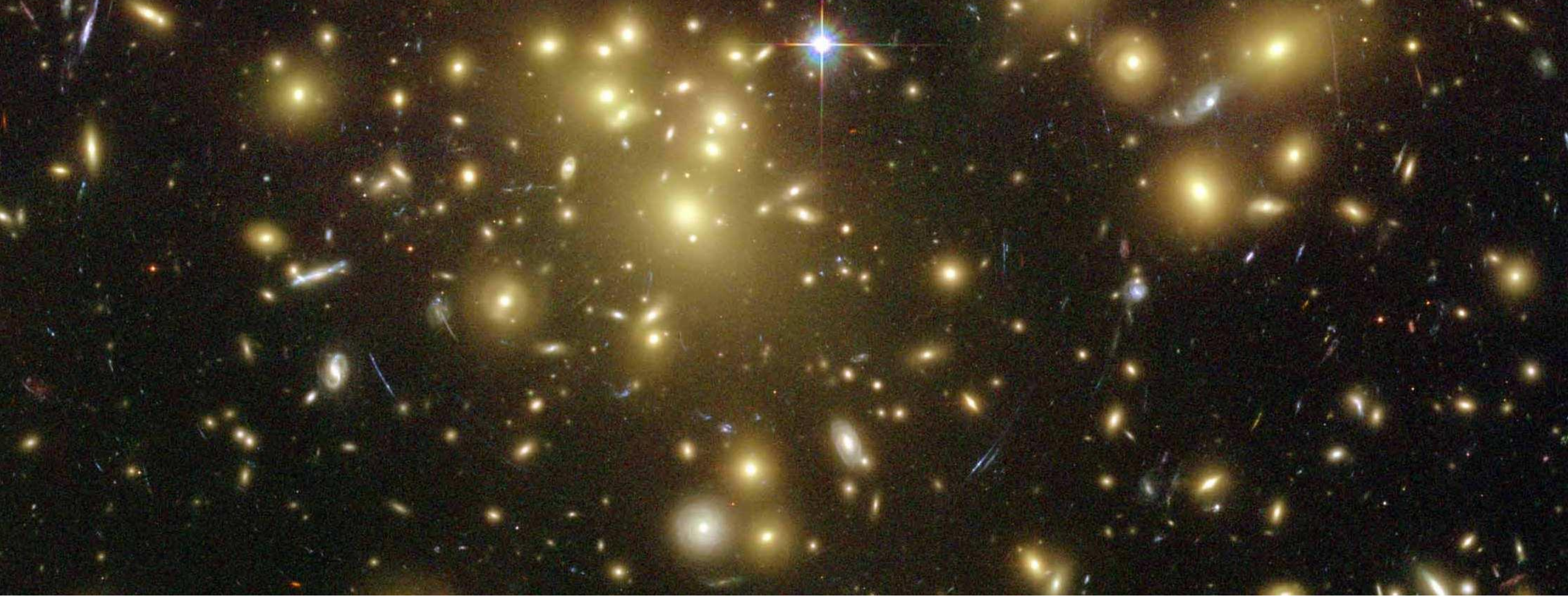

Astronomy in SJTU, and Weak Lensing Measurement

Jun Zhang (张骏) (SJTU)

Collaborators:

Fuyu Dong, Yingke Li, Xiangchong Li, Tianhuan Lu, Xiaohu Yang, Pengjie Zhang, Wentao Luo (SJTU); Nobuhiko Katayama (IPMU); Dezi Liu, Zuhui Fan (PKU); Liping Fu (SHNU); Guoliang Li (PMO). .

KIT, Sep 7, 2017

Outline:

- Introduction & Motivation
- The Fourier_Quad method
- Application on the CFHTlens data

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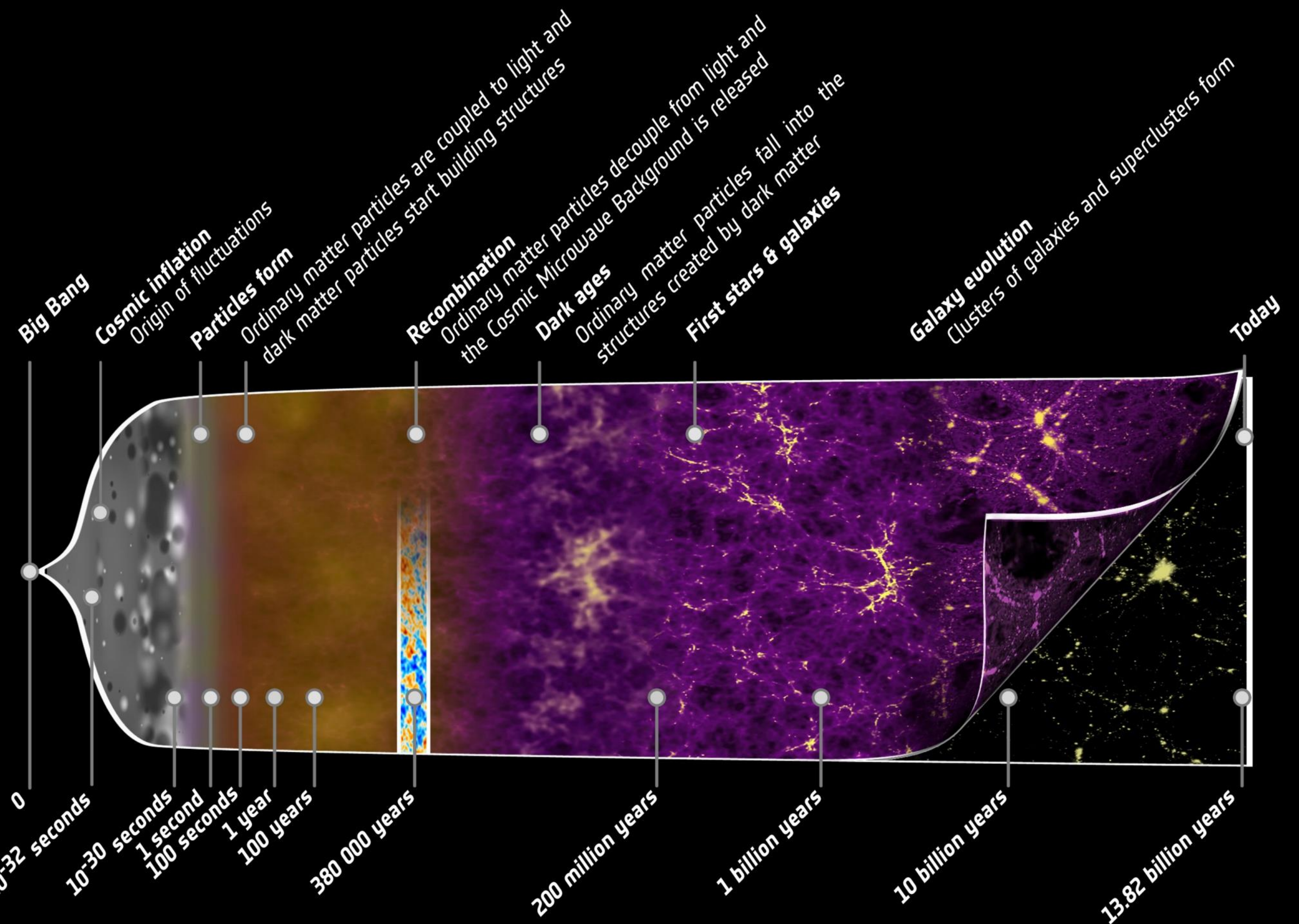
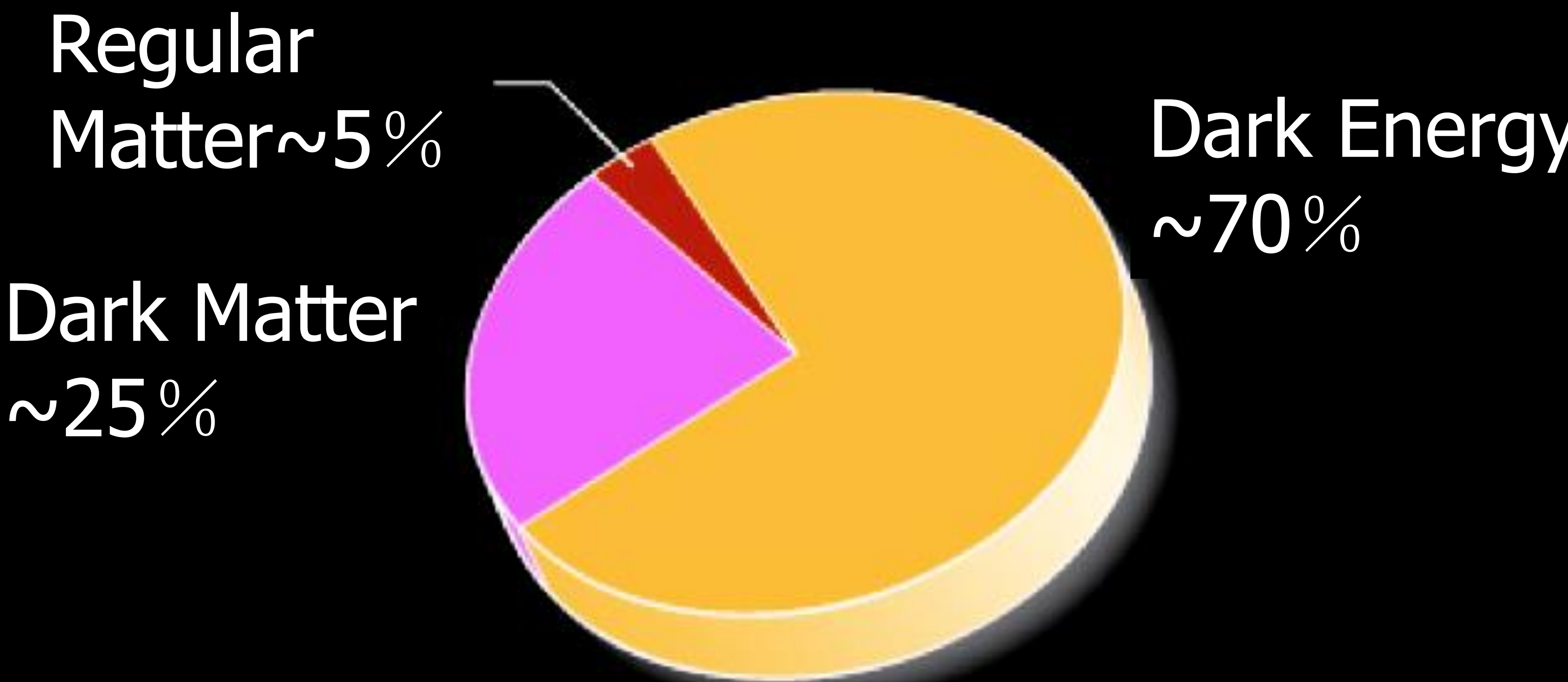
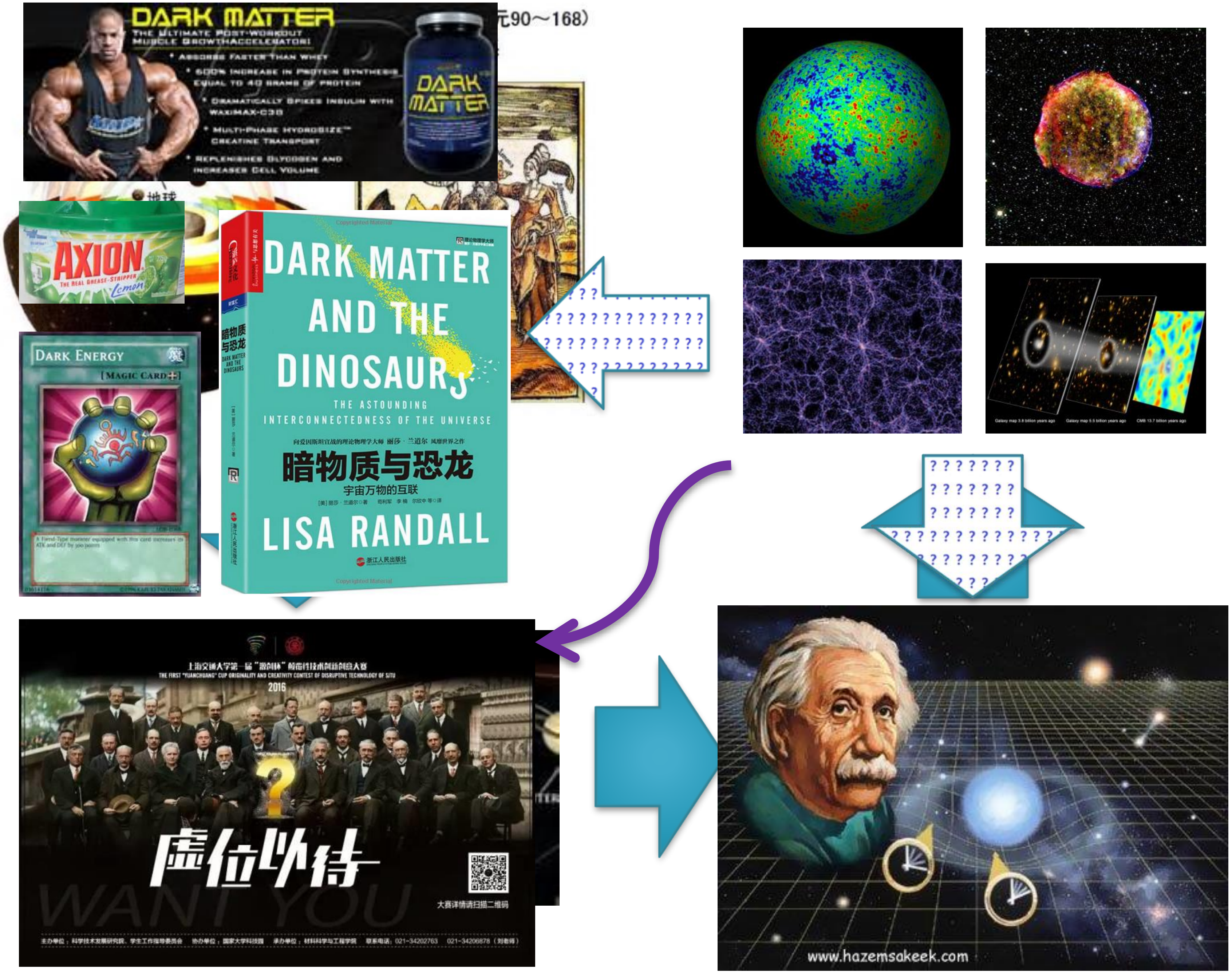


Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and
dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and
the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the
structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10^-32 seconds
10^-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years



Cosmic Energy Budget

Credit: NASA/WMAP


DARK MATTER
DARK MATTER
元90～168）
地球
AXION
THE REAL GREASE-STRIPPER
Lemon
DARK ENERGY
[MAGIC CARD]
DARK MATTER AND THE DINOSAURS
THE ASTOUNDING INTERCONNECTEDNESS OF THE UNIVERSE
暗物质与恐龙
宇宙万物的互联
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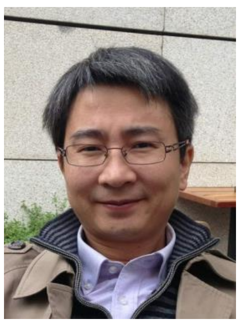
Department of Astronomy of SJTU

