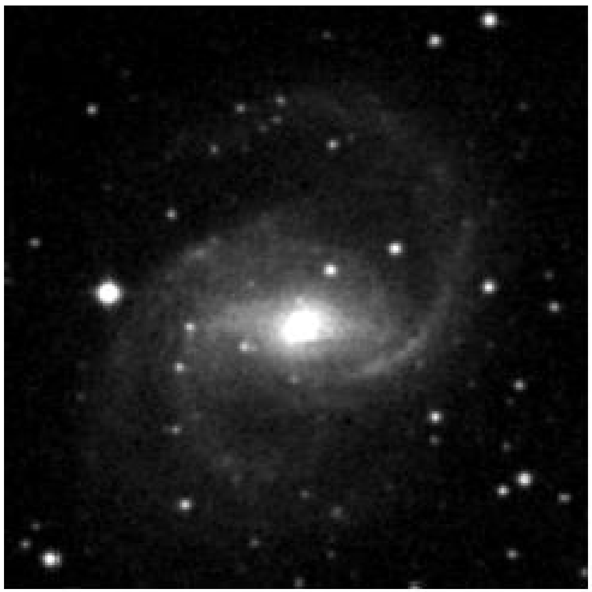
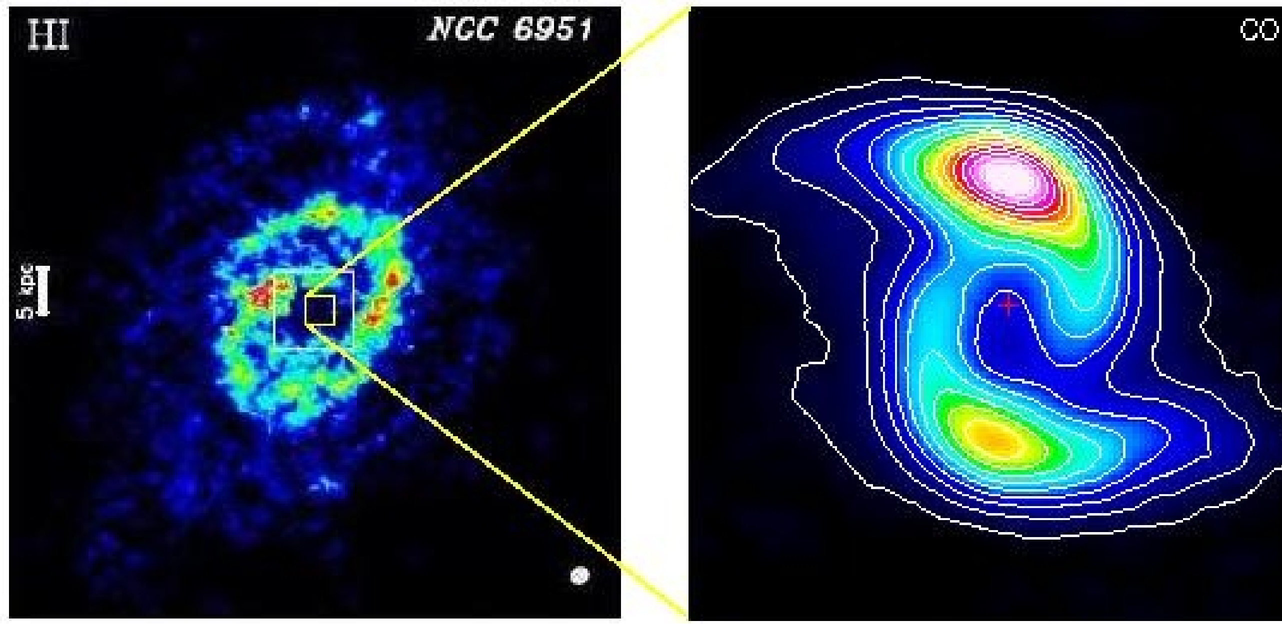
Taking the first step:

bringing gas to the central regions of galaxies

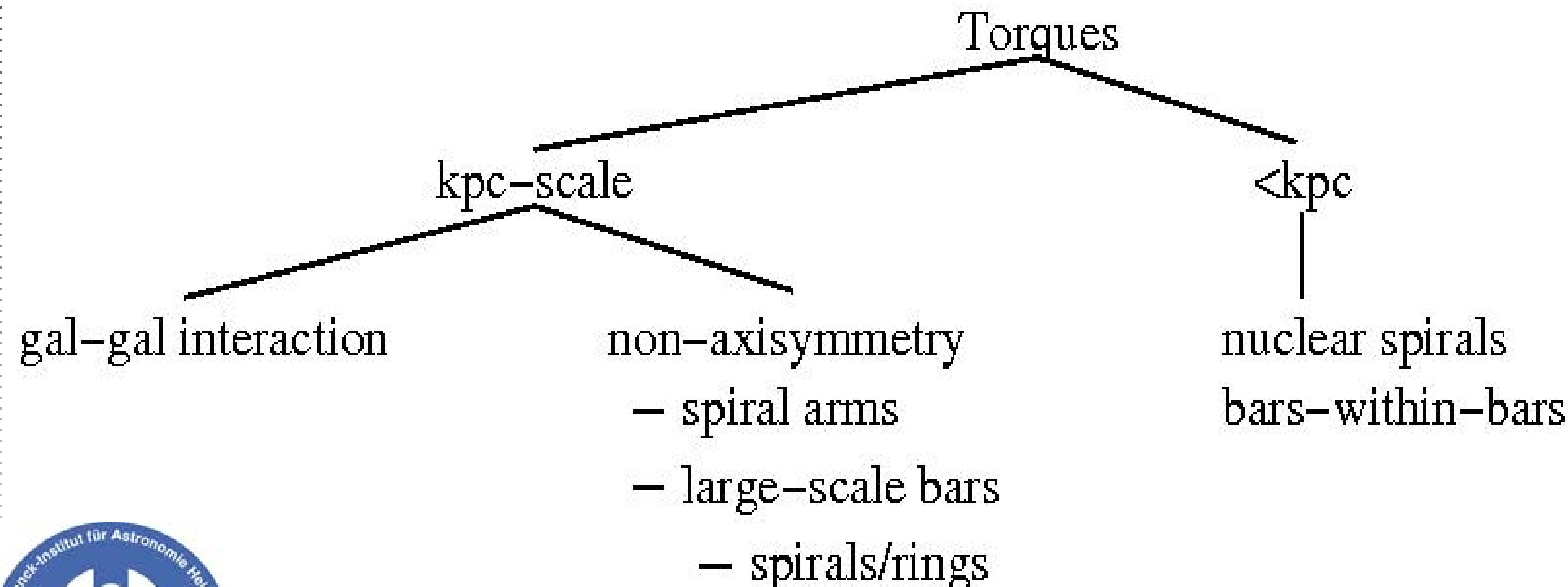




Tessel van der Laan

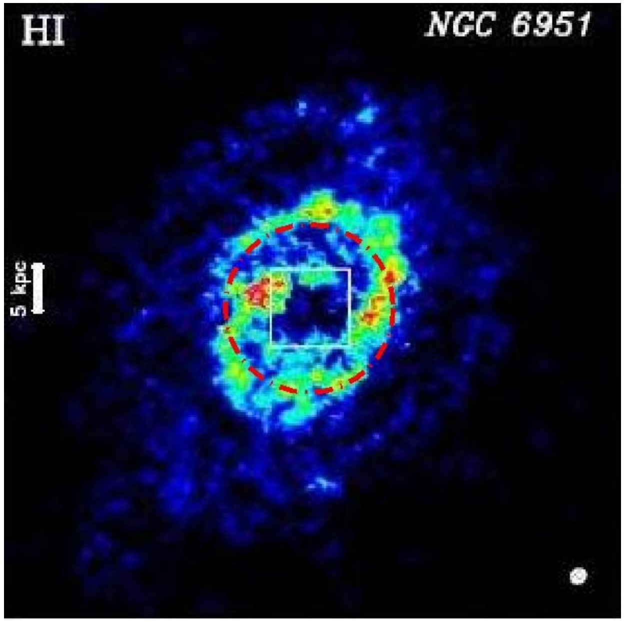
Collaborators:
Eva Schinnerer
Sebastian Haan
Frederic Boone

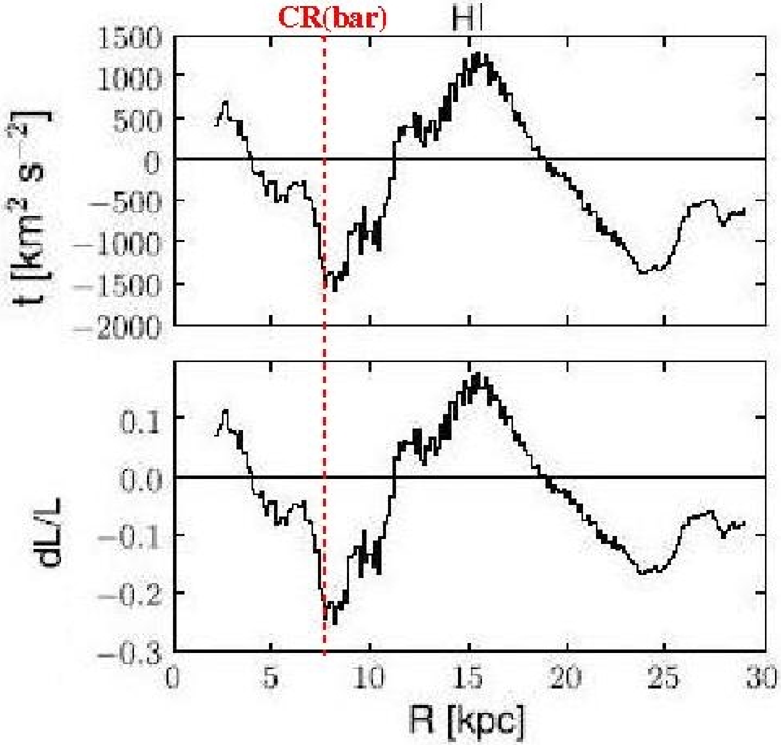
- Gas inflow requires angular momentum loss
- Gravitational torques are an efficient method
- Resonances in the gravitational potential can be a barrier to gas flow

