

Are Solar System Icy Worlds Habitable?

A Case Study : Enceladus

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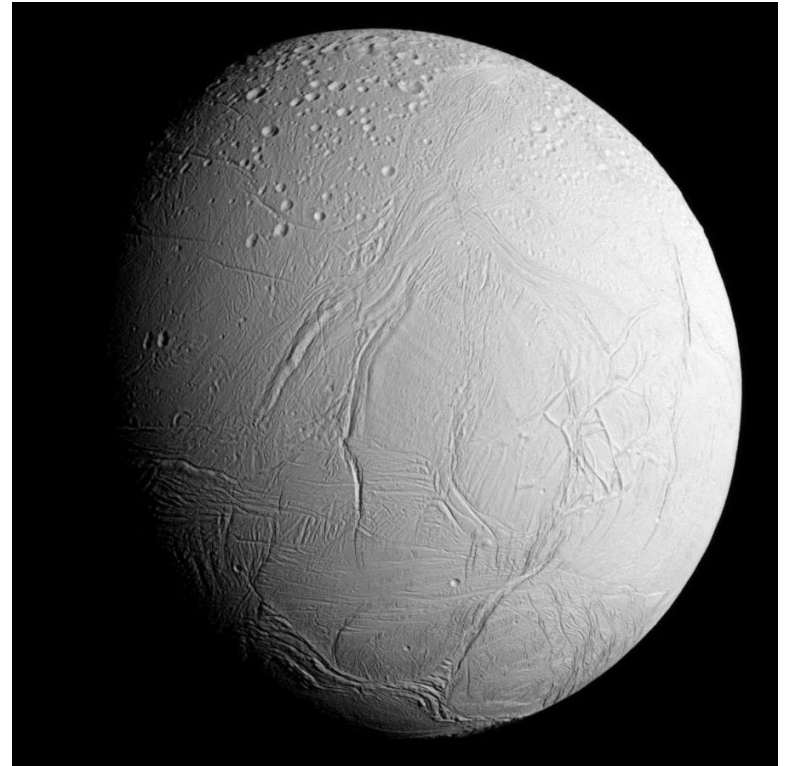
Outline

- Enceladus and Motivations
- Data Processing
 - 3 Data Set
- Conclusion
 - Summary
 - Challenge
 - Future Work



Information of Enceladus

- Sixth largest moon of Saturn
- **Diameter** : $513.2 \times 502.8 \times 496.6$ km
- **Angular Size** : $0''.08$
Distance : 1.38×10^9 km
- **Density** : 1.609 ± 0.005 g/cm³
- **Surface Temp** : 75K (mean)



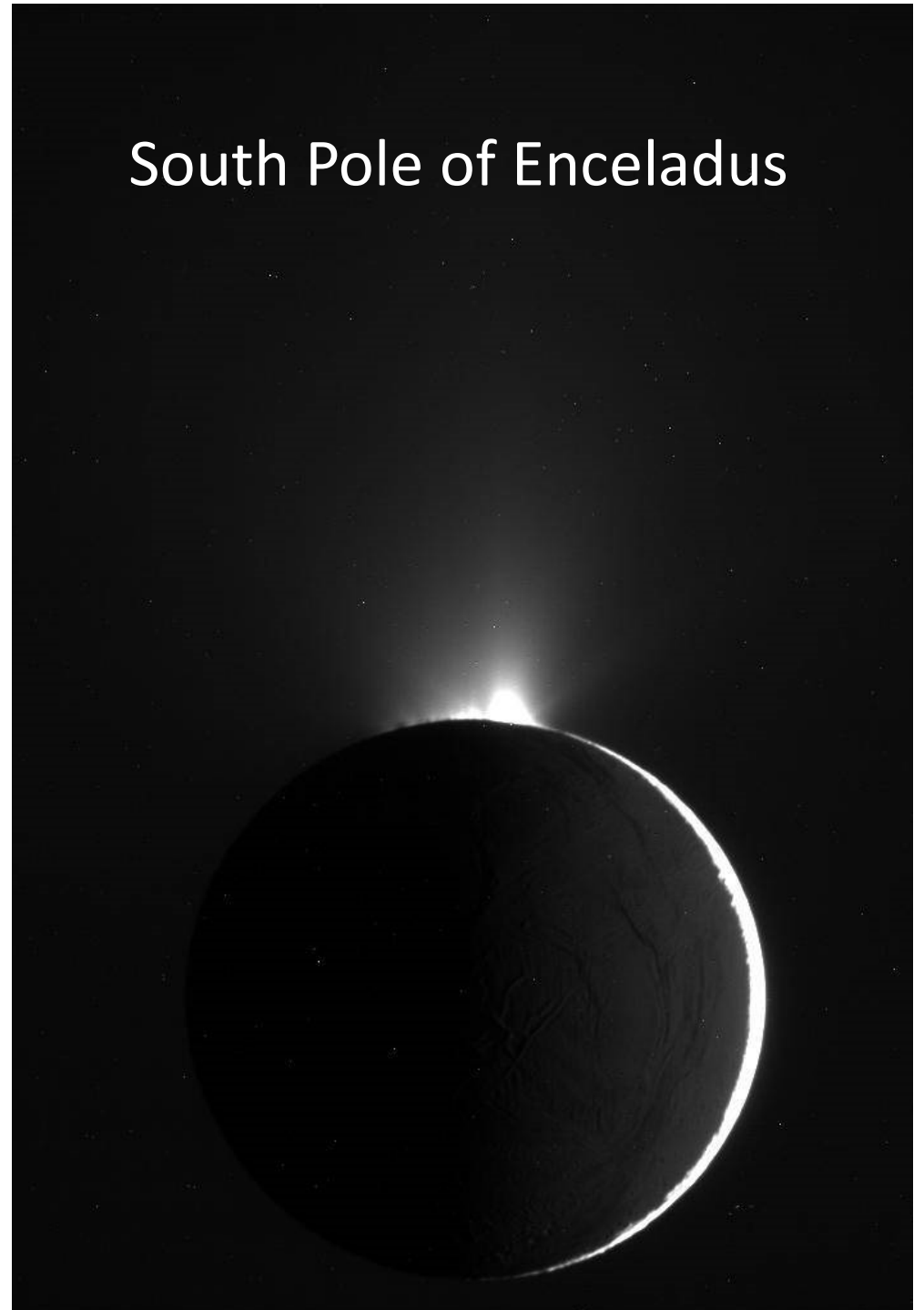
NASA/JPL-Caltech/
Space Science Institute

Discovery of Plumes

- Waite et al. found that plumes of Enceladus contain atomic hydrogen.
 - Suggest water is interacting with rocky core of Enceladus.

NASA/JPL/Space Science Institute

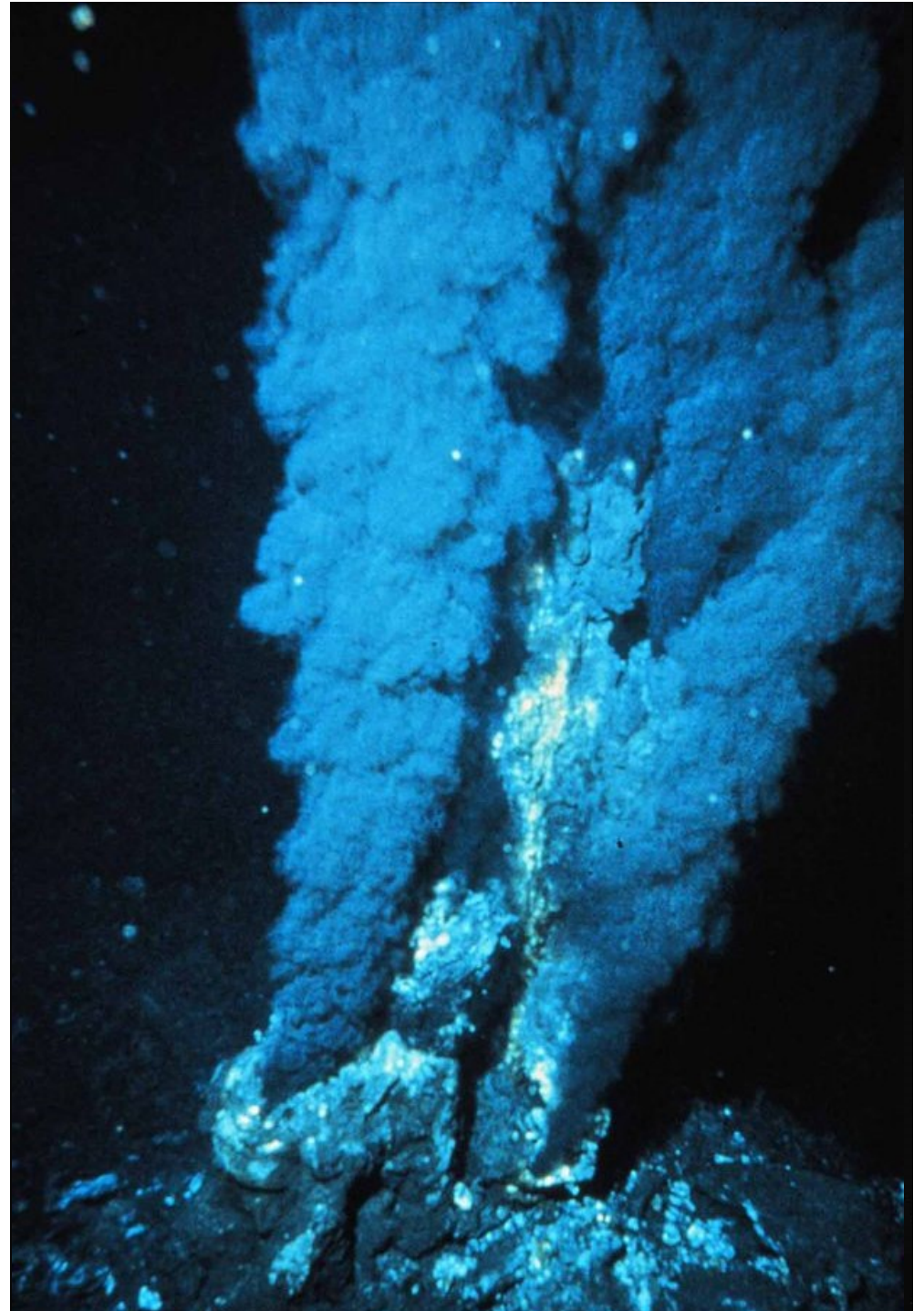
South Pole of Enceladus



Discovery of Plumes

- Waite et al. found that plumes of Enceladus contain atomic hydrogen.
 - Suggest water is interacting with rocky core of Enceladus.
- May imply hydrothermal vents could exist in the subsurface ocean of Enceladus.
 - Enceladus may have life.