- Full Professors

Yipeng Jing

Bin Wang



Xiaohu Yang

Haiguang Xu

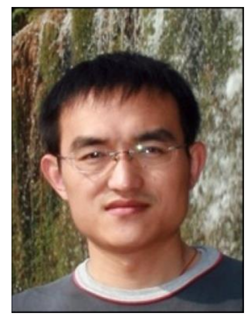
Pengjie Zhang

- Junior Faculty Members

Le Zhang

Ying Zu

Dangbo Liu



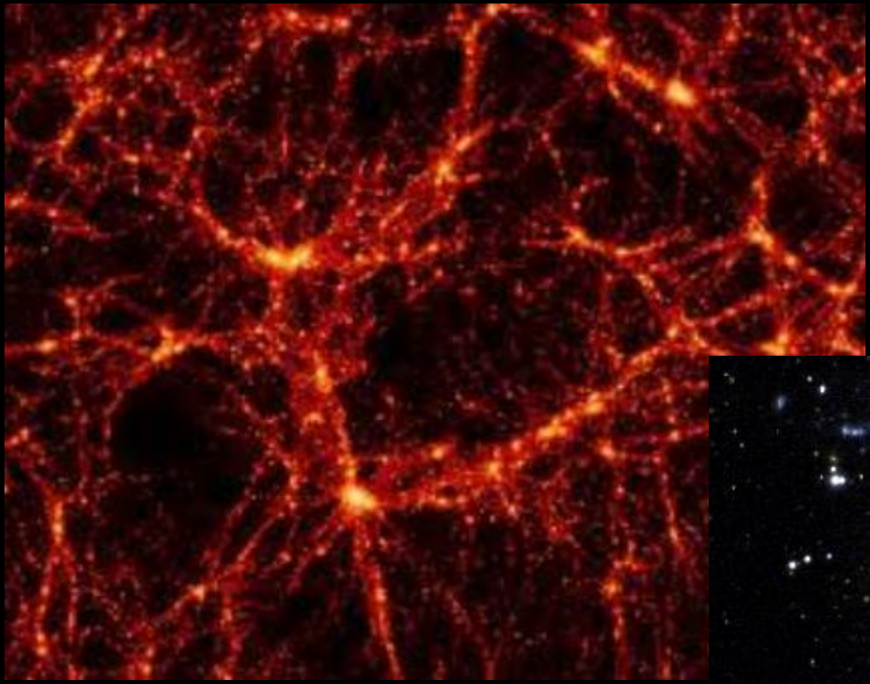
Chengze Liu

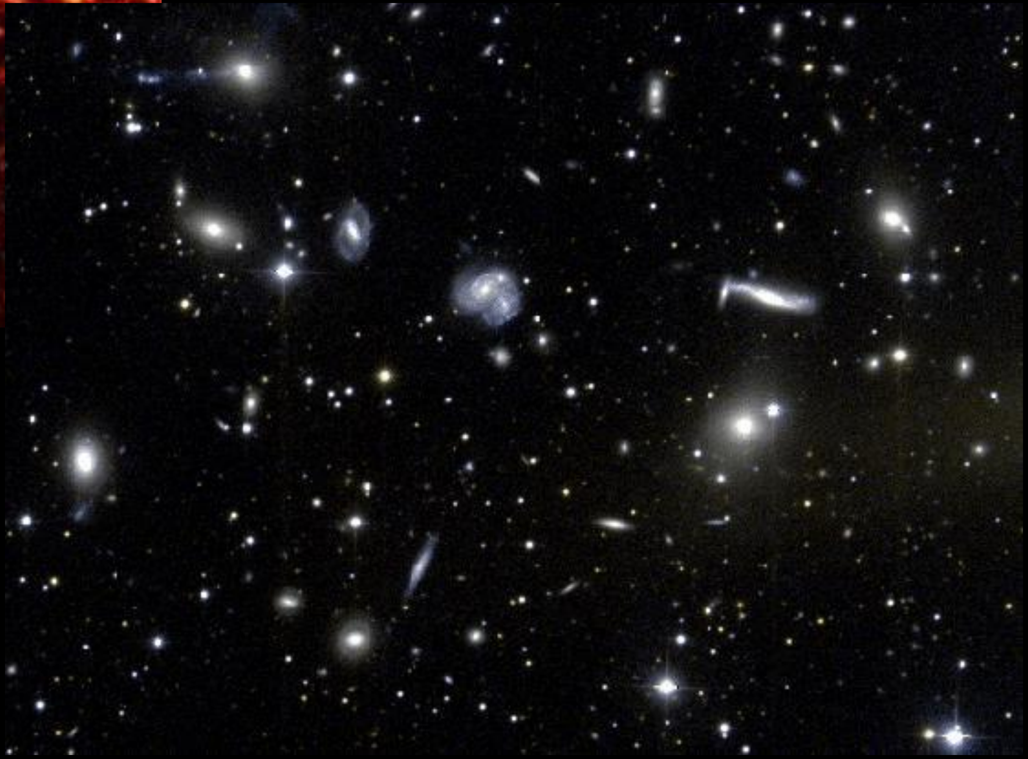
Dechang Dai

Jun Zhang

Yu Yu

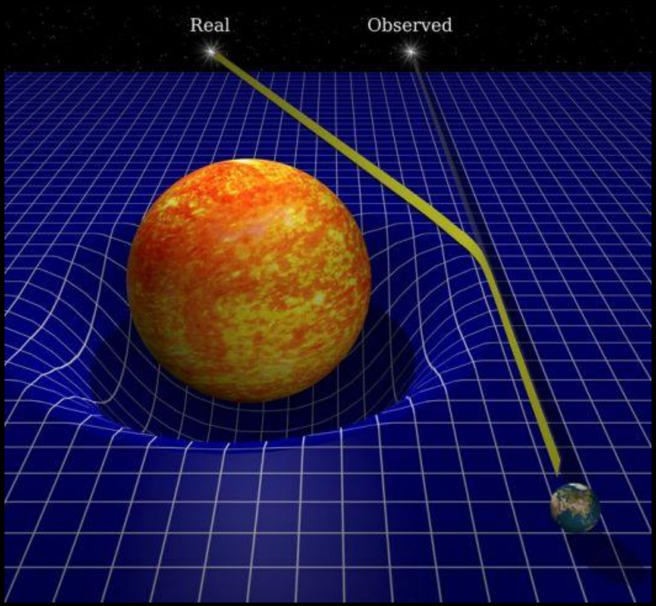
Zhigang Li

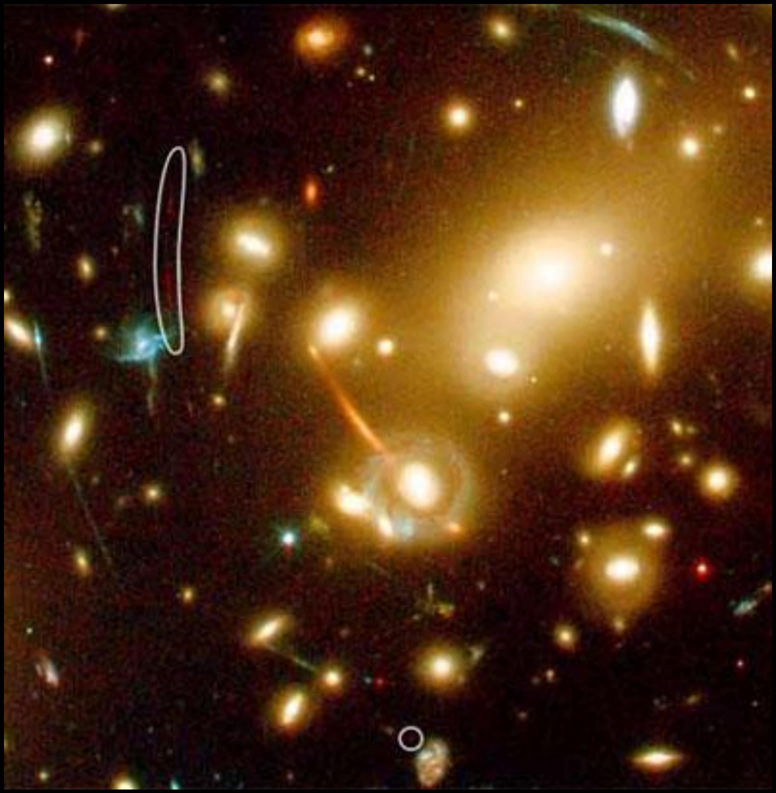


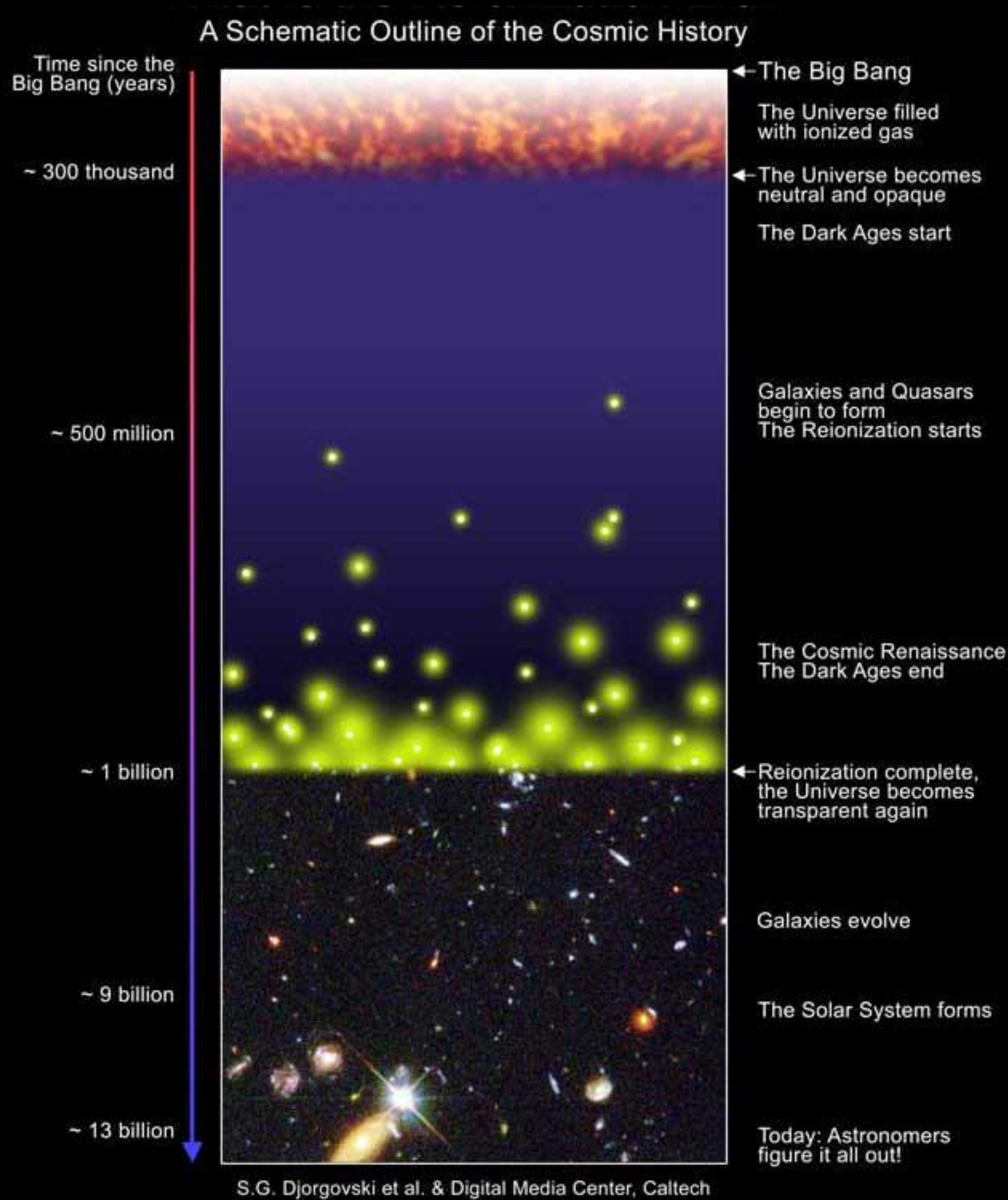


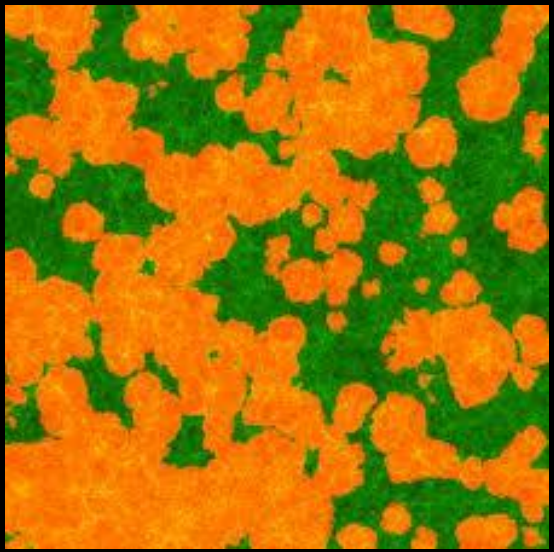
Large Scale Structure

Gravitational Lensing

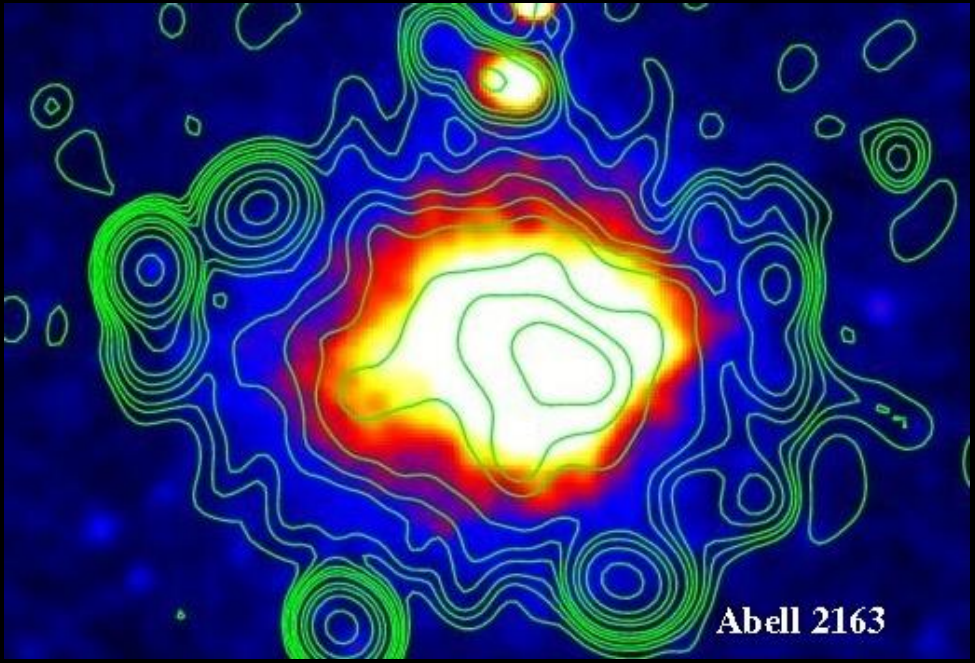


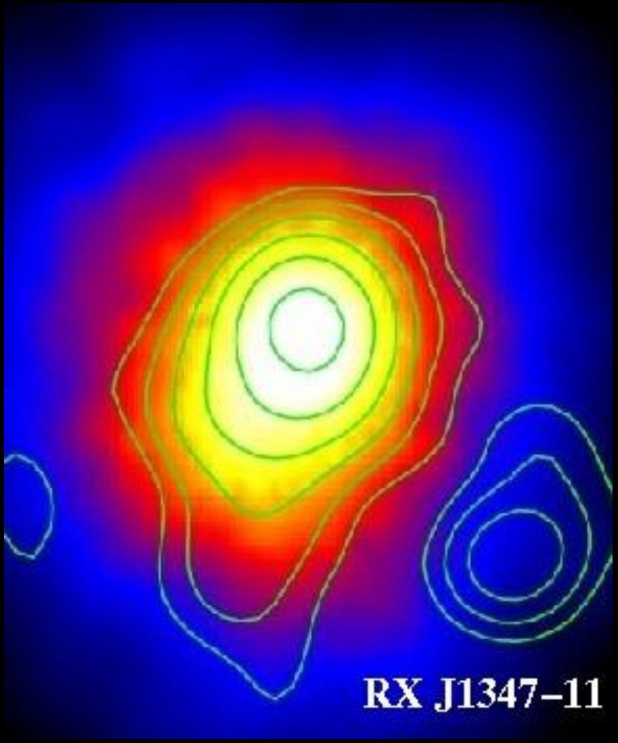


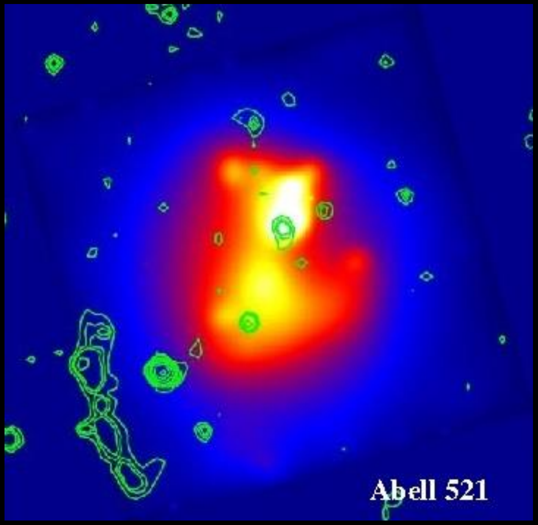




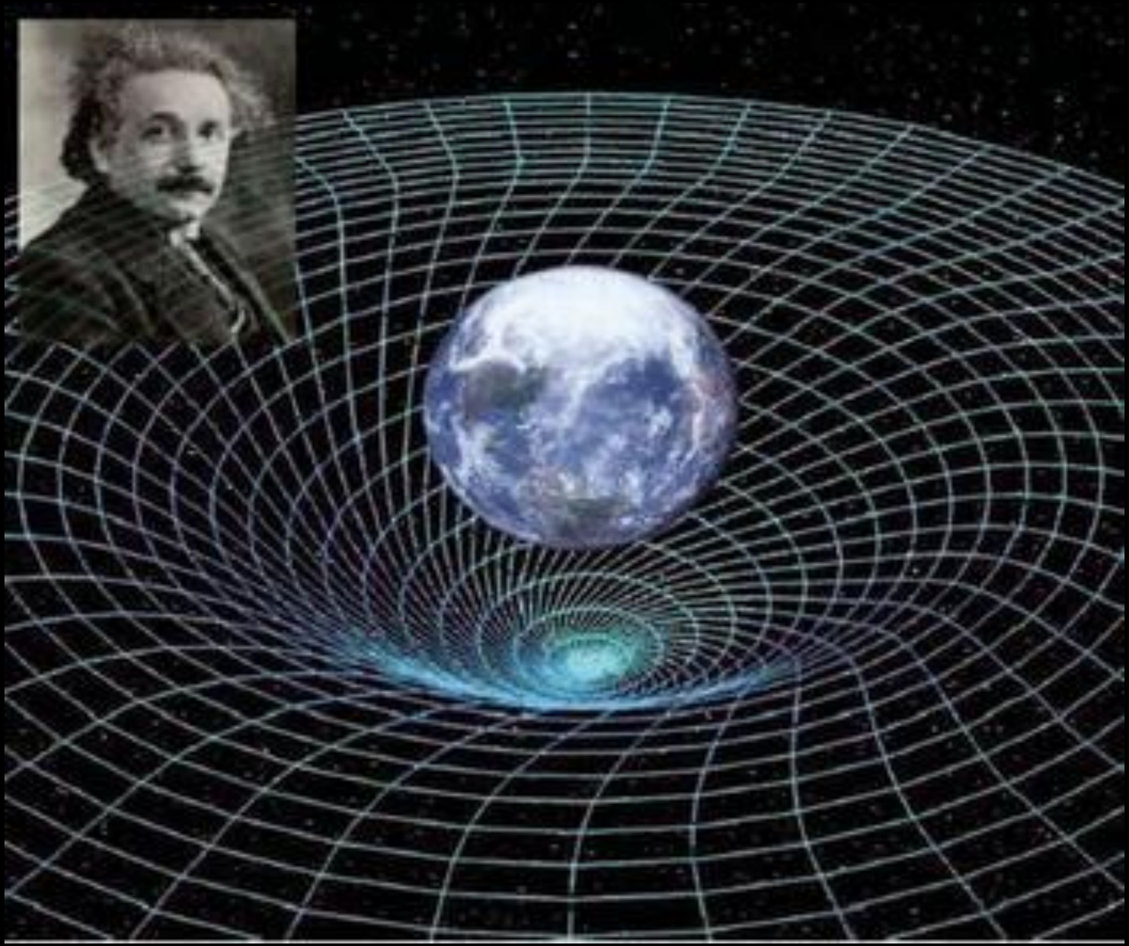
Cosmic Reionization



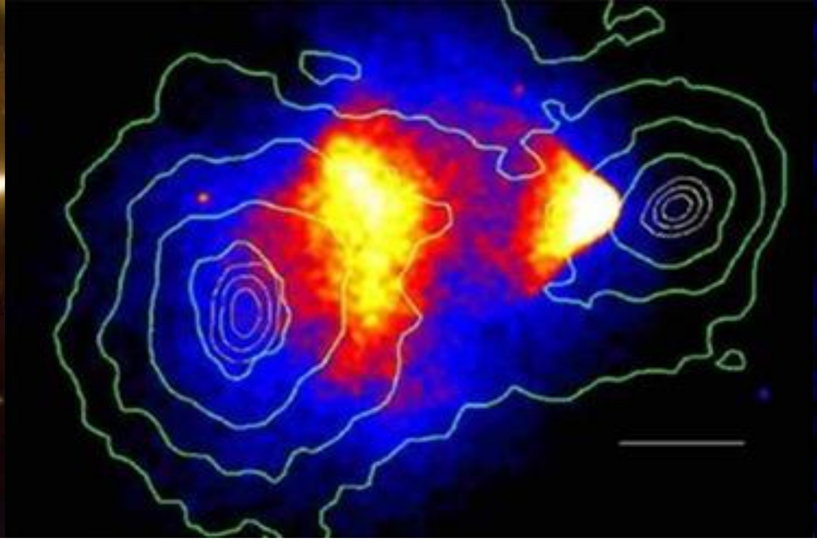
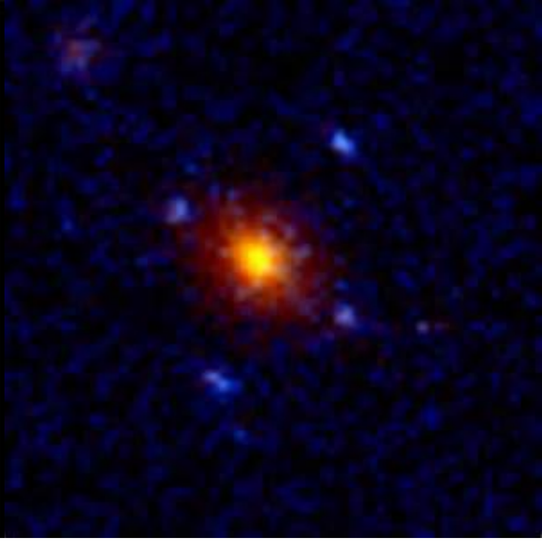




