The TOM Toolkit

Tools for science-driven observing programs in the LSST era

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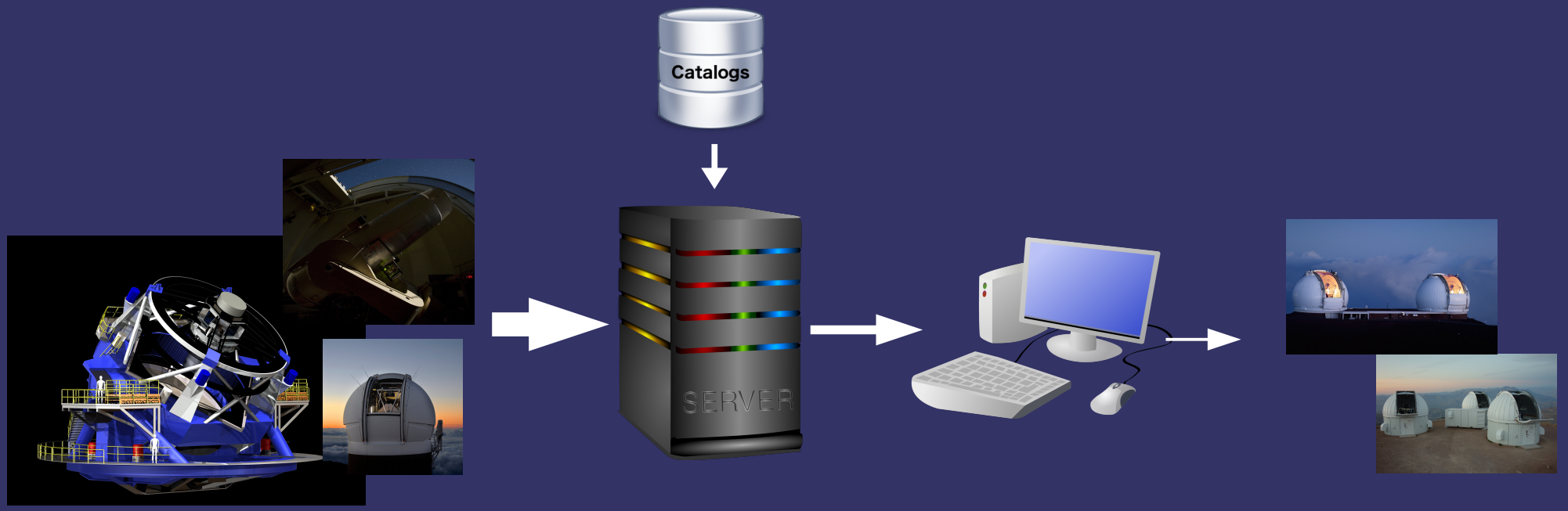
Astronomy's Discovery Chain



Targets discovered by survey

Classified by Broker

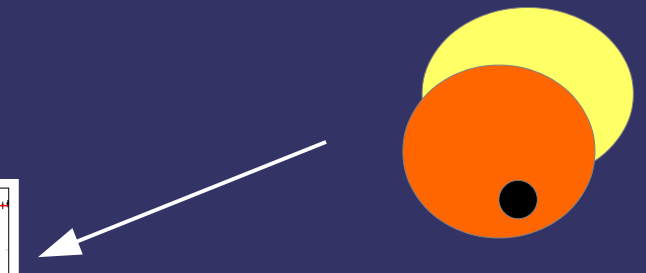
Selected, analyzed by astronomer

Characterized by follow-up

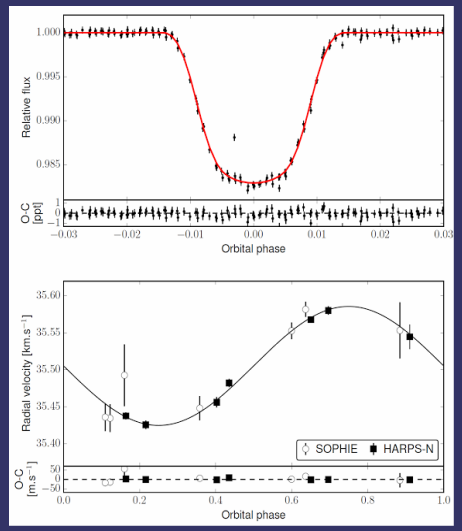
Discovery is not enough...science depends on characterization
But the flood of targets is reaching an industrial scale

Follow-up observations coordinated across a range of facilities

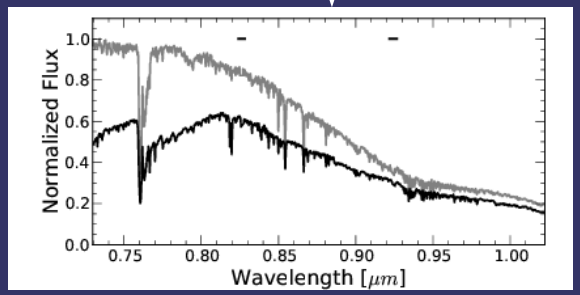
Transiting planet candidate



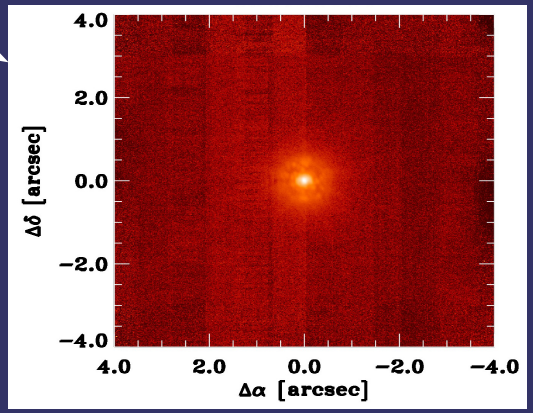
Transit photometry
1m telescopes



From Lillo-Box et al. (2016)



