Weak Lensing Mass Map Reconstruction of Merging Clusters with Convolutional Neural Network

Sungwook E. Hong (UOS)

w/ M. James Jee (Yonsei), Sangnam Park & Dongsu Bak (UOS)

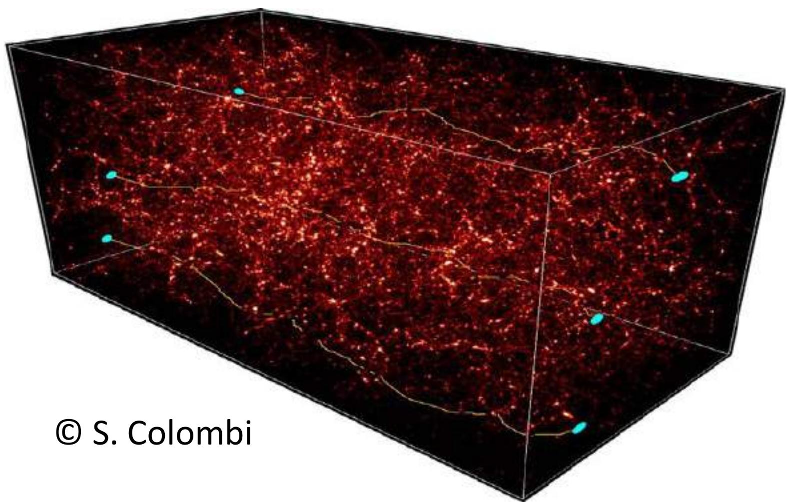
The 9th Survey Science Group Workshop @ Jeongseon, Feb. 11th, 2020

NSRI Natural Science Research Institute

YOUNG Yonsei Observable UNiverse Group

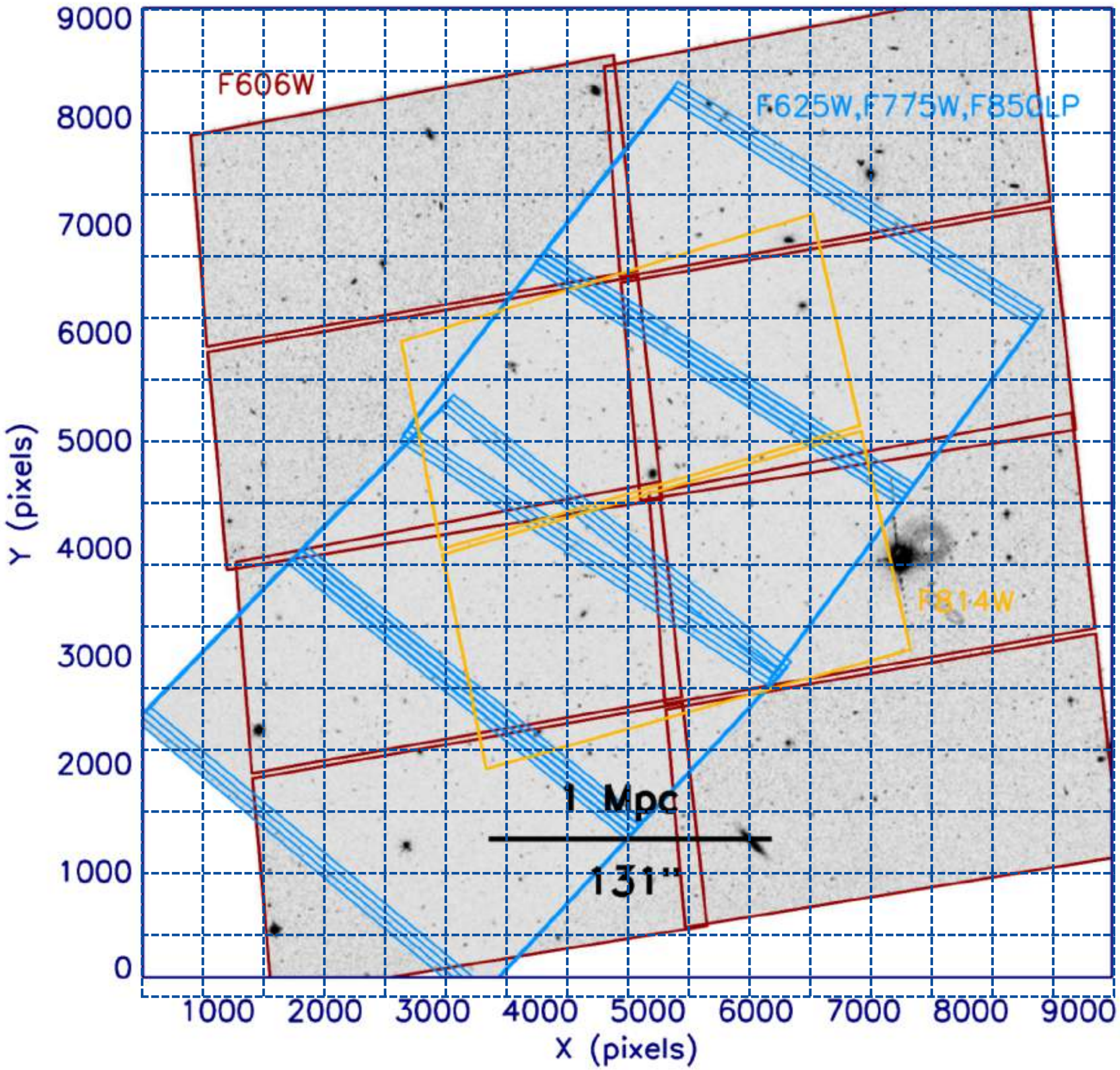
Weak Gravitational Lensing

- Shape of background galaxies is observed as distorted by massive objects (e.g., dark matter in galaxy clusters)
- Shape distortion contains information on the projected dark matter distribution
- Can be used to
  - Understand the evolution of merging clusters *(Jee+2014, …)*
  - Constrain cosmological parameters *(Yoon+2018, …)*
- We don’t know the original shape of a single background galaxy
  → need statistics of background galaxies
  to measure the shape distortion



