Astronomical Source Separation with VAEs

Biswajit Biswas, Eric Aubourg, Alexandre Boucaud, Axel Guinot, Junpeng Lao, Cécile Roucelle

Learning to Discover conference
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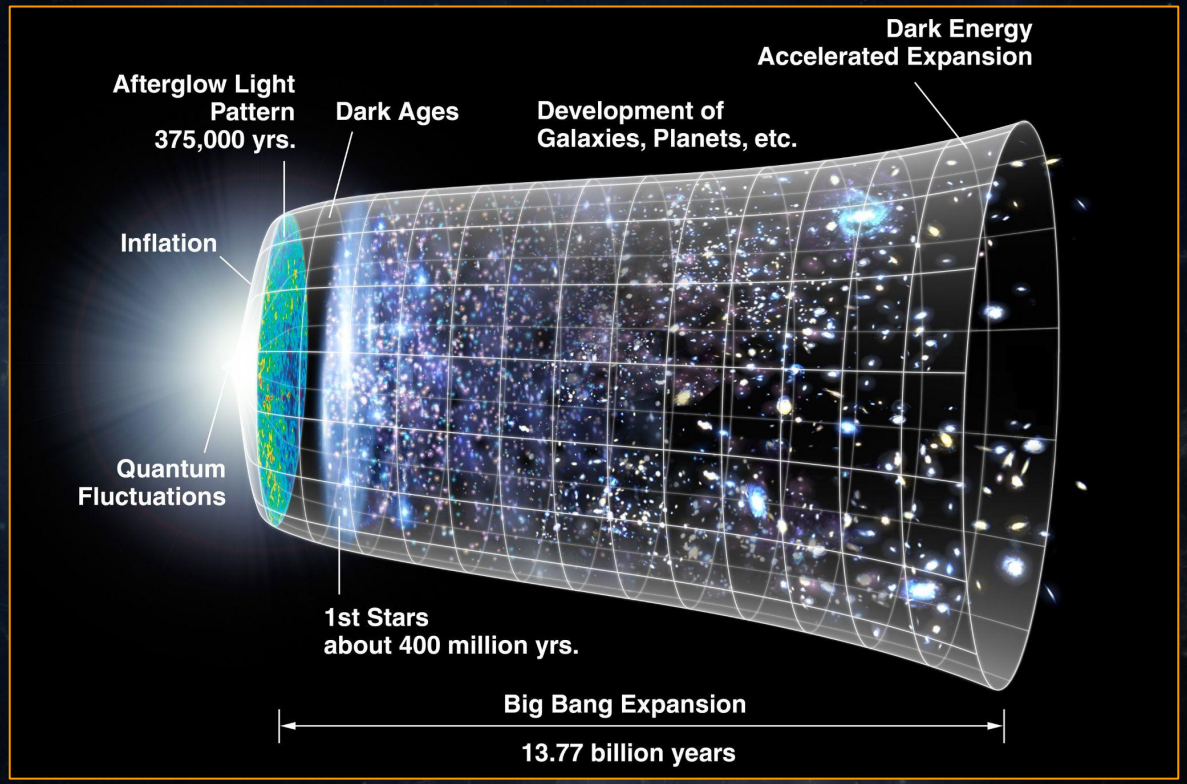
Dark Energy



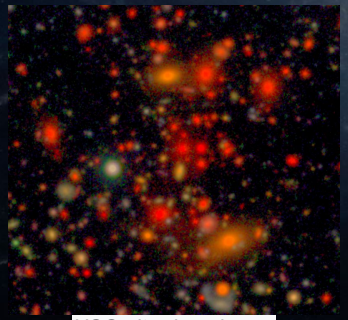
Credits: NASA/WMAP Science Team

Surveys and Challenges

Large survey of Space and Time (LSST) at Vera Rubin Observatory:

- Ground-based
- constrain Dark Energy
- 3.2 billion pixel camera
- 6 observation bands in visible range

more depth + area of coverage ⇒ More statistics!



