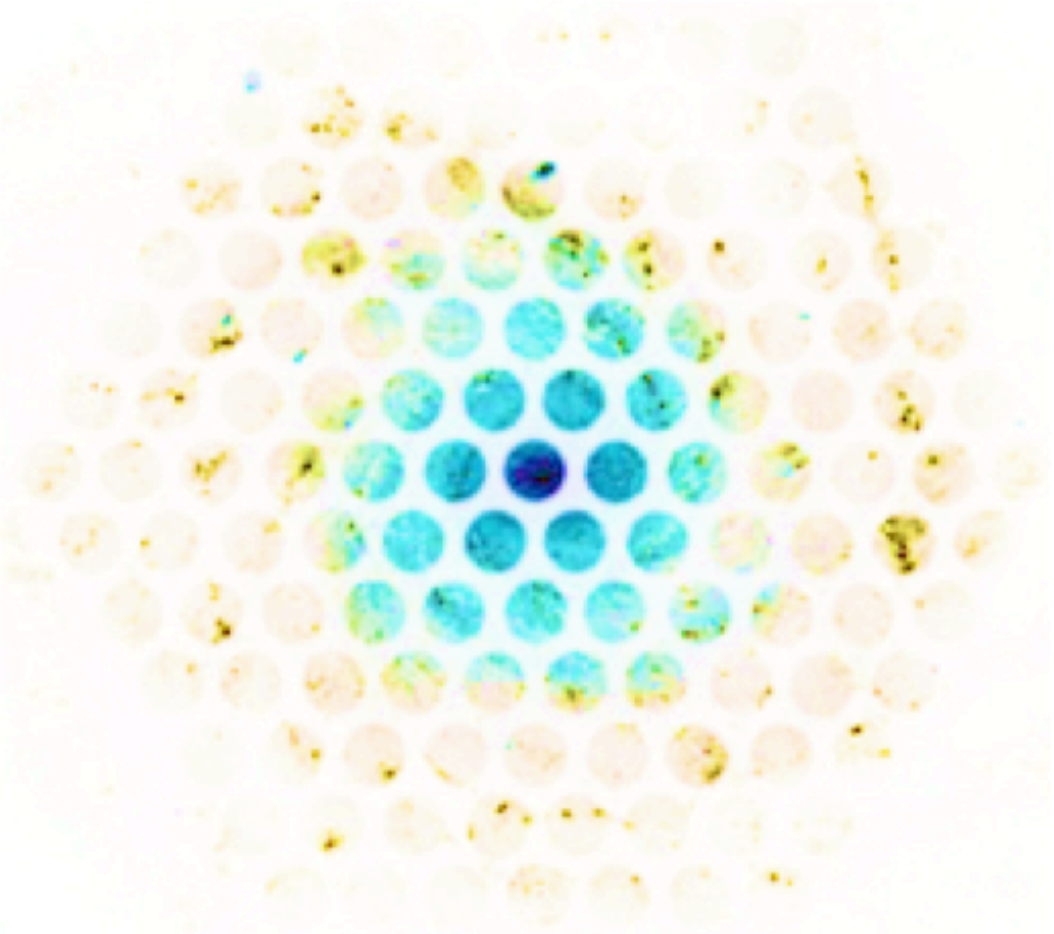
Hidden in Plain Sight: a Deep Learning Approach to Finding Supernovae in Galaxy Maps



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Physics & Astronomy

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University of Pittsburgh

SDSS

Type Ia Supernovae: Measuring the Accelerating Expansion of the Universe

- Accelerating expansion of the Universe
  - thought to be driven by dark energy
  - Nobel Prize in Physics 2011

Image: nobelprize.org

- standardize brightness → measure distances

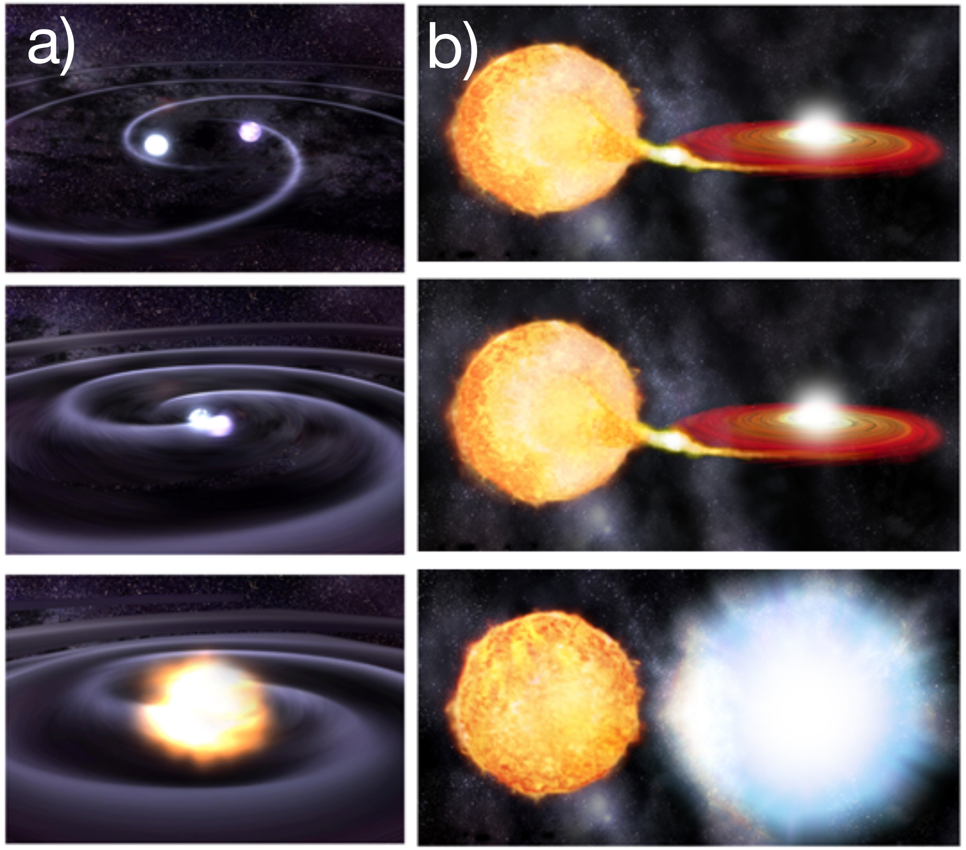
- Thermonuclear explosion of a white dwarf star.
  - White Dwarf: old, compact star as massive as Sun but size of Earth.
  - Normally stable but adding mass past a critical threshold makes them explode.

