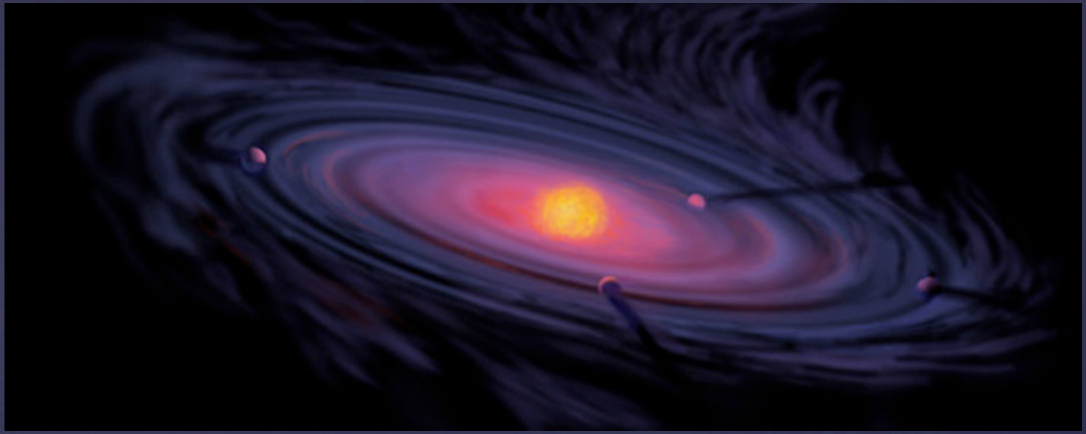
Accretion Outbursts on to Young Stars and Planets



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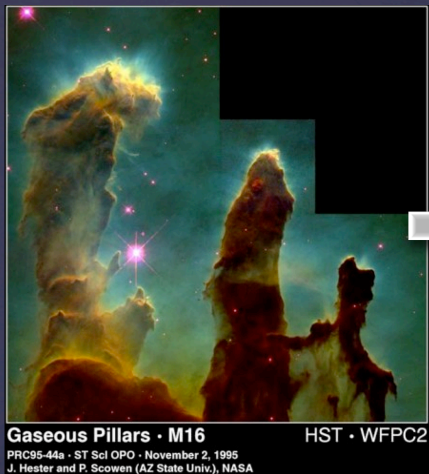
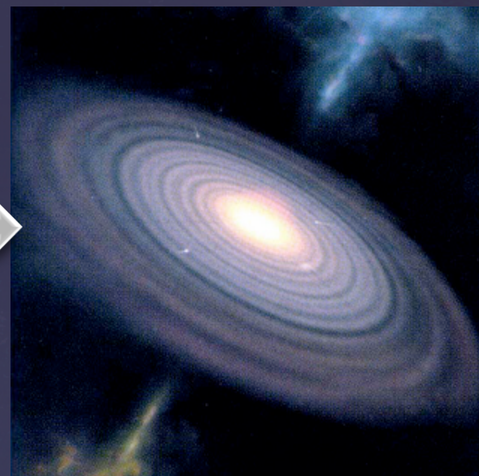
Planet and Satellite Formation

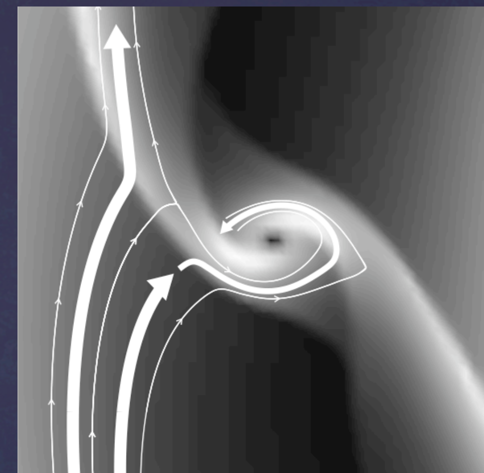
Molecular Cloud



Protostar and accretion disc

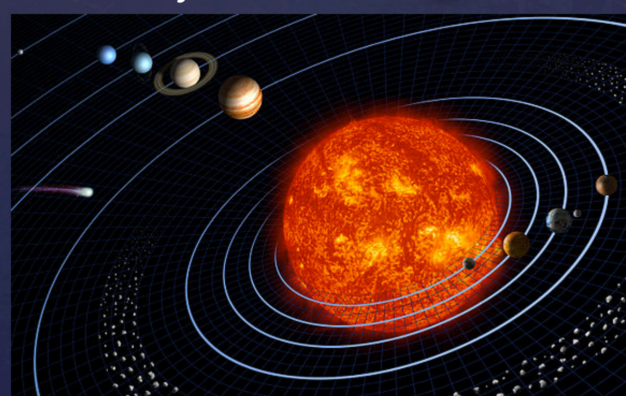


Planet and circumplanetary disc



Lubow et al. (1999)

Solar System



Regular Satellites

How Accretion is Driven

- The magneto-rotational instability (MRI)
  - If the ionisation is high enough (Balbus & Hawley 1991).
  - Parameterised with $\nu = \alpha c_s H$ (Shakura & Sunyaev 1973).
  - A lot of uncertainty in α. MHD simulations suggest 0.01 but observations suggest 0.1-0.4 (King, Pringle & Livio 2007).

