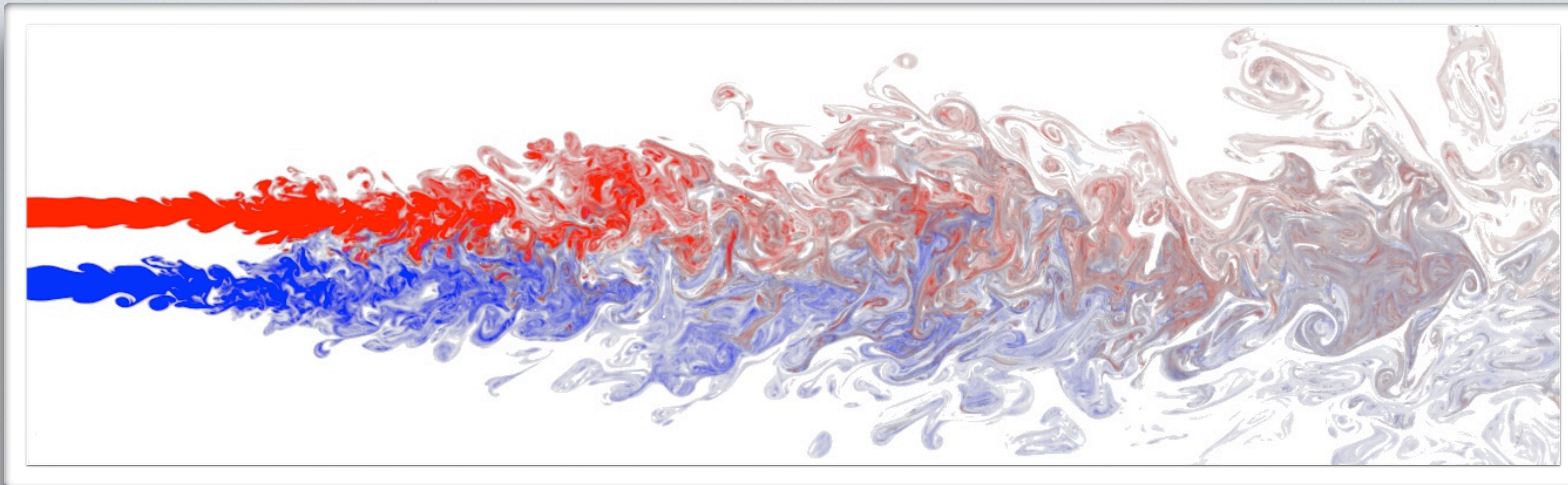
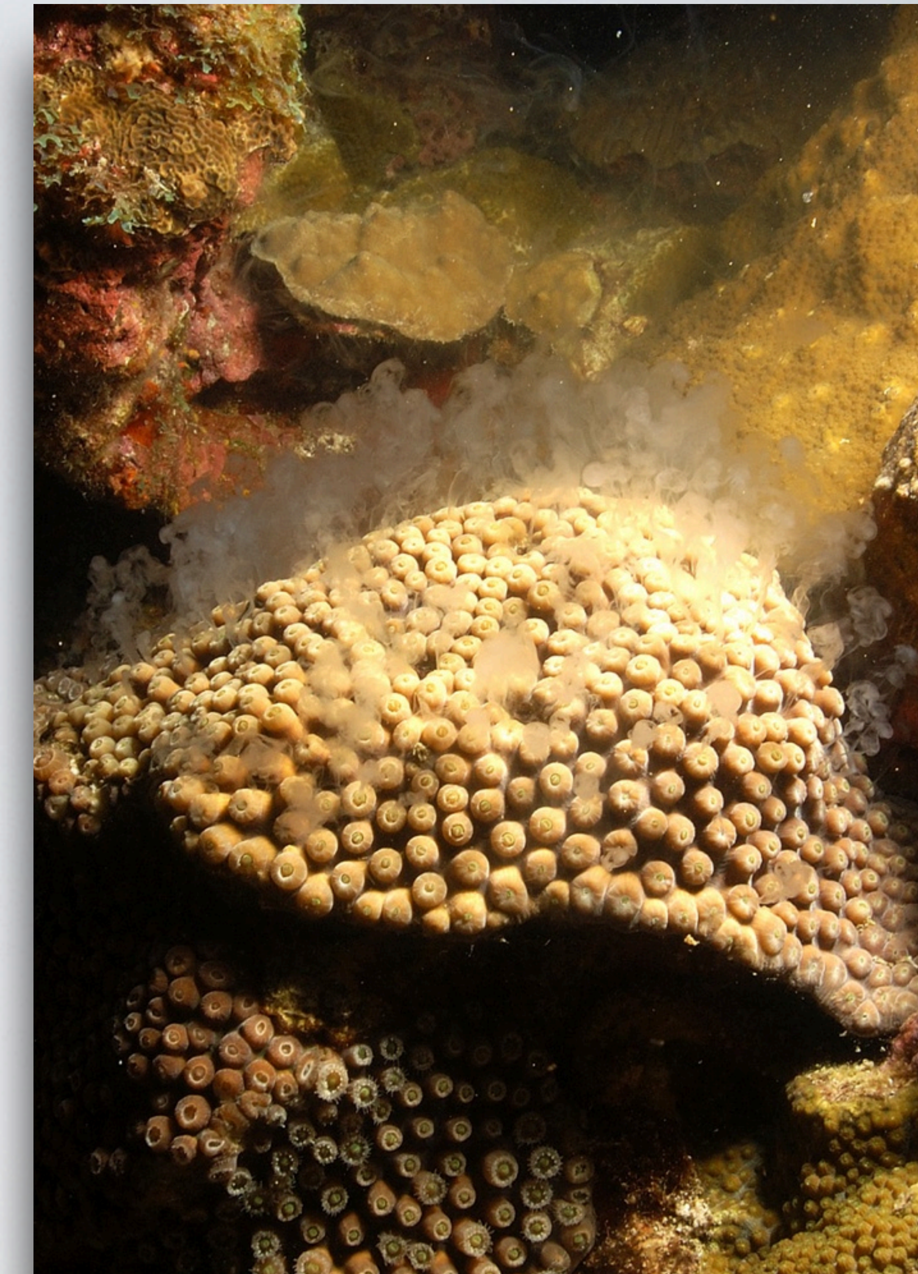


INTERACTIONS BETWEEN ISOLATED SCALARS IN TURBULENT FLOWS

Mike Soltys

6.25.13



BROADCAST SPAWNING

Photo: Emma Hickerson, NOAA sanctuaries web group, http://sanctuaries.noaa.gov/pgallery/pgflower/living/coralspawn_300.jpg
Photo: Flower Garden Banks National Marine Sanctuary, http://flowergarden.noaa.gov/science/fgbcoralspawning.html

REACTIVE ADVECTION

$$\frac{D\Phi_{sperm}}{Dt} = \Gamma\nabla^2\Phi_{sperm} - k\Phi_{sperm}\Phi_{egg}$$

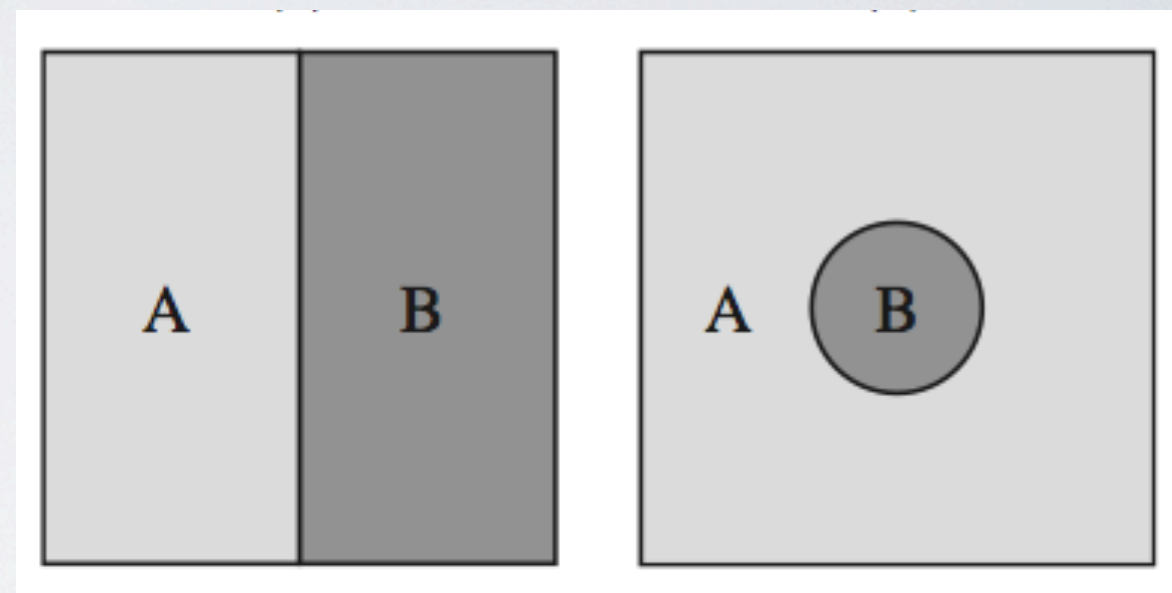
$$\frac{D\Phi_{egg}}{Dt} = \Gamma\nabla^2\Phi_{egg} - k\Phi_{sperm}\Phi_{egg}$$

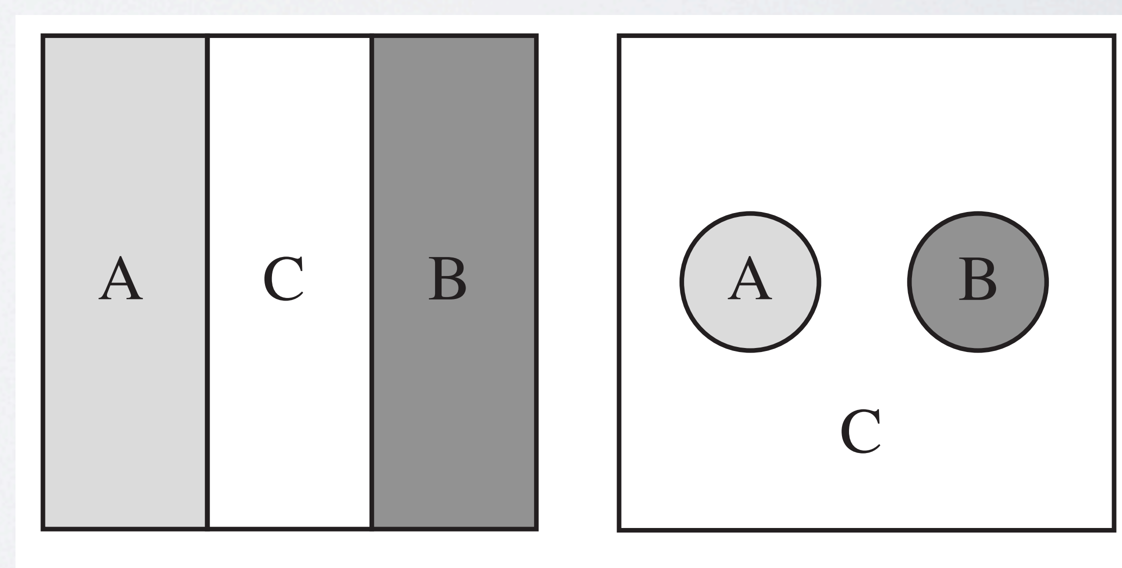
Fertilization → $\Theta = k\Phi_{sperm}\Phi_{egg}$

$$\langle\Phi_{sperm}\Phi_{egg}\rangle = \langle\Phi_{sperm}\rangle\langle\Phi_{egg}\rangle + \underline{\langle\phi'_{sperm}\phi'_{egg}\rangle}$$

ISOLATED TOPOLOGY

- Unique topology: applies to wide range of problems
- In the low Damköhler-limit: conserved scalars can be used to estimate reaction
- Applicable to higher order reactions: but may depend on higher order statistics



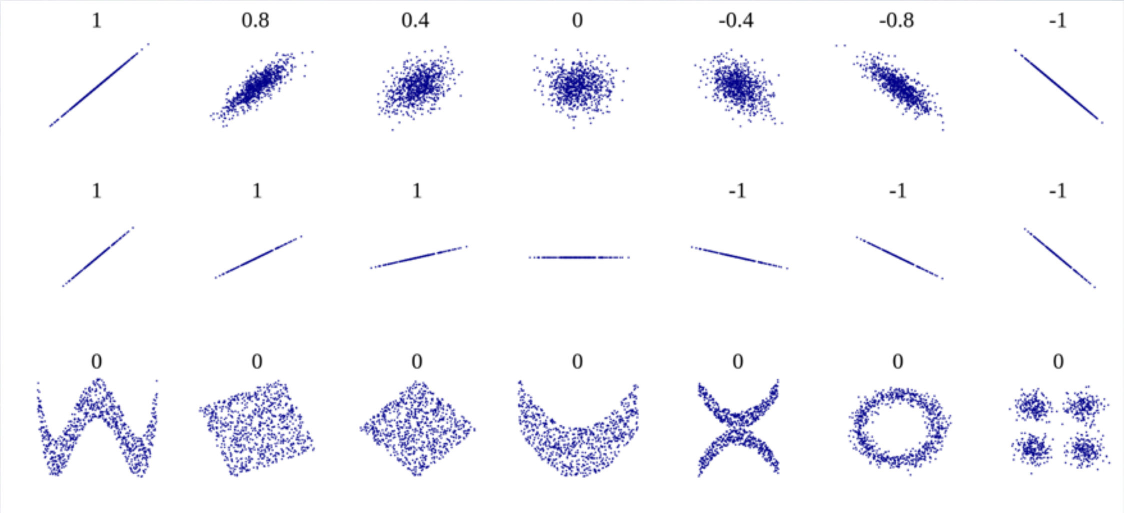


MEASURING MIXEDNESS

$$\langle \Phi_A \Phi_B \rangle = \langle \Phi_A \rangle \langle \Phi_B \rangle + \langle \phi'_A \phi'_B \rangle$$

- Pearson's correlation coefficient:

$$\rho = \frac{\langle \phi'_A \phi'_B \rangle}{\sigma_A \sigma_B}$$



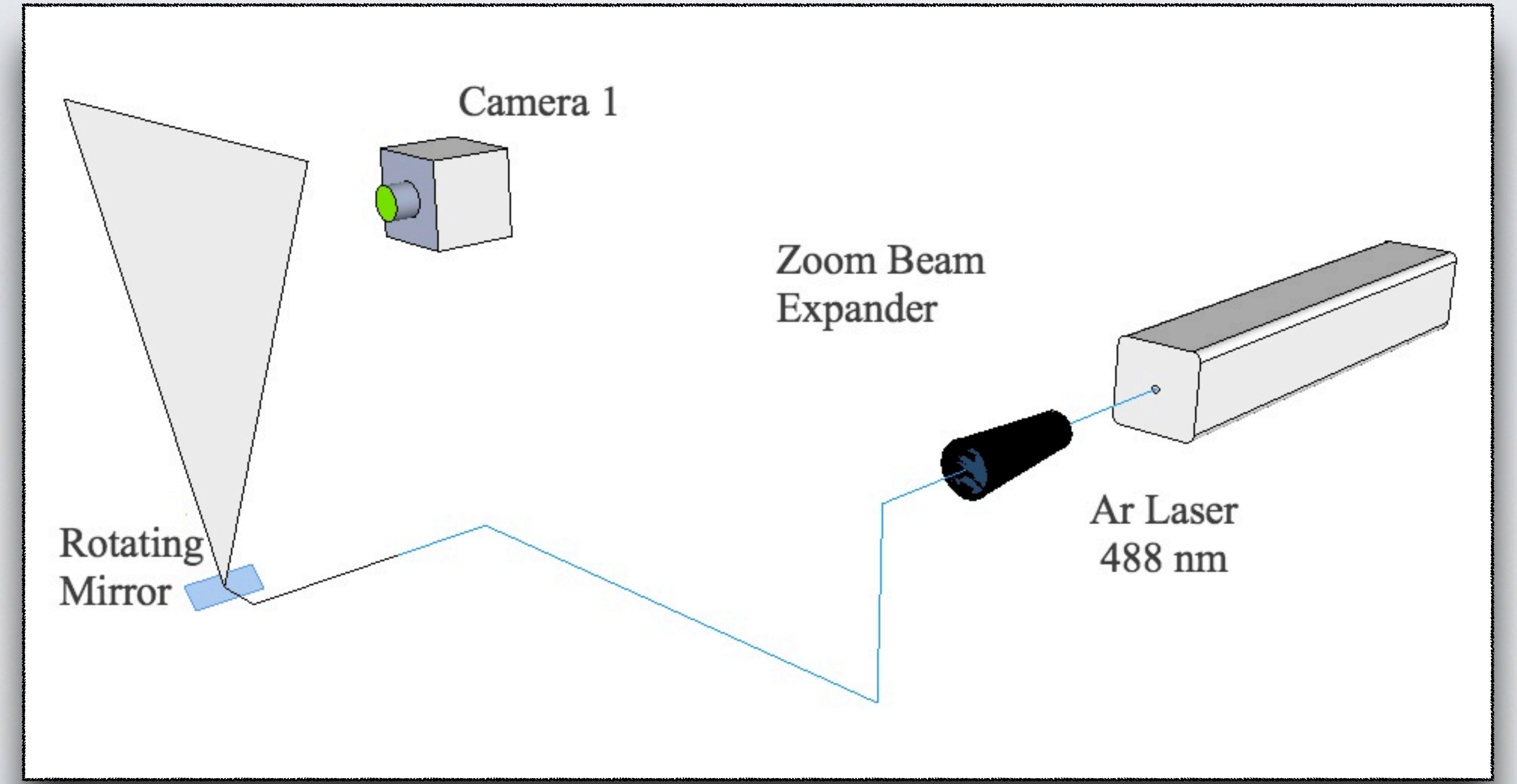
- Segregation Parameter:

$$S = \frac{\langle \phi'_A \phi'_B \rangle}{\langle \Phi_A \rangle \langle \Phi_B \rangle}$$

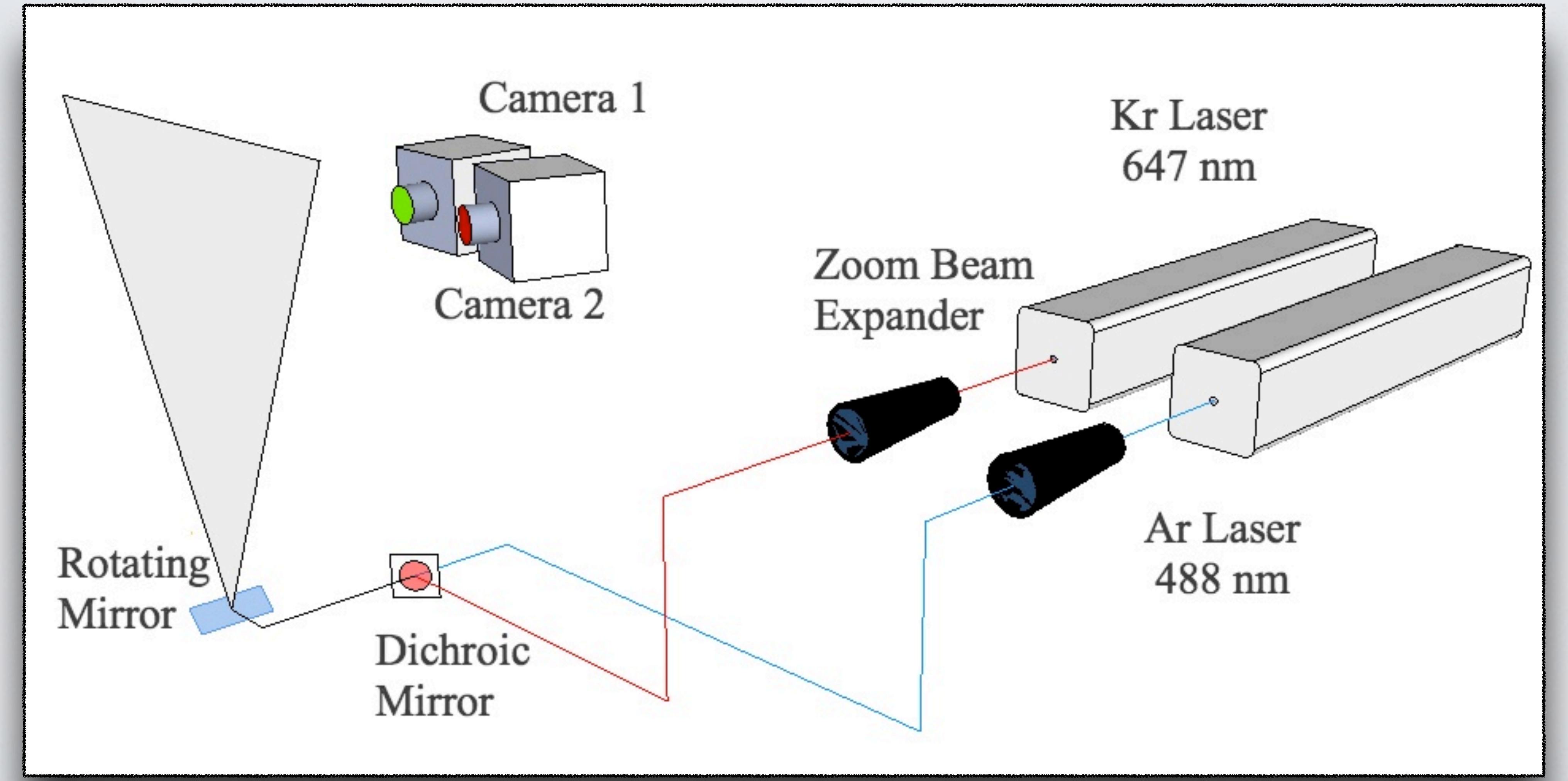
$$\langle \Phi_A \Phi_B \rangle = (1 + S) \langle \Phi_A \rangle \langle \Phi_B \rangle$$

