Legacy Survey of Space and Time (LSST)

Anais Möller

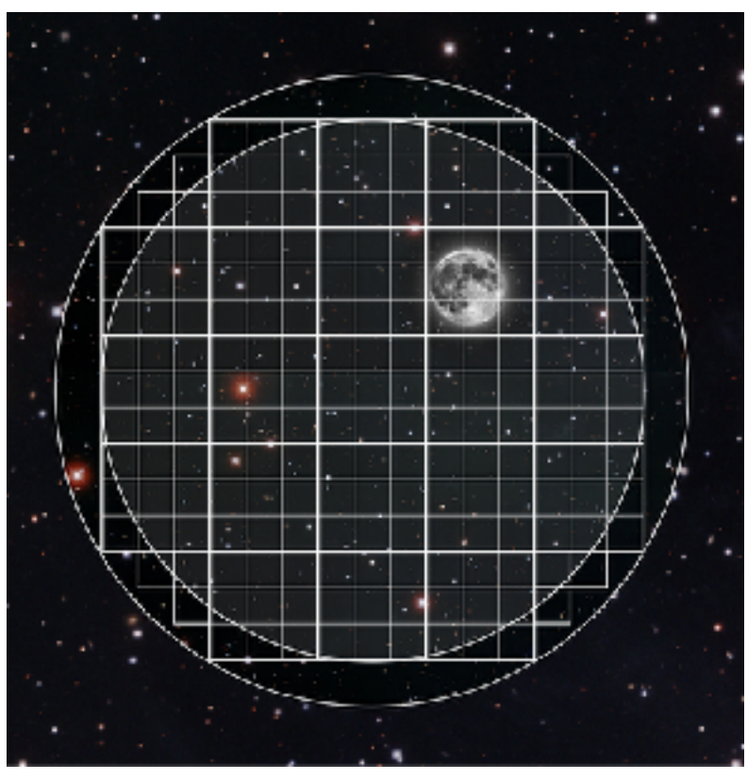
2021 Programme National Hautes Energies

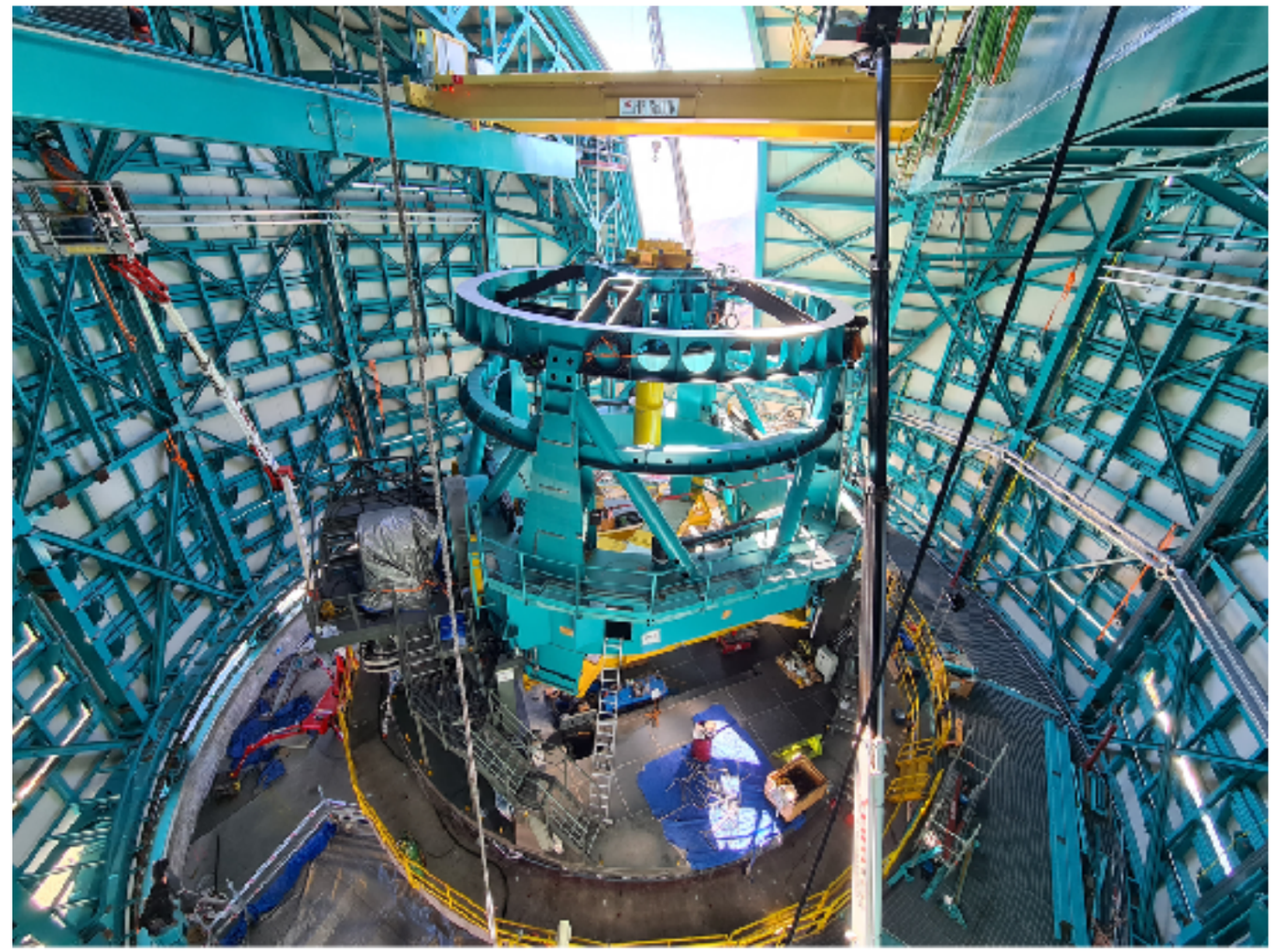
VERA C. RUBIN OBSERVATORY

observing facility to observe + store data

in a nutshell:

- telescope: 6.7-m equivalent
- world's largest CCD camera: $3.2 * 10^9$ pixels
- Resolves a *golf ball 24 kilometers away!*





LSST Project/NSF/AURA

LSST a deep “video” of the sky

in numbers:

- 10-year photometric survey
- 6 optical bands*: ugrizy* (320-1050nm)
- 1,000 images/night = 15 TB/night
- 10 million transient candidates per night
- re-scheduled to start October 2023

TABLE 3: Various science metrics as functions of survey duration.

