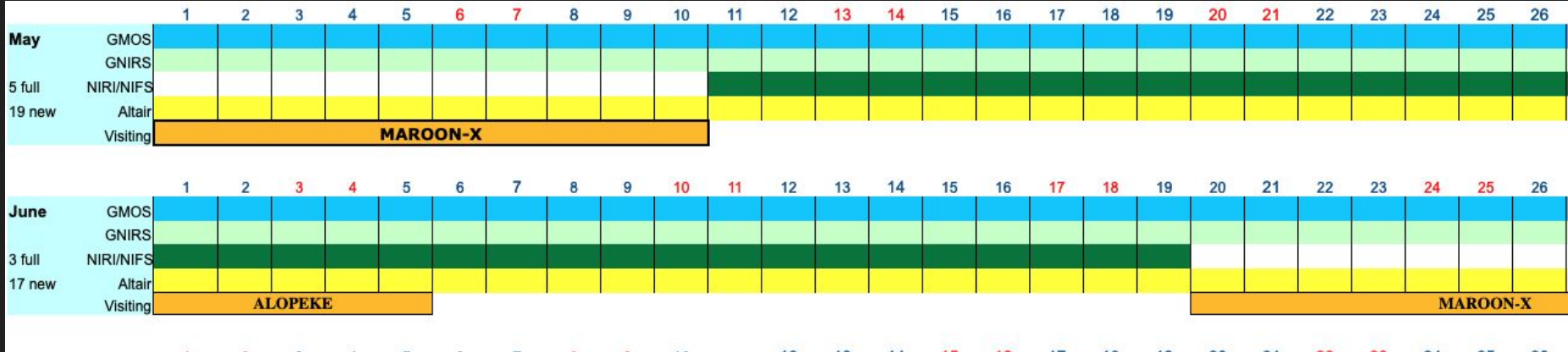


Rubin Observatory Survey Strategy

Peter Yoachim
University of Washington

Traditional telescope scheduling, you have a bunch of proposals ranked by a TAC, then you fill them into a grid.

Here's Gemini North's grid:



Rubin doesn't have a TAC. We just have science pillars

- Dark Matter & Dark Energy
- Catalog the Solar System
- Variable Sky
- Milky Way Structure and Formation

What are some common
observing rules of thumb?

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- Observe at low airmass
- Don't spend too much time slewing around
- (for Rubin), don't change filters too often (takes 2 minutes)
- Use redder filters in bright time

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Is there a common theme to these rules?

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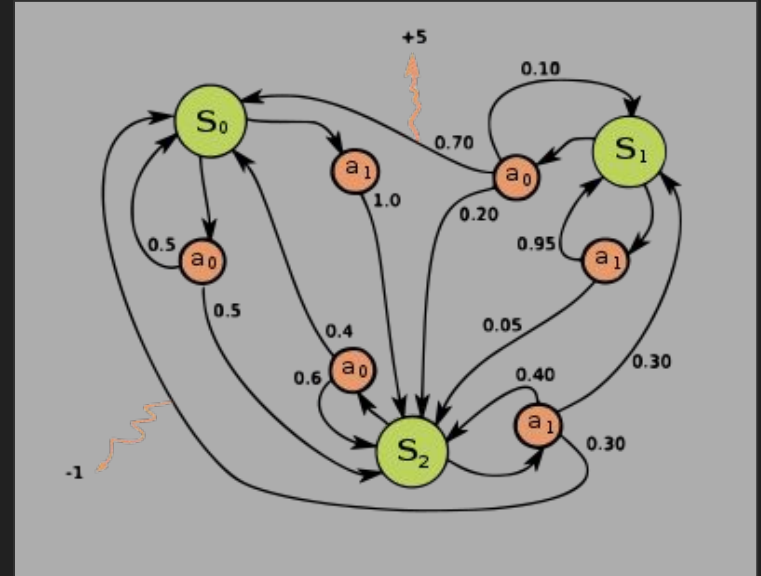
- Observe at low airmass
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Is there a common theme to these rules?

Optimize the signal-to-noise ratio as much as possible

We need an AI capable of observing through the night, and that can recover if there's bad weather or downtime.

Markov Decision Process
Popular with robotics systems



Here's what wikipedia calls a simple Markov Decision Process

MDP

Current state
of telescope
and survey
(features)

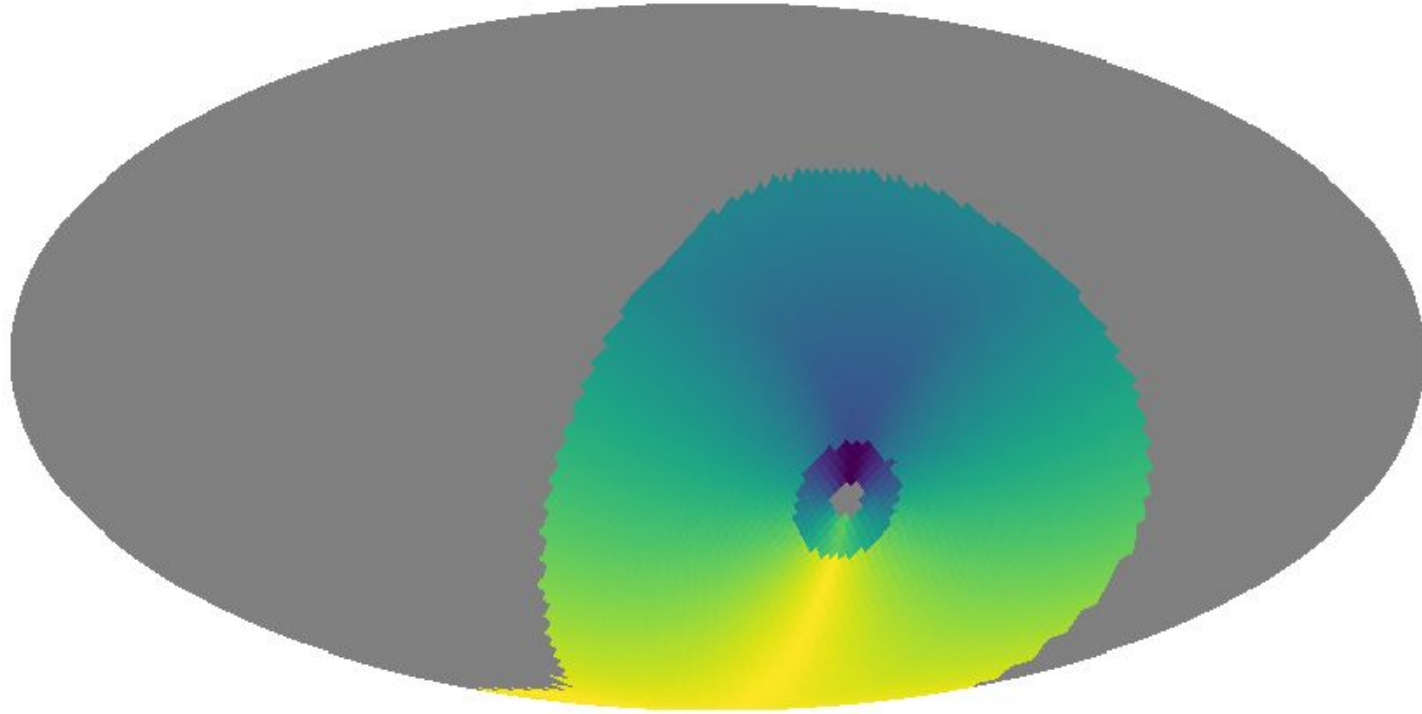
Basis
Functions

Reward
Function

Decision
Function

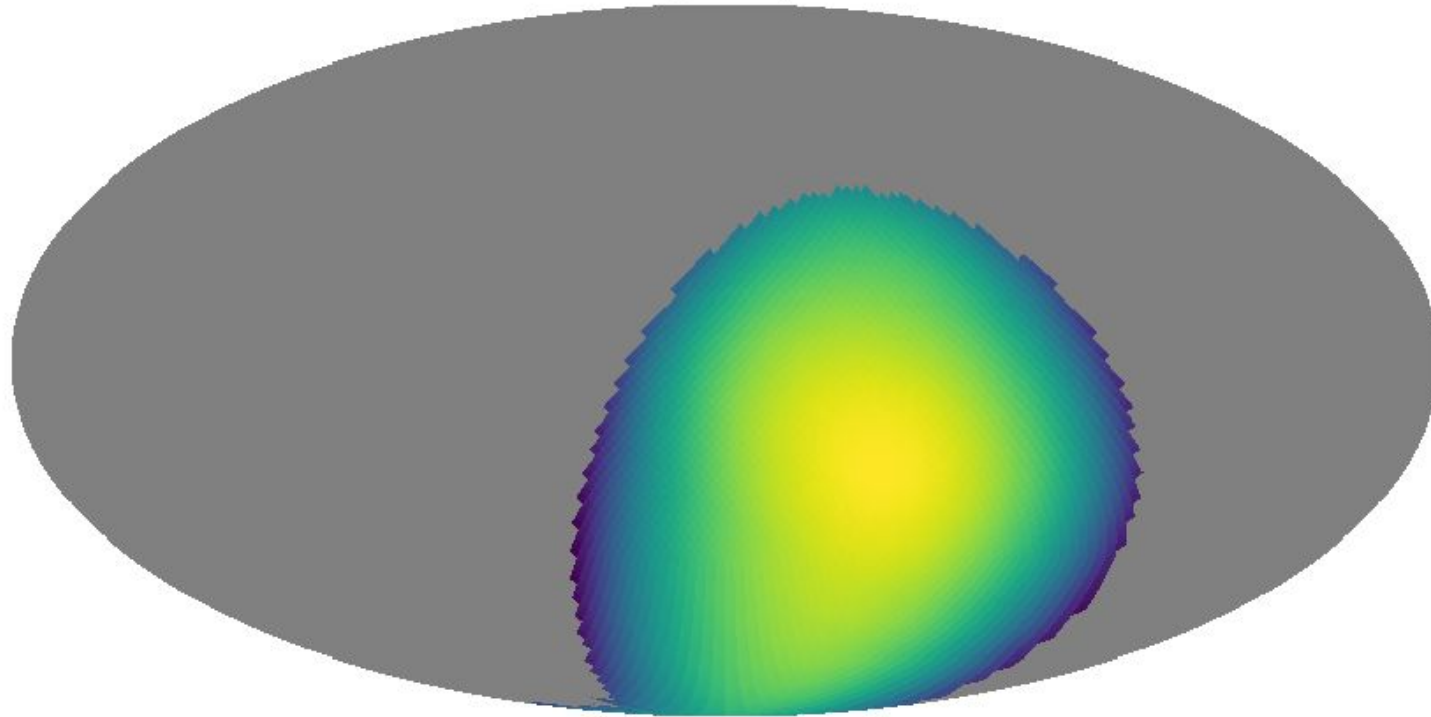
Let's run the telescope for a year, then stop and see what the major basis function look like

