Making GONG Solar Data Accessible Via Afterglow

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Abstract

Afterglow, a web-based astronomical image analysis and processing system developed by the Skynet team at the University of North Carolina at Chapel Hill, was updated to import total intensity images of the sun archived in the Global Oscillation Network Group's FTP server and to implement six different WCS world coordinates into imported images. This fills the need for solar data on Afterglow, which was previously unavailable through the program. Equatorial, Ecliptic, Heliocentric-Cartesian, Helioprojective-Cartesian, Stonyhurst heliographic, and Carrington heliographic coordinates were implemented defining the location of the sun in the sky at the time the observation was taken as well as the location of features of the sun on its surface.

Keywords: image analysis system, file transfer protocol, global oscillation network group, world coordinate system

Introduction

Skynet is a network of robotic telescopes developed by the University of North Carolina at Chapel Hill to be used by Astronomy students, researchers, and strophotographers to take professional optical and radio observations. The Afterglow web application was developed alongside Skynet to enable Skynet users to perform professional data analysis on their observations. However, Skynet is limited in that it cannot be used to take observations of the sun. Solar observation requires expensive specialized instruments which are not currently available through the Skynet network. Although Afterglow can access several data archives in addition to observations taken on Skynet, none of these sources contain solar data to supplement Skynet. The aim of this project was to remedy this issue by updating Afterglow to grant users access to some archive of solar data. The Global Oscillation Network Group (GONG) data archive was selected for this purpose.

GONG is "A community-based program to conduct a detailed study of solar internal structure and dynamics using helioseismology" (Armet, 2017). In pursuit of this goal, GONG has established a six-station network of solar observatories. These observatories are positioned around the globe such that at any time the sun is in view of at least two, barring obstruction by weather. This allows GONG to take nearly continuous observations of the sun, which they have done for over the past two decades. In addition to total intensity images of the sun, data collected at these sites include magnetograms and surface velocity. All these data are stored in the GONG data archive, which is accessible via a File Transfer Protocol (FTP) server.

The FTP is a protocol for transferring files over an internet connection. Using commands, a user can connect to a remote machine over the Internet, navigate file directories, and perform operations such as appending files, storing files, and retrieving copies of files across the connection (J. Postel, 1985). To grant Afterglow access to the GONG data archive, it simply had to be given the ability to connect to GONG's FTP service and request images for download. There was already some groundwork laid for this goal: Python, the language that most of Afterglow is written in, has the ftplib module, which provides several functions that perform some basic FTP commands. This makes writing code to access FTP servers much simpler.

This project additionally aimed to implement the World Coordinate System (WCS) into headers of files imported from the GONG FTP server. This is a standardized method of including coordinate data in FITS headers described by Greisen & Calabretta (E.

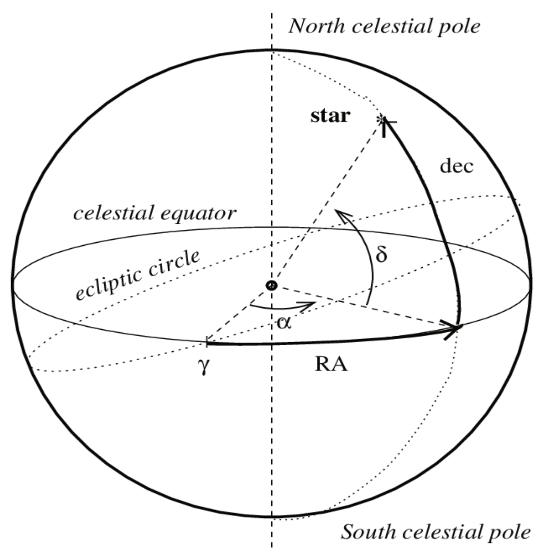


Fig. 1: A star in equatorial coordinates. In the ecliptic system, declination would be measured from the ecliptic circle (Patris, 2010).

