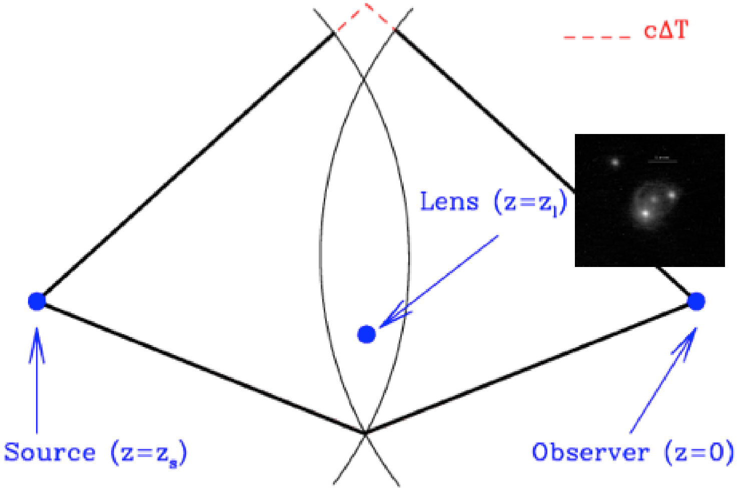
Lensed quasar mining and modeling challenges

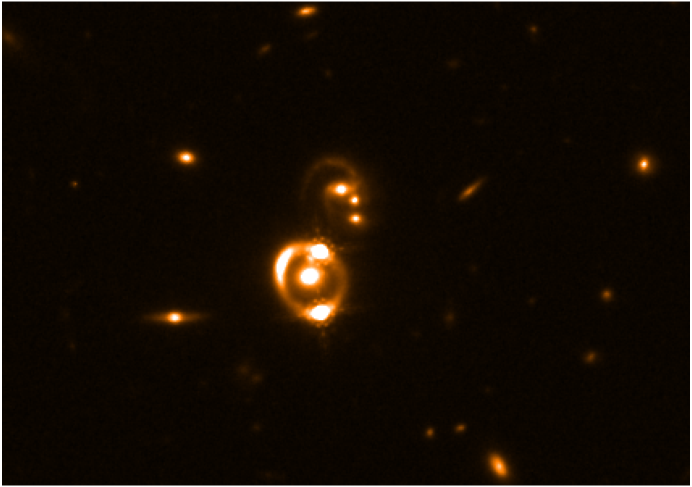
Adriano Agnello

29th June 2017

General configuration of a strong lens:[1]

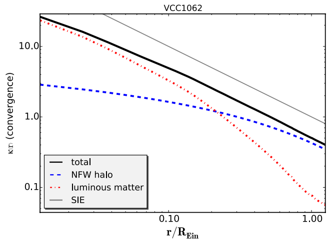


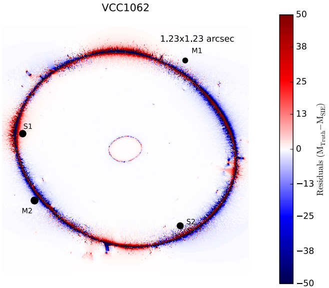
[1] **NB** the time-delay illustration is misleading!

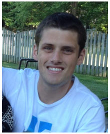


- Time-delay cosmography: low-redshift probe, combined with CMB provides limits on departure from flat-ΛCDM; however, systematics must be constrained to within 1% on 'many' lenses.
- Substructure: spotted via flux-ratio 'anomalies', subhalo abundance is yet another probe of ΛCDM; however, what is the role of subhalos and that of baryons? Must be studied at population level, on 'many' lenses.
- Large samples of lensed quasars (with suitable ancillary data) are needed: these are *very rare* objects to be skimmed in wide-field surveys.

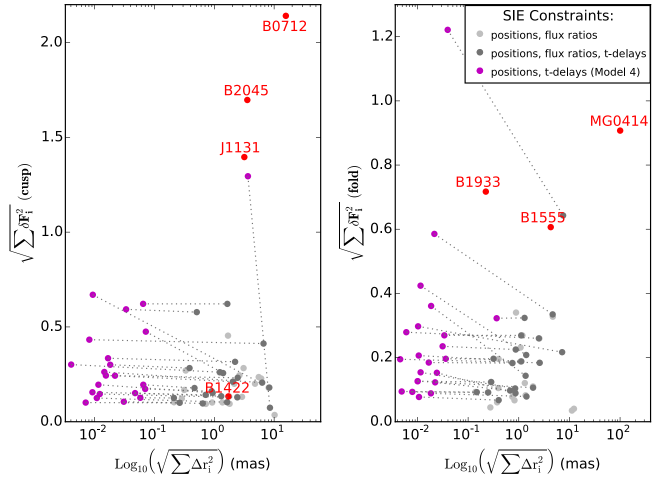
Flux-ratio anomalies from 'baryonic' substructure[2]







