Metric Analysis Framework

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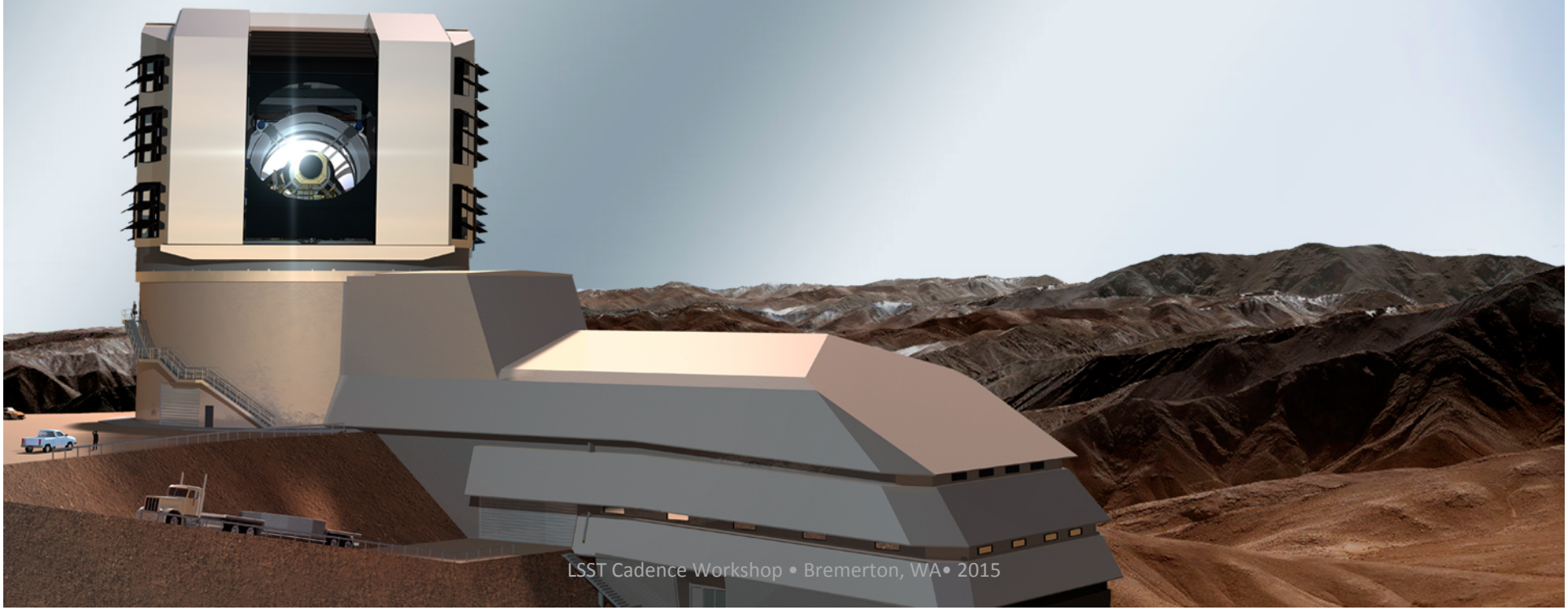


Goals

- Given a list of observations (times, filters, seeing, skybrightness, etc.), quantify how well you can do your science

- For today:
  - Introduction to OpSim and MAF
  - Work through running MAF with iPython notebooks

LSST Ecosystem

Data Management (aka DM): Take a bunch of raw images and process them to make catalogs

Sims:

- **Photon Simulator (aka PhoSim)**: Simulate LSST images by tracing photons
- **Catalog Simulator (aka CatSim)**: A realistic catalog of objects LSST could observe (Stars, galaxies, etc)
- **Calibration Simulation (aka CalSim)**: Uber-cal for LSST
- **Operations Simulator (aka OpSim)**: Simulate the operations of the telescope (motion of the motors) as well as the scheduling of observations.
- **Metric Analysis Framework (MAF)**: Analyze and visualize how well an astronomical survey performs.

The (LSST) Stack

We can't do it all

- While we have all the tools to simulate LSST end-to-end, that's pretty computationally expensive

  CatSim + OpSim -> PhoSim -> DM => source catalog

- We hope we can approximate a few of those components when doing the scheduling strategy optimization
  - Rather than use a catalog of objects, assume a simple distribution of sources (e.g., a uniform grid of galaxies)
  - Rather than use PhoSim+DM, just assume Gaussian noise or simple centroiding errors

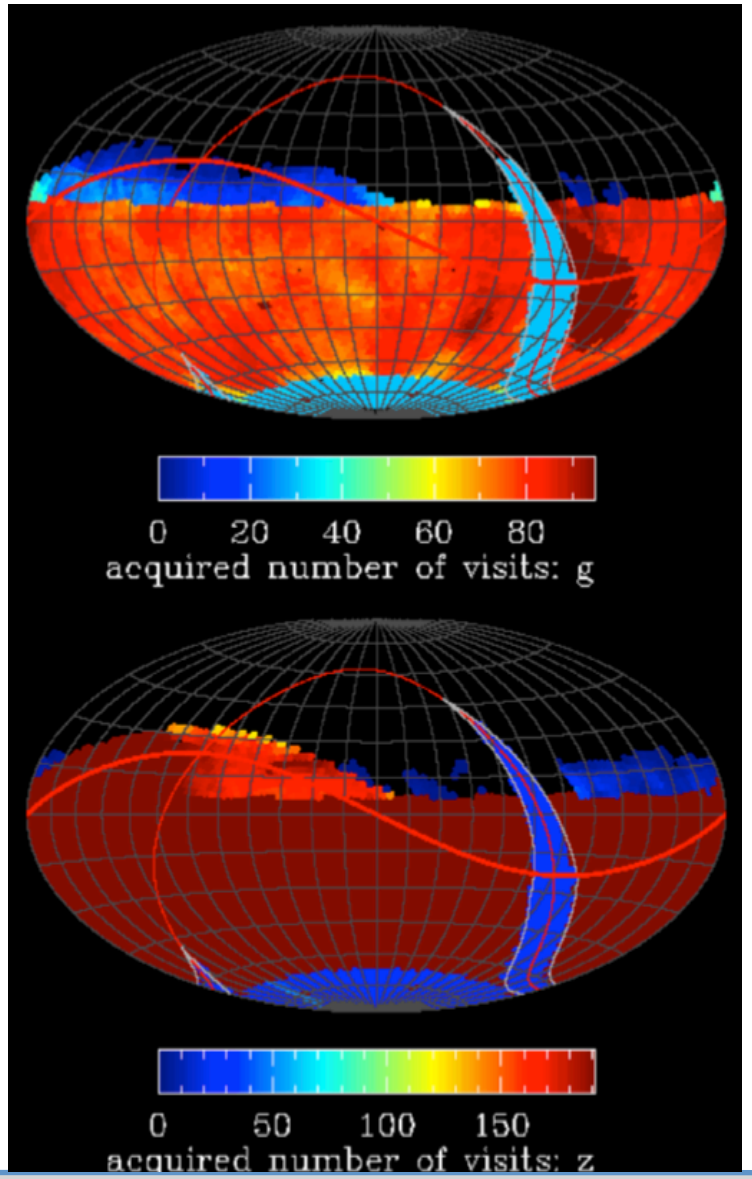
Opsim + MAF -> what fraction of my galaxies are "well observed"

Operations simulations

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

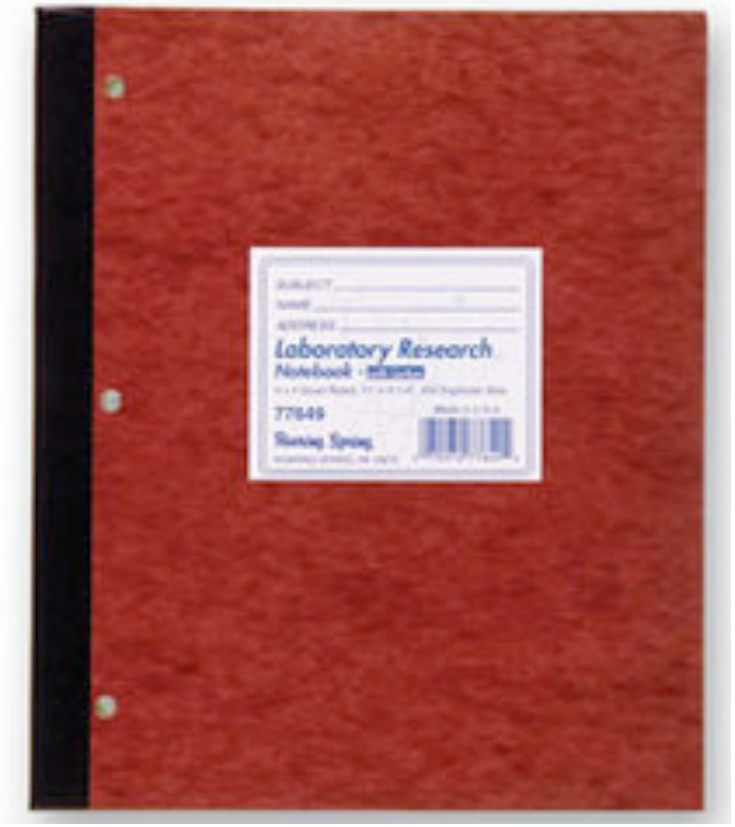
Operations simulator generates sequences of LSST observations together with their properties (seeing, sky brightness, depth, filter). About 2.5 million visits over 10 years

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



Classical Astronomy

- You go to a telescope and take some data
- Did you get enough data to do your science?
    - Flip through the log book and check



LSST Era Astronomy

- Over 10 years, LSST will make around 2.5 million visits
- Need a tool to analyze ~300 log books

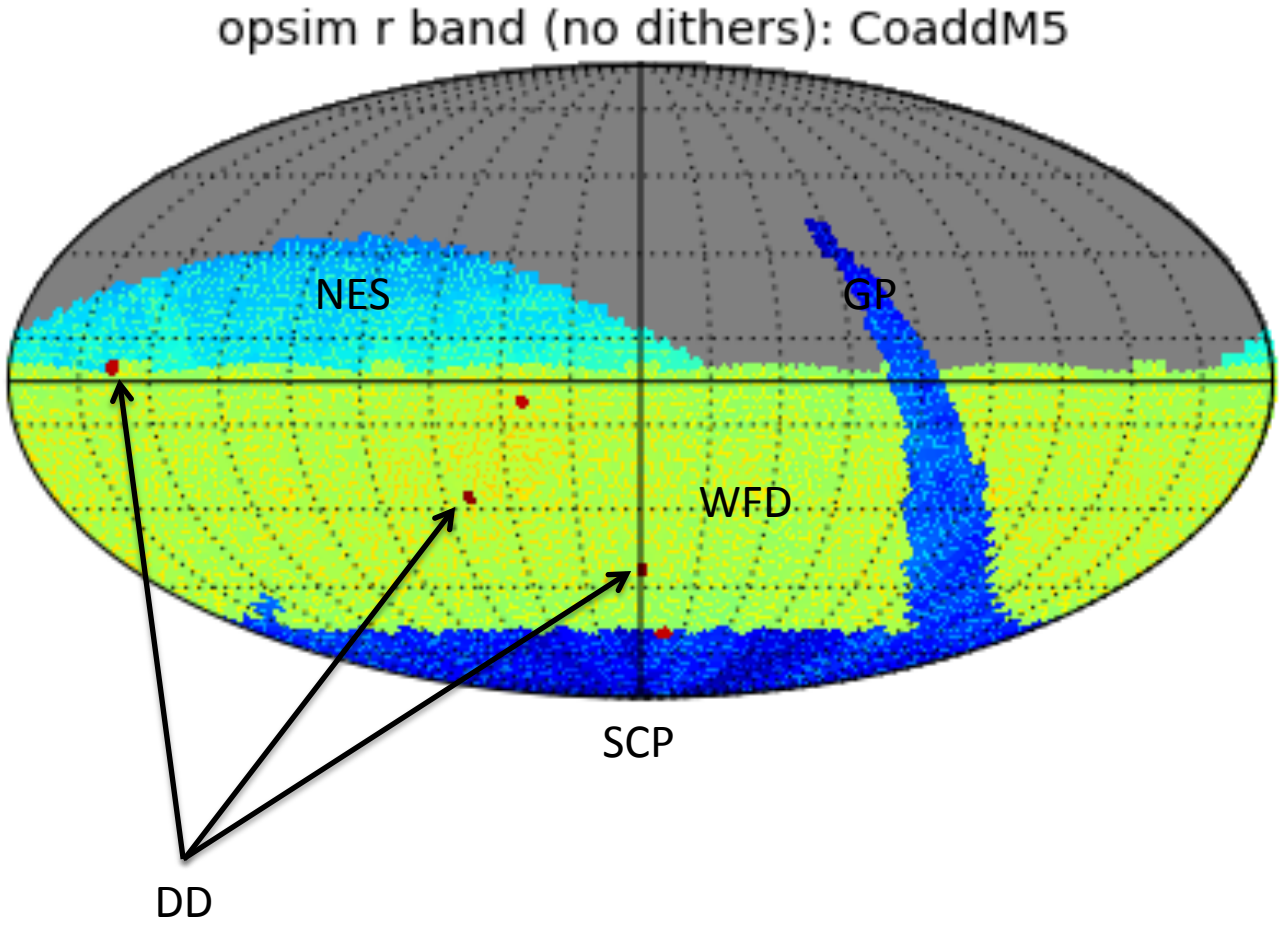
MAF Goals

- 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
- Easily extended so users can contribute their own analysis—we want YOU to show us the best way to measure a survey's performance

The Operations Simulator

- OpSim is our source for what these 2.5 million visits might look like.
  - Includes real weather log
  - Scheduled and unscheduled down time
  - A scheduler that balances several science goals
- OpSim scheduler based on “Proposals”
  - Wide-Fast-Deep (aka, “the main survey”): Cover ~20,000 sq deg
  - North Ecliptic Spur: Solar system objects
  - Deep Drilling Fields: ~6 deep fields
  - Galactic Plane
  - South Celestial Pole

The Proposals



Opsim Output

- An OpSim database (distributed to the community as sqlite files) contains multiple tables that record the observations taken, state of the telescope, configuration of the scheduler, etc.
- For our interests, we will focus on the Summary table in each OpSim run database. This is your very detailed observing log book.

