Molecular gas flows in galaxies

Outline:

➔Angular momentum transfers

➔Bar destruction, role of gas, of DM

➔Cold gas accretion

➔AGN fueling and feedbacks

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Garching, *10 September 2007*

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Angular Momentum transfers

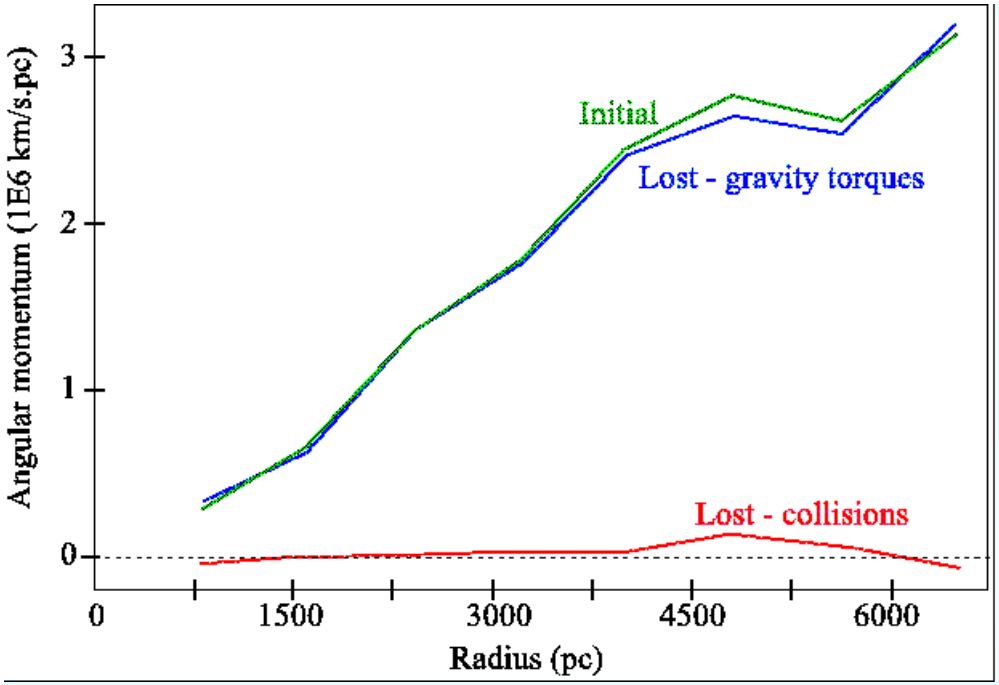
➔The angular momentum (AM) is created by tidal torques between structures at early times, before turn-around $\lambda = J\,|E|^{1/2}/GM^{5/2} \sim 0.035$

➔Same for DM and baryons, but then baryons dissipate and collapse deeper inside haloes

➔In mergers, AM is lost from baryons to the DM haloes
But the haloes have not more AM (mass is lost through the virial radius, D'onghia et al 2007)

➔In secular evolution also: AM transfer from baryons to DM (Athanassoula 2002, 2003)

➔If saturated (already rotating halo or bulge), AM is exchanged with the outer disk and gas
Depends on the amount of DM inside the visible disk



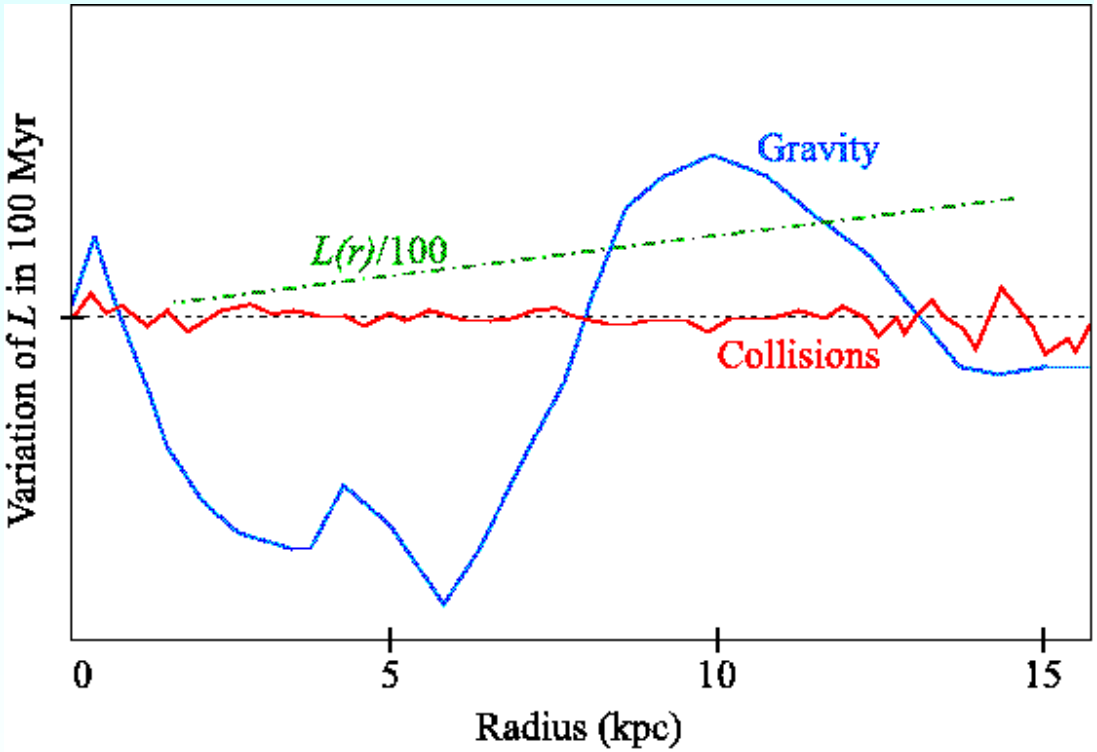
Viscous and gravity torques

The AM lost by the gas is comparable to the AM of the bar wave

The gas loses its AM through gravity torques

Viscous torques are in general negligible

(Bournaud & Combes 04)



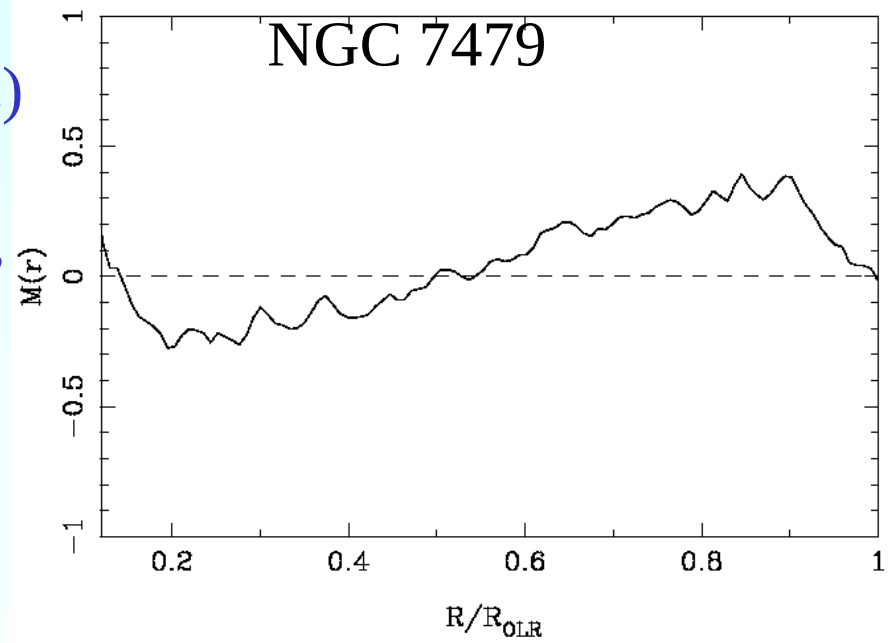
Bar gravity torques

concentrate mass towards the center

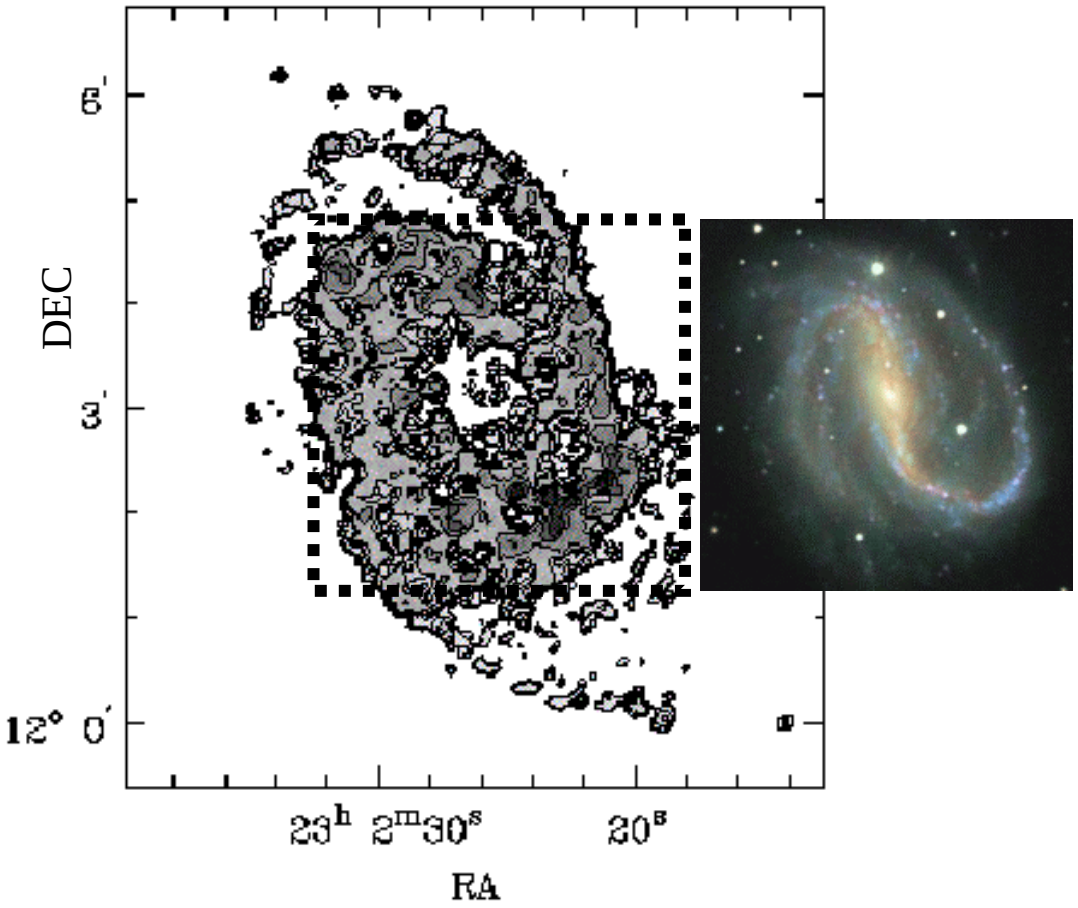
Rate quantified by observations

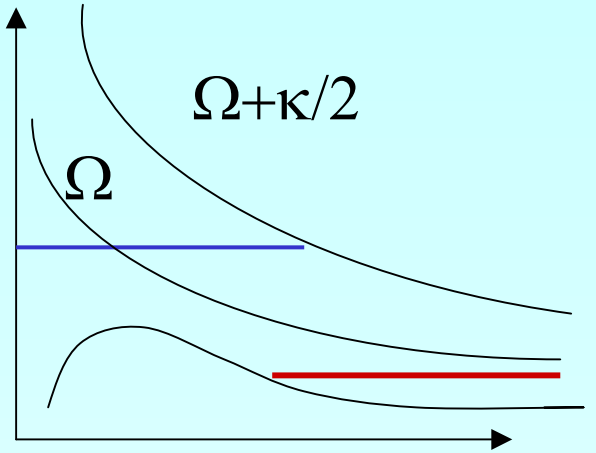
Computations of the torque from the red image, on the gas distribution (Hα)

