Nuclear spirals:
a mechanism of gas inflow to innermost parsecs

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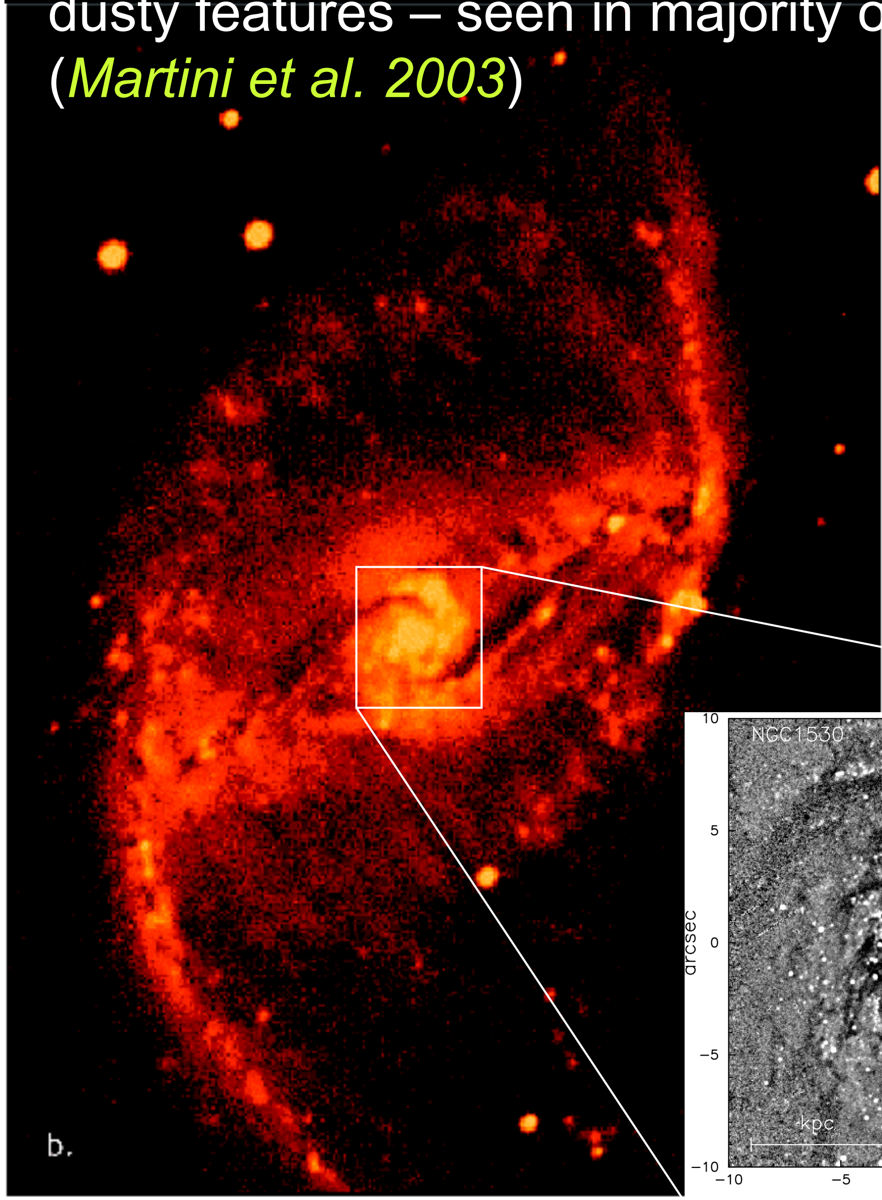
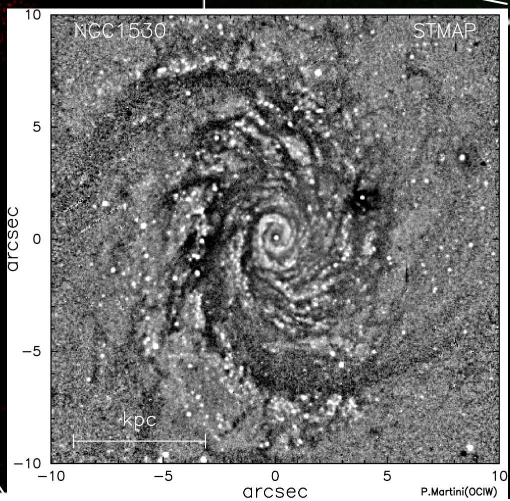
1. Nuclear spirals in weak and strong bars

dusty features – seen in majority of disc galaxies
(*Martini et al. 2003*)