Slevertime



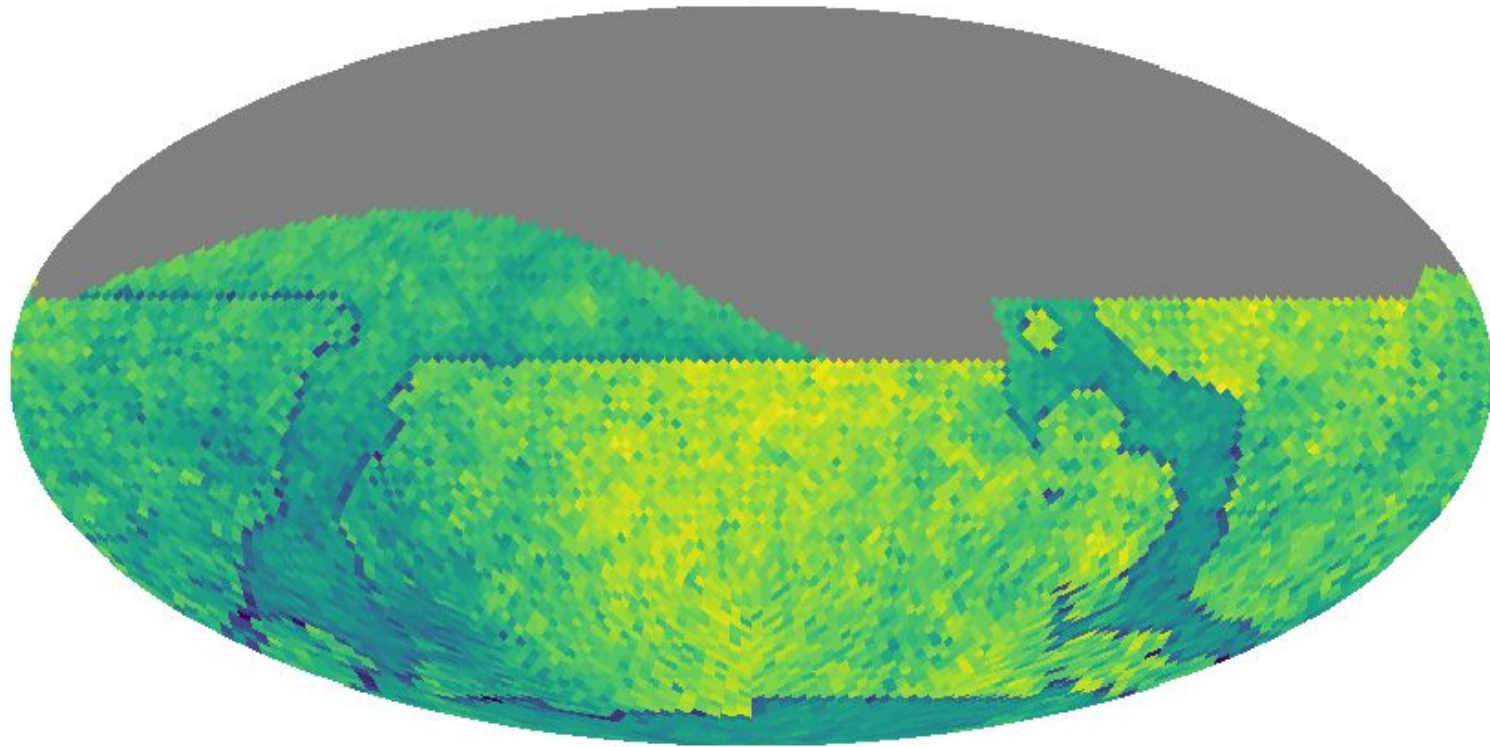
Slevertime map

5-sigma depth



Depth compared to best-possible depth

Footprint

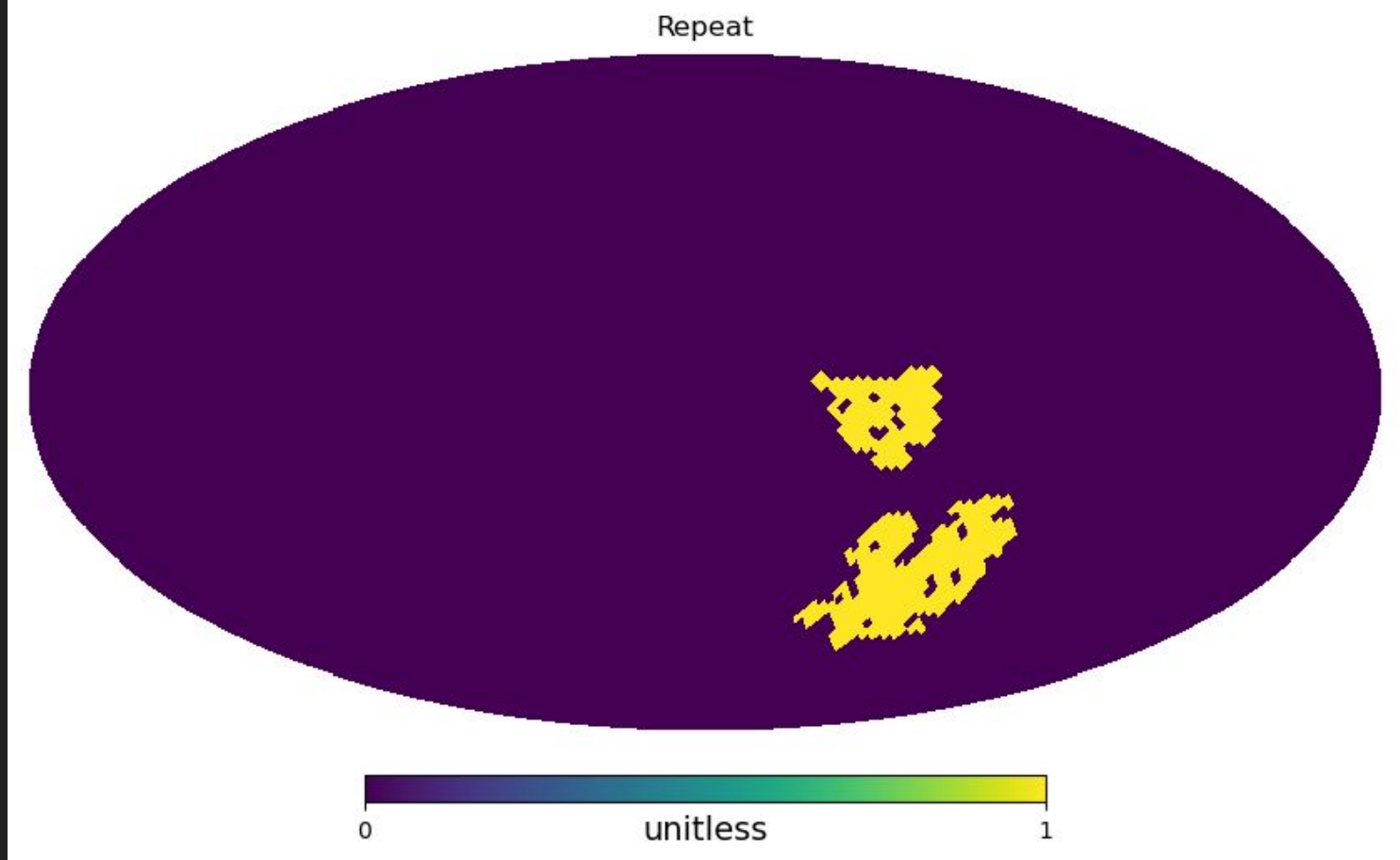


-15.3065

unitless

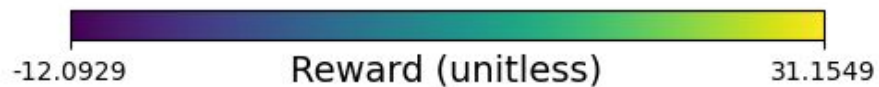
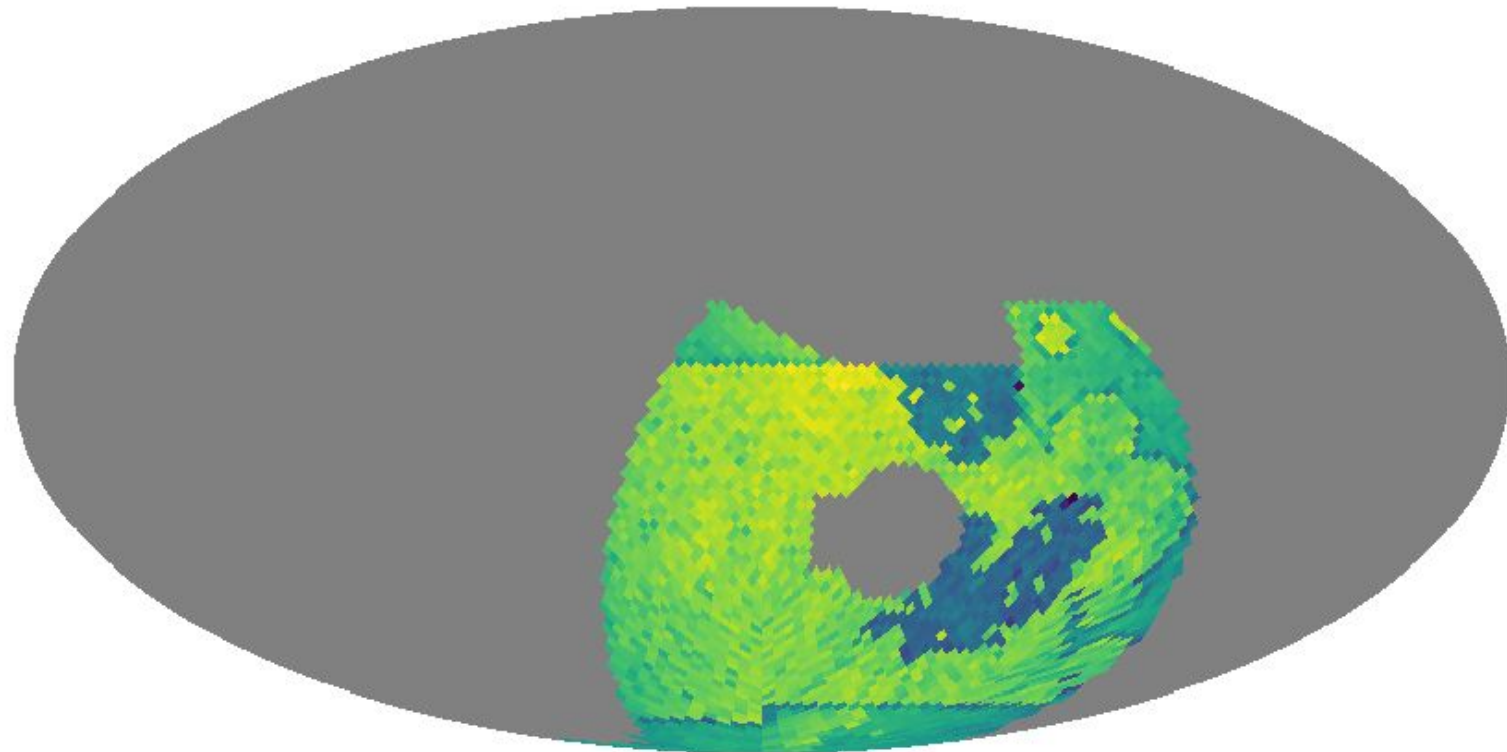
9.69521

Footprint minus desired footprint



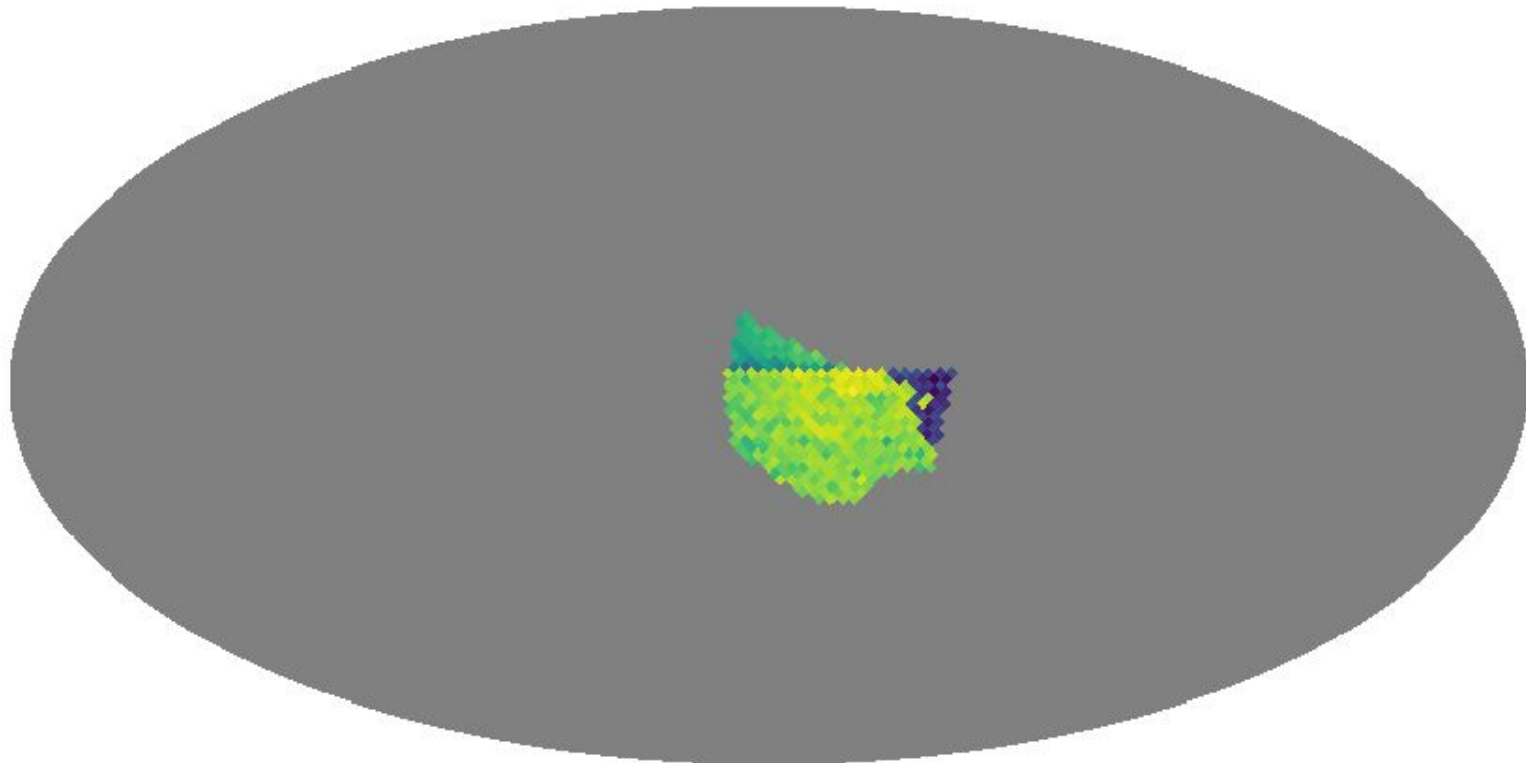
Avoid spots that have already been observed in a night

