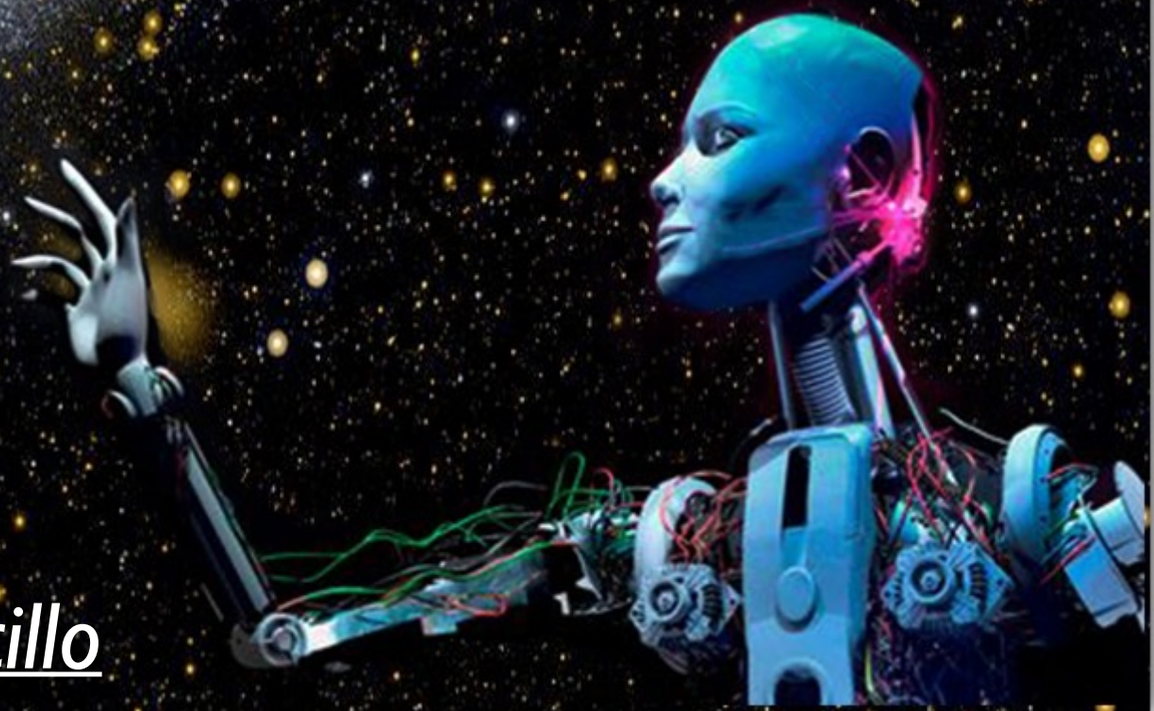
May

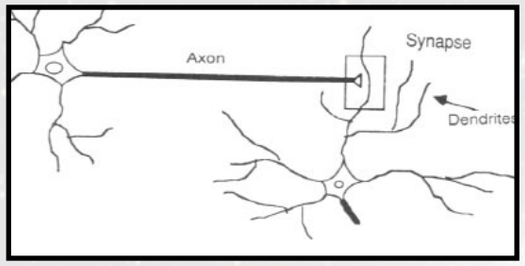
Deep learning for galaxy surface brightness profile fitting

SF2A 2018

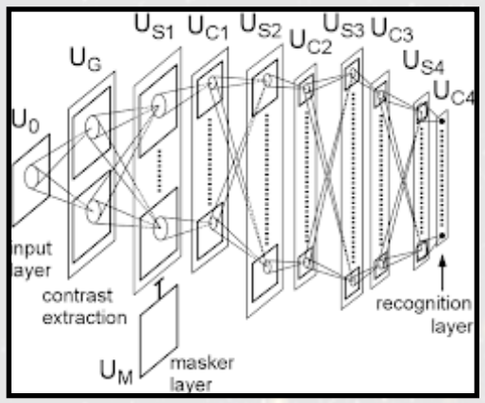


Diego Tuccillo

6/7/2018, Bordeaux

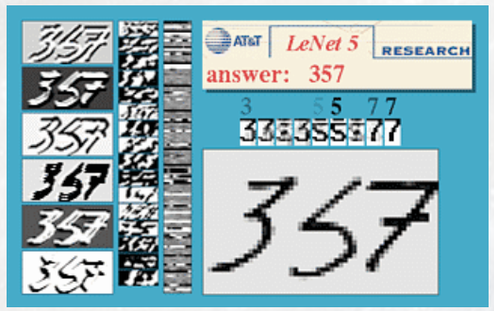


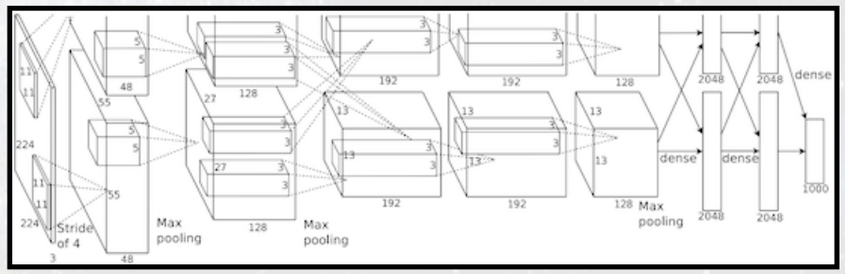
Frank Rosenblatt **1957**
(The **Perceptron)**



Fukushima
Neocognitron

LeCun
LaNet 5





Krizhevsky 2012
AlexNet

cited
> 6,200 times!

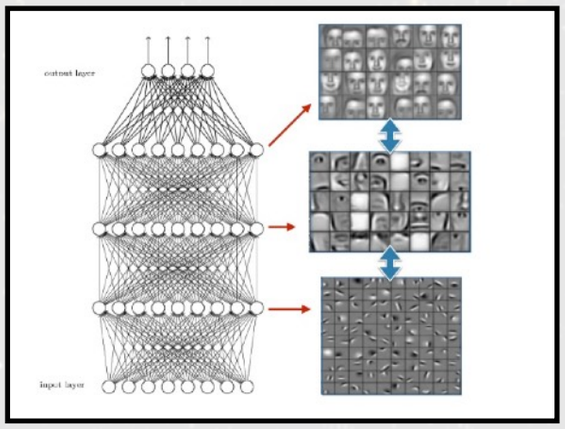
1980's

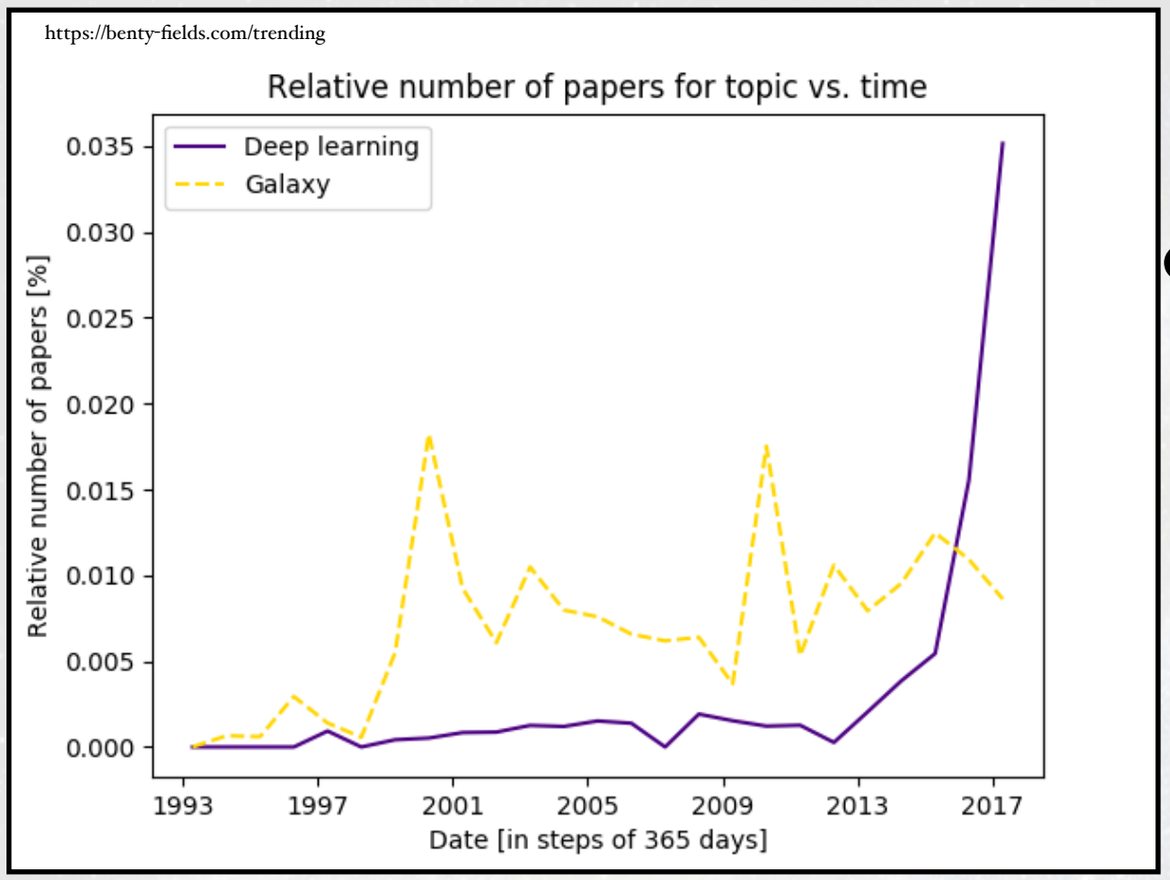
1990's

2000's

2012

Deep Learning in Astronomy





SDSS - galaxy classification

Dieleman, Willett & Dambre (2015)

CANDELs - galaxy classification

Huertas-Company et al. (2015)

Strong Lens Finding

Lanusse et al. (2017)

Star-galaxy separation

Kim & Brunner (2017)

Automated spectral feature extraction

Wang, Guo & Luo (2017)

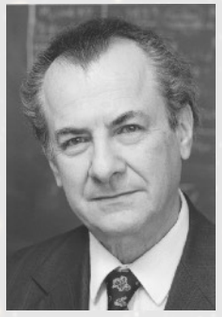
Improving galaxy morphologies for SDSS with Deep Learning

Domínguez Sánchez et al. 2017

Deep learning for galaxy surface brightness profile fitting

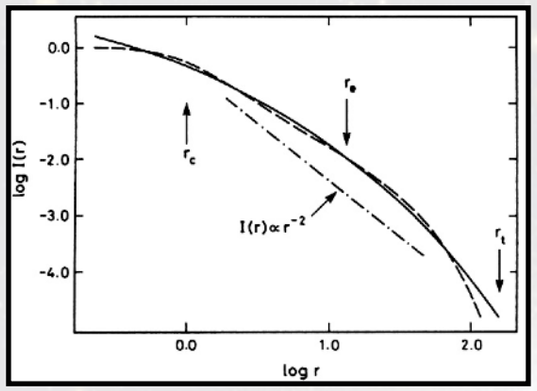
Tuccillo et al. 2018

Galaxy photometrical brightness profiles



de Vaucouleurs profile

(de Vaucouleurs - 1958)



Sersic (1968)

Kormendy (1977) and Kent (1985)

GALFIT

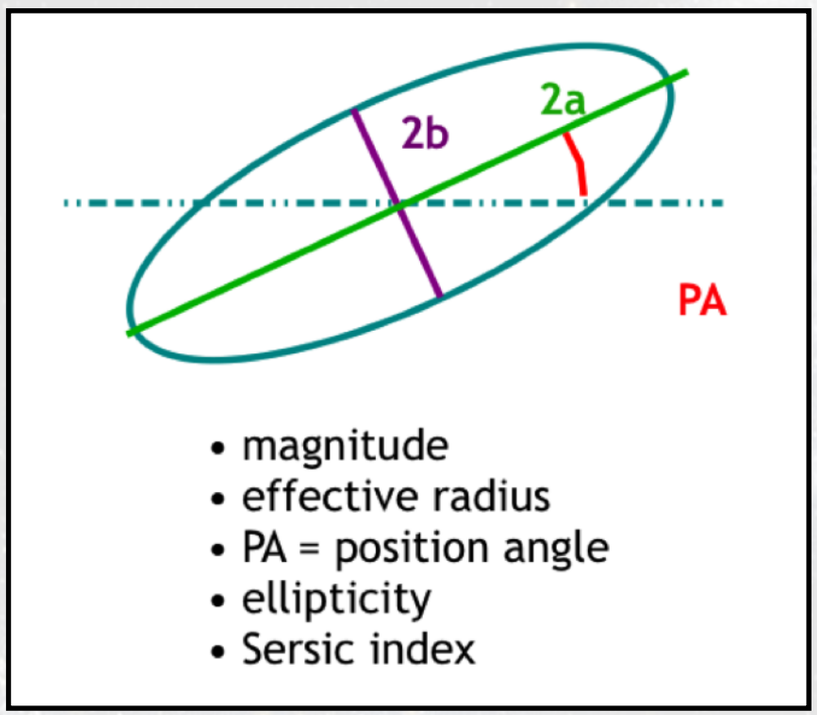
(Peng et al. 2002, 2010),

GIM2D

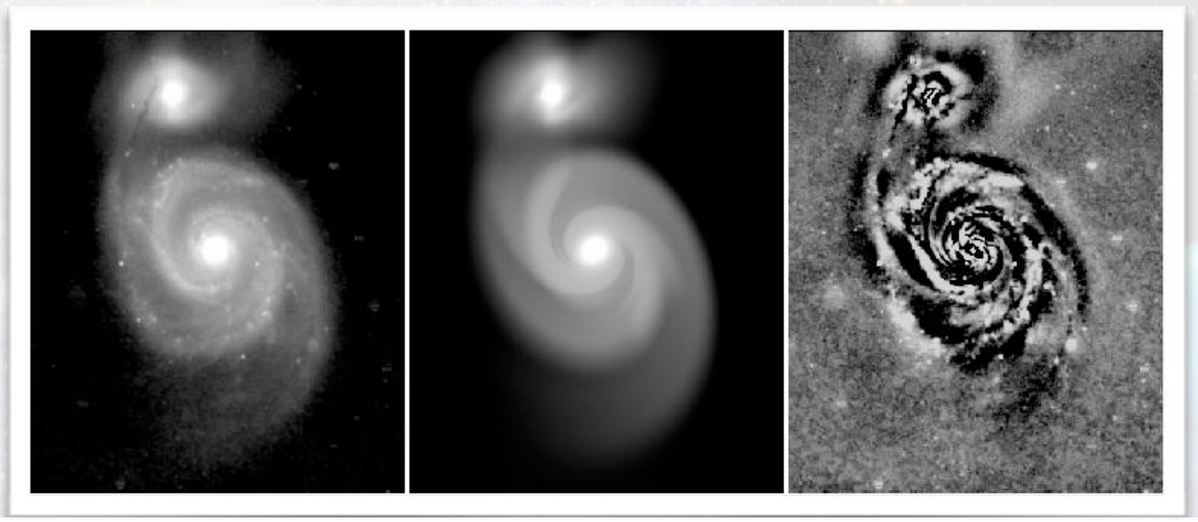
(Simard 1998; 2002)

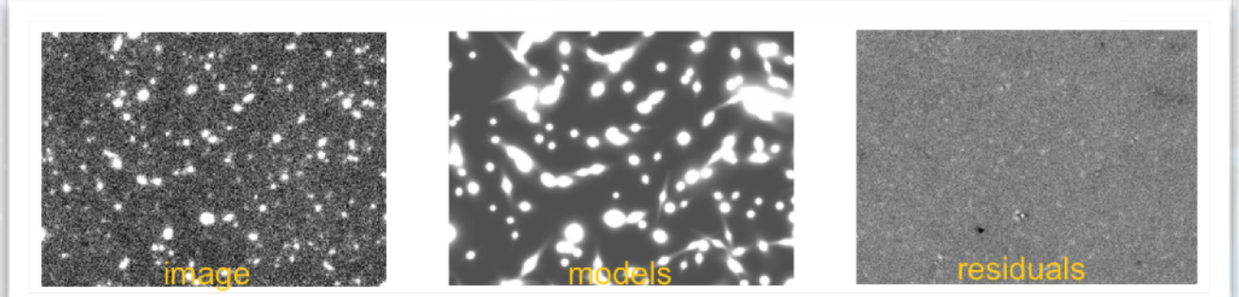
SEXTRACTOR

(Bertin & Arnouts 1996)



- magnitude
- effective radius
- PA = position angle
- ellipticity
- Sersic index

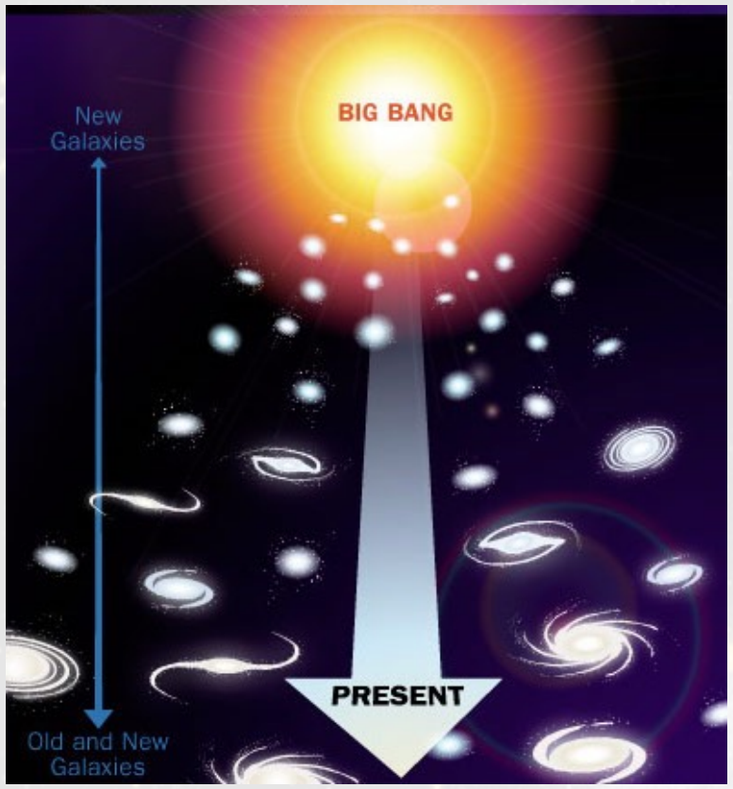




GALFIT
(Peng et al. 2002, 2010),

GIM2D
(Simard 1998; 2002)

SEXTRACTOR
(Bertin & Arnouts 1996)



Models of evolution and formation over cosmic time

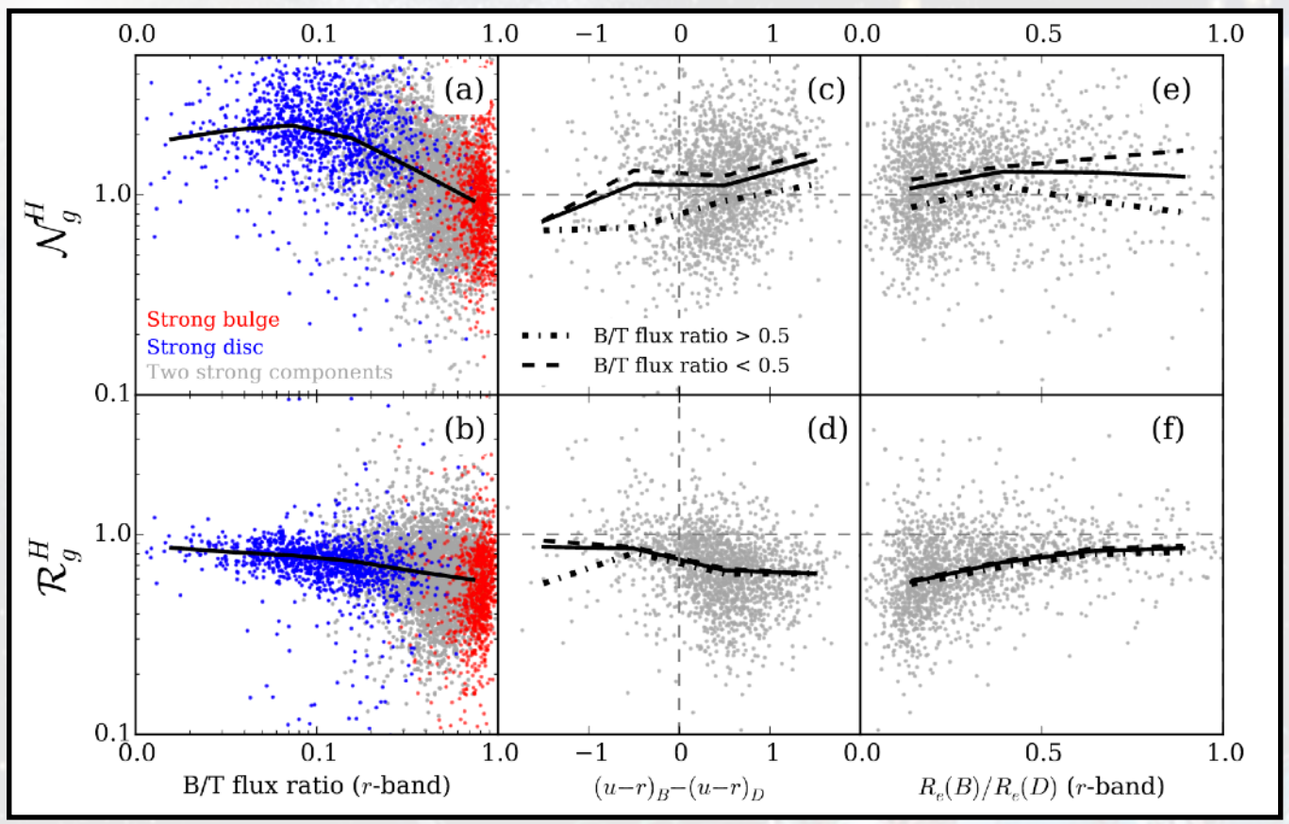
Kormendy & Kennicutt (2004); (Zavala, Okamoto & Frenk 2008; Lacey et al. 2016)

Size distribution of galaxies and its dependence on their luminosity

(Shen et al. 2003, Lange et al. 2016).

Distribution of mass and luminosity-surface brightness in relation of different classes of galaxy and types of structure

(Driver et al. 2007; Kelvin et al. 2014; Kennedy et al. 2016).

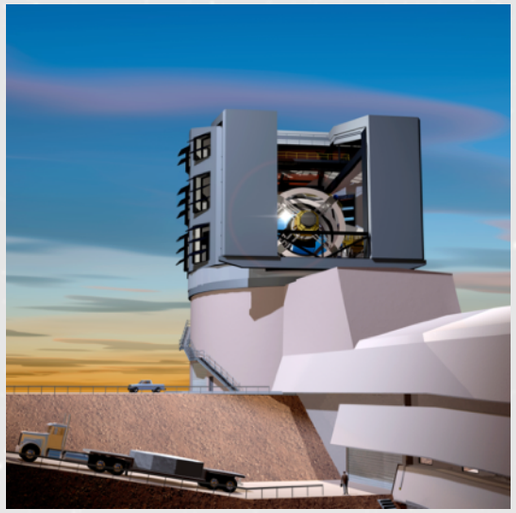


(Kennedy et al. 2016)

Suited for future large are surveys?