What is the companion star?

a) another white dwarf

b) a normal star

- Limits distance accuracy.
- Might introduce systematic biases.
- The stellar population age can help disentangle these two scenarios.



Images: Wikimedia Commons and Discover Magazine

Collaborators

- **Quanbin (Eric) Ma** (CMU Machine Learning; Facebook)
- Barnabas Poczos (CMU Machine Learning)

- **Qiong Zhang** (UBC Statistics)
- **Bo Chang** (UBC Statistics)
- Siamak Ravanbakhsh (UBC Computer Science)

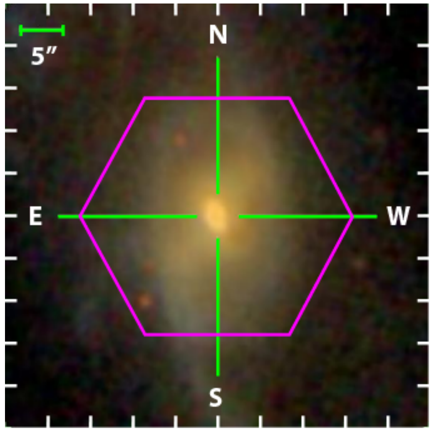
- Ananth Tenneti (CMU Physics)

Supernova Host Galaxy Spectroscopy

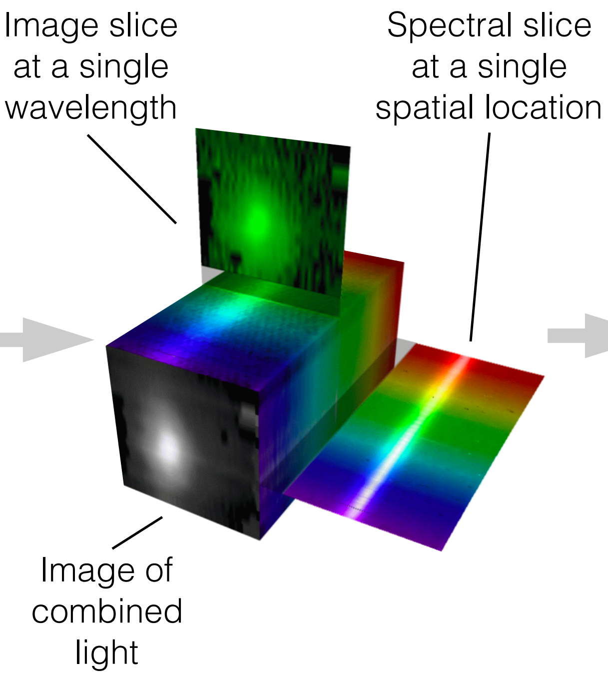
- Find supernovae in imaging and do resource intensive spatially-resolved spectroscopy of the host galaxy.

- Have a large data set of spatially-resolved spectroscopy of galaxies then look for supernovae (known or unknown).