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

OpSim Warnings

- OpSim records LSST "visits"
  - 1 visit = 2 back-to-back exposures!
- By default, OpSim uses fixed fields and does not dither
- There can be "repeated" entries in the Summary table if a visit is used for multiple proposals (e.g., a visit can count towards WFD and Deep Drilling).

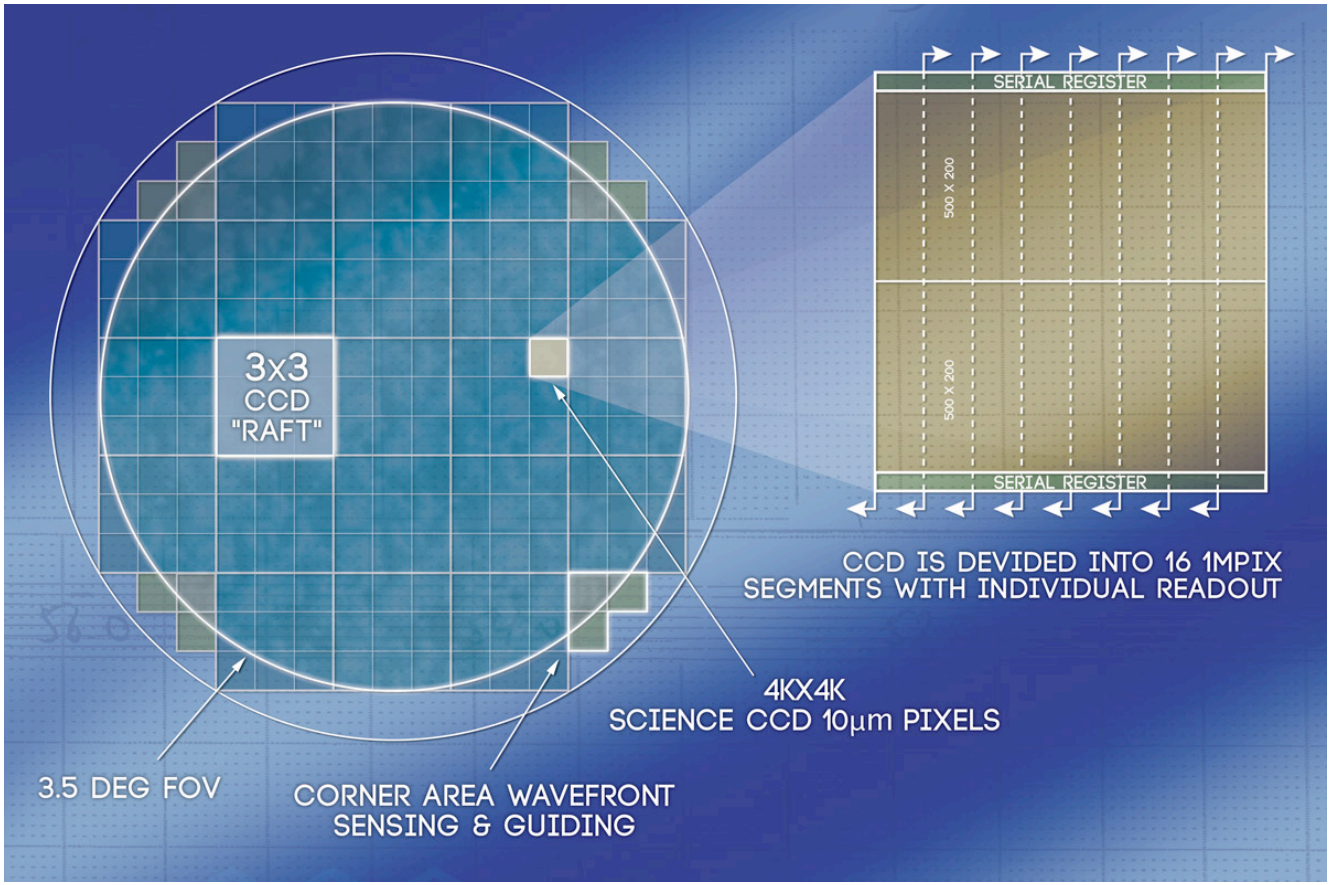
In MAF, we take care of this by doing a SQL "group by" on the expMJD.

Observation for	Object	MJD	RA	DEC
Jen	M31	3456.4	0:42:44	41:16:09
Jen	Feige 34	3456.8	10:39:37	43:06:09
Dave	Feige 34	3456.8	10:39:37	43:06:09
Dave	M1	3457.1	05:34:32	22:00:52

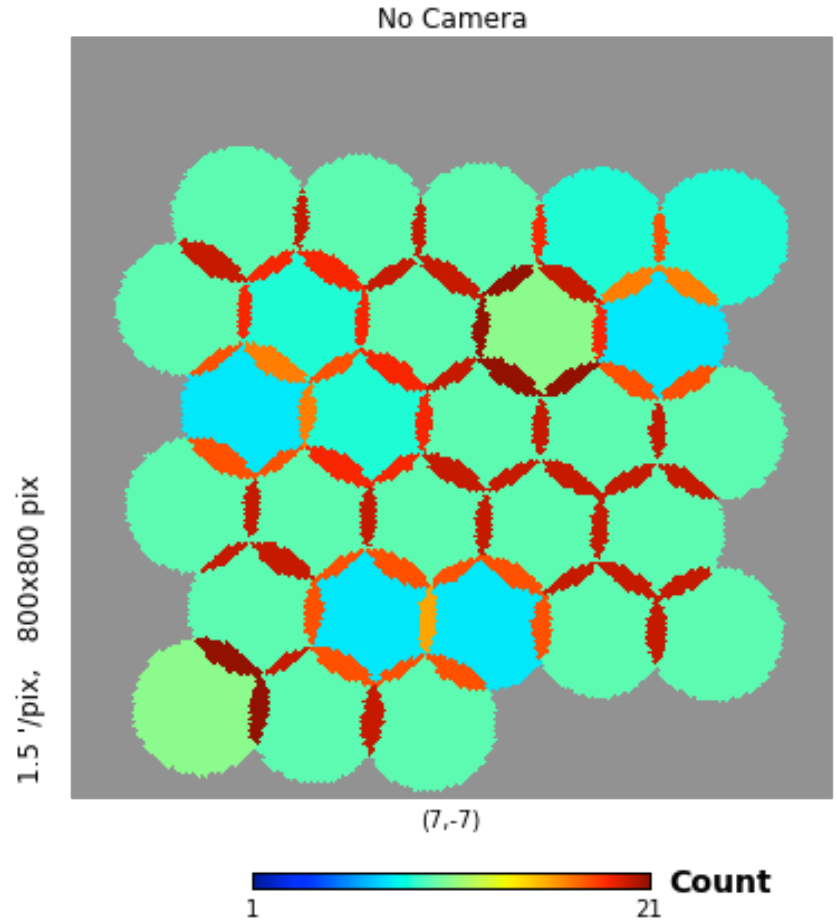
MAF Warnings

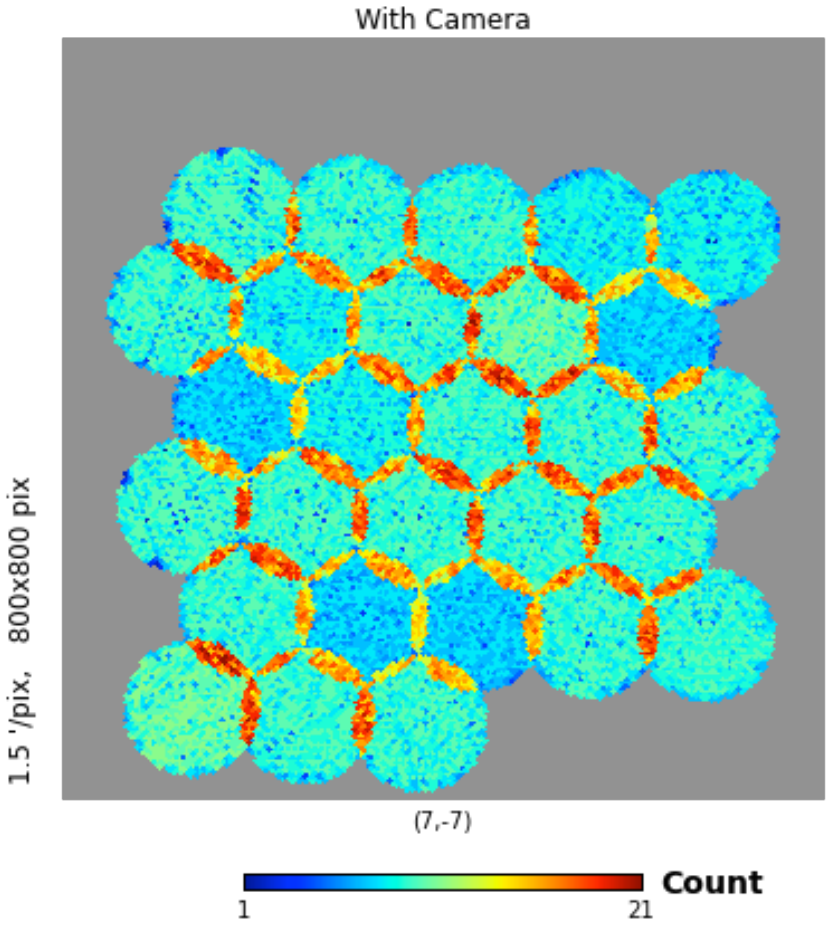
- By default, we assume if an object is within 1.75 degrees of the center, it gets observed.
- This is probably a few % optimistic given chip gaps, etc.

You can run with the full focal-plane geometry, but it slows things down a bit.



With and Without Chip Gaps





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?

To answer these we have to divide the observations up

- Some things we commonly ask
  - What's the median seeing **of all the visits**? All the observations
  - How many exposures do we **get per night**? Observations per night
  - What's the co-added depth of a **deep drilling field**? Observations at a point in the sky
  - What's the average co-added depth at the end of the survey? Observations at many points in the sky

In MAF, splitting the visit up correctly is done by **"slicers"**

To answer these we have to compute some algorithm

- 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?

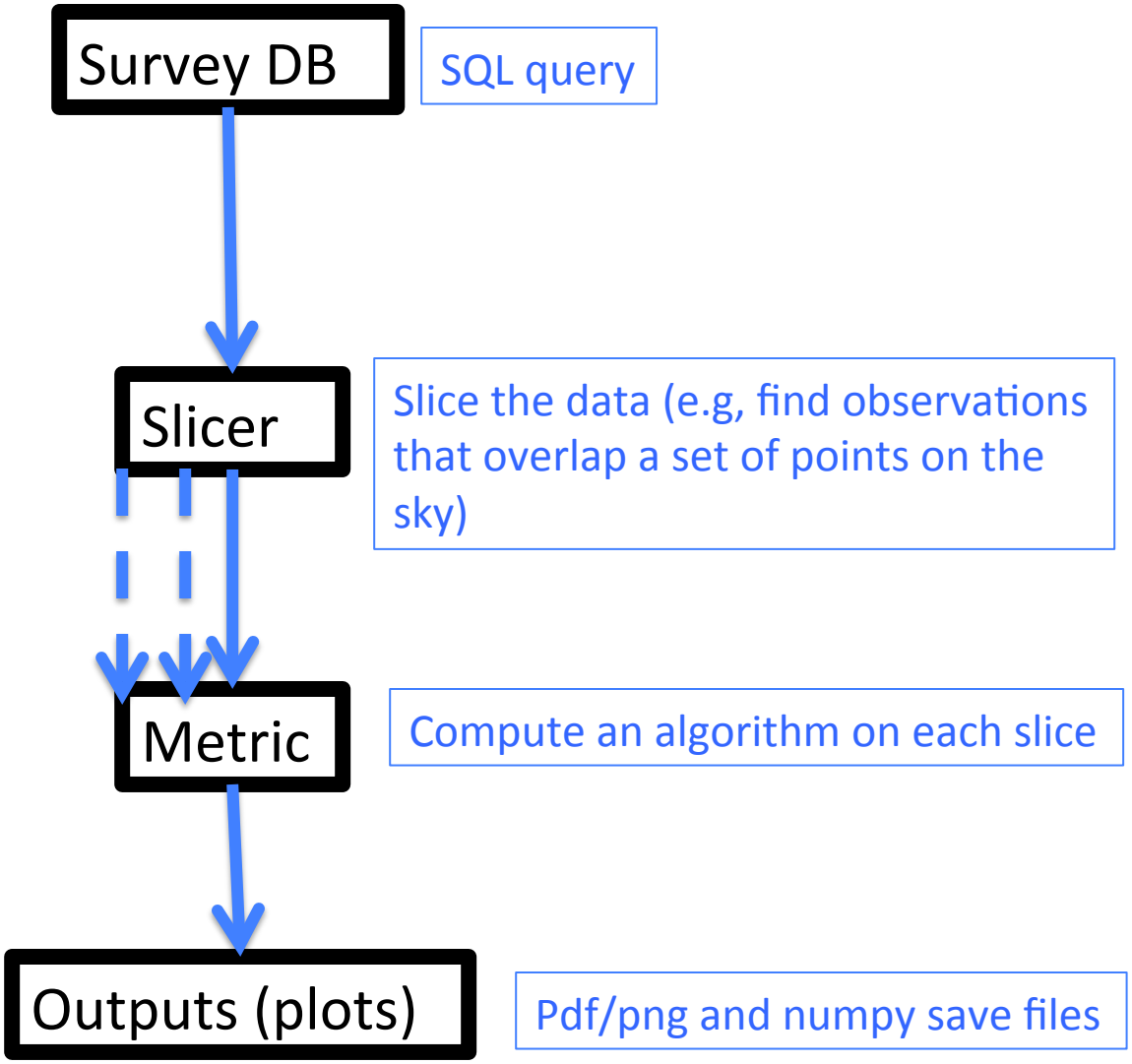
In MAF, computing algorithms is done by **"metrics"**

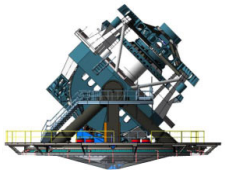
To answer these questions with MAF, you take observations from a database and then pair a slicer and a metric.

