Pecuilar Velocities from Kinetic Sunyaev-Zel'dovich Effect

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Sunyaev-Zel’dovich Effect (SZ effect)

- SZ effect is the distortion of the CMB through inverse Compton scattering by the electrons in galaxy cluster, which leads to changes in CMB temperature as well as spectral distortion.
- Thermal Sunyaev-Zel’dovich Effect (tSZ) is caused by the high energy elections with random velocities in the hot intra-cluster medium, which leads to the spectral distrotion.
- Kinetic Sunyaev-Zel’dovich Effect (kSZ) is caused by the bulk motion of the entire cluster, which leads to a Doppler shift in the CMB temperature.

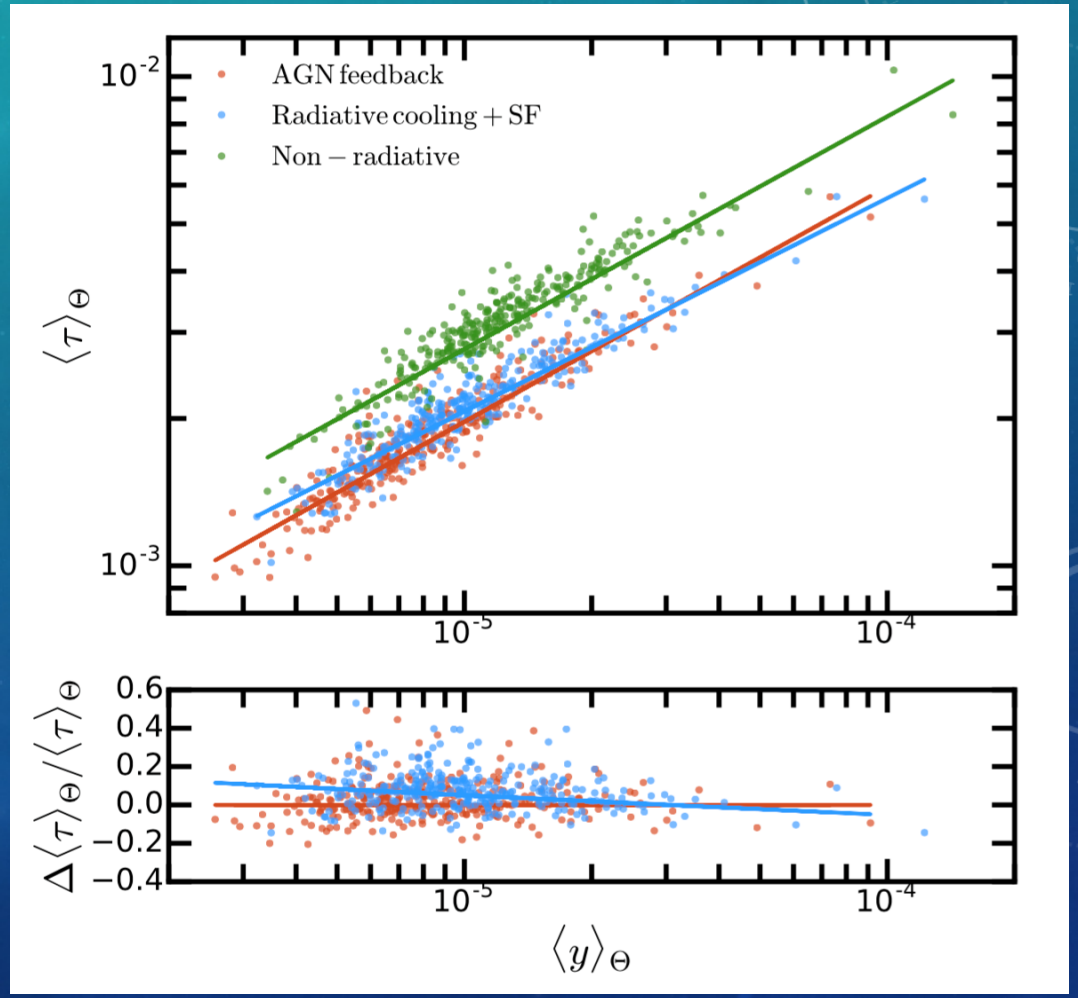
Peculiar Velocities from kSZ Effect

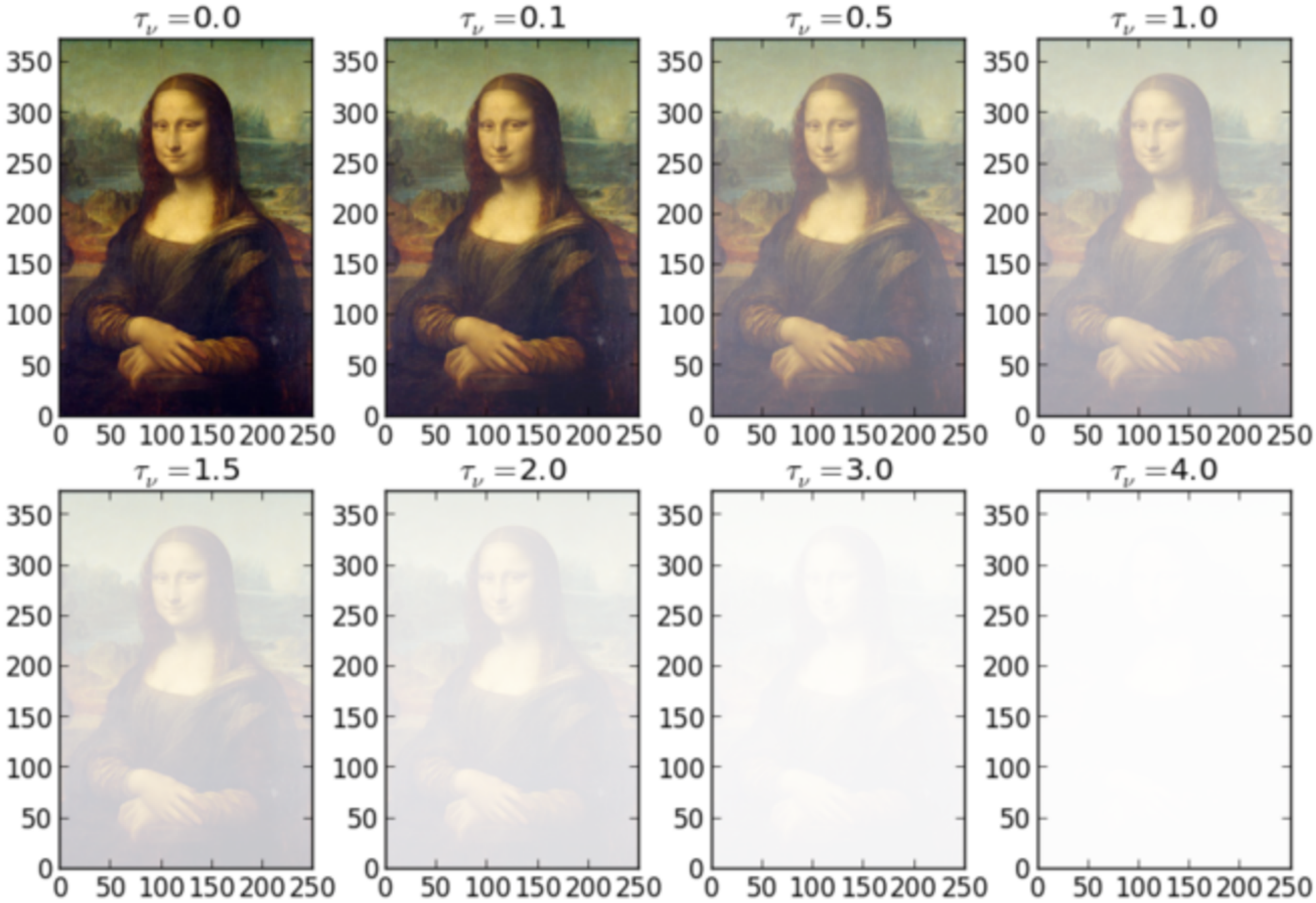
- $-\tau \frac{v}{c} = -\sigma_T \int dl\, n_e(\boldsymbol{r}) \frac{\hat{r} \cdot v_e(\boldsymbol{r})}{c} = \frac{\Delta T_{kSZ}}{T_{CMB}}$

