

# Leveraging Machine Learning for High-Resolution Restoration of Satellite Imagery

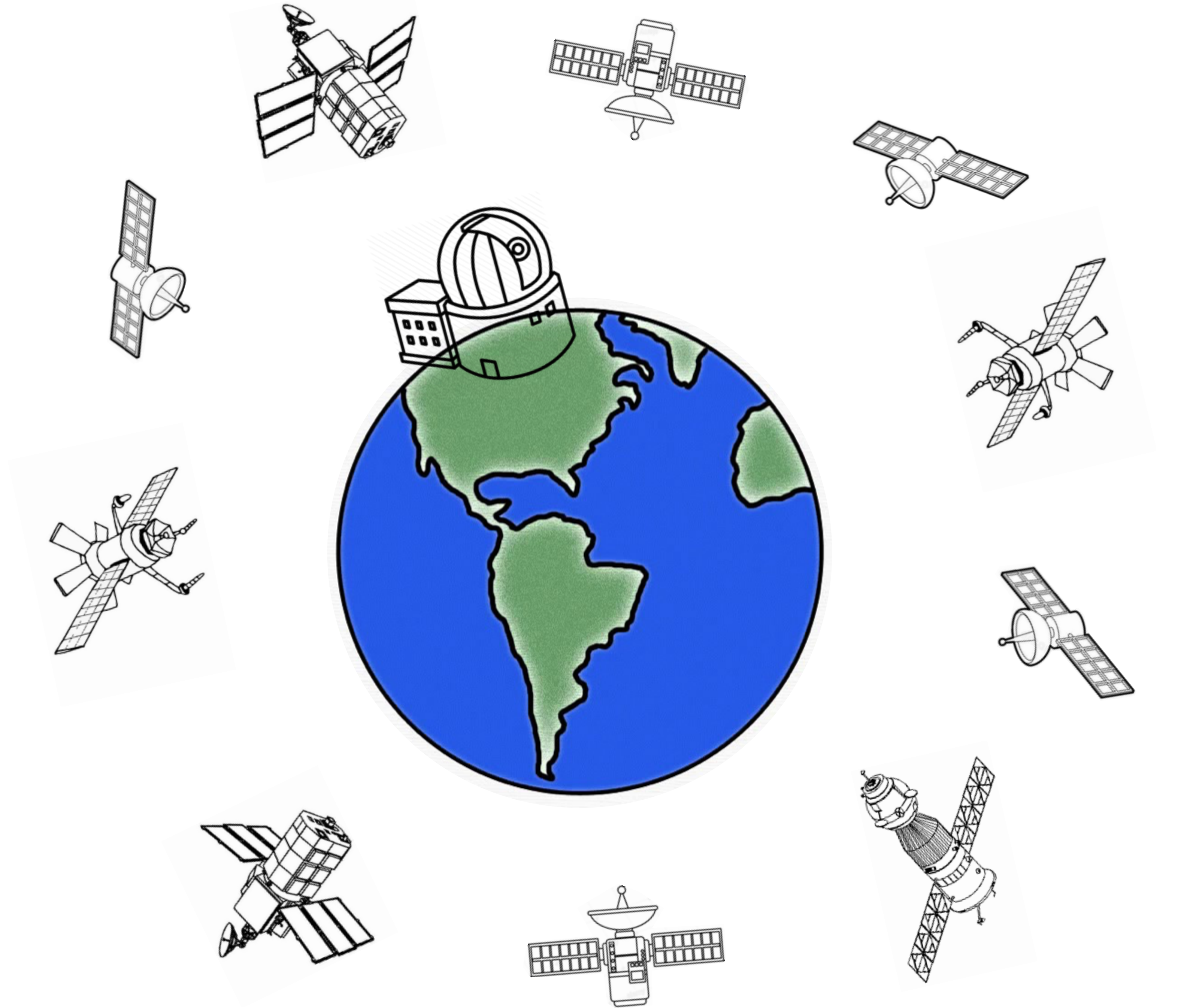
[Daniel L. Pimentel-Alarcón](#), Ashish Tiwari  
*Georgia State University*

Douglas A. Hope  
*Hope Scientific Renaissance LLC*

*Stuart M. Jefferies,*  
*Georgia State University*  
*Institute for Astronomy, University of Hawaii*

