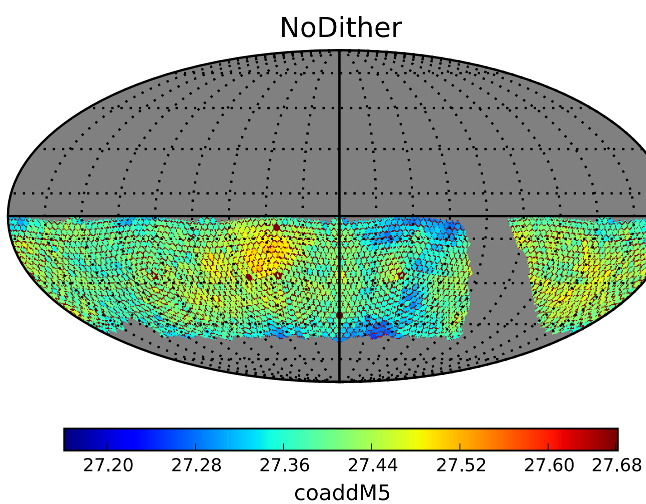
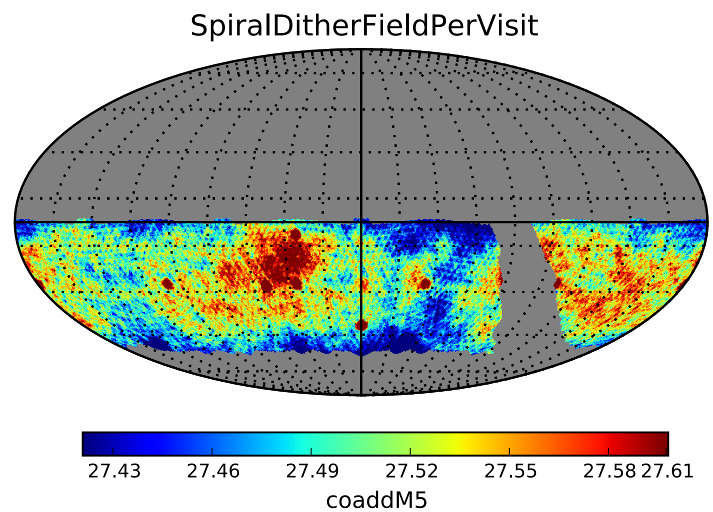
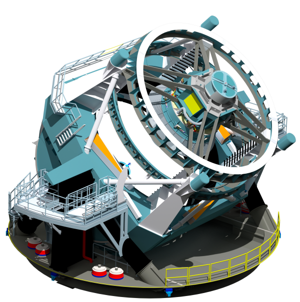
LSST Survey Strategy and Dark Energy Systematics







Eric Gawiser
Rutgers University

The LSST Survey Strategy

TABLE 1
THE LSST BASELINE DESIGN AND SURVEY PARAMETERS

Quantity	Baseline Design Specification
Optical Config.	3-mirror modified Paul-Baker
Mount Config.	Alt-azimuth
Final f-ratio, aperture	f/1.234, 8.4 m
Field of view, étendue	9.6 $\deg^2$, 319 $m^2\deg^2$
Plate Scale	50.9 μm/arcsec (0.2" pix)
Pixel count	3.2 Gigapix
Wavelength Coverage	320 – 1050 nm, *ugrizy*
Single visit depths[a] (5σ)	23.9, 25.0, 24.7, 24.0, 23.3, 22.1
Mean number of visits	56, 80, 184, 184, 160, 160
Final (coadded) depths[a]	26.1, 27.4, 27.5, 26.8, 26.1, 24.9

[a] The listed values for 5σ depths in the *ugrizy* bands, respectively, are AB magnitudes, and correspond to point sources and zenith observations (about 0.2 mag loss of depth is expected for realistic airmass distributions). See Table 2 for more details.

From LSST overview paper, Ivezic et al. ArXiv:0805.2366

Interactive Exercise #1

- Please find the group named for your favorite Dark Energy probe.
- List 2-3 systematics that your group thinks will be the limiting ones for that probe for LSST.
- Which (if any) are sensitive to survey strategy, and how?

DE Probes – Limiting Systematics: Do They Depend on Survey Strategy?