Figure: Denis Boigelot: Public Media

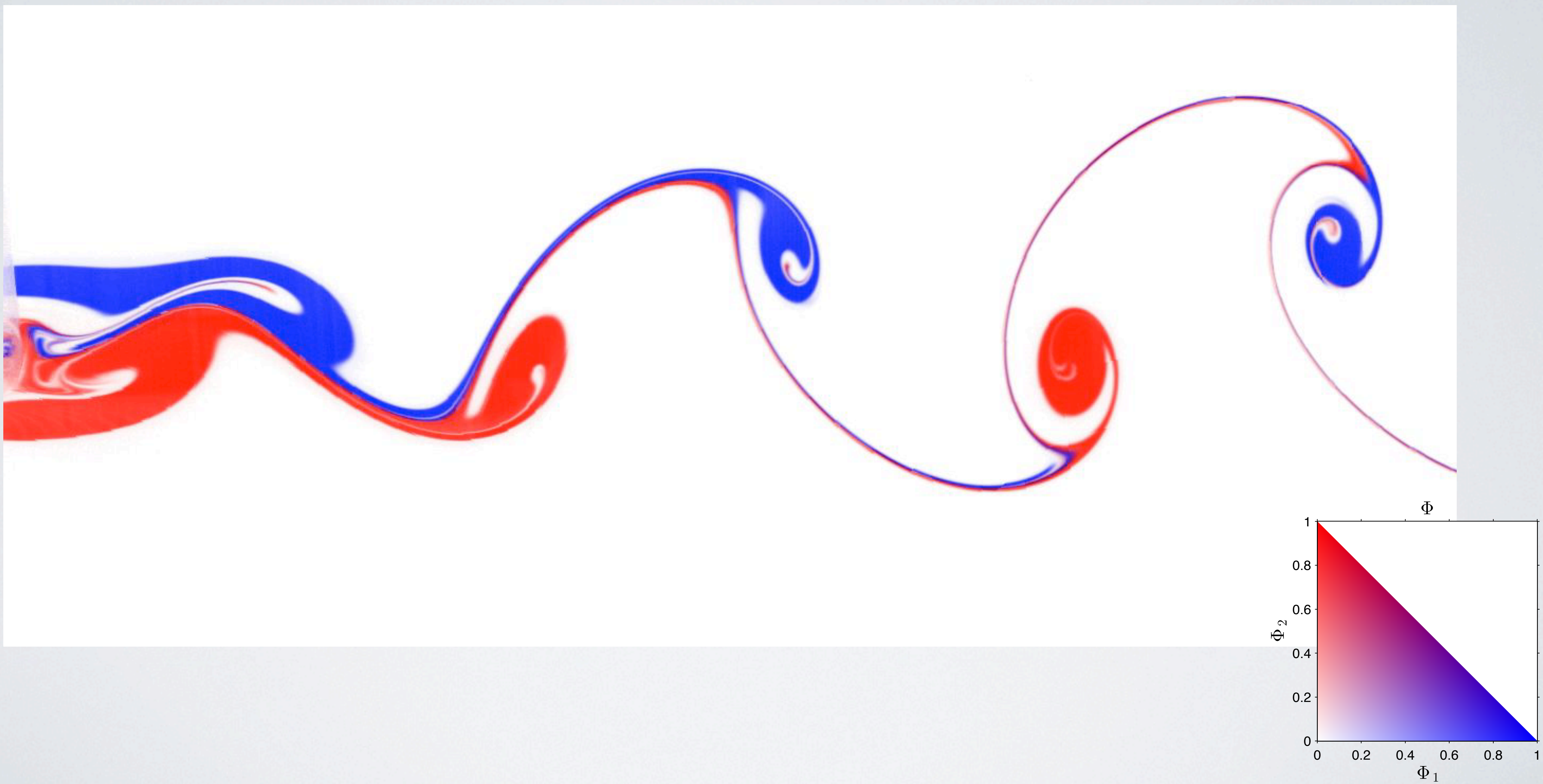
PLANER LASER INDUCED FLUORESCENCE

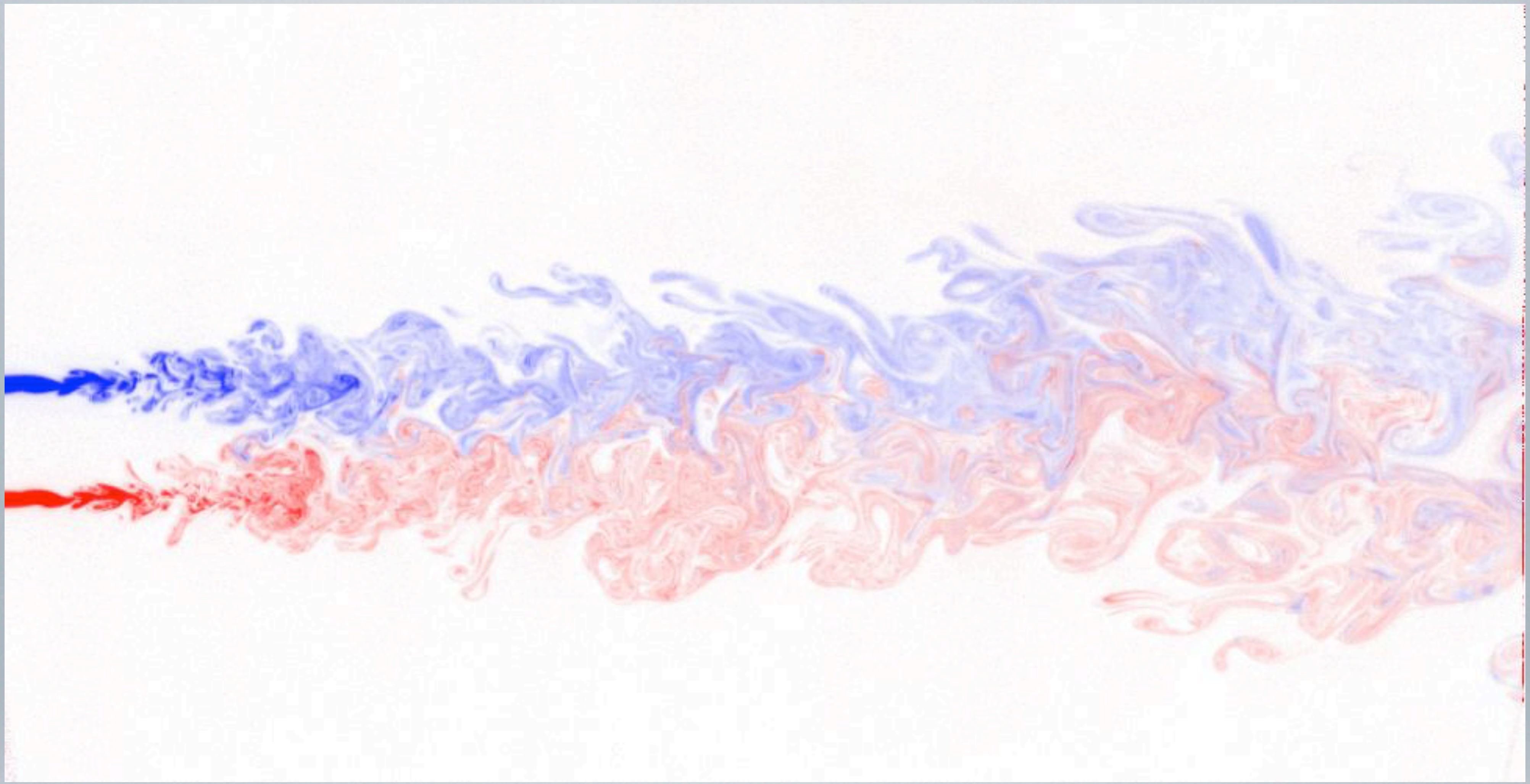


2-CHANNEL PLIF



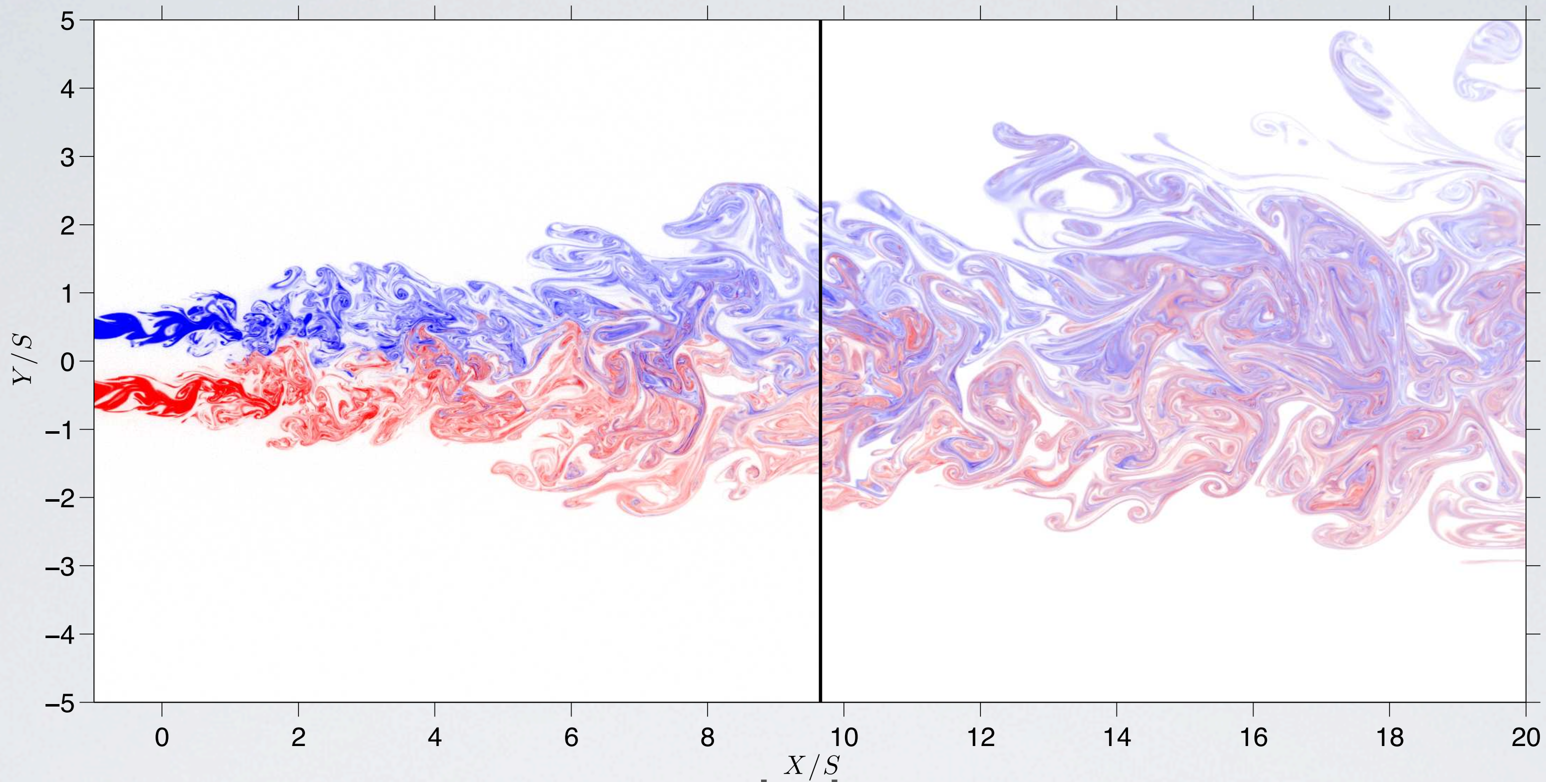
RE=100





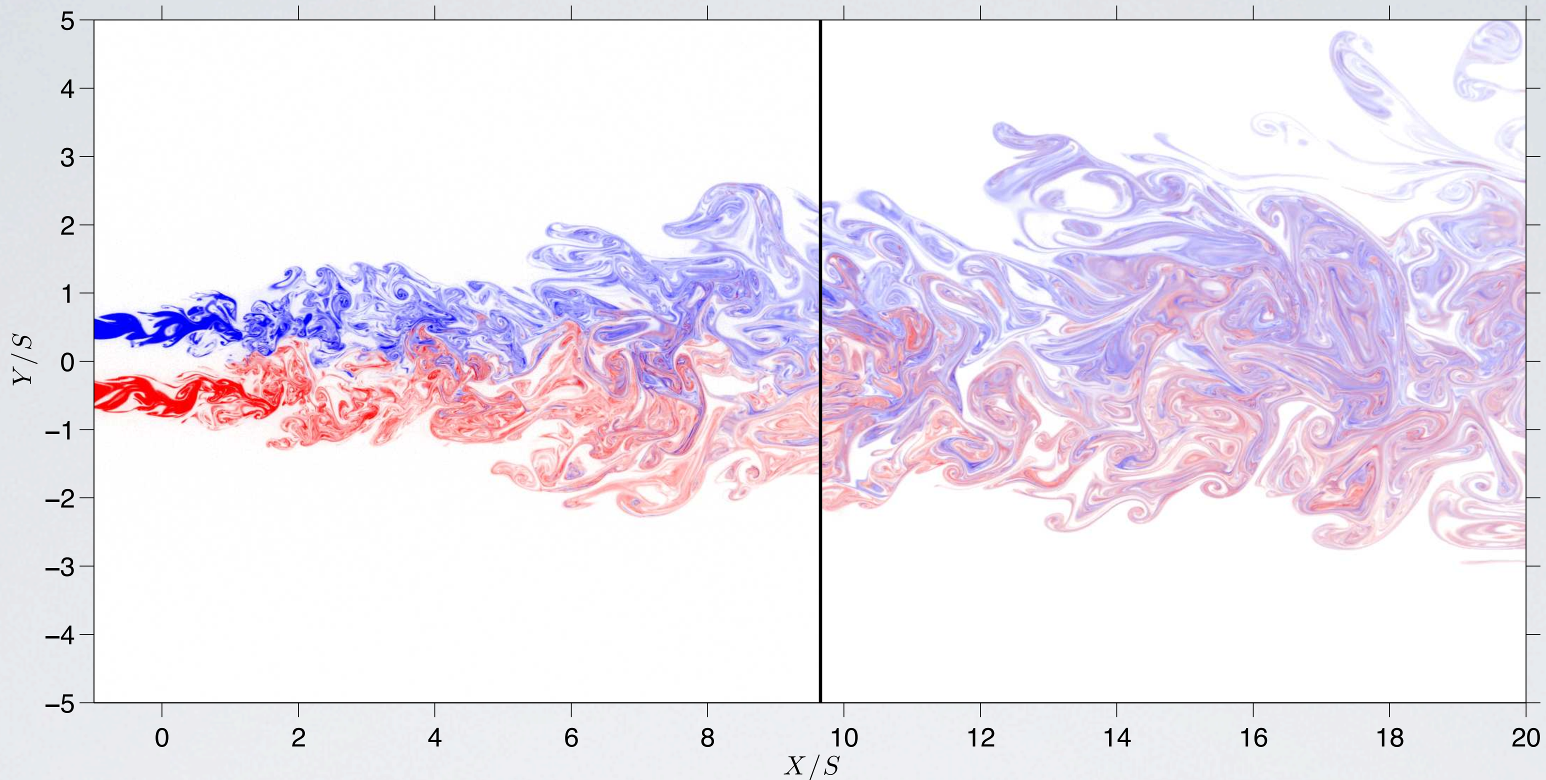
PARALLEL TURBULENT JETS

ϕ_A and ϕ_B

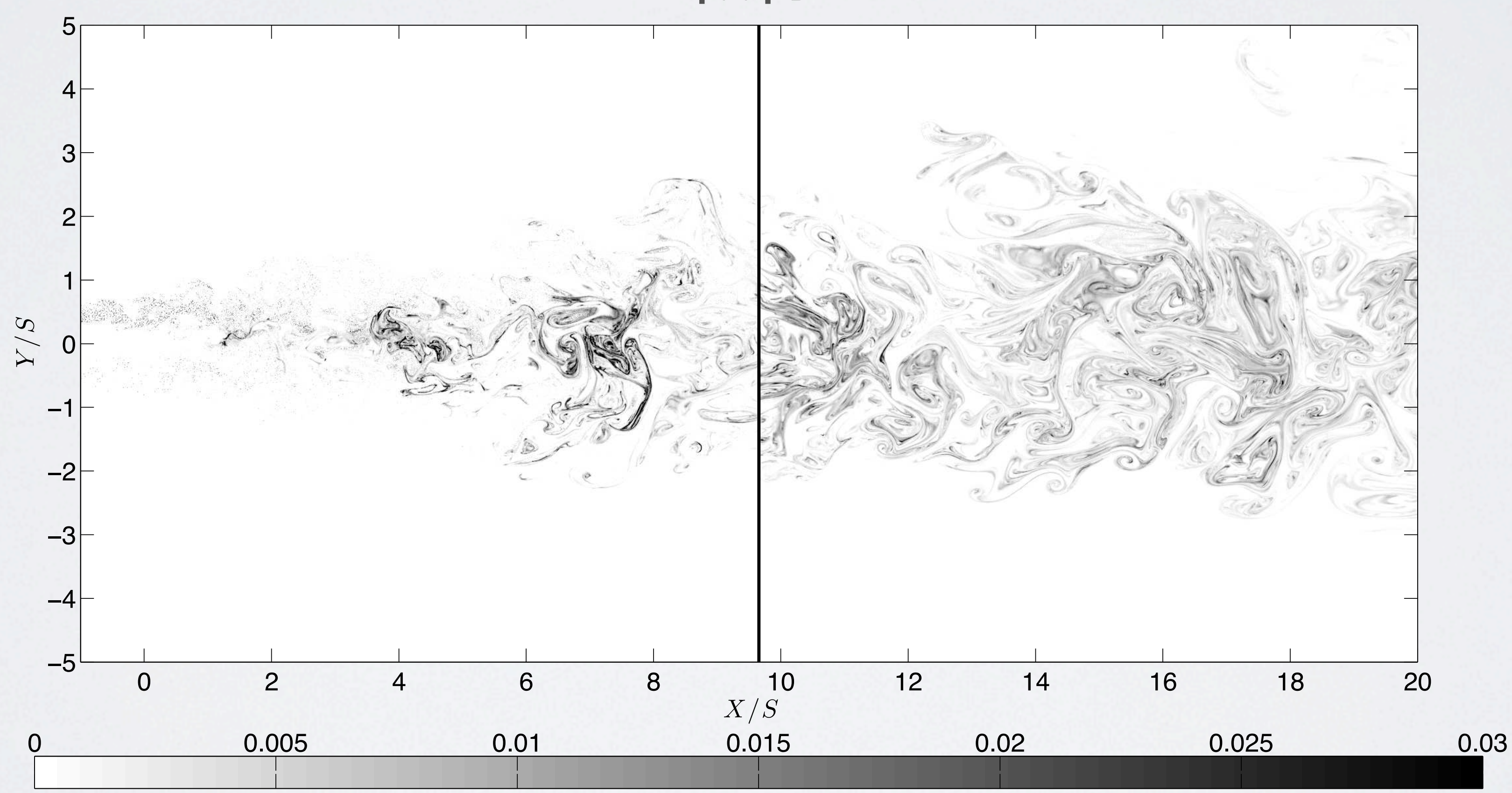


$\phi_A \phi_B$

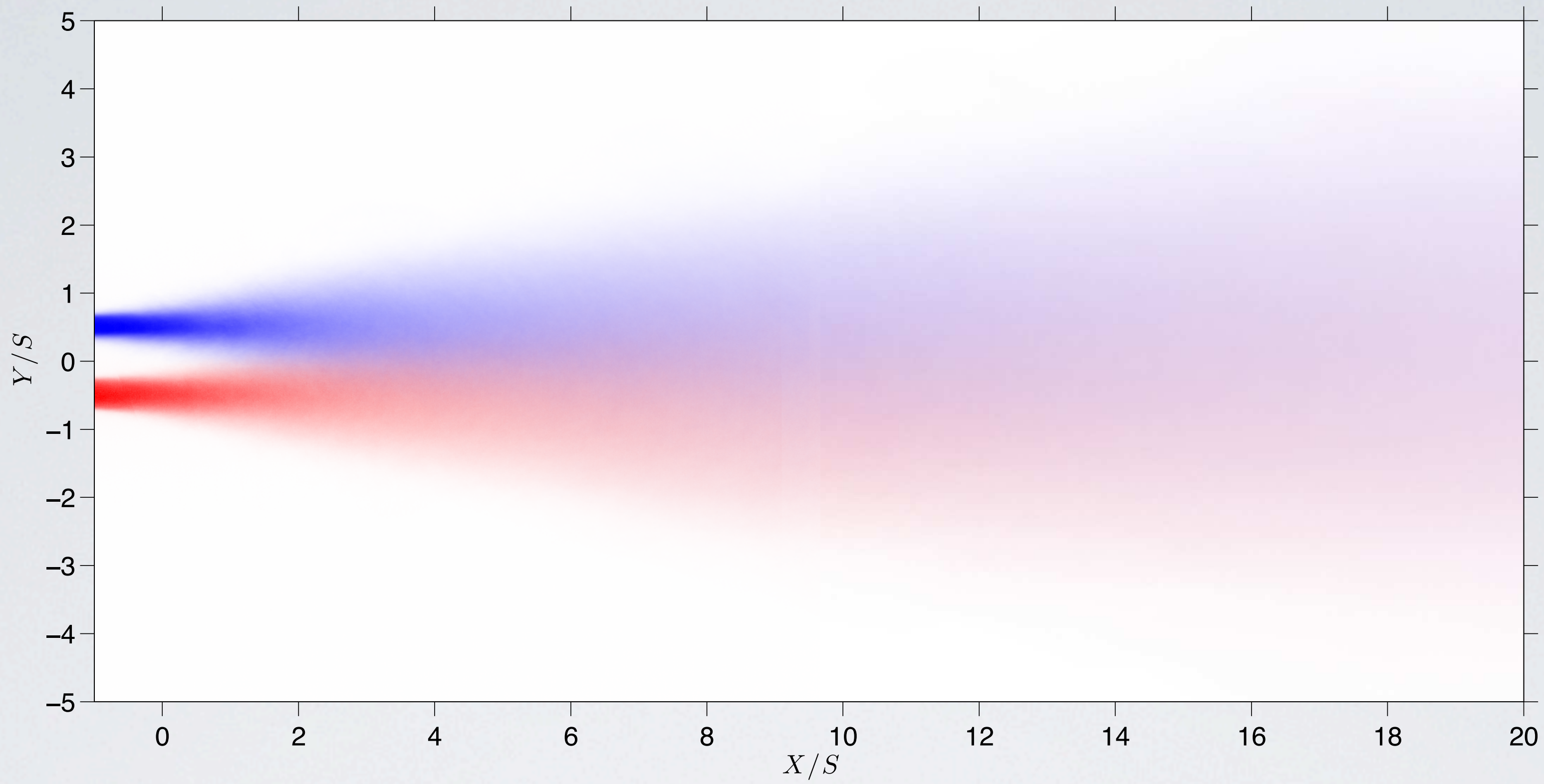
ϕ_A and ϕ_B



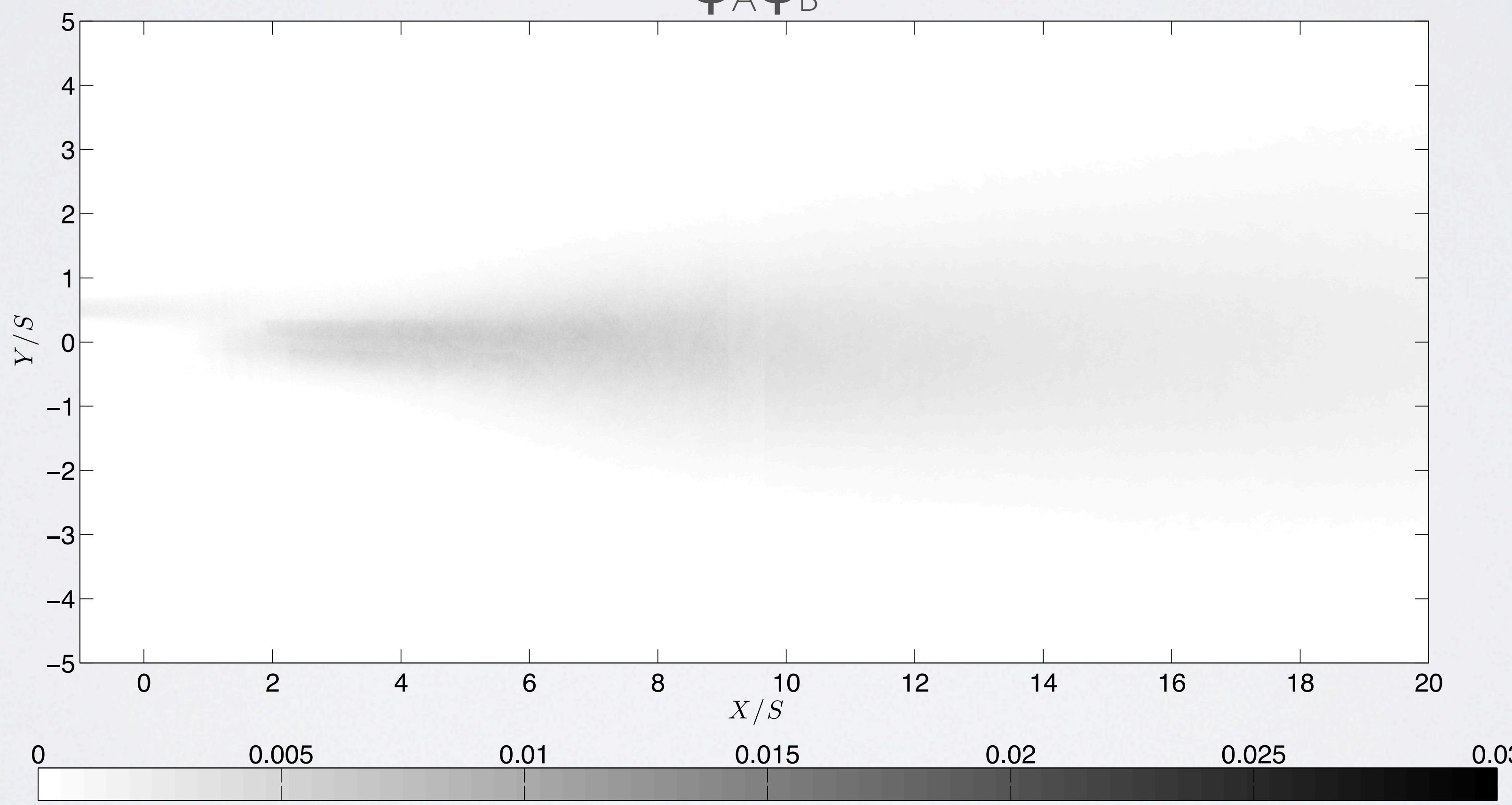
$\phi_A\phi_B$



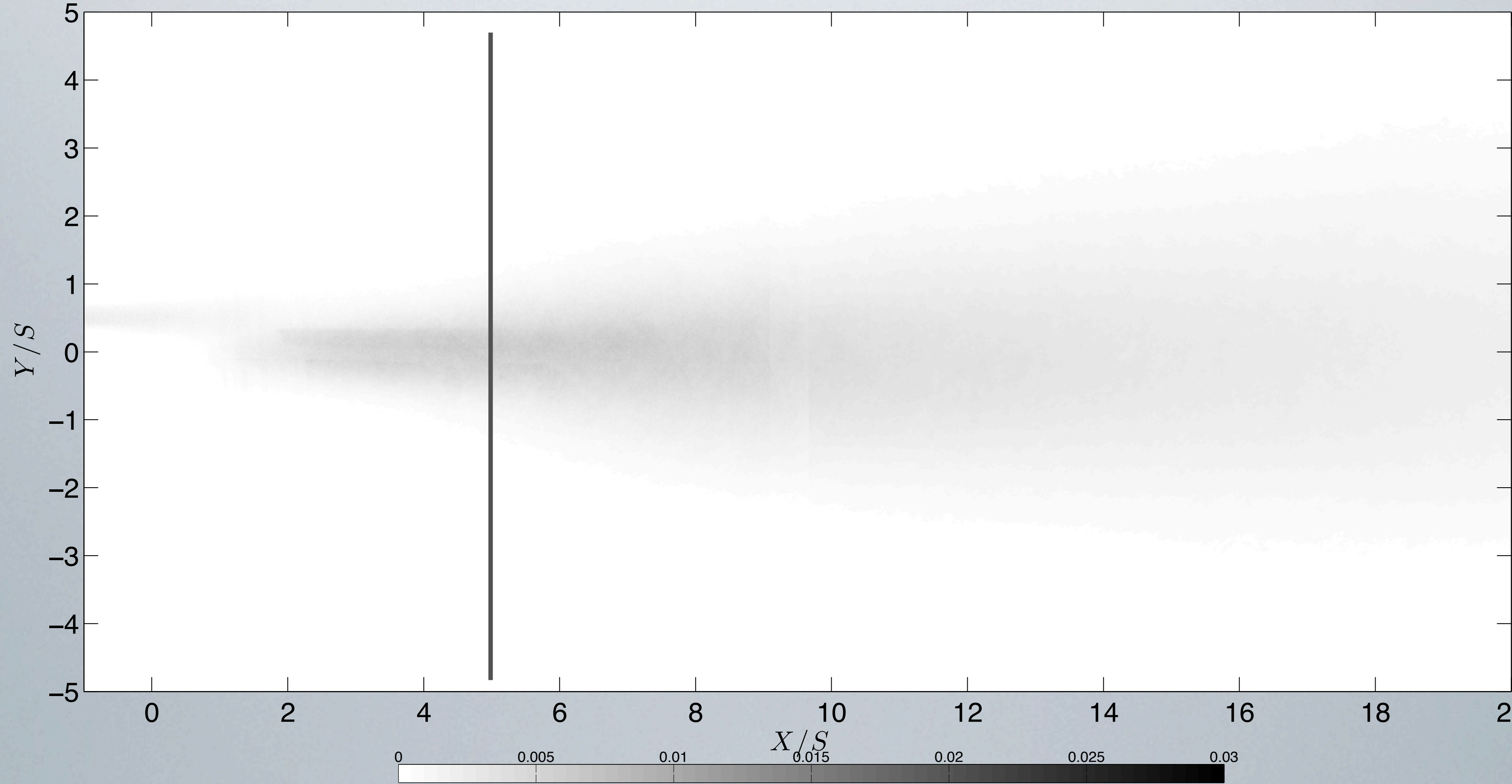
$<\phi_A>$ and $<\phi_B>$



$<\phi_A \phi_B>$

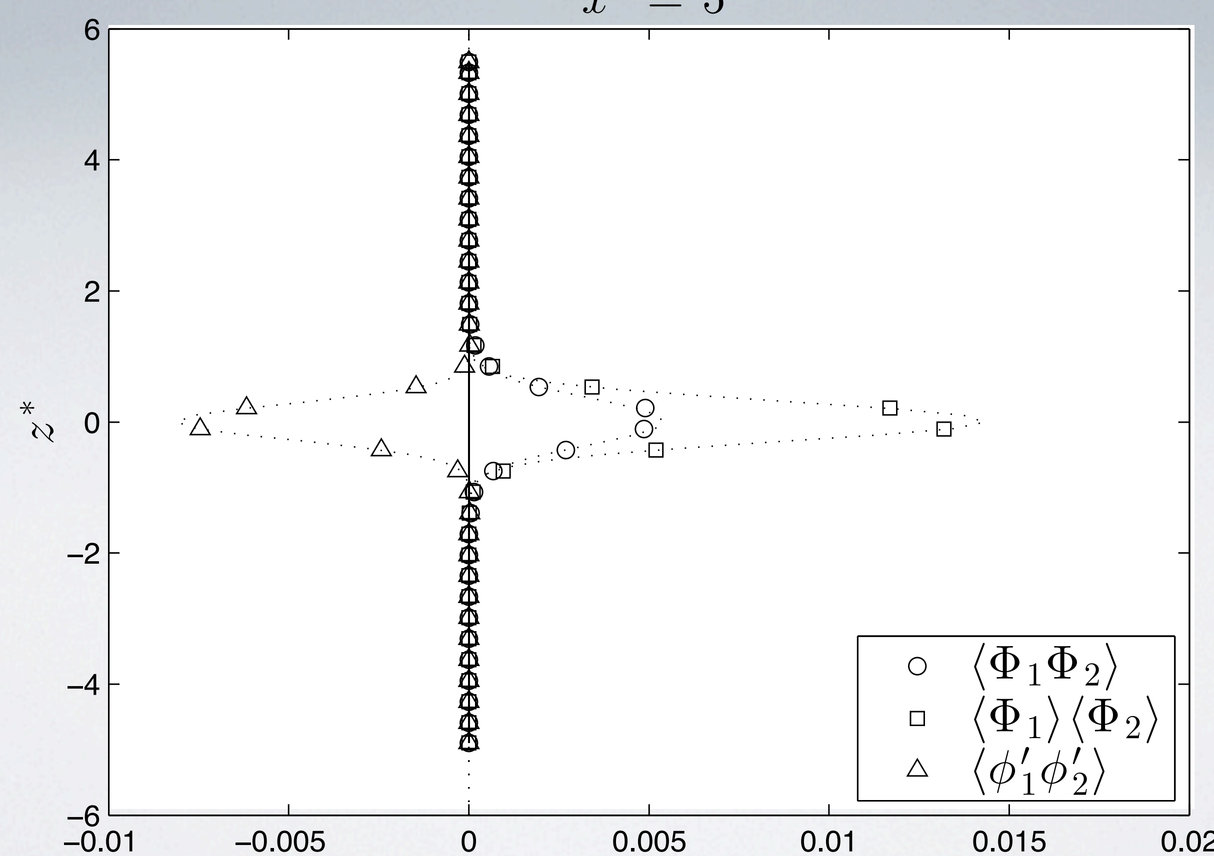


