



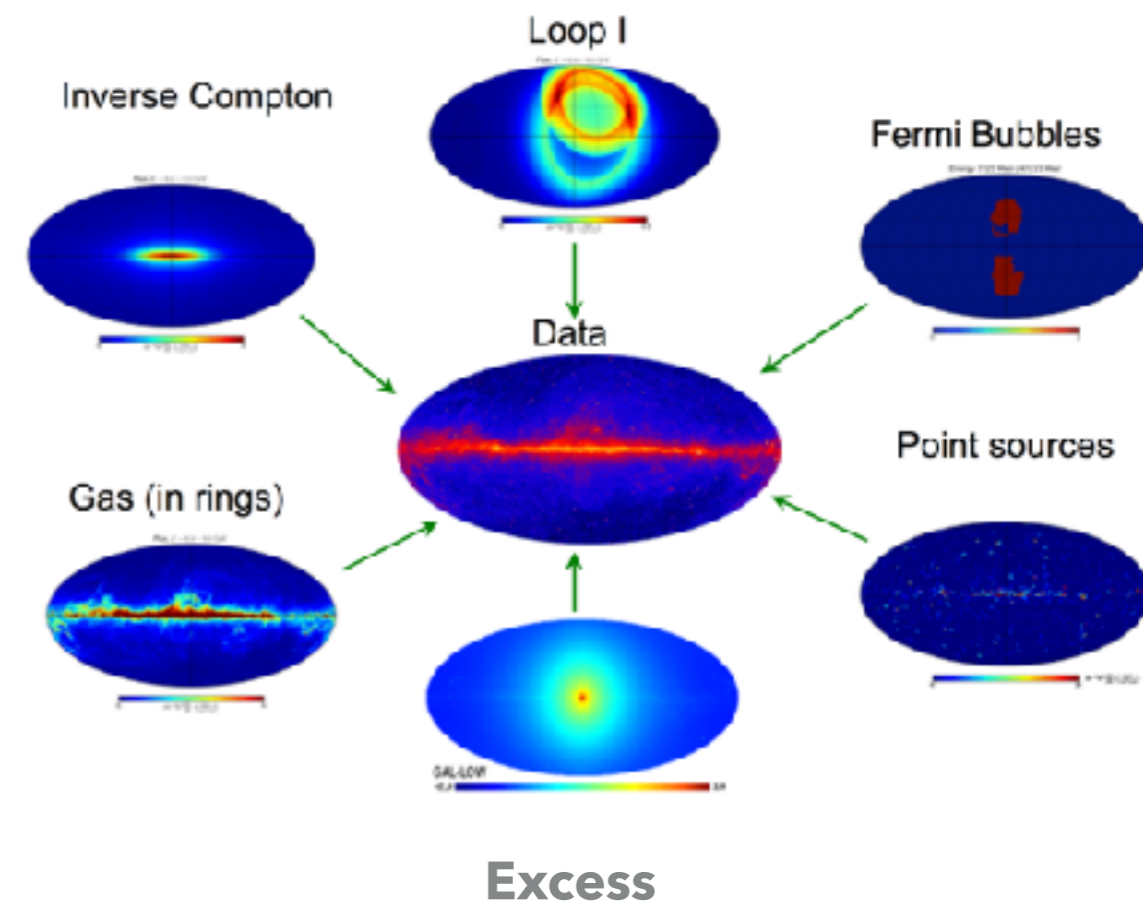
# DETERMINING THE ORIGIN OF THE GALACTIC CENTER EXCESS USING CONVOLUTIONAL NEURAL NETWORKS

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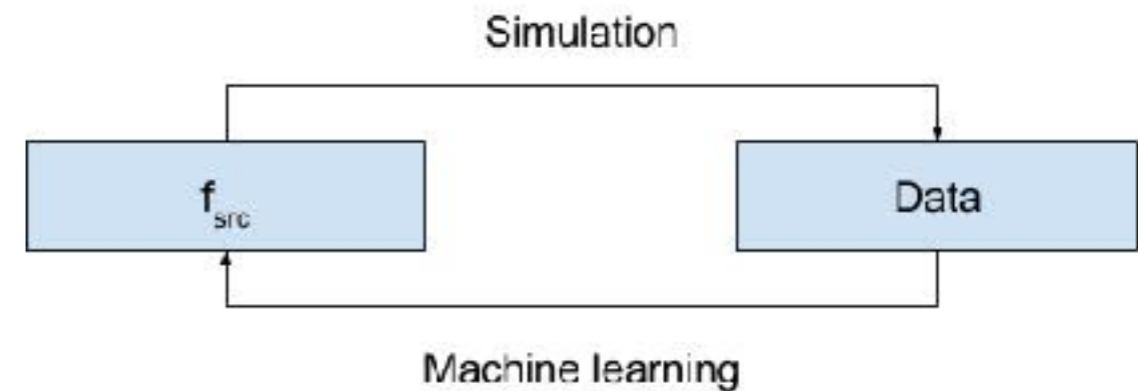
# WHAT IS THE GALACTIC CENTER EXCESS?

