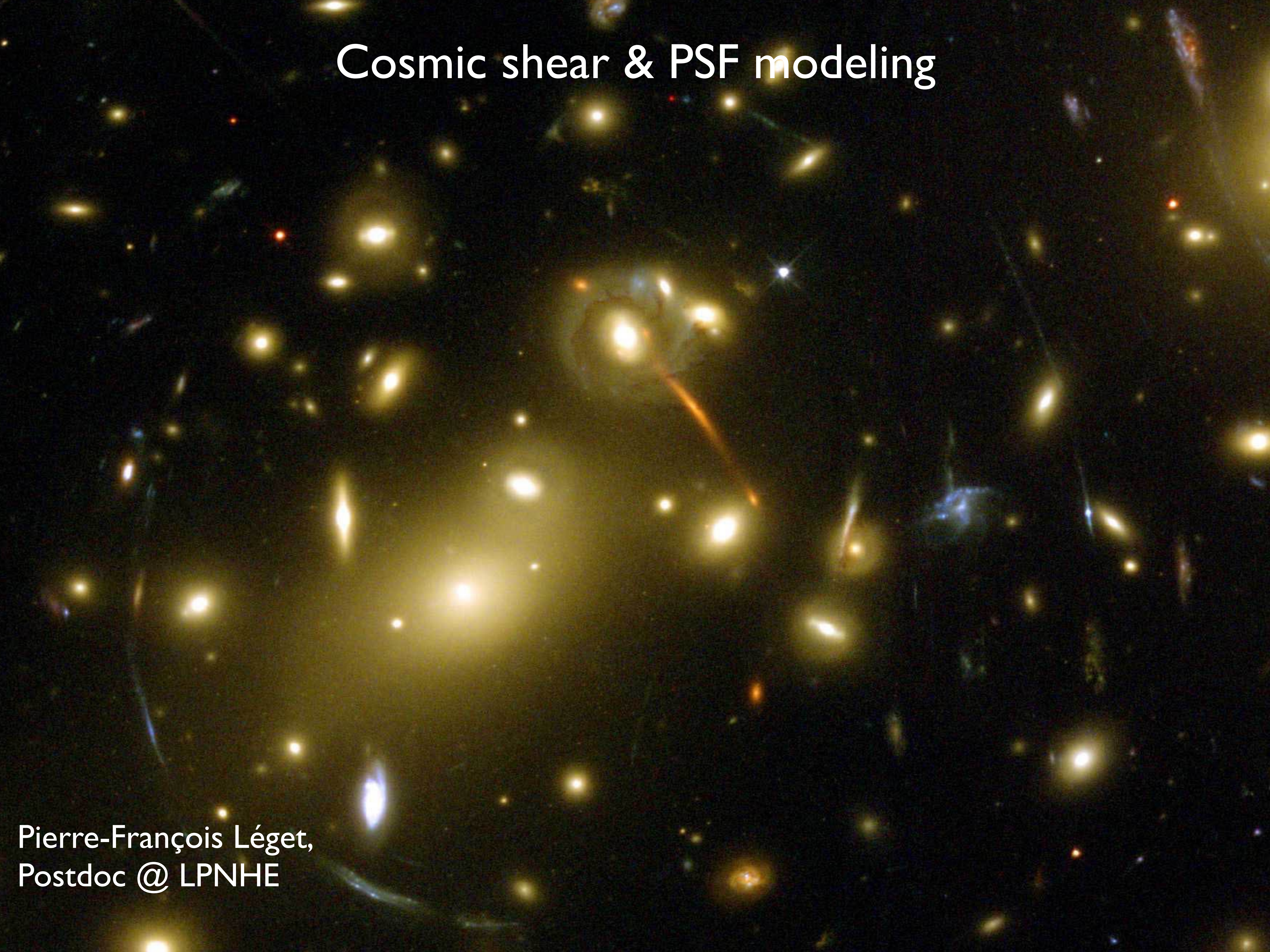
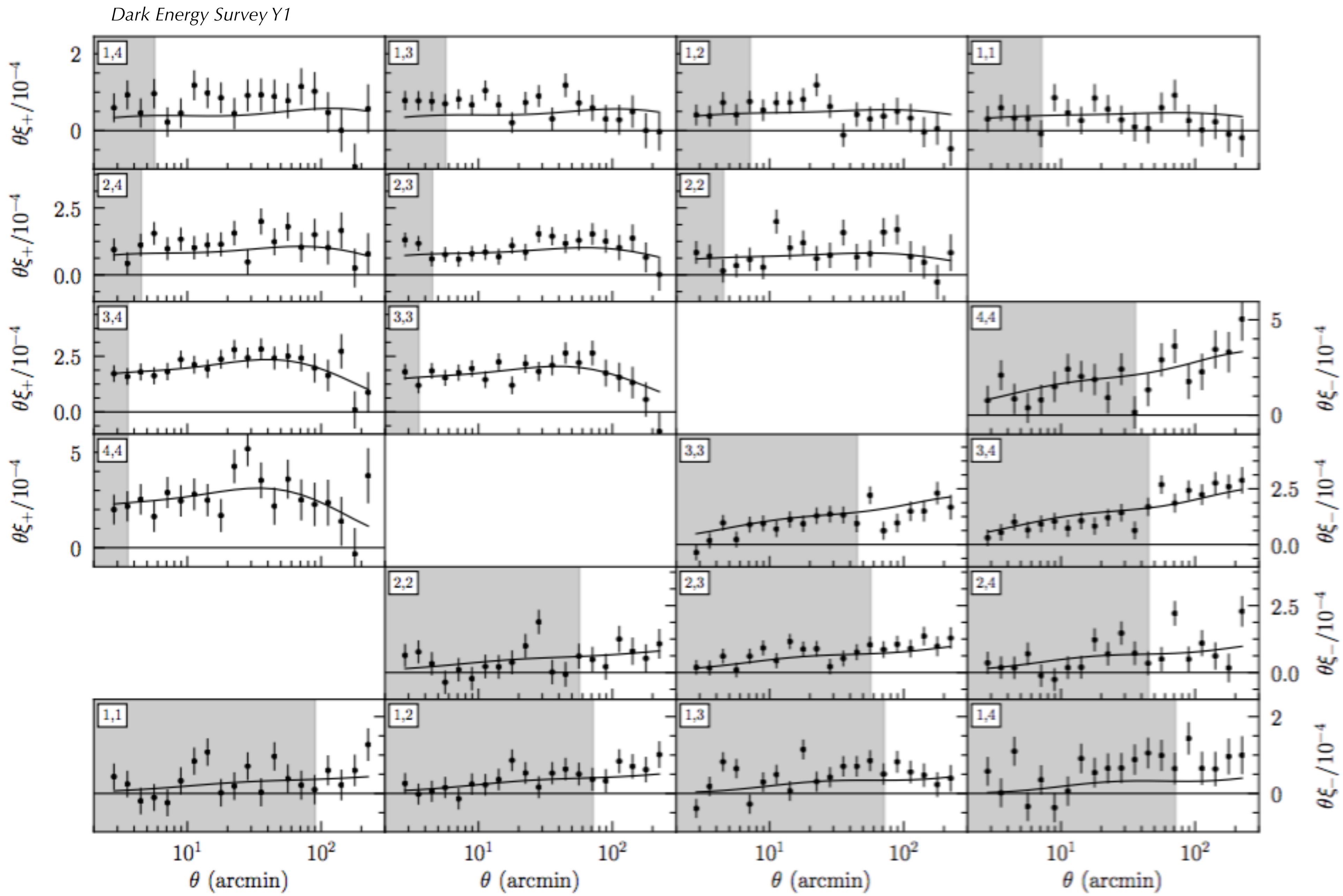
Cosmic shear & PSF modeling