W. Greisen, 2002). Including coordinate data allows the exact location of the sun and it's features to be defined. There are a variety of different world coordinates compatible with the WCS. The six coordinate systems considered for implementation in GONG files were Equatorial, Ecliptic, Heliocentric-Cartesian, Helioprojective-Cartesian, Stonyhurst heliographic, and Carrington heliographic coordinates. In the Equatorial system, celestial objects are viewed as if they are points on a sphere surrounding earth. An object immediately above the earth's equator has a declination (analogous to latitude) of 0°. Right ascension (longitude) is 0° when an object is in line with the Vernal Equinox, the point where the sun crosses the equator in March. Ecliptic coordinates are similar but designed such that the sun is always located at 0° longitude (Figure 1). Helioprojective-Cartesian coordinates are measured relative to the sun's position in the sky: longitude is measured from the center of the solar disk along its rotational axis, and longitude is measured from the center to the sun's west limb. Heliocentric-Cartesian coordinates are an (x, y) coordinate system, with the center of the sun as the origin. Distances are measured in solar radii, so the North pole of the sun's rotational axis is at (0,1). The Stonyhurst and Carrington heliographic coordinates are distinct from those described above in that they are used to define the position of features on the surface of the sun, rather than the position of objects in the night sky. They are analogous to the coordinate system used on earth. In Stonyhurst heliographic coordinates, the prime meridian is always facing earth. In Carrington heliographic coordinates, the prime meridian rotates with the sun. With these six coordinate systems at their disposal, Afterglow users will be able to perform a variety of calculations, e.g., calculating the rotation of the sun using the movement of sunspots and the Stonyhurst heliographic coordinate system. Adding these features to the Afterglow program will enable Astronomy professors to design and implement solar labs that utilize Afterglow and will make the program a tool for Solar Physics research in general.

Analysis

As mentioned previously, Afterglow already has access to data sources aside from Skynet, such as the Sloan Digital Sky Survey and files on a user's computer. Afterglow accesses these data using DataProvider objects. To give Afterglow access to the GONG data archive, a new subclass of DataProvider had to be created to act as a mediator between the FTP server and Afterglow. This was the FTPDataProvider class. There are several basic methods that every subclass of DataProvider must have to work with the Afterglow program: get_asset, get_asset_data, and get_child_assets. An asset is a file or a collection of files, e.g. a folder or directory, available to the Afterglow program. The get_asset method retrieves metadata about a given asset, such as size, creation time, and whether the asset is a file or a collection of other assets. If the asset is a collection, then the creation time of the collection is included in the metadata returned. If the asset is not a collection, then additional data including the size of the image, the location of observation, and the time of observation are returned as well. All GONG files are in the Flexible Image Transport System (FITS) format, and therefore have a header which includes information regarding the image. For GONG files, this information includes the time and place of observation. This is where get_asset obtains its metadata for non-collection assets. The get_asset_data method returns the actual data of a non-collection asset. This method requests a given asset from the GONG FTP server and stores the data in a buffer object. The data is g-zipped, so it is unzipped before it is returned as a bytes object. Finally, the get_child_asset method returns a list of assets within a collection along with some basic metadata such as file size and creation time.

After the FTPDataProvider class was completed, the WCS was implemented into files imported from the GONG FTP server. The get_asset_data method was updated to not only retrieve the data of file from the FTP server, but to also write coordinate systems to the file's header. Files retrieved from the server by Afterglow now support six different coordinate systems: Equatorial, Ecliptic, Heliocentric-Cartesian, Helioprojective-Cartesian, Stonyhurst heliographic, and Carrington heliographic coordinates. For Equatorial and Ecliptic coordinates, there were some key values missing. Every world coordinate in WCS uses a reference pixel, a pixel with a known coordinate position that is used to calculate the coordinate position of every other pixel in the image. Additionally, the angle of rotation of the image is required in the ecliptic and equatorial coordinate systems. The Right Ascension and Declination of the center of the image is provided in the header of every GONG file, so this was used as the reference pixel for Equatorial coordinates. Since this pixel is located at the center of the sun's disk in GONG images, the ecliptic latitude of the reference pixel is by definition 0°. However, the ecliptic longitude of the reference pixel was unknown. Every GONG image is oriented such that the top and bottom of the frame is parallel to the ecliptic lines of longitude. Therefore, the angle of rotation of the image relative to ecliptic coordinates is 0° However, the rotation of the image relative to ecliptic coordinates is absent from the header. Both of these values must be calculated by get_image_data. Ecliptic longitude can be calculated using the conversion equations between Ecliptic and Equatorial coordinates. If β is ecliptic latitude, λ is ecliptic longitude, δ is declination, α is right ascension, and ε is the obliquity of the ecliptic (about 23.4°), then

$$\cos\cos(\beta)\ \sin\sin(\lambda)\ = \cos\cos(\delta)\ \sin\sin(\alpha)\ \cos\cos(\varepsilon)\ + \sin\sin(\delta)\ \sin\sin(\varepsilon);$$
$$\cos\cos(\beta)\ \cos\cos(\lambda)\ = \cos\cos(\delta)\ \sin\sin(\alpha)\,.$$

$$tan(\lambda) = \frac{\cos\cos(\beta)\ \sin\sin(\lambda)}{\cos\cos(\beta)\ \cos\cos(\lambda)} = \frac{\sin\sin(\alpha)\ \cos\cos(\varepsilon)\ + \tan\tan(\delta)\ \sin\sin(\varepsilon)}{\cos\cos(\alpha)}.$$

Arctangent cannot be used to find λ because it is ambiguous whether $\cos\cos(\beta)\ \sin\sin(\lambda)$ and $\cos\cos(\beta)\ \cos\cos(\lambda)$ are positive or negative, which affects the actual value of λ. Fortunately, Python's math module supplies an unambiguous atan2() method which solves this issue by accepting two arguments, in this case $\cos\cos(\beta)\ \sin\sin(\lambda)$ and $\cos\cos(\beta)\ \cos\cos(\lambda)$. Because atan2 returns values in radians, the resulting angle value must be converted to degrees.

