High Performance Computing in Astrophysics

and applications to Radio Interferometry

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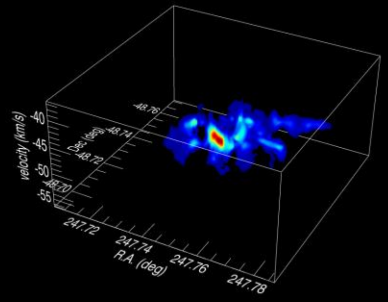
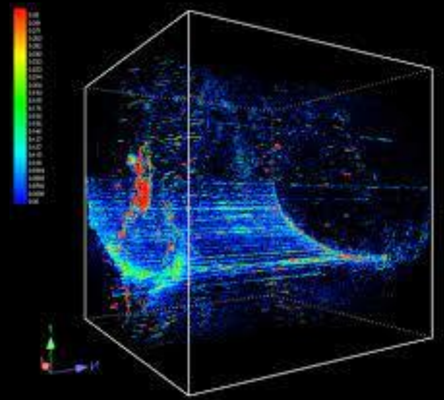
0. Inferring models from Data

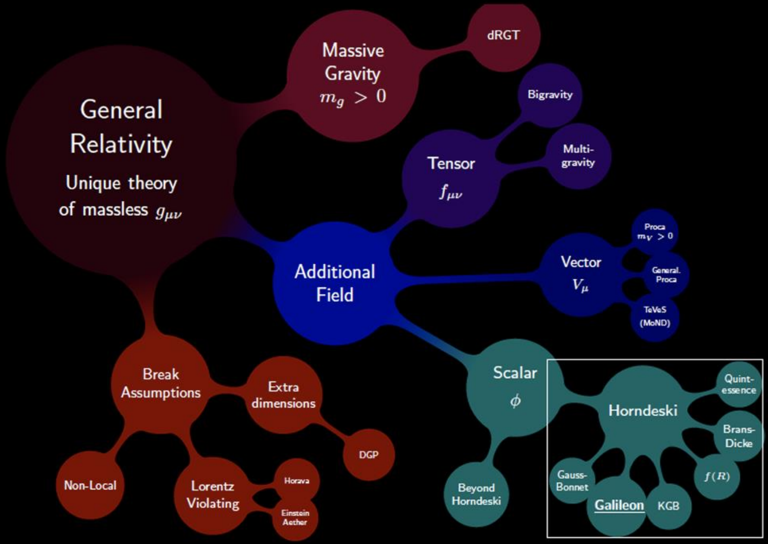
Data Cubes are pushing to the Big Data Regime





Resolution of Inverse
Ill-posed problems

- Deconvolution
- Denoising
- Source Detection
- Source Characterisation
- Regression
- Classification



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1. Inverse Problems

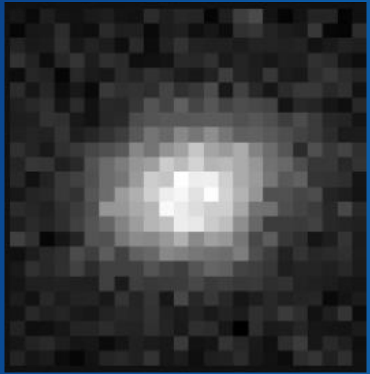
- Inferring causal factors from the observed reality

