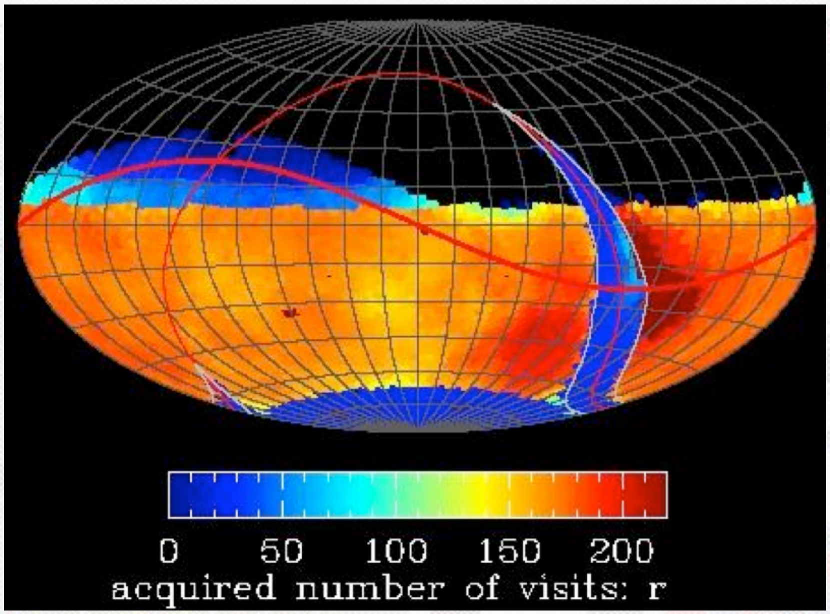
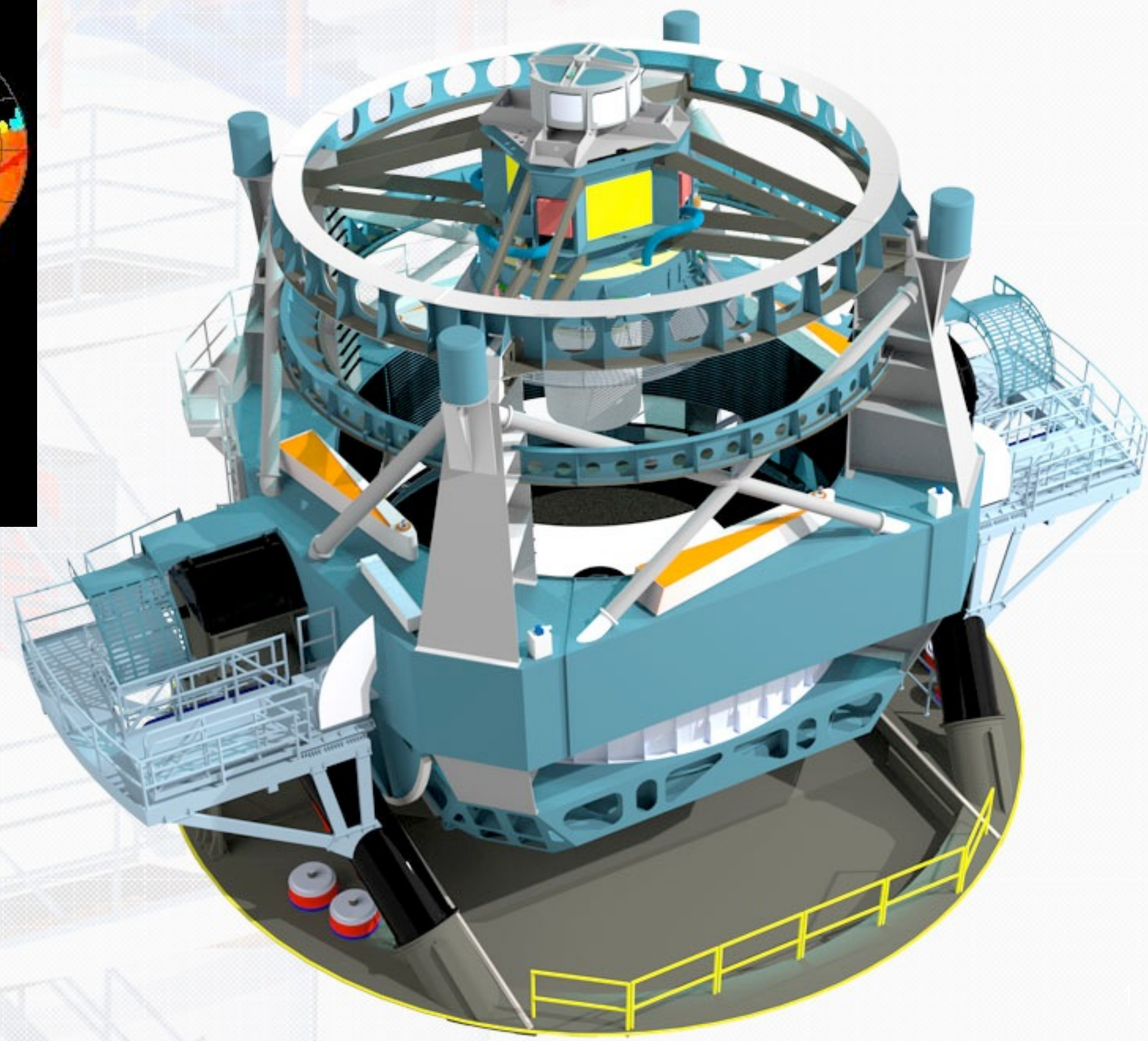
Overview of the LSST Observing Strategy

Željko Ivezić and the LSST Simulations Team

LSST SAC Meeting

Tucson, Nov 16, 2015





Outline

1) Brief overview of tools for simulating LSST surveys: OpSim & MAF

2) Why is survey optimization a hard problem: hierarchy of survey complexity

3) What can and cannot be done? Cadence "conservation laws"

4) Examples of cadence optimization and future optimization directions.

5) The role of the SAC (and community) in advising the Project on cadence-related decisions

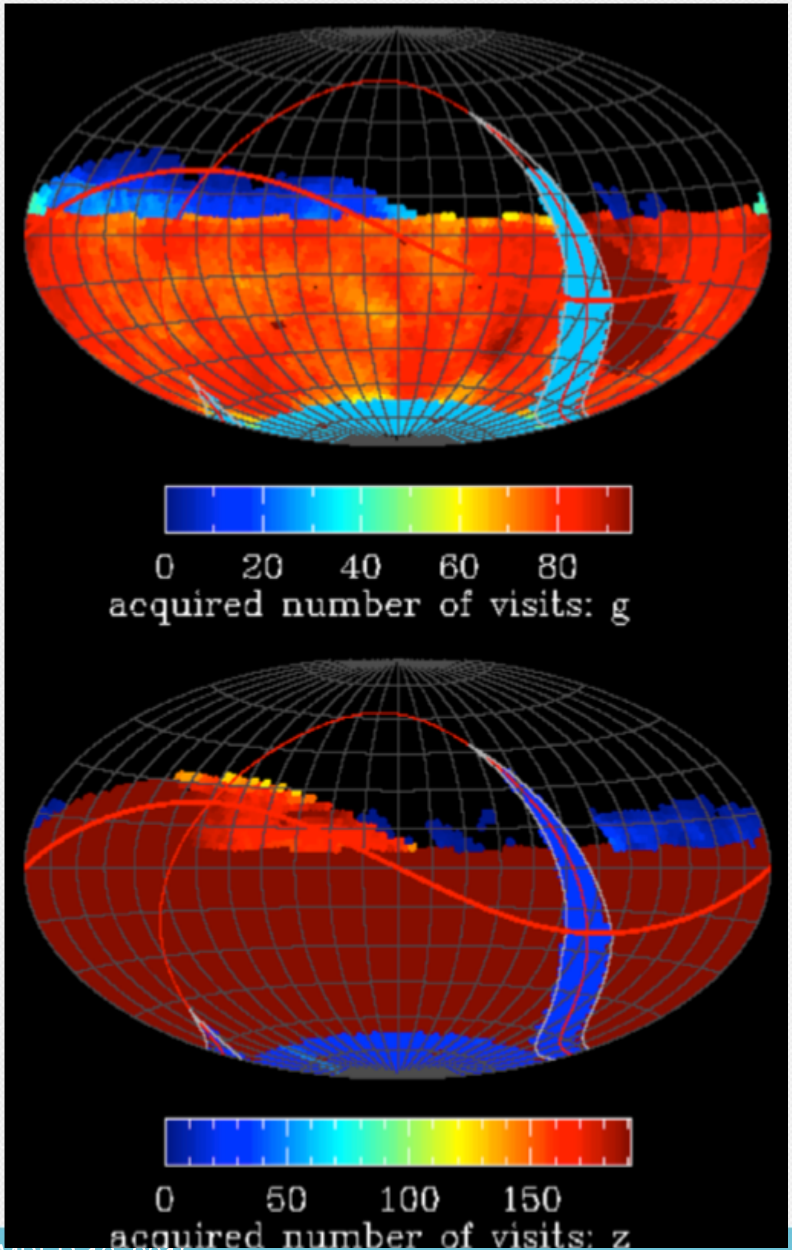
Operations simulations (OpSim & MAF)

Constraints are provided by the astrophysical properties of the site (e.g. sky background), engineering models (e.g. settle time) and science requirements.

Operations simulator generates sequences of LSST observations together with their properties (seeing, sky brightness, depth, filter). About 2.5 million visits over 10 years.

Metrics Analysis Framework calculates statistics about these simulated surveys and relates them to specific science questions (through metrics)

For more technical details about observing strategy, OpSim, MAF and cadence optimization, see talks by Connolly, Yoachim and Ivezic linked to http://ls.st/kaq



Flowdown of Science Goals to System Requirements

System

Atmosphere (transmission,refraction, seeing, sky background)

Telescope (collecting area, mirror reflectivity, slew and settle time, contribution to seeing, scattered light, FOV)

Camera (CCD QE curve, optical transmissions and reflections, charge diffusion, readout noise, crosstalk, filters)

Data processing (data throughput, algorithmic errors, speed, bugs)

Data Properties

Image Depth

Delivered Seeing

Number of images

Distributions with respect to time, bandpass and observing conditions

Key point:
Science goals and technical parameters are connected through, and communicate via, data properties

Science

Dark matter, dark energy, cosmology (spatial distribution of galaxies, gravitational lensing, supernovae)

Time domain (cosmic explosions, variable stars)

The Solar System structure (asteroids)

The Milky Way structure (stars, ISM)