- ▶ Excess found by *Fermi-LAT* in gamma ray spectrum
- ▶ After subtracting all data, some flux remains *unexplained*
- ▶ Diffuse or point sources? Recent research shows 100% diffuse is unfavored, probably a mixture?
- ▶ Point source: (*millisecond*) *pulsars* ( $f_{src}$ )  
Diffuse: *dark matter annihilation* ( $1-f_{src}$ )

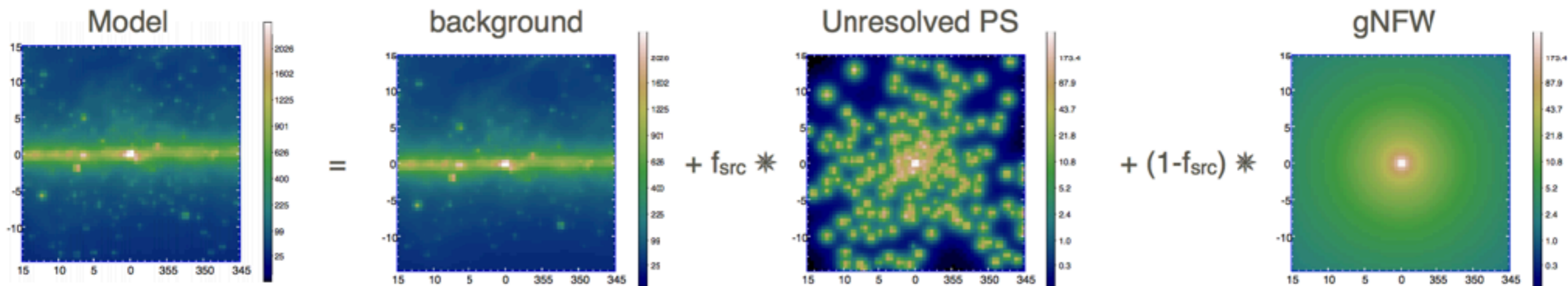


## HOW TO PREDICT FRACTION WITH MACHINE LEARNING

- ▶ Goal: data  $\rightarrow f_{\text{src}}$
- ▶ Generate training data using simulations of what Fermi-LAT *would see* given a value of  $f_{\text{src}}$
- ▶ Train a network to determine  $f_{\text{src}}$  from simulations
- ▶ Apply on real data
- ▶ Network trained on simulated data to predict observables – **simulation inversion**



