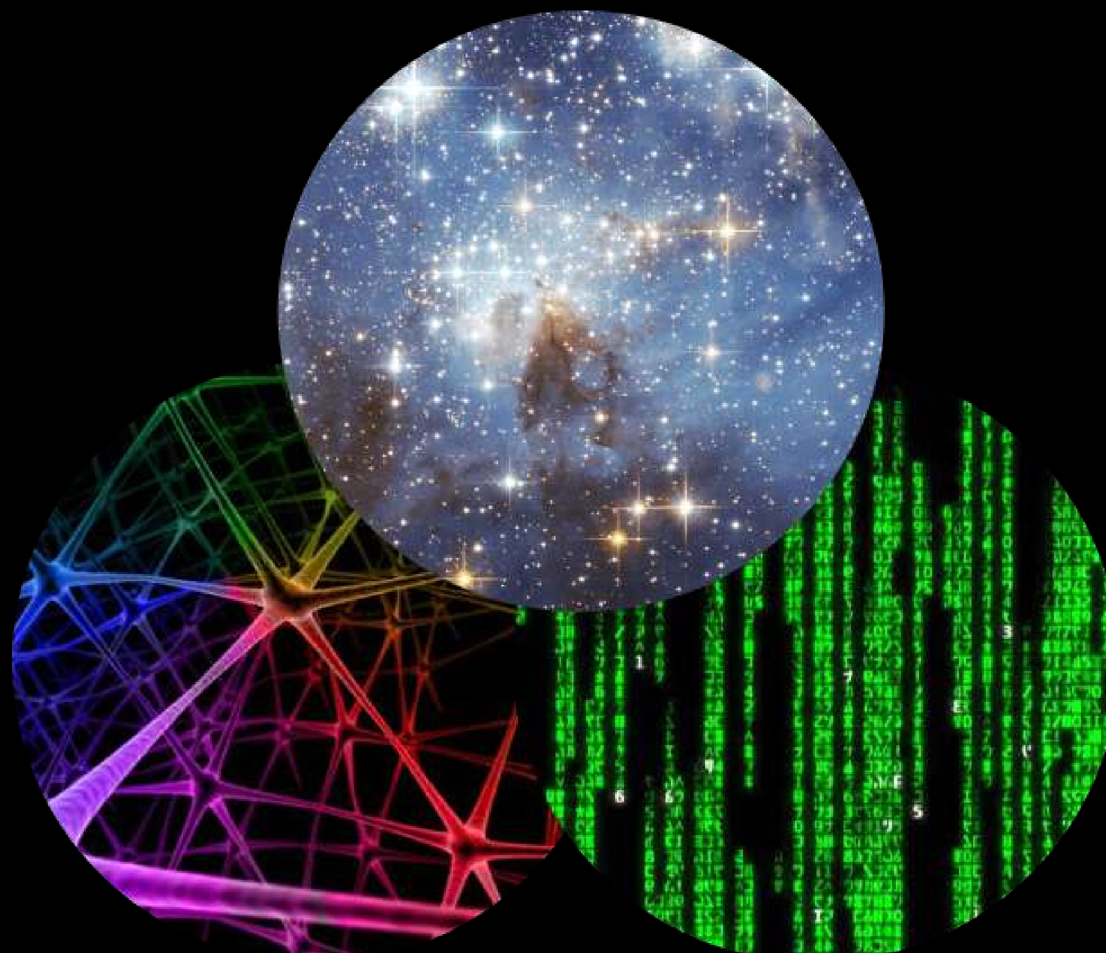
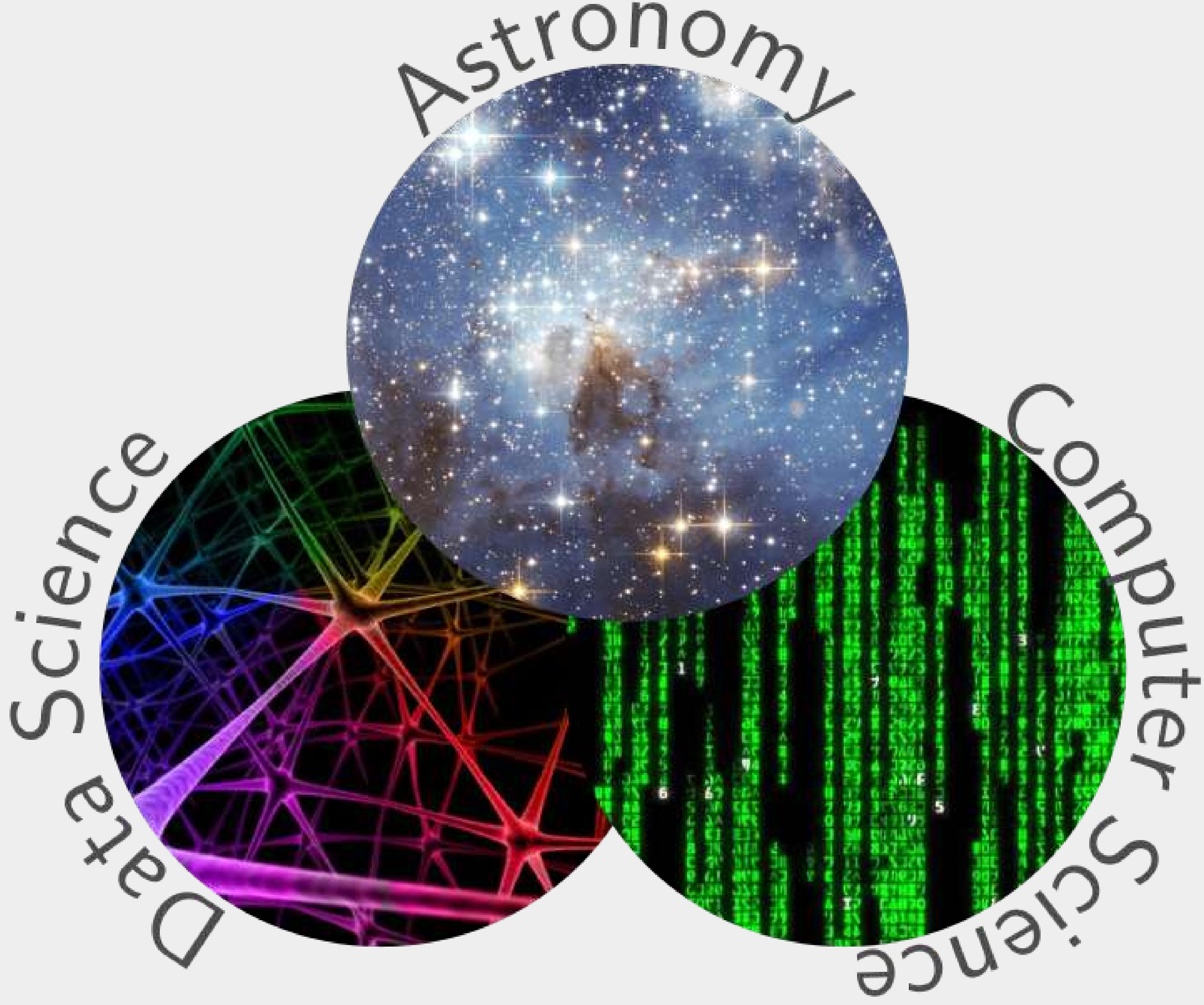
Machine Intelligence in the Era of Survey Astronomy

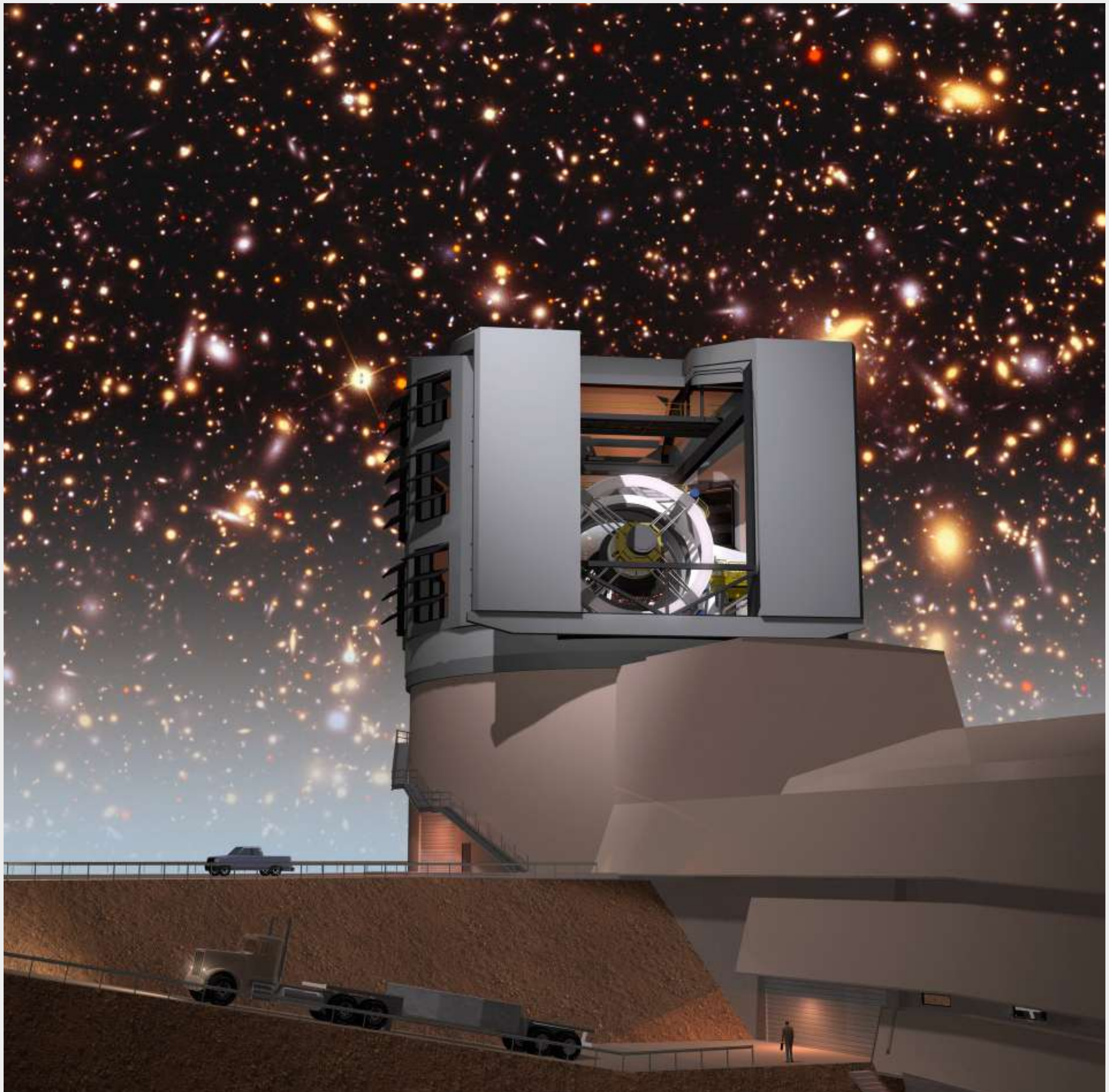


Michelle Lochner

The Era of Survey Astronomy



The Large Synoptic Survey Telescope



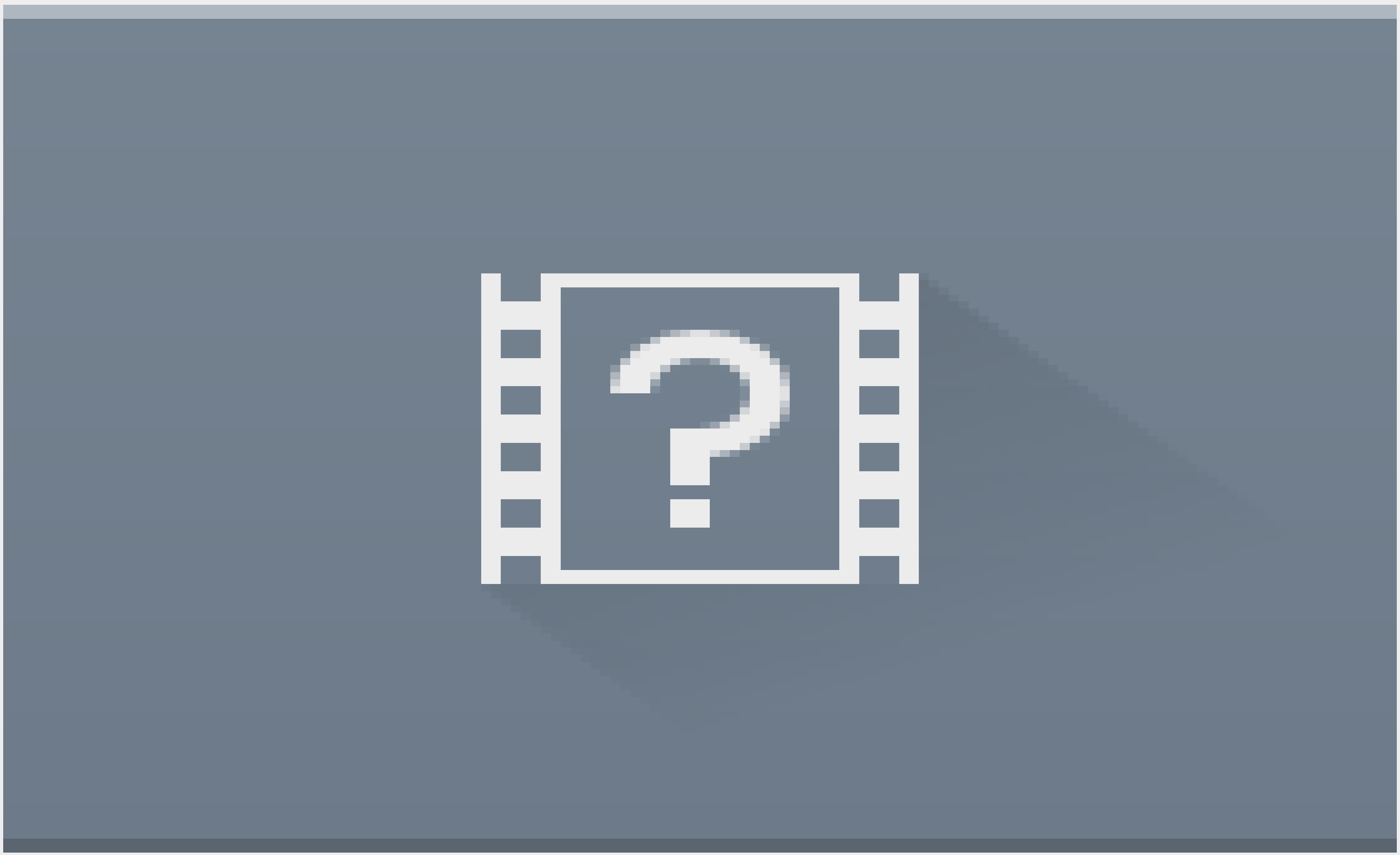
The 10-year LSST survey will be the widest, fastest, deepest optical survey ever done.

Science ranges from asteroids to dark energy

Will detect ∼10 million transient events per night, thousands of which will be new astrophysical objects

LSST

The Large Synoptic Survey Telescope



MeerKAT and the SKA

MeerKAT (64 dishes) under construction in the Karoo

First light ~2019

Huge range of science from transients to deep galaxy surveys

SKA phase 1 (~200 dishes), first light somewhere in the 2020's

SKA SA

MeerKAT and the SKA

T. Abbott

Great Opportunities = Great Challenges

- LSST will be photometric only, very little spectroscopic confirmation of object types!