HSC ultradeep image

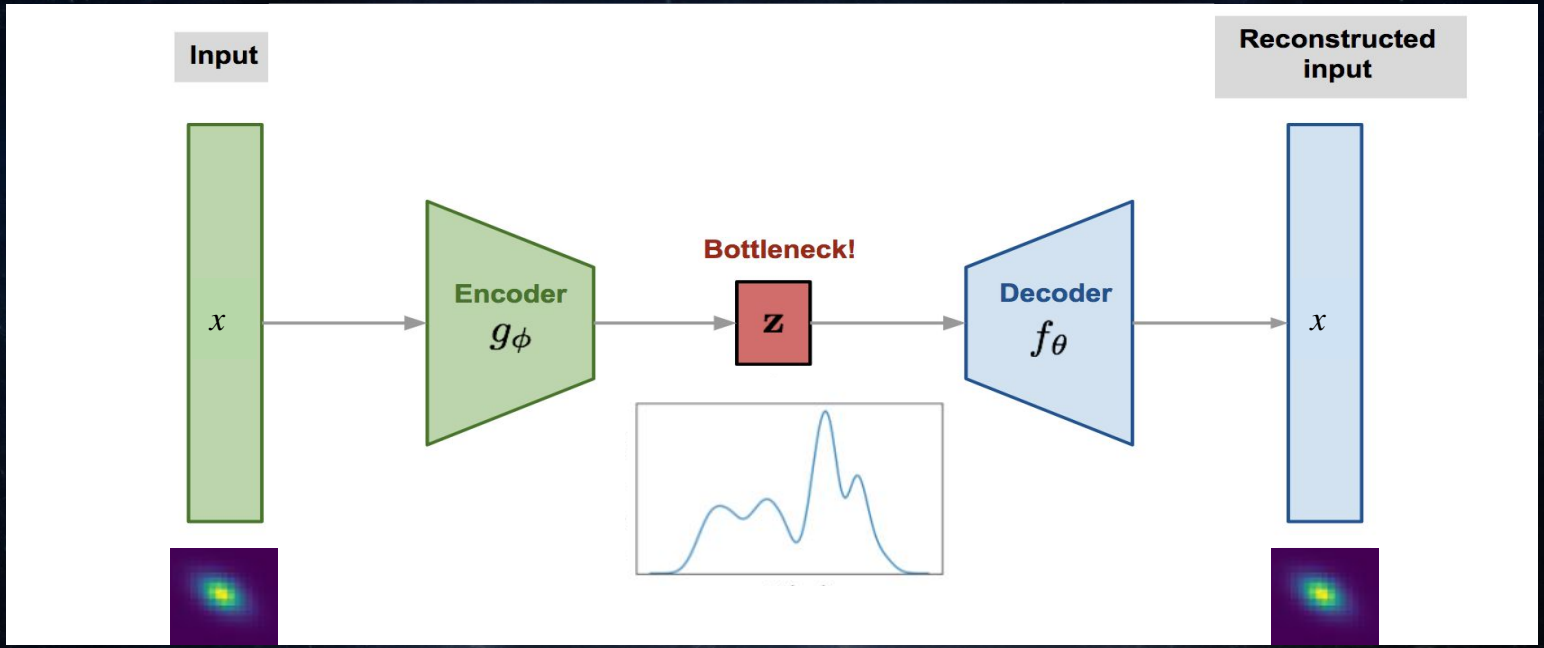
greater depth means more complex data!

~ Galaxies (60% in LSST) are expected to overlap (blending) in images due to increased depth

Why AI for deblending?

- Large data [billions of galaxies]
- Exploit advances in the field of image processing
- predict complex galaxy shapes
- Multi-band, multi-instrumental approach

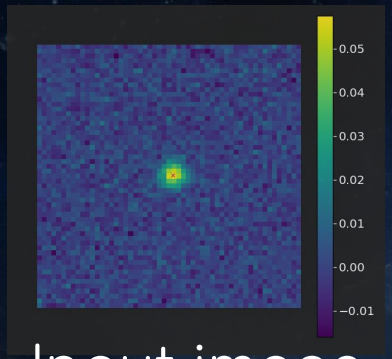
Train VAE as generative model



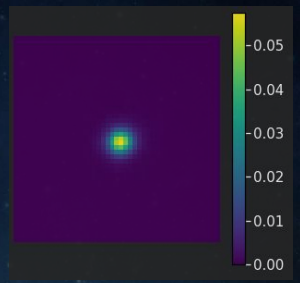
For example: Lanusse et al (arXiv:2008.03833)
Arcelin et al (arXiv:2005.12039)

The VAE creates an underlying distribution from which galaxies are drawn!