# Space Situational Awareness

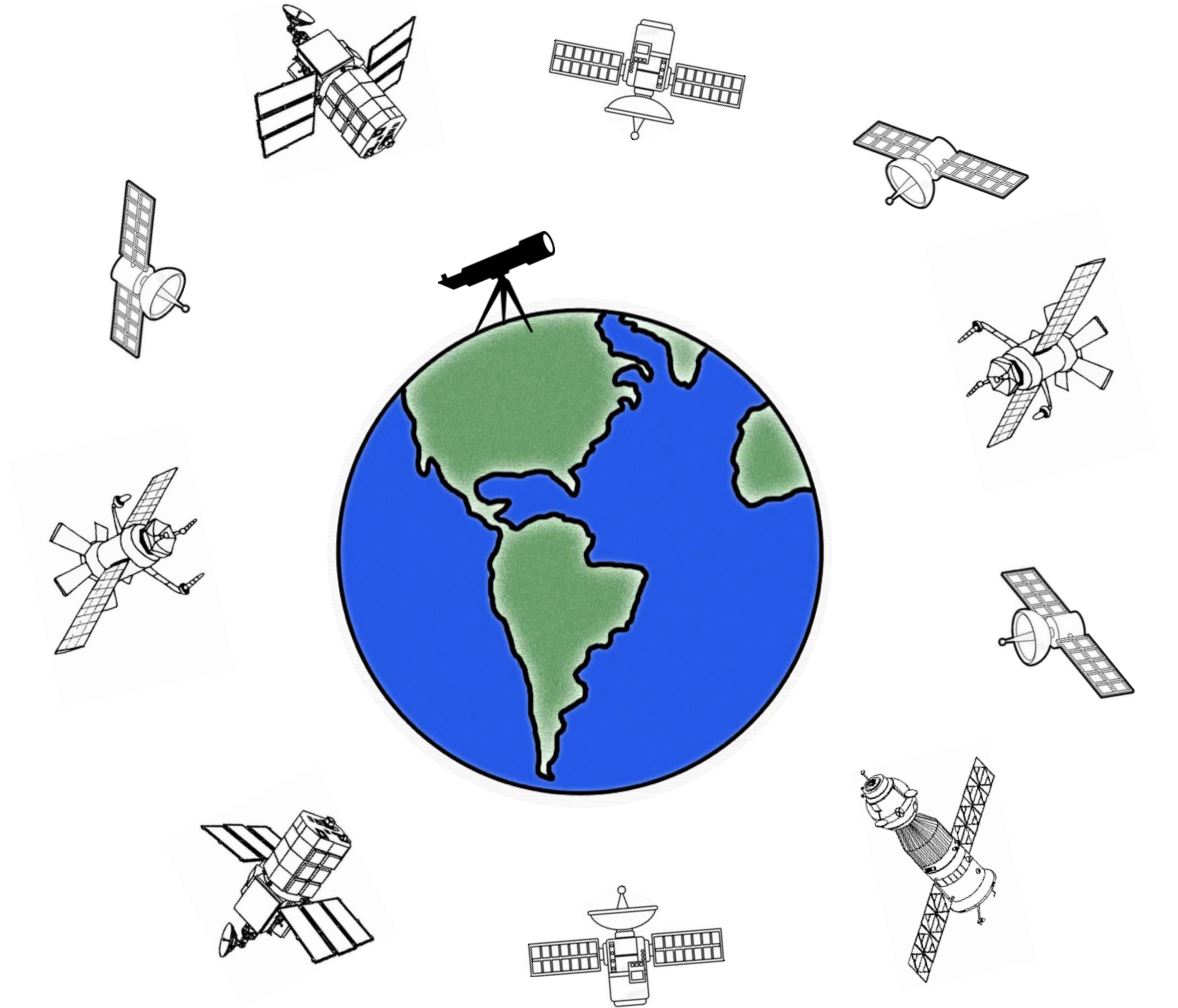
**Goal:** Know what's up there





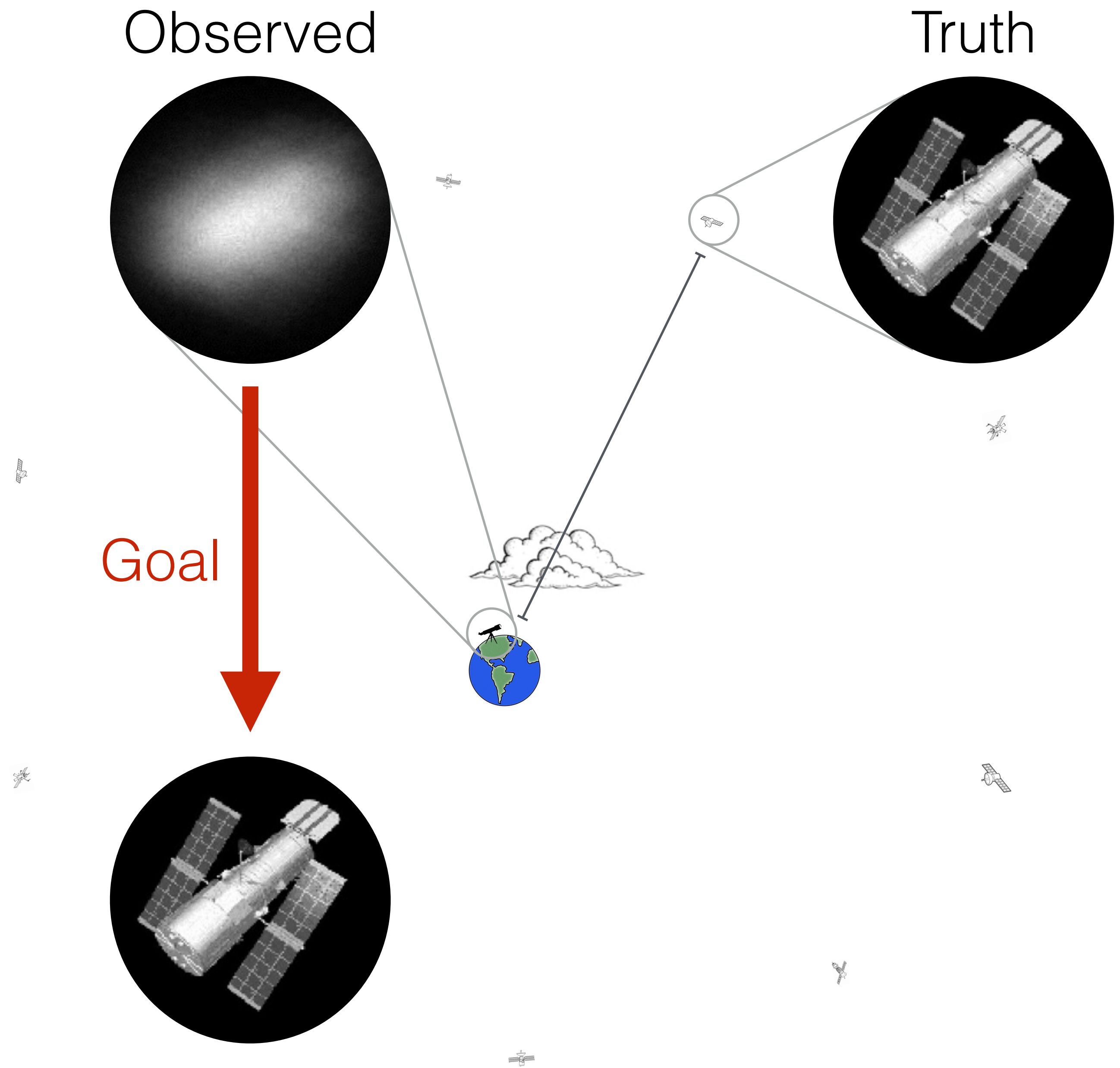
# Space Situational Awareness

**Goal:** Know what's up there



# Space Situational Awareness

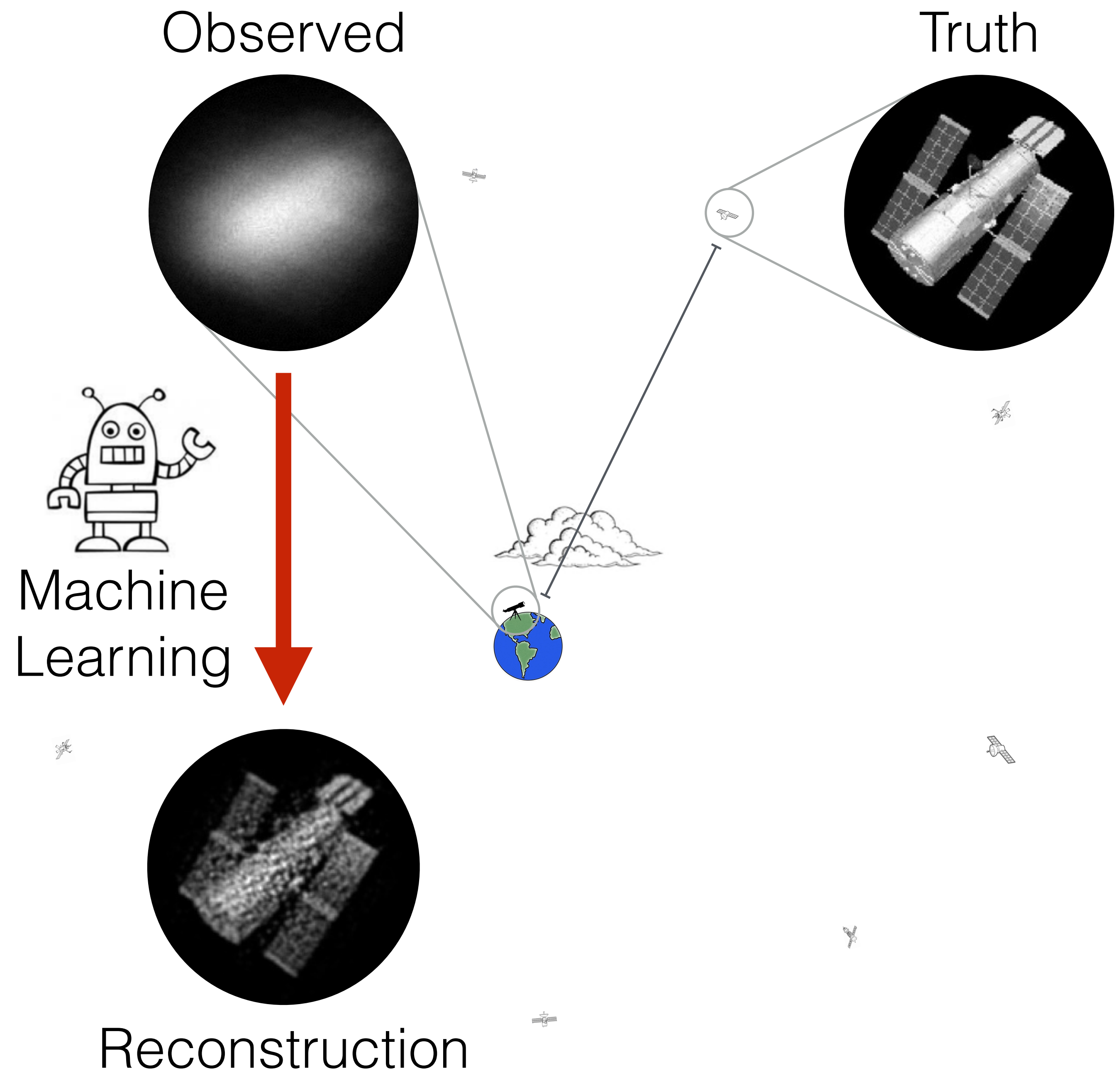
**Goal:** Know what's up there



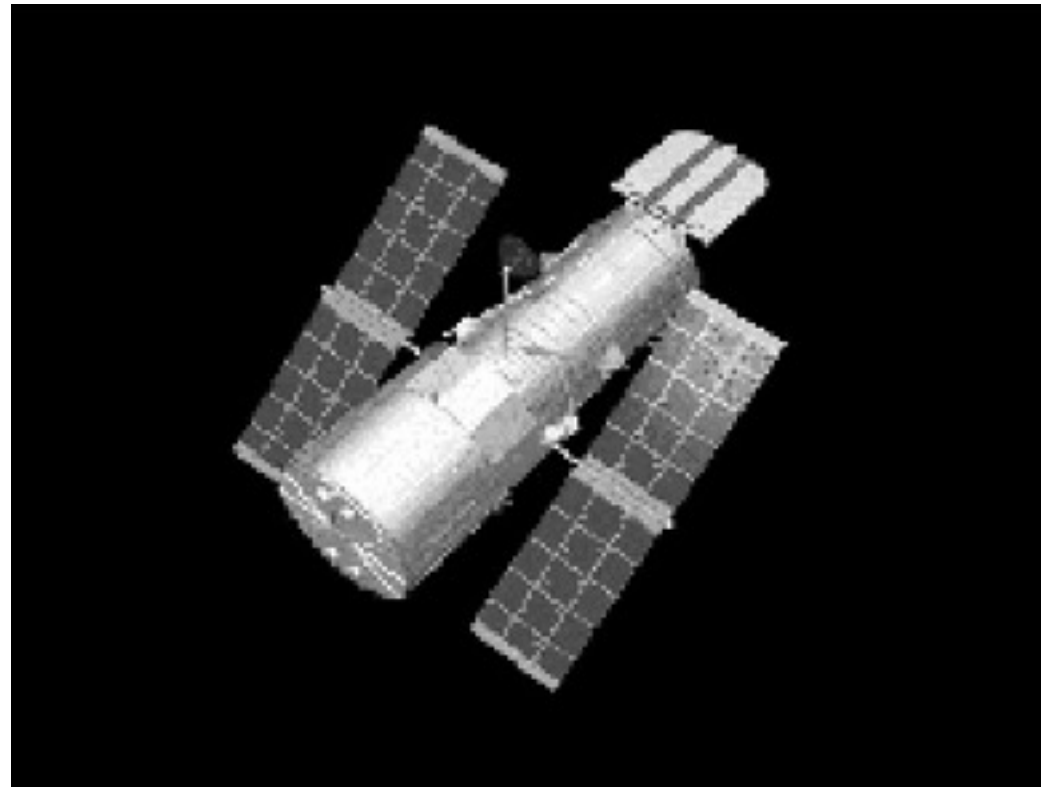


# Space Situational Awareness

**Goal:** Know what's up there

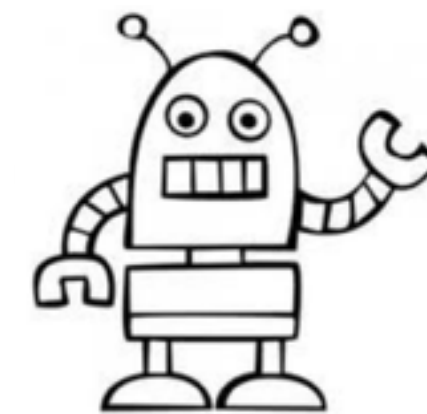
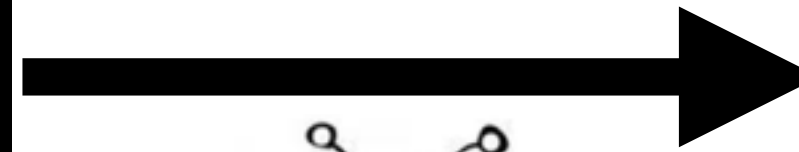
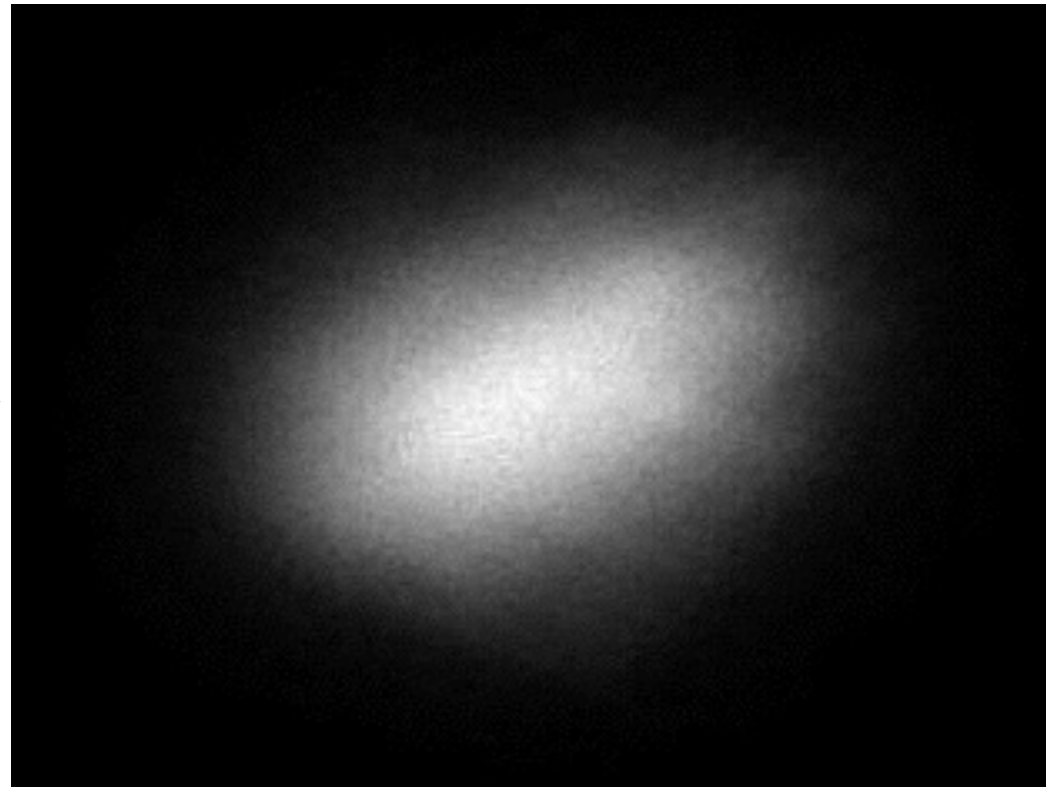


Truth



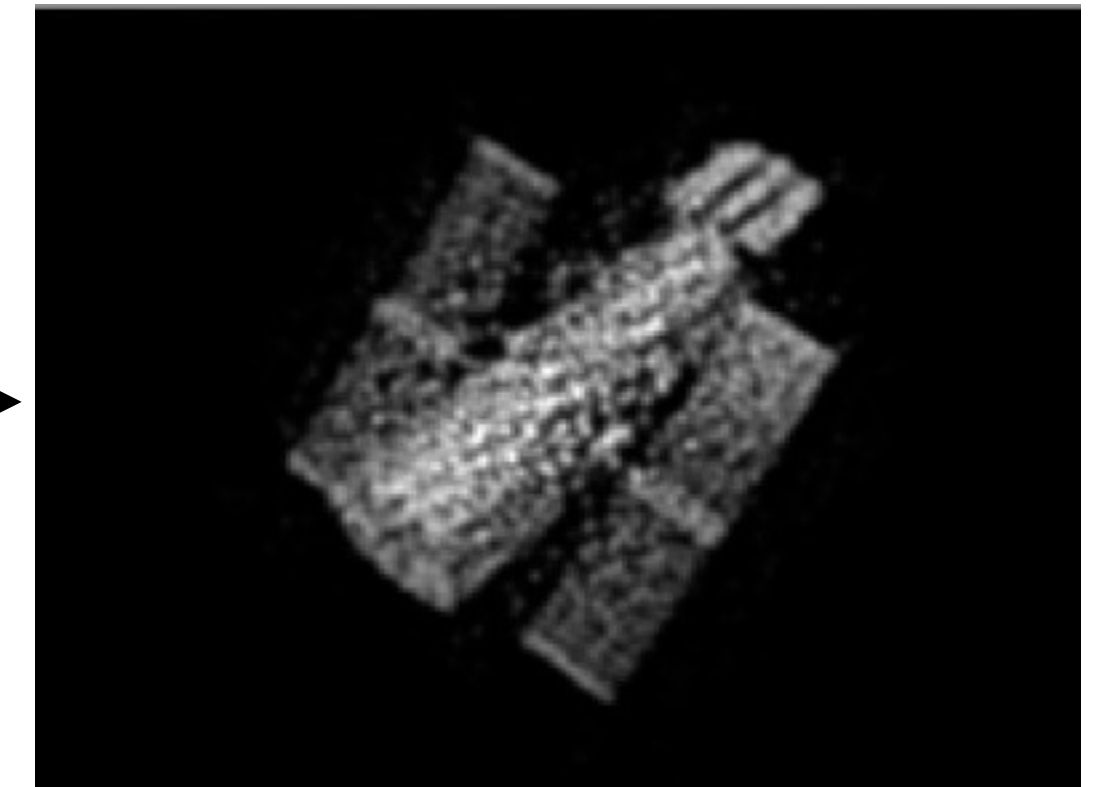
3m

Observed



Machine  
Learning

Reconstruction



# Our Results

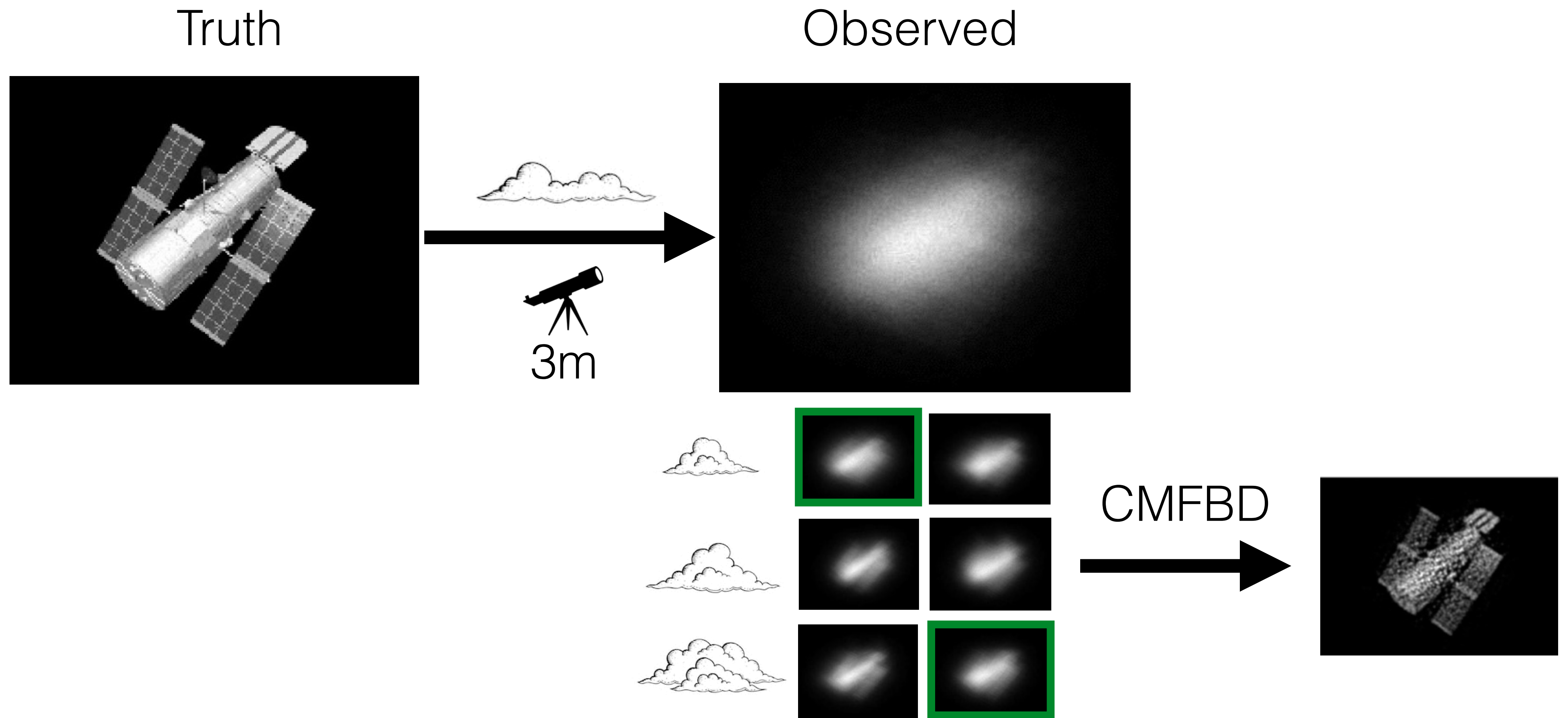
THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR  
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[www.filmratings.com](http://www.filmratings.com)

