Reduction of the vertical transport in stably stratified turbulent shear flows

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Basic equations

Flow in rectangular box sized **6LxL** *(L, vertical height scale)*

At the top and bottom of the flow : Free-slip type for the velocity
Fixed temperature

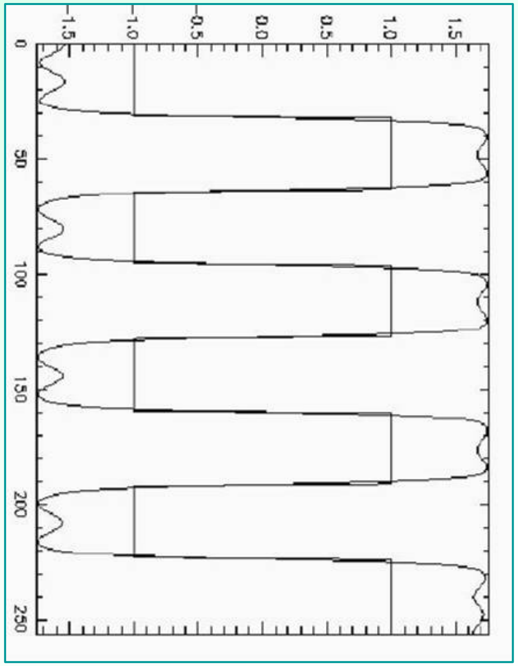
In the horizontal direction : Periodic boundary conditions

Initial temperature profile : dTo/dz = constante > 0

<ins>***Set of equations***</ins> *:*

Navier-Stokes equations in the Boussinesq approximation
with an additional forcing term :

7 shear layers generated (Fo, force intensity per unit mass)



Temperature equation and passive scalar transport equation

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Numerical model

Pseudo spectral method with FFT :

*Non linear terms calculated in the real space with the **Collocation** method*

*Aliasing error removed by **2/3 truncation rule***

Advancement in time : *Second order **Leapfrog** scheme except for the viscous and diffusive terms implicitly treated with the **Cranck-Nicholson** scheme*

*Lagrangian particles tracking : Explicit second order **Heun** scheme for time advancement*

*Fourth order **Hermite** interpolation to obtain the velocity at particle position*

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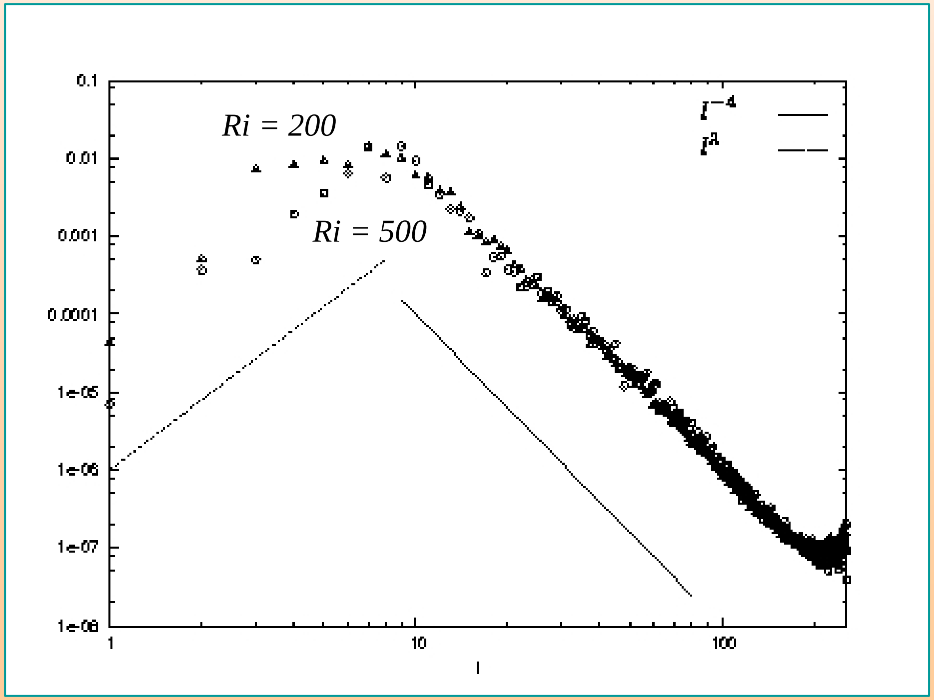
Parameter range

Different flows by increasing the stratification : Ri = 100 up to 2000 (10 simulations)