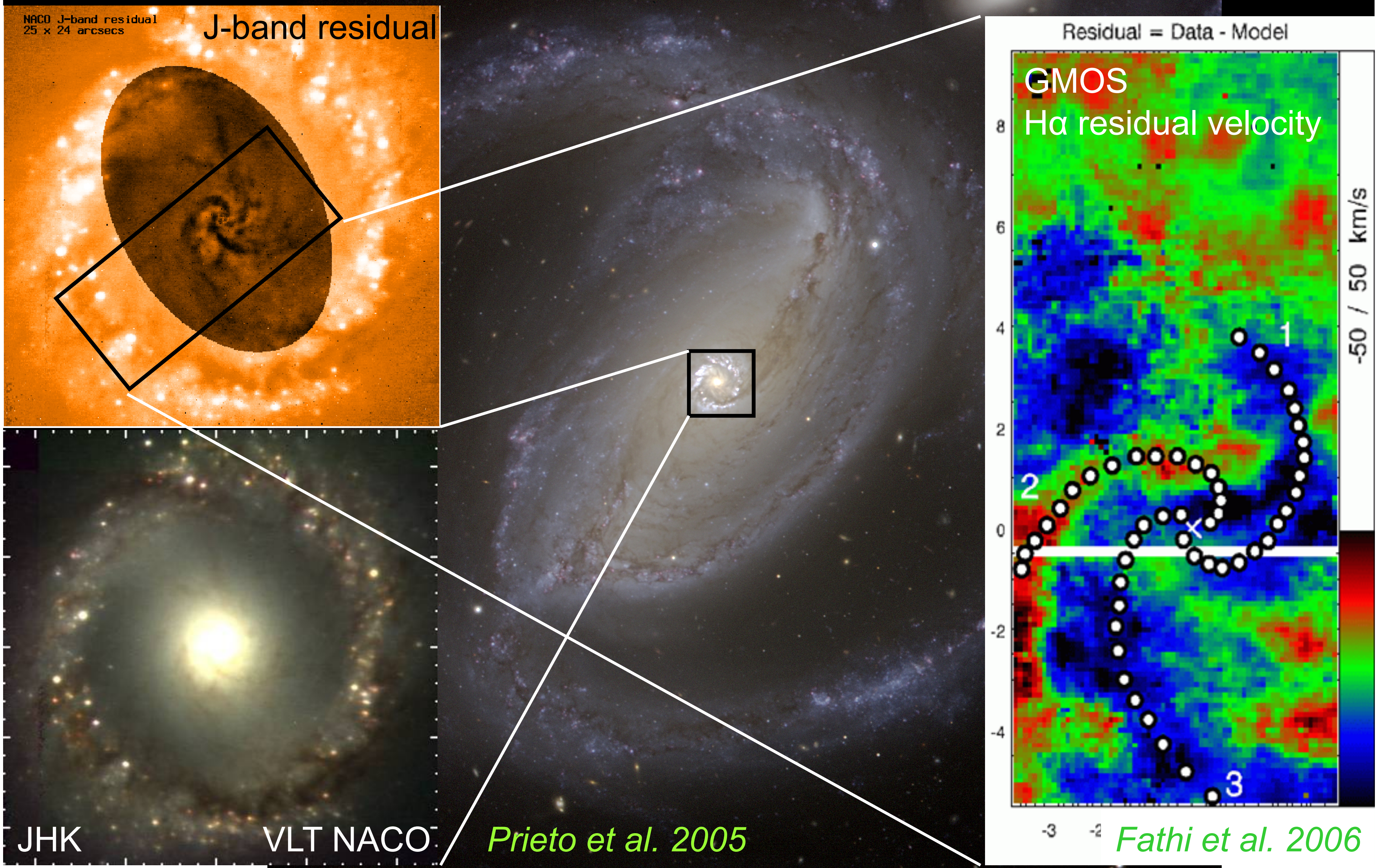




M 100, *Allard et al. 2005*

NGC 1530, *Zurita et al. 2004*

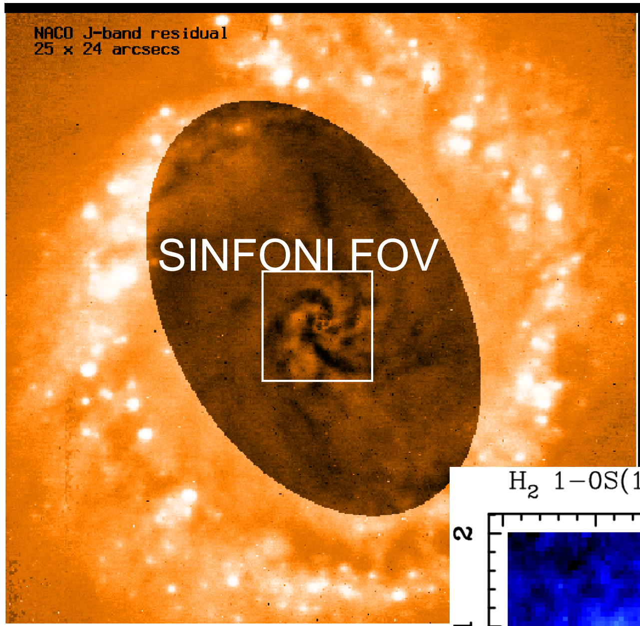
2. Case study: nuclear spiral in NGC 1097