Cluster Physics

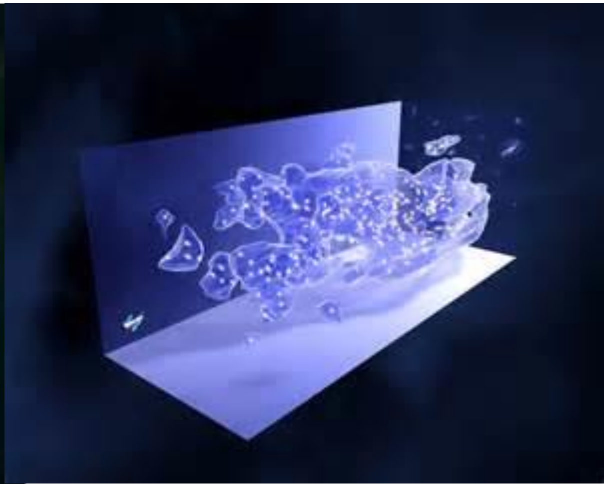


Gravity Theories

According to GR , lights from distant sources are deflected by gravity, causing the lensing effect. This visible effect can be used to probe the cosmic structures on large scales, leading to clues for possible new physics !!

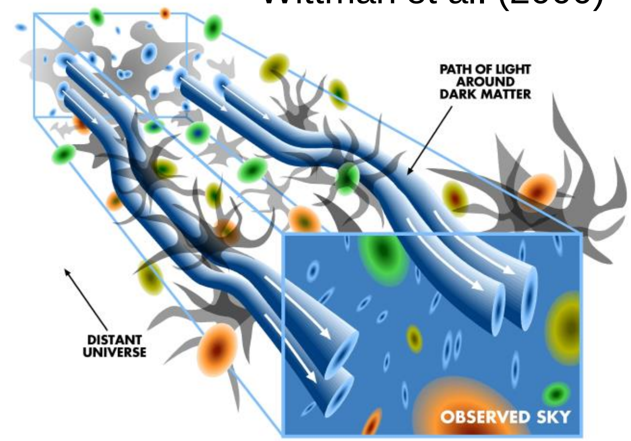


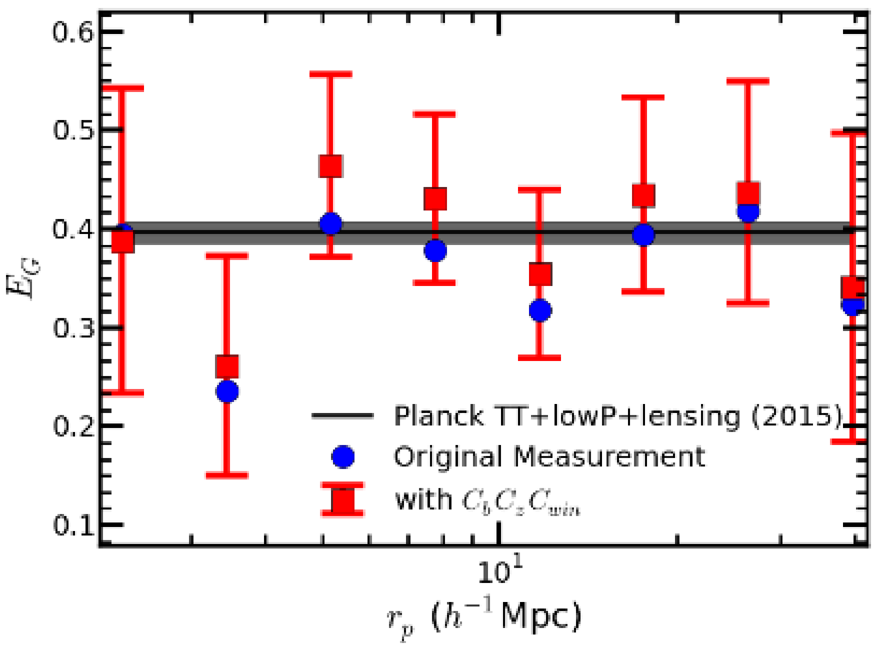


Application of Weak Lensing

- probing the density growth history
- probing the distance-redshift relation
- probing the nature of dark matter/energy
- Testing the theory of GR on cosmic scales

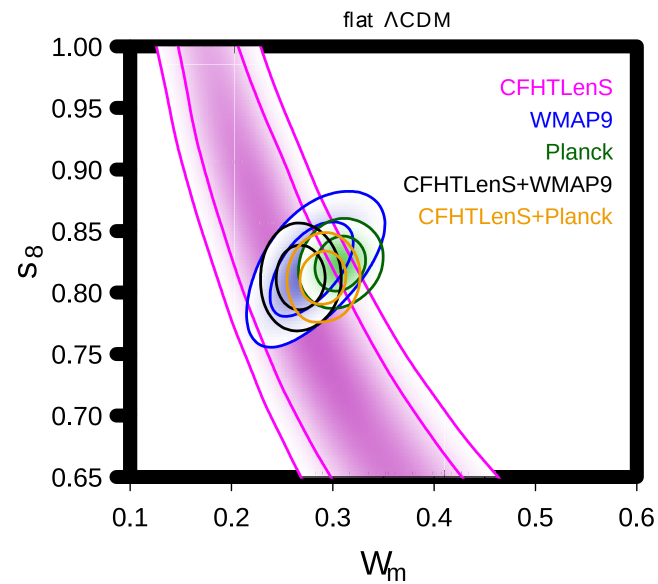
Image credit: Wittman et al. (2000)





Zhang et al. (2007)

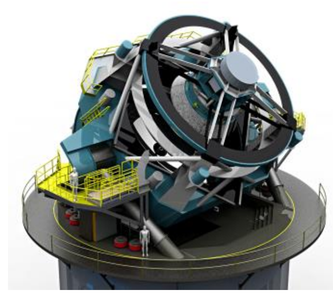
Alam et al. (2017)



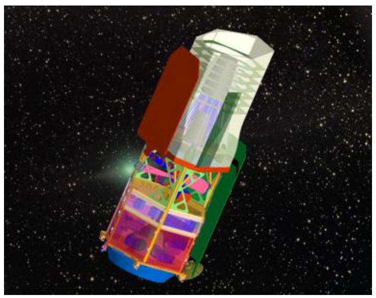
Credit: Fu et al. (2014)

