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# Ordinary weak lensing

Bartlemann & Schneider (2002)

$$\underset{\text{Source plane}}{\vec{x}'} = \underset{\text{Image plane}}{\vec{x}} - \underset{\text{Deflection angle}}{\vec{\alpha}} \qquad \text{where} \quad \vec{\alpha} = \vec{\nabla}\psi(\vec{x})$$

"Locally linear" approximation produces the transformation

$$x_i' = \left[x_i - \frac{\partial \psi}{\partial x_i}\right] + \underbrace{\frac{\partial}{\partial x_j}\left[x_i - \frac{\partial \psi}{\partial x_i}\right]}_{A_{ij}} x_j + \ldots\ldots$$

unmeasurable centroid shift

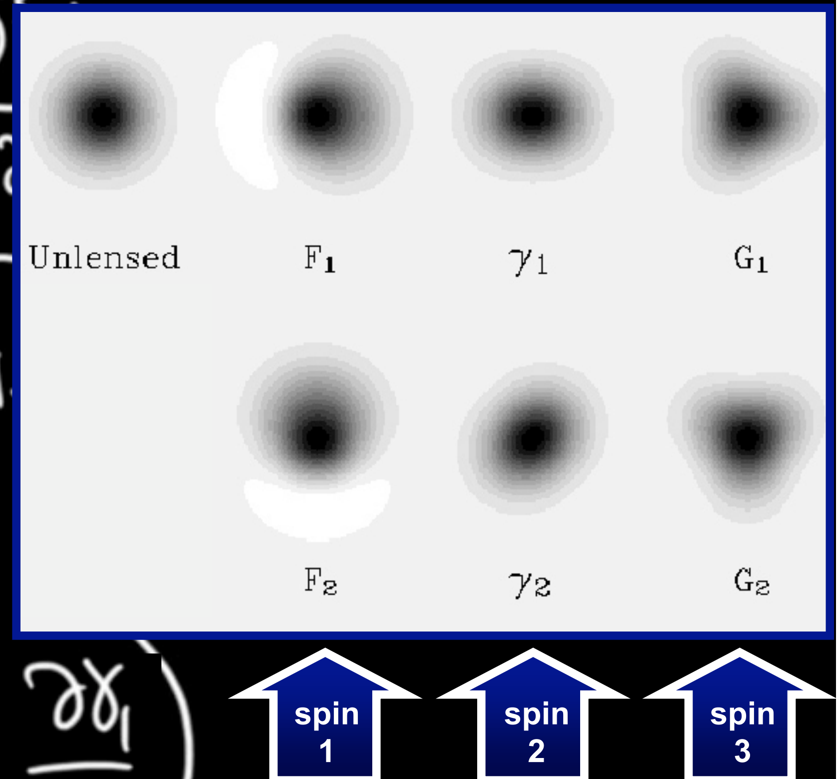
i.e. to all intents and purposes,

$$\boxed{x_i' = A_{ij}\, x_j} \qquad \text{where} \quad A \equiv \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

# Continuing the Taylor series

e.g. Goldberg & Natarajan (2002)

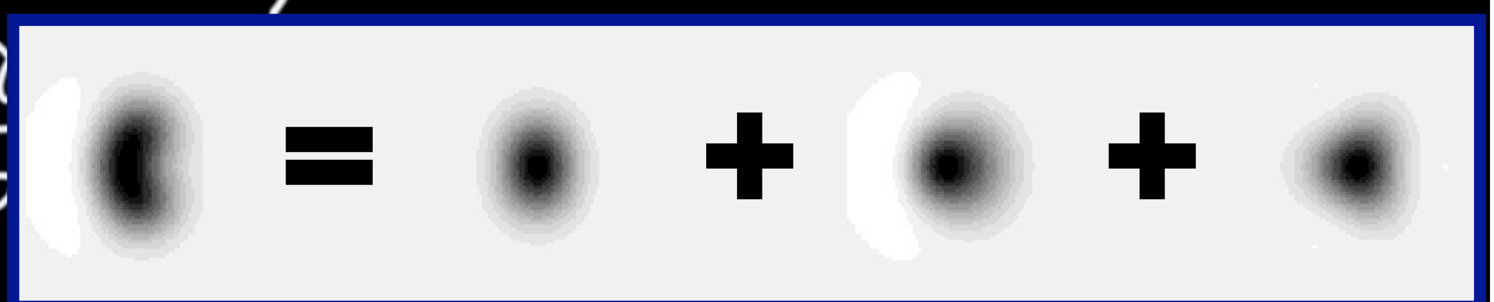
$$x'_i = \underbrace{\delta_{ij} x_j - \frac{\partial^2 \psi}{\partial x_i \partial x_j} x_j}_{A_{ij}} - \frac{1}{2}\frac{\partial^3}{\partial x_i \ldots}$$




Four (unique) combinations of derivatives.

