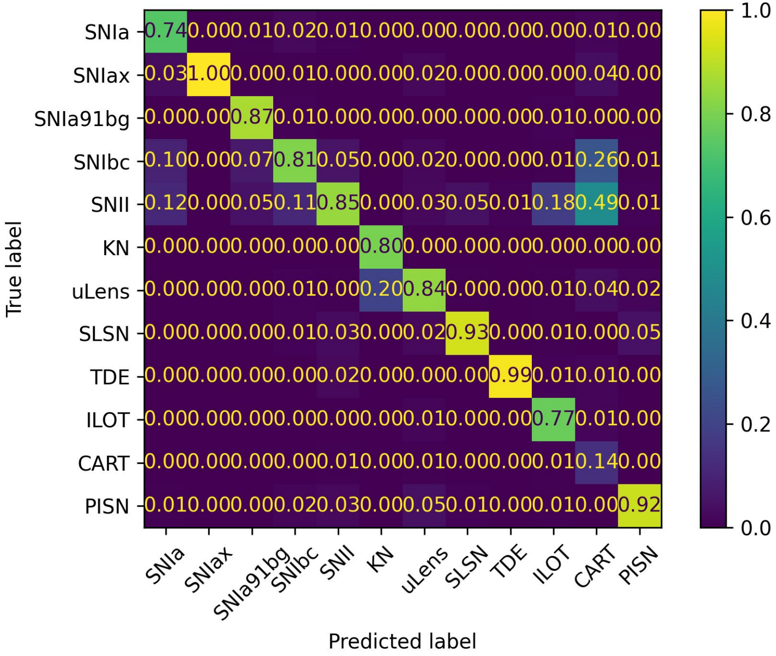
ML in time-domain astrophysics



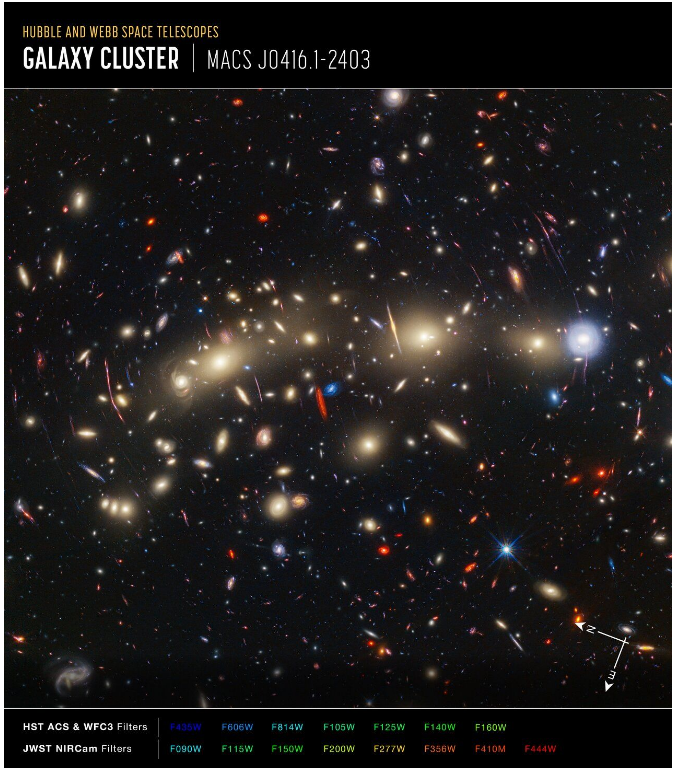
Jakob Nordin

The static Universe

Most astronomers observe the Universe through a range of “telescopes” and create static catalogs and composite images.

These are compared with theoretical ideas to confirm our understanding of e.g. the evolution of galaxies.