NASA/JPL/Space Science Institute



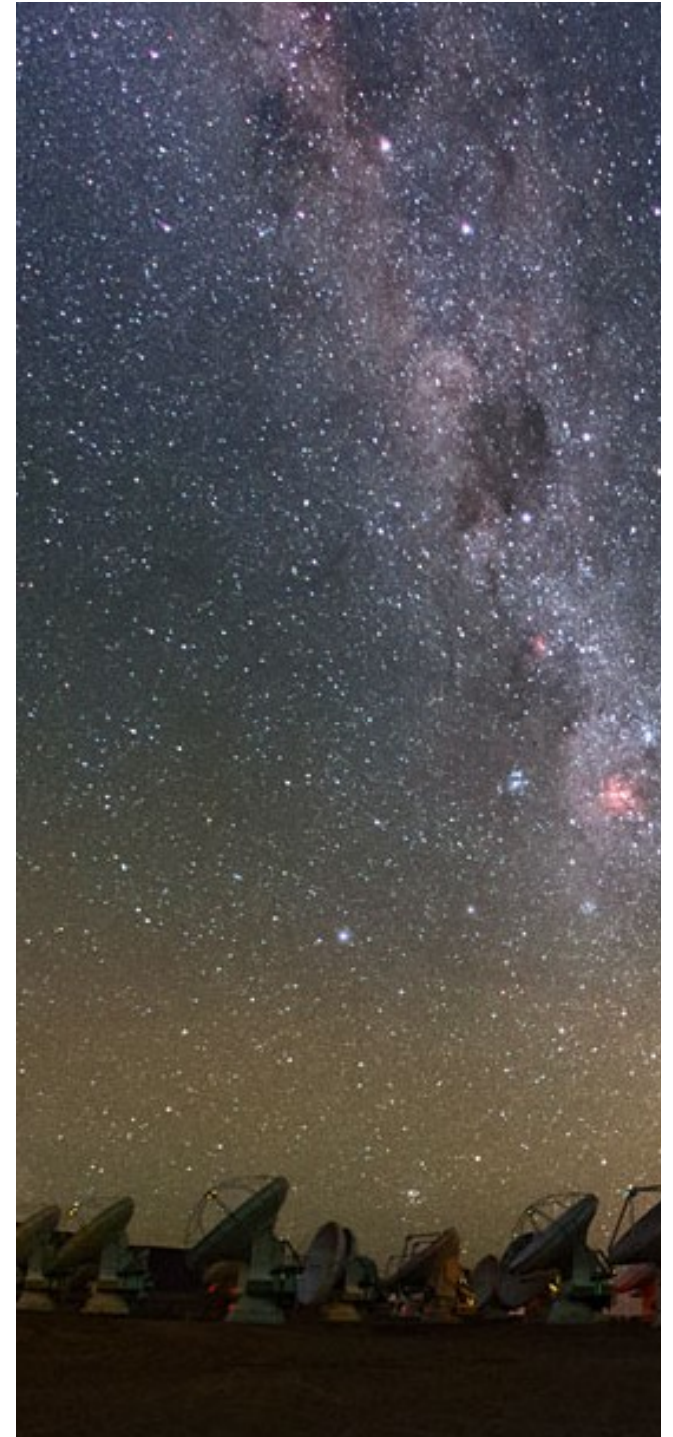
Motivations to study Enceladus

- Ocean under icy surface may have life.
- The concentration of salt is a factor to determine if the environment is habitable.
- Whether the subsurface ocean on Enceladus is similar to that on Earth.
- Our task is to search for NaCl on Enceladus using ALMA.



ALMA Data

- May 19, 2018 10:15 ~ 11:25 UT
Frequency (GHz): 664.076 to 665.013
Number of channels : 1920
- **May 24, 2018 06:22 ~ 06:56 UT**
Frequency (GHz): 664.078 to 665.015
Number of channels : 1920
- May 24, 2018 07:53 ~ 09:03 UT
Frequency (GHz): 664.077 to 665.015
Number of channels : 1920



ALMA Data

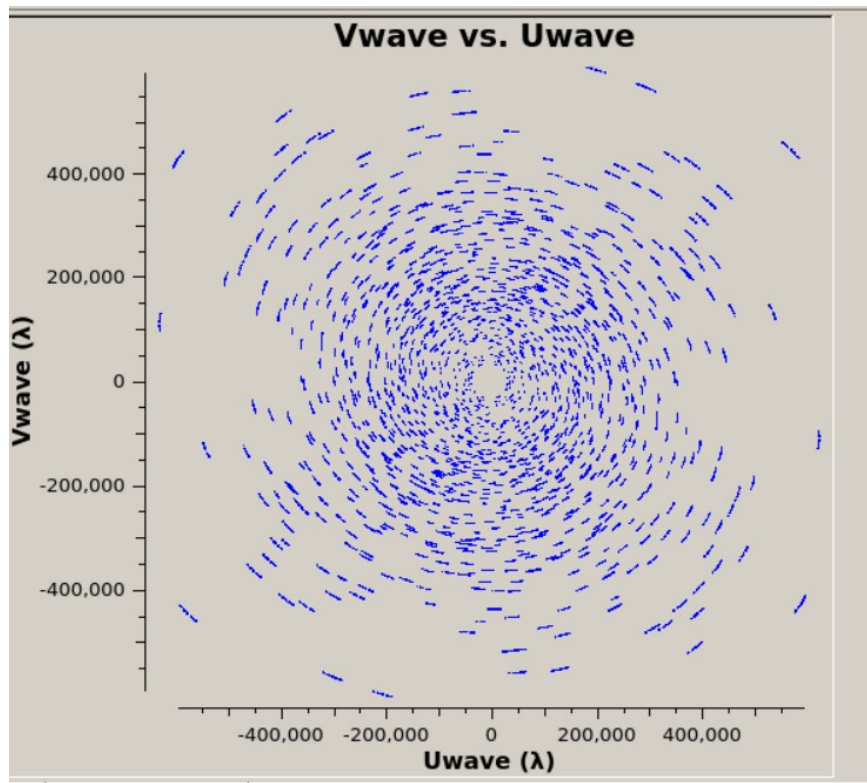
- Observation Time : **May 24, 2018** 06:22 ~ 06:56 UT
- Antenna (the 12-m array) : 46
- Frequency coverage (GHz): 664.078 to 665.015
- Channel Width : 488.273 (kHz) $\sim 0.22 \text{ km s}^{-1}$
- Number of channels : 1920