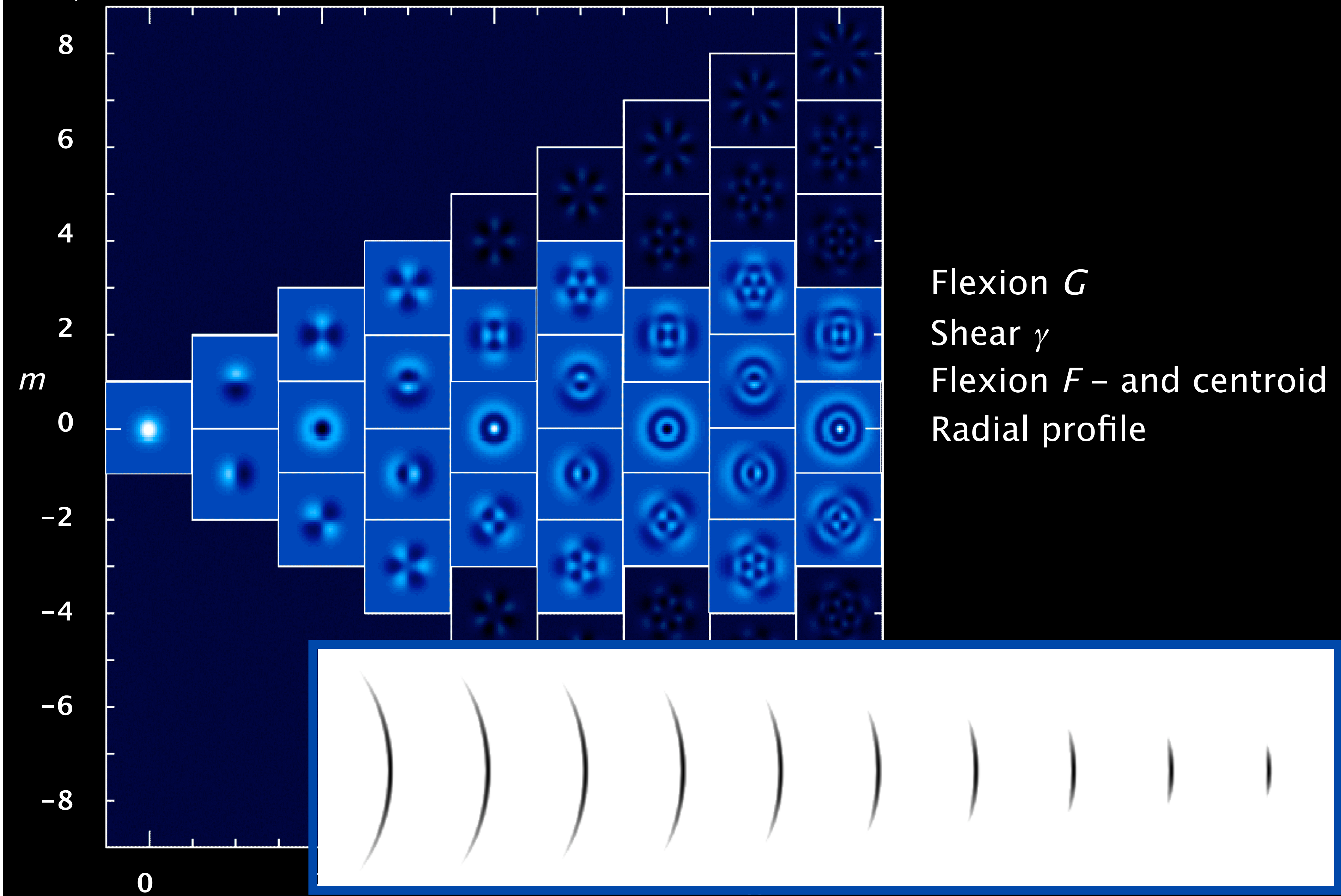
$$\mathcal{F} \equiv \left(\frac{\partial\gamma_1}{\partial x_1} \quad \frac{\partial\gamma_2}{\partial x_2} \quad \frac{\partial\gamma_2}{\partial x_1} \quad \frac{\partial\gamma_1}{\partial x_2}\right)$$

