National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

How to calibrate your shear measurements

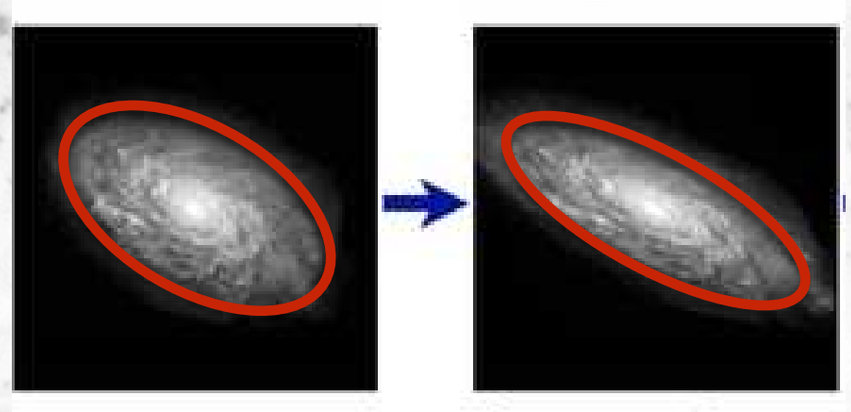
Eric Huff (JPL)

Rachel Mandelbaum (CMU), Erin Sheldon (BNL)

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

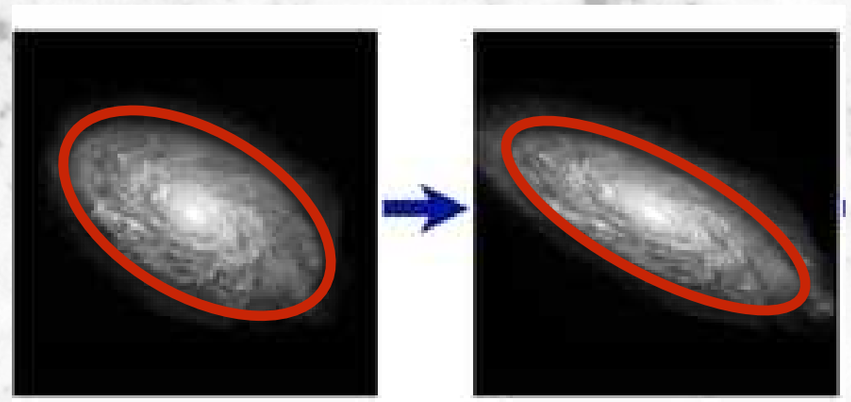
How do we get *g* from a galaxy image?



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

How do we get g from a galaxy image?



ellipticity suggests 2nd moments

$$Q_{ij\ldots k} = \int I(\boldsymbol{\theta})\theta_i\theta_j\ldots\theta_k d^2\theta$$

$$\chi = \frac{(Q_{11} - Q_{22}) + 2iQ_{12}}{Q_{11} + Q_{22}}$$

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Kaiser, Squires, Broadhurst (1995)

1. **Compute second moments.**
2. **Calculate the responses to shear (P_g) and PSF ellipticity (P^{sm}).**
3. **Correct for PSF ellipticity (e^*).**

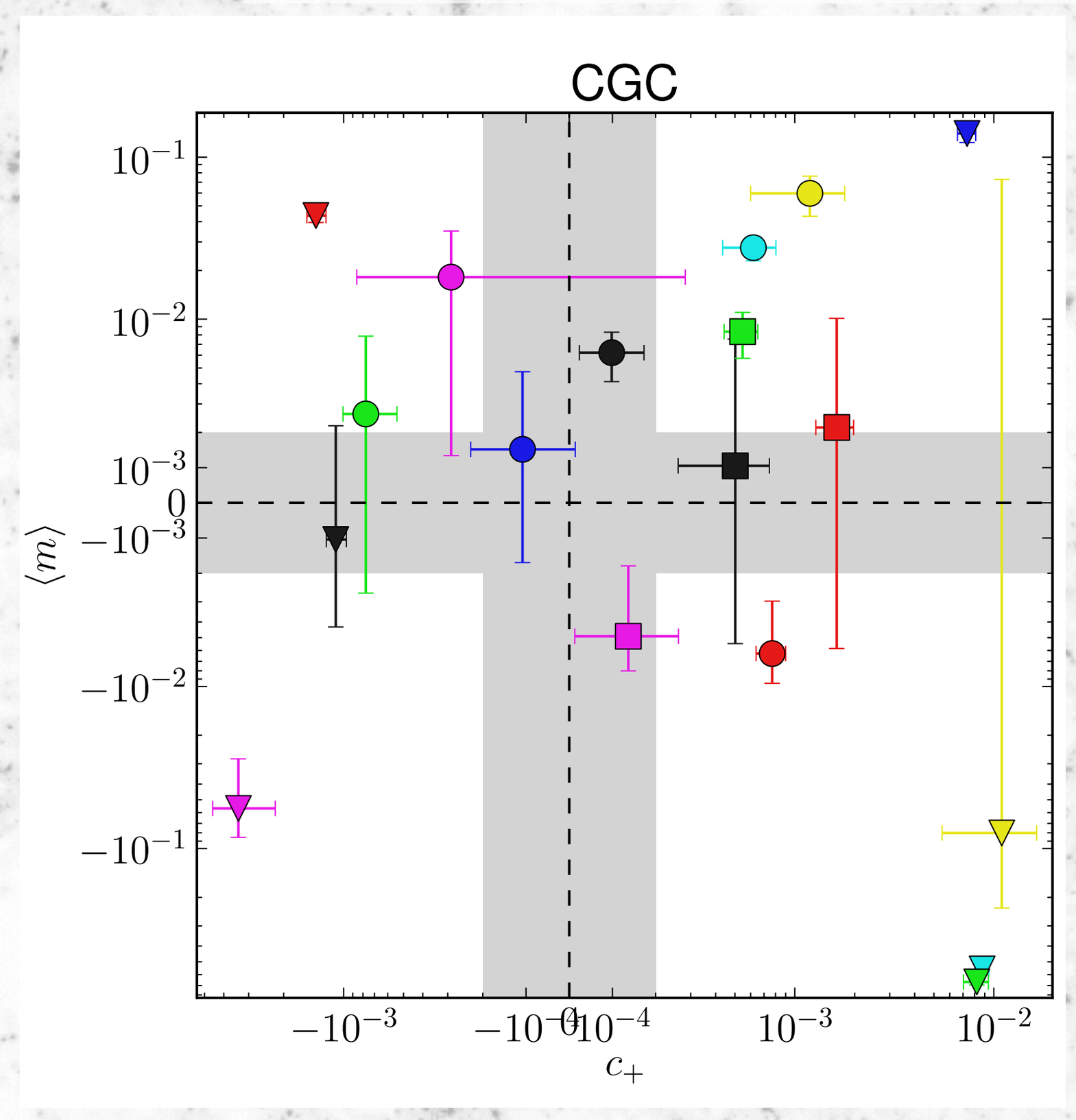
$$g = P_g^{-1}\left(e^{\rm obs} - \frac{P^{\rm sm}}{P^{\rm sm*}}e^*\right)$$

This doesn't seem that bad.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Broad dissensus in blind community challenges