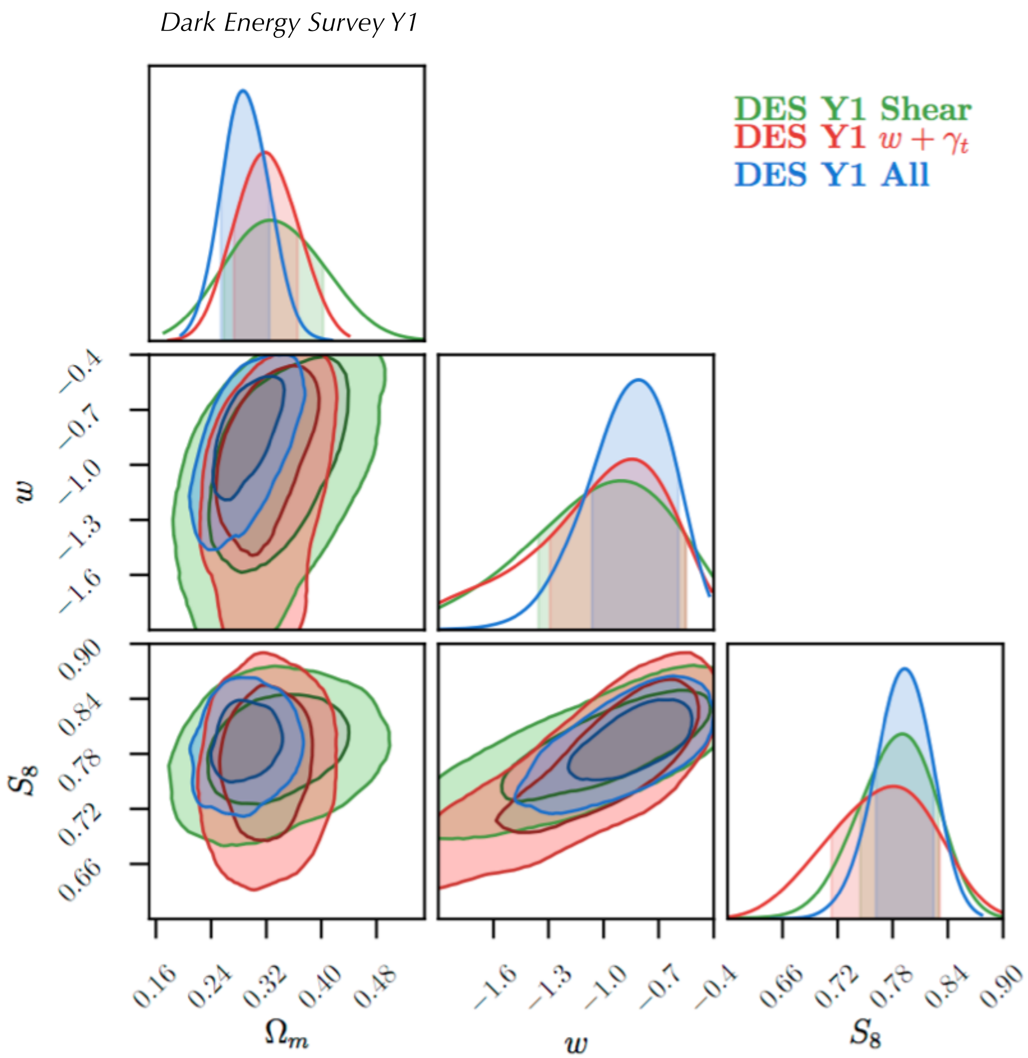
Pierre-François Léget,
Postdoc @ LPNHE

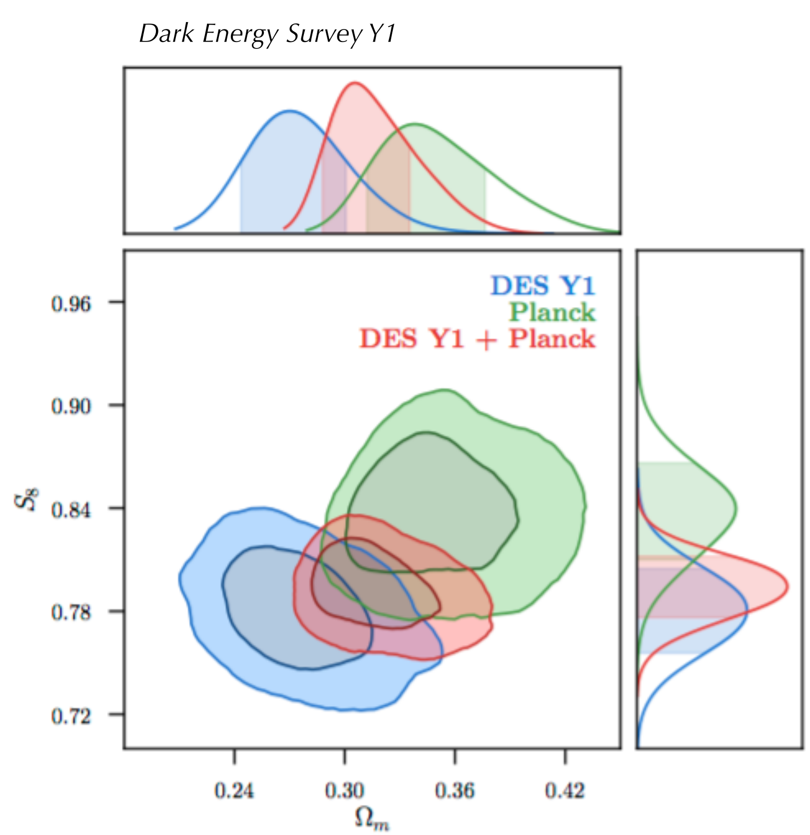


- Principle of cosmic shear:
  - Shape of galaxy are spatially correlated due to weak-lensing effect (if we forget about intrinsic alignement)

- 2-point correlation function of galaxy shape allowed to extract cosmology ($\boldsymbol{\Omega}_m$, $\mathbf{S_8}$, …)

- Cross correlation between different redshift bin allowed to extract more informations





- The following of a cosmic shear analysis is to combine it with two other 2-point correlation function:
  - The galaxy-shear correlation function
  - The galaxy-galaxy correlation function

3 X 2-points correlation Function

- For DES Y1, precision on cosmological parameter is comparable to Planck results!

Cosmic-Shear Systematics

- Weak-lensing will be one of the best probes for LSST
- Last DES Y1 results is a good example
- Already comparable in precision with Planck
- A lot of systematics need to be reduce for LSST (for current survey also)
- Example:
  - PSF
  - Blending
  - Noise bias
  - Photo-z
  - Intrinsic alignement
  - ….

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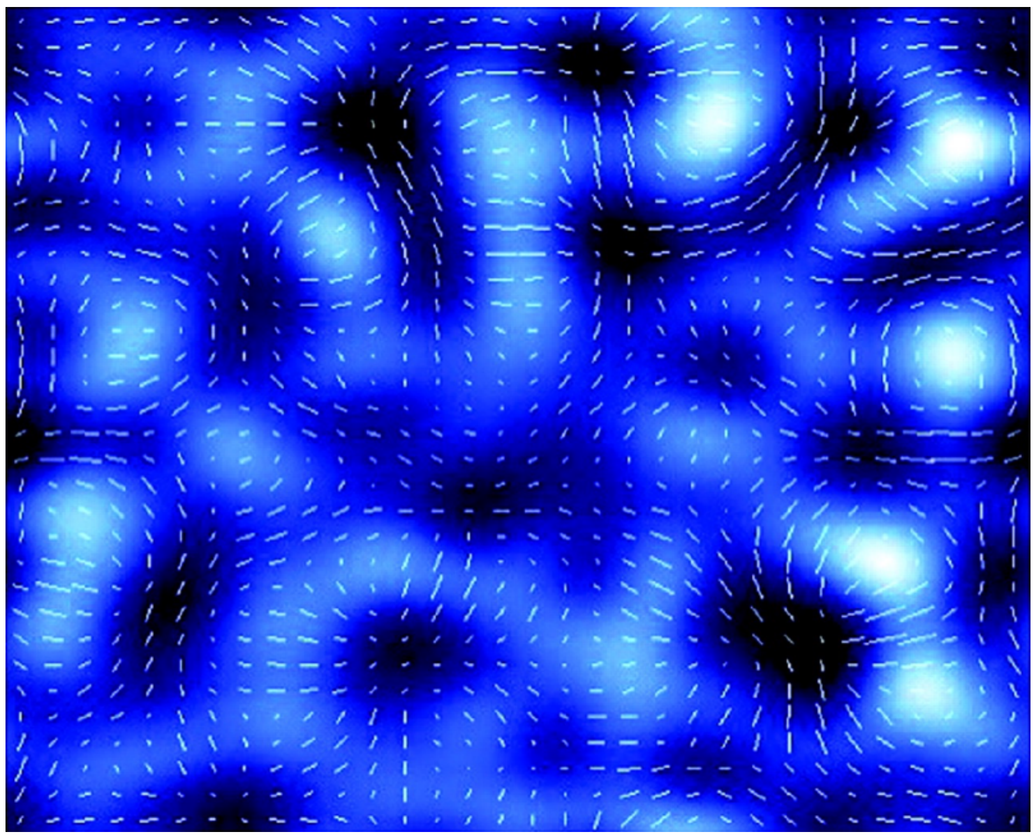
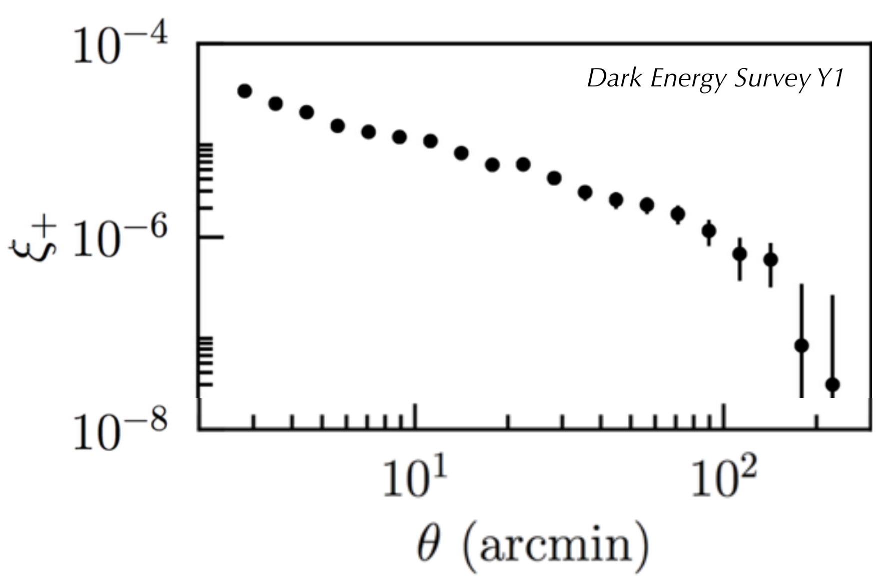
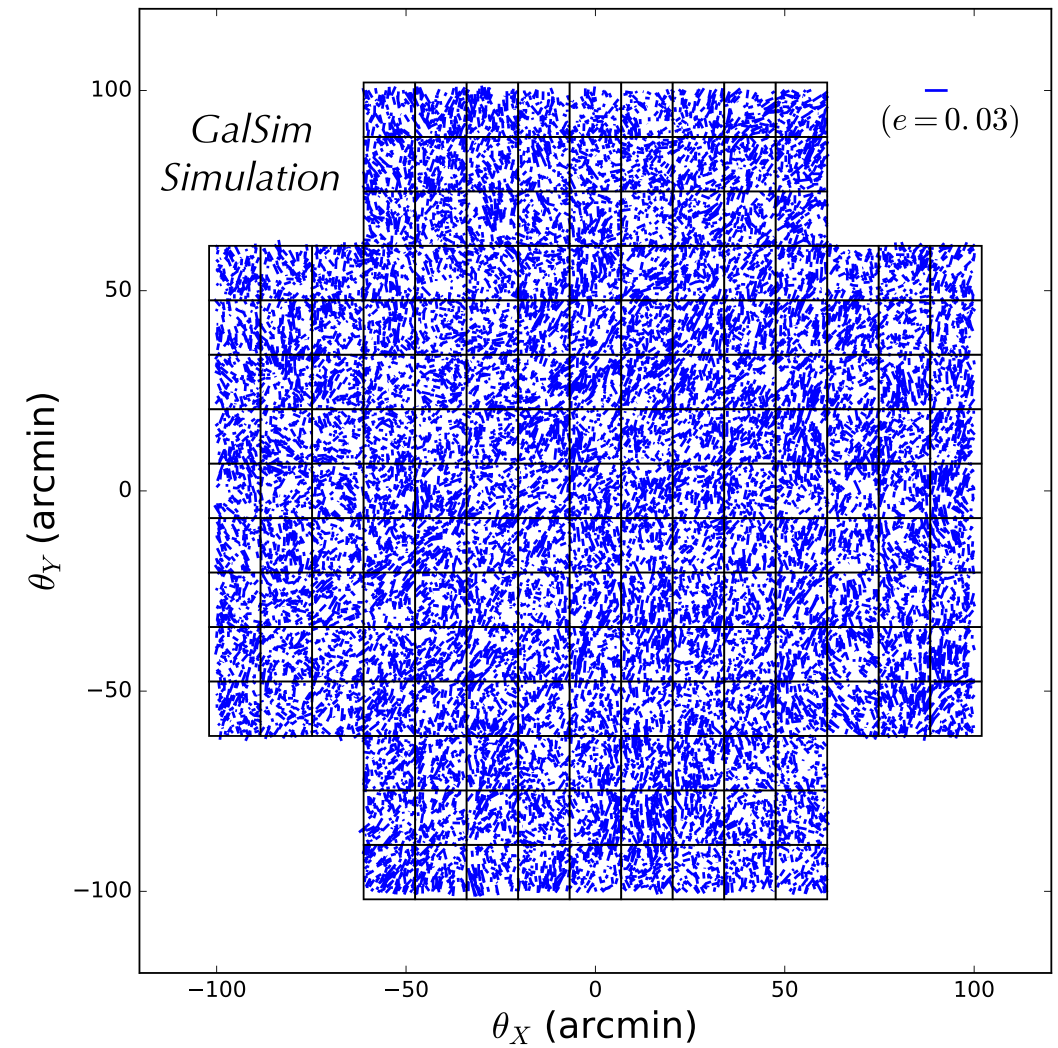
Weak lensing signal