Reward Function



Linear combination to generate reward

Reward Function



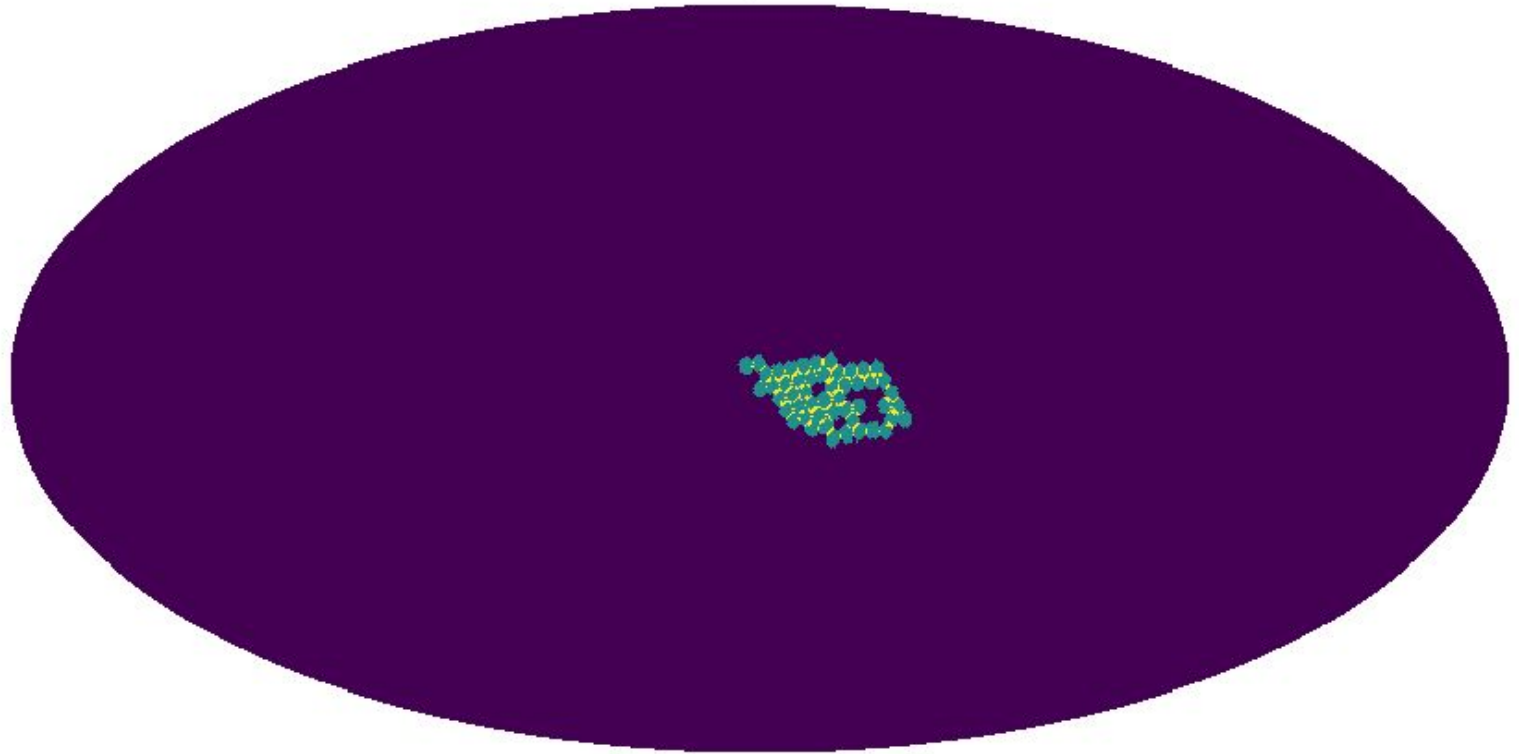
1.59098

Reward (unitless)

31.1549

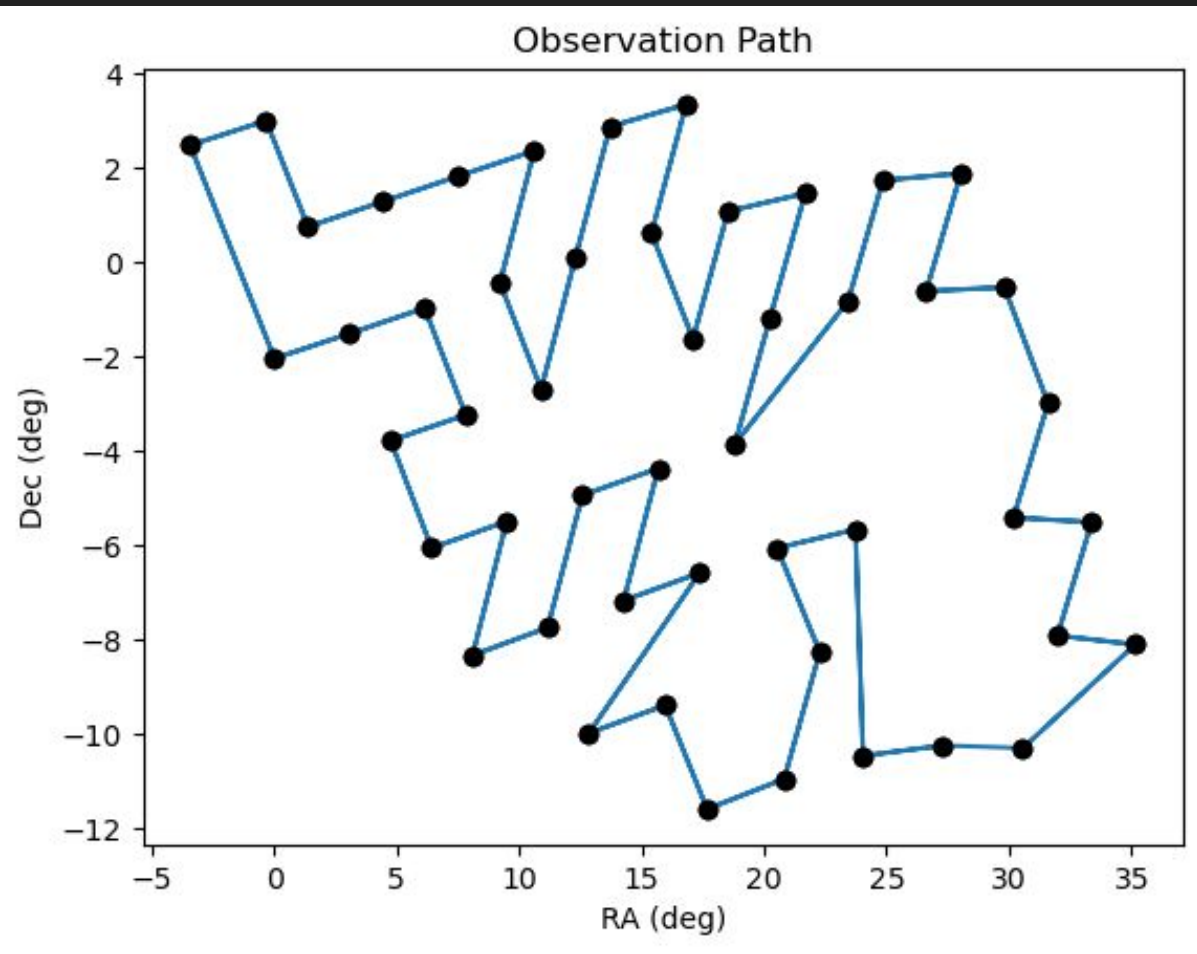
Final reward function

N obs planned



Decision function—takes the reward, generate a list of observations

Send the points to a traveling salesman solver to get a good order.



