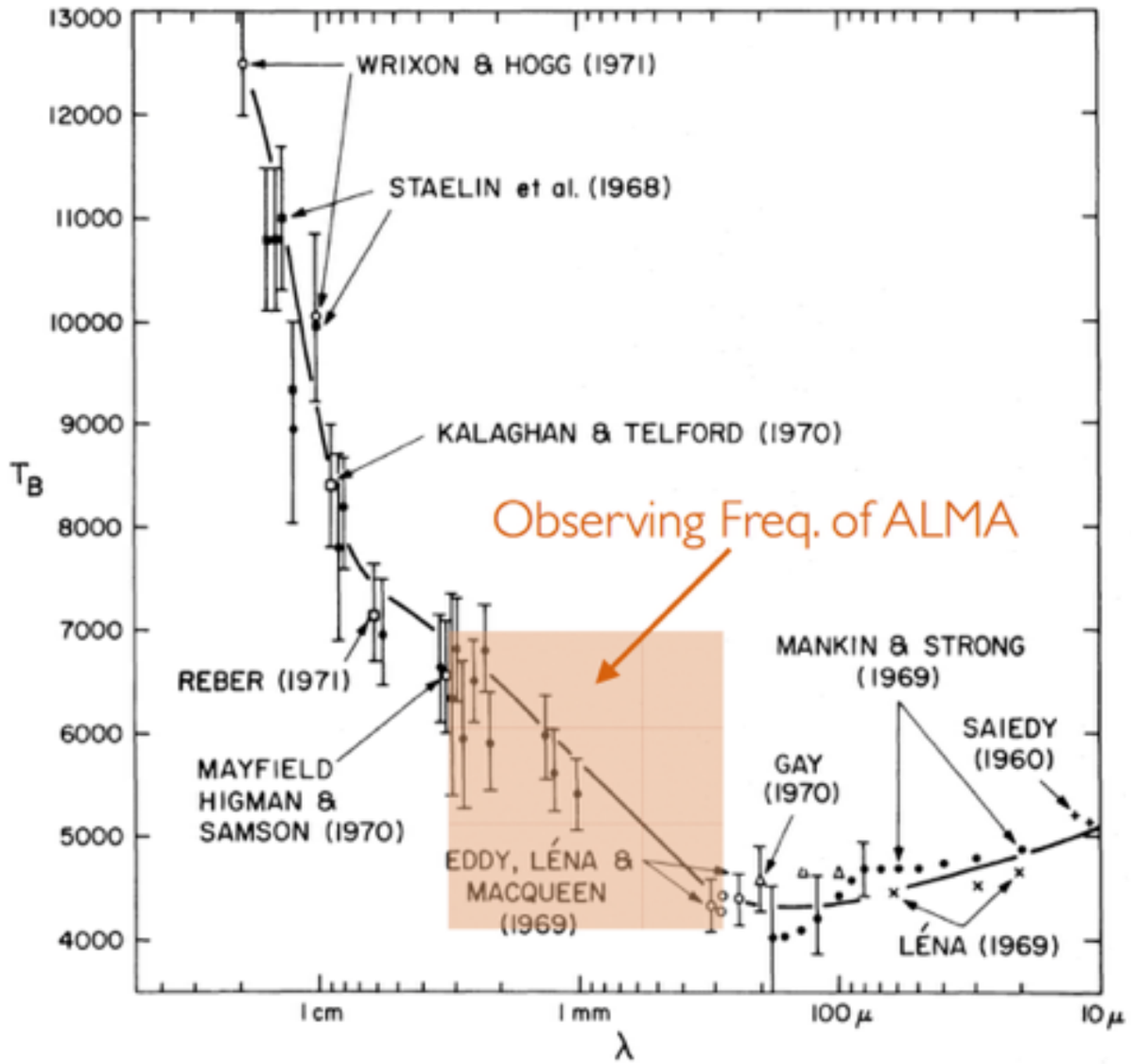
# Solar Observation using ALMA

# Science

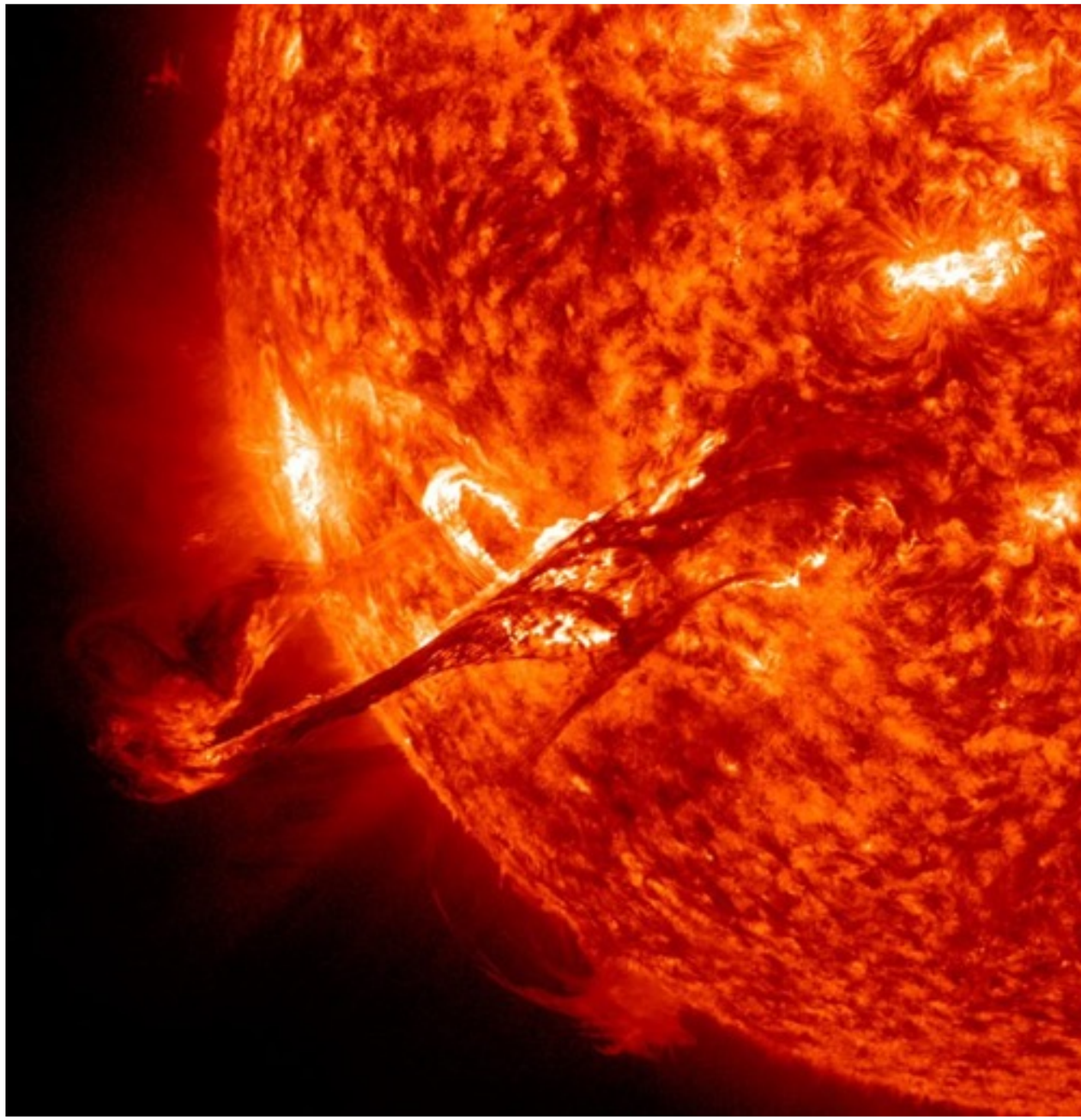
- Chromosphere
  - Continuum radiation at sub-mm, thermal f-f
- Flare physics
  - particle acceleration
  - new insight on spectrum
- Filament/Prominence
- New Diagnostics
  - Oscillation
  - Spectral lines
    (radio recombination line, Co)




