Gas kinematics and excitation in the inner few hundred parsecs of NGC 1068 from Gemini NIFS observations

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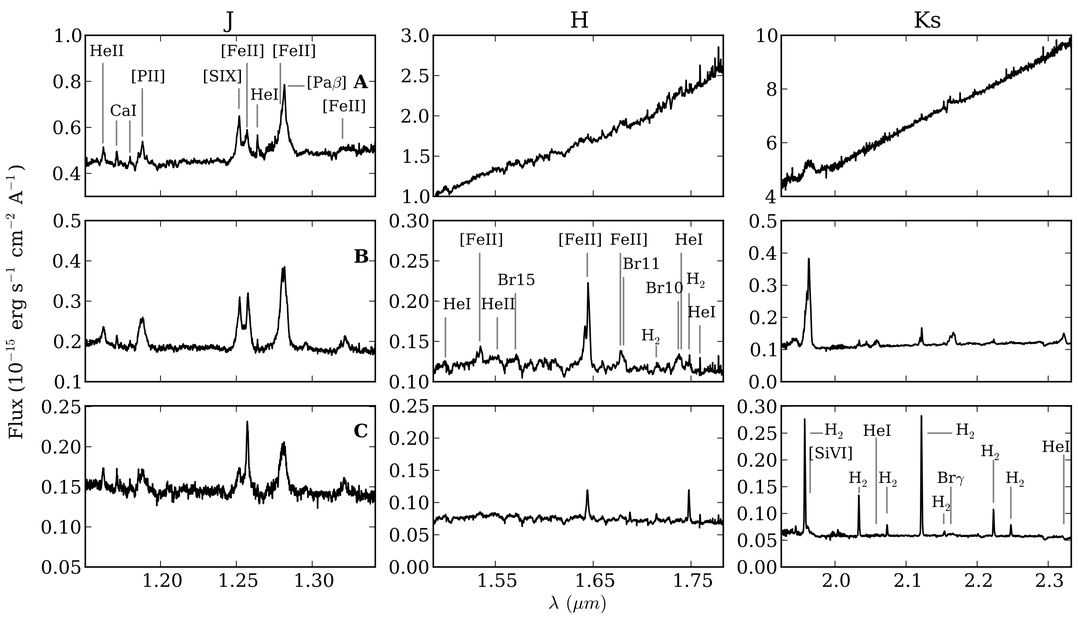
Summary