Radial velocities
1-2m class telescopes



AO imaging,
10m telescope
By D. Ciardi

LCO

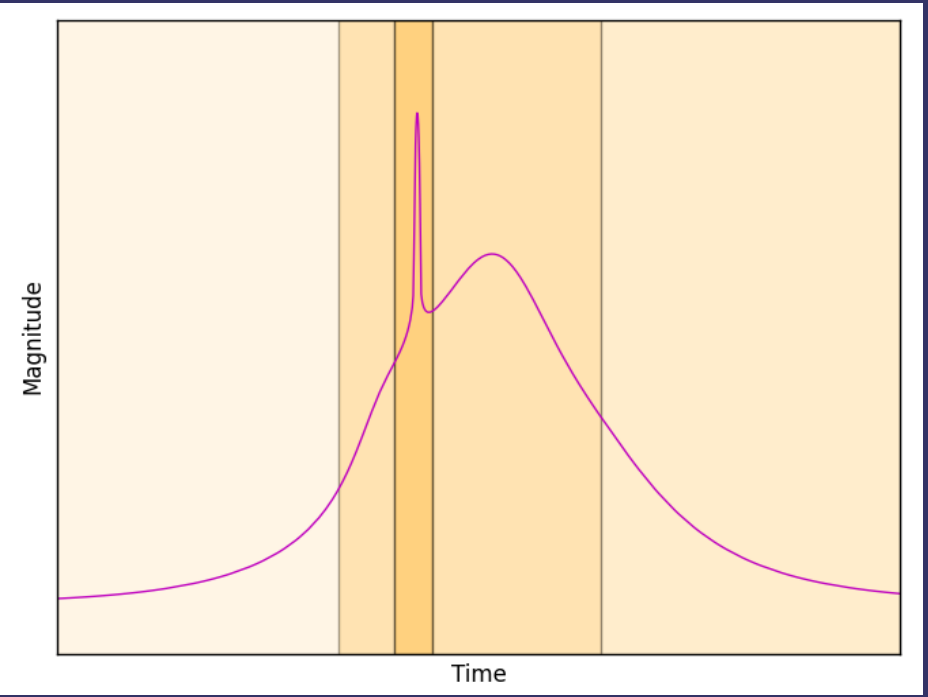
Follow-up is a function of time

Handle many targets in different states simultaneously

- *New alerts*
- *Reconnaissance phase*
- *Intensive phase*
- *Long-term monitoring*

Observe on a range of timescales, cadences, facilities

Microlensing Event with Exoplanet



Photometric cadence

Follow-up in a target-rich era

Already have more targets than programs can follow-up...and getting worse

Observe continuously

- *Need access to filterable target sources (catalog, transient streams)*
- *Need to develop prioritization criteria*

Often need real-time analysis:

- *To select targets*
- *Determine new priorities*
- *Decide future observations*

Follow-up datasets are substantial

→ **Thousands of observations and TB of data**

Microlensing Key Project		Per year	Project (3yrs*)
~15,000	Images @ ~90MB each	~1.3 TB	~4TB
	Reduction products	~4 TB	~12 TB
	Discrete observation requests	~900	2,631

**(and we only observe during the northern summer!)*

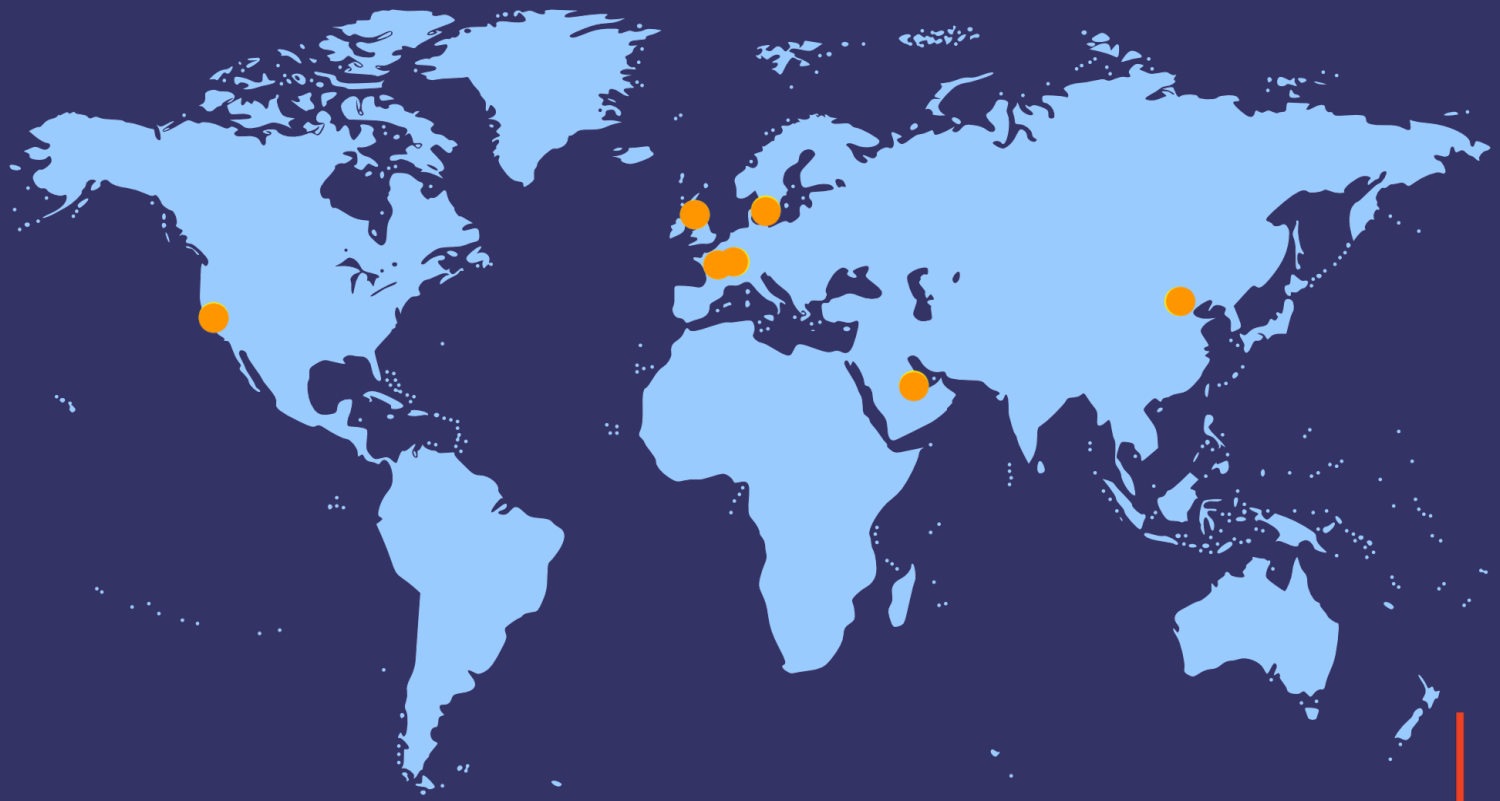
Follow-up Teams

Large collaborations, often international

- but operations/development team usually small

Coordination is important

- geographically-separated team helps, but implies infrastructure needs to facilitate sharing of data



Keeping track is going to get harder

Current and near-future surveys will generate target catalogs of unprecedented size

Rapid alerts and rapid follow-up increasingly possible and scientifically desirable

Managing observations and data is already a major challenge and going to get worse

Infrastructure needs to address this

Goals of TOM Systems

Target and Observation Managers

- Coordinate programs where the workload of keeping track of targets, observations and data products would otherwise be onerous

