



HAL
open science

The strain field of light jets

Laurent Joly, Juan Suarez, Patrick Chassaing

► **To cite this version:**

Laurent Joly, Juan Suarez, Patrick Chassaing. The strain field of light jets. 5th European Fluid Mechanics Conference, Aug 2003, Toulouse, France. pp.0. <hal-04104664>

HAL Id: hal-04104664

<https://hal.science/hal-04104664v1>

Submitted on 24 May 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

The strain field of light jets

L. Joly¹, J. Suarez¹, P. Chassaing^{1,2}

¹*ENSICA - Département de Mécanique des Fluides - Toulouse, France.*

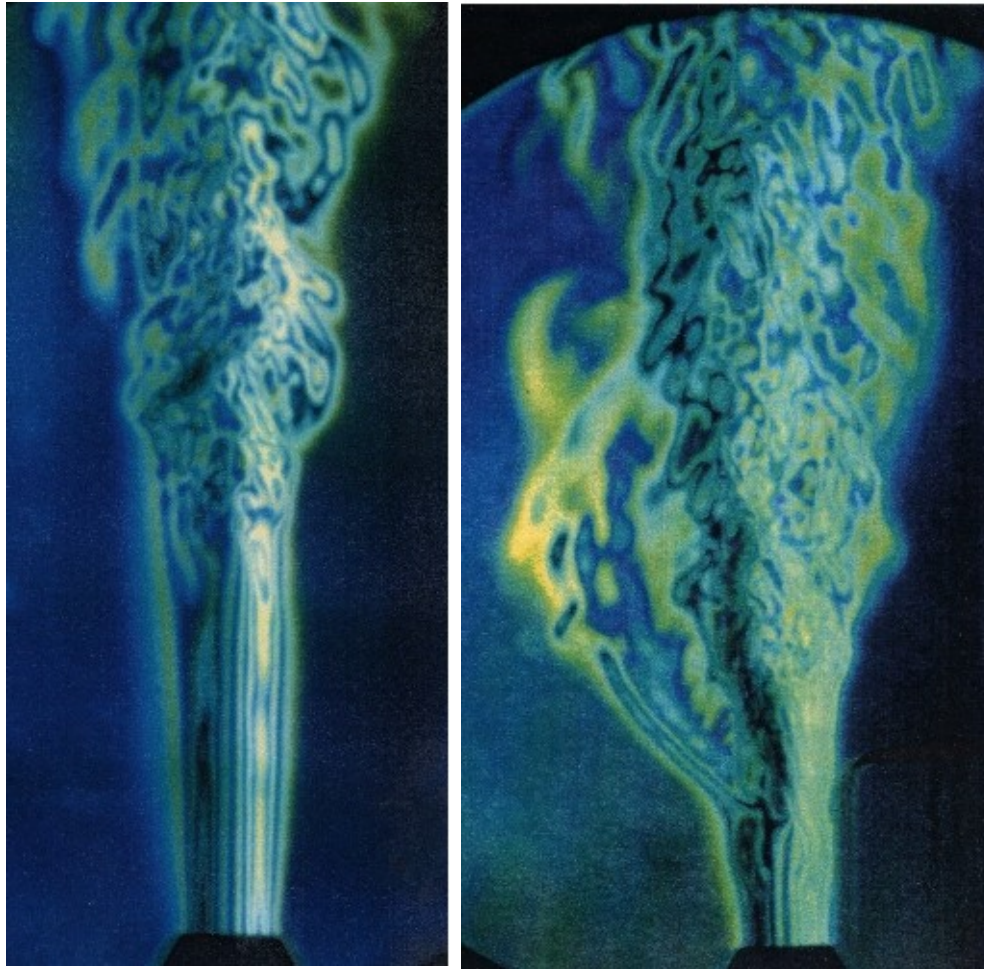
²*Institut de Mécanique des Fluides de Toulouse - Toulouse, France.*

Outline

- Specific features of light jets
- Basics of the 2D development of KH billow in inhomogeneous jets and mixing layers
- The strain field of a light jet with pairing
- Potential growth rate of oblique modes according to the Caufield and Kerswell's criterion

Specific features of light jets : absolute column mode and side jets

First observation by Monkewitz & Bechert (Album of Fluid Motion - 1988)



1. Side jets occur when the jet is absolutely unstable,
2. The jet is absolutely unstable under a critical density ratio $s < 0.7$,
3. Side jets acknowledged within some range of Reynolds number,
4. Side Jets induced by counter-rotative streamwise vortices lying in the braid region between successive vortex rings (Brancher et al. Phys Fluids 1994)
5. A shorter route to the mixing transition and a large increase of the mixing rate,
6. Side Jets recovered in a pulsed homogeneous jet by Monkewitz and Pfizenmaier (1991)

Question: why vortex induction naturally produces side jets in round light jets only ?