$<\phi_1\phi_2>$



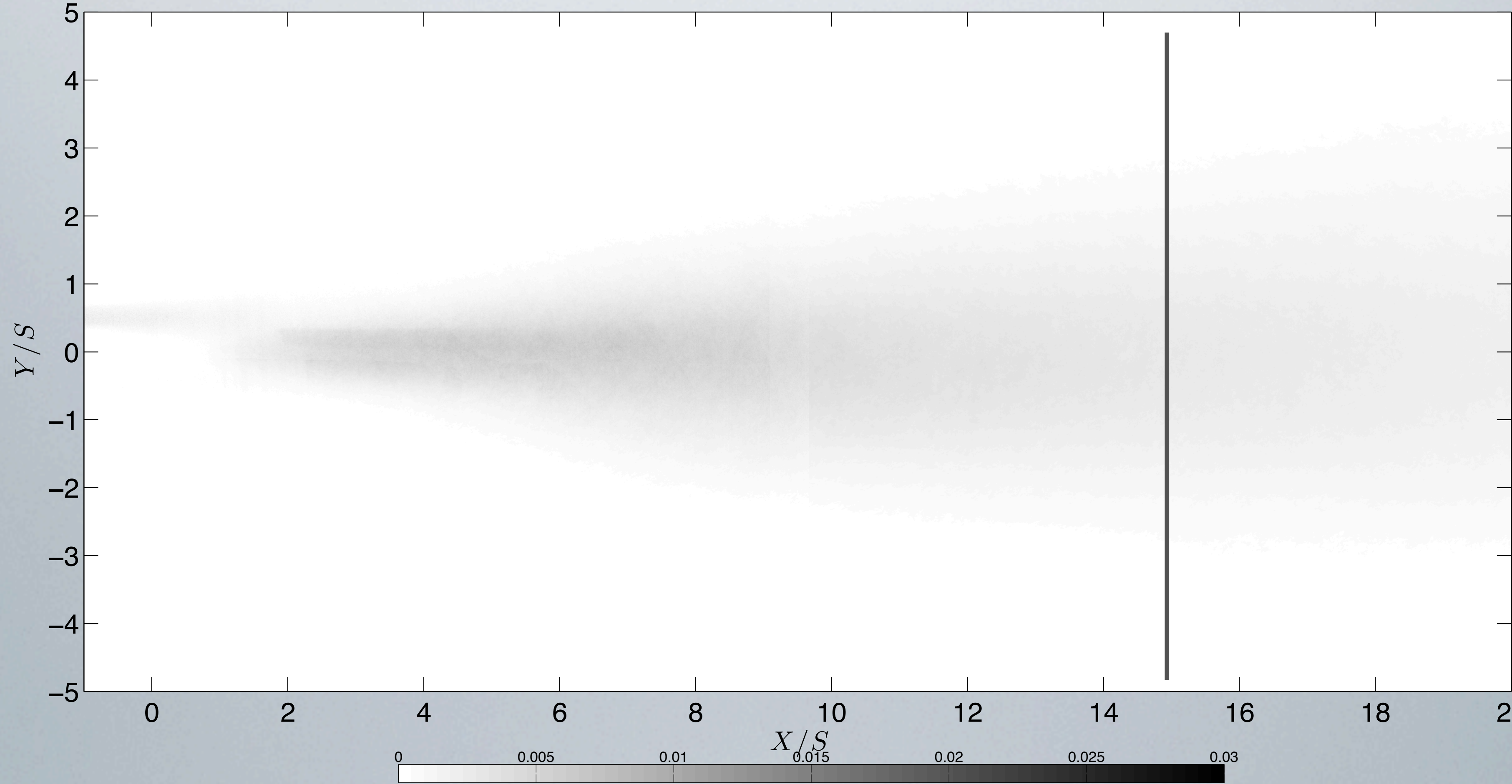
Y/S
X/S
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
2
4
6
8
10
12
14
16
18
20
0
0.005
0.01
0.015
0.02
0.025
0.03

$x^* = 5$

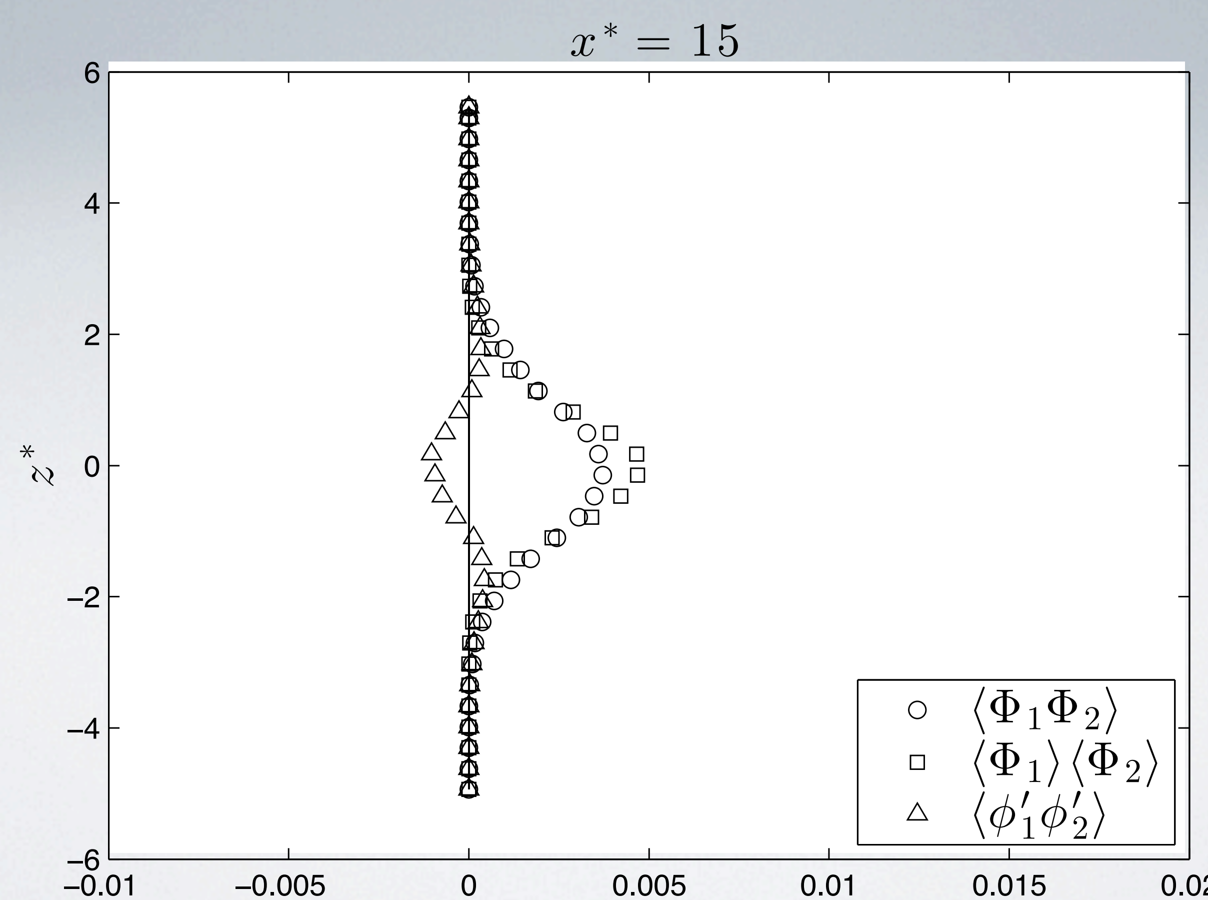


z*
6
4
2
0
−2
−4
−6
−0.01
−0.005
0
0.005
0.01
0.015
0.02
⟨Φ1Φ2⟩
⟨Φ1⟩⟨Φ2⟩
⟨φ′1φ′2⟩

<$\phi_1\phi_2$>

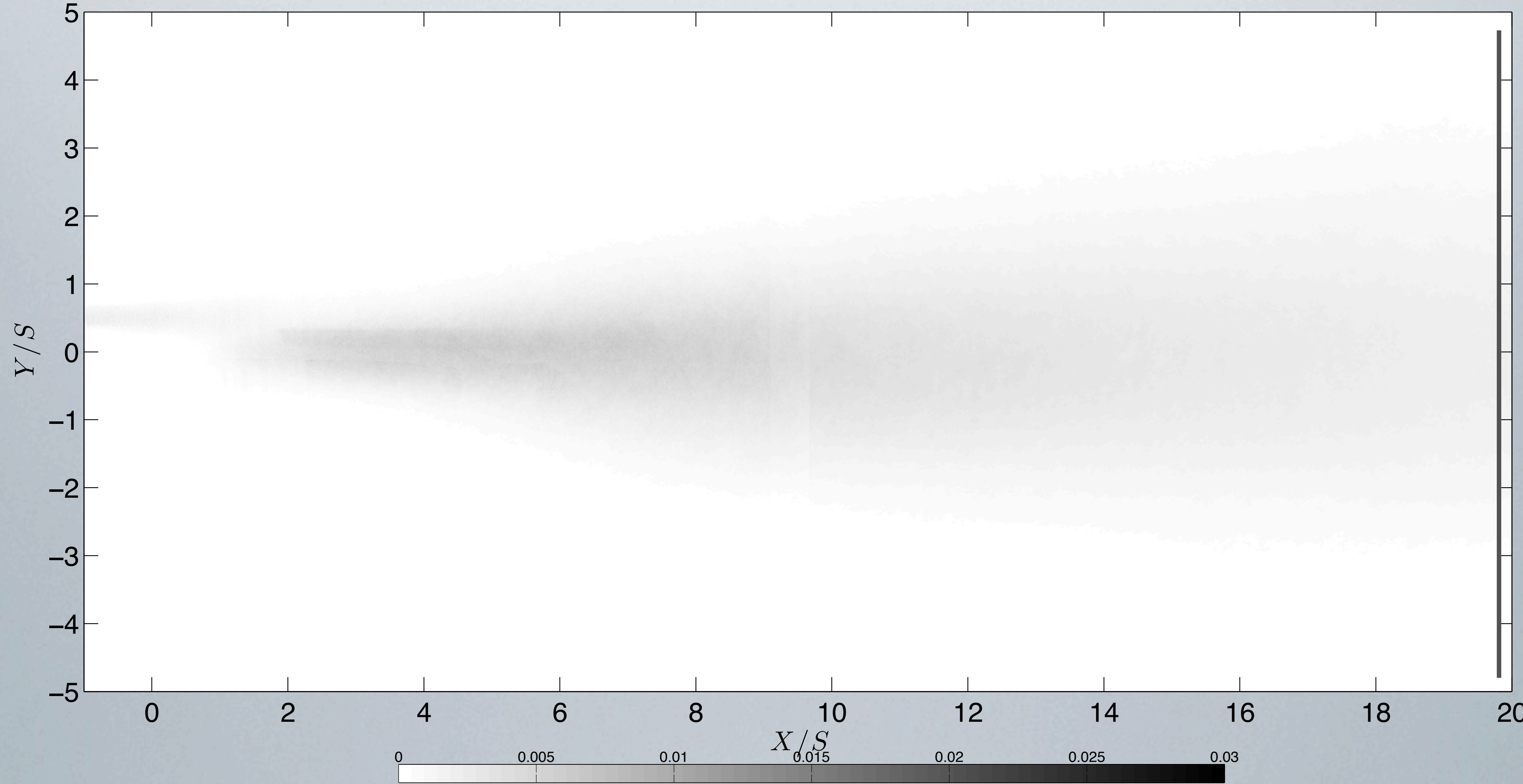


Y/S
X/S

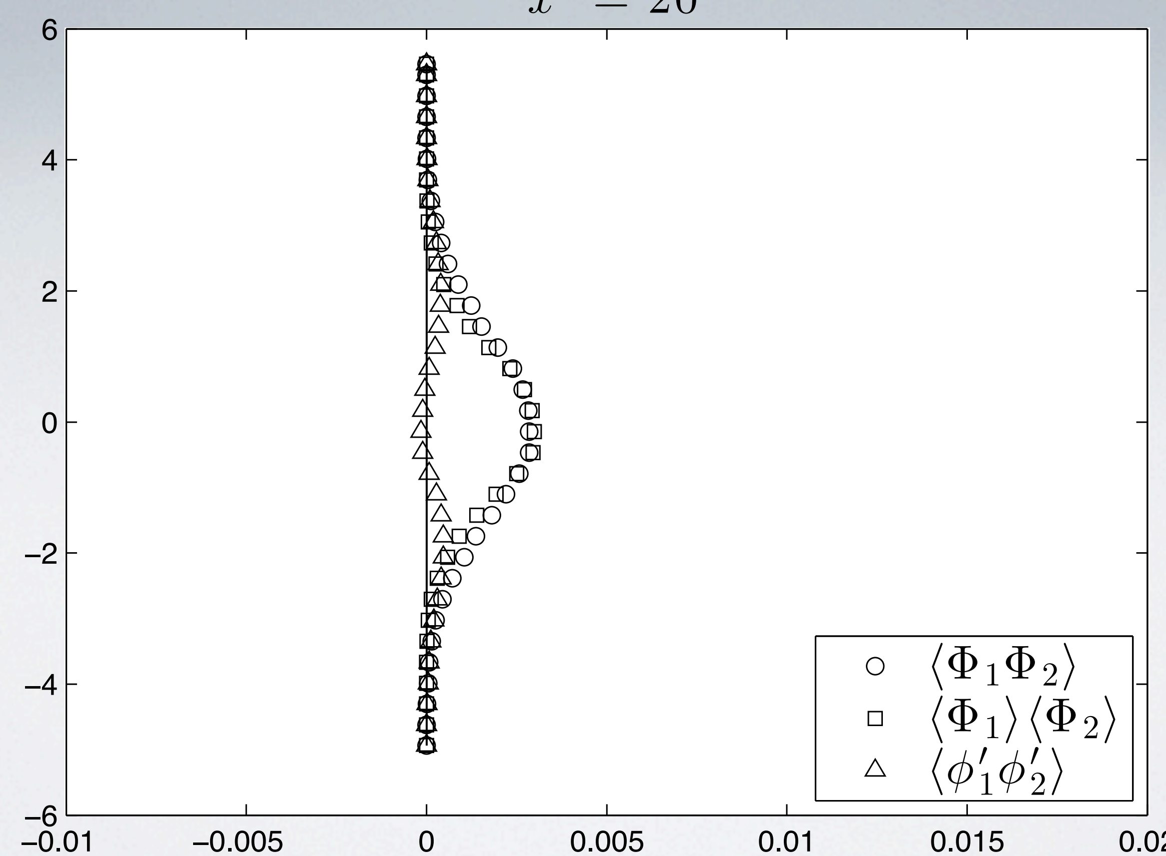


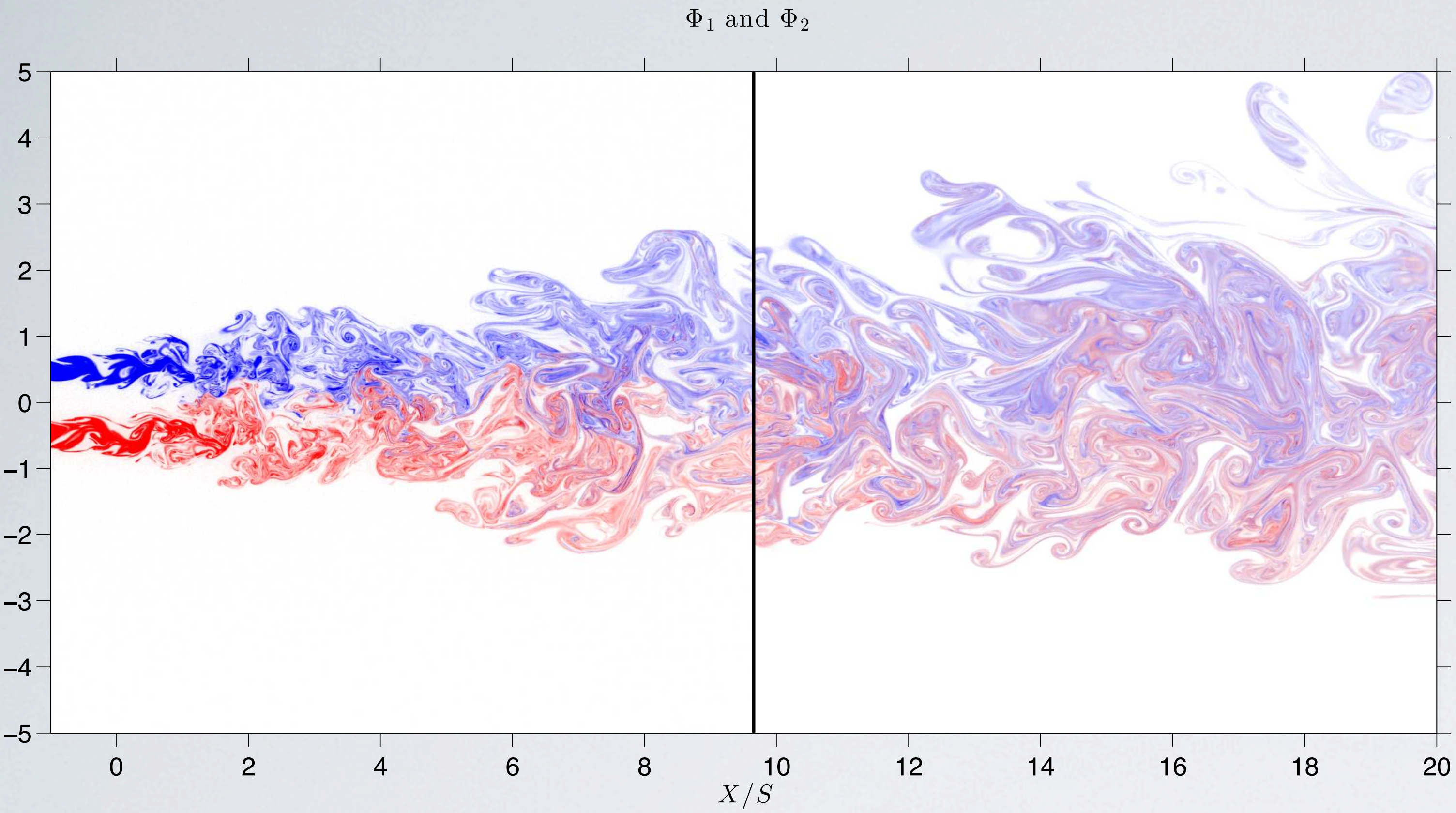
$x^* = 15$
z^*
$\langle \Phi_1 \Phi_2 \rangle$
$\langle \Phi_1 \rangle \langle \Phi_2 \rangle$
$\langle \phi_1' \phi_2' \rangle$

