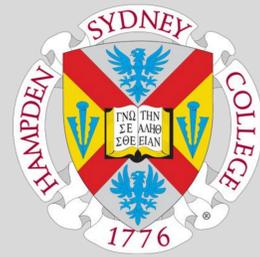# Making GONG Solar Data Accessible Via Afterglow

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## 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 astrophotographers 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. 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 solar observation program with a network of six observation sites positioned around the globe such that the sun is constantly in view of at least two. Data collected by these observatories is made available through a File Transfer Protocol (FTP) server. FTP is a protocol for transferring files over an internet connection, which could be used by Afterglow to access GONG's files.

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. W. Greisen, 2002). Including coordinate data allows the exact location of the sun and it's features to be defined. Six WCS coordinates were considered for implementation (Figure 1). Equatorial, Ecliptic, and Helioprojective-Cartesian coordinates all measure the position of objects in the sky, while Heliocentric-Cartesian, Stonyhurst Heliographic, and Carrington Heliographic coordinates measure the position of features of the sun on its surface. Making this information available to Afterglow users

## Analysis: Accessing the Archive

As mentioned previously, Afterglow already has access to data sources aside from Skynet using `DataProvider` objects. A new subclass of `DataProvider` had to be created to act as a mediator between the FTP server and Afterglow: The `FTPDataProvider` class. Every subclass of `DataProvider` must have the following methods: `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. GONG files are in the FITS (Flexible Image Transport System) file format, meaning they have a header containing metadata of the file. `get_asset` obtains metadata like observation time, observation location, and image dimensions from the header of GONG files. 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.

## Analysis: Implementing WCS

The World Coordinate System was implemented into imported GONG files by changing the `get_asset_data` function to alter the headers of files it imports to include the six different coordinate systems (Figure 1). However, some data required to implement these systems were unknown: the rotation of the camera relative to equatorial coordinates and the Ecliptic longitude of the image. The conversion equations between ecliptic and equatorial coordinates were used to calculate this value. If $\beta$ is ecliptic latitude, $\lambda$ is ecliptic longitude, $\delta$ is declination, $\alpha$ is right ascension, and $\varepsilon$ is the obliquity of the ecliptic (about 23.4°), then

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

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

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

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 $\theta$ is the angle of rotation, then

$$\begin{bmatrix}\Delta\lambda\\\Delta\beta\end{bmatrix} = \begin{bmatrix}\cos(\theta) & \sin(\theta)\\-\sin(\theta) & \cos(\theta)\end{bmatrix}\begin{bmatrix}\Delta\alpha\\\Delta\delta\end{bmatrix}$$

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

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

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

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

The `atan2` function can be used to find $\theta$ once values for $-\sin(\theta)$ and $\cos(\theta)$ are found. Another of the Equatorial and Ecliptic conversion equation can be used to solve for these values:

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

since $\beta$ is of negligible magnitude, by the small angle approximation

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

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

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

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

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.
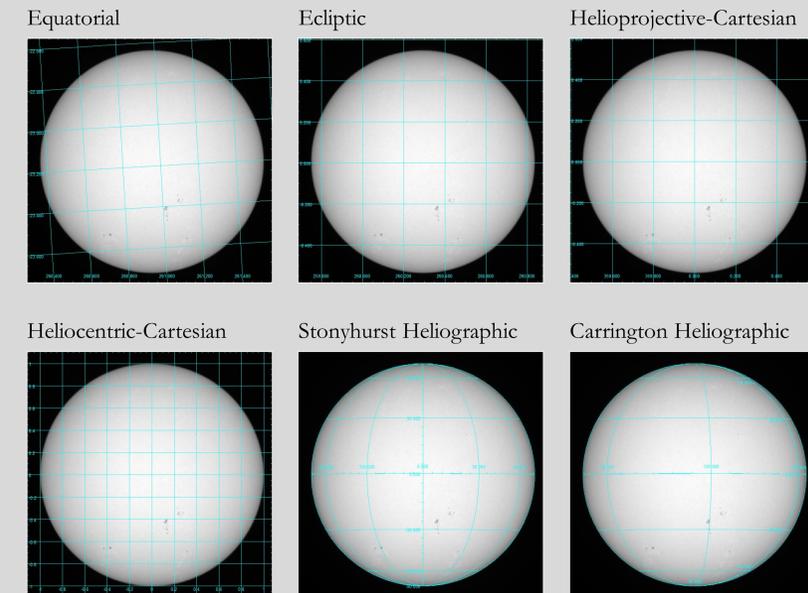

Fig 2: An image from the GONG database overlaid with the six implemented coordinates.

## 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 server's as well, making even more data accessible to Afterglow users.

## References

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