Arguição do Memorial

Wladimir Lyra

Sagan Fellow

NASA/JPL-Caltech

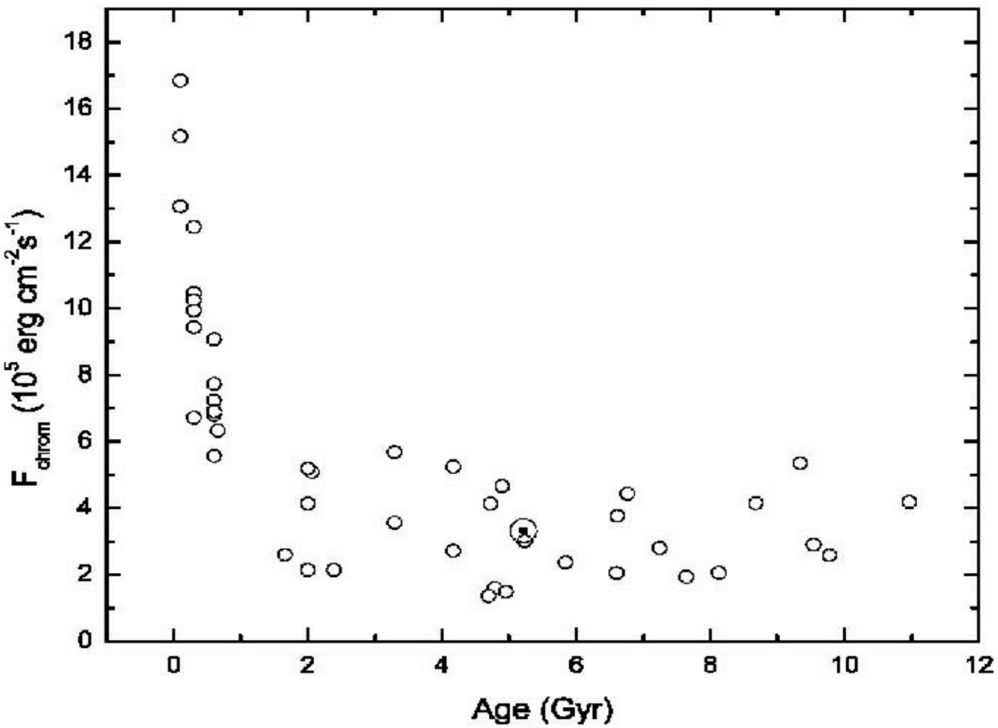
Monografia de Fim de Curso (2003)

Atividade cromosférica

Medida pela linha Hα

Monografia de fim de curso (julho de 2003),

Publicado como primeiro autor em A&A
(Lyra & Porto de Mello, 2005).



A&A 431, 329–338 (2005)
DOI: 10.1051/0004-6361:20040249

Astronomy & Astrophysics

Fine structure of the chromospheric activity in Solar-type stars – The Hα line*,**

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Abstract. A calibration of Hα as both a chromospheric diagnostic and an age indicator is presented, complementing the works previously done on this subject (Herbig 1985; Pasquini & Pallavicini 1991). The chromospheric diagnostic was built with a statistically significant sample, covering nine years of observations, and including 175 solar neighborhood stars. Regarding the age indicator, the presence of stars for which very accurate ages are determined, such as those belonging to clusters and kinematic groups, lends confidence to our analysis. We also investigate the possibility that stars of the same age might have gone through different tracks of chromospheric decay, identifying – within the same age range – effects of metallicity and mass. These parameters, however, as well as age, seem to be significant only for dwarf stars, losing their meaning when we analyze stars in the subgiant branch. This result suggests that, in these evolved stars, the emission mechanism cannot be magnetohydrodynamical in nature, in agreement with recent models (Fawzy et al. 2002c, and references therein). The Sun is found to be a typical star in its Hα chromospheric flux, for its age, mass and metallicity. As a byproduct of this work, we developed an automatic method to determine temperatures from the wings of Hα, which means the suppression of the error inherent to the visual procedure used in the literature.

Key words. stars: activity – stars: atmospheres – stars: chromospheres – techniques: spectroscopic – Galaxy: solar neighbourhood – line: formation

1. Introduction

Losing angular momentum through magnetized stellar winds, cool main sequence dwarfs have their rotation continuously braked, reducing the efficiency of their dynamos and, consequently, their degree of chromospheric activity. Because of this, the chromospheric filling observed in high opacity spectral lines can be translated into a potential indicator of age, a quantity which is still one of the most uncertain parameters in stellar astrophysics.

Although this scenario has a remarkable simplicity, it is a subject which has remained largely unexplored in a quantitative way. Among the works which have been published, most tend to focus on the H and K lines of Ca II (e.g. Skumanich 1972; Linsky et al. 1979), in which the chromospheric emission is more obvious, but also more affected by transient phenomena and phase modulation. The Hα line, although widely used to measure chromospheric activity in solar physics, has received less attention in relation to this particular problem, and the lack of a good calibration of Hα is a drawback for several reasons. First, the line is less sensitive to transient phenomena like flares, coronal mass ejections and localized magnetic explosions; extremely energetic phenomena that flood the X-ray and ultraviolet spectra with energy, but barely affect the visible. Second, it has the property of characterizing the mean chromospheric flux in a better way than Ca II H and K because, showing less chromospheric filling, phase modulations within an activity cycle are greatly reduced: the errors in computing the flux – due, for instance, to normalization and determination of effective temperatures –, largely overcome the intrinsic modulation. Third, the modern solid state detectors have higher quantum efficiency in the red, behaving inversely to the old photographic plates. Also, the studied stars – solar type ones – have their maximum flux in the visible region, favoring better accuracy in narrow band photometry centered on Hα.

Nevertheless, even if Hα did not present any advantage, the need for another diagnostic is crucial. As said before, the majority of works which attacked the problem until the 80s analyzed only the calcium lines, considering them representative of the radiative losses in the chromosphere. The core of Hα, however, is formed in different regions (Schoolman 1972), thus responding differently to changes in the physical conditions of

* Based on observations collected at Observatório do Pico dos Dias, operated by the Laboratório Nacional de Astrofísica, CNPq, Brazil.
** Table 5 is only available in electronic form at the http://www.edpsciences.org

Estágio de Verão (2002) – Space Telescope

Tenth Annual Summer Students Invasion

David Soderblom, *drs@stsci.edu*

This year was the tenth anniversary of the Institute's Summer Student Program. For 2002, we received about 100 applications from students in the U.S. and abroad. Of these, we selected 17 undergraduates and 2 high school seniors from the US and 6 foreign countries to come to the Institute for a summer of astronomical research.

Each student is assigned to a member of the scientific staff, who supervises their research activities and mentors them. The students spend 10 weeks at the Institute, where each works closely with staff astronomers and meets other students from different backgrounds with similar motivations. Their supervisors focus their attention on productive research activities for an intensive period, usually involving Hubble observations. The results are mutually beneficial. Indeed, many of today's front-rank astronomers had similar opportunities during their college years to help guide their early career choices. The research experience and the encounter with an observatory are also helpful when applying to graduate schools.

The Institute's research funds—the Director's Discretionary Fund and staff research grants—support the Summer Student Program.

We will post information about the 2003 Summer Student Program at **http://www.stsci.edu/stsci/summer.shtml** shortly after December 1, 2002. Ω

2002 Summer Students at STScI

Name	*School*	*Institute Supervisor*
Tiffany Borders	Sonoma State U.	Keith Noll & Lisa Frattare
Joseph Converse	Colgate U.	Claus Leitherer
Corey Dow	U. Oregon	Paul Goudfrooij
Hector Galué	Monterrey Inst. of Tech.	Nolan Walborn & Jesus Maiz
Peter Hugger	Virginia Military Inst.	Massimo Stiavelli
Heather Knutson	Johns Hopkins U.	John MacKenty
Katarina Kovac	U. Belgrade	Sangeeta Malhotra
Andrew Levan	U. Leicester	Andy Fruchter
Wladimir Lyra	Federal U. of Rio De Janiero	Daniella Calzetti
Pavel Machalek	University College London	Ken Sembach
Natalie Mintz	U. Washington	Letizia Stanghellini
Alan O'Connor	Linganore HS, Frederick, MD	Duccio Macchetto
Shannon Patel	Cornell U.	Massimo Robberto
Leda Pinto	Federal U. of Rio de Janiero	Claus Leitherer
Aviva Presser	UCLA	Melissa McGrath
Andre Questel	Woodlawn HS, Baltimore, MD	Anton Koekemoer
Kristen Shapiro	Williams College	Roeland van der Marel
Elspeth Suthers	U. Washington	Torsten Boeker
Stefania Varano	U. Bologna	Duccio Macchetto & Bill Sparks

http://www.stsci.edu/~webdocs/STScINewsletter/2002/fall_02.pdf

Gap Year – Cerro Tololo (2003-2004)

Lyra et al. (2006)

A&A 453, 101–119 (2006)
DOI: 10.1051/0004-6361:20053894

Astronomy & Astrophysics

On the difference between nuclear and contraction ages⋆,⋆⋆

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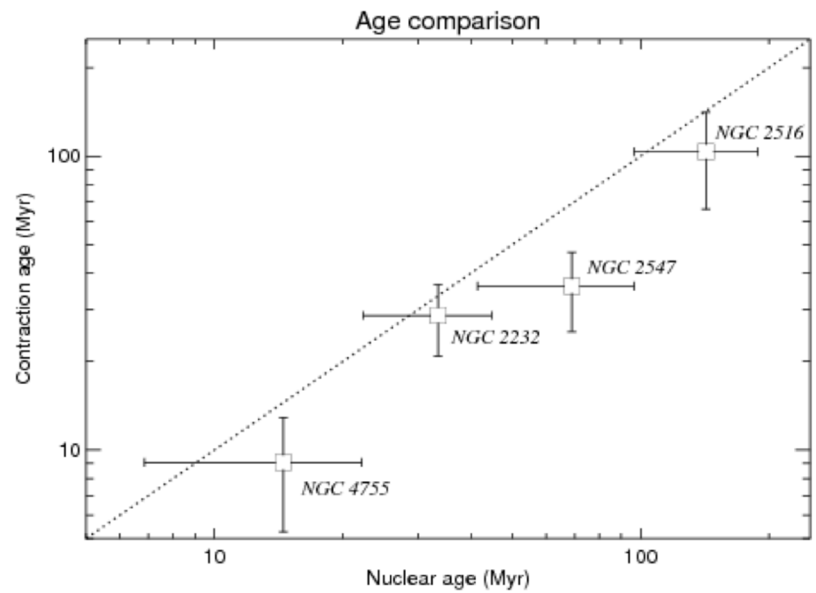
ABSTRACT

Context. Ages derived from low mass stars still contracting onto the main sequence often differ from ages derived from the high mass ones that have already evolved away from it.
Aims. We investigate the general claim of disagreement between these two independent age determinations by presenting *UBVRI* photometry for the young galactic open clusters NGC 2232, NGC 2516, NGC 2547 and NGC 4755, spanning the age range ~10–150 Myr
Methods. We derived reddenings, distances, and nuclear ages by fitting ZAMS and isochrones to color–magnitudes and color–color diagrams. To derive contraction ages, we used four different pre-main sequence models, with an empirically calibrated color-temperature relation to match the Pleiades cluster sequence.
Results. When exclusively using the V vs. $V-I$ color–magnitude diagram and empirically calibrated isochrones, there is consistency between nuclear and contraction ages for the studied clusters. Although the contraction ages seem systematically underestimated, in none of the cases do they deviate by more than one standard deviation from the nuclear ages.

Key words. Galaxy: open clusters and associations: general – galaxies: star clusters – stars: formation – techniques: photometric – Hertzsprung-Russell (HR) and C-M diagrams

NGC 4755 NGC 2232 NGC 2547 NGC 2516



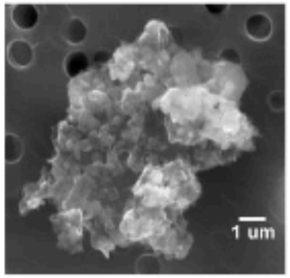
Novos dados em um antigo problema (Herbig 1962) que as idades de contração (turn-on) e nucleares (turn-off) não pareciam concordar.

Doutorado (Out 2004 – Fev 2009)
Universidade de Uppsala, Suécia

Doutorado (Out 2004 – Fev 2009)
Universidade de Uppsala, Suécia

Formação Planetária

"Planetas se formam em discos de gas e poeira"



A miracle happens →

Doutorado (Out 2004 – Fev 2009)
Universidade de Uppsala, Suécia

A hipótese dos planetesimais (Safronov 1969)

De poeira a pedras

μm -> cm: Forças de van der Walls

cm -> km: ainda um milagre....

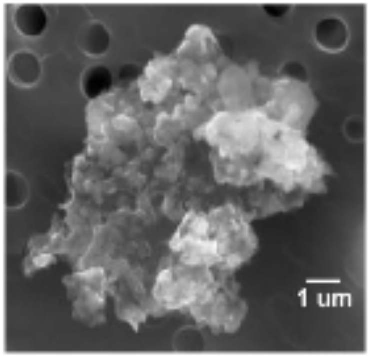
De planetesimais a embriões planetários

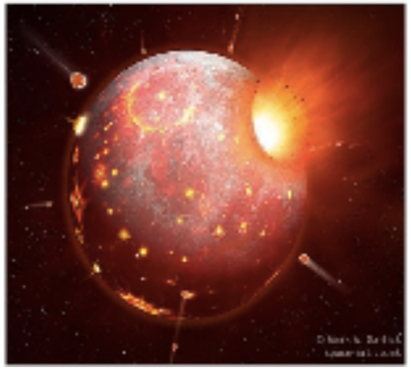
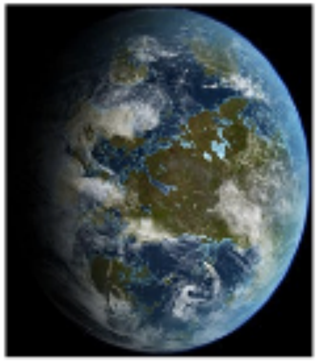
km -> 1000 km: Gravidade

De embriões planetários a planetas

Planetas terrestres: Protoplanetas colidem

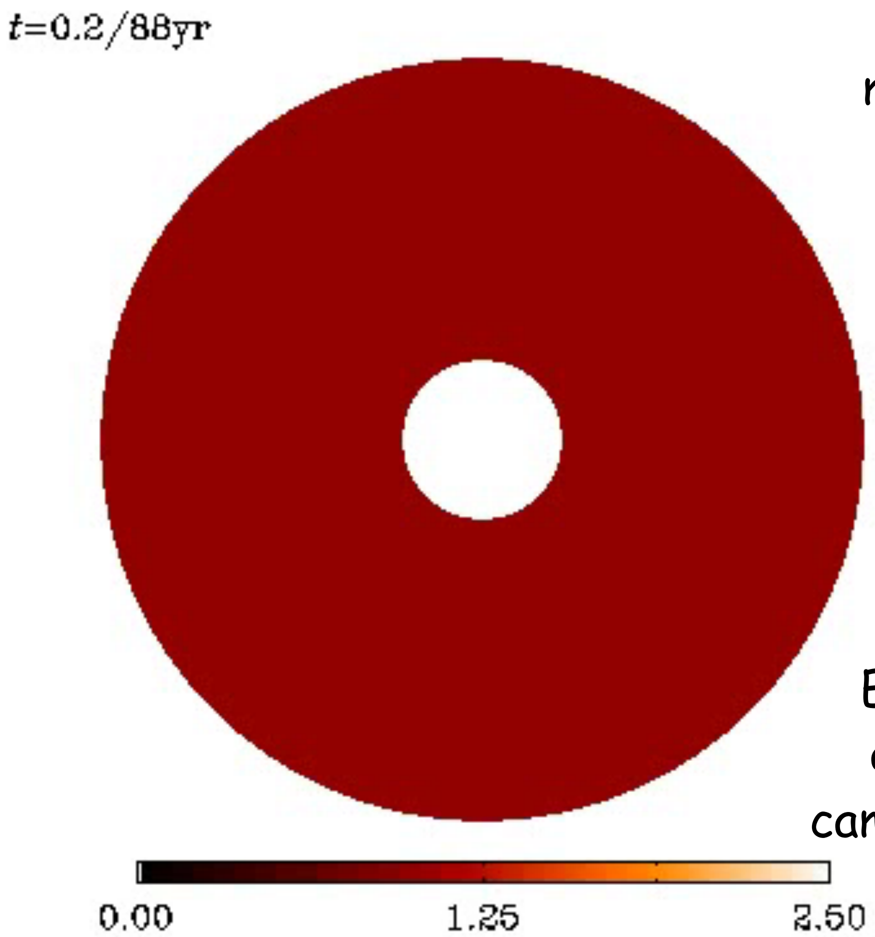
Planetas gigantes: Atraem envoltórios gasosos



