The H_0 bias due to angular structures in lenses

Time-delay cosmography studies generally assume axi-symmetry of the deflector. However, nearby elliptical galaxies show deviation from ellipticity that can be captured by expanding the elliptical isophotes into higher order Fourier modes. Multipoles of order 4, corresponding to discy or boxy shapes, are the most commonly observed perturbations. We have studied how such azimuthal structures manifest in extended lensed images, and if ignoring them yields any bias on H0 in time delay cosmography studies. Specifically, we have mocked images of a QSO+host source lensed by an elliptical mass distribution perturbed by multipolar components. We assess the detectability of those multipoles by modeling the lensed images without angular structure, using state-of-the-art lens modeling technique. When the S/N of the data is too low, the imprints of those multipoles on the lensed images are hidden in the noise, and the value of H0 inferred from the model is biased by up to several percent. Finally, we discuss the impact of angular structure on H0 inference for the TDCOSMO/H0LICOW sample.

The H_0 bias due to angular structures in lenses

By Lyne Van de Vyvere

PhD student

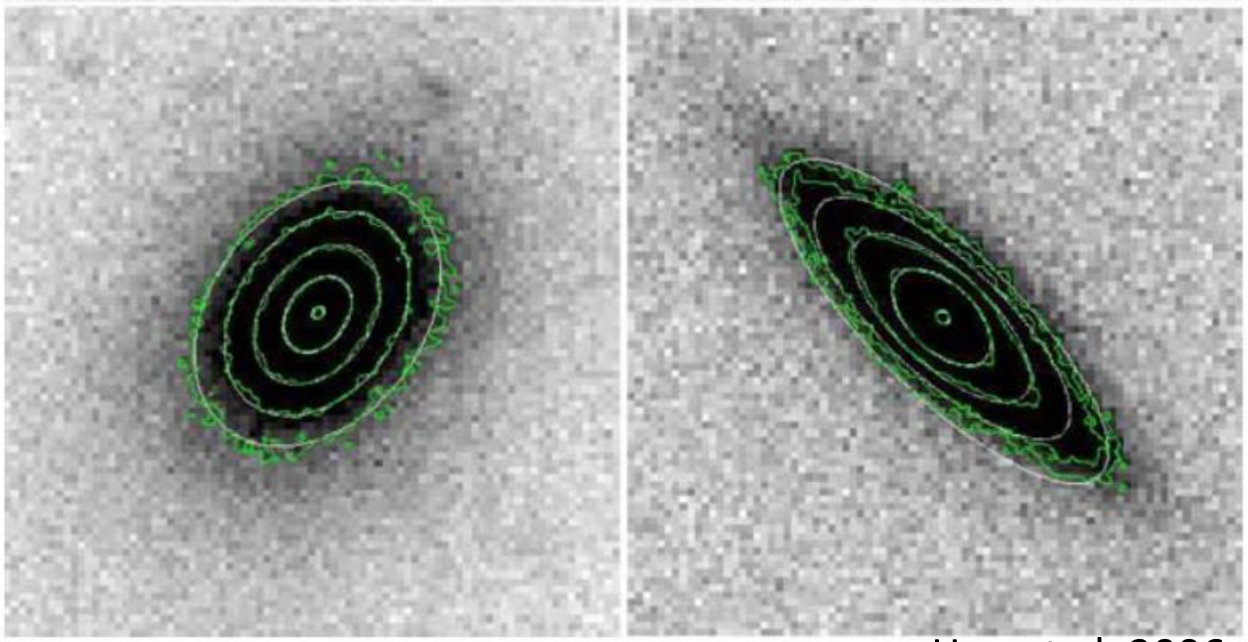
Collaborators : Dominique Sluse, Matthew Gomer, Dandan Xu

LIÈGE université
STAR Institute

erc Cosmiclens

Azimuthal structures in elliptical galaxies

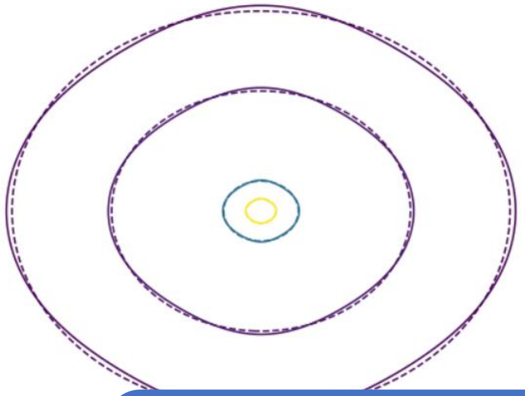
Multipoles of order 4 are present in galaxy light profiles