Supernovae

1. Photometric Calibration Y
2. Photometric Typing Y
3. Light Curve Quality Y

Strong Lensing

1. Cadence – Light Curve Sampling Frequency Y
2. Accurate Weak Lensing Y

Weak Lensing Y

1. Accurate Shape Measurements (PSF varies with position & time) hence dithering critical
2. Photometric redshifts Y

Large Scale Structure

1. Photometric redshifts Y
2. Survey depth uniformity Y

Clusters Y

1. Survey depth uniformity
2. Large area } statistics Y
3. Depth }
4. Mass Calibration – Accurate WL * Y

The LSST Operations Simulator

Non-trivial survey design task to cover

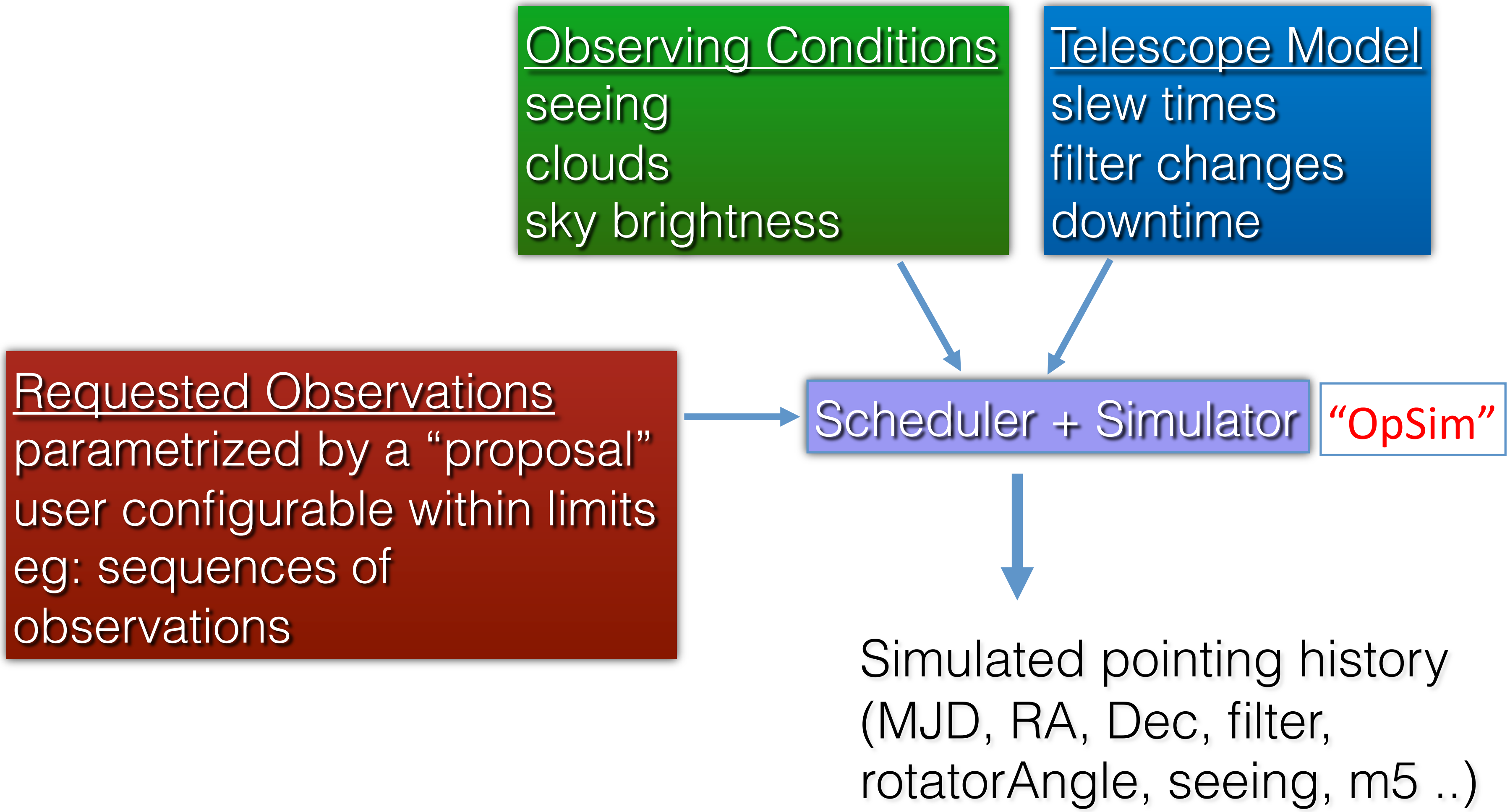
18,000 square degrees divided into

2000 pointings, each observed

~150 times in each of 6 filters.

Feasibility shown via Operations Simulator (OpSim) - decides where telescope should point next & simulates atmospheric and telescope **meta-data** over 10-year survey (>1 million exposures).

Operations Simulator



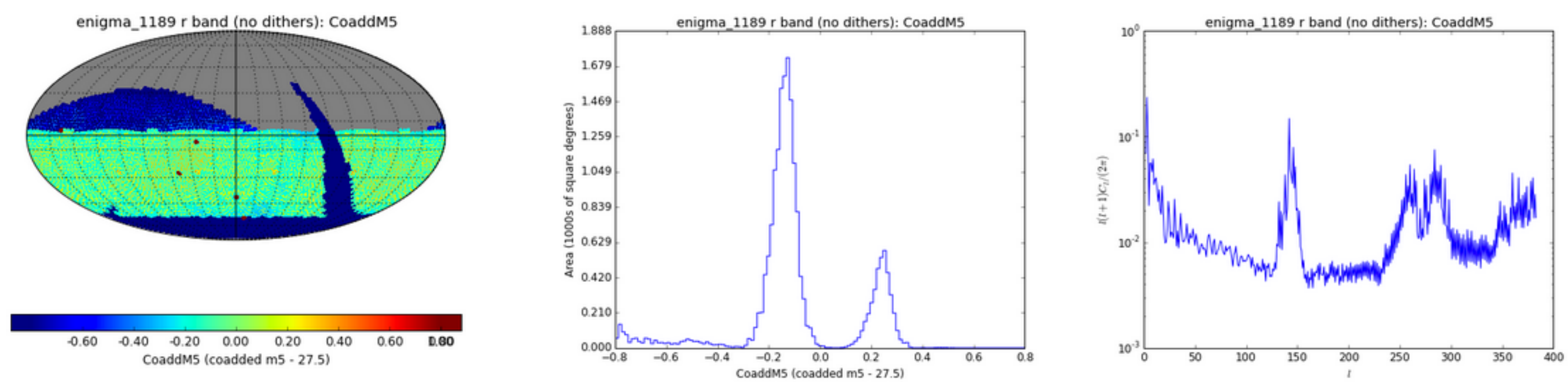
Slide from Lynne Jones (UW)

Metrics Analysis Framework (MAF)

OpSim Output:
Simulated pointing history
(MJD, RA, Dec, filter,
rotatorAngle, seeing, m5 ..)

