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Near-infrared study of OH megamaser galaxies

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Abstract. OH megamaser galaxies (OHMGs), a subset of Ultra-Luminous Infrared Galaxies (ULIRGs), are of particular interest because they may represent a critical short-lived transition phase connected to the onset of rapid nuclear fueling, which in turn leads to the development of a circum-nuclear gas disk and the initiation of Active Galactic Nuclei (AGN) or starburst winds. In this study, we present Near-Infrared (NIR) spectroscopic study of 9 OH Megamaser Galaxies (OHMGs), which 5 were observed using NASA Infrared Telescope Facility (IRTF)/SpeX spectrograph in cross-dispersed mode and 4 were observed using William Hershel Telescope (WHT)/LIRIS, both observations covered the range in the interval of 0.7 to 2.4μm. OHMGs of our sample showed interesting features - among them we have spectra dominated by strong emission lines of HI, HeI, HeII, [SII], [FeII], as well as molecular hydrogen. We can also seen CN and CO absorption lines, which are is related to population of the red (super)giants in the nuclear region. We could conclude that two galaxies in our sample host an AGN, while other two are starburst galaxies.

Resumo. Galaxias Megamaser de OH (OHMGs), um subconjunto de Galaxias Ultra Luminosas no Infravermelho (ULIRGs), são de particular interesse porque podem representar uma fase crítica de transição de curta duração ligada ao início do rápido abastecimento de combustível nuclear, que por sua vez leva ao desenvolvimento de um disco de gás circum-nuclear e o início de ventos do tipo Nucleo Ativo de Galaxias (AGN) ou starburst. Neste estudo, apresentamos dados espectroscópicos NIR de 9 OHMGs, dos quais 5 foram observados usando o espectrógrafo NASA Infrared Telescope Facility (IRTF) / SpeX no modo dispersão cruzada e 4 foram observados usando William Harshel Telescope (WHT) / LIRIS, ambas as observações cobriram a faixa no intervalo de 0,7 a 2,4μm. OHMGs da nossa amostra mostraram características interessantes entre eles temos espectros dominados por linhas de emissão forte de HI, HeI, HeII, [SII], [FeII], bem como hidrogênio molecular. Podemos também ver as linhas de absorção CN e CO, que estão relacionadas com a população dos gigantes (super) vermelha. Foi possível concluir que duas galáxias em nossa amostra possuem um AGNs, enquanto outras duas galáxias são foram classificadas como starburst.

Keywords. Galaxies: interactions–Galaxies: active–Galaxies: stellar content–ISM: molecules–Masers–Radio continuum:galaxies

1. Introduction

The disturbed morphologies of Luminous and Ultra-Luminous Infrared Galaxies (LIRGs and ULIRGS, respectively) suggest that these gas-rich galaxies are undergoing collisions or mergers. They are thought to represent a key stage in galaxy evolution in which tidal torques associated with mergers drive gas into the galaxy core, leading to starbursts and fueling an embedded AGN, with ULIRGs reaching quasar-like powers at infrared wavelengths ($> 10^{11} L_{\odot}$). OHMGs is a subset of ULIRGs that radiate lines at 1665 and 1667 MHz and there are evidence that they contain an energetically important, dust-obscured AGNs. Physical properties that distinguish OHM hosts from other [U]LIRGS are: (i) OHMGs have the highest mean molecular gas densities, $(H_2)=10^{3-4}\mathrm{cm}^{-3}$, (ii) OHM hosts are a distinct population in the nonlinear part of the IR-CO relation; and (iii) their hosts have exceptionally high dense molecular gas fractions ($L_{HCN}/L_{CO} > 0.07$), perhaps associated with a temporal spike in tidally driven density gas inflow (e.g. Ho 2005; Lo 2005; Perr & Dyson 1985; Soifer et al. 1987; Scoville & Norman 1989; Sanders et al. 1988). In this context, OHMGs are therefore signposts marking the most intense, compact, and unusual modes of [U]LIRGS in the local universe.

