BAR-DRIVEN FUELING OF GALACTIC NUCLEI:
A 2D VIEW

Eric Emsellem

Abstract

I briefly discuss evidences for bar-driven gas fueling in the central regions of
galaxies, focusing on scales down to about 10 pc. I thus mention the building
of inner disks, and the link with resonances, as well as the corresponding kine-
matic signatures such as $\sigma$-drops and counter-rotating nuclear disks as probed
via integral-field spectroscopy.

Keywords: Galaxies, inner bars, inner disks, fueling, $\sigma$-drops

1. Introduction

Before embarking onto this short report on bar-driven fueling of the central
regions of galaxies, let me define what I mean by "fueling galactic nuclei". Going from the kpc scale down to the presumed black hole of a galaxy, we
progress through regions where the physical scales and regimes of the involved
processes vary considerably. We should therefore not expect a direct link be-
tween the large-scale dynamical processes (e.g. the presence of a bar), and the
central engine (accretion disk surrounding the black hole). I would also like to
follow the nomenclature advocated by Jean-Luc Nieto, and thus only use the
words "nucleus" and "nuclear" for structures at a scale of the order of $\sim 10$ pc
(an excellent illustration being the nearby nucleus of M 31). I will therefore
focus here on the question of "how to accumulate mass at the scales of galactic
nuclei, i.e. in the central tens of parsecs" (see also Emsellem 2004).

We know that bars can be efficient at redistributing gas within the stellar disk
of a galaxy: outwards when the gas is in between the outer Lindblad resonance
and Corotation, and inwards when it is inside Corotation (and outside the inner
Lindblad resonance - ILR - if there is one). We therefore expect structures to
build up at a scale related to the presumed ILR. The questions are therefore:
do we observe such features, and are they small enough to be considered as "nuclear" structures?
2. Building inner disks

There are numerous examples of galaxy structures which have obviously been formed under the influence of a bar, the most generic ones being galactic rings (see e.g. work by Buta and collaborators). I would however like to focus on another type of dynamically cold systems, namely the building of inner disks. Although the inner disk of e.g., the Sombrero galaxy qualifies as a secularly evolved structure (Emsellem 1995), one of the best case to date remains the photometric features exhibited by the nearly edge-on S0 galaxy NGC 4570: there is strong evidence that the two ring-like structures and the 100 pc inner disk of that galaxy are the result of bar-driven secular evolution (van den Bosch & Emsellem 1998). Numerical simulations by Friedli, Benz & Kennicutt (1994) predicted that a radially decreasing initial abundance gradient should evolve due to the presence of a bar, with a strong flattening of the gradient outside corotation, a weakened one inside the bar region and a possible starburst at the very centre. This seems consistent with the observed colour gradients in NGC 4570 along the minor-axis, which retains the original vertical gradient, and along the major-axis which shows a clear correlation with the presumed location of the bars and its resonances (Fig. 1). The jump from gas to stellar abundances, and the use of broad band colours to assess these gradients should forbid us to conclude too hastily. However, we recently

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Left panel: mean abundance gradients obtained after redistribution due to the presence of a bar (from Friedli, Benz & Kennicutt 1994). The slopes are clearly different inside and outside the bar. Right panel: \(V - I\) colour gradients along the minor and major axis of NGC 4570. The observed gradients are linked with the presumed locations of the resonances as expected.}
\end{figure}
obtained line-strength maps of NGC 4570 within the course of the SAURON survey (Bacon et al. 2001, de Zeeuw et al. 2002, Emsellem et al. 2004), in which we see a direct correspondence between the previously observed structures and the metal enrichment (as probed here by e.g. the Mgb index, Fig. 2).

Figure 2. Top panels: SAURON reconstructed intensity (left) and Mgb (right) maps (to appear in a forthcoming paper of the SAURON team). The structures observed in the Mgb map are clearly correlated with the presumed resonances, emphasized in the isophotes of an unsharp masking image of NGC 4570 (contours plots extracted from van den Bosch & Emsellem 1998).

3. Towards the nucleus

Inner disks with sizes ranging from 100 to 500 pc, such as the one observed in NGC 4570, are quite common in early-type galaxies and could indeed be the result of bar-driven accretion followed by star formation (e.g. see the case of NGC 3115). This would in fact require inner bars with diameter from ~ 200 to 1000 pc, similar to the ones now routinely observed in disk galaxies (Laine et al. 2002, Erwin & Sparke 2002). In some cases, such as the S0/a galaxy NGC 2974, the size of the fueled region (ILR) is less than 20 pc in diameter, a scale at which we can start making the link with the nucleus itself (Emsellem, Goudfrooij & Ferruit 2003).