MAF
Python framework
to calculate metrics

CoaddM5 HealpixSlicer r band (no dithers) [npz](npz) JSON



Coadded depth in filter r, with design value subtracted (27.5), r band, all proposals (no dithers). More positive numbers indicate fainter limiting magnitudes.

Slide from Lynne Jones (UW)

Spherical Harmonics

$$A(\theta, \emptyset) = \sum_{l,m} a_{lm} \; Y_{lm}(\theta, \emptyset)$$

$$c_l = \frac{1}{2l+1} \sum_{m=-l}^{l} |a_{lm}|^2$$

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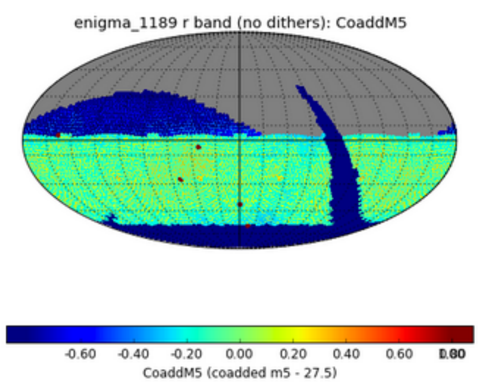
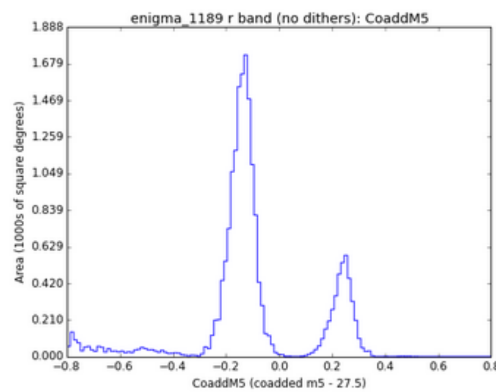
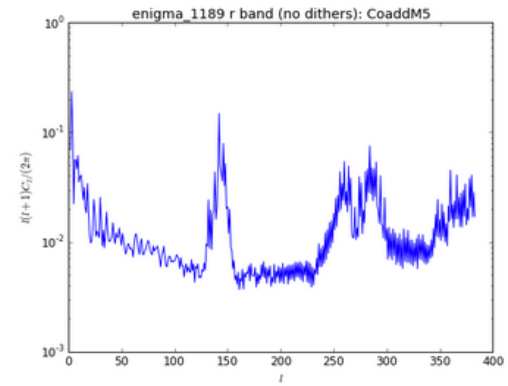






Coadded depth in filter r, with design value subtracted (27.5), r band, all proposals (no dithers). More positive numbers indicate fainter limiting magnitudes.

Slide from Lynne Jones (UW)

- OpSim and MAF can be installed as part of LSST software stack
  - Both available via EUPS or conda (or docker)
  - See https://confluence.lsstcorp.org/display/SIM/Catalogs+and+MAF for more information on installing the stack