This talk is not about that…



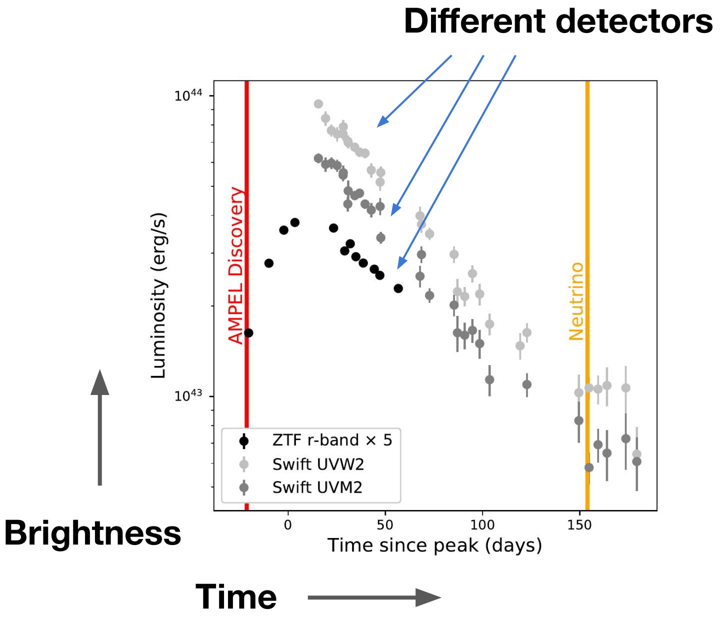
The dynamic Universe

The dynamic Universe

The Universe if full of explosive, short-lived events: supernovae, kilonovae, tidal disruption events, AGN, stellar outbursts …

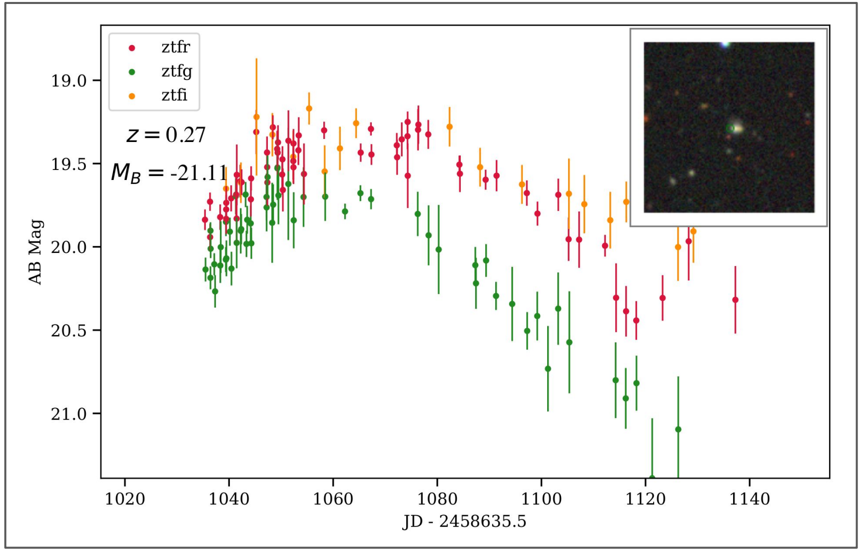
Single, well-defined events!

Unique insights into cosmology, high energy environments and e.g. general relativity.



Cadenced Observations

Multiple telescopes map the visible sky every night, looking for variable sources: transients.



But … only a small fraction can be studied in detail (spectroscopy).

What is this, and what should I do?

High Throughput Time-Domain Astronomy

The Zwicky Transient Facility already saturates what human observers can parse, understand & publish (8000+ SNIa, 2000+ other SN).

ZTF

~ 1 million alerts per night → ~ 10 million alerts per night

~ 1TB / night → ~ 20TB / night

VERA C. RUBIN OBSERVATORY

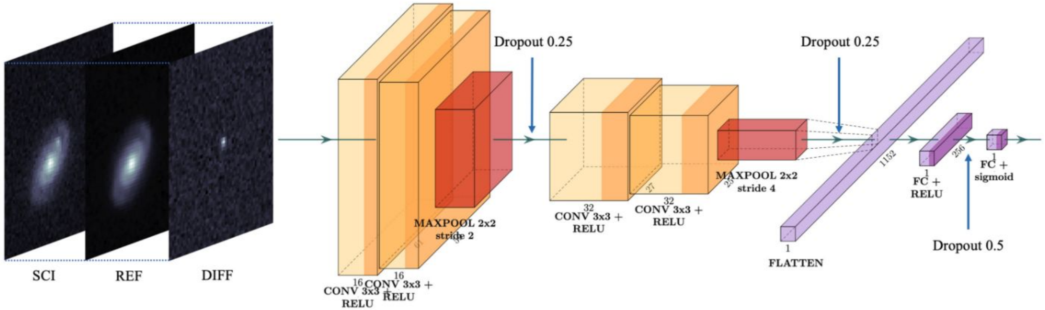
~ Data rate of 2 TB/s → ~ Data rate of 157 TB/s

