



Solar Observations with ALMA

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The development of solar observations with ALMA is carried out by the international team now.

- ❖ East Asia (EA): Masumi Shimojo, Kazumasa Iwai, Sujin Kim
- ❖ North America (NA): Tim Bastian, Stephen White, Hugh Hudson
- ❖ Europe (EU) : Roman Brajsa, Miroslav Barta, Sven Wedemeyer
- ❖ Joint ALMA Observatory (JAO): Antonio Hales, Akihiko Hirota, Anthony Remijan

and the ALMA development team for solar observations of EA/NA/EU-ALMA Regional Center(ARC).

Solar observations with ALMA will be started in Cycle 4 (FY 2016)

- ❖ A solar observation is nominated as one of new functions of ALMA in Cycle 4 (FY2016) at the ALMA 'mode meeting' held in May 2015.
- ❖ Final Go/No-go decision of solar observations in Cycle 4 will be done by the ALMA observatory at the end of this year.

Atacama Large Millimeter/submillimeter Array (ALMA)



- ❖ ALMA is the largest millimeter/sub-millimeter array in the world, constructed from 54 12m-antennas and 12 7m-antennas.
- ❖ Observing Frequency: 84 GHz ~ 950 GHz (Wavelength: 0.3 ~ 3.6 mm)
- ❖ Longest Baseline: 150 m ~ 16 km (The array configuration is changing at all times.)

mm/sub-mm emission in solar atmosphere

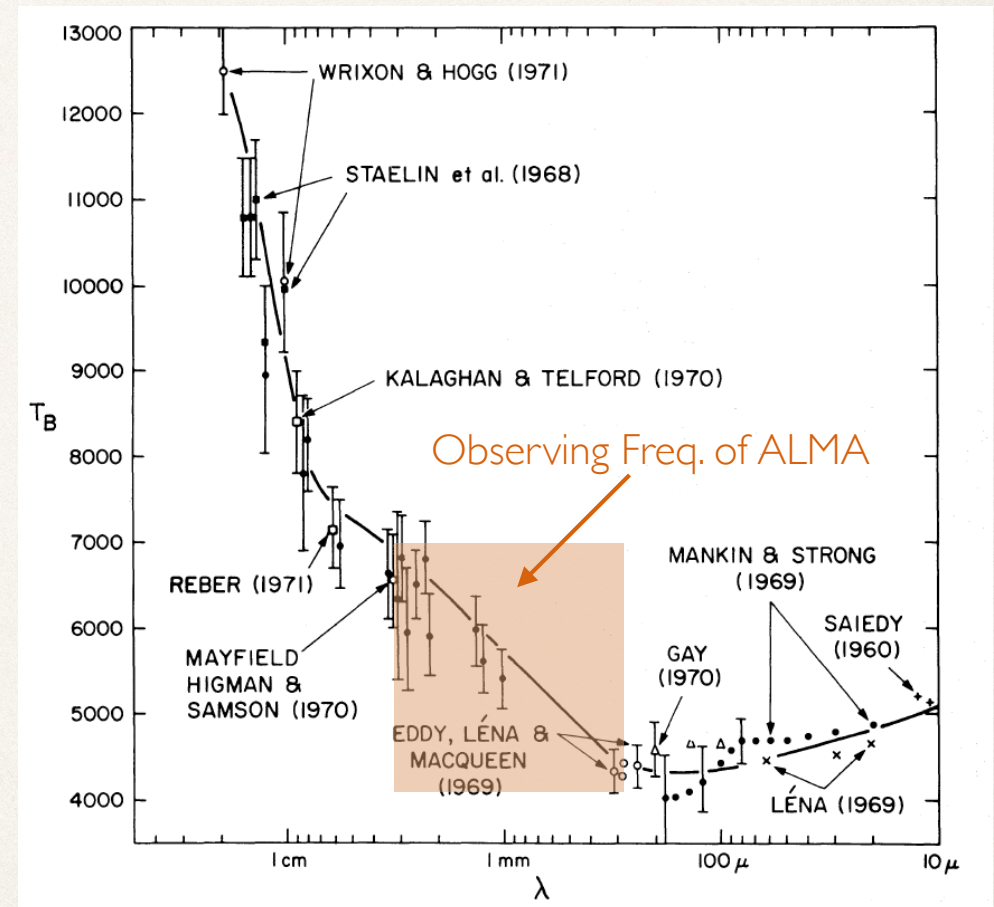
- ❖ When a flare has not occurred, there is no high-energy electrons ($>$ a few keV) in solar atmosphere.
 - ❖ Then, thermal emission dominates in the wavelength range.
- ❖ During a flare, there is high-energy electrons (\sim MeV) in the flare loops (magnetic tube).
 - ❖ Then, non-thermal emission (gyro-synchrotron) dominates even in sub-mm range.