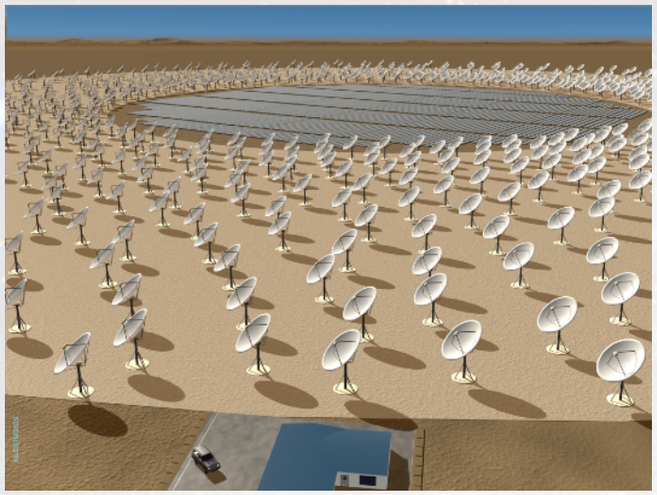
LSST

Large Synoptic Survey Telescope



SKA

(Square Kilometre Array)

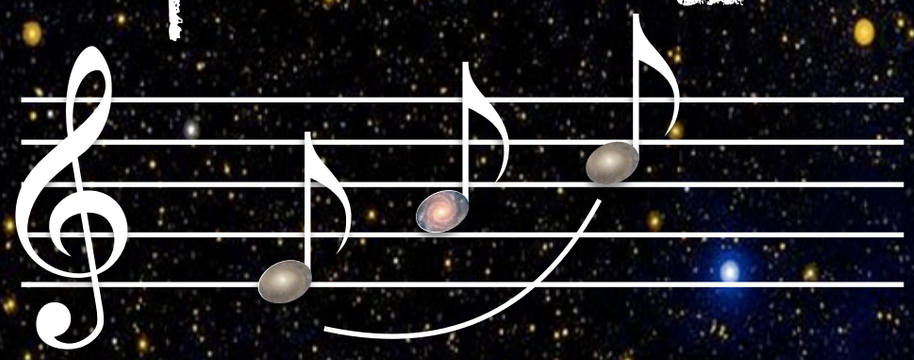


Peng words: “they require some degree of scientific and even artistic sense”

SURVEYS					
	Area (deg2)	Description			
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.			
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey			
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of n = 1.5x10⁹ galaxies			z of n=5x10⁷ galaxies	

http://www.euclid-ec.org/?page_id=2581

Deep LeGATo_1c



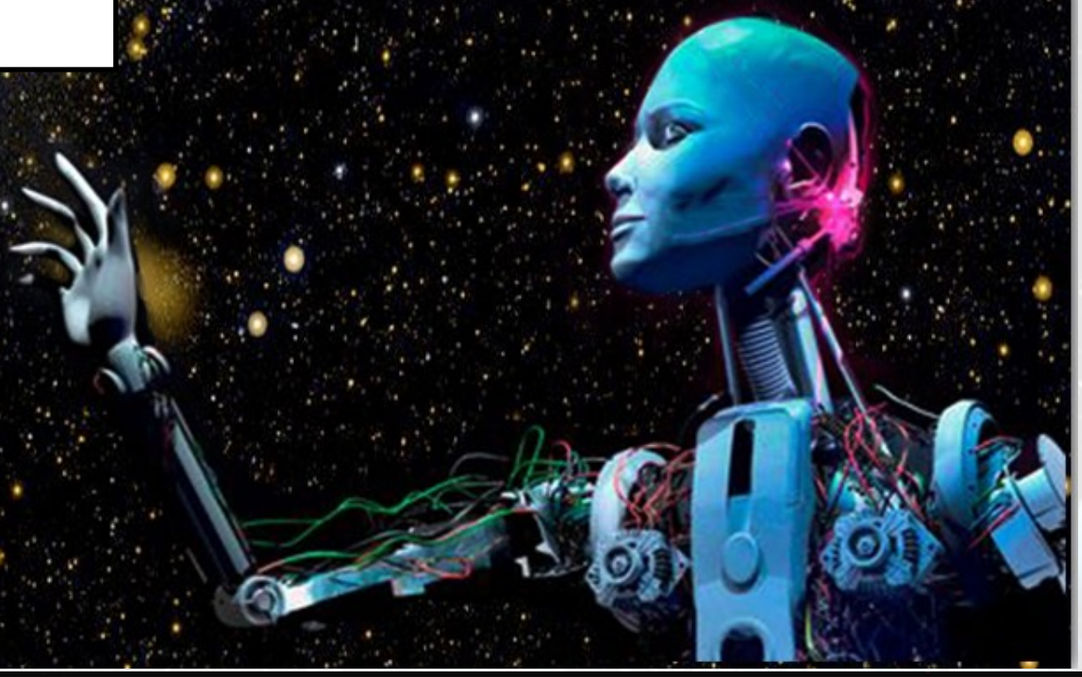
Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **475,** 894–909 (2018) doi:10.1093/mnras/stx3186
Advance Access publication 2017 December 11

Deep learning for galaxy surface brightness profile fitting

D. Tuccillo,[1,2★] M. Huertas-Company,[1,3,4] E. Decencière,[2] S. Velasco-Forero,[2]
H. Domínguez Sánchez[1,3] and P. Dimauro[1]

[1]*LERMA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, F-75014 Paris, France*
[2]*MINES Paristech, PSL Research University, Centre for Mathematical Morphology, Fontainebleau, France*
[3]*Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19104, USA*
[4]*University of Paris Denis Diderot, University of Paris Sorbonne Cité (PSC), F-75205 Paris Cedex 13, France*



CNN for Profiling 1-component galaxies

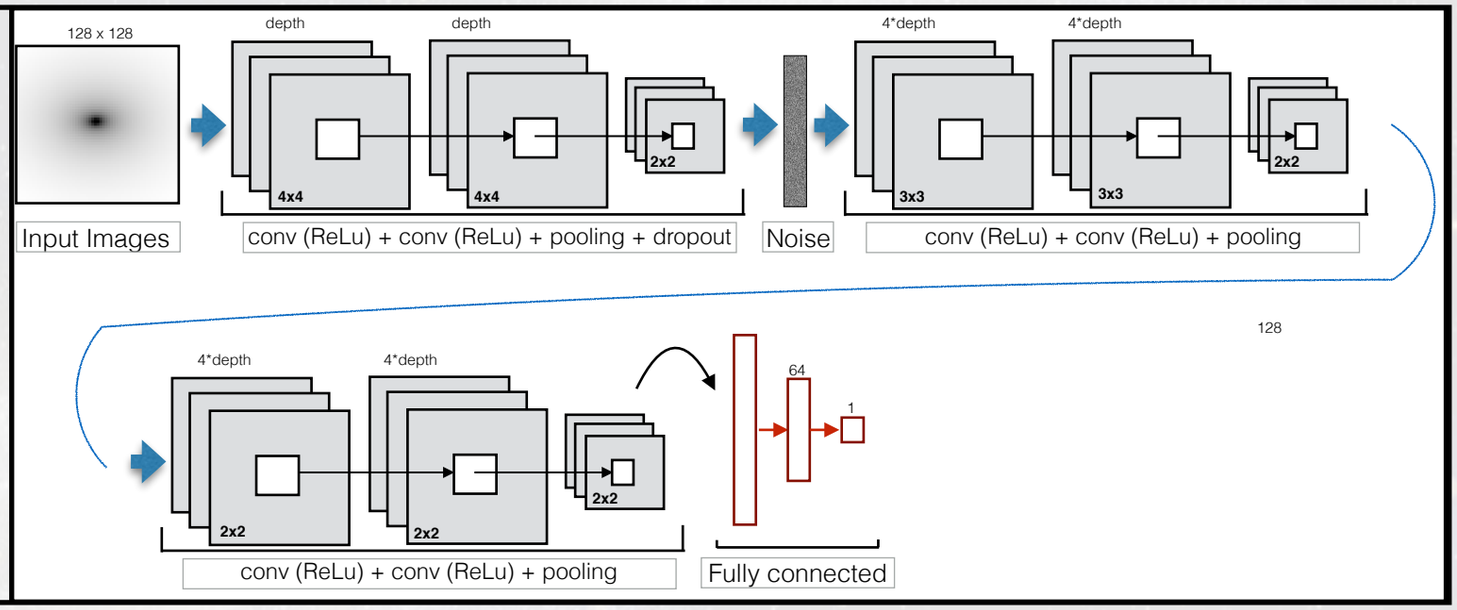
Keras (Chollet 2015) on top of *Theano* (Bastien et al. 2012)

Architectures inspired by VGG-net (Simonyan & Zisserman 2014),

total of 6 convolutional layers, 3 max pooling layers and 2 dropout layers.

Magnitude

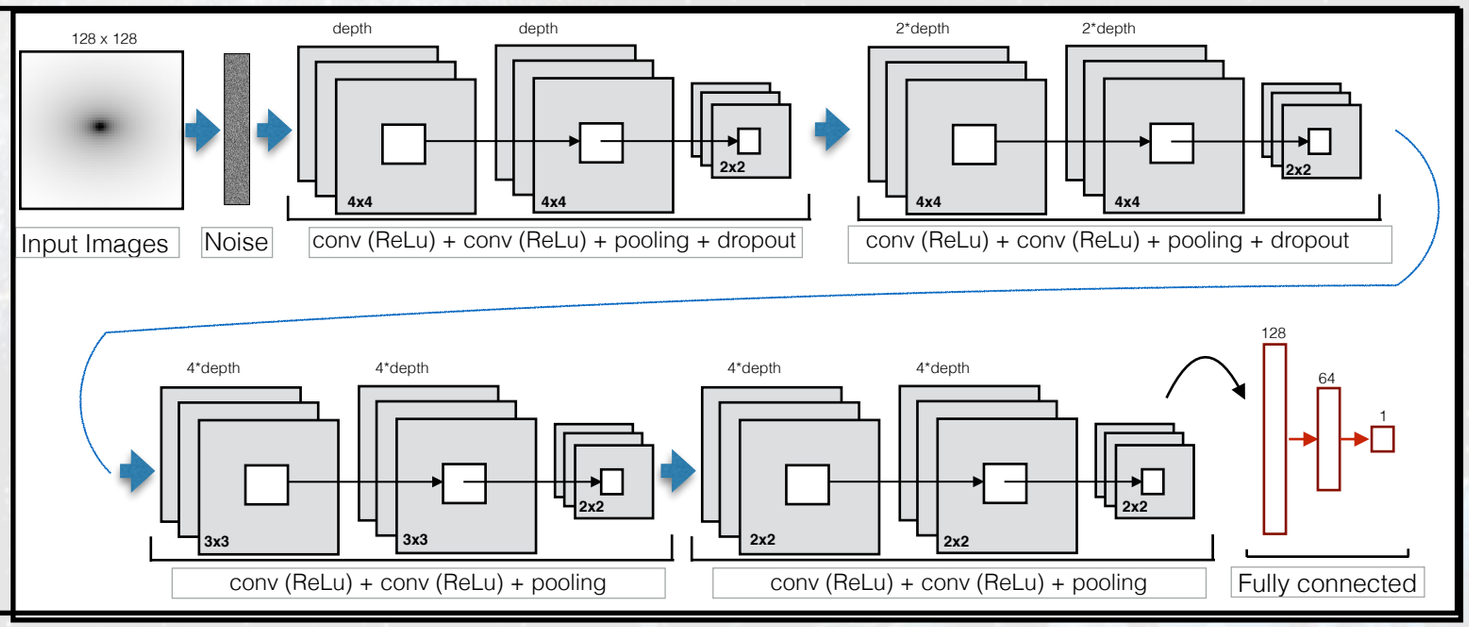
Radius



total of 8 convolutional layers, 4 max pooling layers and 2 dropout layers.

Sersic index

Ellipticity



Simulated Data

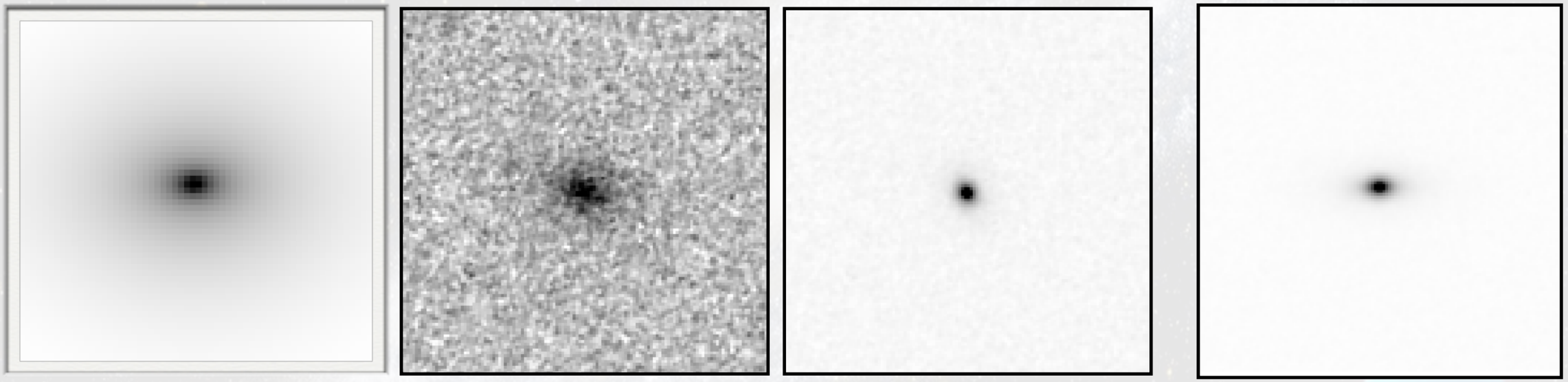
55,000 stamps

one-component F160W filter (H band)
HST/CANDELS

REAL NOISE

PIXEL scale 0.06”

REAL PSF CANDELS

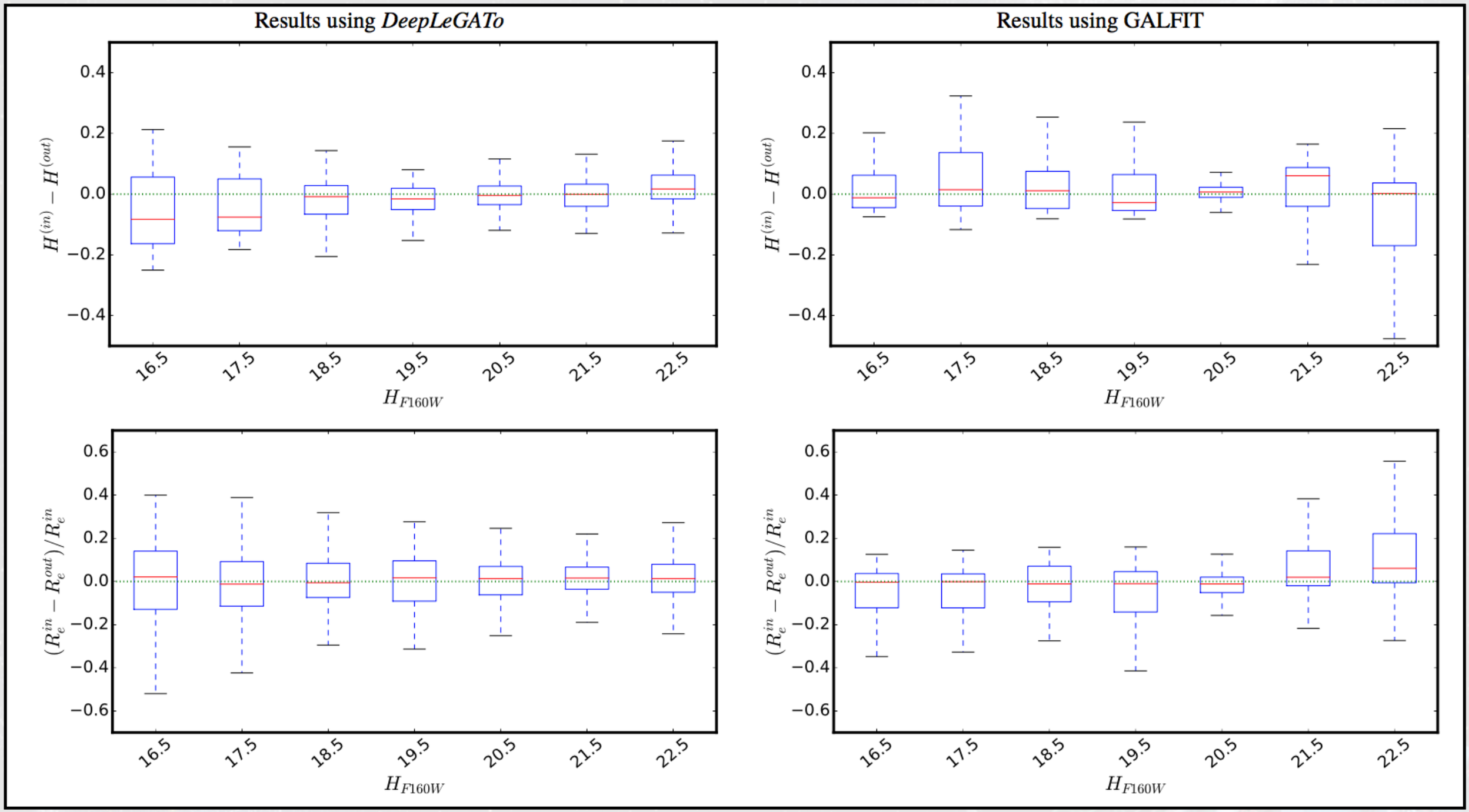


	Magnitude (AB)	Radius (Pixels)	Sérsic index	Ellipticity
Range	16 – 23	1.5 – 31.6	0.3 – 6.2	02 – 08

Tests on Simulated Data

Magnitude, Half-light Radius

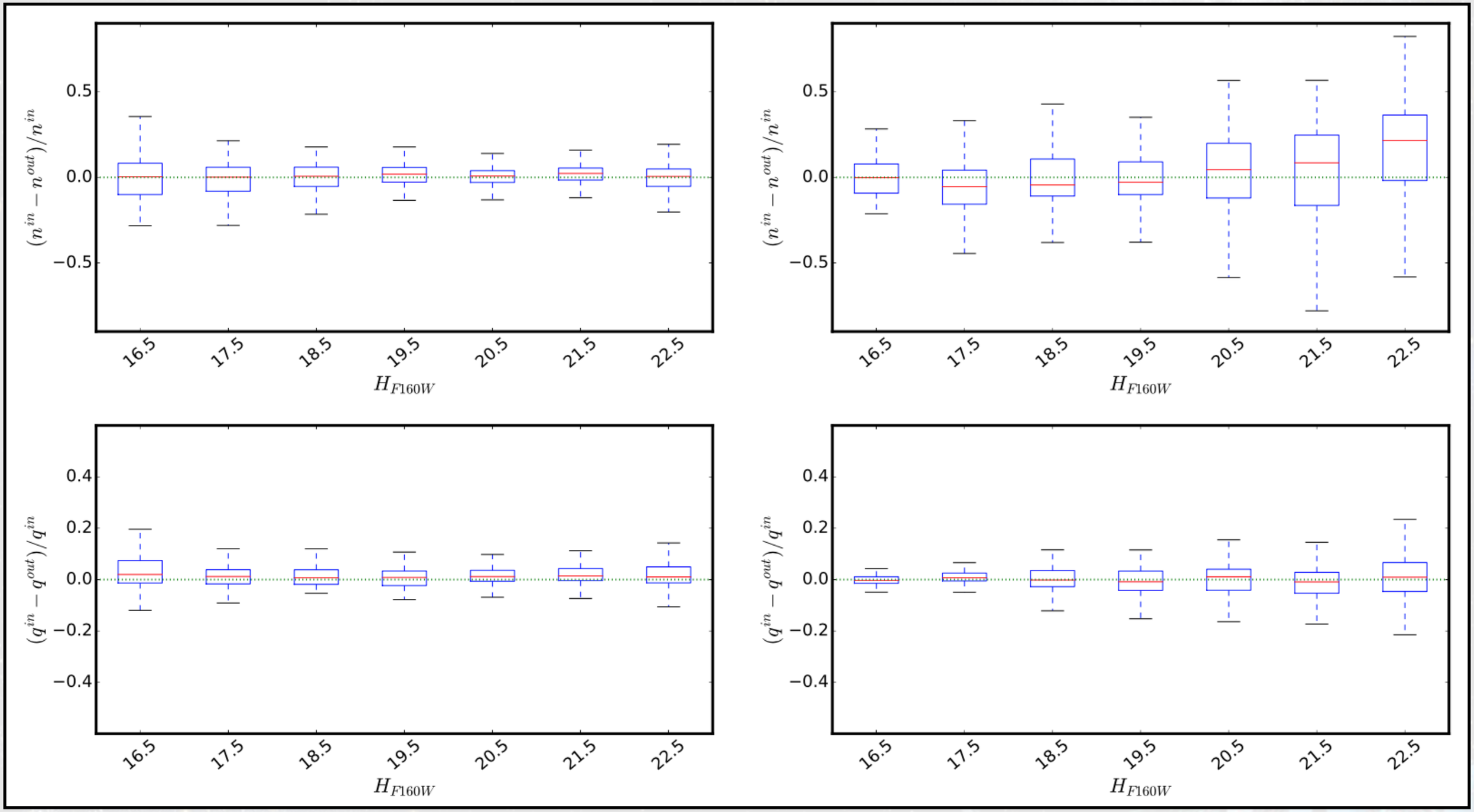
test data seta of 5000 simulated galaxy



Tests on Simulated Data

Sérsic index, ellipticity

test data seta of 5000 simulated galaxy



Summary tests on simulation

	R^2 simulated data		
Parameter	Architecture 1	Architecture 2	GALFIT
Magnitude	0.961	**0.997**	0.983
Radius	0.899	**0.972**	0.877
Sérsic index	**0.968**	0.881	0.607
Ellipticity	**0.983**	0.959	0.903

coefficient of determination

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

~5000 sources fitted

GALFIT/GALAPAGOS

Time: ~ 4 Hours

CNN (ONCE TRAINED)

Time: < 4 seconds (on GPU)
~200 seconds (on CPU)

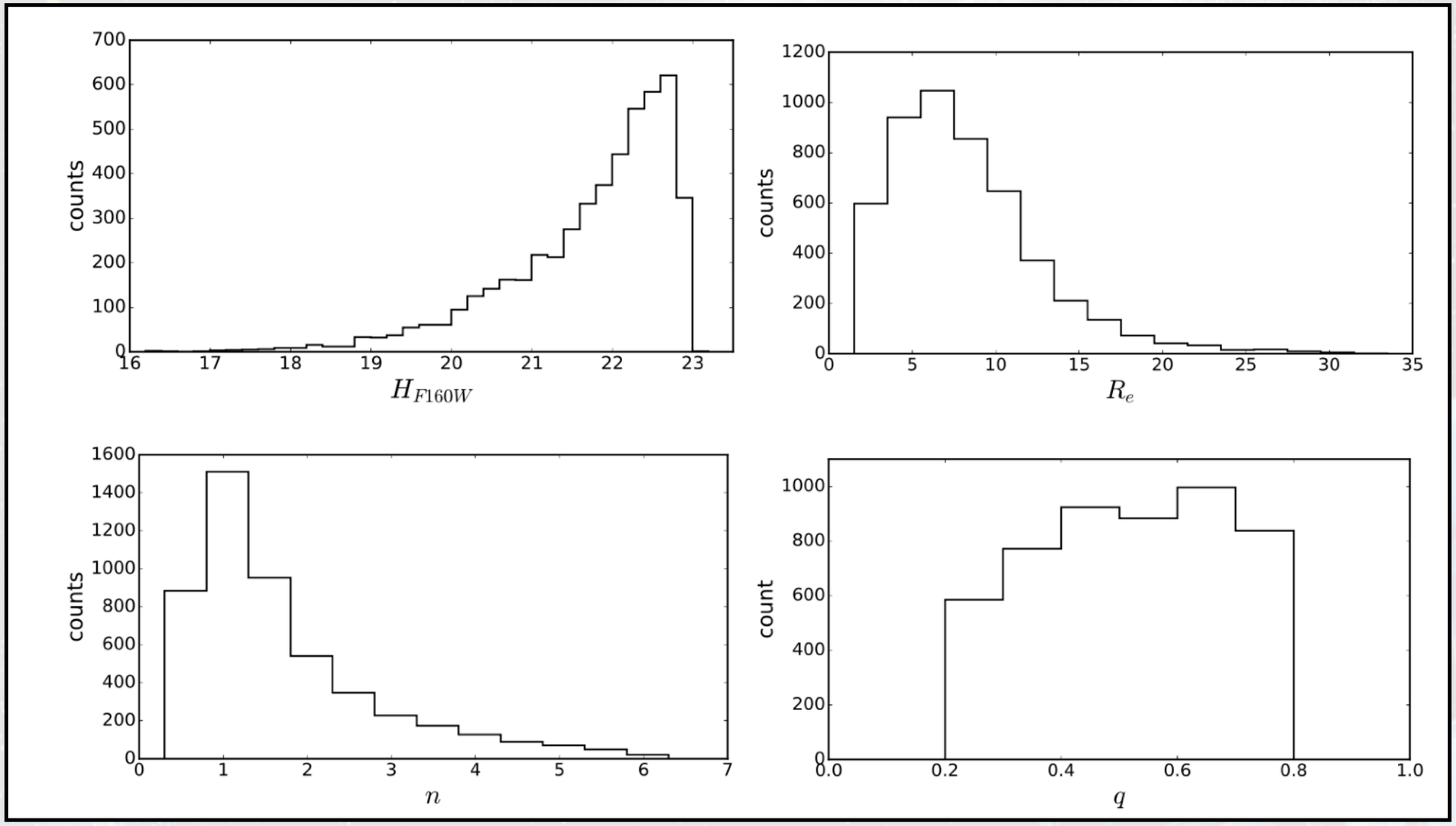
i.e. ~3600 time faster when run on GPU

Real Data

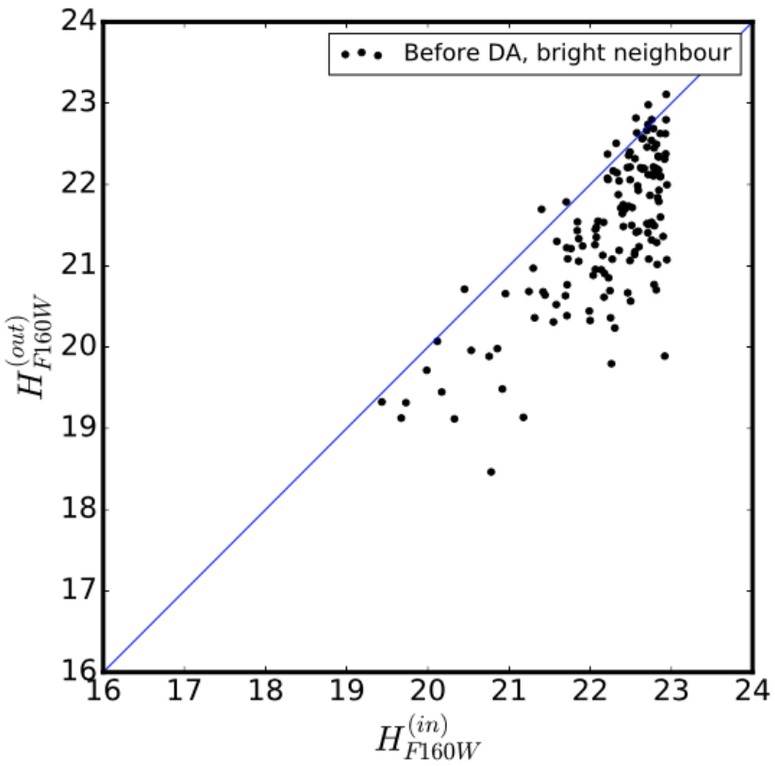
5000 HST/CANDELS galaxies.