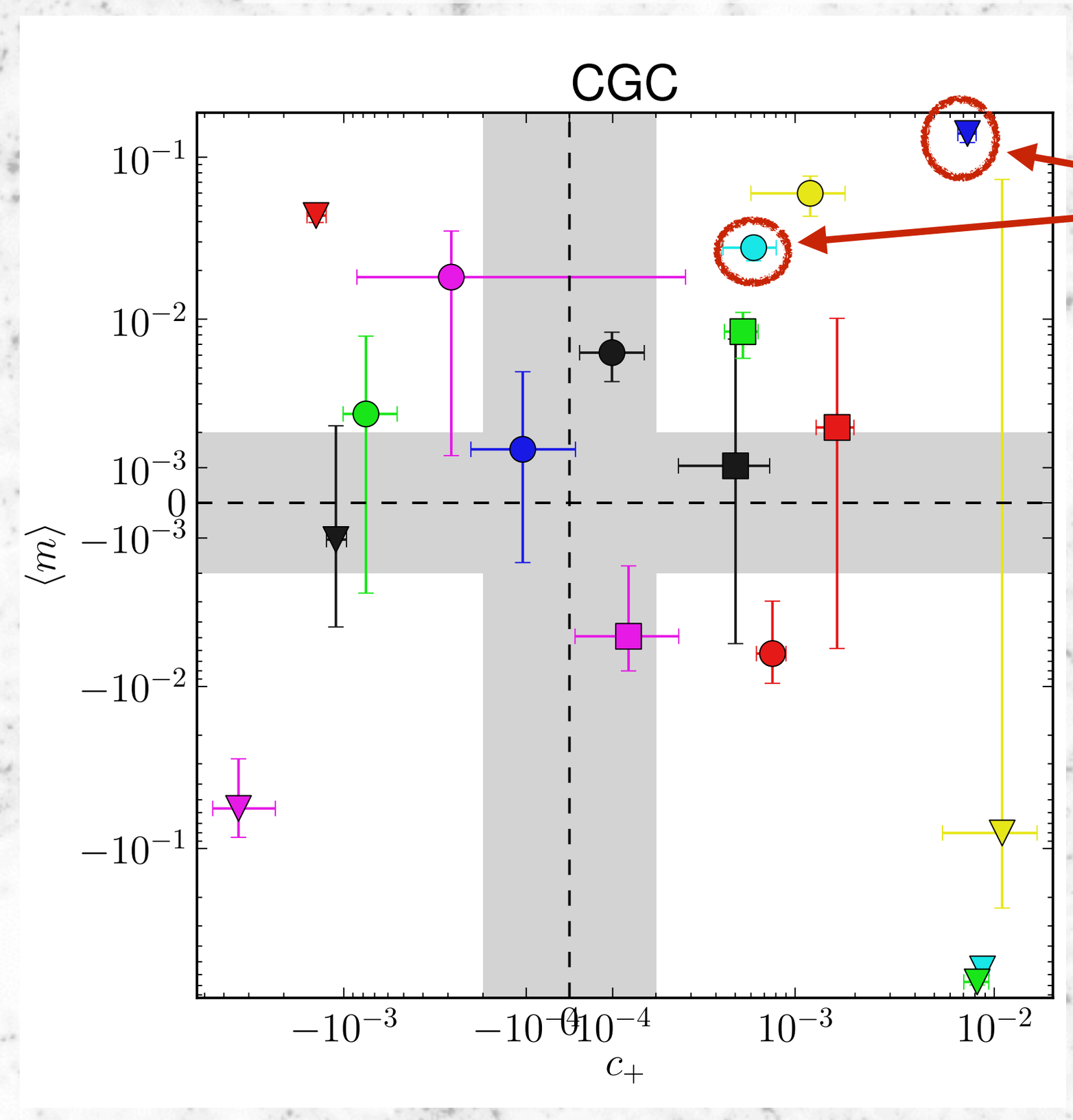


Mandelbaum et al. 2014

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Broad dissensus in blind community challenges

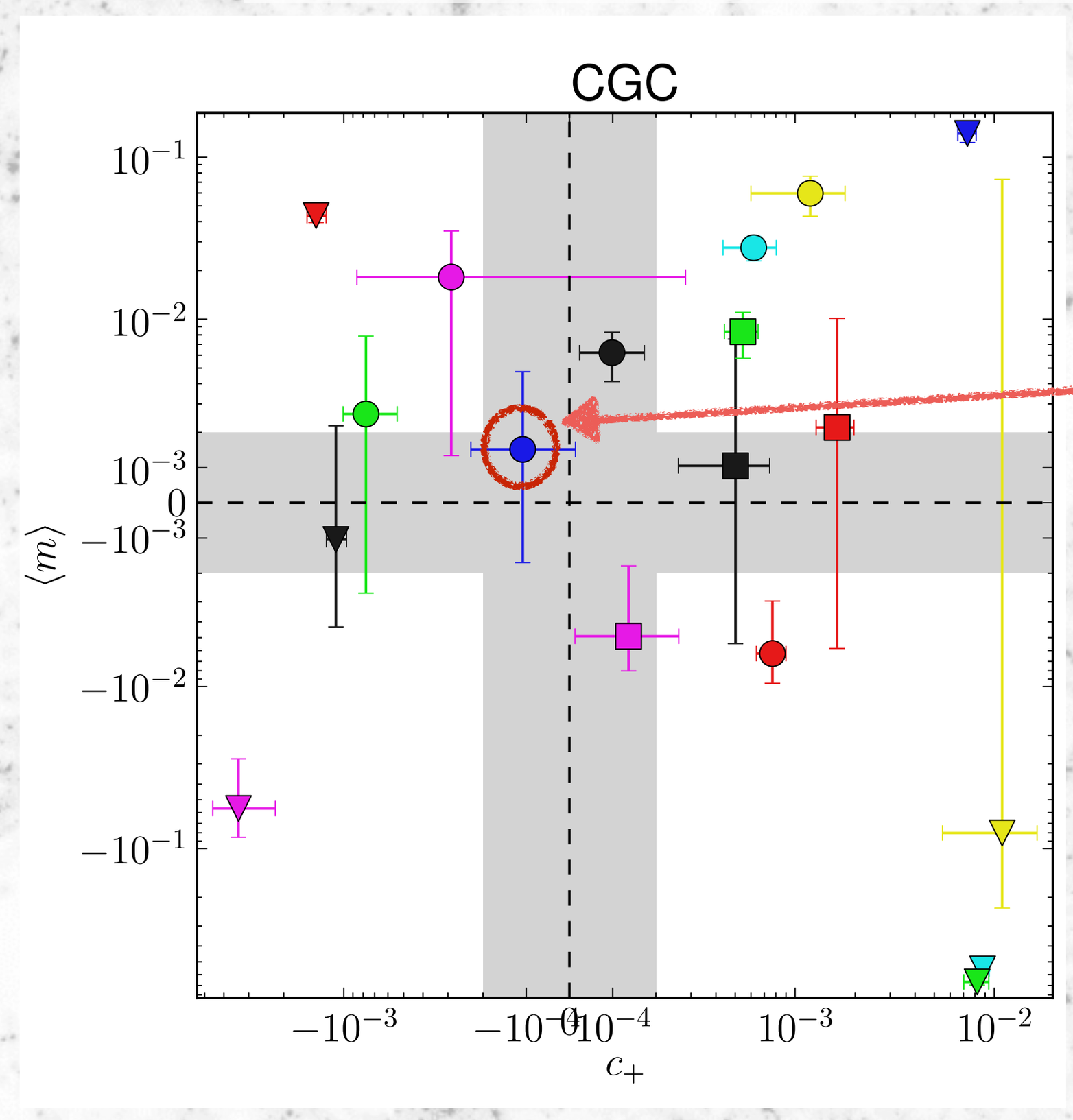


KSB implementations

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Broad dissensus in blind community challenges



Simulation (of a simulation)