© S. Colombi

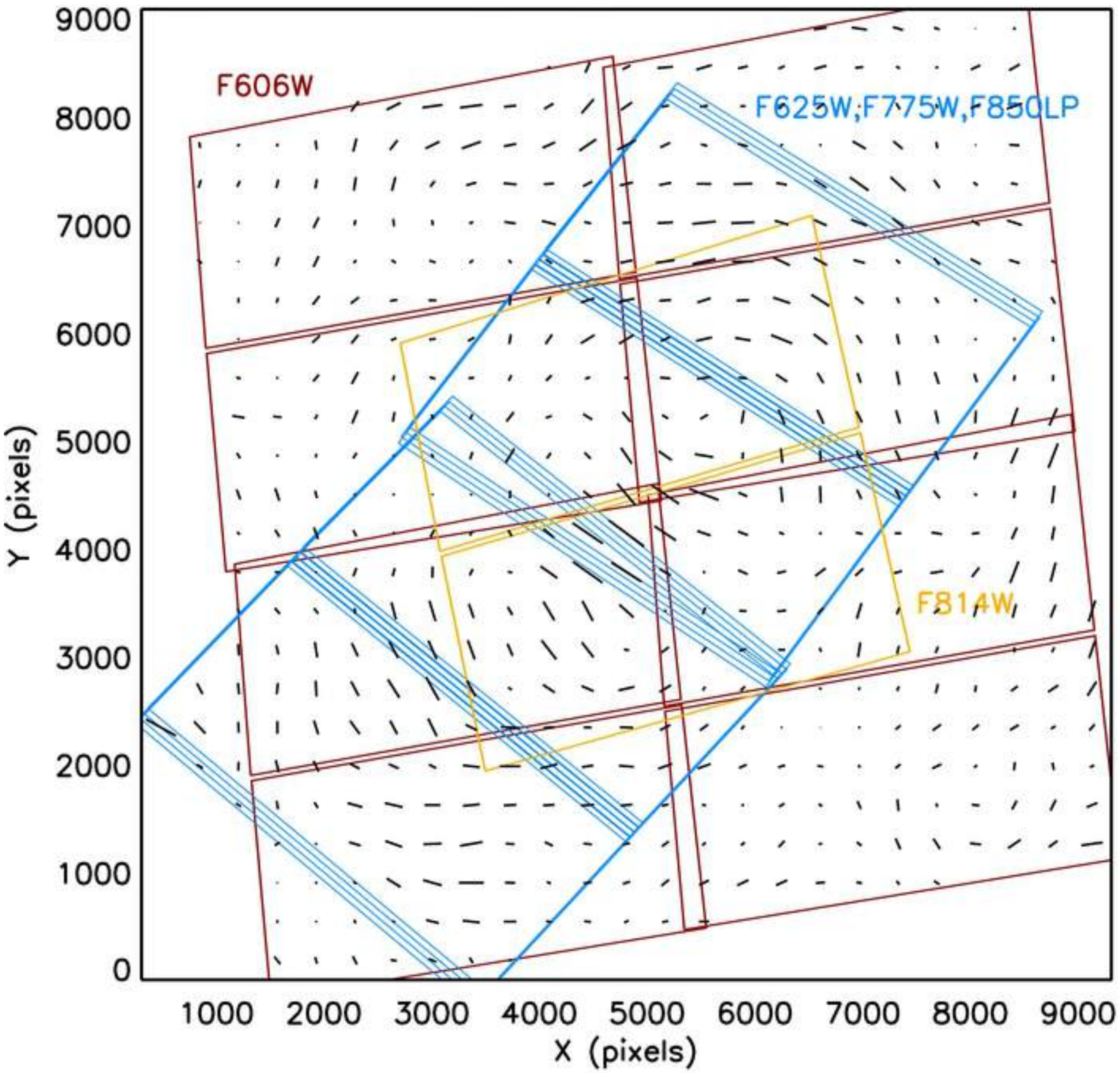
Mass Map Reconstruction



- Identify background galaxies
- Calculate ellipticity & rotational angle
- Average them over given area

