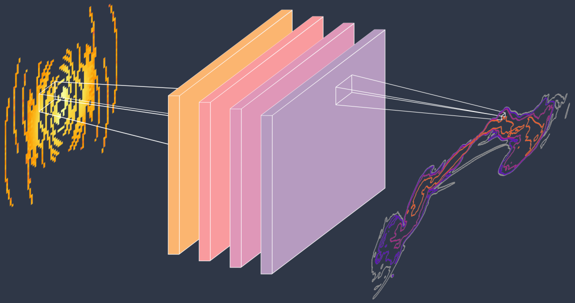
technische universität dortmund

astroparticle physics



pyvisgen: A fully-differential visibility generator in Python

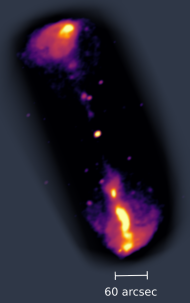
Kevin Schmidt

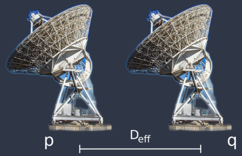
November 16th, 2023

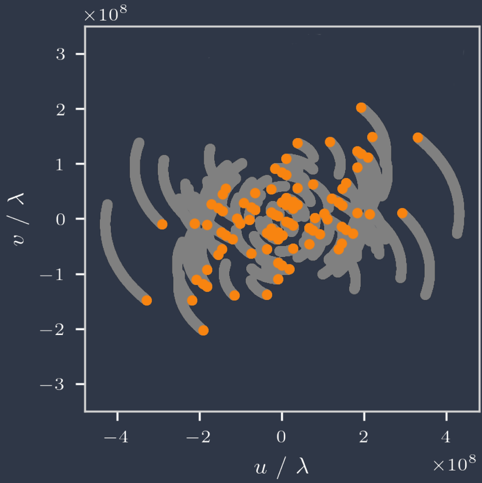
Experimentelle Physik, AG Rhode/Elsässer

Fakultät Physik

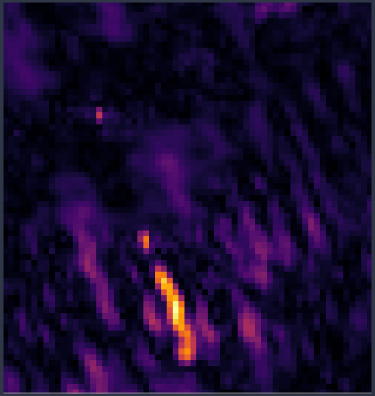
Reconstruction of radio interferometer data

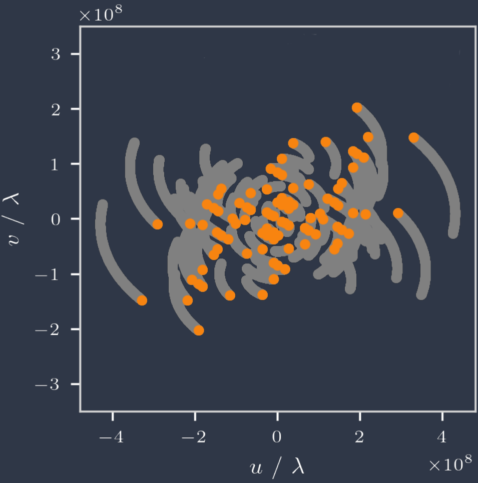




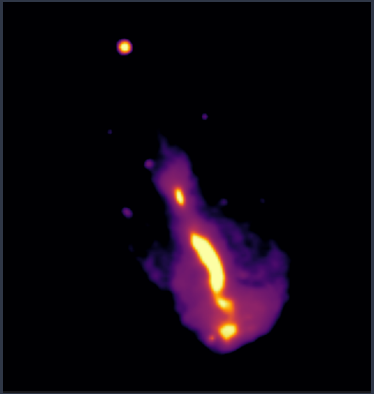


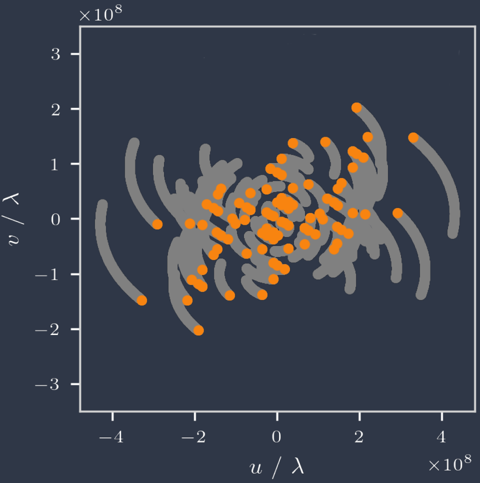
Reconstruction of radio interferometer data