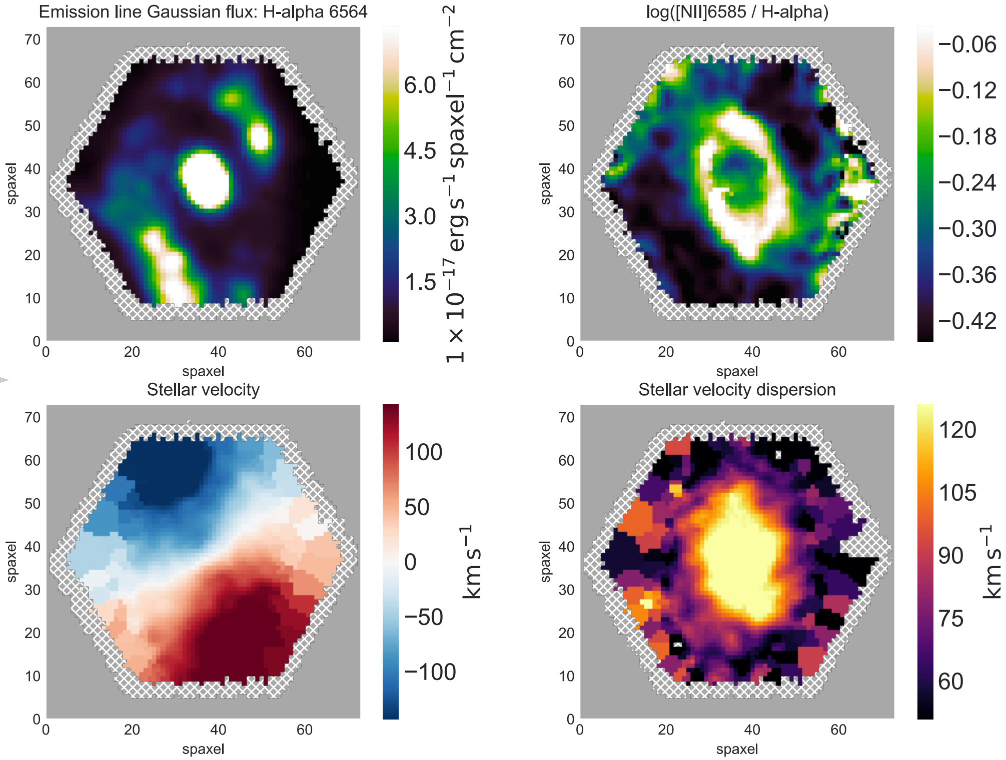
SDSS-IV MaNGA Survey



2,600 galaxies

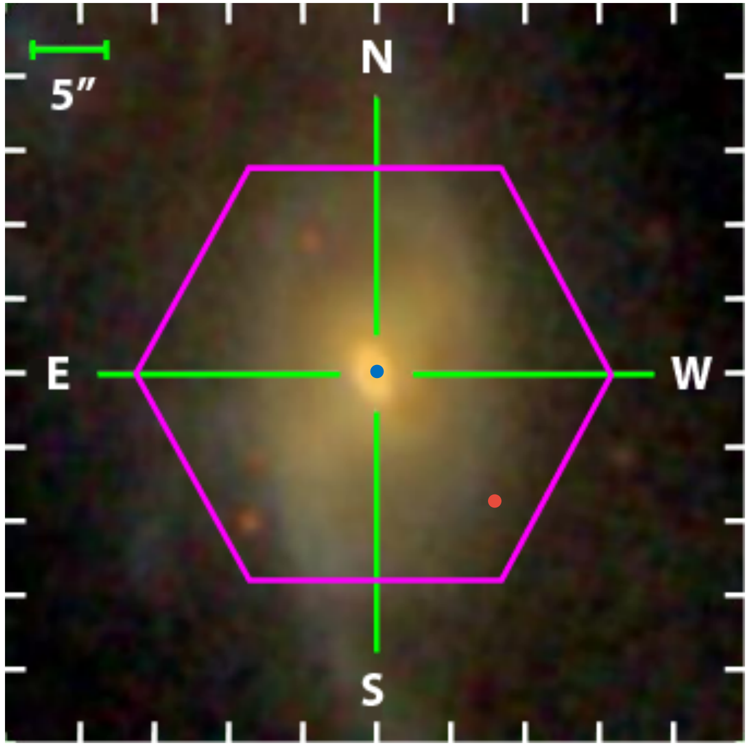


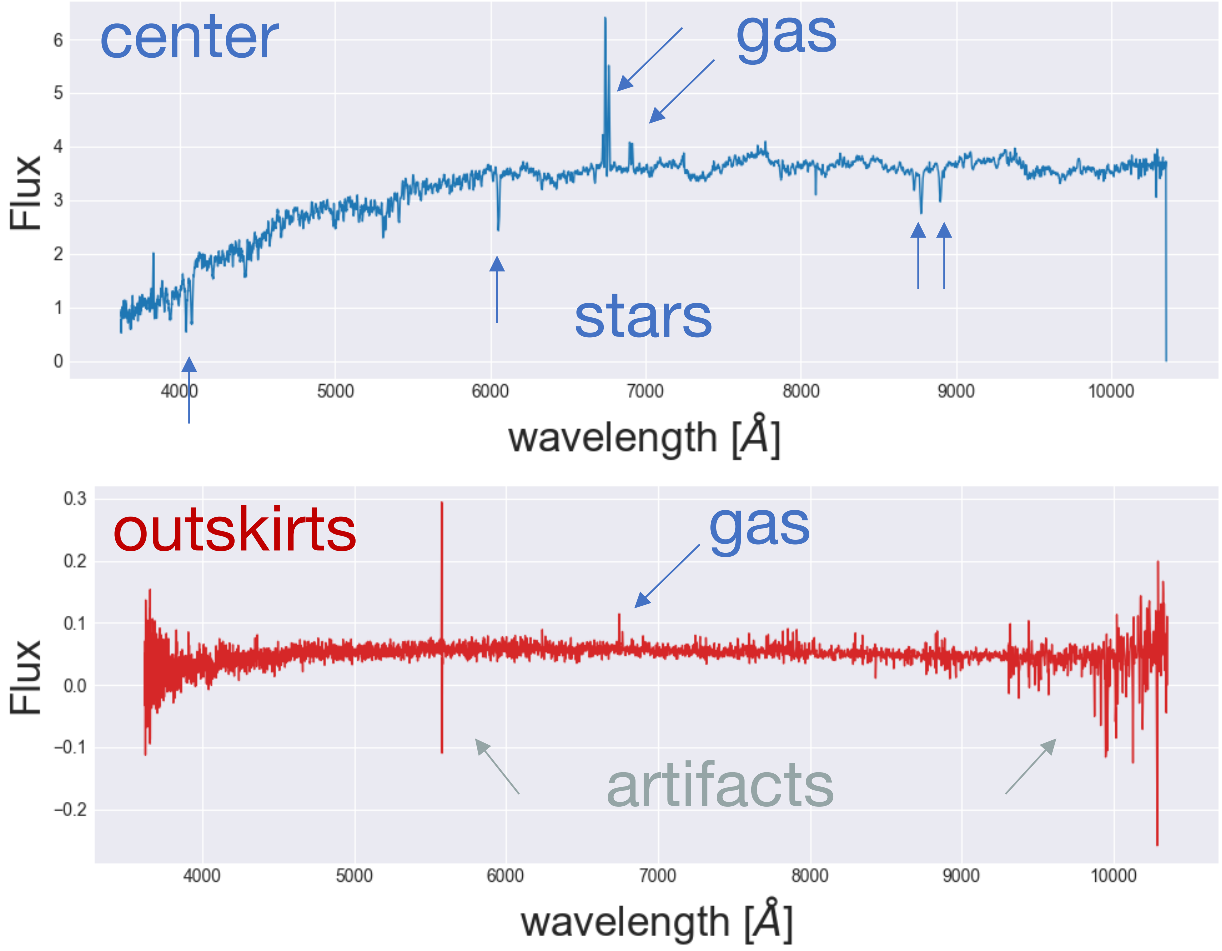
4,500 spectral channels



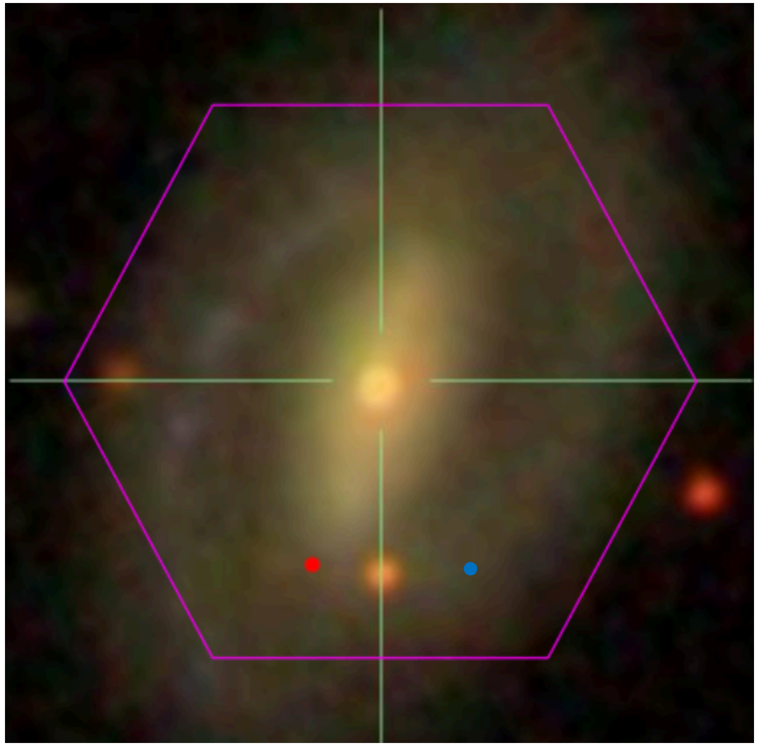
~3,000 spatial elements

Galaxy Spectra

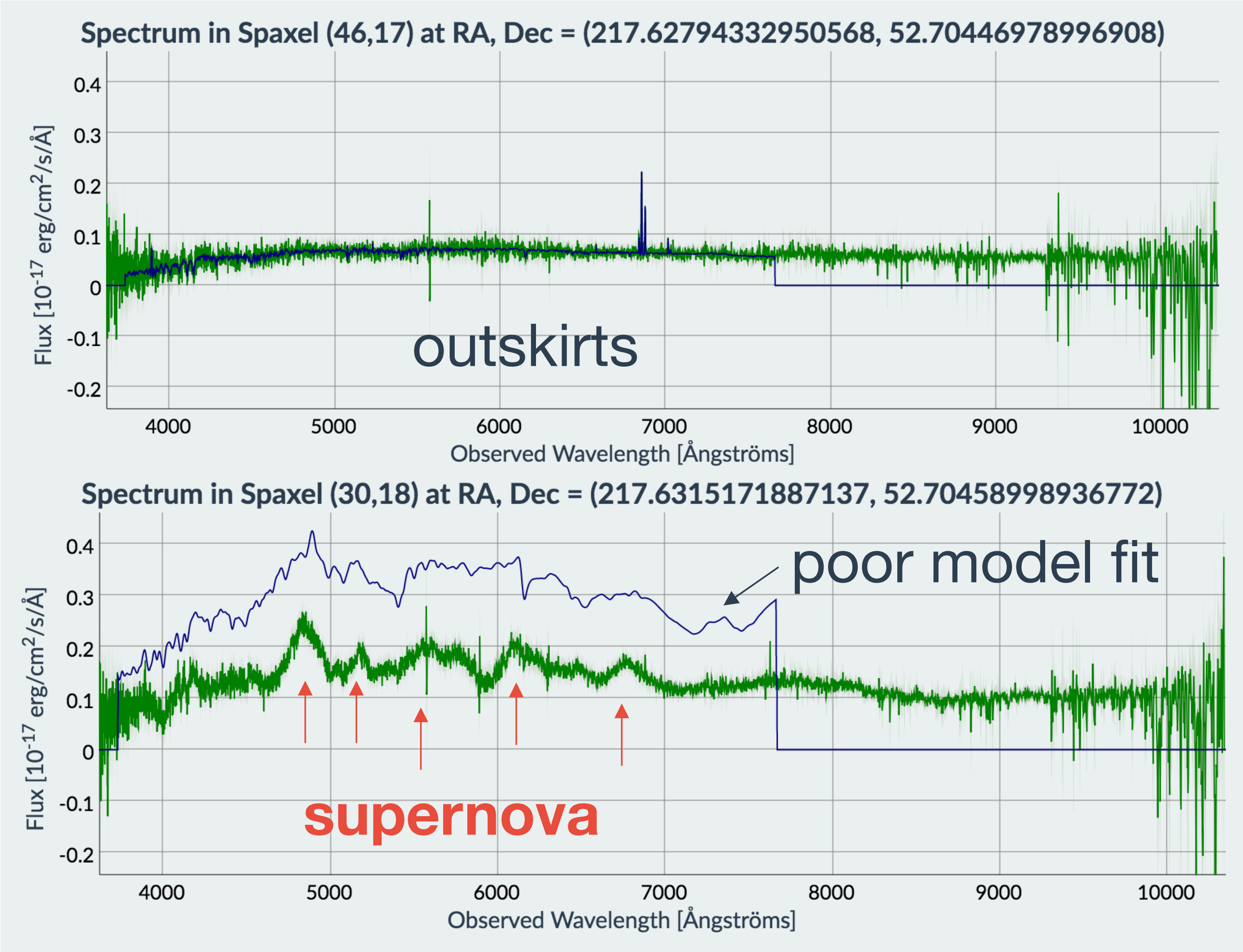




A Serendipitous Supernova



No supernova in image used to select galaxies.



Finding Supernovae: Anomaly Detection

- Data set is too big to apply anomaly detection.

2,600 galaxies * **3,000** spatial elements * **4,000** spectral channels

~ **30,000,000,000** elements

1. Reduce dimensionality with Convolutional Autoencoder.
2. Apply anomaly detection techniques.

Convolutional Autoencoder (CAE)

- Deep dimensionality reduction technique using a Convolutional Neural Network (unsupervised).

