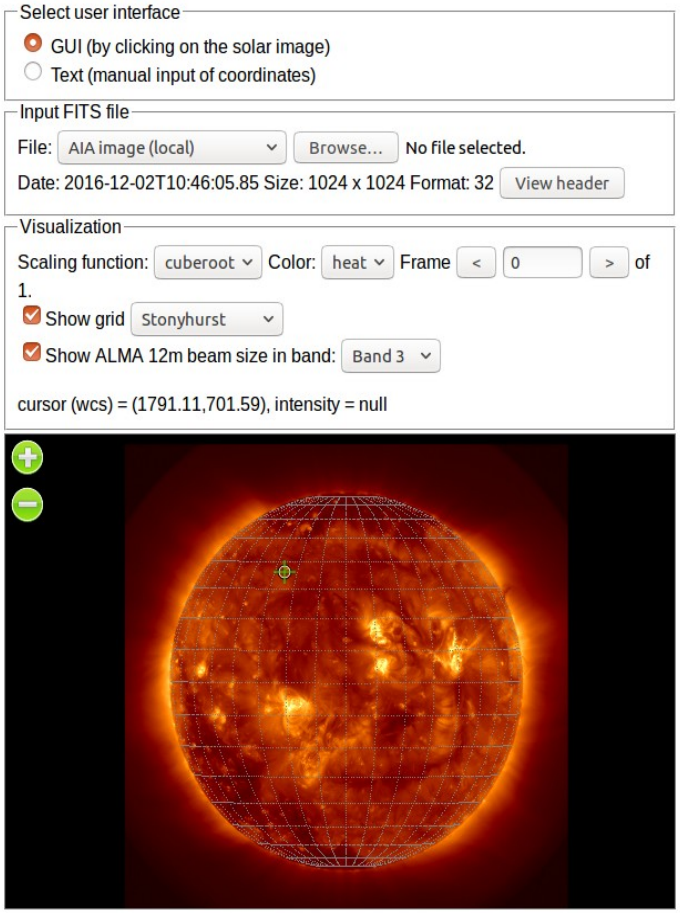
ALMA Solar Ephemeris Generator

User manual

for version 0.9.2

2020 January 26



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Description

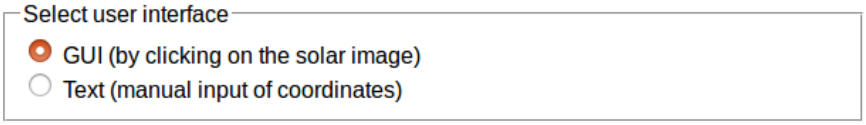
ALMA Solar Ephemeris Generator (SEG) is a software tool for generation of ephemeris files compatible with the ALMA Observing Tool (OT) for user selectable regions on the Sun. It was developed for easy preparation of solar observations with the Atacama Large Millimeter-submillimeter Array (ALMA). It can be used to create “dummy” ephemeris files for the ALMA solar proposals but mainly it is used to prepare ephemeris 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. The SEG was developed with a focus on easy and intuitive interface. The tool consists of the following panels which are ordered and used sequentially:

Select user interface	–	selection between graphical (GUI) and text user interface
Input FITS file (GUI only)	–	selection or upload of the solar image (in FITS file format)
Visualization (GUI only)	–	adjustment of the display parameters of the FITS file
Image display (GUI only)	–	navigation around the image (pan and zoom) and selection of the feature/target (point and 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 Observatory)
Observation	–	input of the observing parameters and generation of the ephemeris file

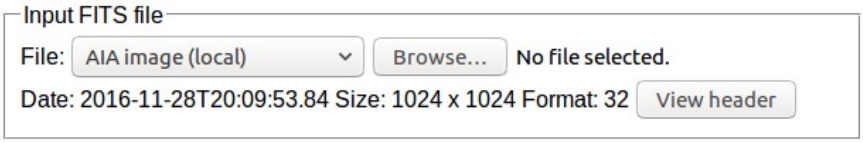
Select user interface



The SEG provides two user interface modes: graphical (GUI) and text mode. In graphical mode, a user selects the target simply by clicking on the desired target on the solar image. In text mode, the helioprojective Cartesian (HPC) coordinates of the target are specified manually.

