Imaging observations from next-generation radio interferometric telescopes

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Mullard Space Science Laboratory (MSSL)
University College London (UCL)

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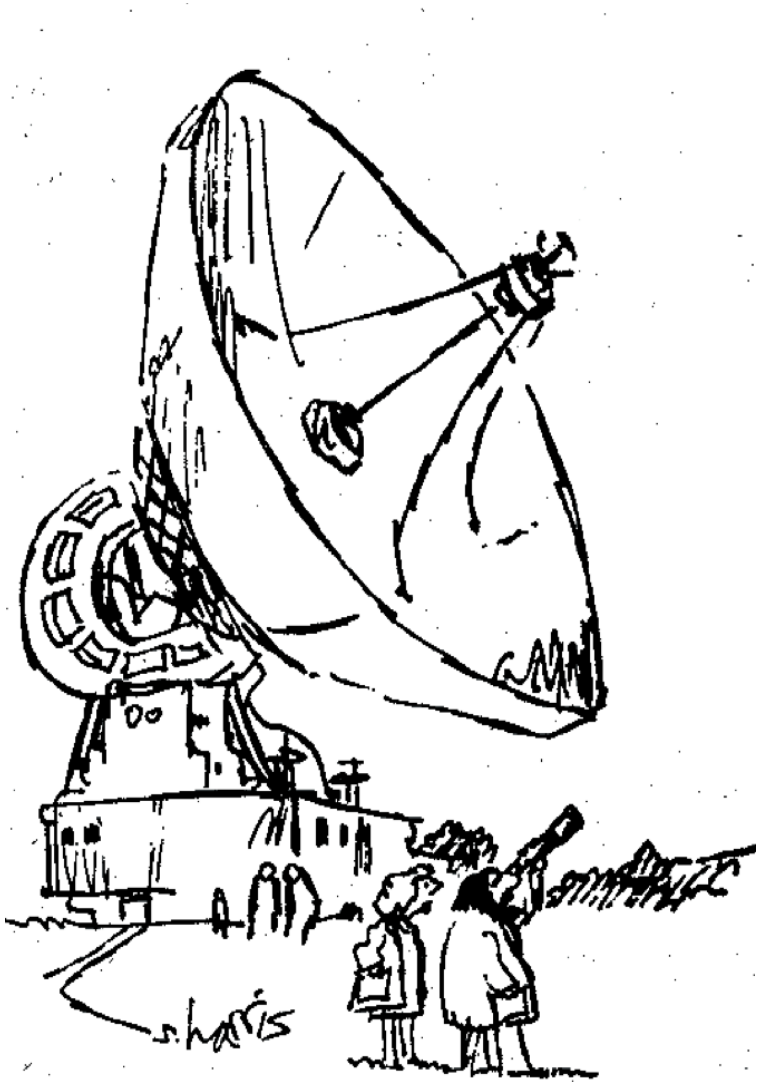
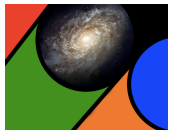
Radio telescopes are big!



"Just checking."



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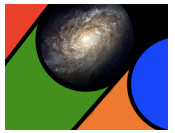
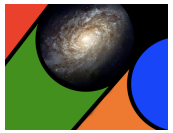


Radio interferometric telescopes



SKA movie

Next-generation of radio interferometry rapidly approaching

- Square Kilometre Array (SKA) construction scheduled to begin in 2018.
- Many pathfinder telescopes coming online, *e.g.* LOFAR, ASKAP, MeerKAT, MWA.
- New modelling and imaging techniques essential.