Hao et al. 2006

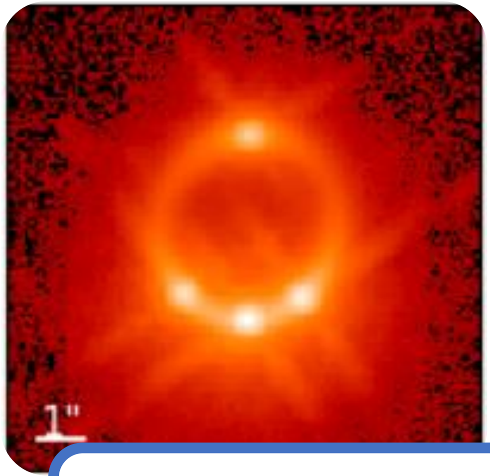
→ Impact on lensing analysis and H_0 inference ?

Methodology and goal



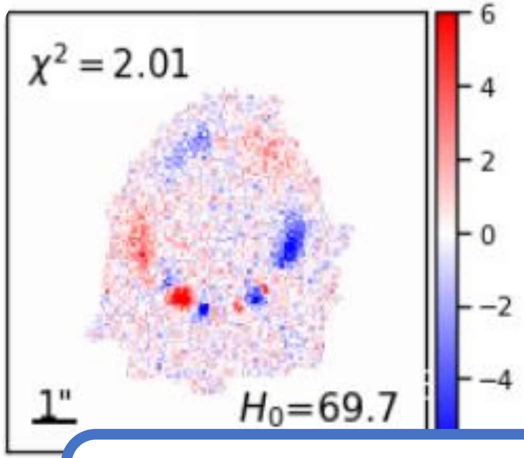
Lensing galaxy

- SIE + shear
- Add multipole a_4



Mock images

- 4 configurations
- Add noise



Fit

- SIE + shear
- NO multipole

→ Multipole detectability in residuals ? Any H_0 bias ?

Base case set-up

Lens model :

- SIE : θ_E = 2'' , q = 0.8
- Shear : 0.05 strength and 30° orientation
- Multipole : a_4 = 0.01, ψ_4 = 0° (discy) or 45° (boxy)

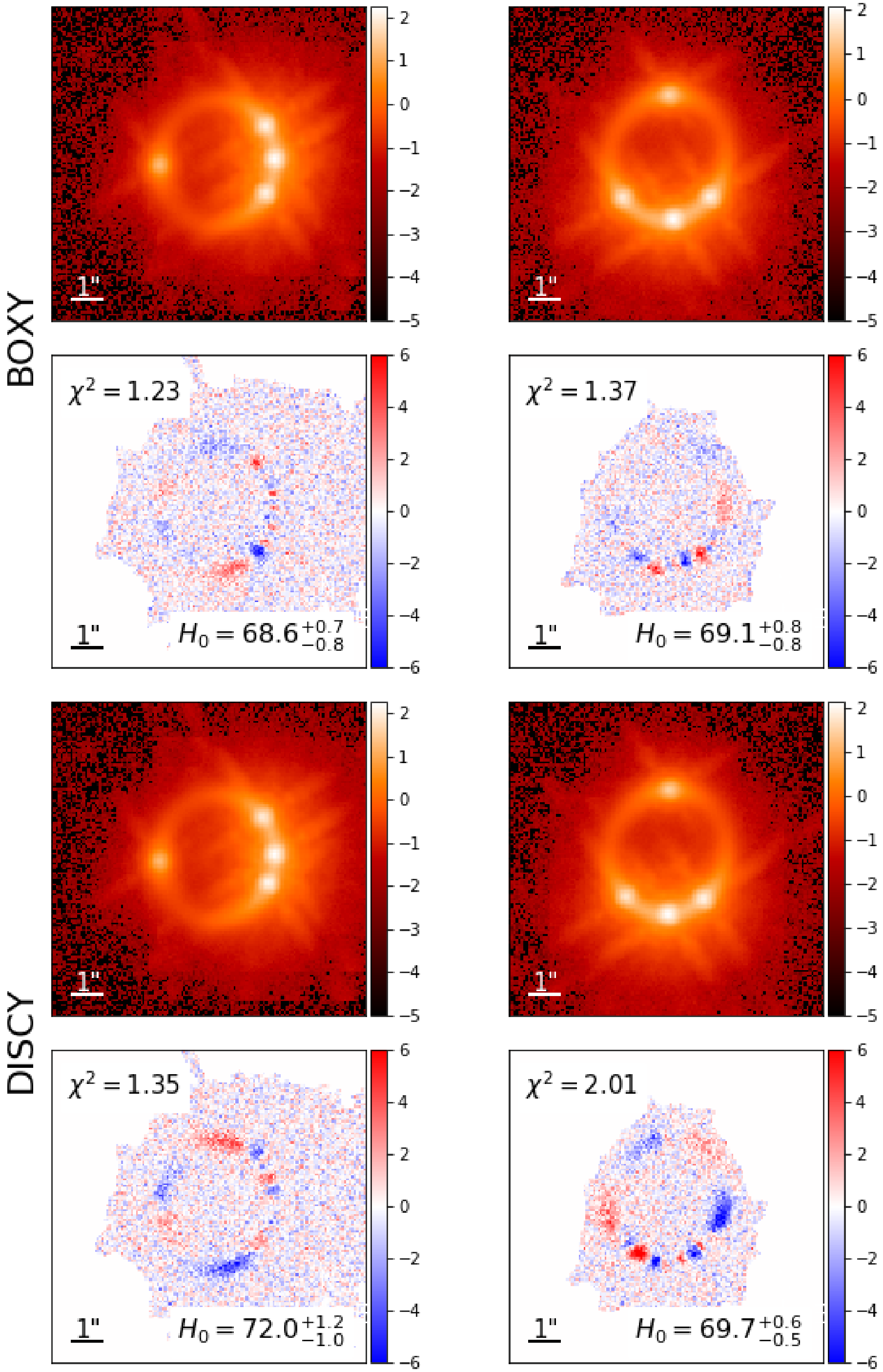
Source model :