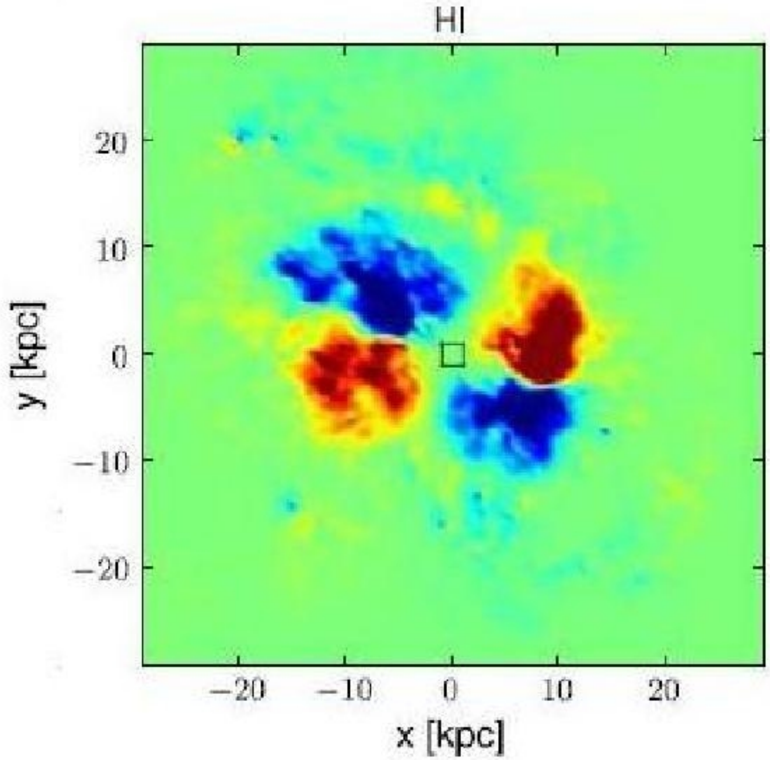


Torques derived from HI

Gas can cross the CR resonance into the region under influence of the large-scale bar