Action on the gas: sign of the torques, depending on the phase shift between gas and stellar potential
Exemple NGC 7479

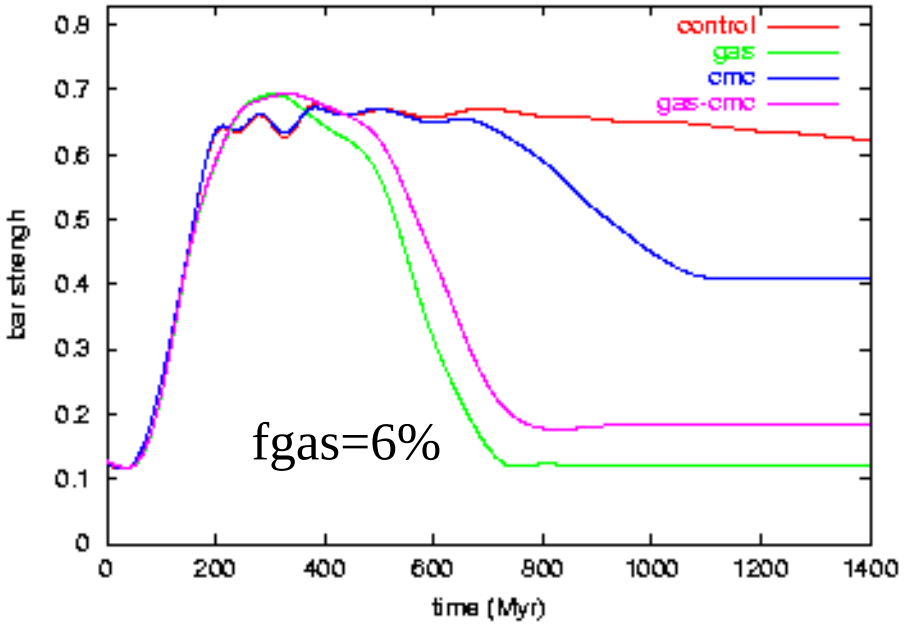


Gas at large scale?





Bar destruction by gas



With negligible DM

Gas is driven in by the bar torques
The angular momentum is **taken up by the bar wave**

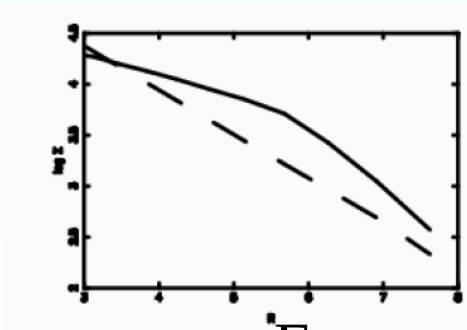
➔ **This destroys the bar**
negative momentum inside CR, ~ A_2 (Ω_b-Ω)
The gas AM from CR to center is of the same order

Not only the presence of the Central Mass Concentration
A CMC of only 1% is not sufficient to destroy the bar
(Shen & Sellwood 2004, Athanassoula et al 2005,
but Hozumi & Hernquist 2005)
But 1-2% of gas infall is enough to transform a bar in a lens
(Friedli 1994, Berentzen et al 1998, Bournaud & Combes 02, 04)

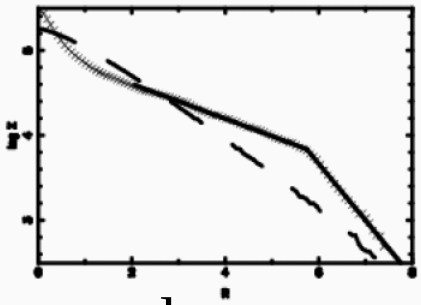
Secular evolution with gas

Effect of gas depends on the cooling:
Isothermal (RC) or adiabatic (A) behaviours
Debattista et al (2006)

Breaks in the density profiles
Consequence of AM exchange
Outer and inner disks breaks
(Pohlen 2002, 79% of galaxies)

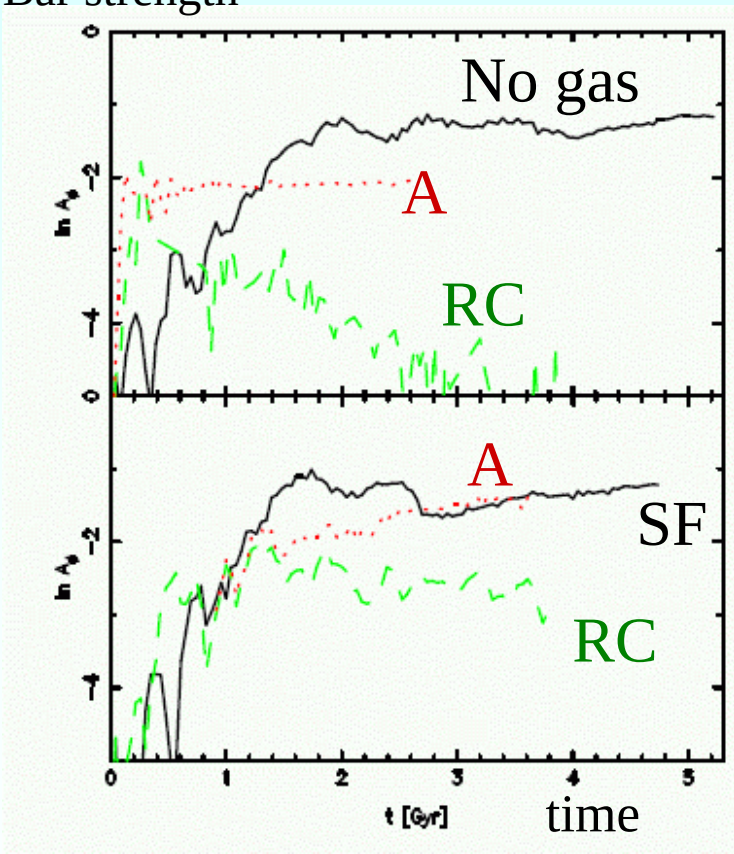


Face-on



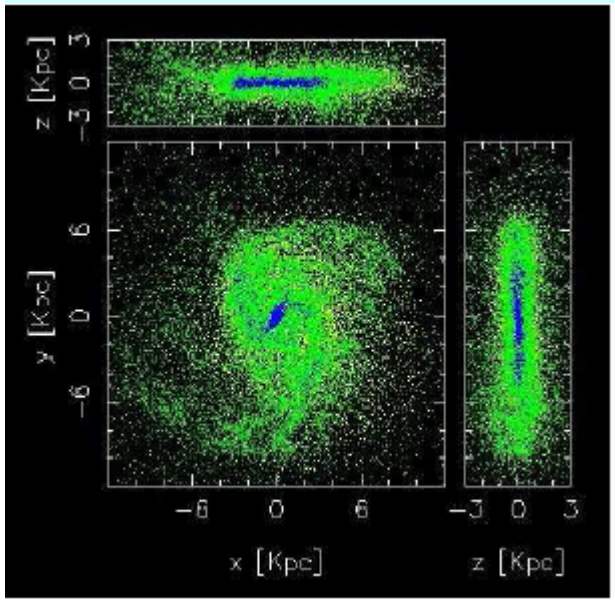
edge-on

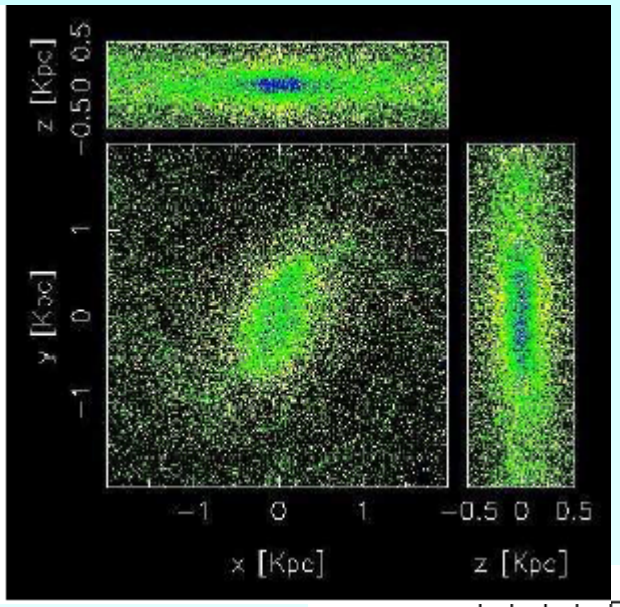
Bar strength



time

Formation in a cosmological context

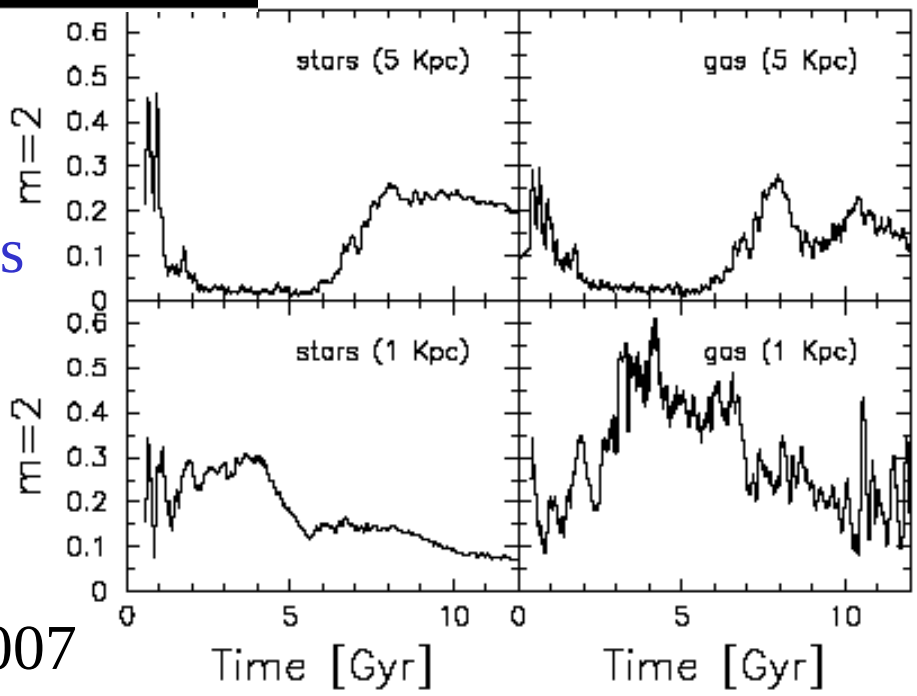




Bars form,
destroy and reform

Gas flows, and accretion

Influence of isothermal/adiabatic gas
Star formation and feedback, etc..