[2]Gilman, AA, Treu, Keeton, & Nierenberg (2017) MNRAS, 467, 3970


B0712
B2045
J1131
B1422
$\sqrt{\sum \delta F_i^2}$ (cusp)
$\mathrm{Log}_{10}\left(\sqrt{\sum \Delta r_i^2}\right)$ (mas)
SIE Constraints:
positions, flux ratios
positions, flux ratios, t-delays
positions, t-delays (Model 4)
MG0414
B1933
B1555
$\sqrt{\sum \delta F_i^2}$ (fold)
$\mathrm{Log}_{10}\left(\sqrt{\sum \Delta r_i^2}\right)$ (mas)

The substructure mass function seen through lensed quasars:[3]

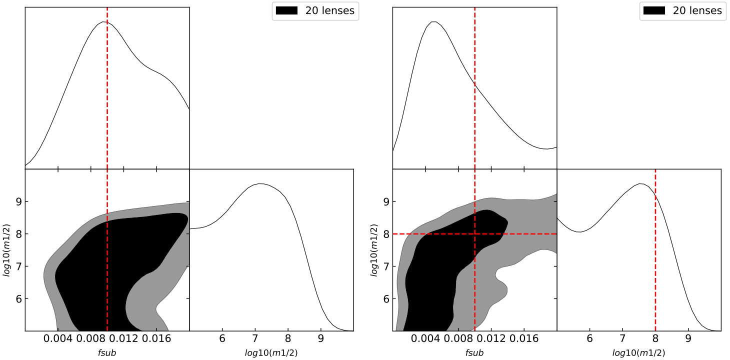
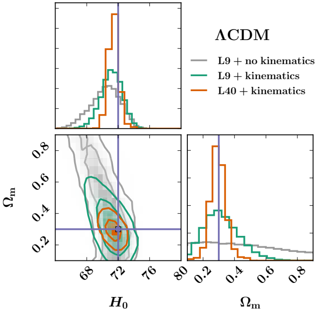
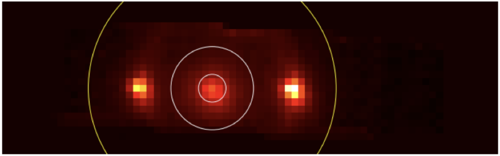


Figure : Inference on substructure mass function (normalization and low-mass cutoff) from 20 mock lenses; each lens requires $\approx 10^6$ substructure realizations.

[3] D. Gilman et al. (2017) in prep.

Unbiasing cosmography with spatially-resolved kinematics:[4]





[4] A. J. Shajib, T. Treu, & AA (2017) MNRAS subm.

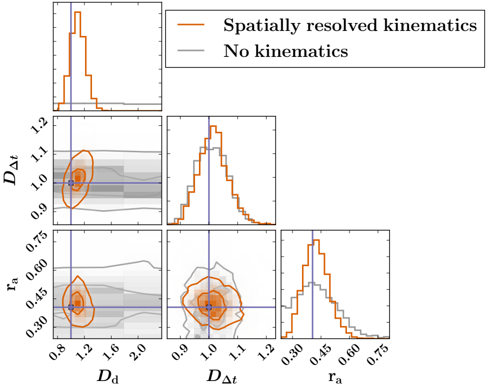


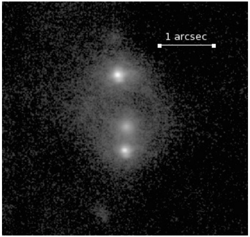
Figure : Inference on cosmological distances from time-delay lensing when aided by dynamics, from a realistic sample of mocks. Lensing and dynamics break respective degeneracies (mass-sheet/-anisotropy). $D_l \propto c^3 \Delta t/\sigma^2$ indep. of κ_{ext}, but dep. on lens model.

Issues: Multiple model-degeneracies, different for each lens; non-trivial role of priors; besides modeling all lenses, must combine them hierarchically (similar lenses should have similar properties), besides sharing the same cosmological parameters.