Chromosperic spectrum calculated by VALC Model
Vernazza, Averett & Loeser, 1973

# Science

- Chromosphere
  - Continuum radiation at sub-mm~ thermometer
- Flare physics
  - particle acceleration
  - new insight on spectrum
- Filament/Prominence
- New Diagnostics
  - Oscillation
  - Spectral lines
    (radio recombination line, Co)



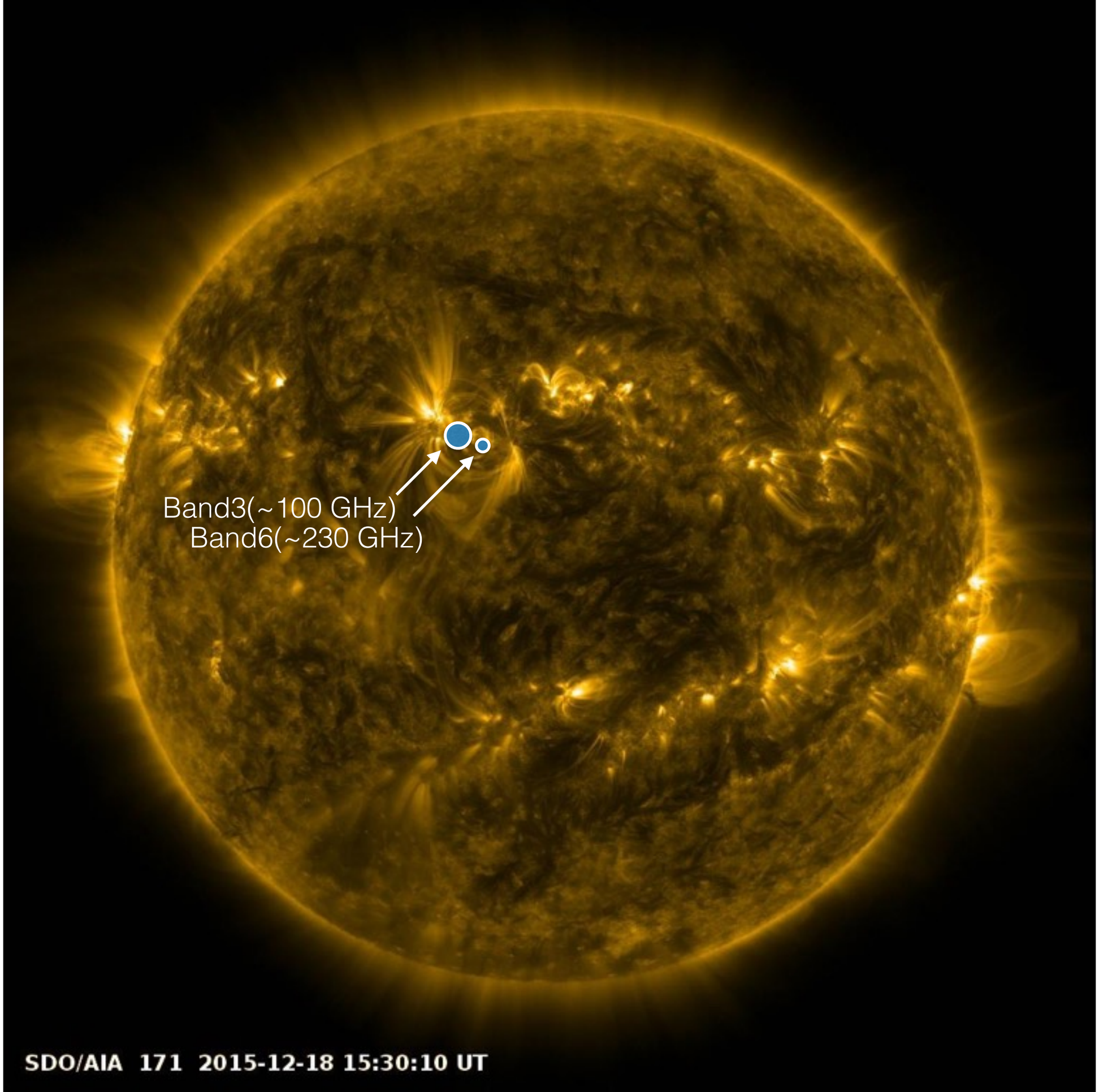
# Solar Observation ALMA Issues

- Sun is big ( ~ 0.5 degree)
  - << ALMA FoV

- Solar $T_B$ ~ 6000 K (Sis Mixer-Detuning Mode:MD1/2)
  - ALMA sensitivity ~ 800 K

- Variable
  - time scale - ms ~ hours
  - spacial scale - 0.1”~

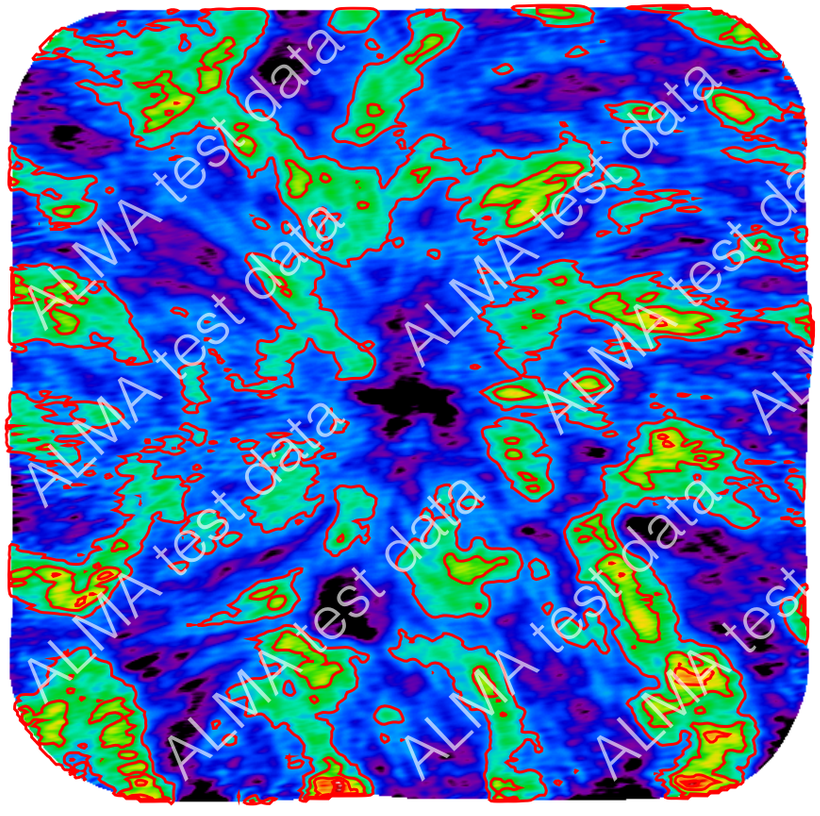
- Support by coordinate observations
  - ground-based: NST, DKIST(2020), so on
  - satellites: IRIS, Hinode