The generalised forward problem $$V^{obs} = [A]T^{m} + n$$

ALMASim

The generalised inverse problem $$T^{m} = [A]^{-1}V^{obs} + n$$

DeepFocus



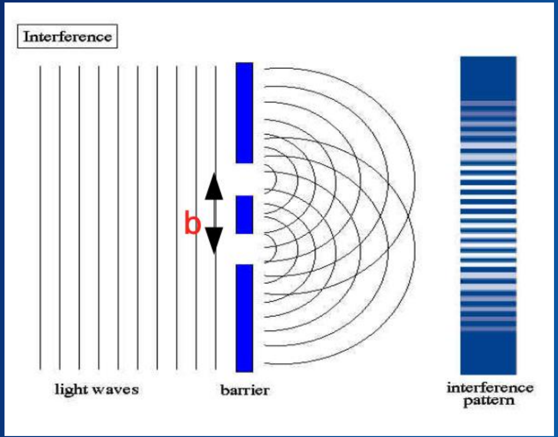
V_{obs}

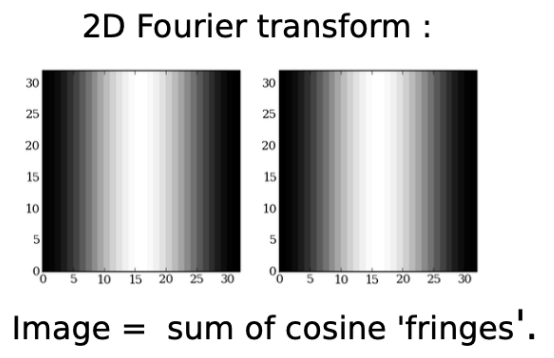
$[A]$

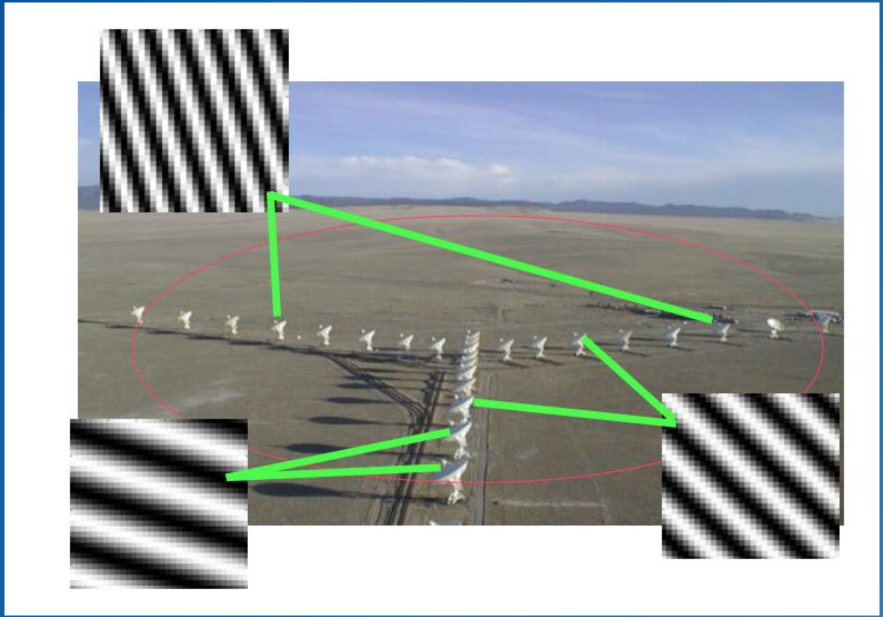
T^{m}

2. Interferometers

- Inverse imaging devices



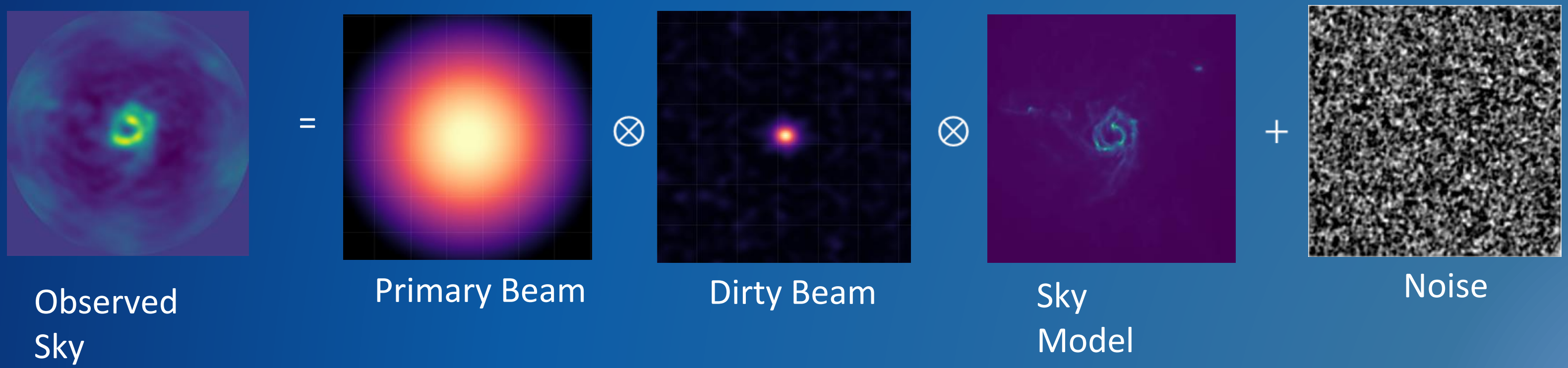




4. The Interferometric Deconvolution Problem

The Radio Astronomer Equation (Van Cittert – Zernike Theorem)

