High-accuracy shear measurement

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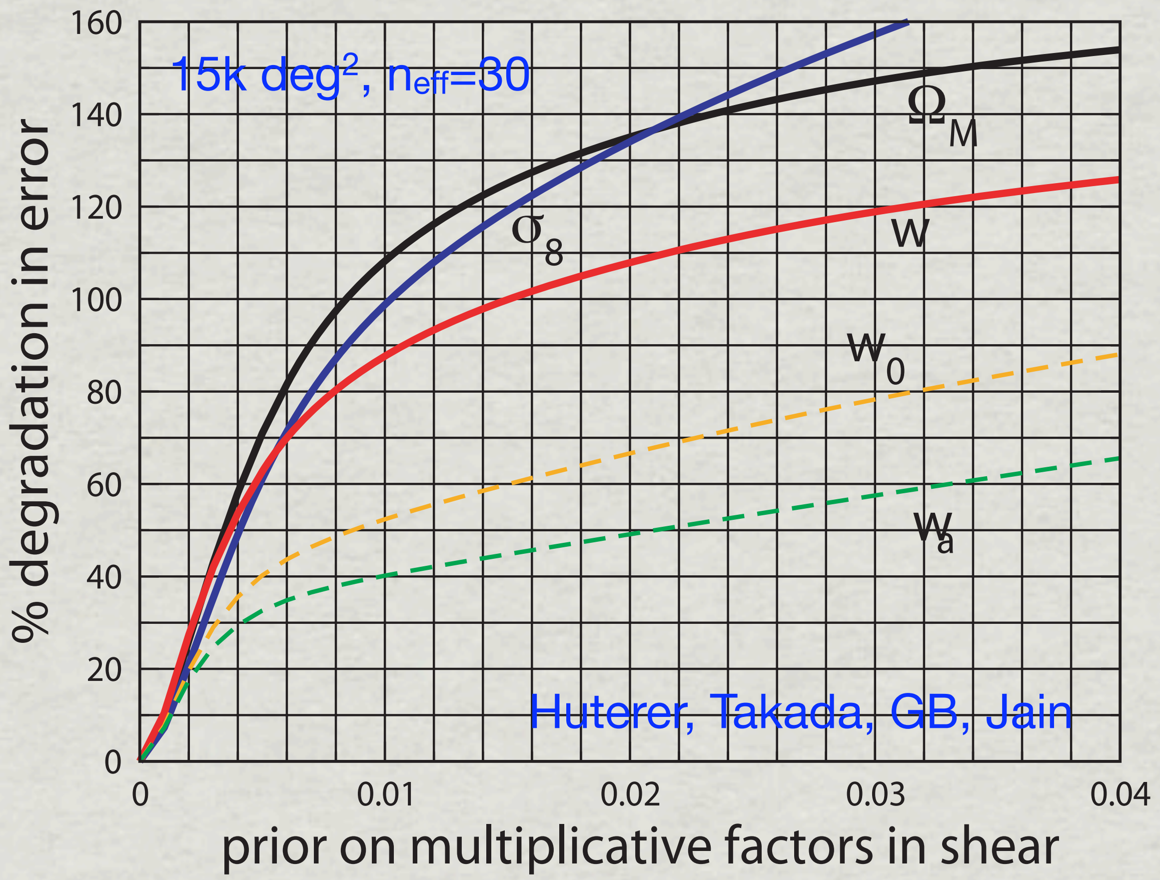
Why and how to bother

- The benefits of being obsessive
- Getting shear from shapes
- Modeling vs other forms of PSF correction
- Ambiguous galaxies and ellipticity gradients
- Results from the *FDNT* method
- Future issues*

**nap or read email until this section if you have read arXiv:1001.2333*

The benefits of being obsessive

- RMS multiplicative shear errors <1 part in 10^3 to avoid degradation.
- Self-calibration possible in principle
- But RMS errors of 1 part in 100 cut effective survey size in half!