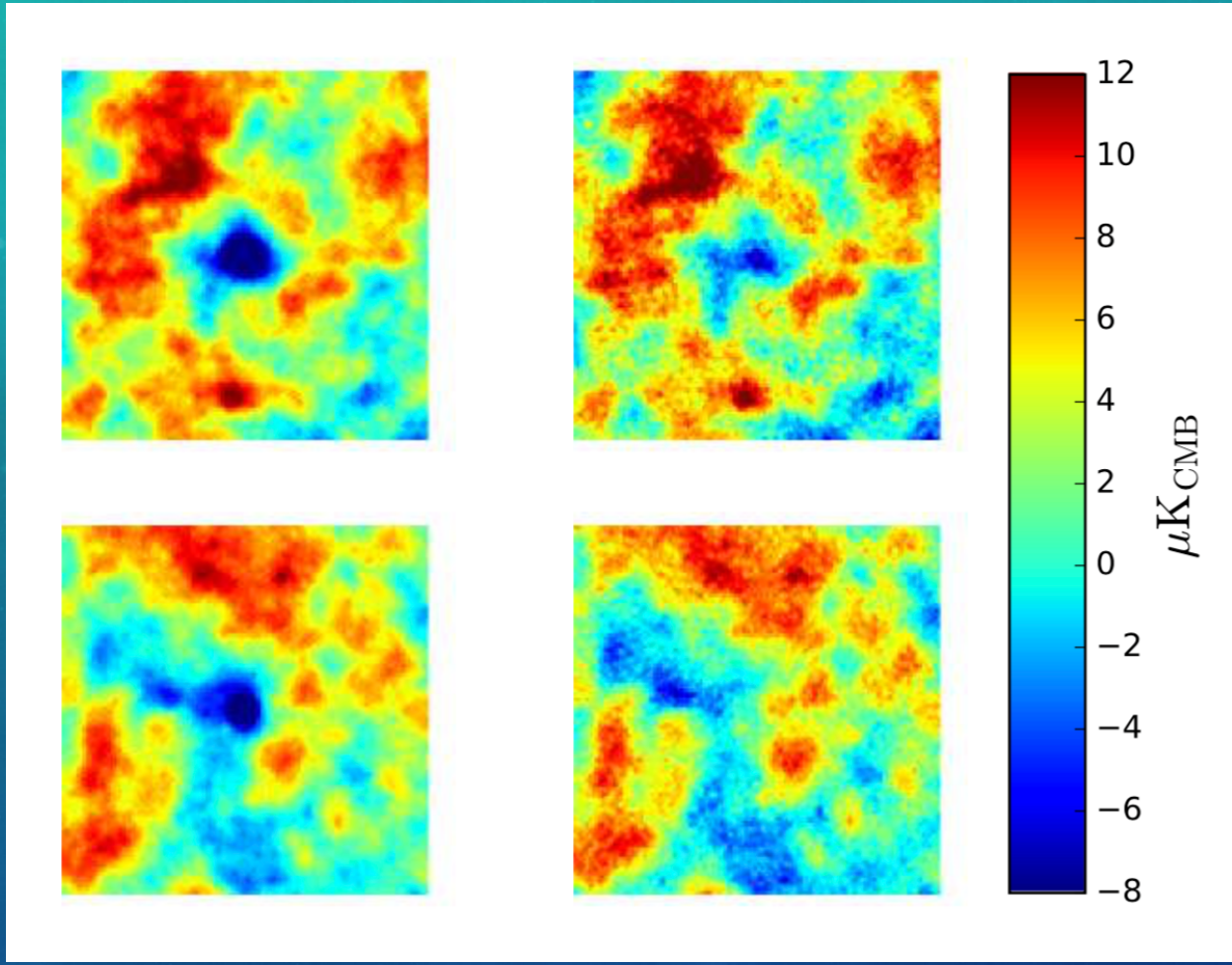
  (Sunyaev & Zel'dovich 1980)

- Difficulty:
  - kSZ signal is about only 10^{-6} times of CMB
  - The optical depth $\boldsymbol{\tau}$ is various from clusters
  - $\boldsymbol{\tau}$ from tSZ, density-weighted average T_e (not observable)
  - Using emission-weighted temperature T_x (20% bias)

