Polarized radiation from accretion disks-drive indicator processes

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X-ray polarization - a window about to open? - Stockholm, Sweden - 25-28 August 2014

The idea of this report is to apply the study of the polarization of the radiation from different accretion disks as a method for describing the structure and dynamics of different formations in them.

Outline

-X-ray polarimetry

-Accretion discs and dissipation processes in them.

-Mechanism of switching three-dimensional in a two -dimensional turbulent and back under the influence of rotation.

-Conclusion

X-ray polarimetry

Definitions

By measuring the polarization angle and the degree of polarization of celestial emissions, it will be possible to increase the number of observational parameters, thereby allowing better discrimination between various models characterizing the same object. Polarimetric observations can provide important information about geometries, magnetic fields, composition and emission mechanisms in a wide variety of x-ray and gamma-ray sources, e.g. Pulsars, Solar Flares , Accretion disks, Active Galactic Nuclei, Galactic Black Holes or Gamma-Ray Bursts.

DIFINITION

Light polarization - the orientation of the electric field vector and the magnetic induction of a light wave in a plane perpendicular to the light beam. Polarization is usually the reflection and refraction of light, as well as the propagation of light in an anisotropic medium or field. Distinguish between linear, circular and elliptical polarization of light.

DIFINITION-!

Something more general would like to set as a polarization-division of the radiation corresponding to the interaction (reflection, refraction or ?) with the environment (dust, plasma, field or any other form of energy)

Why X-ray Astrophysical Polarimetry ?

Polarization from celestial sources in X-rays may derive from:

•Emission processes themselves : cyclotron, synchrotron, non-thermal bremmstrahlung

(Westfold, 1959; Gnedin & Sunyaev, 1974; Rees, 1975)

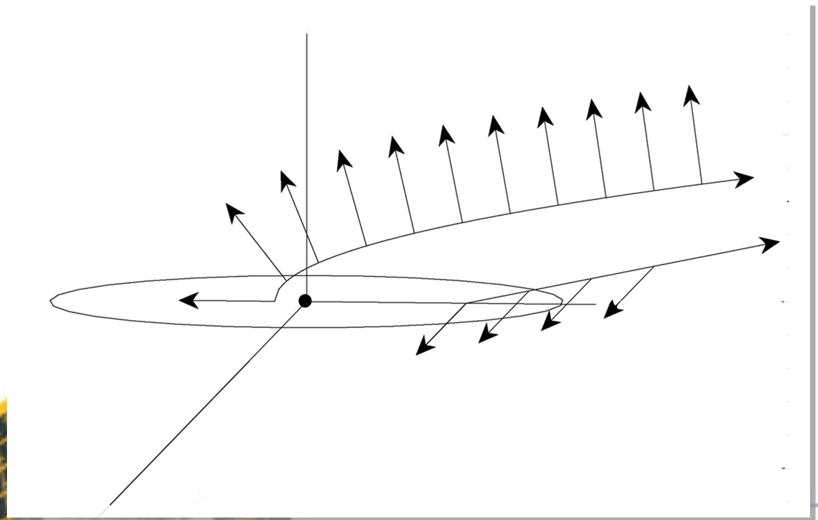
•Scattering on aspherical accreting plasmas : disks, blobs, columns.
Sunyaev & Titarchuk, 1985; Mészáros, P. et al. 1988, Sazonov 2002).

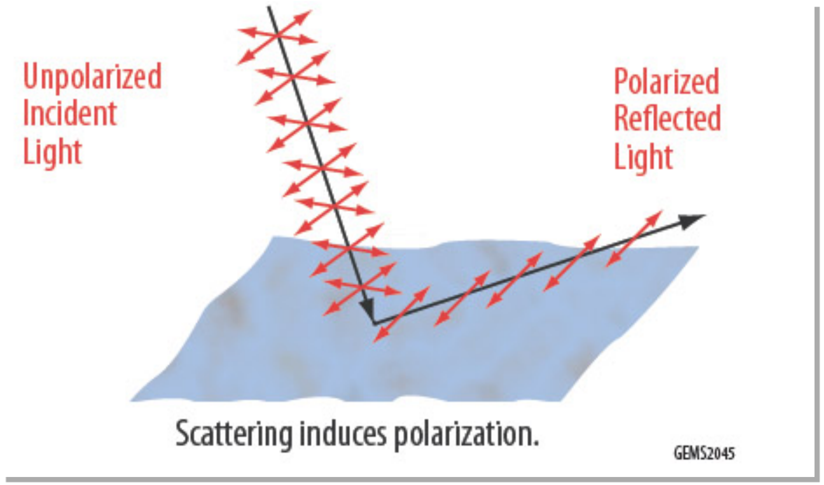
• Vacuum polarization (Gnedin et al., 1978; Ventura, 1979; Mészáros & Ventura, 1979)

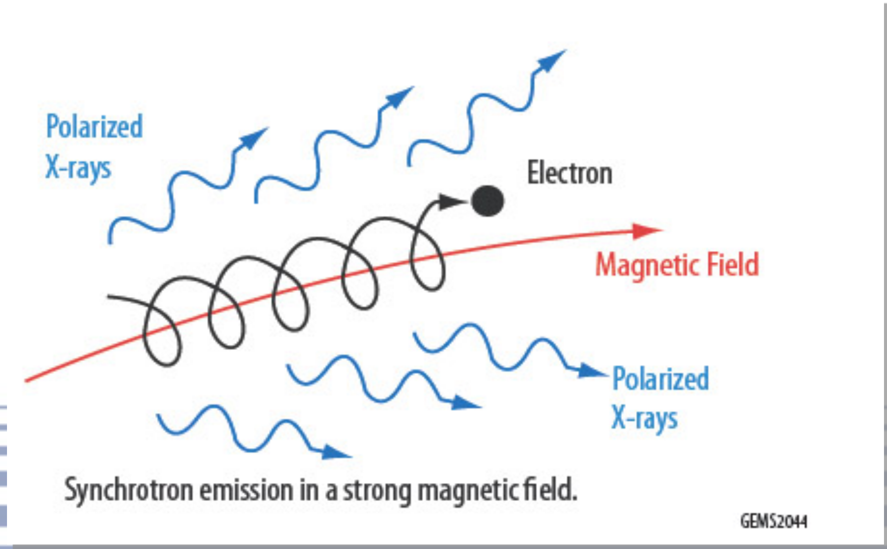
Polarimetry probes physics of photon emission and propagation

Polarization measurements allow us to study:

- Scattering geometry
- Magnetic fields
- Strong gravity





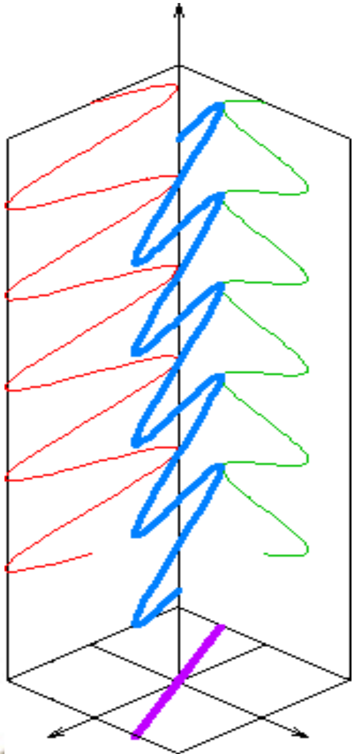


Polarization of light: definitions and terms

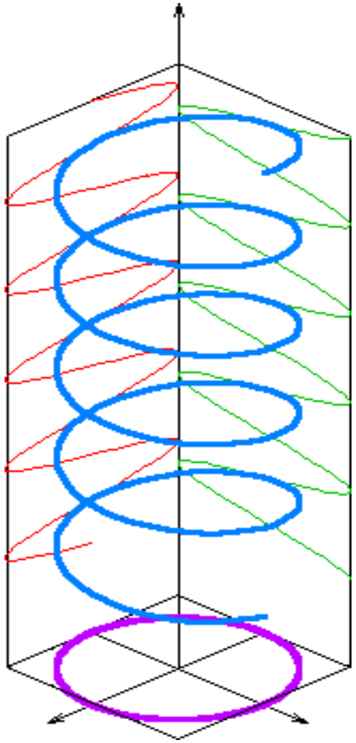
Harmonic electric field monochromatic plane wave:

$$\vec{E}(\vec{r},t) = (A_x \cdot \cos(kz - \omega t), A_y \cdot \cos(kz - \omega t + \phi), 0).$$

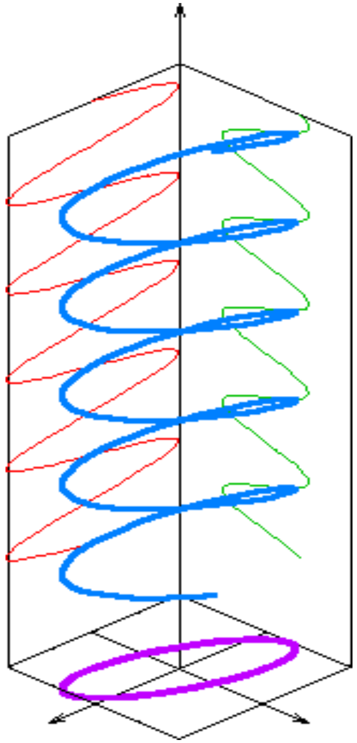
Ax, Ay - two orthogonal components (fashion) e. vector, ϕ - phase difference