mm/sub-mm emission from solar atmosphere at “Quiet”

- ❖ In solar atmosphere, the optical depth in the range depends on free-free & H
- ❖ $\tau=1$ layer is located at lower chromosphere ($T_{\text{phy}} = 4000 \sim 7000$ K).
- ❖ The layer satisfies LTE condition and the source function is Planckian.
- ❖ Rayleigh-Jean law can be applicable.



mm/sub-mm images are
thermograms of
lower chromosphere



Solid line: The spectrum is calculated from VAL model
Vernazza, Averett & Loeser, 1973

mm/sub-mm non-thermal emission from MeV electrons.

Model Spectrum of Gyro-synchrotron

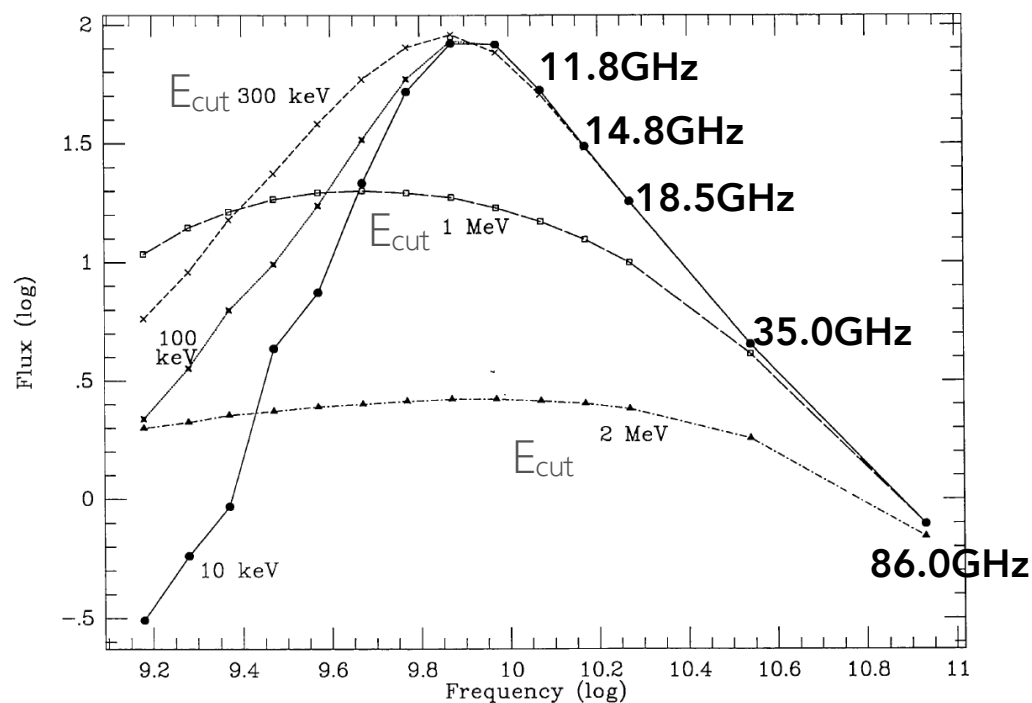


Fig. 1. A plot of nonthermal gyrosynchrotron flux spectra as a function of frequency for different values of the low-energy cutoff. The spectral index is 4, the magnetic field 300 G, the high-energy cutoff is 10 MeV and the angle between the line of sight and the magnetic field is 45°. The flux scale is in s.f.u. (the same values for the source dimensions were used in all cases); the logarithm of the flux is plotted. The curves are labelled according to the low-energy cutoff. The actual values of the frequency plotted are 1.5, 1.89, 2.37, 2.98, 3.75, 4.72, 5.93, 7.46, 9.38, 11.79, 14.82, 18.54, 35.0, and 86.0 GHz.