Early surveys have shown that OHMGs tend to be found in warmest ULIRGs and there is continuing debate as to whether starbursts or AGNs are the dominant sources of dust and gas heating. It also remains unclear how the OH maser emission is related to the nature of the dominant heating source and to the other components of the host galaxies (see Sanders et al. 1988; Treister et al. 2012, and references therein). To address the issues, we are carrying out a comprehensive multiwavelength space and ground study of a large sample (~ 70 objects) of OHMGs with the overall objective of relating the merger state of the OHMG (as traced by the structural properties of the spheroid, including dynamical masses) to the growth phase of the AGN, the nuclear starburst, and the concentration and structure of the

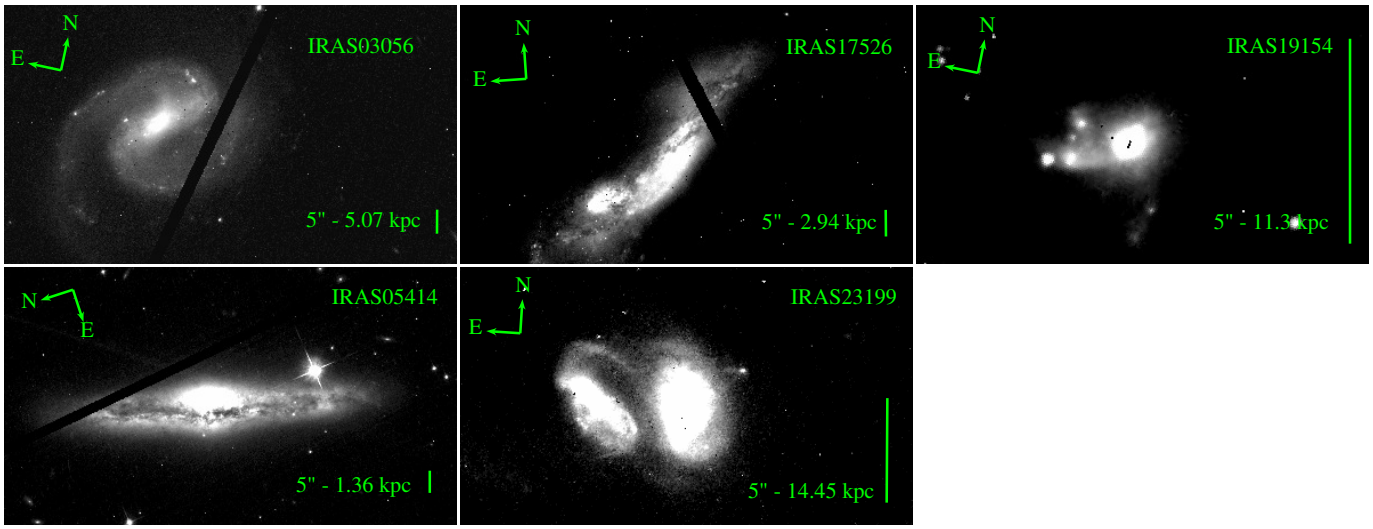

Figure 1: Galaxies that were observed using NIR spectroscopy data. Images obtained with ACS F814W (i band) of our OHMG sub-sample observed in Cycle 17 of the Hubble Space Telescope. The vector in the bottom right corner represents 5 arcseconds.

Table 1: Observation log and basic galactic properties for the sample.

ID (1)	Galaxy (2)	z (3)	R.A. (4)	DEC (5)	Type (6)	Airmass (7)	Date of Observation (8)	On-source Integration time (h) (9)	PA (°) (10)
1	Mrk 926	0.04686	23h04m43.478	-08d41m08.62s	-	1.137	09-14-2016	0.500	85.00
2	IRAS 05414+5840	0.01486	05h45m47.88s	+58d42m03.9s	S2	41.00	09-14-2016	0.150	41.00
3	IRAS 01364-1042	0.04825	01h38m52.921	-10d27m11.42s	-	1.199	09-14-2016	0.399	150.00
4	IRAS 03056+2034	0.02744	03h08m30.710s	+20d46m20.04s	SB	1.07	09/07/2014	0.39	17
5	IRAS 04332+0209	0.01197	04h35m48.369s	+02d15m28.97s	SB	1.399	09-14-2016	0.449	120.00
6	IRAS 17526+3253	0.02601	17h54m29.41s	+32d53m14.2s	-	1.370	09-14-2016	0.399	283.00
7	IRAS 19154+2704	0.09938	19h17m31.41s	+27d10m06.0s	-	1.000387	09-06-2014	1,5	0.00
8	IRAS 23135+2516	0.02742	23h16m00.70s	+25d33m24.1s	S2	1.031443	09-07-2014	1	25.00
9	IRASF 23199+0123	0.13569	23h22m31.63s	+01d39m28.1s	-	1	09-07-2014	1.7	95

