

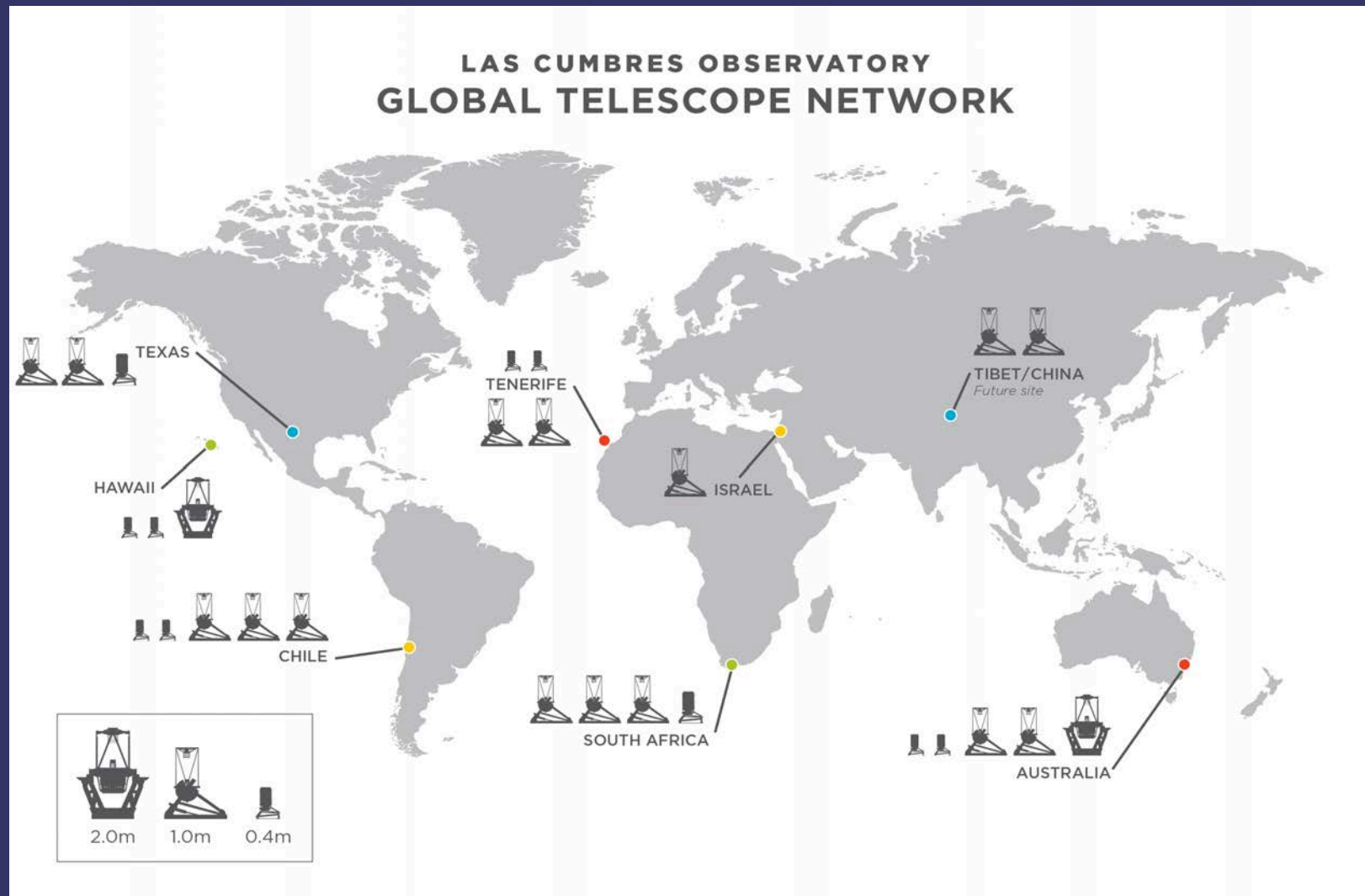
# The LCO NEO Follow-up Network

An intro to TOMs & AEON: Tools for the LSST era

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# The LCO Telescope Network

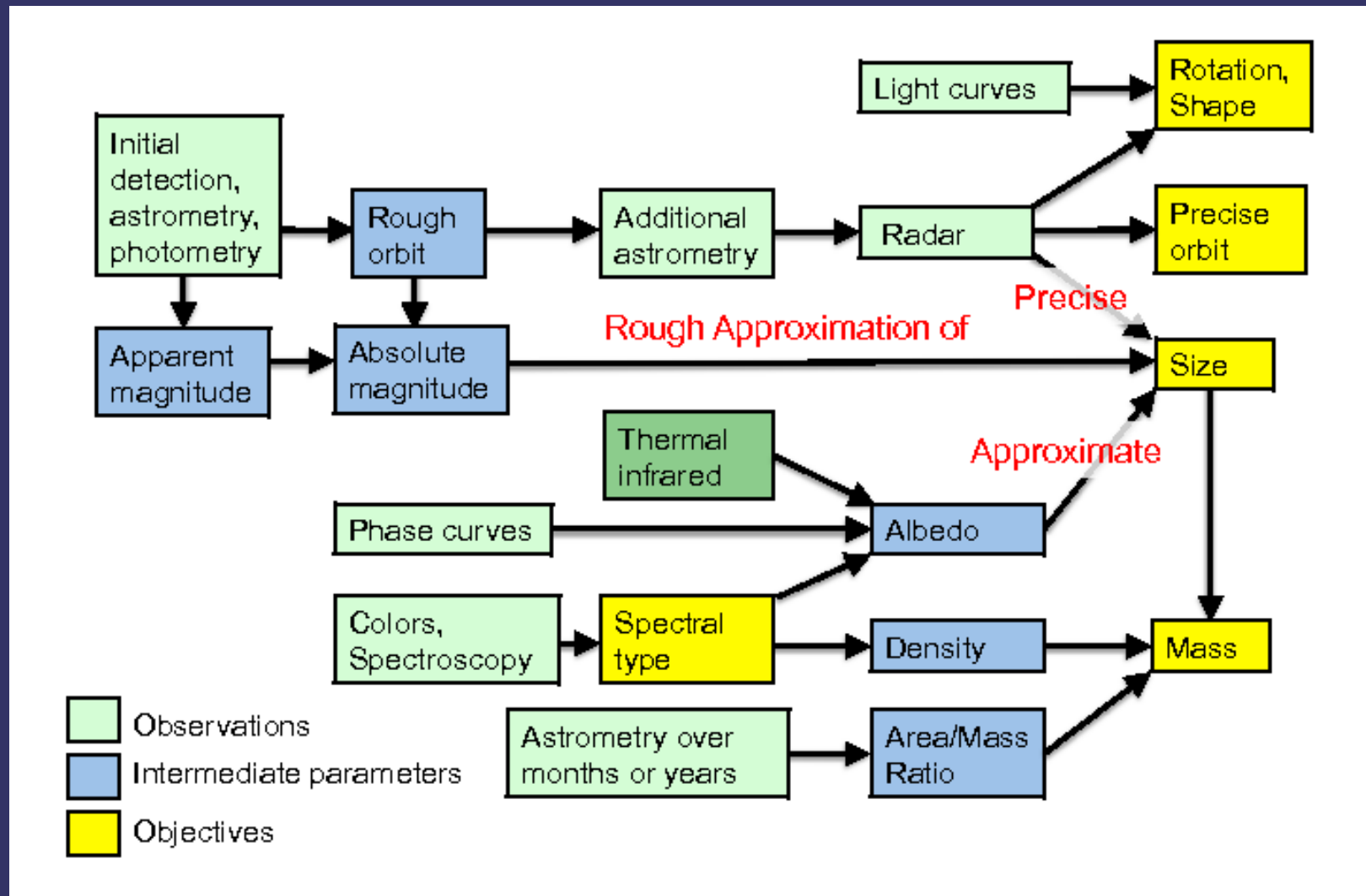


# The LCO Telescope Network

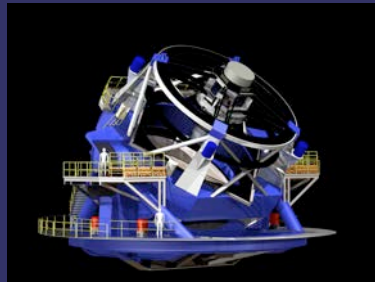
- Network now consists of:
  - 2 x 2m telescopes (imager & low-res spectrograph)
  - 9 x 1m telescopes (imager & fiber-feed to high res. spectrograph)
  - 10 x 0.4m telescopes (imagers)
- All telescopes remote and robotic; network can respond to new requests in <10 mins
- 3 extra 1m telescopes funded and coming:
  - 1 to McDonald Observatory, TX (2019)