Quantity	Year 1	Y3	Y5	Y8	Year 10
r_5 coadd[a]	26.0	26.5	26.8	27.1	27.2
$\sigma(i{=}25)$[b]	0.12	0.07	0.06	0.05	0.04
color vol.[c]	316	20	6	1.7	1
# of visits[d]	83	248	412	660	825
σ_π (r=24)[e]	9.5	5.5	4.2	3.3	3.0
σ_μ (r=24)[f]	32	6.1	2.8	1.4	1.0

[a] The co-added depth in the r band (AB, 5σ; point sources).
[b] The photometric error for a point source with $i = 25$.
[c] The volume of the 5-dimensional color error space, normalized by the final v
[d] The number of visits per sky position (summed over all bands).
[e] The trigonometric parallax accuracy for a point source with r=24 (milliarcsec
[f] The proper motion accuracy for a point source with r=24 (milliarcsec/yr).

LSST a deep “video” of the sky

Wide-Fast-Deep survey (90% time)

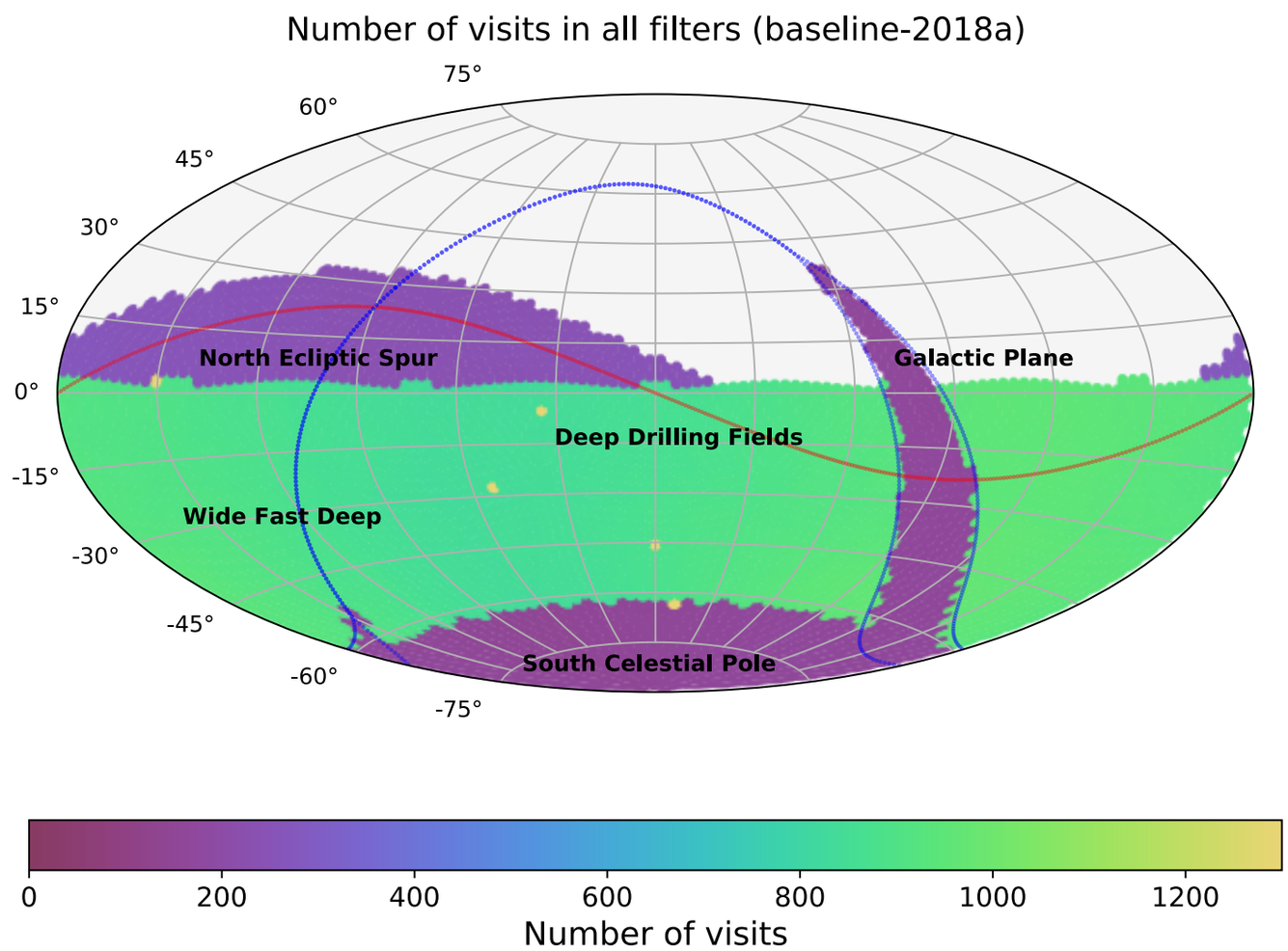
Baseline: 18,000 deg^2 , all visible sky in 3 nights
At least 2 visits per night, +1 color

Deep drilling fields (5%)

4 fields selected (ELAIS-S1, XMM-LSS, CDF-S, and COSMOS), 1 in discussion (EDFS)

Candidate mini surveys (~5%)