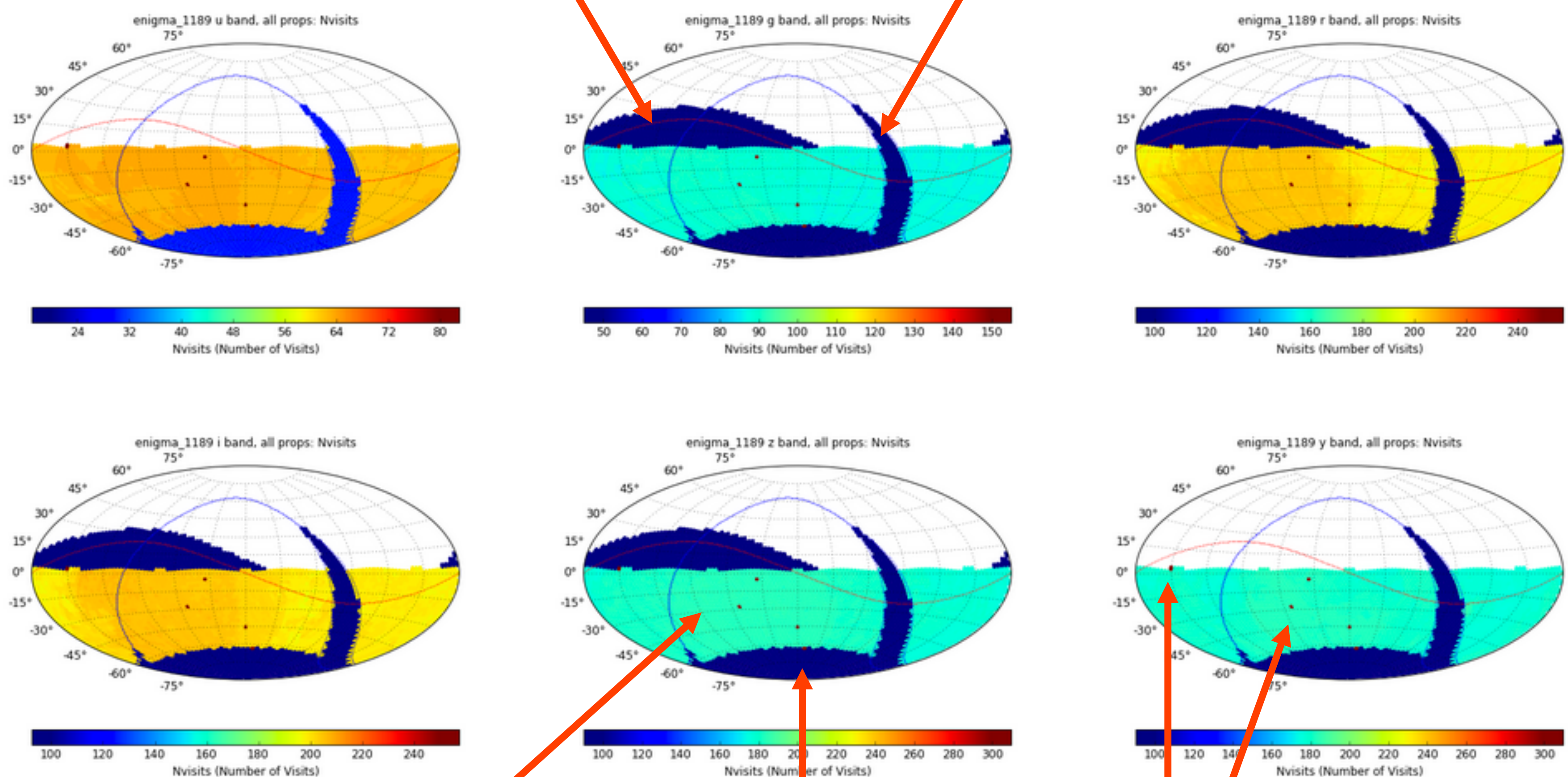
Slide from Lynne Jones (UW)

"Mini-Surveys"

North Ecliptic Spur (NES)

Galactic Plane (MW)

Nvisits



Universal (WFD)

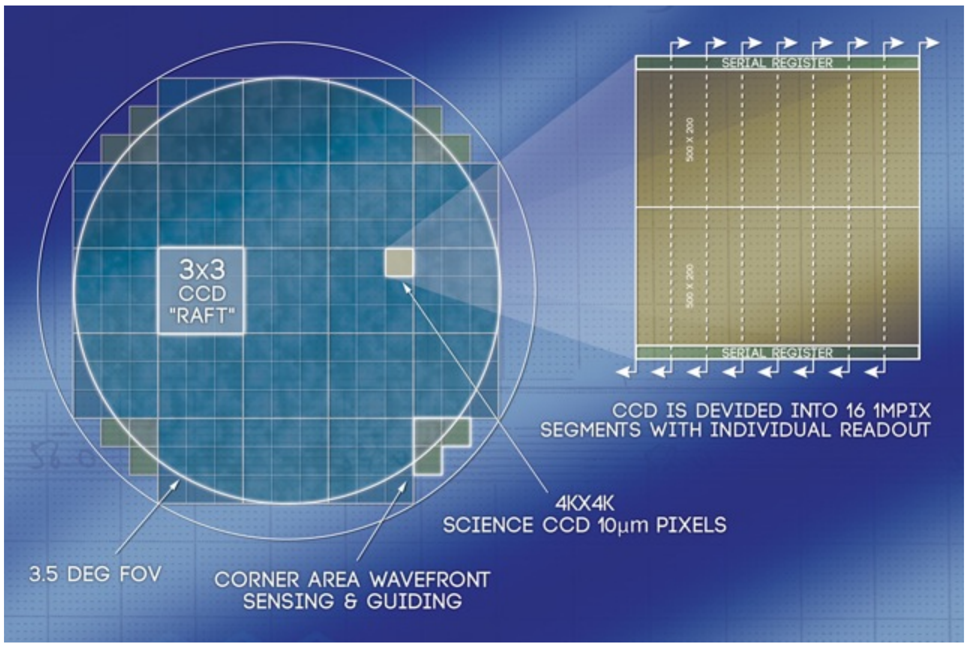
South Celestial Pole (SCP)

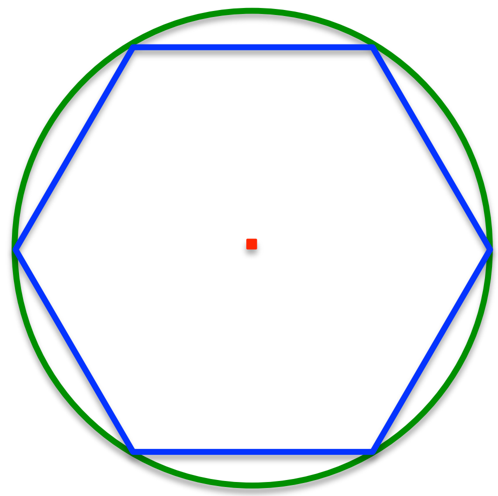
Deep Drilling (DD)