	Magnitude (AB)	Radius (Pixels)	Sérsic index	Ellipticity
Range	16 – 23	1.5 – 31.6	0.3 – 6.2	02 – 08

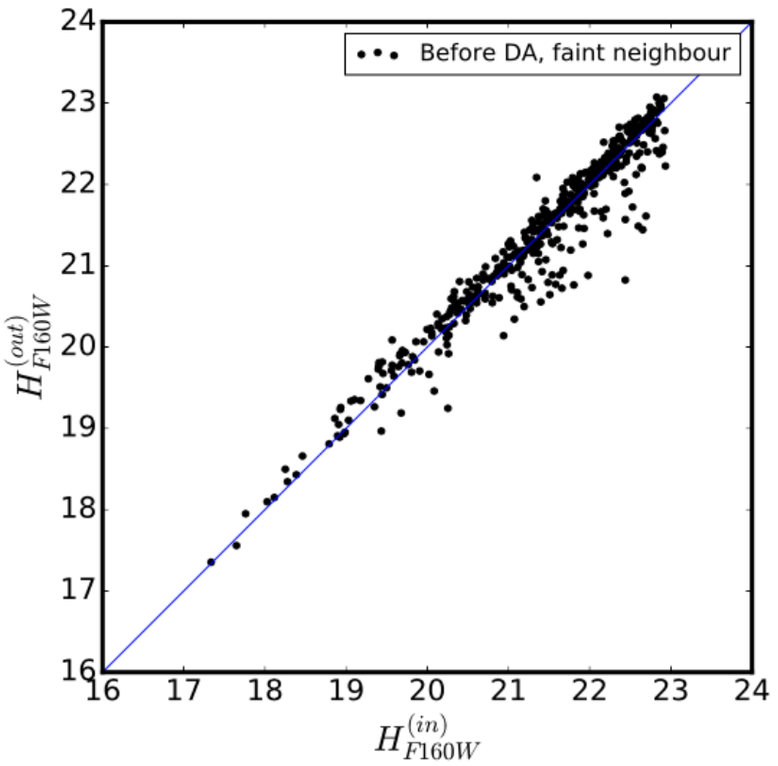
Structural parameters available measured with GALFIT/GALAPAGOS from van der Wel et al. (2012),



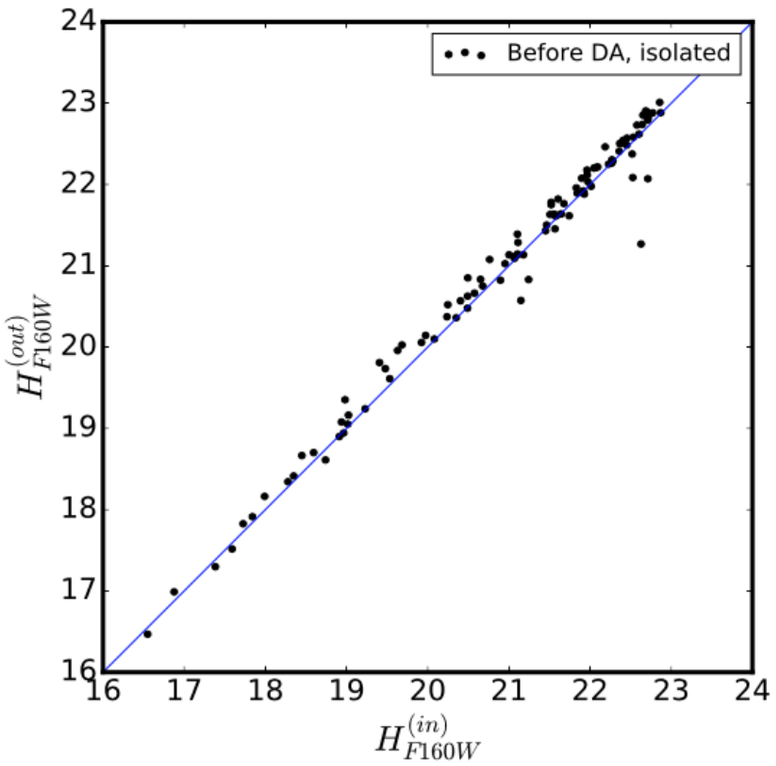
Tests on Real Data



(c) BDA bright neigbours



(d) BDA faint neigbours



(e) BDA isolated galaxies

First plot: galaxies whose companion has at least the 50% of their flux;

Second plot: galaxies whose companion have less than the 10% of the flux of the galaxy;

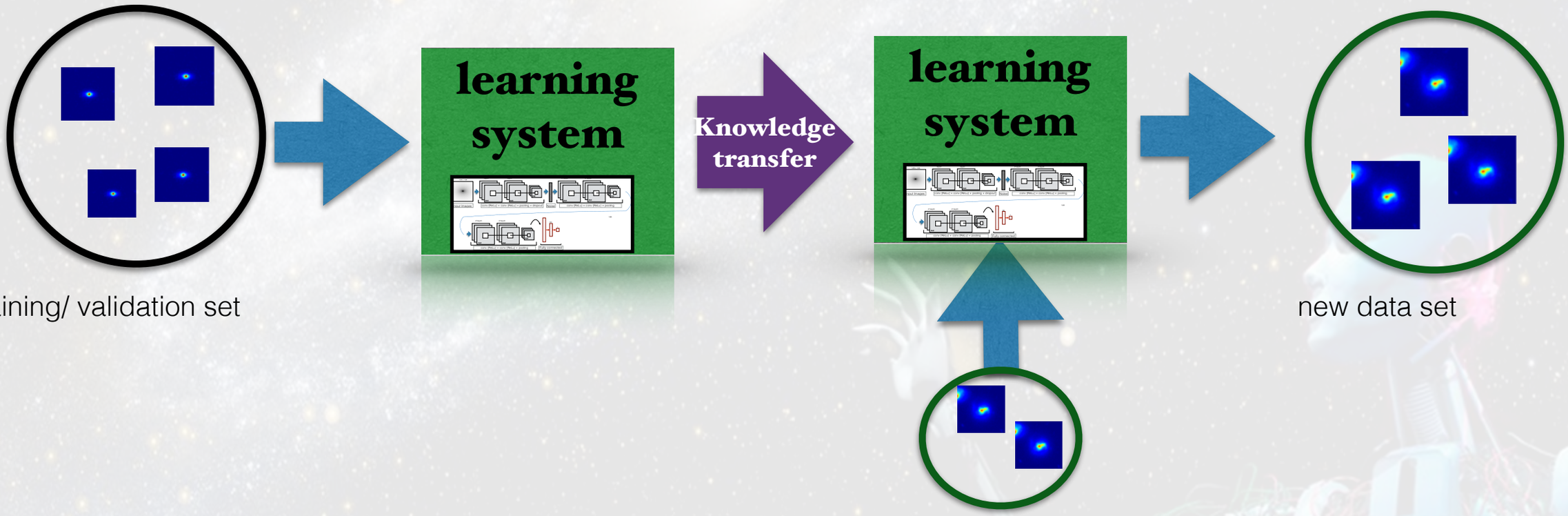
Third plot: isolated galaxies of our test-sample, i.e. without companion within the stamp

Traditional ML

training/ validation set

new data set

Domain adaptation

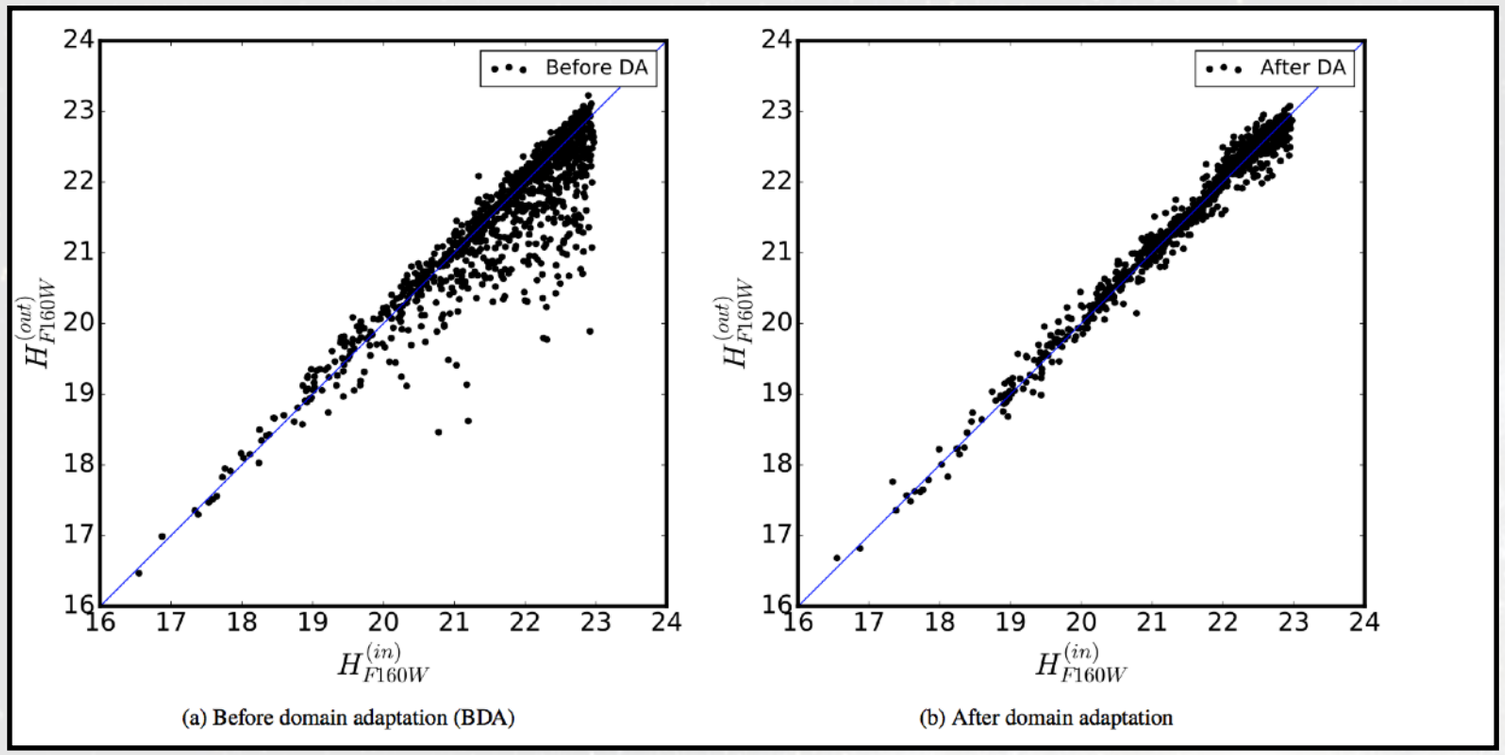


training/ validation set

small new data set type

new data set

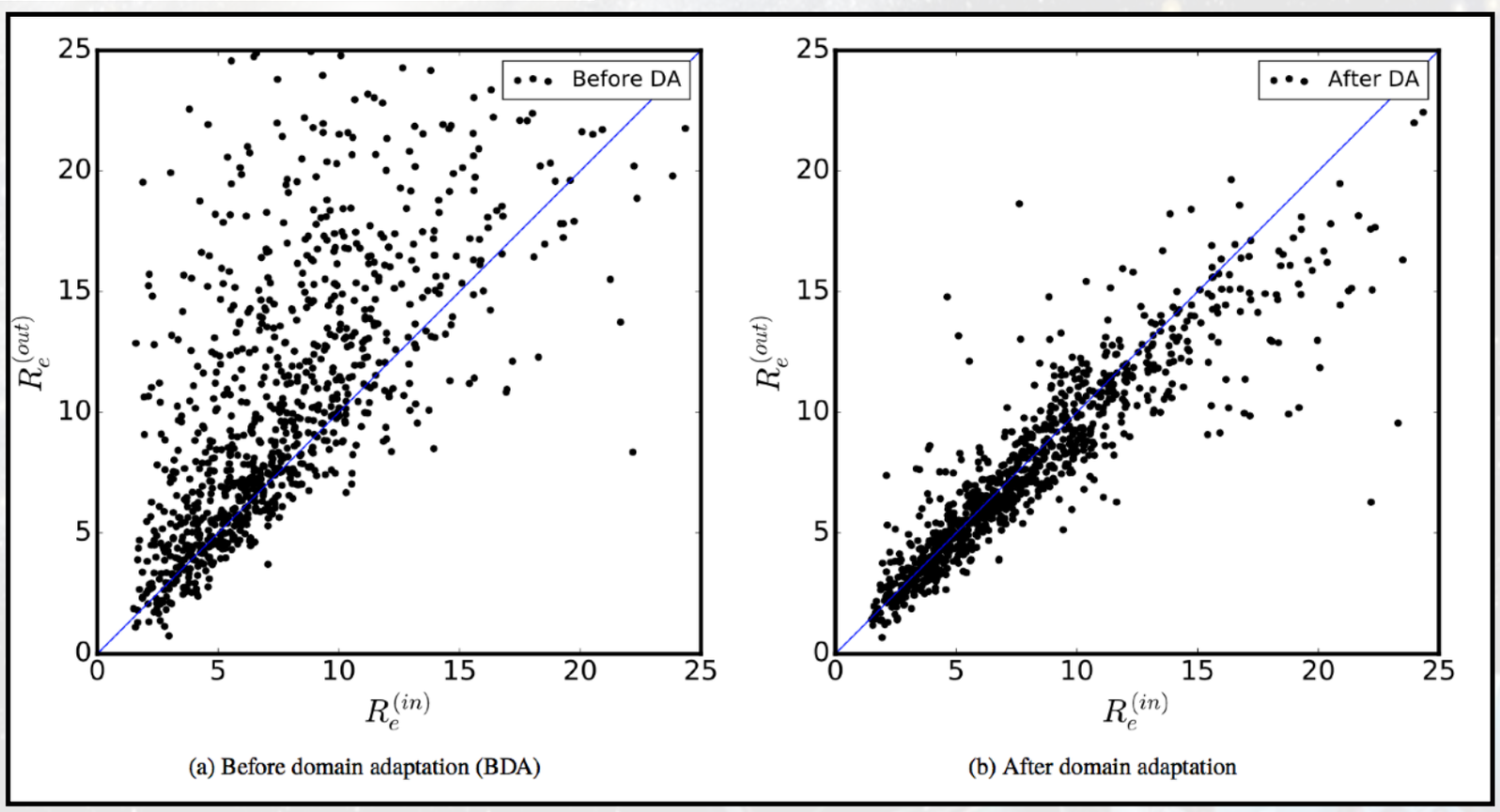
Tests on Real Data



(a) Before domain adaptation (BDA) (b) After domain adaptation

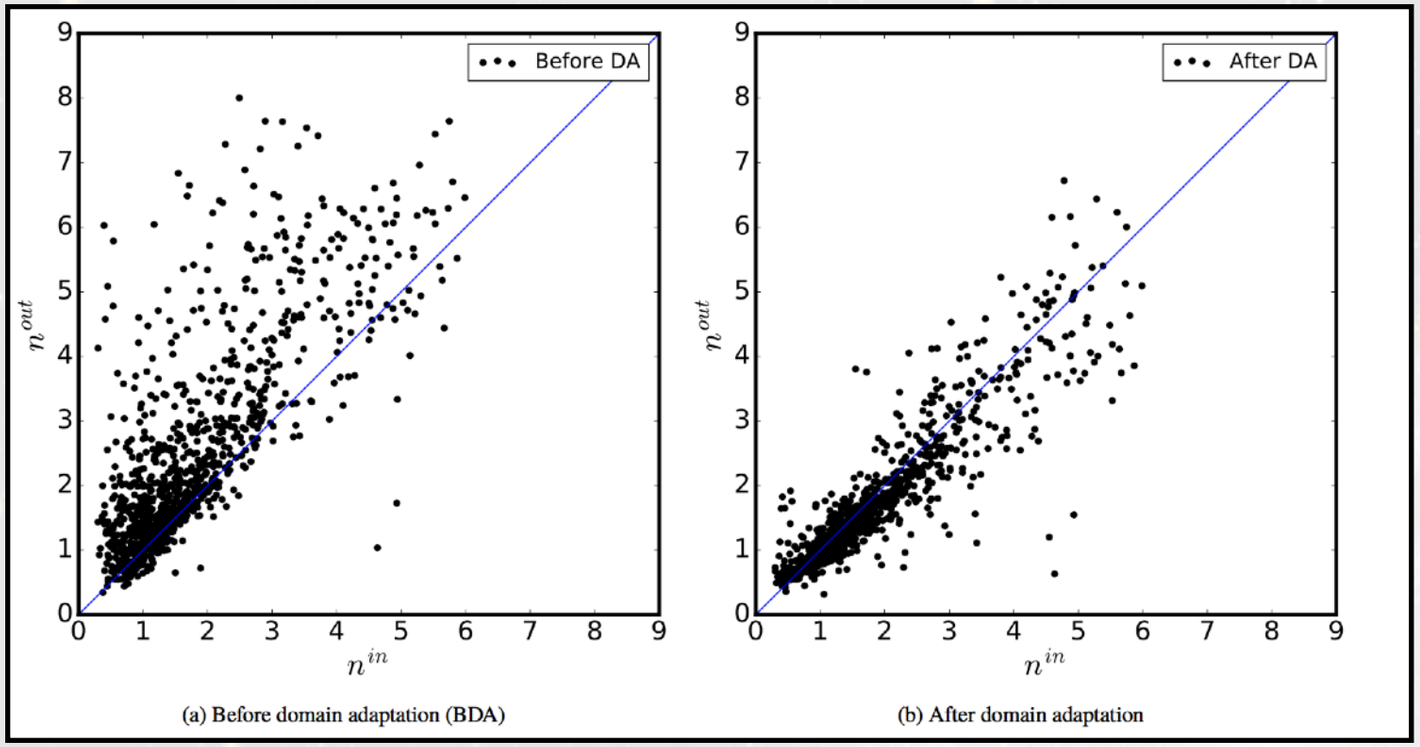
Magnitude, Half-light Radius

1000 CANDELS galaxies
ground truth: Van Der Wel +12



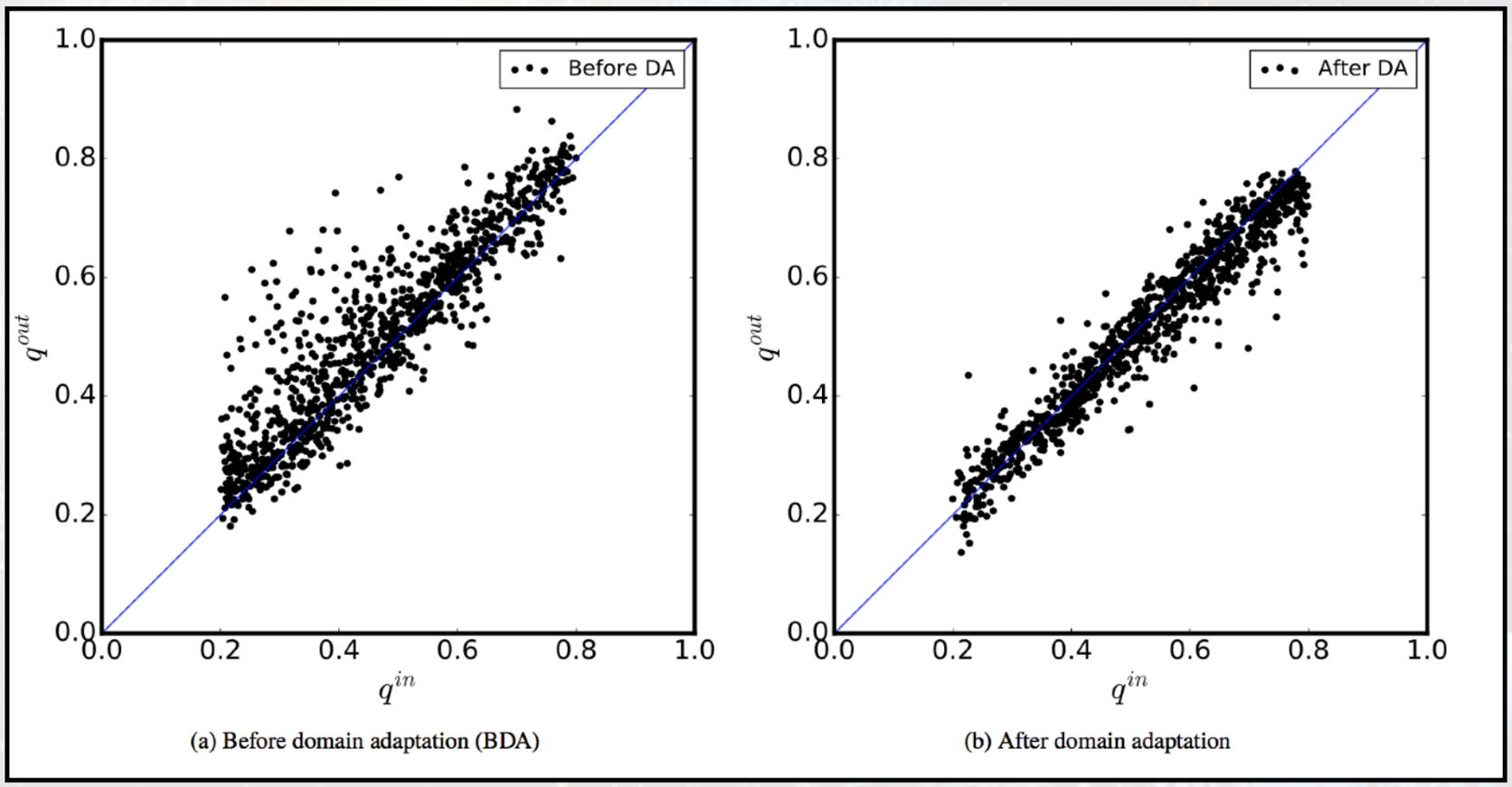
(a) Before domain adaptation (BDA) (b) After domain adaptation