El Gordo Cluster *(Jee+2014)*

Mass Map Reconstruction



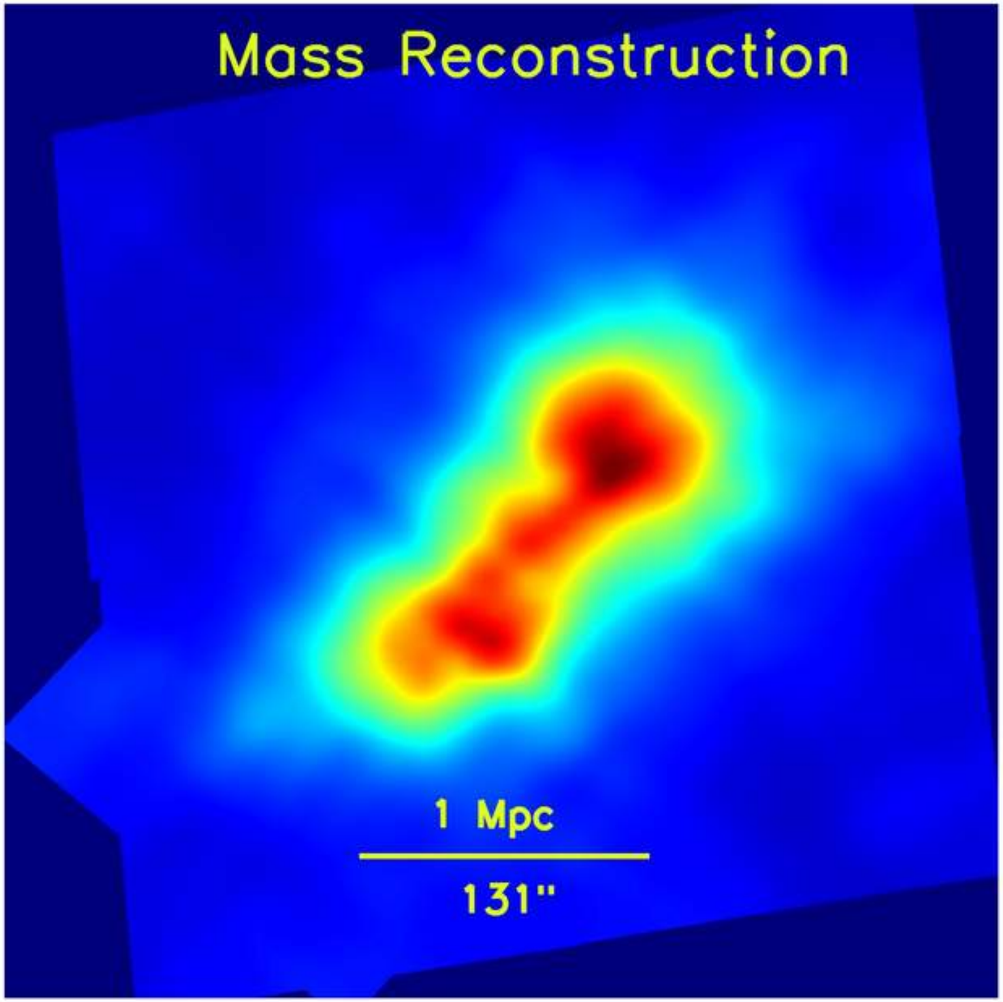
Shear vectors

$$\vec{\gamma}(\vec{\theta}) = \begin{pmatrix}\gamma_1 \\ \gamma_2\end{pmatrix} = \begin{pmatrix}e\cos 2\phi \\ e\sin 2\phi\end{pmatrix}$$

- e: ellipticity
- ϕ: rotational angle

El Gordo Cluster *(Jee+2014)*

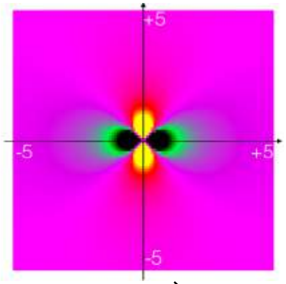
Mass Map Reconstruction

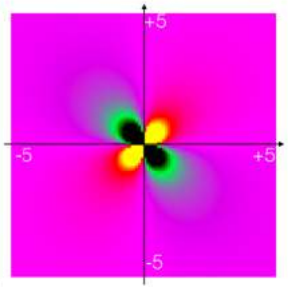


Mass map

(Kaiser & Squires 1993)

$$\kappa(\vec{\theta}) = \frac{1}{\pi}\int \mathrm{d}\vec{\theta}' D_1(\vec{\theta} - \overrightarrow{\theta'})\gamma_1(\vec{\theta}') + \frac{1}{\pi}\int \mathrm{d}\vec{\theta}' D_2(\vec{\theta} - \overrightarrow{\theta'})\gamma_2(\vec{\theta}')$$