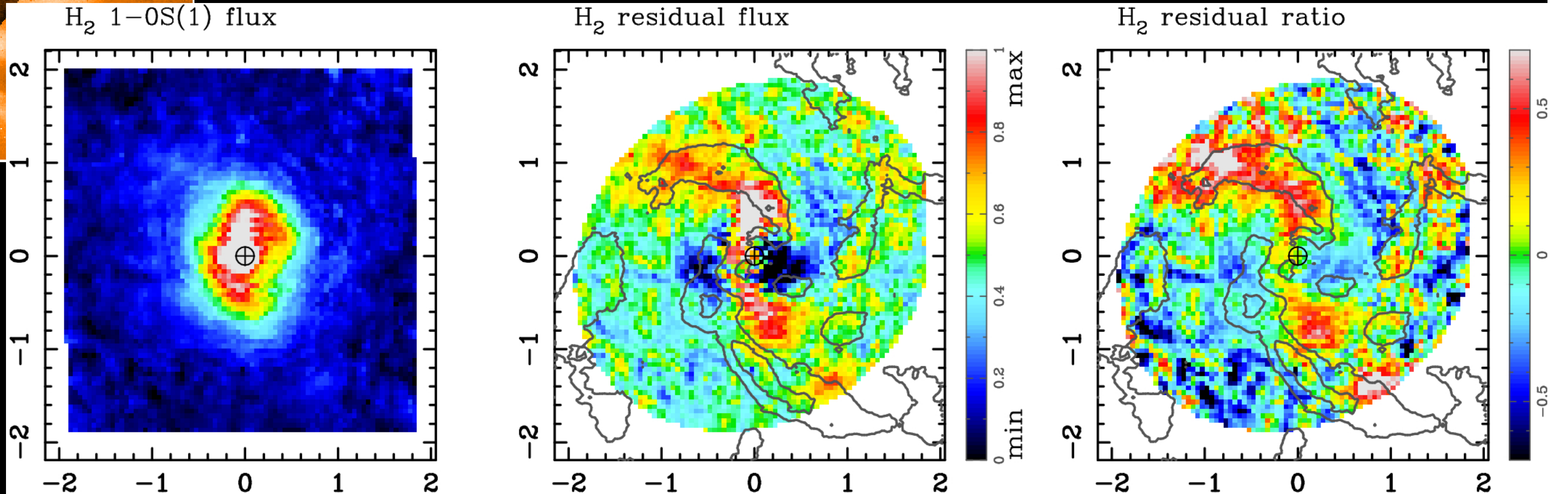
SINFONI observations of NGC 1097

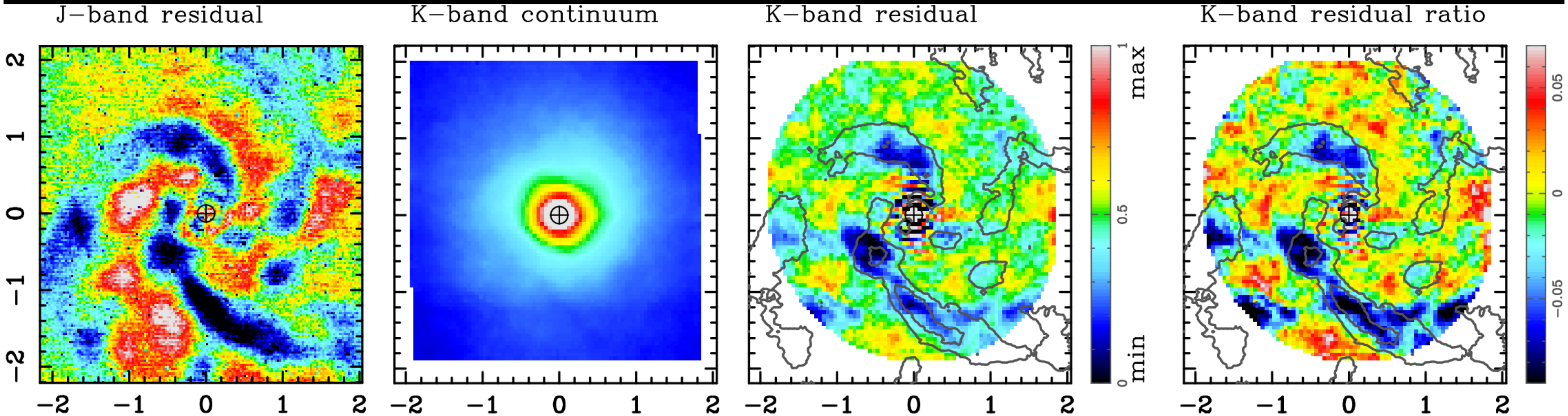
(Davies, Maciejewski, Hicks et al. 2009)

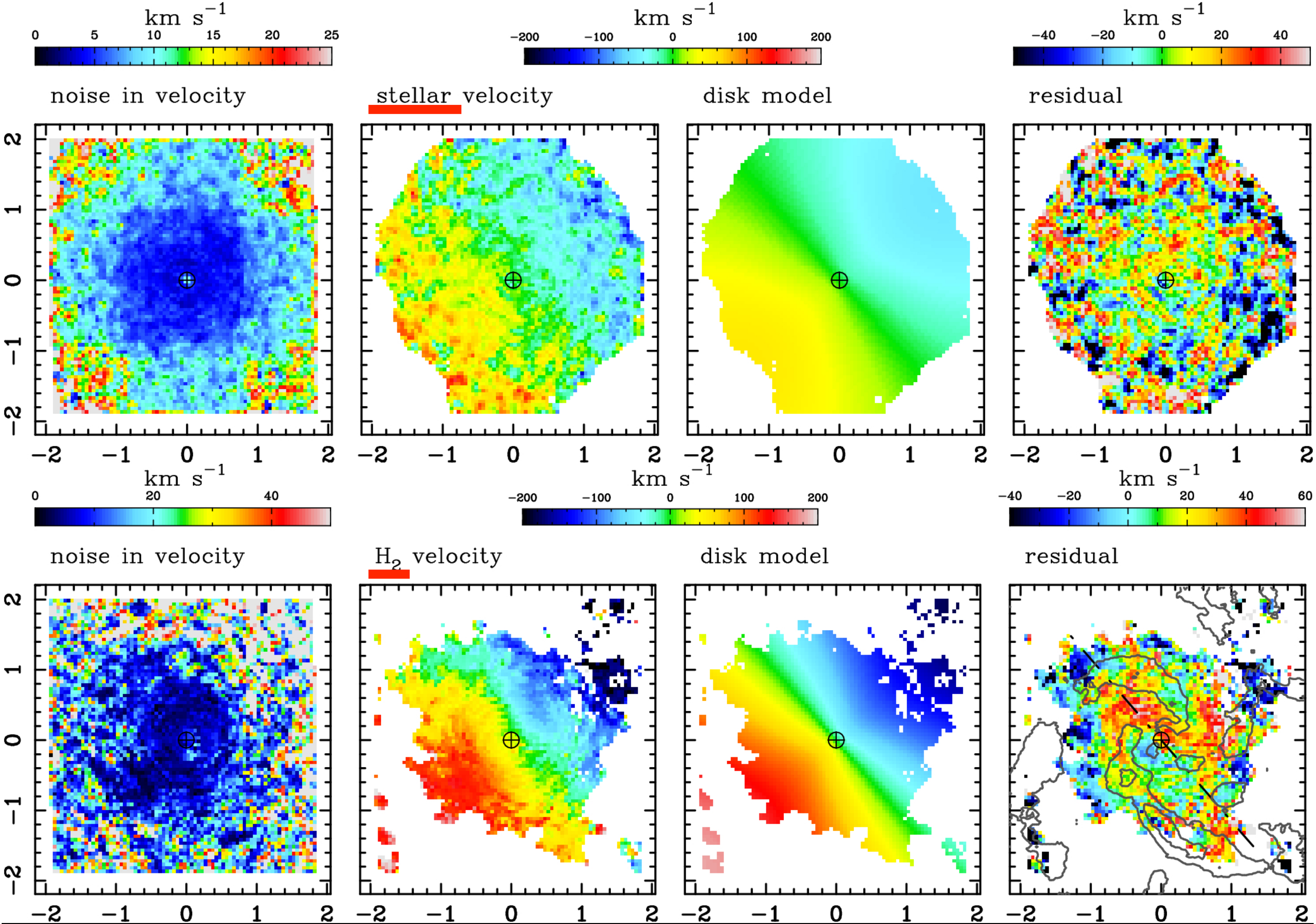
SINFONI: AO NIR IFU (integral field unit) at the VLT
FOV 4”x4”, FWHM 0.25”