ionized gas and radio morphology (Sales et al. 2015; Hekatelyne et al. 2018a,b, Sales et al. 2018 submit). Keeping this in mind, we aim to derive the relative contributions of the embedded AGN and/or staburst activies using near-infrared (NIR) spectroscopy data and we are presenting here a NIR study of 9 OHMG galaxies presented in Figure 1.

2. Observation and reduction

In this study, we present NIR spectroscopic data of 9 OHMGs,of which5 were observed using SpeX spectrograph. SpeX is a medium resolution spectrograph (R = $\Delta\lambda/\lambda$ ~ 2000) that in cross-dispersed mode covers the range in the interval of 0.7 to 2.4μm. This instrument was constructed at the Institute of Astronomy, by the NASA Infrared Telescope Facility (IRTF).The other 4 galaxies were observed by the William Herschel Telescope (WHT) using LIRIS spectrograph with two low-resolution (R = 1000) covering same spectral range of SpeX with two ZJ and HK grisms. Data were obtained in 2014b (WHT/LIRIS: PI - Colina L.) and 2016-B (IRTF/SpeX 2016B125: PI - Sales D.). Observation were executed nodding in an AB-BA source pattern and A0V stars were observed close to the galaxies in order to provide telluric standards at similar airmasses. Table 1 shows information about the our sample and the observation conditions.

Data reduction were performed using SPEXTOOL, which is a code provide by the SpeX team for the IRTF community[1]. To derive emission line fluxes we use our own routine written in python, as well as a package in IRAF software. Figure 2 shows OHMG spectra with normalized fluxes at 1.2μm. Noise coming from the low atmospheric transition was removed and emission lines have been identified (see Figure 2).

[1] SPEXTOOL is available from the IRTF website: http://irtf.ifa.hawaii.edu/Facility/spex/spex.htm

3. Results and discussion

We can see in Figure 2 that NIR spectra of our sample are dominated by ionic lines with low and high ionization species, molecular hot H_2 lines, and hydrogen recombination lines. The following emission lines were observed at least 3σ of the noise: [S III]0.9μm, Paδ, He1.08μm, [Fe II]1.2-1.6μm, Paα, $H_2$1.9-2.2μm, and Brγ emission lines. From Figure 2 we can also see that IRAS19154+2704 presents broad-emission components in the hydrogen recombination lines similar to Seyfert 1 Mrk926 (for comparison).

Our OHMG sample not only presented ionic, hot molecular H_2 lines, and hydrogen recombination lines but also CO molecular bands at 2.29, 2.32 and 2.35μm (Figure 3). According to evolutionary population synthesis and confirmed in some extragalactic observation CN (1.1μm) and CO (2.3μm) bands are features arising from stars in the thermally pulsing asymptotic giant branch (TP-AGB) phase. These signatures have been used as a clear feature of the presence of young/intermediate (0.3≤ t ≤2 Gyr) stellar population, which highlights a presence of starburst activities (Rieke et al. 1980; Maraston 2005; Riffel et al. 2007, 2008).