North Ecliptic Spur, the Galactic Plane, the South Celestial Pole, and five Deep Drilling mini surveys (Elais S1, XMM-LSS, Extended Chandra Deep Field-South, and COSMOS)

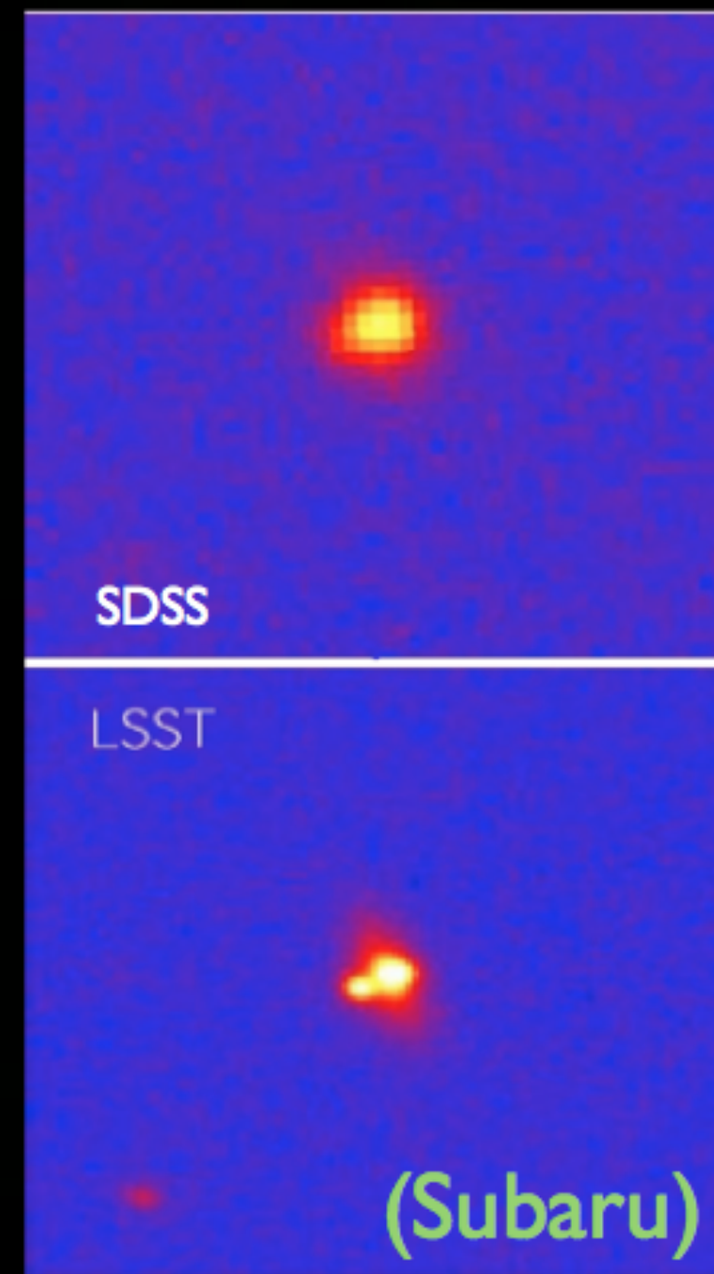


Call for White Papers on LSST Cadence Optimization Document-28382

Ongoing optimization is based on a full simulation of 10 years of operations

SDSS-LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

7x7 arcmin, gri



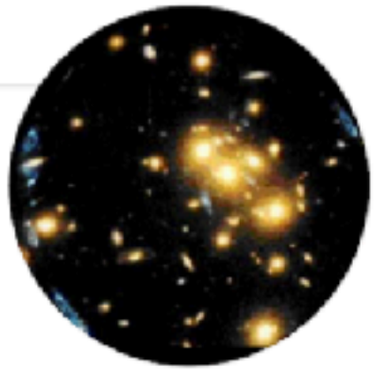
Slide from Ivezic

Four Science Goals

Rubin Observatory

Dark Matter, Dark Energy

- Weak Lensing
- Baryon acoustic oscillations
- Supernovae, Quasars

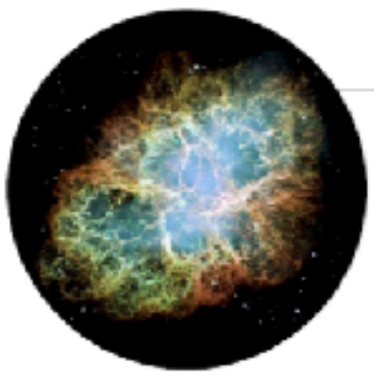


Cataloging the Solar System

- Potentially Hazardous Asteroids
- Near Earth Objects
- Object inventory of the Solar System

