Properties and evolution of massive thick gas disks

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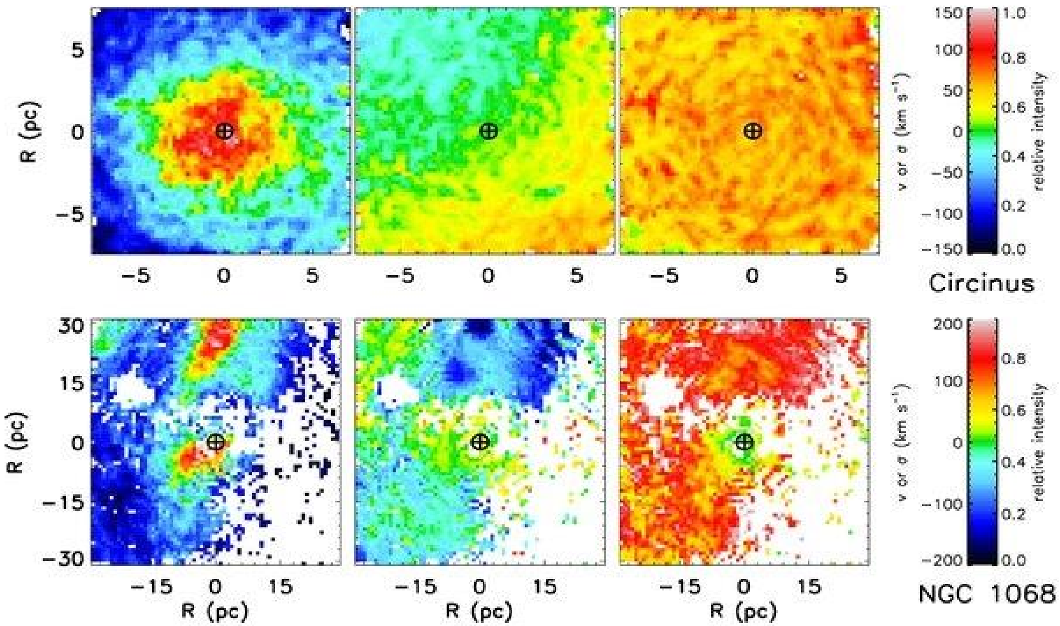
Massive thick gas disks

$R \sim 10\text{-}50$ pc

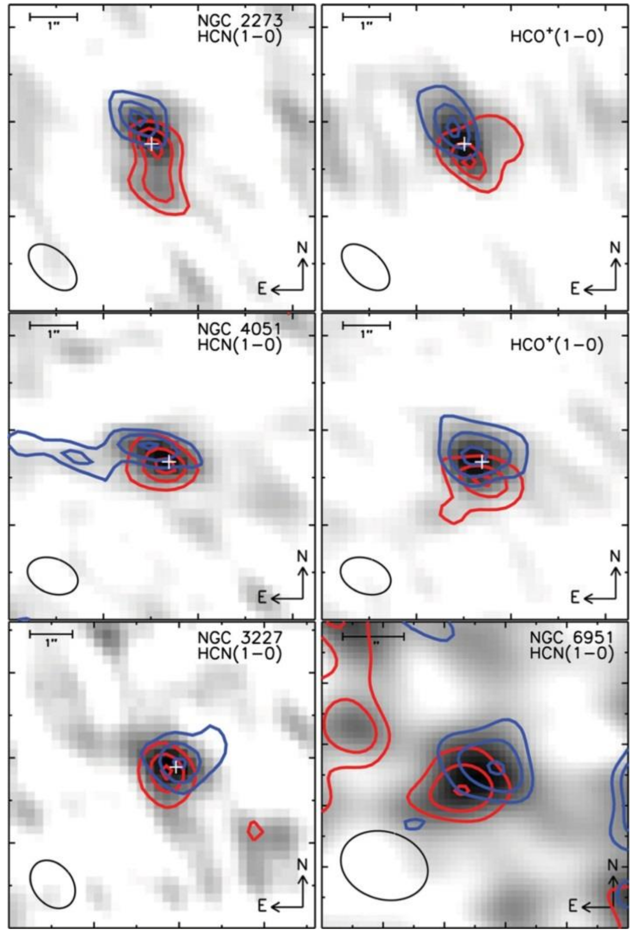
$M_{gas} \sim 10^6\text{-}10^7 M_{solar}$

