Learned Exascale Computational Imaging (LEXCI) overview

UCL ExCALIBUR Meetup

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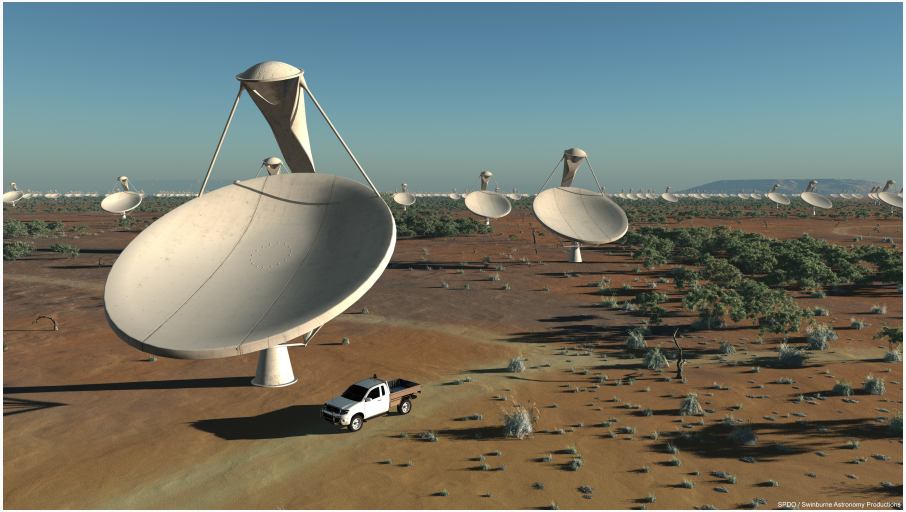
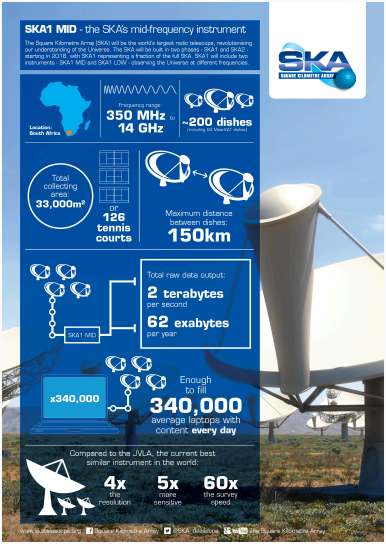
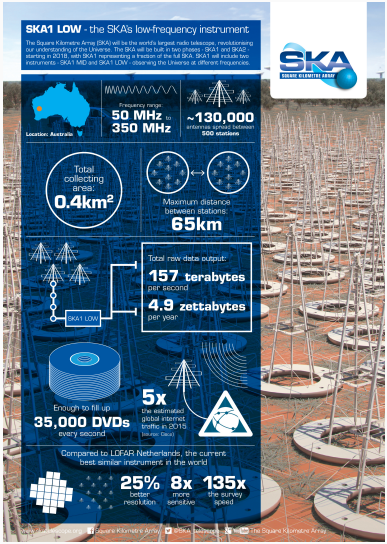
Canonical application: Square Kilometre Array (SKA)



SKA sites

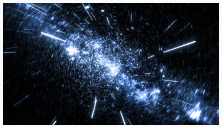

SKA1 MID - the SKA's mid-frequency instrument
The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.
SKA
SQUARE KILOMETRE ARRAY
Location: South Africa
Frequency range: 350 MHz to 14 GHz
~200 dishes
(including 64 MeerKAT dishes)
Total collecting area: 33,000m²
or 126 tennis courts
Maximum distance between dishes: 150km
SKA1 MID
Total raw data output:
2 terabytes per second
62 exabytes per year
x340,000
Enough to fill 340,000 average laptops with content every day
Compared to the JVLA, the current best similar instrument in the world:
4x the resolution
5x more sensitive
60x the survey speed
www.skatelescope.org
Square Kilometre Array
SKA_Telescope
The Square Kilometre Array


