 0242424 \end{array}$		346490.5947	0.0128	-7.5808	3	107.4586 30	46006	33514	2121515	15	1151515	5345
$\begin{array}{c} 346531.7486 \\ 346558.0681 \\ 0.0263 \\ -6.5329 \\ 3 \\ 107.4564 \\ 30 \\ 46006 \\ 33514 \\ 2121515 \\ 15 \\ 1151516 \\ 15 \\ 1151516 \\ 15 \\ 1151615 \\ 15 \\ $		346510.7300	0.0600	-6.5613	3	1101.6884 98	-46006	33548	4444949	49	3475050	
346558.0681 0.0143 -6.1981 3 107.4564 30 46006 33514 2121515 15 1151516 346606.8089 0.0163 -6.2302 3 107.4291 28 46006 33514 2121414 15 1151615 346630.0547 0.0180 -7.6633 3 107.4564 32 46006 33514 2121516 15 1151516 347287.5200 0.0600 -4.9976 3 107.4345 32 -46006 33514 2121516 15 1151617 15 1151617 347297.9100 0.0600 -5.0836 3 107.4291 28 -46006 33514 2121514 15 1151615 15 1151615 347308.1700 0.0600 -5.0563 3 107.4291 28 -46006 33514 2121515 15 1151616 SPWO 347375.8261 0.0126 -7.4940 3 107.4314 30 -46006 33514 2121515 15 1151615 SPWO 347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 SPWO 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424 SPWO		346518.6100	0.0600	-6.5568	3	1101.6858 96	-46006	33548	4444948	49	3475049	
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$		346531.7486	0.0263	-6.5329	3	1101.6914100	46006	33548	4444950	49	3475051	0000
346630.0547 0.0180 -7.6633 3 107.4564 32 46006 33514 2121516 15 1151516 347287.5200 0.0600 -4.9976 3 107.4345 32 -46006 33514 2121516 15 1151617 347297.9100 0.0600 -5.0836 3 107.4291 28 -46006 33514 2121514 15 1151615 347308.1700 0.0600 -5.0563 3 107.4314 30 -46006 33514 2121515 15 1151615 347375.8261 0.0126 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151616 347380.2017 0.0159 -7.4942 107.4314 32 46006 33514 2121516 15 1151615 347809.0826 0.0163 -6.1647 252.3891 48 46006 33524 1232524 24 0242424		346558.0681	0.0143	-6.1981	3	107.4564 30	46006	33514	2121515	15	1151516	5000
347287.5200 0.0600 -4.9976 3 107.4345 32 -46006 33514 2121516 15 1151617 347297.9100 0.0600 -5.0836 3 107.4291 28 -46006 33514 2121514 15 1151615 347308.1700 0.0600 -5.0563 3 107.4314 30 -46006 33514 2121515 15 1151616 347375.8261 0.0126 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151615 347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424		346606.8089	0.0163	-6.2302	3	107.4291 28	46006	33514	2121414	15	1151615	
347297.9100 0.0600 -5.0836 3 107.4291 28 -46006 33514 2121514 15 1151615 347308.1700 0.0600 -5.0563 3 107.4314 30 -46006 33514 2121515 15 1151616 347375.8261 0.0126 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151615 347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424		346630.0547	0.0180	-7.6633	3	107.4564 32	46006	33514	2121516	15	1151516	
347308.1700 0.0600 -5.0563 3 107.4314 30 -46006 33514 2121515 15 1151616 347375.8261 0.0126 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151615 347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424		347287.5200	0.0600	-4.9976	3	107.4345 32	-46006	33514	2121516	15	1151617	
347308.1700 0.0600 -5.0563 3 107.4314 30 -46006 33514 2121515 15 1151616 347375.8261 0.0126 -7.4940 3 107.4291 30 46006 33514 2121515 15 1151615 347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424		347297.9100	0.0600	-5.0836	3	107.4291 28	-46006	33514	2121514	15	1151615	snw()
347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424		347308.1700	0.0600	-5-0563	3	107.4314 30	-46006	33514	2121515	15	1151616	J OPWO
347380.2017 0.0159 -7.4942 3 107.4314 32 46006 33514 2121516 15 1151616 347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424	710	Sin have been a second and a second and a second	and her and the second	-7.4940	3	107.4291 30	46006	33514	2121515	- Second	to be a second and the second second	
347809.0826 0.0163 -6.1647 3 252.3891 48 46006 33524 1232524 24 0242424			0.0159	-7.4942	3							
		347956.2481										