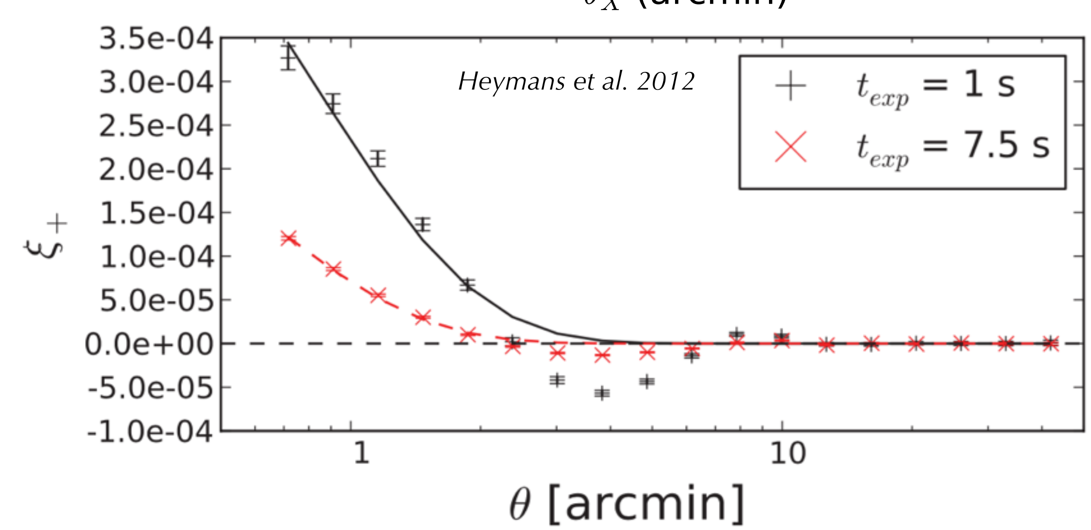
Ellis 2010 (simulation)





Point Spread Function ellipticity





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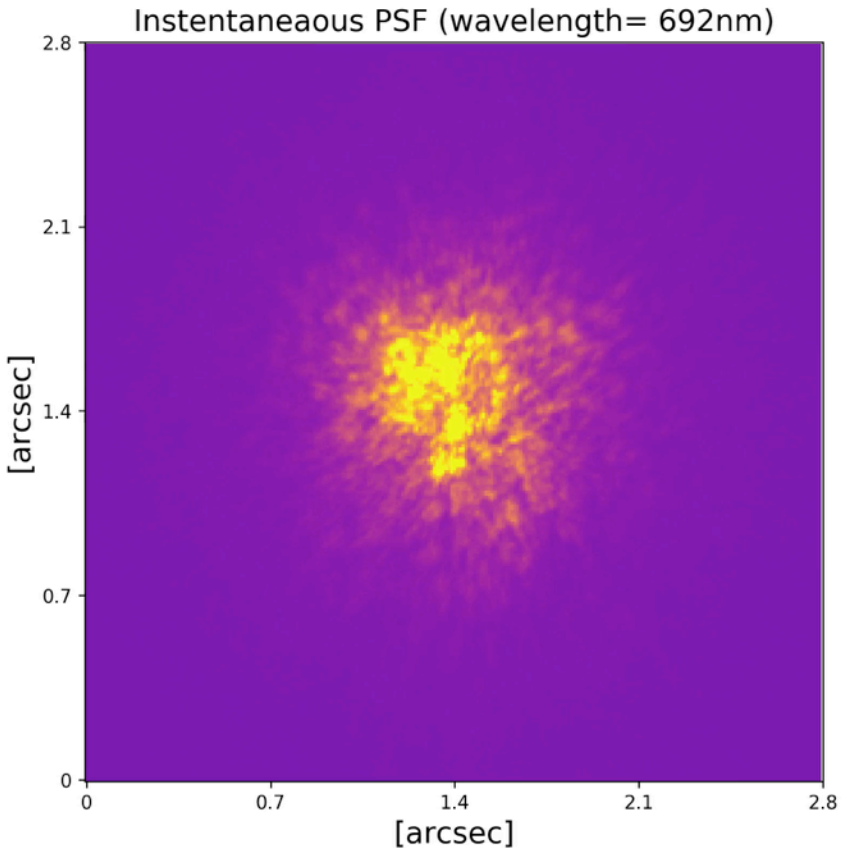
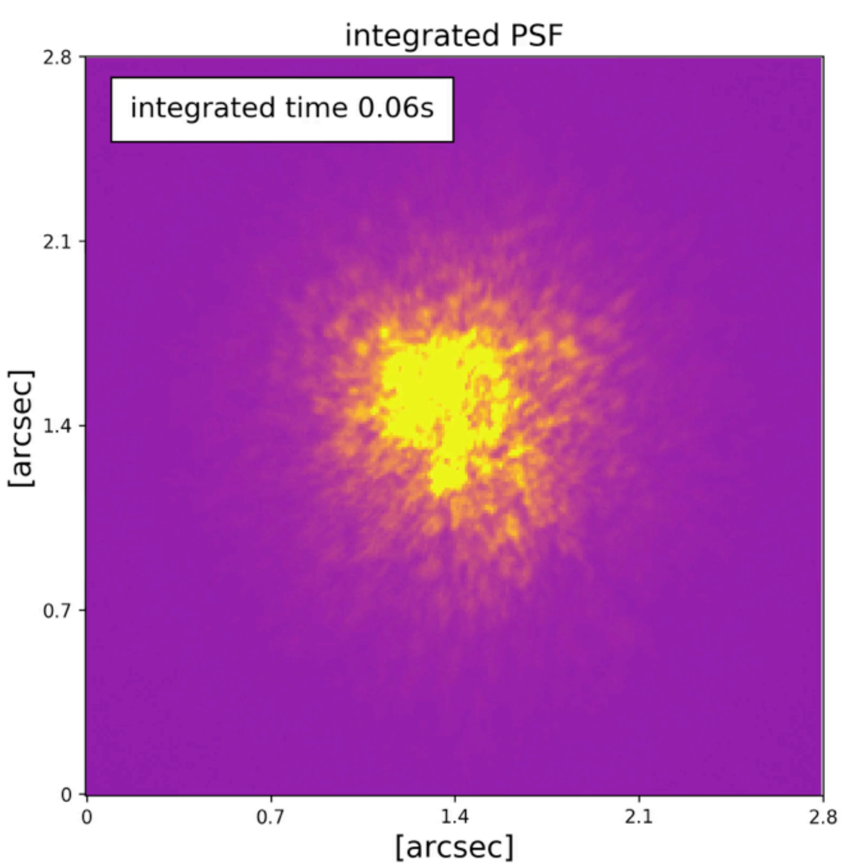
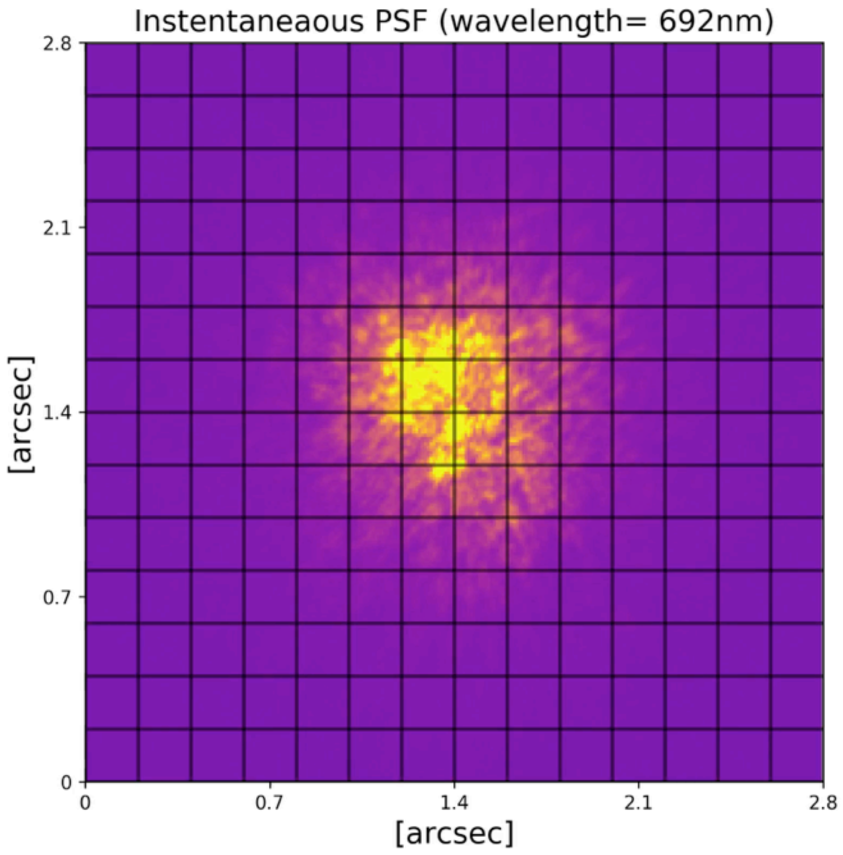
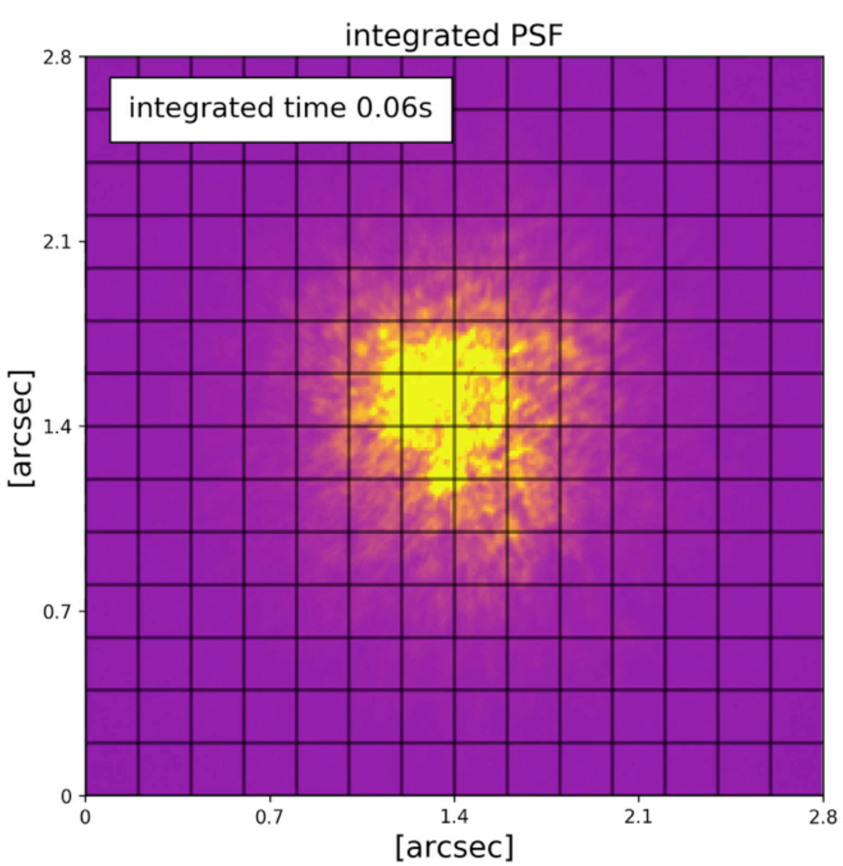