SKA1 LOW - the SKA's low-frequency instrument
The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.
SKA
SQUARE KILOMETRE ARRAY
Location: Australia
Frequency range: 50 MHz to 350 MHz
~130,000 antennas spread between 500 stations
Total collecting area: 0.4km²
Maximum distance between stations: 65km
SKA1 LOW
Total raw data output:
157 terabytes per second
4.9 zettabytes per year
Enough to fill up 35,000 DVDs every second
5x the estimated global internet traffic in 2015
Compared to LOFAR Netherlands, the current best similar instrument in the world:
25% better resolution
8x more sensitive
135x the survey speed
www.skatelescope.org
Square Kilometre Array
SKA_Telescope
The Square Kilometre Array

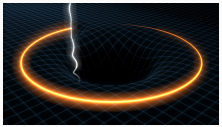
Next-generation of radio interferometry rapidly approaching

Next-generation of radio interferometric telescopes will provide orders of magnitude improvement in sensitivity and resolution.

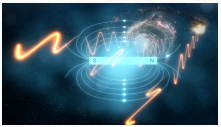
Unlock broad range of science goals.



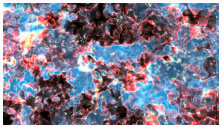
Dark energy



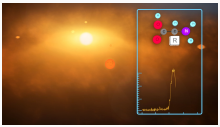
General relativity



Cosmic magnetism

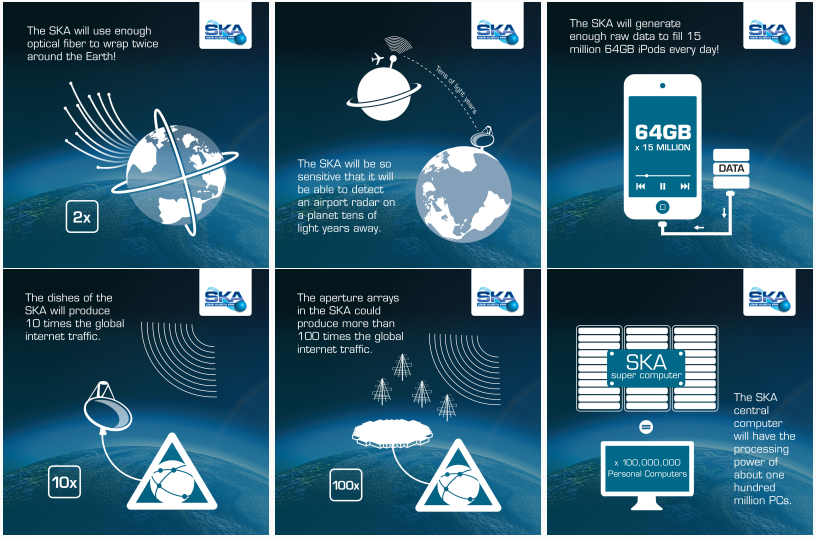


Epoch of reionization



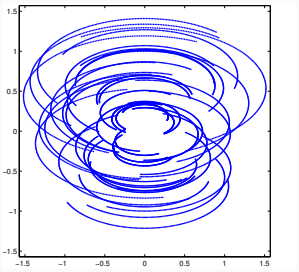
Exoplanets

SKA poses a considerable exascale computational imaging challenge



Radio interferometric telescopes acquire “Fourier” measurements

“Fourier”
Measurements
$\Rightarrow$



Radio interferometric telescopes acquire “Fourier” measurements

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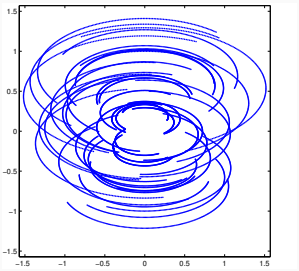


Interferometric imaging is an exascale computational inverse imaging problem:

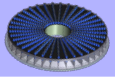
Recover an image from noisy and incomplete “Fourier” measurements.

LEXCI application domains more broadly

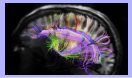
Learned Exascale Computational Imaging (LEXCI)

