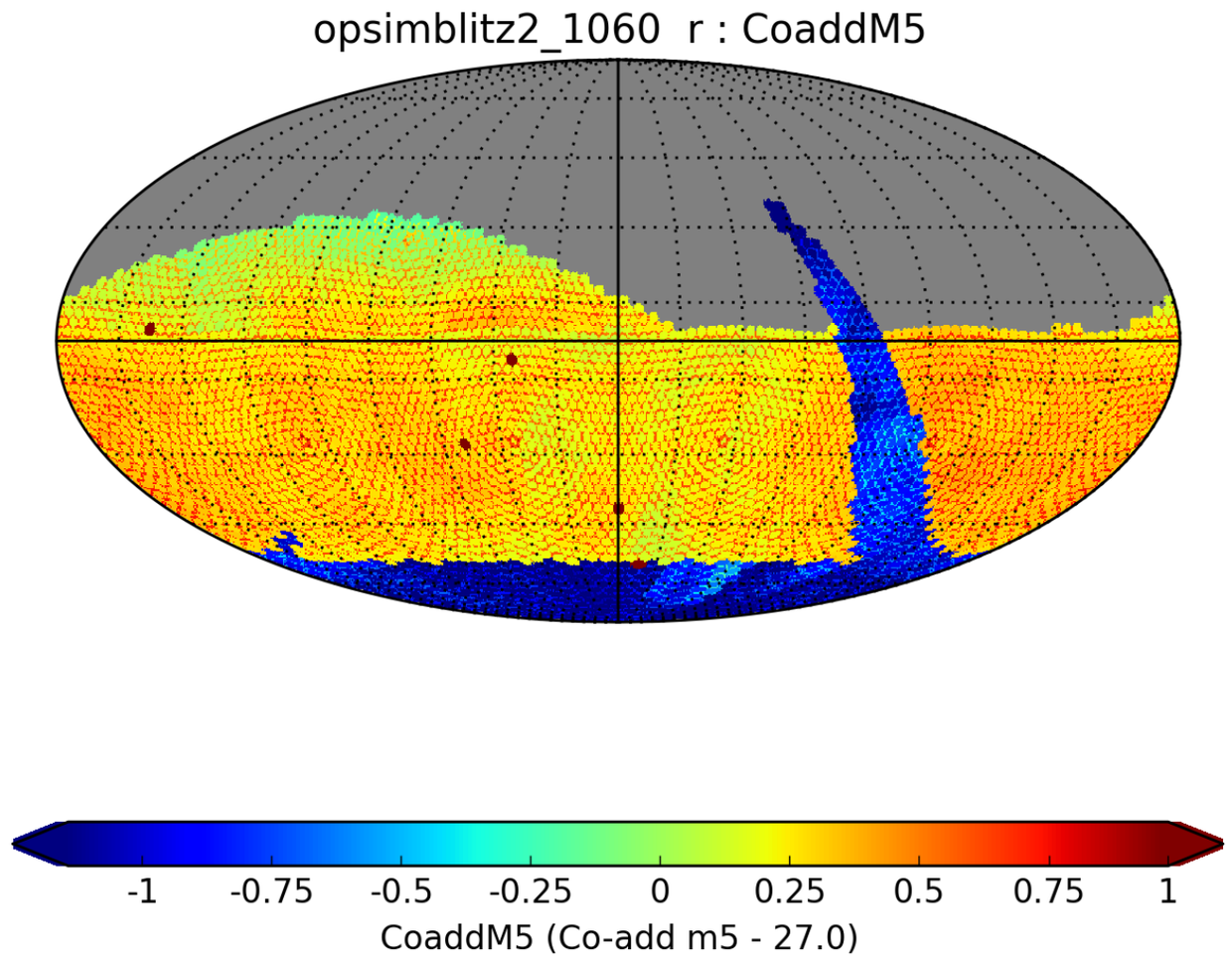
TMT in the era of LSST

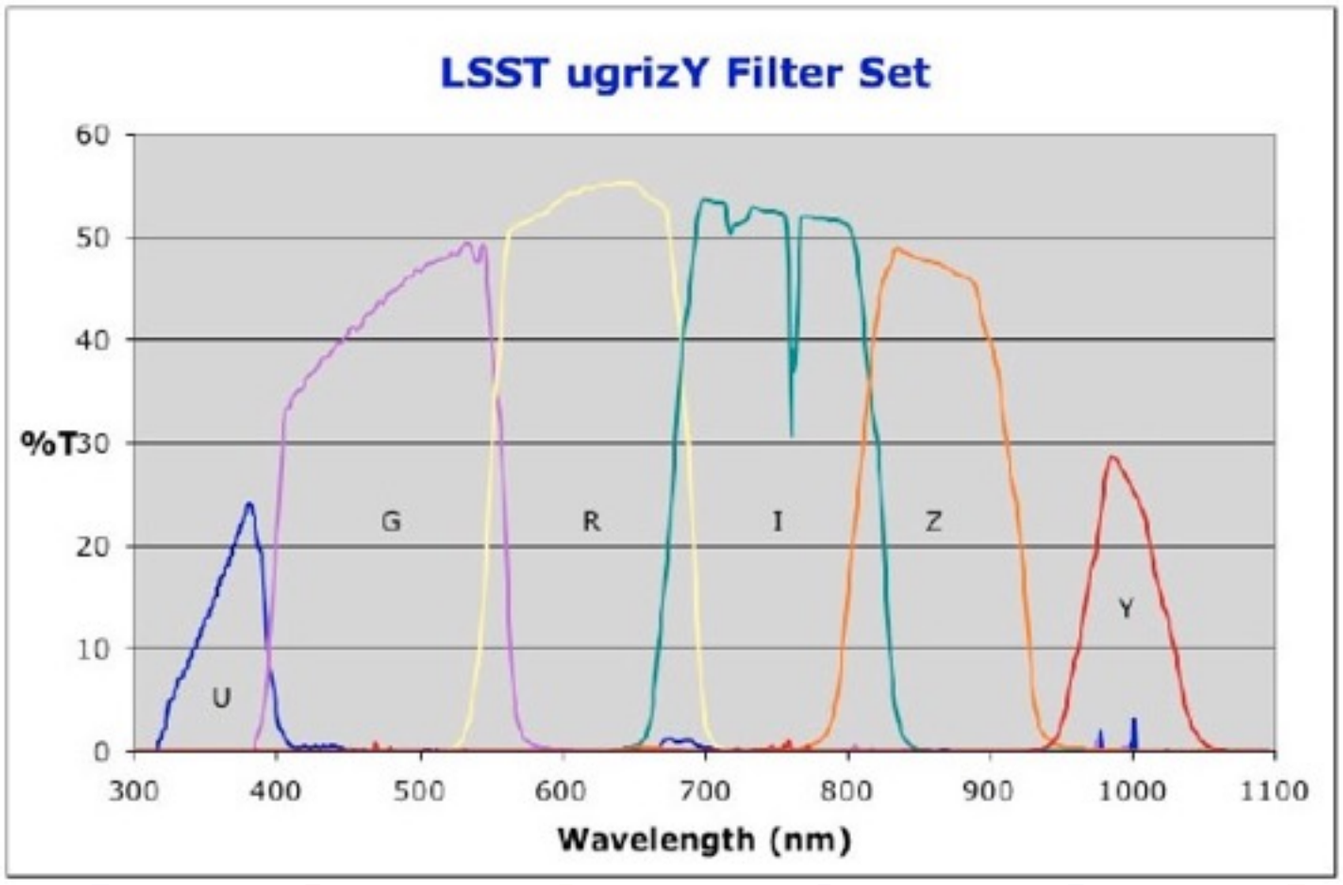


aam at astro.caltech.edu (Caltech)
Co-chair LSST Transients and Variable Stars Science Collaboration

TMT Science Forum

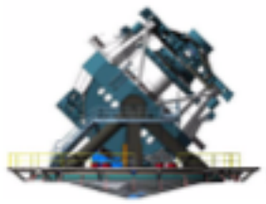
Jun 24th, 2015

Probing faint transients & variables



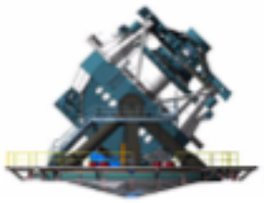
	u	*g*	*r*	*i*	*z*	*y*
Single	*23.9*	*25.0*	*24.7*	*24.0*	*23.3*	*22.1*
Stacked	*26.3*	*27.5*	*27.7*	*27.0*	*26.2*	*24.9*

~0.01 mag precision photometry



Summary of high level requirements

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.9; g = 25.0; r = 24.7; I = 24.0; z = 23.3; y = 22.1
Photometric calibration	< 2% absolute, < 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	< 60 sec after last visit exposure
Data release	Full reprocessing of survey data annually



LSST data volume and scientific yields

Raw Data

- Two 6.4-gigabyte images (one visit) every 39 seconds (15TB per night)
- ~1000 visits each night, ~300 nights a year
- Up to 450 calibration exposures per day

Level 1

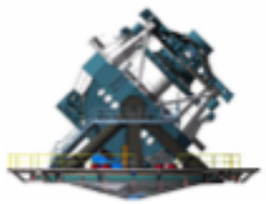
- Can detect >10 million real time events per night, for 10 years
- Changes detected, transmitted, within 60 seconds of the observation

Level 2

- Observe ~38 billion objects (24B galaxies, 14B stars)
- Collect ~5 trillion observations (“sources”) and ~32 trillion measurements (“forced sources”) in a 20 PB catalog

Level 3

- User databases and workspaces (“mydb”)
- Making the LSST software available to end-users
- Feeding the data back to the community



Hierarchical steps of survey complexity

1. **single band, single program, static science**
2. **multi-bandpass data: ugrizy**
3. **time domain**

… not all sky regions were created equal!

Galactic plane
LMC/SMC
northern Ecliptic
south Galactic pole
deep drilling (and other special) fields

It's likely that these regions will need a modified cadence, but not clear yet how exactly (depends on fast-evolving science drivers and the system performance)

