Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Machine Learning and Super resolution for radio astronomical data analysis

ML4Astro, La Valletta, Malta
31st Aug - 4th Sept

SKAVA

Funded by INAF Ricerca Fondamentale Techno Grant 2023

Giorgia Vitanza, (giorgia.vitanza@inaf.it)
F. Cavallaro, B. Montalto, E. Sciacca, F. R. Vitello
INAF - Osservatorio Astrofisico di Catania

Motivation: why Super Resolution in Radio Astronomy?

1. **Unprecedented data volumes** SKA datacubes (up to TB-scale) cannot be fully transferred or loaded

   SR enables interactive "details on demand" visualization

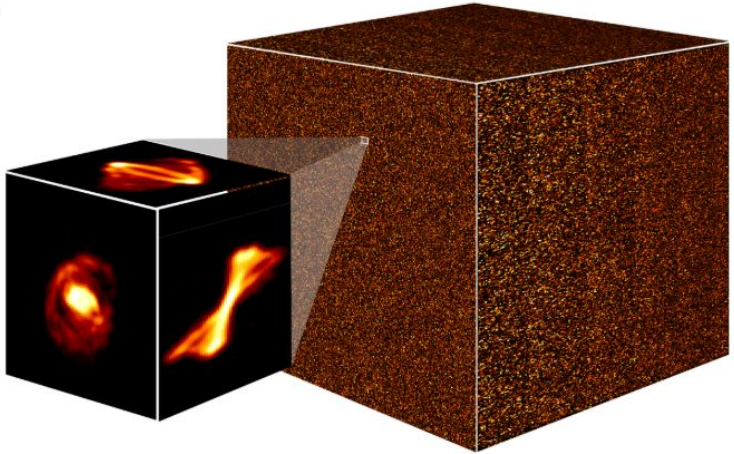
2. **Bandwidth and storage reduction** compressed cubes are moved between SRCs and users,

   SR allows fine detail reconstructed client-side

3. **Enhanced visual inspection** of faint sources and low-contrast structures

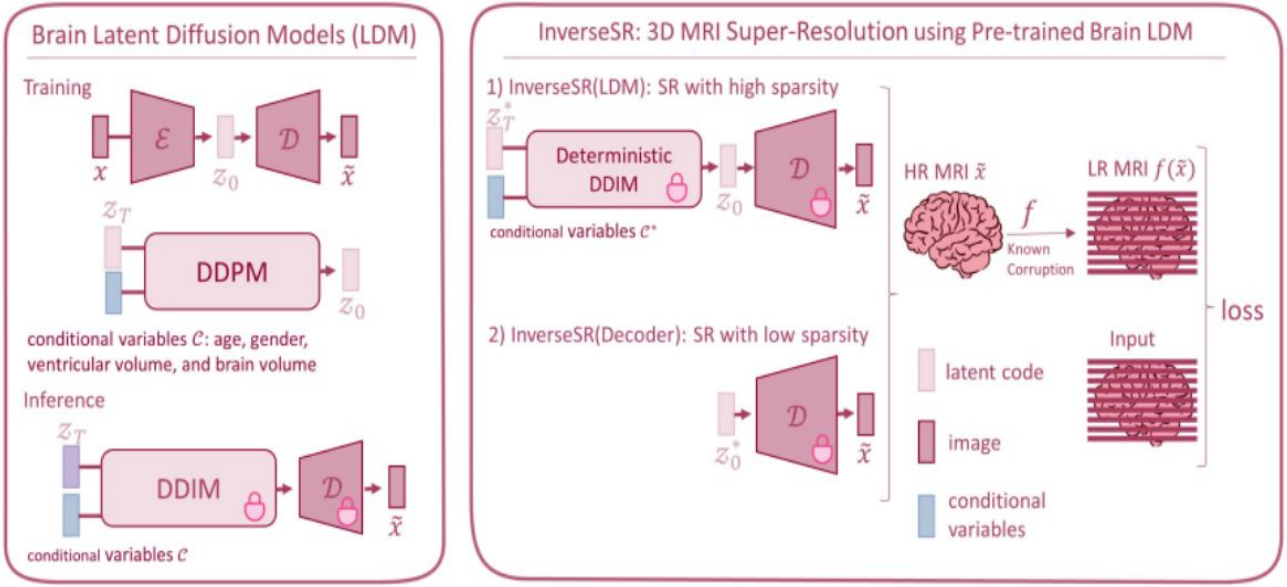
   SR speeds up human-in-the-loop visual source validation

Novelty: Diffusion models for astronomical data.