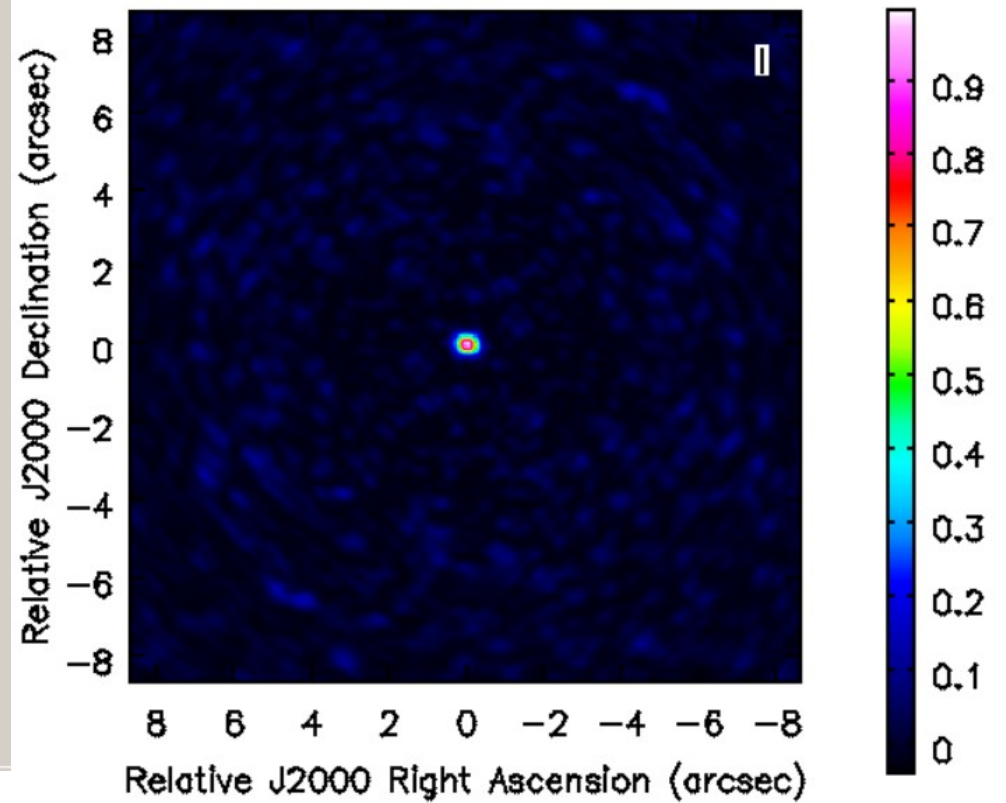
First Data Set

Observation Time : May, 24 06:22 ~ 06:56 UT

UV coverage



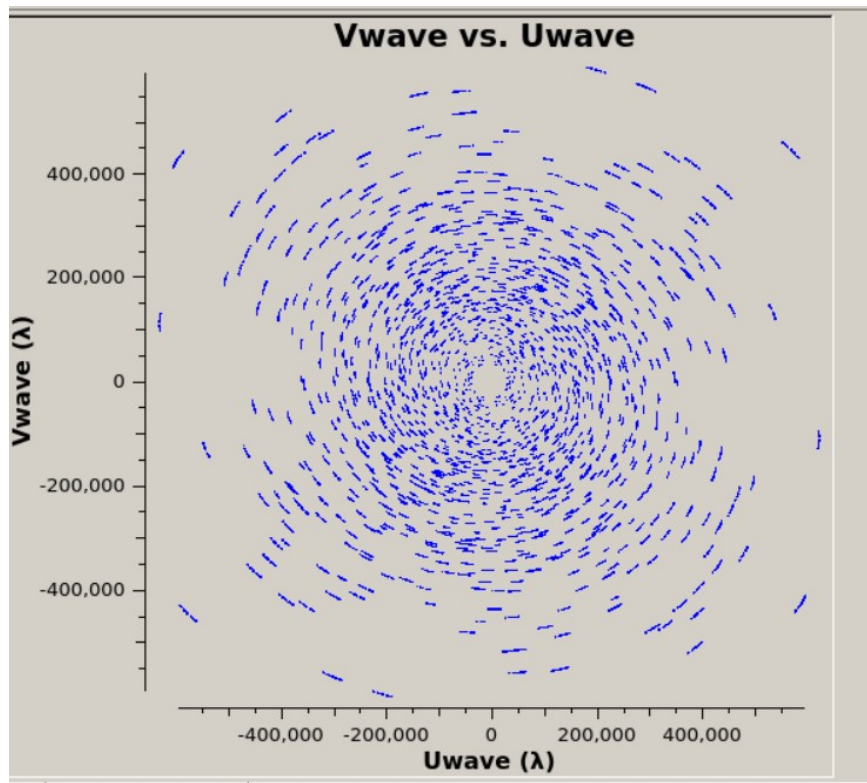
Dirty Beam



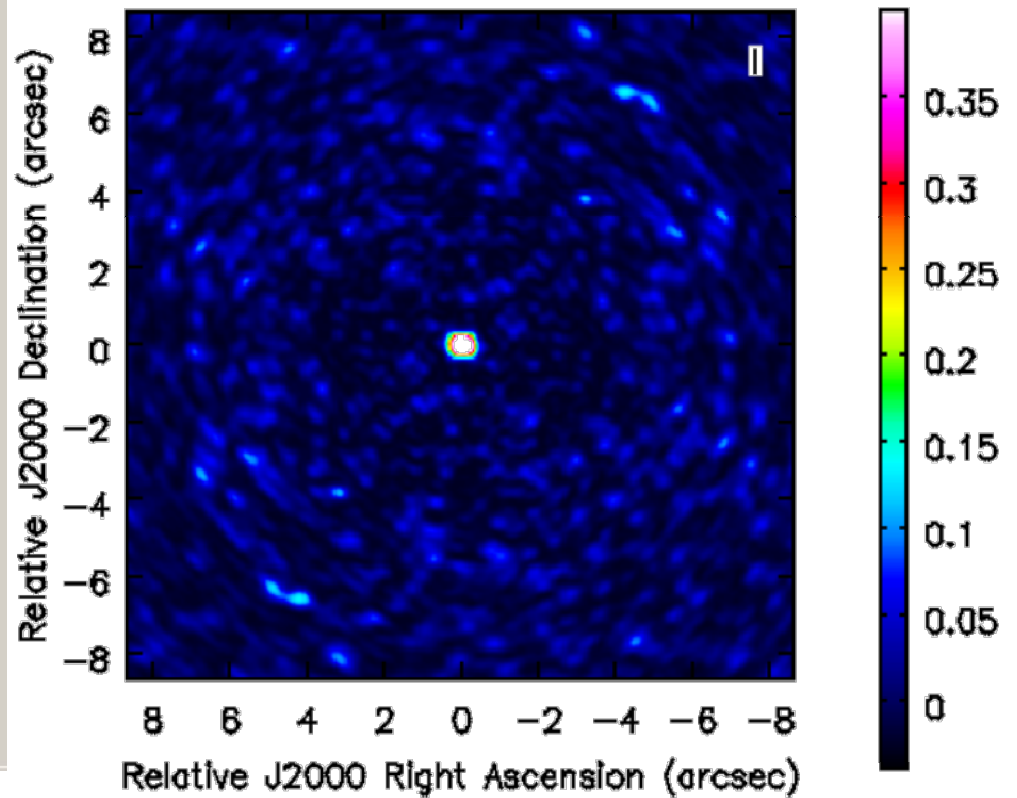
First Data Set

Observation Time : May, 24 06:22 ~ 06:56 UT

UV coverage

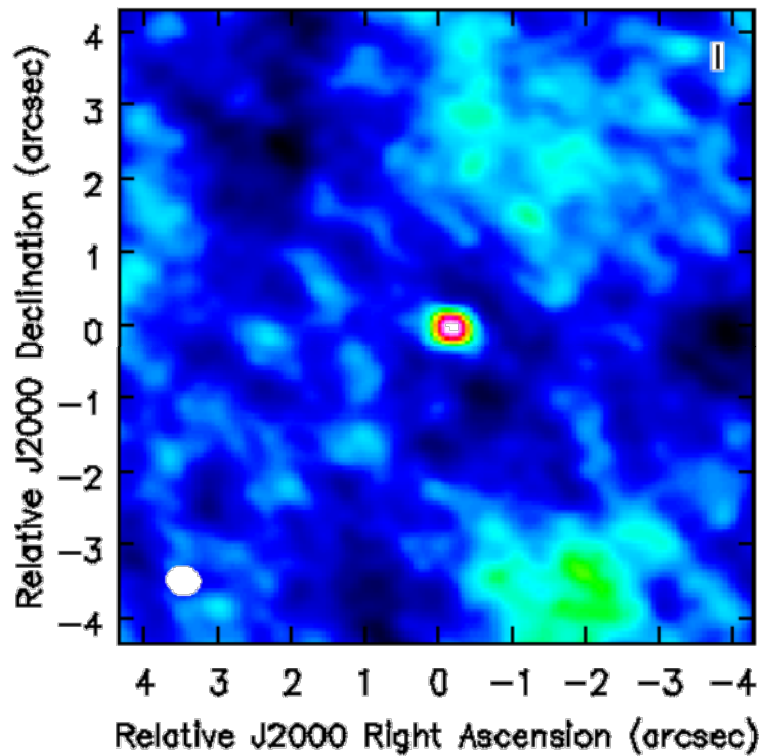


Dirty Beam



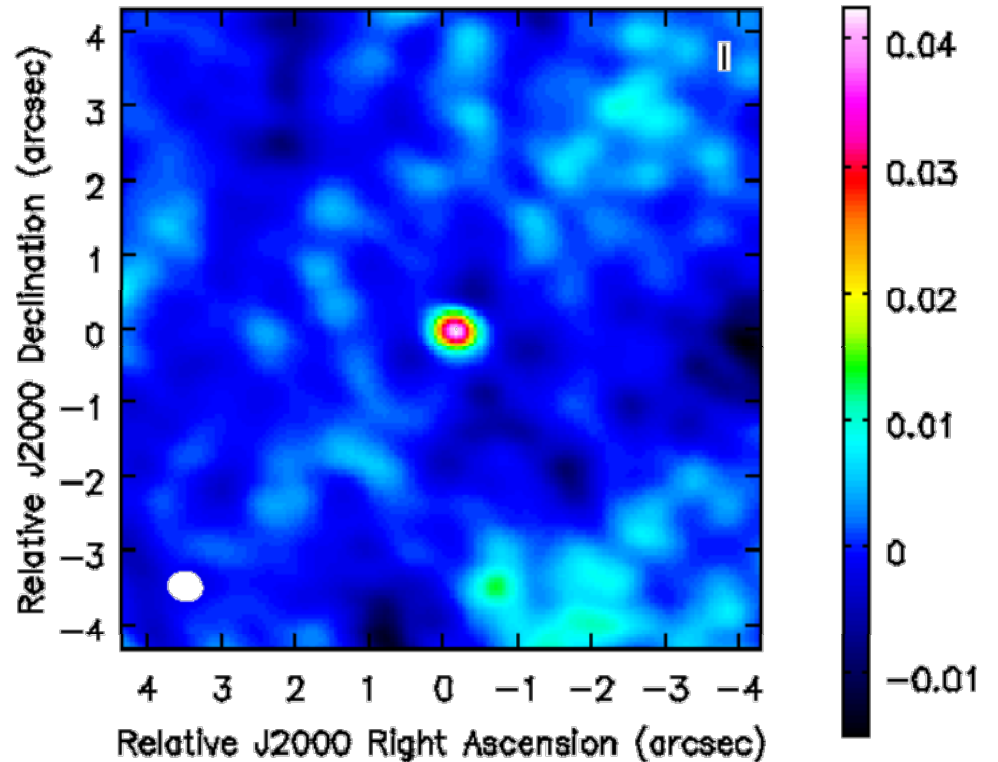
Continuum Map

Dirty Image



Field of view : 8.7"
Rms : 3.09 mJy/bm

Clean Image



Clean Beam : 0".47×0".40
Threshold = 1.8 mJy/bm
Rms : 1.77 mJy/bm

ALMA Data

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ALMA Data

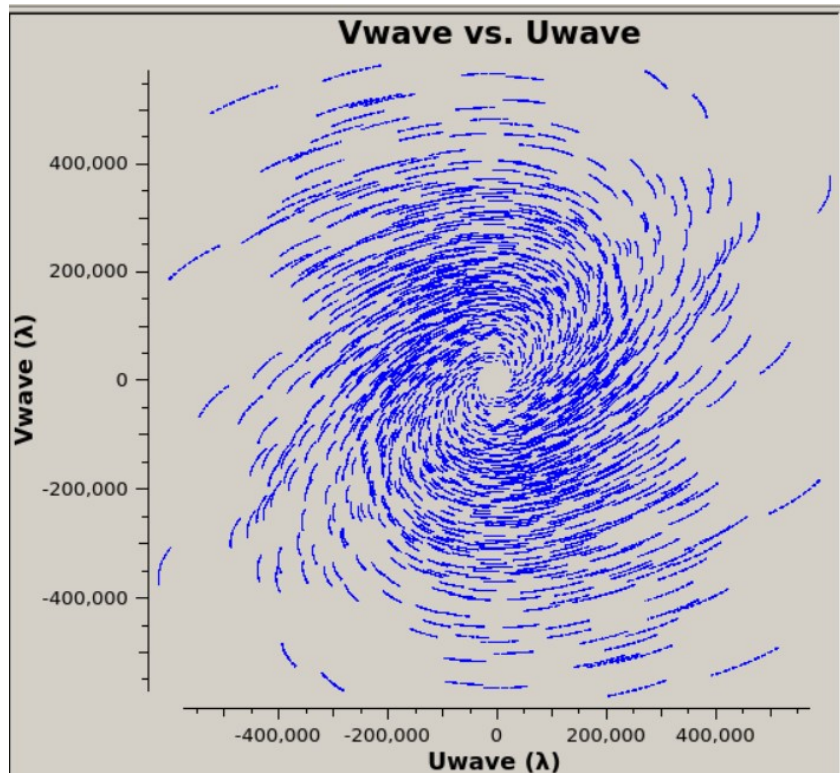
- Observation Time : **May 24, 2018** 07:53 ~ 09:03 UT
- Antenna (the 12-m array) : 46
- Frequency coverage (GHz): 664.077 to 665.015
- Channel Width : 488.272 (kHz) $\sim 0.22 \text{ km s}^{-1}$
- Number of channels : 1920