The Three Primary Slicers

- UniSlicer
  - Passes all data directly to the metric algorithm.
  - How to answer, “what’s the mean seeing?”, “What is median airmass?”, etc.
- OneDSlicer
  - Slice data based on one parameter.
  - How to answer, “what’s the distribution of exposures **per night?**”, “What’s the distribution of slew times?”
- HealpixSlicer
  - Loops over points on the sky and returns overlapping exposures
  - How to get a map of the sky. Calculate co-added depths.

General MAF Outline





Example slicer + metric combinations

Survey DB — Where filter='r'

Slicer — UniSlicer (pass all the data through to the metric)

Metric — Mean of Seeing

Outputs (plots) — Pdf/png and numpy saves

What is the average seeing in r?

0.65 arcsec

Example slicer + metric combinations

Survey DB

All data

Slicer

OneDSlicer
Slice by slewtime
with 10s bins

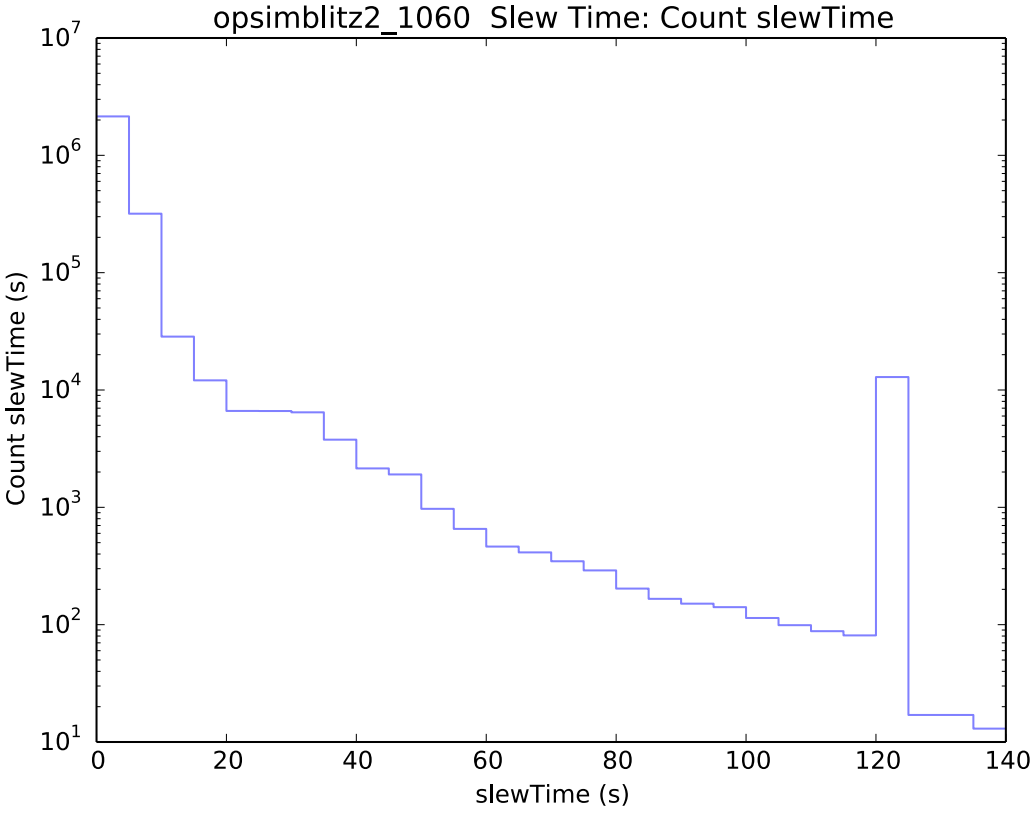
Metric

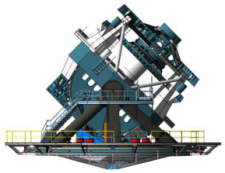
Count

Outputs (plots)

Pdf/png and numpy saves

What is the distribution of slew times?





Example slicer + metric combinations

Survey DB

All data

Slicer

OneDSlicer
Slice by night

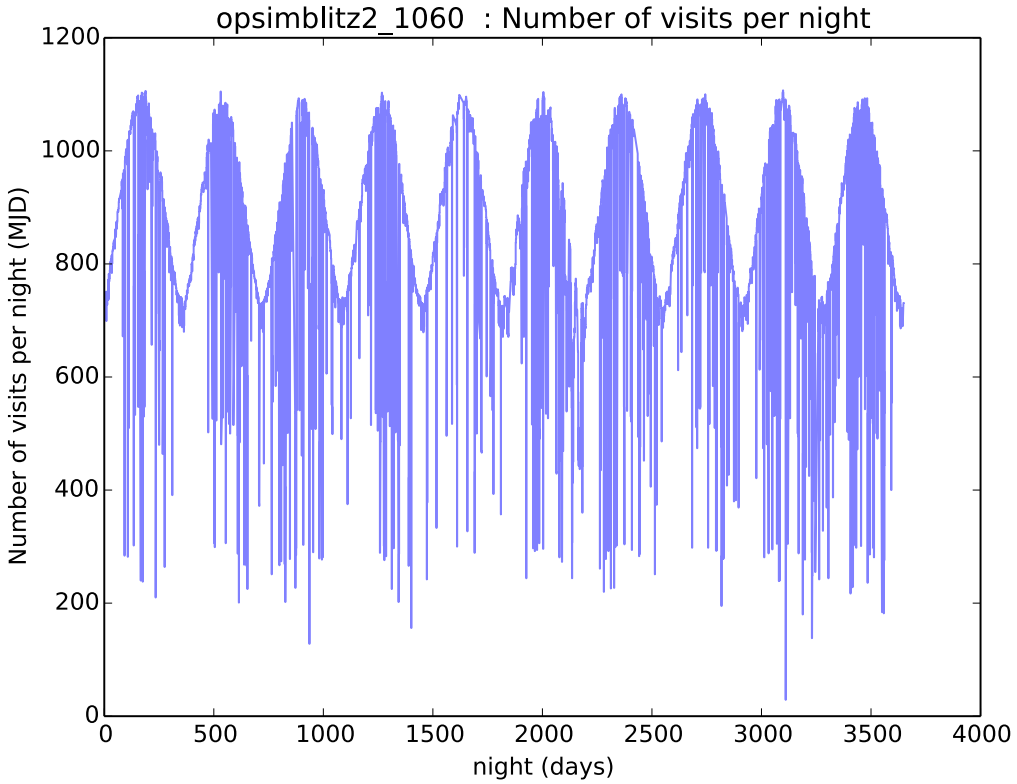
Metric

Number of visits

Outputs (plots)

Pdf/png and numpy saves

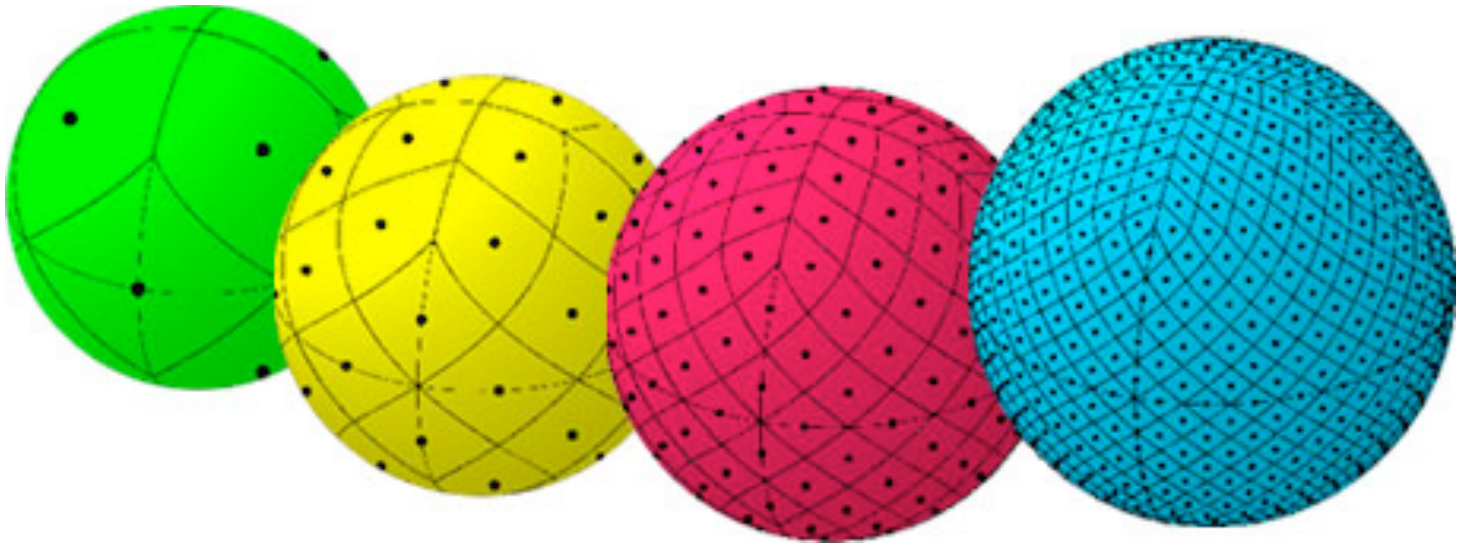
How many visits per night?



Seasonal oscillation and nights with weather and engineering downtime

HEALpixels

- For our spatial binning, we use HEALpixels
  - Equal area pixels
  - Popular with cosmologists, rapidly compute power spectra
  - Or, use a custom list of RA,Dec points
  - Can also bin by OpSim field ID. Faster, but field overlaps are not resolved



MAF Examples

Survey DB

Filter = ‘g’

