TESTING GENERAL RELATIVITY WITH COSMIC MAGNIFICATION

WILL EINSTEIN'S MOST FAMOUS THEORY PASS THE BIGGEST TEST OF ALL?

BY A. D. ASHER

AUTHORS

A. D. Asher,[1,2*] L. A. Barnes,[1]
D. Parkinson,[3] M. D. Filipović,[1]
N. Thyagarajan,[1,4] and R. P. Norris[1,2]

*20202949@student.westernsydney.edu.au

AFFILIATIONS

[1] Western Sydney University, Locked Bag 1797, Penrith South DC, NSW 2751, Australia
[2] CSIRO, Space & Astronomy, PO Box 76, Epping, NSW 1710, Australia
[3] Korea Astronomy & Space Institute, Yuseong-gu, Daedeok-daero 776, Daejeon 34055, Korea
[4] CSIRO, Space & Astronomy, PO Box 1130, Bentley, WA 6102, Australia

WESTERN SYDNEY UNIVERSITY
CSIRO

01. INTRODUCTION

Albert Einstein's General Theory of Relativity (GR) (Einstein 1915) has endured for more than 100 years and accurately describes how gravity works in the Universe. Whilst his theory has withstood numerous tests in our Solar System, Galaxy and beyond the bounds of the Milky Way, we have reason to question whether it describes gravity as accurately on cosmological scales - i.e. there is no known form of matter or energy in the Einstein field equations that can explain late-time cosmic acceleration. We are therefore preparing to conduct a test of GR via cosmic magnification in the weak gravitational lensing regime, using the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope.

02. OBJECTIVES

- To cross-correlate high- and low-redshift galaxies and determine the number of radio and optical galaxies required to generate statistically significant measurements.
- To accurately determine whether the weak gravitational lensing effects conform to the predictions made by GR.
- To determine if GR describes gravity accurately on cosmological scales, and if it does break down, where?