- How the PSF really looks like ?
- High definition movies of bright stars took on Gemini south with the Differential Speckle Survey Instrument
- 0.011 arcsec / pixel (LSST 0.2 arcsec / pixel)
- Exposure time of 60 ms with 2 ms of readout
- See C.-A. Hébert et al. ArXiv: 1807.09337





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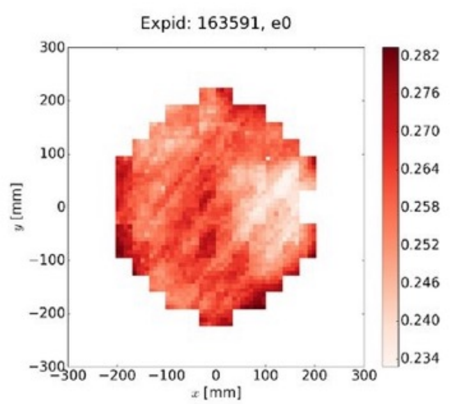
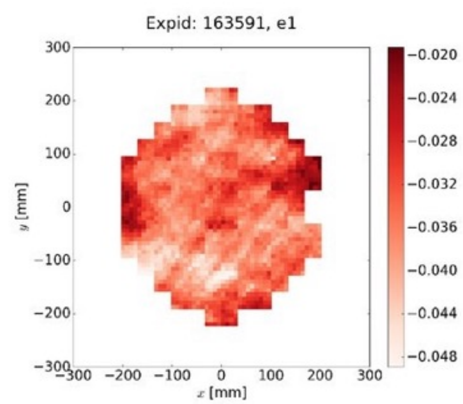
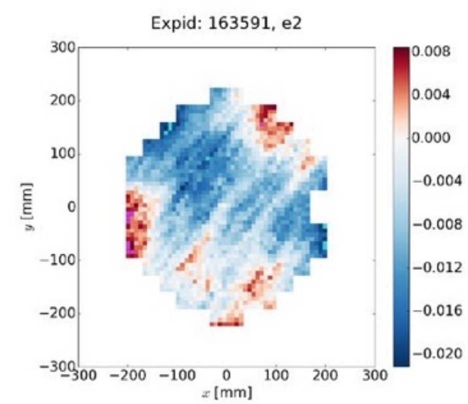
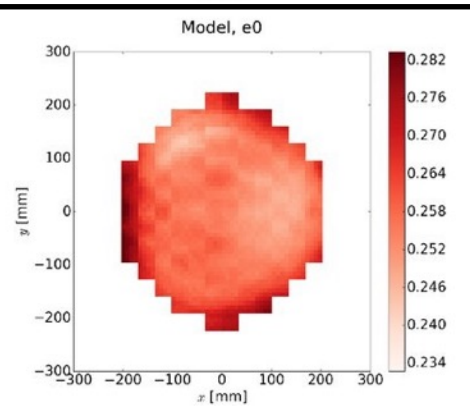
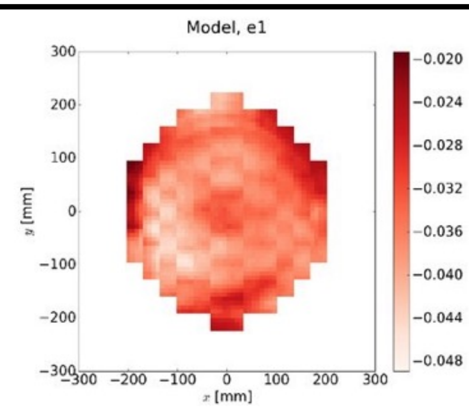
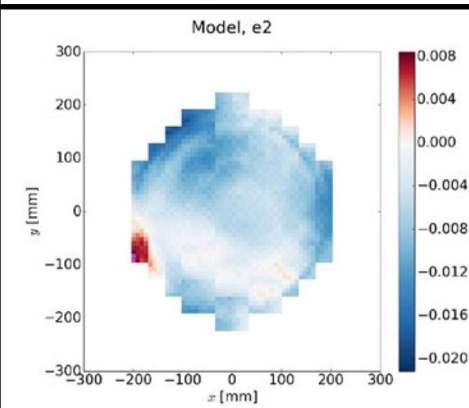
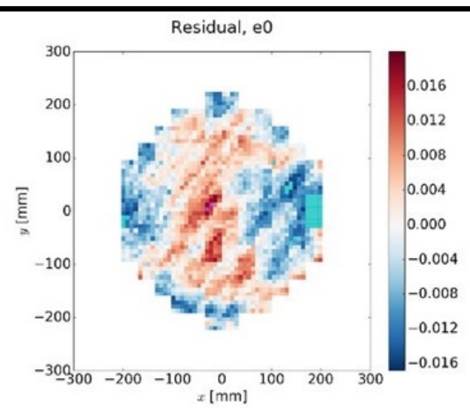
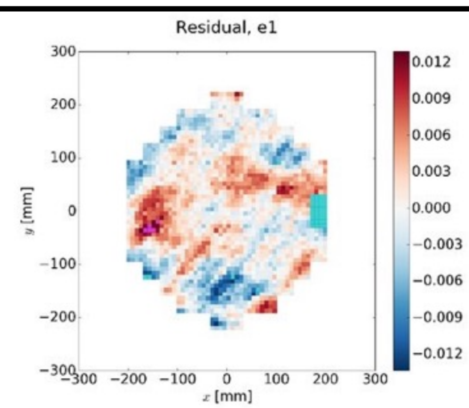
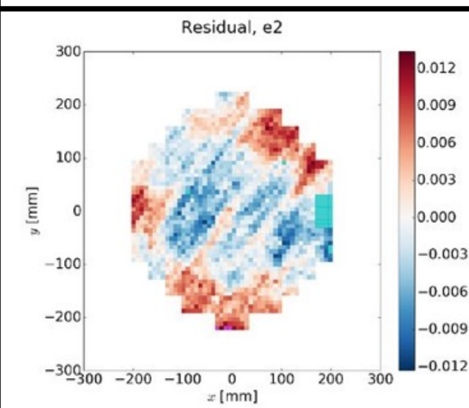
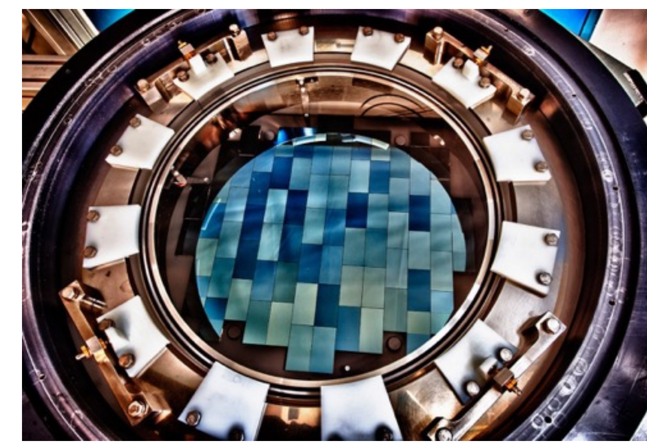
PSF decomposition

For a given exposure

Davis et al. 2016	PSF size	PSF ellipticity 1	PSF ellipticity 2
Total PSF			
Optical PSF			
Atmospheric PSF			



Dark Energy Camera

Current PSF modeling

PSFex package

- PSFex is a common used package for PSF modeling
- A ‘Pixel Basis’ model
- ‘Pixel Basis’ parameters interpolated with a polynomial interpolation per CCD chip in pixel coordinate

Limitations of PSFex:

- Working in sky coordinate would be better
- Does not take into account for spatial correlations that are larger than a CCD chip size

PSFs In the Full FoV (Piff) package

- Piff is a new python software for PSF estimation developed initially to replace PSFex in DES and now also developed for LSST
- Modular package where it is easy to implement new PSF modeling and interpolation scheme over the FoV
- Package with unit testing and code review
- Will be used for the Weak-Lensing analysis of DES Y3
- Contributors:

Mike Jarvis, Pierre-François Léget, Chris Davis, Erin Sheldon, Josh Meyers, Gary Bernstein, Aaron Roodman, Pat Burchat, Daniel Gruen, Ares Hernandez, Andres Navarro, Flavia Sobreira, Reese Wilkinson, Joe Zuntz, Sarah Burnett

Piff improvements respect to PSFex:

- PSF modeling in sky coordinate instead of pixel coordinate.
- Can modeled the PSF per CCD or in the full FoV (great to get PSF variation due to atmosphere)
- Different choices of modeling the PSF are available (Pixel basis, Optical model + Kolmogorov profile, …)
- Different choices of interpolation model are available (polynomial, gaussian process, …)
- The average PSF model over the survey can be a part of the final solution

- Good PSF for Cosmic-shear == uncorrelated spatial residuals

- The Rowe Statistics

- Evaluate spatial correlation of second moments of the PSF (size and ellipticity)

