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

Our goal :

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

image comes from wiki

Io Europa Ganymede **Callisto**

Introduction (Callisto):

image comes from wiki

1. Alternative name: Jupiter IV
2. Orbital distance to Jupiter: 1.88 x 10^6 km
3. Mean radius: 2410.3 km (0.378 Earths)
4. Mass: 1.076 x 10^{23} kg (0.018 Earths)
5. Mean density: 1.834 g/cm^3
6. Surface pressure: 7.4019×10^{-12} atm
7. Atmosphere: CO_2 & O_2

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:

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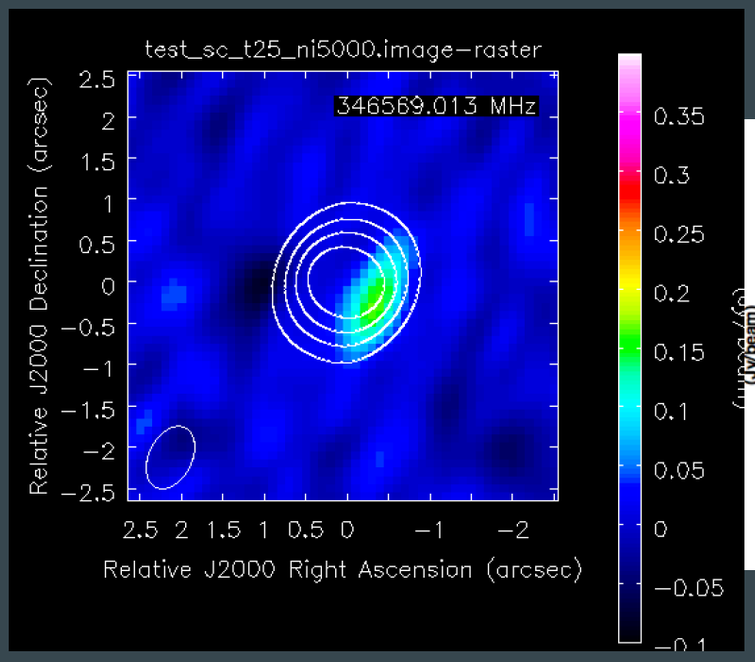
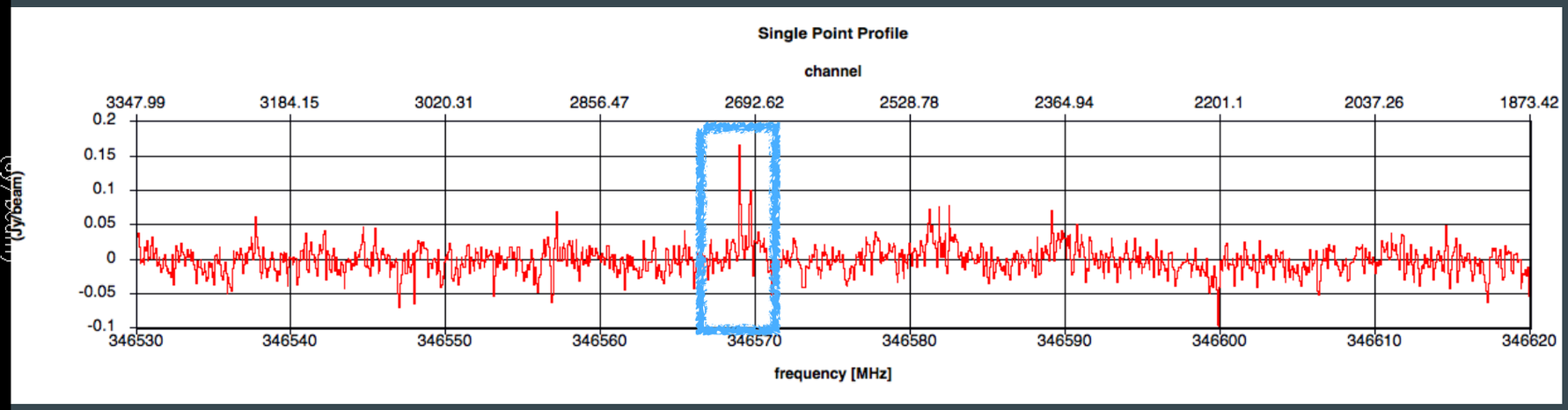
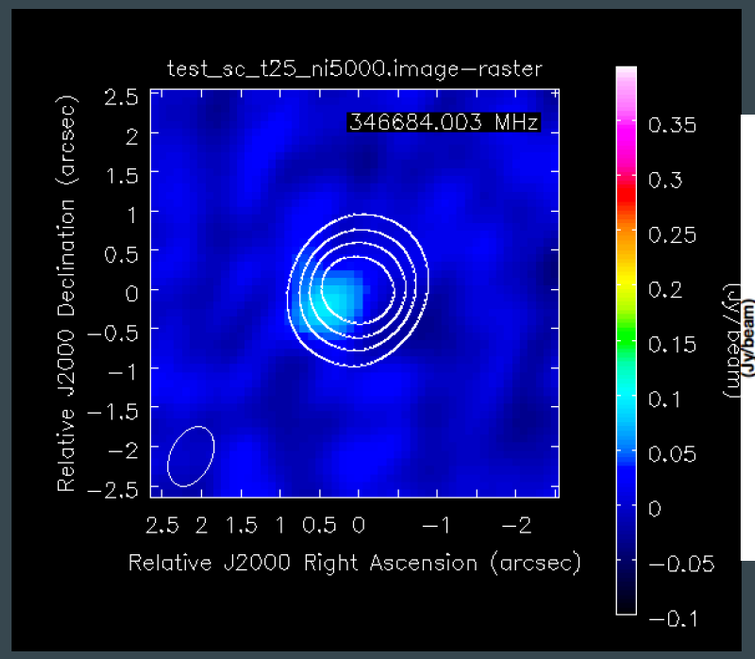
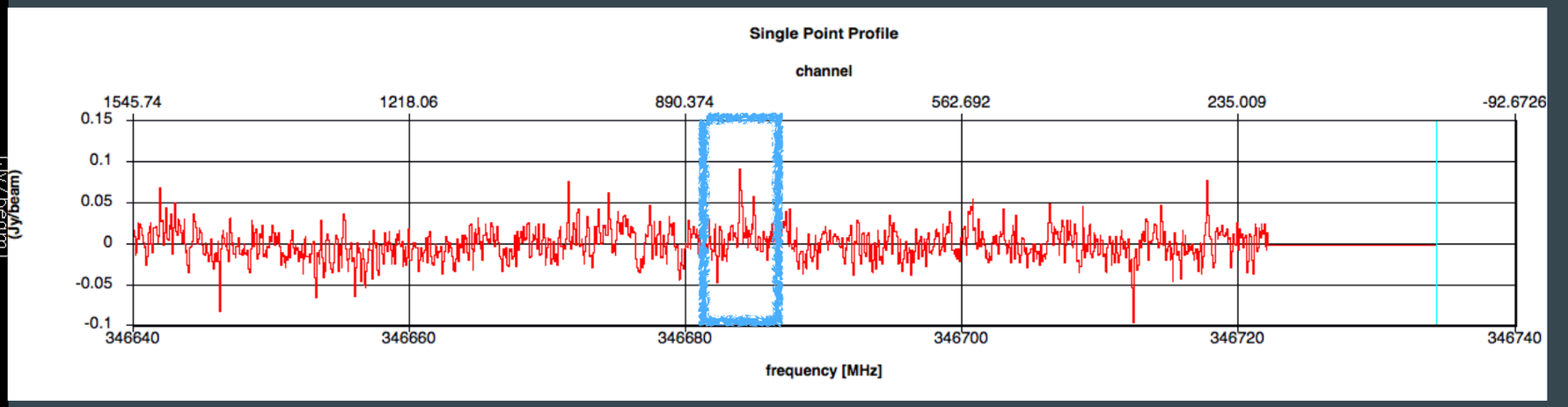
there are 22 candidate lines in spw0 (347111~347345 MHz)
19 candidate lines in spw1 (344760~344994 MHz)
16 candidate lines in spw2 (346550~346734 MHz)
21 candidate lines in spw3 (345735~345969 MHz)