  - 2 to Teide Observatory, Canary Islands (2020)



# Overview of NEO Characterization



# Follow-up observations coordinated across a range of facilities



IR imaging/spectra  
Spitzer/WFIRST/JWST

Eliminate non  
NEOs

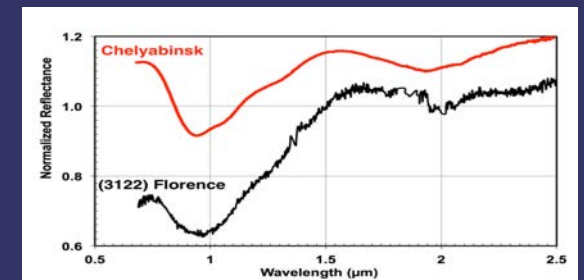
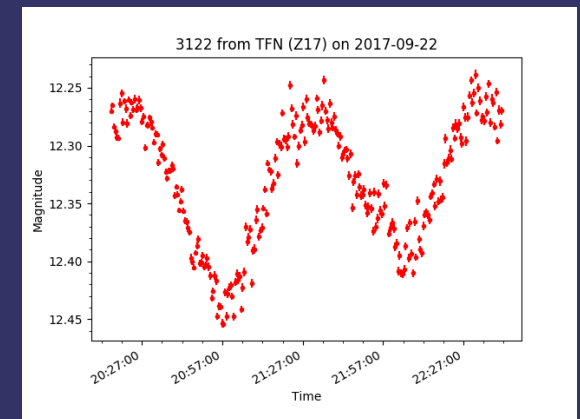
Initial  
Followup

Characterization



Radar imaging  
Goldstone/Arecibo

Photometry/Light curves



Characterization spectra



# Keeping track of follow-up: hard, going to get harder

- Current follow-up programs take 1000s of observations and TB of data
- Managing observations and data is already a major challenge and going to get worse
- Often A Need for Speed to gather follow-up data
- Need to co-ordinate multi-wavelength, multi-method campaigns on important targets (e.g. Didymos, 1999 KW4, 2012 TC4, 46P, 67P)

**Future infrastructure needs to address this**



# Goals of Target and Observation Manager (TOM) Systems

- Coordinate programs which have too many targets, observations and data products to track
- Decide on priority targets for rare/expensive follow-up
- A framework for science-specific analysis to be conducted
- A framework to interact with external services
  - harvesting alerts and new targets
  - submit observation requests
  - feedback (status & data) from telescope facilities
  - accessing data archives
  - coordinating object follow-up with other users

