Class 13 – Mar 5$^{th}$, 2020

# Keplerian disks can't develop hydrodynamical turbulence

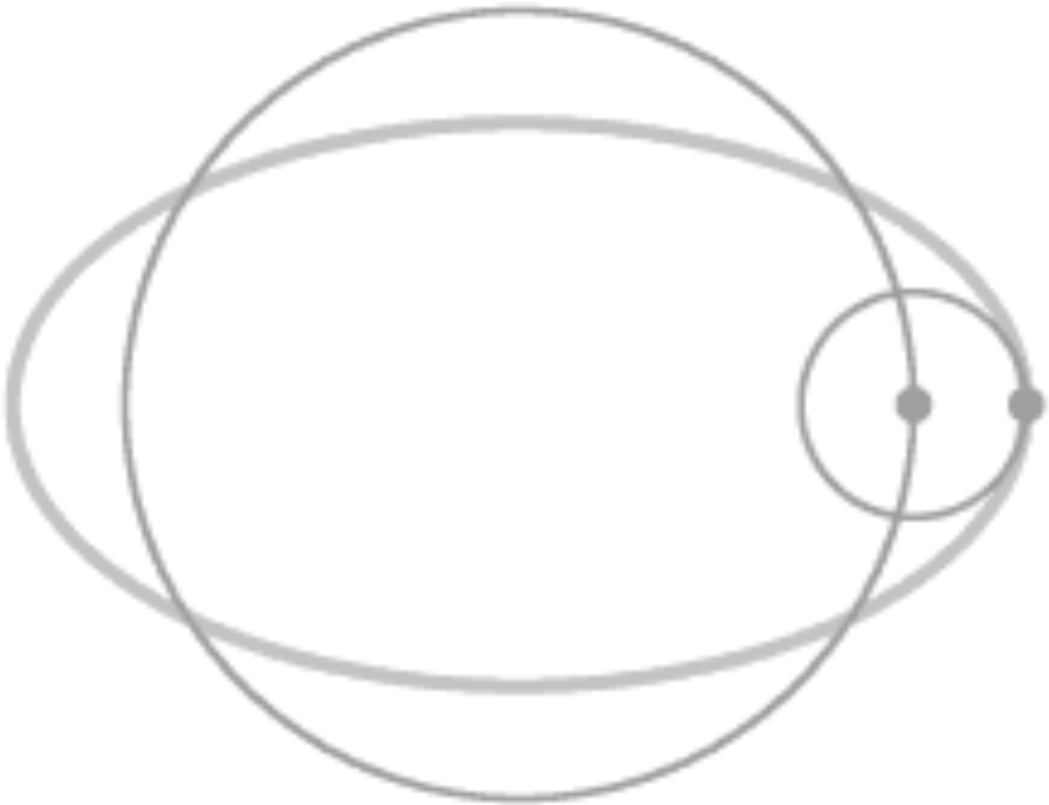
## Most astrophysical discs are close to Keplerian

- nearly circular
- angular velocity profile $\Omega \propto r^{-3/2}$
  - angular momentum $\left(r^2 \Omega\right)$ increases outwards

