ALeRCE
Automatic Learning for the
Rapid Classification of Events

High cadence surveys and the future ecosystem of time domain astronomy

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http://alerce.science/

UTEM · Universidad Austral de Chile · Universidad de Concepción · Pontificia Universidad Católica de Chile · Universidad de Chile · CMM Center for Mathematical Modeling · Millennium Institute of Astrophysics · REUNA Ciencia y Educación en Red · Data Observatory · IACS · Center for Data-Driven Discovery · DiRAC

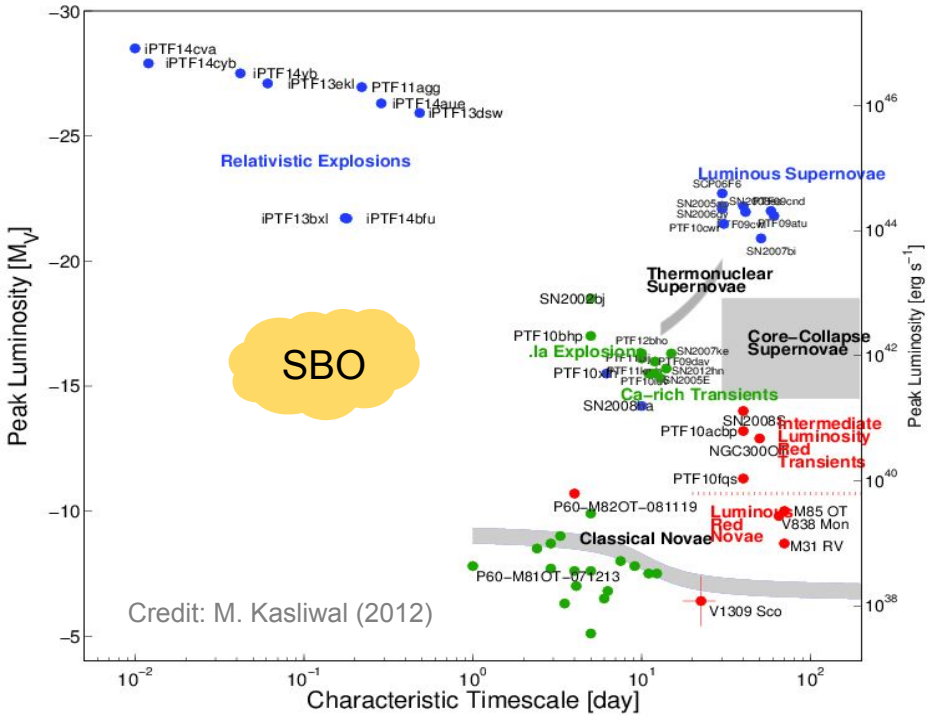

Matt Molloy

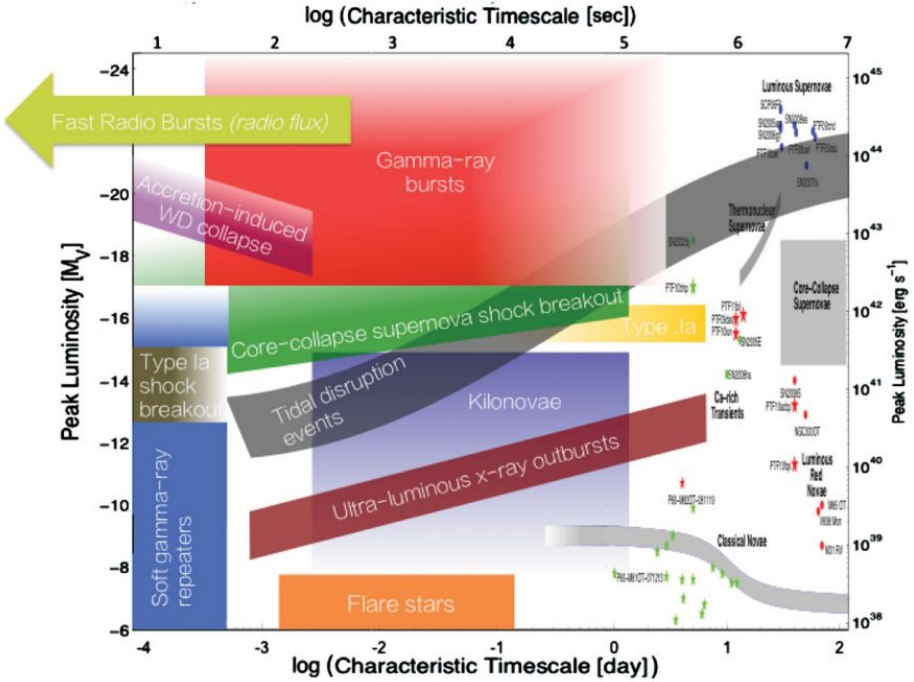
Overview:

1. High cadence surveys & time domain ecosystem
2. The High cadence Transient Survey (HiTS)
3. The ALeRCE broker
4. DEMO!