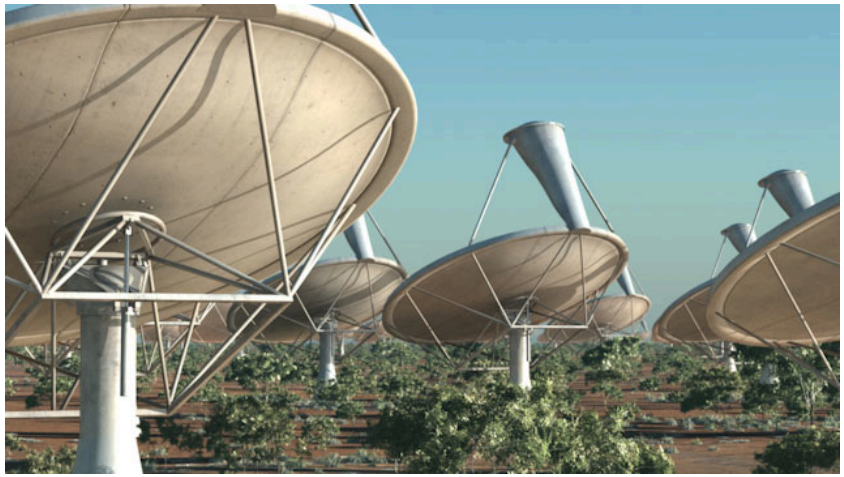
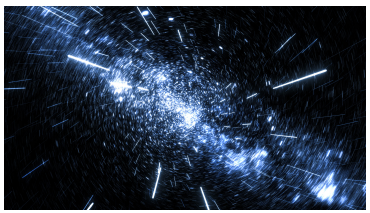


Figure: Artist impression of SKA dishes. [Credit: SKA Organisation]



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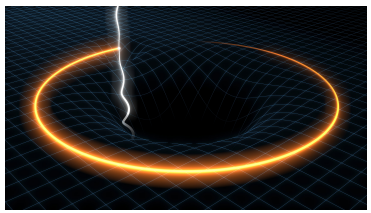

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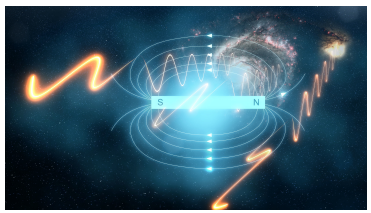

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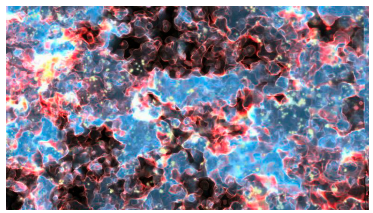

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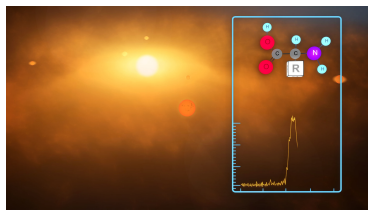

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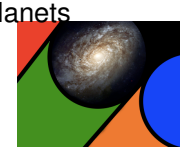

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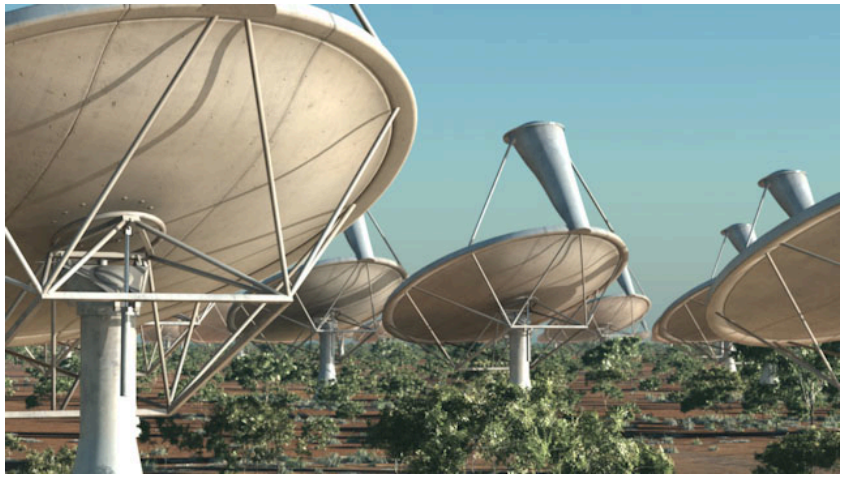

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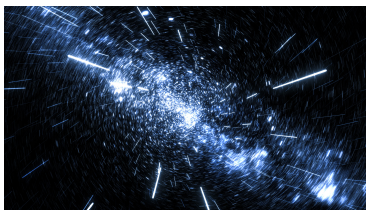

