CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title:	Web application interface to the Lowell Observatory Solar Telescope
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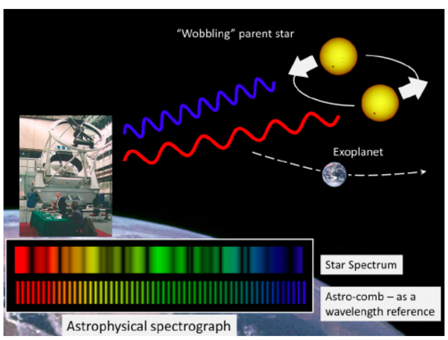
Project Overview:

Since the discovery of the first exoplanet almost 25 years ago, astronomers have discovered over 4,000 new worlds. Exoplanetary systems come in all imaginable configurations, from Jupiter sized planets orbiting within just a few days of their parent star, to the hyper-compact TRAPPIST-1 system, comprising of multiple planets similar in size to our Earth, but orbiting a star one-tenth the size of our Sun. Despite thousands of confirmed exoplanets, the one system we are yet to discover is a planet like our Earth orbiting a star like our Sun.



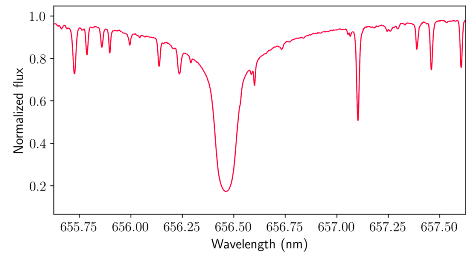
One of the most promising methods for finding a true Earth analog i.e., a planet the mass of the Earth, orbiting at 1 AU, around a solar-type star is through the radial velocity (RV) method. An exoplanet not only orbits a star, but the presence of the planet also impacts the star itself. An exoplanet moves the center of mass of the system, causing the star to move towards- and away- from an observer here on Earth. By making very precise measurements of this Doppler motion astronomers can infer the presence of an orbiting planet. To detect an Earth analog, we must measure the stellar RV with a precision of ~10 cm/s, an order of magnitude better than the previous generation of planet hunting instruments were able to achieve.

Lowell Observatory has partnered with Yale University to build one such next-generation instrument. The EXtreme PREcision Spectrograph (EXPRES) is a pinnacle of a decade of experimentation, and is capable of achieving the precision necessary to detect an Earth twin. EXPRES has been fully commissioned on the 4.3-meter Lowell Discovery Telescope (LDT) and is ushering a new era of extreme RV precision. EXPRES has already demonstrated a ground-breaking instrumental precision of 7 cm/s and formal radial velocity precision on stars of 40 cm/s. This precision is sufficient to detect the type of small rocky planets detected by Kepler, but orbiting bright stars.

LOST in front of the LDT

One fundamental challenge must still be overcome to enable the detection of terrestrial exoplanets in the habitable zones of Sun-like stars. Inhomogeneities on the stellar surface arising from star spots, plages, and granules lead to perturbations in the measured radial velocity, often at amplitudes of m/s, far larger than the 7 cm/s signal of a terrestrial exoplanet. Such signals are also poorly understood and progress in removing them is largely limited by the fact that the surfaces of stars other than our Sun are not resolved. The Sun offers the unique opportunity to observe a resolved star with a planet hunting spectrograph.

Now fully commissioned, the Lowell Observatory Solar Telescope (LOST; right), feeds sunlight through a 75-mm lens into a fiber optic cable and into EXPRES. LOST observes the Sun every day with a cadence of 5-minutes for an average of 8-hours each day. When combined with calibration data, the daily data size is approximately 40 GB. Our team has worked diligently on fully automating the mammoth task of observing the Sun continuously during the day. The LOST control software starts the telescope in the morning, points to the Sun and automatically triggers EXPRES to begin observing. The software also performs the necessary calibrations and data reduction. The final data product is a FITS file that contains an array of wavelength and flux of the solar spectrum and also ancillary data such as time of observation, exposure time etc.



Now that the data taking part of LOST is complete we are turning our attention to data analysis and methods for making the data easily accessible to the astronomy community. Without an intuitive user interface the data will be incredibly hard to work with and will not reach its full scientific value. Our primary data product are 1-d spectra of the Sun consisting of an array of wavelength (in nano-meters) vs normalized flux.

Basic, minimum viable product:

- A secure web2.0 web application with role-based permissions for admins, public users, and other levels as needed.
- Interfaces with our SQL database to search and spectra of the Sun from our file server. The web application will connect to the database of LOST observations, and should provide a form-based search interface to find observations of interest.
- Basic information about each observation should be easily queried and displayed, such as exposure time, signal-to-noise, along with various diagnostics of the spectrum that are all stored in our database.
- Allows basic graphical display of a particular observation to provide a quick overview.
- Provides means to select and download interesting observations for further analysis.

Complete, a well-appointed app:

- Supports more dynamic searching of database, e.g., live updating of matching items as you manipulate search criteria.
- Supports profiling the database, to graphically overview the number of observations of various kinds, i.e., matching various criteria, potentially plotted on a time axis.
- Allows fully flexible visualization and analysis, e.g., zooming in on regions of interest, saving those regions as separate data entities (i.e. cropping the original) for further work.
- Supports more advanced visualization tools, like overplotting multiple spectra, plotting a time series of spectra, integrating flux between two wavelengths.
- Can overlay template observations of the Earth's atmosphere.
- One of the stated science goals of LOST is also to correlate with simultaneous observations of the Sun from other instruments (e.g. NASA's Solar Dynamics Observatory (SDO; https://sdo.gsfc.nasa.gov/data/). Should be able to incorporate such data streams into the analytic interface.
- Supports user accounts, allowing users to specify and run "favorite searches", or set notifications when observations matching certain criteria are added to the DB.

Advanced, stretch goals:

- Supports user "lab notebooks" within their accounts; users can save off interesting datasets along with commentary for later reference, and can easily "share" such items, e.g., as email attachments.
- Provides a dynamic home page for the webapp that shows a variety of "news" about LOST, including stats on latest observations, profile of all observations in the DB, announcements from site admins, and perhaps "staff favorite" datasets.
- Incorporation of educational materials developed by Lowell Observatory's Education team.

A successful LOST user interface webapp will provide a convenient tool for astronomers world-wide to access one of the best datasets on our star. This data will revolutionize our understanding of solar activity and also vastly increase our ability to tease out the tiny signals from an Earth sized exoplanet.

Knowledge, skills, and expertise required for this project:

- Modern web2.0 development frameworks and techniques.
- Front-end web development skills (e.g., HTML, Javascript, react)
- Database access and basic database organizational principles.
- Back-end development using tools such as SQL, Python.

Equipment Requirements:

- Our aim is to make all software developed for LOST publicly available, we therefore only use open-source software.
- Storage of all LOST data is already taken care of. Students will be provided with sample LOST data of all sorts for development, as well as appropriate access to our servers.
- No special equipment beyond a development station and access to publicly available development resources (IDEs) is needed.

Software and other Deliverables:

- The deliverable from this project will be a software suite consisting of a front- and back-end capable of serving and displaying data from our database of solar observations.
- All code must be well documented to provide a strong basis for future development of the product and to ensure ease of use for other telescopes aiming to achieve similar science goals as LOST.
- The final work package will be stored on GitHub and also served to the web on Lowell Observatory's web server.