$$\mathcal{G} \equiv \left(\ldots\right.$$



# Flexion and shapelets

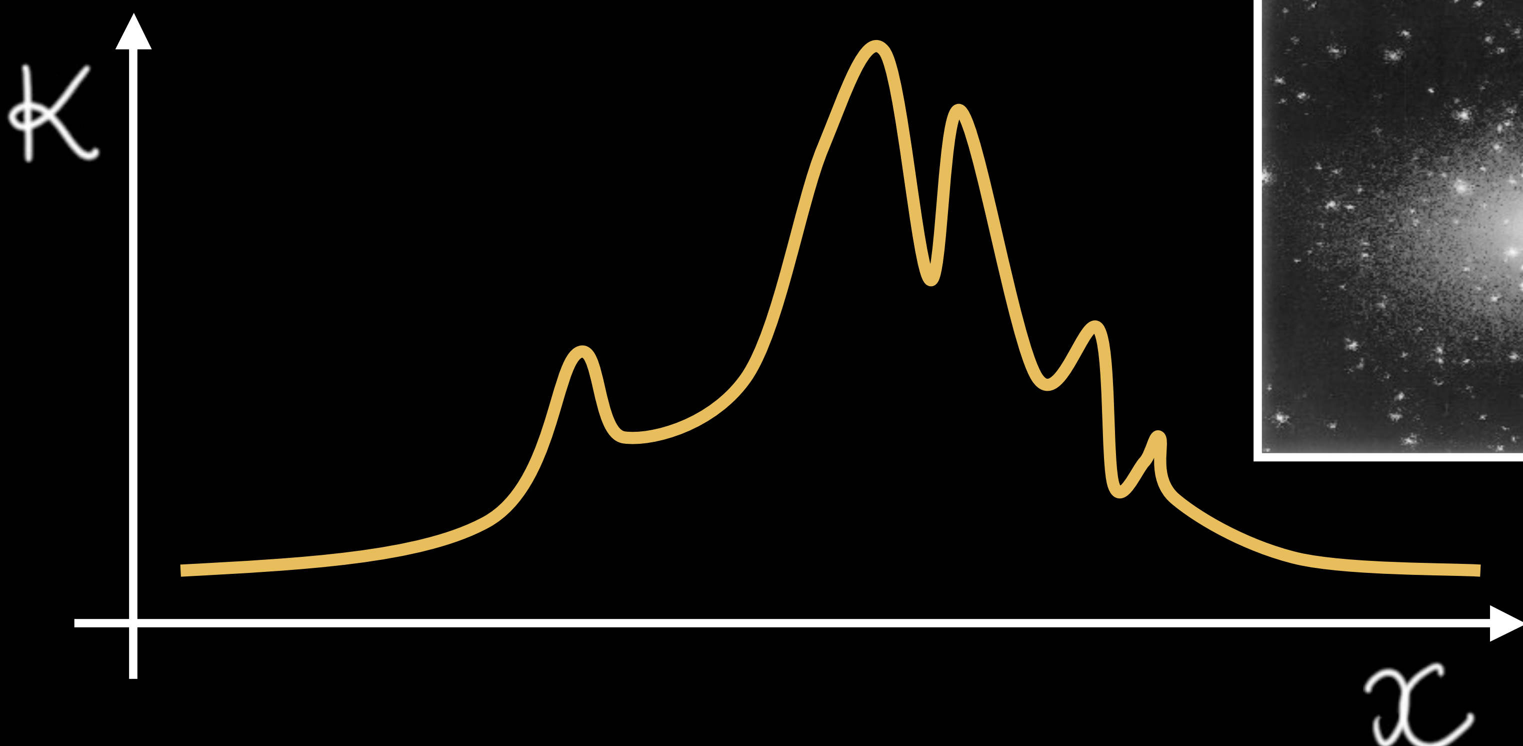
Massey et al. (2007)

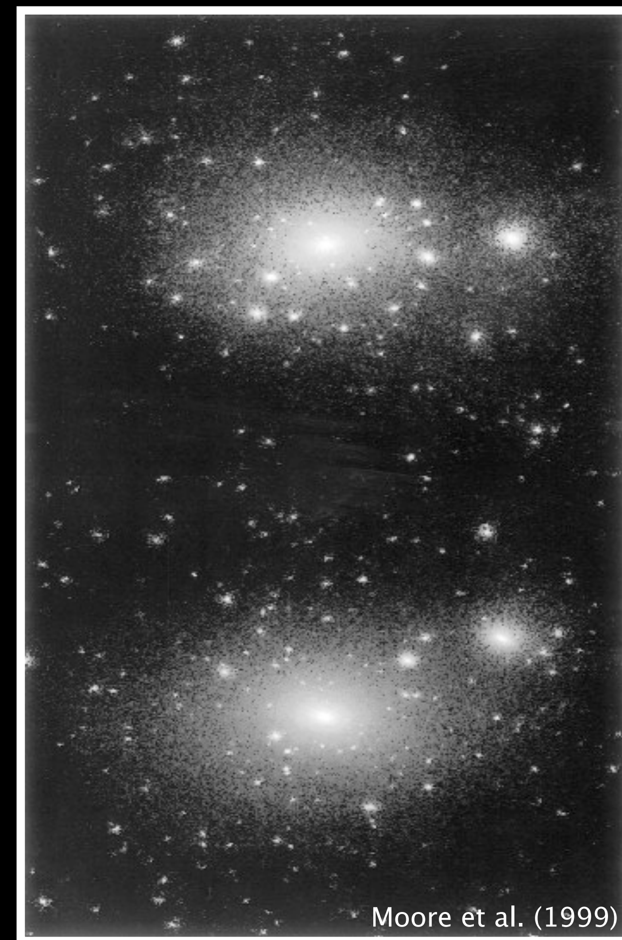


## Where is flexion useful?

$$\mathcal{F}, \mathcal{G} \sim \nabla \kappa$$

A high pass filter of mass distribution




Flexion can probe cluster **cores** and **substructure**, on scales smaller than shear.
Bridges the gap between strong (info/source) and weak lensing (statistical tech).