SRD specifies data properties needed to achieve science goals

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OPSIM

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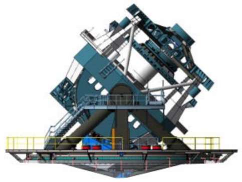
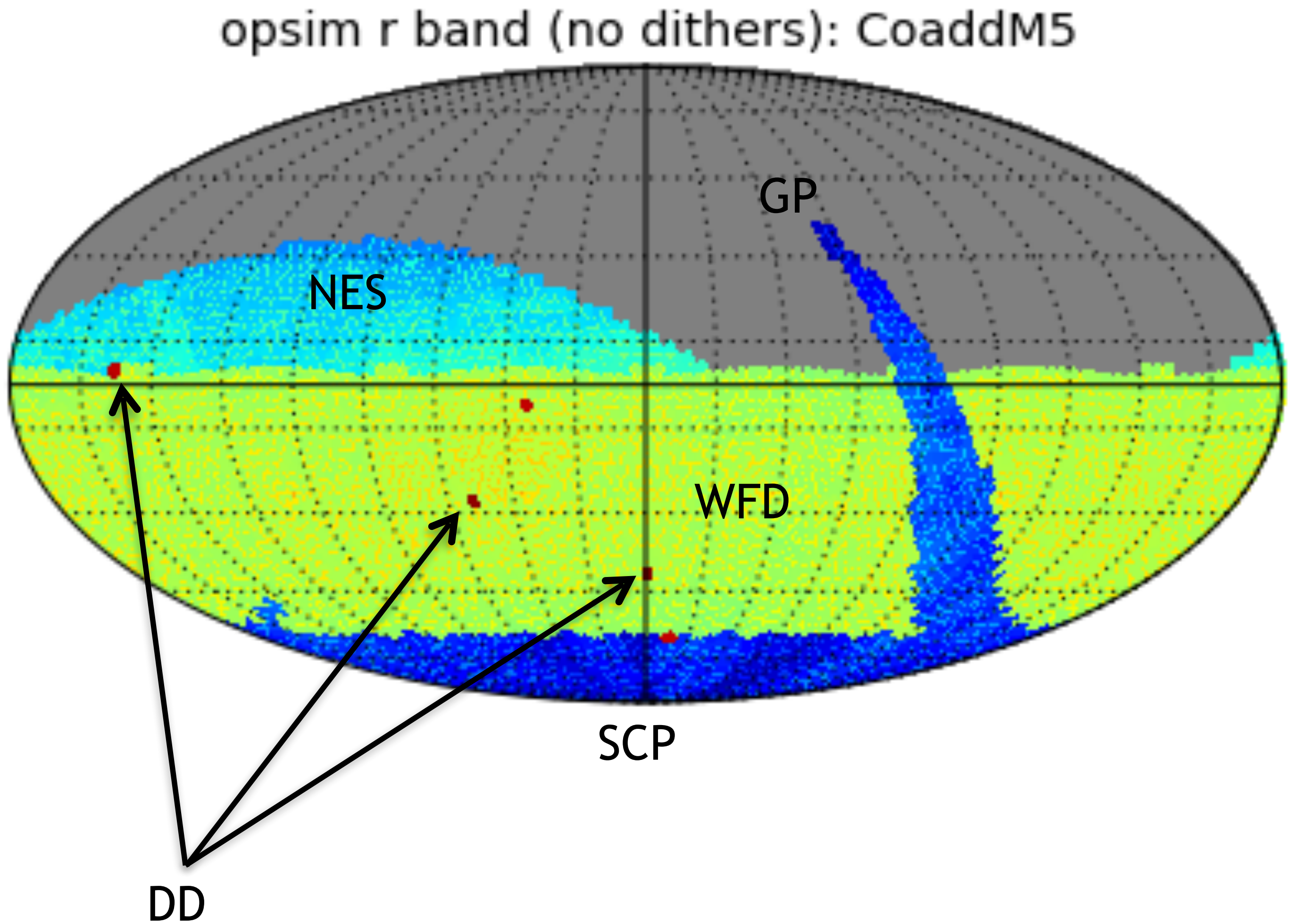


The Operations Simulator output

- What 2.5 million LSST visits might look like.
  - Pointings on the sky, filter, and their timestamp
  - Weather, cloud, sky brightness, seeing for the observation
  - Scheduled and unscheduled down time
  - A scheduler that balances several science goals
- OpSim scheduler based on "Proposals"
  - Wide-Fast-Deep ("the main survey"): 18,000 sq deg
  - North Ecliptic Spur: Solar system objects
  - Deep Drilling Fields: ~6 deep fields
  - Galactic Plane
  - South Celestial Pole

The Proposals



What's in OpSim Output

For each visit, Opsim records

RA,Dec
Filter
MJD
Night
visitTime
Seeing
Airmass
Skybightness
Rotation angle of the camera
LST
Alt,Az
Distance to moon
Distance to Sun
Moon position
Moon phase
5-sigma depth (so can calc SNR of an object)
Dithered RA,Dec
And more…

More documentation on OpSim Summary table here: http://ls.st/5d8

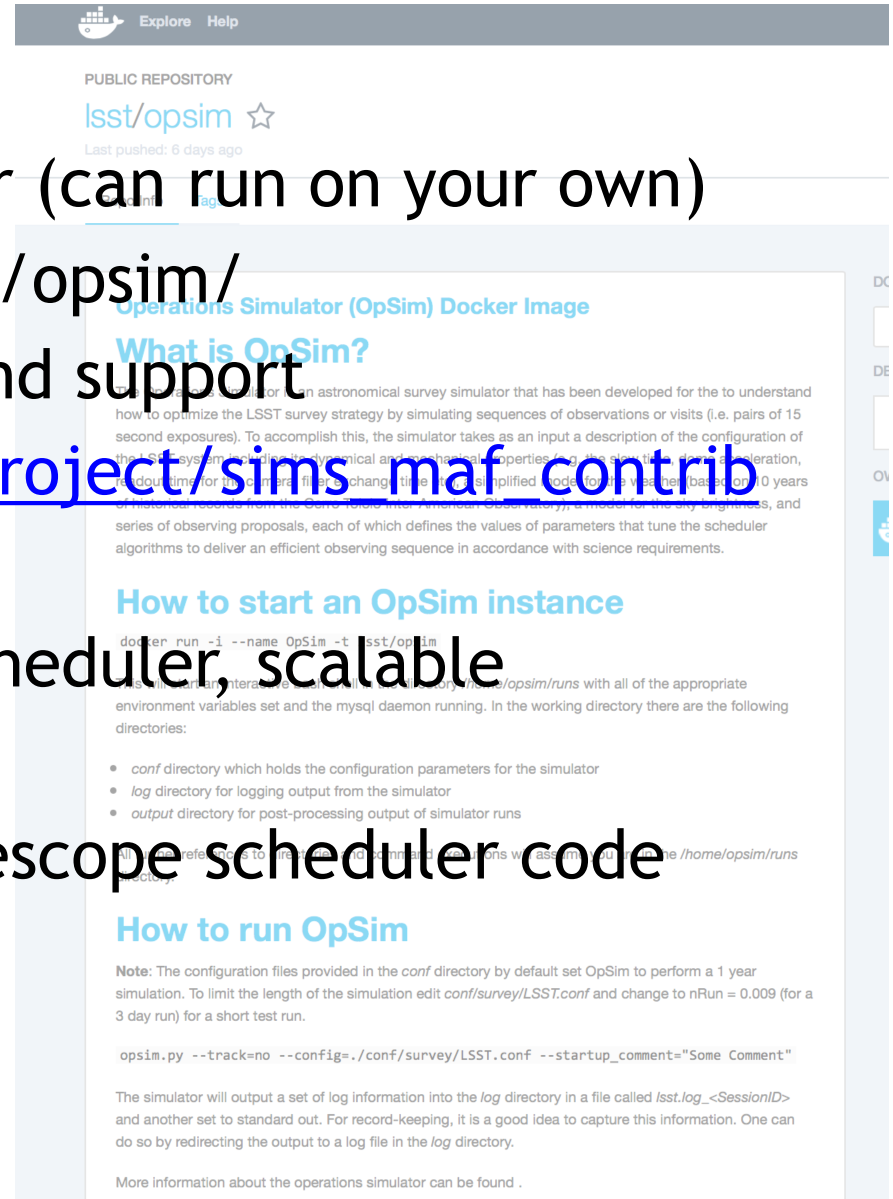
Surveys that exist

Setup	Simulation Name	Description of the Survey Setup
0	enigma_1189	Modern Version of the Baseline Cadence A candidate replacement simulation for the current Baseline Cadence (opsim3.61) produced with the latest version (v3.2.1) of the Operations Simulation (OpSim) code. The following adjustments have been made: includes Science Council approved Deep Drilling fields; Wide-Fast-Deep (WFD) design specification for areal coverage (18,000 deg) & WFD "boosted visits" = 75, 105, 240, 240, 210, 210 for u, g, r, i, z, & y filters where g, r, i and z visits are collected in pairs separated by about 30 minutes; includes revised scheduled downtime as well as random downtime; minAlt = 20 deg; MinDistance2Moon = 30 deg. Note that SRD design visits = 56, 80, 184, 184, 160, 160 for u, g, r, i, z, & y filters.
1	ops2_1098	Uniform cadence (WFD), which asks for visits in pairs, and no other proposal.
2	ops2_1093	Only uniform cadence (WFD), but does not require pairs of visits.
3	kraken_1033	As the baseline cadence (Setup 0), but does not require pairs of visits.
4	enigma_1271 enigma_1266	As the baseline cadence, but requests 3 visits per Wide-Fast-Deep field chosen instead of 2 visits, using the same window function for both 1-2 visits and 2-3 visits. As the baseline cadence, but requests 4 visits per Wide-Fast-Deep field.
5	kraken_1034	As the baseline cadence, except that the u-band exposure time is 60 sec instead of 30 sec.; Nvisit for the u-band remains the same.
6	kraken_1035	As the baseline cadence, except that the u-band exposure time is 60 sec instead of 30 sec;. Nvisit for the u-band is decreased by a factor of 2.
7	kraken_1036	As the baseline cadence, except for a shorter visit exposure time: 20 sec instead of 30 sec. Deep drilling proposal has visits based on 30sec exposure due to code issues.
8	kraken_1037	As the baseline cadence, except for a longer visit exposure time: 60 sec instead of 30 sec.
9	ops2_1092	Pan-STARRS-like Cadence This is the uniform cadence, and no other proposal, keeping pairs of visits, but increase the area to include everything with Dec <+15 deg (about 27,400 deg2), and keeping the default airmass limit of 1.5.
10	kraken_1038	As the baseline cadence, except for the more relaxed airmass limit of 2.0 instead of 1.5.
11	ops2_1096	As Setup1 (uniform cadence with no other proposal), except for the more relaxed airmass limit of 2.0 instead of 1.5.
12	ops2_1097	As Setup 1 (uniform cadence with no other proposal), except for the more stringent airmass limit of 1.3 instead of 1.5.