- This is the *full* error budget for shear errors: includes PSF mis-estimation, CTI, bandwidth effects.
- So the algorithmic errors should be few parts in 10^4 of the cosmic shear.
- Note that m=0.01 on RMS shear 0.02 is Q=2500 on GREAT08 scale. We want m<0.001, Q>10^5!!
- Best without stacking or re-calibration from simulation: Q~100.

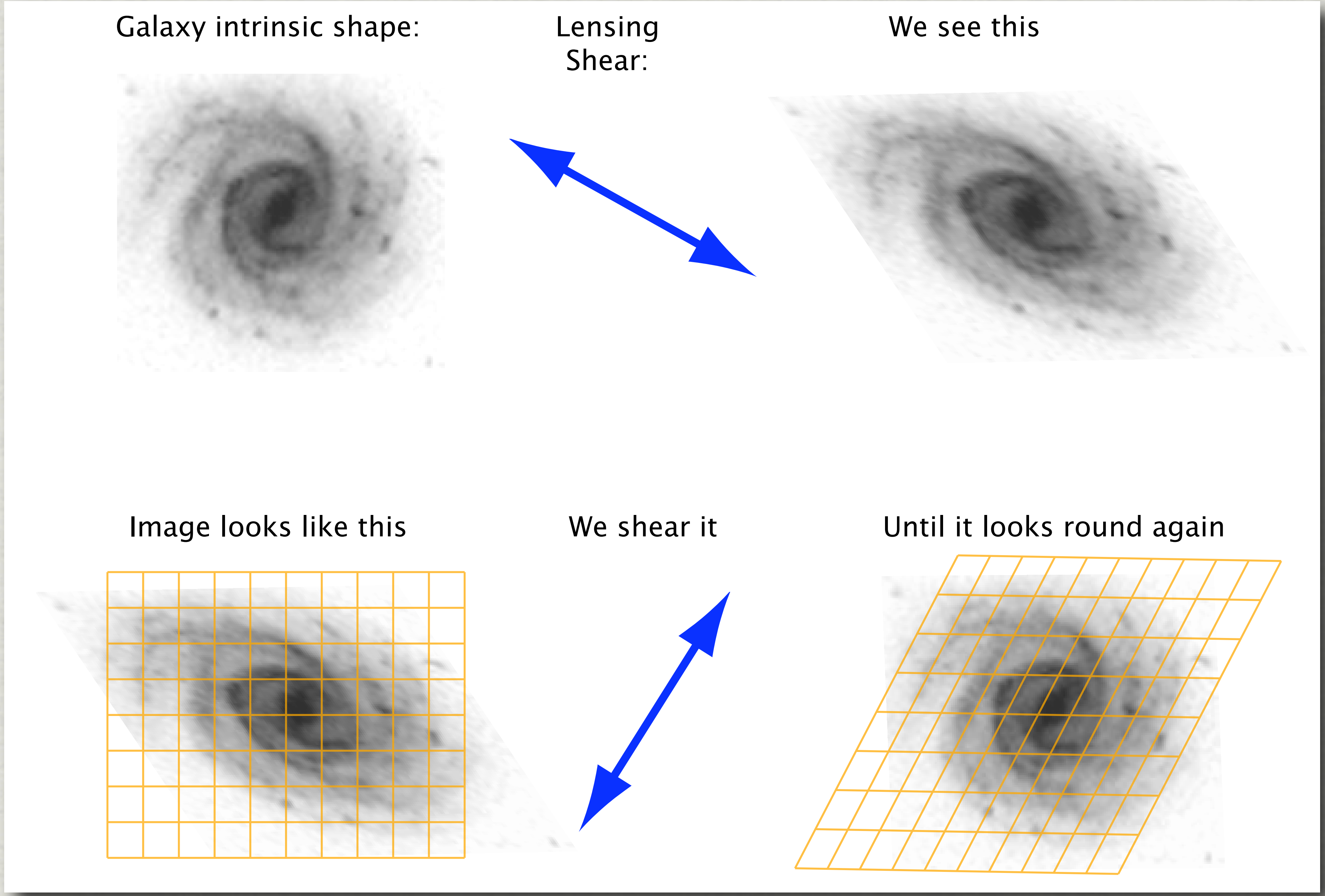
Getting shear from shapes

- We like to think $e_{obs}=e_{int} + \gamma$.
- *There is no way to express ellipticity or shear such that this holds, except for e→ 0 and g→0!*