Great Opportunities = Great Challenges

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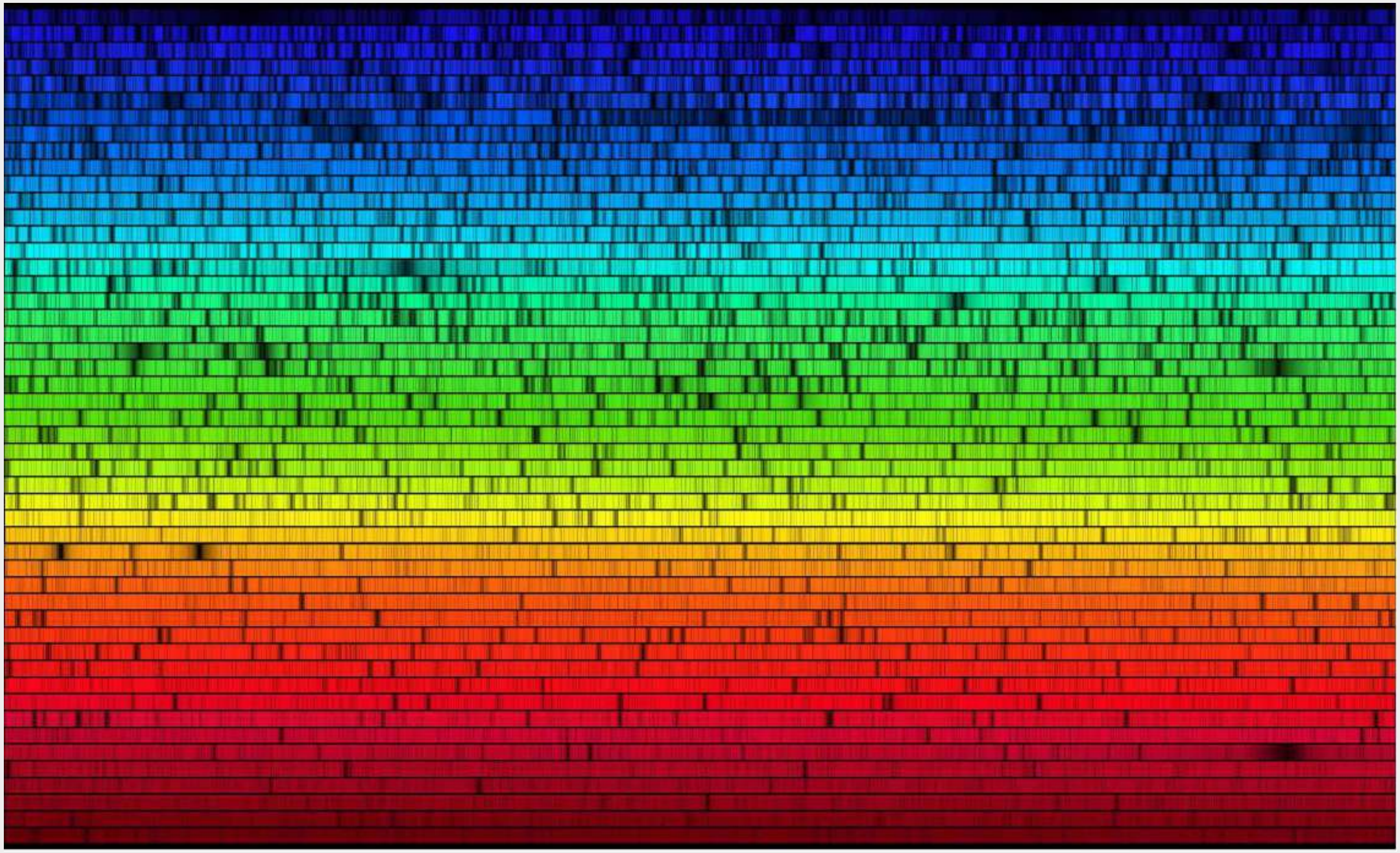

Great Opportunities = Great Challenges

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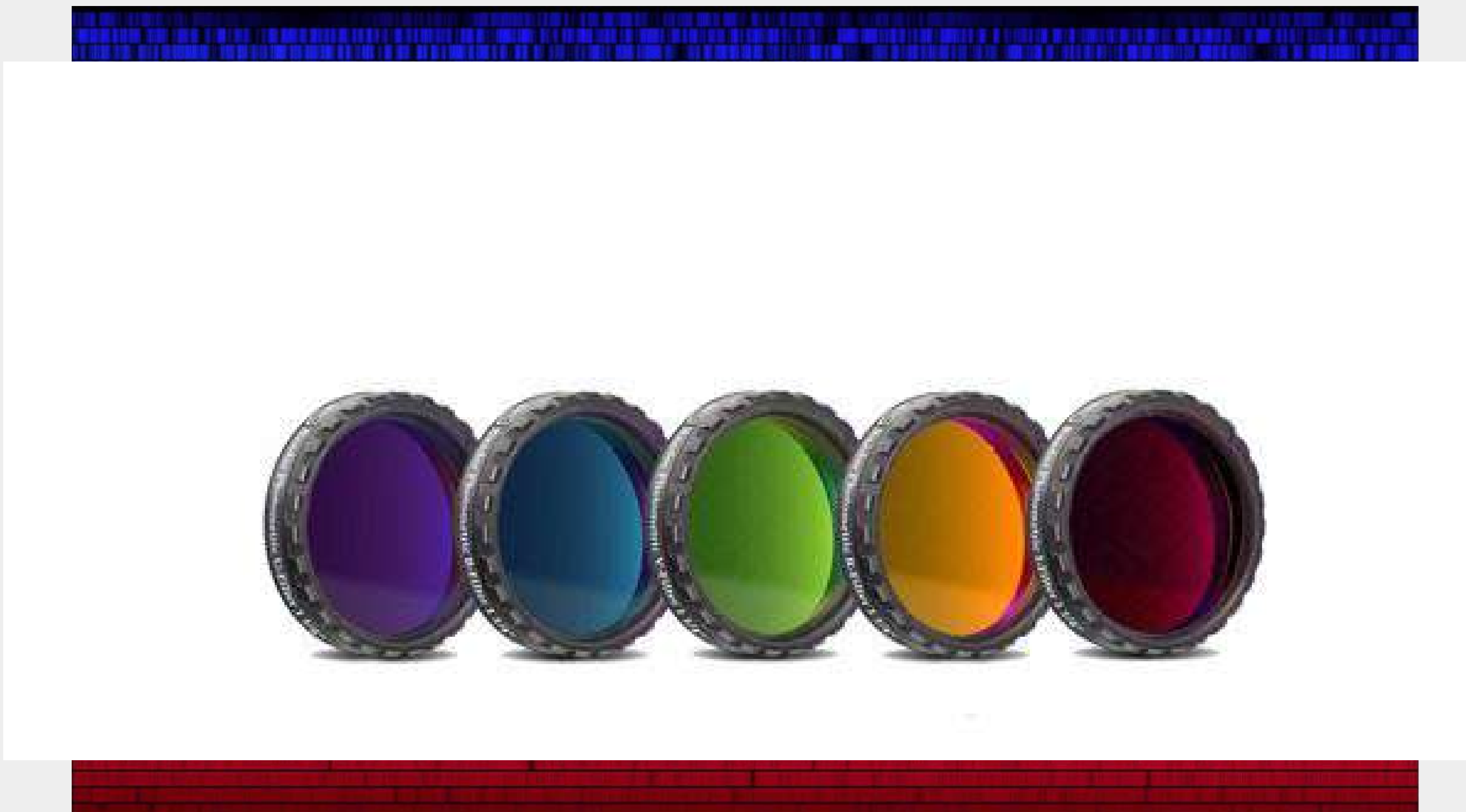


Great Opportunities = Great Challenges

- LSST will be photometric only, very little spectroscopic confirmation of object types!
- 10 million alerts per night to sift through

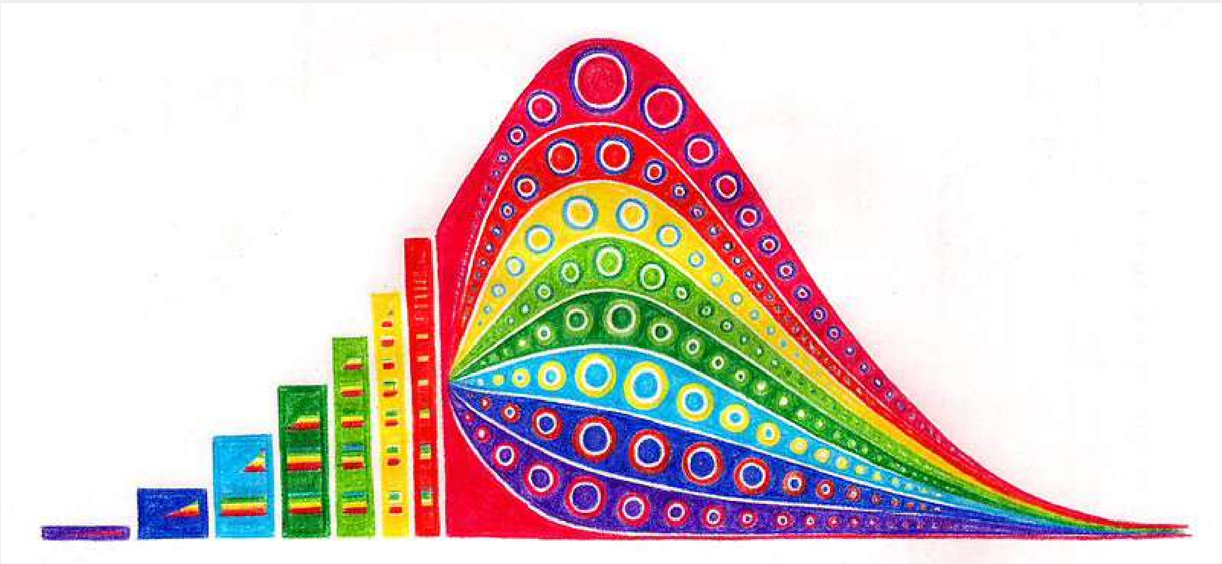
Great Opportunities = Great Challenges

- LSST will be photometric only, very little spectroscopic confirmation of object types!
- 10 million alerts per night to sift through
- SKA data rates will be equally nightmarish

Great Opportunities = Great Challenges

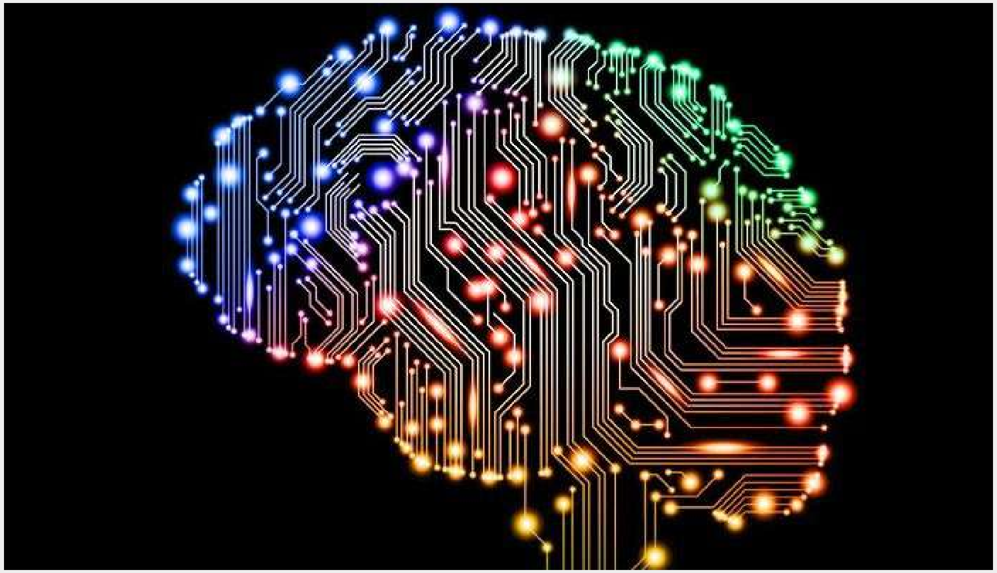
If you converted **one day** of SKA data to an audio file it would take two million years to play back

Two Pillars of Data Science



Statistics

Machine Learning

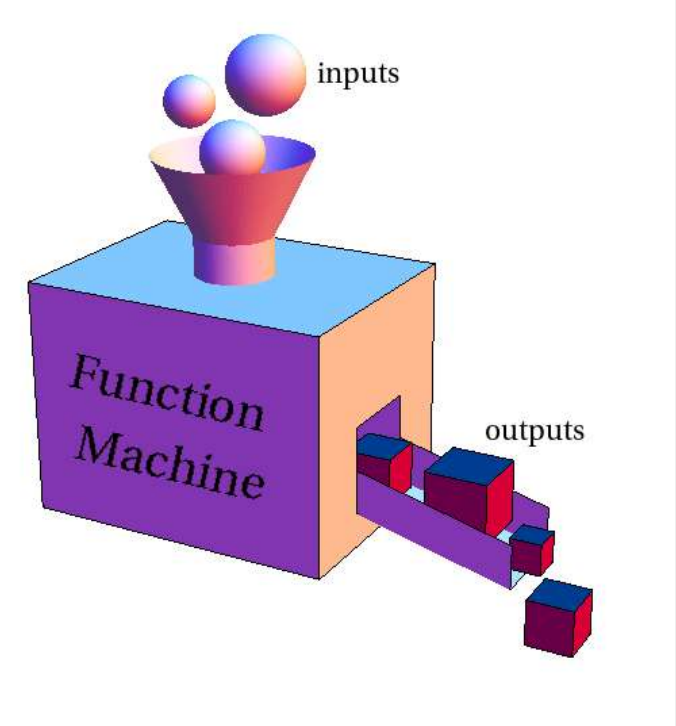


What is machine learning?

What is machine learning?

Essentially, automatically building a (usually highly nonlinear) model that maps a given input to output.

Different algorithms use different prescriptions for building the model



When to use machine learning

For data exploration (unsupervised learning)

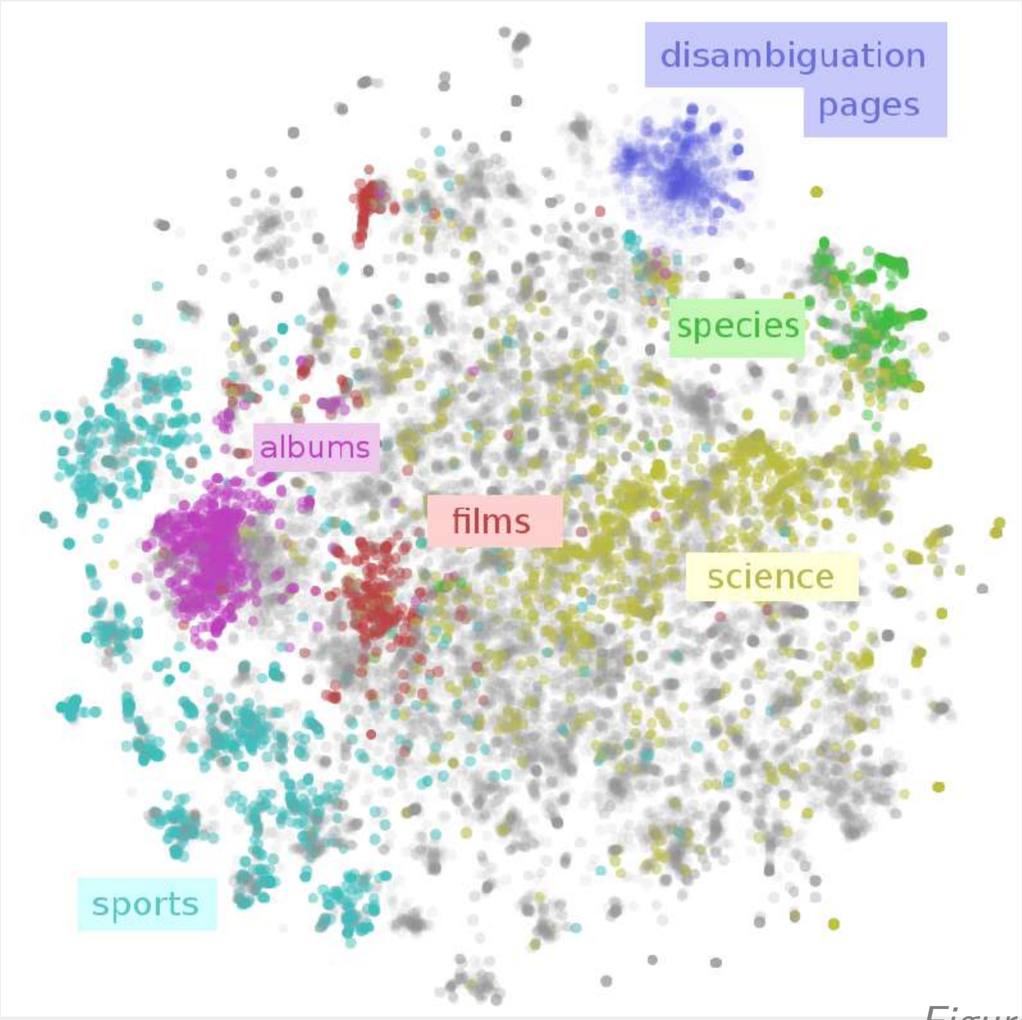
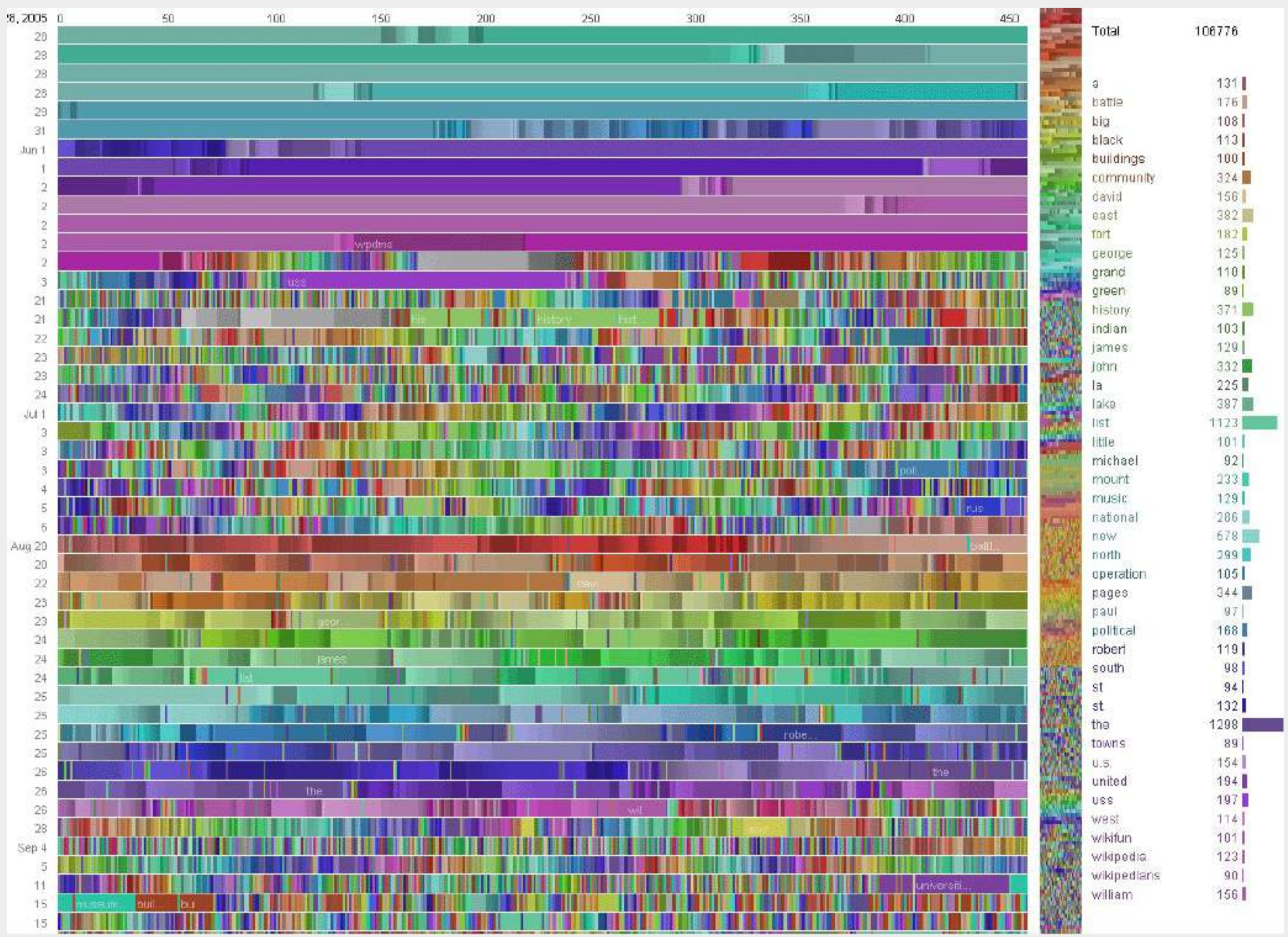