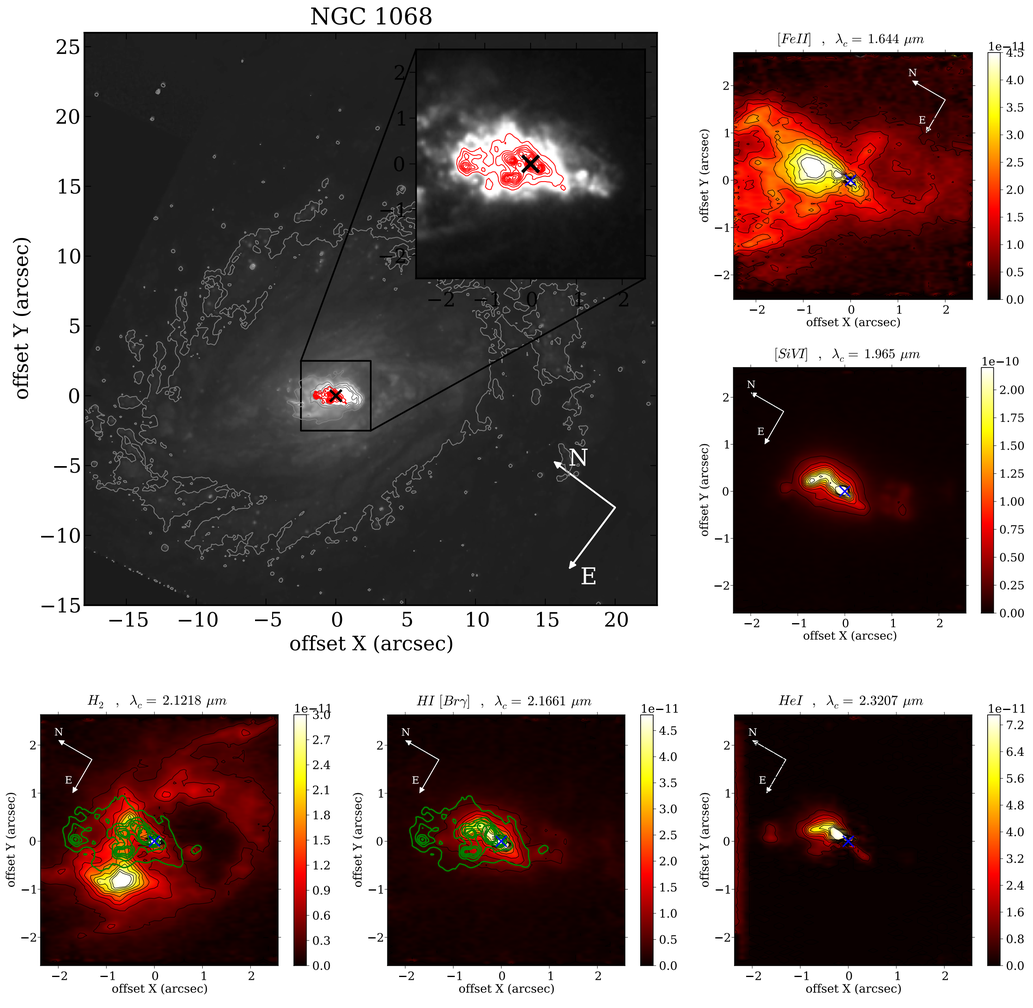
We present integral field spectroscopy in the near-infrared of the inner $350 \times 350\,pc^2$ of NGC 1068, which were used to build emission-line intensity maps, line-ratio maps, and channel maps in order to map the flux distribution, excitation and kinematics of the narrow-line region.

Observations

Spectroscopy in the J, H and K bands at an angular resolution of $0.12\,arcsec$ ($\approx 8\,pc$) obtained with Gemini Near-Infrared Integral Field Spectrograph (NIFS) in combination with the adaptive optics module ALTAIR. The spectral resolution of the data is $R \approx 5300$. Below we show three sample integrated spectra of 0.3"×0.3" at J, H and K_s bands, around three positions: (A) continuum peak, (B) FeII maximum, and (C) H_2 maximum.



Flux Distribution



Above we show emission-line intensity maps of $[FeII]$ ($1.644\,\mu m$), $[SiVI]$, H_2 ($2.1218\,\mu m$), $Br\,\gamma$ and HeI ($2.3207\,\mu m$). The large panel shows an HST F606W image of the galaxy with the field-of-view of the NIFS observations indicated by the square. The insert is an $[OIII]\,5007$Å emission-line intensity map [1], whose contours are overploted in green on the emission-line intensity maps of $Br\gamma$ and H_2.

The $[FeII]$ $1.644\mu m$ emitting gas shows a bi-polar hourglass shaped morphology oriented along NE–SW. The $[SiVI]$, $Br\,\gamma$ and HeI emitting gas are also elongated following the same orientation, being co-spatial with the $[OIII]$ emission, and extend mostly to the N, in the region where the $[FeII]$ emission is brightest. The coronal gas emission is resolved, consistent with an origin in the inner narrow-line region. The flux distribution of the molecular H_2 gas is completely distinct from that of the ionized gas emission, being concentrated in a circumnuclear ring with a diameter of $\approx$ $220pc$.