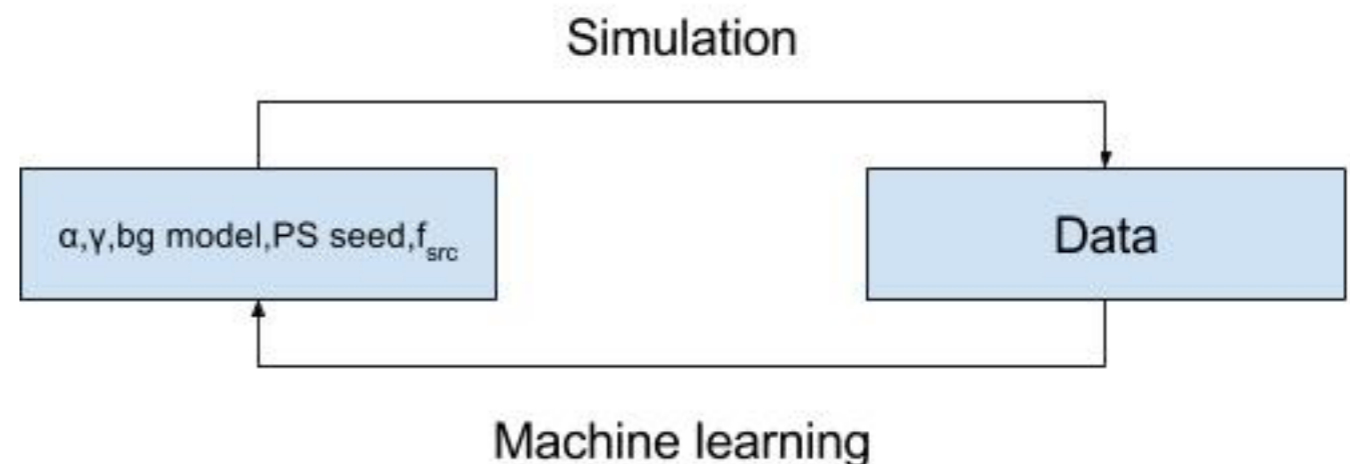
Excess



Preliminary

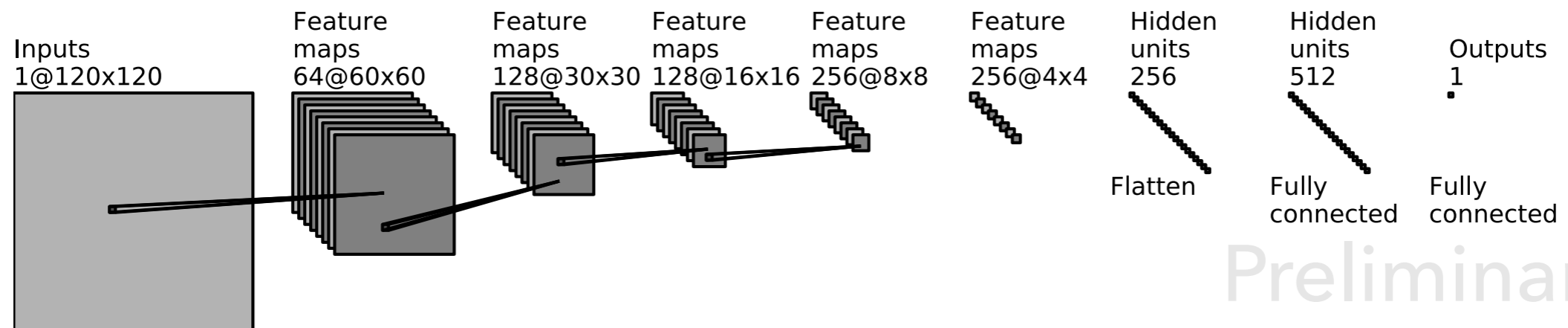
# DATA GENERATION

- ▶ There are other unknowns than just  $f_{src}$ , for example:
  - ▶ The flux distribution of point sources under detection threshold? –  $\alpha$
  - ▶ Randomized locations of the point sources (only spatial distribution is fixed)
- ▶ Force network to generalize:  
predict  $f_{src}$  regardless of values of other unknowns
- ▶ Need many samples (1.2 million models)
- ▶ Reality needs to be somewhere in the training space spanned by all parameters

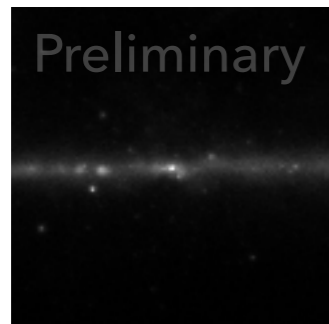


# CONVOLUTIONAL NEURAL NETWORK

## CONVOLUTIONAL NEURAL NETWORK



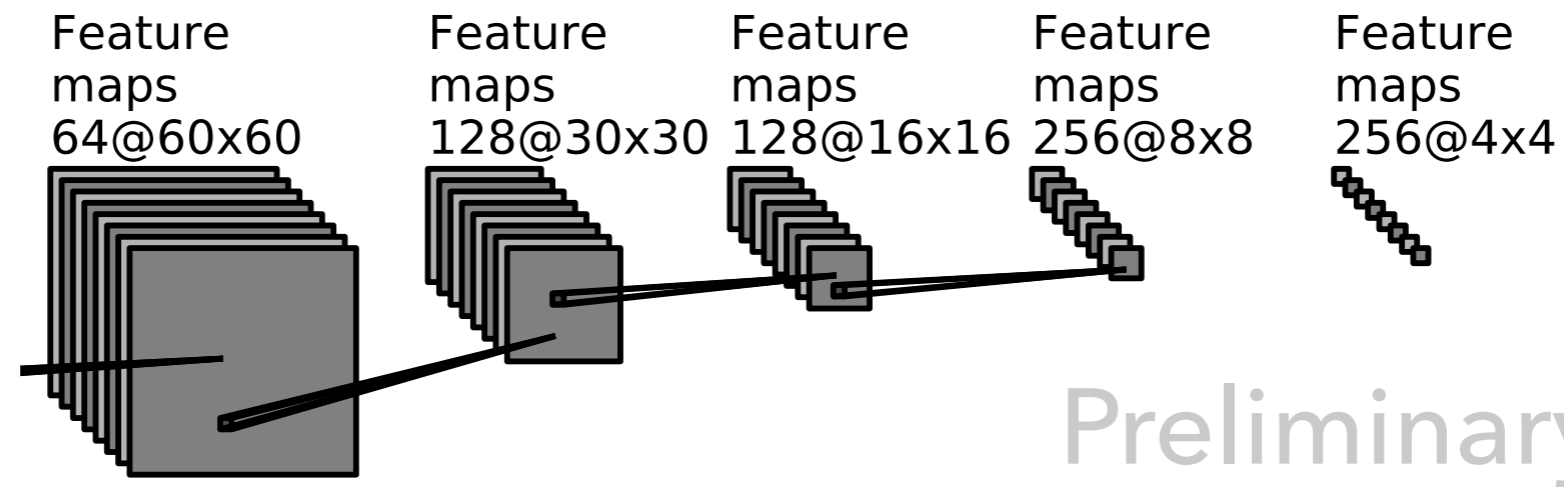
Max-pooling after every convolution  
Local response normalization after every other convolution



