

# Imaging observations from next-generation radio interferometric telescopes

Jason McEwen

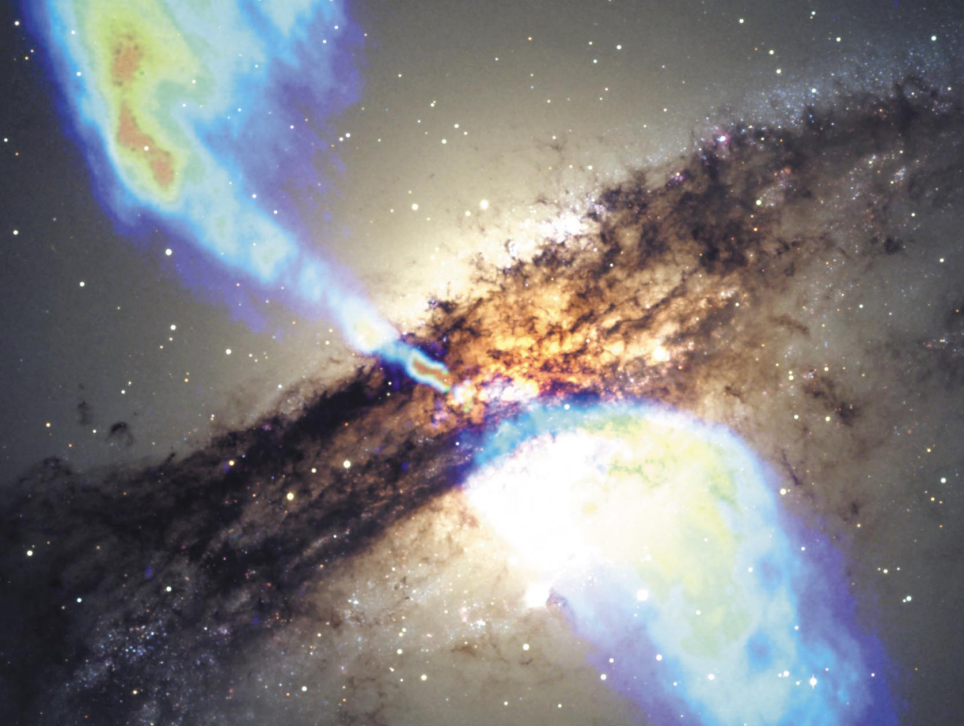
[www.jasonmcewen.org](http://www.jasonmcewen.org)

[@jasonmcewen](https://twitter.com/jasonmcewen)

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

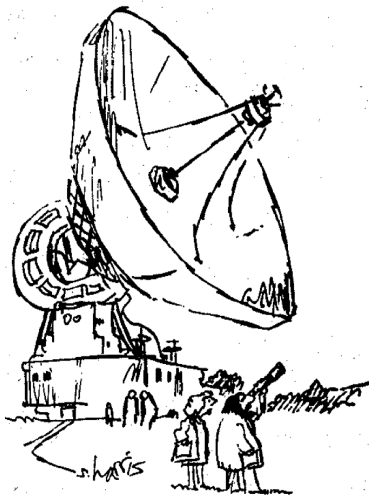
UCL Research IT Services Annual Forum, June 2014







# Radio telescopes are big!



“Just checking.”



# Radio telescopes are big!



# Radio interferometric telescopes



SKA movie

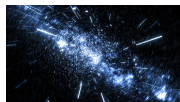


# Next-generation of radio interferometry rapidly approaching

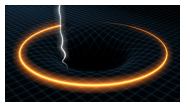
- **Square Kilometre Array (SKA)** construction scheduled to begin in 2018.
- Many pathfinder telescopes coming online, *e.g.* LOFAR, ASKAP, MeerKAT, MWA.
- **New modelling and imaging techniques** essential.



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



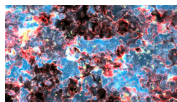
(a) Dark-energy



(b) GR



(c) Cosmic magnetism



(d) Epoch of reionization



(e) Exoplanets

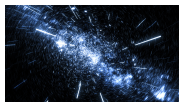
**Figure:** SKA science goals. [Credit: SKA Organisation]

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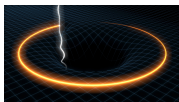
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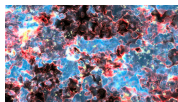
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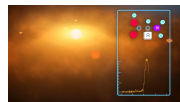
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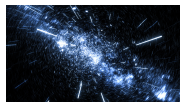
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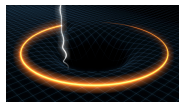
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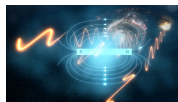
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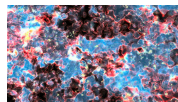
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# The SKA poses a considerable big-data challenge

## Astronomical Data Deluge



### Square Kilometre Array



+ A €1.5 billion global science project



+ Astronomers and engineers from more than 70 institutes in 20 countries



+ 3000 dishes, each 15m wide



+ Using enough optical fibre to wrap twice around the Earth



+ A combined collecting area of about one square kilometre

Megadata



In excess of 1 Exabyte of raw data in a single day - more than the entire daily internet traffic