1. High cadence surveys & the time domain ecosystem

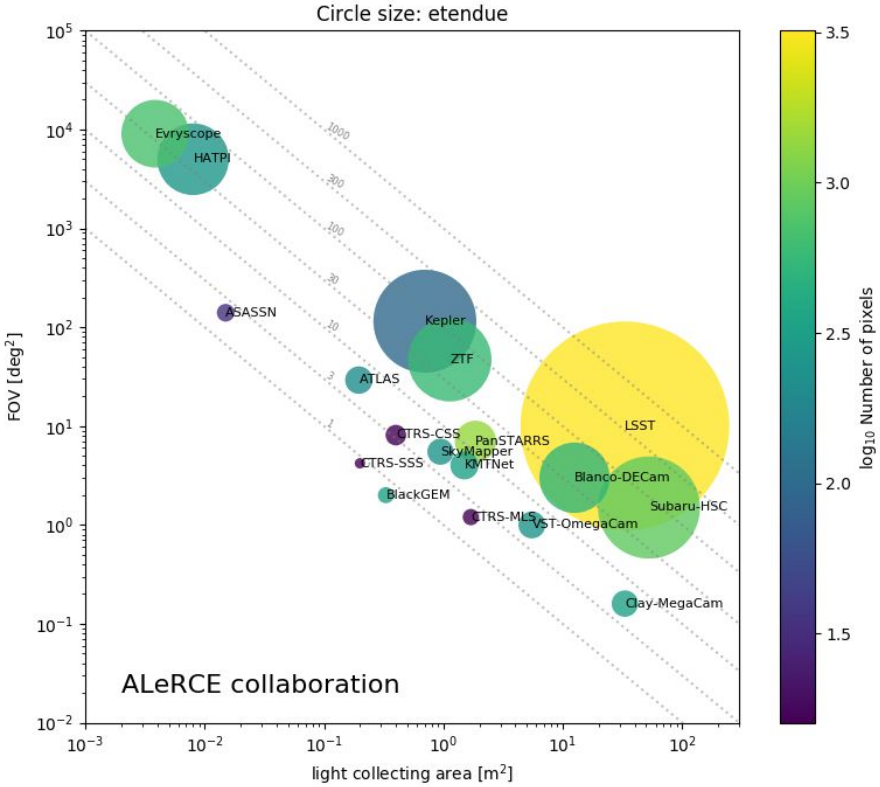
Transient landscape

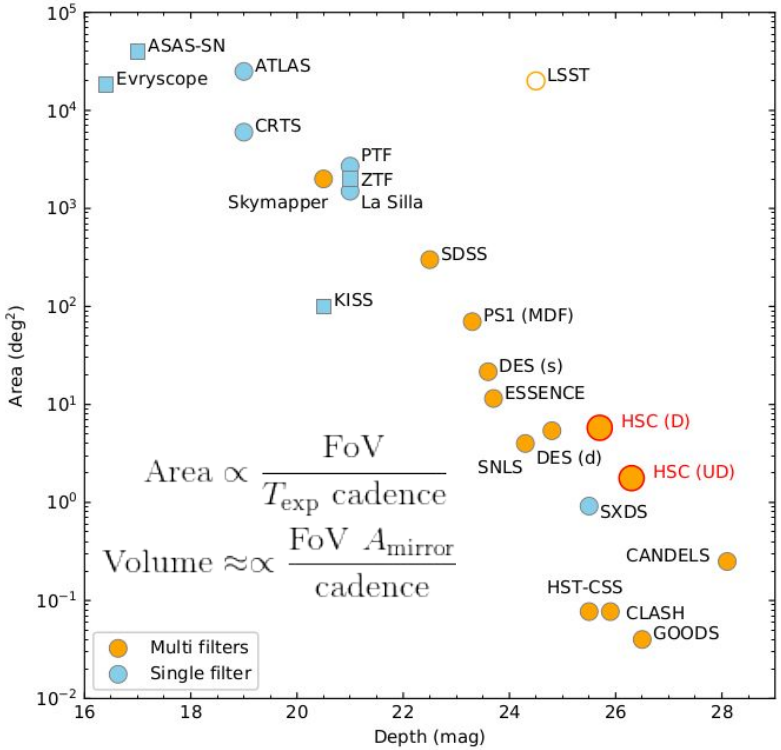




Burton+2016

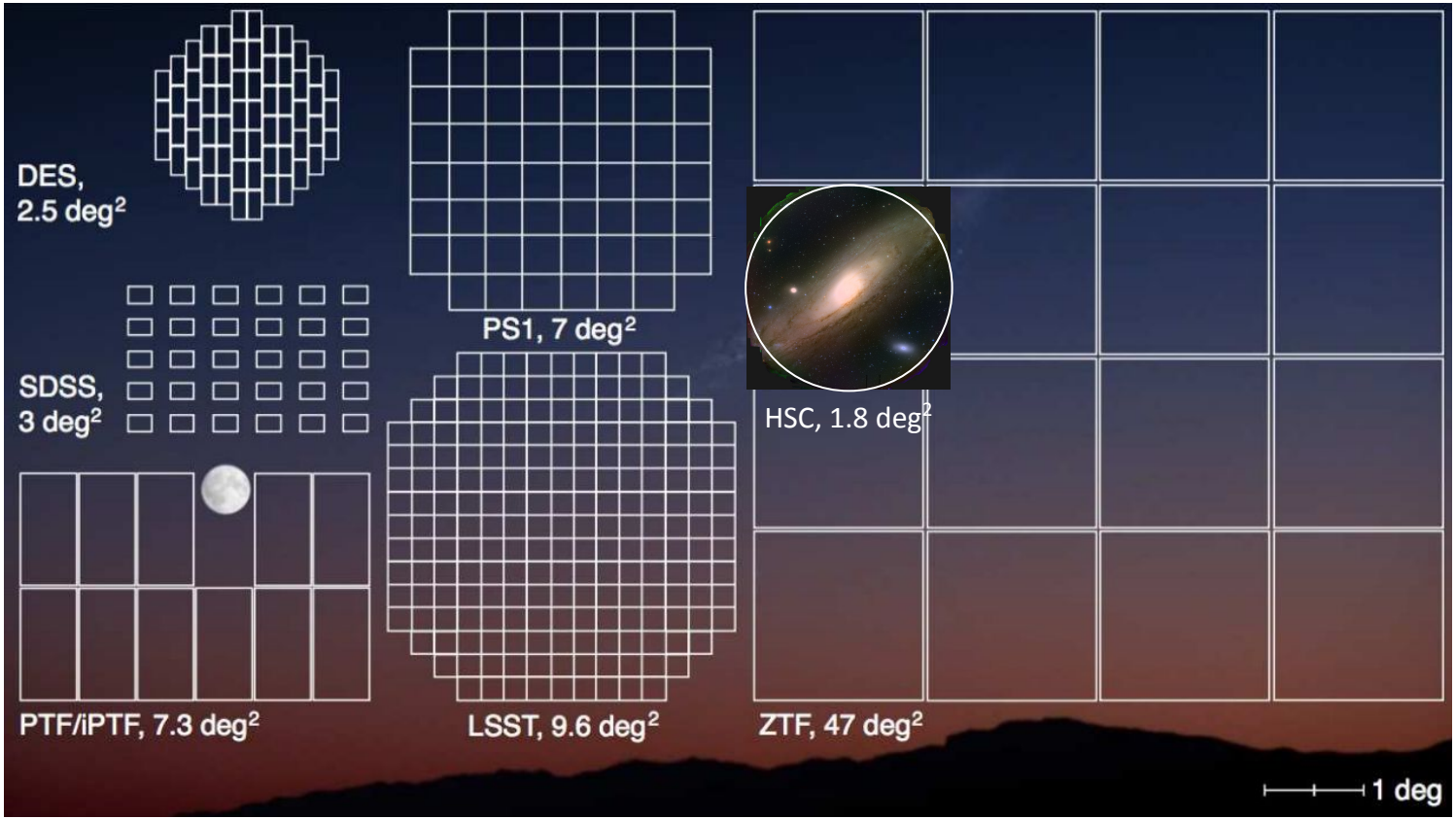
Survey telescopes





Yasuda+2019

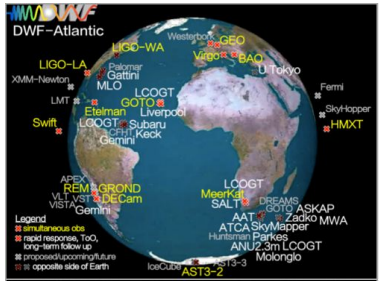
Survey telescopes



Laher+2017

Current follow up strategies

~min cadence



Proactive strategy
DWF (~1 min @ DECam)
Andreoni+17,19

Fast robotic
telescopes
(shallow)

~hour cadence

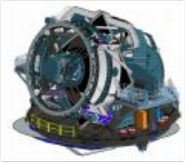
KEGS (30 min @ Kepler), Shaya+15
PS1/MDS (30 min @ PS1),Berger+13
SHOOTS (60 min @ HSC), Tanaka+16
HiTS (100 min @ DECam), Förster+16

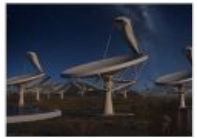
>1 day cadence

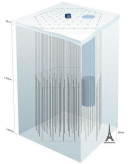
ZTF
HSC Hyper Suprime-Cam Subaru Strategic Program
atlas
THE DARK ENERGY SURVEY
TRANSIENT NAME SERVER
Pesstto
ESO

Future time domain astronomy ecosystem

Survey telescopes







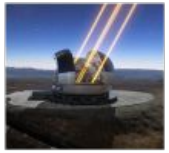
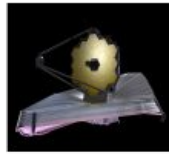
Alert brokers/TOMs

ALeRCE
Automatic Learning for the Rapid Classification of Events

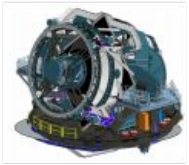
AEON
Astronomical Event Observatory Network

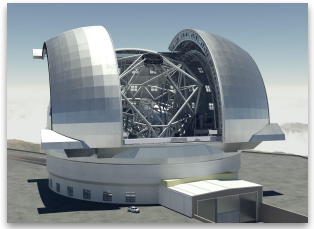
Follow up telescopes



Interoperable tools for new discoveries





API

ALeRCE
Automatic Learning for the Rapid Classification of Events

ANTARES

Lasair

LCO

MARS
Make Alerts Really Simple

TOM

AEON
Astronomical Event Observatory Network

Tools for time domain astronomy

Acquisition & processing → Alert filtering & classification → Prioritization & follow-up → Physical interpretation

Survey telescopes:
image processing,
real/bogus filtering

ANTARES Lasair

ALeRCE
Automatic Learning for the Rapid Classification of Events

LC MARS
Make Alerts Really Simple

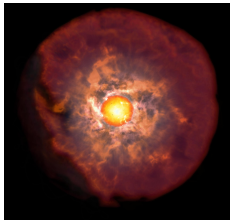
Brokers:
aggregation,
crossmatching,
ML classification

AEON
Astronomical Event Observatory Network

TOM

Prime Focus Spectrograph
SuMIRe

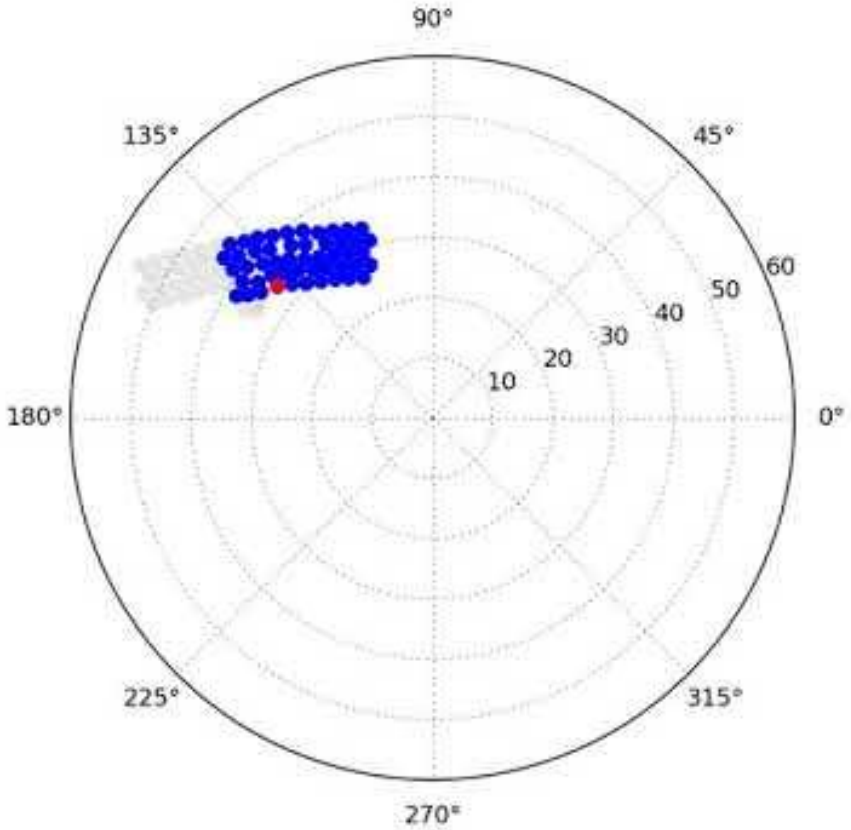
TOMs & follow-up telescopes:
resource optimization
& communication
(APIs), actionable ML