Band3(~100 GHz)
Band6(~230 GHz)
SDO/AIA 171 2015-12-18 15:30:10 UT

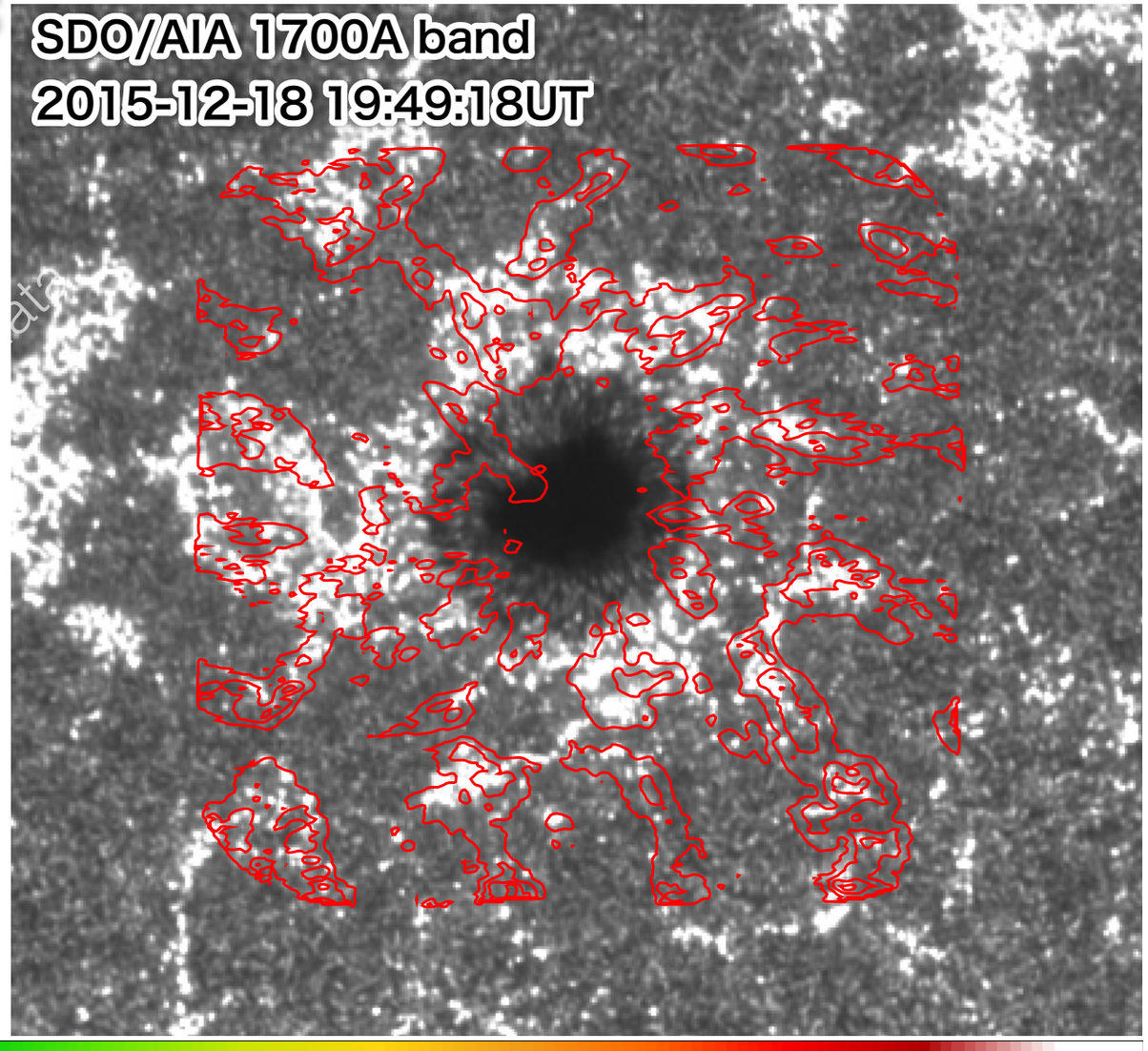
CSV/EOC Data

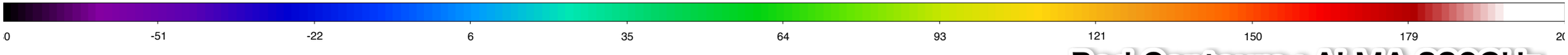
# Mosaic Mode

ALMA 150pts-Mosaic Image
NOAA 12470 Preceding Sunspot
2015-12-18 19:39 -- 20:03UT




Band6 230 GHz (Synth. Beam 2.6" x 0.7")




Red Contours : ALMA 230GHz

# Solar Observation ALMA Issues

- Sun is big ( ~ 0.5 degree)
  - << ALMA FoV

- Solar $T_B$ ~ 6000 K (Sis Mixer-Detuning Mode:MD1/2)
  - ALMA sensitivity ~ 800 K

- Variable
  - time scale - ms ~ hours
  - spacial scale - 0.1”~

- Support by coordinate observations
  - ground-based: NST, DKIST(2020), so on
  - satellites: IRIS, Hinode

# Coordinate Observations(Groundbased)

# ALMA capability for Cycle4

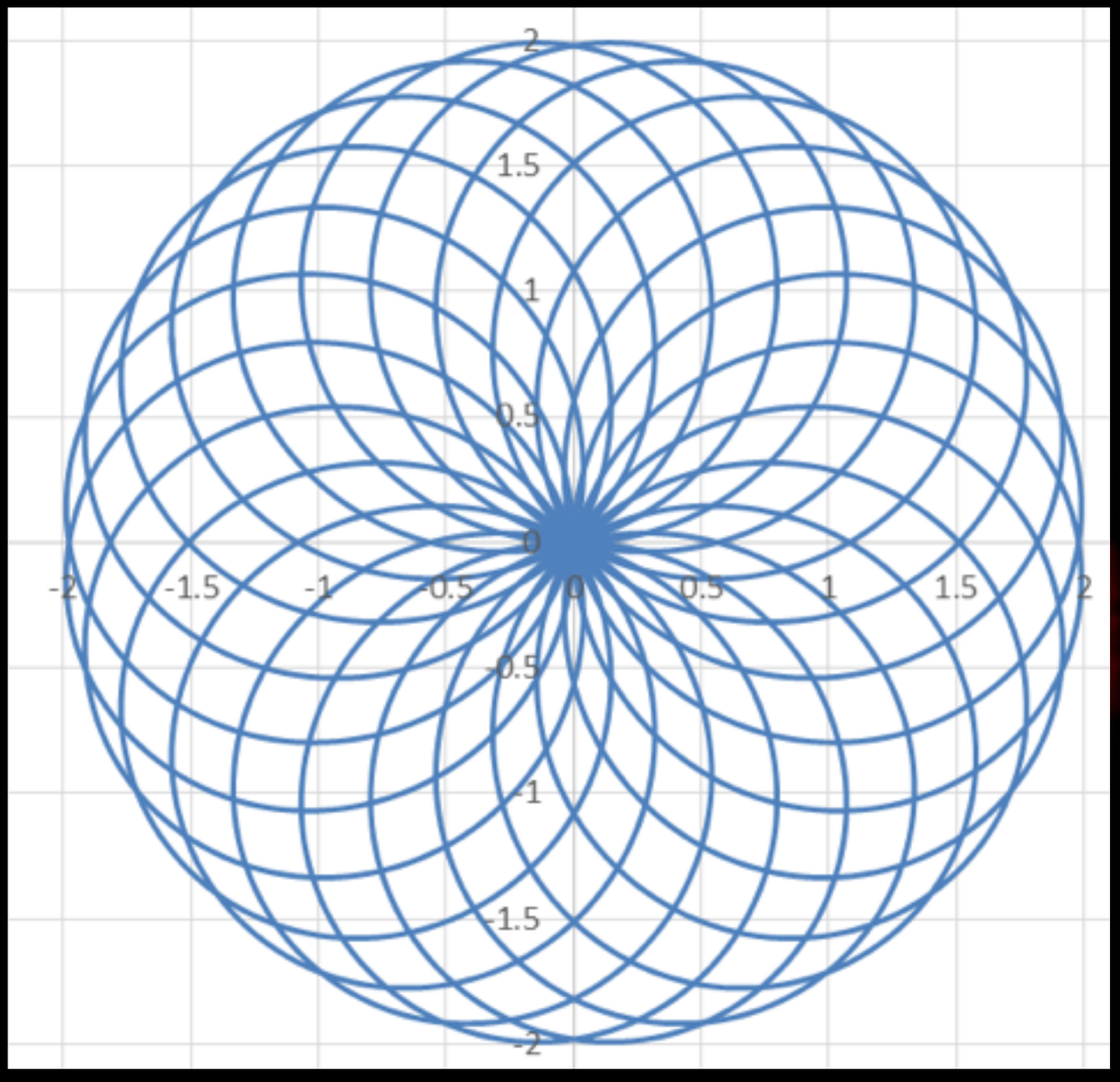
- Band3 & Band6 : 4 windows with128 channels/2 GHz
  - Band3: 93, 95, 105, 107 GHz
  - Band6: 230, 232, 246, 248 GHz
- Spatial Resolution: 1.5”~3.7” @Band3 / 0.63”~1.6”@Band6
  - C40-1(150m), C40-2(273m), C40-3(460m)  +ACA
- Single Pointing(2 s), Mosaic Mode(>20 m, max 150-points)
- Period of solar observations in a day: 13:00UT ~ 20:00UT
- Observing Season: 23 December 2016 ~ 27 April 2017
- Single-Dish(12m) array observation support Interferometric observation

