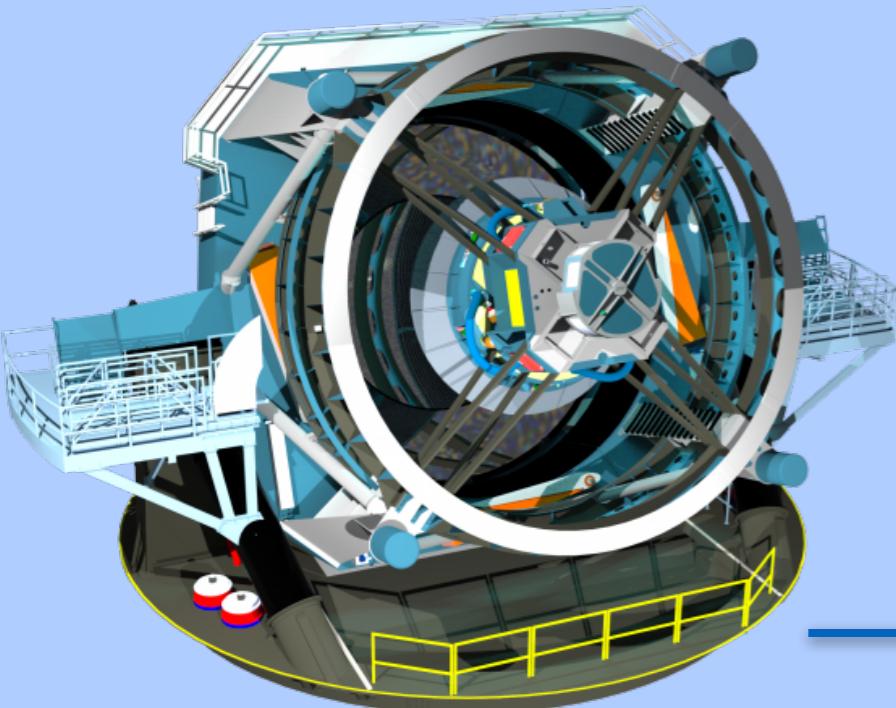


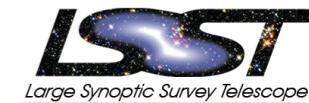
# Asteroid Detection with the Large Synoptic Survey Telescope (LSST)

Lynne Jones (University of Washington/LSST)

Zeljko Ivezic, Mario Juric, Steve Chesley, Paul Abell, Mike Brown, Josef Durech, Yan Fernandez, Alan Harris, Matt Holman, Rob Jedicke, Mikko Kassalainen,  
Nate Kaib, Zoran Knezevic, Andrea Milani, Alex Parker, Steve Ridgway, Dave Trilling, Bojan Vrsnak  
+ the LSST Solar System Science Collaboration



# Planetary science & LSST



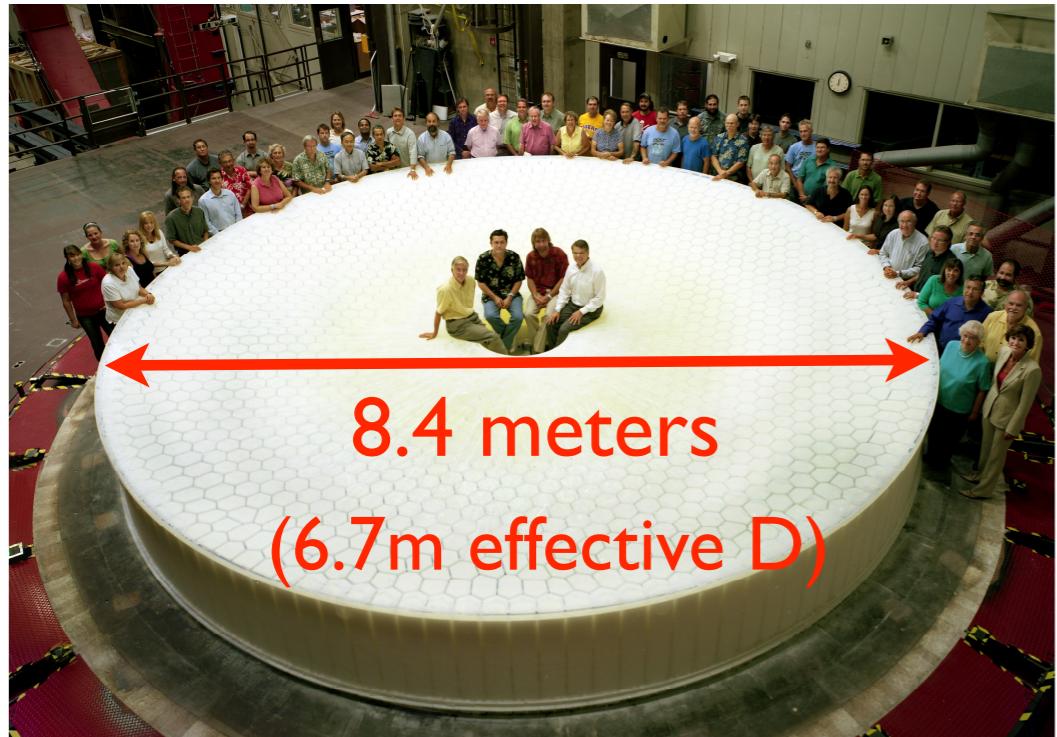
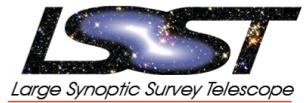
	Currently Known*	LSST Discoveries**	Median number of observations <sup>+</sup>	Observational arc length <sup>+</sup>
Near Earth Objects (NEOs)	12,832	100,000	(H<20) 90	7.0 years
Main Belt Asteroids (MBAs)	636,499	5,500,000	(H<19) 200	8.5 years
Jupiter Trojans	6,387	280,000	(H<16) 300	8.7 years
TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOS)	1,921	40,000	(H<6) 450	8.5 years

\* As reported by the MPC   \*\* Expected by end of survey   +For the brightest objects (near 100% completeness)

Plus: comets, irregular satellites, Earth minimoons and temporary satellites ..

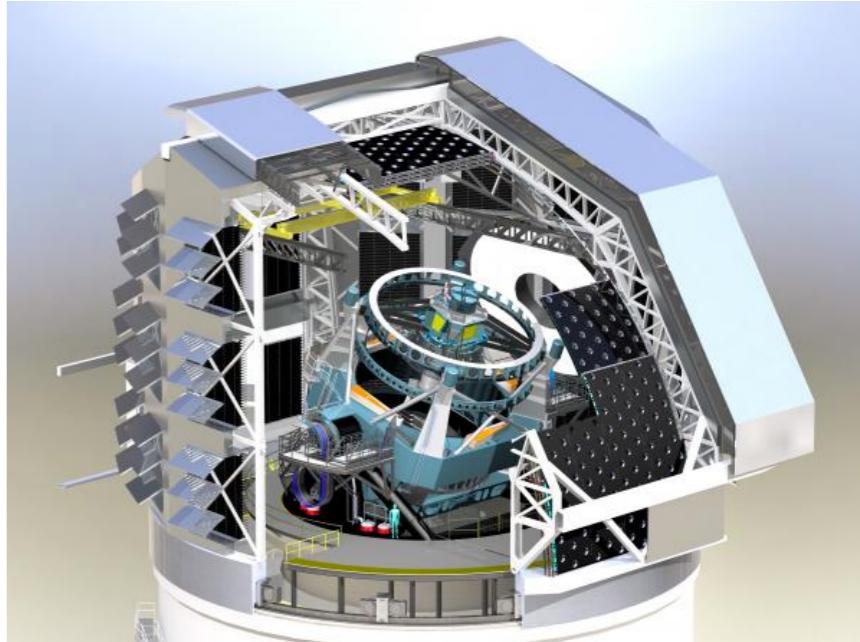
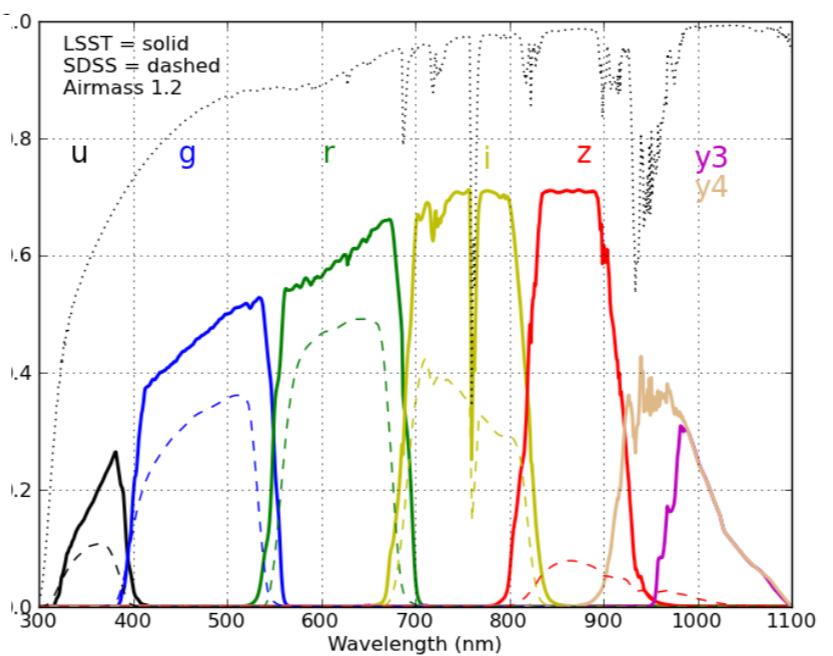
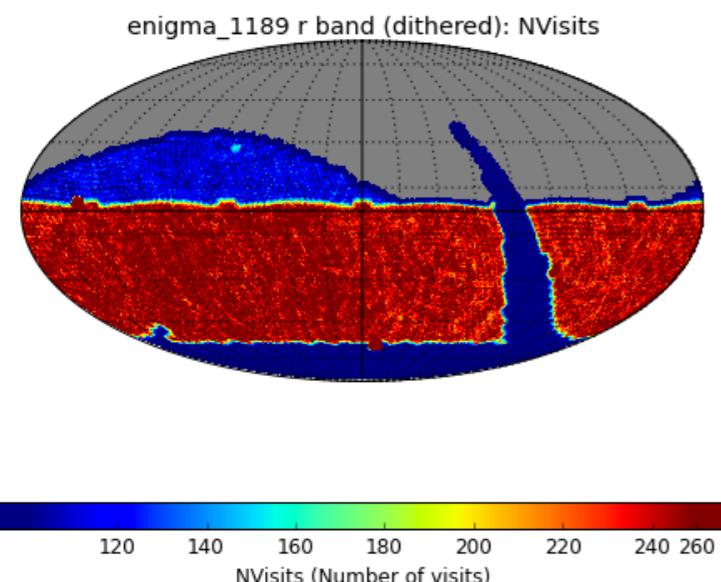
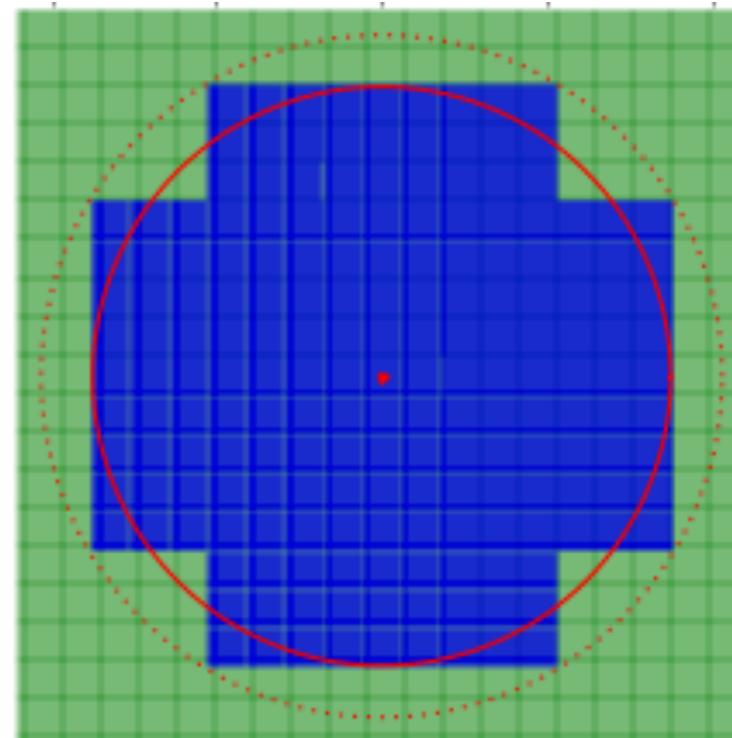
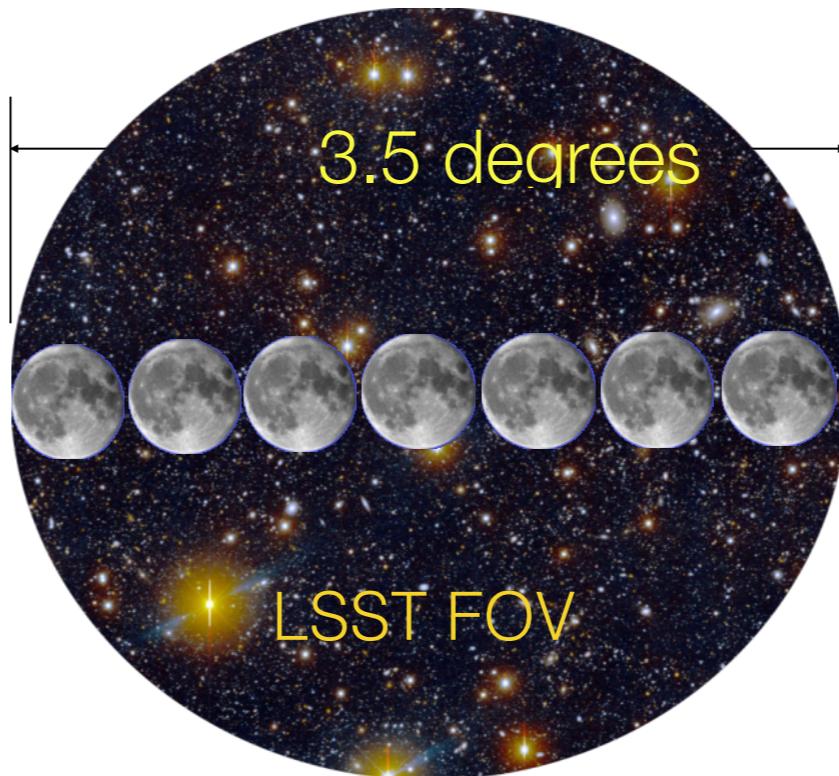
***10-100x increase in sample size for every small body population in the Solar System***

# LSST design

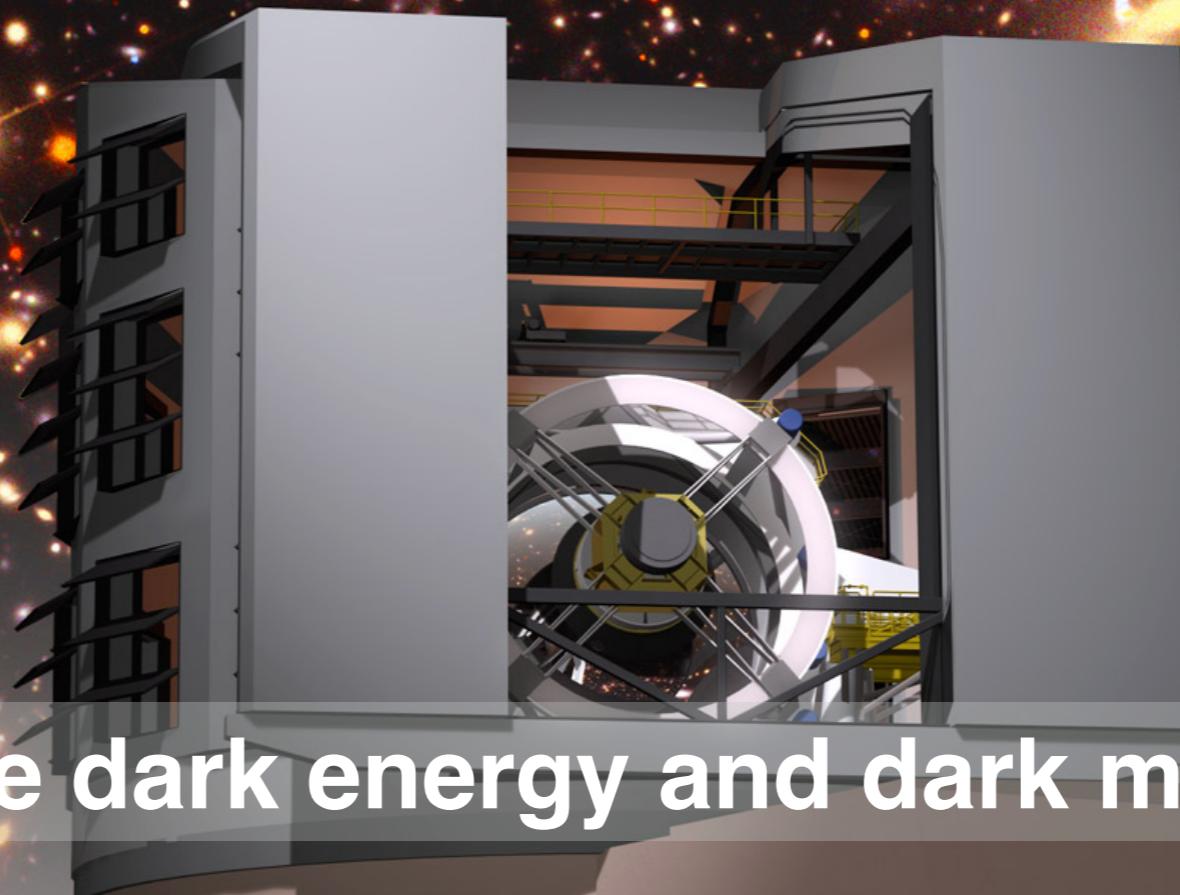


August 2008  
LSST Primary/Tertiary Mirror Blank  
University of Arizona Steward Observatory Mirror Lab

SOML THE UNIVERSITY OF  
ARIZONA.  
TUCSON ARIZONA



# LARGE SYNOPTIC SURVEY TELESCOPE



Explore dark energy and dark matter

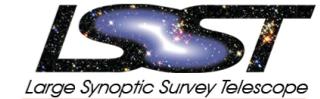
Inventory the Solar System

Explore the transient sky

Map the Milky Way and Local Volume

**LSST**

# Open Data, Open Source: A Community Resource



- LSST data, including images and catalogs, will be available with **no proprietary period** to the astronomical community of the **United States, Chile, and International Partners**
- Alerts to variable and moving sources (explosive transients, variables, asteroids, etc.) will be **available world-wide**, using community-adopted protocols
- LSST **data processing stack will be free software** (licensed under the GPL, v3-or-later)
- **LSST is a public facility: all science will be done by the community (not the Project!), using LSST's data products.**

# LSST From the User's Perspective:

## A Data Stream, a Database, and a (small) Cloud

- A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.
- A catalog of orbits for ~6 million bodies in the Solar System.