DES

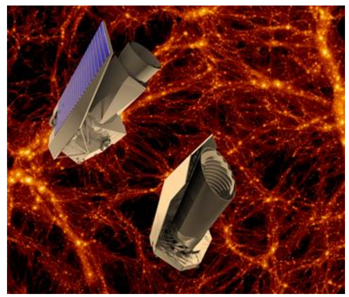
Subaru HSC



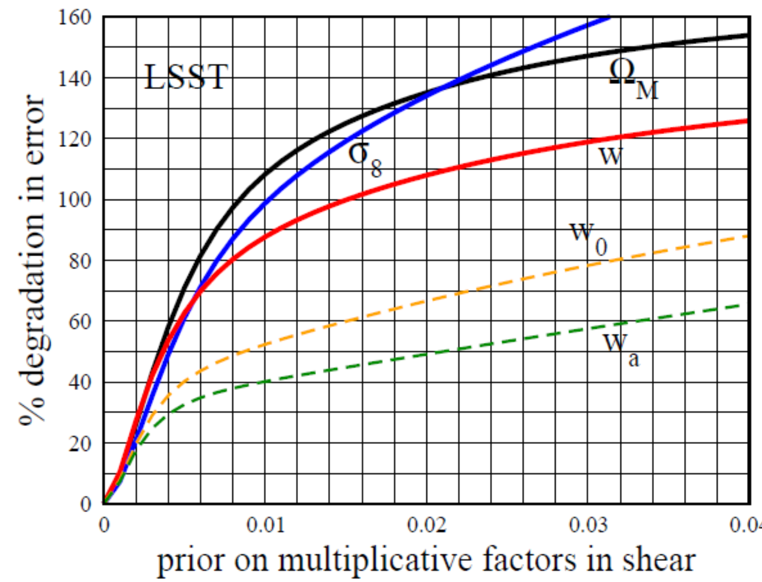
LSST



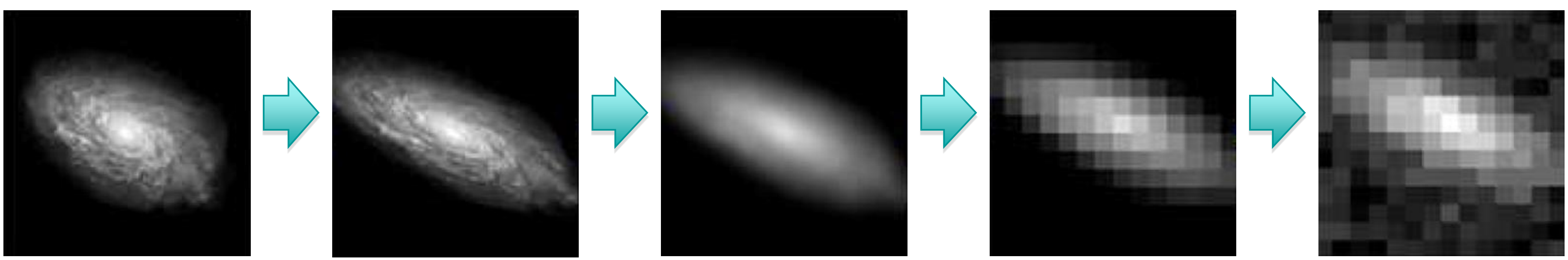
WFIRST



EUCLID



Huterer et al. (2006)



Lensing PSF Pixelation Noise

Shear TEsting Program I

Author	Key	Method
Bridle & Hudelot	SB	Im2shape (Bridle et al. 2001)
Brown	MB	KSB+ [Bacon et al. (2000) pipeline]
Clowe	C1 & C2	KSB+
Dahle	HD	K2K (Kaiser 2000)
Hetterscheidt	MH	KSB+ [Erben et al. (2001) pipeline]
Heymans	CH	KSB+
Hoekstra	HH	KSB+
Jarvis	MJ	Bernstein & Jarvis (2002) Rounding kernel method
Kuijken	KK	Shapelets to 12^{th} order Kuijken (2006)
Margoniner	VM	Wittman et al. (2001)
Nakajima	RN	Bernstein & Jarvis (2002) Deconvolution fitting method
Schrabback	TS	KSB+ [Erben et al. (2001) + modifications]
Van Waerbeke	LV	KSB+

Shear TEsting Program II

Author	Key	Method
Bergé	JB	Shapelets (Massey & Refregier 2005)
Clowe	C1	KSB+ (same PSF model used for all galaxies)
Clowe	C2	KSB+ (PSF weight size matched to galaxies')
Hetterscheidt	MH	KSB+
Hoekstra	HH	KSB+
Jarvis	MJ	Bernstein & Jarvis (2002)
Jarvis	MJ2	Bernstein & Jarvis (2002) (new weighting scheme)
Kuijken	KK	Shapelets (Kuijken 2006)
Mandelbaum	RM	Reglens (Hirata & Seljak 2003)
Nakajima	RN	Bernstein & Jarvis (2002) (deconvolution fitting)
Paulin-Henriksson	SP	KSB+
Schirmer	MS1	KSB+ (scalar shear susceptibility)
Schirmer	MS2	KSB+ (tensor shear susceptibility)
Schrabback	TS	KSB+
Semboloni	ES1	KSB+ (shear susceptibility fitted from population)
Semboloni	ES2	KSB+ (shear susceptibility for individual galaxies)

Heymans et al., 2006, MNRAS, 368, 1323

Massey et al., 2007, MNRAS, 376, 13

Bridle et al., 2009, Annals of Applied Statistics, 3, 6

Kitching et al., 2011, Annals of Applied Statistics, 5, 2231

Mandelbaum et al., 2014, ApJS, 212, 5

KSB+ Method:

$$Q_{ij}\left(x^{O},y^{O}\right)=\frac{\int d^{2}\vec{\theta}\cdot W\left(\vec{\theta}\right)f^{O}\left(\vec{\theta}\right)\theta_{i}\theta_{j}}{\int d^{2}\vec{\theta}\cdot W\left(\vec{\theta}\right)f^{O}\left(\vec{\theta}\right)}$$

$$\begin{pmatrix}\varepsilon_1\\ \varepsilon_2\end{pmatrix}=\frac{1}{Q_{11}+Q_{22}}\begin{pmatrix}Q_{11}-Q_{22}\\ 2Q_{12}\end{pmatrix}$$

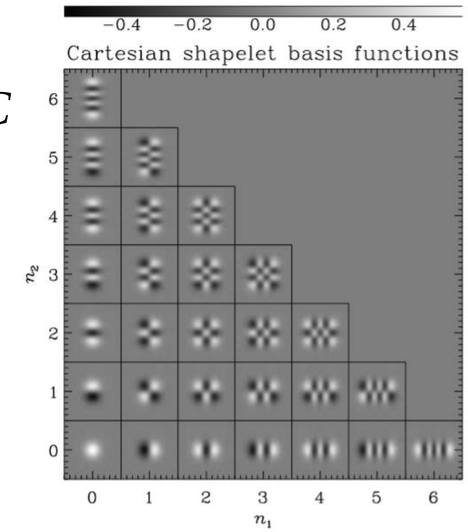
$$\Gamma_{\alpha}=\left(P^{\gamma}\right)^{-1}_{\alpha\beta}\left[\varepsilon_{\beta}-P^{sm}_{\beta\mu}\,p_{\mu}\right]$$

Heymans et al. (2006)

Shapelets Method:

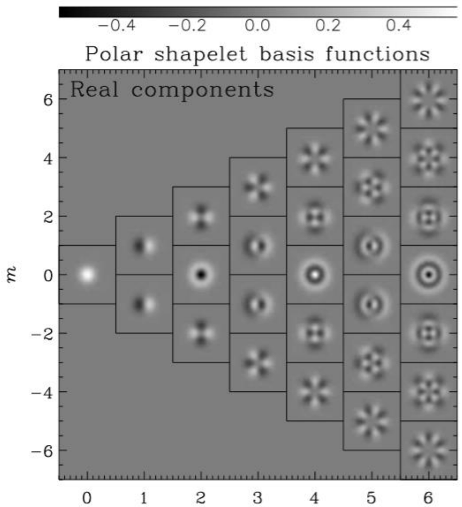
$$G_{\mathrm{model}}=P\cdot\left(1+\varepsilon_1 S_1+\varepsilon_2 S_2\right)\cdot C$$

$$\gamma_i=\frac{\langle\varepsilon_i\rangle}{1-\langle\varepsilon_1^2+\varepsilon_2^2\rangle}$$



Kuijken (2006)

BJ02 Method:



Bernstein & Jarvis (2002)

Bayesian Galaxy Shape Measurement Method: (Lensfit)

$$\chi^2=\sum_i\left[\frac{y_i-SBg_i-S(1-B)f_i}{\sigma_i}\right]^2$$

Miller et al. (2013)

Challenges & Opportunities

Lensing is Low: Cosmology, Galaxy Formation, or New Physics?

Alexie Leauthaud[1,2], Shun Saito[3], Stefan Hilbert[4,5], Alexandre Ba
Martin White[6], Shadab Alam[7,8], Peter Behroozi[6,9], Kevin Bundy
Thomas Erben[11], Catherine Heymans[8], Hendrik Hildebrandt[11], R
Lance Miller[12], Bruno Moraes[13], Maria E. S. Pereira[14], Sergio A.
Fabian Schmidt[3], Huan-Yuan Shan[18], Matteo Viel[19,20], Francisco
[1] *Department of Astronomy and Astrophysics, University of California, Santa Cruz, 1156 High Street, San*
[2] *Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba, 277-8583, Japan*
[3] *Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Starße 1, D-85740 Garching bei München, Gerr*
[4] *Exzellenzcluster Universe, Boltzmannstr. 2, 85748 Garching, Germany*
[5] *Ludwig-Maximilians-Universität, Universitäts-Sternwarte, Scheinerstr. 1, 81679 München, Germany*
[6] *Department of Physics, University of California, Berkeley, CA 94720*
[7] *McWilliams*
[8] *The Scottisl*
[9] *Hubble Fellc*

Problems with KiDS

George Efstathiou and Pablo Lemos
Kavli Institute for Cosmology Cambridge and Institute of Astronomy, Madingley Road,

4 July 2017

ABSTRACT
The Kilo-Degree Survey (KiDS) has been usec
straints on the amplitude of the matter powe
redshift. Some of these analyses have claimed
mology at the $\sim 2-3\sigma$ level, perhaps indic
is consistent with other low redshift probes c
redshift space distortions and the combined
spectra. Here we perform consistency tests of t
for various cuts of the data at $\gtrsim 3\sigma$ significa
understood, we argue that it is premature tc
KiDS.

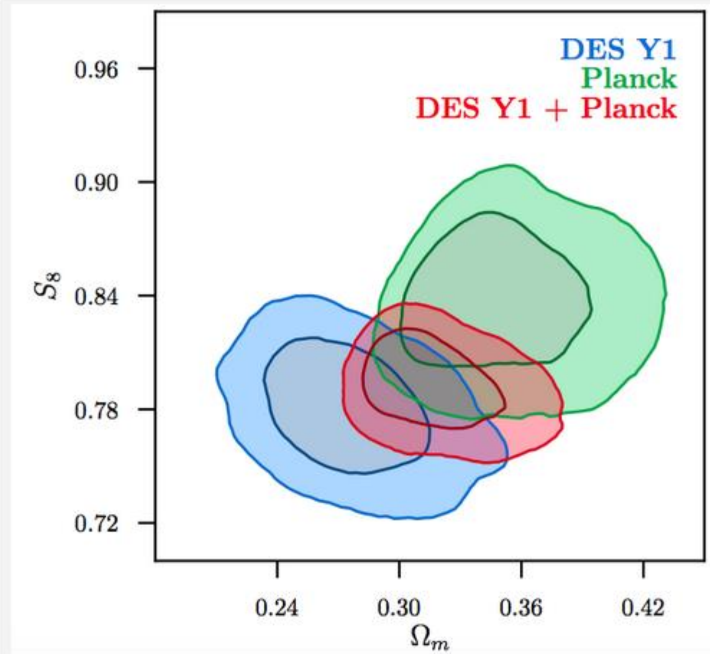
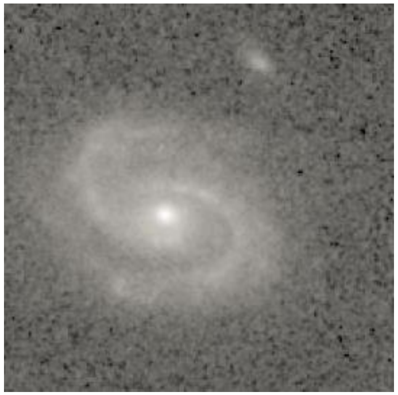


Figure 4. A plot of fluctuation scale S_8 (a robust functional form of σ_8) vs. matter density Ω_m from the DES Cosmology results – Figure 10 of the paper. Assumed here is a likelihood model with ΛCDM (w=-1), with darker contours depicting 68% confidence level intervals. DES Y1 results (weak lensing, clustering, blue) are a 'slight' departure from the Planck results (CMB, no lensing, green), but with combined datasets one can see stronger constraints on the cosmological parameters.

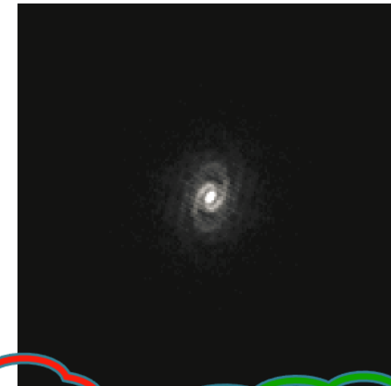
Outline:

- Introduction & Motivation
- The Fourier_Quad method
- Application on the CFHTlens data

The Fourier_Quad Method



$$\tilde{f}(\vec{k}) = \int d^2\vec{x}e^{i\vec{k}\cdot\vec{x}}f(\vec{x}).$$



Galaxy

Noise

$$G_1 = -\frac{C}{2}\sum_{j=1}^{N_T}\left[(\vec{k}_j)_x^2 - (\vec{k}_j)_y^2\right]T(\vec{k}_j)M(\vec{k}_j)$$

$$G_2 = -C\sum_{j=1}^{N_T}(\vec{k}_j)_x(\vec{k}_j)_y T(\vec{k}_j)M(\vec{k}_j)$$

$$N = C\sum_{j=1}^{N_T}\left[\left|\vec{k}_j\right|^2 - \frac{\beta^2}{2}\left|\vec{k}_j\right|^4\right]T(\vec{k}_j)M(\vec{k}_j)$$

$$M(\vec{k}) = \left|\tilde{f}^O(\vec{k})\right|^2 - F^O - \left|\tilde{f}^B(\vec{k})\right|^2 + F^B$$

$$F^O = \frac{\sum_{|\vec{k}_j|>k_c}\left|\tilde{f}^O(\vec{k}_j)\right|^2}{\sum_{|\vec{k}_j|>k_c}}, \quad F^B = \frac{\sum_{|\vec{k}_j|>k_c}\left|\tilde{f}^B(\vec{k}_j)\right|^2}{\sum_{|\vec{k}_j|>k_c}}$$

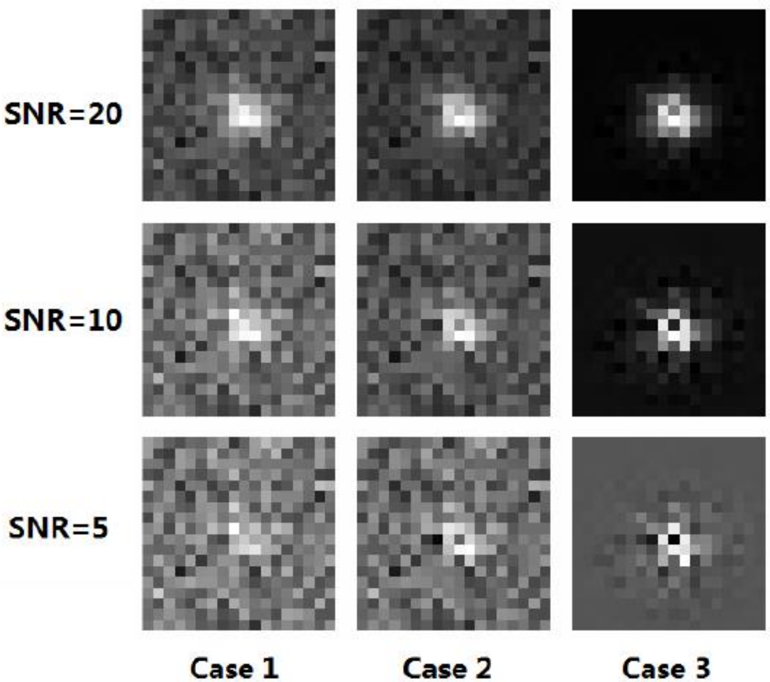
$$\frac{\langle G_1\rangle}{\langle N\rangle} = g_1, \quad \frac{\langle G_2\rangle}{\langle N\rangle} = g_2$$

