

Astrobiology Study with the ALMA:  
Search for Potential Molecular  
Outgassing on the Galilean Moon Io



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# Introduction

Recently water vapor has been observed from the Galilean moon Europa. There are no ALMA data of Europa. Hence, we used existing ALMA data to look for likely outgassing from Io, another Galilean moon.

Io is a geologically active Jovian satellite and has many volcanoes; the surface color of Io is caused by sulfur and sulfurous compounds covering on its surface. Thus Io could provide us a better chance finding molecular outgassing.

## ALMA observations of Io

Date = 2012 /10 /19 \_ 09:37 A.M.~10:28 A.M.

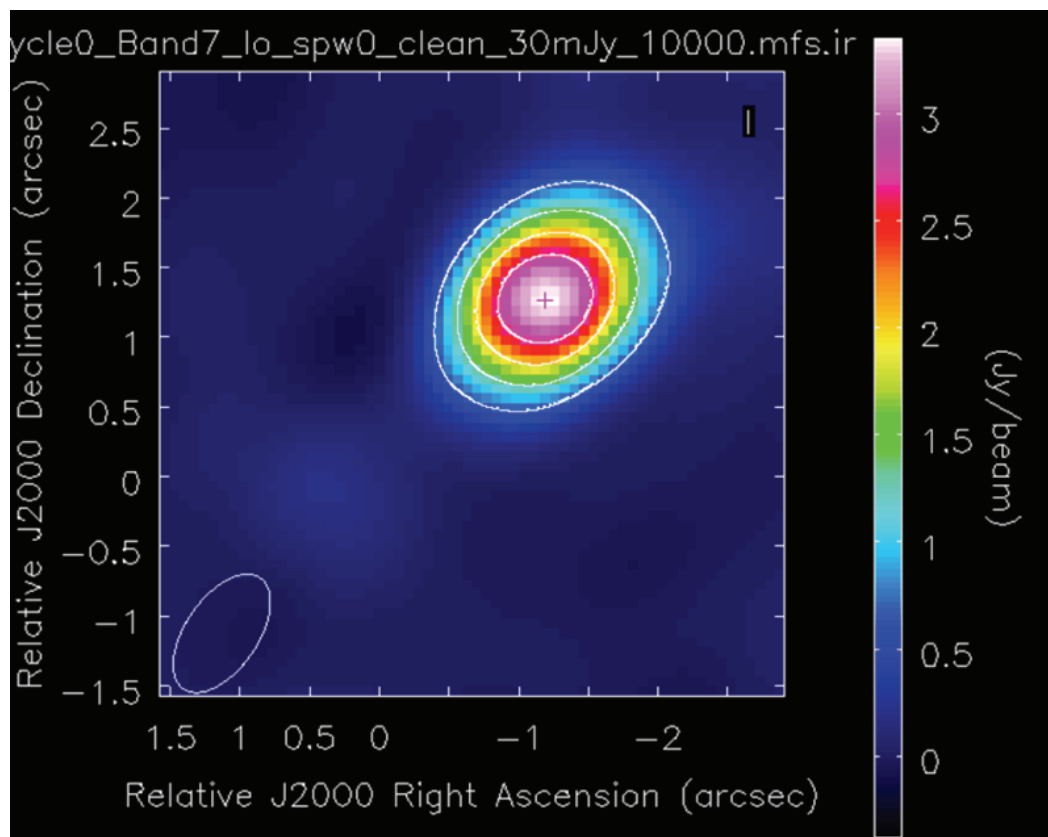
RA =  $04^{\text{h}}58^{\text{m}}57^{\text{s}}.6$       Dec= $+21^{\circ}51'35''.66$

Elevation =  $40^{\circ}.84$

Frequency Rang = 344 ~ 347 GHz (Band 7)