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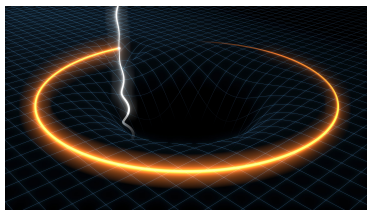

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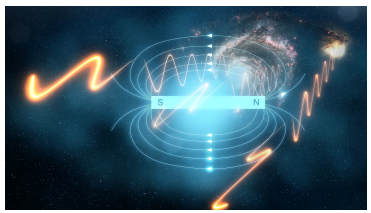

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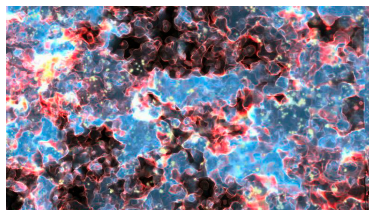

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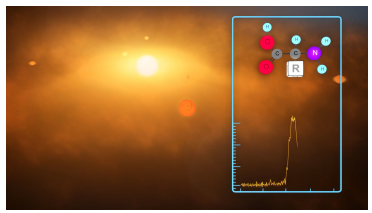

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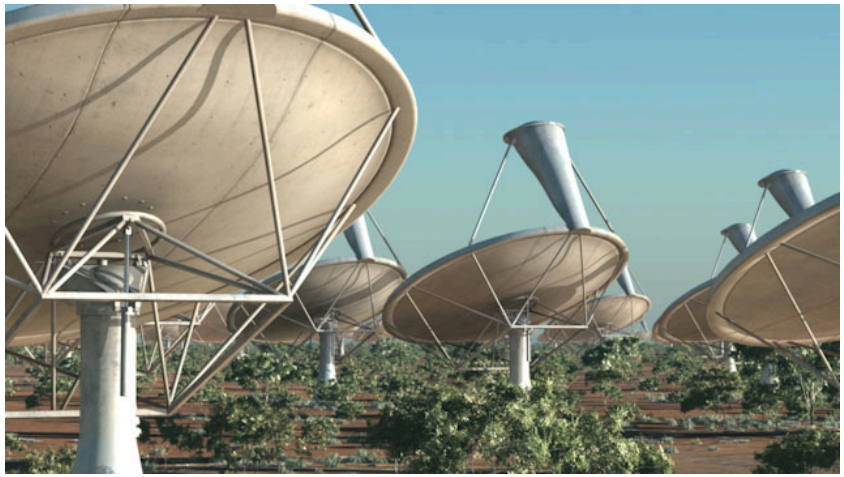

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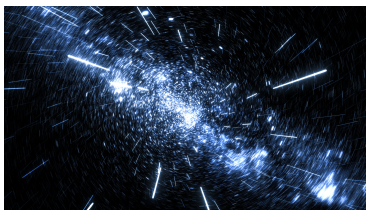

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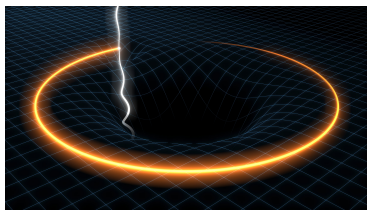

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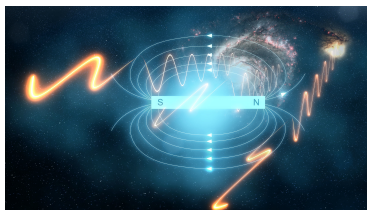

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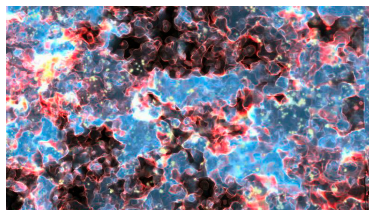

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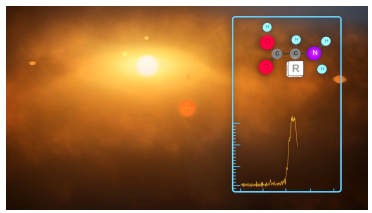