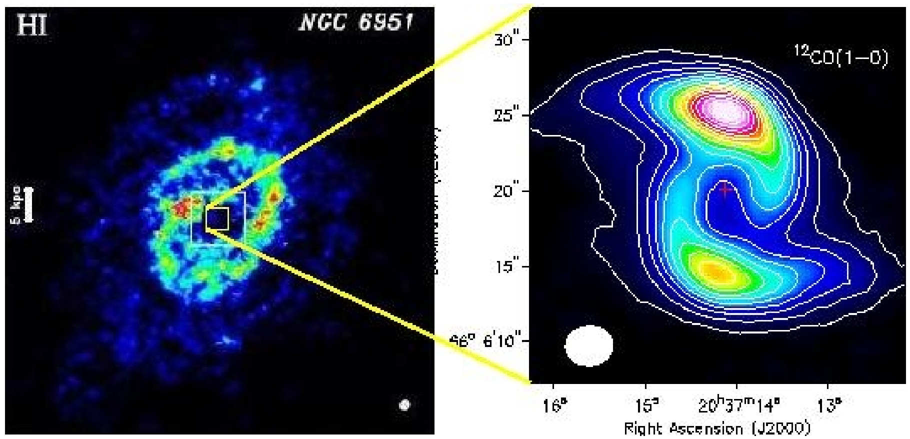




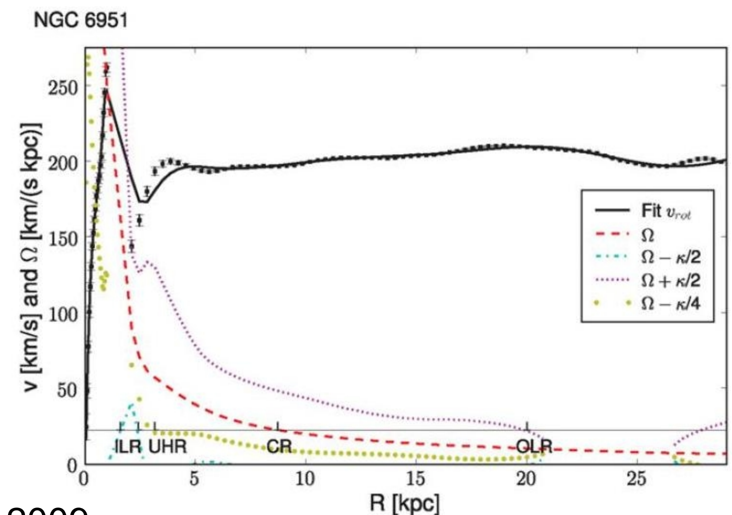


Haan et al. 2009

Inner 1.5kpc of NGC6951



A+B+C+D tracks on the PdBI + short-spacing corrections from IRAM 30M



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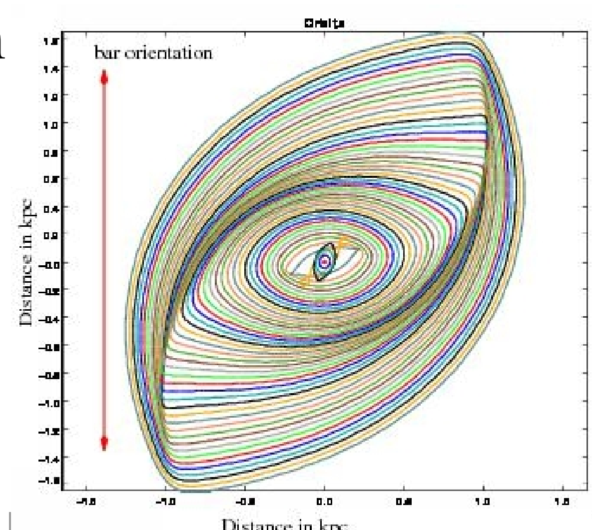
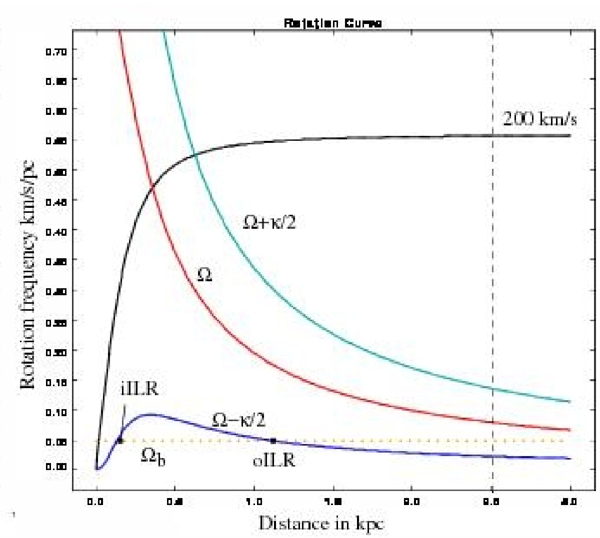
Orbits perturbed by a large-scale bar are populated with gas particles from a radial gas distribution

Van der Laan et al. in prep.

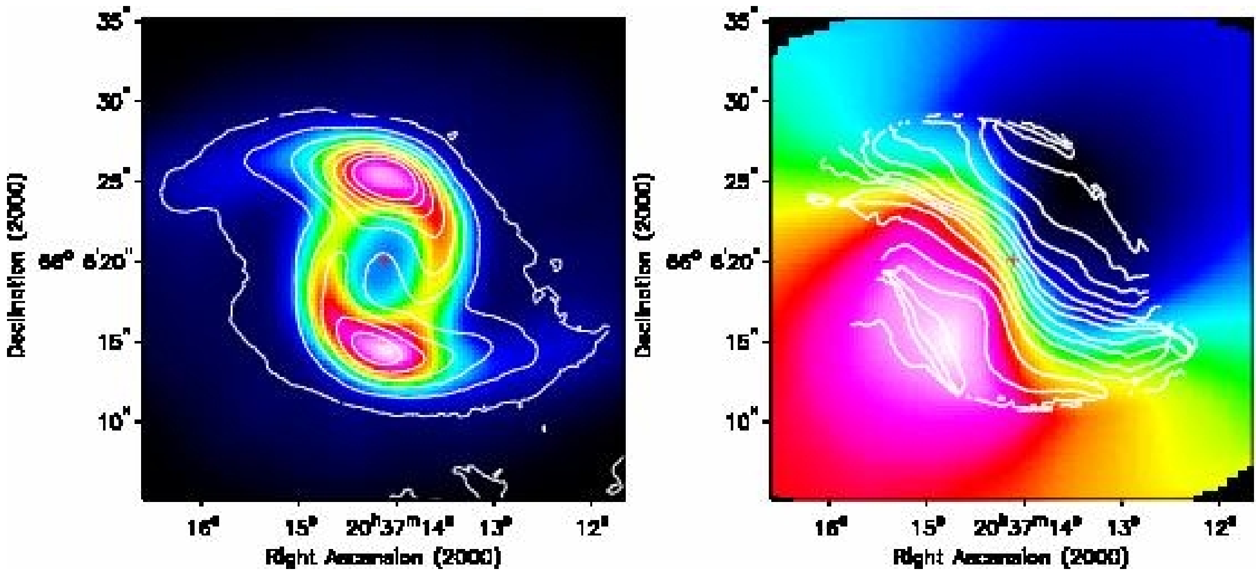
Model potential close match to observations





Best fit model

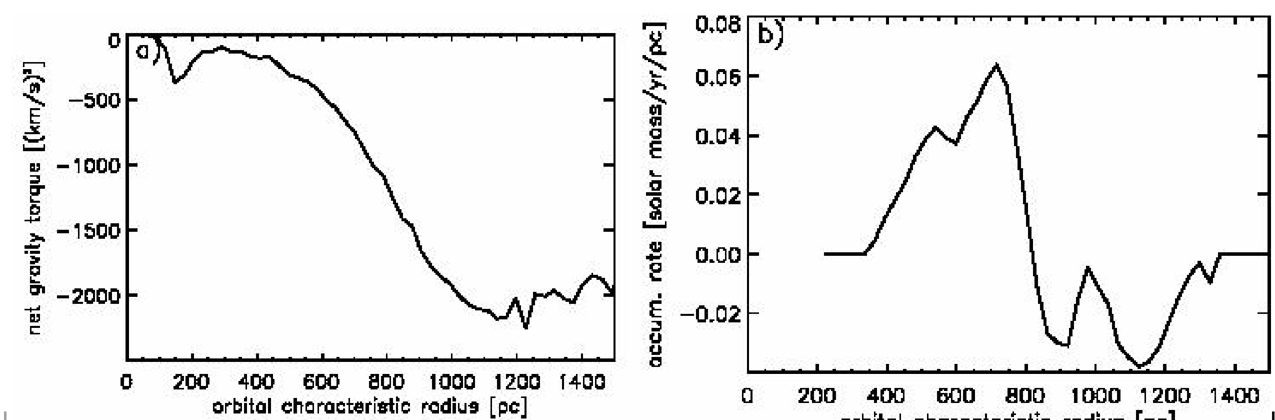
Model is able to reproduce the spiral arms, the circumnuclear ring, the two peak intensities and the velocity field.