Integration time = 468 sec

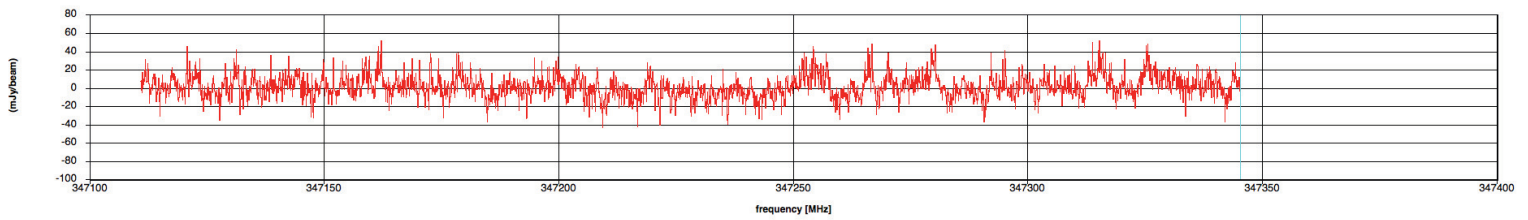
### Continuum image of Io (from SPW 0)



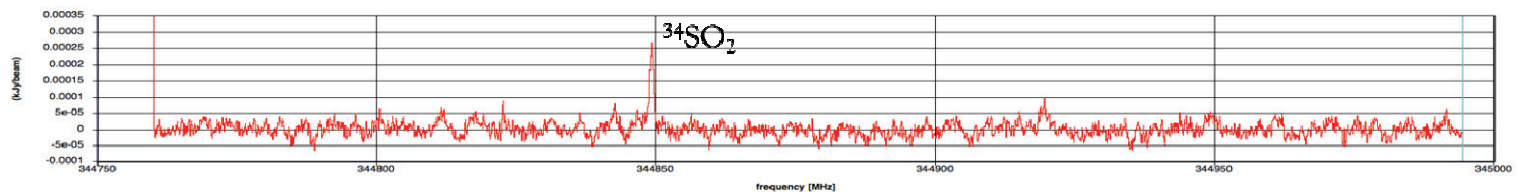
$0.97'' \times 0.52'' \times -34.63^{\circ}$

## Io Spectra in SPW 0, 1, 2 and 3

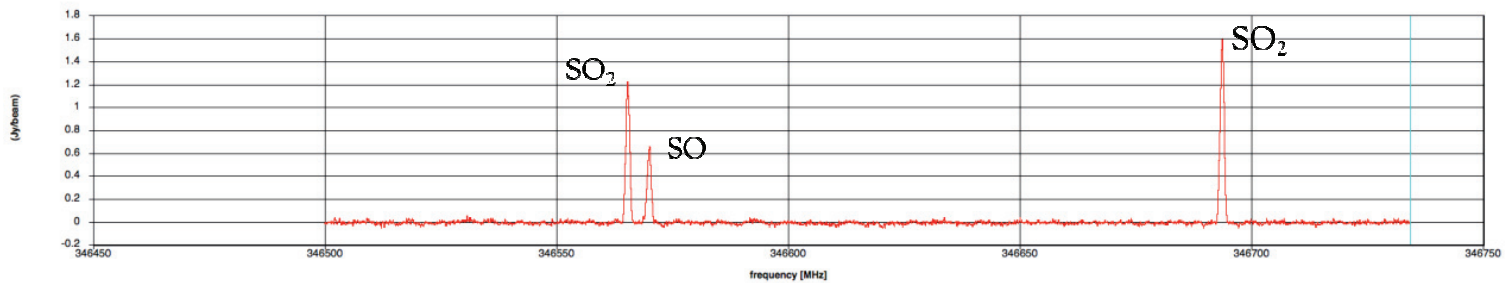
SPW0 frequency range: 347345~347111MHz (No prominent spectral feature found)



