CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE

LEGI
LABORATOIRE DES ECOULEMENTS
GEOPHYSIQUES ET INDUSTRIELS

GRENOBLE 1
UNIVERSITE
JOSEPH FOURIER
SCIENCES TECHNOLOGIE MEDECINE

Expériences de laboratoire et simulations sur des fronts en écoulements géophysiques

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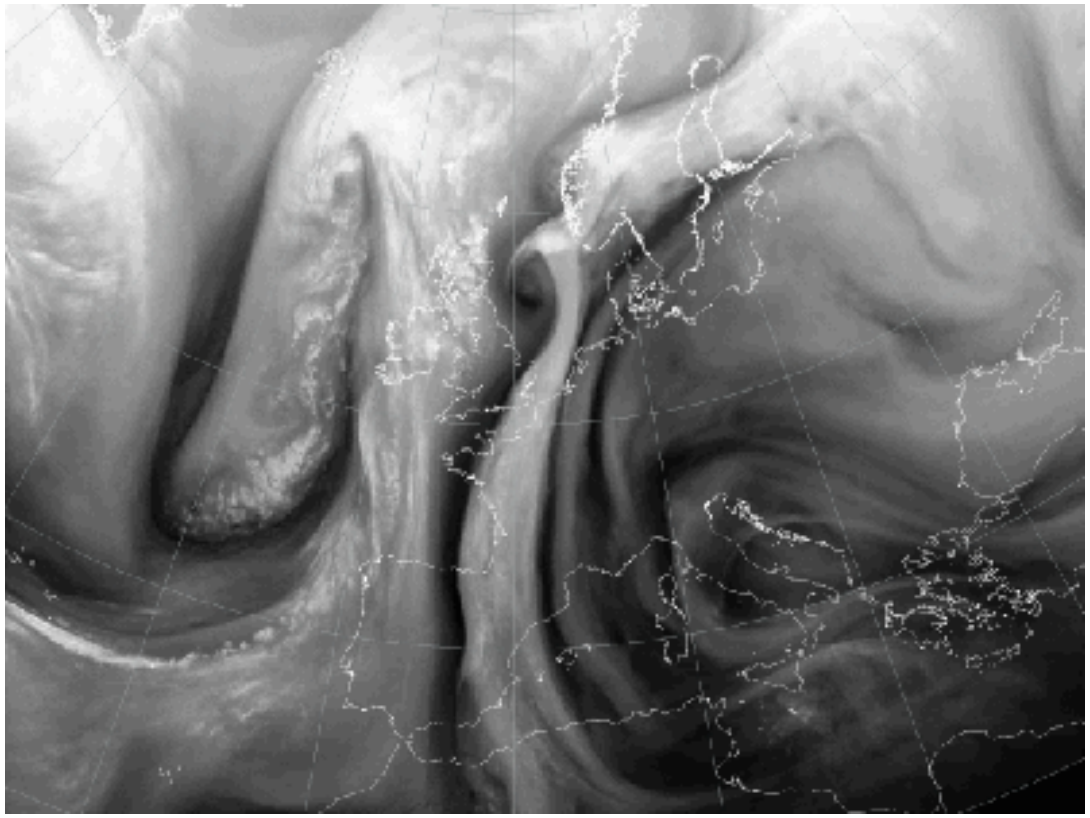
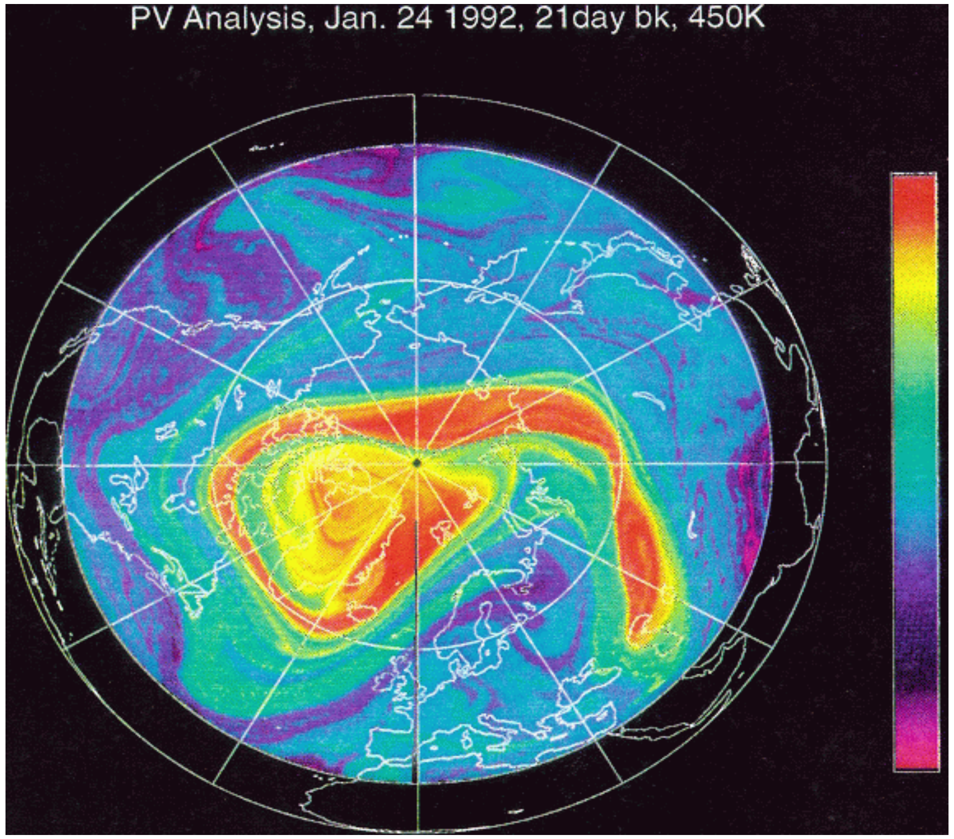
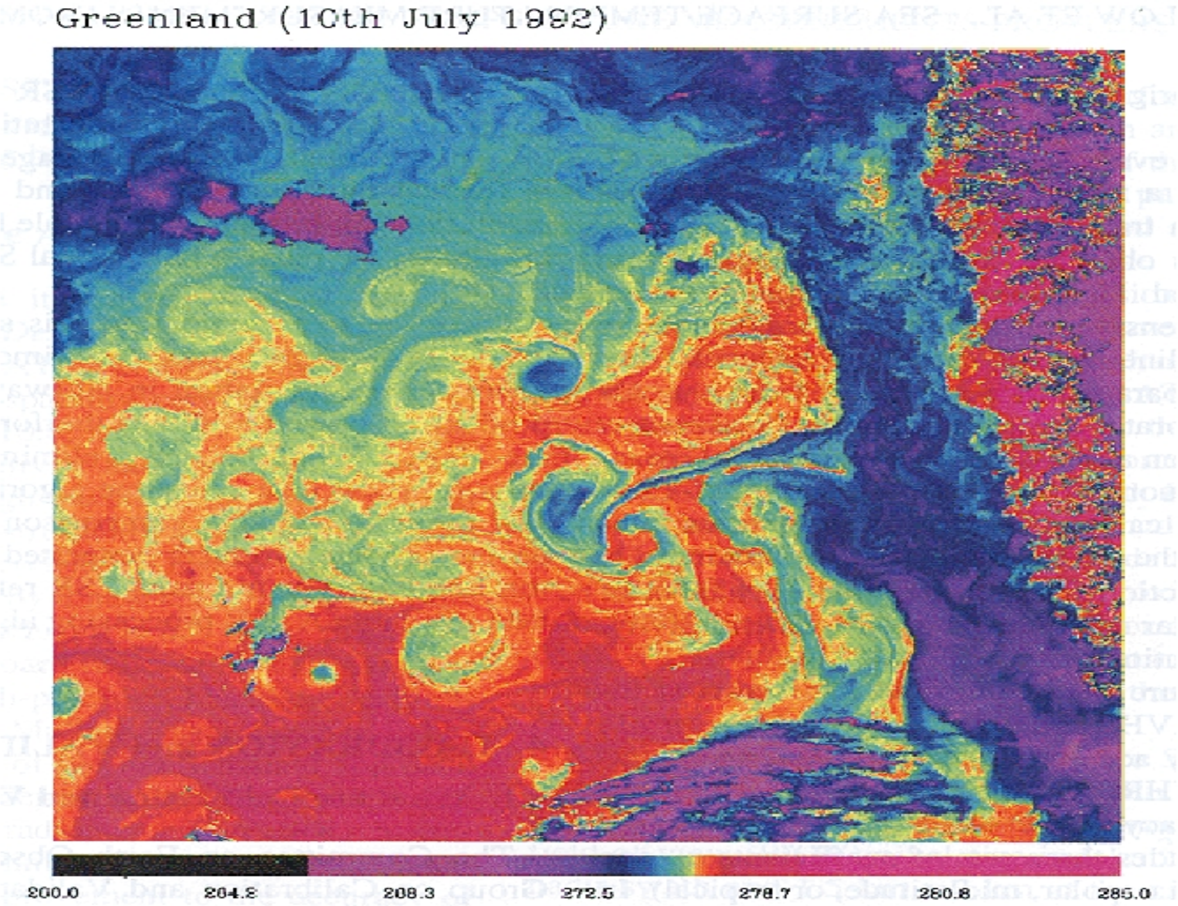
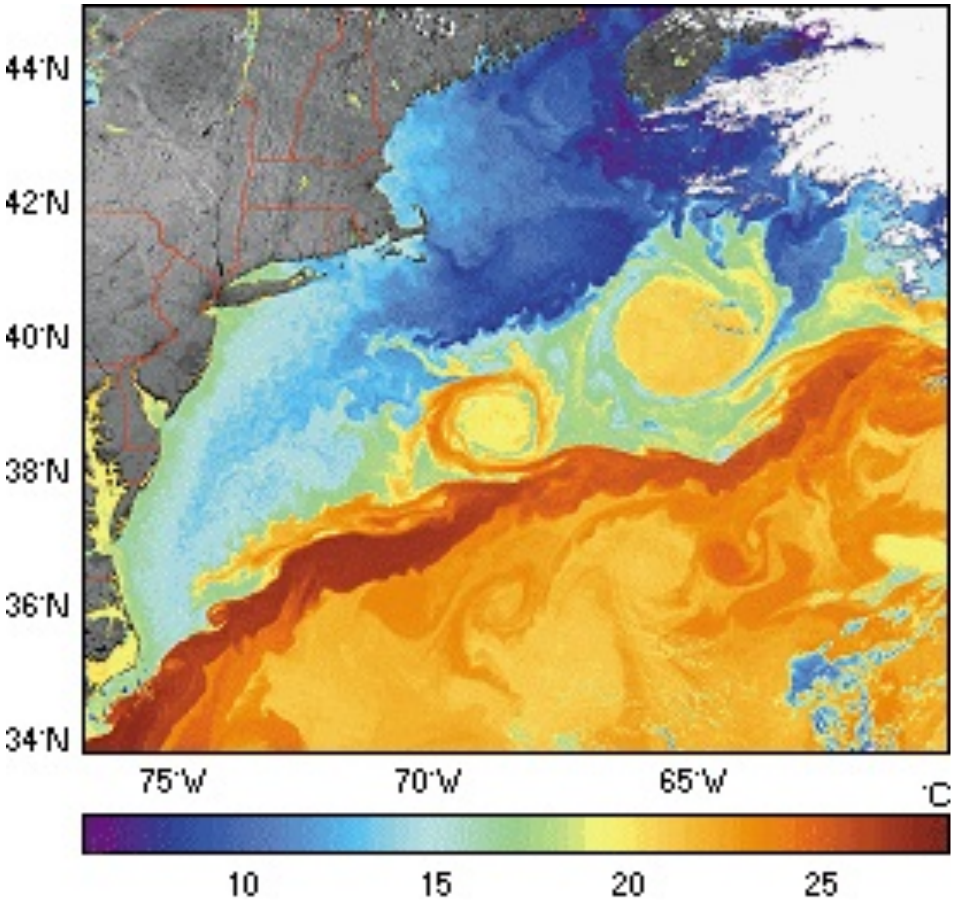
OSUG 18/6/2012