NO₂ transitions in frequency range 344-348 GHz

46006 NO2

*If NO₂ exist, a transition line is expected to be found at 347287MHz.

						and a second		and the second		a second a s	<i>4</i> .
	345753.9933	0.0252 -6.5615	3	1101.7300	94	46006 3	33548	4444847	49	3474948	
	345754.8400	0.0600 -5.0900	3	107.4605	26	-46006 3	33514	2121413	15	1151514	
	345766.3200	0.0600 -6.5591	3	1101.7277	96	-46006 3	33548	4444848	49	3474949	S
,	345774.6600	0.0600 -6.5612	3	1101.7250	98	-46006 3	33548	4444849	49	3474950	

spw3

AAND AND TO BE AN ADD AND A STORE OF A REAL ADD AND A DOLLARS.	A Constitution of a stand standing of the stand of the stand of the stand standing of the stan				
346510.7300	0.0600 -6.5613	3 1101.6884 98	3 -46006 33548	3 4444949 49	9 3475050
346518.6100	0.0600 -6.5568	3 1101.6858 96	5 -46006 33548	3 4444948 49	9 3475049
346531.7486	0.0263 -6.5329	3 1101.6914100	0 46006 33548	3 4444950 49	9 3475051
346558.0681	0.0143 -6.1981	3 107.4564 30	0 46006 33514	2121515 1	5 1151516
346606.8089	0.0163 -6.2302	3 107.4291 28	3 46006 33514	2121414 1	5 1151615
346630.0547	0.0180 -7.6633	3 107.4564 32	2 46006 33514	2121516 1	5 1151516
347287.5200	0.0600 -4.9976	3 107.4345 32	2 -46006 33514	2121516 1	5 1151617
347297.9100	0.0600 -5.0836	3 107.4291 28	3 -46006 33514	2121514 1	5 1151615
347308.1700	0.0600 -5.0563	3 107.4314 30	0 -46006 33514	2121515 1	5 1151616

Results: We identified 1 molecules

SO₂(Sulfur dioxide)

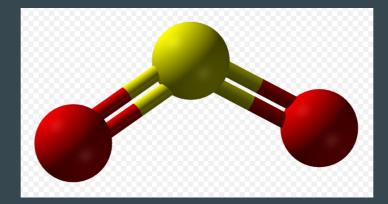


image comes from signaturewinelab

SO₂ transitions in frequency range 344-348 GHz

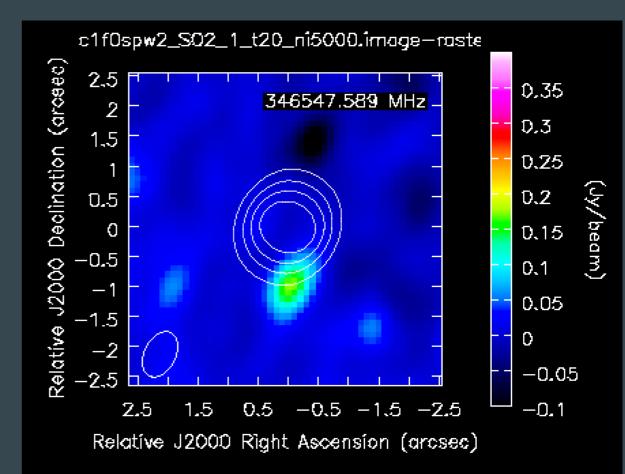
SO2, v=0					
345148.9708	0.0013	-3.9629 3	40.7151 11	64502 303 5 5 1	642
345338.5377	0.0015	-2.2398 3	53.1080 27	64502 30313 212	12 111
345338.7778	0.0028	-8.7297 3	1669.2234125	64502 303621646	631549
345448.9841	0.0017	-3.6806 3	350.5898 53	64502 30326 917	27 820
346523.8784	0.0013	-2.2075 3	102.7498 33	64502 30316 412	16 313 ST
346652.1691	0.0014	-1.9584 3	105.2994 39	64502 30319 119	18 018 S2
346910.9115	0.0049	-9.7834 3	1931.8670135	64502 303671751	681652
347829.2342	0.0038	-6.6123 3	1111.9644115	64502 30357 652	56 749