Level 1

- A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion single-epoch detections (“sources”), and ~30 trillion forced sources, produced annually, accessible through online databases.
- Deep co-added images.

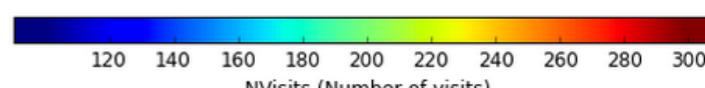
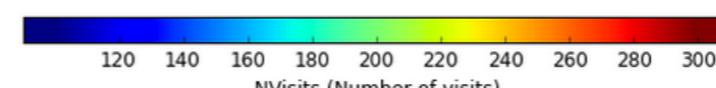
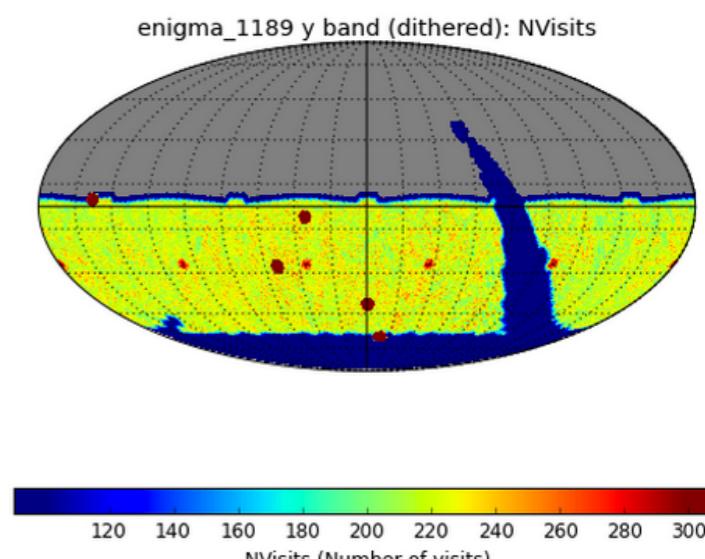
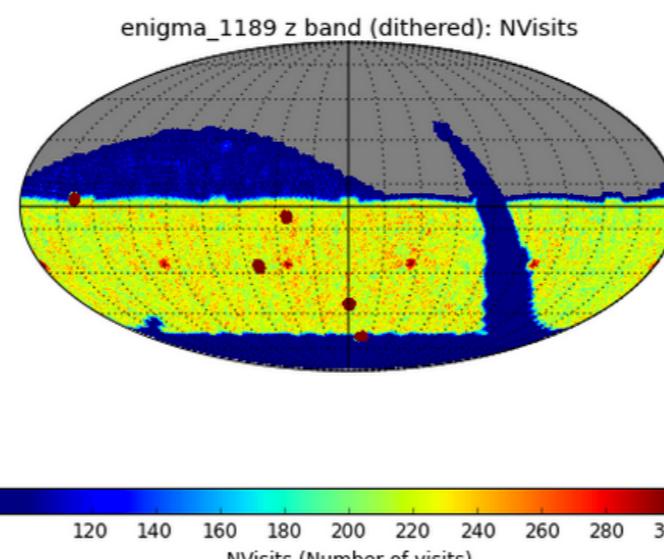
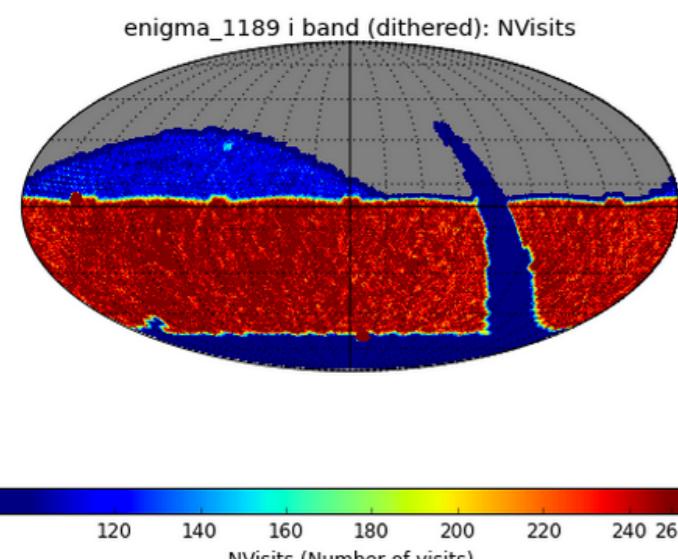
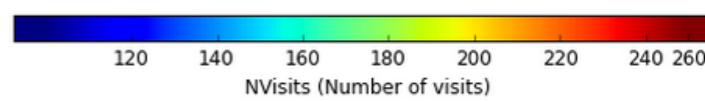
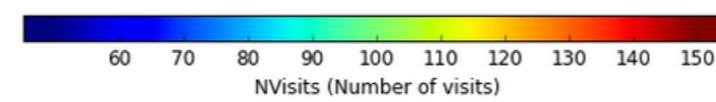
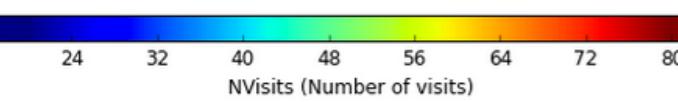
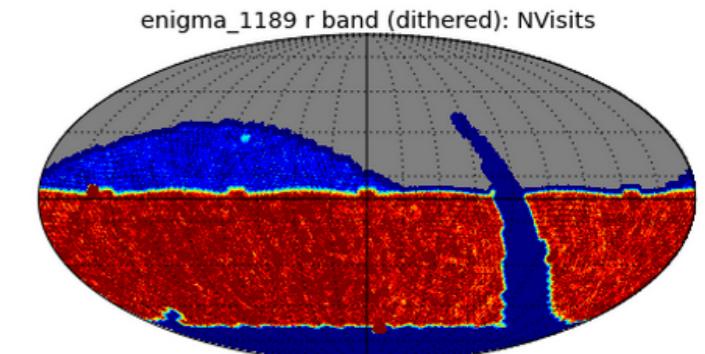
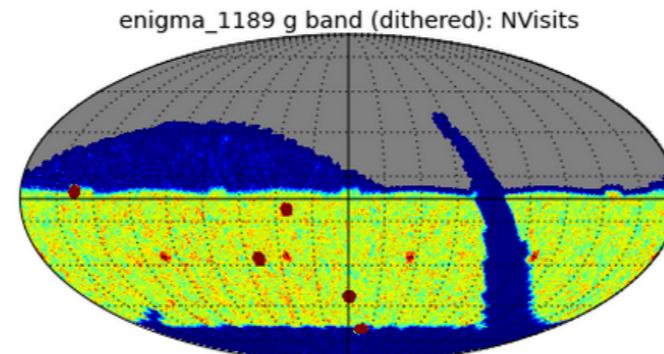
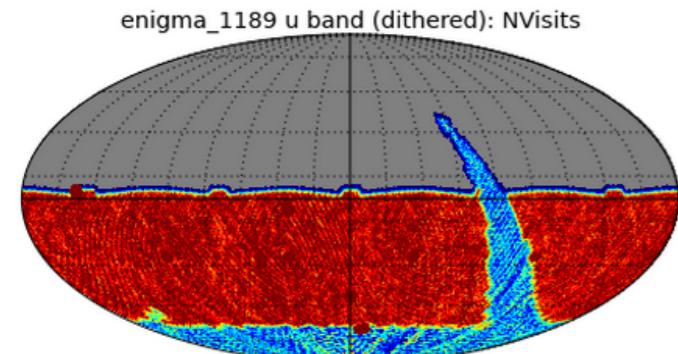
Level 2

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Level 3

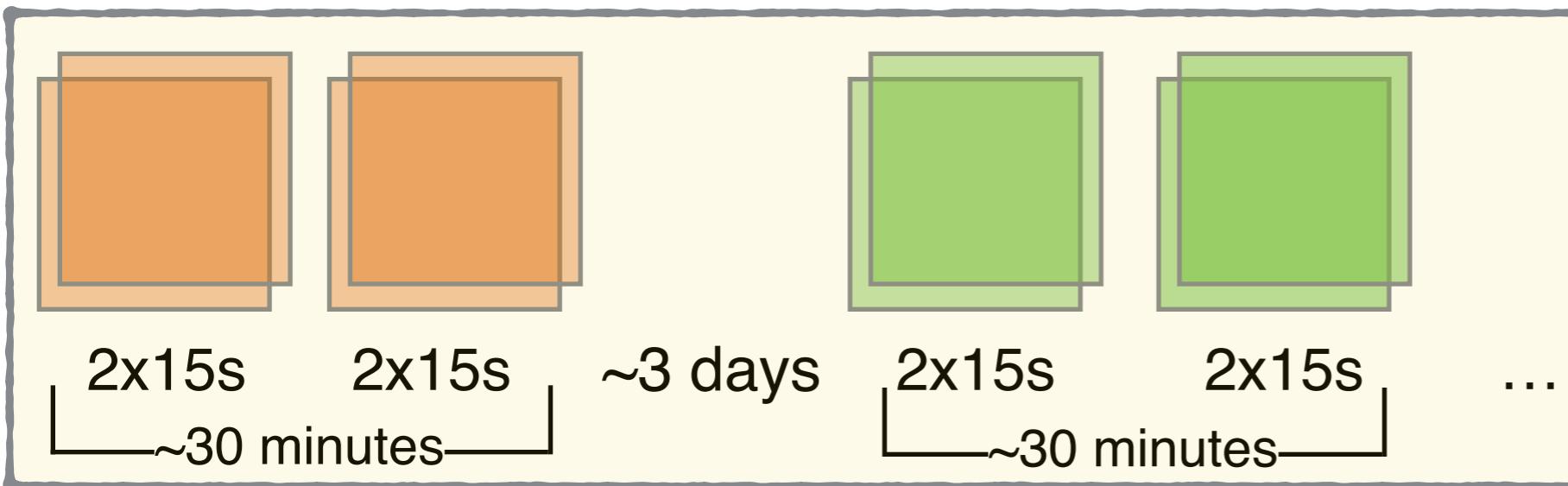
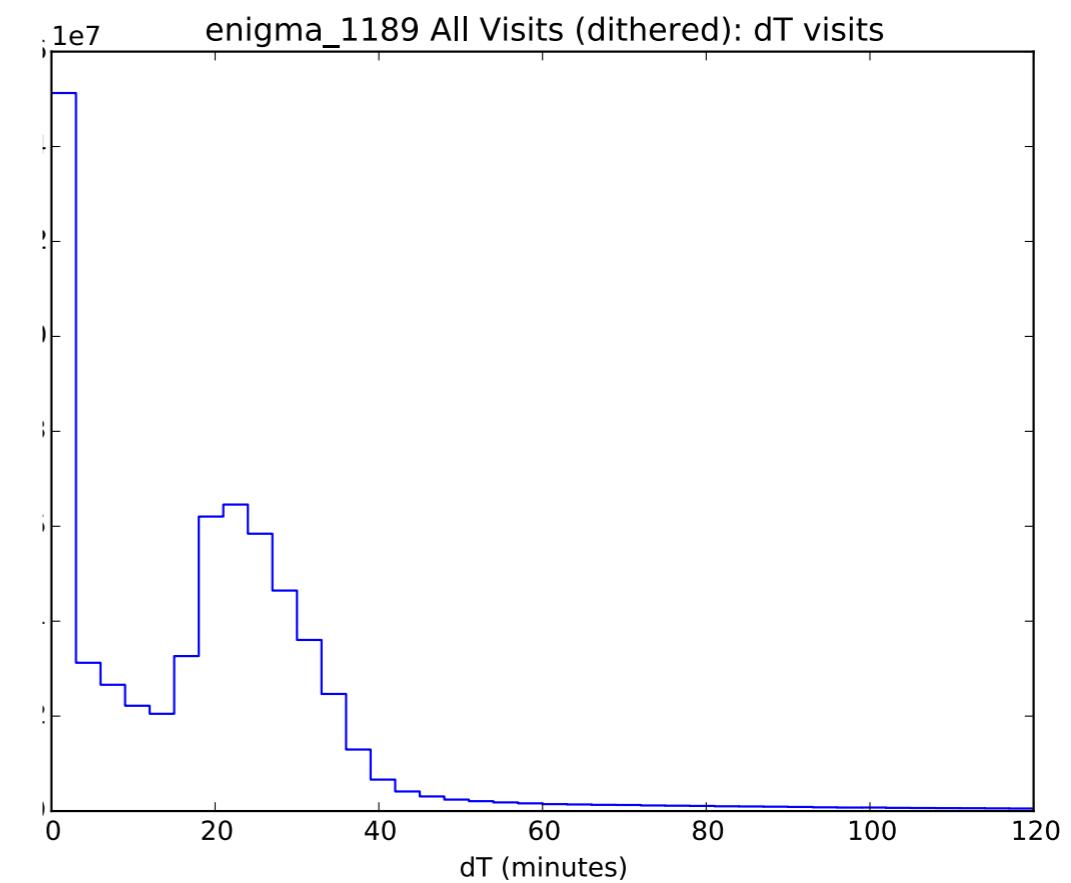
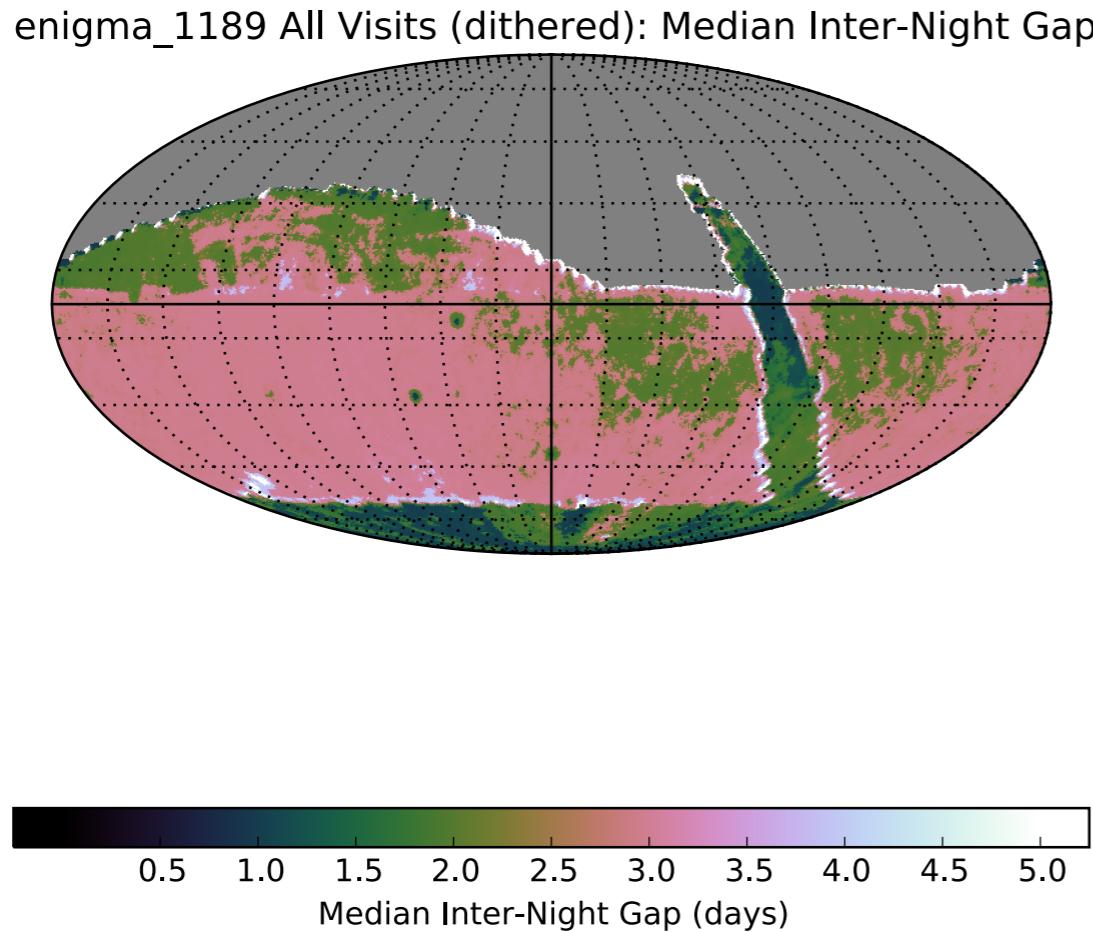
See Mario Juric's talk tomorrow

