Peculiar Transverse Velocities of Galaxies from Microlensing

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Peculiar velocities of galaxies

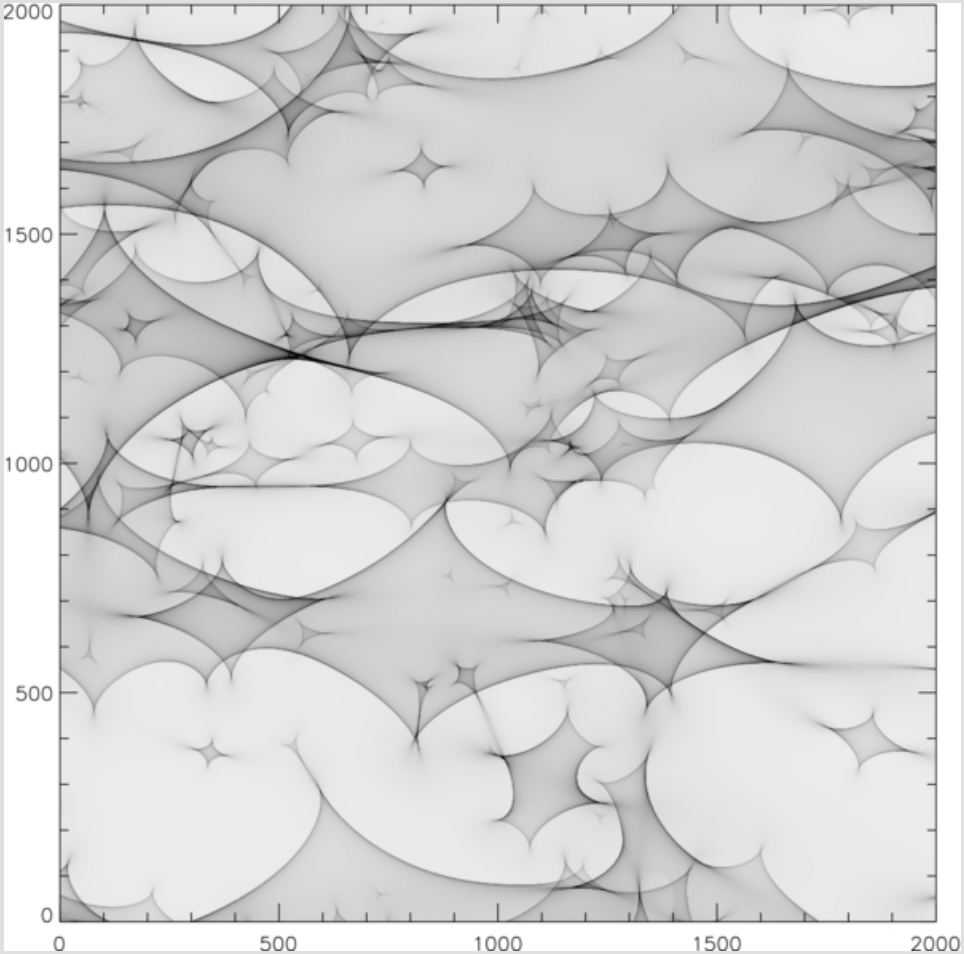
- Microlensing: relative movement between quasar and lens galaxy. Lens transverse velocity from microlensing light curves

- The motion of galaxies with respect to the smooth Hubble flow (i.e. the peculiar velocity field of galaxies) is key to understand the "dynamics" of the Universe