Radio Interferometry
e.g. MWA, SKA

Optical Interferometry
e.g. SPIDER



Medical Imaging
e.g. Diffusion MRI



Seismic Imaging
e.g. Mantle Plumes

Computer Graphics
e.g. Inverse Rendering

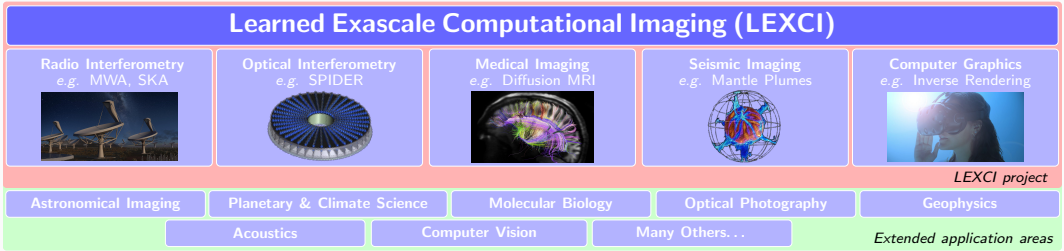
LEXCI project

Astronomical Imaging | **Planetary & Climate Science** | **Molecular Biology** | **Optical Photography** | **Geophysics**

Acoustics | **Computer Vision** | **Many Others...**

Extended application areas

LEXCI application domains more broadly



Partners

- Radio interferometry: Prof. Melanie Johnston-Hollitt (Curtin), Dr Luke Pratley (Toronto)
- SPIDER: Prof. Ben Yoo (UC Davis)
- Medical Imaging: Prof. Gary Zhang (CMIC, UCL)
- Seismic Imaging: Prof. Ana Ferreira (Earth Sciences, UCL)
- Computer Graphics & Virtual Reality: Kagenova
- (ExCALIBUR Benchmarking for AI for Science at Exascale; BASE)

Classical approach to computational inverse imaging

Classically, inverse imaging problems solved by **variational regularization**, where an optimization problem is posed that includes data fidelity and regularization terms:

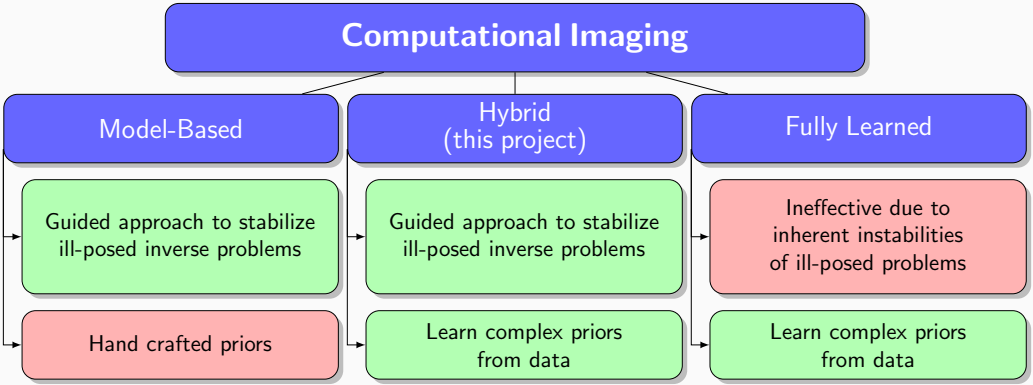
$$\arg\min_{\boldsymbol{x}} \|\boldsymbol{y} - \boldsymbol{\Phi}\boldsymbol{x}\|_2^2 + \lambda f(\boldsymbol{x}).$$

for observational model $\boldsymbol{\Phi} : \mathbb{R}^N \to \mathbb{R}^M$, data $\boldsymbol{y}$ and underlying image $\boldsymbol{x}$.

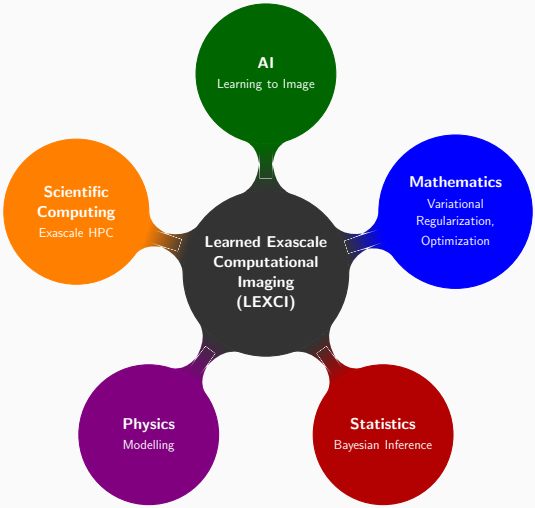
Regularization functional $f : \mathbb{R}^N \to \mathbb{R}$ encodes prior knowledge.

