Self-Driving Telescopes: Intelligent Scheduling for Astronomical Surveys

Paul Chichura
Postdoc | SkAI, UChicago

Invited Talk 3
CosmicAI's Cosmic Horizons
14 July 2026

1. Scheduling
2. AI Approach
3. Future

Scheduling

What?

Deciding what a telescope observes and when.

multi-dimensional
multi-timescale
multi-objective

Why optimize?

Scientific Output

Agility

Efficiency

Data Quality

Balance Objectives

Economic Capital

Efficiency = $$

Example:
Rubin operation
~$70M/yr

Human Capital

Scheduling is Difficult

Task: optimally visit a set of targets on the sky

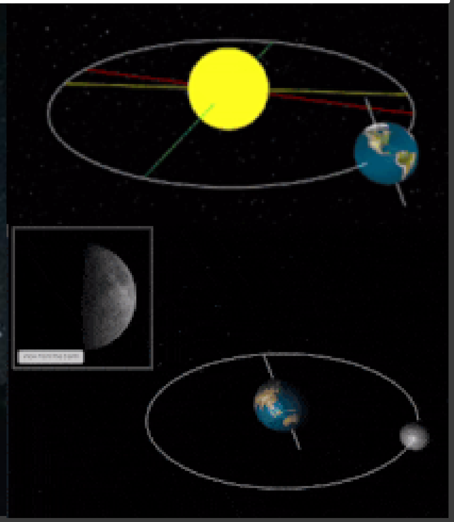
Traveling Salesman Problem…
(NP-hard)

https://mathgifs.blogspot.com/2014/03/the-traveling-salesman.html

… With More Complexity
(weather changes, sky changes, science priorities)

http://ift.tt/1N2iuug

https://pin.it/6rffotr6K



https://www.earthspacelab.com/

short timescales…
stochastic…

…long timescales
…deterministic

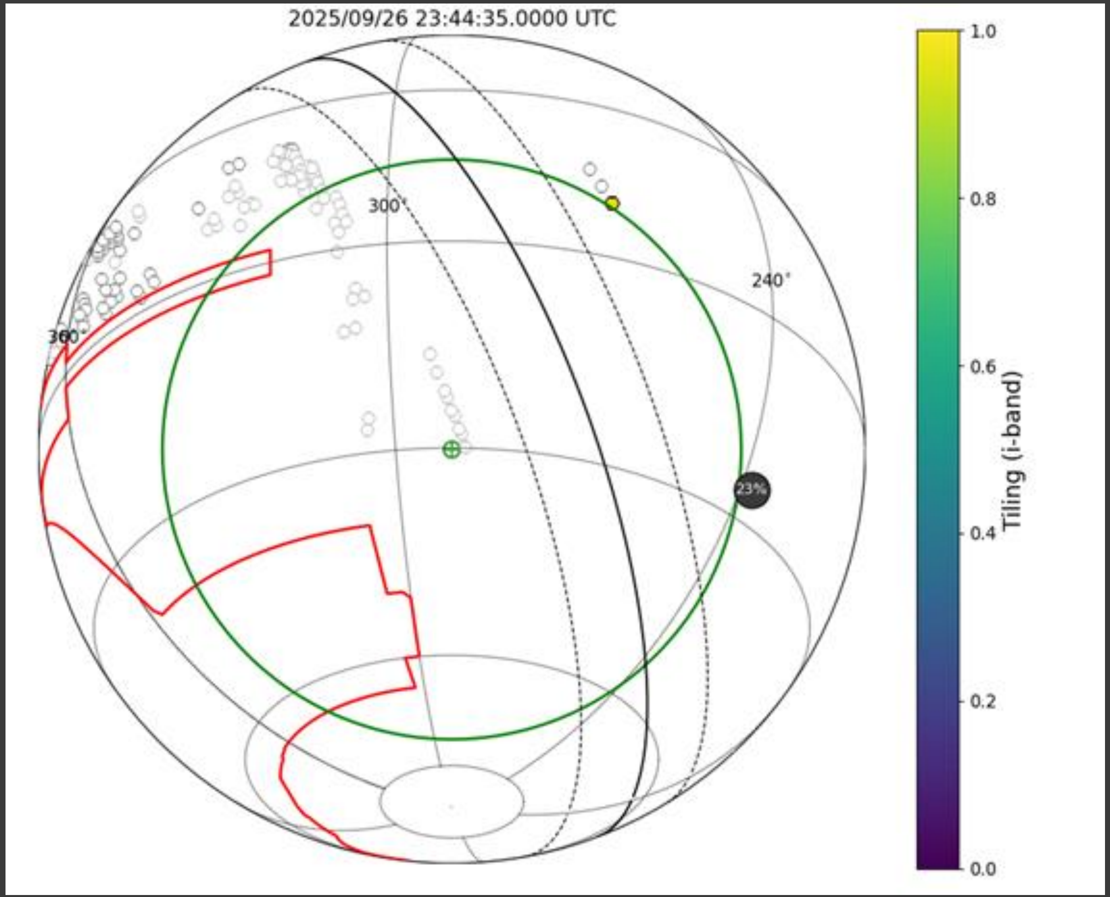
Typical Approach

Greedy, Heuristic Algorithms

```
targets = [...]
weights = [...]

weights += distance_from_current(targets)
weights += sky_brightness(targets)
weights += atmosphere_airmass(targets)
weights += visible_time_remaining(targets)
weights += ...

next_target = targets[argmin(weights)]
```



Alex Drlica-Wagner for DELVE Survey, scheduled with obztak

AI Is Promising

Reinforcement learning (RL) for combinatorial optimization:

- Bello et al. (2016) [1611.09940]

Exploratory training on simulated data:

- Terranova et al. (2023) [2311.18094]
- Jia et al. (2023) [10.3847/1538-3881]
- Naghib et al. (2018) [1810.04815]

Progress for Fundamental AI:

- Multi-objective rewards
- Deferred, multi-timescale rewards
- RL frameworks:
  Deep Q-Networks (DQN)

To progress the field,
an AI scheduler must:

1) Deal with real data.
2) Be tested in the real world.

Our Strategy

Blanco: one of most impactful ground-based optical telescope by publications
https://noirlab.edu/science/documents/scidoc2077

Step 1: compile real schedules, real data
(6+ years DES/DELVE Surveys with DECam on NSF 4-m Blanco Telescope in Chile)

Step 2: develop a Minimum-Viable-Product agent

Step 3: develop control software infrastructure

Step 4: deploy + test MVP *in situ*

Step 5: increase model complexity, capabilities
→ deploy + test
→ repeat

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1. Scheduling
2. **AI Approach**
3. Future

Model Evaluation

A scheduler should:

MVP

now

long-term goal

1) not do anything impossible;
2) be qualitatively reasonable;
3) be quantitatively comparable to heuristics;
4) be quantitatively better than heuristics.