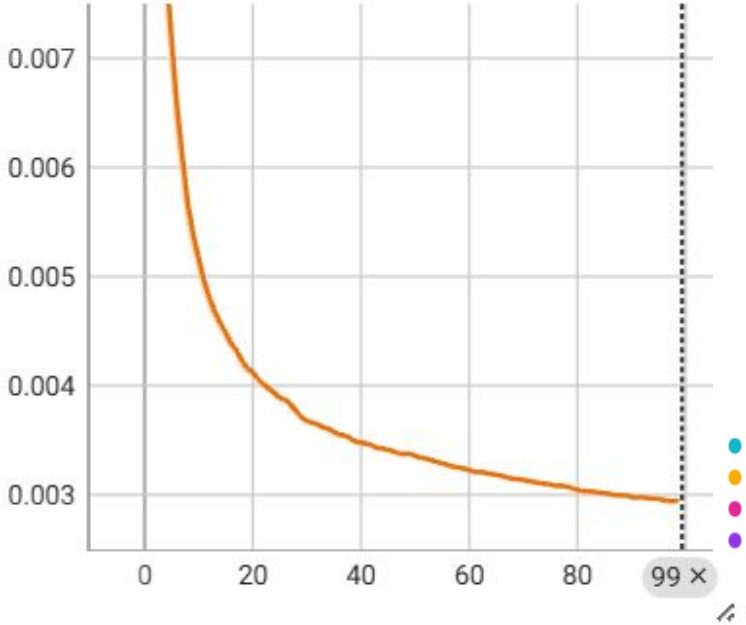
3D Data cube from SKA Data challenge 2.

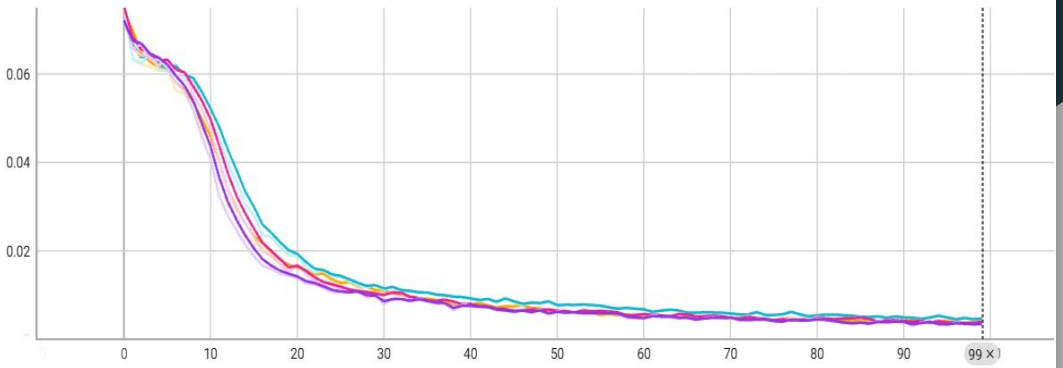
Machine Learning models for Super resolution tasks: 3D case



Wang, Jueqi, et al. "Inversesr: 3d brain mri super-resolution using a latent diffusion model." *International conference on medical image computing and computer-assisted intervention*. Cham: Springer Nature Switzerland, 2023.