# Array

| Config | Lmax | Band | Band 3 | Band 4 | Band 6 | Band 7 | Band 8 | Band 9 | Band 10 |
|---|---|---|---|---|---|---|---|---|---|
| | Lmin | Freq | 100 GHz | 150 GHz | 230 GHz | 345 GHz | 460 GHz | 650 GHz | 870 GHz |
| 7-m Array | 45 m | AR | 12.5" | 8.4" | 5.4" | 3.6" | 2.7" | 1.9" | 1.4" |
| | 9 m | MRS | 66.7" | 44.5" | 29.0" | 19.3" | 14.5" | 10.3" | 7.7" |
| C40-1 | 155 m | AR | 3.7" | 2.5" | 1.6" | 1.1" | 0.80" | 0.57" | 0.42" |
| | 15 m | MRS | 29.0" | 19.4" | 12.6" | 8.4" | 6.3" | 4.5" | 3.3" |
| C40-2 | 273 m | AR | 2.4" | 1.6" | 1.0" | 0.69" | 0.52" | 0.37" | 0.27" |
| | 15 m | MRS | 22.1" | 14.8" | 9.6" | 6.4" | 4.8" | 3.4" | 2.5" |
| C40-3 | 460 m | AR | 1.5" | 0.97" | 0.63" | 0.42" | 0.32" | 0.22" | 0.17" |
| | 15 m | MRS | 13.7" | 9.1" | 5.9" | 4.0" | 3.0" | 2.1" | 1.6" |
| C40-4 | 704 m | AR | 0.93" | 0.62" | 0.40" | 0.27" | 0.20" | 0.14" | 0.11" |
| | 15 m | MRS | 8.9" | 5.9" | 3.9" | 2.6" | 1.9" | 1.4" | 1.0" |
| C40-5 | 1.1 km | AR | 0.54" | 0.36" | 0.23" | 0.16" | 0.12" | 0.083" | 0.062" |
| | 17 m | MRS | 6.0" | 4.0" | 2.6" | 1.7" | 1.3" | 0.93" | 0.69" |
| C40-6 | 1.8 km | AR | 0.35" | 0.23" | 0.15" | 0.10" | 0.076" | 0.054" | 0.040" |
| | 15 m | MRS | 3.1" | 2.1" | 1.3" | 0.90" | 0.67" | 0.48" | 0.36" |
| C40-7 | 3.7 km | AR | 0.21" | 0.14" | 0.090" | 0.060" | 0.045" | 0.032" | 0.024" |
| | 81 m | MRS | 1.8" | 1.2" | 0.77" | 0.52" | 0.39" | 0.27" | 0.20" |
| C40-8 | 6.8 km | AR | 0.12" | 0.079" | 0.052" | 0.034" | N/A | N/A | N/A |
| | 168 m | MRS | 1.3" | 0.87" | 0.57" | 0.38" | | | |
| C40-9 | 12.6 km | AR | 0.066" | 0.044" | 0.029" | N/A | N/A | N/A | N/A |
| | 271 m | MRS | 0.78" | 0.52" | 0.34" | | | | |

