# Solar Observation using ALMA



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# Science Target

- Chromosphere
  - satisfies LTE condition at mm-waves.
  - Thermal free-free emission Brightness temperature
    - = Plasma temperature
- Chromospheric structures
  Prominence, plume, surge
  jet, spicule
- Flares
  - gyro-synchrotron of accelerated particles



# Science Target

- Chromosphere
  - satisfies LTE condition at mm-waves.
  - Thermal f-f at optical depth=1

Brightness temperature

- = Plasma temperature
- Chromospheric structures
  Prominence, plume, surge jet, spicule
- Flares
  - gyro-synchrotron of accelerated particles



# Cycle4 selection statistics: Sun

Proposal Type	Number Submitted	Number Grade A & B	
All	1571	475	(30%)
ACA	315	79	<mark>(25%)</mark>
ACA Standalone	30	5	(17%)
Large Programs	27	2	(7%)
Polarization	90	45	(50%)
Solar	53	15	(28%)
Target of Opportunity	21	13	(62%)
VLBI	22	9	(41%)

- North America (7)
- East Asia (4)
- Europe (3)
- Other (1)

# Cycle4 selection statistics: Sun

	Title	Exec
1	Solar <b>Chromospheric Heating</b>	NA
2	A Study of Solar <b>Spicules</b> at Millimeter, Optical, UV, and EUV Wavelengths	
3	Dynamics and energetics of the quiet-sun solar chromosphere	
4	Turbulence and Wave Propagation in the Solar Internetwork	
5	Unveiling the Nature of Small-Scale Energy Release Events in the Low Solar	
6	A first look at the <b>quiet Sun</b> with ALMA	
7	Measuring the Chromospheric Thermal Structure in Active Regions on the Sun	
8	Energy evaluation of micro- and nano-flaring heating events in solar active regions	EA
9	Wave Heating in Solar Prominences	
10	Magnetohydrodynamic mechanisms of <b>jets</b> in the solar chromosphere	
11	High-energy electrons in magnetic reconnection	
12	Constraining the temperature and heating mechanisms in the solar <b>plage</b> chromosphere	EU
13	Probing the chromospheric heating regions of the solar analogue alpha Centauri with	
14	The Cool Alter Ego of the Solar Corona	
15	Towards solving the Sun's chromospheric/coronal heating problem	Other

# Coordinate observation



# Capability for Cycle5 = Cycle4

- Interferometric Observation
  - Band3 & Band6 : 4 windows with128 channels/2 GHz
    - Band3: 93, 95, 105, 107 GHz
    - Band6: 230, 232, 246, 248 GHz
  - Spatial R.: 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)
    - : Sis Mixer-Detuning Mode:MD1/2
- Single-dish Observation
  - 12m-dishes observation to support Interferometric observation
  - Scanning full-sun

# Science Verification(SV) data

released on 18 Jan. 2017

- Joint ALMA Observatory (JAO) provides the SV data to demonstrate the capability of observations with ALMA.
   <u>https://almascience.nao.ac.jp/alma-data/science-verification</u>
- Everyone, except the staffs of the ALMA project who can touch the data before the release, can use the data for scientific studies without any limitation.
- A staff of the ALMA project cannot submit any scientific papers based on SV data until 10 days after the release.
  - Shimojo et al. 2017, submitted (Interferometry Observation)
  - White et al. 2017, submitted (Single-dish Observation)