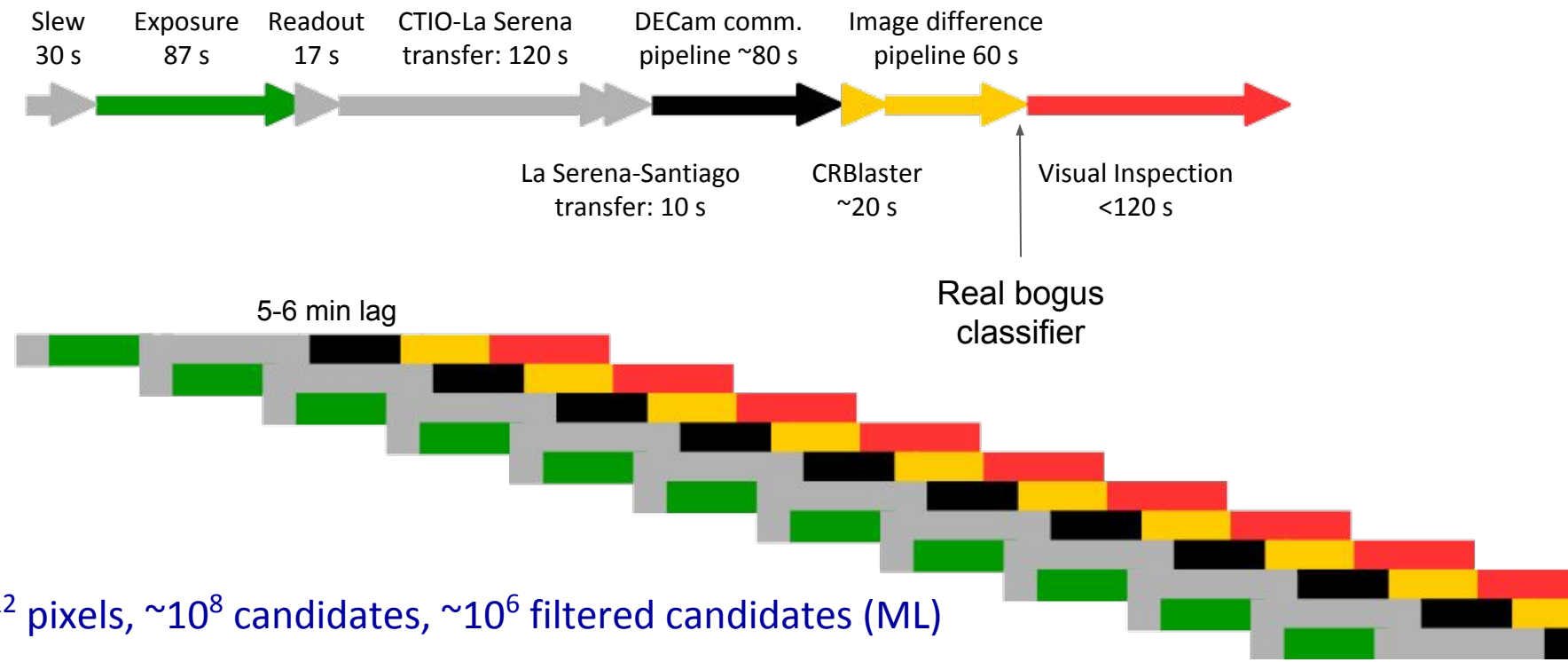
Analysis:
modeling, inference
(e.g. MCMC),
prediction

2. High Cadence Transient Survey (HiTS)

The High cadence Transient Survey (HiTS)



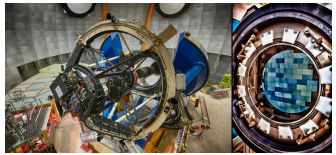
Pipeline flow outline

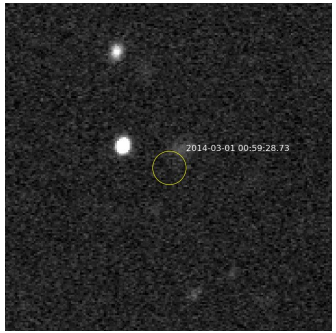


~10^{12} pixels, ~10^{8} candidates, ~10^{6} filtered candidates (ML)

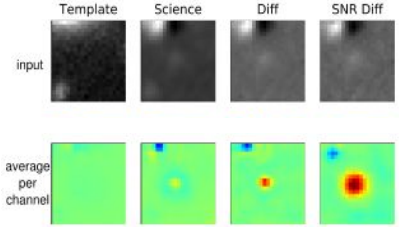
~10^{4} visual inspections, 125 SNe

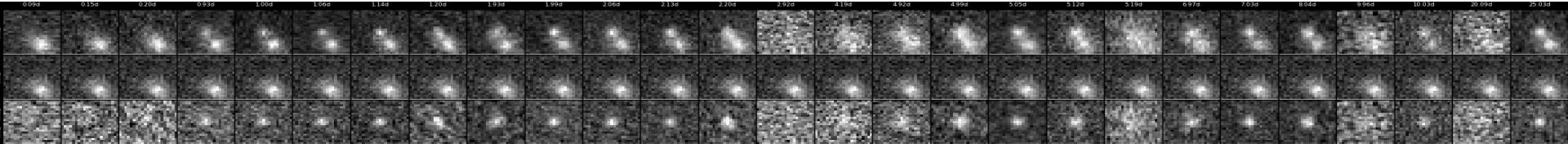
HiTS in a nutshell



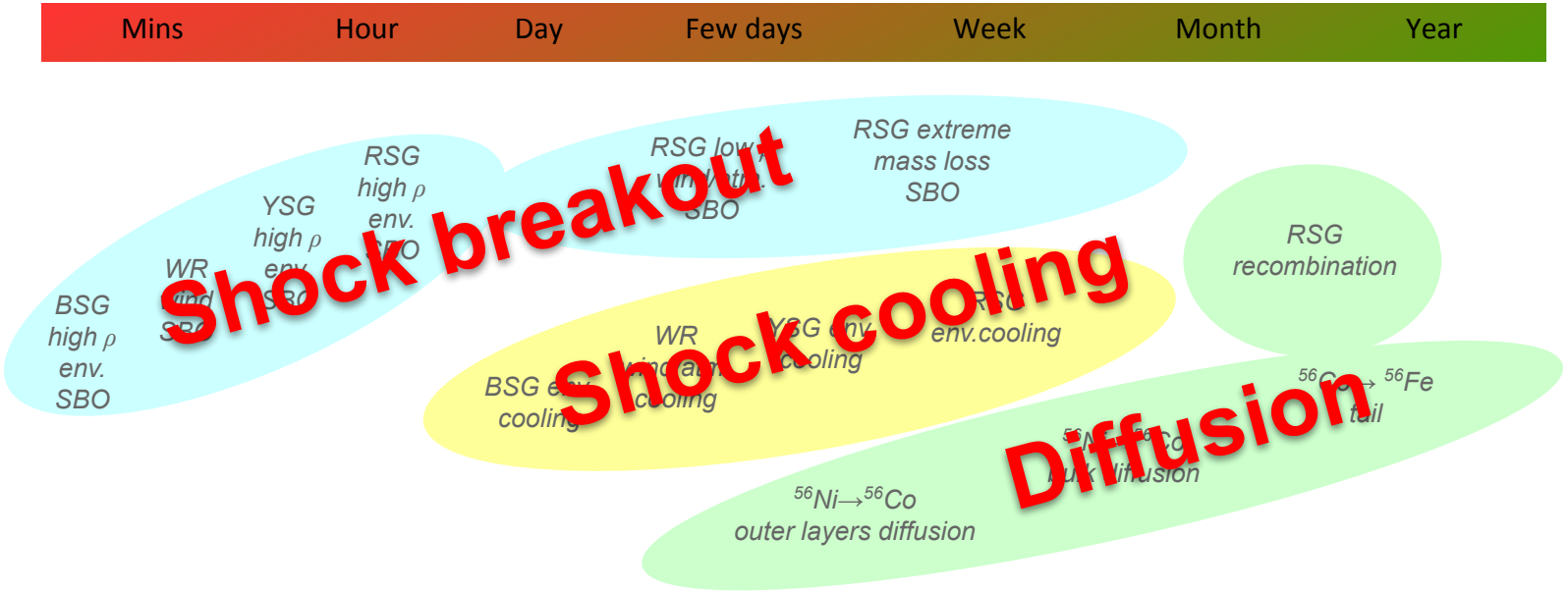


- 320 deg^2 deep & high cadence survey, 1st real time analysis of DECam (Feb 2014), 125 SNe!
- Supernova shock breakout model constraints (Förster+16, ApJ)
- 1st deep learning real/bogus classifier (Cabrera-Vives+16,17; Reyes+18, Huijse+18, Astorga+18)
- Distant RR Lyrae to probe outer MW (Medina+17,18, ApJ)
- ~10k new asteroids (Peña+18, AJ)
- ~22M public variable catalog (Martínez+18, AJ)
- Evidence for CSM around most SNe II (Förster+18, Nat. Ast.)
- 1st CRNN image sequence classifier (Carrasco-Davis+19, PASP)
- New population of intermediate mass black holes (Martínez-Palomera, *submitted*)