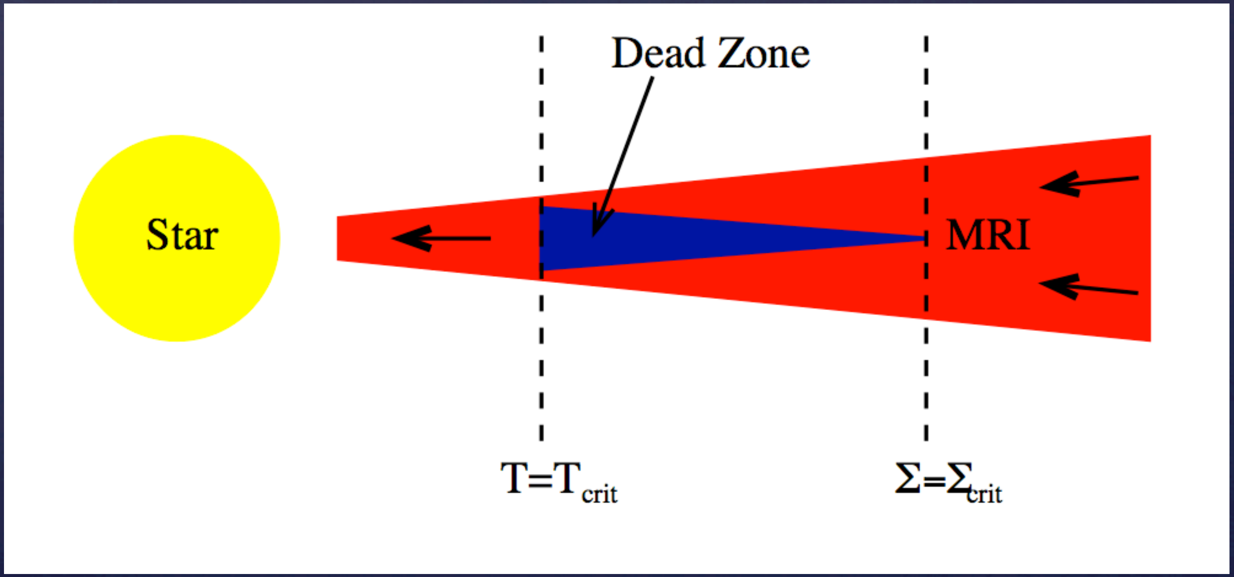
- Gravitational instability
  - If the disc is massive enough, Q=2, (Balbus & Hawley 1991).
  - This drives a second viscosity with an effective alpha

$$\alpha_g = \alpha \left[(Q_{crit}/Q)^2-1\right] \quad \text{if} \quad Q < Q_{crit}.$$

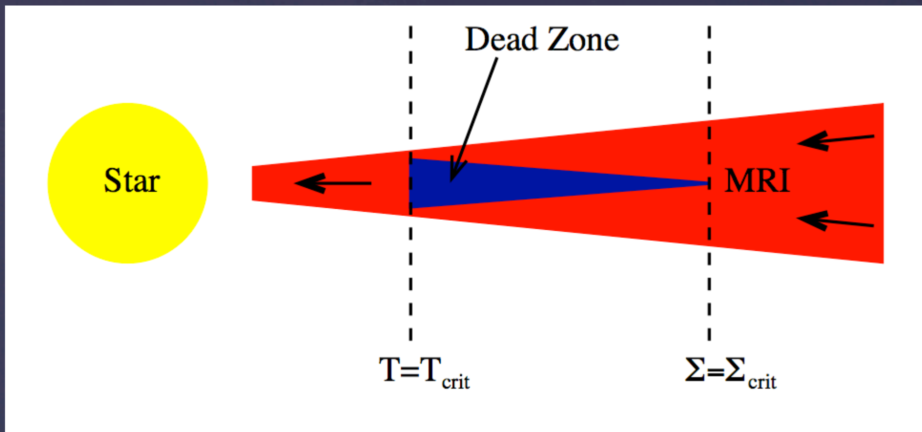
  - Additional viscosity provides extra heating.

Dead Zones

- Dusty protostellar discs have a low ionisation fraction. The magnetic field does not couple to the gas and at midplane regions of the disc the MRI cannot operate – this is known as a dead zone (Gammie 1996).
- Planets and satellites are more likely to form in dead zones because solids settle to the midplane.