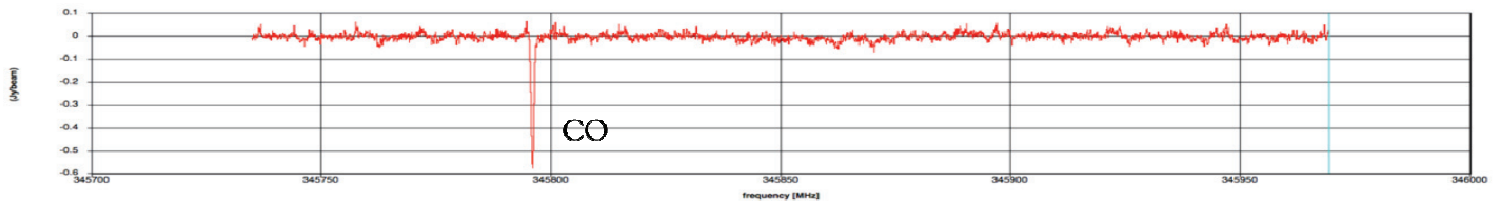
SPW1 frequency range: 344994~344760MHz  
(One prominent spectral feature,  $^{34}\text{SO}_2$ , was found.)



SPW2 frequency range: 346734~346500MHz  
(Three prominent spectral features of  $\text{SO}_2$  and SO were found)

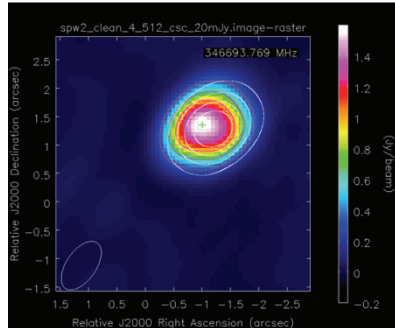


SPW3 frequency range: 345969~345735MHz  
(One prominent absorption feature due to terrestrial CO was found)