# Flexion measurement methods

## Passive methods:

**HOLICS (Okura, Umetsu & Futamase 2007)**
KSB-like moments, but is missing any PSF correction

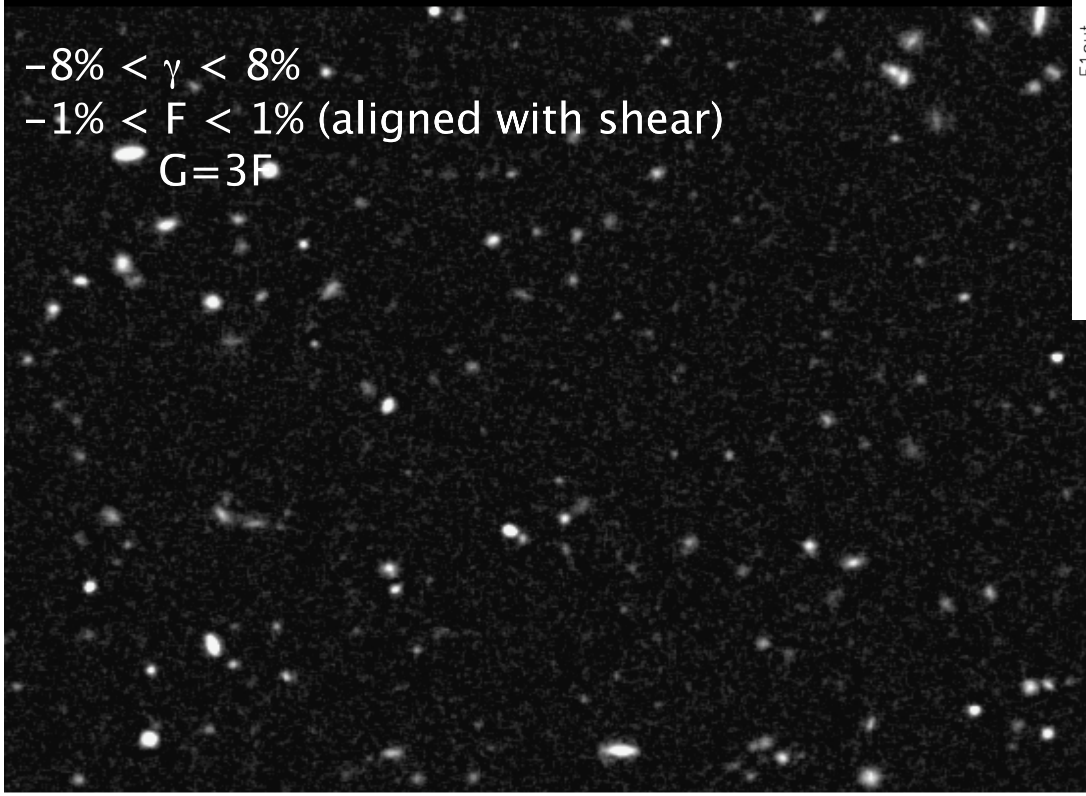
**Shapelets (Massey et al. 2007)**
Adds PSF deconvolution and generalises moments
http://www.astro.caltech.edu/~rjm/shapelets/

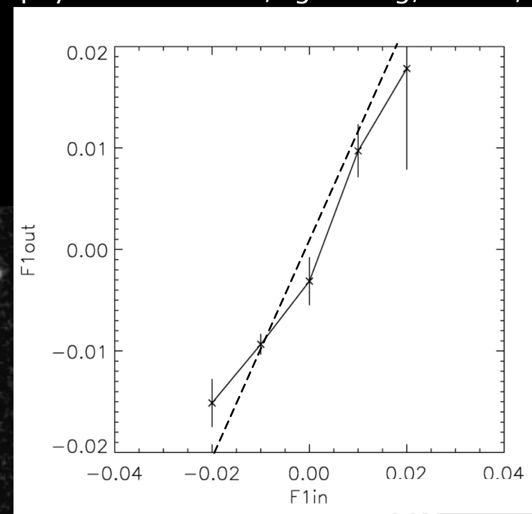
## Active methods:

**Sextupole moments (Irwin & Schmakova 2005)**
Shears and flexions circular models, then convolves with PSF, to match data

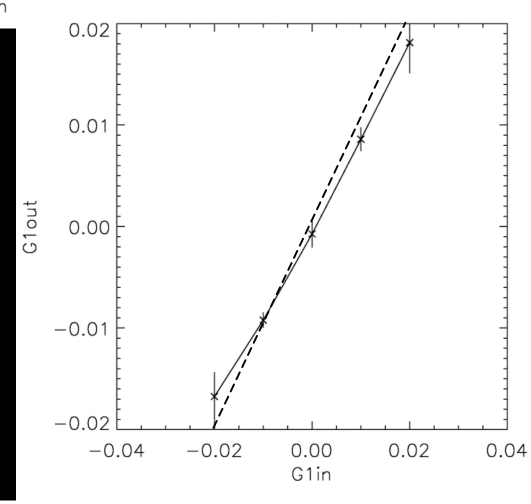
**Shapelet-based Goldberg & Leonard (2006)**
Perturbs even-order coefficients to fit odd-order ones
http://www.physics.drexel.edu/~goldberg/flexion/