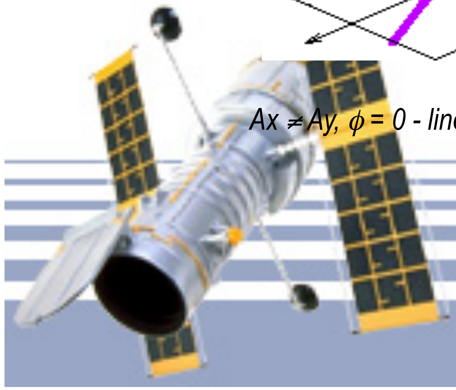
Ax ≠ Ay, ϕ = 0 - linear polarization



Ax = Ay, $\phi = \pi / 2$ - circular polarization



Ax ≠ Ay, $\phi \neq 0$, $\phi / 2$ - is elliptic polarization

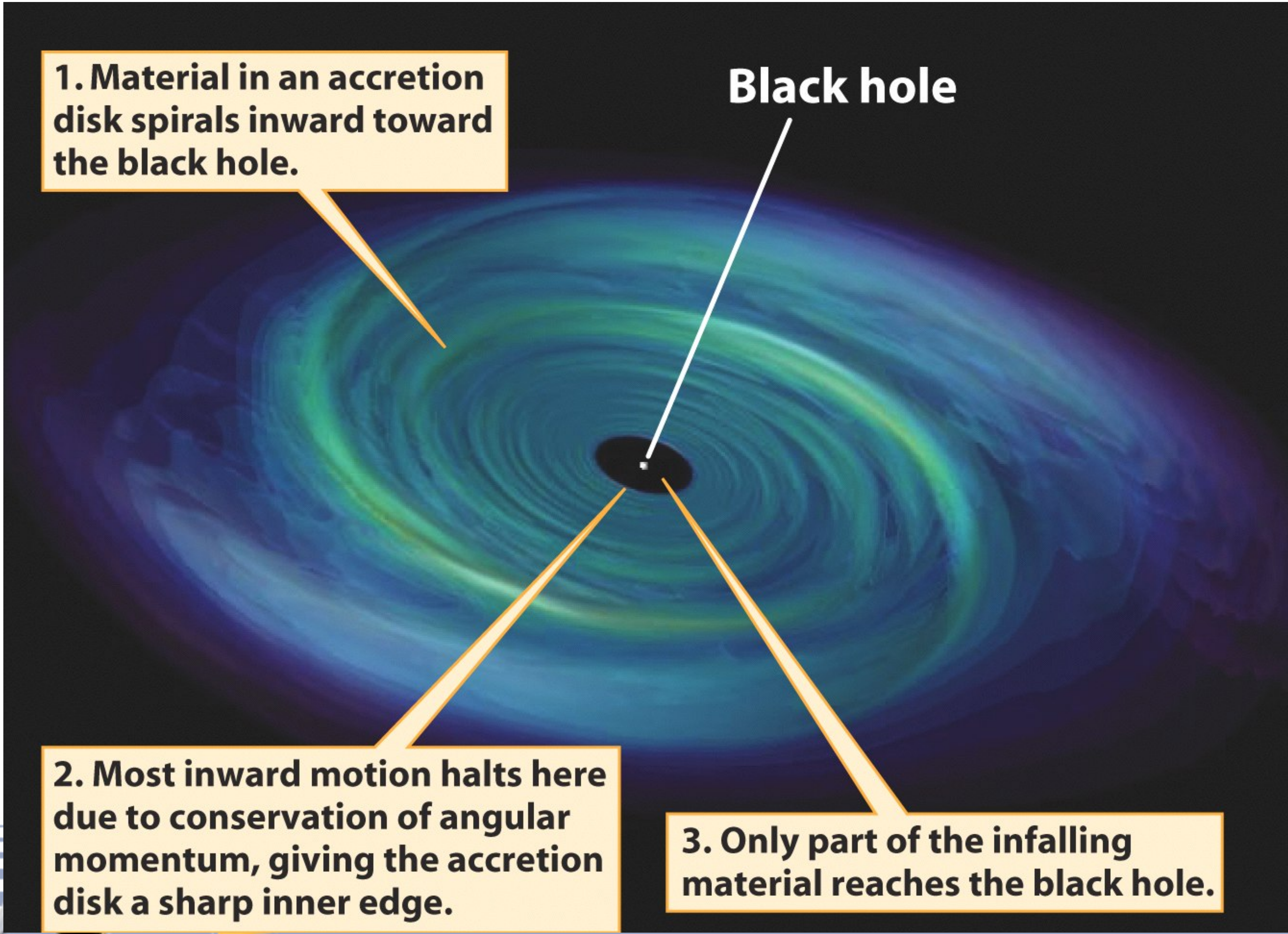


Polarized radiation in astrophysical objects

Main sources of polarized radiation :

- Light scattering in the gas and dust shells around stars
- Polarization of starlight by interstellar dust (interstellar polarization)
- Polarization of light in stellar atmospheres in the presence of magnetic field (Zeeman effect)
- Polarized radiation of electrons moving in a magnetic field (cyclotron and synchrotron radiation)
- Polarization and strong gravity effects around black-holes

Accretion Disks


1. Material in an accretion disk spirals inward toward the black hole.
Black hole
2. Most inward motion halts here due to conservation of angular momentum, giving the accretion disk a sharp inner edge.
3. Only part of the infalling material reaches the black hole.

- **How does the accreting matter lose its angular momentum?**
- **What happens to the gravitational potential energy of the infalling matter?**

Viscous accretion disks

- What allows the accreting gas to lose its angular momentum?

- Suppose that there is some kind of "viscosity" in the disk
  - Different annuli of the disk rub against each other and exchange angular momentum
  - Results in most of the matter moving inwards and eventually accreting
  - Angular momentum carried outwards by a small amount of material

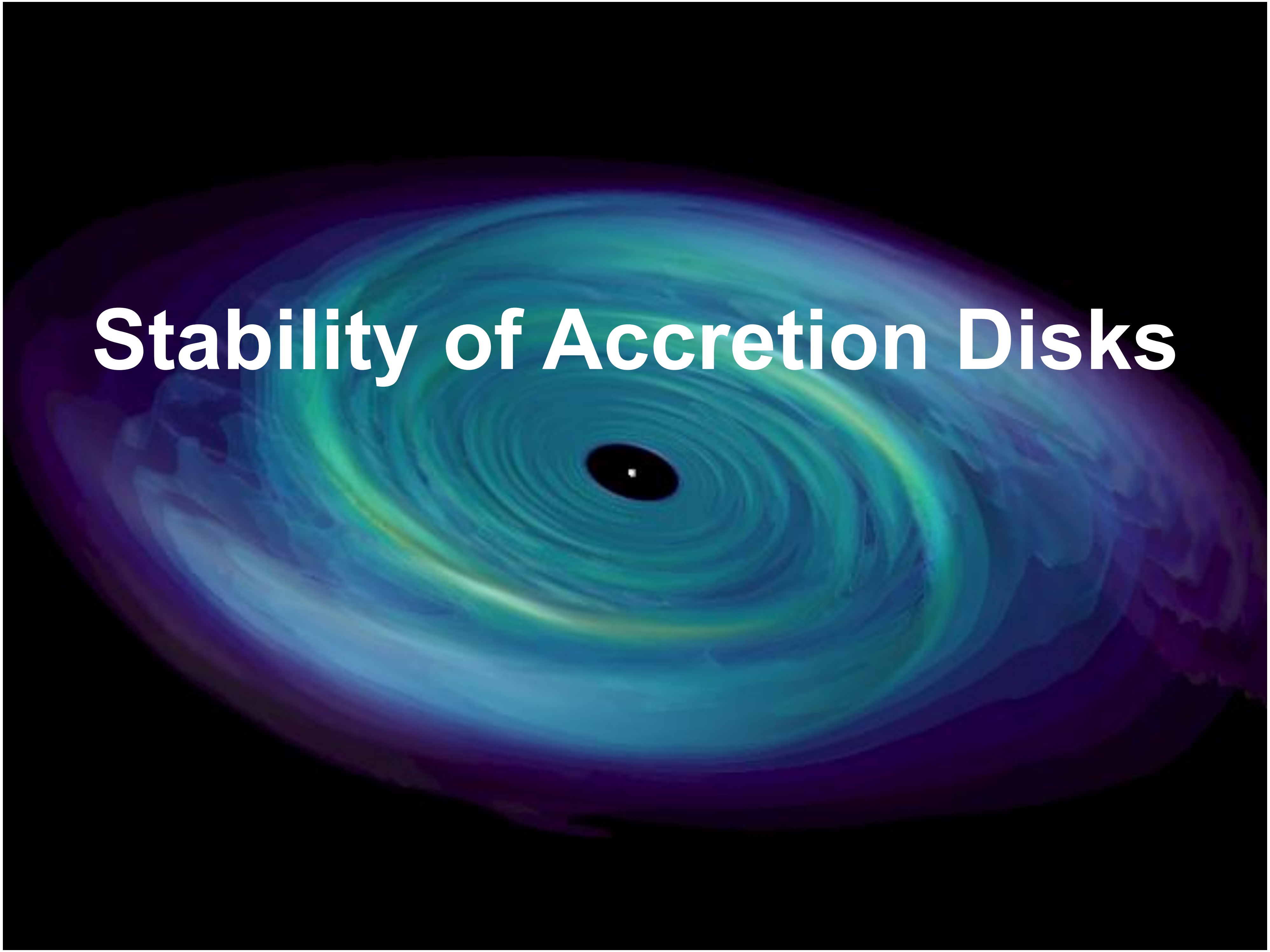
- Process producing this "viscosity" might also be dissipative… could turn gravitational potential energy into heat (and eventually radiation)

What gives rise to viscosity?

- Normal “molecular/atomic” viscosity fails to provide required angular momentum transport by many orders of magnitude!
- Source of anomalous viscosity was a major puzzle in accretion disk studies!
- Long suspected to be due to some kind of turbulence in the gas… then can guess that:
- 20 years of accretion disk studies were based on this “alpha-prescription”…
- But what drives this turbulence? What are its properties?

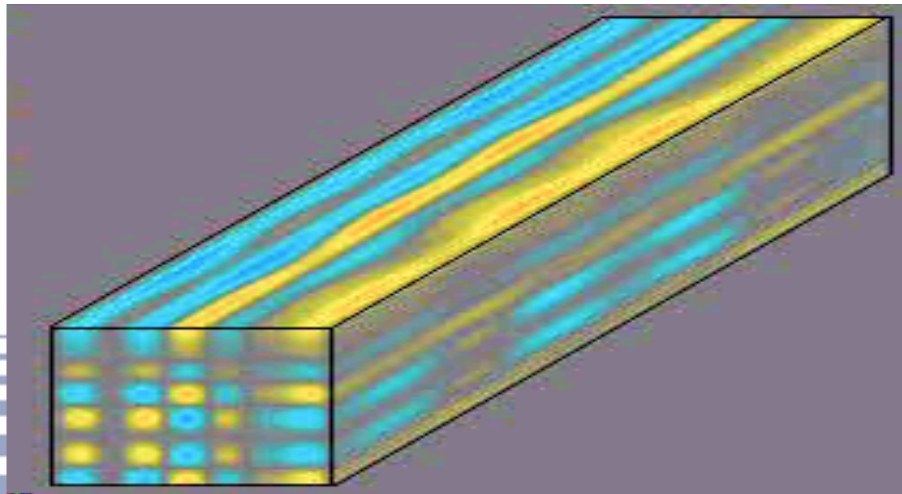
$$\nu = \alpha c_s h$$

Stability of Accretion Disks



Why we need to study stability?

- Some instabilities are needed to create efficient mechanisms for angular momentum transport within the disk (Magneto-rotational instability (MRI); Balbus & Hawley 1991, ApJ, 376, 214)



How to study stability?

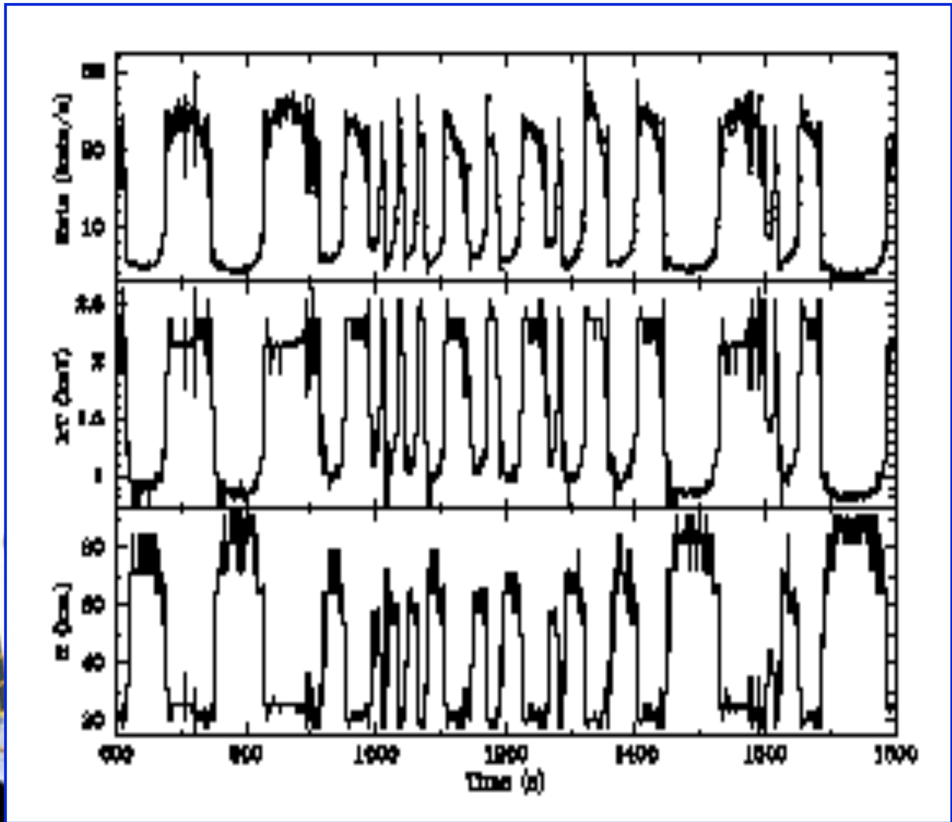
- Equilibrium: steady disk structure
- Perturbations to related quantities
- Perturbed equations
- Dispersion relation
- Solutions:
  - perturbations growing: unstable
  - perturbations damping: stable

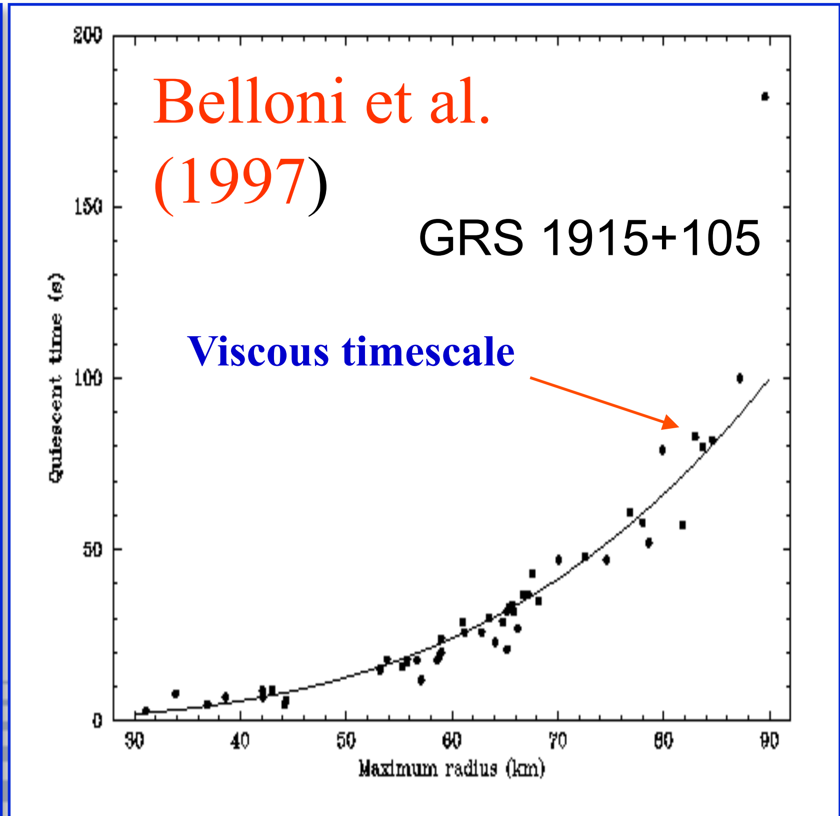
•Typical timescals

Viscous timescale $t_{visc} \sim R^2/\nu \sim R/V_r$

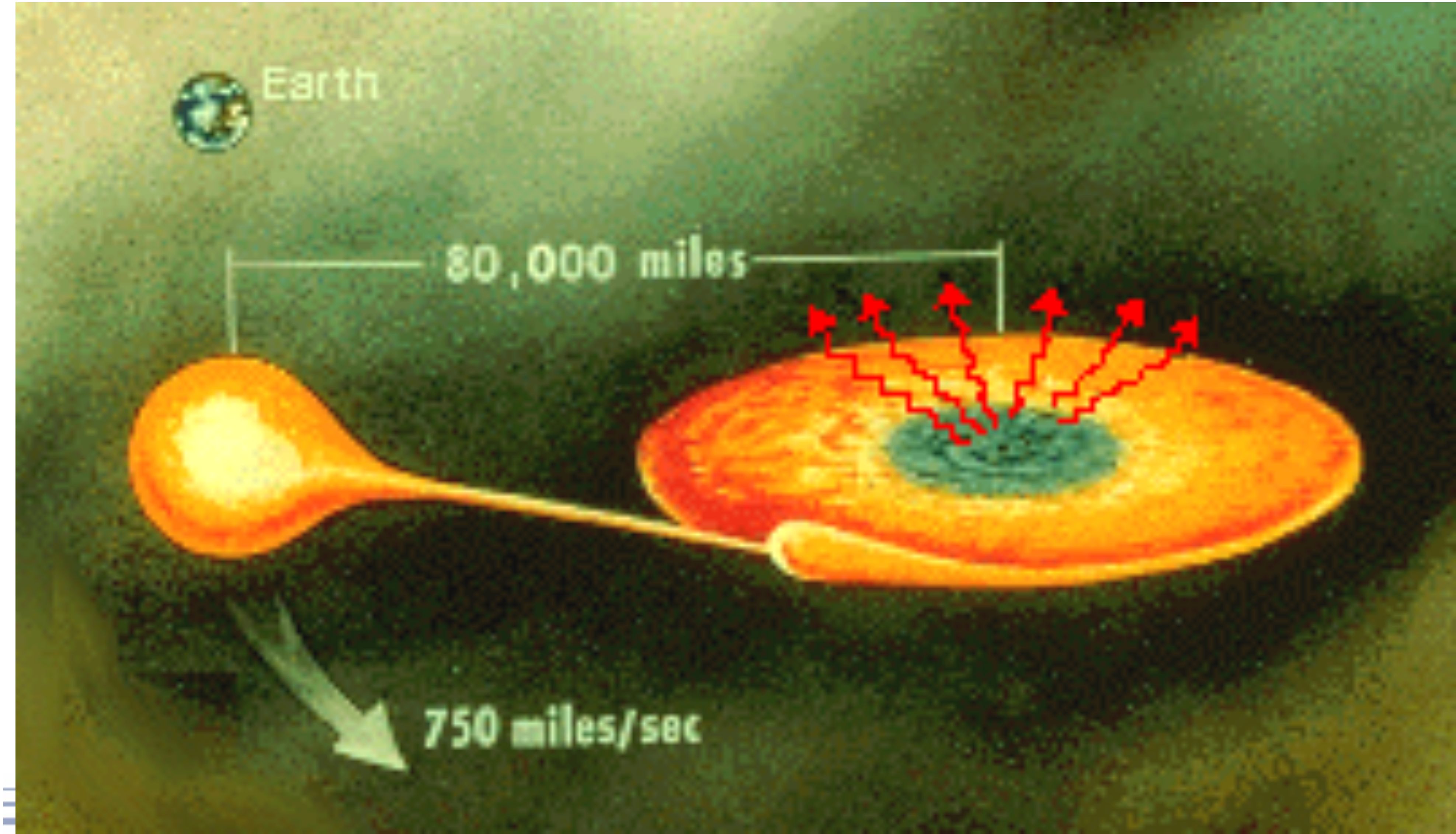
Thermal timescale $t_{th} \sim (c_s^2/V_\phi^2) R^2/\nu$

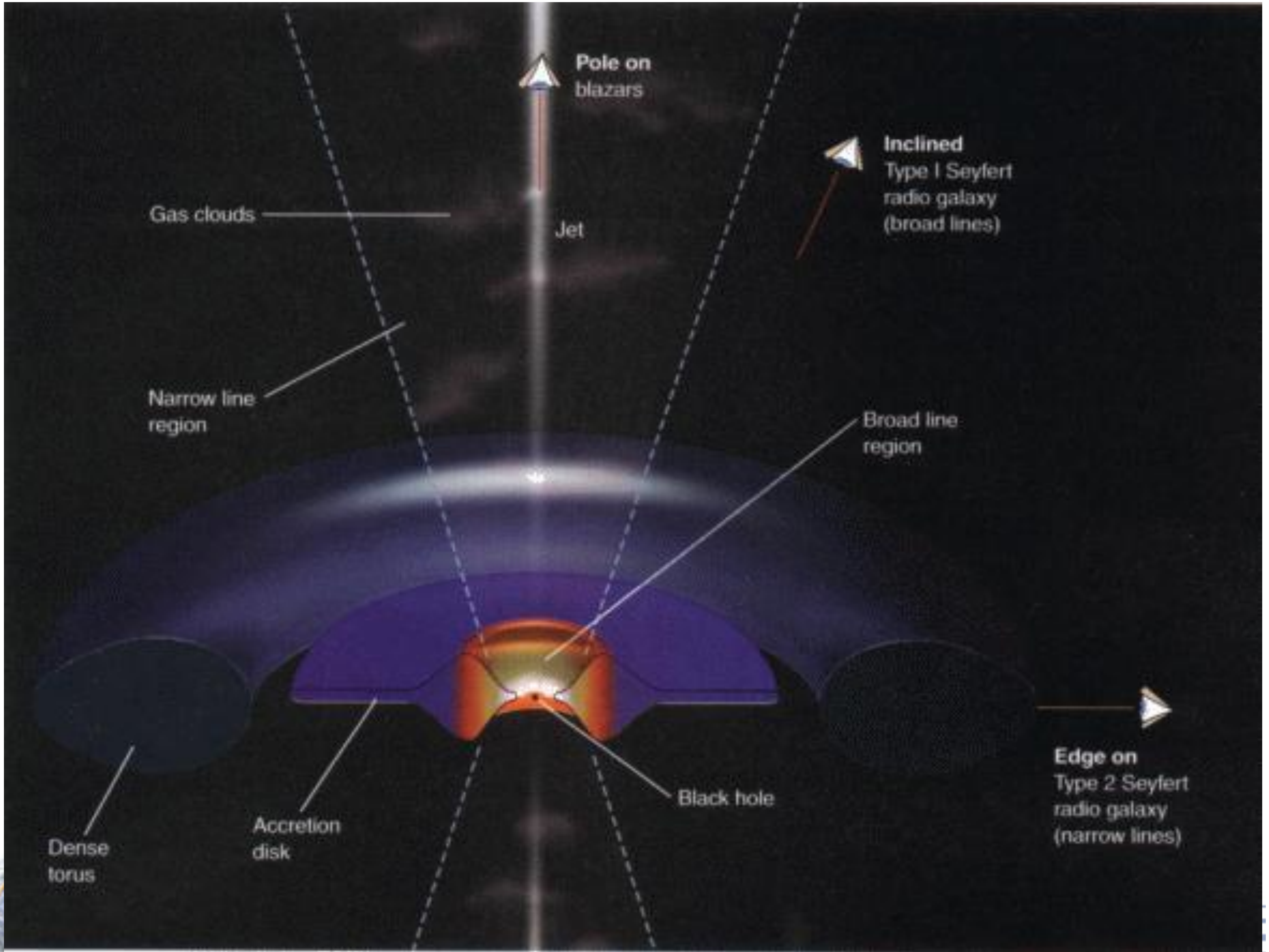
•Variation of soft component in BH X-ray binaries





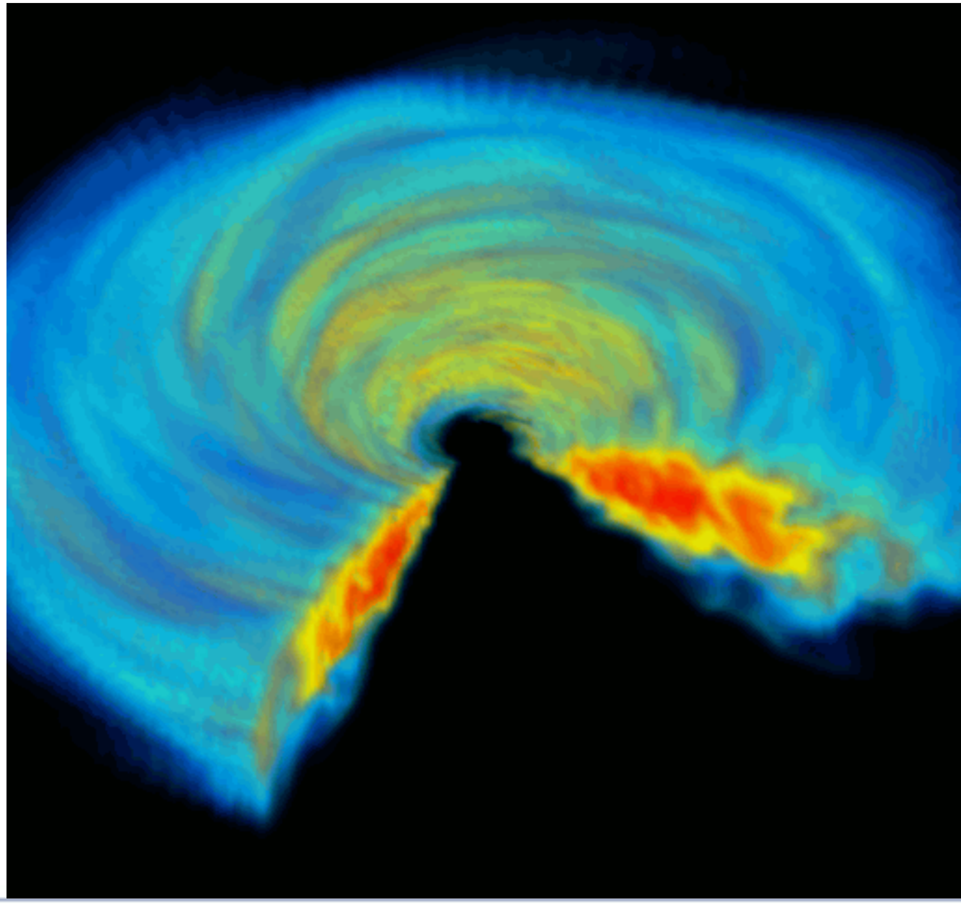
- Stability study is an important part of accretion disk theory
  - to identify the real accretion disk equilibria
  - to explain variabilities of compact objects
  - to provide possible mechanisms for state transition in XRBs (AGNs?)
  - to help us to understand the source of viscosity and the mechanisms of angular momentum transfer in the AD

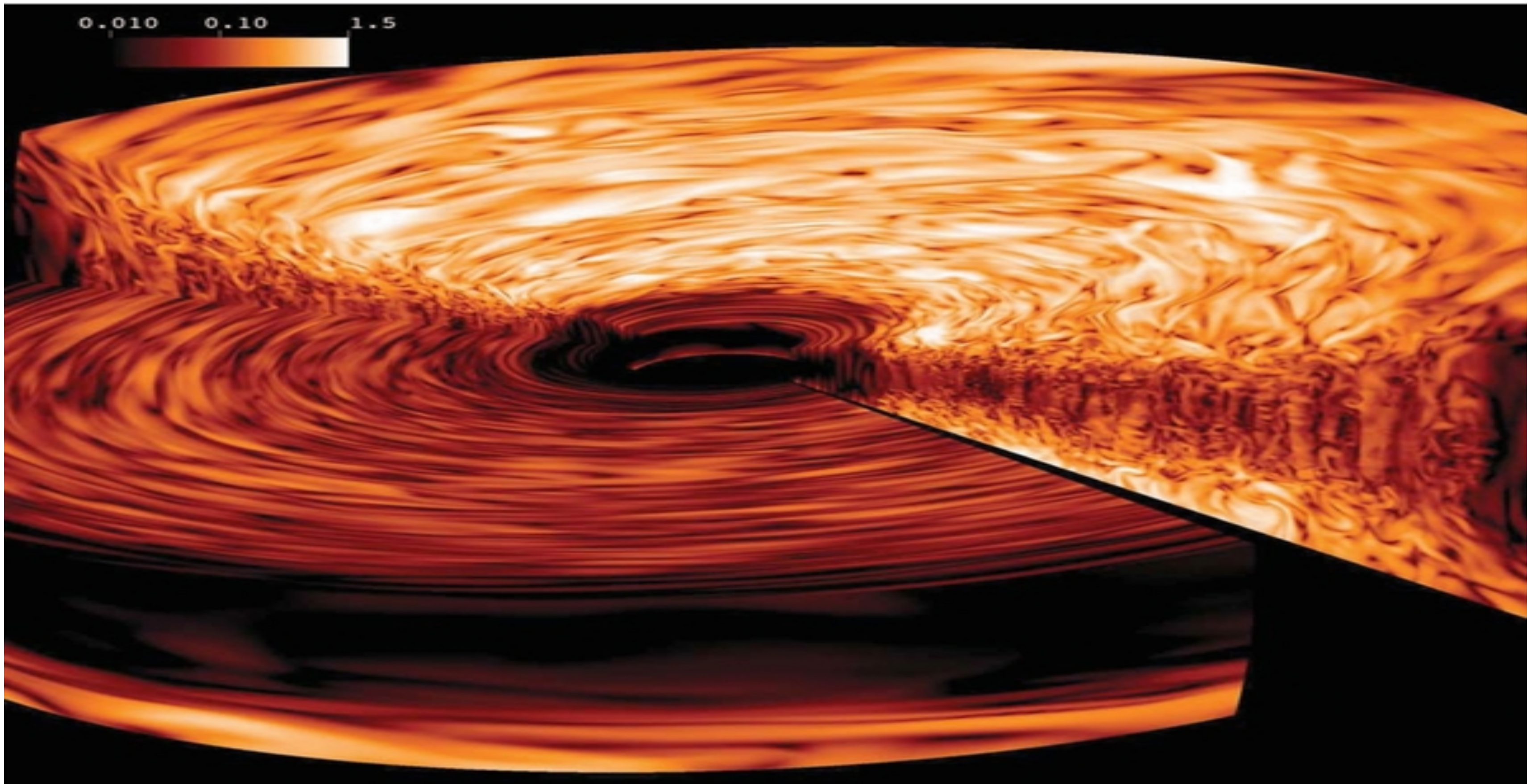

Earth
80,000 miles
750 miles/sec

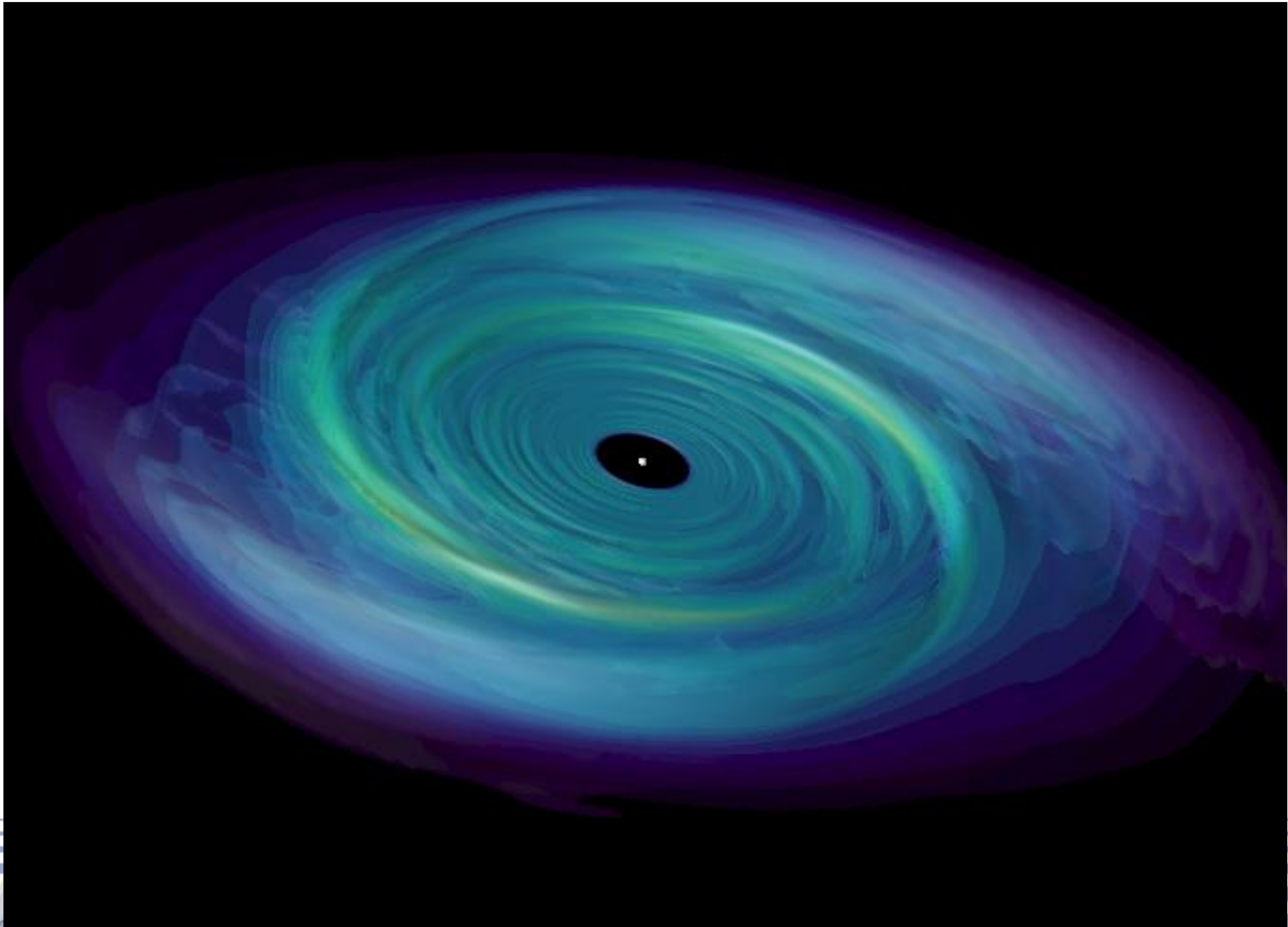


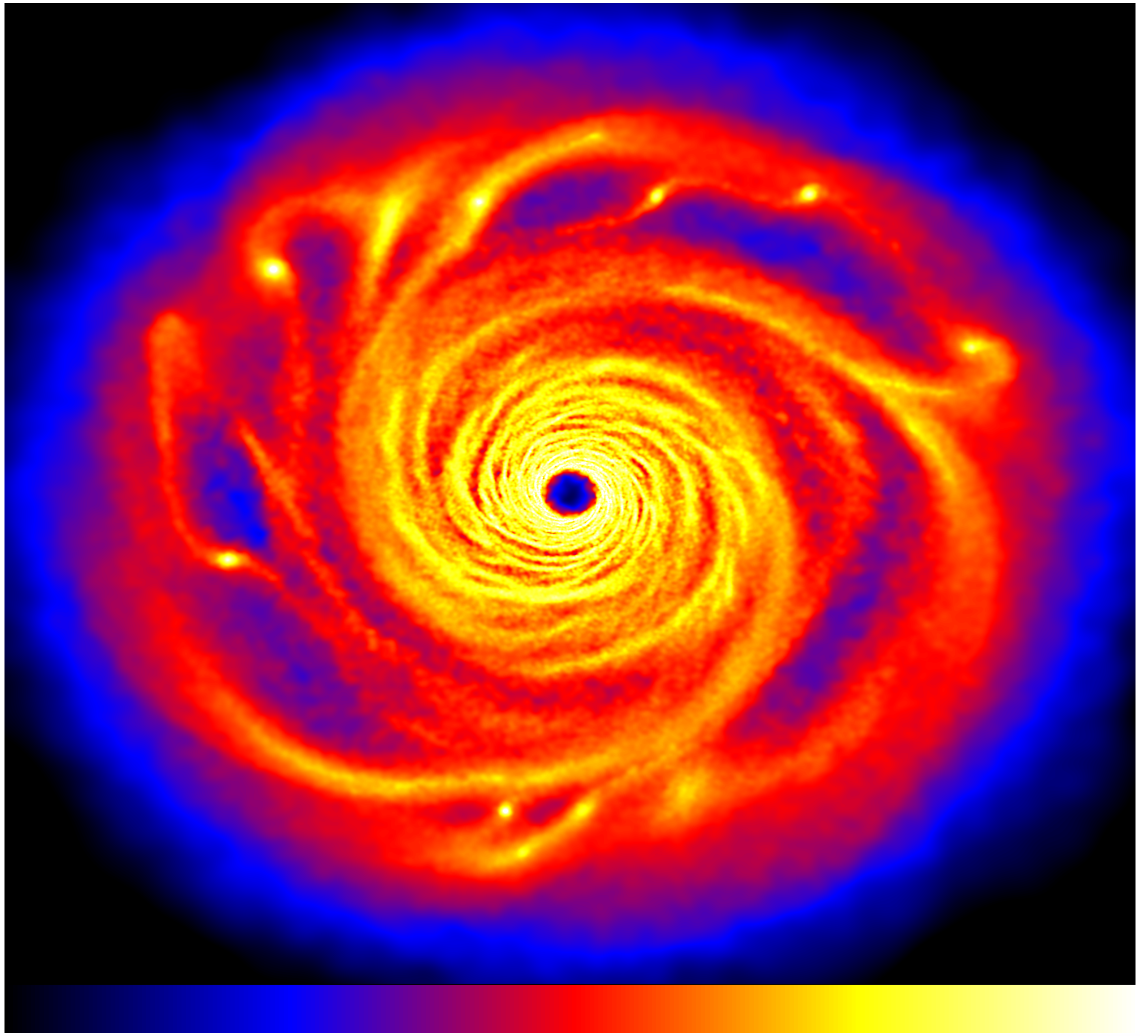
Pole on
blazars
Inclined
Type I Seyfert
radio galaxy
(broad lines)
Gas clouds
Jet
Narrow line
region
Broad line
region
Edge on
Type 2 Seyfert
radio galaxy
(narrow lines)
Black hole
Accretion
disk
Dense
torus

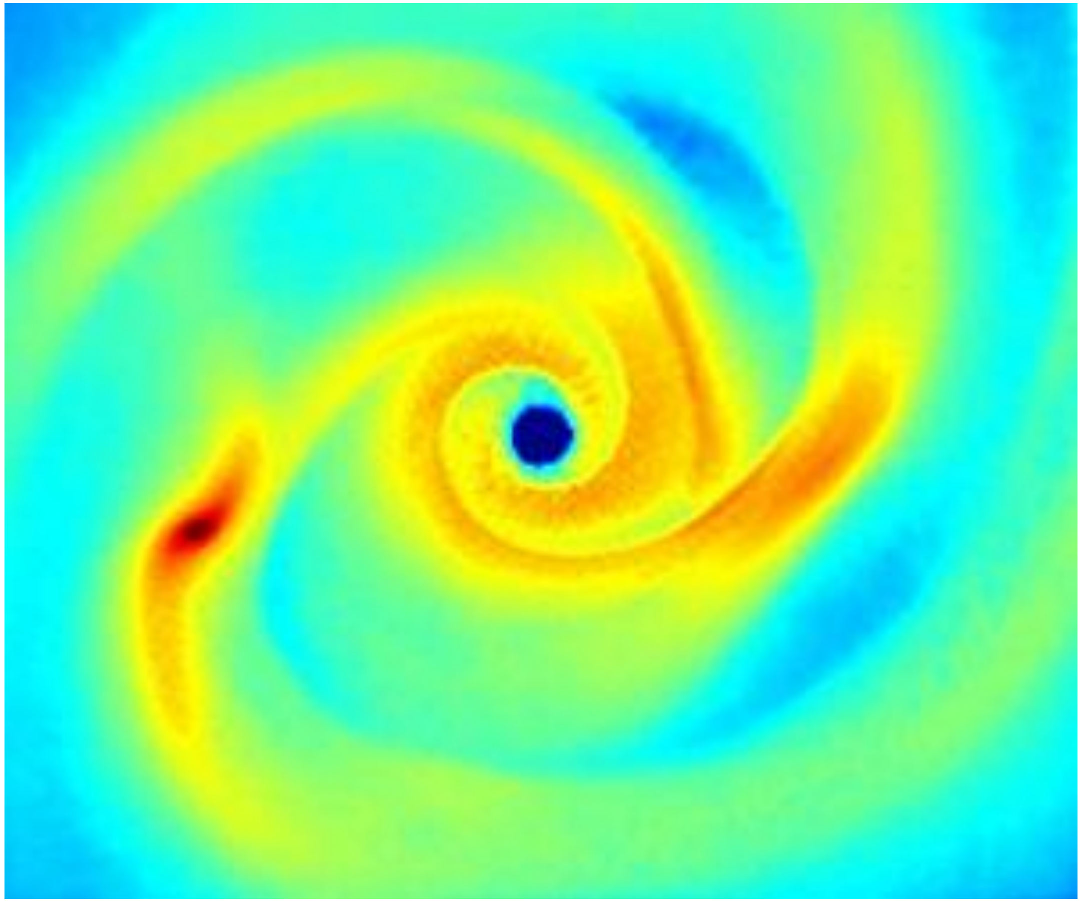
Nonlinear Physics of Astrophysical Discs

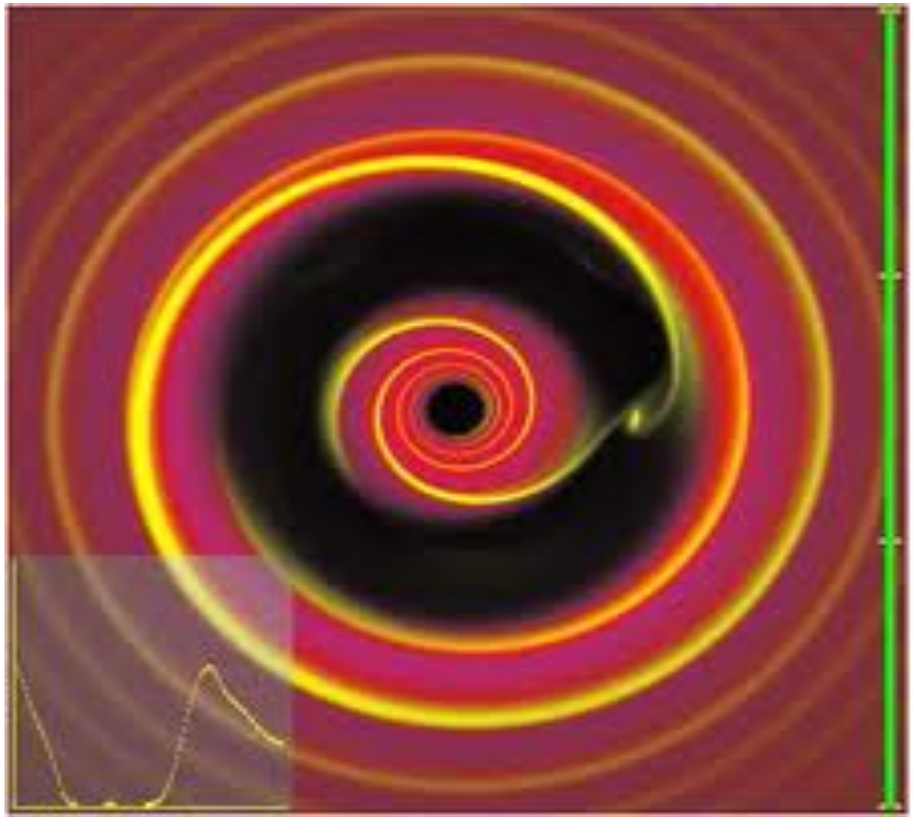



0.010
0.10
1.5









In numerical experiments shows the onset vortex and this requires explanation of their nature.

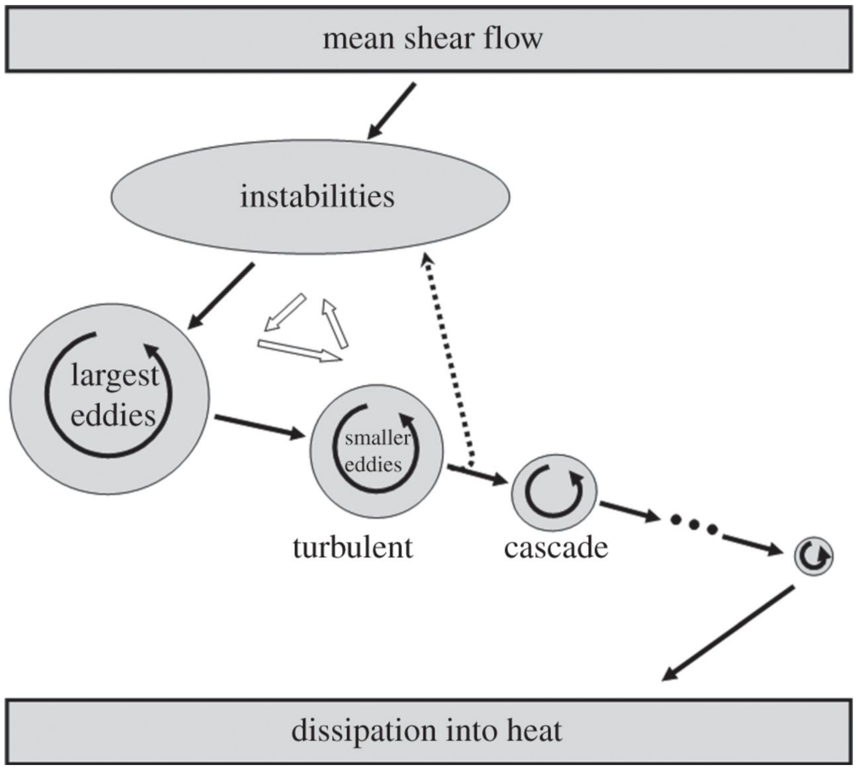
In my opinion, in ascending most natural explanation by two dimensional turbulence.

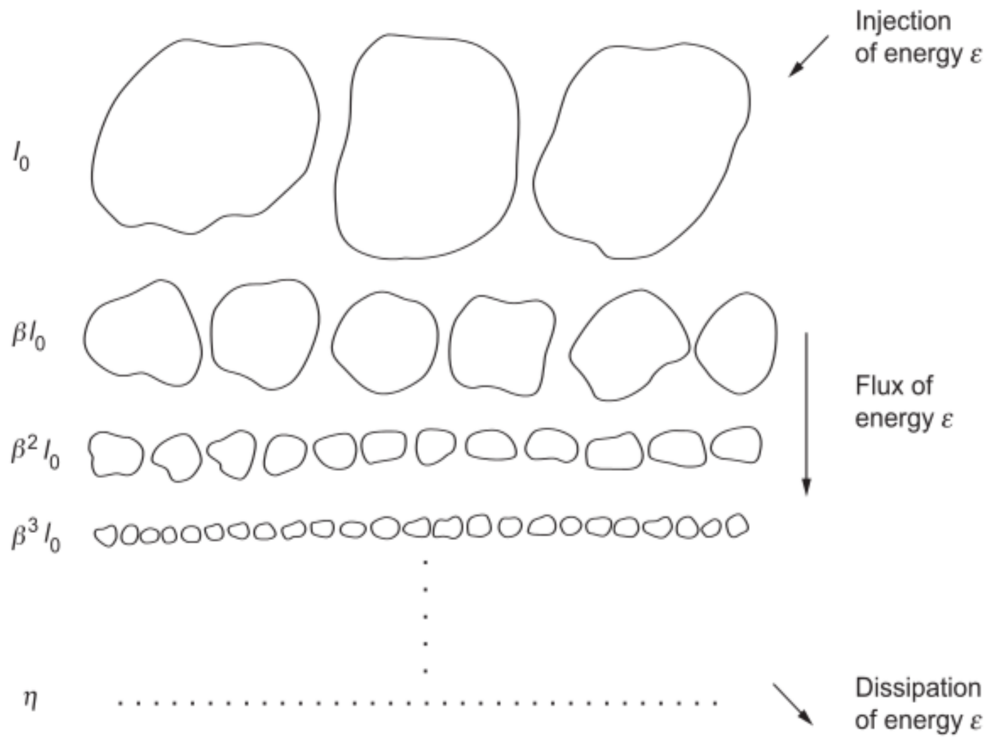
The mechanism of occurrence of this turbulence will stop at the end of my presentation.

- The idea is we study nonlinear physics of accretion discs, which gives us the existence of a wide range of structures.
- The question of how to use the sensitivity of the polarization to use it in the study of these patterns , their dynamics and evolution.

Mechanism of switching three-dimensional in a two-dimensional turbulent and back under the influence of rotation.

As a PhD. student of akad. Ya.Zeldovich the idea that rotation in the accretion disk can cause a change of the type of turbulence. As is well known problem with the emergence of hydrodynamic turbulence in discs is not yet solved . One possible scenario is the emergence of a final perturbation amplitude, i.e. the nonlinear regime. So-called Landau scenarios.


mean shear flow
instabilities
largest eddies
smaller eddies
turbulent
cascade
dissipation into heat


Injection of energy ε
l_0
βl_0
$\beta^2 l_0$
$\beta^3 l_0$
Flux of energy ε
η
Dissipation of energy ε

Mechanism of switching three-dimensional in a two-dimensional turbulent and back under the influence of rotation.

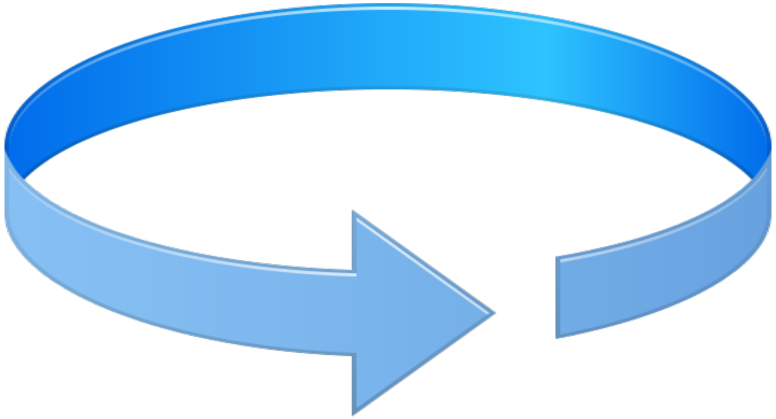
Back in the thirties of the last century J.Teylor shows experimentally that when crossing the rotational speed above a certain critical value in linear stable rotate shear flow explosive turbulence occurs.

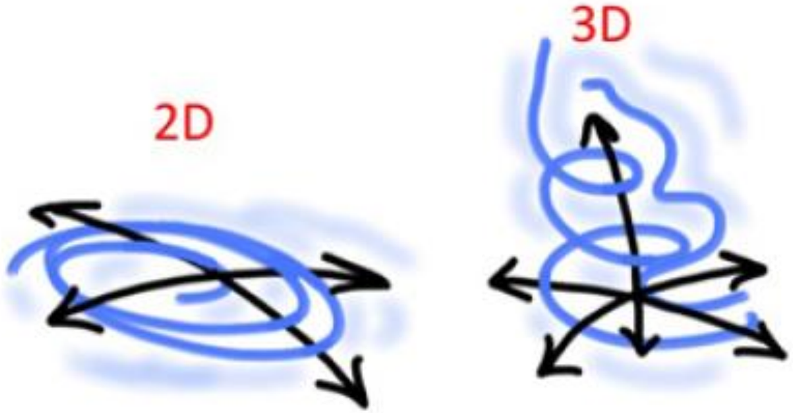
This then led investigators to seek decision precisely in nonlinear physics.

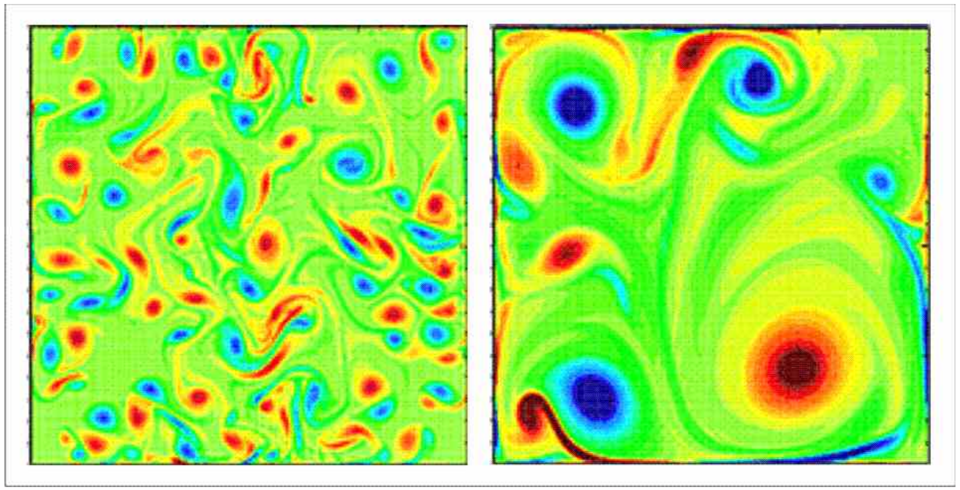
More than 40 years developed the theory of two-dimensional turbulence.

It appears that, contrary to the three-dimensional turbulence which dissipated kinetic energy of rotation into heat, that (two-dimensional turbulence) takes energy from the rotation and then accumulates in the vortex.

These vortices grow at the expense of slowing down the rotation.

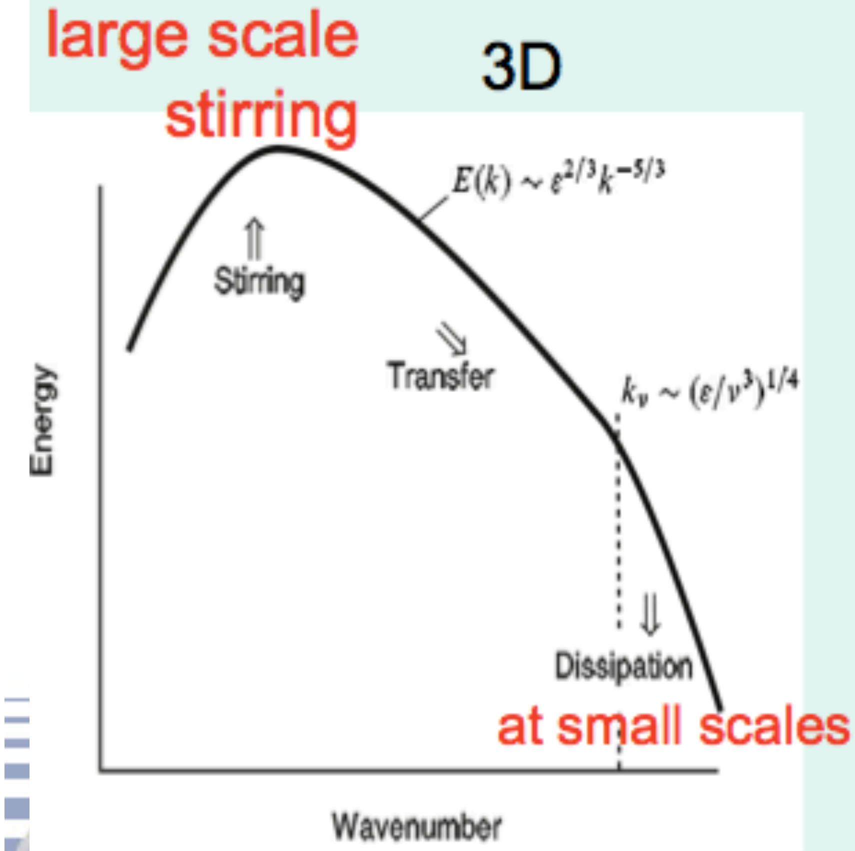



2D
3D



3D vs. 2D cascades: both -5/3

3D downscale of energy source, 2D upscale of it



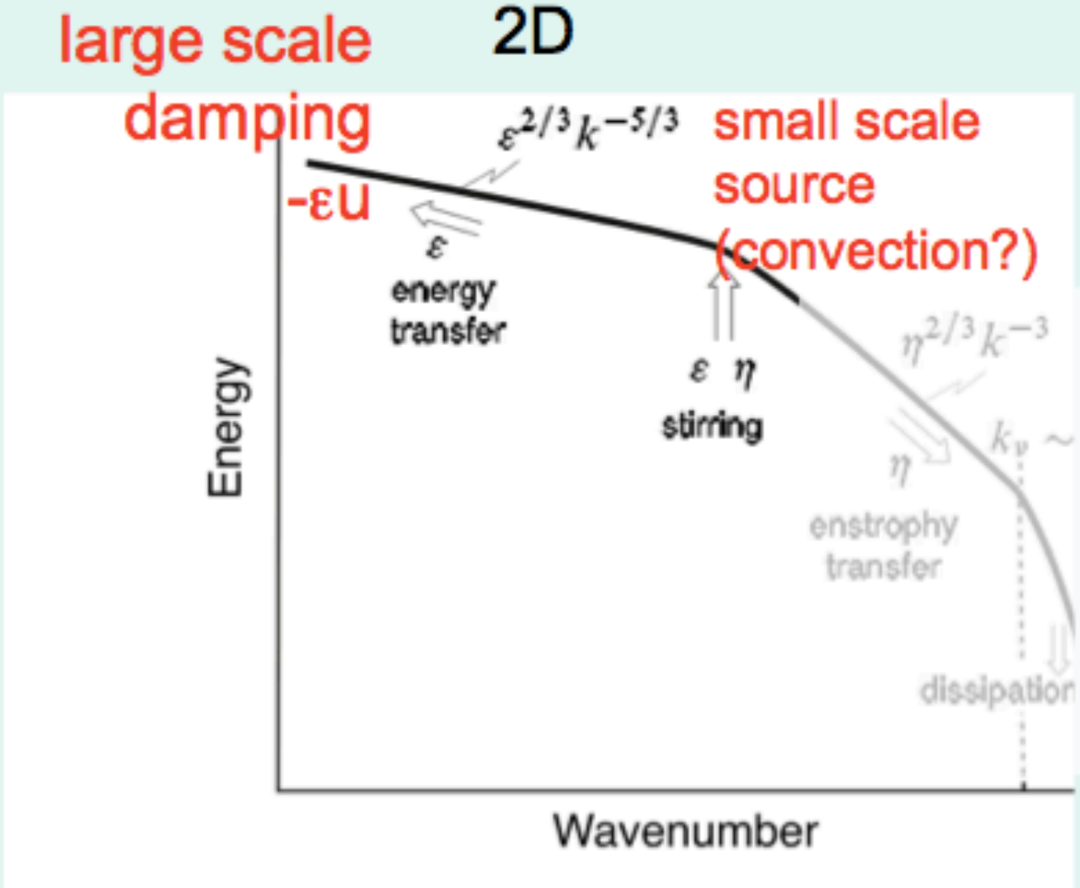
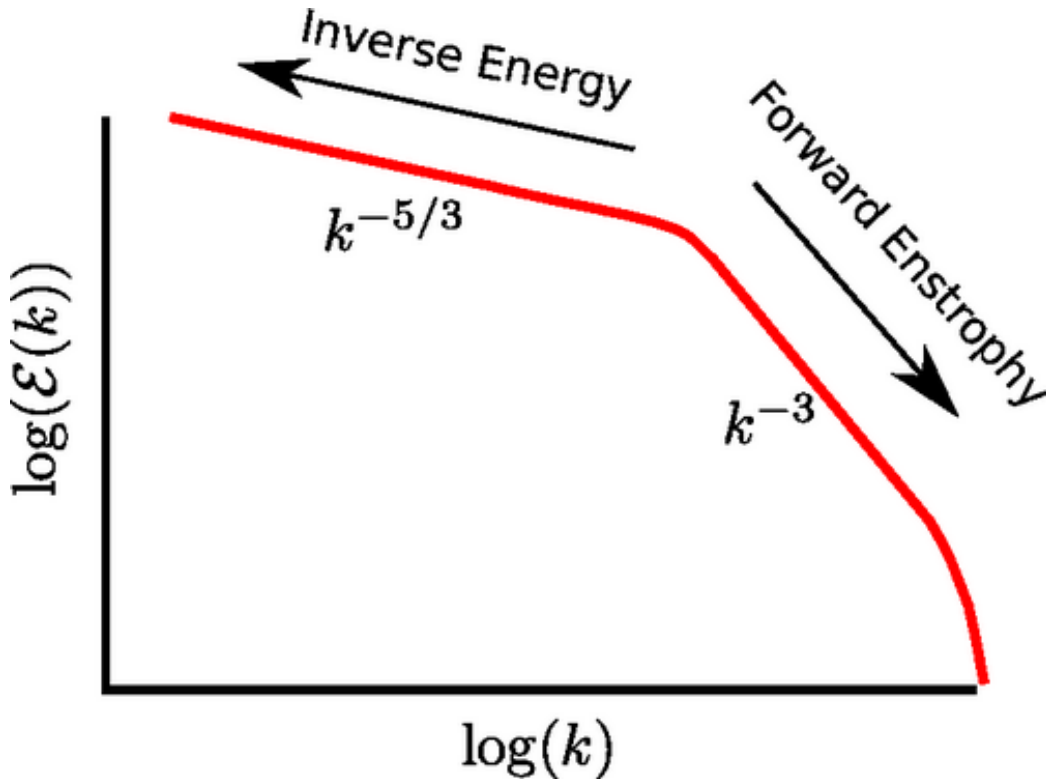


Fig. 8.7 The energy spectrum of two-dimensional turbulence. 8.3.) Energy supplied at some rate ε is transferred to large scales


Inverse Energy
Forward Enstrophy
$k^{-5/3}$
k^{-3}
$\log(\mathcal{E}(k))$
$\log(k)$

Mechanism of switching three-dimensional in a two-dimensional turbulent and back under the influence of rotation.

The scenario that is available is as follows:
The outer layer of the disc is three dimensional turbulent flow of incoming or Papaloizou-Pringle Instability.
This leads to the dissipation of energy and the accelerated roll and fall of the substance to the gravitational center (white dwarf , neutron star or black hole). At a certain critical speed three dimensional turbulence passes in a two dimensional. Which can be observed as a change in radiation as the process of dissipation change in the accumulation of energy in the energy of rotation of vortices in the disc.

CONCLUSION

Given the above, the ideas would be very important to develop theoretical and experimental methods for the accurate diagnosis of relativistic objects.

THANK YOU

FOR

YOUR ATTENTION !