Quasars are rare

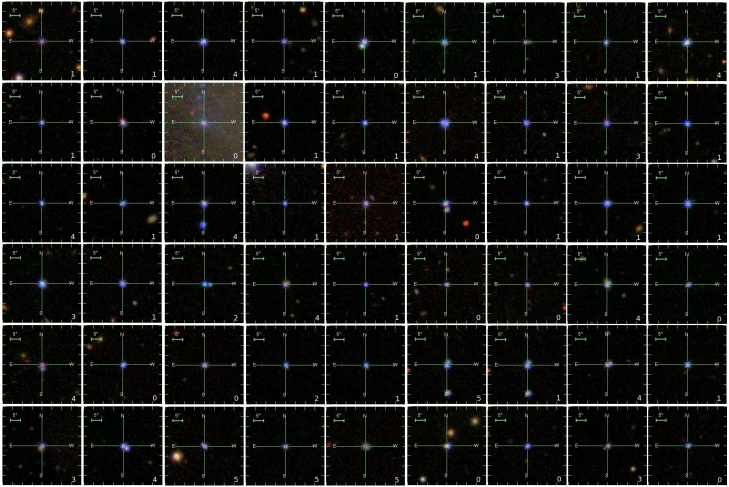
Multi-step skimming, a 'big data' problem:

- Catalog of objects with convenient magnitudes/colours ($10^5 - -10^6$ objects)
- Targets, selected via their catalog properties ($10^2 - -10^3$)
- Candidates, selected via eyeballing/modelling ($10^1 - -10^2$)
- Go to the telescope and cross all fingers...



[Numbers given above refer to samples after some colour pre-selection]

What *don't* they look like?



Techniques: 'recent'

- Object classification: ANNs
- Object classification: population mixtures
- Eyaball *everything*? Model *everything*?
- Look for weird objects in the first place
- Multiplet detection (ground-based or space-based)

Artificial Neural Networks

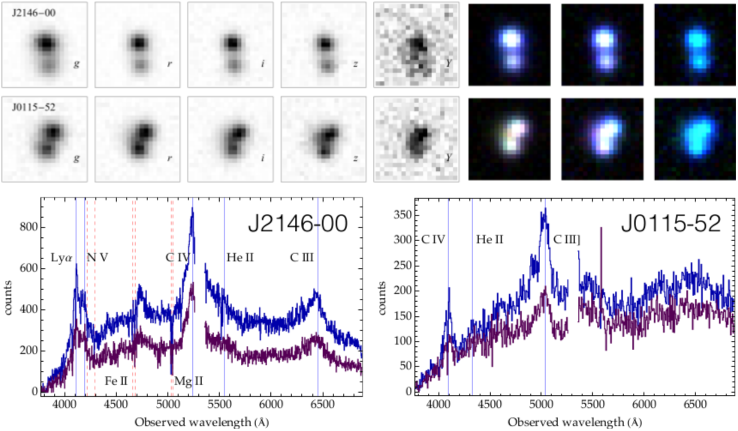
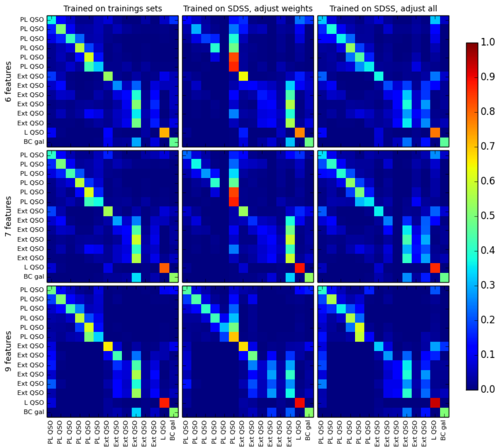


Figure : DES J2146 and J0115 (AA et al. 2015, MNRAS, 454, 1260), discovered using AANs.

Pop-mix classification, with many quasar 'bins' and simulated lenses:[5]



[5]Williams, P., AA, & Treu, T. (2017), MNRAS, 466, 3088

PopMix: Some lenses found this way...

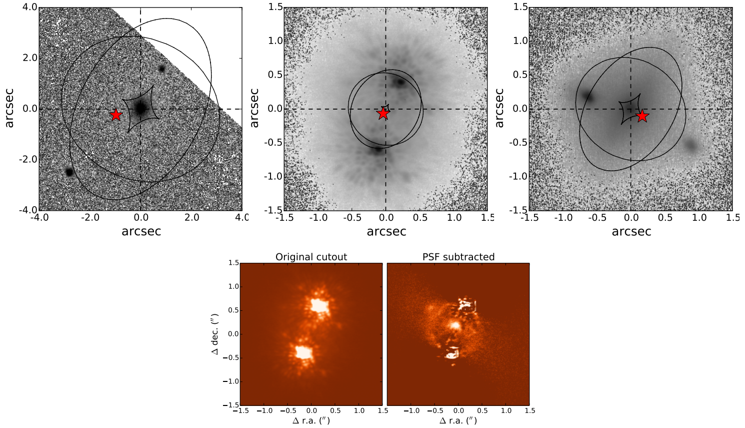


Figure : Lenses discovered via population-mixture and/or outlier selection (Williams, AA, et al. 2017, MNRAS subm.). Imaging+spec confirmation data.

Outlier selection

Once you've excluded everything else, whatever is left...