Slicer

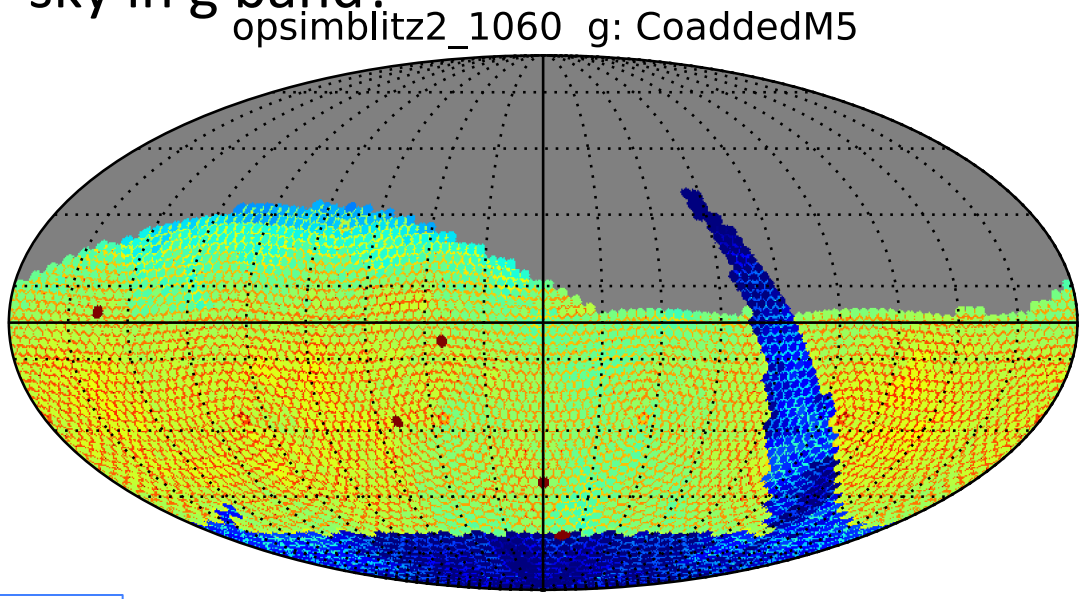
HealpixSlicer

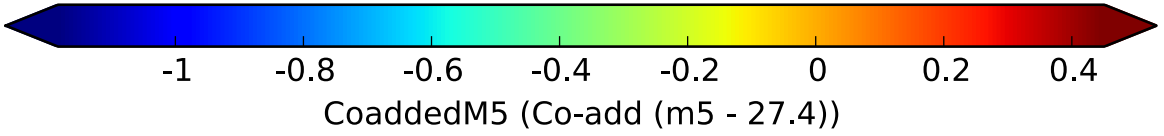
Metric

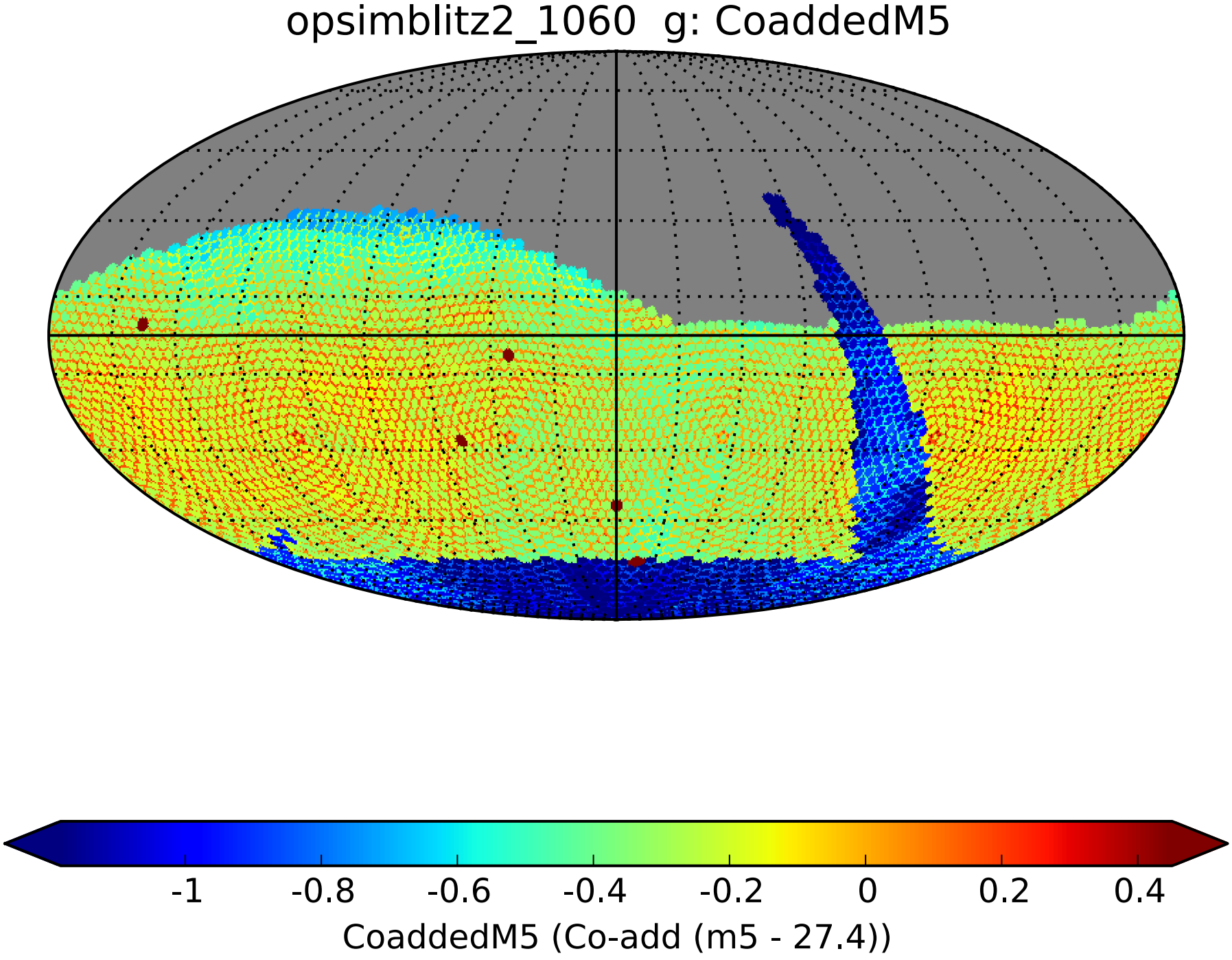
Coadded depth
Given single visit depths

Outputs (plots)

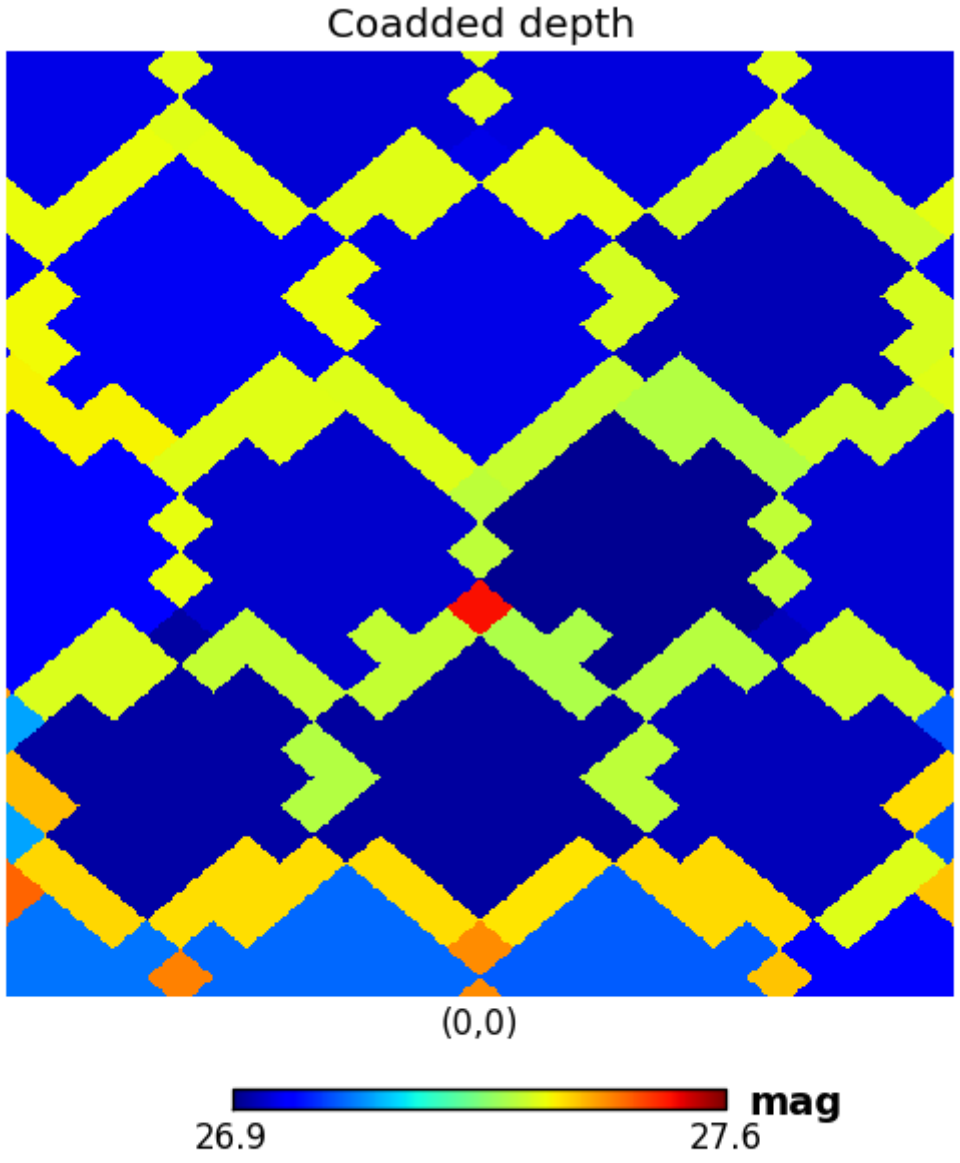
What is the coadded depth across the sky in g band?



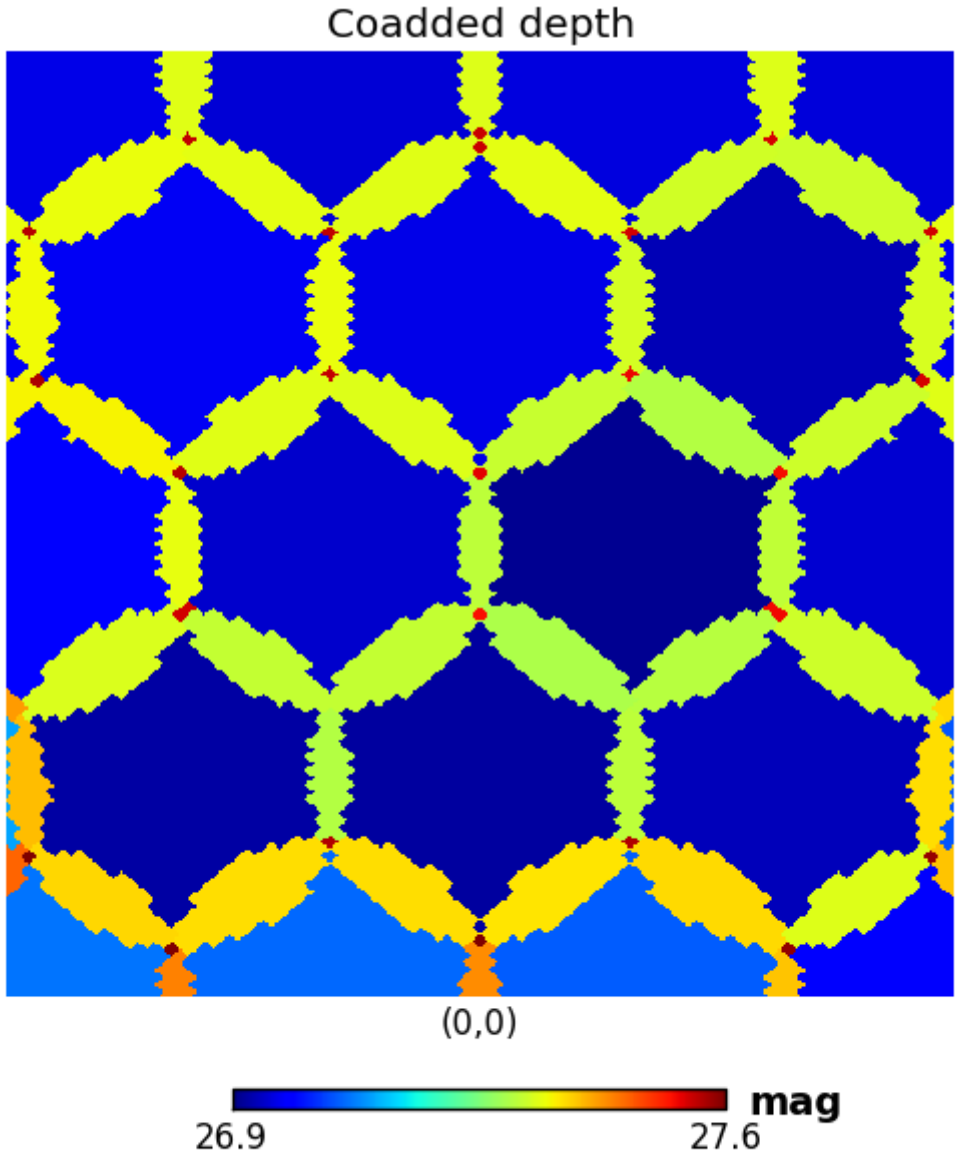



opsimblitz2_1060 g: CoaddedM5
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
CoaddedM5 (Co-add (m5 - 27.4))

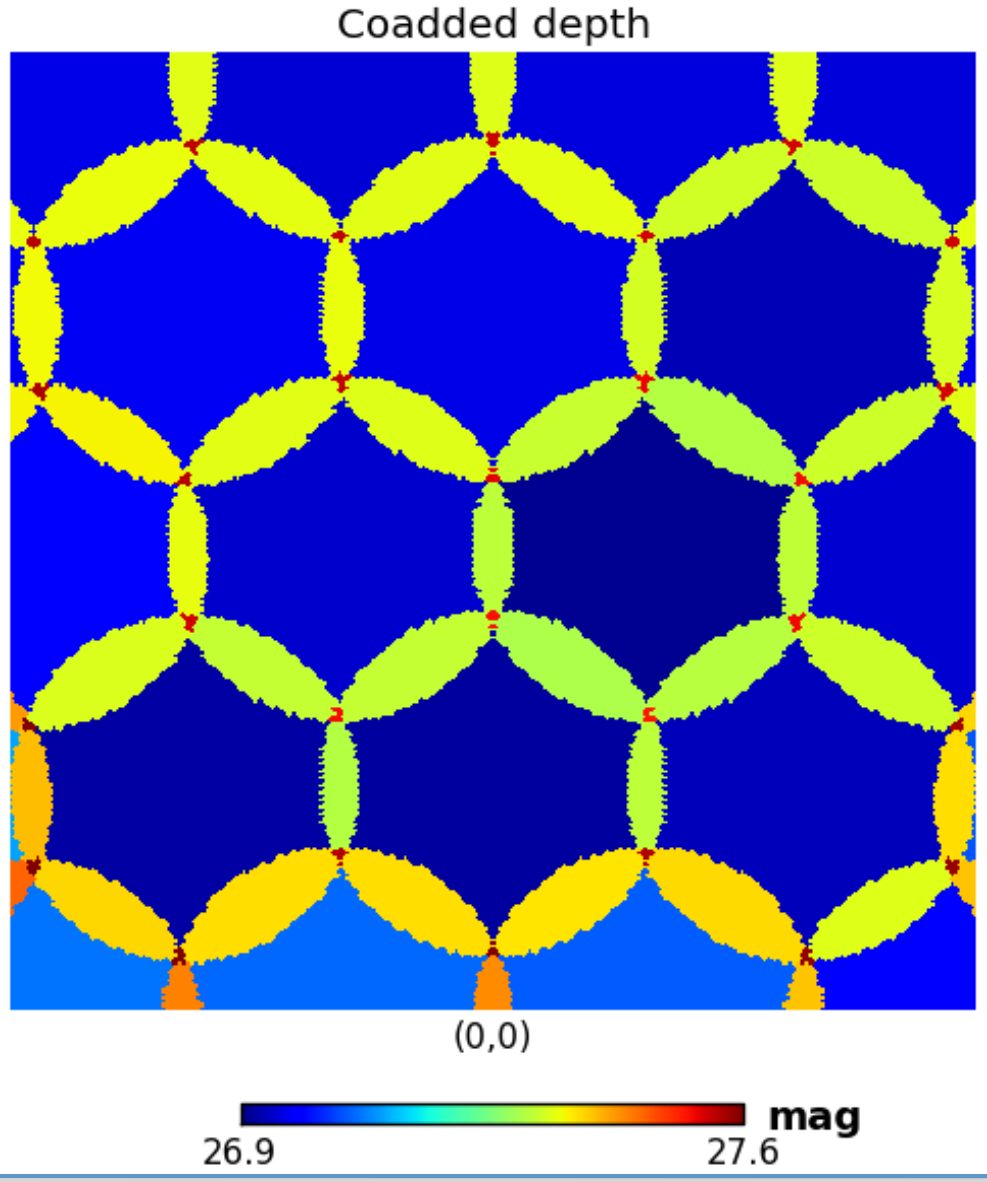
nside=128, 27.5 arcim resolution



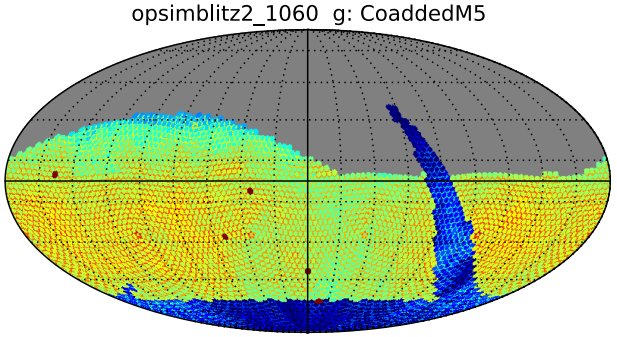
Nside=512, 6.9 arcmin resolution



Nside=1024, 3.4 arcmin resolution



MAF Examples



Survey DB

Filter = ‘g’