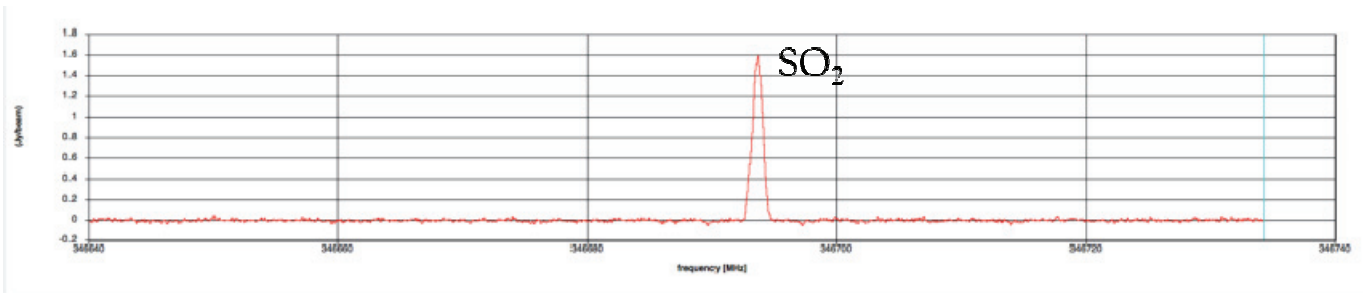
# Molecules in Io's atmosphere

## SO<sub>2</sub>

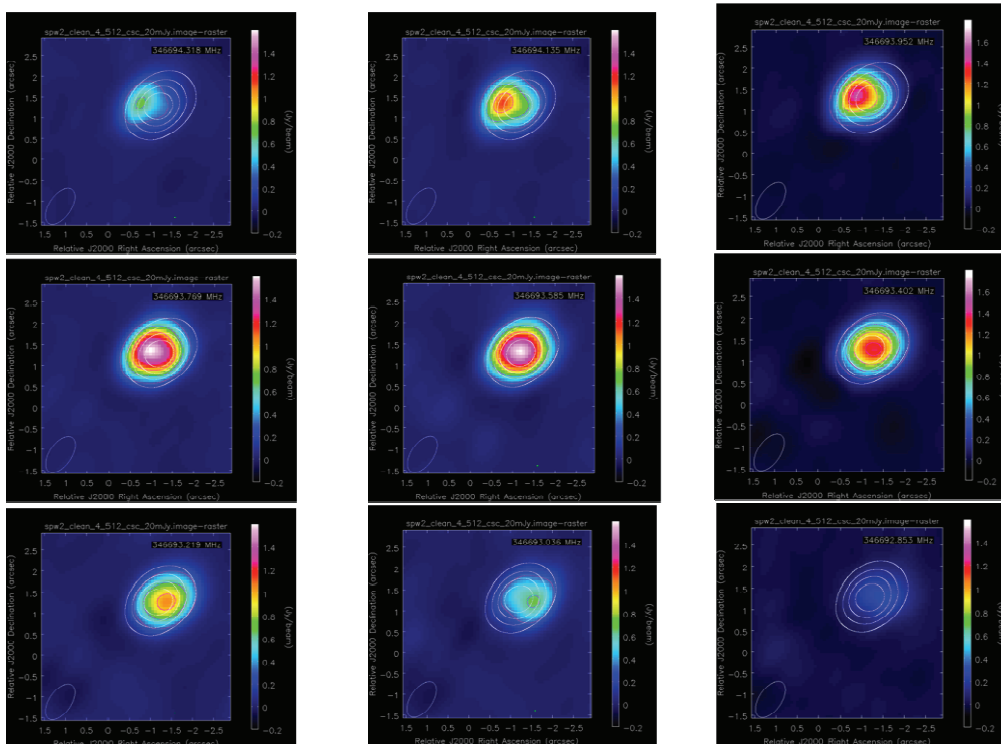


Frequency = 346693.769 MHz  
 Relative velocity = -35.89 km s<sup>-1</sup>  
 Rest frequency = 346652.262 MHz  
 SO<sub>2</sub>: 346652.167 MHz (transition: 19<sub>1,19</sub> - 18<sub>0,18</sub>)  
 E<sub>low</sub>: 105.2994 cm<sup>-1</sup>

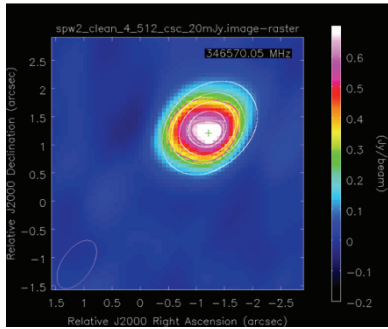
← (Spectral image of SO<sub>2</sub> emission at the peak-emission channel. Color wedge denotes the intensity of SO<sub>2</sub> molecular emission; white contours indicate continuum intensity.)