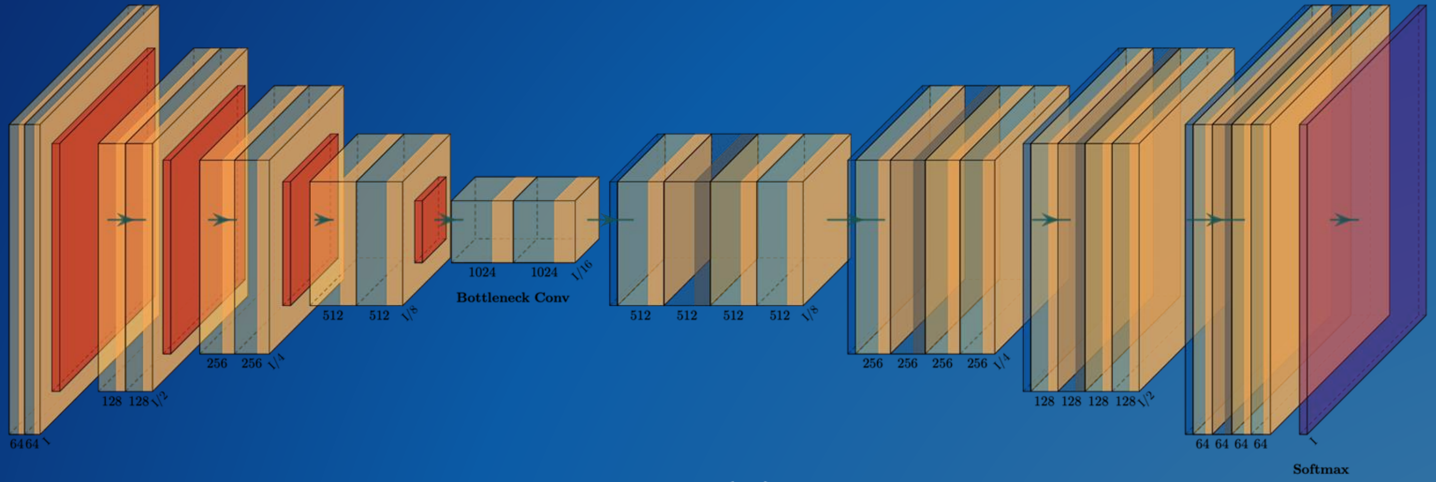
$$\mathrm{D(l,\,m)} = P(l,m) \otimes T(l,m) \otimes G(l,m) \approx \iint W(u,v)g(u,v)e^{2\pi i(ul+vm)}dudv$$



5. Data Cubes are changing the Game

- SKA:
  - weights ~ 1 TB
  - 20 square degrees field of view, high sparsity;
  - Expected to deliver 300 PB per antenna per year, with a total of ~ 8.5 Exabytes over the 15-year expected lifespan of the primary science program
  - Online Processing required to cope with data volume and velocity
- ALMA:
  - Weights ~ 1 GB
  - Extended Sources
  - Delivers 1 TB per day

6. Deep Learning for Inverse Problems



$$L(y\ g(f(x)))$$

Encoder Network

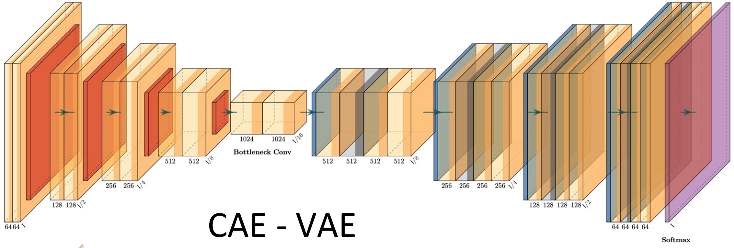
f

Decoder Network

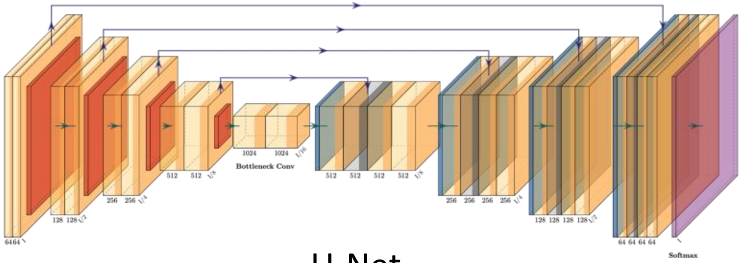
g

Minimizing the expected reconstruction error is equivalent to maximizing the lower bound on mutual information *I(x, h).* By imposing constraints on the *latent space,* it can be forced to capture relevant information in the data.