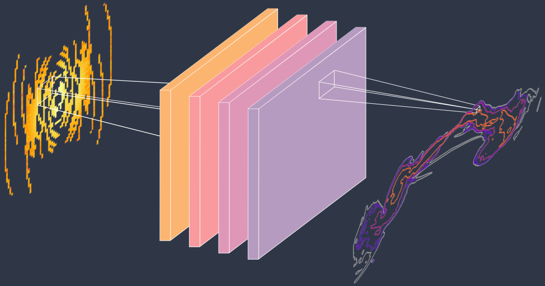
Reconstruction of radio interferometer data





Machine Learning-based Approaches

- Reconstruction in visibility space
  → no iterative source cleaning
- Development of neural network architecture
- Need of simulation data for model training
- Implementation of analysis framework: radionets



[github.com/radionets-project/radionets]

Radio Interferometer Measurement Equation

RIME Formalism:

$$\mathbf{V}_{pq}(l,\ m) = \sum_{l,m} \mathbf{E}_p(l,m)\ \ \mathbf{K}_p(l,m)\ \ \boxed{\mathbf{B}(l,m)}\ \ \mathbf{K}_q^H(l,m)\ \ \mathbf{E}_q^H(l,m)$$

Source Distribution:

$\mathbf{B}(\mathbf{l},\mathbf{m})$

Phase Delay:

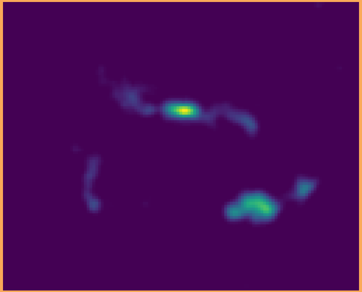
$$\mathbf{K}(l,m) = \exp\left(-2\pi \cdot i \cdot (ul + vm)\right)$$

Telescope Beam:

$$\mathbf{E}(l,m) = \mathrm{jinc}\left(\frac{2\pi}{\lambda_{\mathrm{obs}}} d \cdot \theta_{lm}\right)$$

$$\mathrm{jinc}(x) = \frac{J_1(x)}{x}$$

Source Distribution:



[Smirnov, A&A, 2021]

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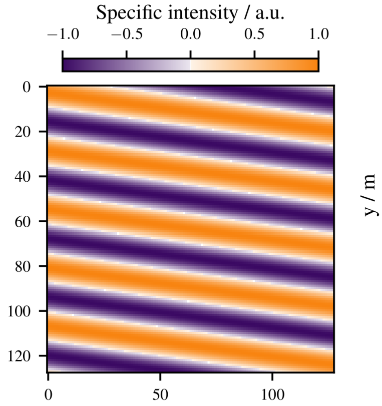
Phase Delay:



[Smirnov, A&A, 2021]

Radio Interferometer Measurement Equation

RIME Formalism:

$$\mathbf{V}_{pq}(l,\ m) = \sum_{l,m} \mathbf{E}_p(l,m)\,\mathbf{K}_p(l,m)\,\mathbf{B}(l,m)\,\mathbf{K}_q^H(l,m)\,\mathbf{E}_q^H(l,m)$$

Source Distribution:

$\mathbf{B(l, m)}$

Phase Delay:

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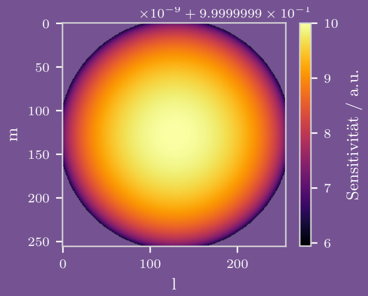
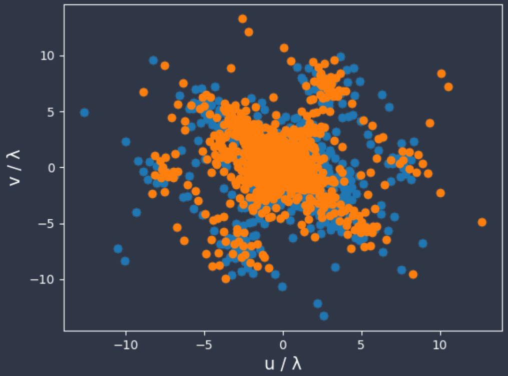
Telescope Beam:



[Smirnov, A&A, 2021]

pyvisgen

- Visibility simulator in Python
- Describe basic corruption effects
- Modular extensible
- Mimicking of radio interferometer observations:
  - Creation of machine learning data sets
  - Comparison betwenn observation and models
  - Estimate sensitivity of upcoming observation / interferometer layouts



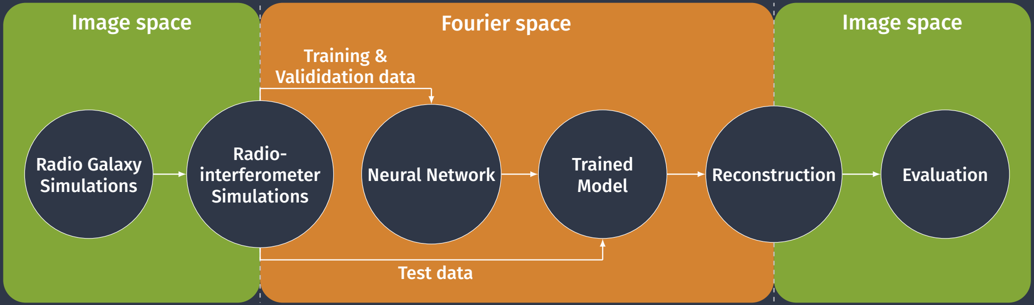
[github.com/radionets-project/pyvisgen]

Why fully-differential?