CSV/EOC Data

# Single-Dish scanning (Band9)

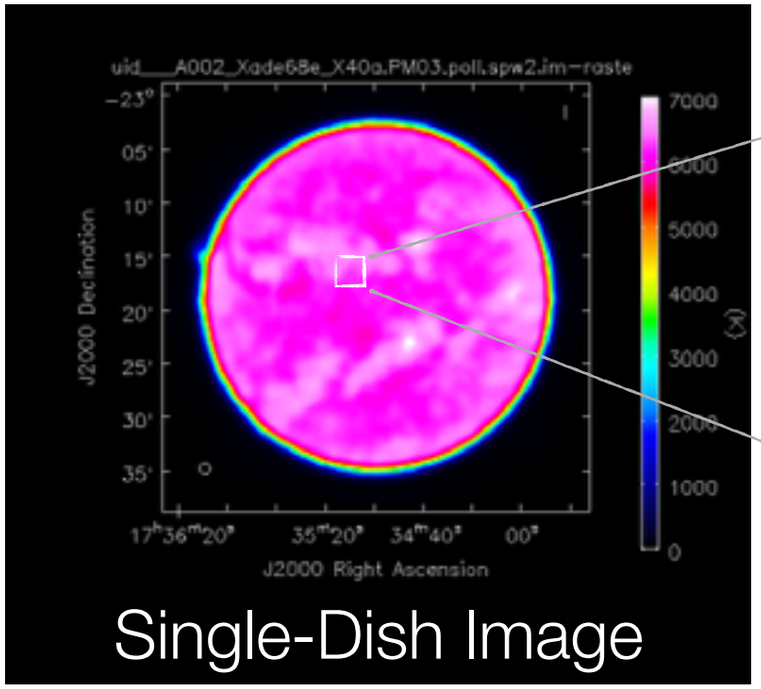




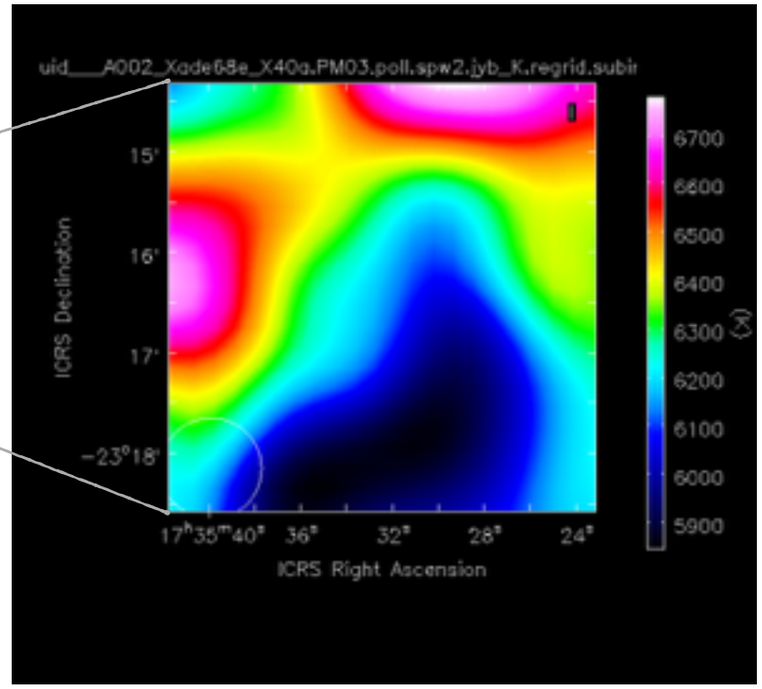
SDO/AIA 304 2015-12-18 15:30:06 UT

# Combine interferometric image with single-dish image

## Example: 149pts-Mosaic Observation with Band3

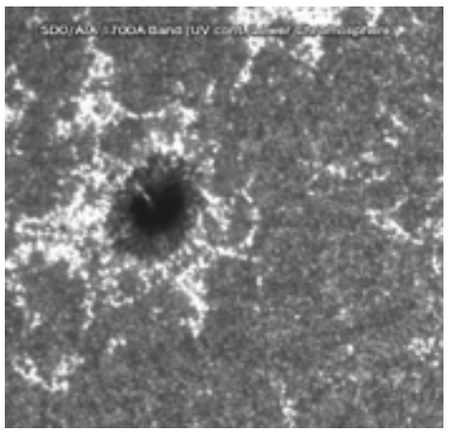



Single-Dish Image

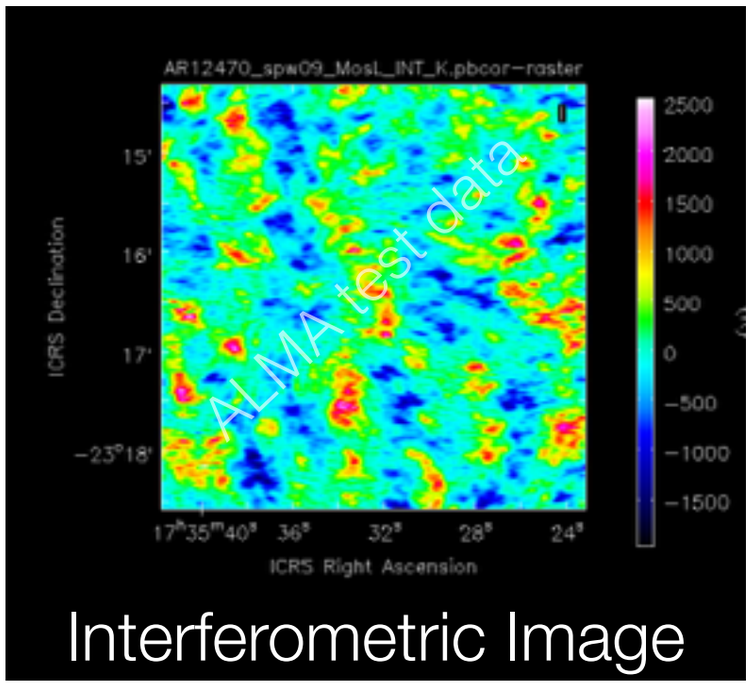



Unit: Brightness Temperature [K]

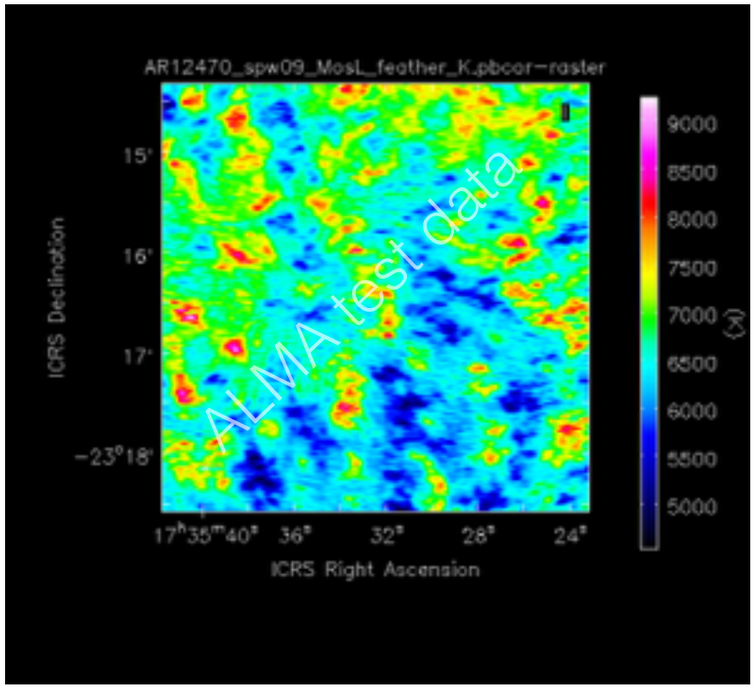
**Feathering**



SDO/AIA 1700A Band




Interferometric Image



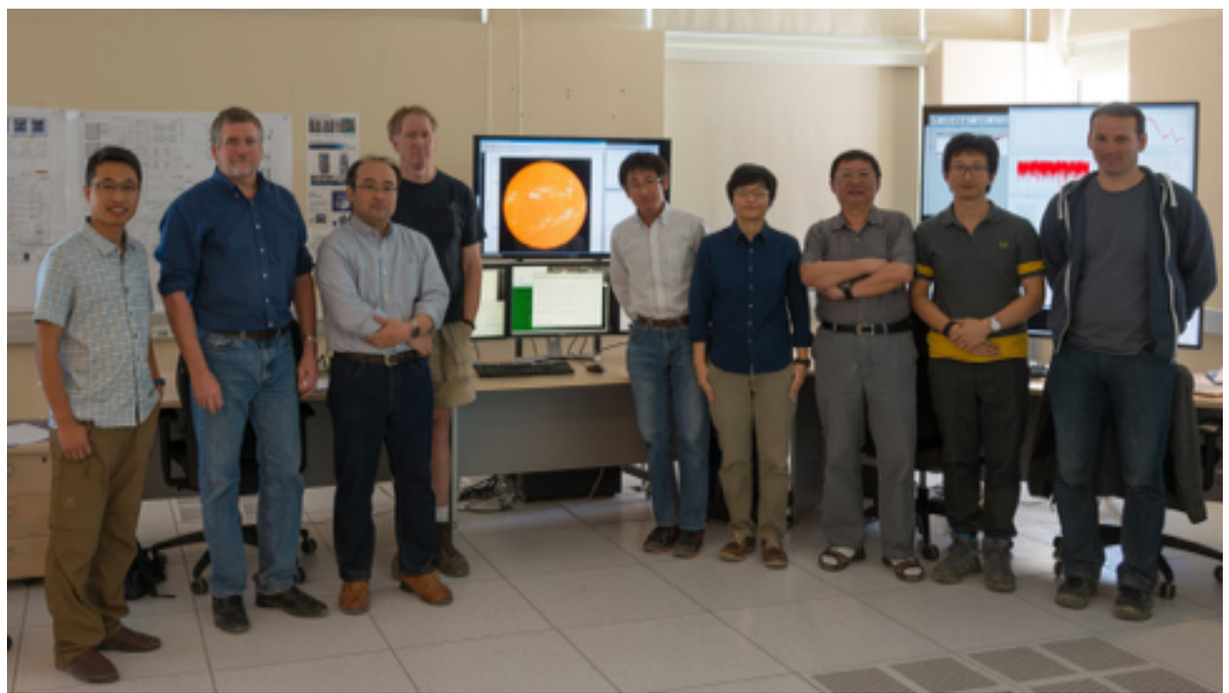
# Solar Commissioning Campaign 2015

- 2015/12/14 - 2015/12/21
  - We could not carry out observations in afternoon 19-21 Dec, because the wind in the antenna site is too strong mainly.
- Goals: **Dress-Rehearsal of Cycle4** / New function of Cycle5
- # of antennas: 20~23 12-m + 7~8 7-m antennas. Total: **27~31 antennas**… with C36-1 (Most compact configuration)
- Lead of The Campaign: Tim Bastian (NRAO)
- Lead of the interferometer: Masumi Shimojo (NAOJ)
- Lead of the single-dish: Stephen White (AFRL)
- Supporters from Joint ALMA Observatory: Antonio Hales, Neil Philips, Akihiro Hirota (Remote)