Milky Way Structure & Formation

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo



Exploring the Transient sky

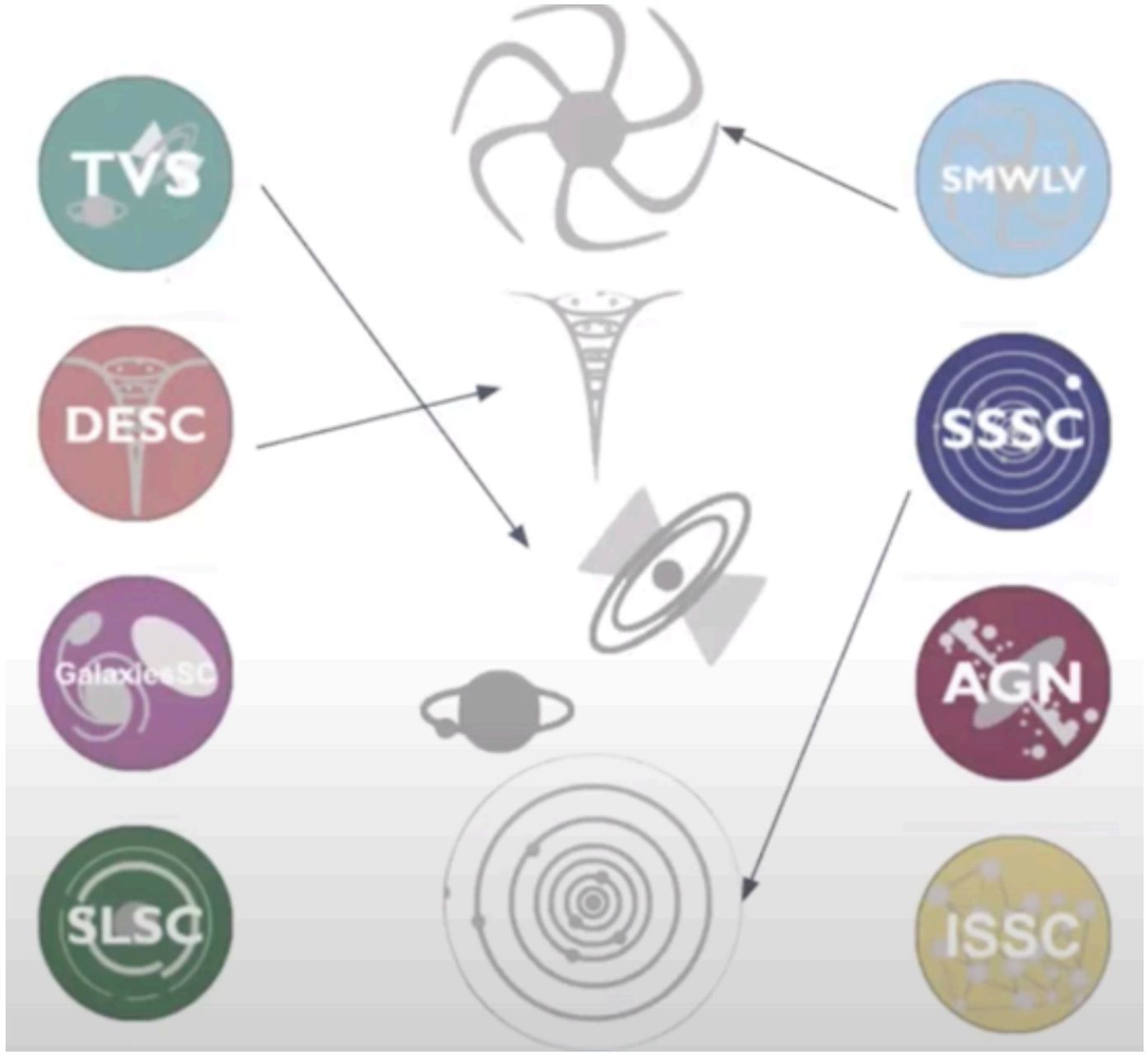
- Variable stars, Supernovae
- Fill in the variability phase-space
- Discovery of new classes of transients

"From Science Drivers to Reference Design", Ivezić et al. (2008), arXiv:0805.2366

Community: ~1500 researchers
Non-US: ~400 international contributors
France: ~80 members (~11 INSU ; ~70 IN2P3) *info from E. Gangler*

LSST science collaborations

- Galaxies
- Stars, MW, local volume
- Solar system
- Dark Energy
- Active Galactic Nuclei
- Transients/variable stars
- Strong lensing
- Informatics and statistics



LSST data products

Now

Raw Data
Sequential 30s image, 20TB/night

37s

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

public in "real time"

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.