- QSO : unlensed brightness 21 mag
- Sersic source : unlensed brightness 20.5 mag

→ integrated lensed brigthness ≈ 16 mag

Other :

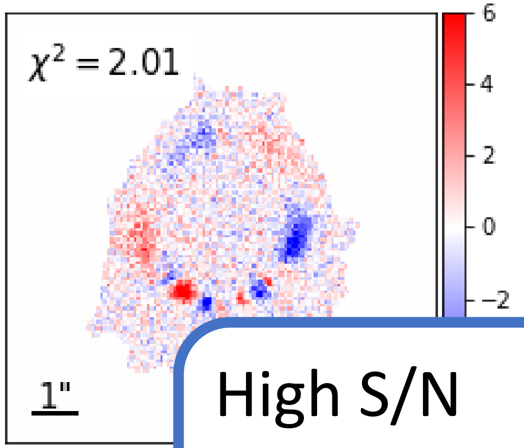
- TDLMC PSF
- Exposure time 5400 s
- F160W noise
- H_0 = 70 km/s/Mpc



Influence S/N

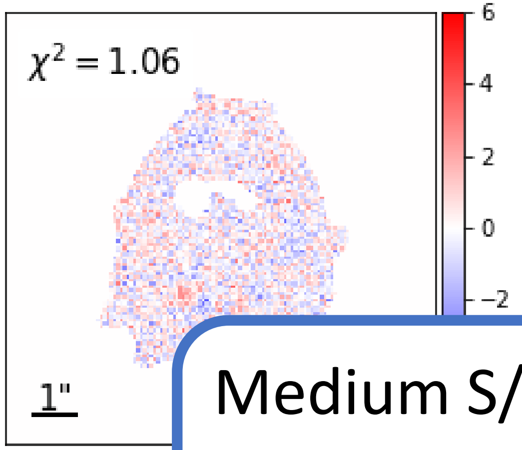
TDCOSMO

Shajib et al. 2019



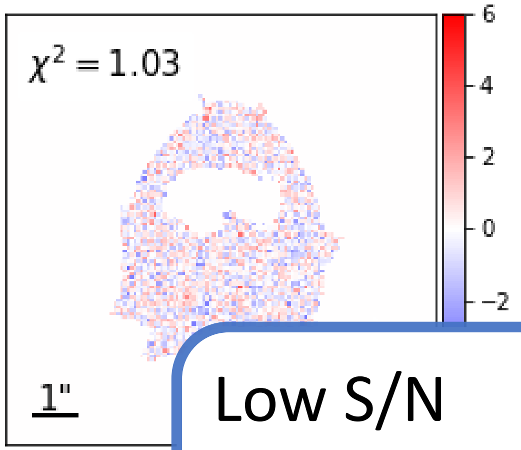
High S/N

- Exp time: 5400s
- Unlensed brightness [mag]: 21 (QSO), 20.5 (host)