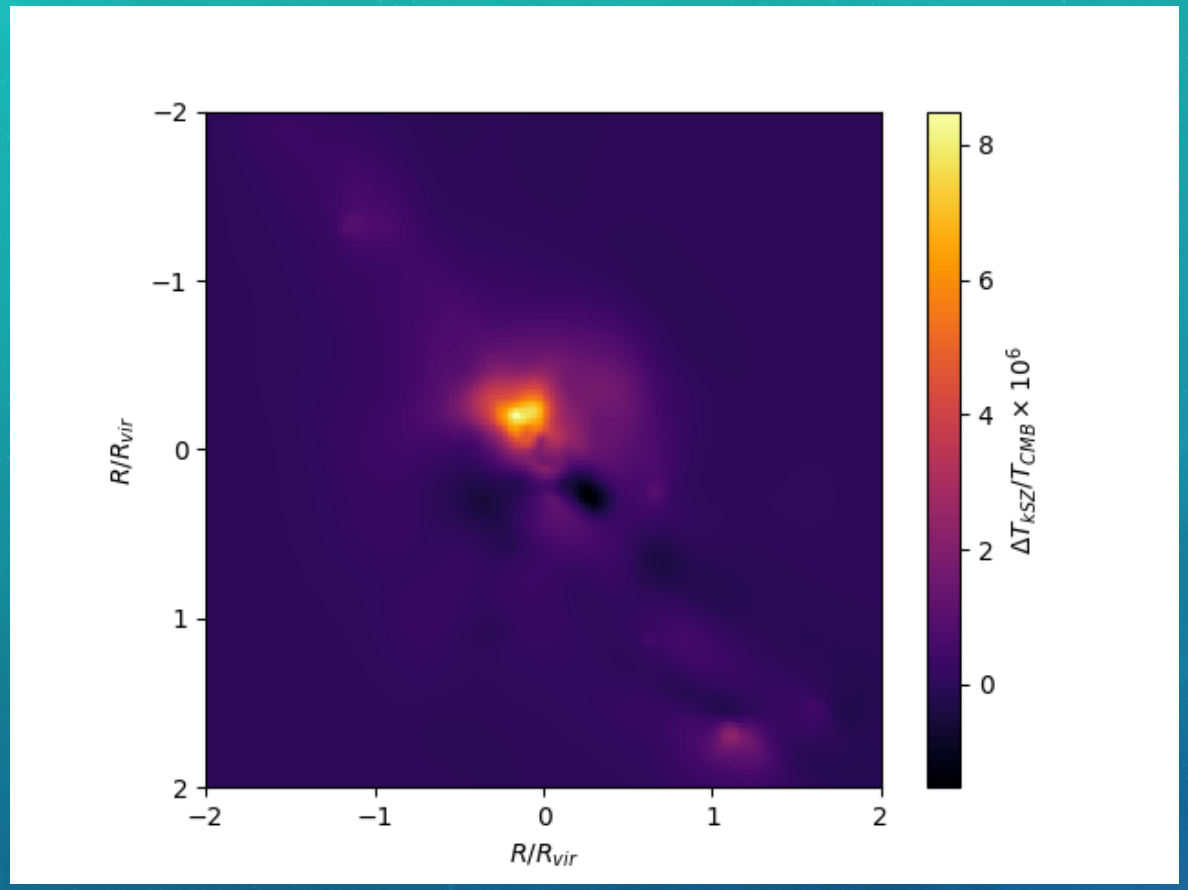
(Battaglia 2017)