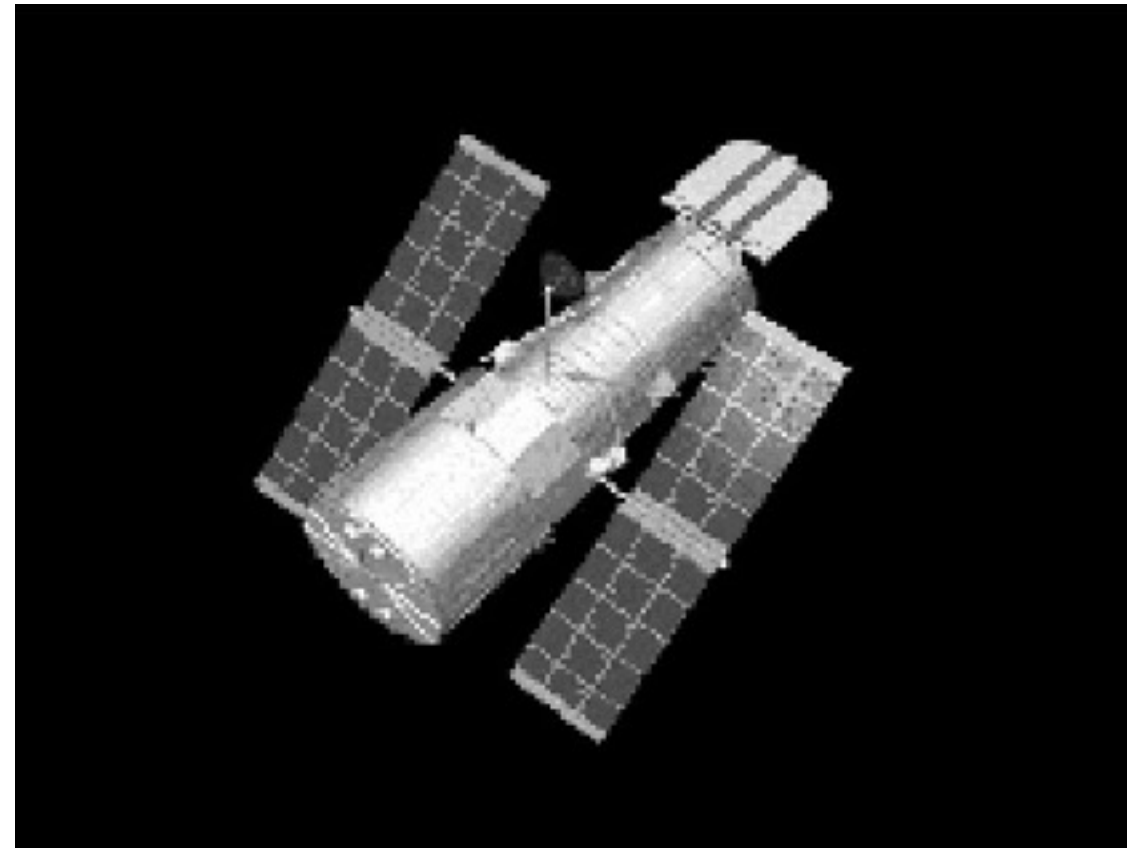
[www.mpaa.org](http://www.mpaa.org)



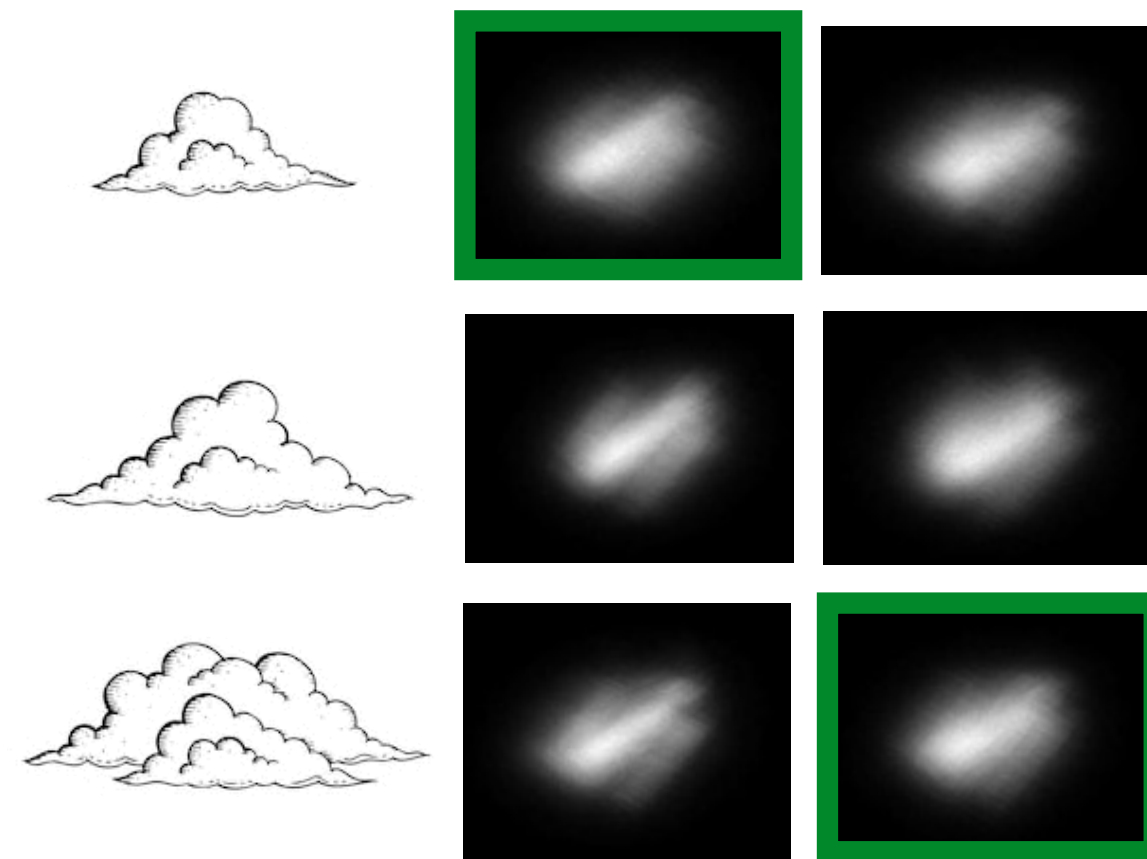
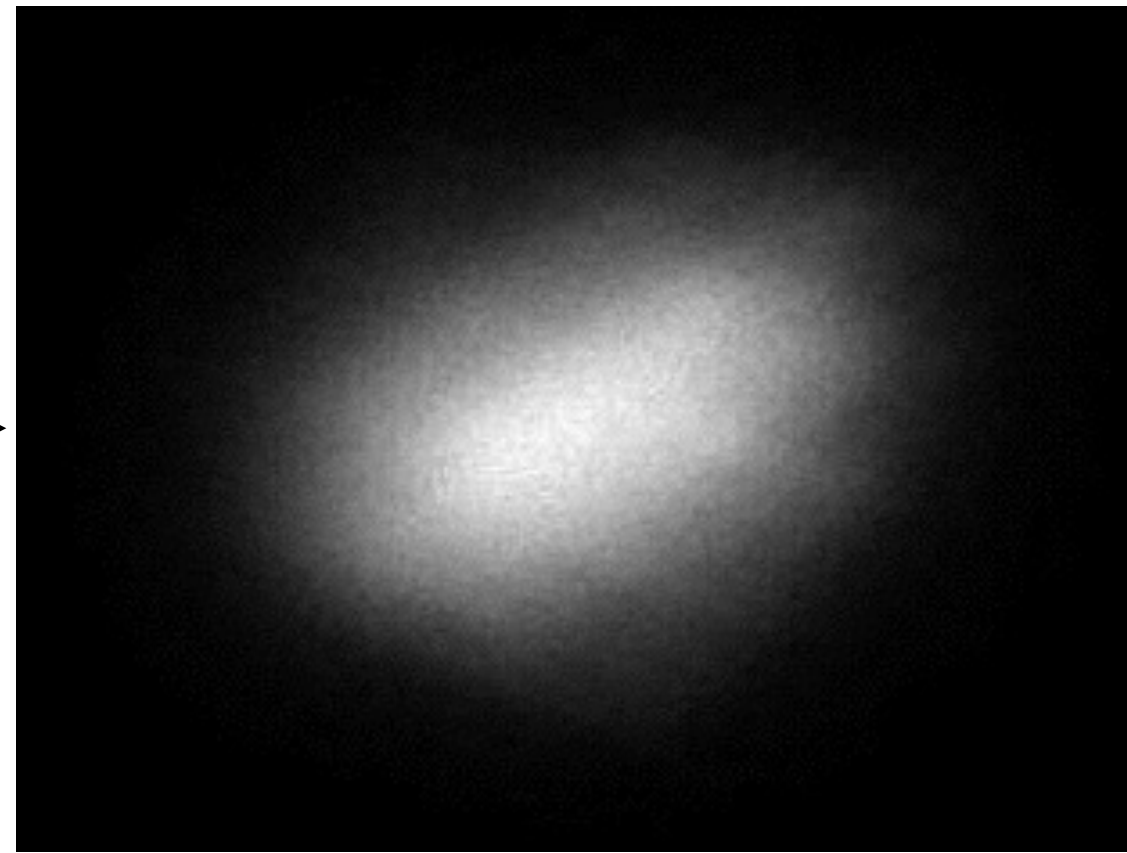
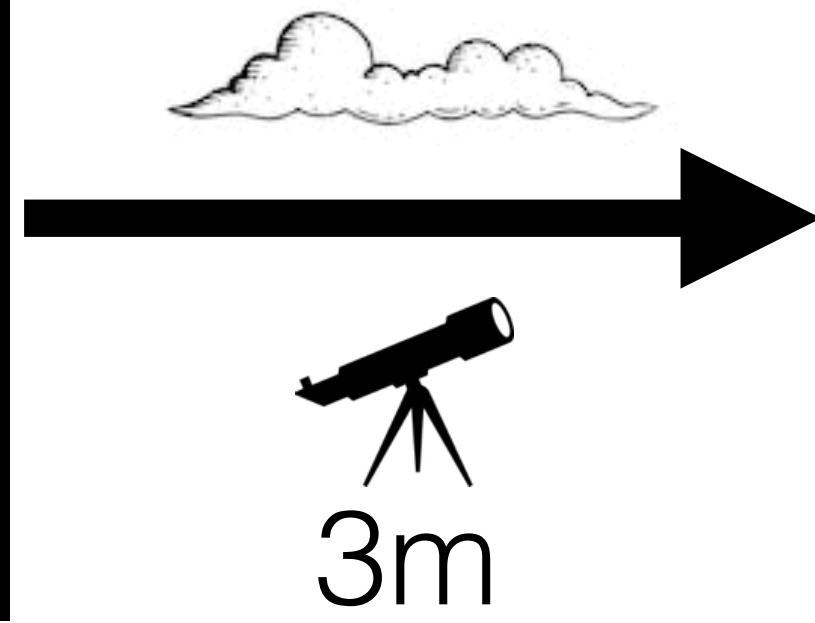
Really, we have many observations



