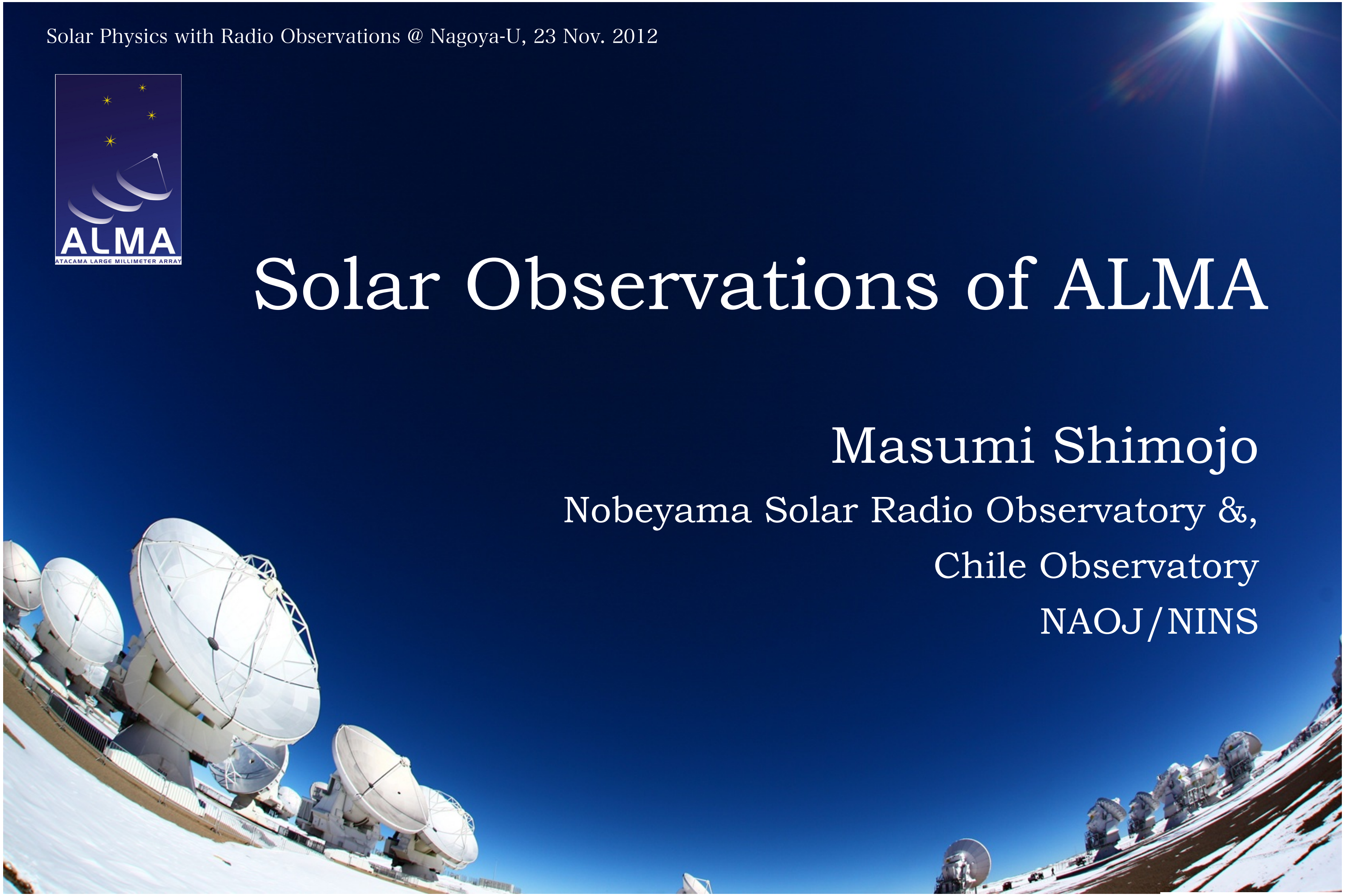


Solar Observations of ALMA

Masumi Shimojo
Nobeyama Solar Radio Observatory &,
Chile Observatory
NAOJ/NINS

Today's Topic

1. Introduction of ALMA
2. Millimeter/sub-millimeter wave observations for Solar Physics
   - Science cases, Previous studies
3. Current status of solar observations by ALMA
   - What is going on in ALMA project for solar observations.

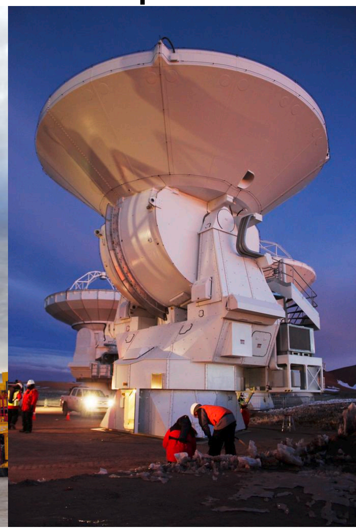
Atacama Millimeter/sub-millimeter Large Array (ALMA)

- ALMA is the largest mm/sub-mm wave interferometer in the world.
- ALMA is located at the Chilean Atacama desert (Chajnator). The altitude of the antenna site is 5000 m for observing sub-mm wave.
- ALMA is constructed from 54 12m-antennas and 12 7m-antennas.