- A framework for science-specific analysis to be conducted

- A framework to interact with external services

Existing need for TOM systems

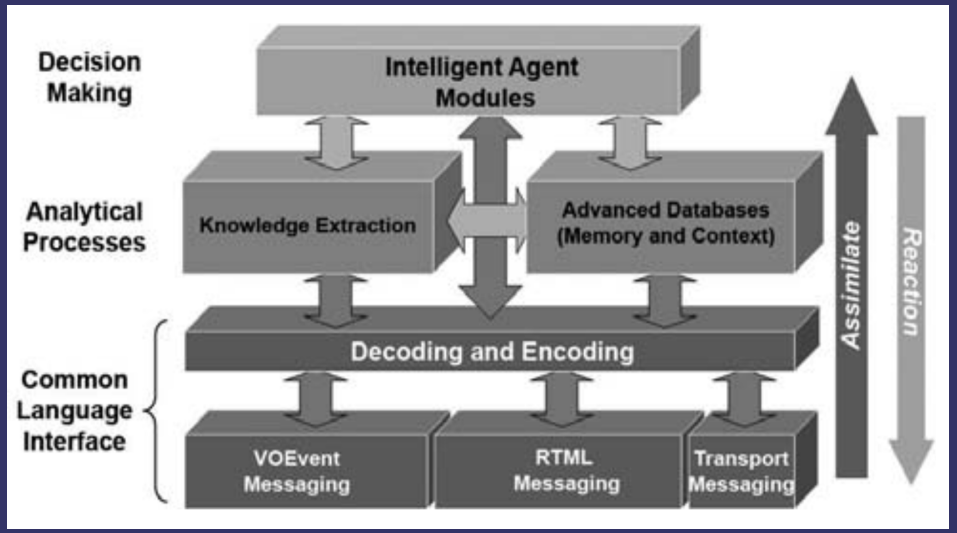
"TOM" is a catch-all name for a genre of systems performing similar functions

Science teams have found it necessary to develop similar systems for ~10-15 years
E.g. PTF Marshall NASA ExoFOP KELT...

All 3 LCO science teams have developed TOM systems:
RoboNet Microlensing Supernova Exchange NEOExchange

"...agent(s) provide the decision making and overall analysis control...software modules that act as proxy for the scientists..."

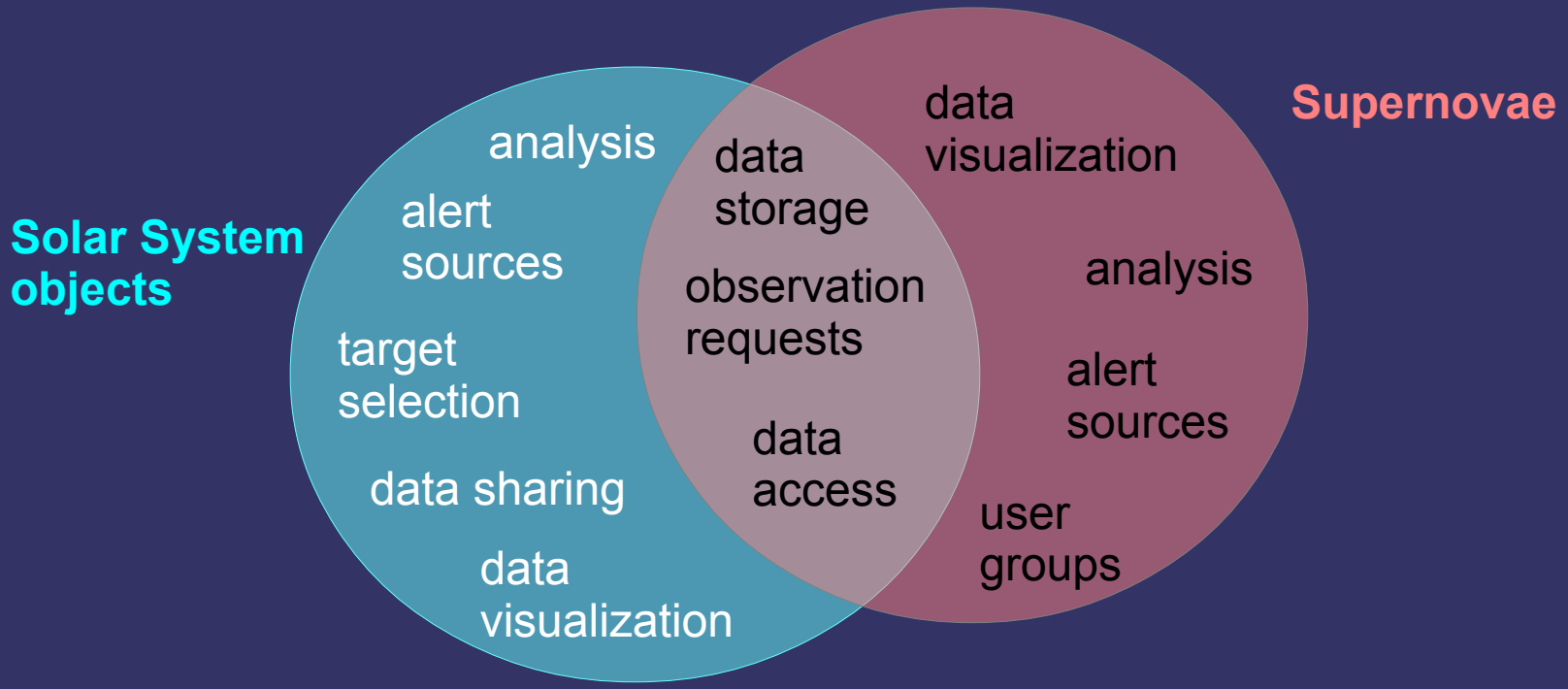
White & Allan (2008)