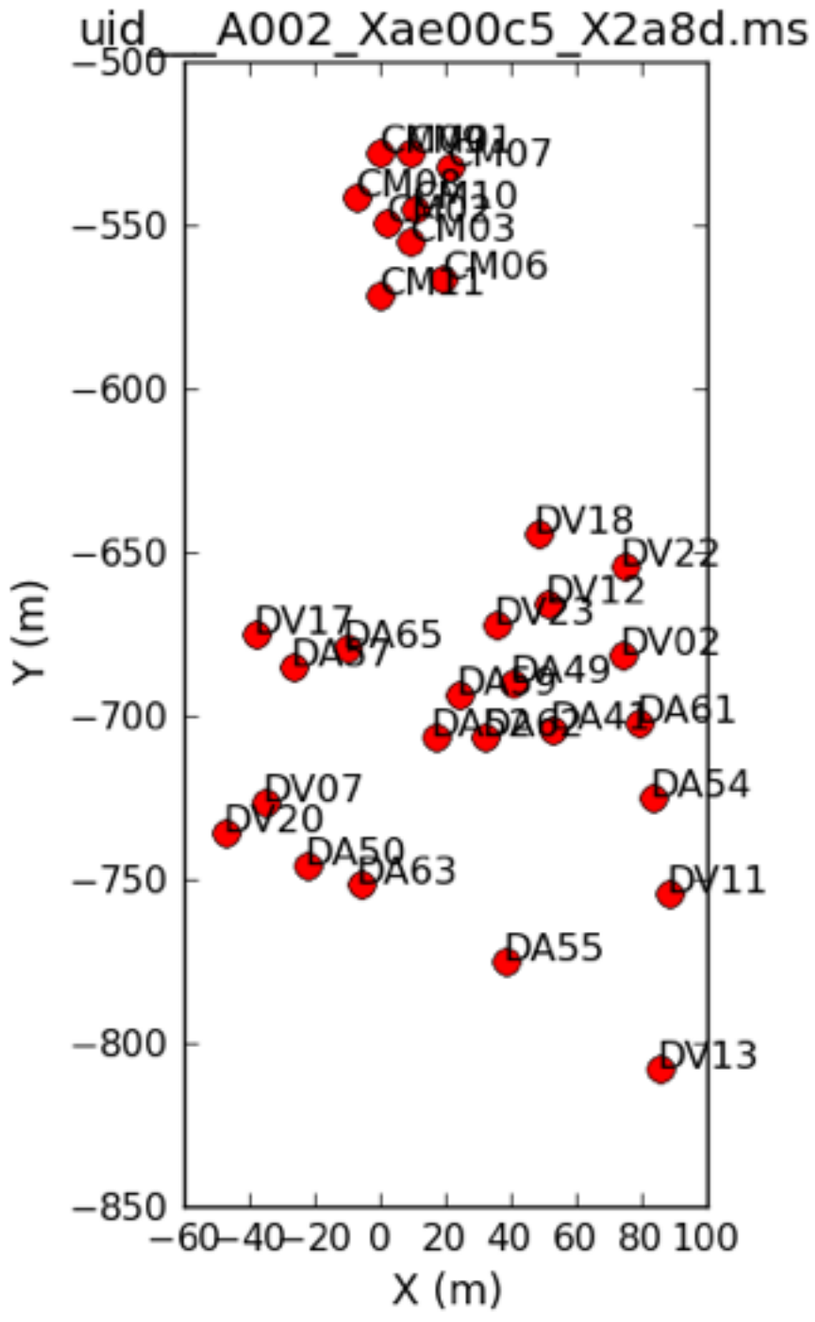
Cycle4 : 12m x 40 + 7m x 10 = 50 antennas

Joint Observations with Hinode, IRIS, NST/BBSO

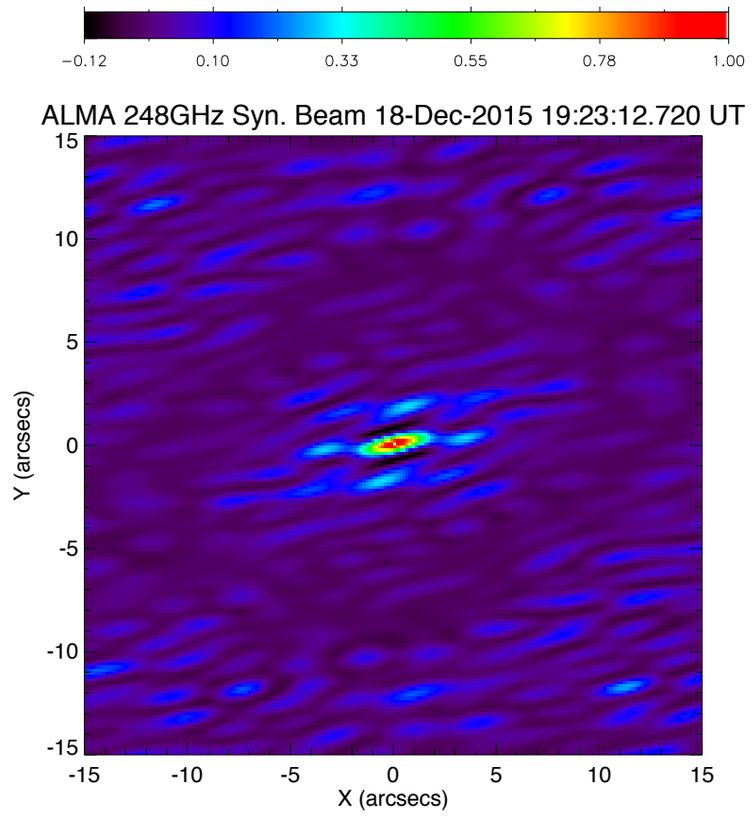
- EastAsia (EA)
  - Masumi Shimojo (NAOJ)
  - Kazumasa Iwai (NICT)
  - Sujin Kim (KASI)
- Europe (EU)
  - Ivica Skokie (Ondřejov Observatory)
- NorthAmerica (NA)
  - Tim Bastian (NRAO)
  - Stephen White (AFRL)
- China (as participants of NA development team)
    - Yihua Yang, Sijie Yu, Donghao Liu (NAOC)



# Typical antenna configuration & synthesized beam during solar development campaign 2015




Pseudo C36-1 configuration
(The number of antennas is shortage.)