## SO<sub>2</sub> channel maps:

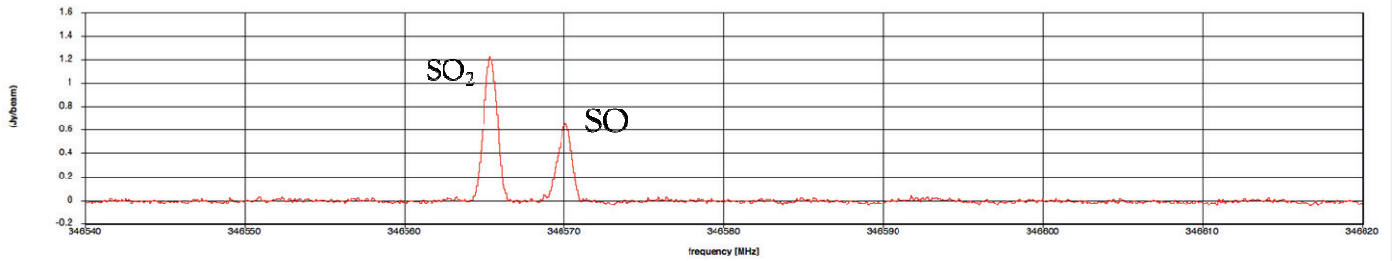


SO

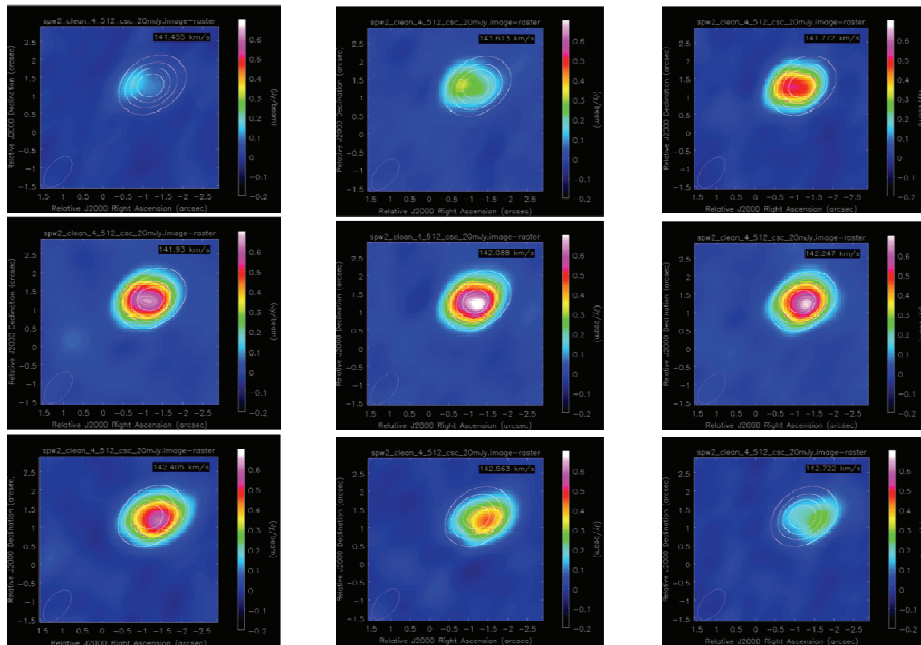


Frequency = 346570.05MHz  
 Relative velocity =  $-35.89 \text{ km s}^{-1}$   
 Rest frequency = 346528.56MHz  
 SO : 346528.481MHz (transition:  $8_9-7_8$   
 $E_{\text{low}} : 43.1928 \text{ cm}^{-1}$ )

← (Spectral image of SO emission at the peak-emission channel. Color wedge denotes the intensity of SO emission; white contours indicate continuum intensity.)

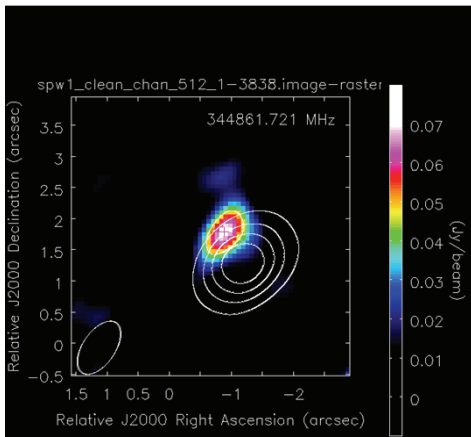


Channel images of SO emission:



Both SO and SO<sub>2</sub> appear to be abundant in Io's atmosphere. The spatial distribution of SO<sub>2</sub> is very similar to that of SO on Io. Likewise, a similar velocity field is revealed by SO and SO<sub>2</sub> emission and is most likely due to the rotation of Io.