Zhang, Luo, Foucaud, 2015

Test Results

$$g_1^{measured} = (1 + m_1) g_1^{input} + c_1$$

$$g_2^{measured} = (1 + m_2) g_2^{input} + c_2$$



	Case 1	Case 2	Case 3
SNR= 20	$m_1(10^{-3})$: -0.2 ± 0.2	-0.2 ± 0.1	-0.08 ± 0.05
	$c_1(10^{-5})$: -1.0 ± 0.7	-0.6 ± 0.4	0.0 ± 0.2
SNR= 10	-0.6 ± 0.6	-0.4 ± 0.4	-0.1 ± 0.1
	-2.6 ± 2.1	-1.6 ± 1.2	0.0 ± 0.4
SNR= 5	-2.2 ± 2.3	-1.1 ± 1.2	0.0 ± 0.2
	-7.9 ± 7.9	-4.6 ± 4.1	0.1 ± 0.8
SNR= 20	$m_2(10^{-3})$: -0.2 ± 0.2	-0.3 ± 0.1	-0.3 ± 0.05
	$c_2(10^{-5})$: 1.4 ± 0.7	1.1 ± 0.4	0.3 ± 0.2
SNR= 10	-0.3 ± 0.6	-0.4 ± 0.4	-0.4 ± 0.1
	3.7 ± 2.1	2.6 ± 1.2	0.6 ± 0.4
SNR= 5	-0.7 ± 2.3	-0.9 ± 1.2	-0.6 ± 0.2
	10.6 ± 7.9	6.6 ± 4.1	1.2 ± 0.8

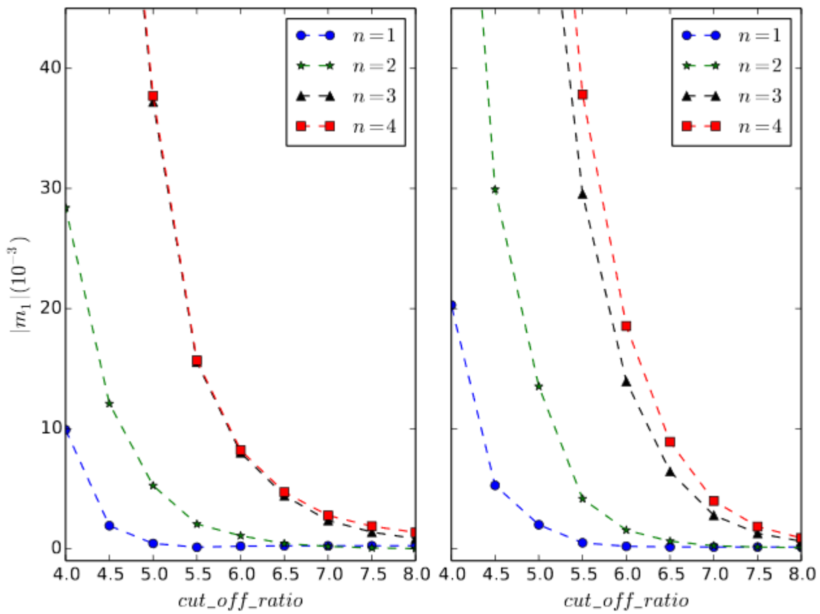
Zhang, Luo, Foucaud, 2015

Team	Class	Weighting scheme	Calibration philosophy	Limitations	$N_{\rm branch}$	Rank	Exact PSF?	New software	Time per galaxy
Amalgam@IAP	Maximum likelihood	Inverse variance	Ellipticity penalty	None	16	2	Yes	Some	0.1–1 s
BAMPenn	Bayesian Fourier	Implicit	$p(\varepsilon)$ from deep data	Variable shear	2	-	Yes	Yes	< 1 s
EPFL_gfit	Maximum likelihood	Constant + rejection	None	None	8	6	Yes	Yes	1–3 s
CEA-EPFL	Maximum likelihood	Various	None	None	20	3	Yes	Yes	1–3 s
CEA_denoise	Moments	Constant	None	None	8	-	Yes	No	0.03 s
CMU experimenters	Stacking	Constant	External simulations	Variable shear	2	N/A	Yes	Some	0.03 s
COGS (IM3SHAPE)	Maximum likelihood	Constant	External simulations	None	12	N/A	Yes	Yes	1 s
E-HOLICS	Moments	Constant + rejection	External simulations	None	12	8	Yes	No	1–3 s
EPFL_HNN	Neural network	Constant	None	None	7	-	Yes	Yes	2-3 s
EPFL_KSB	Moments	Inverse variance	None	None	4	-	Yes	No	0.001-0.002 s
EPFL_MLP / EPFL_MLP_FIT	Neural network	Constant	None	None	5	-	Yes	Yes	2-3 s
FDNT	Fourier moments	Inverse variance	External simulations	None	12	N/A	Yes	Some	~ 1 s
Fourier_Quad	Fourier moments	Various	None	None	6	5	Yes	No	0.001-0.002 s
HSC/LSST-HSM	Moments	Inverse variance	External simulations	None	4	N/A	Yes	Some	0.05 s
MBI	Bayesian hierarchical	Implicit	Inferred $p(\varepsilon)$	Variable shear, PSF	4	9	No	Some	10 s
MaltaOx (LENSFIT)	Partially Bayesian	Inverse variance	Self-calibration	None	3	7	Yes	Some	0.05 s
MegaLUT	Supervised ML	Constant + rejection	External simulations	None	16	4	Yes	Some	0.02 s
MetaCalibration	Moments + self-calibration	Inverse variance	Self-calibration	Variable shear	1	N/A	Yes	Yes	0.3 s
Wentao_Luo	Moments	Inverse variance	None	None	4	-	Yes	Yes	1-2 s
ess	Bayesian model-fitting	Implicit	$p(\varepsilon)$ from deep data	Variable shear	2	-	No	Yes	1 s
sFIT	Maximum likelihood	Inverse variance	External simulations (iterative)	None	20	1	Yes	Yes	0.8 s

Mandelbaum et al. (2015)

Some Recent Progress

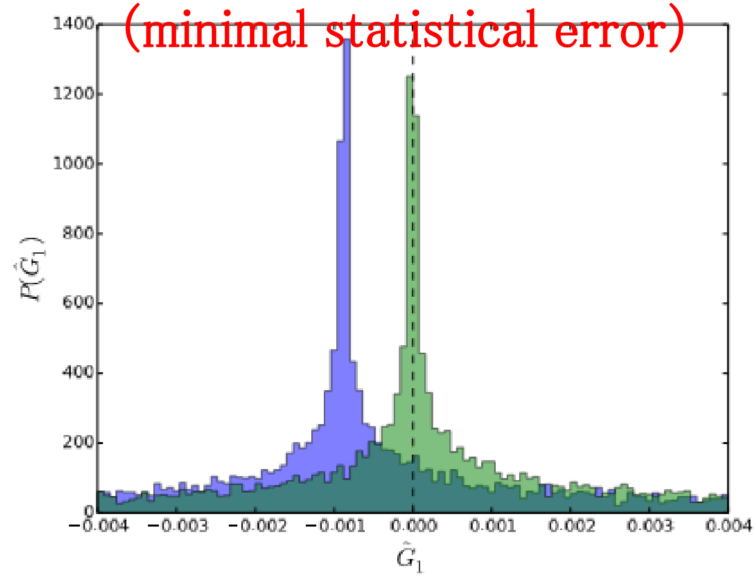
About Image Size



$$f(\vec{x}) = \frac{1}{a(n)r_e^2} e^{-b(n)(|\vec{x}|/r_e)^{\frac{1}{n}}}$$

New Statistics Approaching the C−R Limit

(minimal statistical error)



Method	$g_1(-0.018)$	$g_2(0.011)$
Direct Averaging	−0.017(2)	0.011(2)
PDF-SYM (2 bins)	−0.01798(3)	0.01100(2)
PDF-SYM (4 bins)	−0.01799(2)	0.01102(2)
PDF-SYM (8 bins)	−0.01800(2)	0.01101(2)

Li & Zhang, 2016, ApJ, 830, 116

JZ, Zhang, Luo, 2017, ApJ, 834, 8

APPROACHING THE CRAMER-RAO BOUND IN WEAK LENSING WITH PDF SYMMETRIZATION

C-R BOUND

$$0 = \frac{d}{d\hat{g}} \sum_i \ln P(x_i - \hat{g})$$

$$\sigma_{\hat{g}}^{-2} = -\sum_i \frac{\partial^2 \ln P(x_i - \hat{g})}{\partial \hat{g}^2}$$

Examples

$$P_1(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$$

$$P_2(x) = \frac{2}{\pi}(1+x^2)^{-2}$$

$$P_3(x) = \frac{|x|^{-2/3}}{3\sqrt{2\pi}} \exp\left(-\frac{|x|^{2/3}}{2}\right)$$

$$N_T\sigma_1^2(\mathrm{Ave}) = 1, \quad N_T\sigma_1^2(\mathrm{CR}) = 1,$$

$$N_T\sigma_2^2(\mathrm{Ave}) = 1, \quad N_T\sigma_2^2(\mathrm{CR}) = 0.5,$$

$$N_T\sigma_3^2(\mathrm{Ave}) = 15, \quad N_T\sigma_3^2(\mathrm{CR}) \to 0.$$

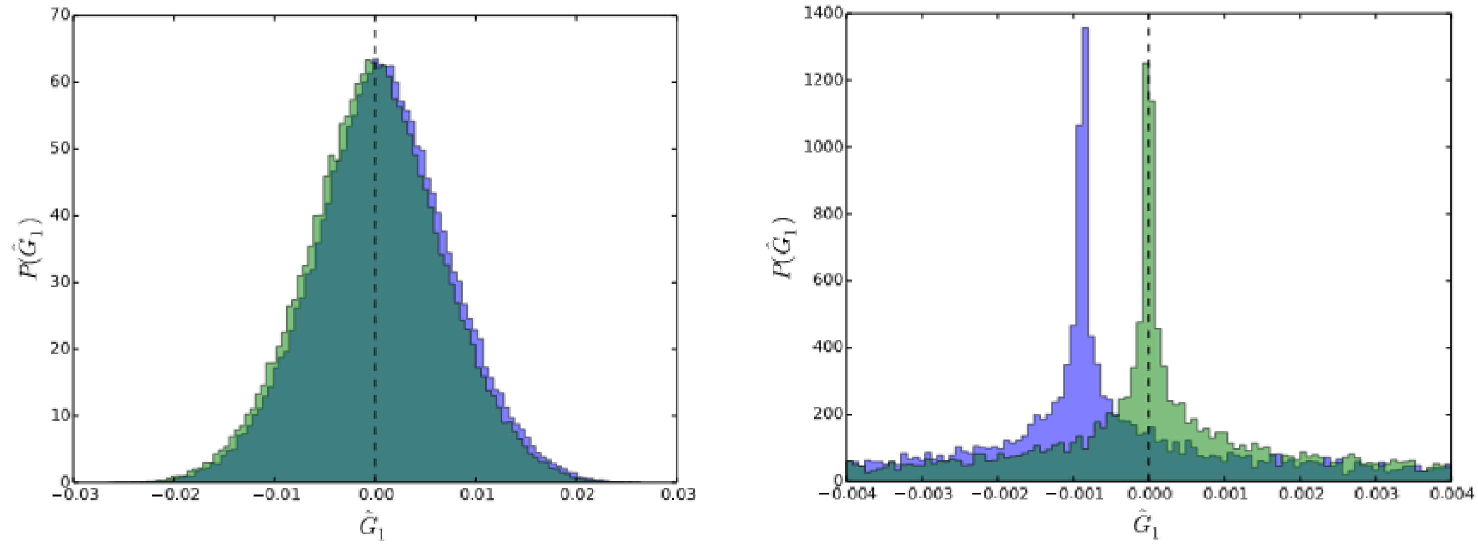
The results of signal recovery (input value is 0.01) for 10^7 data points of three types of PDF's

Results:	Averaging	PDF-SYM (2 bins)	PDF-SYM (8 bins)	PDF-SYM (16 bins)	PDF-SYM (32 bins)
P_1	0.0102(3)	0.0104(4)	0.0101(3)	0.0100(4)	0.0102(3)
P_2	0.0099(3)	0.0101(2)	0.0101(2)	0.0100(2)	0.0101(2)
P_3	0.011(1)	0.0099999998(2)	0.0099999998(1)	0.0099999998(1)	0.0099999999(2)

$N_T\sigma^2$:	Averaging	PDF-SYM (2 bins)	PDF-SYM (8 bins)	PDF-SYM (16 bins)	PDF-SYM (32 bins)
P_1	1.0	1.6	1.1	1.2	0.96
P_2	0.99	0.61	0.52	0.50	0.57
P_3	15	5×10^{-13}	2×10^{-13}	2×10^{-13}	3×10^{-13}

JZ, Zhang, Luo, 2017, ApJ, 834, 8

APPROACHING THE CRAMER-RAO BOUND IN WEAK LENSING WITH PDF SYMMETRIZATION

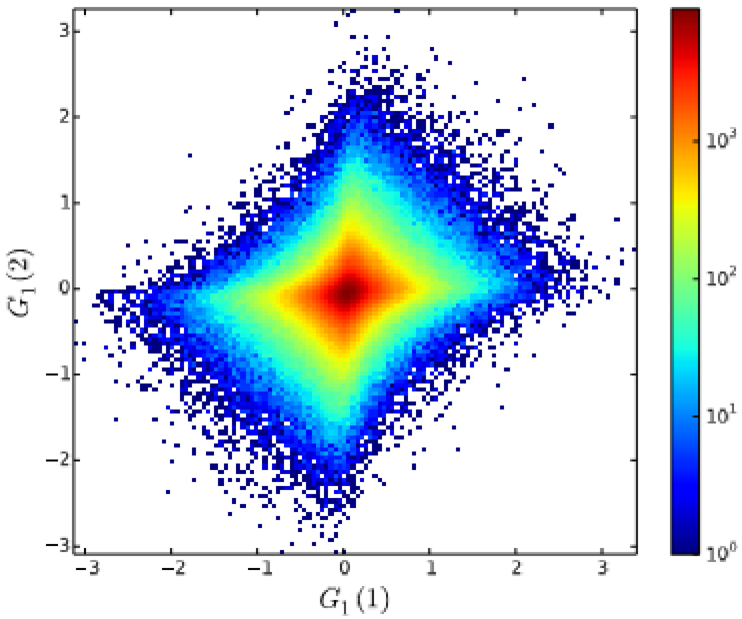


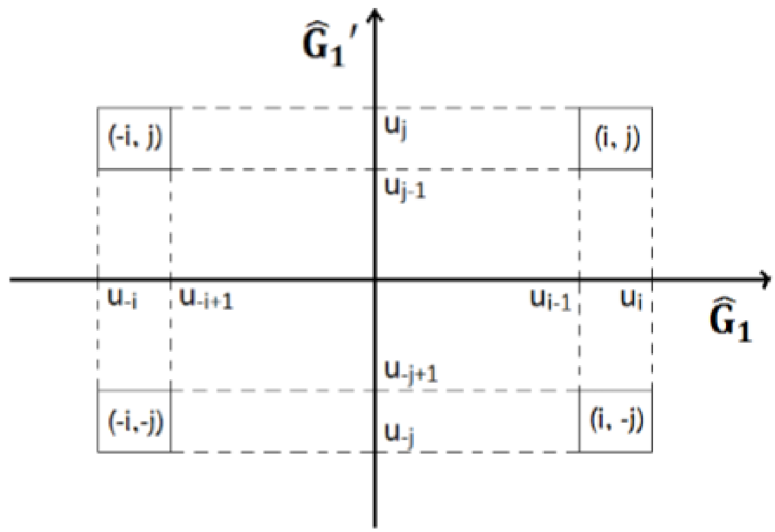
$g_1 = 0.02277,\ g_2 = -0.01386$

Results of $[g_1, g_2]$:	10^5 RW Galaxies	9×10^4 RW+10^4 Ring
Averaging	$[0.0226(6), -0.0130(6)]$	$[0.0231(6), -0.0132(6)]$
PDF-SYM (8 bins)	$[0.0225(7), -0.0129(6)]$	$[0.02278(8), -0.01392(7)]$

JZ, Zhang, Luo, 2017, ApJ, 834, 8

APPROACHING THE CRAMER-RAO BOUND IN WEAK LENSING WITH PDF SYMMETRIZATION





The recovered shear-shear correlations. The inputs are $\langle g_t^{(1)} g_t^{(2)} \rangle = 10^{-4}$ and $\langle g_\times^{(1)} g_\times^{(2)} \rangle = -10^{-4}$.