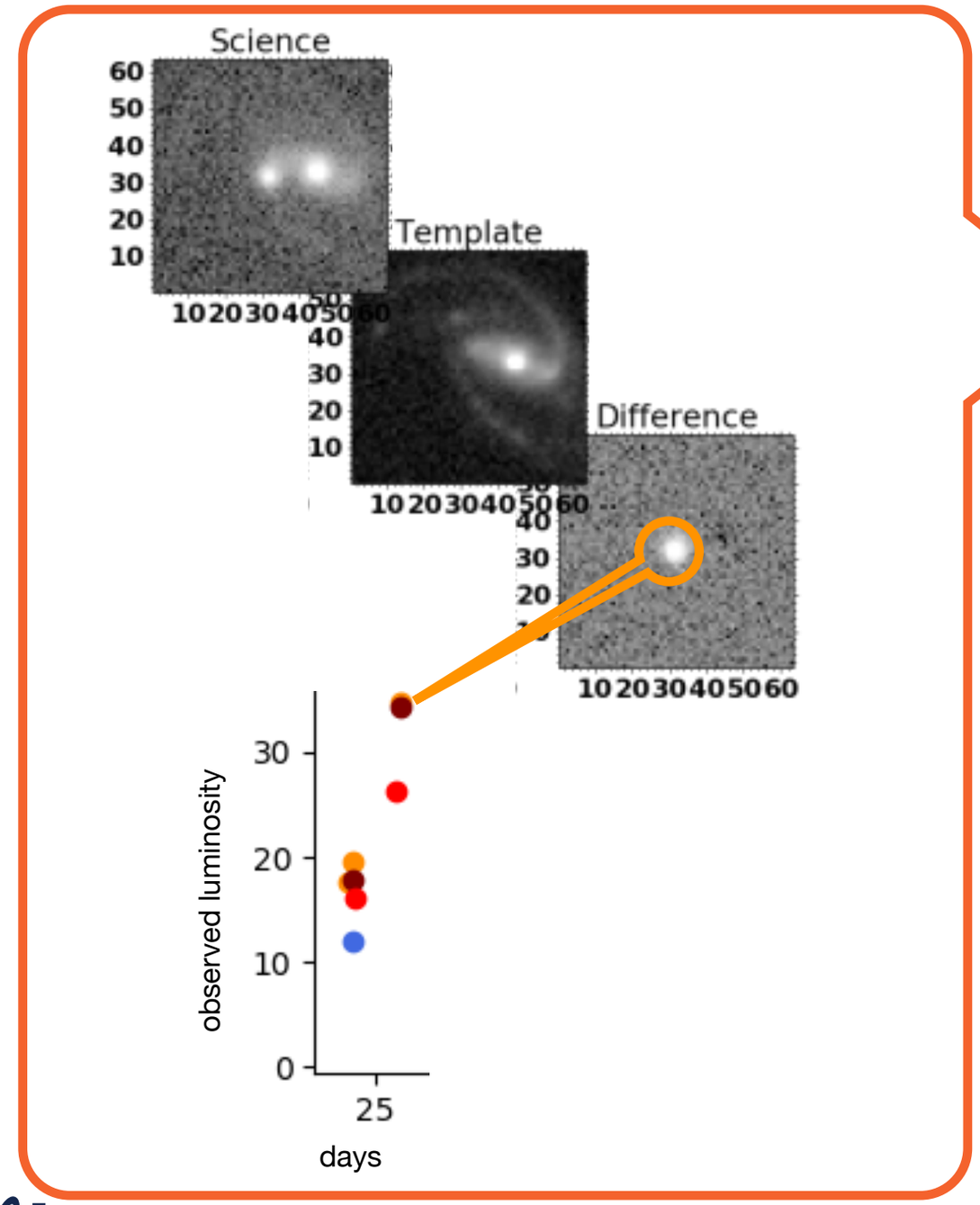
public yearly

End

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

public at the end of the survey

LSST data products



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LSST ~ 10 million transient alerts per night

?

promising candidates for <your science>

+ connecting with multi-wavelength/messenger surveys?

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FINK

promising candidates for <your science>

+ connecting with multi-wavelength/messenger surveys?

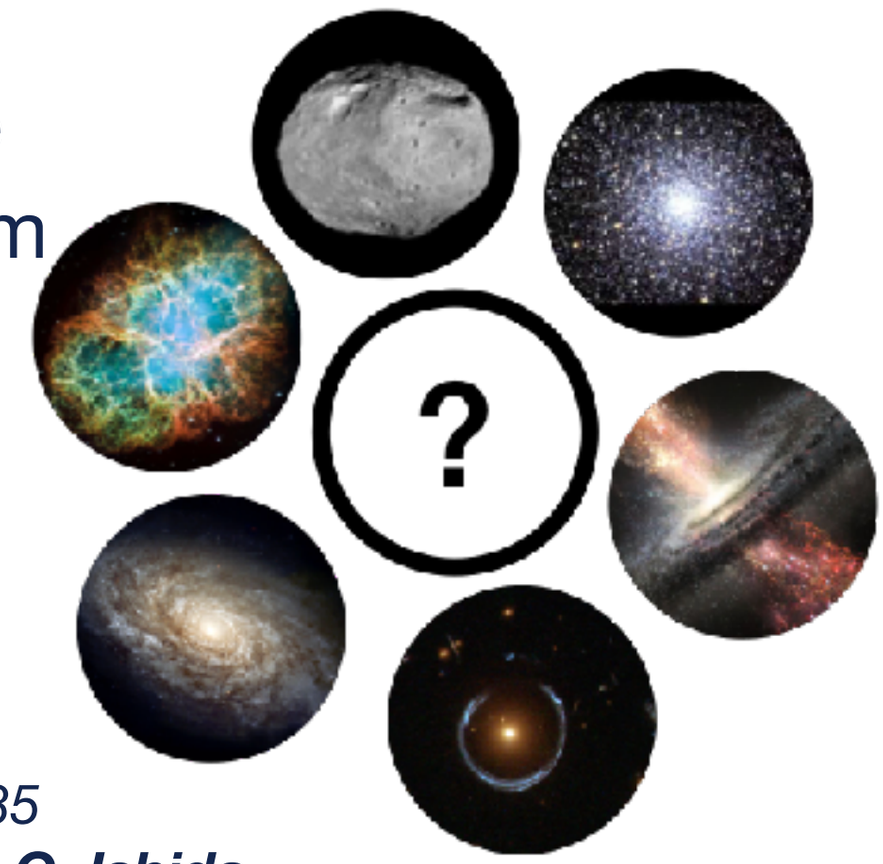
The broker panorama

officially selected to be a full-stream Rubin broker

(August 2021)

Fink is:

- a community driven effort, open to anyone
- a broker designed for the LSST alert stream