Heller, Shlosman & Athanassoula 2007

Reformation of bars

Self-regulated cycle:

➔Formation of a bar in a cold unstable disk

➔Bar produces gas inflow, and

➔Gas inflow destroys the bar

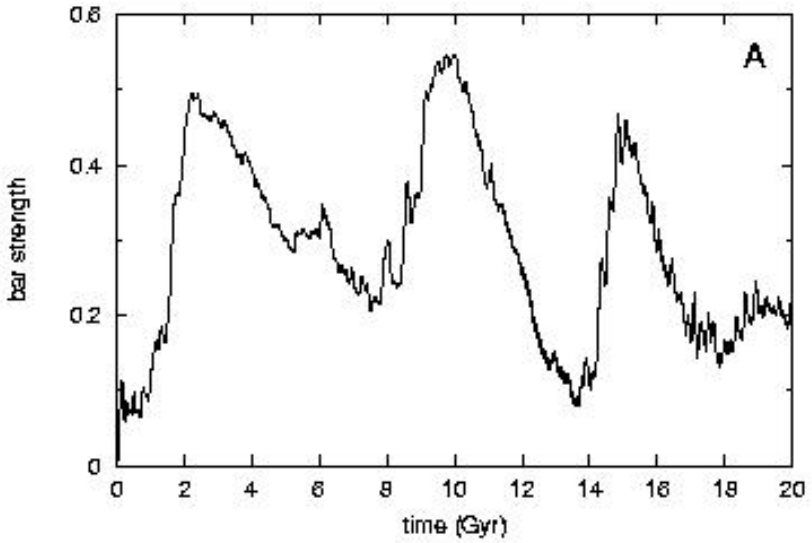
+gas accretion

Gas accretes by intermittence

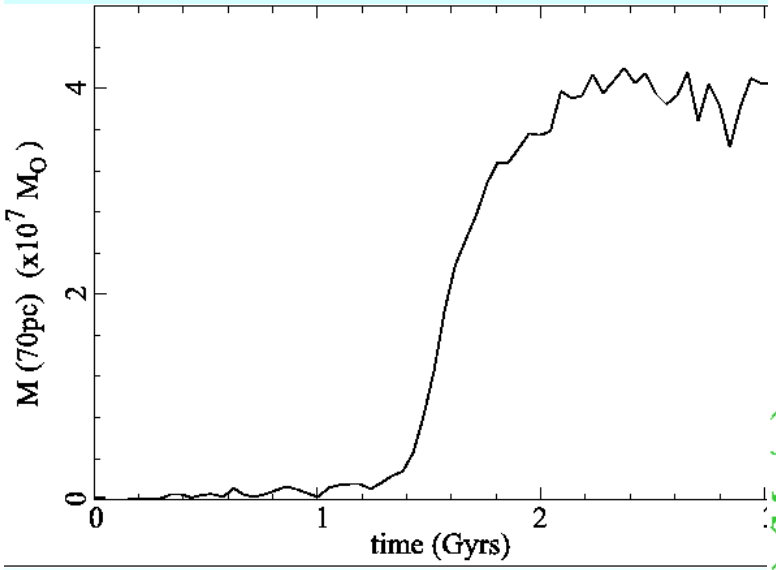
First it is confined

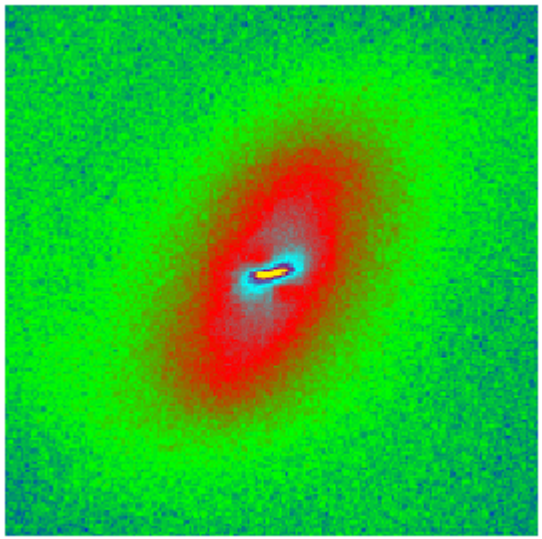
outside OLR until the bar weakens,

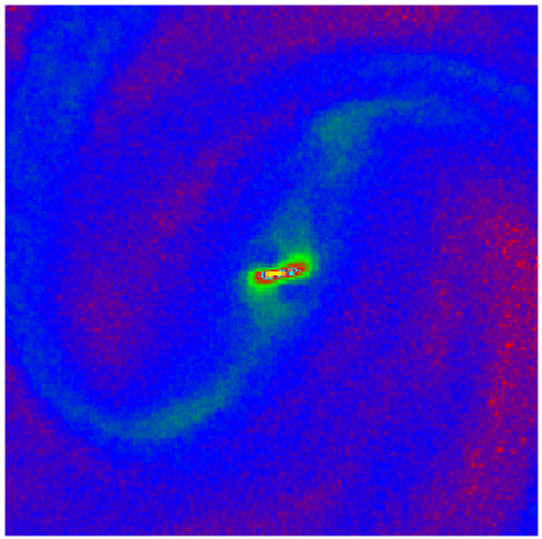
then it can replenish the disk, to make it unstable again to bar formation



Inflow with two embedded bars: **AGN fueling**

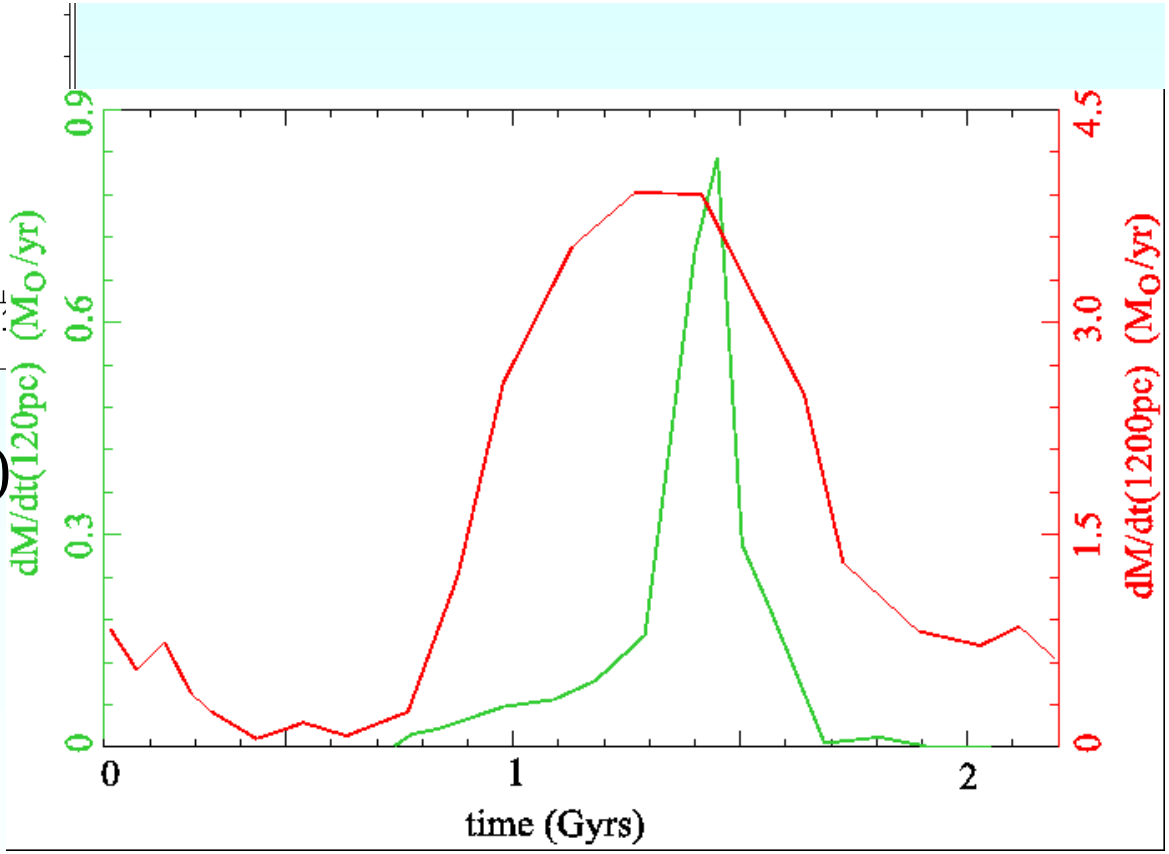






Cumulated gas inflow (70pc)

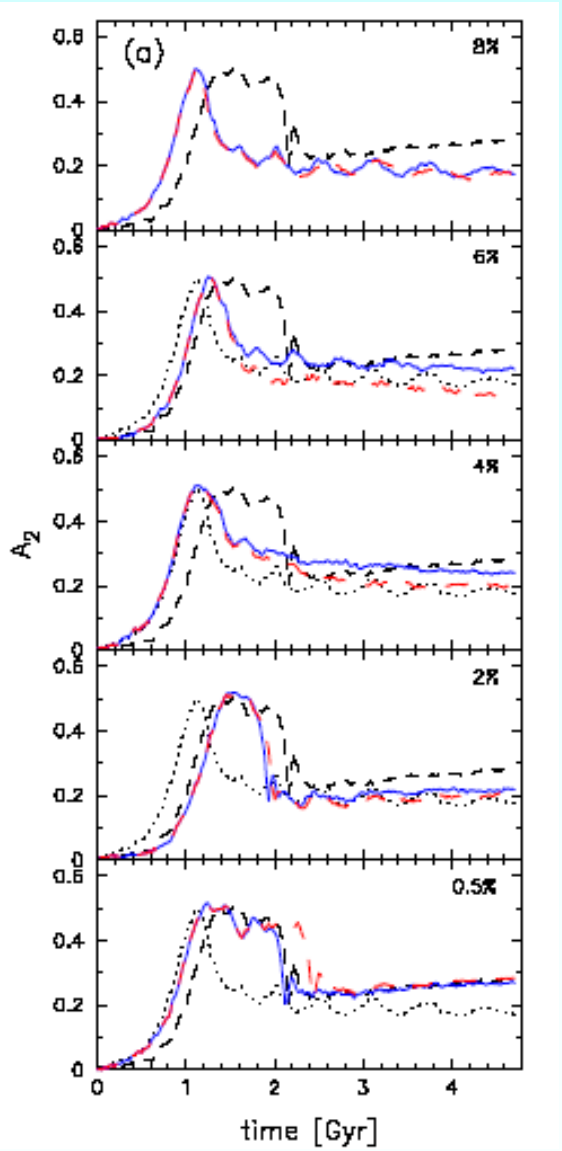
Inflow rate in 20pc and in 200pc



Low importance of AM transfers with gas

Transfer to DM more important (fgas < 8%)