Tests on Real Data



Sérsic index, ellipticity

1000 CANDELS galaxies
ground truth: Van Der Wel +12

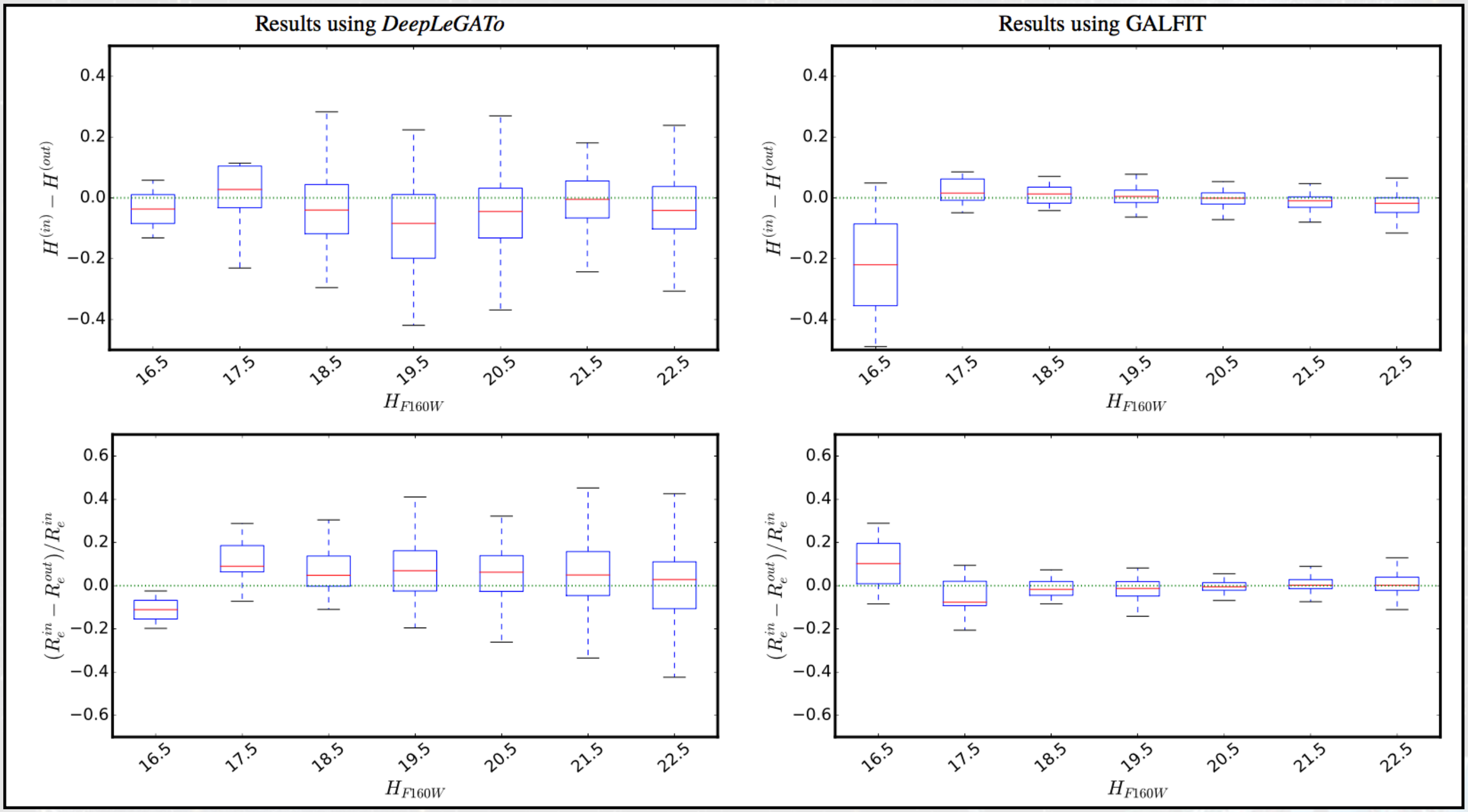


Tests on Real Data

Magnitude, Half-light Radius

1000 CANDELS galaxies
ground truth: Van Der Wel +12

Van Der Wel +12 vs
Dimauro et al. 2017 (submitted)

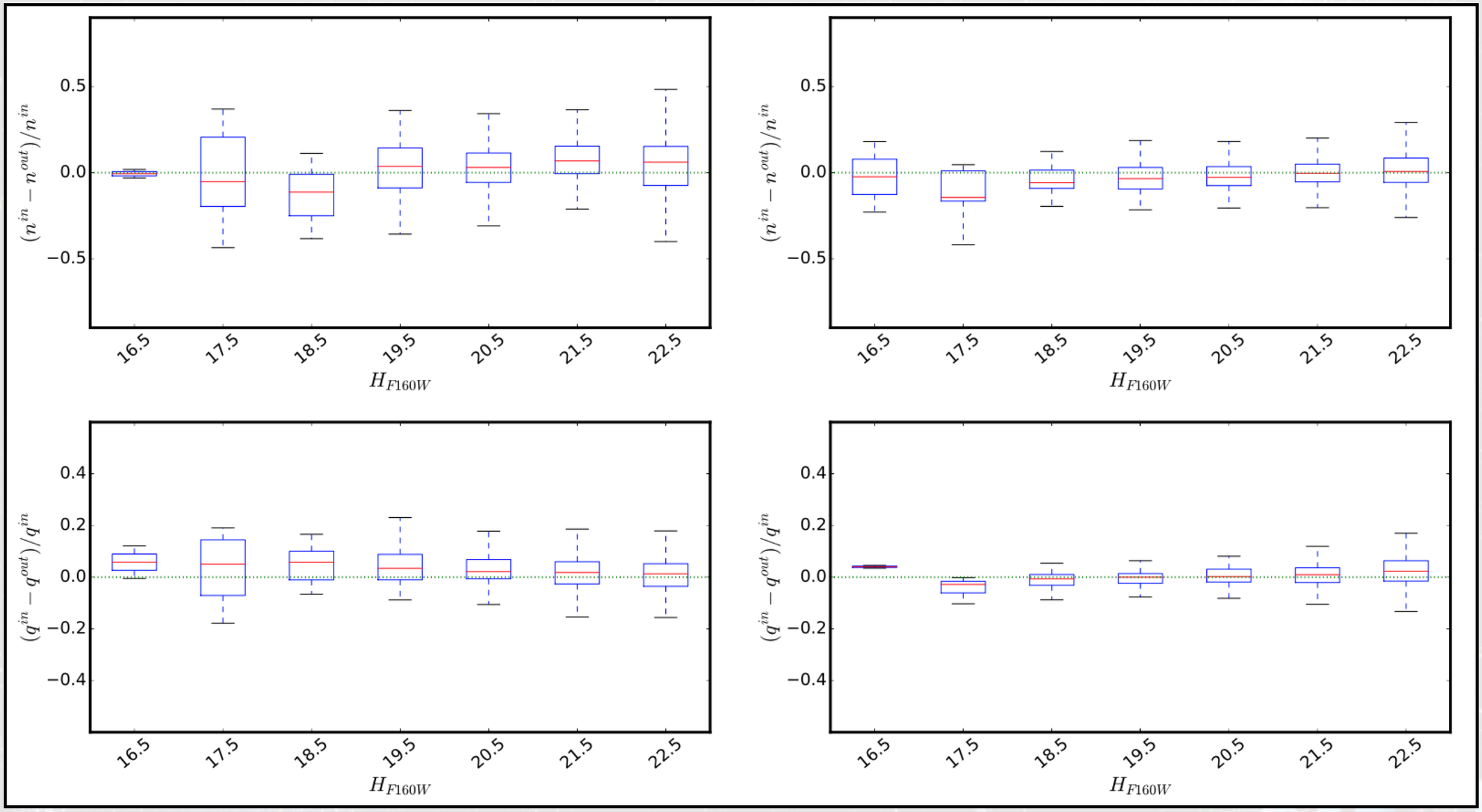


Tests on Real Data

Sérsic index, ellipticity

1000 CANDELS galaxies
ground truth: Van Der Wel +12

Van Der Wel +12 vs
Dimauro et al. 2017 (submitted)



Summary of Predictions on Real Data (after domain adaptation)

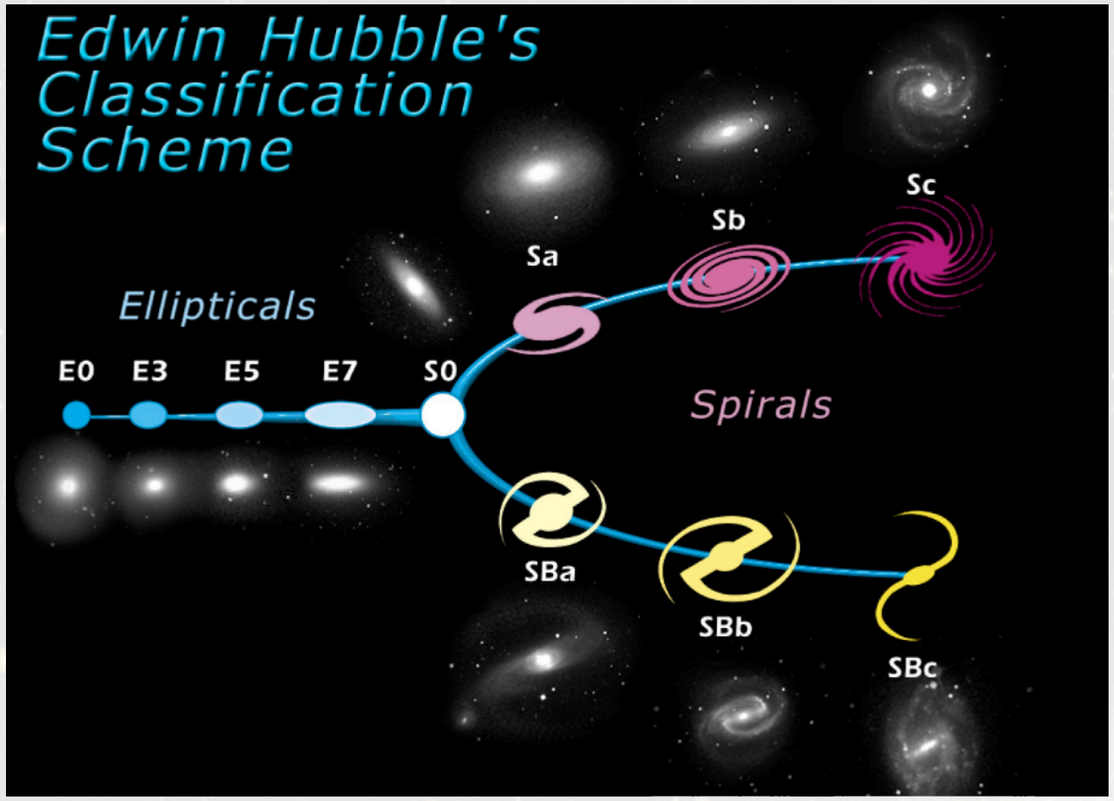
	R^2 Real data			
Parameter	Before TL	BTL isolated	After TL	2 GALFIT
Magnitude	0.795	0.979	0.980	0.984
Radius	-0.431	0.630	0.813	0.860
Sérsic index	-0.331	0.516	0.813	0.819
Ellipticity	0.773	0.915	0.934	0.914

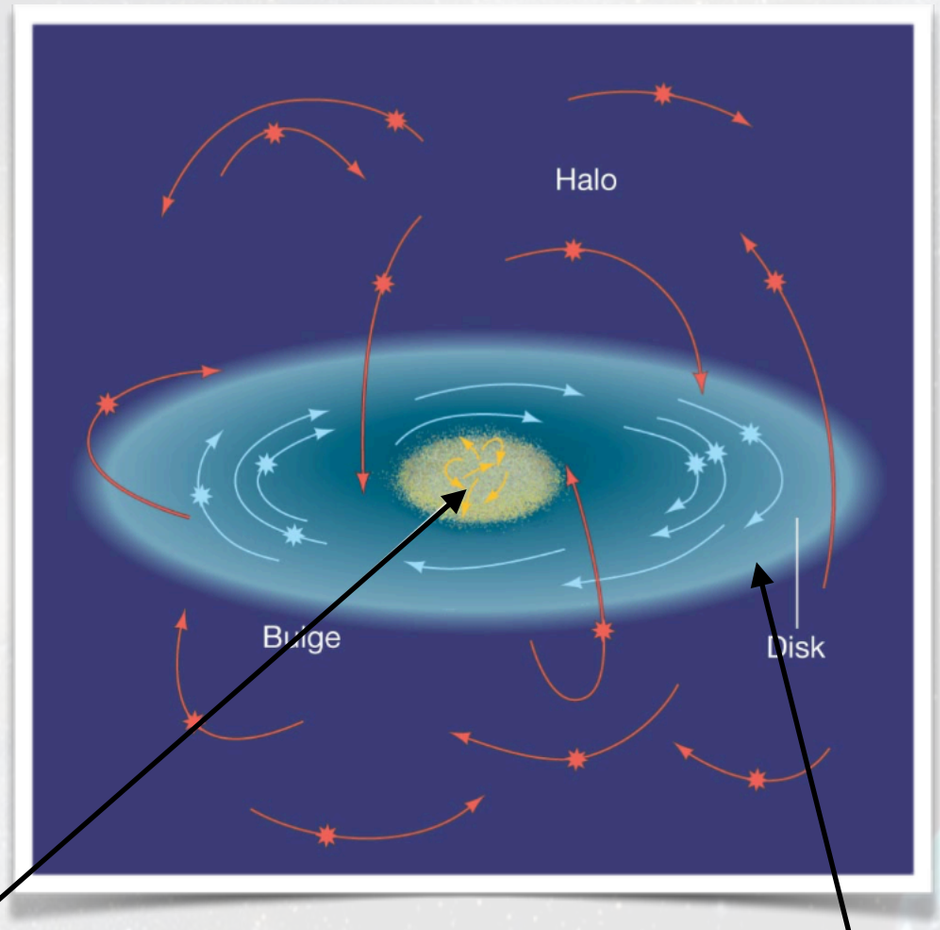
coefficient of determination

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Time: 10 min domain adaptation
+ usual time


DeepLeGATo_2c

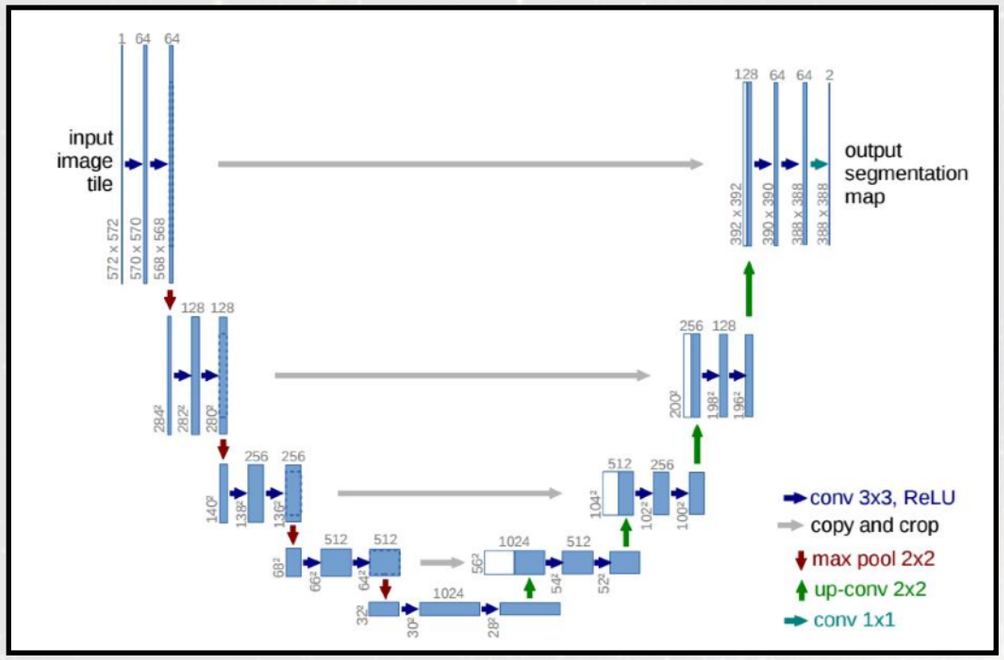

Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
SBa
SBb
SBc


Halo
Bulge
Disk

Bulge

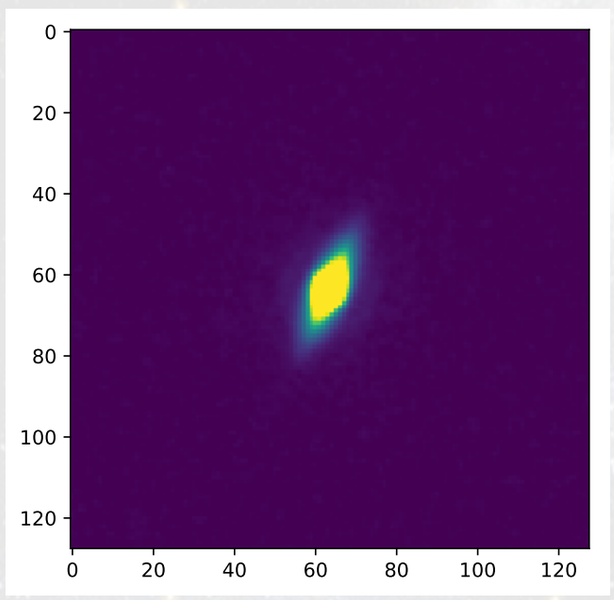
Disk

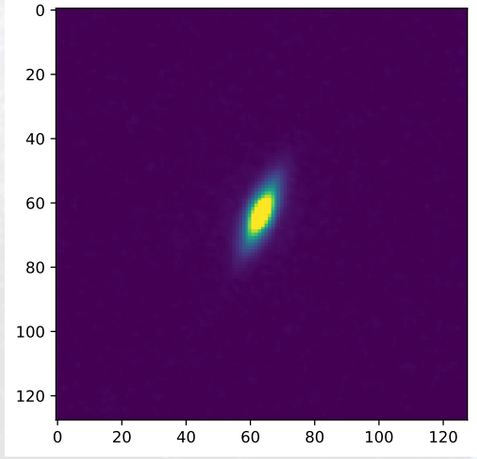
U-Net: Convolutional Networks for Image Segmentation

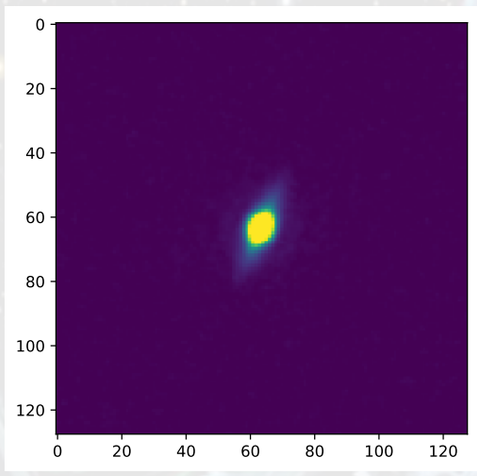


WITHOUT NOISE

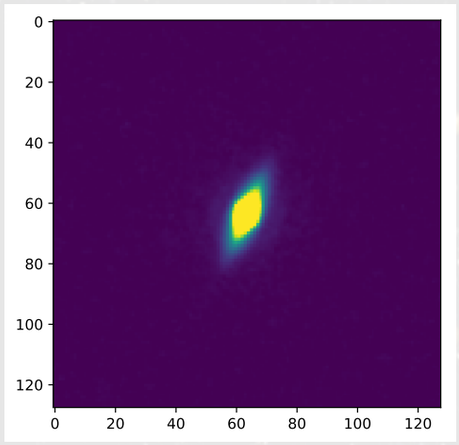
WITH NOISE



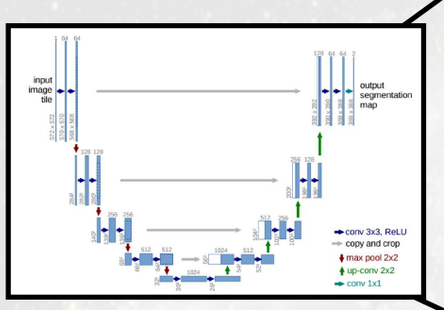


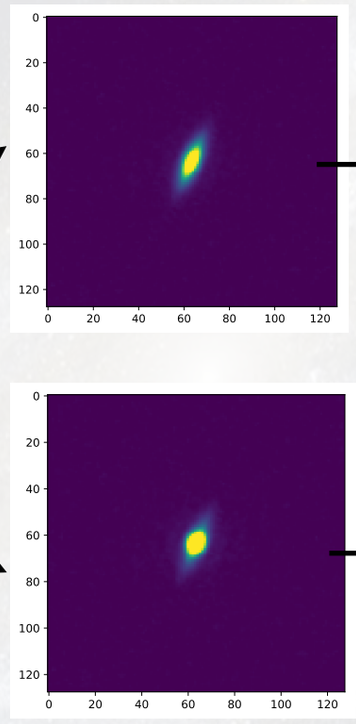


General Flowchart

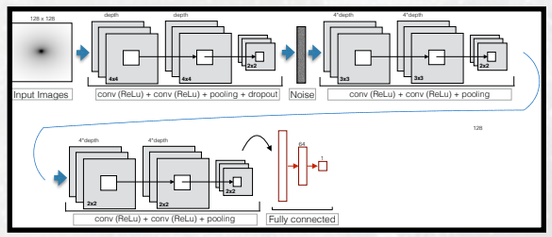


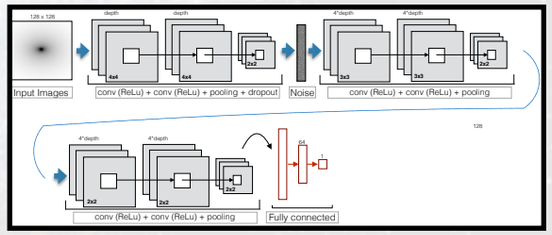
DeepLegato_2c





DeepLegato_1c





Magnitude

Radius

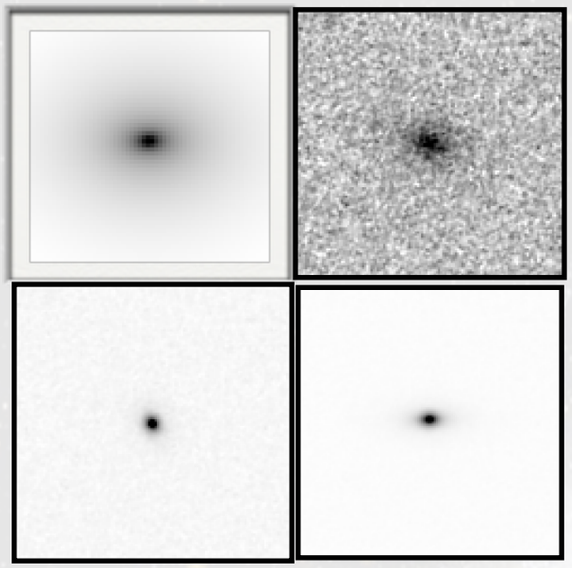
Sersic index

Ellipticity

Dataset 1: simulated Data

38,000 stamps

two-component H band HST/CANDELS



Mag Total	Mag Bulge	Mag Disk	B/T
18-24	18.4-25.3	18.4-25.3	**0.3-0.7**

NSER DISK	NSER Bulge	BA	PA
1	**2.5-6**	0-1	**0-180**

FIXED NOISE

FIXED PSF

Test Battery

$$MSE = \sum_{i}^{N} \frac{(y_i)^2}{N}$$

$$y_i = \sum_{l=0}^{128} \sum_{m=0}^{128} (y_{l,m} - \hat{y}_{l,m})$$

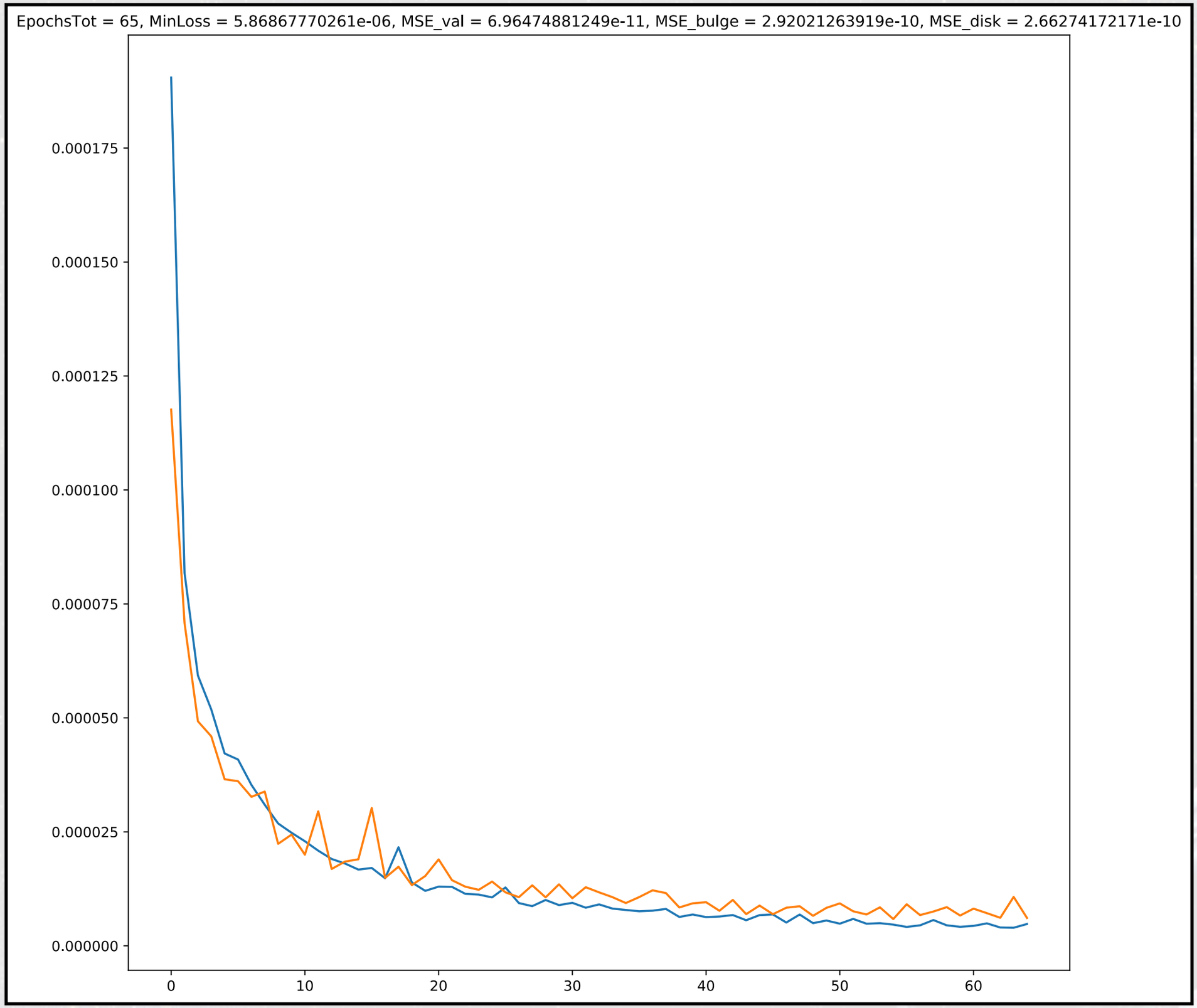
$$y_i = \sum_{l=0}^{128} \sum_{m=0}^{128} \frac{(y_{l,m} - \hat{y}_{l,m})}{\hat{y}_{l,m}}$$