$<\phi_1\phi_2>$

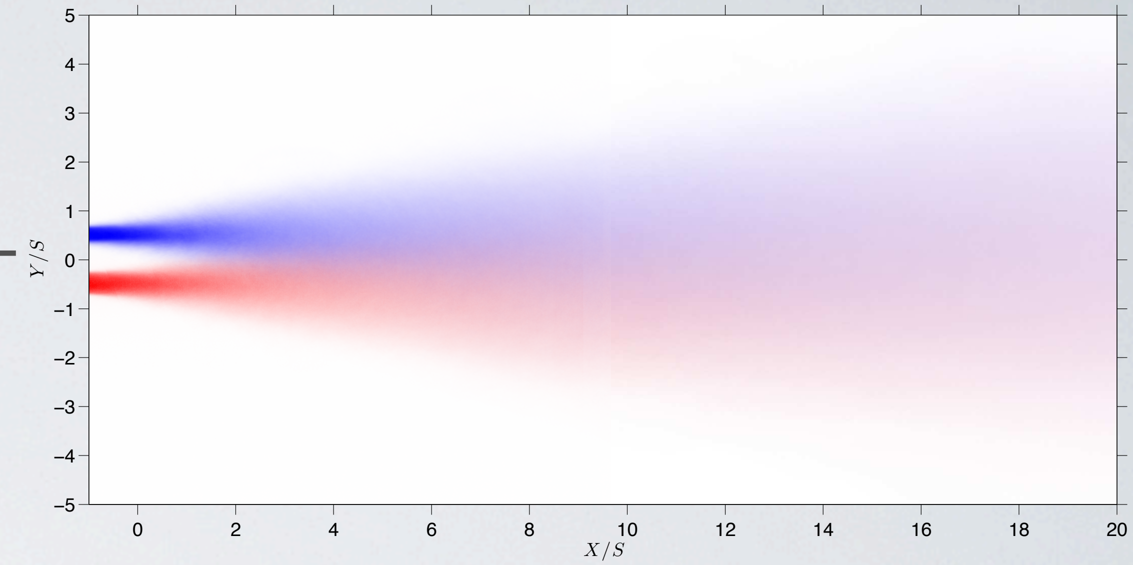


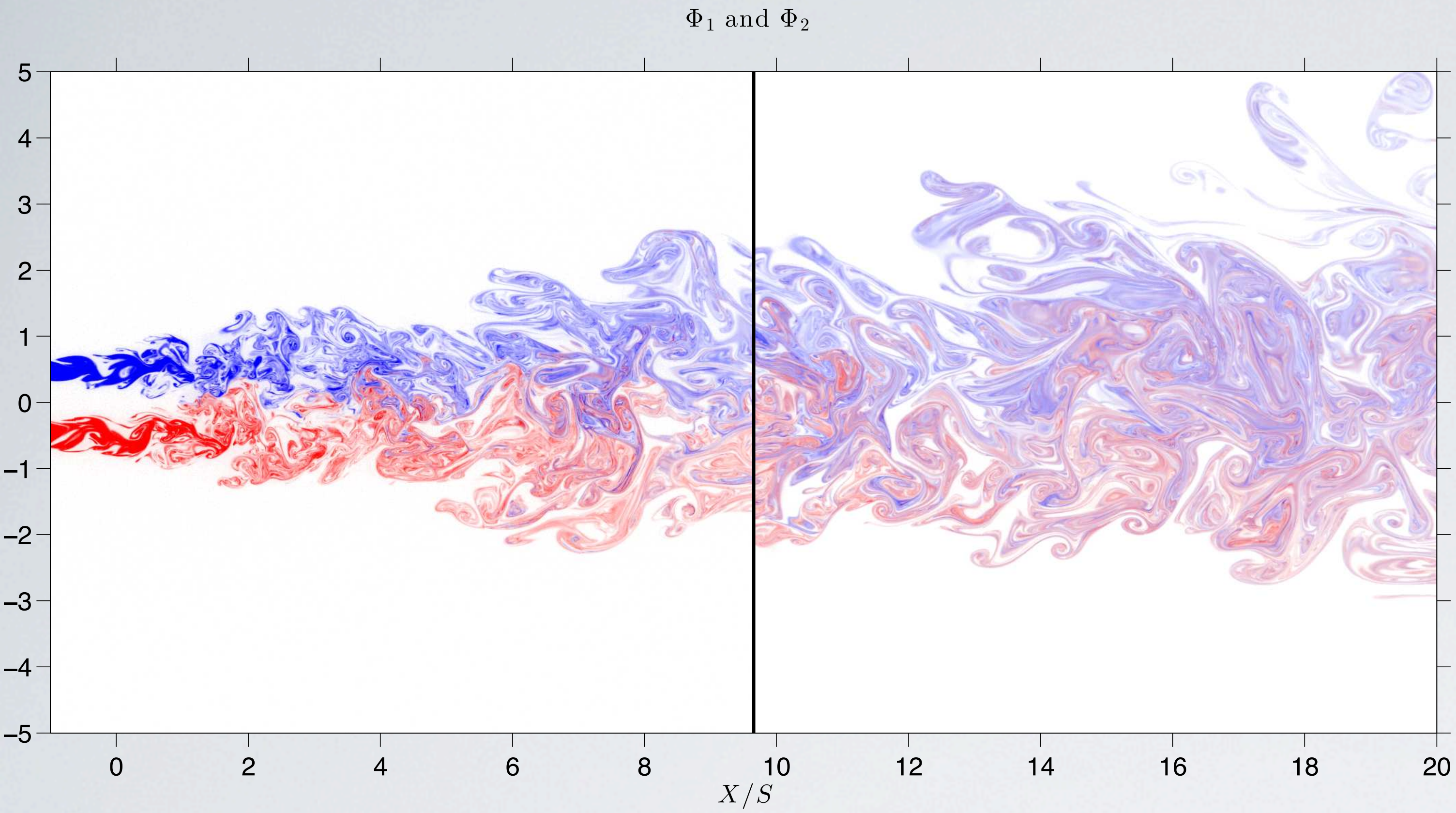
$x^* = 20$



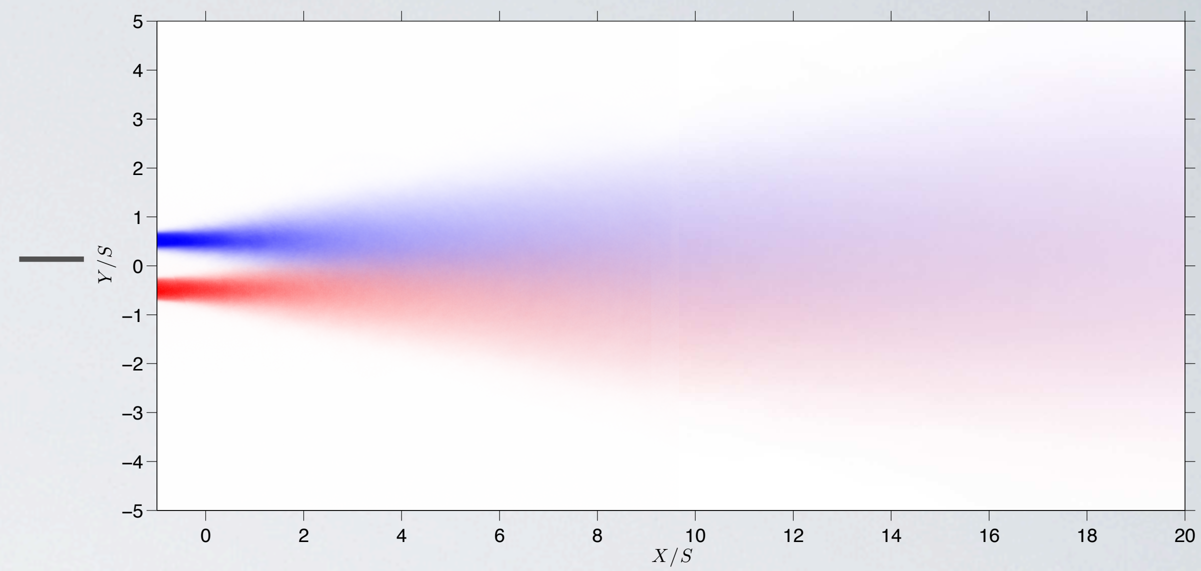


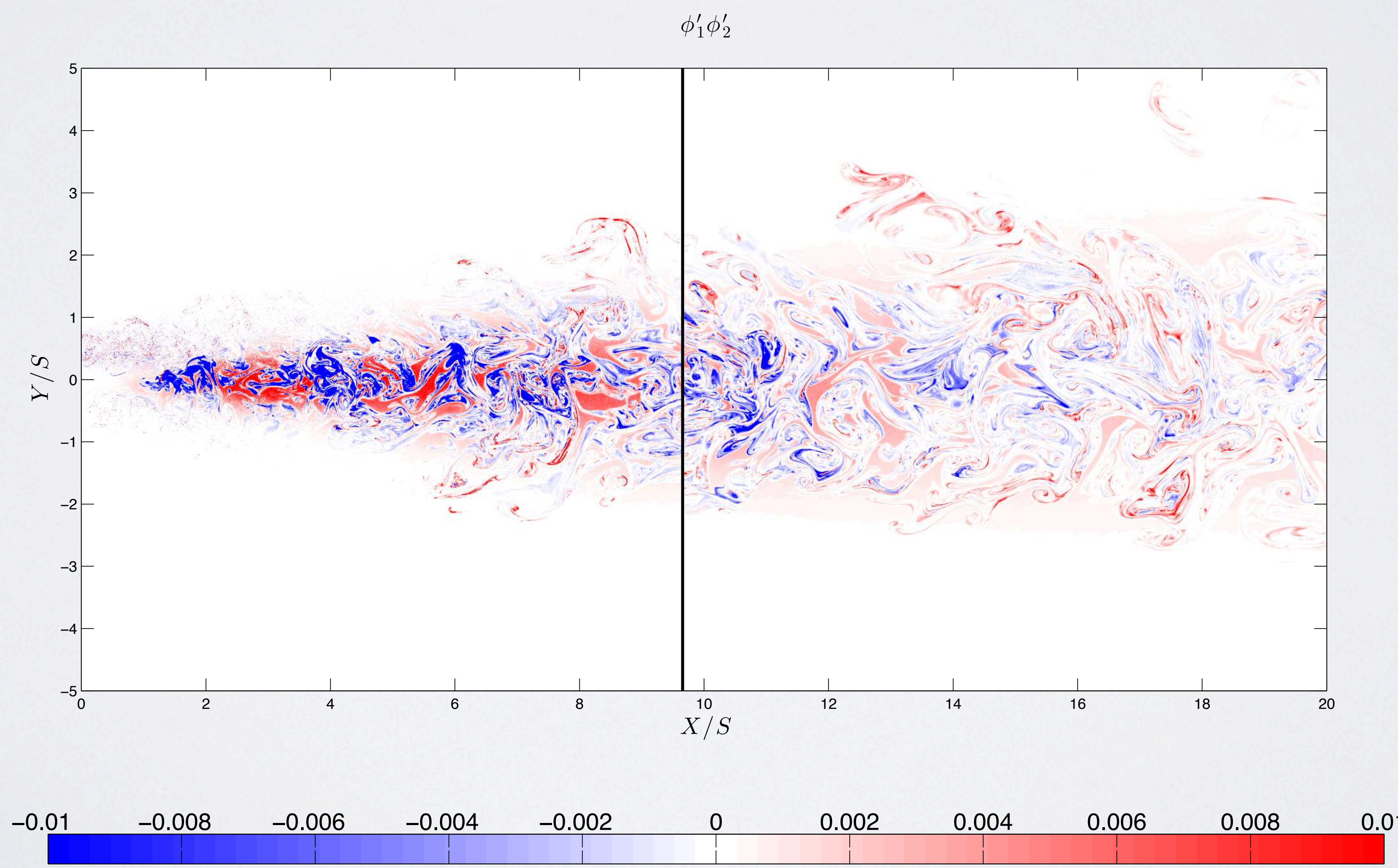
<ϕA> and <ϕB>



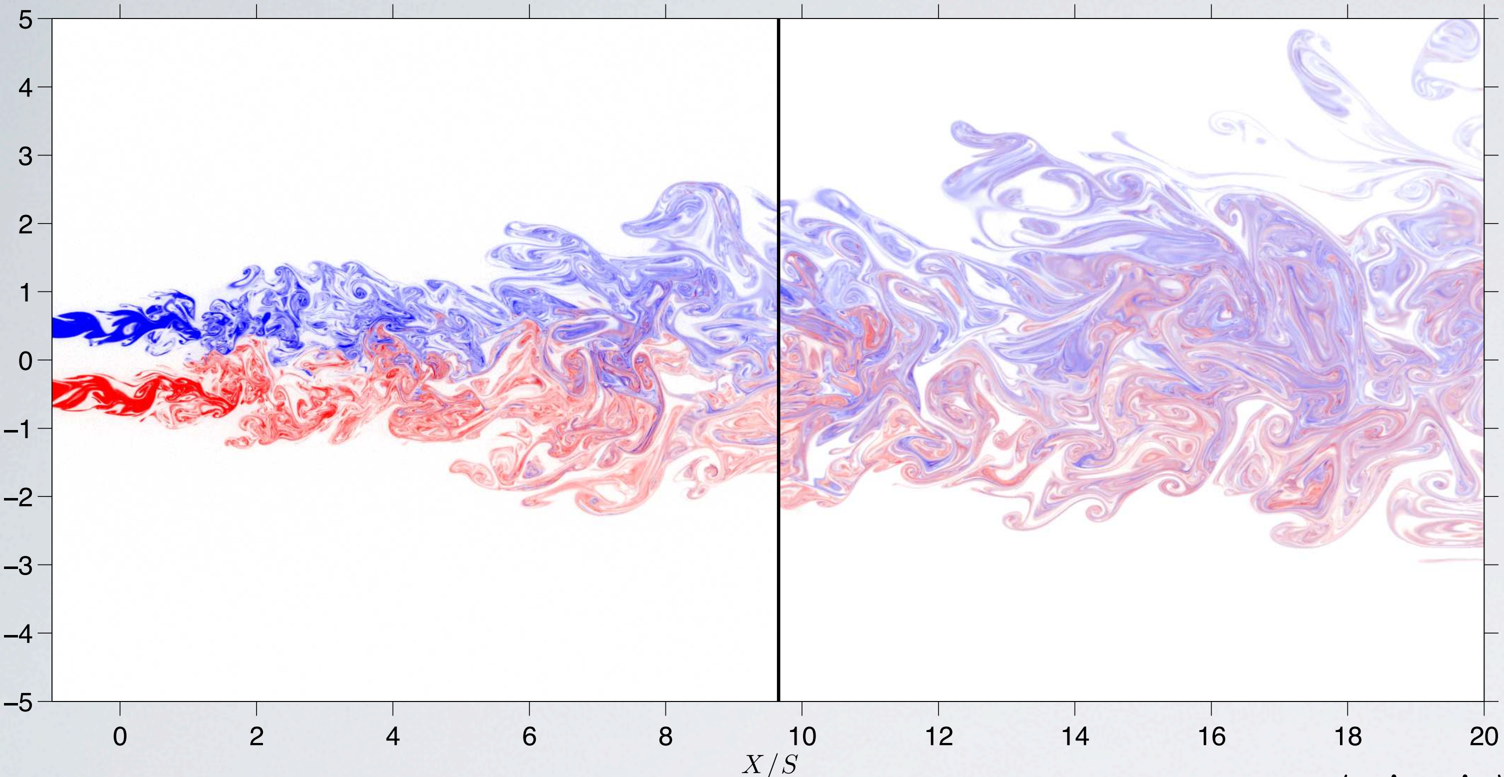


<ϕ_A> and <ϕ_B>



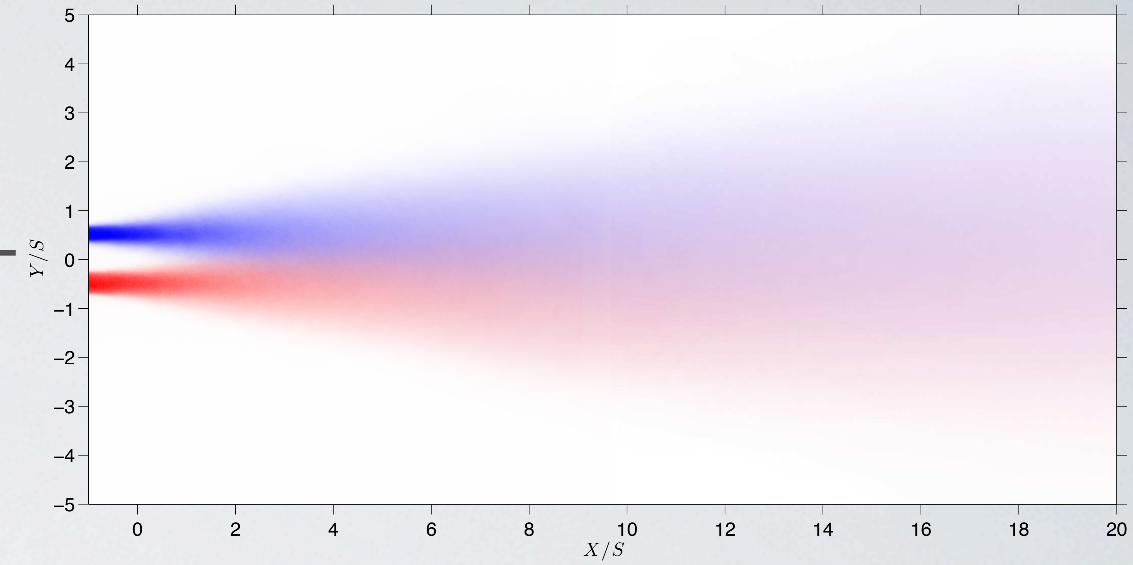


ϕ_A and ϕ_B

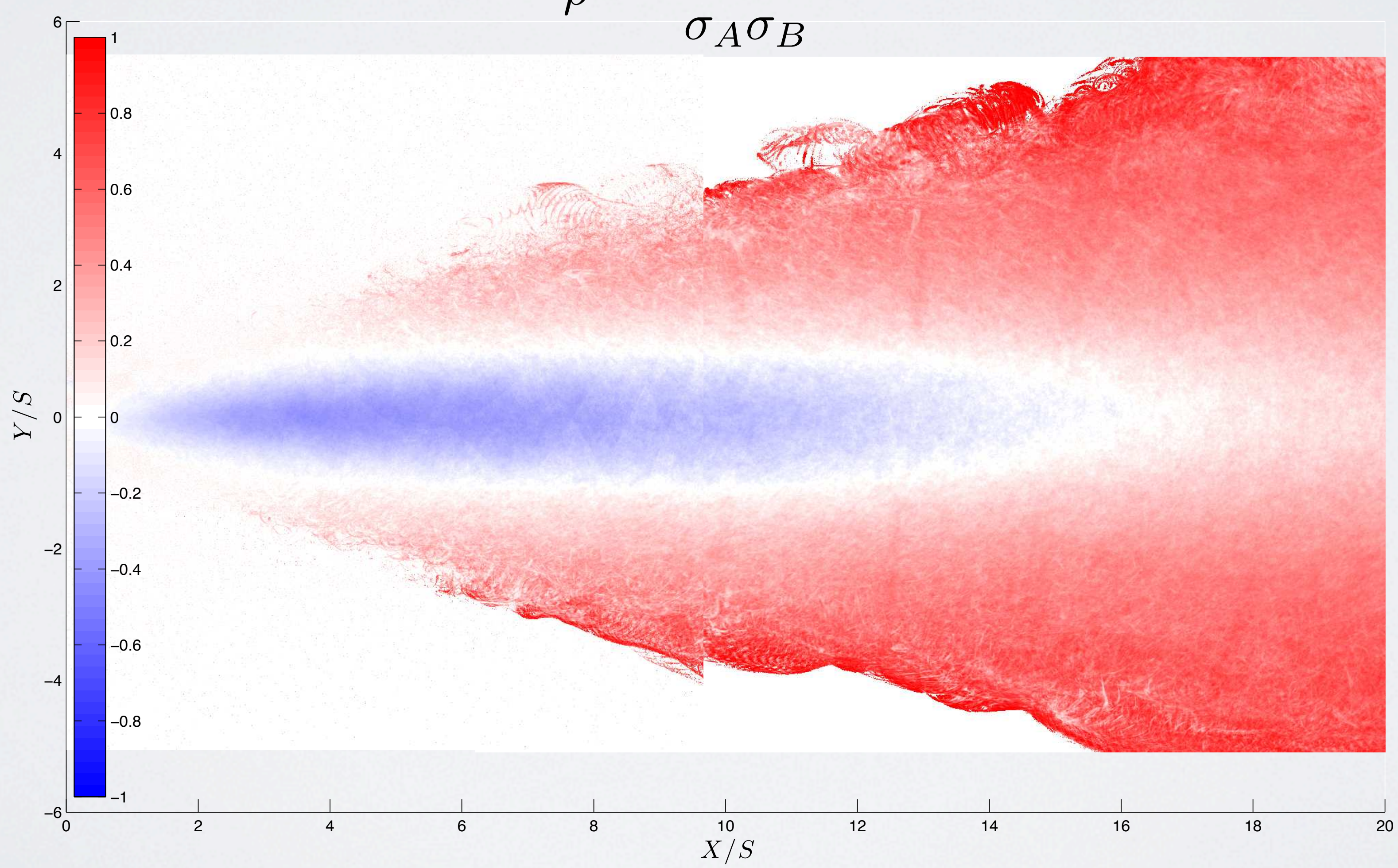


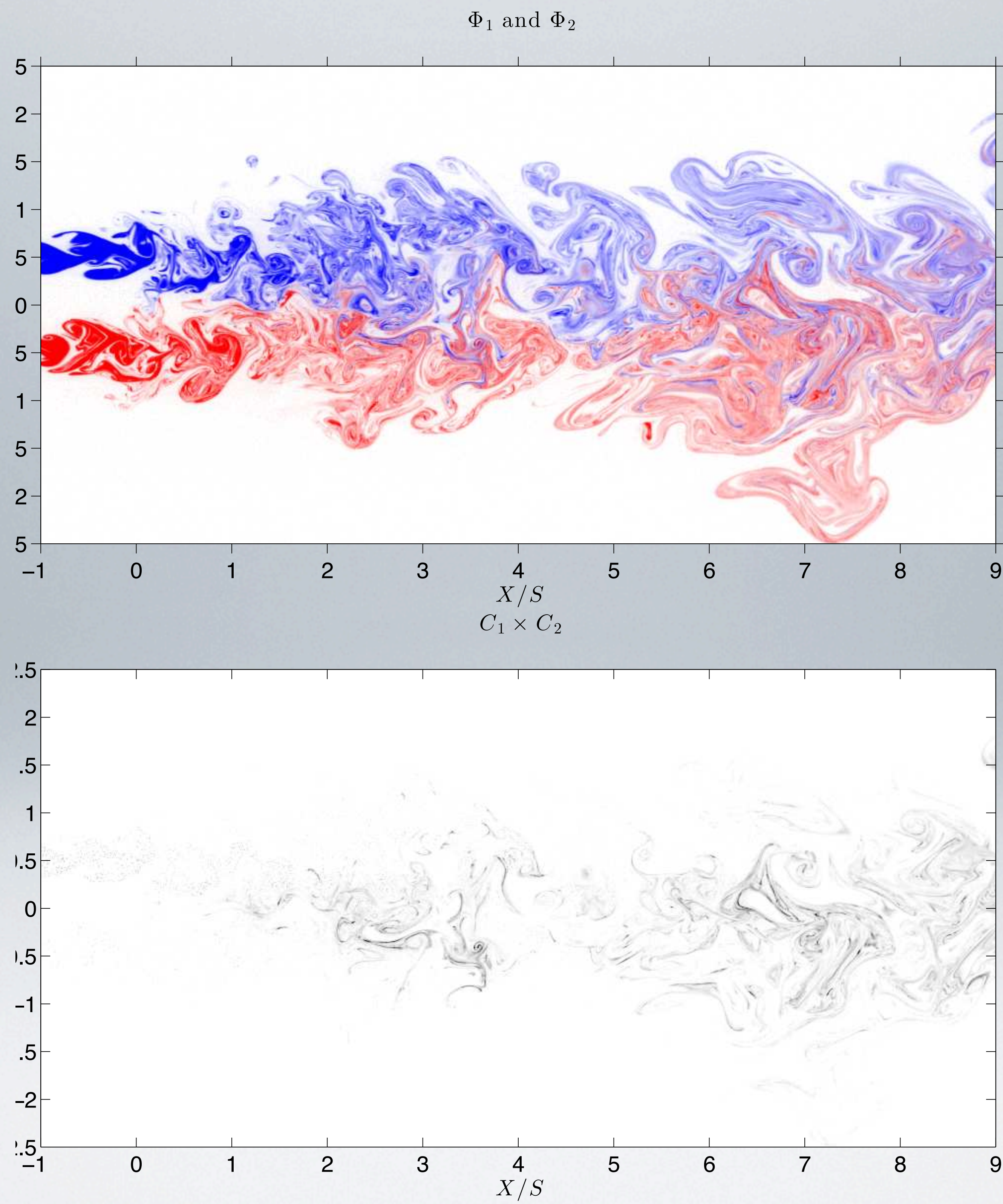
−

$\langle\phi_A\rangle$ and $\langle\phi_B\rangle$



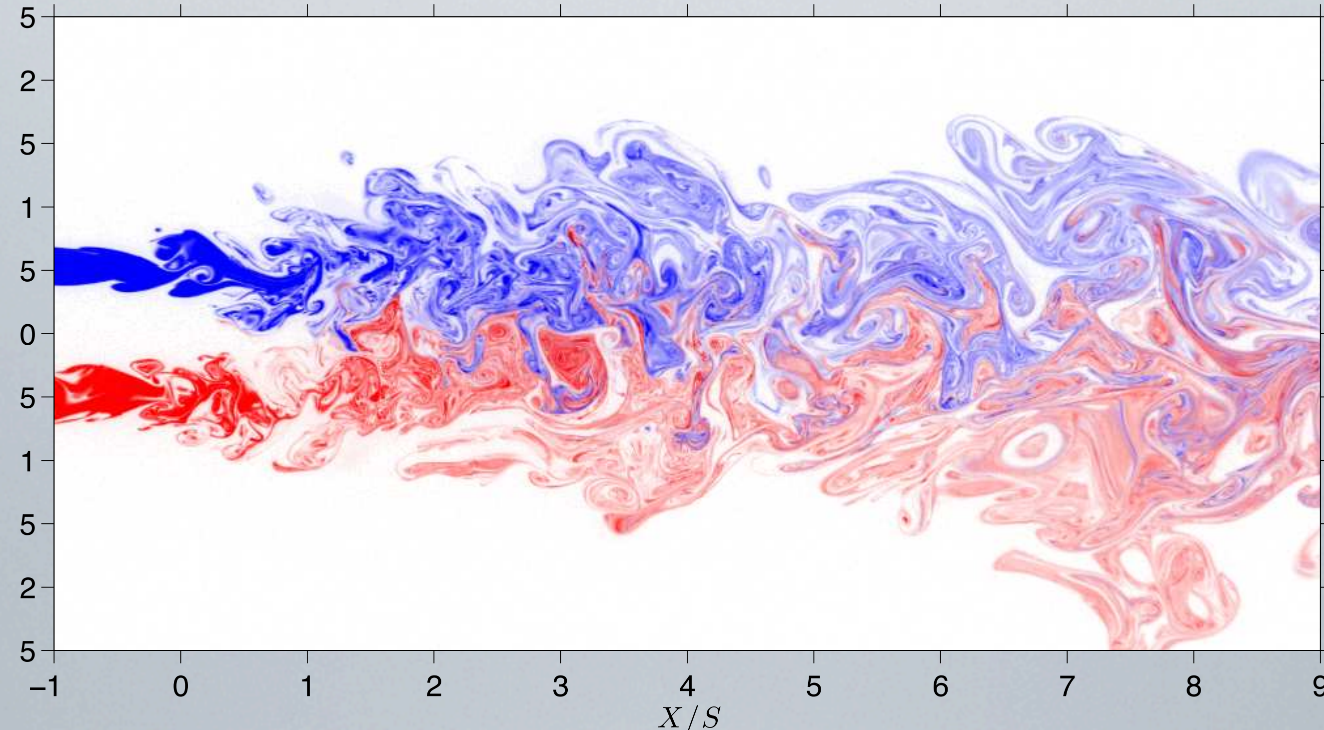
$$\rho = \frac{\langle \phi'_A \phi'_B \rangle}{\sigma_A \sigma_B}$$