Medium S/N

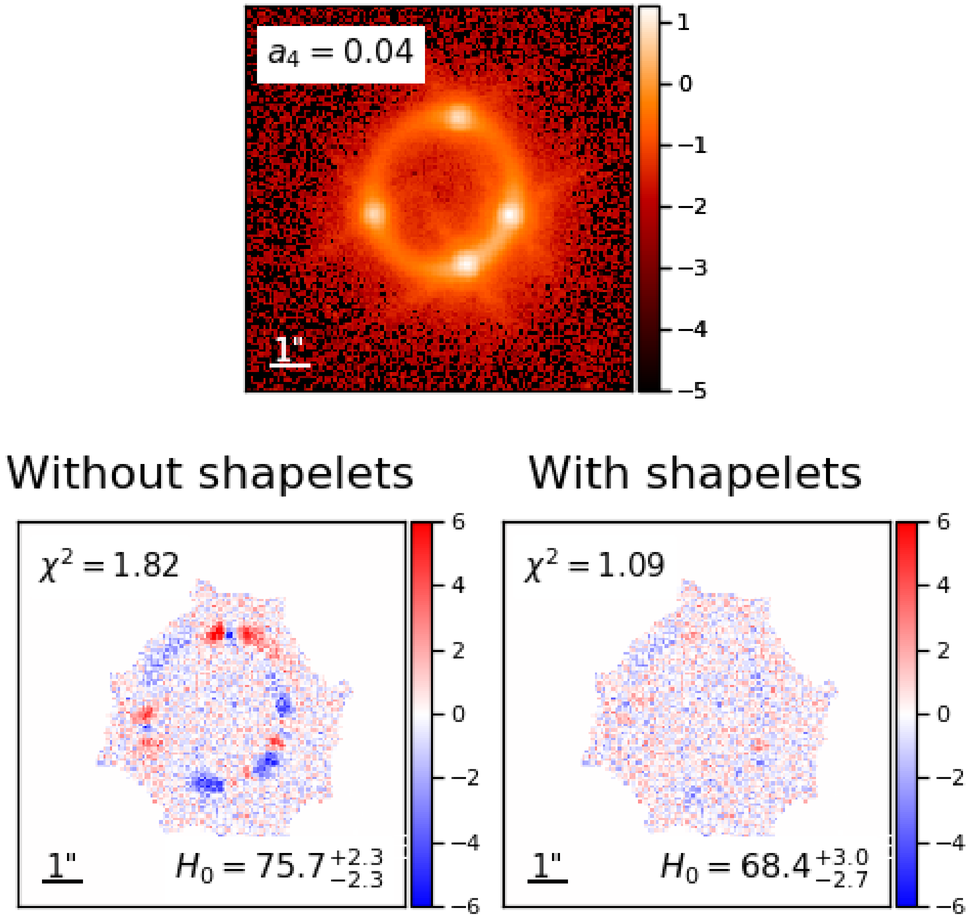
- Exp time: 3000s
- Unlensed brightness [mag]: 22.75 (QSO), 22.25 (host)



Low S/N

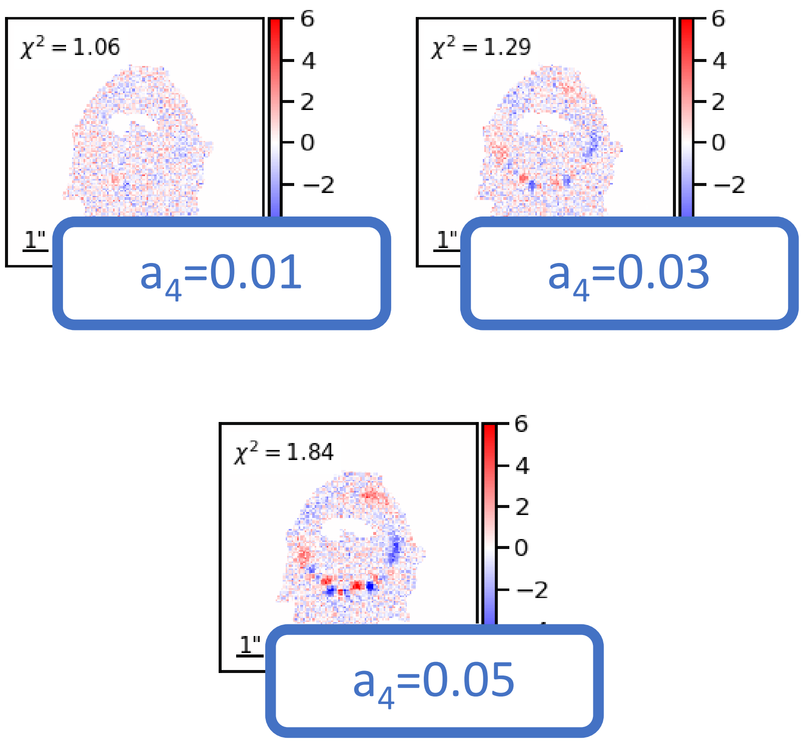
- Exp time : 3000s
- Unlensed brightness [mag]: 23.5 (QSO), 23 (host)

