

# ALMA Solar Ephemeris Generator

## User manual

for version 0.7

2017 April 12

Select user interface

GUI (by clicking on the solar image)  
 Text (manual input of coordinates)

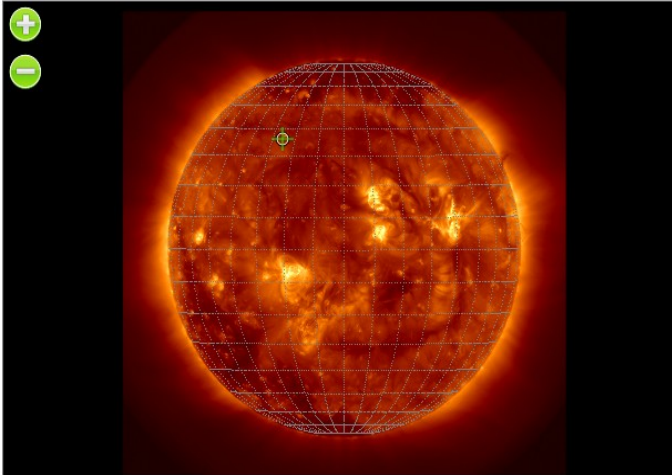
Input FITS file

File: AIA image (local)  No file selected.  
Date: 2016-12-02T10:46:05.85 Size: 1024 x 1024 Format: 32

Visualization

Scaling function: cuberoot  Frame  of 1.  
 Show grid   
 Show ALMA 12m beam size in band:

cursor (wcs) = (1791.11,701.59), intensity = null



The screenshot displays the user interface of the ALMA Solar Ephemeris Generator. It features a control panel with several sections: 'Select user interface' with radio buttons for 'GUI' (selected) and 'Text'; 'Input FITS file' with a file selection dropdown, a 'Browse...' button, and a 'View header' button; and 'Visualization' with dropdowns for 'Scaling function' (cuberoot), 'Color' (heat), and 'Frame' (0 of 1), along with checkboxes for 'Show grid' (Stonyhurst) and 'Show ALMA 12m beam size in band' (Band 3). Below the controls is a solar image with a grid overlay and a cursor. The cursor coordinates are (1791.11, 701.59) and the intensity is null. The image shows the Sun's surface with a grid of latitude and longitude lines.

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## Description

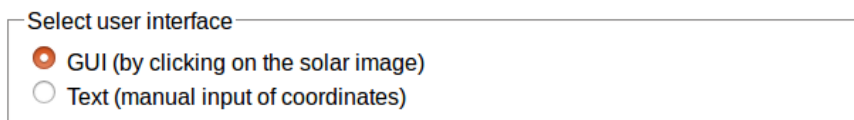
ALMA Solar Ephemeris Generator is a software tool for easy generation of ephemeris files compatible with the ALMA Observing Tool (OT) for user selectable regions on the Sun. It was developed for easy preparation of solar observations with the Atacama Large Millimeter-submillimeter Array (ALMA). It can be used to create dummy ephemeris files to be included in the ALMA solar proposals but mainly it is used just prior the actual solar observations.

## Usage

The Principal Investigator (PI) of the solar ALMA project or the Astronomer on Duty (AoD) may use this tool to prepare the ephemeris file of the solar feature targeted for observation. ALMA Solar Ephemeris Generator was developed with a focus on easy and intuitive usage. The tool consists of the following panels which are ordered sequentially:

- Select user interface – selection between graphical (GUI) and text user interface
- Input FITS file (GUI only) – user first selects or uploads a solar FITS file
- Visualization (GUI only) – user adjusts the parameters for viewing the FITS file
- Image display (GUI only) – user navigates around the image (pan and zoom) and selects the desired feature (click)
- Pointing – a table of the coordinates of the selected feature in various coordinate systems (GUI) or manual specification of target (text)
- Location – selection of the reference location for which the ephemerides will be generated (default: ALMA)
- Observation – user enters the desired parameters of the observation and finally generates the ephemeris