Slide from Lynne Jones (UW)

Fixed Telescope Pointings

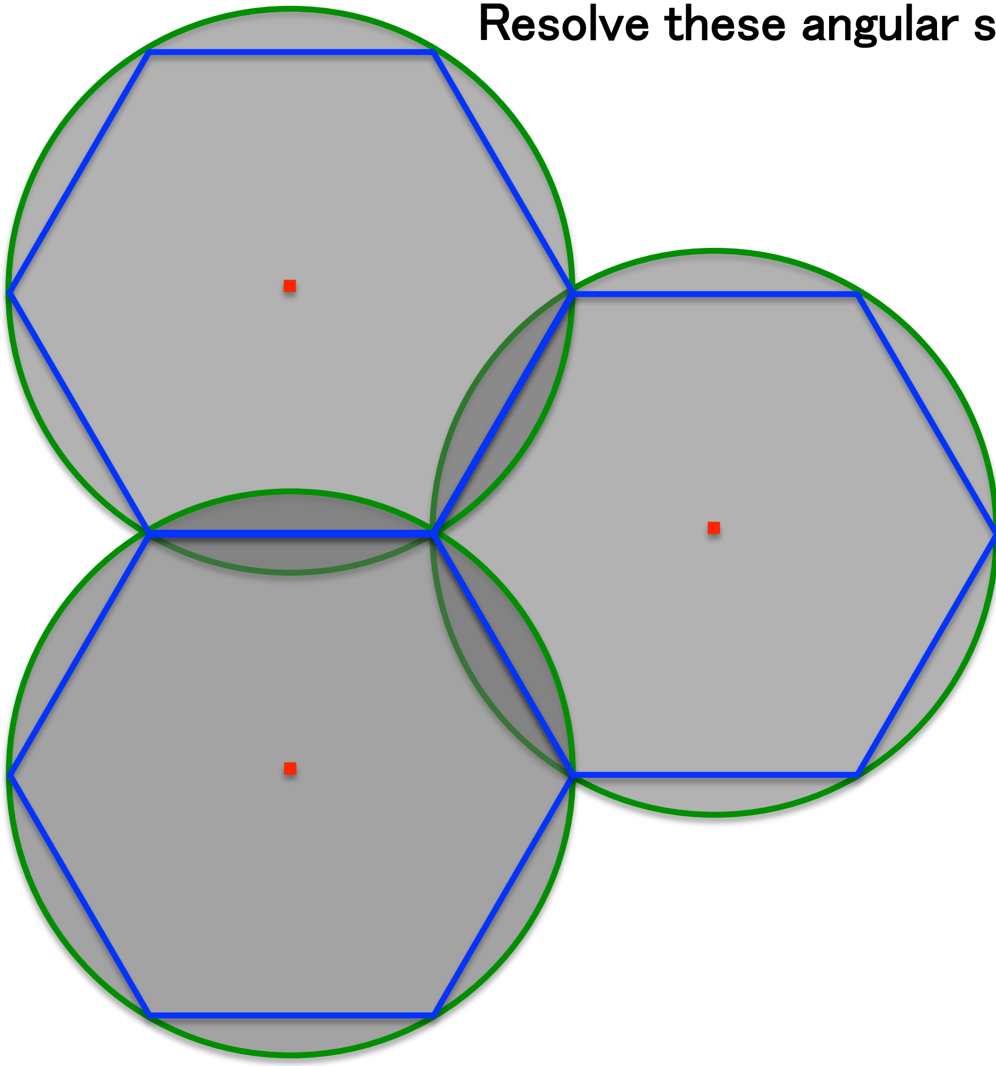
Tile the sky with hexagons inscribed in the circular LSST Field of View



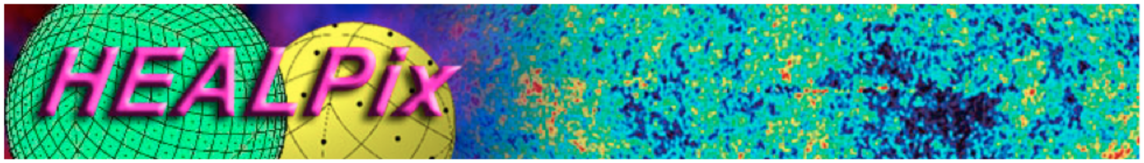


Slide from Tony Tyson

Fixed Telescope Pointings → overlapping regions
Resolve these angular scales to model impact



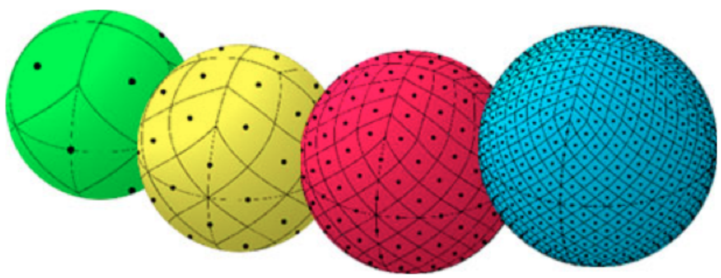
slide from Humna Awan



Introduction

HEALPix is an acronym for **H**ierarchical **E**qual **A**rea iso**L**atitude **Pix**elization of a sphere. As suggested in the name, this pixelization produces a subdivision of a spherical surface in which each pixel covers the same surface area as every other pixel. The figure below shows the partitioning of a sphere at progressively higher resolutions, from left to right. The green sphere represents the lowest resolution possible with the HEALPix base partitioning of the sphere surface into 12 equal sized pixels. The yellow sphere has a HEALPix grid of 48 pixels, the red sphere has 192 pixels, and the blue sphere has a grid of 768 pixels (~7.3 degree resolution).

