Studying Vortex Dynamics of Rotating Convection with PIV

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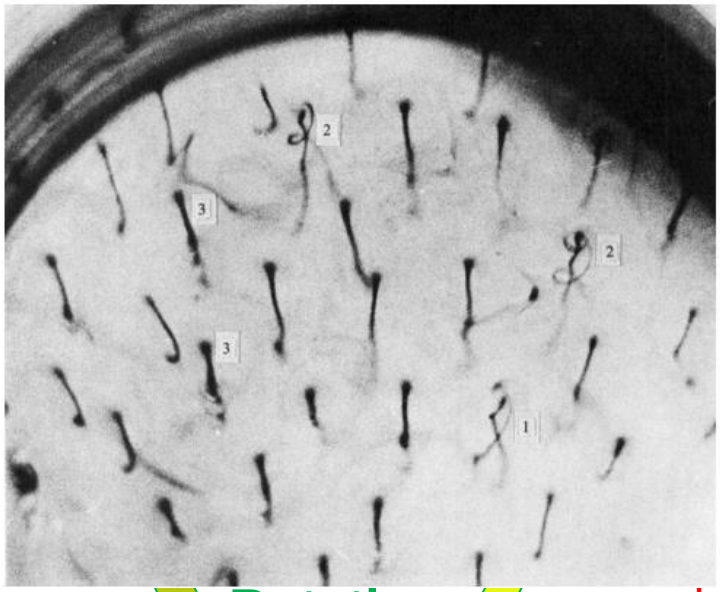
Model problem– Rotating Convection

- **What's the 3D structures of those vortices?**
- **How do vortices interact with each other?**