Influence shapelets

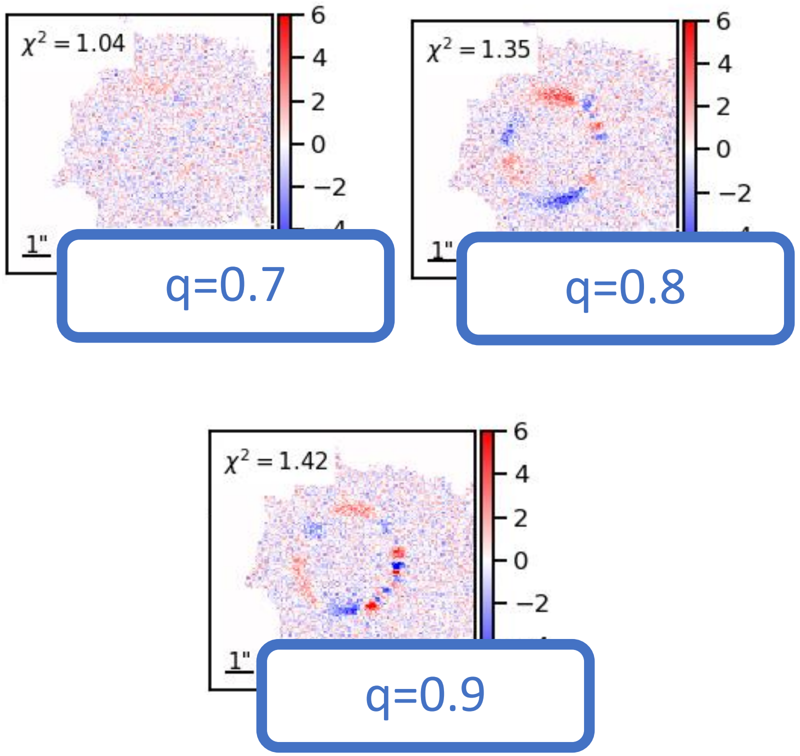


Other influences

Multipole strength

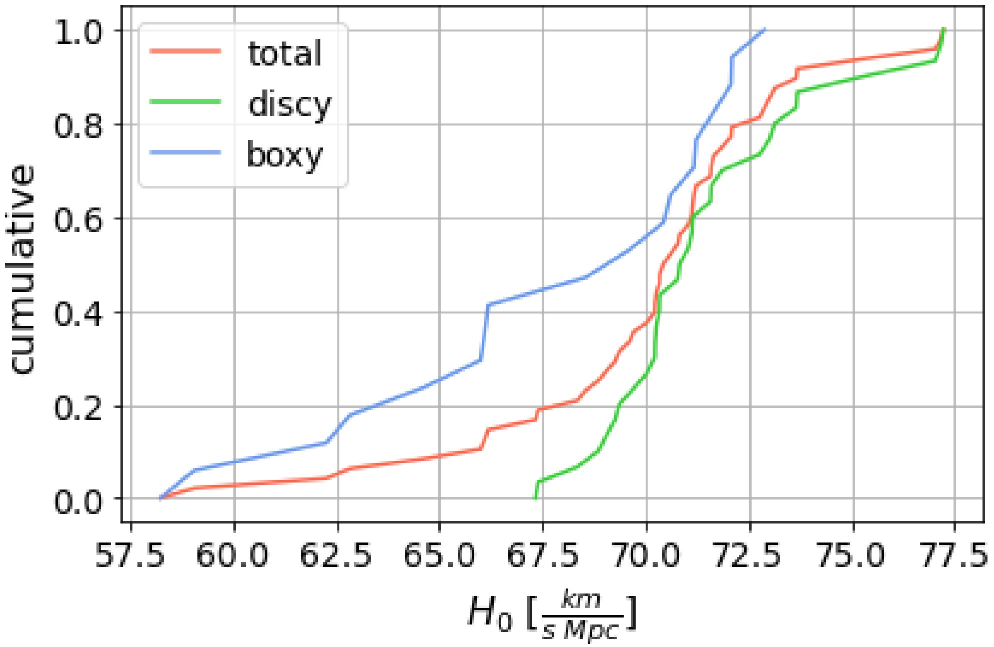


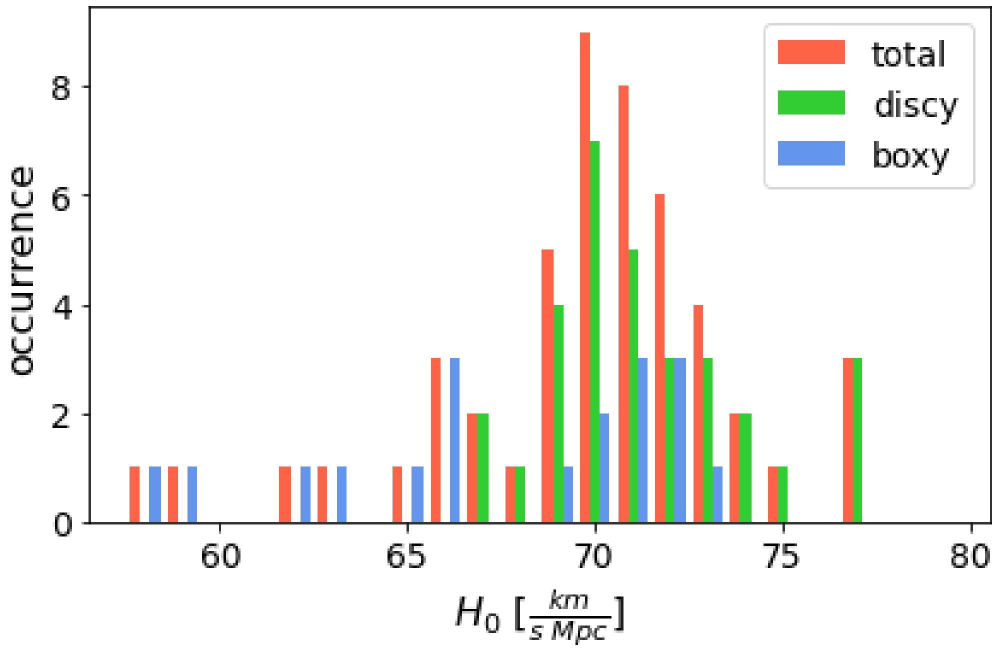
Ellipticity



Impact on H_0

H_0 inference in our analysis when $\chi^2 < 1.2$





Is it a problem for H_0 inference in current analysis ?