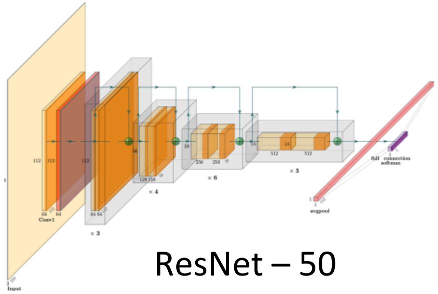
7. Deep Learning for Inverse Problems



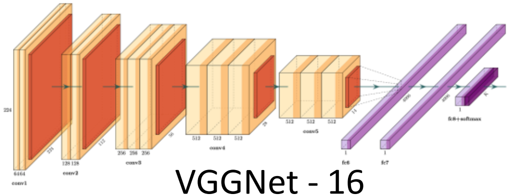
CAE - VAE



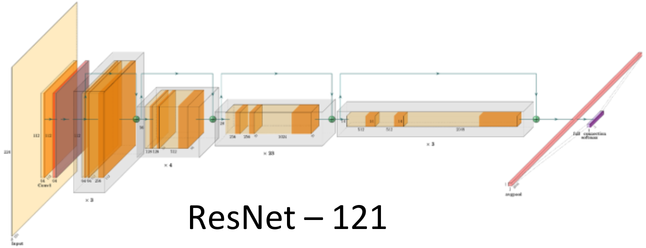
U-Net



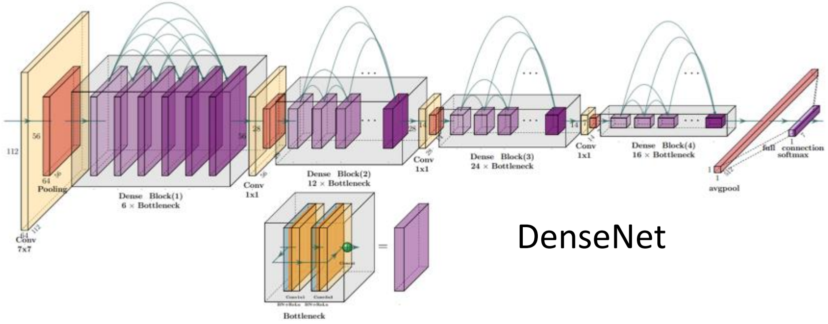
ResNet – 50



VGGNet - 16



ResNet – 121



DenseNet

8. Meta Learning

DeepFocus

N. Layers | Skip Connections | Variational

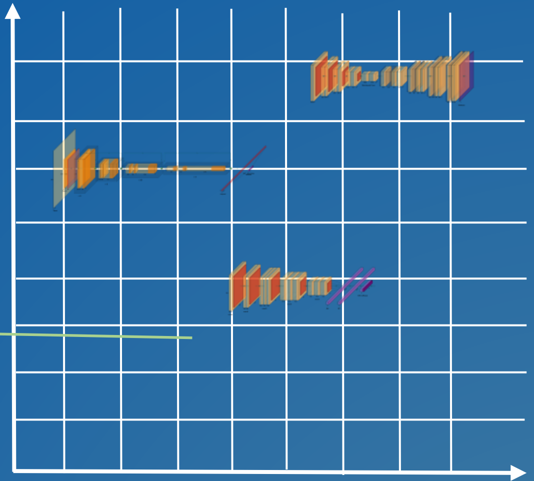
N. Channels | Activation Function | Pool | Dense