# Survey Strategy



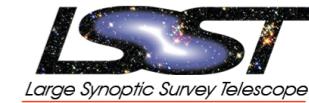
18,000 sq degrees in ‘main’ survey  
Extension in “North Ecliptic Spur”  
ugrizy

# Survey Strategy



1 visit = 2x15s back-to-back exposures  
2 visits per night (30-60 minutes)  
Revisit ~3-4 days

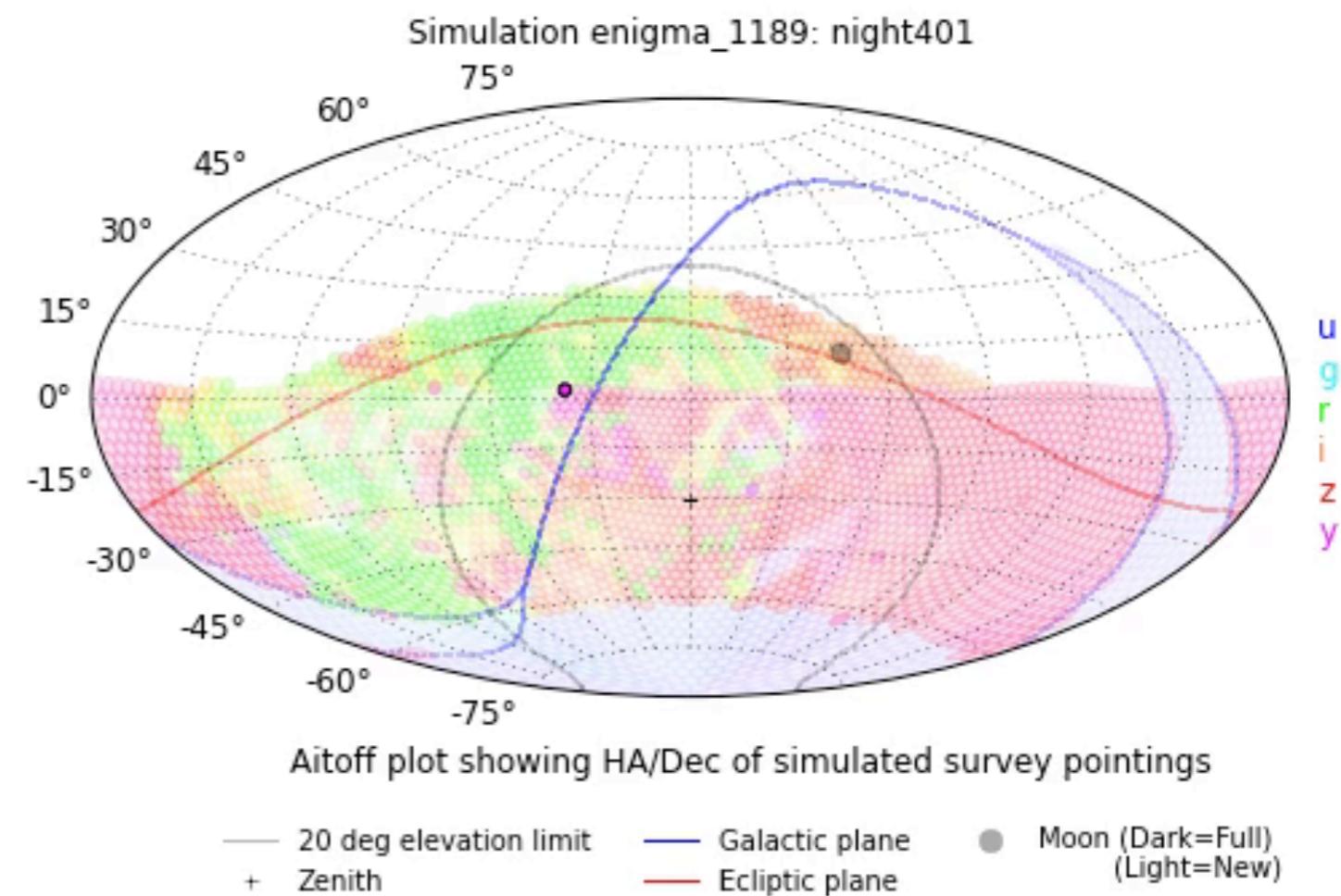
# LSST Performance Summary



<b>Effective Mirror</b>	<b>6.7 m</b>
<b>Field of view</b>	<b>9.6 sq deg</b>
<b>Exposure ('Visit') Time</b>	<b>2x15 s /visit</b>
<b>Survey length</b>	<b>10 years</b>
<b>Data rate</b>	<b>~15 TB/night</b>
<b>Sky coverage</b>	<b>~18,000 sq</b>
<b>Site</b>	<b>Cerro</b>
<b>Filters</b>	<b>ugrizy</b>
<b>Typical seeing</b>	<b>0.7"</b>
<b>Photometric accuracy</b>	<b>10 mmag</b>
<b>Astrometric accuracy</b>	<b>50 mas</b>
<b>Astrometric precision</b>	<b>10 mas</b>

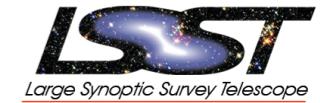
	<i>u</i>	<i>g</i>	<i>r</i>	<i>i</i>	<i>z</i>	<i>y</i>
# visits	70	100	230	230	200	200
m5	23.	25.	24.7	24.	23.	22.1

Year 1 Day 36.3637



Operations Simulation (pointing history)  
Evaluation of cadence - simulating moving objects

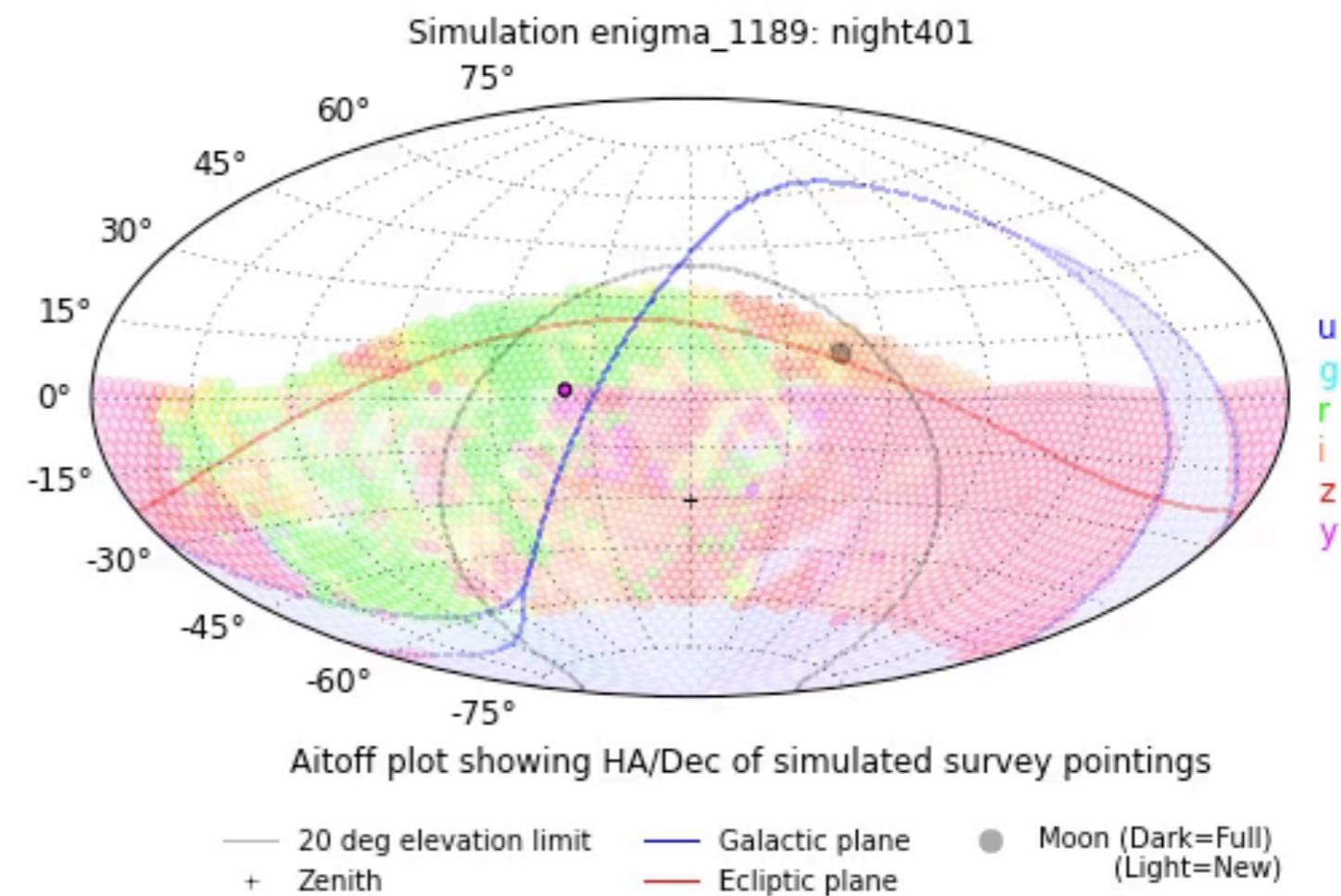
# LSST Performance Summary



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	<i>u</i>	<i>g</i>	<i>r</i>	<i>i</i>	<i>z</i>	<i>y</i>
# visits	70	100	230	230	200	200
m5	23.	25.	24.7	24.	23.	22.1

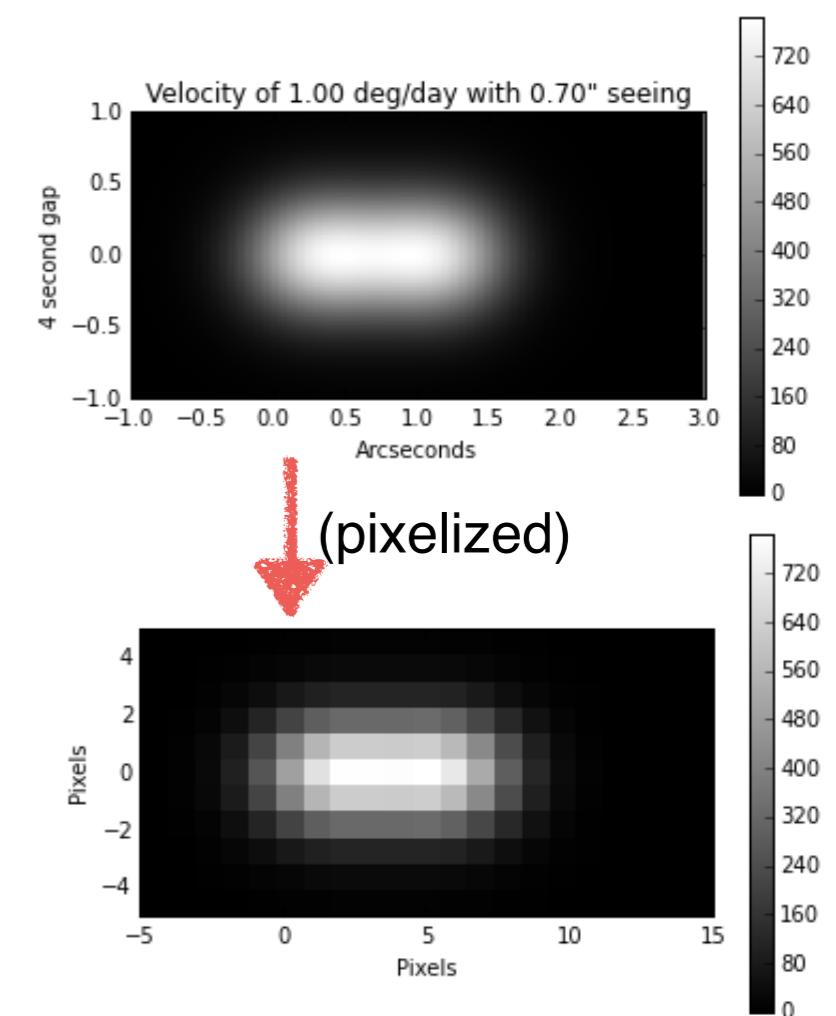
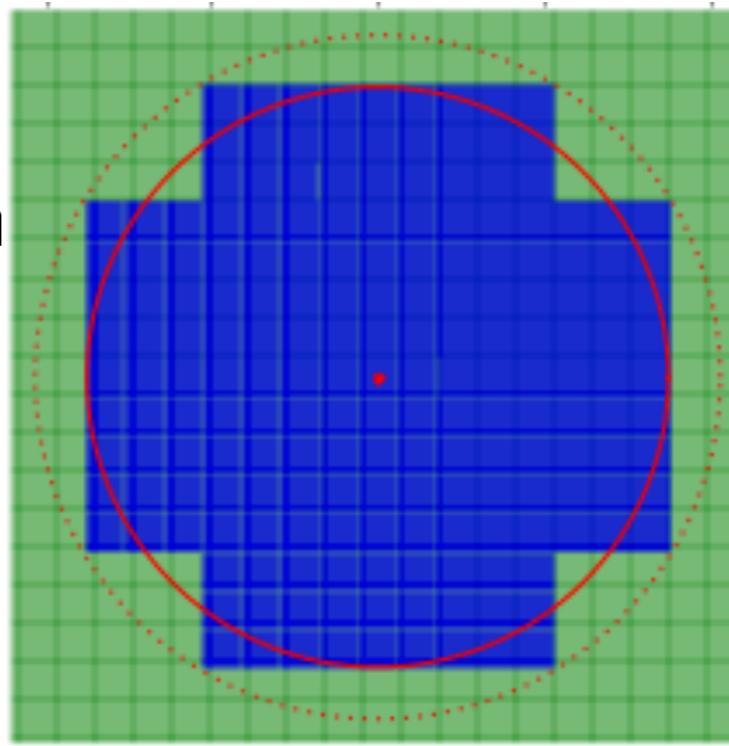
Year 1 Day 36.3637



Operations Simulation (pointing history)  
Evaluation of cadence - simulating moving objects

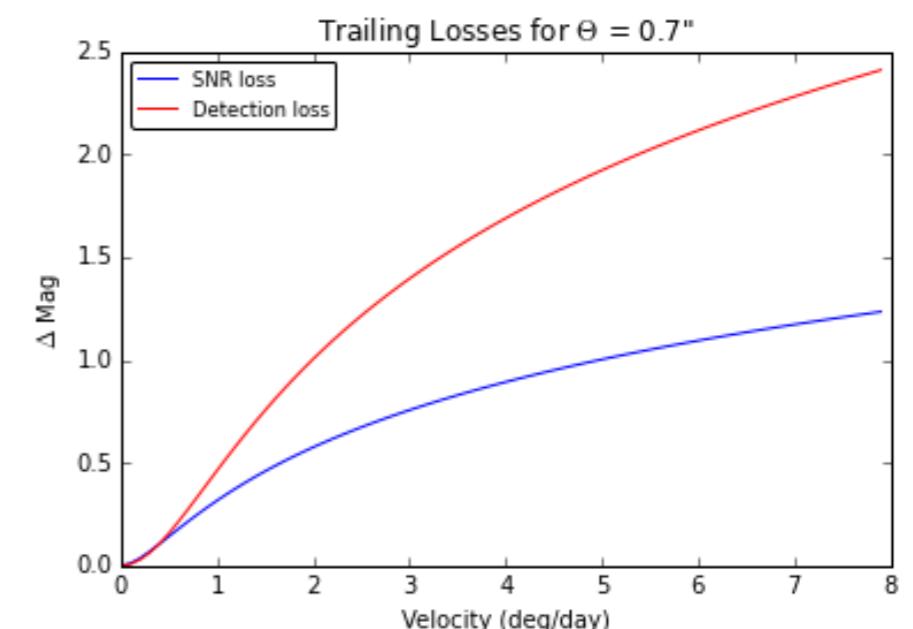
# Moving object simulations

- Include focal plane footprint
- Include trailing and ‘detection losses’
- Include scheduling, realistic weather, seeing and sky brightness (OpSim)
  - <http://ls.st/p1r>
- Simulations: encourage user write their own “metrics” to evaluate performance
  - Open source (+github)
  - Python
  - <http://ls.st/j4l>
  - (sims\_maf)
- Other simulations: images, DM, MOPS