Figure: http://colah.github.io/

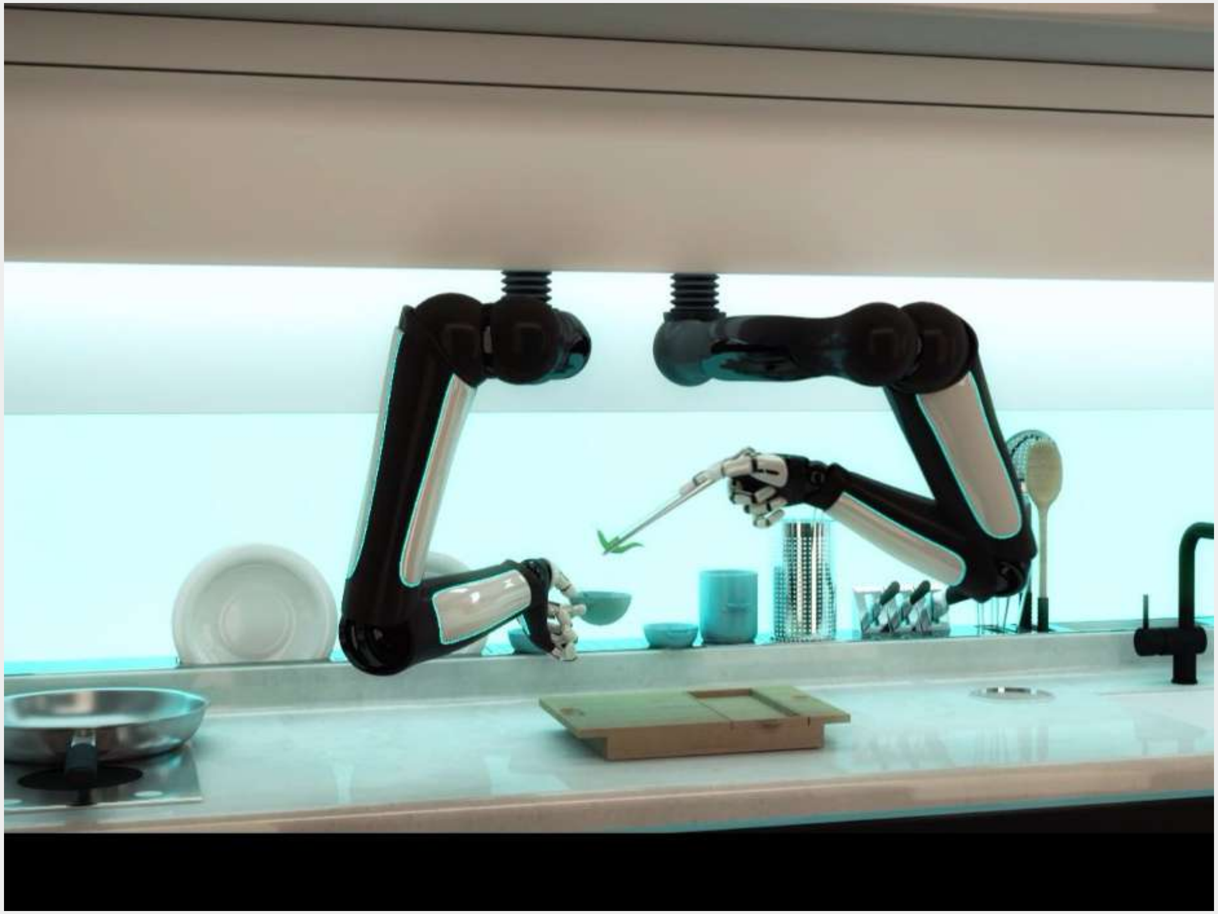
When to use machine learning

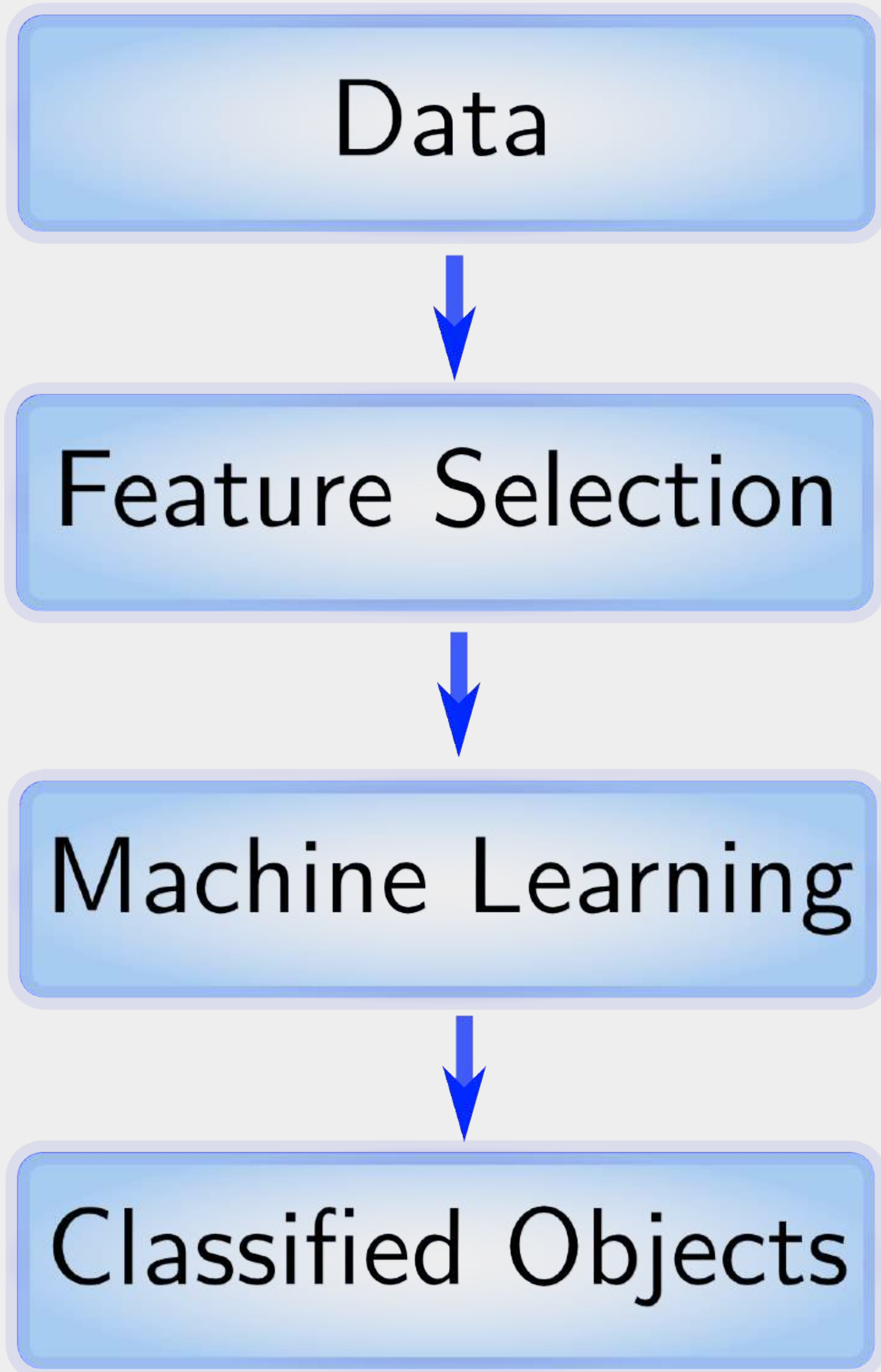
When your data are too complex for traditional model development and fitting with statistics



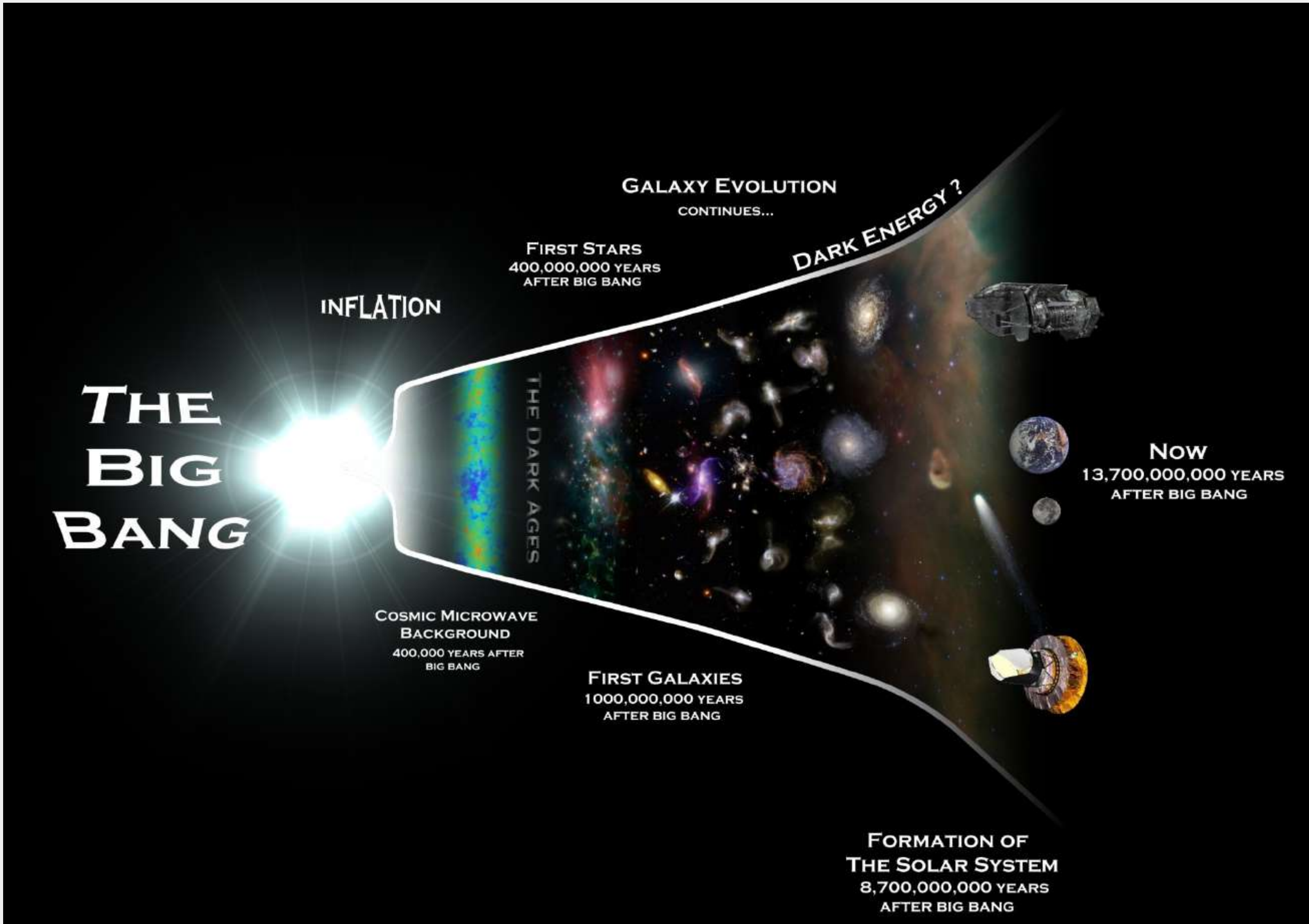
When to use machine learning

When you are too busy/ too lazy to perform a task repeatedly




Data
Feature Selection
Machine Learning
Classified Objects

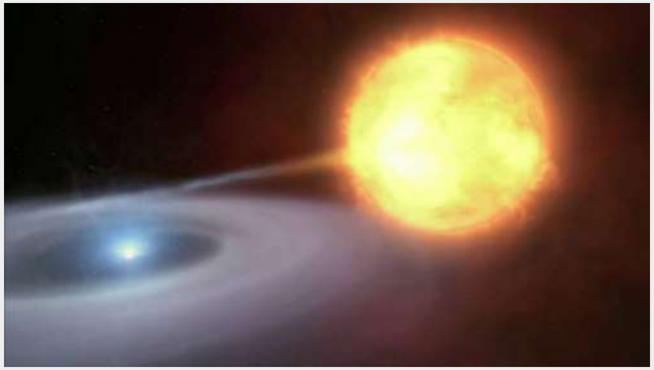
Cosmology



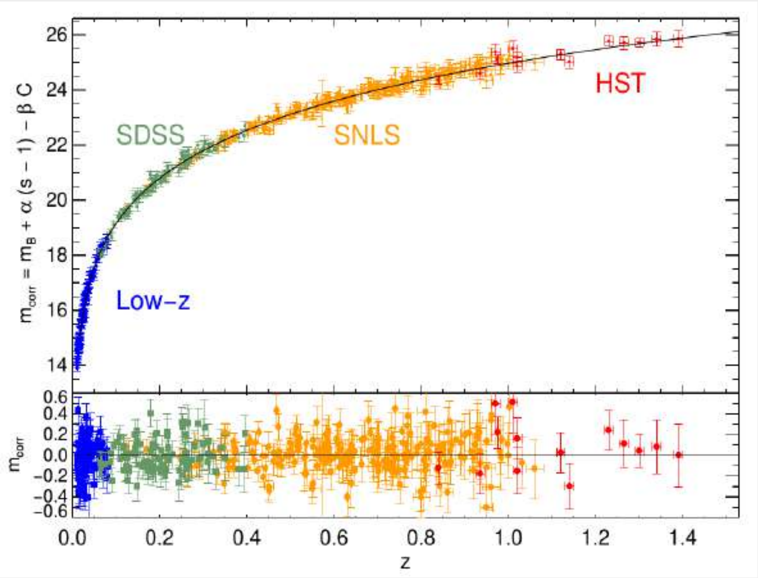
THE BIG BANG
INFLATION
FIRST STARS
400,000,000 YEARS
AFTER BIG BANG
GALAXY EVOLUTION
CONTINUES...
DARK ENERGY ?
THE DARK AGES
COSMIC MICROWAVE
BACKGROUND
400,000 YEARS AFTER
BIG BANG
FIRST GALAXIES
1000,000,000 YEARS
AFTER BIG BANG
NOW
13,700,000,000 YEARS
AFTER BIG BANG
FORMATION OF
THE SOLAR SYSTEM
8,700,000,000 YEARS
AFTER BIG BANG