# LCO's Solar System “TOM”

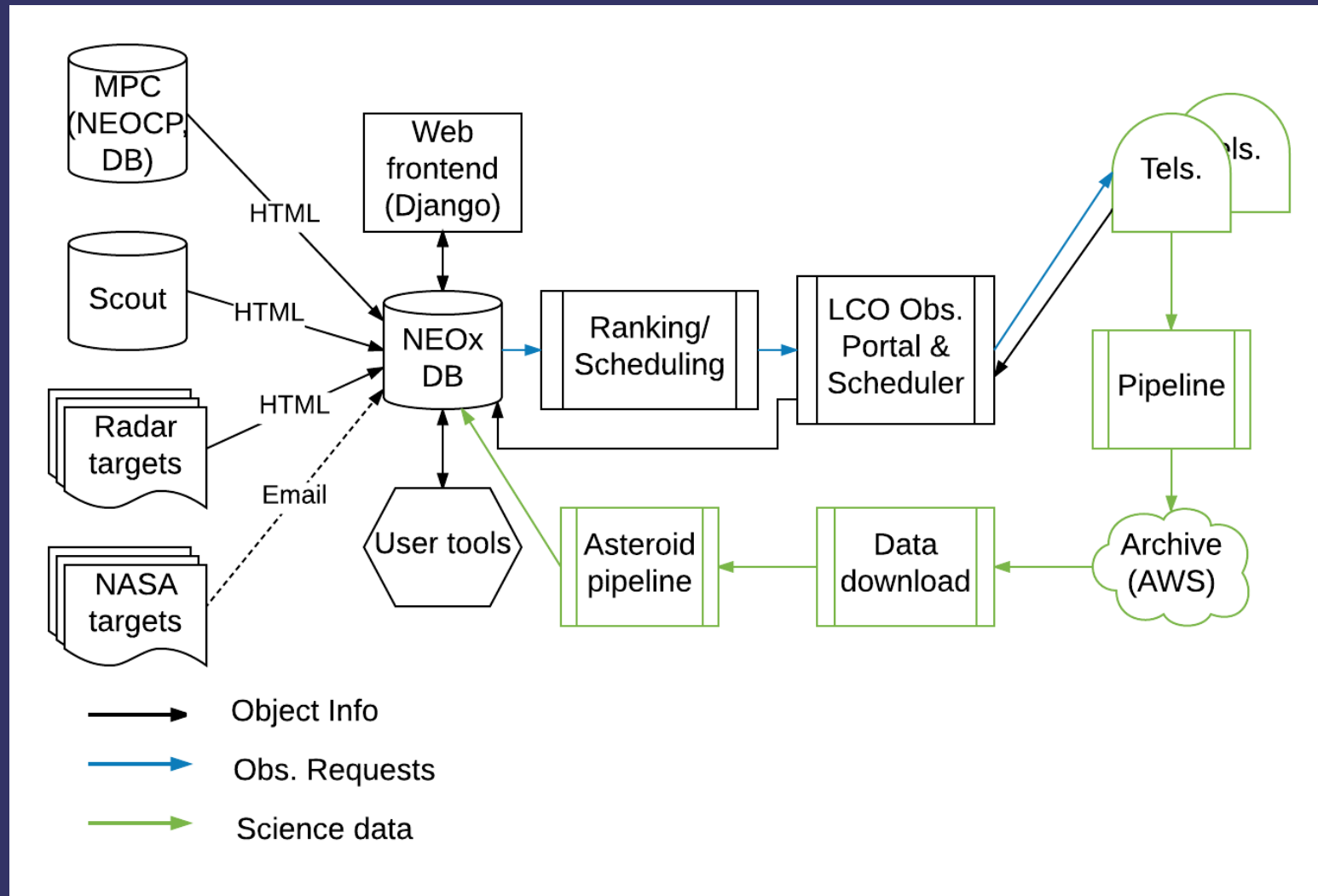
NEOExchange

<https://lco.global/neoexchange/>



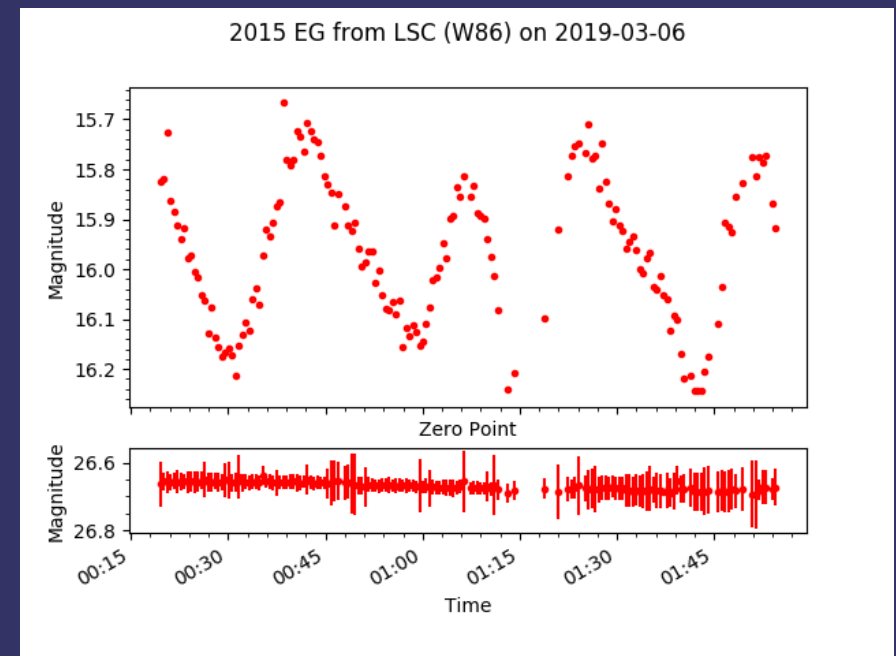


# Overview of NEOExchange



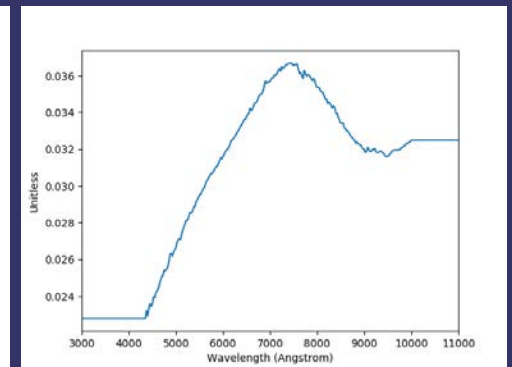
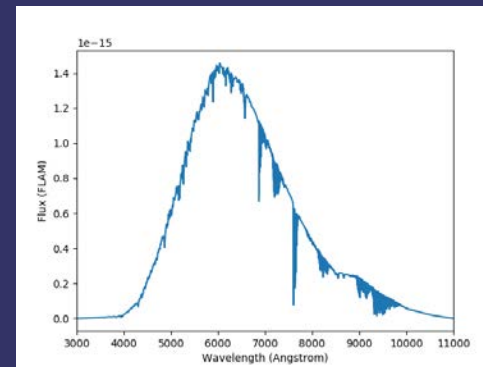
# Observation and Follow-up Planning

- Now balancing 3 main types of follow-up:
  - 1) Astrometry of priority targets for ephemeris error reduction
  - 2) Physical characterization of radar targets:
    - a) Light curves