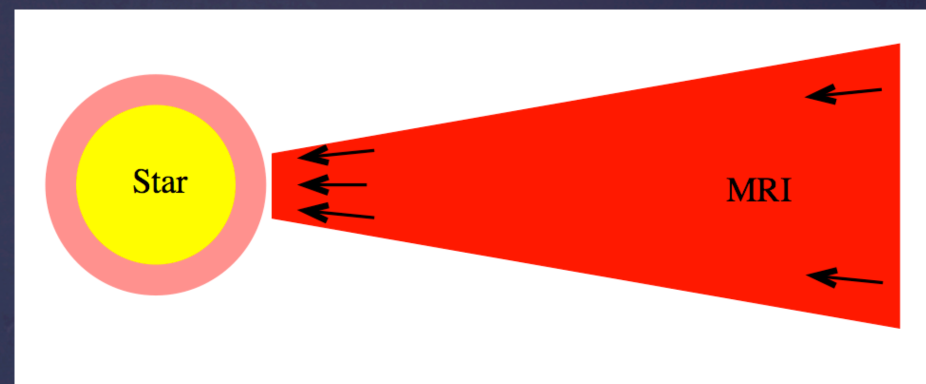


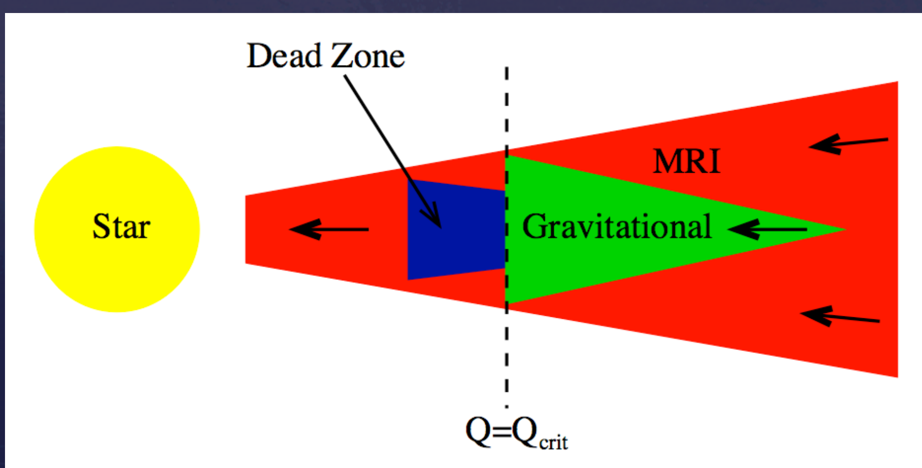
The Gravo-Magneto Instability



The disc empties, cools and the dead zone reforms.

Mass builds up and the dead zone becomes self gravitating.

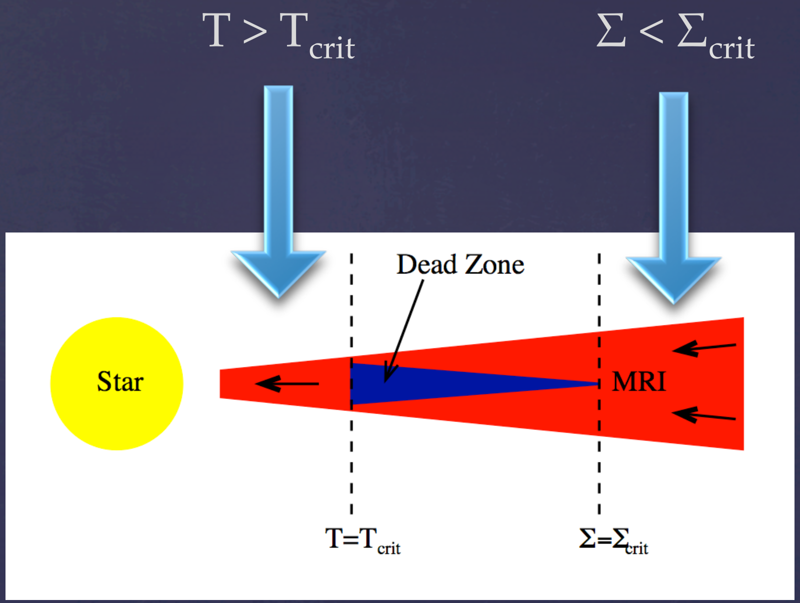


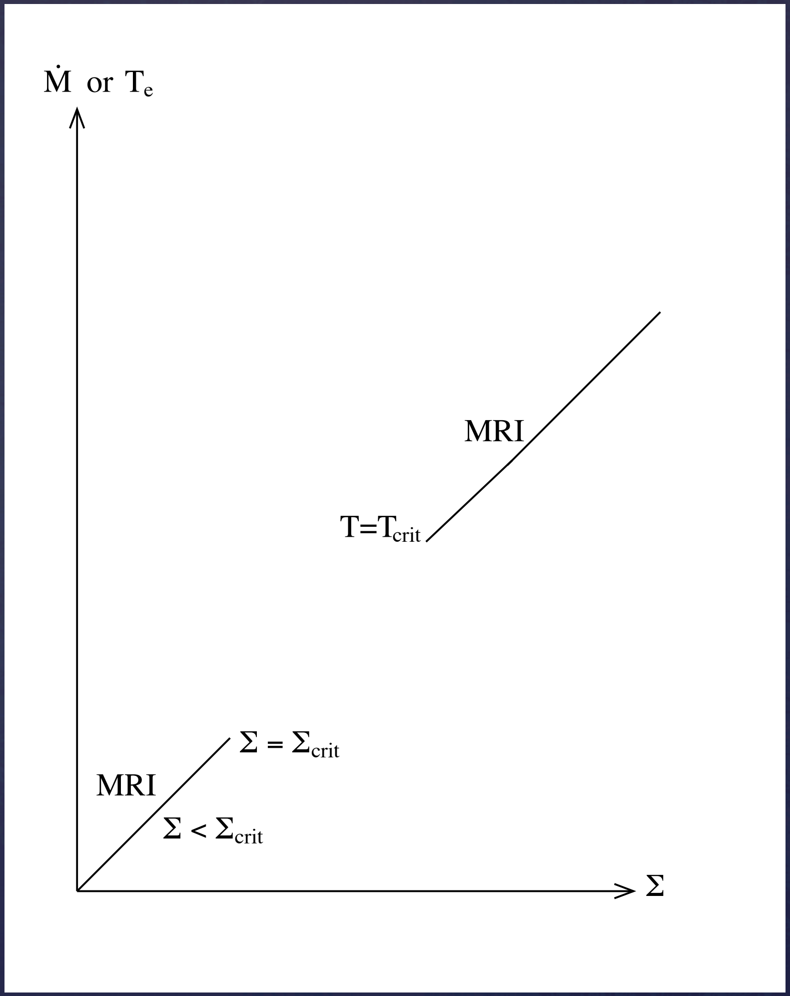


The dead zone is heated by self gravity and the MRI is triggered causing an accretion outburst.