Layer Depth | Bottleneck | Dropout | Kernel Size

Denoising | Residual Connections | Interpolation

Multi-Head Attention

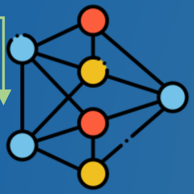
θ_a



JSON

Sampling

DeepFocus



Classical Network Optimization

Momentum | Optimizer | Preprocessing

Batch Size | Learning Rate

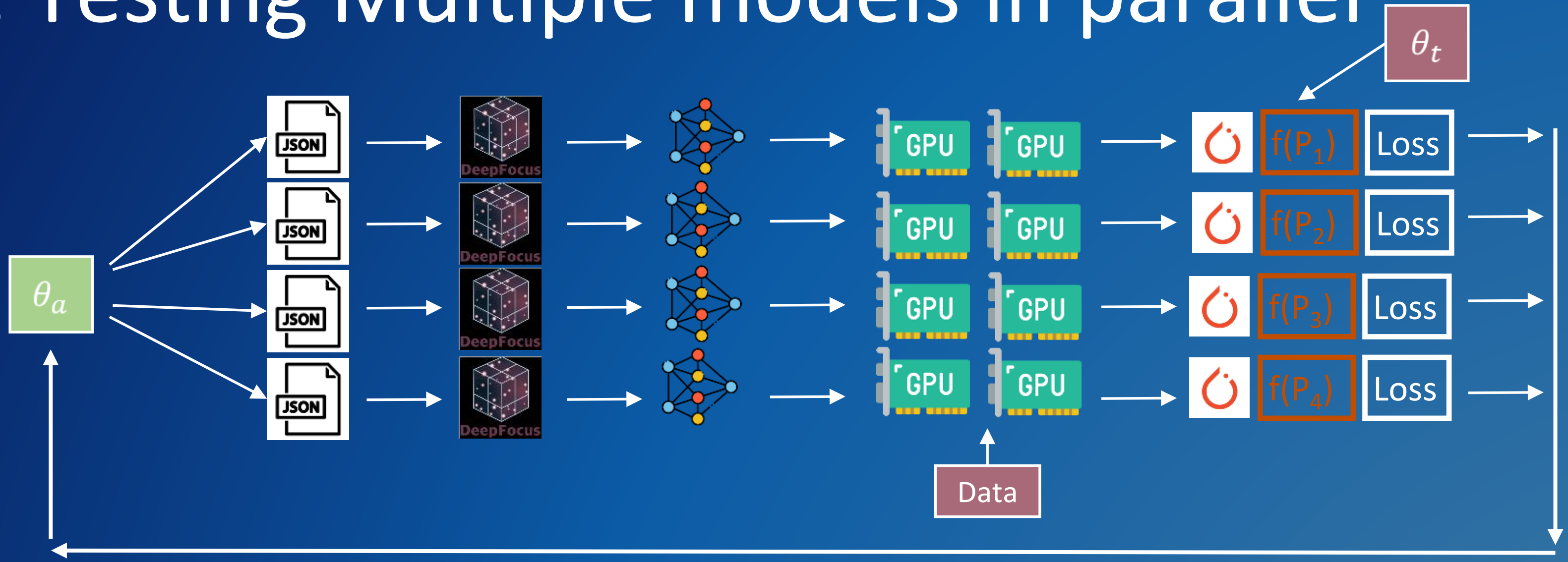
Warm Start | Loss Function

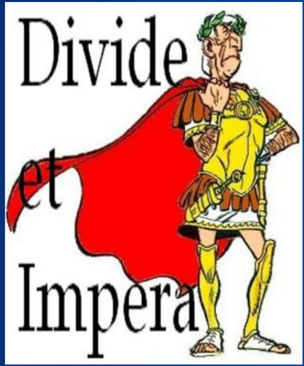
θ_t

Grid Search

$$x^* \in \theta_t : x^* = \underset{x \in \theta}{argmin}\, f(x)$$

9. Testing Multiple models in parallel



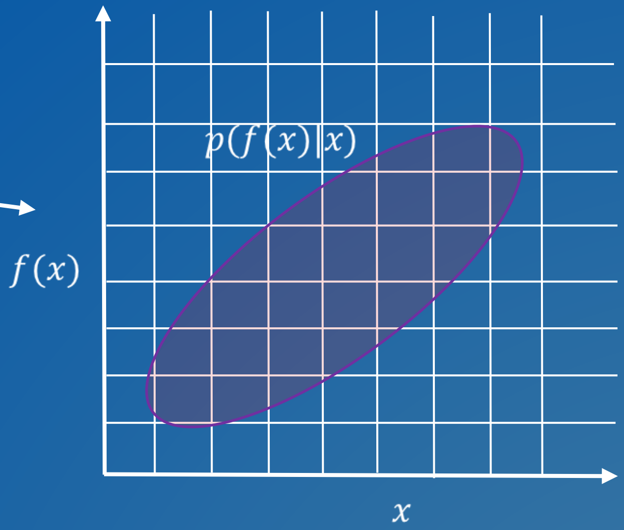


- Multiple Parameter realizations are tested in parallel
- A subsample of the original problem is used to measure performance

10. Bayesian Parameter Search

Surrogate Model

- probability model for f(x)
- For a value *x,* it gives the normal distribution for its prediction of *f*