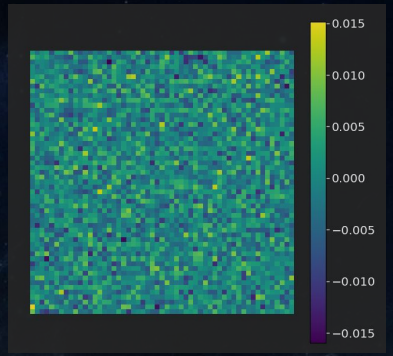
Denoising (Single source)



Input image (y)



Predicted image (x)



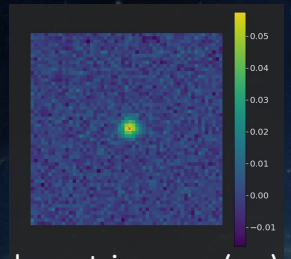
Residual (y-x)

$$x^* = \arg\min_x -\log p(y|x) - \log p(x)$$

$$x^* = \arg\min_x \frac{||\, y - x \,||^2}{2\sigma^2_{noise}} - \log p(x)$$

Where, x^* is the maximum a posteriori probability (MAP) estimate

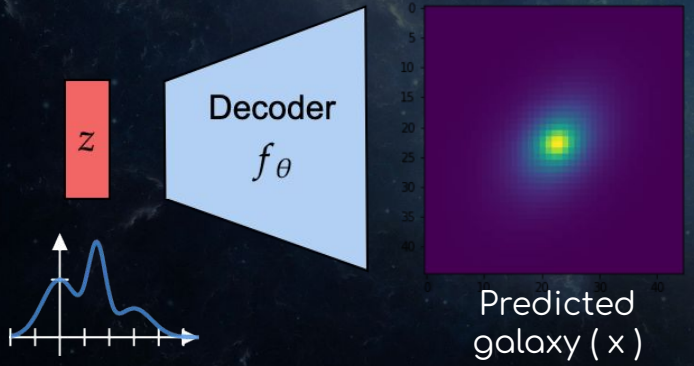
MAP estimate in latent space



Input image (y)

$$x^* = \arg\min_x - \frac{|| y - x ||^2}{2\sigma^2_{noise}} - \log p(x)$$

Going to the latent space

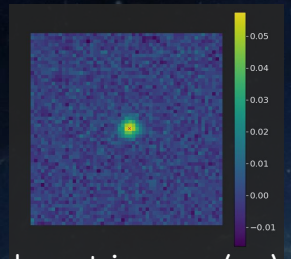


Predicted galaxy (x)

$$z^* = \arg\min_z \frac{|| y - f_\theta(z) ||^2}{2\sigma^2_{noise}} - \log p(z)$$

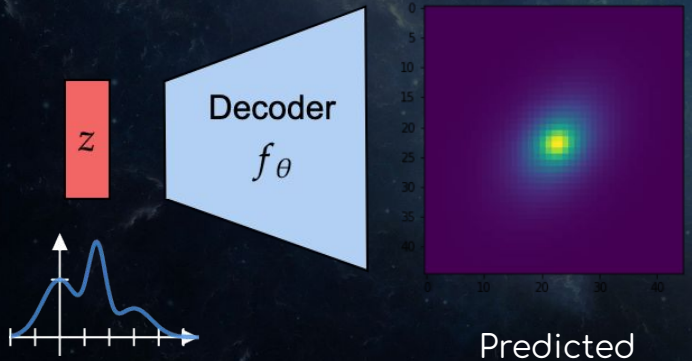
Where, z^* is the maximum a posteriori probability estimate in the latent space

Minimization



Input image (y)

- Start with random z
- Do gradient descent in the latent space to minimize the objective function