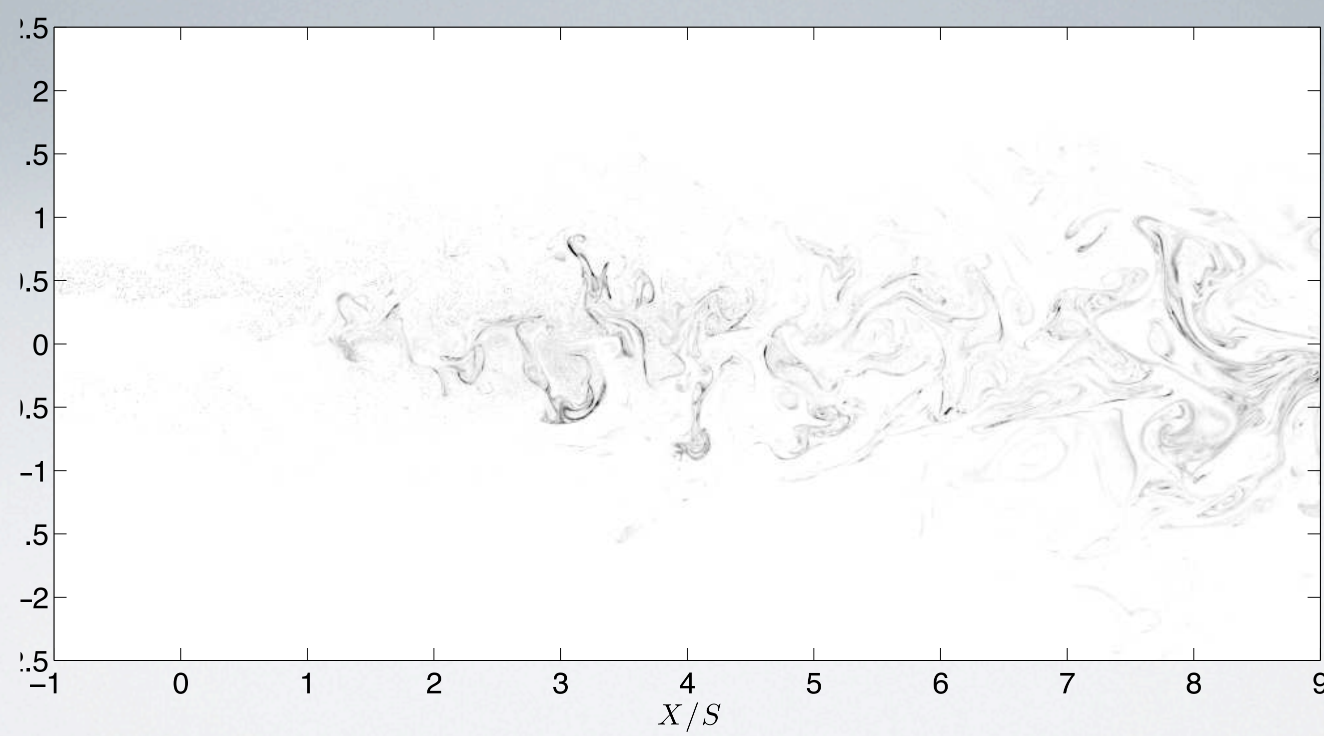


Φ_1 and Φ_2
−1 0 1 2 3 4 5 6 7 8 9
X/S
$C_1 \times C_2$
−1 0 1 2 3 4 5 6 7 8 9
X/S