Goal: Multi-science broker

MNRAS 2020, arXiv: 2009.10185

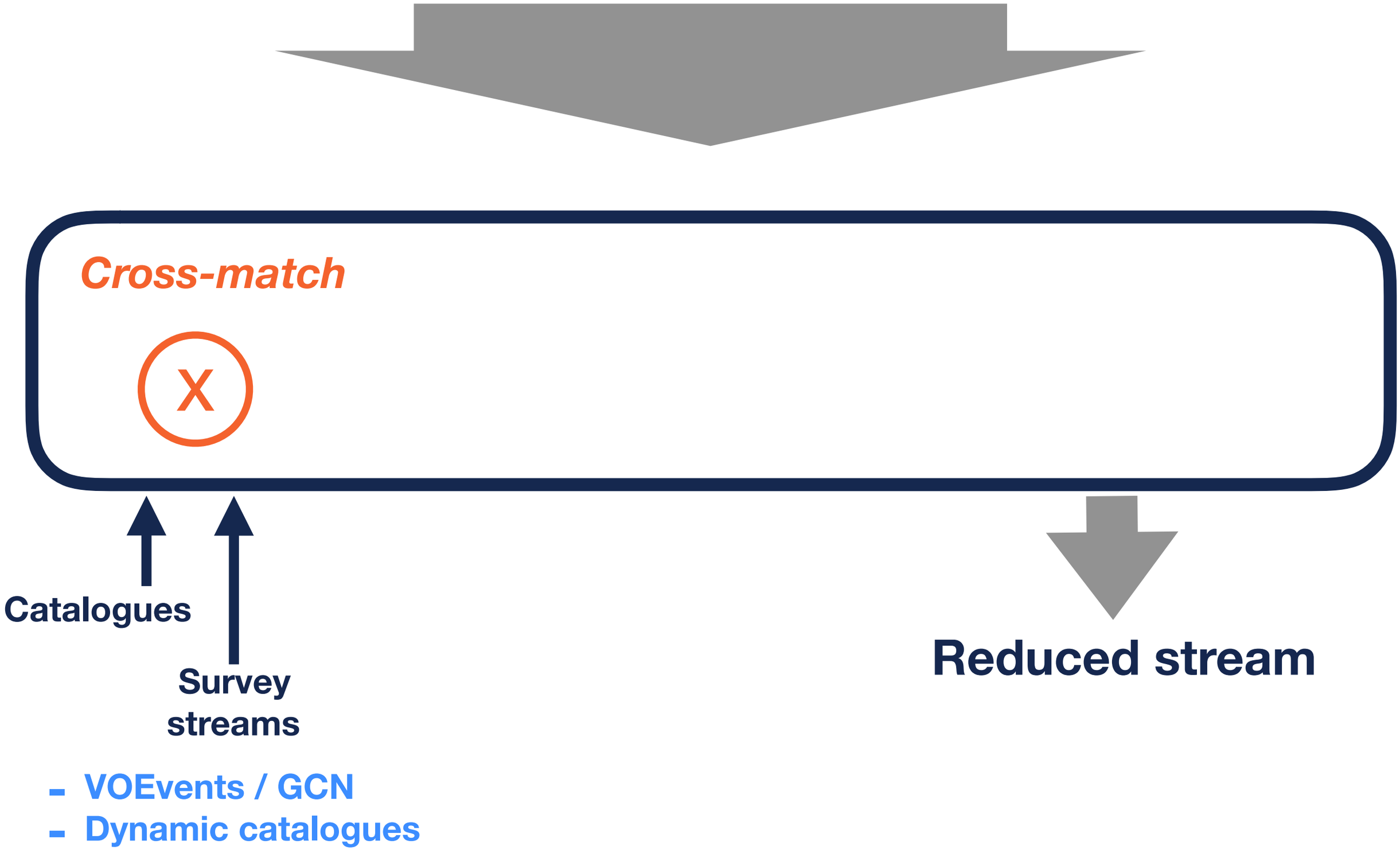
Anais Möller, Julien Peloton, Emille E. O. Ishida,
Chris Arnault, Etienne Bachelet , Tristan Blaineau, Dominique Boutigny, Abhishek Chauhan, Emmanuel Gangler, Fabio Hernandez, Julius Hrivnac, Marco Leoni, Nicolas Leroy, Marc Moniez, Sacha Pateyron, Adrien Ramparison, Damien Turpin, Réza Ansari, Tarek Allam Jr., Armelle Bajat , Biswajit Biswas, Alexandre Boucaud, Johan Bregeon, Jean-Eric Campagne, Johann Cohen-Tanugi, Alexis Coleiro, Damien Dornic, Dominique Fouchez, Olivier Godet, Philippe Gris, Sergey Karpov, Ada Nebot Gomez-Moran, Jérémy Neveu, Stephane Plaszczynski, Volodymyr Savchenko, Natalie Webb

https://fink-broker.org/members/

LSST ~ 10 million transient alerts per night

Reduced stream

LSST ~ 10 million transient alerts per night



LSST ~ 10 million transient alerts per night

Cross-match + *ML classification*

Catalogues

Survey streams

- **VOEvents / GCN**
- **Dynamic catalogues**

Reduced stream

LSST ~ 10 million transient alerts per night

Cross-match + *ML classification* + *Customizable filtering*

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"real-time" API

- Follow-up

<minutes!

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<minutes!