Cold

arm

ate



old

ate

Tank fil
with wa

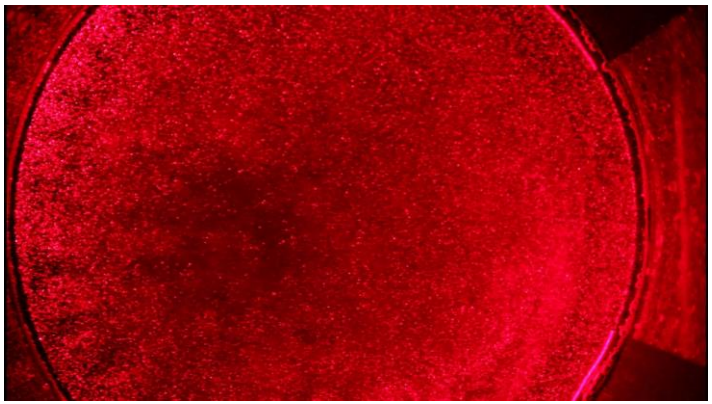
arm

ate

Boubnov, 1986, JFM

dominated by ***plumes /cells***

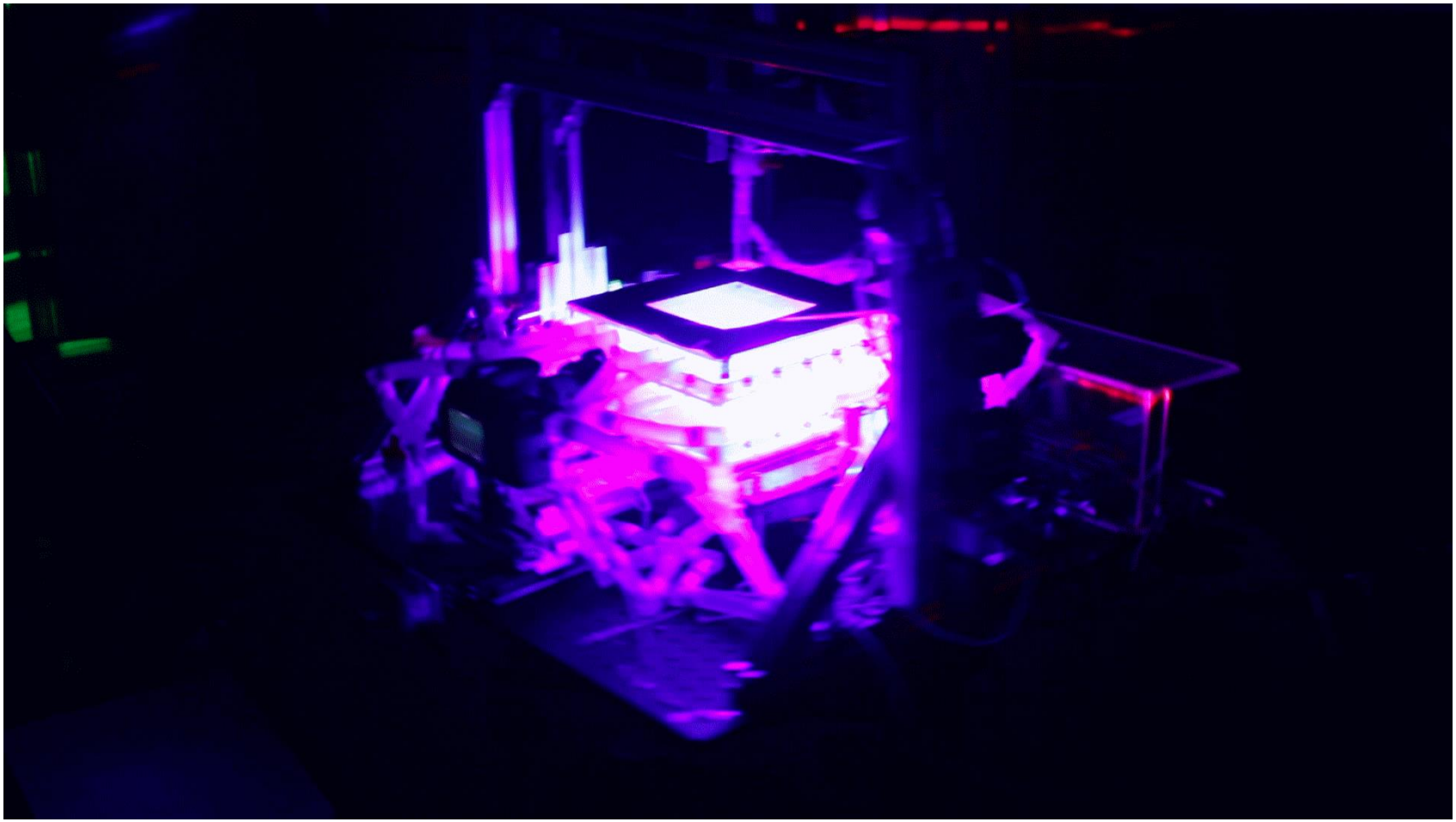
Drazin and Reid, Hydrodynamic Stability



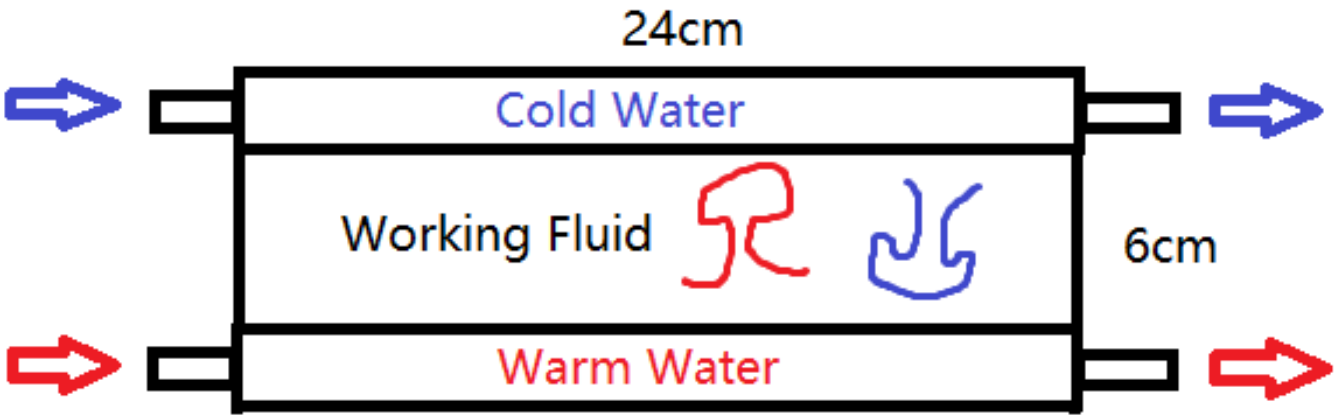
dominated by **vortices**

Photoed by Fu Hao in an old instrument

The rotating instrument



Flow characteristics => PIV method



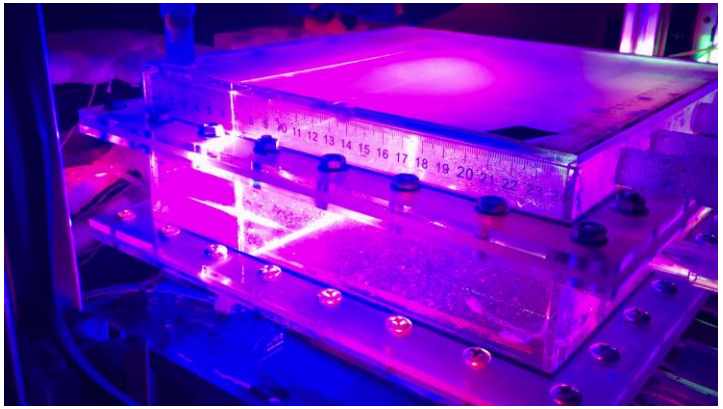
$Ra \approx 1.8 \times 10^7$
$Pr \approx 7$
$Ta \approx 9.4 \times 10^7$
$\widetilde{Ra} \approx 57.3$