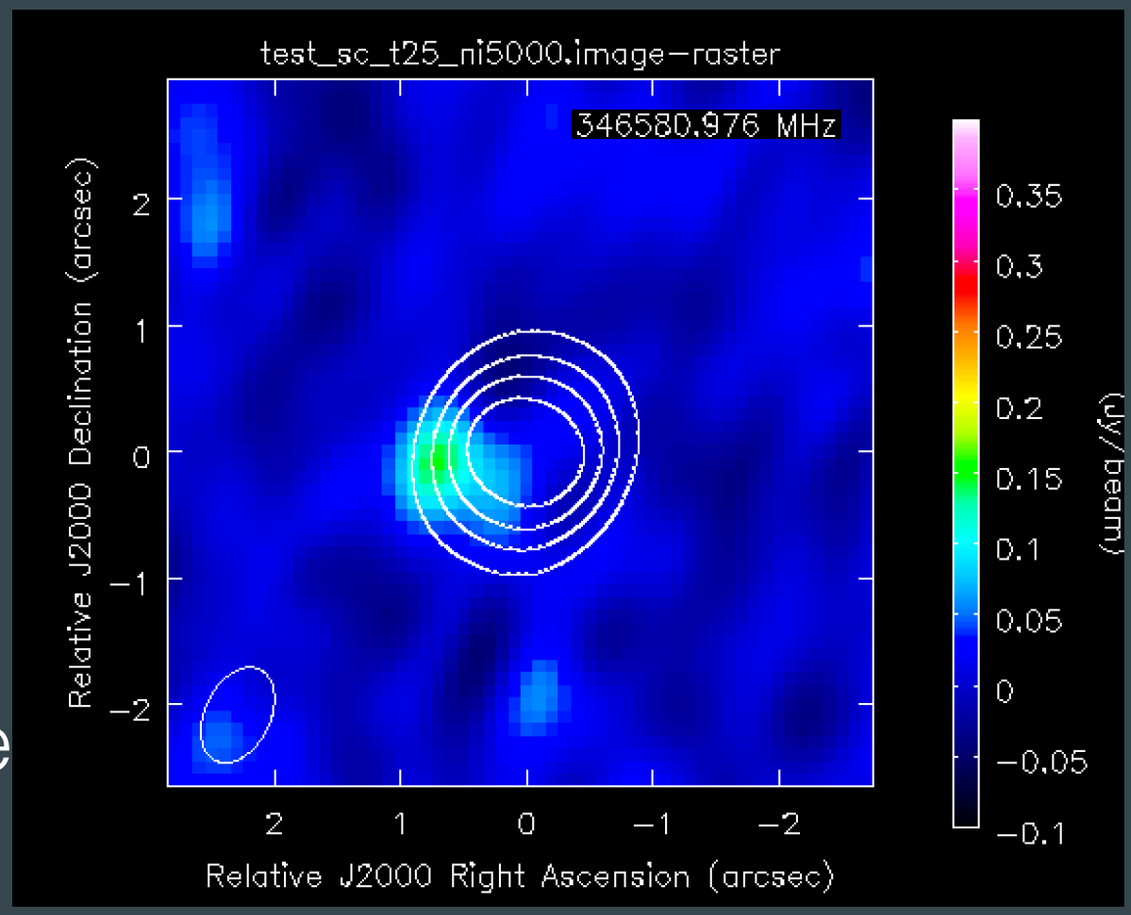


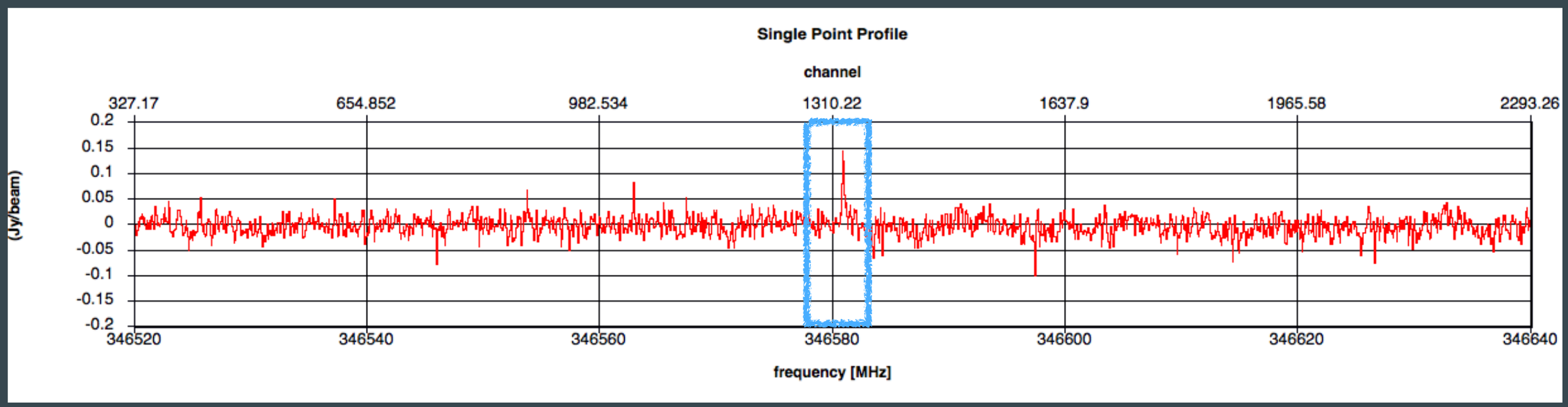




Selection criteria:

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…

Jet Propulsion Laboratory
California Institute of Technology

```
**************************************************************************
Ephemeris / WWW_USER Tue Jul 26 02:20:49 2016 Pasadena, USA      / Horizons
**************************************************************************
Target body name: Callisto (504)                  {source: jup310}
Center body name: Earth (399)                     {source: DE431mx}
Center-site name: GEOCENTRIC
*******************************************************************************************************************************
 Date__(UT)__HR:MN                    r        rdot             delta      deldot     S-O-T /r    S-T-O   PsAng    PsAMV     GlxLon      GlxLat
*******************************************************************************************************************************
 2012-Oct-17 09:33      5.052722997643  -1.1149049 4.37408152108482 -20.9213458 128.3039 /L   8.9096    n.a.    n.a. 179.996304 -12.615693
```

$$\Delta\nu = \nu_{sky} - \nu_{rest} \quad \text{——(1)}$$

$$\Delta\nu = \left(-\frac{V}{c}\right) \nu_{sky} \quad \text{——(2)}$$

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

for example:

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

JPL Catalog Search Form

You need a Browser with Forms Capability to use this.