- HPFW of Synthesized Beam
  - Band3: 4.8” x 1.4”
  - Band6: 2.8” x 0.7”

Spatial resolution in Cycle 4

| | Band3 | Band6 |
|---|---|---|
| C40-1+7m | 3.4” | 1.5” |
| C40-2+7m | 1.8” | 0.8” |
| C40-3+7m | 1.2” | 0.5” |

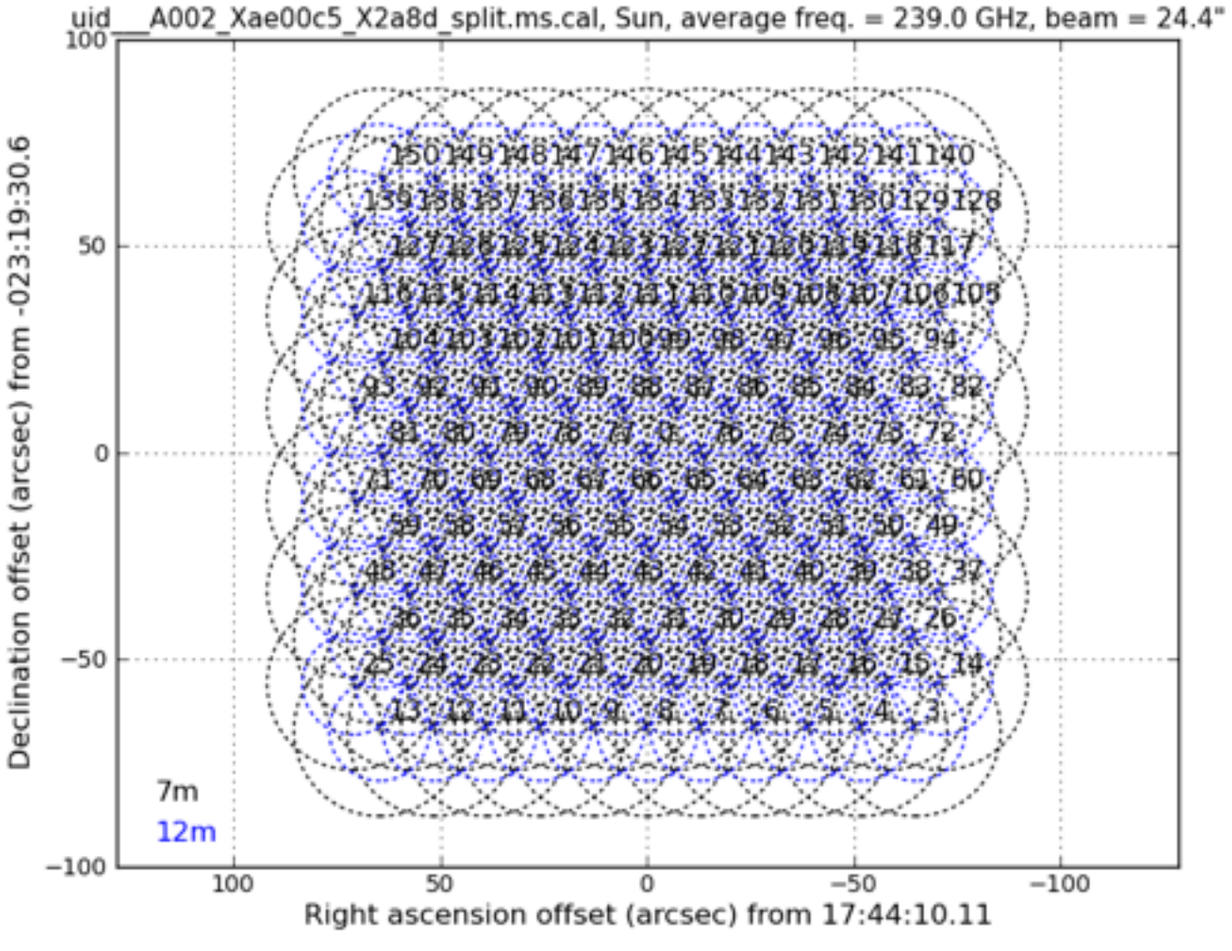
# Observed Targets of the 2015 solar campaign

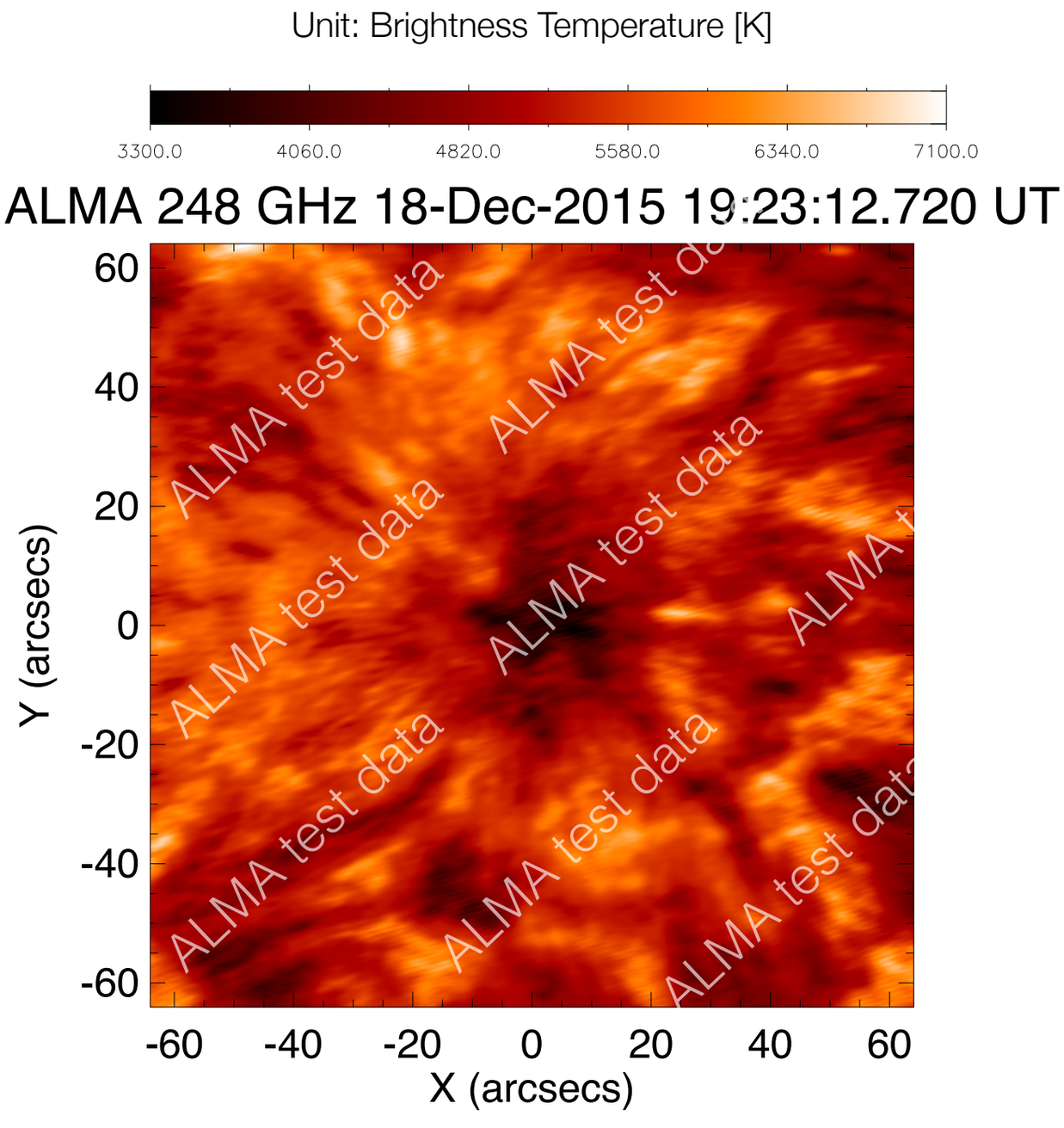
- 149pts-Mosaic Observations
  - **Band3 / Band6: AR12470**
  - **Band6: South Pole**
- 39pts-Mosaic Observations
  - **Band3: Prominence**
  - Band6: Quiet Sun near the Limb
  - ~~Band3: Quiet Sun on the disk~~
- Single-Pointing
  - **Band3** / ~~Band6~~: AR12470