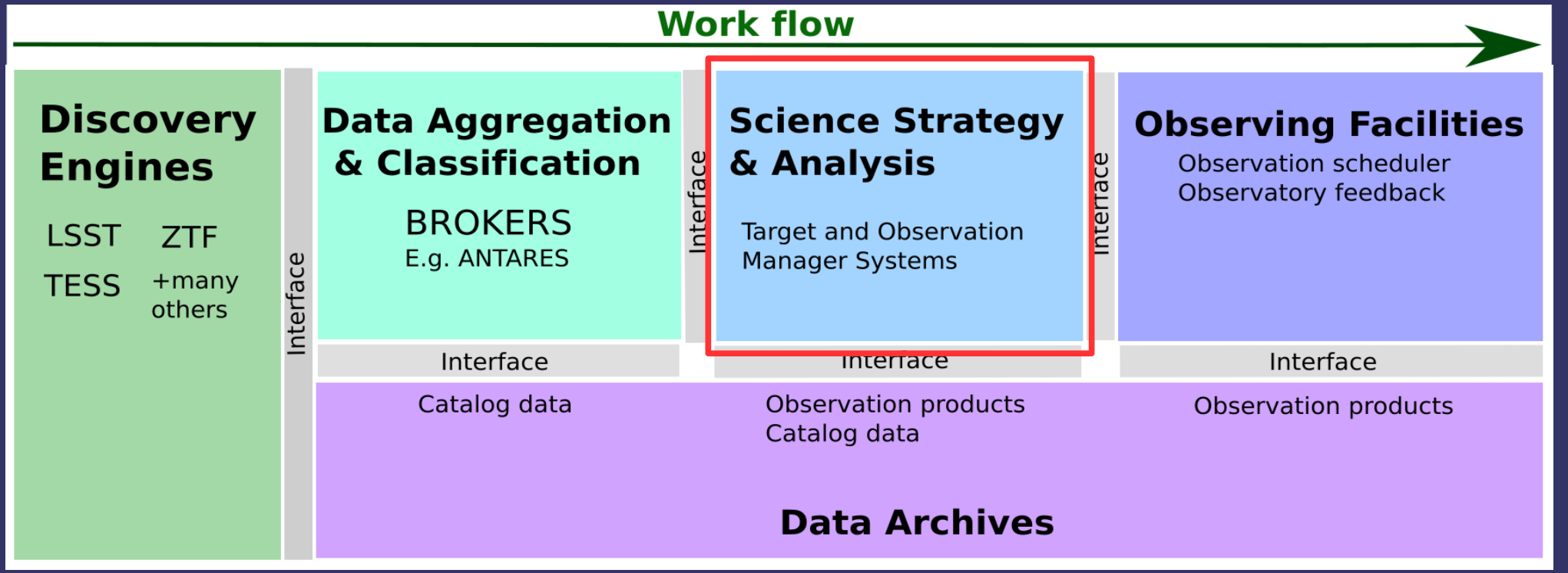
Developing TOM Systems

Much re-inventing of wheels - *existing TOMs have overlapping functionality, but are heavily customized to their science case*