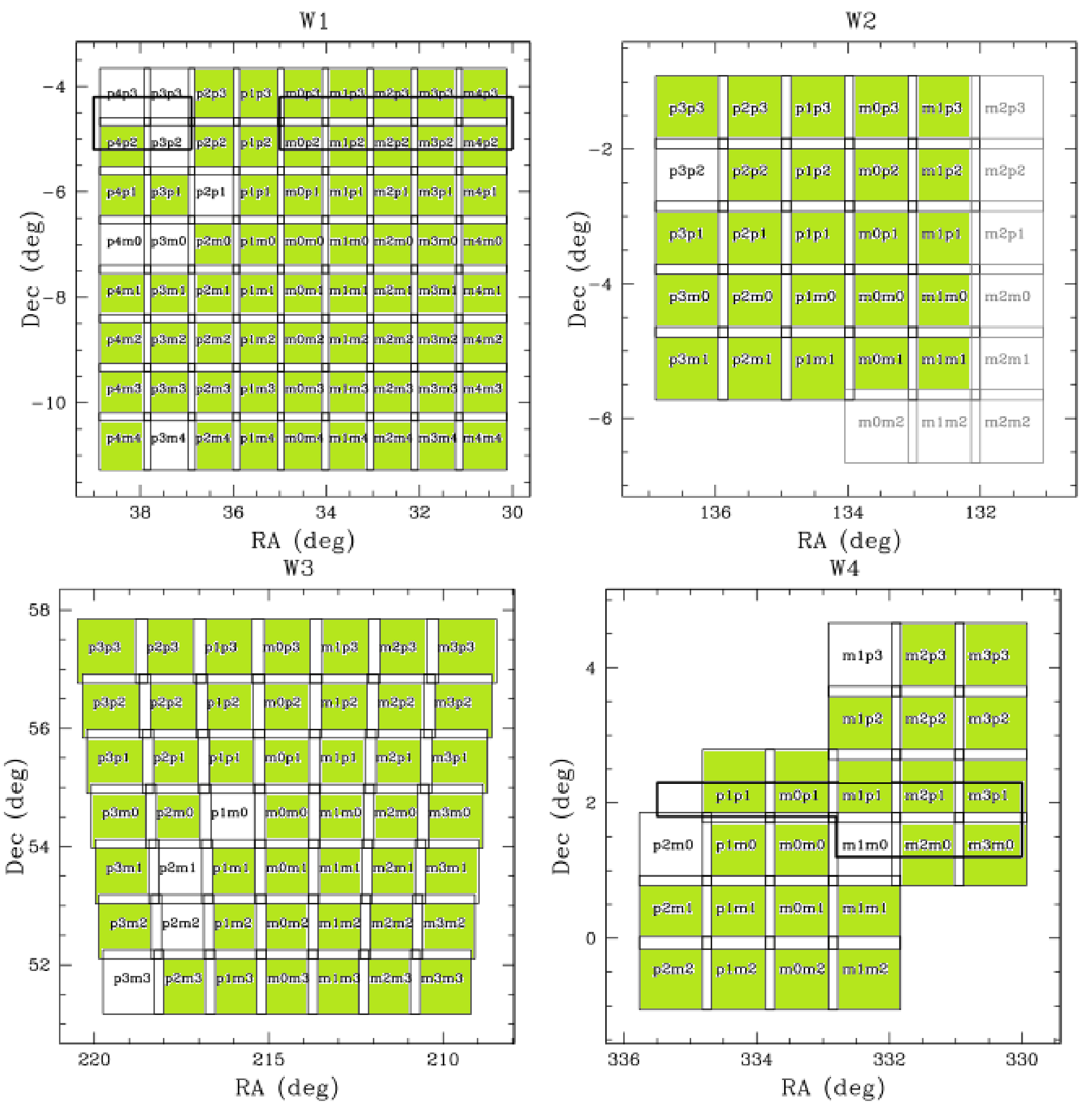
Results of $[\langle g_t^{(1)} g_t^{(2)} \rangle, \langle g_\times^{(1)} g_\times^{(2)} \rangle](10^{-4})$:	Averaging	PDF-SYM (8×8 bins)
4×10^7 RW Gal. Pairs	[1.09(8), −1.00(8)]	[1.09(8), −1.01(9)]
4×10^7 Ring Gal. Pairs	[1.05(7), −1.08(7)]	[1.002(5), −1.002(5)]
4×10^7 Gal. Pairs with 90% RW and 10% Ring	[1.09(8), −1.02(8)]	[0.99(3), −1.00(3)]
1.6×10^8 Ring Gal. Pairs with noise and 10% stars	[0.97(4), −1.05(4)]	[1.000(3), −1.001(3)]

JZ, Zhang, Luo, 2017, ApJ, 834, 8

Outline:

- Introduction & Motivation
- The Fourier_Quad method
- Application on the CFHTlens data

Application on the CFHTlens data



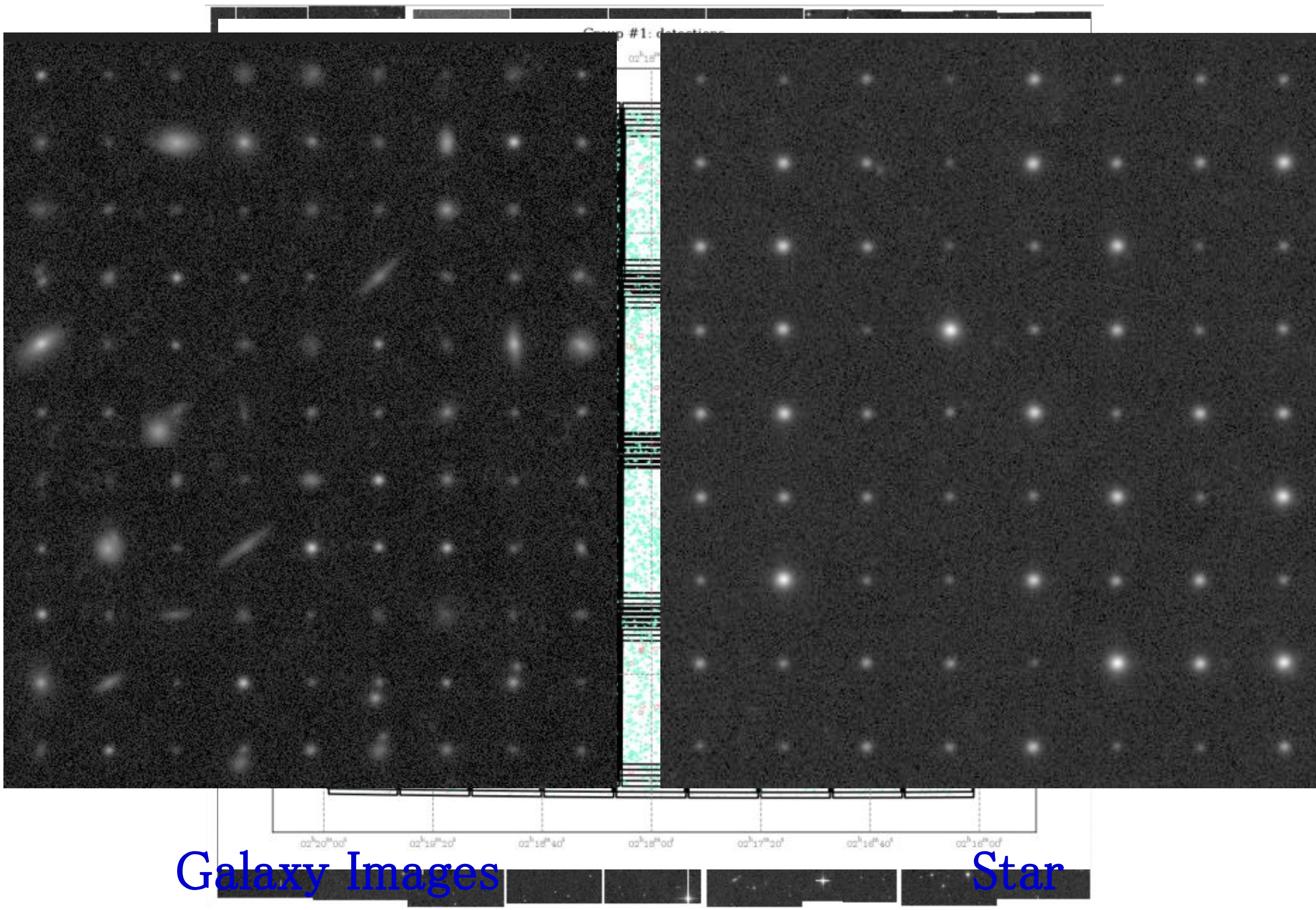
- CFHTlens

Table 1. Characteristics of the final CFHTLenS co-added science data (see the text for an explanation of the columns).

Filter	expos. time [s]	$m_{\rm lim}$ [AB mag] 5-σ lim. mag. in a $2''\!.0$ aperture	seeing [$''$]
$u^*(u.MP9301)$	5×600 (3000)	25.24 ± 0.17	0.88 ± 0.11
$g'(g.MP9401)$	5×500 (2500)	25.58 ± 0.15	0.82 ± 0.10
$r'(r.MP9601)$	4×500 (2000)	24.88 ± 0.16	0.72 ± 0.09
$i'(i.MP9701)$	7×615 (4305)	24.54 ± 0.19	0.68 ± 0.11
$y'(i.MP9702)$	7×615 (4305)	24.71 ± 0.13	0.62 ± 0.09
$z'(z.MP9801)$	6×600 (3600)	23.46 ± 0.20	0.70 ± 0.12

- http://www.cfhtlens.org
- Erben et al (2012)
- Heymans et al (2012)
- Miller et al (2012)