## FLIP (FLexion Implementation Programme):




Courtesy Barney Rowe

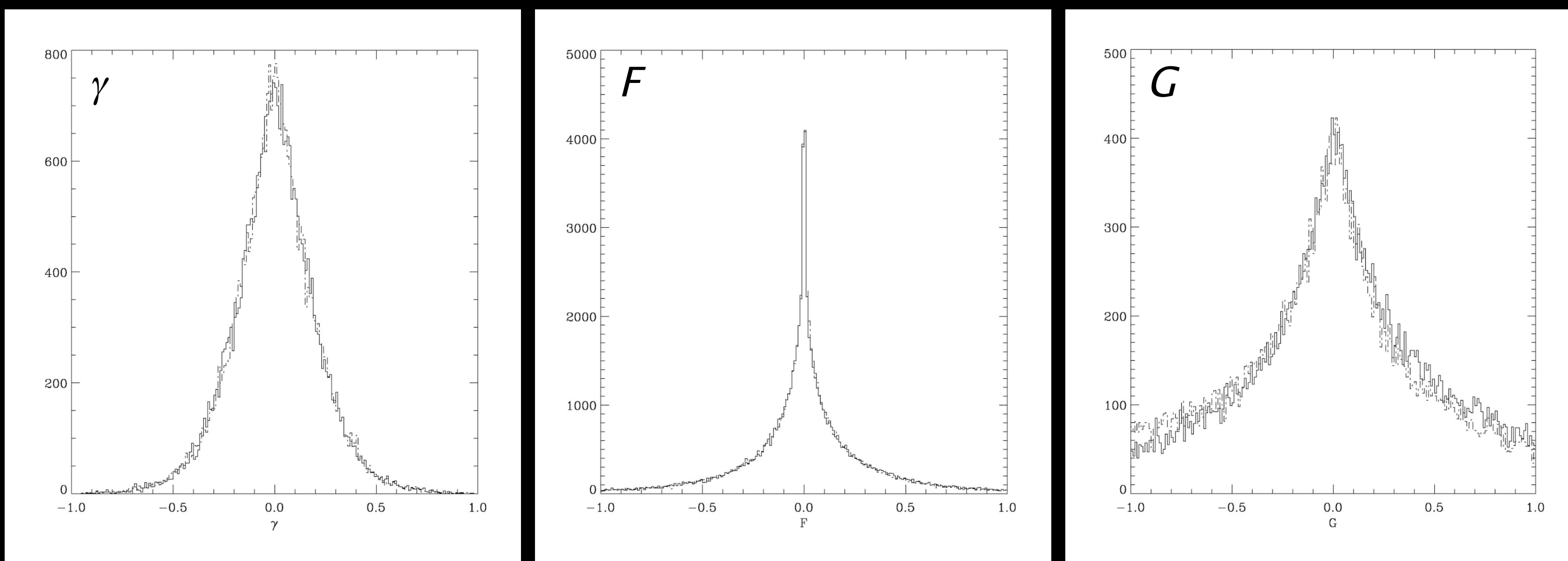


# Flexion noise properties

Bacon, Goldberg, Rowe & Taylor (2006)

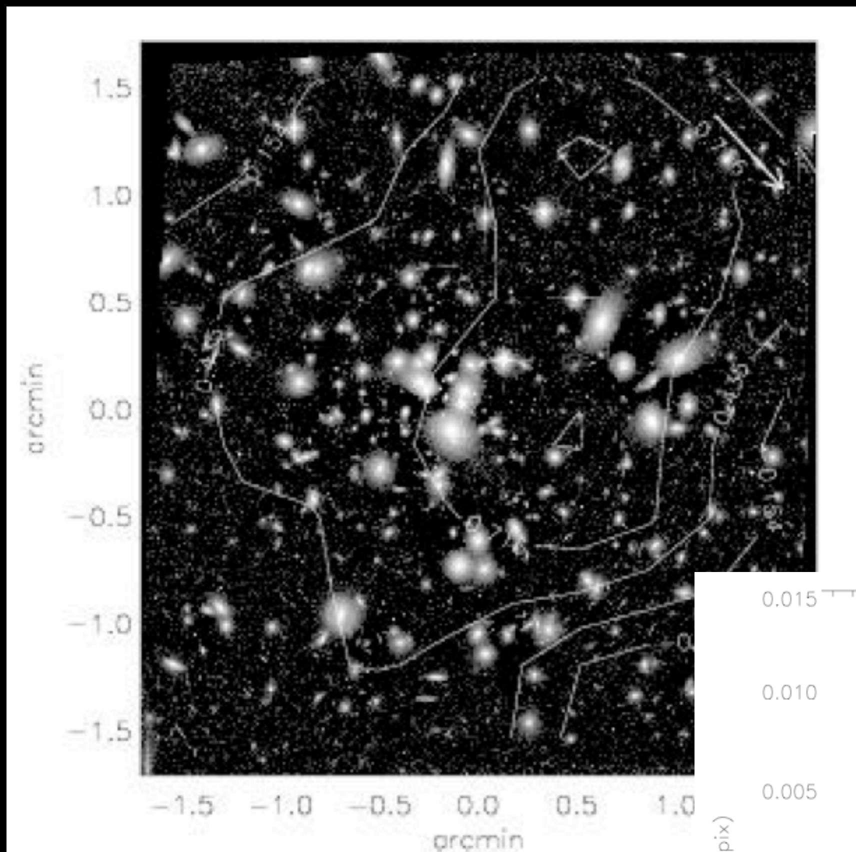
Flexion signal is smaller than shear; but intrinsic flexion is also smaller.
In the right regime (near to cluster cores/substructure), expect similar S/N.