Data-Driven Development

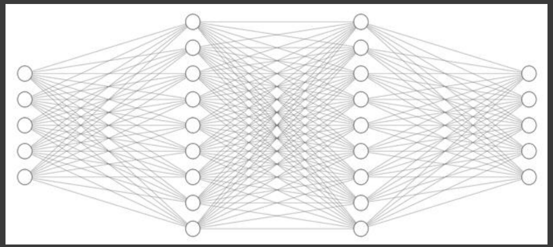
Archival Schedule → **State-Action Pairs**

Time	(RA, Dec)	(Az, El)	Filter	Observing History	Environmental Features...	DQ
2026/05/21 19:00	(..., ...)	(..., ...)	r	{}	...	...
2026/05/21 19:02	(..., ...)	(..., ...)	g	{obs 1}	...	...
2026/05/21 19:04	(..., ...)	(..., ...)	g	{obs 1, 2}	...	...
2026/05/21 19:07	(..., ...)	(..., ...)	r	{obs 1,2, 3}	...	...
2026/05/21 19:09	(..., ...)	(..., ...)	Y	{obs 1, 2, 3, 4}	...	...

state 1
action 1
state 2
action 2
state 3
action 3
state 4
action 4
state 5

Input: state *i* → **Output:** action *i*

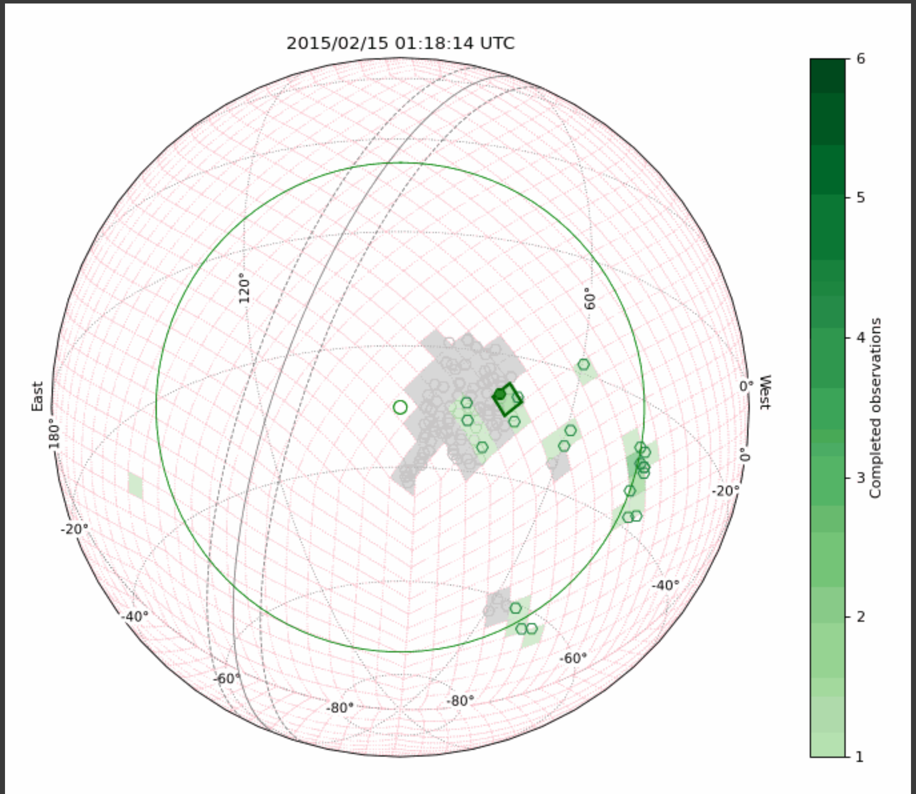
current pointing
sun, moon positions
slew times
expected DQ
target availability
...