$$\langle e_{\rm obs}\rangle = \mathcal{R}_1\gamma + \mathcal{R}_3\gamma^3 + \ldots$$

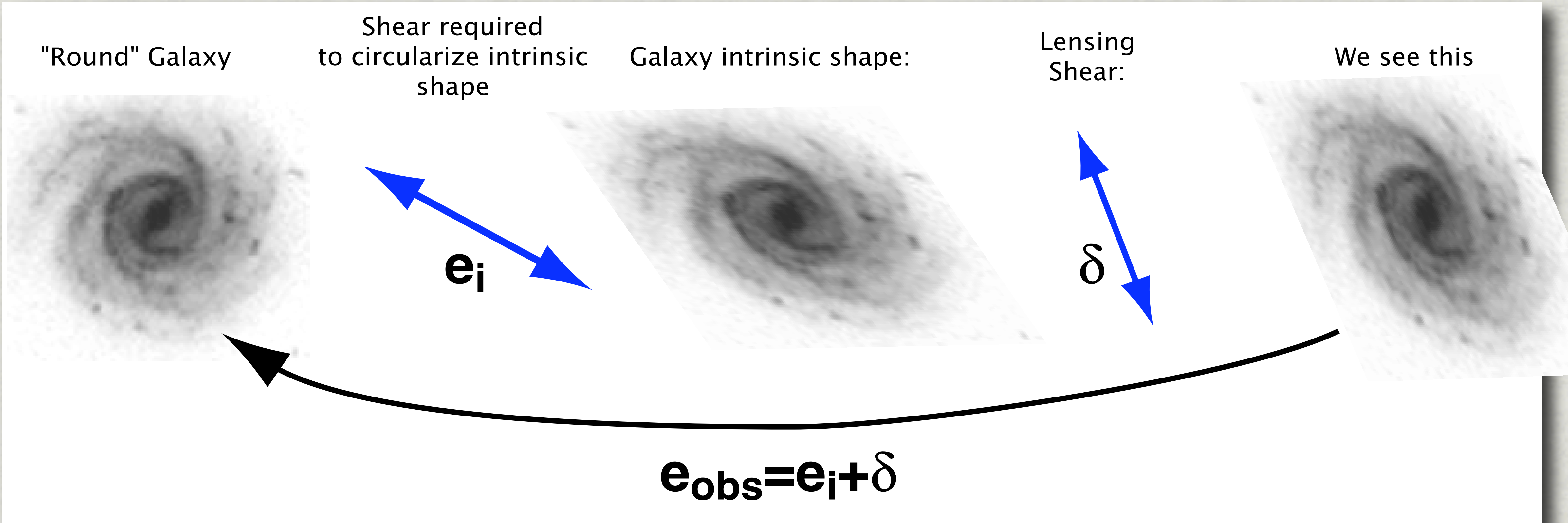
- Must include R_3 term for part in 1000 accuracy when γ~0.03.
- R_1 and R_3 **always** depend on the distribution of intrinsic shapes (except when stacking galaxies, when intrinsic shape can be assumed to be circular!)
- What definition of *e* makes the *R*'s most robust?

“Geometric” shapes



Applied shear to circularize is opposite of the lensing shear, independent of galaxy details

“Geometric” shapes



Applied shear to circularize is now (opposite of) the sum of intrinsic shape and applied shear.