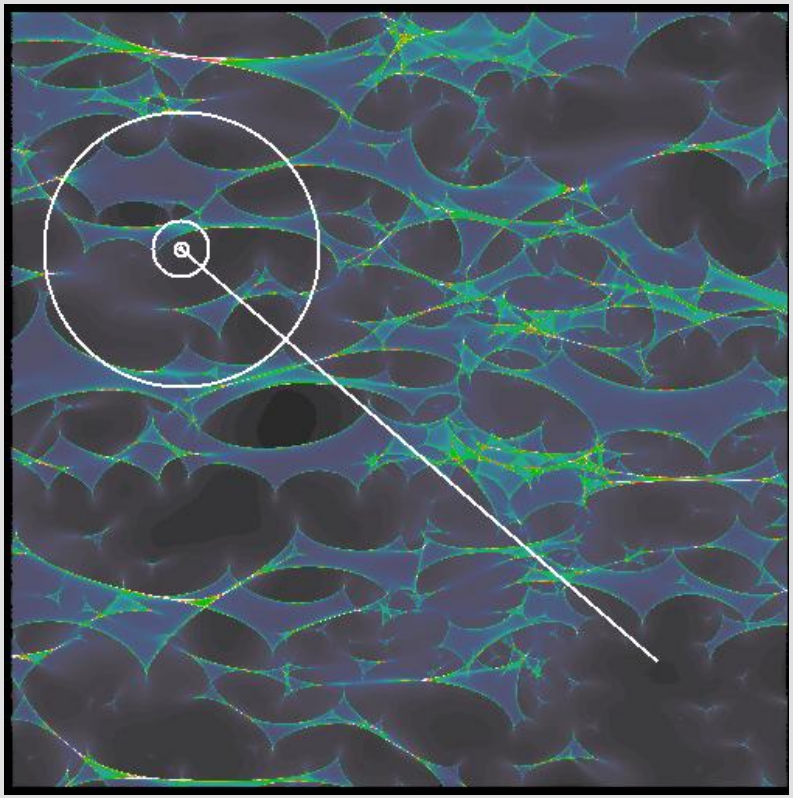
- Dark energy models predict measurable differences in the peculiar velocity field dependence with redshift

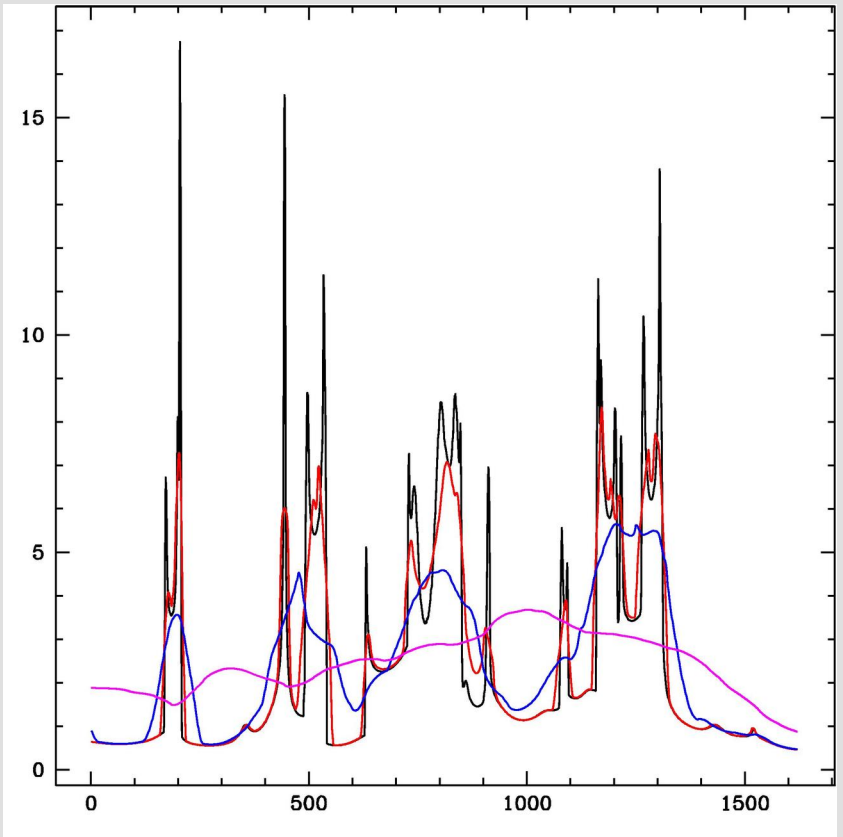
Caustics – crossing counts

- Wyithe et al. 1999; Gil-Merino et al. 2005; Poindexter & Kochanek 2010;
- Mediavilla et al. 2015 (2237+0305)
- Basic idea: caustics are like randomly distributed milestones of known mean separation (<d>)
- $V \approx (N*\langle d \rangle)/t$
- t (1 crossing) ≈ years (Mosquera & Kochanek 2011)
- Count caustic crossings in an ensemble of GL to reduce Poissonian noise



Caustics – Peaks Over a Threshold (POT)