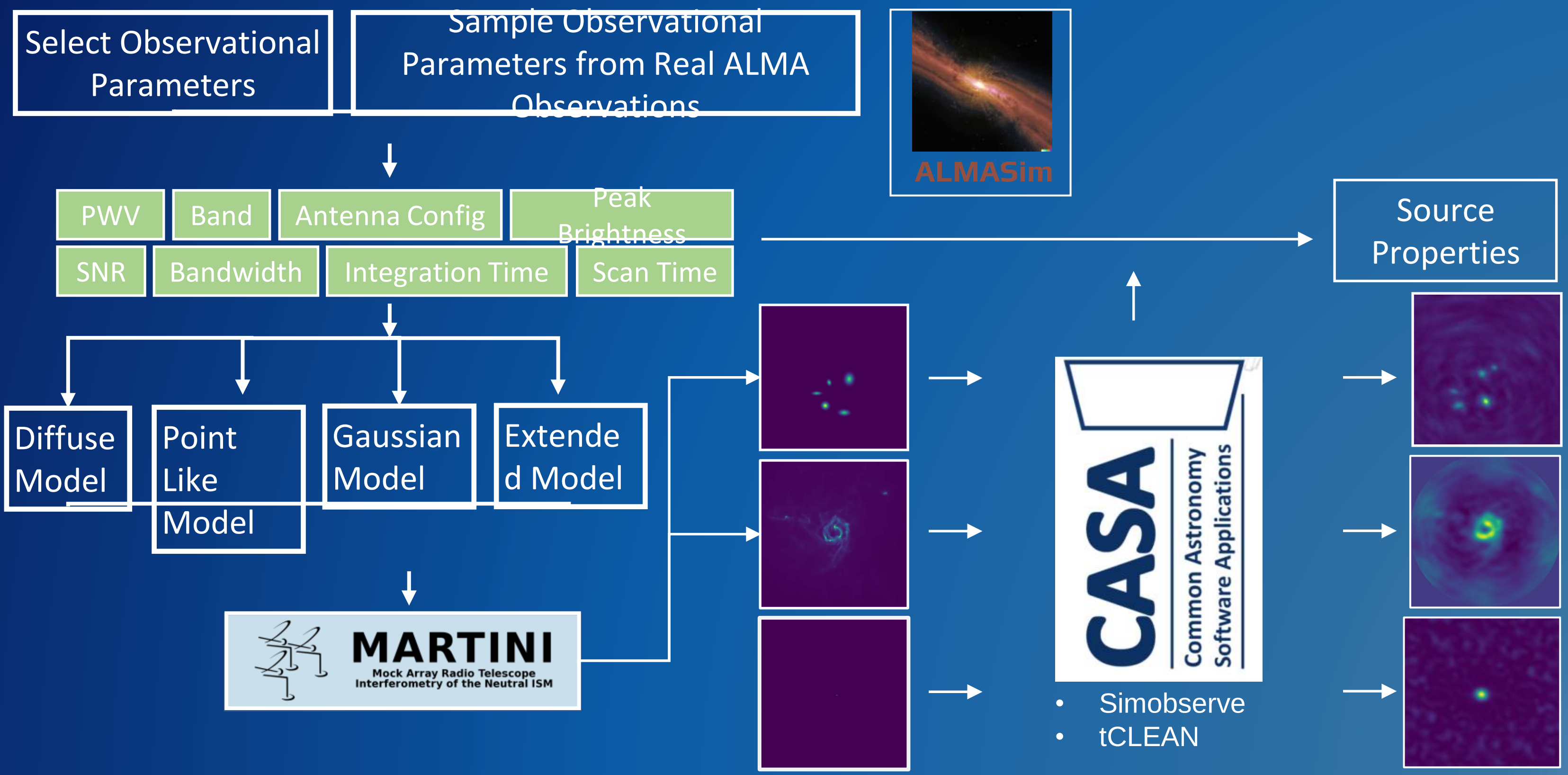
Acquisition Function

- where to search next ?
- probability model for f(x)
- It tell us how advantageous is to evaluate the objective function *f at x*

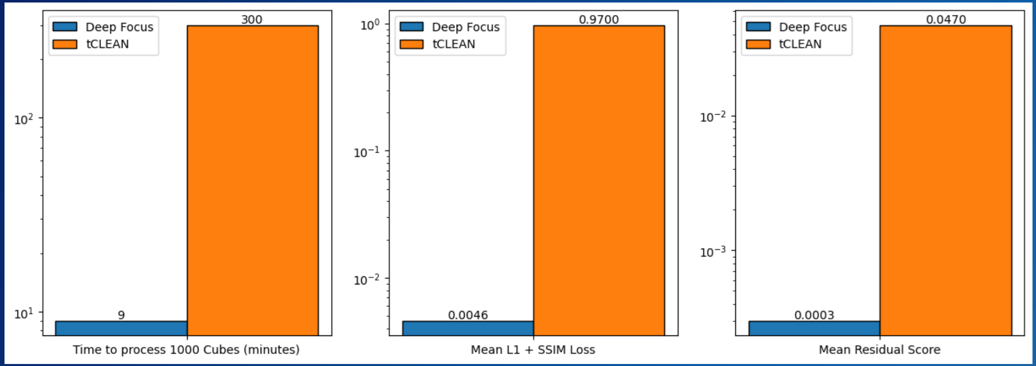
Assumption: the time spent selecting the hyperparameters is inconsequential with respect to the time it takes to evaluate the objective function.