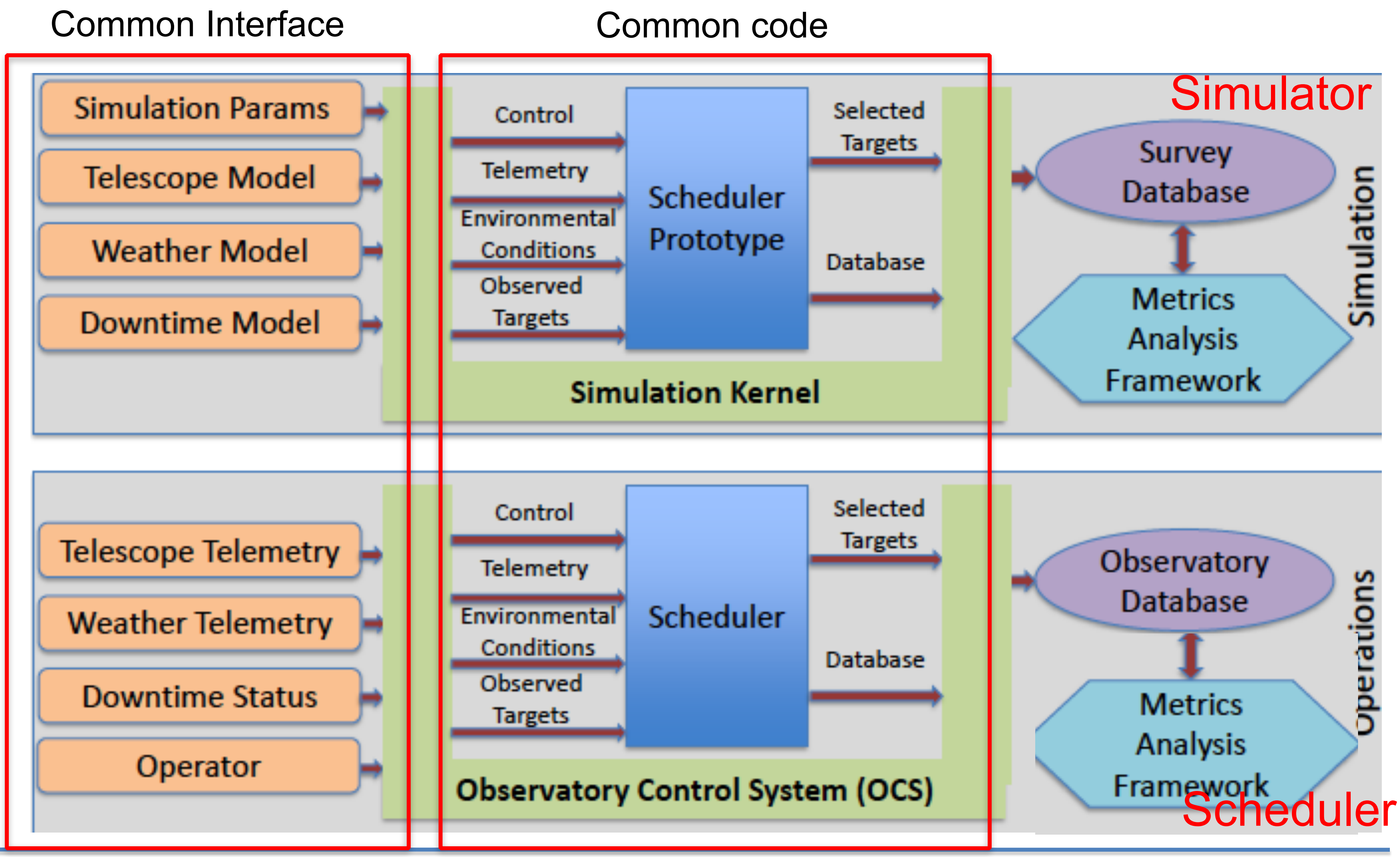
http://ls.st/p1r~

Status and future plans

- Release of OpSim
  - available as a Docker container (can run on your own)
  - https://hub.docker.com/r/lsst/opsim/
- Continued development of MAF and support
  - https://github.com/LSST-nonproject/sims_maf_contrib
- Development of v4
  - Modular, simulated OCS and scheduler, scalable
  - Initial delivery Aug 2016
  - This will eventually be the telescope scheduler code
  - Limited support for v3.3



Scheduler/simulator Interface



MAF Goals

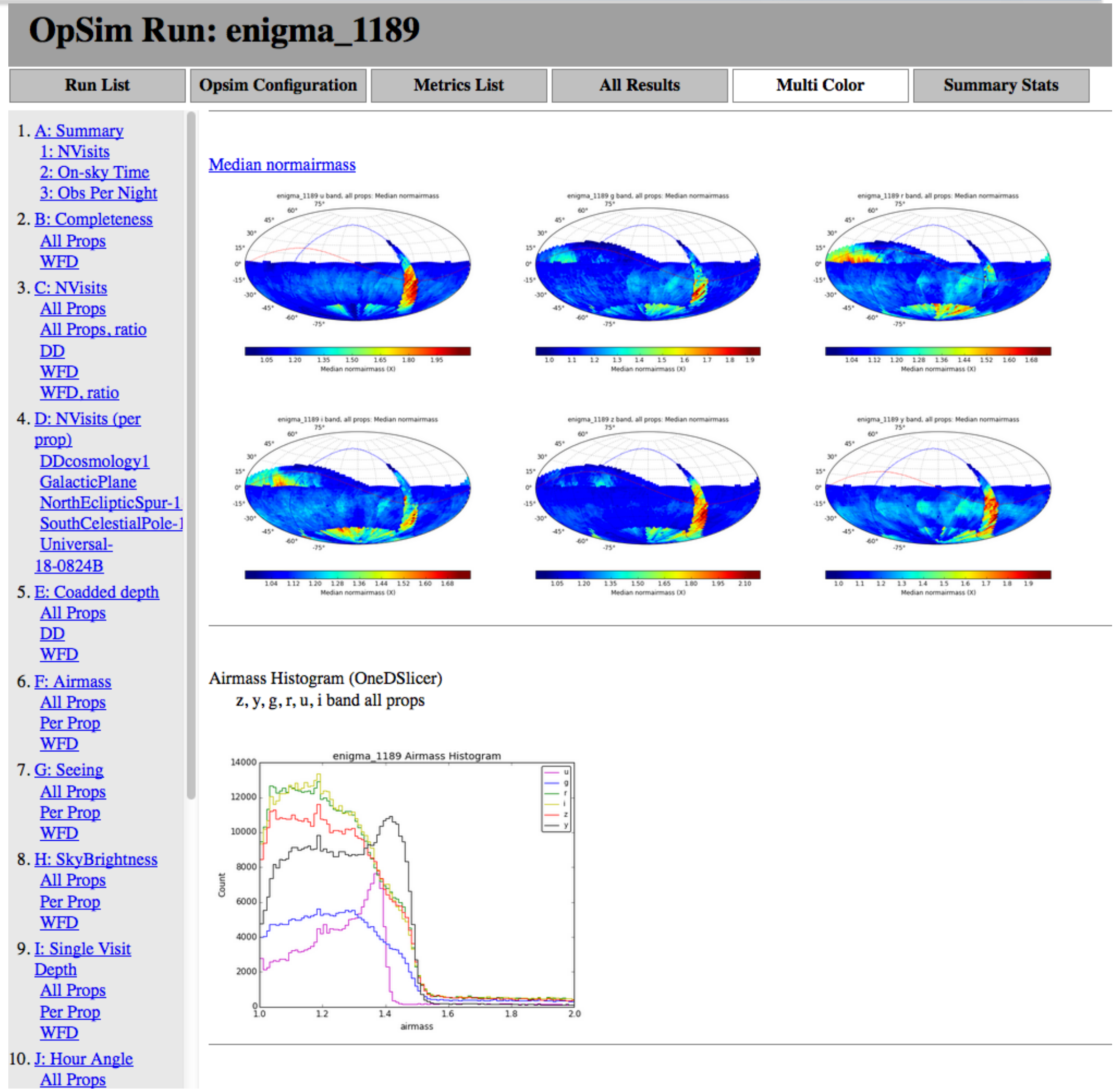
- The goal of the Metric Analysis Framework is to provide an easy way to visualize the properties of a survey and quantify the science that can be done with that survey
- Able to run in an automated fashion so we can compare large numbers of simulated surveys (python)
- Easily extended so users can contribute their own analysis—we want Science Collaborations to communicate the best way to measure a survey's performance from their viewpoint

How do we quantify how well a survey performs?

- Some things we commonly ask
  - What’s the median seeing of all the visits?
  - How many exposures do we get per night?
  - What’s the co-added depth of a deep drilling field?
  - What’s the average co-added depth at the end of the survey?

Scheduler Validation

- Checks things like number of visits, airmass distribution, coadded depth.
- MAF includes a semi-intelligent web display (u,g,r,i,z,y order, etc)



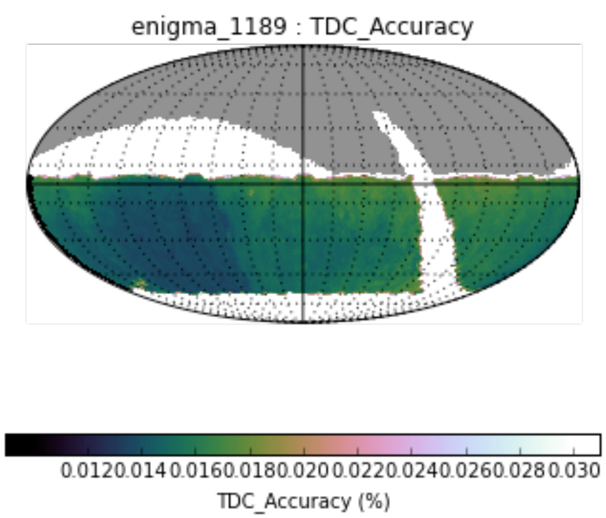
Time Delay Metric

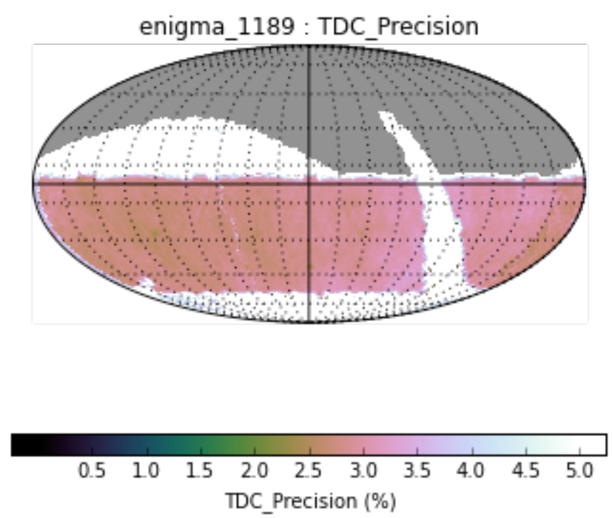
– Strong lens time delay, accuracy, precision and success fraction

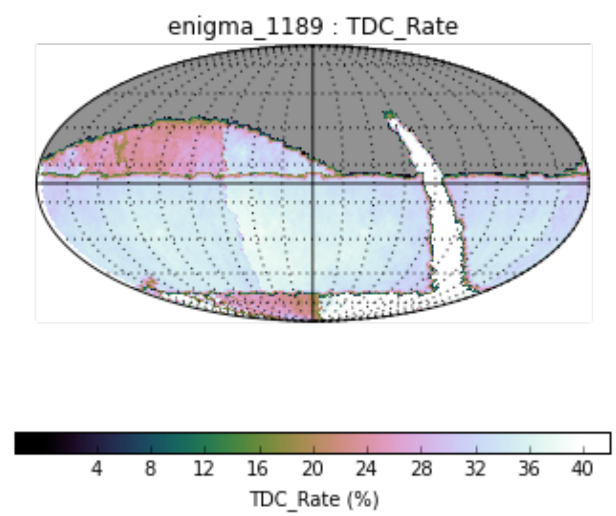
$$|A|_{\rm model} \approx 0.06\% \left(\frac{\rm cad}{\rm 3days}\right)^{0.0} \left(\frac{\rm sea}{\rm 4months}\right)^{-1.0} \left(\frac{\rm camp}{\rm 5years}\right)^{-1.1}$$

$$P_{\rm model} \approx 4.0\% \left(\frac{\rm cad}{\rm 3days}\right)^{0.7} \left(\frac{\rm sea}{\rm 4months}\right)^{-0.3} \left(\frac{\rm camp}{\rm 5years}\right)^{-0.6}$$

$$f_{\rm model} \approx 30\% \left(\frac{\rm cad}{\rm 3days}\right)^{-0.4} \left(\frac{\rm sea}{\rm 4months}\right)^{0.8} \left(\frac{\rm camp}{\rm 5years}\right)^{-0.2}$$