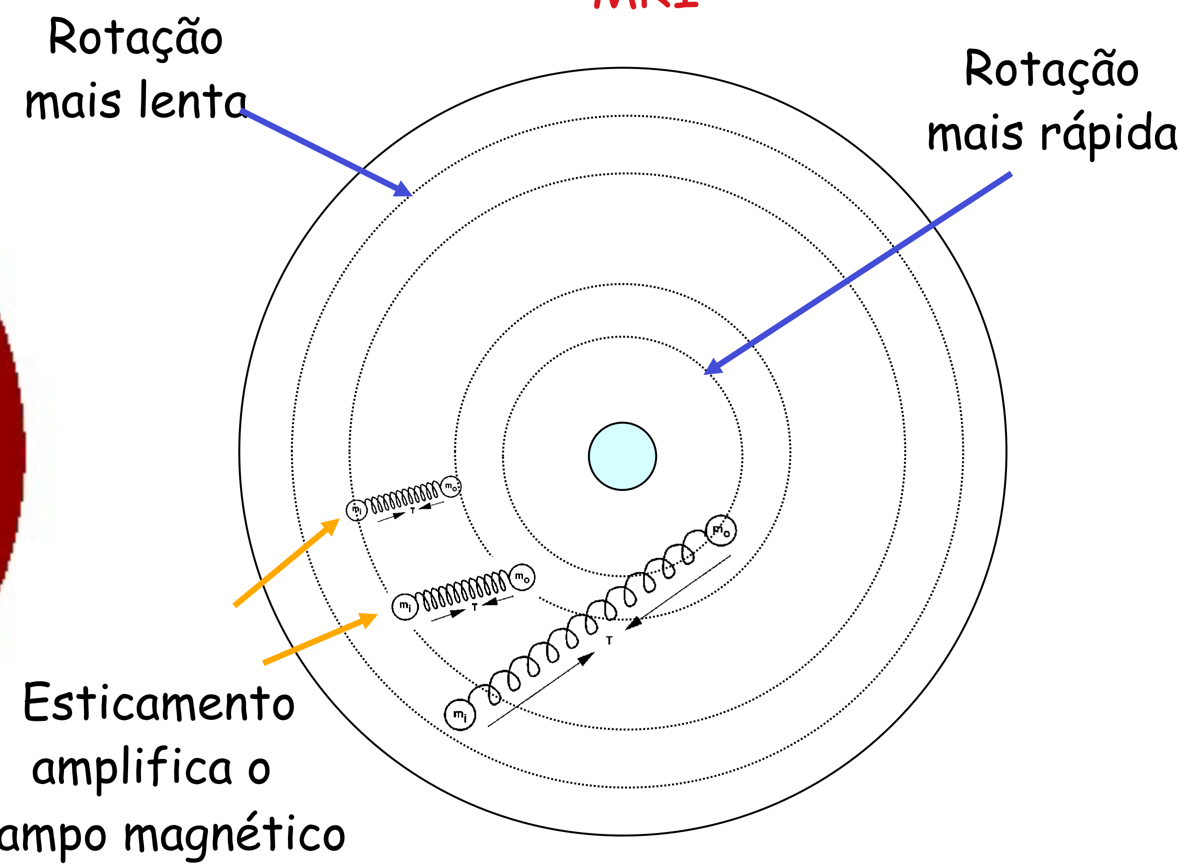

Turbulência

Turbulência em discos é devido à
Instabilidade Magnetorotacional



Disco Magnetizado
Lyra et al. (2008a)

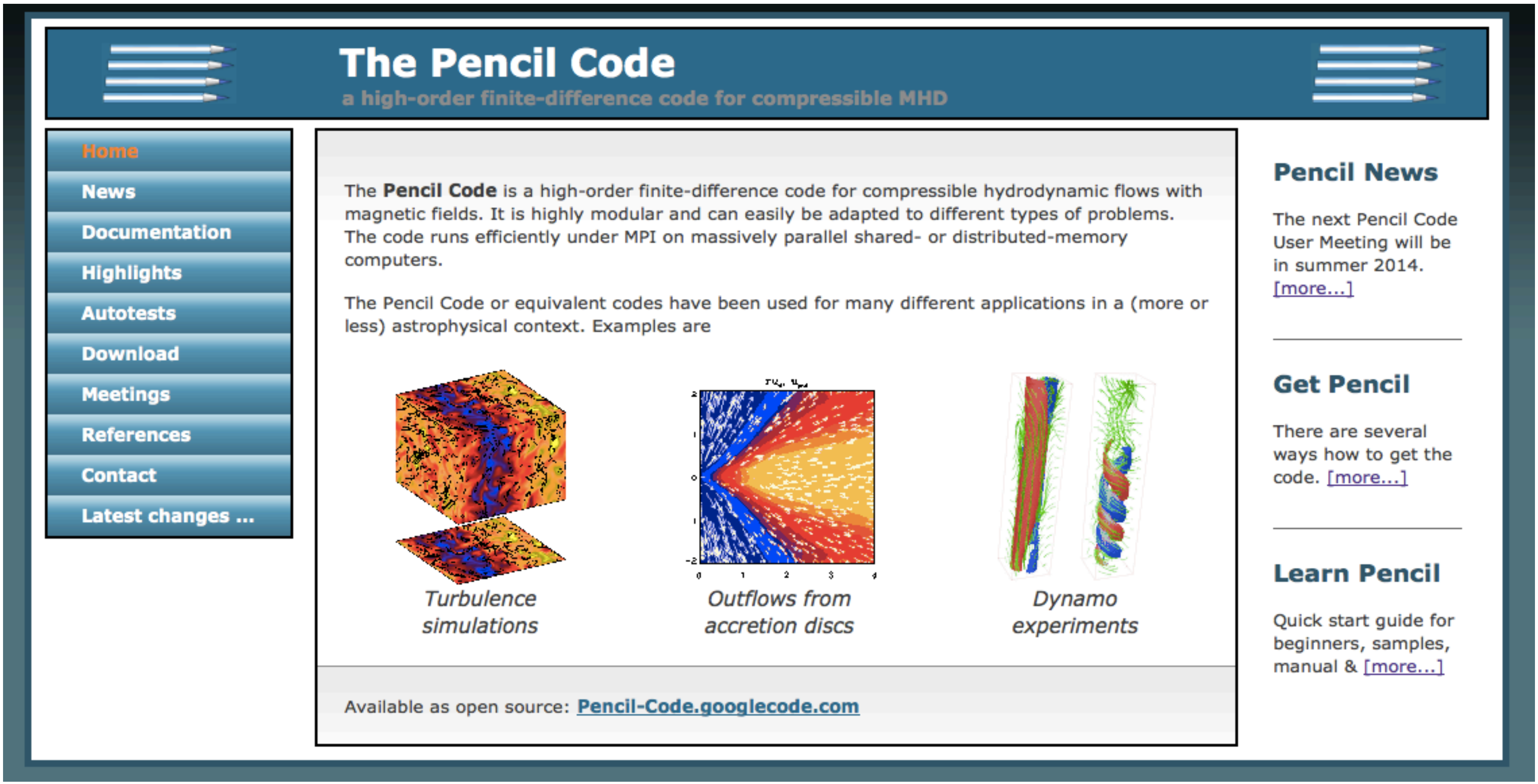
MRI



Instável se a velocidade
angular diminui com a
distância

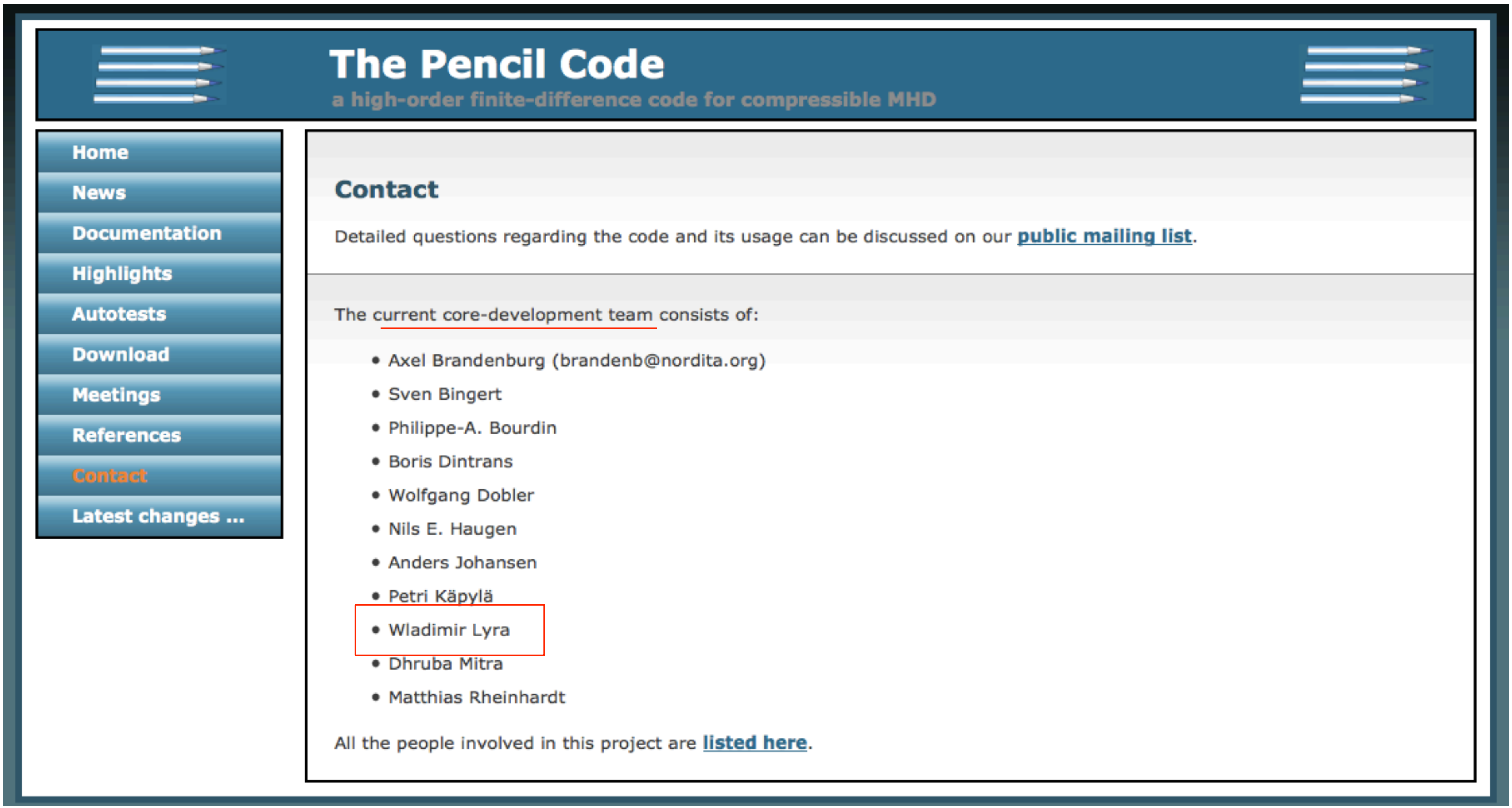
The Pencil Code

Pencil é um software para resolver equações diferenciais parciais, aplicado principalmente a turbulência magnetohidrodinâmica.
Citado em 350+ publicações.



The Pencil Code

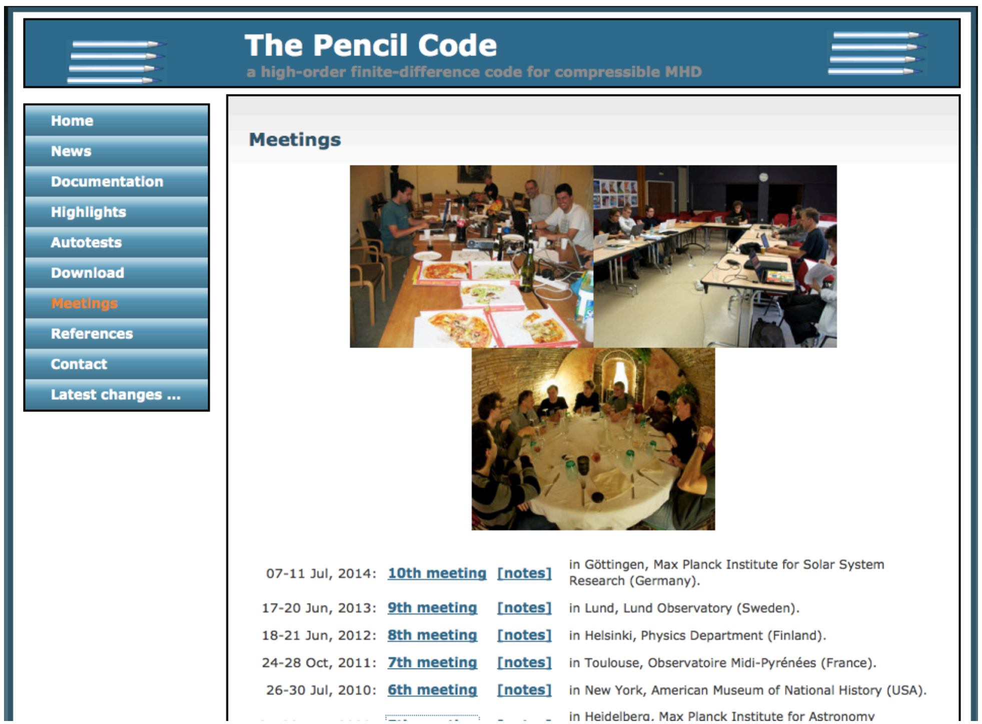
Contribuo para o Pencil desde 2005.

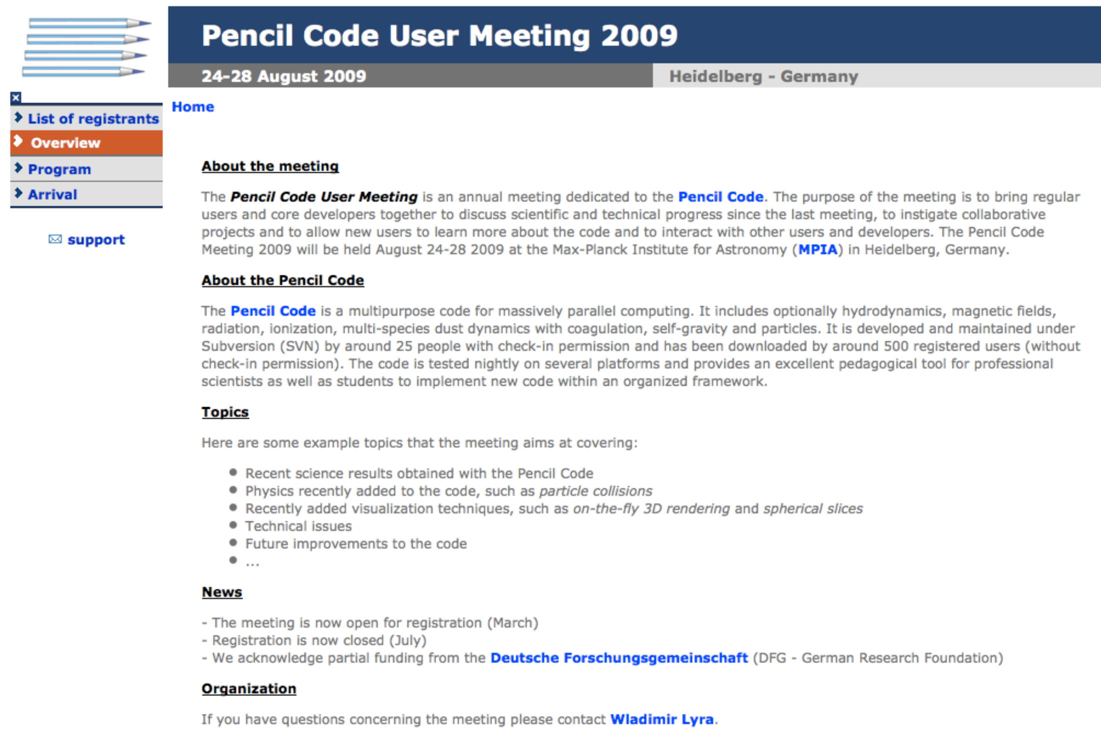


The Pencil Code

Workshops anuais pra avaliar a evolução do programa, e decidir os novos rumos.