    - b) Low res spectroscopy
    - c) Multi-color observations
  - 3) Rapid response to close targets in <1 hour

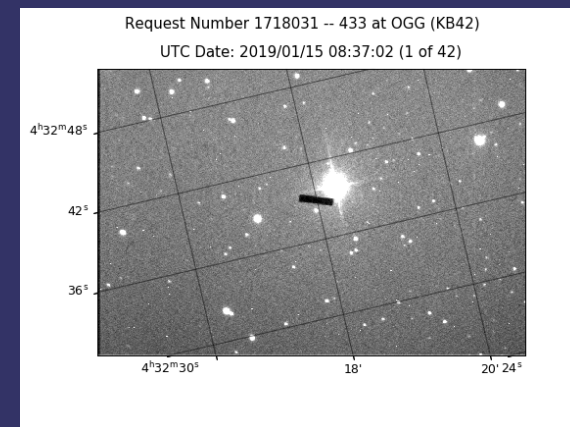


# NEOExchange: Spectroscopy

- Spectroscopy support in NEOExchange:
  - Initially for LCO *FLOYDS* spectrographs
  - Developed generalized SNR estimator based on background, telescope & instrument model
  - Can schedule spectroscopy obs (plus needed calibs) on the LCO network
  - Working to iron-out remaining robotic acquisition & guiding issues



