First detection of galaxy-galaxy-galaxy lensing in RCS-1

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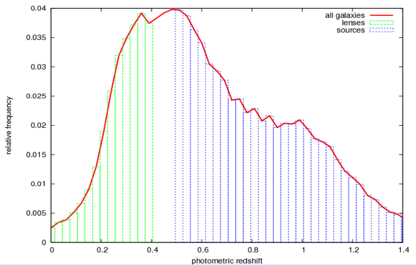
Outline

1. The Red-sequence Cluster Survey
2. From second- to third-order galaxy-galaxy lensing
3. Third-order aperture moments
4. Mapping the excess matter distribution about two lenses
5. Conclusion

Red-sequence Cluster Survey 1

- taken between 1999 and 2001 with CFH12k@CFHT ($2.1 \times 2.3\,\mathrm{deg}^2$) and MOSAICII@CTIO ($1.8 \times 2.4\,\mathrm{deg}^2$)
- total $\approx 100\,\mathrm{deg}^2$ (10/12 patches) $R_\mathrm{c}^\mathrm{limit} \approx 25.0\,\mathrm{mag}/z'_\mathrm{limit} \approx 23.9\,\mathrm{mag}$
- primary goals: large galaxy clusters samples, studying cluster evolution, $\Omega_\mathrm{m}/\sigma_8$

Galaxy redshift distribution



lenses/sources: $2.4 \times 10^5/3.8 \times 10^5$

photo'z & lensing catalogues

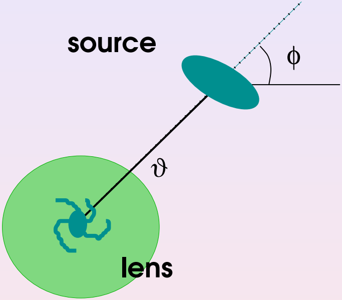
follow-up of CFHT patches (B,V)
photo'z cat. merged with shear cat.
$\sim 34\,\mathrm{deg}^2$, $18 < R_\mathrm{c} < 24$

RCS-1 PIs

Howard Lee, Toronto
Mike Gladders, Toronto
Felipe Barrientos, Santiago

see: Hoekstra et al. (2005), ApJ, 635, 73

Galaxy-galaxy lensing

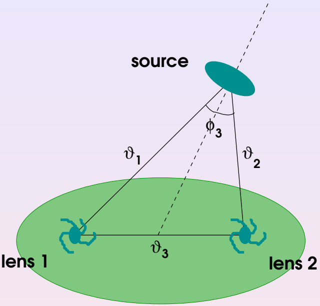


ε : complex ellipticity
"light quadrupole moment"

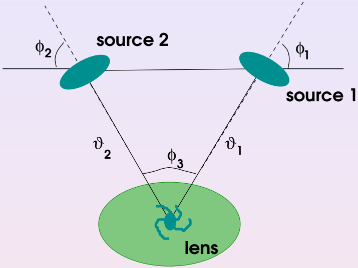
<ε>=0
fundamental assumption

$$\langle\gamma_{\rm t}\rangle(\vartheta) = -\langle\epsilon(\vartheta)\,{\rm e}^{-2{\rm i}\phi}\rangle$$

Schneider & Watts (2005), A&A, 432, 783-795



G



G+−

$$\widetilde{\mathcal{G}}(\vartheta_1, \vartheta_2, \phi_3) = -\langle \epsilon(\vartheta_1, \vartheta_2, \phi_3)\, \mathrm{e}^{-\mathrm{i}\phi_3} \rangle [1 + \omega(\vartheta_3)]$$

$$\widetilde{G}_+(\vartheta_1, \vartheta_2, \phi_3) = +\langle \epsilon_1(\vartheta_1, \phi_1)\, \epsilon_2^*(\vartheta_2, \phi_2)\, \mathrm{e}^{-2\mathrm{i}(\phi_1 - \phi_2)} \rangle$$

$$\widetilde{G}_-(\vartheta_1, \vartheta_2, \phi_3) = +\langle \epsilon_1(\vartheta_1, \phi_1)\, \epsilon_2(\vartheta_2, \phi_2)\, \mathrm{e}^{-2\mathrm{i}(\phi_1 + \phi_2)} \rangle$$