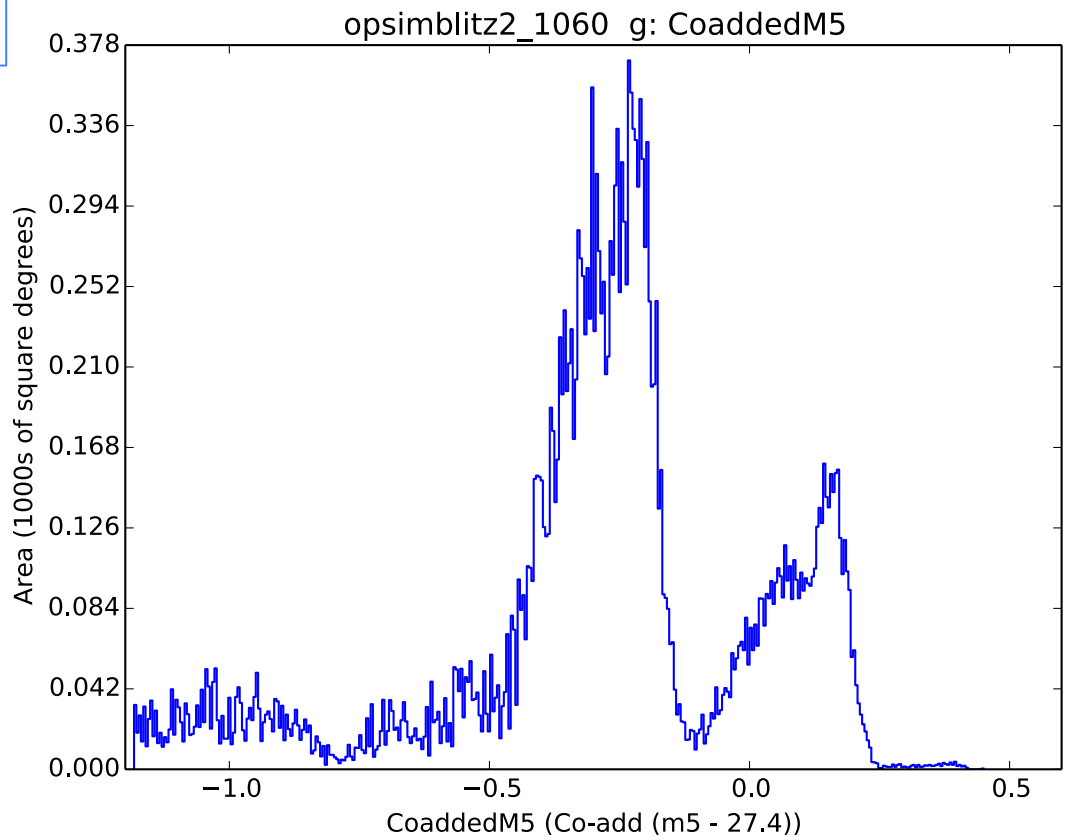
Slicer

HealpixSlicer

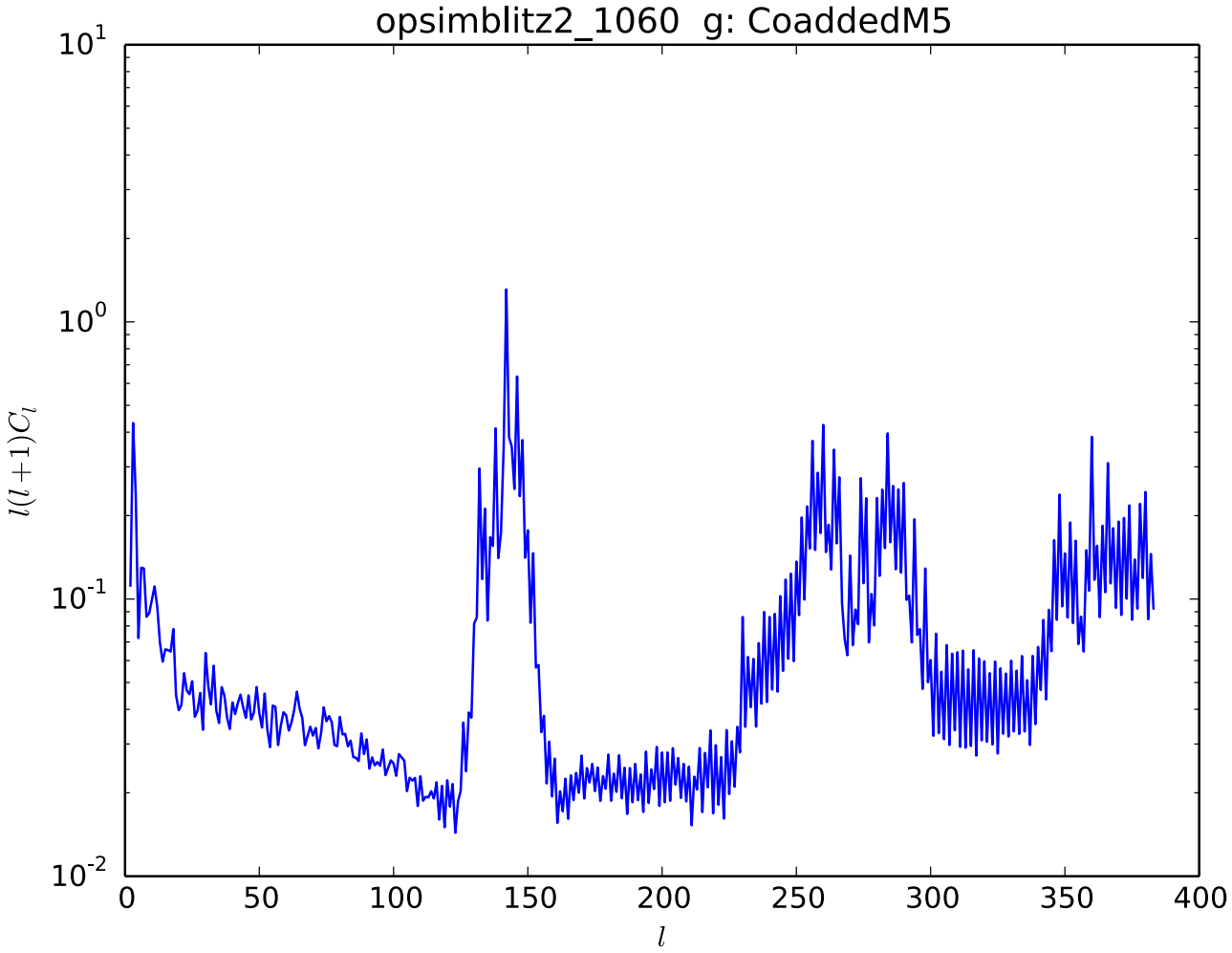
Metric

Coadded depth
Given single visit depths

Outputs (plots)



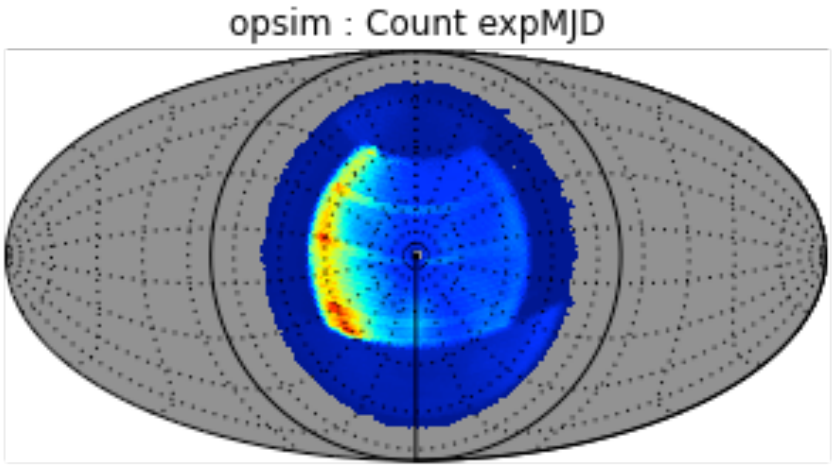
Healpixels let us compute Power Spectra

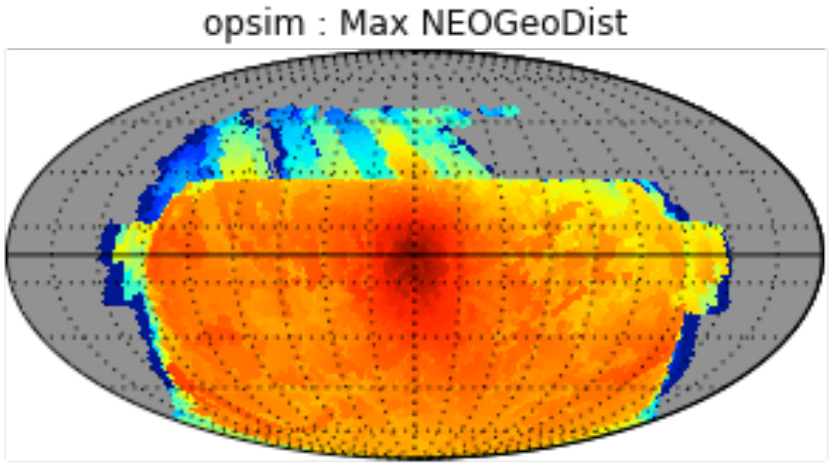


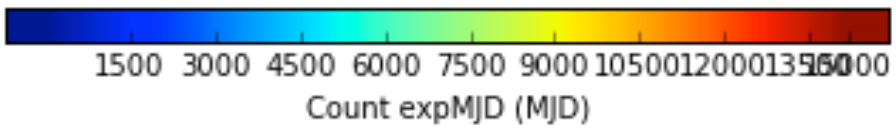
Peak at l=140 (~1 degree), caused by field overlaps
Peak at l=270 from triple overlaps.

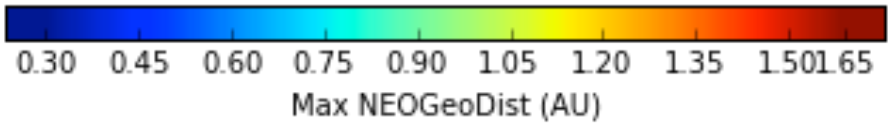
Healpix beyond RA,Dec

- The HealpixSlicer defaults to RA,Dec, but can be set to use Alt,Az or ecliptic coordinates.

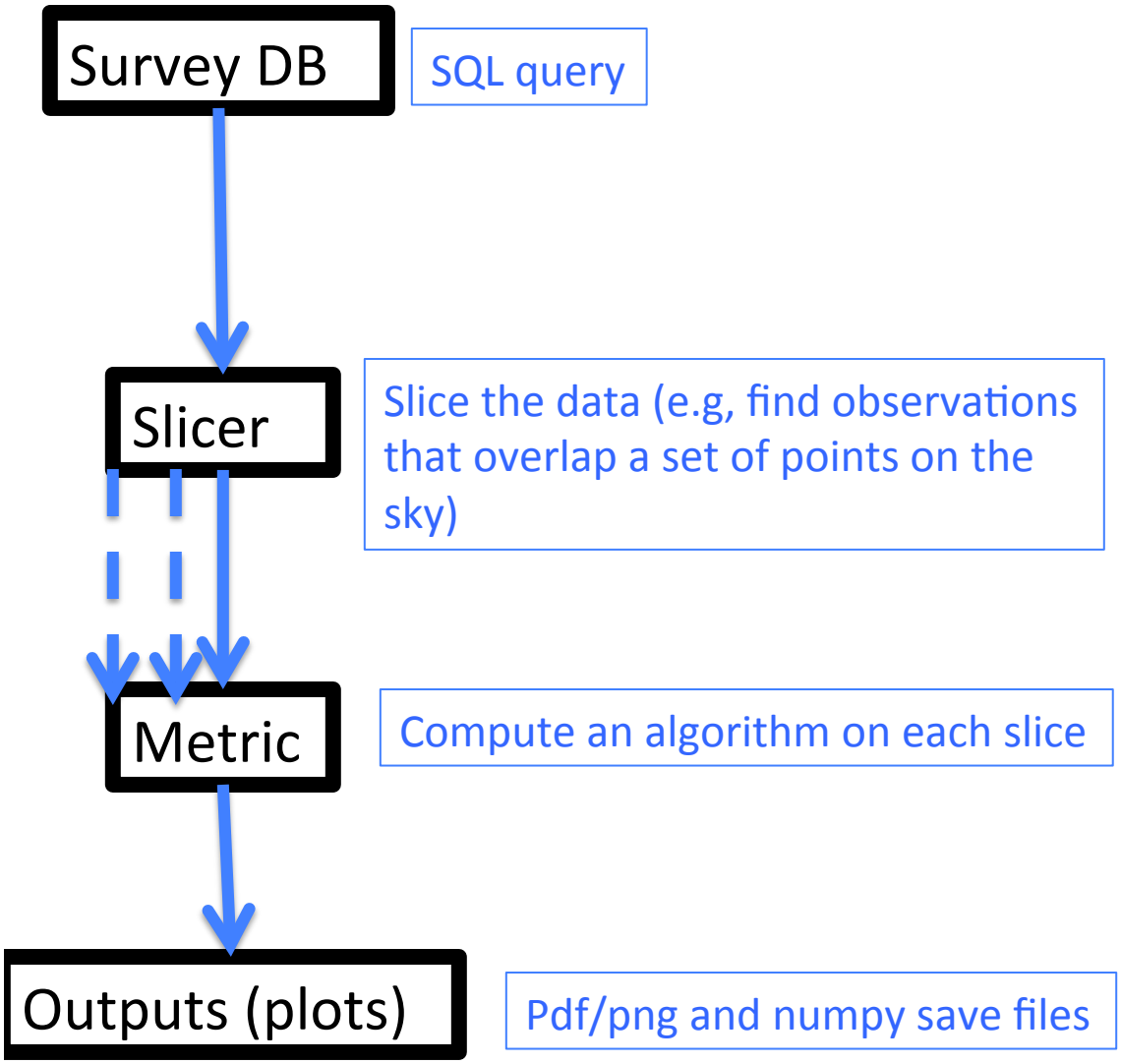








Does it go in the SQL or the Slicer?