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

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: 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-OOH
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   480111404341223 1     341124 4
346558.6272   7.2265 -5.4326 3   535.6030138   480111404341222 2     341123 5
346558.7624   7.2248 -5.4326 3   535.6029138   480111404341223 0     341123 3
346558.7661   7.2248 -5.4326 3   535.6029138   480111404341222 0     341124 3
            49005   HO3
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-OOH
346558.4520   0.0500 -2.7909 3    88.5244
            48007   O3-2v2
346553.5307   0.2497 -7.7715 3  2071.1536
            48011   CH3OOH
346558.4144   7.2242 -5.4326 3   535.60291
346558.6272   7.2265 -5.4326 3   535.6030138   480111404341222 2     341123 5
346558.7624   7.2248 -5.4326 3   535.6029138   480111404341223 0     341123 3
346558.7661   7.2248 -5.4326 3   535.6029138   480111404341222 0     341124 3
            49005   HO3
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
```

rest freq: 346556.997 MHz

Approaches to identify molecular transitions on the atmosphere of Callisto:

1. From spectral lines to molecular database

2. From molecular 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 ? 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

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

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

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

To reset the form, press this button: Reset .

NO_2 transitions in frequency range 344-348 GHz

```
                46006  NO2
345191.9942  0.0591 -6.4889 3 1101.7250102  46006 33550 2485051  49 3474950
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 2485150  49 3475049
345602.4731  0.0585 -6.4874 3 1101.6884102  46006 33550 2485151  49 3475050
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 -5.0605 3  107.4564 30 -46006 33514 2121415  15 1151516
345721.5500  0.0600 -5.0898 3  107.4586 28 -46006 33514 2121414  15 1151515
345753.9933  0.0252 -6.5615 3 1101.7300 94  46006 33548 4444847  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 4444848  49 3474949
345774.6600  0.0600 -6.5612 3 1101.7250 98 -46006 33548 4444849  49 3474950
346357.3728  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
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 4444949  49 3475050
346518.6100  0.0600 -6.5568 3 1101.6858 96 -46006 33548 4444948  49 3475049
346531.7486  0.0263 -6.5329 3 1101.6914100  46006 33548 4444950  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 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
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
347956.2481  0.0151 -5.6421 3  252.3866 50  46006 33524 1232525  24 0242425
```

spw3

spw2

spw0

NO_2 transitions in frequency range 344-348 GHz

46006 NO2

*If NO_2 exist, a transition line is expected to be found at 347287MHz.

```
345753.9933   0.0252 -6.5615 3 1101.7300 94   46006 33548 4444847   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 4444848   49 3474949
345774.6600   0.0600 -6.5612 3 1101.7250 98  -46006 33548 4444849   49 3474950
```

spw3

```
346510.7300   0.0600 -6.5613 3 1101.6884 98  -46006 33548 4444949   49 3475050
346518.6100   0.0600 -6.5568 3 1101.6858 96  -46006 33548 4444948   49 3475049
346531.7486   0.0263 -6.5329 3 1101.6914100   46006 33548 4444950   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 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
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
```

spw2

spw0

Results:

We identified 1 molecules

SO_2(Sulfur dioxide)

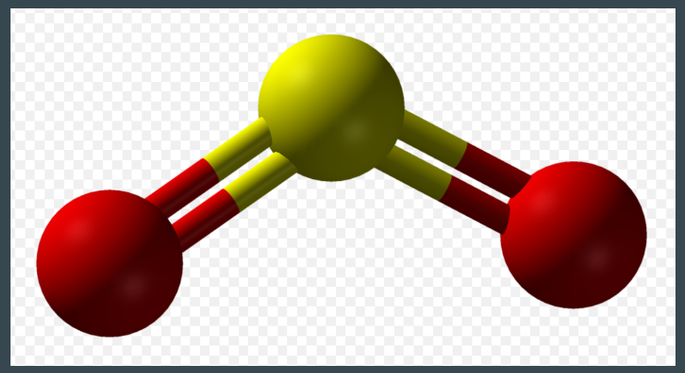


image comes from signaturewinelab

SO_2 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       6 4 2
  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
  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
```