- GPU support
- Huge speed-ups: single CPU / single GPU calculation for one snapshot
- Forward modeling: implementation into deep learning architectures

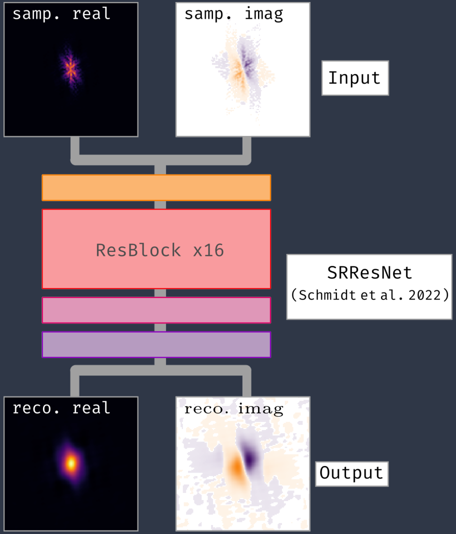
	(128 × 128) px	(512 × 512) px
GPU	3 ms	50 ms
CPU	250 ms	3210 ms

Analysis Overview



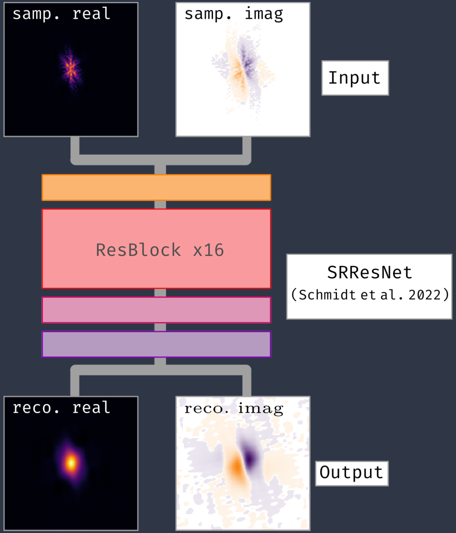
Deep Learning-based Imaging

- Reconstruction of missing visibility data in Fourier space
- Deep learning model influenced by super-resolution applications
- Fast reconstruction times without iterative cleaning
- Initial publication Schmidt et al. (2022, A&A 664 A134)

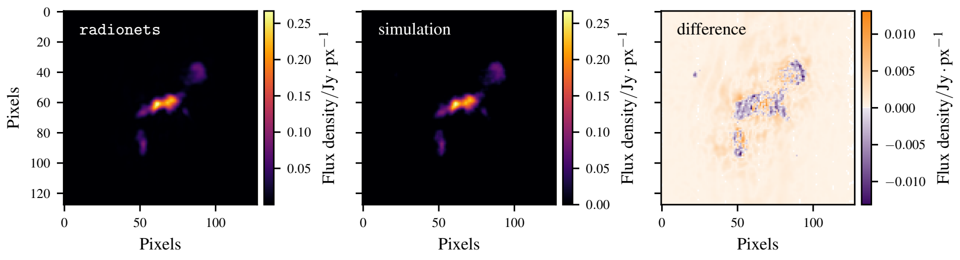


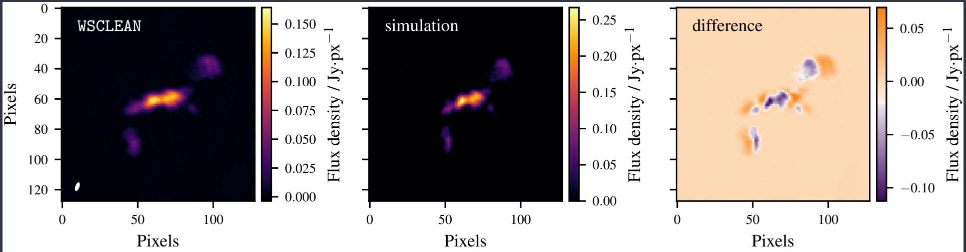
2023 Updates

- Improved results in Geyer et al. (2023, A&A 677 A167)
- Extensive testing on simulation data
- Verify deep learning-based approach
- Reconstruction of complex source morphologies



2023 Updates





Future Prospects

- Currently implementing:
  - Larger image sizes
  - Simulation and training speed-ups
  - Capability for real observation data
- Data ↔ simulation offsets
- High-resolution source images
- Accelaration of existing imaging pipelines

Many thanks to all collaborators from Sternwarte Hamburg, RUB and ESO.