Berentzen et al 2007

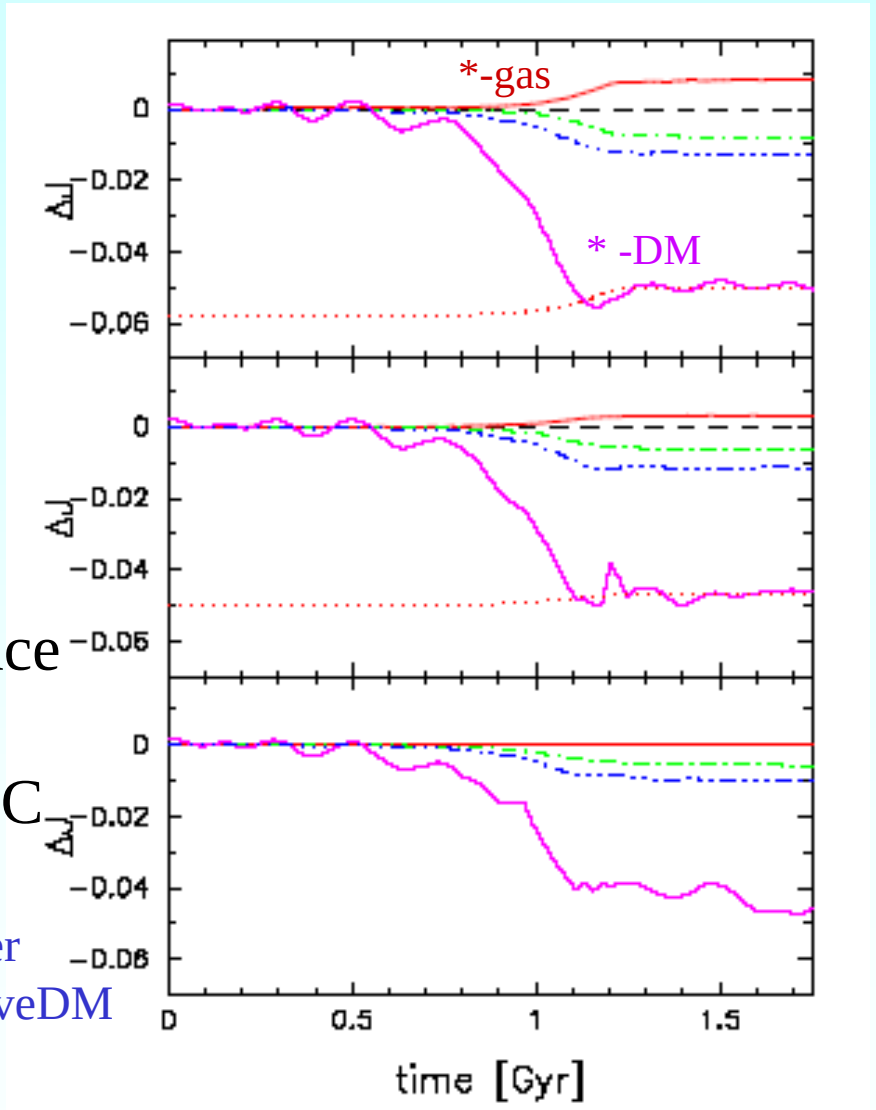


However,
bar destroys
more quickly
with gas

Interpreted as
a function of
destruction of
vertical resonance

Help of the CMC

Fgas should be higher
In presence of massiveDM

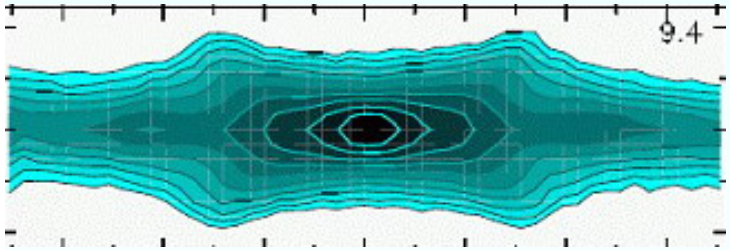


Gas prevents peanuts

The vertical instability is a factor of bar weakening

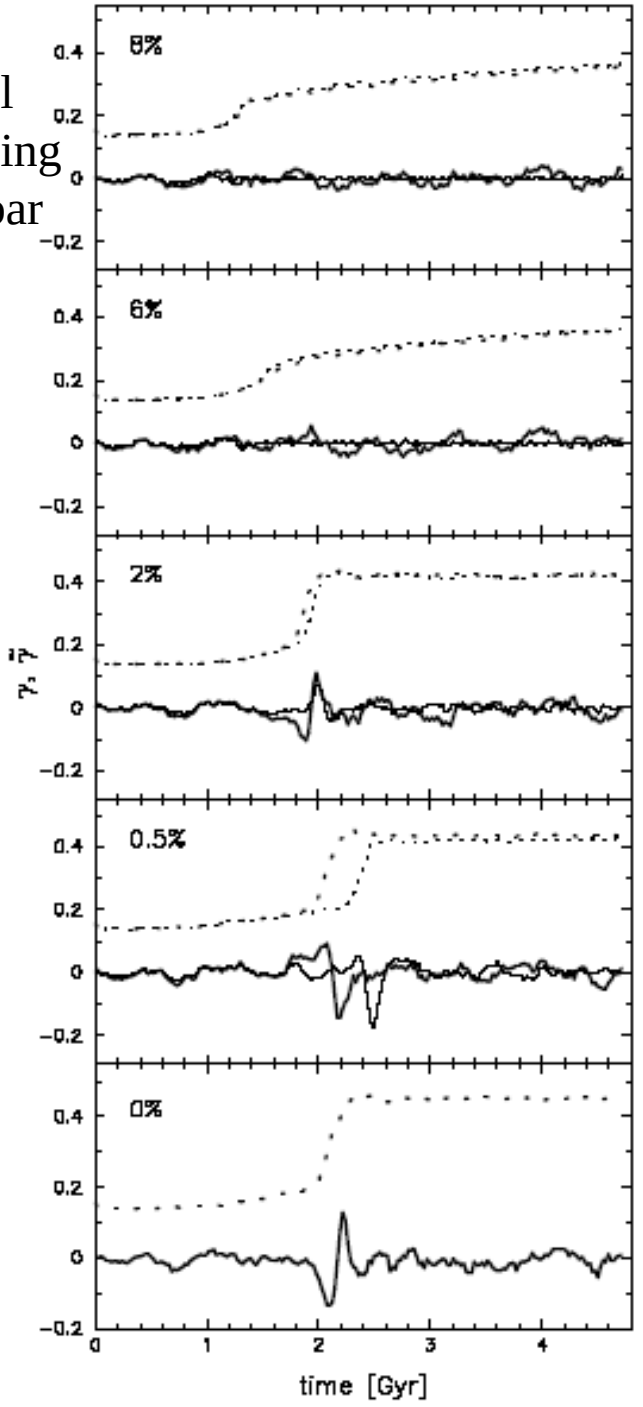
With gas, more chaotic orbits and role of CMC