$Re_t = \frac{lv}{\nu} = 161$, $Pe_{Ct} = \frac{lv}{D} = 158$ and $0.16 < Fr = \frac{v}{lN} < 0.45$

For all simulations, $Pr = 1.9 \times 10^{-4}$



Grid points number : 1536 x 256
Aspect ratio : 6
Lagrangian particles number : 393216

Kinetic energy spectrum with exponent -4
Passive scalar spectrum with exponent -2
Temperature spectrum with exponent -8

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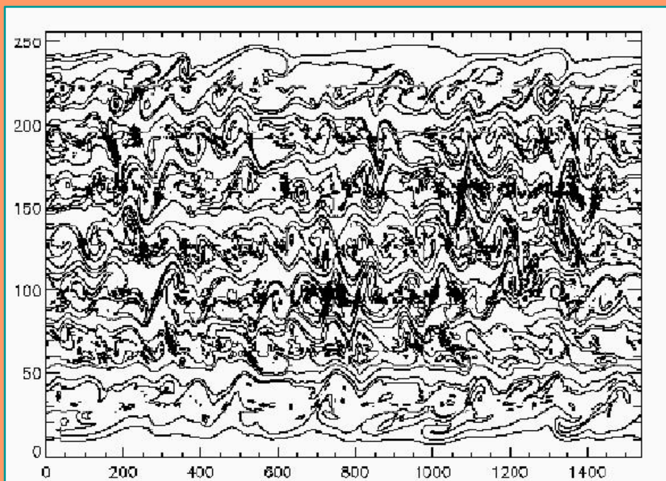
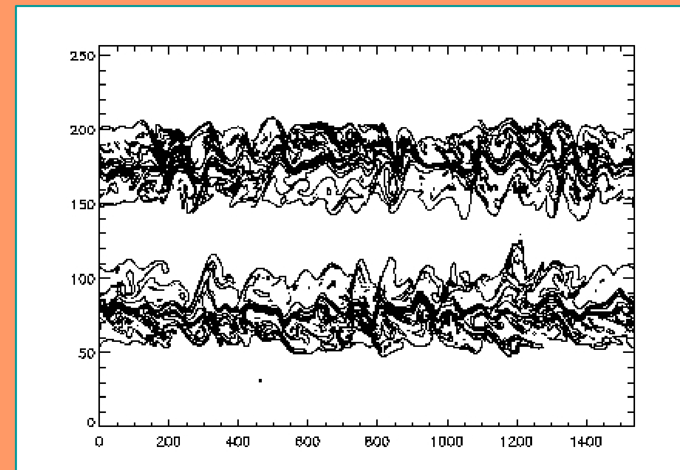
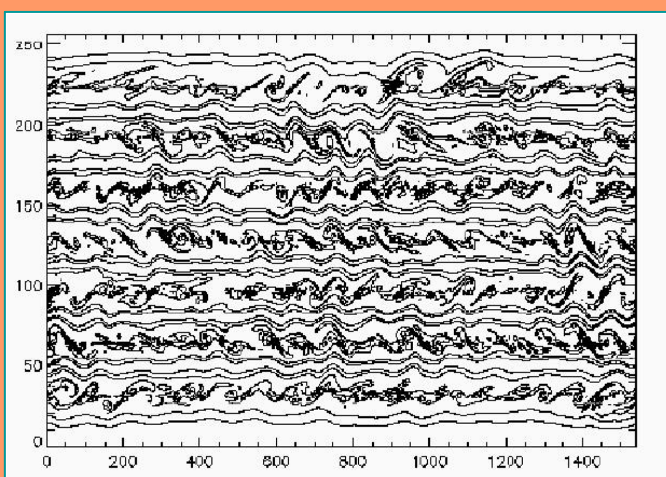
Vorticity outlines

Isotracer outlines

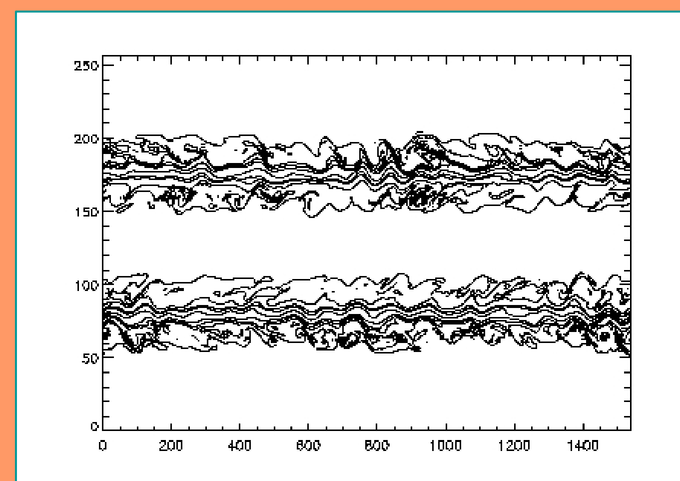


Ri = 200





Ri = 500



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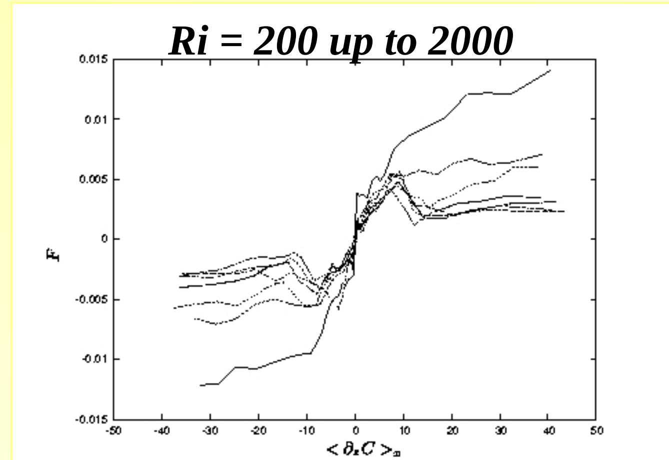
Simulations results I

Definition of two diffusion coefficients:

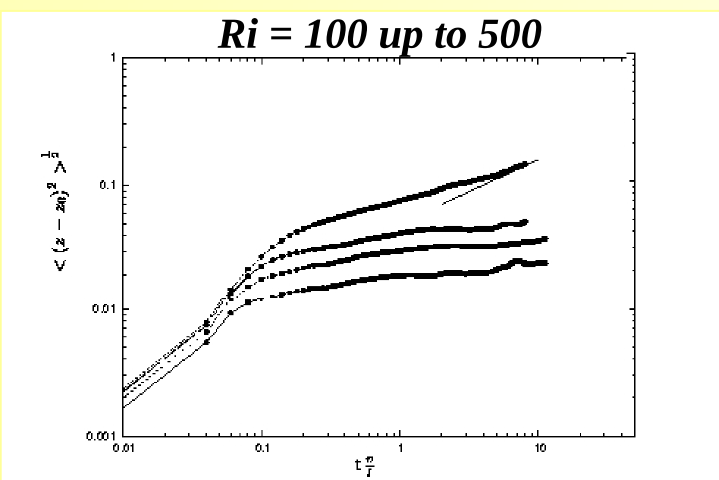
Dt *from the ratio between*

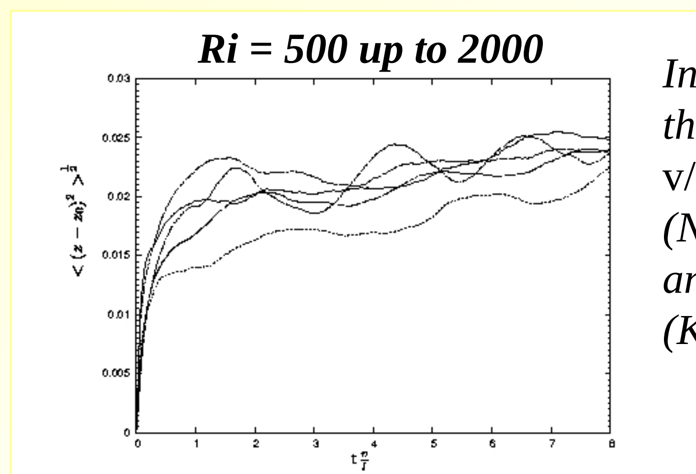
$F(t, z) = < v_z C >_x$ *and* $< \partial_z C >_x$



DL *from the ratio between*

$< (z - z_0)^2 >^{1/2}$ *and time*





In agreement with the asymptotic limit v/N *of the model of (Nicolleau et al. 2000) and with the model of (Kaneda et al. 2000)*

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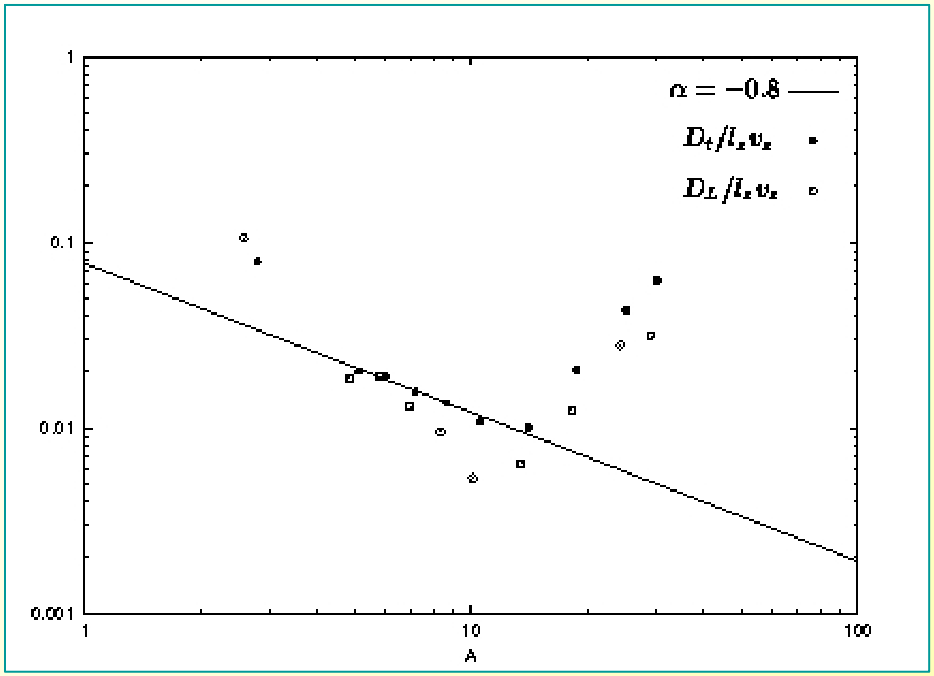
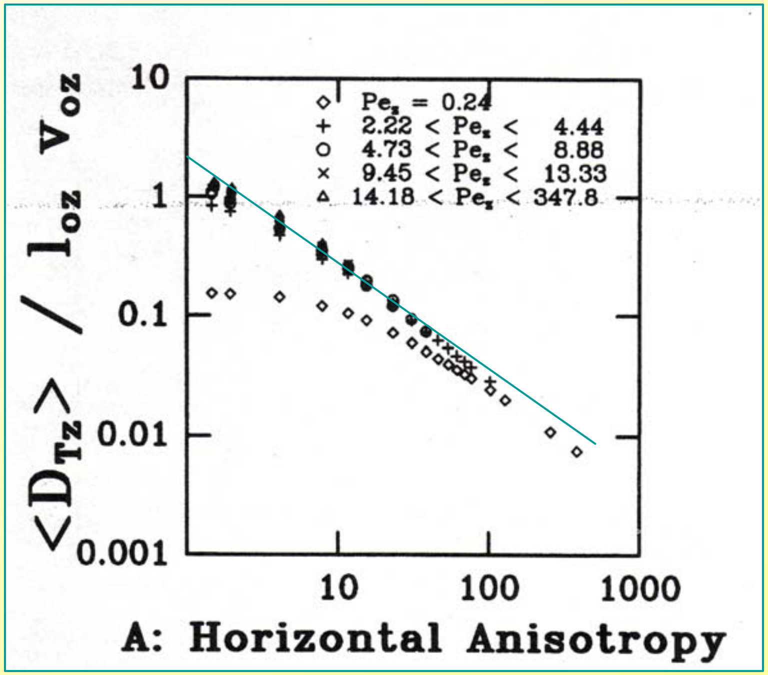
Simulations results II
Comparison with the results of Vincent et al. 1996

$\frac{D_t}{l_z v_z}$ *and* $\frac{D_L}{l_z v_z}$ *versus anisotropy defined as :* $A = \sqrt{\frac{<v_x^2>}{<v_z^2>}}$





Similar evolution *between the two ratios*

Two phases *:*

A *<10, the flux decreases faster than the rms vertical velocity, compatible with the diffusion reduction by horizontal turbulence*

A *>10, no longer compatible with the results of Vincent et al.*

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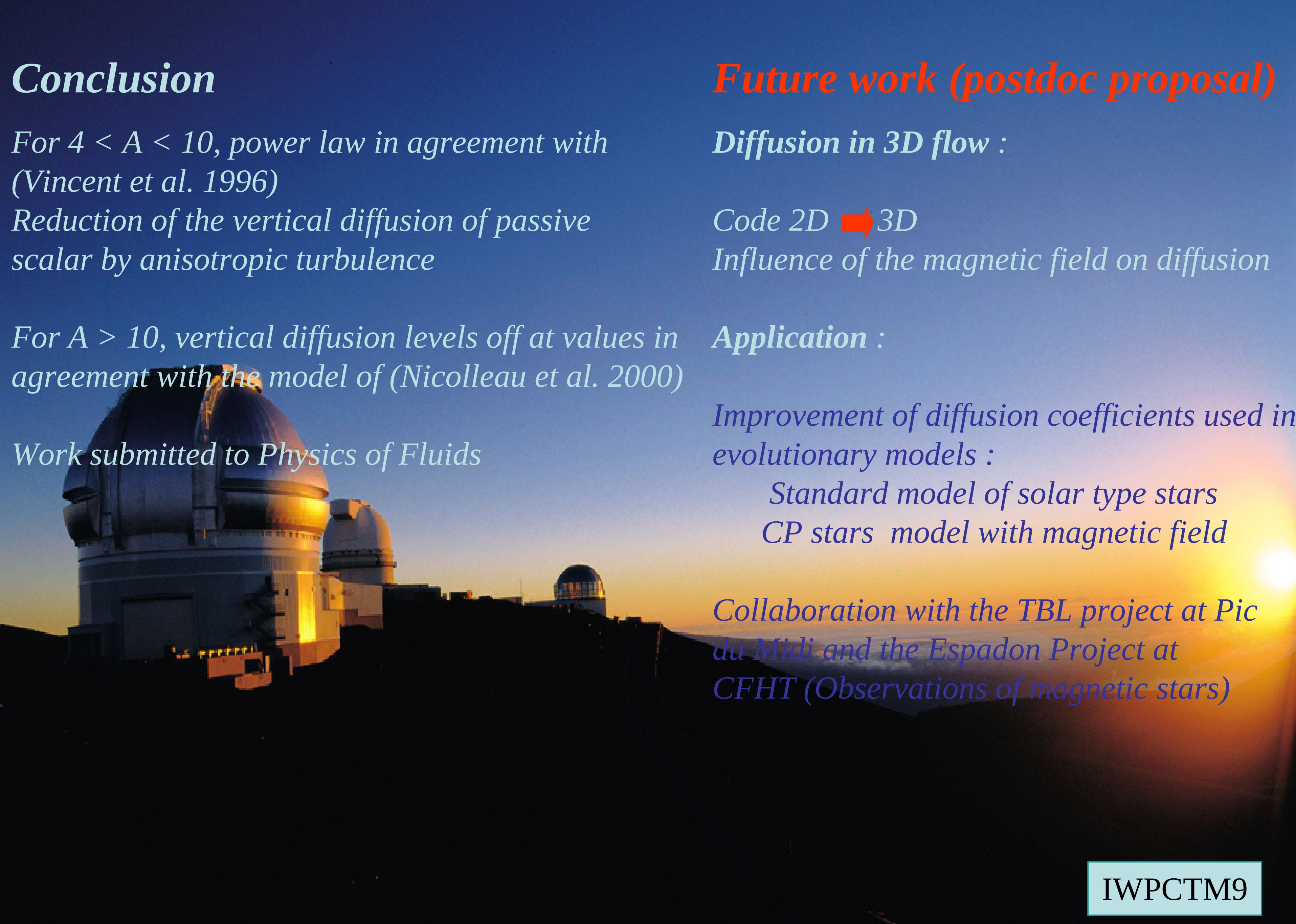
Conclusion
For 4 < A < 10, power law in agreement with (Vincent et al. 1996)
Reduction of the vertical diffusion of passive scalar by anisotropic turbulence
For A > 10, vertical diffusion levels off at values in agreement with the model of (Nicolleau et al. 2000)
Work submitted to Physics of Fluids
Future work (postdoc proposal)
Diffusion in 3D flow :
Code 2D → 3D
Influence of the magnetic field on diffusion
Application :
Improvement of diffusion coefficients used in evolutionary models :
Standard model of solar type stars
CP stars model with magnetic field
Collaboration with the TBL project at Pic du Midi and the Espadon Project at CFHT (Observations of magnetic stars)
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