- My favorite: define galaxy ellipticity via the transformation that restores a “round” galaxy.
- R_1 and R_3 become fully defined by rules for multiplying shear matrices.
- Gets the “right” answer for ellipticity of truly elliptical galaxies, but works for galaxies of any appearance.
- Can choose many definitions for a “round” galaxy - fitting an elliptical galaxy model to data is implicitly defining a roundness test.

Modeling vs PSF correction

- Advantages of fitting pixel data with model:
  - Obvious means of including PSF and instrumental effects to arbitrary accuracy.
  - Rigorous propagation of errors, even with varying pixel error levels
  - Works for irregular pixelization.
  - Models often contain natural roundness tests
  - Robust to missing data* (cosmic rays, finite aperture, high frequencies killed by PSF)
  - Robust to aliasing*

* *if the remaining data fully constrain the model!*

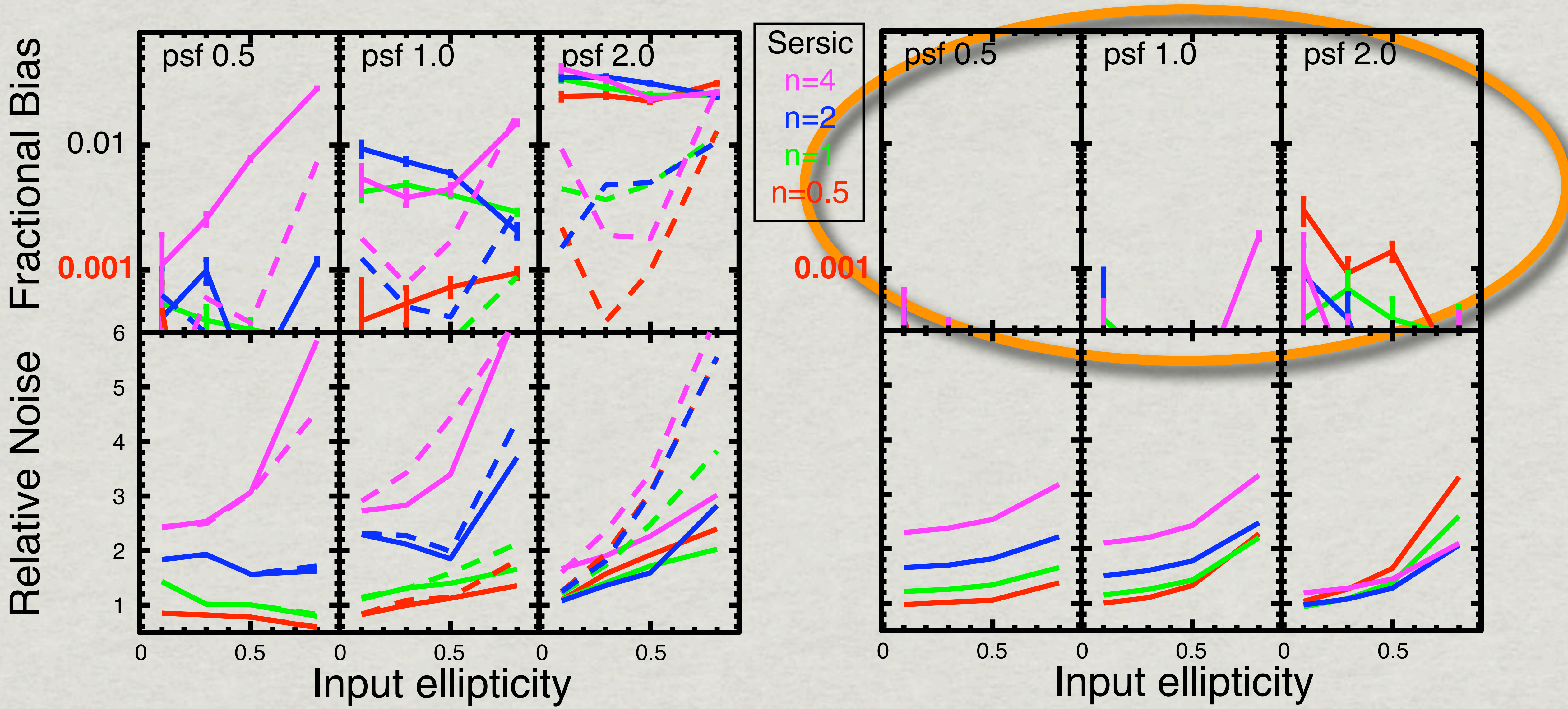
Modeling vs PSF correction

- Disadvantages of fitting pixel data with model:
  - Fills in missing data* (cosmic rays, finite aperture, high frequencies killed by PSF)
  - Breaks aliasing*
  - Very difficult to find a model that is complete over the universe of galaxies with small number of parameters
  - Roundness tests from model fits are easily biased if there is missing data that has been “filled in” by interpolating/extrapolating with an incorrect model! *(“underfitting bias”)*

Never trust a galaxy