Predicted galaxy (x)

$$z^* = \arg\min_z \frac{|| y - f_\theta(z) ||^2}{2\sigma^2_{noise}} - \log p(z)$$

Where, z^* is the maximum a posteriori probability estimate in the latent space

Deblending (Multiple sources)

$$Z = \{z_i \mid z_i \text{ being the latent space representation of } i^{th} \text{ galaxy}\}$$

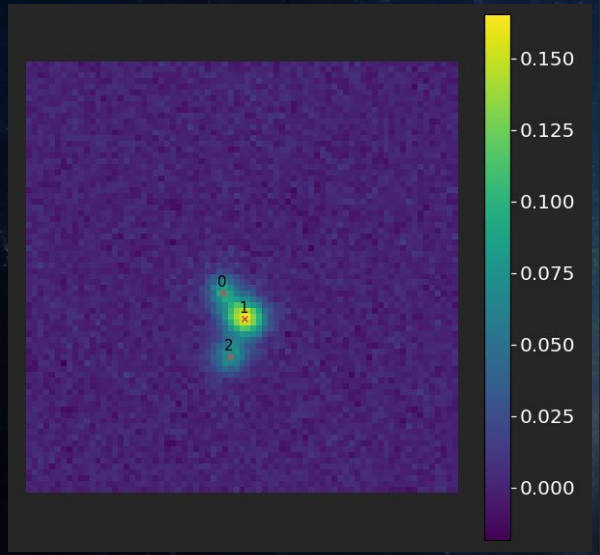
$$Z^* = \arg\min_Z \; -\log p(y|Z) - \log p(Z)$$

Reconstructed field

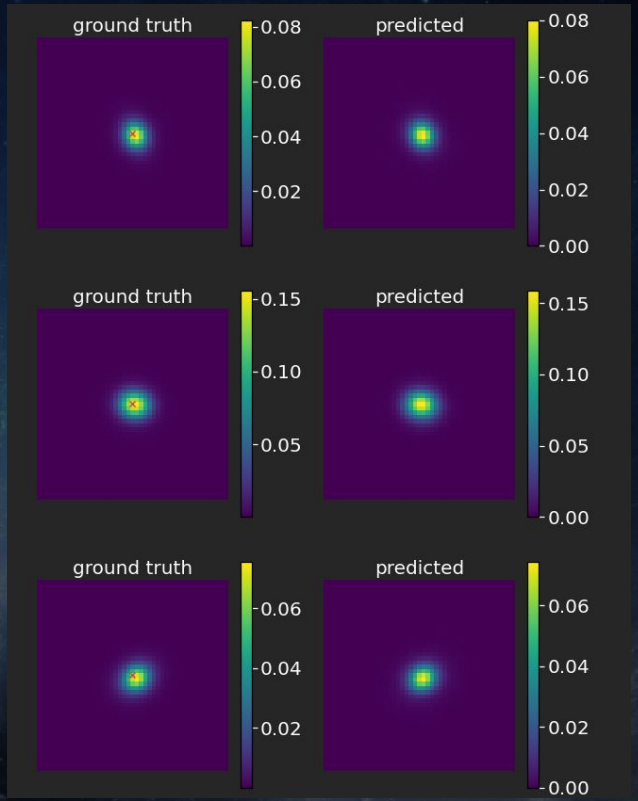
Probability that predictions are galaxies!

$$Z^* = \arg\min_Z \frac{|| y - \sum_i f_\theta(z_i) ||^2}{2\sigma^2_{noise}} - \sum_i \log p(z_i)$$