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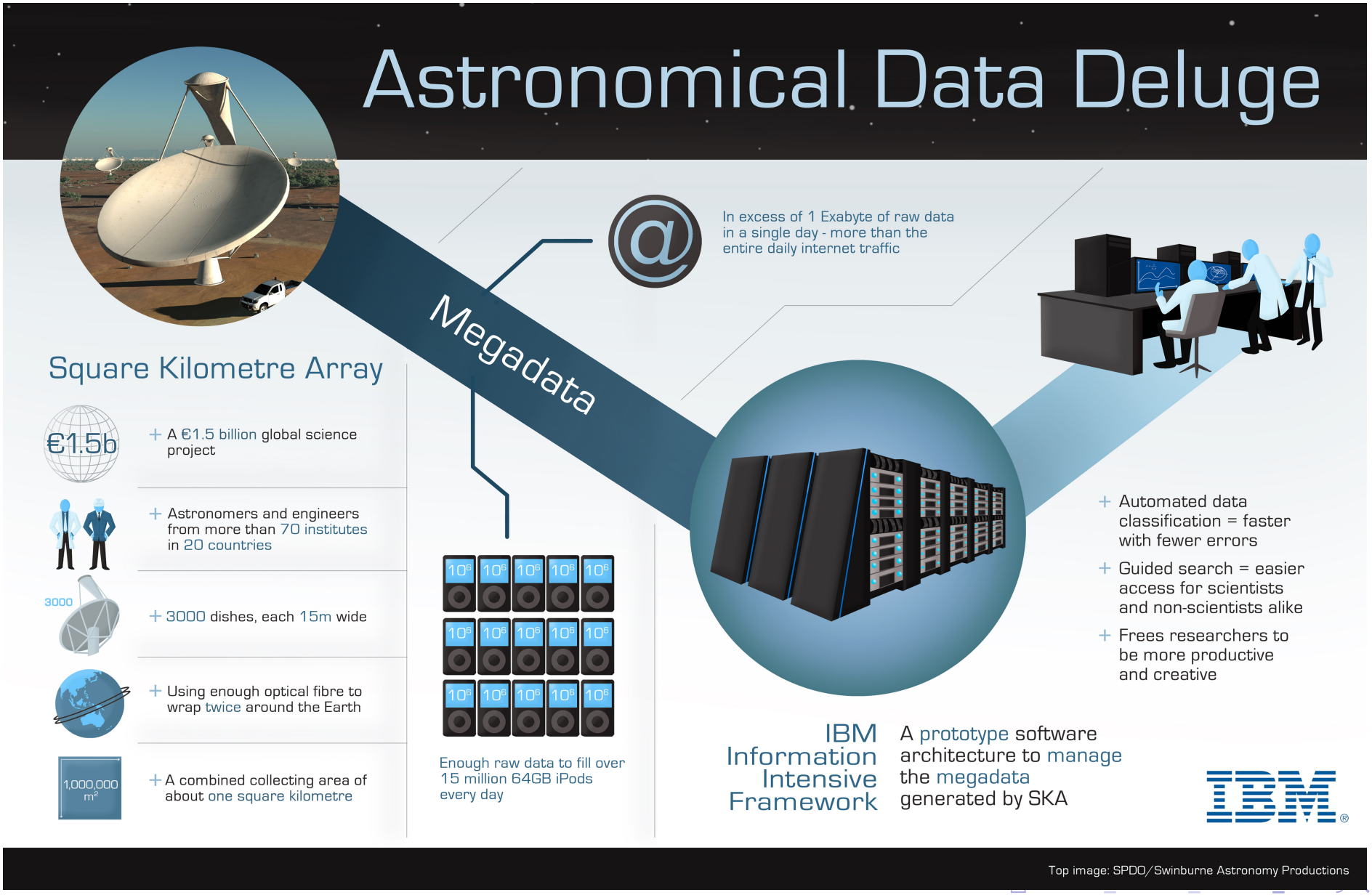
The SKA poses a considerable big-data challenge



Compressive sensing

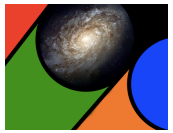
"Nothing short of revolutionary."