Unet		
Dropout		
	X (log) **[test2]**	mse,sgd
X(no norm) **[Hyper_04]**	X (no norm) **[test1]**	msle,adm
	X(no norm) **[Hyper_05]**	msle,sgd
0	**0.25**	

Deeper Unet		
Dropout		
		mse,sgd
X (no norm) **[Hyper_00]**	X(no norm) **[Hyper_06]**	msle,adm
	X (no norm) **[Hyper_02]**	msle,sgd
0	**0.25**	

Unet Dilanet		
Dropout		
	X (log) **[Hyper_03]**	mse,sgd
	X(no norm) **[Hyper_07]**	msle,adm
	X (no norm) **[Hyper_01]**	msle,sgd
0	**0.25**	

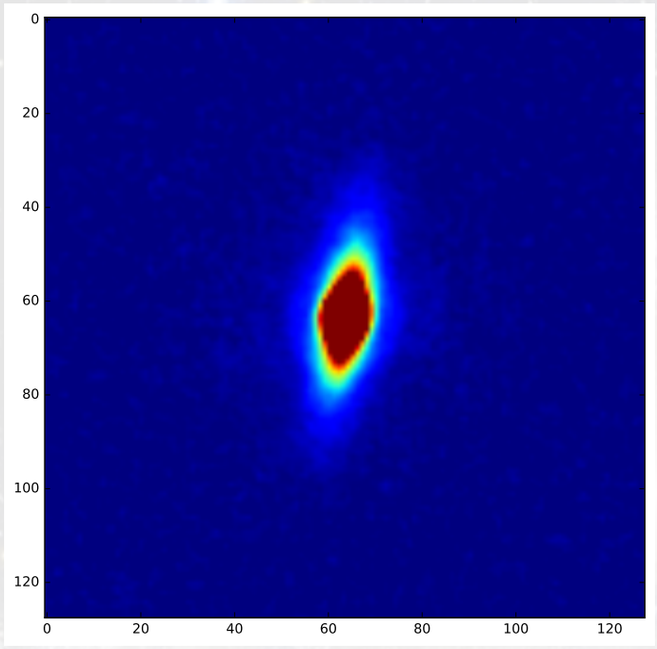
-*test3* = prob ,simplerAutonc, adadelta,binaryCrossE, dropout = 0		

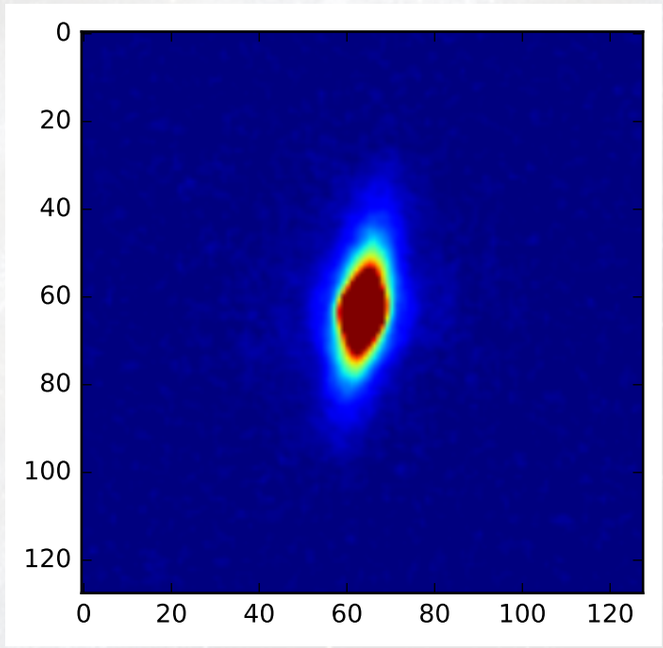

EpochsTot = 65, MinLoss = 5.86867770261e-06, MSE_val = 6.96474881249e-11, MSE_bulge = 2.92021263919e-10, MSE_disk = 2.66274172171e-10
0.000175
0.000150
0.000125
0.000100
0.000075
0.000050
0.000025
0.000000
0
10
20
30
40
50
60

Results. Typical:

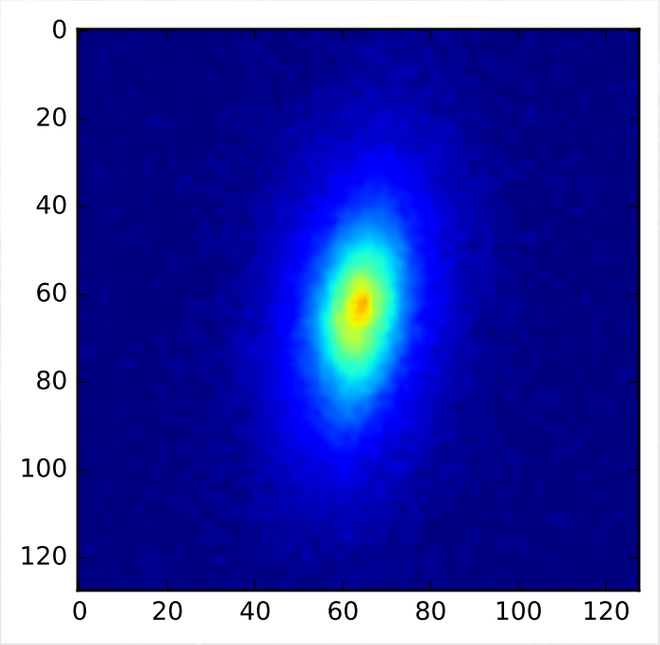
Validation **Predicted**

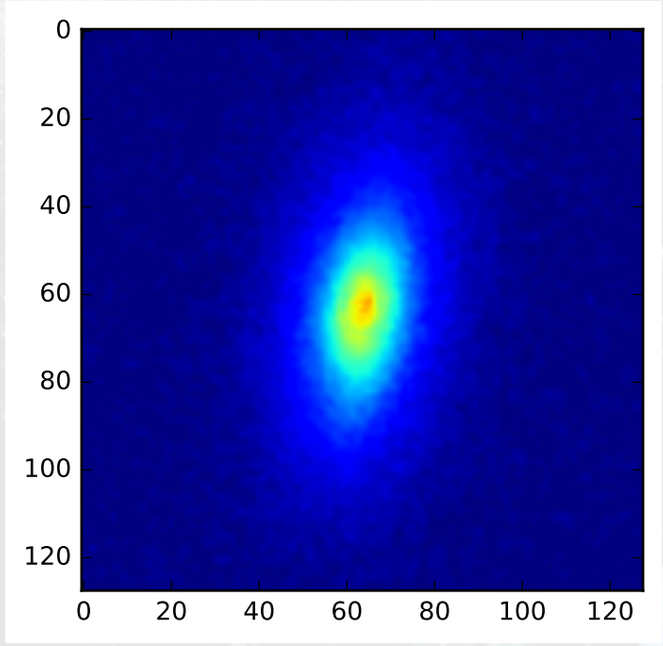
Bulge





Disk

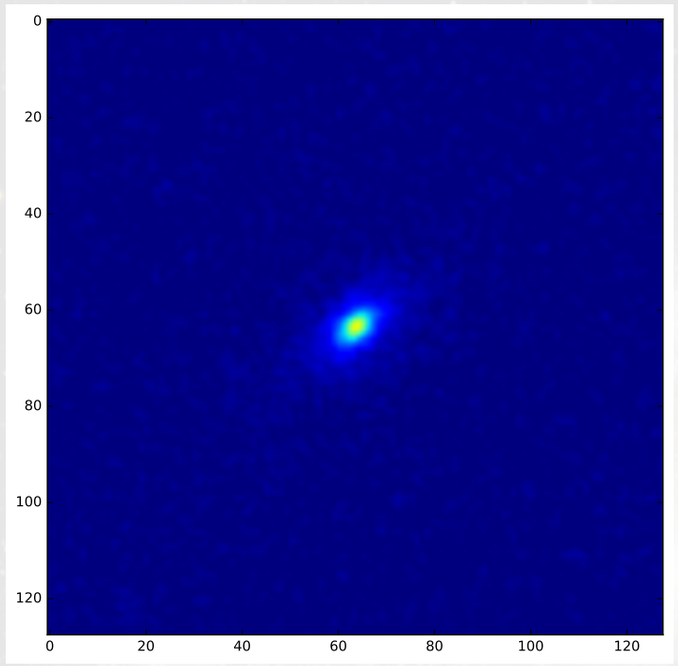


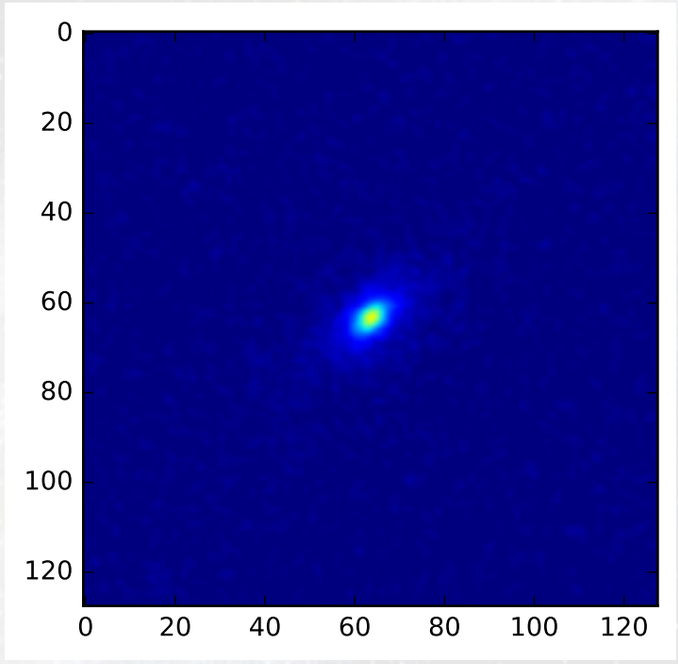


Results. Typical:

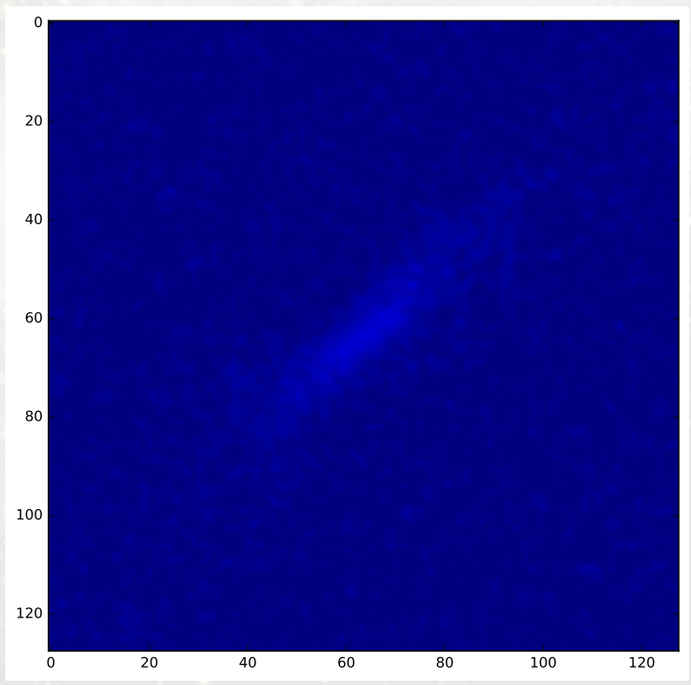
Validation **Predicted**

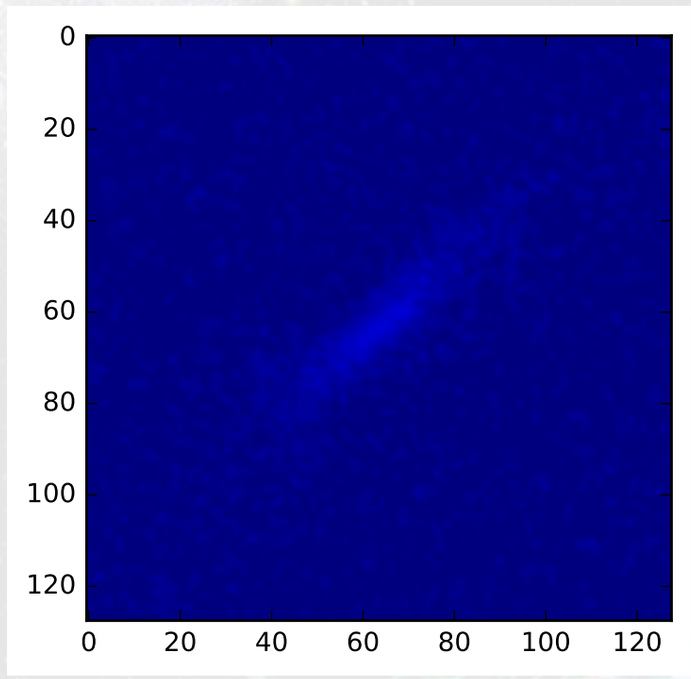
Bulge



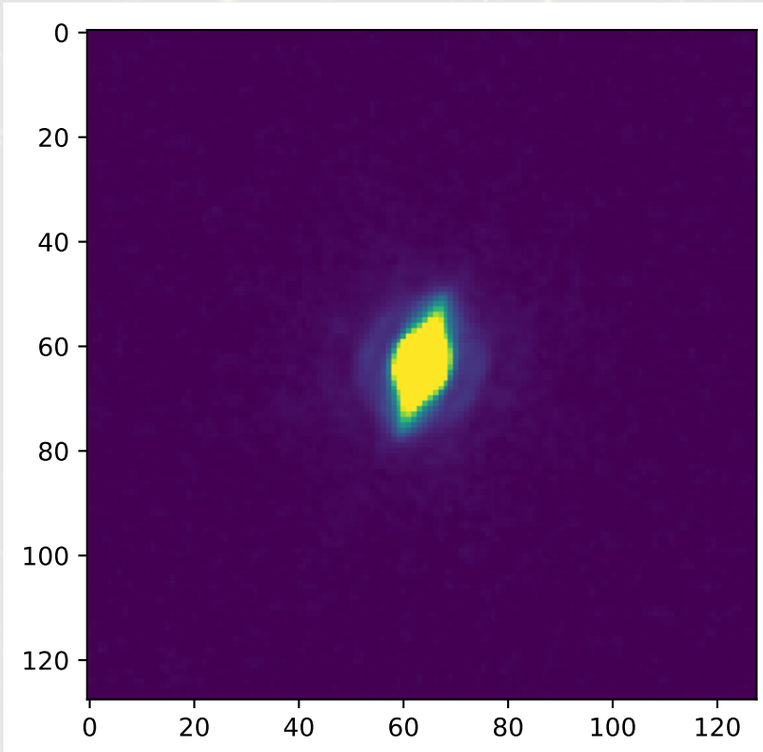
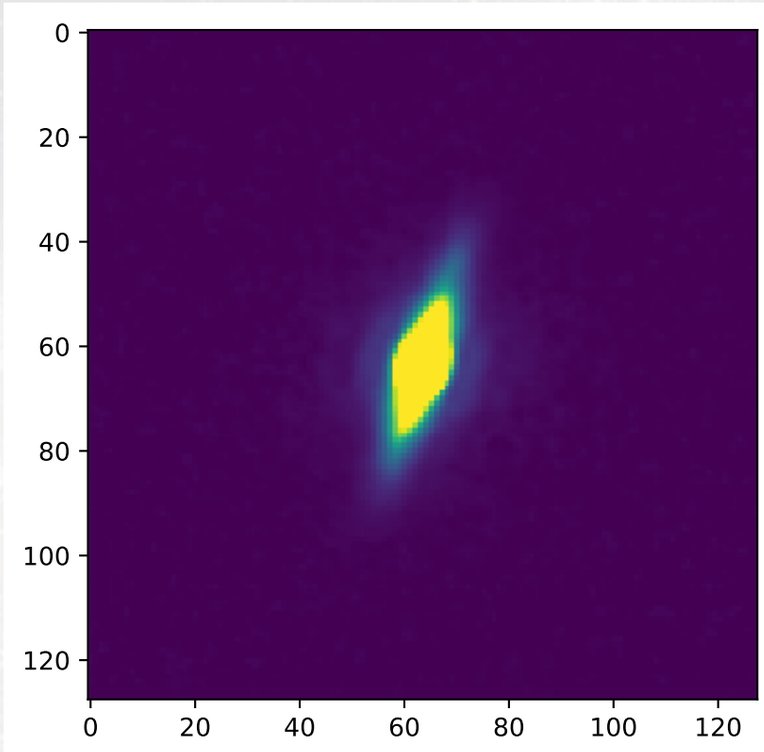
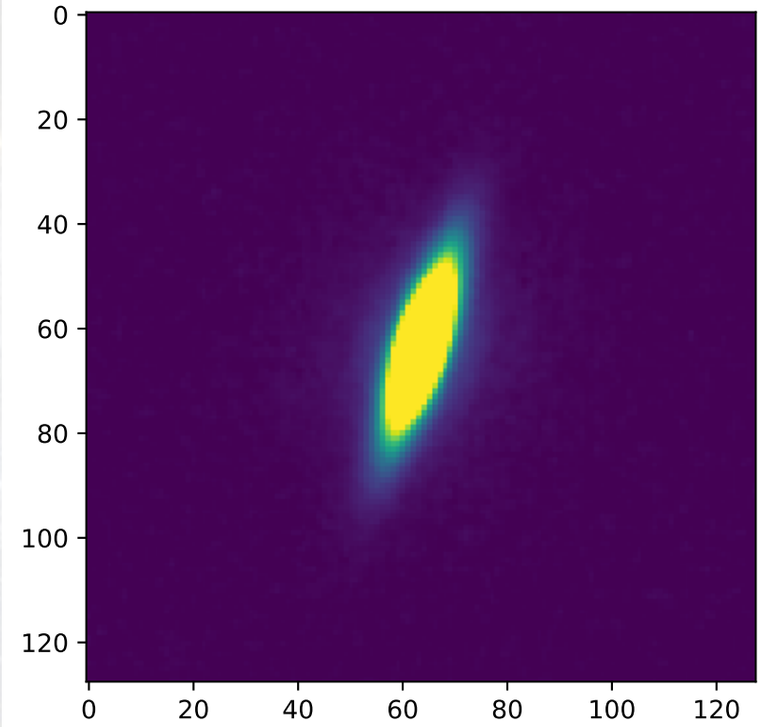
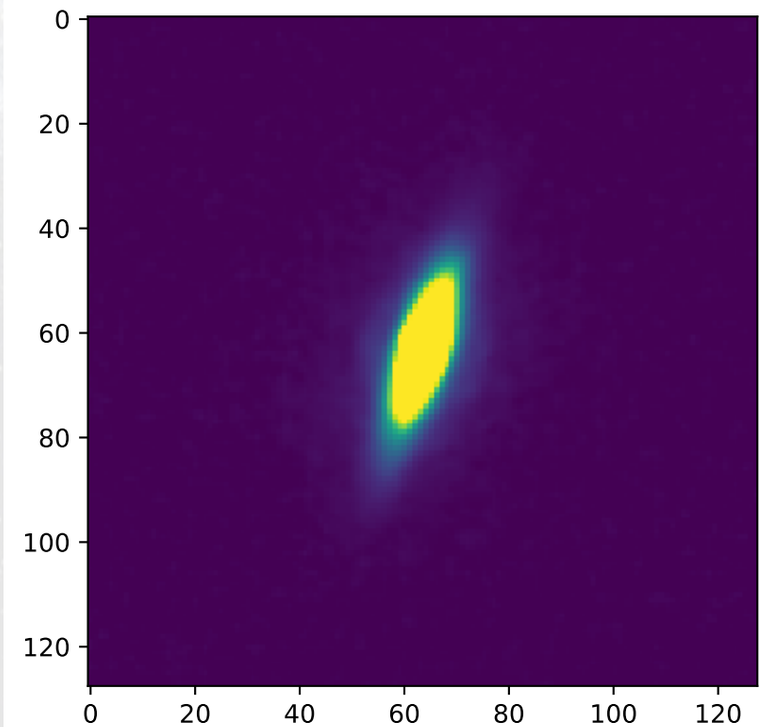


Disk





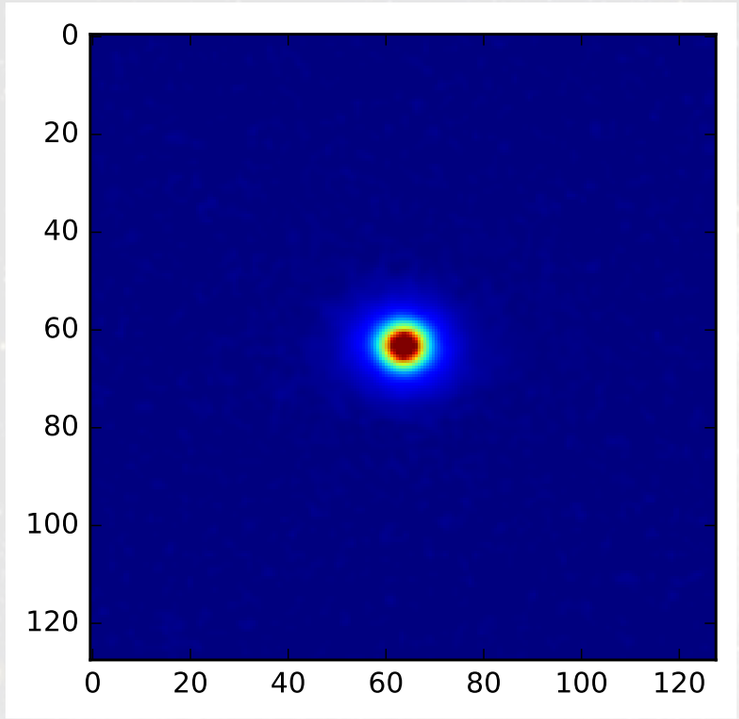
Results. Worse:

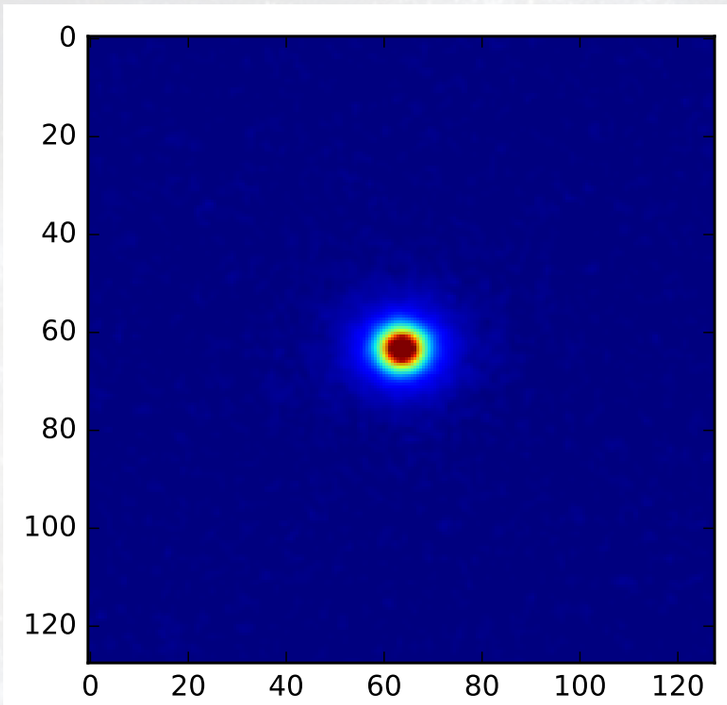
	Validation	Predicted
Bulge		
Disk		

Results: "best"

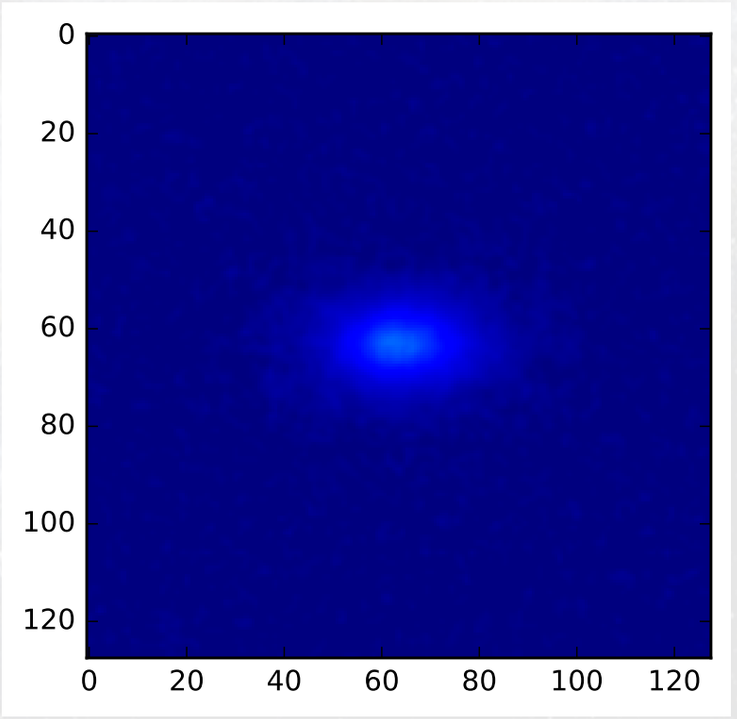
Validation **Predicted**

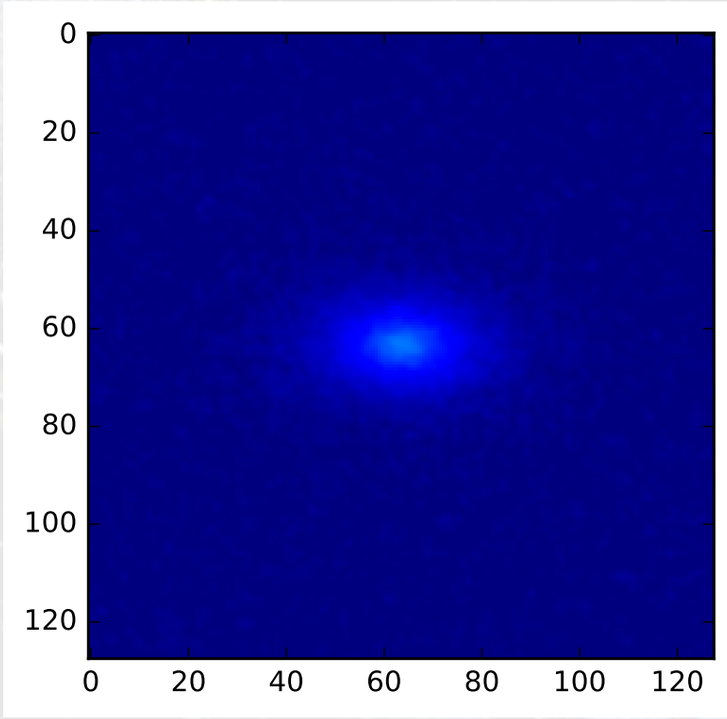
Bulge



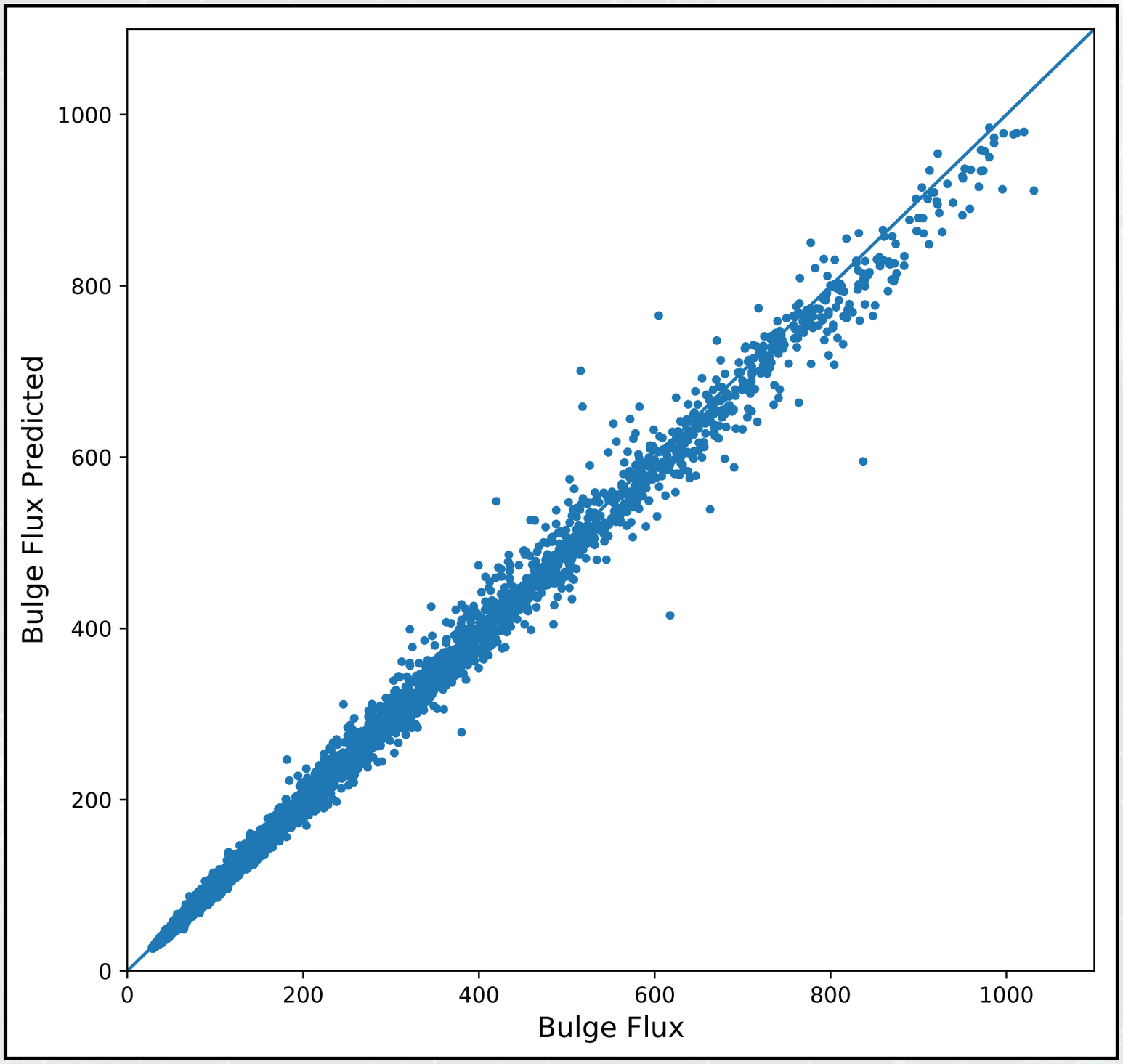


Disk

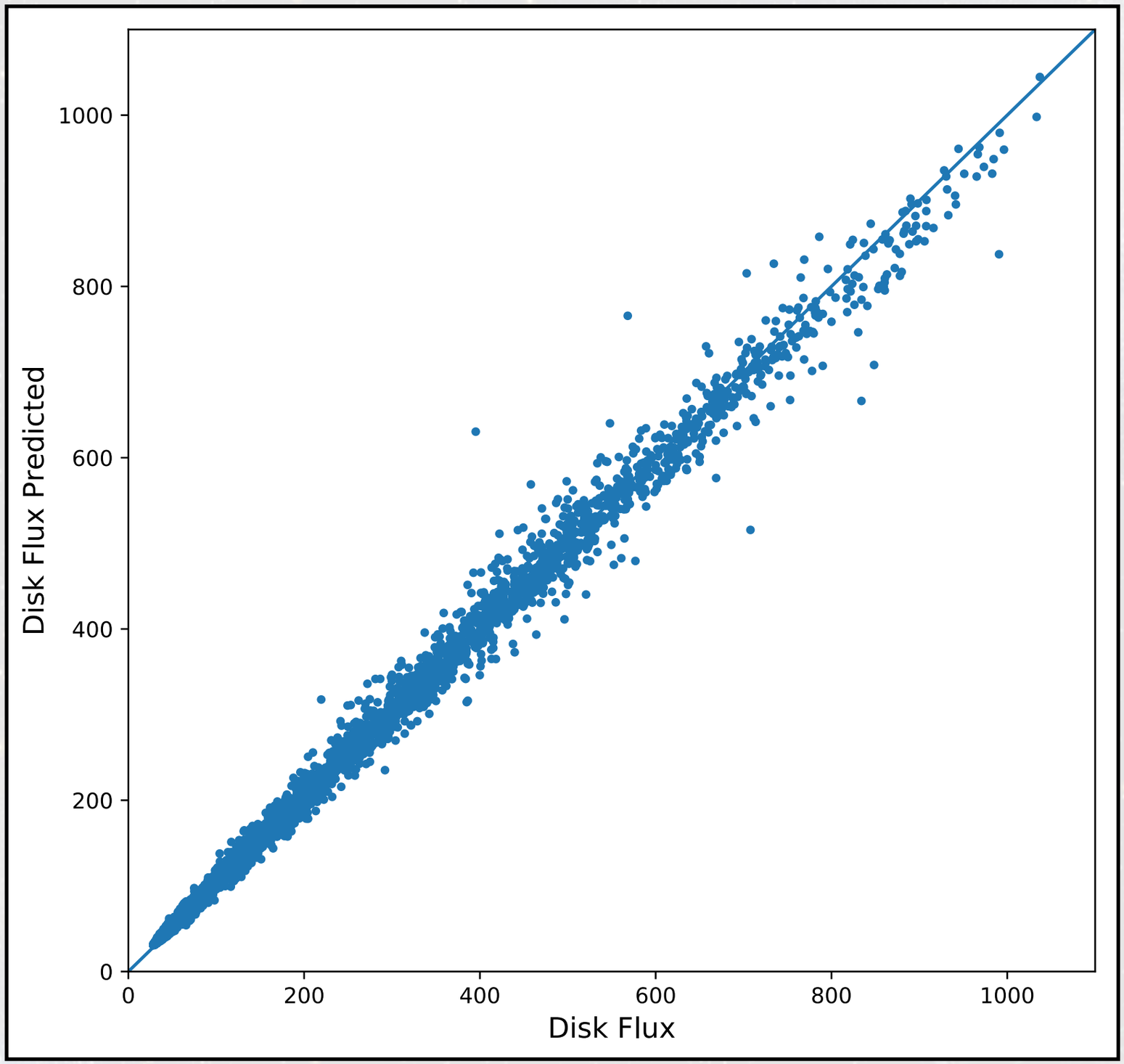




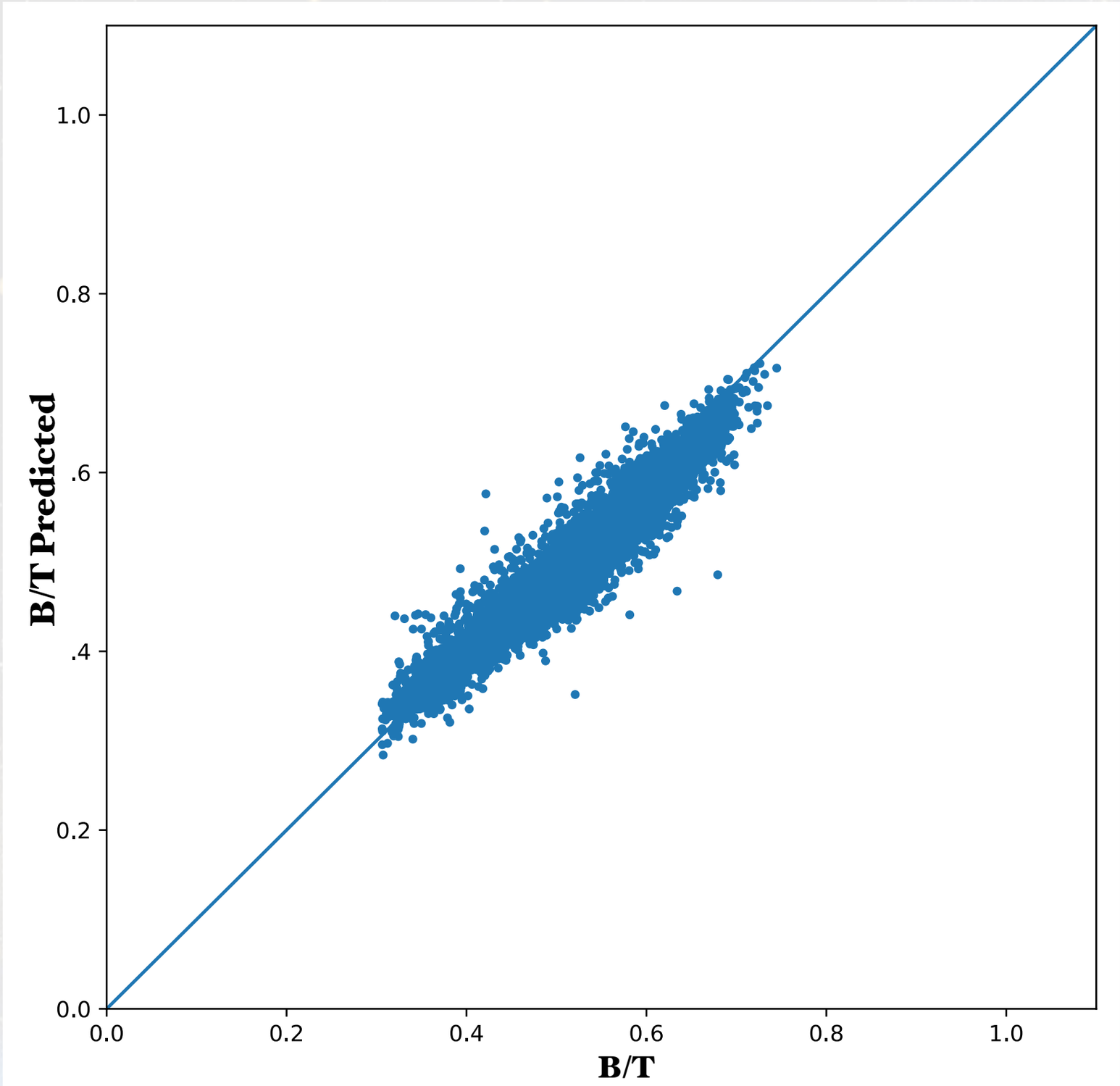
Bulge flux (as pixels sum)



Disk flux (as pixels sum)



B/T flux (as pixels sum)



Dataset 2: simulated Data

38,000 stamps

two-component H band HST/CANDELS

~~FIXED NOISE~~

VARIABLE NOISE

including companions

~2000 BG stamps

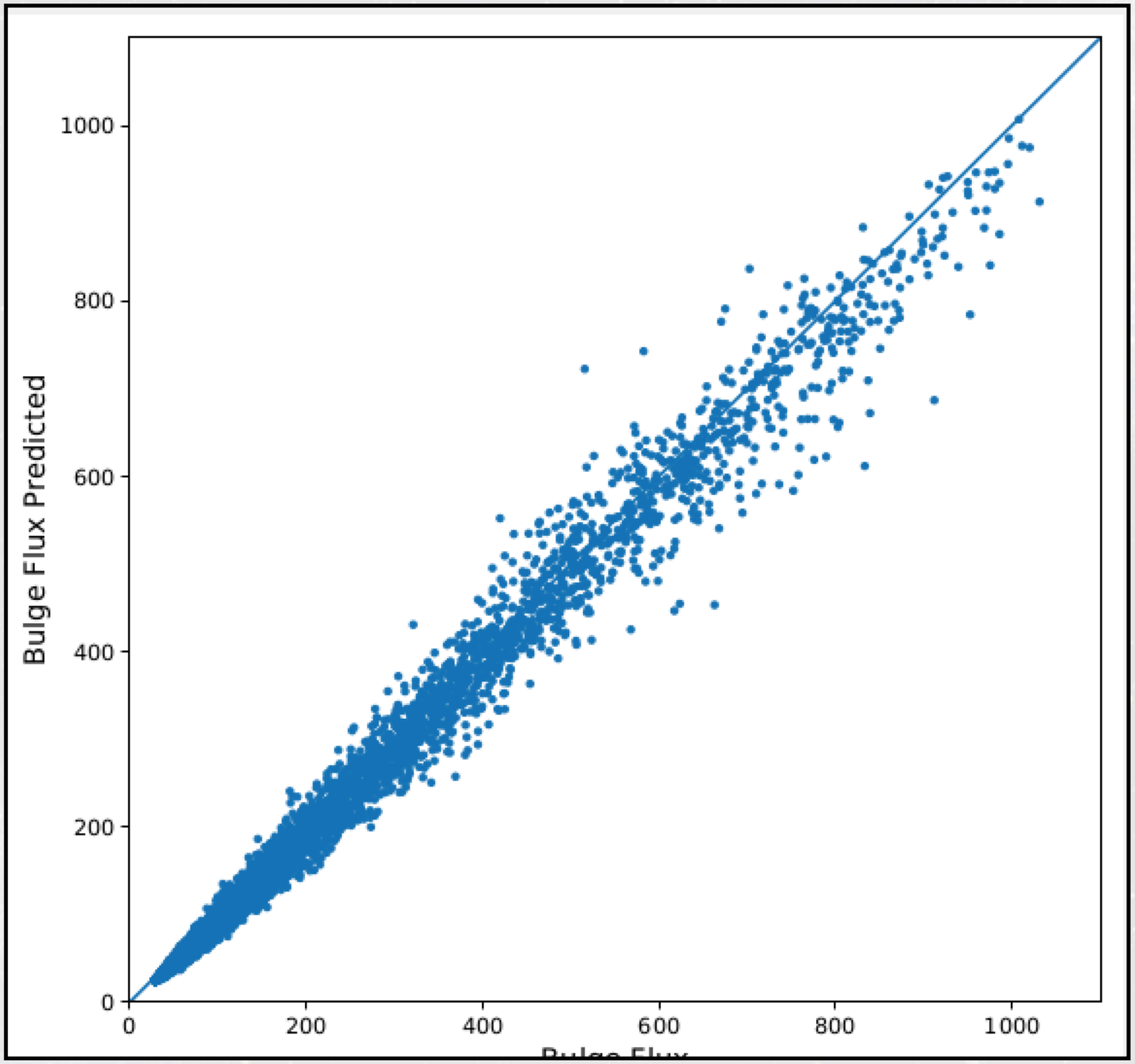
~20 same noise

Mag Total	Mag Bulge	Mag Disk	B/T
18-24	18.4-25.3	18.4-25.3	**0.3-0.7**

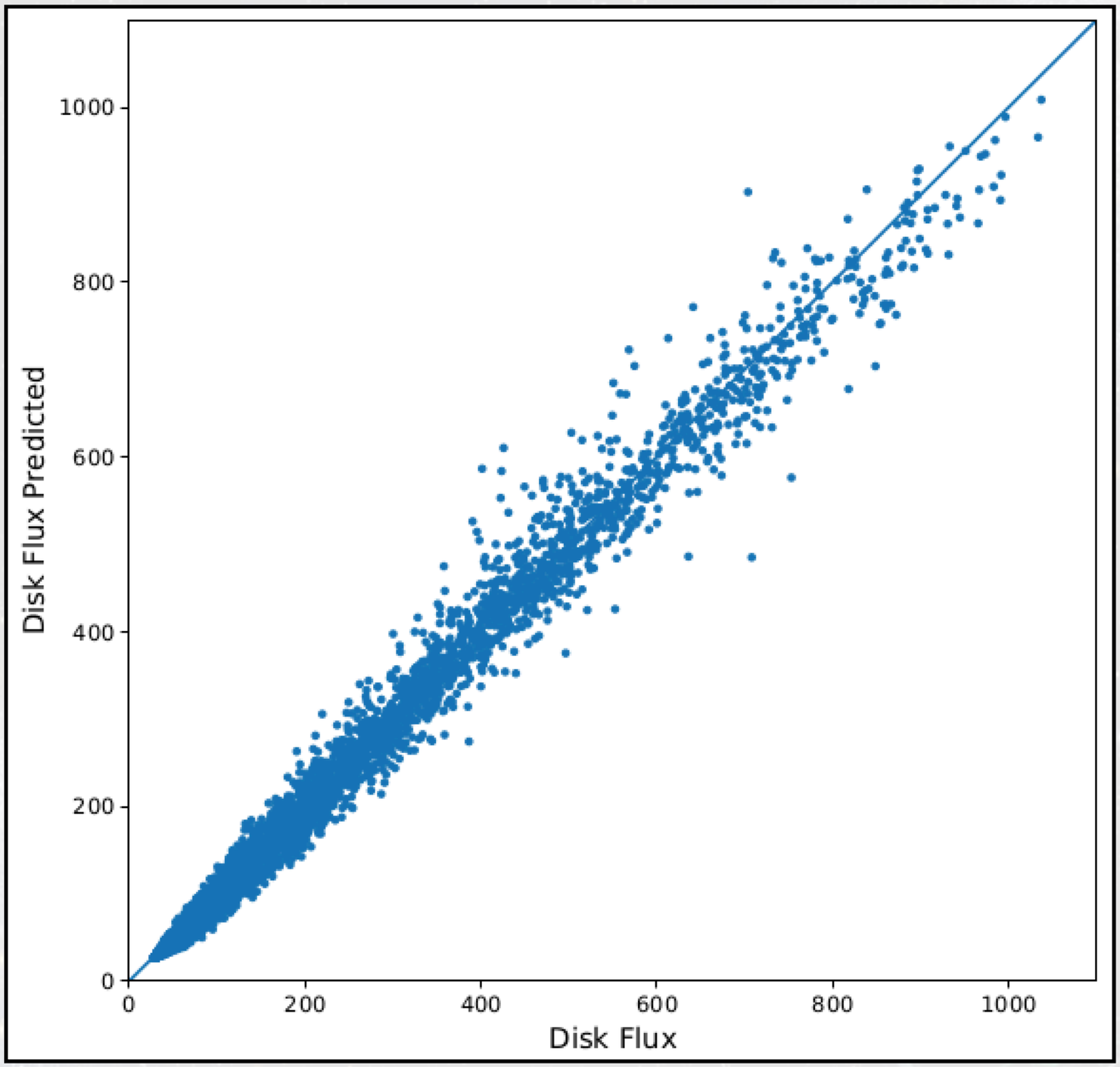
NSER DISK	NSER Bulge	BA	PA
1	**2.5-6**	0-1	**0-180**