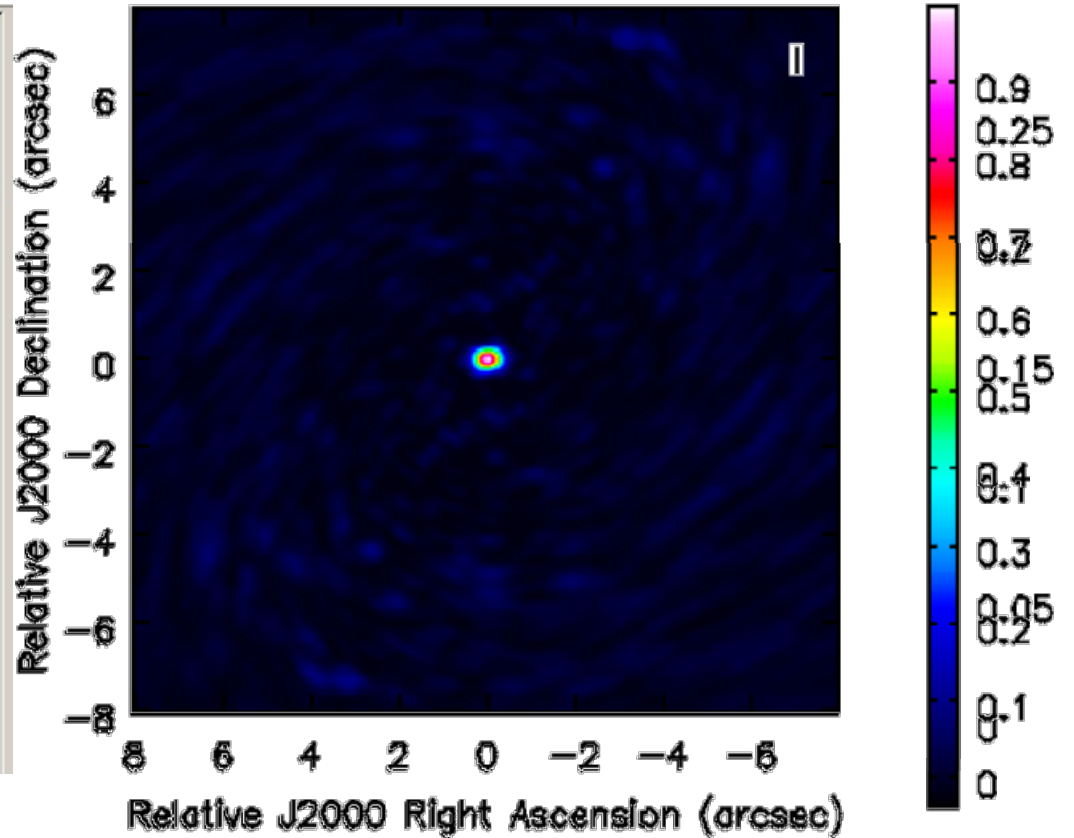
Second Data Set

Observation Time : May, 24 07:53 ~ 09:03 UT

UV coverage



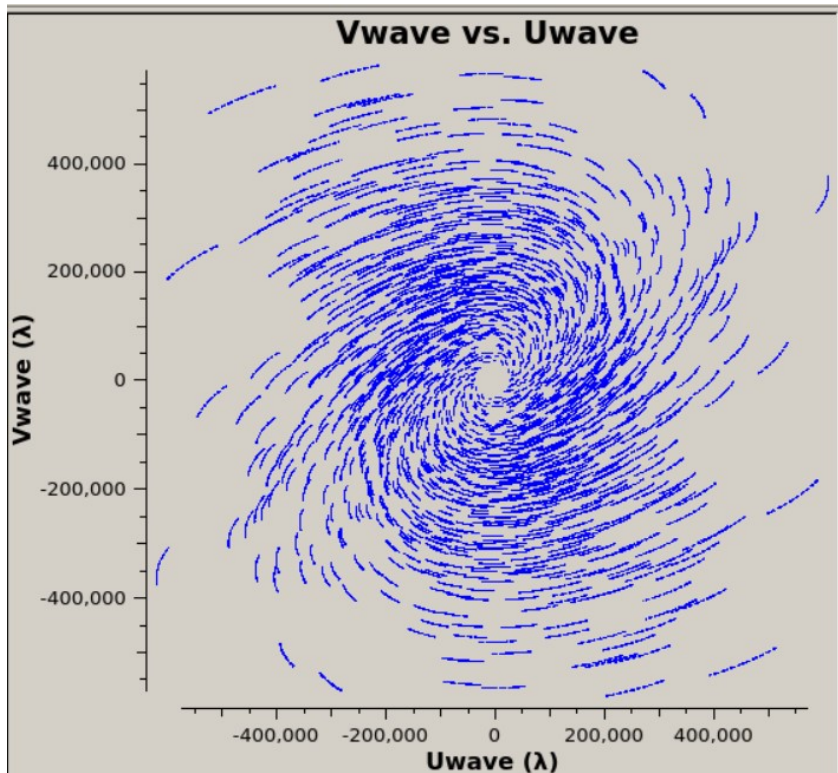
Dirty Beam



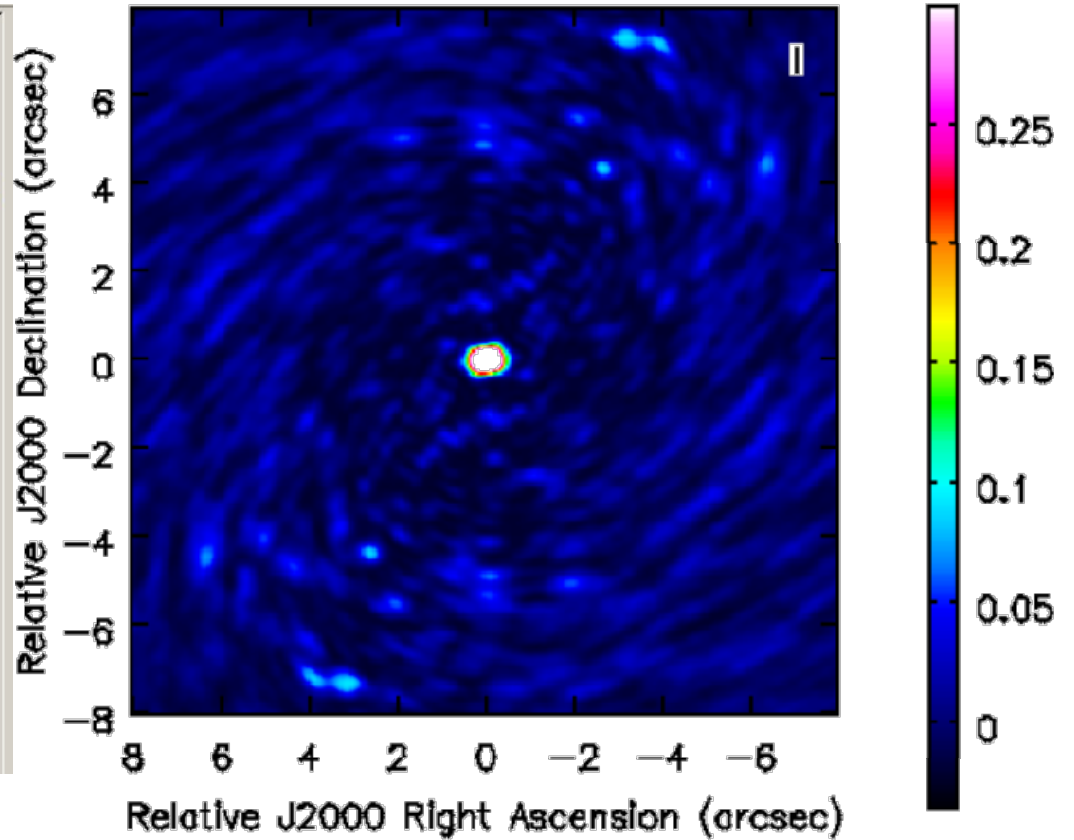
Second Data Set

Observation Time : May, 24 07:53 ~ 09:03 UT

UV coverage

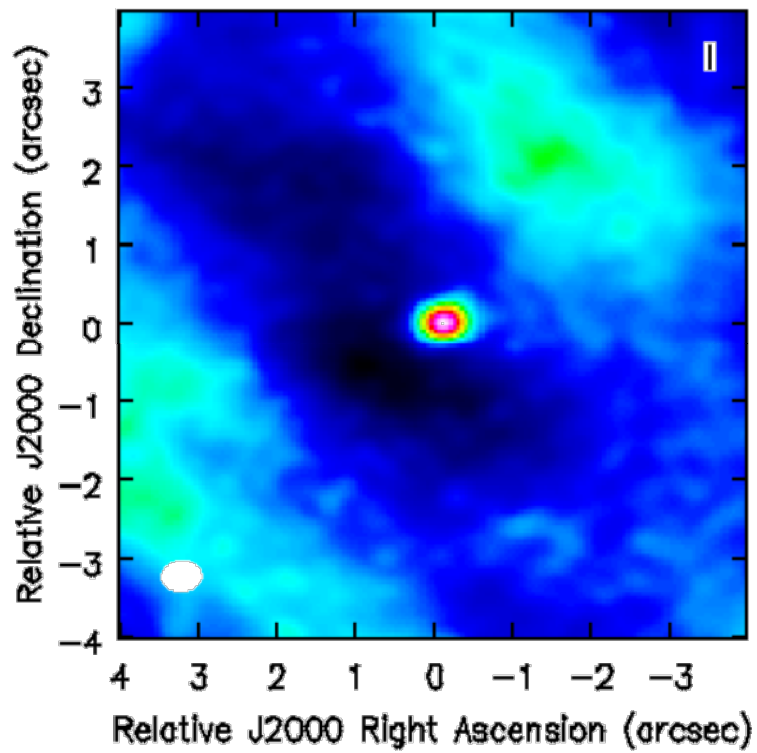


Dirty Beam



Continuum Map

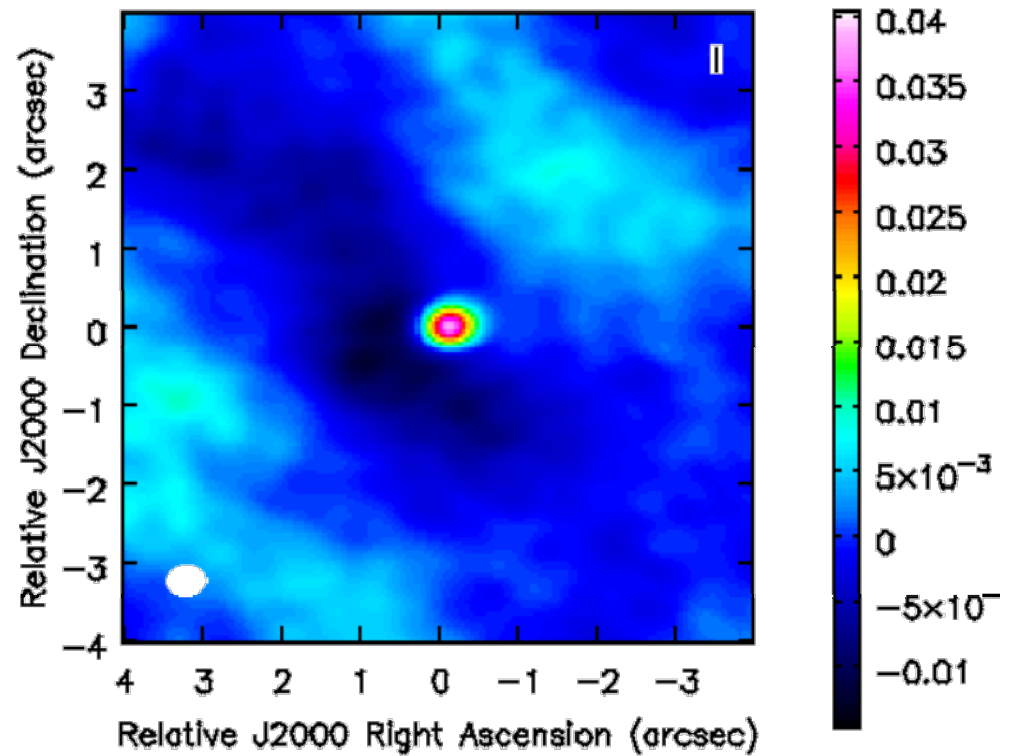
Dirty Image



Field of view : 8.7''