US 12m

Japan 12 m

Europe 12 m

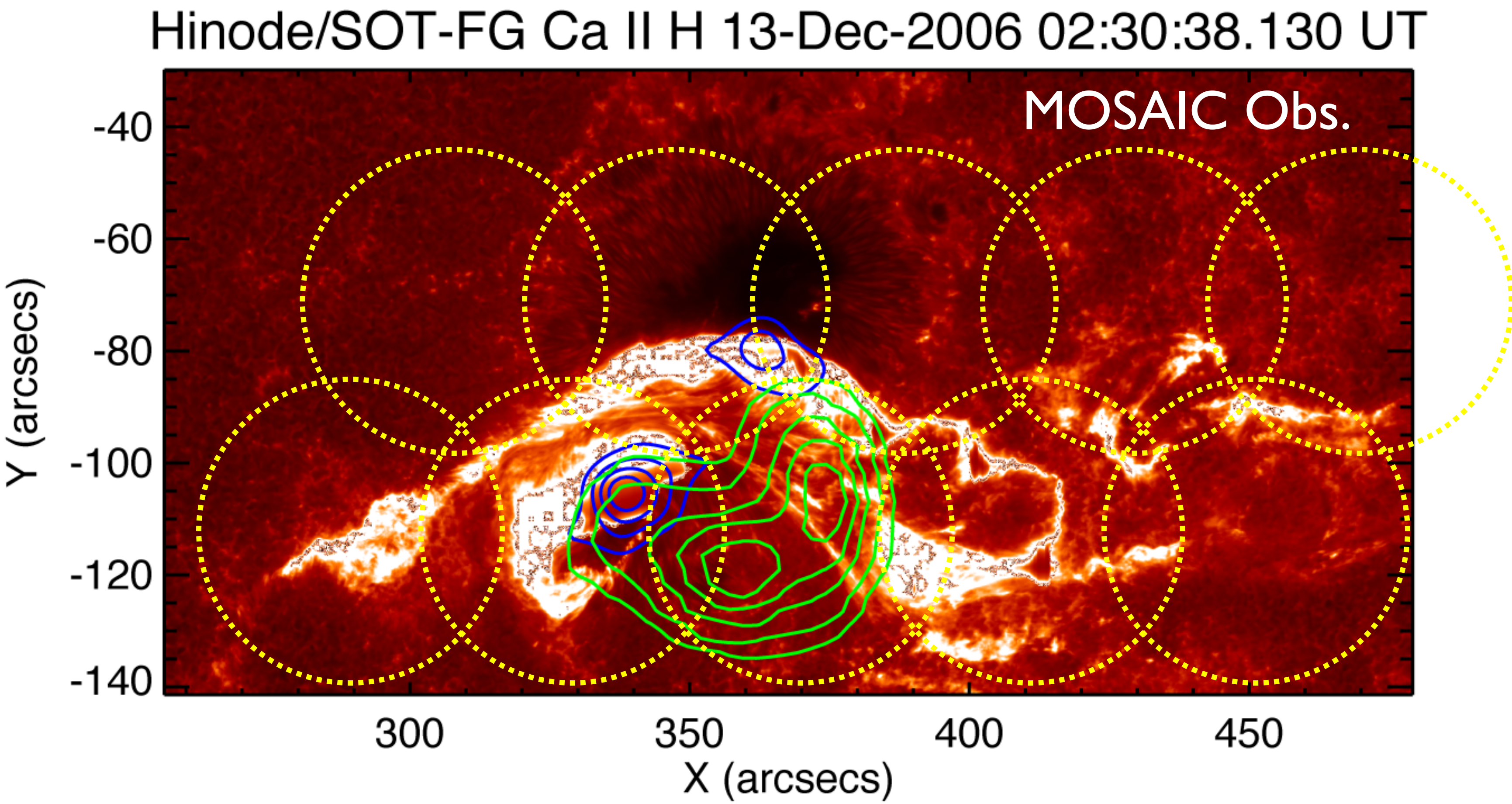


Japan 7m(ACA)

Spatial Resolution, FoV & Shortest Integration Time

- The spatial resolution of interferometer depends on the observing frequency & the longest baseline.
  - FWHM of synthesized beam [“] = 76 / max. baseline [km] / Freq. [GHz]
  - Maximum of the longest baseline of ALMA: 16 km
    - FWHM of synthesized beam : 0.06”@85GHz - 0.005”@950GHz
      - In solar observations, the spatial resolution is not possible.
- Basically, the size of FoV is depend on the diameter of the antenna & the obs. frequency.
  - FoV: 62”@100GHz, 18”@300GHz, 7”@950GHz
  - The large FoV is possible by MOSAIC, but the time resolution is down.
- Shortest Integration Time : 32 msec
  - The value is not “time resolution”. The time resolution of synthesized images strongly depends on a target. We need to verify the time resolution for solar observations in the CSV activities.