Stops the effect of vertical resonance



Berentzen et al 2007

Vertical thickening of the bar



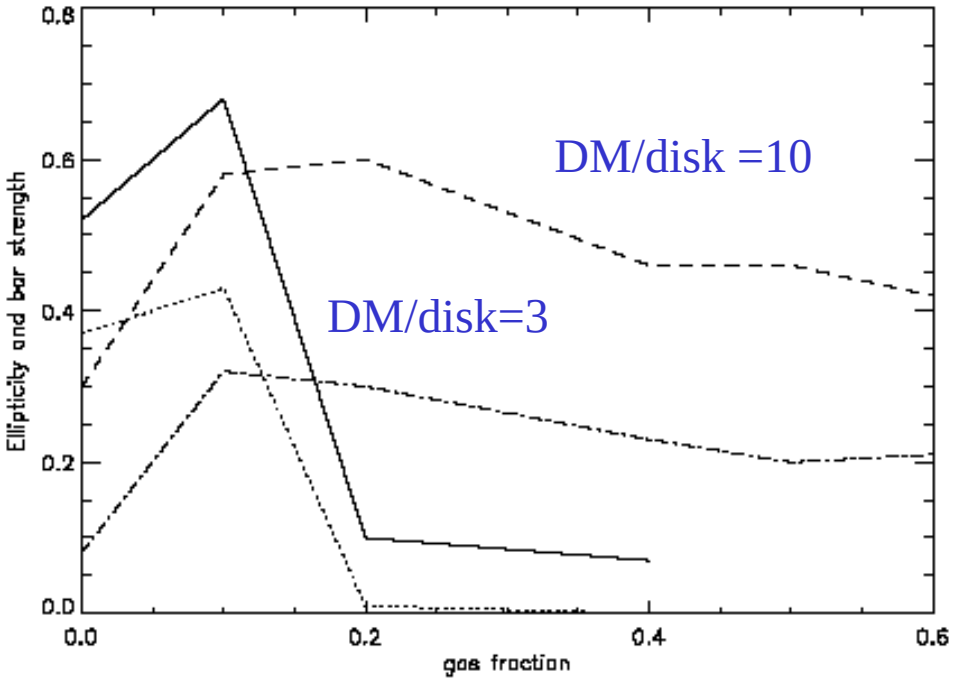
Gas threshold to destroy the bar

Fraction of gas able to destroy the bar: **depends on the DM/disk ratio**

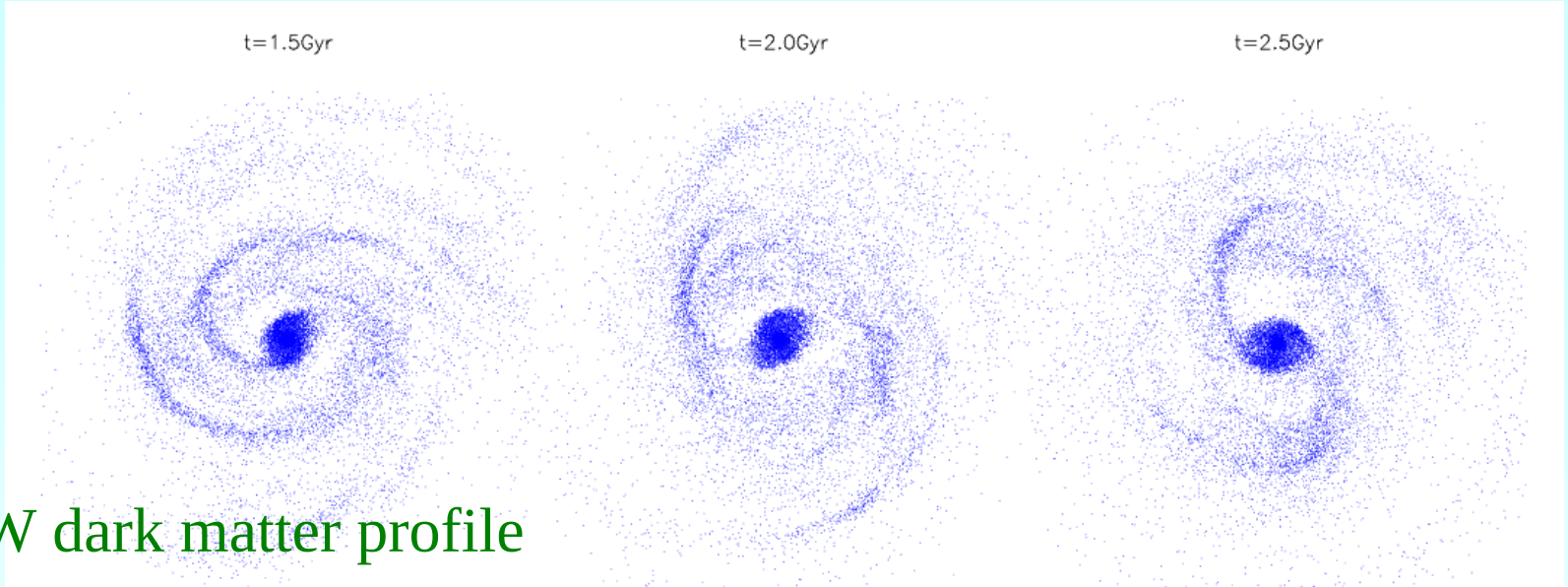
It is 0.2, when DM/disk = 3 (Curir et al 2007)

When the DM halo mass
is negligible within the disk

Fgas ~ 6%

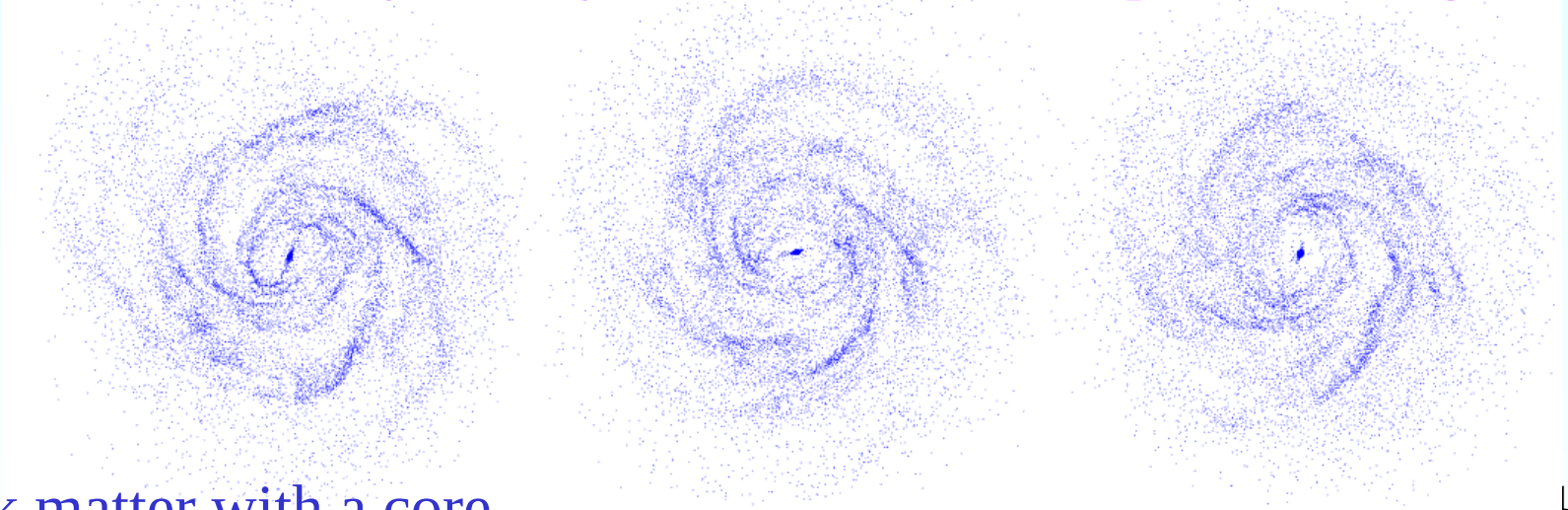


Influence of the central potential on gas flows



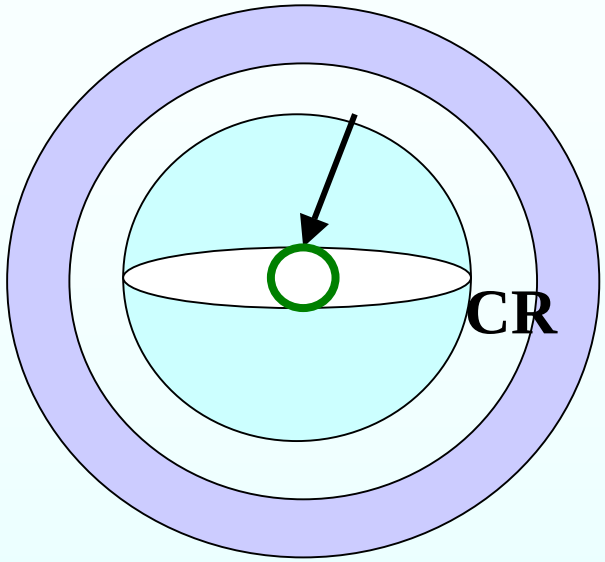
NFW dark matter profile

More axisymmetry in the center ➔ stops the inner gas flow



Dark matter with a core

Gas flows and AGN/SB feedback



Bar torques ➔ gas inflow inside CR
➔ bar destruction
➔ gas inflow from OLR & inside ILR

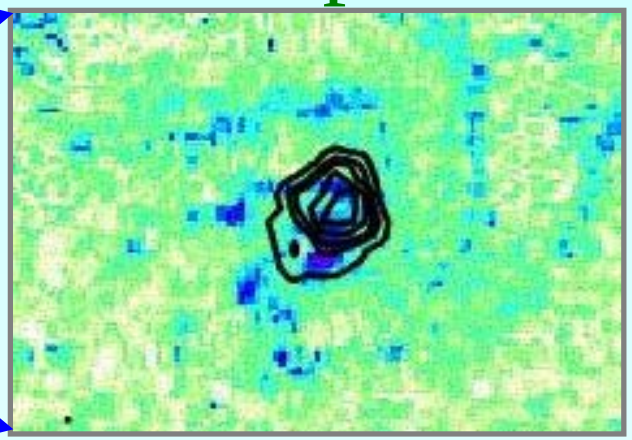
At each cycle, Starburst in inner rings, AGN fueling

NUGA observations: ➔The AGN fueling phase is very short

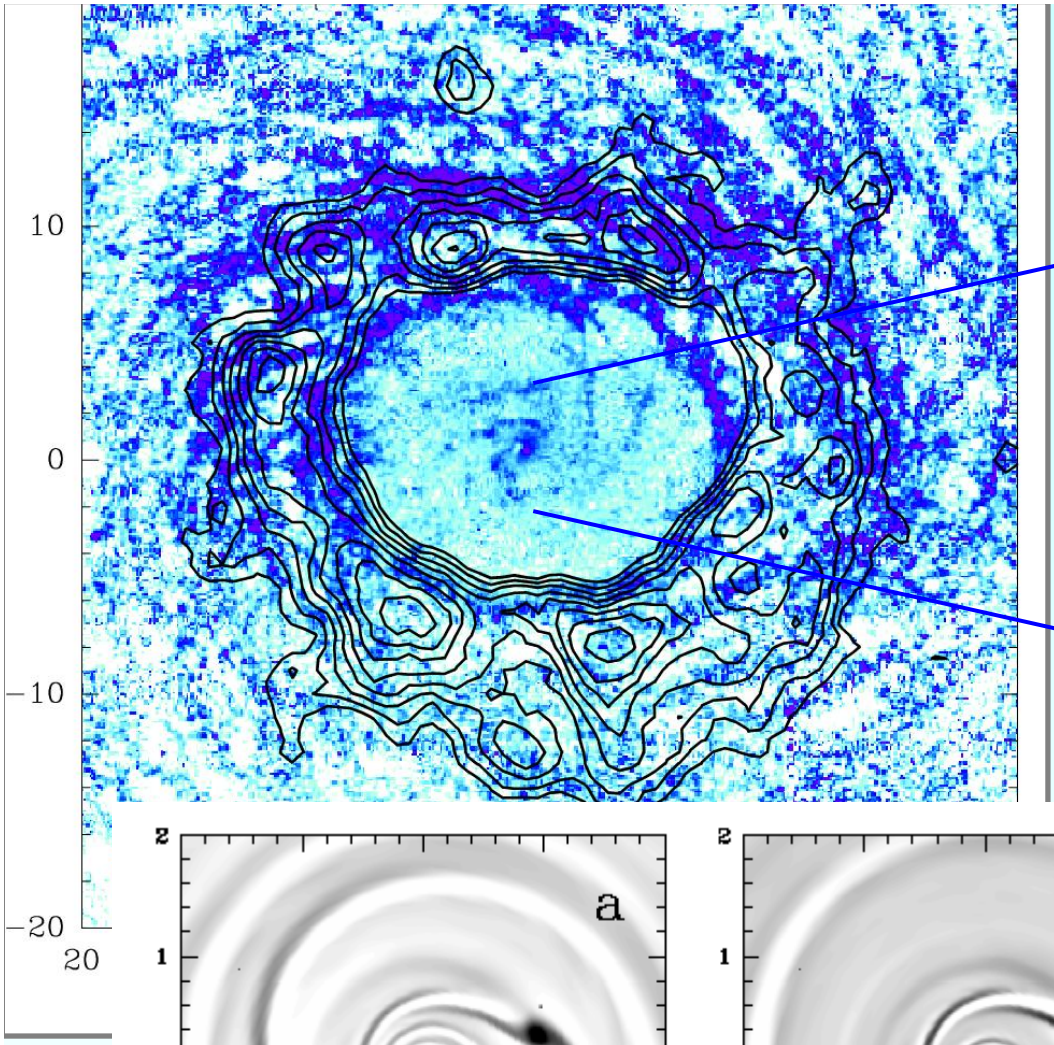
Also a feedback coming from energy of starburst
+simple rebound parameter in collisions $\beta = V_{after}/V_{before}$