- My current favorite: no models! *"Fourier Domain Null Testing" (FDNT):*
  - Move observations directly into Fourier domain
  - PSF correction is exact and simple.
  - "Roundness test" is quadrupole moment in Fourier space
  - Choose quadrupole radial weight to avoid regions of *k*-space that have been destroyed by PSF (or by finite windows) - only use what you can measure!
  - Use models only to fill in missing pixels or help propagate inhomogeneous errors.

FDNT Results (1)



Nakajima & Bernstein:

Elliptical Gauss-Laguerre fitting. Notice >0.01 errors for n=4 Sersic or high ellipticity.

FDNT:

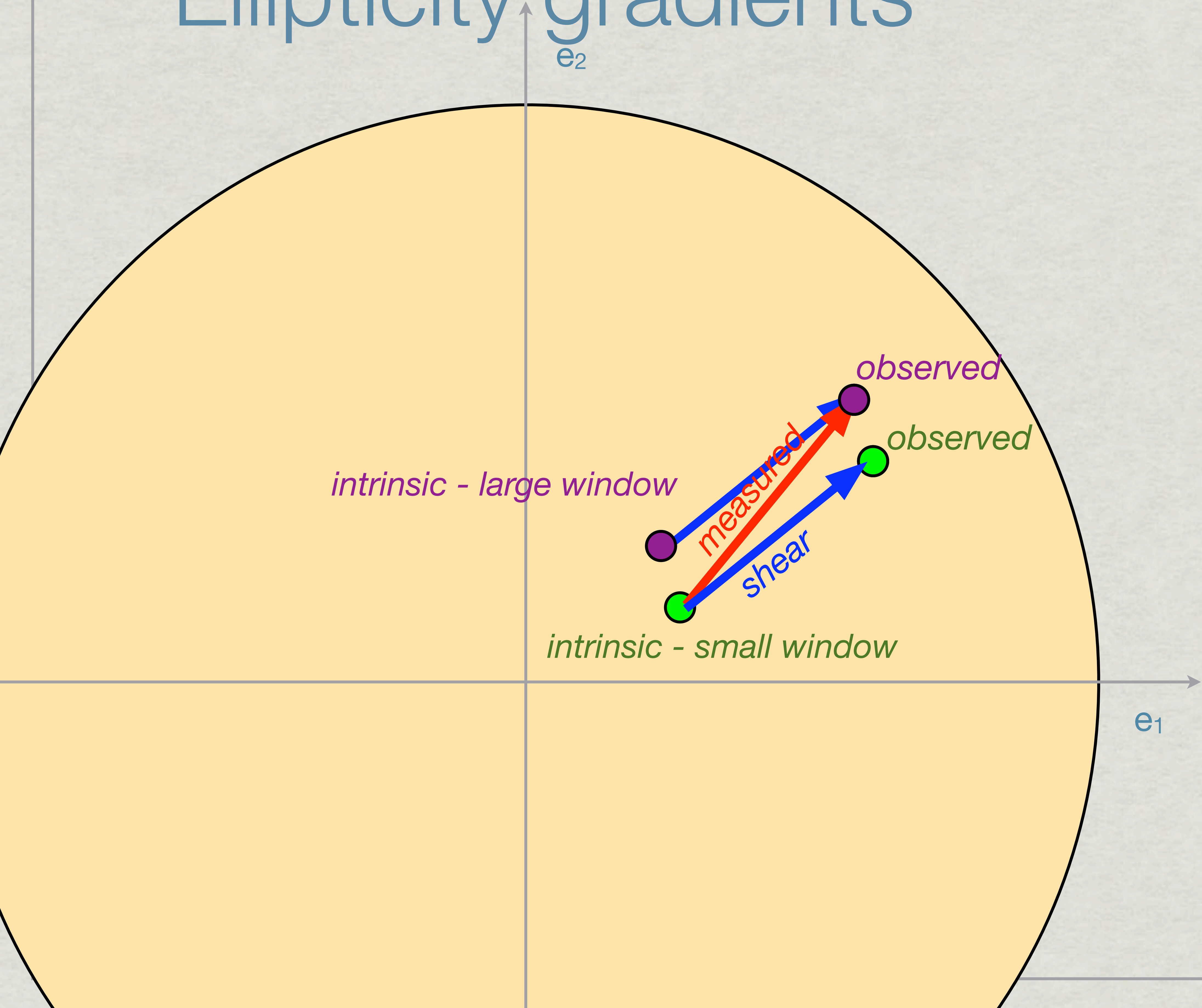
Multiplicative errors below 0.001, even for high Sersic indices, poor resolution, high ellipticity!