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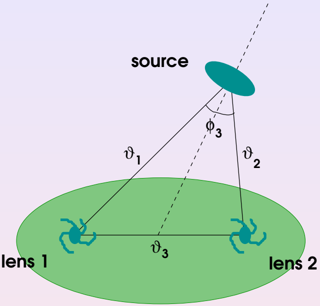

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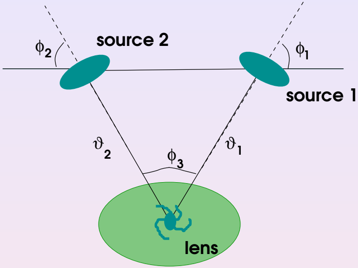

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$$\widetilde{G}_-(\vartheta_1,\vartheta_2,\phi_3) = +\langle \epsilon_1(\vartheta_1,\phi_1)\,\epsilon_2(\vartheta_2,\phi_2)\,\mathrm{e}^{-2\mathrm{i}(\phi_1+\phi_2)}\rangle$$

Correlators contain (known) 2nd-order statistics...

$$"\widetilde{\mathcal{G}}" \quad : \quad \langle \epsilon | \text{lens at 1 and 2} \rangle = \frac{\langle \epsilon n_1 n_2 \rangle}{\langle n_1 n_2 \rangle}$$

$$= \left(\langle \epsilon \delta_1 \delta_2 \rangle + \langle \epsilon \delta_1 \rangle + \langle \epsilon \delta_2 \rangle \right) \left(1 + \langle \delta_1 \delta_2 \rangle \right)^{-1}$$

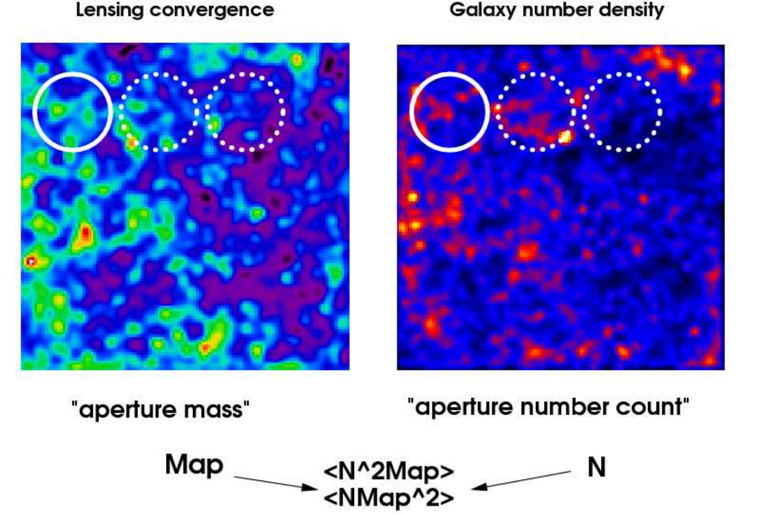
and

$$"\widetilde{G}_+" \quad : \quad \langle \epsilon_1 \epsilon_2^* | \text{lens at 3} \rangle = \frac{\langle \epsilon_1 \epsilon_2^* n \rangle}{\langle n \rangle} = \langle \epsilon_1 \epsilon_2^* \rangle + \langle \delta \epsilon_1 \epsilon_2^* \rangle$$

$$"\widetilde{G}_-" \quad : \quad \langle \epsilon_1 \epsilon_2 | \text{lens at 3} \rangle = \frac{\langle \epsilon_1 \epsilon_2 n \rangle}{\langle n \rangle} = \langle \epsilon_1 \epsilon_2 \rangle + \langle \delta \epsilon_1 \epsilon_2 \rangle$$

$$n = \langle n \rangle (1 + \delta) \qquad \delta : \text{ number density contrast of lenses}$$

Aperture statistics: local moments of smoothed fields



Relation between correlators and aperture moments

Aperture statistics is linear transformation of $\widetilde{\mathcal{G}}$ and $\widetilde{G}_\pm$:

- E-mode: $\langle N(\theta_1)N(\theta_2)M_\mathrm{ap}(\theta_3)\rangle = \mathrm{L}_1[\widetilde{\mathcal{G}}]$
  - Parity-mode: $\langle N(\theta_1)N(\theta_2)M_{\mathrm{ap},\perp}(\theta_3)\rangle = \mathrm{L}_2[\widetilde{\mathcal{G}}]$ should be zero in parity invariant Universe
- E-mode: $\langle N(\theta_1)M_\mathrm{ap}(\theta_2)M_\mathrm{ap}(\theta_3)\rangle = \mathrm{L}_3[\widetilde{G}_\pm]$
  - Parity-mode: $\langle N(\theta_1)M_{\mathrm{ap},\perp}(\theta_2)M_\mathrm{ap}(\theta_3)\rangle = \mathrm{L}_4[\widetilde{G}_\pm]$
  - B-mode: $\langle N(\theta_1)M_{\mathrm{ap},\perp}(\theta_2)M_{\mathrm{ap},\perp}(\theta_3)\rangle = \mathrm{L}_5[\widetilde{G}_\pm]$ not generated by lensing (but: intrinsic alignment, IA-density correlation, source clustering)

$M_{\mathrm{ap},\perp}$: M_ap after rotating ellipticities by 45°
$\mathrm{L}_i[x]$: some linear operators (integrals) on x

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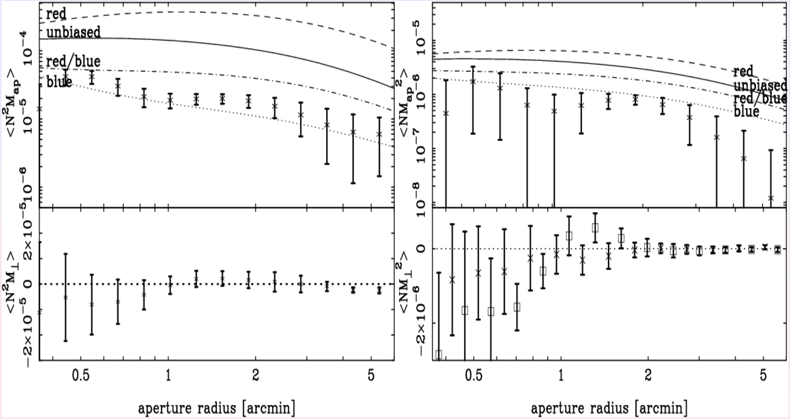
Results: third-order aperture statistics in RCS



lenses: $\bar{z} \sim 0.3$, sources: $\bar{z} \sim 0.85$ *left: "$\mathcal{G}$", right: "$G_\pm$"*
halo-model: flat ΛCDM, $\Omega_\mathrm{m} = 0.3$, $\sigma_8 = 0.9$

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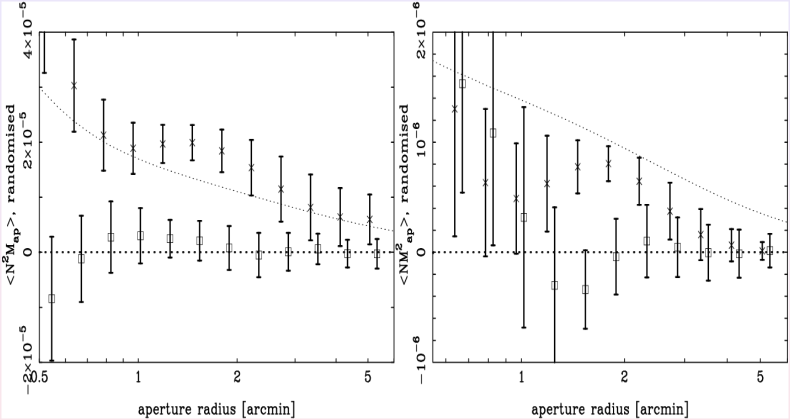