spw2

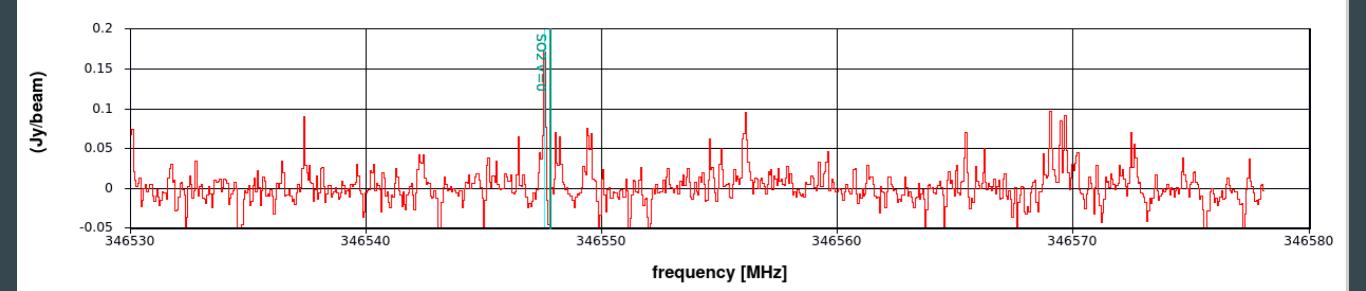
SO₂ line s1

sky:346547.589 MHz rest:346523.6121 MHz amp:173mJy/beam

SO2, v=0					
345148.9708	0.0013	-3.9629 3	40.7151 11	64502 303 5 5 1	642
345338.5377	0.0015	-2.2398 3	53.1080 27	64502 30313 212	12 111
345338.7778	0.0028	-8.7297 3	1669.2234125	64502 303621646	631549
345448 9841	0 0017	-3 6806.3	350 5898 53	64502 30326 917	27 820
346523.8784	0.0013	-2.2075 3	102.7498 33	64502 30316 412	16 313
346652.1691	0.0014			64502 30319 119	18 018
01091039110					001052
347829.2342	0.0038	-6.6123 3	1111.9644115	64502 30357 652	56 749



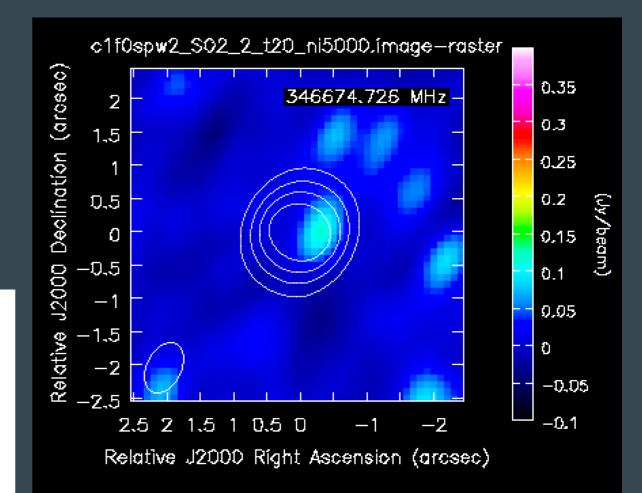
Single Point Profile



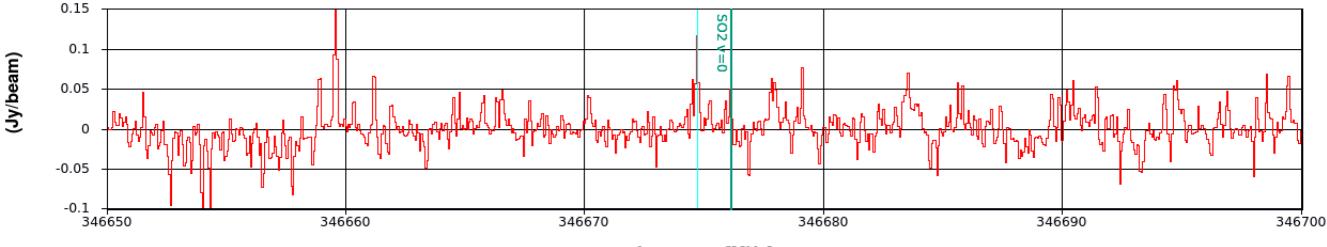
SO_2 line s2

sky:346674.726 MHz rest:346650.7403 MHz amp:118mJy/beam

SO2, v=0					
345148.9708	0.0013	-3.9629 3	40.7151 11	64502 303 5 5 1	642
345338.5377	0.0015	-2.2398 3	53.1080 27	64502 30313 212	12 111
345338.7778	0.0028	-8.7297 3	1669.2234125	64502 303621646	631549
345448 9841	0 0017	-3 6806 3	350 5898 53	64502 30326 917	27 820
346523.8784	0.0013	-2.2075 3	102.7498 33	64502 30316 412	16 313
346652.1691	0.0014	-1.9584 3	105.2994 39	64502 30319 119	18 018
510/10(5115	010015			04002-000011-01	001002
347829.2342	0.0038	-6.6123 3	1111.9644115	64502 30357 652	56 749