#### Shimojo(NAOJ)'s talk given at EA-ALMA science workshop

# SV data list

- 1. Single pointing in Band 3 obtained on 11 December 2014 UT of a quiet solar region
- 2. Single pointing in Band 6 obtained on 11 December 2014 UT of a quiet solar region
- 3. Single pointing in Band 3 obtained on 12 December 2014 UT of an active solar region
- 4. Single pointing in Band 6 obtained on 12 December 2014 UT of an active solar region
- 5. <u>149 pt mosaic in Band 3 obtained on 16 December 2015 UT of a preceding sunspot of the active</u> region AR12470
- 6. 39 pt mosaic in Band 3 obtained on 16 December 2015 UT of a quiet sun region near the east limb and the foot of a prominence
- 7. Single pointing in Band 3 obtained on 16 December 2015 UT of the west side of the preceding sunspot of the active region AR12470
- 8. <u>Single pointing in Band 3 obtained on 17 December 2015 UT of the west side of the preceding</u> sunspot of the active region AR12470
- 9. 39 pt mosaic in Band 6 obtained on 17 December 2015 UT of a quiet sun region near the east limb
- 10.149 pt mosaic in Band 6 obtained on 18 December 2015 UT of a preceding sunspot of the active region AR12470
- 11.149 pt mosaic in Band 6 obtained on 20 December 2015 UT of the limb near the Sun's south pole

### Caution: Spatial resolution of SV data is 2~3 x worse than Cycle 4 data. 10

## Single-dish solar observations with ALMA

- Fast-scan imaging
  - double-circle pattern
  - FoV: 2400"Φ
  - One map per ~7mins



### **Double Circle Pattern**



## Single-dish solar observations with ALMA

### Band 3/107 GHz

### Band 6/248 GHz



T<sub>B</sub>@Sun Center: ~7300 K@100 GHz / ~5900 K@239 GHz (White et al. 2017)<sub>12</sub>

### Shimojo et al. (2017) in preparation Single-pointing observation near the sunspot Self-Cal Movie (2 sec)+ AIA/SDO movies (12 sec)



X (arcsecs)

-240-220 -200 X (arcsecs)

Y (arosecs)

220

180

Z40

*220* 

160

280

Y (areaeca)

-180

X (arcsecs)

### 149-points MOSAIC observation. A sunspot observed with Band3 (100GHz)



### Band3/100GHz White Light(HMI)

White Light(HMI)

Note: ~25 mins is needed for obtained the 100G Hz map.

### 149-points MOSAIC observation. A sunspot observed with Band6 (239GHz)



### Band6/239GHz

White Light(HMI)

White Light(HMI)

Note: ~25 mins is needed for obtained the 239 GHz map.

### Result of the Joint Observation between ALMA and Hinode in 2015 Solar Commissioning Campaign

ALMA 239 GHz 18-Dec-2015 19:39 -- 20:03 UT



Hinode SOT Ca II H 18-Dec-2015 19:49:32.732 UT



#### Shimojo et al. (2017)

20

-40

-20

0

X (arcsecs)

40

### ALMA-Band6 (239 GHz) & IRIS (Mg II k)

20

-20

0

X (arcsecs)

-40

40

-40

-20

0

X (arcsecs)

20

40

-40

-20

0

X (arcsecs)





40

20

# New capabilities near future

- Band 7 (275-373 GHz: 850 μm) and Band 9 (602-720 GHz: 450 μm) continuum observations
- Low resolution spectroscopy (TDM mode) in Bands 3, 6, 7, and 9
- Support of full Stokes polarimetry
- Support of sub-second integration times



# How to estimate the noise level of non-solar images

#### HL Tau (Band7)



- Usually, the standard deviation of the brightness at "BLANK SKY" is used as the noise level of synthesized image.
- · There is no "BLANK SKY" in solar images, except limb observations.

#### How to estimate the noise level of solar images?

# How to do we estimate the noise level of a synthesized solar image?



The emission mechanism shown in the images is thermal emission.

Therefore, the polarization degree is negligible small. The difference between two different orthogonal linear polarizations indicate the noise level.

Noise levels of the sunspot images

- Band3: 7.4 K / 6 sec / 8 GHz
- Band6: 16.7 K / 6 sec / 8 GHz

You have to consider the uncertainty of single-dish observations, when you estimate the error of the combined images.

#### Shimojo et al. (2017) <sub>21</sub>