FIXED PSF

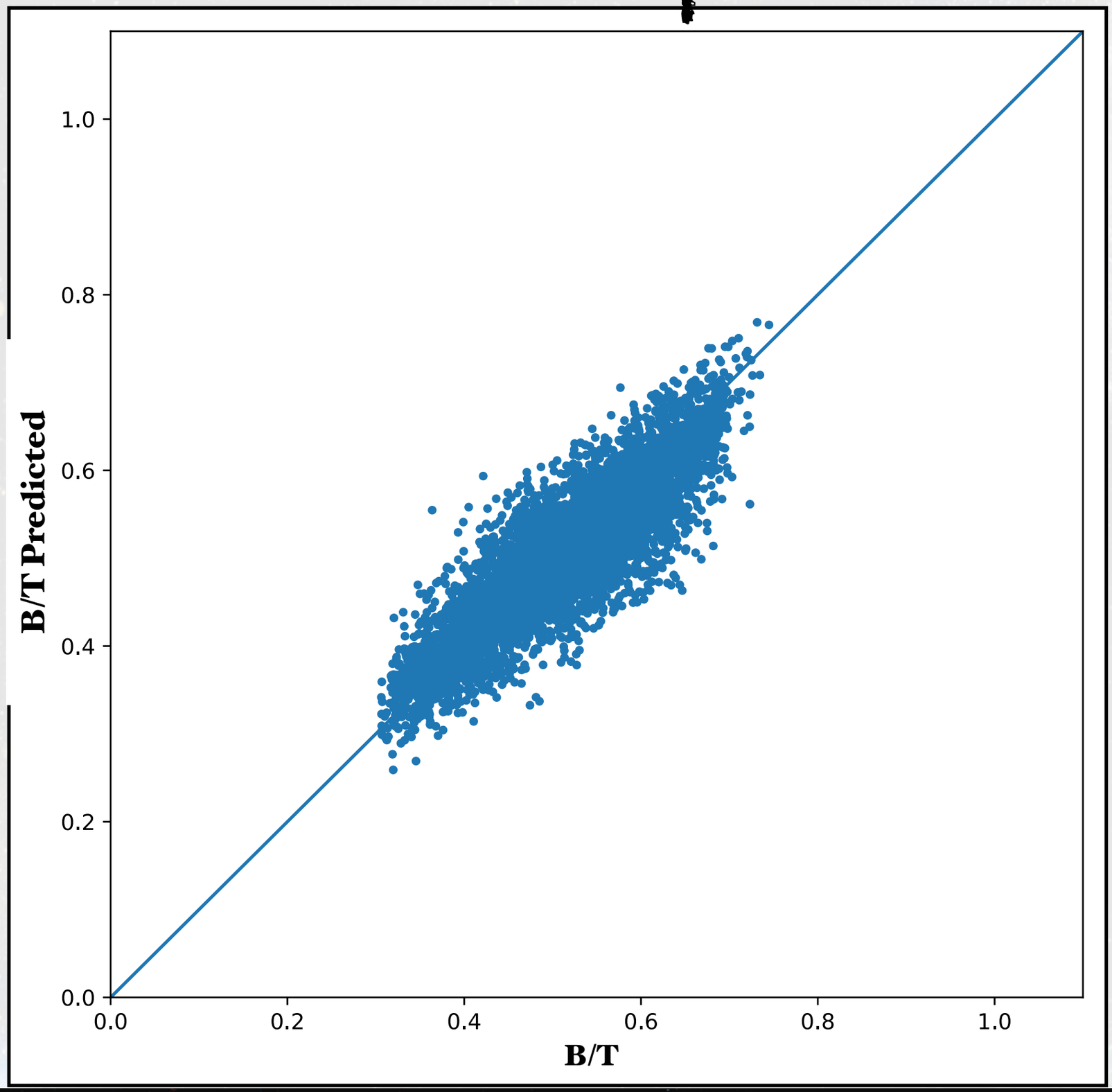
Bulge flux



Disk flux



B/T flux (as pixels sum)



Dataset 3: simulated Data

1) Simulations with extended parameters range

dataset 1-2

Mag Total	Mag Bulge	Mag Disk	B/T
18-24	18.4-25.3	18.4-25.3	**0.3-0.7**

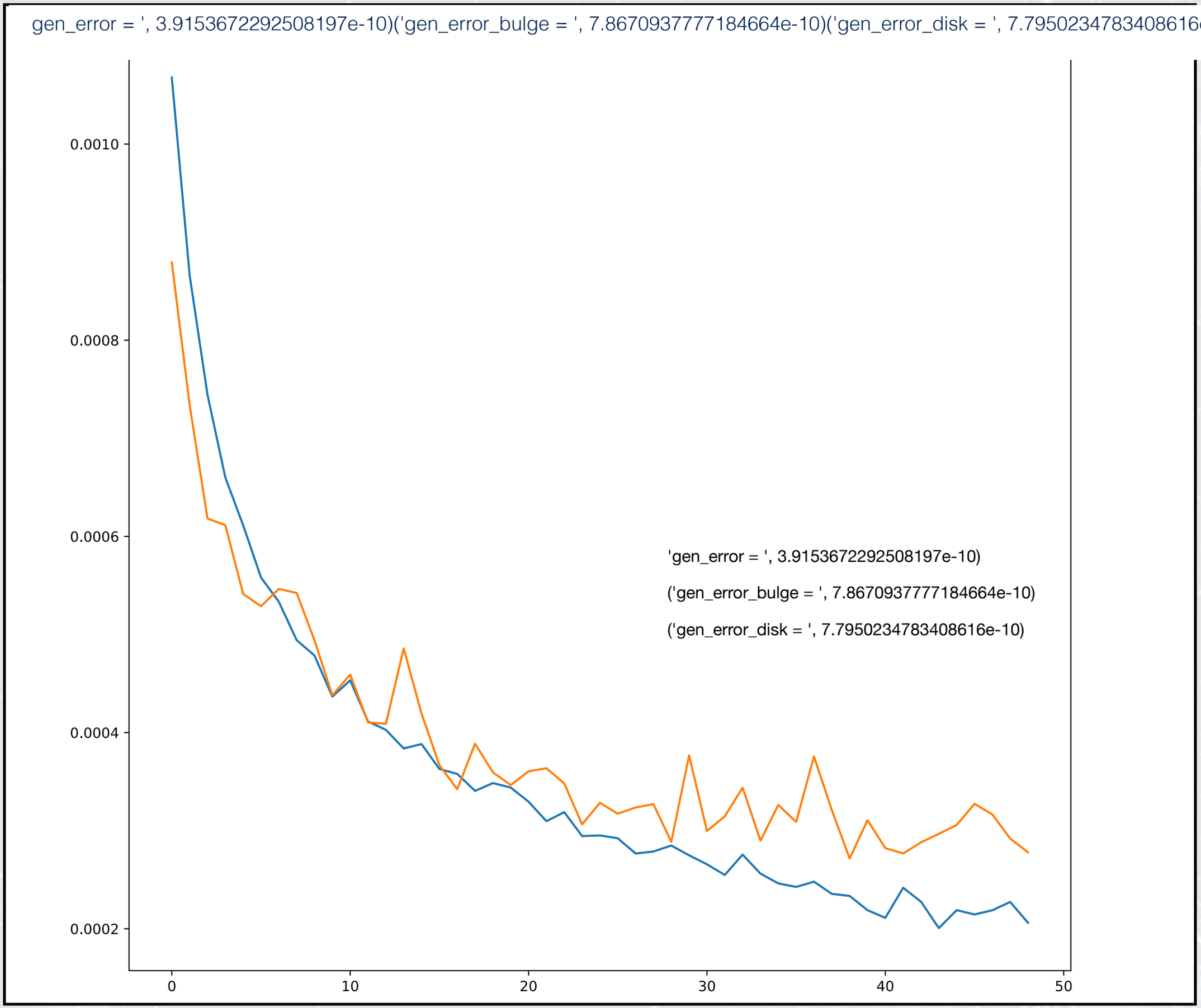
NSER DISK	NSER Bulge	BA	PA
1	**2.5-6**	0-1	**0-180**

dataset 3

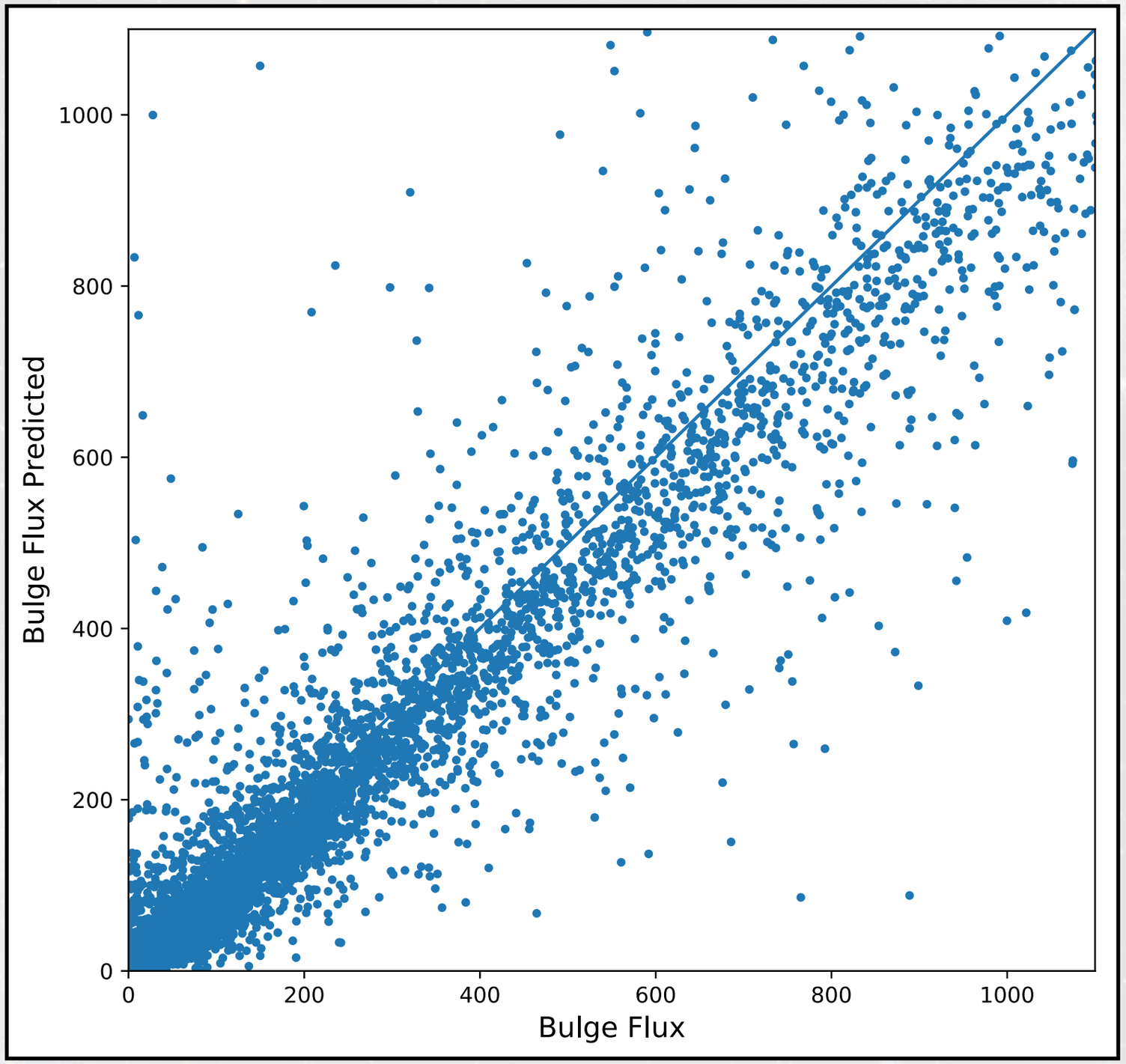
Mag Total	Mag Bulge	Mag Disk	B/T
17-24			**0-1**

NSER DISK	NSER Bulge	BA	PA
0.9-1.1	**0.5-6.5**	0-1	**0-180**

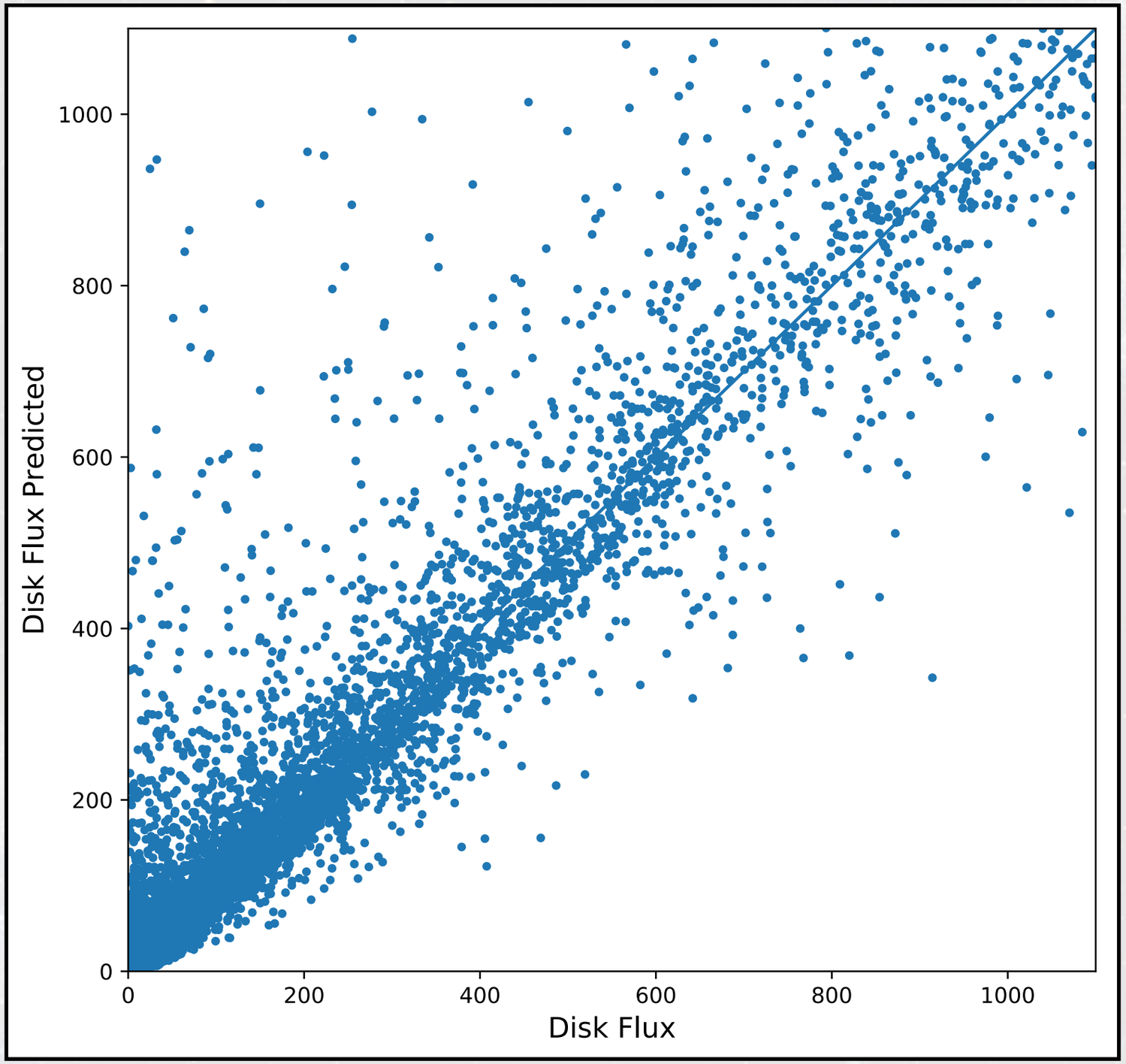
VARIABLE NOISE


gen_error = ', 3.9153672292508197e-10)('gen_error_bulge = ', 7.8670937777184664e-10)('gen_error_disk = ', 7.7950234783408616e-10)
0.0010
0.0008
0.0006
0.0004
0.0002
0
10
20
30
40
50
'gen_error = ', 3.9153672292508197e-10)
('gen_error_bulge = ', 7.8670937777184664e-10)
('gen_error_disk = ', 7.7950234783408616e-10)

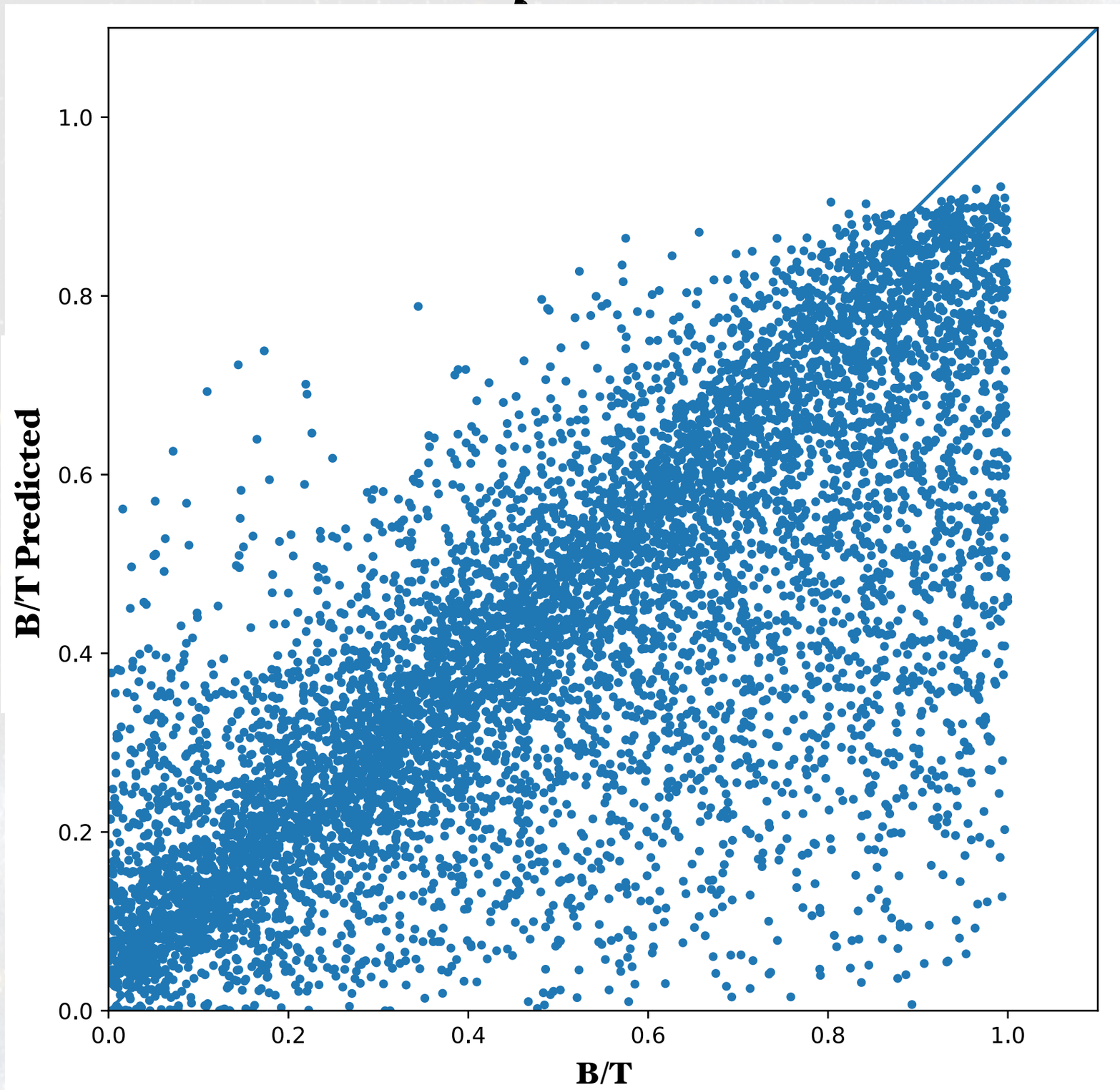
Bulge flux



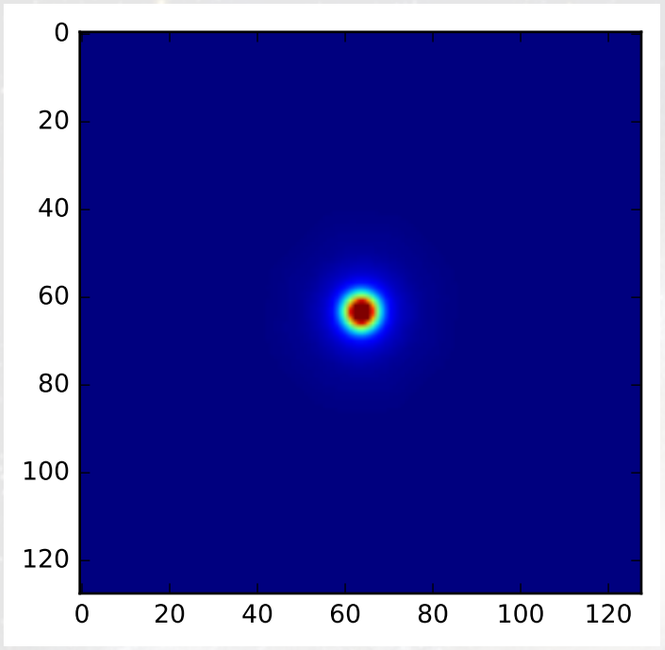
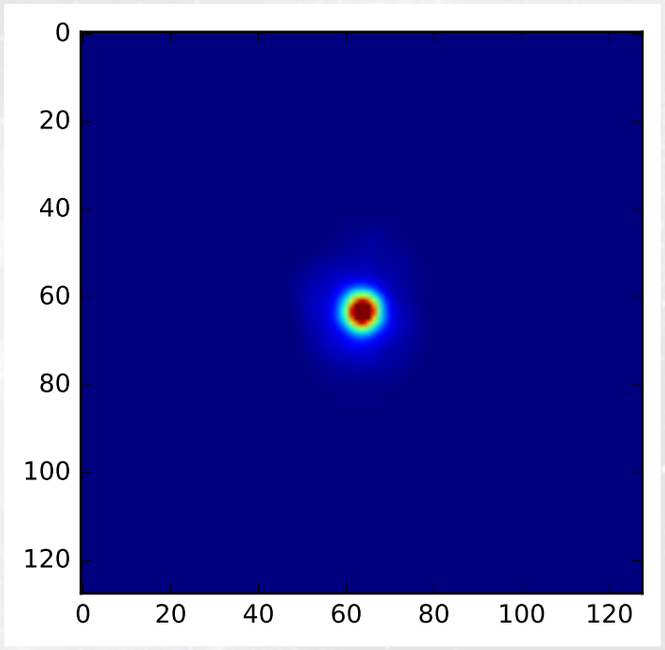
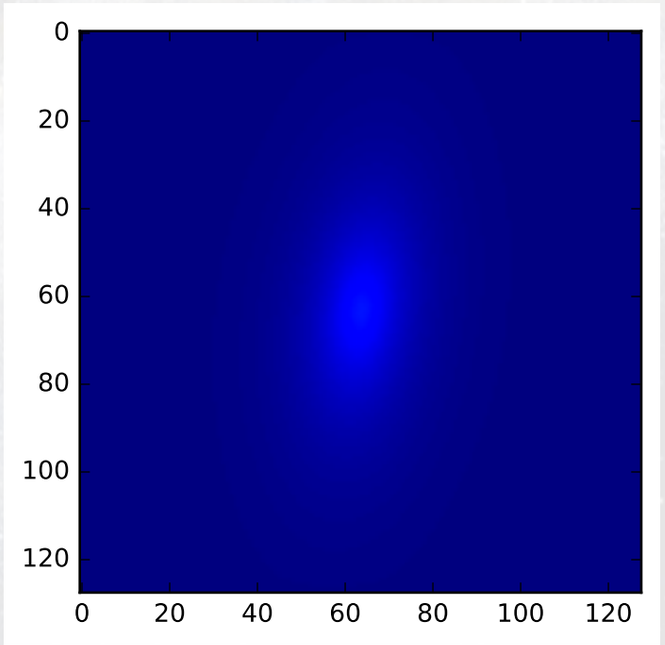
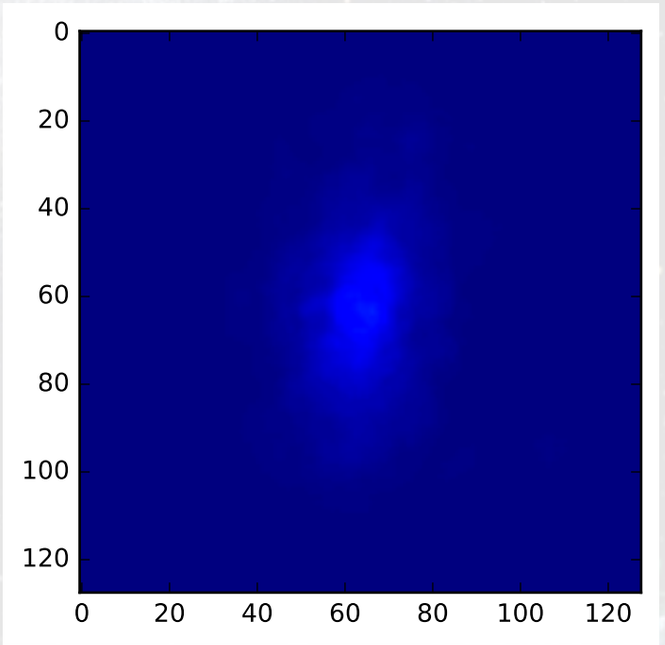
Disk flux