Single Point Profile

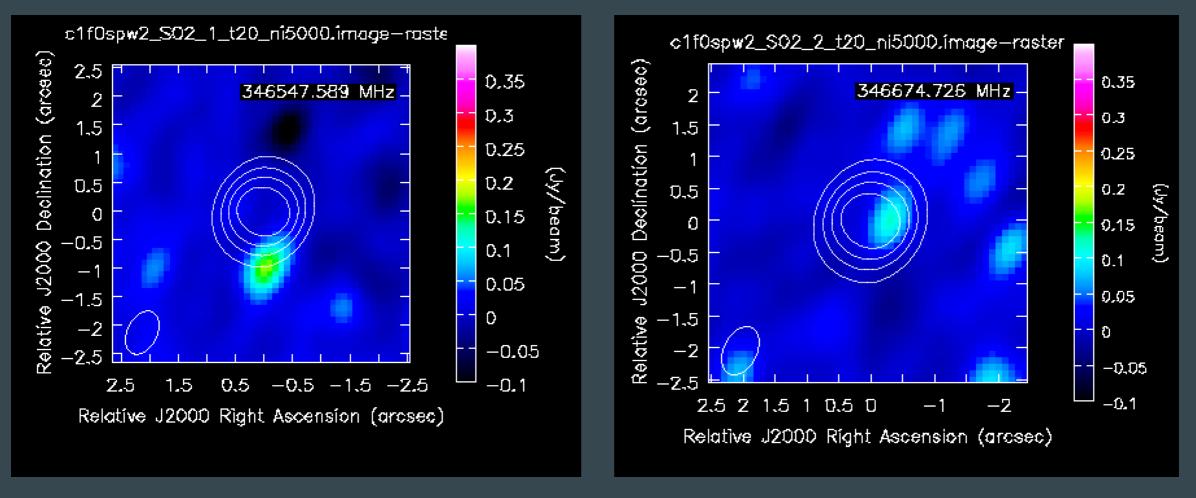


frequency [MHz]

Discussions:

We have identified the transition line of SO₂, however, there are still some questions need to be answered.

1. In the case of SO₂, peaks don't show at same place on Callisto.

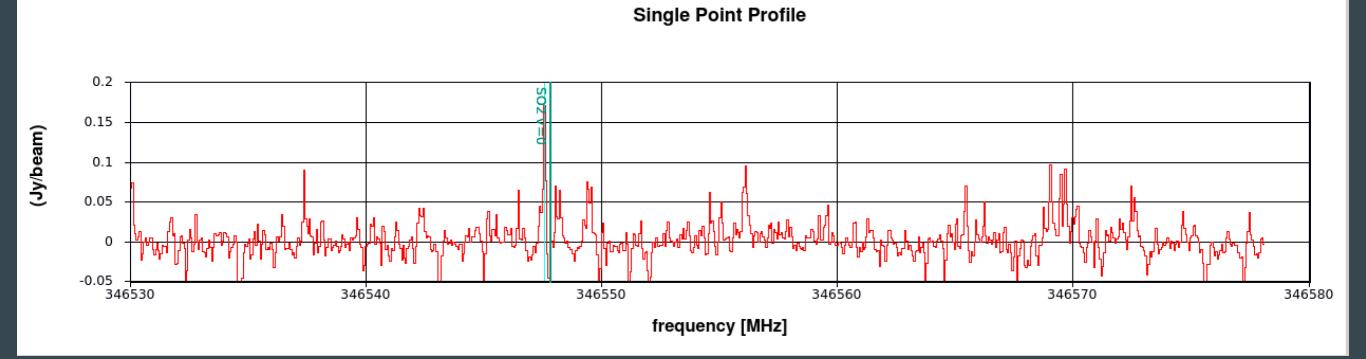


SO₂ line s1

SO₂ line s2

2. Observed frequency doesn't match the lab frequency precisely

Take SO₂ line s1 for example:



SO₂ line s1

Summary

1. High spectral and spatial resolution of ALMA helps us getting more information about Callisto.

2. We have found SO₂ on Callisto, however we still need more datas to prove it.

3. Finding SO₂ may help us know more about Callisto, especially for astrobiology.

The end