fronts en écoulements géophysiques

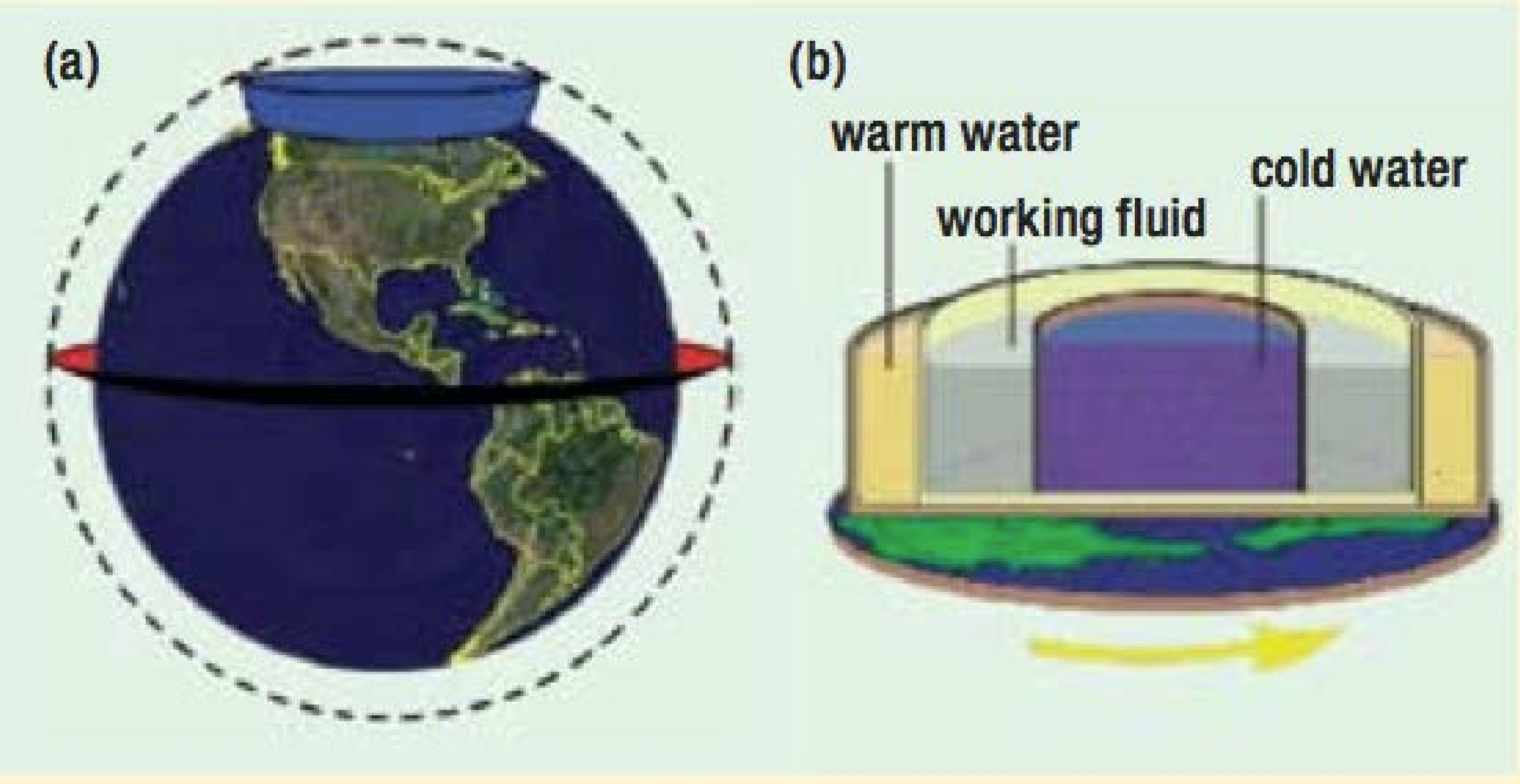




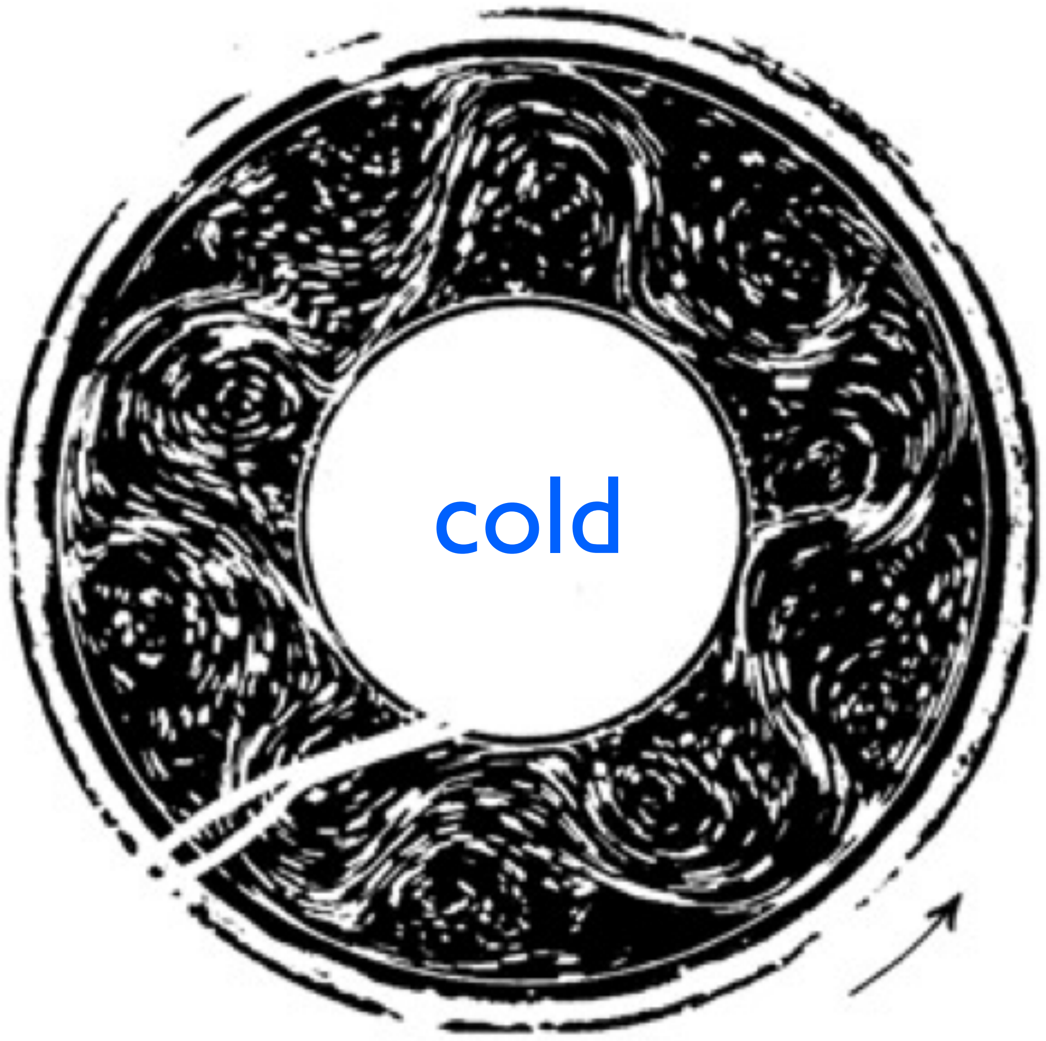




Hide 1953 1958
Fultz et al 1959
Hart 1972, 1985 ... etc.
Read 1985 - ...
Williams 2005 - ...



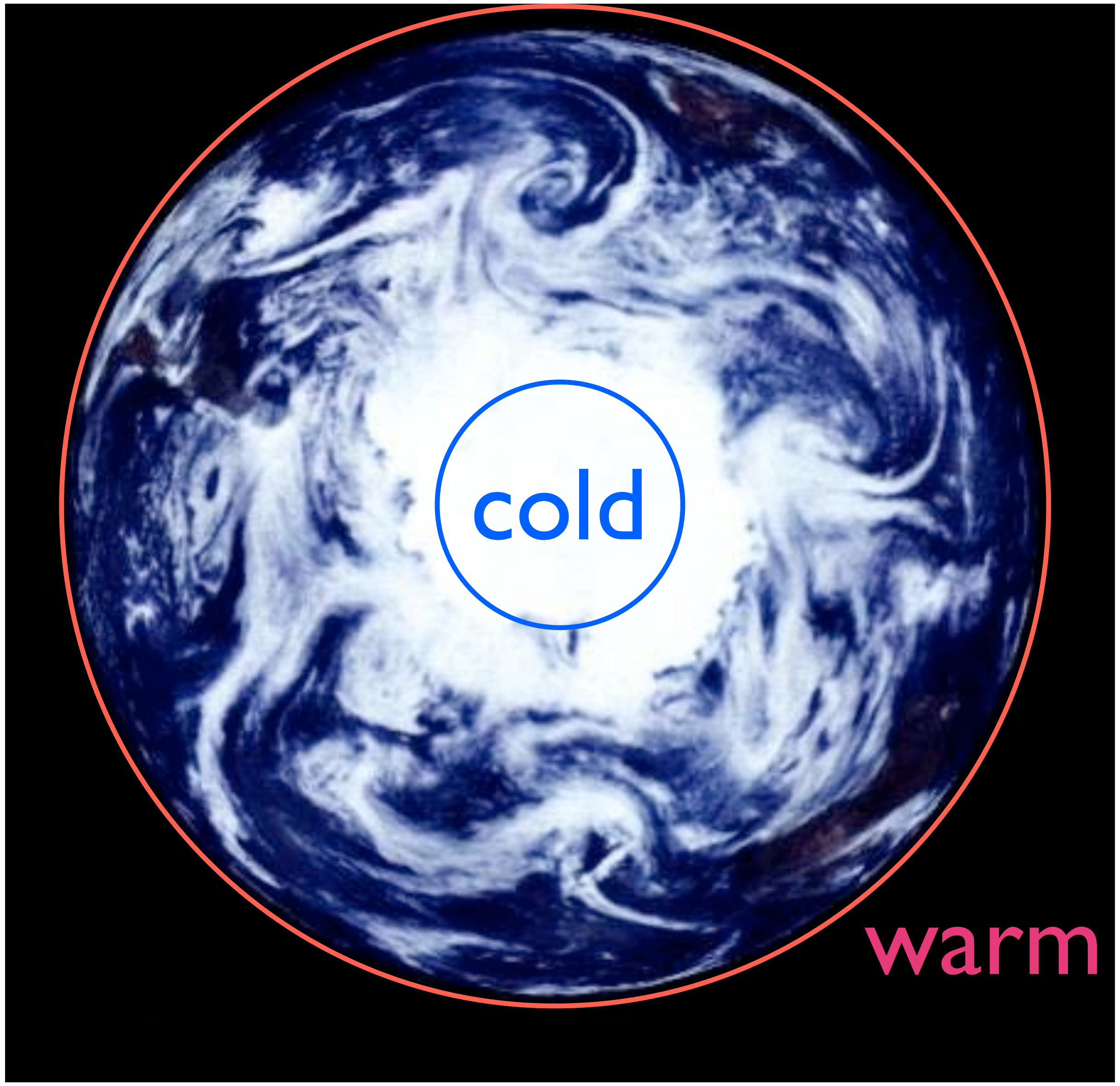
Baroclinic instability Experiments



Ω- 3.64 rad s^{-1}

Regular baroclinic waves, m= 5

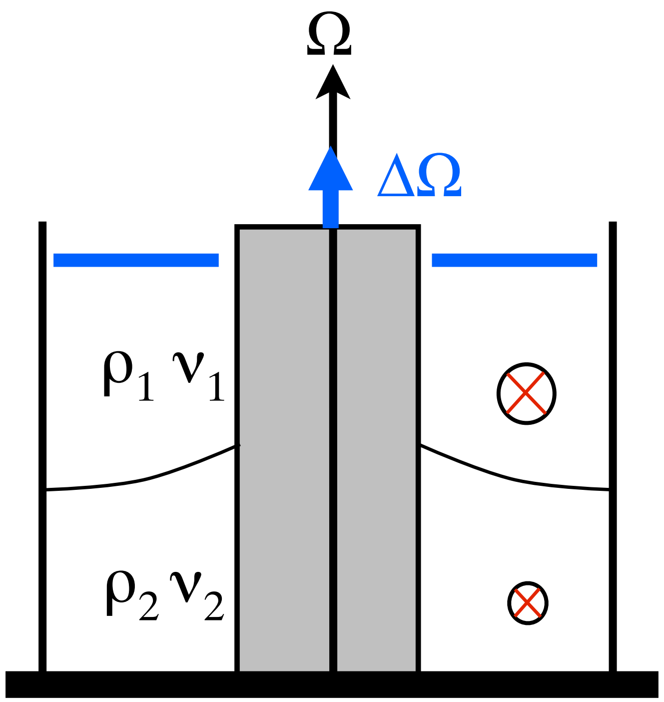
Hide, GAFD 2011



South Polar Projection of Earth

http://photojournal.jpl.nasa.gov/

Recent results



differentially rotating
Frictionally induced shear

Thermal wind balance $$-\frac{g}{\rho}\frac{\partial \rho}{\partial r} \approx 2\Omega \frac{\partial v}{\partial z}$$

Immiscible fluids,
small size tank,

Hart 1979 Ann Rev.; Mundt 1995
Lovegrove et al. 2000, Williams et al. 2005

Kelvin Helmholtz instability
Baroclinic instability, route to chaos
Inertia Gravity waves emission

Motivations:

- d’autres instabilités ?

moyen échelle
petites échelles

Motivations:

- d’autres instabilités ?

moyen échelle
petites échelles

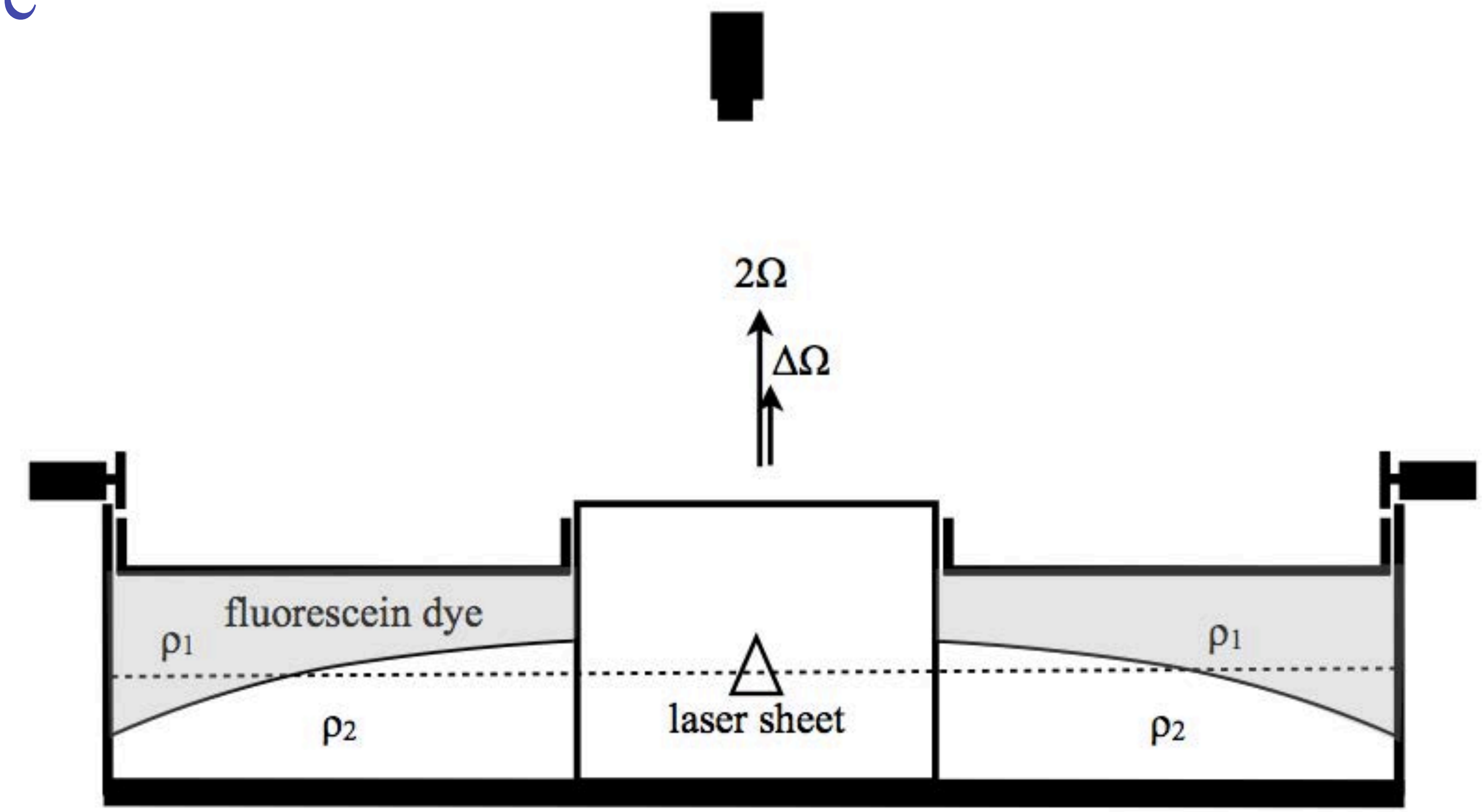
Modélisation plus réaliste :

- interface avec stratification continue entre deux fluides miscibles

- grand cuve permettant (facteur 8 fois plus grande) plus grande gamme d’échelles

- approche d’écoulements peu profonde

Rotation différentielle

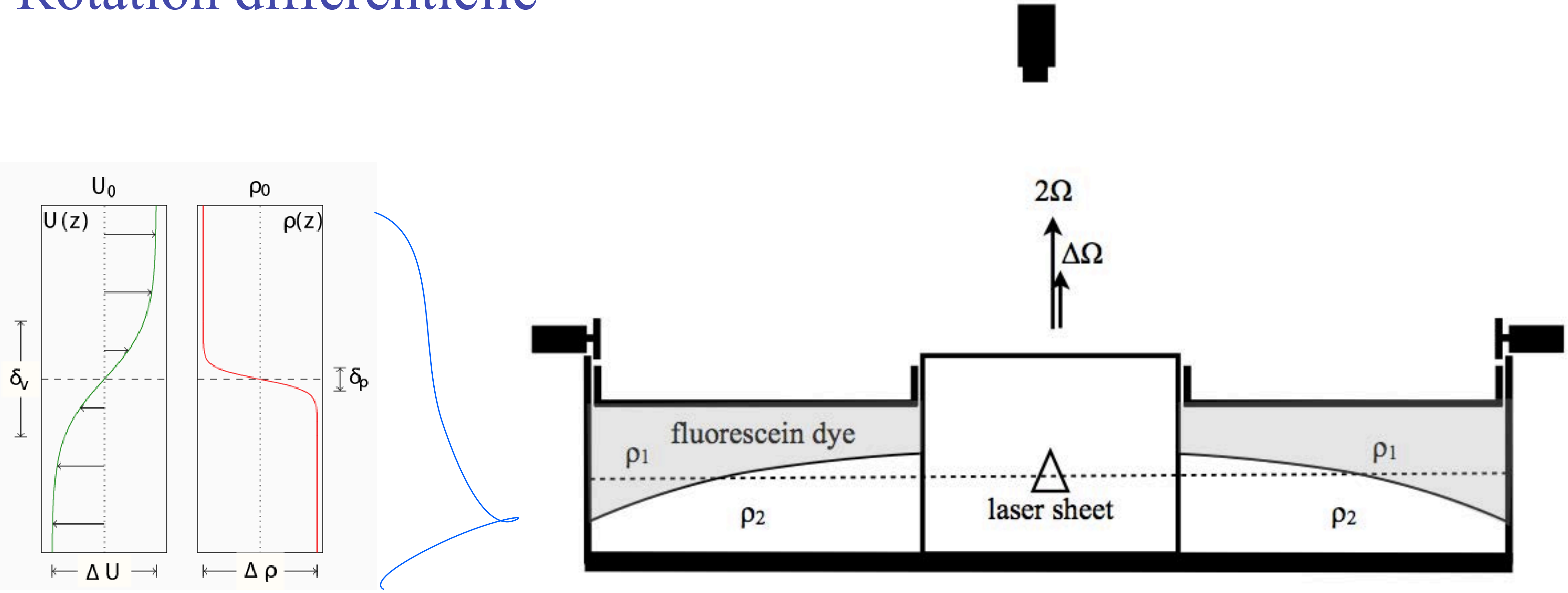


frontal instability

$$Bu = \frac{g' H}{4\Omega^2 L^2} \qquad Ro = \frac{\Delta\Omega}{2\Omega}$$

$$d = \frac{\tau_{forcing}}{\tau_{spin-down}} = \frac{\sqrt{\nu\Omega}}{\Delta\Omega H}$$

Rotation différentielle



interface

$$Ri = \frac{g' 2\delta_v}{(\Delta U)^2} R$$

$$R = \frac{\delta_u}{\delta_\rho} \qquad Sc = \frac{\nu}{\kappa}$$

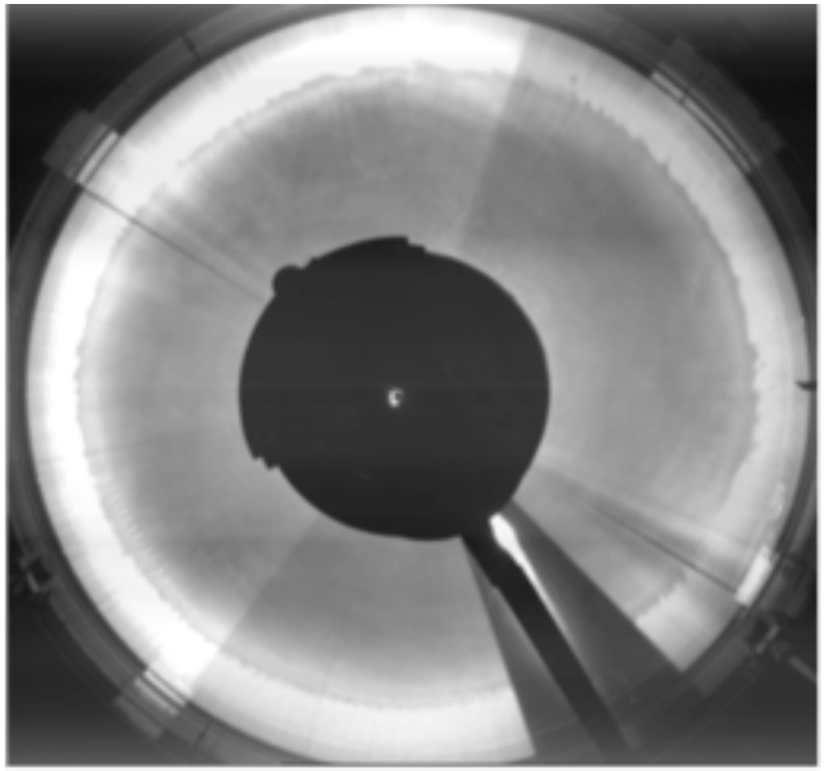
frontal instability

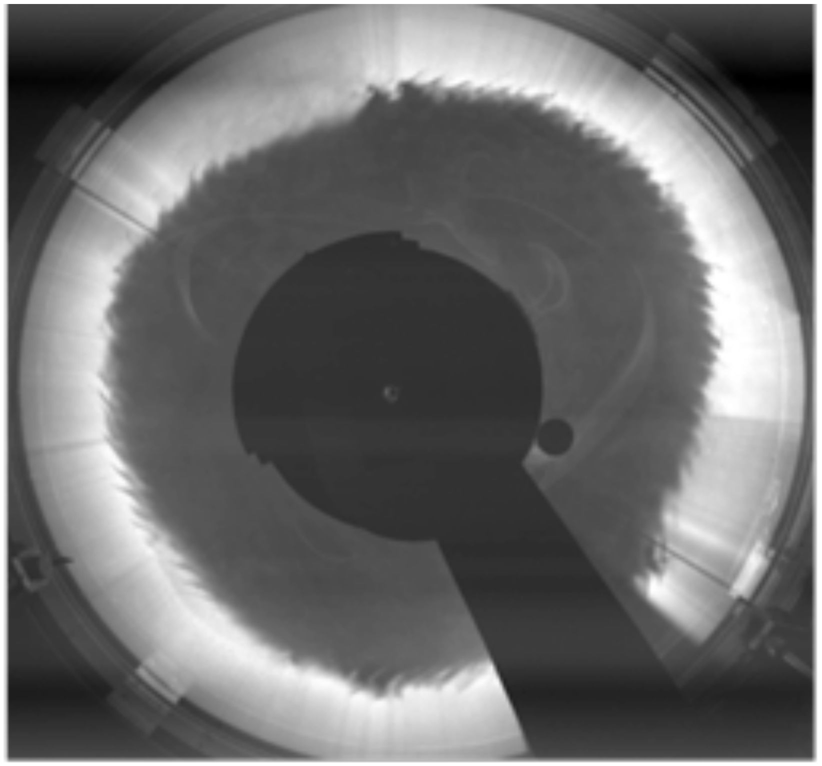
$$Bu = \frac{g' H}{4\Omega^2 L^2} \qquad Ro = \frac{\Delta\Omega}{2\Omega}$$

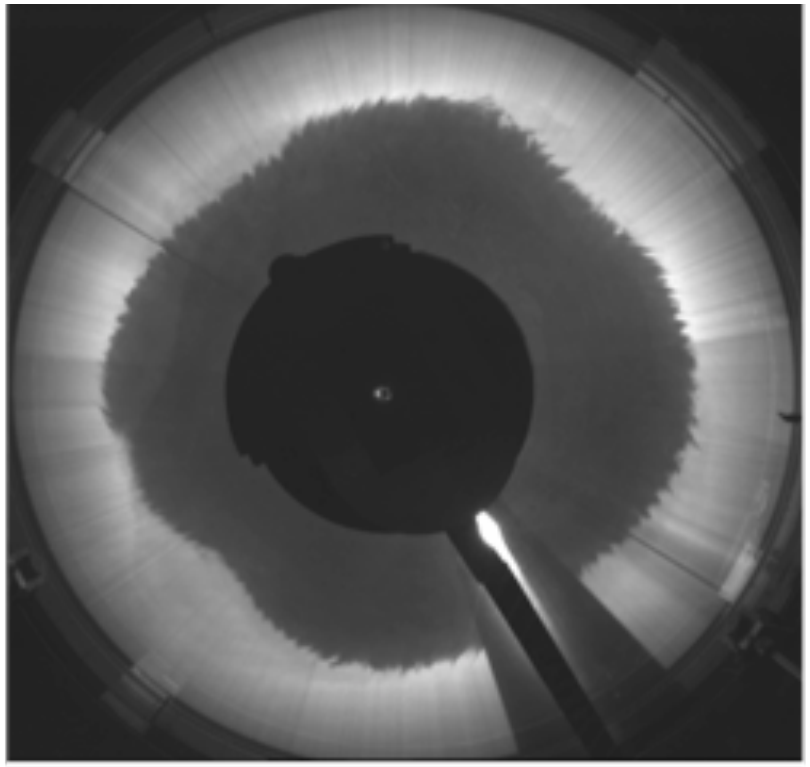
$$d = \frac{\tau_{forcing}}{\tau_{spin-down}} = \frac{\sqrt{\nu\Omega}}{\Delta\Omega H}$$

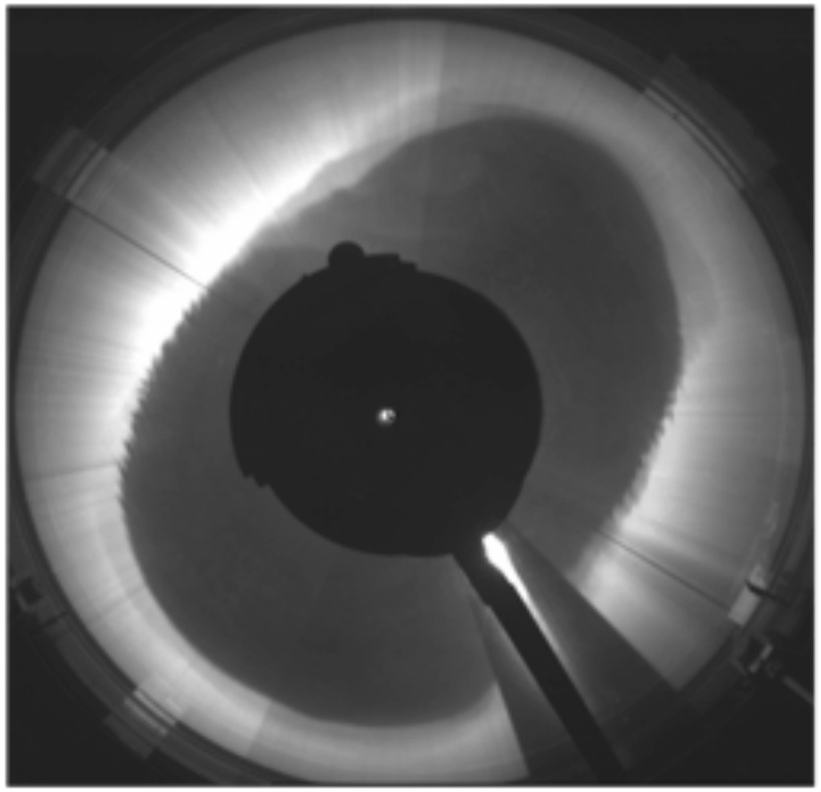
TOP VIEW

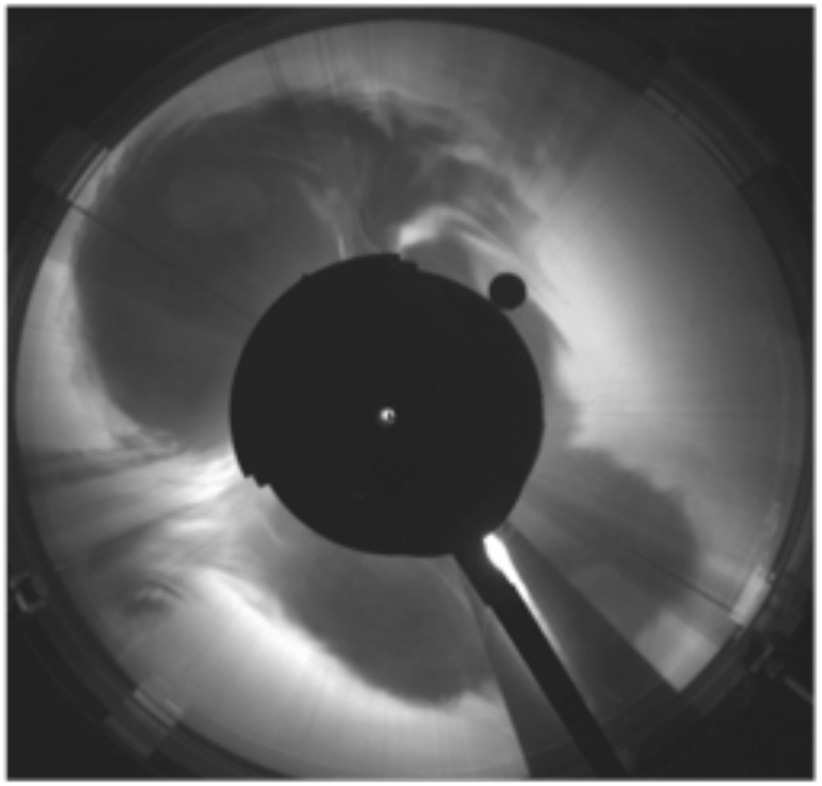
Ω —> increasing (Bu decreasing, d increasing)

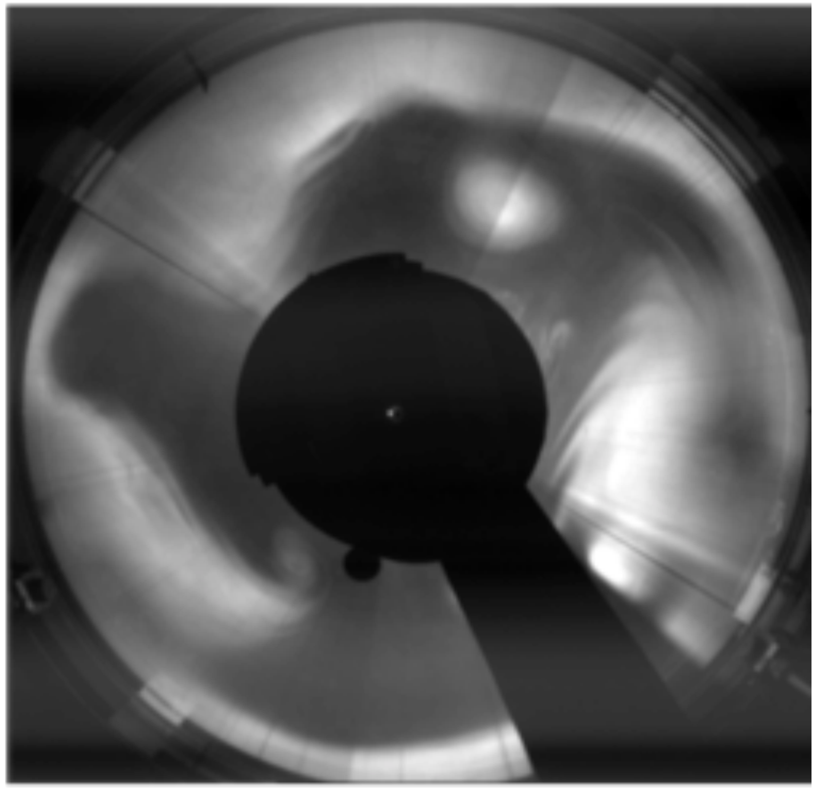

axisymmetric


KH -Hölmböe

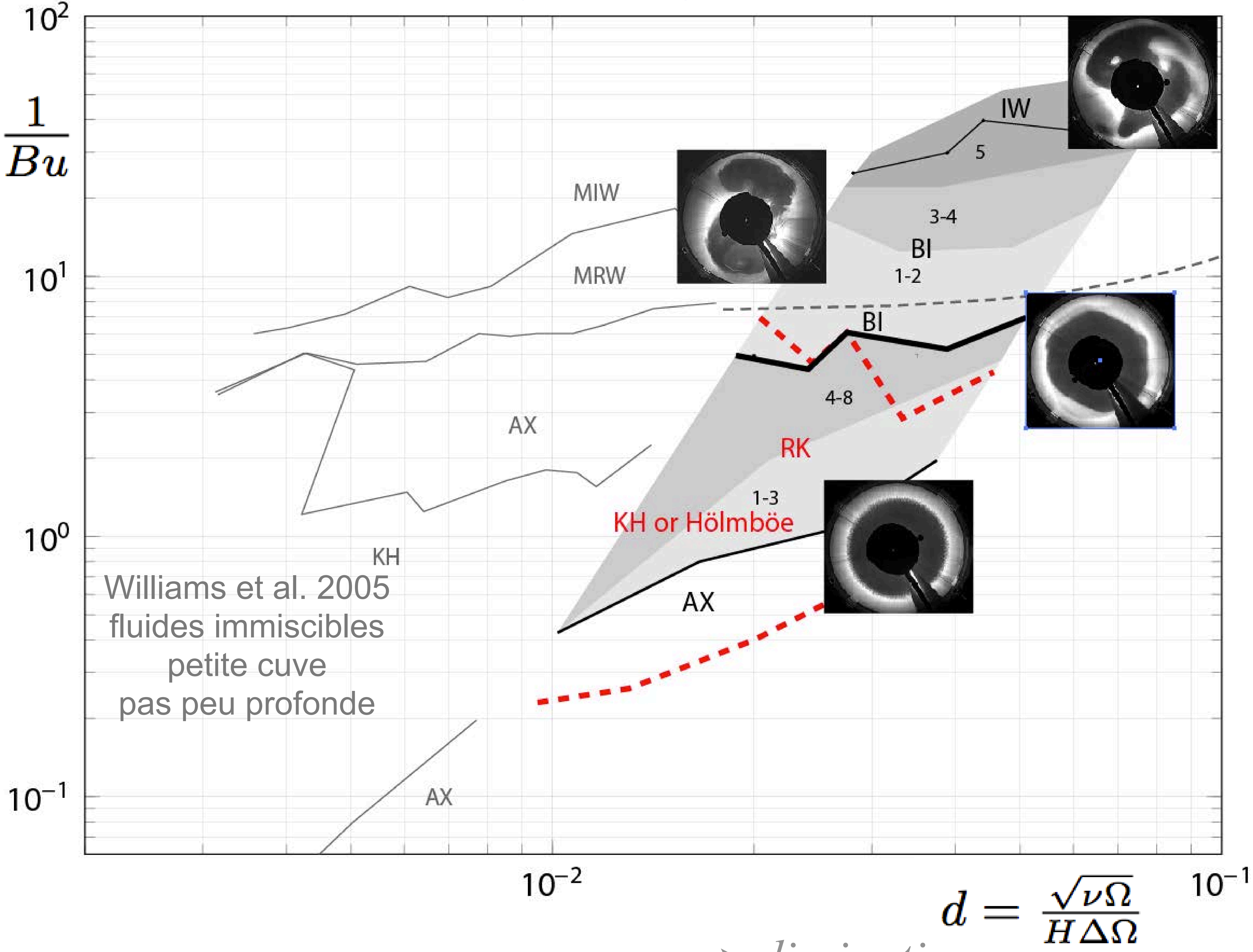

Rossby Kelvin


baroclinic instability


baroclinic instability


mixed irregular waves + vortices

Regime diagram

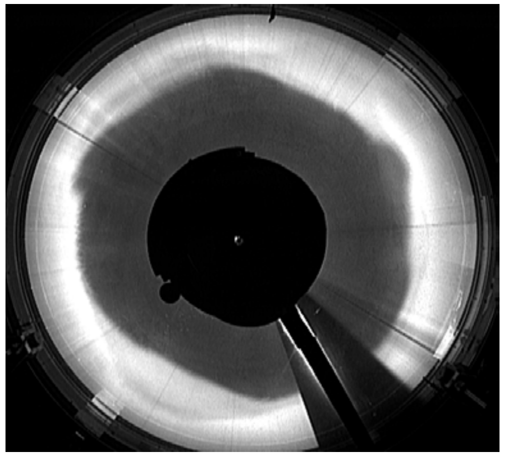


Williams et al. 2005
fluides immiscibles
petite cuve
pas peu profonde

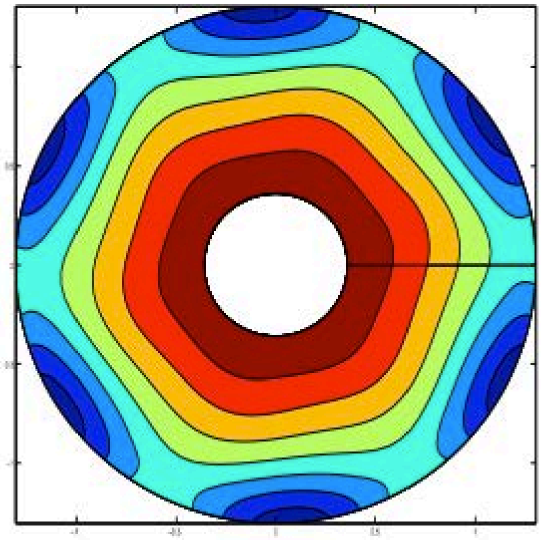
⟶ *dissipation*

Rossby Kelvin instability

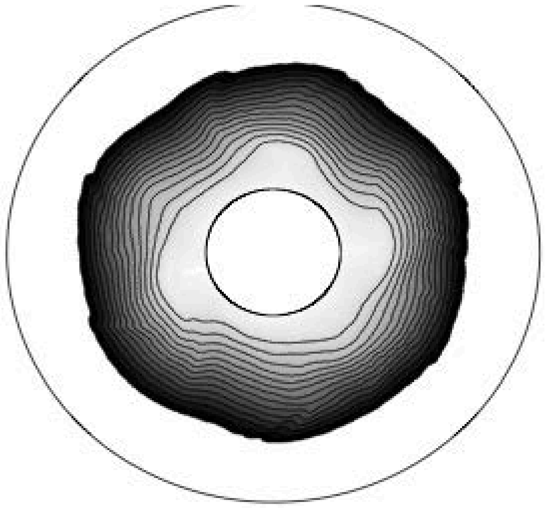
LAB



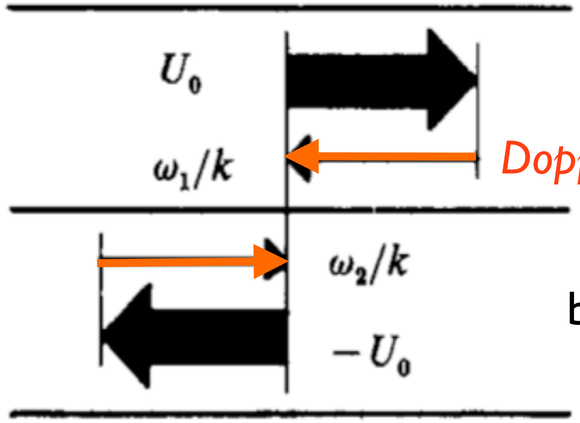
theory



DNS



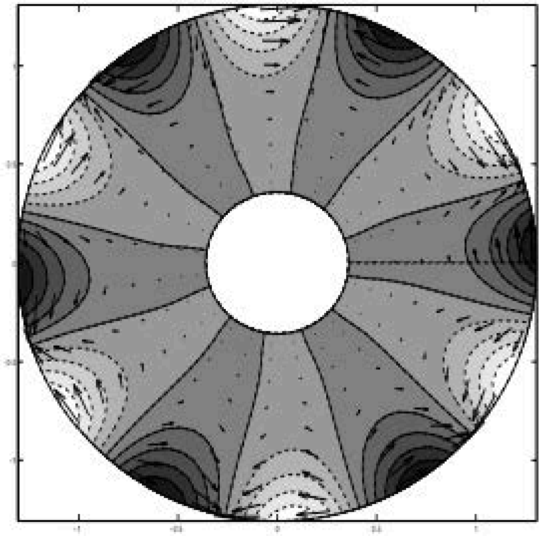
density height

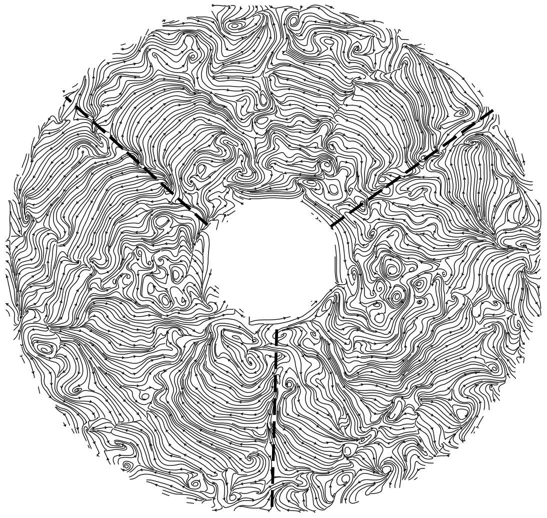


top Kelvin wave

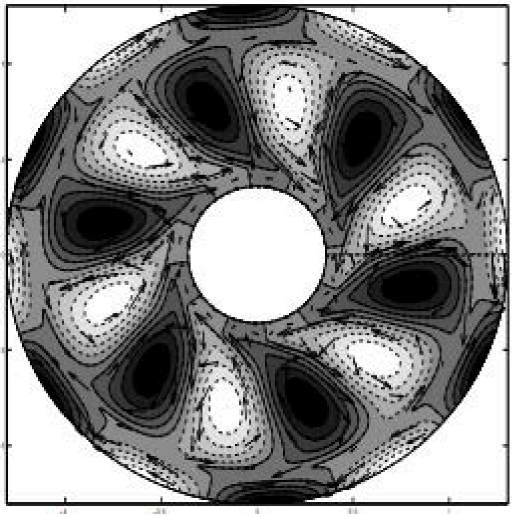
Doppler shift

bottom Rossby wave





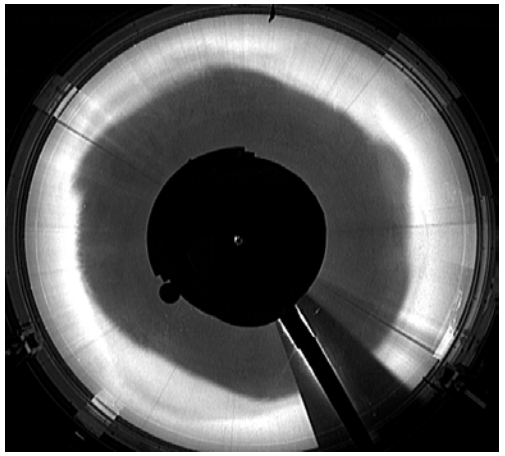
top Kelvin wave



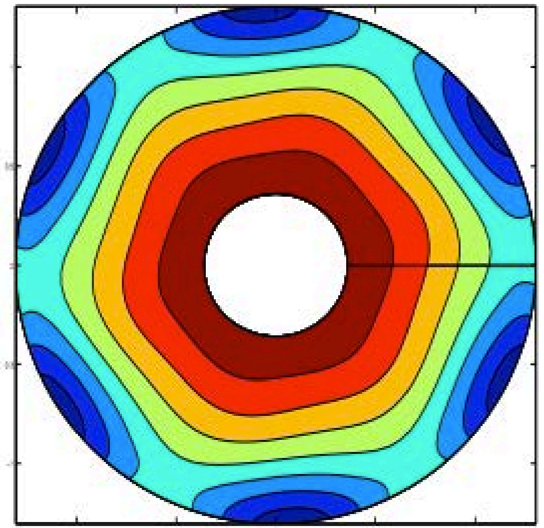
bottom Rossby wave

Rossby Kelvin instability

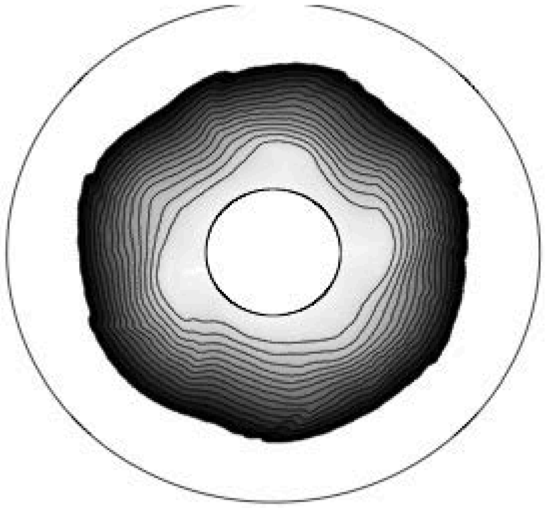
LAB



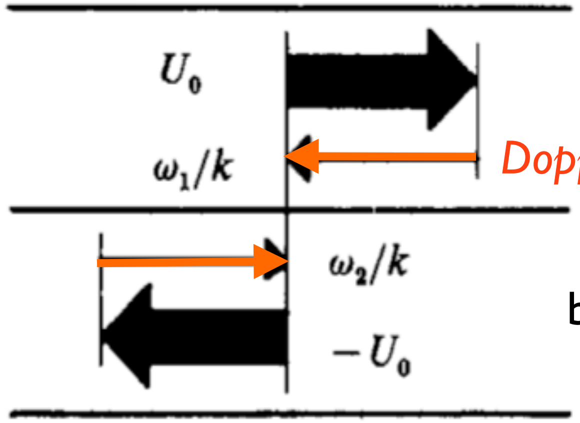
theory



DNS

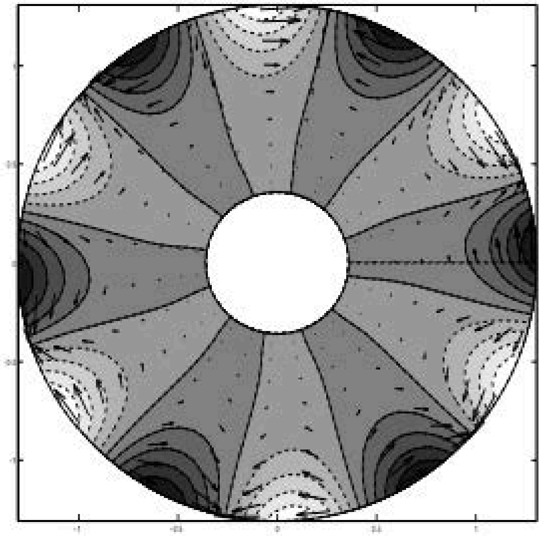


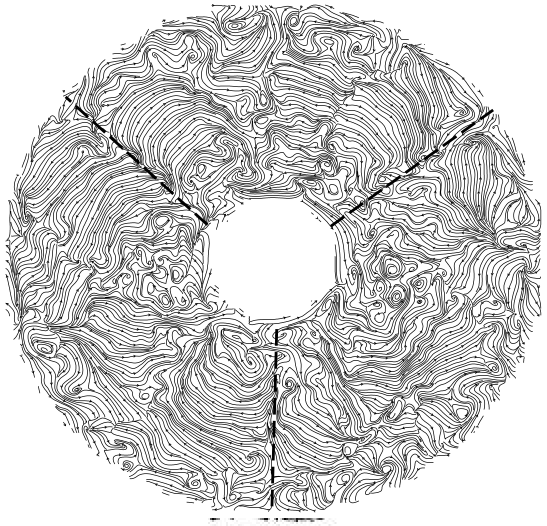
density height



top Kelvin wave

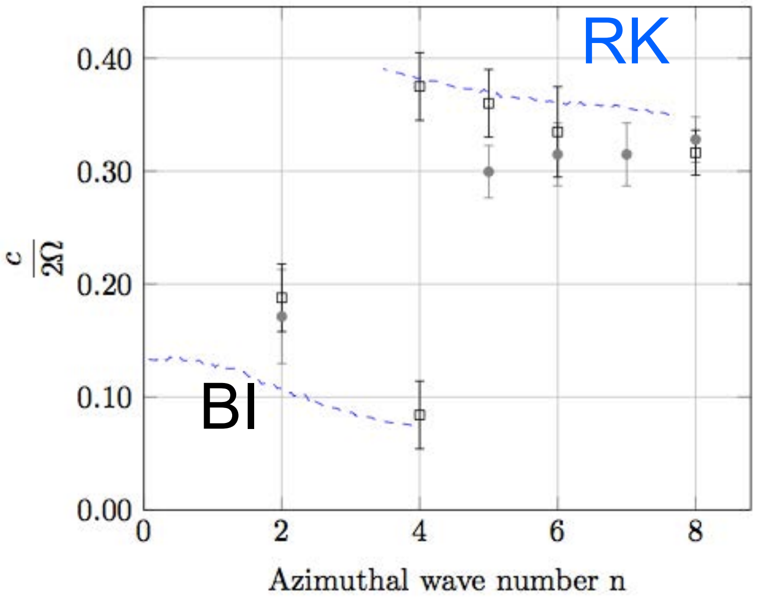
bottom Rossby wave

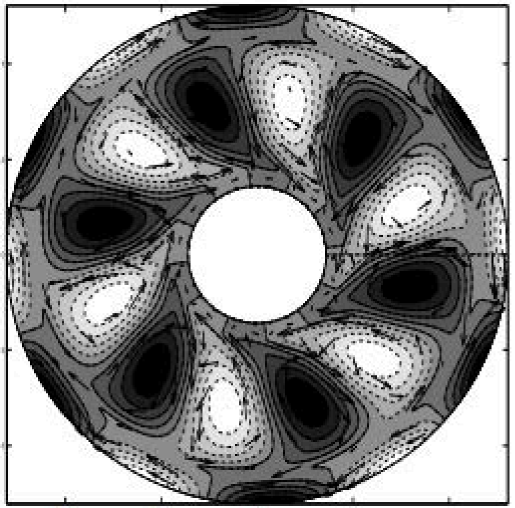




top Kelvin wave

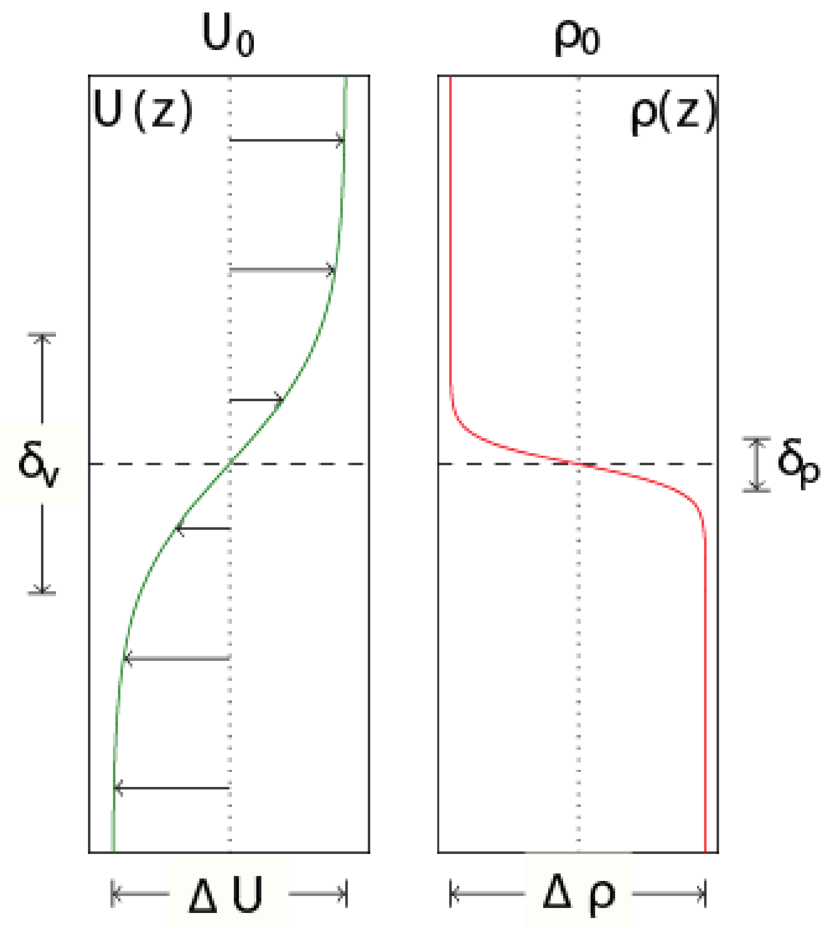
Phase speed/2Ω



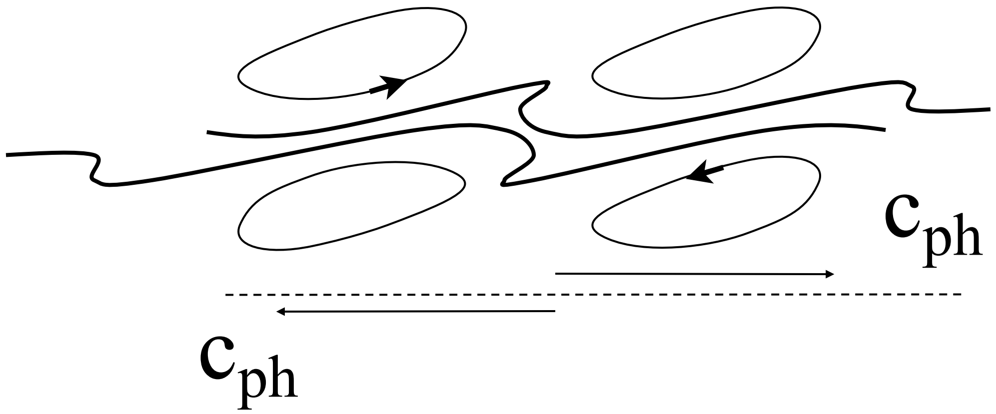


bottom Rossby wave

Hölmböe or Kelvin Helmholtz instability

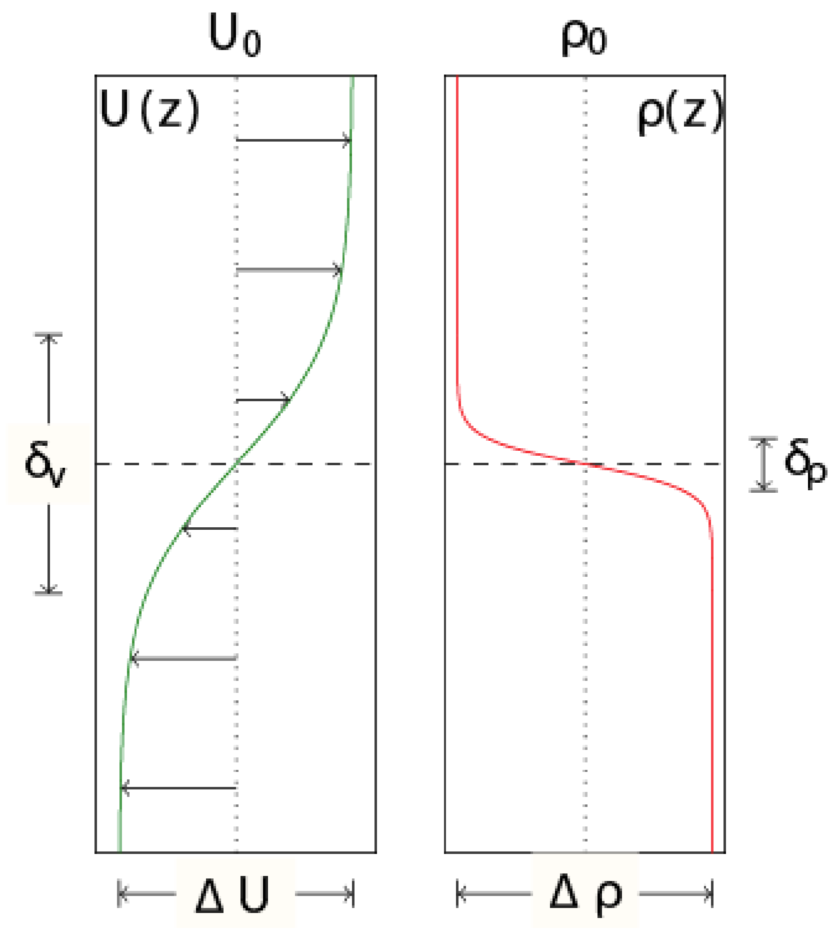


$$R = \frac{\delta_u}{\delta_\rho}$$

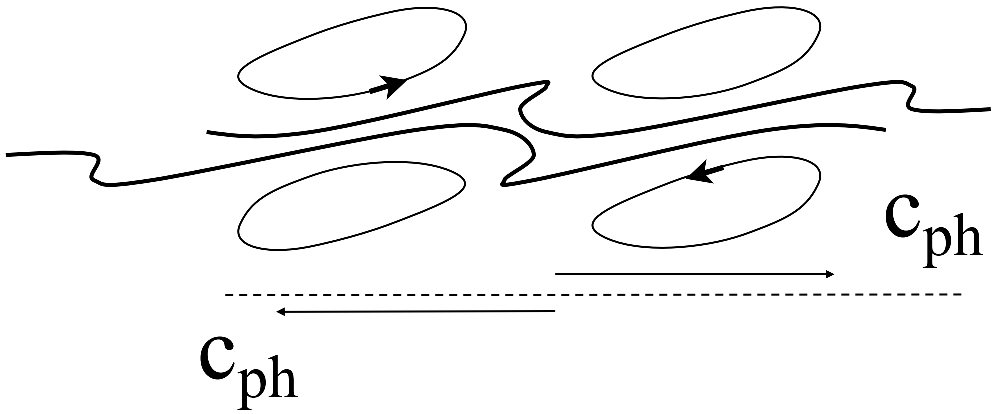


Hölmböe: retrograde phase speed: $-\Delta\Omega$!

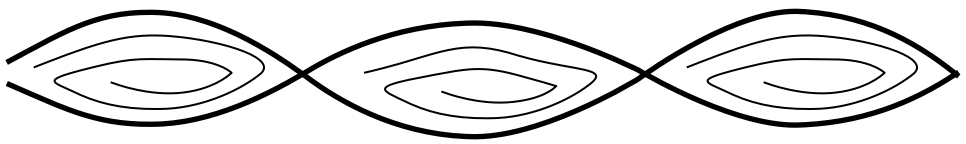
Hölmböe or Kelvin Helmholtz instability



$$R = \frac{\delta_u}{\delta_\rho}$$



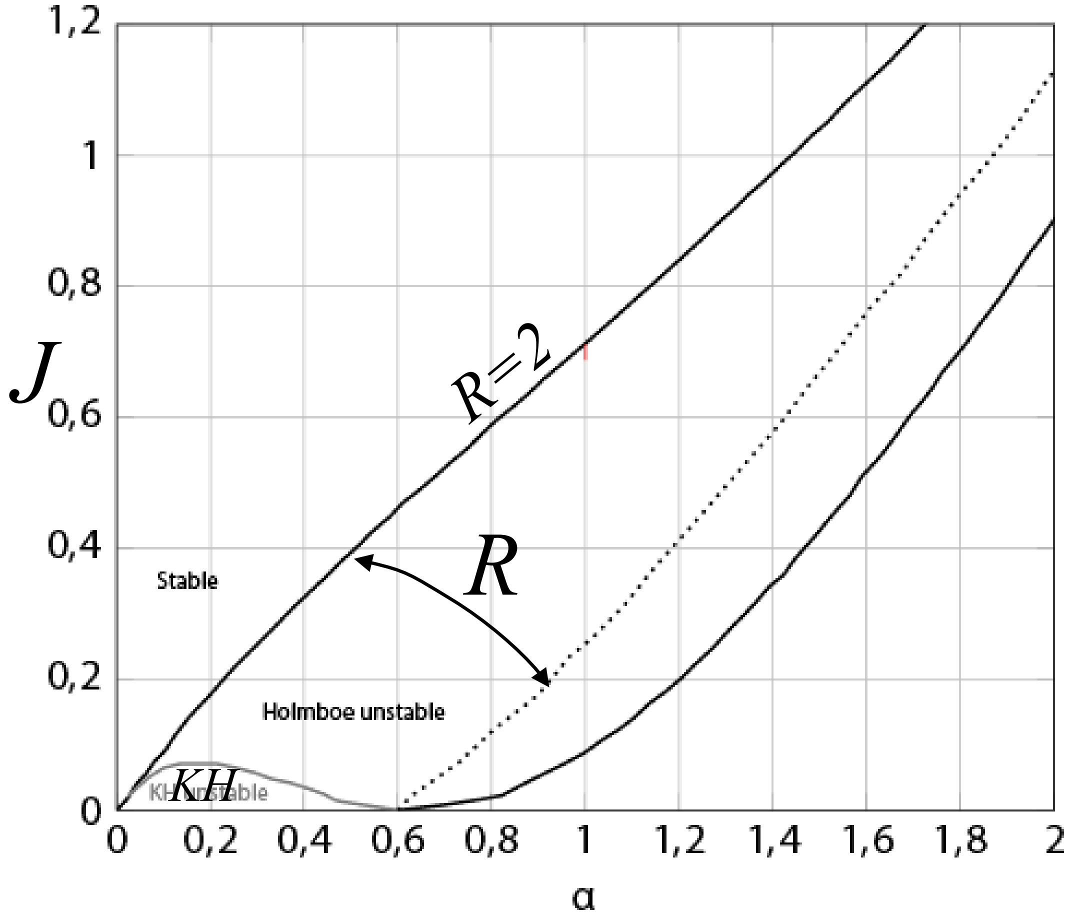
Hölmböe: retrograde phase speed: – ΔΩ !

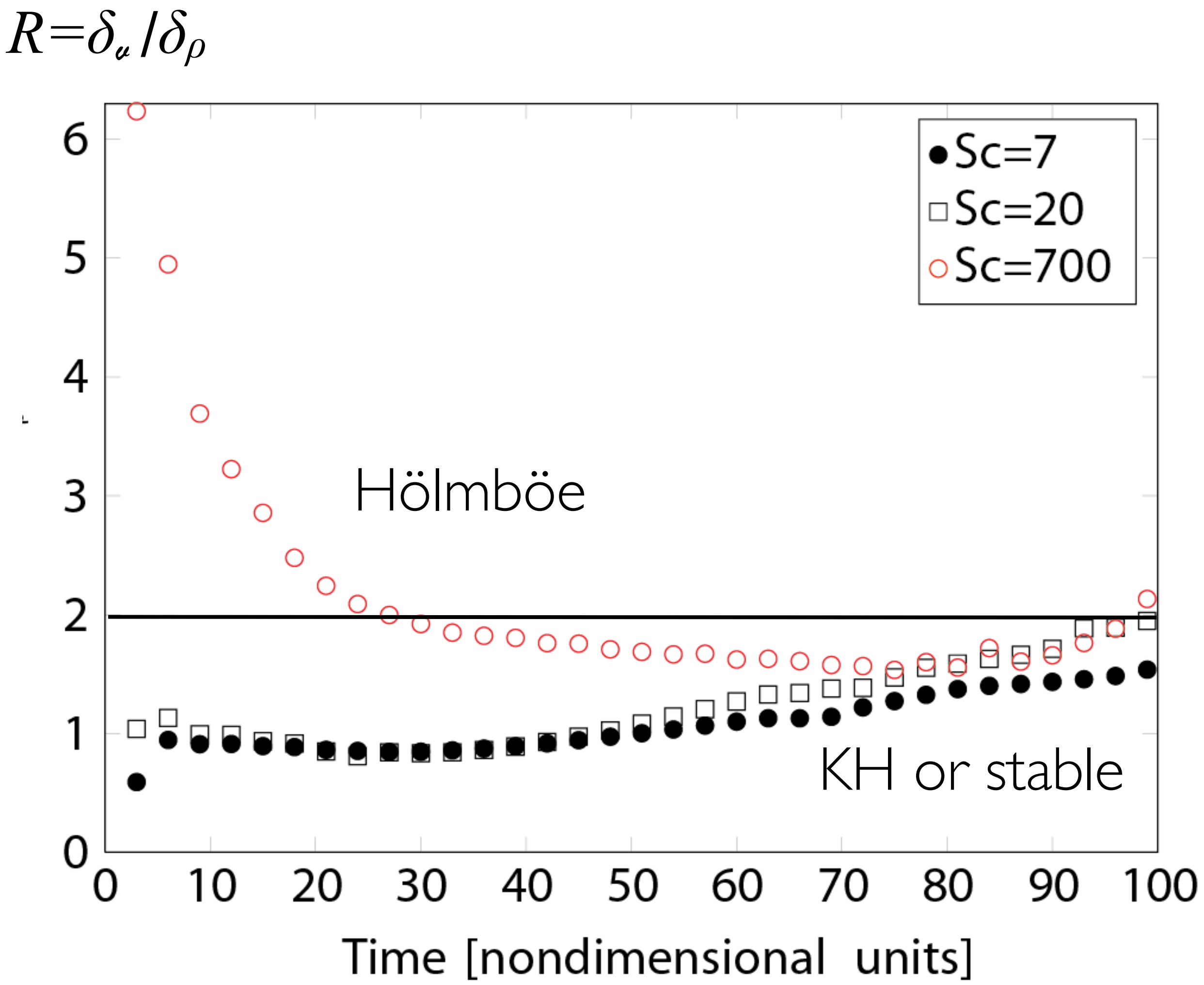


KH: advected by the mean flow

Hölmböe instability

R>2 Hölmböe





$$Ri = \frac{g' 2\delta_v}{(\Delta U)^2} R = JR$$

$$R = \frac{\delta_u}{\delta_\rho}$$

and observation of retrograde phase speed: – ΔΩ

→ Hölmböe

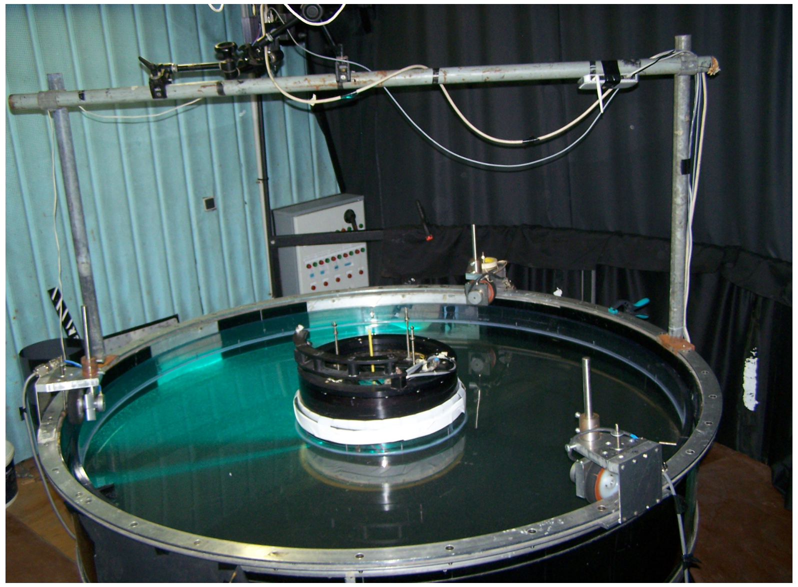
Conclusions

- Observation : instabilité Rossby-Kelvin au laboratoire
- Instabilité Holmboe.

---- examples géophysiques…

- Importance des conditions de l'interface pour la dynamique des fronts

Perspectives :

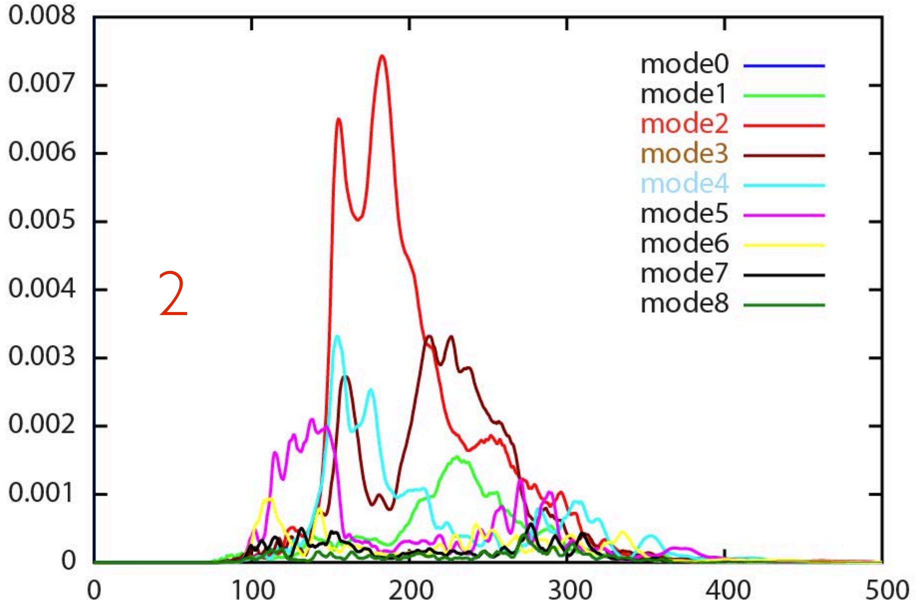


Effet de *Schmidt* (Prandtl) sur Holmböe et RK

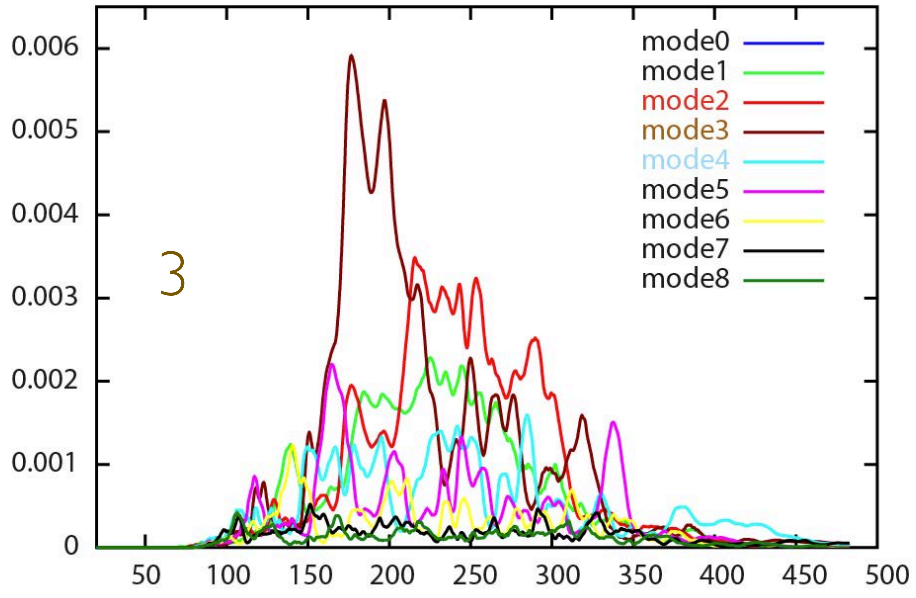
Diagramme 3D, parametres (Ro, Bu, et d)

Flor et al JFM 2011, Préparation: Scolan et al, AGU-Geopress 2012 , PoF 2012, JFM 2013.

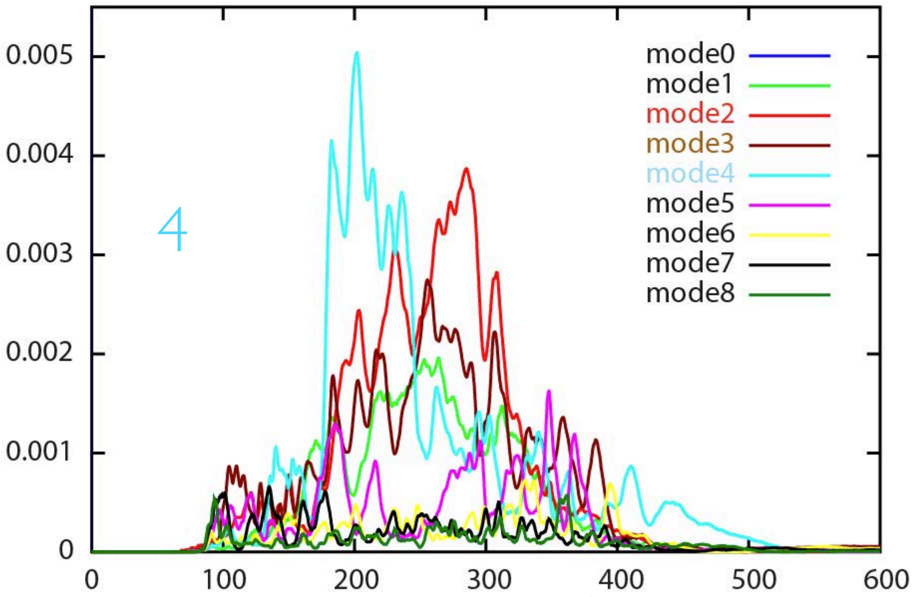
Growth rate



Sc=15



Sc=20



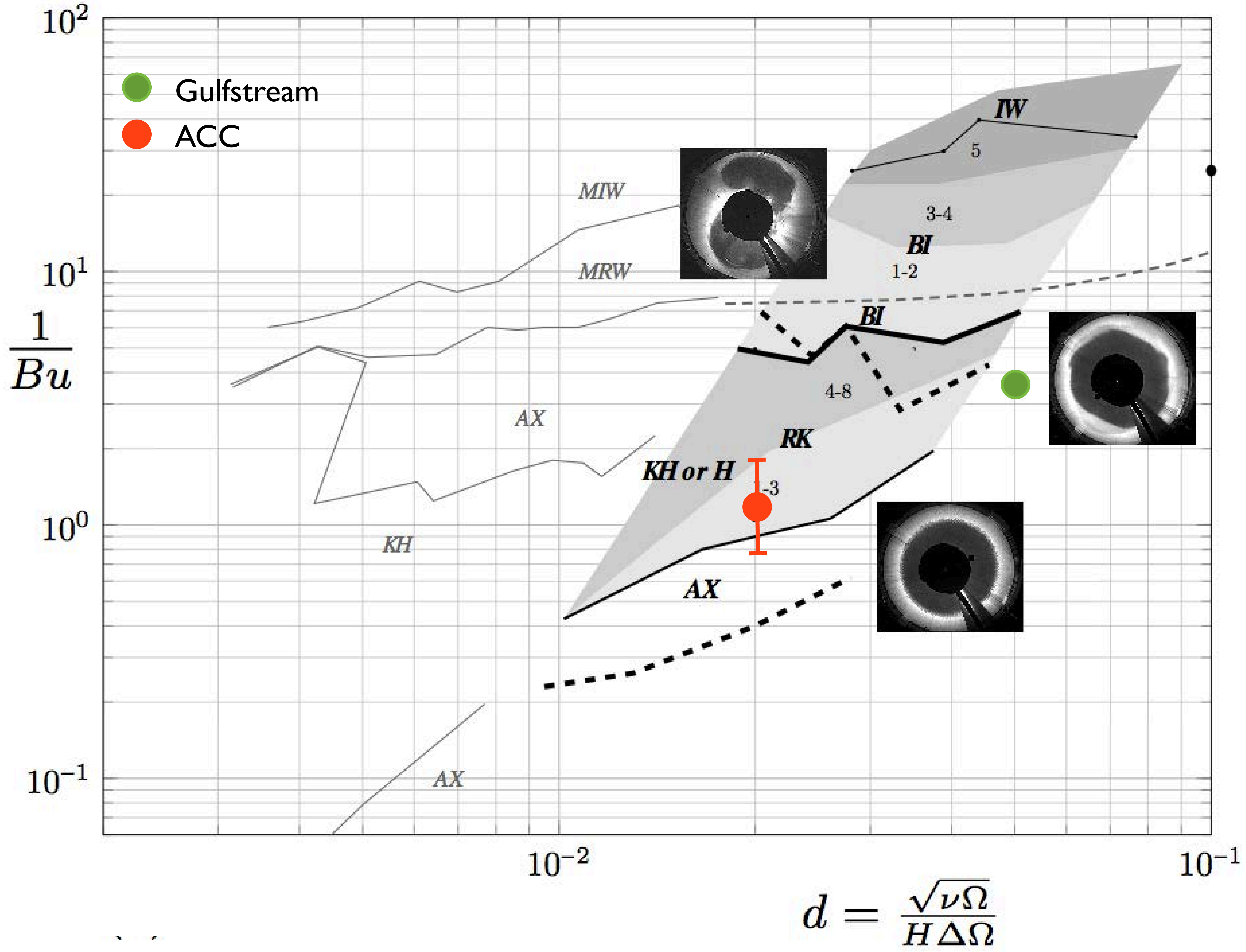
time

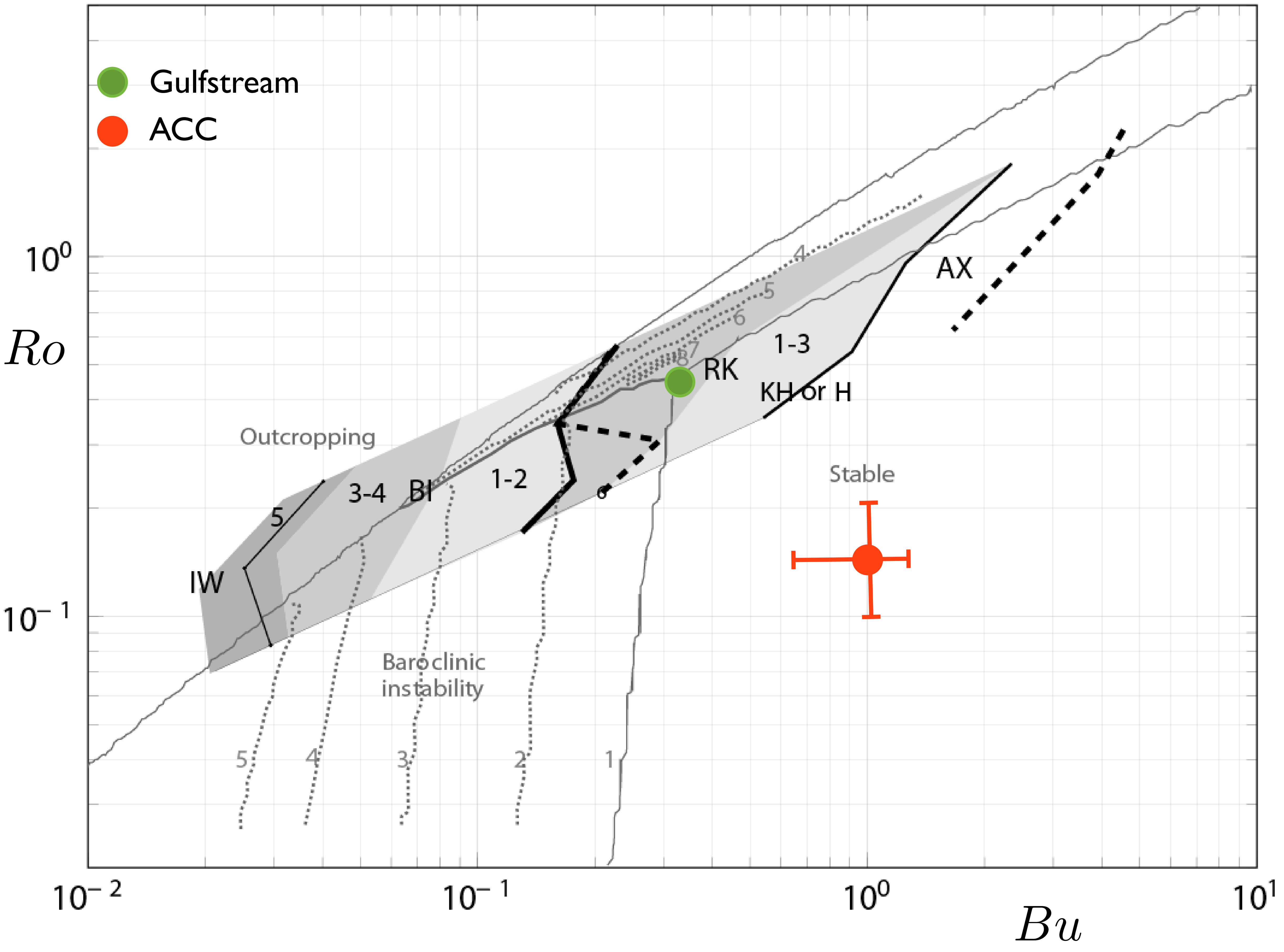
Sc=25

Sharper interface

higher modes
grow faster

Bu=0,3, d=0.022, Ro=0.5


● Gulfstream
● ACC
10^2
10^1
10^0
10^{-1}
$\frac{1}{Bu}$
10^{-2}
10^{-1}
$d = \frac{\sqrt{\nu\Omega}}{H\Delta\Omega}$
MIW
MRW
AX
KH
AX
IW
5
3-4
BI
1-2
BI
4-8
RK
KH or H
-3
AX


● Gulfstream
● ACC
Ro
Bu
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
Outcropping
IW
5
3-4
BI
1-2
RK
1-3
KH or H
AX
Stable
Baroclinic instability
4
5
6
7
8
6
5
4
3
2
1

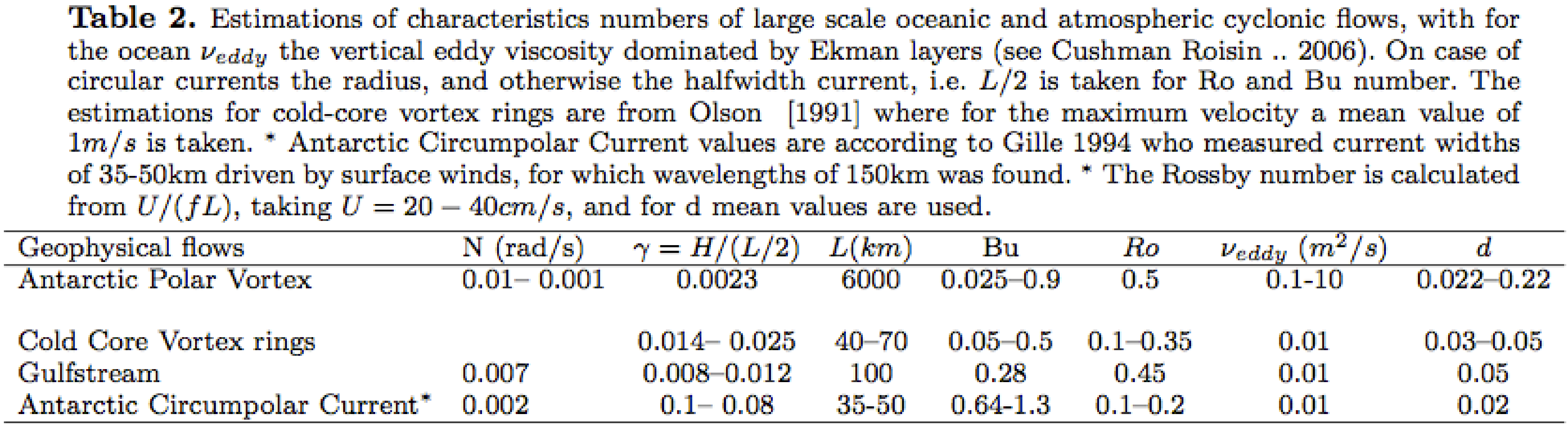


Table 2. Estimations of characteristics numbers of large scale oceanic and atmospheric cyclonic flows, with for the ocean ν_{eddy} the vertical eddy viscosity dominated by Ekman layers (see Cushman Roisin .. 2006). On case of circular currents the radius, and otherwise the halfwidth current, i.e. $L/2$ is taken for Ro and Bu number. The estimations for cold-core vortex rings are from Olson [1991] where for the maximum velocity a mean value of $1m/s$ is taken. * Antarctic Circumpolar Current values are according to Gille 1994 who measured current widths of 35-50km driven by surface winds, for which wavelengths of 150km was found. * The Rossby number is calculated from $U/(fL)$, taking $U = 20 - 40cm/s$, and for d mean values are used.

Geophysical flows	N (rad/s)	$\gamma = H/(L/2)$	$L(km)$	Bu	Ro	ν_{eddy} (m^2/s)	d
Antarctic Polar Vortex	0.01– 0.001	0.0023	6000	0.025–0.9	0.5	0.1-10	0.022–0.22
Cold Core Vortex rings		0.014– 0.025	40–70	0.05–0.5	0.1–0.35	0.01	0.03–0.05
Gulfstream	0.007	0.008–0.012	100	0.28	0.45	0.01	0.05
Antarctic Circumpolar Current*	0.002	0.1– 0.08	35-50	0.64-1.3	0.1–0.2	0.01	0.02

Experimental set-up