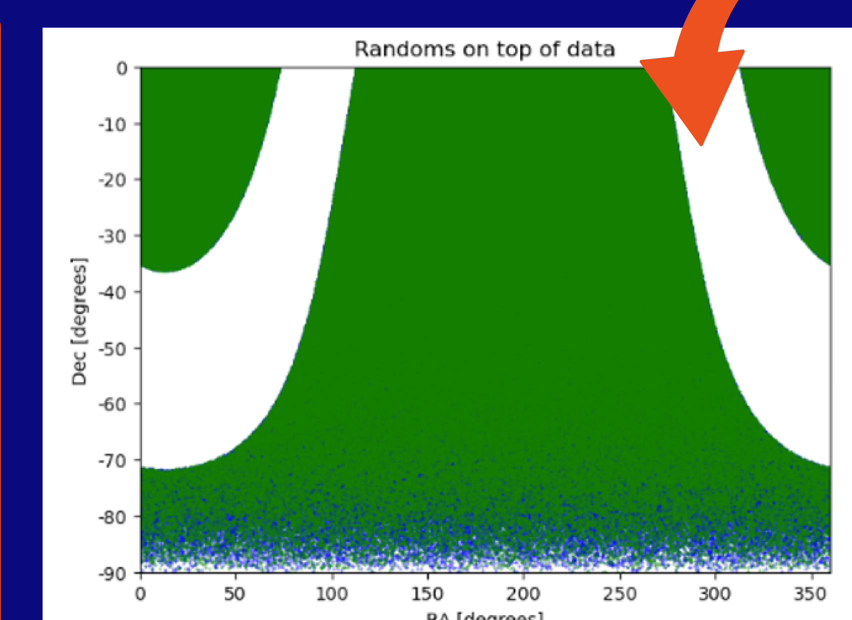
03. METHODOLOGY

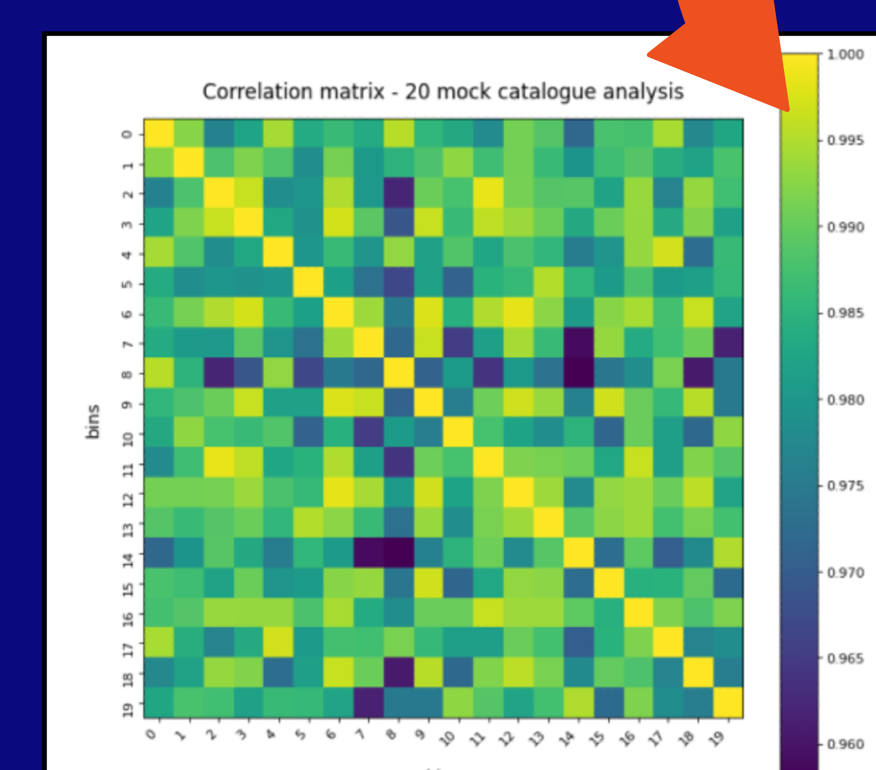
- Create a simulation and analysis pipeline: generate mock (simulated) galaxy catalogues, measure clustering statistics and conduct cosmological analyses.
- Using ASKAP's Evolutionary Map of the Universe (EMU) radio galaxy data (Norris et al. 2011), measure the angular correlation function, w(θ), with and without a predicted lensing effect using our ray-tracing algorithm.
- Cross-correlate high-z galaxies from the RACS survey (McConnell et al., 2020) with low-z galaxies from the DESI Legacy surveys (Dey et al. 2019).
- Using ASKAP-EMU data, cross-correlate tens of millions of radio galaxies with available optical data from the Sloan Digital Sky Survey.
- Measure the weak gravitational lensing observables (brightness distribution) and compare to predictions made in the simulations.
- Determine whether the results conform to GR physics.

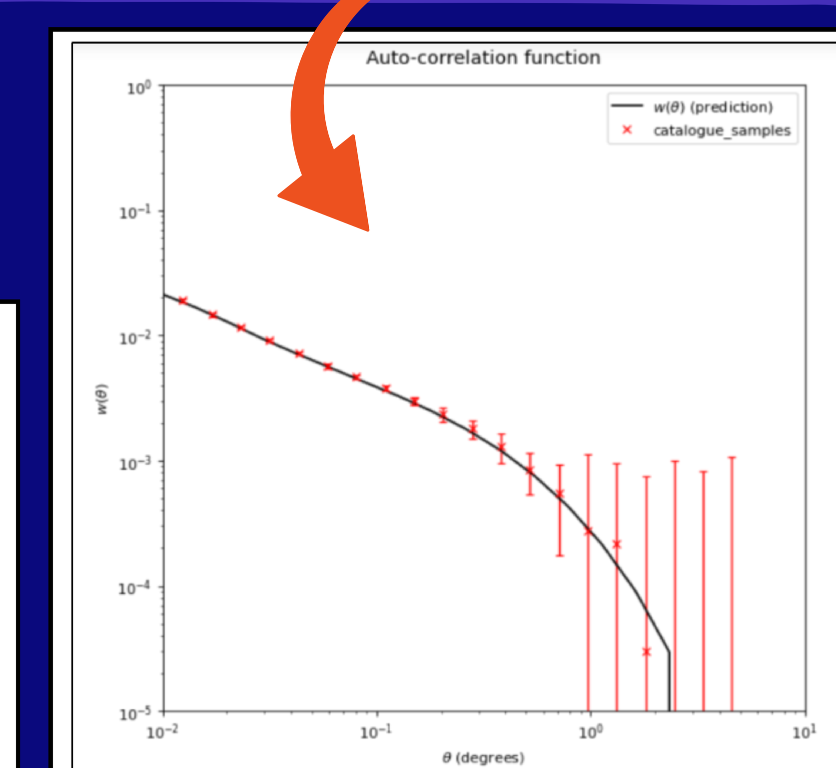
04. RESULTS: SIMULATION & ANALYSIS PIPELINE

The pipeline involves the following steps:

- Generate mock galaxy catalogues (modified GLASS cosmology code).
- Make theoretical predictions of correlation statistics (modified pyccl code).
- Compute auto/cross-correlations (modified TreeCorr code).
- Bootstrap resampling (modified TreeCorr code).
- Generate covariance / correlation matrices (new code).
- Chi-squared estimator (new code).
- Log-likelihood grid (new code).
- Metropolis-Hastings MCMC analysis (new code).
- Lensed / unlensed cross-correlations (modified GLASS / pyccl / TreeCorr codes).