Plots loss VAE and DDPM





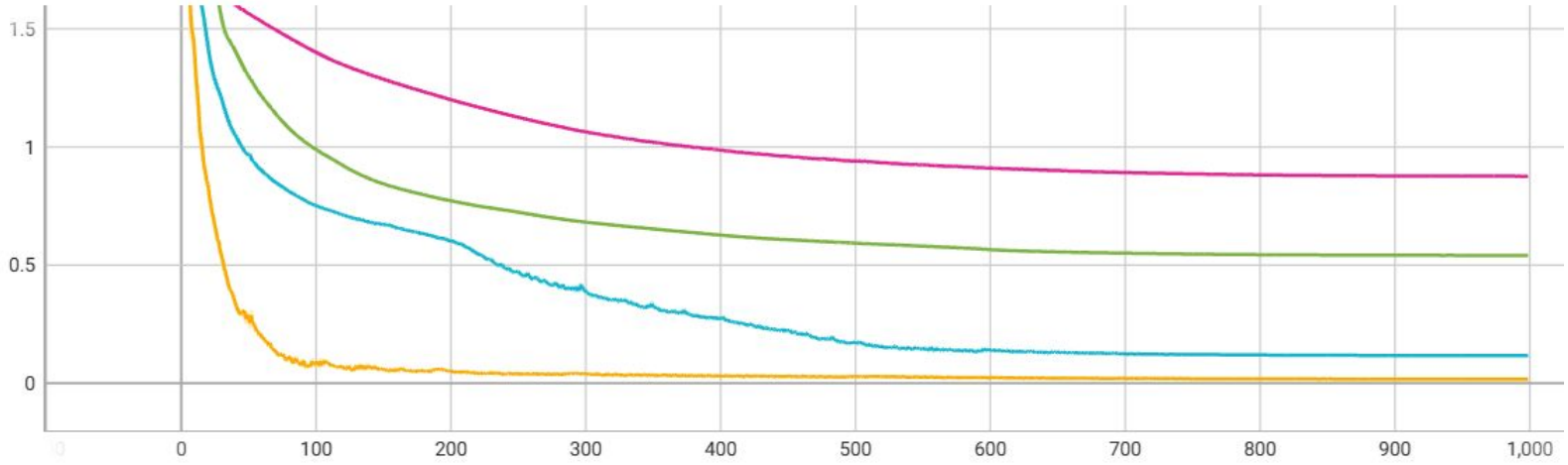
Run ↑	Smoothed	Value	Step	Relative
ddpm_None_100_z3_local_cont_ldev_logvarFalse/run_Aug17_10-22-30_lr_0.0001_z3	0,0047	0,0048	99	1.639 day
ddpm_concat_100_z3_local_cont_ldev_logvarFalse/run_Aug19_17-52-49_lr_0.0001_z3	0,004	0,0041	99	1.657 day
ddpm_crossattn_100_z3_local_cont_ldev_LogvarFalse/run_Aug19_17-52-19_lr_0.0001_z3	0,004	0,0042	99	1.895 day
ddpm_hybrid_100_z3_local_cont_ldev_logvarFalse/run_Aug19_17-52-55_lr_0.0001_z3	0,0034	0,0035	99	1.914 day

Loss VAE. 100 epochs.

Loss DDPM with different conditioning cases. 100 epochs.

BRGM Inversion procedure: DDIM + Decoder

Loss Inversion DDIM plots with different conditioning



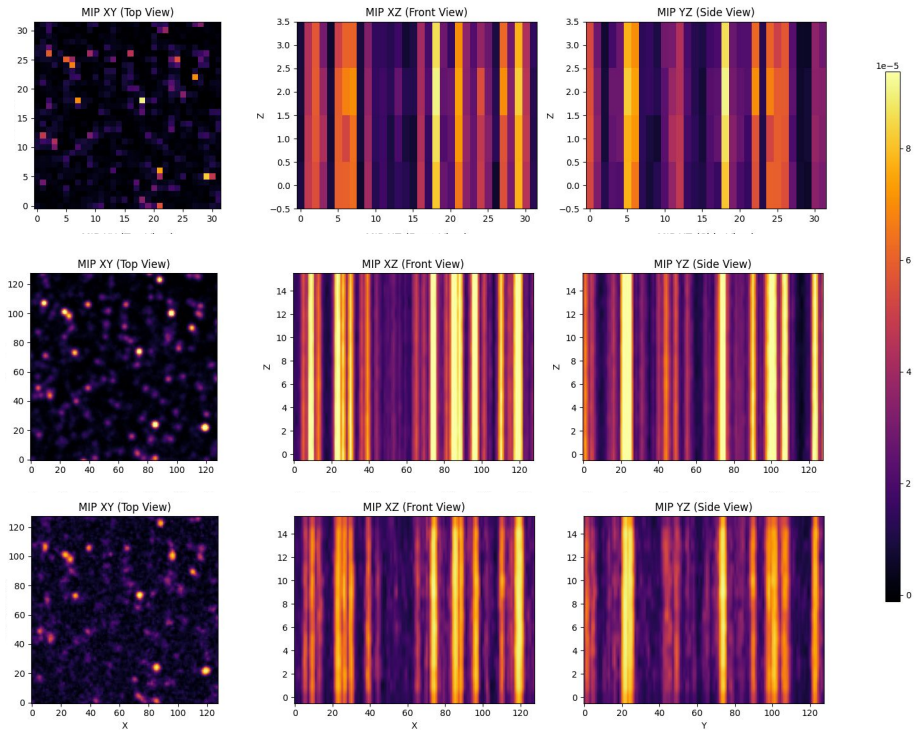
Run ↑	Smoothed	Value	Step	Relative
opt_lr0.01_lam100_steps1000_Hybrid	0,8763	0,8763	999	3.591 hr
opt_lr0.05_lam100_steps1000	0,117	0,117	999	2.73 hr
opt_lr0.05_lam100_steps1000_crossattn	0,5412	0,5413	999	3.573 hr
opt_lr0.1_lam100_steps1000_None	0,0166	0,0166	999	2.742 hr