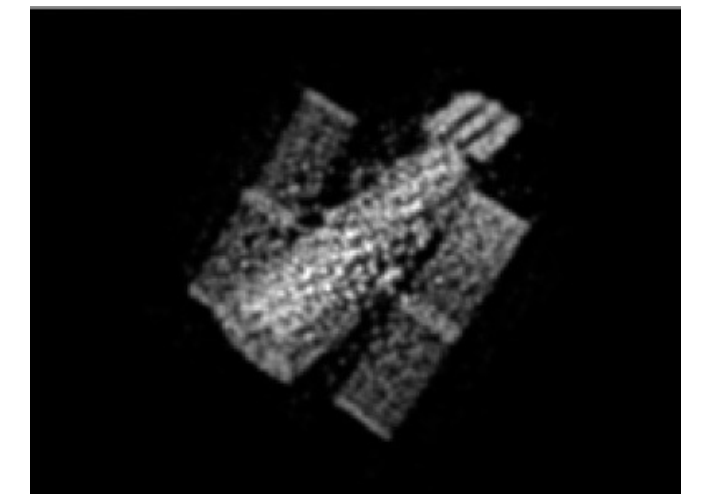
Truth



Observed



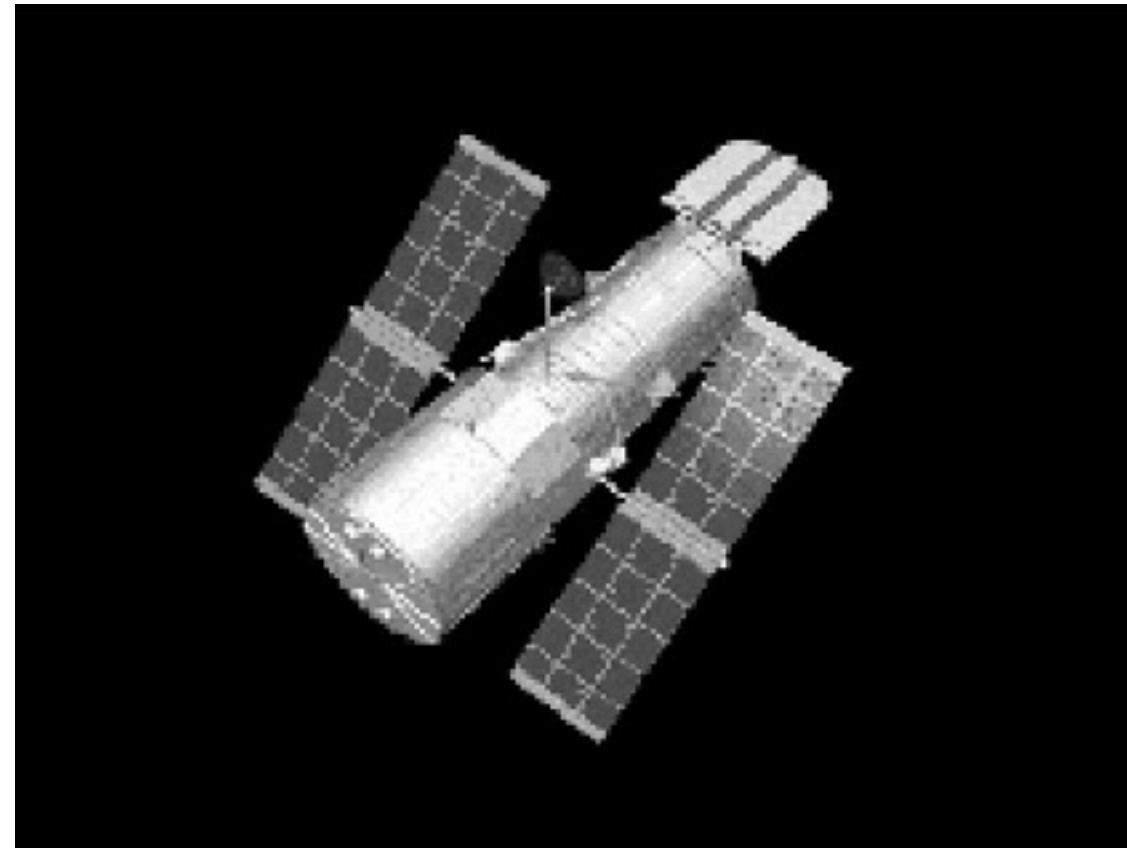
CMFBD



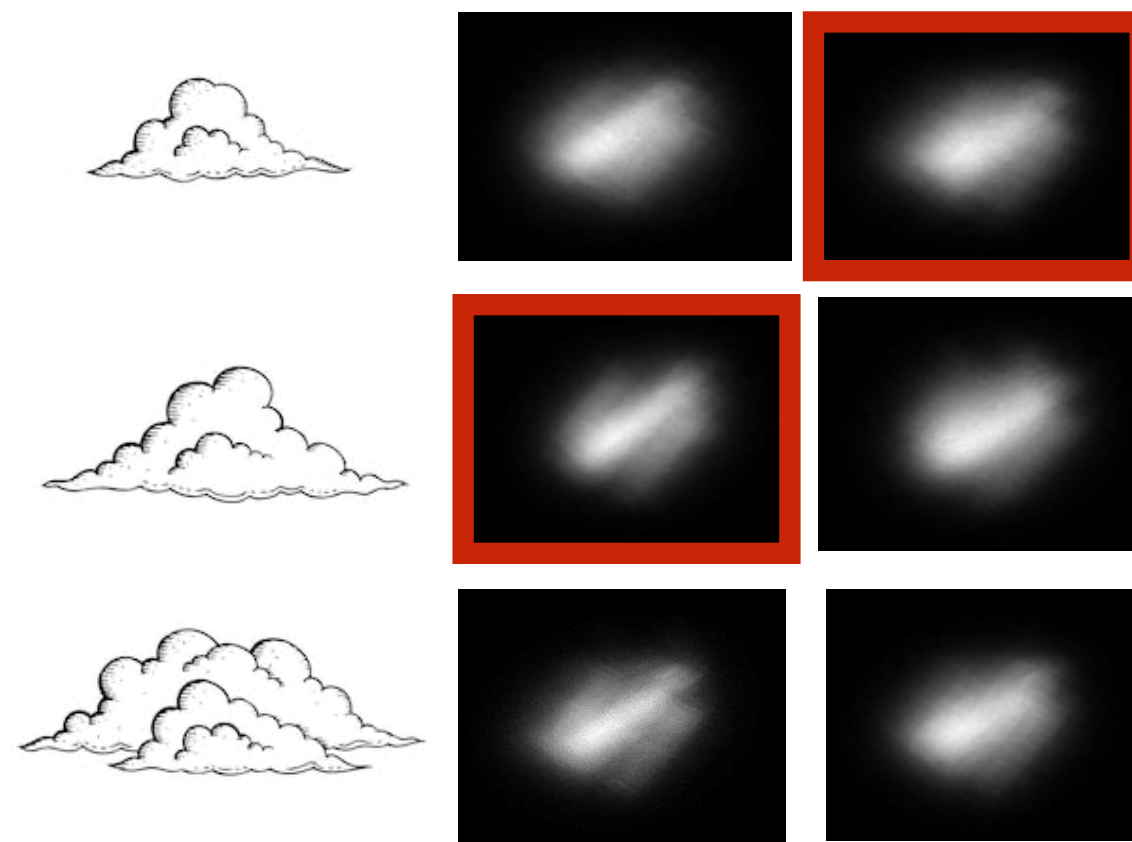
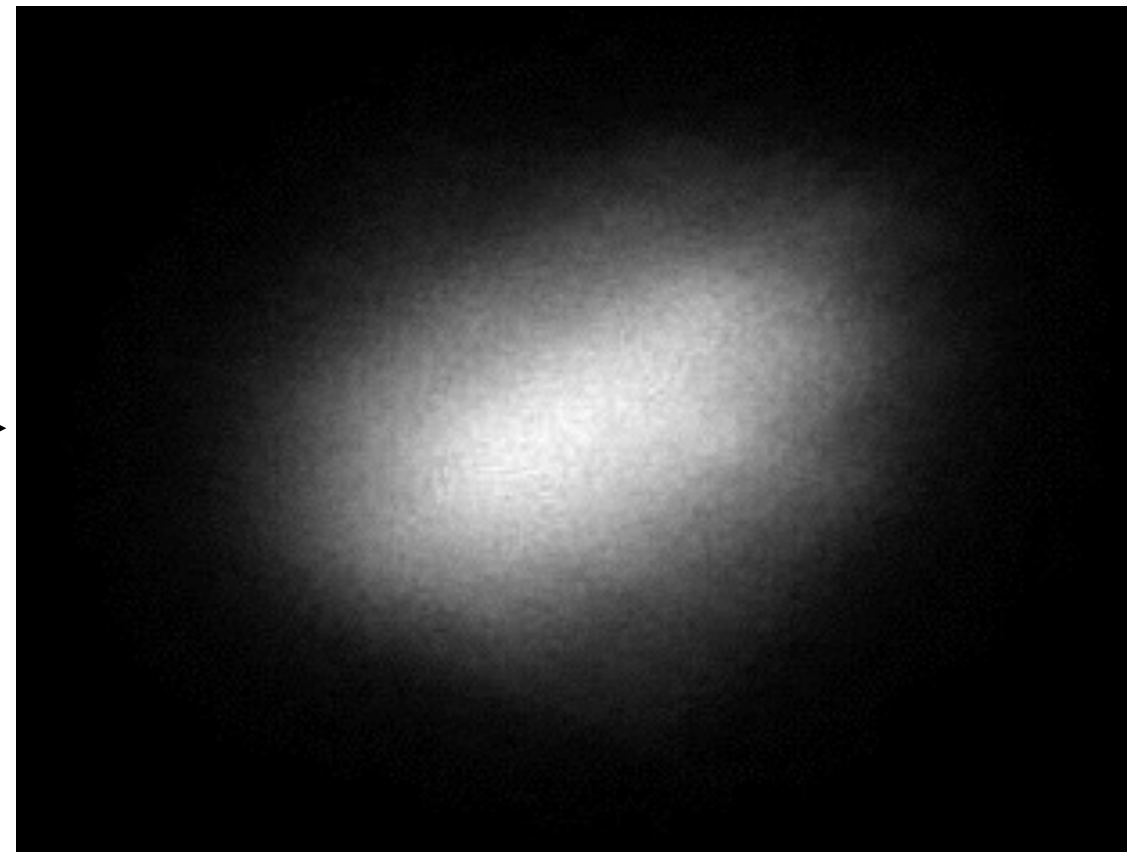
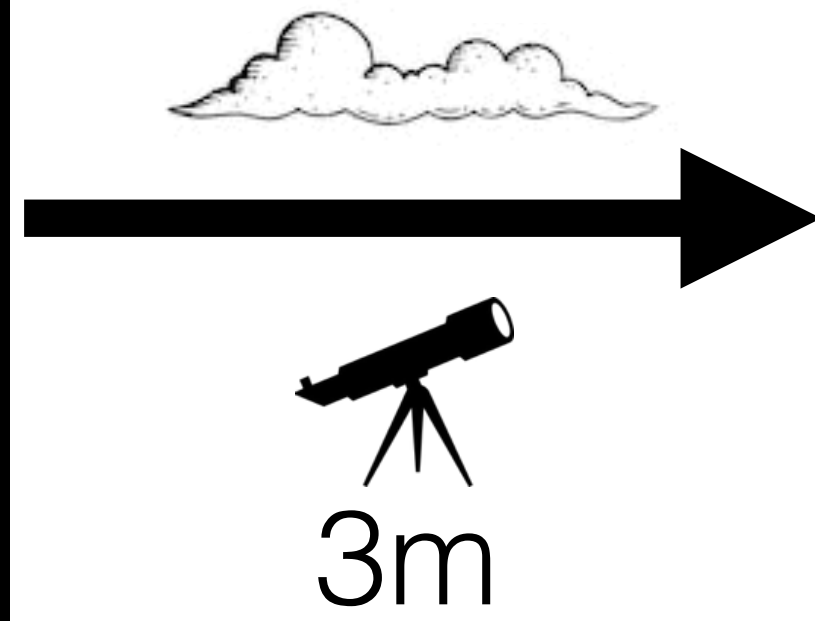
The Key is: Selecting The Right Frames

