How Weak Lensing Can Help Us Understand Galaxy Physics

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Lensing is the distortion of background images by foreground mass:

\[ \kappa (\theta) = \int_0^{z_s} \frac{c}{H_0} \frac{d\alpha}{d\beta} \frac{\rho_m(z)}{a} \Sigma_{\text{crit}} \]

\[ \Sigma_{\text{crit}} = \frac{3H_0^2}{8\pi G} \frac{d_s}{d_L d_{LS}} \]

Sensitive to geometry and lens mass
what weak lensing measures:

Foreground mass shears and magnifies background galaxies.

\[ \gamma_t \propto \Delta \Sigma = \bar{\Sigma}(< r) - \Sigma(r) \]

\[ \kappa \propto \Sigma(r) \]
Weak lensing is weak.

The signal-to-noise is very small.

$$\langle \gamma \rangle \sim 0.001 - 0.01$$

Especially compared to the random noise from intrinsic galaxy shapes

$$\sigma_\gamma = 0.2$$
Consider magnification.
The Effect of Magnification on galaxy sizes and luminosities
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Traditionally, magnification measurements are much noisier than shear.

This is because the intrinsic scatter in magnified properties is much larger than that in shapes.
Very recently, there have been several successful measurements. 

Schmidt et al. 2012

but the signal-to-noise is still far below that of shear.

Morrison et al. 2012
There is unexploited signal here to use it, remember that the source galaxies are more than just a size and a shape...
The Fundamental Plane of Early Type Galaxies

\[ \sim 15\% \text{ intrinsic scatter} \]

no\* significant variation with environment

Jørgensen et al 1996

\*maybe
The Fundamental Plane of Early Type Galaxies

But we cannot get spectra for enough galaxies to do weak lensing this way.

\[ \sim 15\% \text{ intrinsic scatter} \]

\[ \text{no* significant variation with environment} \]

*maybe

Jørgensen et al. 1996
There is a photometric FP analogue

$$\kappa = \log (R_{eff}) - f (\mu, \log \text{conc})$$
There is a photometric FP analogue

This is what it looks like in SDSS.

\[ \kappa = \log(R_{eff}) - f(\mu, \log \text{conc}) \]
There is a photometric FP analogue

\[ \kappa = \log (R_{\text{eff}}) - f(\mu, \log \text{conc}) \]

This is the result of a small magnification.
Constructing a magnification source sample using SDSS

60,000 Lenses:
\[ \log (\text{stellar mass}) > 11.0 \]
\[ 0.2 < z < 0.4 \]

10 million Sources:
resolved galaxies
early-type SEDs (35%)
Why this is not an easy measurement:

photo-z’s and clustering produce spurious signal
Why this is not an easy measurement: all existing photometric pipelines are flawed.

Lenses bias the measurement of faint source properties.
SDSS Magnification Results

Errors $\sim$ 1.5-2x those of shear,
(but there is room for improvement)
What we gain from combining shear and magnification:

shear

magnification
A novel combination of kinematics and lensing using the Tully-Fisher relation
Weak lensing is weak.

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\[ \sigma_\gamma = 0.2 \]
A novel combination of kinematics and lensing using the Tully-Fisher relation

Reyes et al 2011

Schlegel (private comm.)

Reyes et al 2011
If we know TF, we can use rotation curves to estimate the ellipticities independently.

For a disk, \(\sin(i)\) tells us what ellipticity we should measure in the absence of lensing.
Cartoon: How TF improves lensing signal.

- **Image**: face-on, face-on, but sheared, inclined, but not sheared

- **Rotation Curve**: 
  - Face-on: Flat rotation velocity with no significant variation.
  - Face-on, but sheared: Rotation velocity shows a slight variation with shearing.
  - Inclined, but not sheared: Rotation velocity shows a smooth incline with no shearing.
This controls for much of the shape noise.

LSST weak lensing: 37 galaxies per sq. arcmin equivalent S/N to 0.5 Tully-Fisher galaxies per sq. arcmin

a major reduction in certain systematic errors

\( \sigma_\gamma = 0.02 \)
This controls for much of the shape noise.

\[ \sigma_\gamma = 0.02 \]

a **major** reduction in certain systematic errors:

- no photo-z’s

- brighter, better resolved galaxies drastically reduce psf correction, shear calibration issues
And allows for dramatic improvements to the cosmological constraints
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