Metric contributed by Phil Marshall

2. Why is survey optimization a hard problem?
Hierarchy of survey complexity:

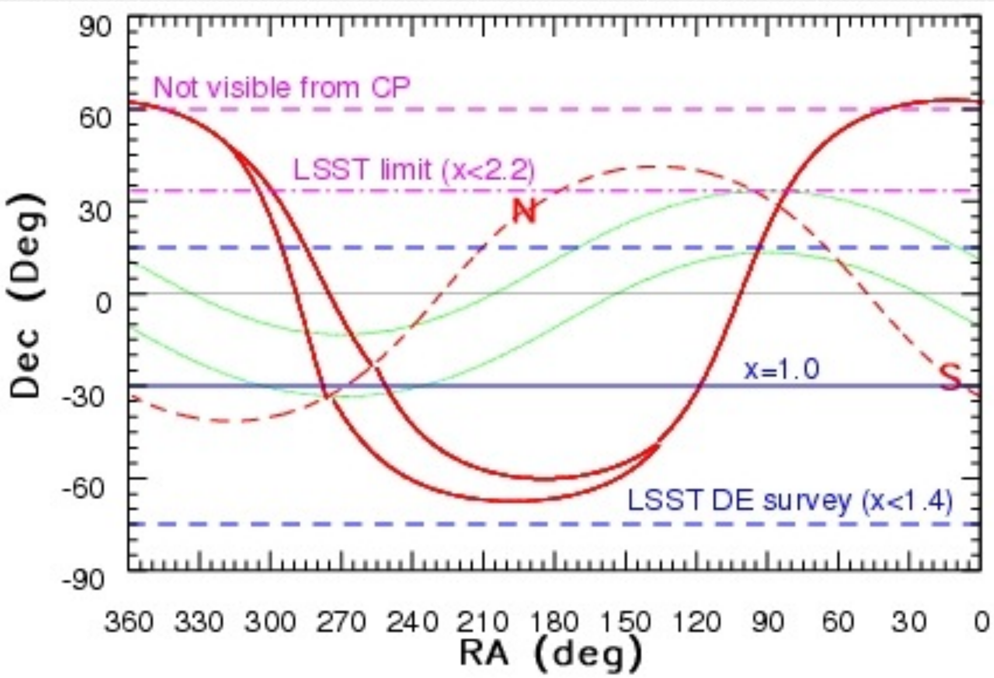
1) single band, single program, static science

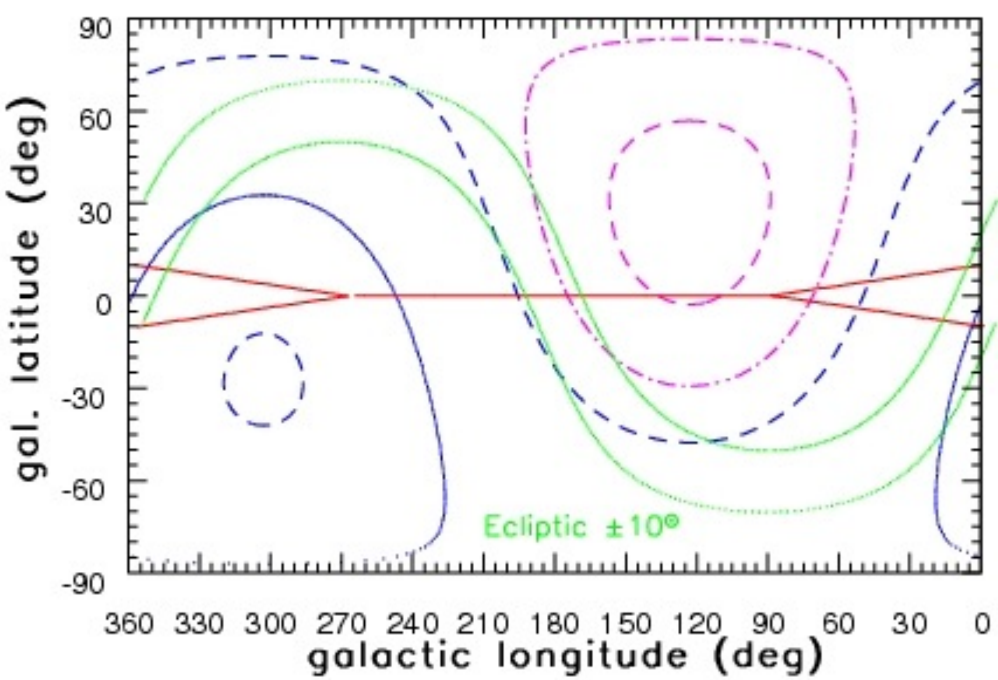
Goal: maximize the number of detected sources, e.g. galaxies.

Unless looking at unusual populations (e.g. low-redshift quasars), it is always advantageous to first maximize the sky area and *then* depth.

Detailed optimization takes into account airmass effects and Galactic plane: about 18,000-20,000 sq.deg. of sky

(NB this is about the main survey - deep drilling fields and other "special" regions are "different")





Sky coverage:

for the main survey, maximize the number of objects (area vs. airmass tradeoff)

X<1.4 corresponds to

–75° < Dec < +15°

(25,262 sq. deg.)

X=2.2 corresponds to Dec < +33°, but note that the telescope can reach Dec = +40° (X=2.9)

2. Hierarchy of survey complexity:

1) single band, single program, static science

2) **...but need multi-bandpass data: ugrizy**

Goal: apportion time per band so that there is no dominant bad band for photometric redshifts of galaxies (it turns out it's ok for stars too)

- **Photometric redshifts:** random errors smaller than 0.02, bias below 0.003, fewer than 10% >3σ outliers
- These photo-z requirements are one of the primary drivers for the photometric depth and accuracy of the main LSST survey (and the definition of filter complement)

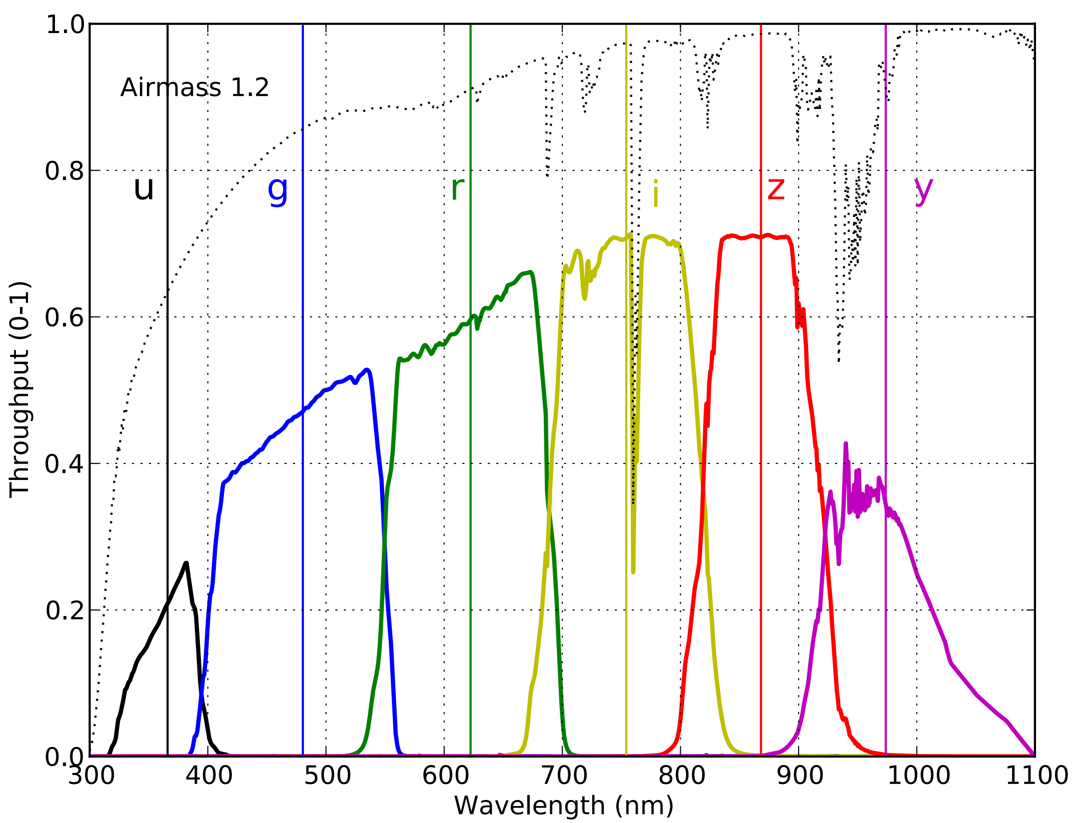


Photo-z requirements correspond to r~27.5 with the following per band time allocations:

u: 8%; g: 10%

r: 22%; i: 22%

z: 19%; y: 19%

Consistent with other science themes (stars)

2. Hierarchy of survey complexity:

1) single band, single program, static science
2) need multi-bandpass data: ugrizy

3) **time domain (temporal sampling function)**

Asteroids: (still) believing that two visits per night, about an hour apart, are needed to “connect the dots”.

The simplest strategy: roughly uniform coverage, addresses range of time scales, from diurnal to secular changes

However: if the sampling doesn’t meet the science-driven threshold, then it’s better to cover a smaller active sky area more frequently (e.g. supernovae) - "rolling cadence”

2. Hierarchy of survey complexity:

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

4) **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)

2. Hierarchy of survey complexity:

1) single band, single program, static science
2) need multi-bandpass data: ugrizy
3) time domain
4) not all sky regions were created equal!

5) **evolution over time**

- algorithm optimization, evolving science goals, possibly system performance changes

6) **systematics**

- field-of-view position (rotator angle), parallax factor, dithering, etc.

3. What can and cannot be done?
Cadence "conservation laws"

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

(assume that the sky area is about 20,000 sq. deg. - we will see why in a few slides)

VISIT: two back-to-back exposures of the same field, separated by a readout (2 seconds); **baseline: 2x15 sec**

3. Cadence "conservation laws"

How can we optimize the main deployment parameters:
exposure time per visit, t_{vis}, single-visit depth, m_5, the mean revisit time, $n_{revisit}$, 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):

$$m_5 = 24.7 + 1.25 * \log(t_{vis} / 30 \text{ sec})$$

$$n_{revisit} = 3 \text{ days} * (t_{vis} / 30 \text{ sec})$$

$$N_{vis} = 1000 * (30 \text{ sec} / t_{vis}) * (T / 10 \text{ years})$$

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

3. Cadence "conservation laws"

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Direct and indirect constraints on the shortest and longest acceptable exposure time per visit span **a remarkably narrow range:**

20 sec < t_{vis} < 40 sec for the main survey **t_{vis} = 30 sec as default**

(see section 2.2.2 in the "overview" paper, arXiv:0805.2366)

3. Cadence “conservation laws”

Constraints on exposure time per visit (20-40 sec):

Lower limit:

surveying efficiency must be high enough

(readout time, slew & settle time)

depth per visit must be deep enough

(SNe, RR Lyrae, NEOs)

Upper limit:

the mean revisit time cannot be too long

(SNe, NEOs)

the number of visits must be large enough

(light curves, systematics, proper motions)

(trailing losses for moving objects)

There is no fundamental reason why t_{vis} should be exactly the same for all visits (i.e. filters, programs, during the survey)!