Good IN, Good OUT

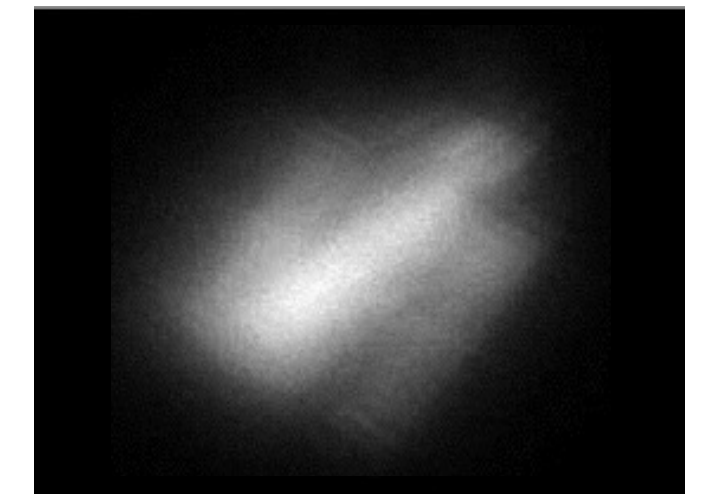
Truth



Observed



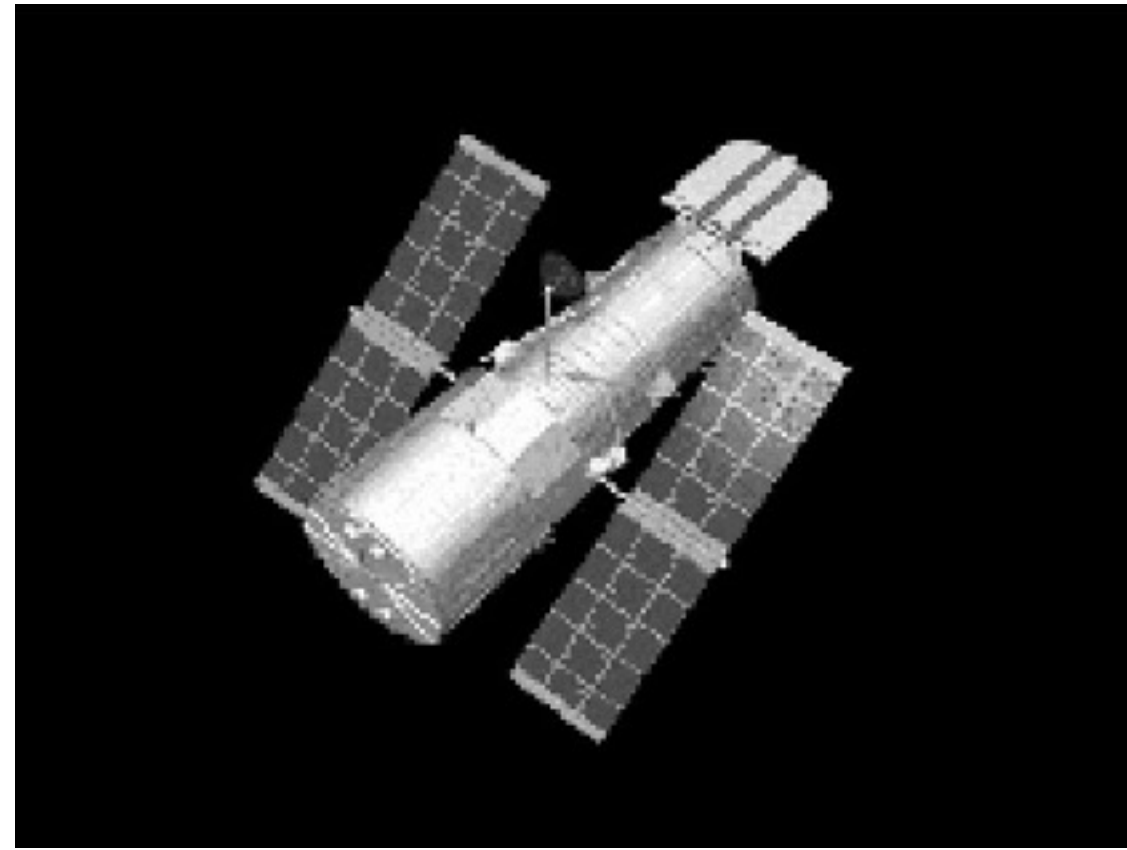
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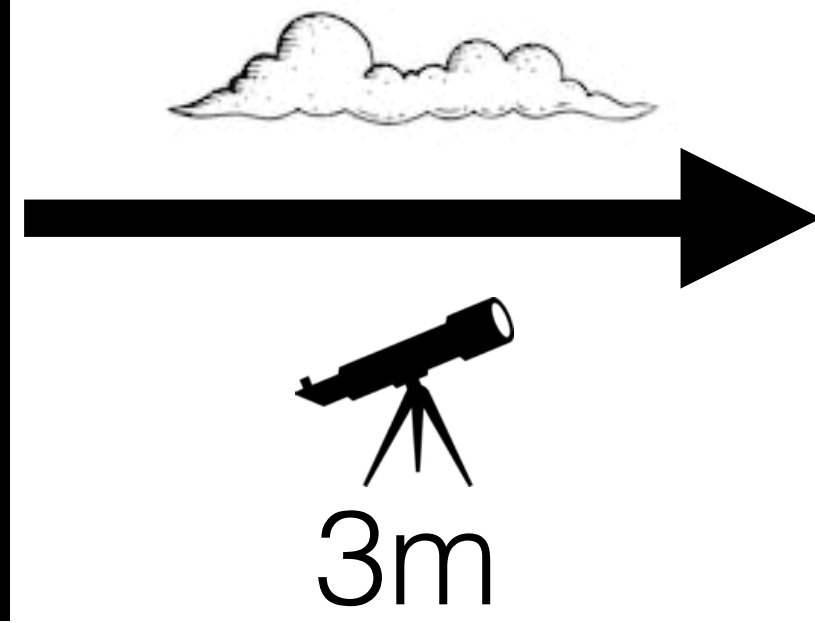
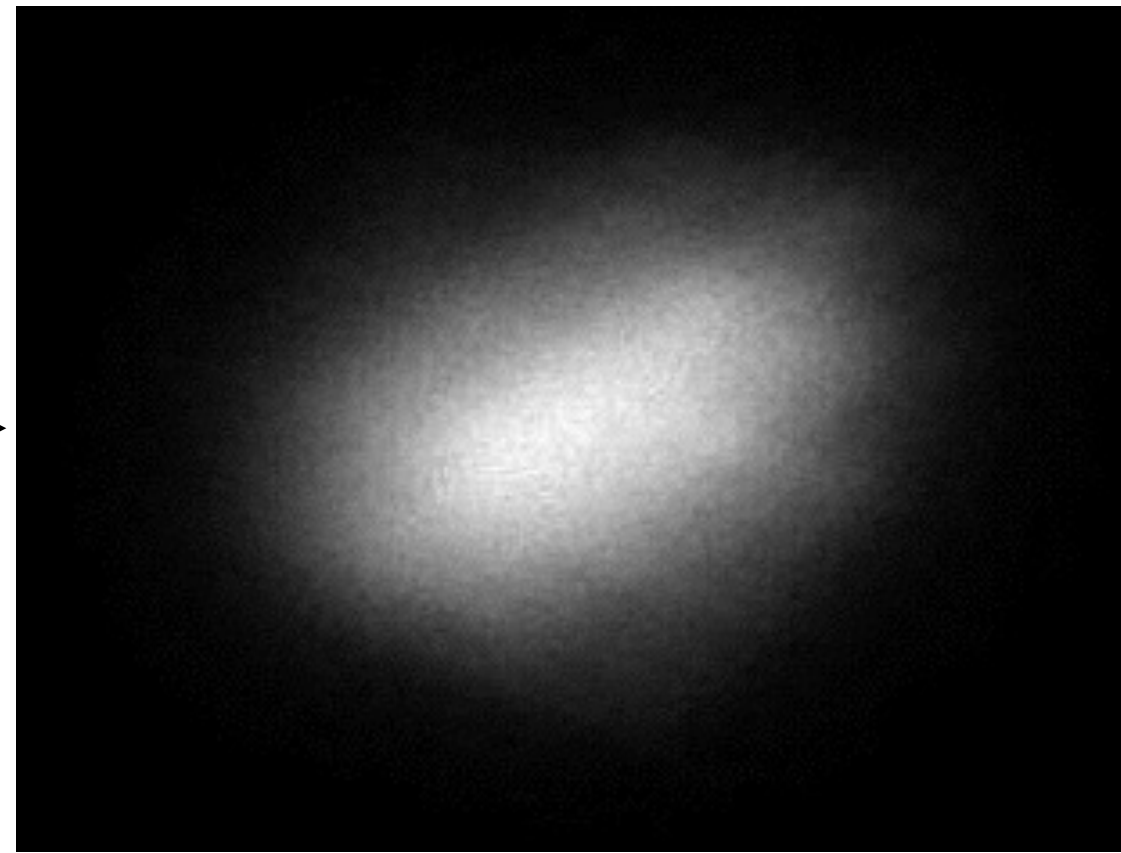
# The Key is: Selecting The Right Frames

Garbage IN, Garbage OUT

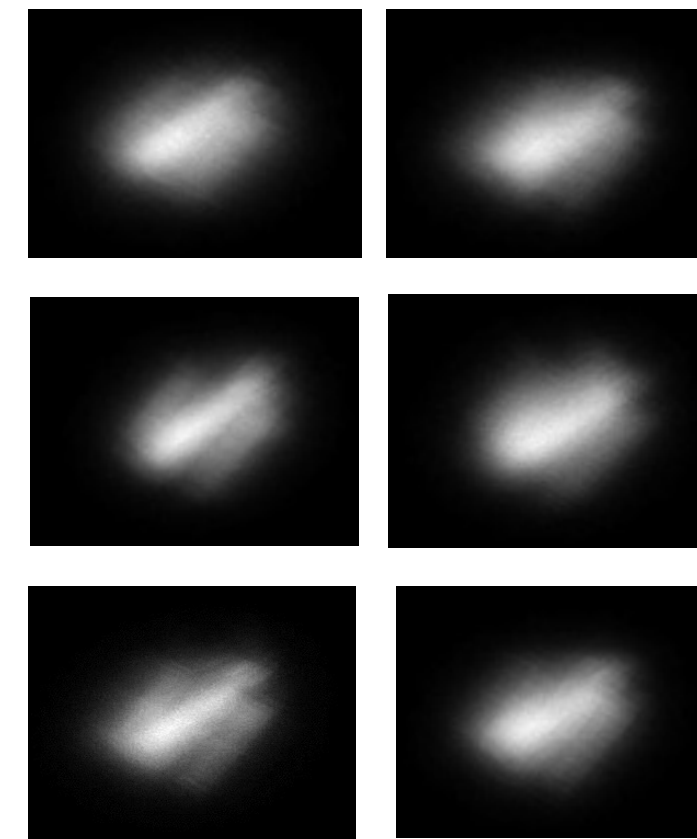
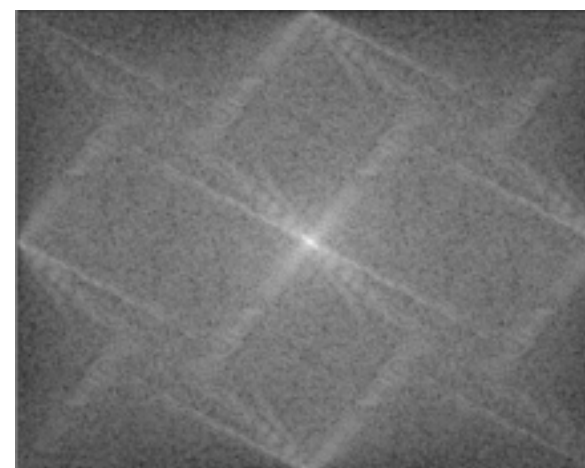
Truth



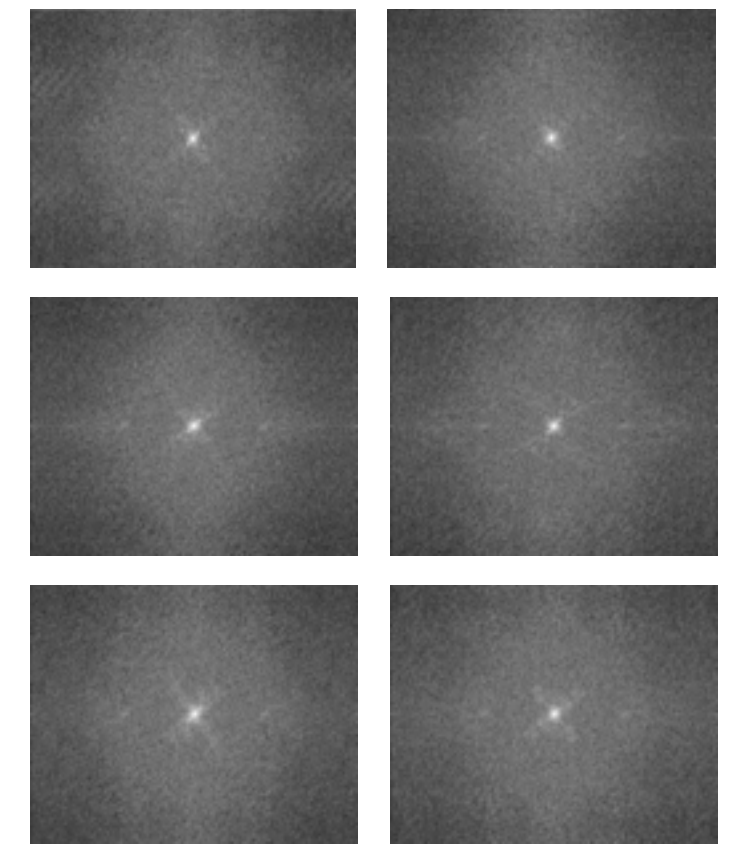
Observed



Fourier

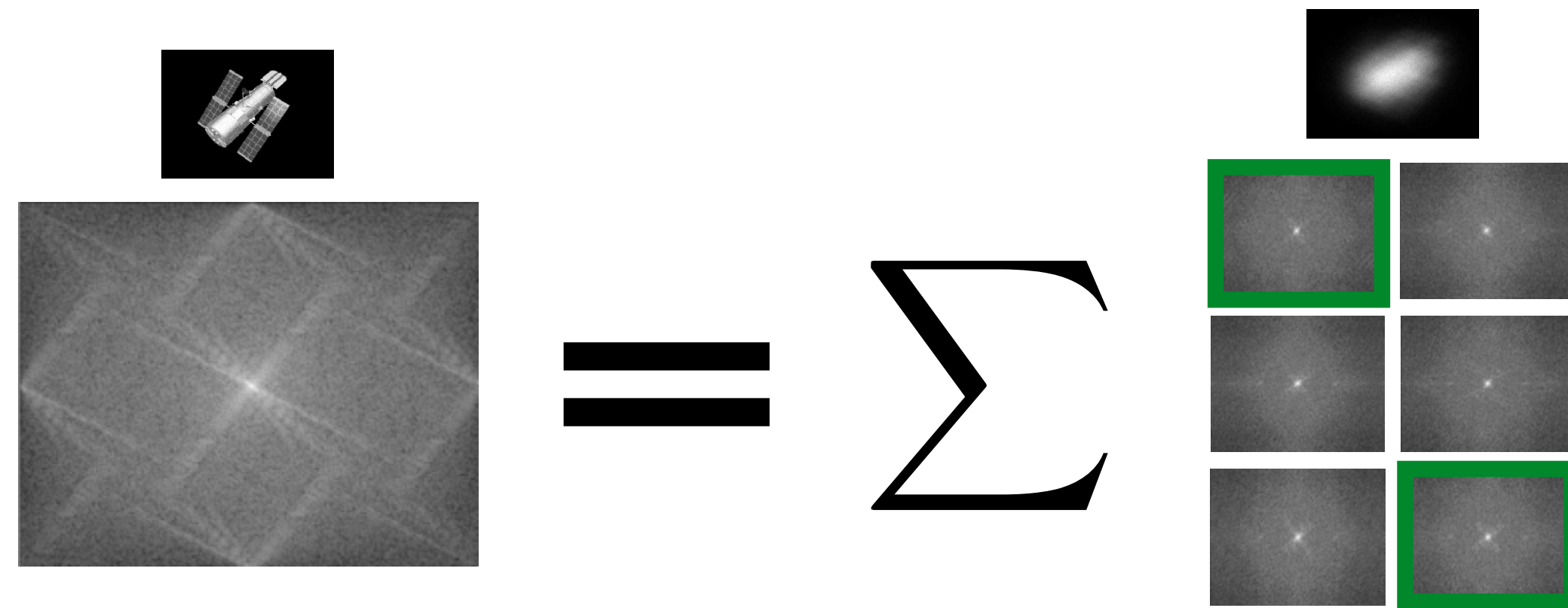


Fourier



How do we Select The Right Frames?

