Feeding the central black hole and nuclear starbursts: gas inflow in nuclear spirals

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NGC 1097

Prieto et al. 2005
Bars as efficient drivers of inflow on large scales

velocity gradient

V band

Hα

LOS velocity

NGC 1530

Zurita et al. 2004

- but inflow stagnates in the innermost kpc
Possible drivers of inflow in the central kpc:

I. Nuclear bars

- 25-30% of barred galaxies host nested bars (*Erwin & Sparke 2002, Laine et al. 2002*)
- the two bars rotate with different angular velocities (*Corsini et al. 2003*)
- but it remains unclear whether nested bars can drive gas inflow
Possible drivers of inflow in the central kpc: II. Nuclear spirals

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

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

ILR

Illegible text: Maciejewski 2004
Nuclear spiral in NGC 1097

J-band residual

3-arm spiral

Prieto et al. 2005
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 continuum) 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

- subtracting from stellar velocity a simple axisymmetric disc model (DYSMAL code, Cresci et al. 2009) gives residual velocity
- no coherent structure in residual velocity – no peculiar bulk motions of stars in bulge and disc
- stellar velocity dispersion $\sigma \sim 150 \text{ km/s} > v_{\text{circ}}$
Absorption in continuum and molecular emission

- same 3-arm spiral structure in NACO J-band residuals and SINFONI K-band residuals
- low continuum coincides with H2 emission $\rightarrow$ absorption
• brightest H$_2$ emission along the inside edge of the negative stellar residuals (gas entering the arm heated in the shock?)
• molecular spiral of arm-width 0.4” can be traced to within 0.2” of the centre (resolution limit)
• extinction $A_v = 4.9 \pm 1.9$ from comparing K-band slope with stellar templates (screen approximation)
• extinction in the arm $A_v = 8.0 \pm 2.3$ with arm/interarm extinction ratio $2.0 \pm 0.3$ from J- and K-band contrasts
• gas surface density $140 \pm 40$ Msun/pc$^2$ in the arms and $70 \pm 17$ Msun/pc$^2$ between arms up to 4x smaller than CO estimates
H2 kinematics

• subtracting disk model (fixed PA & axial ratio) from H2 velocity gives residual velocity
• 2-arm kinematic spiral in residual velocity, projected amplitude 40 km/s
• consistent with ionized gas kinematics traced by [NII] emission (GMOS, *Fathi et al. 2006*)
Kinematics and dynamics of spiral density waves

- Velocity residuals of an m-arm spiral take shape of (m-1)-arm spiral inside corotation (Canzian 1993)
- Gaseous inner disk in NGC 1097 gravitationally stable $\rightarrow$ the spiral most likely pressure wave driven by bar or other mass asymmetry
- Intrinsic velocity dispersion in H2: 30-45 km/s; intrinsic amplitude of radial motion: 75 km/s $\rightarrow$ spiral is a shock in gas
- Shock on the inside of the arm in models of nuclear spiral shocks (Maciejewski 2004)
Gas inflow in nuclear spiral shock

- naive estimate of inflow from molecular gas density and radial velocity: $1.23 \pm 0.35$ Msun/yr – LARGE!
- models show that inflow in the arms balanced by outflow between the arms
- in the model most similar to gas kinematics in NGC 1097 the inflow is 0.1 Msun/yr while the naive estimate gives 2 Msun/yr
- after correction, the net inflow in the nuclear spiral in NGC 1097 is $\sim 0.06$ Msun/yr
Inside the 0.2” or 17 pc radius

- gas velocity dispersion exceeds its rotation velocity – **disk approximation no longer valid**
- nuclear starburst *(Storchi-Bergmann et al. 2005, Davies et al. 2007)* → nuclear spiral feeds gas reservoir that gives rise to nuclear starburst?
- 0.06 Msun/yr inflow rate consistent with the mass (10^6 Msun) and age (8 Myr or less) of starburst
- at this rate, ~2 Gyr is needed to drain all gas inside the nuclear ring → **nuclear spiral in quasi-equilibrium** (refilling from nuclear ring?)
Outstanding questions and future work

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

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

- 3-arm spiral inside the nuclear ring in NGC 1097 extends in to radius of 17 pc (resolution limit)
- the spiral indicates shock in gas: shocked H2 on inside edge of the arms, radial velocity amplitude, 2-arm kinematic spiral in residual velocity
- gas surface density in arms \( \sim 70 \text{ Msun/pc}^2 \), inflow rate 0.06 Msun/yr
- nuclear spiral can feed recurrent episodes of star formation in the innermost \( \sim 17 \text{ pc} \) radius for \( \sim 1 \text{ Gyr} \)
- gas dynamics within the \( \sim 17 \text{ pc} \) radius probably dominated by energy input from star formation