## Select user interface



Select user interface

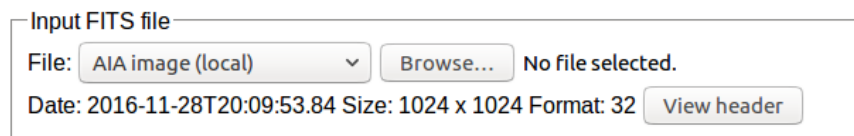
GUI (by clicking on the solar image)

Text (manual input of coordinates)

ALMA Solar Ephemeris Generator provides two user interfaces: graphical (GUI) and text. In graphical mode, a user selects the target simply by clicking on the solar image. In text mode, the helioprojective Cartesian (HPC) coordinates are entered manually.

## GUI interface

### Input FITS file



Input FITS file

File: AIA image (local)  No file selected.

Date: 2016-11-28T20:09:53.84 Size: 1024 x 1024 Format: 32

User can select between:

- AIA image (local) – last used AIA image, locally saved (if allowed by the server)

- one of the available SDO/AIA channels (see table below)
- AIA image (for testing)

AIA channel (Angstroms)	Source	Region	Characteristic temperature (K)
94	Fe XVIII	Flaring regions	$6.3 \times 10^6$
131	Fe VIII, XX, XXIII	Flaring regions	$4 \times 10^5, 10^7, 1.6 \times 10^7$
171	Fe IX	Quiet corona, upper transition region	$6.3 \times 10^5$
193	Fe XII, XXIV	Corona. hot flare plasma	$1.2 \times 10^6, 2 \times 10^7$
211	Fe XIV	Active region corona	$2 \times 10^6$
304	He II	Chromosphere, transition region	50000
335	Fe XVI	Active region corona	$2.5 \times 10^6$
1600	C IV + continuum	Transition region, upper photosphere	$10^5, 5000$
1700	continuum	Temperature minimum, photosphere	5000
4500	continuum	Photosphere	5000

The user can also upload his own FITS image. This image should conform to the (old) FITS standard, without compression and needs to have the following solar WCS keywords as defined by Thompson (2006):

- DATE-OBS - date and time of observation
- CRPIXn - reference pixel
- CRVALn - value of the reference pixel
- CDELTn - plate scale
- CROTA2 - rotation angle
- CRUNIT - units of the CRVALn
- CRLN - Carrington longitude of the observer
- CRLT - Carrington latitude of the observer
- DSUN\_OBS - Sun-observer distance

Without these keywords ALMA Solar Ephemeris Generator will not function properly.

## Visualization

Visualization

Scaling function: cuberoot Color: heat Frame < 0 > of 1.

Show grid Stonyhurst

Show ALMA 12m beam size in band: Band 3

cursor (wcs) = (586.93,326.83), intensity = 632

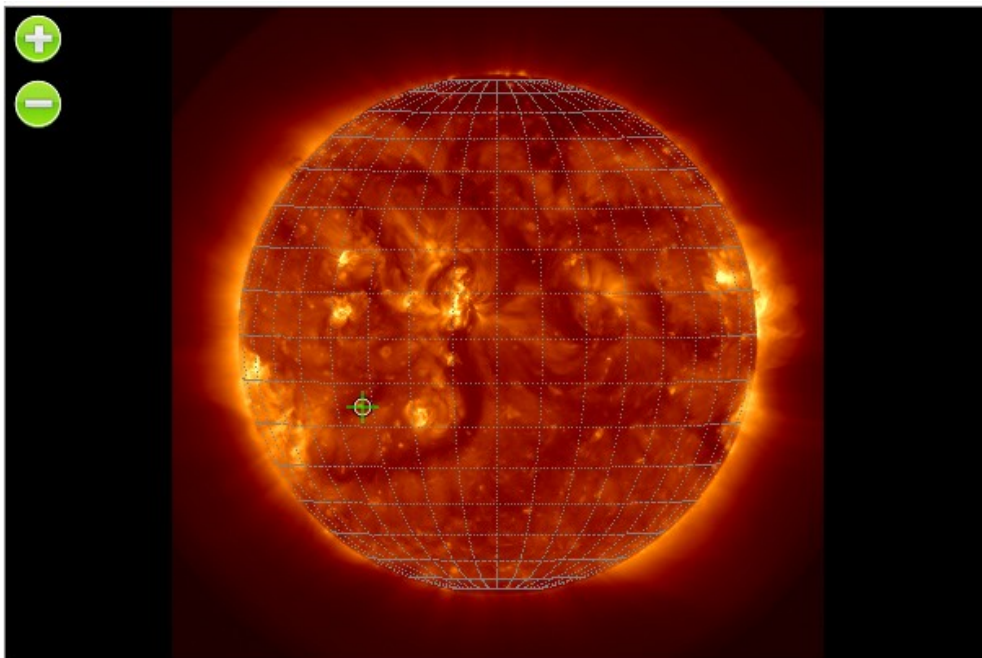
Scaling function is used to scale the FITS data values for better visual presentation. Available functions are:

- linear – no scaling, use original FITS data
- sqrt
- cube root
- log
- sqrt-log

- log-log

Color selects the colormap: gray, heat, A or B (as in SAOImage DS9). In multi-frame FITS images, frame selects the desired image. Show grid overlays a coordinate grid over the image, Stonyhurst heliographic, Carrington heliographic or helioprojective Cartesian. Show ALMA 12m beam size overlays the 12m ALMA antenna FoV in a selected ALMA band.

## Image display



The user can use the mouse or touch input to move the image around. Zoom in/out is achieved by clicking the “+” or “-” buttons or with mouse scroll button. Clicking without dragging will select the desired feature and a green cross will mark the position. If Show ALMA 12m beam size is checked then the circle marking the 12m antenna FoV will also appear and if mosaic is selected, a blue box will be visible too.

## Pointing

Pointing			
Pixel (x, y)	<input type="text" value="372.05"/>	<input type="text" value="744.96"/>	
Helioprojective (x, y)	<input type="text" value="-334.67"/>	<input type="text" value="560.30"/>	arcsec
Heliographic (CMD, B)	<input type="text" value="335.077"/>	<input type="text" value="35.602"/>	degrees
Heliographic (L, B)	<input type="text" value="128.039"/>	<input type="text" value="35.602"/>	degrees
<input type="checkbox"/> Mosaic observation			
Width:	<input type="text" value="120"/>	<input type="text" value="60"/>	arcsec
Height:	<input type="text" value="60"/>	<input type="text" value="0"/>	arcsec
Angle:	<input type="text" value="0"/>	<input type="text" value="0"/>	degrees

The coordinates of the selected feature are displayed in four coordinate systems: pixel (from FITS), helioprojective Cartesian, Stonyhurst heliographic and Carrington heliographic. A manual input into any of the fields is possible and all the other fields will update automatically. It is also possible to select a feature outside the solar disc. In that case, no heliographic coordinates will be displayed.

Here it is also possible to visualize the required box size and angle for a mosaic observation. Note that angle is in heliographic frame (0 degrees means solar east-west). To get the sky angle (in equatorial RA-Dec frame) as required by ALMA Observing Tool, user should add solar P angle to angle value:

$$\text{angle\_sky (for OT)} = \text{angle\_sun} + \text{solar\_P}$$

## Text interface

### Pointing

The screenshot shows a 'Pointing' section with the following fields and controls:

- Reference date:
- HPC X:  HPC Y:  arcsec
- Sun distance:  m
- P:  B0:  L0:  deg
- Get from JPL Horizons:

The coordinates of the target in text mode are entered as helioprojective Cartesian coordinates with a reference date. Reference date should be entered in ISO date format YYYY-MM-DDTHH:NN:SS. For the calculation of ephemerides, several solar parameters at the reference date are needed: Sun distance from the observer in meters, solar position (P) angle, and heliographic latitude (B0) and longitude (L0) of the solar center as seen by the observer. If unknown, these quantities can be acquired from JPL Horizons service by clicking “Get from JPL Horizons”. Note that JPL Horizons returned values are based on ALMA observing site and not the actual observer position which can introduce a negligible error.