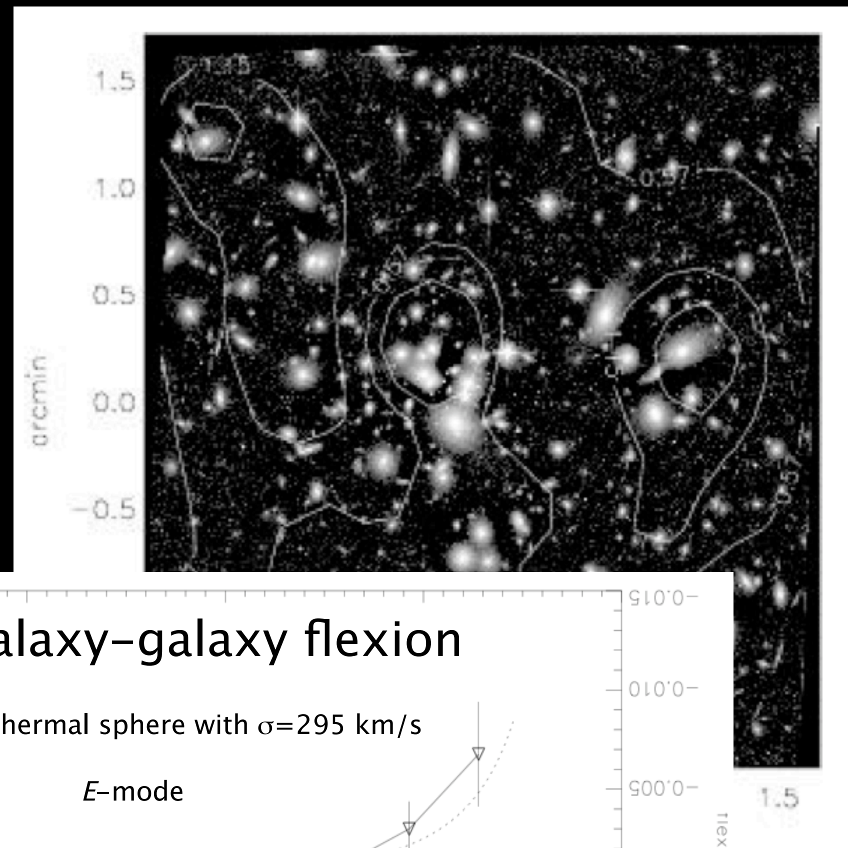
But, the observed flexion distribution is much less Gaussian than shears.
This makes life very difficult – particularly for *G*.



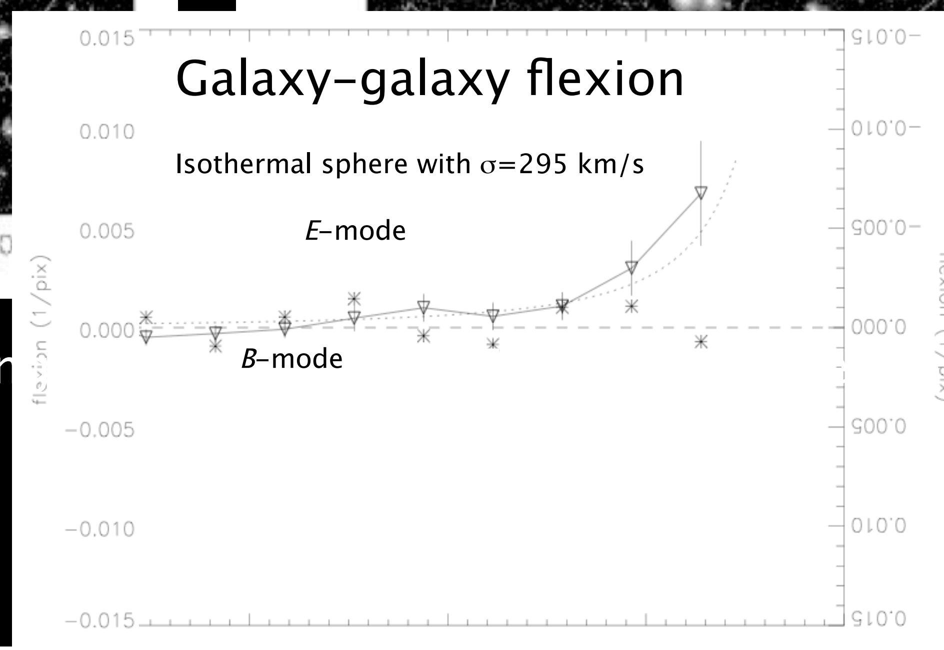
# Flexion measurements – mass reconstruction in A1689

Leonard et al. (2007)