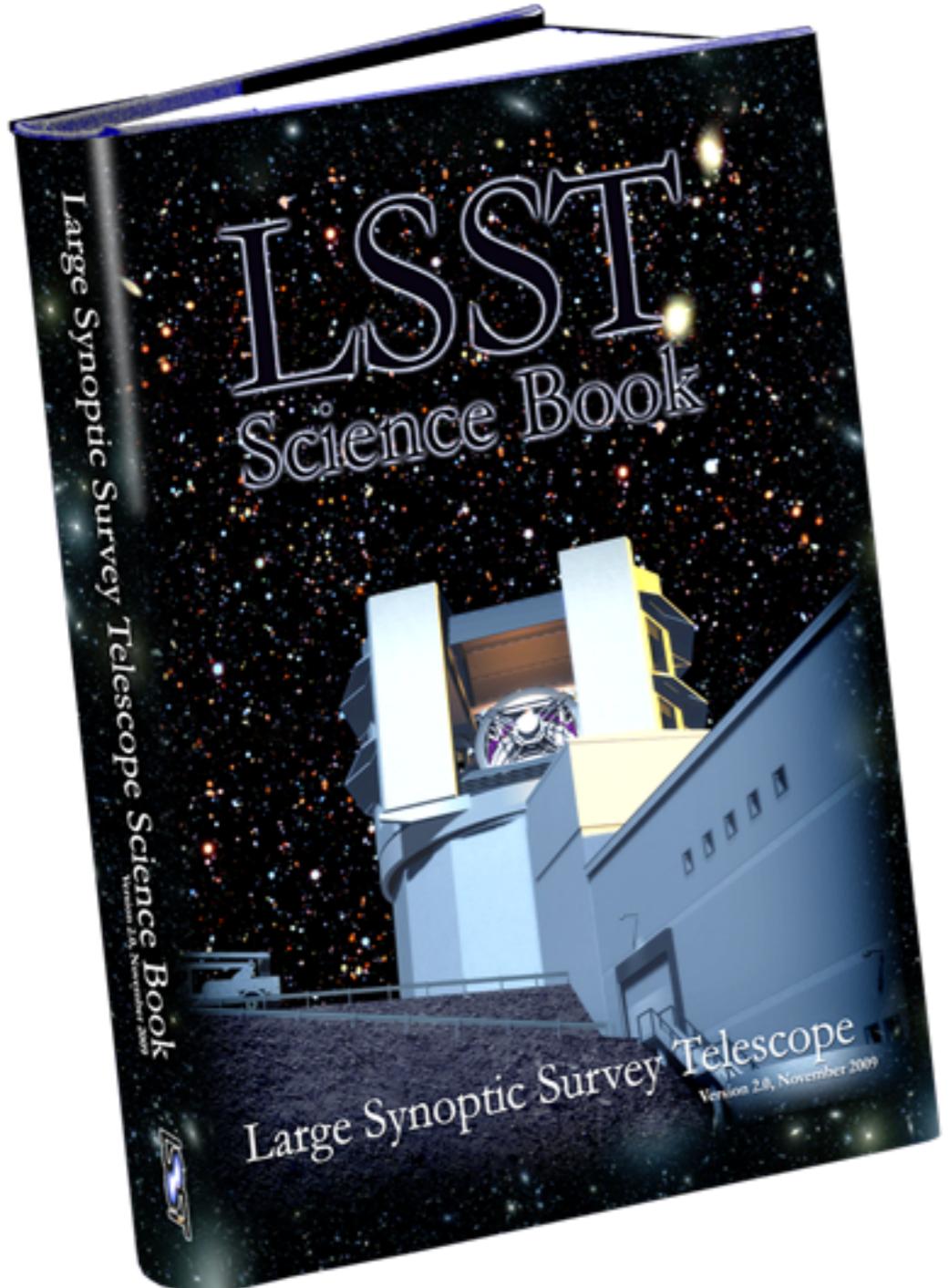
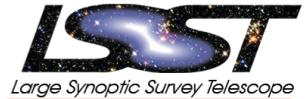


Trailing & Detection Losses:

$$x = \frac{vT_{exp}}{\theta}$$
$$\text{fluxratio} = \sqrt{1 + ax^2/(1 + bx)}$$



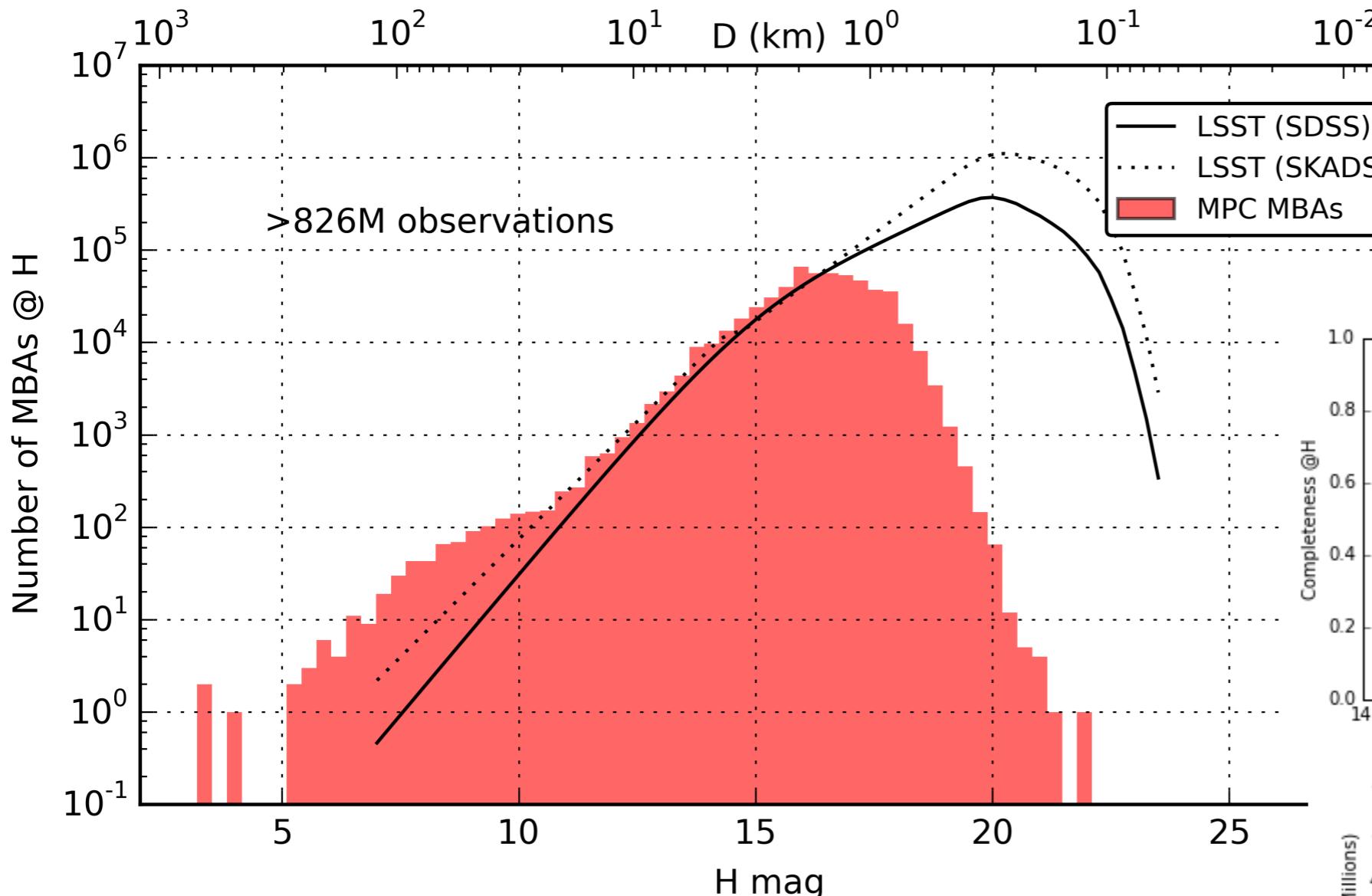
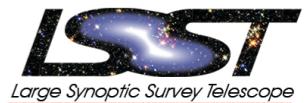
# Much science



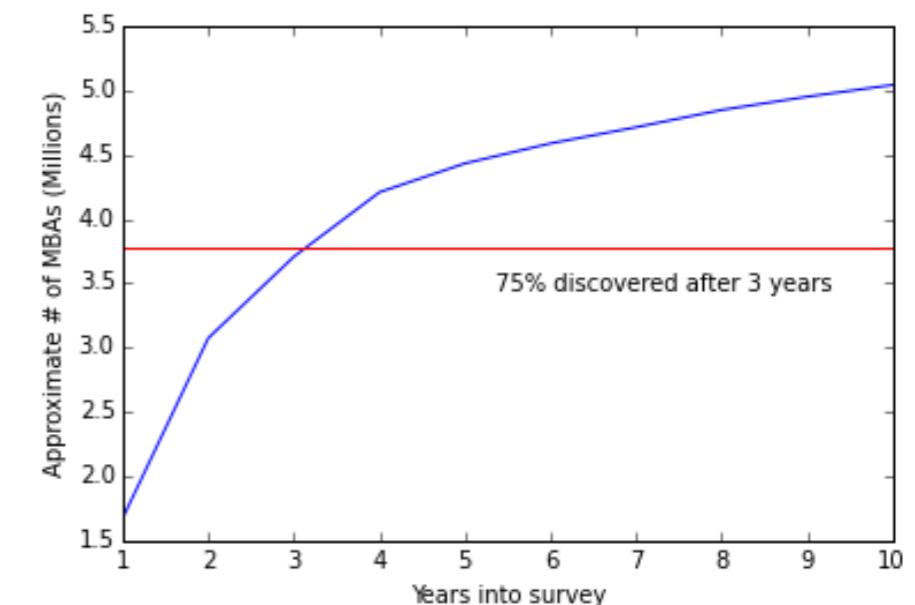
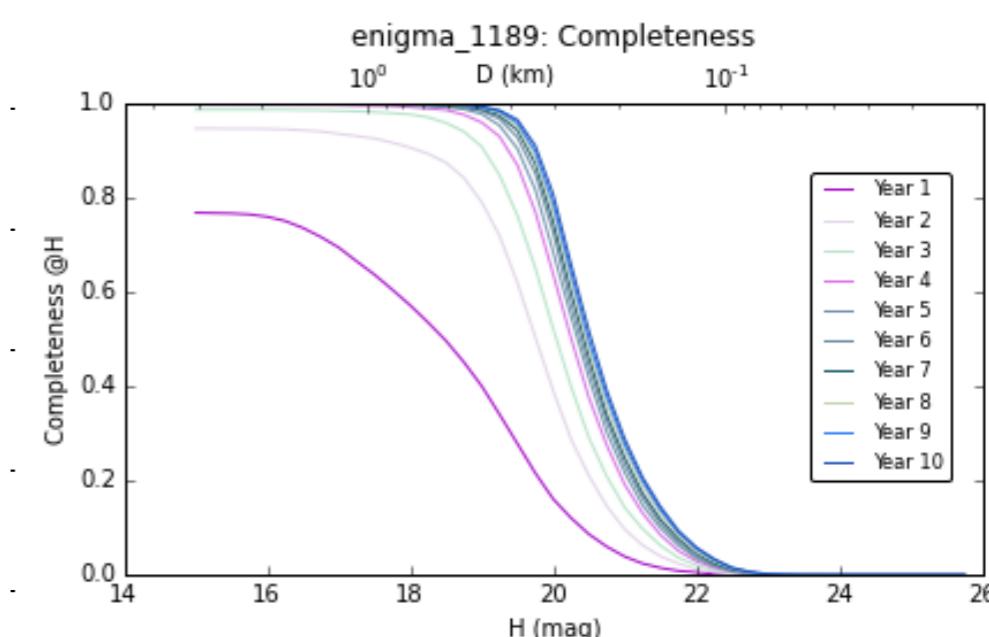
The LSST Solar System Science Collaboration wrote a chapter about lots of interesting science we can do with LSST (2009).