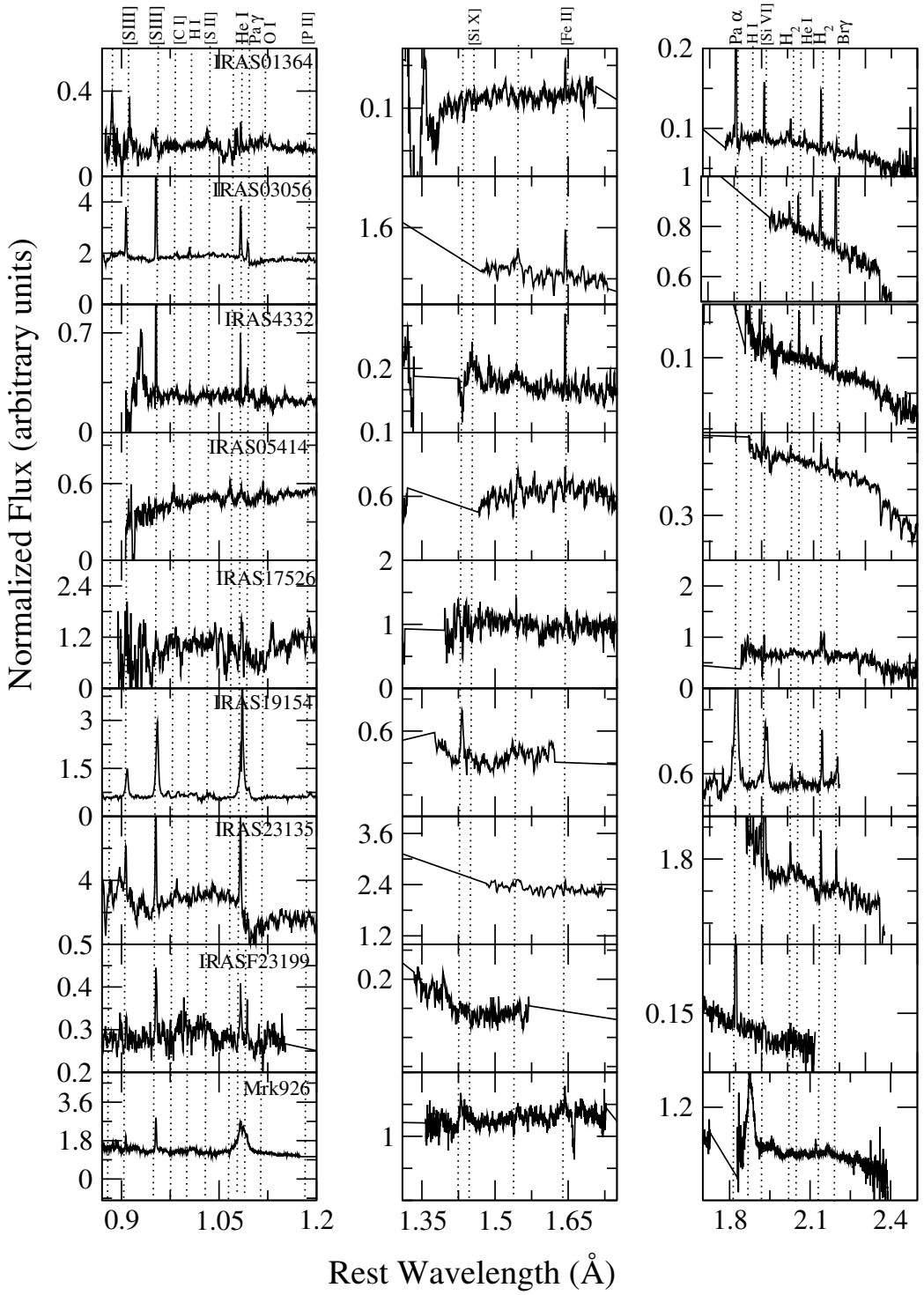

Figure 2: NIR spectra of our OHMG's sample. Spectra have normalized fluxes and rest wavelength in Åunits. Left-panels show H band, middle- and right-painels present J and K bands respectively.

In order to investigate excitation mechanisms of our OHMG's sample we present a diagnostic diagram suggested by Rodríguez-Ardila et al. (2004) that uses emission line ratios of H_2 2.1μm, Brγ and [Feii] 1.2μm, Paβ (see also (Riffel et al. 2013). We had four galaxies that provided these emission lines and it is clear from this diagram that two galaxies are dominated by starburst activities.