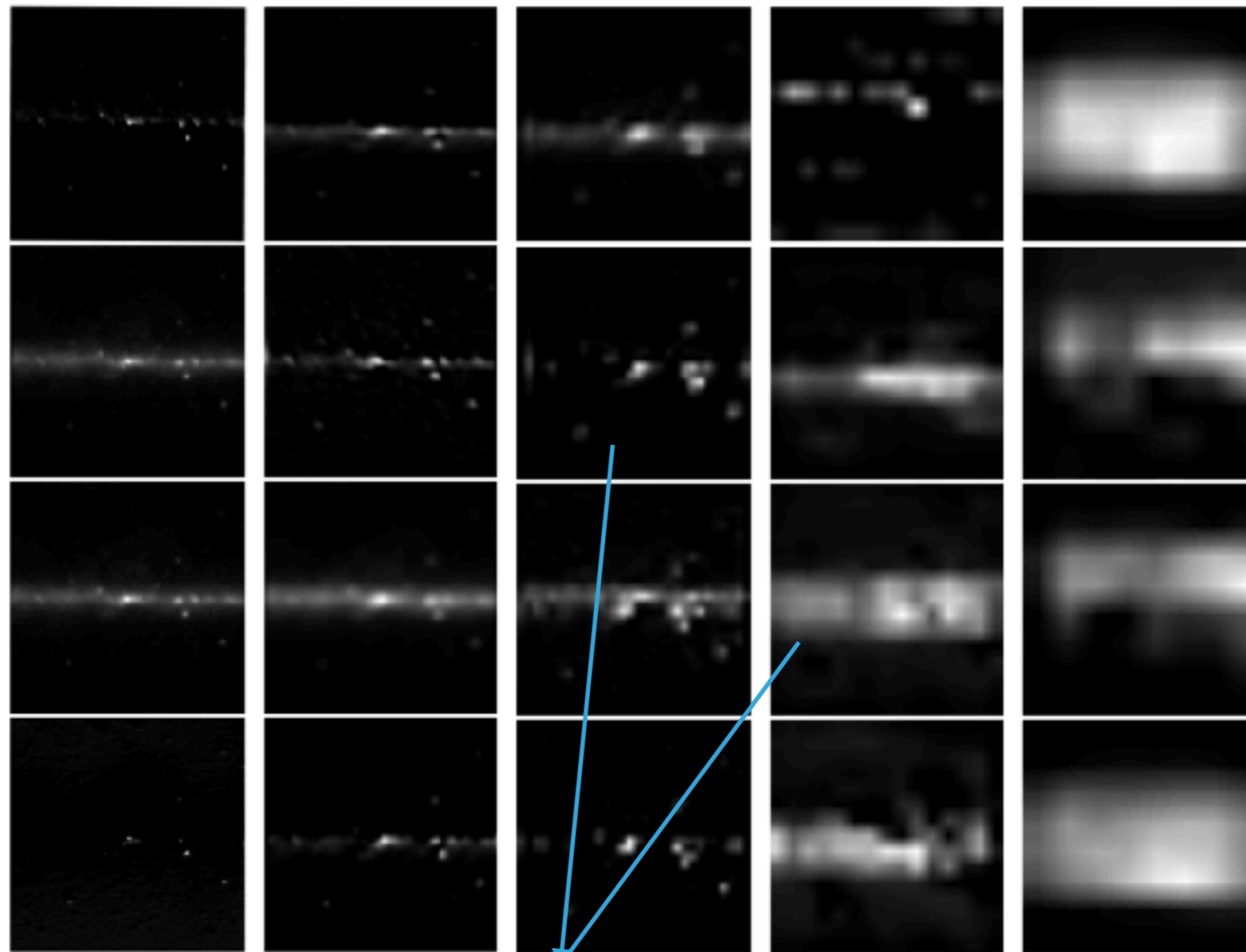
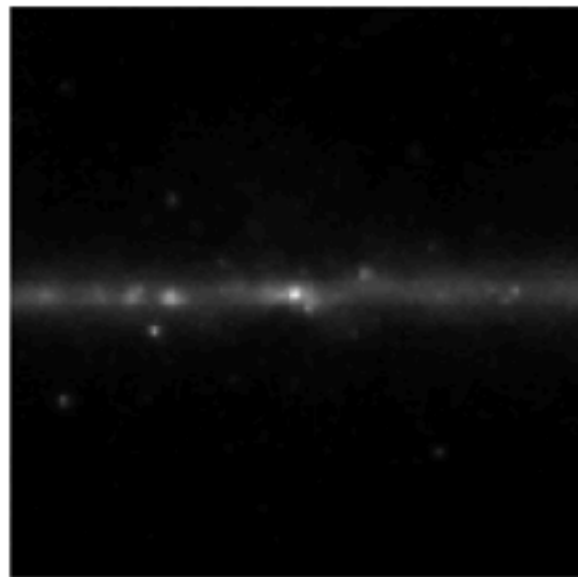
$f_{\text{src}} = 0.89$