These tests use pure elliptical Sersic galaxies convolved with elliptical Gaussian PSF.

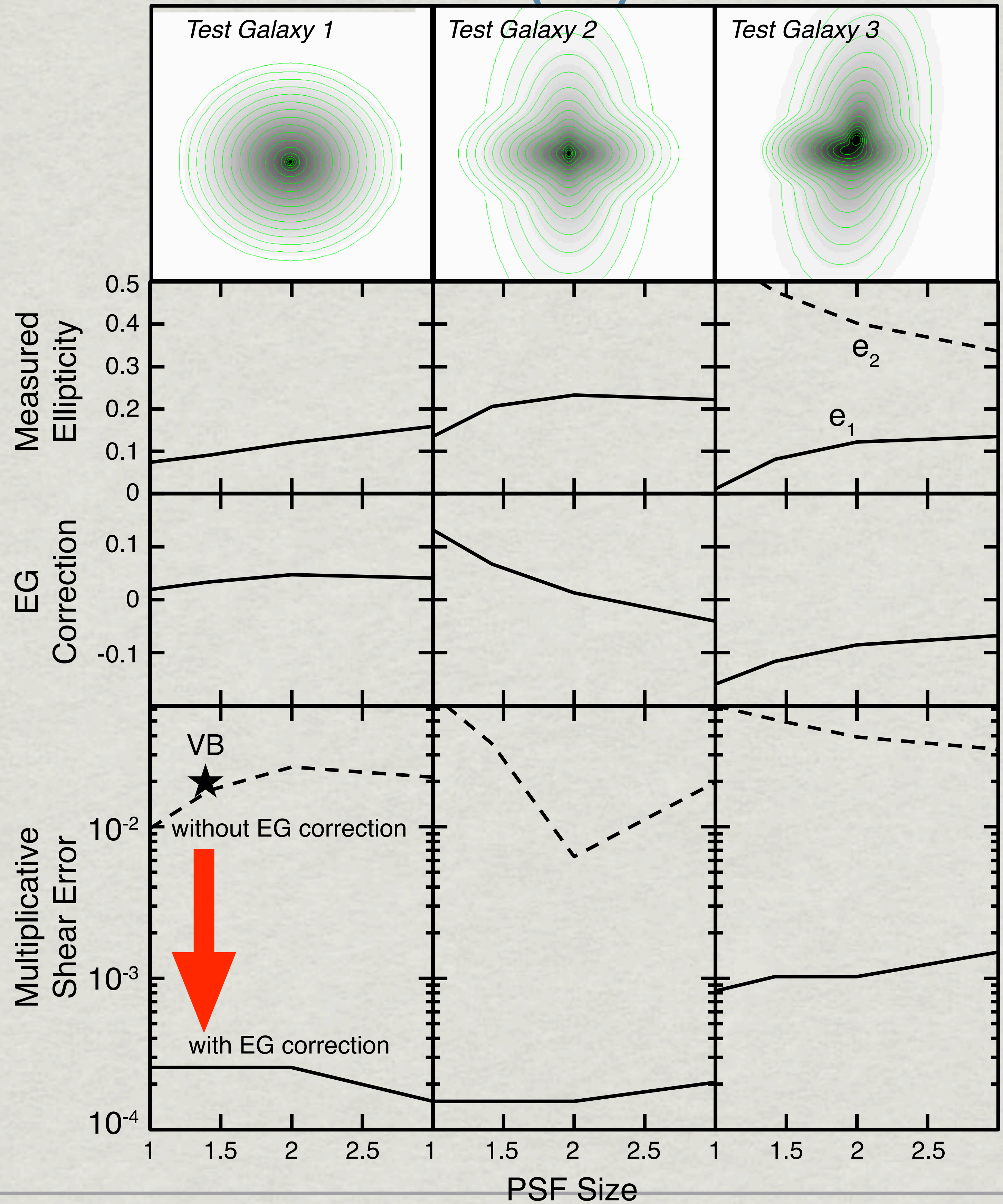
Ellipticity gradients

- All ellipticity measurements place a window or weight on the galaxy to keep noise finite.
- Do you know what your window is?
- If a sheared galaxy gets a different window than an unsheared one, you have a problem.

Ellipticity gradients



FDNT Results (2)