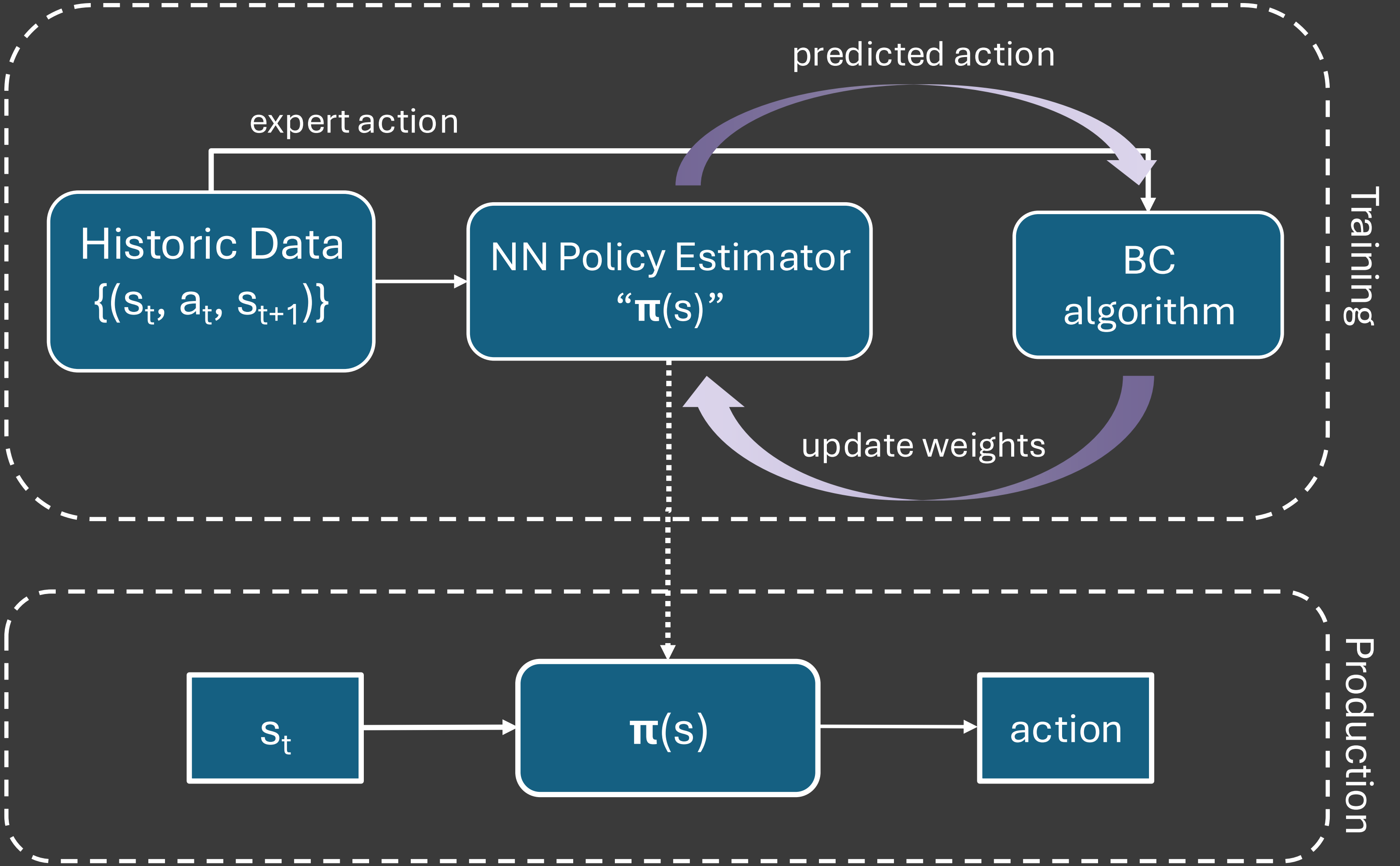


sky location
camera filter

Behavior Cloning

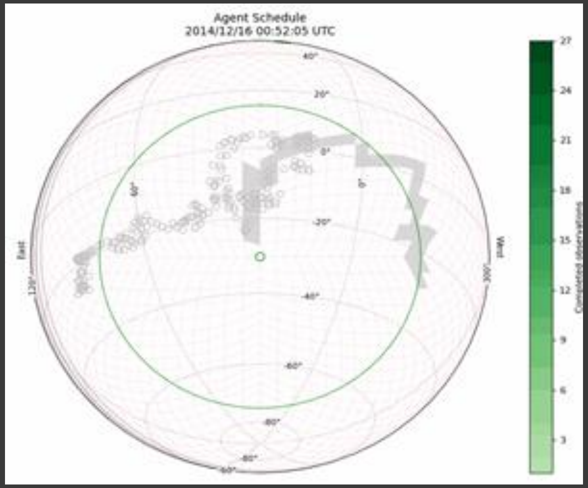
Learning Target: *P(action | state)*

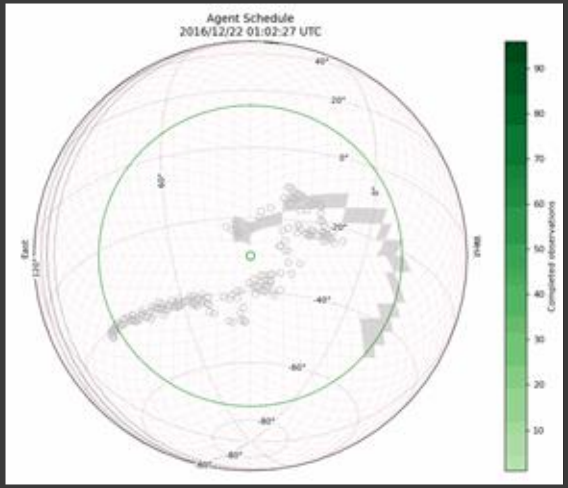


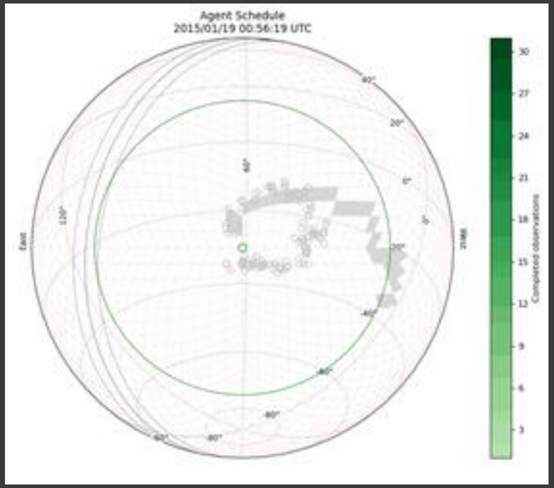


Behavior Cloning Active Rollout

BC Agent

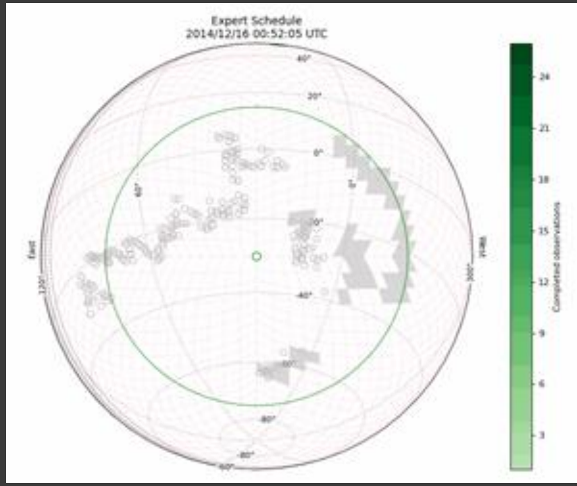


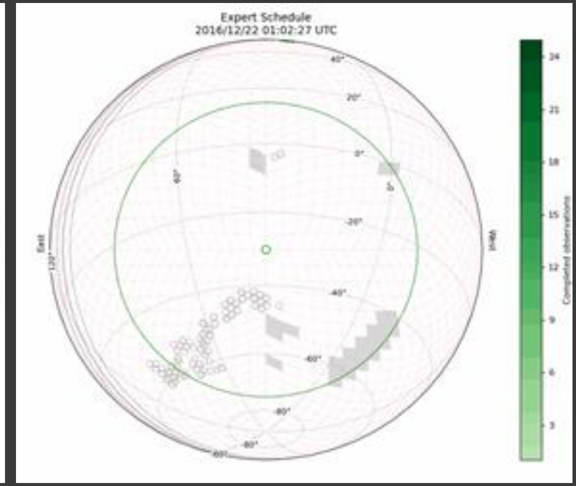