Channel Maps movies

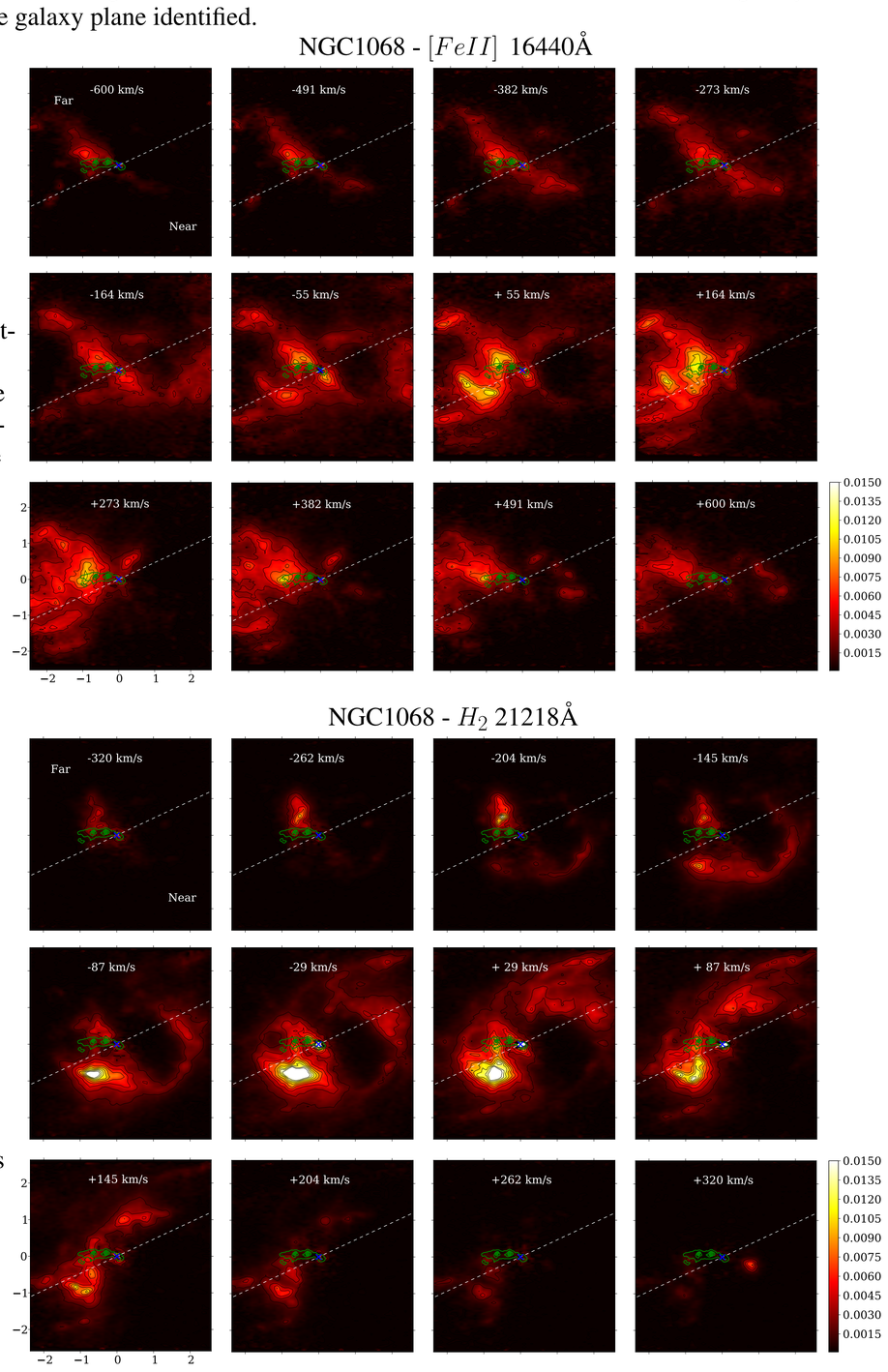
We also created a code (developed in Python) to make movies from sequences of channel maps extracted from the datacube along the emission-line profiles in velocity space. These movies enable us to quickly inspect the kinematics of the emitting gas and are available at http://www.if.ufrgs.br/∼thaisa/ifu_movies.