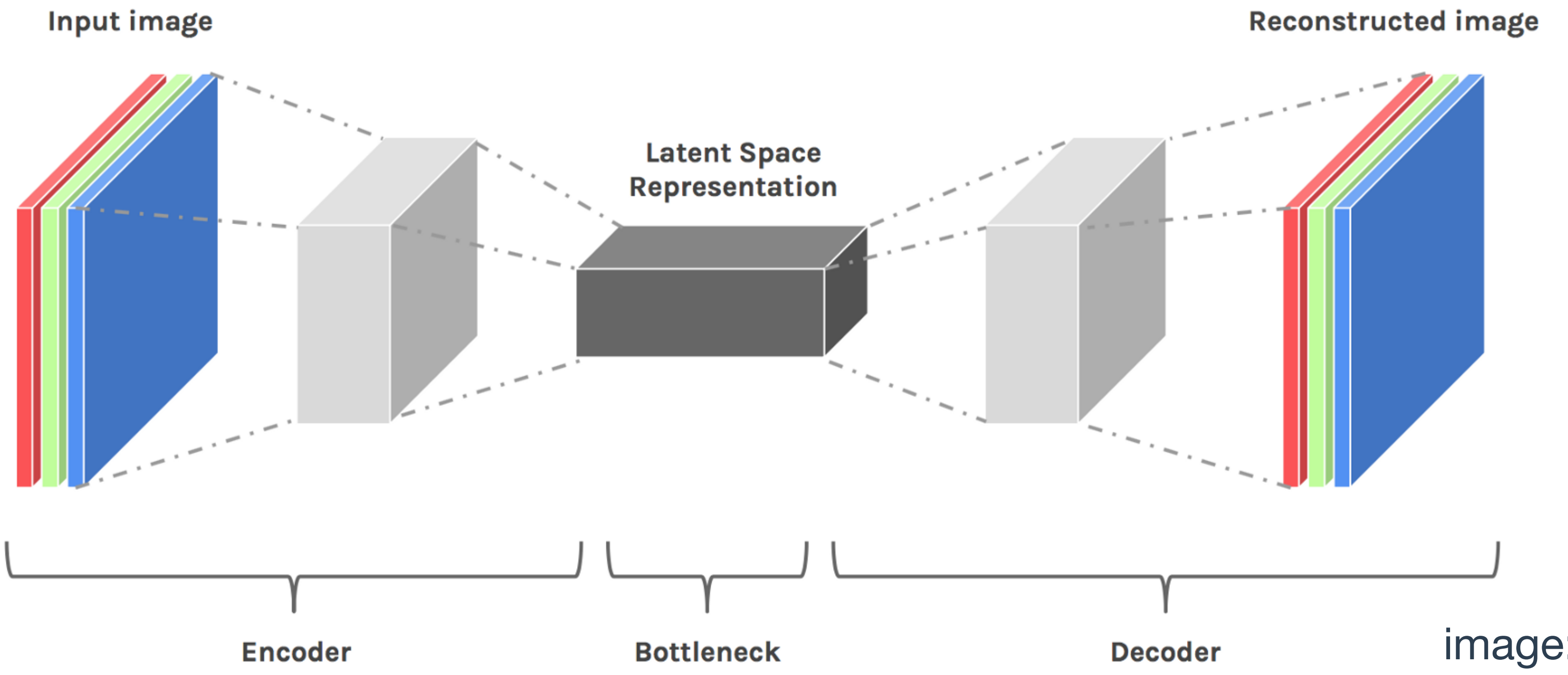
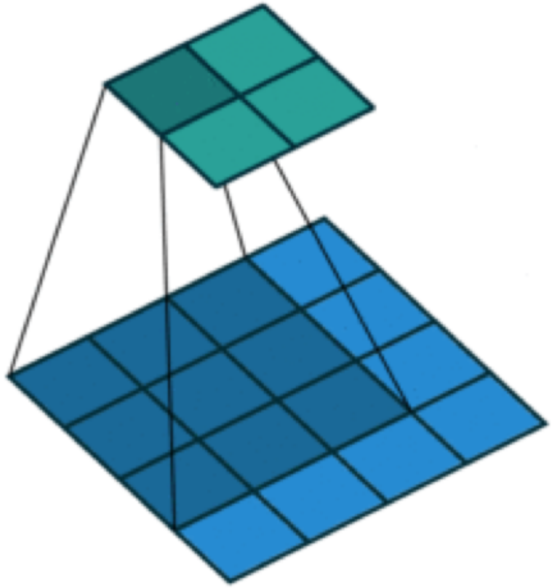
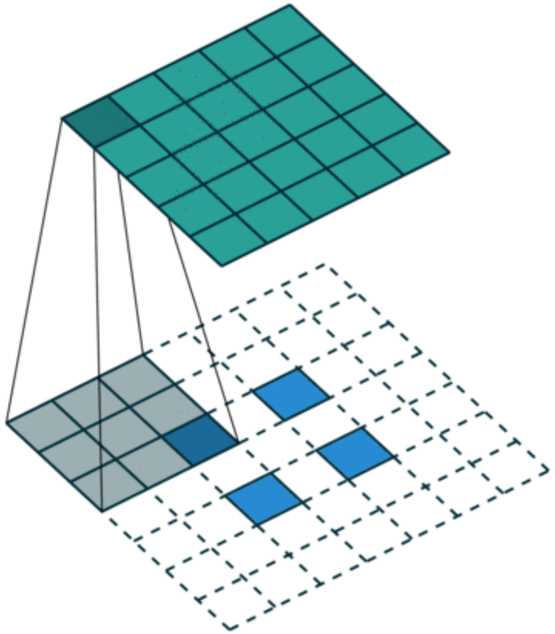


image: S. Singh

What is convolution?