Gravity torques and mass accumulation are integrated over the perturbed orbits.

Gravity torques are negative everywhere.

Mass accumulation is ~5 M_{sun}/yr between 400pc and 800pc.



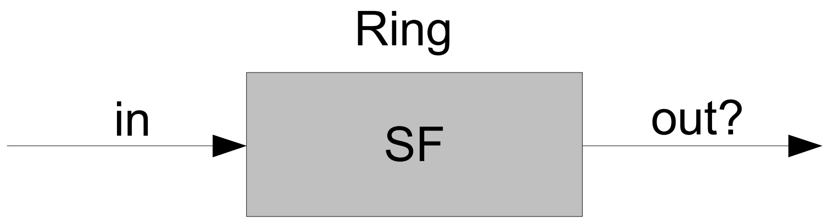
Star formation in the ring

Gas accumulation $\dot{M}$ at the ring is ~ 5 M_{sun}/yr

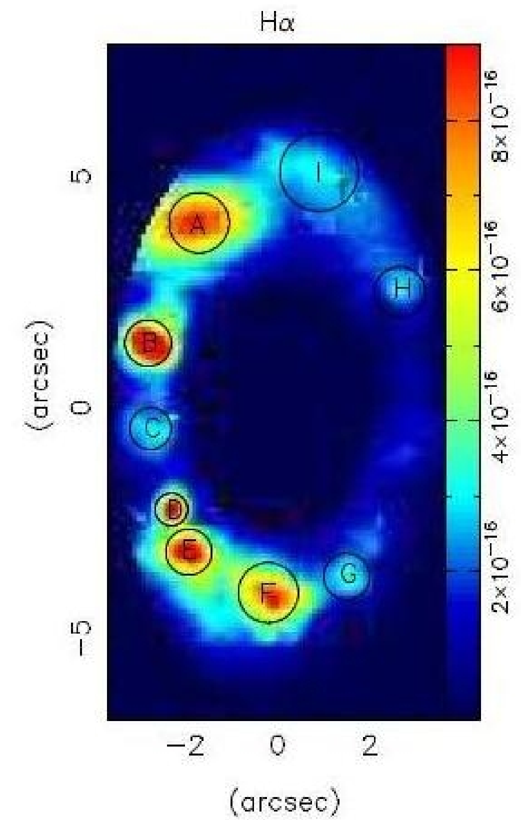
SFR in the ring estimated at 0.4 M_{sun}/yr (Dors Jr. et al. 2008)

Currently $M(H_2) \approx 1.6x10^9\ M_{sun}$ in the ring

$T_{ring} = M/\dot{M} \approx 0.3$ Gyr



~5 M_{sun}/yr – 0.4M_{sun}/yr >> 0



Dors Jr. et al. 2008

Gas reservoir at the nucleus

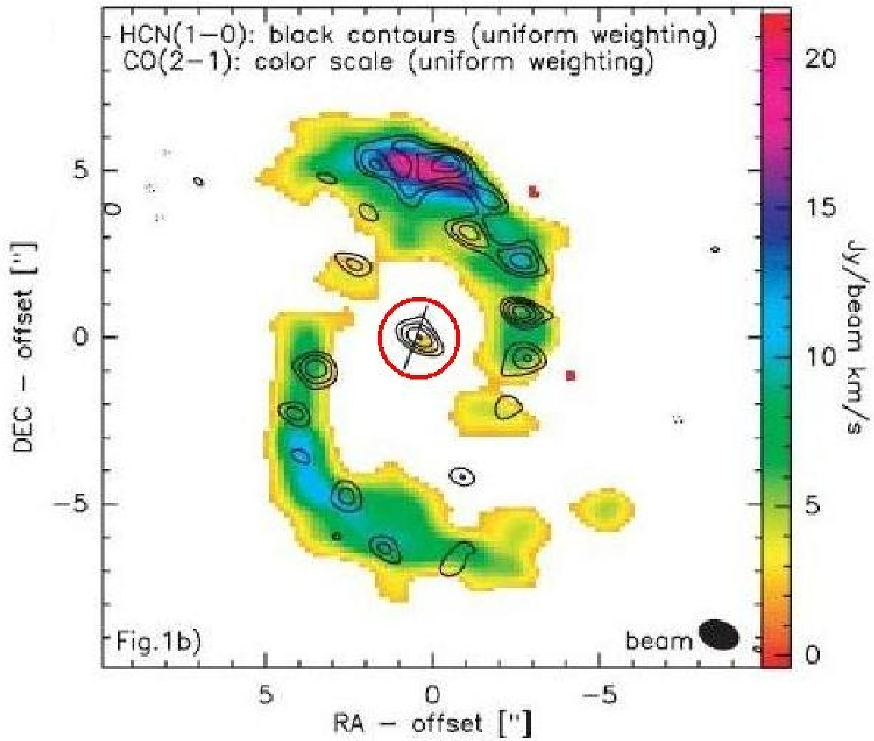
Detected in HCN $M(H_2) = 2\text{-}10 \times 10^7\ M_{sun}$