– National Science Foundation

- Developed by Emmanuel Candes and David Donoho (and others).

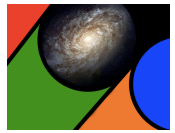
(a) Emmanuel Candes

(b) David Donoho



Compressive sensing

- The mystery of JPEG compression (discrete cosine transform; wavelet transform).
- Move compression to the acquisition stage $\rightarrow$ compressive sensing.
- Acquisition versus imaging.



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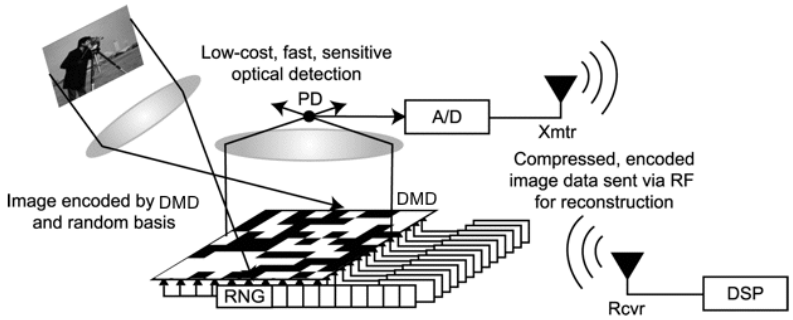

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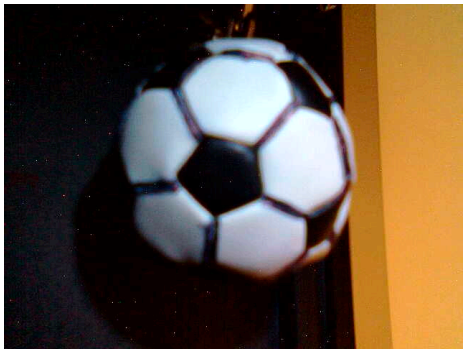
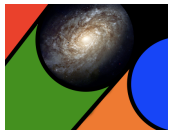


(b) Scene

(c) Recov. (20% meas.)

Figure: Single pixel camera



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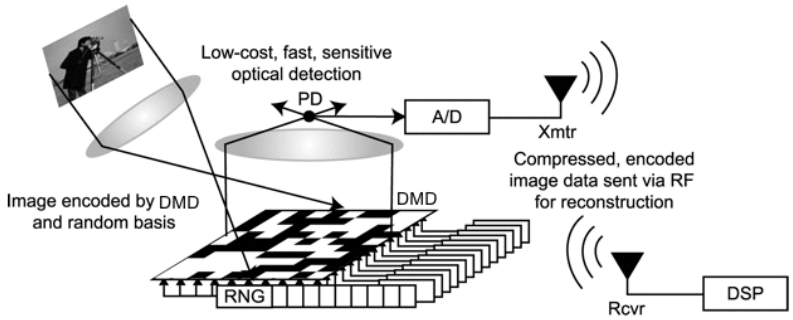

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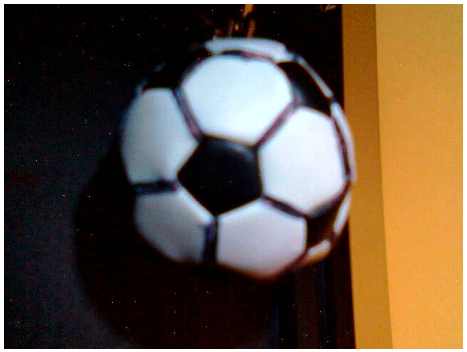

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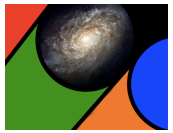


Interferometric imaging with compressive sensing

- Solve the interferometric imaging problem

$$\boxed{y = \Phi x + n \quad \text{with} \quad \Phi = \mathbf{M}\,\mathbf{F}\,\mathbf{C}\,\mathbf{A}}\,,$$

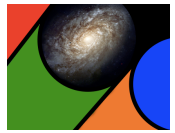
to recover image x from Fourier measurements y, where Φ models the telescope measurement operator.