<http://lsst.org/scientists/scibook>

# Number of asteroids / Detections

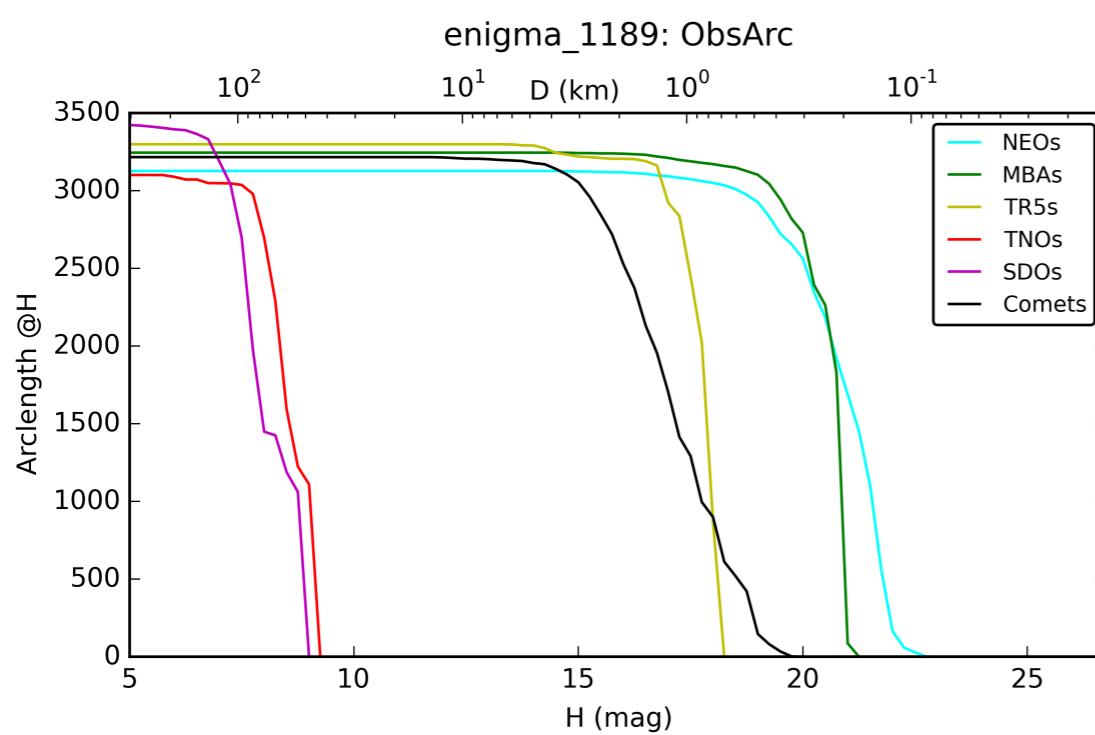
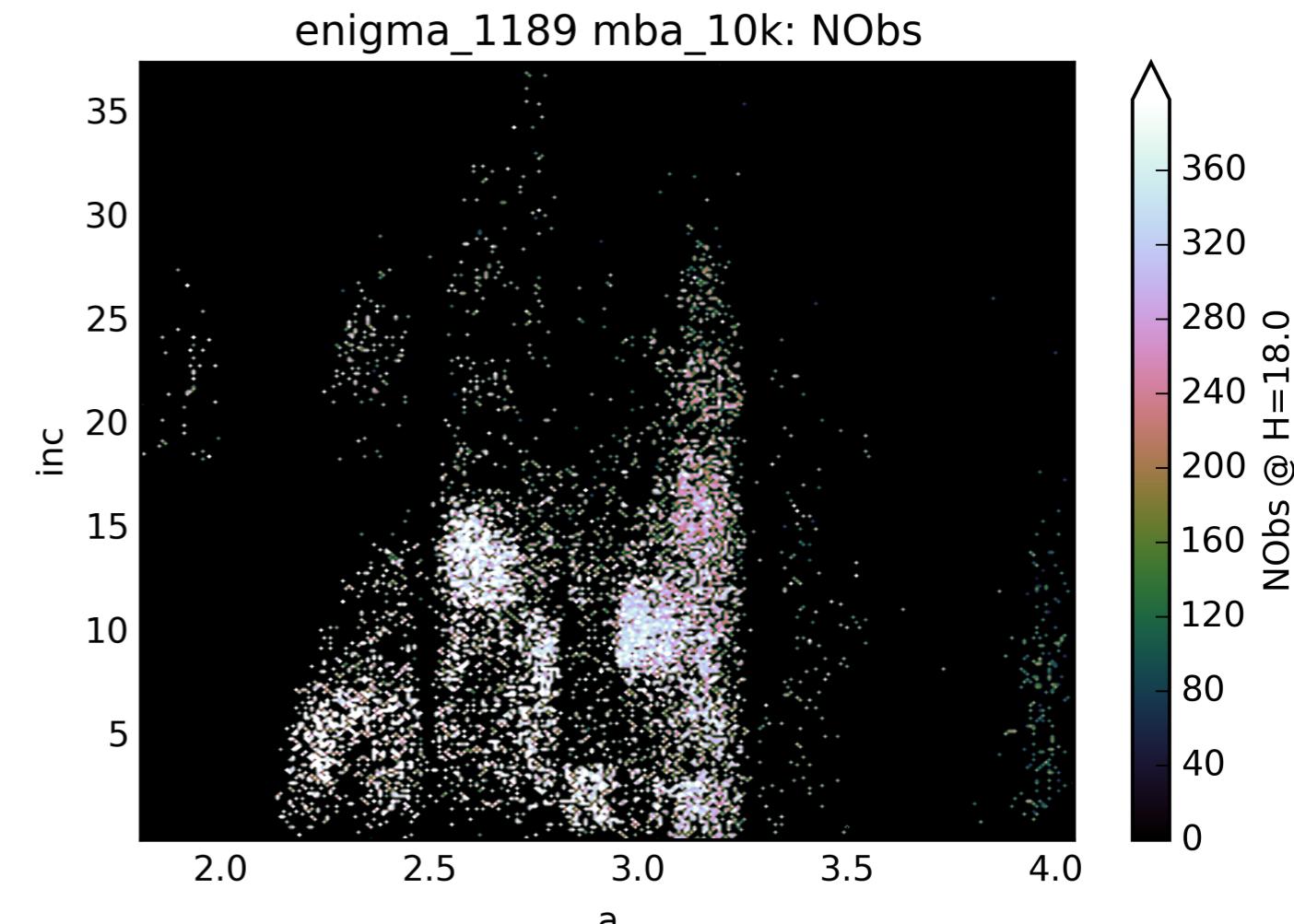
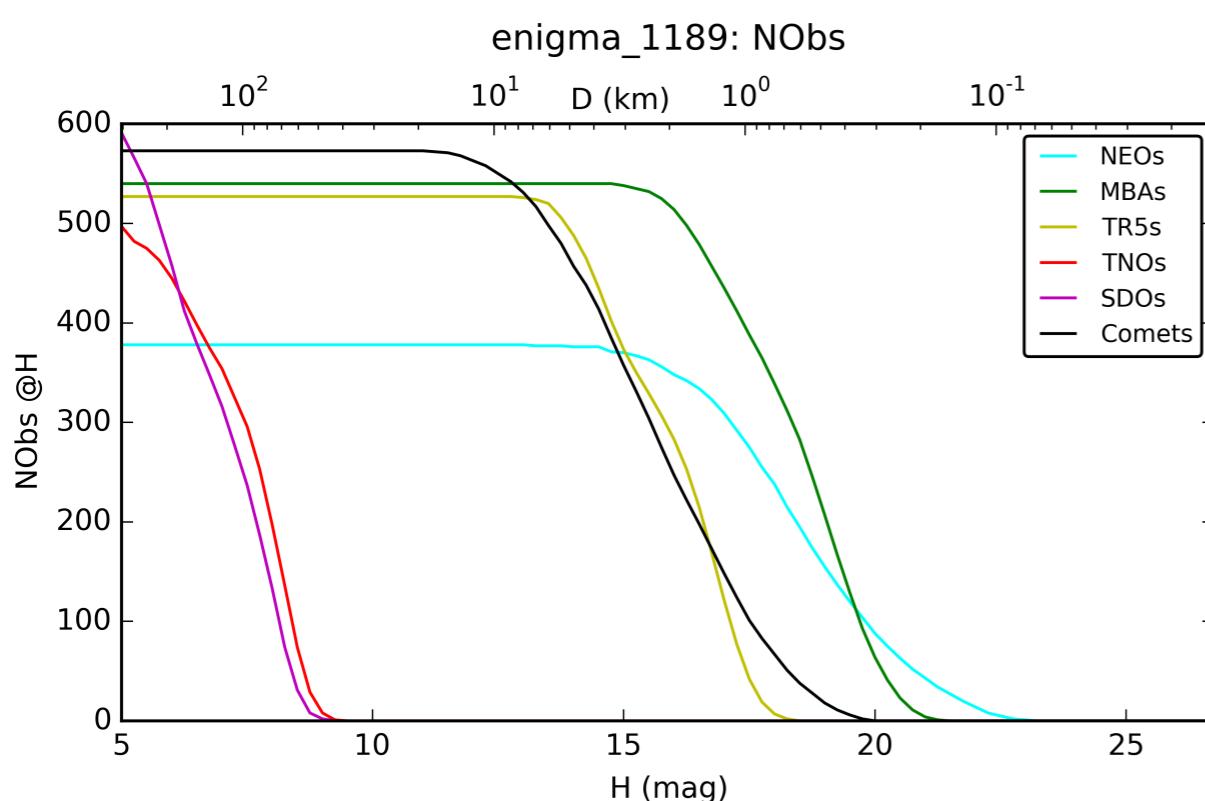
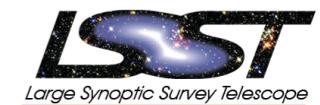


H distributions:  
SDSS from Ivezić et al 2001,  
SKADS from Gladman et al 2009



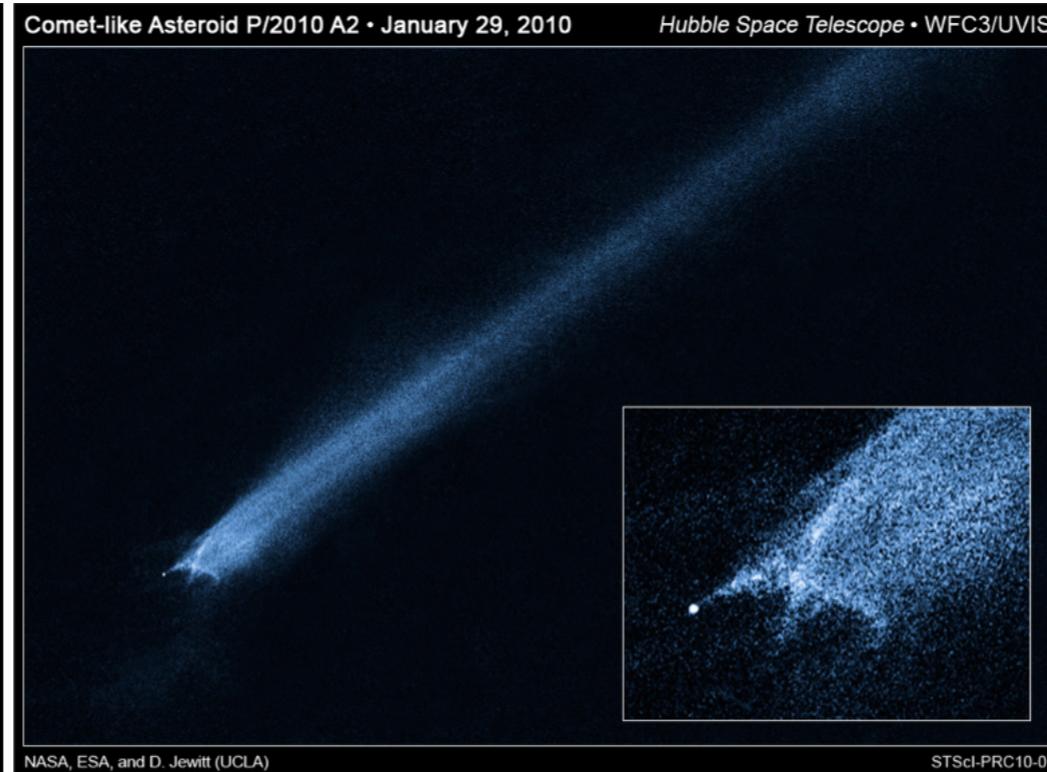
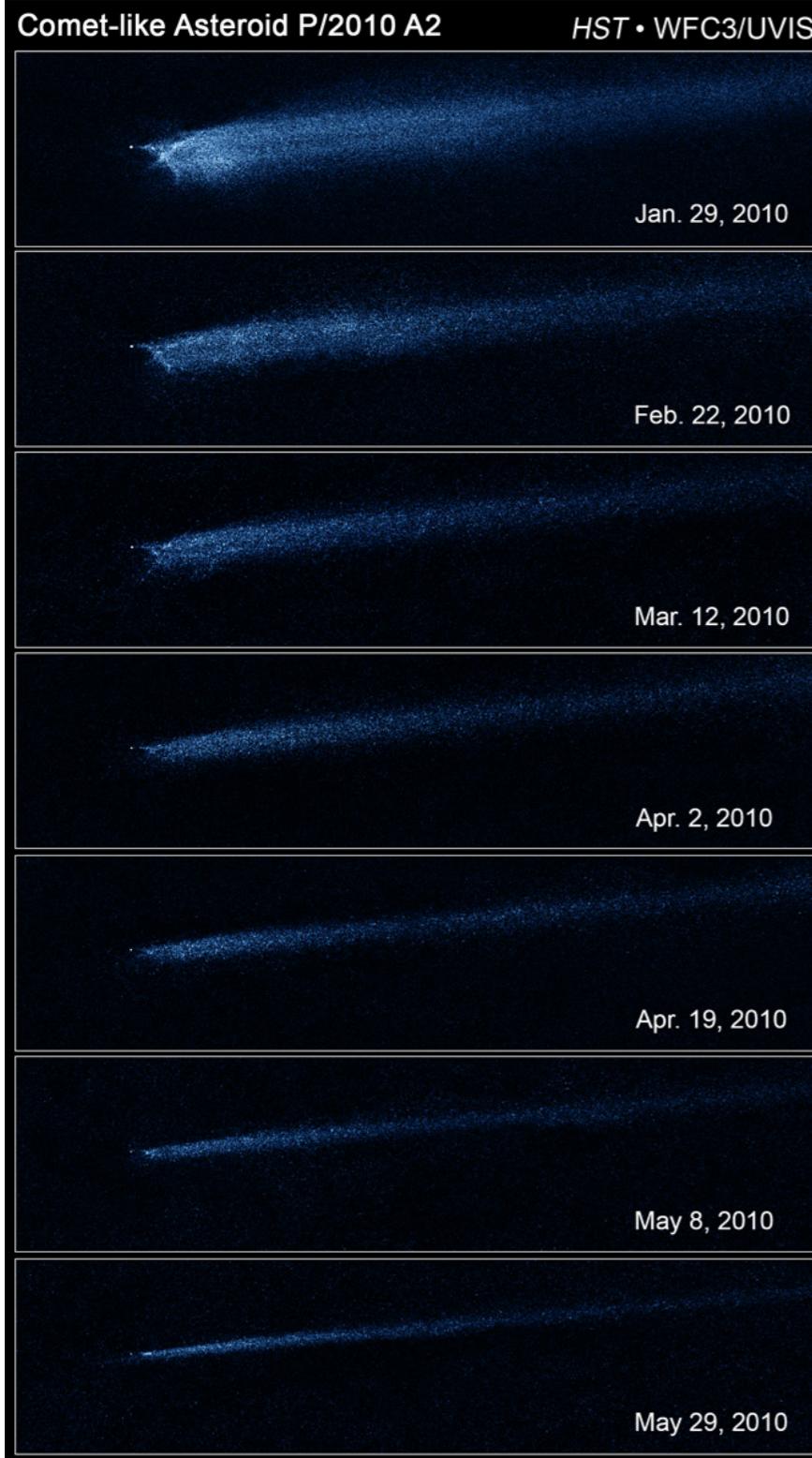
- Current baseline OpSim run (enigma\_1189)
- S3M MBA + H distribution

# Arc length, number of observations, etc

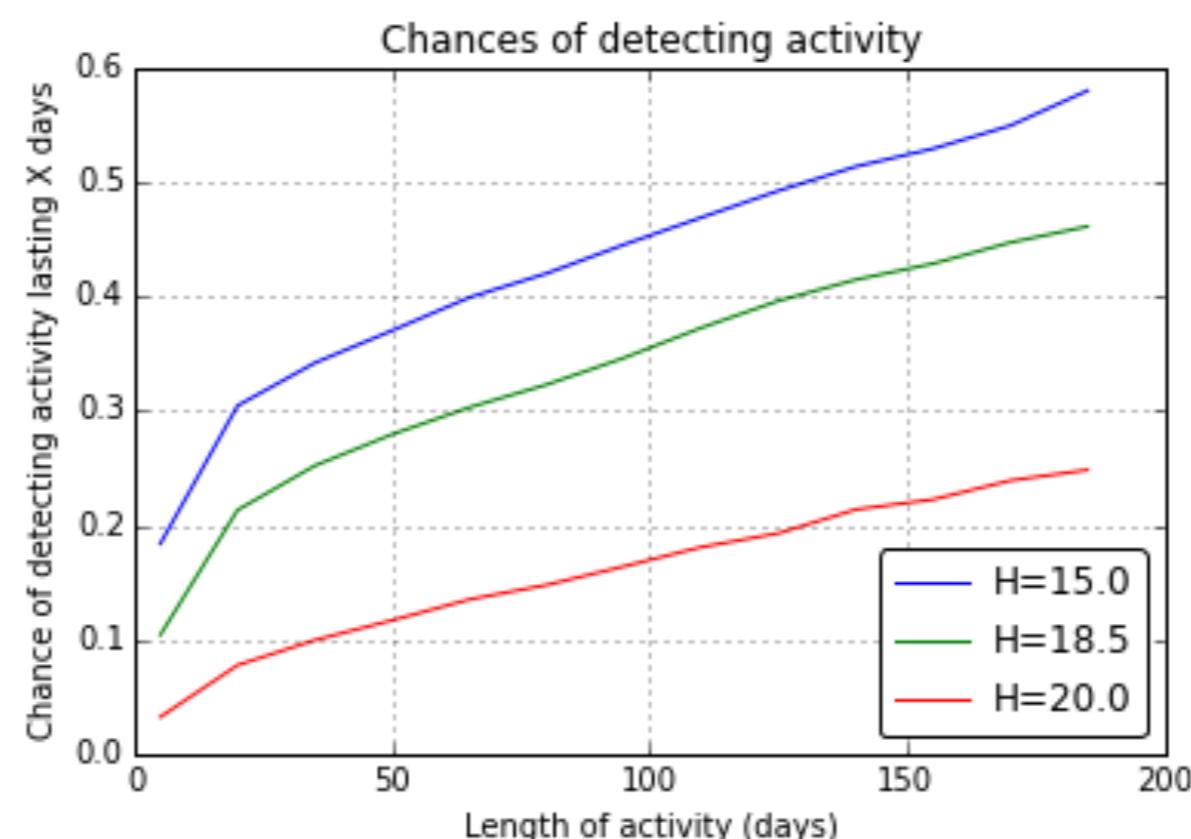


- Opsim:
  - <http://ls.st/p1r>
  - MAF
  - <http://ls.st/j4l>
  - LSST sims\_maf