The slicer determines the type of output plot. We tend not to plot things as a function of filter or proposal ID, so those are set with the SQL where-clause

Sometimes we use SQL for time, e.g., if we want to look at the first year performance of the survey. Other times the slicer will slice on time.

Recap: slicer + metric

- Which slicer you pick will determine your output plots
- Three main slicers
  - UniSlicer: Pass all the data, returns a number
  - OneDSlicer: Slice by one variable (like per night), returns a single plot (like histogram)
  - HealpixSlicer: Slice on observations overlapping healpixels, return a skymap, histogram, and powerspectum
- Many metrics to pick from
  - coaddm5
  - Max
  - Mean
  - Median
  - Min
  - FullRange
  - Rms
  - Sum
  - RobustRMS
  - Binary
  - FracAbove
  - FracBelow
  - OpenShutter
  - Completeness
  - Parallax
  - ProperMotion
  - Fft
  - Supernova
  - Uniformity
  - TemplateExists
  - VisitGroups

Additional Capabilities

- Summary Statistics
- Stackers: Adding derived columns

Summary Stats on a HealpixSlicer

Survey DB

Filter = 'g'

Slicer

HealpixSlicer

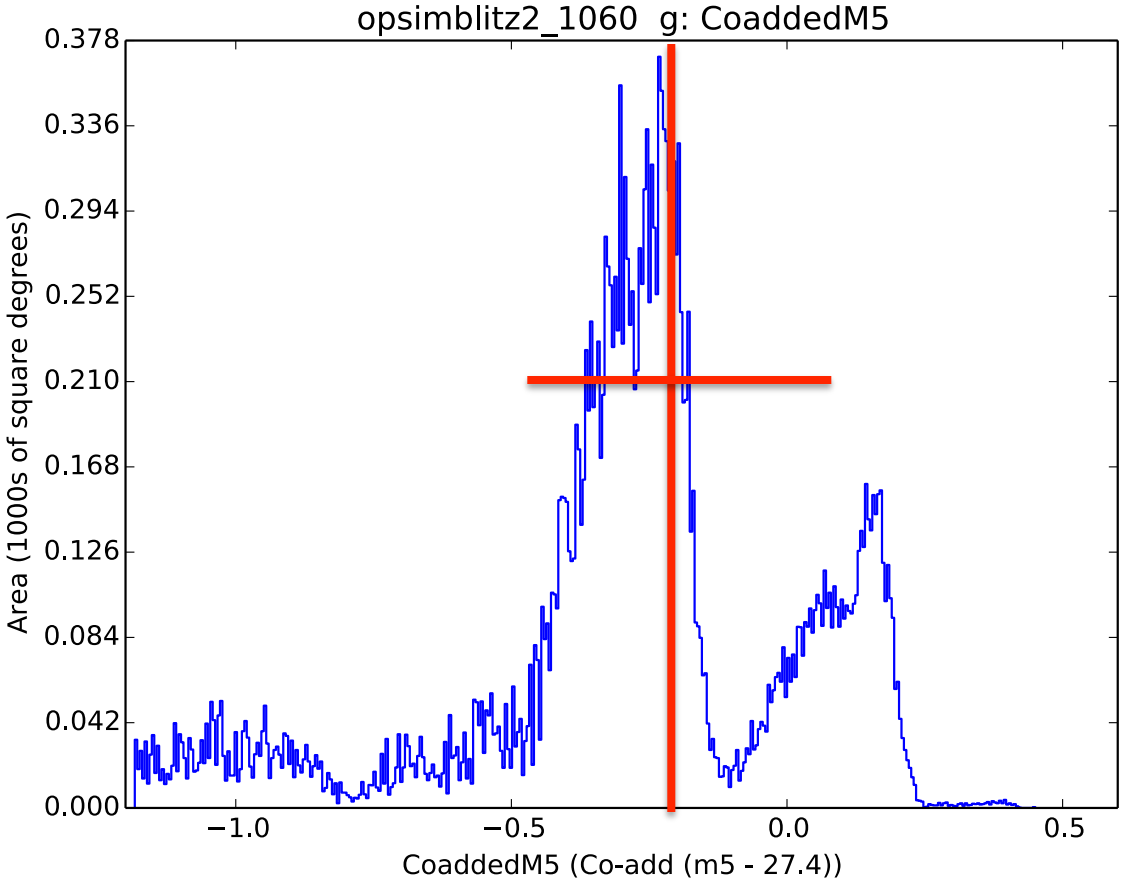
Metric

Coadded depth
Given single visit depths

Outputs (plots)

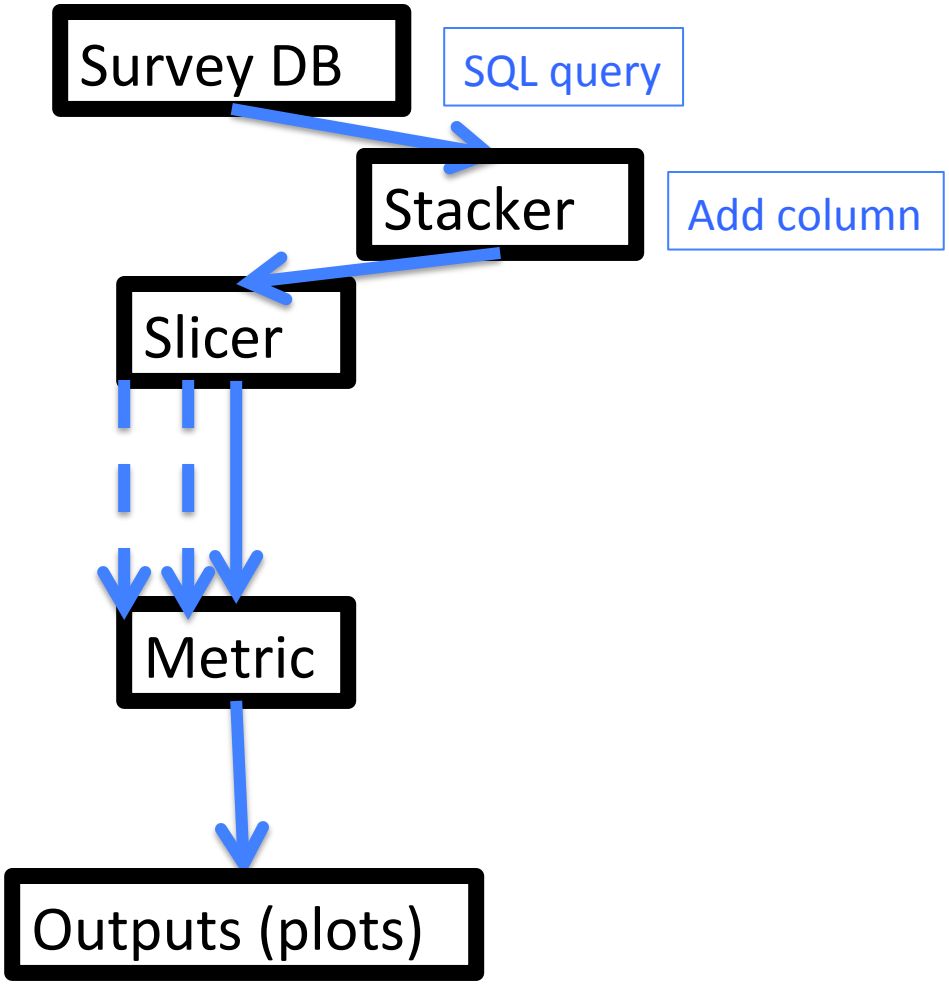
Summary stats

Compute a metric on your results



e.g.,
Mean and RMS of metric values

Add a psudo-column



Sometimes it's convenient to calculate a new column that isn't present in Opsim before slicing the data.

For example, normalized airmass, parallax factor, dither offset, hour angle.

We have "stackers" that allow you to stack new columns onto the SQL results before they are passed to the slicer. (we're calling them stackers since we are using the numpy stack functions to add columns to numpy arrays)

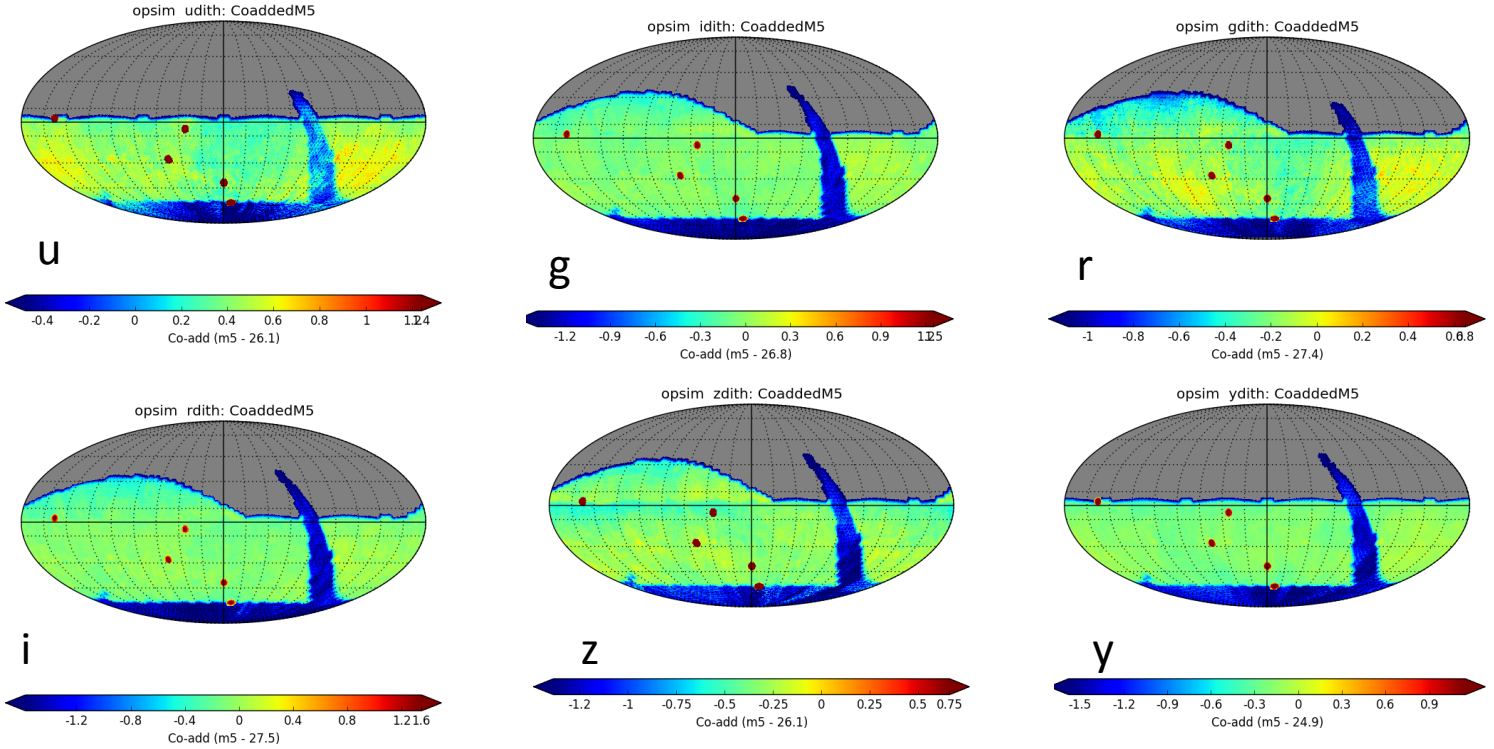
Slicer + metric summary

- UniSlicer + metric = single number (mean seeing)
- OneDSlicer + metric = histogram (or something per night)
- HealpixSlicer + metric = skyplot, histogram, power spectra

As we'll see in the code, to run MAF you define a "metricBundle" that has a metric, slicer, and sql constriant (and optionally stackers, summary stats, plot kwargs).