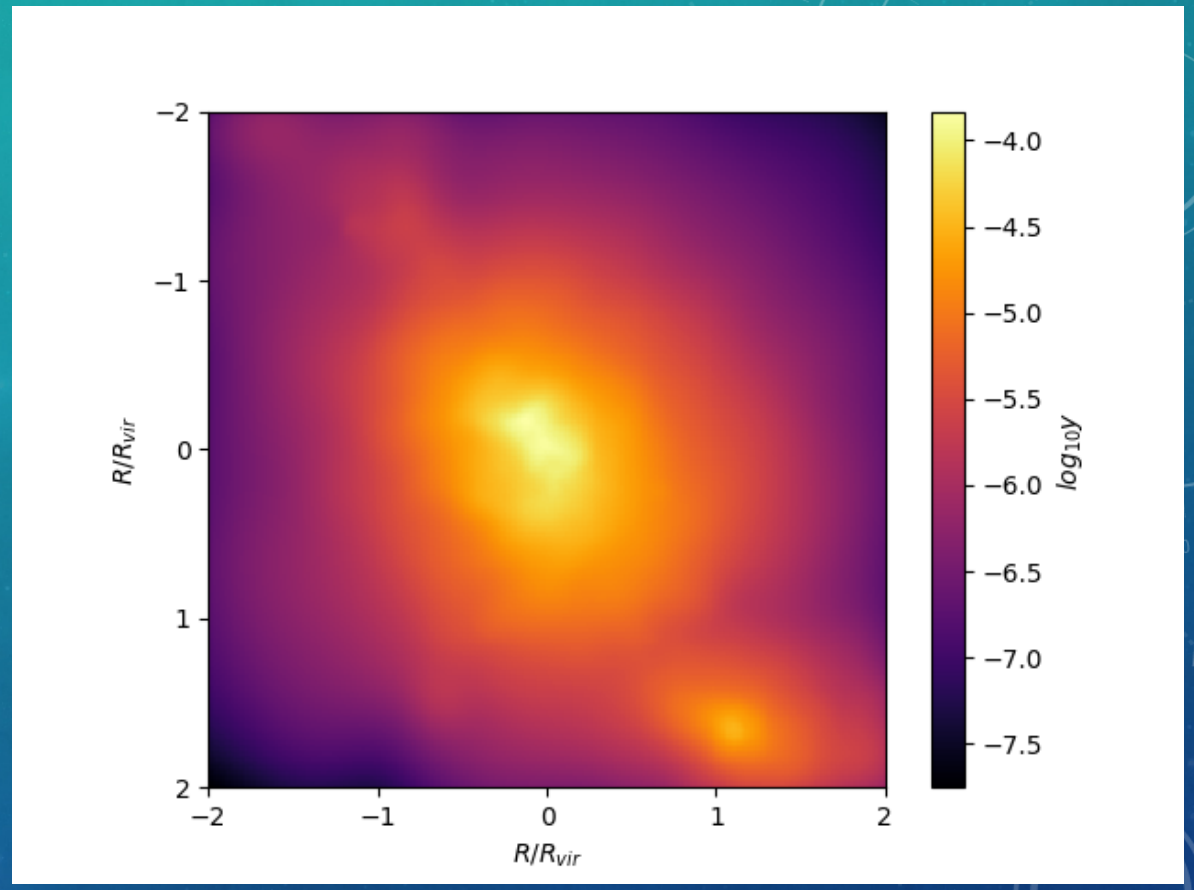



$\tau_\nu = 0.0$
$\tau_\nu = 0.1$
$\tau_\nu = 0.5$
$\tau_\nu = 1.0$
$\tau_\nu = 1.5$
$\tau_\nu = 2.0$
$\tau_\nu = 3.0$
$\tau_\nu = 4.0$
0 50 100 150 200 250
0 50 100 150 200 250 300 350



(Planck Collaboration 2017)





40,000 sets of images with corresponding peculiar velocities

Input Volume (+pad 1) (7x7x3)

x[:,:,0]

0	0	0	0	0	0	0
0	0	0	1	0	2	0
0	1	0	2	0	1	0
0	1	0	2	2	0	0
0	2	0	0	2	0	0
0	2	1	2	2	0	0
0	0	0	0	0	0	0

x[:,:,1]

0	0	0	0	0	0	0
0	2	1	2	1	1	0
0	2	1	2	0	1	0
0	0	2	1	0	1	0
0	1	2	2	2	2	0
0	0	1	2	0	1	0
0	0	0	0	0	0	0

x[:,:,2]

0	0	0	0	0	0	0
0	2	1	1	2	0	0
0	1	0	0	1	0	0
0	0	1	0	0	0	0
0	1	0	2	1	0	0
0	2	2	1	1	1	0
0	0	0	0	0	0	0

Filter W0 (3x3x3)

w0[:,:,0]

-1	0	1
0	0	1
1	-1	1

w0[:,:,1]

-1	0	1
1	-1	1
0	1	0

w0[:,:,2]

-1	1	1
1	1	0
0	-1	0

Bias b0 (1x1x1)

b0[:,:,0]

1

Filter W1 (3x3x3)

w1[:,:,0]

0	1	-1
0	-1	0
0	-1	1

w1[:,:,1]

-1	0	0
1	-1	0
1	-1	0

w1[:,:,2]

-1	1	-1
0	-1	-1
1	0	0

Bias b1 (1x1x1)

b1[:,:,0]

0

Output Volume (3x3x2)