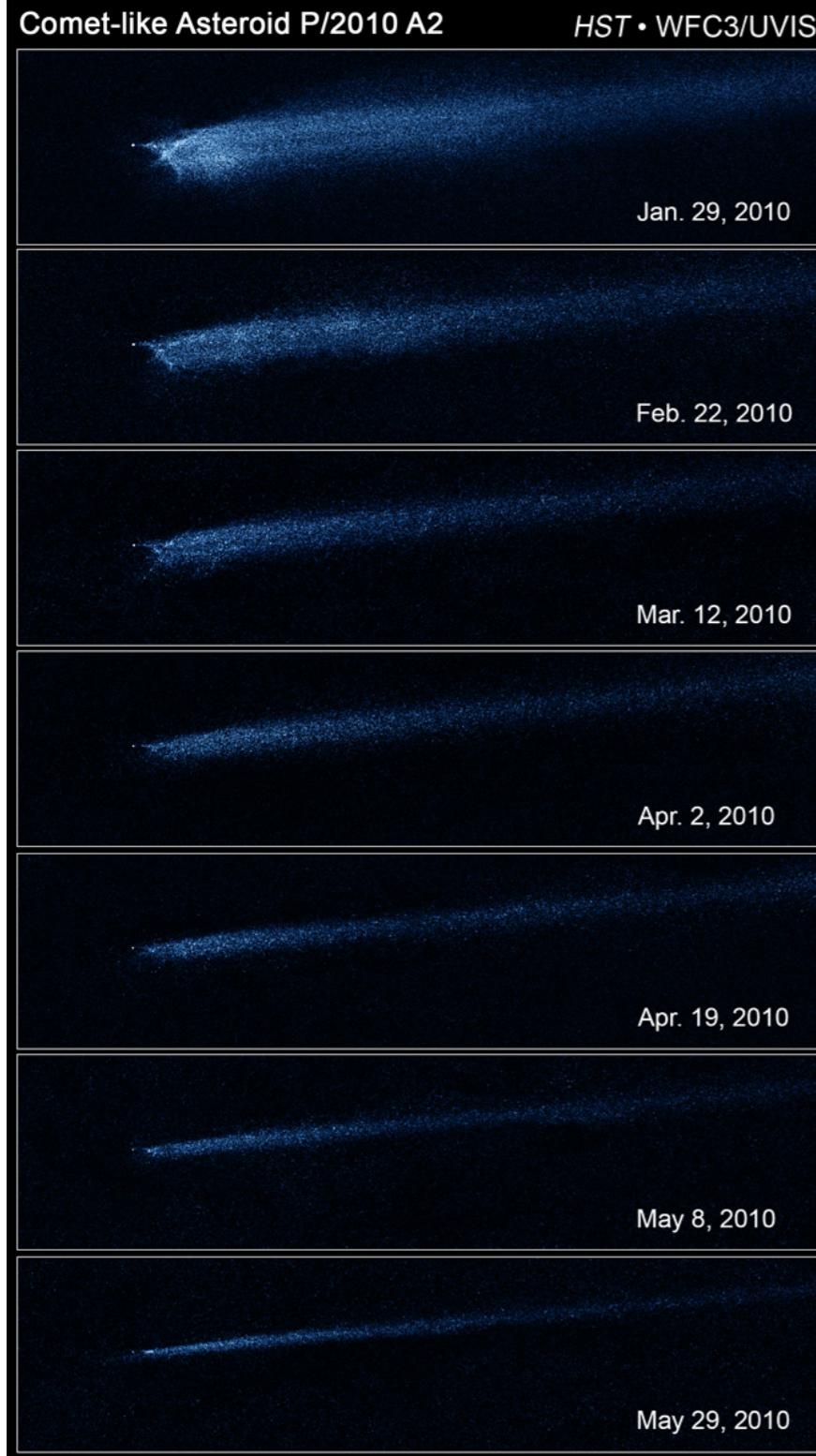
# Finding active asteroids



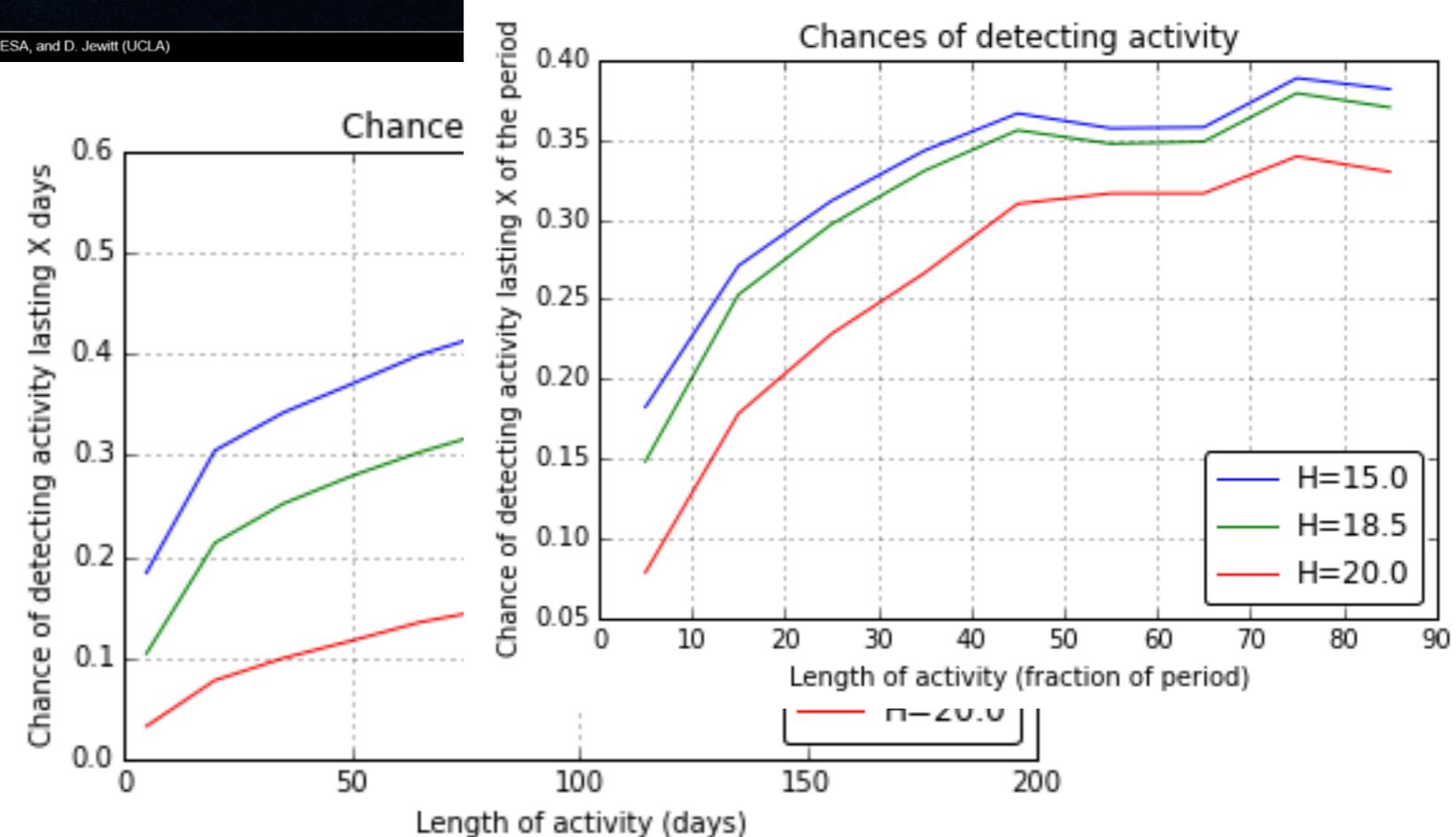
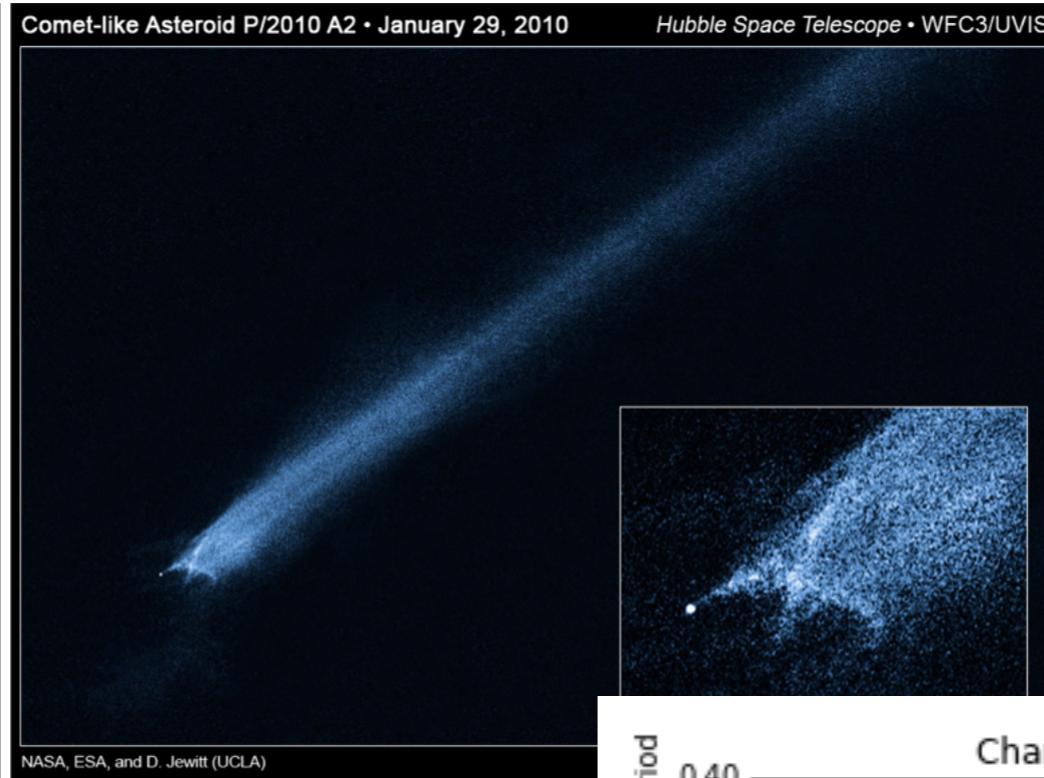
Jewitt et al 2010



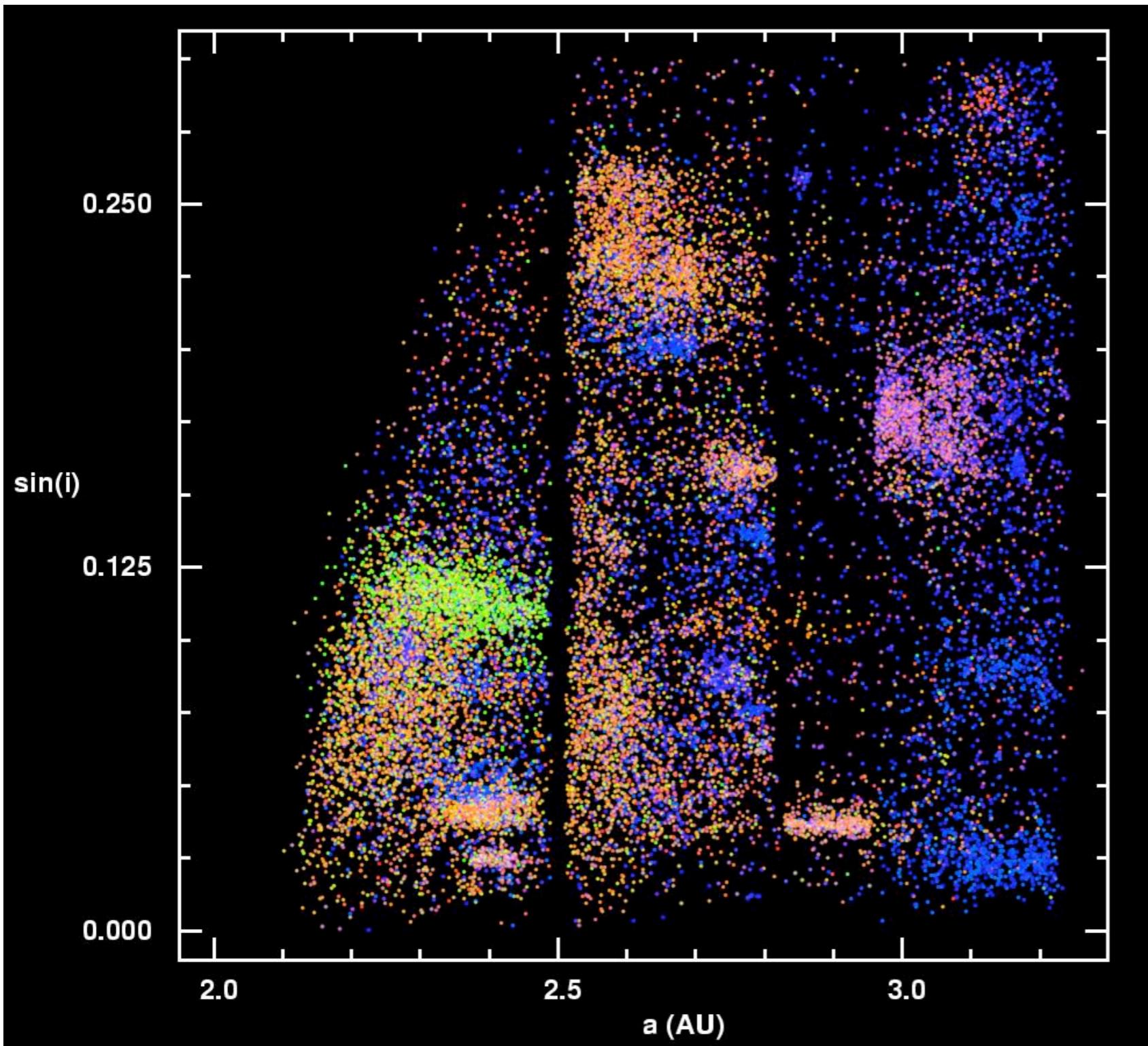
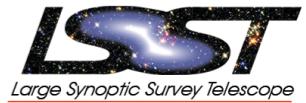
# Finding active asteroids



Jewitt et al 2010



# Family identification, size distribution, and collisional history

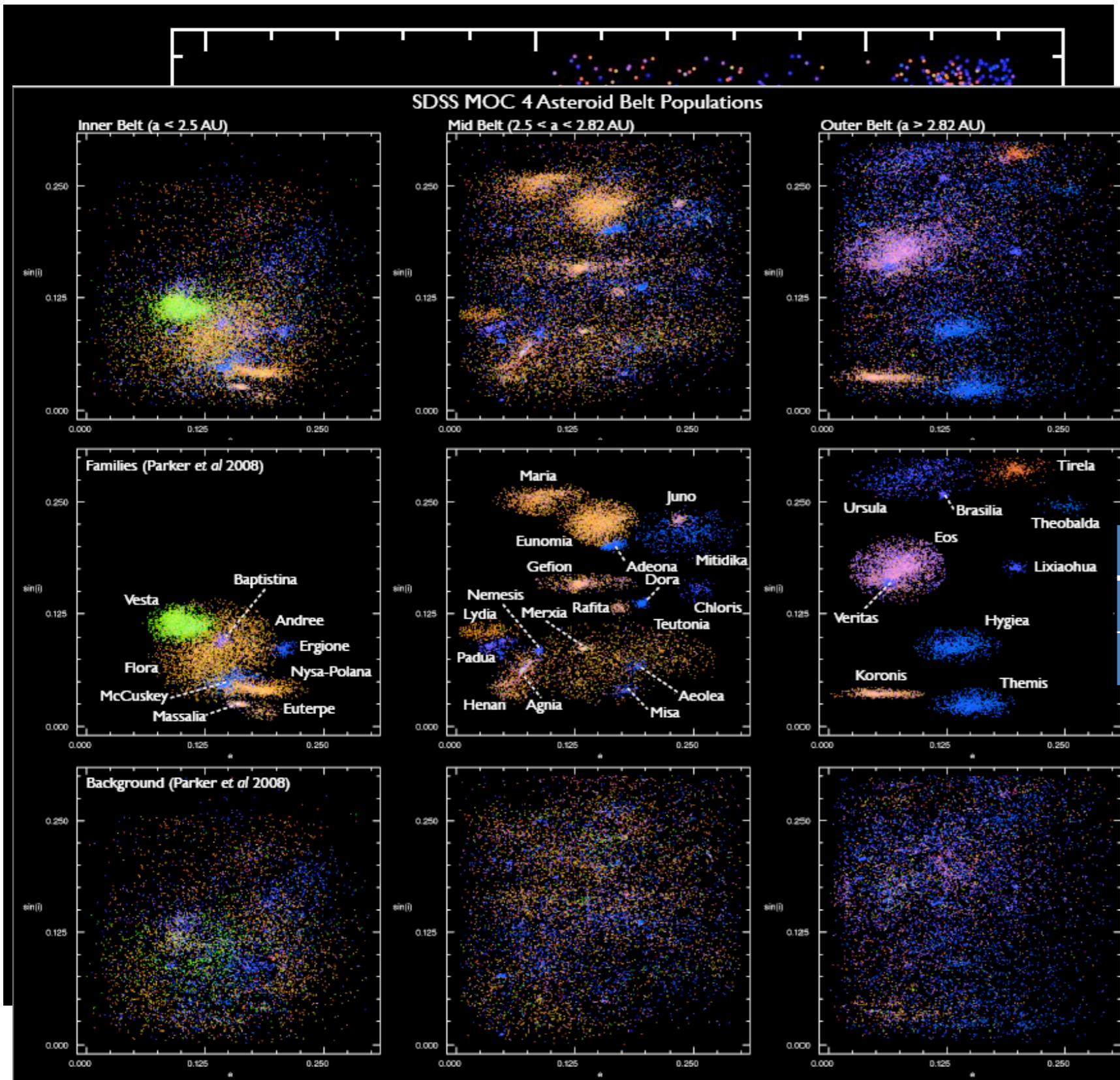
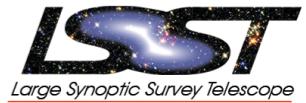


Main belt asteroids detected in the Sloan Digital Sky Survey (SDSS), color coded according to their observed colors — 88,000 MBAs (Parker et al 2008)

Mag	<i>u</i>	<i>g</i>	<i>r</i>	<i>i</i>	<i>z</i>	<i>y</i>
SDSS	22.0	22.	22.	21.	20.	-
LSST	23.	25.	24.	24.	23.	22.