GUI interface

Input FITS file



A selection from the following options is possible:

- *AIA image (local)* – shows the last used *Solar Dynamics Observatory*/Atmospheric Imaging Assembly (SDO/AIA) image, saved locally (if allowed by the server)
- one of the available SDO/AIA channels (see Table 1). This is the option to use in a typical scenario as it will load and show the latest available AIA image. AIA images are retrieved from the Joint Science Operations Center (JSOC).
- *AIA image (for testing)* – test AIA image, used for SEG testing

Table 1: SDO/AIA channels

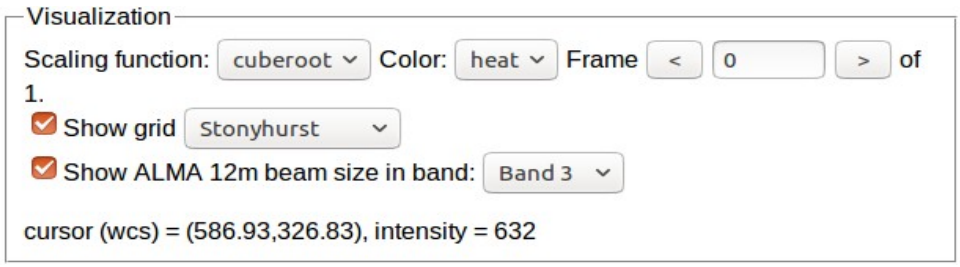
AIA channel (Angstroms)	Source	Region	Characteristic temperature (K)
94	Fe XVIII	Flaring regions	6.3×10^6
131	Fe VIII, XX, XXIII	Flaring regions	4×10^5, 10^7, 1.6×10^7
171	Fe IX	Quiet corona, upper transition region	6.3×10^5
193	Fe XII, XXIV	Corona. hot flare plasma	1.2×10^6, $2x10^7$
211	Fe XIV	Active region corona	2×10^6
304	He II	Chromosphere, transition region	50000
335	Fe XVI	Active region corona	2.5×10^6
1600	C IV + continuum	Transition region, upper photosphere	10^5, 5000
1700	continuum	Temperature minimum, photosphere	5000
4500	continuum	Photosphere	5000

It is also possible to upload your own FITS image of the Sun. The image should conform to the (old) FITS standard, be without compression, and should have the following minimum set of 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 FITS header keywords, the SEG will not function properly.