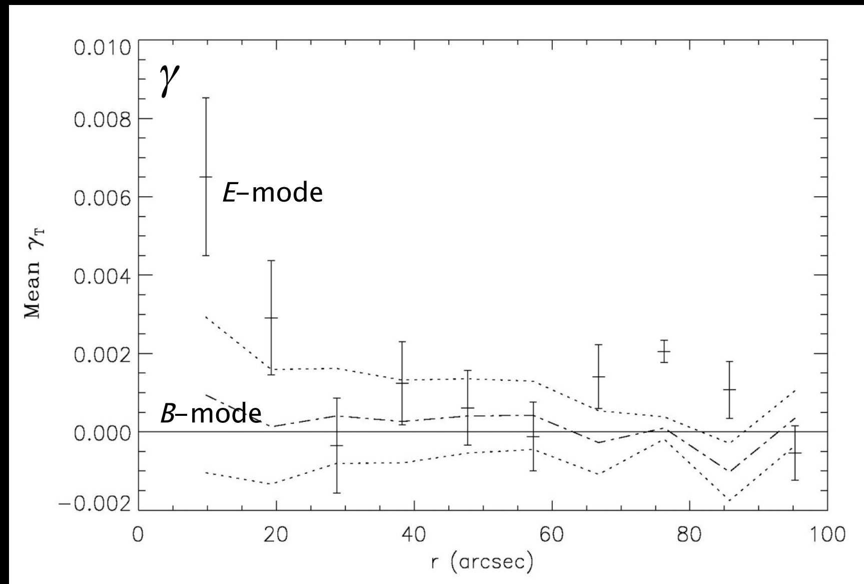


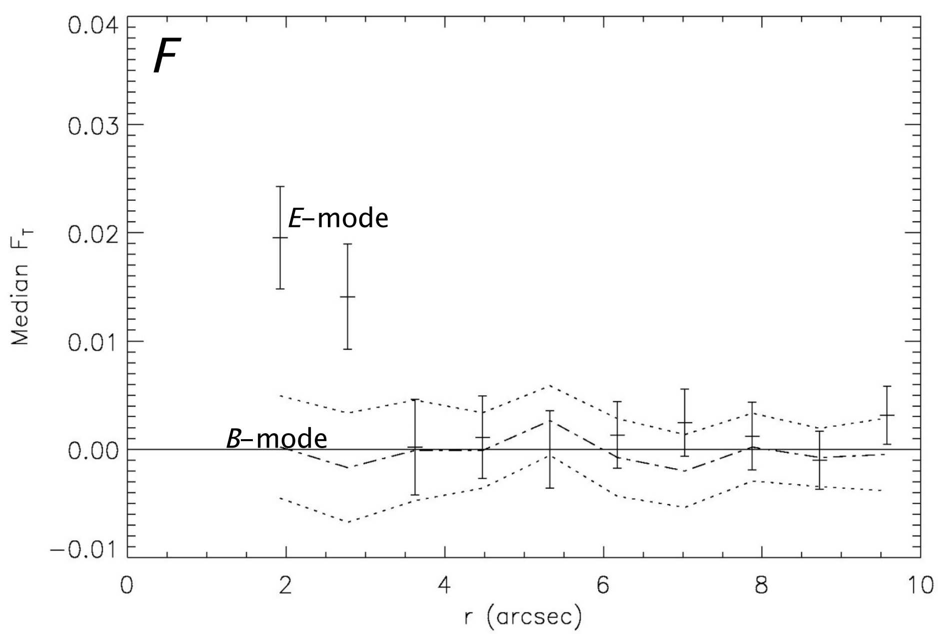
Weak + strong lensing
(non-parametric)

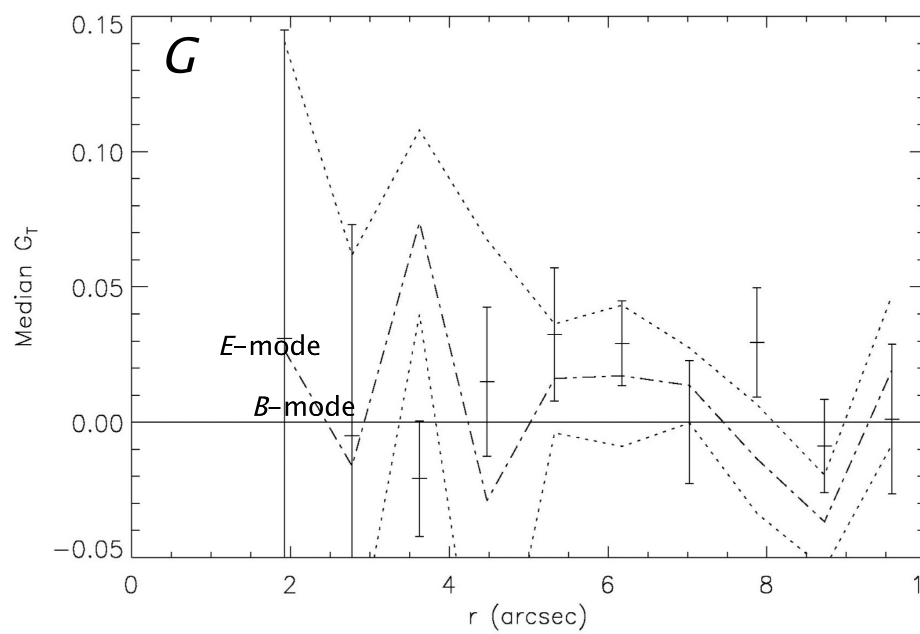


# Flexion measurements – galaxy-galaxy lensing in GEMS

Rowe et al. (in prep)