2.12 μm 1-0 S(1) H2 emission line traces warm molecular gas



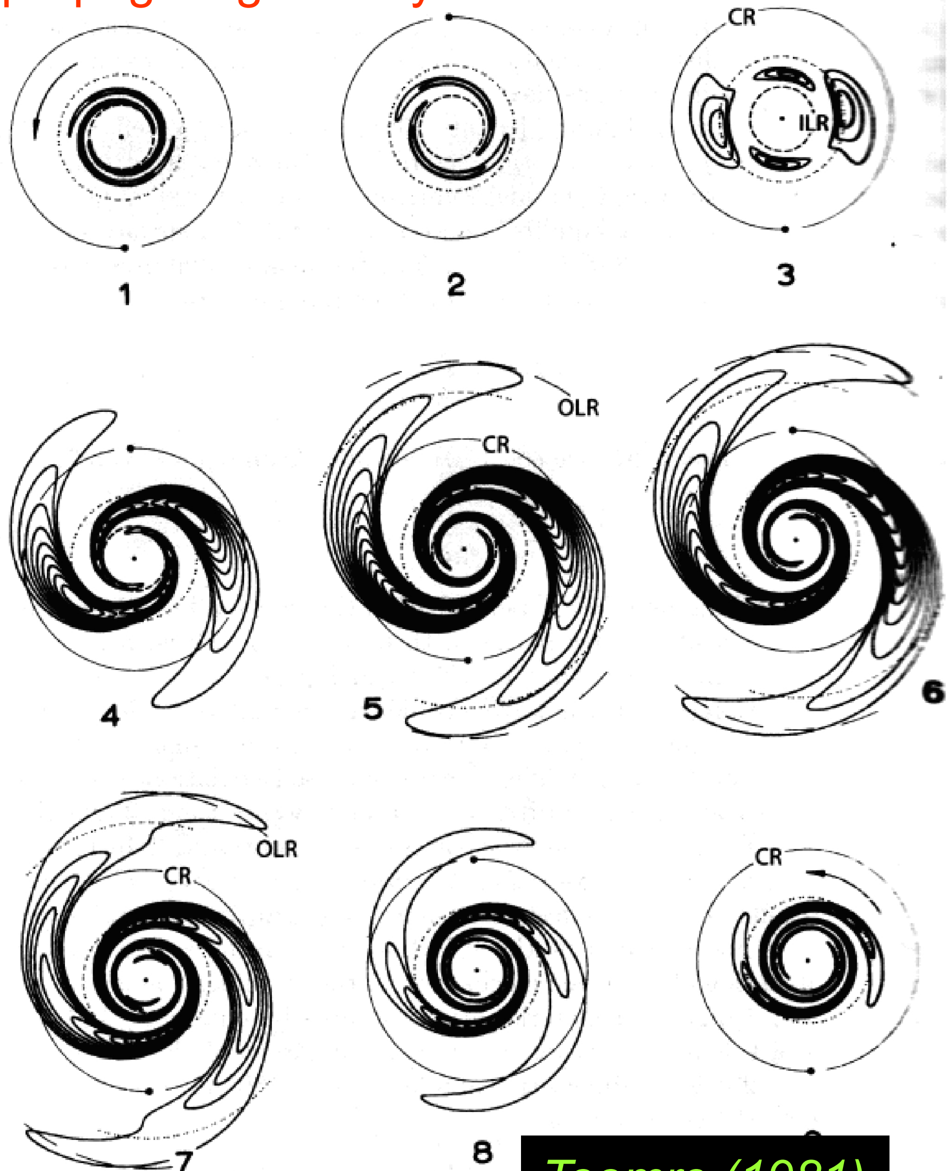




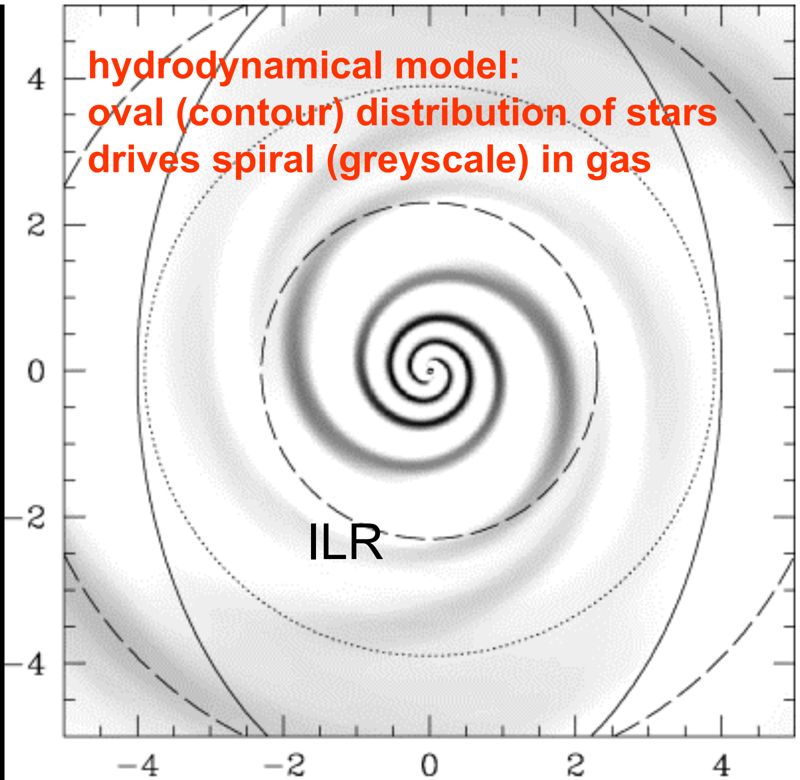
kinematic spiral in residual gas velocity

3. Nuclear spirals as waves in gas disc

propagating density wave in stars



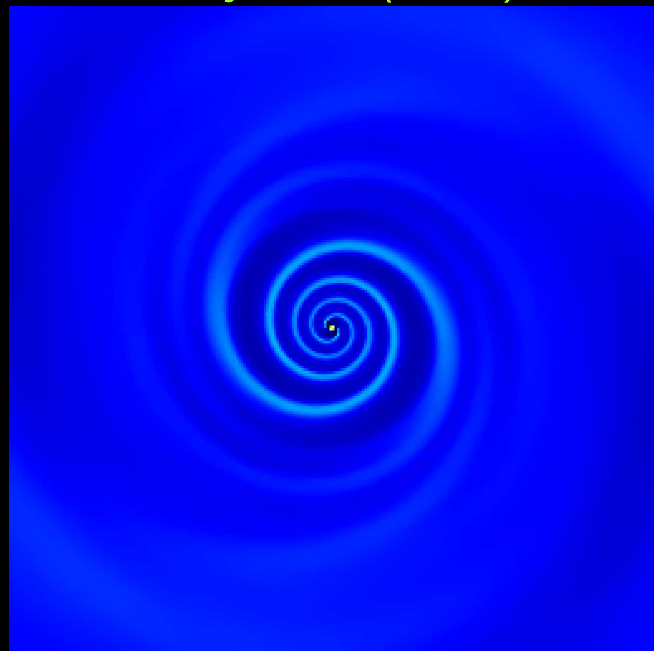
Toomre (1981)