LSST Problem 1 – Supernova Types

Type Ia supernovae



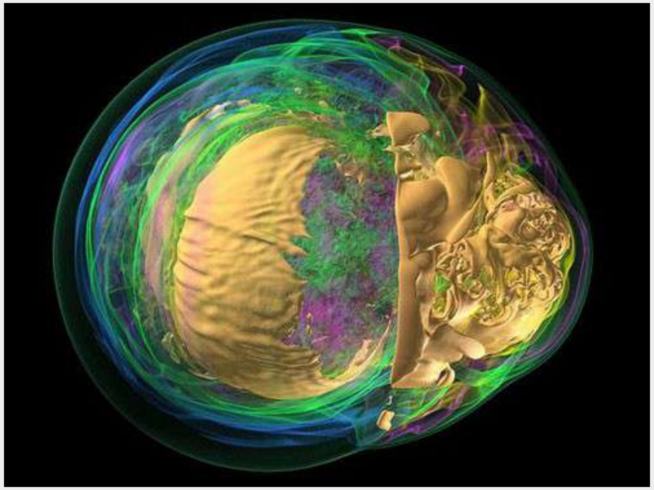
Cosmology



Conley et al. 2011

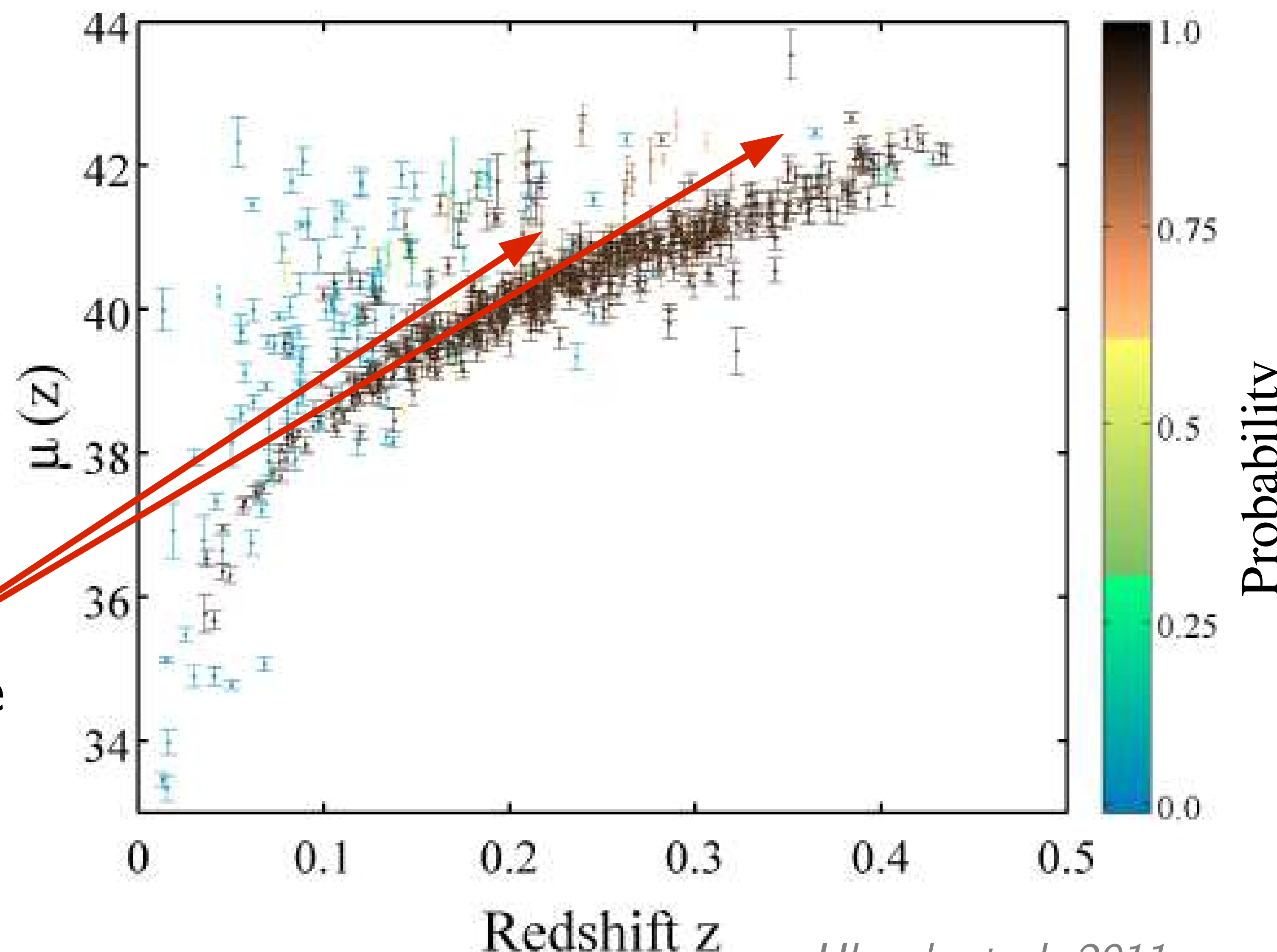
Core collapse supernovae

Supernova astrophysics



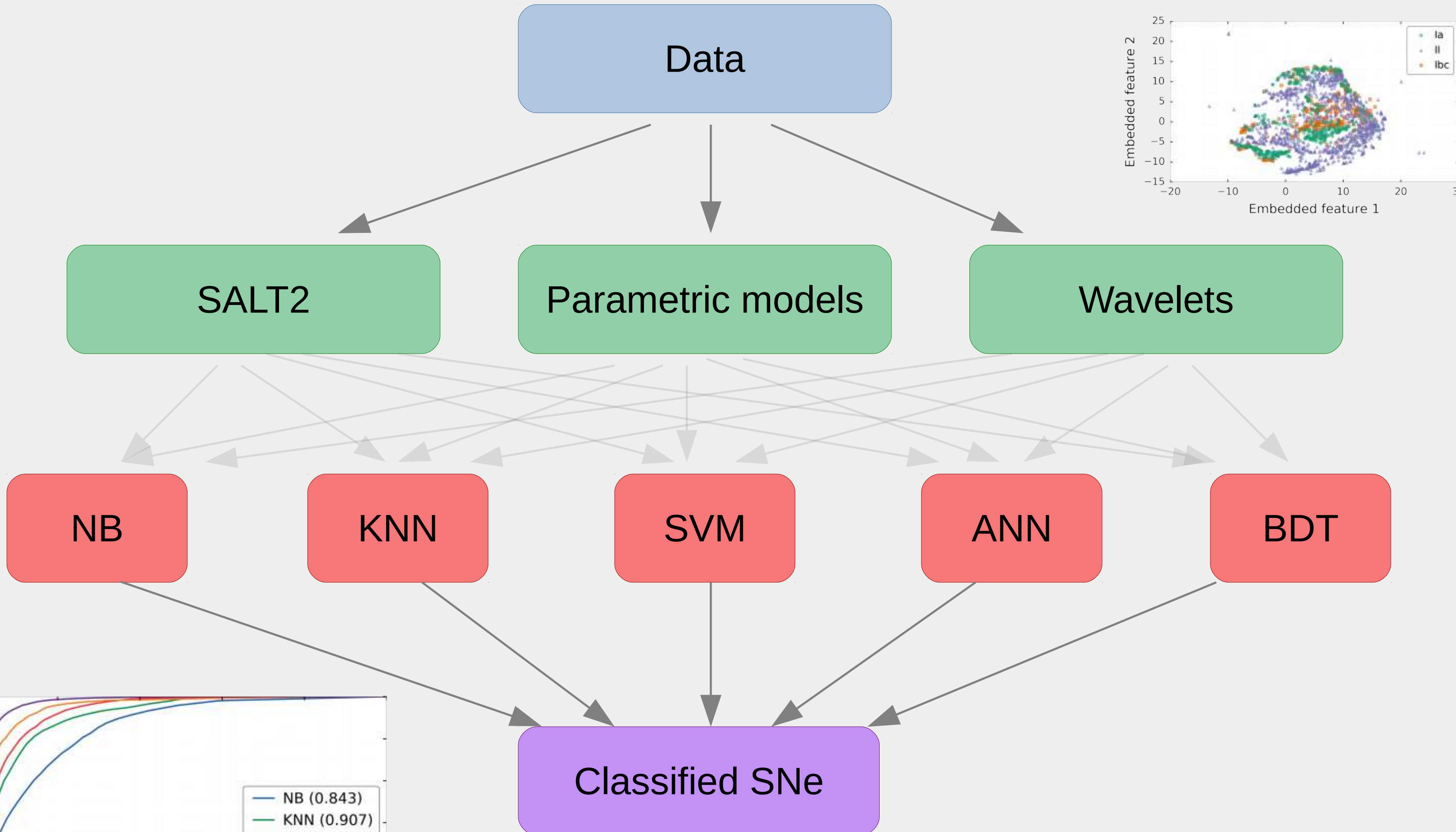
Non-Ia contamination is bad

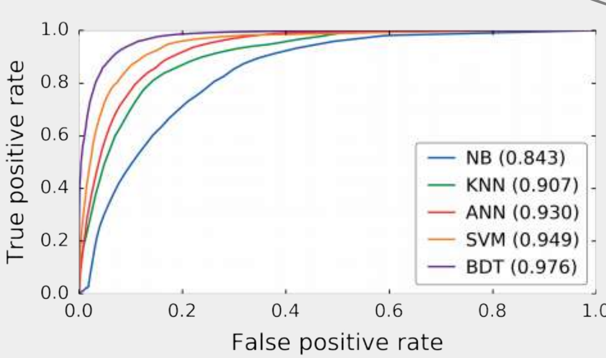
Non-Ia's tend to lie above the true cosmology line and bias the best fit.