Organizei o Pencil Code Meeting de 2009 em Heidelberg





Uma pequena amostra...

www.wladimirlyra.com/research.html

NSPIRES

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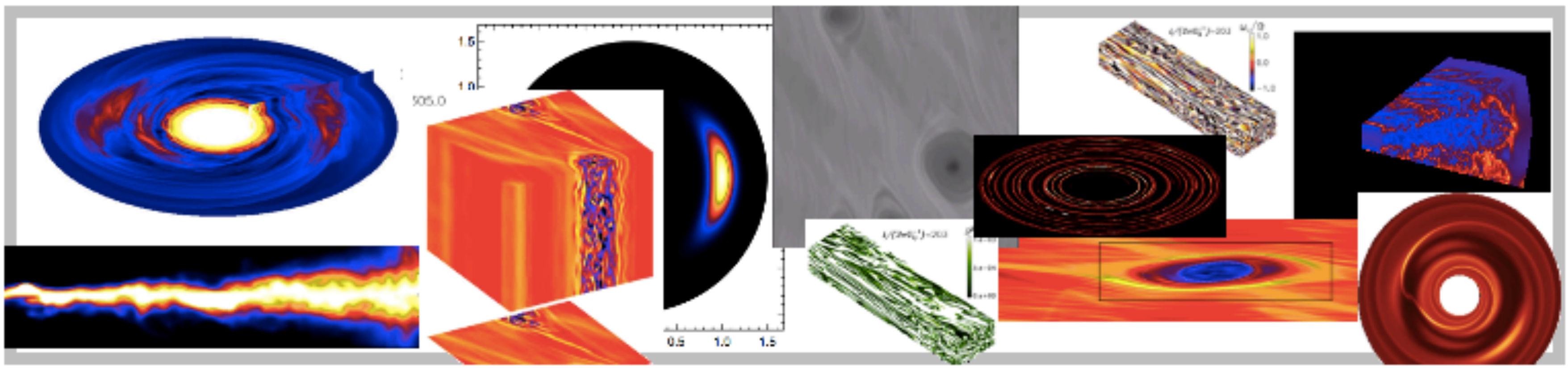

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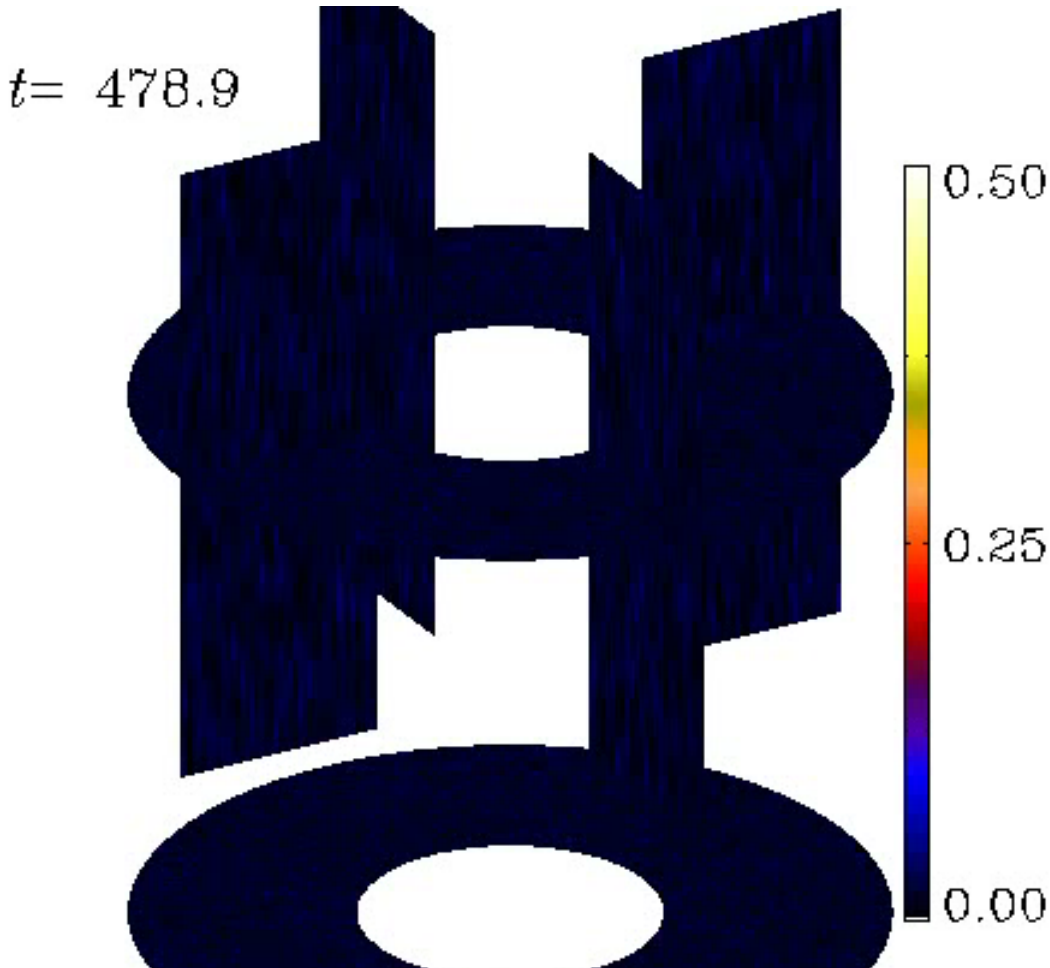
Circumstellar Disks and Planet Formation

My current research interests revolve around the processes taking place in circumstellar disks, with emphasis on their importance for planet formation. As these disks are gaseous, hydrodynamics is a component of paramount importance. Since the central equation of hydrodynamics (the Navier-Stokes equation) is non-linear, we have to resort to numerical simulations in order to progress in our understanding. You can find here some movies of my computer models.

All simulations were done with the **Pencil Code**, a an open source, collaborative, high order finite difference MHD code that is highly modular and versatile. I have been a co-developer of Pencil since 2005.

The videos are also available in my YouTube channels: **channel 1** and **channel 2**.

Concentração de seixos e pedras em turbulência MHD



A&A 479, 883–901 (2008)
DOI: 10.1051/0004-6361:20077948

Astronomy & Astrophysics

Global magnetohydrodynamical models of turbulence in protoplanetary disks

I. A cylindrical potential on a Cartesian grid and transport of solids

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ABSTRACT

Aims. We present global 3D MHD simulations of disks of gas and solids, aiming at developing models that can be used to study various scenarios of planet formation and planet-disk interaction in turbulent accretion disks. A second goal is to demonstrate that Cartesian codes are comparable to cylindrical and spherical ones in handling the magnetohydrodynamics of the disk simulations while offering advantages, such as the absence of a grid singularity, for certain applications, e.g., circumbinary disks and disk-jet simulations.

Methods. We employ the Pencil Code, a 3D high-order finite-difference MHD code using Cartesian coordinates. We solve the equations of ideal MHD with a local isothermal equation of state. Planets and stars are treated as particles evolved with an *N*-body scheme. Solid boulders are treated as individual superparticles that couple to the gas through a drag force that is linear in the local relative velocity between gas and particle.

Results. We find that Cartesian grids are well-suited for accretion disk problems. The disk-in-a-box models based on Cartesian grids presented here develop and sustain MHD turbulence, in good agreement with published results achieved with cylindrical codes. Models without an inner boundary do not show the spurious build-up of magnetic pressure and Reynolds stress seen in the models with boundaries, but the global stresses and alpha viscosities are similar in the two cases. We investigate the dependence of the magnetorotational instability on disk scale height, finding evidence that the turbulence generated by the magnetorotational instability grows with thermal pressure. The turbulent stresses depend on the thermal pressure obeying a power law of 0.24 ± 0.03, compatible with the value of 0.25 found in shearing box calculations. The ratio of Maxwell to Reynolds stresses decreases with increasing temperature, dropping from 5 to 1 when the sound speed was raised by a factor 4, maintaing the same field strength. We also study the dynamics of solid boulders in the hydromagnetic turbulence, by making use of 10^6 Lagrangian particles embedded in the Eulerian grid. The effective diffusion provided by the turbulence prevents settling of the solids in a infinitesimally thin layer, forming instead a layer of solids of finite vertical thickness. The measured scale height of this diffusion-supported layer of solids implies turbulent vertical diffusion coefficients with globally averaged Schmidt numbers of 1.0 ± 0.2 for a model with $\alpha \approx 10^{-3}$ and 0.78 ± 0.06 for a model with $\alpha \approx 10^{-1}$. That is, the vertical turbulent diffusion acting on the solids phase is comparable to the turbulent viscosity acting on the gas phase. The average bulk density of solids in the turbulent flow is quite low ($\rho_p = 6.0 \times 10^{-11}$ kg m^{-3}), but in the high pressure regions, significant overdensities are observed, where the solid-to-gas ratio reached values as great as 85, corresponding to 4 orders of magnitude higher than the initial interstellar value of 0.01.

Key words. magnetohydrodynamics (MHD) – accretion, accretion disks – instabilities – turbulence – solar system: formation – diffusion

1. Introduction

Planets have long been believed to form in disks of gas and dust around young stars (Kant 1755; Laplace 1796), interacting with their surroundings via a set of complex and highly nonlinear processes. In the core accretion scenario for giant planet formation (Mizuno 1980), dust coagulates first into km-sized icy and rocky planetesimals (Safronov 1969; Goldreich & Ward 1973; Youdin & Shu 2002) that further collide, forming progressively larger solid bodies that eventually give rise to cores of several Earth masses. If a critical mass is attained, these cores become gas giant planets by undergoing runaway accretion of gas (Pollack et al. 1996). Otherwise, just a small amount of nebular gas is retained by the core, which ends up as an ice giant.

The success of this picture in explaining the overall shape of the solar system was shaken by the discovery of the extra-solar planets. In less than a decade, the zoo of planetary objects received exotic members such as close-in Hot Jupiters (Mayor & Queloz 1995), pulsar planets (Wolszczan & Frail 1992), highly eccentric giants (Marcy & Butler 1996), free-floating planets (Lucas & Roche 2000), and super-Earths (Rivera et al. 2005). Thus, understanding the diversity of these extra-solar planets is a crucial task in planet formation theory.

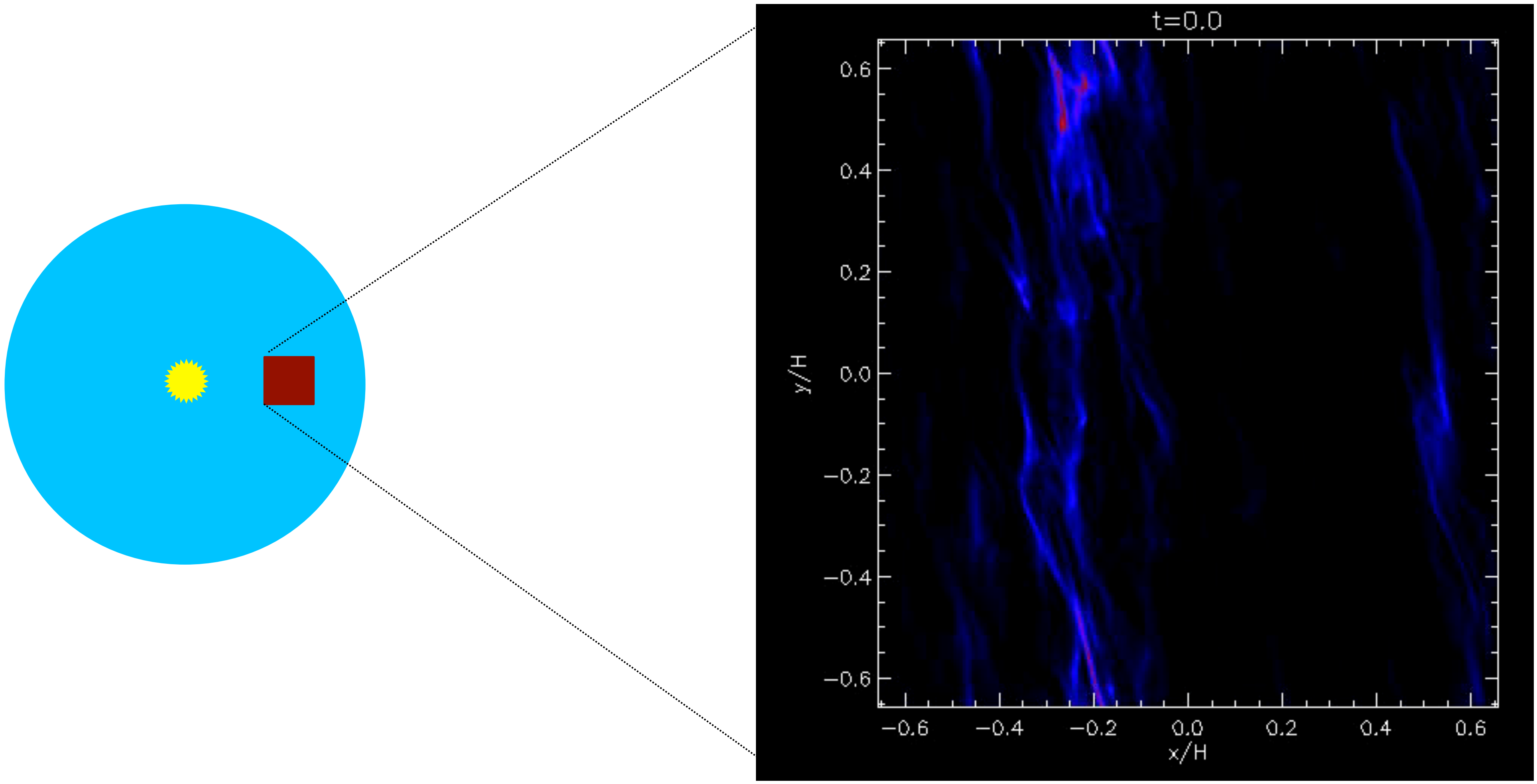
Planet-disk interaction seems to be one of the obvious candidates to account for this diversity. Planets exchange angular momentum with the disk, leading to either inward or outward migration (Ward 1981; Lin & Papaloizou 1986; Ward & Hourigan 1989; Masset et al. 2006). An understanding of the physical state of accretion disks is essential to provide a detailed picture of the effect of migration on planetary orbits.

Analytical theory must necessarily contain a number of linearizing simplifications. Therefore, numerical simulations are a

Article published by EDP Sciences

Lyra et al. (2008a)

Colapso gravitacional em planetesimais



Johansen et al. (2007)

Formação planetária por vórtices na zona inativa

A&A 491, L41–L44 (2008)
DOI: 10.1051/0004-6361:200810626

Astronomy & Astrophysics

Letter to the Editor

Embryos grown in the dead zone

Assembling the first protoplanetary cores in low mass self-gravitating circumstellar disks of gas and solids*

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ABSTRACT

Context. In the borders of the dead zones of protoplanetary disks, the inflow of gas produces a local density maximum that triggers the Rossby wave instability. The vortices that form are efficient in trapping solids.
Aims. We aim to assess the possibility of gravitational collapse of the solids within the Rossby vortices.
Methods. We perform global simulations of the dynamics of gas and solids in a low mass non-magnetized self-gravitating thin protoplanetary disk with the Pencil Code. We use multiple particle species of radius 1, 10, 30, and 100 cm. The dead zone is modelled as a region of low viscosity.
Results. The Rossby vortices excited in the edges of the dead zone are efficient particle traps. Within 5 orbits after their appearance, the solids achieve critical density and undergo gravitational collapse into Mars sized objects. The velocity dispersions are of the order of 10 m s^{-1} for newly formed embryos, later lowering to less than 1 m s^{-1} by drag force cooling. After 200 orbits, over 300 gravitationally bound embryos were formed, 20 of them being more massive than Mars. Their mass spectrum follows a power law of index -2.3 ± 0.2.

Key words. accretion, accretion disks – instabilites – stars: planetary systems: formation

1. Introduction

The formation of planets is one of the major unsolved problems in modern astrophysics. In the standard core accretion scenario, sub-μm grains assemble into progressively larger bodies through electrostatic interactions (Natta et al. 2007), eventually growing into centimeter and meter sized boulders. Growth beyond this size, however, is halted since these boulders have very poor sticking properties and are easily destroyed by collisions at the velocities assumed to be prevalent in circumstellar disks (Benz 2000). Furthermore, centimeter and meter sized solids are loosely decoupled from the gas, but remain sufficiently small to be affected by significant gas drag. The resulting headwind from the sub-Keplerian gas reduces their angular momentum and forces them into spiral trajectories onto the star in timescales as short as a few thousand years (Weidenschilling 1977a).

A mechanism for overcoming these barriers was presented by Kretke & Lin (2007). In the presence of sufficient ionization, the gaseous disk couples with the ambient weak magnetic field, which triggers the growth of the magneto-rotational instability (MRI; Balbus & Hawley 1991). In its saturated state, a vigorous turbulence drives accretion onto the star by means of magnetic and kinetic stresses. However, in the water condensation front (snowline) the abundant presence of snowflakes effectively removes free electrons from the gas, lowering the degree of ionization. The turbulence is weakened locally and the accretion flow is stalled. As the radial inflow proceeds from the outer disk, gas accumulates at the snowline. Since embedded solid bodies move towards gas pressure maxima (Haghighipour & Boss 2003), the snowline environment proposed by Kretke & Lin (2007) is potentially an efficient particle trap. This scenario was further explored by Brauer et al. (2008), who demonstrated that as solids concentrate at this local pressure maximum, rapid growth into kilometer sized planetesimals occurs by coagulation.

Kretke et al. (2008) emphasized that an identical mechanism is supposed to occur elsewhere in the disk. Ionization ought to be present in the very inner disk due to the high temperatures, as well as in the outer regions where the gas is sufficiently thin for cosmic rays to penetrate to the disk midplane and provide ionization throughout. In between, however, temperatures are too low and gas columns too thick to allow sufficient ionization either by collisions or by cosmic rays. In the midplane of this region, the gas is neutral and the turbulence is largely suppressed (Gammie 1996). As in the snowline, the accretion flow from the MRI-active regions halts at the borders of this "dead" zone, where the gas then accumulates.

These models have been tested only by one-dimensional simulations, and these tests have therefore not benefitted from an interesting development. As shown by Varnière & Tagger (2006), the density pileup at the border of the dead zone triggers the Rossby wave instability (RWI; Li et al. 2001). The azimuthal symmetry of the problem is broken and long-lived anticyclonic vortices are formed as the waves break and coalesce. Such entities are of significant interest because, by rotating clockwise

* Appendices A–C are only available in electronic form at http://www.aanda.org

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Lyra et al. (2008b)

A&A 497, 869–888 (2009)
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Astronomy & Astrophysics

Planet formation bursts at the borders of the dead zone in 2D numerical simulations of circumstellar disks

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Received 31 October 2008 / Accepted 23 February 2009

ABSTRACT

Context. As accretion in protoplanetary disks is enabled by turbulent viscosity, the border between active and inactive (dead) zones constitutes a location where there is an abrupt change in the accretion flow. The gas accumulation that ensues triggers the Rossby wave instability, which in turn saturates into anticyclonic vortices. It has been suggested that the trapping of solids within them leads to a burst of planet formation on very short timescales.
Aims. We study in the formation and evolution of the vortices in greater detail, focusing on the implications for the dynamics of embedded solid particles and planet formation.
Methods. We performed two-dimensional global simulations of the dynamics of gas and solids in a non-magnetized thin protoplanetary disk with the Pencil code. We used multiple particle species of radius 1, 10, 30, and 100 cm. We computed the particles' gravitational interaction by a particle-mesh method, translating the particles' number density into surface density and computing the corresponding self-gravitational potential via fast Fourier transforms. The dead zone is modeled as a region of low viscosity. Adiabatic and locally isothermal equations of state are used.
Results. The Rossby wave instability is triggered under a variety of conditions, thus making vortex formation a robust process. Inside the vortices, fast accumulation of solids occurs and the particles collapse into objects of planetary mass on timescales as short as five orbits. Because the drag force is size-dependent, aerodynamical sorting ensues within the vortical motion, and the first bound structures formed are composed primarily of similarly-sized particles. In addition to erosion due to ram pressure, we identify gas tides from the massive vortices as a disrupting agent of formed protoplanetary embryos. We find evidence that the backreaction of the drag force from the particles onto the gas modifies the evolution of the Rossby wave instability, with vortices being launched only at later times if this term is excluded from the momentum equation. Even though the gas is not initially gravitationally unstable, the vortices can grow to $Q \approx 1$ in locally isothermal runs, which halts the inverse cascade of energy towards smaller wavenumbers. As a result, vortices in models without self-gravity tend to rapidly merge towards a $m = 2$ or $m = 1$ mode, while models with self-gravity retain dominant higher order modes ($m = 4$ or $m = 3$) for longer times. Non-selfgravitating disks thus show fewer and stronger vortices. We also estimate the collisional velocity history of the particles that compose the most massive embryo by the end of the simulation, finding that the vast majority of them never experienced a collision with another particle at speeds faster than 1 m s^{-1}. This result lends further support to previous studies showing that vortices provide a favorable environment for planet formation.

Key words. accretion, accretion disks – hydrodynamics – instabilities – stars: planetary systems: formation – methods: numerical – turbulence

1. Introduction

The ill fate of the building blocks of planets in gaseous disks around young stars stands as one of the major unsolved problems in the theory of planet formation. Beginning with micron-sized interstellar dust grains, coagulation models predict growth to centimeter and meter size (Weidenschilling 1980; Dominik et al. 2007) in the denser environments of a circumstellar disk. Such bodies, however, are large enough to have already decoupled slightly from the sub-Keplerian gas, yet still small enough to be subject to a significant gas drag. The resulting headwind drains their angular momentum, leading them into spiral trajectories towards the star, on timescales as short as a hundred years at 1AU (Weidenschilling 1977a). Another acute problem is that such bodies have poor sticking properties and a low threshold velocity for fragmentation (Chokshi et al. 1993), such that collisions between them usually lead to destruction rather than growth (Benz 2000; Sirono 2004; Ormel & Cuzzi 2007). Such problems severely hinder growth to km-size by coagulation (Brauer et al. 2008a).

In view of these problems, other routes for breaching the meter size barrier have been pursued. A distinct alternative is gravitational instability of the layer of solids (Safronov 1969; Lyttleton 1972; Goldreich & Ward 1973; Youdin & Shu 2002). When the dust aggregates had grown to centimeter and meter size the gas drag is reduced and the solids are pushed to the midplane of the disk due to the stellar gravity. Although such bodies do not have enough mass to attract each other individually, sedimentation increases the solids-to-gas ratio by orders of magnitude when compared to the interstellar value of 10^{-2}. It was then hypothesized (Safronov 1969) that due to the high densities of this midplane layer, the solids could collectively achieve critical number density and undergo direct gravitational collapse. Such a

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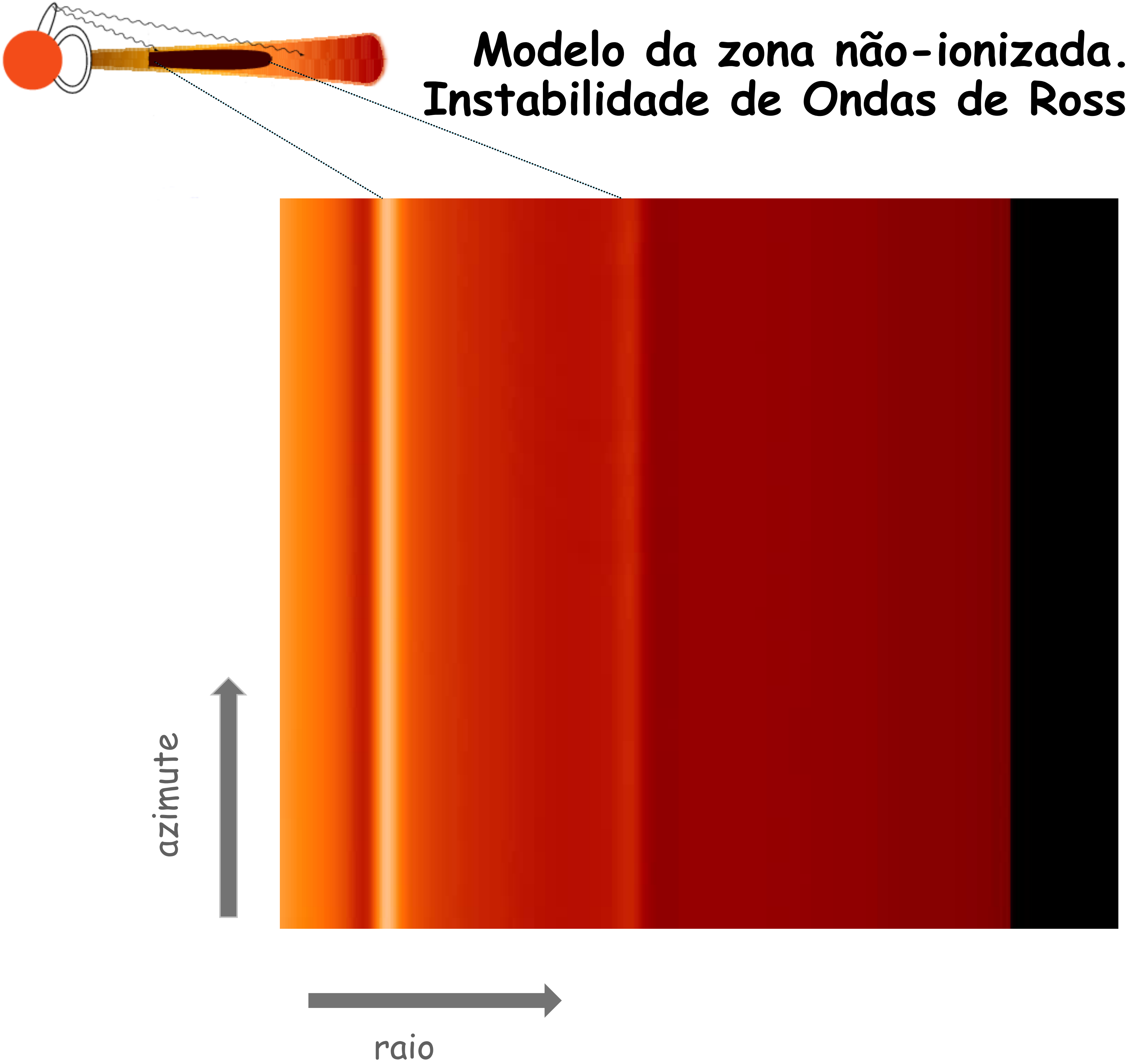
Lyra et al. (2009b)

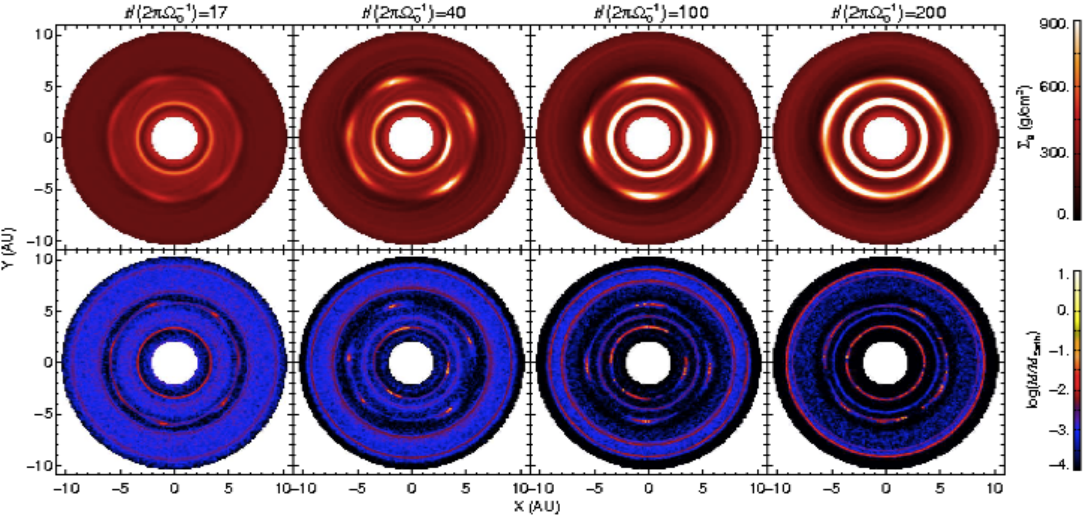
Modelo da zona não-ionizada.
Instabilidade de Ondas de Rossby



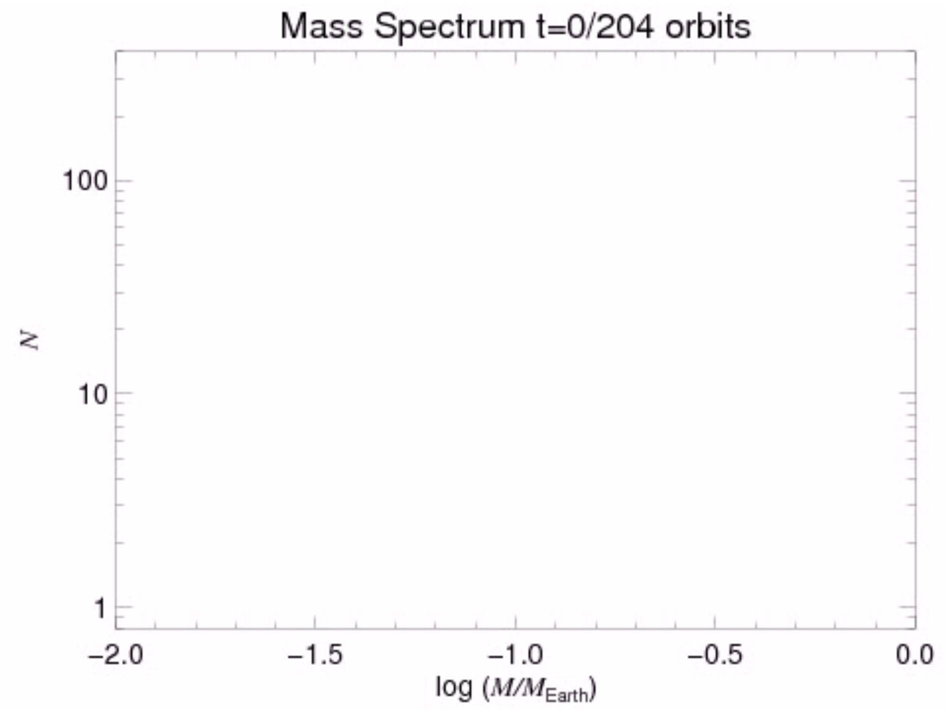
Lyra et al. (2008b)

Vórtices e Formação Planetária

Gas



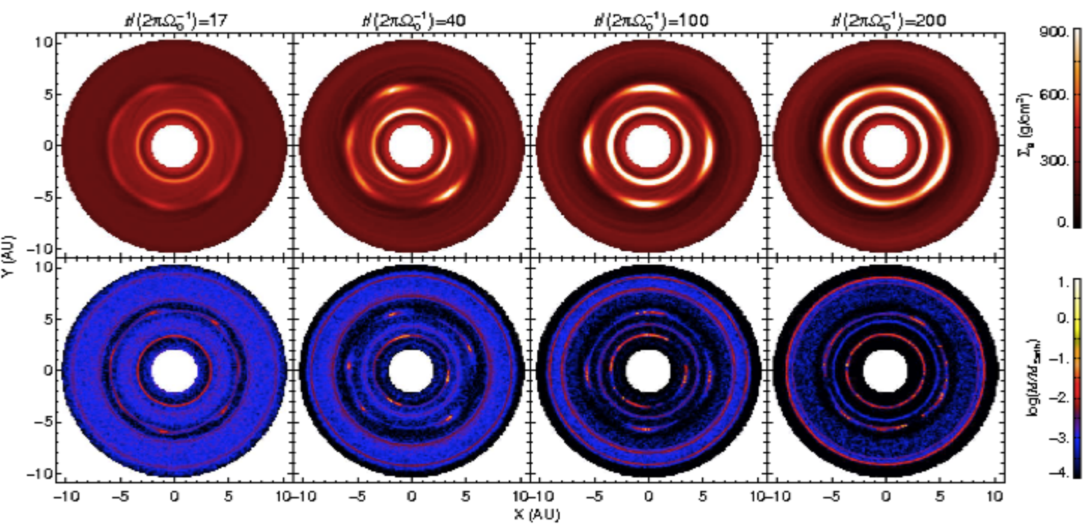
Partículas



Colapso em objetos
da massa de Marte

Vórtices e Formação Planetária

Gas



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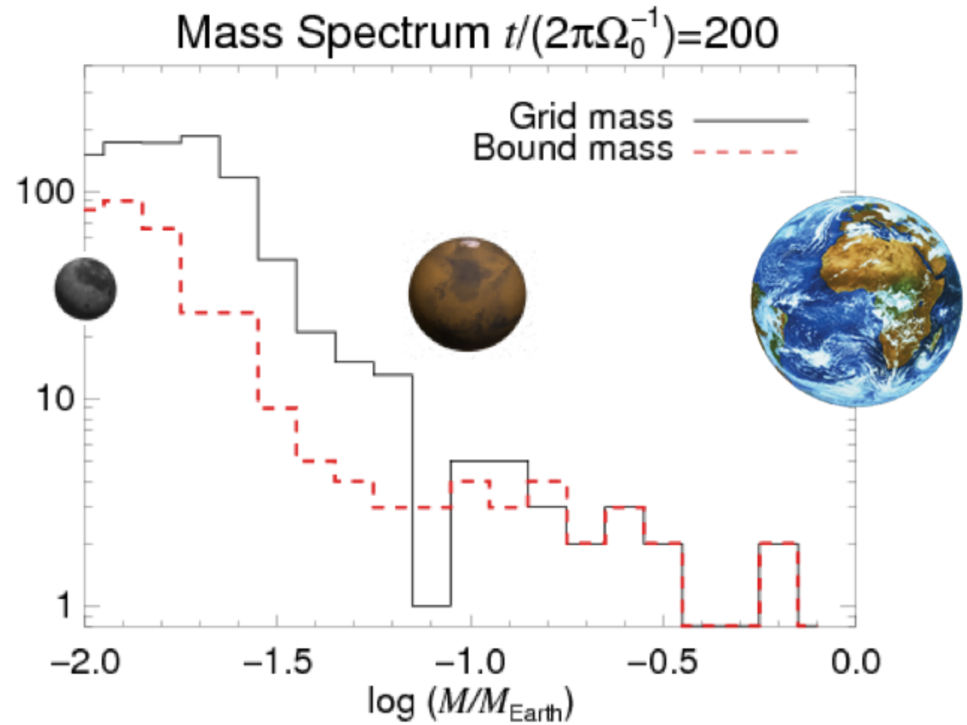

Colapso em objetos
da massa de Marte

Formação de Planetas Troianos e Super-Terras

A&A 493, 1125–1139 (2009)
DOI: 10.1051/0004-6361:200810797

Astronomy & Astrophysics

Standing on the shoulders of giants

Trojan Earths and vortex trapping in low mass self-gravitating protoplanetary disks of gas and solids

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ABSTRACT

Context. Centimeter and meter-sized solid particles in protoplanetary disks are trapped within long-lived, high-pressure regions, creating opportunities for collapse into planetesimals and planetary embryos.

Aims. We aim to study the effect of the high-pressure regions generated in the gaseous disks by a giant planet perturber. These regions consist of gas retained in tadpole orbits around the stable Lagrangian points as a gap is carved, and the Rossby vortices launched at the edges of the gap.

Methods. We performed global simulations of the dynamics of gas and solids in a low mass non-magnetized self-gravitating thin protoplanetary disk. We employed the Pencil code to solve the Eulerian hydro equations, tracing the solids with a large number of Lagrangian particles, usually 100 000. To compute the gravitational potential of the swarm of solids, we solved the Poisson equation using particle-mesh methods with multiple fast Fourier transforms.

Results. Huge particle concentrations are seen in the Lagrangian points of the giant planet, as well as in the vortices they induce at the edges of the carved gaps. For 1 cm to 10 cm radii, gravitational collapse occurs in the Lagrangian points in less than 200 orbits. For 5 cm particles, a 2 $M_\oplus$ planet is formed. For 10 cm, the final maximum collapsed mass is around 3 $M_\oplus$. The collapse of the 1 cm particles is indirect, following the timescale of gas depletion from the tadpole orbits. Vortices are excited at the edges of the gap, primarily trapping particles of 30 cm radii. The rocky planet that is formed is as massive as 17 $M_\oplus$, constituting a Super-Earth. Collapse does not occur for 40 cm onwards. By using multiple particle species, we find that gas drag modifies the streamlines in the tadpole region around the classical L4 and L5 points. As a result, particles of different radii have their stable points shifted to different locations. Collapse therefore takes longer and produces planets of lower mass. Three super-Earths are formed in the vortices, the most massive having 4.5 $M_\oplus$.

Conclusions. A Jupiter-mass planet can induce the formation of other planetary embryos at the outer edge of its gas gap. Trojan Earth-mass planets are readily formed; although not existing in the solar system, might be common in the exoplanetary zoo.

Key words. accretion, accretion disks – hydrodynamics – instabilities – methods: numerical – solar system: formation – planets and satellites: formation

1. Introduction

Losing angular momentum by friction with the ambient gaseous headwind, centimeter to meter-sized bodies in protoplanetary disks spiral into the star on timescales as short as a hundred years (Weidenschilling 1977). Avoiding this fate is a major unsolved problem in modern astrophysics. The question of the formation of rocky planets is intimately connected with this problem, since the kilometer-sized bodies (planetesimals) whence they are believed to form (Safronov 1969) must be formed faster than the already rapid timescale of radial drift of the rocks (0.1–1 m-size) and boulders (1–10 m-size).

As colliding boulders have very poor sticking properties (Benz 2000), a possible scenario for the formation of planetesimals is direct gravitational collapse of the layer of boulders (Goldreich & Ward 1973). This hypothesis has met with criticism because no route for achieving critical densities could be found (Weidenschilling & Cuzzi 1993), but it has recently gained momentum due to a series of advances in modeling the coupled dynamics of gas and boulders through both analytical calculations and numerical simulations. Youdin & Goodman (2005) showed that when rocks and boulders migrate due to the drag force, they trigger a streaming instability that develops into a traffic jam in their migrating flow, with dramatic effects for the particle concentrations (Johansen et al. 2006b; Paardekooper 2006; Johansen & Youdin 2007; Balsara et al. 2008). Fromang & Nelson (2005) modeled the dynamics of particles in magnetized global disks and showed that trapping occurs in the pressure maxima of the turbulence generated by the magneto-rotational instability (MRI). The number of particles, however, was too low (≲3000) to say anything about possible gravitational collapse. Johansen et al. (2006a) simulated the flow in an MRI-active local box using a statistically significant number of particles (10^6), and showed that the particle concentration is high enough to achieve critical densities.

Studies with self gravity to follow the collapse are restricted to local boxes (Johansen et al. 2007) and the massive disk case (Rice et al. 2004; Rice et al. 2006). The former couples the effects of particle concentrations due to the streaming instabilities

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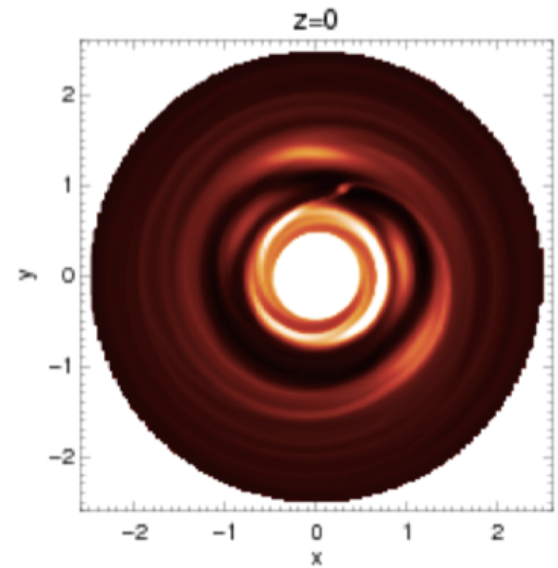
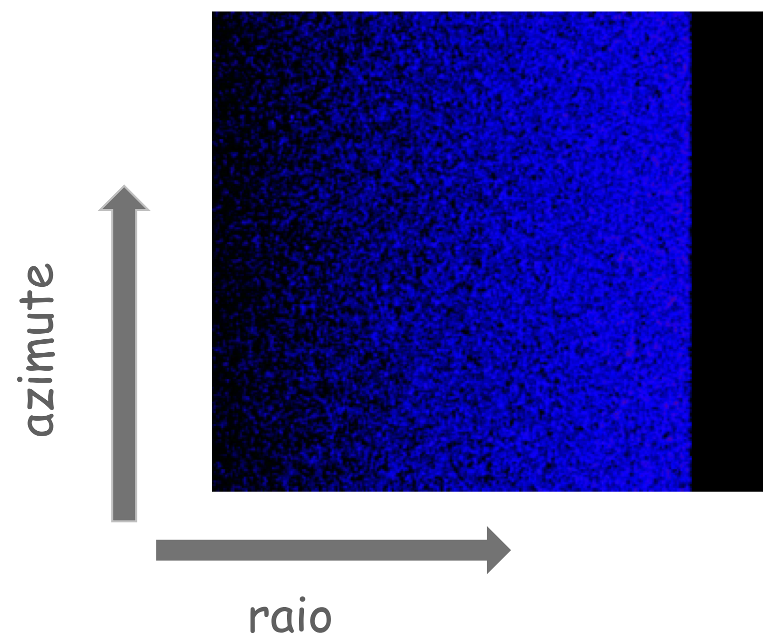
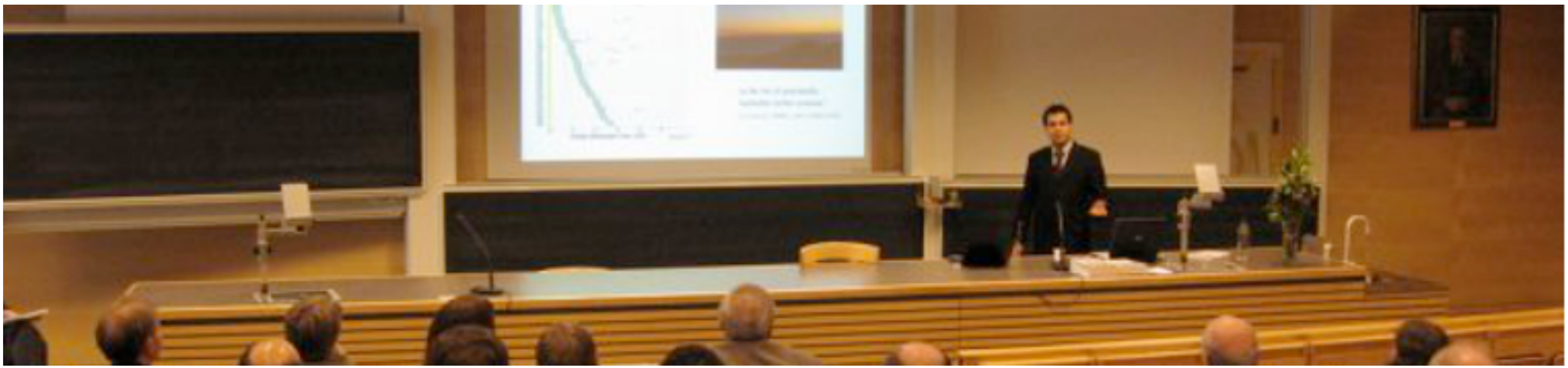
Lyra et al. (2009b)





Congratulations, Dr Lyra!



By the way…

A&A 488, 653–666 (2008)
DOI: 10.1051/0004-6361:200810031

Astronomy & Astrophysics

The Alpha Centauri binary system*,**

Atmospheric parameters and element abundances

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ABSTRACT

Context. The α Centauri binary system, owing to its duplicity, proximity and brightness, and its components' likeness to the Sun, is a fundamental calibrating object for the theory of stellar structure and evolution and the determination of stellar atmospheric parameters. This role, however, is hindered by a considerable disagreement in the published analyses of its atmospheric parameters and abundances.
Aims. We report a new spectroscopic analysis of both components of the α Centauri system, compare published analyses of the system, and attempt to quantify the discrepancies still extant in the determinations of the atmospheric parameters and abundances of these stars.
Methods. The analysis is differential with respect to the Sun, based on spectra with $R = 35\,000$ and signal-to-noise ratio ≥ 1000, and employed spectroscopic and photometric methods to obtain as many independent T_{eff} determinations as possible. We also check the atmospheric parameters for consistency against the results of the dynamical analysis and the positions of the components in a theoretical HR diagram.
Results. The spectroscopic atmospheric parameters of the system are found to be $T_{eff} = (5847 \pm 27)$ K, [Fe/H] $= +0.24 \pm 0.03$, $\log g = 4.34 \pm 0.12$, and $\xi_t = 1.46 \pm 0.03$ km s^{-1}, for α Cen A, and $T_{eff} = (5316 \pm 28)$ K, [Fe/H] $= +0.25 \pm 0.04$, $\log g = 4.44 \pm 0.15$, and $\xi_t = 1.28 \pm 0.15$ km s^{-1} for α Cen B. The parameters were derived from the simultaneous excitation & ionization equilibria of Fe I and Fe II lines. T_{eff}s were also obtained by fitting theoretical profiles to the Hα line and from photometric calibrations.

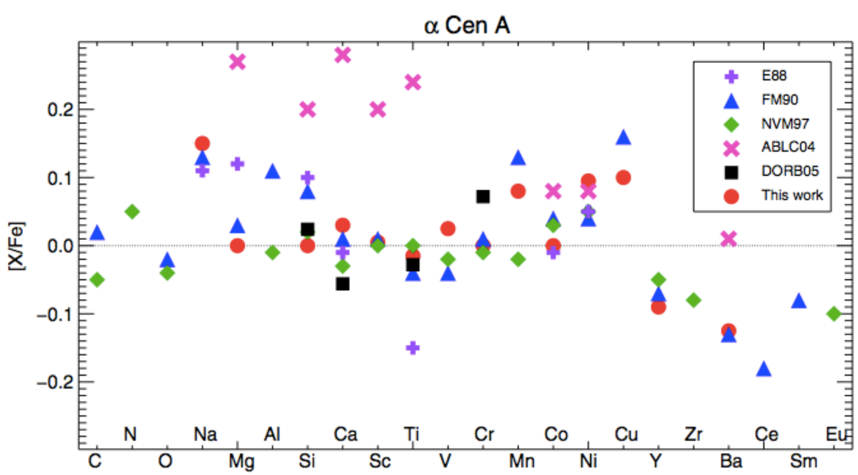
Porto de Mello et al. (2008)

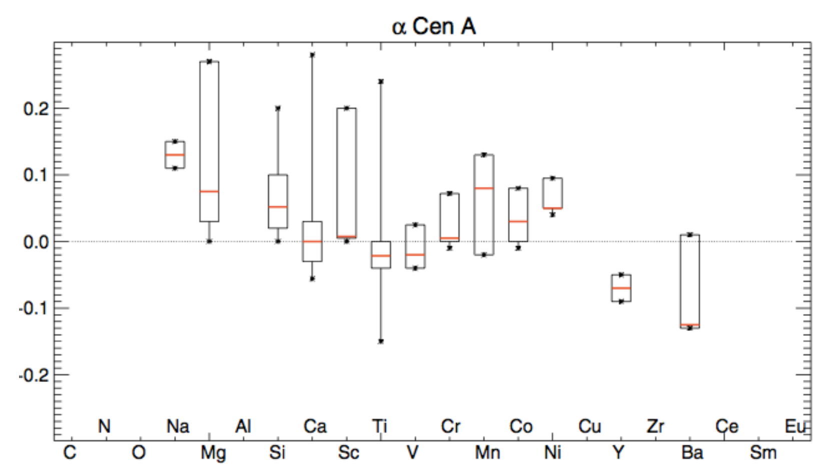
Análise de abundâncias em Alfa Centauri

Projeto de Iniciação Científica começado em 2000
Apresentado na Jornada de IC, 2001
Poster na SAB 2001

History becomes legend, legend becomes myth…

O material é exumado em 2007.
Publicado em 2008!





[Mini-]Postdoc em Heidelberg

A&A 527, A138 (2011)
DOI: 10.1051/0004-6361/201015568

Astronomy & Astrophysics

The baroclinic instability in the context of layered accretion

Self-sustained vortices and their magnetic stability in local compressible unstratified models of protoplanetary disks

W. Lyra[1,2] and H. Klahr[1]

[1] Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
[2] American Museum of Natural History, Department of Astrophysics, Central Park West at 79th Street, New York, NY 10024-5192, USA
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Received 11 August 2010 / Accepted 29 November 2010

ABSTRACT

Context. Turbulence and angular momentum transport in accretion disks remains a topic of debate. With the realization that dead zones are robust features of protoplanetary disks, the search for hydrodynamical sources of turbulence continues. A possible source is the baroclinic instability (BI), which has been shown to exist in unmagnetized non-barotropic disks.
Aims. We aim to verify the existence of the baroclinic instability in 3D magnetized disks, as well as its interplay with other instabilities, namely the magneto-rotational instability (MRI) and the magneto-elliptical instability.
Methods. We performed local simulations of non-isothermal accretion disks with the Pencil Code. The entropy gradient that generates the baroclinic instability is linearized and included in the momentum and energy equations in the shearing box approximation. The model is compressible, so excitation of spiral density waves is allowed and angular momentum transport can be measured.
Results. We find that the vortices generated and sustained by the baroclinic instability in the purely hydrodynamical regime do not survive when magnetic fields are included. The MRI by far supersedes the BI in growth rate and strength at saturation. The resulting turbulence is virtually identical to an MRI-only scenario. We measured the intrinsic vorticity profile of the vortex, finding little radial variation in the vortex core. Nevertheless, the core is disrupted by an MHD instability, which we identify with the magneto-elliptic instability. This instability has nearly the same range of unstable wavelengths as the MRI, but has higher growth rates. In fact, we identify the MRI as a limiting case of the magneto-elliptic instability, when the vortex aspect ratio tends to infinity (pure shear flow). We isolated its effect on the vortex, finding that a strong but unstable vertical magnetic field leads to channel flows inside the vortex, which stretch it apart. When the field is decreased or resistivity is used, we find that the vortex survives until the MRI develops in the box. The vortex is then destroyed by the strain of the surrounding turbulence. Constant azimuthal fields and zero net flux fields also lead to vortex destruction. Resistivity quenches both instabilities when the magnetic Reynolds number of the longest vertical wavelength of the box is near unity.
Conclusions. We conclude that vortex excitation and self-sustenance by the baroclinic instability in protoplanetary disks is viable only in low ionization, i.e., the dead zone. Our results are thus in accordance with the layered accretion paradigm. A baroclinicly unstable dead zone should be characterized by the presence of large-scale vortices whose cores are elliptically unstable, yet sustained by the baroclinic feedback. Since magnetic fields destroy the vortices and the MRI outweighs the BI, the active layers are unmodified.

Key words. accretion, accretion disks – hydrodynamics – instabilities – magnetohydrodynamics (MHD)– turbulence – methods: numerical

1. Introduction

Turbulence is the preferred mechanism for enabling accretion in circumstellar disks, and the magneto-rotational instability (MRI, Balbus & Hawley 1991) is the preferred route to turbulence. However, the MRI requires sufficient ionization since the magnetic field and the gas must be coupled, so it should not be expected to occur in regions of low ionization such as the "dead zone" (Gammie 1996; Turner & Drake 2009). Therefore, the search for hydrodynamical sources of turbulence continues, if only to provide some residual accretion in the dead zone. A distinct possibility is the baroclinic instability (BI; Klahr & Bodenheimer 2003; Klahr 2004), the interest in which has been recently rekindled (Petersen et al. 2007a,b; Lesur & Papaloizou 2010).

A baroclinic flow is one where the pressure depends on both density and temperature, as opposed to a barotropic flow where the pressure only depends on density. In such a flow, the non-axyssimmetric misalignment between surfaces of constant density ρ (isopycnals) and surfaces of constant pressure p (isobars) generates vorticity. Mathematically, this translates into a non-zero baroclinic vector, $\nabla \times (-\rho^{-1}\nabla p) = \rho^{-2}\nabla p \times \nabla\rho$. Baroclinicity has long been known in atmospheric dynamics to be responsible for turbulent patterns on planets and for weather patterns of Rossby waves (planetary waves), cyclones, and anticyclones on Earth.

The difference between the baroclinic instability of weather patterns on planetary atmospheres and the baroclinic instability in accretion disks is that the former is linear, whereas the latter is nonlinear (Klahr 2004; Lesur & Papaloizou 2010). This is because in accretion disks, the disturbances have to overcome the strong Keplerian shear that causes perturbations to be heavily dominated by restoring forces in all Reynolds numbers.

The nature of the instability was clarified in the work of Petersen et al. (2007a,b), who highlighted the importance of finite thermal inertia. When the thermal time is comparable to the eddy turnover time, the vortex is able to establish an entropy

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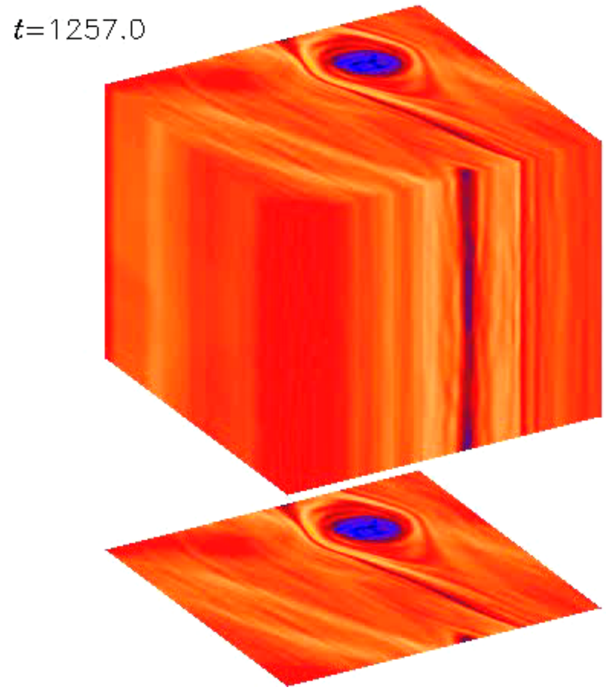
Lyra & Klahr (2011)



J. Fluid Mech. (2012), *vol.* 698, *pp.* 358–373.
doi:10.1017/jfm.2012.95

On the connection between the magneto-elliptic and magneto-rotational instabilities

Krzysztof A. Mizerski[1]† and Wladimir Lyra[2,3]

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[2] Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024-5192, USA
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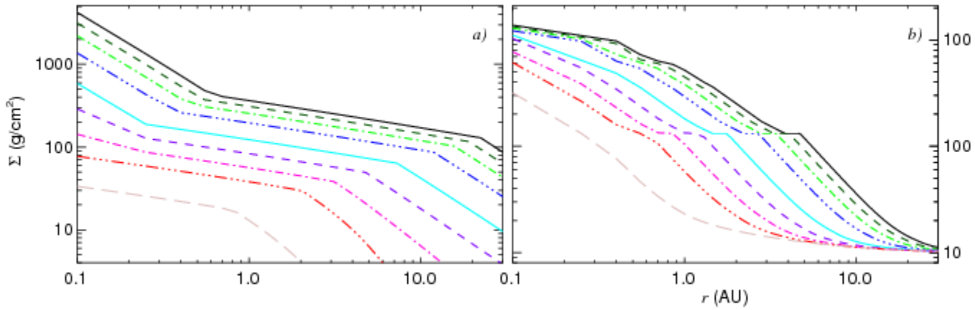
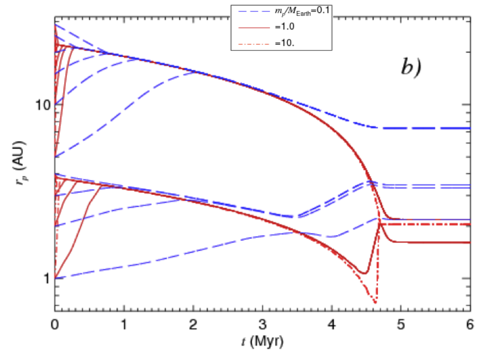
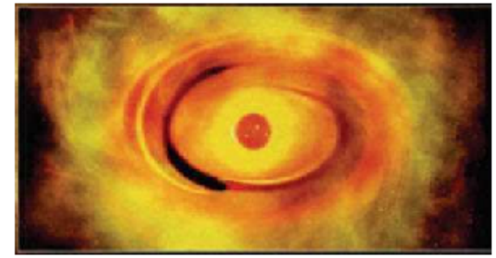
It has recently been suggested that the magneto-rotational instability (MRI) is a limiting case of the magneto-elliptic instability (MEI). This limit is obtained for

Mizerski & Lyra (2012, *J. Fluid Mech.*)

Postdoc em NYC







The Astrophysical Journal Letters, 715:L68–L73, 2010 June 1 doi:10.1088/2041-8205/715/2/L68

ORBITAL MIGRATION OF LOW-MASS PLANETS IN EVOLUTIONARY RADIATIVE MODELS: AVOIDING CATASTROPHIC INFALL

Wladimir Lyra[1], Sijme-Jan Paardekooper[2], and Mordecai-Mark Mac Low[1]

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ABSTRACT

Outward migration of low-mass planets has recently been shown to be a possibility in non-barotropic disks. We examine the consequences of this result in evolutionary models of protoplanetary disks. Planet migration occurs toward equilibrium radii with zero torque. These radii themselves migrate inwards because of viscous accretion and photoevaporation. We show that as the surface density and temperature fall the planet orbital migration and disk depletion timescales eventually become comparable, with the precise timing depending on the mass of the planet. When this occurs, the planet decouples from the equilibrium radius. At this time, however, the gas surface density is already too low to drive substantial further migration. A higher mass planet, of 10 $M_\oplus$, can open a gap during the late evolution of the disk, and stops migrating. Low-mass planets, with 1 or 0.1 $M_\oplus$, released beyond 1 AU in our models avoid migrating into the star. Our results provide support for the reduced migration rates adopted in recent planet population synthesis models.

Key words: accretion, accretion disks – hydrodynamics – methods: numerical – planet–disk interactions – protoplanetary disks – radiation mechanisms: general

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Award Abstract #1009802

Layered accretion, vortex excitation, and planet formation in circumstellar disks

NSF Org:	AST Division of Astronomical Sciences
Initial Amendment Date:	September 14, 2010
Latest Amendment Date:	April 17, 2012
Award Number:	1009802
Award Instrument:	Continuing grant
Program Manager:	Maria Womack AST Division of Astronomical Sciences MPS Directorate for Mathematical & Physical Sciences
Start Date:	September 15, 2010
Expires:	August 31, 2014 (Estimated)
Awarded Amount to Date:	$460,911.00
Investigator(s):	Mordecai-Mark Mac Low mordecai@amnh.org (Principal Investigator) Wladimir Lyra (Former Principal Investigator) Wladimir Lyra (Co-Principal Investigator) Mordecai-Mark Mac Low (Former Co-Principal Investigator)
Sponsor:	American Museum Natural History Central Park West at 79th St New York, NY 10024-5192 (212)769-5975
NSF Program(s):	STELLAR ASTRONOMY & ASTROPHYSC
Program Reference Code(s):	0000, 1206,
Program Element Code(s):	1215

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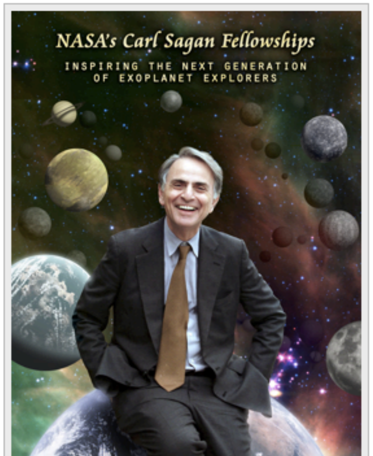


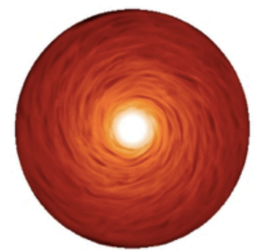
Carl Sagan

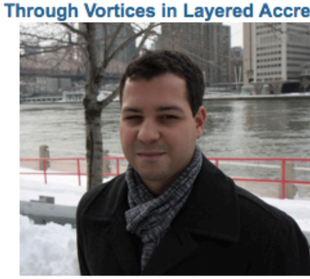
News Items

September 2011: Former Michelson Fellow Remi Soummer leads a team,

Wladimir Lyra - Jet Propulsion Laboratory

Planet Formation in Protostellar Disks Through Vortices in Layered Accretion Flows





I was born and raised in Rio de Janeiro, Brazil, where I also did my undergraduate in Astronomy, with a bachelor thesis and published spectroscopy work on the chromospheric activity of Solar-type stars. Before graduate school, I was a research assistant at CTIO - La Serena, ESO - Garching, and Lisbon Observatory, working on optical and infrared photometry of young stellar objects. It was by that time that I decided to take the bold step from stellar observer to planet theorist.

My interest in astronomy started before elementary school, and planets were the focus of that interest. Moreover, although the combination of mountain tops, dark skies, and big telescopes is pretty exciting, I missed dealing with quantitative physics. Therefore, for my Ph.D. in Uppsala, I chose a topic on theory, and began working on magnetohydrodynamical simulations of turbulence in circumstellar disks and planet formation. Turbulence is the greatest unsolved problem of classical physics, and planet formation is a very ancient question. "How did the Earth come to be?". Virtually every society in recorded history tried at some point to answer this question.

Ondas de Rossby em 3D-MHD

The Astrophysical Journal, 756:62 (10pp), 2012 September 1 doi:10.1088/0004-637X/756/1/62

ROSSBY WAVE INSTABILITY AT DEAD ZONE BOUNDARIES IN THREE-DIMENSIONAL RESISTIVE MAGNETOHYDRODYNAMICAL GLOBAL MODELS OF PROTOPLANETARY DISKS

Wladimir Lyra[1,2,3] and Mordecai-Mark Mac Low[1]
[1] Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024, USA; wlyra@jpl.nasa.gov, mordecai@amnh.org
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Received 2012 April 25; accepted 2012 June 23; published 2012 August 16

ABSTRACT

It has been suggested that the transition between magnetorotationally active and dead zones in protoplanetary disks should be prone to the excitation of vortices via Rossby wave instability (RWI). However, the only numerical evidence for this has come from alpha disk models, where the magnetic field evolution is not followed, and the effect of turbulence is parameterized by Laplacian viscosity. We aim to establish the phenomenology of the flow in the transition in three-dimensional resistive-magnetohydrodynamical models. We model the transition by a sharp jump in resistivity, as expected in the inner dead zone boundary, using the Pencil Code to simulate the flow. We find that vortices are readily excited in the dead side of the transition. We measure the mass accretion rate finding similar levels of Reynolds stress at the dead and active zones, at the $\alpha \approx 10^{-2}$ level. The vortex sits in a pressure maximum and does not migrate, surviving until the end of the simulation. A pressure maximum in the active zone also triggers the RWI. The magnetized vortex that results should be disrupted by parasitical magneto-elliptic instabilities, yet it subsists in high resolution. This suggests that either the parasitic modes are still numerically damped or that the RWI supplies vorticity faster than they can destroy it. We conclude that the resistive transition between the active and dead zones in the inner regions of protoplanetary disks, if sharp enough, can indeed excite vortices via RWI. Our results lend credence to previous works that relied on the alpha-disk approximation, and caution against the use of overly reduced azimuthal coverage on modeling this transition.

Key words: accretion, accretion disks – instabilities – magnetohydrodynamics (MHD) – methods: numerical – planets and satellites: formation – protoplanetary disks

Online-only material: color figures

1. INTRODUCTION

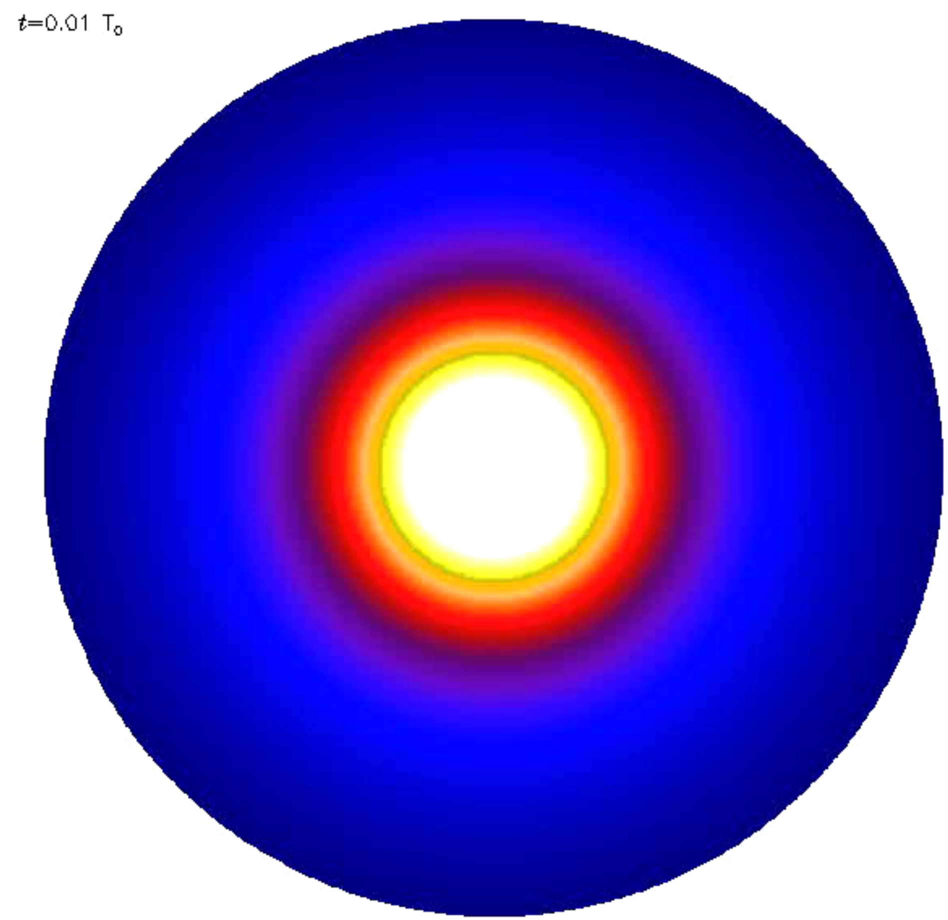
The formation of planets remains one of the most challenging problems of contemporary astrophysics. The current paradigm in planet formation theory describes a hierarchical growth of solid bodies, from interstellar dust grains to rocky planetary cores (Safronov 1969; Lyttleton 1972; Goldreich & Ward 1973; Youdin & Shu 2002). A particularly difficult phase in the process is the growth from centimeter-sized pebbles and meter-sized boulders to planetary embryos the size of our Moon or Mars. Objects in the pebble to boulder range are expected to drift inward extremely rapidly in a protoplanetary disk, so that they would generally fall into the central star well before larger bodies can form by simple accumulation (Weidenschilling 1977; Brauer et al. 2008).

Ways to bypass this problem have focused on inhomogeneities in the flow, in order to trap particles in their migrating path. Cuzzi et al. (2008) proposed a model in which millimeter-sized particles are trapped in the smallest eddies in the flow, forming "sandpile" planetesimals in the 10–100 km range (though that model has been criticized by Chang & Oishi 2010 and Pan et al. 2011). Particles may also be trapped in mesoscale "zonal flows" (Lyra et al. 2008b; Johansen et al. 2009; Simon et al. 2012) that are local inversions in the angular velocity profile, brought about by spatial variations in magnetic pressure. The particles themselves can give rise to the necessary inhomogeneities, as their migrating streaming flow develops into a traffic-jam instability (Youdin & Shu 2002; Youdin & Goodman 2005; Youdin & Johansen 2007), leading to intense particle clumping (Johansen & Youdin 2007) and subsequent planetesimal formation at the Ceres-mass range (Johansen et al. 2007). It has also been recently proposed that icy planetesimals may form from direct coagulation (Okuzumi et al. 2012) due to the enhanced sticking properties of ices.

Another process has been suggested, that combines several of the advantages (as well as many of the problems) of the scenarios described above, and is the subject of this work. Turbulence in the largest scales of the flow, in the form of large-scale vortices, has been independently proposed by Barge & Sommeria (1995) and Tanga et al. (1996) as fast routes for planet formation, for two main reasons. First, vortices are equilibrium solutions of the Navier–Stokes equations and thus are persistent structures in hydrodynamic flows, as seen in the Great Red Spot of Jupiter, a remarkable high pressure vortex stable since first spotted, over three hundred years ago (Hooke 1665; Cassini 1666).[4] The second is that the equilibrium is geostrophic, i.e., between the Coriolis force and the pressure gradient force. As solids do not feel the pressure force, the Coriolis force will lead them out of the vortex if cyclonic and into the eye if anticyclonic. As the shear enforces that only anticyclonic vortices persist (Marcus 1993; Adams & Watkins 1995; Bracco et al. 1999; Godon & Livio 1999), this becomes a very effective mechanism to concentrate solid particles (Klahr 2006), as also observed in numerical simulations (Godon & Livio 2000; Johansen et al. 2004; Fromang & Nelson 2005; Inaba & Barge 2006). It was

[3] NASA Carl Sagan Fellow

[4] The reader is refereed to the fascinating account of Falomi (1987) on the history of the discovery of the Spot, where the author debates the claims of primacy to Hooke or Cassini.



Lyra & Mac Low (2012)

"Solução de Lyra-Lin"

THE ASTROPHYSICAL JOURNAL, 775:17 (10pp), 2013 September 20 doi:10.1088/0004-637X/775/1/17

STEADY STATE DUST DISTRIBUTIONS IN DISK VORTICES: OBSERVATIONAL PREDICTIONS AND APPLICATIONS TO TRANSITIONAL DISKS

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ABSTRACT

The Atacama Large Millimeter Array has returned images of transitional disks in which large asymmetries are seen in the distribution of millimeter sized dust in the outer disk. The explanation in vogue borrows from the vortex literature and suggests that these asymmetries are the result of dust trapping in giant vortices, excited via Rossby wave instabilities at planetary gap edges. Due to the drag force, dust trapped in vortices will accumulate in the center and diffusion is needed to maintain a steady state over the lifetime of the disk. While previous work derived semi-analytical models of the process, in this paper we provide analytical steady-steady solutions. Exact solutions exist for certain vortex models. The solution is determined by the vortex rotation profile, the gas scale height, the vortex aspect ratio, and the ratio of dust diffusion to gas-dust friction. In principle, all of these quantities can be derived from observations, which would validate the model and also provide constrains on the strength of the turbulence inside the vortex core. Based on our solution, we derive quantities such as the gas-dust contrast, the trapped dust mass, and the dust contrast at the same orbital location. We apply our model to the recently imaged Oph IRS 48 system, finding values within the range of the observational uncertainties.

Key words: methods: analytical – planet–disk interactions – planets and satellites: formation – protoplanetary disks

Online-only material: color figures

1. INTRODUCTION

Transitional disks are a class of circumstellar disks that lack a significant near-infrared (1–5 μm) excess, while showing steep slopes in mid-infrared (5–20 μm) and far-infrared (>20 μm) excesses typical of classical T-Tauri disks (Strom et al. 1989; Skrutskie et al. 1990; Gauvin & Strom 1992; Wolk & Walter 1996; Calvet et al. 2002, 2005; Muzerolle et al. 2006; Sicilia-Aguilar et al. 2006; Currie et al. 2009; Currie & Sicilia-Aguilar 2011). This "opacity hole" implies the absence of optically thick warm dust in the inner disk, with a dust wall generating the mid-IR emission, followed by cold dust in the outer disk. These observations, together with the age of these systems (in the 1–10 Myr range; see, e.g., Currie 2010 for a review), provide strong evidence that these are objects caught in the evolutionary stage between gas-rich primordial and gas-poor debris disks, hence their name.

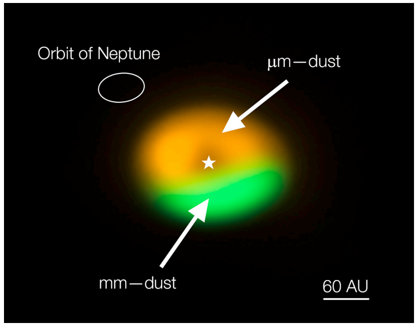
Explanations for the opacity hole generally fall in four distinct categories. These are, namely, grain growth and dust settling (Brauer et al. 2007; Dominik & Dullemond 2008; Zsom et al. 2011; Birnstiel et al. 2012), photoevaporation (Alexander et al. 2006; Cieza 2008; Pascucci & Sterzik 2009; Owen et al. 2010), dynamical interaction with close stellar or substellar companions (Ireland & Kraus 2008), and planet formation via dust locking (Safronov 1969; Lyttleton 1972; Goldreich & Ward 1973; Youdin & Shu 2002; Johansen et al. 2007) and gap carving (Papaloizou & Lin 1984; Lin & Papaloizou 1986a, 1986b; Bryden et al. 1999; Paardekooper & Mellema 2004; Quillen et al. 2004; Najita et al. 2007; Andrews et al. 2011). Analyses of individual disks (Calvet et al. 2004, 2005; Espaillat et al. 2008) tend to favor one process over another, and even census studies of statistically significant samples of disks find one process to be dominant (Najita et al. 2007; Cieza 2008). These seemingly conflicting results in fact illustrate the heterogeneity of transitional disks, where a combination of all the suggested processes are needed to explain the rich diversity observed (Cieza 2010; Muzerolle et al. 2010; Merín et al. 2010; Rosotti et al. 2013; Clarke & Owen 2013).

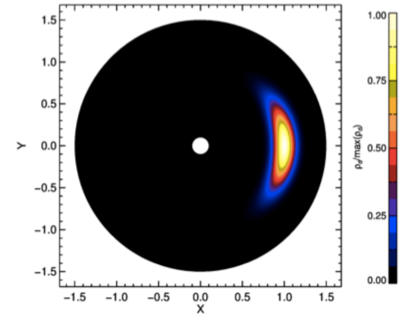
Recently, high angular resolution imaging of the outer regions of transitional disks have become available, showing a myriad of puzzling asymmetries that beg for explanation. These asymmetries come in the shape of spiral arms (Piétu et al. 2005; Corder et al. 2005; Muto et al. 2012; Tang et al. 2012), elliptical dust walls (Isella et al. 2012), and non-axisymmetric dust clouds (Oppenheimer et al. 2008; Brown et al. 2009; Casassus et al. 2012). In particular, giant horseshoe-shaped dust distributions are seen in images obtained with the Combined Array for Research in Millimeter-wave Astronomy (Isella et al. 2013) and with the Atacama Large Millimeter Array (ALMA; Casassus et al. 2013; van der Marel et al. 2013). The planet interpretation is particularly attractive for explaining these asymmetries, since they generally match the range of structures predicted by hydrodynamical models of planet–disk interactions.

A deep gap is one of the expected structures, as the planet tides expel material from the vicinity of its orbit (Papaloizou & Lin 1984; Lin & Papaloizou 1986a, 1986b; Nelson et al. 2000; Masset & Snellgrove 2001; Paardekooper & Mellema 2004; Quillen et al. 2004; de Val-Borro et al. 2006; Klahr & Kley 2006; Lyra et al. 2009a; Zhu et al. 2011; Kley et al. 2012; Kley & Nelson 2012). The gas gap walls constitute steep pressure gradients that, by modifying the rotational profile locally, are prone to excite what has been called the Rossby wave instability (RWI; Lovelace & Hohlfeld 1978; Toomre 1981; Papaloizou &

[4] Sagan Fellow.
[5] Both authors contributed equally to this work.

Lyra & Lin (2013)





$$\rho_d(a,z) = \varepsilon\rho_0\,(S+1)^{3/2}\exp\left\{-\frac{[a^2 f^2(\chi)+z^2]}{2H^2}(S+1)\right\} \quad (65)$$

Lyra & Lin (2013)

LARGE-SCALE ASYMMETRIES IN THE TRANSITIONAL DISKS OF SAO 206462 AND SR 21

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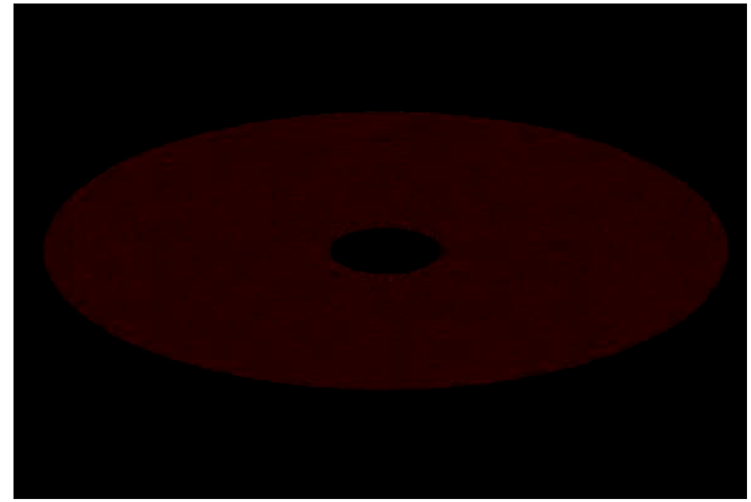
Draft version February 5, 2014

ABSTRACT

We present Atacama Large Millimeter/submillimeter Array (ALMA) observations in the dust continuum (690 GHz, 0.45 mm) and ^{12}CO $J = 6-5$ spectral line emission, of the transitional disks surrounding the stars SAO 206462 and SR 21. These ALMA observations resolve the dust-depleted disk cavities and extended gaseous disks, revealing large-scale asymmetries in the dust emission of both disks. We modeled these disks structures with a ring and an azimuthal gaussian, where the azimuthal gaussian is motivated by the steady-state vortex solution from Lyra & Lin (2013). Compared to recent observations of HD 142527, Oph IRS 48, and LkHα 330, these are low-contrast ($\lesssim 2$) asymmetries. Nevertheless, a ring alone is not a good fit, and the addition of a vortex prescription describes these data much better. The asymmetric component encompasses 15% and 28% of the total disk emission in SAO 206462 and SR 21 respectively, which corresponds to a lower limit of $2M_{Jup}$ of material within the asymmetry for both disks. Although the contrast in the dust asymmetry is low, we find that the turbulent velocity inside it must be large ($\sim$ 20% of the sound speed) in order to drive these azimuthally wide and radially narrow vortex-like structures. We obtain residuals from the ring and vortex fitting that are still significant, tracing non-axisymmetric emission in both disks. We compared these submillimeter observations with recently published H-band scattered light observations. For SR 21 the scattered light emission is distributed quite differently from submillimeter continuum emission, while for SAO 206462 the submillimeter residuals are suggestive of spiral-like structure similar to the near-IR emission.
Subject headings: protoplanetary disks

Discos de debris: Instabilidade Fotoelétrica



LETTER

doi:10.1038/nature12281

Formation of sharp eccentric rings in debris disks with gas but without planets

W. Lyra[1,2,3] & M. Kuchner[4]

'Debris disks' around young stars (analogues of the Kuiper Belt in our Solar System) show a variety of non-trivial structures attributed to planetary perturbations and used to constrain the properties of those planets[1–3]. However, these analyses have largely ignored the fact that some debris disks are found to contain small quantities of gas[4–9], a component that all such disks should contain at some level[10,11]. Several debris disks have been measured with a dust-to-gas ratio of about unity[4–9], at which the effect of hydrodynamics on the structure of the disk cannot be ignored[12,13]. Here we report linear and nonlinear modelling that shows that dust–gas interactions can produce some of the key patterns attributed to planets. We find a robust clumping instability that organizes the dust into narrow, eccentric rings, similar to the Fomalhaut debris disk[14]. The conclusion that such disks might contain planets is not necessarily required to explain these systems.

Disks around young stars seem to pass through an evolutionary phase when the disk is optically thin and the dust-to-gas ratio ε ranges from 0.1 to 10. The nearby stars β Pictoris[5,6,15–17], HD32297 (ref. 7), 49 Ceti (ref. 4) and HD 21997 (ref. 9) all host dust disks resembling ordinary debris disks and also have stable circumstellar gas detected in molecular CO, Na I or other metal lines; the inferred mass of gas ranges from lunar masses to a few Earth masses (Supplementary Information). The gas in

We present simulations of the fully compressible problem, solving for the continuity, Navier–Stokes and energy equations for the gas, and the momentum equation for the dust. Gas and dust interact dynamically through a drag force, and thermally through photoelectric heating. These are parametrized by a dynamical coupling time τ_f and a thermal coupling time τ_T (Supplementary Information). The simulations are performed with the Pencil Code[21–24], which solves the hydrodynamics on a grid. Two numerical models are presented: a three-dimensional box embedded in the disk that co-rotates with the flow at a fixed distance from the star; and a two-dimensional global model of the disk in the inertial frame. In the former the dust is treated as a fluid, with a separate continuity equation. In the latter the dust is represented by discrete particles with position and velocities that are independent of the grid.

We perform a stability analysis of the linearized system of equations that should help interpret the results of the simulations (Supplementary Information). We plot in Fig. 1a–c the three solutions that show linear growth, as functions of ε and $n = kH$, where k is the radial wavenumber and H is the gas scale height ($H = c_s/\sqrt{\gamma}\Omega_K$, where c_s is the sound speed, Ω_K the Keplerian rotation frequency and γ the adiabatic index). The friction time τ_f is assumed to be equal to $1/\Omega_K$. The left and middle panels show the growth and damping rates. The

Lyra & Kuchner (2013)

nature International weekly journal of science

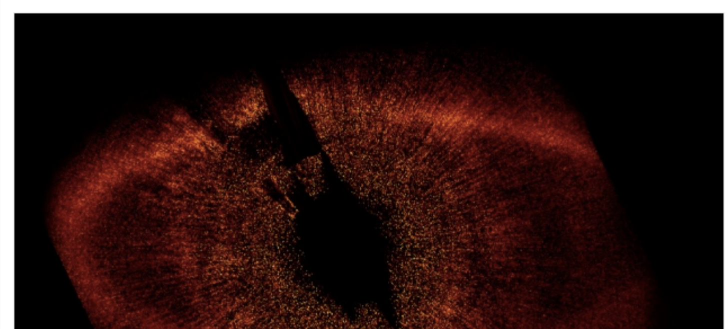
NATURE | NEWS

Proposed exoplanets may be just gas and dust

Lopsided rings around stars need not have been carved by planets.

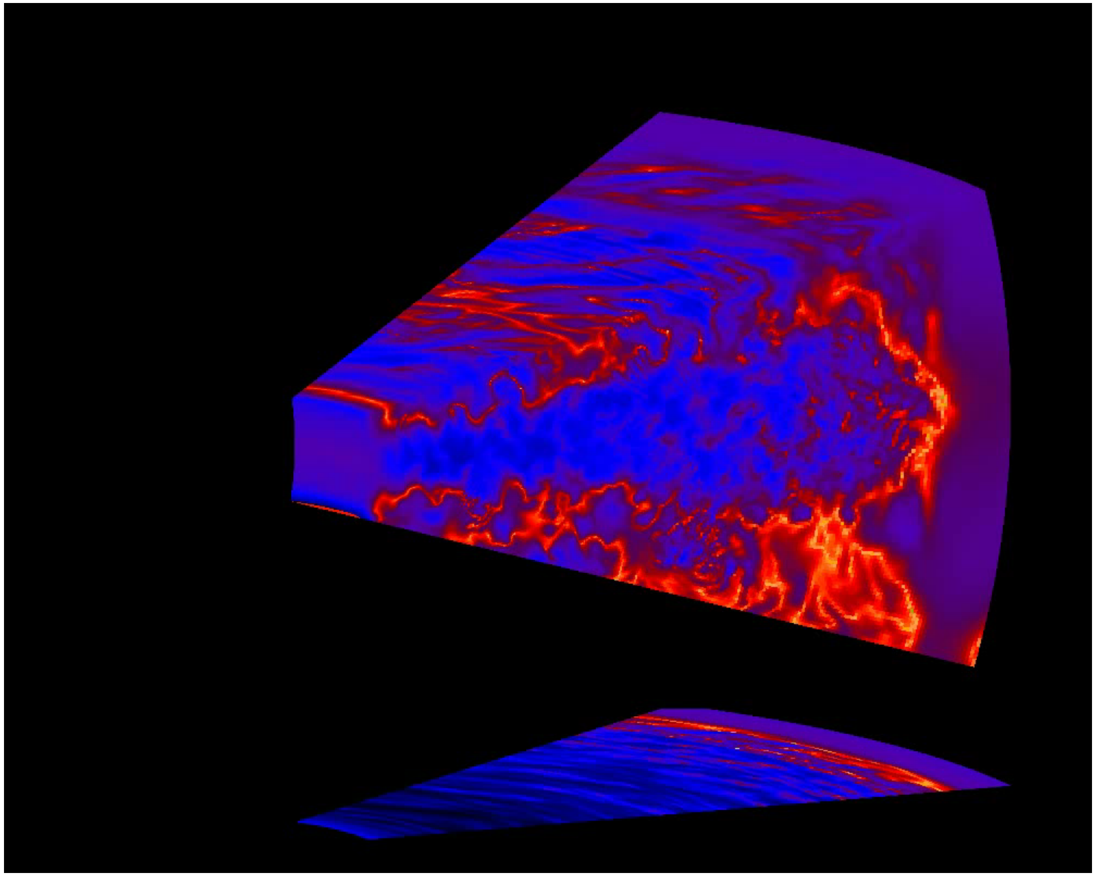
Sid Perkins

10 July 2013



Projetos

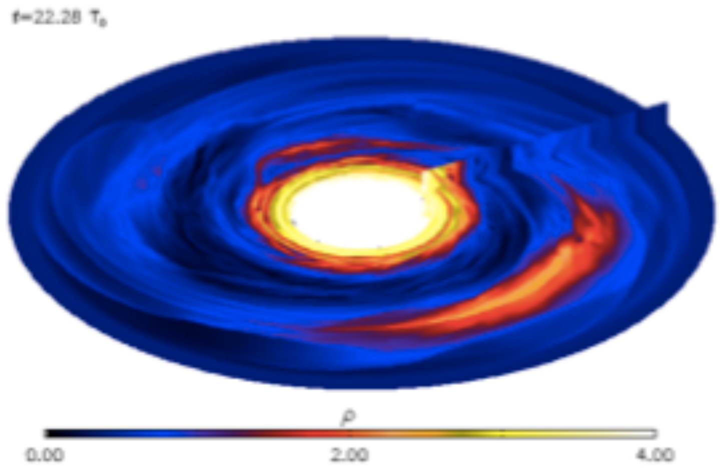
1. Formação Planetária em modelos 3D-MHD.

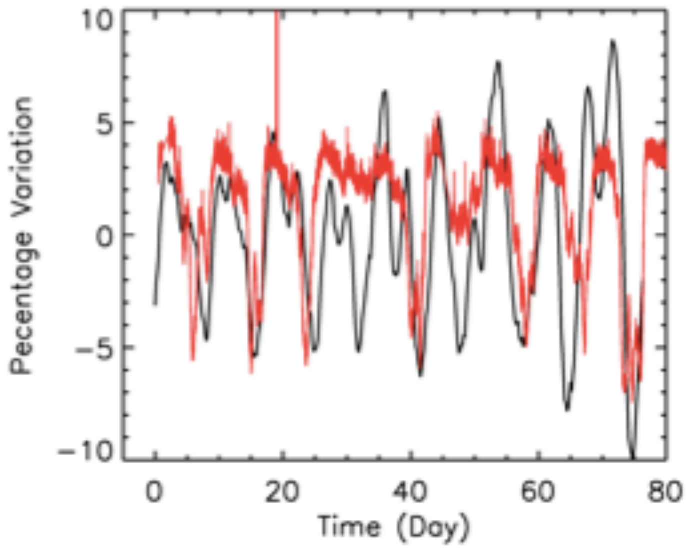


* Modelos do gás com resistividade em 3D já prontos.
* Adicionar partículas.
* Aluno de doutorado (Alex Richert) trabalhando no momento em adicionar a gravidade das partículas.

Projetos

2. Conexão entre modelos de vórtices e observações



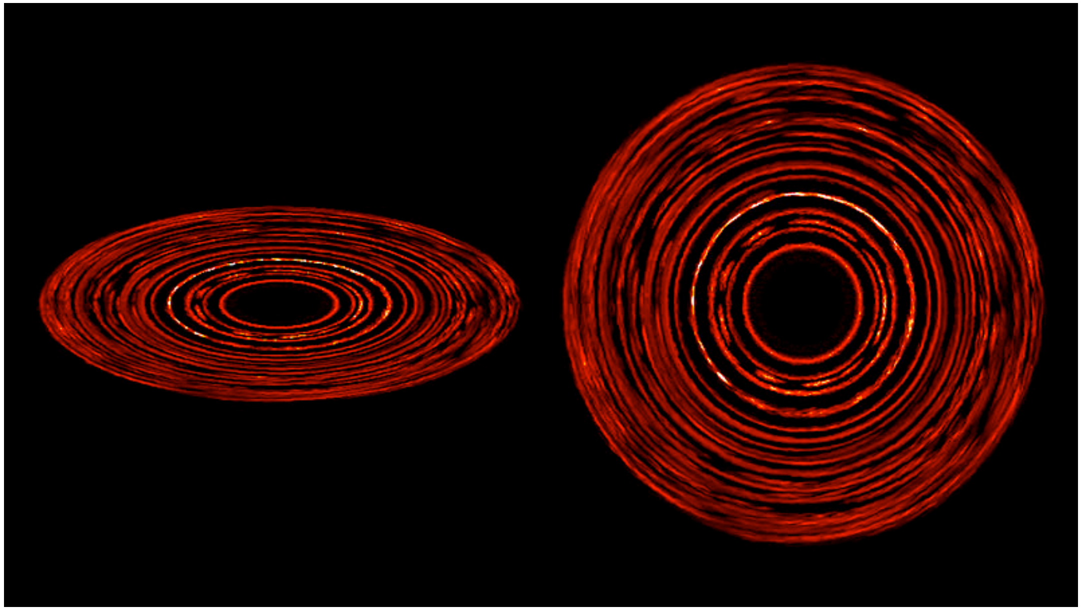


- Adicionar partículas de milímetros em modelos dinâmicos,
- Rodar transporte radiativo para obter observáveis

* Contrastar com observações.

Projetos

3. Caracterizar a instabilidade fotoelétrica em discos de debris e de transição
(Lyra & Kuchner, 2013, Nature)



- Adicionar pressão de radiação, arrasto de Poynting-Robertson, fotoforese, turbulência, colisões, etc….

Estudante de verão (Leonardo Cassara, UFRJ-Berkeley) trabalhará em radiação.

Orientação

THE ASTROPHYSICAL JOURNAL, 750:34 (14pp), 2012 May 1 doi:10.1088/0004-637X/750/1/34

ORBITAL MIGRATION OF INTERACTING LOW-MASS PLANETS IN EVOLUTIONARY RADIATIVE TURBULENT MODELS

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Received 2011 December 14; accepted 2012 February 15; published 2012 April 13

ABSTRACT

The torques exerted by a locally isothermal disk on an embedded planet lead to rapid inward migration. Recent work has shown that modeling the thermodynamics without the assumption of local isothermality reveals regions where the net torque on an embedded planet is positive, leading to outward migration of the planet. When a region with negative torque lies directly exterior to this, planets in the inner region migrate outward and planets in the outer region migrate inward, converging where the torque is zero. We incorporate the torques from an evolving non-isothermal disk into an *N*-body simulation to examine the behavior of planets or planetary embryos interacting in the convergence zone. We find that mutual interactions do not eject objects from the convergence zone. Small numbers of objects in a laminar disk settle into near resonant orbits that remain stable over the 10 Myr periods that we examine. However, either or both increasing the number of planets or including a correlated, stochastic force to represent turbulence drives orbit crossings and mergers in the convergence zone. These processes can build gas giant cores with masses of order 10 Earth masses from sub-Earth mass embryos in 2–3 Myr.

Key words: methods: numerical – planets and satellites: formation – planet–disk interactions – protoplanetary disks

Online-only material: color figures

Brandon Horn, Columbia; 2012

THE ASTROPHYSICAL JOURNAL, 765:115 (12pp), 2013 March 10 doi:10.1088/0004-637X/765/2/115

A PARAMETER STUDY FOR BAROCLINIC VORTEX AMPLIFICATION

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ABSTRACT

Recent studies have shown that baroclinic vortex amplification is strongly dependent on certain factors, namely, the global entropy gradient, the efficiency of thermal diffusion and/or relaxation as well as numerical resolution. We conduct a comprehensive study of a broad range and combination of various entropy gradients, thermal diffusion and thermal relaxation timescales via local shearing sheet simulations covering the parameter space relevant for protoplanetary disks. We measure the Reynolds stresses as a function of our control parameters and see that there is angular momentum transport even for entropy gradients as low as $\beta = -d \ln s / d \ln r = 1/2$. Values we expect in protoplanetary disks are between $\beta = 0.5$–2.0 The amplification-rate of the perturbations, Γ, appears to be proportional to β^2 and thus proportional to the square of the Brunt-Väisälä frequency ($\Gamma \propto \beta^2 \propto N^2$). The saturation level of Reynolds stresses, on the other hand, seems to be proportional to $\beta^{1/2}$. This highlights the importance of baroclinic effects even for the low entropy gradients expected in protoplanetary disks.

Key words: accretion, accretion disks – circumstellar matter – hydrodynamics – instabilities – methods: numerical – planetary systems – turbulence

Online-only material: color figures

Natalie Raettig, Heidelberg, AMNH; 2013

DRAFT VERSION
Preprint typeset using LaTeX style emulateapj v. 5/2/11

TURBULENT WAKES DESTROY GAPS AROUND HIGH-MASS PLANETS OR BROWN DWARFS IN RADIATIVELY INEFFICIENT DISKS

ALEXANDER J.W. RICHERT[1,2,3,4], WLADIMIR LYRA[3,4,5], MORDECAI-MARK MAC LOW[6] & NEAL TURNER[3]
Draft version

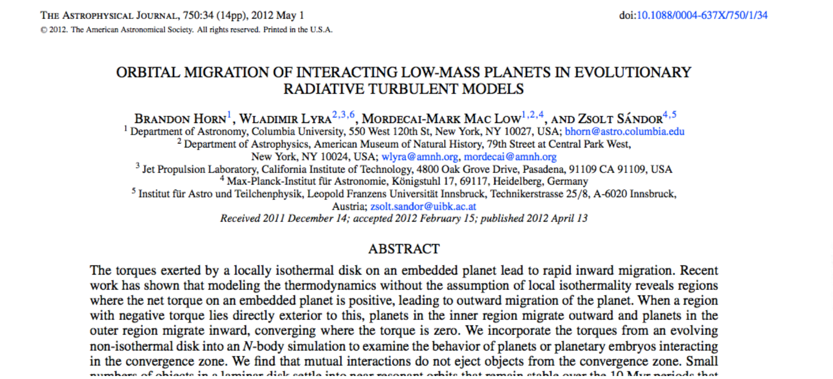
ABSTRACT

Recent observations of gaps and non-axisymmetric features in the dust distributions of protoplanetary disks have been interpreted as evidence of embedded massive protoplanets. In this work, we conduct two-dimensional, global, hydrodynamical simulations of disks with embedded protoplanets with a range of planet-to-star mass ratios (1–10 $M_{\rm Jup}$ for a 1 $M_\odot$ star) with and without the assumption of local isothermality. We use the PENCIL CODE in polar coordinates for our models. We find that massive protoplanets ($M \gtrsim 5\,M_{\rm Jup}$) significantly heat nearby gas, which can drive buoyant instabilities that produce sustained turbulence throughout the disk. We confirm that the buoyant instabilities originate from shock heating in the planet's inner and outer spiral wakes. The effect is strongly dependent on the mass of the planet and the thermal relaxation timescale; for a 10 $M_{\rm Jup}$ planet embedded in a purely adiabatic disk, the gaps and vortices typically associated with planet-disk interactions are completely disrupted. We find that the effect is only weakly dependent on the initial radial temperature profile. The driven turbulence substantially increases the effective Shakura-Sunyaev α-viscosity of the disk (to as high as $\alpha \sim 0.2$ for the adiabatic, 10 $M_{\rm Jup}$ case), leading to inward mass transport rates much higher than in the locally isothermal case. This effect may explain the observed dearth of massive substellar companions at close separations—the brown dwarf desert—as the turbulence generated by such objects in the disk causes the gas to be accreted rapidly onto the central star, effectively halting further growth.

Subject headings: hydrodynamics — planet-disk interactions — planets and satellites: formation — protoplanetary disks — shock waves — turbulence

Alex Richert, Penn State, Caltech-JPL; 2014

Orientação



THE ASTROPHYSICAL JOURNAL, 750:34 (14pp), 2012 May 1 doi:10.1088/0004-637X/750/1/34

ORBITAL MIGRATION OF INTERACTING LOW-MASS PLANETS IN EVOLUTIONARY RADIATIVE TURBULENT MODELS

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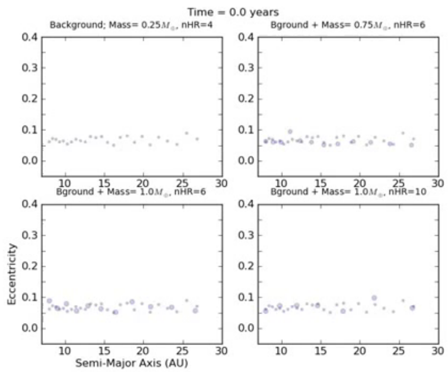
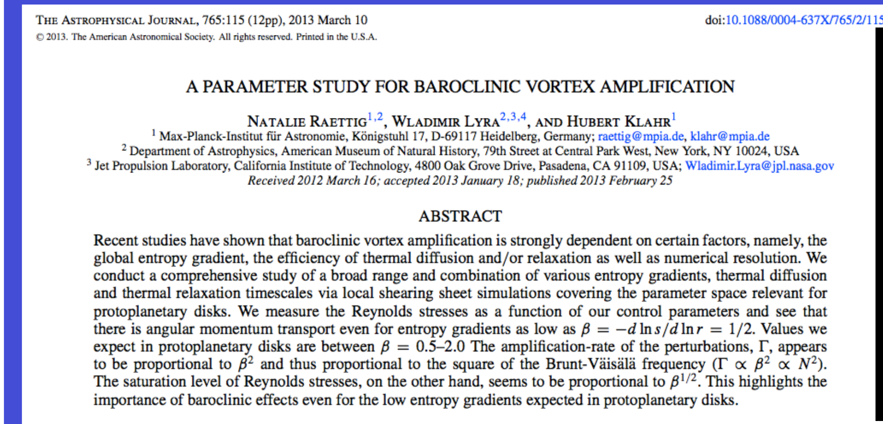


Brandon Horn
Columbia, AMNH; 2012



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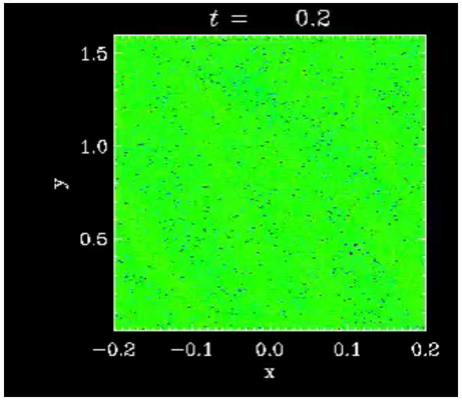
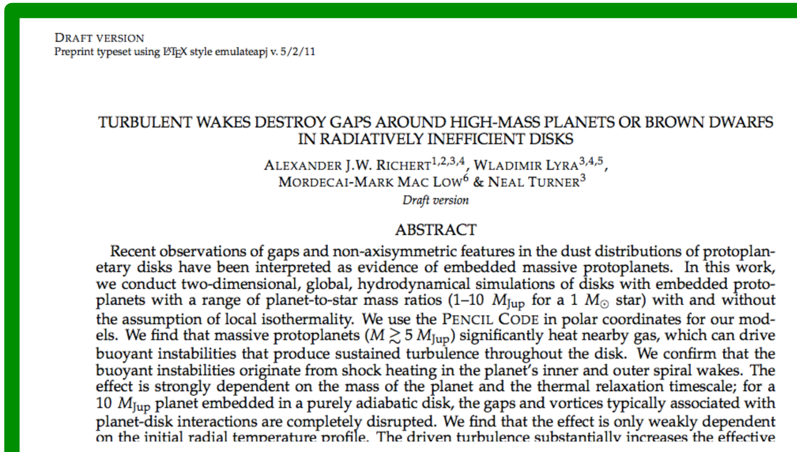
Received 2012 March 16; accepted 2013 January 18; published 2013 February 25

ABSTRACT

Recent studies have shown that baroclinic vortex amplification is strongly dependent on certain factors, namely, the global entropy gradient, the efficiency of thermal diffusion and/or relaxation as well as numerical resolution. We conduct a comprehensive study of a broad range and combination of various entropy gradients, thermal diffusion and thermal relaxation timescales via local shearing sheet simulations covering the parameter space relevant for protoplanetary disks. We measure the Reynolds stresses as a function of our control parameters and see that there is angular momentum transport even for entropy gradients as low as $\beta = -d\ln s/d\ln r = 1/2$. Values we expect in protoplanetary disks are between $\beta = 0.5$–2.0 The amplification-rate of the perturbations, Γ, appears to be proportional to β^2 and thus proportional to the square of the Brunt-Väisälä frequency ($\Gamma \propto \beta^2 \propto N^2$). The saturation level of Reynolds stresses, on the other hand, seems to be proportional to $\beta^{1/2}$. This highlights the importance of baroclinic effects even for the low entropy gradients expected in protoplanetary disks.



Natalie Raettig
Heidelberg, AMNH; 2013



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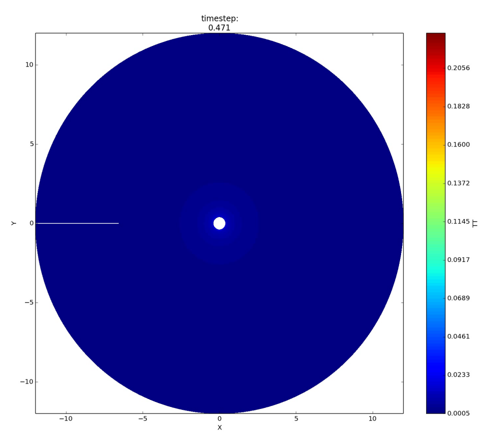
TURBULENT WAKES DESTROY GAPS AROUND HIGH-MASS PLANETS OR BROWN DWARFS IN RADIATIVELY INEFFICIENT DISKS

ALEXANDER J.W. RICHERT[1,2,3,4], WLADIMIR LYRA[3,4,5], MORDECAI-MARK MAC LOW[6] & NEAL TURNER[3]
Draft version

ABSTRACT

Recent observations of gaps and non-axisymmetric features in the dust distributions of protoplanetary disks have been interpreted as evidence of embedded massive protoplanets. In this work, we conduct two-dimensional, global, hydrodynamical simulations of disks with embedded protoplanets with a range of planet-to-star mass ratios (1–10 $M_{\rm Jup}$ for a 1 $M_\odot$ star) with and without the assumption of local isothermality. We use the PENCIL CODE in polar coordinates for our models. We find that massive protoplanets ($M \gtrsim 5\,M_{\rm Jup}$) significantly heat nearby gas, which can drive buoyant instabilities that produce sustained turbulence throughout the disk. We confirm that the buoyant instabilities originate from shock heating in the planet's inner and outer spiral wakes. The effect is strongly dependent on the mass of the planet and the thermal relaxation timescale; for a 10 $M_{\rm Jup}$ planet embedded in a purely adiabatic disk, the gaps and vortices typically associated with planet-disk interactions are completely disrupted. We find that the effect is only weakly dependent on the initial radial temperature profile. The driven turbulence substantially increases the effective



Alex Richert
Penn State, Caltech-JPL; 2014

Ensino

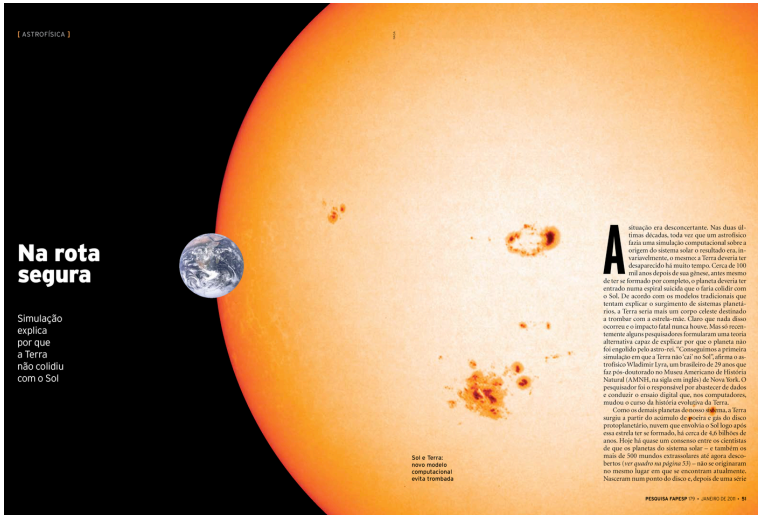
Dois cursos co-desenvolvidos para o programa *after-school* do Museu.
Para estudantes *auto-selecionados* de segundo-grau.

O museu continua oferecendo os dois cursos,
que ainda amplamente baseados nos cursos que eu co-desenvolvi.

Mídia e Extensão

Astronomia da bandeira brasileira,
Revista do Professor, in press,
Museu da Republica.

Entrevista para *Fysikaktuellt*,
Suécia, 2009.



Highlight de pesquisa
na revista FAPESP, 2010.

Contribuição de artigo popular para
Fysikakyuellt, Suécia, 2009.

Highlight de pesquisa na
Science et Vie, França, 2010.

Ciel et Espace, França, 2010.

Outros

- Referee para A&A (x7), MNRAS (x5), ApJ (x2), Planet. Space Sc. (x1).
- Panelista para NSF (x3), NASA (x1). Revisor externo (x2).
- 5 palestras/reviews convidadas em conferências internacionais.
- 15 palestras e seminários convidados em institutos.
- ~20 palestras contribuídas em conferências internacionais.
- Co-orientação de tese de 4 alunos de graduação (Uppsala).
- Dois estudantes de verão (JPL-Caltech, 2013).
- Entrevistas na *Radiovetenskap* (Suécia, 2009), *Southern California Science Radio* (2012, ao vivo), podcasting *Stuttering is Cool* (2013), Palestra pública na conferência BIL (2013).