(Krips et al. 2007)

Detected in CO(2-1) $M(H_2) = 5 \times 10^6\ M_{sun}$

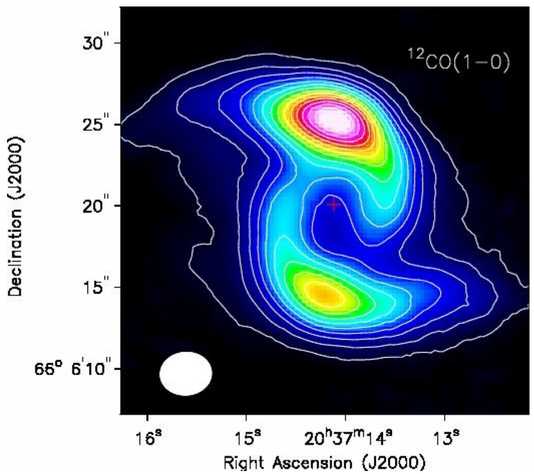
(Garcia-Burillo et al. 2005, Van der Laan et al. in prep)

If $T_{nuc} = ½\ T_{ring}$ then a radial inflow rate of only $0.06\ M_{sun}$/yr is needed



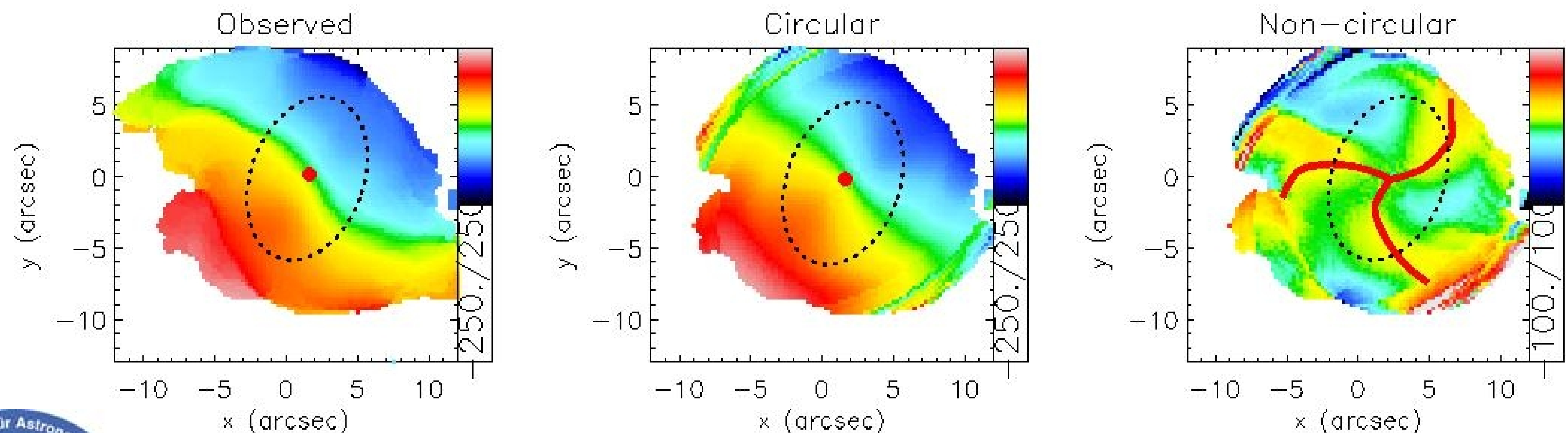
Krips et al. 2007

Evidence for nuclear spirals



Harmonic decomposition of the observed line-of-sight velocity field

m spirals in the velocity field means (m-1) or (m+1) spirals in the gravitational potential

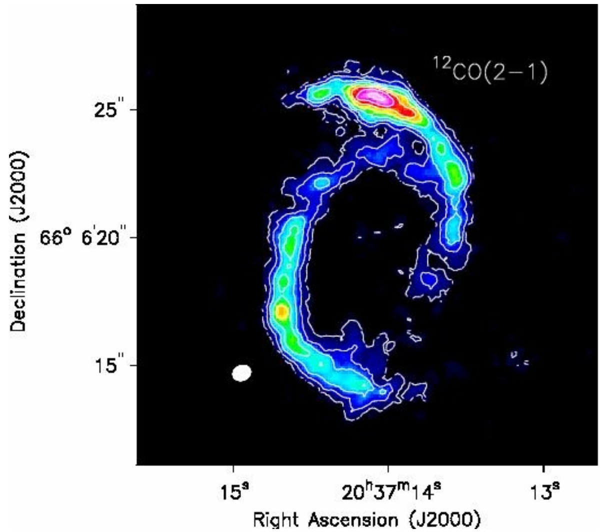


$$P = c_0(R) + \sum_{m=1}^{n} c_m(R) \cos m\psi + s_m(R) \sin m\psi.$$

Schoenmakers et al. 1997, Fathi et al. 2005, Van de Ven & Fathi 2009

Nuclear spirals in molecular gas

Inflow ~0.06 Msun/yr
η 10% radial
Δv ~40 km/s
m 2 (spiral arms)



$$M = \frac{l * Inflow}{m * \eta * \Delta v}$$

CO(1-0): $M_{(beam)} \sim 2.6 \times 10^6\ M_{sun}$

CO(2-1): $M_{(beam)} \sim 5.8 \times 10^5\ M_{sun}$

Detection threshold:

$1\sigma \sim 1.3 \times 10^5\ M_{sun}$ beam^{-1}

$1\sigma \sim 3.9 \times 10^5\ M_{sun}$ beam^{-1}

Inflow rate based on Hα $3 \times 10^{-4}\ M_{sun}$/yr (Storchi-Bergmann et al. 2007, lower limit)
Only $6 \times 10^{-6}\ M_{sun}$/yr needed for AGN accretion (Dumas et al. 2007)

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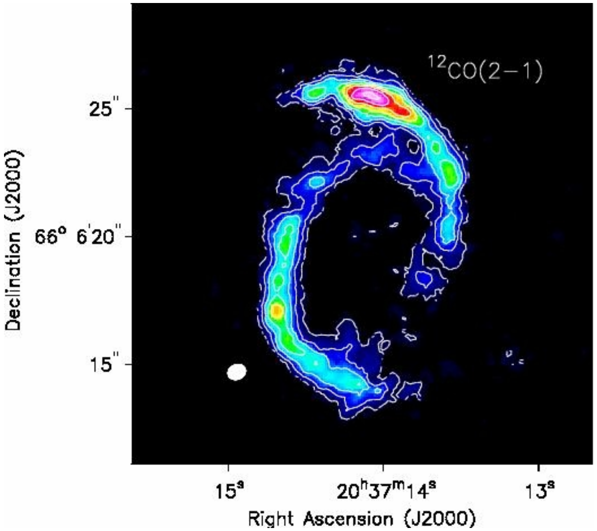

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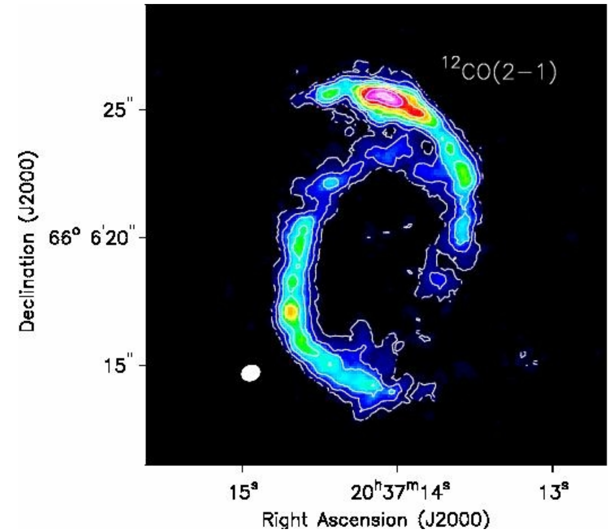