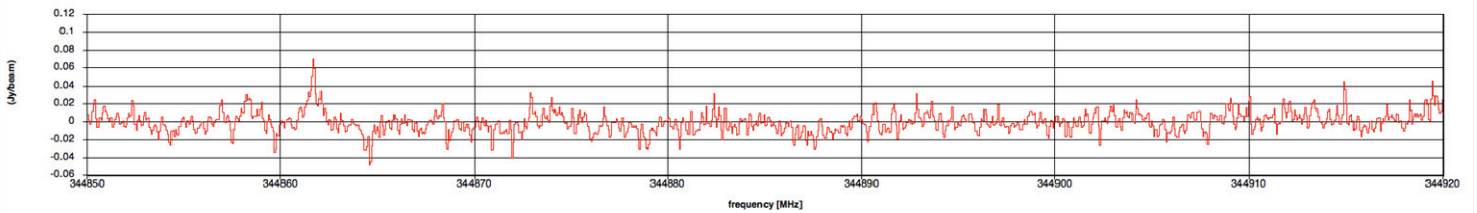
# KCl



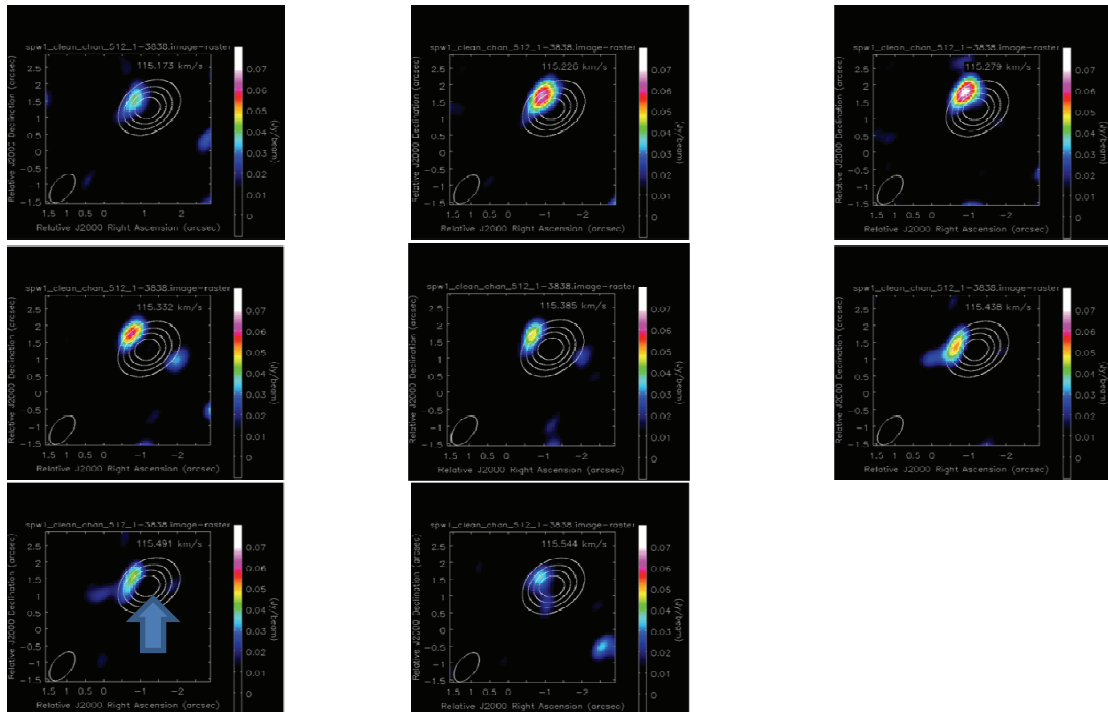
Frequency = 344861.721 MHz  
 Relative velocity =  $-35.89 \text{ km s}^{-1}$   
 Rest frequency = 344820.435 MHz

KCl : 344820.4760 MHz (transition:  $45_0 - 44_0$ )  
 $E_{\text{low}} : 253.4892 \text{ cm}^{-1}$

← Spectral image of KCl emission at the peak-emission channel. Color wedge denotes the intensity of KCl emission; white contours indicate continuum intensity.)

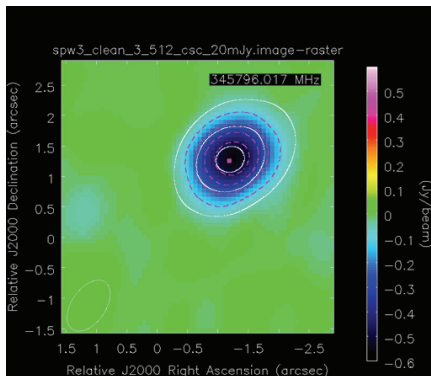


## Channel images of KCl emission:



The spatial distribution of KCl in Io's atmosphere is not uniform that might be due to localized origin of KCl and its short lifetime which prevents KCl from being well mixed in Io's atmosphere.