s1
s2

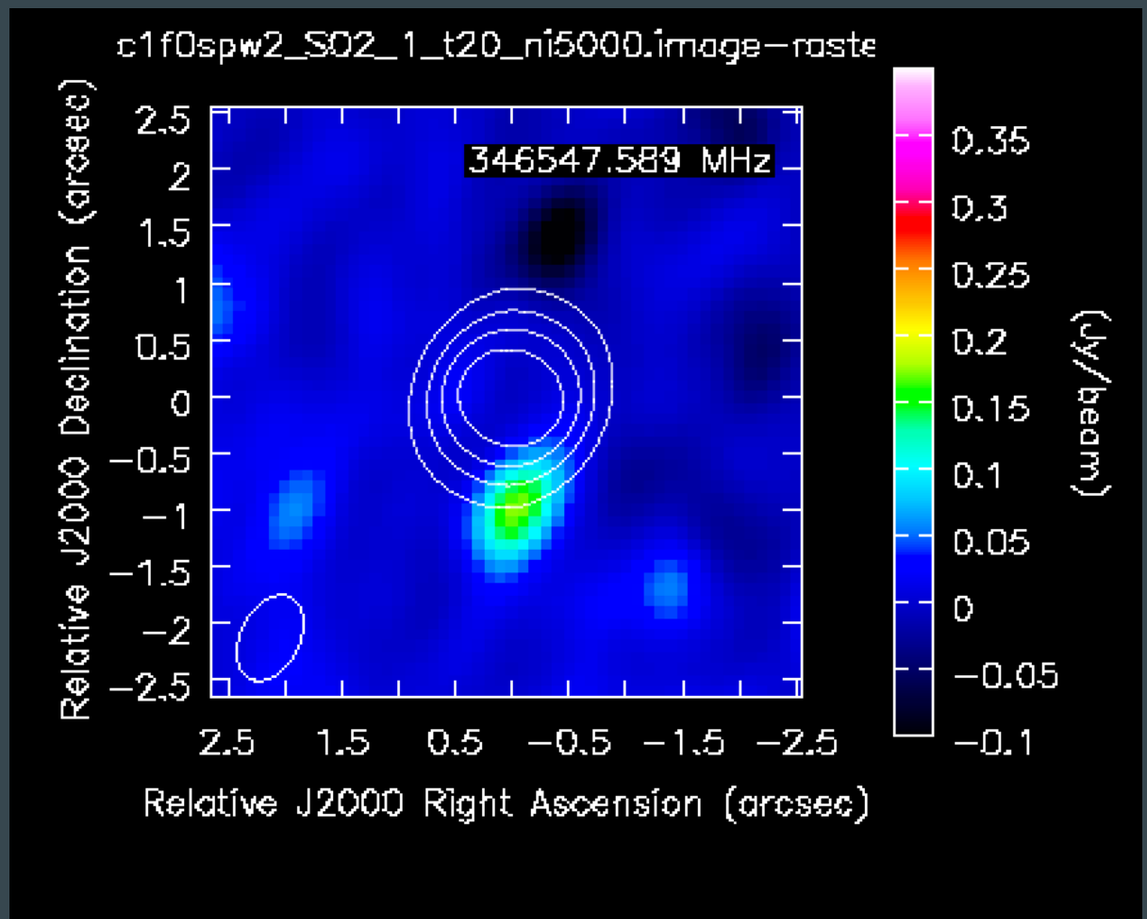
spw2

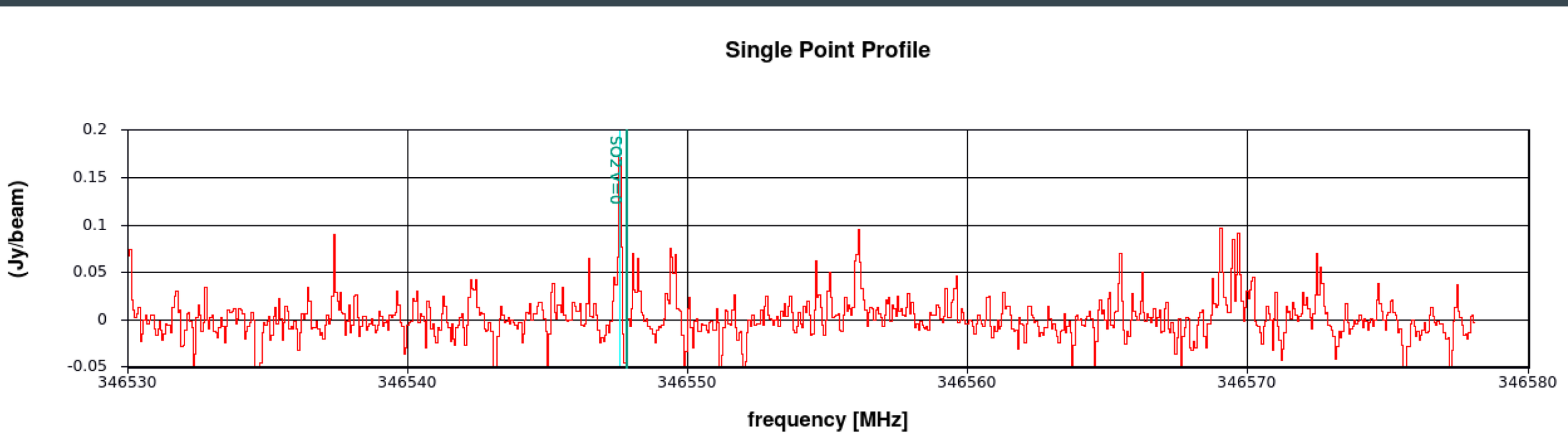
SO_2 line s1

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 6 4 2
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
346910.9115	0.0049	-5.7854	3	1551.8070135		64502 303671751 681052
347829.2342	0.0038	-6.6123	3	1111.9644115		64502 30357 652 56 749