Slew time

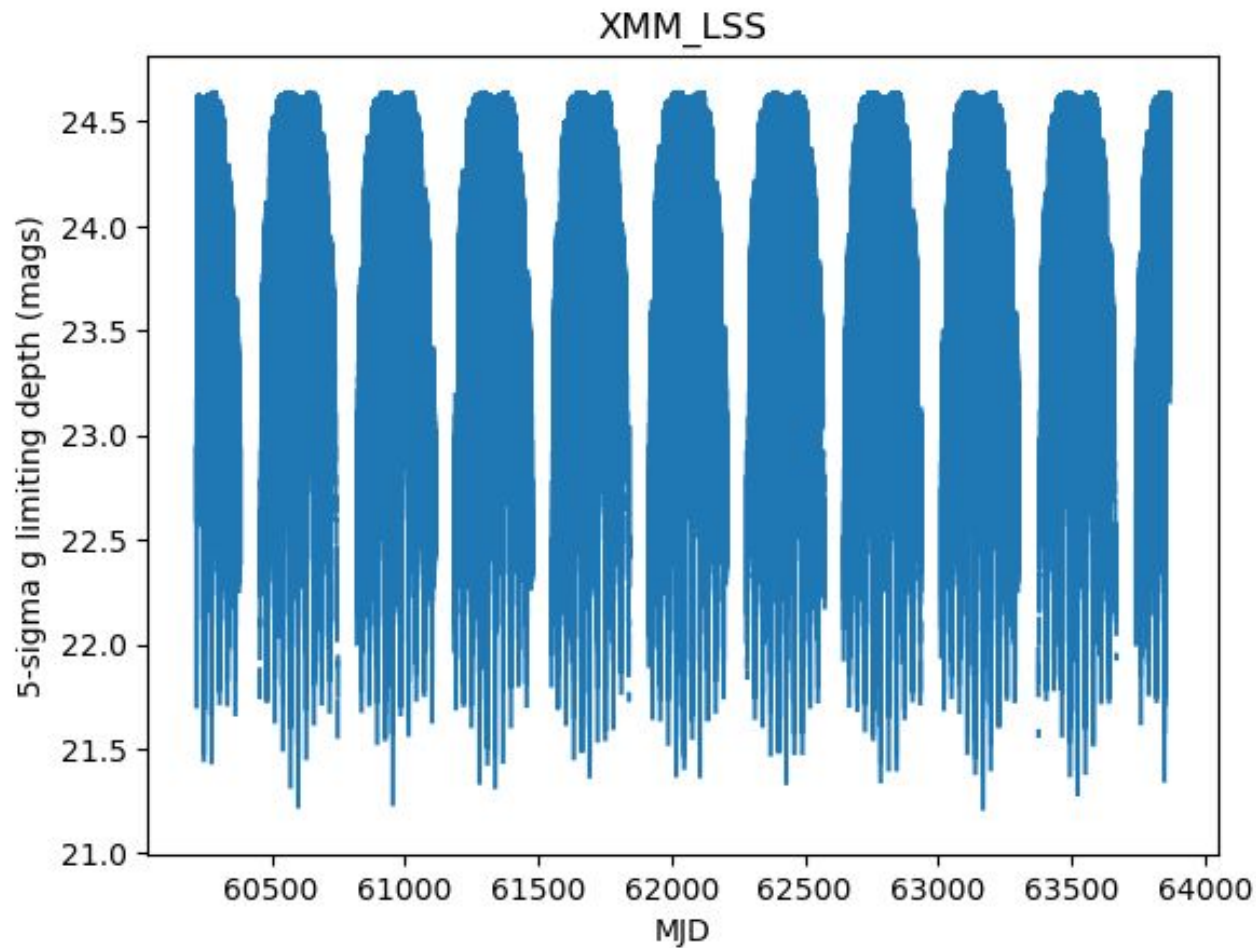
Footprint

Image depth

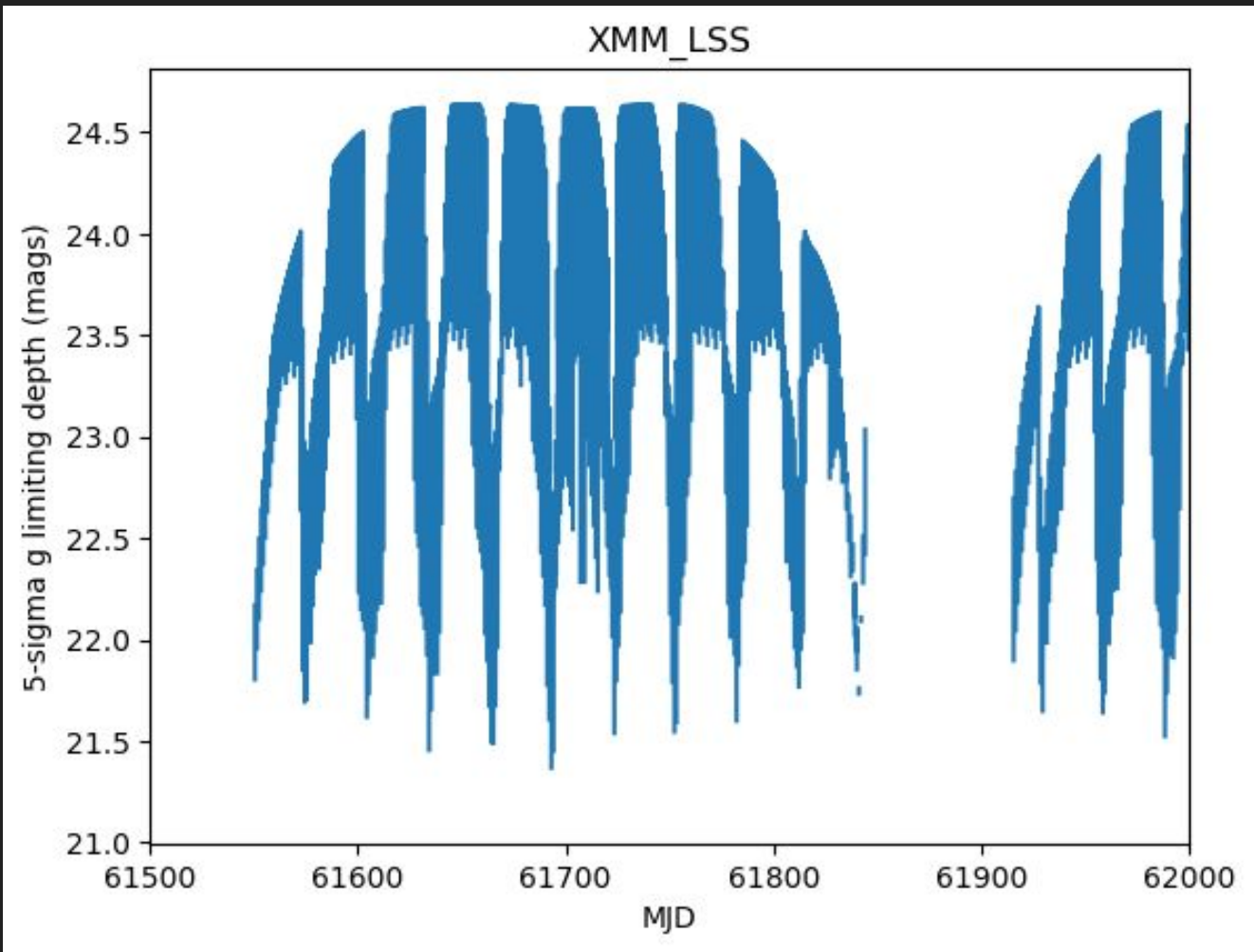


Put too much weight on any one and it'll kill at least one of the others

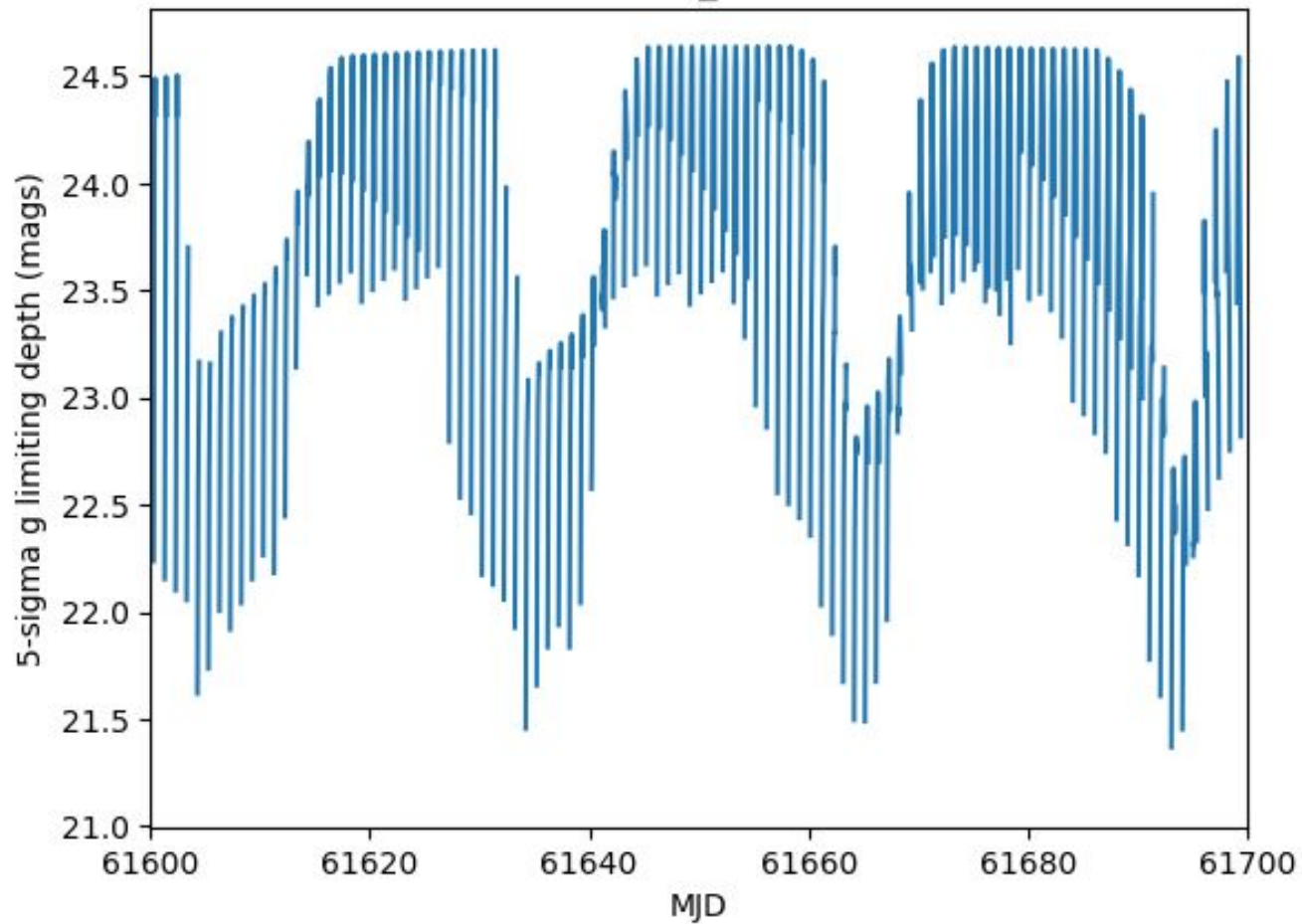
DDFs



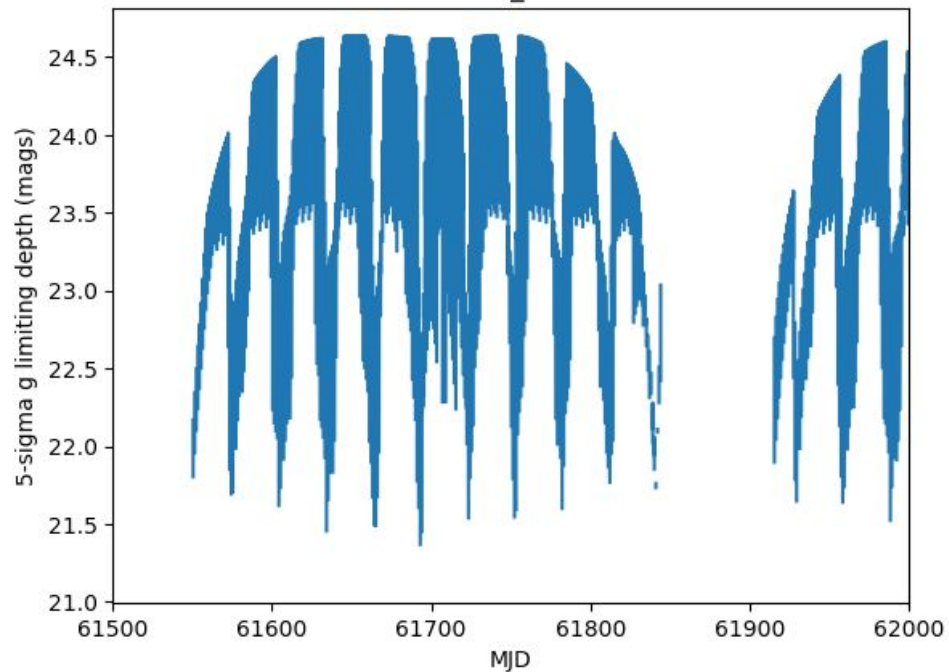
Text



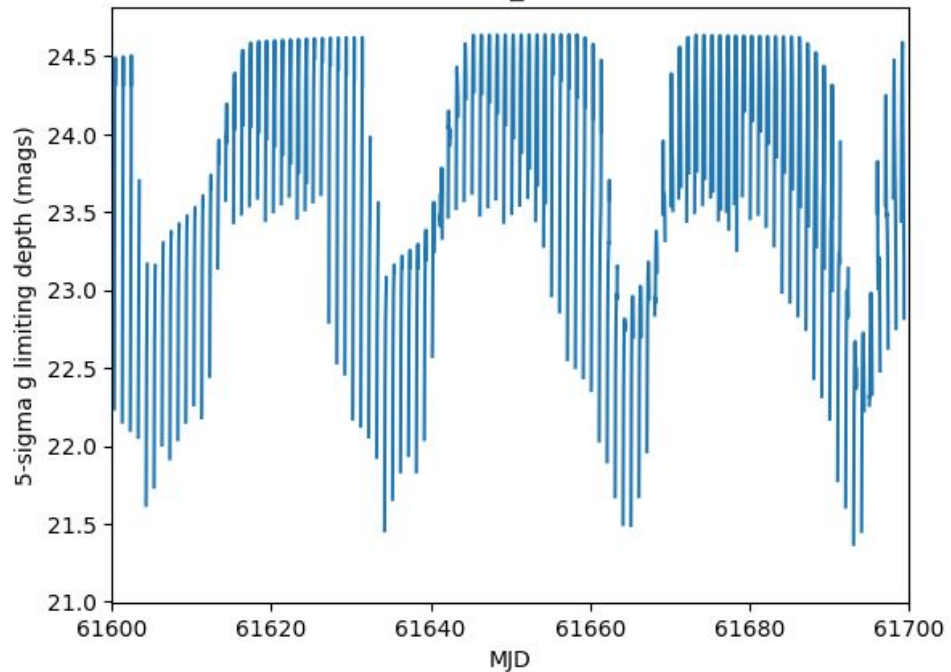
XMM_LSS



XMM_LSS

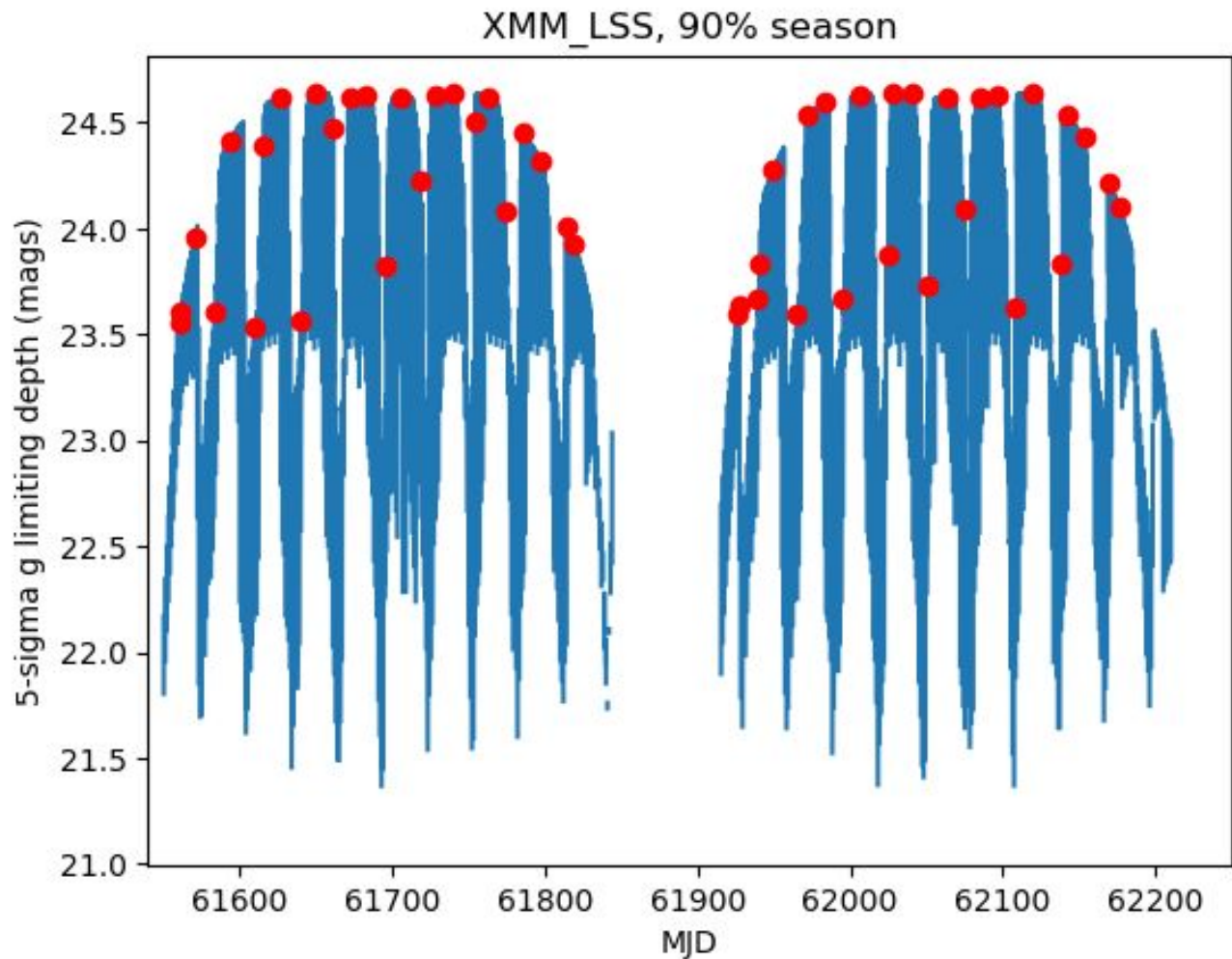


XMM_LSS

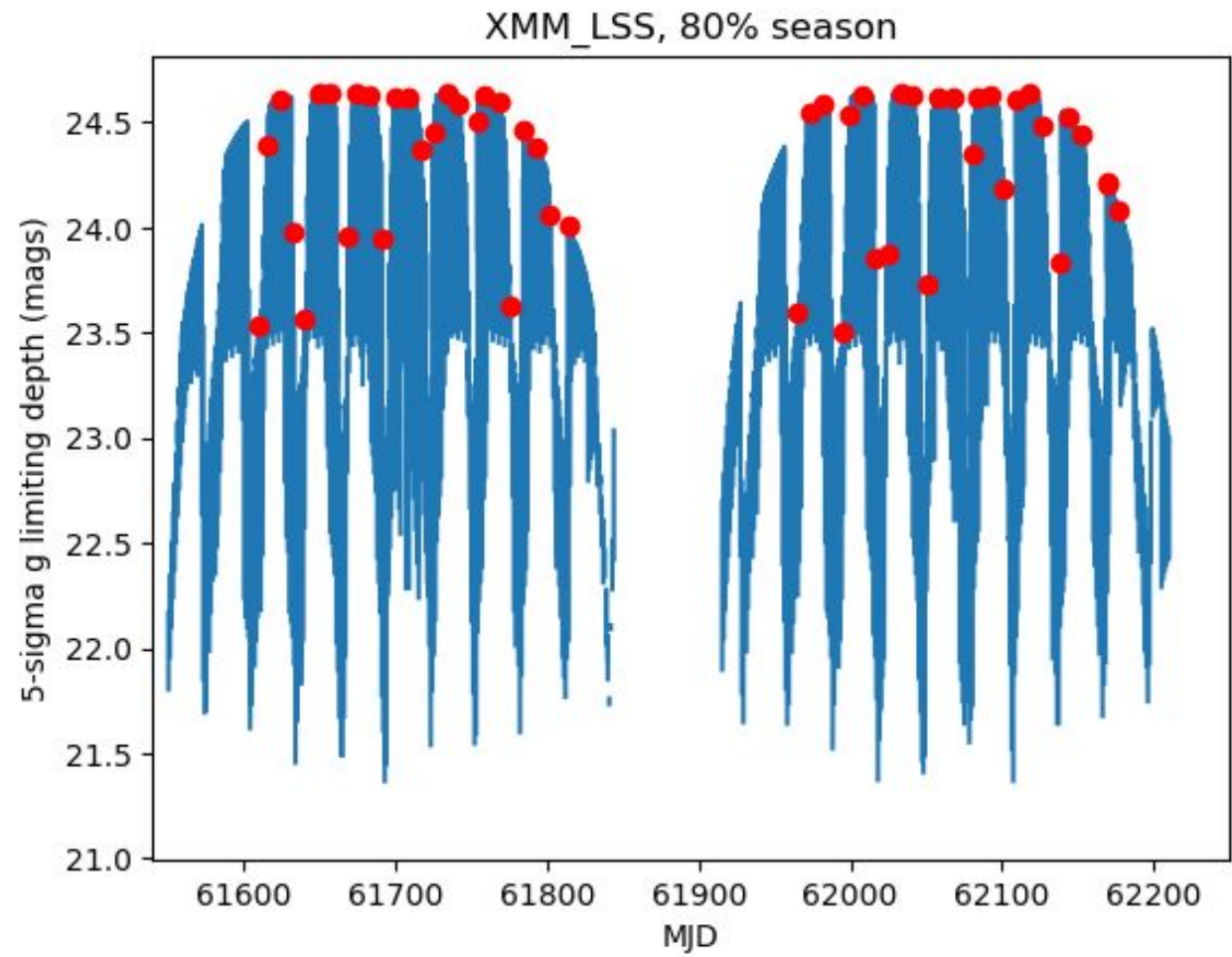


Who can explain the pattern?

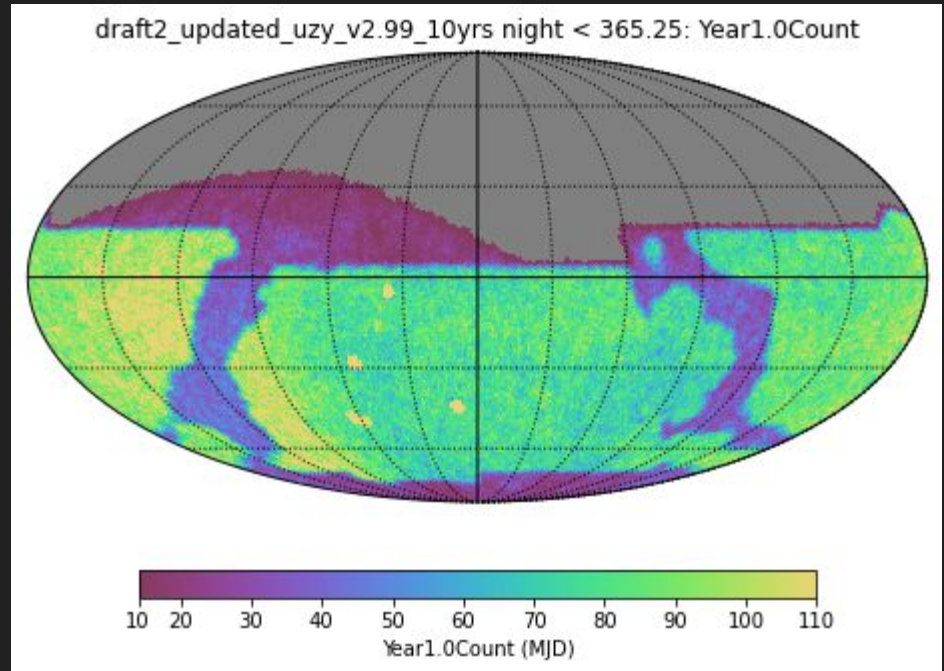
We'd like to get images as deep as possible, but also regularly spaced