Hlozek et al. 2011

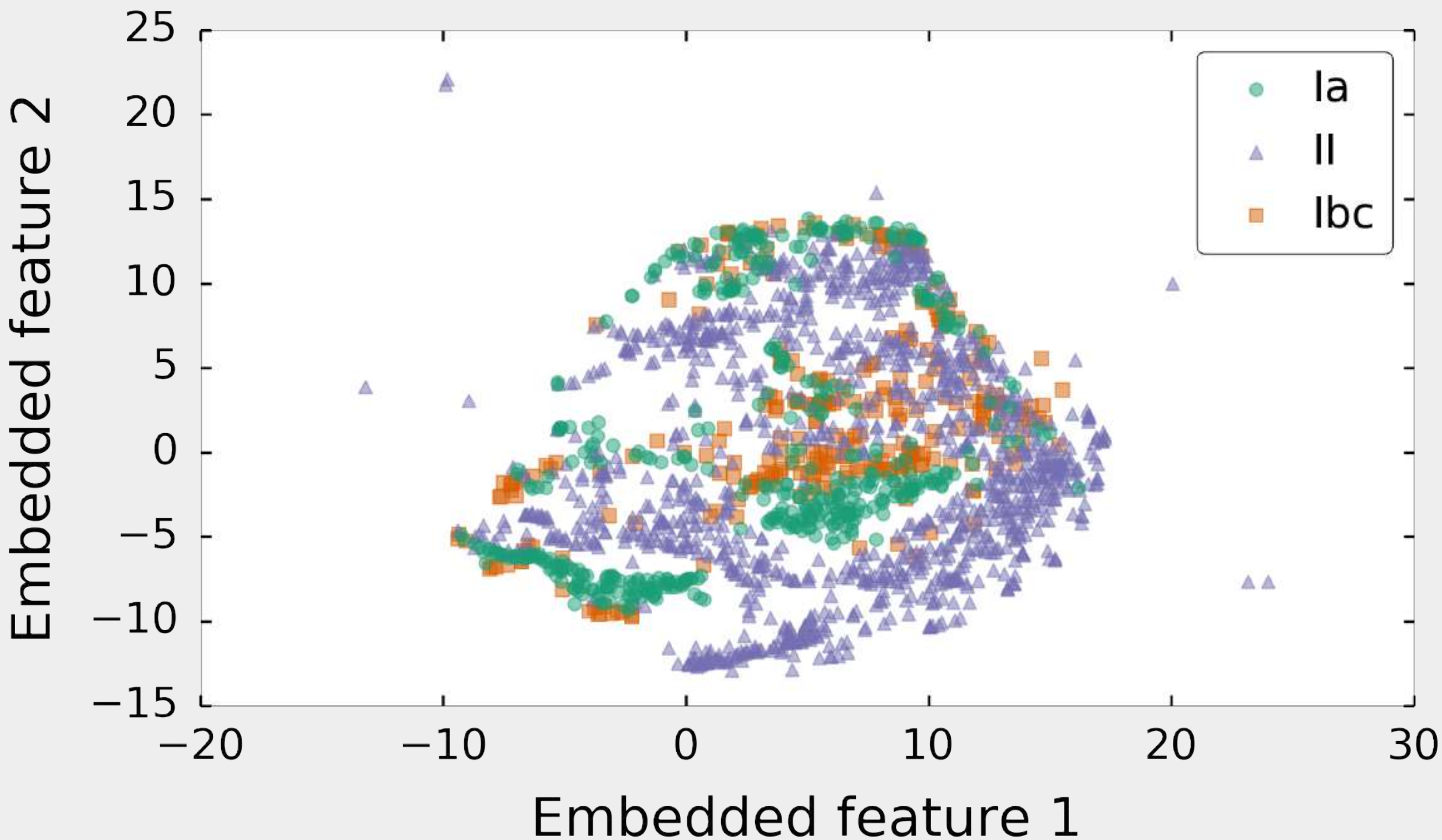
Solution – Machine Learning





Lochner et al. 2016

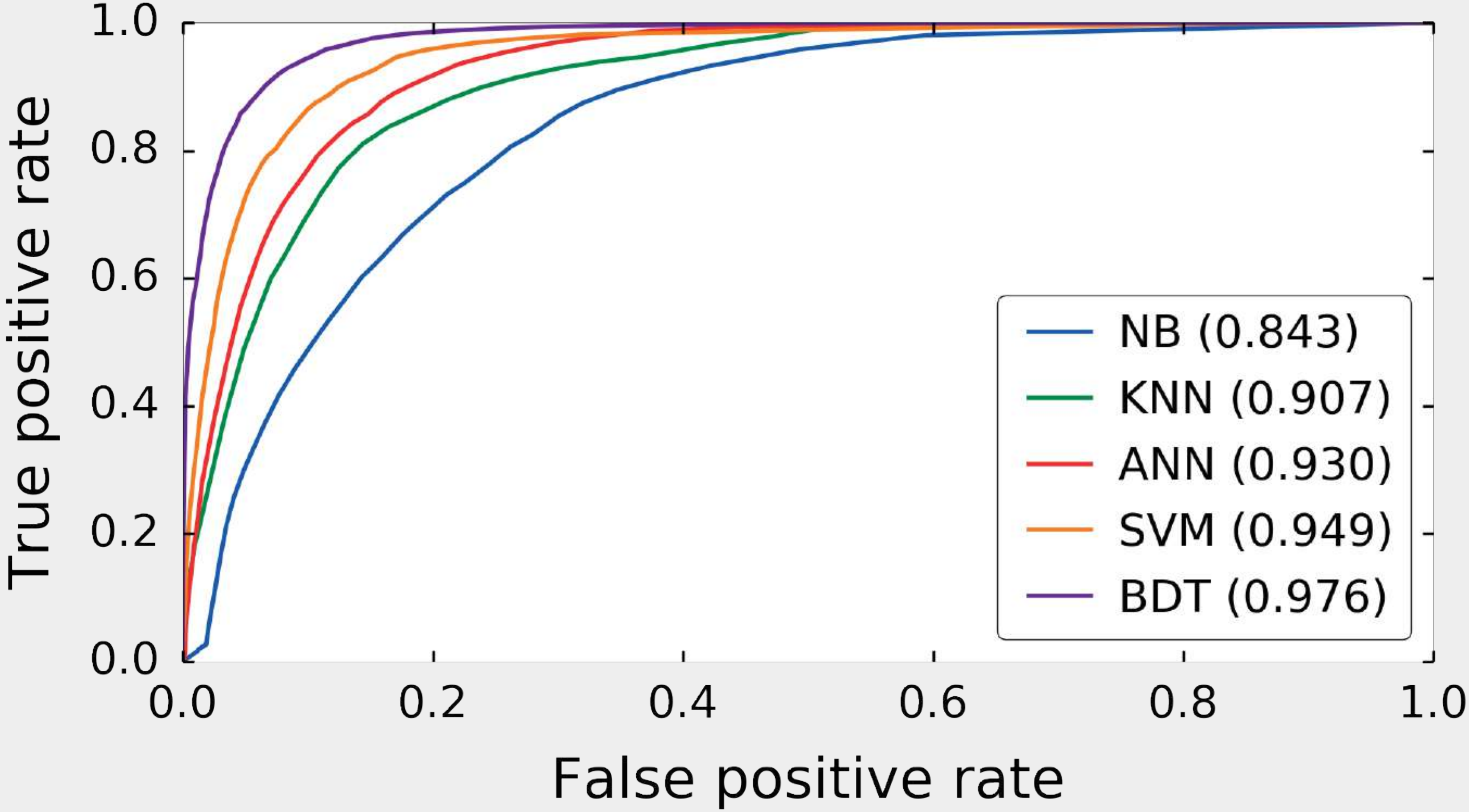
Results



Machine learning can classify different types of supernovae with high accuracy

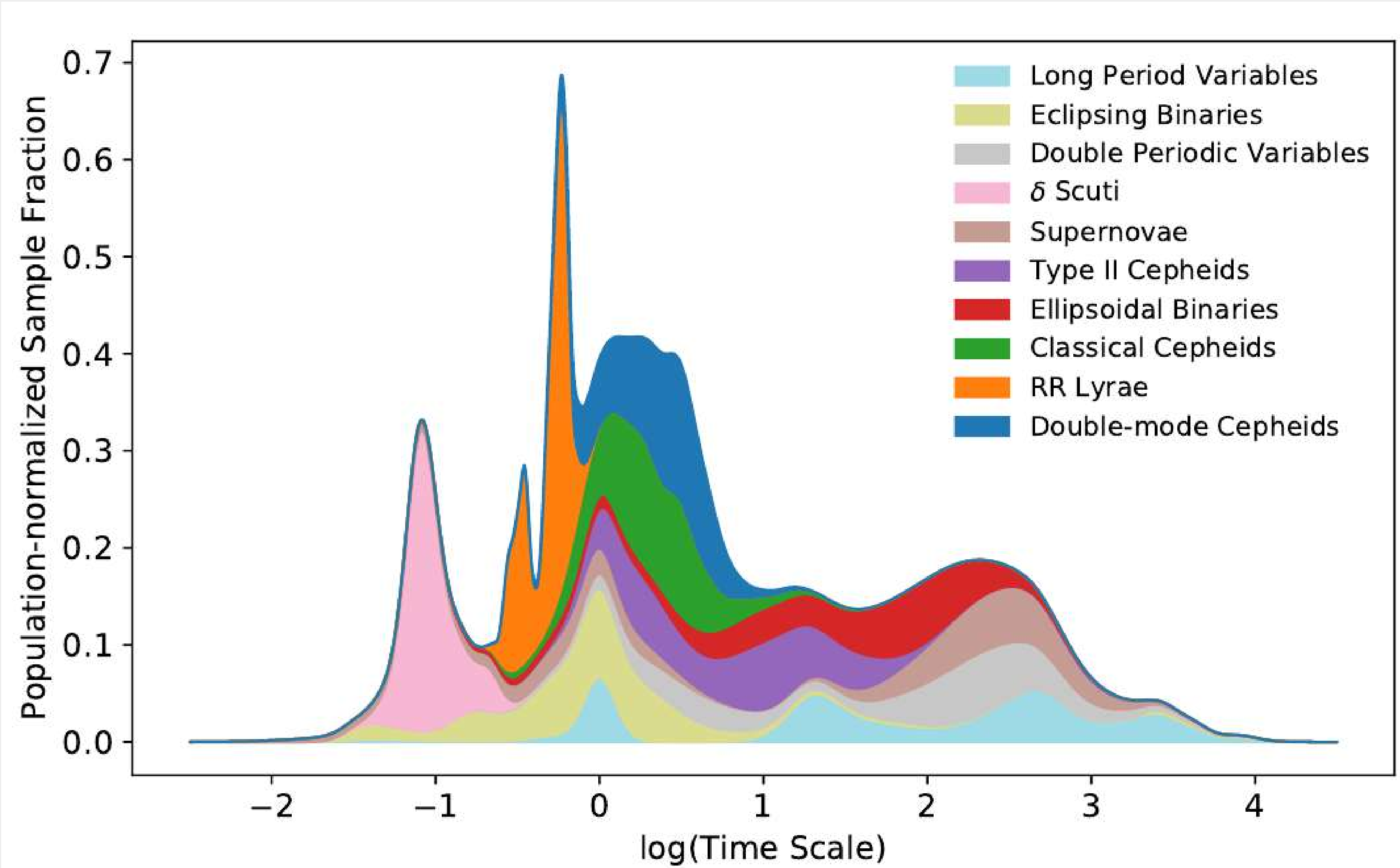
Lochner et al. 2016

Results



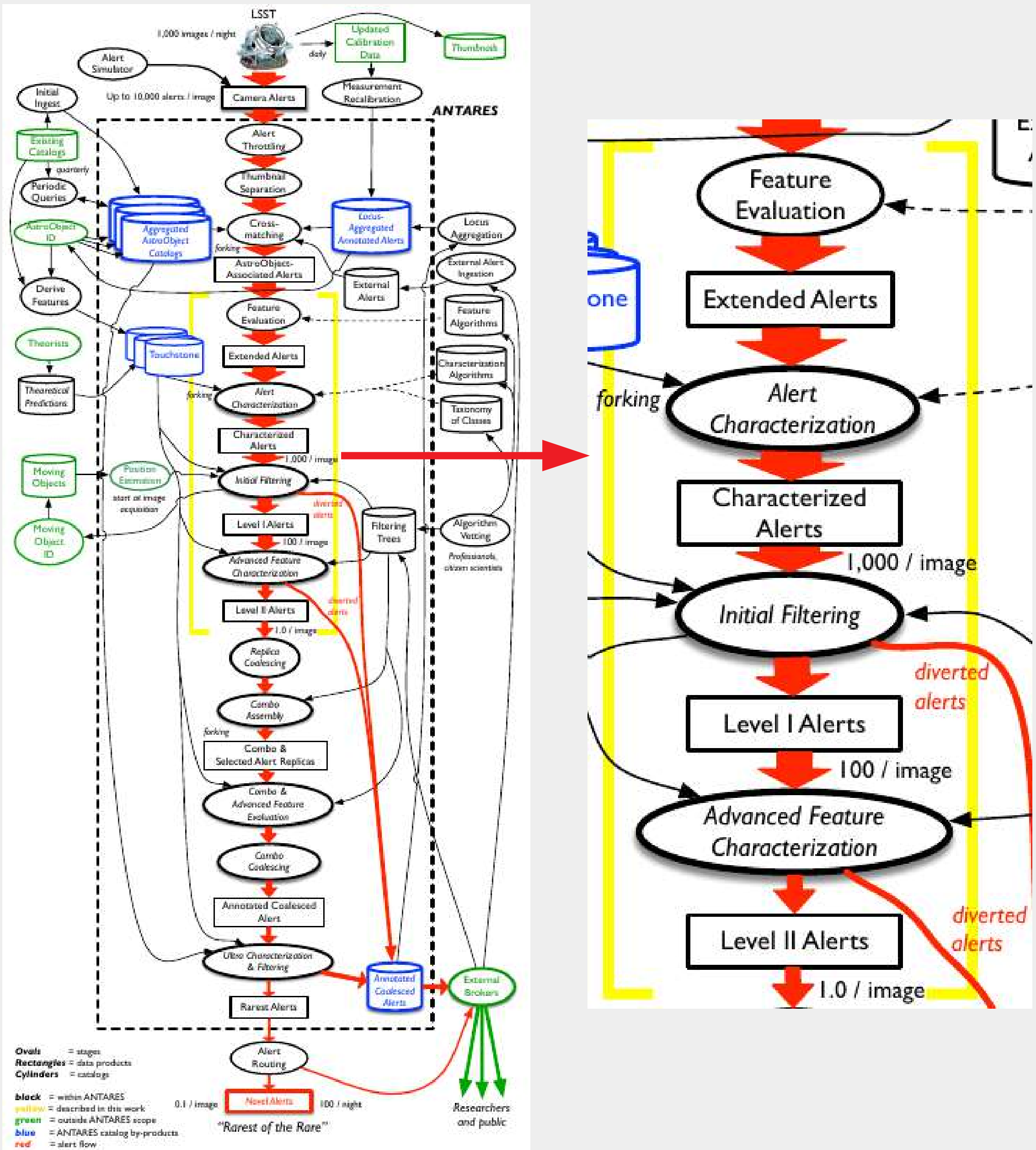
Lochner et al. 2016

LSST Problem 2 – 10 Million Transients



Narayan et al. 2018

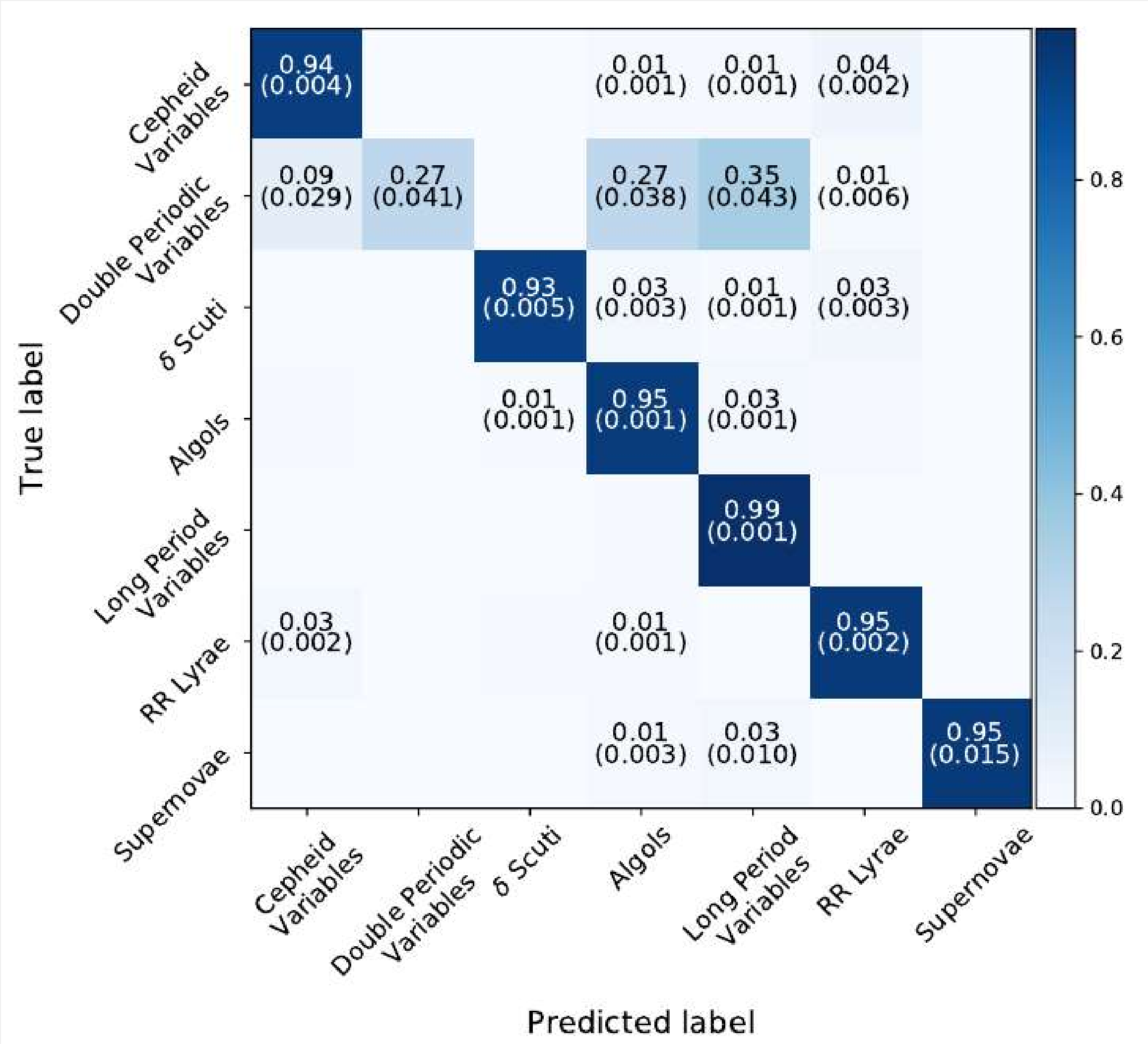
Solution – Machine Learning



ANTARES is a transient broker and our algorithms form a central part of its classification pipeline