Visualization

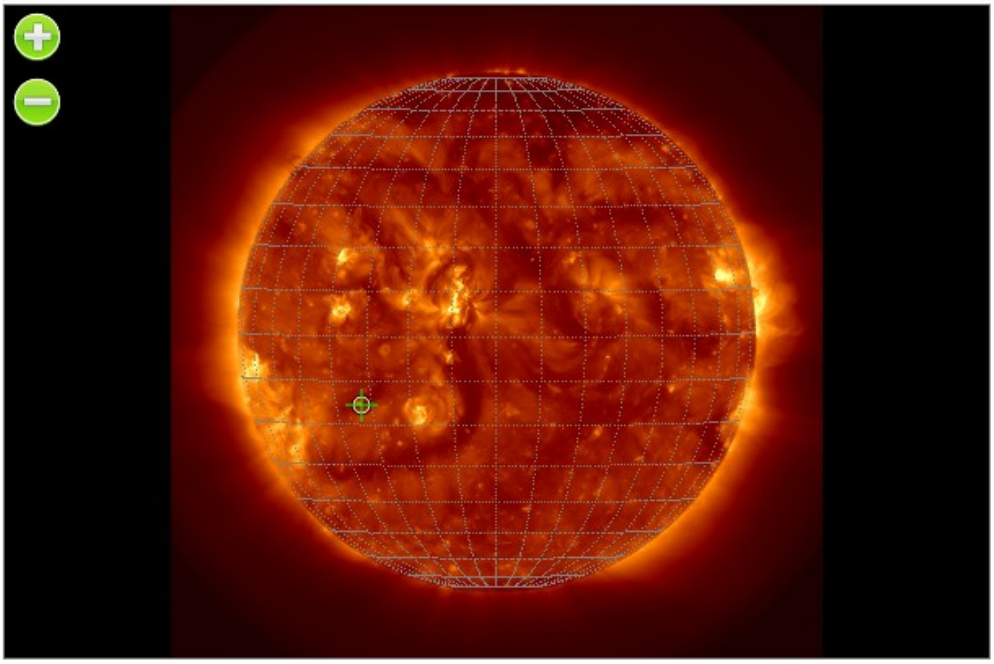


Visualization panel is used to tweak the display parameters of the supplied FITS image. *Scaling function* is used to scale the FITS data values for better visual presentation. Available functions are:

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

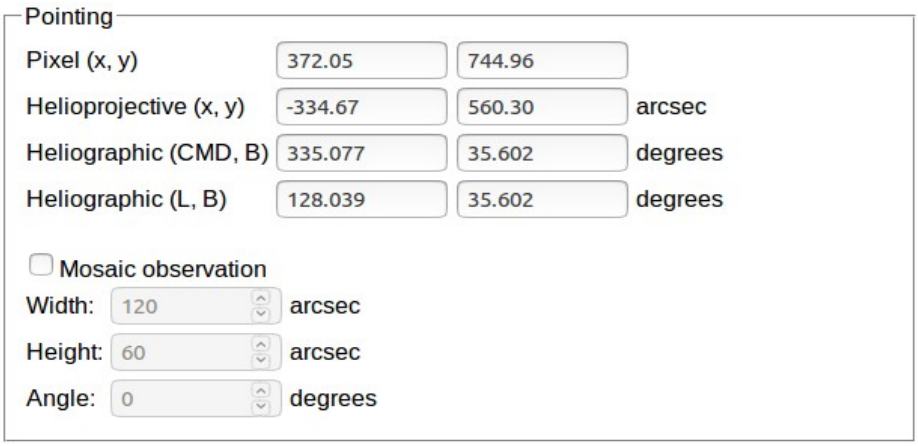
Color selects the colormap: gray, heat, A or B (as in SAOImage DS9). In multi-frame FITS images, *frame* selects the desired image. *Show grid* overlays a coordinate grid over the image, Stonyhurst heliographic, Carrington heliographic or helioprojective Cartesian. *Show ALMA 12m beam size* overlays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

Image display



In image display, a user can define the target by using the mouse or touch input. Zoom in/out is achieved by clicking the “+” or “-” buttons or with mouse scroll button, while panning is performed by dragging the image with the left mouse button pressed. Clicking without dragging will select the desired feature and a green cross will mark the selected 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 marking the mosaic outline will be shown as well.

Pointing



The coordinates of the selected feature are displayed in four coordinate systems: pixel (from FITS image), helioprojective Cartesian, Stonyhurst heliographic, and Carrington heliographic. A manual input into any of the fields is possible and if any coordinate is changed, 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, only helioprojective Cartesian and pixel coordinates will be shown.

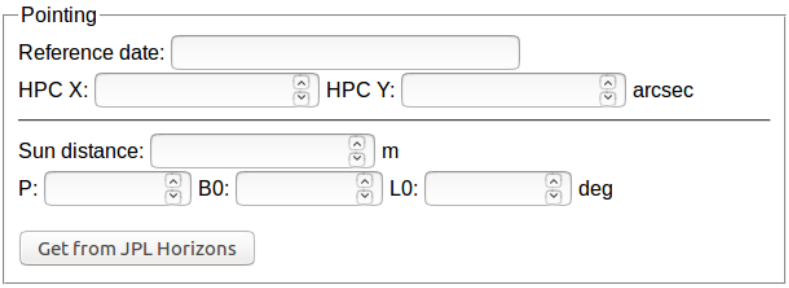
In the pointing panel it is also possible to specify the size and position angle for a mosaic observation. Note that angle is in heliographic frame (0 degrees means solar east-west). To get the sky angle (in equatorial RA-Dec frame) as required by ALMA Observing Tool, user should add solar P angle to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

angle_sky (for OT) = angle_sun + solar_P

The values of the sky angle for the start and end of the observation are given in the generated ephemeris file, in the header parameter section added by the SEG.