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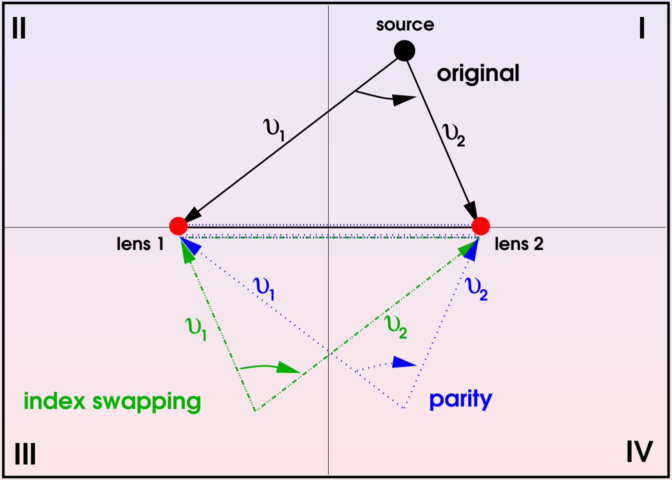
Map of the galaxy^3-lensing correlator $\mathcal{G}$



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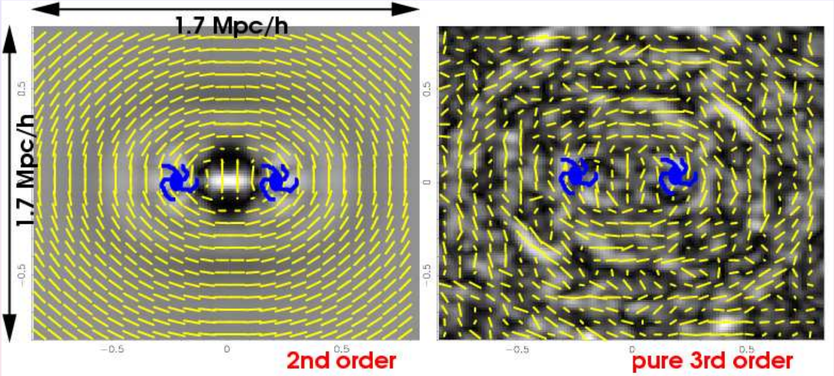

$$\widetilde{\mathcal{G}}(\vartheta_1, \vartheta_2, \phi) = \mathcal{G}(\vartheta_1, \vartheta_2, \phi) + \langle\gamma_{\rm t}\rangle(\vartheta_1)\mathrm{e}^{-\mathrm{i}\phi} + \langle\gamma_{\rm t}\rangle(\vartheta_2)\mathrm{e}^{+\mathrm{i}\phi}$$

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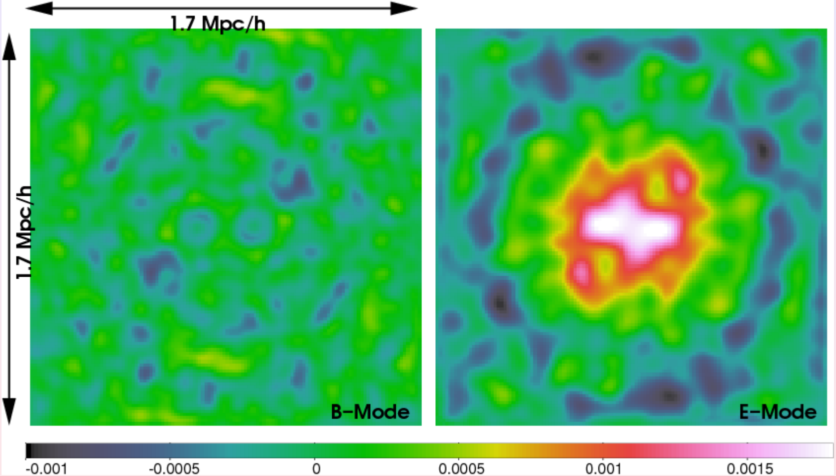

Conclusions

- significant detection of GGGL in RCS-1 (most: $\mathcal{G}$)
- systematics are negligible
- compatible with crude halo-model estimates (cosmological origin)
- already RCS's $\sim$ 34 deg^2 distinguish strongly between different HODs
  $\longrightarrow$ new tool to constrain halo model parameters
- GGGL can be used to map the average excess matter distribution about two lenses

for more details see: Simon et al. (2007), astroph/0707.0066