Example MAF Output

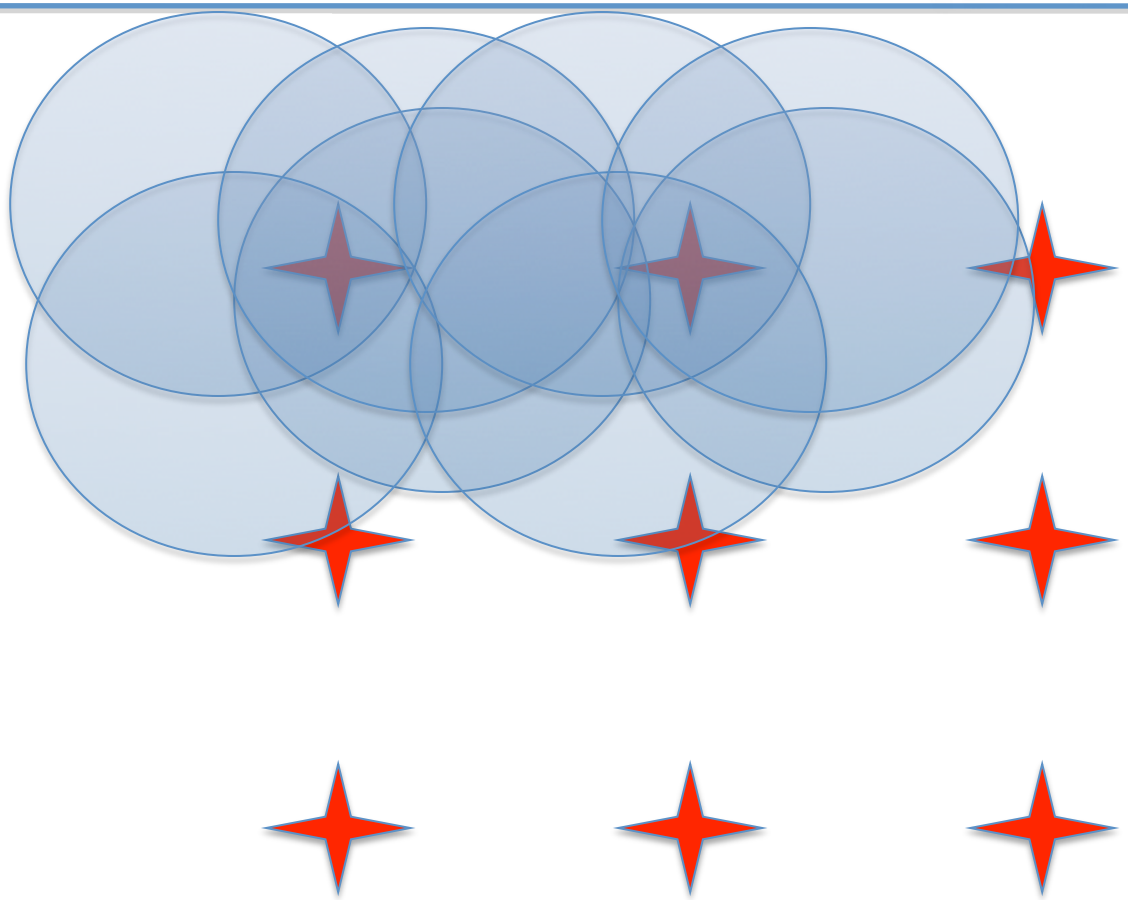
- Can create large reports with MAF
  - Number of Visits, coadded depth, median single-visit depth, median airmass, median seeing
    - Per filter, Per proposal ID



One way to think about the Healpix grid

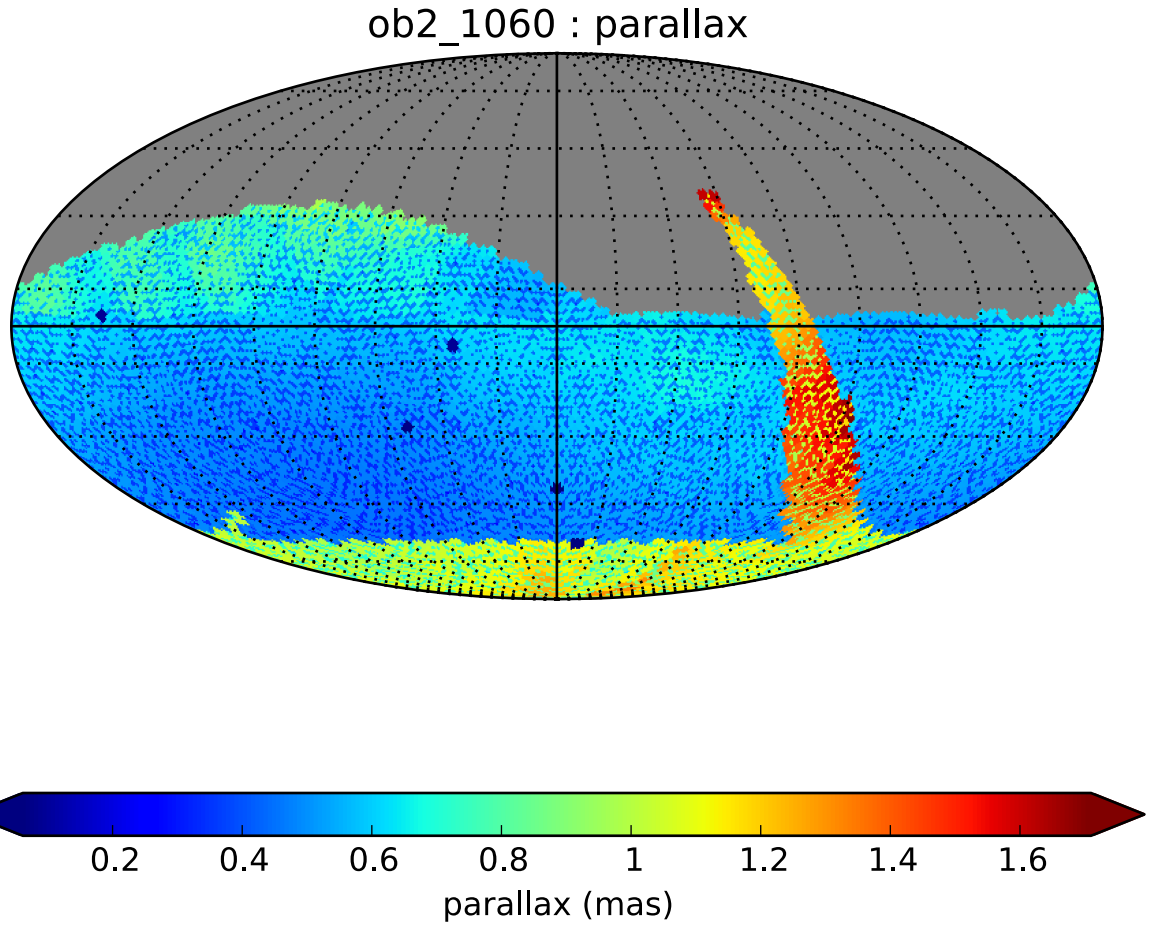
Which observations overlap star/galaxy/ healpixel #1?
Pass those to the metric algorithm and save the result

Which observations overlap star/galaxy/ healpixel #2?
Pass those to the metric algorithm and save the result.



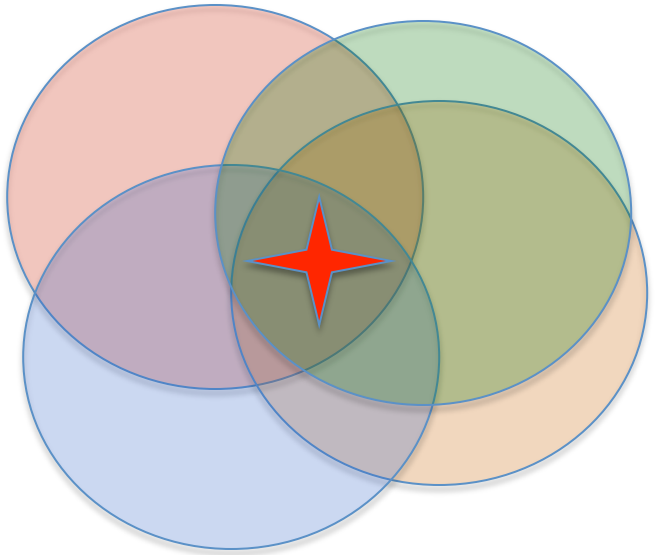
Parallax Example Metric

- For each observation, compute the parallax factor of the observation (with a stacker)
- At each healpixel, assume there is a mag=20 star with 1” parallax
- Use the 5-sigma depth and seeing to compute the expected centroid uncertainty



How well can we measure X given a sequence of observations?

Given the list of observations (dates, filters, seeing, etc.) of your favorite type of object, can we quantify how well we can do a science?



Given those observations:

- X% of z=1.5 supernova would be discovered
- The proper motion fit for a star would have a precision of X milliarcseconds
- The shape of a galaxy could be recovered to X%
- We could get follow-up spectra on X of the observations

We need the algorithms to convert an observation list into a science result.

Metrics we have developed already

- Proper Motion and Parallax fit uncertainties
- Transient light curve detection and characterization
- Period fitting
- NEO detection distance

All of these can be sub-classed and extended to write your own metrics, you don't have to start from scratch!

MAF vocab

- OpSim: The Operations Simulator that outputs a database of simulated observations
- Slicer: The part of MAF that slices data correctly to make histograms, sky maps, etc.
- Metric: The algorithm that is computed on each slice from the slicer
- Stacker: Adds a psudo-column to the OpSim
- Healpixel: A single pixel on an equal area tessellation of the sky.
- Summary Statistic: A metric that gets computed on the results of all the slice points (e.g., a mean-of-means across the sky).

Conclusions

- The essence of MAF
  - Select a set of OpSim observations using a SQL query
  - Use a slicer + metric to analyze the resulting set of observations

Example iPython Notebooks

Github repo: http://ls.st/nm3

Introductory Notebooks

IntroductionNotebook.v3.ipynb: Our introductory notebook, including installation instructions.
Slicers.v3.ipynb: Shows how the same metric can be run with three different slicers to produce different outputs.
TestNotebook.v3.ipynb: Test that ipython is working and you can load the MAF modules.

Advanced Capabilities

Stackers.v3.ipynb: Example of calculating and adding a new column to the OpSim output "on-the-fly" with MAF. Here, we calculate the hour angle of each pointing and then look at the distribution.
WritingNewMetric.v3.ipynb: A guide on how you can write and add your own algorithm into MAF by sub-classing an existing metric.
UsingMetricBundleData.v3.ipynb: Example of saving/restoring analysis and then adjusting and combining plots.

Static Science Notebooks

DepthGoodSeeing.v3.ipynb: Using SQL constraints to compare coadded depth and coadded depth of only visits taken under good seeing conditions.
DepthPerYear.v3.ipynb: An example of using SQL constraints to see the evolution of the coadded depth through the survey.
Dithers.v3.ipynb: MAF includes several potential dithering schemes. This notebook demonstrates those dither patterns and compares their effect on the resulting power spectrum.
NVisitsCoadd_AllFilters_DitherComparison.v3.ipynb: Examines the number of visits in each filter as well as comparing dithered and undithered surveys.

Solar System and Astrometry Notebooks

AstrometryMetrics.v3.ipynb: Example of running our proper motion and parallax metrics.

Transient Notebooks

TransientMetric.v3.ipynb: Example of our transient metric where you can set a simple transient light-curve shape and set a variety of detection criteria to measure the fraction of such transients LSST can recover.

Variable Notebooks

Our variable metrics are in the sims_maf_contrib repo. A notebook example of them can be found here.

Clone and Launch Notebooks

1st time only

> git clone git@github.com:lsst-sims/sims_maf_notebooks.git

> cd sims_maf_notebooks/notebooks

> ln –s <path to OpSim database enigma_1189_sqlite.db> . #or cp

Every time

> source loadLSST.bash #setup the LSST stack

> setup sims_maf –t sims #setup MAF

> ipython notebook #Launch ipython

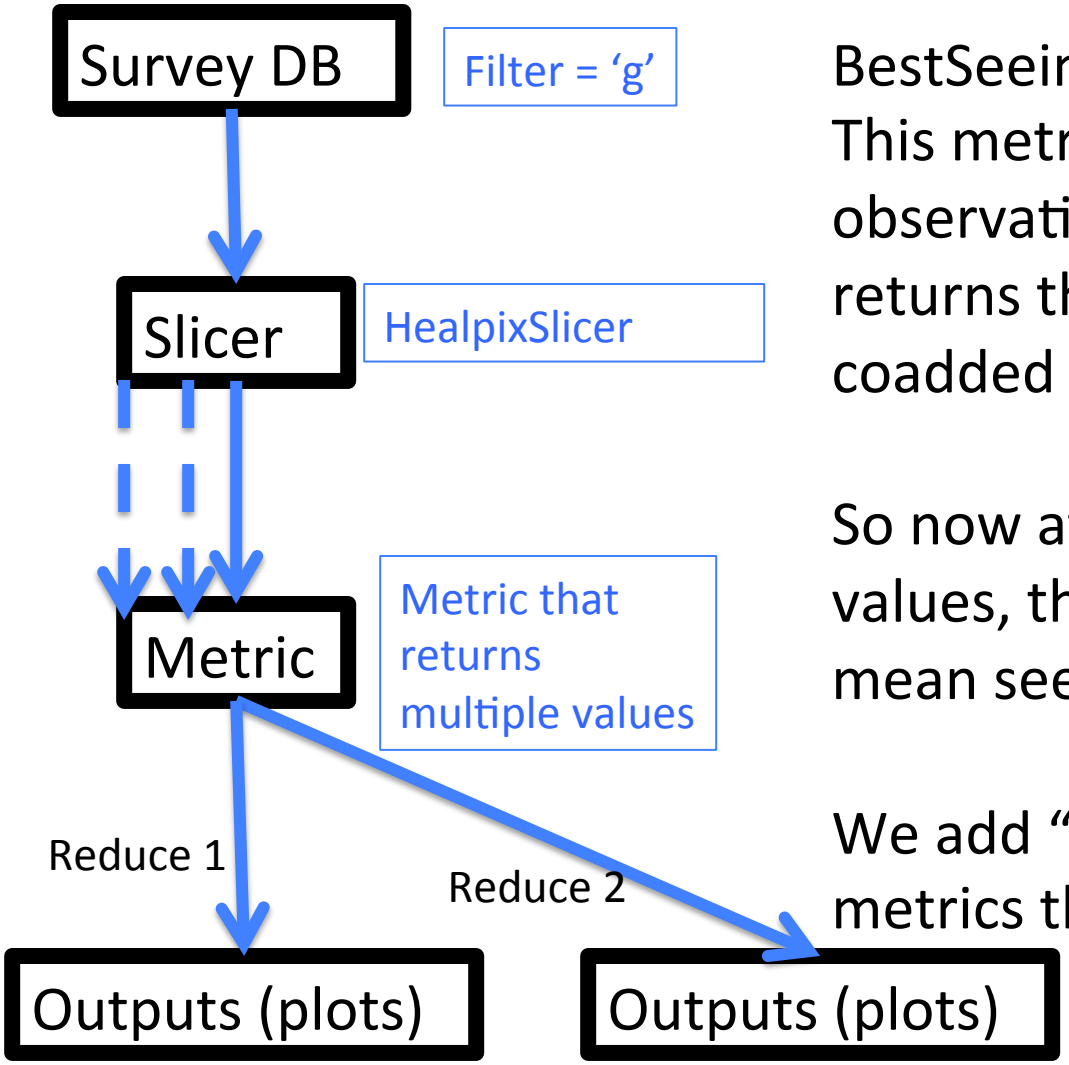
Cadence Metrics

- We have developed a number of metrics to help optimize the scheduler for time-domain science.
  - Early good seeing
  - Parallax and proper motion
  - Supernova
  - AGN
  - Solar System
  - Temporal uniformity

We want MOAR!!