Convolution



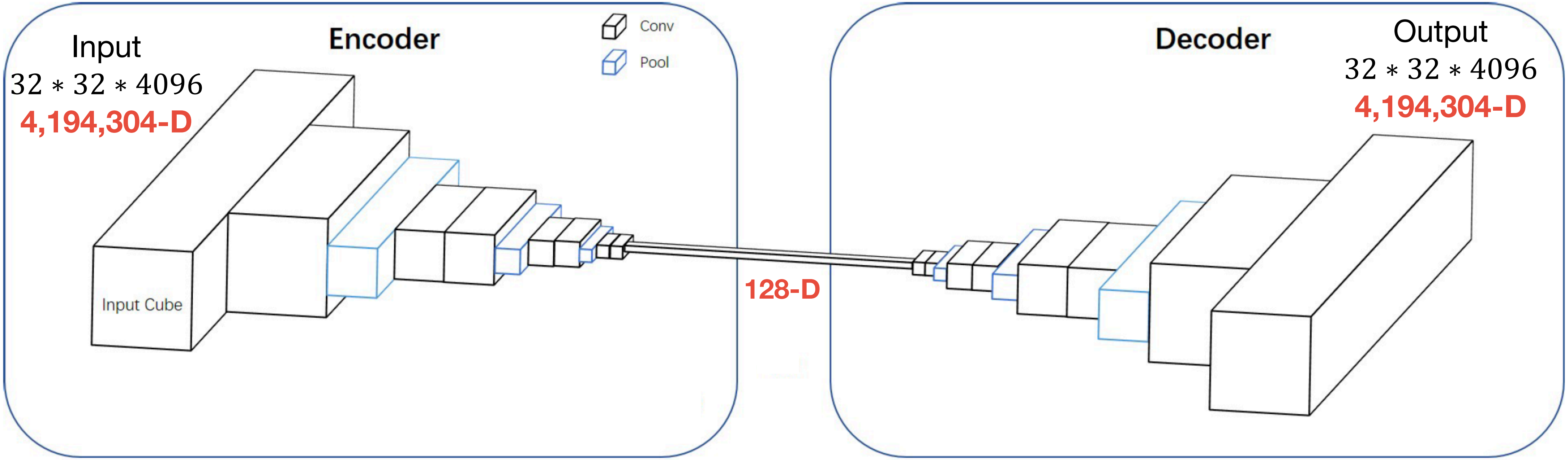
Transpose
Convolution

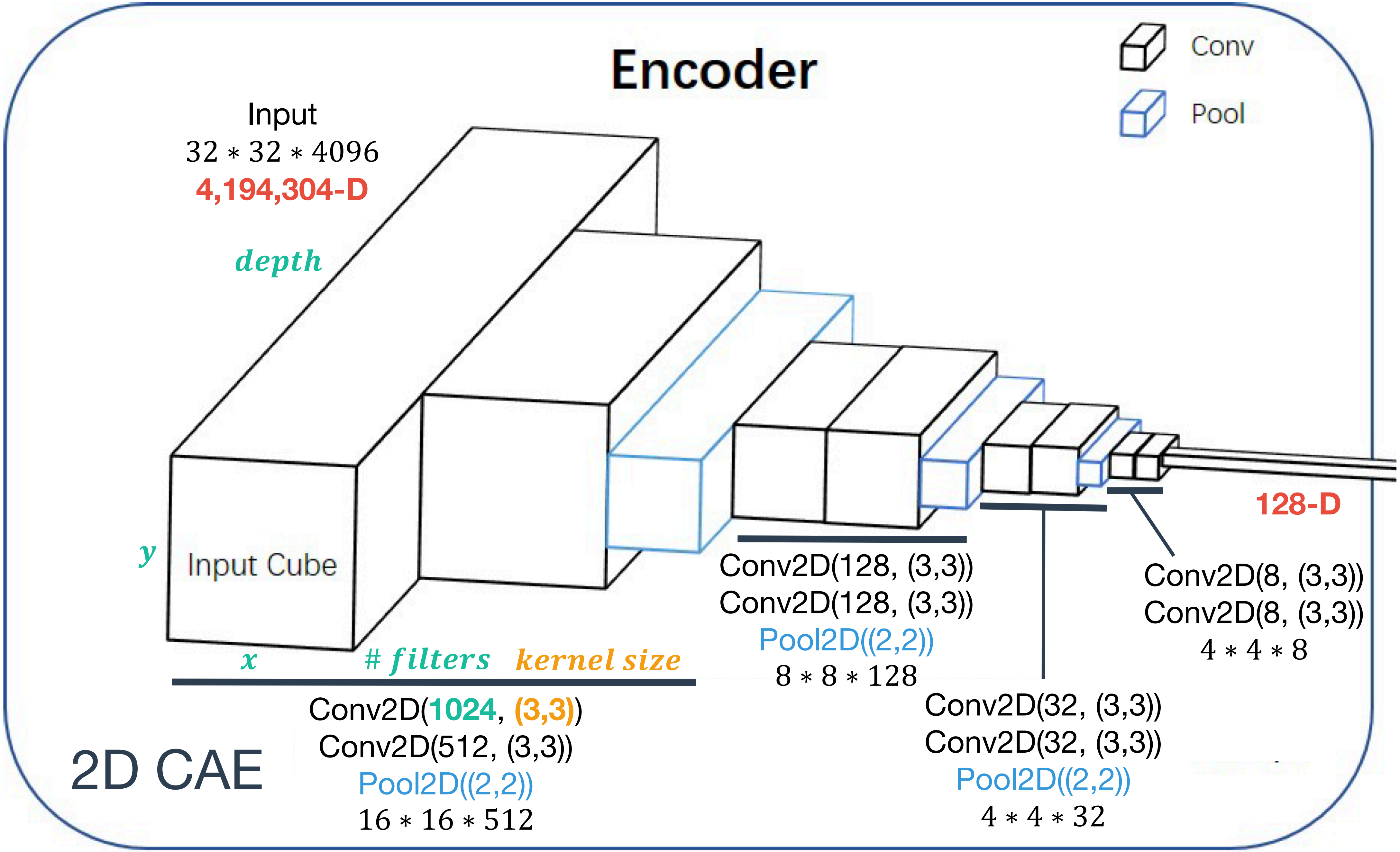
Animations: [Dumoulin & Visin (2016)]

CAE Architectures

- 2D CAE
  - standard for RGB images
- 3D CAE
  - kernel is 3x3x3 cube; take advantage of spectral correlations

Example Architecture (2D CAE)