SKAO

ML case 1: Bogus rejection

Identify image subtraction artifacts: Real / Bogus

E.g. Duev (2019) - Convolutional-neural-network



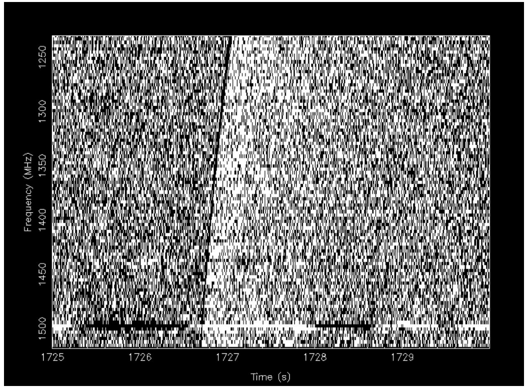
ML case 2: FRB detection

Fast Radio Bursts are ~ms events seen at radio wavelengths.

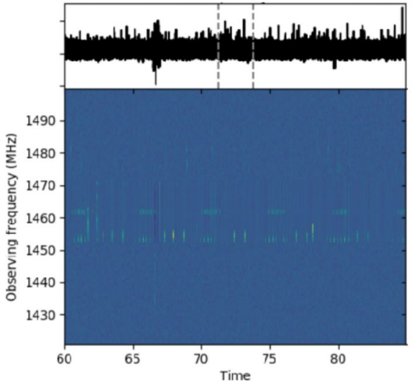
Source unknown!

Most data thrown away…

How to identify in time, and know what we have missed?
(Domain of Ramesh, Andrey & Laura)



Lorimer 2016

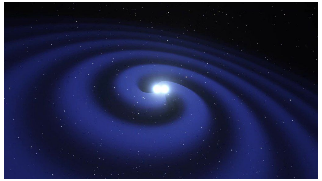


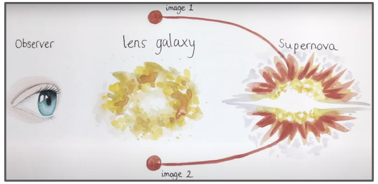
ML case 3: Classification

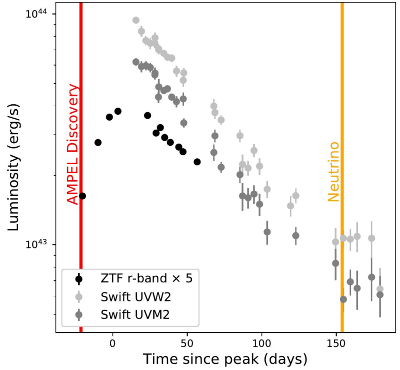
Transients have subtly different evolution with time and wavelength.

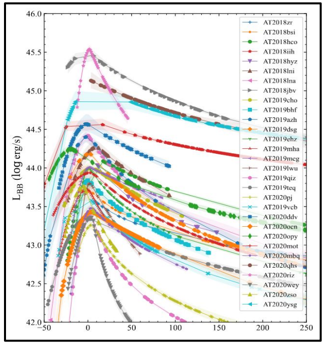
Identify "correct" event for follow-up.

Failure can mean missed chances for rare events, wasted resources and systematically biased cosmological inference.







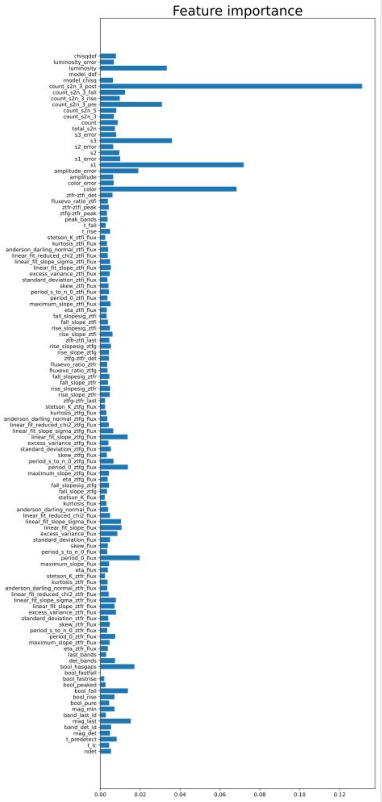


ML case 3: Classification

Feature based classifiers, often based on decision trees, are fast, flexible and work fairly well - especially when limited information is available.