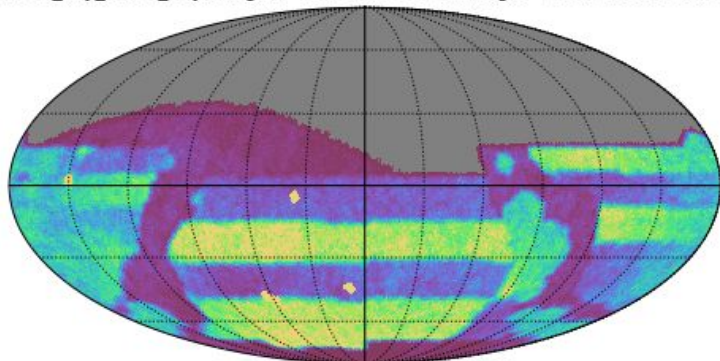
Can compress the season to get higher sampling rate (and deeper observations)



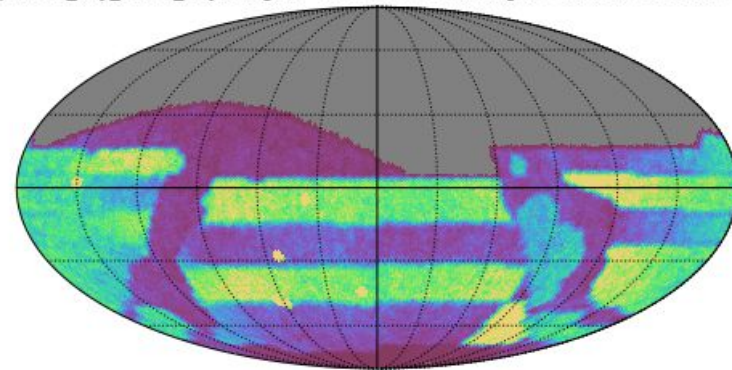
Added wrinkle, we can make the footprint a function of time, “rolling”



draft2_updated_uzy_v2.99_10yrs night > 1278.375000 and night < 1643.625000: Year3.5Count

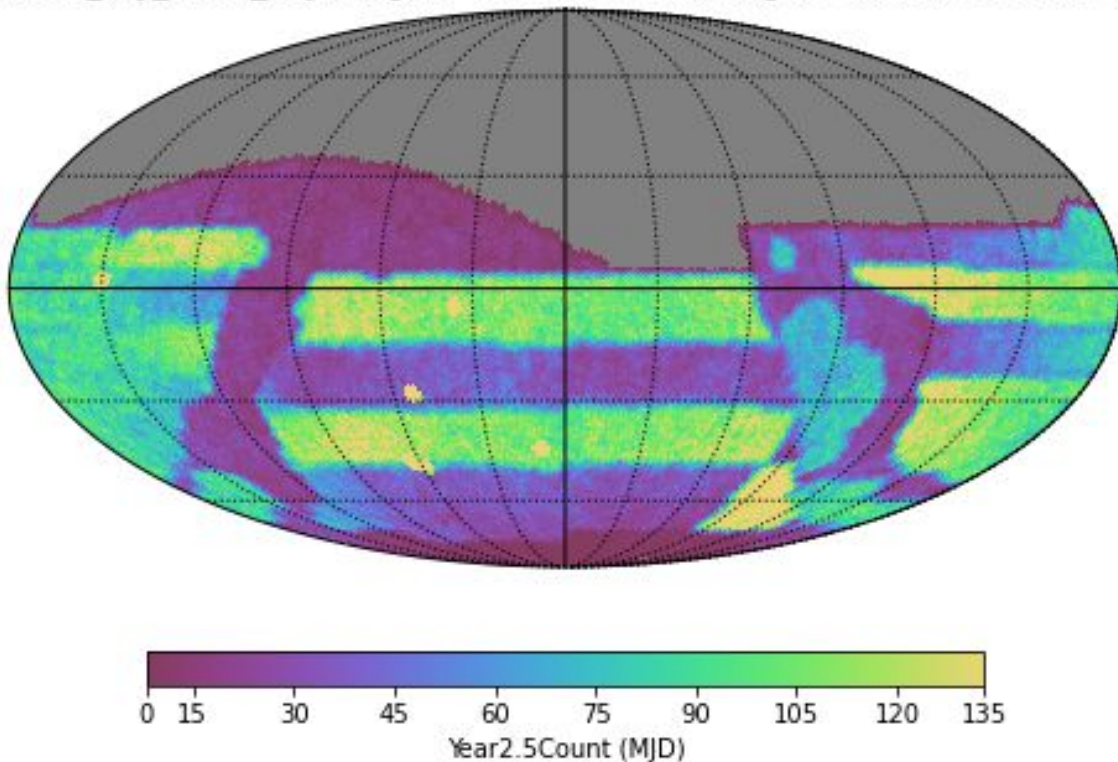


draft2_updated_uzy_v2.99_10yrs night > 913.125000 and night < 1278.375000: Year2.5Count



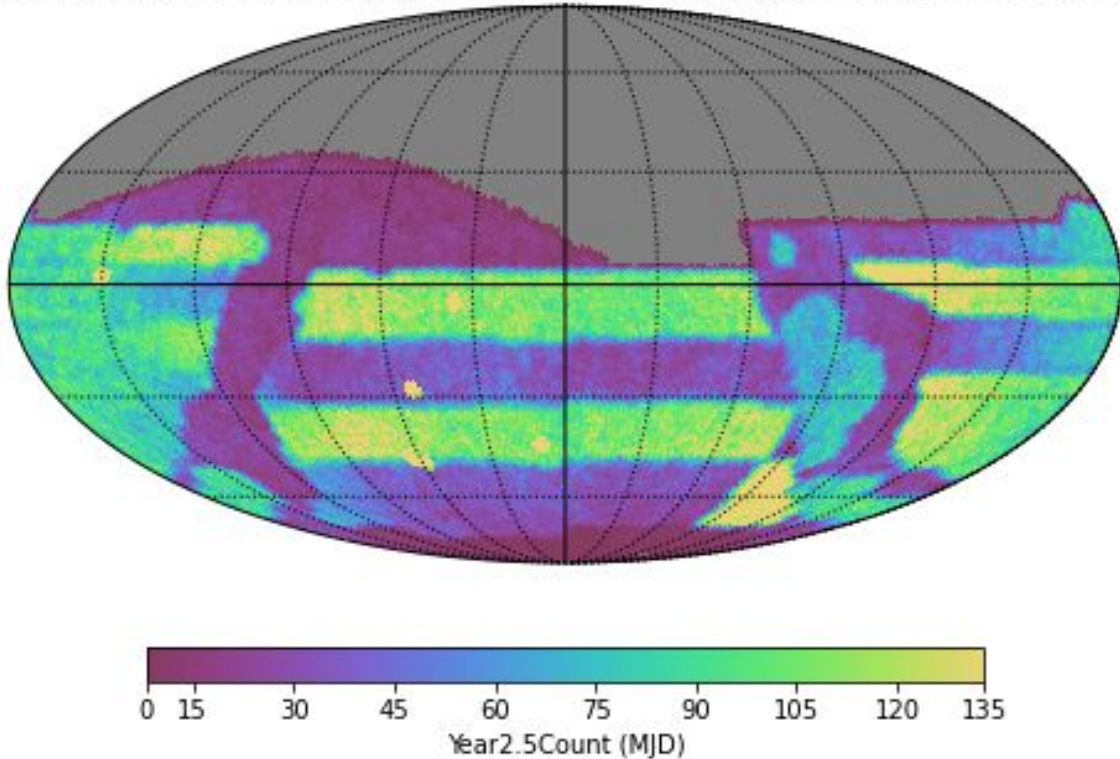
Emphasize different regions in different years.