3. Cadence "conservation laws"

CONCLUSION:

Direct and indirect constraints on the shortest and longest acceptable exposure time per visit span **a remarkably narrow range:**

20 sec < t_{vis} < 40 sec for the main survey **t_{vis} = 30 sec as default**

However, there are reasons to depart from t_{exp} = 15 sec, more later…

4. Examples of cadence optimization and future optimization directions.

Maximize the number of objects (area vs. airmass)

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

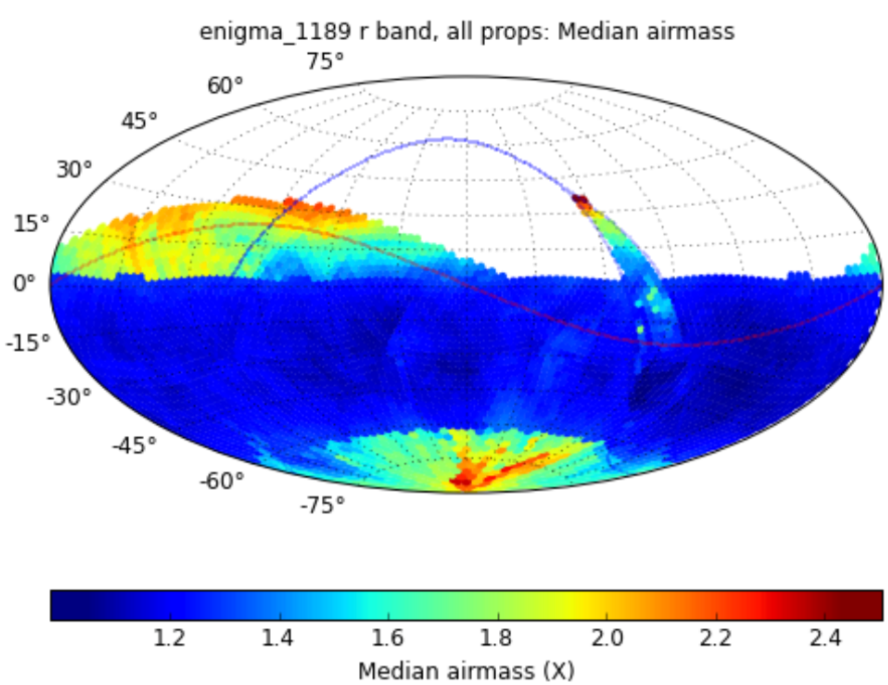
From photo-z

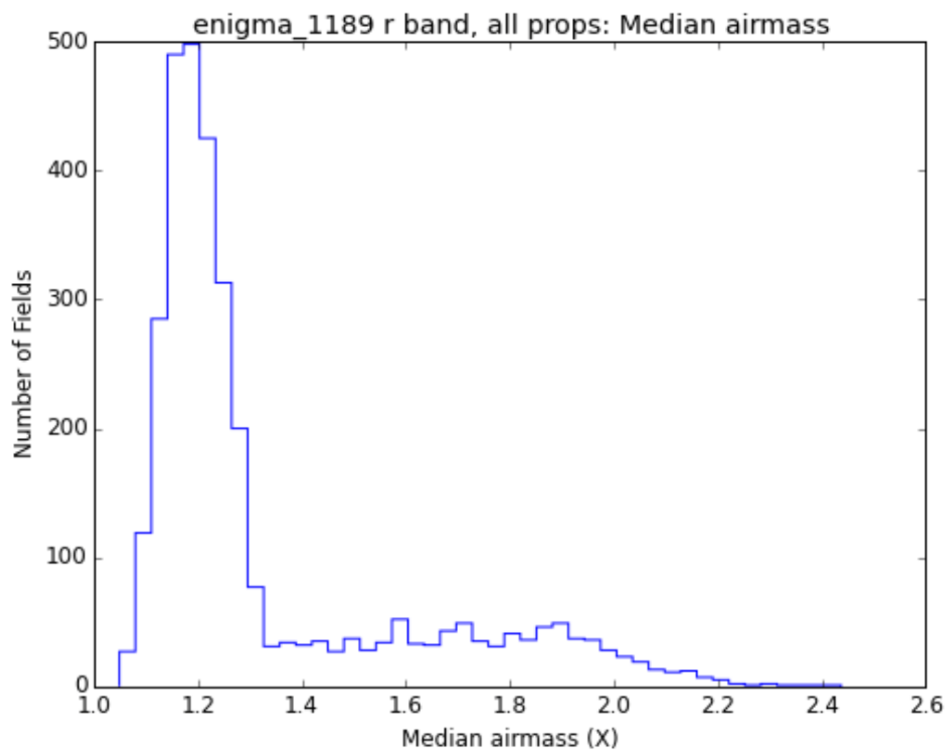
Valid for baseline cadence: t_{vis}=30 s

Candidate new Baseline (enigma_1189)

Basic characteristics:

- the total number of visits is 2.47 million, with 85.4% spent on the Universal proposal (the main deep- wide-fast survey), 6.4% on the North Ecliptic proposal, 1.7% on the Galactic plane proposal, 2.1% on the South Celestial pole proposal, and 4.5% on the Deep Drilling proposal (5 fields)





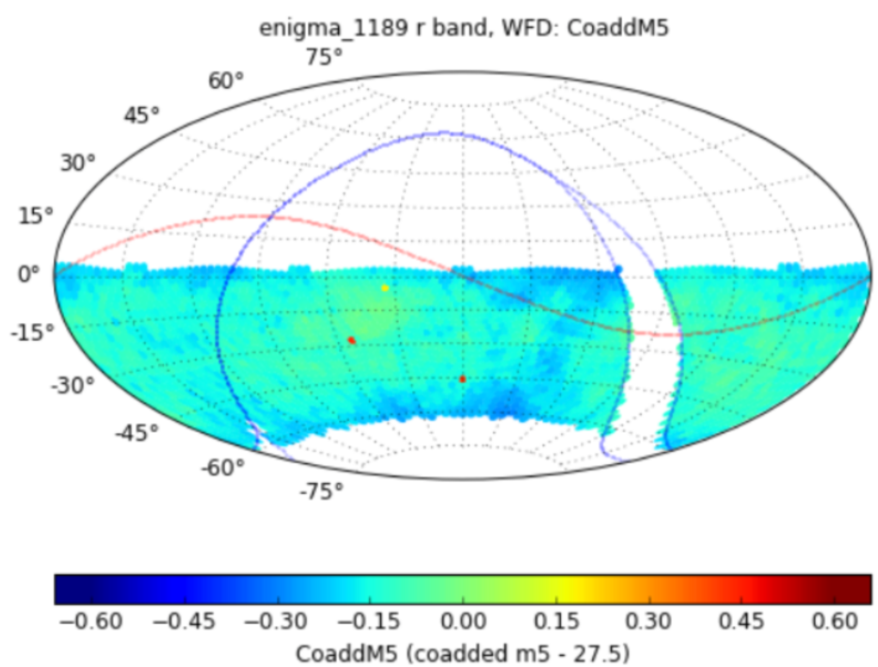
Candidate new Baseline (enigma_1189)

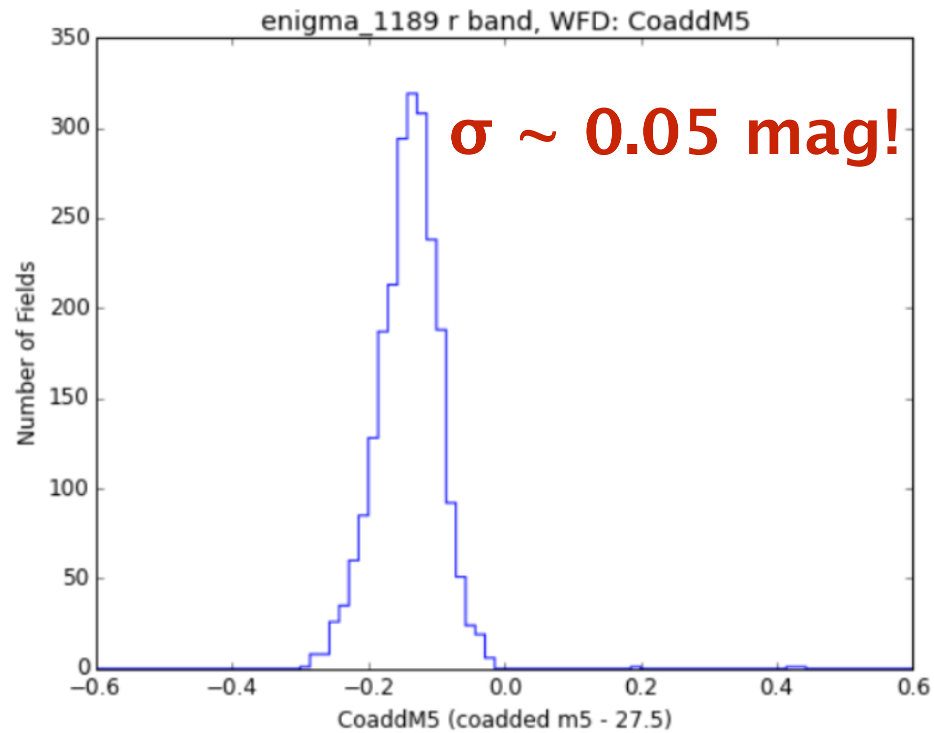
Basic characteristics:

- the distribution of coadded depth across the sky is fairly **uniform** (26.1, 27.3, 27.4, 26.7, 25.4, 24.4 in ugrizy)

r band coadded depth (dithered):