Text interface

Pointing



The coordinates of the target in text mode are entered as helioprojective Cartesian coordinates at the specific time instant called the reference date. The reference date should be supplied in ISO date format YYYY-MM-DDTHH:NN:SS. For the calculation of ephemerides, several additional 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*". They will be also automatically updated whenever the reference date is

changed. Note that JPL Horizons returned values are valid for the ALMA observing site and not the actual observer position (e.g. SDO) which may introduce a small but usually negligible error, if the observer is located on Earth. However, for HPC coordinates specified for observers far from the Earth, e.g. Stereo A or B satellite, the proper values of observer-Sun distance, B0, and L0 should be entered manually. Note that changing the reference date will again automatically fill these parameters with values for the ALMA observing site, so caution is advised.

Location

In Location panel, it is possible to define the geographic location for which the ephemeris will be calculated. This panel is not relevant for ALMA, since it is specified as the default location, and should be skipped if the tool is to be used with ALMA. However, due to user requests, the SEG may also be used 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 the user can specify any location on Earth manually.

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

In the observation panel the observing parameters are specified. For *start* and *end date*, ISO date format YYYY-MM-DDTHH:NN:SS is expected. *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:

No rotation (as seen from Earth) - the feature is fixed on the solar disc when viewed from the Earth, it is co-rotating with Earth's motion around the Sun and appears not to move on the solar disc.

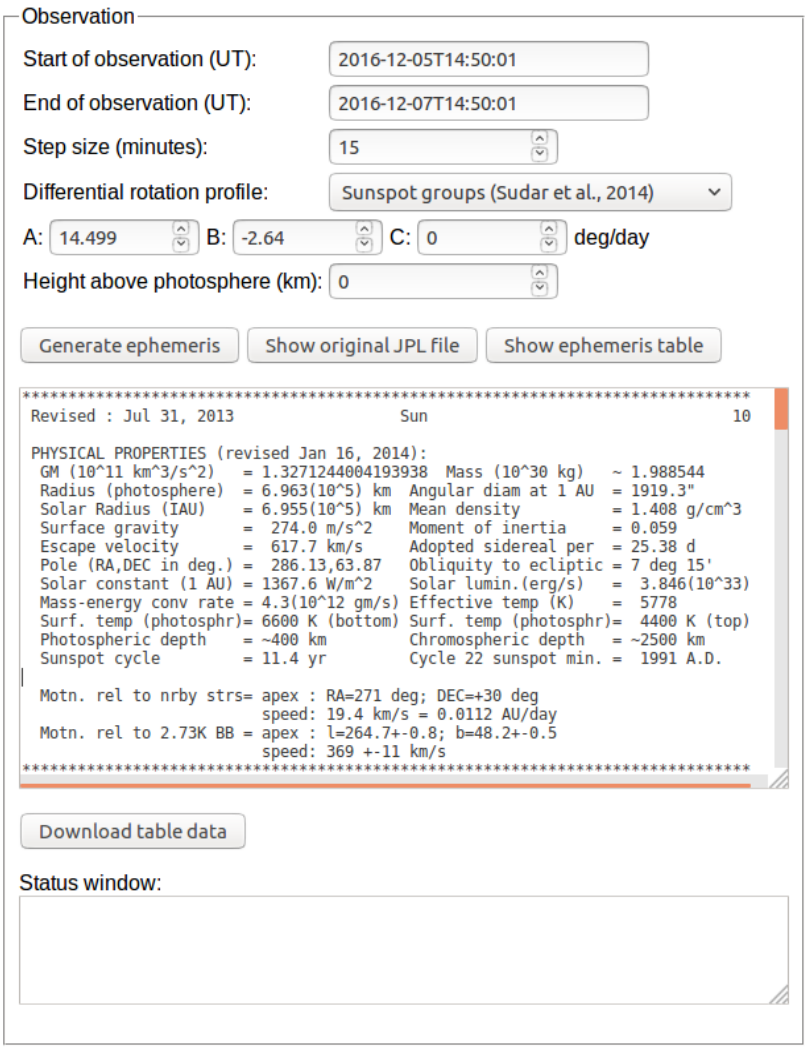
Solid rotation (Carrington) - a solid rotation where the Sun rotates as a solid body