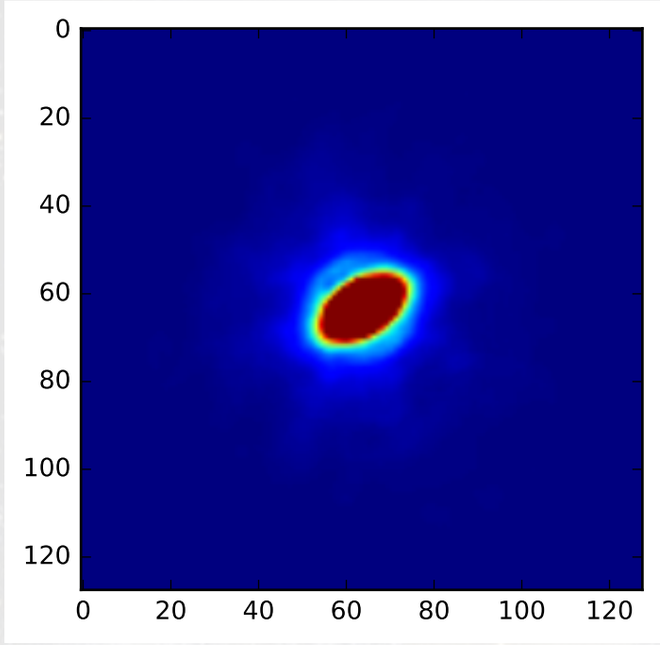
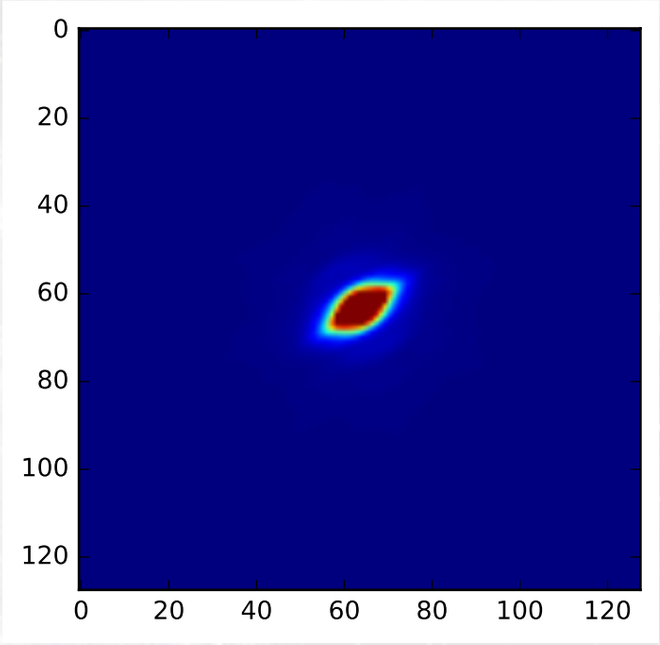
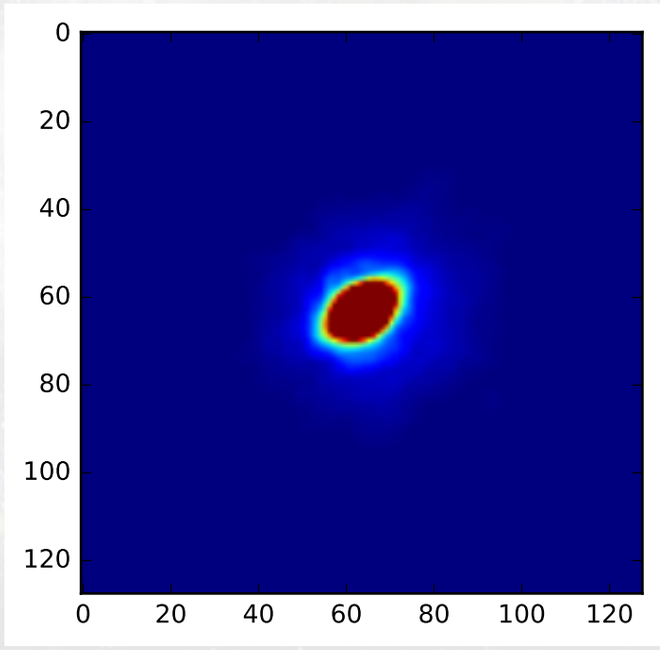
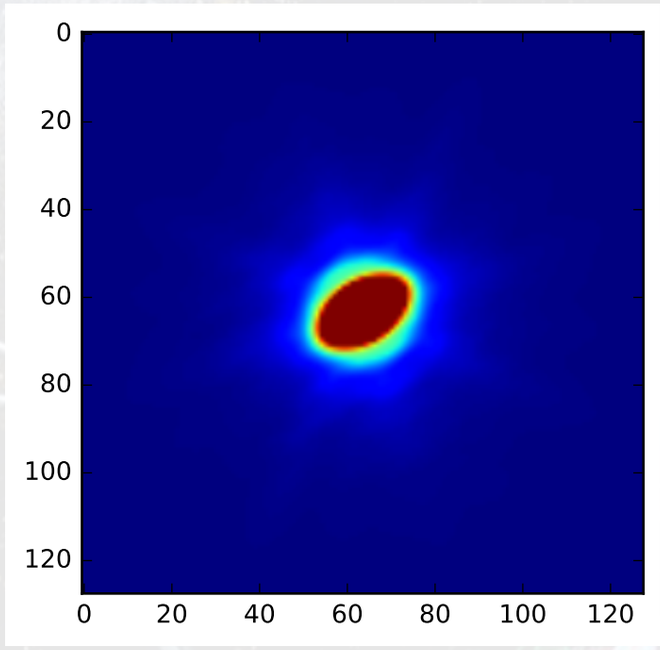
B/T (as pixels sum)



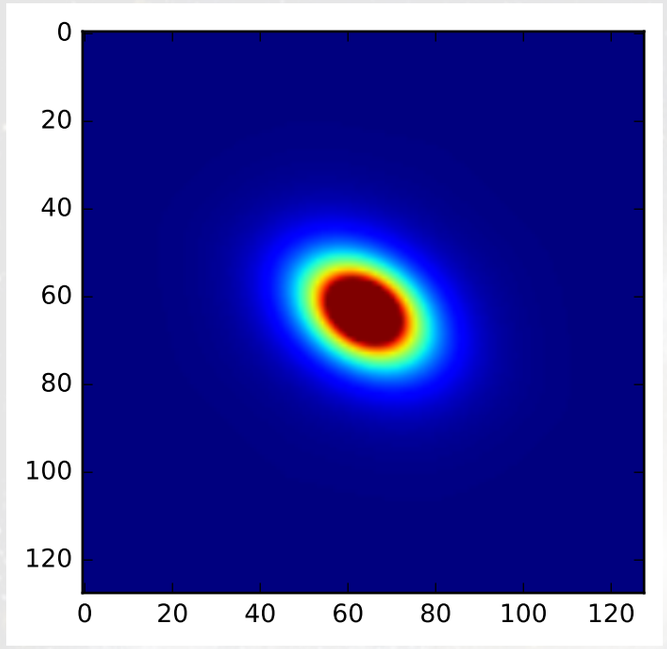
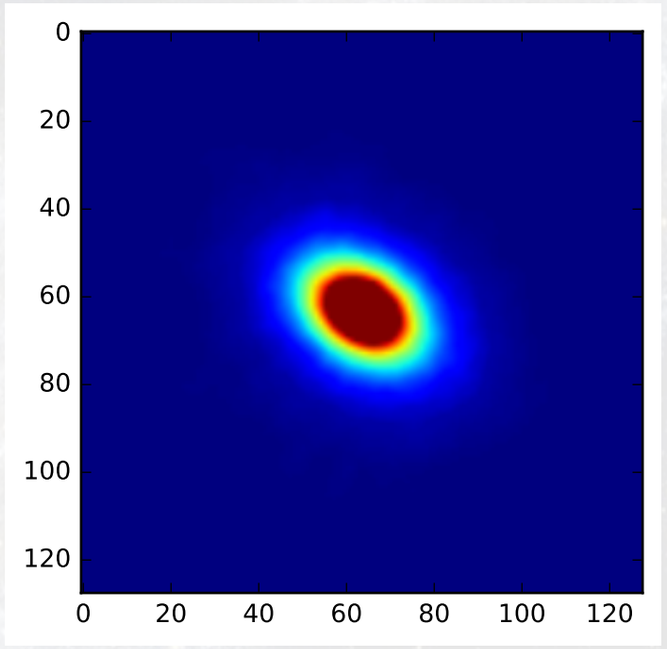
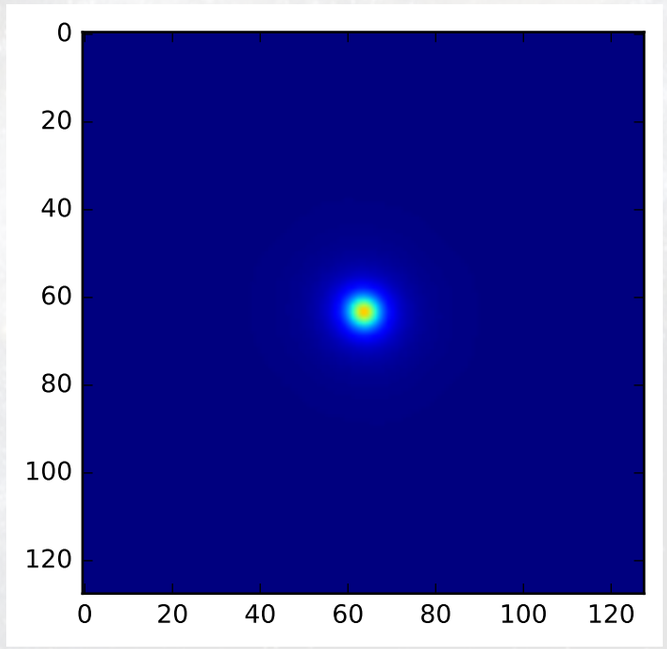
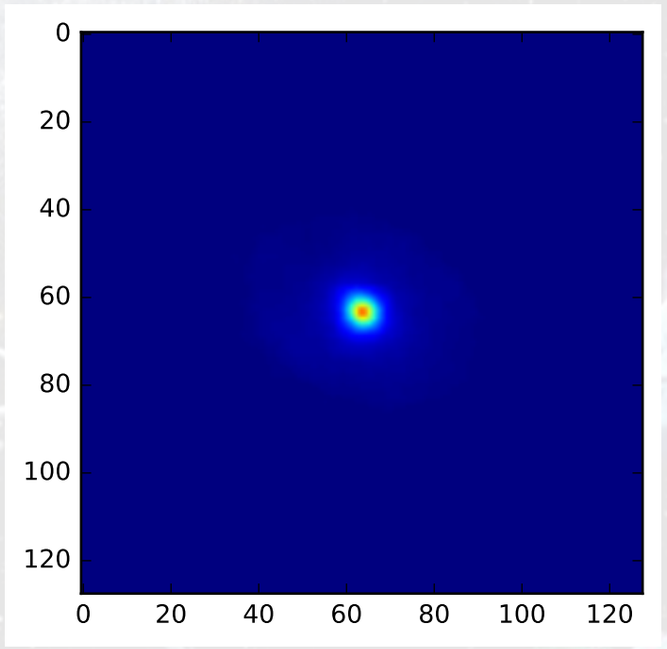
Results. Typical:

	Validation	Predicted
Bulge		
Disk		

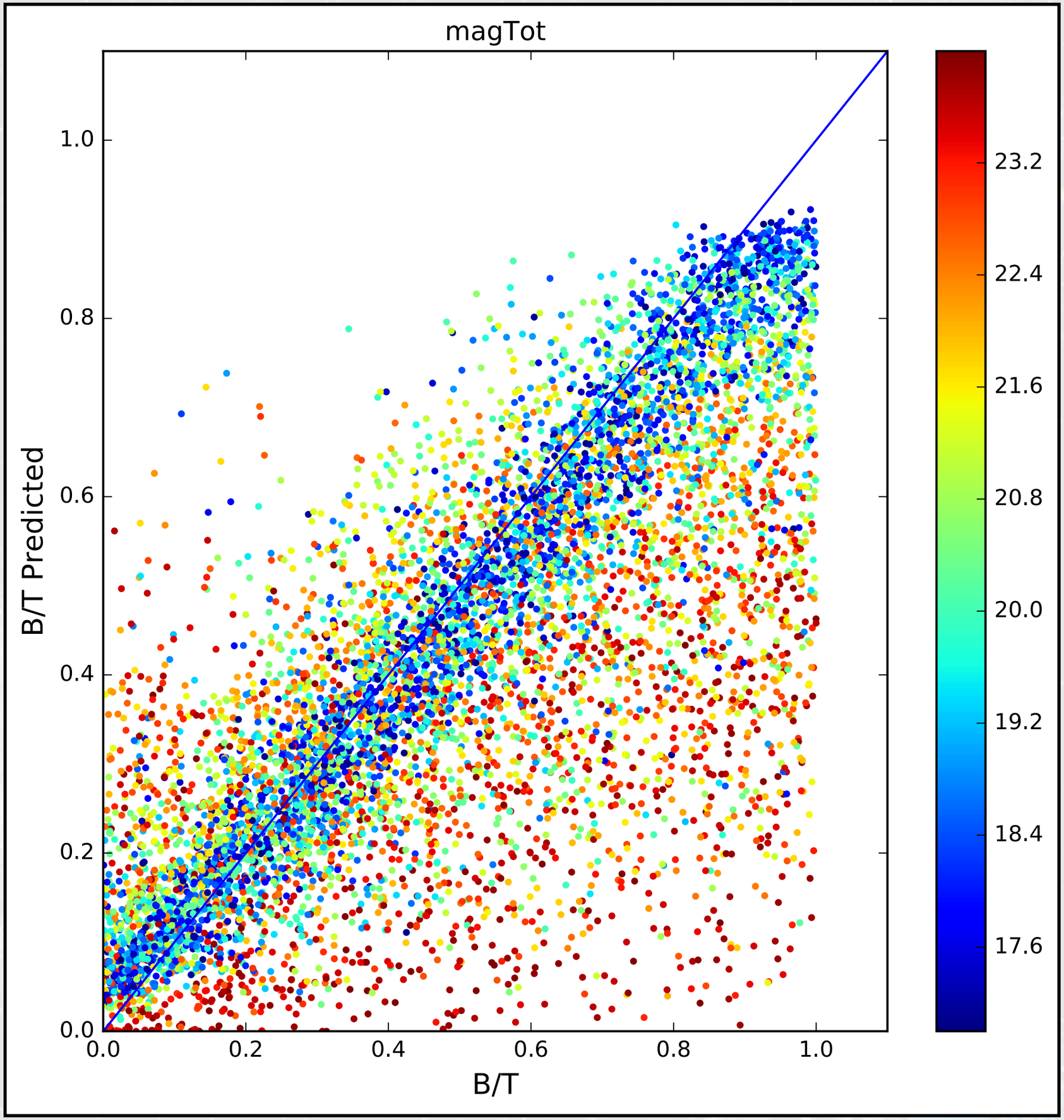
Results. Worse:

	Validation	Predicted
Bulge		
Disk		

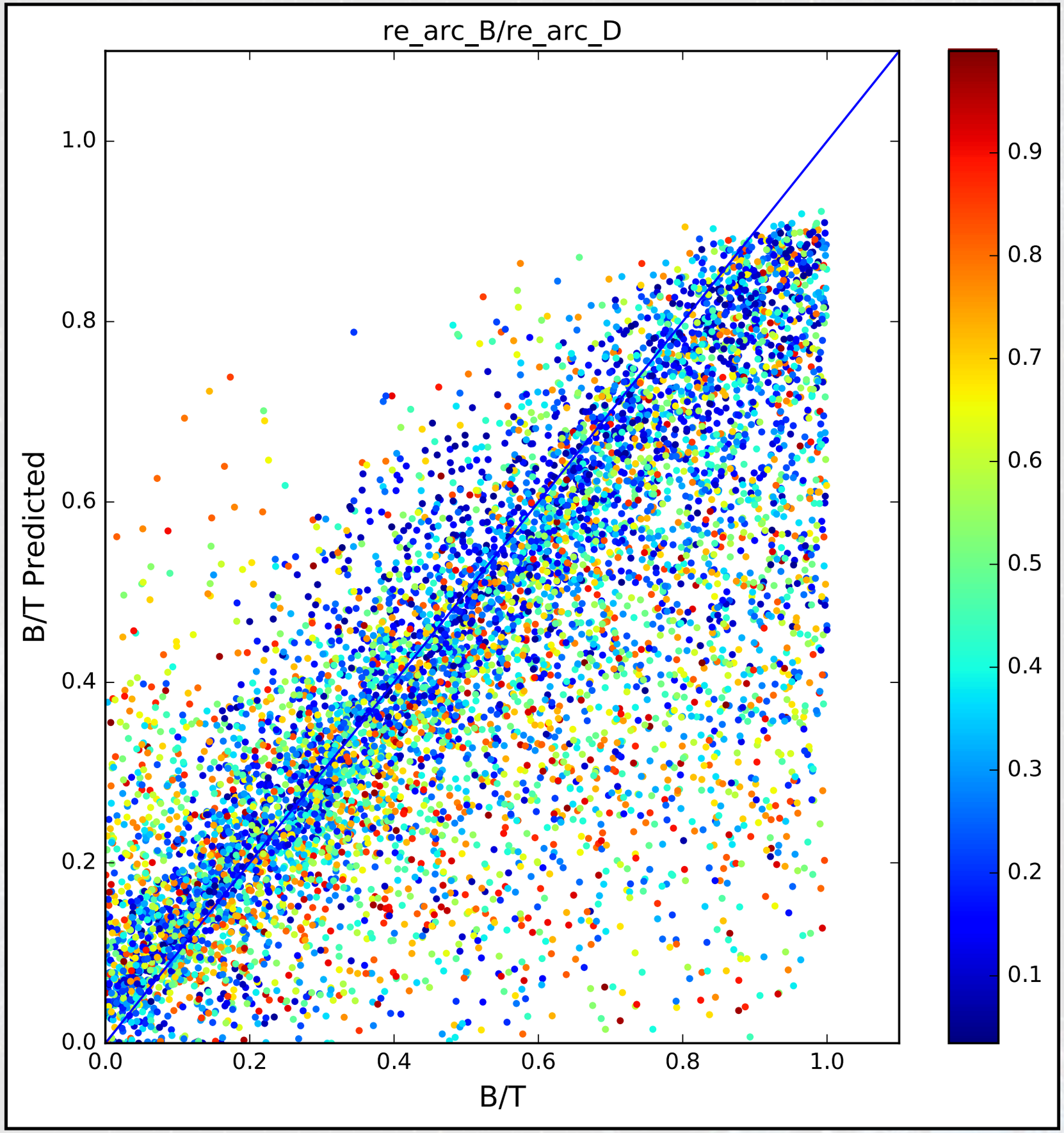
Results. Best:

	Validation	Predicted
Disk		
Bulge		

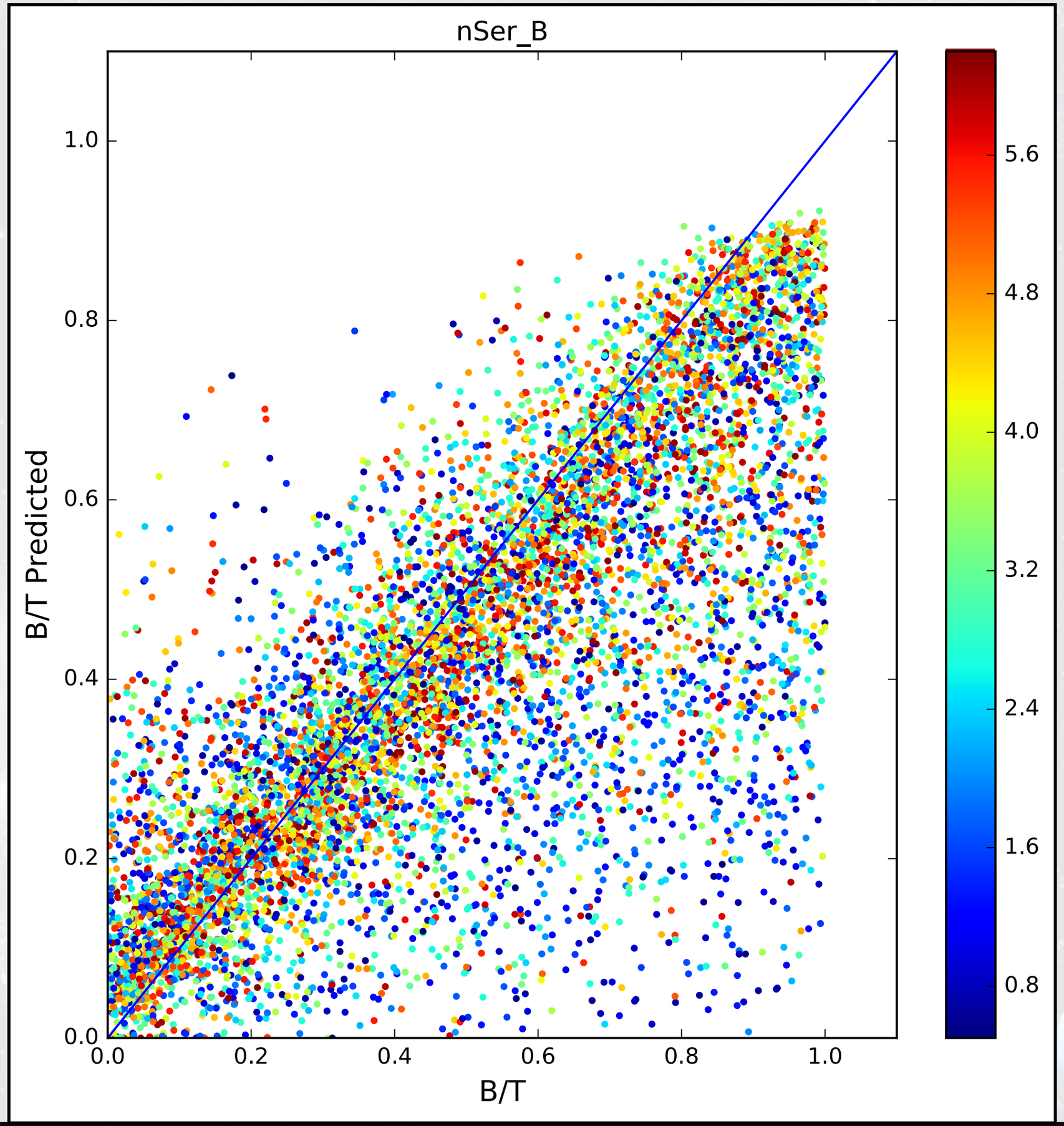
Disentangling



Disentangling



Disentangling



Thanks for listening!

l'Observatoire de Paris | LERMA

Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

PSL RESEARCH UNIVERSITY PARIS

MINES ParisTech

Marc Huertas-Company

- ***Galaxy Profiling***
- ***Galaxy Classification***
- ***Strong lensing detection***
- ***Deblending***

Diego Tuccillo

Etienne Decenciere

Santiago Velasco-Forero