Thermal Instability of Thin Accretion Disks in the Presence of Wind and a Toroidal Magnetic Field

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Accretion

- Black hole accretion is a fundamental physical process in the universe, and is the primary power source behind active galactic nuclei (AGNs), black hole X-ray binaries (BHBs) and possibly gamma-ray bursts.

- The first genuine model of an accretion disk by which we mean a rotating flow with viscous transport of angular momentum is the celebrated thin disk model developed in the early 1970s (Shakura & Sunyaev 1973, Novikov & Thorne 1973, Lynden-Bell & Pringle 1974).

- Depending on the mass of the central black hole, the gas temperature in this model lies in the range $10^4 - 10^7$ K. The disk is geometrically thin, while the gas is optically thick and radiates thermal blackbody-like radiation. Many accreting black hole sources have been successfully modeled as thin disks, e.g., luminous AGNs,…

- The thin disk model applies whenever the disk luminosity L is somewhat below the Eddington luminosity $L_{\rm edd}$.

Standard Thin Disks(cold disks)

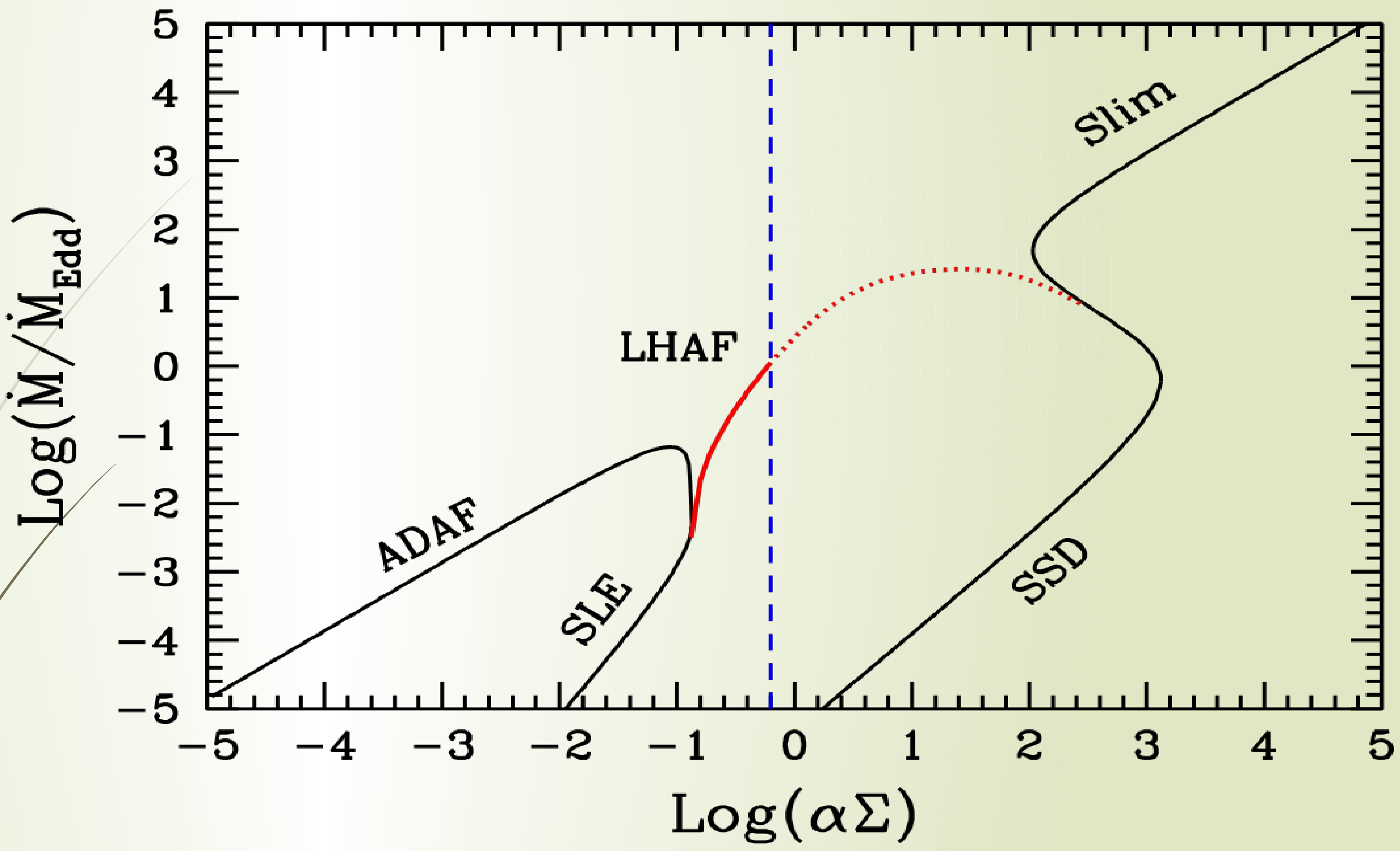
- **Geometrically thin**
- **Cold (T~ 10^6 K)**
- **Optically thick**
- **Spectrum: Black body**
- **Radiative Efficiency is High ~ 0.1**
- **Thin disk systems are bright (high $\dot{M}$, high efficiency)**

Accretion Models

- Bondi (1952) first investigated the simplest possible case, which is the spherical accretion at a steady state. His model gave the relationship among the efficiency, the radius and the sonic speed in the accretion processes.

- Based on Bondi's work, Parker(1969) and others developed this theory by working on the spherical stellar wind and accretion phenomenon.

- Shakura & Sunyaev (1973) proposed turbulence in the gas as the source of an increased viscosity, as so called α model, in which the gas viscosity made the angular momentum transferred radially outward, and dissipated energy was emitted by radiation.
- Advection Dominated Accretion Flow(ADAF).



Thermal equilibrium curves of various accretion solutions

Yuan & Narayan 2014

- If the solution track has a positive slope, the solution is viscously stable, and vice versa.

- ADAF and SLE solutions belong to the sequence of hot solutions on the left, and the Shakura-Sunyaev disk (SSD) and slim disk solutions belong to the sequence of cold solutions on the right. All four of these solution branches are viscously stable since each track has a positive slope.

- At a given Σ, if there are multiple solutions, the uppermost (highest $\dot{M}$) solution is thermally stable to long wavelength perturbations, the next one below is unstable, and the next is stable. Therefore, the ADAF, slim disk and SSD solutions are thermally stable.

- So, the SLE solution on the left is thermally unstable, as is the segment between the SSD and slim disk on the right.

- Radiation pressure dominated thin disk: Using numerical radiation MHD simulations, Hirose et al. (2009) concluded that a thin disk in this regime is thermally stable. However, later work by Jiang et al. (2013) showed that the disk is, in fact, thermally unstable. The reason for the discrepancy is discussed by the latter authors.

- According to the standard thin disk theory, the radiation-pressure-dominated inner region of a thin disk is both thermally and viscously unstable when the Eddington-scaled mass accretion rate is larger than a critical value. It was found that in this case the disk will be both secularly (Lightman & Eardley1974) and thermally (Shakura & Sunyaev1976; Piran1978) unstable.

- However, the high/soft state of X-ray binaries appears to be quite stable on observation. Gierlinski & Done (2004) found that black hole X-ray binaries with luminosities ranging from 0.01 to 0.5 Ledd show little variability, which obviously conflicts with the accretion disk theory. In contrast to some expectations, however, observations show little variability, which convincingly indicates that they are thermally stable.

- Some efforts have been made to solve this puzzle. For example, if a large fraction of the dissipated energy is channeled into a corona or outflow/jet, the disk would be stable(Svensson & Zdziarski1994).

- Observationally confirmed that the absence of hard X-ray and radio emission directly rules out the existence of corona or jet.

- Another idea is to assume that the viscous stress is proportional to the gas pressure only, rather than the sum of the gas and radiation pressure (Lightman & Eardley1974; Stella & Rosner1984).