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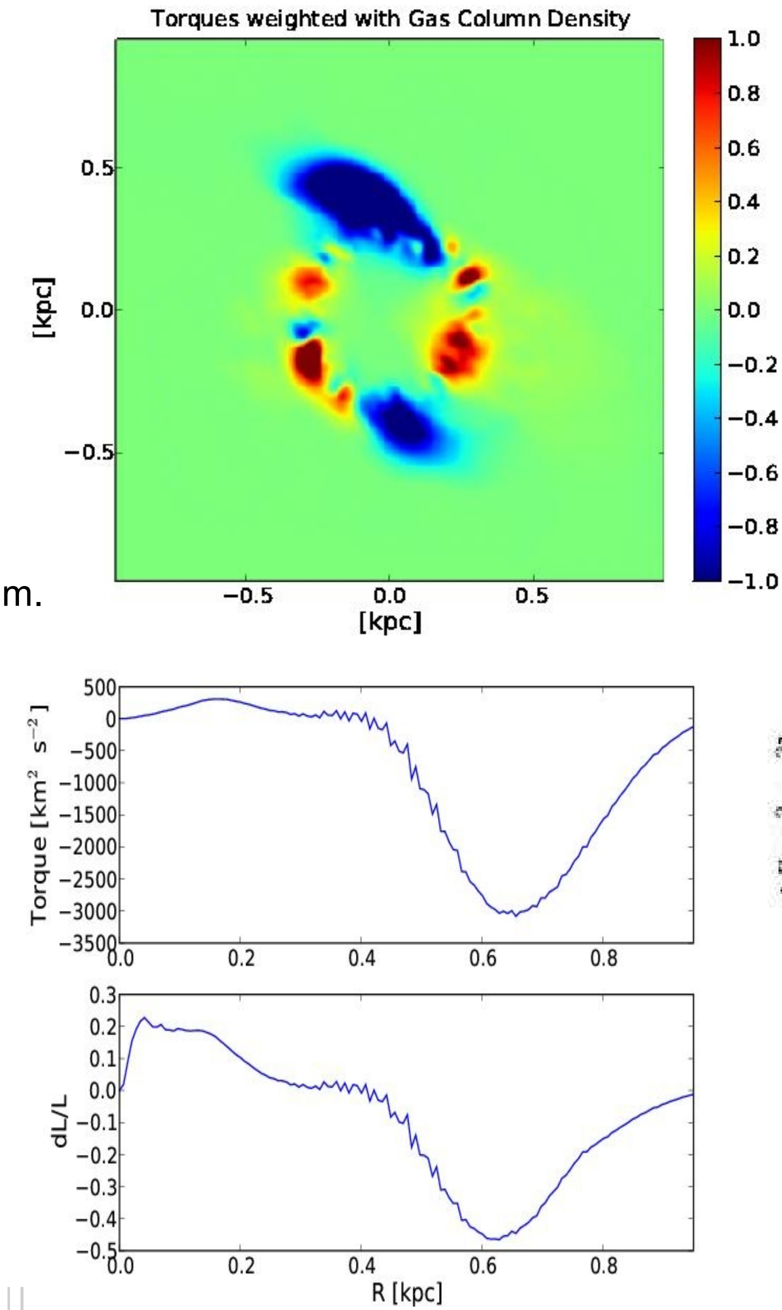
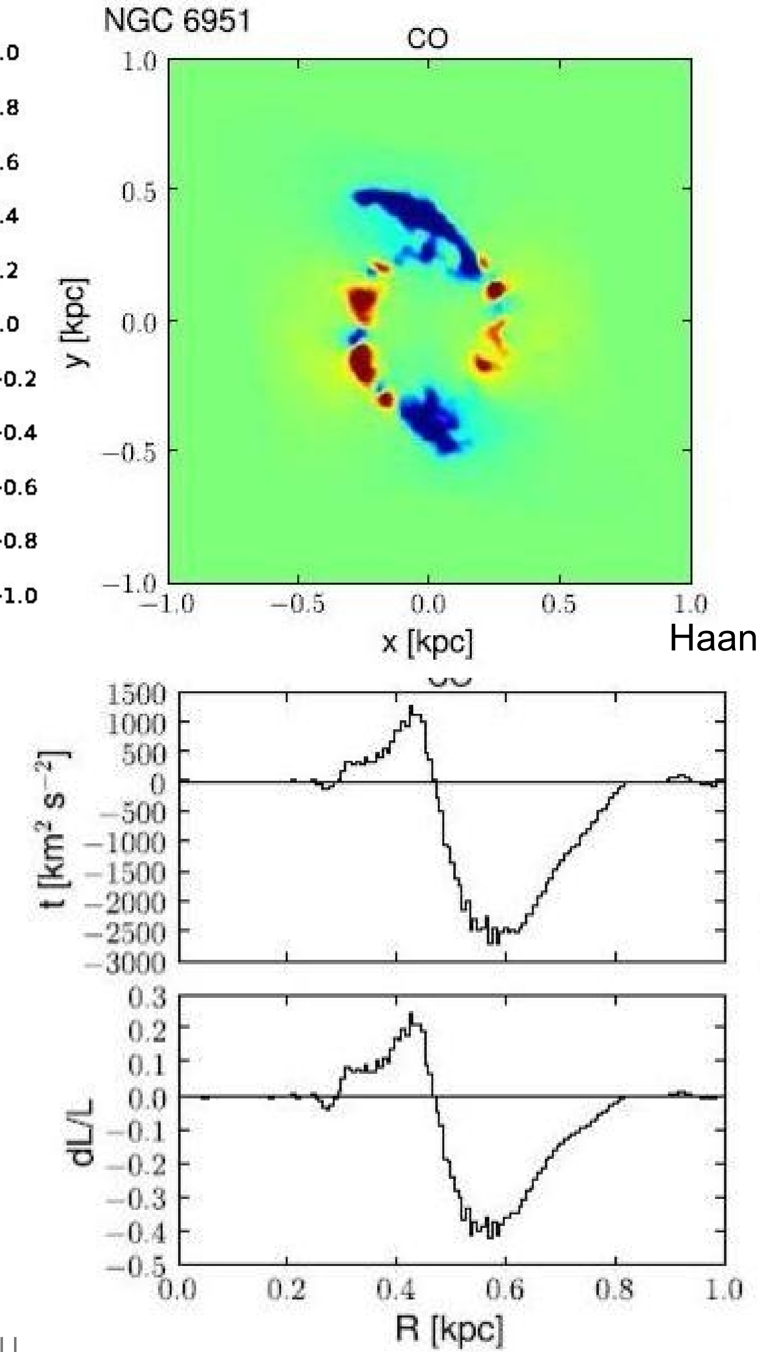
Missing flux on torque balance



Haan, priv. comm.



Haan et al. 2009

Conclusion

- Gas inflow is in most galaxies a combination of several components/processes
- The large-scale bar in NGC6951 causes an accumulation rate of 5 M_{sun}/yr onto the circumnuclear ring
- In the CO velocity fields we have detected evidence for nuclear spirals down to ~50 pc from the nucleus
- Radial inflow along these spiral arms must be below 0.06 M_{sun}/yr
- Missing flux can hinder computation of the correct torque budget