National Aeronautics and
Space Administration

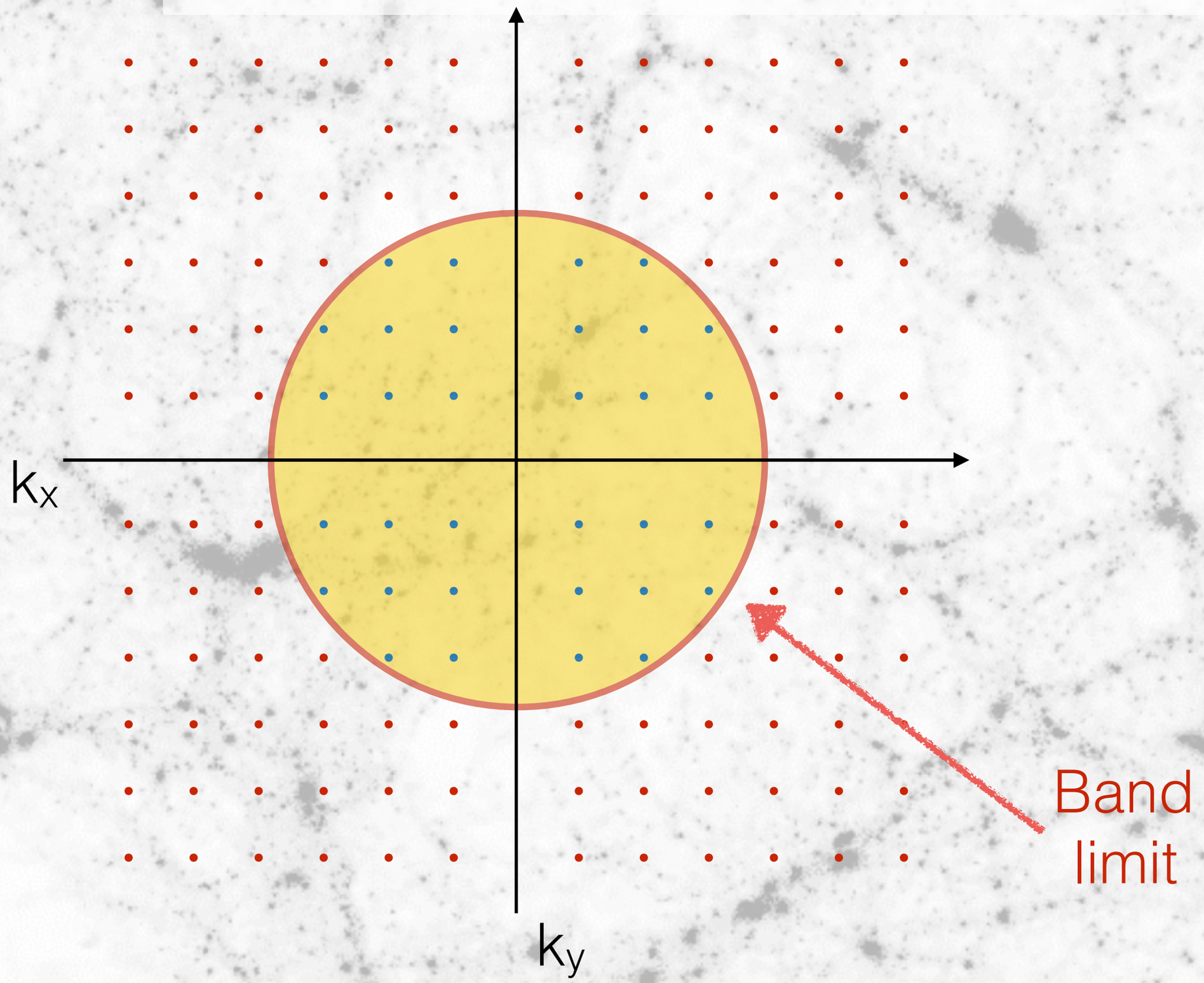
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Why is this hard?

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

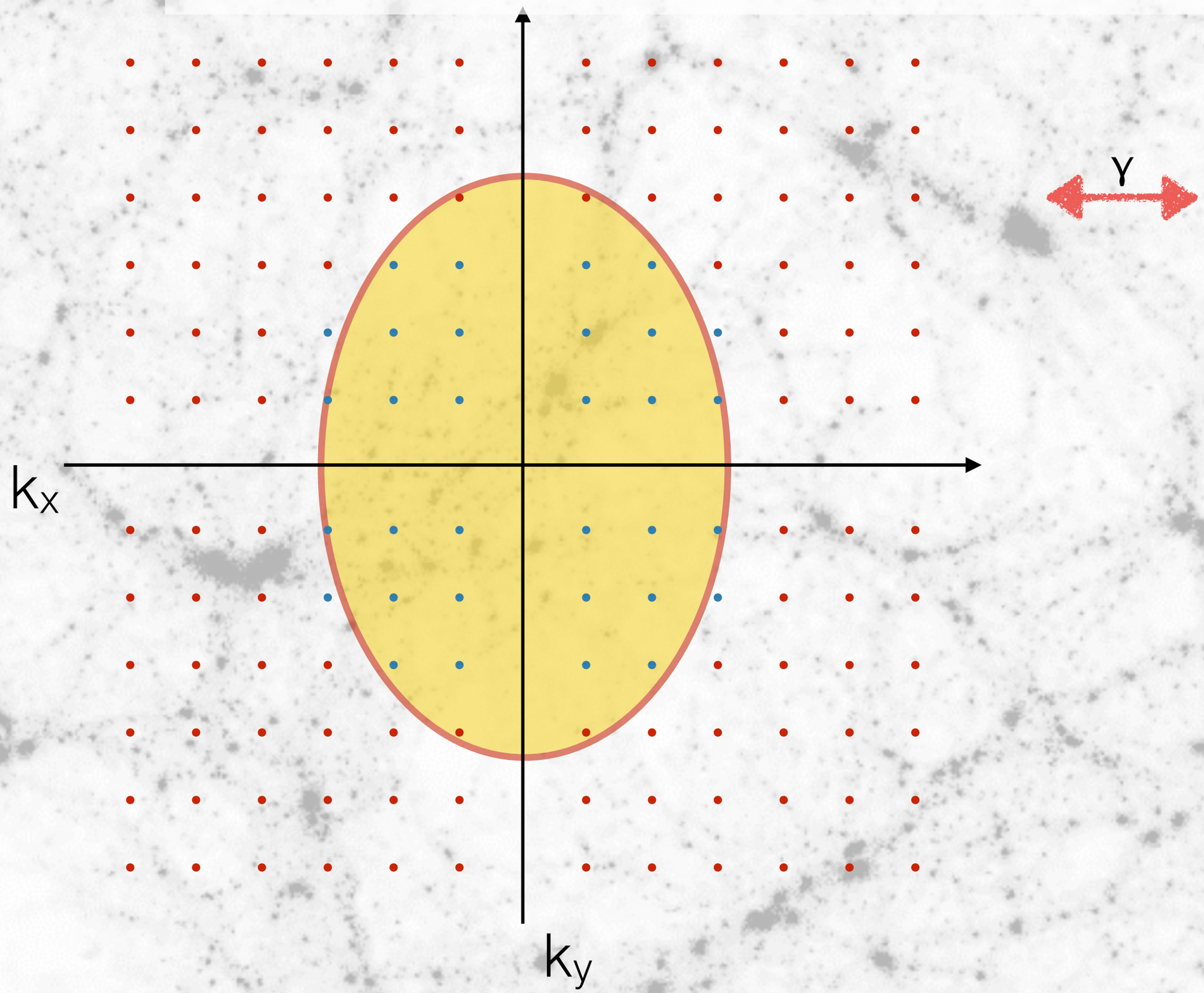
the full shear response depends on unresolved modes



