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Tracing the External Origin of the AGN Gas Fueling Reservoir

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Near-infrared observations of the active galaxy MCG–6-30-15 provide strong evidence that its molecular gas fueling reservoir is of external origin. MCG–6-30-15 has a counter-rotating core of stars within its central 400 pc and a counter-rotating disc of molecular gas that extends as close as ∼50–100 pc from the central black hole. The gas counter-rotation establishes that the gas reservoir in the center of the galaxy originates from a past external accretion event. In this contribution we discuss the gas and stellar properties of MCG–6-30-15, its past history and how the findings on this galaxy can be used to understand AGN fueling in S0 galaxies with counter-rotating structures.

Keywords: Active Galactic Nuclei, black hole, MCG–6-30-15, counter-rotation, fueling, infrared

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1. INTRODUCTION

Supermassive black hole accretion, the powering mechanism behind Active Galactic Nuclei (AGN), requires a supply of gas to the central supermassive black hole. To understand the physics of how AGN are powered, or fueled, it is therefore essential to study the environment in the host galaxy and the mechanisms able to drive gas to its central regions. The active S0 galaxy MCG–6-30-15 provides an excellent opportunity to study the origin of the AGN fueling gas. It has recently been discovered that the stellar core in MCG–6-30-15 counter-rotates with respect to the main stellar body of the galaxy (Raimundo et al., 2013). The counter-rotating core has a relatively small size ($r < 1.25'' \sim 200$ pc) and was only discovered as a result of the high spatial resolution achievable with SINFONI on the VLT, using a combination of adaptive optics and infrared integral field spectroscopy.

The formation scenarios for counter-rotating stellar cores require the accretion of stars and/or gas with a distinct angular momentum, into the center of the galaxy. The main mechanisms to form counter-rotating structures are thought to be: (i) major mergers (e.g., Hernquist and Barnes, 1991; Bois et al., 2011; Tsatsi et al., 2015), (ii) non-merger mechanisms that include the infall of gas with misaligned spin through large scale filaments, early in the history of the galaxy (Algorry et al., 2014) or (iii) late accretion of gas (from galaxy neighbors or via a minor merger) followed by in-situ star formation (e.g., McDermid et al., 2006). The late accretion of gas from companions is thought to produce small stellar counter-rotating cores (diameter < 1 kpc). The stellar populations in these cores are younger than the main stellar body of the galaxy, similar to what is observed in MCG–6-30-15 (Raimundo et al., 2013).

In this contribution we present the stellar and molecular gas dynamics in the nucleus of MCG–6-30-15 and use the results on this galaxy to discuss the implications of counter-rotating stellar core formation to AGN fueling.

2. RESULTS

To evaluate the impact on AGN fueling we are interested in identifying mechanisms that can drive molecular gas to the center of galaxies so that it can then be accreted by the supermassive black

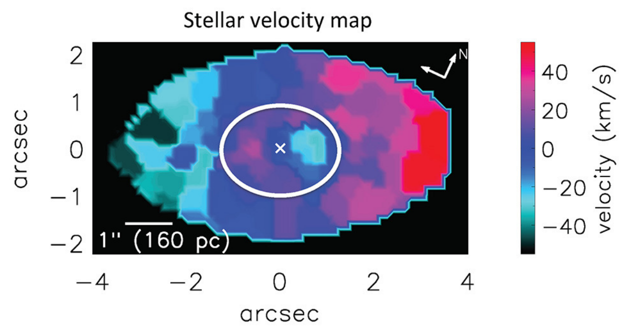

FIGURE 1 | Stellar velocity field for MCG–6-30-15. The region of the counter-rotating core is indicated by the white ellipse. The cross indicates the position of the AGN. Reproduced with permission from Raimundo et al. (2017).

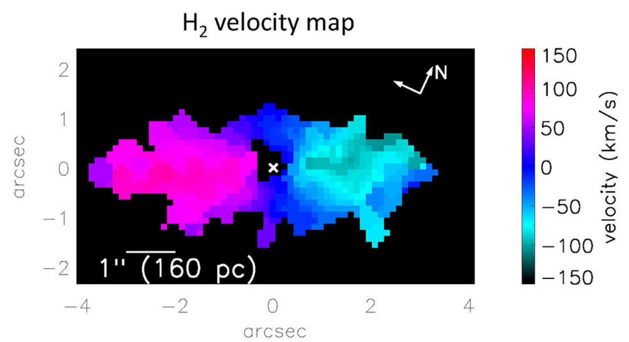

FIGURE 2 | Molecular gas velocity field determined from the H_2 2.12 μm emission line. The cross indicates the position of the AGN. Reproduced with permission from Raimundo et al. (2017).

