# Partie VIII

# Bibliographie

# Bibliographie


- Bailly, C. et Comte-Bellot, G. 2003, *Turbulence*, CNRS Editions.
- Balbus, S. A. et Hawley, J. F. 1991a, A powerful local shear instability in weakly magnetized disks. I - Linear analysis., *Astrophysical Journal* **376**, 214.
- Balbus, S. A. et Hawley, J. F. 1991b, A powerful local shear instability in weakly magnetized disks. II - Nonlinear evolution, *Astrophysical Journal* **376**, 223.
- Balbus, S. A. et Hawley, J. F. 1998, Instability, turbulence, and enhanced transport in accretion disks, *Reviews of Modern Physics* **70**, 1.
- Balbus, S. A. et Hawley, J. F. 2003, Numerical Simulations of MHD Turbulence in Accretion Disks, dans E. Falgarone et T. Passot (éditeurs), *LNP Vol. 614: Turbulence and Magnetic Fields in Astrophysics*, pp. 329–348.
- Balbus, S. A., Hawley, J. F. et Stone, J. M. 1996, Nonlinear Stability, Hydrodynamical Turbulence, and Transport in Disks, *Astrophysical Journal* **467**, 76.
- Balbus, S. A. et Terquem, C. 2001, Linear Analysis of the Hall Effect in Protostellar Disks, *Astrophys. J.* **552**, 235.
- Bardeen, J. M. et Petterson, J. A. 1975, The Lense-Thirring Effect and Accretion Disks around Kerr Black Holes, *Astrophysical Journal, Letters* **195**, L65+.
- Barranco, J. A. et Marcus, P. S. 2005, Three-dimensional Vortices in Stratified Protoplanetary Disks, *Astrophysical Journal* **623**, 1157.
- Bate, M. R., Bonnell, I. A. et Bromm, V. 2002, The formation of close binary systems by dynamical interactions and orbital decay, *Mon. Not. of the Royal Astron. Soc.* **336**, 705.
- Blaes, O. M. 1987, Stabilization of non-axisymmetric instabilities in a rotating flow by accretion on to a central black hole, *Mon. Not. of the Royal Astron. Soc.* **227**, 975.
- Blaes, O. M. 2004, Course 3: Physics Fundamentals of Luminous Accretion Disks around Black Holes, dans V. Beskin, G. Henri, F. Menard et et al. (éditeurs), *Accretion Discs, Jets and High Energy Phenomena in Astrophysics*, pp. 137–185.
- Blaes, O. M. et Balbus, S. A. 1994, Local shear instabilities in weakly ionized, weakly magnetized disks, *Astrophys. J.* **421**, 163.
- Blandford, R. D. et Payne, D. G. 1982, Hydromagnetic flows from accretion discs and the production of radio jets, *Mon. Not. of the Royal Astron. Soc.* **199**, 883.
- Brandenburg, A. 2003, *Computational aspects of astrophysical MHD and turbulence*, pp. 269–+, Advances in Nonlinear Dynamics.
- Brandenburg, A., Nordlund, A., Stein, R. F. et Torkelsson, U. 1995, Dynamo-generated Turbulence and Large-Scale Magnetic Fields in a Keplerian Shear Flow, *ApJ* **446**, 741.
- Brandenburg, A. et Ruediger, G. 2005, The angular momentum transport by the strato-rotational instability in simulated Taylor-Couette flows, *astro-ph/0512409* .

