Multiscale VLBI imaging

Hendrik Müller Max-Planck Institut für Radioastronomie EVN Meeting July 2022

Cork

- Müller, H. & Lobanov, A. 2022: Multiscale and Multidirectional VLBI imaging with CLEAN, review
- Müller, H. & Lobanov, A. 2022: DoG-HiT: A novel VLBI Multiscale Imaging Approach, accepted for publication in A&A
- Müller, H. & Lobanov, A. 2022: MrBeam (DoG-HiT/DoB-CLEAN/regpy), https://github.com/hmuellergoe/mrbeam (to be published)



Everything that is wrong with CLEAN

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- Conceptual errors:
 - model ≠image
 - Image does not fit data
- Missing regularization
 - Spurious interpolation of gaps in uv-coverage
 - Image robustness?
- Worse representation of extended emission
- Need more control over the fit in the Fourier domain



... and with RML/Bayesian

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Synthetic EHT coverage

- Excellent super-resolving images
- Forward approach
- Very flexible
- But:
 - many hyper-parameters (parameter surveys)
- Blind, automatic (data-driven) imaging pipeline with fewer parameters desired



Multiscale Dictionaries

Mar Dlanak Inatitut

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-10.0 -7.5 -5.0 -2.5 0.0 2.5 5.0 7.5 10.0



Scales fitted to uv-coverage

22.07.22

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drik Müller

Optimal Dictionaries

Synthetic RadioAstron coverage

....







Scale: 5







Scale: 9



Fourier domain:

- Heaviside maks
- orthogonal ٠









DoB

DoG

100





Image domain:

- Smooth atoms •
- No sidelobes ٠
- Positive flux ٠



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Imaging Pipeline: DoG-HiT (RML)





Objective functional is non-convex and non-smooth:

Proximal point based forward backward splitting

Comparison/Conclusion



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Imaging with a DoG-Dictionary and hart iterative thresholing (DoG-HiT) provides:

- Super-resolution
- Better representation of extended emission
- Effective regularization
- Data-driven, blind, automatic imaging
- Robust recovery of characteristic structural patterns

ngEHT Analysis challenge

DoB-CLEAN



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log10(Jy / pixel)

CLEAN still has some advantages:

- Interactive
- Straightforward
- Calibration/Issues/False data detection

Pathologies by CLEAN (missing regularization, representation of extended features, convolution with clean beam ...) are effectively tackled by a multiscale approach fitted to the uv-coverage!

log₁₀(Jy / pixel)

log₁₀(Jy / pixel)



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Byproducts/Software

- MrBeam: New imaging software
 - DoG-HiT, DoB-CLEAN, NNPen, ...
 - based on
 - regpy: multidisciplinary inverse problems package
 - medical imaging
 - scattering
 -).
 - helioseismology, Ly-alpha forest tomography (Müller+ 2020, Müller+ 2021, Hamaide+ 2022), reverberation mapping, optical interferometry ...
 - ehtim (Chael+ 2016, Chael+ 2018)
 - imagingbase
 - WISE: wavelet-based analysis tools for jet dynamics (Mertens&Lobanov 2015)
- https://github.com/hmuellergoe/mrbeam (to be published soon)

Outlook



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- Compressed Sensing Bayesian imaging
- Compressed Sensing Neural Networks
- Global optimization instead of pipelines, self-calibration
- Dynamic Imaging: Multiresolution support as temporal regularizer
- Polarization: Multiresolution support as correlation prior between Stokes parameters
- Applications:
 - EVN+eMerlin: Crab Nebula
 - EHT/ngEHT
 - RadioAstron

Stay tuned, there is a lot to come !!!