Transients and Variable Stars Science Collaboration
Co-chairs: Ashish Mahabal, Lucianne Walkowicz

Classification/Characterization
Distance Scale
Multiwavelength Characterization/Counterparts
Cosmological
Fast Transients
Galactic
Gravitational Waves
Interacting Binaries
Magnetically Active Stars
Microlensing Subgroup
Non-degenerate Eruptive Variables
Pulsating Variables
Supernovae Subgroup
Tidal Disruption Events
Transiting Planets

Developing roadmaps (~100 members)

roadmaps based on aims, simulations, data and lessons from other surveys
[testing co-add pipeline for CRTS images]

Variability on huge range of timescales

Class	Timescale	Amplitude (Δmags)
WD Pulsations	4-10 min	0.01 - 0.1
AM CVn (orbital period)	10-65 min	0.1 - 1
WD spin (int. polars)	20-60 min	0.02 - 0.4
AM CVn outbursts	1-5 days	2 - 5
Dwarf Novae outburst	4 days - 30 years	2 - 8
Symbiotic (outburst)	weeks-months	1 - 3
Novae-like high/low	days-years	2 - 5
Recurrent Novae	10-20 year	6 - 11
Novae	10^3-10^4 yr	7 - 15

Slide from Lucianne Walkowicz

Expected Rate of Transients

Class	Mag	t (days)	Universal Rate	LSST Rate
Luminous SNe	-19...-23	50 - 400	10^{-7} Mpc^{-3} yr^{-1}	**20000**
Orphan Afterglows SHB	-14...-18	5 -15	3 x$10^{-7...-9}$ Mpc^{-3} yr^{-1}	**~10 - 100**
Orphan Afterglows LSB	-22...-26	2 - 15	3 x $10^{-10...-11}$ Mpc^{-3} yr^{-1}	**1000**
On-axis GRB afterglows	...-37	1 - 15	10^{-11} Mpc^{-3} yr^{-1}	**~50**
Tidal Disruption Flares	-15...-19	30 - 350	10^{-6} Mpc^{-3} yr^{-1}	**6000**
Luminous Red Novae	-9...-13	20 - 60	10^{-13} yr^{-1} Lsun^{-1}	**80 - 3400**
Fallback SNe	-4...-21	0.5 - 2	<5 x 10^{-6} Mpc^{-3} yr^{-1}	**< 800**
SNe Ia	-17...-19.5	30 - 70	3 x 10^{-5} Mpc^{-3} yr^{-1}	**200000**
SNe II	-15...-20	20 - 300	(3..8) x 10^{-5} Mpc^{-3} yr^{-1}	**100000**

Table adapted from Rau et al. 2009 by Lucianne Walkowicz

Number of transients and variables

10^6 – 10^7 per night (thats 1000/minute!)