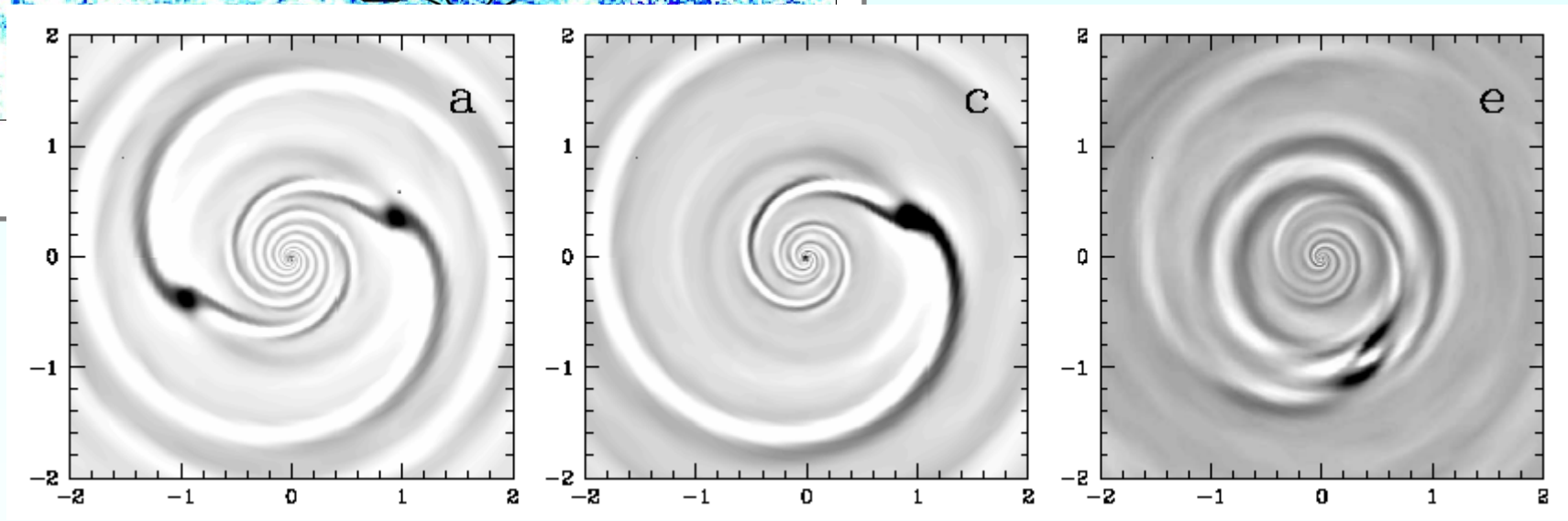
many influent parameters: mass loss from stars,
Recycling: instantaneous or not

Driven Gas nuclear spirals



NGC 7217, HST dust spiral





Etherington & Maciejewski (2006)

CONCLUSION

➔ Secular evolution plays a fundamental role, in the **fueling of SB, AGN, and bulge formation**

➔ Requires « diffuse » **cold gas accretion**, from cosmic filaments

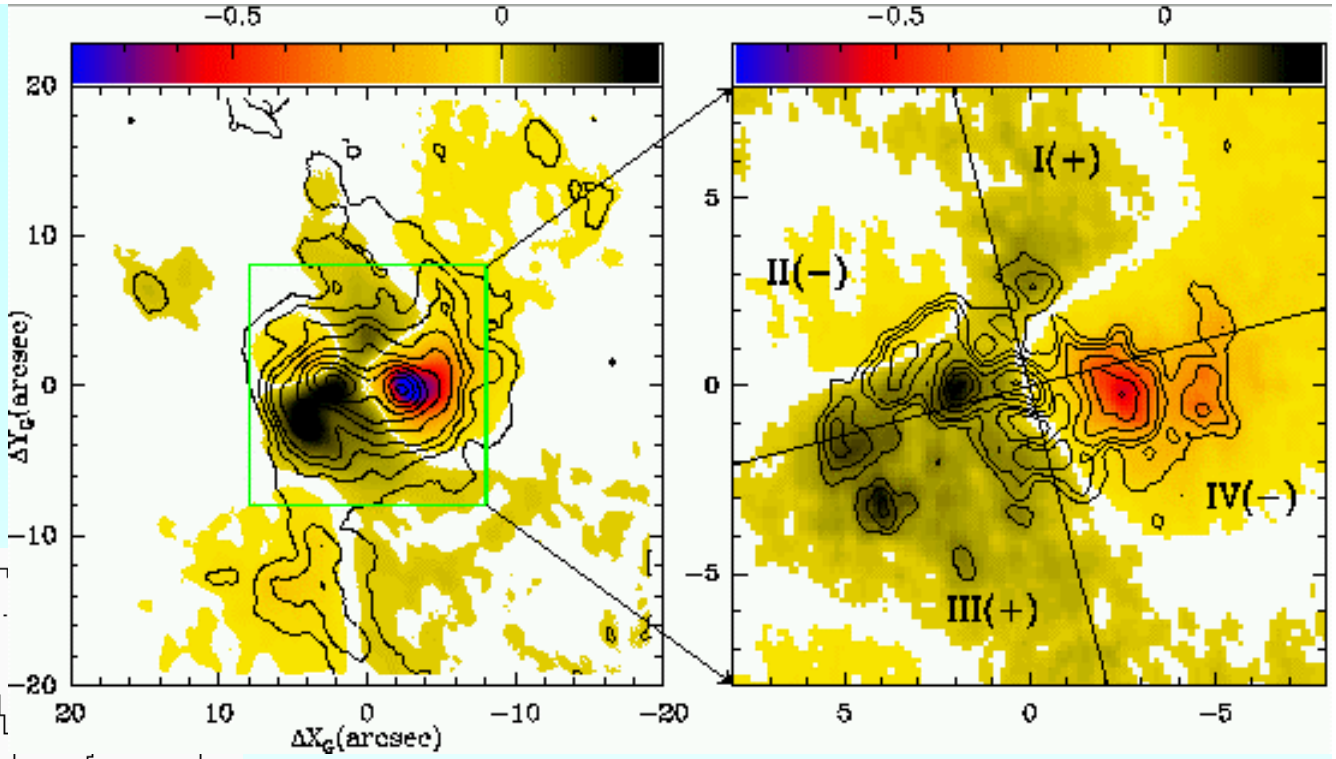
➔ Angular momentum transfer with DM or with outer disk according to mass ratio, saturation, kinematics

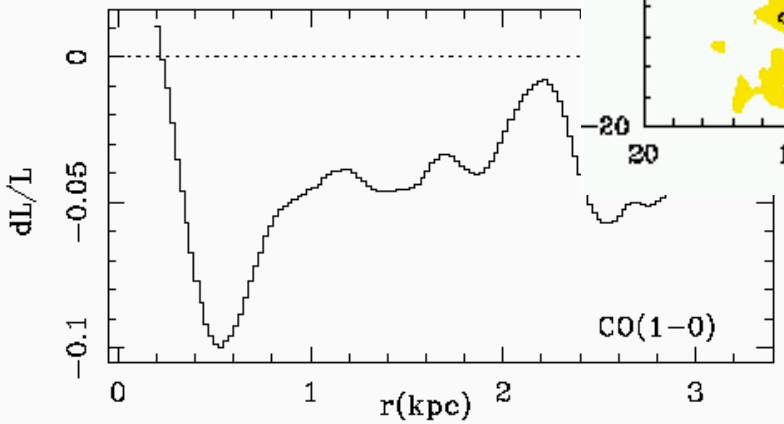
➔ Gas fraction able to destroy bars depend on the DM/disk ratio

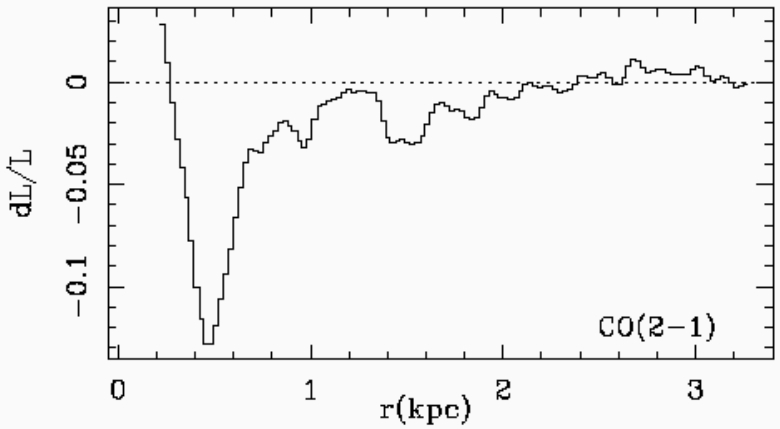
➔Bars trigger gas flows in galaxy interactions and mergers
Starbursts are more efficient with retrograde orbits

➔ *Gas flows and bar strength depend on orbital chaos, DM fraction, gas fraction, vertical feedback (peanut), etc..*