- T == Trace of second moments

- e == complex ellipticity

Rowe Statistics:

$$\rho_1(\theta) \equiv \left\langle \Delta e^*(x) \Delta e(x+\theta) \right\rangle$$

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- Good PSF for Cosmic-shear == uncorrelated spatial residuals
- The Rowe Statistics
- Evaluate spatial correlation of second moments of the PSF (size and ellipticity)
- T == Trace of second moments
- e == complex ellipticity
- Those coefficient comes from the propagation of error modeling of the PSF to the cosmic shear signal
- See Jarvis et al. 2016, Rowe 2010 and Paulin-Henriksson et al. 2008

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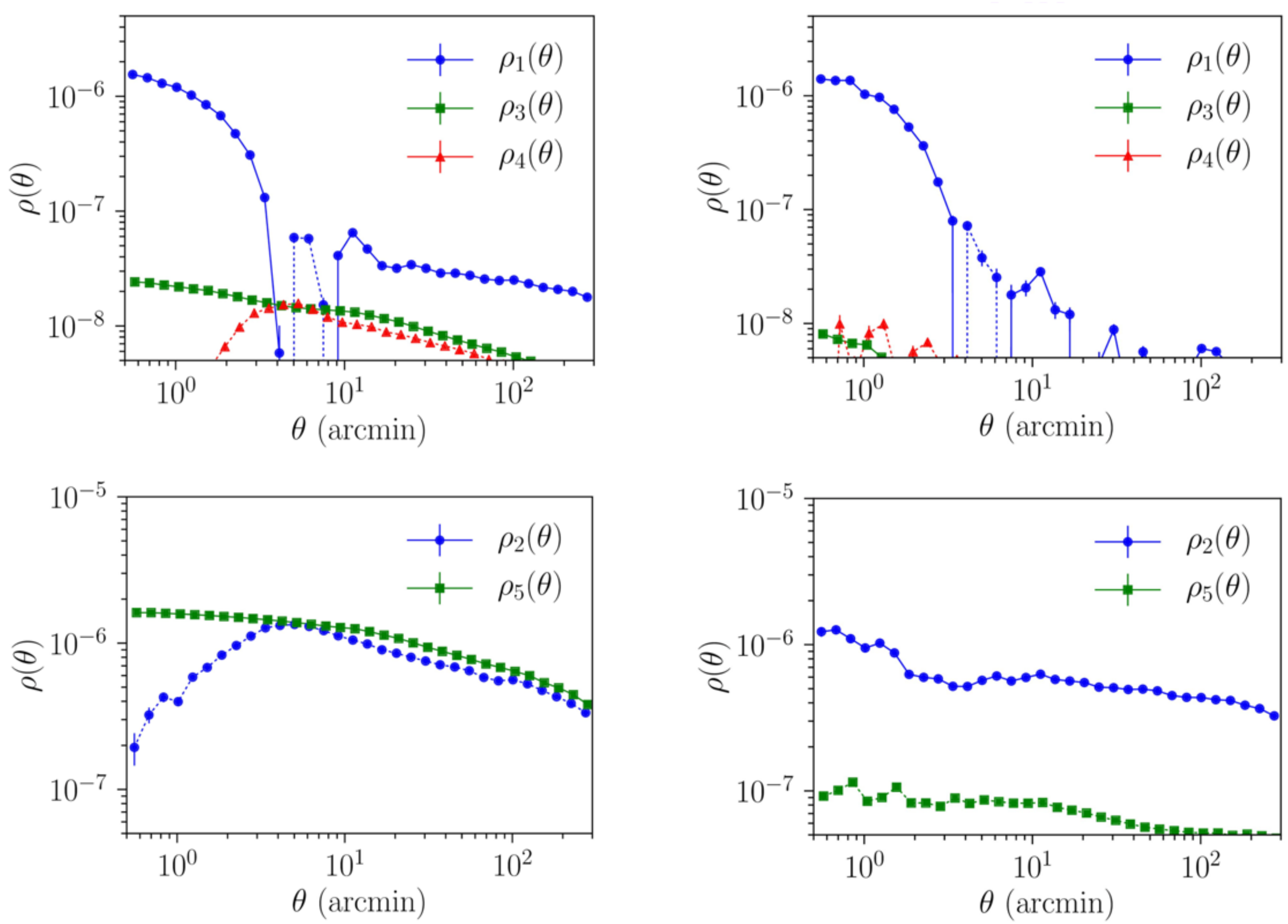
$$\Delta\xi_+ = 2\left\langle \frac{T_{PSF}}{T_{gal}} \frac{\Delta T_{PSF}}{T_{PSF}} \right\rangle \xi_+(\theta) + \left\langle \frac{T_{PSF}}{T_{gal}} \right\rangle^2 \rho_1(\theta) - \alpha \left\langle \frac{T_{PSF}}{T_{gal}} \right\rangle \rho_2(\theta) + \left\langle \frac{T_{PSF}}{T_{gal}} \right\rangle^2 \rho_3(\theta) + \left\langle \frac{T_{PSF}}{T_{gal}} \right\rangle^2 \rho_4(\theta) - \alpha \left\langle \frac{T_{PSF}}{T_{gal}} \right\rangle \rho_5(\theta)$$

PSFex | Piff



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- Piff and PSFex are applied on ~50% of DES Y3 data
- Both used the same ‘Pixel Basis’ model of the PSF
- Both used a Polynomial interpolation per CCD chip
- The main difference is the coordinate system
- Rowe statistics is computed to compare both
- Analysis and plots done by Mike Jarvis

The Optical and Atmospheric PSF model

PSF profile $\sim$ Optical part of the PSF $\otimes$ Atmospheric part of the PSF

The Optical and Atmospheric PSF model

PSF profile ~ Optical part of the PSF as a Fraunhofer Diffraction $\otimes$ Atmospheric part of the PSF

$$\overbrace{I(u,v)}^{\text{PSF profile}} \sim \overbrace{\left| F\left\{ \underbrace{P(\rho,\theta)}_{\text{Pupil function}} e^{2\pi i \underbrace{W(\rho,\theta)}_{\text{Wavefront}}/\lambda} \right\} \right|}^{\text{Optical part of the PSF}}$$

Wavefront

Pupil function

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Wavefront decomposed as a double Zernike polynomial that depend on the focal plane coordinate

$$W(\rho,\theta) = \sum_i \left[a_{i,reference}(u,v) + a_{i,corr}(u,v) \right] Z_i(\rho,\theta)$$

$$a_{i,corr}(u,v) = \sum_j b_{i,j}(u,v) Z_j(\rho,\theta)$$

The Optical and Atmospheric PSF model

PSF profile $\sim$ Optical part of the PSF as a Fraunhofer Diffraction $\otimes$ Atmospheric part of the PSF as a Kolmogorov profile

$$I(u,v) \sim \left| F\left\{ P(\rho,\theta) e^{2\pi i W(\rho,\theta)/\lambda} \right\} \right| \otimes K(\alpha(u,v), g_1(u,v), g_2(u,v))$$

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Kolmogorov parameters modeled as a Gaussian Process drive by a Von-Karman correlation function

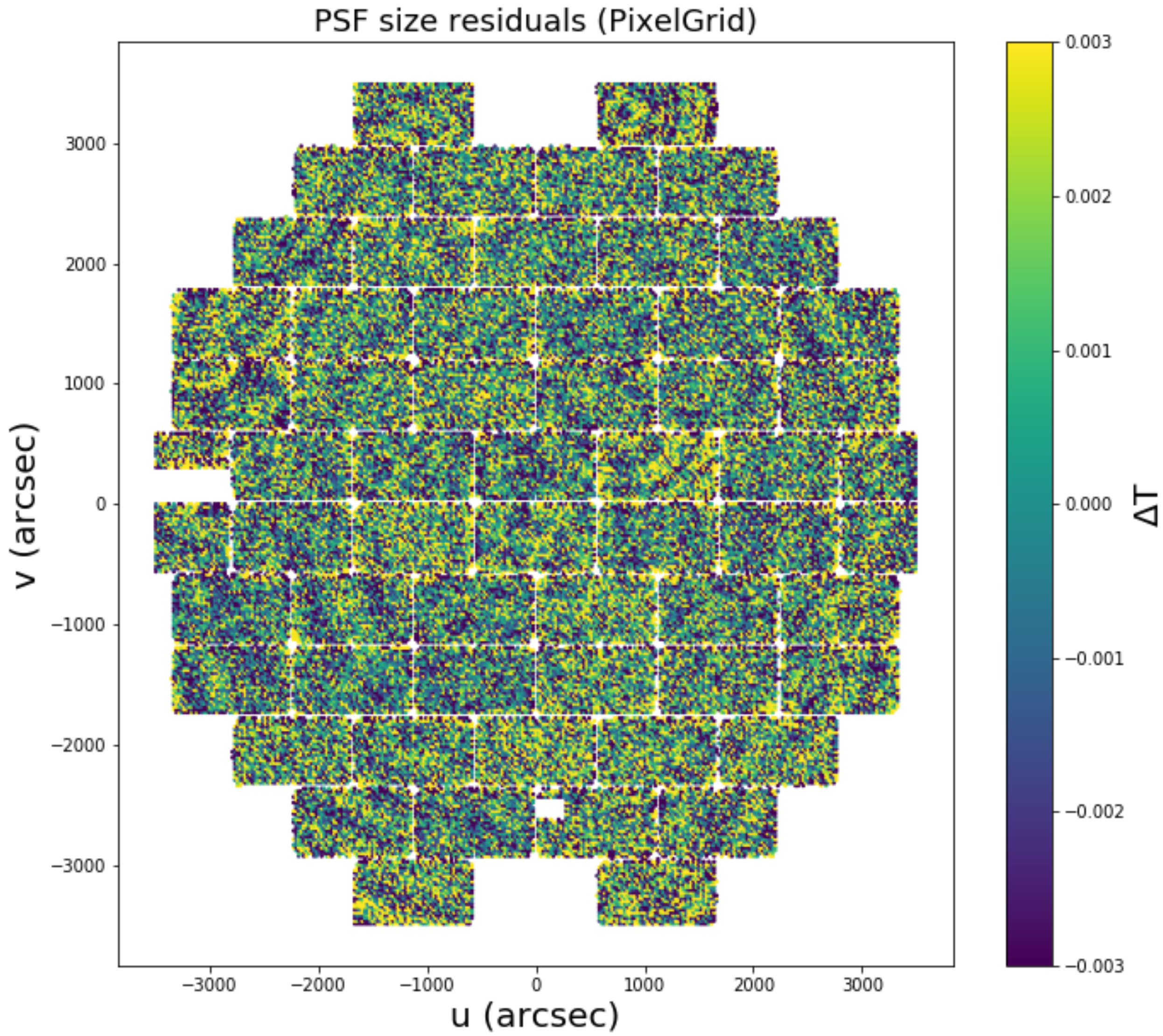
$$\alpha(u,v) \sim N(\alpha_0(u,v), \xi)$$