Kinematics

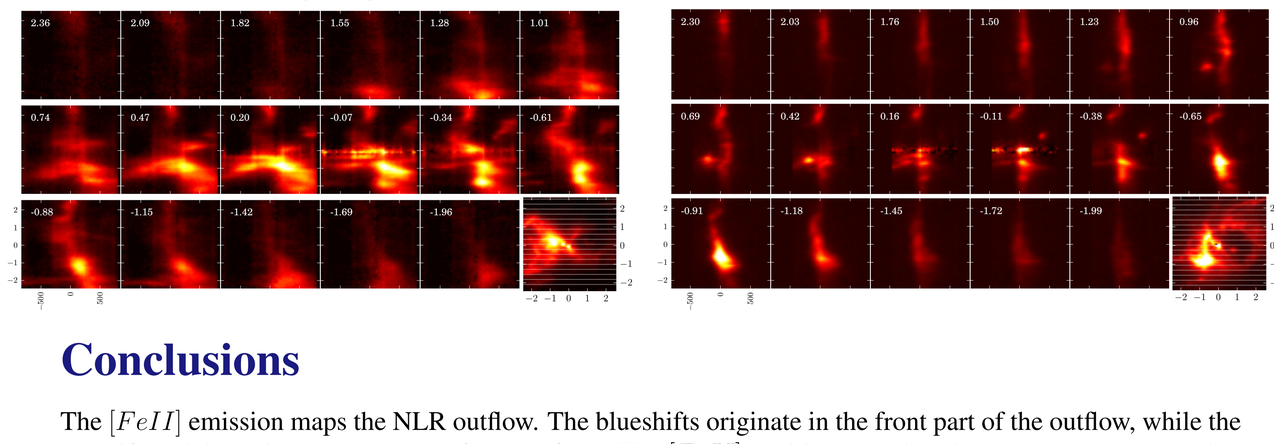
Channel maps were obtained along the emission-line profiles. Below we show $[FeII]$ $1.644\mu m$ (top) and H_2 $2.1218\mu m$ (bottom) lines, with the velocities identified at the top of each panel. Superposed as green contours we show a 5GHz radio MERLIN image from [2]. The dashed white line is the line of nodes of the galaxy, with the near and far sides of the galaxy plane identified.

The highest blueshifts in the $[FeII]$ channel maps are observed to the North, in approximate alignment with the radio map, and are not at the nucleus, indicating that the gas increases its velocity outwards (acceleration as pointed out in [4]). At somewhat lower blueshifts, there is a structure running north-south, delineating one edge of the hour-glass shape observed in the integrated flux distribution. At lower blueshifts, the flux distribution delineates both edges of the hourglass, while at positive velocities, the emission is restricted mostly the NE part of the hourglass.

The H_2 channel maps reach much lower velocities than those of $[FeII]$, with blueshifts restricted mostly to the near side of the galaxy and redshifts to the far side, suggesting that the H_2 ring is expanding in the galaxy plane. A "tongue" to the North (connecting the nucleus and the ring) shows gas in blueshift, which can be interpreted as an inflow towards the nucleus, as previously reported in [3].



Position-velocity Diagrams



Conclusions

The $[FeII]$ emission maps the NLR outflow. The blueshifts originate in the front part of the outflow, while the redshifts originate in the back part of the outflow. The $[FeII]$ position velocity diagrams show acceleration of the gas outwards from the nucleus. As previously proposed by [5] and [6], our observations also indicate that the NE part of the cone is tilted toward us and is in front of the plane of the galaxy, while the SW part has fainter emission, consistent with being behind the galaxy plane. The H_2 emission maps gas in the plane of the galaxy; its kinematics is dominated by expansion of gas with small rotation in the galaxy plane. We also observe the "tongue" reported by [3] which suggests inflow of molecular gas from the ring towards the nucleus.

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