- Promote sparsity by minimising ℓ_1 norm of wavelet representation of image:

$$\boxed{\alpha^\star = \arg\min_{\alpha} \|\alpha\|_1 \;\text{ such that }\; \|y - \Phi\Psi\alpha\|_2 \leq \epsilon}\,,$$

where we synthesise the image from its recovered wavelet coefficients by $x^\star = \Psi\alpha^\star$.

- Solve with convex optimisation algorithms.
- Many new developments (*e.g.* analysis vs synthesis, reweighting, cosparsity, structured sparsity).



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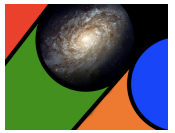
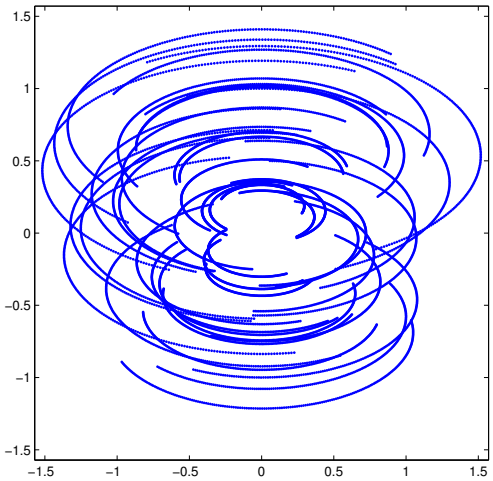
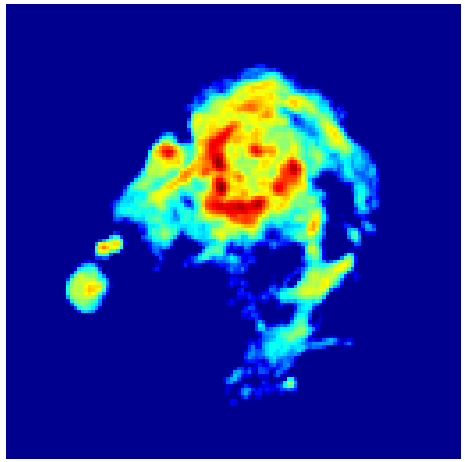


PURIFY

Results on simulations



(a) Coverage



(b) M31 (ground truth)

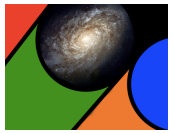


Figure: Reconstructed images from continuous visibilities.

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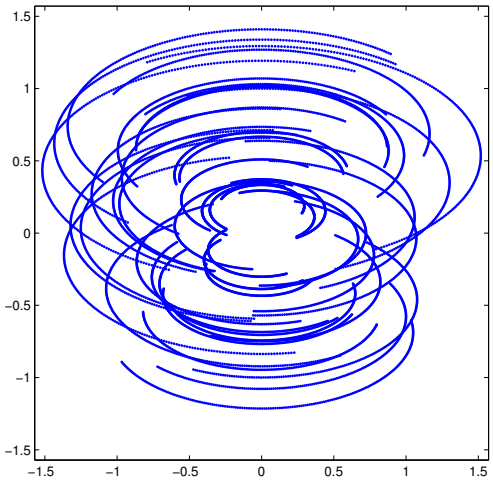

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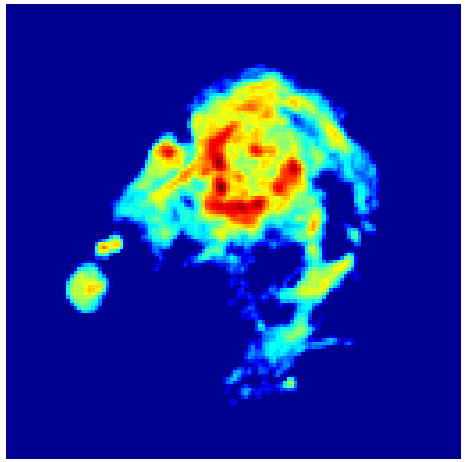