$v_{turb} \sim 30\text{-}50$ km/sec

$\dot{M} \sim 1 M_{solar}$/yr



warm H_2 (Hicks et al. 2009)



sizes ~ 1¨ ~ 50-100 pc

HCN/HCO+ (Sani et al. 2012)

How to model massive thick gas disks

2 different **analytical** model classes for clumpy accretion disks:

Å **Collisional disks** (Krolik & Begelman 1988)

Energy injection through **external gas infall**

(Vollmer et al. 2004, 2008)

Å **Turbulent disks**

Energy injection to maintain turbulence:

- **external gas infall** (Vollmer & Davies 2013)
- SN explosions (Vollmer & Beckert 2003)

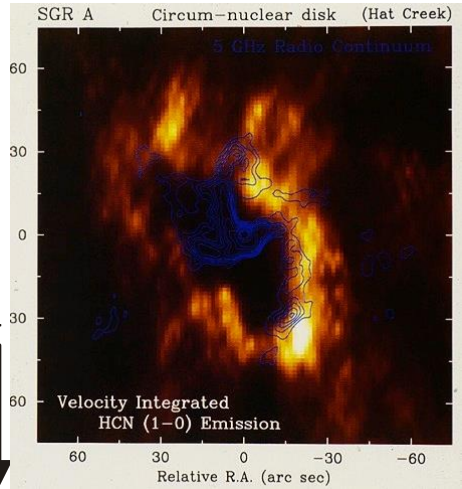
Modelling of a clumpy circumnuclear disk

(picture of Krolik & Begelman 1988)