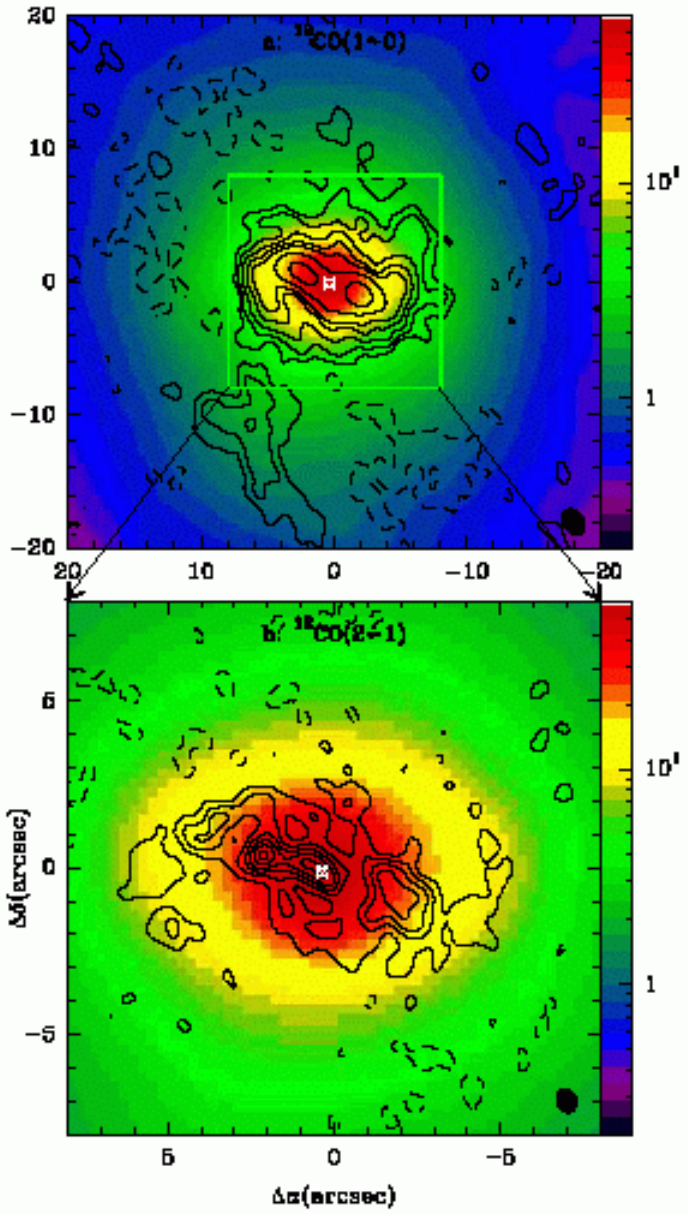
NGC 2782: torques

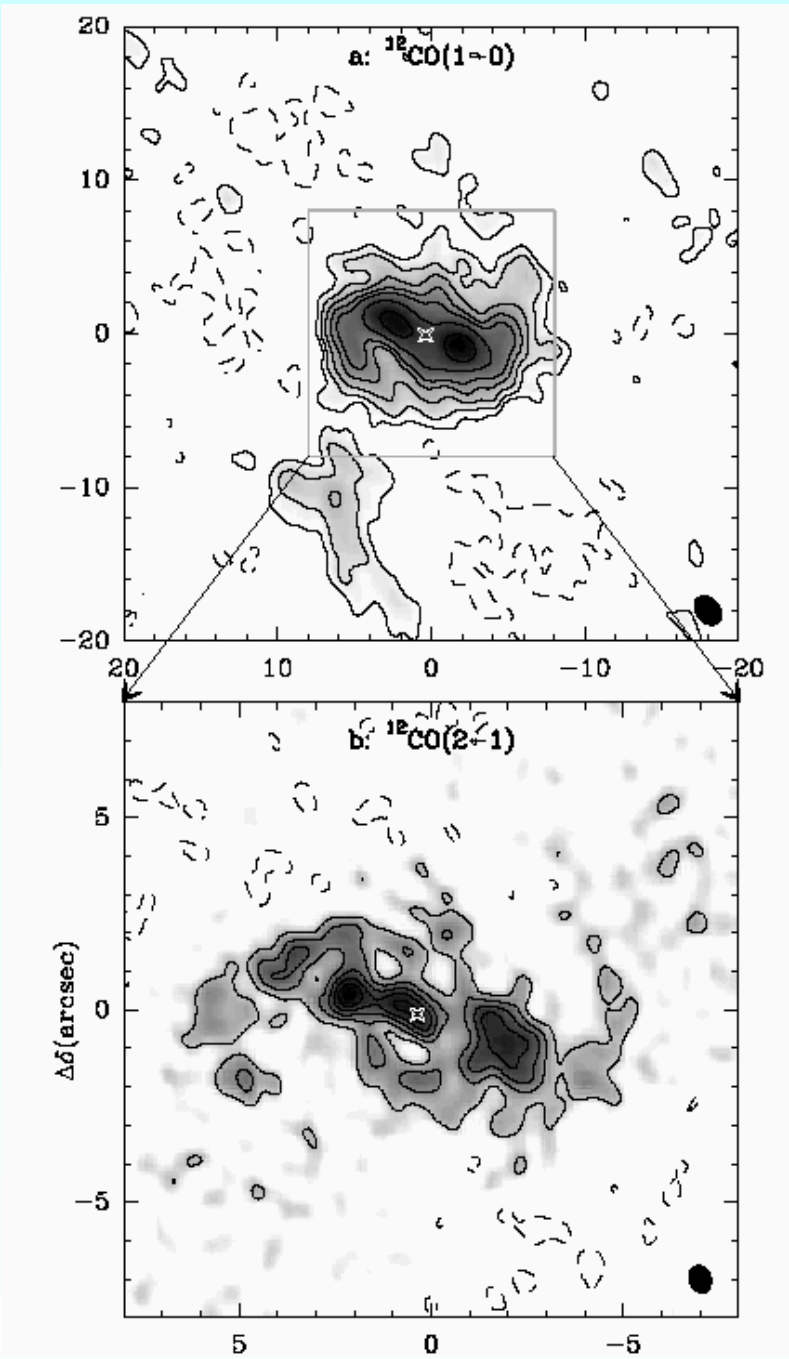




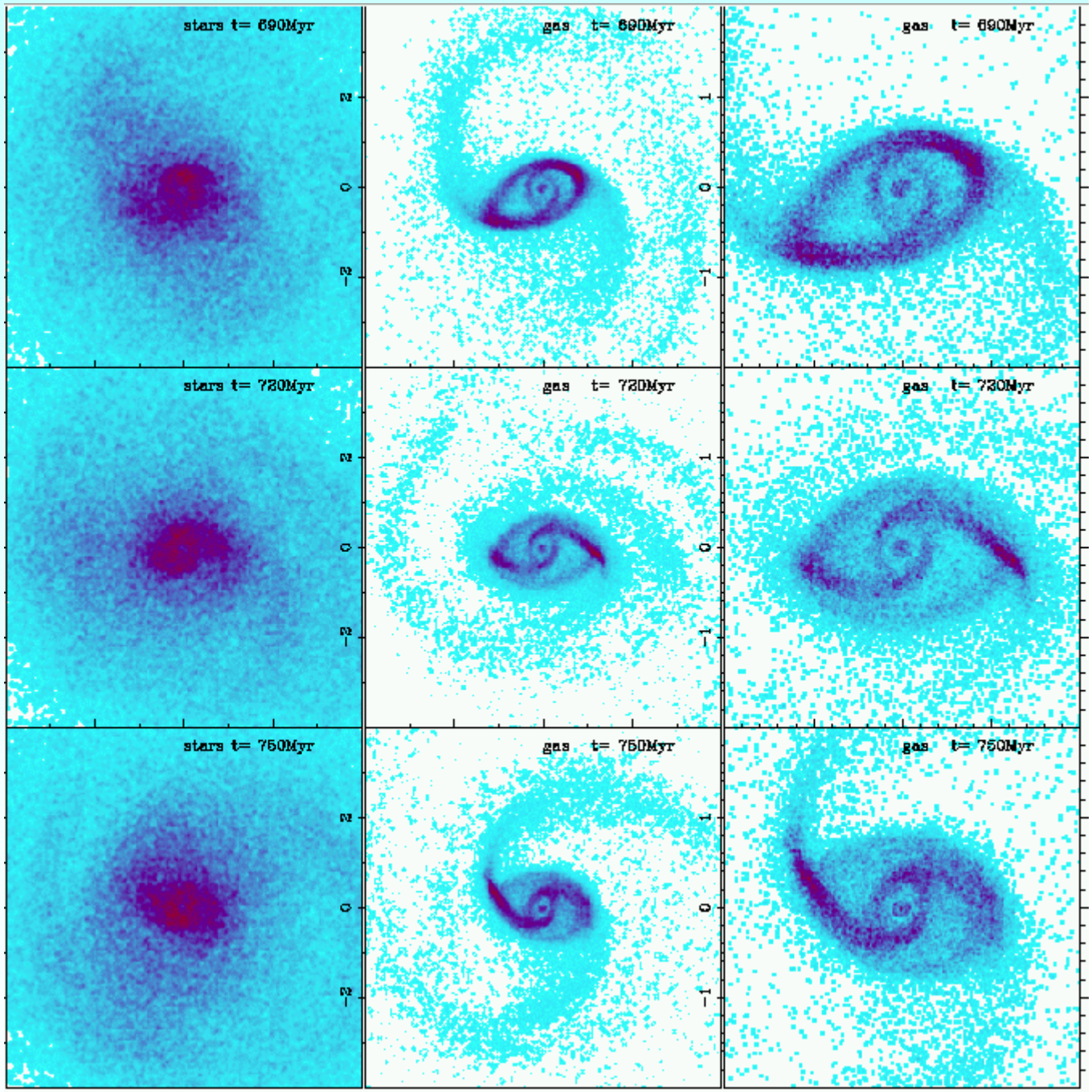


N2782: double bar





N2782: model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gas t= 690Myr
gas t= 690Myr
stars t= 720Myr
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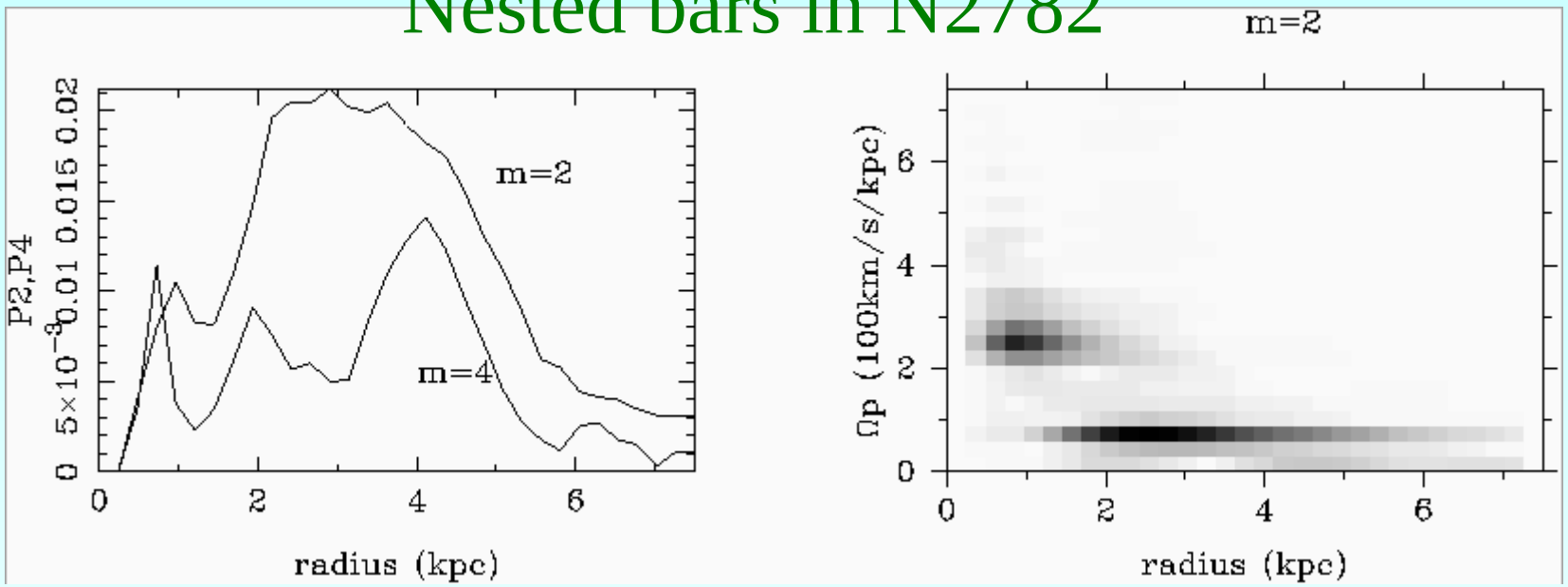