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

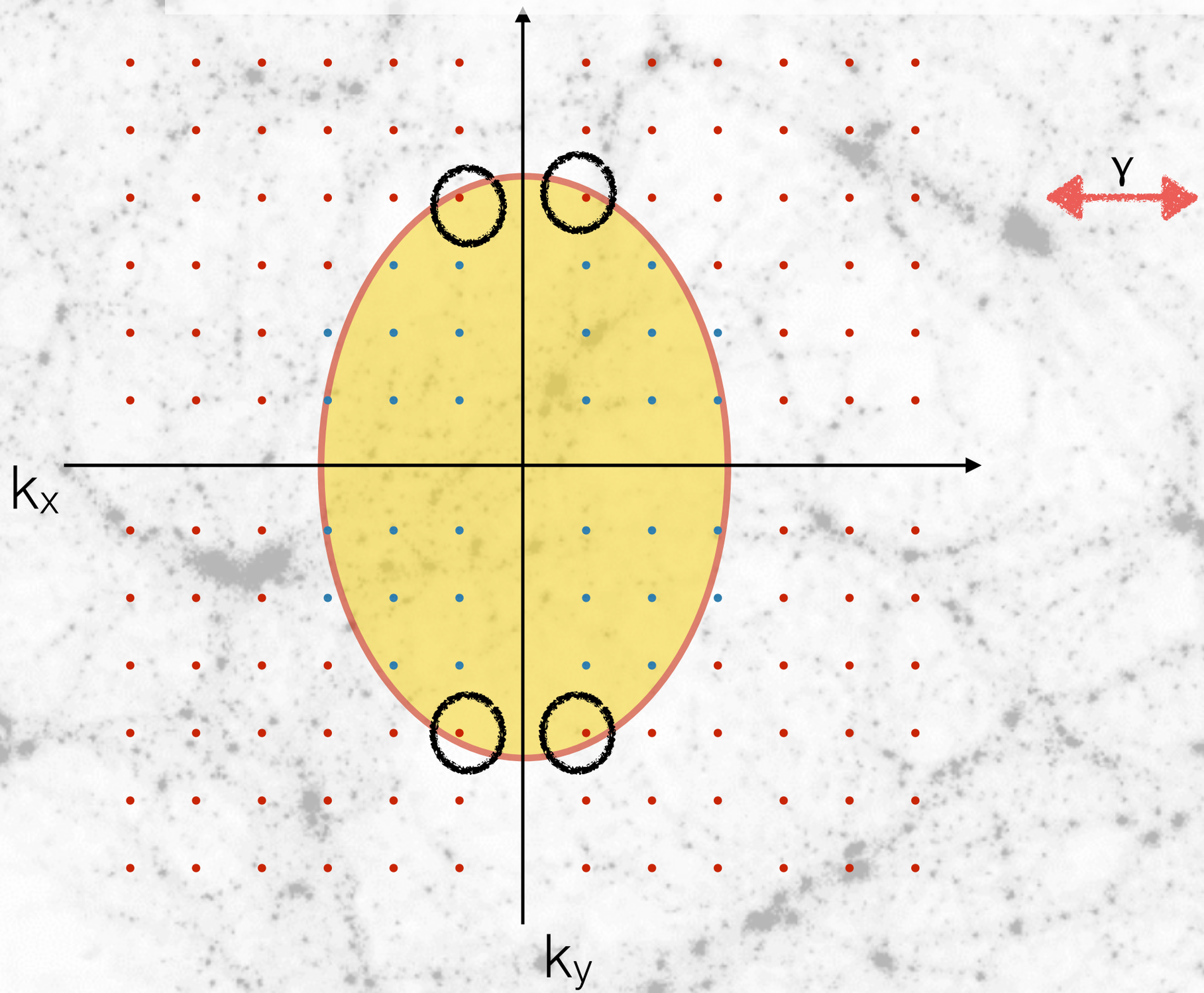
the full shear response depends on unresolved modes



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

the full shear response depends on unresolved modes



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Selection biases matter

$$\langle \boldsymbol{R} \rangle = \int \left. \frac{\partial S(\boldsymbol{e}) P(\boldsymbol{e}) \boldsymbol{e}}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} d\boldsymbol{e}$$

$$= \int \left[S(\boldsymbol{e}) \left. \frac{\partial P(\boldsymbol{e}) \boldsymbol{e}}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} + P(\boldsymbol{e}) \boldsymbol{e} \left. \frac{\partial S(\boldsymbol{e})}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} \right] d\boldsymbol{e}$$

Shear selection biases:
calibration depends on sub-threshold galaxy population

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

The measurement process is complicated.

but the images are simple
(linear)

This suggests the following procedure:

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Construct counterfactual images

$$I'(\mathbf{x}|\mathbf{g}) = P * (\hat{\mathbf{s}}_{\mathbf{g}} G)$$

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Construct counterfactual images

$$I'(\mathbf{x}|\mathbf{g}) = P * (\hat{\mathbf{s}}_{\mathbf{g}} G)$$

$$I'(x|g) = \Gamma * \left[\hat{s}_g (P^{-1} * I)\right]$$

remove the PSF, shear, and add a new PSF

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Construct counterfactual images

$$I'(\mathbf{x}|\mathbf{g}) = P * (\hat{\mathbf{s}}_{\mathbf{g}} G)$$

$$I'(x|g) = \Gamma * \left[\hat{s}_g (P^{-1} * I)\right]$$

we get to choose our final PSF

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Construct counterfactual images

$$I'(\mathbf{x}|\mathbf{g}) = P * (\hat{\mathbf{s}}_{\mathbf{g}} G)$$

$$I'(x|g) = \Gamma * \left[\hat{s}_g (P^{-1} * I)\right]$$

$$e^+ = \hat{E}\left\{\, I'(\boldsymbol{x}|\boldsymbol{g}^+)\right\}$$

any ~linear measurement algorithm

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Construct counterfactual images