draft2_updated_uzy_v2.99_10yrs night > 913.125000 and night < 1278.375000: Year2.5Count



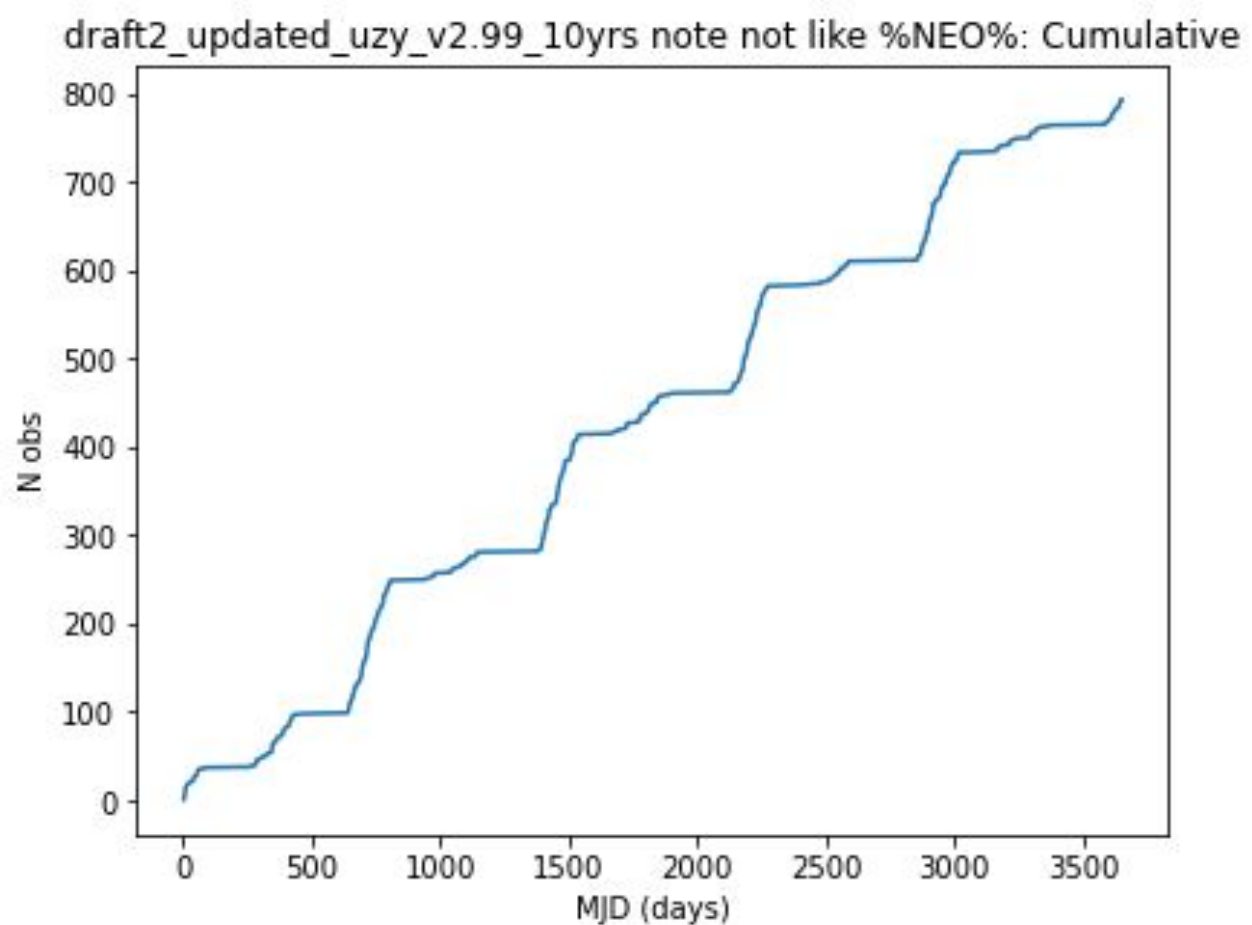
Rolling is happening on half the sky. Why 4 bands instead of just 2?

draft2_updated_uzy_v2.99_10yrs night > 913.125000 and night < 1278.375000: Year2.5Count



Rolling is happening on half the sky. Why 4 bands instead of just 2? *Always have transients for northern hemisphere telescopes*

Cumulative number of observations of a single point over time



We have grown to a 6-tier decision process when deciding what to observe

- Deep Drilling Fields—just pre-schedule them
- Observations with “long” (multi-hour) gaps
- Large contiguous area observed in 2 filters, separated by ~33 minutes
- Medium contiguous area observed in 2 redder filters separated by ~15 minutes (if in/near twilight time)
- High airmass observations towards the sun in bright twilight time to search for NEOs with 15s visits
- If all else fails, greedy algorithm selects observations one at a time

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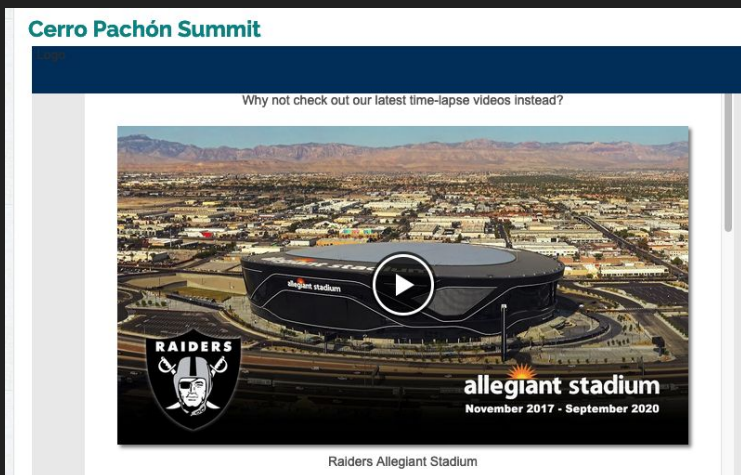
All use a Markov Decision Process, with slight variations on the Basis Functions and Decision Functions

Motivations

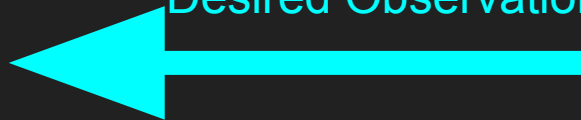
- Pairs are there so we can see solar system objects move
- Different filters in pairs so transients get color information
- Rolling to get better sampled light curves
- Contiguous area and red filters in twilight to keep SNR up

The model observatory

- Historical seeing log
- Historical weather log
- Scheduled and unscheduled downtime
- Kinematic model of the telescope, dome, camera, shutter
- Sky brightness model



Desired Observations



Scheduler

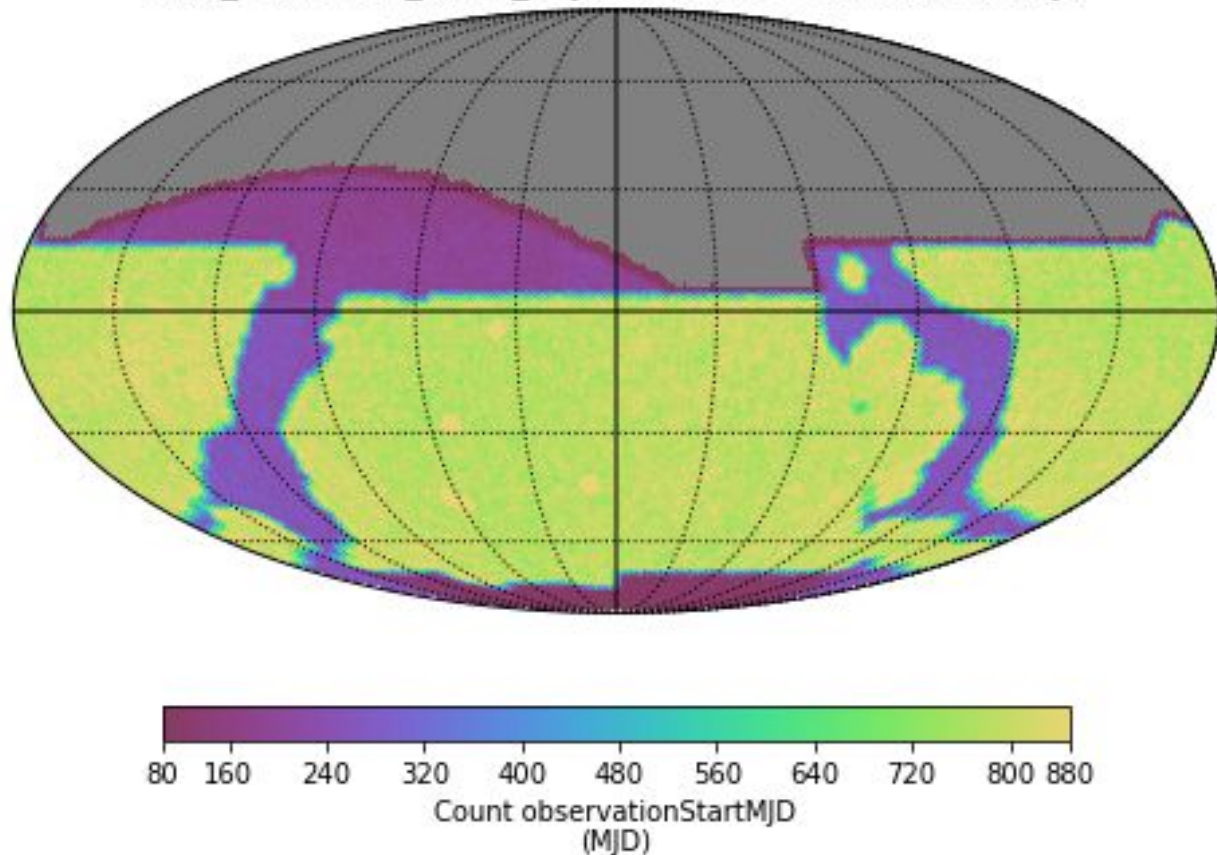
Current Conditions
Completed Observations



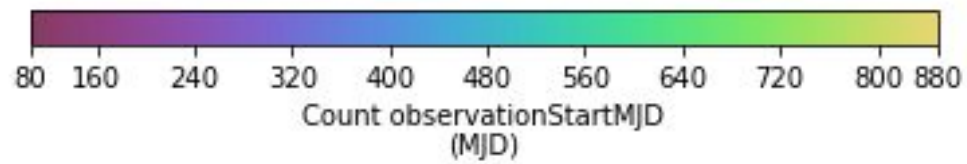
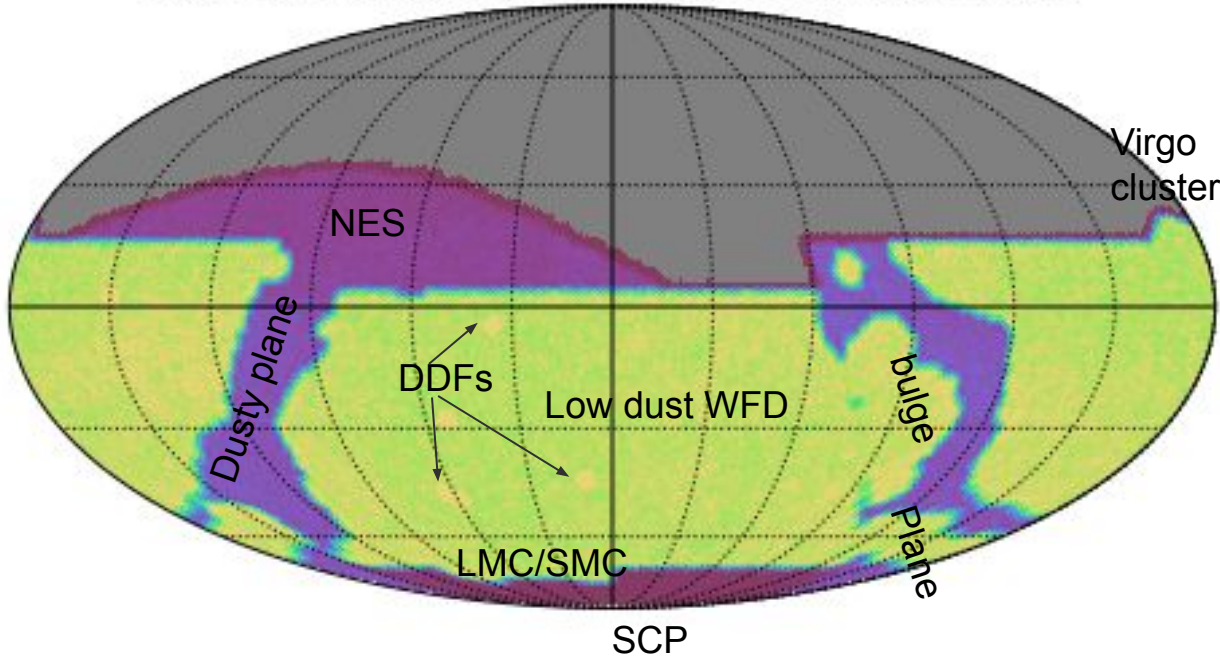
Run for 10 years