Narayan et al. 2018

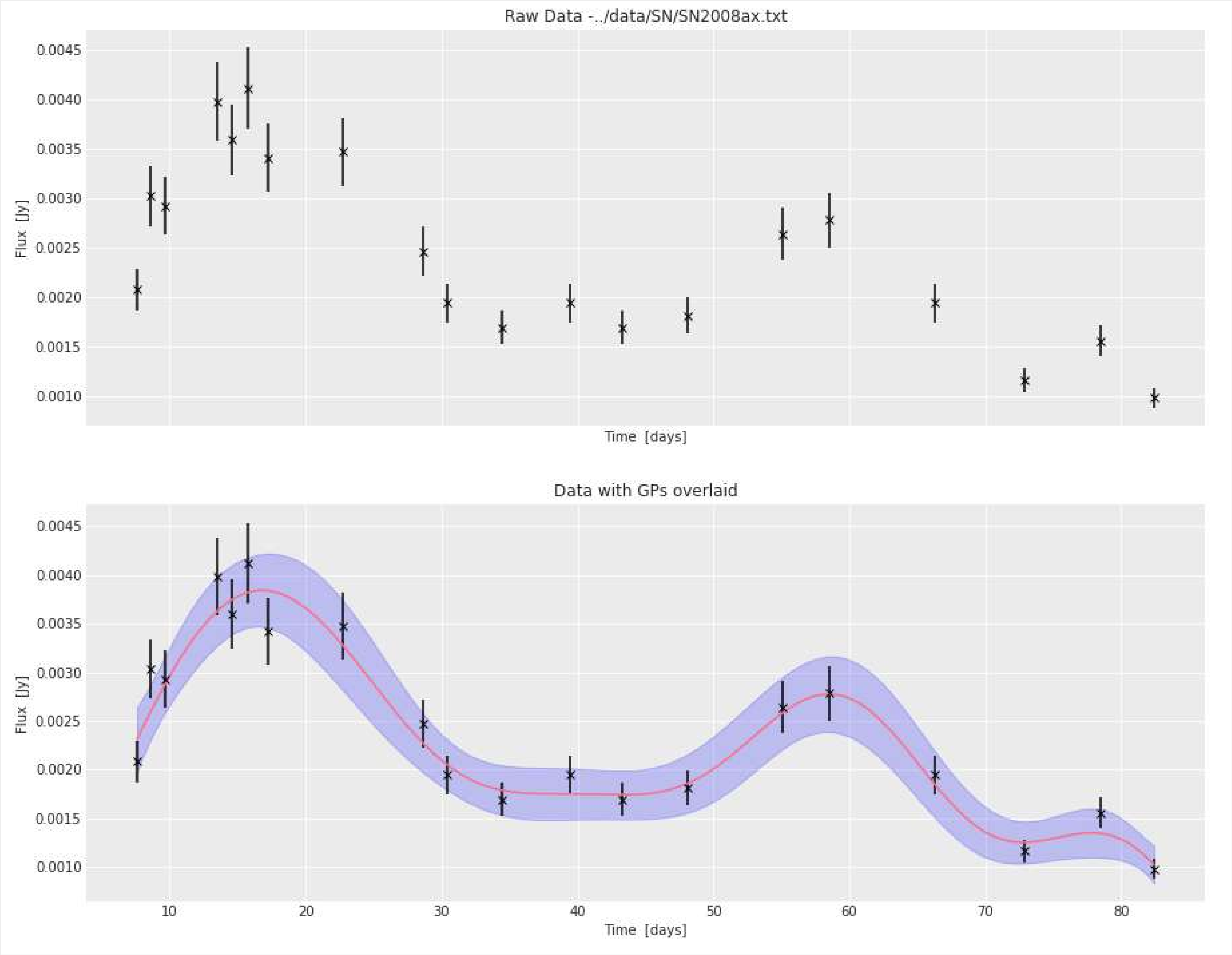
Results



Once again, ML does a good job separating out different types of objects

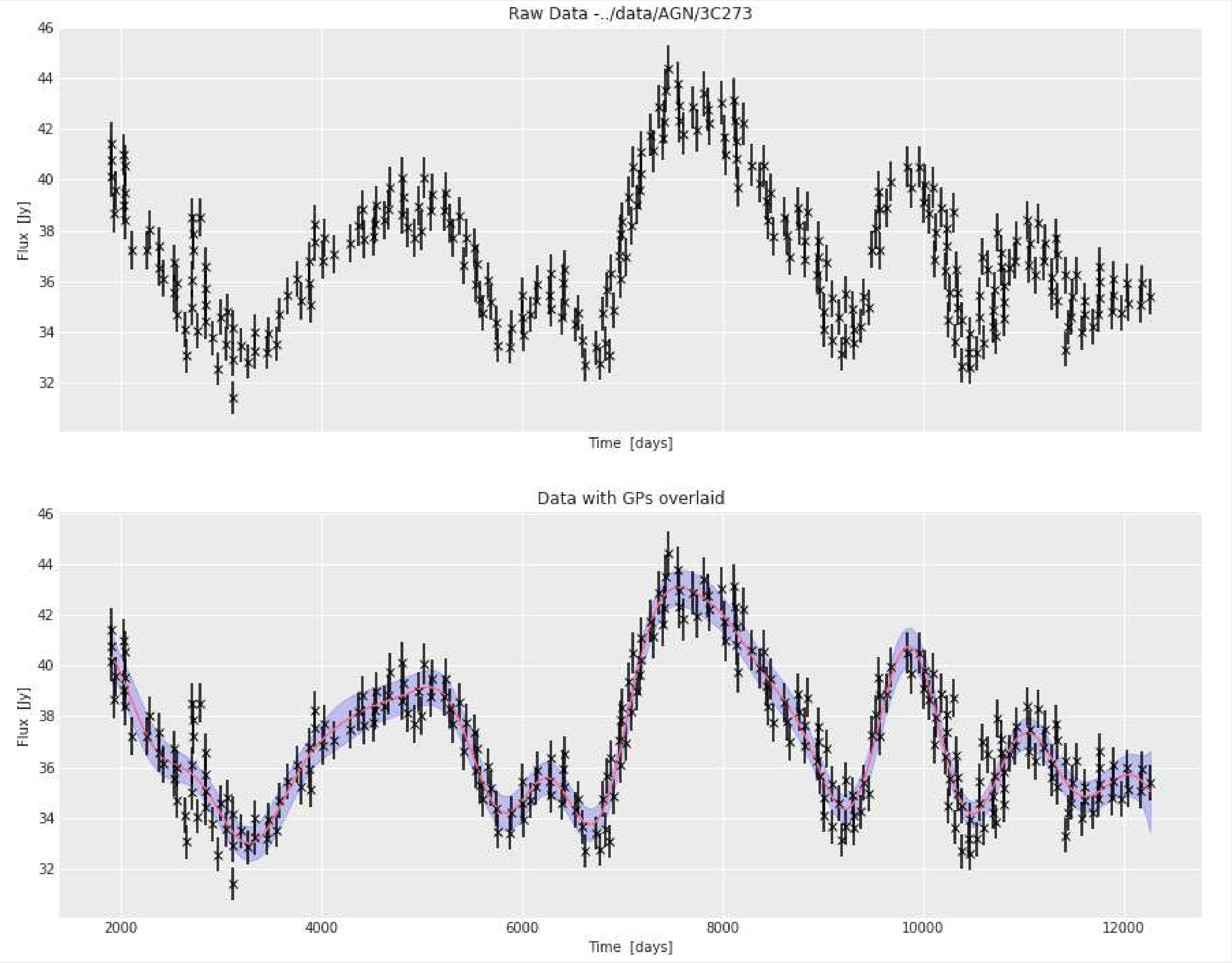
Narayan et al. 2018

SKA Problem 1 – Radio Transients



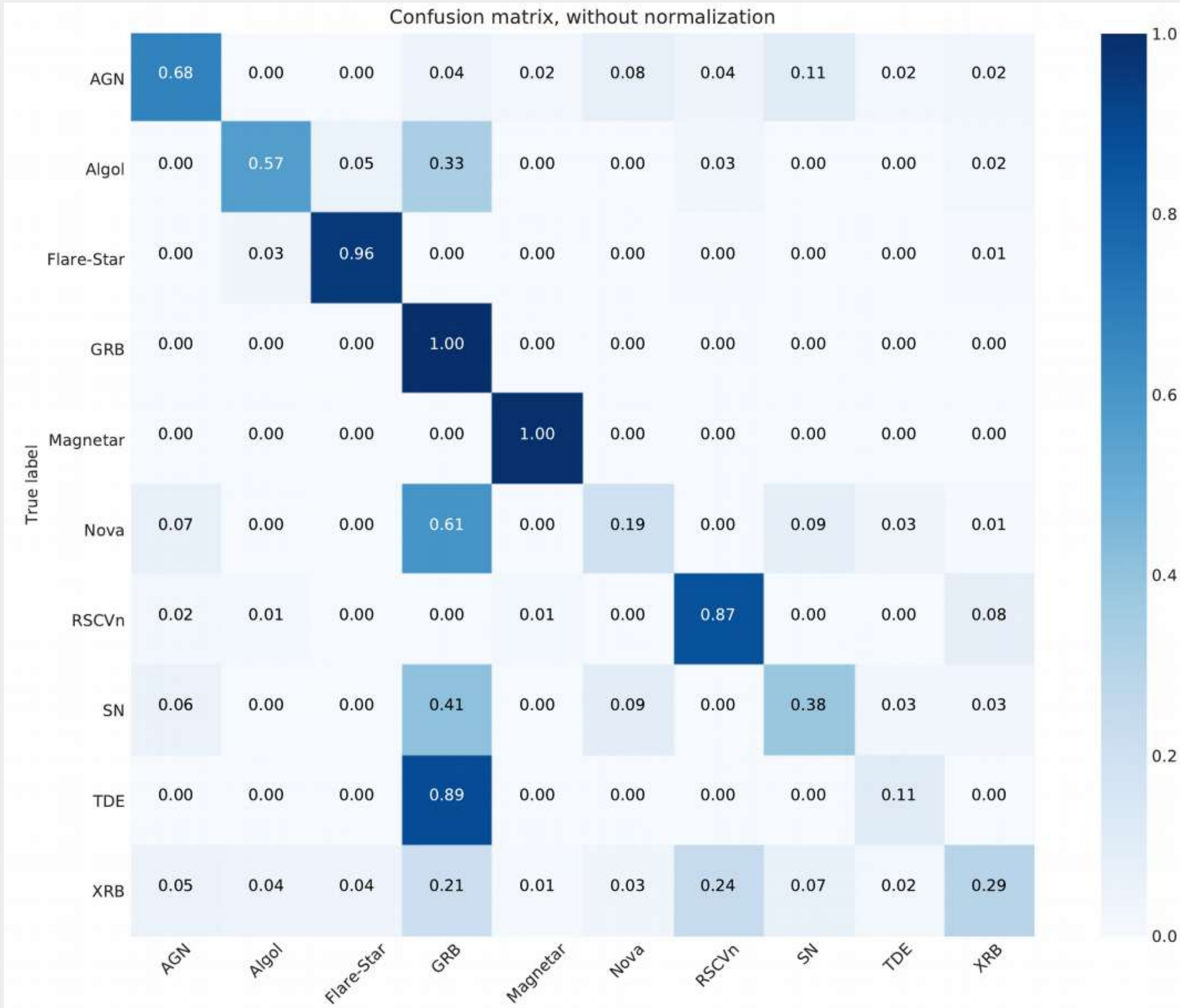
Sooknunan et al. in prep

SKA Problem 1 – Radio Transients



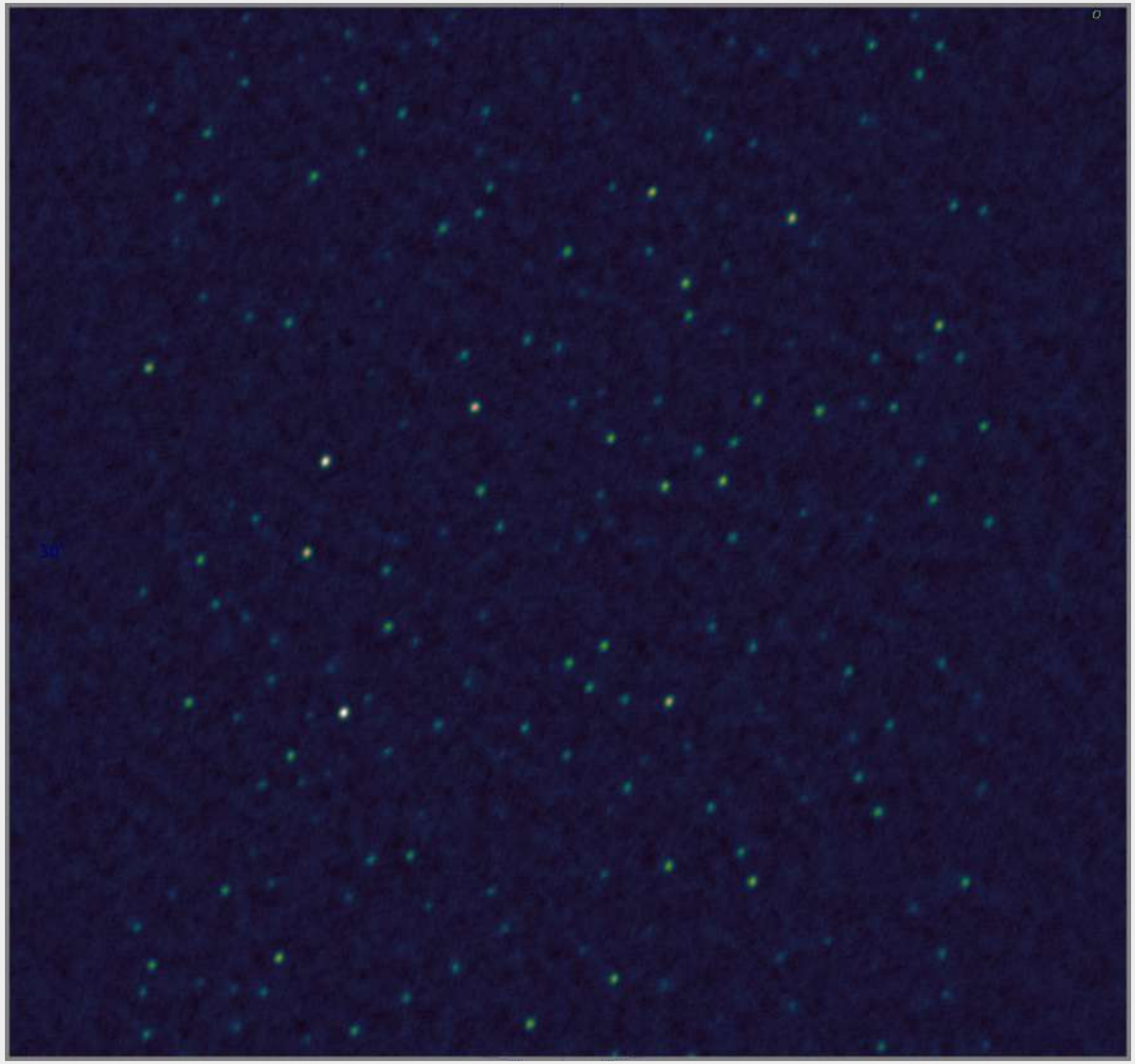
Sooknunan et al. in prep

SKA Problem 1 – Radio Transients



Sooknunan et al. in prep

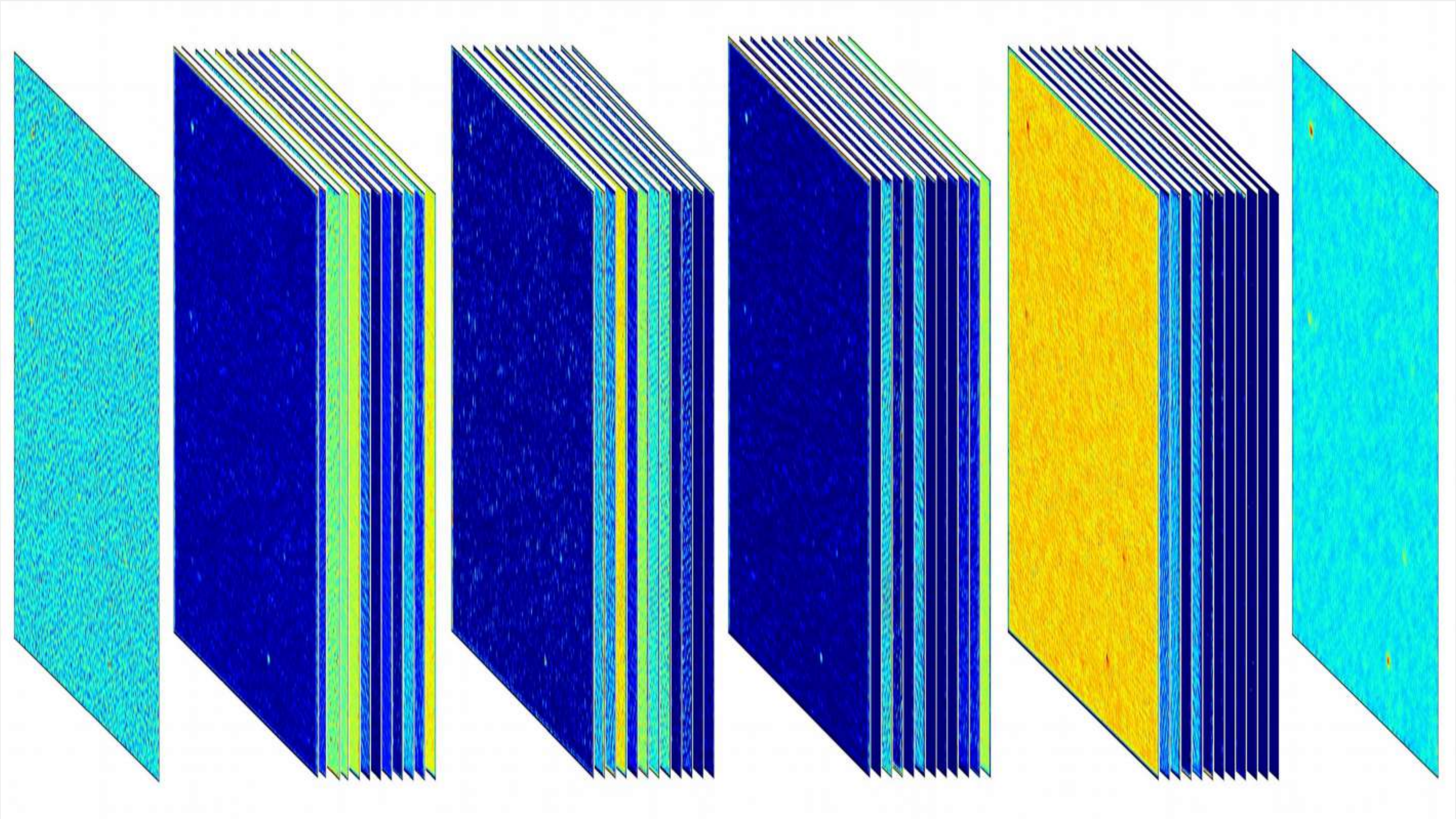
SKA Problem 2 – Source Finding



Need a fast, automated, reliable way to turn radio images into source catalogues

Vos et al. in prep

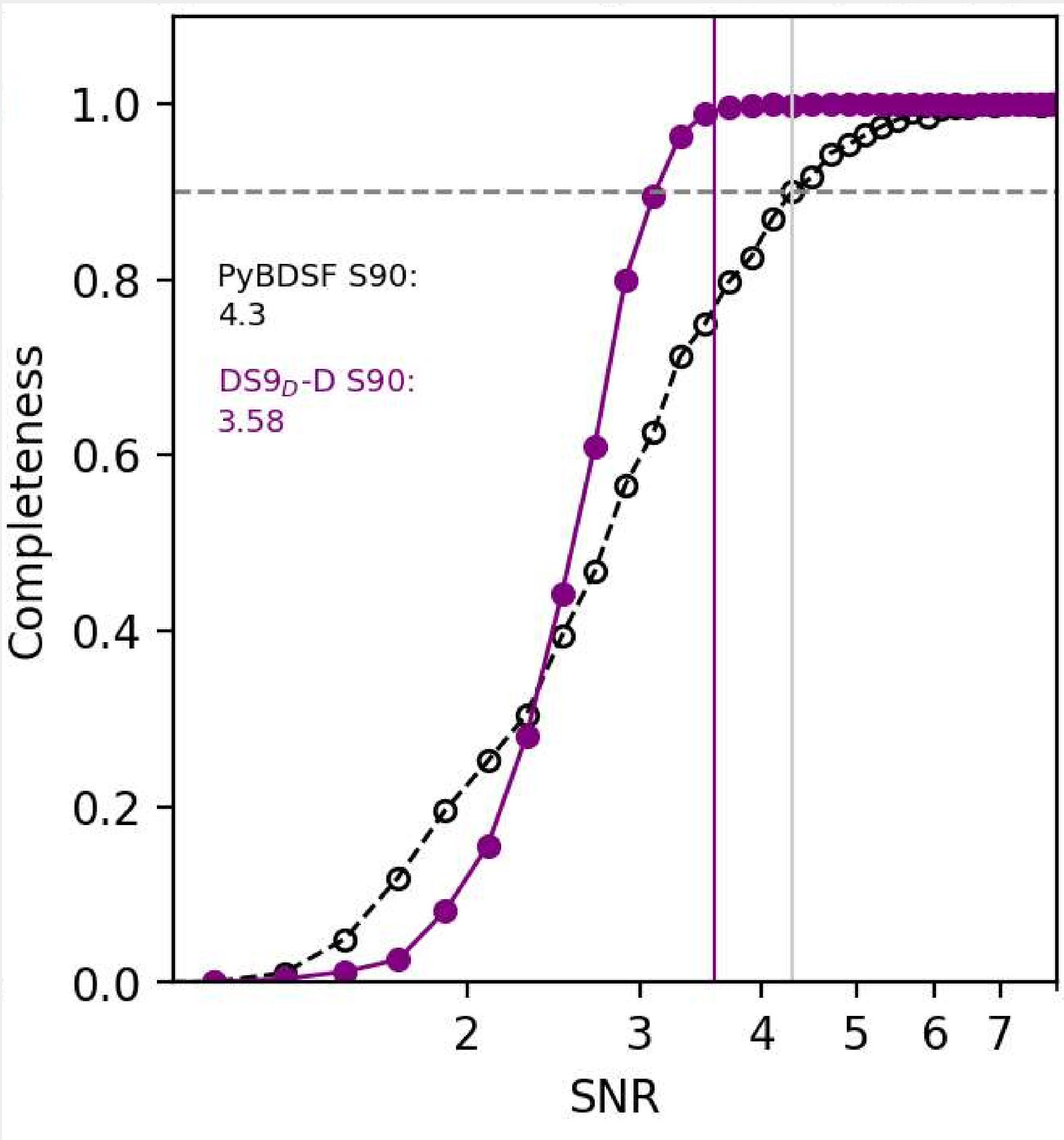
Solution – Machine Learning



Convolutional Neural Networks, a type of deep learning algorithm, can learn about correlated noise and instrumental effects