- ▶ TensorFlow
- ▶ 1.2 million images of 120x120 values
- ▶ ~10 million internal parameters
- ▶ 1 day to train each network (2x GTX1080, >5000 cores, ~16 TFLOPs)

# A LOOK INSIDE THE NETWORK



Input



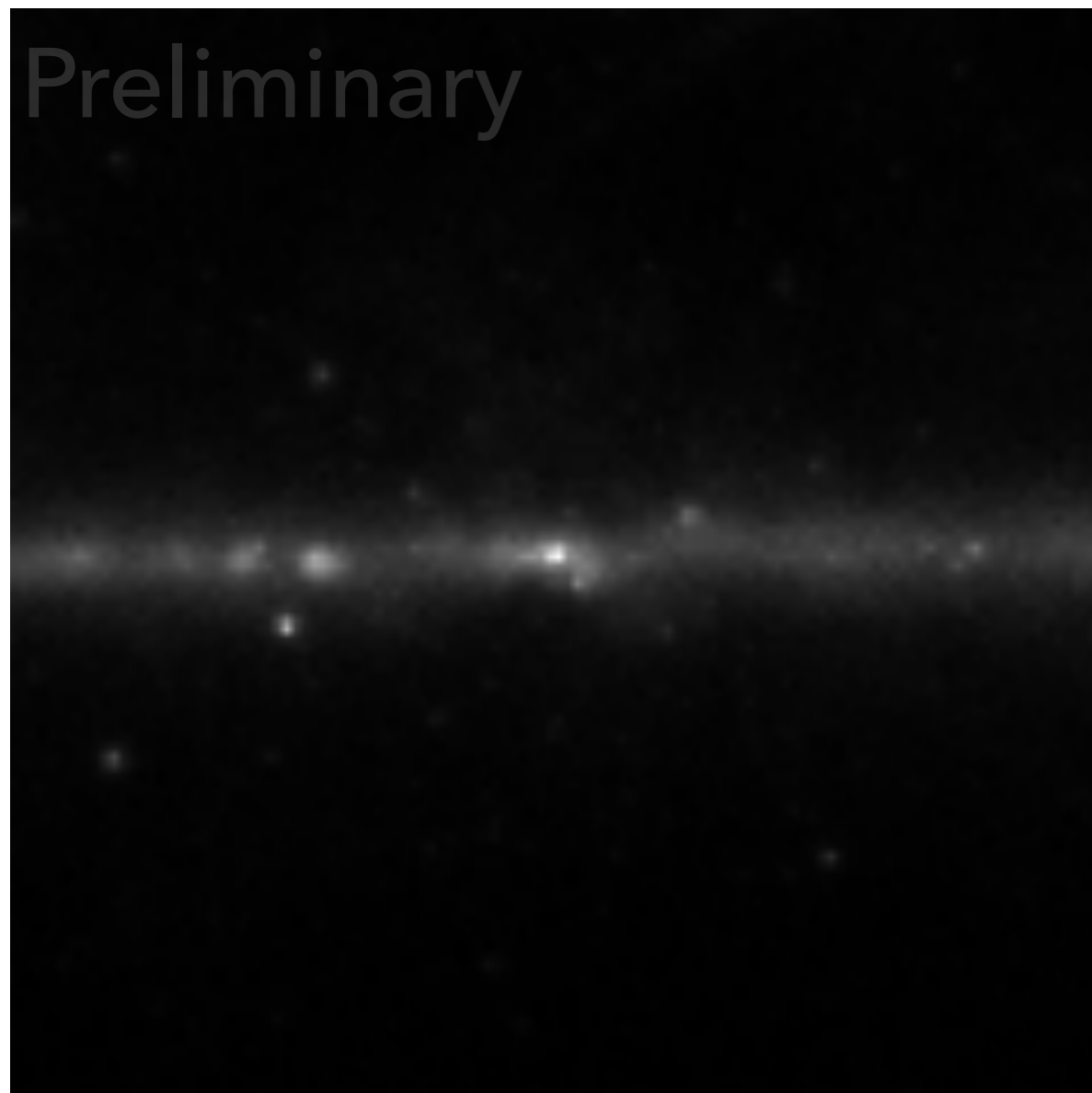
Prediction: 0.86  
Truth: 0.82

It learned to decompose diffuse and point sources from the input!

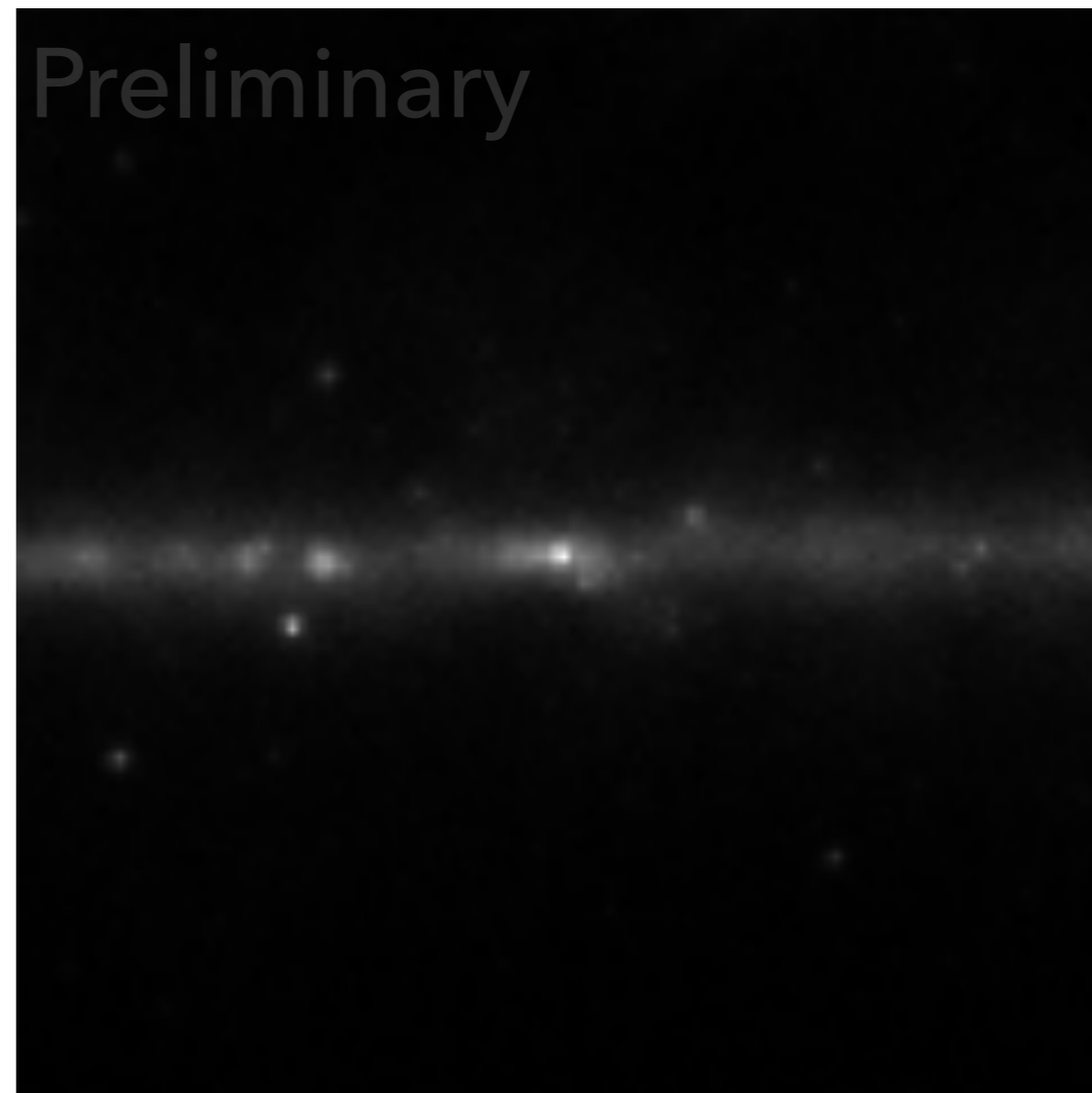
CAN YOU SPOT THE DIFFERENCE?