Science Portal + API

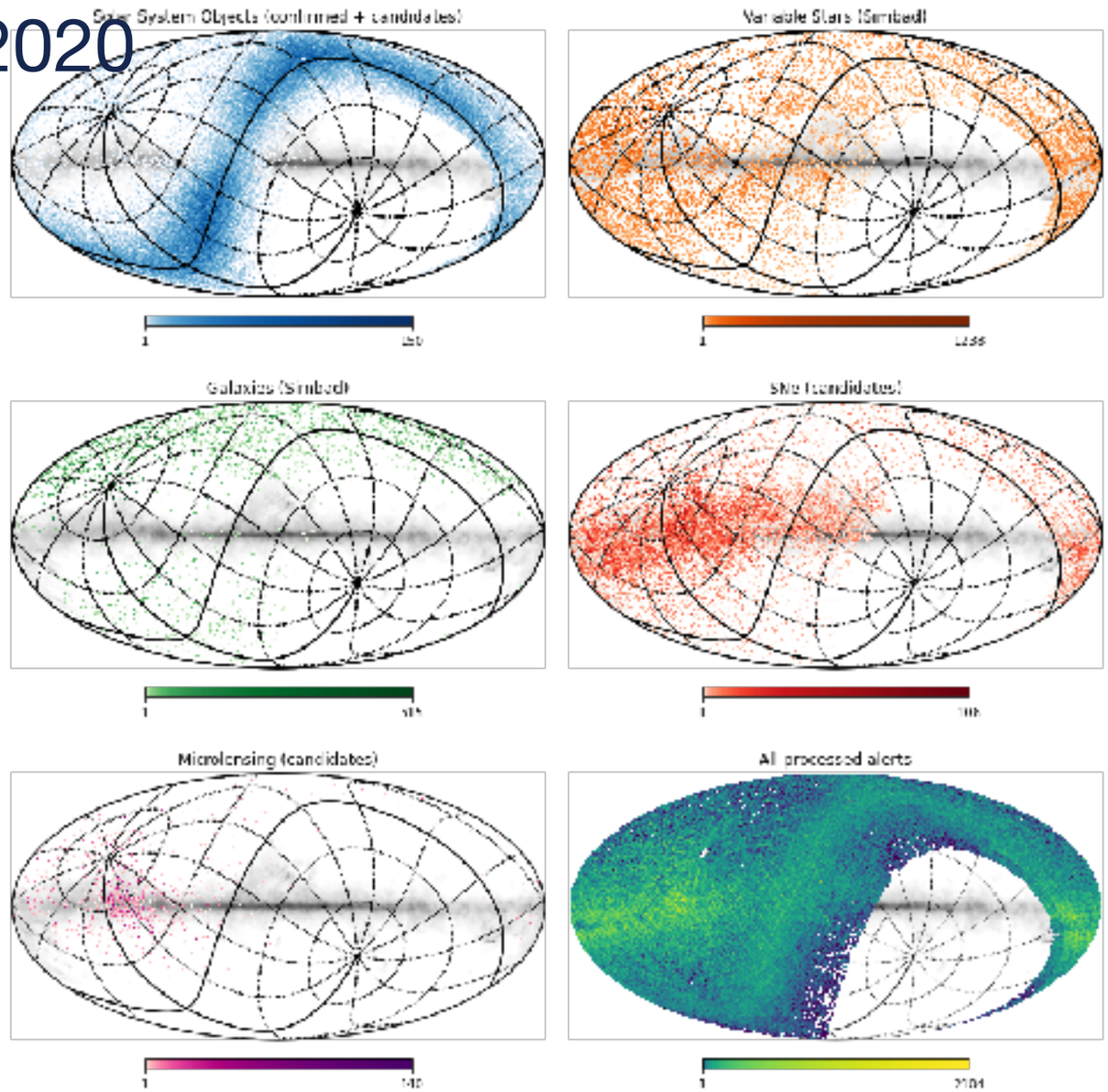
- Visualisation
- Analysis

FINK deployment with ZTF

MoU with Zwicky Transient Facility (ZTF).
>110 million alerts collected since 2020

Reduced streams:

- Supernovae
- Microlensing
- Variable stars
- Solar System objects
- GRB afterglows
- Kilonovae (new)
- Early type Ia supernovae (new)



ZTF alerts November 2019 to June 2020

Möller, Peloton, Ishida et al. 2021 arXiv:2009.10185

Case study: early kilonovae

LSST stream: 10,000 alerts / 37 s

Cross-match

X

Footprint w. survey stream: LIGO/Virgo

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- **Contextual**: e.g. host-galaxy not a known object
- Other **multi-messenger/wavelength** surveys

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Other multi-messenger/wavelength surveys

ML classification

Discard other types of astrophysical events

Algorithm for kilonovae **identification**

Case study: early kilonovae

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Footprint w. survey stream: LIGO/Virgo


Contextual: e.g. host-galaxy not a known object


Other multi-messenger/wavelength surveys

ML classification



Discard other types of astrophysical events

Algorithm for kilonovae identification

Filtering **Select** promising kilonovae candidates

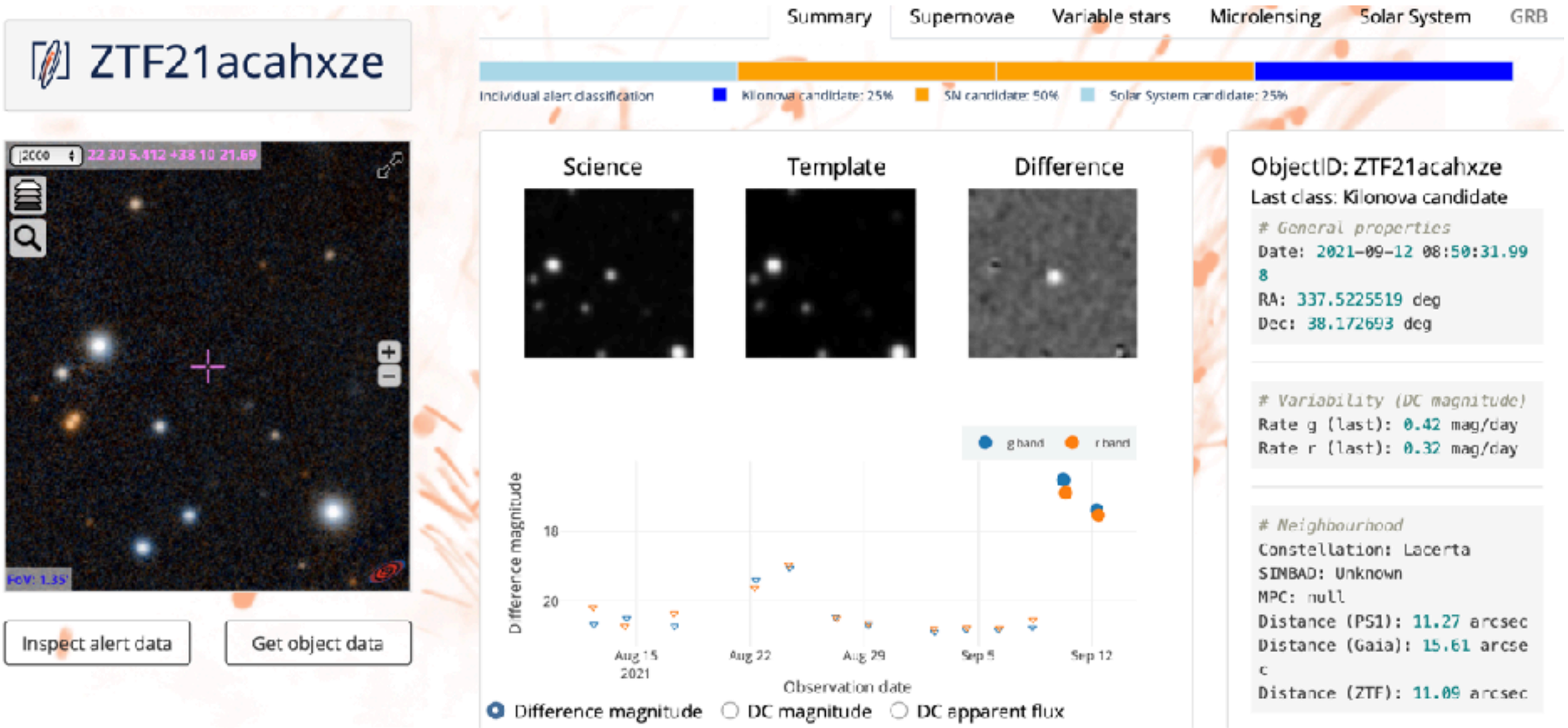
Communicate **All automatically done in <minutes**