CoaddM5 OpsimFieldSlicer r band, WFD npz JSON



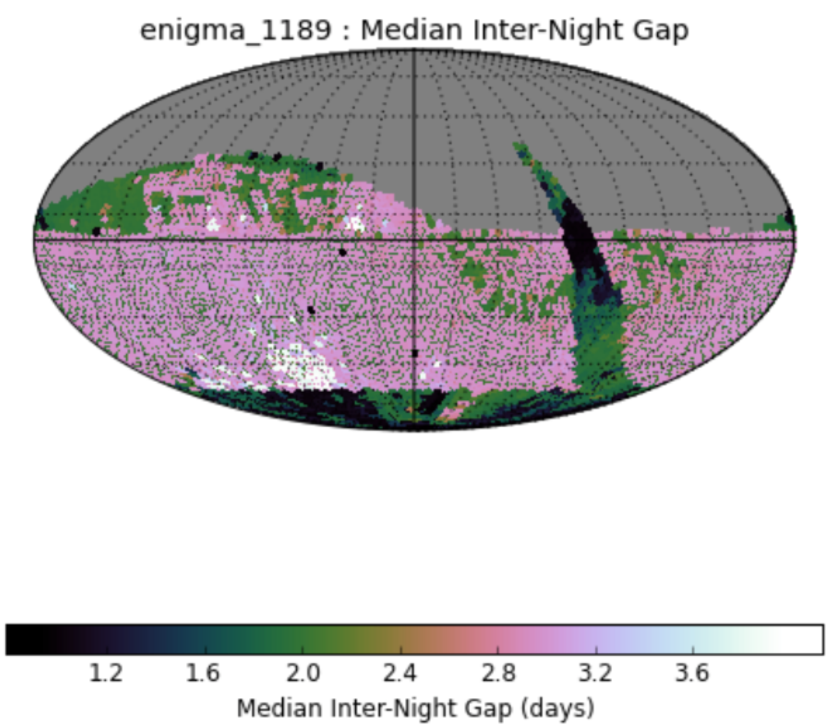


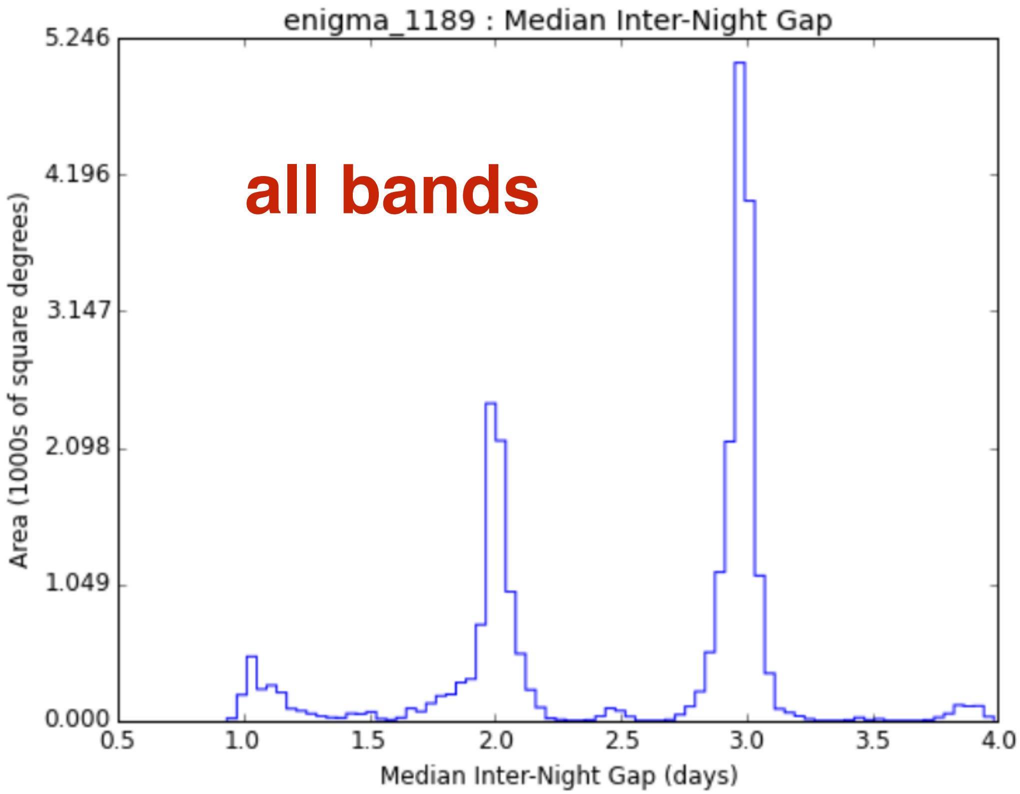
Candidate new Baseline (enigma_1189)

Time domain: the median intra-night gap: 20-30 min

Time domain: the median inter-night gap (revisit time)

On average, fields in the main survey are revisited every 3 days (all bands together):

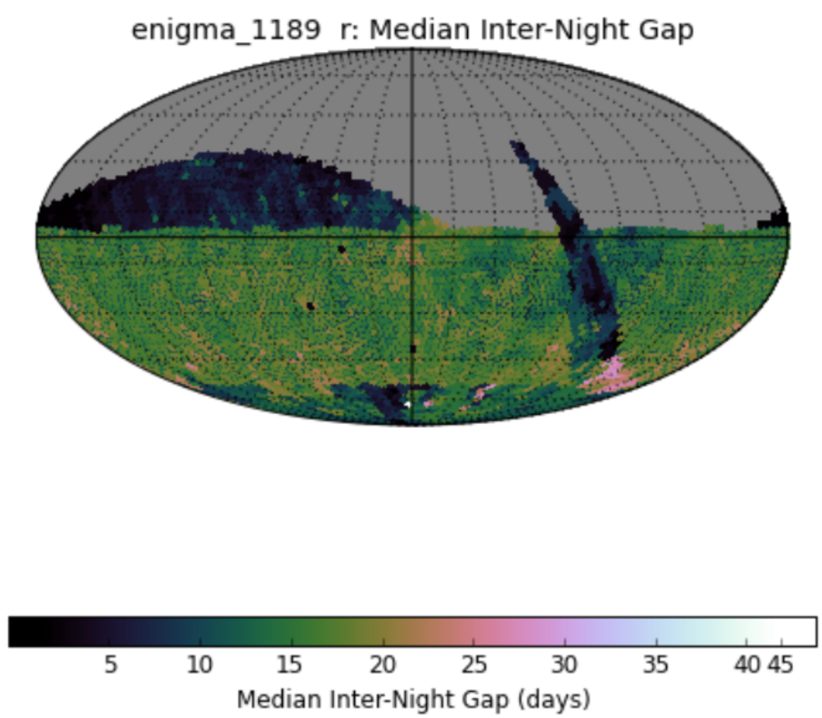


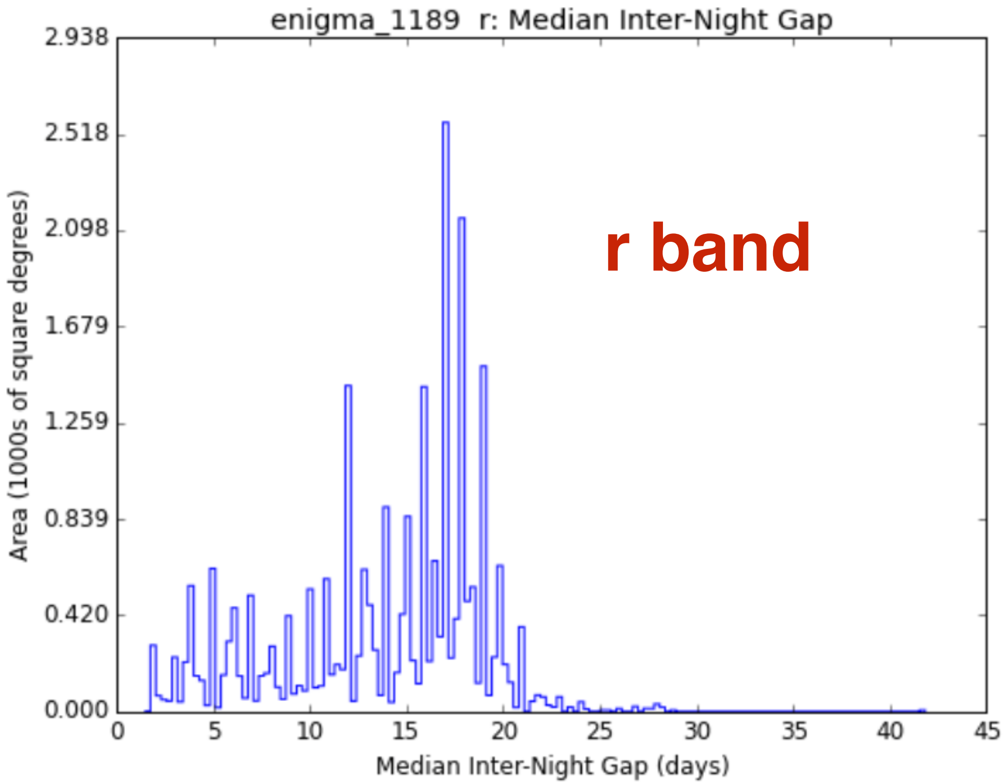


Candidate new Baseline (enigma_1189)

Time domain: the median inter-night gap (revisit time)

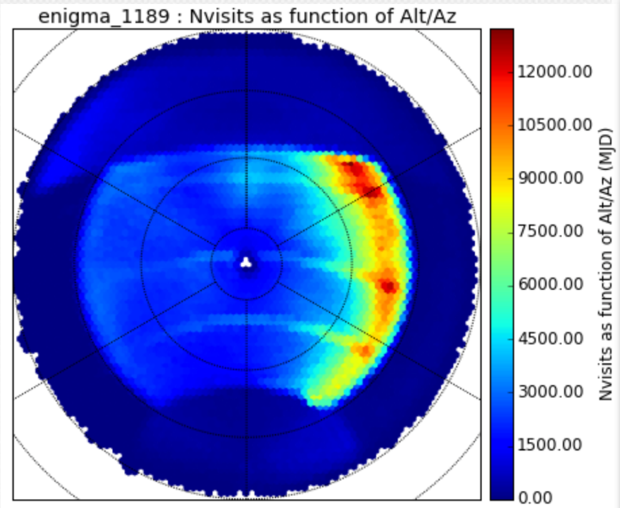
On average, fields in the main survey are revisited every 15 days in r band (most other bands similar, 30 days for u band)



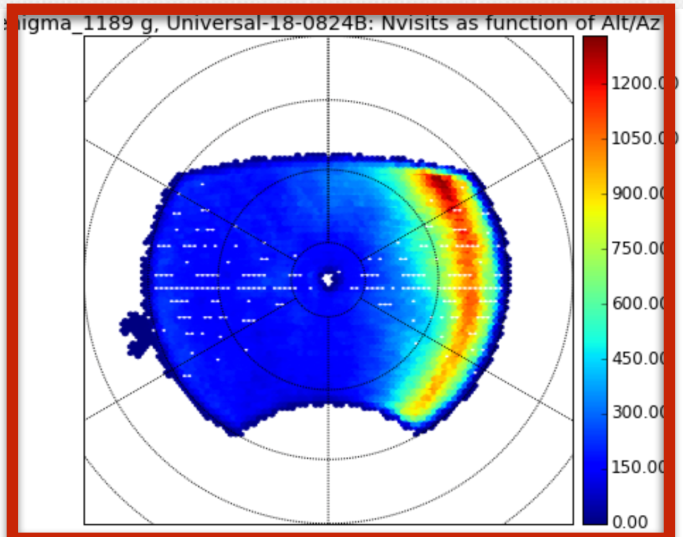


Candidate new Baseline (enigma_1189)

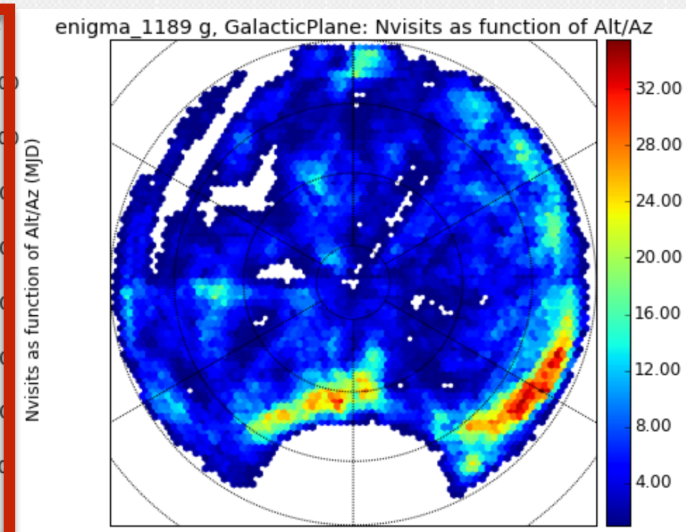
The main current problem: “the western bias”, Alt-Az



