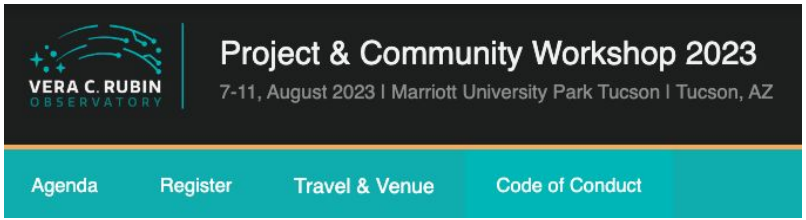
Discovering the Unknown in the LSST era

Organizers:
Ashish Mahabal, Xiaolong Li, Federica Bianco

#day4-thu-1600-discovering-unknown

Get Notifications for @ MentionsHuddle

Reminder - Code of Conduct



Harassment and unprofessional conduct (including the use of offensive language) of any kind is not permitted at any time and should be reported to:

- Andrew Connolly (ajc@astro.washington.edu),
- John Franklin Crenshaw (jfc20@uw.edu), and/or
- Alysha Shugart (ashugart@lsst.org).

Rubin Observatory adheres to the principles of kindness, trust, respect, diversity, and inclusiveness in order to provide a learning environment that produces rigor and excellence.

full code of conduct

Check name-tags for these contact comfort level stickers.

Wear a mask if you want to!

Use the confidential email rubin2023-covid@lists.lsst.org to request a test, report your test results, or ask questions.

If someone is wearing a pin like this, and it indicates a low social battery, please give them their space or offer to restart the conversation at a later time.

If you feel unsafe at any time send an email to rubin2023-helpline@lists.lsst.org

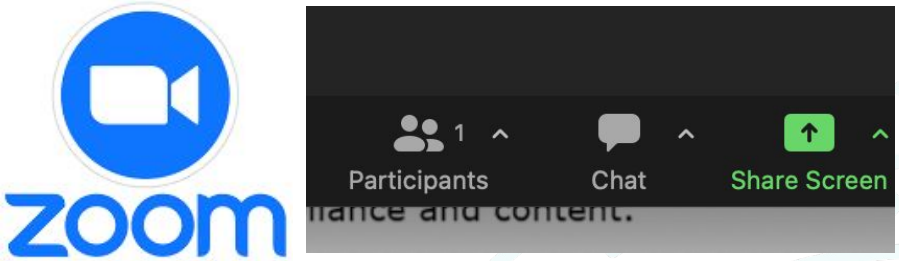
Reminder - Virtual Participation

Virtual participants should be muted when they're not speaking.

In-person participants should speak into the room microphone(s), or the chair should repeat all questions into the microphone, so that the virtual participants can hear what is said.

In the Rubin2023_PCW Slack Space, all participants can use the session's channel for Q&A and discussion.

The channel name convention is, e.g.: #day1-mon-slot3a-intro-to-rubin



In Zoom, use the chat to:
- request to unmute to ask a question, or
- type your question so someone can speak it aloud.

The Zoom "raise hand" feature is generally harder for moderators to track, and is not preferred, but may be used at the discretion of the session chair.

The Plan

- Federica Bianco: Rules of engagement, intro, TVS anomalies subgroup (<=7 min)
- Ashish Mahabal: new ISSC anomaly detection interest group (<=7 min)
- Xiaolong Li: Time domain perspective (<=10 min)
- Will Clarkson: Proper motion perspective (<=10 min)
- Ari Heinze: Solar System Perspective (<=10 min)
- Agnieszka Pollo: Extragalactic Perspective (<=7min)
- Konstantin Malanchev: Precursors: detection of anomalies in ZTF (<=10 min)
- Ashley Villar (remote): detection of time domain anomalies with AI (<=10 min)

1 sliders:
Chris Lintott (video); Ashish Mahabal; Abi Saha; Patrick Aleo (by proxy)

Anyone else who wants to speak and panel discussion!

Mahabal | ISSC anomaly interest group

Includes members from TVS with similar interest

Patrick Aleo
Federica Bianco
Eric Feigelson
Bryce Kalmbach
Xiaolong Li
Ashish Mahabal
Alex Malz
Konstantin Malanchev
Anais Moller
Gautham Narayan
Priscila Pessi
Fabio Ragosta
Monika Soraisam
Ashley Villar

https://docs.google.com/document/d/1Ilu11fCLXt4wFk-1a7wS41tsyyj36cV7f8pG9_MkwsU/edit

Mahabal | TVS anomaly subgroup group

There is also a TVS anomaly subgroup, but it's not very active…
contact Federica if you want to be the new chair!

Federica Bianco
Neven Caplar
Sid Chaini
Tatiana Acero Cuellar
Shar Daniels
James Davenport
Tansu Daylan
Rafael Martínez-Galarza
Swayamtrupta Panda
Kaylee de Soto
Elahe'e Khalouei
Andrew Levan
Ashish Mahabal
Keming Zhang

https://docs.google.com/document/d/1Ilu11fCLXt4wFk-1a7wS41tsyyj36cV7f8pG9_MkwsU/edit

Mahabal | ISSC anomaly interest group

Intended meeting frequency: once a month

- Talks
- Discussions
  - Datatypes, Datasets
  - Types of anomalies
  - Methods
  - Cross fertilization

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Discussions

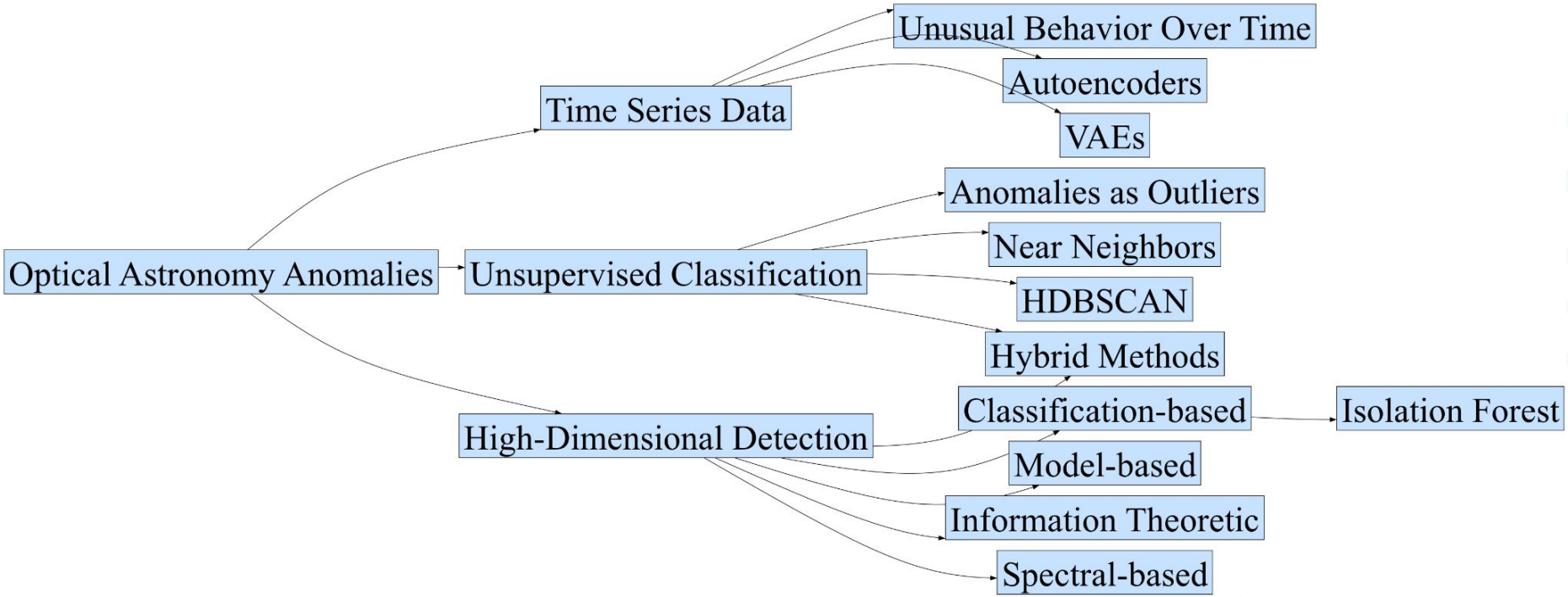
- Datatypes, Datasets
- Types of anomalies
- Methods
- Cross fertilization

→

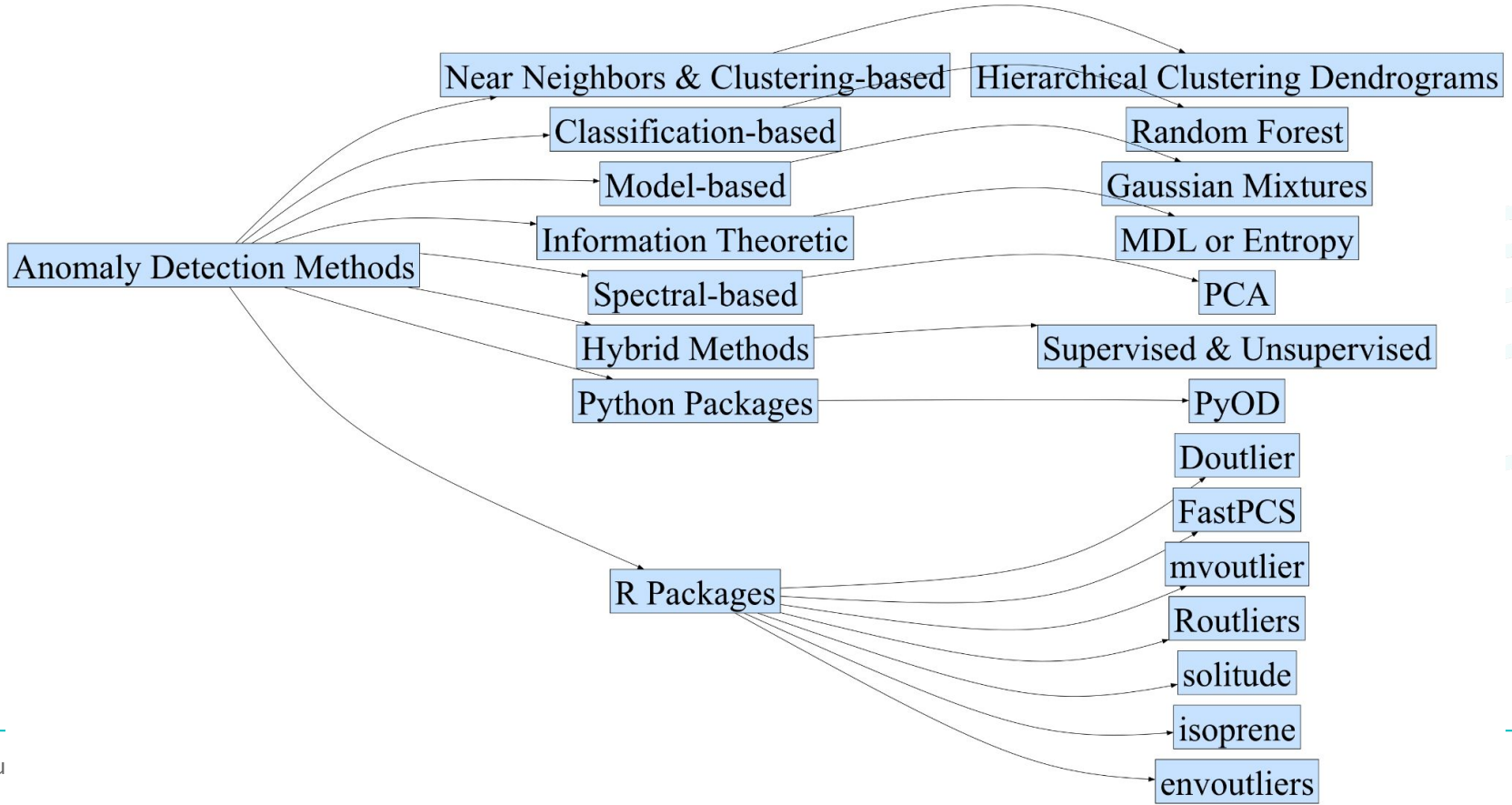
Rare events
In-class outliers (extreme)
Inter-class objects
New phenomena/classes

Artifacts -> improvements

Mahabal | ISSC anomaly interest group



Mahabal | ISSC anomaly interest group



Mahabal | ISSC anomaly interest group

Possible first project (proposed by Alex Malz)

Analyze audio data from stress testing the camera system at SLAC
Filters, motions, …

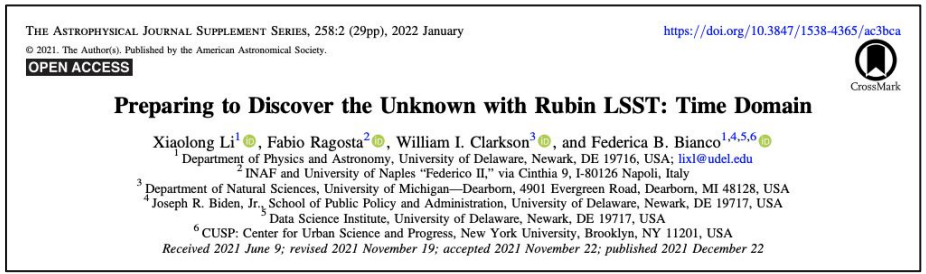
Look for anomalies

Alex Boucaud

Xiaolong Li

Unknowns Unknowns with Rubin LSST: Time Domain and Proper motion

We wrote two papers aimed at optimizing the survey cadence for the discovery of never-before seen phenomena
Xiaolong Li, Fabio Ragosta, Will Clarkson, Federica Bianco



The Astrophysical Journal Supplement Series, 258:2 (29pp), 2022 January https://doi.org/10.3847/1538-4365/ac3bca

Preparing to Discover the Unknown with Rubin LSST: Time Domain

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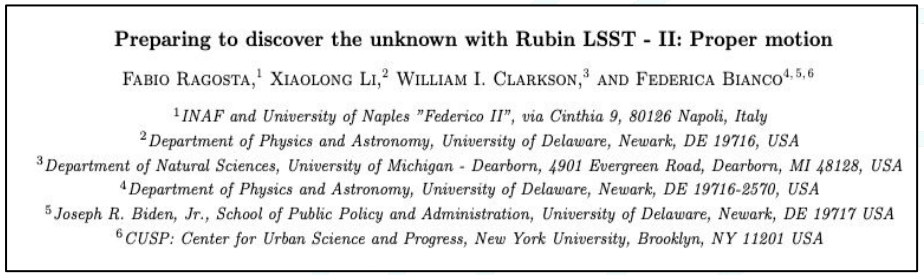
Received 2021 June 9; revised 2021 November 19; accepted 2021 November 22; published 2021 December 22



Preparing to discover the unknown with Rubin LSST - II: Proper motion

Fabio Ragosta,[1] Xiaolong Li,[2] William I. Clarkson,[3] and Federica Bianco[4,5,6]

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[2] *Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA*
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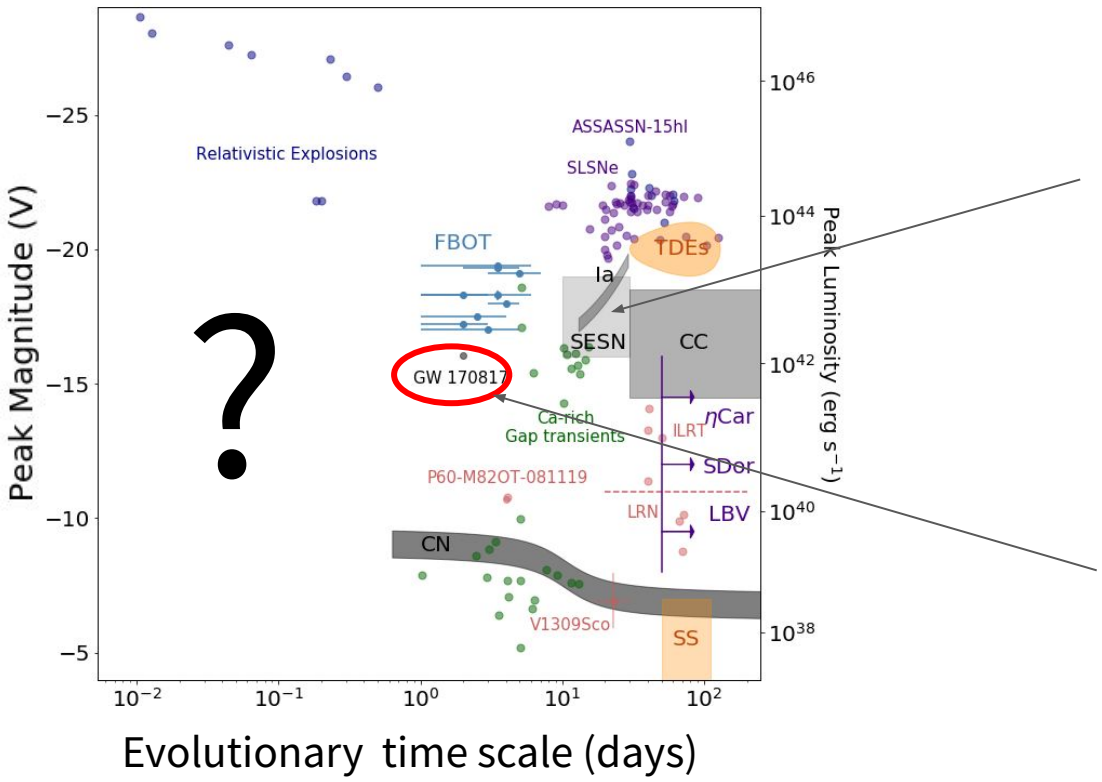
https://iopscience.iop.org/article/10.3847/1538-4365/ac3bca
Published in ApJS Rubin Survey Strategy Focus Issue

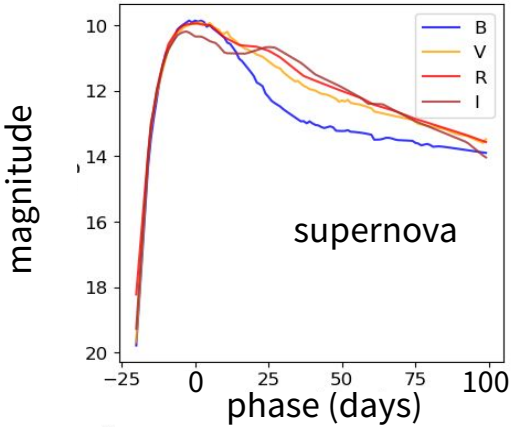
To be submitted to
ApJS Rubin Survey Strategy Focus Issue

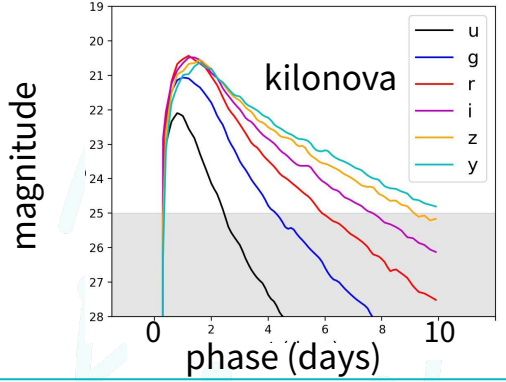
Rubin LSST PCW 2023 August 10

- **Unknown unknowns with Rubin LSST : Time domain**
  - Feature space
  - Designing algorithms to discover the unknown
  - Recommended Observing Strategy
- Unknown unknowns with Rubin LSST : Proper motion
  - Confusion Index
  - Likelihood Score
  - Transient proper motion

Time domain novelties







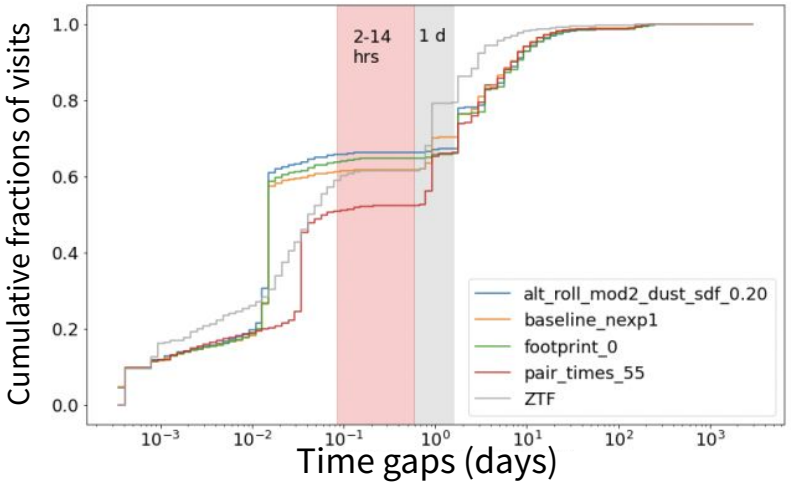
Unknown unknowns with Rubin LSST: Metrics

Goal: evaluate the ability of the LSST survey to discover “true novelties”: phenomena never before seen nor predicted from theory

Model-independent approach: to measure completeness in the space of features that Rubin can observe

➔ Brightness & changes

➔ Color & changes



From Bellm et al. 2021 Most LSST simulations have no observations between 2 and 14 hours and around 24 hours

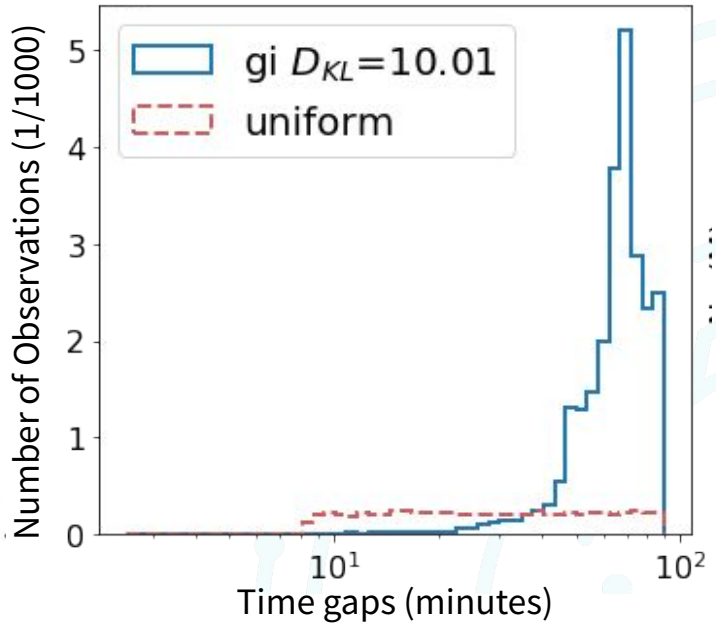
Unknown unknowns with Rubin LSST: Metrics

Algorithm 1: Time gaps metric

```
for filter f1, f2 in [u, g, r, i, z, y] do
    select visits in pairs, i.e. uu, ug...
    measure all time gaps
    if f1 ≠ f2 then
        select time gaps within 2 days
    if f1 = f2 then
        select time gaps from minutes to 10 years
    measure KL divergence or variance
Sum over filter pairs, weighted by number of visits N
```

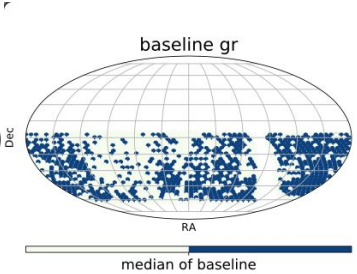
Kullback–Leibler divergence $D_{KL}(P||Q) = \sum P \log(\frac{P}{Q})$

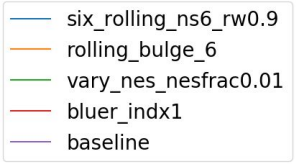
Time gaps in observations taken with pairs of different filters within 48 hours,

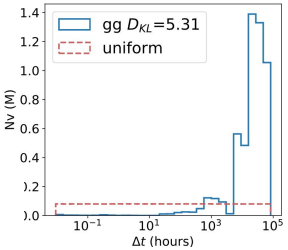


Unknown unknowns with Rubin LSST: Metrics

Footprint
(fields well observed)

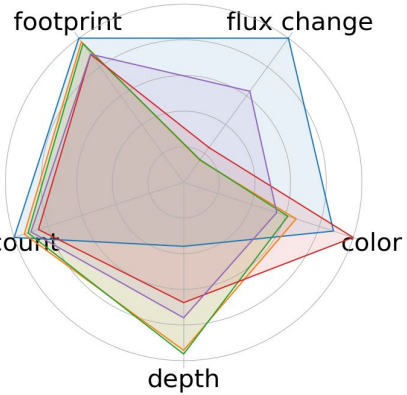




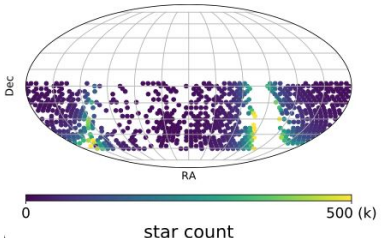


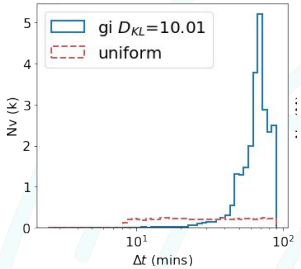
Brightness

Repeated visits in the same filter



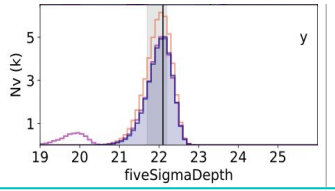
Star density





Color

Pairs of different filters

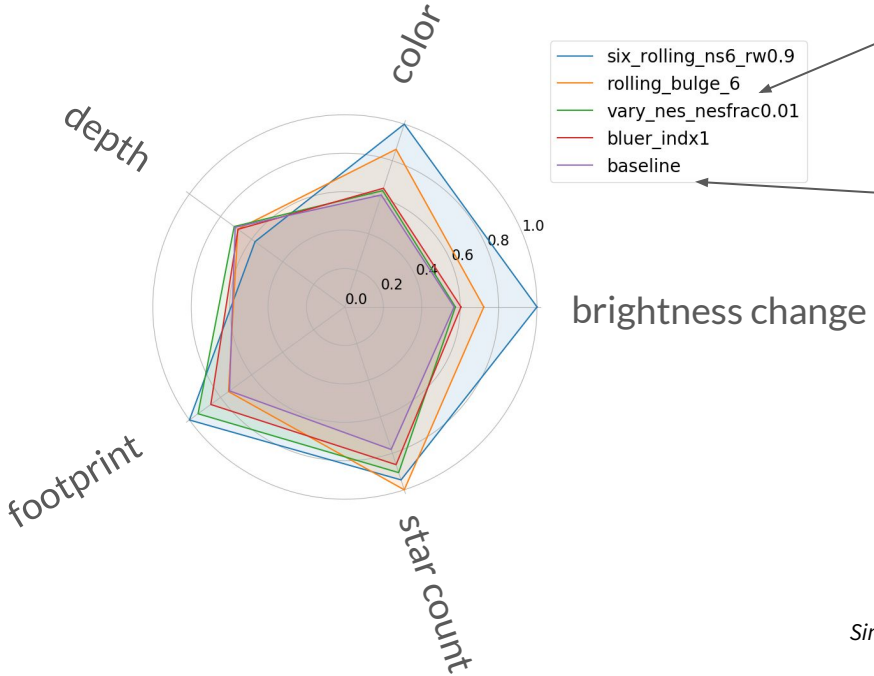


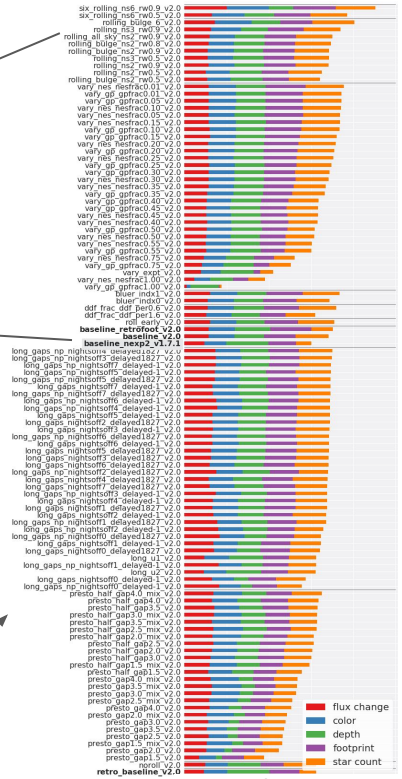
Median depth

Unknown unknowns with Rubin LSST: Figure of Merit

Concatenate the FoM pieces

$$FoM_{TD} = FoM_{color} + FoM_{flux\ change} + FoM_{depth} + FoM_{footprint} + FoM_{stars}$$





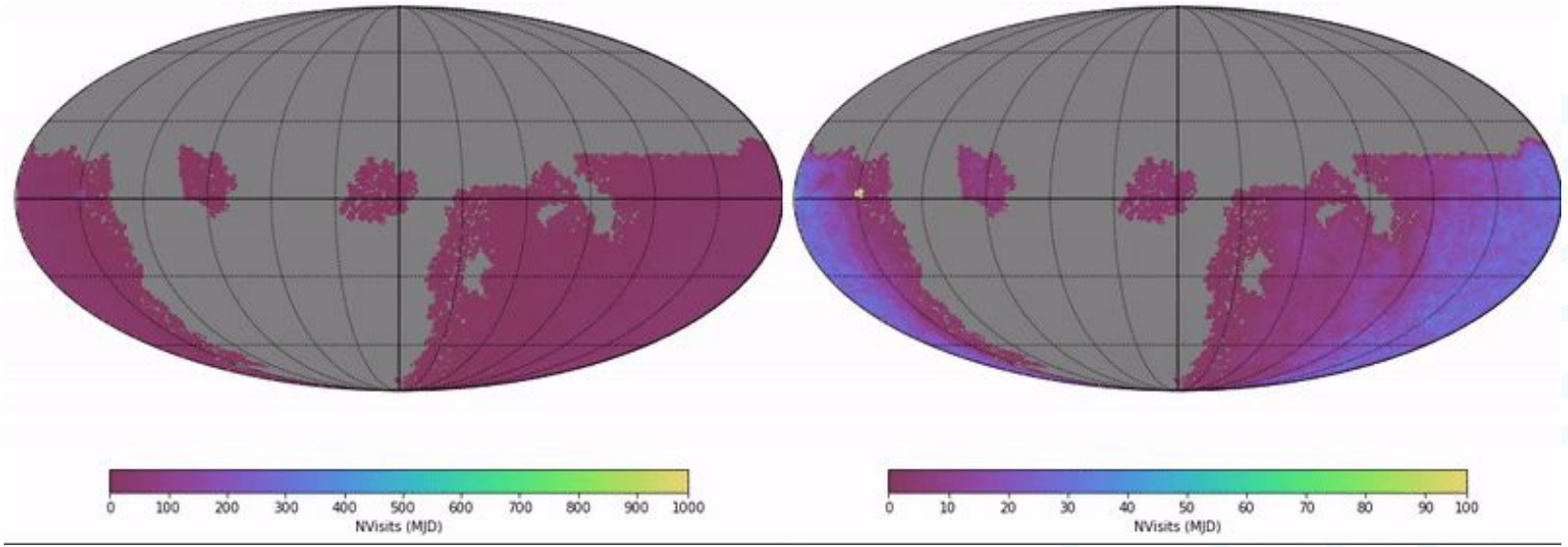
Rolling simulations

Baseline survey

Simulation name

Anomaly score →

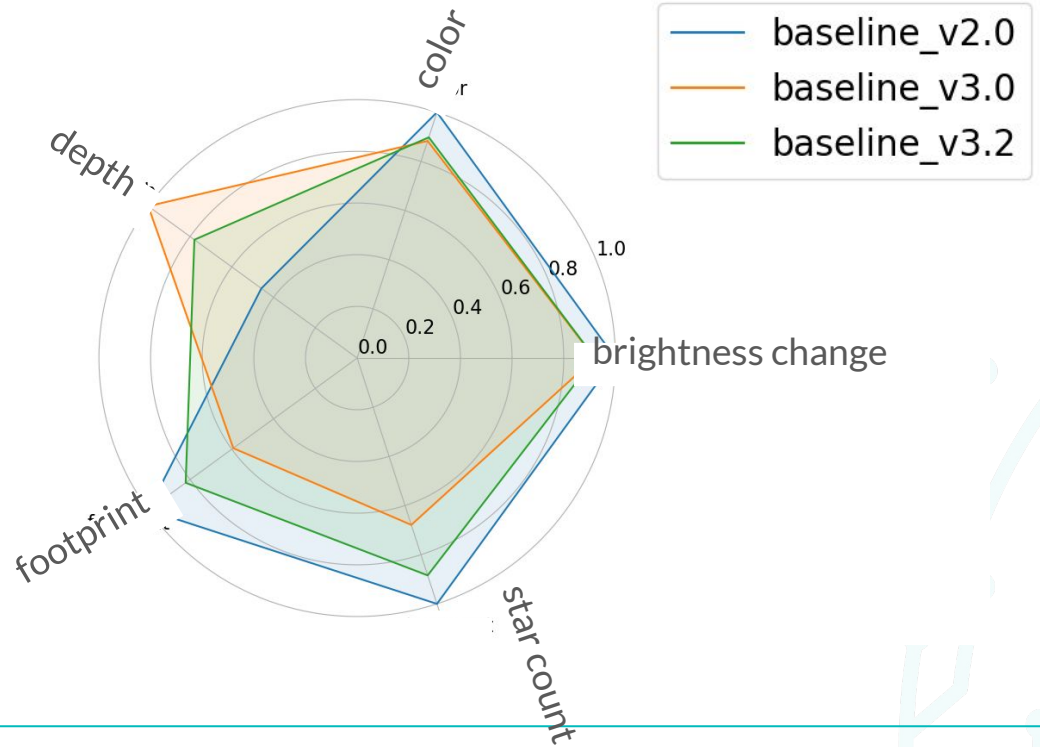
Observing strategy for unknown unknowns



Credit: Lynne Jones https://epyc.astro.washington.edu/~lynnej/opsim_downloads/ender_a1_v3.1_10yrs__N_Visits.mp4

PSTN-055 Official Rubin Cadence Recommendation 1/2023 : Rolling is recommended on the WFD, with the sky split into two 1/2-sky regions defined by declination limits and with a 0.9 rolling weight.

Opsim 3.0 and 3.2 - 2023



Will Clarkson

- Unknown unknowns with Rubin LSST : Time domain
  - Feature space
  - Designing algorithms to discover the unknown
  - Recommended Observing Strategy
- **Unknown unknowns with Rubin LSST : Proper motion**
  - Confusion Index
  - Likelihood Score
  - Transient proper motion

Presenter: Will Clarkson

LSST: proper motions ~1 mas/yr @ r=24 (full 10y)

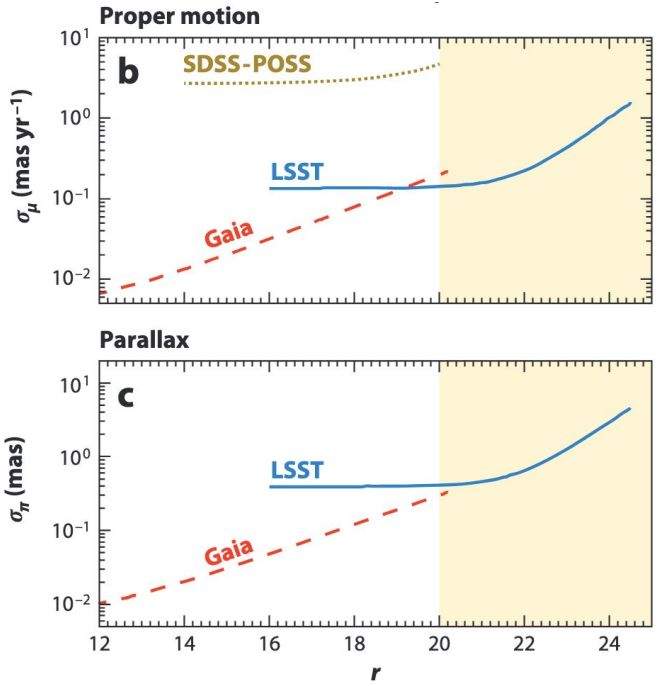
E.g. Ivezic, Monet et al. 2008:

> "*LSST will smoothly extend Gaia's error-vs-magnitude curve to a four-magnitude fainter level.*"

LSST will attach proper motion to objects which…

- … are too intrinsically faint for Gaia, and/or
- … lie in regions too highly extincted for Gaia, and/or
- … are only bright enough for proper motion measurement for a short interval during the LSST survey

Thanks to the **rubin_sim** team, a metric for the predicted proper motion uncertainty for LSST observations is available, calculating proper motion uncertainty as straight-line gradient uncertainty incorporating individual position-measurement uncertainty.



Ivezic, Beers & Juric 2012 ARA&A

Proper motions for true anomalies

Led by Fabio Ragosta (now at INAF/Rome), we have been investigating the ability of LSST to add proper motion evidence to previously-unexpected astrophysical objects it may discover, using the **rubin_sim** framework to assess candidate observational strategies.

fabio.ragosta@inaf.it

Three figures of merit:

- Confusion Index (CI);
- Likelihood Score (LS);
- Transient Proper Motion (TPM);

In general, stellar populations are simulated in 6D (position, velocity) following standard prescriptions for the “known” Galactic components, and the capability of LSST to isolate objects of interest against this “known” background is assessed using the metadata for candidate observing strategies (“opsims”)..

Proper motion: Confusion Index (CI)

The CI parameterizes the ability of LSST to kinematically identify comoving populations via their locations in the diagram of reduced proper motion (RPM) vs (g-r) color.

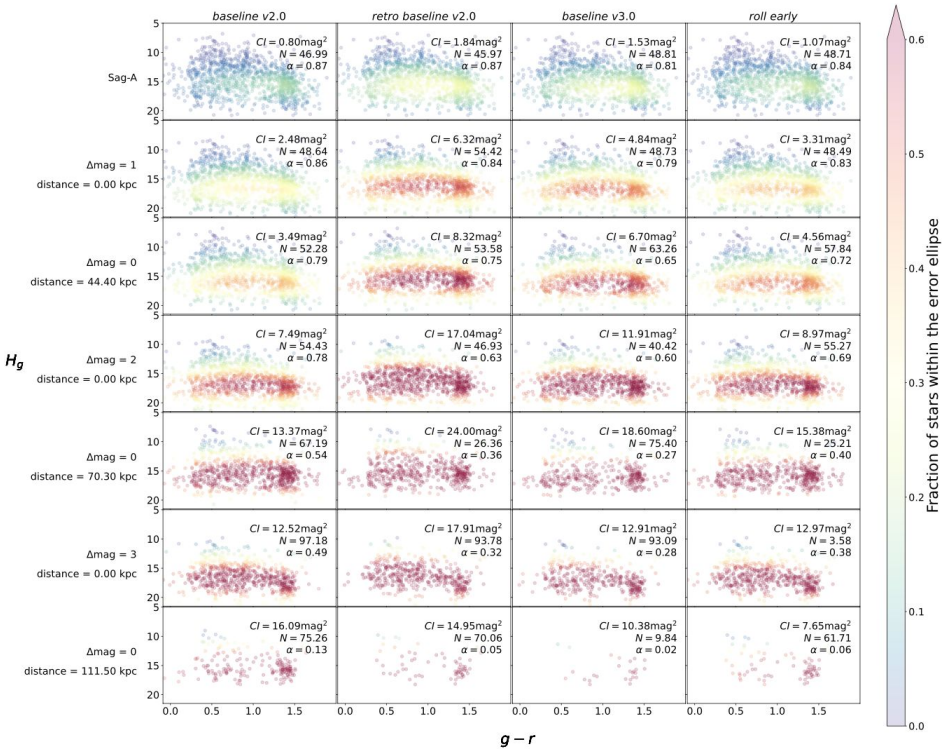
For each simulated object, measurement uncertainty inthe RPM/g-r diagram is parameterized by the “area” of the uncertainty ellipse in this space (right, below).

$$H_g = g + 5\log_{10}\left[\frac{\mu}{\mathrm{mas/yr}}\right] - 10 - A_g$$

$$\pi \times \det(C_{H,gr}) = \pi\left(\sigma_g^2\sigma_r^2 + \frac{4.715\sigma_\mu^2}{\mu^2}\left[\sigma_g^2 + \sigma_r^2\right]\right)$$

This is then used as the input uncertainty for mixture models for Sgr-dwarf-like objects injected at various distances from the observer. The result is a map in RPM/g-r space of objects that are considered confused (i.e. ambiguous membership probability to the field or the desired population).

Proper motion: Confusion Index (CI)



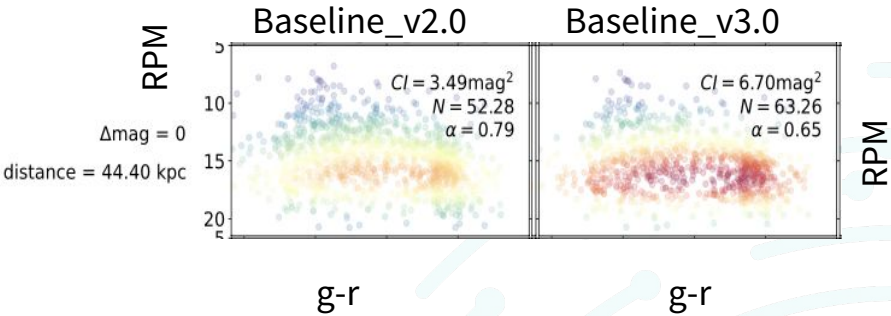


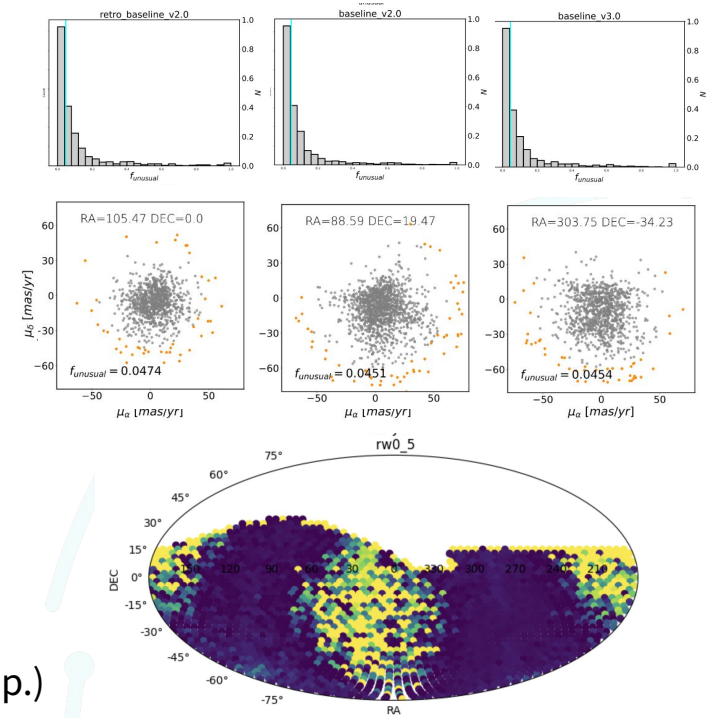
Figure from Ragosta et al. (in prep.)

Proper motion: Likelihood Score (LS)

The LS parameterizes LSST's ability to kinematically separate a point source from the "background" due to known Galactic components using LSST proper motions.

Galactic populations are simulated for each sight-line (the "known" population) and an "unknown" (i.e. anomalous population) is simulated on top of them. Objects are then recovered as "unusual" if they are **measured** to fall outside the inter-quartile range corresponding to the Galactic population.

Finally, the fraction of injected "unusual" objects that are recovered as "unusual" is evaluated for the entire simulated survey.



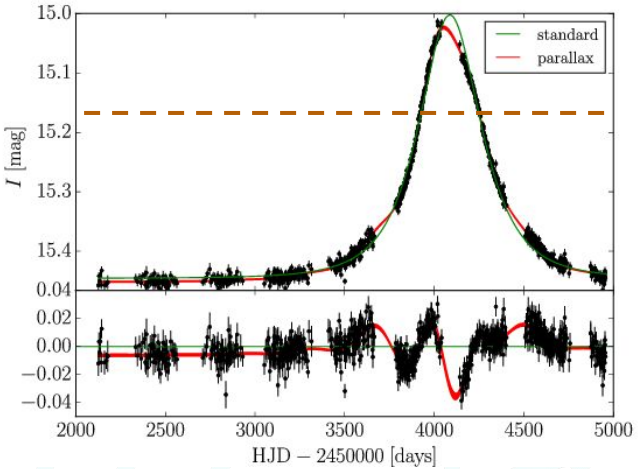
Figures from Ragosta et al. (in prep.)

Proper motion: Transient Proper Motion Metric (TPM)

The TPM parameterizes LSST's ability to attach proper motion information to transients (particularly those that are only bright enough for proper motion measurement during the transient event).

A population of transients is simulated (for a few example regimes). Then the Transients metric (of Li et al. 2023) is assessed to determine which objects LSST would detect as transients.

For the subset that LSST would detect as transients, the proper motion uncertainty is evaluated over those observations for which the transient is sufficiently bright for LSST detection at 5 sigma.



Microlensing lightcurve from the [OGLE-III website]

Proper motions for True Anomalies: status

Three figures of merit:

- Confusion Index (CI) - **Implemented**.
- Likelihood Score (LS) - **Implemented.**
- Transient Proper Motion (TPM) - **Finalizing implementation.**

Next steps:

- Finish implementing and testing TPM
- Run on the latest **opsim**s to determine which candidate strategies are best for proper motion anomaly detection.

Ragosta et al. 2023 in prep for ApJS special issue on LSST strategy**.**

Input is welcome!

fabio.ragosta@inaf.it

Ari Heinze

VERA C. RUBIN OBSERVATORY

Finding the Unexpected in the Solar System

Ari Heinze

DiRAC Institute and the Department of Astronomy, University of Washington

DiRAC

NSF NOIR Lab AURA SLAC U.S. DEPARTMENT OF ENERGY

Possible surprising discoveries

- New types of objects
- New types of orbits
- New types of behavior
- New associations of objects
- New objects in the solar system (interstellar objects)
- How to find/recognize the unexpected

Ari Heinze

Image credit: Bruno C. Quint

New types of objects

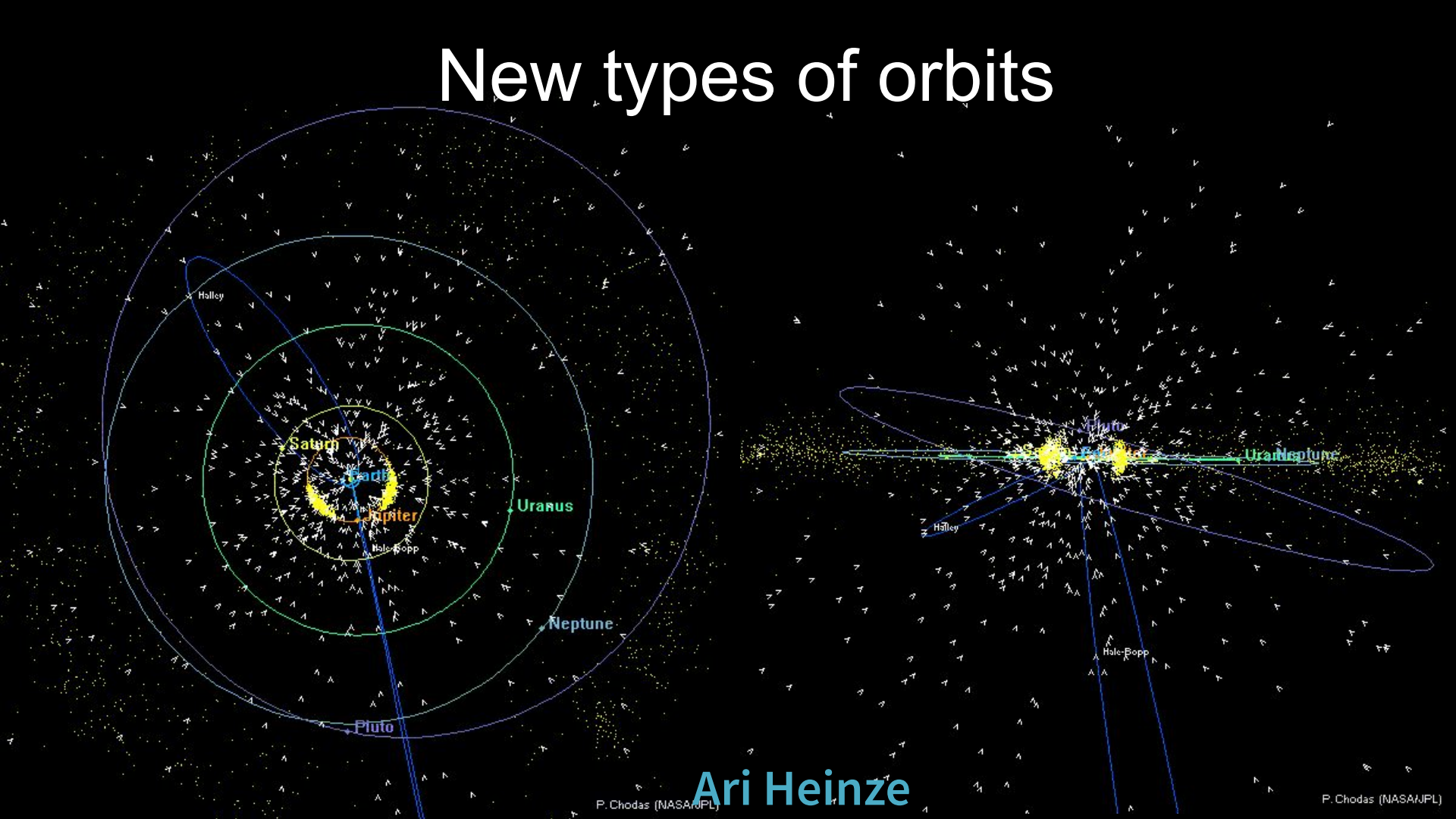
- Unlikely to see objects of an entirely different composition
- Might see new types of fragments from known bodies (e.g., nitrogen icebergs) but still unlikely.

Ari Heinze

Ari Heinze

Image credit: Bruno C. Quint

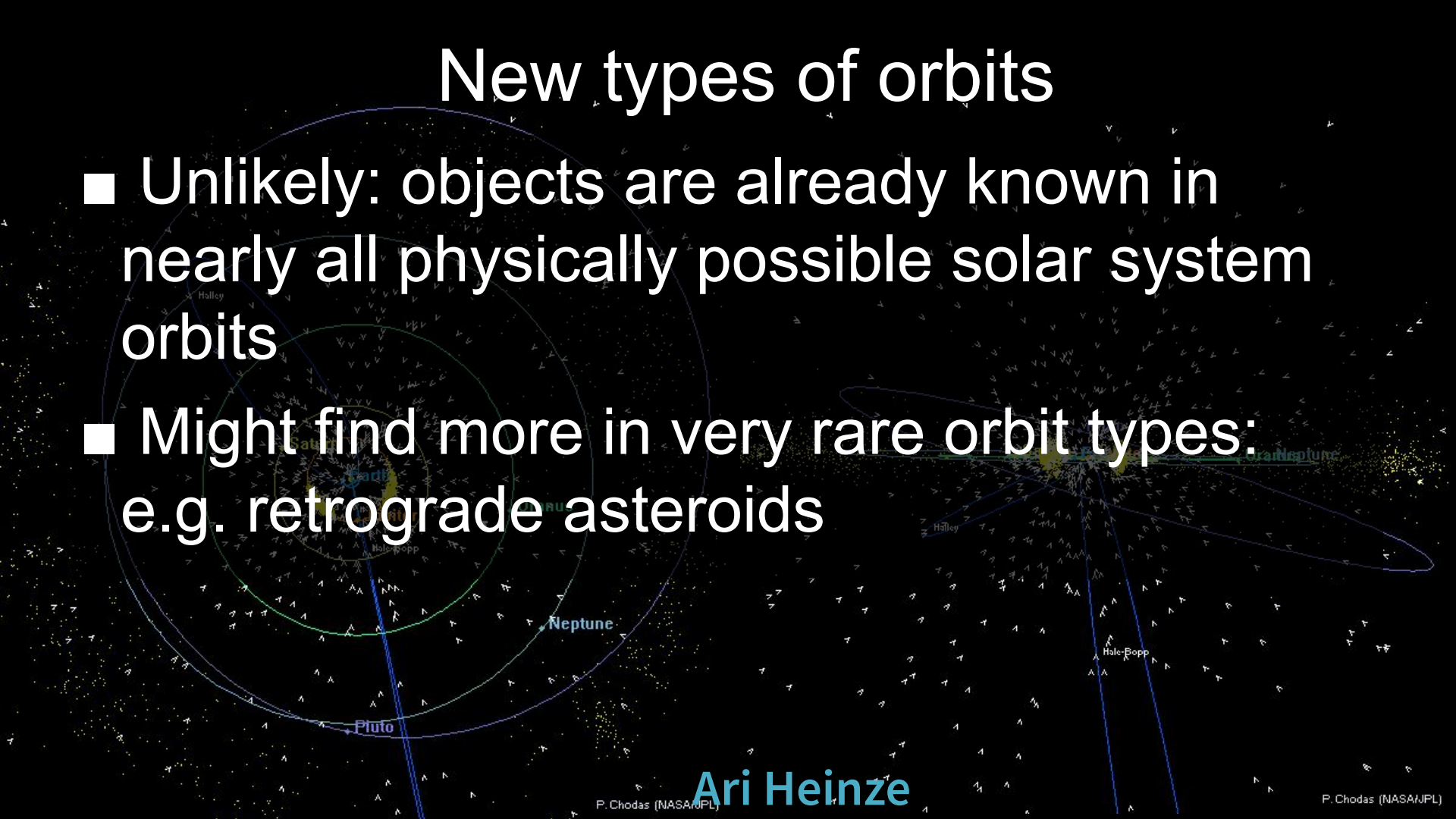
New types of orbits



Ari Heinze

New types of orbits

- Unlikely: objects are already known in nearly all physically possible solar system orbits
- Might find more in very rare orbit types: e.g. retrograde asteroids



Ari Heinze

New types of behavior

- Likely – the only question is what type
- Objects suddenly appearing (emission of dust, ??)
- Objects suddenly disappearing (slow, high-amplitude rotation, *clearing* of dust, ??)
- Change in orbit (gas emission, Yarkovsky effect, ??)

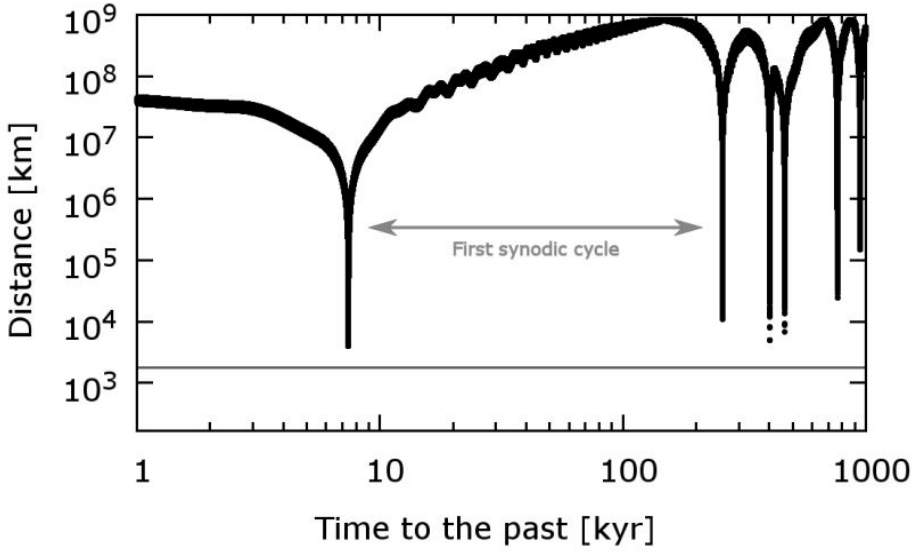
Ari Heinze

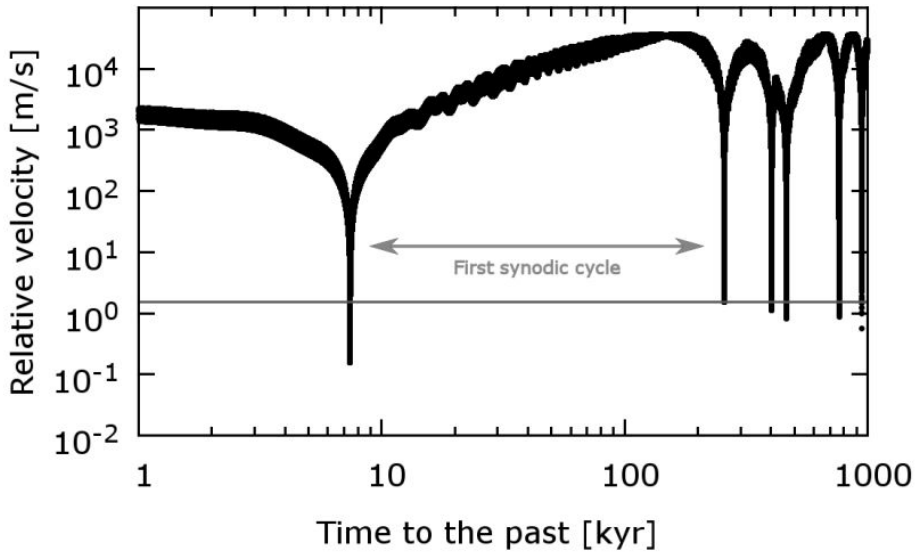
Image credit: Bruno C. Quint

New associations of objects

- **Guaranteed** to be found
- Collisional families in almost the same orbits
- Asteroid pairs from YORP fission
- Will reveal recent exciting events in the asteroid belt
- Will cause me a lot of trouble (but it's worth it)

New associations of objects





Asteroids 87887 – 415992: the youngest known asteroid pair?

J. Žižka[1], A. Galád[2], D. Vokrouhlický[1], P. Pravec[3], P. Kušnirák[3], and K. Hornoch[3]

Ari Heinze

Interstellar objects

- Rates are highly uncertain, but no major obstacle to detection

Ari Heinze

Image credit: Bruno C. Quint

How to find the unexpected

- Only humans can discover
- Computers can sort through the normal stuff, show us anomalies we should check out
- Experts and beginners may see different things
- Write fast, efficient code
- Search areas of parameter space you know are empty

Ari Heinze

Image credit: Bruno C. Quint

Agnieszka Pollo

Search for anomalous objects in the ALLWISE survey

Agnieszka Pollo
National Centre for Nuclear Research (Warsaw) & Jagiellonian University (Cracow); Poland
with
Aleksandra (Ola) Solarz;
Maciek Bilicki, Mariusz Gromadzki, M., Anna Durkalec, Michal Wypych

Tucson, 7.08.2023

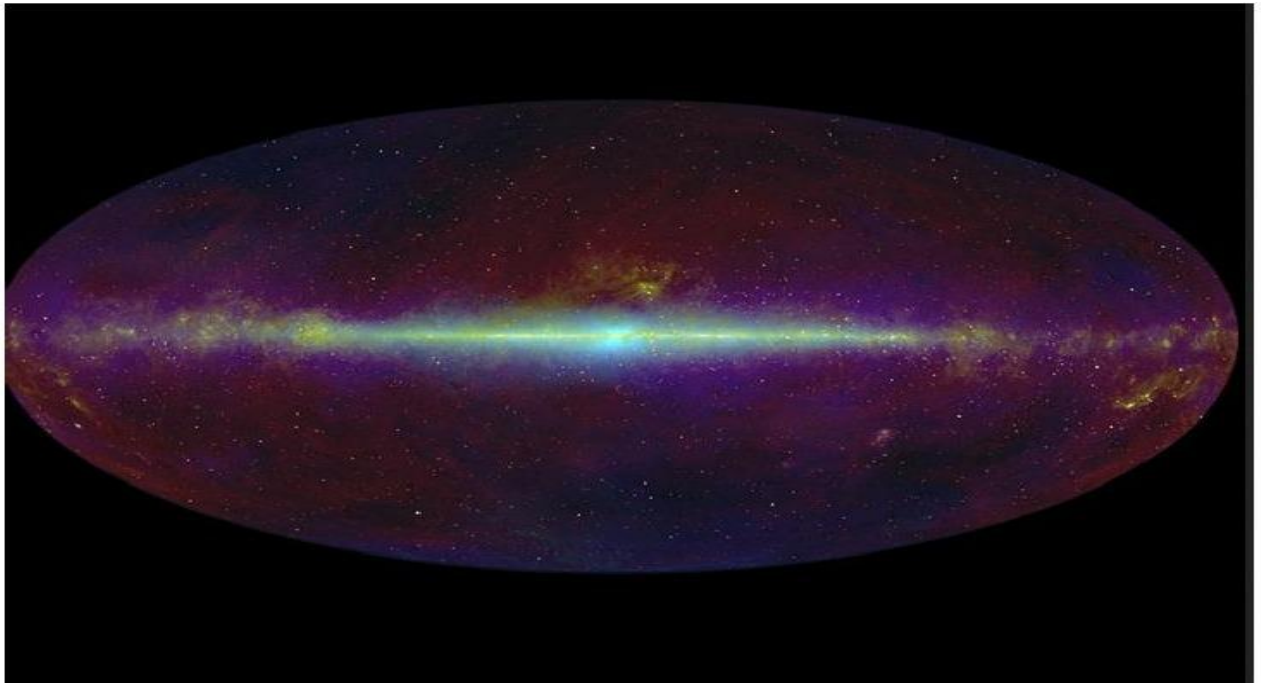
Based on the paper:
”Automated novelty detection in the WISE survey with one-class support vector machines”,
Solarz et al. 2017
Astronomy & Astrophysics, Volume 606, id.A39

Angieszka Pollo

Wide-field Infrared Survey Explorer (WISE)

- All-Sky survey in IR
- Detected over 747 mln sources
- (15 PB of data; tables + images)
- Publicly available (position, photometry in 4 bands (3.6-22 um))
- Low angular resolution (~6”)
- No redshift information

Solarz et al. 2017



(http://wise2.ipac.caltech.edu/docs/release/allsky/)

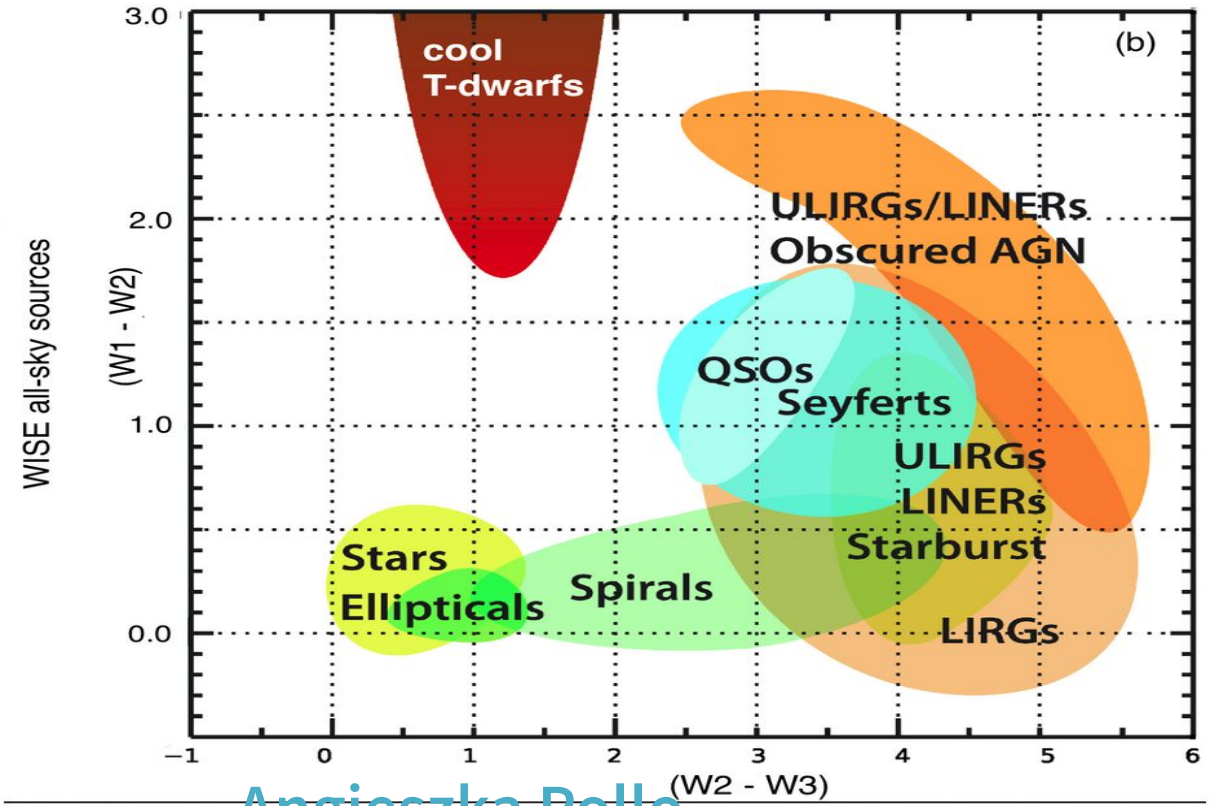
Angieszka Pollo

Exploration of parameter spaces

→ The usual first approach to selection: CC diagrams

→ **Novel or anomalous sources** deviate from expectations but could mimic a behaviour of a ‘normal’ object

→ need for new ML approaches based on larger parameter spaces



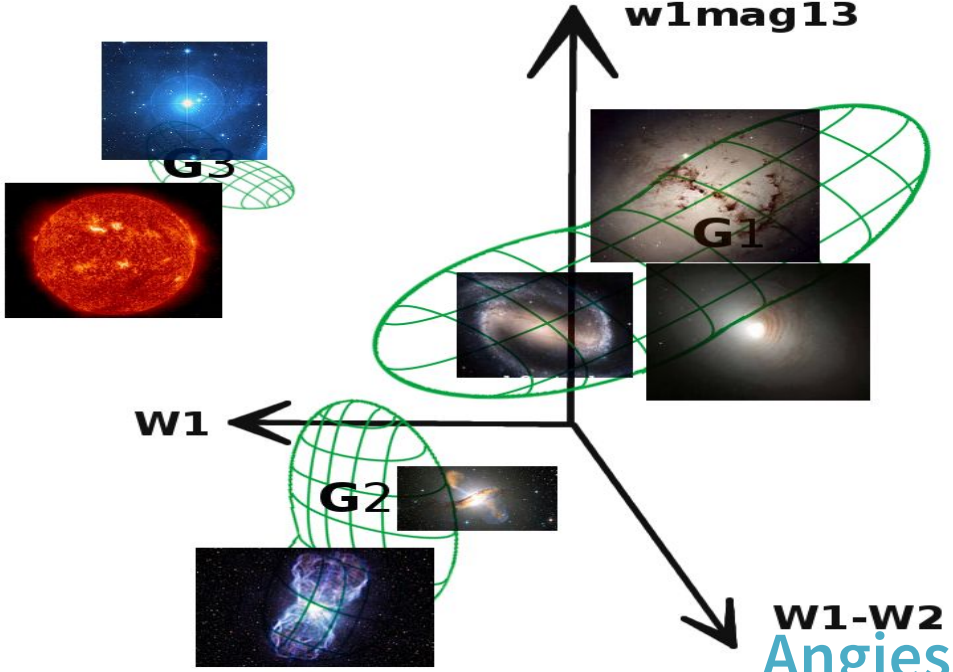
Angieszka Pollo

- Credit: Wright+10

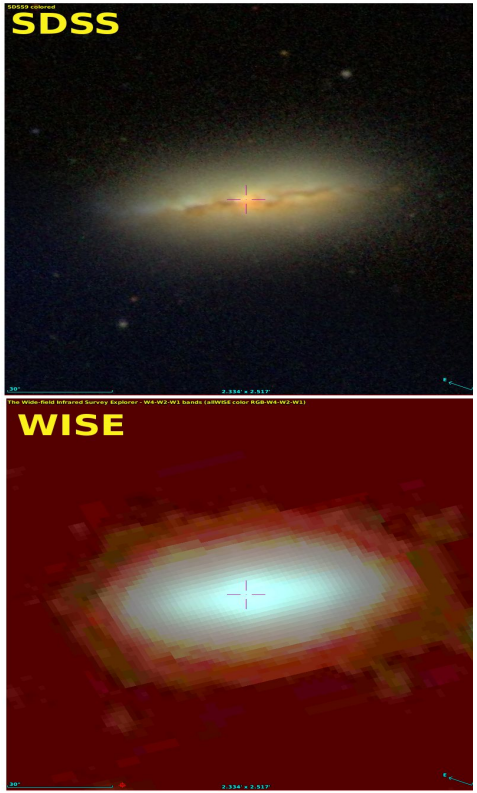
WISE: first step towards ML novel source detection

Training set:

→ AllWISE x SDSS (α,δ) with secure spectro-z



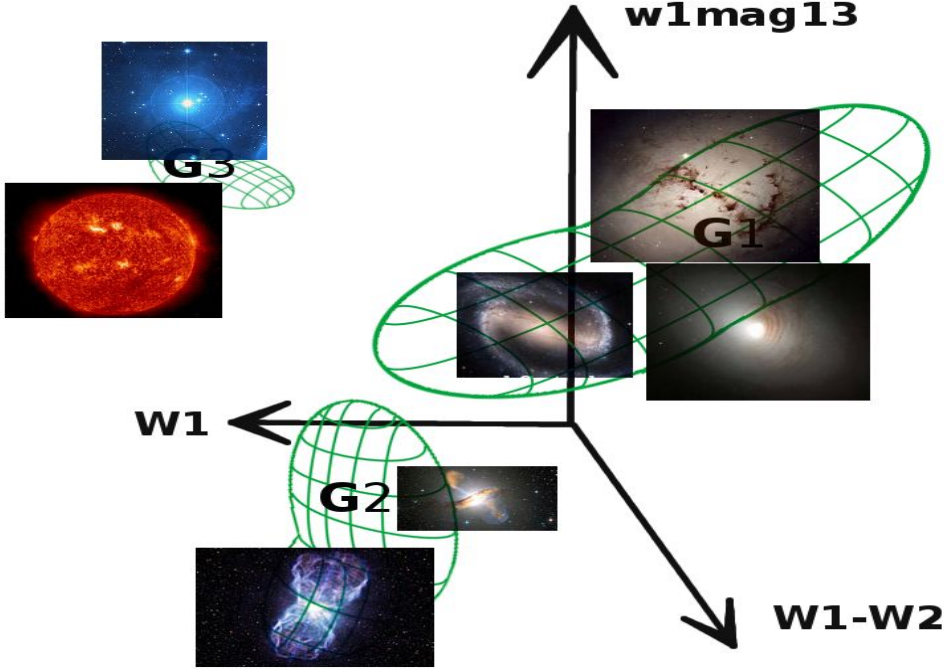
Solarz et al. 2017

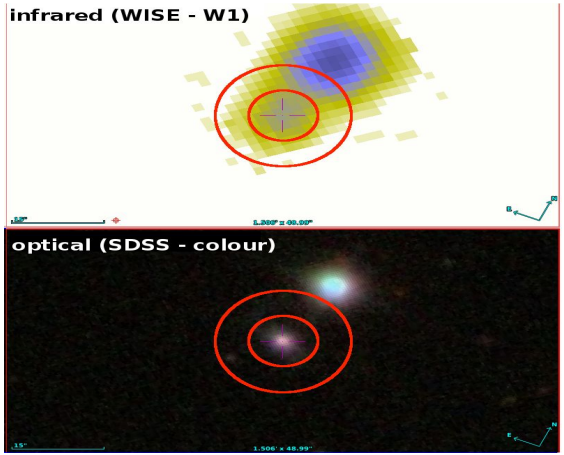


Angieszka Pollo

WISE: first step towards ML novel source detection

Solarz et al. 2017





Parameter space:

→ Brightness W1

→Color W1-W2

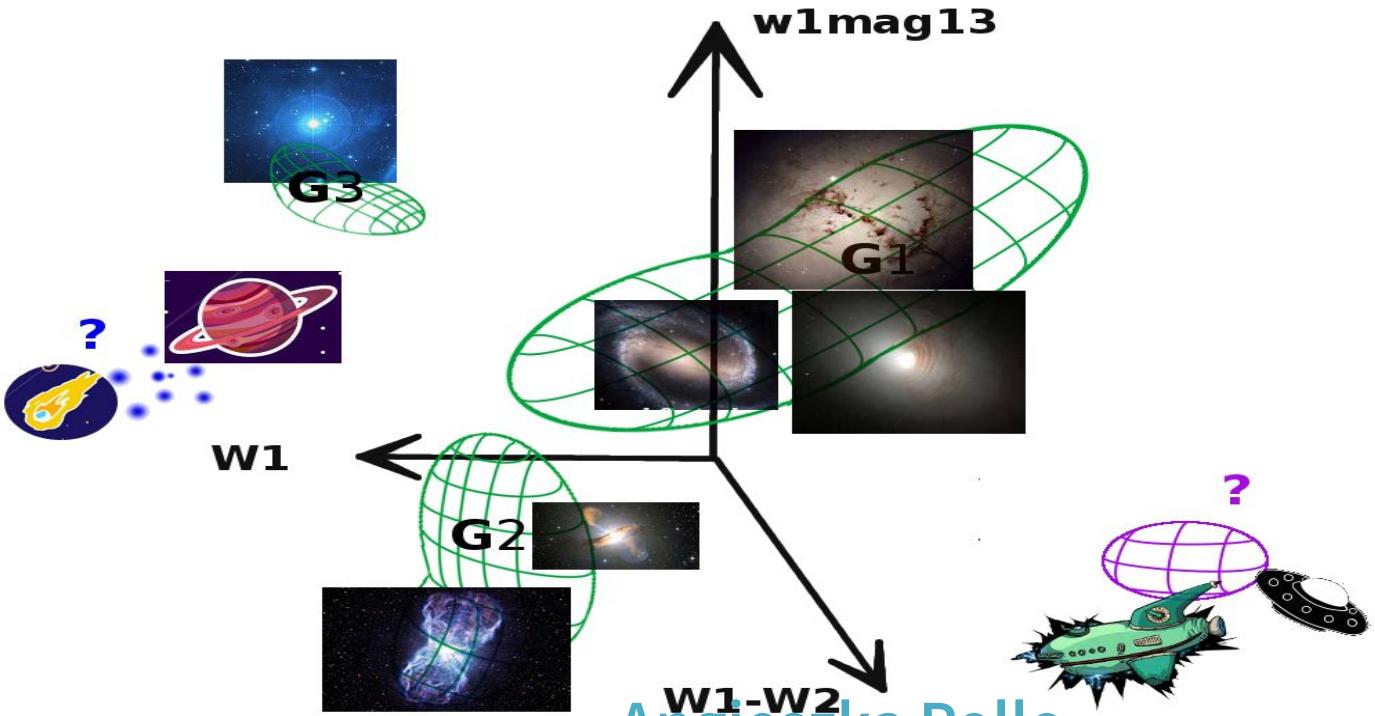
→Compactness

W1mag13 = w1mpro(5”) - w1mpro(11”)

Angieszka Pollo

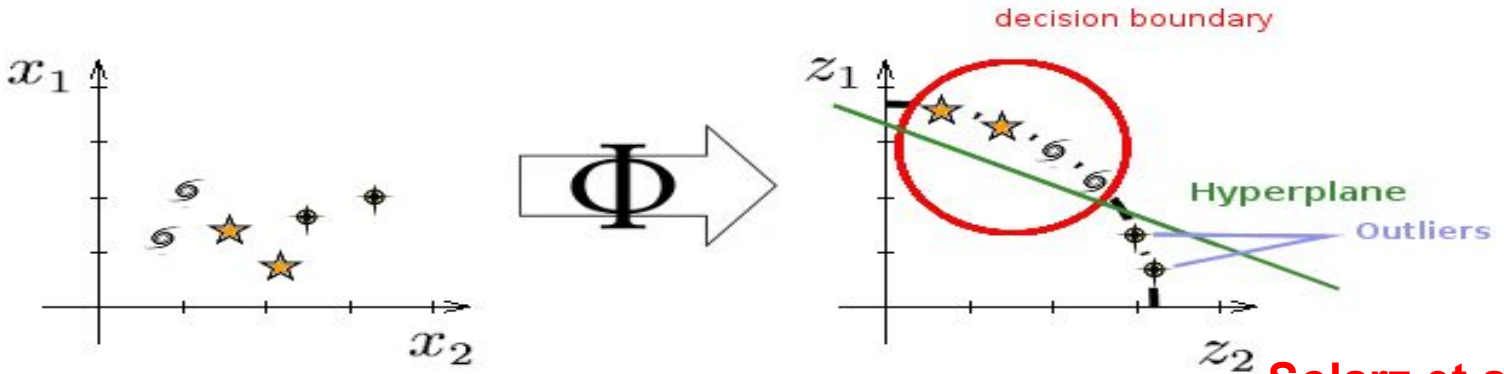
WISE: accounting for unknown unknowns

Solarz et al. 2017



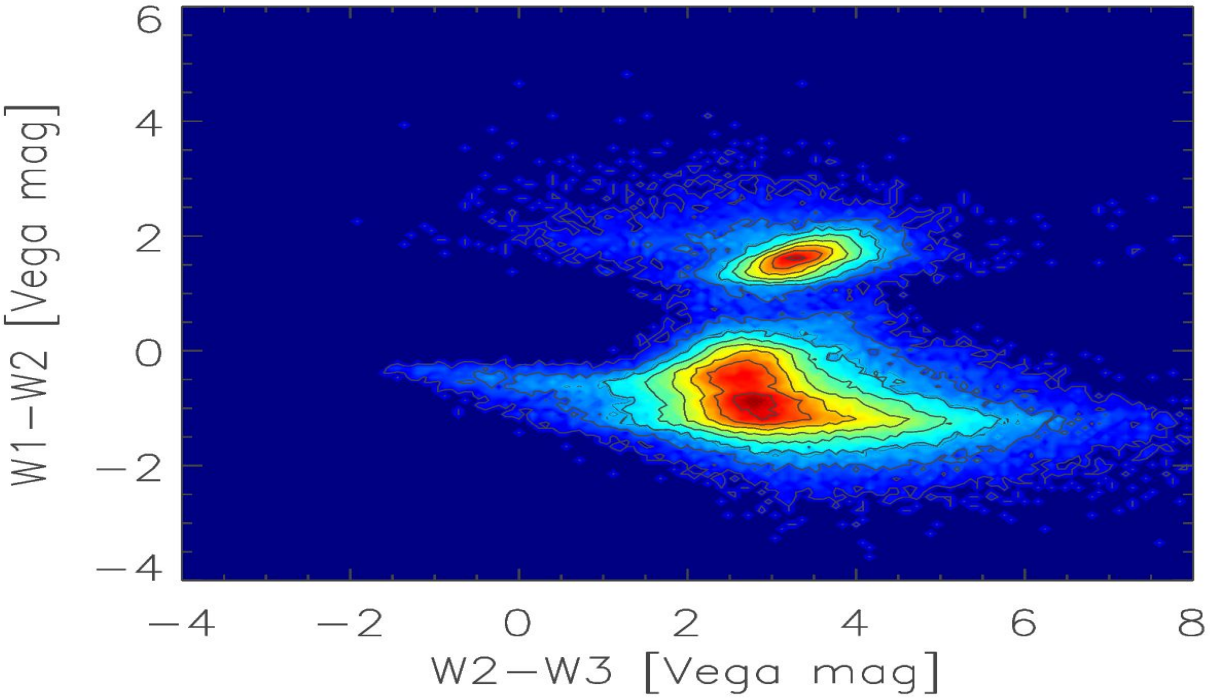
Angieszka Pollo

Novelty detection with One-Class Support Vector Machines



Solarz et al. 2017

- Create one ‘known’ class (mix of AllWISE x SDSS galaxies, stars, QSOs)
- Maps input data to a higher D parameter space (based on Kernel methods)
- Hypersurface hugging the expected sources
- Anything with ‘unknown’ patterns falls outside the hypersurface => novelties



Results:

~650,000 anomalous sources

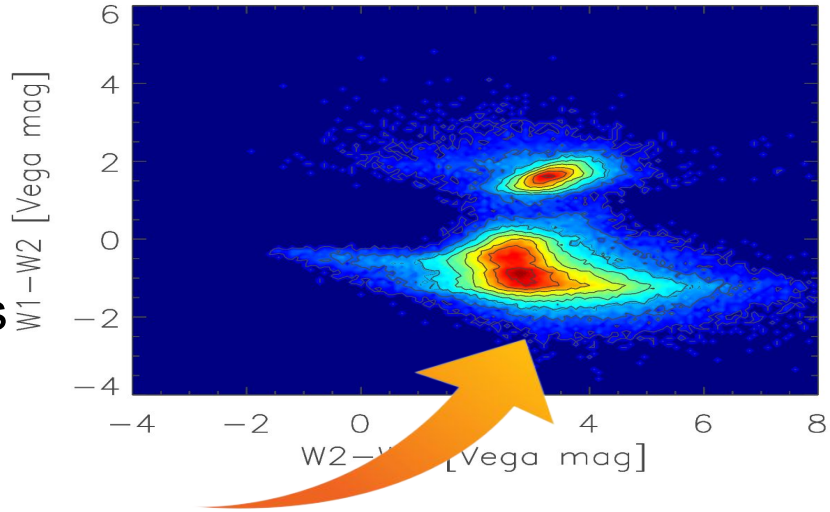
What are they?

Solarz et al. 2017

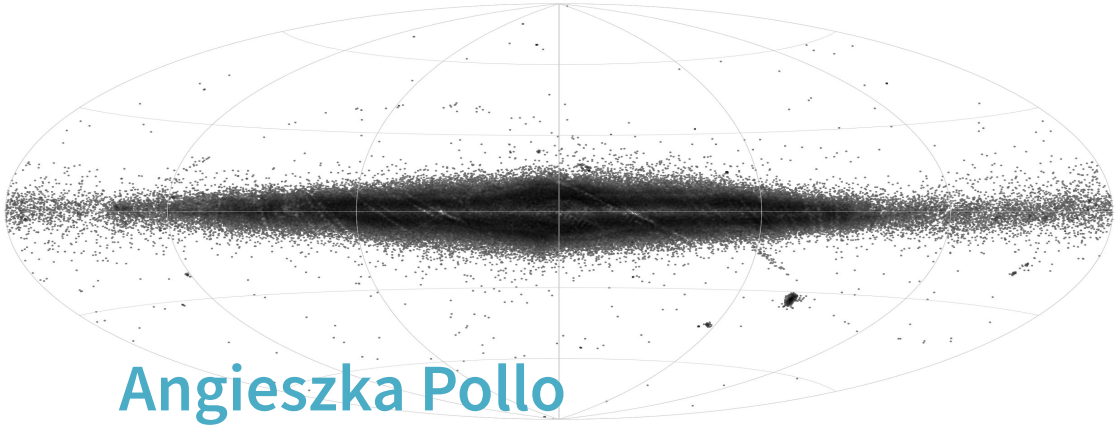
Angieszka Pollo

Spurious sources

- W1-W2 ~ -1 ; 80%; Spitzer GLIMPSE: IRAC I1 [3.6 um], IRAC I2 [4.5 um]
- Low WISE resolution (6”) in crowded fields => blends
- OCSVM: good tool for selecting hidden artefacts



Solarz et al. 2017



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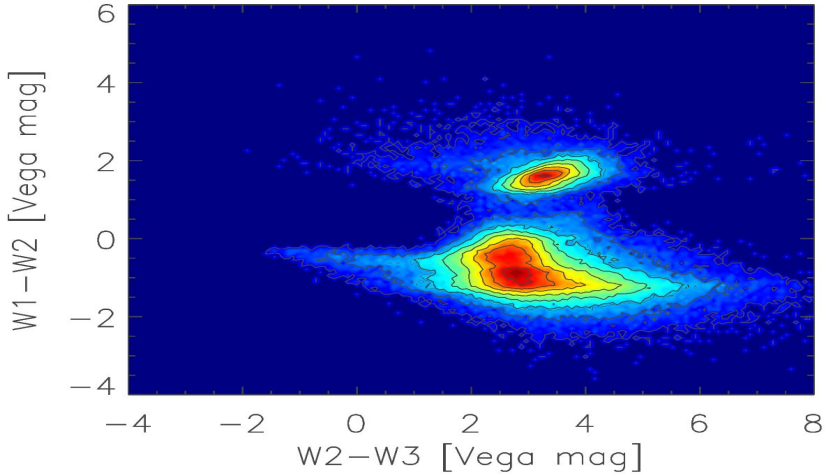
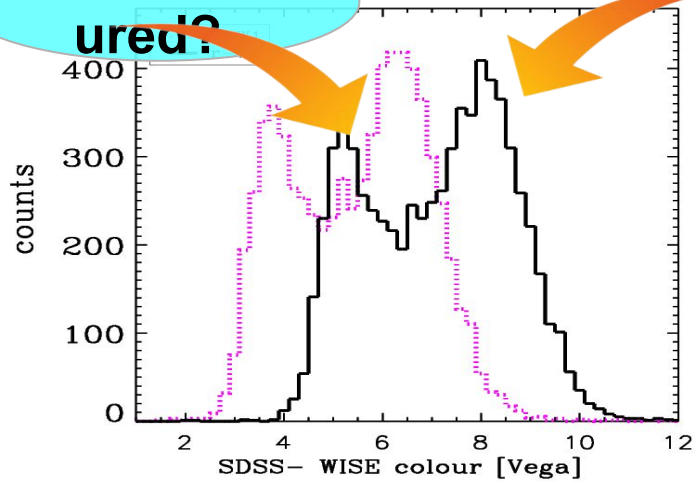
AGN candidates?

- 30,000 sources (those in Galactic Plane: still mostly blends)
- 76% undetected at other wavelengths!
- ~7 000 objects with SDSS photometry (no spectro-z), follow-up observations
  - Peculiar (dusty) QSOs
  - Low-z very dusty galaxies
  - Very dusty Galactic objects – like YSO

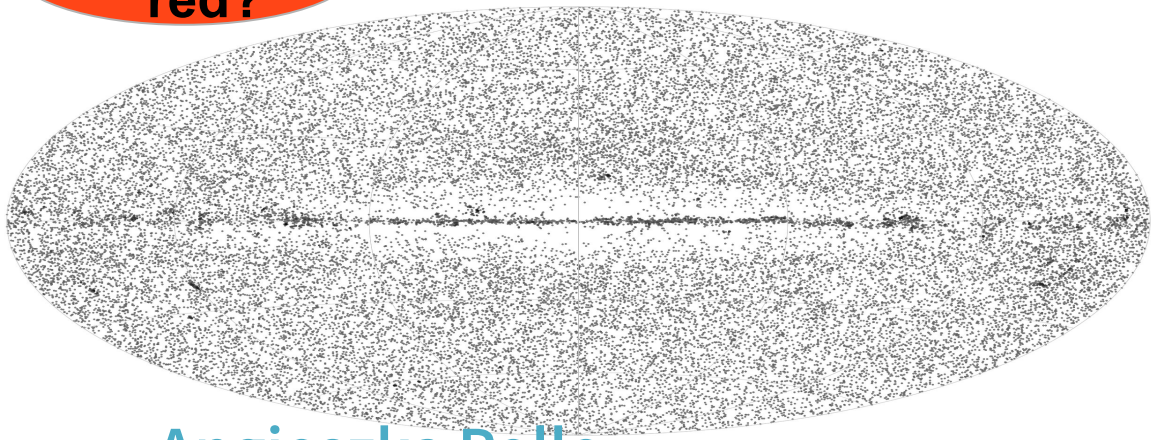
- Solarz et al. 2020



- **Unobscured?**
- **Obscured?**



- Solarz et al. 2017



Angieszka Pollo

Conclusions

- With sufficiently big data (like LSST) anomalies may come in big numbers
- Parameter space is important
- What we find is mostly trash but
  - valuable trash if not found by other methods → novelty search as a method for additional cleaning of catalogs
  - some genuine atypical sources
  - nedeed methods of separation (clustering in different parameter spaces/with DL)

Angieszka Pollo

Konstantin Malanchev

Carnegie Mellon University

SNAD

SNAD – personalized anomaly detection for astronomy

Konstantin Malanchev (LINCC Frameworks @ CMU)
& SNAD Team

Rubin Project and Community Workshop, 10 August 2023

Konsta Malanchev

Anomaly Detection is Discovery

"An anomaly is an observation which deviates so much from the other observations as to arouse suspicions that it was generated by a different mechanism"
- Hawkins, 1980

Stages of Discovery in Astronomy:

- Detection
- Interpretation
- Understanding
- Acceptance

Which mechanism?
Is it something we are familiar with but fail to proper model or recognize?
Is it something we have never seen before?

Is there something new for us to learn?

In order to identify the unusual we need to have a clear ideal of what is usual …

.. and that is a social construct. It changes and adapts with time!

Pipeline

ML produces recommendations only

Light curves

Preprocessing

Machine learning e.g. outlier detector

Potentially interesting anomalies:

- Candidate 1
- Candidate 2
- Candidate 3
- …
- …
- …
- …

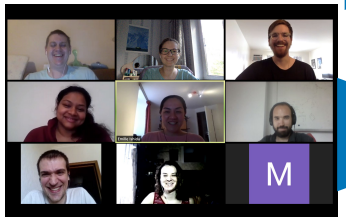
Active anomaly detection loop

Get more data and Publication

Not interesting

Interesting

Very interesting!



Experts

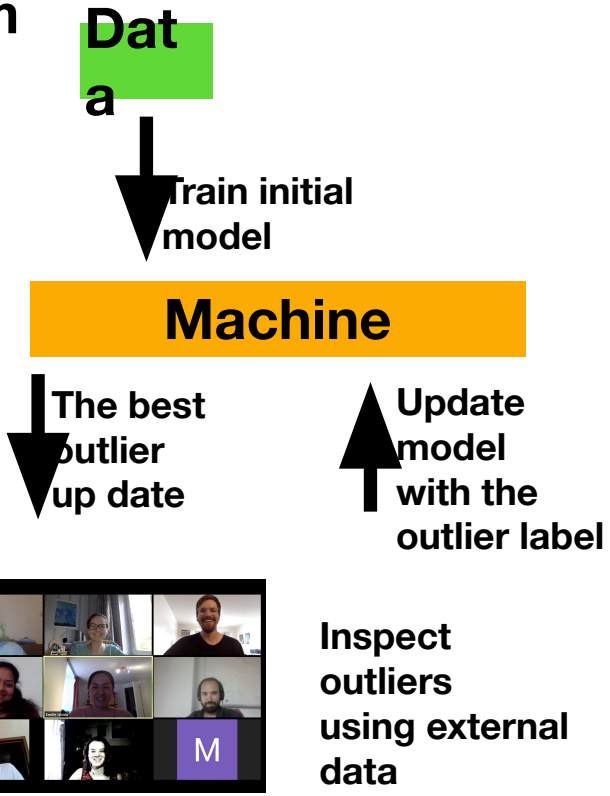
- SNAD Viewer
  - Metadata
  - Images
  - Catalogs
- Simulations
- Follow up
- Literature

Active anomaly detection

From outlier to anomaly detection algorithm

How to discriminate annoying non-anomalies sources and bogus light curves?

- We can ask an expert interactively about each new outlier
- If it is not an anomaly, show similar objects less often
- Retrain, ask the expert again



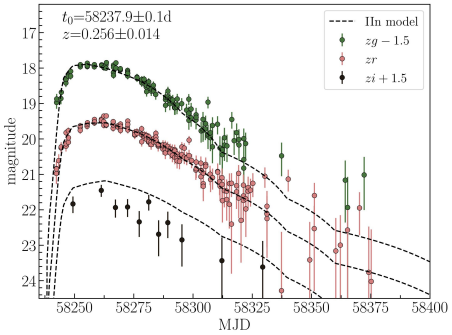
Some interesting objects

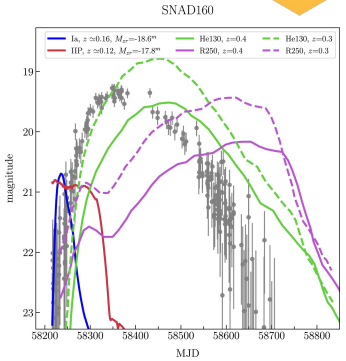
144 objects reported to TNS, mostly PSNe and AGNs
https://snad.space/catalog

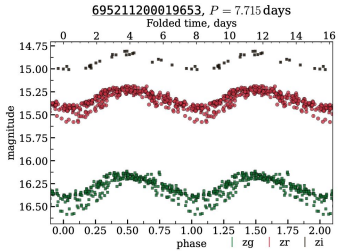
Two SLSNe (one spec.-confirmed by other group afterwards)

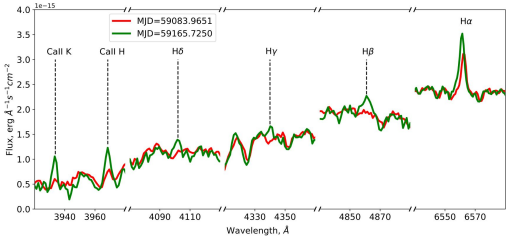
Various variable stars: RS CVn (spec. confirmed by us), binary Mira, YSOs

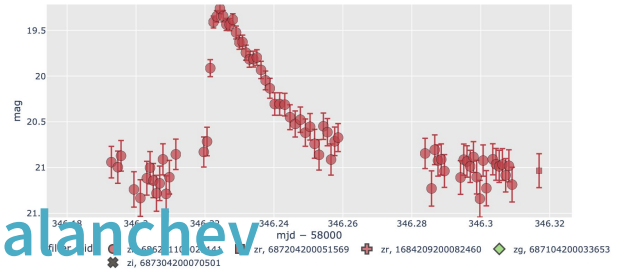
Hundreds of well-sampled ~hour long flares







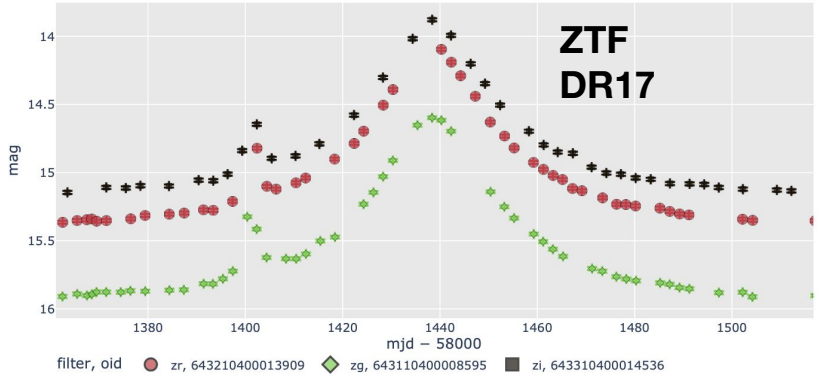




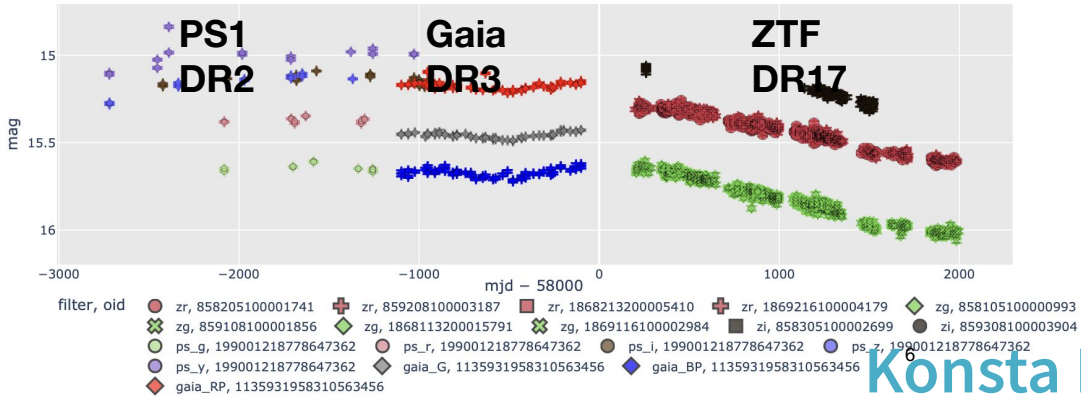
Konsta Malanchev

Objects found at SNAD-VI (June 2023)

2023RNAAS...7..155V



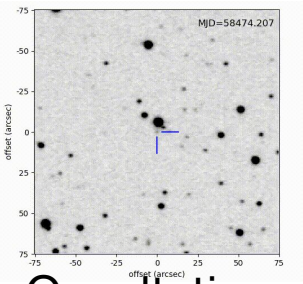
μ-lens candidate



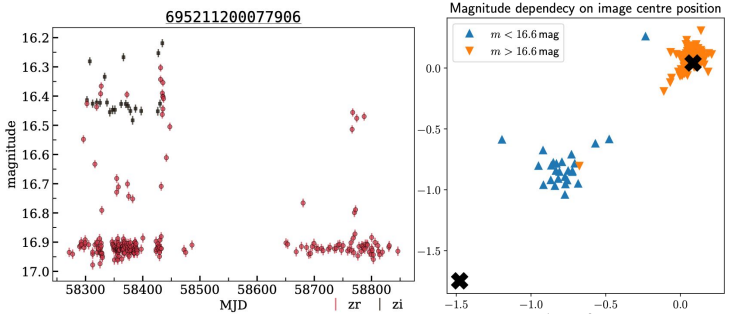
Optical counterpart of radio source
NVSS J080730+755017

Konsta Malanchev

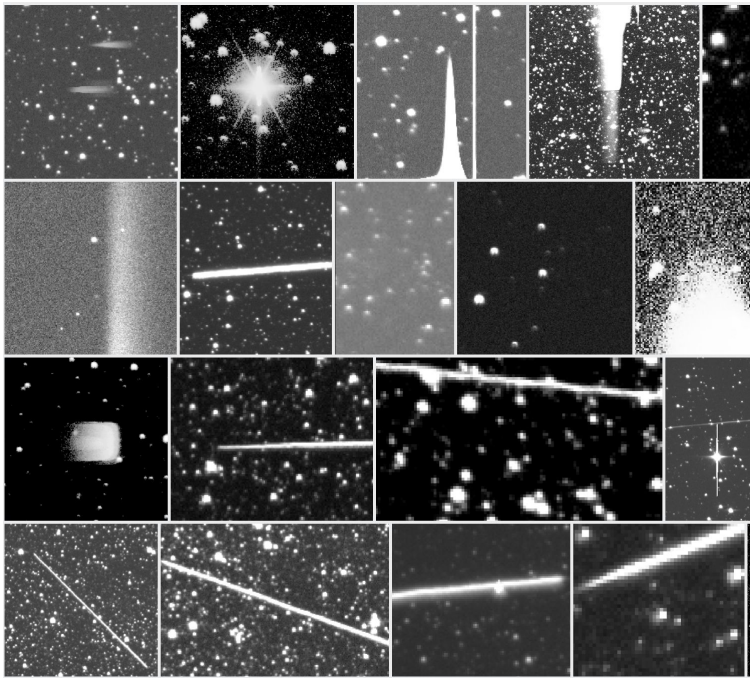
Artifacts and bogus variability

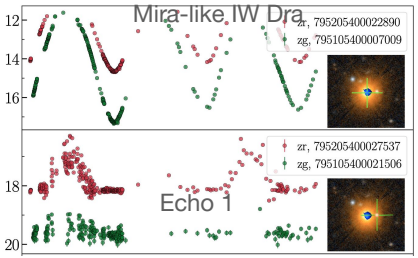


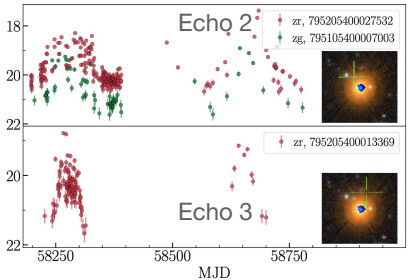
Occultation by asteroid



Double star defocusing







Photometric contamination from a bright variable

https://snad.space/art/

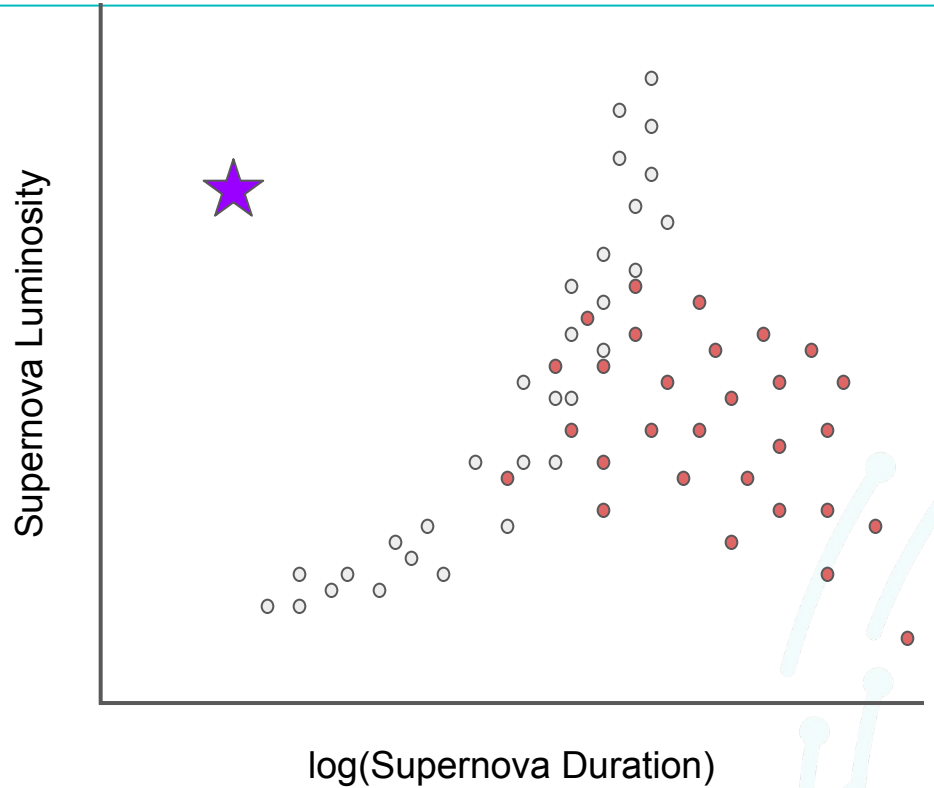
remote

Ashley Villar

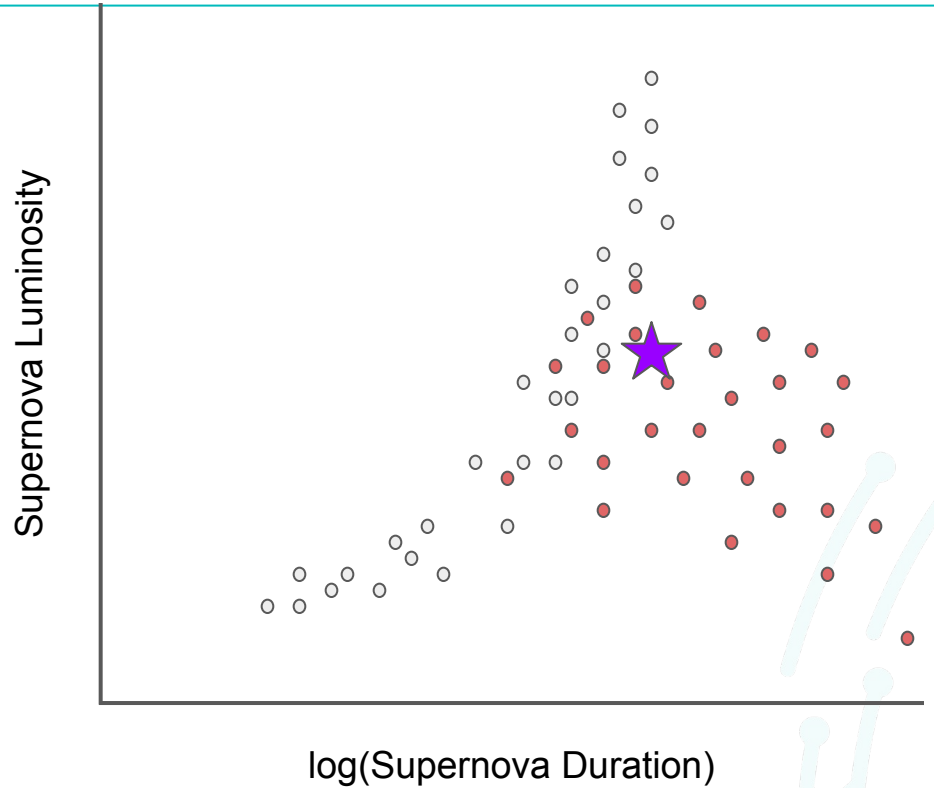
Anomaly Detection for LSST transients

V. Ashley Villar
Harvard University

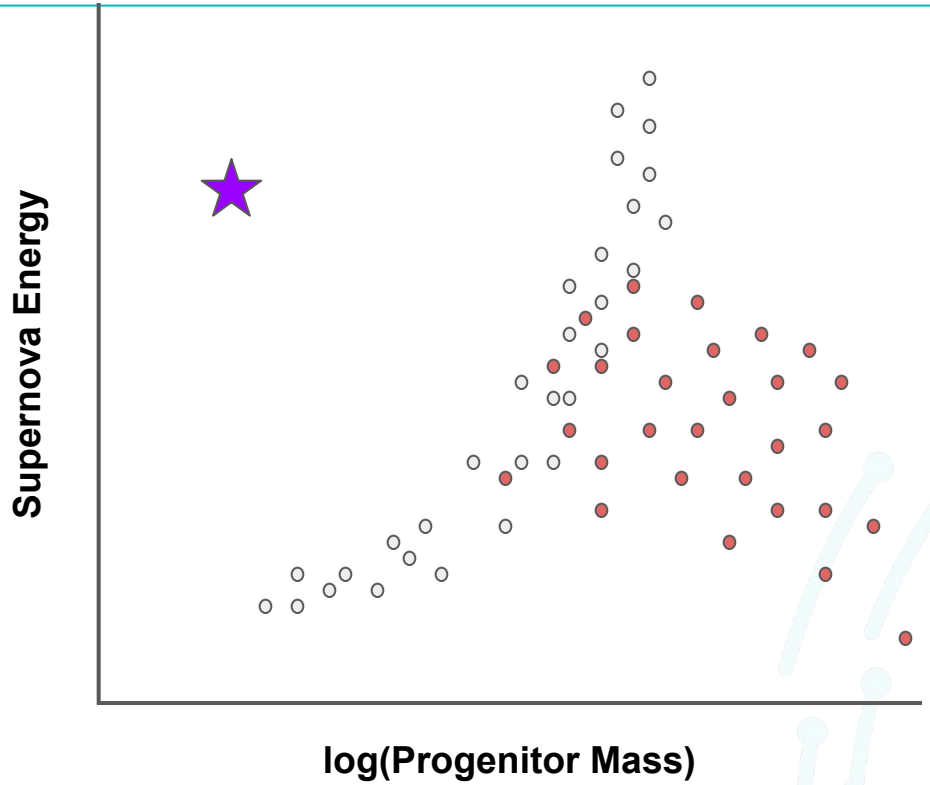
Out-of-distribution anomalies are “easy” to find



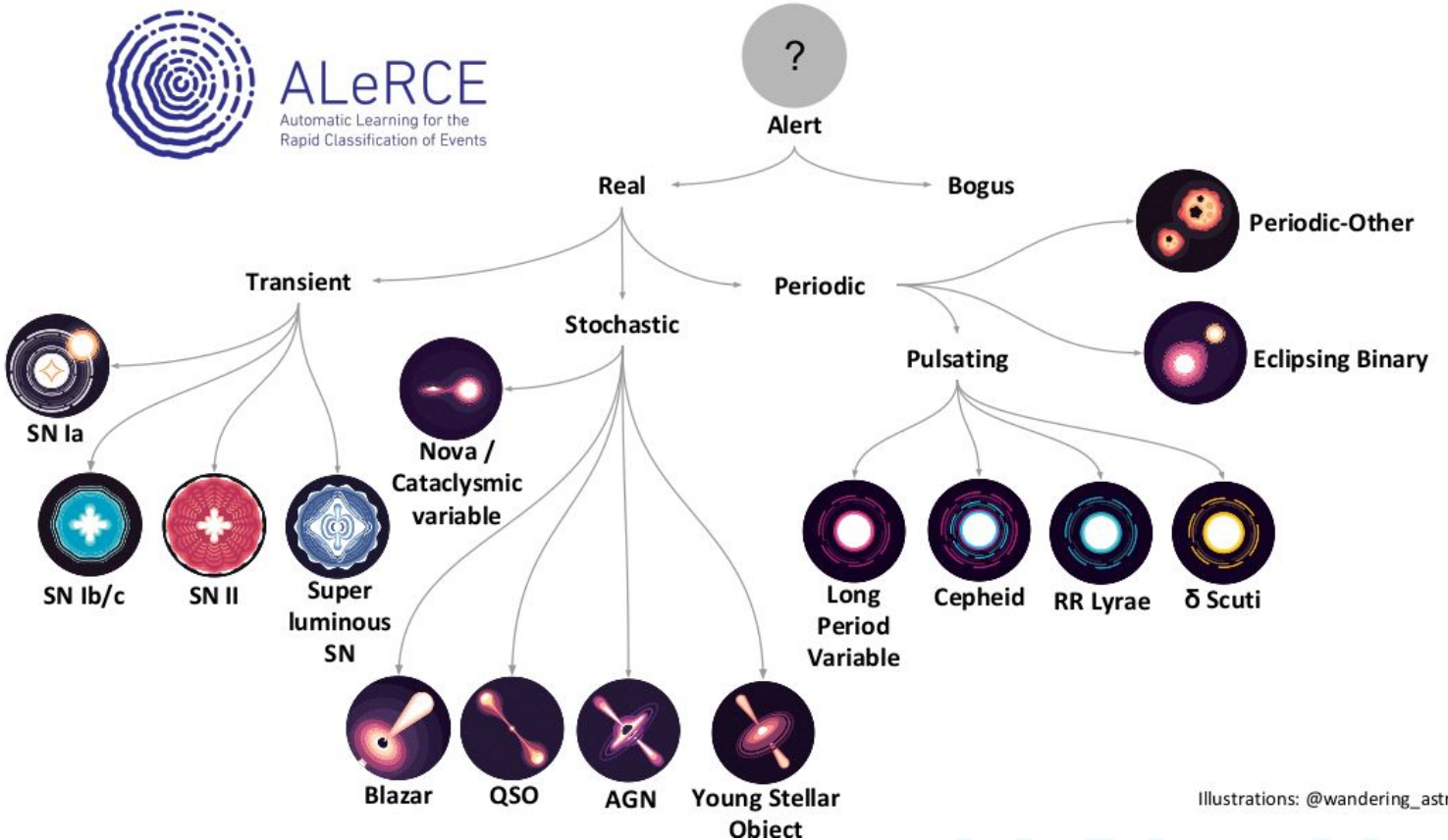
Out-of-distribution anomalies are “easy” to find



But how do we choose the axes..?

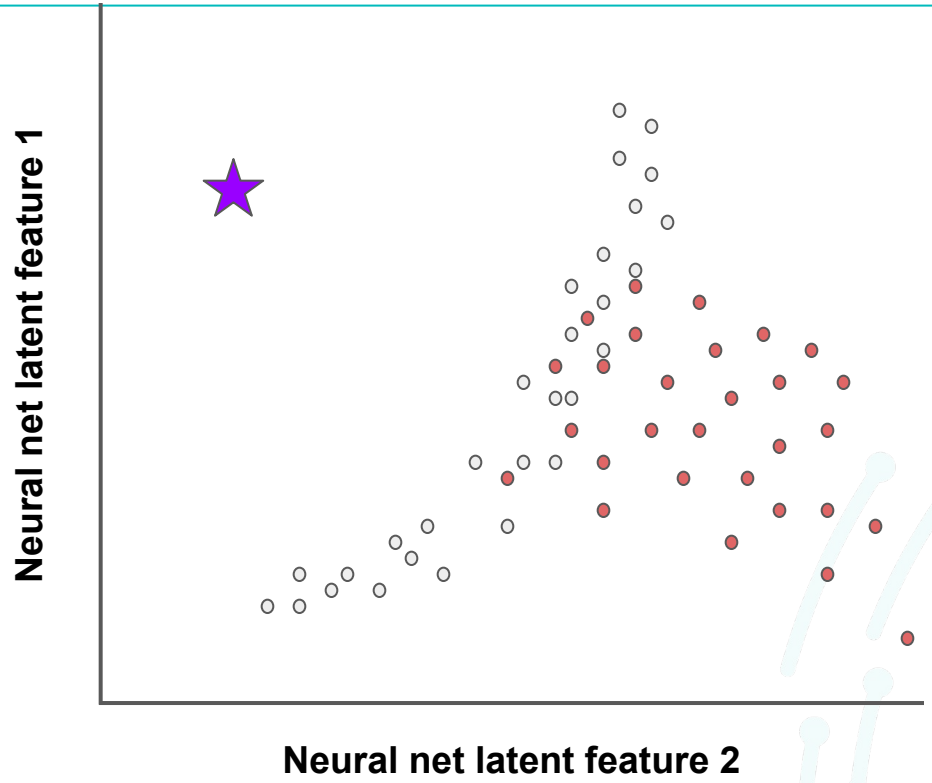


But there is no physical model to describe ALL physics

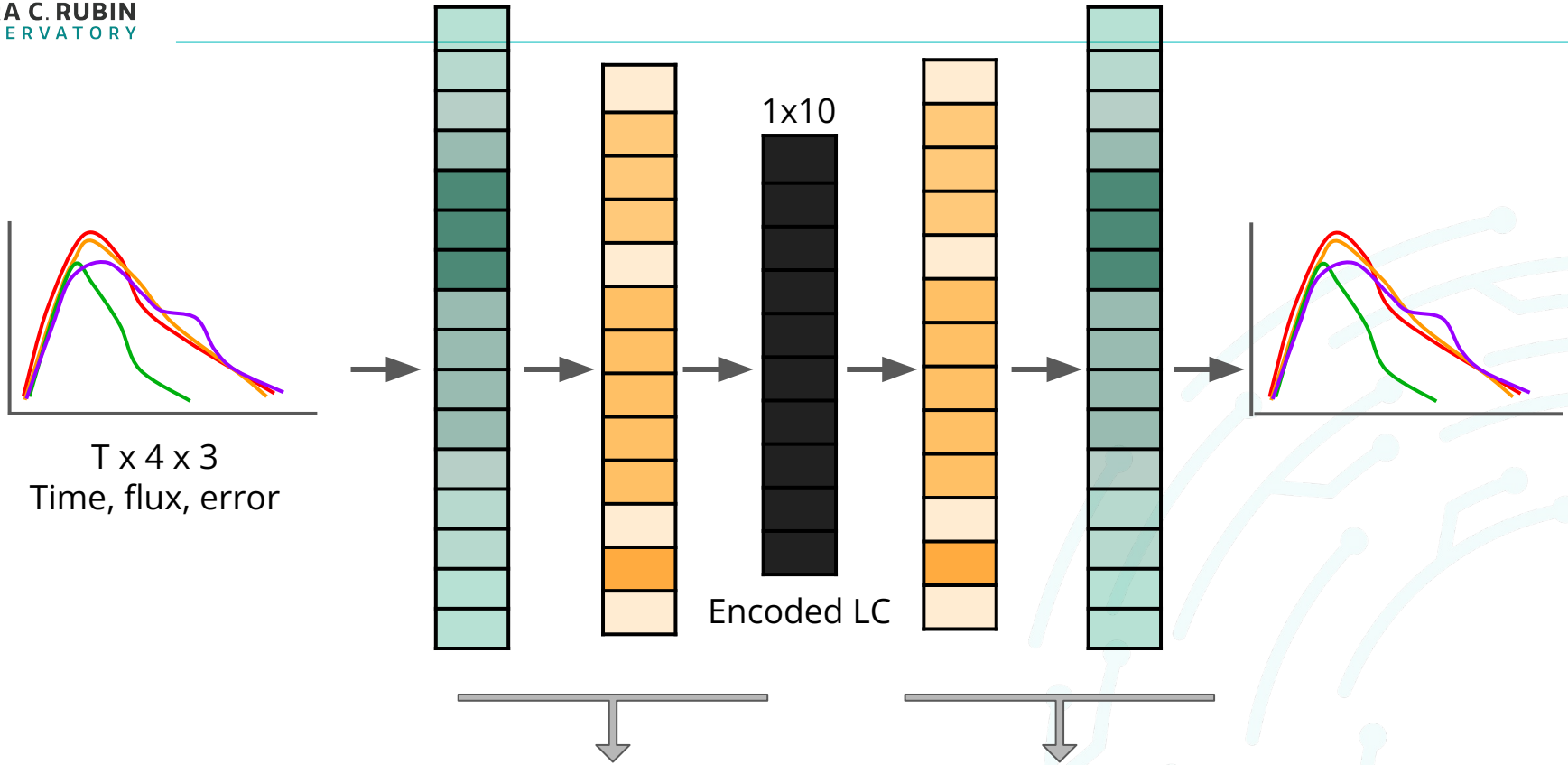


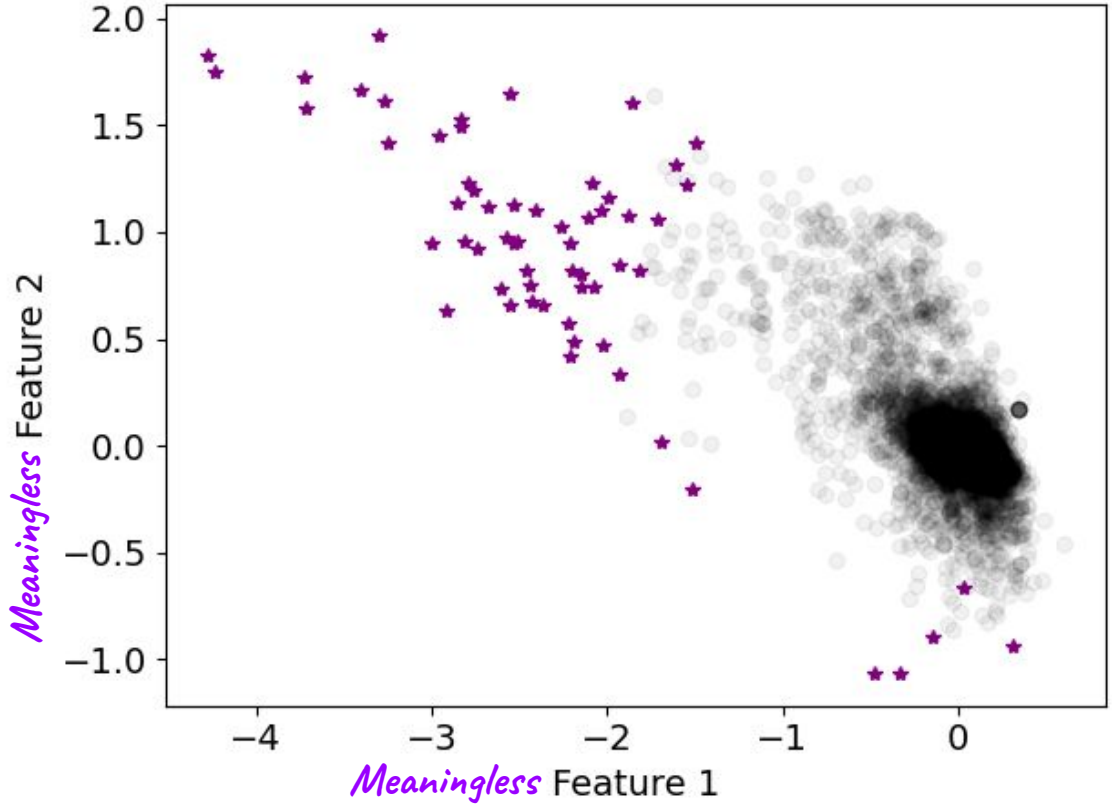
Illustrations: @wandering_astro

And so, we become data-driven



Use an autoencoder to *encode* the full sample

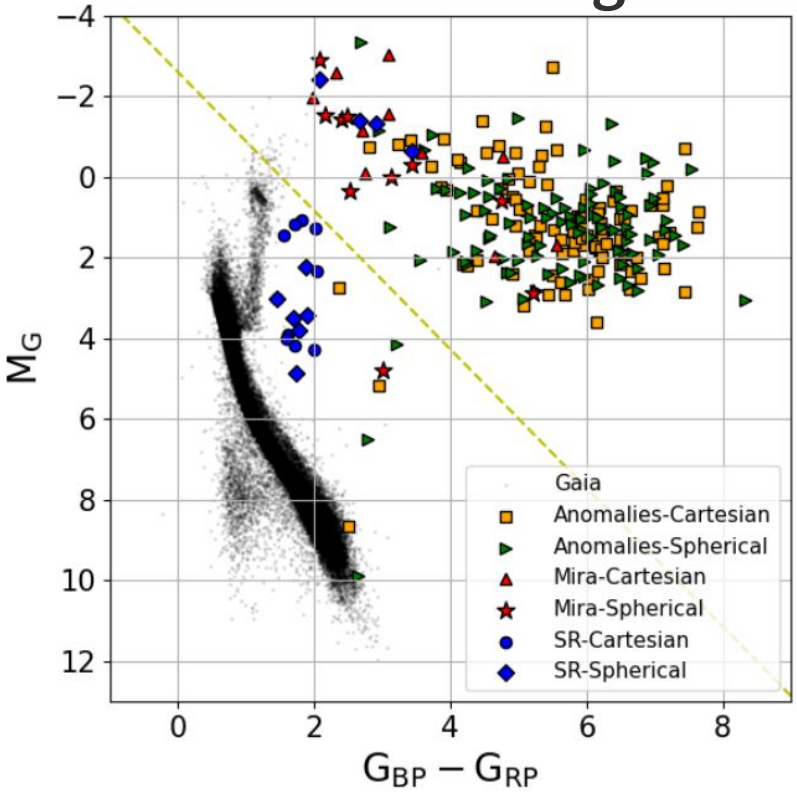




Ashley Villar

Acronyms & Glossary

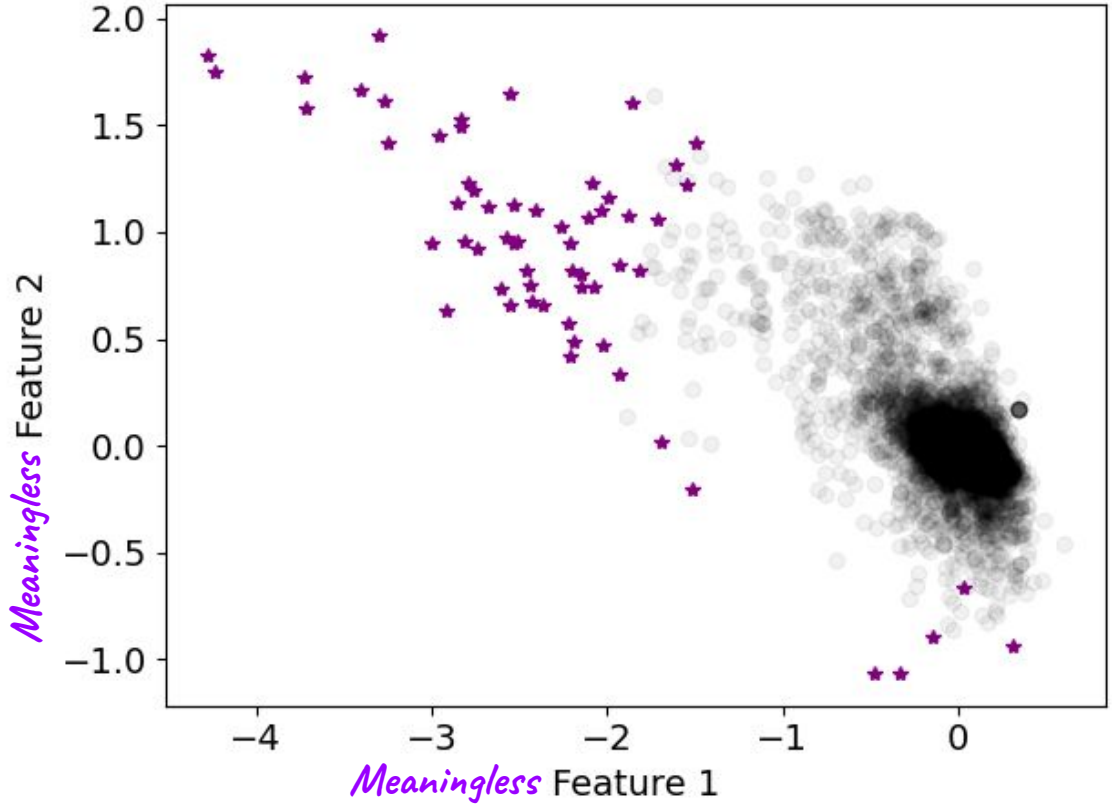
Similar pipeline finds interesting, evolved stars in the ZTF Catalog



Such methods can be extended to the ~135 million variable stars LSST will observe

Chen, Cheung, VAV, Ho 2021; 2022

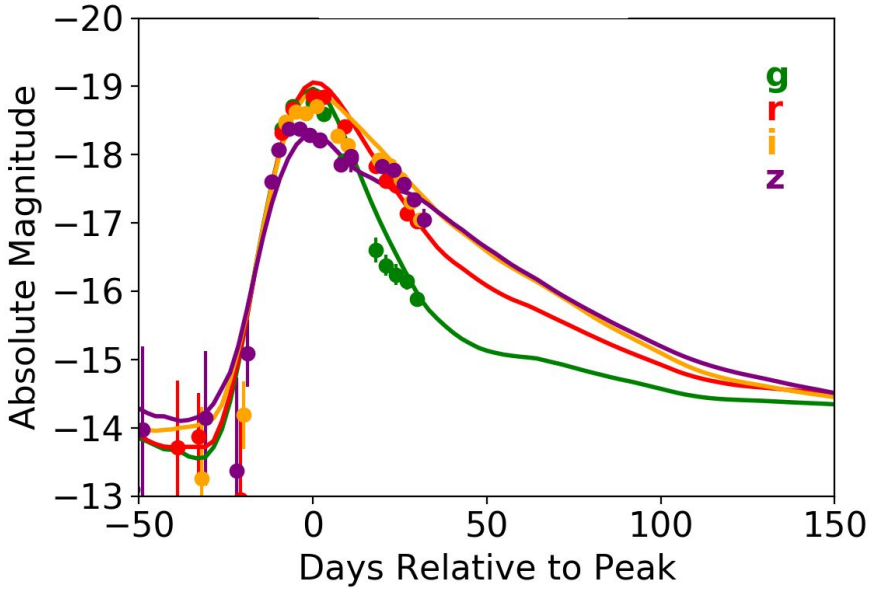
Our latent space is physics-unaware



Ashley Villar

Acronyms & Glossary

That is because our neural net wants to optimize one thing*



The NN's objective:

Minimize the difference between the model and data

***This is a lie. The variational AE I showed earlier also encourages a specific (Gaussian) distribution.**

But we know about other, reasonable distance metrics

E.g.,

Minimize the difference between the model and data

And

Make signals of similar types cluster together (called contrastive learning)

And

Make the latent features independent of redshift (e.g., group-invariant learning)

Thank you!

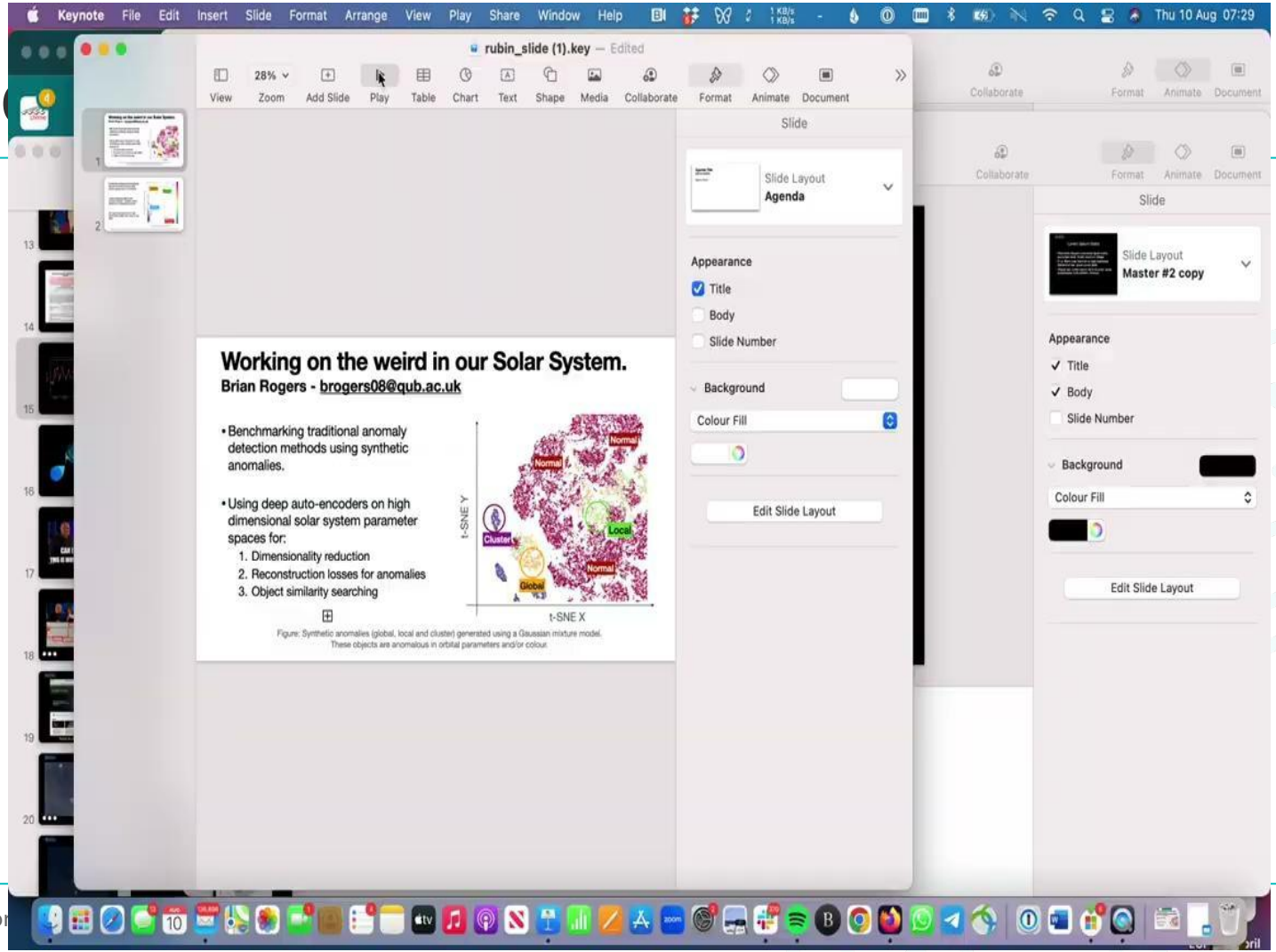
Ashley Villar

Acronyms & Glossary

Lightening talks

VERA C. RUBIN OBSERVATORY

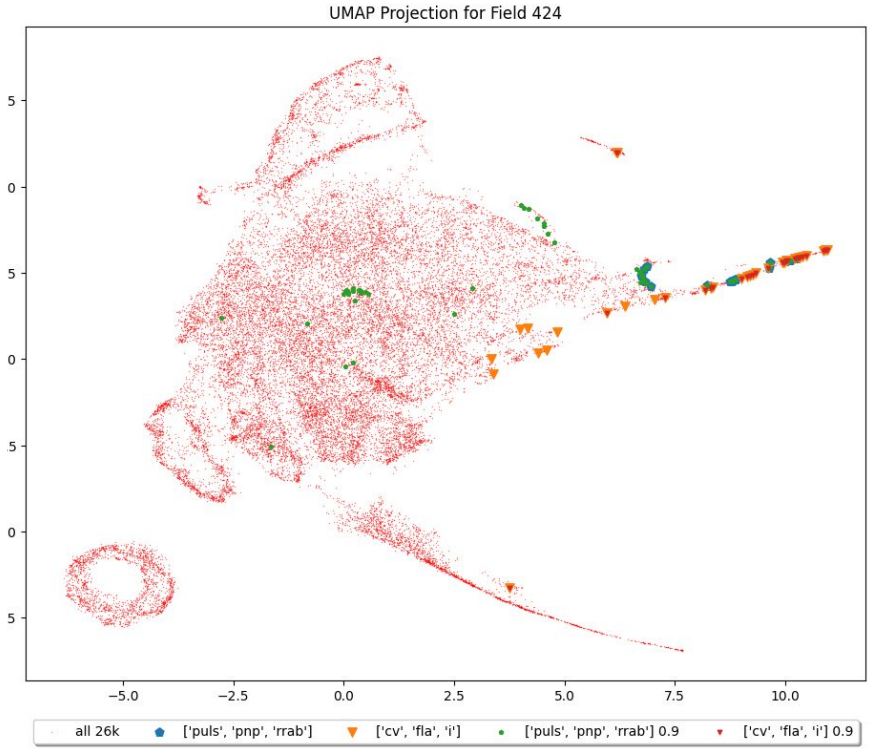
Chris Lintott



Ashish Mahabal | ZTF anomalies

ZTF SCoPe Fields

With Palak Purohit,
Saagar Parikh,
Md. Yusuf, …

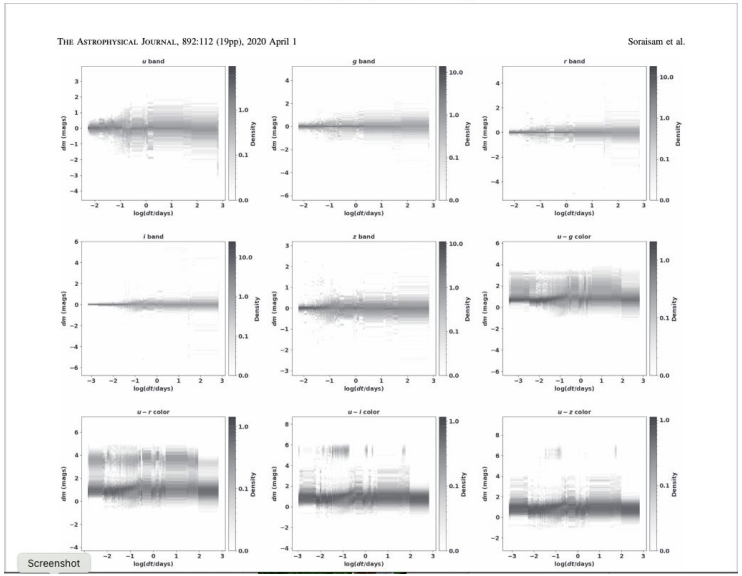


Abi Saha | EARLY detection of rare TD phenomena

The Astrophysical Journal, 892:112 (19pp), 2020 April 1
https://doi.org/10.3847/1538-4357/ab7b61

A Classification Algorithm for Time-domain Novelties in Preparation for LSST Alerts. Application to Variable Stars and Transients Detected with DECam in the Galactic Bulge

Monika D. Soraisam[1,2], Abhijit Saha[3], Thomas Matheson[3], Chien-Hsiu Lee[3], Gautham Narayan[2], A. Katherina Vivas[4], Carlos Scheidegger[5], Niels Oppermann[6], Edward W. Olszewski[7], Sukriti Sinha[8], and Sarah R. DeSantis[8]
(ANTARES collaboration)



Screenshot

Southern Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 339, 2018
E. Griffin, B.D. Editor & C.E. Editor, eds.

DOI: 00.0000/X000000000000000X

Recognition of Rare and Peculiar Temporal Phenomena from LSST Alert Streams

Abhijit Saha[1]

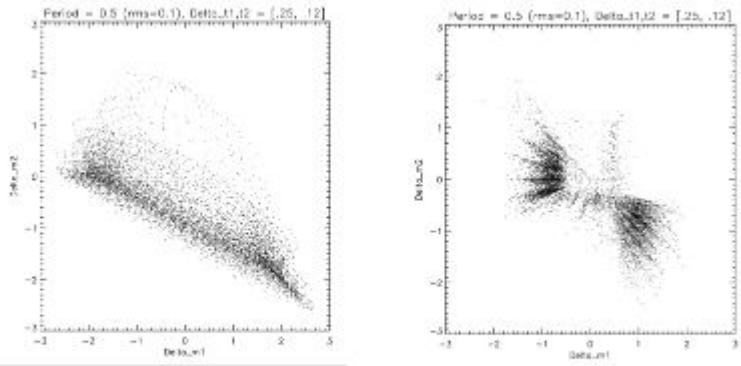
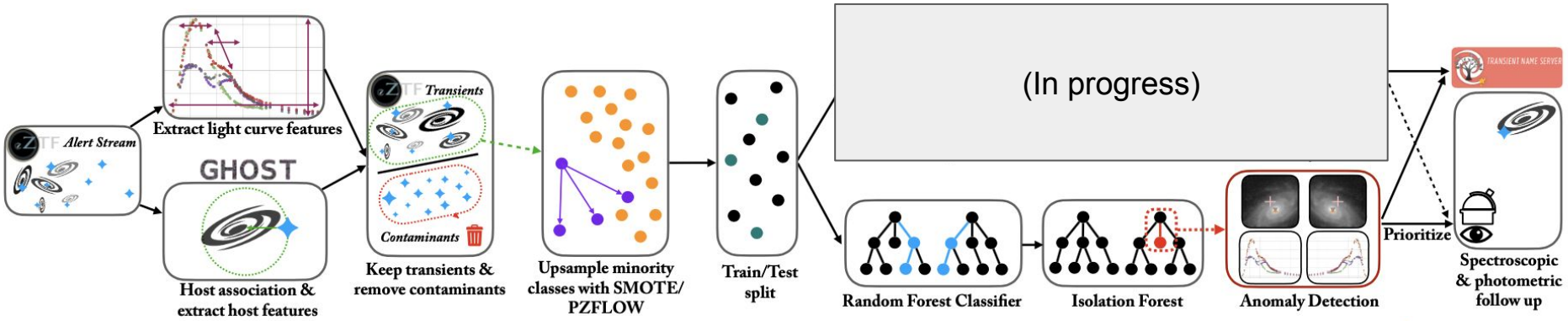
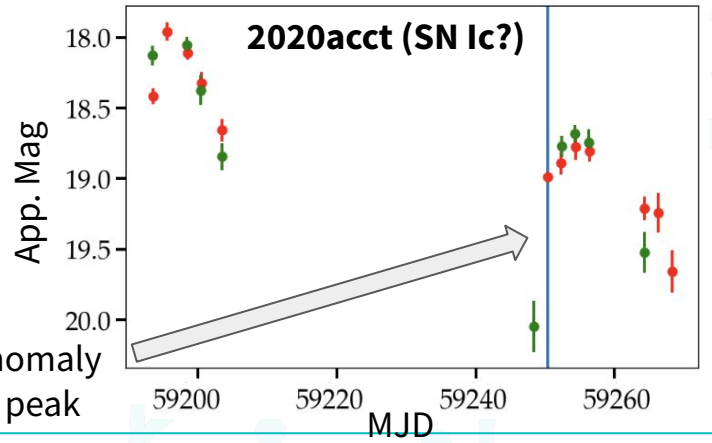


Figure 2. The frequency distribution of magnitude differences for 2 measurements of a sine wave (left) and a sawtooth (right) light curve with period 0.5 days, when sampled at three epochs separated successively by 0.25 and then 0.12 days. See description in § 3.2 for a complete description.

Patrick Aleo | Real-time Anomaly Detection in ZTF



- Implemented as ANTARES Filter*
- Uses light curve features & host galaxy features
- Prioritizes purity of anomalies
- Expanding to similarity search & VAEs
- Understanding how anomalies evolve over time in latent space



Identified as anomaly right at second peak