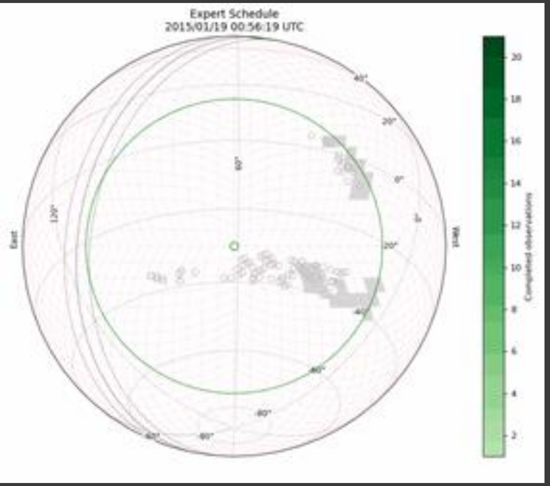


Rachel Hur
UChicago Physics PhD

Expert

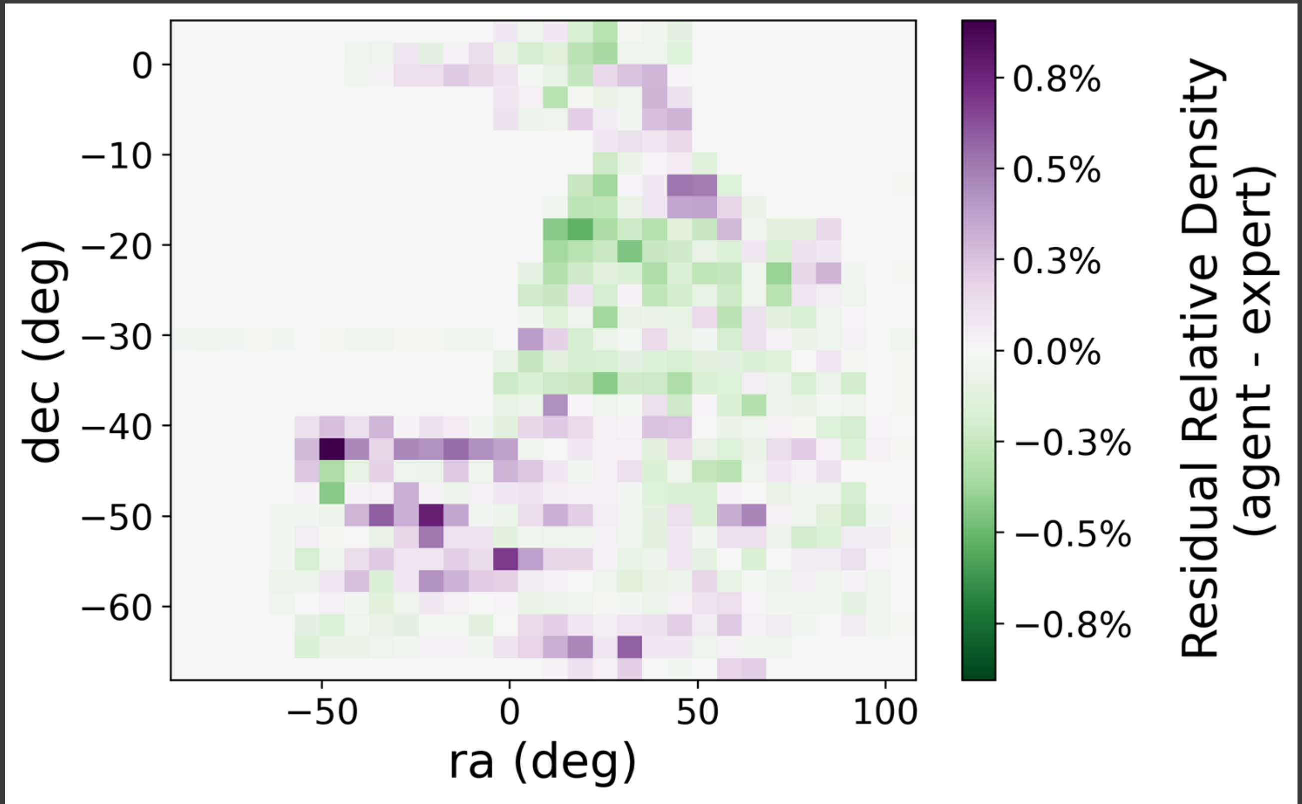






Behavior Cloning Active Rollout

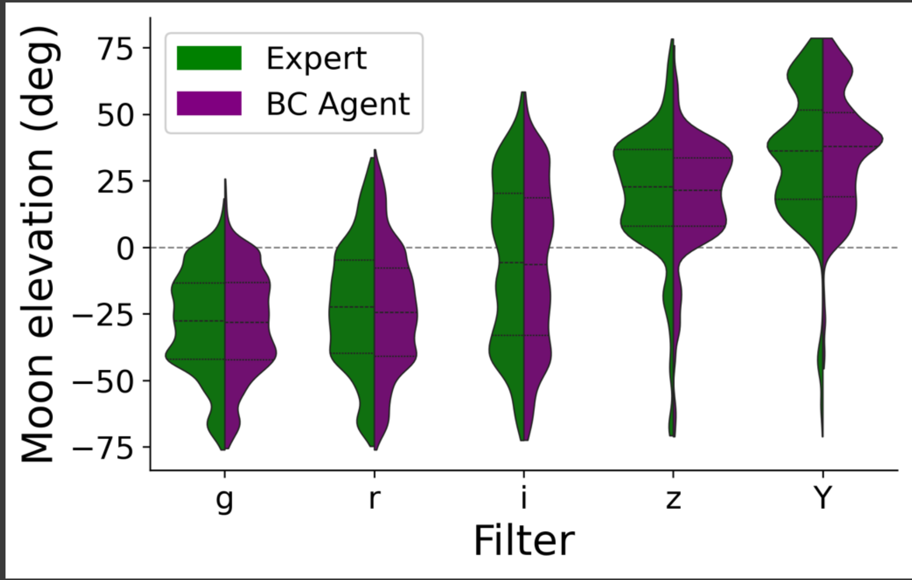
Full rollout roughly recovers DES coverage.

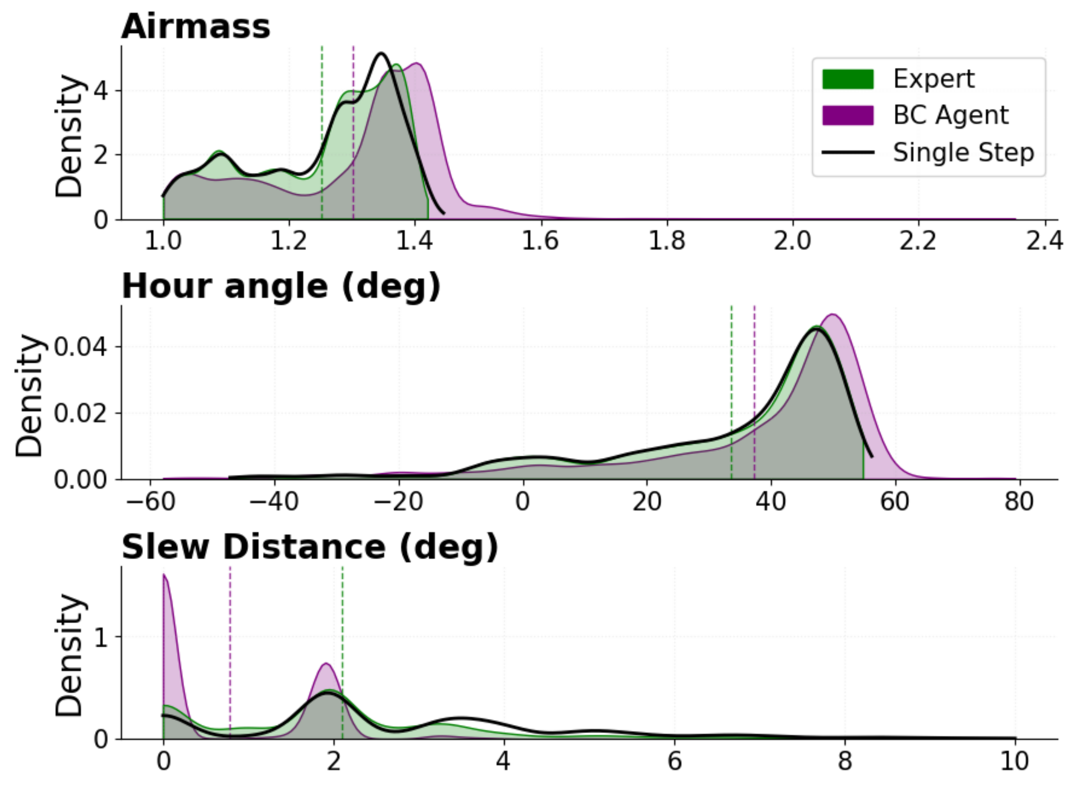


Rachel Hur
UChicago Physics PhD

Behavior Cloning Active Rollout

Under differing conditions, model resembles human expert.