Vos et al. in prep

Results



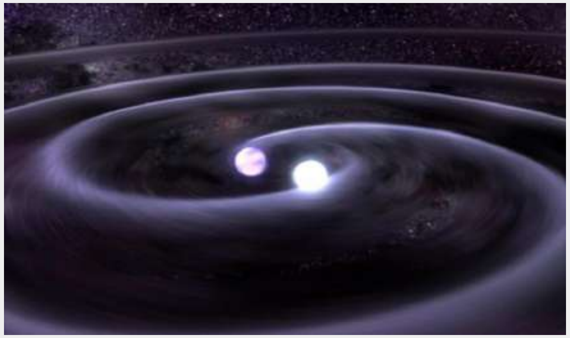
Our CNN can accurately detect more faint point sources than a commonly used source-finding algorithm

Vos et al. in prep

Other Astronomy Applications

- Detecting gravitational waves

  https://arxiv.org/abs/1711.07966



Other Astronomy Applications

- Detecting gravitational waves
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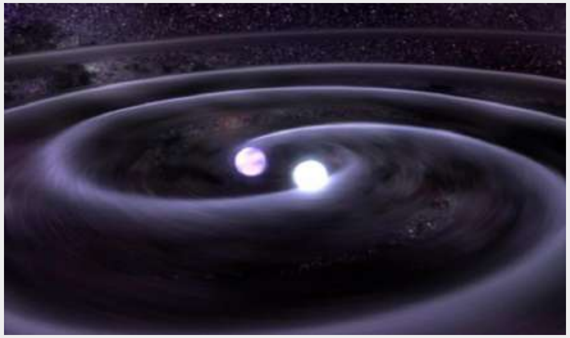
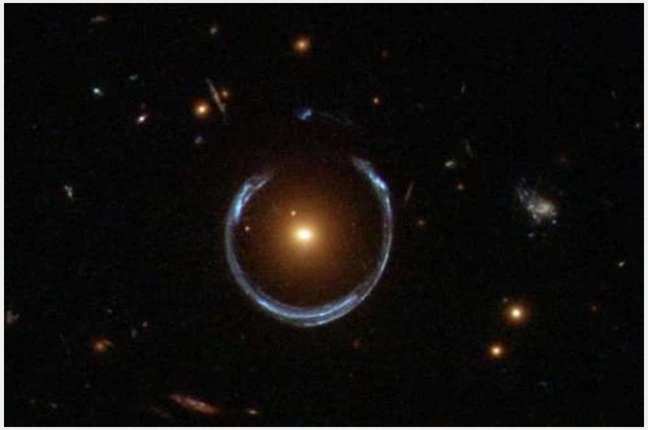
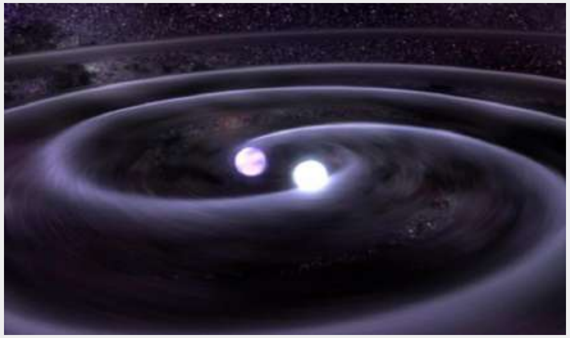
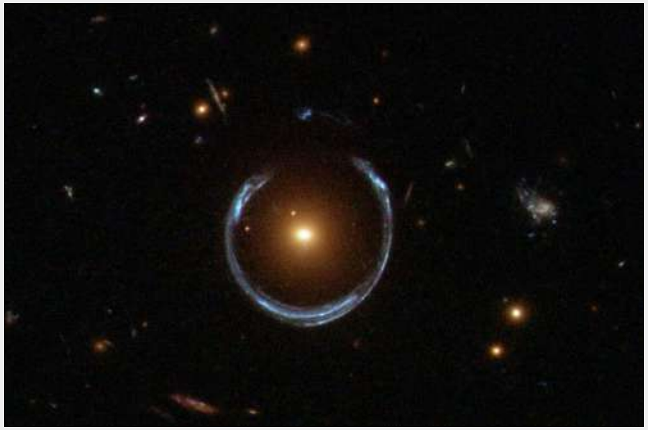
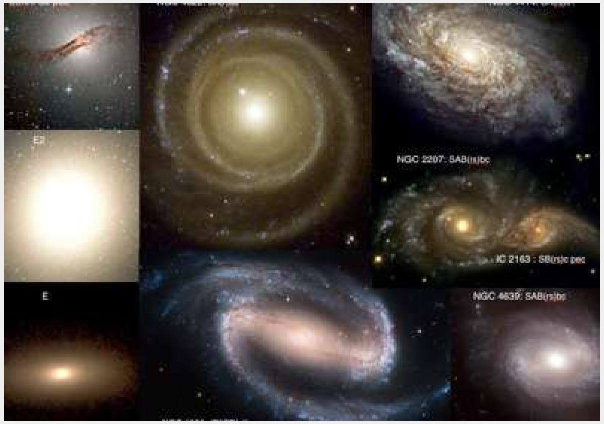
- Finding strong gravitationally lensed galaxies
  https://arxiv.org/abs/1703.02642





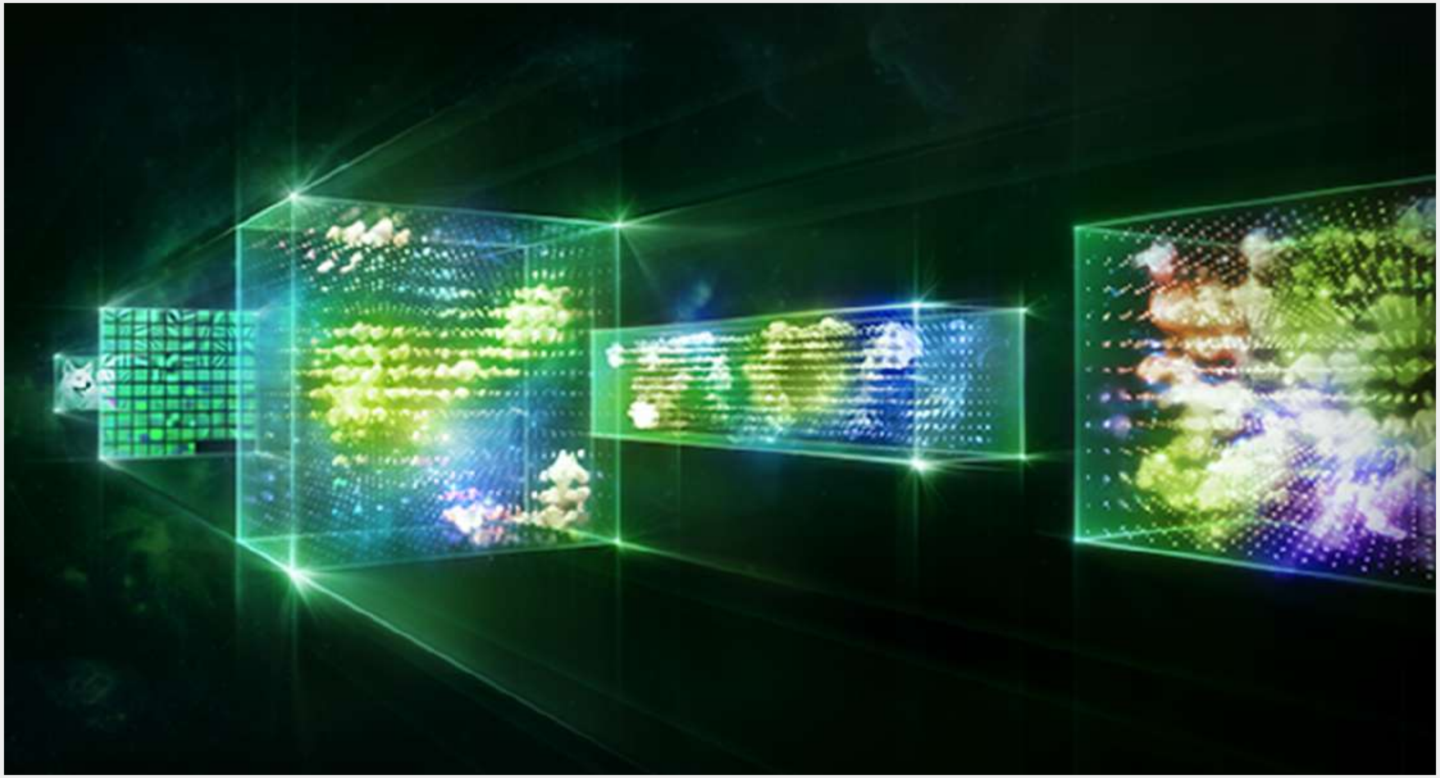
Other Astronomy Applications

- Detecting gravitational waves
  https://arxiv.org/abs/1711.07966
- Finding strong gravitationally lensed galaxies
  https://arxiv.org/abs/1703.02642
- Combining humans and machines to classify galaxies
  https://arxiv.org/abs/1802.08713

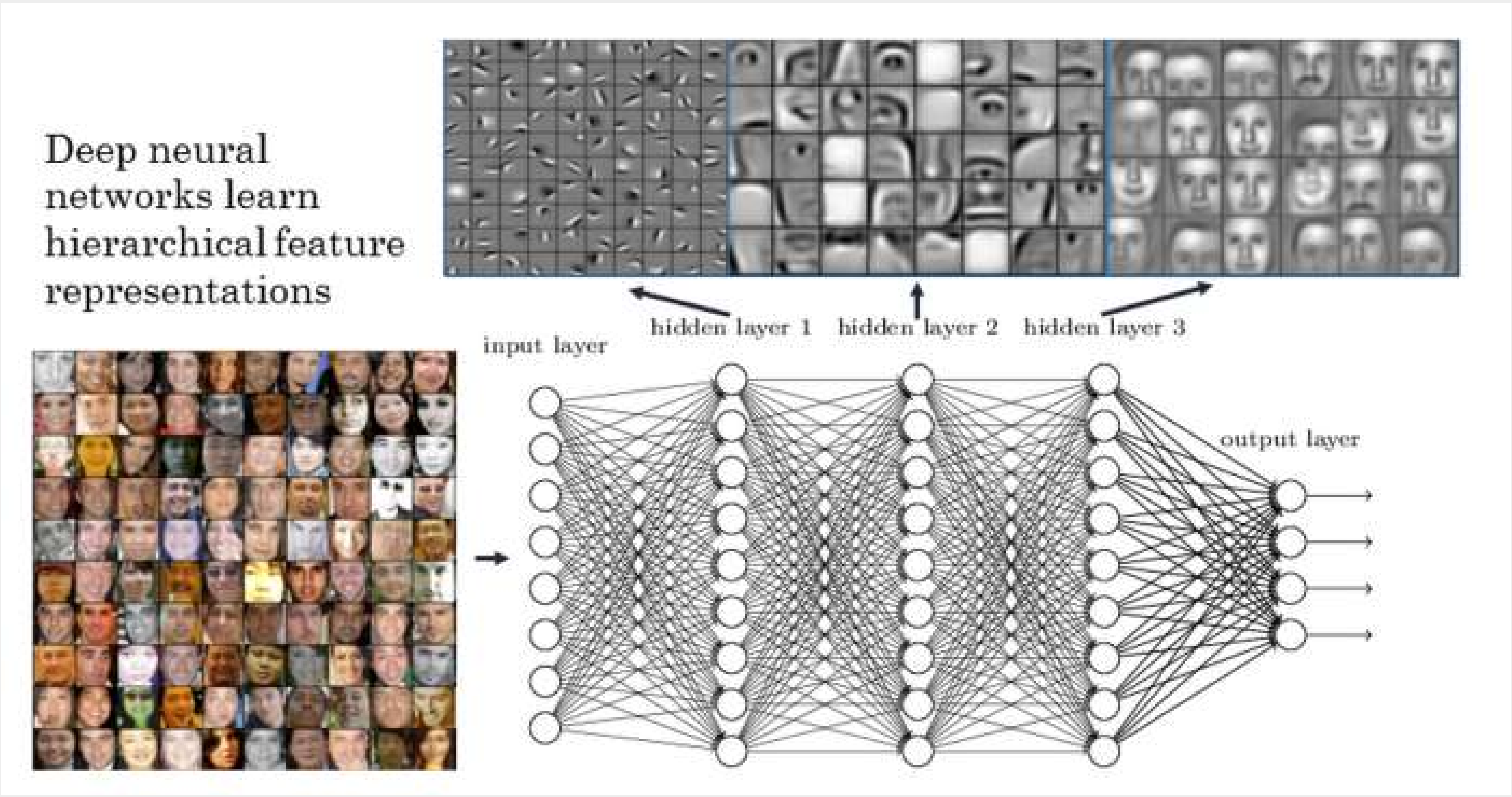
Going Deep

Deep learning has revolutionised machine learning in recent years, solving problems that have baffled computers for decades



Going Deep

Convolutional neural networks



Why Deep Learning is hard

You need a huge amount of training data

You need a GPU, unless you're very patient

It's an art to get the right architecture

Hard to interpret

Making Deep Learning Easier

You need a huge amount of training data

Use data augmentation

You need a GPU, unless you're very patient

Get a GPU

It's an art to get the right architecture

Use existing architectures known to work. Also look at Dufourq & Bassett (https://arxiv.org/abs/1709.09161)

Hard to interpret

The Deep Learning Revolution

Convolutional neural networks for image classification, recurrent neural network for image descriptions

construction worker in orange safety vest is working on road.

two young girls are playing with lego toy.

Karpathy & Fei-Fei (2015)

Towards AI

Technically, the Turing Test was passed in 2001...

Art

Art

Art

Art

Elgammal et al. (2017) 1706.07068

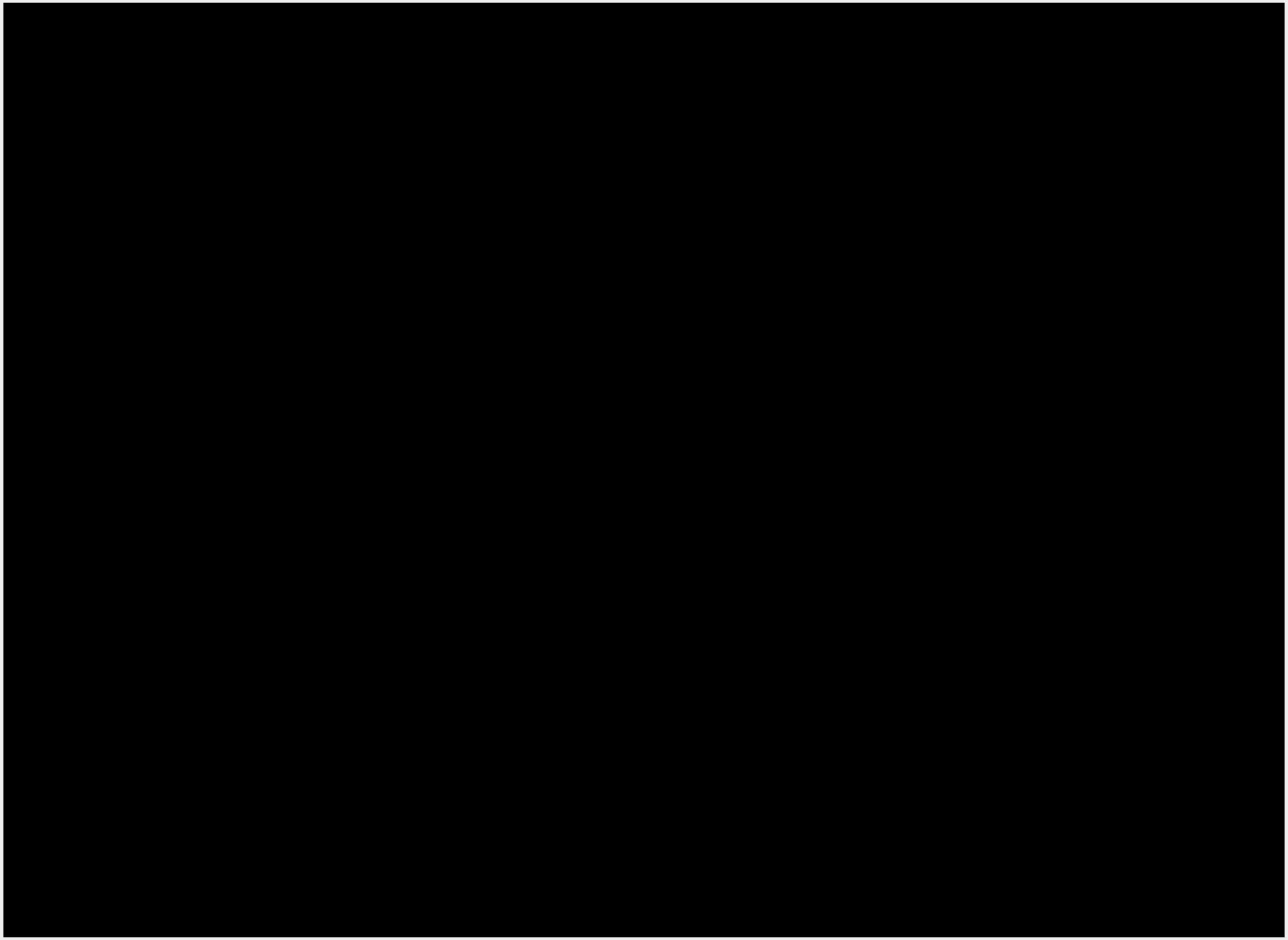
Music

Music

https://www.youtube.com/watch?v=j60J1cGINX4

Sci-Fi

Sci-Fi



https://www.youtube.com/watch?v=LY7x2Ihqjmc

Sci-Fi

INT. SHIP

We see H pull a book from a shelf, flip through it while speaking, and then put it back.