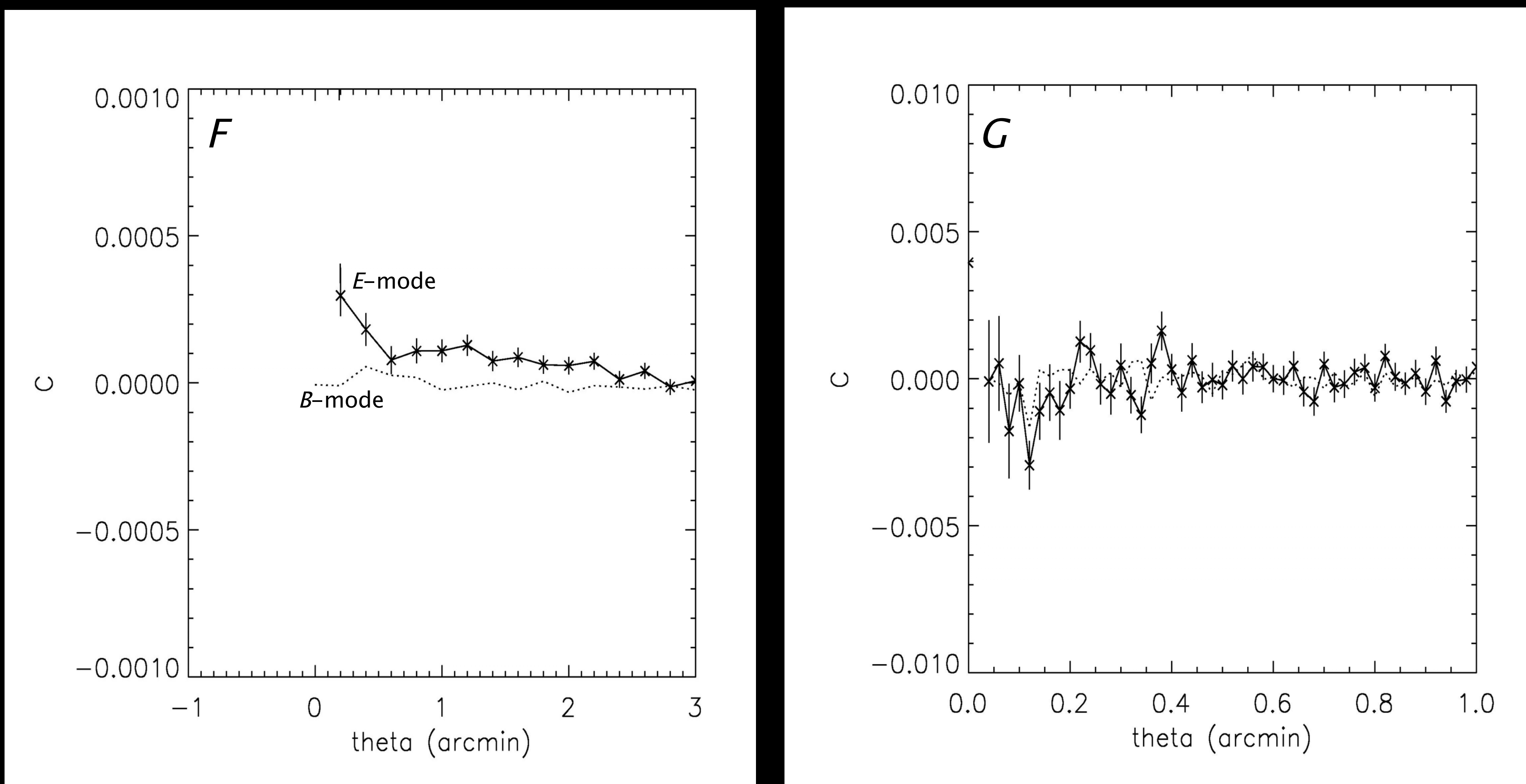


# Flexion measurements - cosmic flexion in GEMS

Rowe et al. (in prep)



# Conclusions

Changes in deflection angle across the width of a galaxy produces shear.
Changes in shear across the width of a galaxy produces flexion (arclets).

## Successes

- Flexion operates in a very interesting regime of cluster cores and substructure, bridging the gap between strong lensing and weak lensing.
- Independent from shear – you get flexion for free.
- Methods actually in operation, and first results are already available.

## Caveats

- Eventual results will depend on how wide that regime is…
- Images are crowded in the sweet spot.
- Realistically requires space-based imaging (to resolve galaxies “twice”).
- Noise distribution is horribly non-Gaussian.
- The centroid shift during F-flexion is awkward,
  yet this is the most easily measured component.

Fin

# Reference