$$I'(\mathbf{x}|\mathbf{g}) = P * (\hat{\mathbf{s}}_{\mathbf{g}} G)$$

$$I'(x|g) = \Gamma * \left[\hat{s}_g (P^{-1} * I)\right]$$

$$e^+ = \hat{E}\left\{ I'(\boldsymbol{x}|\boldsymbol{g}^+)\right\}$$

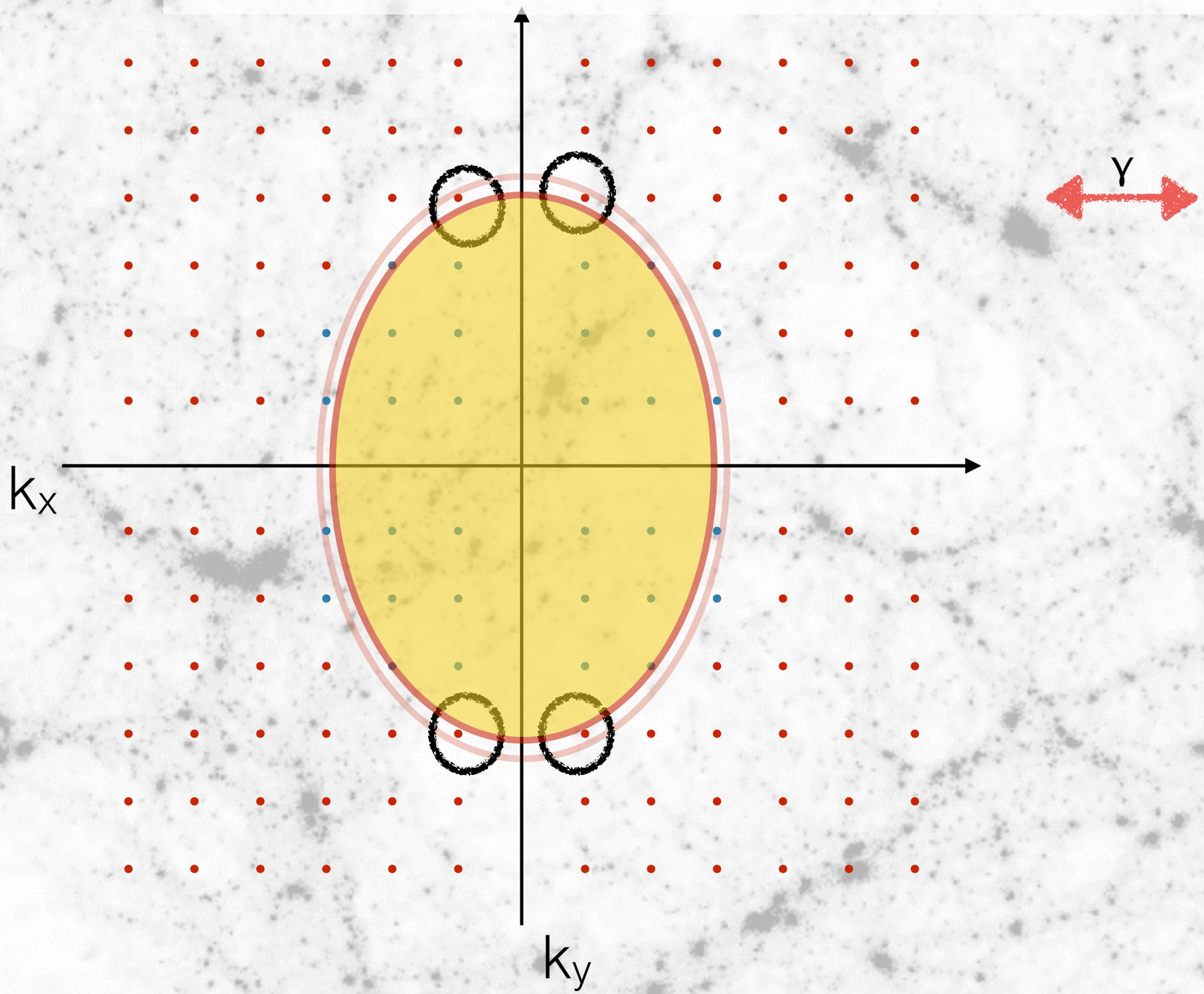
$$1 + m = \frac{e^+ - e^-}{2\Delta g}$$

repeated measurement on counterfactuals

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

smear the data further to hide the band-limited modes



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Correcting for selection effects:

$$\langle \boldsymbol{R} \rangle = \int \left. \frac{\partial S(\boldsymbol{e}) P(\boldsymbol{e}) \boldsymbol{e}}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} d\boldsymbol{e}$$

$$= \int \left[S(\boldsymbol{e}) \left. \frac{\partial P(\boldsymbol{e}) \boldsymbol{e}}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} + P(\boldsymbol{e}) \boldsymbol{e} \left. \frac{\partial S(\boldsymbol{e})}{\partial \boldsymbol{\gamma}} \right|_{\gamma=0} \right] d\boldsymbol{e}$$

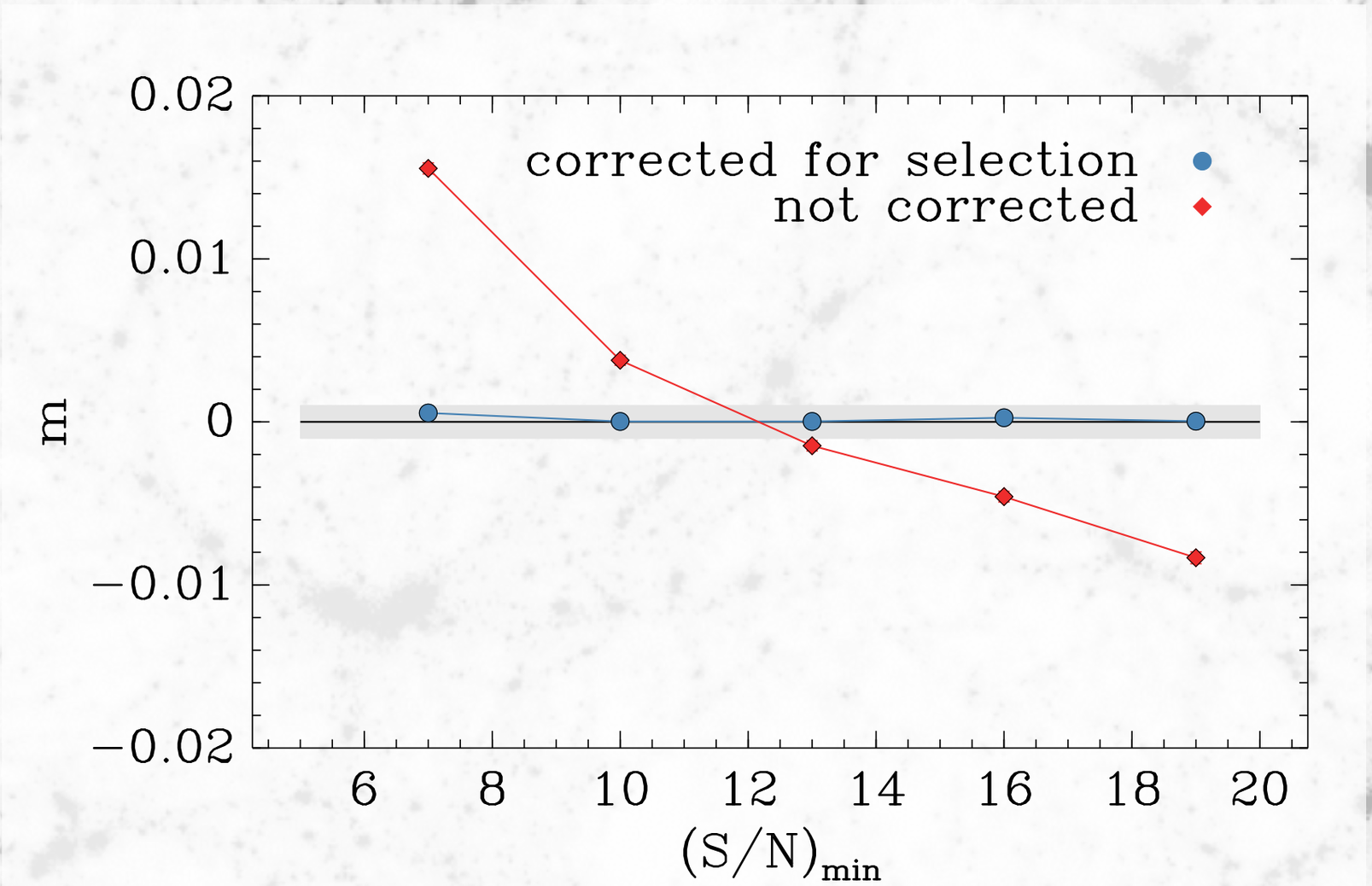
$$= \frac{\langle e_i^+ \rangle^S - \langle e_i^- \rangle^S}{\Delta \gamma_j} + \frac{\langle e_i \rangle^{S+} - \langle e_i \rangle^{S-}}{\Delta \gamma_j}$$

Apply a shear.
See how your measured shapes change.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Selection effects are large, but now effectively mitigated.



There is no evidence for any remaining calibration bias.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

This space intentionally left blank.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

There will be blending

Image courtesy of / stolen from
Peter Melchior

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

summary of blending effects:

1. **Reducing overall number density**

2. **Mixing shear across redshifts**

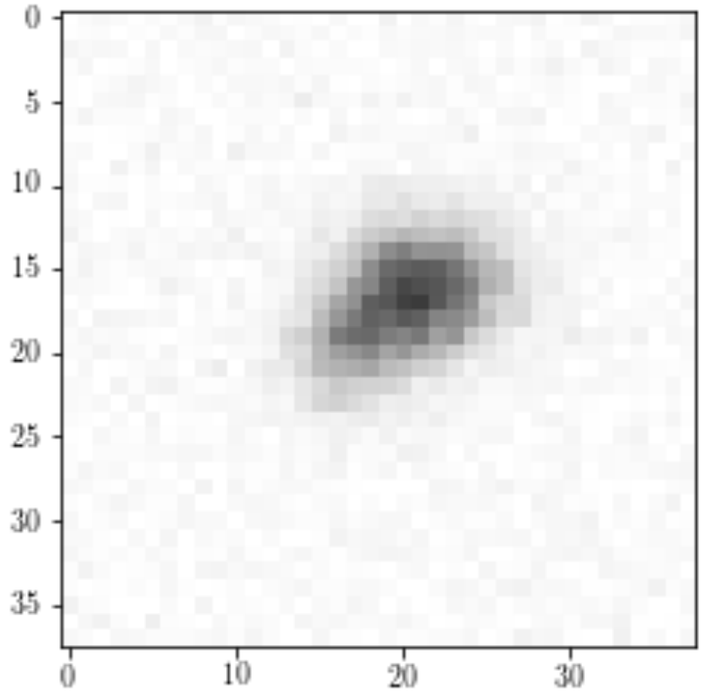
3. **Photo-z mis-estimation**

4. **Density-dependent selection**

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Consider the effects of blending on shear