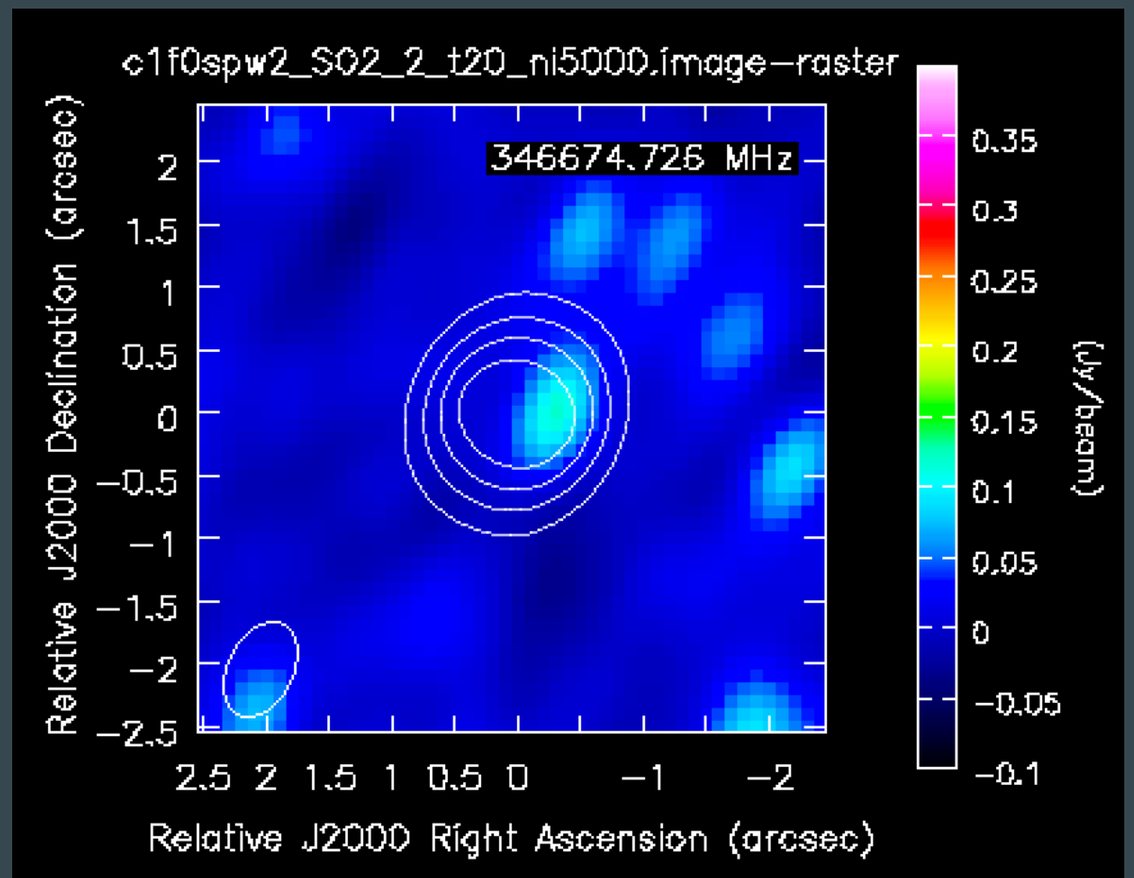


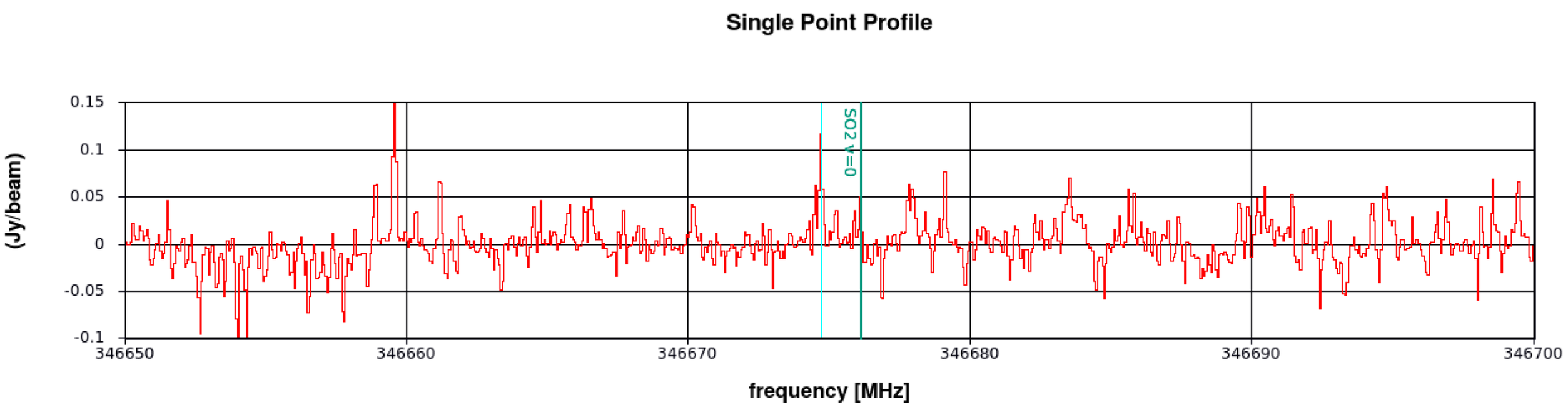
SO_2 line s2

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	6 4 2
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
346910.9115	0.0049	-9.7854	3	1951.8070135		64502 303671751	681052
347829.2342	0.0038	-6.6123	3	1111.9644115		64502 30357 652	56 749