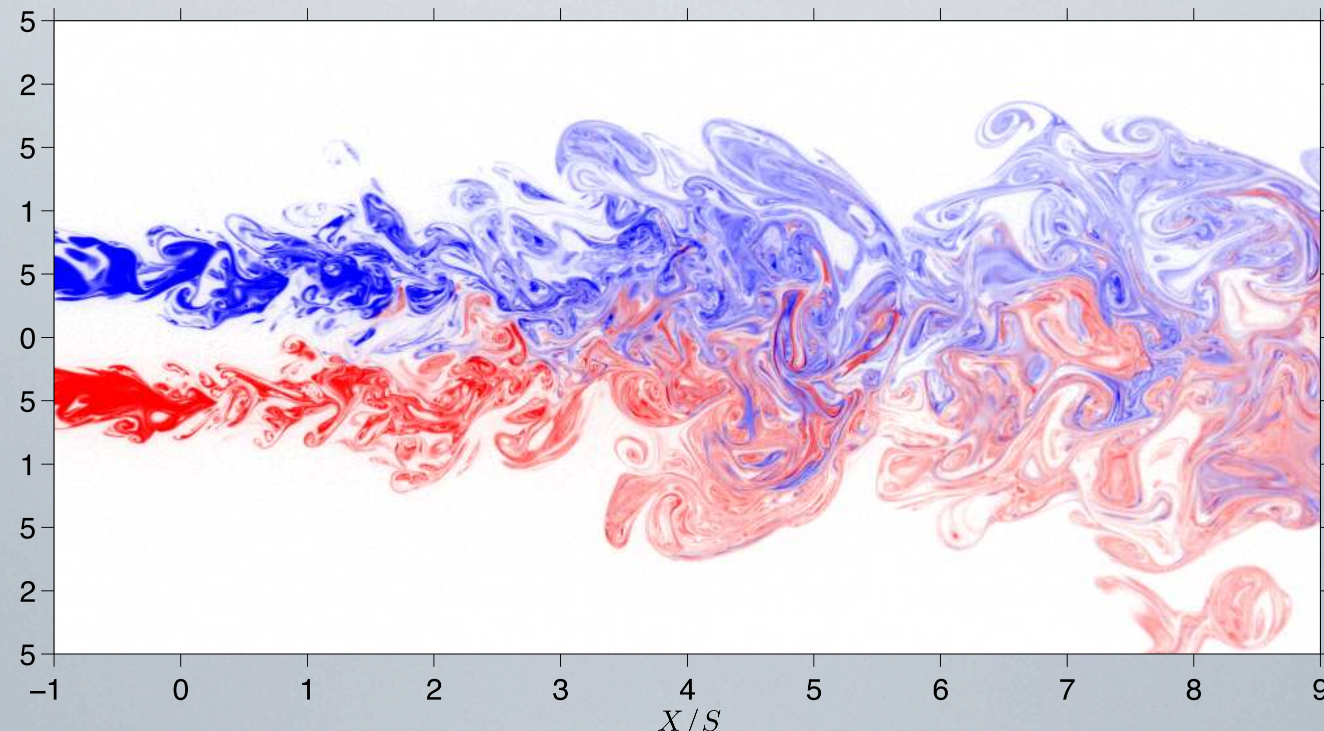
Φ_1 and Φ_2



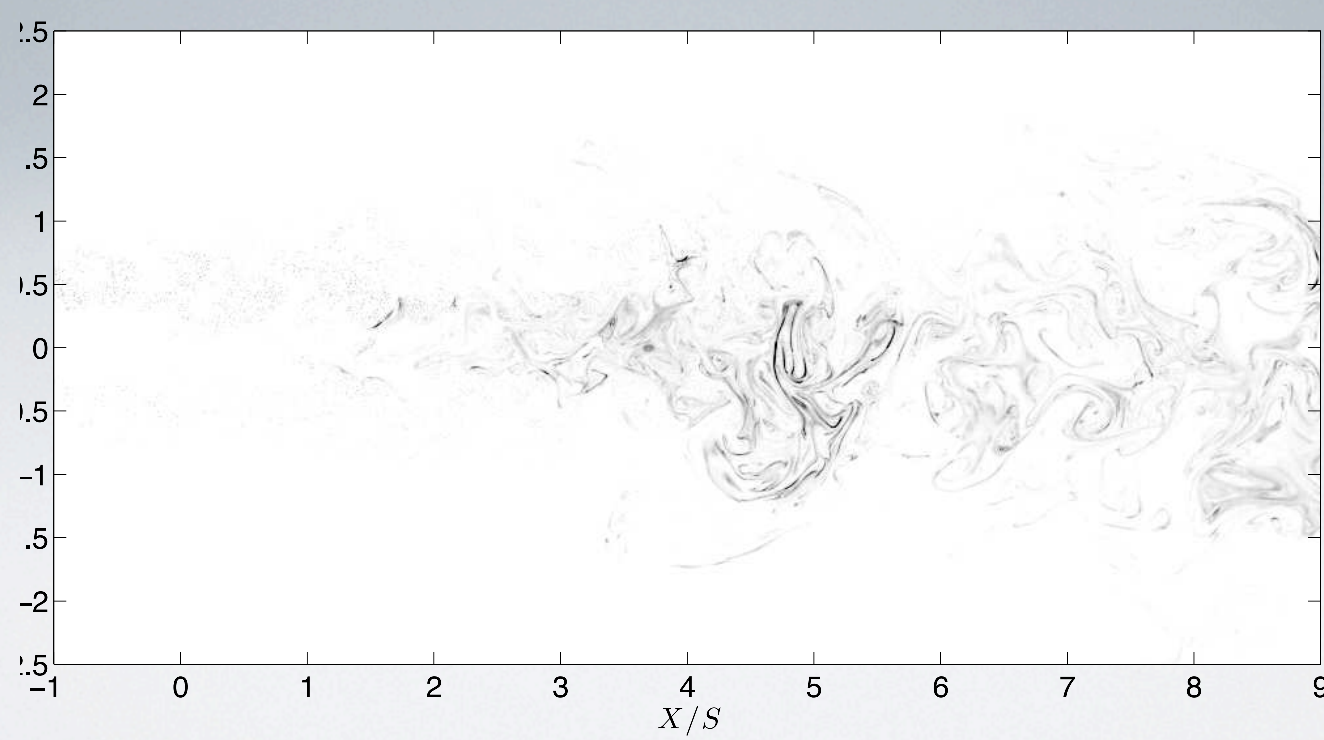
$C_1 \times C_2$

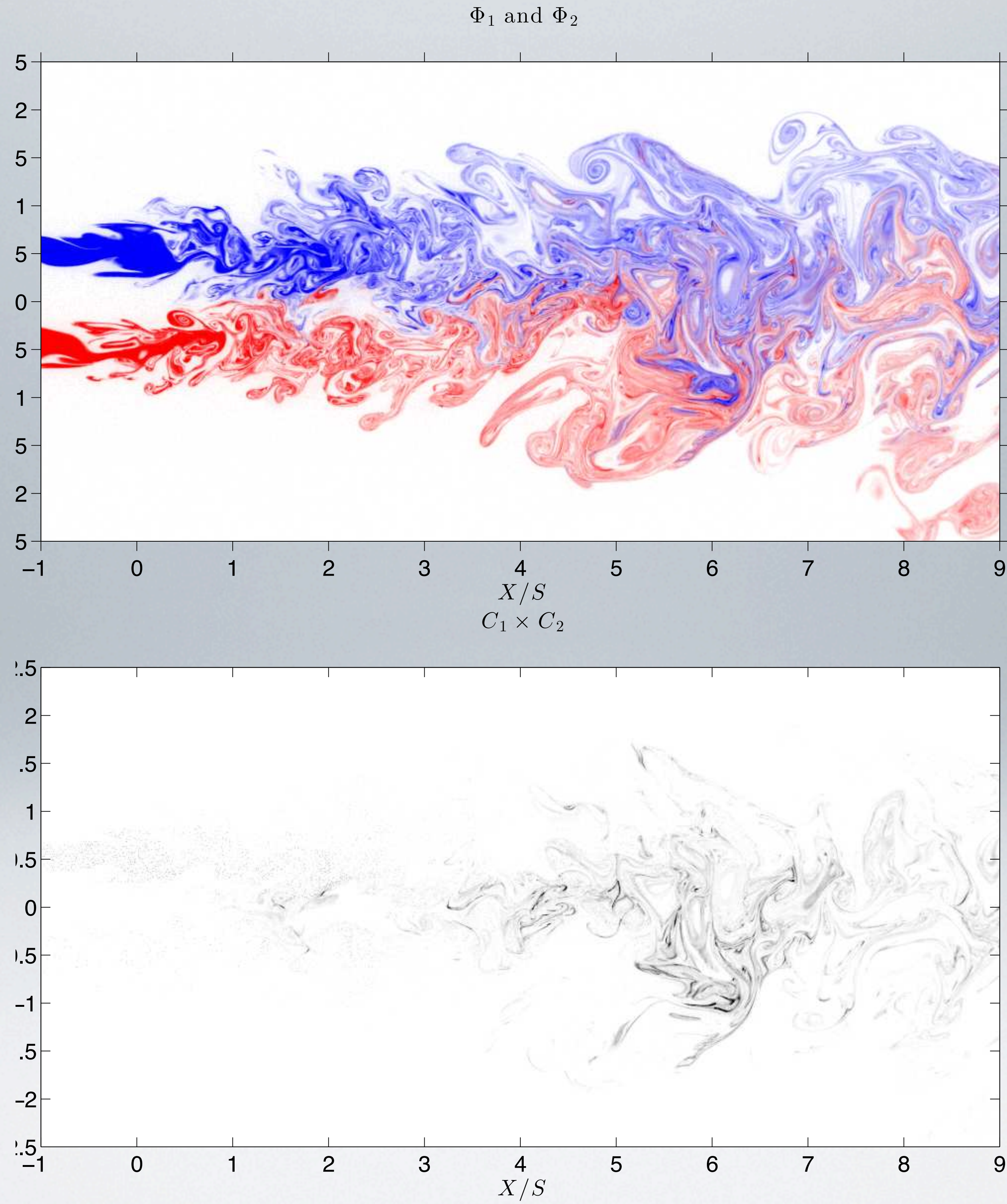


Φ_1 and Φ_2



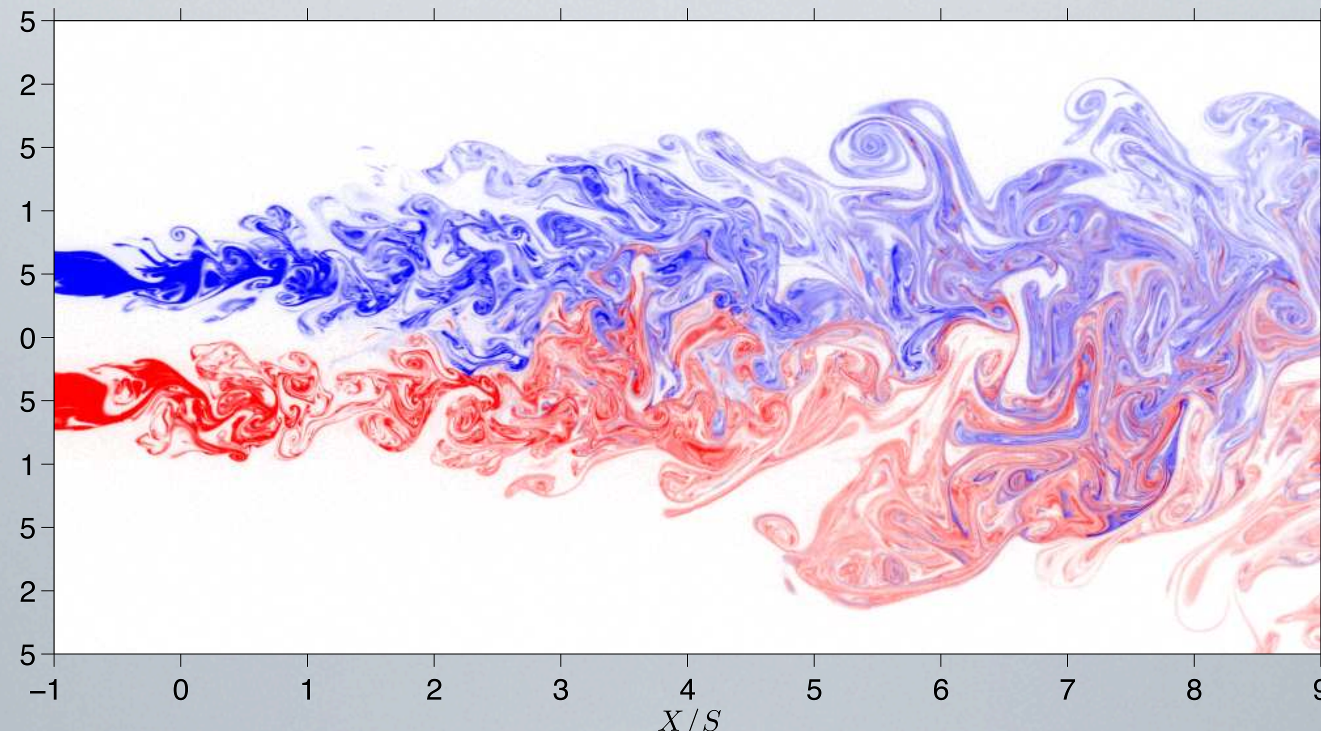
$C_1 \times C_2$



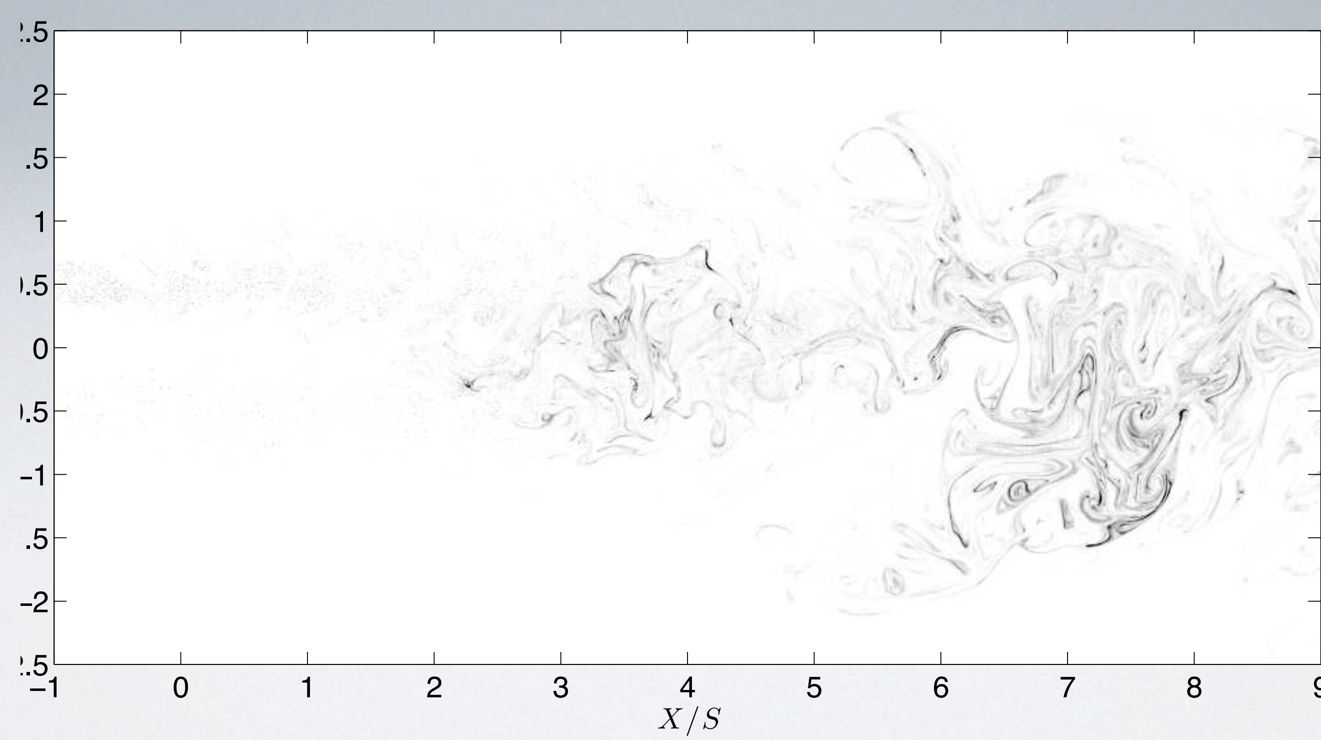


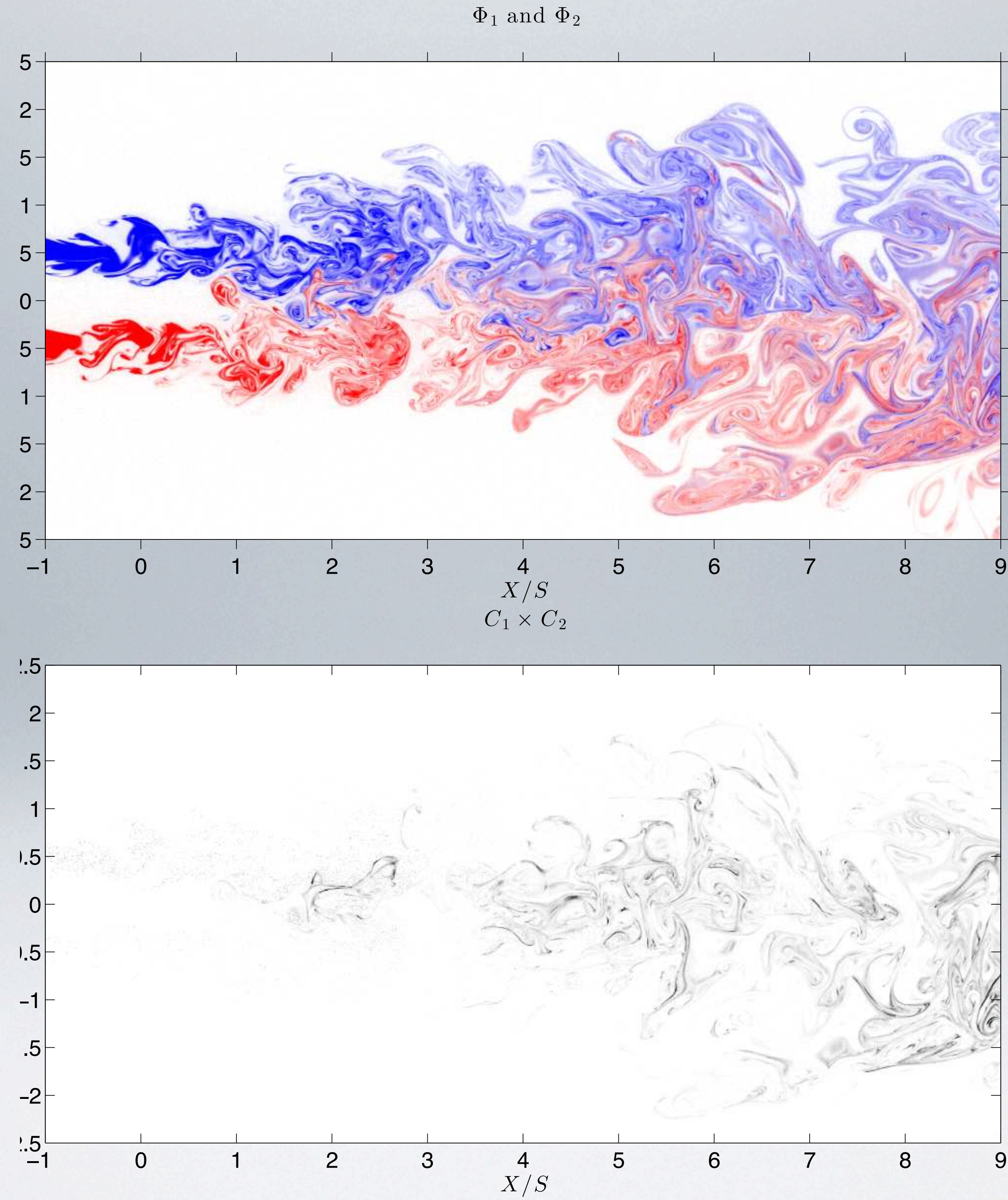
Φ_1 and Φ_2
X/S
$C_1 \times C_2$
X/S

Φ_1 and Φ_2



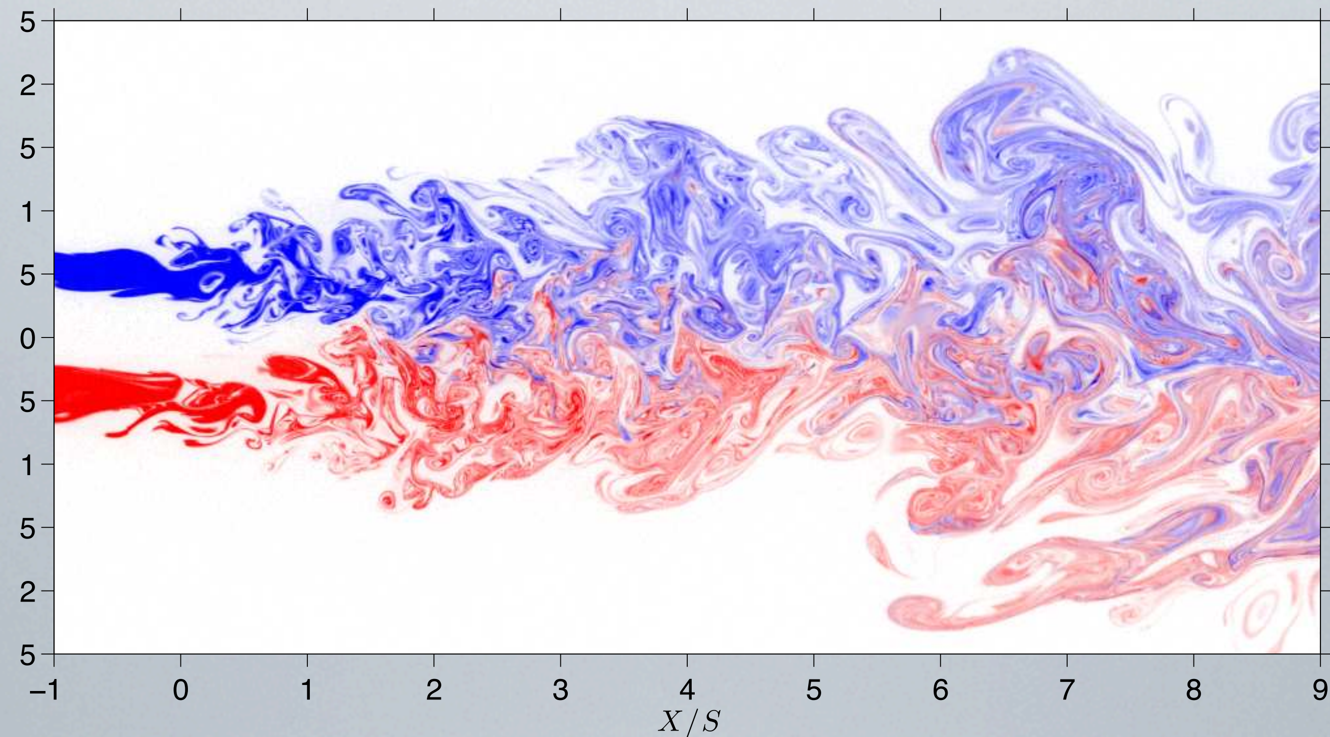
$C_1 \times C_2$



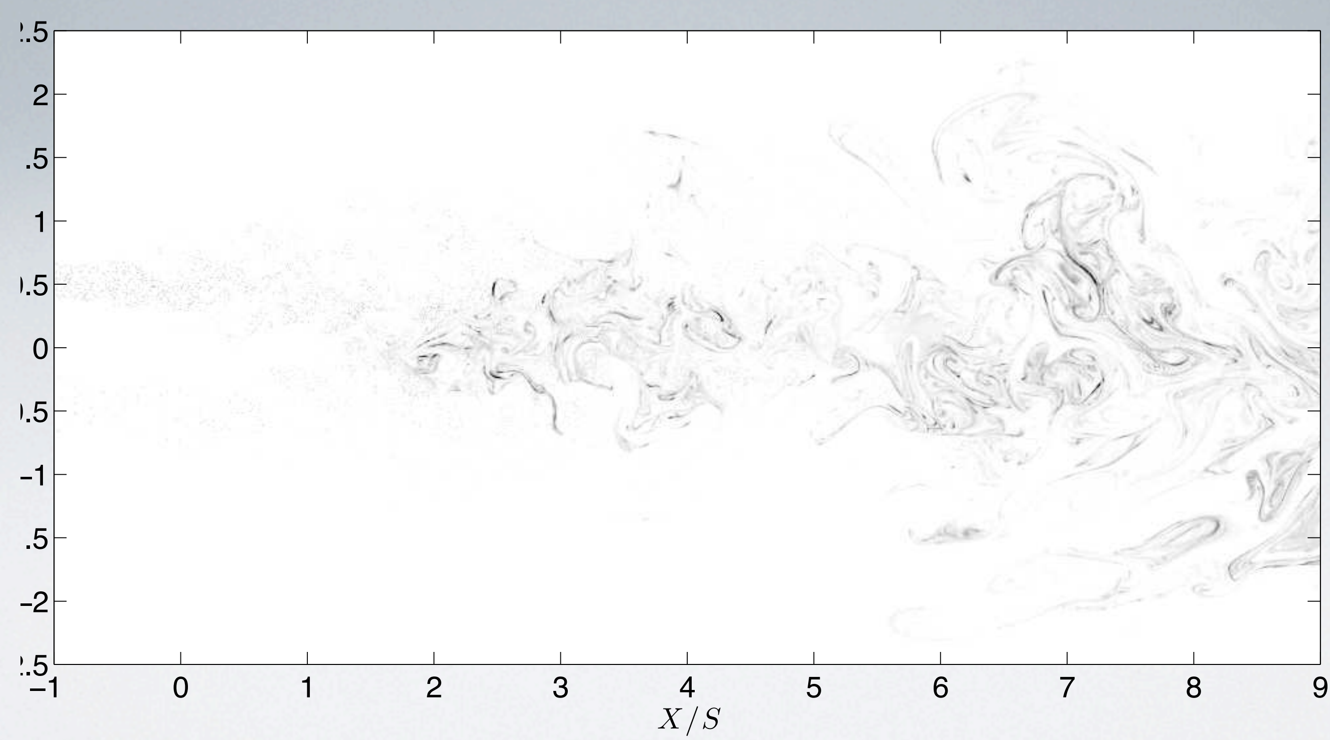


Φ1 and Φ2
X/S
C1 × C2
X/S

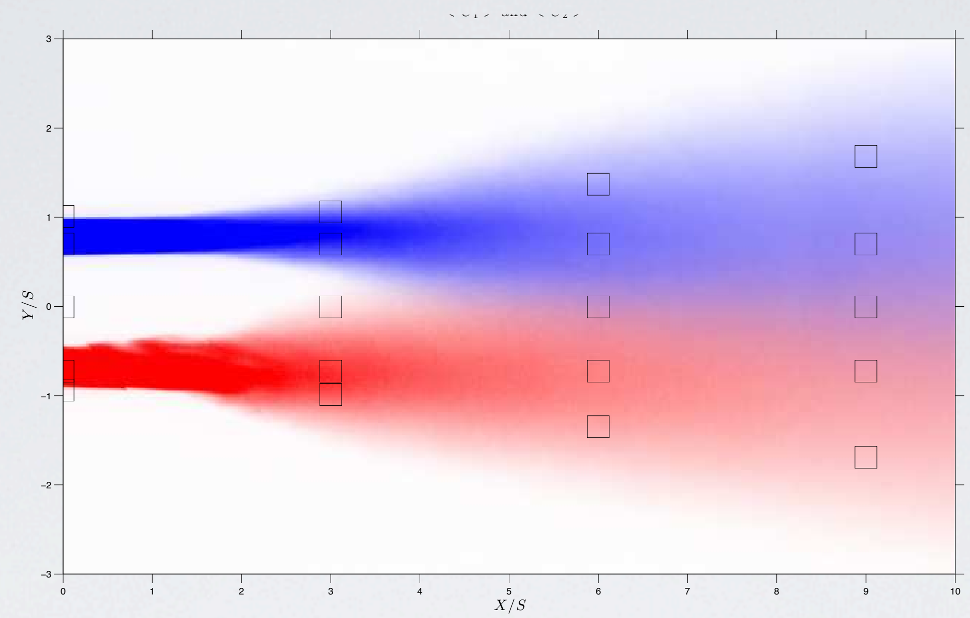
Φ_1 and Φ_2



$C_1 \times C_2$

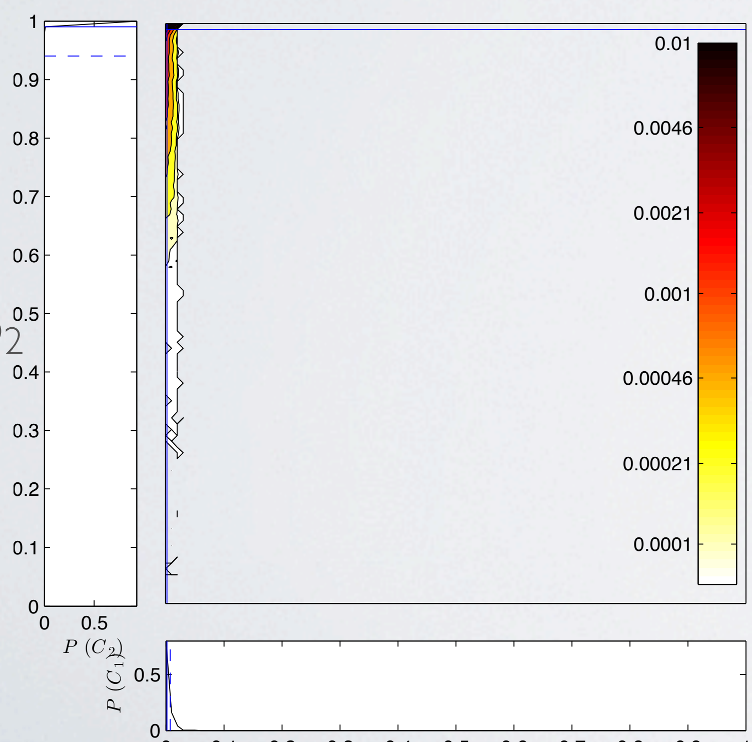


JOINT PROBABILITIES



$P(\phi_1, \phi_2)$

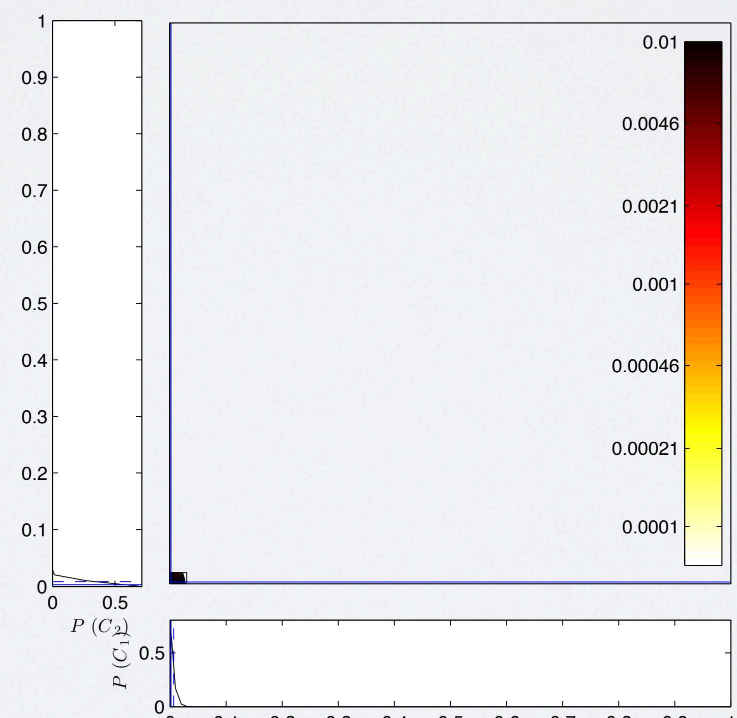
ϕ_2



ϕ_1

$P(\phi_1, \phi_2)$

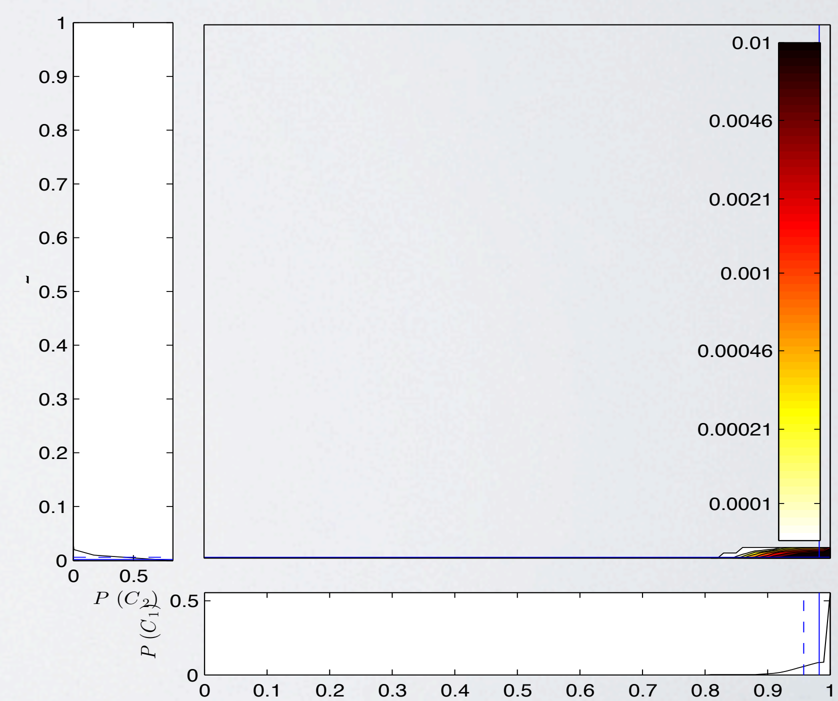
ϕ_2



ϕ_1

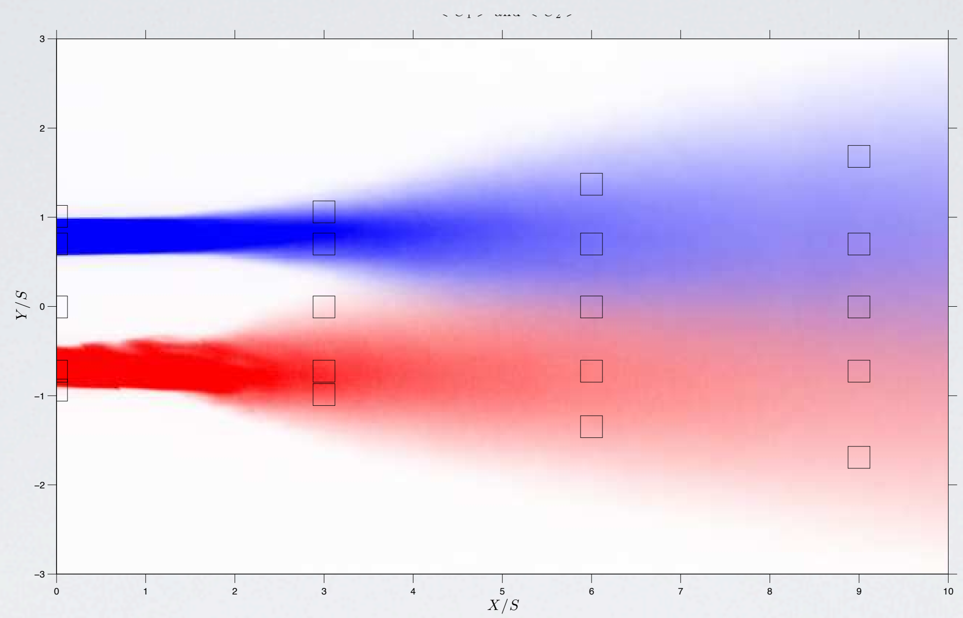
$P(\phi_1, \phi_2)$

ϕ_2

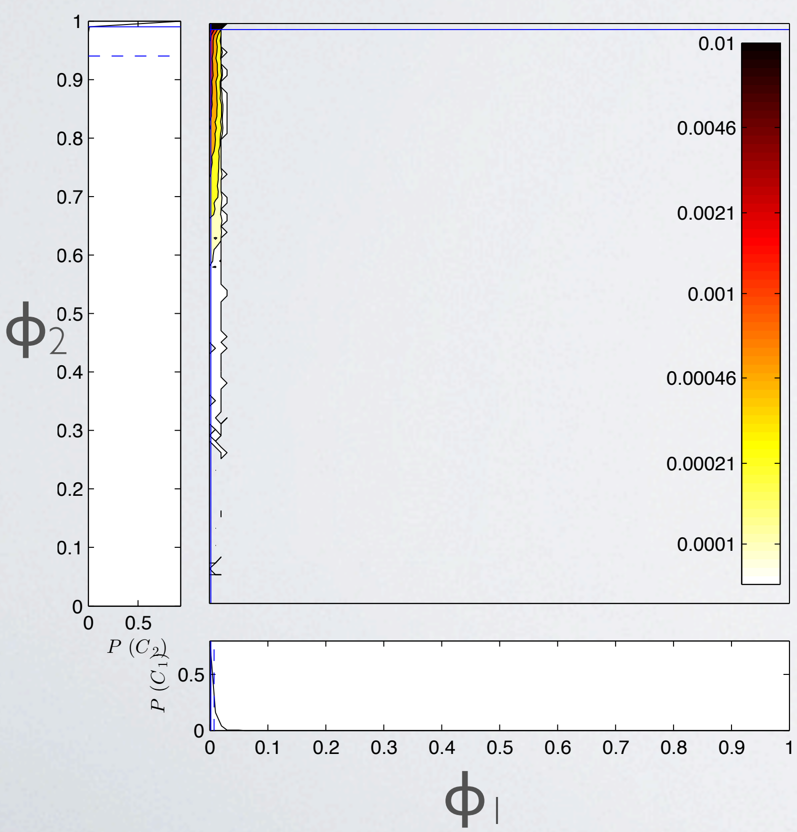


ϕ_1

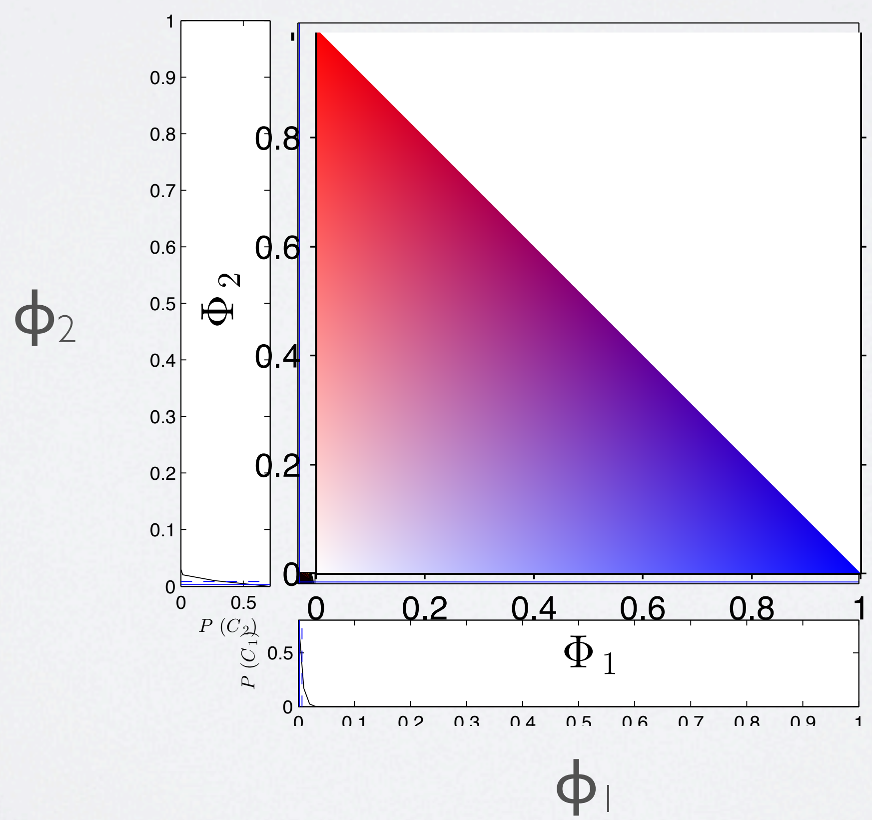
JOINT PROBABILITIES



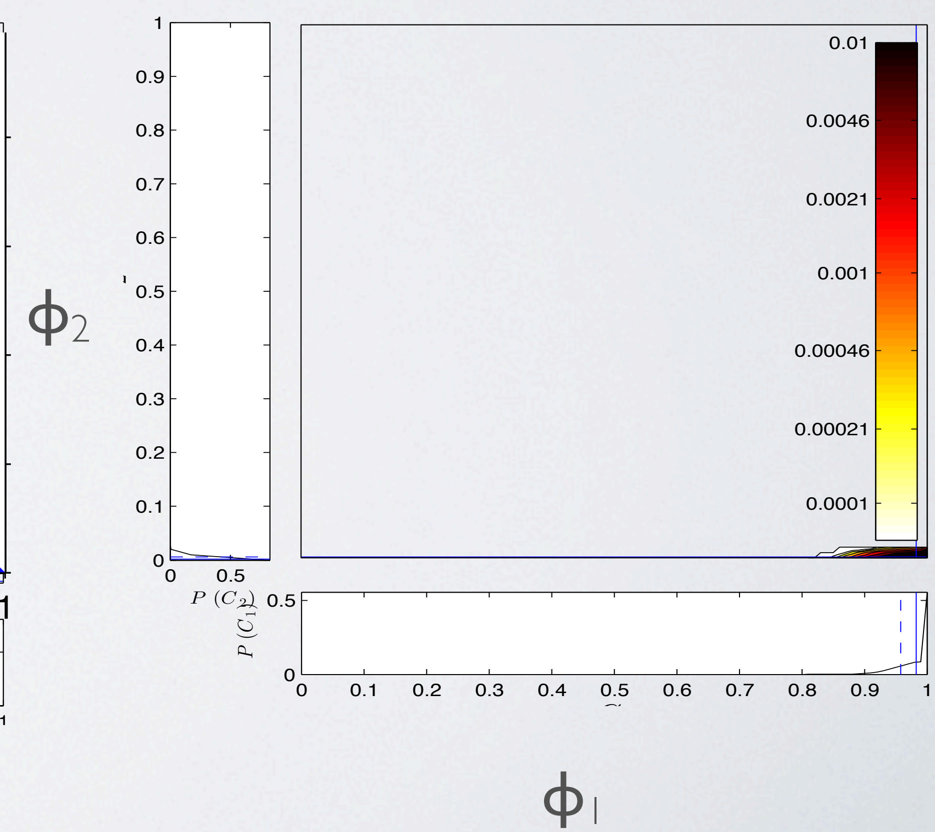
P(ϕ_1, ϕ_2)