Single blob, imperfectly deblended, 2 or more galaxies

$$R_1 = \frac{\partial e}{\partial \gamma_1} \qquad R_2 = \frac{\partial e}{\partial \gamma_2}$$

$$e_{\rm blob} = R_1\gamma_1 + R_2\gamma_2$$

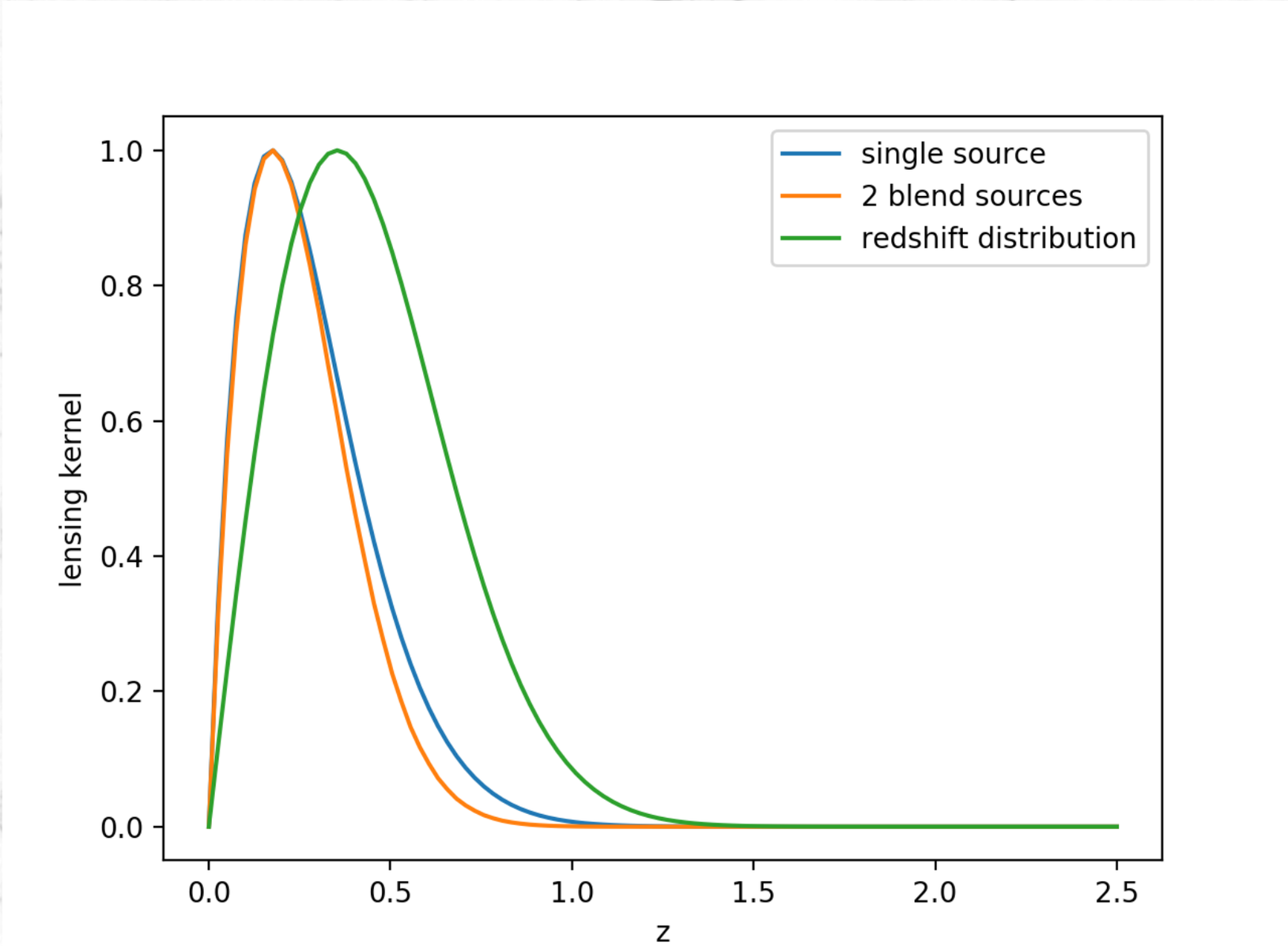
$$\langle e_i, e_{\rm blob}\rangle = R_1\langle e_i, \gamma_1\rangle + R_2\langle e_i, \gamma_2\rangle$$

Then we can write effects on 2pt correlations

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

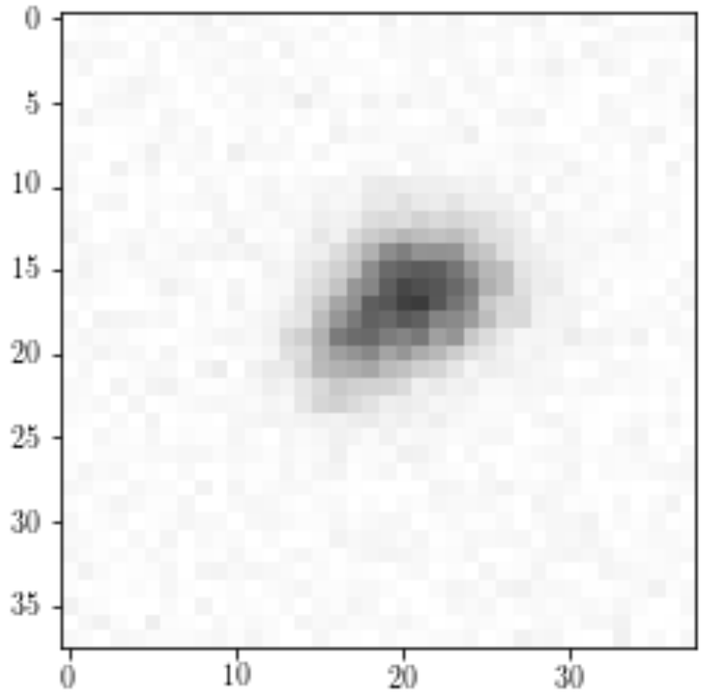
Blending and shear



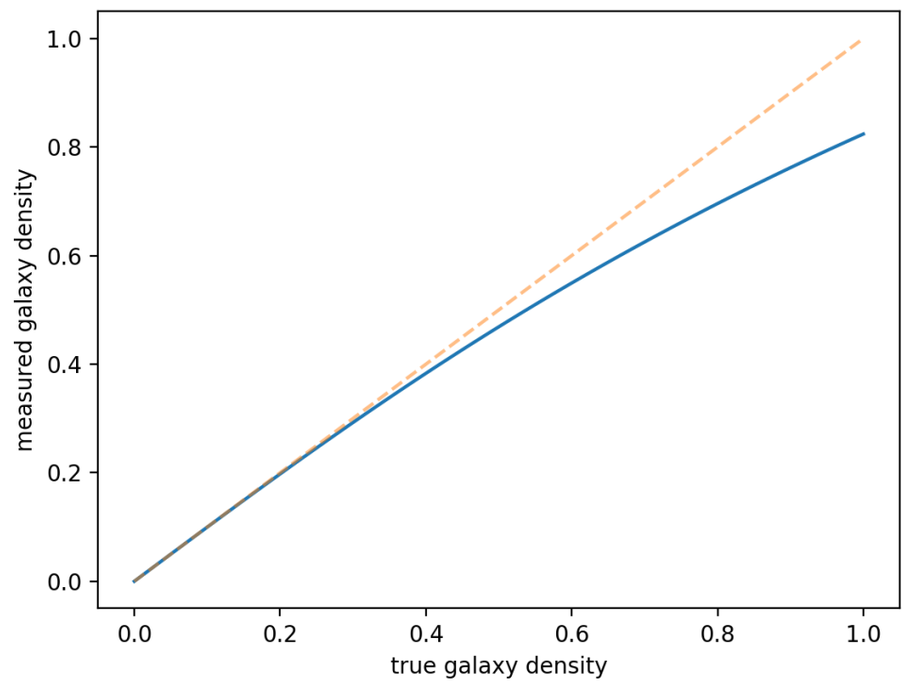
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Consider the effects of blending on clustering