### Location

This feature is not relevant for ALMA and should be skipped if the tool is to be used with ALMA. However, due to user requests, Ephemeris tool may now be used also with other observatories/locations. There are several predefined locations (ALMA in Chile, VLA in the USA, Nobeyama in Japan, MUSER in China, SSRT in Russia and Earth geocenter) but user can specify manually any location on Earth.

The screenshot shows a 'Location' section with the following fields and controls:

- Change default location (ALMA)
- ALMA (Chile)
- Lat. (N):  Lon. (E):  Alt.:  m

If default (ALMA) location is changed, the ephemerides will refer to this new location.

**WARNING:** use with caution! Don't change the location if you are using the Tool for ALMA observations, otherwise the pointing might be off by several arcseconds.

## Observation

Here the parameters of the observation are specified. For start and end date use ISO date format YYYY-MM-DDTHH:NN:SS. Step size is the step between consecutive entries in the ephemeris. Differential rotation profile specifies which profile will be used for the calculation of the feature position in time. Several predefined profiles are available:

- Don't use (Earth synchronized rotation) - the feature is fixed on the solar disc when viewed from Earth, it is co-rotating with Earth motion around the Sun and appears not to move on the solar disc.
- No rotation - the feature is fixed as if the Sun is not rotating at all. Note that because of the Earth revolution, the coordinates of the feature will change when viewed from Earth.
- Solid rotation (Carrington) - a solid rotation where the Sun rotates as solid body
- Sunspot groups - profile derived from sunspot groups (Sudar et al. 2014)
- H-alpha filaments - profile derived from observation of filaments visible in H-alpha images (Brajša et al. 1991)
- Coronal bright points - profile derived from movements of coronal bright points in SOHO/EIT images (Wöhl et al. 2010)
- User specified - user specified rotation profile in typical form  

$$\omega = A + B \sin^2 \varphi + C \sin^4 \varphi$$
 where  $\varphi$  is heliographic latitude and  $A$ ,  $B$  and  $C$  are given in degrees per day.

**Observation**

Start of observation (UT):

End of observation (UT):

Step size (minutes):

Differential rotation profile:

A:  B:  C:  deg/day

Height above photosphere (km):

```

*****
Revised : Jul 31, 2013                Sun                10
PHYSICAL PROPERTIES (revised Jan 16, 2014):
GM (10^11 km^3/s^2) = 1.3271244004193938  Mass (10^30 kg) ~ 1.988544
Radius (photosphere) = 6.963(10^5) km  Angular diam at 1 AU = 1919.3"
Solar Radius (IAU) = 6.955(10^5) km  Mean density = 1.408 g/cm^3
Surface gravity = 274.0 m/s^2  Moment of inertia = 0.059
Escape velocity = 617.7 km/s  Adopted sidereal per = 25.38 d
Pole (RA,DEC in deg.) = 286.13,63.87  Obliquity to ecliptic = 7 deg 15'
Solar constant (1 AU) = 1367.6 W/m^2  Solar lumin.(erg/s) = 3.846(10^33)
Mass-energy conv rate = 4.3(10^12 gm/s)  Effective temp (K) = 5778
Surf. temp (photosphr)= 6600 K (bottom)  Surf. temp (photosphr)= 4400 K (top)
Photospheric depth = ~400 km  Chromospheric depth = ~2500 km
Sunspot cycle = 11.4 yr  Cycle 22 sunspot min. = 1991 A.D.

Motn. rel to nrby str= apex : RA=271 deg; DEC=+30 deg
                        speed: 19.4 km/s = 0.0112 AU/day
Motn. rel to 2.73K BB = apex : l=264.7+-0.8; b=48.2+-0.5
                        speed: 369 +-11 km/s
*****
          
```

Status window:

If the selected feature is not on the solar disc but off the limb, selection of the rotation profile will be disabled and the ephemeris calculation will assume that the feature is co-rotating with Earth i.e. appearing in the same place on the solar disc when viewed from Earth.

Finally, the height of the selected feature can be specified in kilometers. Selecting the desired profile will automatically fill the height field with a typical value.