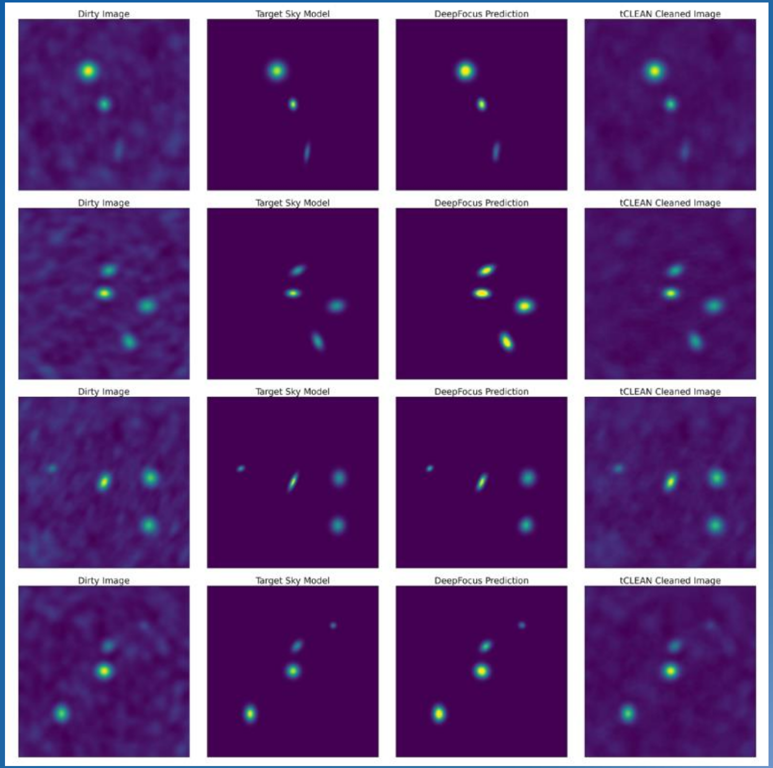
Absolutely True for Deep Learning Models

11. Building a Training Set with ALMASim



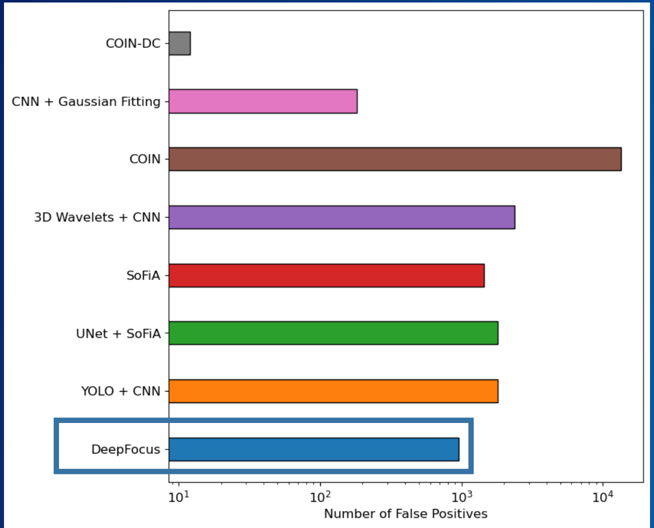
13. Deep Focus – Comparison with tCLEAN in solving the Deconvolution Problem