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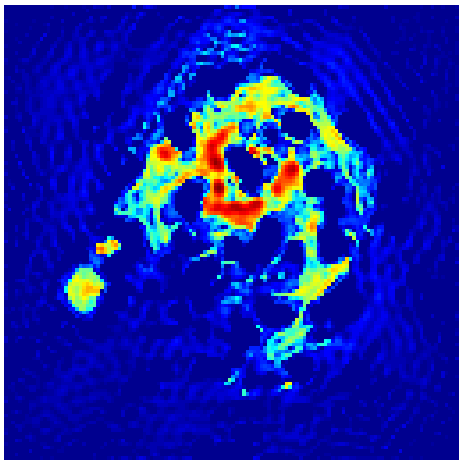
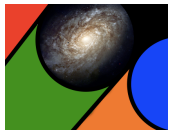


(c) CLEAN $\rightarrow$ SNR$= 8.2$dB



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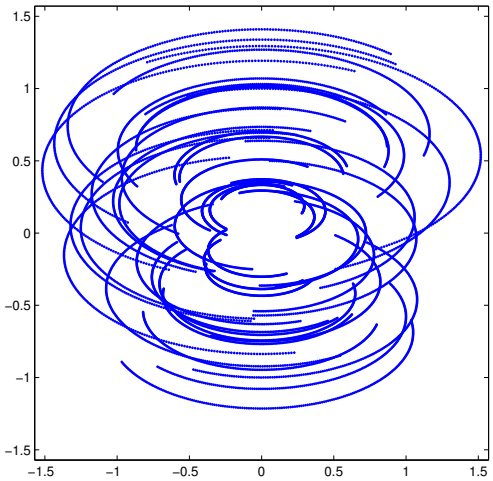

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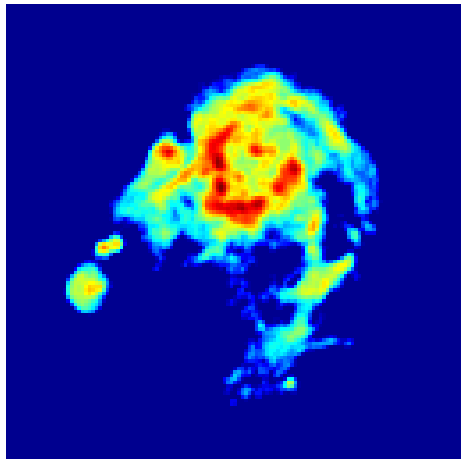

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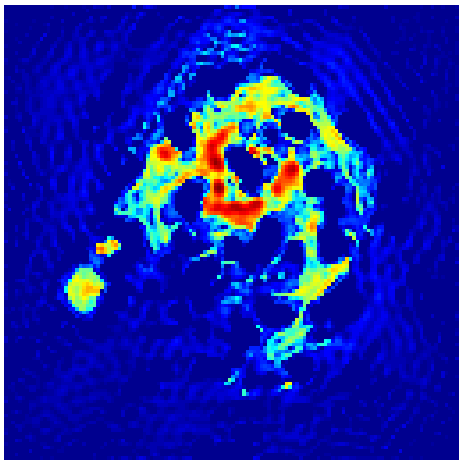

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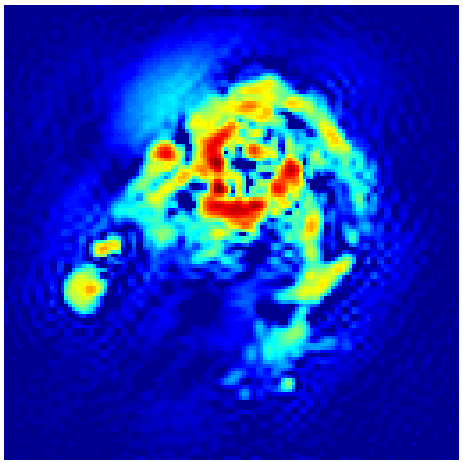
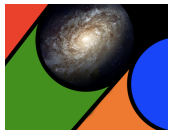