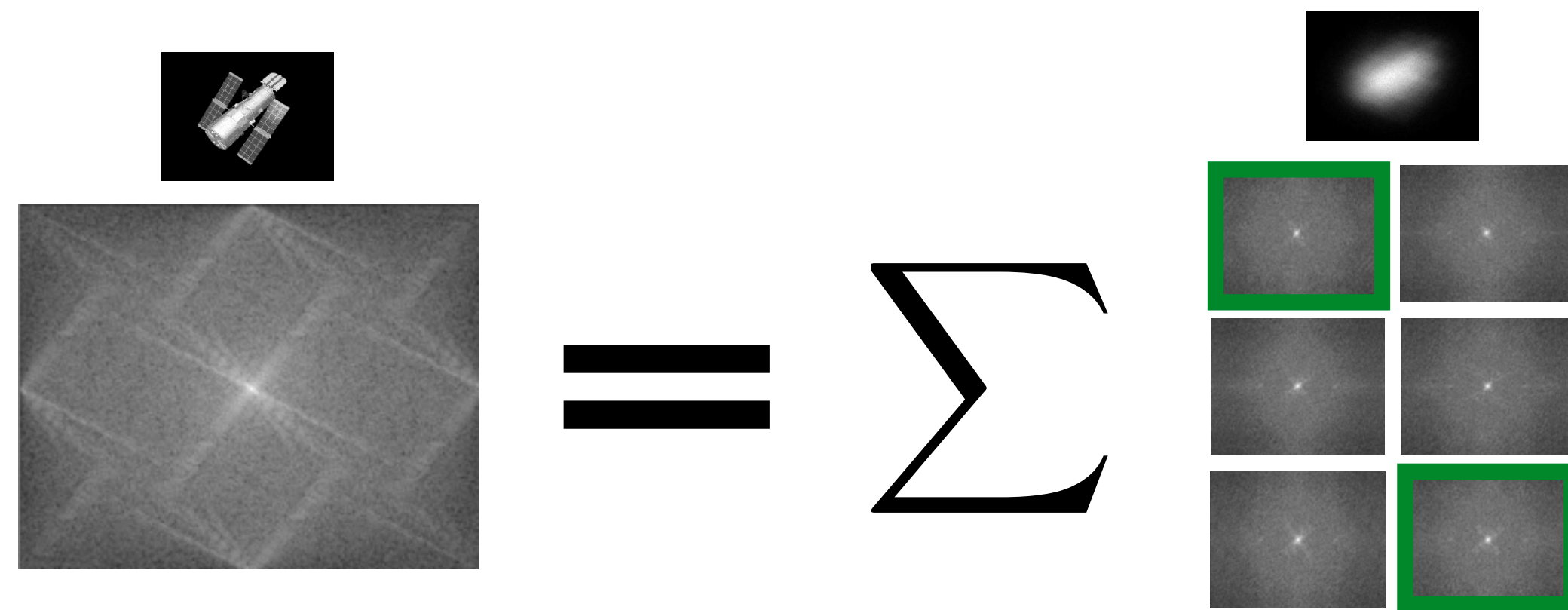




$$\mathbf{x} = \sum_{i=1}^N \omega_i \mathbf{y}_i$$

# A Flavor of our Ideas

Write  $\mathbf{x}$  as Sparse Linear Combination of  $\mathbf{y}_i$ 's



The diagram illustrates the sparse representation of an image. On the left, a target image (a satellite) is shown above a large, blurry version of itself. This is followed by an equals sign and a summation symbol  $\Sigma$ . To the right of the summation is a 3x2 grid of six small, blurry images, which form a dictionary. The top-left and bottom-right images in this grid are highlighted with green borders, indicating they are the selected basis elements for the reconstruction.

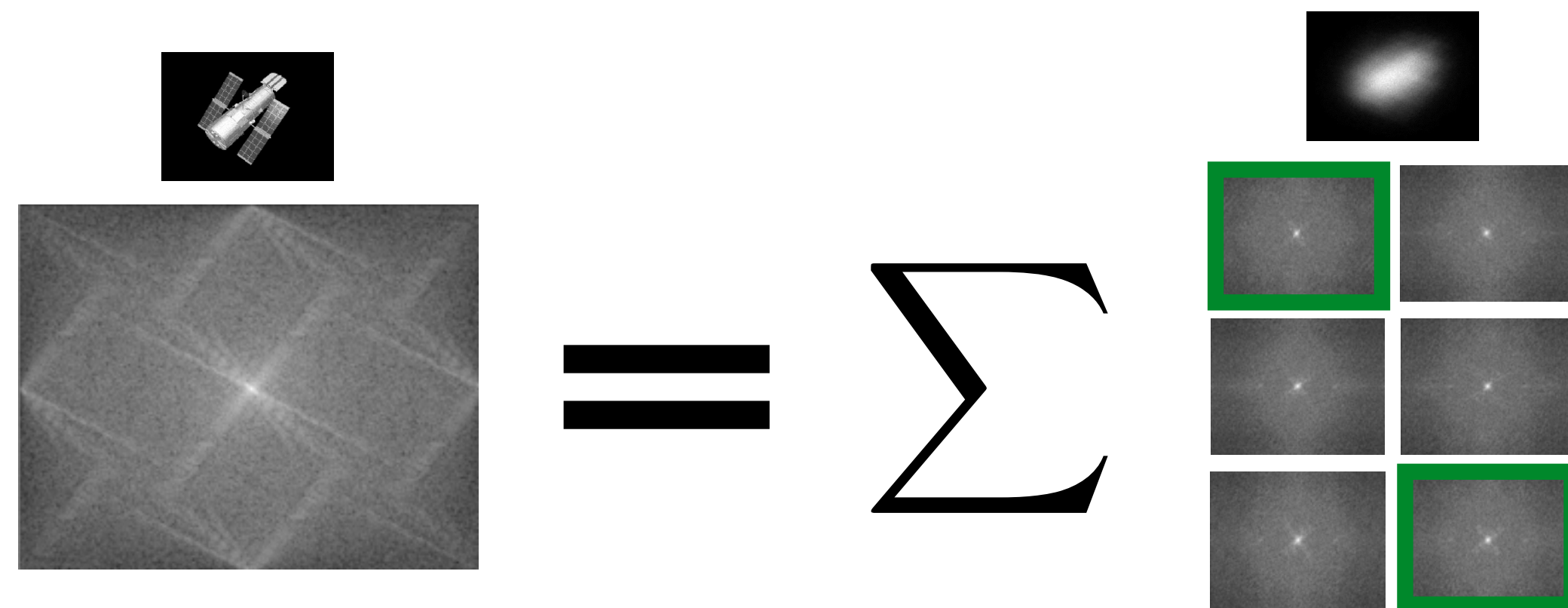
$$\arg \min_{\omega \in \mathbb{R}^N} \|\omega\|_0 \quad \text{subject to} \quad \mathcal{X} = \sum_{i=1}^N \omega_i \mathcal{Y}_i$$

NP-Hard

The diagram shows the optimization problem for finding a sparse representation. The objective function is  $\|\omega\|_0$ , which is circled in red. A red arrow points from the text "NP-Hard" to this circled term. The constraint is  $\mathcal{X} = \sum_{i=1}^N \omega_i \mathcal{Y}_i$ , where  $\omega_i$  is circled in green.

# A Flavor of our Ideas

Write  $\mathcal{X}$  as Sparse Linear Combination of  $\mathcal{Y}_i$ 's



$$\arg \min_{\omega \in \mathbb{R}^N} \|\omega\|_1 \quad \text{subject to} \quad \mathcal{X} = \sum_{i=1}^N \omega_i \mathcal{Y}_i$$

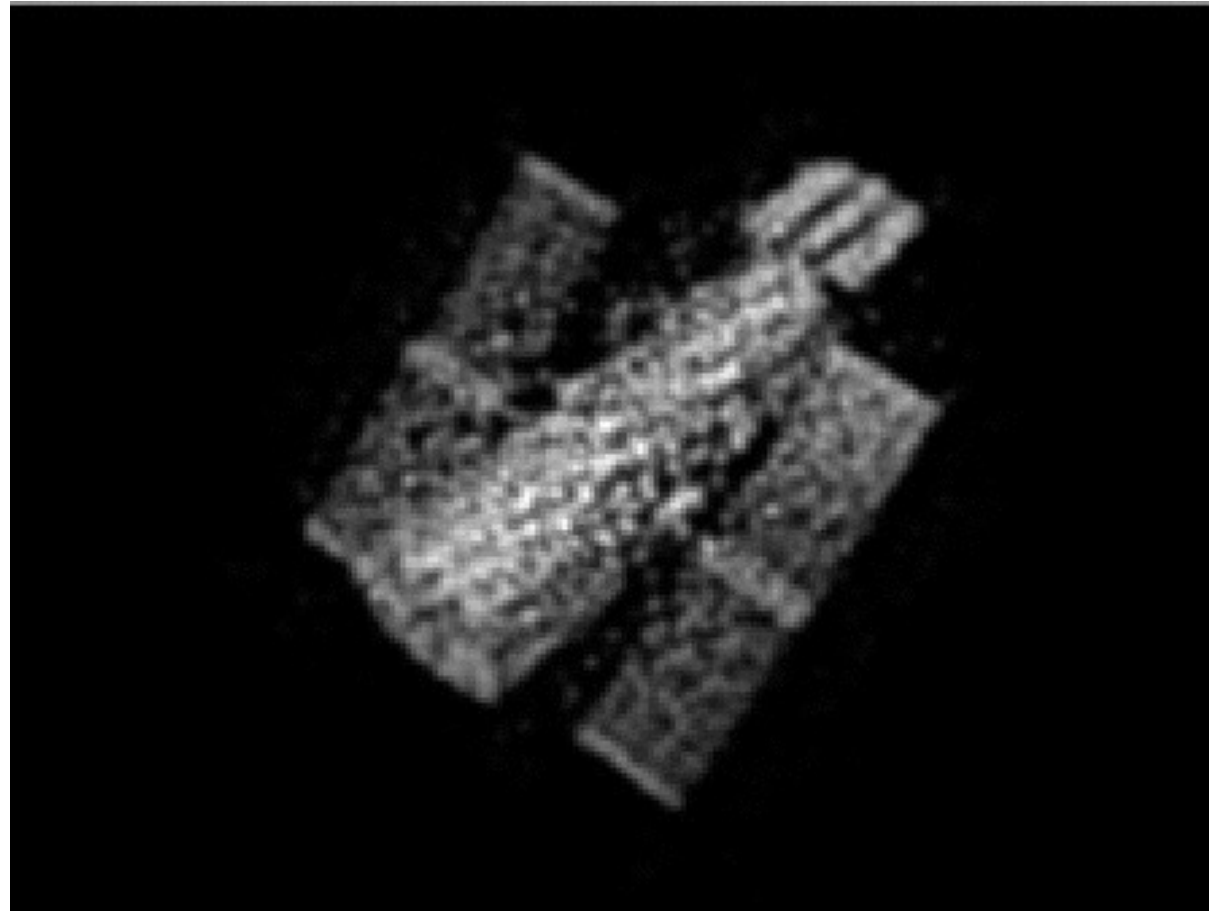
Convex :)