Need for scaleability – *existing systems will not scale to LSST*



Role of a TOM in the Discovery Chain

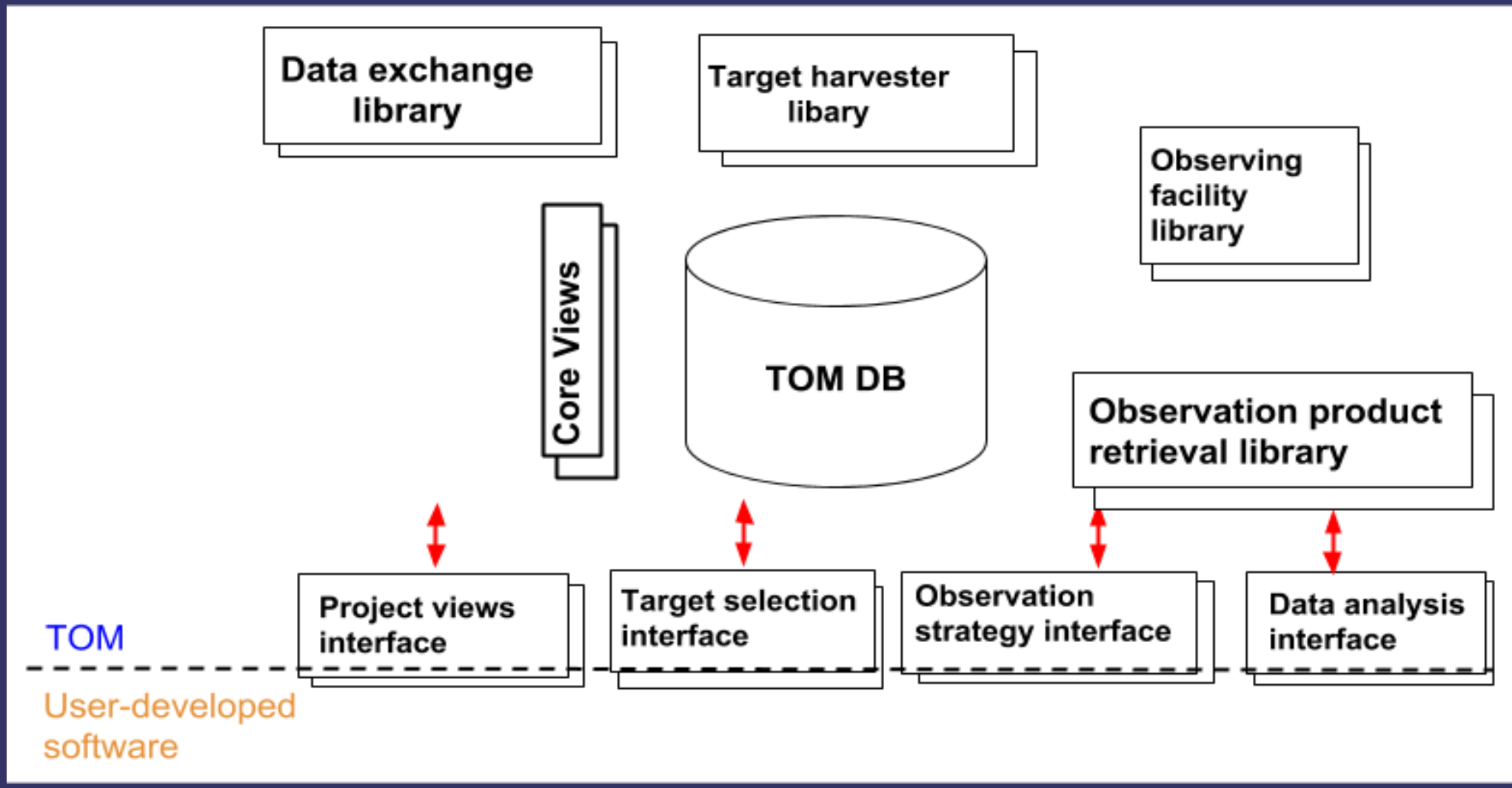


Discovery → Classification → Selection/analysis → Characterization

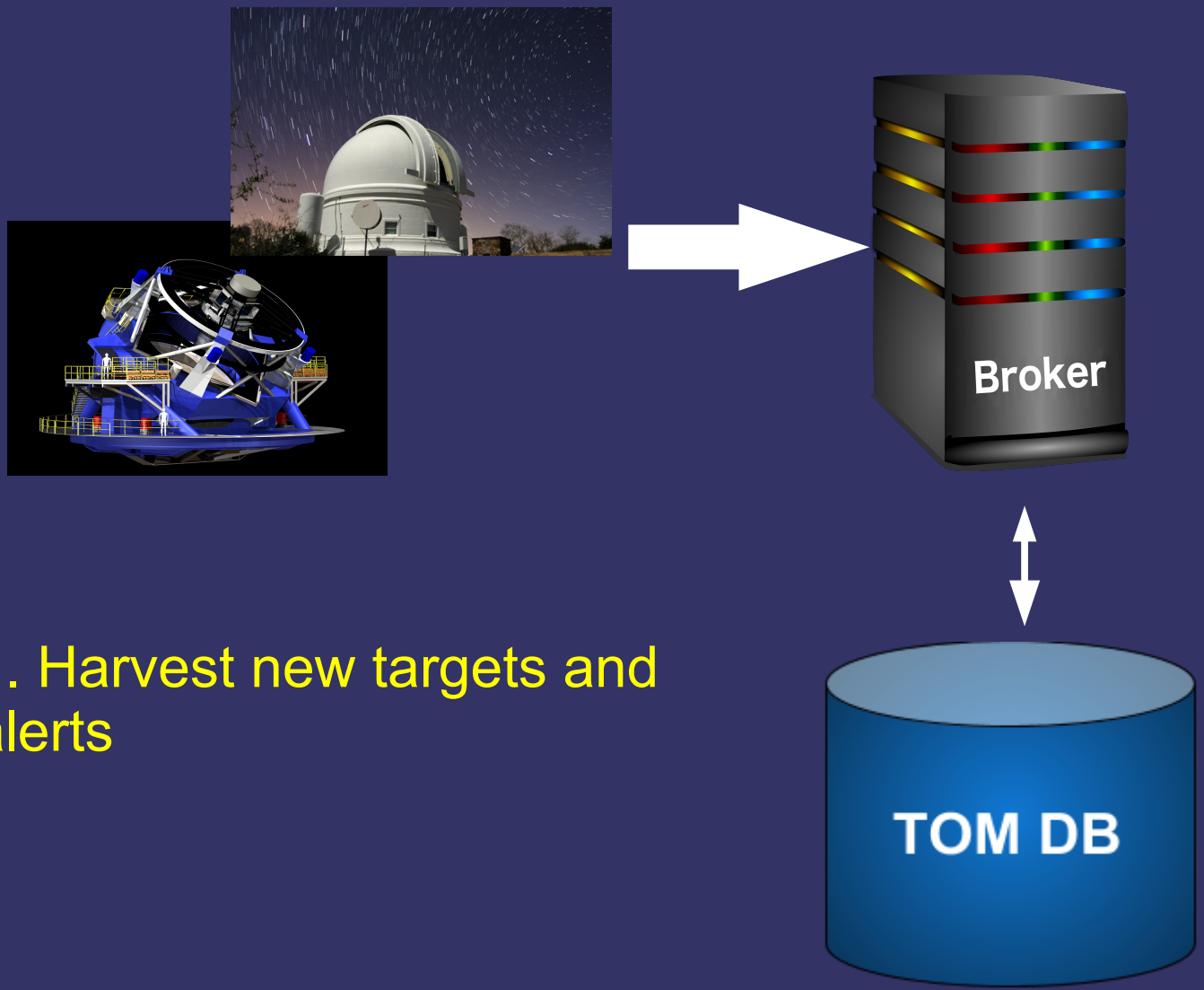
Goals of the TOM Toolkit Project

- To develop a general-purpose software toolkit
- Enable astronomers to easily build TOM systems that they can customize to suit their needs
- Provide a professionally-developed codebase that will ensure that the systems are capable of scaling to future programs.