Application on the CFHTlens data

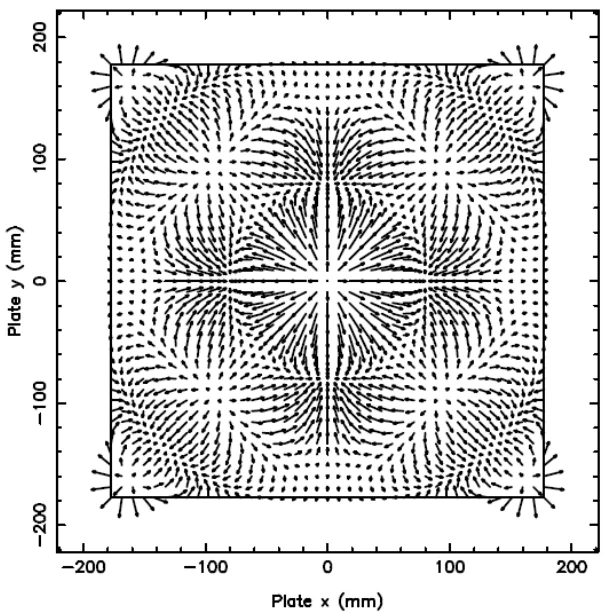


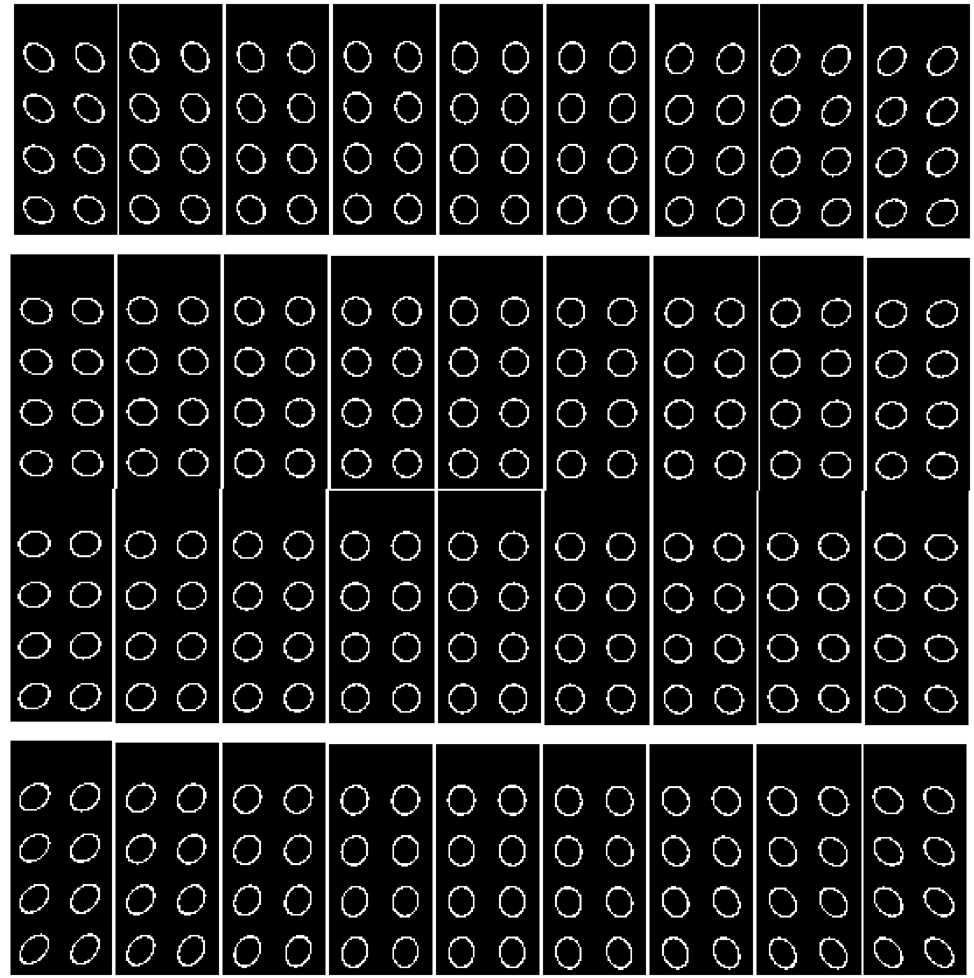
Galaxy Images

Images

Star

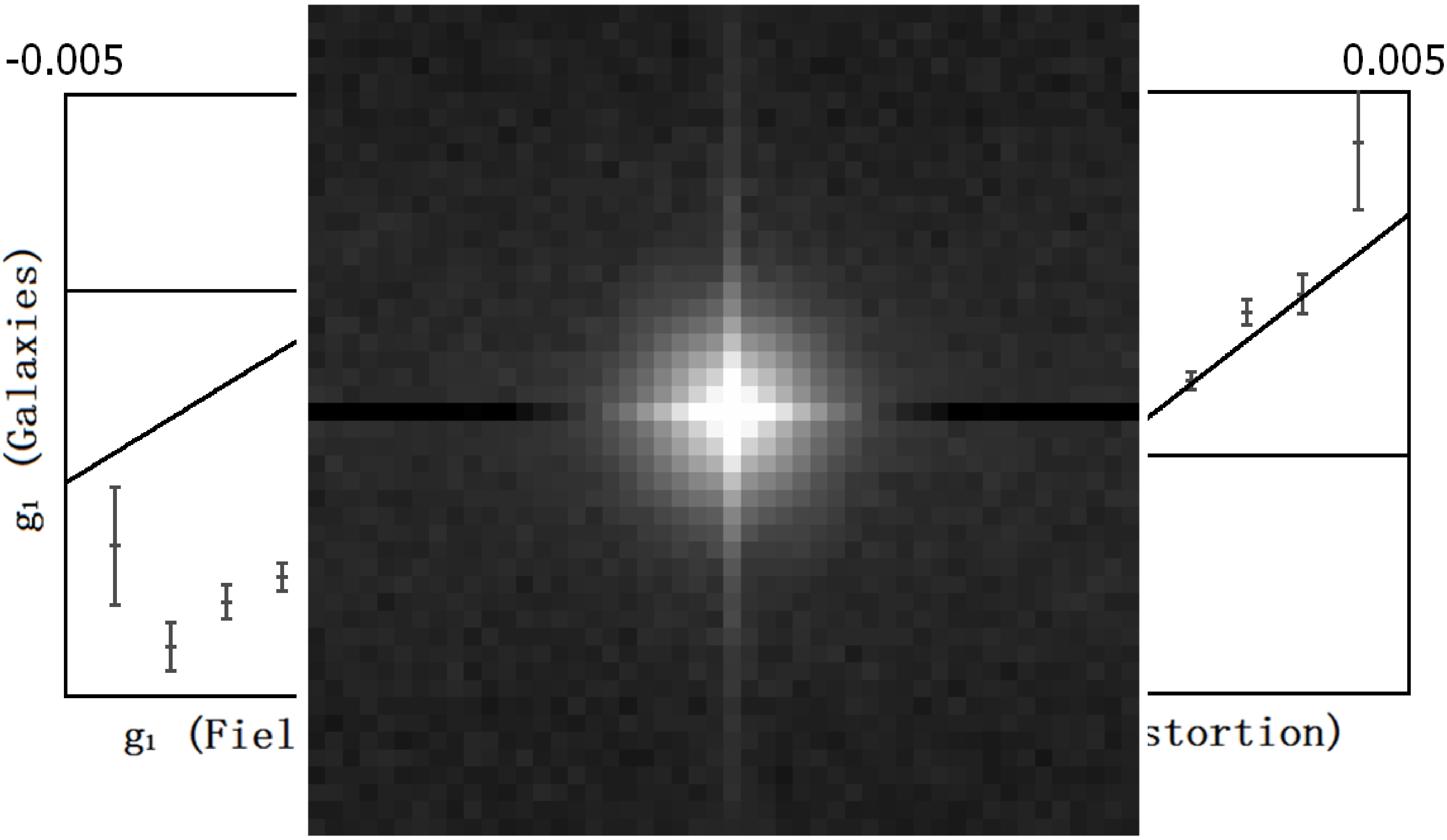
Test with Field Distortion



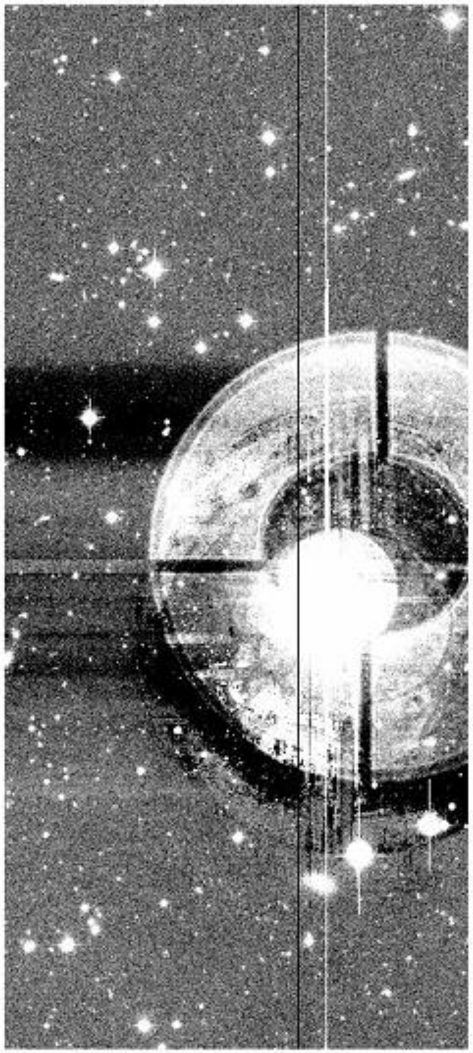


Dong et al. in preparation

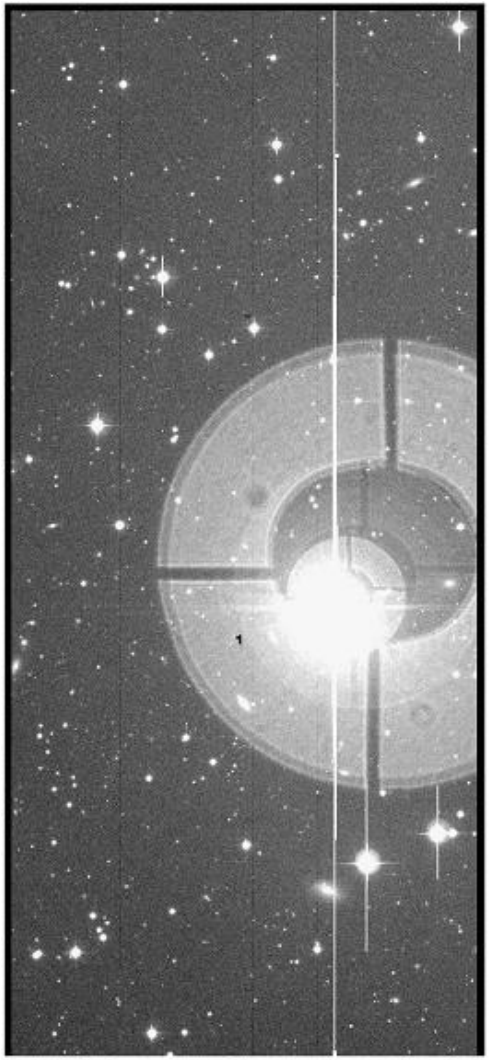
Test with Field Distortion



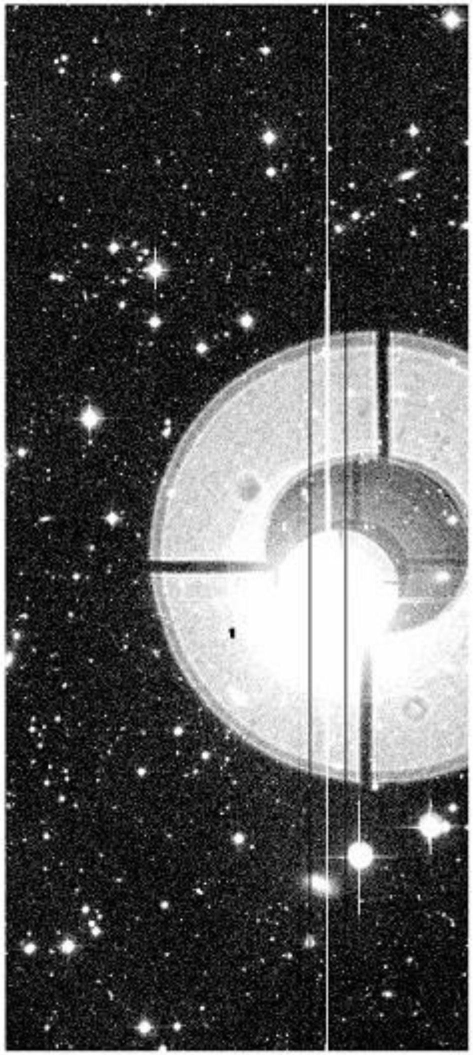
Application on the CFHTlens data



THELI Processed

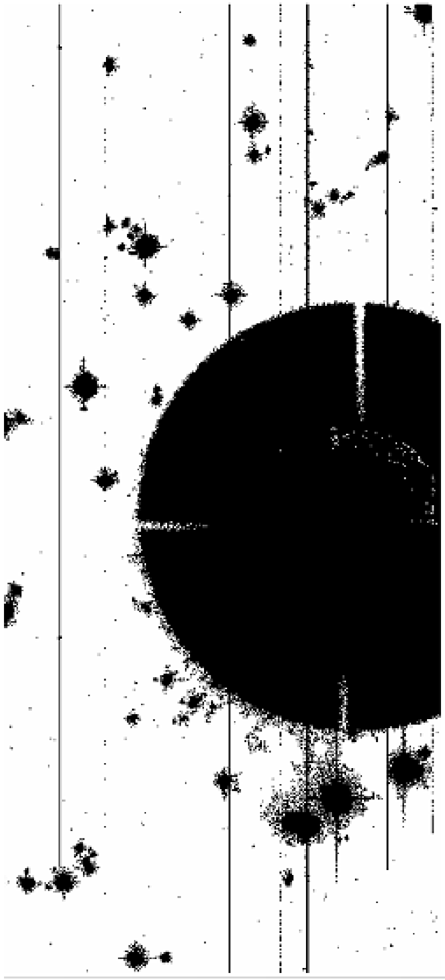


Original Image



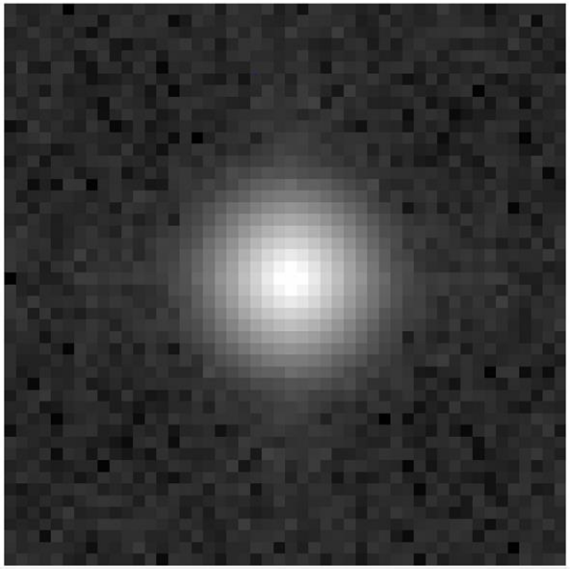
We Processed

Application on the CFHTlens data



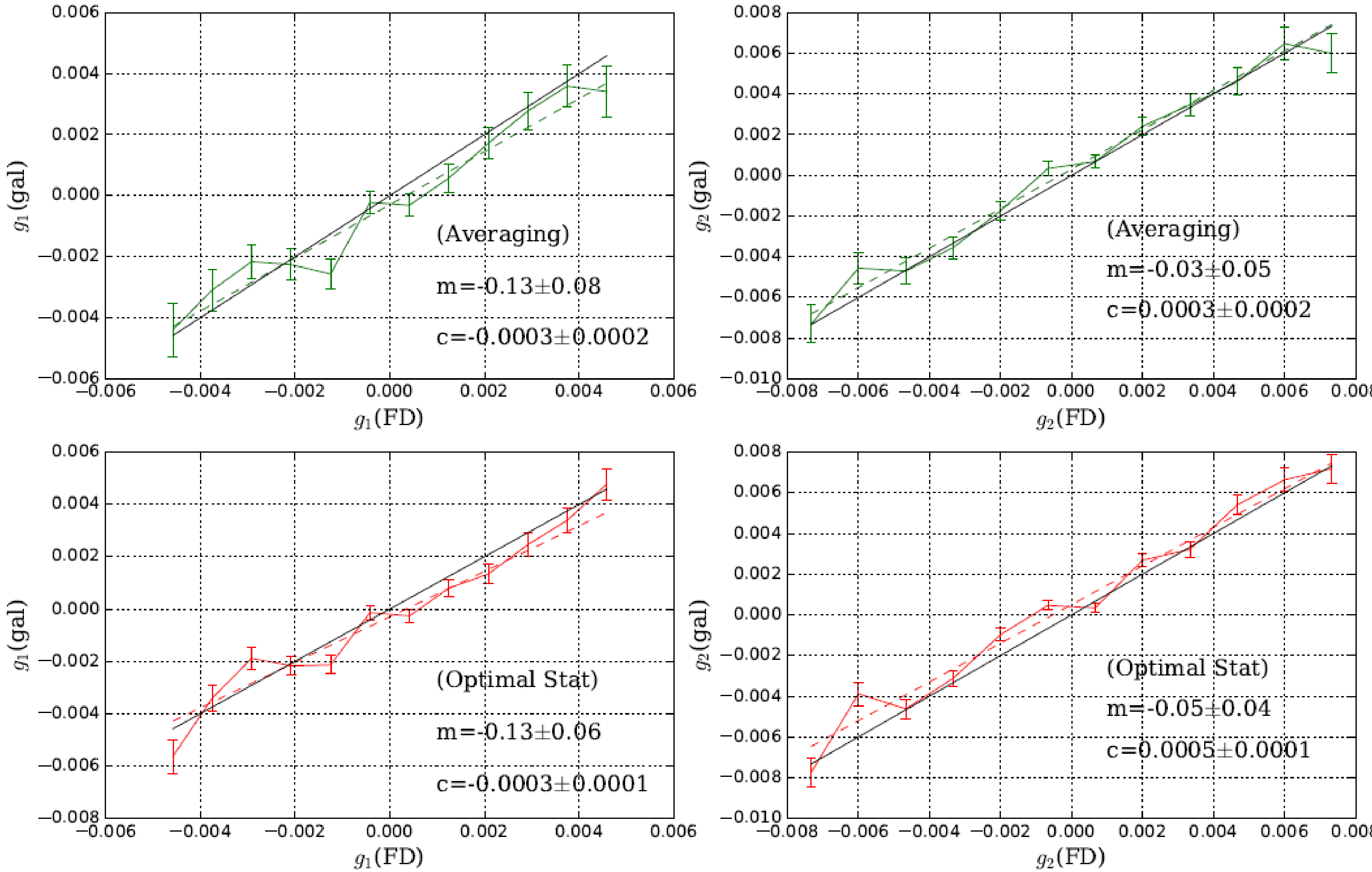
Mask Image