Another property of the HEALPix grid is that the pixel centers, represented by the black dots, occur on a discrete number of rings of constant latitude, the number of constant-latitude rings is dependent on the resolution of the HEALPix grid. For the green, yellow, red, and blue spheres shown, there are 3, 7, 15, and 31 constant-latitude rings, respectively.

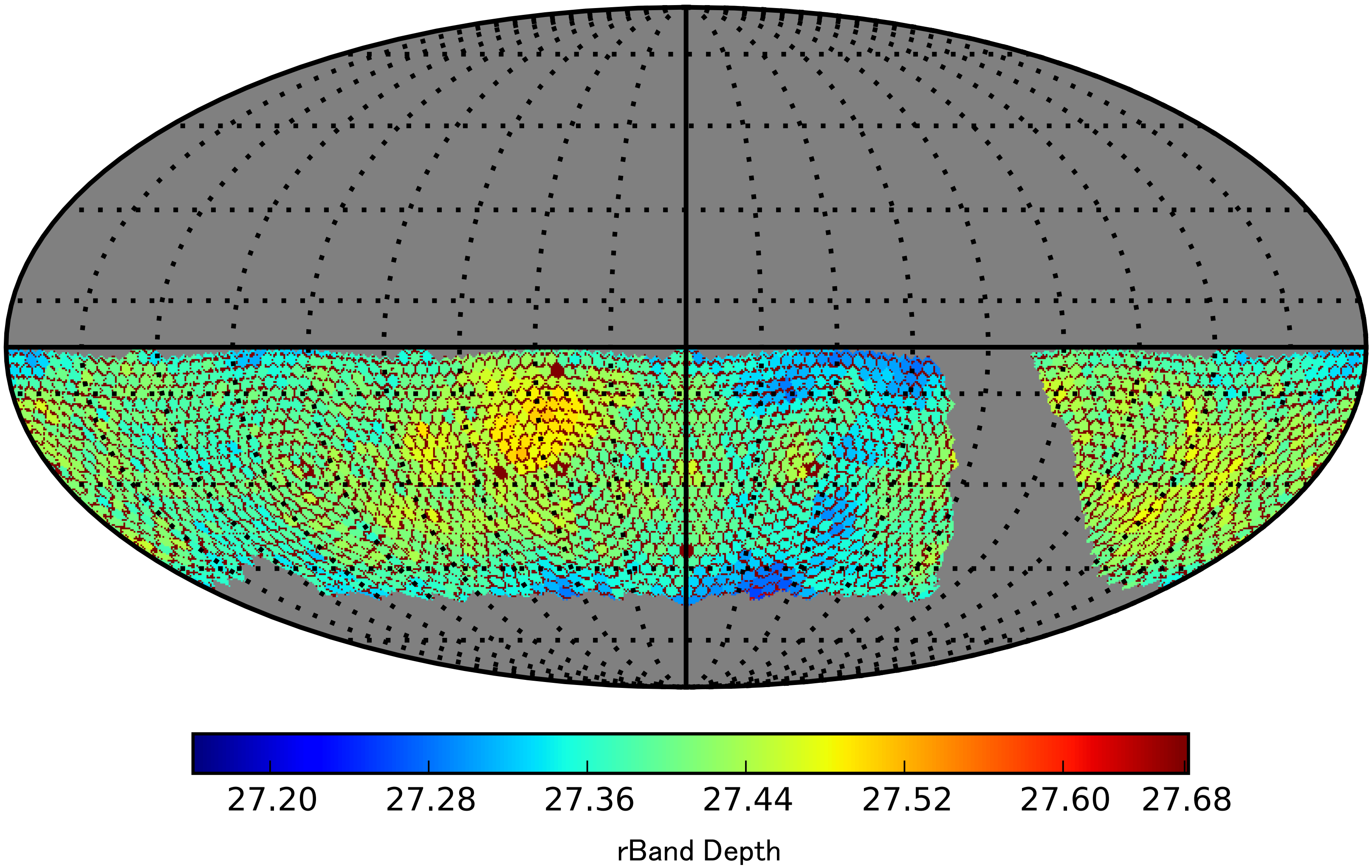


HEALPix turns the sphere into equal-area ~square pixels ordered by declination.
Good for fast spherical harmonic transforms.