Functionality of the TOM Toolkit

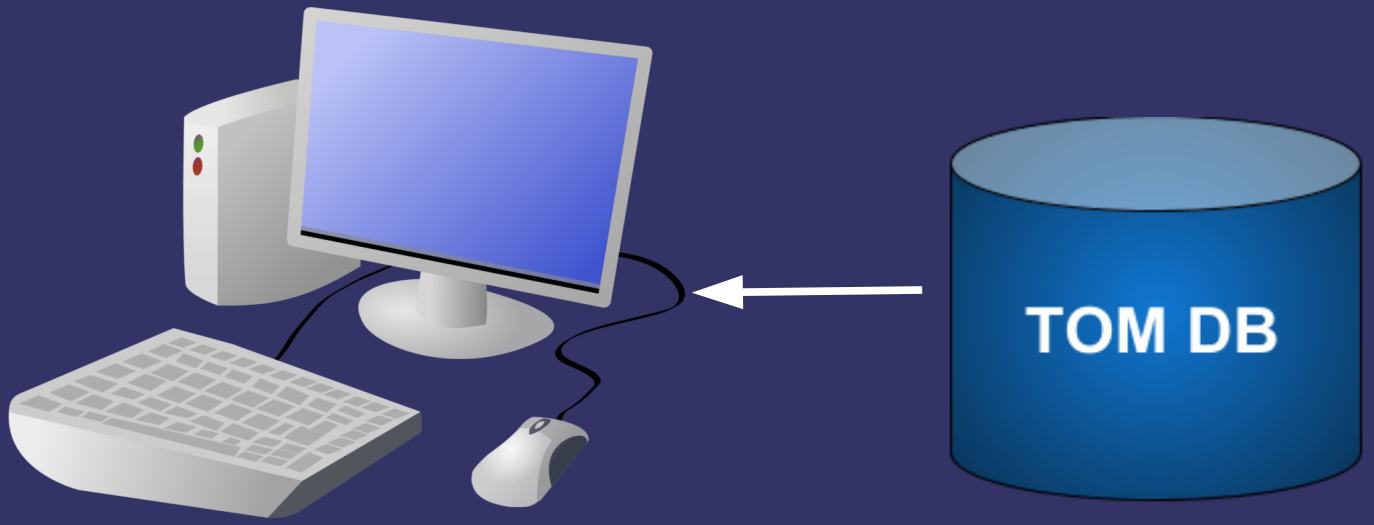


Functionality of the TOM Toolkit



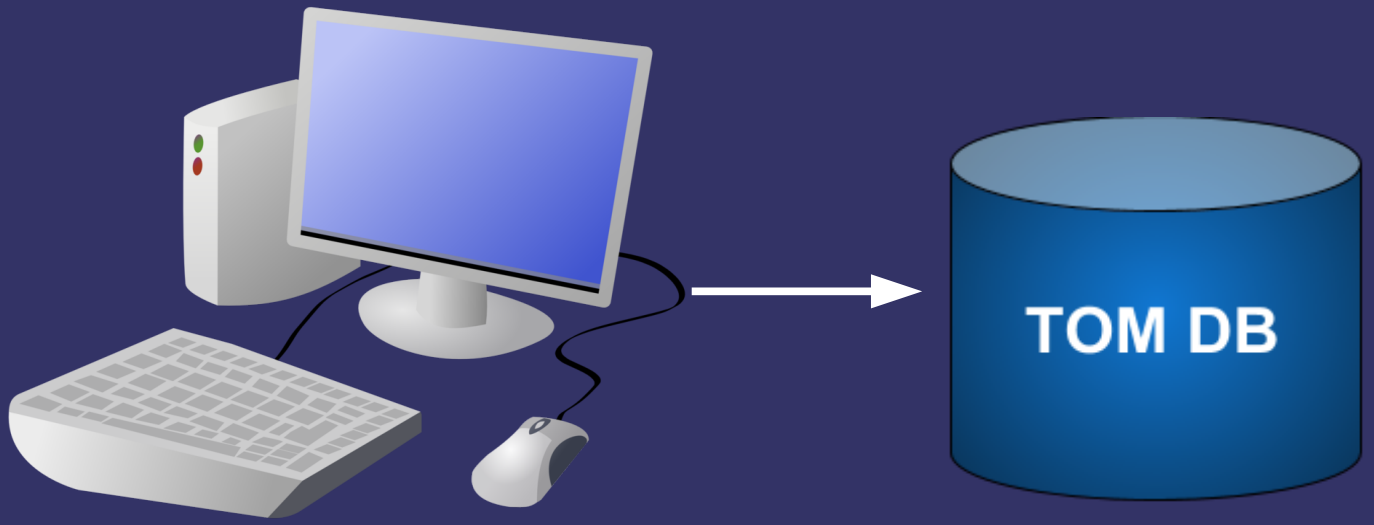
1. Harvest new targets and alerts

Functionality of the TOM Toolkit



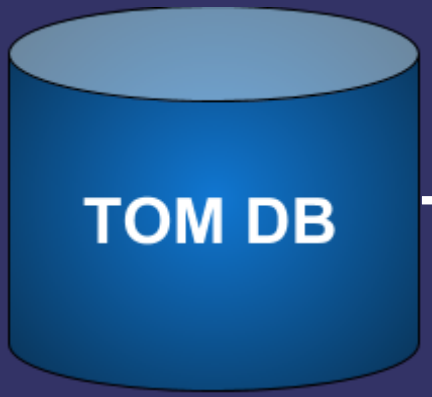
2. Informative display tools, customizable for science needs

Functionality of the TOM Toolkit



3. APIs enable science-specific (user-developed) software to interact, making decisions on target evaluation target selection observation strategy data analysis

Functionality of the TOM Toolkit

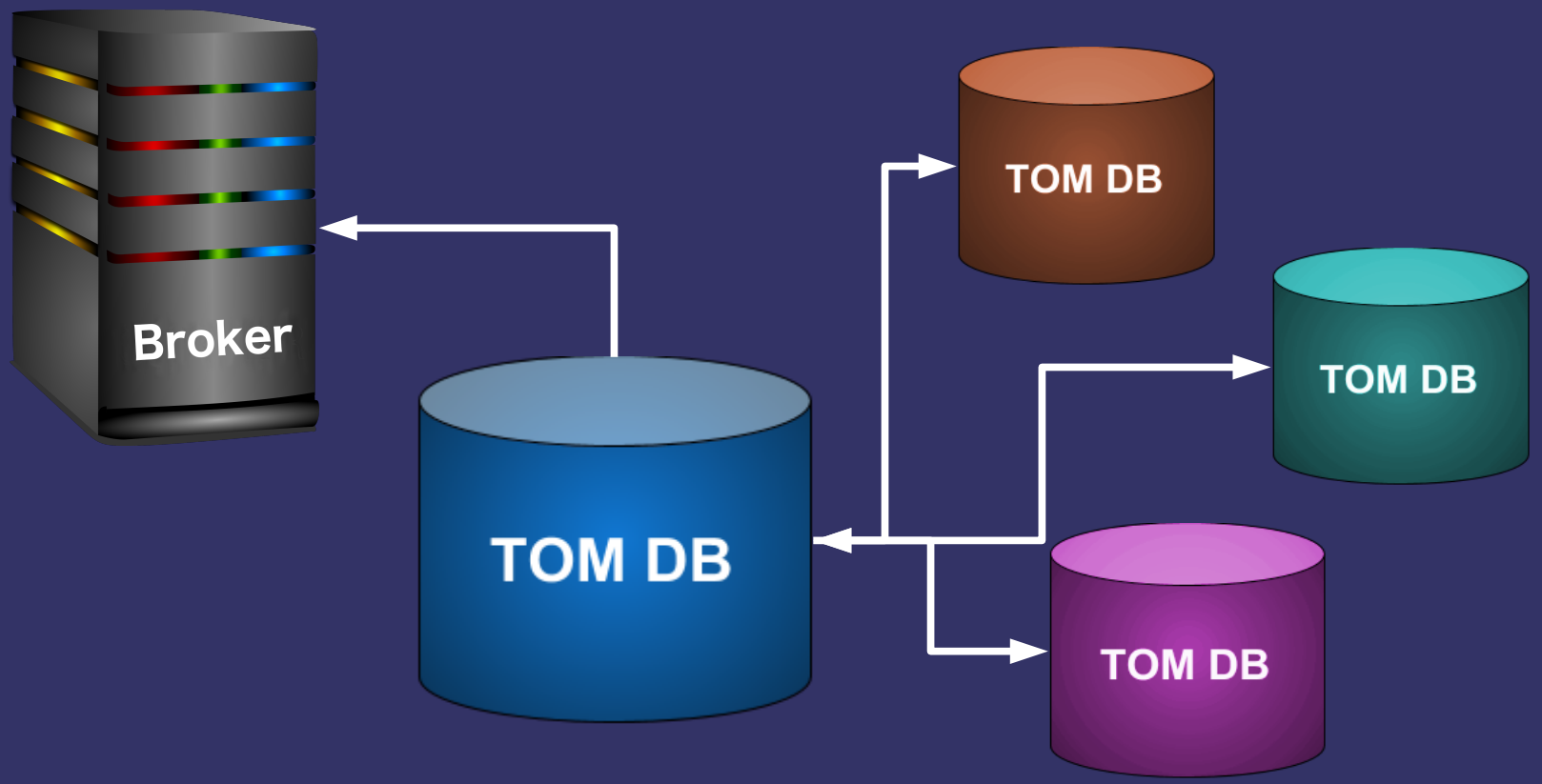


4. APIs enable observation requests to be submitted directly to participating facilities, and status info returned

Functionality of the TOM Toolkit

5. APIs enable data products to be retrieved from common-user data archives

Functionality of the TOM Toolkit



6. APIs to facilitate data sharing with other projects, brokers, collaborators...

TOM Toolkit Project

Software development of core modules:

- Target Harvester Library
- Core Views Library
- Project Views Interface
- Observing Facility Interface
- Observation Product Retrieval Library
- Target Selection Interface
- Observation Strategy Interface
- Data Analysis Interface