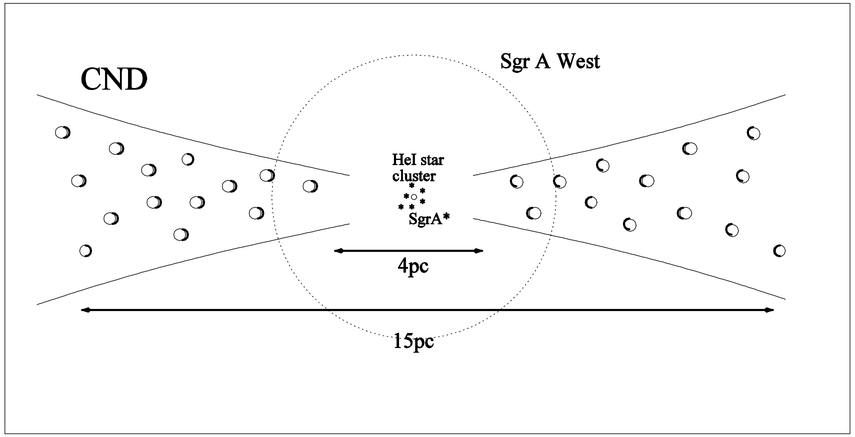
Large scale

Small scale

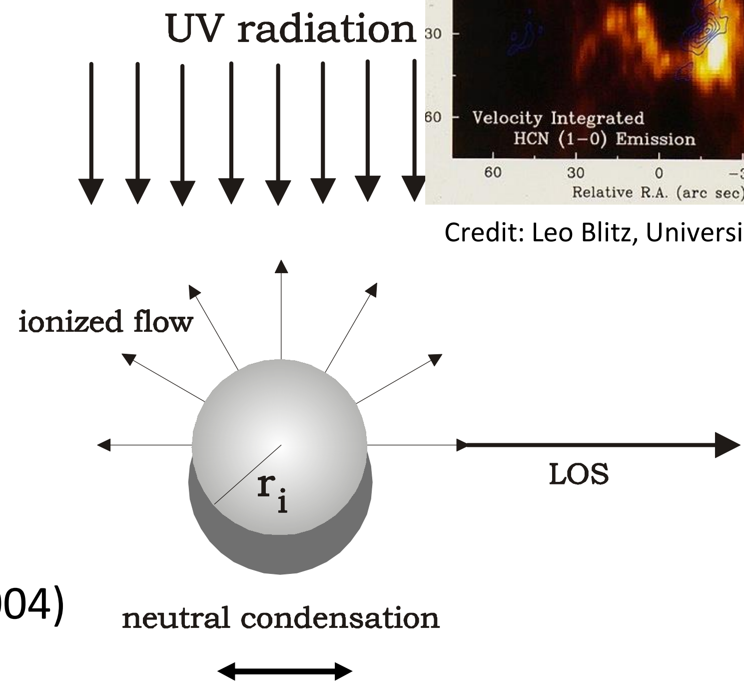
CND Galactic Center



Credit: Leo Blitz, University of Maryland



15 pc



0.1 pc

Galactic Center CND:

Vollmer & Duschl (2001a, b); Vollmer et al. (2004)

AGN gas disks:

Vollmer et al. (2008)

Collisional gas disks: Basic equations I

Large scale:

Å Angular momentum equation:

$\nu\Sigma=-\dot{M}/(2\pi R)\Omega/\Omega'$; mass accretion rate $\dot{M}$

Å Vertical pressure equilibrium:

$\rho v_{turb}{}^2=\pi G\Sigma^2$ or $\Sigma(d\Phi/dz)$