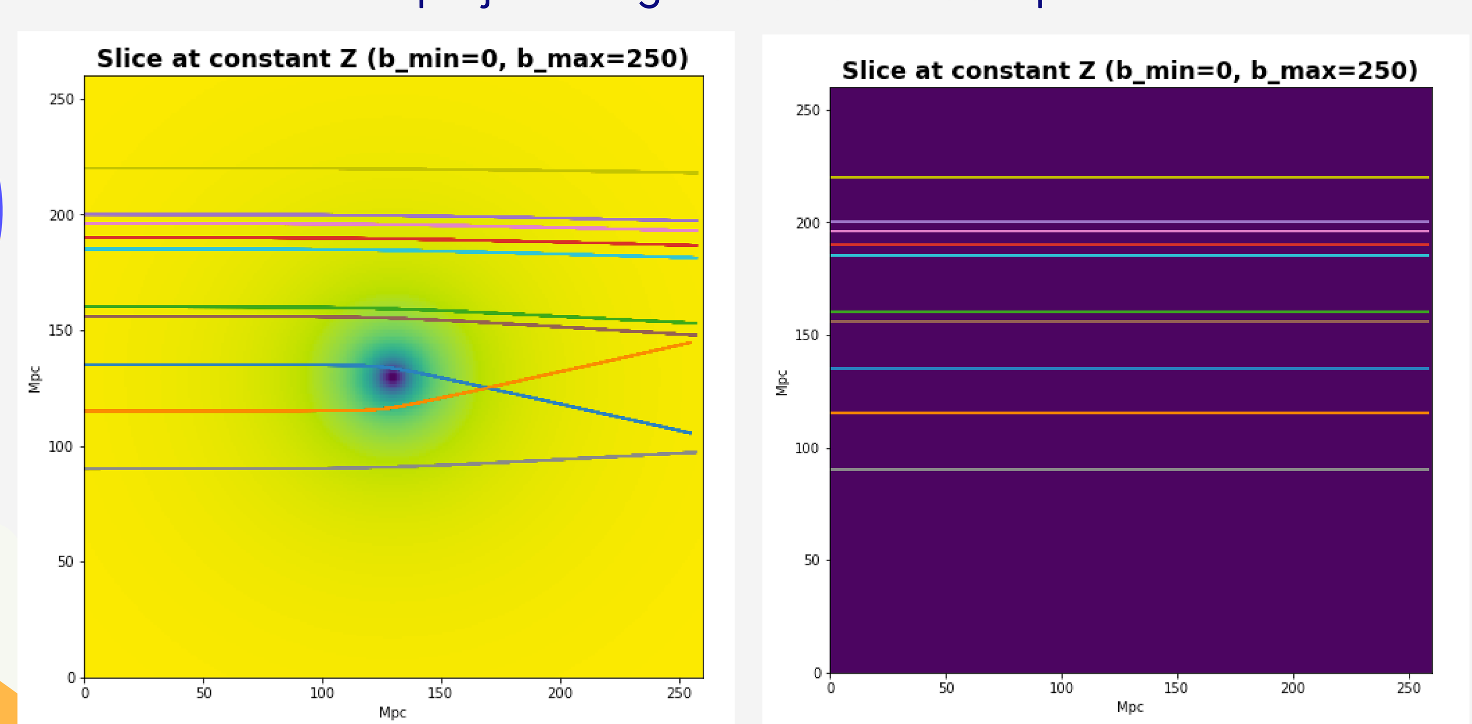






Deflection check: A central particle mass vs no mass

In the left image, ten photon bundles are projected past a central particle mass, from 0 to 250 Mpc. In the right image, the particle mass has been removed and the ten bundles are projected again from 0 to 250 Mpc.