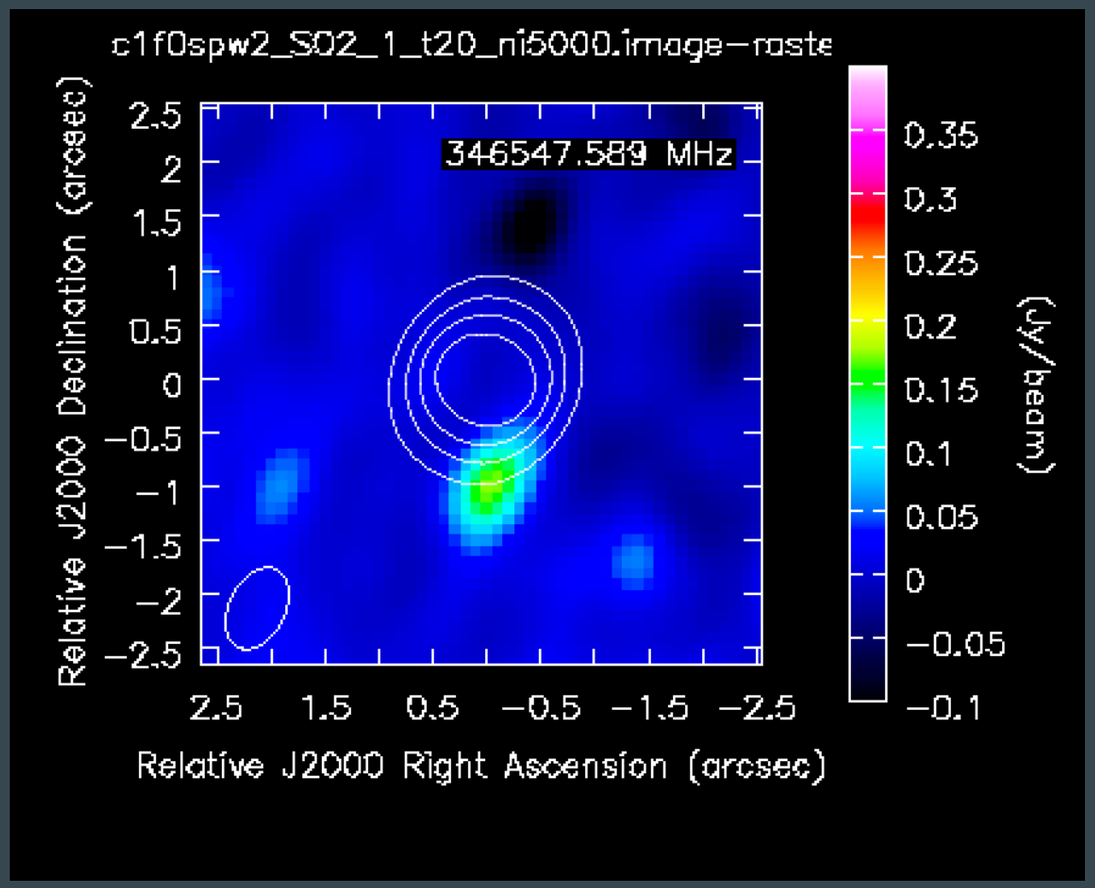




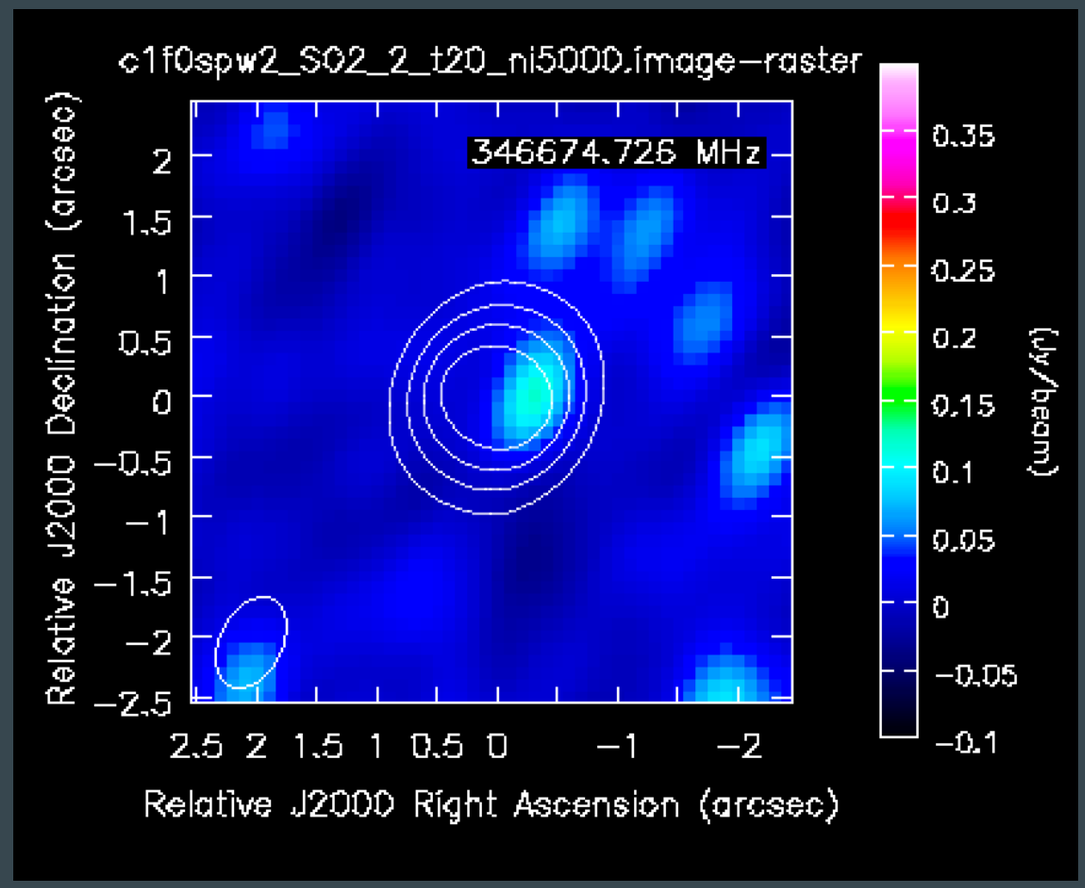
Discussions:

We have identified the transition line of SO_2, however, there are still some questions need to be answered.

1. In the case of SO_2, peaks don't show at same place on Callisto.



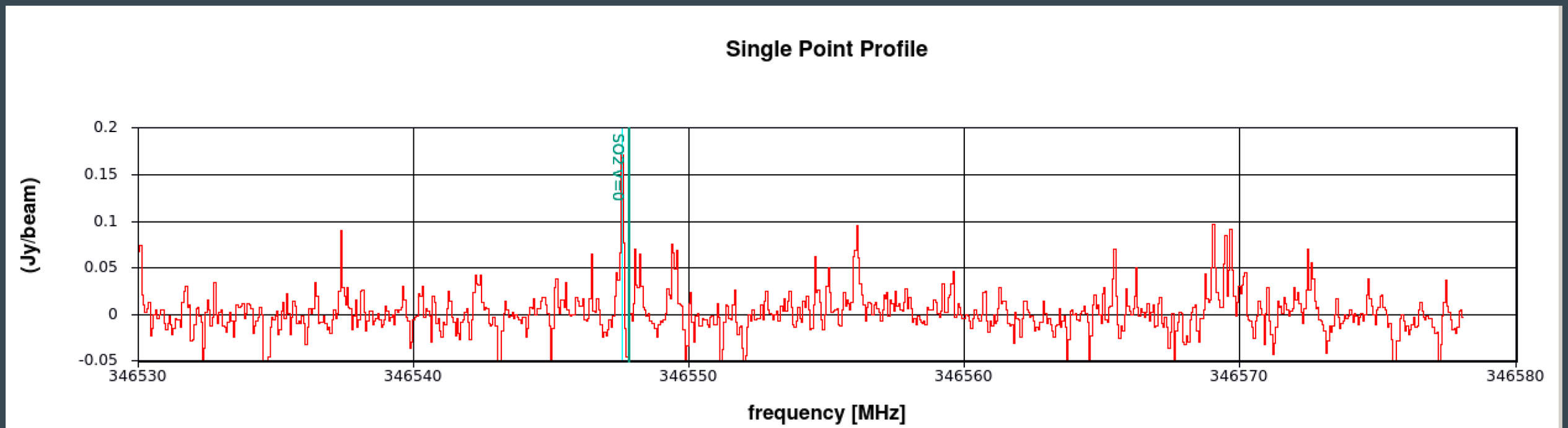
SO_2 line s1



SO_2 line s2

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

Take SO_2 line s1 for example:



SO_2 line s1

Summary

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

2. We have found SO_2 on Callisto, however we still need more datas to prove it.

3. Finding SO_2 may help us know more about Callisto, especially for astrobiology.

The end