$D_1(\vec{\theta})$ $D_2(\vec{\theta})$

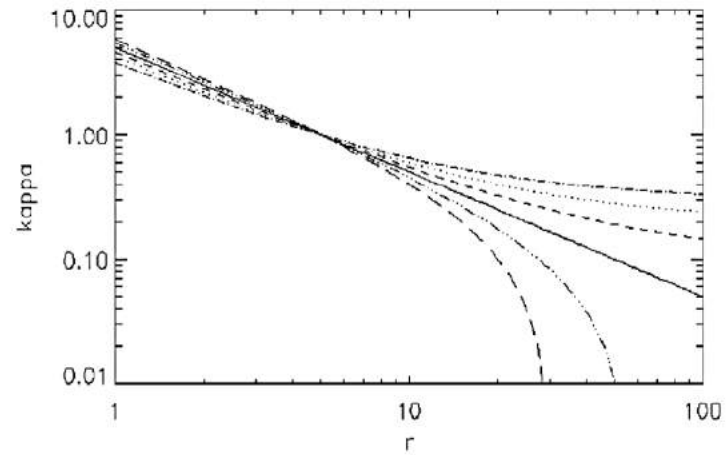
El Gordo Cluster *(Jee+2014)*

Limitation of Classical Method

Mass-sheet Degeneracy

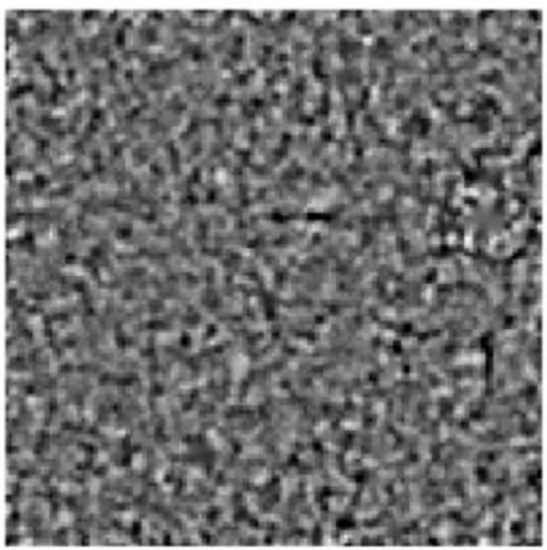
$\kappa(\vec{\theta})$ and $\lambda\kappa(\vec{\theta}) + (1-\lambda)$ could give the same shear vectors.

(Bradač, Lombardi & Schneider 2004)

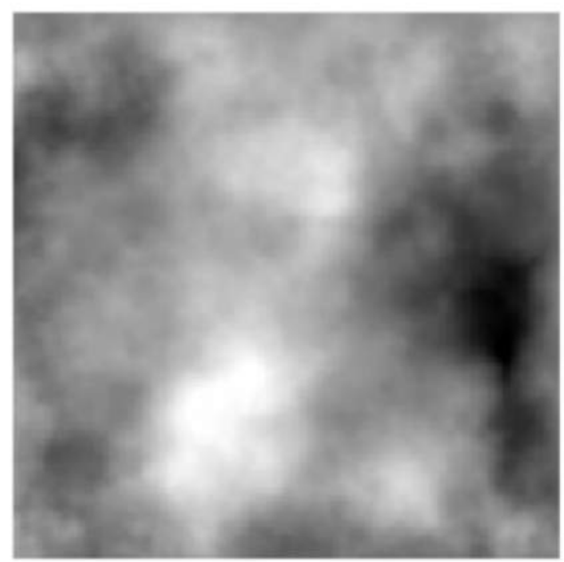


Overfitting & Edge Effect

$\kappa(\vec{\theta})$ can significantly vary for different levels of data averaging.

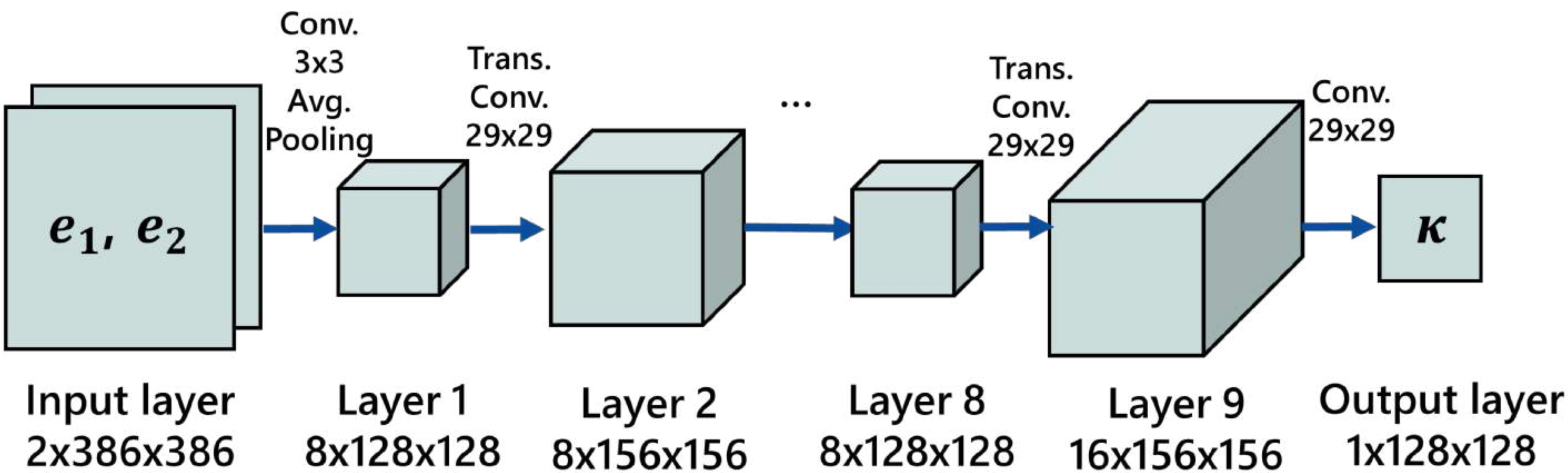


Small-scale smoothing



Large-scale smoothing

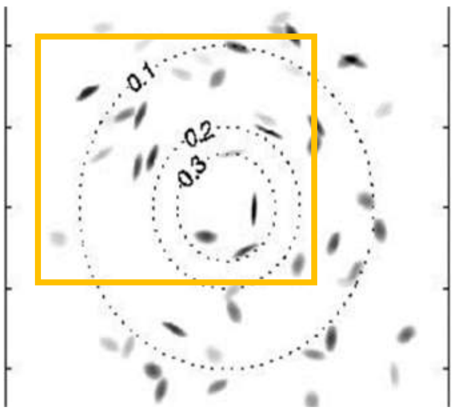
New Method: CNN



Train & test: ~2,000 Subaru HSC-like WL map simulations

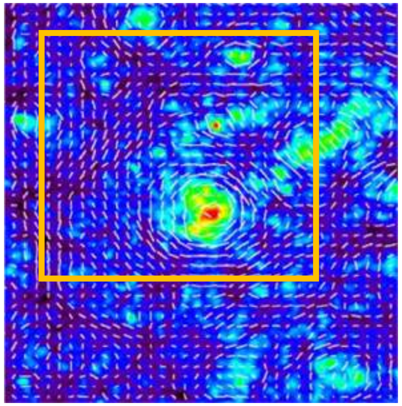
- Field of View: 32’ x 32’
- Number of background sources: 25,000