- ~2 million visits over 10 years
- 1 “visit” = 2x15s “snaps”

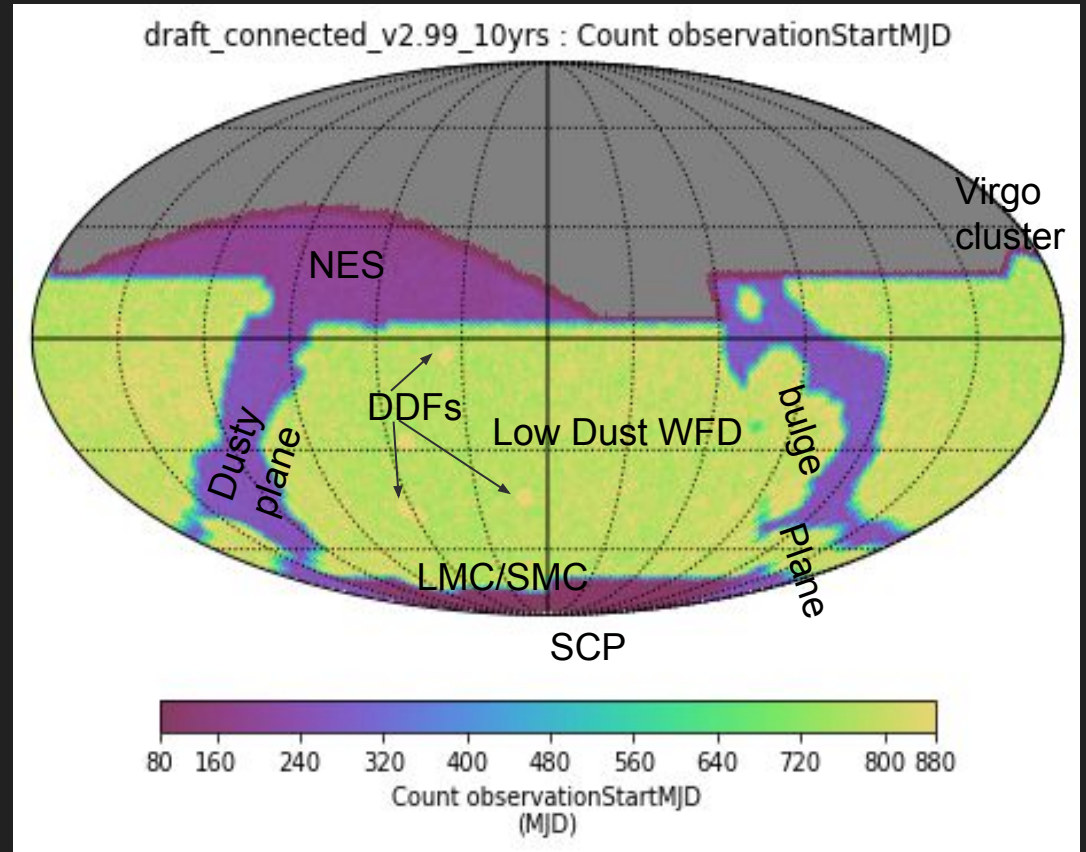
draft_connected_v2.99_10yrs : Count observationStartMJD



draft_connected_v2.99_10yrs : Count observationStartMJD



- North Ecliptic Spur only in griz
 - Mainly for solar system objects
- Bulge and Plane have redder filter distribution than Low Dust WFD
- 5 deep drilling fields
- Fewer observations in high extinction areas
- Fewer observations in South Celestial Pole since it's high airmass
- Low Dust WFD
 - Includes LMC/SMC and Virgo cluster
 - Varied upper declination limit to help with seasonal over-subscription

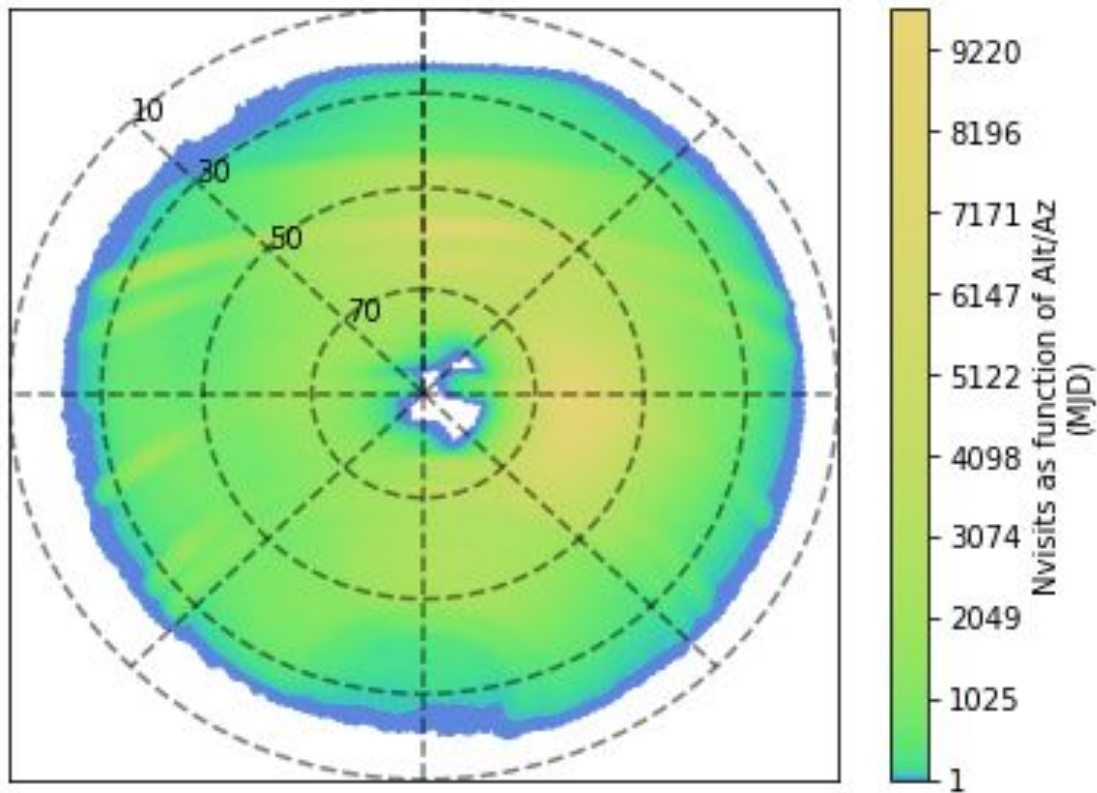


Distribution of pointings in alt/az

Note log-stretch on colorbar

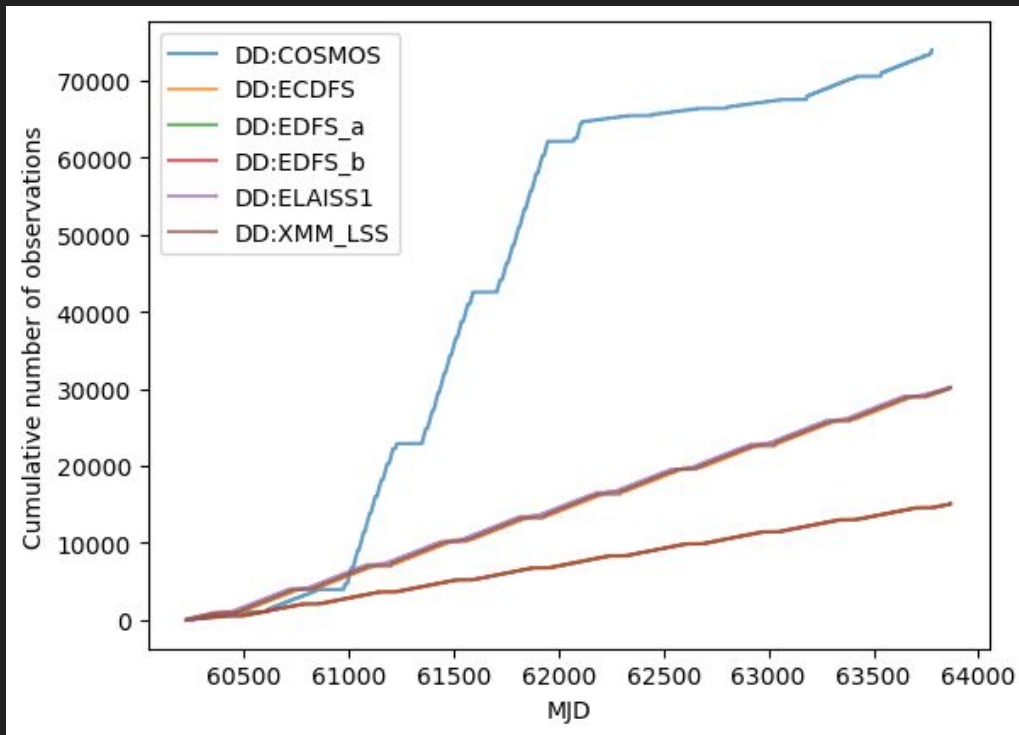
We can't track through zenith

draft2_updated_uzy_v2.99_10yrs : Nvisits as function of Alt/Az

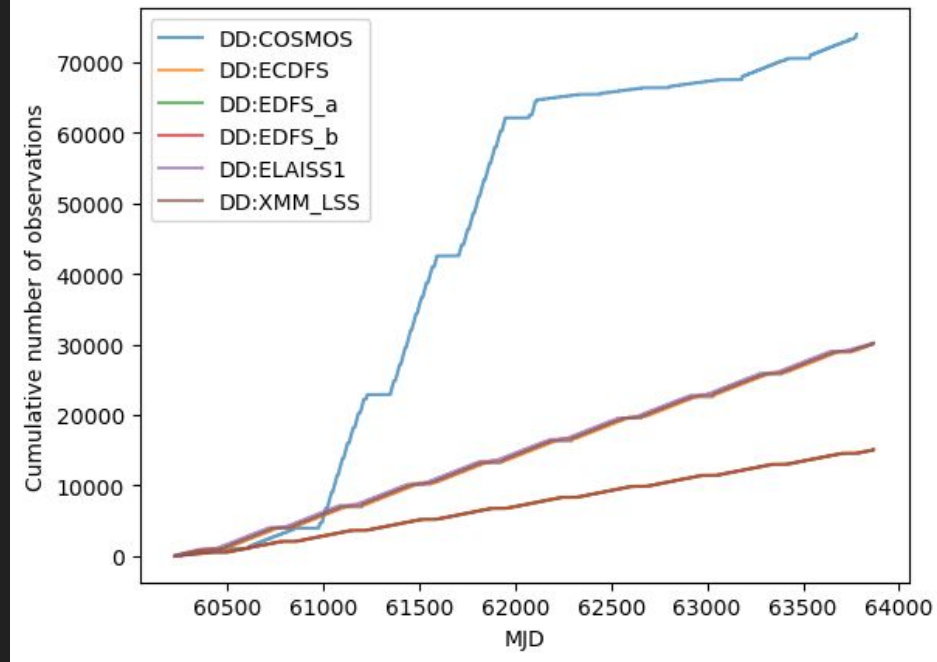
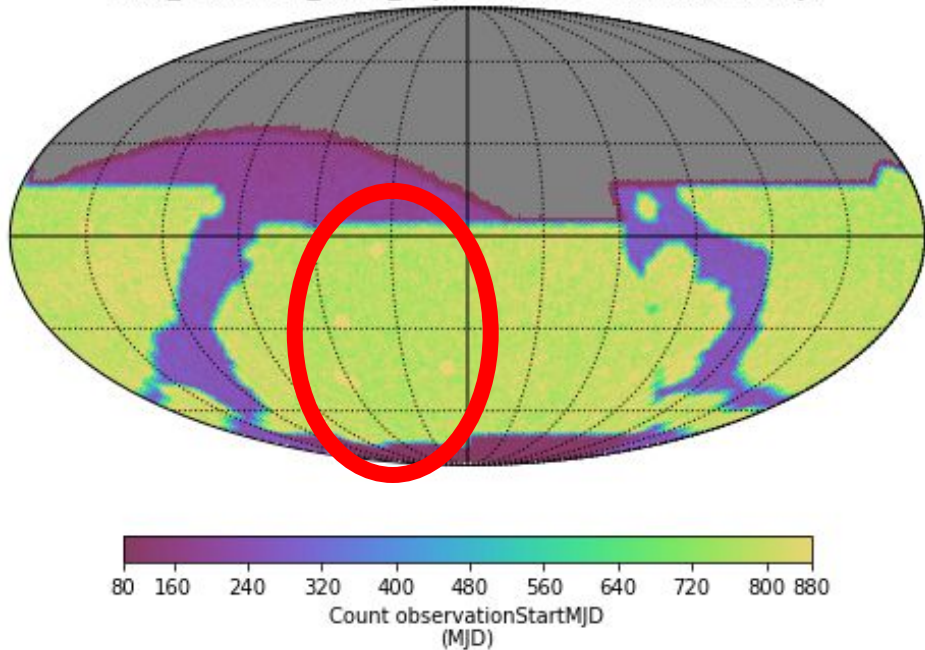