# A Flavor of our Ideas

Write  $\mathcal{X}$  as Sparse Linear Combination of  $\mathcal{Y}_i$ 's

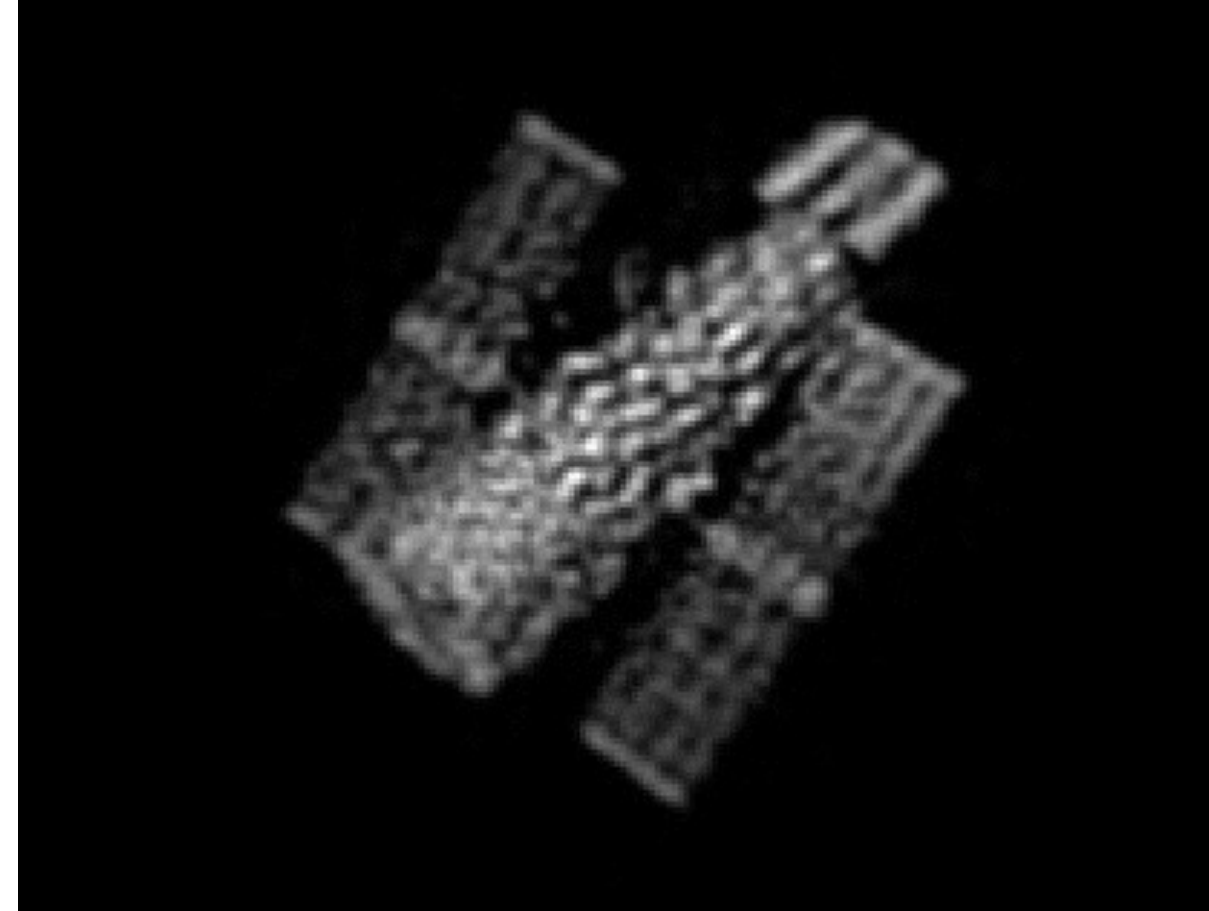


**This Work**



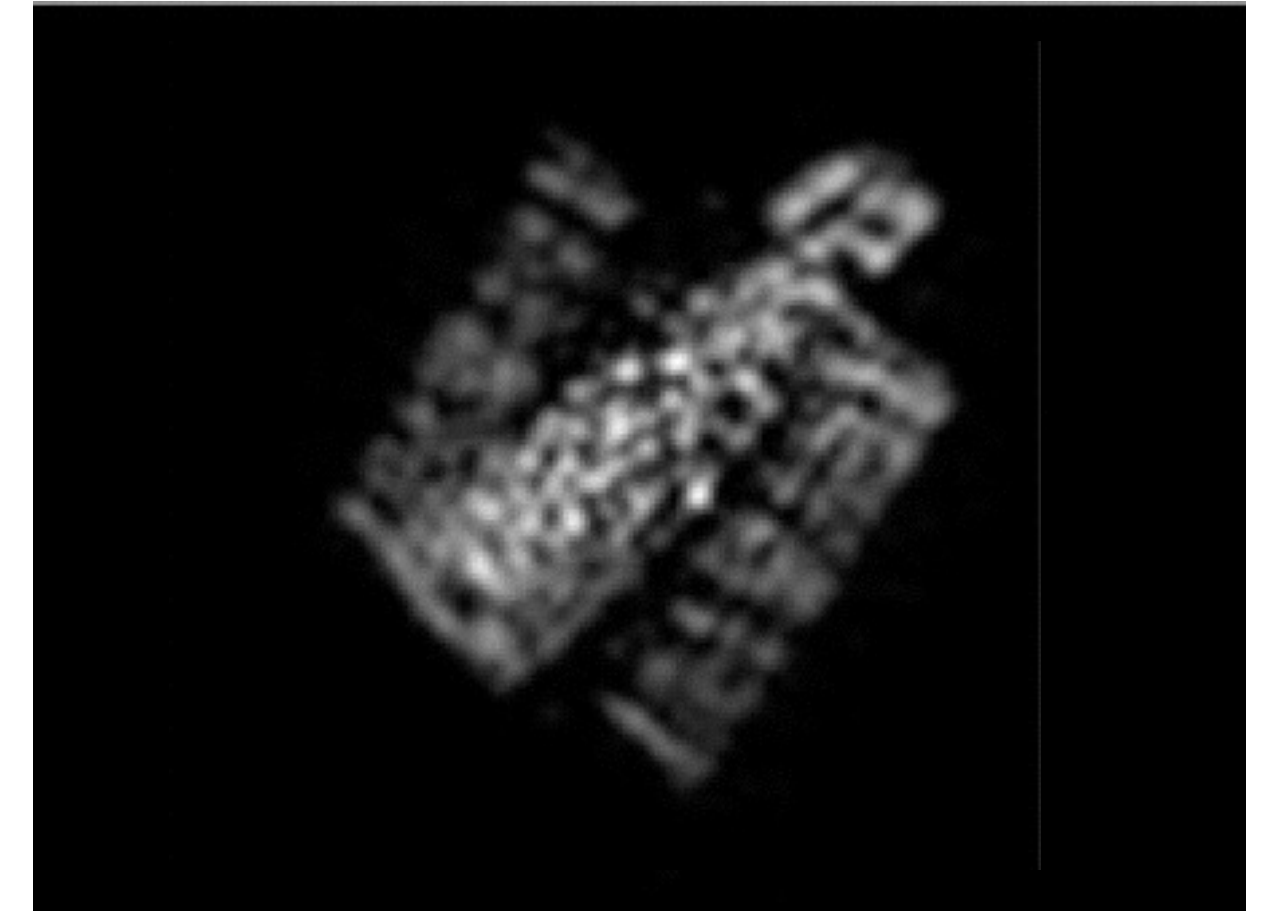
**RMSE=0.337**

State-of-the-Art



RMSE=0.352

Random



RMSE=0.431

# The Numbers

Outperforms State-of-the-Art

But wait...

These are NOT even the Good News!

The good news are:

We are Just Scratching the Surface!

# The Good News Are...

- This is the “Basic” formulation:

$$\arg \min_{\boldsymbol{\omega} \in \mathbb{R}^N} \|\boldsymbol{\omega}\|_1 \quad \text{subject to} \quad \boldsymbol{x} = \sum_{i=1}^N \omega_i \boldsymbol{y}_i$$

We can include:

- Outliers

$$\arg \min_{\boldsymbol{\omega} \in \mathbb{R}^N} \|\boldsymbol{\omega}\|_1 \quad \text{subject to} \quad \boldsymbol{x} = \sum_{i=1}^N \omega_i \boldsymbol{y}_i + \boldsymbol{s}$$

- More Regularizers

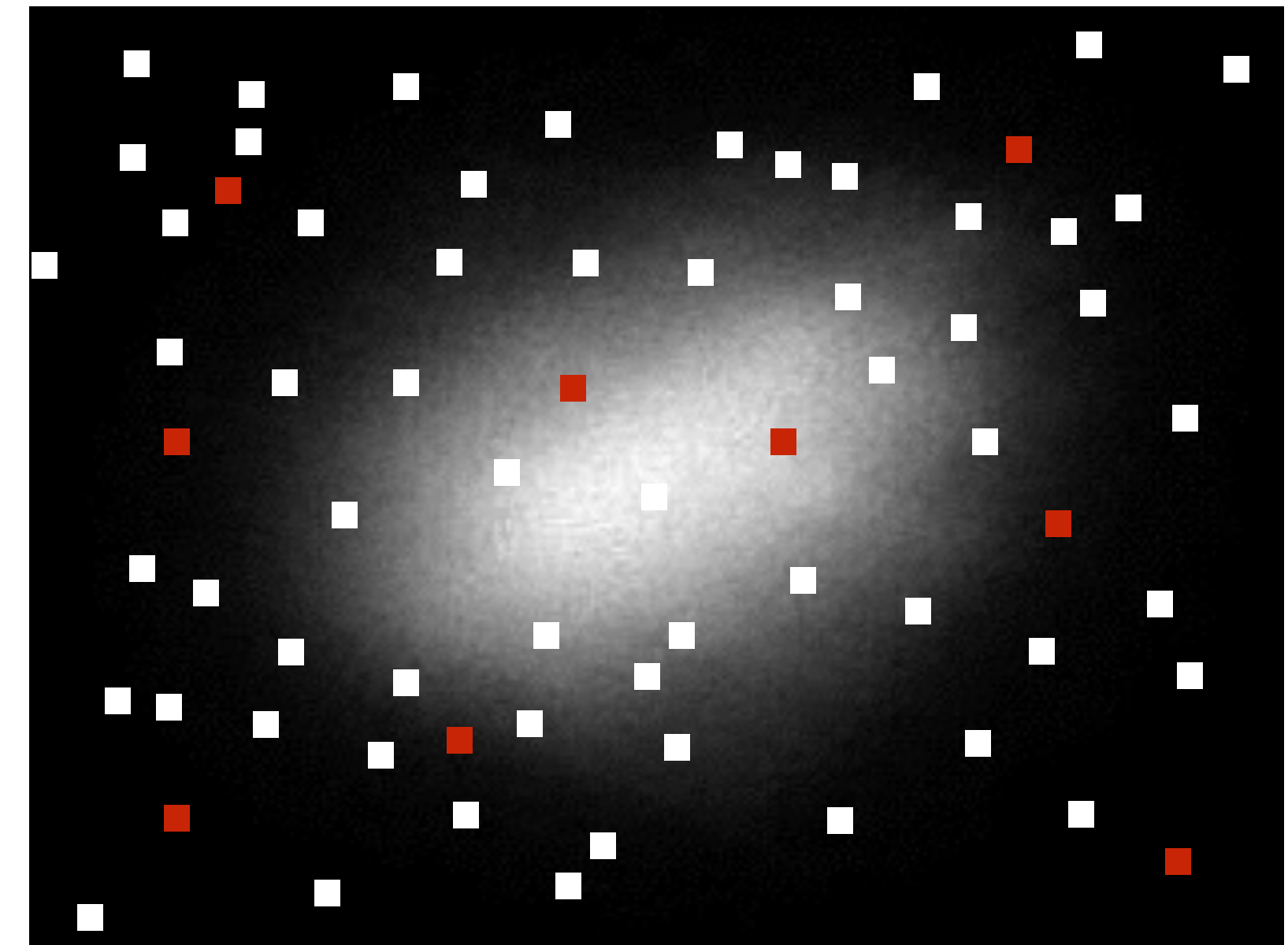
$$\arg \min_{\boldsymbol{\omega} \in \mathbb{R}^N} \|\boldsymbol{\omega}\|_1 + \lambda \|\boldsymbol{\omega}\|_2 \quad \text{subject to} \quad \boldsymbol{x} = \sum_{i=1}^N \omega_i \boldsymbol{y}_i$$

- Dimensionality Reduction

$$\arg \min_{\boldsymbol{u}, \boldsymbol{D}, \boldsymbol{v}} \|\boldsymbol{x} - \boldsymbol{u} \boldsymbol{D} \boldsymbol{v}^T\|_F$$