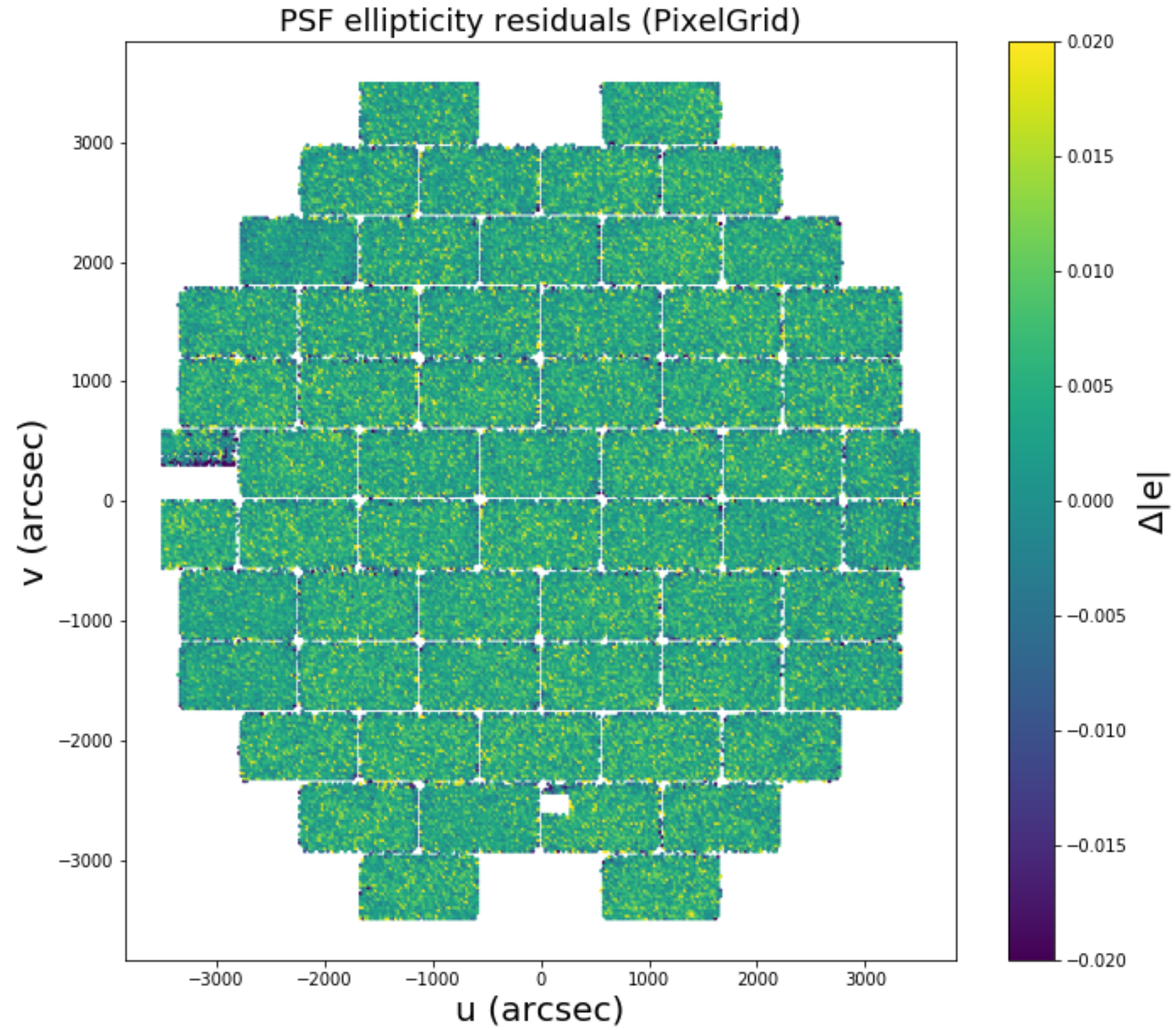
$$g_1(u,v) \sim N(g_{1,0}(u,v), \xi)$$

$$g_2(u,v) \sim N(g_{2,0}(u,v), \xi)$$

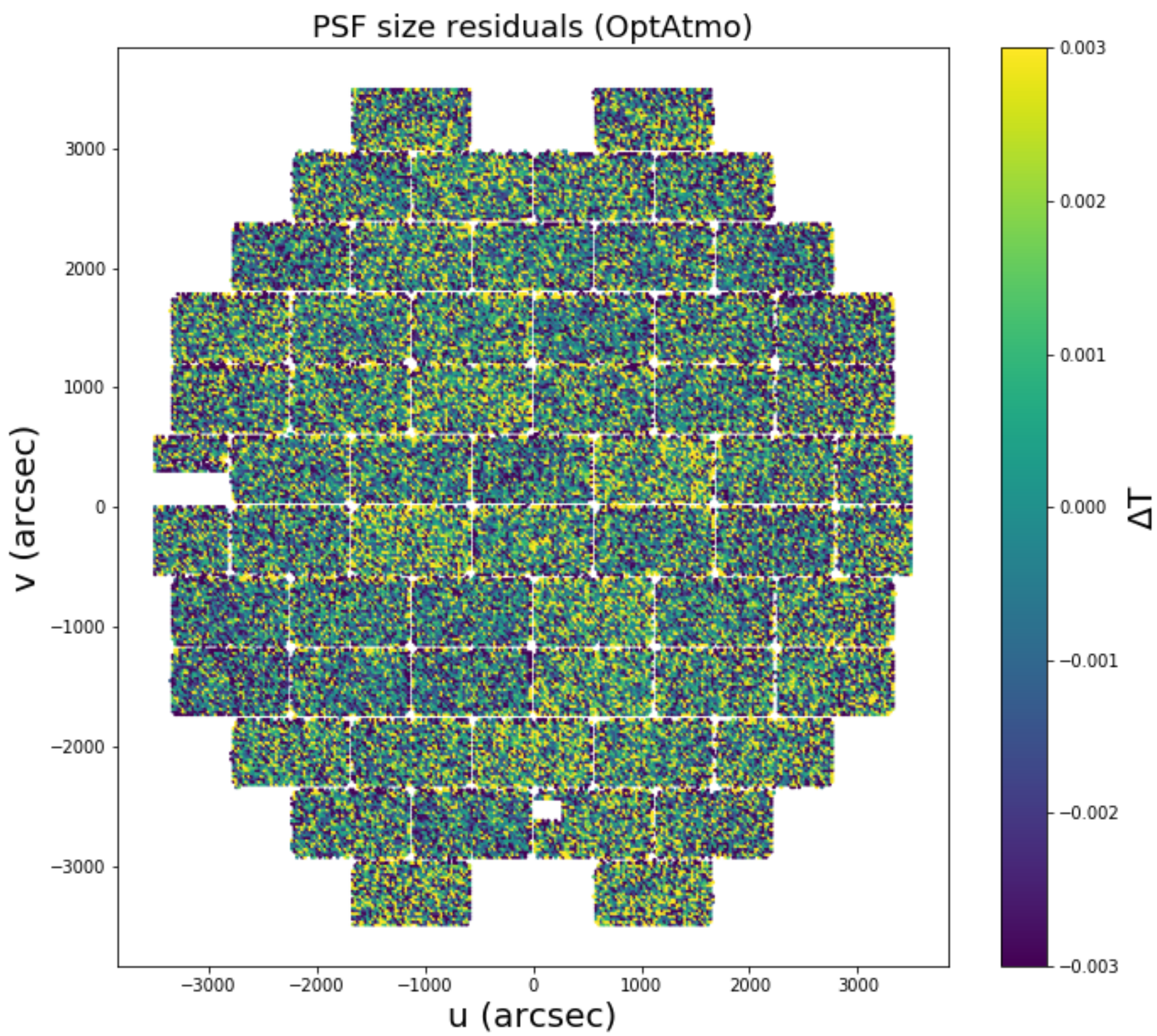
Preliminary results on the Dark Energy Survey Y3

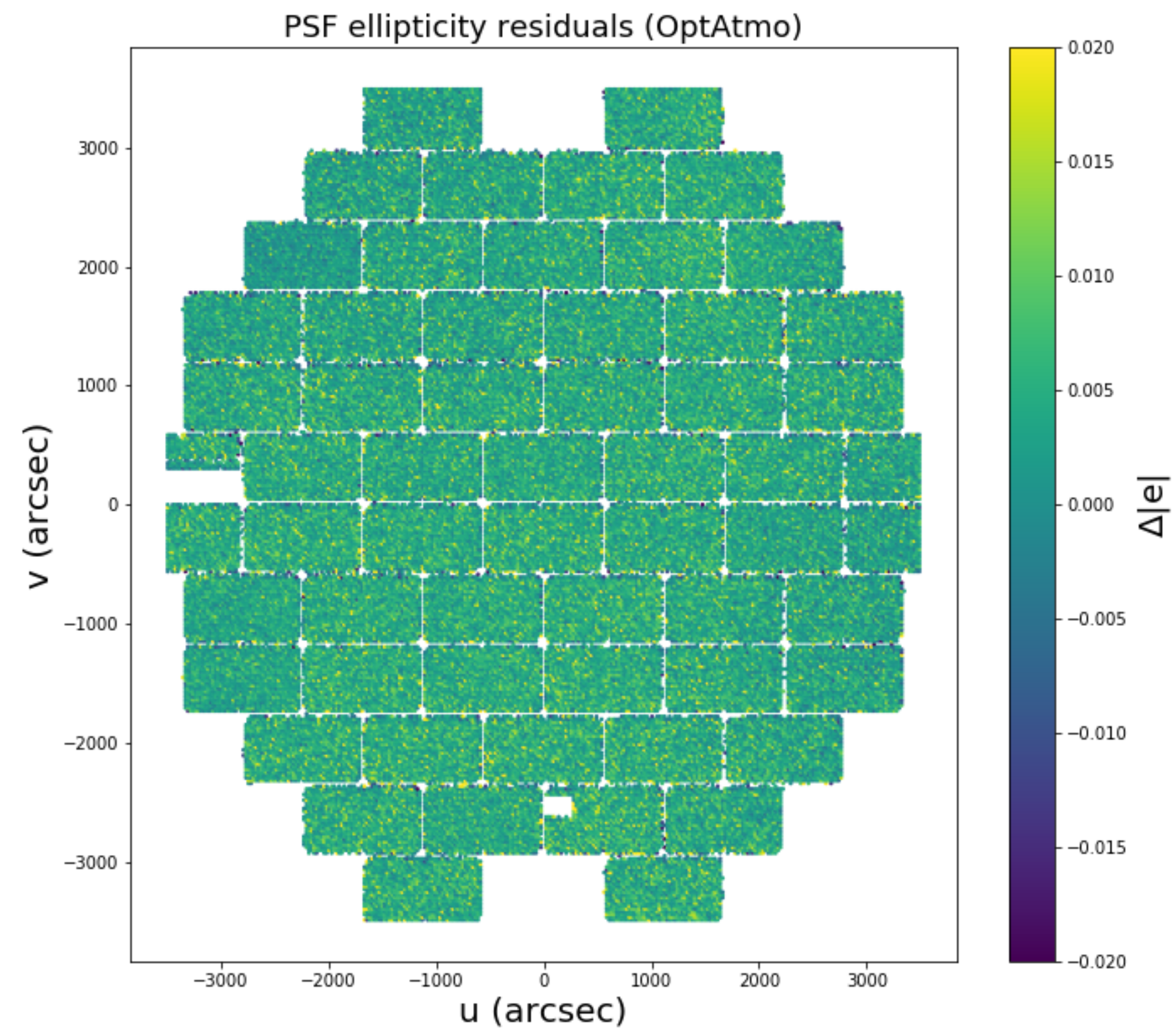
- Method applied on DES Y3
- On ~1000 exposures in grizY
- Compare the optical & atmosphere model to the Pixel Basis model (that will be used for Y3 Weak-lensing analysis) —> Both from Piff
- Training (modeling + interpolation) on 80% of stars
- 20% of stars kept for validation
- Results shown on the validation sample only