Input Data Augmentation



500

Weak lensing map from catalog data



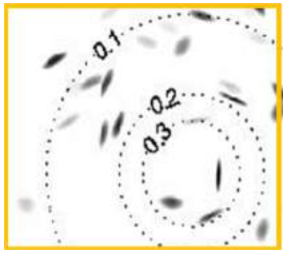
498

One-pixel trimmed truth map

Cost to be optimized during training :

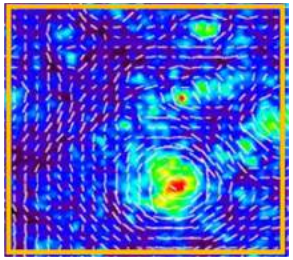
L(x,y) = $(y-\hat{y})^2$, $\hat{y}$= f(x)

Crop sub-map with randomly positioned window



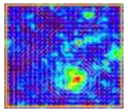
386

Input: x



384

Coarse graining

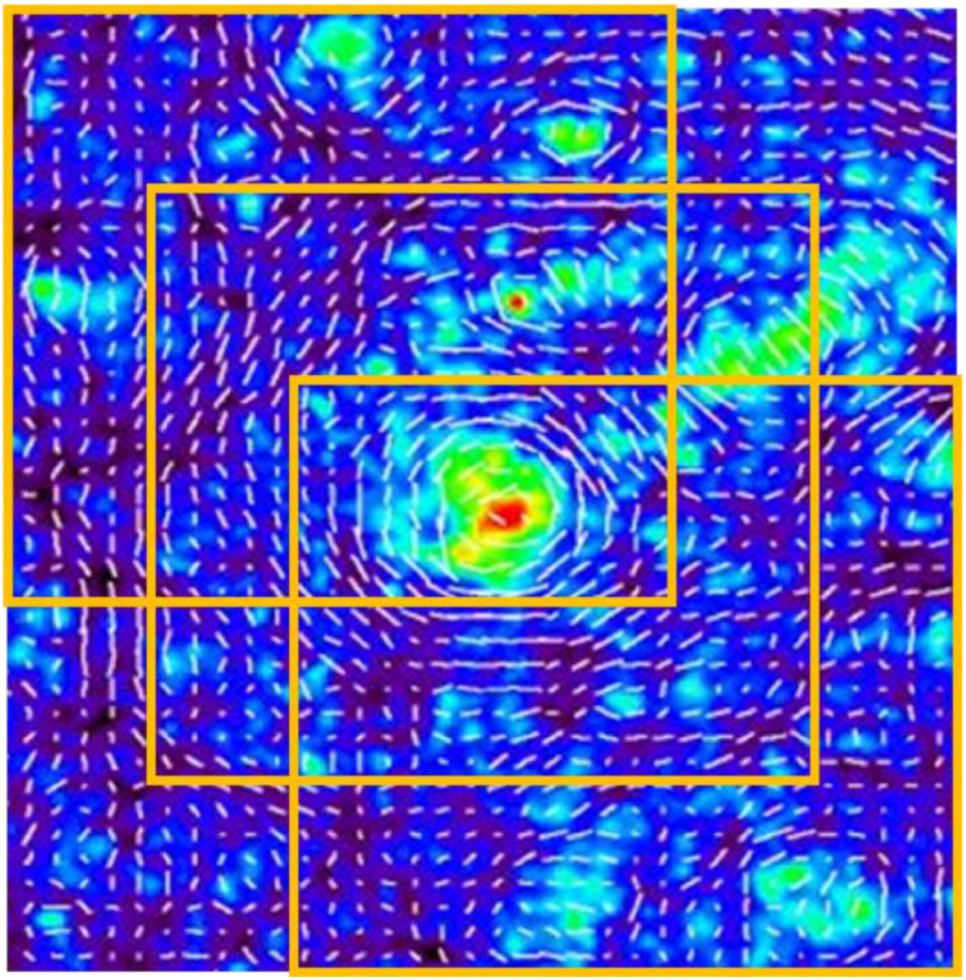


128

Truth: y

Reconstructed Mass Map

166x166

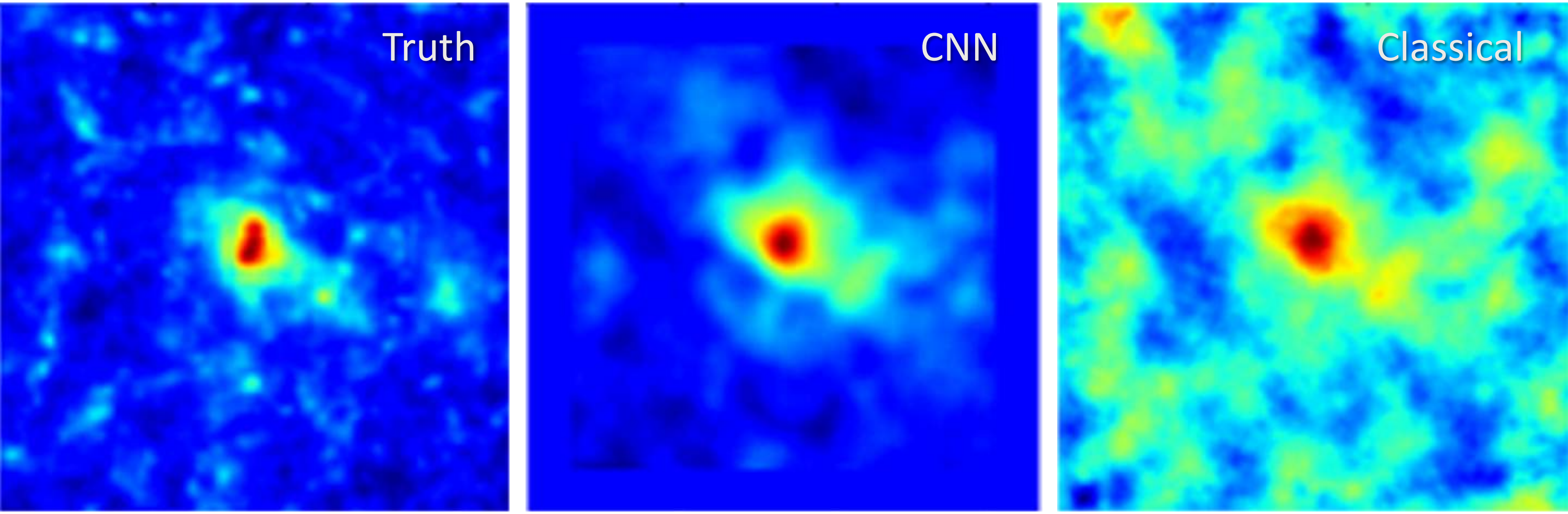


128x128

Superposition of many sub-maps of size 128x128

Values of pixels
in overlapped region are divided by the number of superpositions.

Result: Visual Inspection



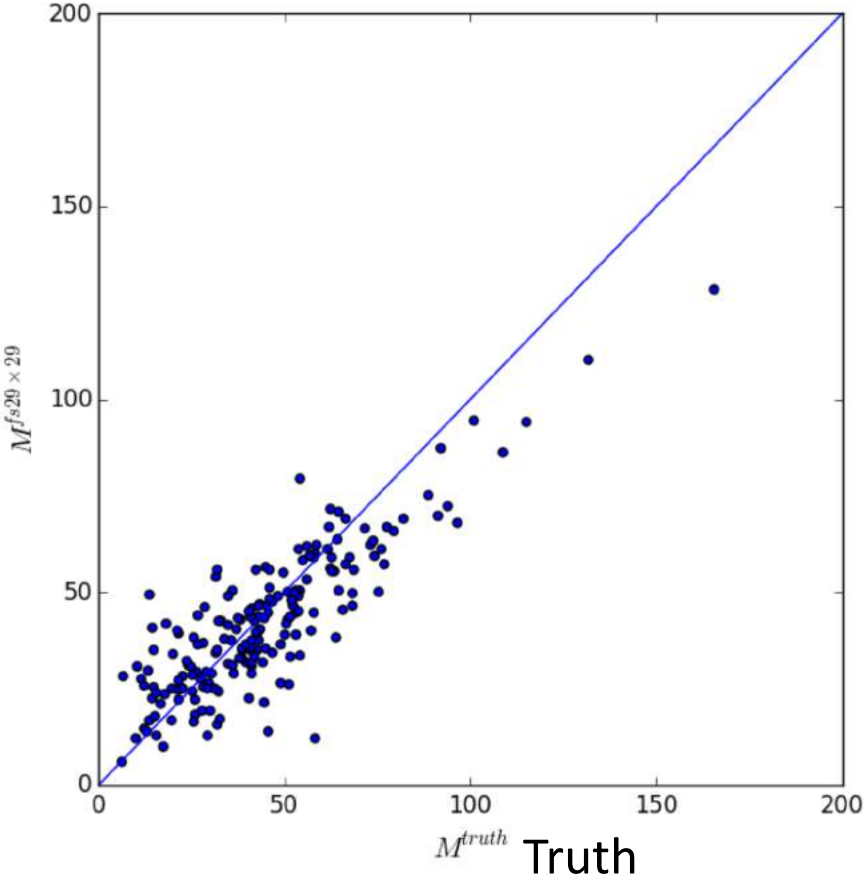
Good overall shape & pixel-to-pixel value
w/ low dependence on the smoothing scale