After specifying the desired observation parameters, an ephemeris file for the ALMA Observing Tool can be generated by clicking “Generate ephemeris” button. This file will be displayed in text box below and can be easily downloaded by clicking “Download table data”. Two more buttons are available just for user convenience, “Show original JPL file” will display the JPL Horizons file with solar center coordinates for ALMA center of the array, while “Show ephemeris table” will generate a formatted table of ephemeris data.

## How it works

ALMA Solar Ephemeris Generator uses JPL Horizons service for high precision solar ephemeris. It sends a request to JPL Horizons service with parameters specified in Observation and uses the received data to calculate offsets from the solar center for the selected feature. Then it transforms everything into equatorial J2000.0 Ra-Dec frame. Coordinates of the Sun are astrometric J2000 coordinates from JPL Horizons for the ALMA center of array (default) or specified location. Atmospheric refraction is not taken into account. Physical ephemeris of the Sun (P, B0, L0) used in the calculation are also from JPL Horizons referred to the ALMA center of array or the specified location.

Calculation of the target equatorial coordinates ( $\alpha$ ,  $\delta$ ) from the helioprojective Cartesian coordinates ( $\theta_x$ ,  $\theta_y$ ) and the equatorial coordinates of the solar center ( $\alpha_0$ ,  $\delta_0$ ) including the solar  $P$  angle, is done according to the following equations:

$$\tan(\phi - P) = -\frac{\tan \theta_x}{\tan \theta_y}$$

$$\tan \rho = \sqrt{\tan^2 \theta_x + \tan^2 \theta_y}$$

$$\sin \delta = \sin \delta_0 \cos \rho + \cos \delta_0 \sin \rho \cos \phi$$

$$\tan(\alpha - \alpha_0) = \frac{\sin \rho \sin \phi}{\cos \rho \cos \delta_0 - \sin \rho \sin \delta_0 \cos \phi}$$

## Notes

### Warnings

The ephemeris should not be older than 2 days from the reference image because of the unpredictable nature of solar features. If the ephemeris is older than 2 days, the tool will display a warning in the Status window. This can happen in two ways: either the reference image is too old (please select the latest SDO/AIA image or use a newer image) or the observation is scheduled too far ahead (see the note on the precision for more information).



If the feature is close to the limb, it could happen that it will move behind (to the back side of the Sun) in the specified time period. The ephemeris will then be invalid and a warning will be displayed in the Status window.

## Precision

Precision in calculated HPC x,y is  $\sim 0.2$  arcsec. This is due to the precision of the input solar angles B0, L0 which are given to 0.01 degrees by JPL Horizons and many almanacs. In the worst case scenario (Earth at perihelion, feature on the disc center) 0.01 deg error in heliographic coordinates corresponds to 0.17 arcsec in HPC coordinates.

When calculating RA-Dec offsets, solar P angle affects its precision. P is given as 0.0001 in JPL Horizons, so it adds  $\sim 0.002$  arcsec for 1000 arcsec from the solar disc. If it is given as 0.01, the error rises to 0.17 arcsec and the total error is  $\sim 0.4$  arcsec. For reference, 12m ALMA antenna has a beam size of 26 arcsec at 240 GHz (Band 6).

However, features on the Sun are carried by differential rotation, meridional motions and other velocity fields that are not known. In addition, the features evolve, change appearance. All this significantly affects the precision, much more than errors in the angles given above. They accumulate over time so it is not possible to accurately predict positions of features for more than a few days.

## Mirror links

- <http://www.asu.cas.cz/~skokic/alma/CoordTool.html>
- <http://celestialszenes.com/alma/coords/CoordTool.html>

## Version history

v0.7, 2017 Apr 12

- \* Improved calculation methods.
- + Added zooming limits.
- + Added possibility to use other locations besides ALMA.
- + Added Earth-synchronized solar rotation for solar targets that appear static when viewed from Earth.
- + Added Ephemeris Tool version info to output ephemeris.
- + Added estimated number of pointings calculated by eqs. from the ALMA Technical Handbook.
- ! Helioprojective grid rotation was in a wrong direction.
- ! PHP warnings were inserted into FITS when it was not possible to save the file locally.

v0.6, 2016 Dec 05

- + New text interface for manual input of pointing coordinates as HPC(x,y) with a reference date.
- + Added mosaic info into output ephemeris.
- + Added solar parameters info to output ephemeris.
- \* Text areas are now readonly.
- \* Default step size changed from 20 to 15 minutes.
- \* Default observation end time changed from 1 day to 2 days after observation start date.

v0.5, 2016 Nov 28

- + Added mosaic observation for illustration purposes only.
- + Added status window for errors/warnings.