- Brandenburg, A. et Subramanian, K. 2005, Astrophysical magnetic fields and nonlinear dynamo theory, *Phys. Rep.* **417**, 1.
- Cabot, W. 1996, Numerical Simulations of Circumstellar Disk Convection, *Astrophysical Journal* **465**, 874.
- Cabrit, S. 2002, Constraints on accretion-ejection structures in young stars, dans J. Bouvier et J.-P. Zahn (éditeurs), *EAS Publications Series*, vol. 3, pp. 147–182.
- Canuto, C., Hussaini, M. Y., Quarteroni, A. et Zang, T. A. 1988, *Spectral methods in fluid dynamics*, Springer.
- Casse, F. et Ferreira, J. 2000, Magnetized accretion-ejection structures. IV. Magnetically-driven jets from resistive, viscous, Keplerian discs, *Astron. & Astrophys.* **353**, 1115.
- Casse, F. et Keppens, R. 2002, Magnetized Accretion-Ejection Structures: 2.5-dimensional Magnetohydrodynamic Simulations of Continuous Ideal Jet Launching from Resistive Accretion Disks, *Astrophysical Journal* **581**, 988.
- Cho, J., Lazarian, A. et Vishniac, E. T. 2002, New Regime of Magnetohydrodynamic Turbulence: Cascade below the Viscous Cutoff, *Astrophysical Journal, Letters* **566**, L49.
- Cho, J. et Vishniac, E. T. 2000, The Anisotropy of Magnetohydrodynamic Alfvénic Turbulence, *Astrophysical Journal* **539**, 273.
- Cooley, J. W. et Turkey, J. W. 1965, An algorithm for the machine calculation of complex Fourier series, *Math. Comput* **19**, 297.
- Darbyshire, A. G. et Mullin, T. 1995, Transition to turbulence in constant-mass-flux pipe flow, *J. Fluid Mech.* **289**, 83.
- Dauchot, O. et Daviaud, F. 1995a, Finite amplitude perturbation and spots growth mechanism in plane Couette flow, *Phys. Fluids* **7**, 335.
- Dauchot, O. et Daviaud, F. 1995b, Streamwise vortices in plane Couette flow, *Phys. Fluids* **7**, 901.
- Daviaud, F., Hegseth, J. et Bergé, P. 1992, Subcritical transition to turbulence in plane couette flow, *Phys. Rev. Lett.* **69**, 2511.
- Dubrulle, B., Dauchot, O., Daviaud, F., Longaretti, P.-Y. *et al.* 2005a, Stability and turbulent transport in Taylor-Couette flow from analysis of experimental data, *Phys. Fluids* **17**, 095103.
- Dubrulle, B., Marié, L., Normand, C., Richard, D. *et al.* 2005b, An hydrodynamic shear instability in stratified disks, *Astron. & Astrophys.* **429**, 1.
- Evans, C. R. et Hawley, J. F. 1988, Simulation of magnetohydrodynamic flows - A constrained transport method, *Astrophysical Journal* **332**, 659.
- Faisst, H. et Eckhardt, B. 2004, Sensitive dependence on initial conditions in transition to turbulence in pipe flow, *J. Fluid Mech.* **504**, 343.
- Ferreira, J. 1995, *Structures magnétiques d'accrétion-éjection*, Thèse de doctorat, Université Joseph Fourier.
- Ferreira, J. 1997, Magnetically-driven jets from Keplerian accretion discs., *Astron. & Astrophys.* **319**, 340.
- Ferreira, J. et Pelletier, G. 1995, Magnetized accretion-ejection structures. III. Stellar and extragalactic jets as weakly dissipative disk outflows., *Astron. & Astrophys.* **295**, 807.

- Fleming, T. et Stone, J. M. 2003, Local Magnetohydrodynamic Models of Layered Accretion Disks, *Astrophysical Journal* **585**, 908.
- Fleming, T. P., Stone, J. M. et Hawley, J. F. 2000, The Effect of Resistivity on the Nonlinear Stage of the Magnetorotational Instability in Accretion Disks, *Astrophysical Journal* **530**, 464.
- Forsythe, G. E. et Wasow, W. 1964, *Finite-difference methods for partial differential equations*, J. Wiley & Sons.
- Freidberg, J. P. 1987, *Ideal Magneto-Hydro-Dynamics*, Plenum Press.
- Fromang, S., Papaloizou, J., Lesur, G. et Heinemann, T. 2007, Zero net flux MHD simulations of the magnetorotational instability in the shearing box. II. The effect of dissipative coefficients, *Soumis à Mon. Not. of the Royal Astron. Soc.* .
- Gammie, C. F. 1996, Layered Accretion in T Tauri Disks, *Astrophysical Journal* **457**, 355.
- Gardiner, T. A. et Stone, J. M. 2005, Energetics in MRI driven Turbulence, dans E. M. de Gouveia dal Pino, G. Lugones et A. Lazarian (éditeurs), *AIP Conf. Proc. 784: Magnetic Fields in the Universe: From Laboratory and Stars to Primordial Structures.*, pp. 475–488.
- Gauss, C. F. 1866, Nachlass: Theoria interpolationis methodo nova tractata, *Werke* **3**, 265.
- Goldreich, P. et Lynden-Bell, D. 1965, II. Spiral arms as sheared gravitational instabilities, *Mon. Not. of the Royal Astron. Soc.* **130**, 125.
- Goldreich, P. et Sridhar, S. 1995, Toward a theory of interstellar turbulence. 2: Strong alfvenic turbulence, *Astrophysical Journal* **438**, 763.
- Goodman, J. et Balbus, S. A. 2001, Stratified disks are locally stable, *astro-ph/0110229* .
- Goodman, J. et Xu, G. 1994, Parasitic instabilities in magnetized, differentially rotating disks, *Astrophysical Journal* **432**, 213.
- Hamilton, J. M., Kim, J. et Waleffe, F. 1995, Regeneration mechanisms of near-wall turbulence structures, *J. Fluid Mech.* **287**, 317.
- Hawley, J. F. 1991, Three-dimensional simulations of black hole tori, *Astrophysical Journal* **381**, 496.
- Hawley, J. F. 2000, Global Magnetohydrodynamical Simulations of Accretion Tori, *Astrophysical Journal* **528**, 462.
- Hawley, J. F., Balbus, S. A. et Winters, W. F. 1999, Local Hydrodynamic Stability of Accretion Disks, *Astrophysical Journal* **518**, 394.
- Hawley, J. F., Gammie, C. F. et Balbus, S. A. 1995, Local Three-dimensional Magnetohydrodynamic Simulations of Accretion Disks, *Astrophysical Journal* **440**, 742.
- Hill, G. W. 1878, Researches in lunar theory, *American Journal of Mathematics* **1**, 5.
- Jackson, J. D. 1975, *Classical electrodynamics*, John Wiley & Sons.
- Jaffe, W., Ford, H. C., Ferrarese, L., van den Bosch, F. *et al.* 1993, A large nuclear accretion disk in the active galaxy NGC4261, *Nature* **364**, 213.
- Ji, H., Burin, M., Schartman, E. et Goodman, J. 2006, Hydrodynamic turbulence cannot transport angular momentum effectively in astrophysical disks, *Nature* **444**, 343.
- Ji, H., Goodman, J. et Kageyama, A. 2001, Magnetorotational instability in a rotating liquid metal annulus, *Mon. Not. of the Royal Astron. Soc.* **325**, L1.
- Johnson, B. M. et Gammie, C. F. 2005, Linear Theory of Thin, Radially Stratified Disks, *Astrophysical Journal* **626**, 978.

- Johnson, B. M. et Gammie, C. F. 2006, Nonlinear Stability of Thin, Radially Stratified Disks, *Astrophysical Journal* **636**, 63.
- King, A. R., Pringle, J. E. et Livio, M. 2007, Accretion disc viscosity: how big is alpha?, *Mon. Not. of the Royal Astron. Soc.* pp. 226–+.
- Klahr, H. 2004, The Global Baroclinic Instability in Accretion Disks. II. Local Linear Analysis, *Astrophysical Journal* **606**, 1070.
- Klahr, H. H. et Bodenheimer, P. 2003, Turbulence in Accretion Disks: Vorticity Generation and Angular Momentum Transport via the Global Baroclinic Instability, *Astrophysical Journal* **582**, 869.
- Komminaho, J., Lundbladh, A. et Johansson, A. V. 1996, Very large structures in plane turbulent Couette flow, *J. Fluid Mech.* **320**, 259.
- Kozlowski, M., Wiita, P. J. et Paczynski, B. 1979, Self-gravitating accretion disk models with realistic equations of state and opacities, *Acta Astronomica* **29**, 157.
- Krall, N. A. et TrivelPiece, A. W. 1986, *Principles of plasma physcis*, San Francisco press.
- Kuiper, G. P. 1941, On the Interpretation of $\beta$ Lyrae and Other Close Binaries., *Astrophysical Journal* **93**, 133.
- Kunz, M. W. et Balbus, S. A. 2004, Ambipolar diffusion in the magnetorotational instability, *Mon. Not. of the Royal Astron. Soc.* **348**, 355.
- Landau, L. D. et Lifshitz, E. M. 1959, *Fluid mechanics*, Course of theoretical physics, Oxford: Pergamon Press, 1959.
- Lesieur, M. 1990, *Turbulence in fluids third edition*, Kluwer.
- Lesur, G. 2004, *Etude de la turbulence sous critique dans un écoulement de Couette en rotation*, Mémoire de DEA, Ecole normale supérieure de Lyon.
- Lesur, G. et Longaretti, P.-Y. 2005, On the relevance of subcritical hydrodynamic turbulence to accretion disk transport, *Astron. & Astrophys.* **444**, 25.
- Lin, D. N. C. et Papaloizou, J. C. B. 1996, Theory of Accretion Disks II: Application to Observed Systems, *Annual Review of Astron and Astrophys* **34**, 703.
- Livio, M. 1999, Astrophysical jets : a phenomenological examination of acceleration and collimation., *Phys. Rep.* **311**, 225.
- Longaretti, P.-Y. 2002, On the Phenomenology of Hydrodynamic Shear Turbulence, *Astrophysical Journal* **576**, 587.
- Lynden-Bell, D. 1969, Galactic Nuclei as Collapsed Old Quasars, *Nature* **223**, 690.
- Lynden-Bell, D. et Pringle, J. E. 1974, The evolution of viscous discs and the origin of the nebular variables., *Mon. Not. of the Royal Astron. Soc.* **168**, 603.
- Marcus, P. S. 1993, Jupiter's Great Red SPOT and other vortices, *Annual Review of Astron and Astrophys* **31**, 523.
- Menou, K., Balbus, S. A. et Spruit, H. C. 2004, Local Axisymmetric Diffusive Stability of Weakly Magnetized, Differentially Rotating, Stratified Fluids, *Astrophysical Journal* **607**, 564.
- Narayan, R., Goldreich, P. et Goodman, J. 1987, Physics of modes in a differentially rotating system - Analysis of the shearing sheet, *Mon. Not. of the Royal Astron. Soc.* **228**, 1.
- Orszag, S. A. et Patterson, G. S. 1972, Numerical Simulation of Three-Dimensional Homogeneous Isotropic Turbulence, *Phys. Rev. Lett.* **28**, 2, 76.

- Paczynski, B. 1978, A model of selfgravitating accretion disk with a hot corona, *Acta Astronomica* **28**, 241.
- Papaloizou, J. C. B. et Lin, D. N. C. 1995, Theory Of Accretion Disks I: Angular Momentum Transport Processes, *Annual Review of Astron and Astrophys* **33**, 505.
- Papaloizou, J. C. B. et Pringle, J. E. 1984, The dynamical stability of differentially rotating discs with constant specific angular momentum, *Mon. Not. of the Royal Astron. Soc.* **208**, 721.
- Peyret, R. 2002, *Spectral Methods for Incompressible Viscous Flow*, Springer.
- Prendergast, K. H. et Burbidge, G. R. 1968, On the Nature of Some Galactic X-Ray Sources, *Astrophysical Journal, Letters* **151**, L83+.
- Press, W. H., Teukolsky, S. A., Vetterling, T. V. et Flannery, B. P. 2002, *Numerical recipes in C++ : the art of scientific computing*, Cambridge University Press.
- Price, D. J. et Monaghan, J. J. 2004, Smoother particle magnetohydrodynamics : some shocking results, *Astrophysics and Space Science* **292**, 279.
- Pringle, J. E. 1981, Accretion discs in astrophysics, *Annual Review of Astron and Astrophys* **19**, 137.
- Rüdiger, G., Arlt, R. et Shalybkov, D. 2002, Hydrodynamic stability in accretion disks under the combined influence of shear and density stratification, *Astron. & Astrophys.* **391**, 781.
- Richard, D. 2001, *Instabilités Hydrodynamiques dans les Ecoulements en Rotation Différentielle*, Thèse de doctorat, Université de Paris VII.
- Richard, D. et Zahn, J. 1999, Turbulence in differentially rotating flows. What can be learned from the Couette-Taylor experiment, *Astron. & Astrophys.* **347**, 734.
- Rincon, F., Ogilvie, G. I. et Cossu, C. 2007, On self-sustaining processes in Rayleigh-stable rotating plane Couette flows and subcritical transition to turbulence in accretion disks, *Astron. & Astrophys.* **463**, 817.
- Rüdiger, G. et Shalybkov, D. 2002, Stability of axisymmetric Taylor-Couette flow in hydromagnetics, *Phys. Rev. E* **66**, 1, 016307.
- Salmeron, R. 2004, *Magnetorotational instability in protostellar disks*, Thèse de doctorat, University of Sydney.
- Satomura, T. 1981, An Investigation of Shear Instability in a Shallow Water, *J. Meteor. Soc. Japan* **59**, 148.
- Shakura, N. I. et Sunyaev, R. A. 1973, Black holes in binary systems. Observational appearance., *Astron. & Astrophys.* **24**, 337.
- Sod, G. A. 1978, A survey of several finite difference methods for systems of nonlinear hyperbolic conservation laws, *J. Comp. Phys.* **27**, 1.
- Speziale, C. G. 1991, Analytical methods for the development of Reynolds-stress closures in turbulence, *Ann. Rev. Fluid Mech.* **23**, 107.
- Spiegel, E. A. et Veronis, G. 1960, On the Boussinesq Approximation for a Compressible Fluid., *Astrophysical Journal* **131**, 442.
- Spitzer, L. 1962, *Physics of fully ionized gases*, Interscience.
- Stone, J. M. et Balbus, S. A. 1996, Angular Momentum Transport in Accretion Disks via Convection, *Astrophysical Journal* **464**, 364.

- Stone, J. M., Hawley, J. F., Gammie, C. F. et Balbus, S. A. 1996, Three-dimensional Magnetohydrodynamical Simulations of Vertically Stratified Accretion Disks, *Astrophysical Journal* **463**, 656.
- Stone, J. M. et Norman, M. L. 1992, ZEUS-2D: A radiation magnetohydrodynamics code for astrophysical flows in two space dimensions. I - The hydrodynamic algorithms and tests., *Astrophysical Journal, Supplement* **80**, 753.
- Taylor, G. I. 1936, , *Proc. Roy. Soc. London A* **157**, 546.
- Terebey, S., Shu, F. H. et Cassen, P. 1984, The collapse of the cores of slowly rotating isothermal clouds, *Astrophysical Journal* **286**, 529.
- Tillmark, N. et Alfredsson, P. H. 1996, Experiments on rotating plane Couette flow, dans S. Gavrilakis, L. Machiels et P. A. Monkewitz (éditeurs), *Advances in Turbulence VI.*, pp. 391–394, Kluwer.
- Toro, E. F. 1999, *Riemann Solvers and Numerical Methods for Fluid Dynamics*, Springer.
- Toro, E. F., Millington, R. C. et Nejad, L. A. M. 2001, Toward very high-order Godunov schemes, dans Toro, E. F. (éditeur), *Godunov methods : theory and applications*, pp. 905–938, Kluwer Academic/Plenum Publishers.
- Tritton, D. J. 1992, Stabilization and destabilization of turbulent shear flow in a rotating fluid, *J. Fluid Mech.* **241**, 503.
- Tritton, D. J. et Davies, P. A. 1981, Instabilities in geophysical fluid dynamics, dans *Hydrodynamic instabilities and the transition to turbulence*, pp. 229–270, Springer-Verlag.
- Tscharnuter, W. M. et Winkler, K. H. 1979, A method for computing selfgravitating gas flows with radiation, *Comp. Phys. Comm* **18**, 171.
- Umurhan, O. M. 2006, On the stratorotational instability in the quasi-hydrostatic semigeostrophic limit., *Mon. Not. of the Royal Astron. Soc.* **365**, 85.
- Umurhan, O. M. et Regev, O. 2004, Hydrodynamic stability of rotationally supported flows: Linear and nonlinear 2D shearing box results, *Astron. & Astrophys.* **427**, 855.
- Von Neumann, J. et Richtmyer, R. D. 1950, A method for the numerical calculation of hydrodynamic shocks, *J. Appl. Phys* **21**, 232.
- Waleffe, F. 1997, On a self-sustaining process in shear flows, *Phys. Fluids* **9**, 883.
- Wardle, M. 1999, The Balbus-Hawley instability in weakly ionized discs, *Mon. Not. of the Royal Astron. Soc.* **307**, 849.
- Wendt, G. 1933, , *Ing. Arch.* **4**, 577.
- Wisdom, J. et Tremaine, S. 1988, Local simulations of planetary rings, *Astronomical Journal* **95**, 925.
- Yavneh, I., McWilliams, J. C. et Molemaker, M. J. 2001, Non-Axisymmetric Instability of Centrifugally-Stable Stratified Taylor-Couette Flow, *J. Fluid Mech.* **448**, 1.
- Zanni, C., Ferrari, A., Rosner, R., Bodo, G. *et al.* 2007, MHD simulations of jet acceleration from Keplerian accretion disks: the effects of disk resistivity, *Accepté pour publication dans Astron. & Astrophys.* .

# Instabilités et sources locales de turbulence dans les disques d'accrétion

**Geoffroy LESUR**

## Résumé

Le problème du transport de moment cinétique dans les disques d'accrétion astrophysiques fait l'objet d'un vif débat depuis maintenant une trentaine d'années. On propose ici une étude de ce transport en considérant plusieurs instabilités pouvant conduire à de la turbulence développée dans les disques. La première instabilité proposée est l'instabilité hydrodynamique sous critique de cisaillement. Une étude numérique de cette instabilité nous permet de montrer que, bien que non détectable dans les simulations, le transport obtenu sera très probablement bien trop faible pour expliquer les observations actuelles. Nous étudions ensuite l'instabilité stratorotationnelle et nous montrons par un développement analytique que les contraintes sur les conditions aux limites empêchent la formation de cette instabilité dans un vrai disque. Enfin, nous nous intéressons à l'instabilité magnéto-rotationnelle en présence d'effets non idéaux (viscosité et résistivité magnétique). Nous montrons alors que ces effets non idéaux, bien que faibles a priori, ont un fort impact sur l'efficacité de la turbulence finalement engendrée. Ce dernier point montre le rôle que peut avoir la microphysique dans le processus de saturation, et la nécessité d'avoir une modélisation de ces effets afin d'obtenir un modèle de transport cohérent dans les disques d'accrétion.

*Mots clé :* Disque d'accrétion, méthodes numériques, théorie de la turbulence, MHD

## Abstract

Angular momentum transport in accretion disks has been a highly controversial debate for 30 years now. We present here a study of this transport, considering some instabilities that can leads to developed turbulence in disks. The first instability considered is the subcritical hydrodynamic instability. Our numerical study shows that, although not directly observed in simulations, this instability should lead to a very weak turbulent transport, and is probably not relevant to explain disks observations. We then concider the stratorotational instability, and we show using an analytical approach that it requires very specific boundary conditions, which prevent this instability from appearing in disks. Finally, we study the magnetorotational instability, including non ideal MHD effect (resistivity and viscosity). We show numerically that these effects, although small compared to ideal MHD terms, can have a strong impact on the turbulence efficiency. This point emphasize the role of microphysic effects in the saturation process, and the necessity to modelize these phenomena to get a self-consistant accretion disk transport model.

*Keywords :* Accretion disc, numerical methods, turbulence theory, MHD