TDCOSMO sample

- ⊕ Mostly high or very high S/N
- ⊕ Regular ellipticities
- ⊙ Source reconstruction with high freedom

→overall safe

Conclusion

Are the multipoles :

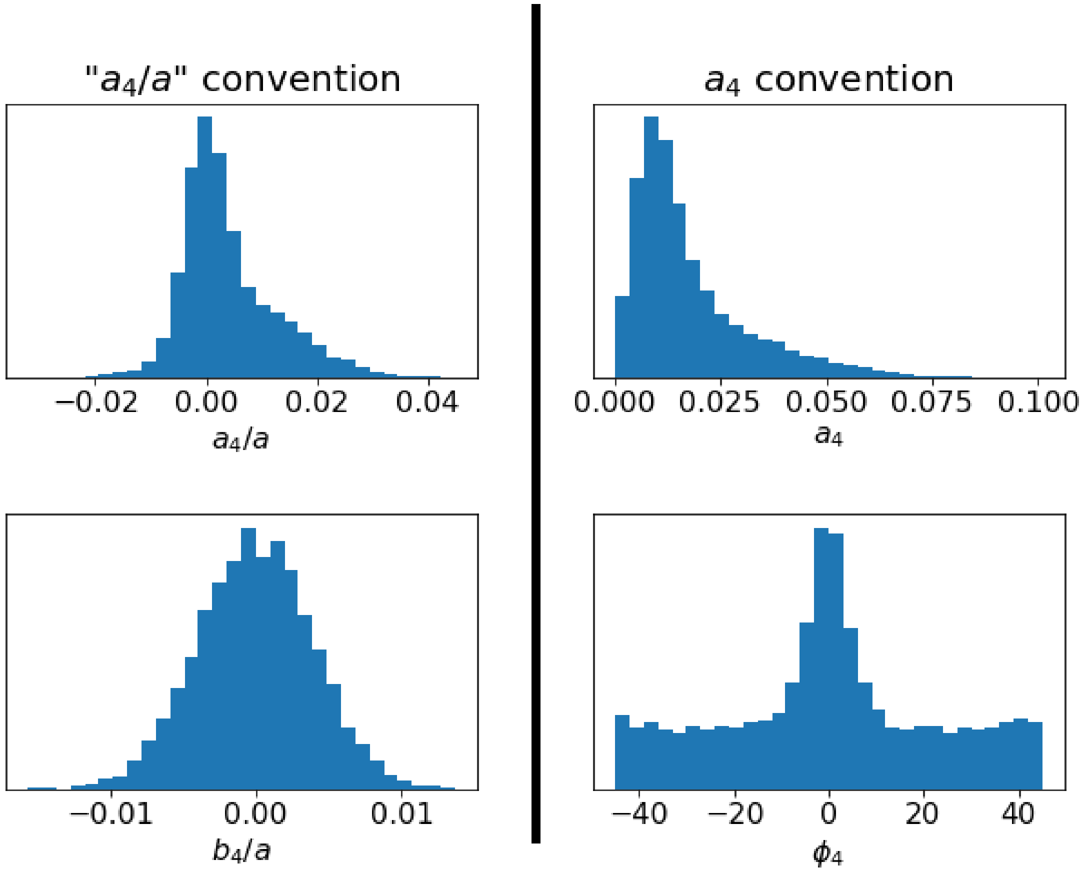
- Detectable ? YES, if high S/N, roundish galaxy
- Biasing H_0 ? YES, up to 10%