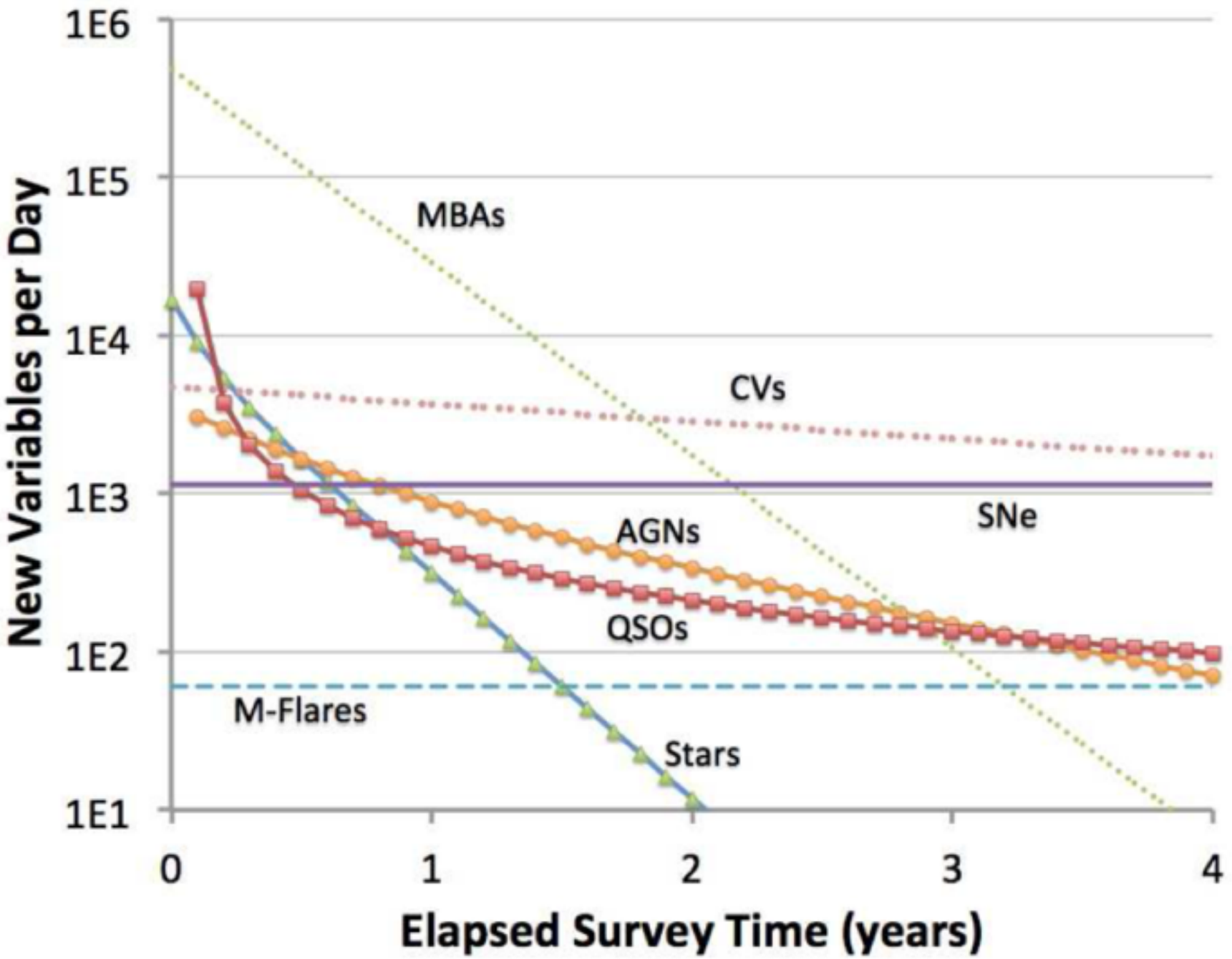
Most of them of a typical/known nature

Characterizing them to get to the rare ones is important

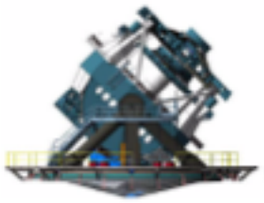
iPhone app

“Transient Events”

The tapering down



- Ridgeway et al., arXiv: 1409.3265



Cadence "conservation laws"

How can we optimize the deployment parameters:
exposure time per visit, t_{vis}, single-visit depth,
m_5, the mean revisit time, $t_{revisit}$, and the number of visits, N_{vis}?

While each of these four parameters has its own drivers, they are not independent (scaled to nominal LSST):

$$m_5 = 24.7 + 1.25 * \log(t_{vis} / 30 \text{ sec})$$
$$t_{revisit} = 3 \text{ days} * (t_{vis} / 30 \text{ sec})$$
$$N_{vis} = 1000 * (30 \text{ sec} / t_{vis}) * (T / 10 \text{ years})$$

How to allocate the total observing time per position of ~7 hours to ugrizy, and how do we split allocations into individual visits?

2014, 2015 cadence meetings

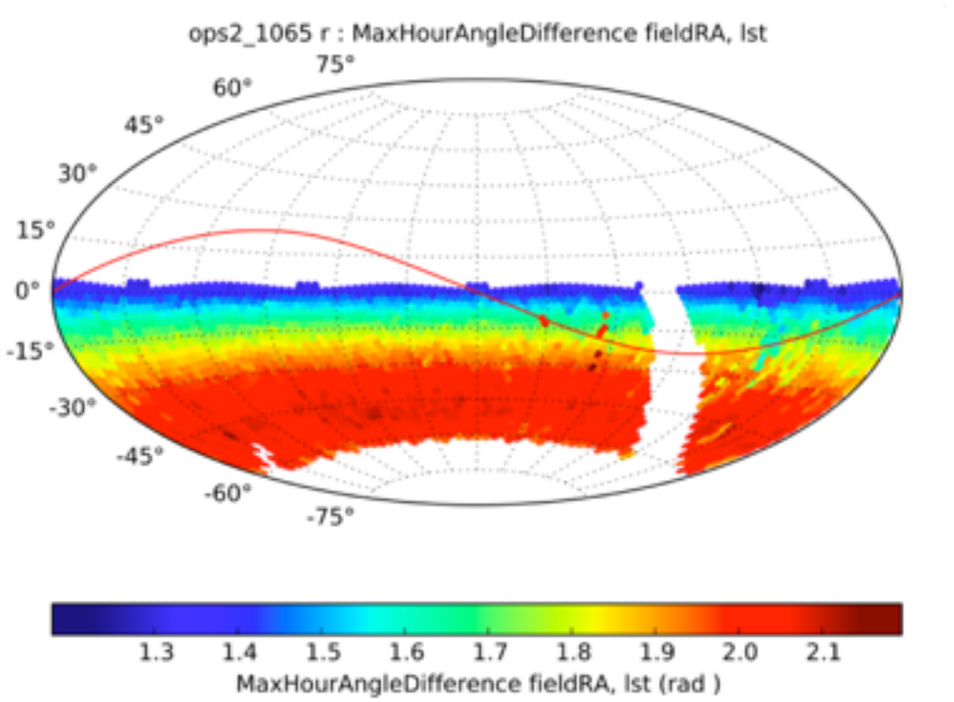
Sensitivity (visit? coadd?) by filter (especially u and g), needed for several (many? all?) variable types

Phased uniformity (periodic variables): for a given period how uniformly would the lightcurve be sampled?*

Window function (per filter/all filters) FWHM, ...
statistics of **revisit time histogram** (per filter/all filters) e.g. min/max/ median/5th & 95th percentiles

Hour angle distribution (to check aliasing), at a given sky position, maximum difference, rms ...