ALMA's Field of View [Band 3]



An X class flare observed with NoRH, RHESSI and Hinode. Green Contours: NoRH 34 GHz, Blue Contours: RHESSI 35-100keV, Color Scale: Hinode Ca II H band.

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Disadvantage of solar observations

- **During solar observations, we can not use "Water Vapor Radiometer (WVR)" of ALMA.**
  - During observations, WVR always observes the absorption line that is caused by water vapor in the earth's atmosphere, and monitors the gross volume of the water vapor in the line of sight in realtime.
  - Because of the realtime water-vapor monitoring, ALMA can use long (over a few km) baselines.
  - During solar observations, WVR can not detect the line because the background level (= solar emission) is very high.
- For solar observations, the baselines that is shorter than a few km may be available.
  - The maximum length of baseline depends on the condition of seeing!!.
    - Nominal: 0.3arcsec@100GHz
    - Future Plan: Fast Switchng

Observing frequencies of ALMA

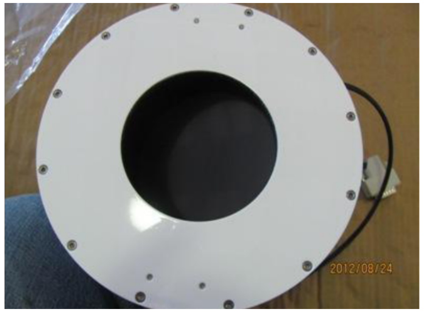
- ALMA will have 7 observing bands when the full operation is started in 2013.
  - **Band 3: 84 – 116 GHz** * (3.6 – 2.6 mm)
  - Band 4: 125 – 163 GHz *
  - **Band 6: 211 – 275 GHz** *
  - **Band 7: 274 – 373 GHz** * Circular Polarization
  - Band 8: 385 – 500 GHz *
  - **Band 9: 602 – 720 GHz**
  - Band 10: 787 – 950 GHz (0.4 – 0.3 mm)

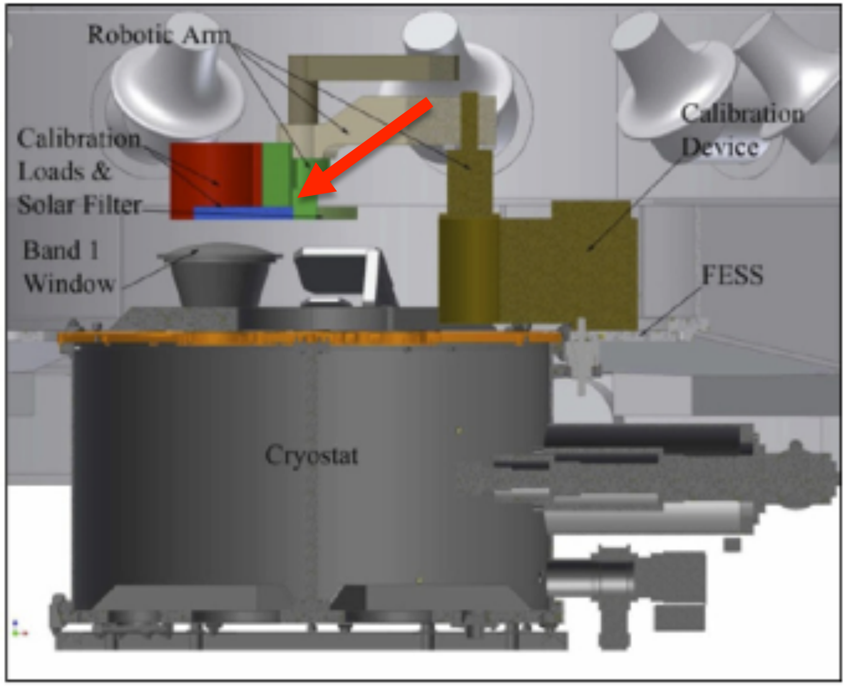
Ex. Nobeyama Radioheliograph
17 GHz (1.7cm) & 34GHz (8.8mm)

  - Asterisks indicate that the receiver (band) can observe 4 frequency ranges in the band (Width of each range is 2 GHz) simultaneously. Band 9 /10 can observe 2 frequency ranges simultaneously.
  - A few mins is needed for changing the band.