(d) MS-CLEAN $\rightarrow$ SNR$=11.1$dB



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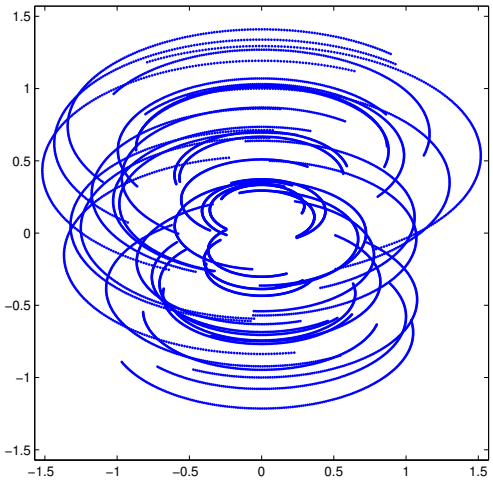

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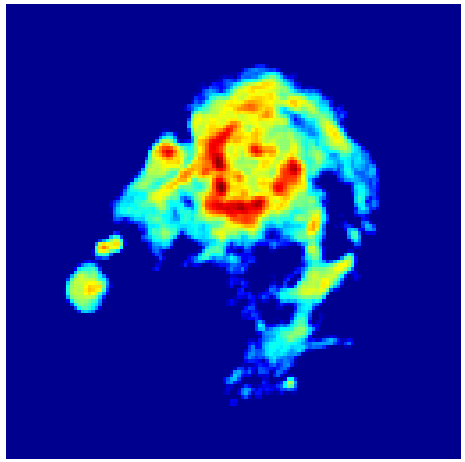

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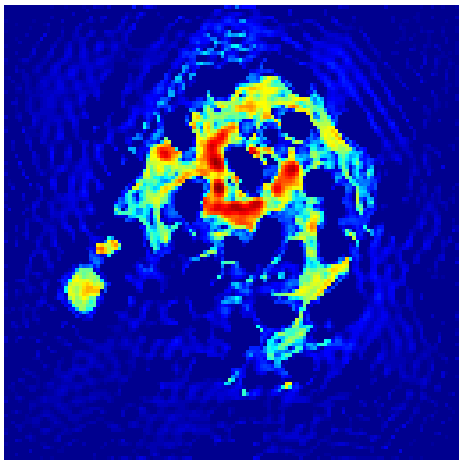

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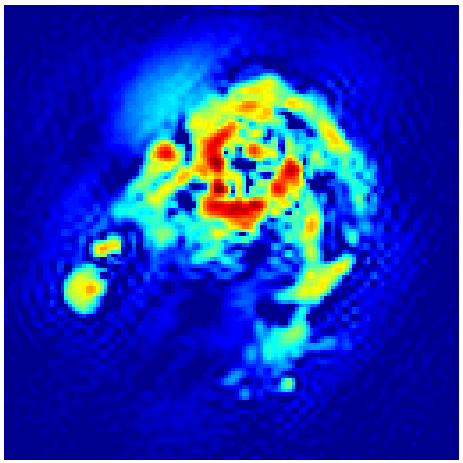

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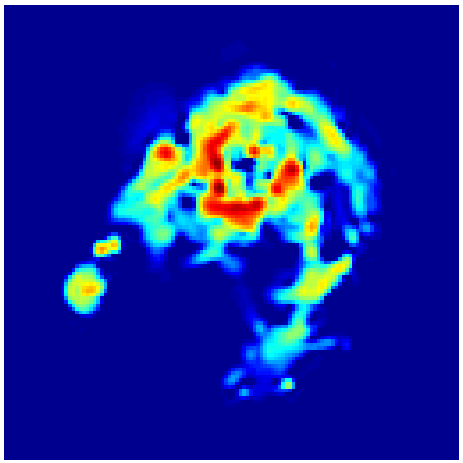

(e) PURIFY $\rightarrow$ SNR$=13.4$dB

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PURIFY

- Recently released the PURIFY code.
- Shown dramatic improvement over state-of-the-art on simulations.
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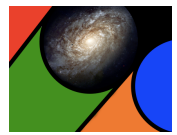
PURIFY is an open-source code that provides functionality to perform radio interferometric imaging, leveraging recent developments in the field of compressive sensing and convex optimisation.



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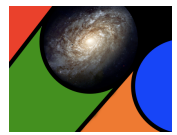

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