H

In a future with mass unemployment, young people are forced to sell blood. That's the first thing I can do.

H2

You should see the boys and shut up. I was the one who was going to be a hundred years old.

H

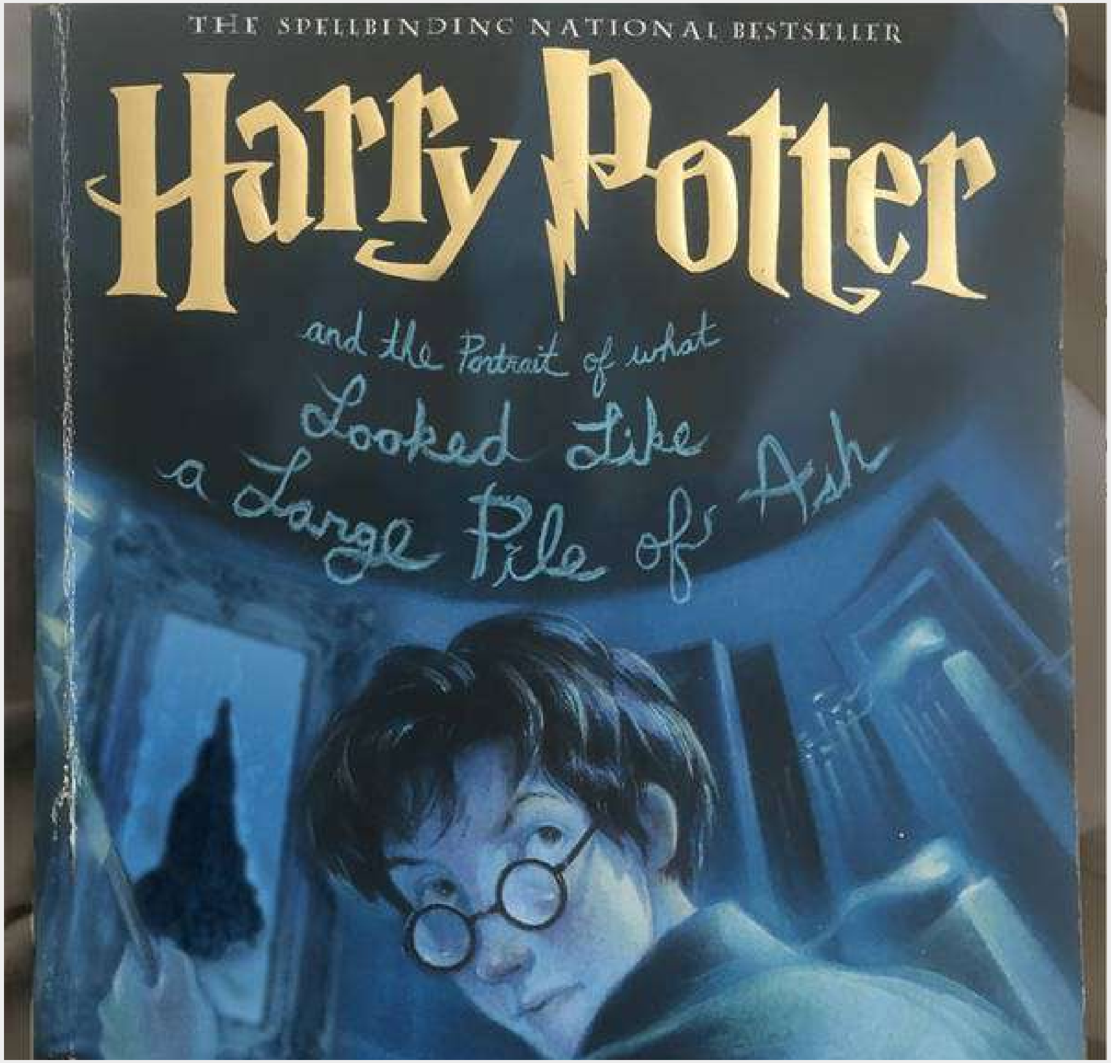
I saw him again. The way you were sent to me... that was a big honest idea. I am not a bright light.

C

Well, I have to go to the skull. I don't know.

https://www.youtube.com/watch?v=LY7x2Ihqjmc

Harry Potter



http://botnik.org/content/harry-potter.html

Harry Potter

Harry could tell that Voldemort was standing right behind him. He felt a great overreaction. Harry tore his eyes from his head and threw them into the forest. Voldemort raised his eyebrows at Harry, who could not see anything at the moment.

"Death Eaters are on top of the castle!" Ron bleated, quivering. Ron was going to be spiders. He just was. He wasn't proud of that, but it was going to be hard to not have spiders all over his body after all is said and done.

http://botnik.org/content/harry-potter.html

Games

The Future

Does the future look like this?

The Future

Or this?

The Future

Or this?

References

https://www.coursera.org/learn/neural-networks-deep-learning

http://cs231n.github.io/convolutional-networks/

http://colah.github.io/posts/2014-07-Conv-Nets-Modular/

http://playground.tensorflow.org

Email me at: dr.michelle.lochner@gm

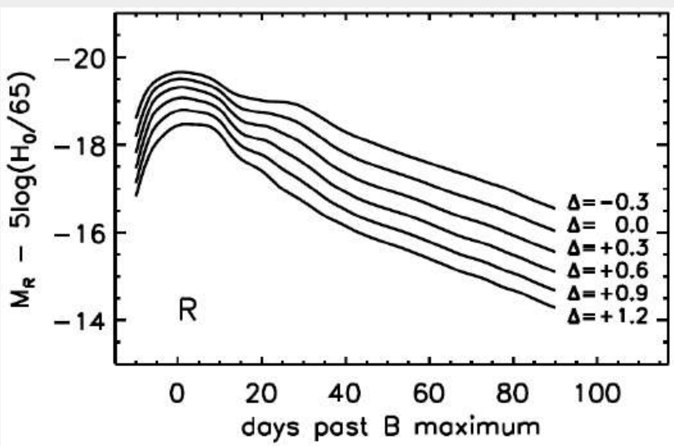
References

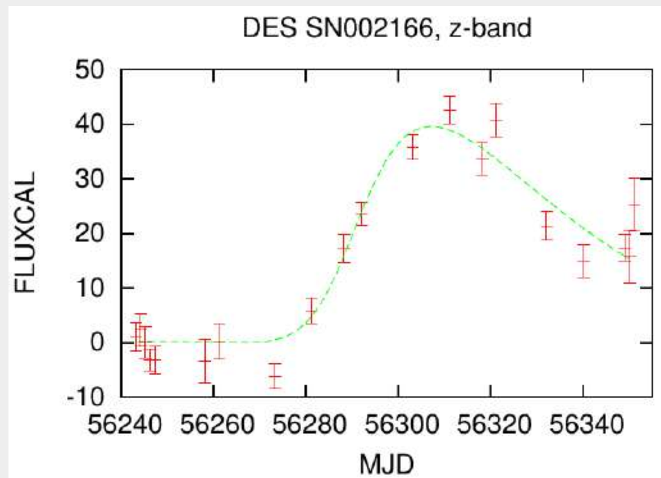
- SN classification https://arxiv.org/abs/1603.00882
- Transient classification https://arxiv.org/abs/1801.07323
- SN cosmology https://arxiv.org/abs/1704.07830
- HI spectral line fitting https://arxiv.org/abs/1704.08278

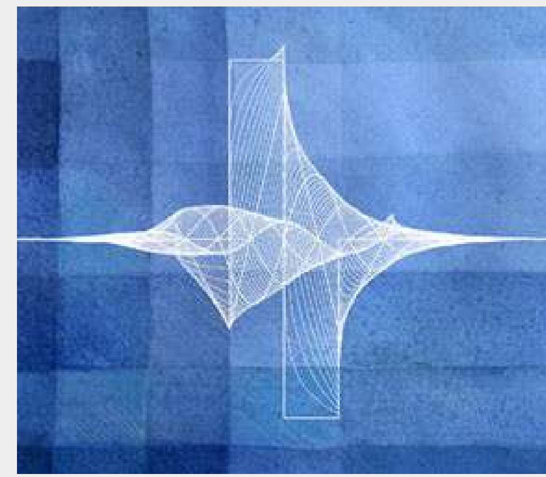
dr.michelle.lochner@gmail.com

Feature selection

So far, we've identified three promising approaches:







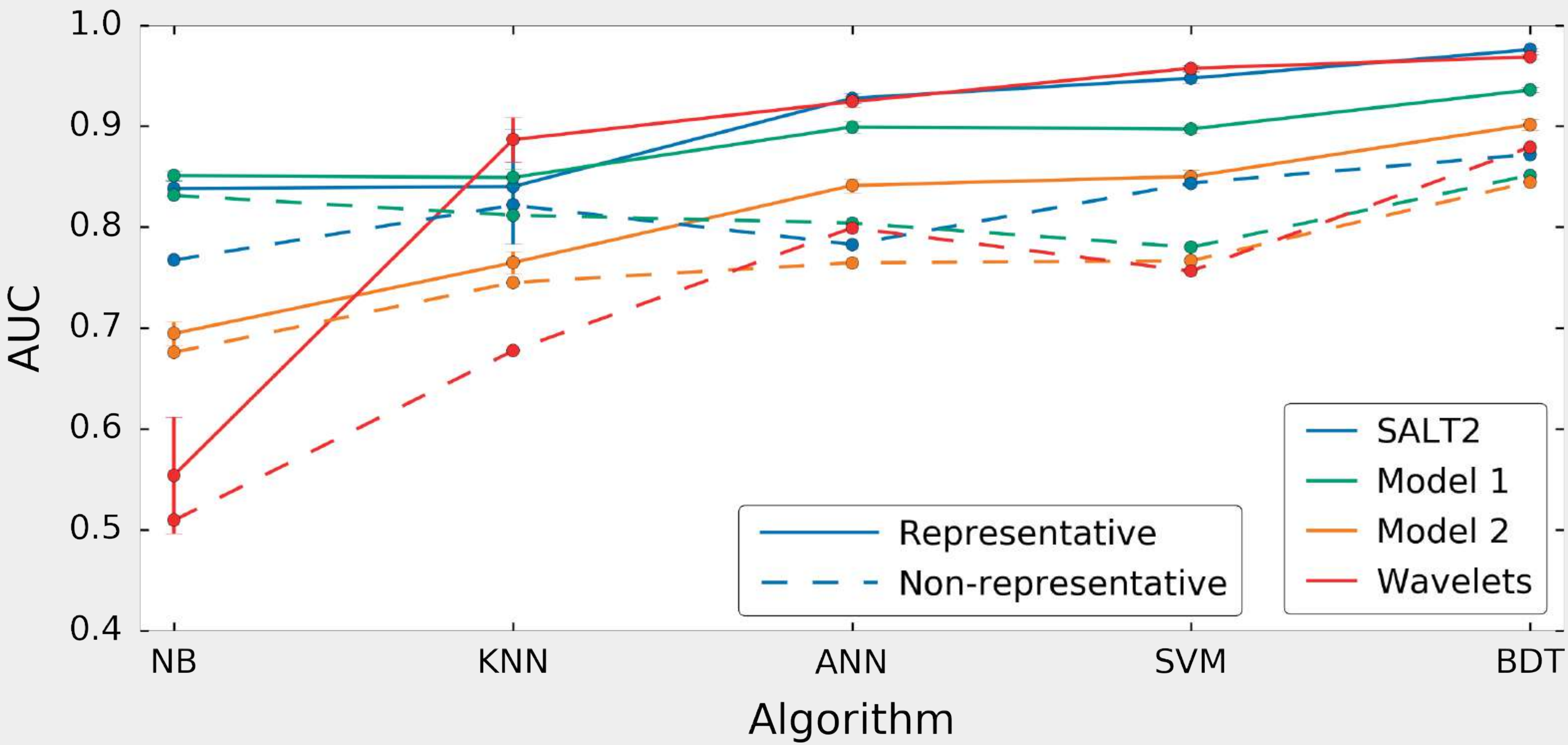
1) Template fitting

2) General light curve parameterisations

3) Wavelets

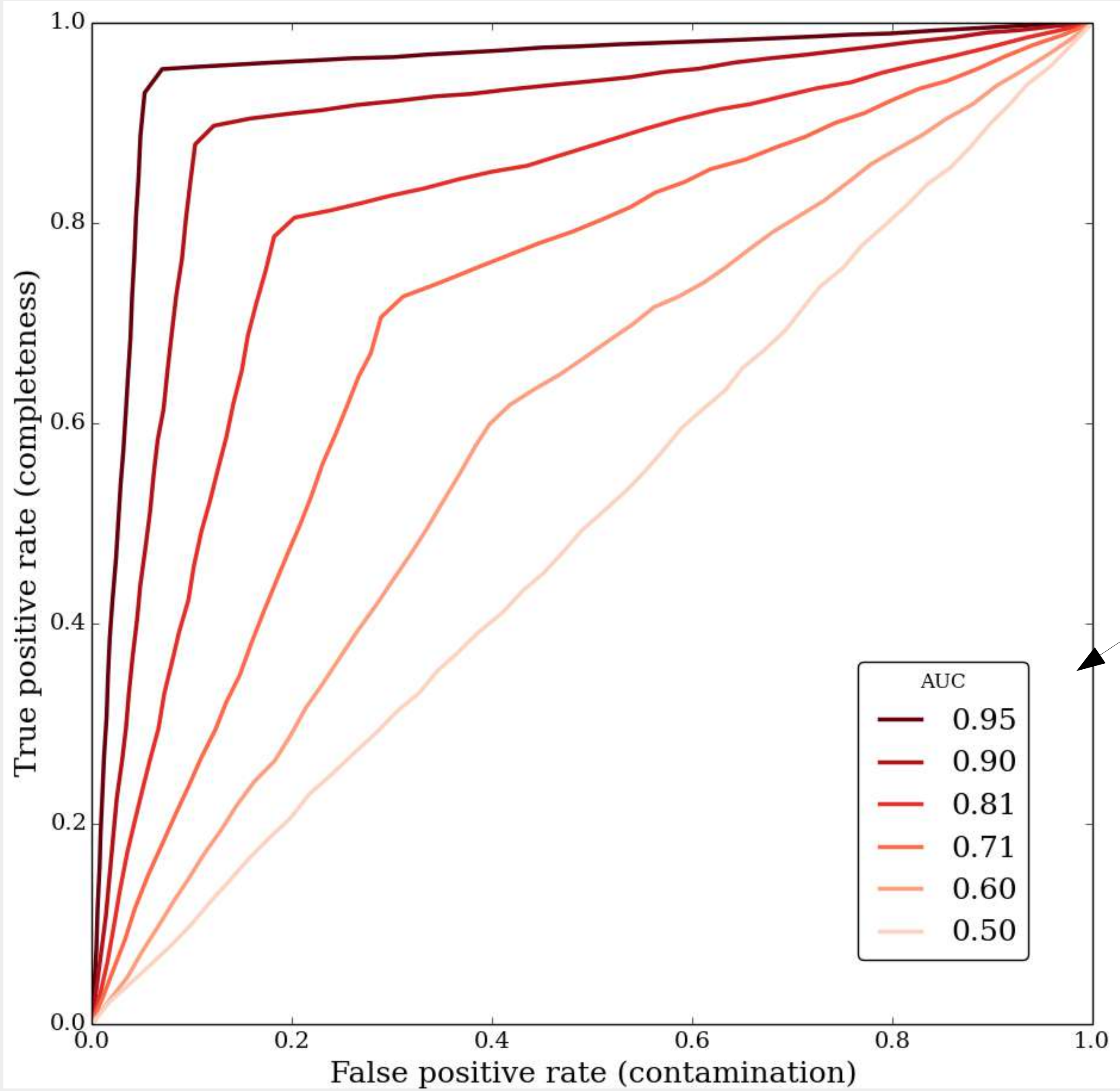
Model independence

Results



Lochner et al. 2016

Receiver Operator Characteristic (ROC) curves



AUC =

Area Under Curve