White & Kundu 1992

* Assumptions

* Energy spectrum of electrons

- * Power-law (Index -4)
- * Energy range: $E_{\text{cut}} \sim 10$ MeV
- * Cut-off energy (E_{cut}) is indicated in the plot.
 - * E_{cut} = lower-end energy of the energy distribution)

* Magnetic field

- * Strength: 300 Gauss
- * The angle between the LoS and field: 45 degree

- * Note: In lower frequency (< 10GHz), the self absorption by lower energy electrons is effective.

The prediction of the observing mode for solar observations in Cycle 4: 1

CAUTION: There is quite a possibility that the items in the page are revised when ALMA observatory announces the opening of solar observations in Cycle 4.

❖ Observing Frequency: Specific Bands and Specific Frequencies

❖ We can observe with 4 spectrum windows in one Band (Band3 or Band6) simultaneously.

- ❖ The bandwidth of each spectrum window is 2 GHz.

- ❖ Center frequencies of the 4 spectrum windows in Band 3: 93, 95, 105, 107 GHz

- ❖ Center frequencies of the 4 spectrum windows in Band 6: 230, 232, 246, 248 GHz

- ❖ *Caution: We **CANNOT** observe the Sun using two bands simultaneously, nor band switching in one observation of Cycle 4. Such functions might be realized in future Cycle.*

❖ Correlation Setup (Spectral resolution)

- ❖ Time Domain Mode (TDM) only

- ❖ $2 \text{ GHz [one spw]} / 128\text{ch} = 15 \text{ MHz} \Rightarrow \sim 45 \text{ km/s@100GHz} / \sim 20 \text{ km/s@230GHz}$

- ❖ *Note: There is no report of line detection within the frequency ranges of Band 3 & 6 up to the present. A spectrum survey observation has to be done using the Frequency Domain Mode (FDM: the mode is for higher spectral resolution). However, FDM can be realized in future Cycle, not Cycle 4.*

The prediction of the observing mode for solar observations in Cycle 4: 2

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- ❖ **Array Configuration** (*Spatial Resolution & dynamic range*) [*Based on the array configurations of Cycle 3*]
 - ❖ Heterogenous Array constructed from >10 7m- and >40 12m-antennas.
 - ❖ Array Configuration of the 12m Array for solar observations
 - ❖ C36-1: Longest Baseline 160.7 m = 3.4"@100 GHz / 1.5"@230 GHz
 - ❖ C36-2: Longest Baseline 376.9 m = 1.8"@100 GHz / 0.8"@230 GHz
 - ❖ (C36-3: Longest Baseline 538.9 m = 1.2"@100 GHz / 0.5"@230 GHz: *Questionable*)
- ❖ **Field of View and Time Cadence of Images**
 - ❖ Single Pointing: ~58"@Band3 / ~25"@Band6 (per 2 seconds)
 - ❖ MOSAIC observation might be enable in Cycle 4, and the number of points might be up to 150?
If 150-pts can be done, Max: 300"x300"@Band3 / 130"x130"@Band6 (per ~40 mins)
 - ❖ For MOSAIC observations, we have to consider the trade-off between the time cadence and the size of FoV.
- ❖ **Polarization**: Stokes-I Only

The prediction of the observing mode for solar observations in Cycle 4: 3

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❖ Longest Duration of a Continuous Observation for a Scientific Target

- ❖ ALMA sometimes has to observe a quasar as a calibrator during a solar observation.
- ❖ Longest Duration for solar case (Current value) : ~5 mins
 - ❖ Longest Duration for non-solar case: 10mins
 - ❖ *5 mins is short. We are considering how to extend the duration now.*