Quantify your science for us

What if my metric returns multiple values?

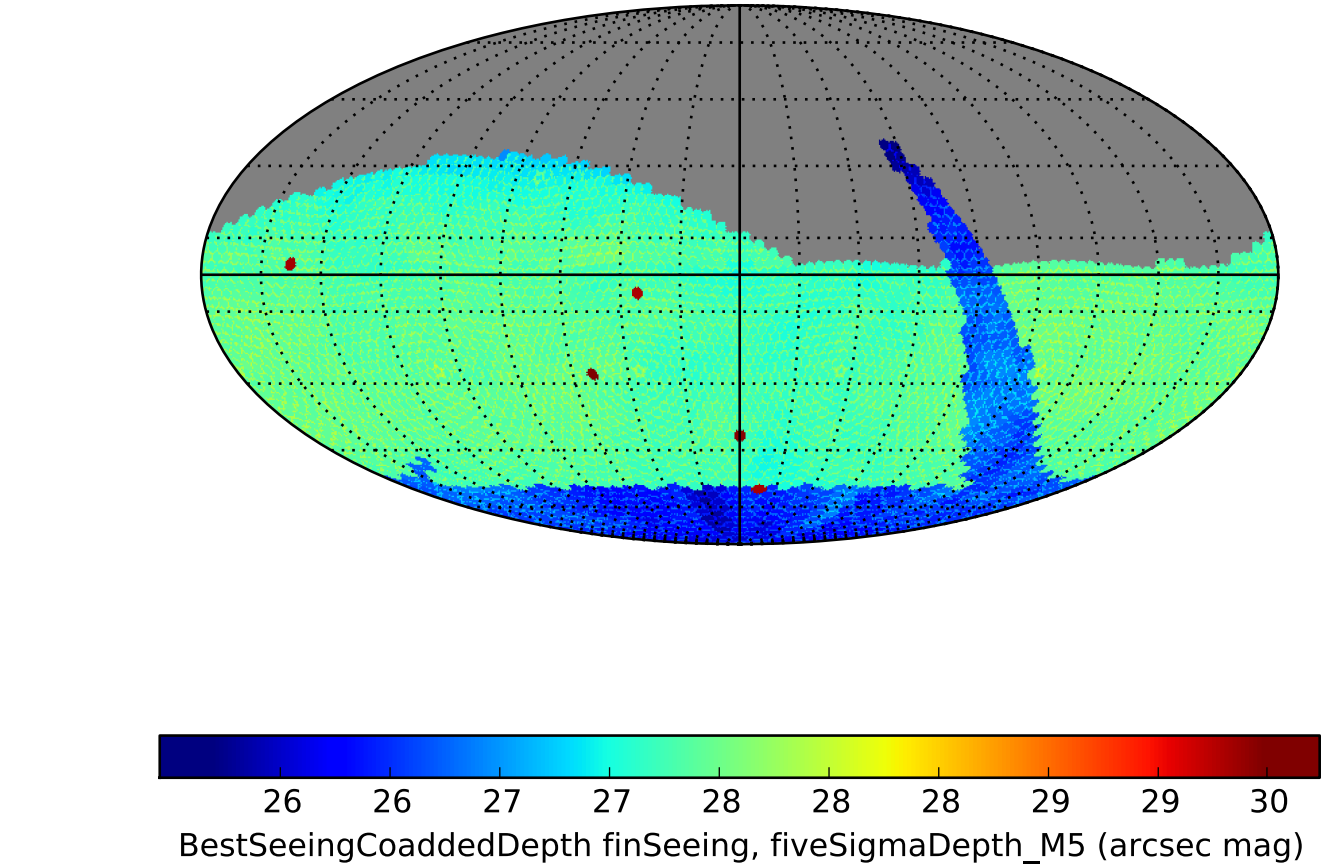


BestSeeingCoaddMetric:
This metric takes half of the observations with the best seeing and returns the resulting mean seeing and coadded depth.

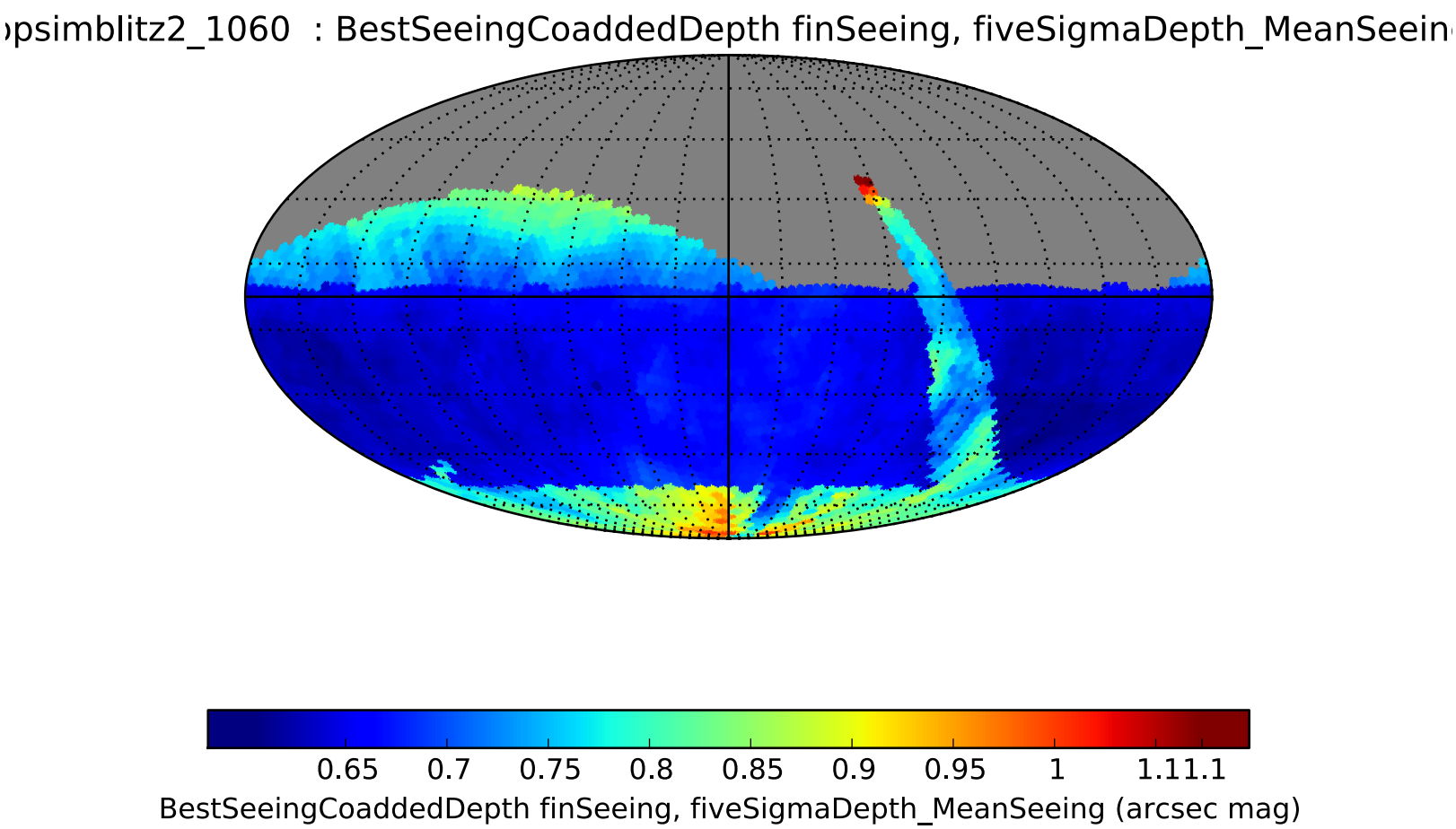
So now at each Healpixel, we have 2 values, the coadded depth and the mean seeing.

We add "reduce functions" to these metrics that return single values

Result from 1st reduce function, coadded depth



Result from 2nd reduce function, mean seeing



Make sure you have the latest version

Setup your stack and update to the latest version

```
>source ~/lsst_home/loadLSST.sh #or similar
>eups distrib install sims_maf --t sims
>setup sims_maf --t sims
```

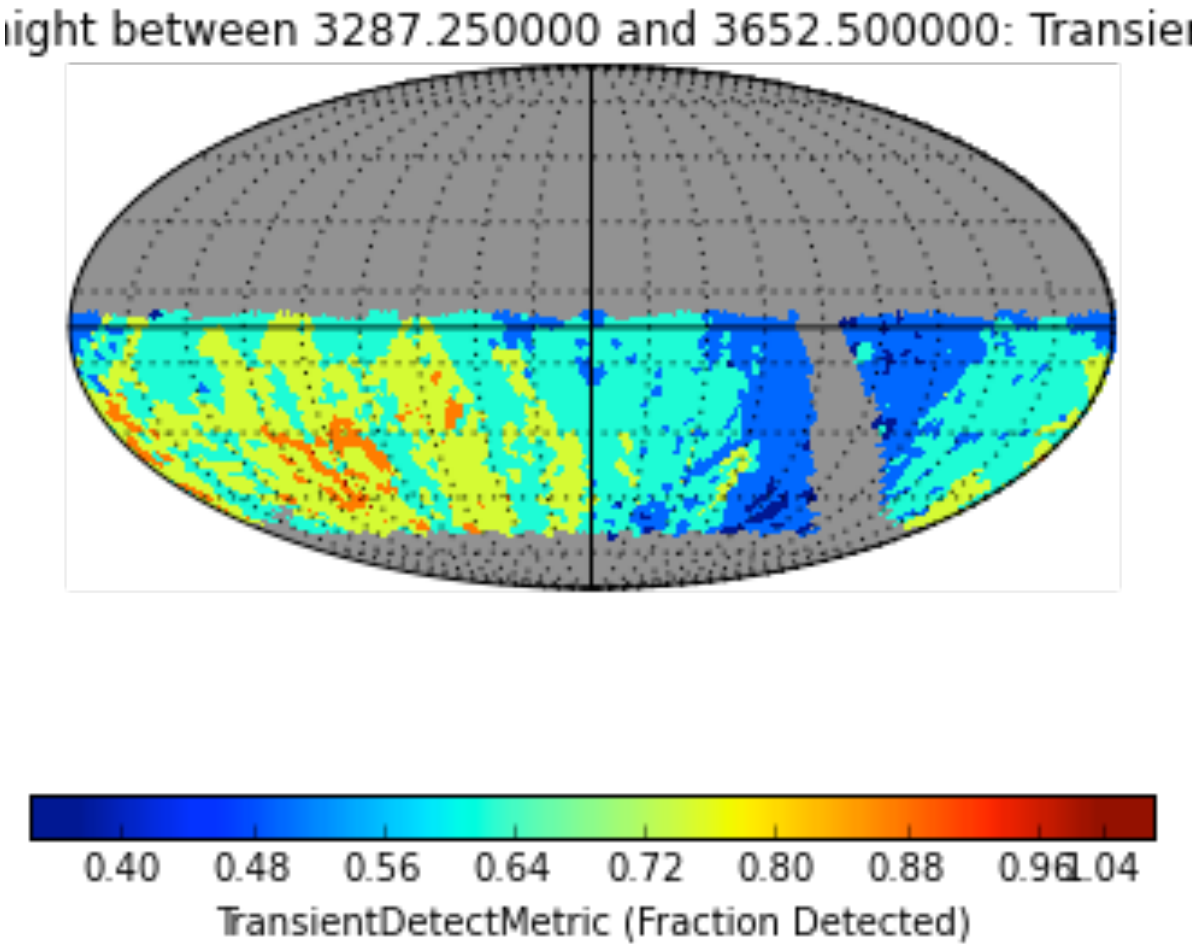
links

- Emails
  - Peter: yoachim@uw.edu
  - Lynne: ljones.uw@gmail.com

- Conference talks:
  - https://github.com/LSST-nonproject/XXX

Supernova Metric

- Construct a simple saw-tooth light curve
- At each healpixel, have a z=0.5 SN blow up every 45 days.
- Determine what fraction of them are detected in any filter



MAF

- Basic info about MAF
  - A framework for finding out how well an executed survey meets your science needs.
  - All Python, part of the LSST stack
  - Install instructions here:
    https://confluence.lsstcorp.org/display/SIM/Catalogs+and+MAF

General problem of data analysis and dimensionality reduction
2.5 million observations → data cube → sky map → single number

A better name?

Survey Performance Analysis Tool

SPAT