DDF scheduling

- Set a desired cumulative count
- Find a best fit schedule that matches the cumulative under depth constraint
- COSMOS currently has 3 deep seasons
- Euclid Deep Field South has two pointings with same total number of observations as other DDFs (Recommended by the SCOC as the 5th official DDF)



draft_connected_v2.99_10yrs : Count observationStartMJD

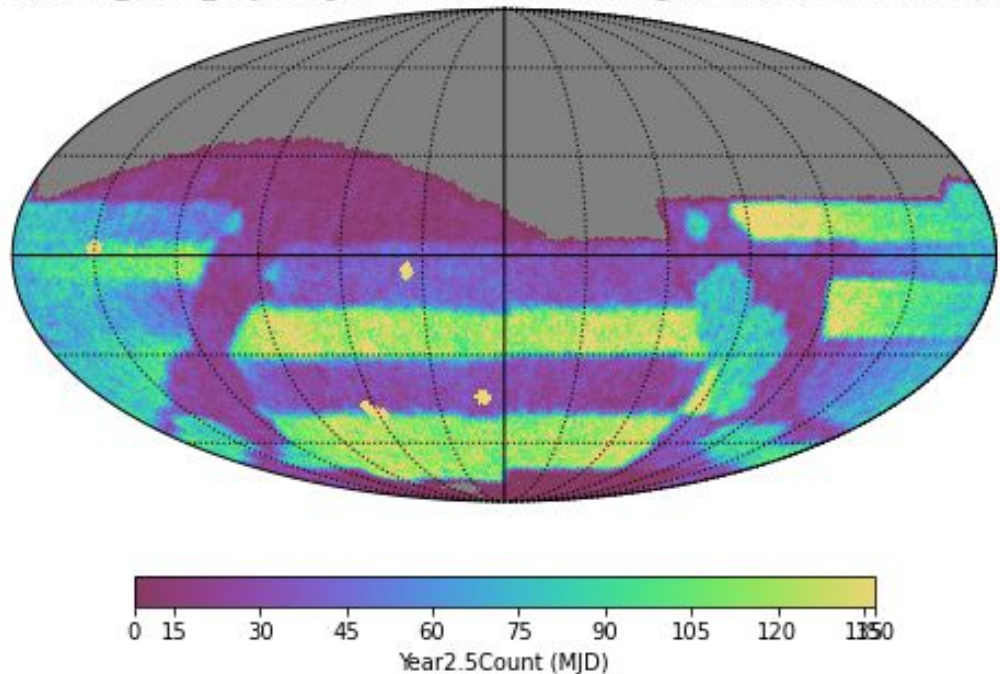


Lots of flexibility on DDFs, but they are in an over-subscribed area of sky, so there is a tradeoff between DDF depth and general low-extinction WFD depth

3-4 seasons of rolling

- Could also roll in the bulge?

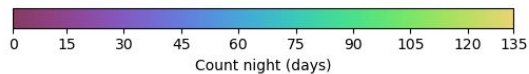
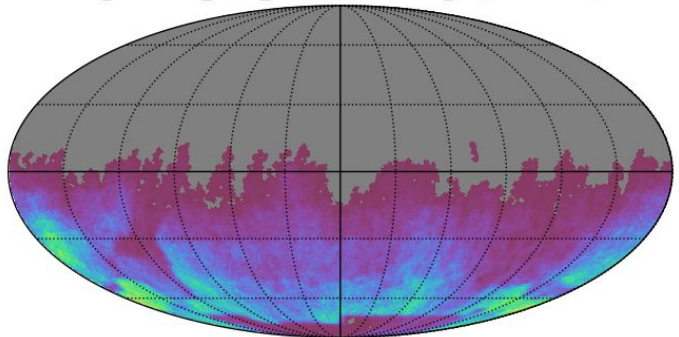
draft_connected_v2.99_10yrs night > 913.125000 and night < 1278.375000: Year2.5Count



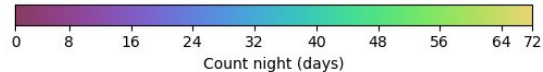
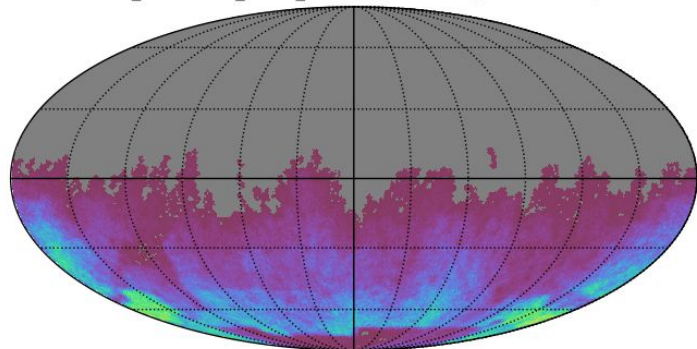
Our default half-sky rolling

Coverage of pointings trying to get long (2-7 hour) gaps. Executes every 6th night

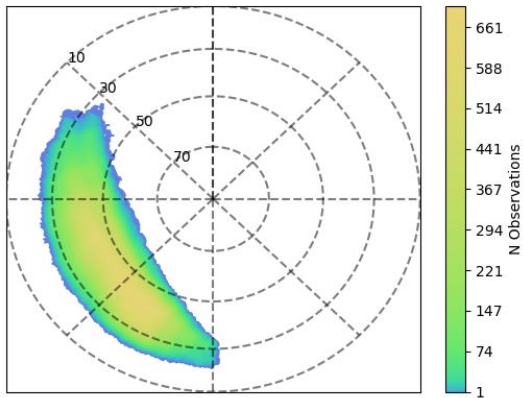
draft_connected_v2.99_10yrs note like blob_long%: Count night



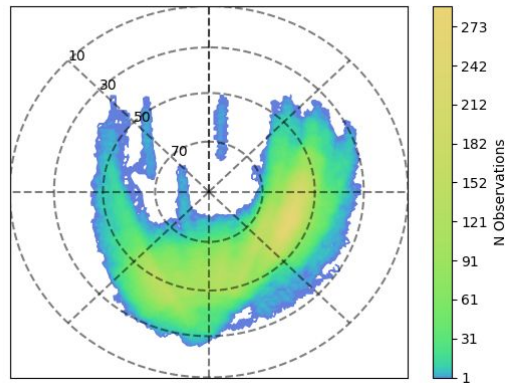
draft_connected_v2.99_10yrs note like long%: Count night



draft_connected_v2.99_10yrs note like blob_long%: Count night



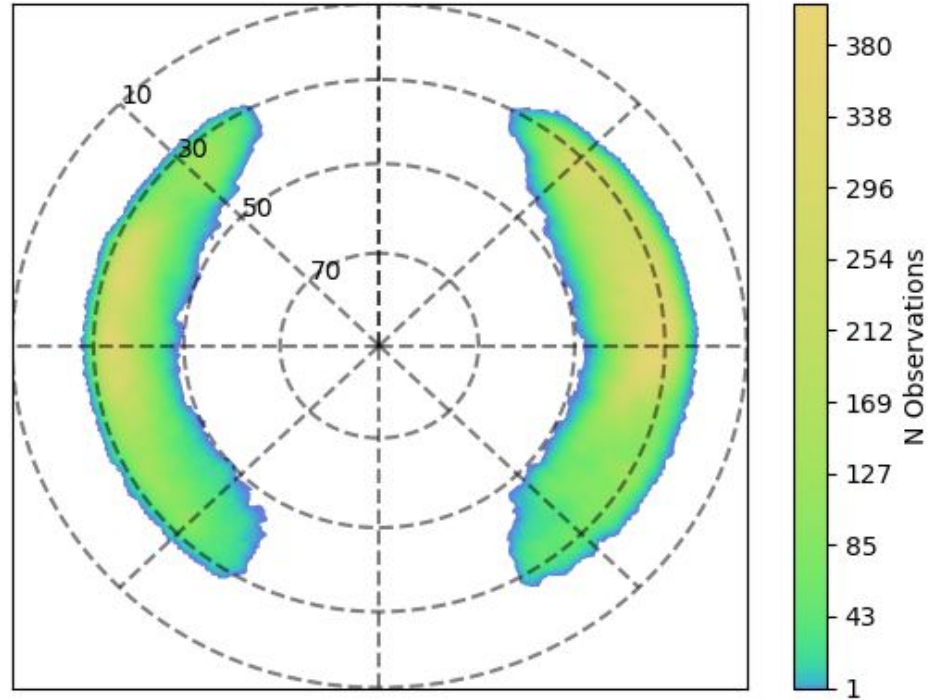
draft_connected_v2.99_10yrs note like long%: Count night



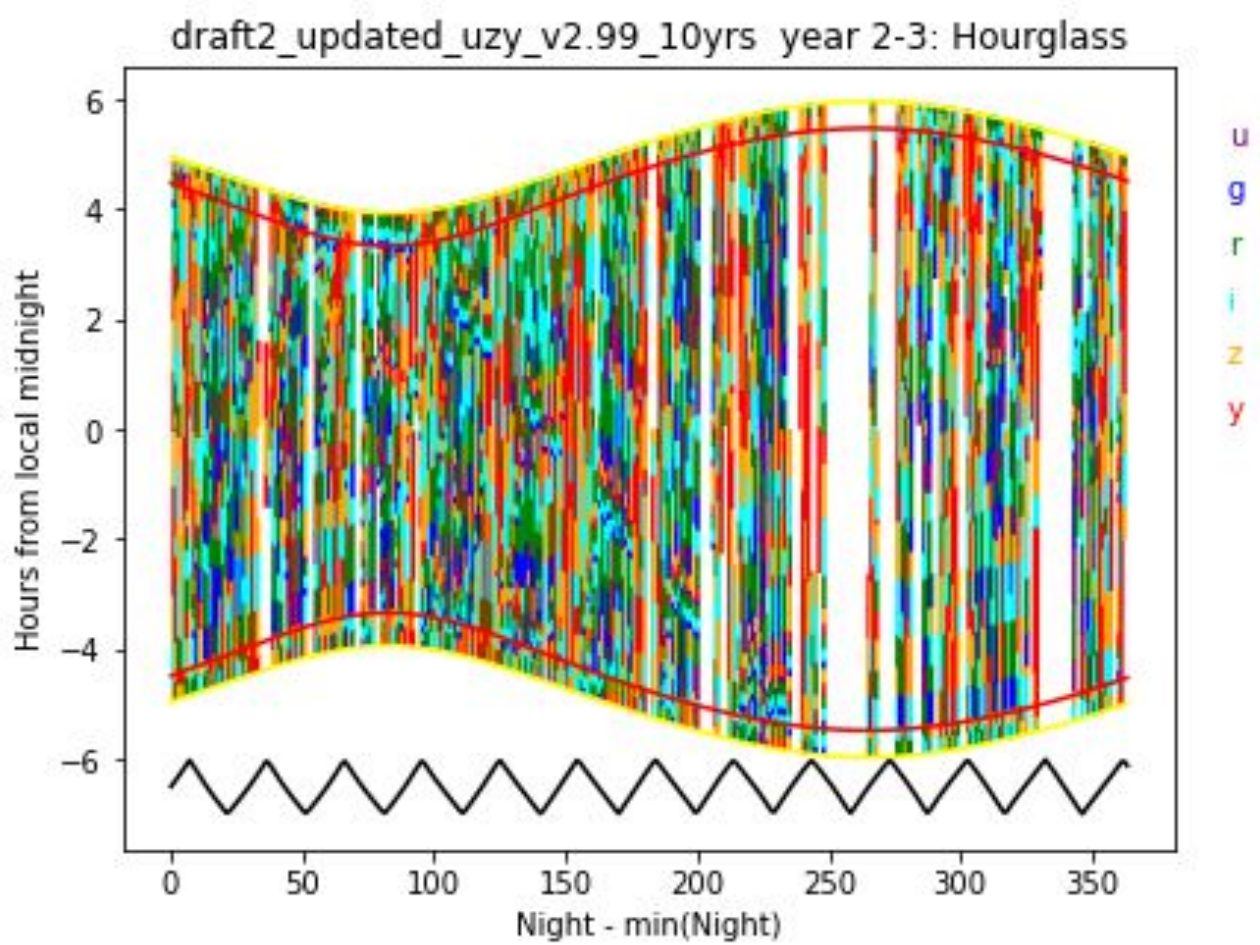
draft2_updated_uzy_v2.99_10yrs visitExposureTime < 20: Count night

Coverage of pointings looking for inner solar system objects

- Observations in quads
- Executes every 4th night



What the filter distribution looks like in a year



Conclusions

- We have an AI code that looks like it can drive Rubin in a reasonable way real-time
- We've run lots and lots of simulations. Our current baseline simulation is a database with ~2 million observations

Next time:

- How can we go from info about simulated observations to how well we can do a science no pixels in simulation, just a list of RA,dec,filter,time,depth,etc