Rms : 1.61 mJy/bm

Clean Image



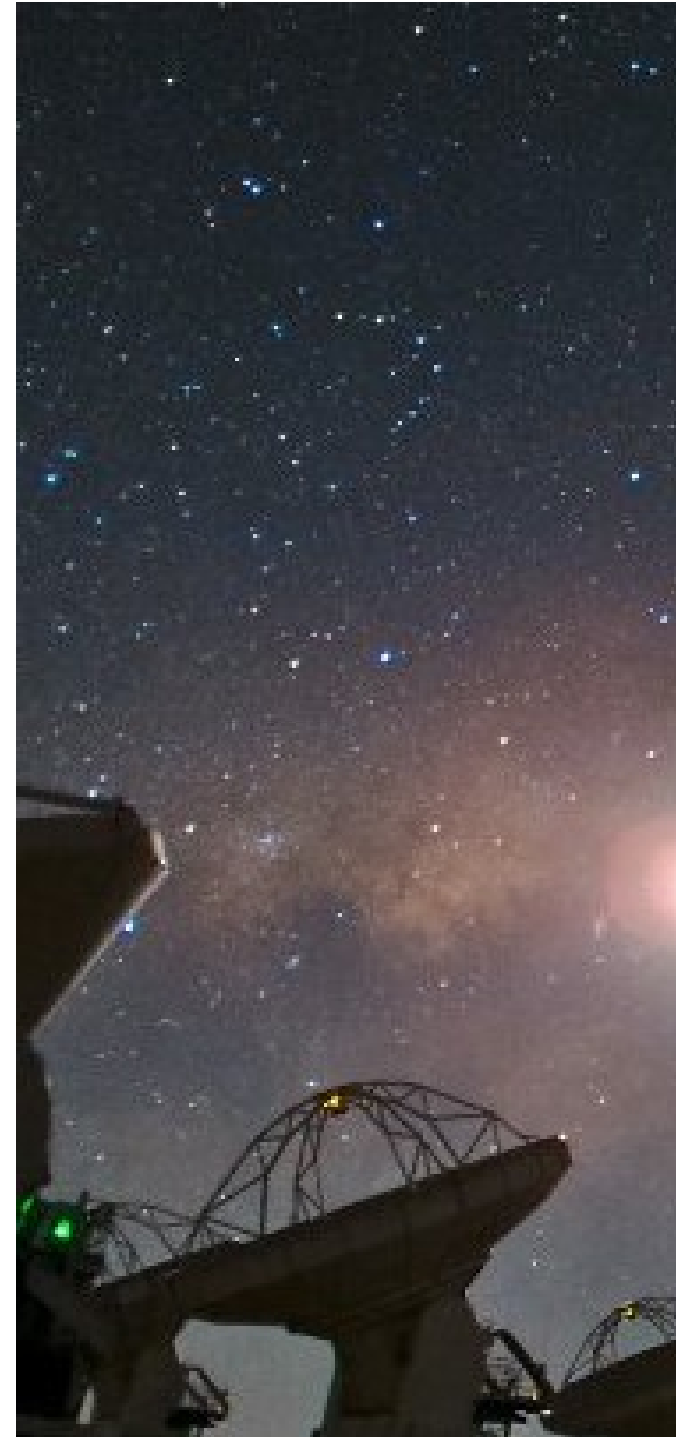
Clean Beam : 0''.52×0''.41

Threshold = 1.7 mJy/bm

Rms : 1.54 mJy/bm

ALMA Data

- **May 19, 2018** **10:15 ~ 11:25 UT**
Frequency (GHz): 664.076 to 665.013
Number of channels : 1920
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Frequency (GHz): 664.078 to 665.015
Number of channels : 1920
- May 24, 2018 07:53 ~ 09:03 UT
Frequency (GHz): 664.077 to 665.015
Number of channels : 1920



ALMA Data

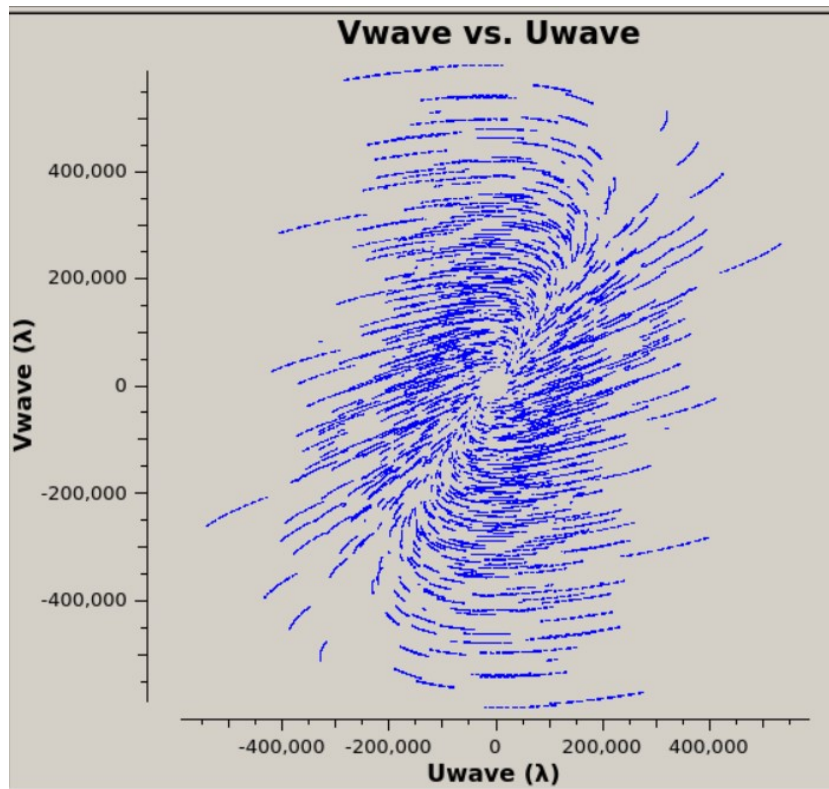
- Observation Time : **May 19, 2018** 10:15 ~ 11:25 UT
- Antenna (the 12-m array) : 46
- Frequency coverage (GHz): 664.076 to 665.013
- Channel Width : 488.233 (kHz) $\sim 0.22 \text{ km s}^{-1}$
- Number of channels : 1920