Case study: early kilonovae

Coordinating follow-up:

- ranked lists with promising candidates
- Downward stream <minutes
- Ongoing collaboration with GRANDMA

see Pierre Duverne's talk later today!



With Juliette Vlieghe, Biswajit Biswas, Julien Peloton, GRANDMA team and many others!

ZTF ~ 100,000 transient alerts per night

Cross-match + *ML classification* + *Customizable filtering*

Catalogues

Survey streams

- VOEvents / GCN
- Dynamic catalogues

Reduced stream

"real-time" API

- Follow-up

<minutes!

Science Portal + API

- Visualisation
- Analysis

Live demo science portal

https://fink-broker.org

API

Fink Science portal 0.5 Explorer Xmatch API Info

Fink API

Summary of services

HTTP Method	URI	Action	Availability
POST/GET	http://134.158.75.151:24000/api/v1/objects	Retrieve single object data from the Fink database	☑
POST/GET	http://134.158.75.151:24000/api/v1/explorer	Query the Fink alert database	☑
POST/GET	http://134.158.75.151:24000/api/v1/latests	Get latest alerts by class	☑
POST/GET	http://134.158.75.151:24000/api/v1/sso	Get Solar System Object data	☑
POST/GET	http://134.158.75.151:24000/api/v1/cutouts	Retrieve cutout data from the Fink database	☑
POST/GET	http://134.158.75.151:24000/api/v1/xmatch	Cross-match user-defined catalog with Fink alert data	✗
GET	http://134.158.75.151:24000/api/v1/classes	Display all Fink derived classification	☑
GET	http://134.158.75.151:24000/api/v1/columns	Display all available alert fields and their type	☑

Retrieve object data | Query the database | Get latest alerts | Get Solar System Objects | Get image data | Xmatch

Retrieve single object data

The list of arguments for retrieving object data can be found at http://134.158.75.151:24000/api/v1/objects.

In a unix shell, you would simply use

```
# Get data for ZTF19acnjwgm and save it in a CSV file
curl -H "Content-Type: application/json" -X POST -d '{"objectId":"ZTF19acnjwgm", "output-format":"csv"}' http://134.158.75.151:24000/api/v1/objects -
o ZTF19acnjwgm.csv
```

In python, you would use

```
import requests
import pandas as pd

# get data for ZTF19acnjwgm
r = requests.post(
  'http://134.158.75.151:24000/api/v1/objects'
```

API

https://github.com/broker-workshop/tutorials/tree/main/fink

Fink case study: multi-messenger/wavelength astronomy

Goal

The goal of this notebook is to show how Fink can contribute to multi-messenger and multi-wavelength science. This notebook includes queries for science related to **Kilonovae** and **gamma ray bursts (GRBs) counterparts.**

Real-time analysis for follow-up coordination will be better done through the Fink livestreams which processes and makes available the alert data within minutes of reception. Access through this notebook uses the API access which is not real-time based. We aggregate the data into our API and Science Portal database at the end of each observing night. API access can be useful to analyze last night and older alerts. For example in case of reprocessing analysis in the search for low signal-to-noise events in gravitational wave or other wavelength detectors.

What is behind?

This notebook will use:

- **Fink cross-match** with close by sources in the SIMBAD (Wenger et al. 2020) catalogue (within 1'') using xmatch service provided by the Centre de Données astronomiques de Strasbourg (CDS) .
- **Fink's machine learning (ML) classification** scores trained with (Muthukrishna et al. 2019) and (Stachie et al. 2019):
  - Random Forest to classify Kilonovae (Biswas et al. in prep)
  - SuperNNova (Möller & de Boissière 2019) to classify SNe at all light-curve epochs
  - Random Forest (Leoni et al. in prep) and (Ishida et al. 2019b) to classify early (pre-max) SN candidates
- **Fink's extra features** such as color `g-r` and `rate` when possible.

Environment set up

To run this notebook, you need to import the following libraries (already installed in colab):

In [1]:
```
import requests

import pandas as pd
import numpy as np

import matplotlib.pyplot as plt
import seaborn as sns
sns.set_context('talk')
```

synergies

- Discussions and work with teams from:
  - SVOM, GRANDMA, CTA, Integral, KM3NET, …
  - Work on GRB (Fermi/SWIFT-ZTF) to prepare SVOM-LSST
  - GRANDMA: accepted CFHT observing proposal for Kilonovae search (2021A Coleiro+) using Fink's filtered ZTF alert stream.

summary

VRO LSST starting end 2023! unveiling the Southern Sky like never before!

Rubin optical time-domain data will be a great asset for multi-messenger/wavelength studies!

How to unravel it?

- Fink is already processing ZTF data stream (MoU 2020).
- First science modules deployed: SNe, GRB, microlensing, …
- Automatic filtered streams <minutes for follow-up coordination
- Analysis capabilities with the web portal and API (python callable)
- for VRO deployment at CC-in2p3
- ***We want to connect to new teams, collaborations and facilities!***

Möller, Peloton, Ishida et al. 2021
MNRAS, arXiv: 2009.10185

https://fink-broker.org
contact@fink-broker.org