Solar Filter

- Sun is too strong source for ALMA.
  - The saturation occurred at the receivers.
- When we observe the Sun, the solar filters are inserted above the window for the receivers.
  - The solar filter cause the phase shift…





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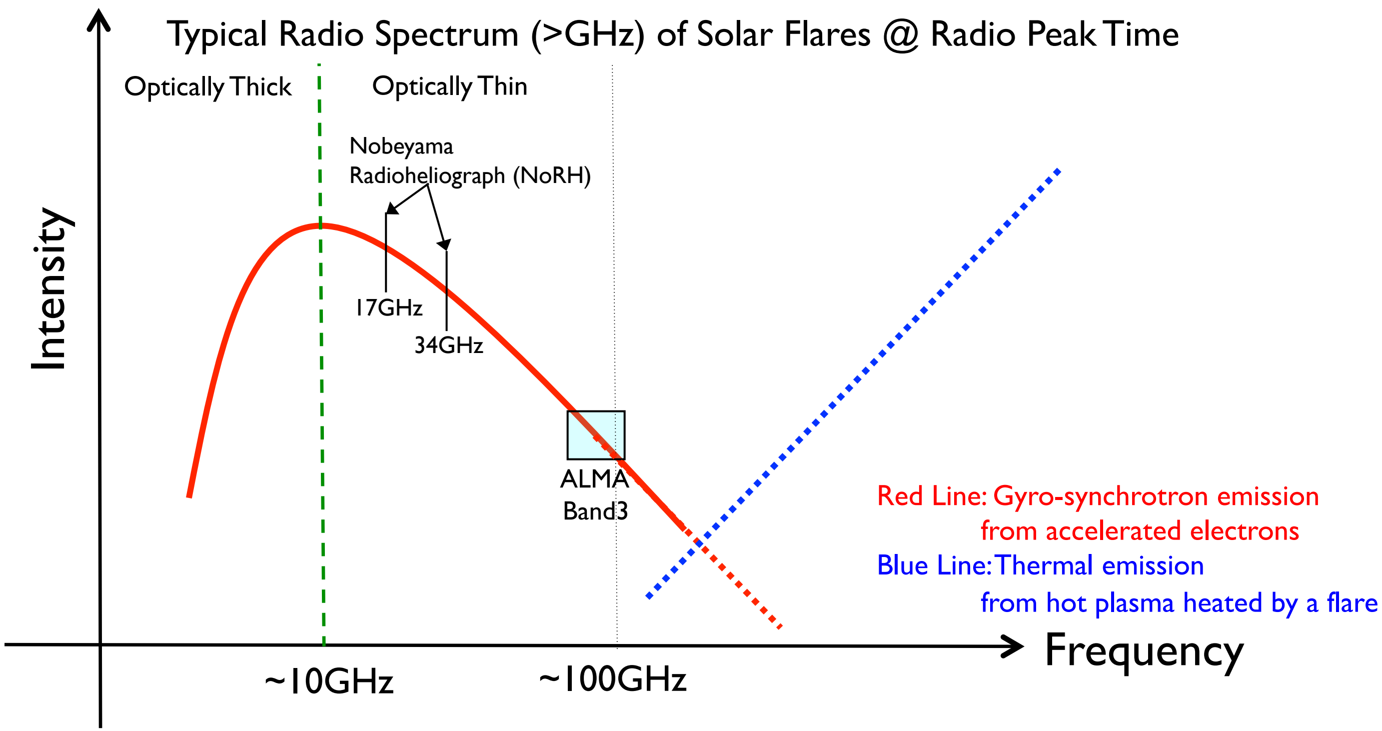
Sciences of mm/sub-mm observation in solar physics

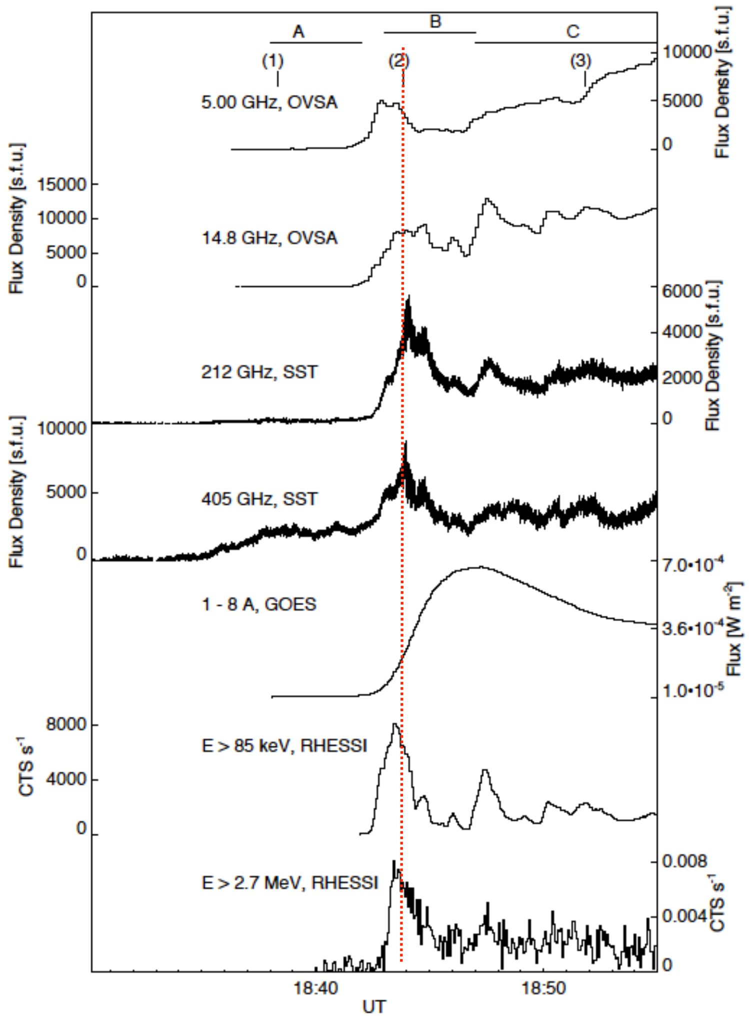
- The high-energy particle physics in flares
  - The topic is continued from the current main stream of solar radio physics.
- The chromospheric science
  by mm/sub-mm obs.
  - The topic will be expanded in ALMA era, I think.