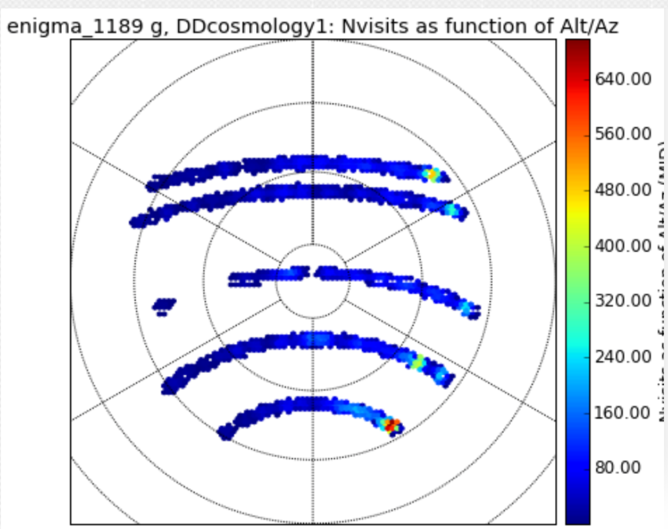
All data, g band



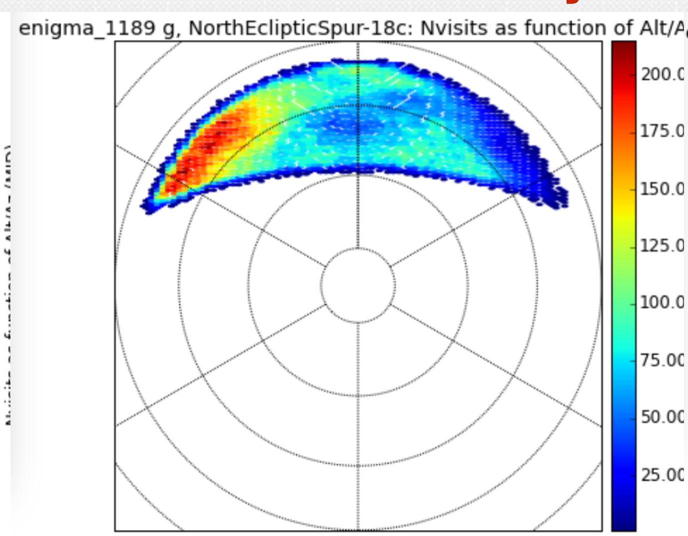
the main survey



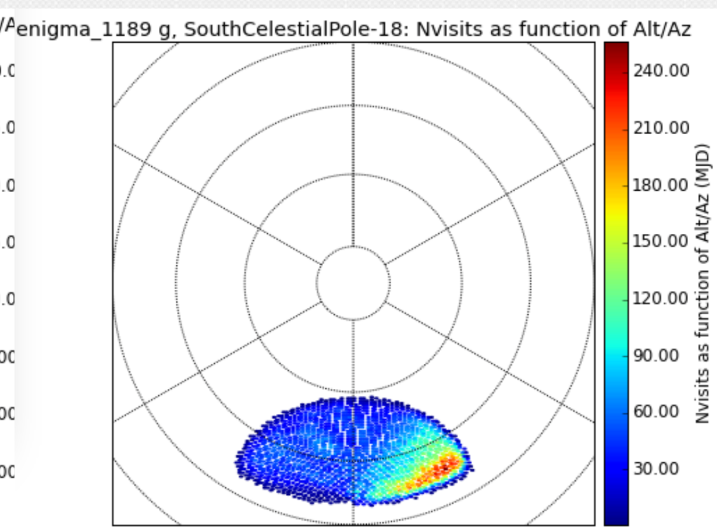
Galactic Plane



Deep drilling

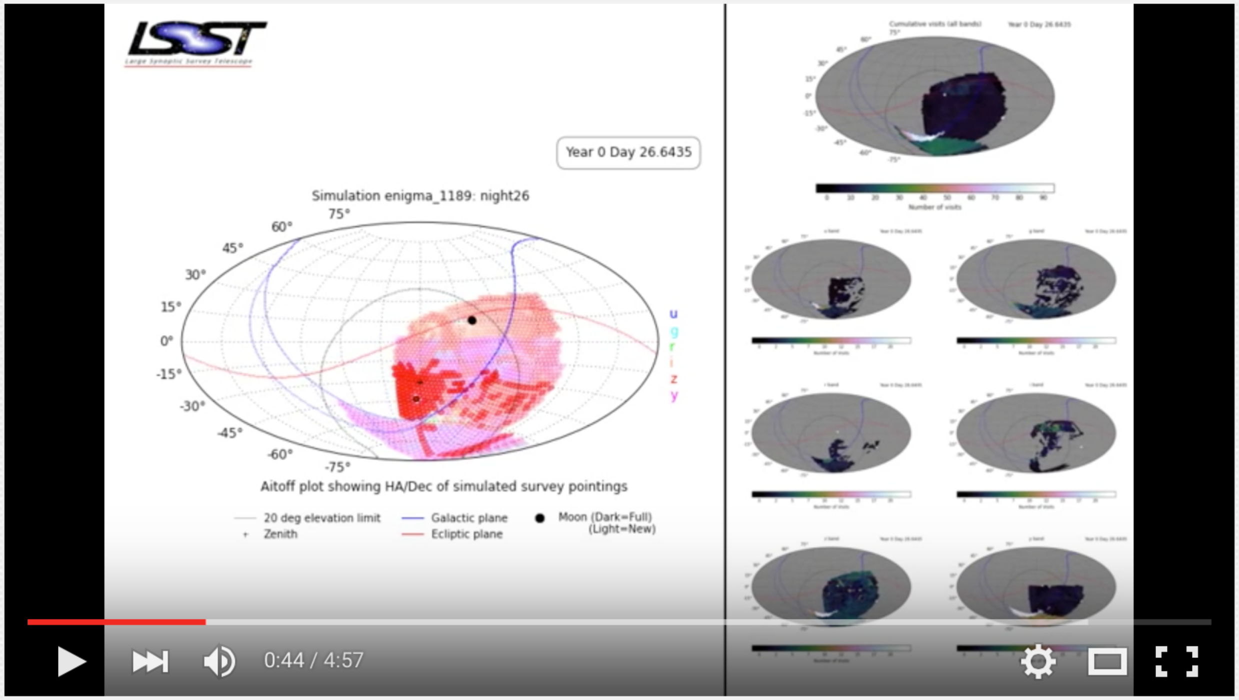


North Ecliptic



South Cel. Pole

Candidate new Baseline (enigma_1189)



enigma 1189 combo movie

Lynne Jones

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5 views

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Published on Aug 12, 2015
This is an animation of a potential LSST observing strategy, from simulated survey 'enigma_1189'. For more information on LSST simulated surveys, see https://confluence.lsstcorp.org/displ..., which includes a link to a set of additional simulated surveys.

http://ls.st/vl1

First steps towards animation: proving to be extremely useful for understanding resulting scanning patterns!

4. Examples of optimization and future optimization directions

- **how could "reserve" wrt WFD be used?**
- the impact of special programs
- the impact of pairs of visits
- optimization of the visit exposure time
- **optimization of u band exposure time**
- optimization of NEO completeness

4. Examples of optimization and future optimization directions

how much "reserve" do we have?

What would be the effect on the number of visits of ignoring special programs and spending all of the observing time on the main Universal Cadence fields?

ops2_1098, using only fields from the uniform cadence proposal, delivered 99.2% of the total number of visits obtained by Baseline Cadence (for all proposals).

With dithering, the effective number of visits is increased by 43%, **relative to the SRD design** specification of 825 visits over 18,000 sq.deg. for the main (WFD) survey.

4. Examples of optimization and future optimization directions

how much “reserve” do we have?

We have about 40% reserve, which could be spent on:

i) increase the no. of visits per field for the WFD area

ii) increase the surveyed area while keeping the number of visits per field statistically unchanged

iii) increase both area and the number of visits

iv) execute additional programs (the current baseline).

(or to mitigate performance losses, e.g. in SNR)

4. Examples of optimization and future optimization directions

What would be the effect on the sky coverage of ignoring special programs and applying the main Universal Cadence strategy everywhere?

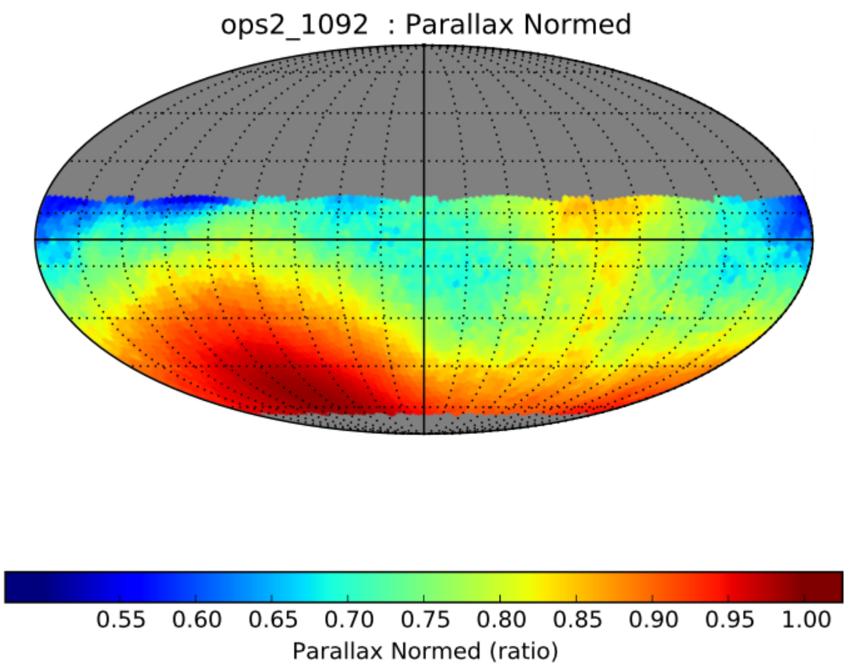
ops2_1092, also known as "Pan-STARRS" cadence, shows that the survey area could be increased by about 40% (to 25,000 sq.deg.), while still delivering the mean number of fields at the level of 98% of that in Baseline Cadence (or 92% of the SRD design value).