Rachel Hur
UChicago Physics PhD

Architecture & Workflow

Setup
(load model, etc)

Roll Out Policy
N Steps

User Approval

disapprove

approve

Readiness Waiting Loop

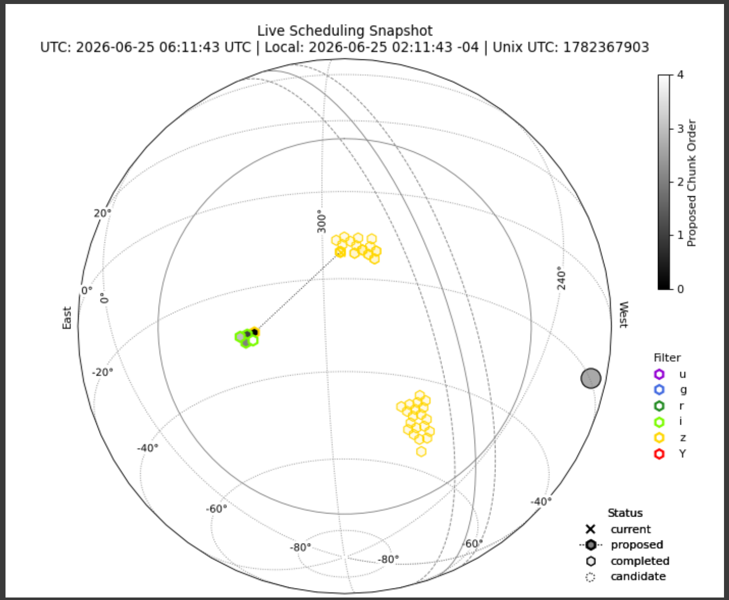
N obs < min_N,
conditions change,
user disapproval,

ready

Submit Obs

Exit

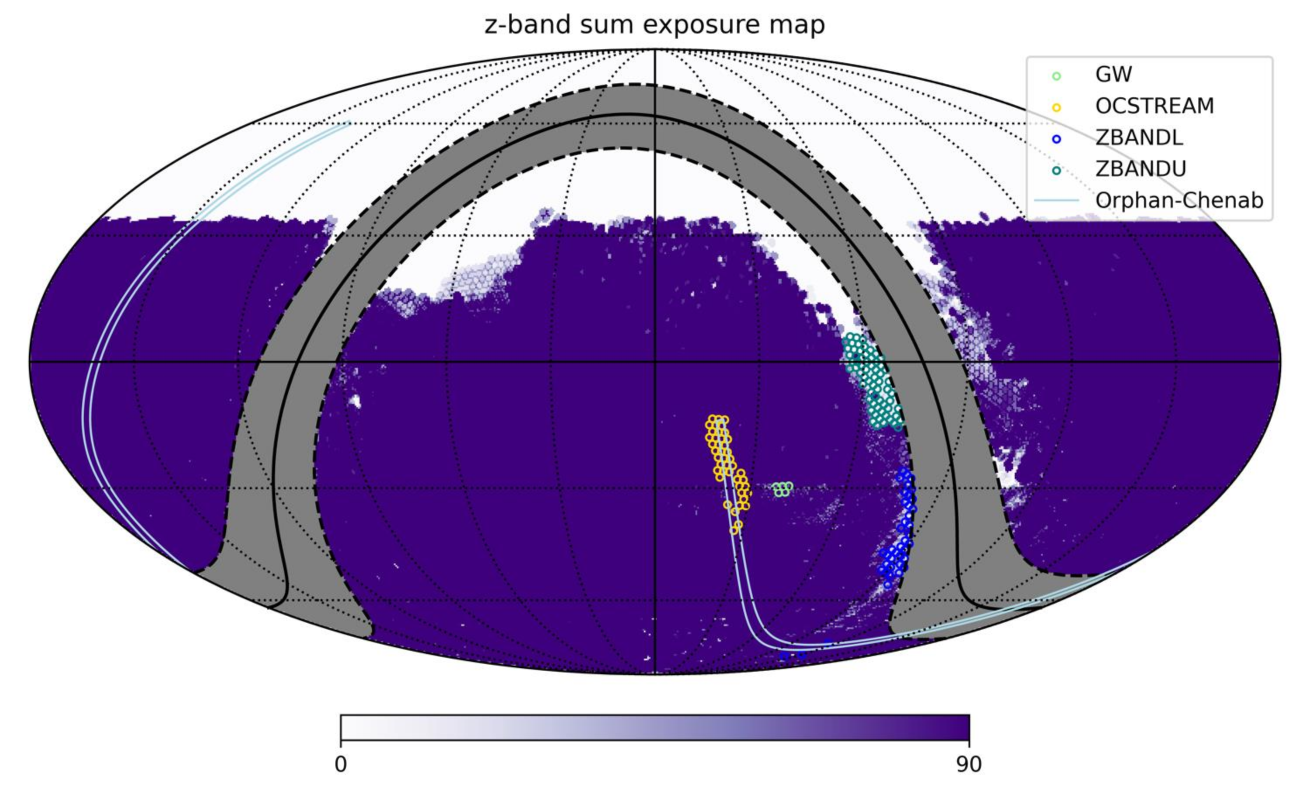
user interrupt, time limit,
targets complete, safety conditions,