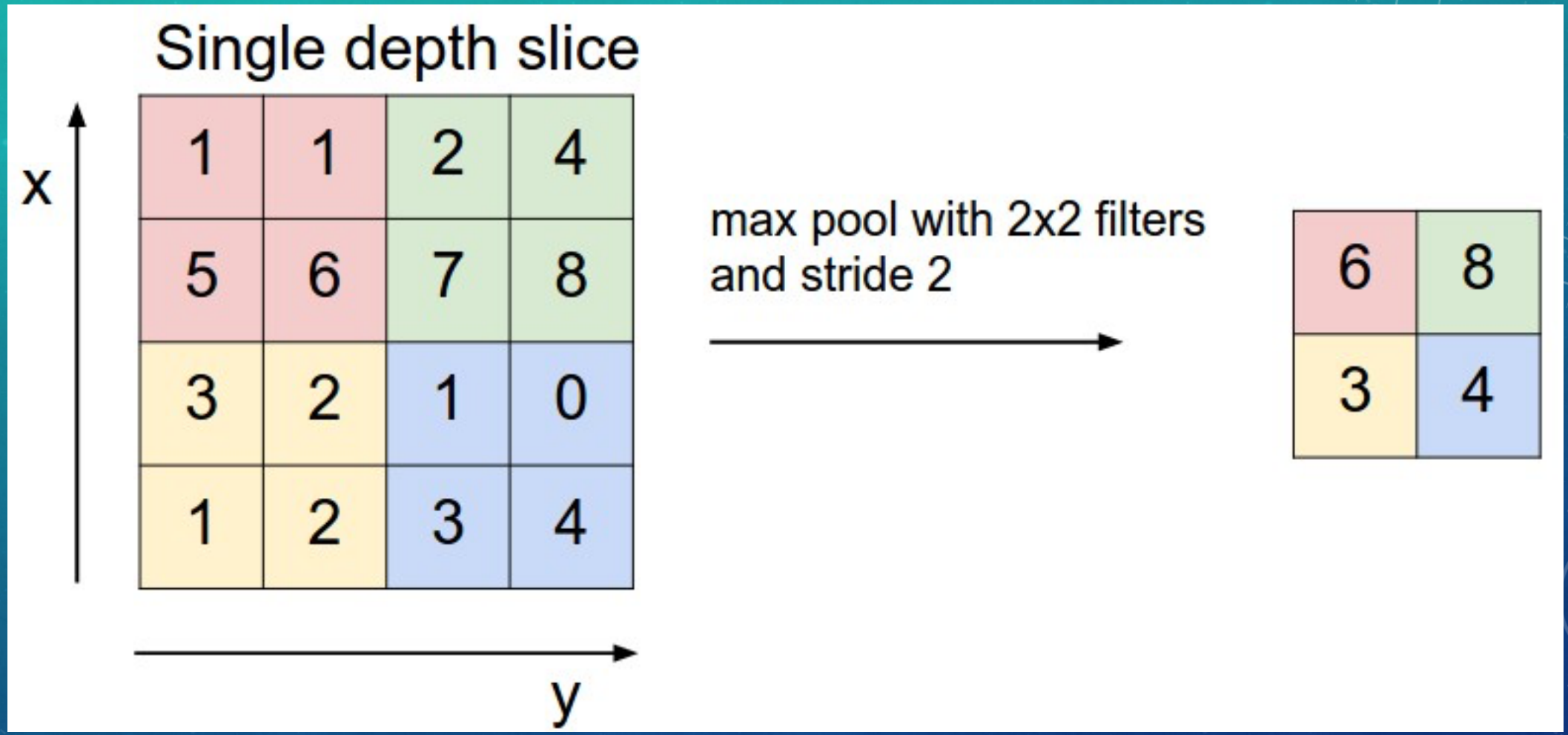
o[:,:,0]

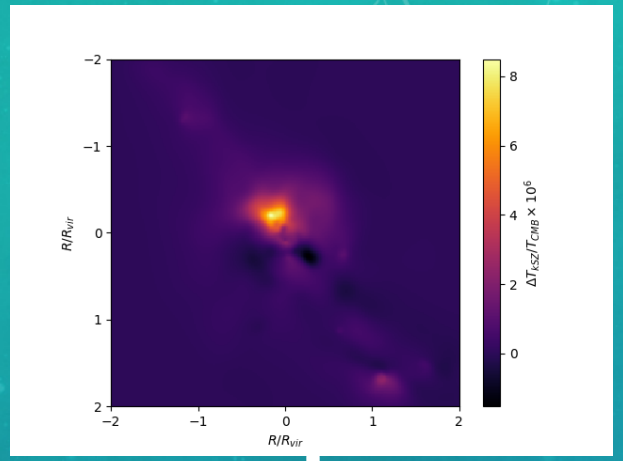
2	3	3
3	7	3
8	10	-3

o[:,:,1]

-8	-8	-3
-3	1	0
-3	-8	-5

toggle movement


Single depth slice
x
y
1 1 2 4
5 6 7 8
3 2 1 0
1 2 3 4
max pool with 2x2 filters
and stride 2
6 8
3 4