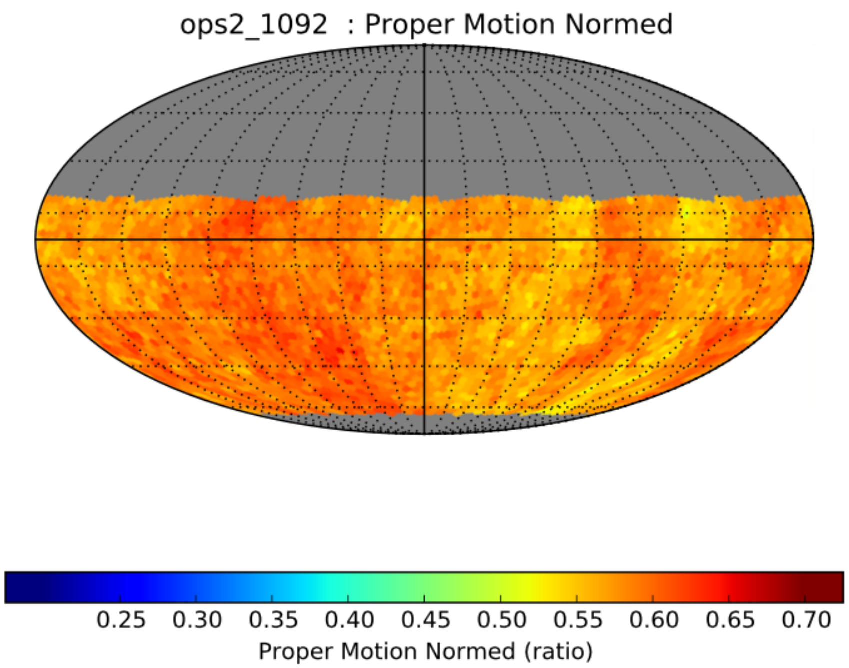
Should we drastically simplify observing strategy and just deploy this idea?

4. Examples of optimization and future optimization directions

Should we simply apply Universal Cadence everywhere?

If you are interested in trigonometric parallax and proper motions, it certainly looks nice! Note, though, that the Galactic Plane may not be that good due to crowding issues. (also good: self-calibration, legacy,…)

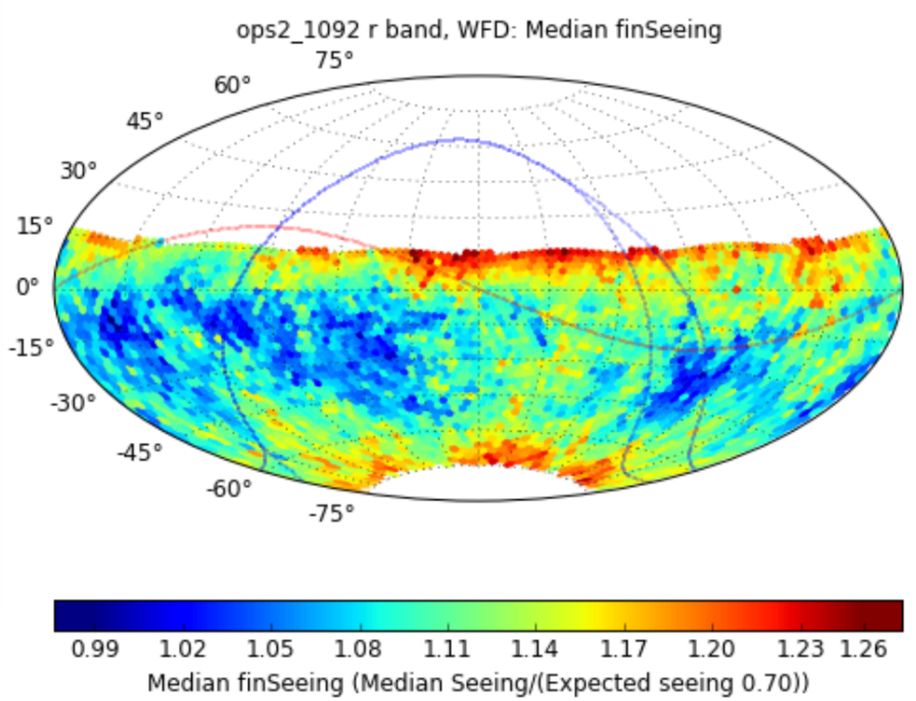


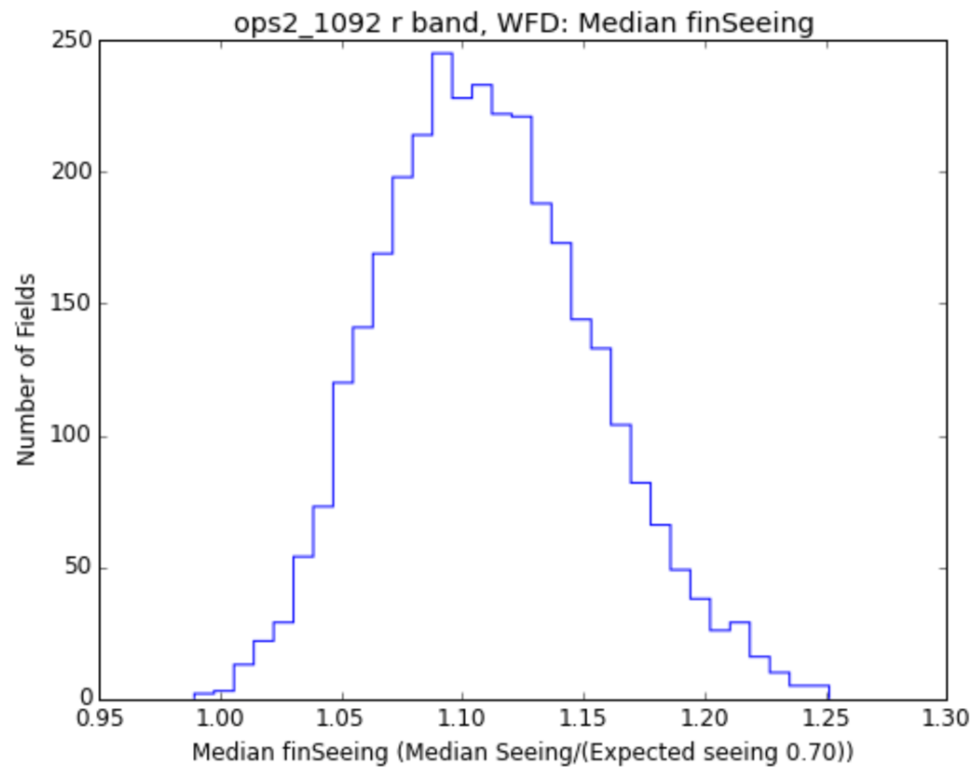


4. Examples of optimization and future optimization directions

Should we simply apply Universal Cadence everywhere?

If you are interested in maximizing the counts of "effectively resolved" galaxies (for WL), the total count of galaxies is similar as in Baseline Cadence:





4. Examples of optimization and future optimization directions

optimization of the visit exposure time: u band

The read-out noise in the u band is not negligible compared to the background noise as in other bands, due to darker u band sky. The **coadded** depth in the u band could be improved by 0.24 mag by increasing the exposure time per visit from 30 seconds to 60 seconds (but with a factor of 2 fewer visits).

Two simulations with 60 sec visit exposure time in u:
- cut the requested number of visits to 1/2
- keep the requested number of visits unchanged: it effectively doubles the allocation of observing time to the u band from 5% to 10%.

4. Examples of optimization and future optimization directions

Two simulations with 60 sec visit exposure time in u:

ops1_1162: 1/2 visits; **confirms expectations**: gain 0.24 mag in the coadded depth, with the number of visits decreased by about a factor of two (with a negative impact on time-domain science).

ops1_1161: keep the requested number of visits unchanged; it effectively doubles the allocation of observing time to the u band from 5% to 10%.
It shows that **we could improve the u-band depth by 0.6 mag** (both single-epoch and coadded) at the expense of decreasing the number of visits in other bands by ~5% (and coadded depth by ~3%).

4. Examples of optimization and future optimization directions

Drivers for baseline cadence modifications:

- improved knowledge of the system (now due to simulations, eventually due to performance measurements)
- changing science landscape on timescales of a few years
- unscheduled technical delays or substandard performance (e.g. broken filter, dead CCD, extra noise)
- even 10% improvement in surveying efficiency would be significant accomplishment (c.f. entire DD observing time)
- improved time-domain programs
- improved special programs

4. Examples of optimization and future optimization directions

Potential optimization directions:

- minimizing the impact of read-out noise (mostly in u band)
- optimizing sky coverage (Galactic plane, south celestial pole, LMC/SMC, Ecliptic)
- temporal sampling (SNe, variable stars, asteroids)
- interplay between sky coverage and temporal sampling
- deep drilling fields
- dynamic cadence (in response to expected SNR)
- evolving cadence (in response to science drivers)

4. Examples of optimization and future optimization directions

Existing to-do list:

For input from the community, see http://ls.st/smg

1. Further exploration of the main survey (e.g., exposure time in general, and u band exposure time in particular; fixing western bias; exploring airmass limit and sky coverage; investigations of variable, perhaps SNR-driven, exposure time).

2. Exploration of temporal sampling function in general, and of Rolling Cadence in particular.

3. NEO completeness studies: what would it take for LSST to reach 90% completeness for 140m and larger NEOs? Based on previous analysis, directions to explore are deeper visits along the Ecliptic and longer survey duration (about 12 yrs).

4. Examples of optimization and future optimization directions

4. Exploration of Galactic plane and Bulge science programs (e.g. should we extend the main survey to the Galactic plane per A.Gould's proposal, arXiv:1304.3455)

5. Optimization of LMC/SMC coverage (and somewhat less importantly, the South Celestial Pole coverage).

6. Deep drilling exploration (detailed analysis of existing proposals; investigation of gains from going to a larger observing time allocation, e.g. 20%).

7. Twilight short-exposure time observing (per internal Stubbs proposal).

4. Examples of optimization and future optimization directions

8. Planning commissioning observations (e.g. the tension between going wide to enable self-calibration, and dense temporal sampling to obtain various light curve templates and fine tune image differencing and multi-epoch data processing and data analysis software tools).

9. Dynamic cadence explorations (the main goal at this time is to answer: are our tools good enough to act and react swiftly and robustly in operations?).

5. The role of the SAC (and community) in advising the Project on cadence-related decisions

1. We need to define quantitative science drivers for the observing strategy of the LSST (e.g. the depth and filters required for early science; the sky region, cadence and number of filters required to "measure something").
   The SRD is intentionally vague on these details!

2. To express these drivers in terms of "metrics" by which the science returns (simulated surveys) can be quantified

3. To define the (OpSim) experiments needed to develop and test these metrics so that we can determine how much science is gained or lost as a function of the current survey strategy or future modified strategies

5. The role of the SAC (and community) in advising the Project on cadence-related decisions

Questions that are hard to answer:

1. **Quantitative science drivers:**
   - an example: the proposal to extend WFD survey to the Galactic plane (Gould, A. 2013, arXiv:1304.3455)
   Is the anticipated science worth 10% of LSST?

2. **Metrics:**
   - an example: how does a 10% improvement in “early SNe” metric compare to a 10% improvement in proper motion metric?

3. **OpSim experiments:** we don’t have infinite resources; for example, which X% of proposed modifications shall we study?

Existing means for discussing LSST cadence

LSST Science Advisory Council (SAC)

- the main mechanism for officially collecting and delivering community input to the Project.

For input from the community, see http://ls.st/smg

LSST Project Science Team (PST)

- an operational unit, within the Project, that includes key scientists (Angeli, Claver, Connolly, Ivezić, Jurić, Kahn, Lupton, Ritz, Strauss, Stubbs, Thomas, Tyson, Willman). **The PST provides input on critical technical decisions as the project construction proceeds.**

LSST Project Scientist

- chairs PST, maintains the SRD and supporting documentation, responsible for cadence optimization efforts and liaison to the LSST Simulations team (led by Andy Connolly), reports directly to the LSST Director.