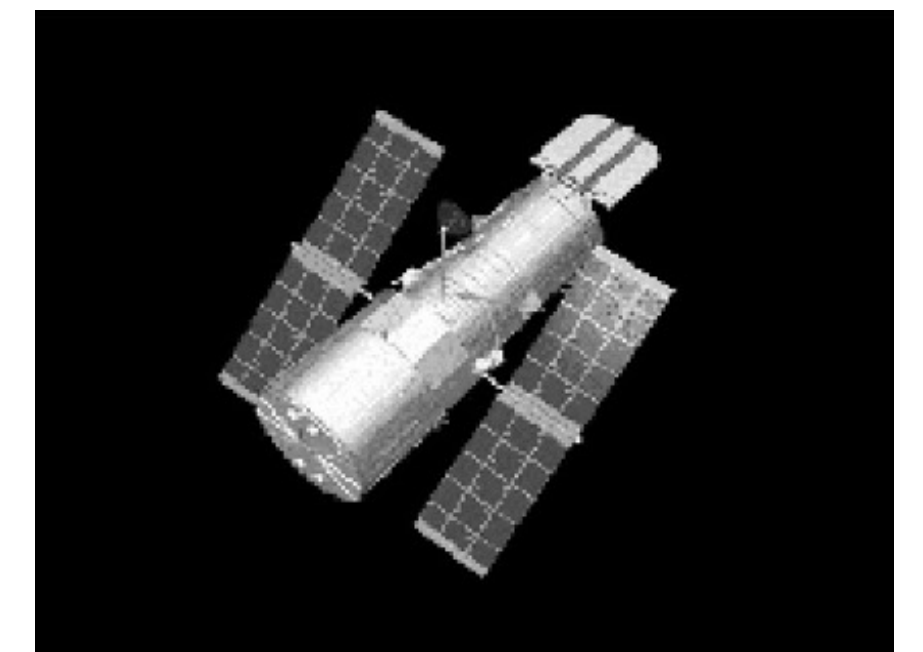
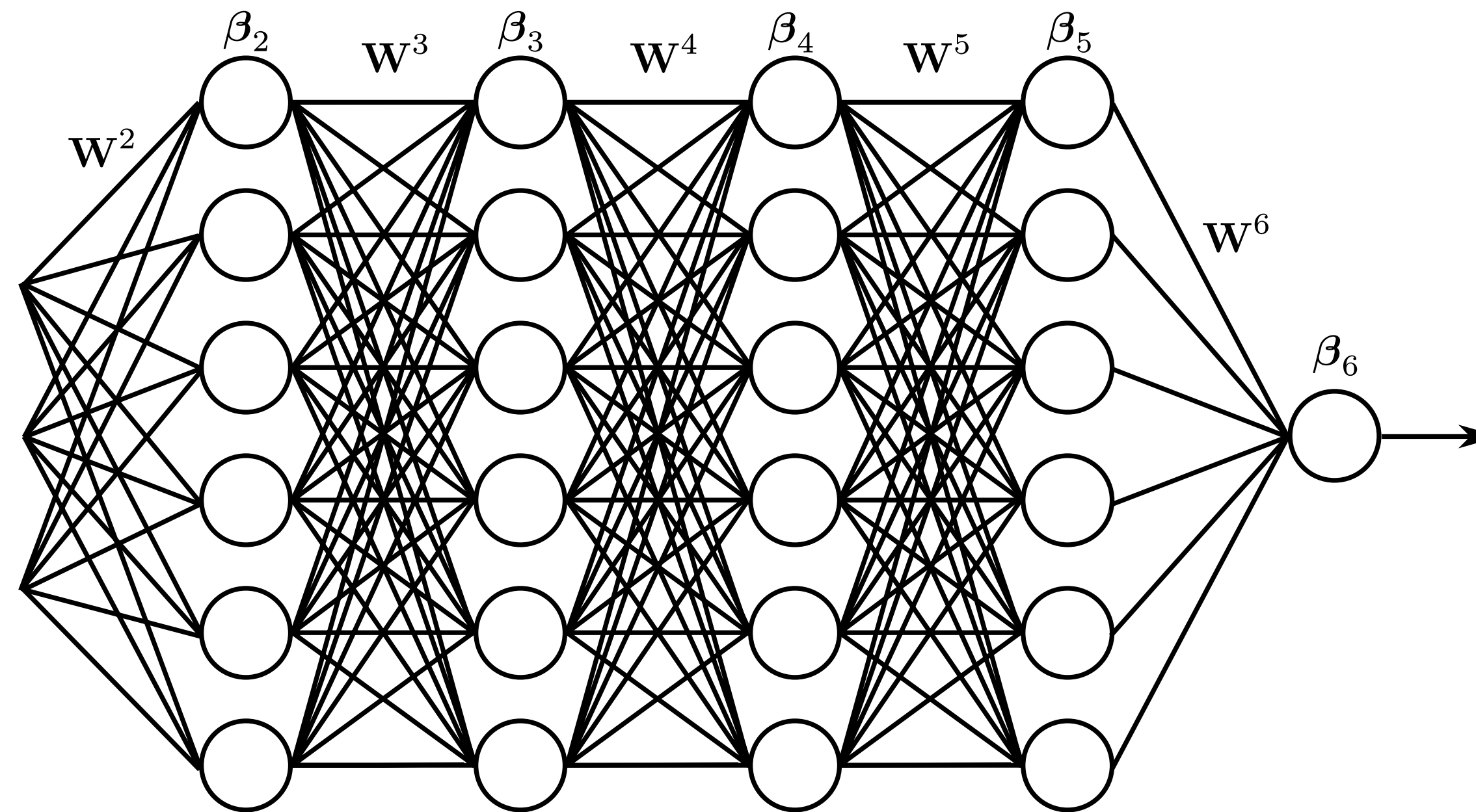
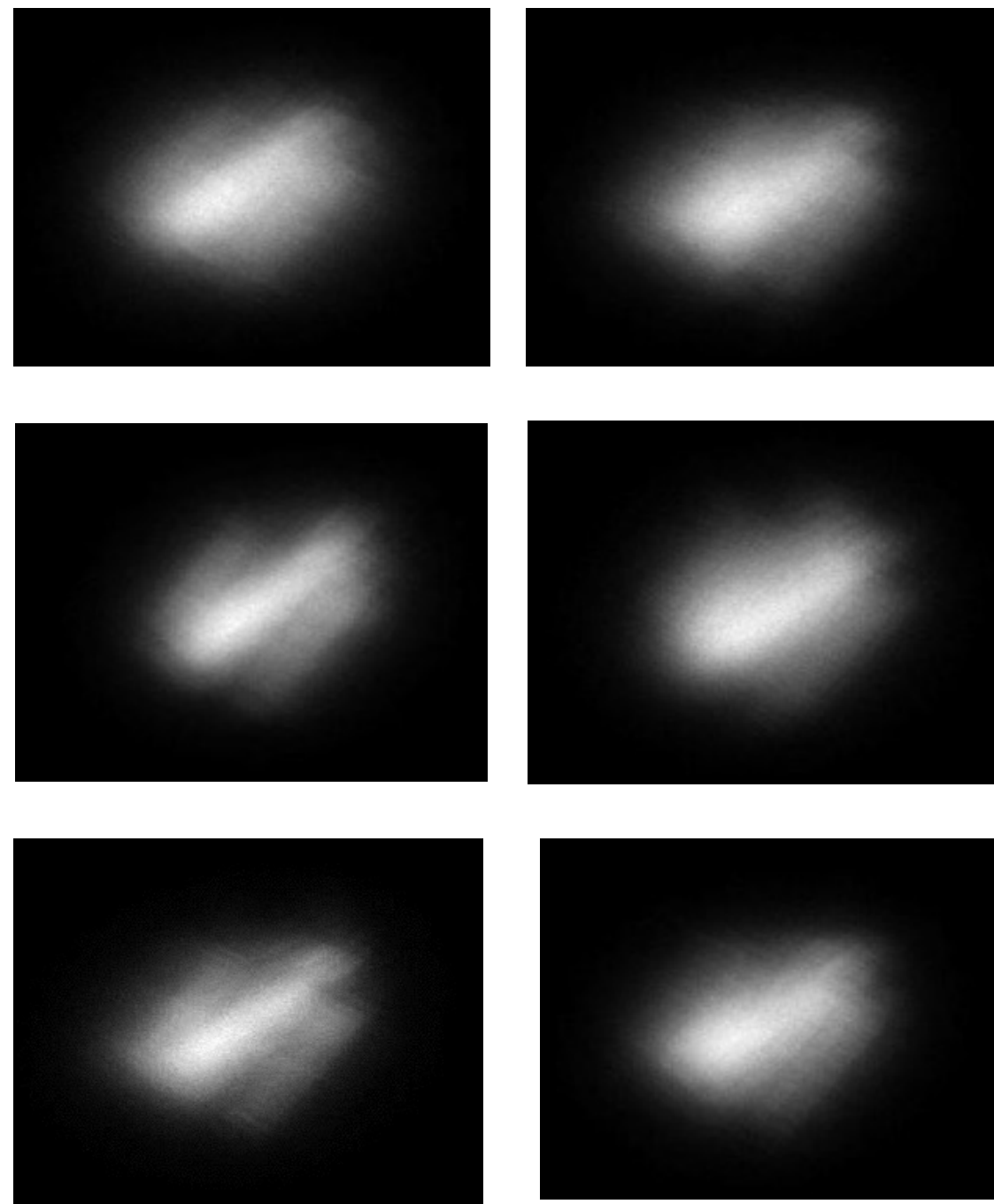


# The Good News Are...



# Extend Machine Learning to Develop A Robust System

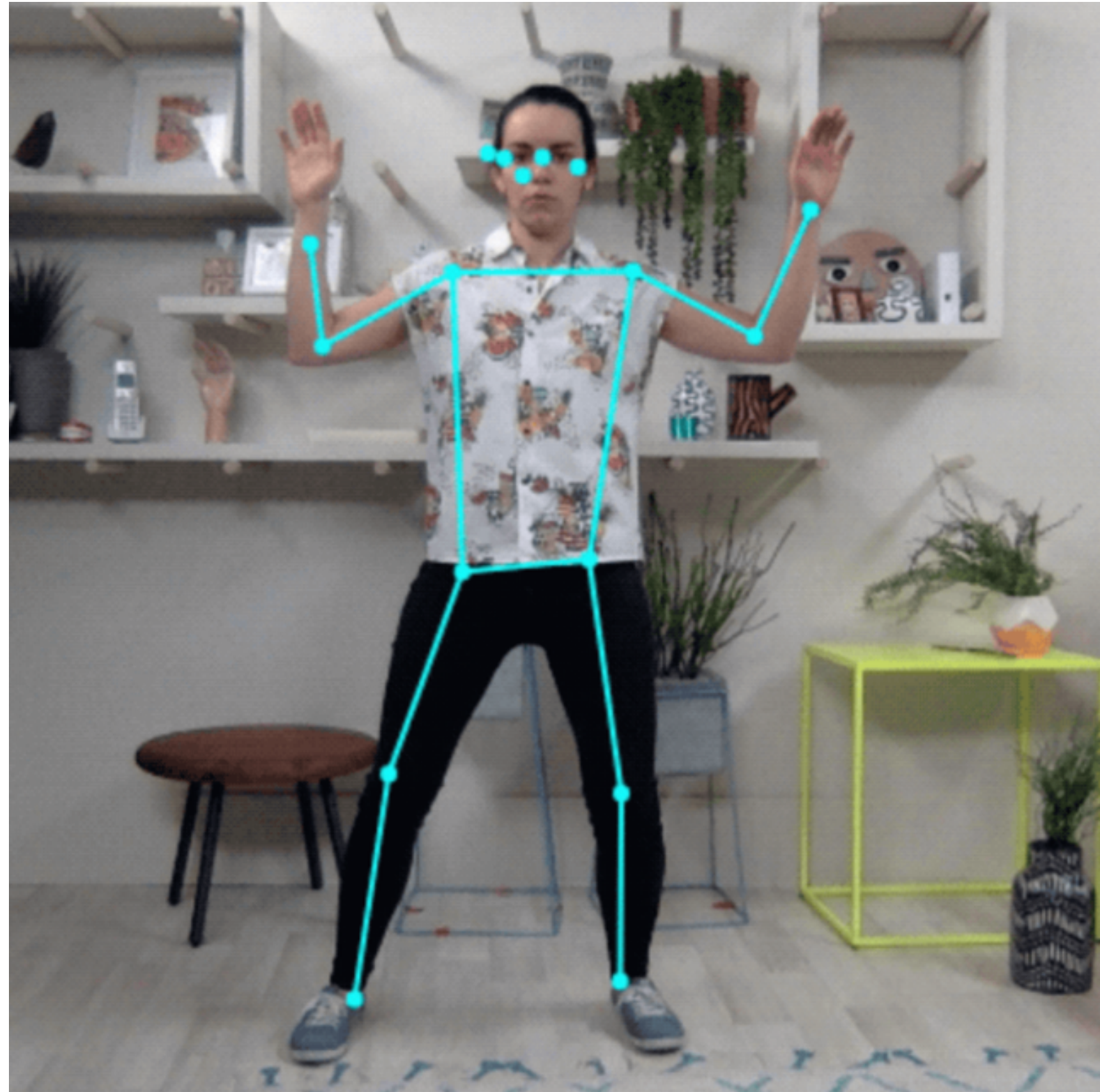
# The Good News Are...



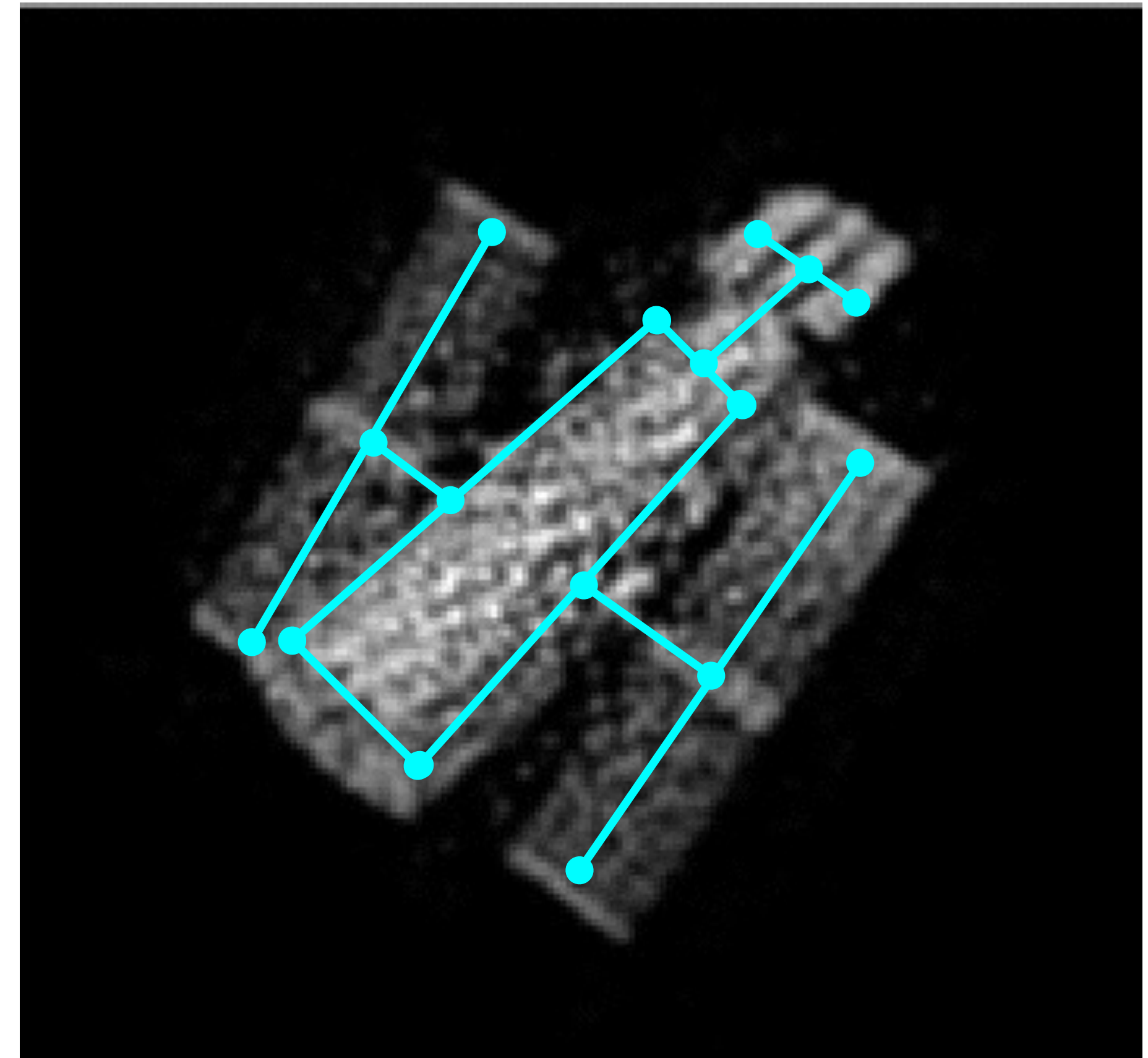
Extend Machine Learning to Develop **A Neural Network**  
That Learns to Reconstruct  
(Deep Learning)



# What Else Can We Learn?



Are we Online?



Model, Position, Orientation  
What is it Observing/Doing?



# Mahalo!

pimentel@gsu.edu

<https://danielpimentel.github.io>