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**CAN YOU SPOT THE DIFFERENCE?**



$$f_{\text{src}} = 0.9883$$

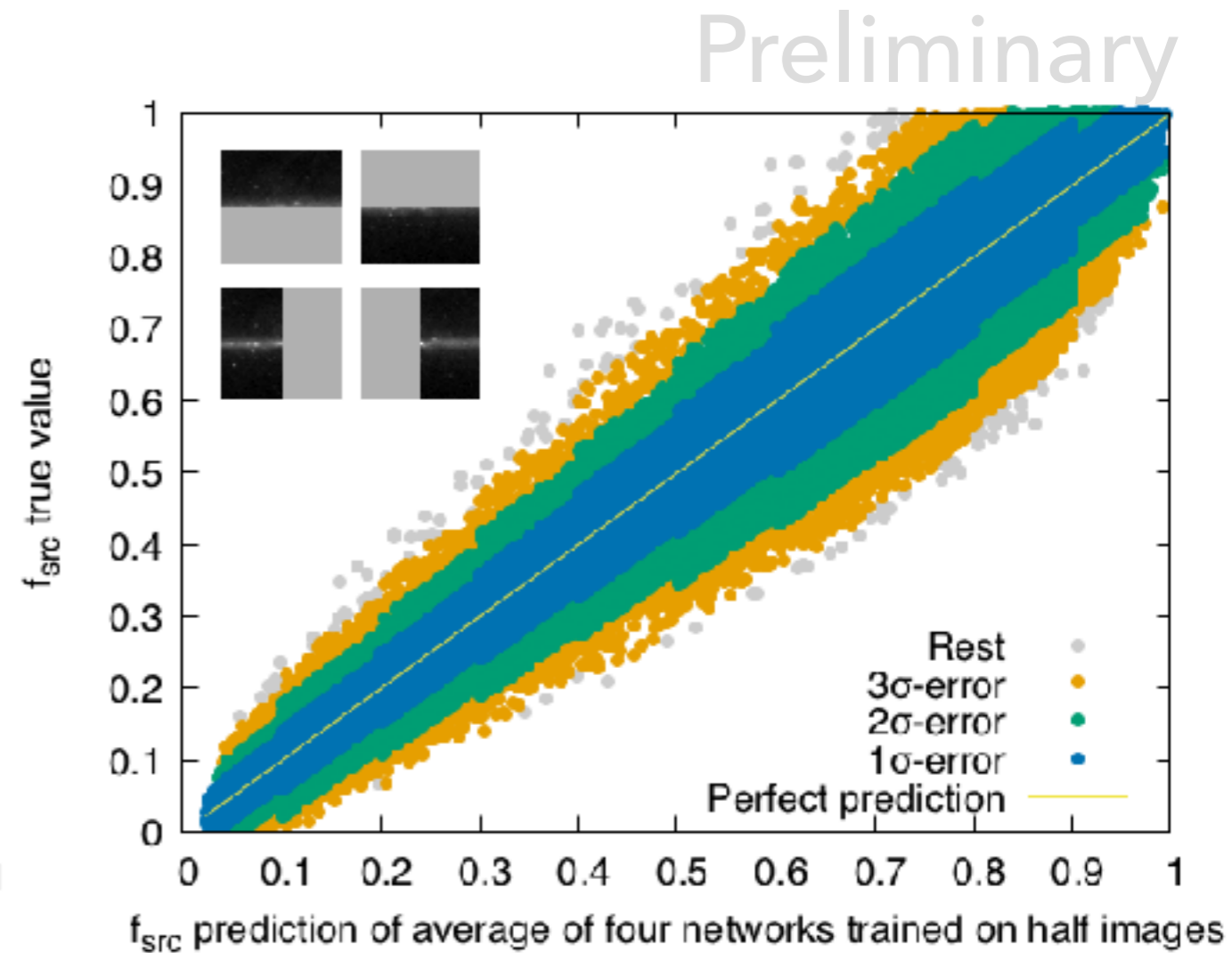
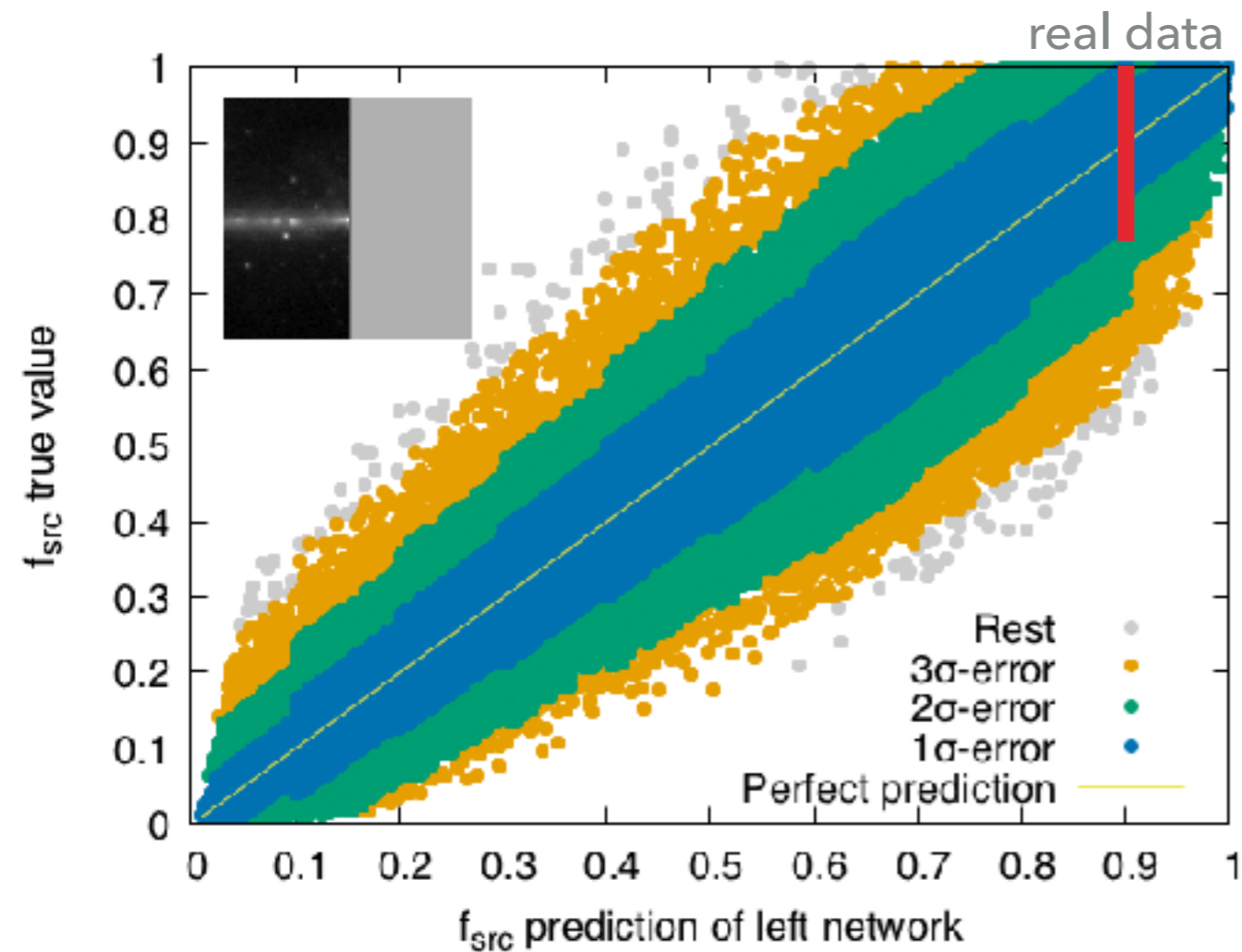


$$f_{\text{src}} = 0.0275$$

# RESULTS

## RESULTS

- ▶ Train using 3 background models, test on 2 others
- ▶ Test data: 2x30000 test points



Because we are doing a followup study, real result is only evaluated on the left network to not bias ourselves



# CONCLUSIONS

- ▶ Network successfully generalized over all training parameters – **simulation inversion** works
  - ▶ Applicable to many other problems as well
- ▶ Disfavors 100% diffuse (in agreement with other studies)
  - ▶ Give a prediction of actual mixture
- ▶ Followup study for more accurate results, better generalization