Points are color-coded by ' $a^*$ ' (a combination of  $g, r, i$  colors) and ' $i-z$ '; aids family identification.

# Family identification, size distribution, and collisional history

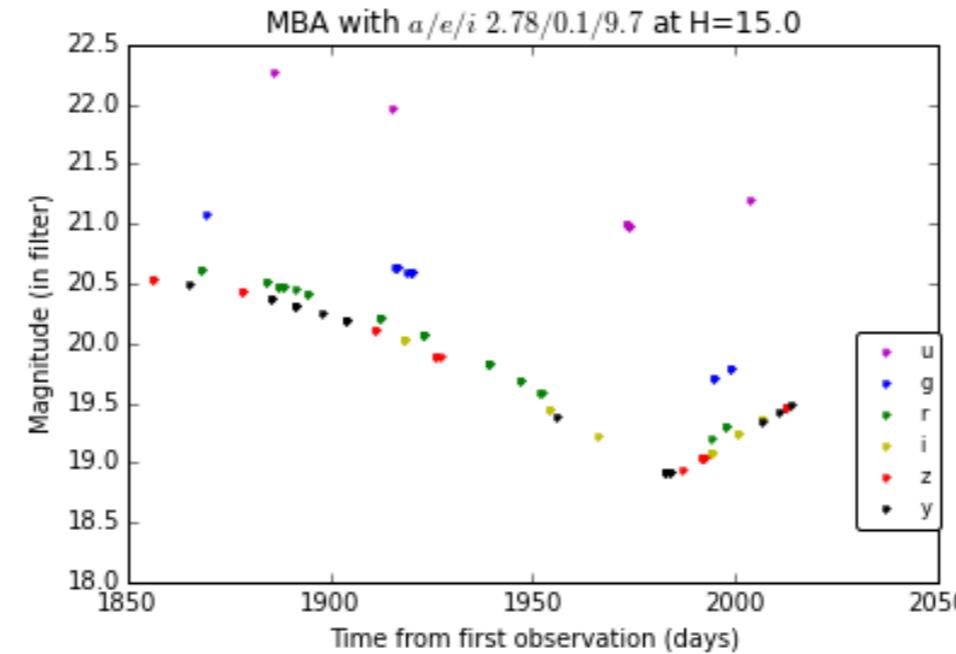
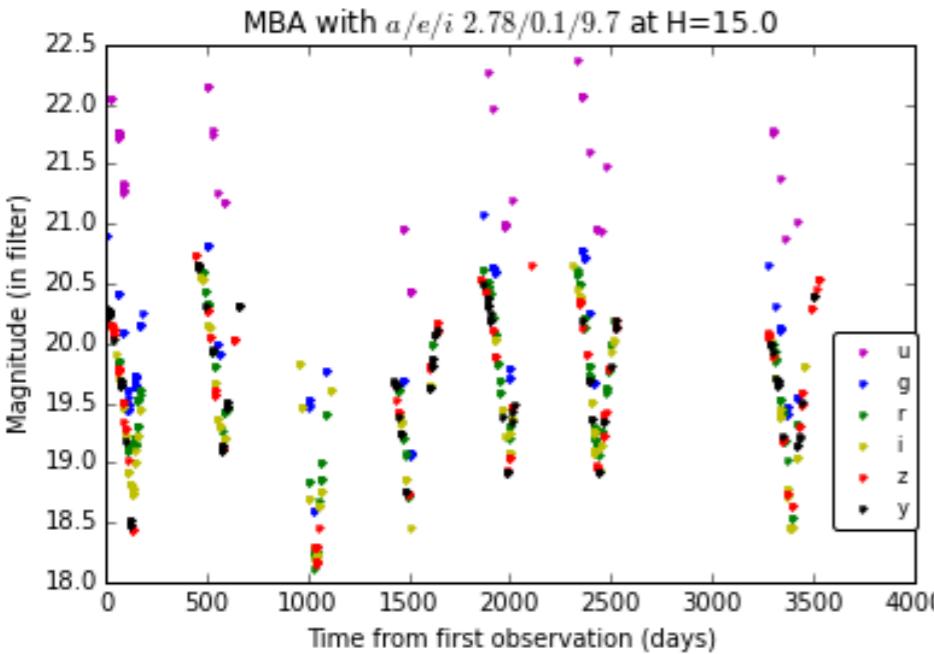
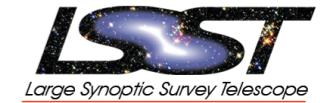


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LSST	23.	25.	24.	24.	23.	22.

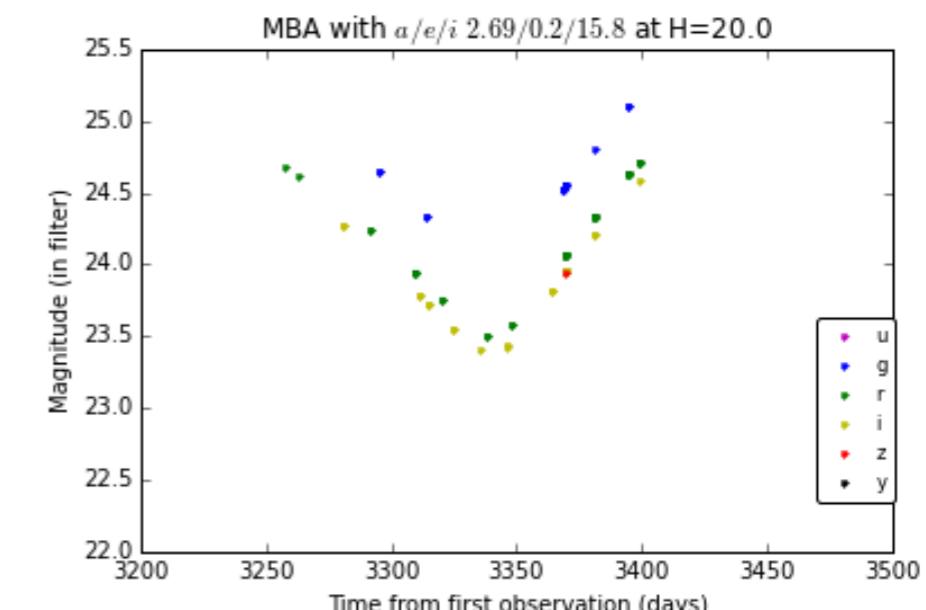
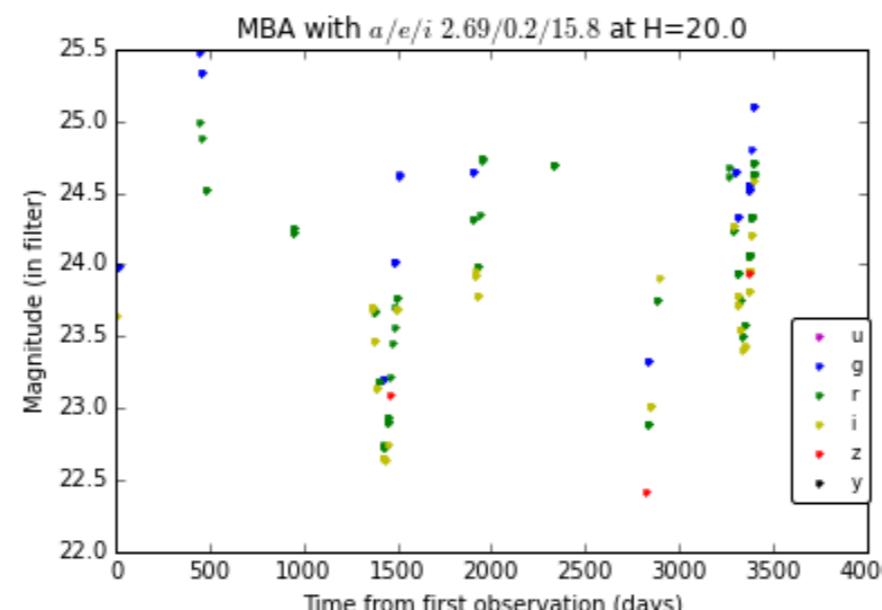
Points are color-coded by ' $a^*$ ' (a combination of  $g,r,i$  colors) and ' $i-z$ '; aids family identification.

# Problem (+opportunity?): Multiband photometry

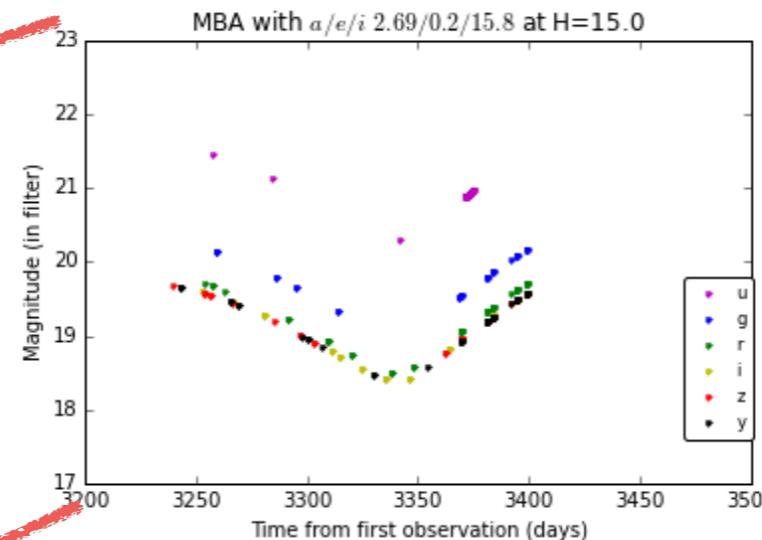
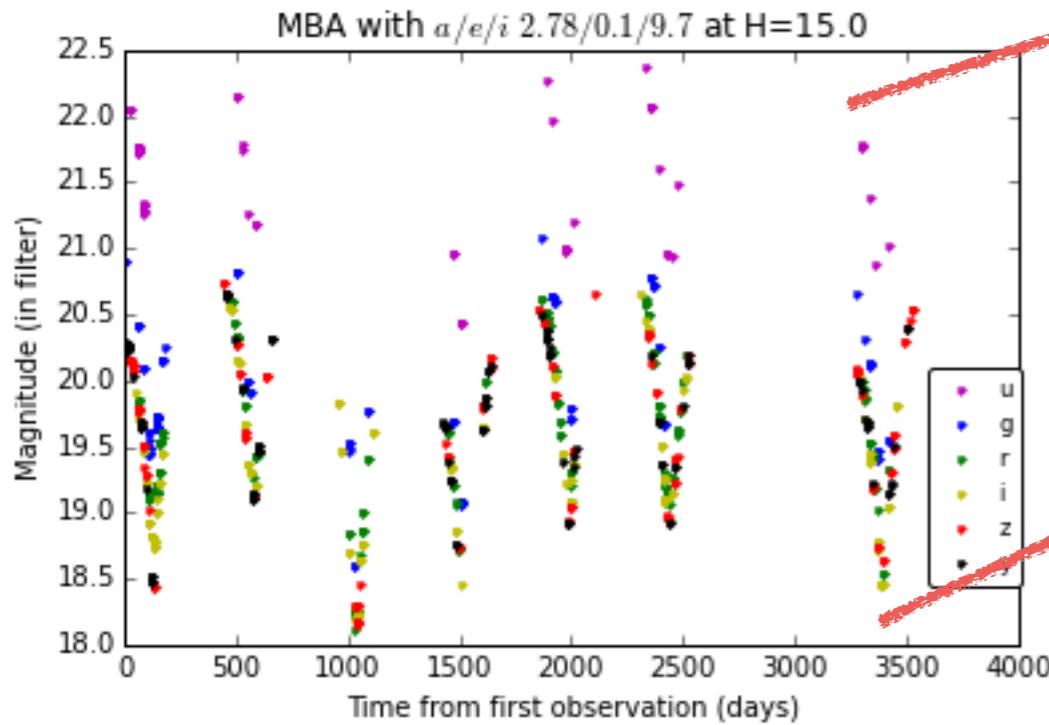
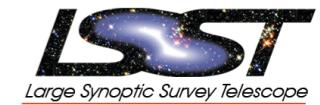


We must understand how to combine photometric measurements taken in different filters at different times. Individual measurements can be accurate to 10mmag; what will color accuracy be? what will light curve accuracy be?

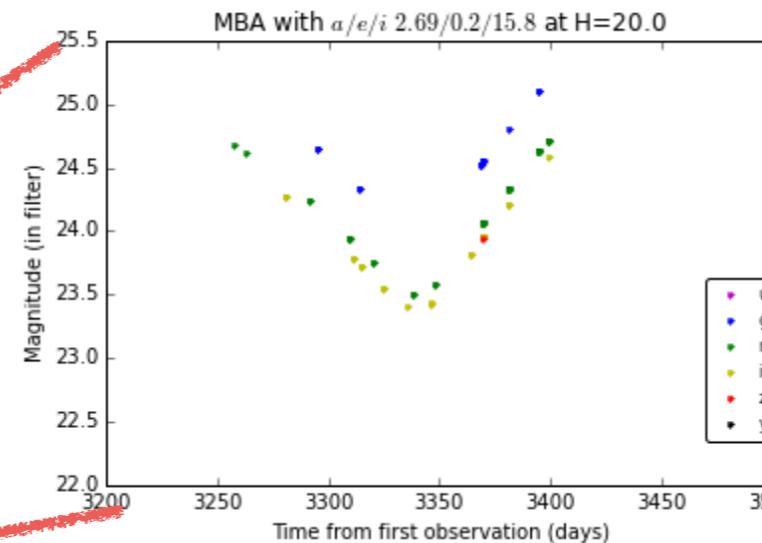
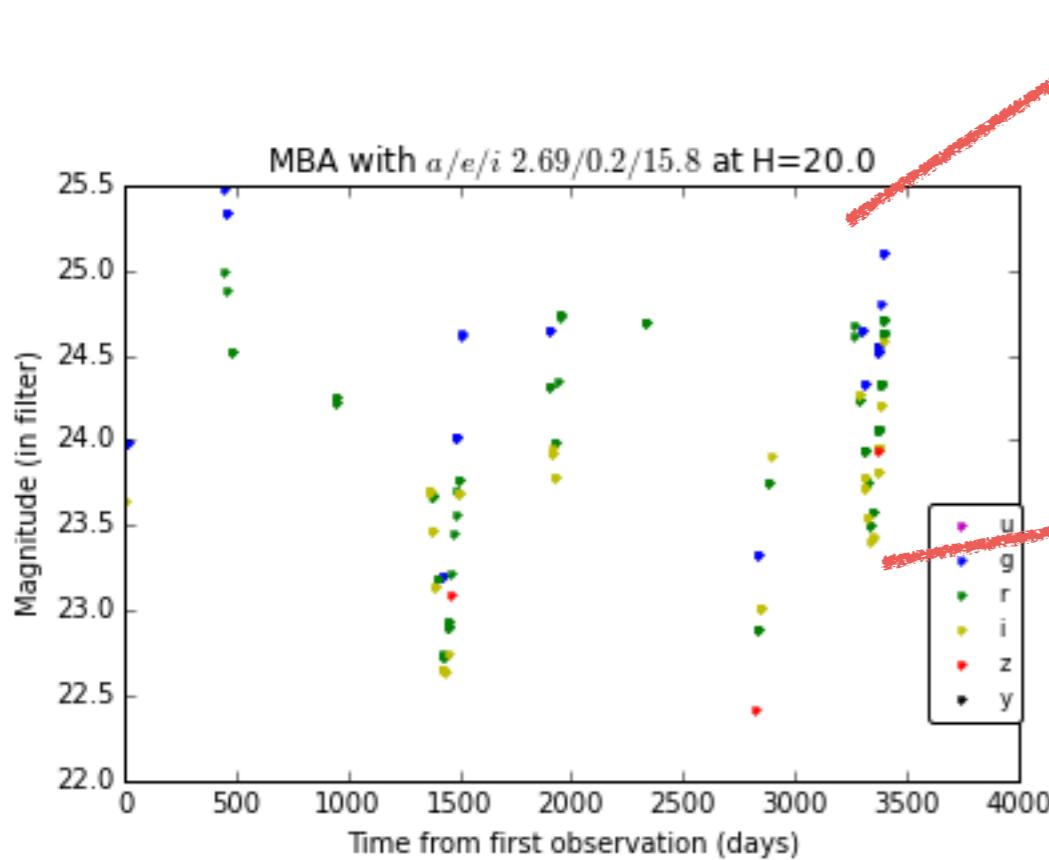
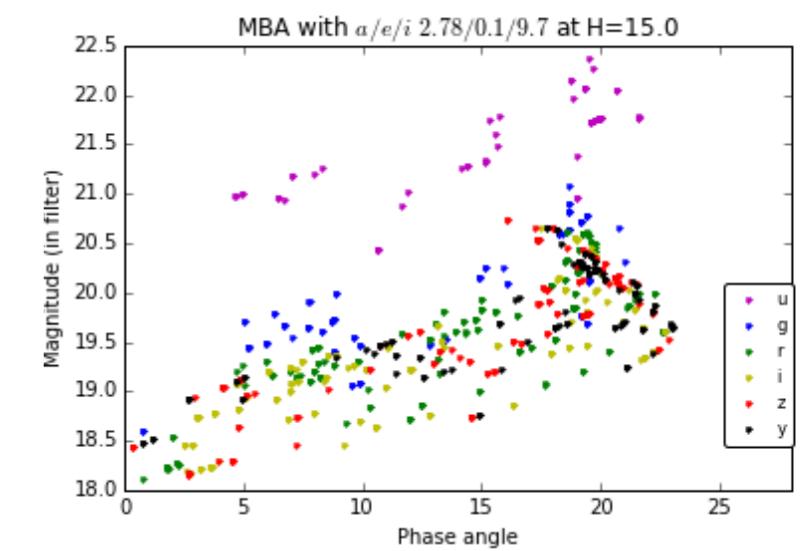
Opportunity: phase curves, colors for space weathering, classification, ...