The rotation of the image relative to equatorial coordinates was more difficult to calculate. There must exist a transformation matrix R which describes the rotation between Ecliptic coordinates, which the image is oriented with, and equatorial coordinates. If θ is the angle of rotation, then

$$[\Delta\lambda\ \Delta\beta\ ] = [\cos\cos(\theta)\ \ \sin\sin(\theta)\ \ -\sin\sin(\theta)\ \ \cos\cos(\theta)\ ][\Delta\alpha\ \Delta\delta\ ]$$

$$\Delta\beta = -\sin\sin(\theta)\Delta\alpha\ + \cos\cos(\theta)\ \Delta\delta$$

$$\Delta\beta = \Delta\alpha\ + \frac{d\beta}{d\delta}\Delta\delta$$

$$\frac{d\beta}{d\alpha} = -\sin\sin(\theta)$$

$$\frac{d\beta}{d\delta} = \cos\cos(\theta)\,.$$

The atan2 function can be used to find θ once values for $-\sin\sin(\theta)$ and $\cos\cos(\theta)$ are found. Another of the conversion equations for equatorial and ecliptic coordinates can be used to solve for these values:

$$\sin(\beta) = \sin\sin(\delta)\ \cos\cos(\varepsilon)\ - \cos\cos(\delta)\ \sin\sin(\varepsilon)\ \sin(\alpha)$$

since β is of negligible magnitude, by the small angle approximation

$$\beta \approx \sin(\beta) = \sin\sin(\delta)\ \cos\cos(\varepsilon)\ - \cos\cos(\delta)\ \sin\sin(\varepsilon)\ \sin(\alpha)$$

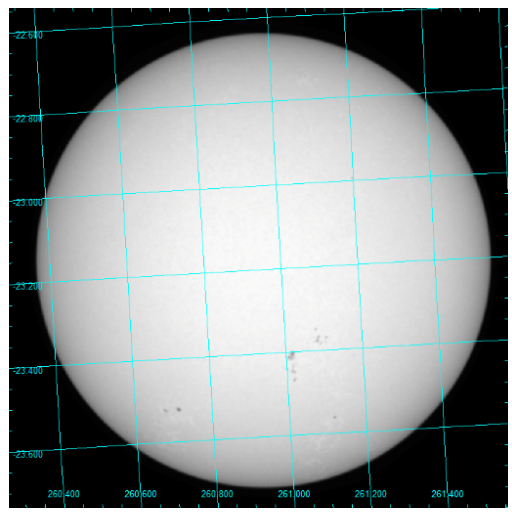
Now by taking the derivative of this equation with respect to δ and α, values for $\cos\cos(\theta)$ and $-\sin\sin(\theta)$ can be found.

$$\beta \approx \sin\sin(\delta)\ \cos\cos(\varepsilon)\ - \cos\cos(\delta)\ \sin\sin(\varepsilon)\ \sin\sin(\alpha)$$

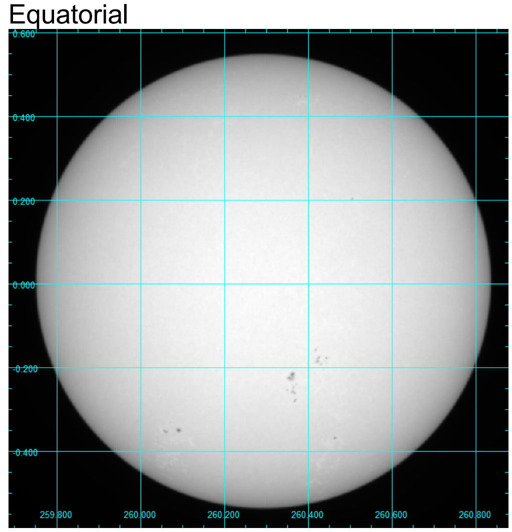
$$-\sin\sin(\theta)\ = \frac{d\beta}{d\alpha} \approx (\delta)\ \sin\sin(\varepsilon)\ \cos\cos(\alpha)$$

$$\cos\cos(\theta)\ = \frac{d\beta}{d\delta} \approx \cos\cos(\delta)\ \cos\cos(\varepsilon)\ + \sin\sin(\delta)\ \sin\sin(\varepsilon)\ \sin(\alpha)$$

