Nuclear spirals: a mechanism of gas inflow to innermost parsecs

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Prieto et al. 2005
Waves in disc in linear theory

Linear dispersion relation for waves in a disc:

\[ m^2(\Omega - \Omega_p)^2 - \kappa^2 - k^2c^2 + 2\pi G F |k| \rho = 0 \]

rotation curve  
gas pressure  
self-gravity

\[ (\Omega + \kappa/m - \Omega_p)(\Omega - \kappa/m - \Omega_p) = (kc/m)^2 > 0 \]
\[ = - 2\pi G F |k| \rho / m^2 < 0 \]

- spiral morphology of the waves
- pressure waves can propagate all the way to the galaxy centre → nuclear spirals
Stellar density waves vs. pressure waves in gas

- Stellar density waves amplified at the ILR
- Pressure waves in gas generated at the ILR

Toomre (1981)
Maciejewski (2004)
Properties of nuclear spirals in linear approximation

- radial \textit{inflow} along the arms, \textit{outflow} between the arms
- \textit{m}-arm photometric spiral corresponds to \textit{m-1}-arm \textit{kinematic spiral} in LOS velocity residuals \textit{(Canzian 1993)}
- linear analysis limited to $\Delta \rho/\rho << 1$ and residual velocity $<<$ sound speed
Hydrodynamical model of a nuclear spiral shock driven by a bar

- shock on the inside edges of the arms
- radial velocities up to 60 km/s when sound speed 20 km/s
- location of inflow/outflow and m/m-1 multiplicity of photometric/kinematic spiral like in the linear case

colour: gas density
contour: shock

projected density
residual LOS velocity
Gas inflow in nuclear spiral shock

- because of dissipation in the shock there is inflow
- naive estimate of inflow from gas density in the arms and radial velocity:
  \(~1.2 \text{Msun/yr} – \text{LARGE!}\)
- models show that inflow in the arms balanced by outflow between the arms
- hydrodynamical model indicates that the naive estimate must be reduced by a factor of \(~20\)
- nuclear spiral shocks not always associated with star formation
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
Case study: nuclear spiral in NGC 1097

- Intrinsic gas velocity dispersion: 30-45 km/s
- Intrinsic amplitude of LOS velocity residuals: 75 km/s

→ Spiral is a shock in gas

Prieto et al. 2005

GMOS

Fathi et al. 2006
SINFONI observations of NGC 1097

(Davies, Maciejewski, Hicks et al. 2009)

• SINFONI: AO NIR IFU (integral field unit) at the VLT, 4”x4” FOV
• data taken with the H+K grating, R~1500 resolution
• pixel scale: 0.05”x0.1” observed, 0.05”x0.05” of processed data cube
• total on-source integration time 40 mins
• PSF fitted with a Moffat function yield a K-band (non-stellar continnum) FWHM of 0.25” with 75% of the flux within the ‘core’
• kinematics of absorption and emission lines derived with LINEFIT (Davies et al. 2009 & in prep)
Stellar kinematics

- no coherent structure in residual velocity – no peculiar bulk motions of stars in bulge and disc
  → stars do not participate in the spiral pattern
- stellar velocity dispersion $\sigma \sim 150 \text{ km/s} > v_{\text{circ}}$
Absorption in continuum and molecular emission

• same 3-arm spiral in NACO J-band residuals and SINFONI K-band residuals

• low continuum coincides with H2 emission → both trace high density of gas

• H2-emission arm inside the extinction arm: gas entering the arm is heated in the shock

NACO

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

- Subtracting disk model (fixed PA & axial ratio) from H2 velocity gives residual velocity.
- **2-arm kinematic spiral** in residual velocity.
- Consistent with ionized gas kinematics traced by [NII] emission (GMOS, *Fathi et al. 2006*).
• 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?)

• why 3 arms? orbiting object *(Etherington & Maciejewski 2006)* or coupling of waves from 2 bars?

• nuclear spirals seen in extinction only in IR → search for kinematic signatures instead?
Kinematic signatures of other nuclear spirals

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

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

• nuclear spirals as pressure waves in gas, (different from classical stellar density waves)
• nuclear spirals can be shocks in gas, hence dissipation & inflow, but correct for interarm outflow
• 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