Another clear case of gas fueling of the nuclear regions is provided by the high resolution $^{12}$CO(2-1) map of NGC 6946 (Schinnerer et al., in preparation; Fig.3). The spiral-like distribution of the molecular gas is reminiscent of the
dust lanes observed in barred galaxies, and indeed a small inner bar has been detected via K band imaging in this galaxy (Elmegreen et al. 1998). The amount of gas which is fueled within the central 20 pc is uncertain, but star formation is already ongoing there, which may thus lead to the formation of a flattened nuclear disk.

Figure 3. Right panel: $^{12}$CO(2-1) map obtained with the IRAM interferometer (from Schinnerer et al., in preparation) of the central kpc of NGC 6946, showing a two-arm spiral-like structure reminiscent of dust lanes in bars. Left panel: K band image (from Elmegreen et al. 1998) showing the presence of an inner bar in NGC 6946.

4. Signatures and the importance of bars

Looking for signatures of past accretion events, we should turn away from purely photometric features. The dynamical status of the central regions of galaxies may help us to probe such accretion events long after the nucleus itself has been formed. The so-called $\sigma$-drops (the DEBCA project: Emsellem et al. 2001), a central depression in the stellar velocity dispersion profile, are now routinely detected in disk galaxies (e.g. Marquez et al. 2004) and could indeed be the signatures we are looking for (Wozniak et al. 2003). It would be interesting to examine if there is any link between the blue nuclei observed in most spiral galaxies (e.g. Böker et al. 2004) and the presence of such $\sigma$-drops.

It should finally be made clear that bars are not the only way gas can be transported inside the central 10 pc or so. The first ingredient for a successful fueling is obviously the availability of gas. In this context, interactions and/or external accretion have certainly a significant role in galaxy evolution.
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(either with companions, or from large-scale structures; see Bournaud’s, and Combes’ contributions, these Proceedings). This is now clearly witnessed in NGC 7332, for which two-dimensional SAURON spectrography has been obtained (Falcon-Barroso et al. 2004). The ionized gas distribution and kinematics does not leave any doubt on the external origin of part of the dissipative component which is counter-rotating with respect to the stars. Evidences for the presence of a strong bar are also very strong: e.g. a boxy bulge, a cylindrical stellar velocity field. An hybrid scenario emerges in this case where the interaction with a companion provides the gas which is then fueled to the central inner 50 pc with the help of a bar (the formation of which could have been triggered by the interaction). It is finally important to note that the central stellar kinematics shows the presence of a counter-rotating stellar disk, less than 100 pc in diameter, a possible remnant of a past accretion episode.

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References

Bacon, R., et al. 2001, MNRAS, 326, 23
Boker, T., Sarzi, M., McLaughlin, D. E., van der Marel, R. P., Rix, H., Ho, L. C., & Shields, J. C. 2004, AJ, 127, 105
Elmegreen, D. M., Chromey, F. R., & Santos, M. 1998, AJ, 116, 1221
Emsellem, E., 1995, A&A, 303, 673
Emsellem, E., 2004, in The interplay between black holes, Stars, the ISM in galactic nuclei, IAU 222, Gramado, in press
Emsellem, E., Greusard, D., Combes, F., Friedli, D., Leon, S., Pecontal, E., & Wozniak, H. 2001, A&A, 368, 52
Emsellem, E., Goudfrooij, P., & Ferruit, P. 2003, MNRAS, 345, 1297
Erwin, P. & Sparke, L. S. 2002, AJ, 124, 65
Falcon-Barroso, J., Peletier, R. F., Emsellem, E., Kuntschner, H., Fathi, K., Bureau, M., Bacon, R., Cappellari, M., Copin, Y., Davies, R. L., de Zeeuw, T., 2004, MNRAS, 350, 35
Friedli, D., Benz, W., Kennicutt, R., 1994, ApJL, 430, 105
Laine, S., Shlosman, I., Knapen, J. H., & Peletier, R. F. 2002, ApJ, 567, 97
Marquez, I., Masegosa, J., Durret, F., Gonzalez Delgado, R. M., Moles, M., Maza, J., Perez, E., & Roth, M. 2003, A&A, 409, 459
van den Bosch, F. C. & Emsellem, E. 1998, MNRAS, 298, 267
Wozniak, H., Combes, F., Emsellem, E., & Friedli, D. 2003, A&A, 409, 469
de Zeeuw, P. T., et al. 2002, MNRAS, 329, 513