05. RAY-TRACING RESULTS

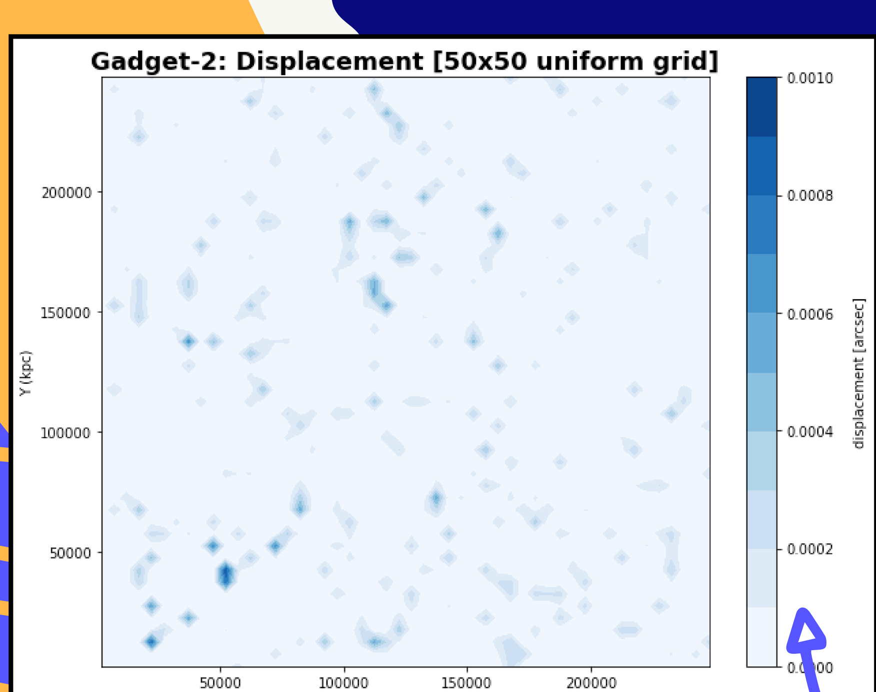
The primary results include:

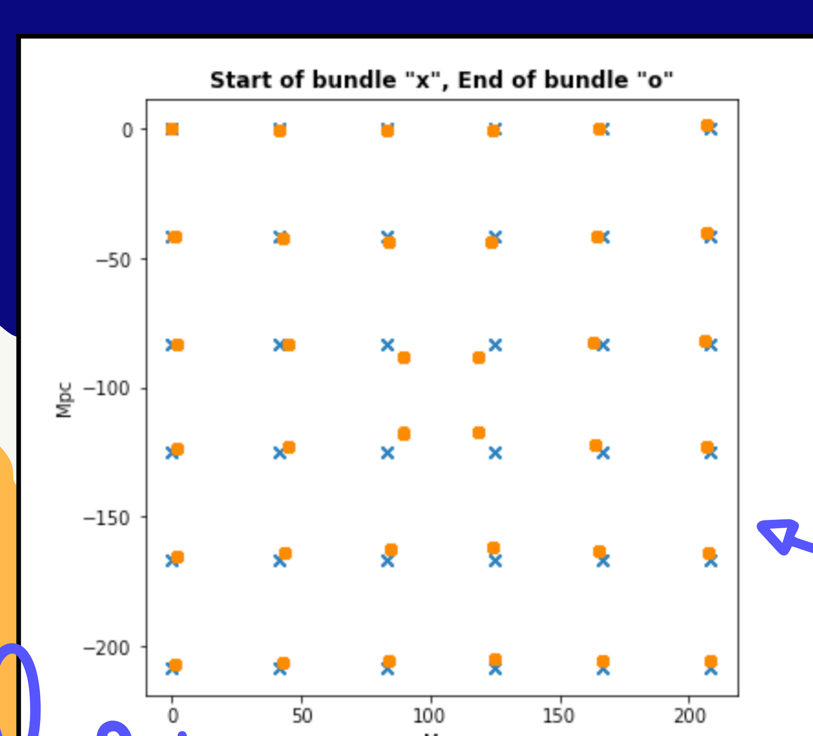
(i) A new gravitational potential function that can generate the potentials for a three-dimensional grid, based on the input of one or more particles.

(ii) A new function to read in the potential values from a Gadget-2 simulation file, assign them to a three-dimensional grid and conduct interpolation.

(iii) A modified function that can solve the geodesics as bundles on a uniform grid, as well as input a set of ray-tracing coordinates and output the deflection angles in the one run of the code. The image below left allows us to look 'down the barrel of the ray bundle'.

(iv) An analysis of displacement angles was conducted as an additional mode of verification (see contour plot below far left).





References

Dey, A., Schlegel, D. J., Lang, D., Blum, R., Burleigh, K., Fan, X., ... & Vivas, A. K. (2019). Overview of the DESI legacy imaging surveys. The Astronomical Journal, 157(5), 168.
Einstein, A. (1915). The field equations of gravitation. Sitzungsber. Preuss. Akad. Wiss. Berlin (Math. Phys.), 1915:844–847.
McConnell, D., Hale, C. L., Lenc, E., Banfield, J. K., Heald, G., Hotan, A. W., ... & Westmeier, T. (2020). The Rapid ASKAP Continuum Survey I: Design and first results. Publications of the Astronomical Society of Australia, 37, e048.
Norris, R. P., Hopkins, A. M., Afonso, J., Brown, S., Condon, J. J., Dunne, L., Feain, I., Hollow, R., Jarvis, M., Johnston-Hollitt, M., et al. (2011). EMU: Evolutionary Map of the Universe. Publications of the Astronomical Society of Australia, 28(3):215–248.