Armitage et al. (2001), Zhu et al. (2010)
Martin & Lubow (2011)

MRI Disc Branches

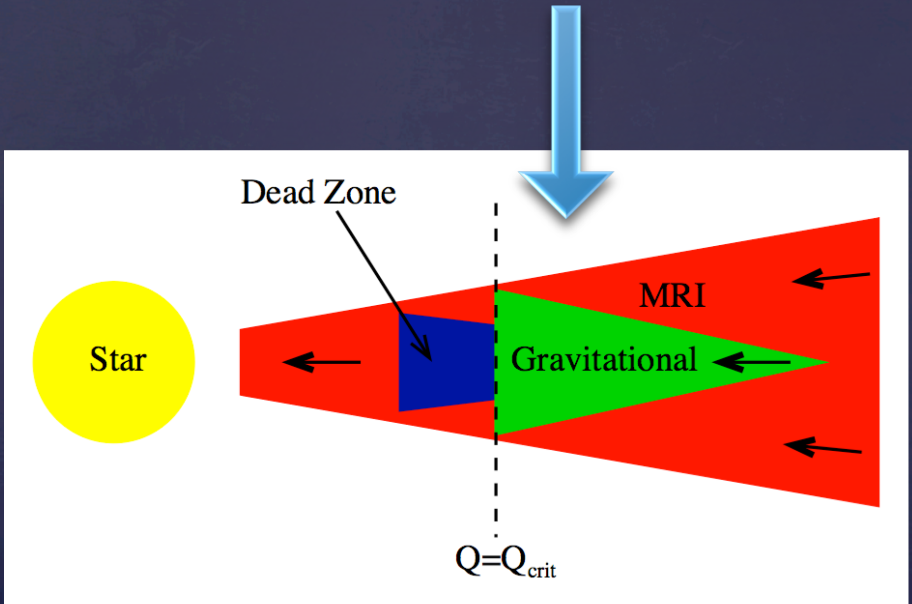


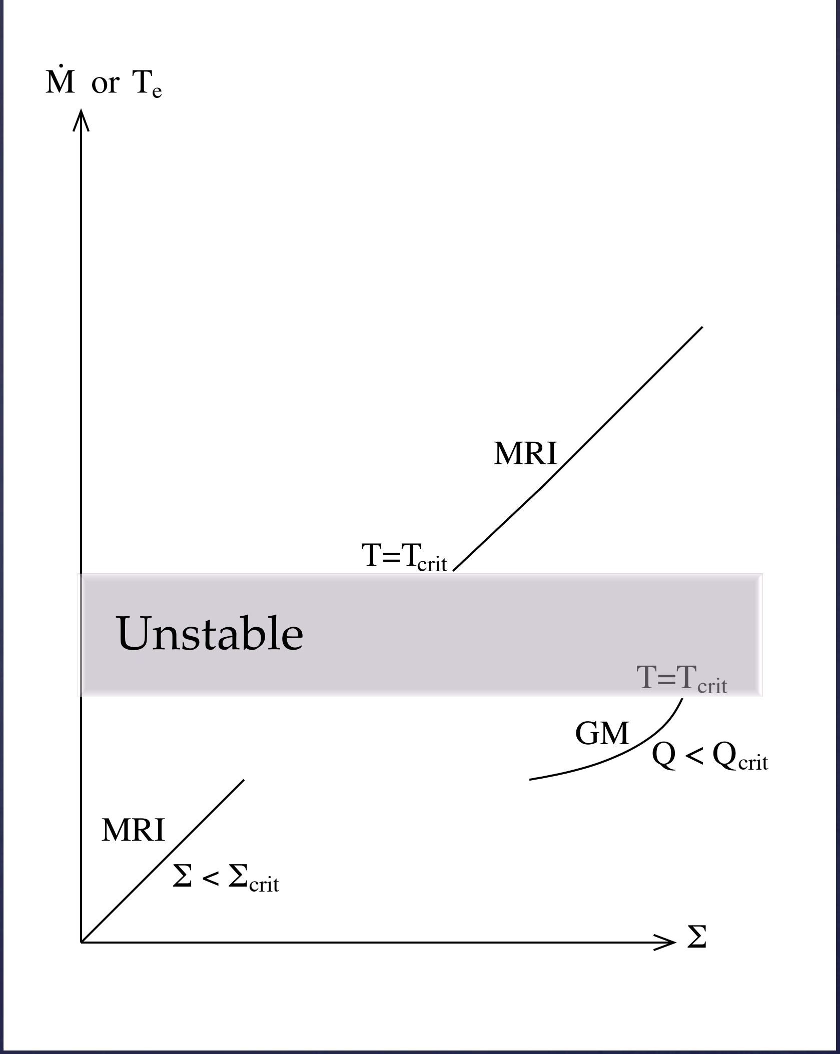


Fixed Radius in the disc

Gravo-Magneto Branch

Self gravitating dead zone with MRI active surface layers (GM).