Synthesized observed Eros spectrum convolved with Earth atmosphere, telescope and instrument models





# Astronomical Events Observatory Network

- Goal of AEON is to provide platform to serve as single point of access & coordination to variety of observing resources for time-domain and alert response obs.
- LCO working with NOAO to automate SOAR & send requests from LCO scheduler for follow-up
  - Queue mode obs. with Goodman spec. with operator overwatch
  - APIs to send obs. requests and return status/data implemented
  - Work ongoing at SOAR to automate some aspects of operations
  - 2 nights already with LCO scheduler sending to SOAR to execute





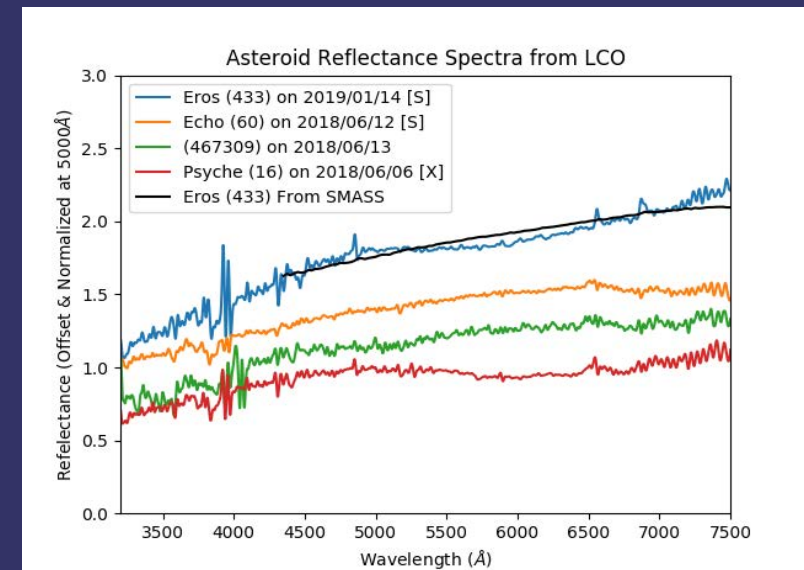
# Astronomical Events Observatory Network

- 2<sup>nd</sup> Phase to coordinate observations with Gemini
  - Most likely to be Gemini-South through their scheduler
  - TOM Toolkit already has a module to allow Gemini observation requests (by Bryan Miller@Gemini)
  - Gemini in the process of major upgrades to operations and scheduling software with time-domain as a major driver
  - Also talking to Liverpool Telescope (& LT2) and SALT/SAAO



# Future Work

- Extend LCO NEO Follow-up Network:
  - Develop a model for SOAR Goodman spectrograph
  - Submit NEOs from NEOexchange to SOAR + Goodman as part of AEON
  - Extend model into NIR for Gemini/IRTF ?
- Automate more & improve spectroscopy data reduction
- More use of faster cameras for rapid rotating NEOs



# Extra Slides

# Overview

- The LCO Telescope Network
- NEO characterization efforts
- Overview of Target & Observation Managers (TOMs)
- LCO's TOM for NEOs: NEOexchange
- AEON: Astronomical Events Observatory Network



# The TOM Toolkit Project

Tools for managing targets and observing programs



# TOM Toolkit Project

**Developing a general purpose software toolkit for common target, observation & data management functions with easy interfaces to user-written software.**

- Enable astronomers to build TOM systems easily
- Provide large set of core functions for commonly-used components
- Provide well-defined interfaces to allow science-specific code to interact with the TOM
- Being developed by LCO with community input



# TOM Toolkit Design Philosophy

- Astronomers shouldn't need a software engineering degree to build or use a TOM
- One size doesn't fit all
  - Need to use the tools demanded by their project customize the system to their needs – which may evolve over time.
- Astronomers know how to do their science best
- TOMs encourage data share/collab. - but don't force it
- Toolkit itself built by professional software engineers

# Time-Domain Astronomy Network