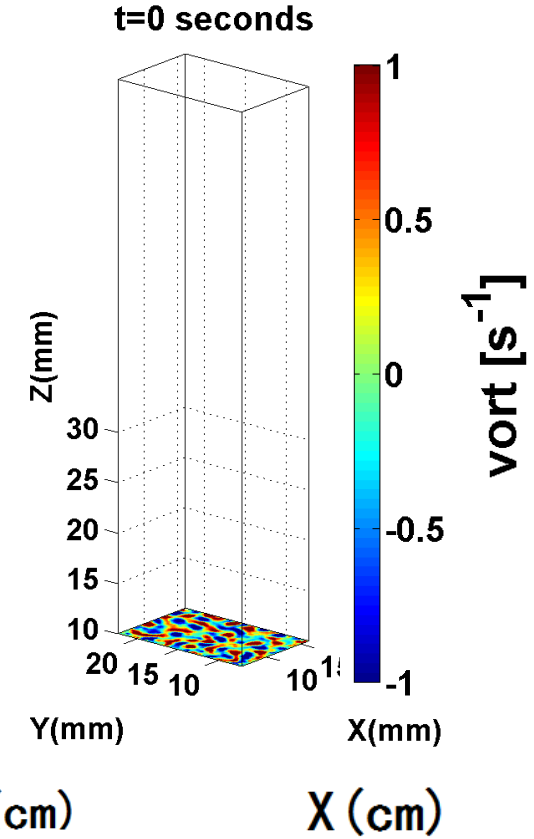
→ Slowly-evolving flow field → Scanning PIV?

Two Measure Strategies

- **Scanning PIV**
- **Continuous Measurement (no scanning)**

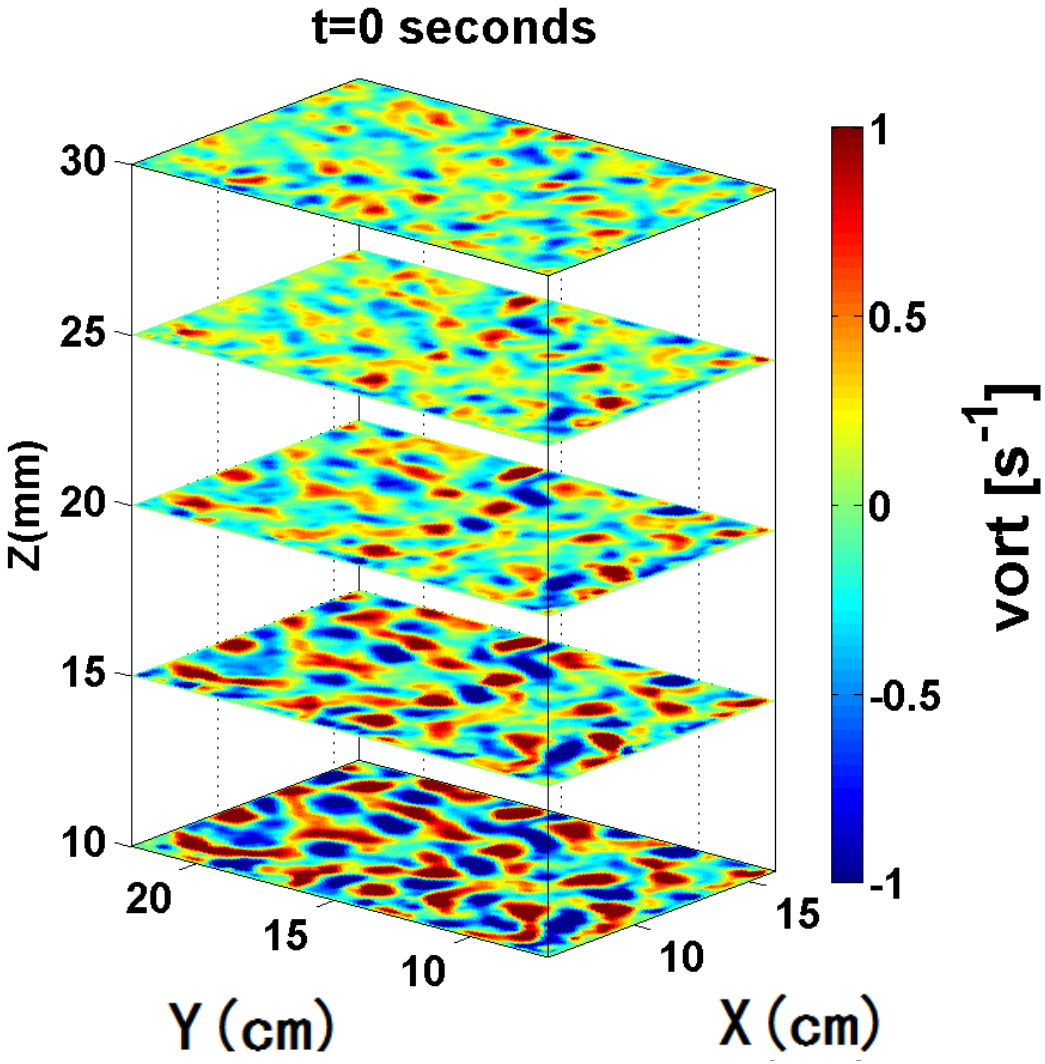
Vertical scanning with a smart phones





Only the vertical vorticity of lower layers were measured Scanning period: 12 seconds

Scanning measurement (0.167Hz)

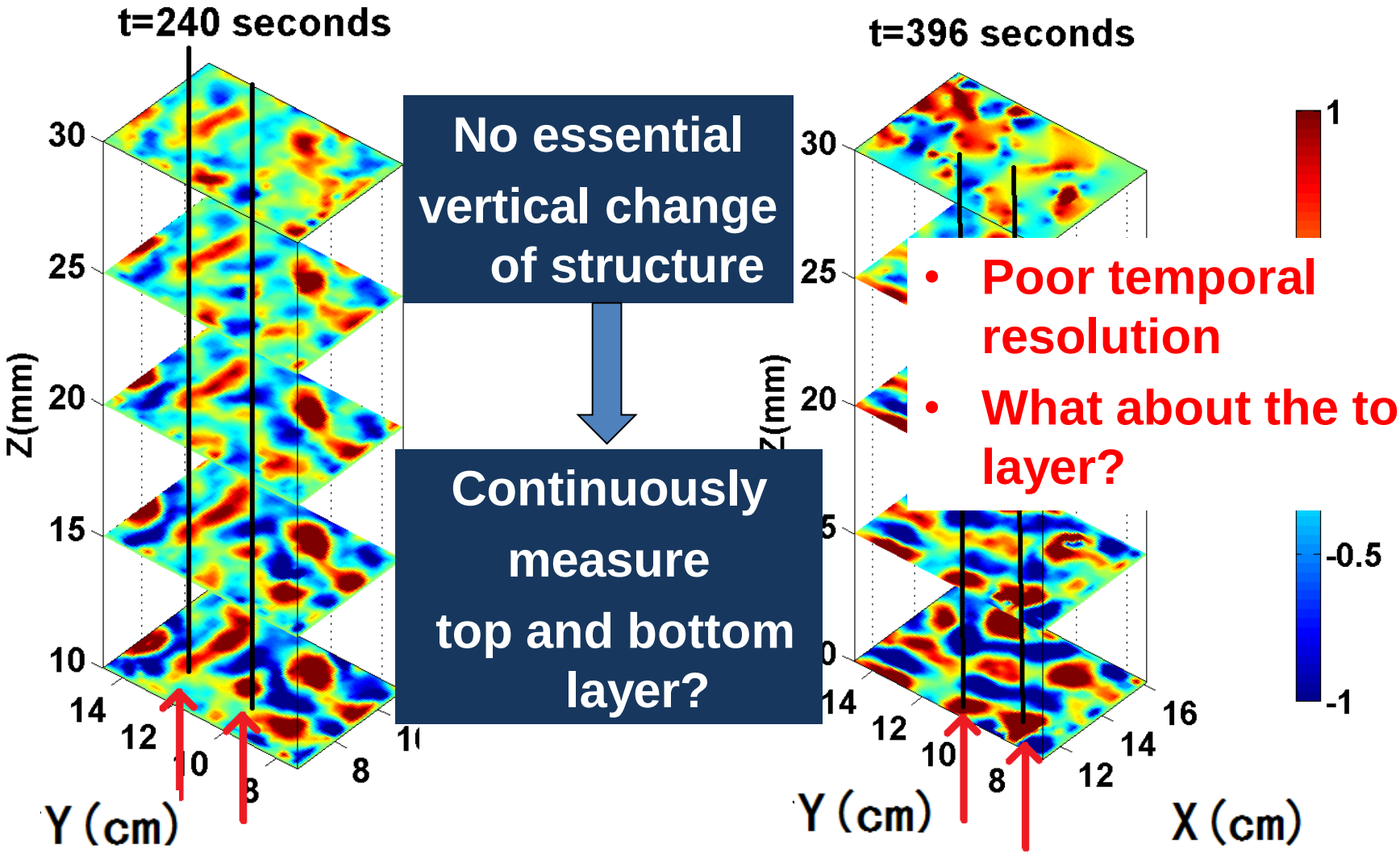


- Plot the five cross-sections together (6s time interval)
- Similar patterns
- Strongest vortex at the lowest level.

Defect:

- Poor temporal resolution
- What about the top layer?

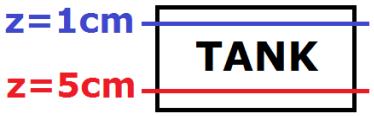
A closer look: vortex merge cases

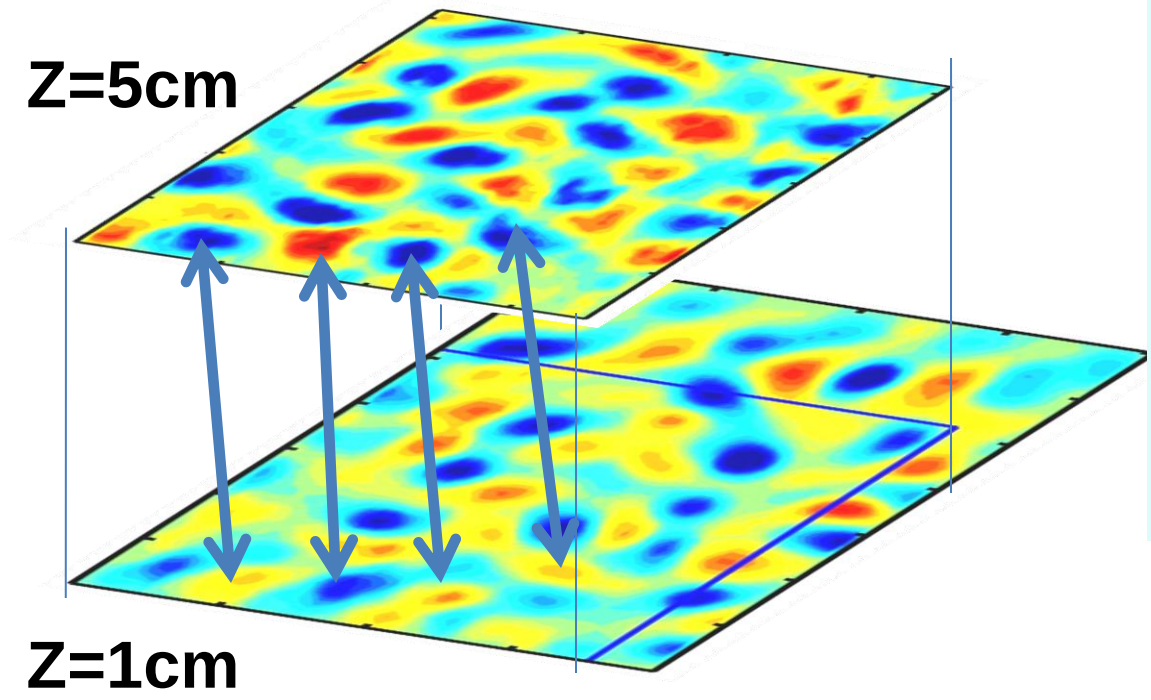


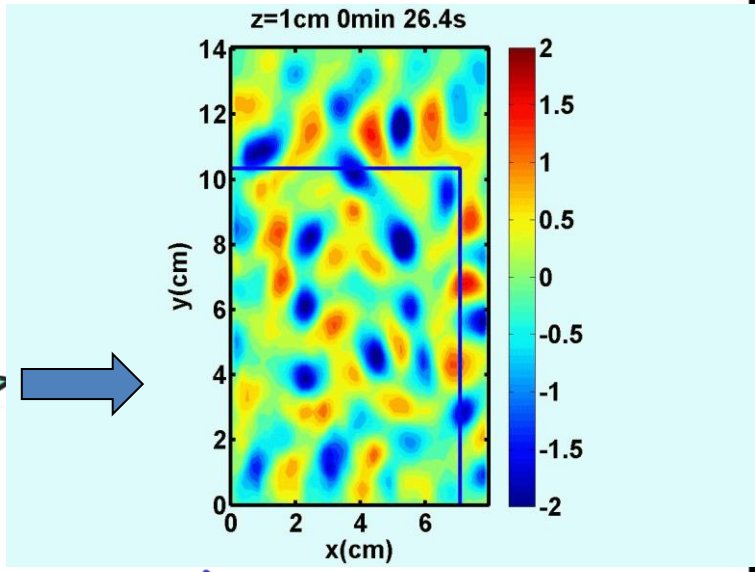
Two Measure Strategies

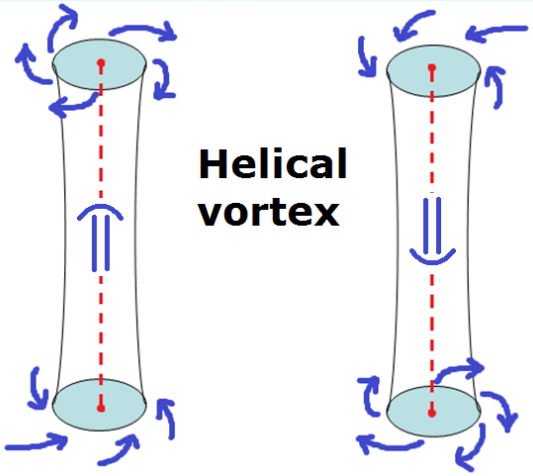
- **Scanning PIV**
- **Continuous Measurement (no scanning)**

A snapshot of continuous measurement (0.5 Hz)





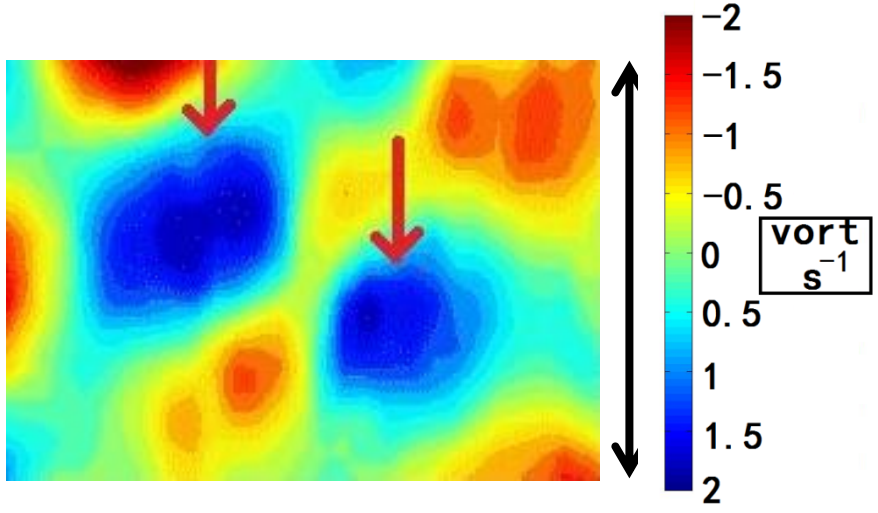




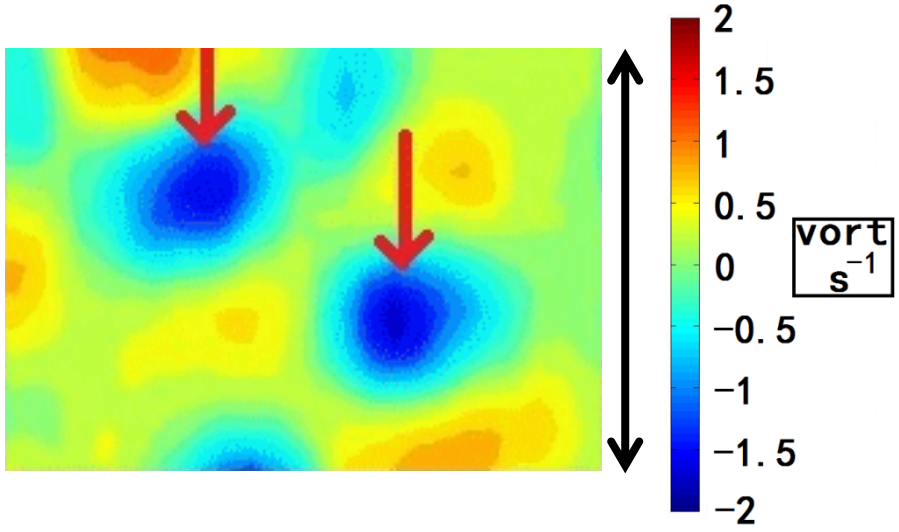
For each vortex,
vorticity are vertically antisymmetric,
with comparable strength

Case 1: double vortices merge

Z= 5cm



Z= 1cm



L~2.4cm Δt~3s

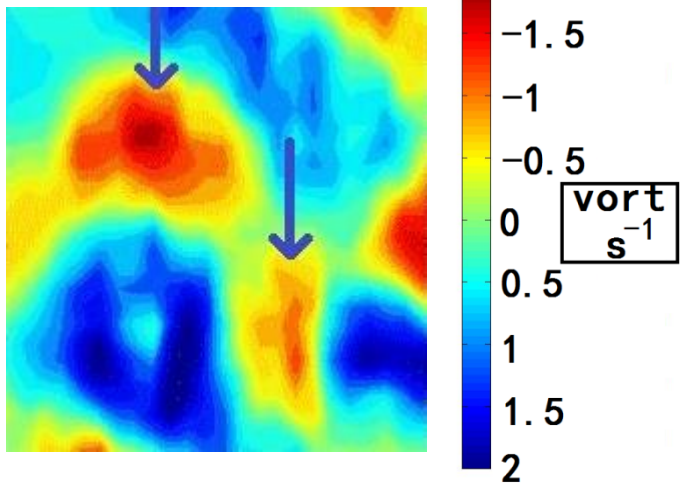
Similar pattern for lower and upper layer

Vortices collide directly without co-rotation

L~2.5cm Δt~2s

Case 2: merge and split again

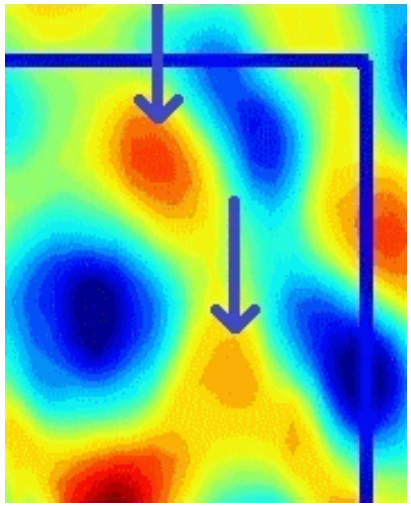
Z= 5cm

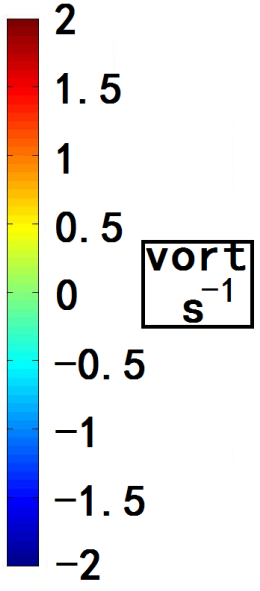


L~3.2cm Δt~3s

- Similar behaviour for lower & upper layer
- Thin vortex filaments cut by another vortex

Z= 1cm



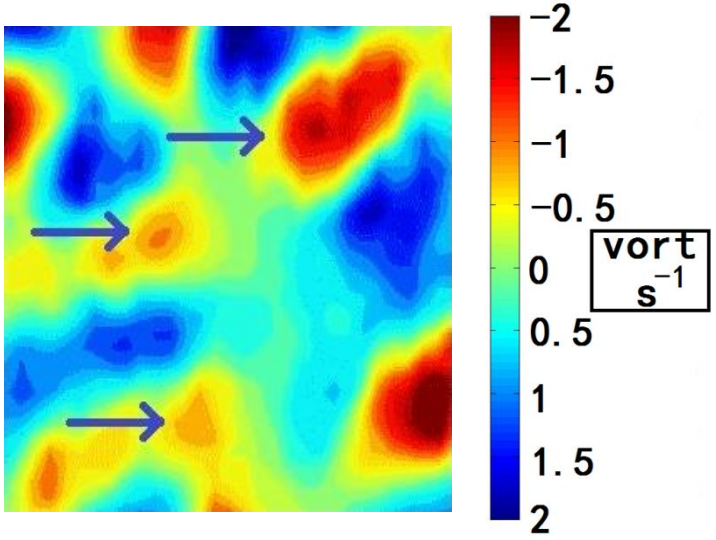


- Influence from other vortices should be accounted

L~4.3cm Δt~2s

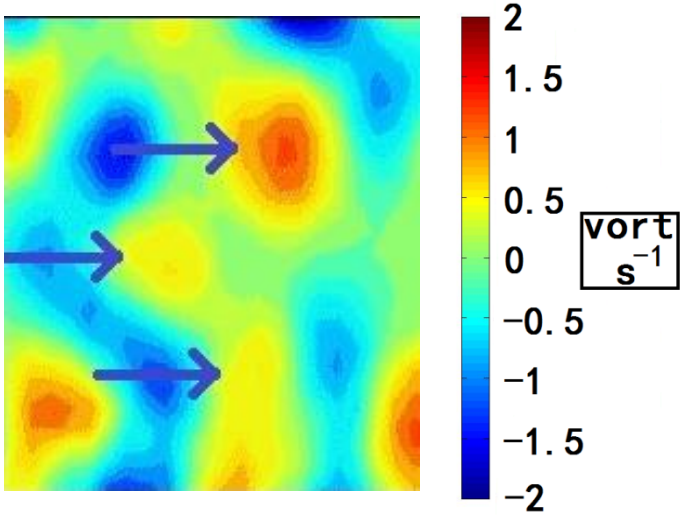
Case 3: triple vortices interaction

Z= 5cm



L~3.9cm Δt~2s

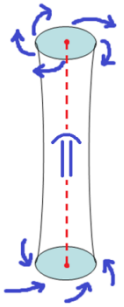
Z= 1cm



Counter-clockwise co-rotation!

L~4.1cm Δt~3s

Hypothesis of dynamics-
2D horizontal viewpoint

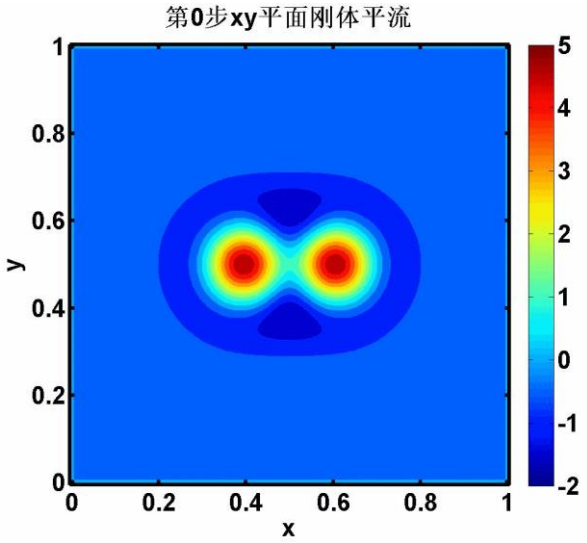


- **Non-convectional vortices can be depicted with 2D vorticity equation**

Evolving vortices: (high Ra number)

$$\frac{D(curl\,\vec{V})}{Dt} = f\frac{\partial w}{\partial z} + \nu\Delta(curl\,\vec{V})$$

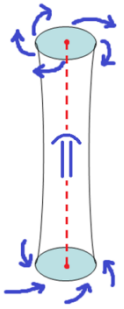
Sprague et al. , 2006



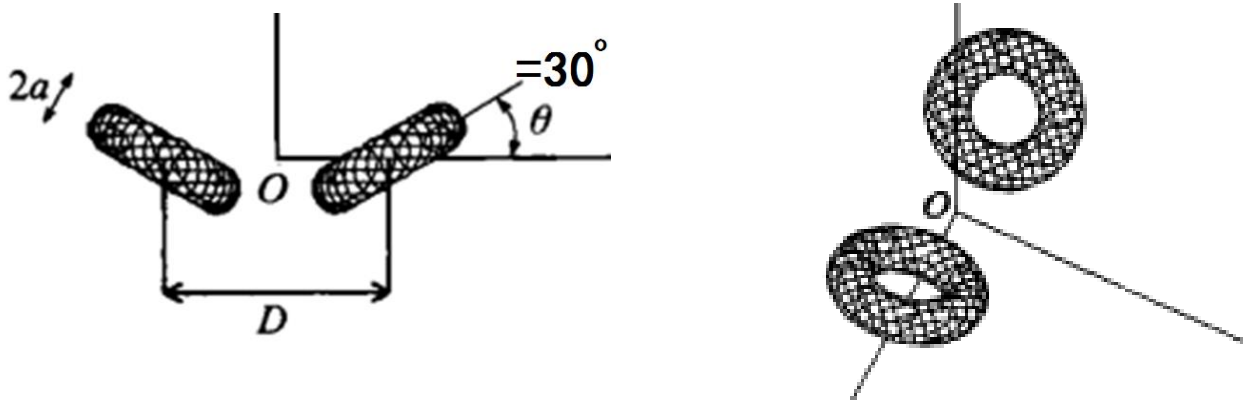
- Co-rotation sometimes occurs
- Hard to parameterize $f\frac{\partial w}{\partial z}$

$$\frac{D(curl\,\vec{V})}{Dt} = \nu\Delta\left(curl\,\vec{V}\right), \text{with } \mathbf{Re} = \mathbf{1000}$$

Hypothesis of dynamics-
3D vortex rings viewpoint



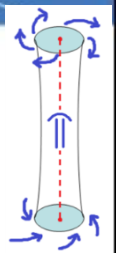
- **Vortex rings appear in non-rotating convection**
- **At certain inclined angle,**
  2 vortex rings merge directly, without co-rotation



Copied from Kida et al., 1991, JFM

- **another approach – "helicical-vortex instability" may be of help.** G. Levina et al., 2000

Concluding Remarks



- Two measurement methods are applied to rotating convection in a square tank:
  (1) scanning PIV
  (2) fixed-point consecutive measuement

Structure:

- vertically alligned with little vertical of pattern.
- rotate oppositely at lower and upper layer, with comparable strength. Synchronized motion.

Kinetics:

- Vortex merge events are prevalent and diverse, some exhibit co-rotational behavior but some do not.

The dynamics without the surrouding vortices remains unknown

unnegligible influence from surrouding vortices

Thanks
for your attention !

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