Result: Analysis Summary

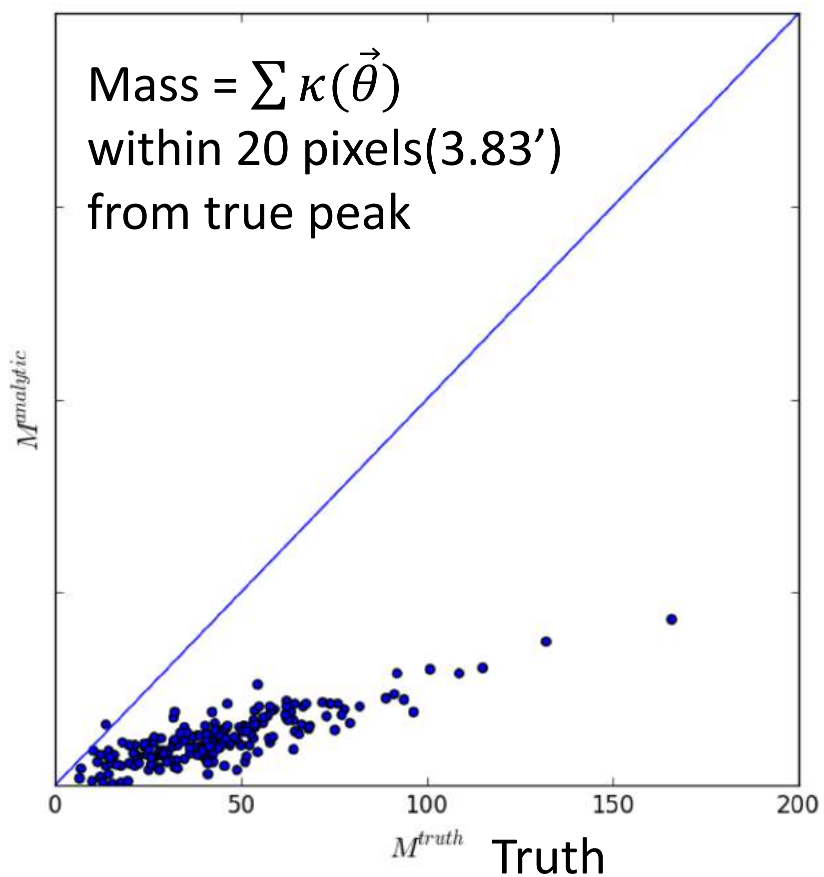
	CNN	Classical
$\kappa_{\mathrm{pred}}/\kappa_{\mathrm{true}}$	1.06 ± 0.49	0.30 ± 0.13
$M^{\mathrm{cl}}_{\mathrm{pred}}/M^{\mathrm{cl}}_{\mathrm{true}}$	0.95 ± 0.42	0.28 ± 0.15
$\left\lvert\frac{\kappa_{\mathrm{pred}} - \kappa_{\mathrm{true}}}{\kappa_{\mathrm{true}}}\right\rvert_{\mathrm{cl}}$	0.028 ± 0.0045	0.036 ± 0.0070
Peak Position Difference	$0.44' \pm 0.56'$	$2.96' \pm 5.07'$

Result: Mass Comparison

CNN

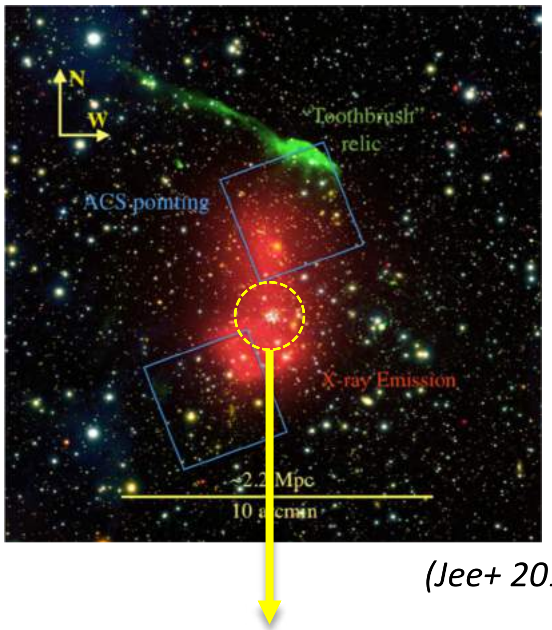


Classical



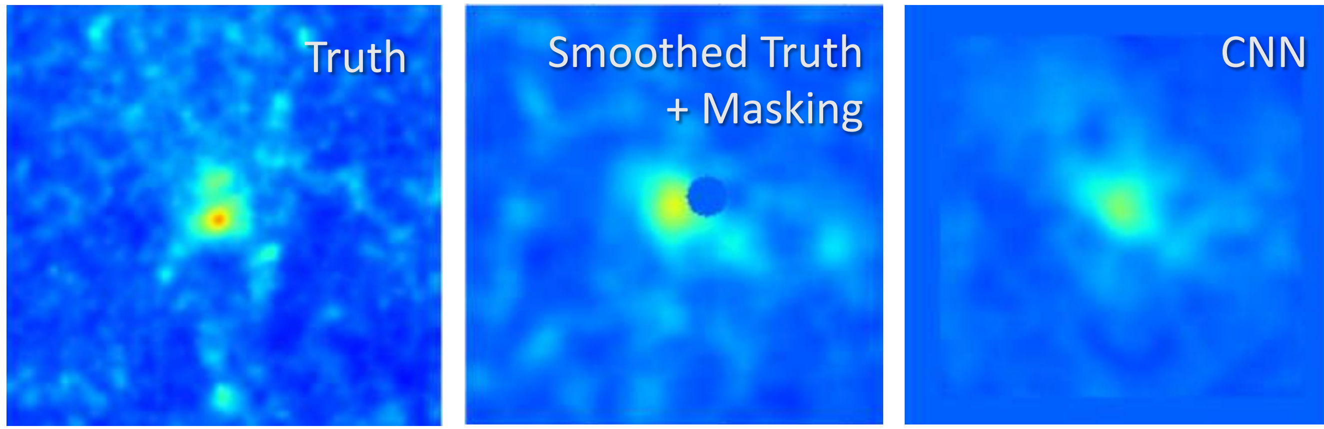
Better cluster mass estimation with less bias