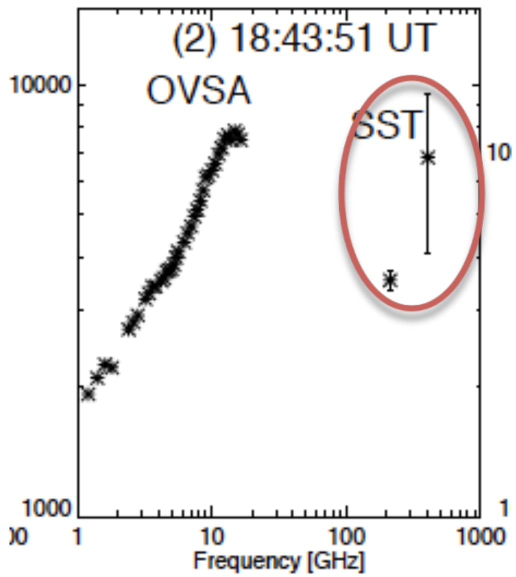
cm/mm-Wave from a Solar Flare

- The cm/mm-wave spectrum has the information of the energy distribution of the non-thermal electrons accelerated in a solar flare



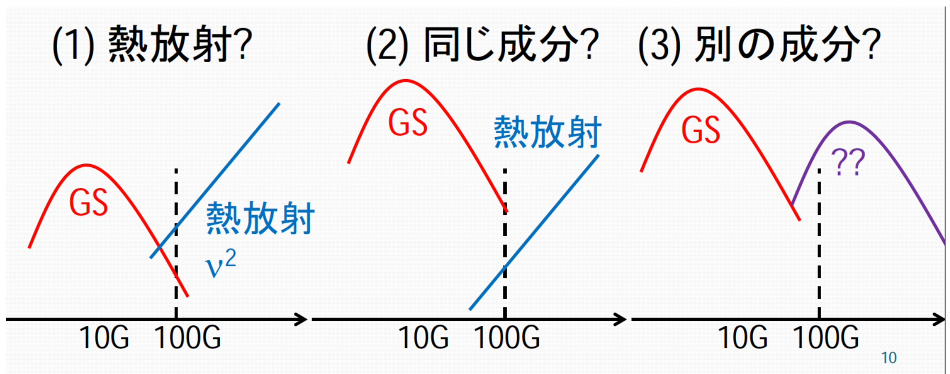
New Component in mm/sub-mm wave?





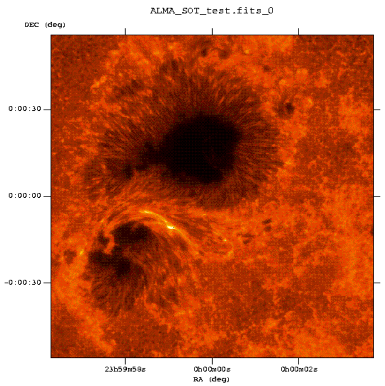
Kaufmann, et al. 2008

an X-class flare observed by SST (Single-Dish)

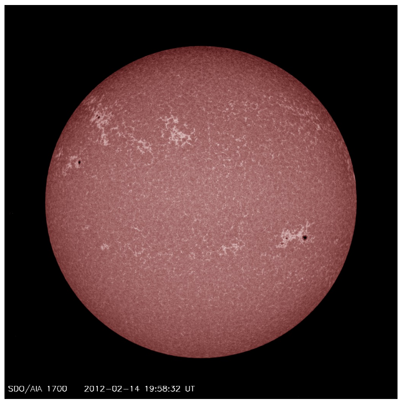


Where is the mm/sub-mm emission layer except flares ?