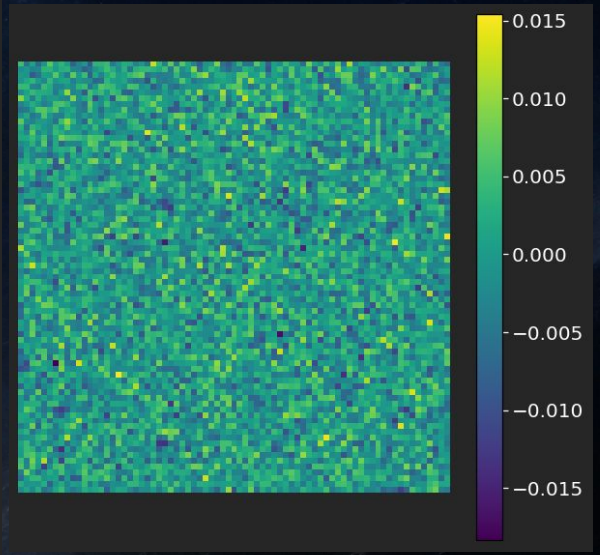
Deblending Example



Input image



Predictions



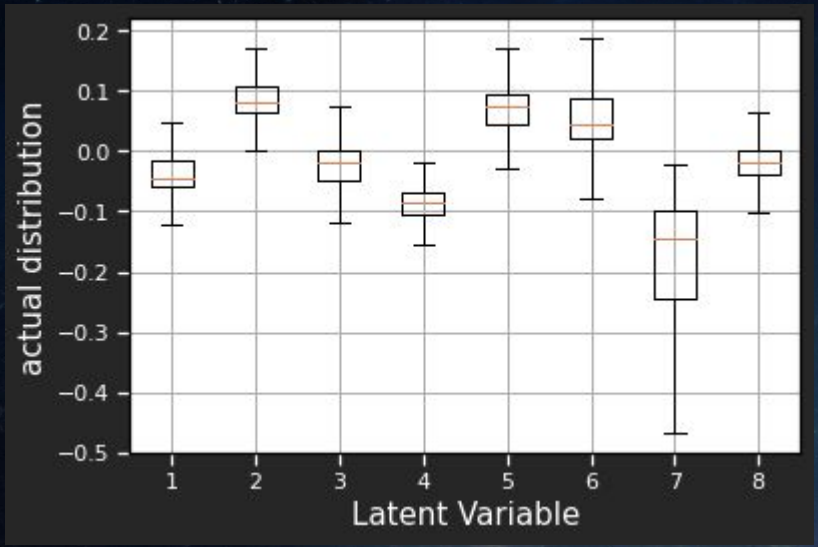
Residual image

Conclusion and Future work

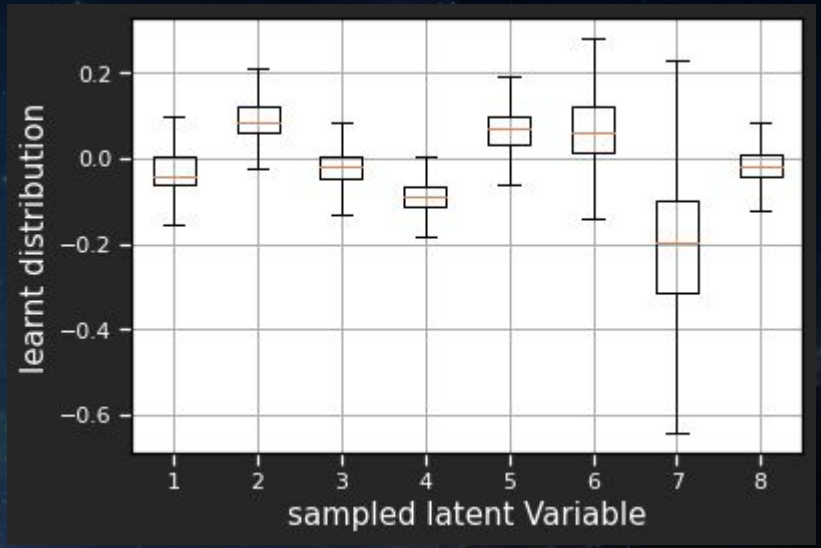
- Encouraging initial results!
- Choose metrics to evaluate the deblending results. (Flux reconstruction, SSIM...)
- Correlation between outputs of different bands
- Real data?

Thank you!

Sanity check



Distribution in the latent space when encoder is fed with noiseless isolated galaxies



Distribution of data when sampled from the distribution learnt by the normalizing flow (NF)

From the plots we see that the NF is able to model the VAE latent space.

Log prob distribution