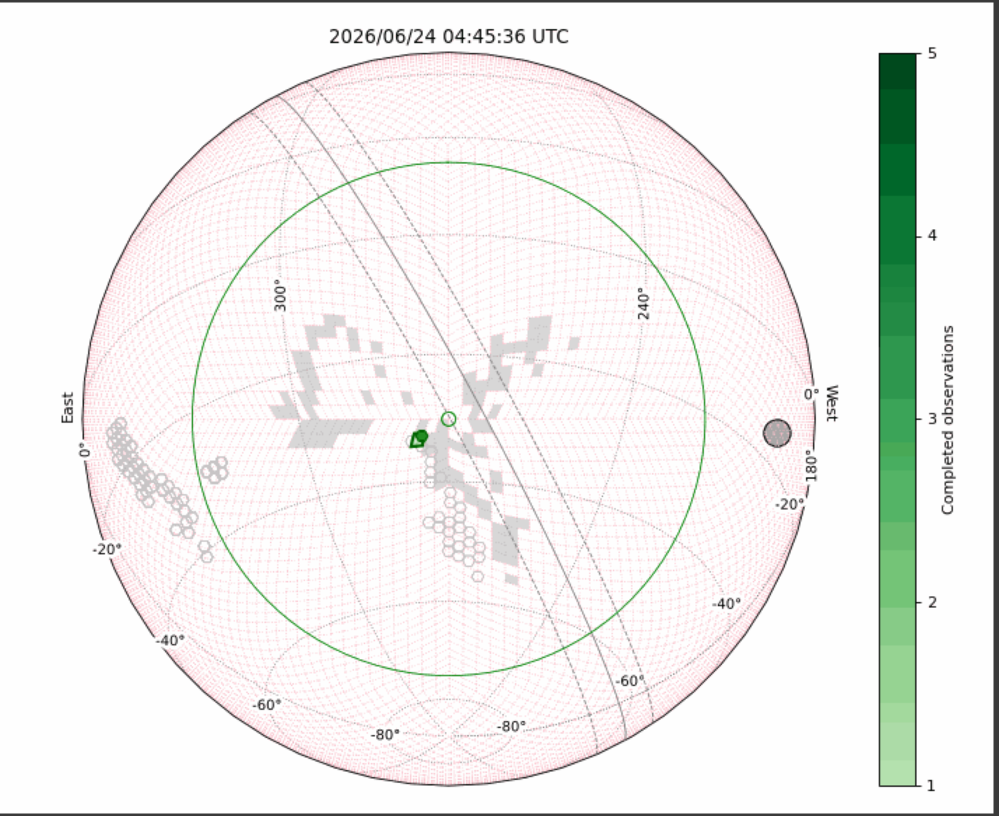


Online Assessment on Set of Targets

Deployed, tested during 2x ½-nights: June 23 & 24

Take useful data while monitoring real-time DQ and responding to mock ToO trigger.