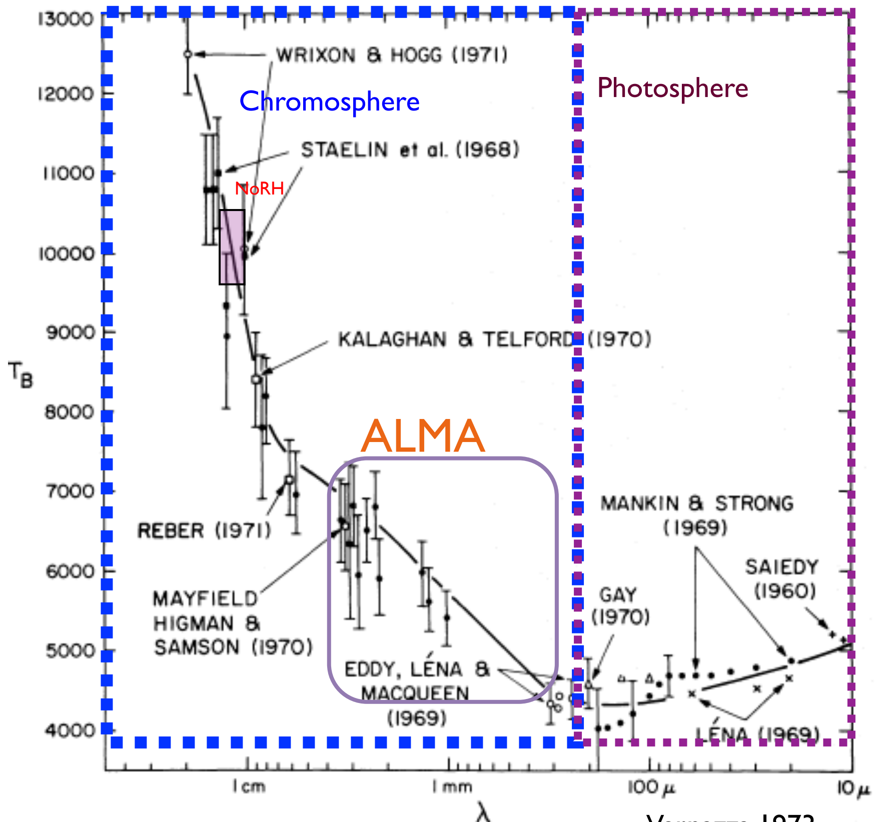
- The mm/sub-mm emission from non-flare sun is **thermal continuum from around [τ = 1] layer** = lower chromosphere.



Ca II (SOT)



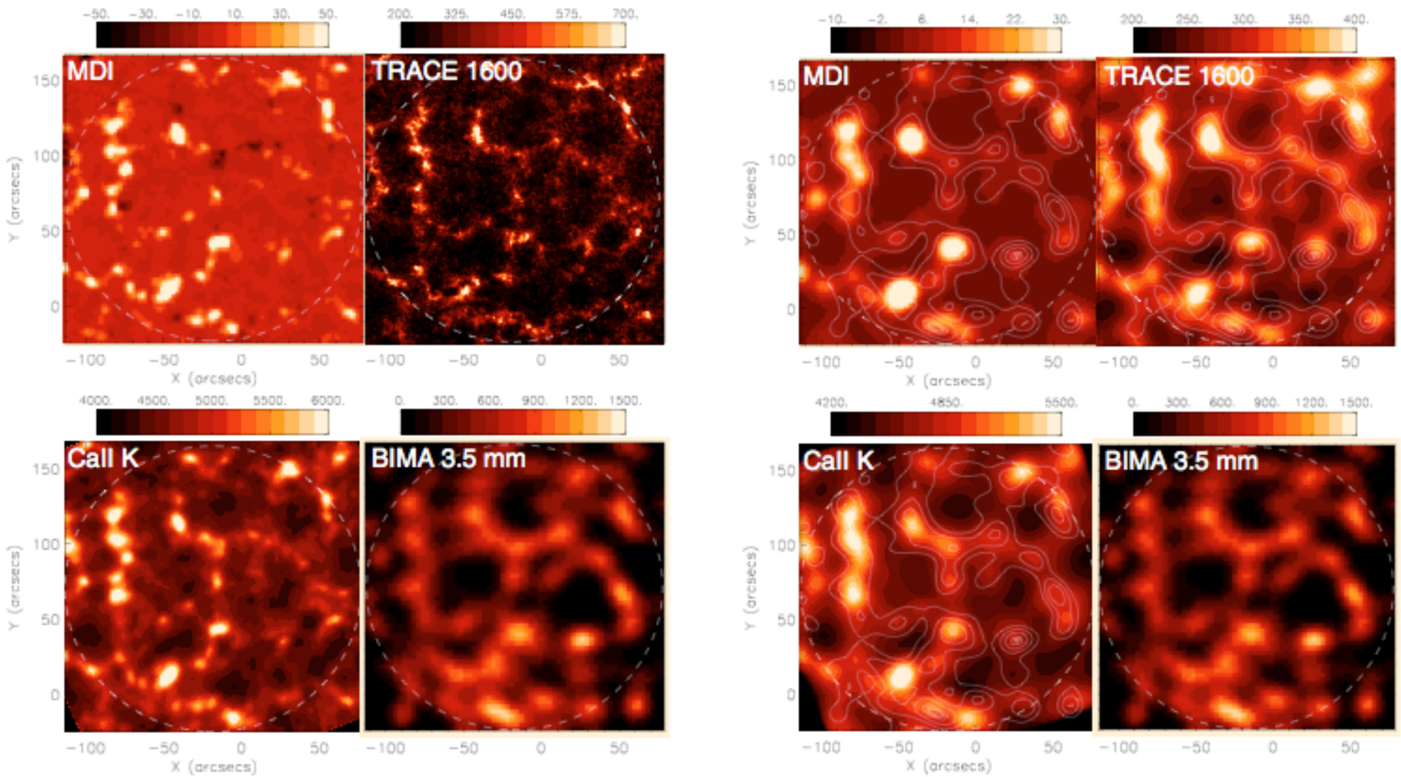
UV (AIA 1700)