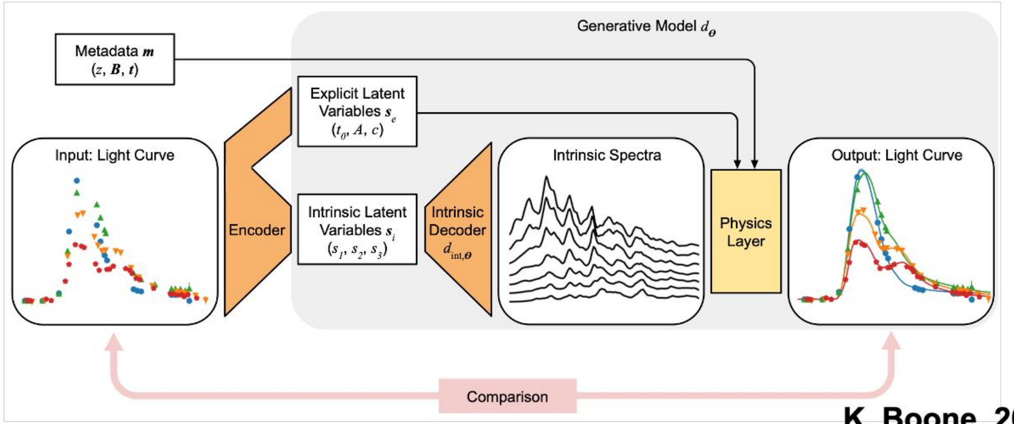
Eg. Miranda (2022)

Name	Type	Description
tPredetect	Time	Time between final good upper limit and first detection.
tLC	Time	Duration (time between first and most recent detection).
ndet	Int	Number of significant detections.
peaked	Bool	Is the lc estimated to be declining?
pure	Bool	No significant nondetections after first detection.
rising	Bool	Max brightness close to the most recent detection.
norise	Bool	No (significant) detected rise.
hasgaps	Bool	The light curve has a gap between detections of at least 30 days.
mPeak	Mag	Magnitude at peak light (any band). Only calculated if peaked==True.
mDet	Mag	Magnitude at first detection (any band).
mLast	Mag	Magnitude of the current (i.e. latest) detection (any band).
cPeak	g-r	Color at peak (if peaked and with g and r).
cDet	g-r	Color at detection (if with g+r).
cLast	g-r	Color at last detection (if with g+r).
slopeRise g,r	Mag/time	g or r mag slope between detection and peak (None if norise).
slopeDecline g,r	Mag/time	g/r magnitude slope between peak and last detection (None unless peaked).

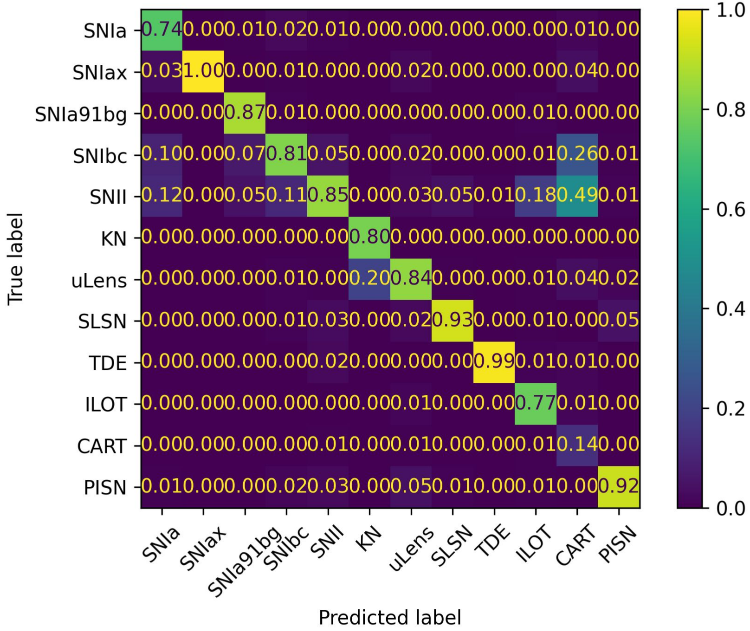


ML case 3: Classification

A range of deep learning based models have been presented. Works well - on simulated data.