Å Gas surface density: $\Sigma=\rho H$

Å **Toomre Q**$=(v_{turb}\Omega)/(\pi G\Sigma)=$const.

Å Energy flux conservation:

$(\Delta E)/(\Delta t\Delta A)=\xi\dot{\Sigma}_*$ or $(2\pi R)^{-1}M\dot{\Omega}/\Omega'$

Collisional gas disks:
Basic equations II

Small scale:

Å Cloud size l_{cl} -> **selfgravitating clouds**

Å Volume filling factor: $\Phi_V=\rho/\rho_{cl}$

Å Area filling factor: $\Phi_A=\Sigma/\Sigma_{cl}$ -> **transparency**

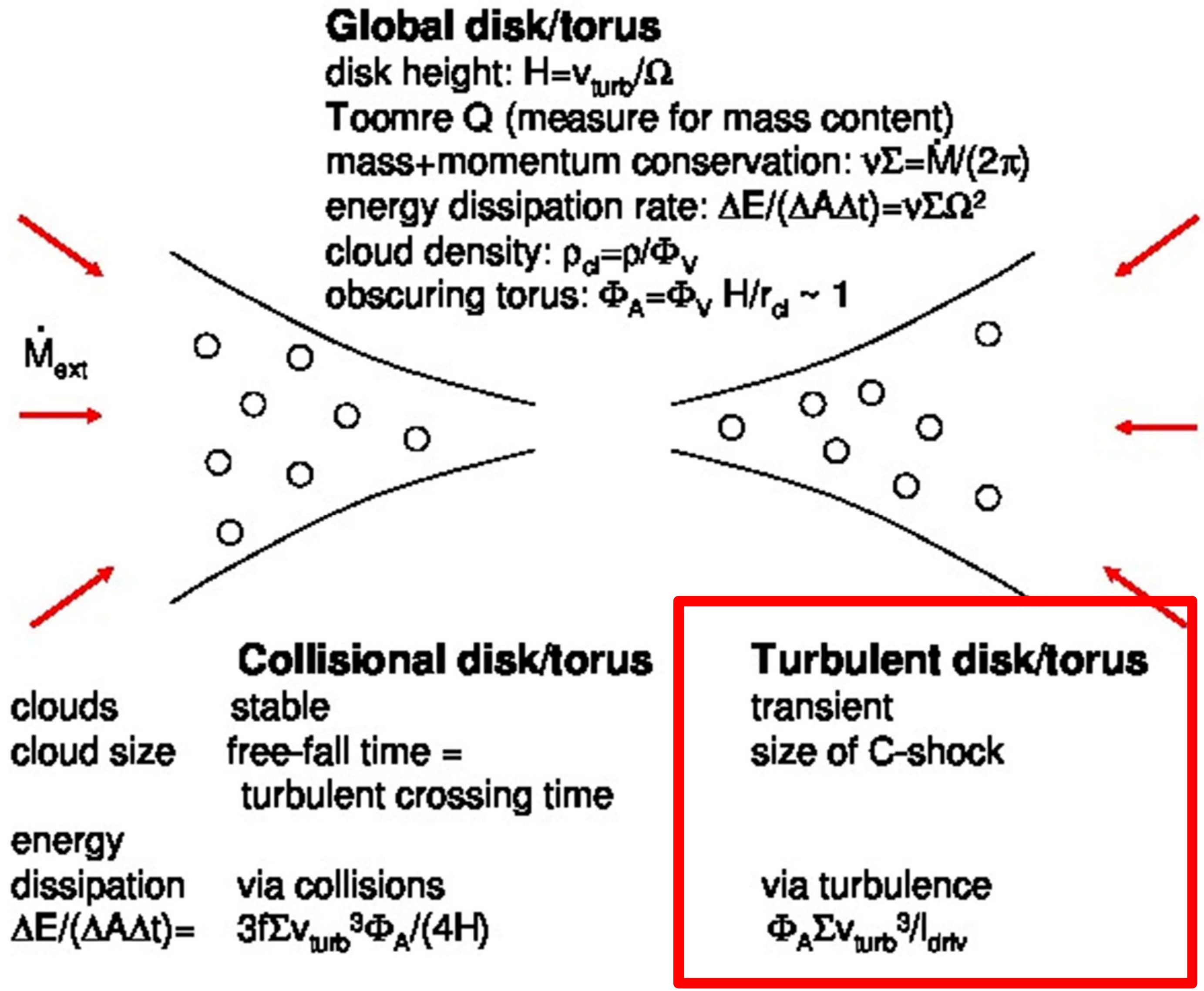
Å Fixed sound speed and cloud mass ~10 M_{solar}