Source Distribution

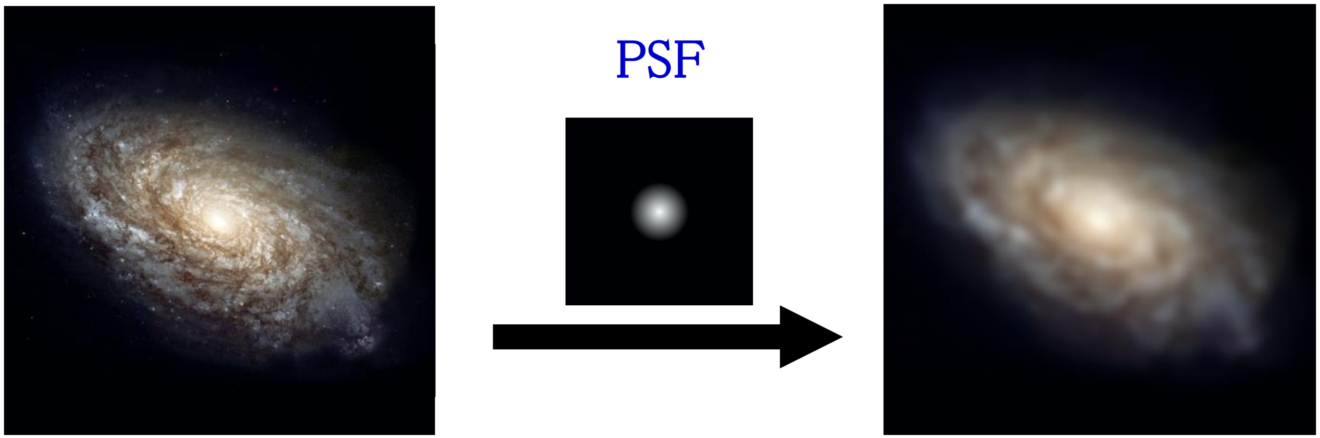


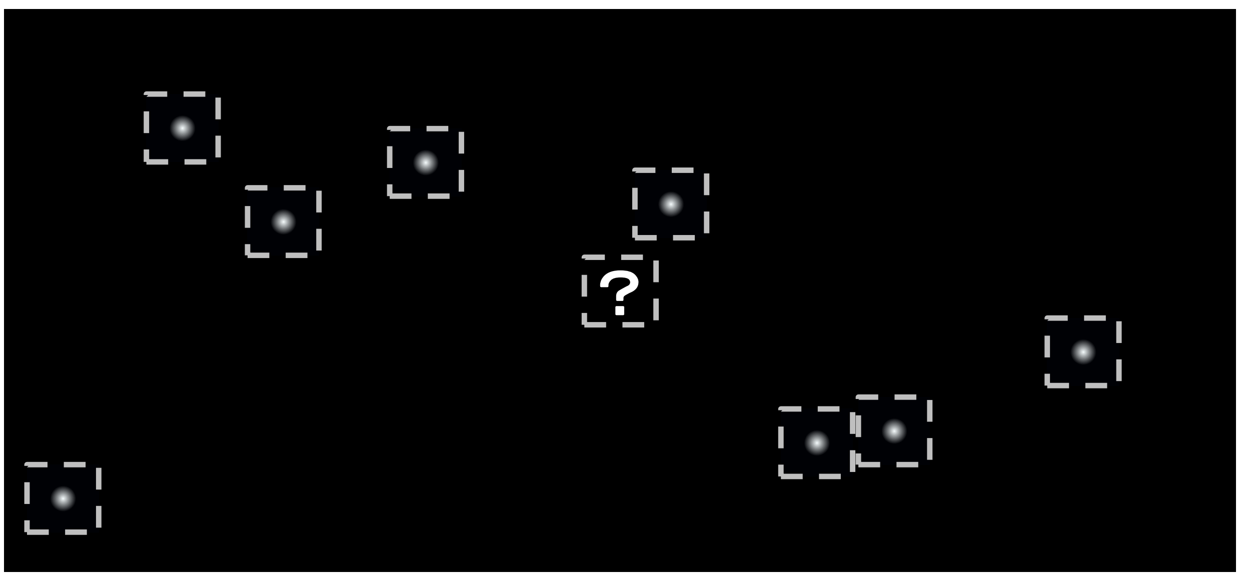
Stacked Source PS

Application on the CFHTlens data

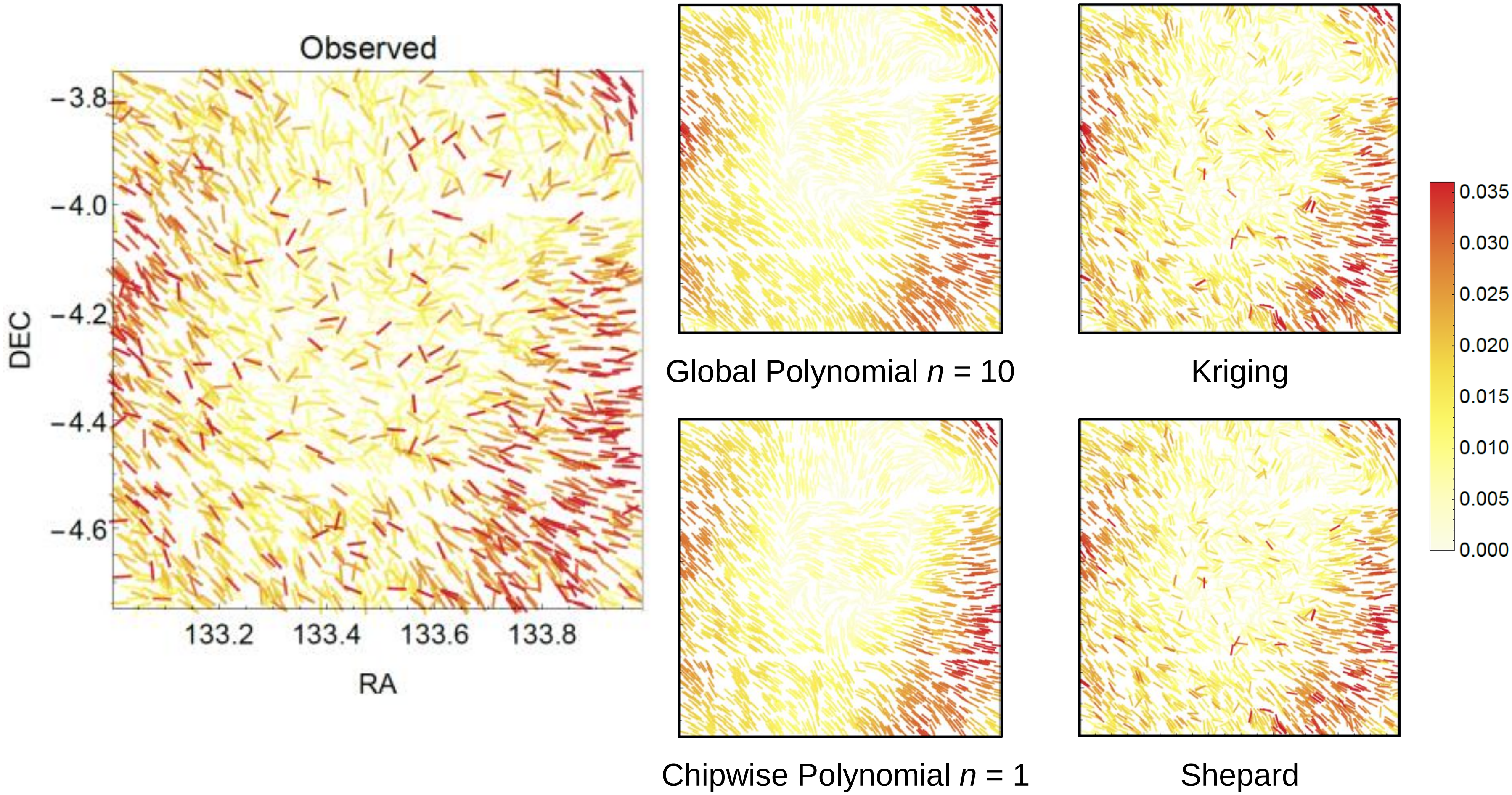


About PSF Interpolation



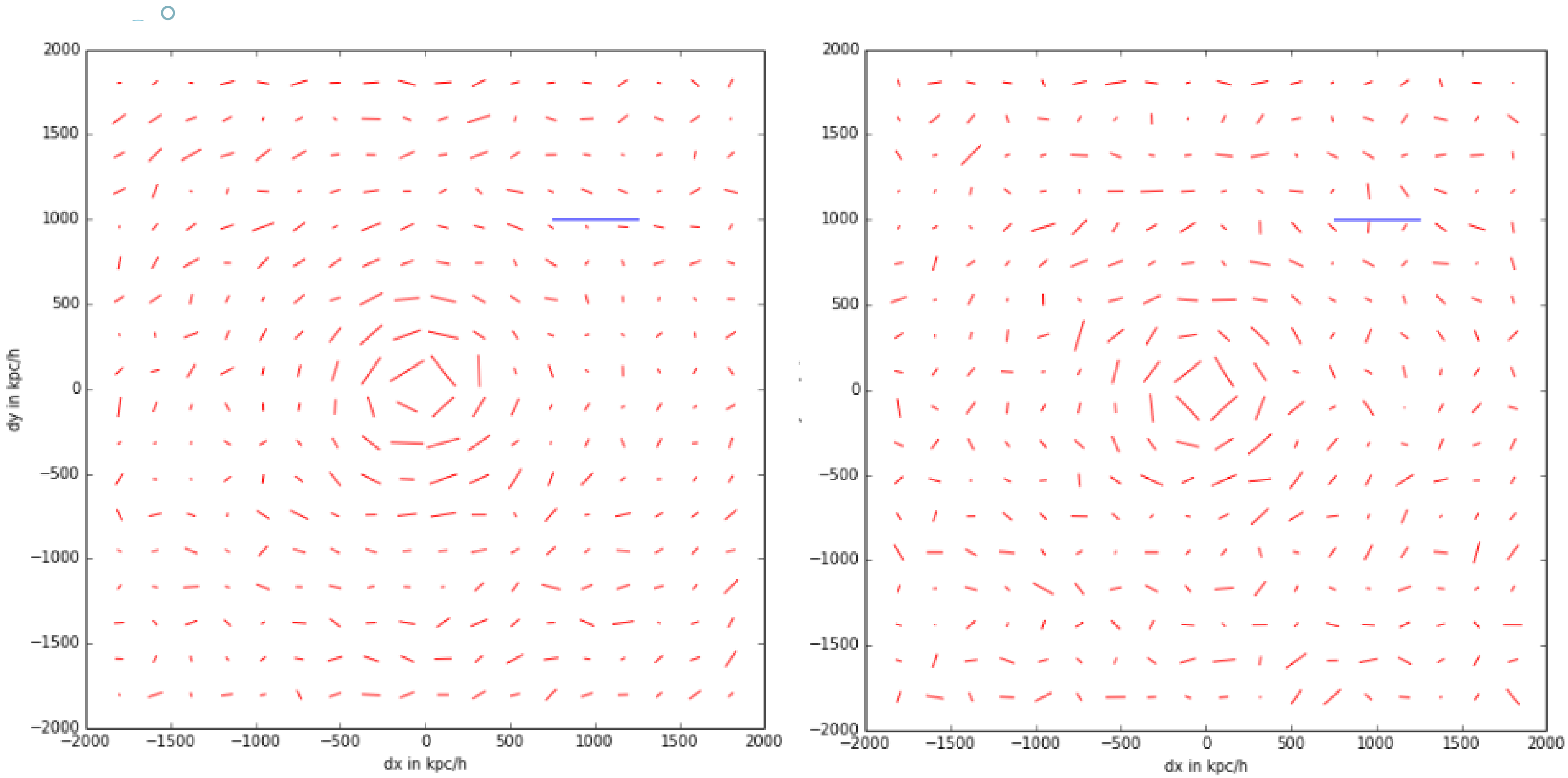


About PSF Interpolation



Lu, et al. , 2017, AJ in press

Preliminary Results on Cluster Lensing

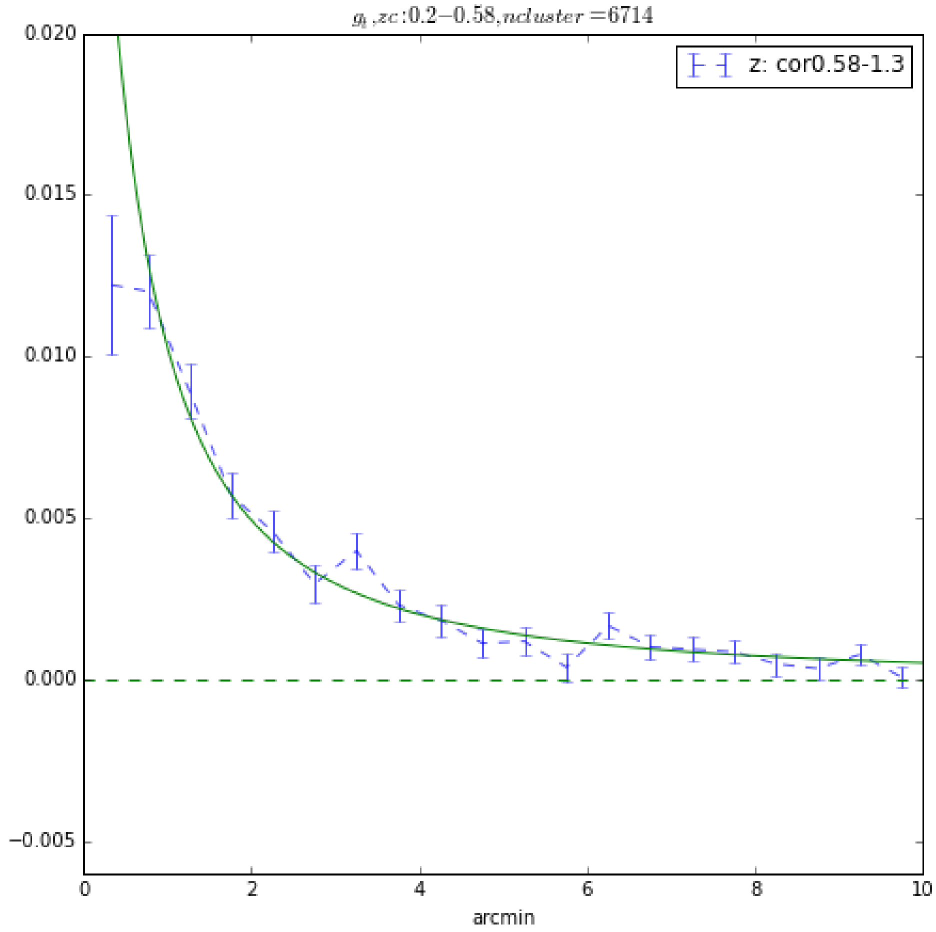


From Lensfit Method

From Our Method

Cluster catalog from Ford et al.(2015)

Preliminary Results on Cluster Lensing



$$lgm_{vir}(M_{\odot}/h)=13.3552^{+0.0301}_{-0.0304}, c=4.8900^{+0.9807}_{-0.7608}$$

Dong et al. in preparation

Stay Tuned !

Thank You !