Typically **model-based regularizers** are used, *e.g.* $f(\boldsymbol{x}) = \|\boldsymbol{\Psi}^\dagger \boldsymbol{x}\|_1$ to promote sparsity in some dictionary $\boldsymbol{\Psi} : \mathbb{R}^D \to \mathbb{R}^N$.

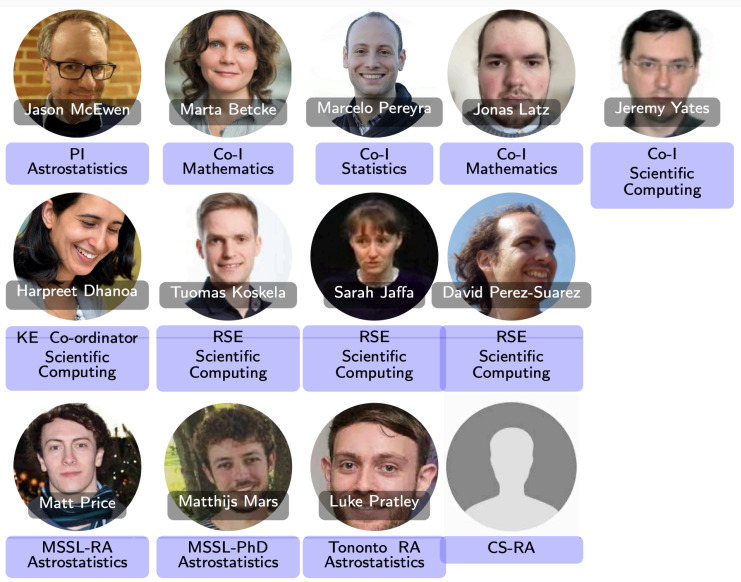
LEXCI hybrid approach



Cross-cutting research areas



LEXCI team


Jason McEwen
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Astrostatistics
Marta Betcke
Co-I
Mathematics
Marcelo Pereyra
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Statistics
Jonas Latz
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Mathematics
Jeremy Yates
Co-I
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Harpreet Dhanoa
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Scientific
Computing
Tuomas Koskela
RSE
Scientific
Computing
Sarah Jaffa
RSE
Scientific
Computing
David Perez-Suarez
RSE
Scientific
Computing
Matt Price
MSSL-RA
Astrostatistics
Matthijs Mars
MSSL-PhD
Astrostatistics
Luke Pratley
Tononto RA
Astrostatistics
CS-RA

Methodological developments

- ▷ Hybrid deep learning & model-based approach
- ▷ Learned image model
- ▷ Learned instrument model
- ▷ Learned convex models to support uncertainty quantification
- ▷ Geometric imaging (*e.g.* spherical)

Computing paradigms

- ▷ Data partitioning algorithms
- ▷ Distributed compute, storage & memory
- ▷ Stochastic distributed algorithms
- ▷ Parallelized & distributed uncertainty quantification
- ▷ Exploit mixed-precision arithmetic

ExCALIBUR use cases

- ▷ Learned computational imaging
- ▷ Efficient data IO & workflows
- ▷ Visualization
- ▷ Mixed-precision arithmetic
- ▷ Fault tolerance
- ▷ Uncertainty quantification

ExCALIBUR testbeds

- Novel Hardware/Software Architecture Testbed (University of Birmingham, NextSilicon, Lenovo)
- Cerebras Testbed (EPCC, Cerebras, HPE)
- UCL Adaptable Cluster Testbed (UCL, Mellanox)
- FPGA Testbed (EPCC, UCL, University of Warwick, Xilinx)

Events

- Traditional conference: *Computational Inverse Imaging*
- Unconference: *Applying LEXCI software to cross-cutting problems across domains*

Public open-source codes

PURIFY code

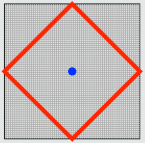
`https://github.com/astro-informatics/purify`

Next-generation radio interferometric imaging

PURIFY is a highly distributed and parallelized open-source C++ code for radio interferometric imaging, leveraging recent developments in the field of variational regularization and convex optimisation.

SOPT code

`https://github.com/astro-informatics/sopt`



Sparse OPTimisation

SOPT is a highly distributed and parallelized open-source C++ code for variational regularization and convex optimisation.