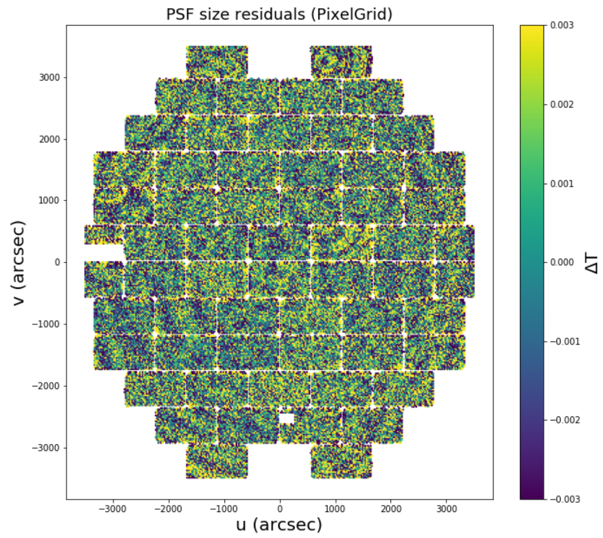
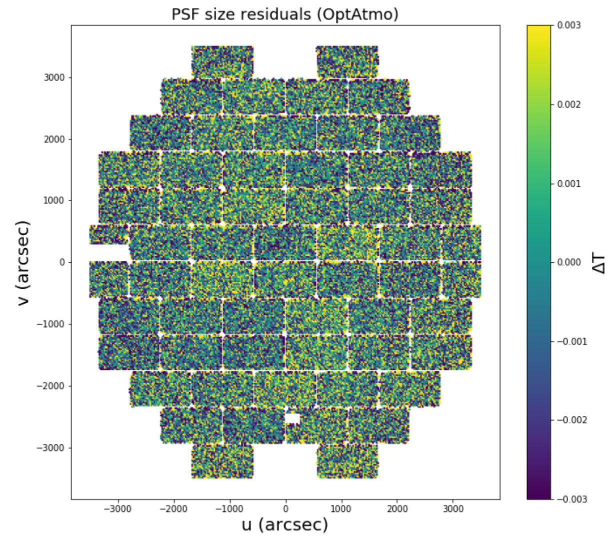
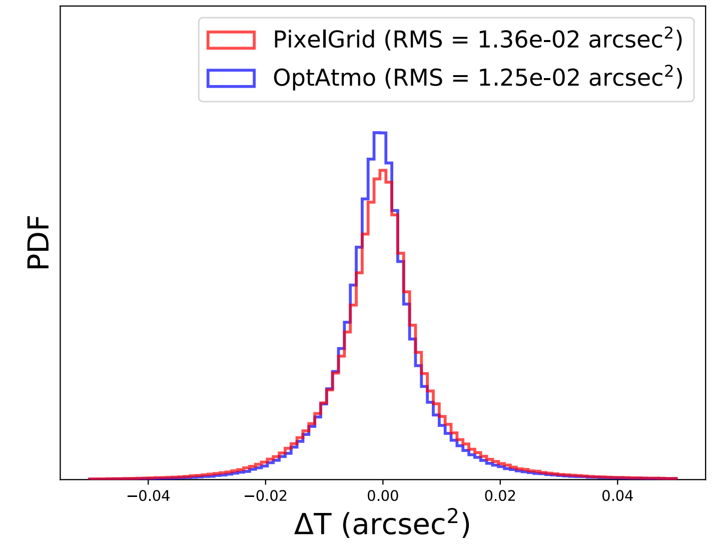
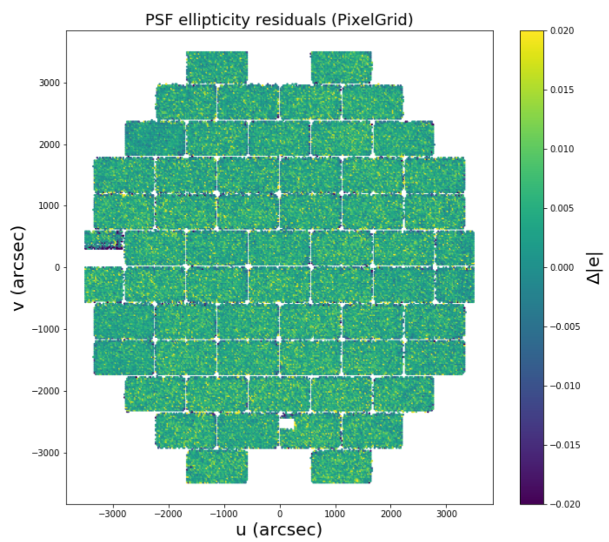
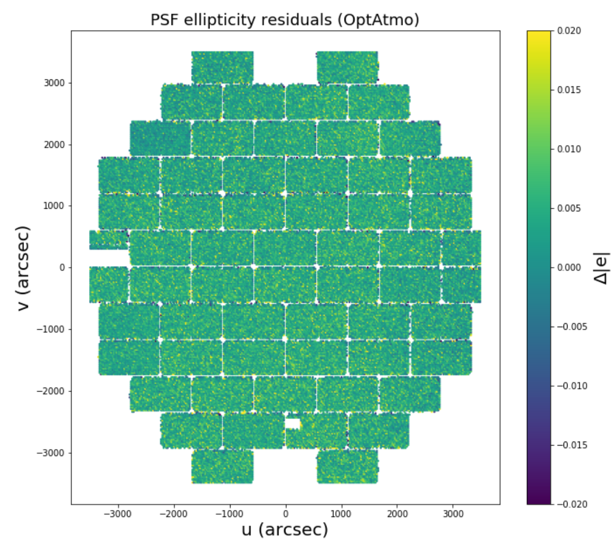
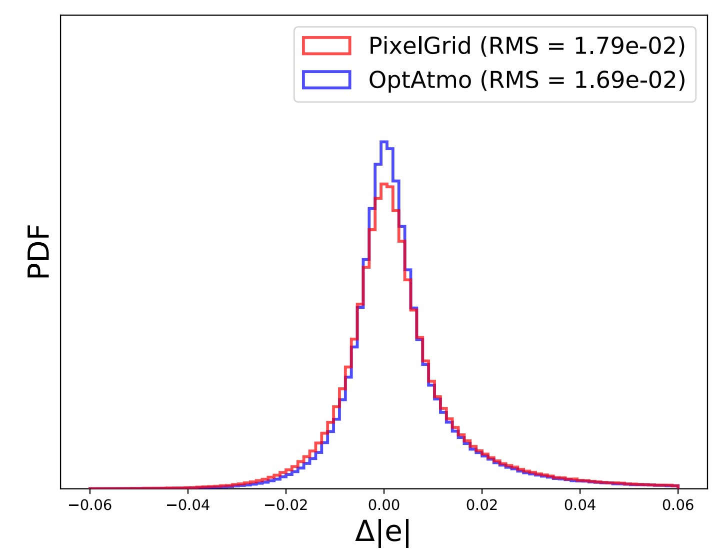


- Residual size (Trace of second moments matrix) and ellipticity averaged across the DES FoV
- For the **Pixel Basis** model using Piff and an **interpolation done per CCD chip**



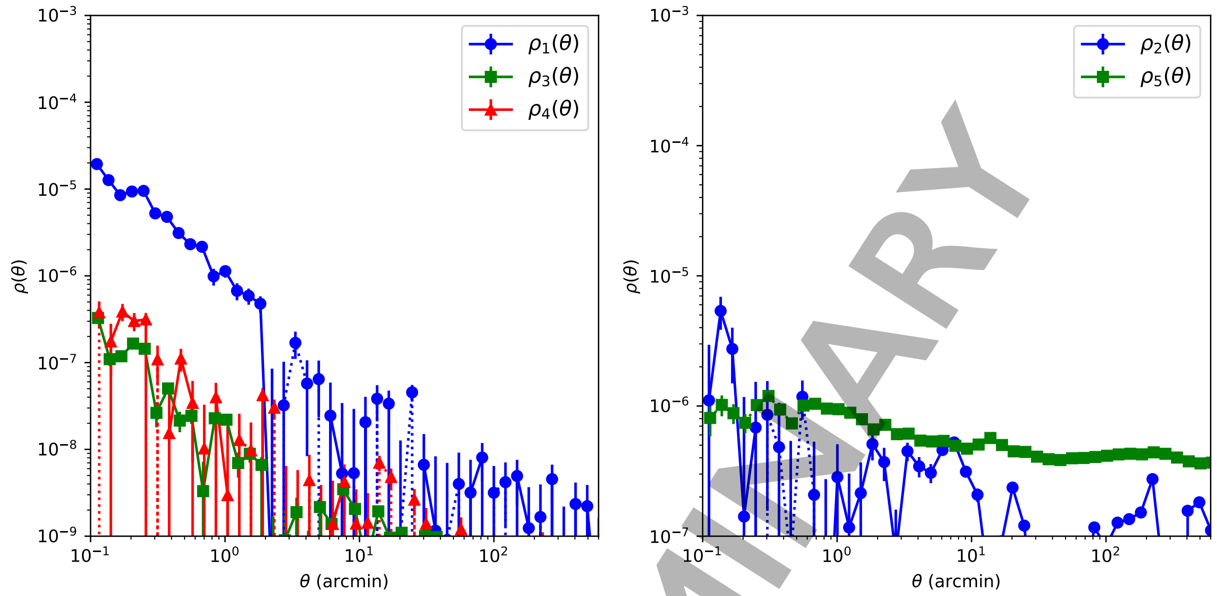


- Residual size (Trace of second moments matrix) and ellipticity averaged across the DES FoV
- For the **Optical and the Atmospheric model** using Piff and an **interpolation done on the full FoV**