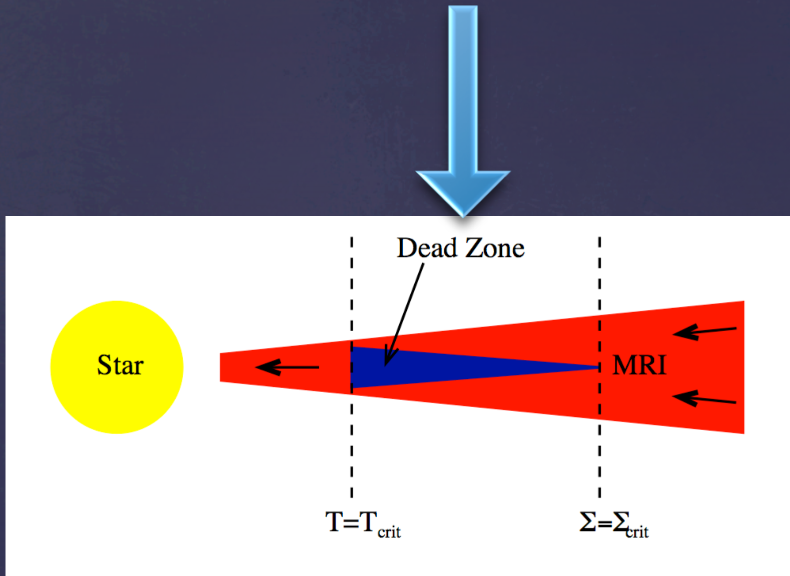


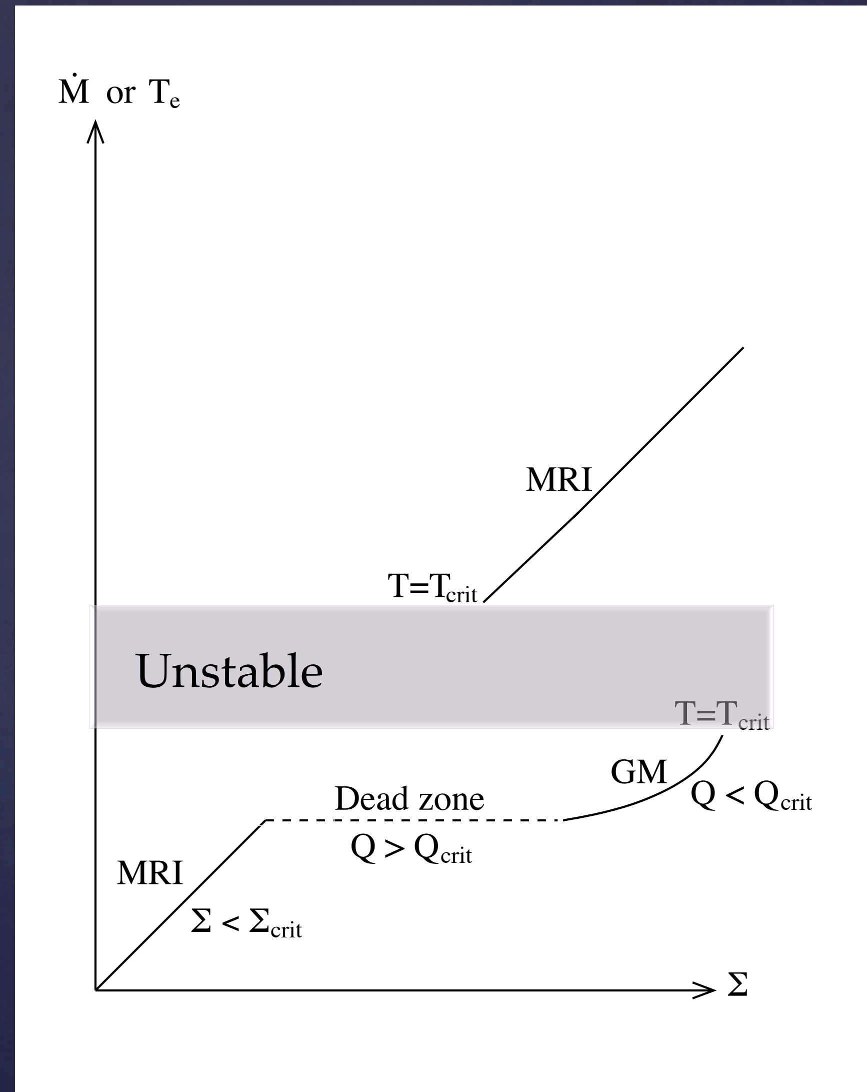


Fixed Radius in the disc

Dead Zone Branch

Dead zone with MRI active surface layers.