❖ Observing Time in a Day

- ❖ To avoid shadowing, we cannot observe the Sun when Sun's elevation is lower than 40 deg.
- ❖ Summer[Max]: 13:00~20:00UT / Equinox: 13:30~16:30UT / Winter[Min] 15:30~17:30UT

❖ Season of Solar Observations

- ❖ The array configuration is changing at all times. Based on the schedule of the array configuration in Cycle 3, the array configurations that are suitable for solar observations might be formed in Chilean summer (December ~ April).
 - ❖ February is the month of ALMA's maintenance.

The prediction of the observing mode for solar observations in Cycle 4: 4

CAUTION: There is quite a possibility that the items in the page are revised when ALMA observatory announces the opening of solar observations in Cycle 4.

❖ Single-Dish (Total Power: TP) Observation

- ❖ A simultaneous TP observation with an interferometric observation might be accepted in Cycle 4.
 - ❖ The proposal only for TP observations **NOT** be accepted too.
- ❖ The observing frequencies are the same as that of an interferometric observation, but there is no spectral resolution. (4 ch per a band).
- ❖ One full sun scan @ Band3 per ~10 min / @ Band6 per ~15 min
 - ❖ In Cycle 4, the FoV of TP observations is limited to full sun.

Who can submit proposals to ALMA observatory ?


- ❖ ALMA observations are carried out based on the proposals, and *everyone* can submit proposals to ALMA observatory as PI.
 - ❖ “Call for Proposal” of ALMA is opened once per a year, basically.
- ❖ The proposals are classified to EastAsia(EA), Europe(EU), North America(NA), Chile and the other, by the nationality of the institute that employs PI. (NOT the nationality of PI)
 - ❖ EastAsia(EA), Europe(EU), and NorthAmerica(NA) are ALMA jargon.
 - ❖ EastAsia(EA): Japan, Taiwan, and Republic of Korea.
 - ❖ Europe(EU): the member nations of European Southern Observatory (ESO)
 - ❖ North America(NA): USA, Canada, and Taiwan
- ❖ *The machine time of ALMA is assigned to the proposals of the ALMA regional partners (EA, EU, NA, and Chile) by following ratio basically, based on the result of the proposal review.*
 - ❖ EA: 22.5% , EU: 33.75%, NA: 33.75%, and Chile: 10%
 - ❖ There is no allocation to the proposal submitted by non-partners countries based on above ratio.
Actually, the proposals submitted from non-partners countries are accepted as “OpenSkies” program.
 - ❖ In the case of Cycle 3 (FY2015), the ratio of the ALMA machine time for **OpenSkies is 1.7%**.

No observing time for solar observations are guaranteed.

- ❖ We must fight against other fields (cosmology, galaxies, astronomical jet, molecular cloud, star-formation, solar system, etc.etc.etc.) by proposals, and gain machine times for solar observations.
- ❖ The proposal review panel of ALMA makes one ranking from all proposals finally, and selects accepted proposals from top.
- ❖ If there is no accepted solar proposal, solar observations with ALMA are never carried out in the Cycle. It means that there is no new ALMA solar data that can be used for researchers.

Who can use ALMA solar data?

- ❖ The demonstration data (SV data) of the Sun, which will be obtained in next solar commissioning campaign held in this December, will be provide to the solar community for preparing proposals in next year.
 - ❖ Everyone can use the solar SV data for their studies.
- ❖ The observing solar data obtained based on the proposal, is possessed by the PI and Co_I during 12 months.
 - ❖ The clock of the proprietary period (12 months) is started when the ALMA Regional Center (ARC) provides the data to the PI.
- ❖ After the proprietary period, the observing data is opened to the community, and everyone can use the data for their studies.
 - ❖ The opened data are provided by ARC through the Internet.
 - ❖ You can know the titles of the accepted proposals at the web site of ARC.



ALMA era of solar physics,
coming soon !!



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 and the Korea Astronomy and Space Science Institute (KASI). 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.