Single blob, imperfectly deblended, 2 or more galaxies



blending reduces completeness, preferentially in overdense regions

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Impact on galaxy clustering

Model for the impact of the neighbor bias on the 2PCF:

$n_{obs} = \tilde{n}_t(1+\delta)\, W_s\, (1-\Gamma\delta)$

…

to first order in Γ

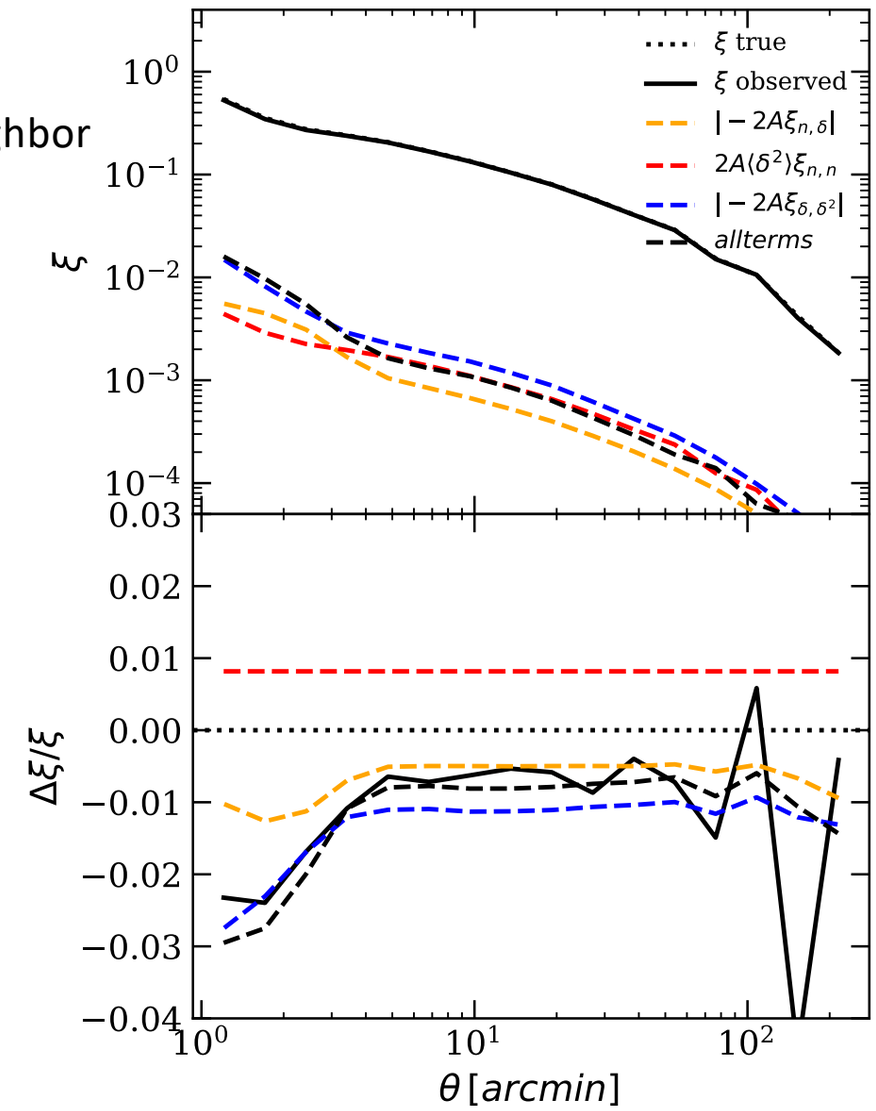
…

$\langle n_o\, n_o' \rangle / \tilde{n}_o^2 - 1 =$

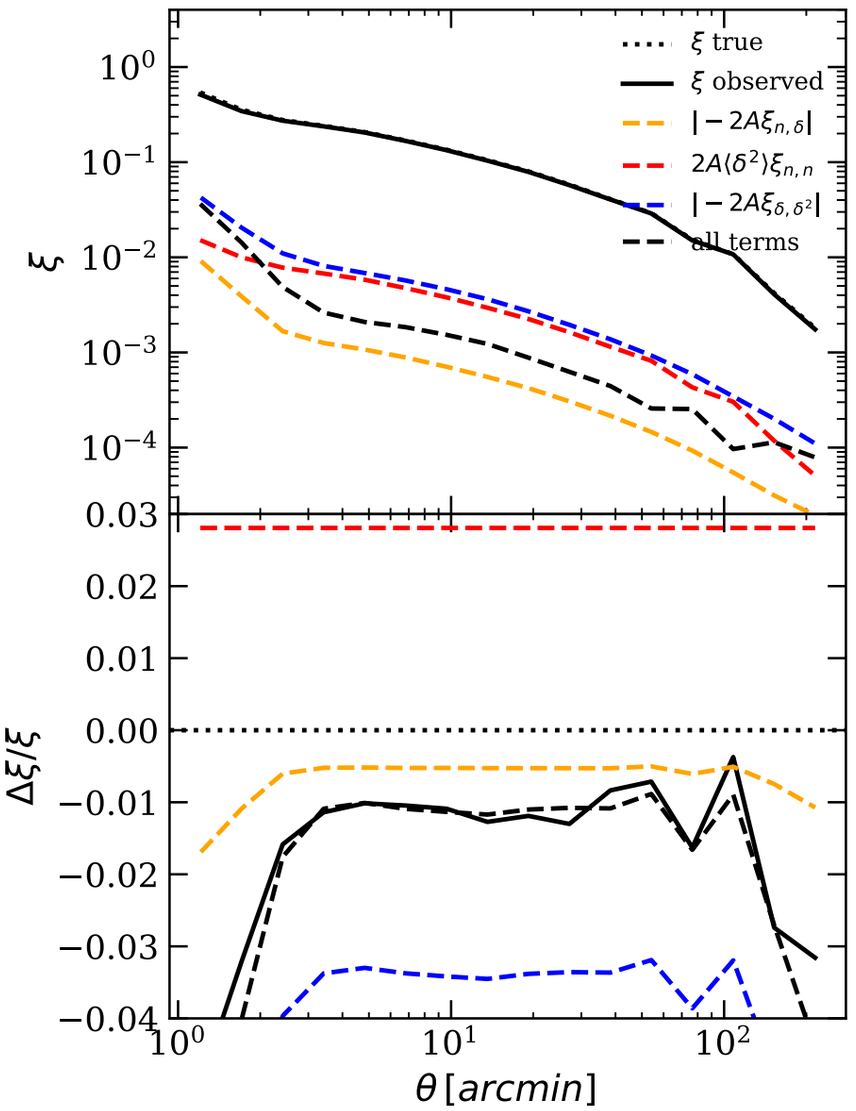
$[1 + 2\Gamma(\langle\delta^2\rangle - 1)]\xi - 2\Gamma\langle \delta\delta'^2 \rangle$