hole. Counter-rotating stellar nuclear structures may contribute to AGN fueling if their formation is associated with inflow of gas into the center of the galaxy. With new K-band SINFONI data, Raimundo et al. (2017) determined the molecular gas dynamics in MCG–6-30-15 to investigate if the stellar counter-rotating core and molecular gas share similar dynamics. In **Figure 1** we show the stellar velocity field first measured in Raimundo et al. (2013). The stellar core rotates in the opposite direction of the main stellar body of the galaxy. The black ellipse delimits the counter-rotating stellar core. In **Figure 2** we show the dynamics of the molecular gas determined from the H_2 2.12 μm emission line observed in the K-band. It is clear from **Figures 1**, **2** that the molecular gas has the same direction of rotation as the stellar counter-rotating core, i.e. the molecular gas counter-rotates with respect to the main stellar body of the galaxy (Raimundo et al., 2017). From the integrated H_2 2.12 μm line luminosity and using a conversion between line luminosity and molecular gas mass (Mazzalay et al., 2013), the estimated total molecular gas mass is $M_{mol} = 3.4 \times 10^7$ $M_\odot$ within the spatial region of the counter-rotating core and $M_{mol} = 5.8 \times 10^7$ $M_\odot$ in total (i.e. for $r < 3.5''$).

3. DISCUSSION

3.1. Origin of the Counter-Rotating Gas

Molecular gas counter-rotation is a clear signature of its external origin, in particular in S0 galaxies (e.g., Bertola et al., 1992; García-Burillo et al., 1998; Davis and Bureau, 2016). MCG–6-30-15 is part of a small group of galaxies and therefore there are neighbor galaxies that could in theory provide this gas. There is also a dust lane across the plane of the galaxy that indicates the possibility of a past galaxy interaction. The dynamics of the molecular gas indicates that it is associated with the counter-rotating stellar core, as they both counter-rotate in the same direction, 180 degrees from the rotation of the main stellar body of the galaxy. Additionally, there is evidence that the stellar population in the counter-rotating core is somewhat younger than in the main body of the galaxy (Raimundo et al., 2013). The best explanation for the set of observations and properties of MCG–6-30-15 is that this galaxy had an external accretion event in its recent past. The external accretion event could have been the accretion of gas from a neighbor or a minor merger with a small gas-rich satellite galaxy. From this external interaction, gas with a distinct angular momentum was driven to the center of the galaxy, where it settled on a disc that counter-rotates with respect to the galaxy's main body rotation. A younger stellar population formed from the accreted gas and created the stellar counter-rotating core we observe. The external gas formed or replenished the AGN fueling reservoir at hundreds of parsecs scales and the molecular gas observed today is a remnant of the initial gas inflow.

3.2. Impact on AGN Fueling

S0 galaxies have typically low levels of native gas and therefore external gas can be a significant source of fresh fuel. As can be seen from the observations of MCG–6-30-15, the externally accreted gas is able to reach the central $r \sim 50$–100 pc of the galaxy which is the physical scale of the AGN molecular gas fueling reservoir. The presence of counter-rotating molecular gas at these scales means that the external gas creates or replenishes the AGN gas reservoir. The amount of molecular gas is significant, we observe $M_{mol} = 3.4 \times 10^7$ $M_\odot$ in the central 400 pc. This means that the counter-rotating gas is enough to power the AGN for 6.9 Gyr, assuming that the gas is used solely to power the AGN at its current mass accretion rate of $\dot{M} = 5 \times 10^{-3} M_\odot/yr$ (assuming accretion efficiency $\epsilon = 0.1$ and $L_{bol} = 3 \times 10^{43}$ erg s^{-1} from Lira et al., 2015). The reservoir of molecular gas in the central hundreds of parsecs can also be used to form stars which may in turn fuel the AGN (Davies et al., 2007). Our results on MCG–6-30-15 are in line with suggestions that AGN fueling in S0 galaxies is predominantly driven by external gas accretion (Davies et al., 2014).

3.3. General Implications

MCG–6-30-15 is one of the brightest AGN with a counter-rotating core of stars. Most of the other systems with counter-rotating stellar cores are quiescent or show low level of nuclear activity. This does not necessarily mean that there is lack of AGN with counter-rotating cores. To detect small counter-rotating cores, high spatial resolution observations are needed and integral field spectroscopy has opened up the possibilities in this field. However, AGN are typically selected out of studies with integral field spectroscopy since the frequent goal of these studies is to probe the host galaxy properties. The presence of an AGN hinders this goal due to the characteristic broadband AGN emission that masks the host galaxy spectral features. Therefore it is possible that our current knowledge of counter-rotating systems is biased toward quiescent galaxies and low luminosity AGN. To understand if there is a direct connection between external gas accretion and AGN fueling, future work will have to extend the study of counter-rotating cores to target galaxies with a broad range of AGN activity.

3.4. Conclusions

In this contribution we presented the results on the origin of the AGN molecular gas fueling reservoir in the S0 galaxy MCG–6-30-15, determined from the dynamics of the stars and gas in the central hundreds of parsecs of the galaxy. The work on MCG–6-30-15 shows that counter-rotating stellar cores, when associated with gas, may act as a tracer of external gas inflow into the nuclei of galaxies. In S0 galaxies in particular, the external accretion of gas is likely to create, or make a significant contribution to the existing central gas reservoir for AGN fueling.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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