Vernazza, 1973

Only one interferometic observations of quiet sun by BIMA

Original

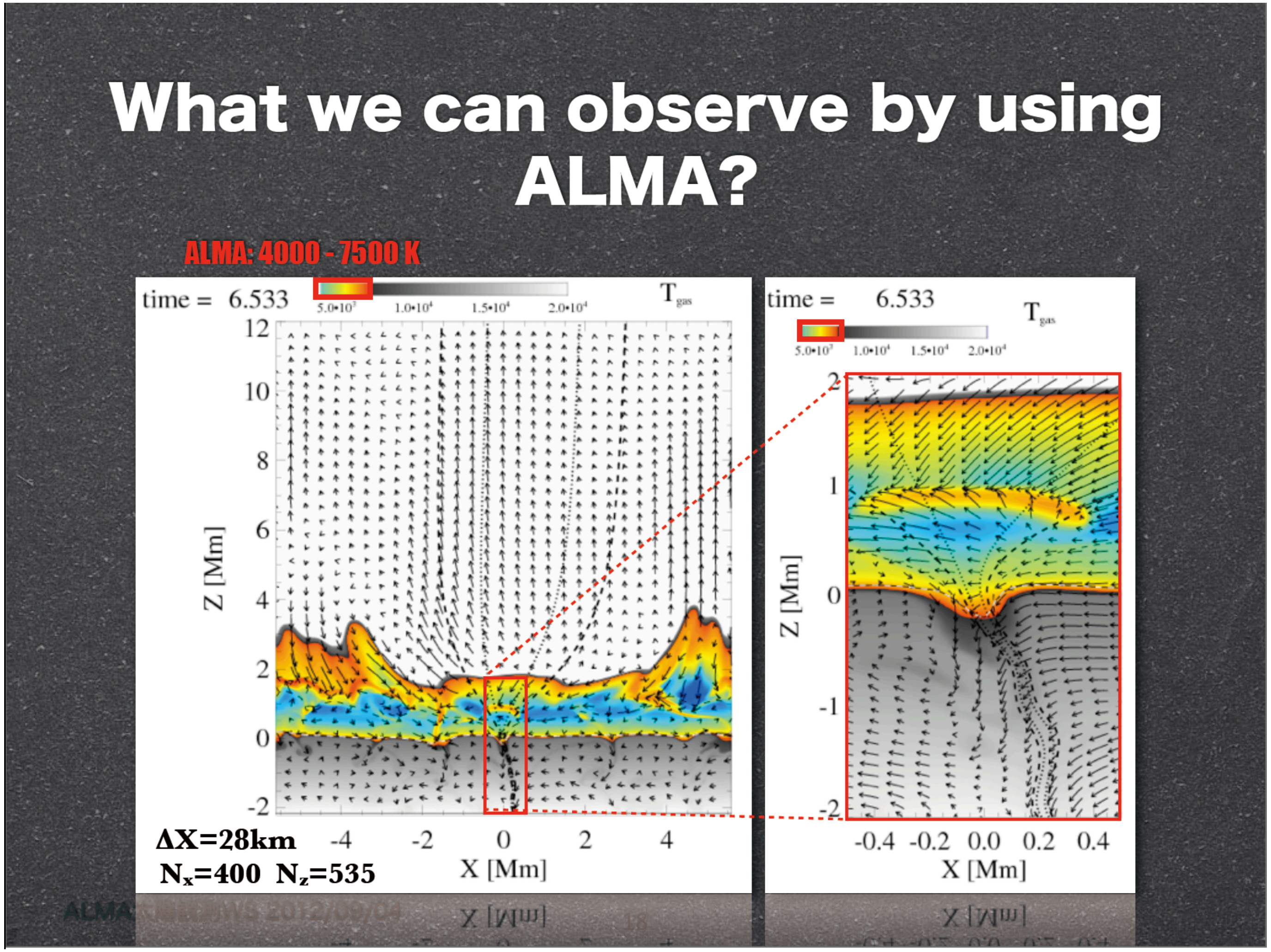


Convolved
by 12” Gaussian Beam

BIMA Synthesized beam : 12”

- White et al. 2006, Loukicheva et al. 2009
  - They observe the quiet sun using 10 BIMA antennas and synthesized the images using MEM.
  - BIMA 86GHz images are very similar to UV/chromospheric images

Detect the waves (sound, MHD, shocks…)at lower chromosphere



Kato et al.