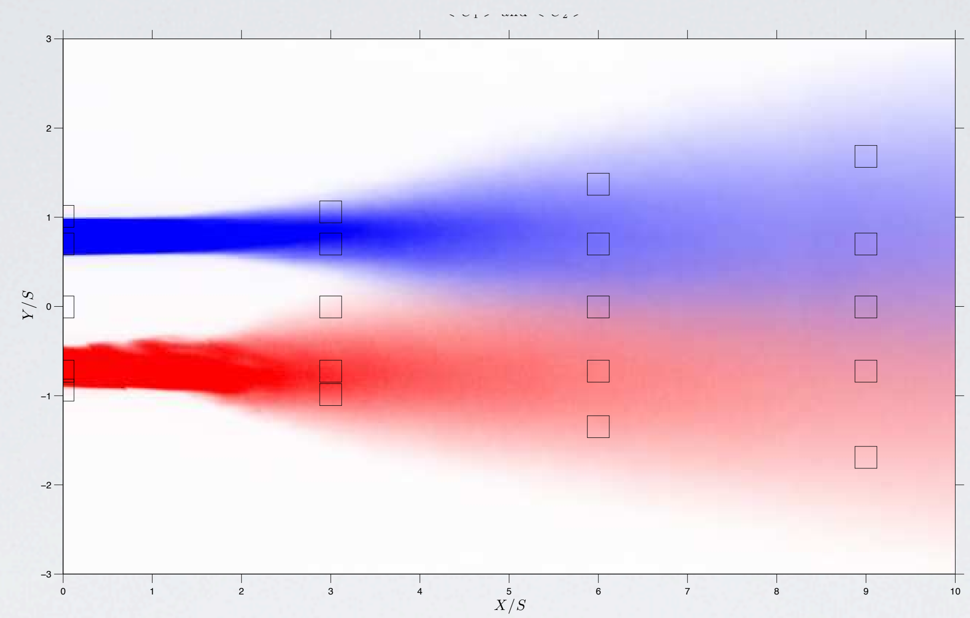
P(ϕ_1, ϕ_2)



P(ϕ_1, ϕ_2)

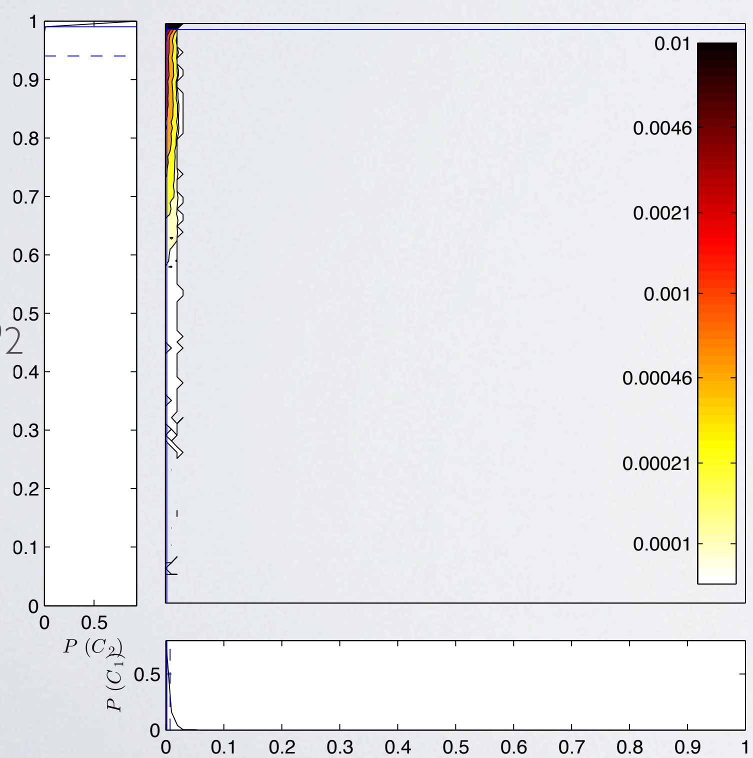


JOINT PROBABILITIES



$P(\phi_1, \phi_2)$

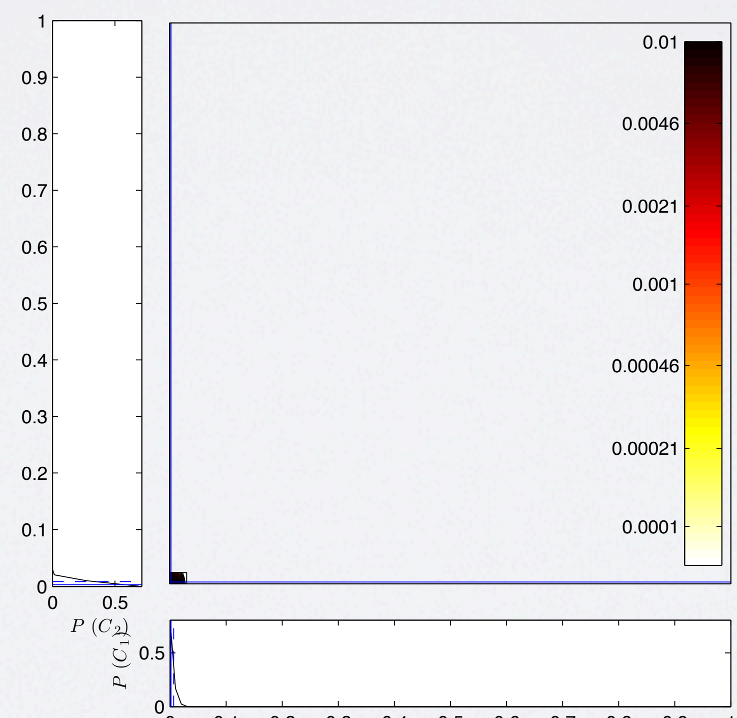
ϕ_2



ϕ_1

$P(\phi_1, \phi_2)$

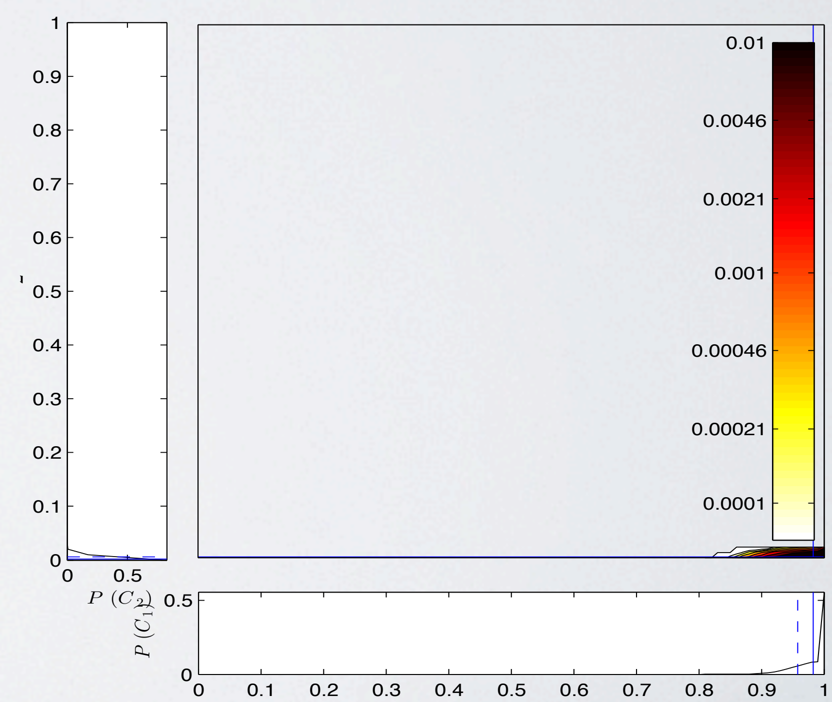
ϕ_2



ϕ_1

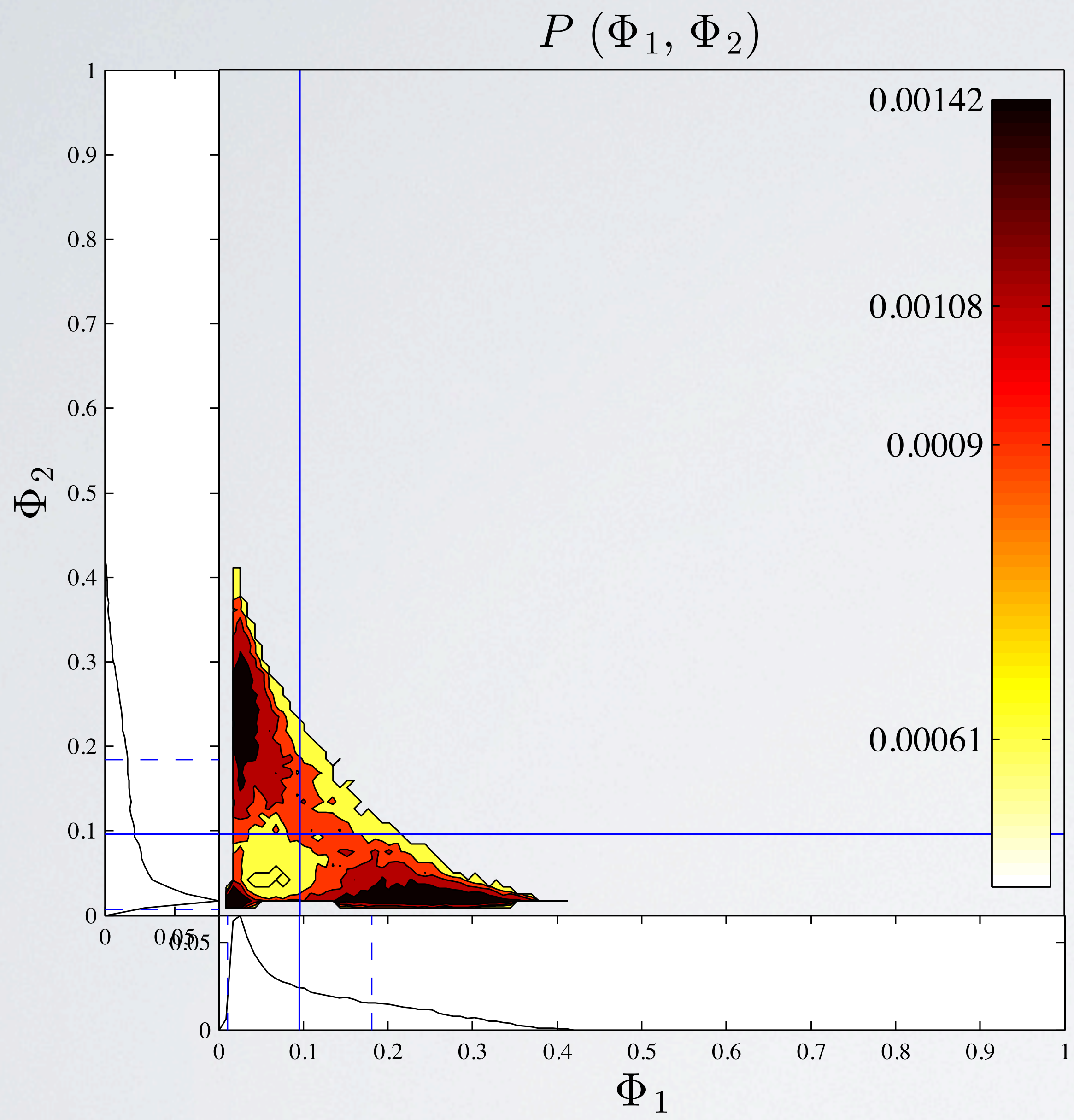
$P(\phi_1, \phi_2)$

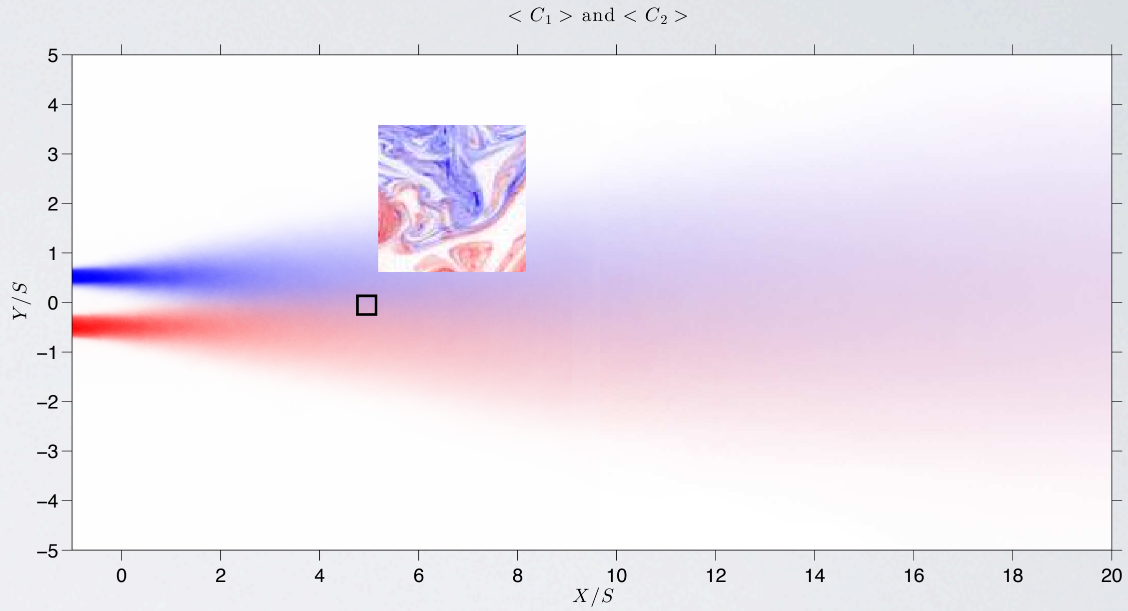
ϕ_2

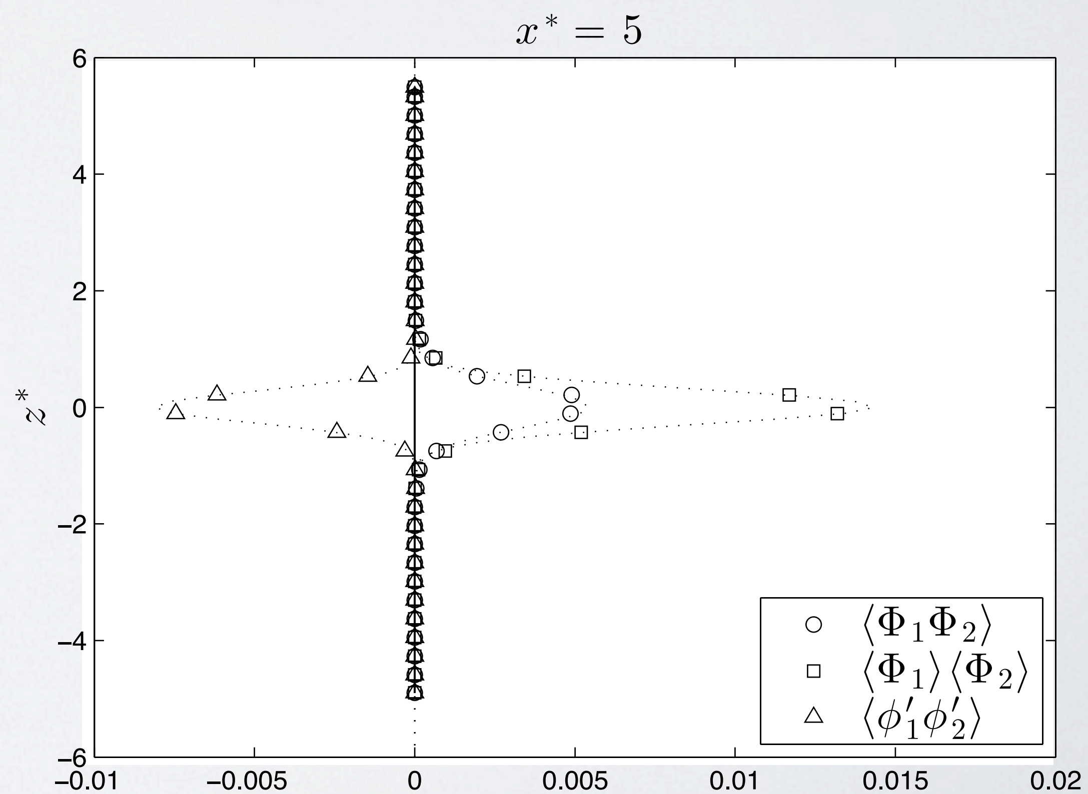


ϕ_1

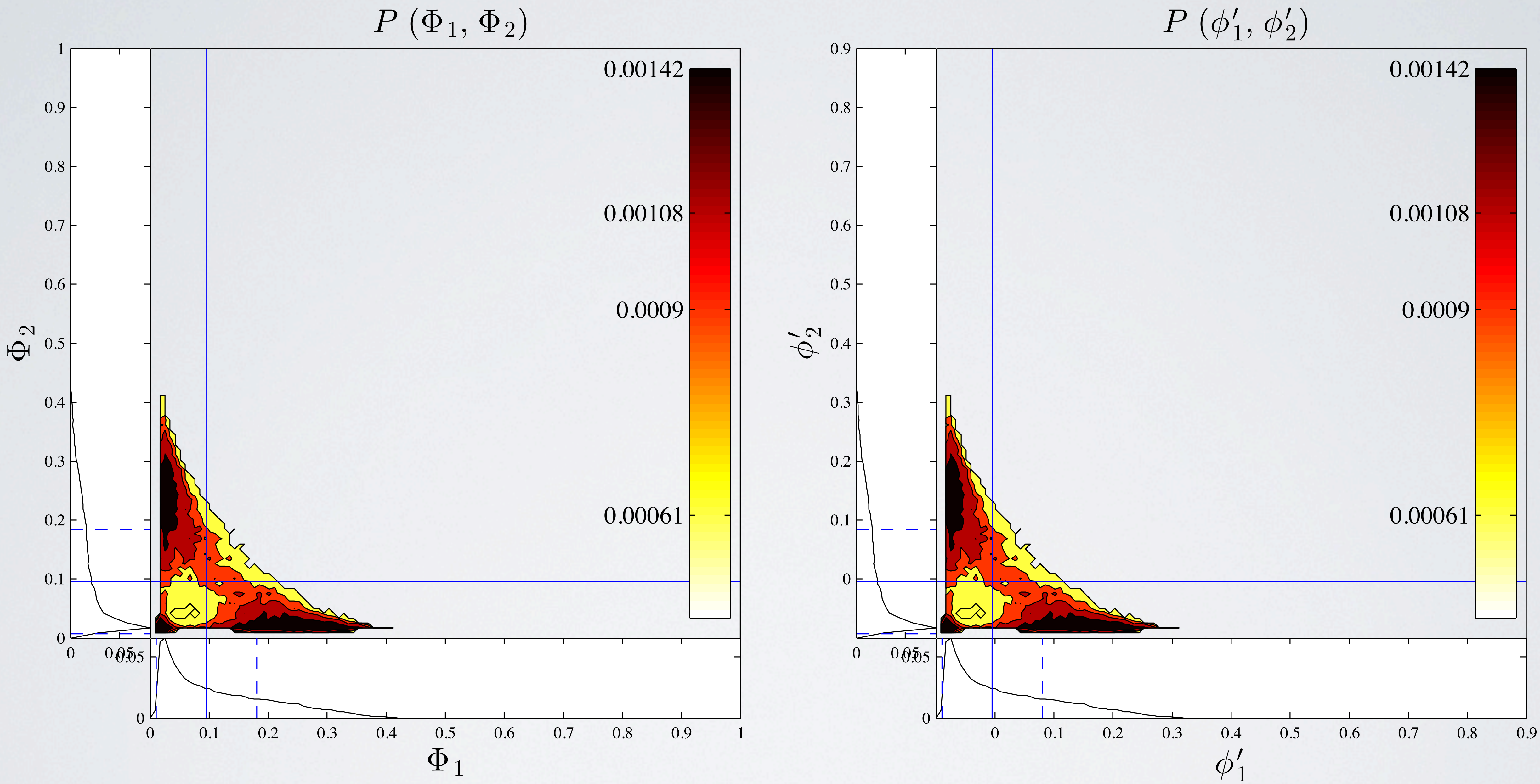
Y*=0, X*=5


$P\ (\Phi_1, \Phi_2)$
0.00142
0.00108
0.0009
0.00061
Φ_2
Φ_1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.05


$< C_1 >$ and $< C_2 >$
Y/S
X/S

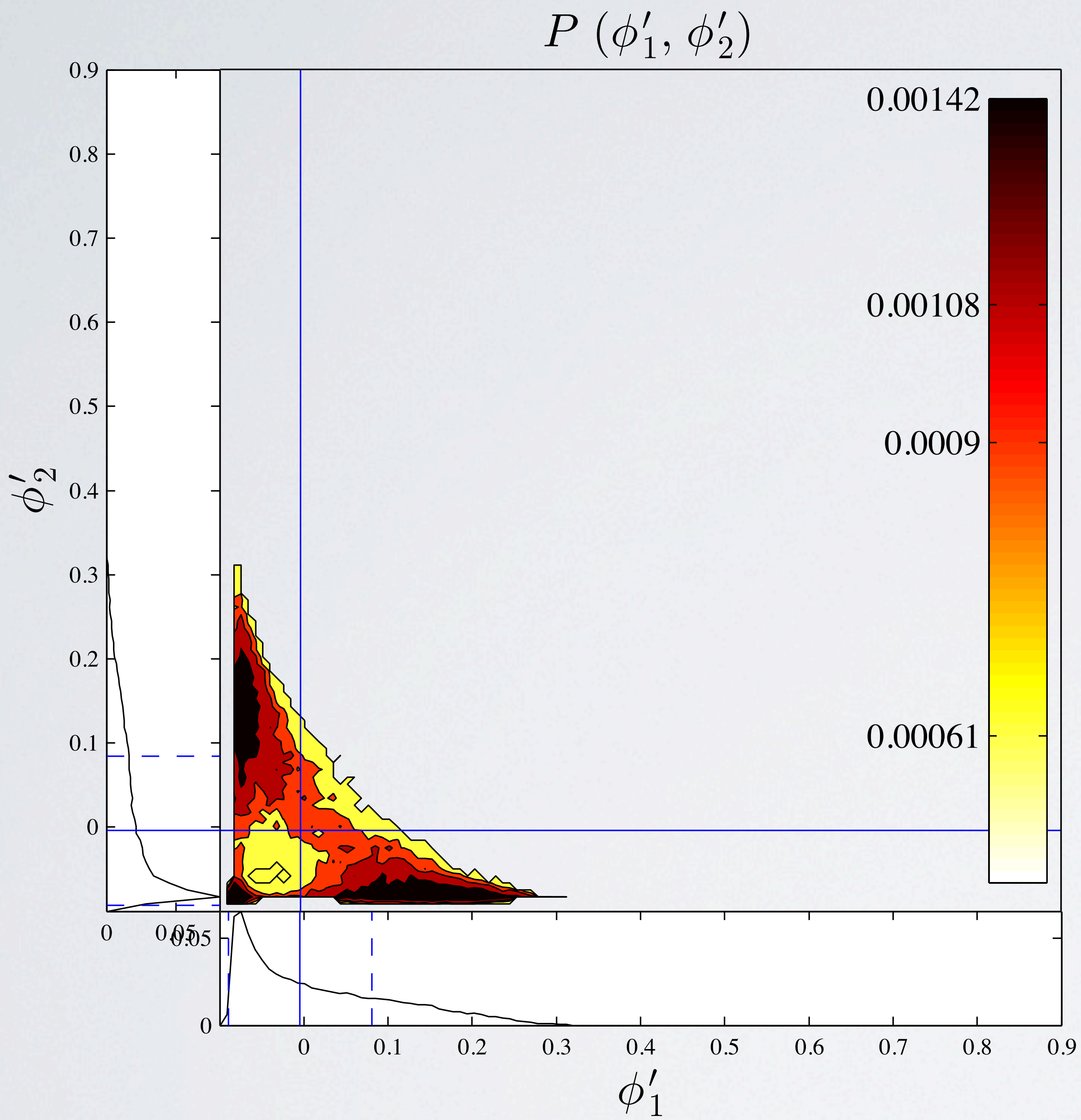

$x^* = 5$
z^*
$\langle \Phi_1 \Phi_2 \rangle$
$\langle \Phi_1 \rangle \langle \Phi_2 \rangle$
$\langle \phi'_1 \phi'_2 \rangle$
−0.01
−0.005
0
0.005
0.01
0.015
0.02