Encoder
Conv
Pool
Input
32 * 32 * 4096
4,194,304-D
depth
y
Input Cube
x
filters
kernel size
Conv2D(1024, (3,3))
Conv2D(512, (3,3))
Pool2D((2,2))
16 * 16 * 512
Conv2D(128, (3,3))
Conv2D(128, (3,3))
Pool2D((2,2))
8 * 8 * 128
Conv2D(32, (3,3))
Conv2D(32, (3,3))
Pool2D((2,2))
4 * 4 * 32
Conv2D(8, (3,3))
Conv2D(8, (3,3))
4 * 4 * 8
128-D
2D CAE

Reconstruction: Image Slice

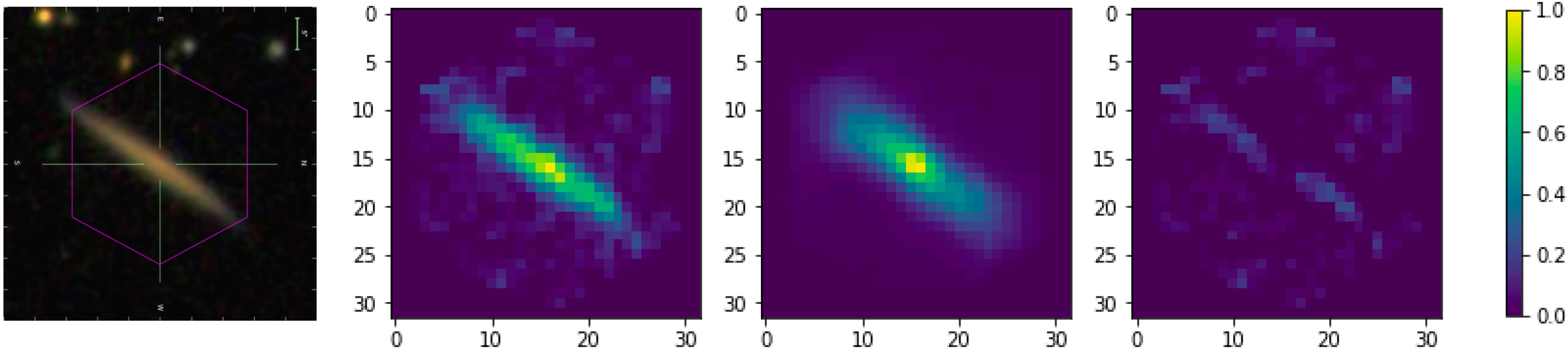
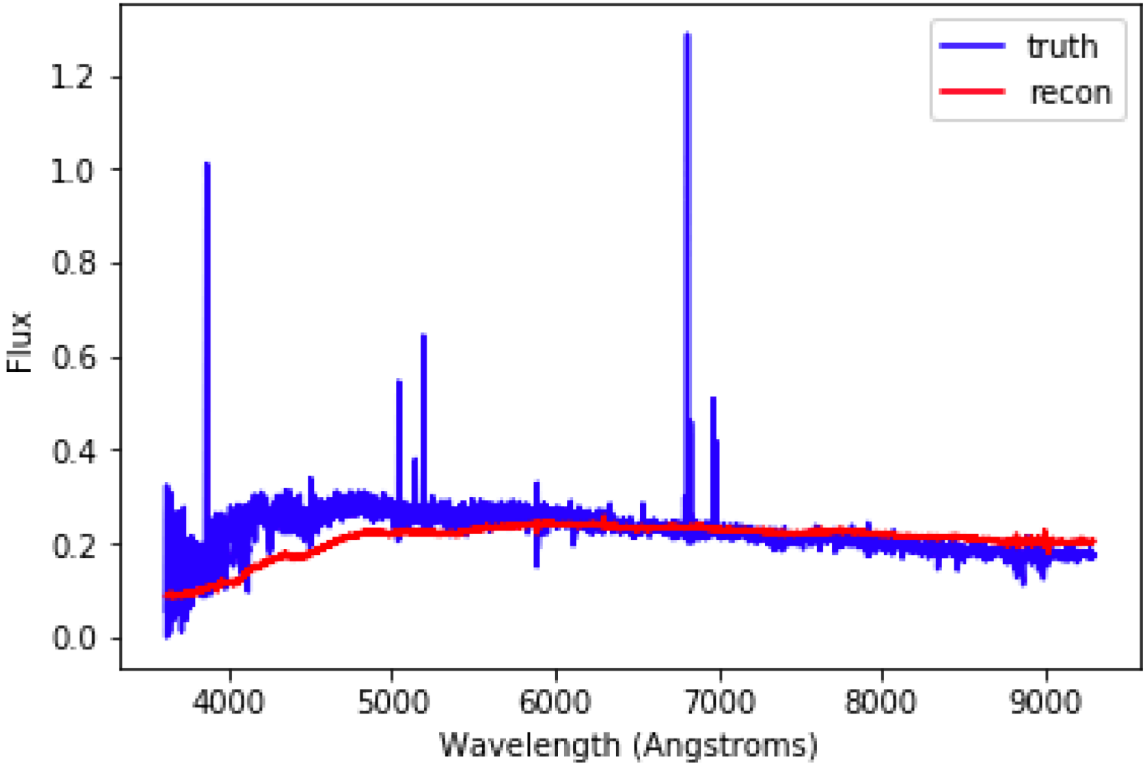