IRAS05414+5840 was the only OHMG galaxy that falled in to AGN's region of NIR diagnostic diagram, exhibing a clear AGN classification (see figure 4). This galaxy has a spiral edge-on morphology (see figure 1) with a well formed bulge. IRAS19154+2704 also was classified as an AGN source because its OHMG shows broad components at Paβ, He 1.08μm, Paα, and Brγ emission lines(Rodríguez-Ardila et al. 2004; Riffel et al. 2013). IRAS19154+2704 shows a point like core morphology with smaller with smaller interacting galaxies connected by tidal tails (see figure 1).

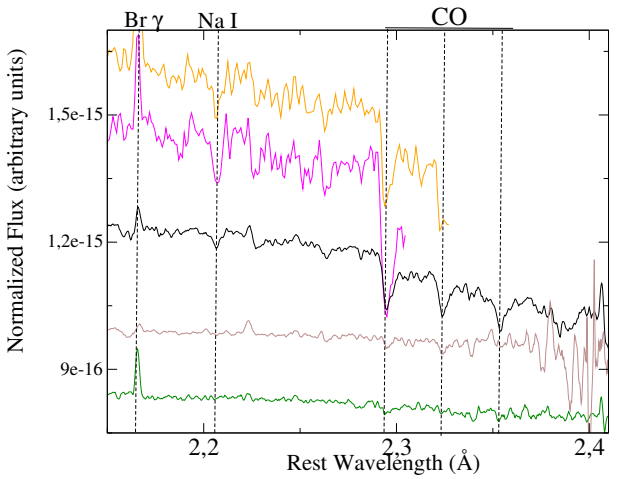

Figure 3: One-dimensional spectra of our sample highlighting CO absorption lines (dashed-lines) at 2.29μm, 2.32μm and 2.35μm. spectrum yellow IRAS03056+2034, pink IRAS23135+2516, black IRAS05414+5840, brown IRAS01364-1042, green IRAS332+0209 all in normalized at arbitrary flow and with wavelength in μm.

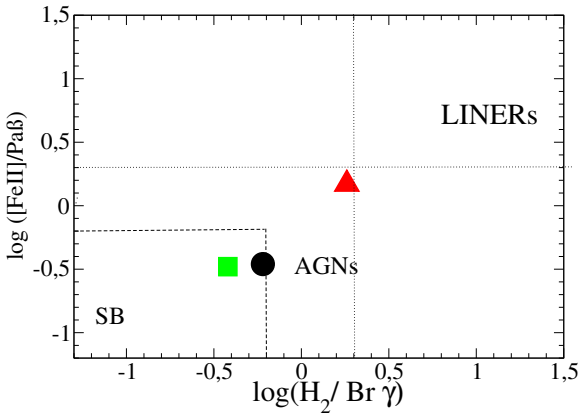

Figure 4: Diagnostic diagram of the H_2 2.1μm/Brγ and [FeII]1.2μm/Paβ line ratios of our OHMG's sample. Red triangle IRAS05414+5840, black circle IRAS03056+2034, green square IRAS04332+0209.

4. Conclusions and perspectives

Of the 9 observed OHMGs, we were able to derive excitation mechanism for three targets using a diagnostic diagram, where two of them were classified as Starburst galaxies and one as AGN source. Other AGN signature was found in IRAS19154+2704 by strong coronal lines as well as broad components in Paδ, He 1.08μm, Paα, and Brγ emission lines. This broad emission has equivalent width comparable with those found in Seyfert 1 galaxies (see Mrk926 spectrum in figure 2). IRAS17526 + 3253 showed low signal-to-noise ratio, it being possible to observe only H2 lines at 2.12μm and MgII at 2.13μm. We also could see that most of galaxies in our sample showed CN and CO molecular absorption lines indicating presence of young/intermediate stellar population (Figure 3).

Our perspective of continuing this study will follow the next step, and aims to: Derive the stellar population of OHMGs that presented absorption lines of CN and CO. Determine the mass and kinematics of the hot (2000 K) molecular gas of H_2.

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