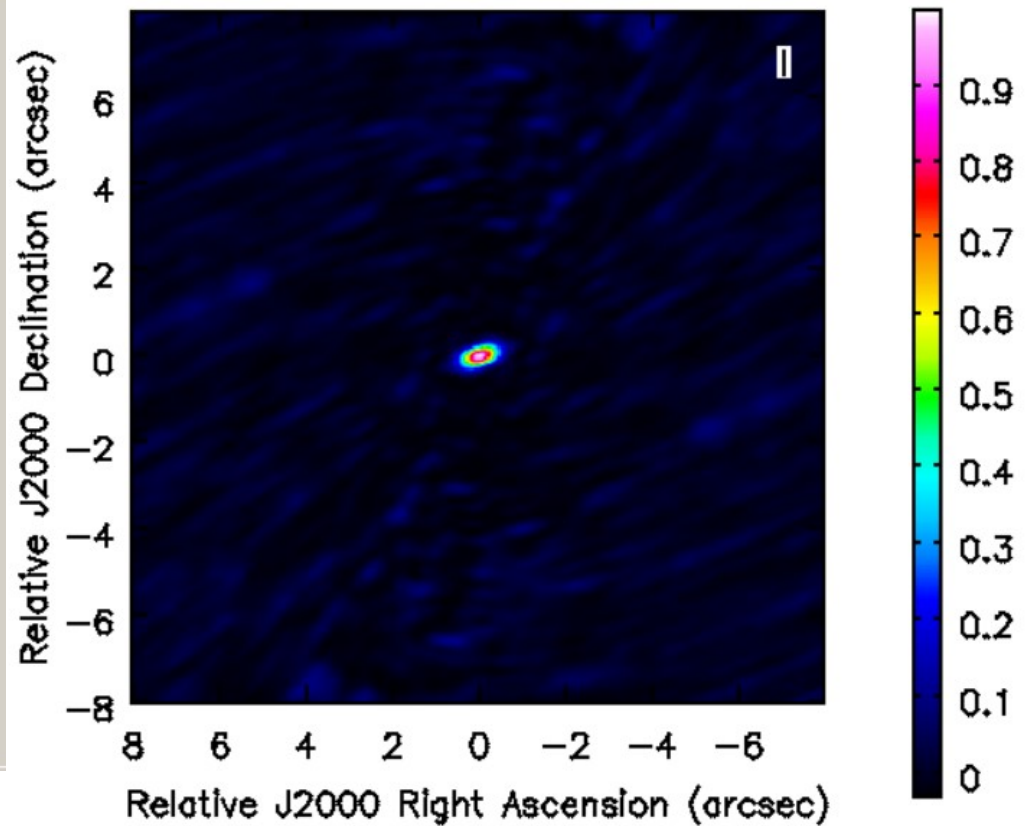
Third Data Set

Observation Time : May, 19 10:15 ~ 11:25 UT

UV coverage



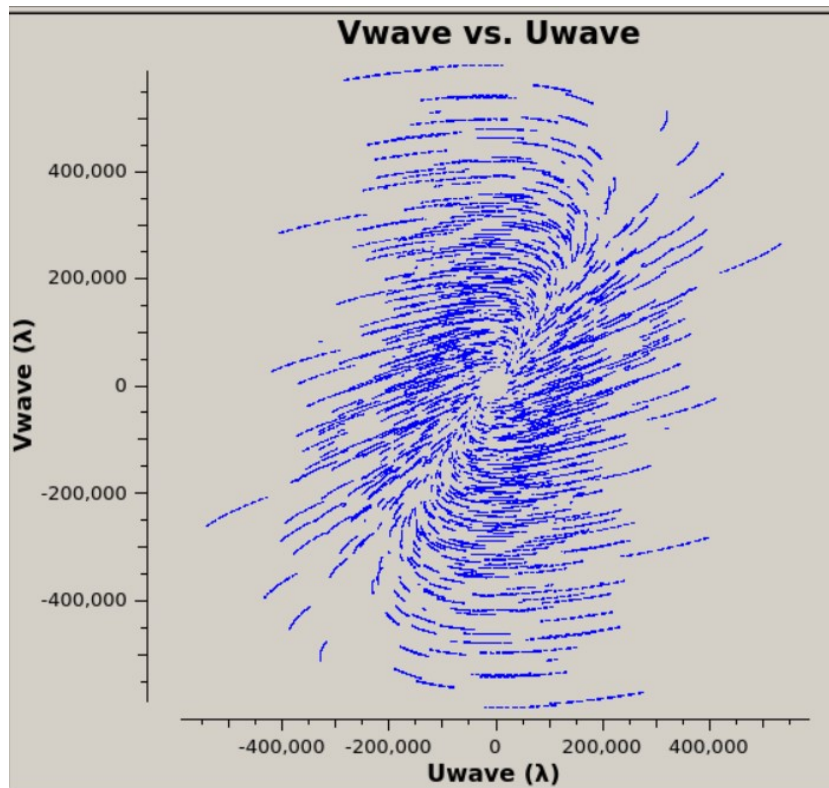
Dirty Beam



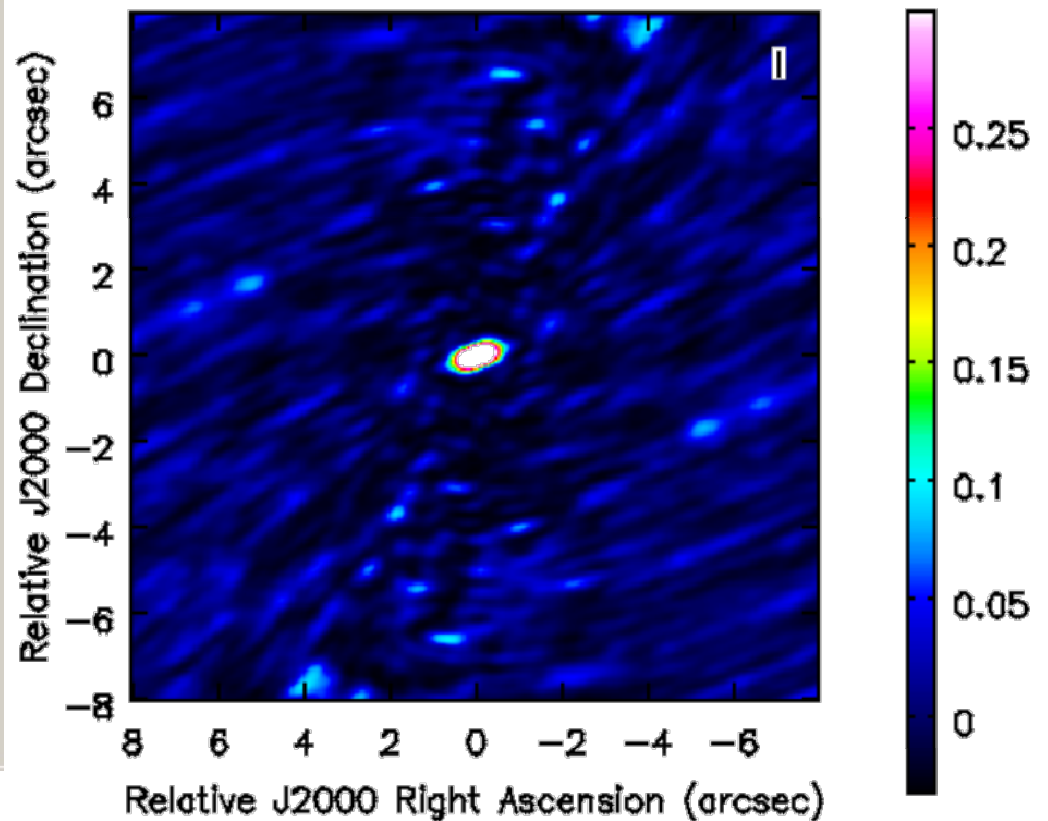
Third Data Set

Observation Time : May, 19 10:15 ~ 11:25 UT

UV coverage

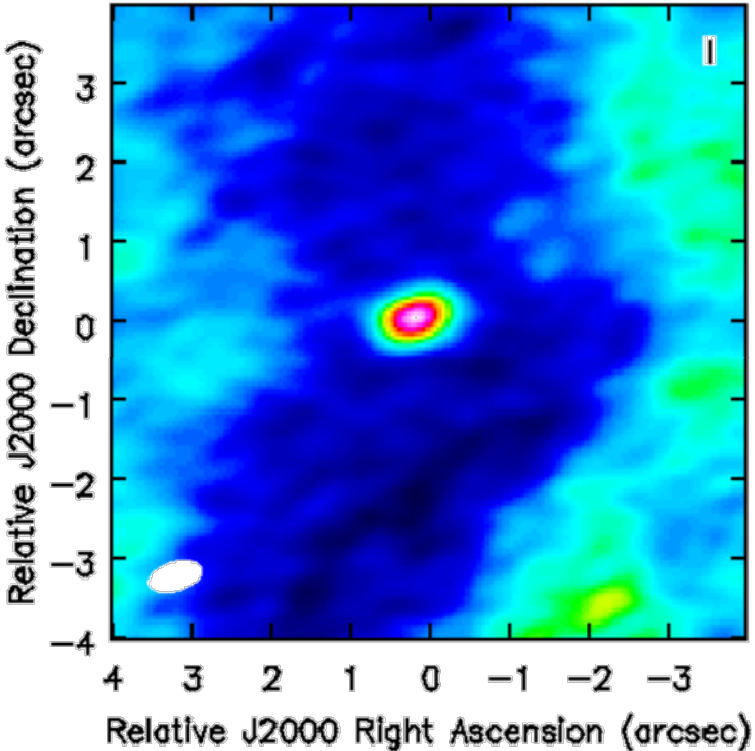


Dirty Beam



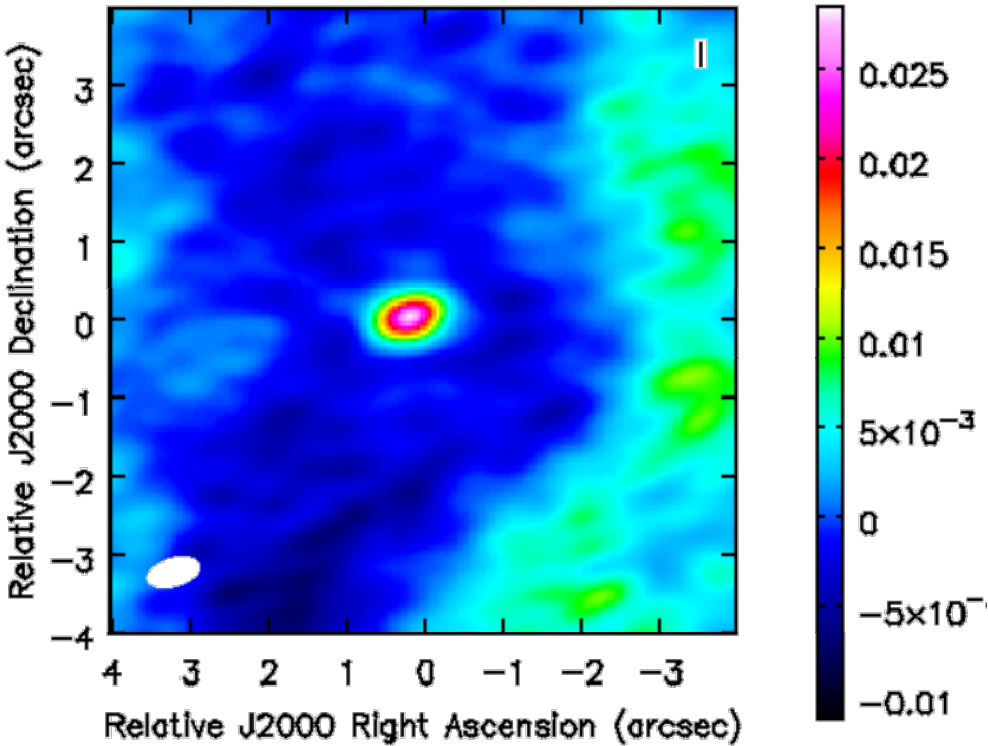
Continuum Map

Dirty Image



Field of view : 8.7"
Rms : 3.03 mJy/bm

Clean Image



Clean Beam : 0".69x0".37
Threshold = 1 mJy/bm
Rms : 1.85 mJy/bm

Next Step : Combine Three MS Sets

Plumes



South Pole of Enceladus

Plumes on Enceladus are always there.

Plumes on Enceladus, 2012
NASA/JPL/SSI

ALMA Data

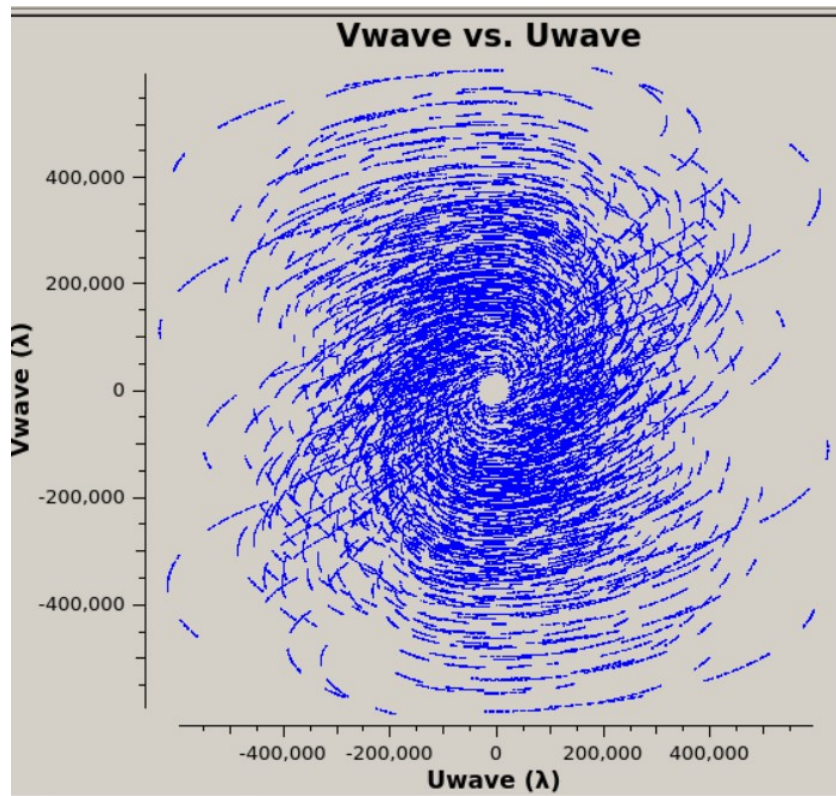
- May 19, 2018 10:15 ~ 11:25 UT
Frequency coverage (GHz): 664.076 to 665.013
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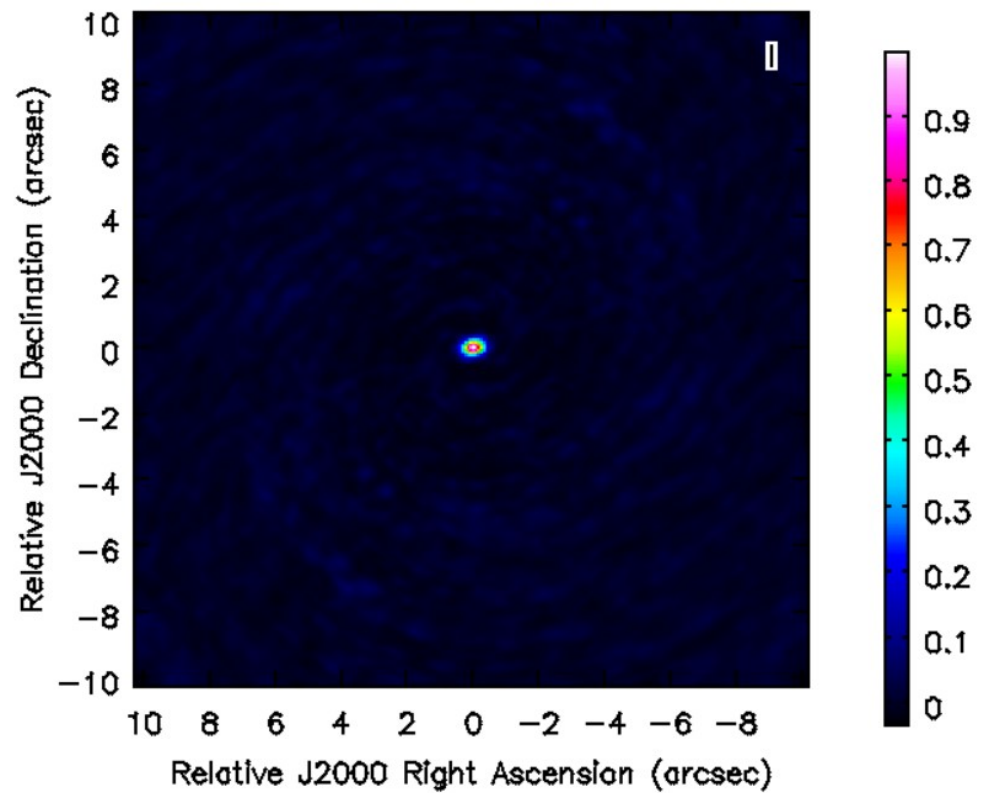
**Using
Concat**