We use HEALPix at level 128 with 196608 pixels on the sphere to resolve each ~circular LSST FOV into~50 pixels.

see http://healpix.jpl.nasa.gov/index.shtml, ArXiv:astro-ph/0409513, ArXiv:astro-ph/9905275

Ten-Year Survey Depth: Fixed Telescope Pointing



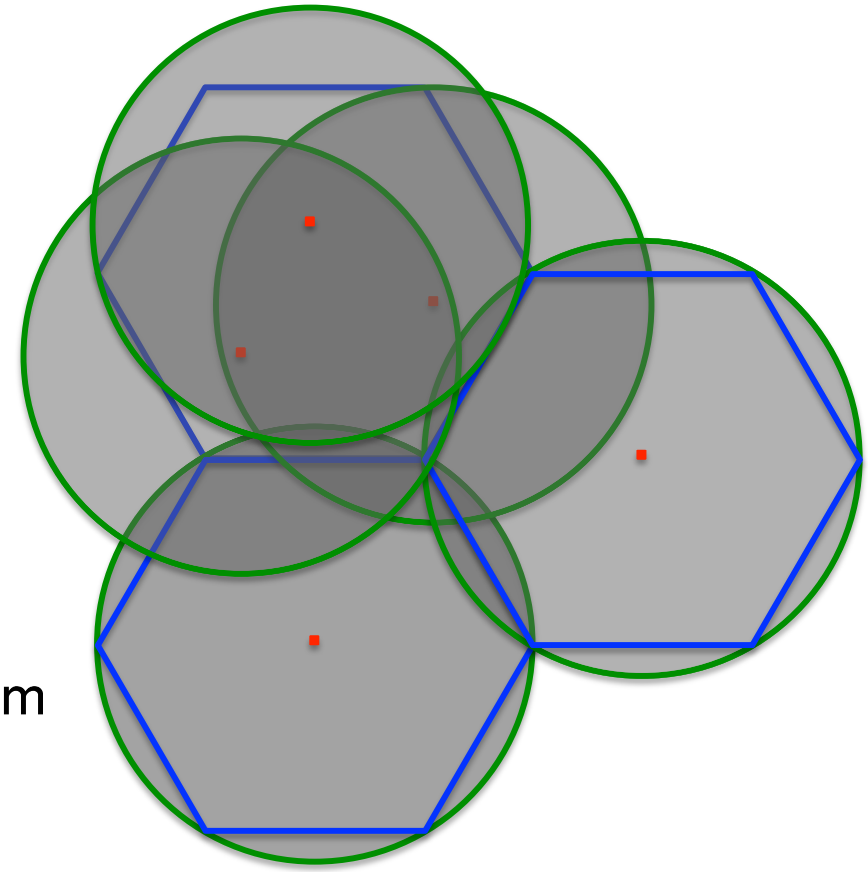
Honeycomb pattern: angular scale close to that of Baryon Acoustic Oscillation (BAO) signal. **NOT GOOD.**

from Awan et al., in prep

Dithering

Dithers:

- Telescope-pointing offsets within a single FOV



Advantages:

- Observation through many CCDs
- Reduce systematic errors from variations in sensitivity

Goal: explore different kinds of dithering strategies

slide from Humna Awan

Dithering

Need to choose:

•geometrical pattern for telescope offsets versus centers of hexagonal tiles

•possibly an angular pattern for rotational dithers of the camera

•a timescale on which to implement these offsets

•whether to increment the offset for each field independently

Interactive Exercise #1 – Take Two

- Would anyone like to change their answers about the (lack of) observing strategy dependence of limiting systematics for their favorite DE probe?
- Any other questions so far?

Interactive Exercise I

- Please form new groups of ~3, mixing between favorite probes.
- Propose an improvement to LSST survey strategy (e.g., dither pattern/timescale or a mini-survey) that will help static DE science
  (Weak Lensing, Large Scale Structure, Clusters).

Static Science Improvements to Survey Strategy

- ~10-year depth early in ~100s of $\square^\circ$
- Synergies with Euclid, WFIRST, VISTA (for NIR imaging)
  - + other λ's
  - + spectroscopy
- Tighten airmass constraints (better PSF)
- Try to counteract seasonal variations (year-to-year, summer vs. winter)
- favor certain region in best seeing - or - try to spread it out?
- Only image in g, r when seeing $<0.5''$

OpSim Proposal configuration

Can specify:

- number of visits per filter
- time between visits in a sequence
- (potentially) subsequences within each sequence
- number of visits in each filter in each sequence or subsequence

Slide from Lynne Jones (UW)

OpSim Outputs

- Proposals feed scheduler suggested observations (based on their configuration + weather conditions)
- Scheduler chooses visits based on rankings from proposals + added cost function (basically slew time and filter change time) using a 'greedy algorithm' (choose next best field at that time)
- Telescope model makes sure that visits are realistically obtained — slew time, filter change time, cable wrap requirements.
- Many runs already available covering range of different survey strategies
  - https://confluence.lsstcorp.org/display/SIM/OpSim+Datasets+for+Cadence+Workshop+LSST2015
- Common characteristics: median slew time is close to minimum, filter changes generally occur due to sky brightness changes, typically just under 2.5M visits over 10 years.