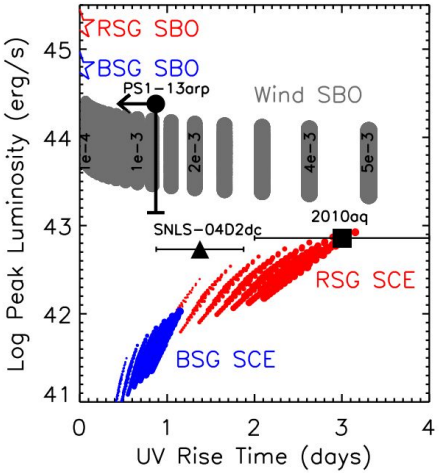




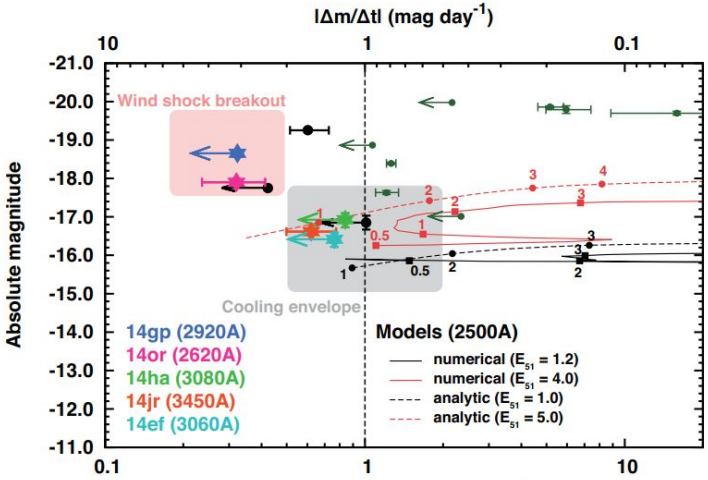
Physical processes and timescales in supernovae



Type II SNe: characteristic timescales and luminosities

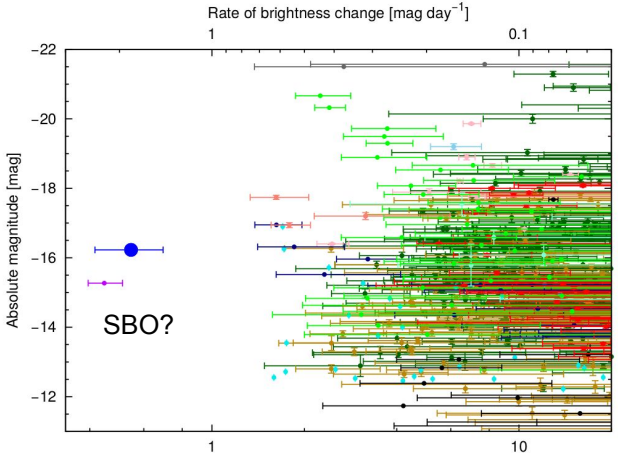


Gezari+2015



Rising time scale [day mag^{-1}]

Tanaka+2016

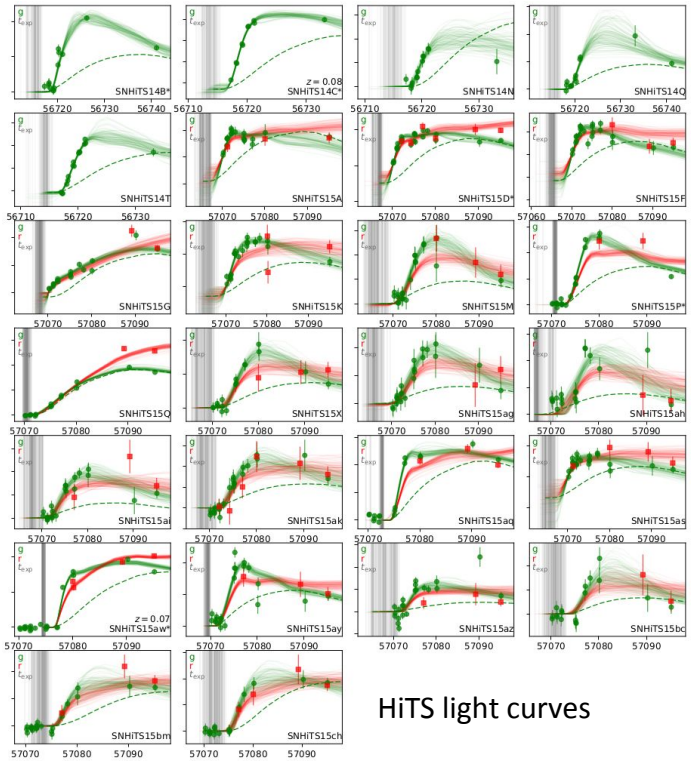


Decline time scale [day mag^{-1}]