Thank you

References

Abbott, T. M. C., Abdalla, F. B., Annis, J., et al. 2018, MNRAS, 480, 3879
Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, A&A, 558, A33
Bender, R., Doebereiner, S., & Moellenhoff, C. 1988, A&AS, 74, 385
Bender, R., Surma, P., Doebereiner, S., Moellenhoff, C., & Madejsky, R. 1989, A&A, 217, 35
Birrer, S. & Amara, A. 2018, Physics of the Dark Universe, 22, 189
Birrer, S., Amara, A., & Refregier, A. 2016, J. Cosmology Astropart. Phy: 2016, 020
Birrer, S., Shajib, A. J., Galan, A., et al. 2020, arXiv e-prints, arXiv:2007.029
Birrer, S., Treu, T., Rusu, C. E., et al. 2019, MNRAS, 484, 4726
Bolton, A. S., Burles, S., Koopmans, L. V. E., Treu, T., & Moustakas, L. A. 200 ApJ, 638, 703
Brewer, B. J. & Lewis, G. F. 2008, MNRAS, 390, 39
Chu, Z., Lin, W. P., Li, G. L., & Kang, X. 2013, ApJ, 765, 134
Claeskens, J. F., Sluse, D., Riaud, P., & Surdej, J. 2006, A&A, 451, 865
Courbin, F. & Minniti, D. 2002, Gravitational Lensing: An Astrophysical Toc Vol. 608
Ding, X., Treu, T., Birrer, S., et al. 2020, arXiv e-prints, arXiv:2006.08619
Ding, X., Treu, T., Shajib, A. J., et al. 2018, arXiv e-prints, arXiv:1801.01506
Dressel, L. 2012, Wide Field Camera 3 Instrument Handbook for Cycle 21 v. 5
Dunlop, J. S., McLure, R. J., Kukula, M. J., et al. 2003, MNRAS, 340, 1095
Frigo, M., Naab, T., Hirschmann, M., et al. 2019, MNRAS, 489, 2702
Galan, A., Peel, A., Joseph, R., Courbin, F., & Starck, J. L. 2020, arXiv e-print arXiv:2012.02802
Gilman, D., Birrer, S., Nierenberg, A., et al. 2020a, MNRAS, 491, 6077
Gilman, D., Du, X., Benson, A., et al. 2020b, MNRAS, 492, L12
Gomer, M. R. & Williams, L. L. R. 2018, MNRAS, 475, 1987
Hao, C. N., Mao, S., Deng, Z. G., Xia, X. Y., & Wu, H. 2006, MNRAS, 37 1339
Hsueh, J. W., Enzi, W., Vegetti, S., et al. 2020, MNRAS, 492, 3047
Hunter, J. D. 2007, Computing in Science Engineering, 9, 90
Impey, C. D., Falco, E. E., Kochanek, C. S., et al. 1998, ApJ, 509, 551
Jahnke, K. & Wisotzki, L. 2003, MNRAS, 346, 304
Keeton, C. R., Gaudi, B. S., & Petters, A. O. 2003, ApJ, 598, 138
Keeton, C. R., Gaudi, B. S., & Petters, A. O. 2005, ApJ, 635, 35
Keeton, C. R. & Kochanek, C. S. 1998, ApJ, 495, 157
Kochanek, C. S. 2006, in Saas-Fee Advanced Course 33: Gravitational Lensing: Strong, Weak and Micro, ed. G. Meylan, P. Jetzer, P. North, P. Schneider, C. S. Kochanek, & J. Wambsganss, 91–268
Kochanek, C. S. 2020, MNRAS, 493, 1725
Koopmans, L. V. E., Treu, T., Fassnacht, C. D., Blandford, R. D., & Surpi, G. 2003, ApJ, 599, 70
Krajnović, D., Alatalo, K., Blitz, L., et al. 2013, MNRAS, 432, 1768
Lagattuta, D. J., Vegetti, S., Fassnacht, C. D., et al. 2012, MNRAS, 424, 2800