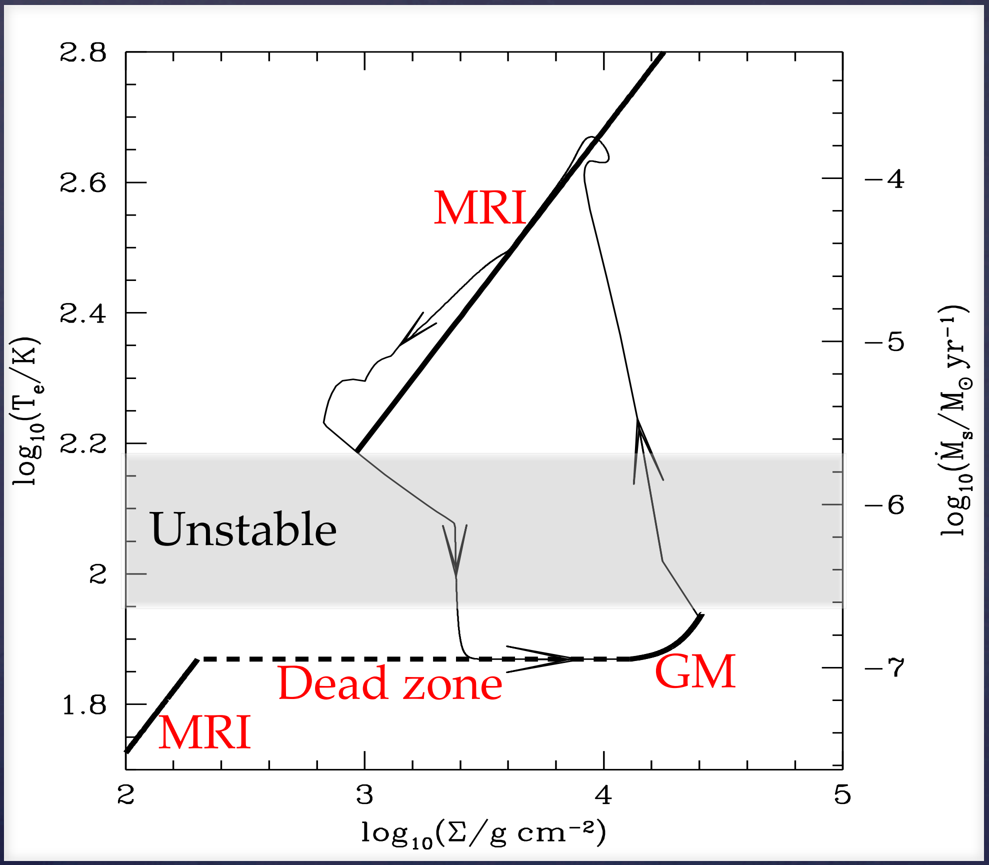


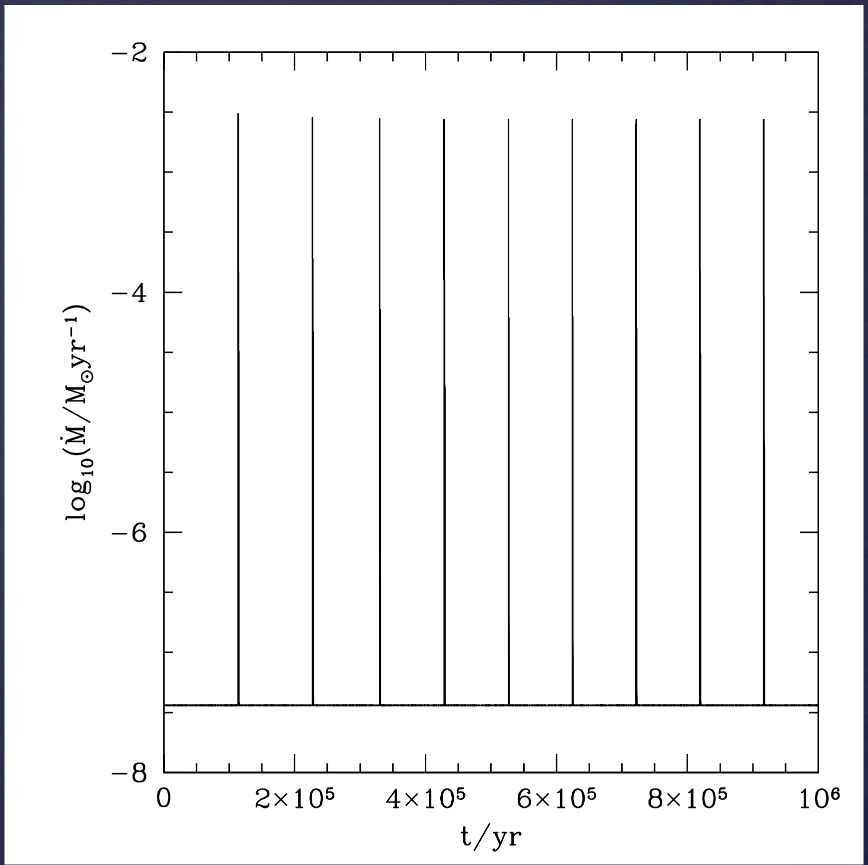


Fixed radius in the disc

Time Evolution

Radius = 3 AU   Accretion rate on to the disc = $10^{-6}\ M_{sun}/yr$

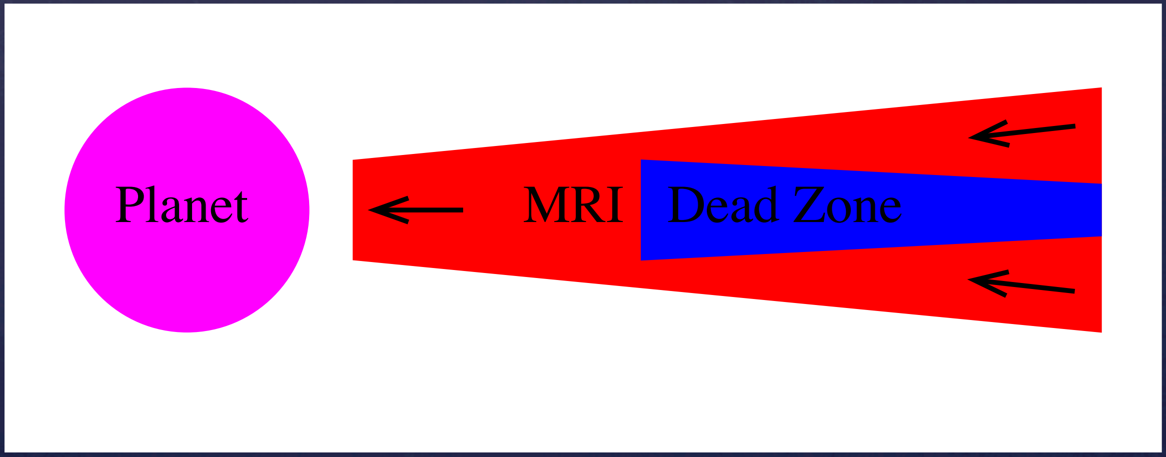




Martin & Lubow (2011)

Circumplanetary Discs

- Circumplanetary discs are much thicker (H/r = 0.3) than circumstellar discs (H/r=0.05) (Martin & Lubow 2011a).
- They are truncated by tides from the central star at $0.4R_H$ (Martin & Lubow 2011b).
- They have higher surface density than the local circumstellar disc - dead zone formation is even more favourable in these discs than circumstellar discs.
- The gravo-magneto instability is likely to occur in circumplanetary discs (Lubow & Martin 2012).