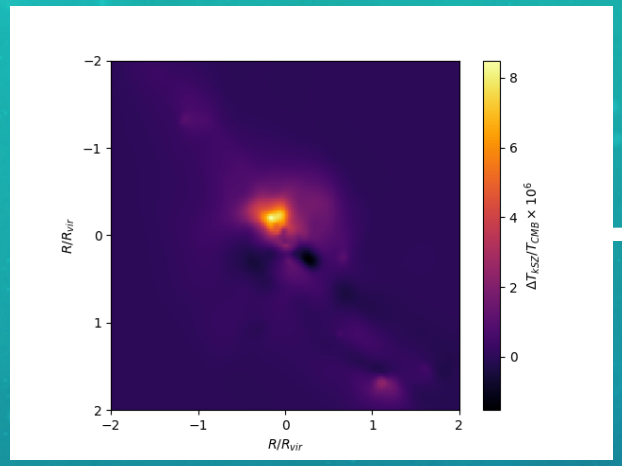
Conv2D
+
Pooling

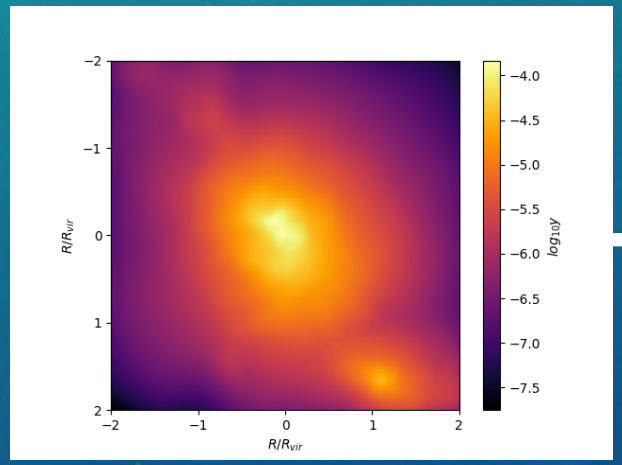
Flatten

Dense

Peculiar Velocity

conv2d_12_input: InputLayer	input:	(None, 256, 256, 1)
	output:	(None, 256, 256, 1)
conv2d_12: Conv2D	input:	(None, 256, 256, 1)
	output:	(None, 256, 256, 32)
activation_20: Activation	input:	(None, 256, 256, 32)
	output:	(None, 256, 256, 32)
conv2d_13: Conv2D	input:	(None, 256, 256, 32)
	output:	(None, 254, 254, 32)
activation_21: Activation	input:	(None, 254, 254, 32)
	output:	(None, 254, 254, 32)
max_pooling2d_6: MaxPooling2D	input:	(None, 254, 254, 32)
	output:	(None, 127, 127, 32)
flatten_3: Flatten	input:	(None, 127, 127, 32)
	output:	(None, 516128)
activation_22: Activation	input:	(None, 516128)
	output:	(None, 516128)
dense_10: Dense	input:	(None, 516128)
	output:	(None, 8)
activation_23: Activation	input:	(None, 8)
	output:	(None, 8)
dense_11: Dense	input:	(None, 8)
	output:	(None, 1)
activation_24: Activation	input:	(None, 1)
	output:	(None, 1)