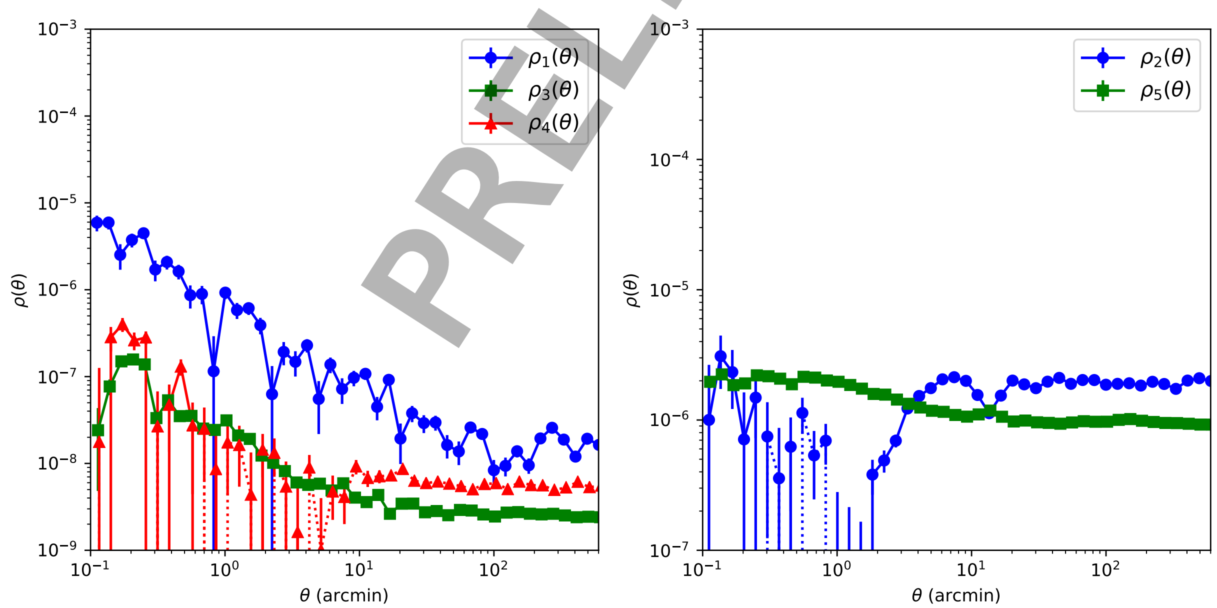
	Pixel Basis model	Optical and the Atmospheric model	Residuals distribution
Residual size			
Residual ellipticity			

- Residual size (Trace of second moments matrix) and ellipticity averaged across the DES FoV
- The **Optical and the Atmospheric model** seems to do a better job to reconstruct the second moments compared to the **Pixel Basis model**

Pixel Basis model



Optical and the Atmospheric model



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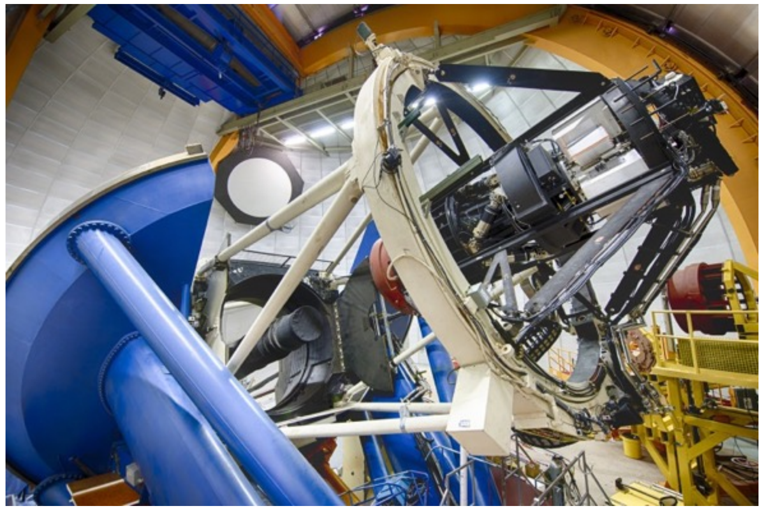
- Rowe statistic are compatible for both modeling
- **Optical and the Atmospheric model** is better at small angular separation
- Can be improve on larger scale (and we know how!)

Ongoing improvement of the PSF modeling:

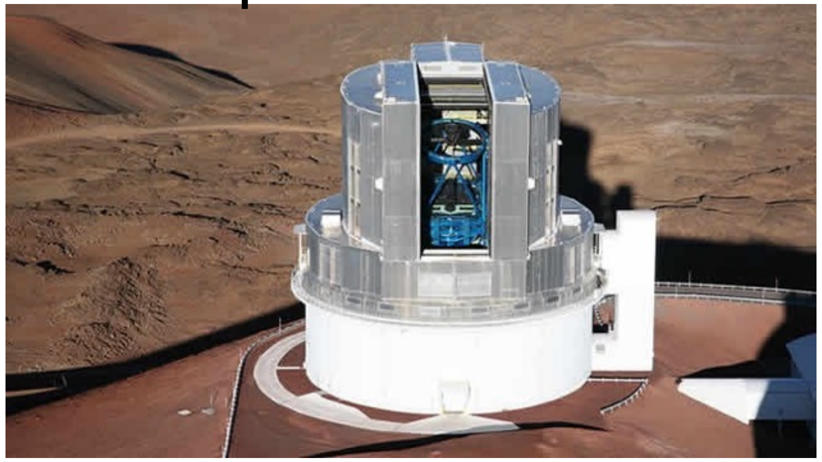
- Average function of the atmosphere done per filter instead of across all filter
- Anisotropic Gaussian Processes instead of isotropic
- Add more Zernike coefficient, especially more spherical component
- Add third moment in the procedure of fitting for the optical part
- Adjust wavelength dependence in the optical model (set at 700nm currently)

The near terms goals is to make work the physical model for DES Y5



DES

The next stage for PSF modeling: HSC.
More complicate optical system on an 8 meters telescope



Subaru / HSC

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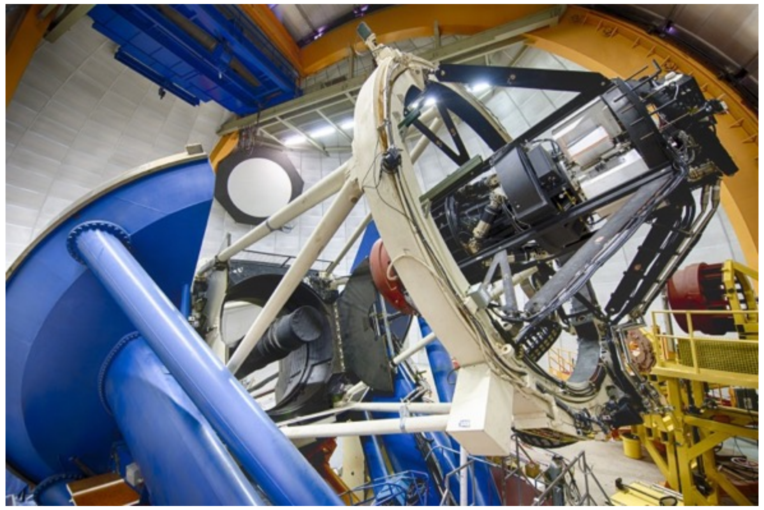

DES

LSST

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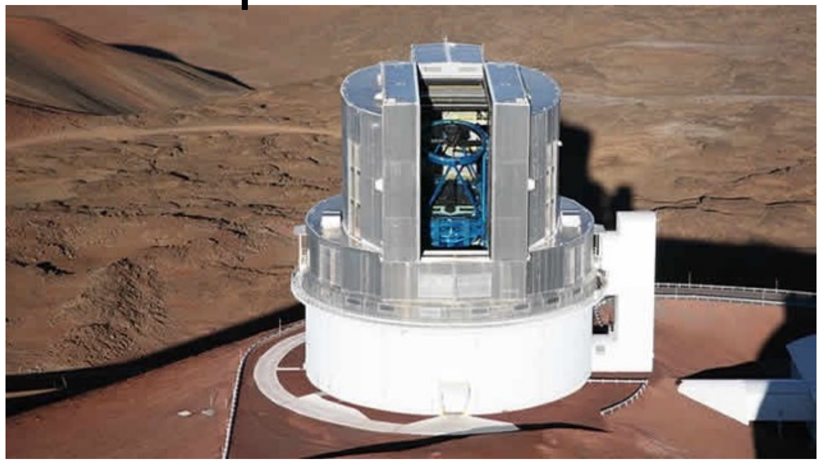
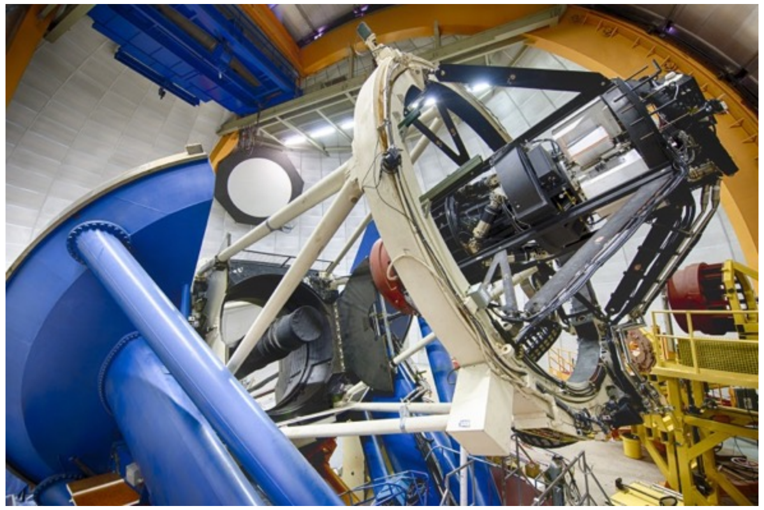


Subaru / HSC

The near terms goals is to make work the physical model for DES Y5



DES

MERCI !