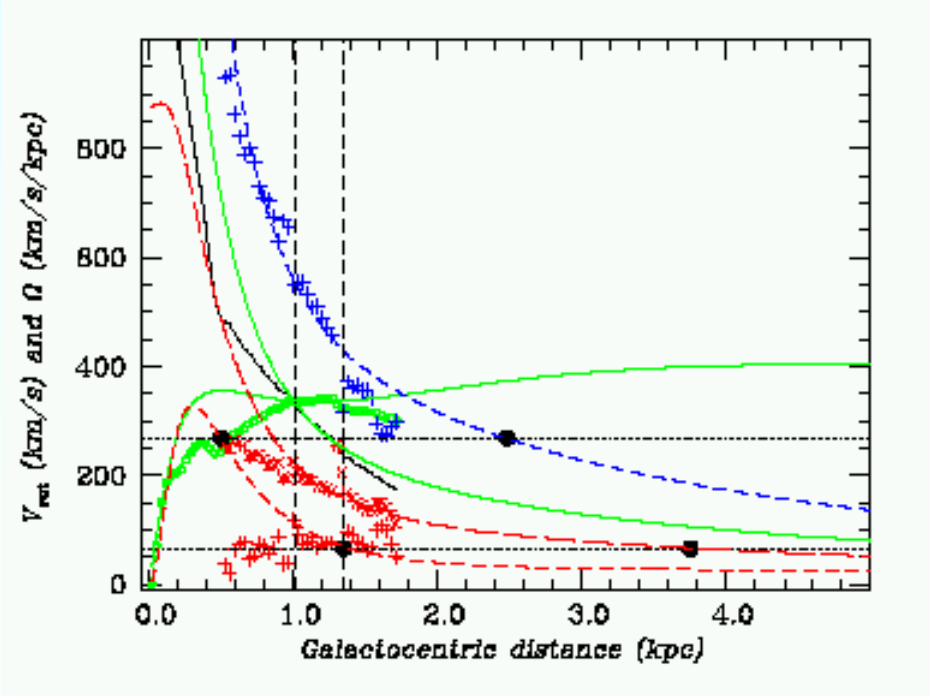
gas t= 720Myr
stars t= 750Myr
gas t= 750Myr
gas t= 750Myr

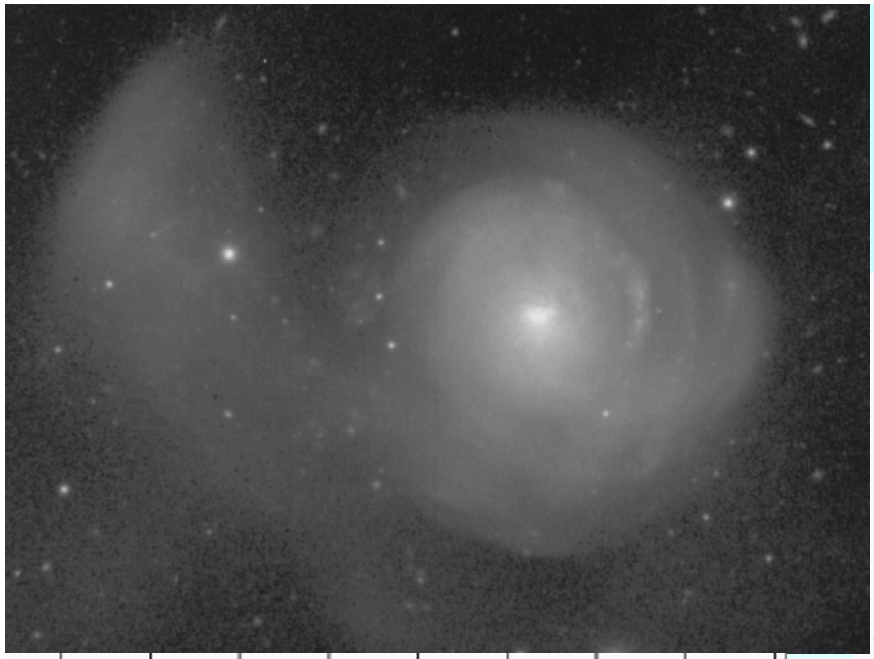
Nested bars in N2782

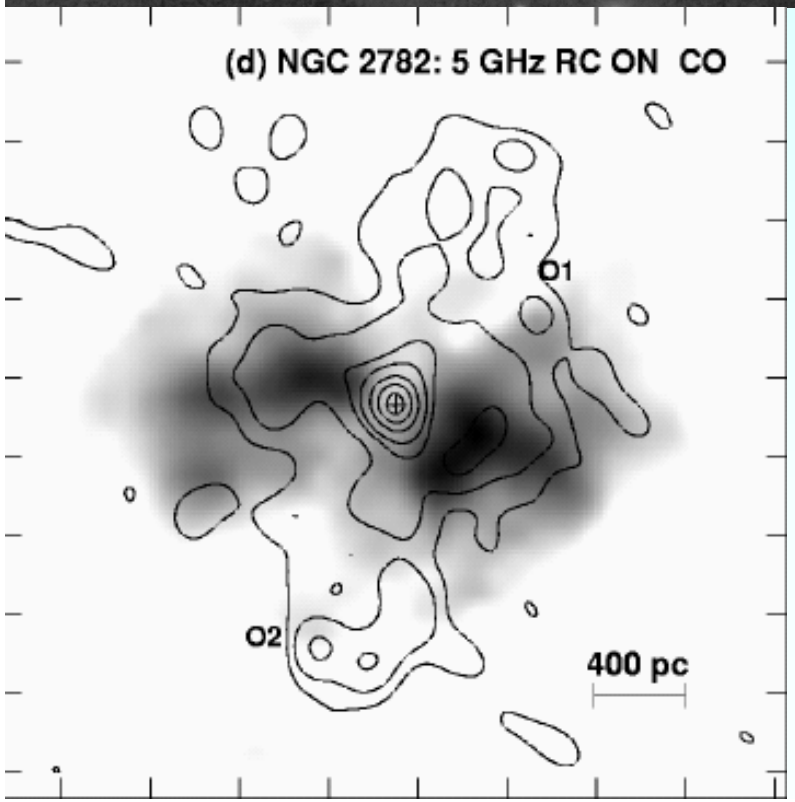


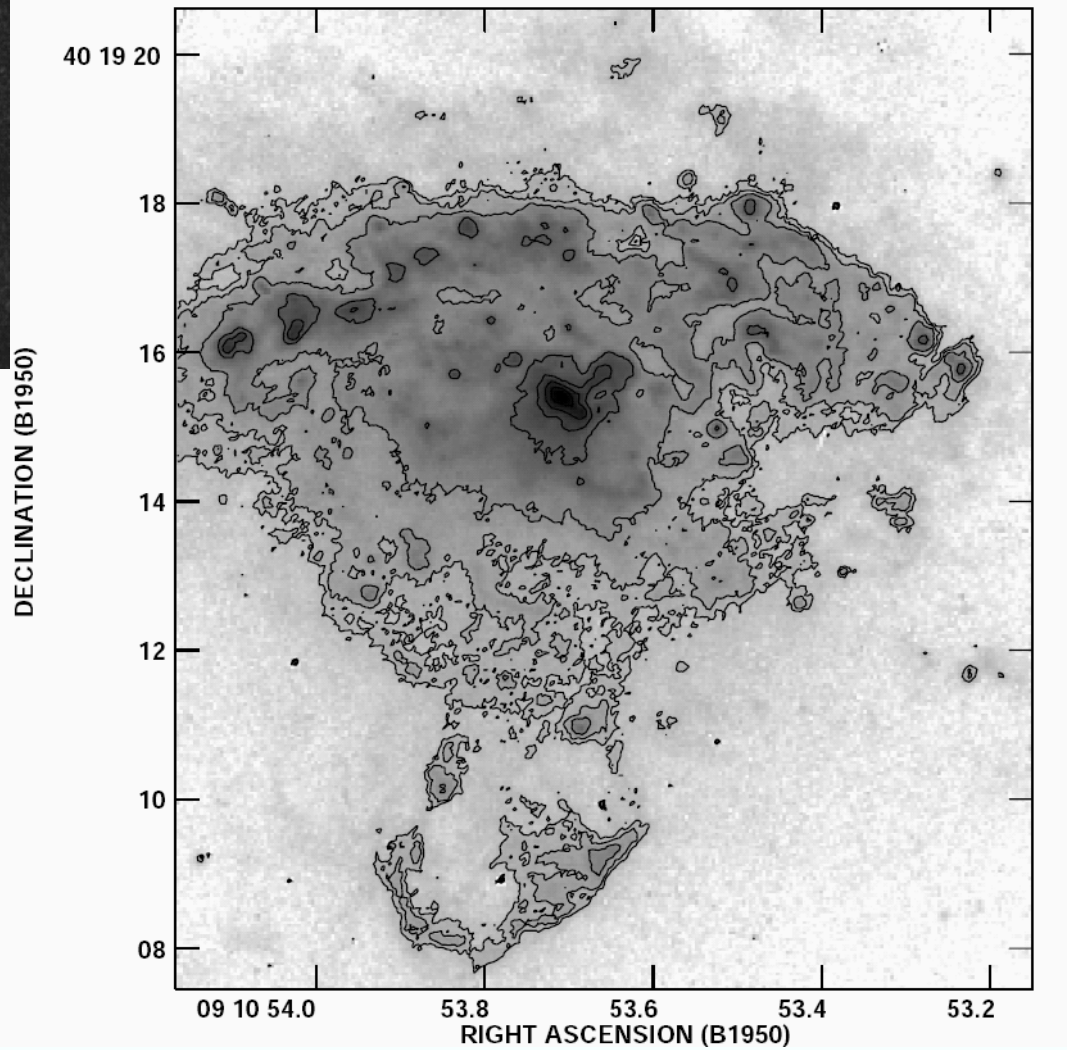


N2782 nuclear disk + outflow

Jogee et al 1999







N2782 – HI tail