Pilot study - computations

- 17 lensed quasars ensemble with published (and very heterogeneous) light curves
- We count 9, and 7 POT, respectively for thresholds of 0.1 and 0.2 mag

$$\langle n \rangle = \sum_i \langle n_i \rangle = \sum_i \frac{v_{\mathrm{eff}\,i} t_i}{\sqrt{\langle m \rangle / 0.3 M_\odot}} l_{1i}^{-1}(R, \alpha).$$

$$v_{\mathrm{eff}\,i} = \sqrt{\left(\frac{v_{oi}}{1+z_{li}} \frac{D_{\mathrm{LS}i}}{D_{\mathrm{OL}i}}\right)^2 + \left(\frac{\sqrt{2}\,\sigma_{*i}}{1+z_{li}} \frac{D_{\mathrm{OS}i}}{D_{\mathrm{OL}i}}\right)^2 + \left(\frac{\sqrt{2}\,\sigma_{\mathrm{pec}}(z_{li})}{1+z_{li}} \frac{D_{\mathrm{OS}i}}{D_{\mathrm{OL}i}}\right)^2 + \left(\frac{\sqrt{2}\,\sigma_{\mathrm{pec}}(z_{si})}{1+z_{si}}\right)^2},$$

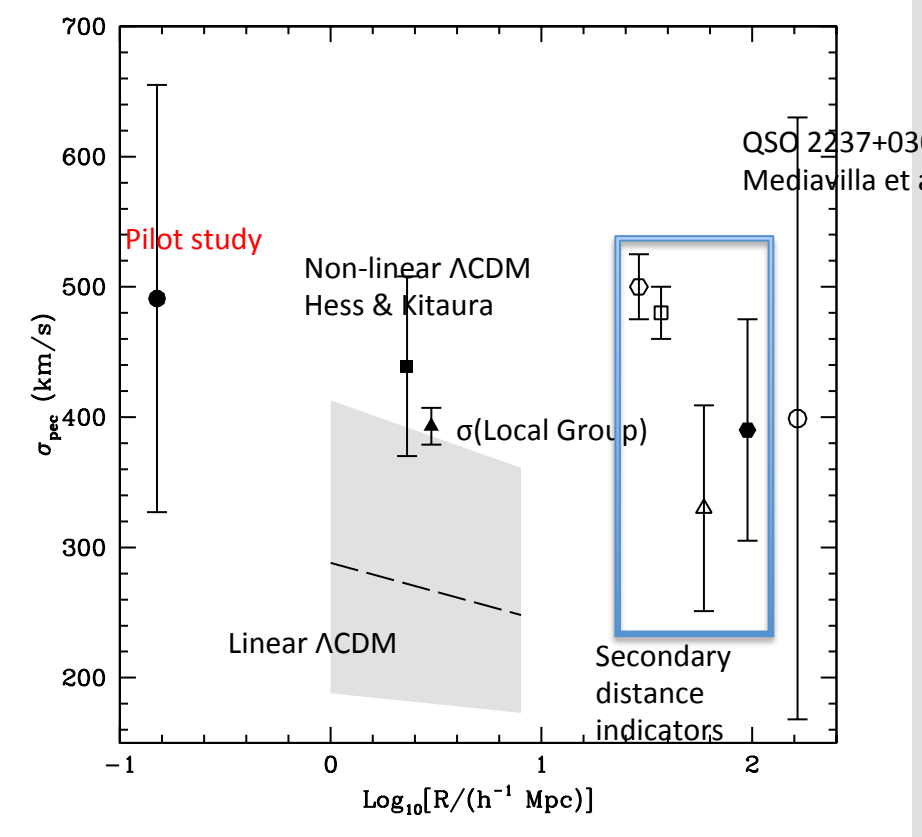
- R ≈ 4.3 light-days $(\langle M \rangle / 0.3 M_{sun})^{0.5}$ (Morgan et al. 2010, Mosquera et al. 2013, Jiménez-Vicente et al. 2015a,b)

Pilot study - results

- $\sigma_{pec}(0.53\pm 0.18) \approx 638 \pm 213$ km/s
- $\sigma_{pec}(0.53\pm 0.18) \approx 657 \pm 248$ km/s

- Comparison with Bulk Flow: average the *radial* peculiar velocity field of a certain volume of universe centered on us

- $\sigma_{pec}(0) \approx 491 \pm 164$ km/s compatible with σ_{LG} and ΛCDM predictions