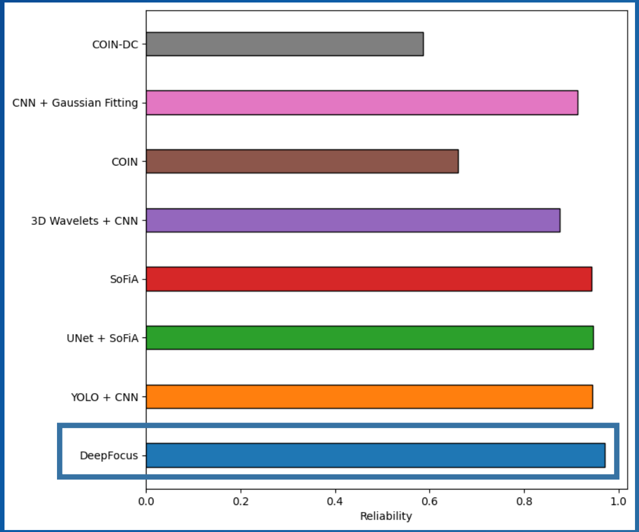


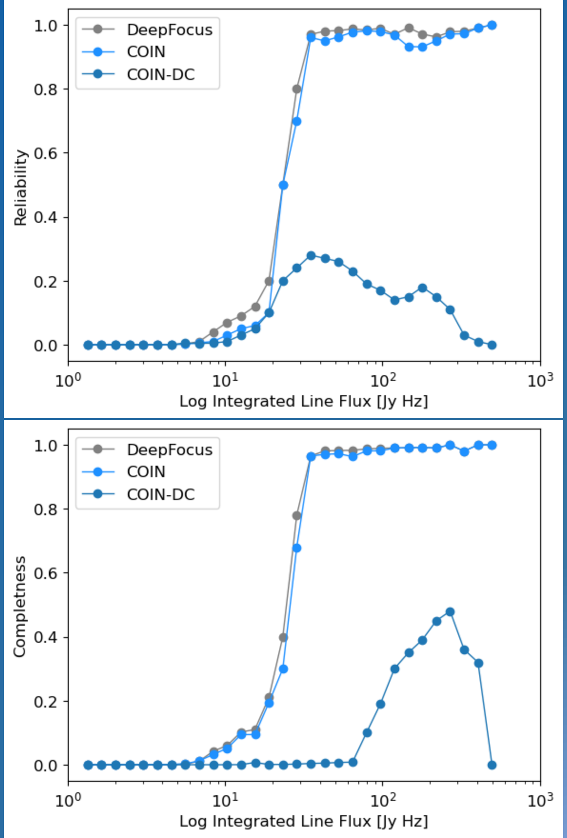


- The cube average size is 0.65 GBs
- Benchmarks have been performed using the following hardware:
  - 2 Intel Xeon E5-2680 (8 Cores each) -> 16 Cores
  - 1 NVIDIA Tesla V100 GPU
  - 1 TB of DDR5 RAM

14. Deep Focus – Comparison with other DL models on Source Finding Task

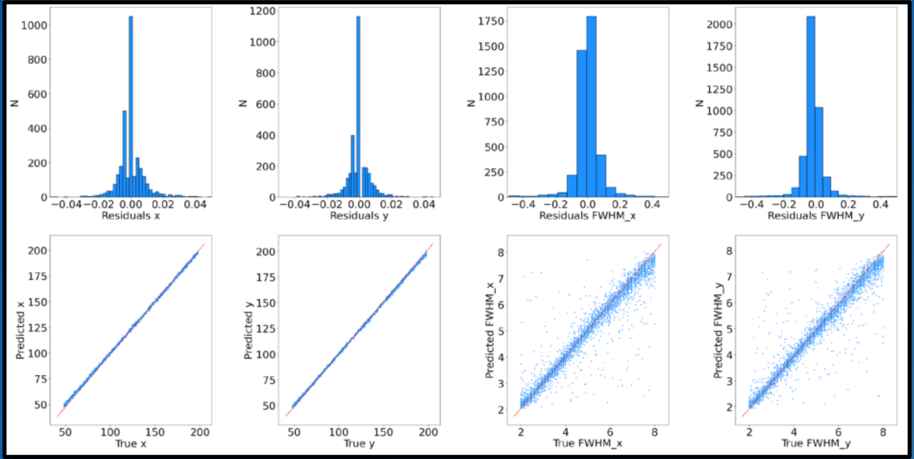


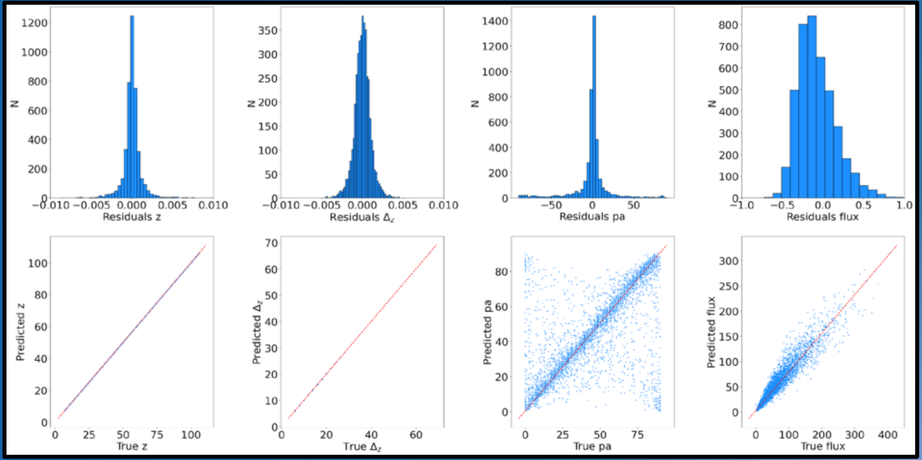




15. Deep Focus – Characterizing Sources around Calibrators

Algorithm	Completeness	Reliability
DF	96.7%	99.6%
Sofia 2	22.2%	20.1%
BlobCat	60.9%	53.0%
CAE	78.1%	82.0%





Grazie per l'attenzione