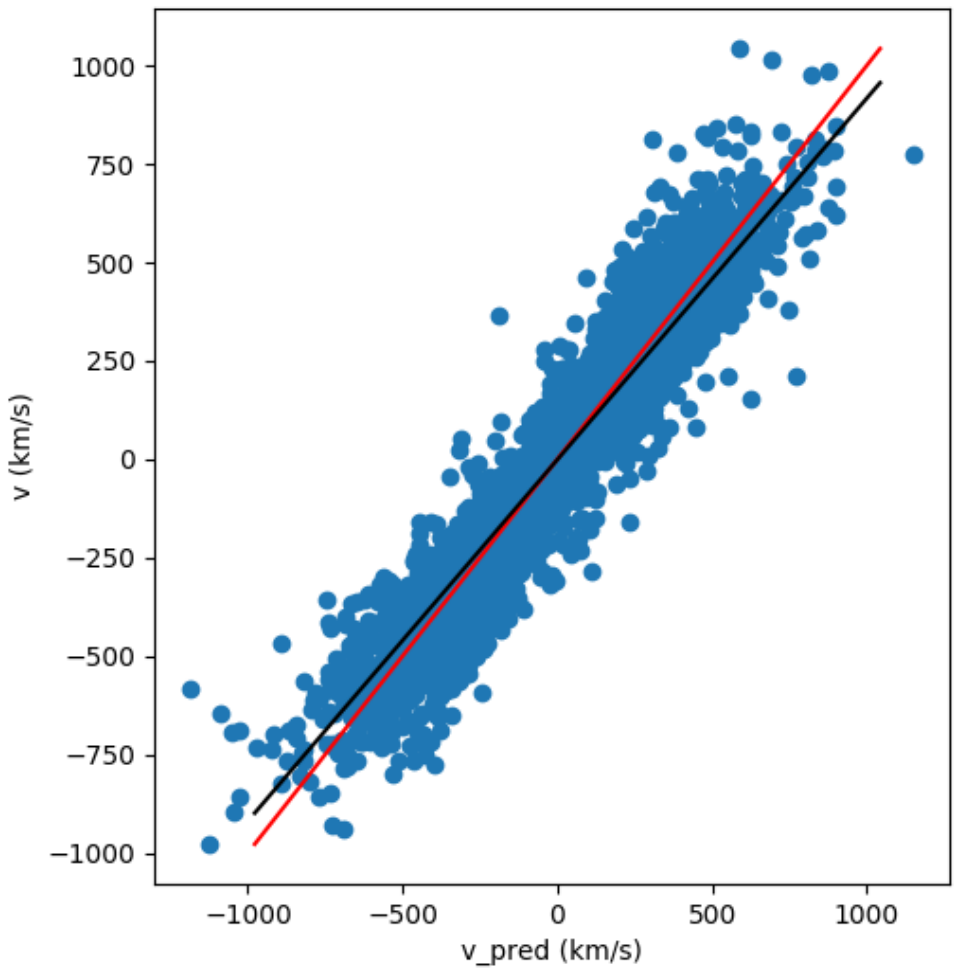


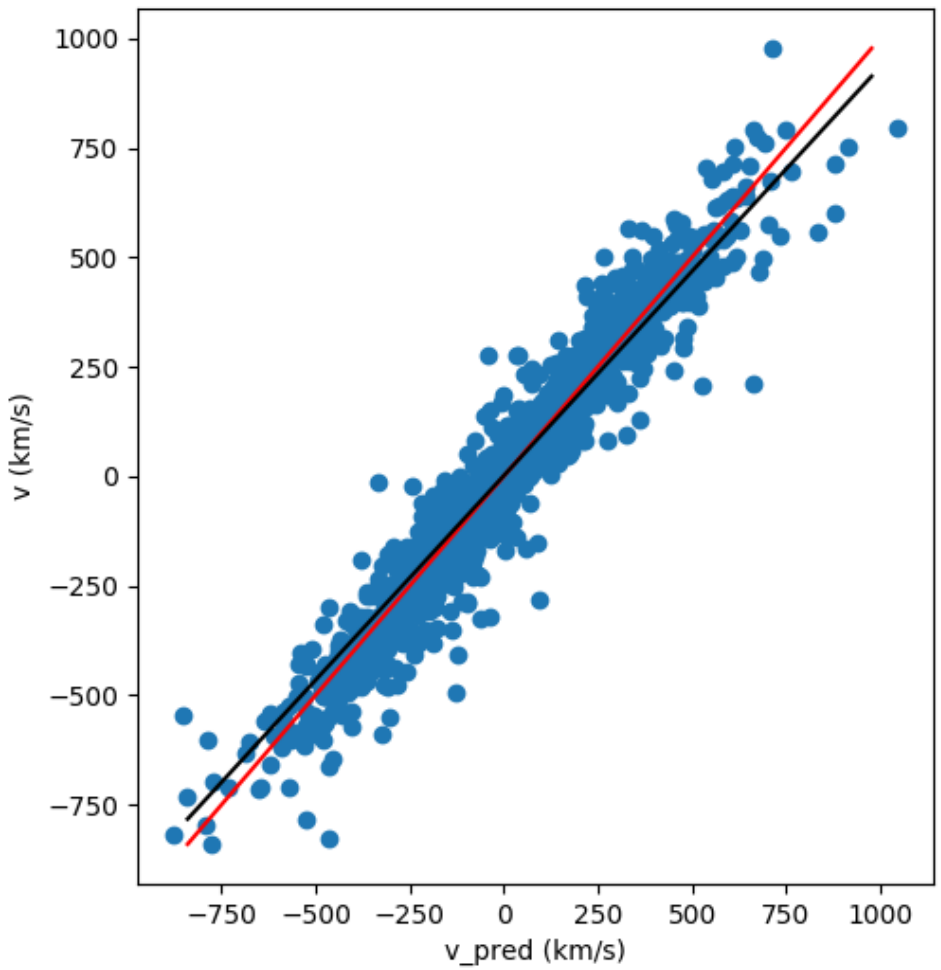
Conv2D
Pooling
Flatten

Conv2D
Pooling
Flatten

Dense

Peculiar Velocity


1000
750
500
250
0
−250
−500
−750
−1000
v (km/s)
−1000
−500
0
500
1000
v_pred (km/s)


1000
750
500
250
0
−250
−500
−750
v (km/s)
−750
−500
−250
0
250
500
750
1000
v_pred (km/s)

THANK YOU