**Preliminary Results!!**

- **FoV of the 149pts MOSAIC**
  - **350”x350”for Band3**
  - **150”x150’ for Band6**
- **FoV of Single-points:**
  - **60” for Band3/ 25” for Band6**
- **The coordinate of most images is the RA/DEC coordinate.**

# NOAA12470 Preceding Sunspot on 18-Dec-2015 Band6-248GHz 149pts-MOSAIC observation

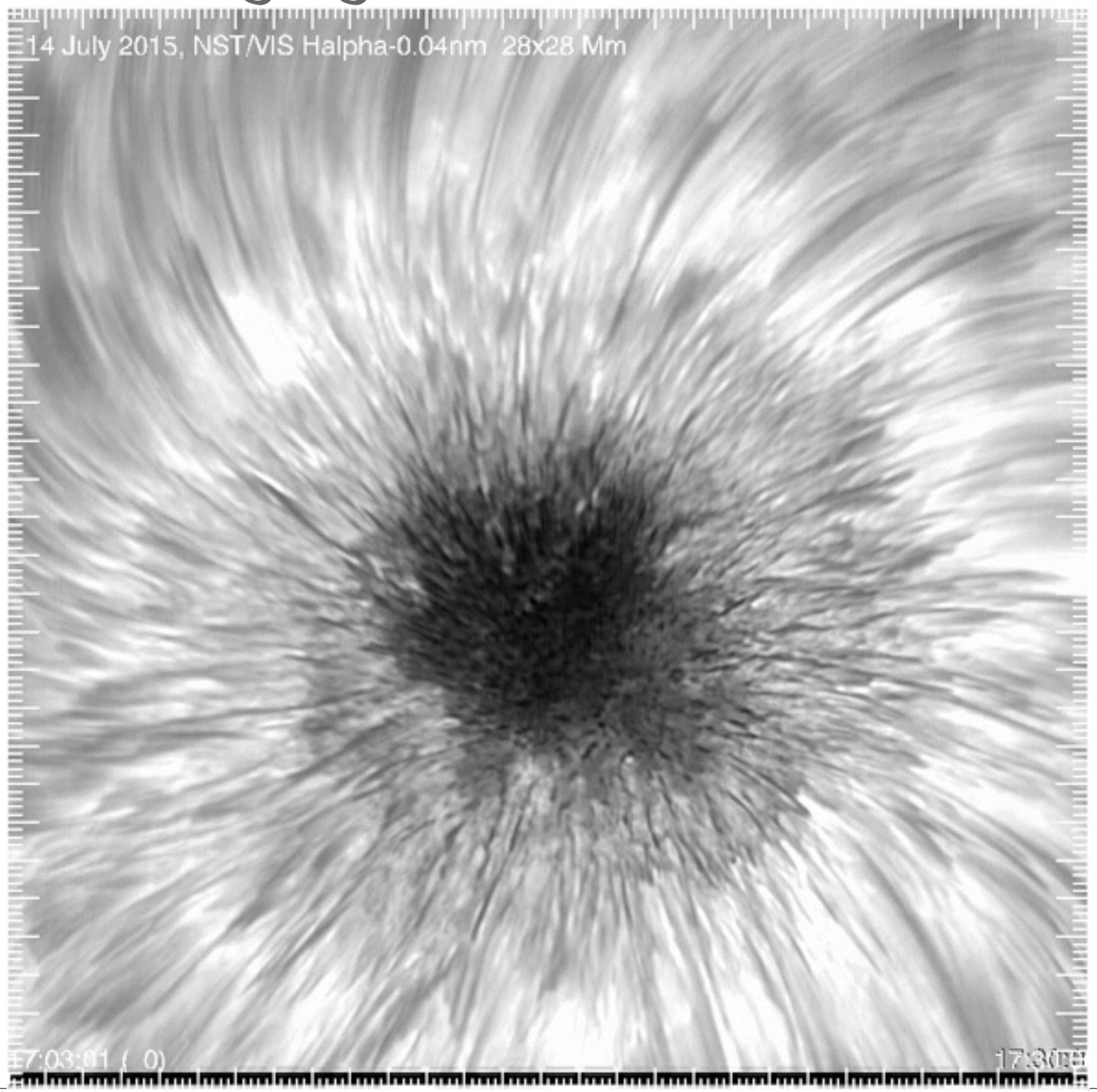


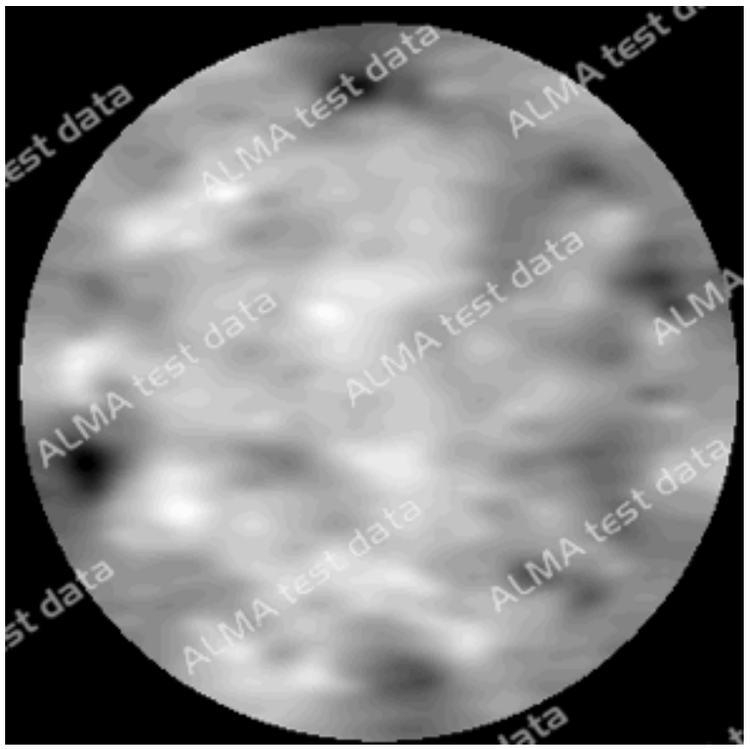



# Time cadence of MOSAIC images

- The required time for one point: 7.6 sec
  - [Integration Time : 6 sec] + [Overhead: 1.6 sec]
- Time cadence of the MOSAIC image
- **# of point in one MOSAIC image x 7.6 sec**
- **Exception**
  - When the phase calibration is carried out during scanning of one map, the required time for one map becomes to # of point x 7.6 sec + 3mins.
  - Ex. 149-pt: 7.6s x 149 = 19 mins / Actual: ~22 mins

# Science highlights—umbral waves




Example ALMA movie
*Dec. 2016 campaign (2 s)*
*(Yi Chai)*

Yurchyshyn et al., in preparation

# Cycle5

- Band7 & Band9
- Spectral line in Band3/6/7/9
- Polarimetry
- Subarray
- Fast TP mapping
- Integration time <2s