20-22 Aug 2015
Bremerton



Optimization more than in Tzolk'in

Temples
Technologies
Currency
Buildings
Resources

Rohit Gawande

Victory points == science

Large number of variables and each player wants to win.

Optimizing is (generally) a zero-sum game

Easy to make the survey “greatest” in one science

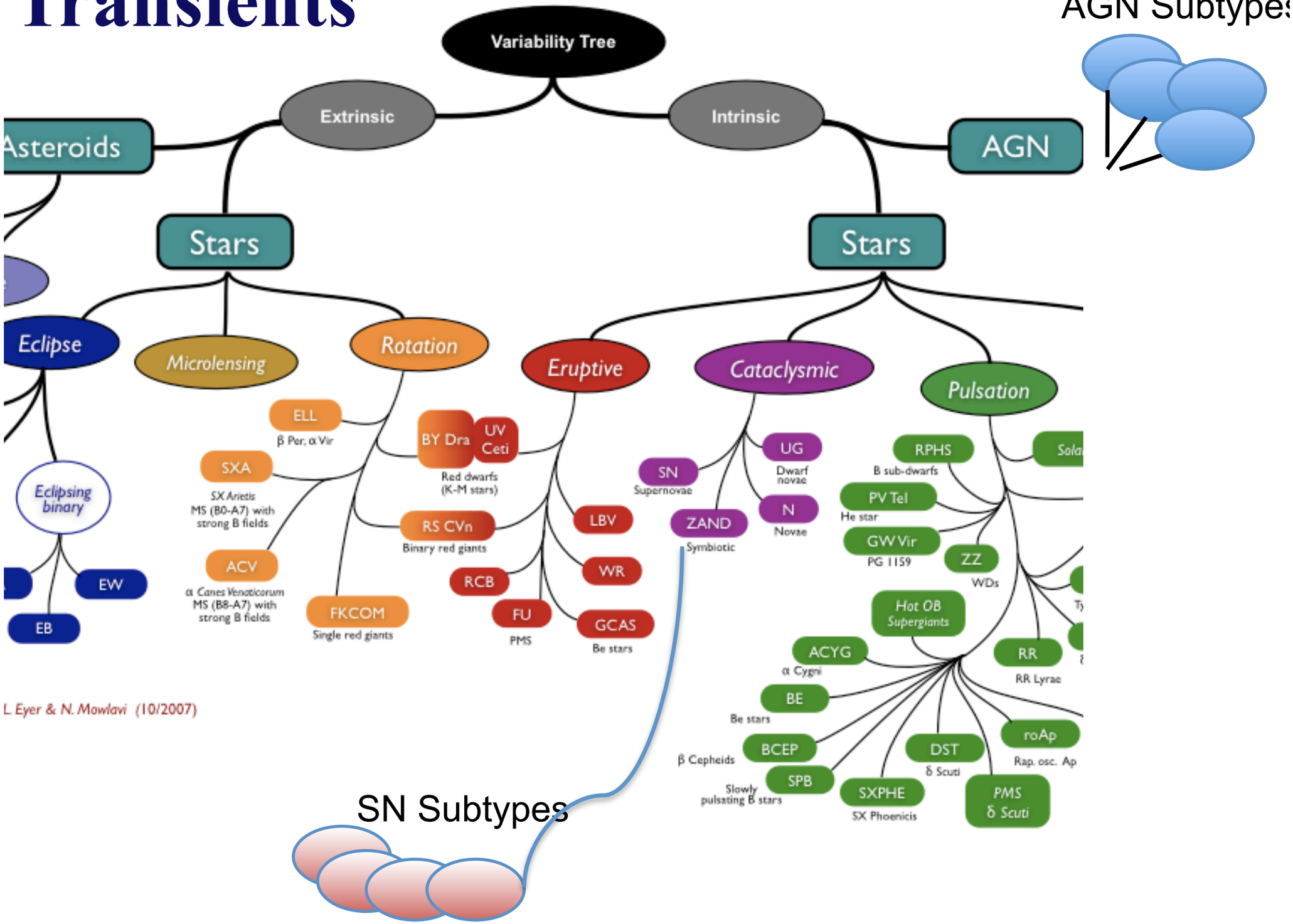
Optimization means compromise

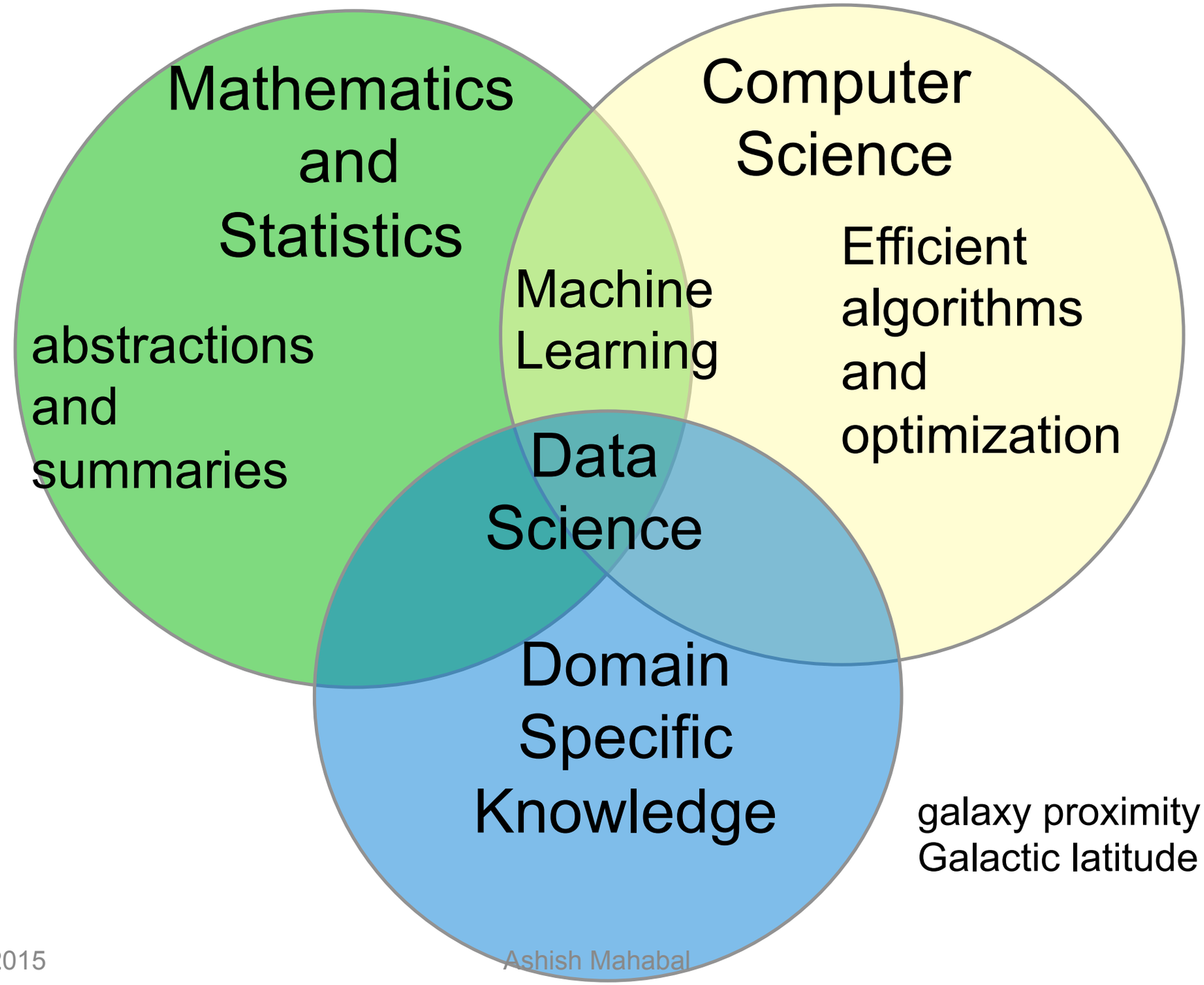
BUT, the sum of parts is GREATER than the whole i.e.
compromise does NOT mean sacrifice
In other words, the players are **NOT** playing AGAINST each other