Train w/ Bright Star Masking



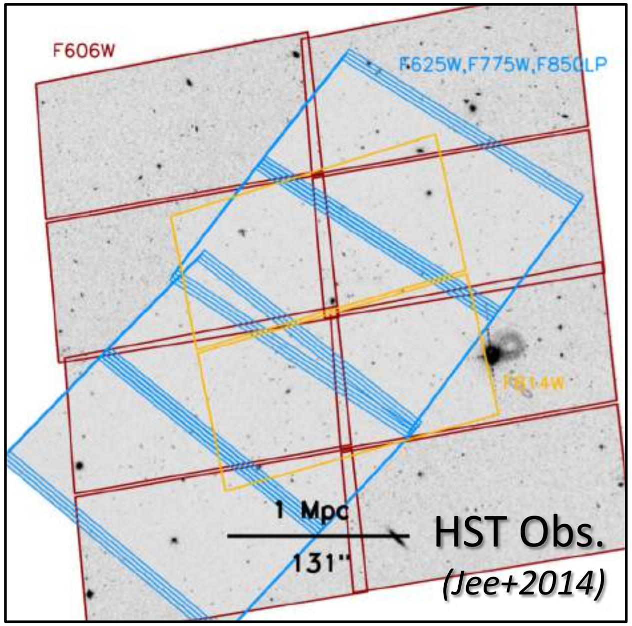
(Jee+ 201

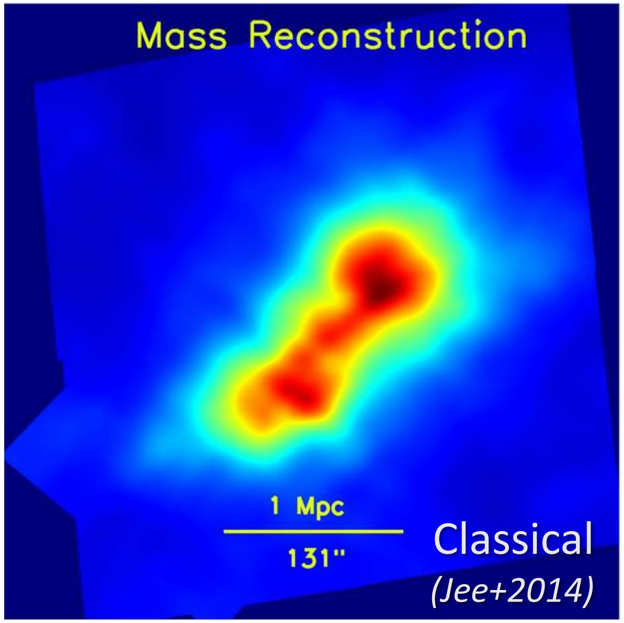
1~2 bright stars are expected in 20'x20' Subaru HSC field

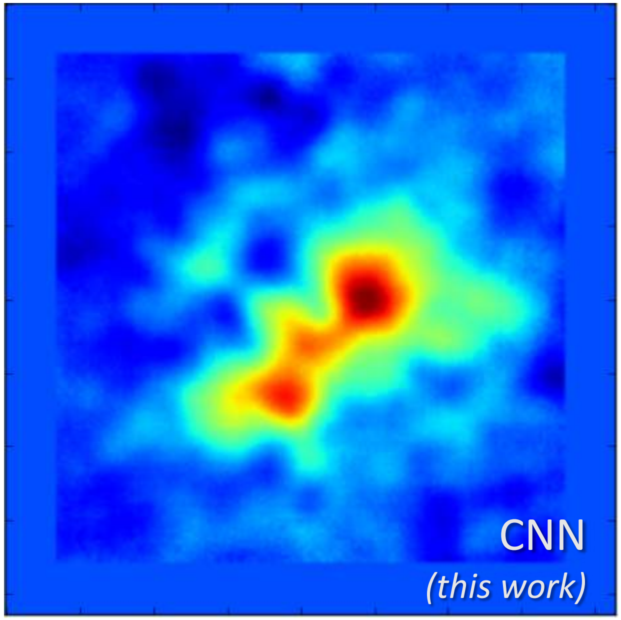


	No BS	BS + Masking
$\kappa_{\mathrm{pred}}/\kappa_{\mathrm{true}}$	1.06 ± 0.49	0.97 ± 0.43
$M^{\mathrm{cl}}_{\mathrm{pred}}/M^{\mathrm{cl}}_{\mathrm{true}}$	0.95 ± 0.42	0.89 ± 0.39
$\left\|\frac{\kappa_{\mathrm{pred}} - \kappa_{\mathrm{true}}}{\kappa_{\mathrm{true}}}\right\|_{\mathrm{cl}}$	0.028 ± 0.0045	0.029 ± 0.0049
Peak Position Difference	$0.44' \pm 0.56'$	$0.61' \pm 1.23'$

Application: El Gordo Cluster







- Overall mass distribution: similar to *Jee+2014*
- Possibility of reconstructing smaller-scale (need more check)
- Cluster mass comparison: work in progress

WARNING: The current CNN is not optimized for the HST

Conclusion

- Deep learning can reconstruct the projected mass map from weak lensing well!
- (Can be) better than classical method *(Kaiser & Squire 1993)*:
  - Better pixel-to-pixel value match
  - Better cluster mass estimation
  - Better cluster center position identification
- Future works:
  - Add more observational effect (error in sheer map, …)
  - Apply it to real observations of merging clusters

Mass vs. Peak Position Accuracy