Maciejewski (2004)

stellar density waves amplified at the ILR

pressure waves in gas generated at the ILR



Density-wave theory: linear approximation

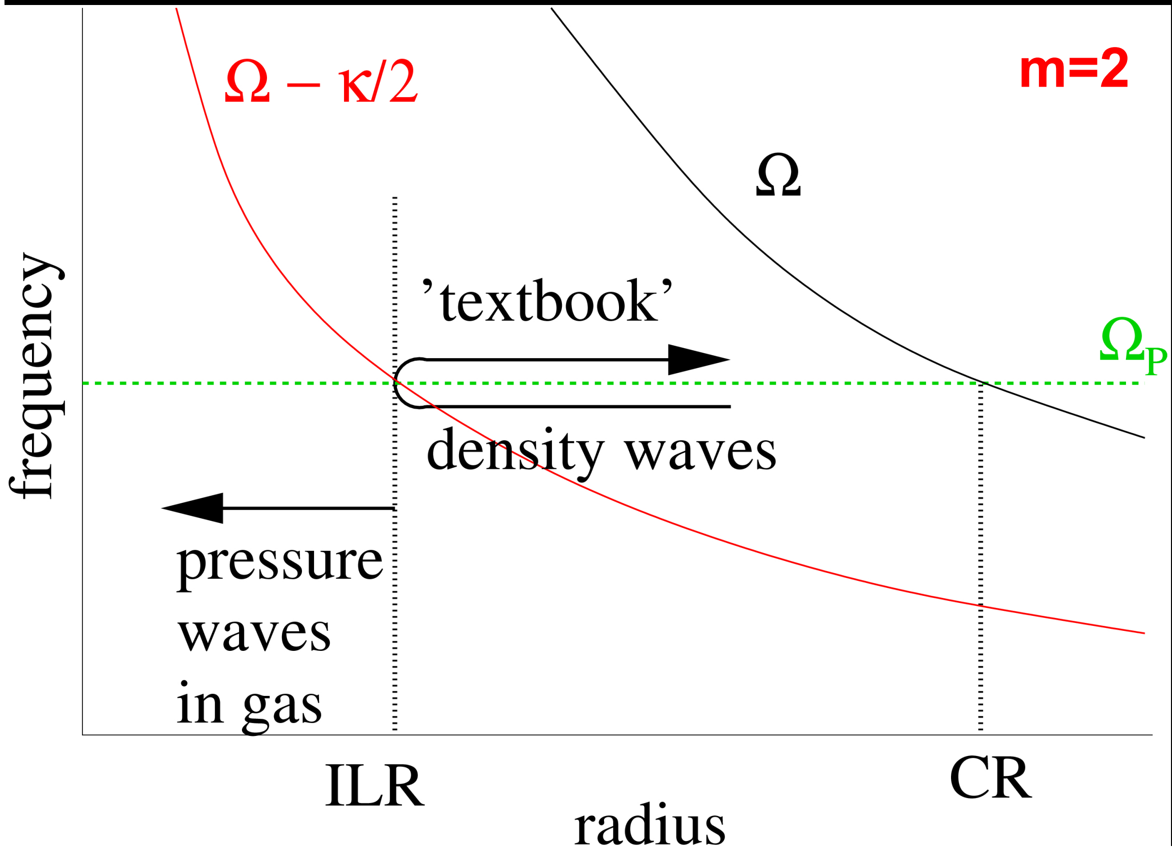
Linear dispersion relation for waves in a disc:

$$m^2(\Omega - \Omega_p)^2 \quad - \quad \kappa^2 \quad - \quad k^2c^2 \quad + \quad 2\pi G \mathcal{F} |k| \rho \quad = \quad 0$$

rotation curve — gas pressure — self-gravity

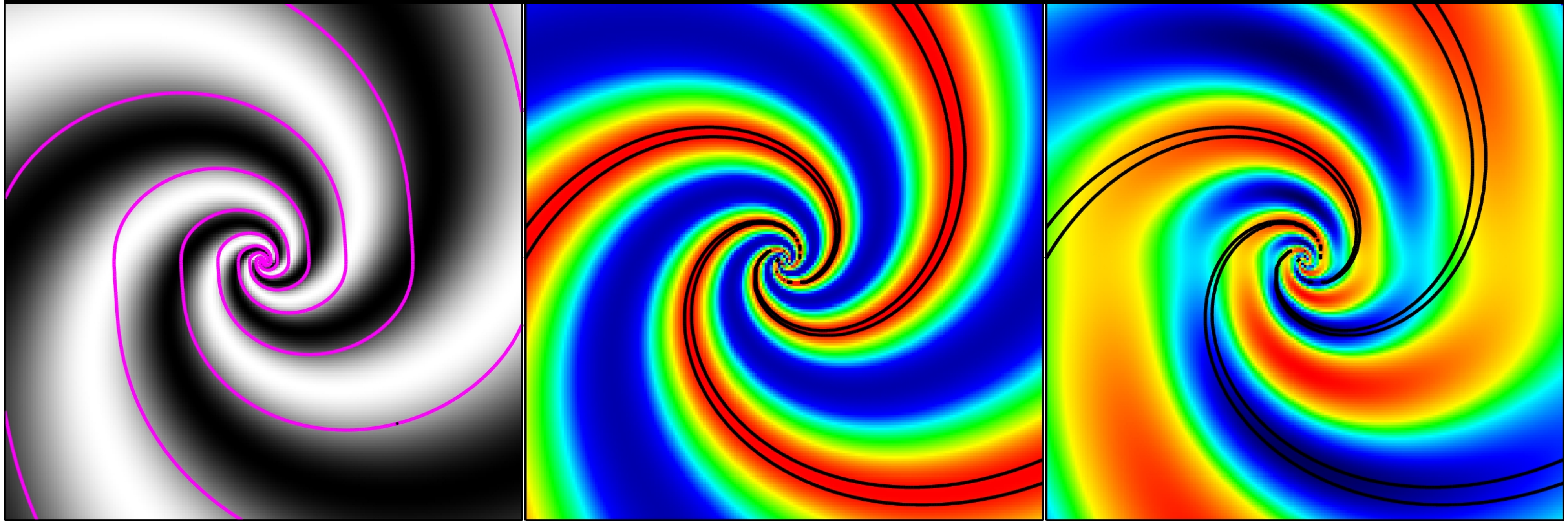
$$(\Omega + \kappa/m - \Omega_p)(\Omega - \kappa/m - \Omega_p) = (kc/m)^2 \qquad > 0$$