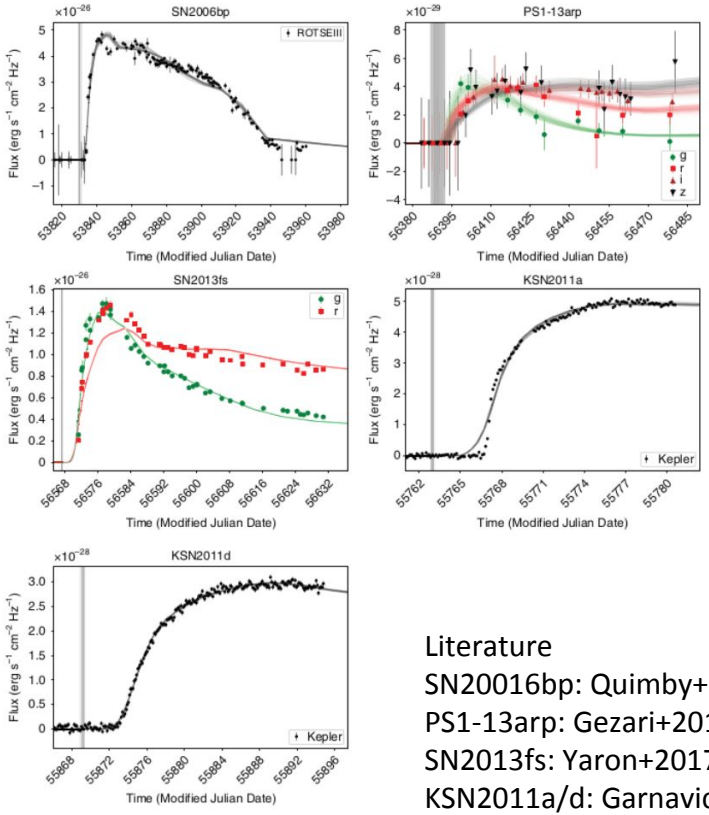
Tominaga+2019

SHOOTS @ HSC

Type II SNe: detailed modeling and inference



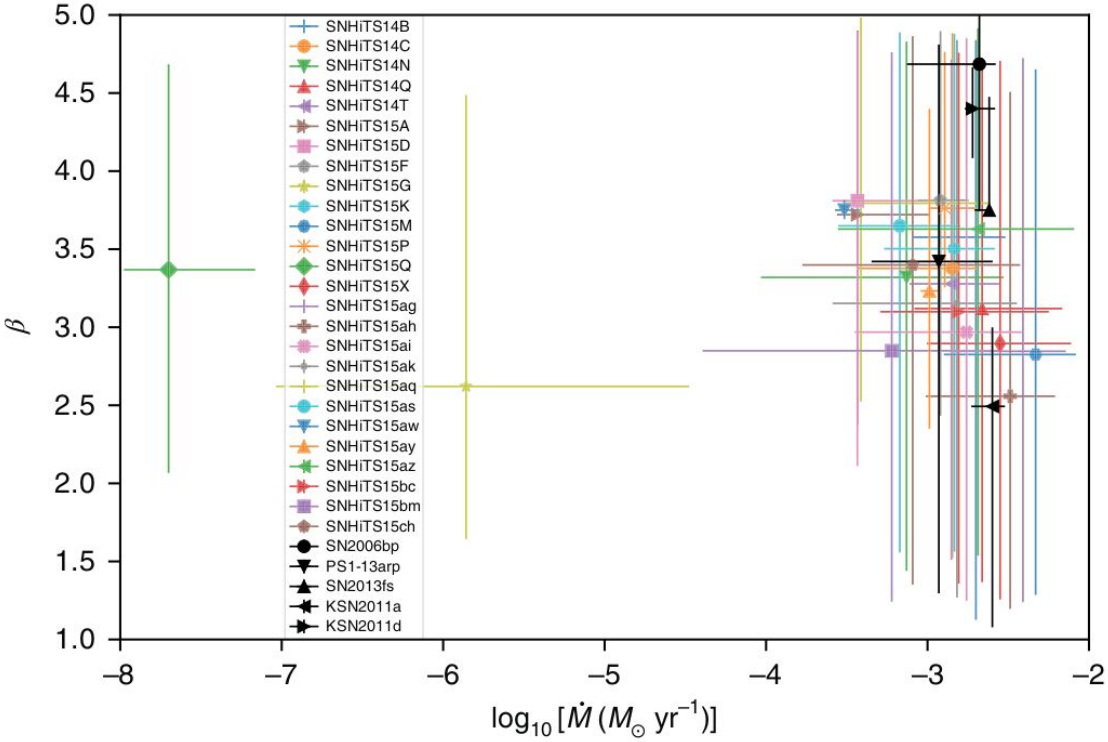
HiTS light curves

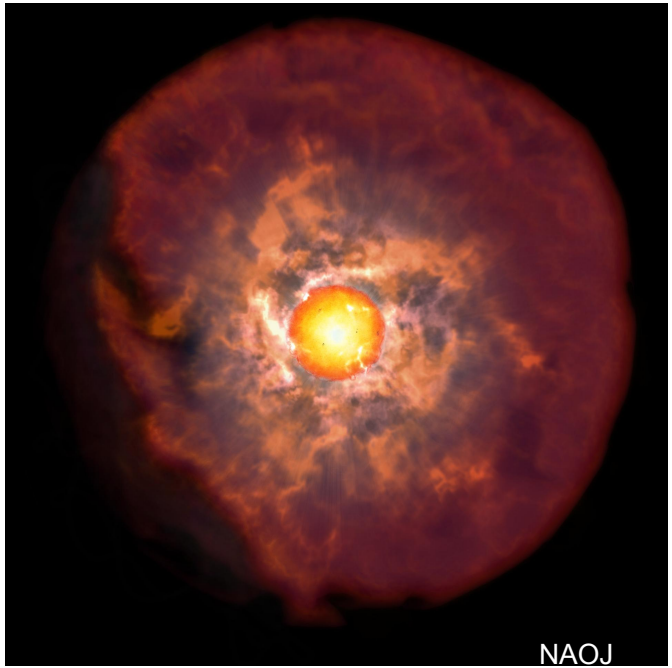


Literature
SN20016bp: Quimby+2007
PS1-13arp: Gezari+2015
SN2013fs: Yaron+2017
KSN2011a/d: Garnavich+2016

Models & inference: Moriya+18 & Förster+18

Dense CSM around type II SNe just before explosion

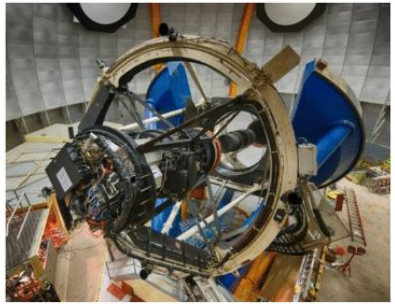




Förster et al. 2018, Nature Astronomy

3. Automatic Learning for the Rapid Classification of Events (ALeRCE)

ALeRCE: from HiTS to LSST



HiTS

2013-2015 (~3 weeks)

0.2 TB per night

~20 million objects

~100 million measurements

~0.1 million alerts per night

→ **~1-10x** →

ZTF

2018-2020

.4 TB per night

1 billion objects

~1 trillion measurements

~1 million alerts per night

→ **~10-100x** →

LSST

2022-2032

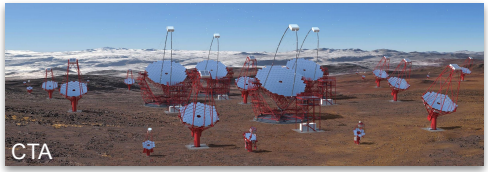
15 TB per night

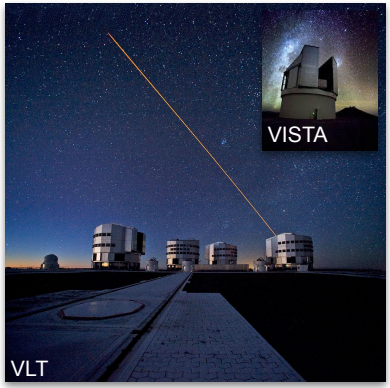
~37 billion objects

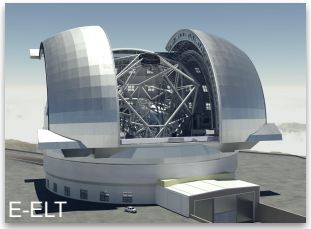
~7 trillion measurements

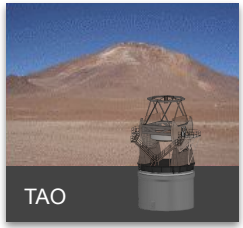
~10 million alerts per night

Astronomical infrastructure in Chile









Chilean institutions: access to **~10% observing time**

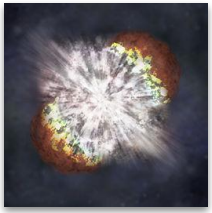
ALeRCE is a Chilean-led initiative to build a community broker for LSST and other large etendue survey telescopes

Goals

To facilitate the study of non-moving, variable and transients objects:

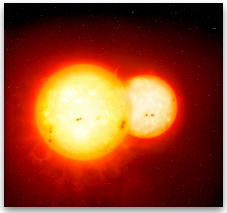
- **Fast classification** of transients, variable stars and active galactic nuclei
- **Flexibility** to adapt to different **science cases** (taxonomy, data products)
- **Connect** survey and **follow up** resources in Chile and abroad

Scientific Questions



Transients

Progenitors of stellar explosions (outermost layers) & **explosion physics** (ejecta structure)

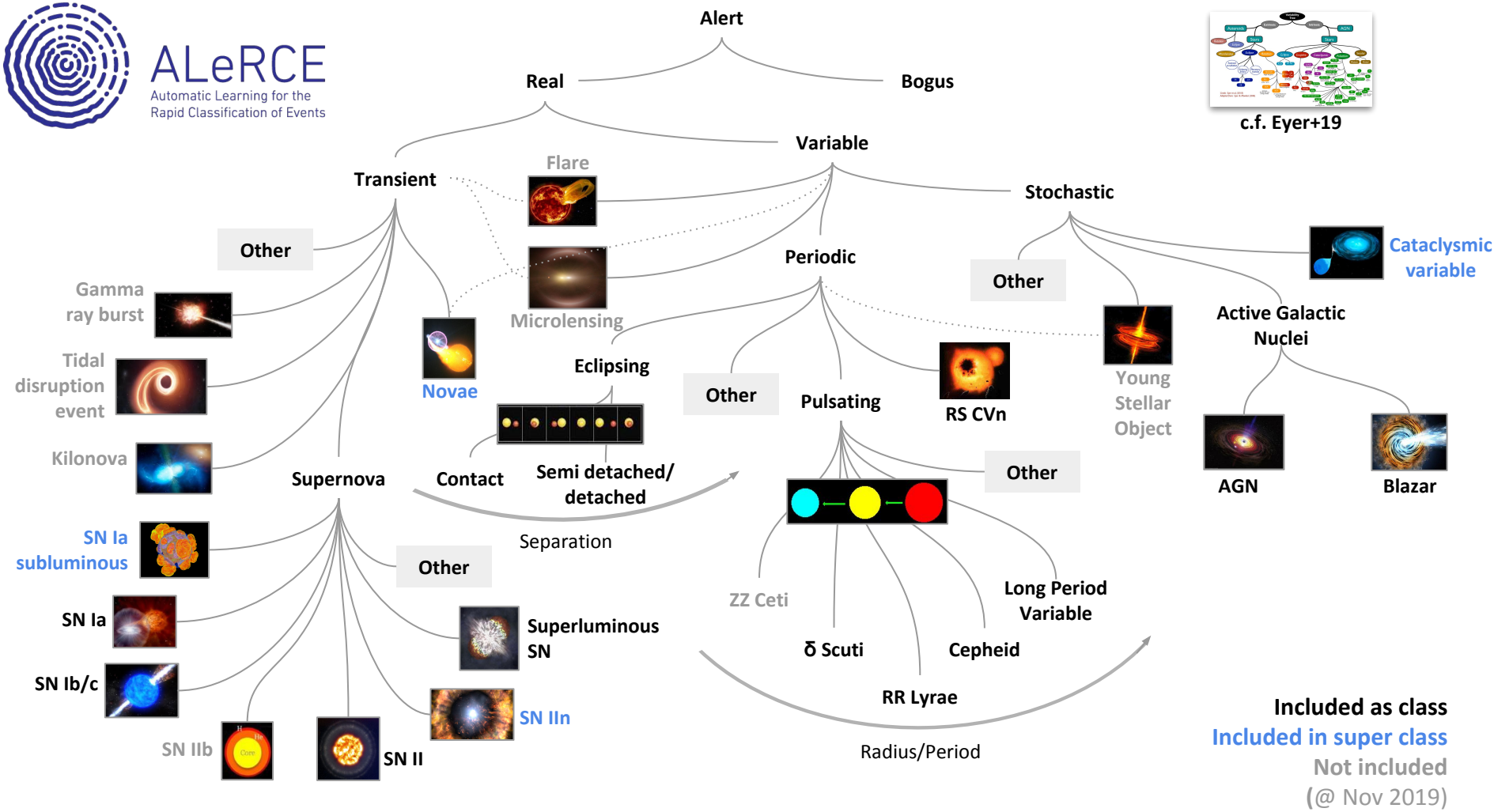


Variable stars

Low mass **microlensing** events, **changing mode** stellar pulsators, rapid reaction to **eclipsing events**, **eruptive** events