- + Hints added on some controls.
- + Support for 64-bit float FITS files.
- \* More SDO/AIA channels available in the drop-down menu.
- \* More ALMA channels for beam size visualization.
- \* Better handling on touch enabled devices.
- \* Better handling of table data download.
- \* Minor code refactorings.
- ! Using mouse scroll to zoom in/out on image also scrolled the entire page.
- ! Loading local files finally works.
- ! When seconds were 0 in start time for ephemeris, e.g. 2016-11-23T12:23:00, no ephemeris was generated.

v0.4, 2016 Apr 13

- + Off the limb pointing is now possible (differential rotation is not applied in this case).
- + The last user selected (latest) 193 AIA image is saved locally and loaded as default.
- ! Generated ephemeris table: julian day calculation was off by one month.

v0.3, 2016 Mar 03

- + Ephemeris file: info about selected position, image source, etc., embedded as comment fields in header.
- ! Ephemeris file: declination coordinates, leading zero was missing.
- ! Ephemeris file: comment lines trimmed to 80 chars.
- ! Ephemeris file: cleaned unnecessary fields in the last line.
- ! Fixed parsing string keywords with comments in FITS files.
- \* Changed calculation for the heliographic coords to include height before differentially rotating.

v0.2, 2015 Dec 13

- + Ephemeris file: option to download generated file directly.
- + Display ALMA 12 m dish beam in selected bands.
- + Display coordinate grid (helioprojective and heliographic).
- + Manual input of position (pixel, helioprojective, Stonyhurst, Carrington).
- + User specified rotation profile.
- + Generate table of ephemeris info.

v0.1, 2015 Apr 23

- + Initial release (beta).

Legend:

- + new feature
- removed feature
- \* update/change
- ! corrected bug
- ? known issue

## Acknowledgements

1. ALMA, <http://www.almaobservatory.org>
2. ESO, <http://www.eso.org>
3. Czech ARC node Ondřejov, <http://www.asu.cas.cz/alma>
4. AIA synoptic images courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.
5. jsFITS, JavaScript FITS library, <https://github.com/slowe/jsFITS>
6. JPL Horizons, <http://ssd.jpl.nasa.gov/horizons.cgi>
7. Joint Science Operations Center (JSOC), <http://jsoc.stanford.edu>

8. Hvar Observatory, <http://oh.geof.unizg.hr>
9. Kanzelhöhe Observatory, <http://www.kso.ac.at/>

Special thanks to the members of the ALMA Solar Development Team for comments, improvement suggestions and testing.

## References

1. Brajša, R.; Vršnak, B.; Ruždjak, V.; Schroll, A.; Pohjolainen, S. (1991) Solar differential rotation determined by polar crown filaments. *SoPh*, 133, p. 195-203.([ADS](#))
2. Sudar, D.; Skokić, I.; Ruždjak, D.; Brajša, R.; Wöhl, H. (2014) Tracing sunspot groups to determine angular momentum transfer on the Sun. *MNRAS*, 439-3, p. 2377-2385.([ADS](#))
3. Thompson, W. T. (2006) Coordinate systems for solar image data. *A&A*, 449-2, p. 791-803. ([ADS](#))
4. Wöhl, H.; Brajša, R.; Hanslmeier, A.; Gissot, S. F. (2010) A precise measurement of the solar differential rotation by tracing small bright coronal structures in SOHO-EIT images. Results and comparisons for the period 1998-2006. *A&A*, 520-A29.([ADS](#))