Y*=0, X*=5

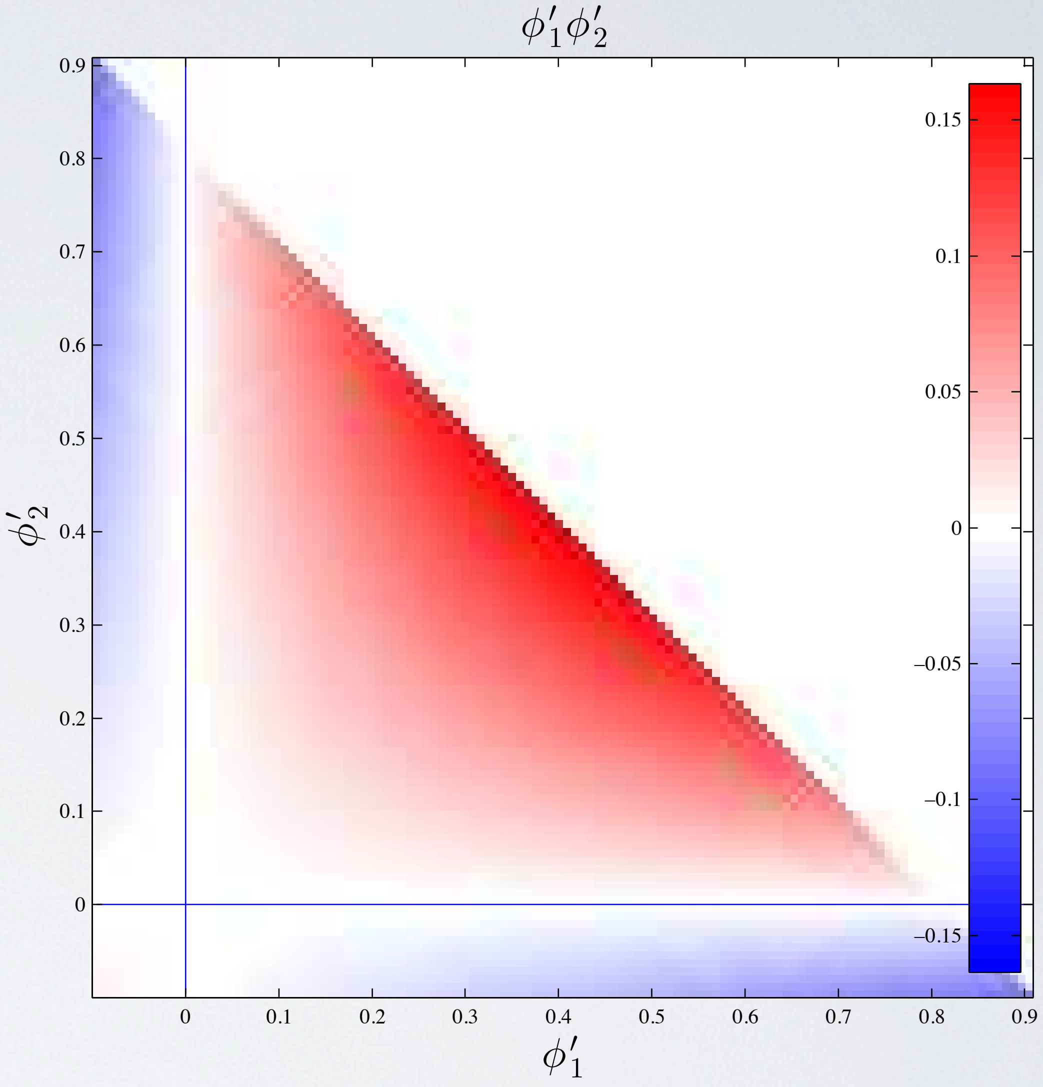


$P\ (\Phi_1, \Phi_2)$
$P\ (\phi'_1, \phi'_2)$
Φ_1
Φ_2
ϕ'_1
ϕ'_2
0.00142
0.00108
0.0009
0.00061

Y*=0, X*=5

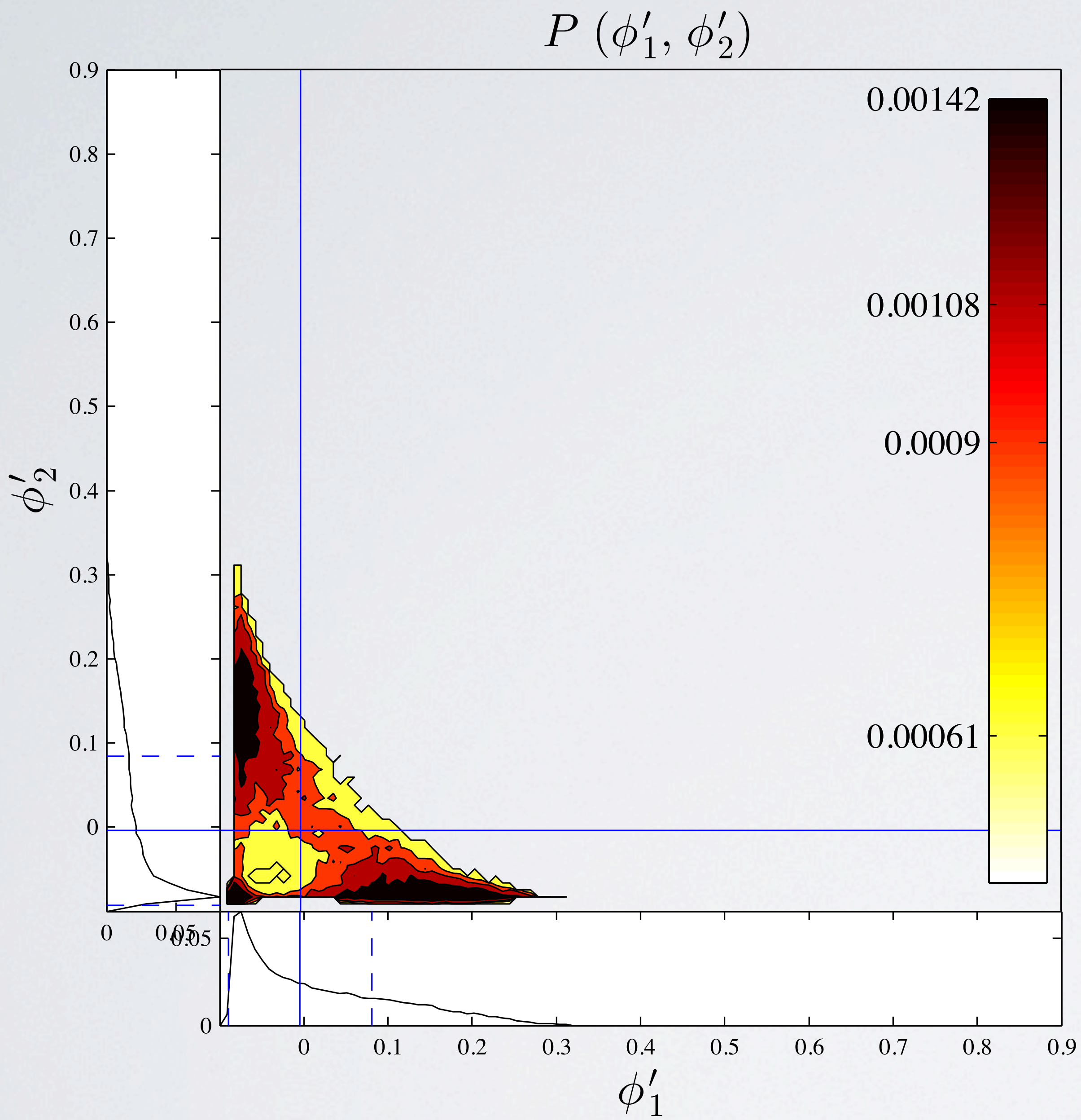


$P\,(\phi'_1, \phi'_2)$
0.00142
0.00108
0.0009
0.00061
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ϕ'_2
0
0.05
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ϕ'_1

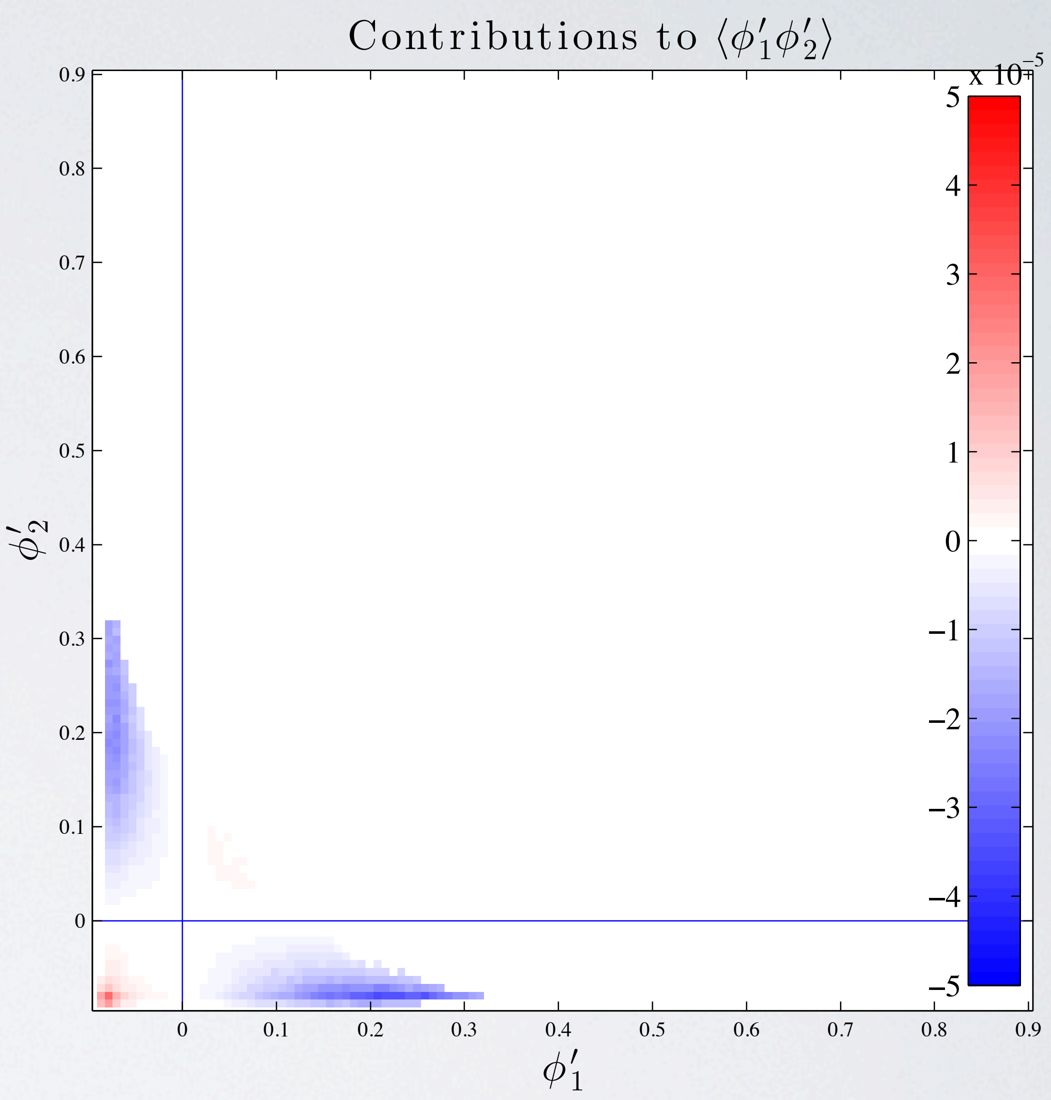


$\phi'_1\phi'_2$
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ϕ'_2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ϕ'_1

Y*=0, X*=5



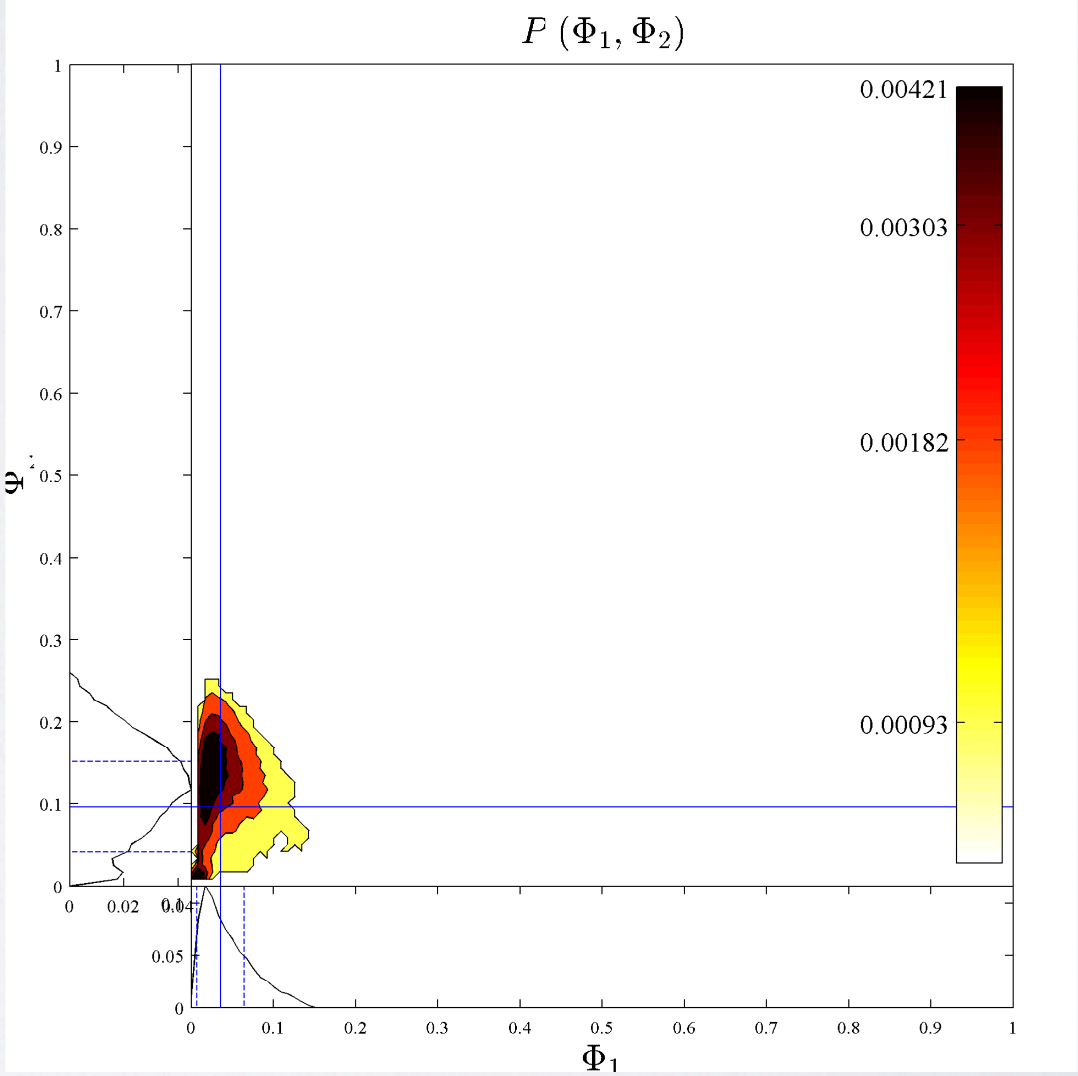
$P\ (\phi'_1, \phi'_2)$
0.00142
0.00108
0.0009
0.00061
ϕ'_2
ϕ'_1



Contributions to $\langle \phi'_1 \phi'_2 \rangle$
x 10^{-5}
ϕ'_2
ϕ'_1

Y*=0.5, X*=10

- JPDFs are not joint normal
- Relationships between scalars is non-linear



QUESTIONS?

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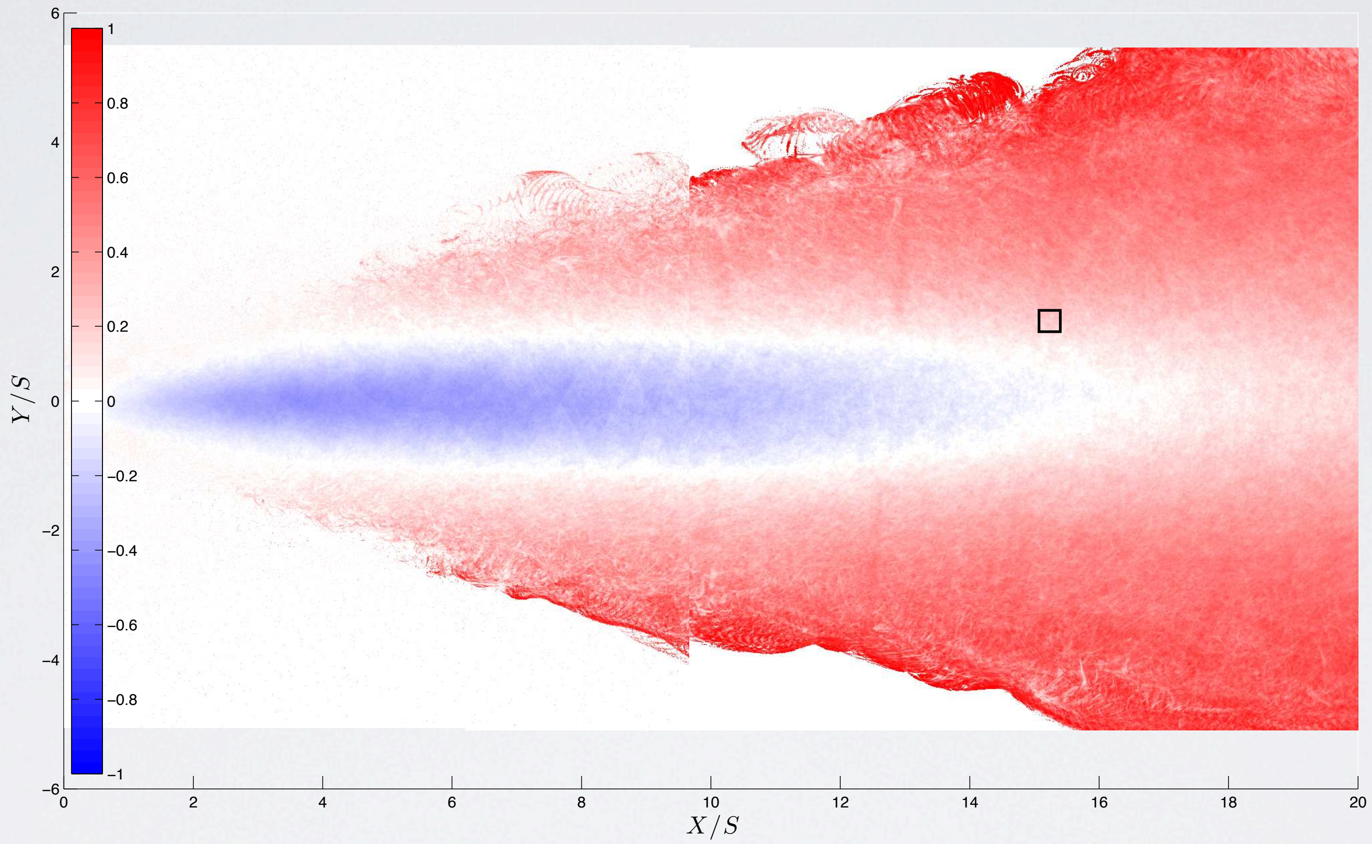
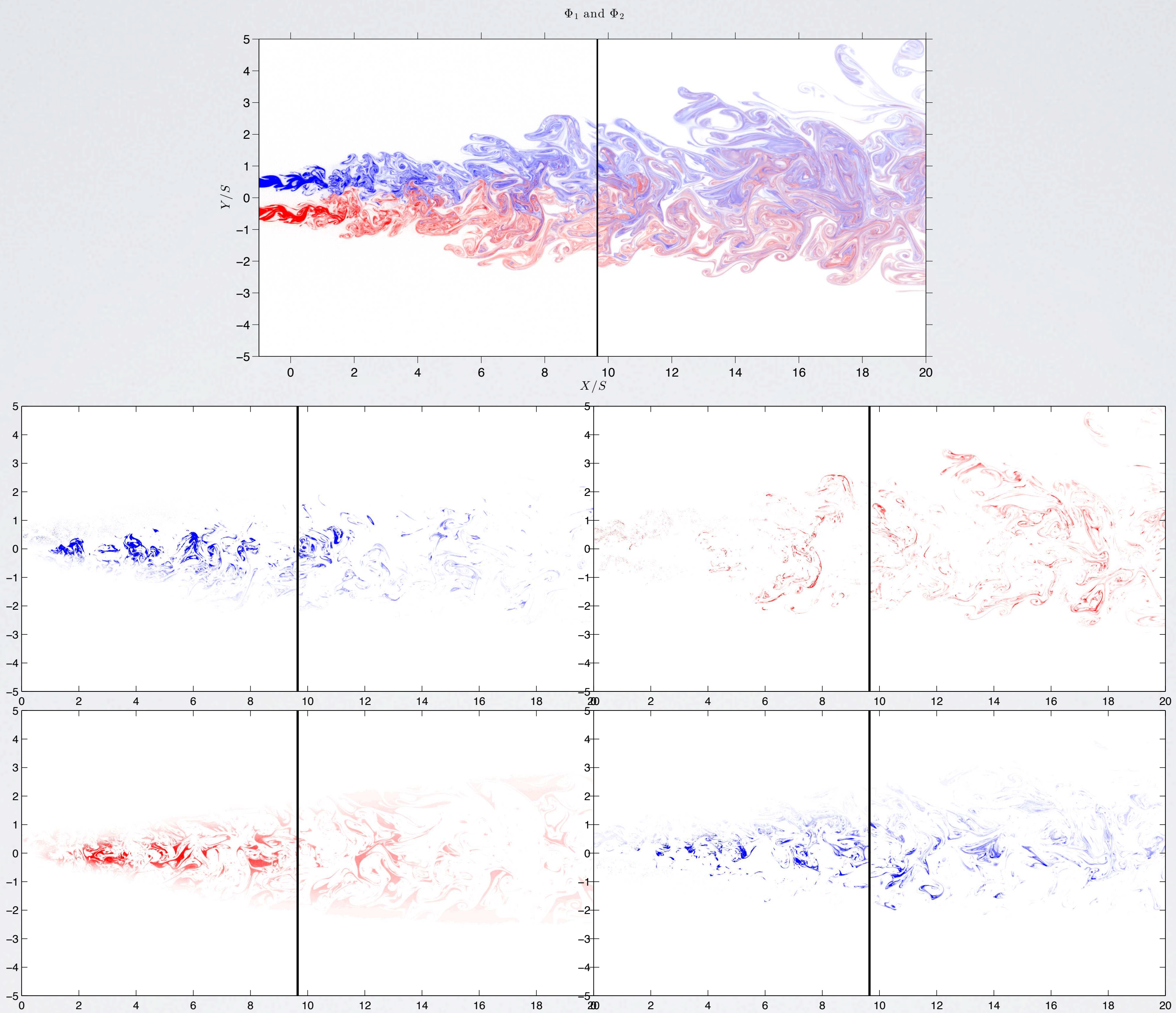
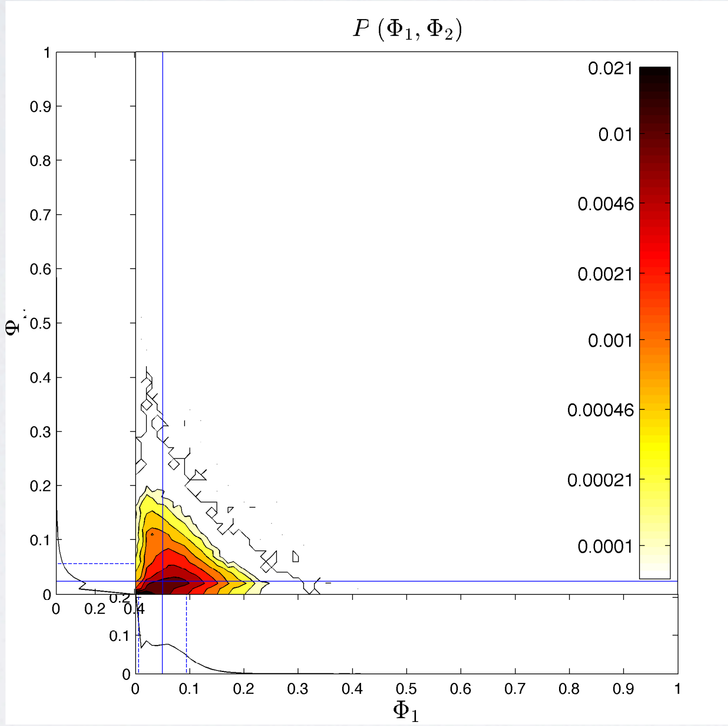
$$\rho = \frac{<\phi_1' \phi_2'>}{<\sigma_1><\sigma_2>}$$

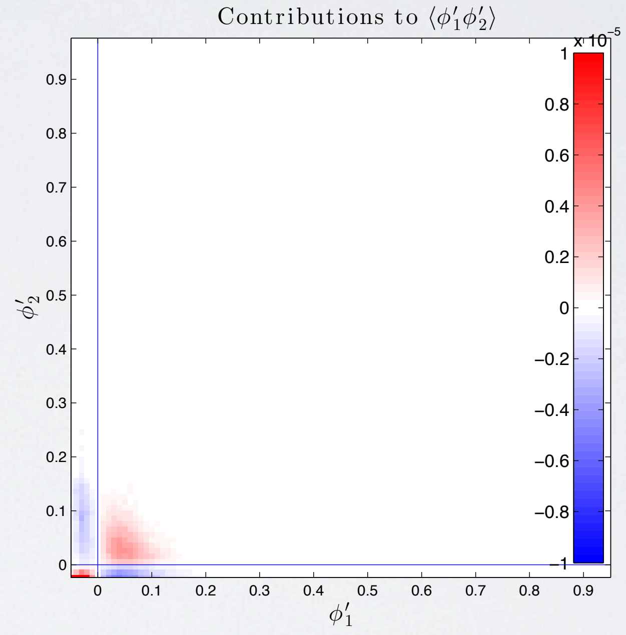



Φ_1 and Φ_2
Y/S
X/S

Y*=1 X*=15



$P(\Phi_1, \Phi_2)$
0.021
0.01
0.0046
0.0021
0.001
0.00046
0.00021
0.0001
Φ_1



Contributions to $\langle \phi_1' \phi_2' \rangle$
x 10^{-5}
ϕ_2'
ϕ_1'