- + Automated data classification = faster with fewer errors
- + Guided search = easier access for scientists and non-scientists alike
- + Frees researchers to be more productive and creative



Enough raw data to fill over 15 million 64GB iPods every day

IBM  
Information  
Intensive  
Framework

A prototype software architecture to manage the megadata generated by SKA



# 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 → **compressive sensing**.
- **Acquisition versus imaging**.



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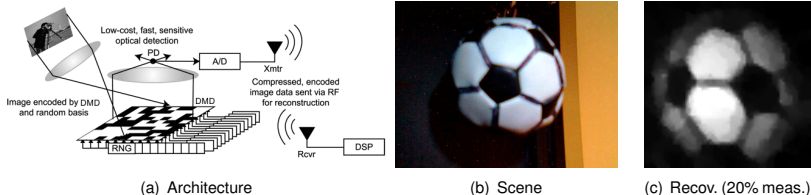


Figure: Single pixel camera



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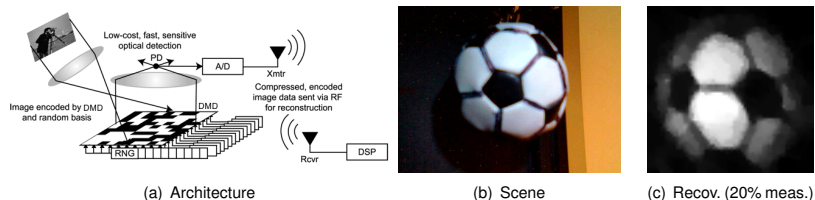


Figure: Single pixel camera





# Interferometric imaging with compressive sensing

- Solve the interferometric imaging problem

$$y = \Phi x + n \quad \text{with} \quad \Phi = \text{MFCA} ,$$

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

- Promote sparsity by minimising  $\ell_1$  norm of wavelet representation of image:

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

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

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



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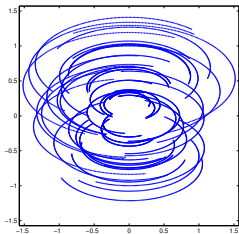
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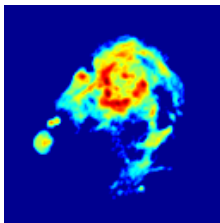


# PURIFY

## Results on simulations



(a) Coverage



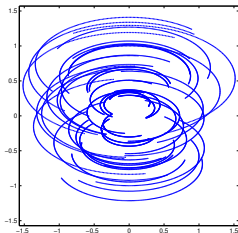
(b) M31 (ground truth)

Figure: Reconstructed images from continuous visibilities.

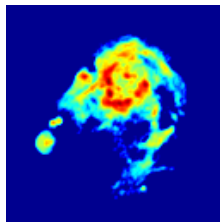


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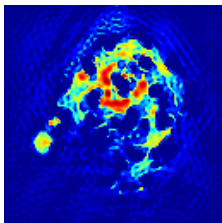
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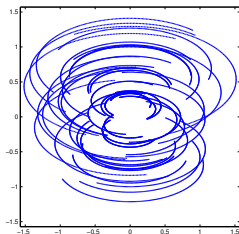
(c) CLEAN  $\rightarrow$  SNR= 8.2dB

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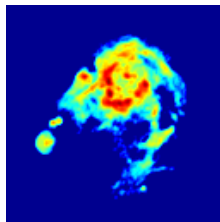


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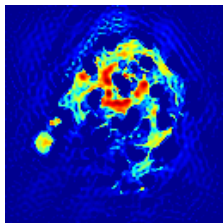
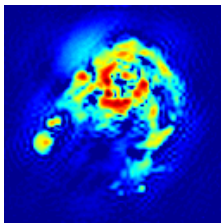
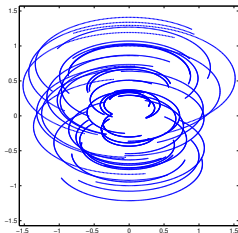
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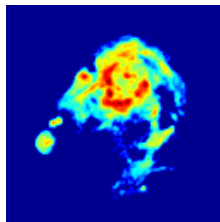


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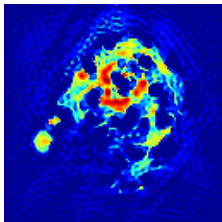
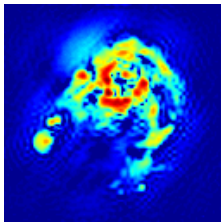
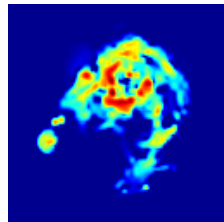
(c) CLEAN  $\rightarrow$  SNR= 8.2dB(d) MS-CLEAN  $\rightarrow$  SNR= 11.1dB(e) PURIFY  $\rightarrow$  SNR= 13.4dB

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# PURIFY

- Recently released the **PURIFY** code.
- Shown dramatic improvement over state-of-the-art on simulations.
- Further development by **Research Software Development Team (RSDT)** to handle real telescope data...

Apply to observations made by real interferometric telescopes.

## PURIFY code

<http://basp-group.github.io/purify/>



### *Next-generation radio interferometric imaging*

Carrillo, McEwen, Wiaux  
Ongoing development by RSDT

**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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