$$= -2\pi G \mathcal{F} |k| \rho / m^2 \qquad < 0$$



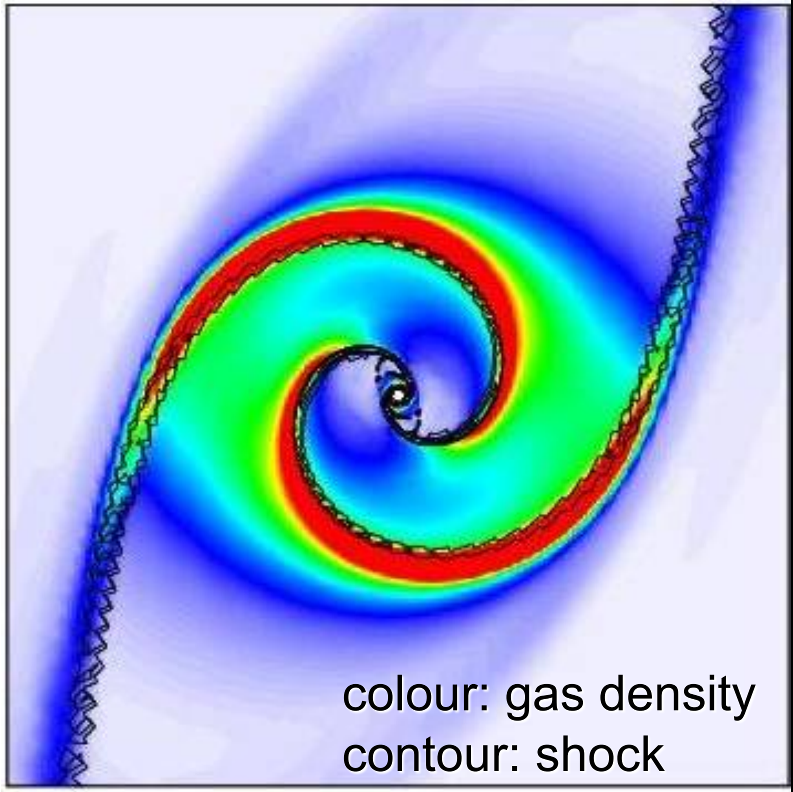
- waves generated in gas by a tumbling stellar component (e.g. oval or bar)
- spiral morphology of the waves
- pressure waves can propagate all the way to the galaxy centre
  → **nuclear spirals**

Properties of nuclear spirals in linear approximation



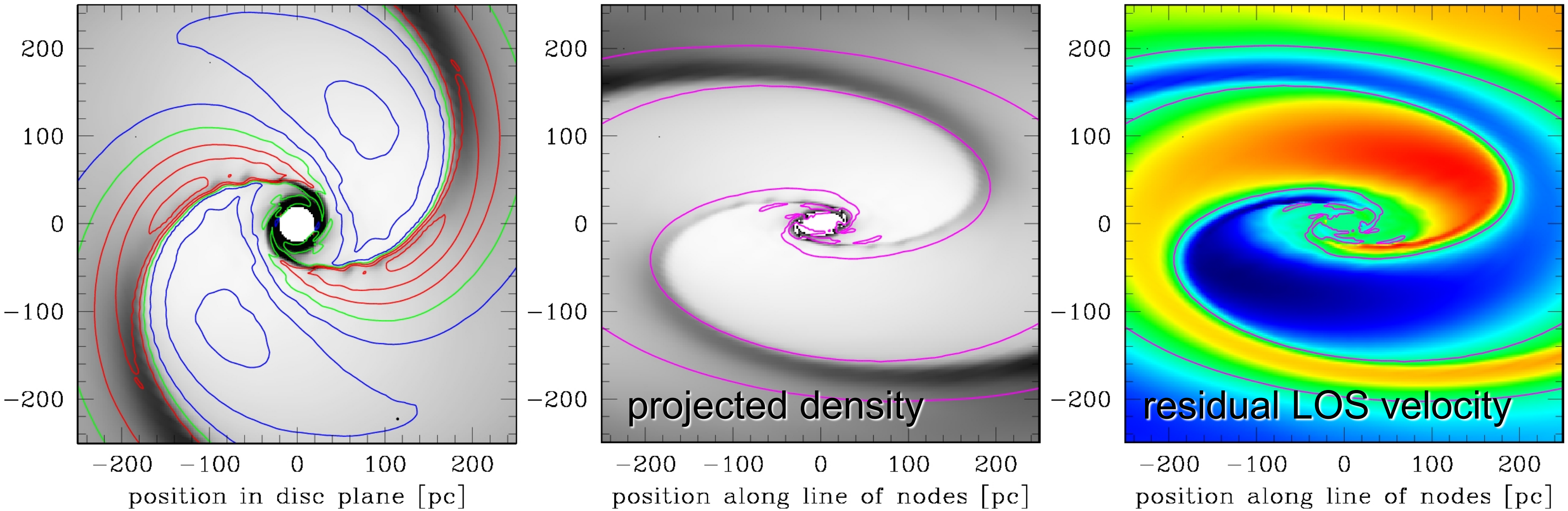
density (3 arms) (high density darker) — radial velocity — residual LOS velocity (morphological spiral arms in contours)

- radial inflow along the arms, outflow between the arms
- m-arm photometric spiral corresponds to m-1-arm kinematic spiral in LOS velocity residuals *(Canzian 1993)*
- linear analysis limited to $\Delta\rho/\rho \ll 1$ and residual velocity << sound speed



4. Hydrodynamical model of a nuclear spiral shock driven by a bar

- shock on the inside edges of the arms
- residual velocities up to 3 times higher than the velocity dispersion in gas
- location of inflow/outflow and m/m-1 multiplicity of photometric/kinematic spiral like in the linear case



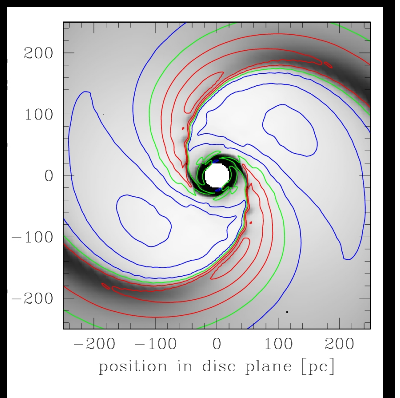
5. Gas inflow in nuclear spiral shock in NGC 1097

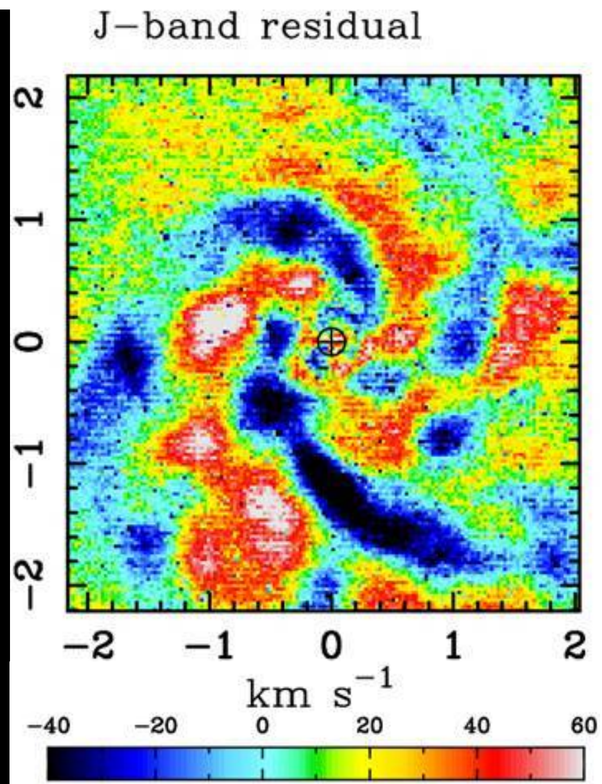
Nuclear spiral shock in NGC 1097 because:

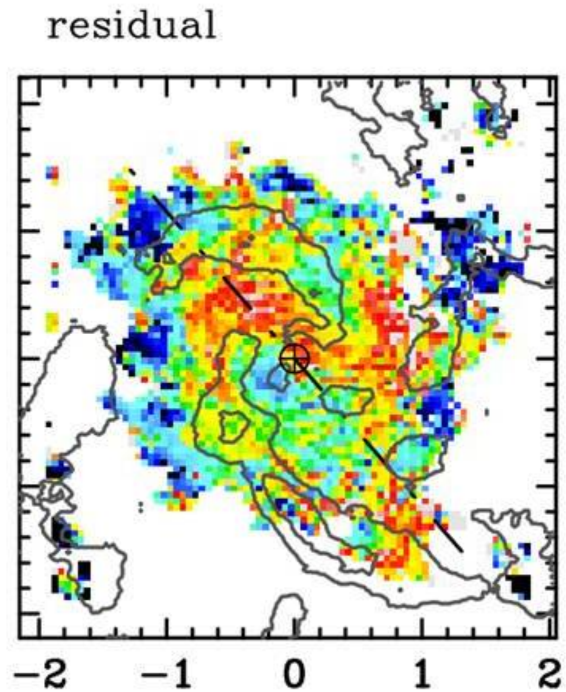
- 3-arm photometric, 2-arm kinematic spiral
- residual velocity > velocity dispersion
- H2 emission on the inside edges of the dust arms

Inflow in NGC 1097:

- **dissipation in the shock → inflow**
- hence inflow in the arms balanced by outflow between the arms, corrected net inflow in the nuclear spiral in NGC 1097 is 0.06 Msun/yr – consistent with SF history *(Storchi-Bergmann et al. 2005, Davies et al. 2007)*
- ~2 Gyr needed to drain all gas inside the nuclear ring → nuclear spiral in quasi-equilibrium (refilling from nuclear ring?)

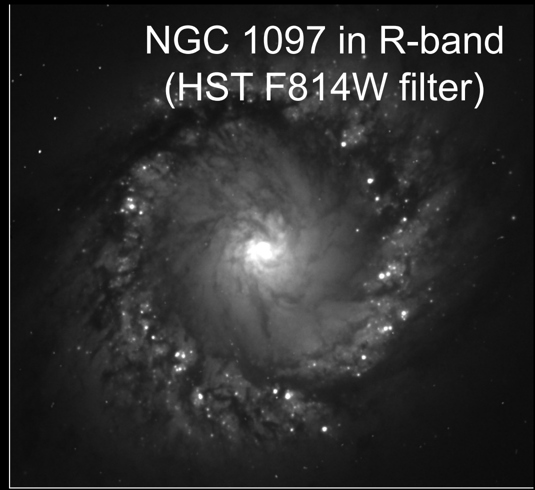


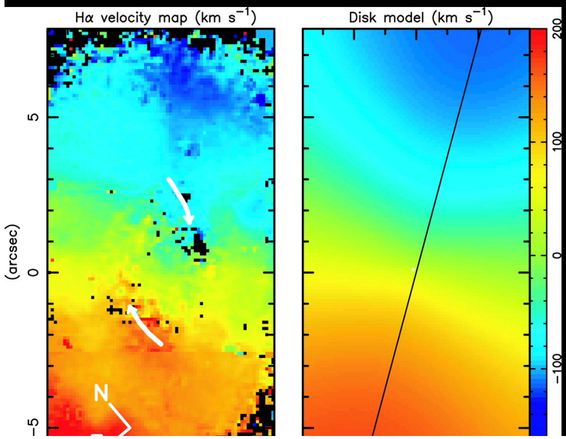




6. Kinematic signatures of other nuclear spirals

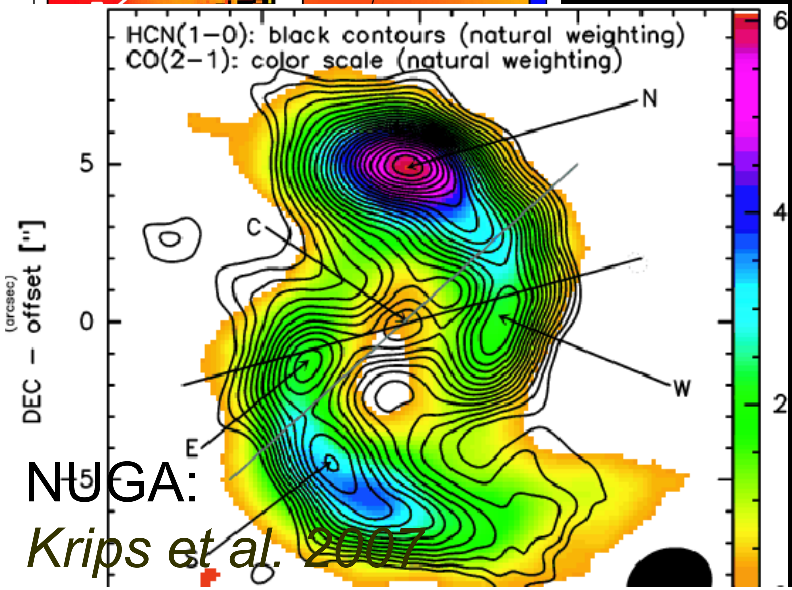
nuclear spirals seen in extinction only in IR → search for kinematic signatures instead?