Software development of example implementation

- A 'demo' TOM system

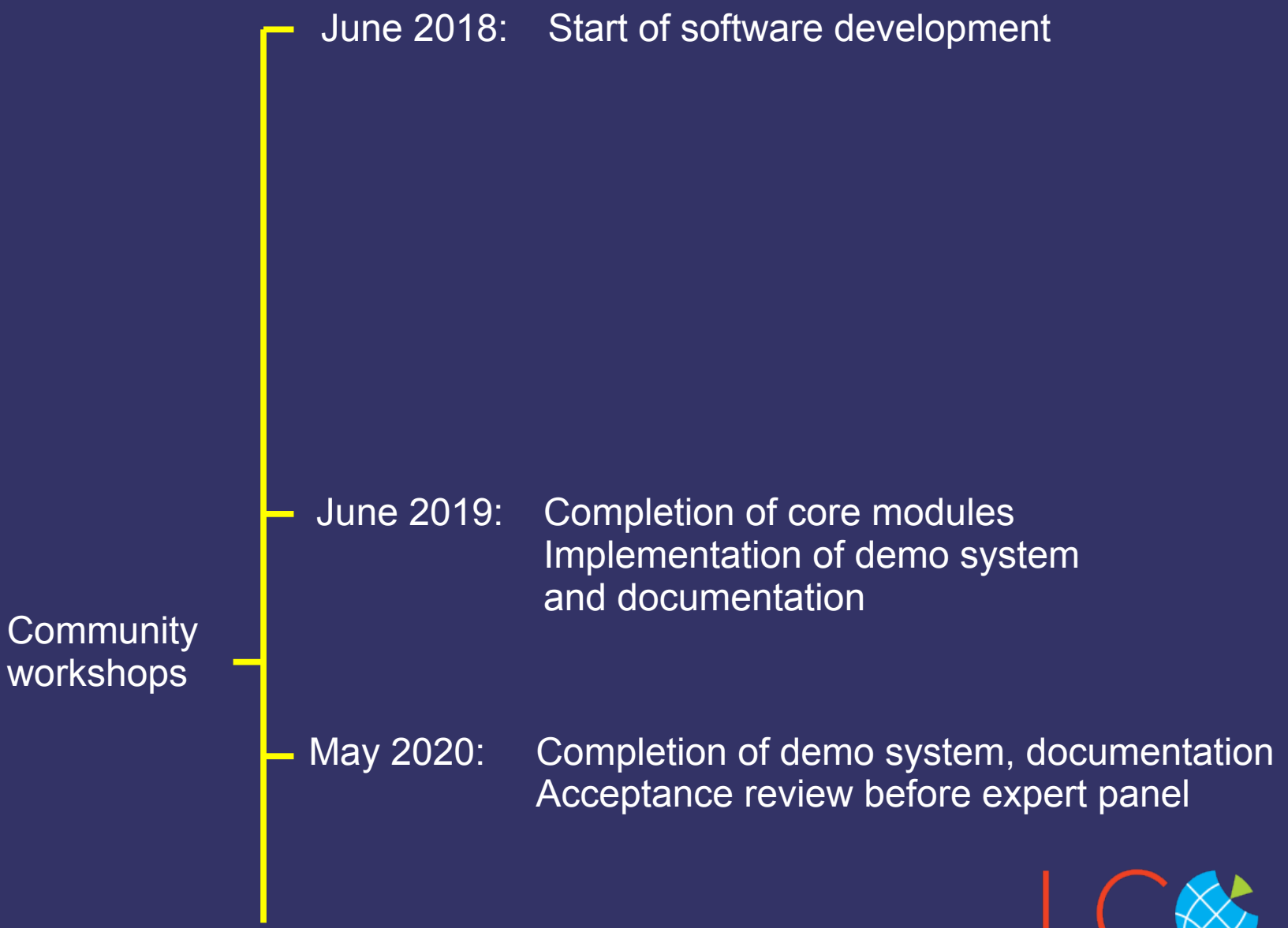
Documentation

- Full package description
- User tutorials

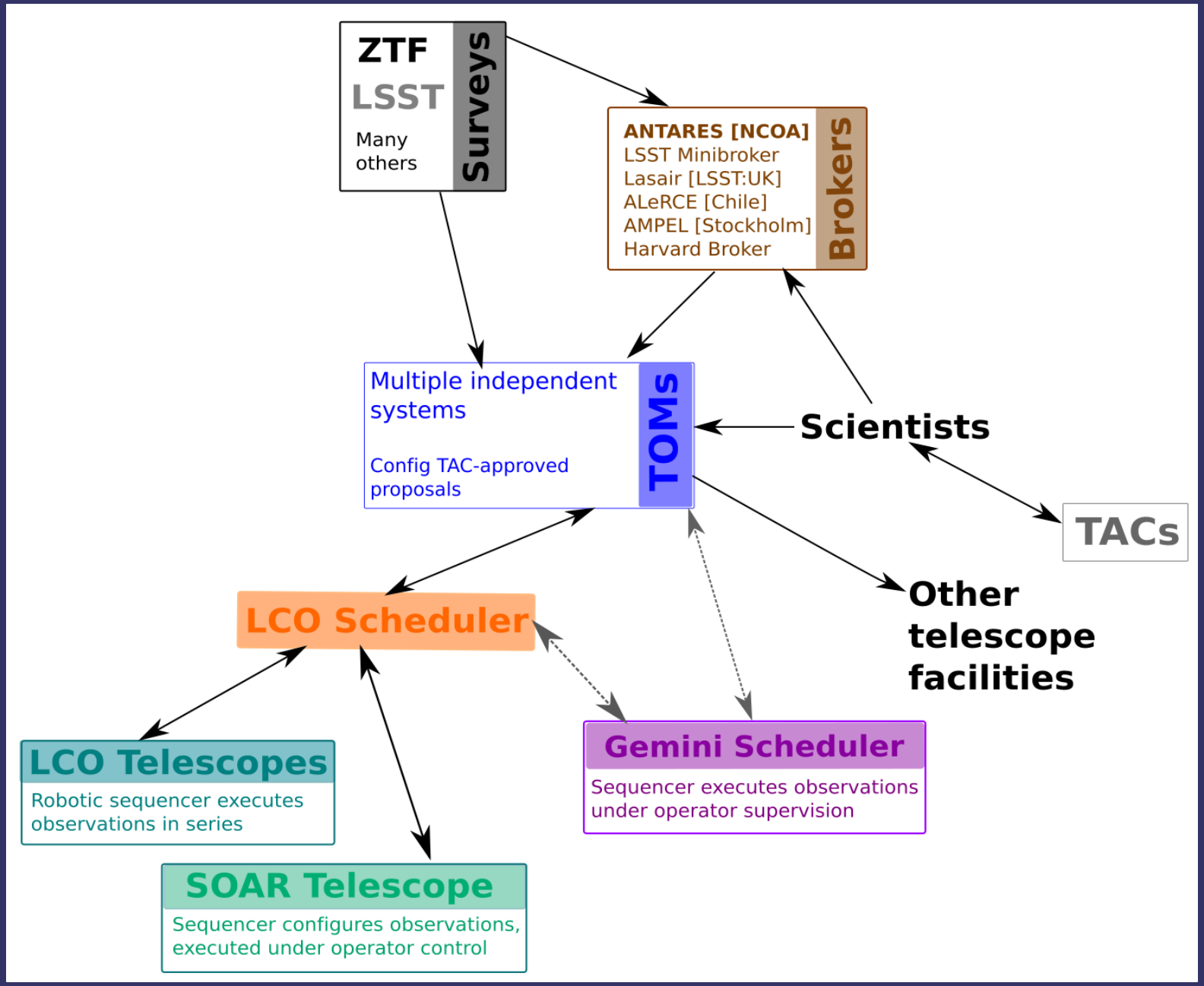
Community Engagement

- Expert panel review
- Conference presentation
- Outreach to connected facilities
- Hands-on workshops
- Small grants competition