It’s the best middle ground we are seeking

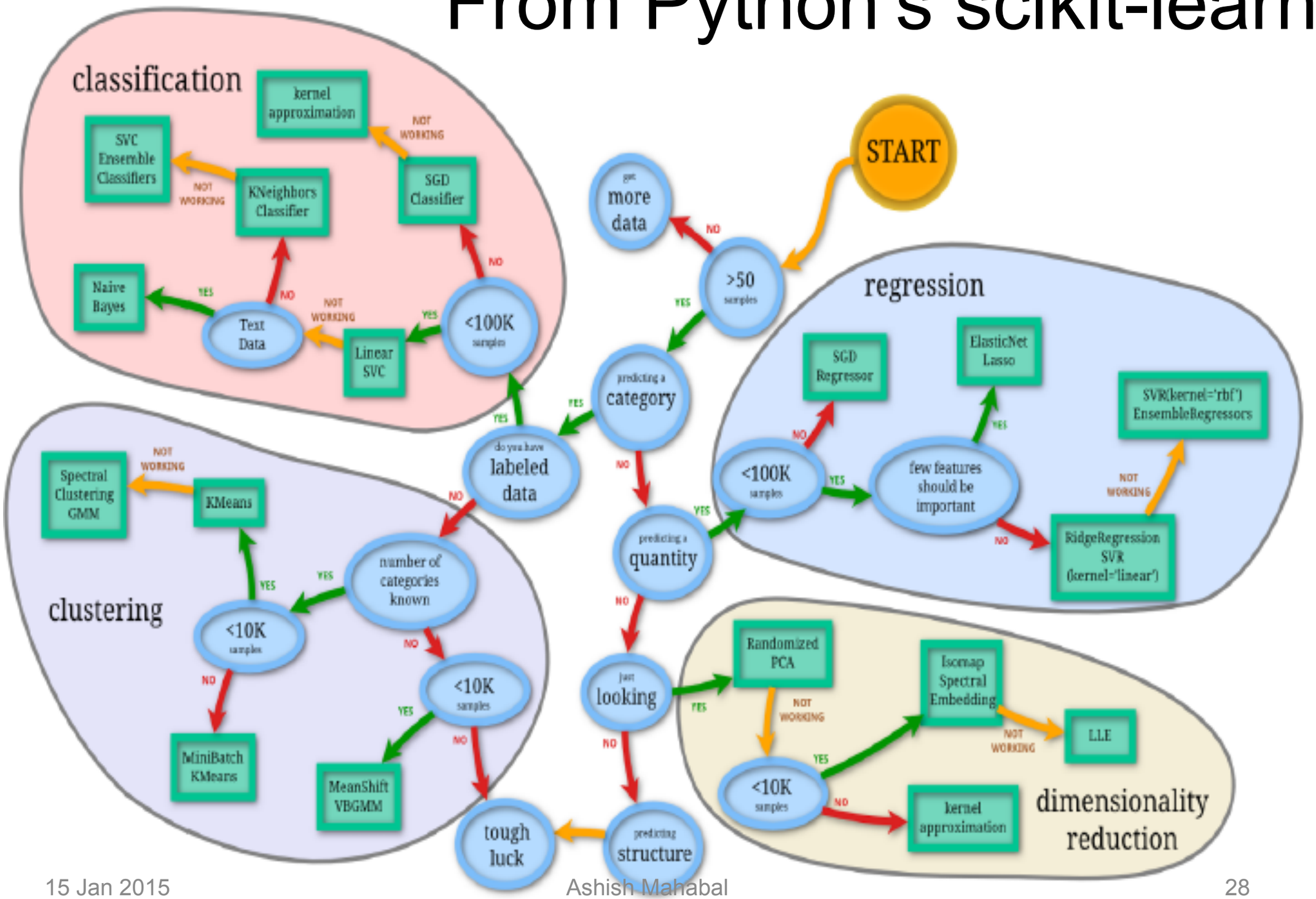
LSST is its own follow-up machine in a proactive way.
By coming up with a good cadence we can minimize the follow-up needed.
And you can help. And get the science you love done in the process.

Semantic Tree of Astronomical Variables and Transients




Mathematics and Statistics
abstractions and summaries
Computer Science
Efficient algorithms and optimization
Machine Learning
Data Science
Domain Specific Knowledge
galaxy proximity
Galactic latitude etc.