FDNT Results: GREAT08

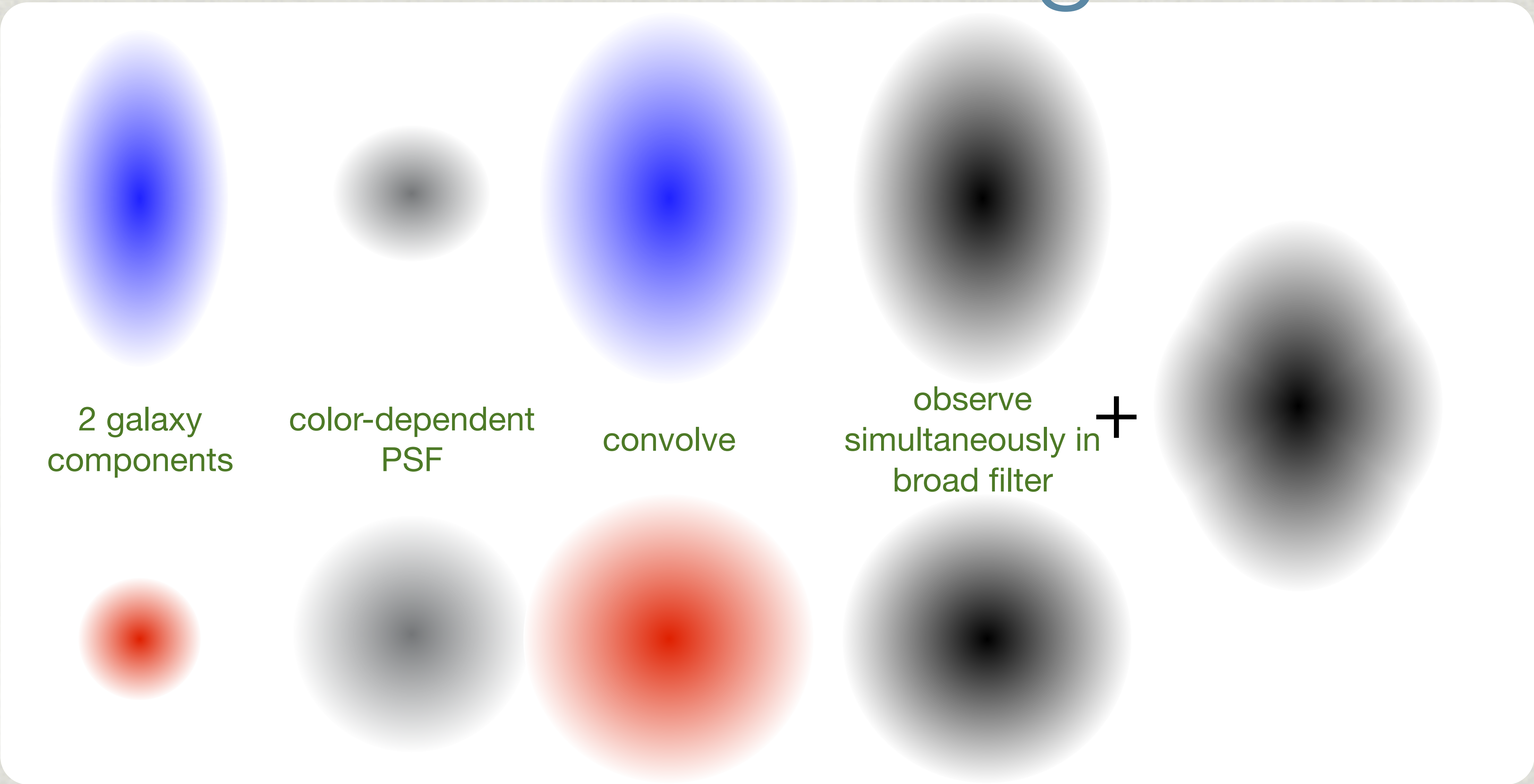
- Low-noise blind only
- Require images with larger postage stamps than GREAT08 - provided by Donnacha Kirk & Sree Balan, thank you.
- Use exact Moffat PSF - N=20 Gauss-Laguerre model leads to few parts per 1000 sys. error!
- One shear value revealed, 14 analyzed blind.
- Q=2997, within 20% of value expected from noise in the input images.

Future issues

- Easily extended to multiple exposures from multiple filters - no need to assume that shape is the same in all filters.
- Think about making windows compact in real space.
- Extend to S/N=10-20 regime. Biases will arise and *R*'s get messy.
  - Amenable to Bayesian calibration *a la* Miller *et al.*, ***if***
  - Noise-induced biases are robust to details of galaxy appearances, ***or***
  - can achieve high S/N on a small fraction of survey area to calibrate shear biases in each photo-z bin.

IN PROGRESS

Future issue: color gradients



- ***Deconvolution is ambiguous without knowing whether each photon was blue or red!***
- Not just issue for FDNT!
- Easily percent-level.
- Essential to obtain some info on color gradients.

Summary

- Controlling window function is key to part-per-thousand shear measurements.
- FDNT is a simple method to obtain geometric shapes, no assumptions on galaxy profiles, correct for ellipticity gradients.
- Pegs the meter on GREAT08 Low-Noise tests and first demonstration of <1 part in 10^3 shear measures without training or recalibration.
- Nonlinear shear response must be included!
- Implementation on higher-noise, real data in progress. Issues will surely arise!
- Color gradients are a fundamental problem for shear measurement from broadband imaging.