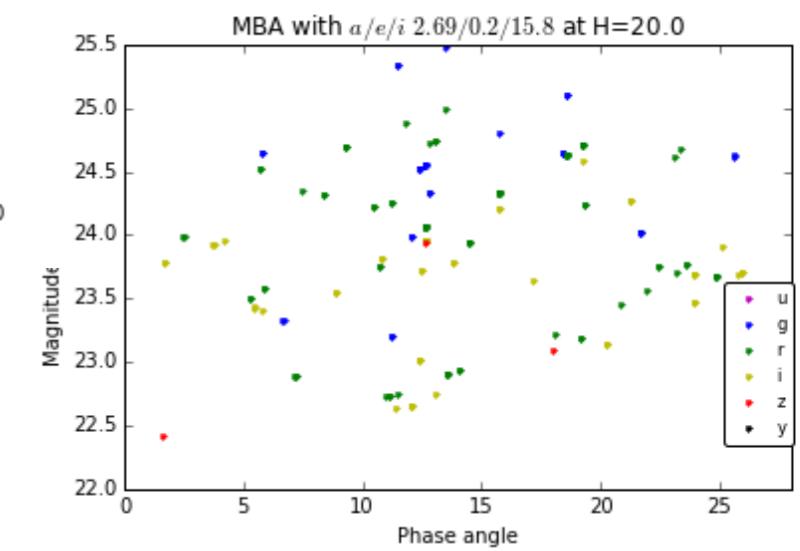
# Lightcurves, spin periods, and shapes



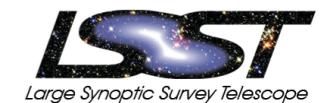
H=15 MBA with 796 visits



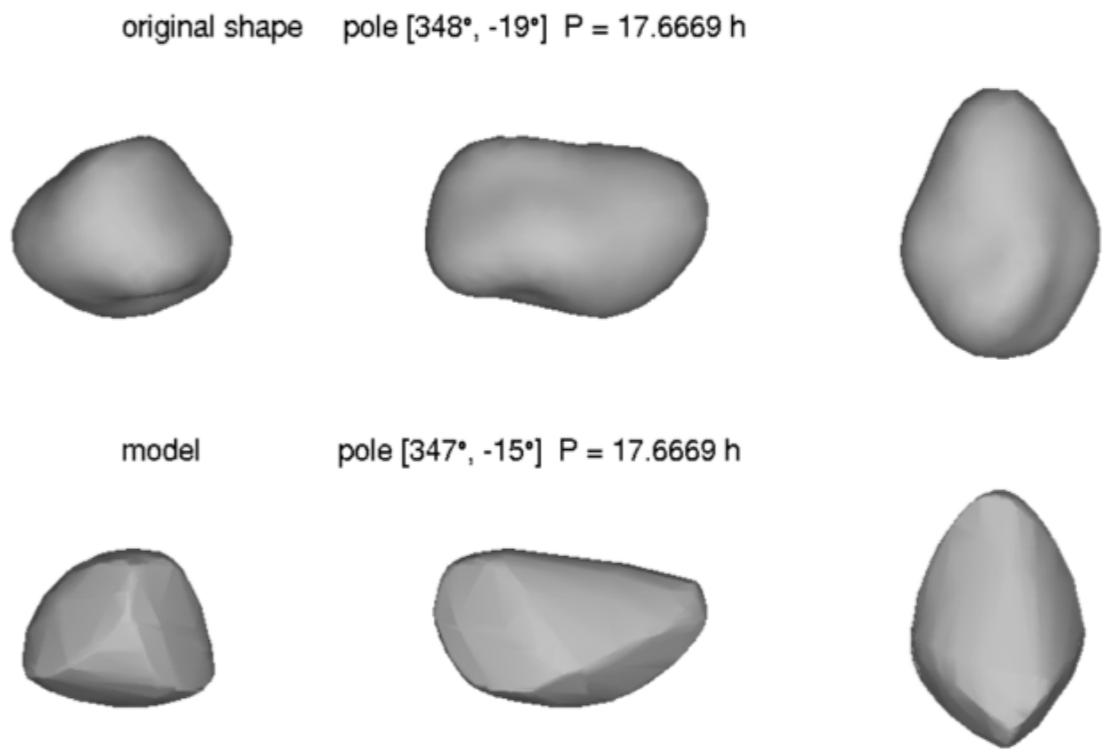
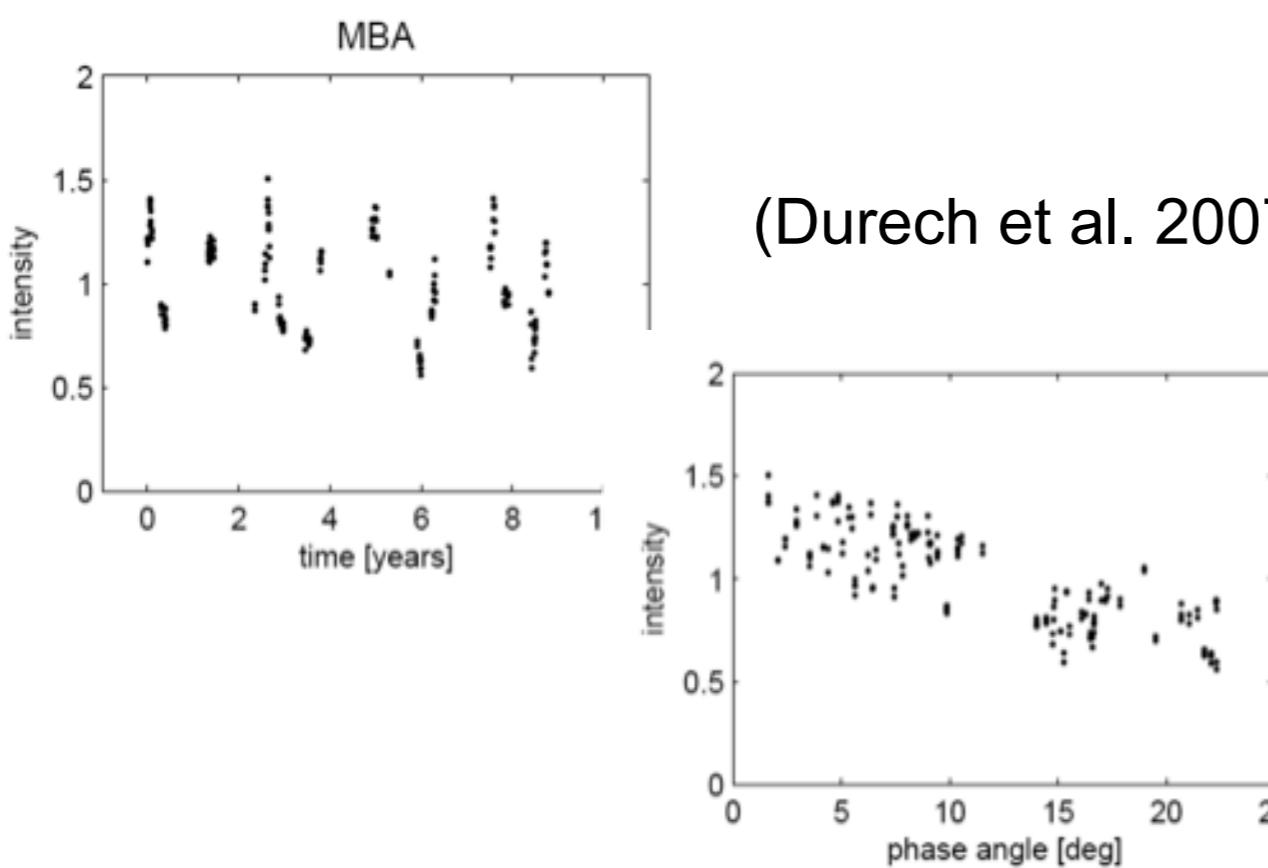
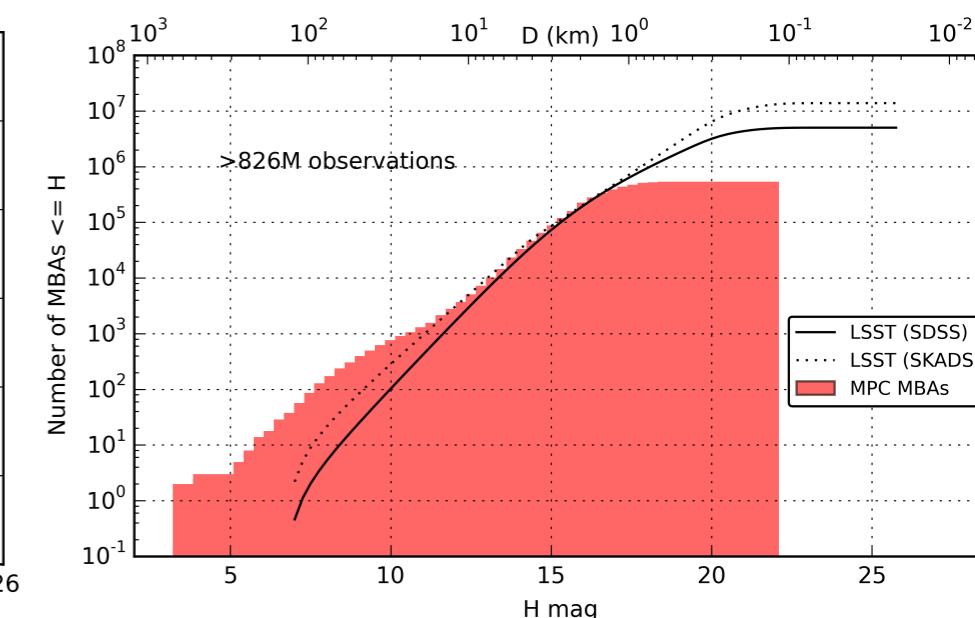
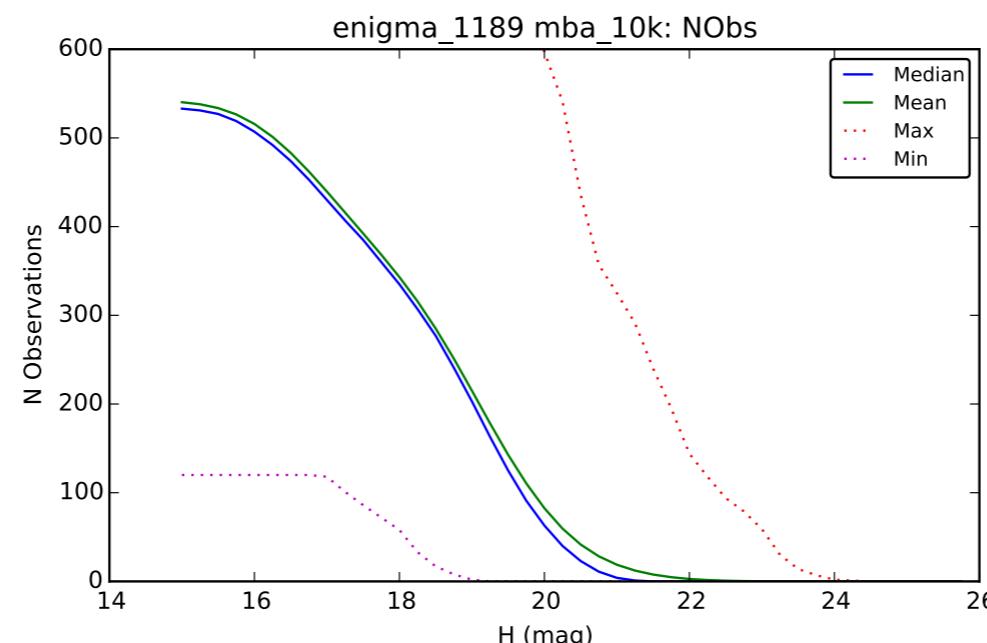
H=20 MBA with 213 visits



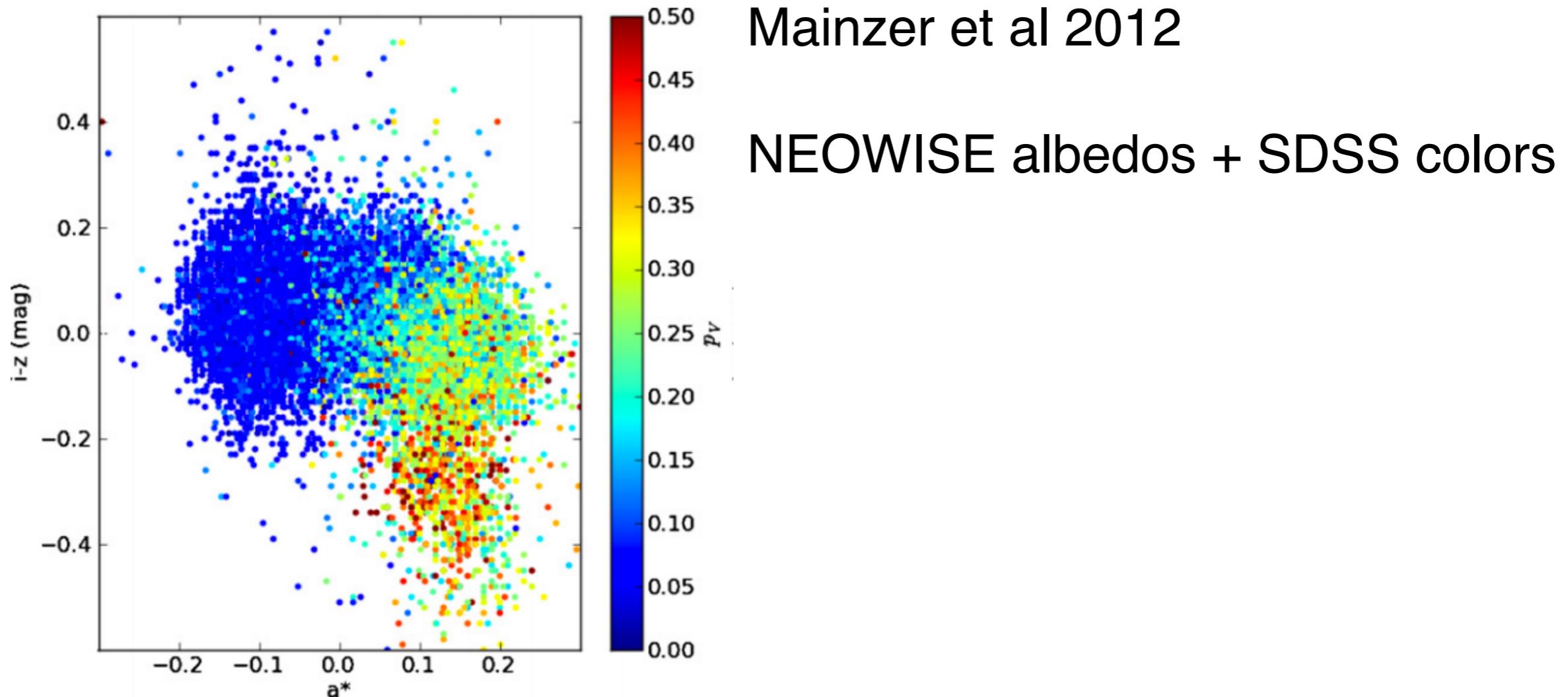
# Lightcurves, spin periods, and shapes



Sparse lightcurve  
inversion can  
provide shapes for  
10,000-100,000  
NEOs and MBAs



# Colors and albedos



- SDSS colors map to albedos - statistically speaking
- LSST colors have similar bandpasses, add  $y$

# More science

- Masses for ~100 MBAs
- More occultation opportunities
- Links between NEOs and MBAs
- Finding binaries
- Shift & Stack - special mini-survey to r=27