## Terrestrial CO (CO absorption in Earth's atmosphere)

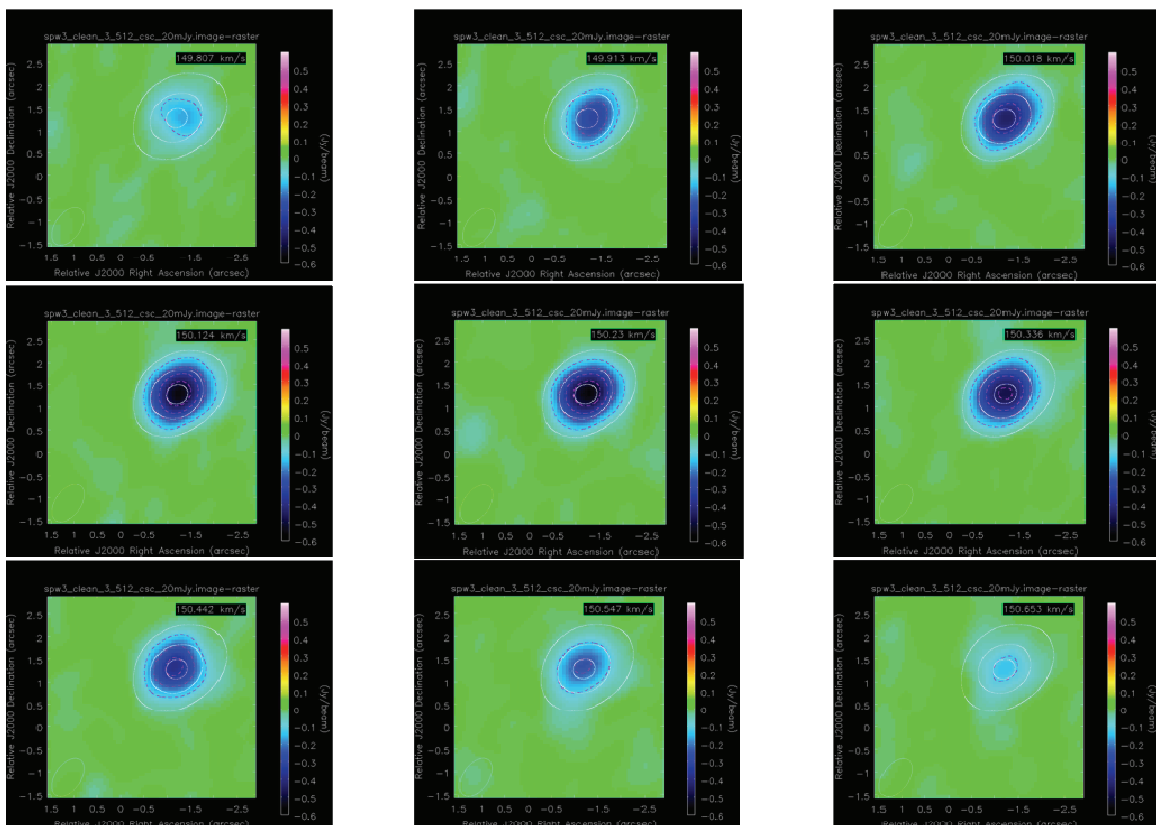


Frequency = 345796.017 MHz

CO : 345795.99 MHz (transition: 3-2  
 $E_{\text{low}} : 11.5350 \text{ cm}^{-1}$ )

← (Spectral image of CO absorption at the strongest-absorption channel. Color wedge and negative dash contours denote the absorption intensity of CO; white contours indicate continuum emission of Io.)

### Channel maps of CO absorption:



In addition to the perfectly-matched sky frequency with the rest frequency of CO 3-2 transition, the nicely-centered CO absorption toward the Io disk without showing the rotational velocity pattern of Io is the further evidence which implies the CO absorption is terrestrial in nature.