Timeline


June 2018: Start of software development
June 2019: Completion of core modules
Implementation of demo system
and documentation
Community
workshops
May 2020: Completion of demo system, documentation
Acceptance review before expert panel

Time-Domain Astronomy Network



SOAR TELESCOPE

GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders

LCO

Time-Domain Astronomy Network

Collaboration between LCO, NCOA, SOAR and Gemini

→ Funded contract with NOAO to integrate the SOAR telescope with LCO Network

→ Expect to integrate Gemini in phase 2

→ Interest in joining expressed by a number of other facilities

Time-Domain Astronomy Network

Collaboration between LCO, NCOA, SOAR and Gemini

Funding from foundations to develop the TOM Toolkit

Time-Domain Astronomy Network

Collaboration between LCO, NCOA, SOAR and Gemini

Funding from foundations to develop the TOM Toolkit

Immediate goals:

- to robotically submit observation requests to SOAR/Goodman spectrograph through the LCO scheduler
- to robotically submit observation requests to Gemini telescopes

TOM Toolkit

- A highly flexible tool for time domain observing programs in the LSST era
- Critical link in the discovery chain
- Development underway, v1.0 expected mid-2019
- Will interface directly with follow-up facilities in the Time-Domain Astronomy Network

Extra Slides

Example Science Use Cases

Supernovae

Spectra, multi-band imaging

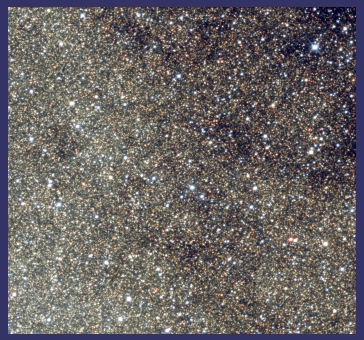
ToO alert then Every 1-3d for >month

Near-Earth Asteroids

Short timeseries imaging

Rapid-response short (<1hr) series, daily for 1-3d

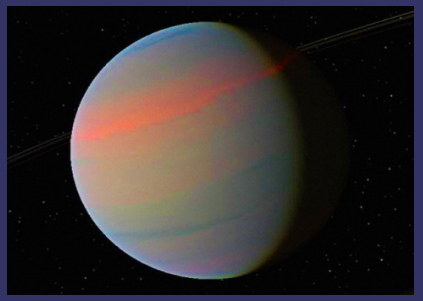
Microlensing



Time series imaging

Medium-high cadence continuous monitoring for weeks

Transiting exoplanets



Spectra, imaging

Phase-dependent continuous imaging, spectra monitoring for weeks-years

Current Science Use Cases

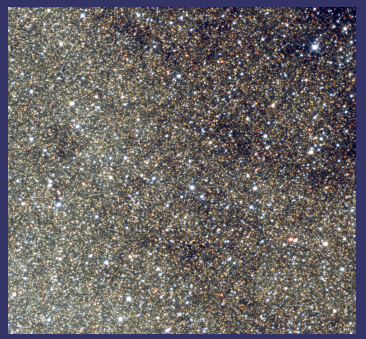
Supernovae

~7000

Near-Earth Asteroids

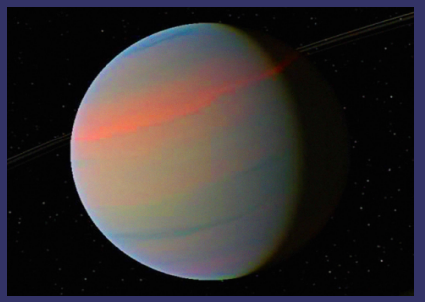
~5400

Microlensing



~2100

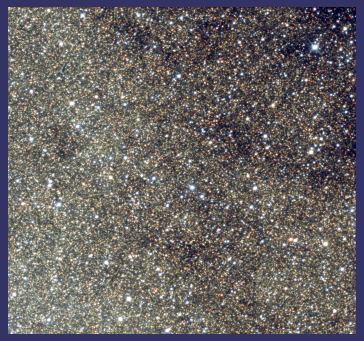
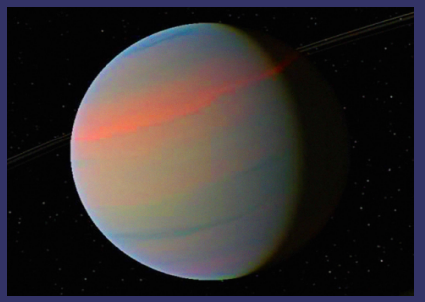
Transiting exoplanets



3486 confirmed
~4500 candidates

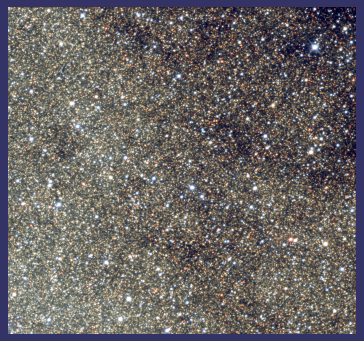
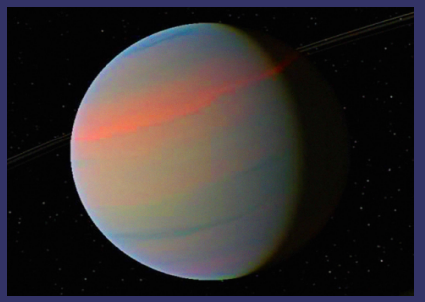
Total targets (per year for transient targets)

Current Science Use Cases

Supernovae	Near-Earth Asteroids	Microlensing	Transiting exoplanets
			
~7000	~5400	~2100	3486 confirmed ~4500 candidates
~20	~100	~8	Lots turn up at once

Total new targets per day

Current Follow-up Programs

Supernovae	Near-Earth Asteroids	Microlensing	Transiting exoplanets
			
~7000/year	~5400/year	~2100/year	3486 confirmed ~4500 candidates
~20/day	~100/day	~8/day	Lots turn up at once
40-60	~10	~10	<10-20

Targets being observed at any one time at LCO

Big surveys will exceed combined follow-up capability