From Python's scikit-learn



Many features
- not all are independent

Adam Miller

flux_%_mid20
flux_%_mid35
flux_%_mid50
flux_%_mid65
flux_%_mid80

scatter_res_raw

fold_2p_slope_10%
fold_2p_slope_90%

medperc90_p2_p

p2p_scatter_pfold_over_mad

p2p_scatter_2praw

pair_slope_trend

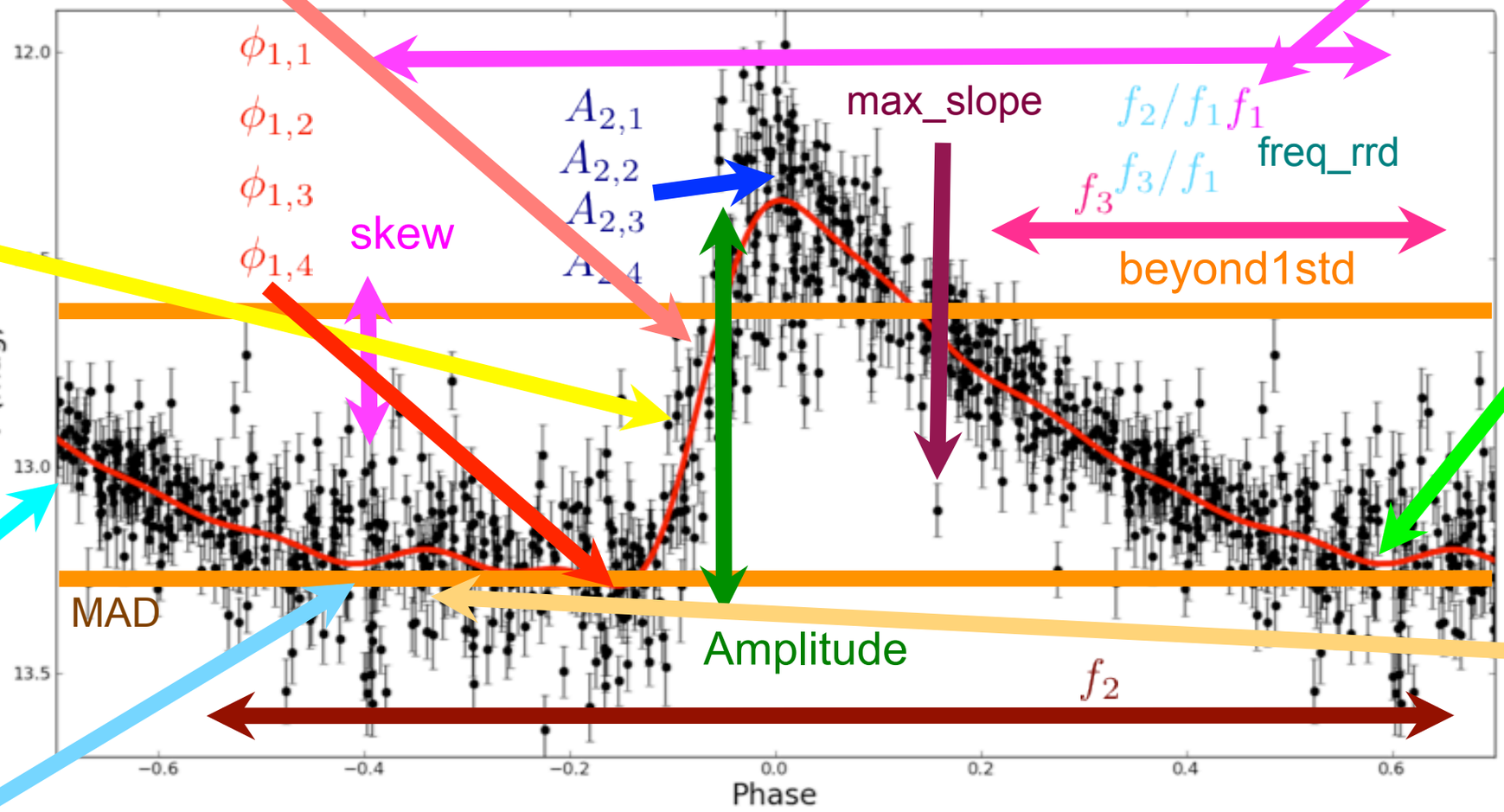
QSO
non_QSO

percent_difference_flux_percentile

freq_signif

freq_n_alias

freq_varrat



small_kurtosis

p2p_scatter_over_mad

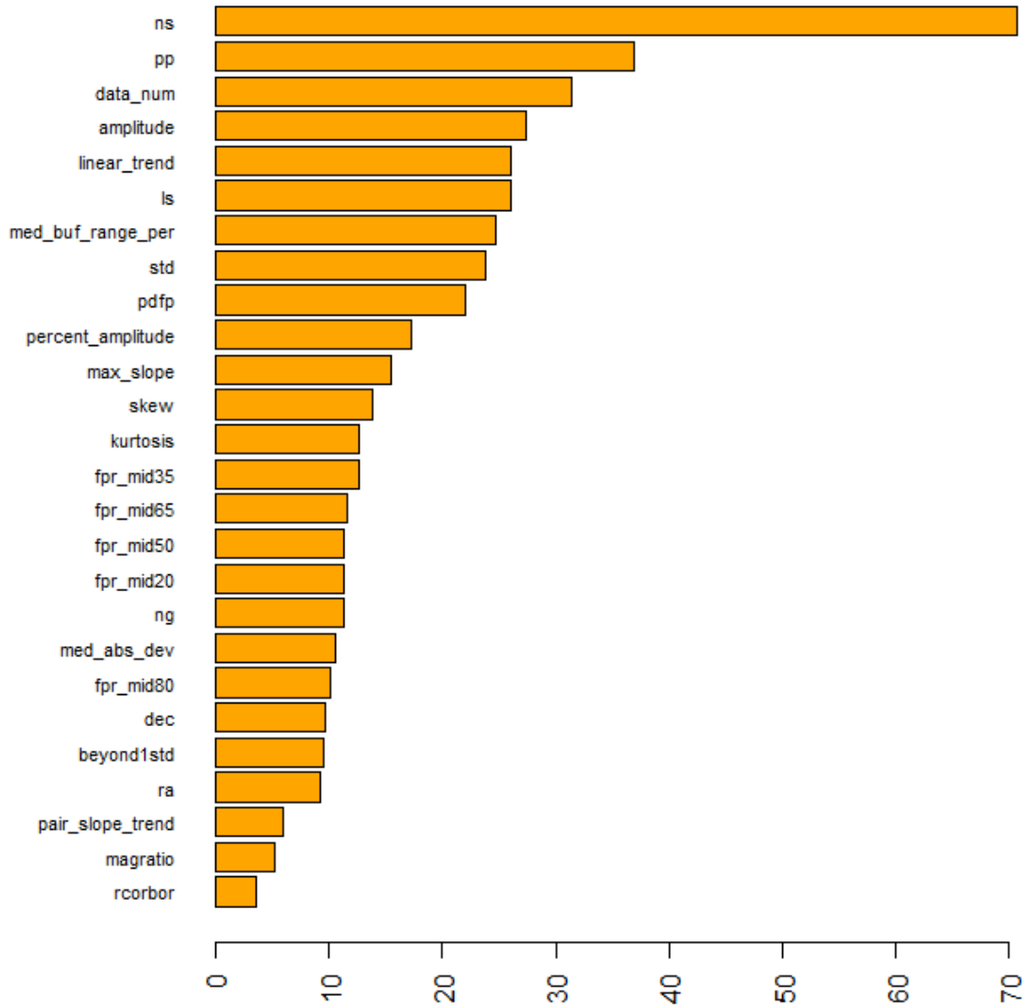
freq_model_min_delta_mag
freq_model_max_delta_mag
freq_model_phi1_phi2
p2p_ssqr_diff_over_var