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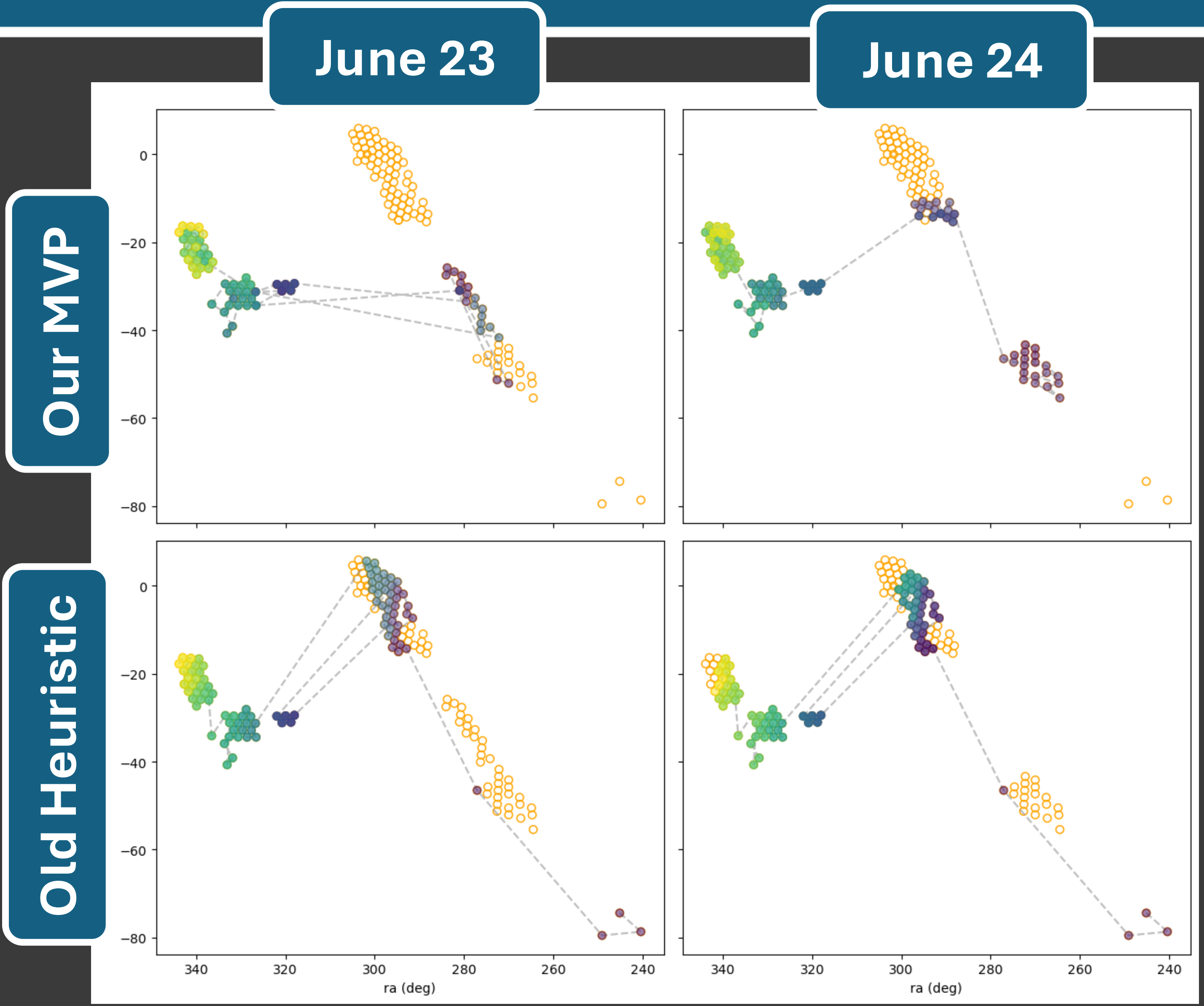
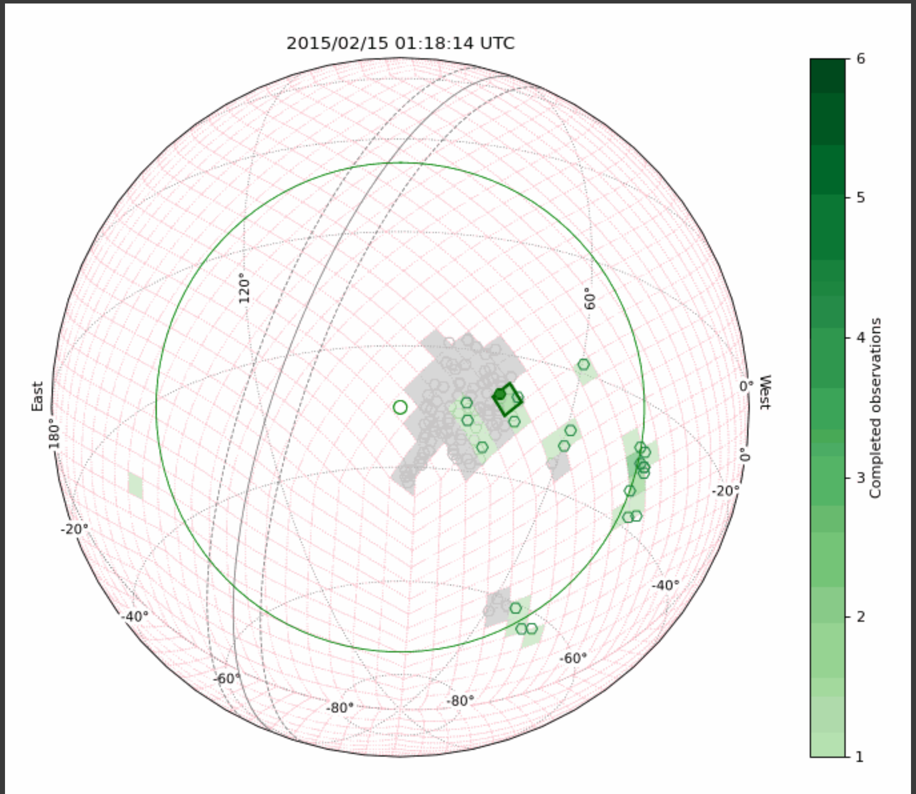
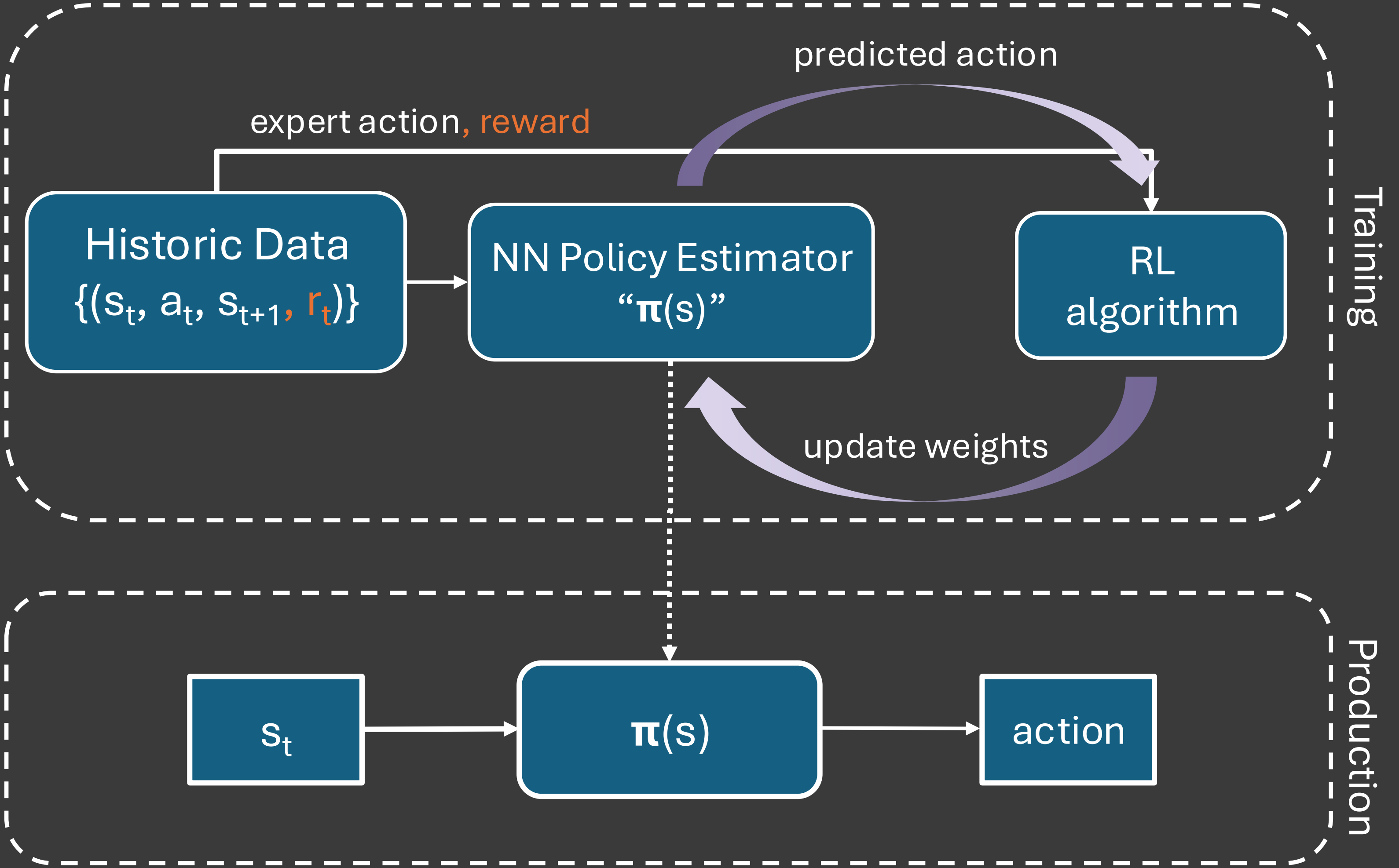


Reinforcement Learning

Learning Target (Deep Q Network): *ExpectedReward(state, action)*





Reward Quantification

Examples:

- **Surveys**: min/avg depth, completion, ...
- **Time domain**: frequency of revisits, ...
- **Efficiency**: fraction of time spent observing, ...

Exploratory, Offline Training:

- **Simulations:** *Reward(simulated environment)*
- **Data**: *CounterfactualReward(real reward)*

T_{eff}: "this observation was same as observing for T_{eff} time in ideal conditions"

$$T_{\text{eff}} \propto \eta^2 \left(\frac{0.9''}{\text{PSF FWHM}} \right)^2 \left(\frac{b_{\text{dark}}}{b} \right)$$

sky transmission

seeing (blur)

sky brightness

1. Scheduling
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Challenges, Future Vision

Current Model

- Engineer optimal **state features**
- Efficiently use **archival data**
- Monitor **real-time** conditions
- Designing **robust testing** surveys

Astro Domain

- Efficiently schedule **ToO followup**
- Expand **astro program** directions

AI Domain

- Handle realistic, multi-timescale **rewards**
- Balance **competing objectives** from programs
- Bridge discrete RL + continuous real-world **action spaces**

Future Reach

- Enable **automatic tiling** of sky regions
- **Generalize** to other telescopes
- **Generalize** to other science goals
- Incorporate **LLMs**: text analysis → schedule proposal?

Other Telescopes, Wavelengths

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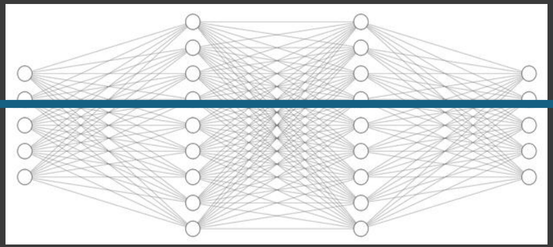
2026/05/21 19:09	(..., ...)	(..., ...)	...	...

state 1 → reward1
action 1
state 2 → reward 2
action 2
state 3 → reward 3
action 3
state 4 → reward 4
action 4
state 5 → reward 5

+ counterfactuals

Input: state *i*



Output: action *i*

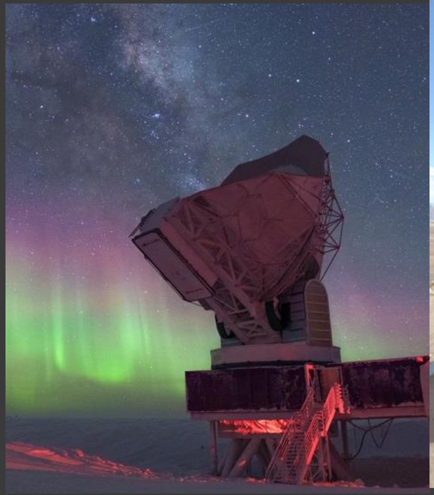
Other Telescopes, Wavelengths

Blanco → Rubin

CTIO/NOIRLab/NSF/AURA/P. Marenfeld

Rubin Obs/NSF/AURA

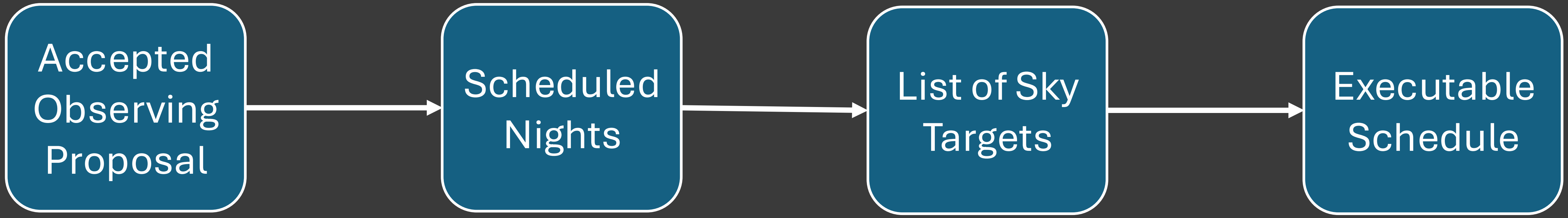
CMB Surveys (SPT, SO)



South Pole Telescope, Amon Chokshi

simonsobservatory.org

End-to-End Scheduling



Integrated Observatories

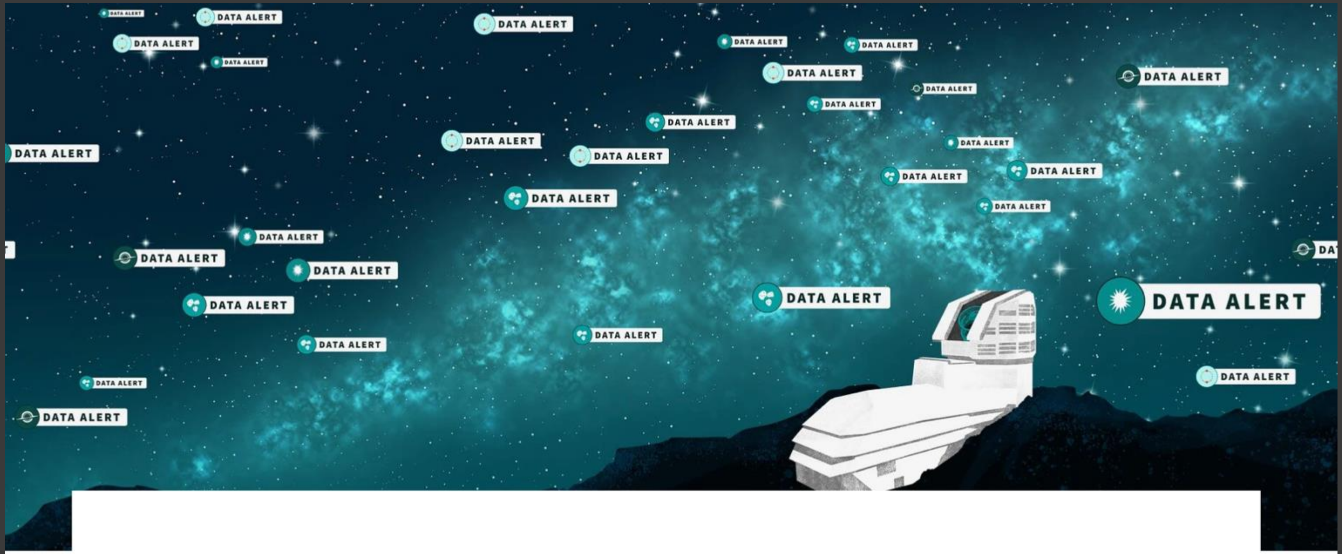
Part of the new LIGO/Virgo public gravitational wave alert page. The public can keep track of and learn about the latest public alerts at https://gracedb.ligo.org/latest/

First Public Gravitational Wave Alert Issued!

News Release • April 11, 2019

By Kimberly Burtnyk

The LIGO Scientific and Virgo Collaborations are excited to announce that they have sent out their first ever "public alert", informing the world at large of a possible gravitational wave detection. Beginning with this current observing run (dubbed O3 for the third observing run with advanced detectors), LIGO and Virgo will publicly announce candidate gravitational wave triggers with a high likelihood of astrophysical origin within minutes of the waves arriving in the three detectors (LIGO Hanford, LIGO Livingston, and Virgo).



NSF–DOE Vera C. Rubin Observatory Launches Real-Time Discovery Machine for Monitoring the Night Sky

The near-real-time alert system will enable scientists around the world to coordinate follow-up observations like never before

February 25, 2026

SkAI Institute

SkAI Institute

Chicago, IL
Founded 2024

skai-institute.org

Lead Institutions

Partner Institutions

Astro-AI Pillars

1: Enhanced inference from cosmic survey data

2: AI-accelerated simulations with multiscale astrophysics

3: Learning-based survey and instrument design

SkAI Institute

SkAI @ Cosmic Horizons 2026

Elena González Prieto
Tue, July 14
Machine Learning Methods for Stellar Collisions

Philipp Moura Srivastava
Tue, July 14
A Mesh-Free PINN Framework for Scalable Stellar Structure Modeling

Ved Shah
Wed, July 15
ORACLE: A Real-Time, Multi-Modal, Hierarchical Classifier for Time Domain Astronomy

Noelle Samia
Thu, July 16, Invited Talk 7
SELDON: Continuous-Time AI Foundations for Real-Time Transient Astrophysics in the Rubin Era

Attend Open SkAI 2026

When: September 8-11, 2026
Early Registration: Wed, July 15

Still accepting poster abstracts

openskai-conference.org

Thank you!

Paul Chichura

pchichura.github.io