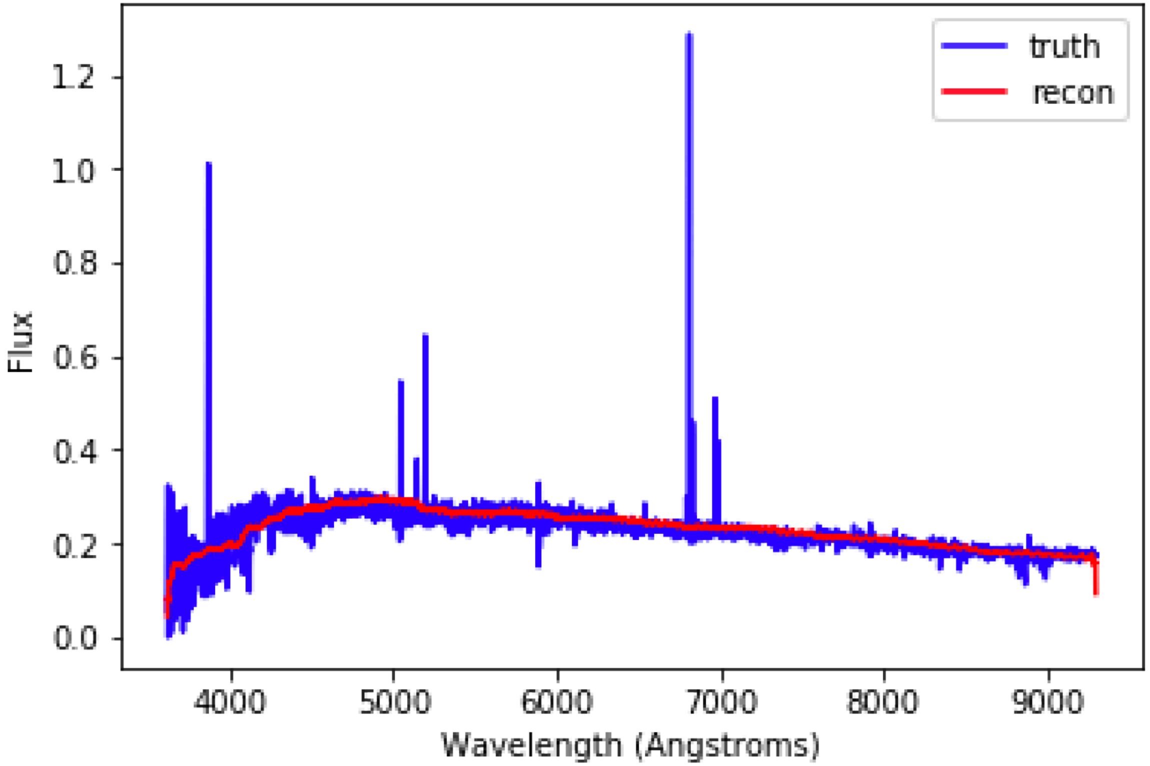
image original reconstructed residual

Reconstruction: Spectral Slice

2D CAE

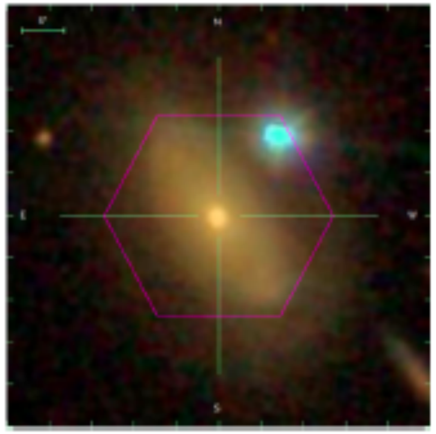


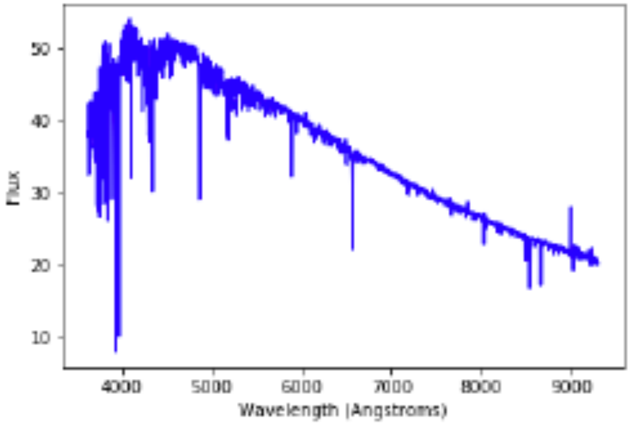
3D CAE

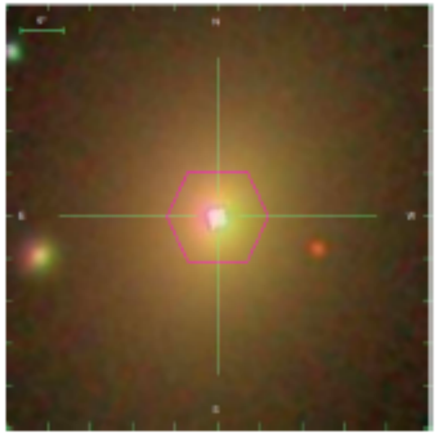


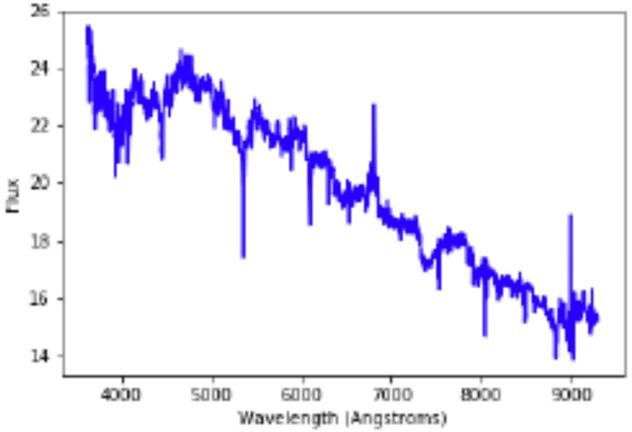
Anomaly Detection on Low-D Encoding

- Applied multiple anomaly detection methods, including isomap and k nearest neighbors.
- Could not recover our supernova example.
- But detected more extreme outliers:









foreground Milky Way star

blazar (beamed black hole accretion)

Looking Ahead

- Supernova features are subtle.
- Need to improve reconstruction of sharp features.
  - incorporate signal-to-noise ratio
  - more galaxies (4x more will be available)

- Supernovae are only one science driver for anomaly detection.
- Other rare, interesting, and potentially unknown phenomenon could be discovered.