percent_amplitude

linear_trend

median_buffer_range_percentage

Feature selection strategies



ief Algorithm (wt and
d)

iscriminant Ratio

on based Feature
n

relation Based Filter

ss Feature Selection

Donalek et al. arXiv:1310.1976

ZTF (2016): an order of magnitude faster than PTF.

	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Readout Time	36 sec	10 sec
Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**14.7x**
Relative Volumetric Survey Rate	1x	**12.3x**

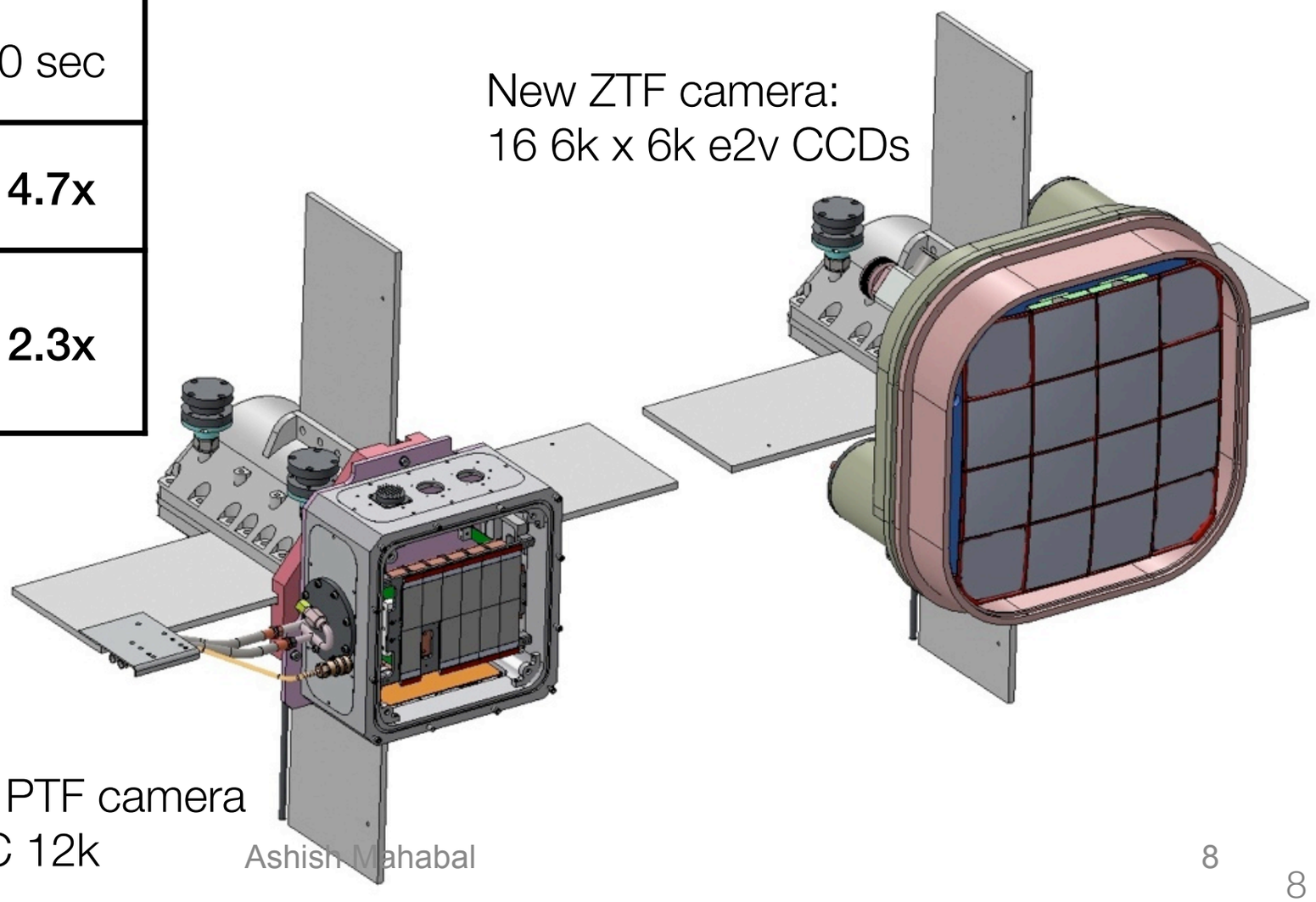
3800 deg^2/hour

⇒ 3π survey in 8 hours,

> 250 observations/field/year

Kulkarni/ Prince/Bellm/ Kasliwal

New ZTF camera:
16 6k x 6k e2v CCDs



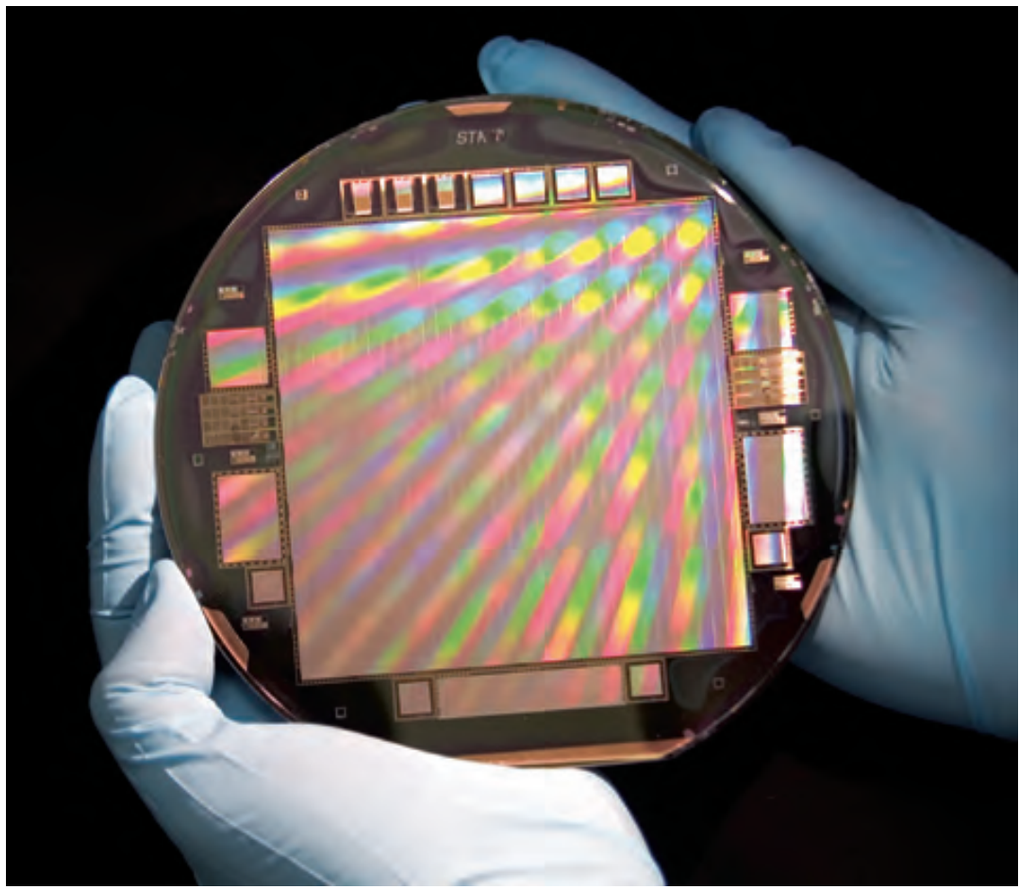