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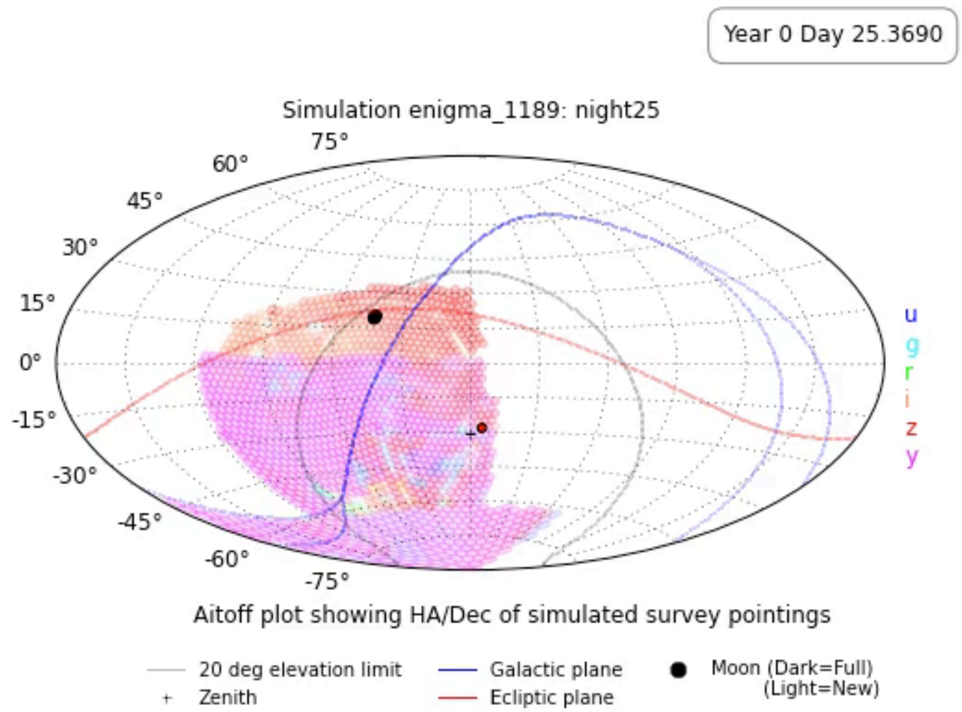

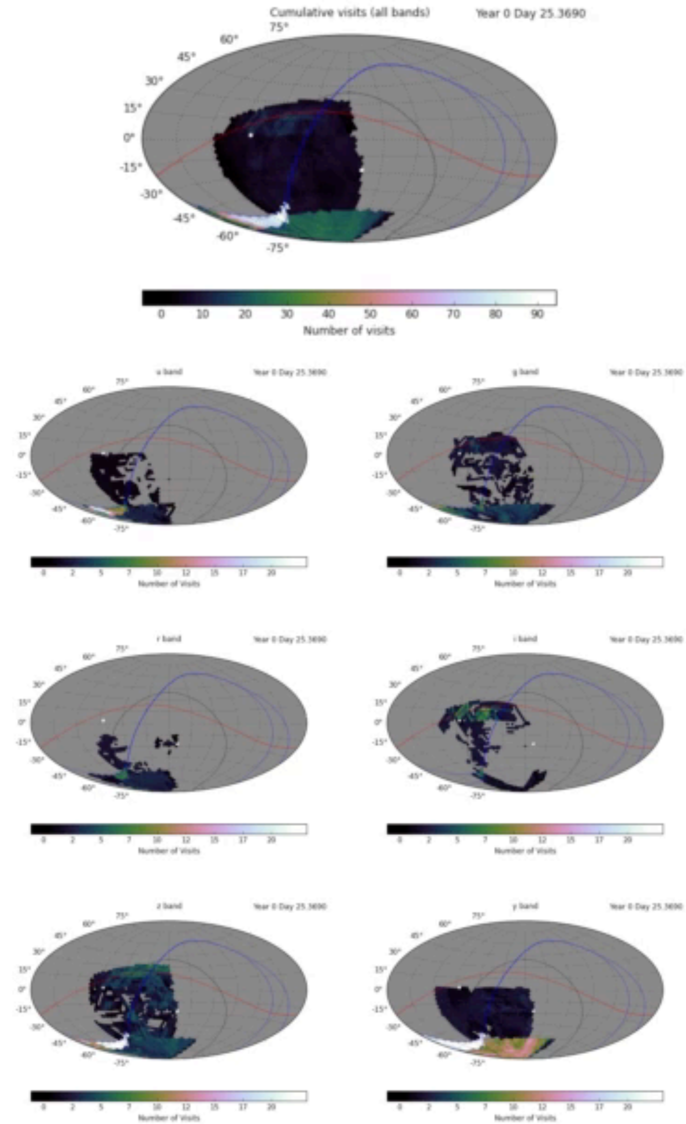

https://www.youtube.com/watch?v=GW---5VehuE

Slide from Lynne Jones (UW)

Interactive Exercise A

- Please work with the same groups of ~3.
- Propose an improvement to strategy (e.g., observing cadence, filter proportions/ sequence, or a mini-survey) that will help time domain DE science (Supernova, Strong Lensing).
- Does your proposal conflict with static science improvements suggested earlier?

Improvements to Time Domain Science via Survey Strategy

- Watch Moon distance / prefer Southern declinations (SNe)
- Do at least 2 filters on same night in same field (SNe)
- Get rid of visit pairs (on same night) at high Galactic & ecliptic latitude (SL)
- Dynamic cadence – "lucky surveying" – once an overdensity of SNe is found, make that a temporary Deep Drilling Field
  also keep a list of rare objects that trigger "preferred locations"?
- (Make a nightlong movie of Magellanic Clouds)
- Train dynamic scheduler to recover optimally from bad weather & weather forecasts

Conflict: dynamic cadence vs. intermediate data release uniformity