Å Gas viscosity depends on cloud properties

Å (Star formation rate: $\dot{\rho}_* \alpha\ \rho/t_{coll}$)

From collisional to turbulent gas disks

Vollmer & Davies (2013)



Properties of the massive turbulent thick gas disk

Alfvén velocity	v_A	1	km s^{-1}
torus radius	R	5	pc
torus gas mass	M_{torus}	1.2×10^6	$M_\odot$
rotation velocity	v_{rot}	110	km s^{-1}
torus velocity dispersion	v_{turb}	50	km s^{-1}
Toomre parameter	Q	5	
torus height	H	2.27	pc
Mass accretion rate	$\dot{M}$	0.2–4.8	$M_\odot$ yr^{-1}
Cloud area filling factor	Φ_A	0.41	
cloud volume filling factor	Φ_V	0.014	
cloud mass	M_{cl}	115	$M_\odot$
cloud size	l_{cl}	0.08	pc
cloud velocity dispersion	v_{cl}	6	km s^{-1}
cloud density	ρ_{cl}	9×10^6	cm^{-3}
cloud column density	N_{cl}	2×10^{24}	cm^{-2}

Turbulent versus collisional model

turbulent

Å Cloud column density, density decrease with distance

Å Area filling factor decreases with radius

Å Clouds at the inner edge obscure central engine

Å High mass accretion rates

Å Gas clouds are overpressured

collisional

Å Cloud properties independent of distance

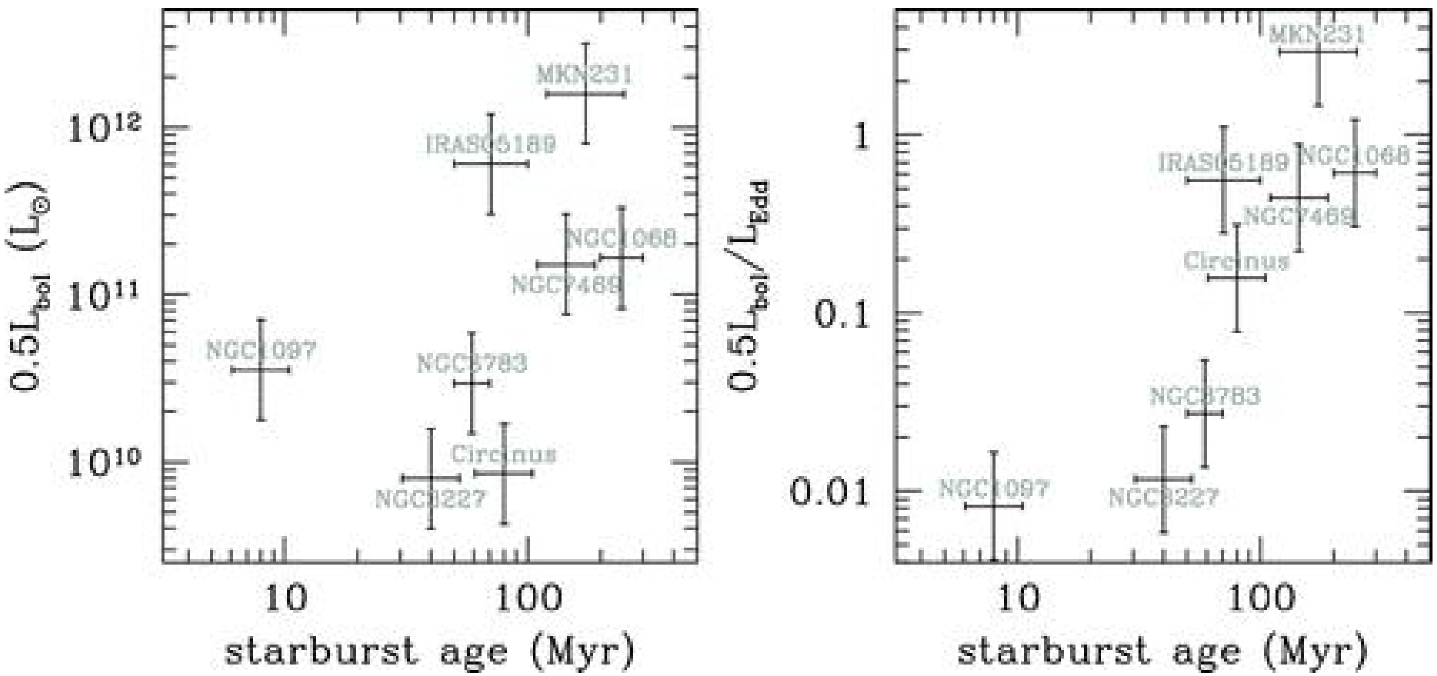
Å Constant area filling factor

Å All clouds can obscure central engine

Å Lower mass accretion rate

Å Gas clouds are selfgravitating

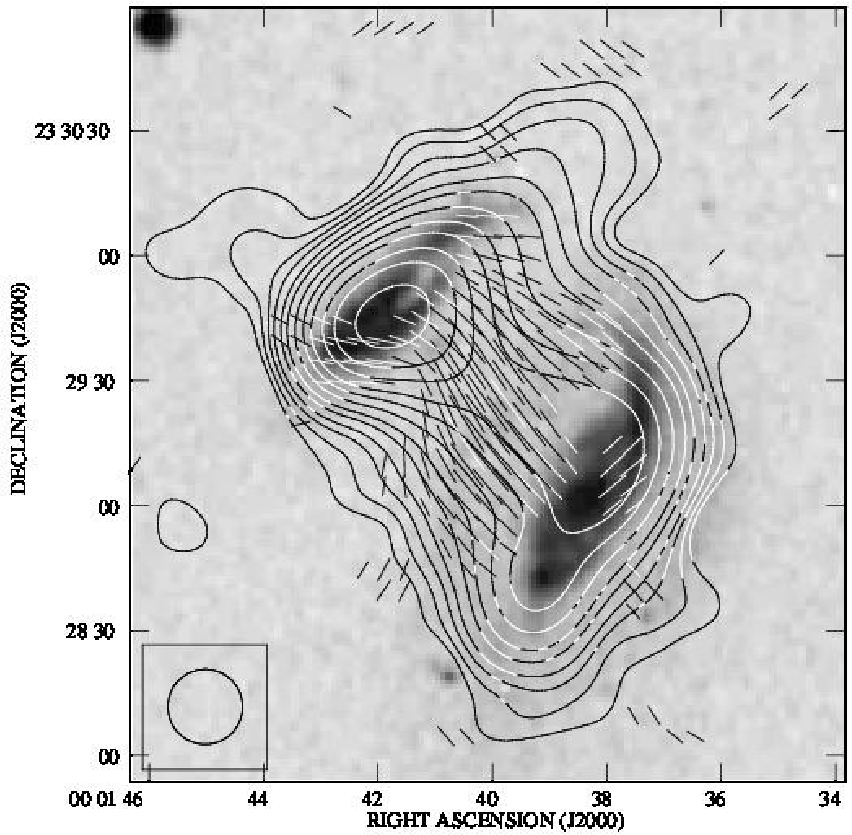
Why do these disks not produce violent starbursts?