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 the motions of coronal bright points in SOHO/EIT images (**Wöhl et al. 2010**)

User specified - user specified rotation profile in a typical form $\omega = A + B\sin^2\varphi + C\sin^4\varphi$ where φ is heliographic latitude and *A*, *B*, and *C* are given as sideric values in degrees per day.



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 the Earth, i.e. always appearing at the same location on the solar disc when viewed from the 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 for that tracer type (e.g. 0 km for sunspots, 40 000 km for filaments).

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 downloaded by clicking "*Download table data*". Two more buttons are available just for user convenience, "*Original JPL file*" will display the JPL Horizons file with solar center coordinates for the ALMA center of the array, while "*Info table*" will generate a formatted table of ephemeris data and target coordinates in many coordinate systems.

How it works

The SEG uses JPL Horizons service for high precision solar ephemeris. It sends a request to the JPL Horizons service with parameters specified in Observation and uses the received data to calculate offsets from the solar center for the selected feature, taking into account the selected differential

rotation profile and the height of the 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 the 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 and specified for the ALMA center of array or the specified location. More details about the inner workings and calculations of the SEG can be found in **Skokić and Brajša (2019)**.

Citing

If you use SEG tool in research or observation planning, please acknowledge it by citing the SEG paper, **Skokić and Brajša (2019)**.

Notes

Warnings

The ephemeris should not be older than 3 days from the reference image because of the unpredictable nature of solar features. If the ephemeris is older than 3 days, the tool with display a warning in the Status window. This can happen in two ways: either the reference image is to 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 west 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 the calculated helioprojective Cartesian (HPC) coordinates is ~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 at 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 ~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 ~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 generally known. In addition, the features evolve and 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 - not working currently
- http://celestialscenes.com/alma/coords/CoordTool.html

Software version history

```
v0.9.2, 2020 Jan 26
  * Some more improvements in calculations.
  + Added support for YYYY/MM/DD HH:NN:SS.ZZZ date format in text mode.
  ! Change in JPL ephemeris (removal of "J2000.0" string from the header) caused
    parser problems.

v0.9.1, 2019 Oct 03
  * Text interface, Sun parameters (distance, P, B0, L0) are automatically
    retrieved from JPL when focus changes from reference date input field.
  * Improvement in calculation precision.
  * Renamed Sun orientation parameters in the ephemeris file.
  ! Mosaic sky angle was calculated from the solar image P value, not from the
    observing location P value.

v0.9, 2018 Dec 14
  * Removed "No rotation" profile because it was mistakenly used instead of
    "Don't use (Earth synchronized rotation)", which was renamed to "No rotation
    (as seen from Earth)".

v0.8, 2018 Mar 02
  * Improved error checking during FITS loading.
  * Switched to https call to JPL Horizons.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
```

Acknowledgments

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.

Revision history

v0.9.2 (2020-01-26) – version history updates.

v0.9.1 (2019-10-02) – updates and text corrections to reflect changes in the software.
v0.7 (2017-04-12) – text and image updates.
v0.6 (2016-12-15) – initial release.

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. Skokić, I.; Brajša, R. (2019) ALMA Solar Ephemeris Generator. MGPB, Vol. 34 No. 2, 59-65. (ADS)
3. 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)
4. Thompson, W. T. (2006) Coordinate systems for solar image data. A&A, 449-2, p. 791-803. (ADS)
5. 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)