- Moreover, on the theoretical side, in contrast to the above two ideas, numerical simulations have shown that only a very small fraction of the dissipated energy is channeled into the corona, which is consistent with the absence of hard X-ray emission in the high state of black hole X-ray binaries, and the stress is proportional to the sum of gas and radiation pressure (Hirose et al.2006; Hirose et al.2009b)

- Recently, the issue of thermal instability has been addressed by the radiation magneto-hydrodynamic (MHD) simulations of a vertically stratified shearing box (Hirose et al.2009b). Their results indicate that the radiation-dominated disk is stable over~40 cooling timescales.

Standard model challenges

Standard model is extremely successful in explaining the physical properties of black hole X-ray binaries. However, after more than four decades there are still unsolved questions and puzzles concerning the structure of thin disks.

We focus on one of these puzzles dealing with the local thermal stability of the disk.

There are two processes which may likely change this inconsistency between theory and observations:

1. If the disks viscous stress is proportional to the gas pressure instead of the total pressure, then the disk will be stable (Sakimoto & Coroniti1981; Stella & Rosner1984)..

2. **Some possible mechanism for making the disk cooler**: thus increasing the relative importance of gas pressure in comparison to radiation pressure.

- Magnetic field: another possible mechanism for cooling the disk relies on magnetic pressure to provide part of the vertical hydro-dynamical support (Zheng et al.2011).

- winds driven by a large-scale magnetic field or centrifugally driven wind can remove most of the gravitational energy released in the disk, thereby considerably reducing the disk temperature

- Main references:

1-REVISITING THE THERMAL STABILITY OF RADIATION-DOMINATED THIN DISKS

Zheng, S.-M., Yuan, F., Gu, W.-M., & Lu, J.-F. 2011, ApJ, 732, 52

2-THERMAL STABILITY OF A THIN DISK WITH MAGNETICALLY DRIVEN WINDS

Li, S.-L., & Begelman, M. C. 2014, ApJ, 786, 6

- We revisit the thermal stability of thin disks by linear analysis.

- Different from previous analyses, we include the role of the magnetic pressure and wind simultaneously.

- To add a wind/outflow effect we use a parametric simple model presented by Knigge (1999) which derived the radial distribution of the dissipation rate and effective temperature across a Keplerian, steady-state, mass losing accretion disk, using a simple parametric approach.

Assumptions

- We choose the cylindrical coordinate system (R, φ, z).
- The flow is static and axisymmetric.
- We restrict ourselves to regions far enough from the center of the disk to ignore relativistic effects.
- We assume that the gravitational potential is dominated by the central mass and ignore the contribution of the disk itself.
- Newtonian gravitational potential is chosen for the central mass.
- The gas content of the disk is an ideal classic gas.
- The magnetic field is assumed to be toroidal, i.e.,

Hydrodynamics Equations in the Presence of Wind and a Magnetic Field

Continuity equation:

$$\frac{\partial}{\partial t}(2\pi R\Sigma) - \frac{\partial \dot{M}_{\mathrm{acc}}}{\partial R} + \frac{\partial \dot{M}_{\mathrm{w}}}{\partial R} = 0 \qquad (1)$$

$$\dot{M}_{\mathrm{w}}(R) = 4\pi \int_{R_*}^{R} \dot{m}_{\mathrm{w}}(R')R'dR' \qquad (2)$$

Where $\dot{m}_w$ is the mass−loss rate per unit area and R_* is the inner edge of the disk.

$$-\dot{M}_{\mathrm{acc}}(R) + \dot{M}_{\mathrm{w}}(R) = \dot{M}_{\mathrm{acc}}(R_*) \qquad (3)$$

Hydrodynamics Equations in the Presence of Wind and a Magnetic Field

Angular momentum conservation:

$$\frac{\partial}{\partial t}(\Sigma R^2\Omega) + \frac{1}{R}\frac{\partial}{\partial R}(R^3\Sigma v_r\Omega) = \frac{1}{R}\frac{\partial}{\partial R}\left(R^3\Sigma\nu\frac{\partial\Omega}{\partial R}\right) - \frac{l^2R^2\Omega}{2\pi R}\frac{\partial\dot{M}_W}{\partial R} \qquad (4)$$

υ is the kinematic viscosity.

is the angular momentum per unit mass which carries away through the wind.

: non-rotating disk wind

: corresponds to outflowing material that carries away the angular momentum

: belongs to centrifugally driven disk winds

Hydrodynamics Equations in the Presence of Wind and a Magnetic Field

By integrating equation (3) along the radial coordinate in the interval and using continuity equation:

$$\dot{M}_{\rm acc}(R)(\Omega_K R^2 - l_{\rm in}) + C_{\rm w}(R) = 2\pi R^2 T_{R\phi} \qquad (5)$$

is the correction term induced by the existence of the wind in the system.

$$C_{\rm w}(R) = \frac{4\pi K(l^2 - 1)l_{\rm in}}{\sqrt{R_*}(\xi + 5/2)}(R^{\xi+5/2} - R_{\rm in}^{\xi+5/2}) \qquad (6)$$

We have taken a simple power-law model for the mass-loss rate per area

$$\dot{m}_{\rm w}(R) = KR^{\xi} \qquad (7)$$

Hydrodynamics Equations in the Presence of Wind and a Magnetic Field

Energy equation in the presence of wind

$$Q^+_{\rm vis} = Q^-_{\rm rad} + Q^-_{\rm adv} + Q^-_{\rm win} \qquad (8)$$

$$Q^+_{\rm vis} = -T_{R\phi} R \frac{d\Omega}{dR} \quad , \quad Q^-_{\rm rad} = \frac{32\sigma T^4}{3\tau} \quad , \quad Q^-_{\rm adv} = \mu \frac{\dot{M}_{\rm acc}(R)\Omega_K^2 H^2}{2\pi R^2}$$

$$Q^-_{\rm win} = \frac{1}{2}(\eta_b + \eta_k f^2) K R^{\xi+2} \Omega_K^2$$

For $l < \sqrt{3/2}$: $\eta_b = 3 - 2l^2$ and $\eta_k = 1$

For $l > \sqrt{3/2}$: $\eta_b = 0$ and $\eta_k = 1 - 2f^{-2}(l^2 - 3/2)$

Hydrodynamics Equations in the Presence of Wind and a Magnetic Field

With defining new parameter s as , we can obtain

$$\dot{M}_{\rm w}(R_d) = \frac{4\pi K}{s}(R_d^s - R_*^s)$$

$$\dot{m}_{\rm w}(R) = \frac{s\dot{M}_{\rm w}(R_d)}{4\pi}\frac{R^{s-2}}{R_d^2 - R_*^s}$$

$$\dot{M}_{\rm acc}(R) = \dot{M}_{\rm acc}(R_*) + \frac{\dot{M}_{\rm w}(R_d)}{R_d^s - R_*^s}(R^s - R_*^s)$$

In order to construct a complete set of equations to describe the unknown functions, we need one more constraint on the magnetic field. Based on MHD simulations (Machida et al.2006), one may assume that the strength of the magnetic field decreases with vertical height from the disk mid-plane. Therefore we simply assume that

$$B_\phi H^\gamma = \text{constant} = \Phi_\gamma$$

Thermal Instability

we use the main equations presented in the previous section and find a general criterion for the thermal stability of the disk in the presence of wind. We generalize the analysis of Zheng et al.(2011) to include wind:

$$\left[\frac{\partial(Q^+_{\rm vis} - Q^-_{\rm rad} - Q^-_{\rm adv} - Q^-_{\rm win})}{\partial T}\right]_\Sigma \frac{T}{Q^+_{\rm vis}} = \frac{\psi}{1 + 2\gamma\beta_{\rm mag} + \beta_{\rm gas}}$$

Where

$$\psi = 4 - 10\beta_{\rm gas} - 8(1-\gamma)\beta_{\rm mag} - 12f_{\rm adv} + 16f_{\rm adv}\beta_{\rm gas} + (16+8\gamma)\beta_{\rm mag}f_{\rm adv} + 4f_{\rm win}(1 + 2\gamma\beta_{\rm mag} + \beta_{\rm gas})$$

$$\beta_{\rm mag} = p_{\rm mag}/p_{\rm tot} \qquad \beta_{\rm gas} = p_{\rm gas}/p_{\rm tot} \qquad \beta_{\rm rad} = p_{\rm rad}/p_{\rm tot}$$

$$p_{\rm tot} = p_{\rm gas} + p_{\rm rad} + p_{\rm mag}$$

$$f_{\rm adv} = \frac{Q^-_{\rm adv}}{Q^+_{\rm vis}} \qquad f_{\rm win} = \frac{Q^-_{\rm win}}{Q^+_{\rm vis}}$$

Thermal Instability

Thermal instability occurs when

$$\left[\frac{\partial(Q^+_{\rm vis} - Q^-_{\rm rad} - Q^-_{\rm adv} - Q^-_{\rm win})}{\partial T}\right]_\Sigma > 0$$

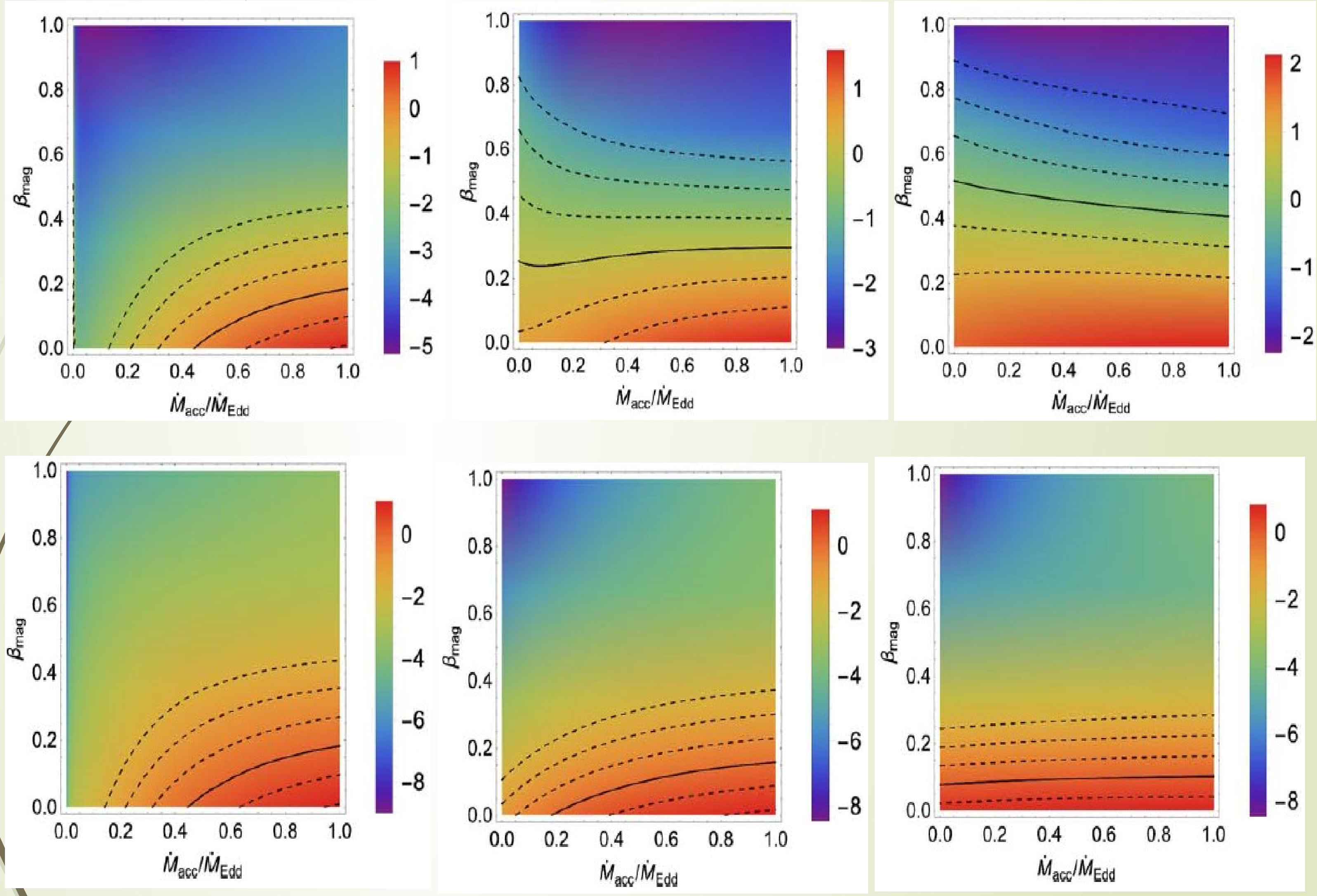
There are several parameters that can influence stability:
The accretion rates, magnetic pressure, and wind parameters l and s.

The response of the system is sensitive to the magnitude of l.
For and the system behaves completely different .

- When   we have >0 We expect destabilizing behavior due to wind.
- When   we have 0 Wind stabilizes the disk.

Stability Function for Different

We have plotted ψ as a function of and . The solid curve shows the stability boundary. Contours indicate curves with constant ψ.



$$l^2=2$$

For both rows

whenl2<5/2, the existence of wind destabilizes the disk in the sense that higher values of β mag are required to stabilize the disk

in the bottom row that by increasing the wind accretion rate the stability zone gets wider.

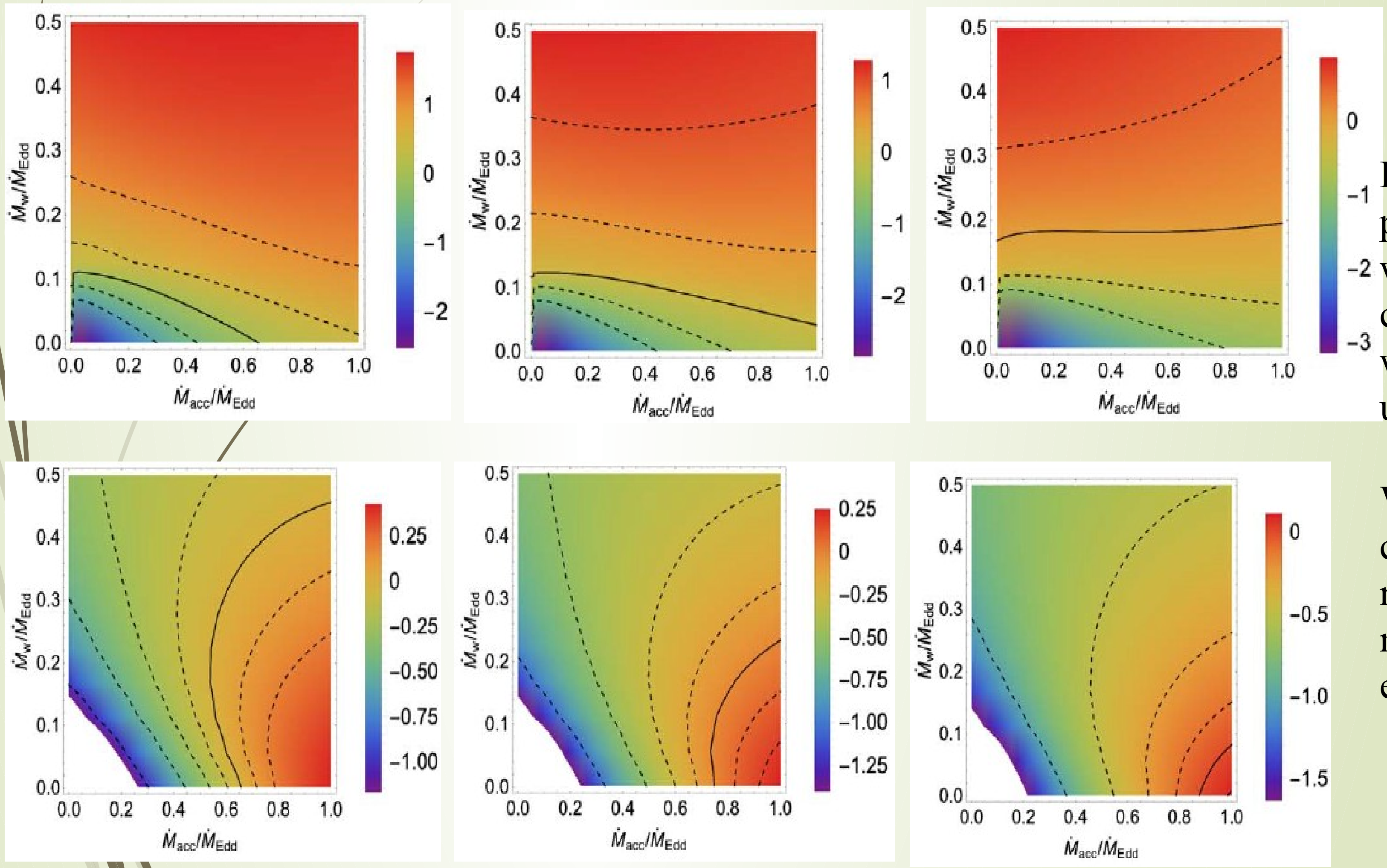
$$l^2=3$$

from bottom to top

For both rows

Stability Function for Different

In this case, we have plotted stability parameter, ψ, as a function of and .



$l^2 = 2$

$\psi = 1, 0.5, 0, -0.5, -1$

It is clear that by increasing the magnetic pressure contribution the stability region gets wider. Also if we keep the mass accretion rate constant and increase the wind accretion rate, we see that the disk eventually becomes unstable.

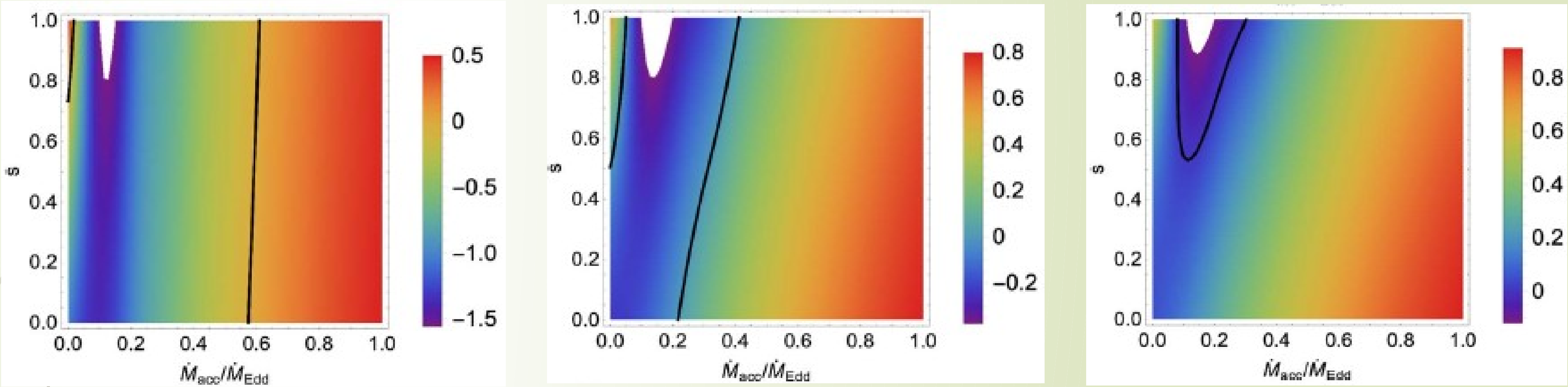
We see that if we keep the mass accretion rate constant and move along the wind accretion rate, the disk becomes stable. As already mentioned, for l2>5/2,we expect that the existence of wind stabilizes the disk

$l^2 = 3$

$\psi = 0.2, 0.1, 0, -0.1, -0.25, -0.5$

=0.1,0.125, 0.15

Stability Function for Different Mass Accretion Rate



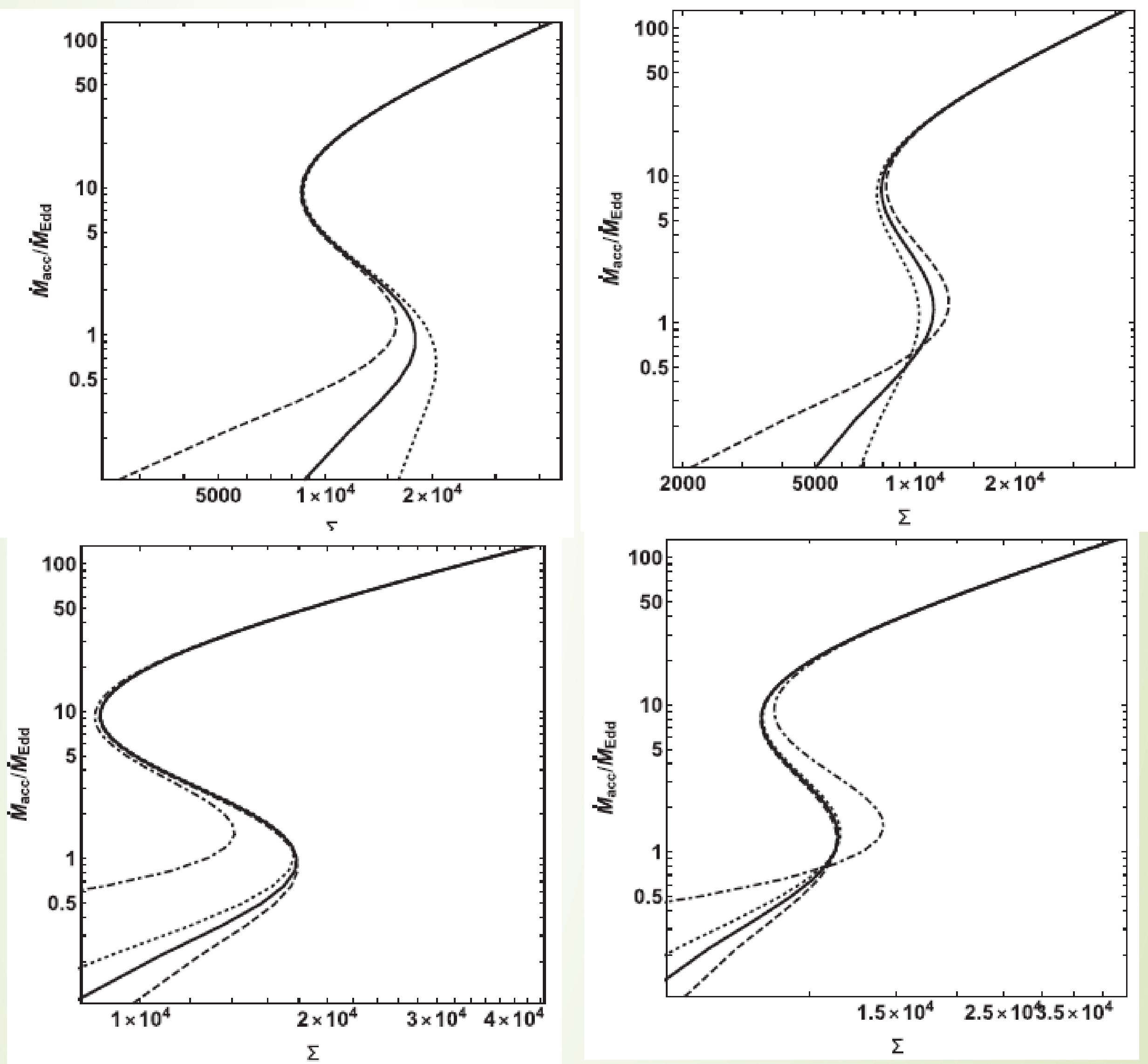
- From left to right we increase the wind mass accretion rate as = 0.01, 0.05, and 0.07, when

- In this case, the behavior of the system in is not significantly sensitive to the magnitude

of .

- When the wind accretion rate is small, the s parameter does not have any impact on the local stability of the system.

Local Thermal Equilibria



Left panels:; right panels:. In the top panels s is fixed as and and ; the dashed, solid, and dotted curves indicate = 0.05, 0.1, and 0.15 respectively. In the bottom panels the dashed, thick, dotted, and dotted–dashed curves indicate 0.2, 0.4, 0.6, and 10 respectively.
The wind accretion rate is constant: = 0.1.

Summary

- We present a full local stability analysis when the disk is magnetized and there is a wind mechanism in the system.

- One should note that we have considered the magnetic field and the wind to be totally independent!

- We showed that, depending on the type of wind, the disk can be stabilized or destabilized. when the wind parameter then the presence of wind makes the disk unstable. On the other hand, for , the wind significantly stabilizes the disk.

- Our analysis confirms the stabilizing role of the magnetically driven wind reported by Li & Begelman (2014). This consistency shows that Knigge's parametric wind model is a viable one at least for the magnetically driven disk case.

A full dynamical model is required to obtain an accurate description of thermal instability of thin accretion disks in presence of the wind.

- A new development:

Puffy accretion disks: sub-Eddington, optically thick, and stable

Debora Lancova et al 2018, Apj

they report on a new class of solutions of black hole accretion disks that they have found through three-dimensional, global, radiative magneto-hydrodynamic simulations in general relativity.

It combines features of the canonical thin, slim and thick disk models but differs in crucial respects from each of them. they expect these new solutions to provide a more realistic description of black hole disks than the slim disk model.

Omar Khayyam

Literal:

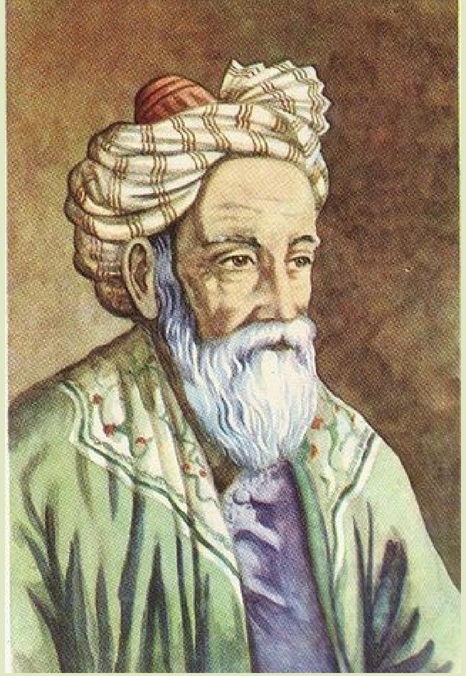
- The caravan of life shall always pass
  Beware that is fresh as sweet young grass
  Let's not worry about what tomorrow will amass
  Fill my cup again, this night will pass, alas
-

Meaning:

- To be aware of each moment spent
  Is to live in the now, and be present
  Worry for morrow shan't make a dent
  Caring for the now, your mind must be bent.

Fitzgerald:

- One Moment in Annihilation's Waste,
  One moment, of the Well of Life to taste--
  The Stars are setting, and the Caravan
  Starts for the dawn of Nothing--Oh, make haste!



IRAN

General Information

General Information

Ancient Name:

Perse, Pars, Persia (Until 1935) ***Persians (Parsians)***

Conventional Name:

Iran (After 1935) ***Iranians***

Type of Government:

Republic (Islamic Republic)

Conventional Long Full Name:

Islamic Republic of Iran

Reference: CIA Facebook

General Information

Race Background:

Aria (Arya)

Area: 1.648 million sq km (Slightly Larger than Alaska)

Population: 80,688,433 (July 2016 est.)

Religion: Shi'a Muslim 89%, Sunni Muslim 9%, Zoroastrian, Jewish, Christian, and Baha'i 2%

Reference: CIA Facebook

Wikipedia.org

General Information

Capital: **Tehran**

Calendar: **Persian Calendar**

This year: 1398

A Solar Calendar which is more accurate than Gregorian calander

Persian New Year: **21st March**

Official Language: **Farsi (Persian)**

Reference: CIA Facebook
wikipedia.com

General Information

Natural Scenery

Reference: dreamview.net

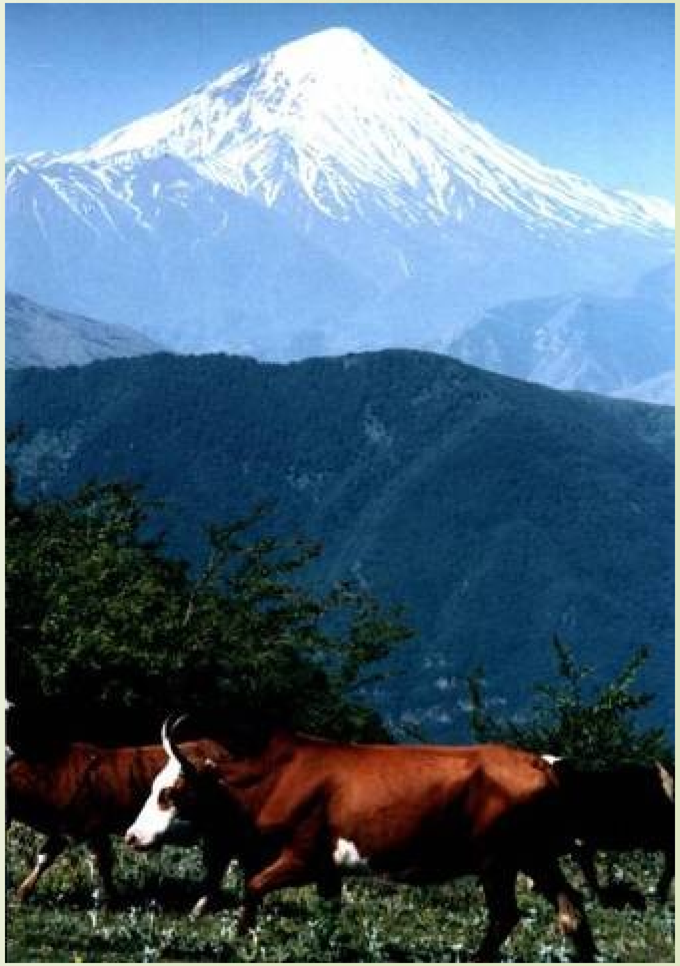
Natural Scenery

Reference: dreamview.net

Natural Scenery

Reference: dreamview.net
Fars News Agency

Natural Scenery



Reference: dreamview.net

Natural Scenery

Reference: dreamview.net

Natural Scenery

Reference: dreamview.net

Natural Scenery

Reference: dreamview.net

Tourism Attractions

Chehel sotun, Esfahan

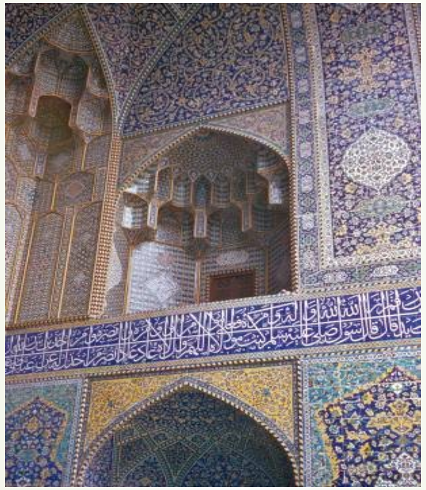
Imam Square, Esfahan

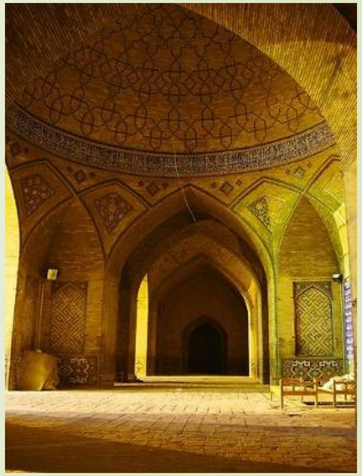
Reference: dreamview.net

Tourism Attractions

Eram Garden, Shiraz

A mosque, Esfahan





Interior Design of mosques

Reference: dreamview.net
shirazcity.org

Tourism Attractions

Naqsh Jahan Square, Esfahan

Tourism Attractions

Alisadr Cave, Hamedan

An Ancient Chruch, Isfahan

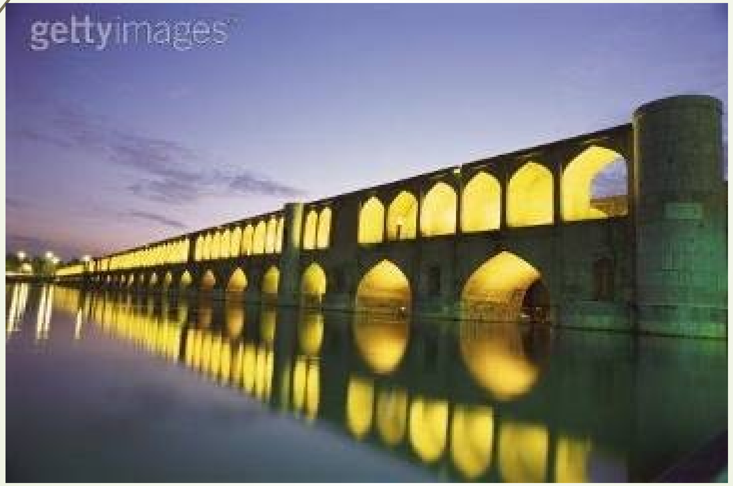
Eel Goli, Tabriz

Reference: dreamview.net

Tourism Attractions

Ferdowsi Monument, Mashad

Ali Qapu, Esfahan

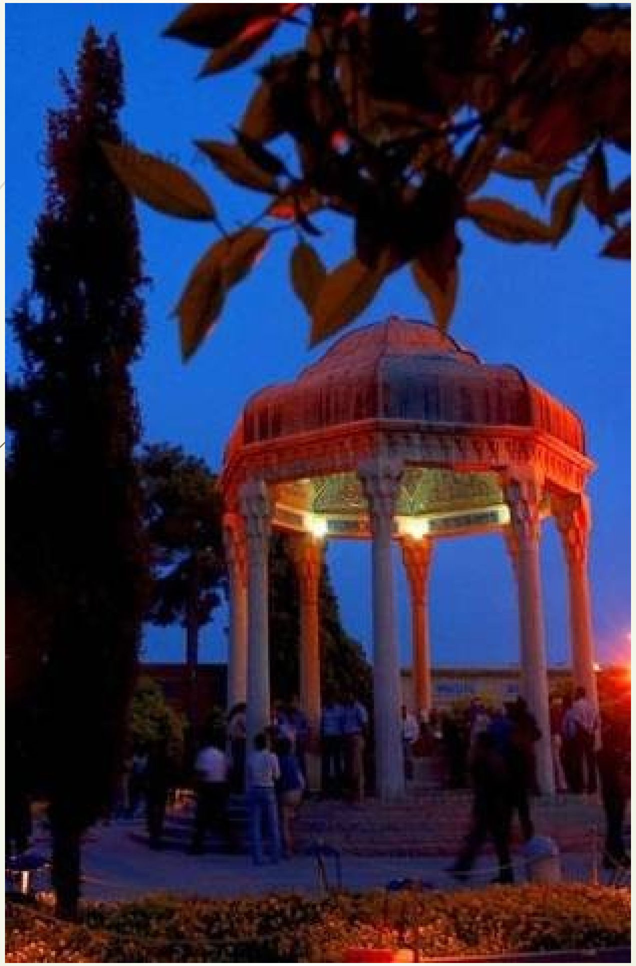


Sioseh Pol(33 Bridges), Esfahan

Khajoo Bridge Esfahan

Reference: dreamview.net
gettyiamges.com

Tourism Attractions

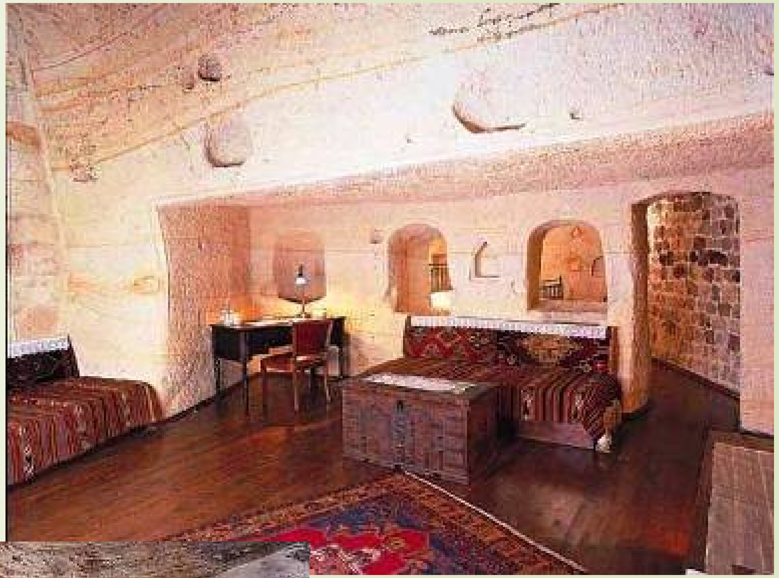


Hafez Monument, Shiraz

Namak Abrood resort, Northern Iran

Reference: dreamview.net
flicker.com

Tourism Attractions



Kandovan

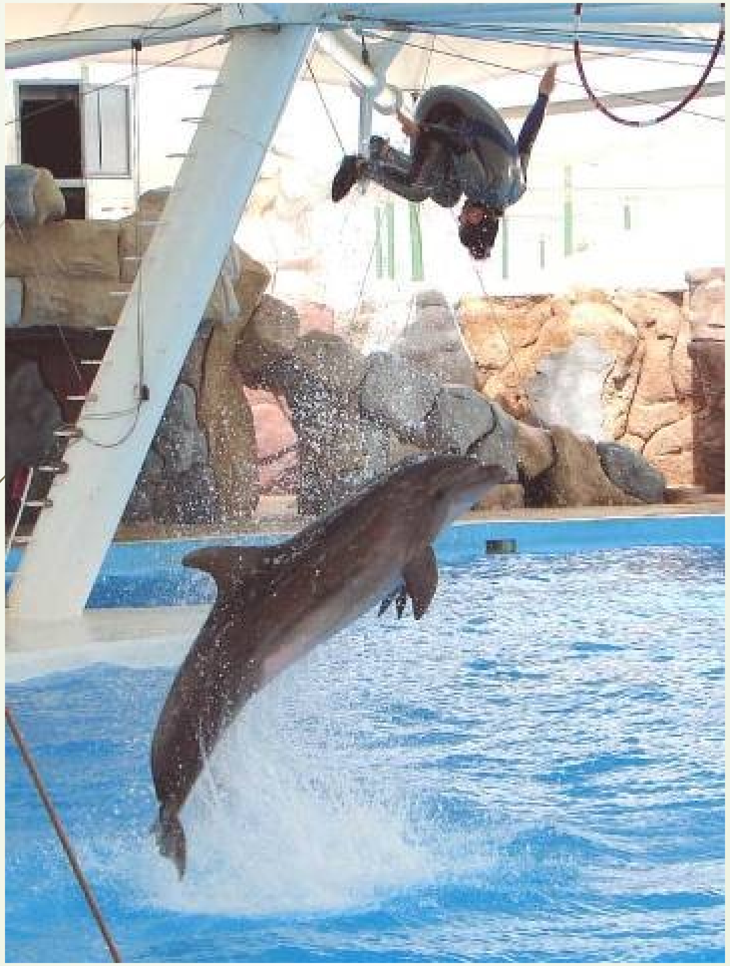
Reference: mandalay.pl
tourism.chn.ir

Tourism Attractions

Qeshm Island

Reference: flicker.com

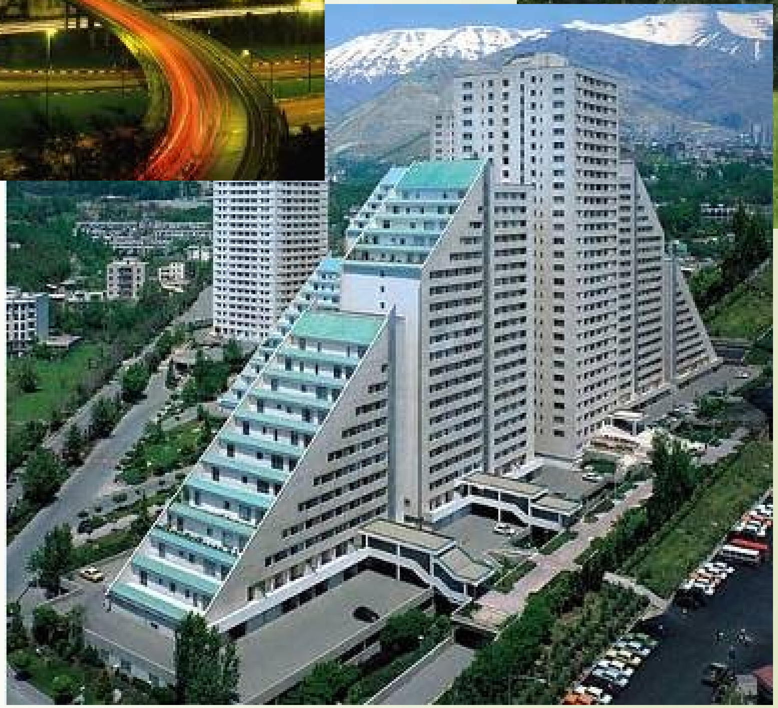
Tourism Attractions



Dolphin Park, Kish Island

Reference: flicker.com

Tehran



Reference: dreamview.com
flicker.com

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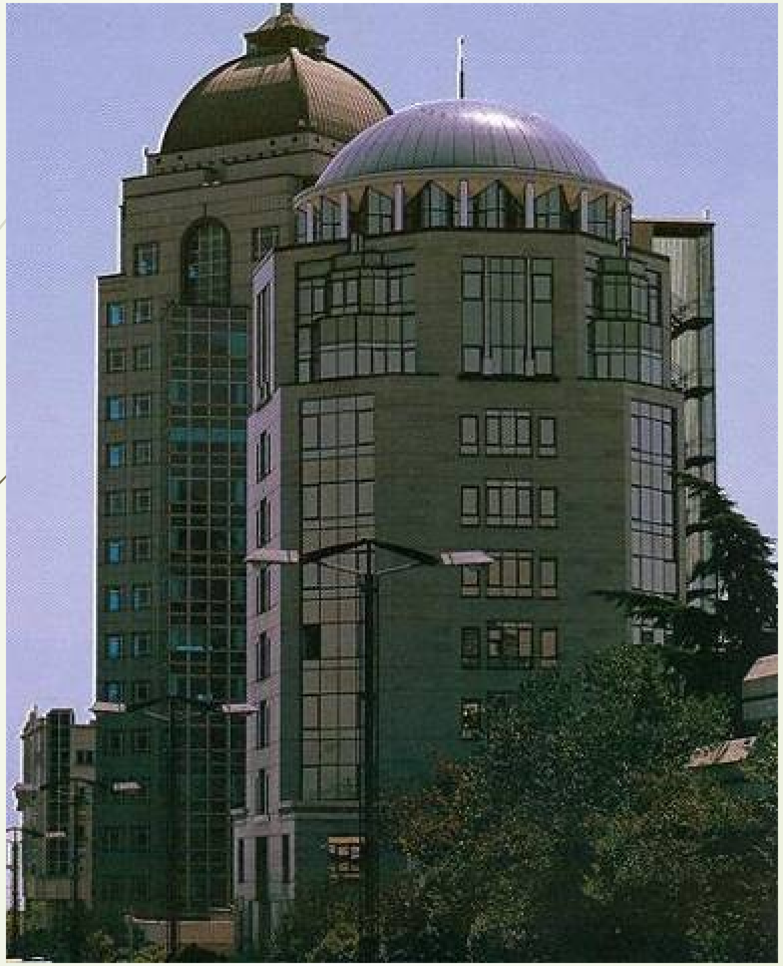
Reference: dreamview.com

Tehran



Reference: flicker.com

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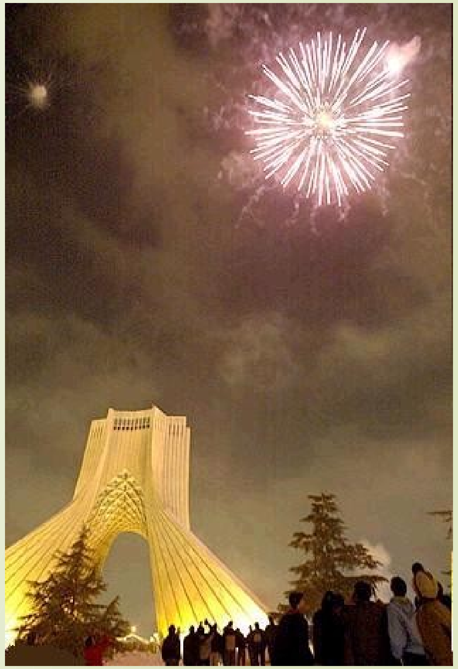
Reference: flicker.com
bia2.com

Tehran

Tehran

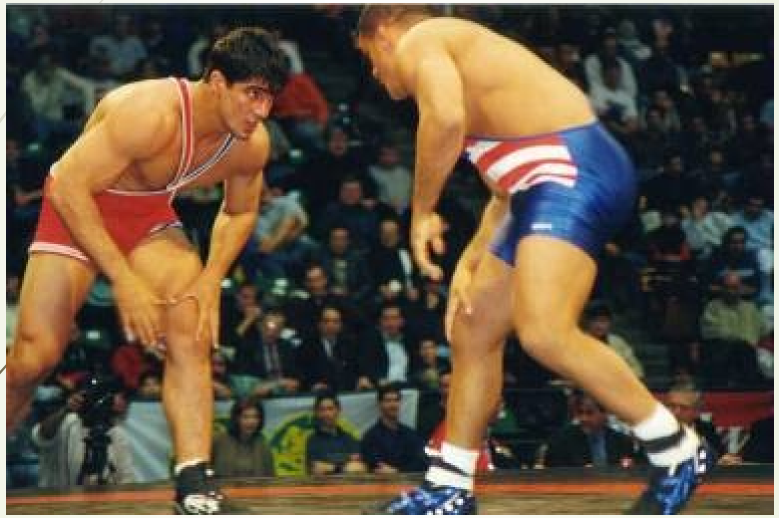


Tehran

Subway Stations in Tehran

Reference: tehranmetro.com

Social Life after 1979 Revolution



Iranian Wrestling Team
Top Three of the World

Iranian Soccer Team
Top 20 of the World

Reference: ipna.ir

Tehran Symphonic Orchestra

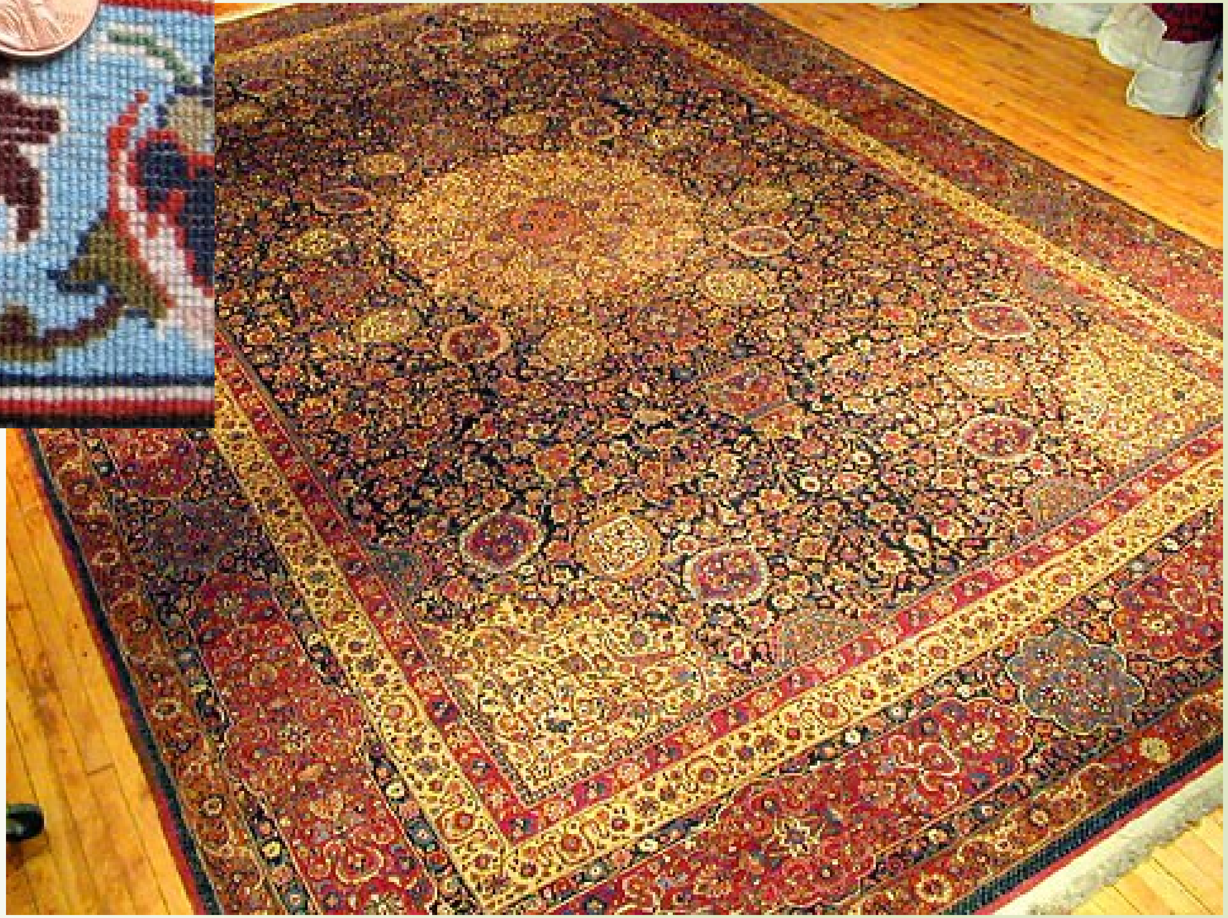
Reference: worldisround.com

Art and Iranians

Iranian Miniature

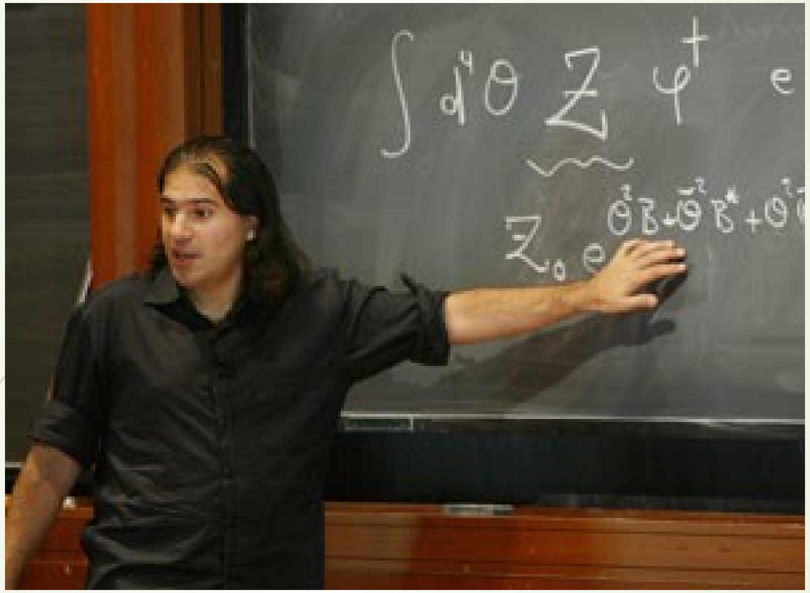
Reference: iranonline.com

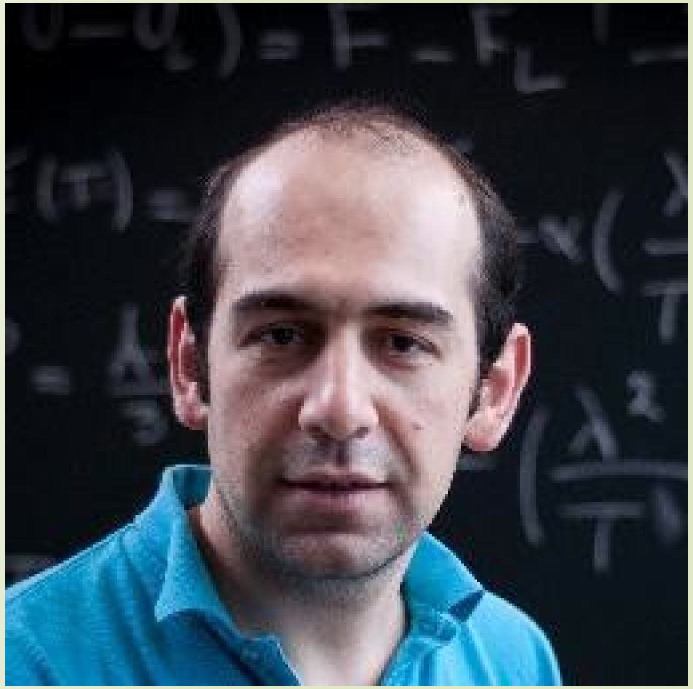
Art and Iranians



Hand-knotted Persian
Silk/wool Rug

Reference: manhattanrugs.com





Status of astronomy in Iran Today

Background - Persian/Iranian Astronomy

In spite of Iran's renowned pivotal role in the advancement of astronomy on the world scale during 9th to 15th centuries, rekindled interest in astronomy in modern Iran is a recent and very exciting development.

Astronomical Community in Iran

At present the astronomical community of Iran consists of ~65 professionals – half university faculty members and half MSc and PhD students.

Research and Publications

The yearly scientific contributions of its members have a healthy growth rate.

Over the last 3 years an average of 80 papers/year have been published in refereed international journals.

- Thanks for your attentions