Mao, S. & Schneider, P. 1998, MNRAS, 295, 587
Millman, K. J. & Aivazis, M. 2011, Computing in Science Engineering, 13, 9
Millon, M., Galan, A., Courbin, F., et al. 2020, A&A, 639, A101
Mitsuda, K., Doi, M., Morokuma, T., et al. 2017, ApJ, 834, 109
Möller, O., Hewett, P., & Blain, A. W. 2003, MNRAS, 345, 1
Muñoz, J. A., Falco, E. E., Kochanek, C. S., et al. 1998, Ap&SS, 263, 51
Nierenberg, A. M., Gilman, D., Treu, T., et al. 2020, MNRAS, 492, 5314
Nightingale, J. W. & Dye, S. 2015, MNRAS, 452, 2940
Oliphant, T. E. 2007, Computing in Science Engineering, 9, 10
pandas development team, T. 2020, pandas-dev/pandas: Pandas
Pasquali, A., Ferreras, I., Panagia, N., et al. 2006, ApJ, 636, 115
Penoyre, Z., Moster, B. P., Sijacki, D., & Genel, S. 2017, MNRAS, 468, 3883
Philcox, O. H. E., Ivanov, M. M., Simonović, M., & Zaldarriaga, M. 2020, J. Cosmology Astropart. Phys., 2020, 032
Planck Collaboration, Aghanim, N., Akrami, Y., et al. 2020, A&A, 641, A6
Price-Whelan, A. M., Sipőcz, B. M., Günther, H. M., et al. 2018, AJ, 156, 123
Refsdal, S. 1964, MNRAS, 128, 307
Rest, A., van den Bosch, F. C., Jaffe, W., et al. 2001, AJ, 121, 2431
Riess, A. G., Casertano, S., Yuan, W., Macri, L. M., & Scolnic, D. 2019, ApJ, 876, 85
Schneider, P. & Sluse, D. 2013, A&A, 559, A37
Schneider, P. & Sluse, D. 2014, A&A, 564, A103
Shajib, A. J., Birrer, S., Treu, T., et al. 2019, MNRAS, 483, 5649
Suyu, S. H., Bonvin, V., Courbin, F., et al. 2017, MNRAS, 468, 2590
Suyu, S. H. & Halkola, A. 2010, A&A, 524, A94
Suyu, S. H., Marshall, P. J., Auger, M. W., et al. 2010, ApJ, 711, 201
Treu, T. & Marshall, P. J. 2016, A&A Rev., 24, 11
Trotter, C. S., Winn, J. N., & Hewitt, J. N. 2000, ApJ, 535, 671
van der Walt, S., Colbert, S. C., & Varoquaux, G. 2011, Computing in Science Engineering, 13, 22
Verde, L., Treu, T., & Riess, A. G. 2019, Nature Astronomy, 3, 891
Virtanen, P., Gommers, R., Oliphant, T. E., et al. 2020, Nature Methods, 17, 261
Vogelsberger, M., Genel, S., Springel, V., et al. 2014, MNRAS, 444, 1518
Wagner-Carena, S., Park, J. W., Birrer, S., et al. 2020, arXiv e-prints, arXiv:2010.13787
Wes McKinney. 2010, in Proceedings of the 9th Python in Science Conference, ed. Stéfan van der Walt & Jarrod Millman, 56 – 61
Winn, J. N., Hall, P. B., & Schechter, P. L. 2003, ApJ, 597, 672
Wong, K. C., Suyu, S. H., Chen, G. C. F., et al. 2020, MNRAS, 498, 1420
Xu, D., Sluse, D., Gao, L., et al. 2015, MNRAS, 447, 3189
Yıldırım, A., Suyu, S. H., & Halkola, A. 2020, MNRAS, 493, 4783
Yoo, J., Kochanek, C. S., Falco, E. E., & McLeod, B. A. 2005, ApJ, 626, 51

Distribution of multipole of order 4 in elliptical galaxies



Based on Hao et al. 2006