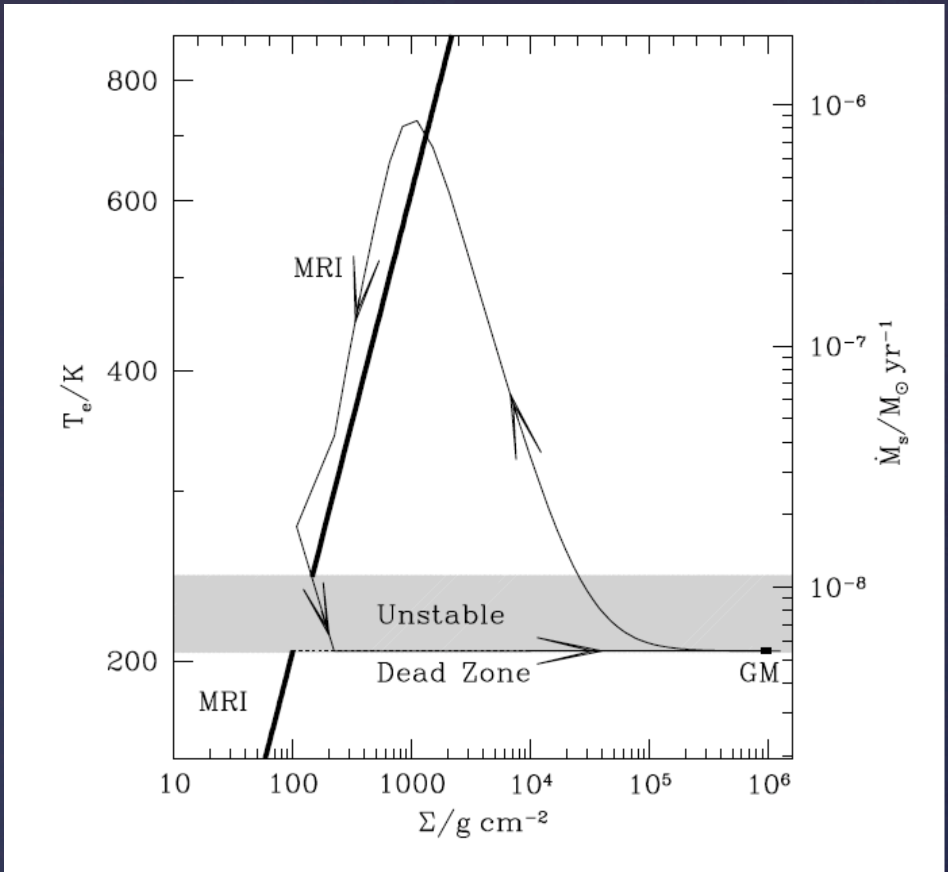
Limit Cycle

Planet mass = 1 M_J

Accretion rate on to the disc
= 10^{-8} M_{sun}/yr

Radius = 0.07 R_H

Each outburst accretes 0.1 M_J



Lubow & Martin (2012)

- Circumplanetary discs around a proto Jupiter are unstable for a range of accretion rates, 10^{-9} – 10^{-7} Msun/yr. These are typical of accretion rates in the T Tauri phase.
- The gas accreted on to the planet is much hotter than that predicted by a steady accretion disc model. This has implications for the initial state of a newly formed planet.

Observational Consequences

- Accretion outbursts repeat on a timescale of a few 10^4 years and last around 10 years.
- During quiescence the luminosity of the circumplanetary disc is around 0.01 times that of the circumstellar disc.
- During outburst the luminosity of the circumplanetary disc will increase significantly to be even brighter than the circumstellar disc.
- The outbursts in the accretion rate on to the planet may help to find planets while they are still in the circumstellar disc.

Galilean Satellite Formation

- Regular satellites are thought to form within a circumplanetary disc.