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For solar observations by ALMA

1. Track the features on the solar surface
    - The features move on the solar surface by the differential rotation.
        - We can not use the normal ephemeris file of the Sun.
2. Huge heat load from the Sun
    - The antennas of ALMA were developed for the solar observation.
        - We need to check the spec based on the nominal observing sequence of solar observations.
3. The Sun is too bright for ALMA.
    - When we use the solar filter, how do we calibrate the component of the filters?
4. Image Synthesis for the radio sources that expand over the FoV of ALMA.
    - Limitation of the configuration for solar observations?
    - The normal clean method can be apply to the solar data?
5. High-time (< 1 sec) resolution for solar flare science.
    - The sub-second time resolution is most important for solar flare science.

History of the preparation for solar observations by ALMA

- Feb. 2011: The Single-Dish Solar Observations
- May. 2011: 1st Solar Campaign
- Dec. 2011: 2nd Solar Campaign
  - The 2nd campaign was failed by the software troubles of the solar filter operation.
- Jun. 2012: 3rd Solar Campaign

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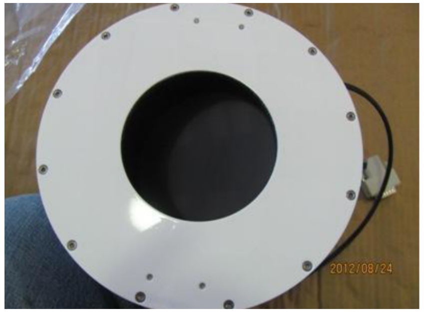

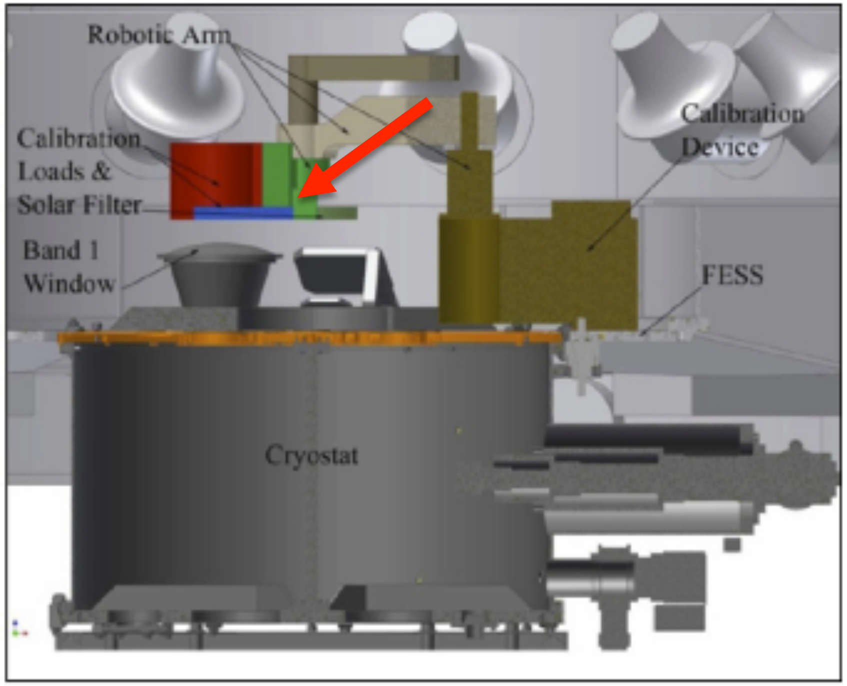

For solar observations by ALMA

1. Track the features on the solar surface
   - The features move on the solar surface by the differential rotation.
     - We can not use the normal ephemeris file of the Sun.
2. Huge heat load from the Sun
   - The antennas of ALMA were developed for the solar observation.
     - We need to check the spec based on the nominal observing sequence of solar observations.
3. The Sun is too bright for ALMA.
   - The receivers do not saturate? or we need to use the physical filter?
   - *If we use the physical filter, how do we calibrate the component of the filters?*
4. Image Synthesis for the radio sources that expand over the FoV of ALMA.
   - Limitation of the configuration for solar observations?
   - The normal clean method can be apply to the solar data? (maybe need the MEM…)
5. High-time (< 1 sec) resolution for solar flare science.
   - The sub-second time resolution is most important for solar flare science.

ALMA

ATACAMA LARGE MILLIMETER ARRAY

www.almaobservatory.org

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership among Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in Japan by the National Institutes of Natural Sciences (NINS) in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA..