Future optical instruments & transient factories relevant for CTAO science

Julien Peloton
IJCLab, Orsay

Transient factories

ZTF
2018 – 2025
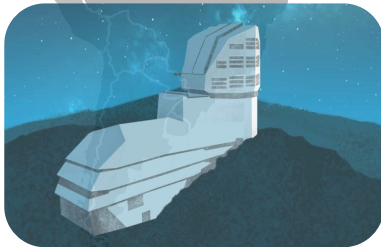
ATLAS
2017 –

WFST
2023 –

GOTO-N
2023 –

ATLAS
2011 –

Pan-STARRS
2010 –

BlackGEM
2022 –

Rubin Observatory
2025 – 2035

ATLAS
2014 –

ATLAS
2017 –

GOTO-S
2023 –

+ networks such as MASTER, GRANDMA, …

Transient factories for today

ZTF
2018 – 2025

Rubin Observatory
2025 – 2035

What Rubin can bring for CTAO science

Sorry to all others!

Julien Peloton

IJCLab, Orsay

Rubin science goals

Four main science themes

- Probing dark energy and dark matter.
- Taking an inventory of the solar system.
- Exploring the transient optical sky.
- Mapping the Milky Way.

Eight science collaborations (about 1,500 scientists) - several dozens of roadmaps

LSST
AGN Science Collaboration
Roadmap

1. AGN Selection, Classification, and Characterization
2. AGN Redshift Estimates
3. AGN Variability Science
4. Ancillary Data & Follow-up

Active Galaxy Science in the LSST Deep-Drilling
Fields: Footprints, Cadence Requirements, and
Total-Depth Requirements

W.N. Brandt (Penn State), Q. Ni (Penn State), G. Yang (Penn State),
S.F. Anderson (Univ Washington), R.J. Assef (Univ Diego Portales), A.J. Barth (UC Irvine),
F.E. Bauer (Católica), A. Bongiorno (Oss Ast Roma), C.-T. Chen (MSFC)

zars and Fast Radio Bursts with LSST

, M.I. Carnerero, B. Balmaverde, F. D'Ammando, C. Righi et al.

November 30, 2018

Publications of the Astronomical Society of the Pacific, 135:105002 (182pp), 2023 October

OPEN ACCESS

Rubin Observatory LSST Transients and Variable Stars Roadmap

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Nina Hernitschek[11], Michael B. Lund[12], Elena Mason[13], Joshua Pepper[14], Andrej Prša[1], Markus Rabus[15],
Claudia M. Raiteri[16], Róbert Szabó[17,18,19,20], Paula Szkody[11], Igor Andreoni[21,22,23], Simone Antoniucci[13],
Barbara Balmaverde[16], Eric Bellm[11], Rosaria Bonito[24], Giuseppe Bono[25], Maria Teresa Botticella[13], Enzo Brocato[24,26],
Katja Bučar Bricman[27], Enrico Cappellaro[13], Maria Isabel Carnerero[16], Ryan Chornock[4], Riley Clarke[5],
Phil Cowperthwaite[28], Antonino Cucchiara[13,33], Filippo D'Ammando[30], Kristen C. Dage[31], Massimo Dall'Ora[13],
James R. A. Davenport[11], Domitilla de Martino[13], Giulia de Somma[13], Marcella Di Criscienzo[13], Rosanne Di Stefano[32],
Maria Drout[33], Michele Fabrizio[13], Giuliana Fiorentino[13], Poshak Gandhi[34], Alessia Garofalo[30], Teresa Giannini[13],
Andrzeja Gomboc[27], Laura Greggio[13], Patrick Hartigan[35], Markus Hundertmark[36], Elizabeth Johnson[14],
Michael Johnson[37,40], Tomislav Jurkic[41], Somayeh Khakpash[5], Silvio Leccia[13], Xiaolong Li[14], Davide Magurno[26],
Konstantin Malanchev[42,50], Marcella Marconi[13], Raffaella Margutti[14], Silvia Marinoni[13], Nicolas Mauron[43],
Roberto Molinaro[13], Anais Möller[44], Marc Moniez[13], Tatiana Muraveva[13], Ilaria Musella[13], Chow-Choong Ngeow[45],
Andrea Pastorello[13], Vincenzo Petrecca[25], Silvia Piranomonte[13], Fabio Ragosta[13], Andrea Reguitti[30,34,13], Chiara Righi[13],
Vincenzo Ripepi[13], Liliana Rivera Sandoval[46], Kev2 Sp_Sp_Sp

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Rubin/LSST data products

Rubin Observatory (2025+)

- **20TB of images / night**
- **1TB of alerts / night**: x100-x1000 above current streams
- *Everything matters a priori*

Now

Raw Data
Sequential 30s image, 20TB/night

60s

Prompt Data Product
Difference Image Analysis
Alerts: up to 10 million per night

24h

Prompt Products DataBase
Images, Object and Source catalogs from DIA
Orbit catalog for ~6 million Solar System bodies

Year

Annual Data Release
Accessible via the LSST Science Platform &
LSST Data Access Centers.

End

Final 10yr Data Release
Images: 5.5 million x 3.2 Gpx
Catalog: 15PB, 37 billion objects

Rubin alert system

Image data sent from Chile to the USA. Alert system will identify sources that move or vary within 60 seconds.

- Sources packaged with contextual information into world-public alert packets for distribution.

Suite of open source technologies considered for distributing alerts

- Binary serialization format: Apache Avro
- Alert distribution: Apache Kafka
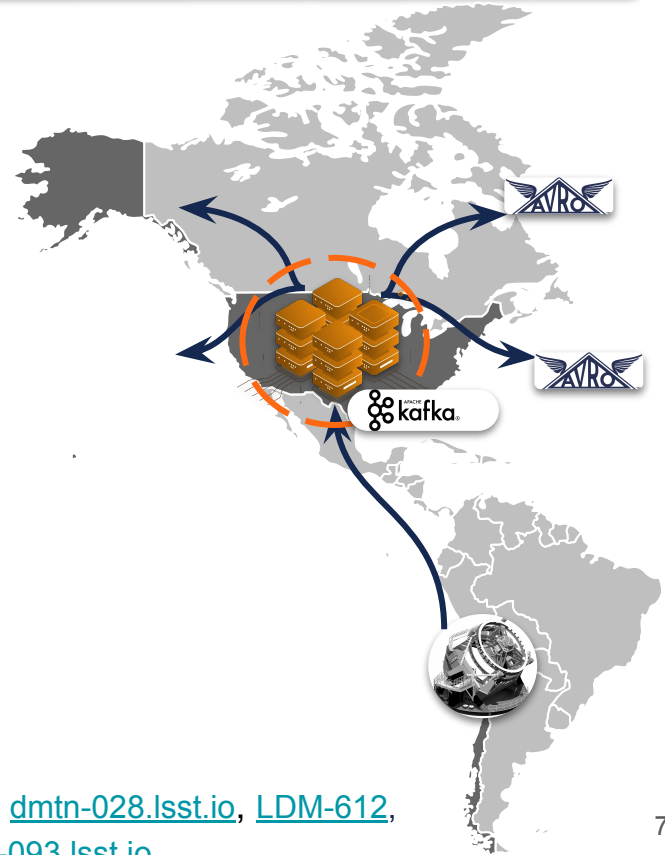
Technical notes: dmtn-028.lsst.io, LDM-612, ls.st/dpdd, dmtn-093.lsst.io

Alert content

Alerts based on **Difference Image Analysis**

Each ZTF alert contains
- Information about the new detection (magnitude, position, ...)
- Neighbours information (Gaia, Panstarrs)
- Historical information if the object has been seen previously
- Small images around the detection (60x60 pixels)

LSST alert content will be similar:
https://github.com/lsst/alert_packet

Markarian 501
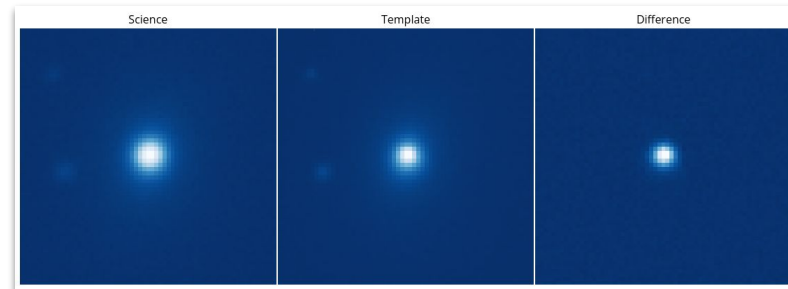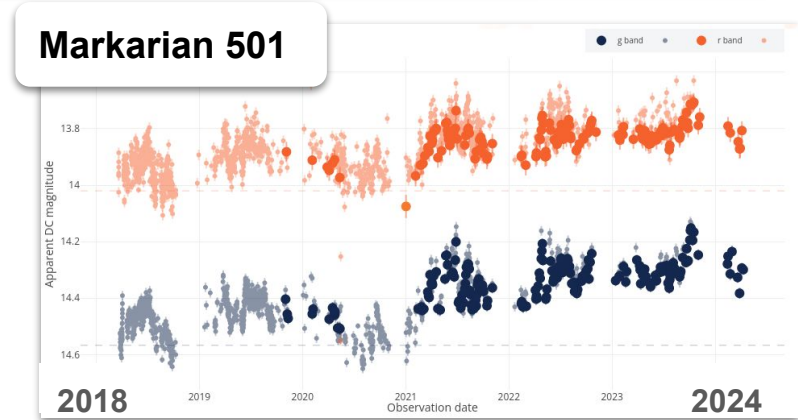
Cadence for ZTF (2021)

99% objects

2 days cadence major – 99% objects revisited after 16 days
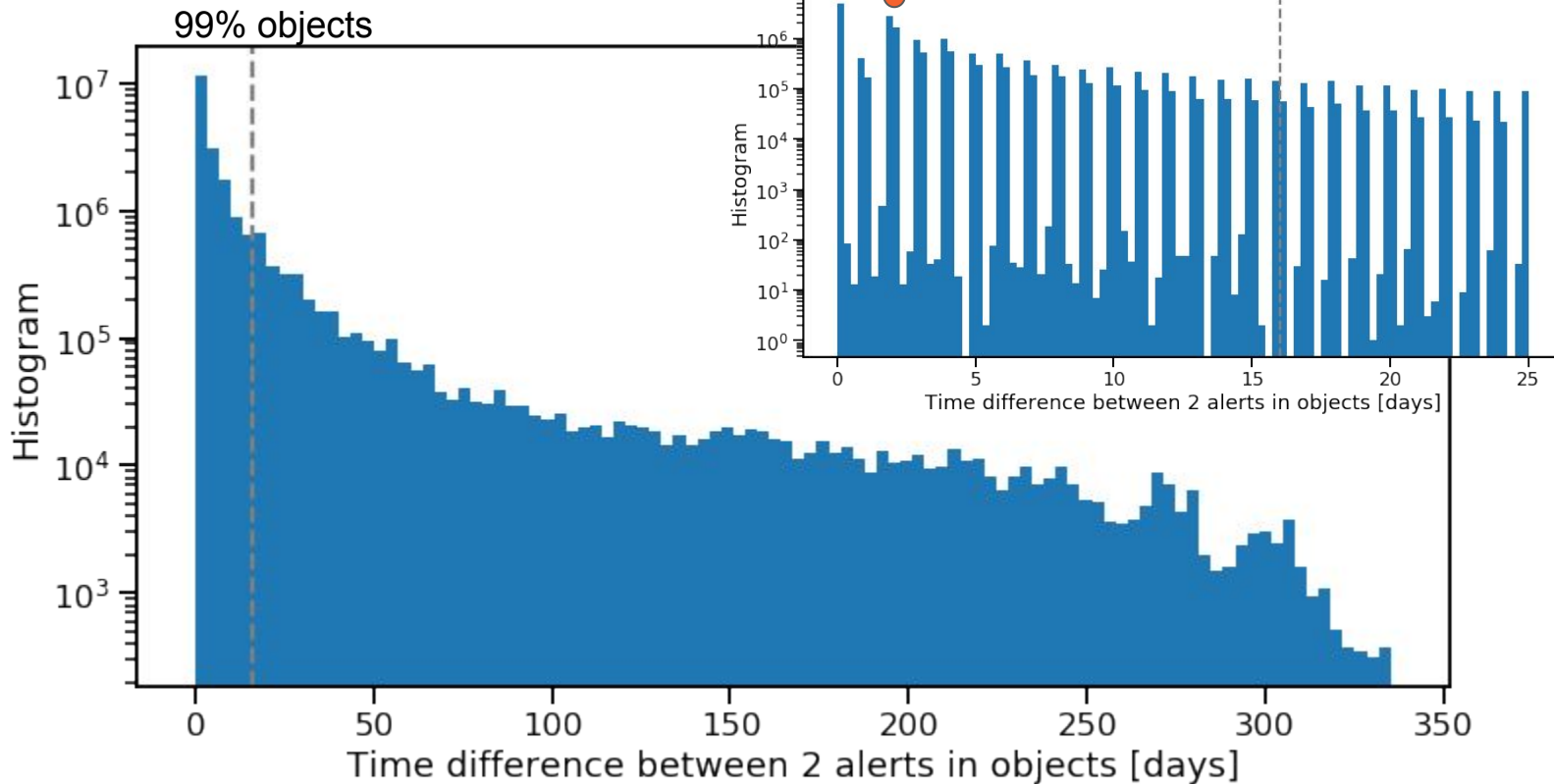
Cadence evolution

1-3 days cadence major – 99% objects revisited after 19 days

2019
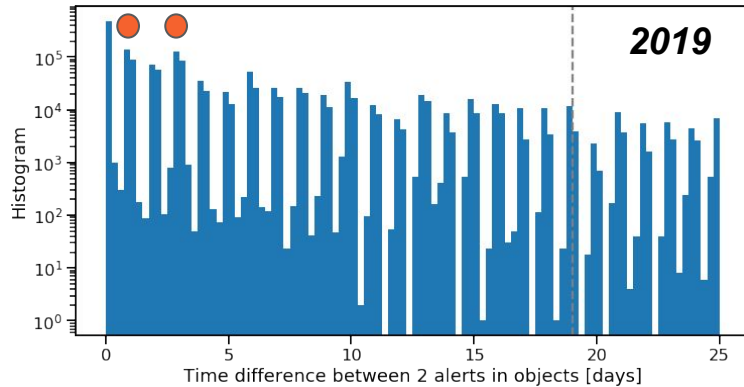
2-3 days cadence major – 99% objects revisited after 7 days

2020
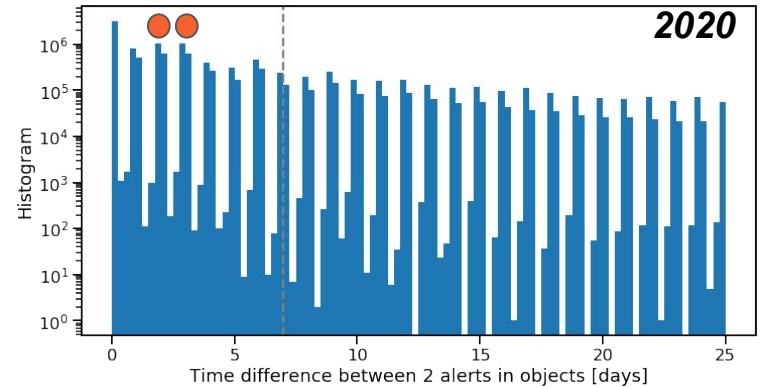
2 days cadence major – 99% objects revisited after 16 days

2021
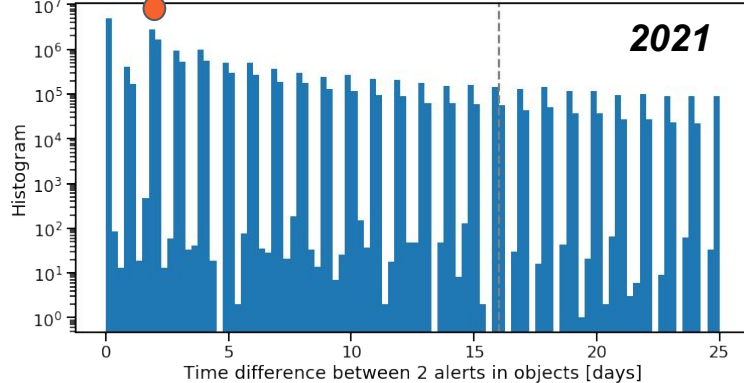
2 days cadence major – 99% objects revisited after 8 days

2022
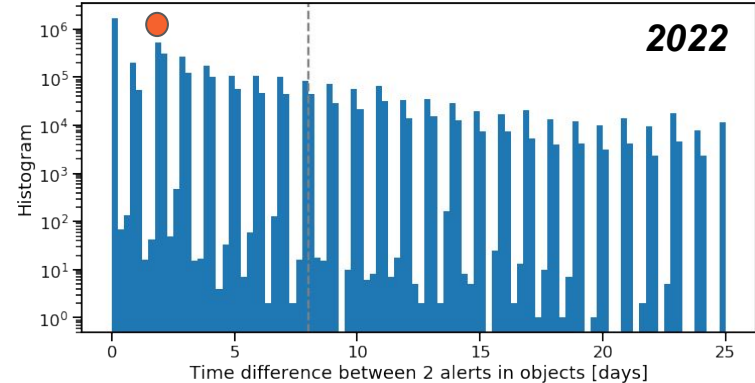
The needle in a needlestack

Our scientific ambition clearly leads to technical challenges!

- What to (realistically) do with 10 million alerts per night? (and for 10 years)
  - Not all 5-sigma alerts in LSST will be "interesting" variability
- Do we need dedicated follow-up resources?
  - LSST alert rate outstrips all our follow-up resources combined.
  - Need coordination in the community

2019-2023
122,834,252 alerts
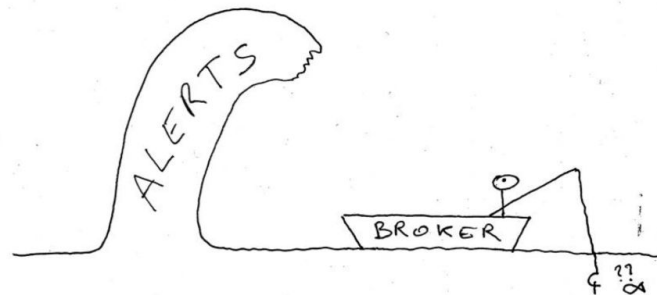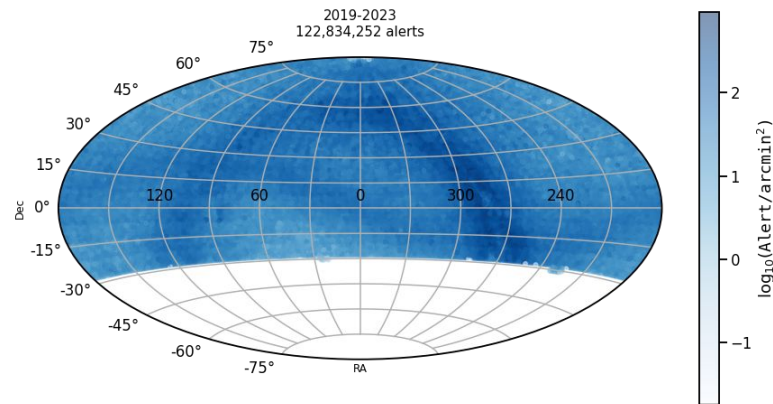
Rubin alert brokers

Rubin will send the full alert stream to seven brokers: they are the public interface to the LSST alert stream

- ALERCE, AMPEL, ANTARES, Babamul, Fink, Lasair, Pitt-Google

Serve a large scientific community by ingesting, **classifying**, filtering, and redistributing alerts. Classification is a community-driven effort.

All prototyping on ZTF (300k alerts/night), and test deployment of the Rubin Alert Distribution system.

Fink (2019 –)

Comet - *Credits: ESO*

Operating 24/7 since 2019, serving 100+ unique users per day (scientists & follow-up facilities).

- Real-time components (million+ event/night)
- Event database (~1B entries)

Processing the ZTF alert stream since 2019

- 210 million ZTF alerts received
- ⅔ is classified: 50% galactic, 15% Solar System few% extra-galactic
- Coupled to GCN: Fermi, Swift, Icecube, LVK, …

Community-driven: scientists bring building bricks

- 60+ members, 15+ scientific topics covered

Active Galactic nucleus

Supernova

Tidal disruptive event
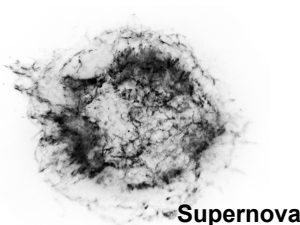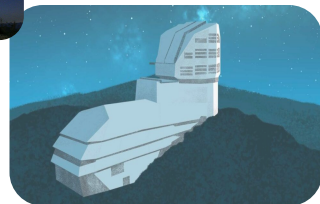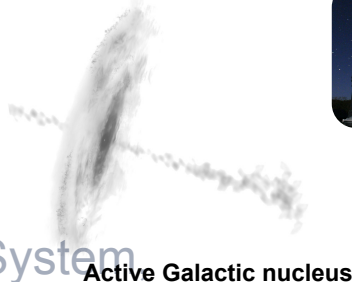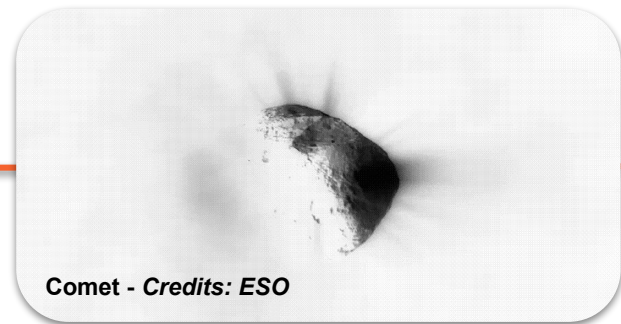
Efficiently selecting alerts

Alert information solely is not enough – we need experts to extract the science. Brokers add values in real-time:

- Crossmatch with catalogs
- Crossmatch between streams
- Lightcurve processing (incl. ML)
- Image processing

The challenge, for each science case, is to reach 99.9999+% rejection!

"Your contaminant is my gold"

Searching for extra-galactic fast transients
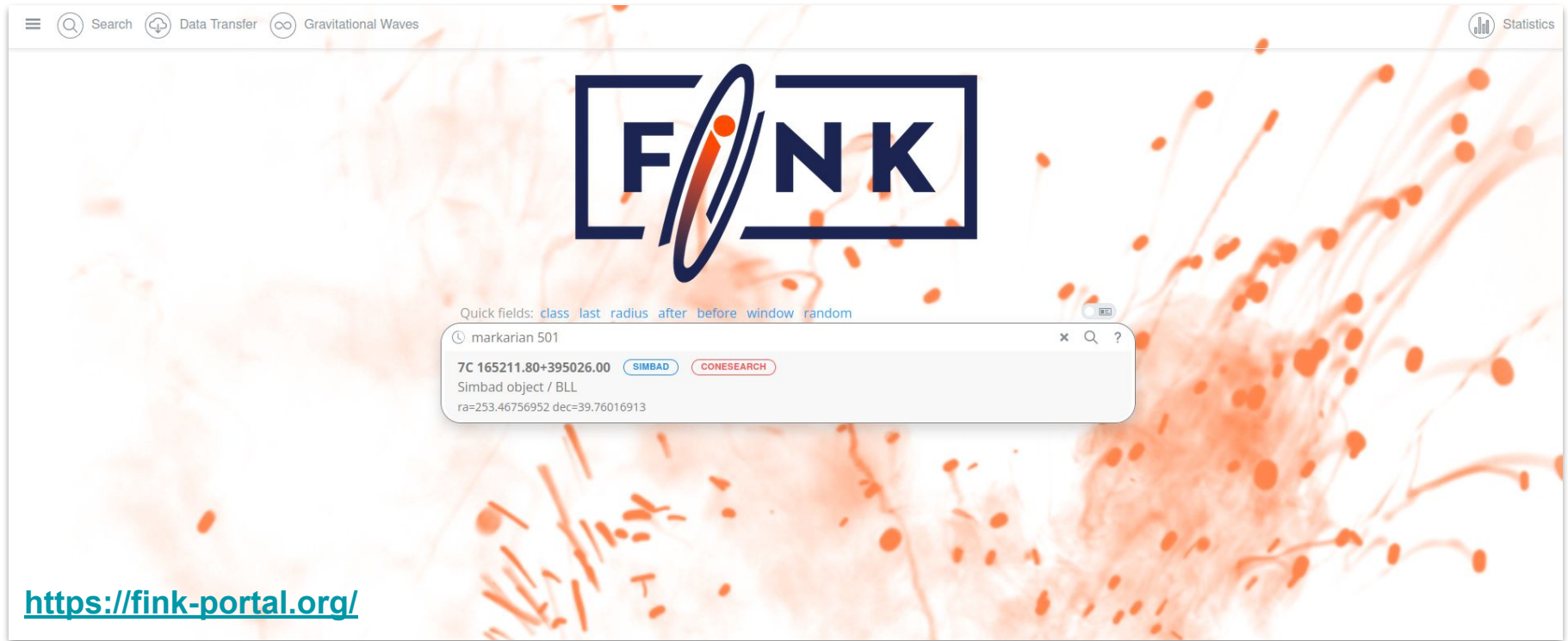credit: D. Turpin, R. Le Montagner
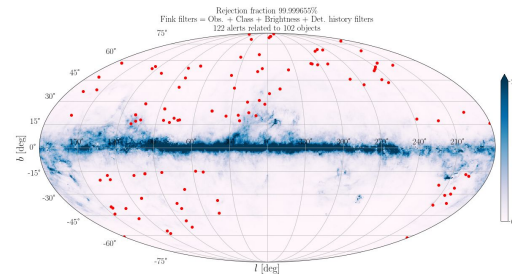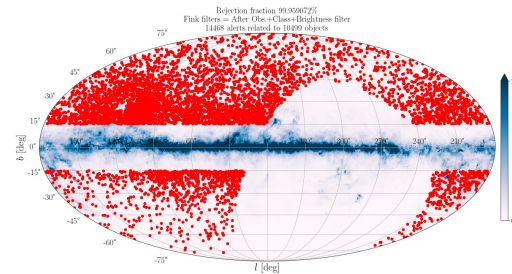
35,000,000

Time, space, brightness compatibility & classification

14,000

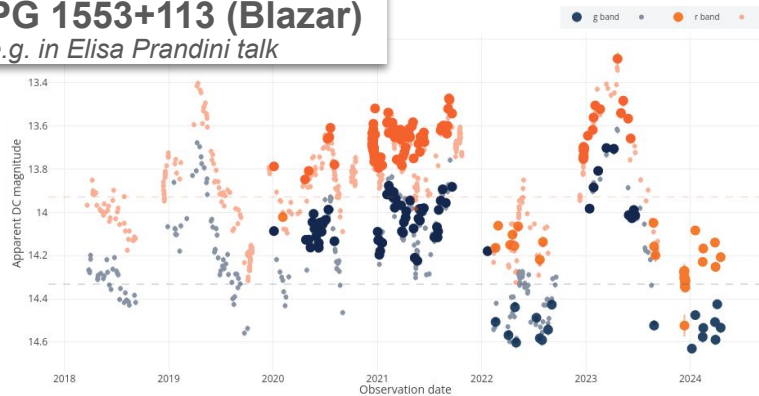*Lightcurve morphology*

100 alerts

Accessing alert data

https://fink-portal.org/

More information at https://fink-broker.readthedocs.io
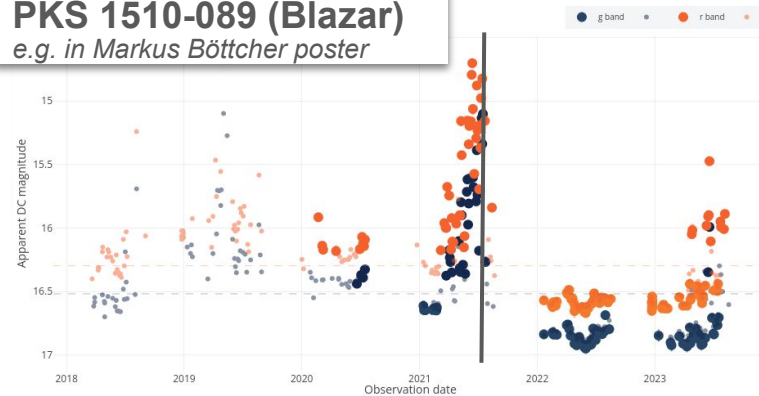
While listening to your talks...

PG 1553+113 (Blazar)
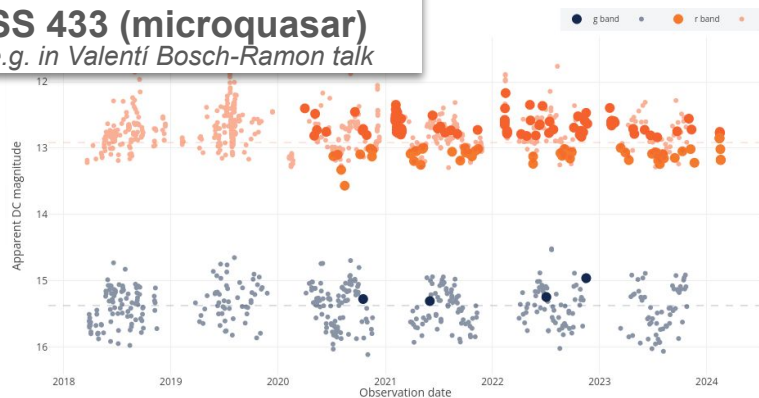*e.g. in Elisa Prandini talk*
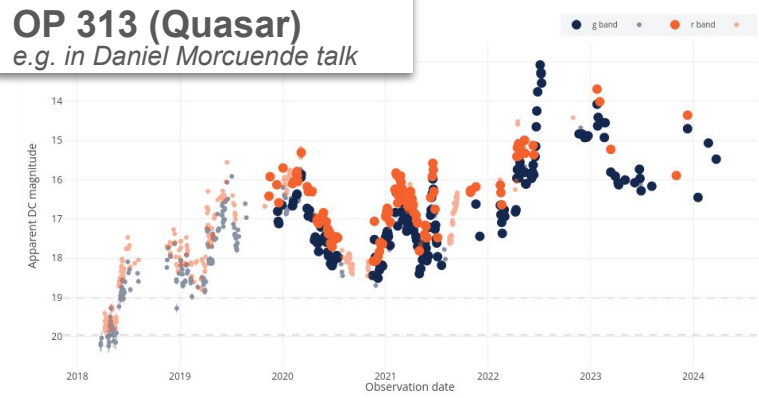
PKS 1510-089 (Blazar)
e.g. in Markus Böttcher poster

SS 433 (microquasar)
e.g. in Valentí Bosch-Ramon talk

OP 313 (Quasar)
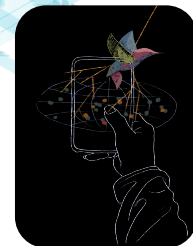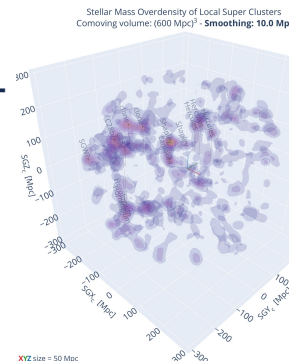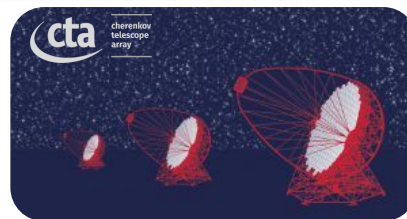*e.g. in Daniel Morcuende talk*

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4D mapping of blazars: from optical to gamma-ray emission

Goal: characterise altogether the optical and gamma-ray properties of blazars.

Why: deduce the duty cycle of blazars and automate the detection of transient events from these sources.

How: Learning on ZTF x Fermi-LAT blazars, and moving progressively towards the LSST & CTA beasts.

It takes time to build an efficient strategy: **starting early (before) is the key!**

Stellar Mass Overdensity of Local Super Clusters
Comoving volume: (600 Mpc)³ - Smoothing: 10.0 Mpc

XYZ size = 50 Mpc

https://astro-colibri.science/

Hamo, Biteau, Peloton, et al. in progress

Lessons learned from ZTF

If we want to capitalise on the full scientific potential of Rubin & CTAO, we must
- Deal efficiently with sources of contamination
- Model targeted sources
- Define tools and protocols early to work together
- Perform coordinated follow-up observations to palliate effects of the cadence

Open science

Gammapy (2022) & Fink (2023) have been awarded the open science prize for Free Software in research by the French Ministry of Research

*"The award recognizes projects and research teams [...] contributing to the construction of a crucial **common good**."*

"They highlight exceptional or highly promising achievements, which can inspire both the scientific community and society as a whole."

Credit: D. Longieras, IJCLab

Conclusion

Optical & gamma: ambitious time-domain scientific programs

(Optical) Transient factories are rising up to provide a wealth of information…
- *Rubin/LSST: wide, deep, fast*
- *Already 5-10 years of data on precursors worth checking!*

… but the volume of data is too big! You have allies here
- *Alert brokers, such as Fink, have proven useful to work efficiently*

Science must be defined collectively, and as early as possible
- *How to define what is "unusual" variability?*
- *What deserves triggering of time-sensitive follow-up?*
- *What tools or protocols should be developed?*