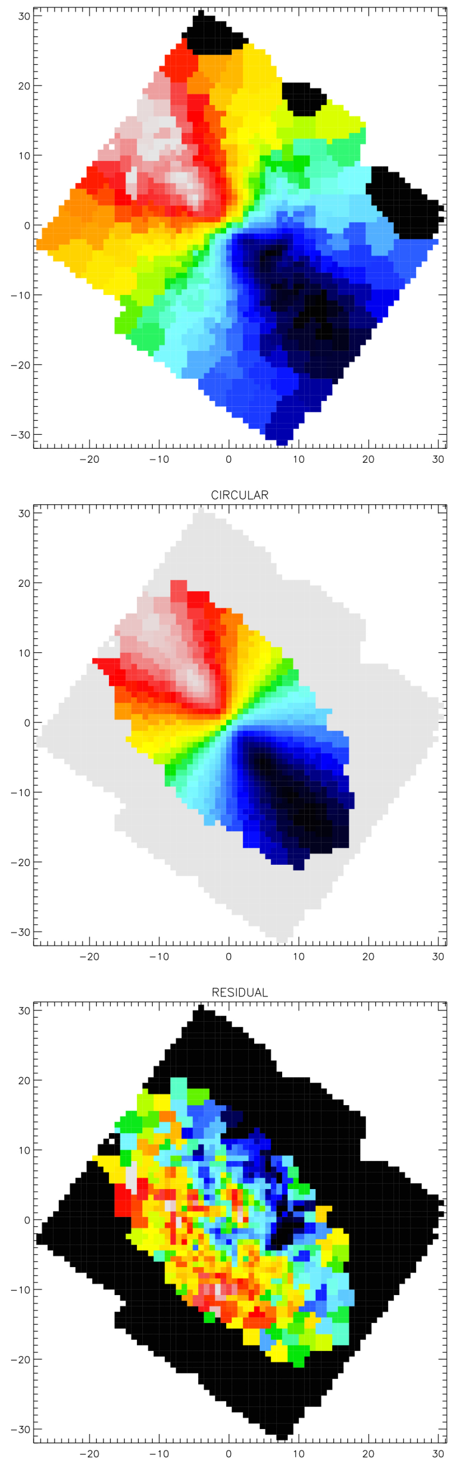
NGC 6951 (GMOS *Storchi-Bergmann et al. 2007*)

NGC 2974 (SAURON *D. Krajnovic - priv. comm.*)



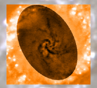
NUGA: *Krips et al. 2007*

COMMENT: nuclear spirals are just one of many inflow mechanisms; e.g. they will not form in thick clumpy disks seen in many Seferts by Hicks et al. 2009



Conclusions

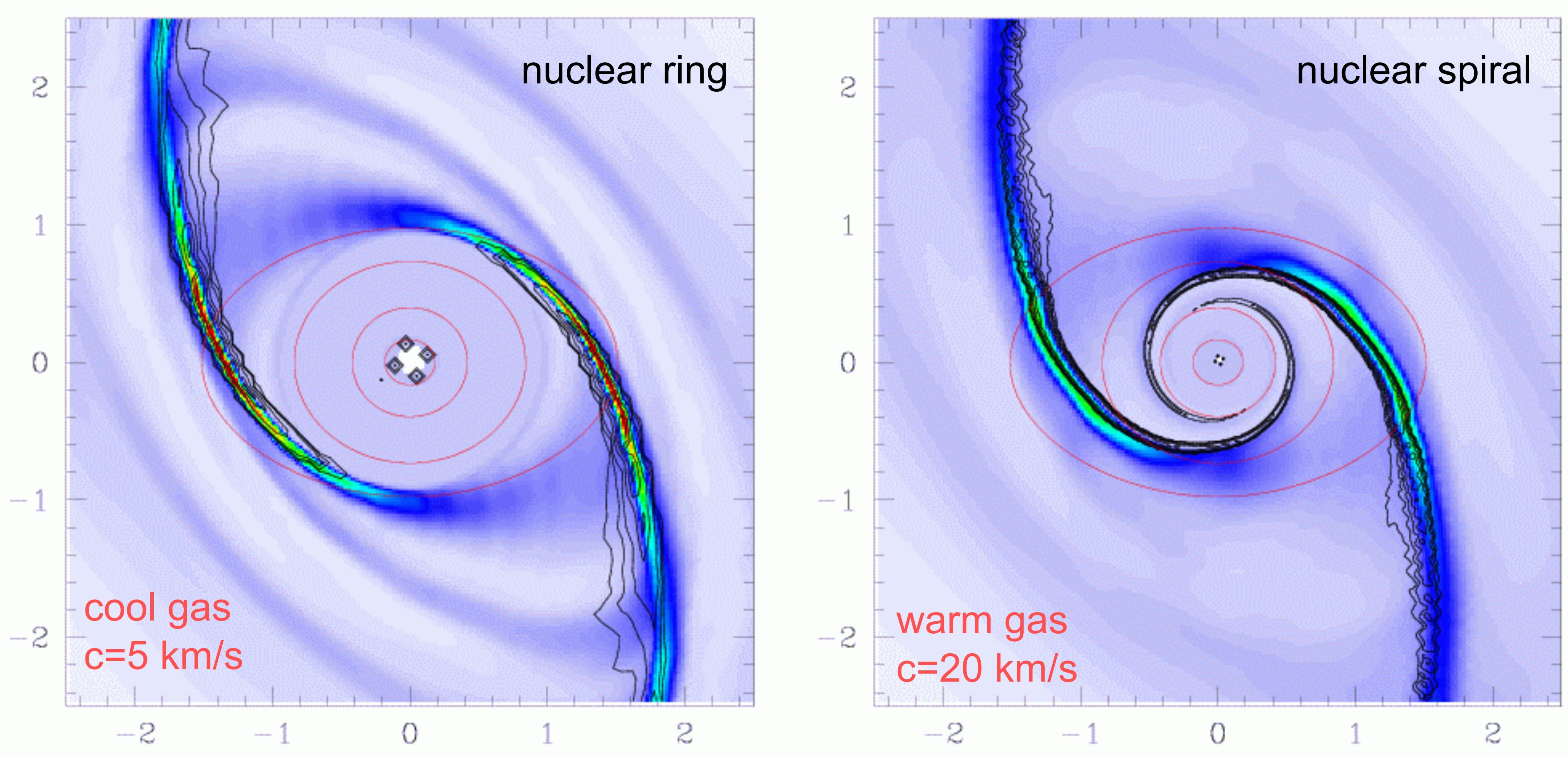
- nuclear spirals as pressure waves in gas triggered by asymmetry in mass distribution
  (different from classical stellar density waves)
- nuclear spirals can be shocks in gas, hence dissipation & inflow



- stellar & gas morphology & kinematics in the innermost 300 pc of NGC 1097 unveil a spiral shock in gas
- nuclear spiral shock in NGC 1097 can last for Gyrs, and cause gas inflow consistent with SF history

Formation of nuclear ring and of nuclear spiral:

pitch angle of the spiral higher at higher velocity dispersion in gas



Maciejewski 2004b