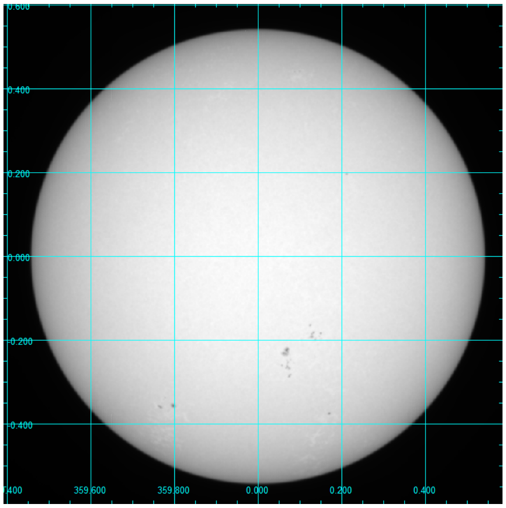
Right ascension and declination are supplied in the header, and the obliquity of the ecliptic is a constant value. Using these equations, the rotation of the camera relative to the equator can be approximated in radians. With this value, equatorial coordinates could be implemented into the headers of GONG files, along with the other five coordinate types (Figure 2).

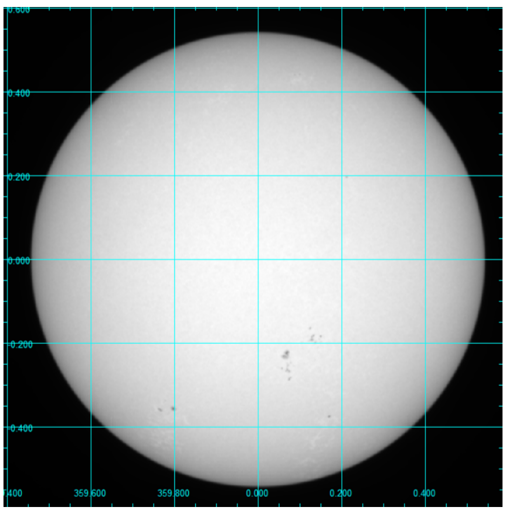


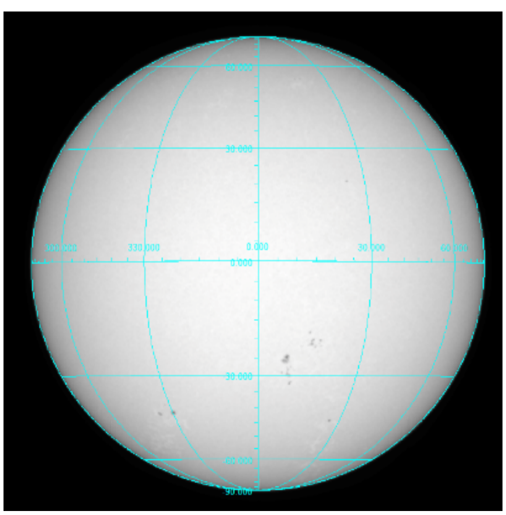
Equatorial



Ecliptic


Heliocentric-Cartesian


Helioprojective-Cartesian


Stonyhurst heliographic

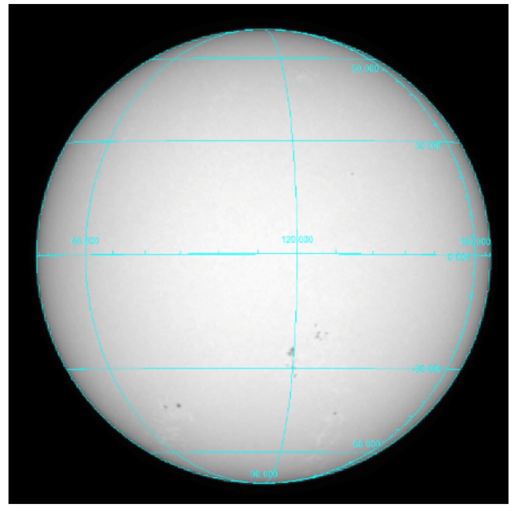

Carrington heliographic

Fig 2: An image from the GONG database overlaid with the six implemented coordinate systems.

Conclusion

Now that the FTPDataProvider class has been completed, Afterglow can access the entirety of the GONG data archive. GONG has been observing the sun every minute of every day since 1995 and will continue to do so. Previously, there was no way to access any solar data through Afterglow, but users will be able to browse all these data and use Afterglow's analysis tools on them once the update is released. Professors of astronomy and solar physics can now design solar lab experiences for their students utilizing the Afterglow web application. The addition of coordinate data to GONG files makes defining the location of features in observations possible. In the future, the FTPDataProvider class can be diversified to not only access the GONG FTP server, but other FTP servers as well, making even more data accessible to Afterglow users.

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