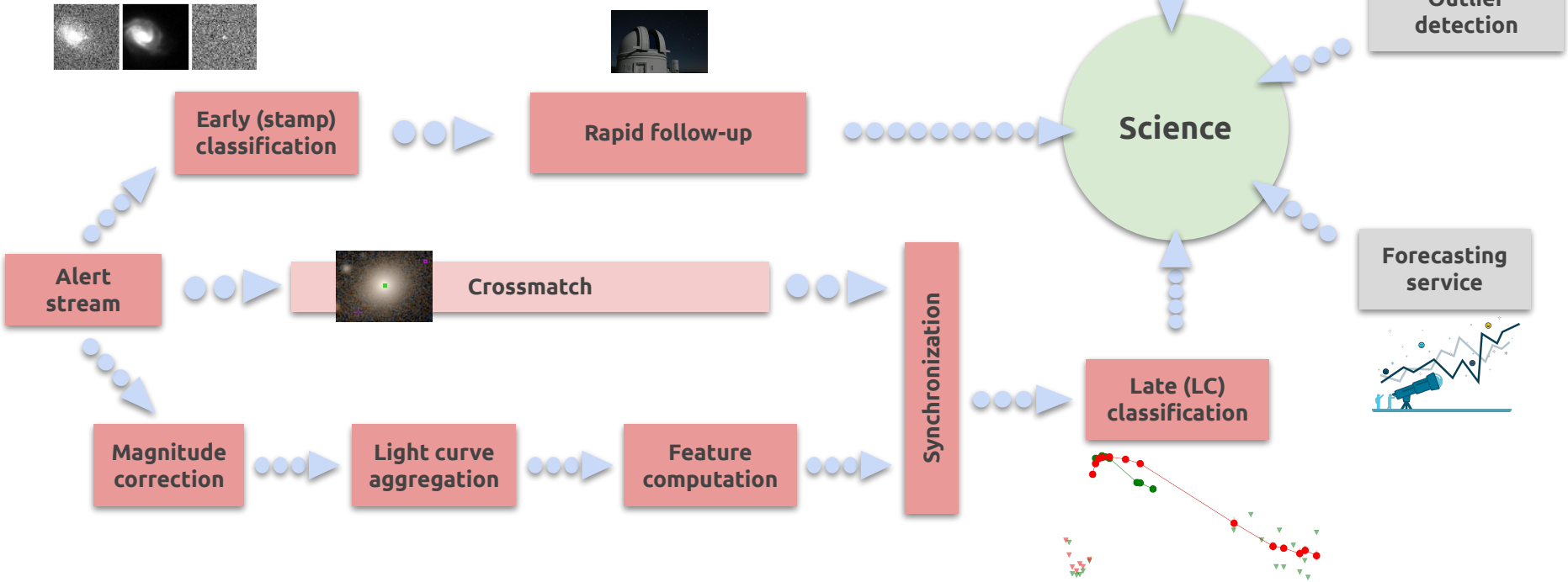
Active Galactic Nuclei

Changing state AGNs, **reverberation mapping** studies, detection of **intermediate mass black holes**, **tidal disruption events**


ALeRCE
Automatic Learning for the Rapid Classification of Events
Alert
Real
Bogus
c.f. Eyer+19
Variable
Transient
Flare
Stochastic
Other
Gamma ray burst
Tidal disruption event
Kilonova
Microlensing
Novae
Periodic
Eclipsing
Other
Pulsating
RS CVn
Young Stellar Object
Other
Cataclysmic variable
Active Galactic Nuclei
AGN
Blazar
Contact
Semi detached/ detached
Separation
Supernova
SN Ia subluminous
Other
SN Ia
SN Ib/c
SN IIb
SN II
Superluminous SN
SN IIn
Other
ZZ Ceti
δ Scuti
RR Lyrae
Cepheid
Long Period Variable
Radius/Period
Included as class
Included in super class
Not included
(@ Nov 2019)

ALeRCE pipeline:

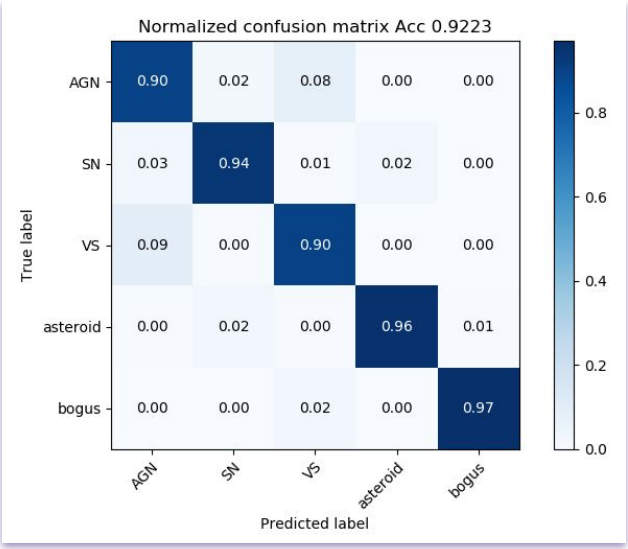
From streaming alerts to science



Early Classifier

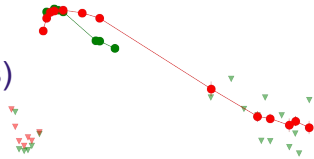
Convolutional Neural Network
(using first stamps)

AGN, SN, VS, asteroid, bogus

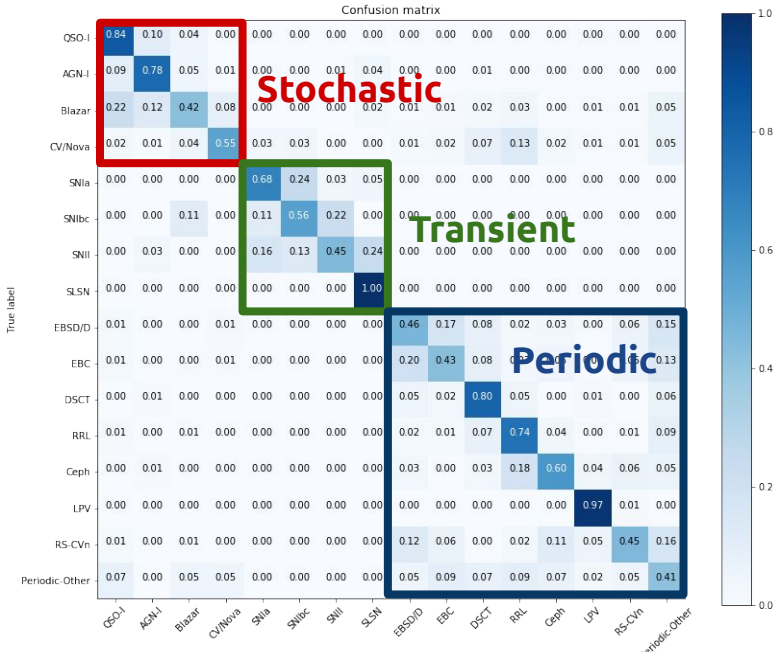


Late Classifier

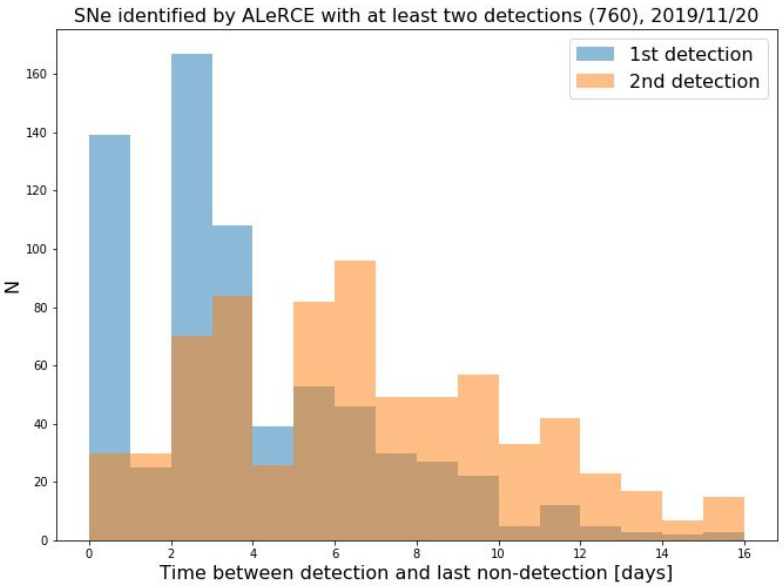
Random Forest Classifier
(using light curve, at least 5 observations)