K. Boone, 2021

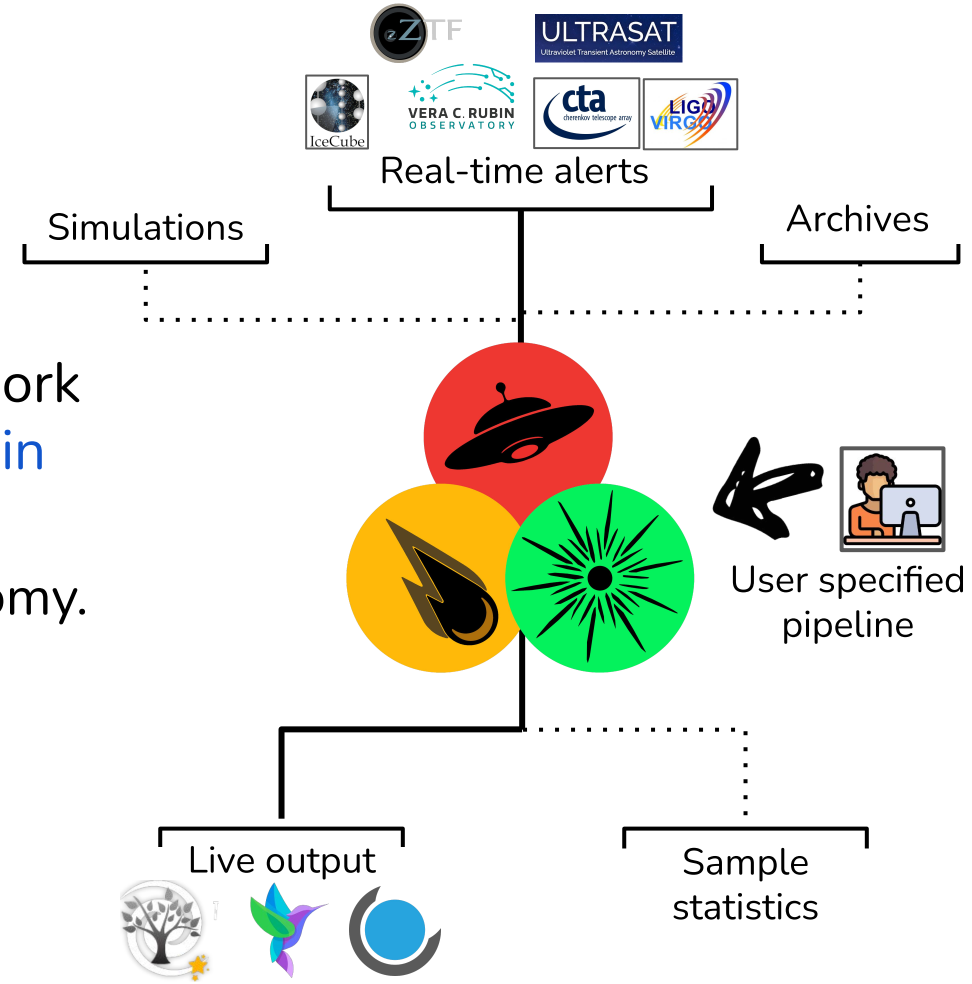


AMPEL

Analysis and workflow framework for high throughput time-domain astronomy.

Realizes code-to-data in astronomy.

https://github.com/AmpelAstro



Current status

ML techniques are already accepted as critical components for e.g. noise detection.

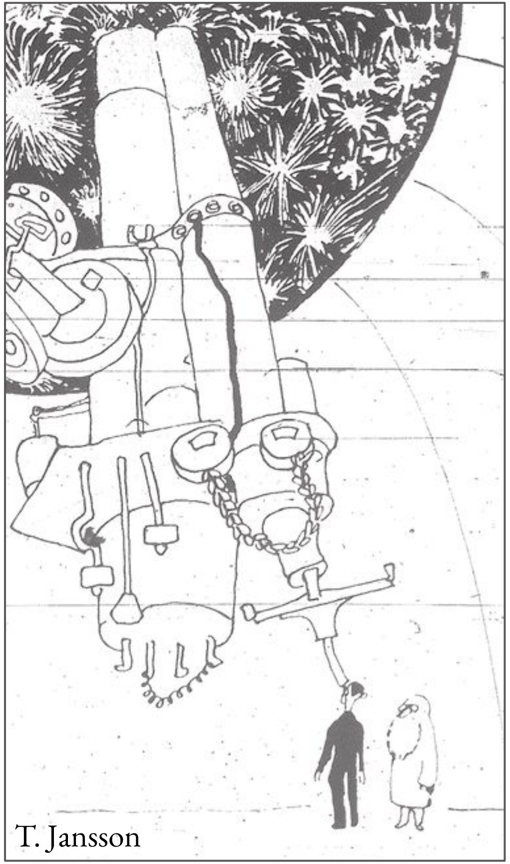
ML methods will be necessary for future high throughput observatories.
Increasing detector sensitivity means

Challenges:

- Small training samples (rare events).
- Maximal bias (training samples are bright, target samples faint).
- Provenance.
- "The astronomer"

Next step(s):

- Foundation models / transfer learning not widely used.
- More specialized models for single use cases.



T. Jansson