Combined Data Set

UV Coverage

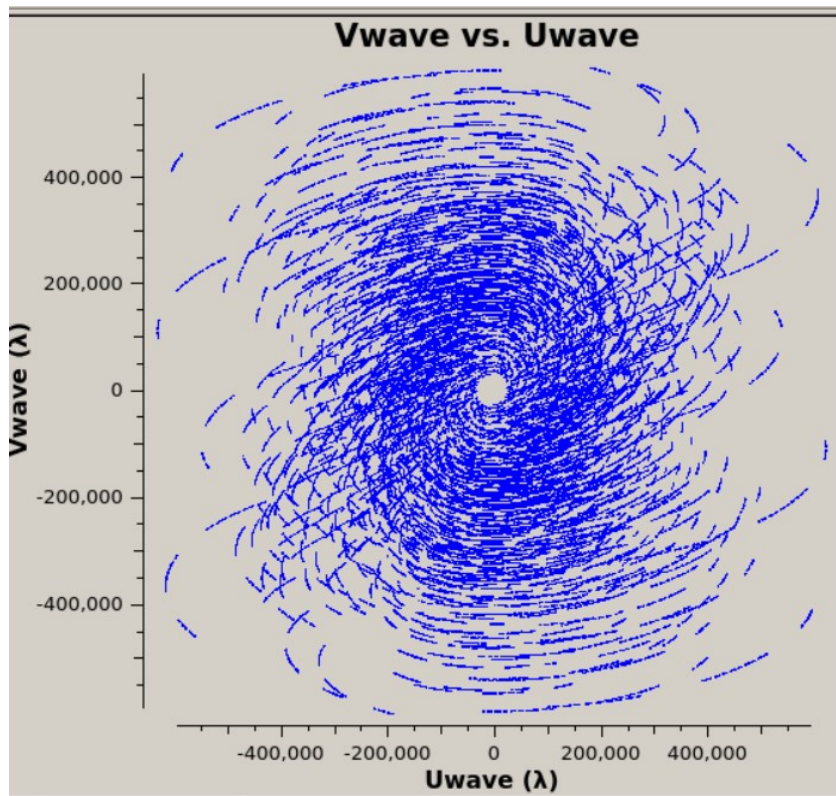


Dirty Beam

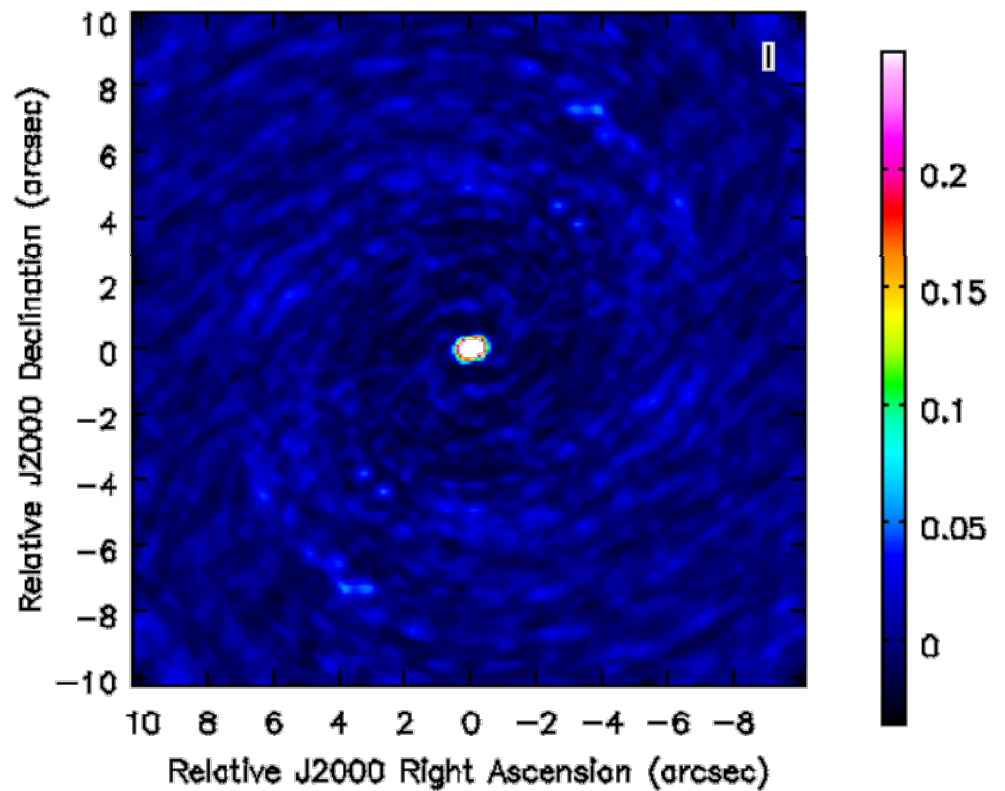


Combined Data Set

UV Coverage

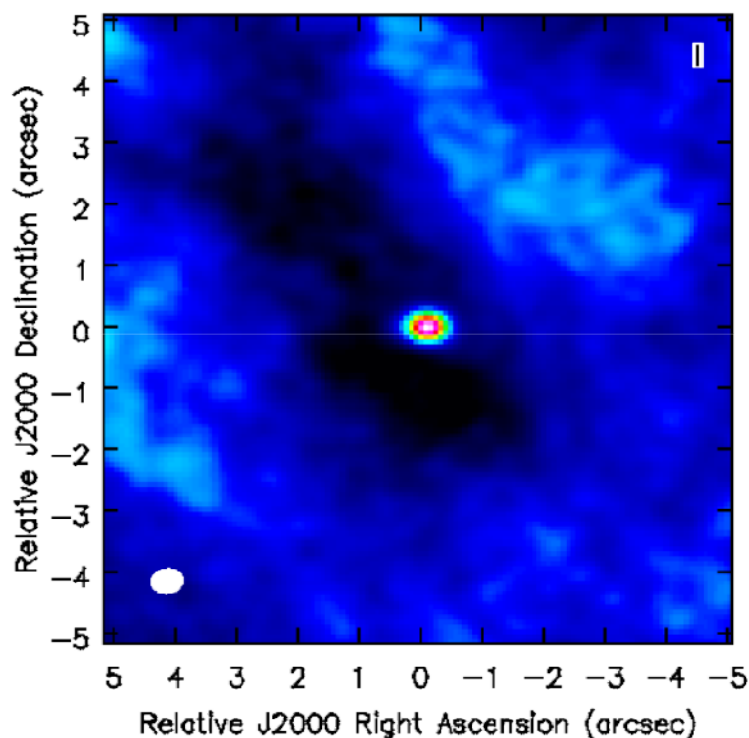


Dirty Beam



Continuum Map of the Concated Data

Clean Image

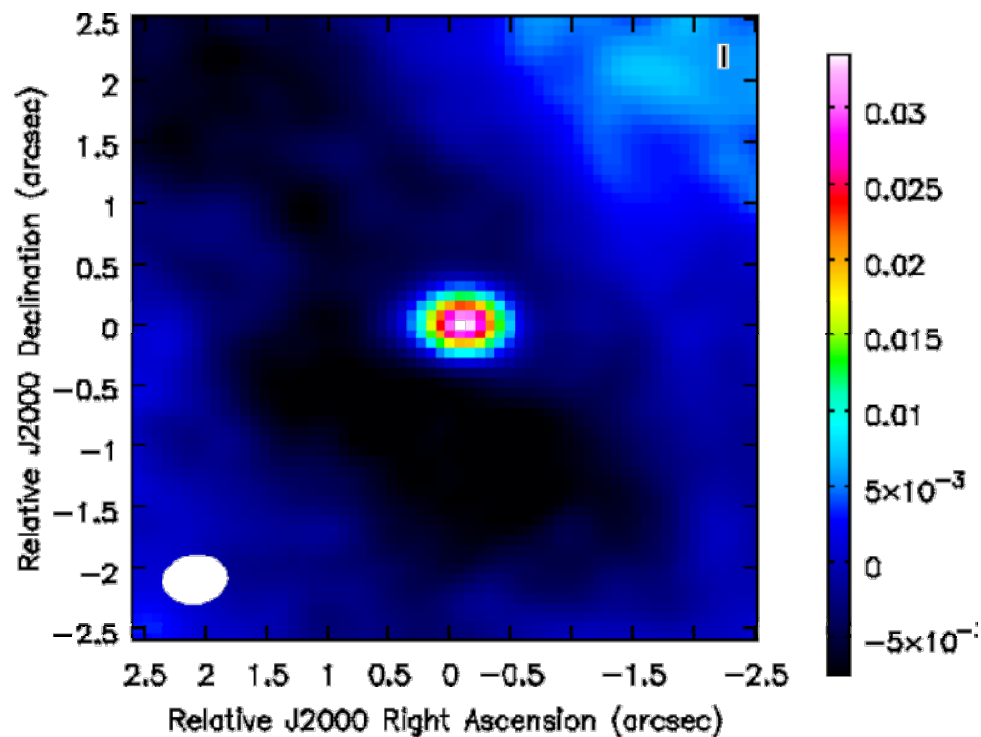


Field of view : 8.7"