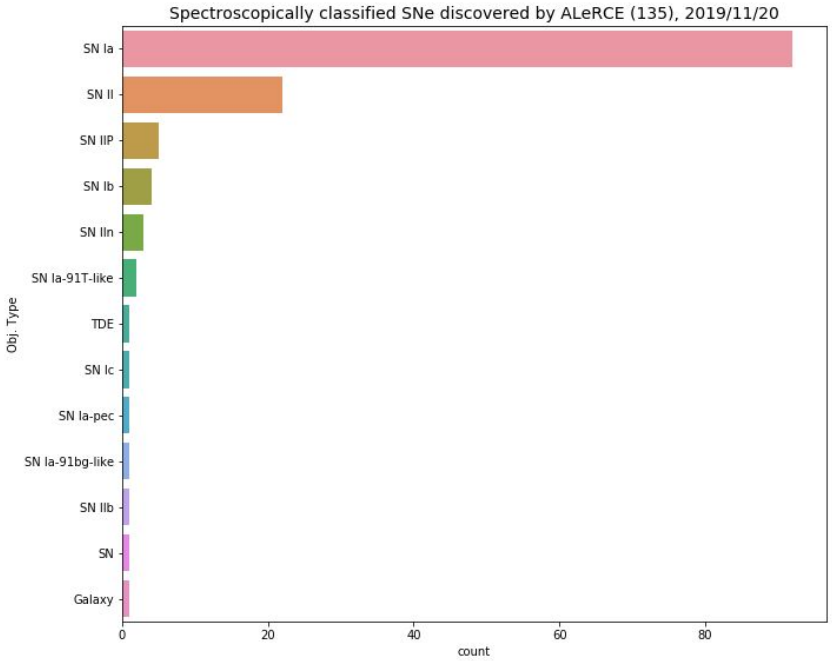


QSO-I, AGN-I, Blazar, CV/Nova
SN Ia, SN Ibc, SN II, SLSNe
EBSD/D, EBC, DSCT, RRL, Ceph, LPV, Periodic Other



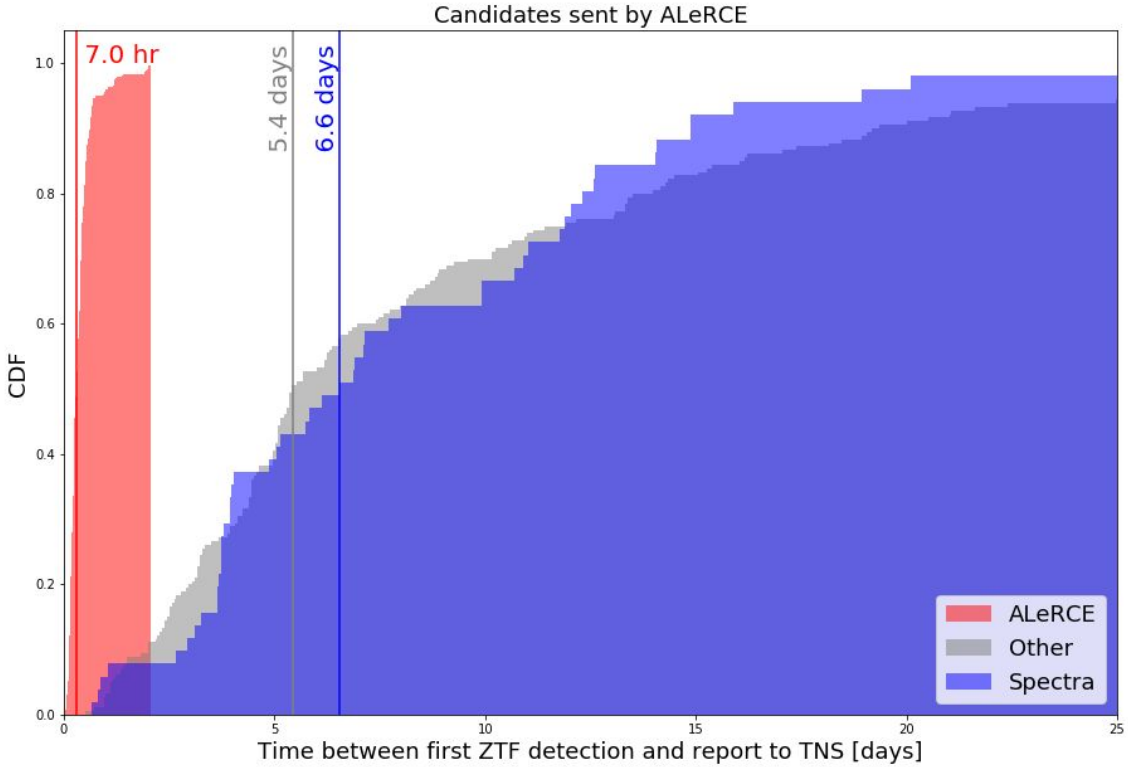
SNe detected by ALeRCE (early classifier)





http://alerce.online/object/ZTF19abvdgqo

SNe detected by ALeRCE (early classifier)