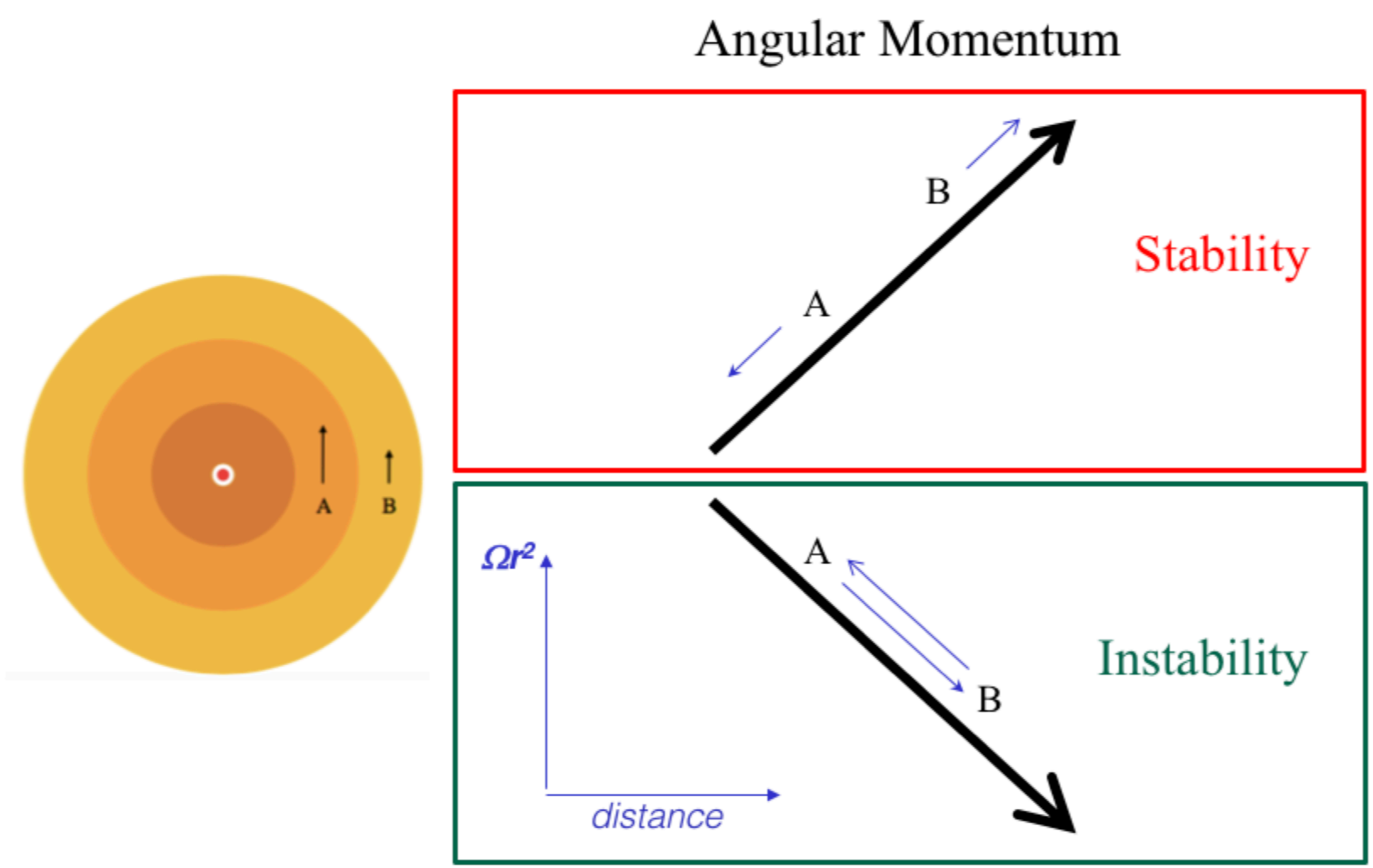
Stable to axis-symmetric disturbances

(Rayleigh criterion)

# Epicyclic frequency



# Rayleigh instability



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# A POWERFUL LOCAL SHEAR INSTABILITY IN WEAKLY MAGNETIZED DISKS. I. LINEAR ANALYSIS

STEVEN A. BALBUS AND JOHN F. HAWLEY
Virginia Institute for Theoretical Astronomy, Department of Astronomy, University of Virginia, P.O. Box 3818, Charlottesville, VA 22903
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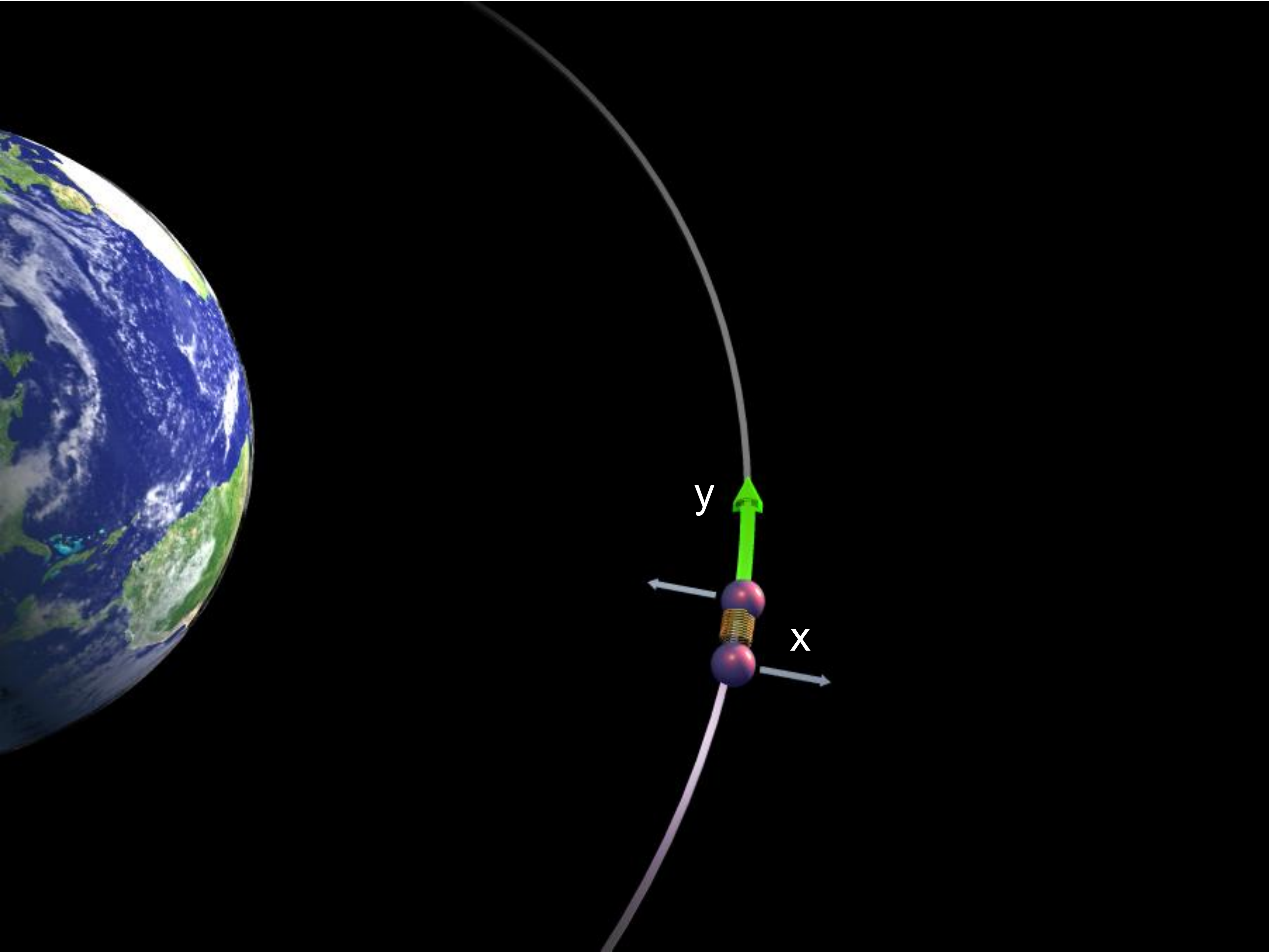
## ABSTRACT

In this paper and a companion work, we show that a broad class of astrophysical accretion disk is dynamically unstable to axisymmetric disturbances in the presence of a weak magnetic field. Because of the ubiquity of magnetic fields, this result bears upon gaseous differentially rotating systems quite generally. This work presents a linear analysis of the instability. (The companion work presents the results of nonlinear numerical simulations.) The instability is local and extremely powerful. The maximal growth rate is of order the angular rotation velocity and is *independent* of the strength of the magnetic field, provided only that the energy density in the field is less than the thermal energy density. Unstable axisymmetric disturbances require the presence of a poloidal field component, and are indifferent to the presence of a toroidal component. The instability also requires that the angular velocity be decreasing outward. In the absence of a powerful dissipation process, there are no other requirements for instability. Fluid motions associated with the instability directly generate both poloidal and toroidal field components. We discuss the physical interpretation of the instability in detail. Conditions under which saturation occurs are suggested. The *nonemergence* of the classical Rayleigh criterion for shear instability in the limit of vanishing field strength is noted and explained. The instability is sensitive neither to disk boundary conditions nor to the constituative fluid properties. Its existence precludes the possibility of internal (noncompressive) wave propagation in a disk. If present in astrophysical disks, the instability, which has the character of an interchange, is very likely to lead to generic and efficient angular momentum transport, thereby resolving an outstanding theoretical puzzle.

*Subject headings:* accretion — hydrodynamics — hydromagnetics — instabilities


y
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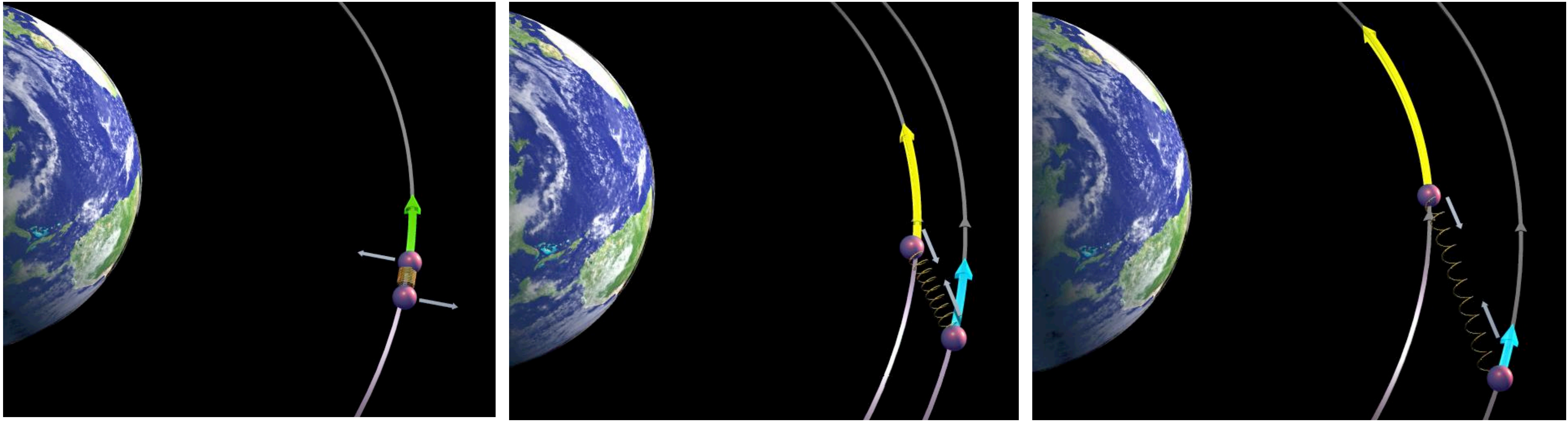
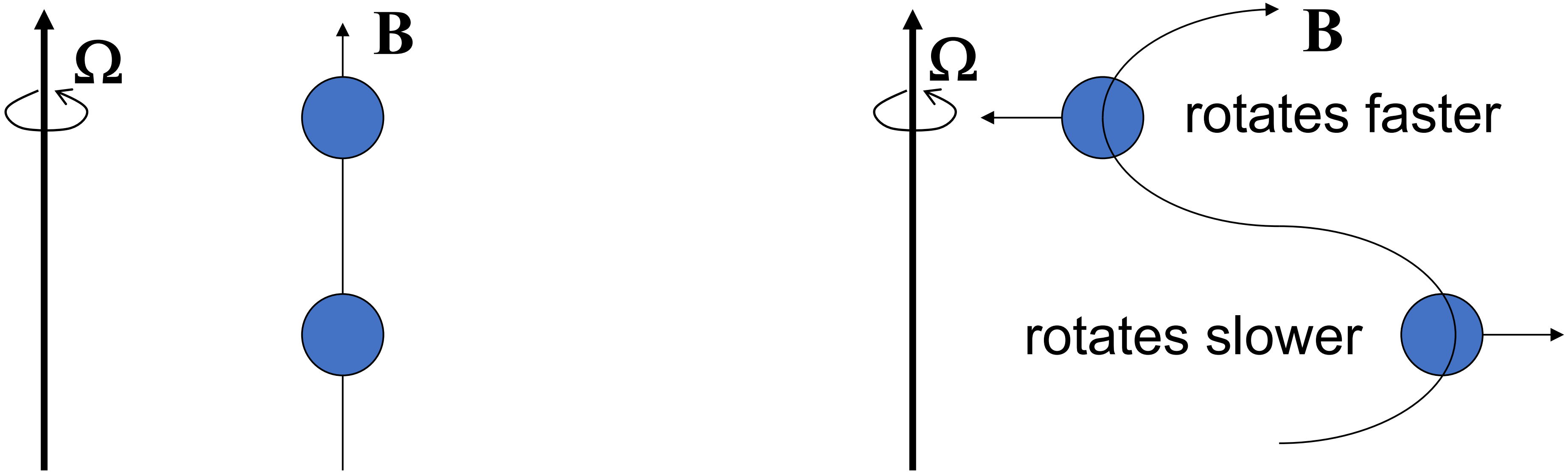
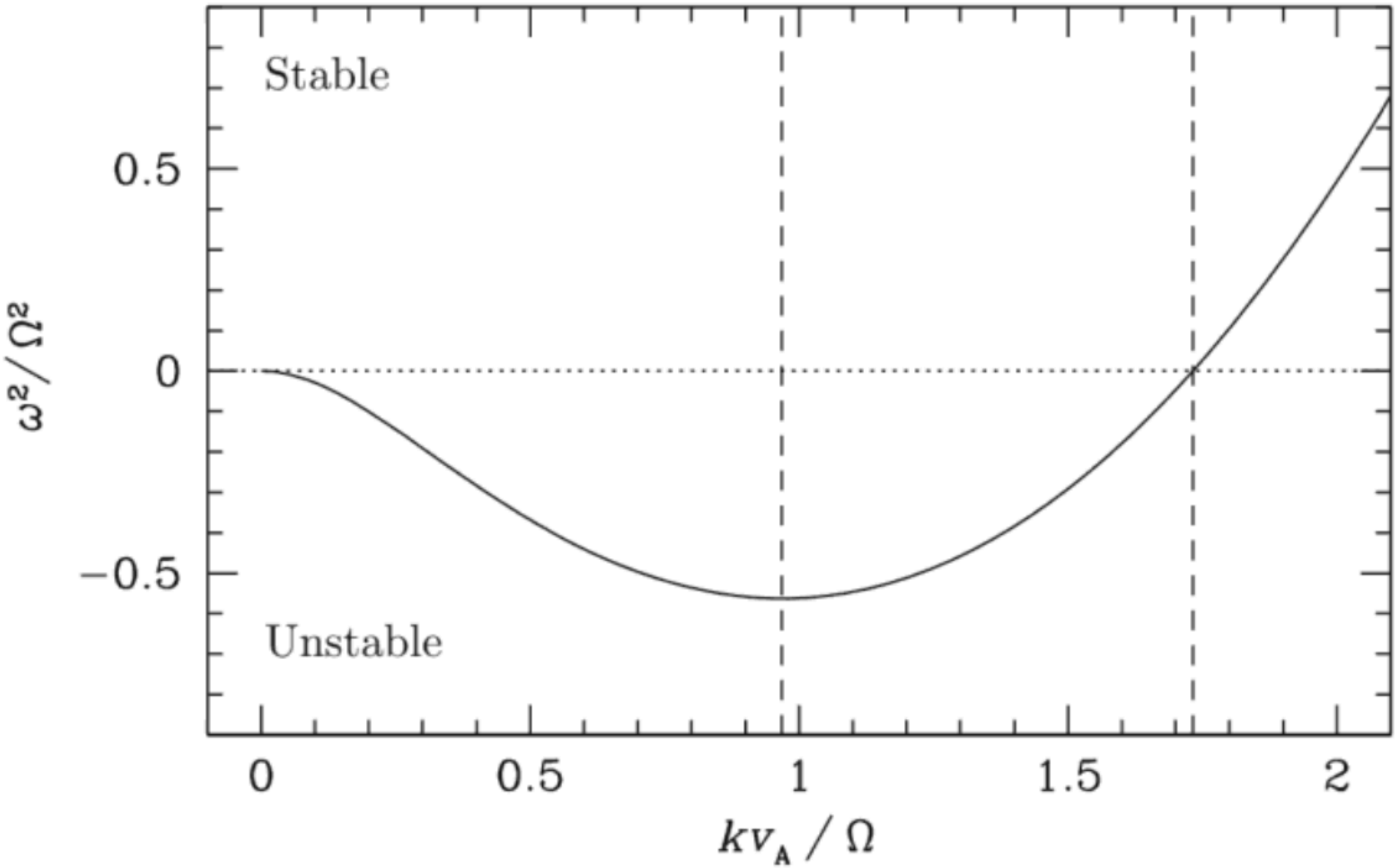


# Magnetorotational Instability (MRI)



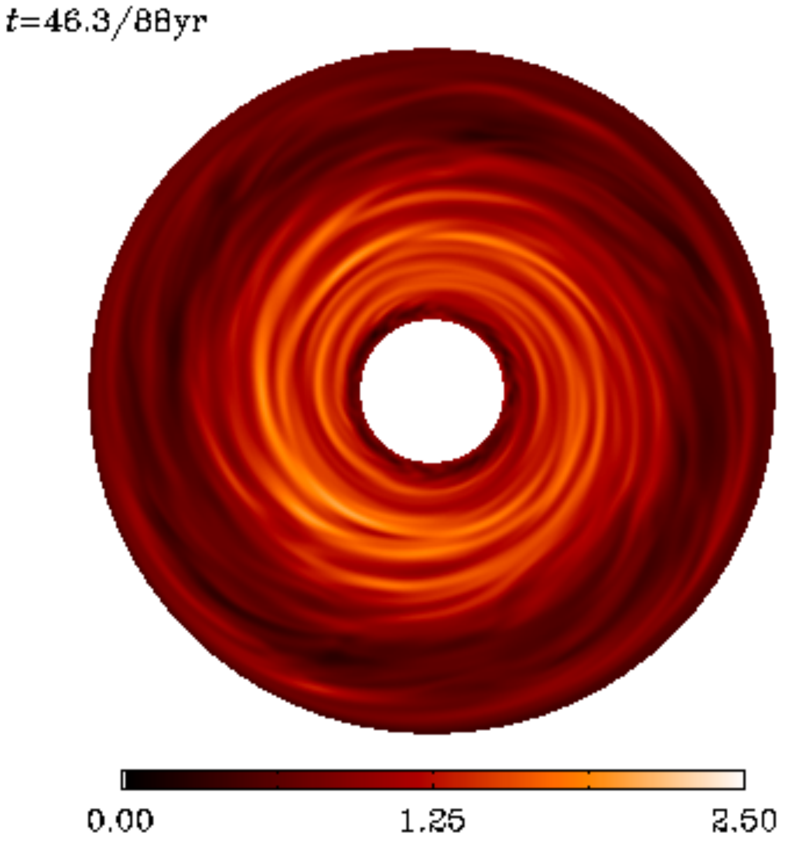

Magnetic fields in a conducting, rotating plasma behave EXACTLY like springs!

# Magneto-Rotational Instability – Dispersion relation



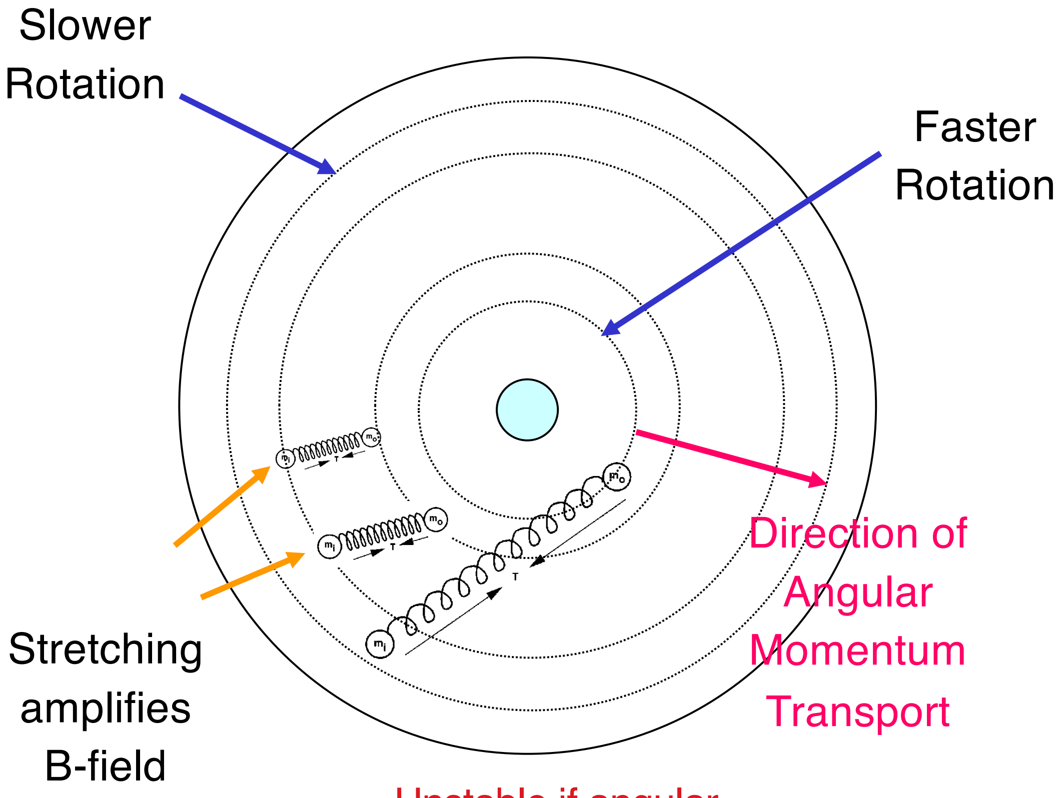
# Magneto-Rotational Instability

Turbulence in disks is enabled by the
Magneto-Rotational Instability (Balbus & Hawley, 1991)



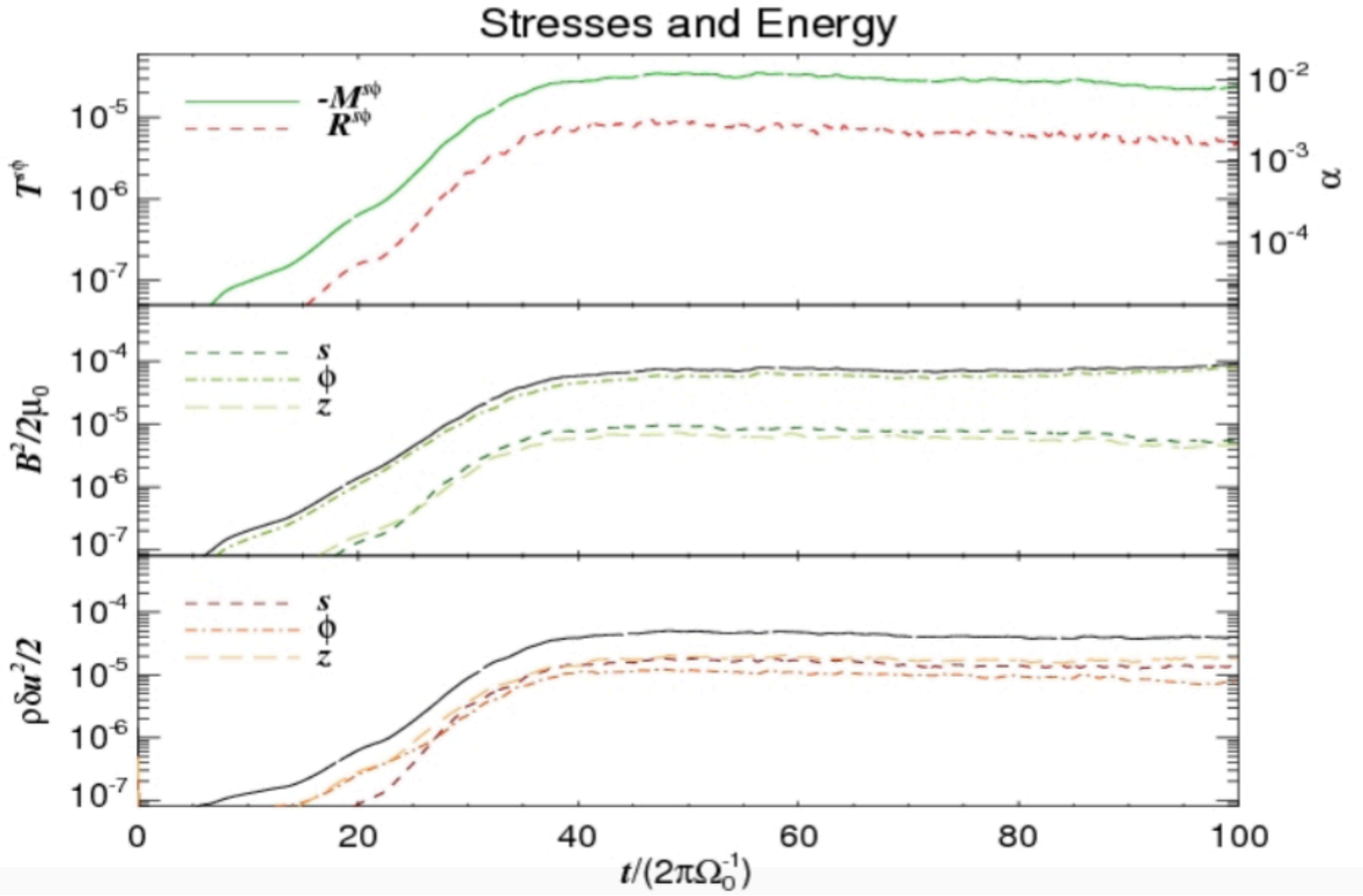

Magnetized disk
Lyra et al. (2008a)

MRI sketch




Unstable if angular
velocity decreases
outward

# Magneto-Rotational Instability



## Press Release

The Shaw Prize in Astronomy for 2013 is awarded to **Steven A Balbus**, Savilian Professor of Astronomy, University of Oxford, UK and **John F Hawley**, Associate Dean for the Sciences and VITA Professor and Chair of Department of Astronomy, University of Virginia, USA for their discovery and study of the magnetorotational instability, and for demonstrating that this instability leads to turbulence and is a viable mechanism for angular momentum transport in astrophysical accretion disks.

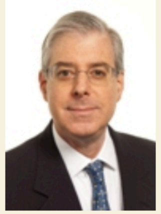
Accretion is a widespread phenomenon in astrophysics. It plays a key role in star formation, mass transfer in stellar binaries, and the growth of supermassive black holes in the centres of galaxies. Sources powered by accretion can even outshine those of similar mass powered by nuclear fusion.

Accreting matter typically carries angular momentum which causes it to flatten into a disk that orbits the central body. It was recognized long ago that disk accretion requires a mechanism for the outward transfer of angular momentum. Moreover, astronomical observations had established that many accretion powered sources are surrounded by disks. However, for many years the mechanism enabling the outward transfer of angular momentum remained elusive. All this was changed by **Balbus** and **Hawley**. Their discovery and elucidation of the magnetorotational instability (MRI) provides what to this day remains the only viable mechanism for the outward transfer of angular momentum in accretion disks.

Astronomy Selection Committee
The Shaw Prize

28 May 2013 Hong Kong

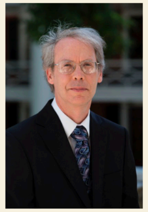
### Autobiography of Steven Balbus



I was born in Philadelphia in 1953 and attended the William Penn Charter School for my secondary education. I was particularly drawn to mathematics. In my last year in high school, I was excused from these classes. I also developed an interest in astronomy, then a sort of hobby.

In 1971, I entered the Massachusetts Institute of Technology. I thoroughly enjoyed my experience. I was much taken with my applied mathematics and physics courses, and elected to double major in these two subjects. I still followed astronomy at the *Scientific American* level, so at the conclusion of my undergraduate studies I decided to continue in theoretical astrophysics, a natural union of all my interests.

### Autobiography of John Hawley



I was born in Annapolis, Maryland in 1958. My family lived in Severna Park, Maryland until early 1965 when we moved to Salina, Kansas. Our family consisted of my parents, Bernard and Jeanne Hawley, my brothers Jim and Steve, my sister Diane, and assorted cats. My interest in astronomy was stoked by my fascination with the 1960s era space programme. Isaac Asimov's essays, especially those on cosmology, black holes and space, were also influential. My older brother Steve served as a role model. His abiding interest in astronomy led him eventually to a PhD in astronomy and a career as a space shuttle astronaut.

I graduated from Salina Central High School in 1976 and attended Haverford College in Pennsylvania where I majored in astronomy and physics. My senior thesis project was computational; I modelled the nuclear reactions of the helium-burning shell of a red giant star. Sometime in my senior year I attended a seminar on accretion disks, then a novel subject. I was struck by the comment that no one knew the nature or strength of the internal stress that drove accretion, but that ignorance could be reduced to a single parameter, "alpha." This was my introduction to the fundamental problem in accretion.