Error budget – RM

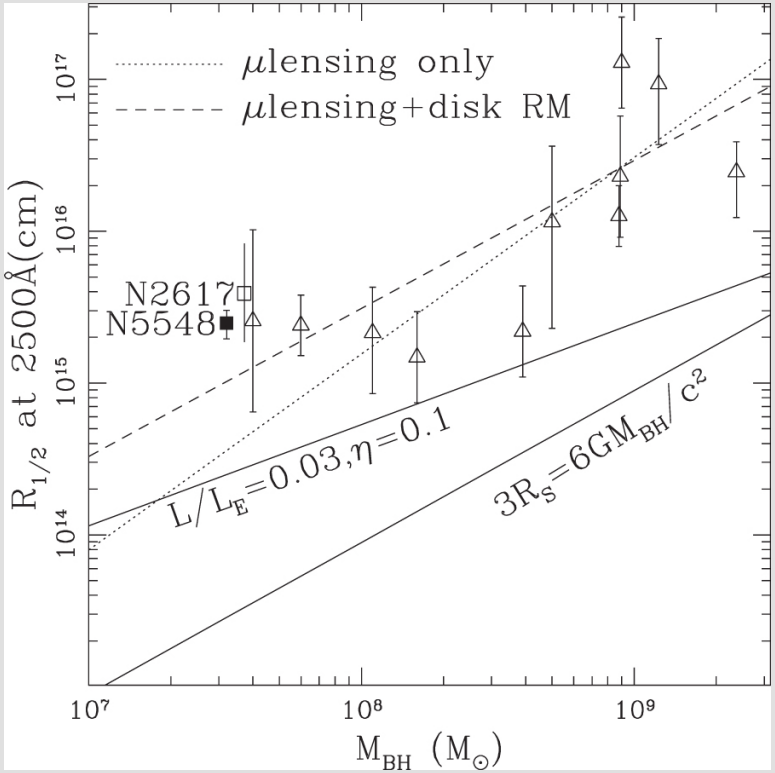
Table 2. σ_{pec} Relative Error Budget

Source	present ensemble	LSST survey
R	<0.10	<0.05[1]
profile	<0.07	<0.07
α	<0.04	<0.04[1]
$\langle m \rangle$	<0.15	<0.15
(κ, γ)	<0.03	<0.03[1]
σ_*	<0.00	<0.00
v_0	<0.00	<0.00
$1/\sqrt{n}$	0.29	0.02−0.07

[1]Overestimated upper limit

Reverberation mapping – sizes

- Edelson et al.



- Jiang et al. (Pan-STARRS1 Surveys – PS1)

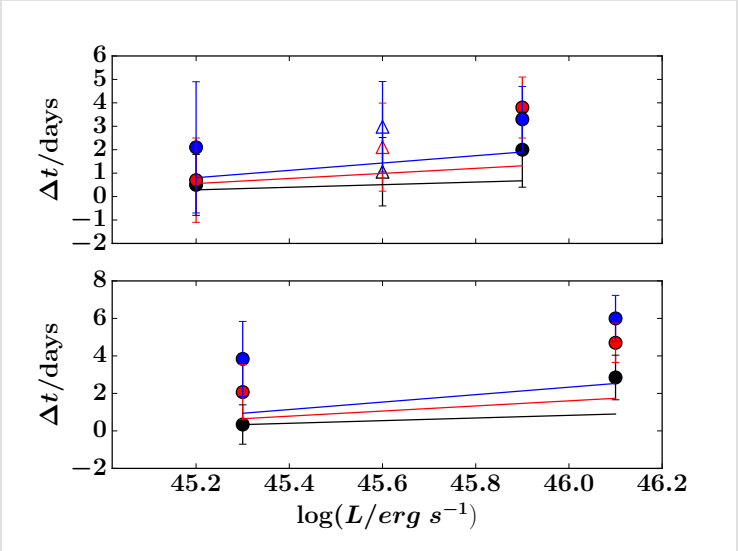


Figure 17. *Top:* summary of the stacked lag signals with median luminosity for the whole sample. The open black, red and blue triangles are the stacked $g-r$, $g-i$ and $g-z$ lags as shown in Figure 10. The filled black, red, and blue circles are the stacked $g-r$, $g-i$ and $g-z$ lags for two luminosity bins with the theoretically expected values for each luminosity bin connected by the black, red and blue lines. *Bottom*: the corresponding stacked lags of the subsample *cLD* for two luminosity bins as shown in Figure 13.

Future surveys – cadence

- Gaia: 2000 new gravitational lenses (better than monthly cadence?)
- LSST: 2600 new gravitational lenses (better than weekly cadence?)
- ~~Euclid: 2500 new gravitational lenses?~~
- Objective: accurate estimate of $\sigma_{pec}(z)$ for different bins in z to test dark energy models
- … using CCC and LCF