Side ejections on helium jets from Hermouche, *Imft* (1996)

Re = 750

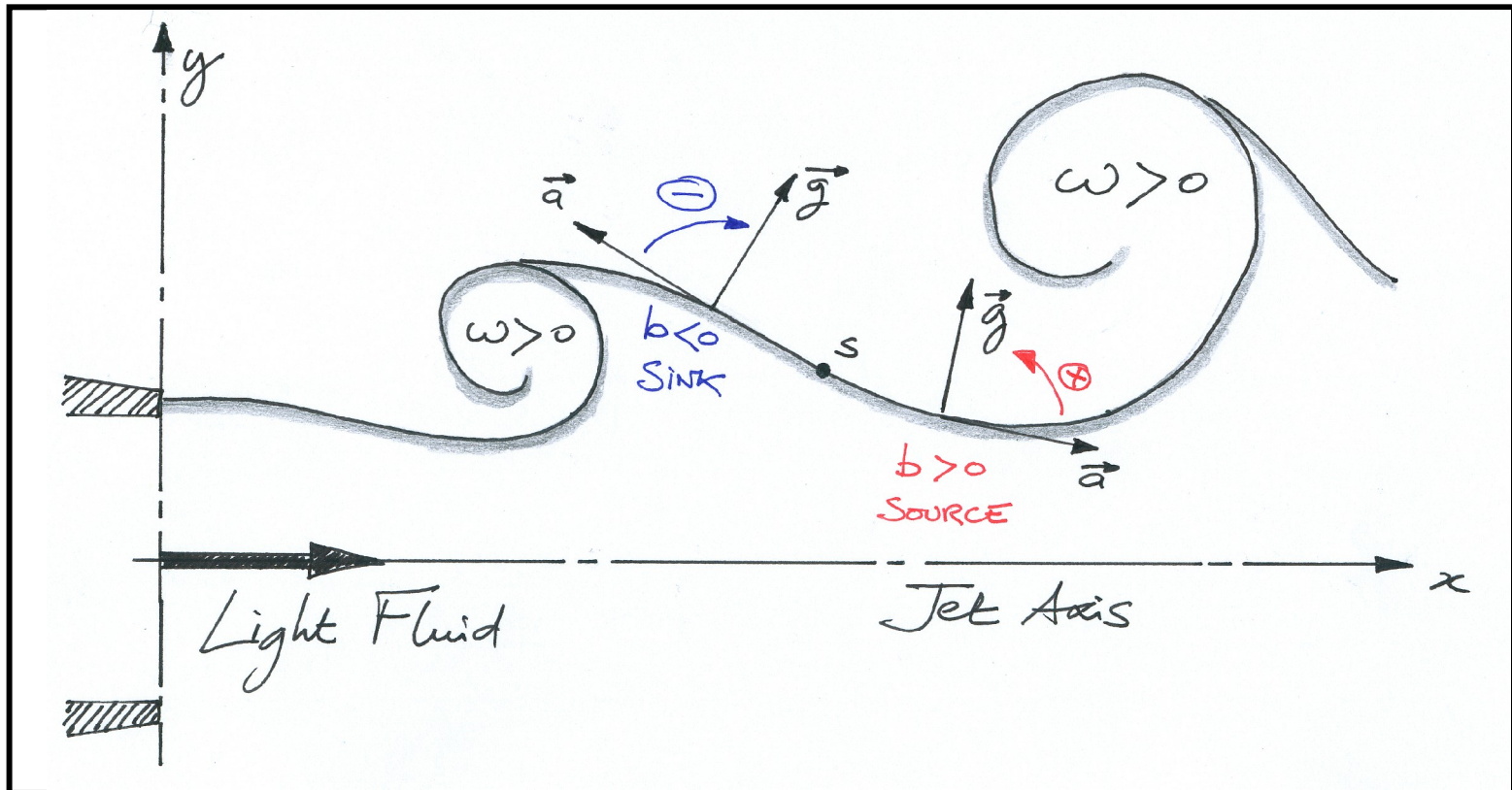
Re = 1000

The nature of the baroclinic torque in infinite Froude number jets

$$\frac{d\omega}{dt} = \underbrace{(\omega \cdot \nabla)\mathbf{u}}_{\text{green}} - \frac{1}{\rho^2} \nabla P \times \nabla \rho - \underbrace{d\omega}_{\text{blue}} + \underbrace{\nu \Delta \omega}_{\text{yellow}}$$

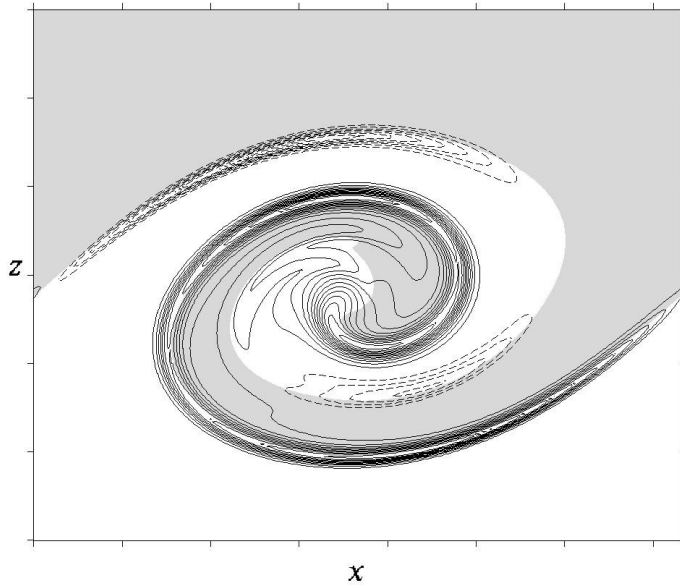
$$\mathbf{b} = \mathbf{a} \times \frac{1}{\rho} \nabla \rho$$

- vanishes in barotropic flows
- signature of inertia difference



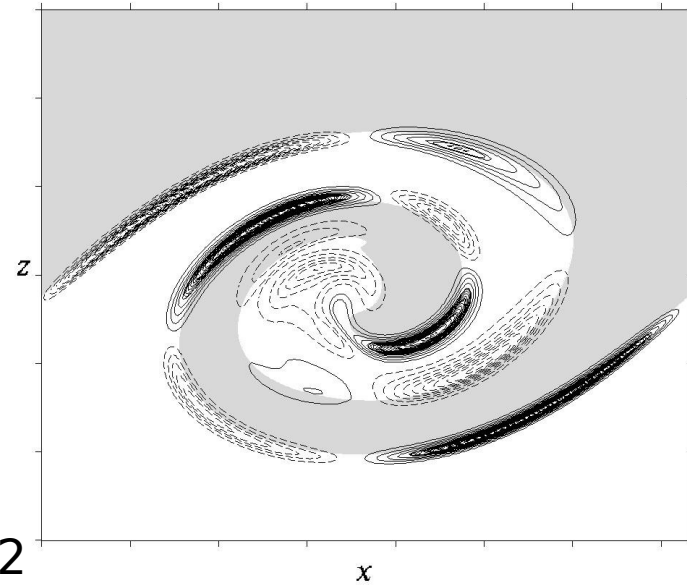
The baroclinic torque in the inhomogeneous mixing layer

Kelvin-Helmoltz Instability in the temporal mixing layer $s=3$, $Re = U\delta/\nu = 1500$



Vorticity

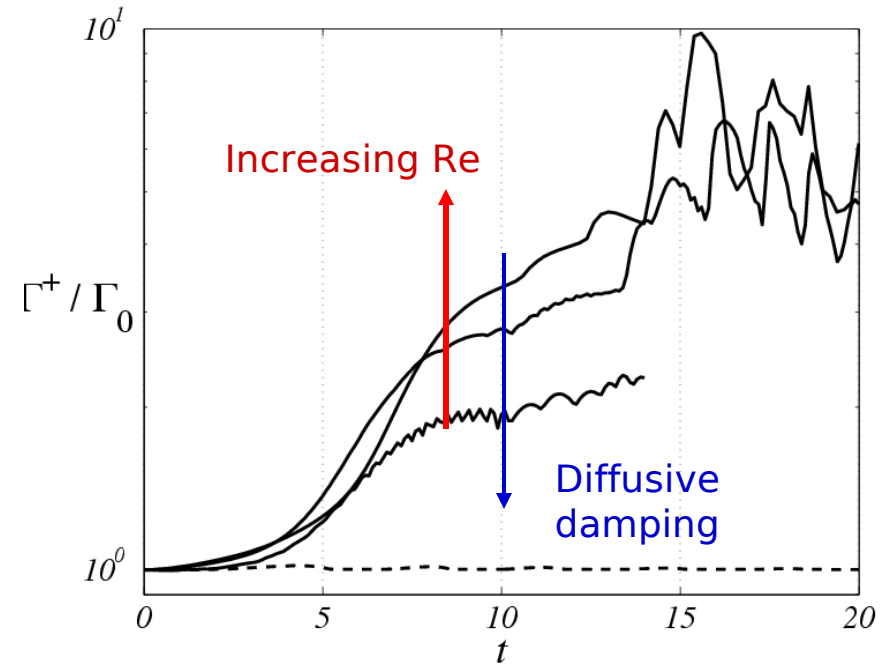
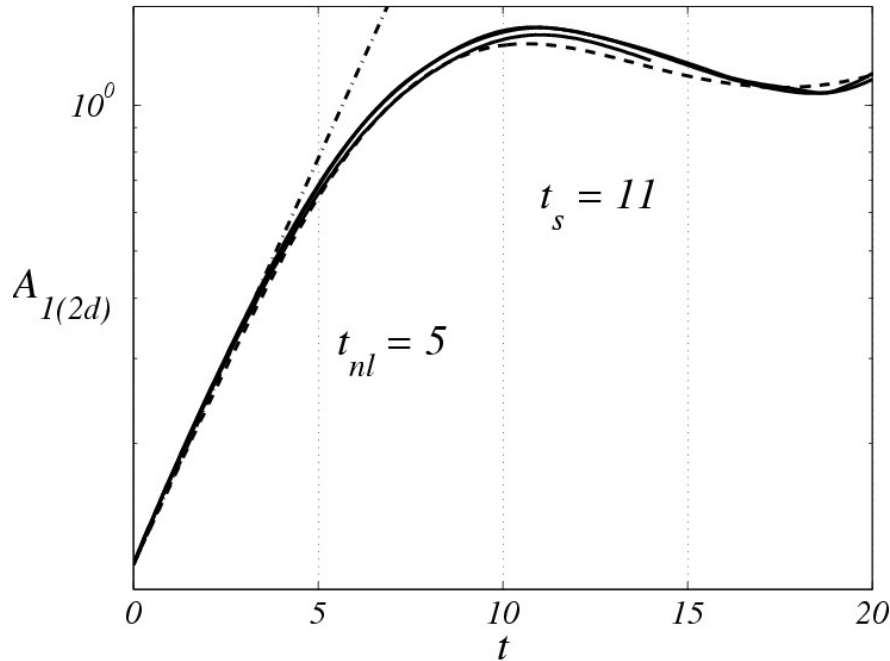
t=12



Baroclinic torque

The order of magnitude of the baroclinic torque

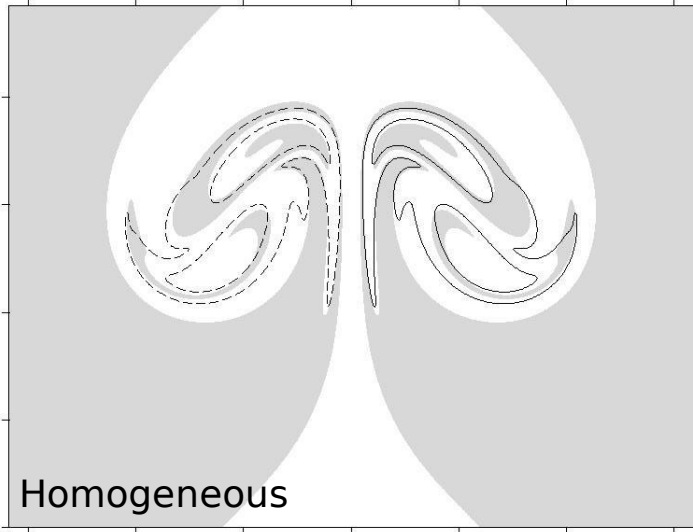
Temporal mixing layer $s=3$, $Re = Ud/n = 500, 1500, 3000$



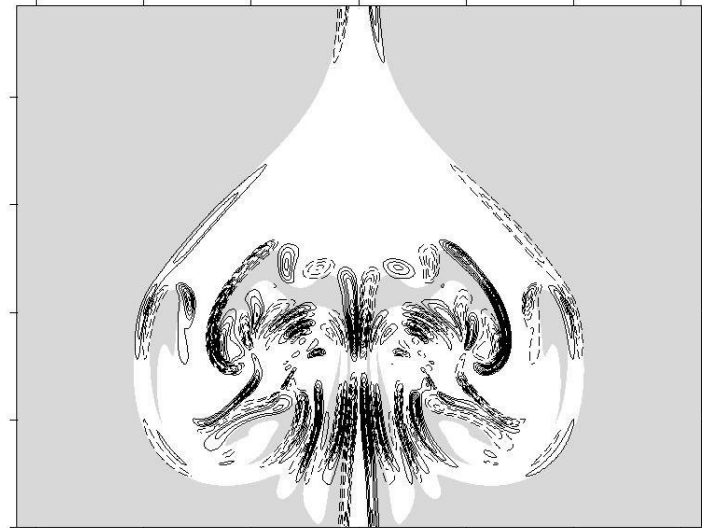
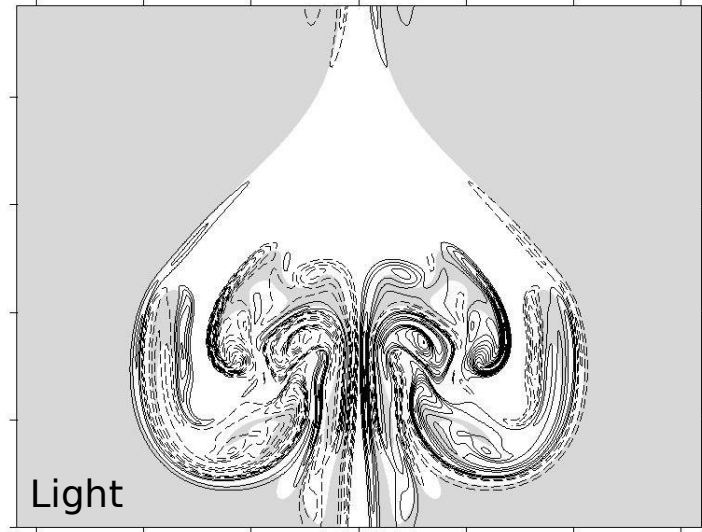
- Small changes in the growth rate
- Vorticity redistribution **within one KH wavelength**
- Positive/negative generated circulation increases with the **Reynolds/Schmidt numbers**

The structure of the 2D light Jet (with pairing)

Temporal jet $s=1/3$, $Re = UD/\nu = 2500$



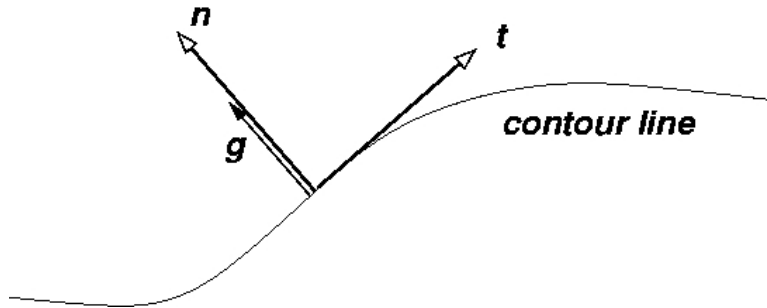
Vorticity



Kyle et Sreenivasan JFM 249 (1993)

Analysis of the strain field

The shear and the strain rate across a contour line



$$\lambda = \frac{\partial u_t}{\partial n} \quad , \quad \gamma = \frac{\partial u_t}{\partial t}$$

$$\lambda = \mathbf{n} \cdot \nabla \mathbf{u} \cdot \mathbf{t} \quad , \quad \gamma = \mathbf{t} \cdot \nabla \mathbf{u} \cdot \mathbf{t}$$

The model of the braid region according to Caulfield and Kerswell (PoF vol 12, 2000)

Model flow with strain rate γ and rotation rate $r = \frac{\omega}{2}$

$$\mathbf{u} = \begin{pmatrix} \gamma & -r \\ r & -\gamma \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \equiv \mathbf{A} \cdot \mathbf{x} \quad |\gamma| > |r|, \Delta \text{ real} \quad \textit{Hyperbolic region}$$

$$\Delta^2 = \gamma^2 - r^2 = -\det \mathbf{A} \quad |\gamma| < |r|, \Delta \text{ imaginary} \quad \textit{Elliptic region}$$

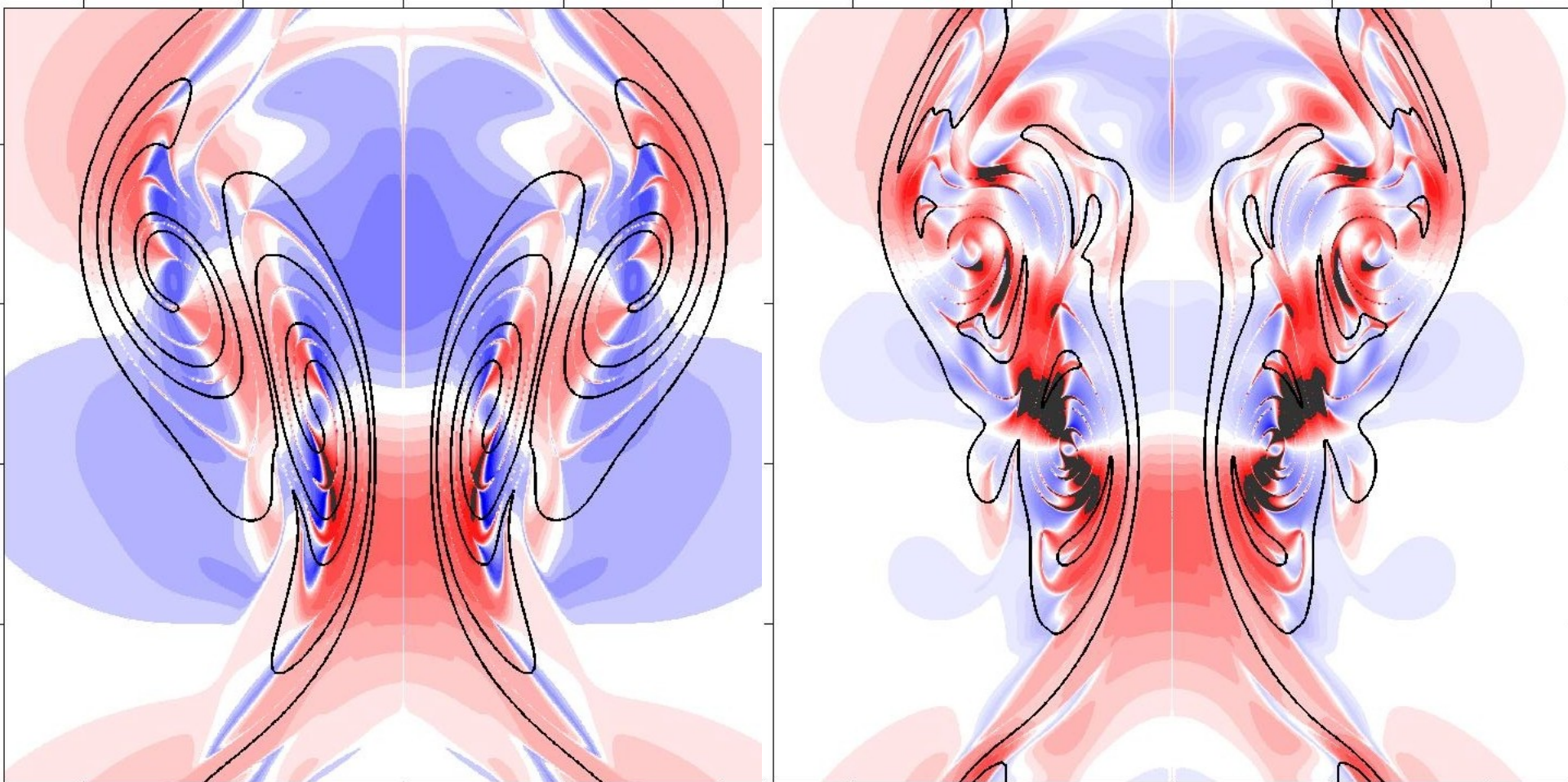
Application to real flows

$$r = \frac{\omega}{2} \quad \Delta^2 = \frac{\partial u}{\partial y} \frac{\partial v}{\partial x} + \left(\frac{\partial v}{\partial y} \right)^2 \quad \gamma_{ck}^2 = \Delta^2 + r^2$$

The strain field along material lines

Temporal jet $s=1/3$, $Re = UD/\nu = 2500$

Red : positive γ (**stretching**) - Blue : negative γ (**compression**) - Shaded : above same positive level



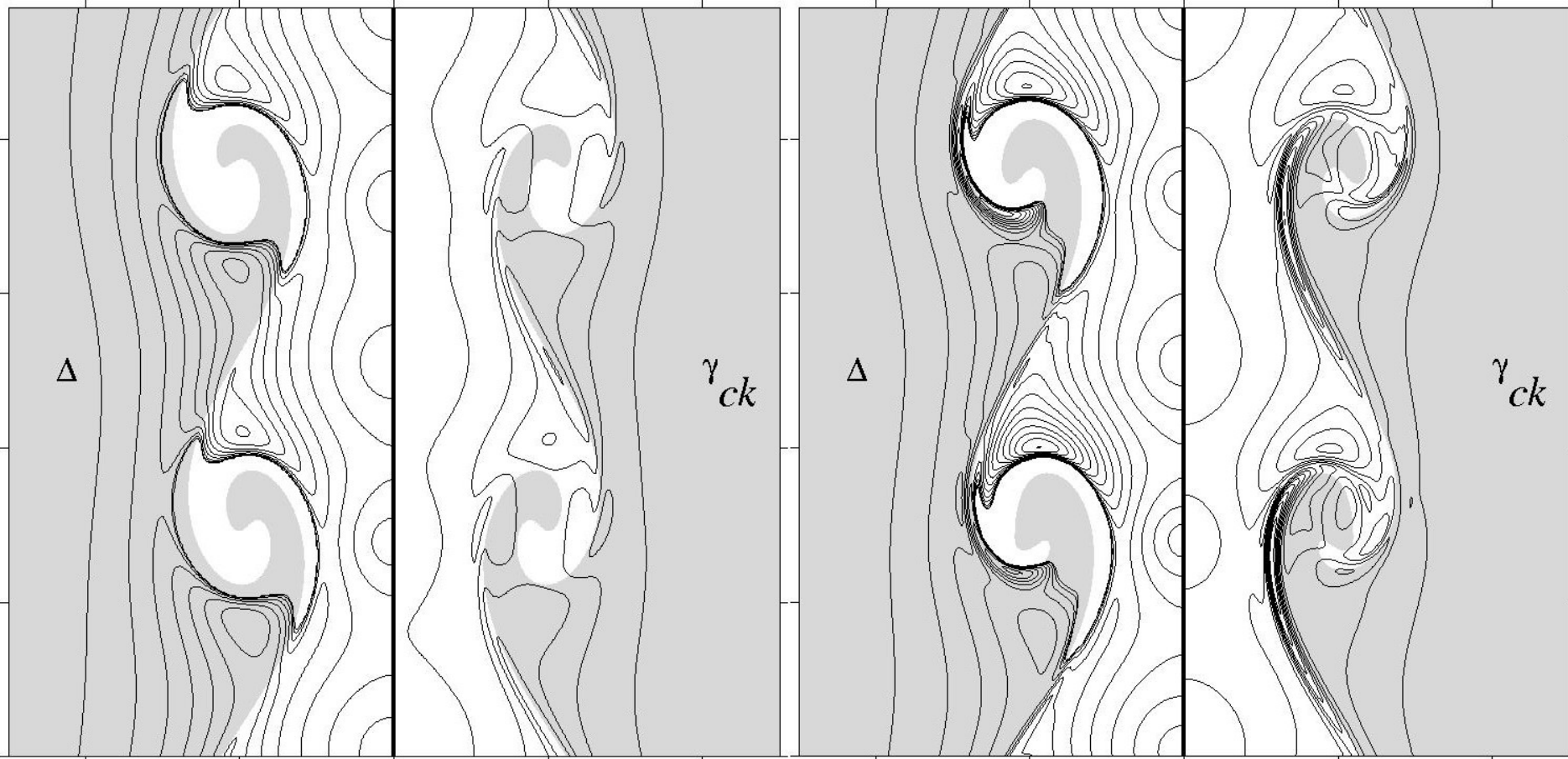
Passive scalar

t = 12

Light jet

The strain field according to the Caulfield and Kerswell's analysis

Temporal jet $s=1/3$, $Re = UD/\nu = 2500$



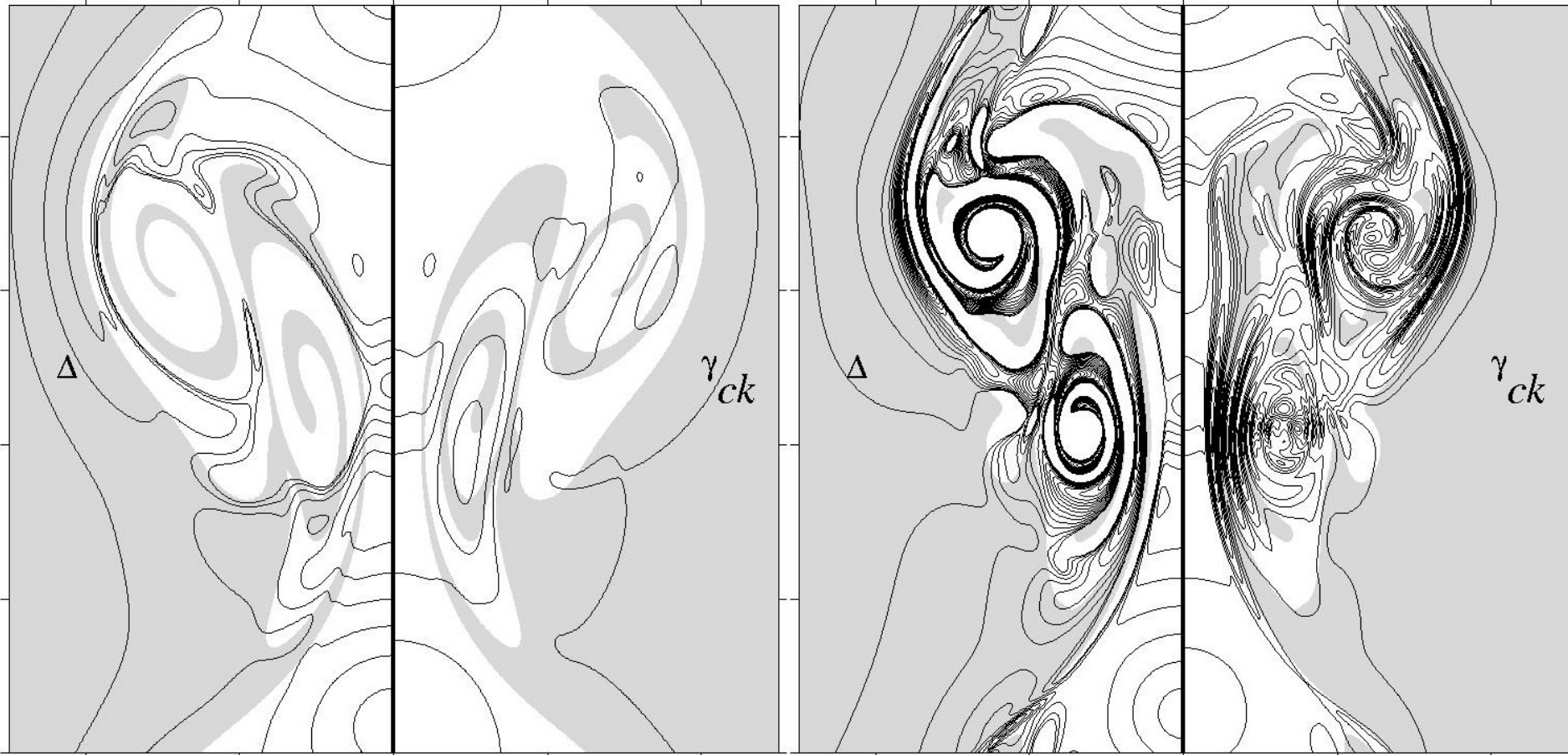
Passive scalar

t = 4,5

Light jet

The strain field according to the Caulfield and Kerswell's analysis

Temporal jet $s=1/3$, $Re = UD/\nu = 2500$



Passive scalar

t = 12

Light jet

Transient and asymptotic growth rates of 3D disturbances according to CK2000

Before the pairing - $t = 4.5\tau$

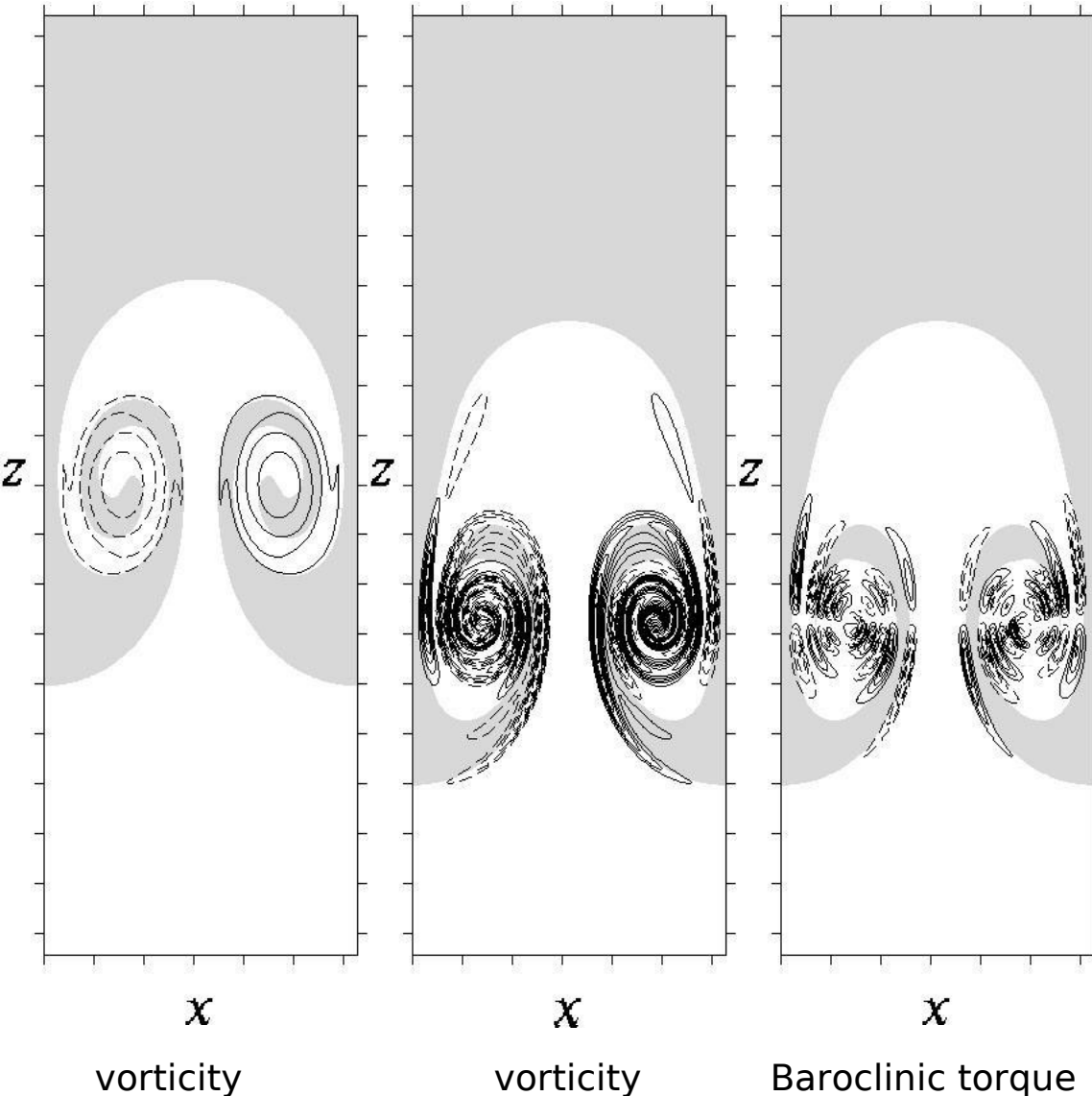
During the pairing - $t = 12.0\tau$

	γ_{ck}	$r = \frac{\omega}{2}$	Δ		γ_{ck}	$r = \frac{\omega}{2}$	Δ	
Homogeneous Jet								
Elliptic	0.52	1.33	<0		0.57	1.37	<0	
Hyperbolic	1.22	0.96	0.75		0.27	0.11	0.25	
Light Jet								
Elliptic	0.71	1.53	<0		0.34	3.83	<0	
Hyperbolic	1.00 to 2.47	1.04	0.51 to 0.73		0.49	0.45	0.18	
Homogeneous Jet								
Elliptic	$\sigma \sim \gamma_{ck}$	0.52			$\sigma \sim$	0.57		
Hyperbolic	$\sigma_{tr} \leq 2\gamma_{ck}$	2.44	$\sigma_{as} \sim 2\Delta$	1.5	$\sigma_{tr} \leq$	0.54	$\sigma_{as} \sim$	0.5
Light Jet								
Elliptic	$\sigma \sim$	0.71			$\sigma \sim$	0.34		
Hyperbolic	$\sigma_{tr} \leq$	2. to 5.	$\sigma_{as} \sim$	1. to 1.46	$\sigma_{tr} \leq$	0.98	$\sigma_{as} \sim$	0.36

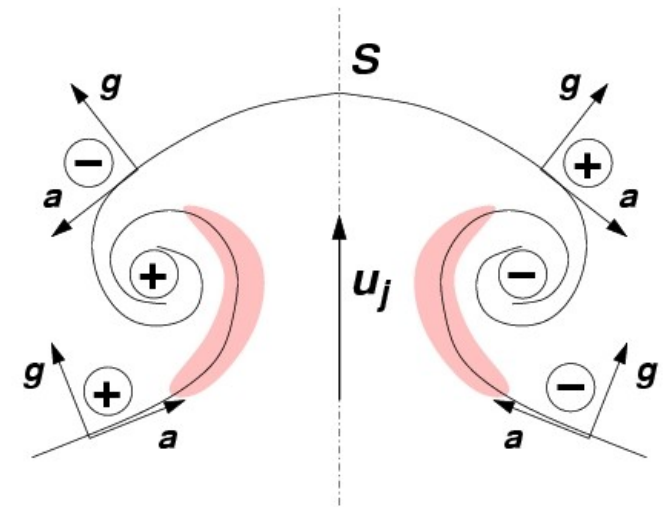
- The structure of the infinite Froude number inhomogeneous jet is biased by the baroclinic torque,
- The baroclinic torque is Reynolds-number and density-ratio sensitive,
- The strain fields of light jets present a folded layered structure and higher pick values,
- According to the theoretical prediction by CK00 the growth rate of transient « pressureless modes » is bounded above by $\sigma_{tr} \leq 2\gamma_{ck}$.
- Growth rates of transient modes may be up to twice more than their homogeneous counterpart before and during the pairing process,
- This may ensure the rapid growth of streamwise-aligned structures yielding side ejections of light fluid,
- The baroclinic torque mechanism produces thinner braids indicating higher spanwise or azimuthal wavenumbers,
- A need for an (ongoing) direct stability approach « à la » Klaassen and Peltier JFM 227 (1991).

Streamwise baroclinic torque on a pair of counter-rotating vortices

Counter-rotating vortices on a density-gradient layer



Spatial structure of the baroclinic torque on the pattern of counter-rotating vortices



- **Offset** of vortex centers toward the light side Potential
- Potential amplification by the strain field via the density-gradient