Clean Beam : 0".53x0".40

Threshold = 1.3 mJy/bm

Clean Image (Zoom in)

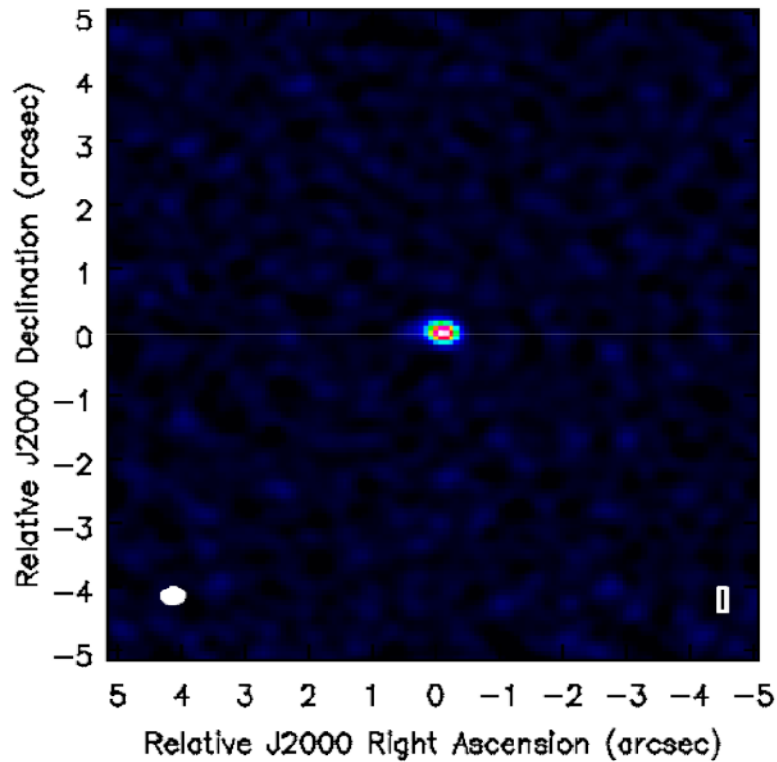


Rms : 1.11 mJy/bm

Peak : 33.6 mJy

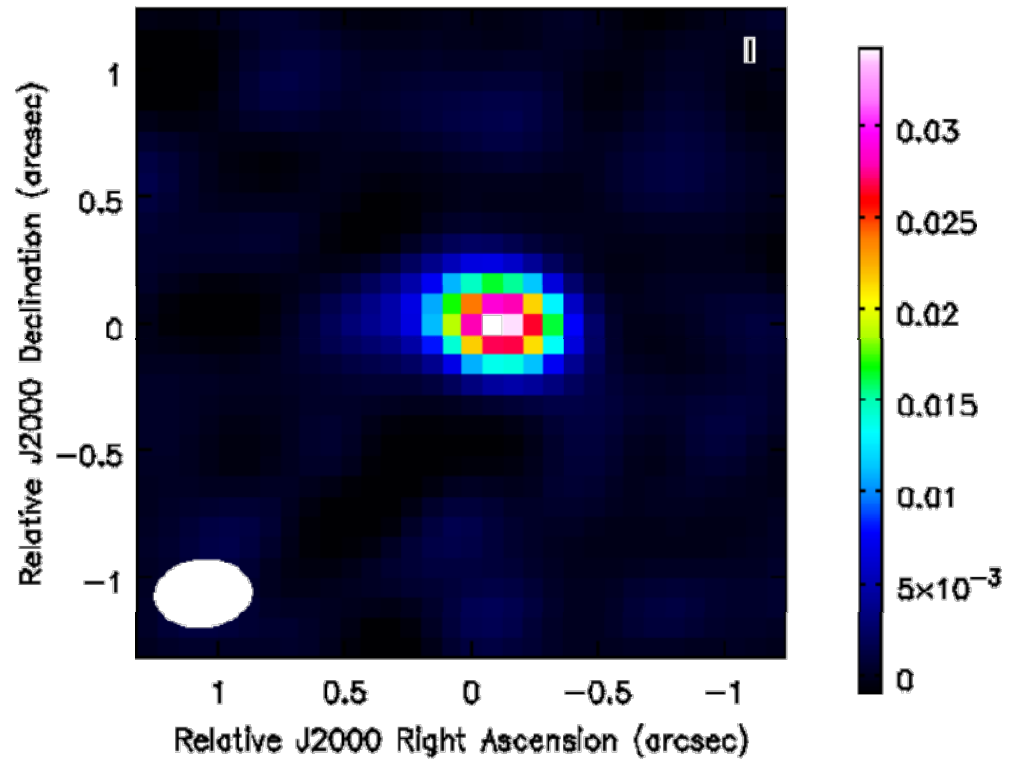
Clean Images of separated Uvrange

Uvrange > 200k λ



Field of view : 8.7"
Clean Beam : 0".38 \times 0".27
Threshold = 0.5 mJy/bm

Uvrange > 200k λ (Zoom in)



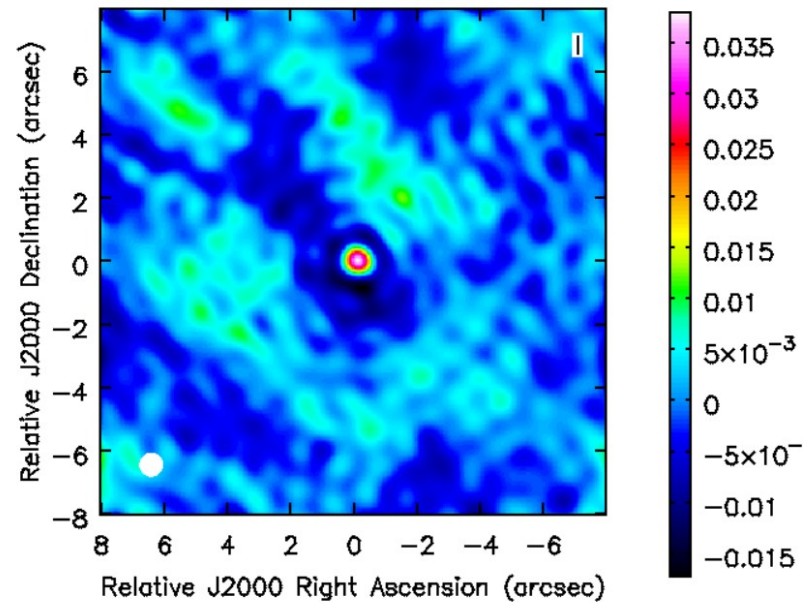
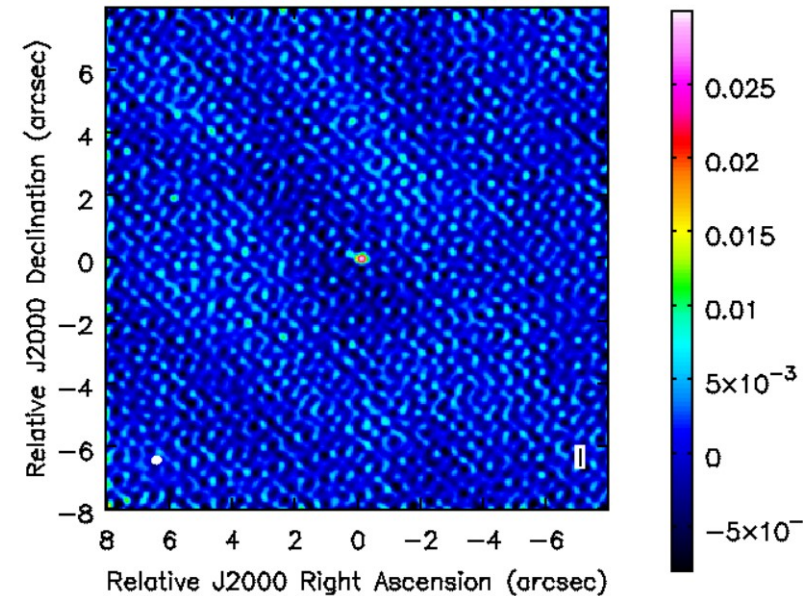
Peak : 34.3 mJy
Flux Density : 42.2 mJy

Summary

- The best continuum map is the image of concat'ed data using uv range $> 200k\lambda$.
- Cloudy things around Enceladus are from extended source.

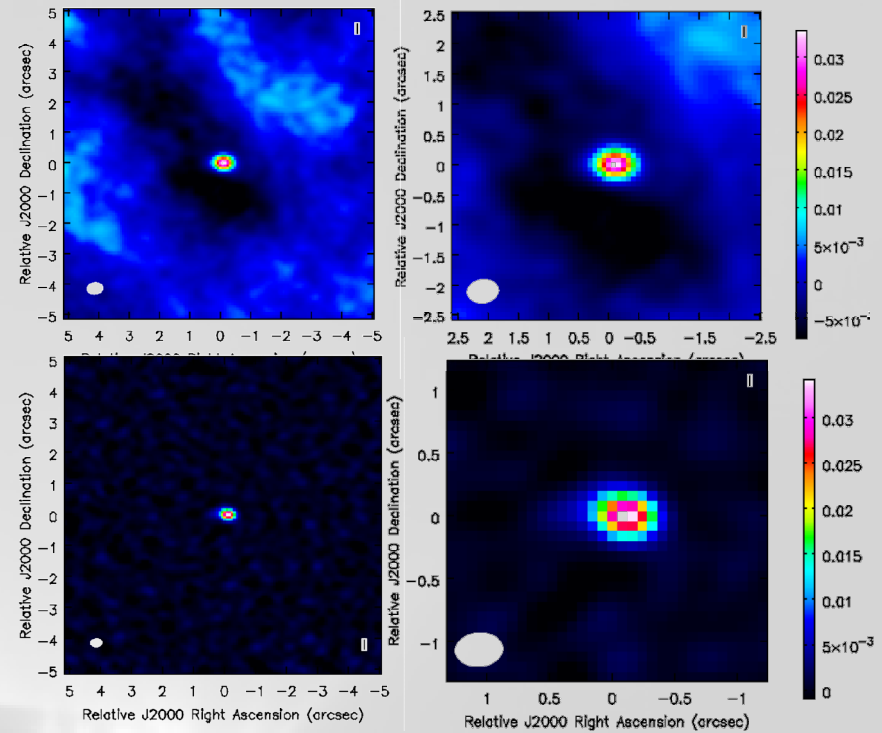
Challenge

- Clean image using uniform weighting has strange pattern, but we haven't found out where's the problem.



Future Work

- Check the channel map of the concat'ed data.
- Find the signal of NaCl.



Concat'ed Data



The End.

Thank you for your listening!