Davies et al. (2007)

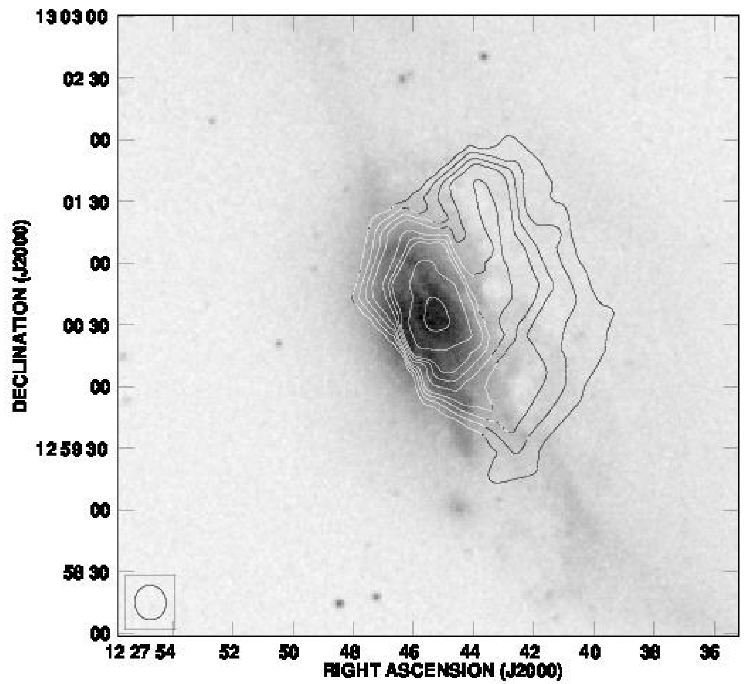
Adiabatic compression through ISM-ISM collisions

Taffy galaxies



Radio continuum: Condon et al. (1993), Vollmer et al. (2012)

NGC 4438 (Virgo cluster)



CO: Vollmer et al. (2005, 2009)

The evolution of gas disks

turbulent

Å Phase I: light gas disk; low mass accretion rate makes gas mass grow slowly

Å Phase II: massive gas disk with $\dot{M}_{infall} > \dot{M}$; adiabatic compression; thick disk with suppressed star formation

Å Phase III: $\dot{M}_{infall} < \dot{M}$; turbulent massive thin disk (Q~1) -> starburst

collisional

Å Phase I: turbulent massive thin disk (Q~1) -> starburst

Å Phase II: at constant mass accretion rate and turbulent velocity

Å Phase III: at constant gas mass with decreasing mass accretion rate, disk becomes thin

What can a massive thick disk do for you?

- Obscuration of the central engine (vertical disk stratification)
- High mass accretion rates (~ 1 M_{solar}/yr)
- No violent starburst
- Viscous heating leads to T ~ few 100 K at high densities
- Compton-thick reflector at inner edge (~ 1 pc)
- Transition to thin maser disk at R < 1 pc
- Necessity of a molecular/dusty wind/outflow to remove angular momentum and mass ->

  decrease of the mass accretion rate toward the center