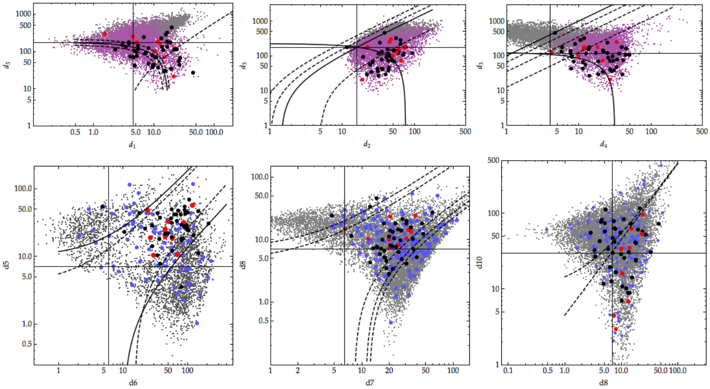


Figure : Selecting outliers (AA (2017), MNRAS acc., arXiv:1705.08900), based on combinations of pseudo-differences from different object clusters in colour space.

For example:

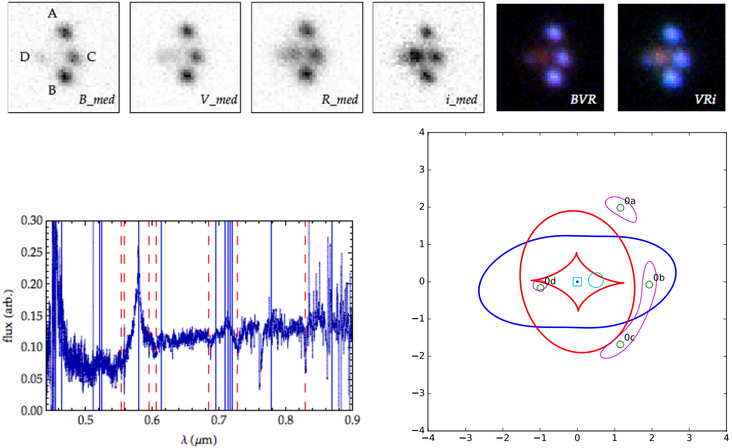


Figure : SDSS J1433+60 ($z_s = 2.738 \pm 0.002$, $z_s = 0.407 \pm 0.005$), AA et al.(2017), MNRAS subm., arXiv:1702.03942

Gaia Multiplet Detection

About 30% lenses are resolved by Gaia, down to $G = 20.7$, even when blended in ground-based surveys.[6]

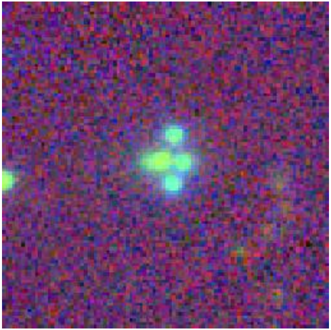


Figure : J1433+60 re-discovered this way (currently embargoed lenses have been found this way for the first time).

[6] AA (2017), MNRAS acc., arXiv:1705.08900

Contaminants: quasar+star LOS pairs → MW substructure?!

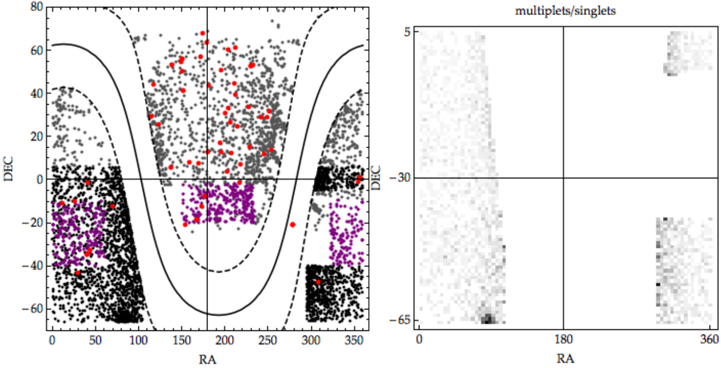


Figure : Multiplet distribution over three survey footprints. Candidate MW streams among foreground contaminants (AA 2017, MNRAS acc., arXiv:1705.08900), being found independently by DES.

Summing up...

Lensed quasars are intersting for astrophysics and cosmology...

- substructure mass-function from lensing 'anomalies'
- H_0 to percent accuracy from time-delay lensing
- (plus quasar hosts at $z \approx 2$, micro-lensing, LOS absorbers, dust... not discussed here)

...but they are rare

- lots of more common stuff in the Universe $\rightarrow$ different strategies for different surveys
- 30 new lenses confirmed over 2016-2017, several new quads
- Spin-off discoveries: MW streams?

Some 'new' lenses were already visible in the DSS! Could have we discovered them earlier on?

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