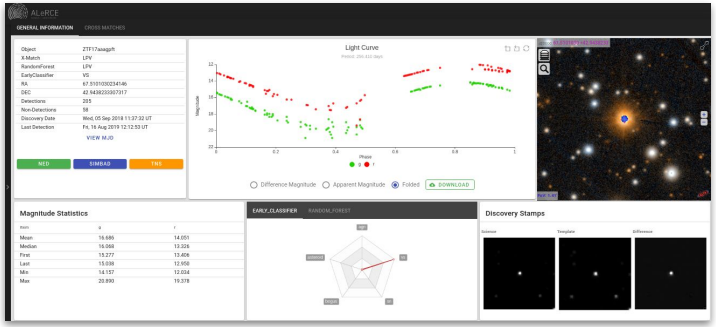


3. DEMO

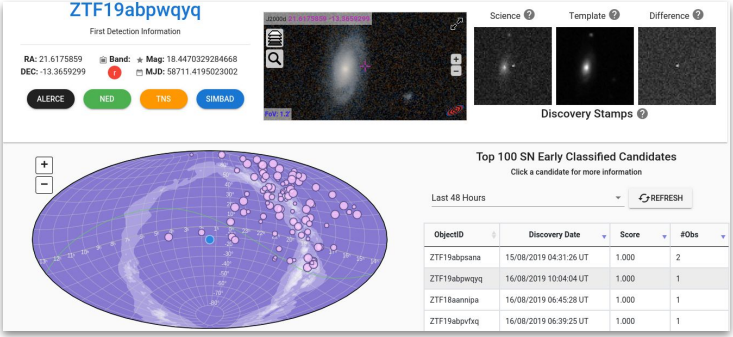
http://alerce.science

Web Interfaces

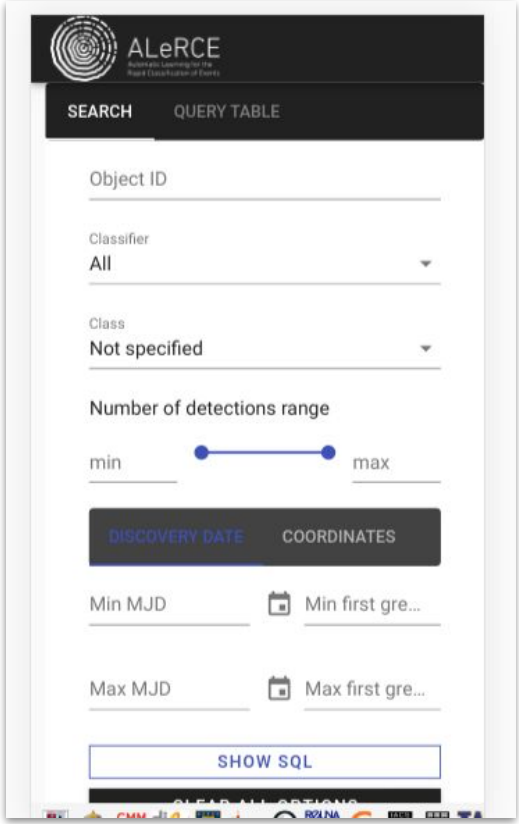
ZTF Explorer
http://alerce.online

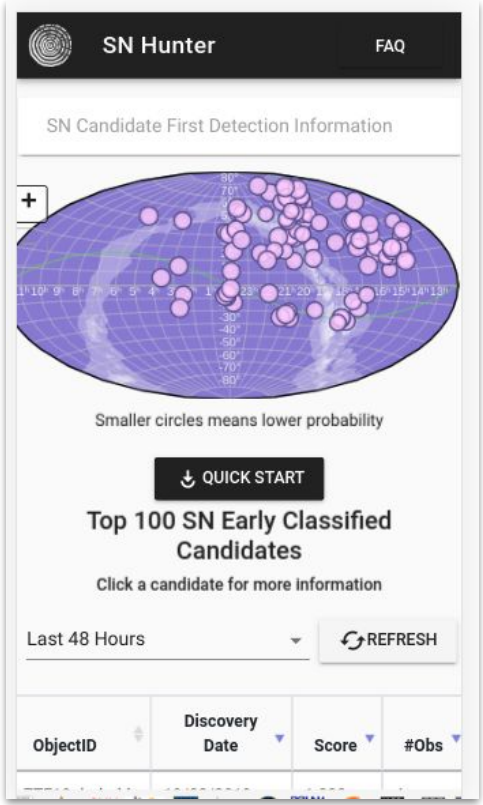


SN Hunter
http://snhunter.alerce.online

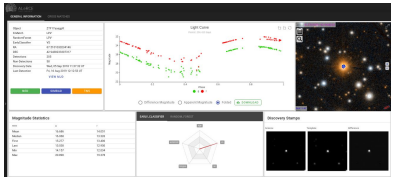


Mobile Phones

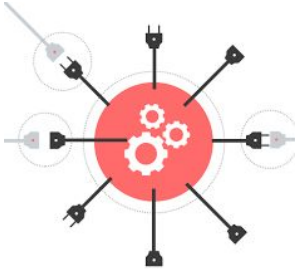




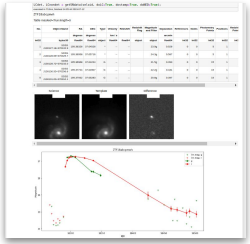
Web Interfaces



API



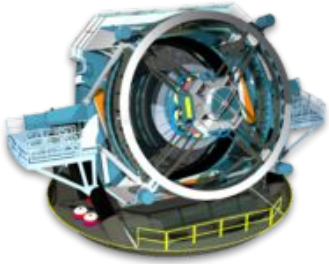
Jupyter Notebooks



ALeRCE

Automatic Learning for the Rapid Classification of Events

http://alerce.science



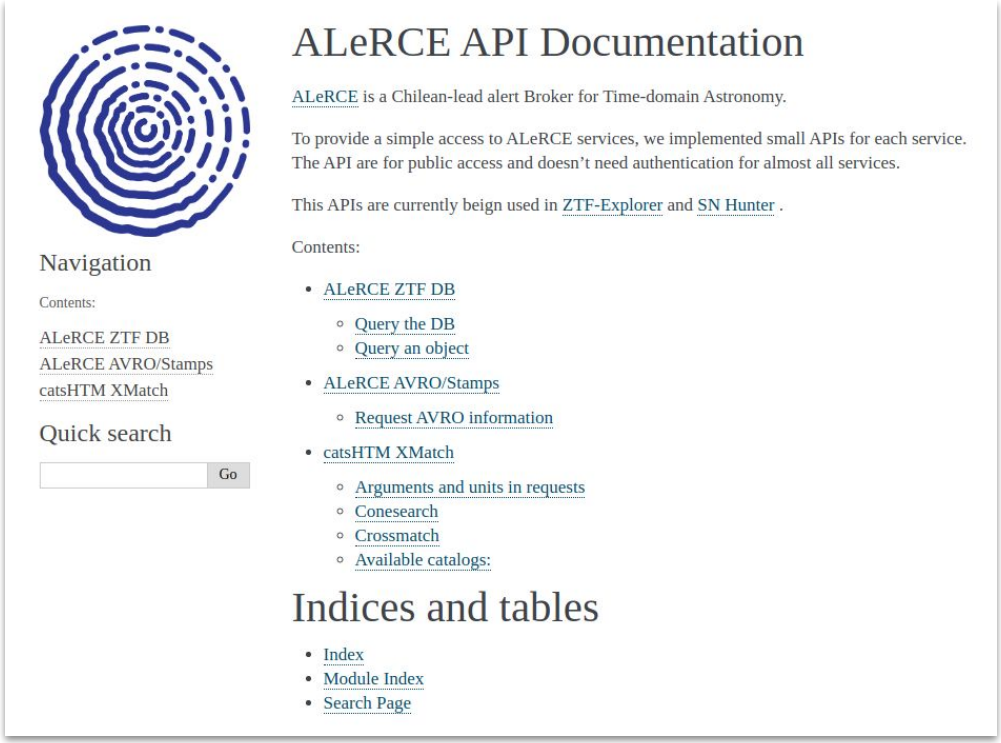
Output stream

(real-time follow-up)

TOMs

API

- **ZTF Database:**
  http://ztf.alerce.online
- **Avro/Stamps:**
  http://avro.alerce.online
- **catsHTM Cone Search & Xmatch:**
  http://catshtm.alerce.online *



ALeRCE API Documentation

ALeRCE is a Chilean-lead alert Broker for Time-domain Astronomy.

To provide a simple access to ALeRCE services, we implemented small APIs for each service. The API are for public access and doesn't need authentication for almost all services.

This APIs are currently beign used in ZTF-Explorer and SN Hunter .

Contents:

- ALeRCE ZTF DB
  - Query the DB
  - Query an object
- ALeRCE AVRO/Stamps
  - Request AVRO information
- catsHTM XMatch
  - Arguments and units in requests
  - Conesearch
  - Crossmatch
  - Available catalogs:

Indices and tables

- Index
- Module Index
- Search Page

Navigation

Contents:

ALeRCE ZTF DB
ALeRCE AVRO/Stamps
catsHTM XMatch

Quick search

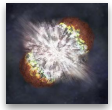
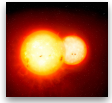
Go

https://alerceapi.readthedocs.io/en/latest/

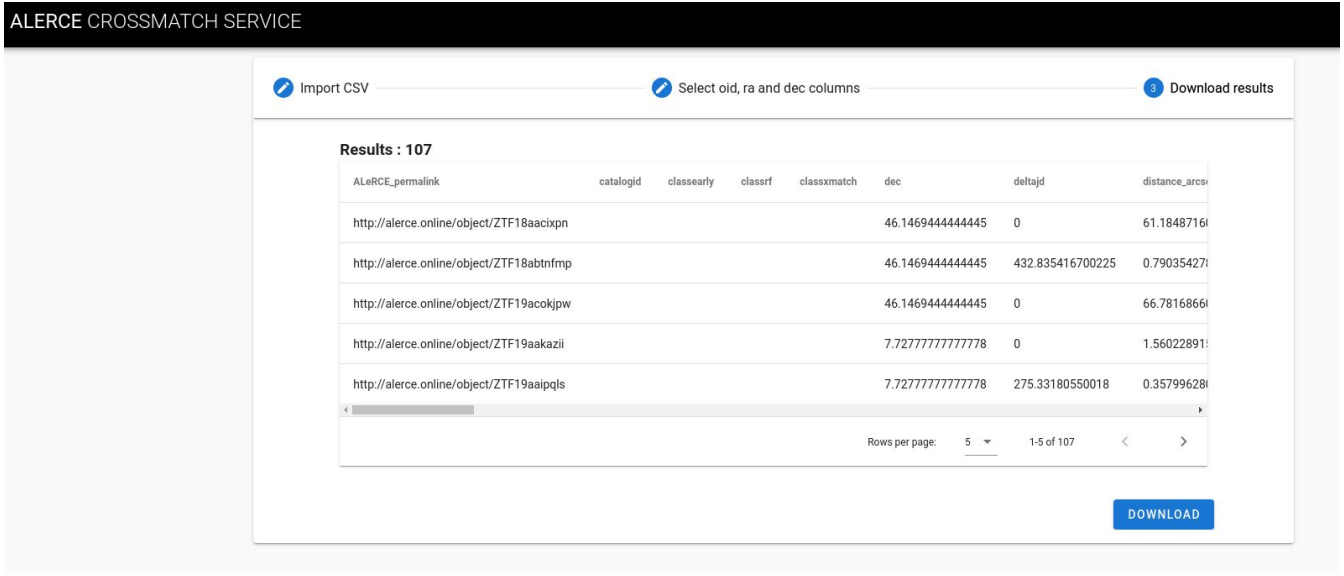
* *Soumagnac & Ofek (2018), (Ofek 2014; ascl.soft 07005)*

Jupyter Notebooks

https://github.com/alercebroker/usecases

-  API
-  Transients
-  Variable Stars
-  Active Galactic Nuclei

Simple xmatch service



http://xmatch.alerce.online/

Summary

- **Future time domain ecosystem**: survey & follow up telescopes, brokers and TOMs, interoperability and diversity for robust and resilient operations
- **Tools:** image processing, machine learning, scheduling, modeling and inference
- Brokers learning from **ZTF** to prepare for **LSST**. Challenges: infrastructure, databases, classification, visualization, transfer learning, forecasting, outlier detection
- **ALeRCE: interdisciplinary** research team born from HiTS survey + young developer team building **distributed** and **scalable** system **(human capital >> infrastructure).**
- Products: living **catalog** of objects, early and late classifiers, annotated & classified **streams**, DB/avro/xmatch **APIs**, **jupyter** notebooks
- Large efforts needed to compile **training sets** to prepare for new paradigm of **machine learning aided astronomy.** HSC SSP will play key role for LSST classification!


Happy 20th anniversary!
Credit:NAOJ