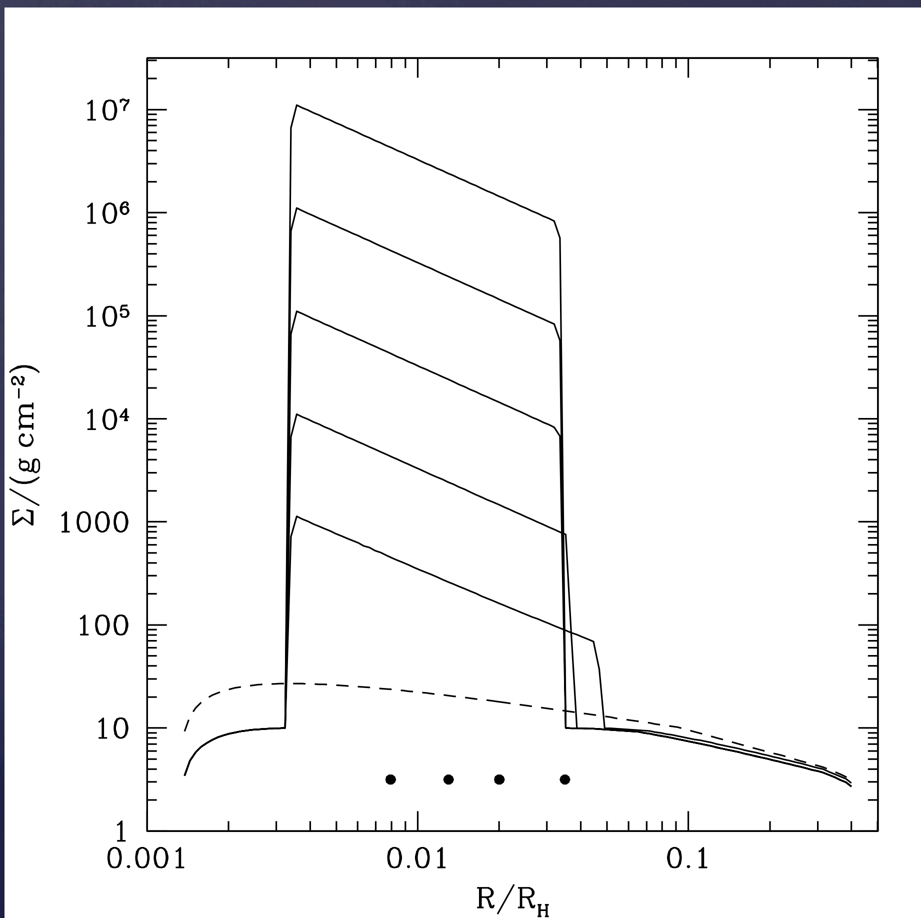
- Fully turbulent discs are too hot for icy satellite survival unless the accretion rate is $< 10^{-10}$ Msun/yr (Canup & Ward 2002; Ward & Canup 2011). The mass of such a disc is too small to form the Galilean satellites without a constant flow of material.

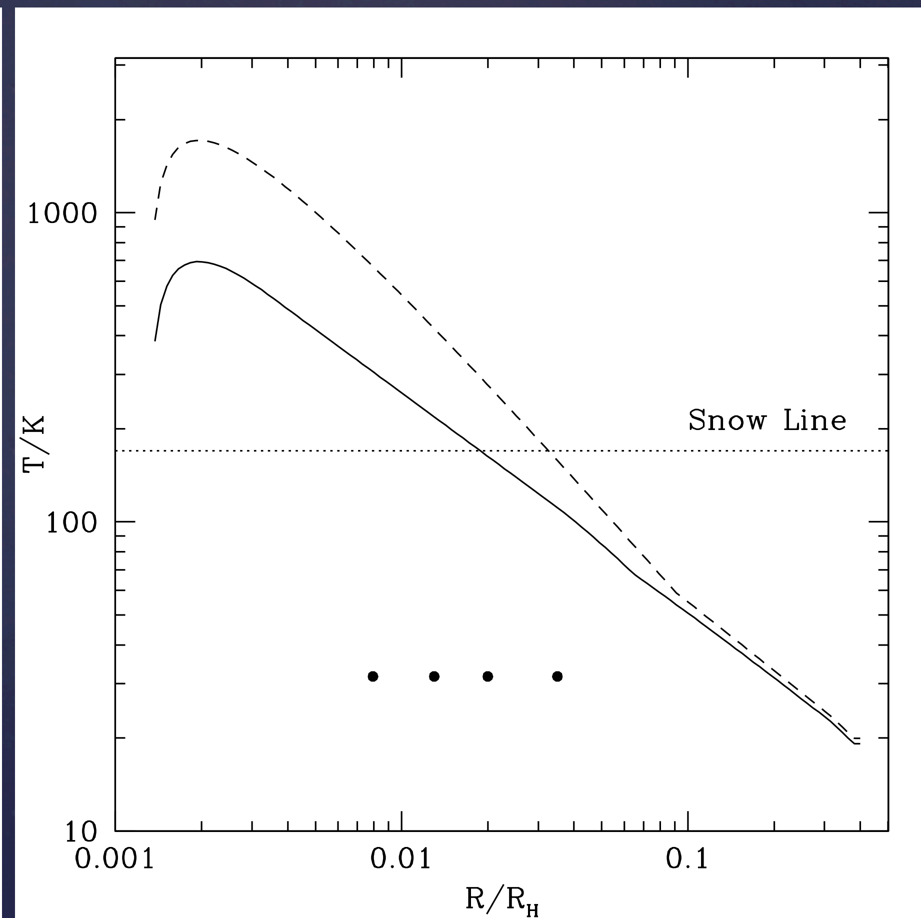
- With a dead zone model, when the disc is gravo-magneto unstable, the high temperatures do not allow the formation of icy satellites.

- Sattellites must form at later times when the accretion rate has dropped and the outbursts have finished. A dead zone may still be present.

Galilean Satellite Formation

The dead zone model can explain the compact satellite structure and allow the formation of icy satellites.





Lubow & Martin (2012, in press)

Conclusions

- The gravo-magneto instability can be explained with a state diagram that plots the accretion rate against the surface density.
- The instability can explain FU Orionis outbursts.
- Circumplanetary discs should also show outbursts from the gravo-magneto instability – a modification to the core accretion model.
- The dead zone provides a quiescent environment for both planet and satellite formation.
- The dead zone model for the Galilean satellites is cool enough to allow icy satellites and can explain why the satellites are all close to Jupiter.