Visual comparison among HR LR and SR (DDIM+Decoder None cond)

LOW RESOLUTION (4x)

HIGH RESOLUTION

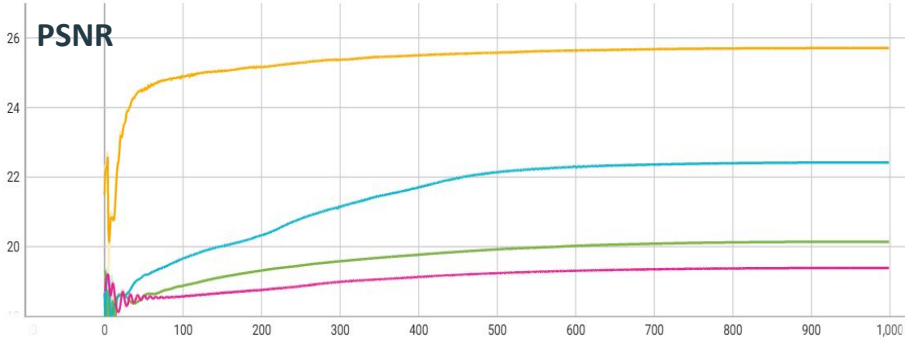
SUPER RESOLUTION



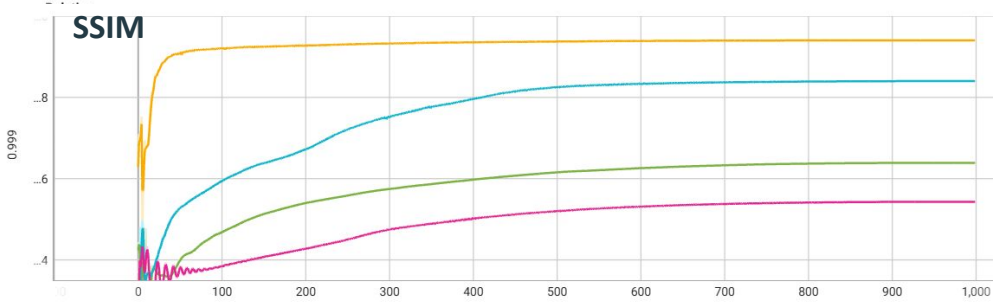
shape: 16x128x128

step of optimization: 990

Metrics plots: PSNR and SSIM



Run ↑	Smoothed	Value	Step
opt_lr0.01_lam100_steps1000_Hybrid	19,3882	19,3882	999
opt_lr0.05_lam100_steps1000	22,4202	22,4202	999
opt_lr0.05_lam100_steps1000_crossattn	20,1417	20,1417	999
opt_lr0.1_lam100_steps1000_None	25,707	25,7069	999



Run ↑	Smoothed	Value	Step	Relative
opt_lr0.01_lam100_steps1000_Hybrid	0,9995	0,9995	999	3.591 hr
opt_lr0.05_lam100_steps1000	0,9998	0,9998	999	2.73 hr
opt_lr0.05_lam100_steps1000_crossattn	0,9996	0,9996	999	3.573 hr
opt_lr0.1_lam100_steps1000_None	0,9999	0,9999	999	2.742 hr

Conclusion and future goals

1. A 3D LDM for radio astronomical data cube with conditioning has been developed;
2. The model is a novelty in the ML field with radio astronomical data;
3. The memory usage has been optimized thanks to the latent approach.

Future goals include:

- integration of this model in visual analytics (VisIVO) and immersive visualization (iDAVIE) tools in order to help the scientists in the data analysis and source finding, through the HR data reconstruction.
- improvement of the conditional mechanism.

Thank you for your attention!

Questions?