Existing PTF camera
MOSAIC 12k

CRTS-II

- Same telescopes
- Bigger cameras and FOVs:

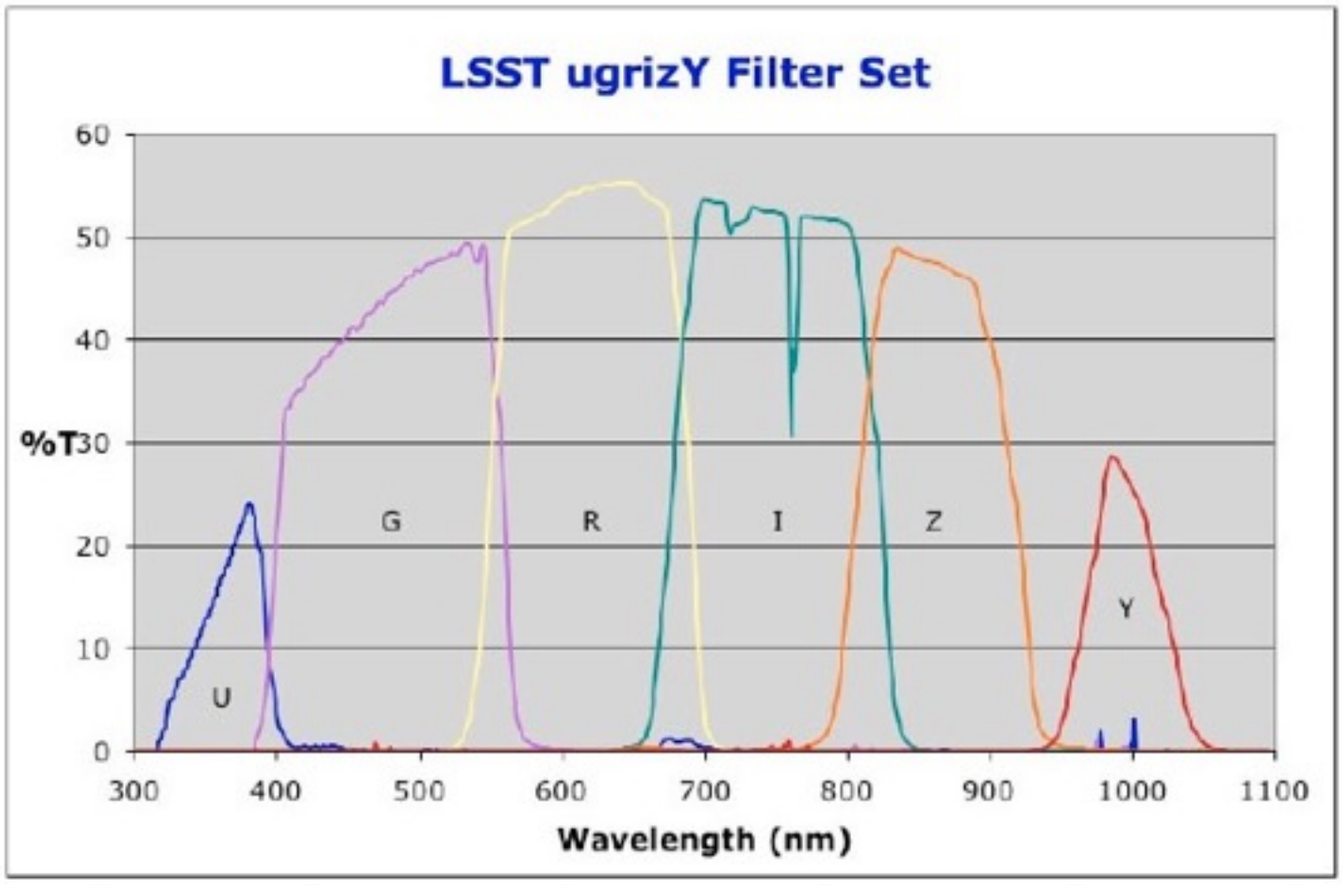
MLS 1.5m, 1.2 -> **5 sq. deg**

CSS 0.7m, 8.2 -> **19 sq. deg**



Upgrades funded and underway.

Probing faint transients & variables



	u	*g*	*r*	*i*	*z*	*y*
Single	*23.9*	*25.0*	*24.7*	*24.0*	*23.3*	*22.1*
Stacked	*26.3*	*27.5*	*27.7*	*27.0*	*26.2*	*24.9*

~0.01 mag precision photometry

Enter TMT

- What fraction of time will be ToO?
- Capabilities of the instruments …
- Demands of observers (only bright transients?)
- LSST/(A-)LIGO/other fractions?
- All object types (that can be done only by TMT) are fair game [Paula Szkody's talk on specific types]