Lenses z=0.45-0.55, m_z<22

Θ_{pix} = 2 arcmin



Θ_{pix} = 1 arcmin

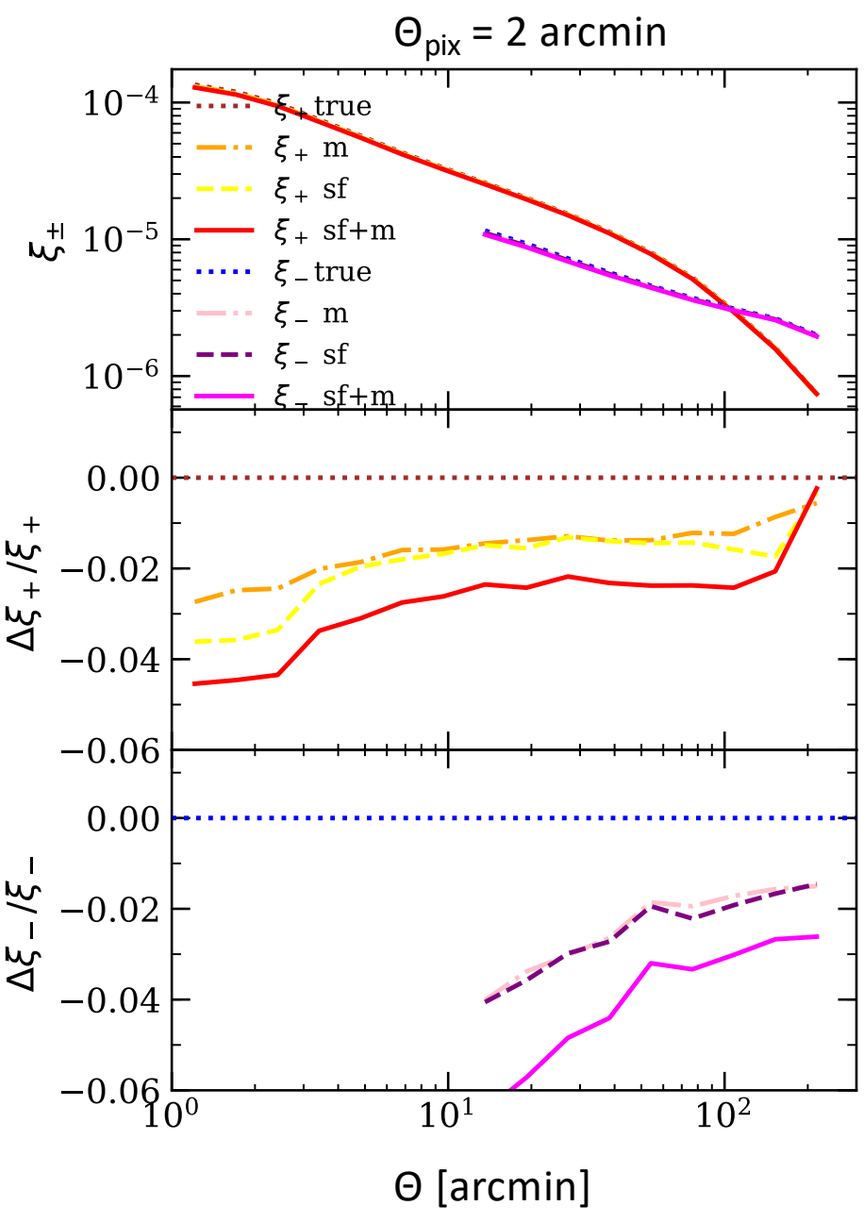


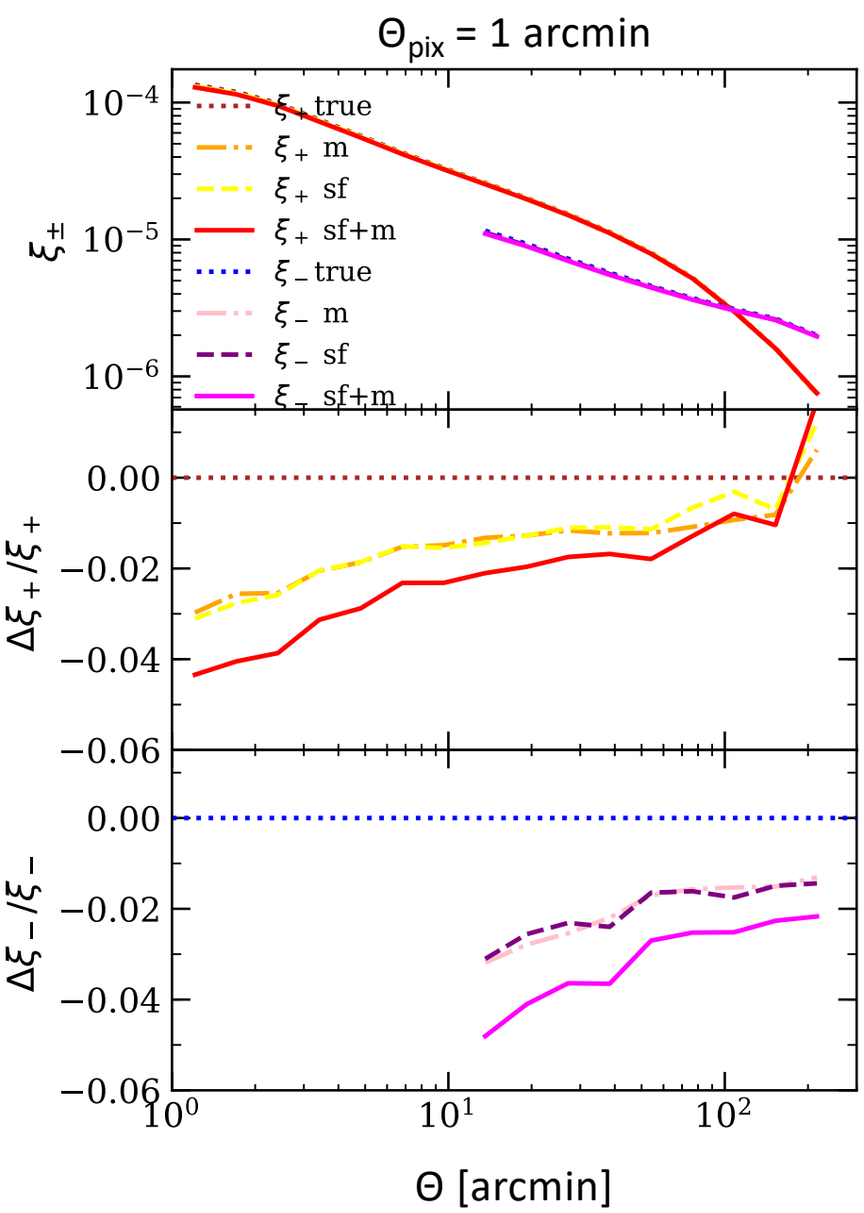
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Impact on cosmic shear

Sources z=0.95-1.05, m_z<24



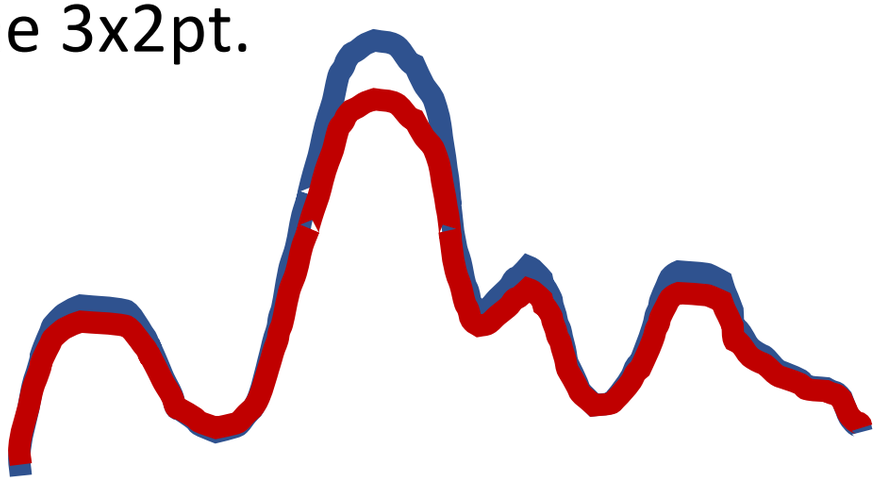


National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Summary

- We developed a general framework to capture any systematic that depends on the local number density of galaxies.
- It is a single parameter model: θ_{excl}
- All this is captured by Γ: E~Γ δ (Γ is related to θ_{excl})
- We have an analytic model for the impact on the 2PCF (it works!)
- Doing the same for all the 3x2pt.



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Gratuitous omphaloskepsis