A Structural and Spectroscopy Study of the Clusters Surrounding the Orion Nebula: NGC 1977 and NGC 1981

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Introduction

The study of young open clusters (OCs) provides constraints to models of star formation and evolution as well as to the properties of the Galactic disc (Cantat-Gaudin et al. 2018; Ferreira et al. 2020; Holanda et al. 2021). The surrounding OCs of the Orion Nebula (ON) stands out as an interesting science cases to investigate star and cluster formation and evolution, because:

- NGC 1981 presently inhabits a relatively dust-free field, while NGC 1977, located about 20' southward of it, remains embedded within its progenitor cloud.
- A sequential star formation scenario for the OCs in the ON region was suggested by Maia et al. (2010);
- A hypothesis that the feedback from the massive and earlier formed OCs played a crucial role in triggering the subsequent star formation events in the ON and its surrounding younger populations was suggested by Bouy et al. (2014) (Fig. 1).

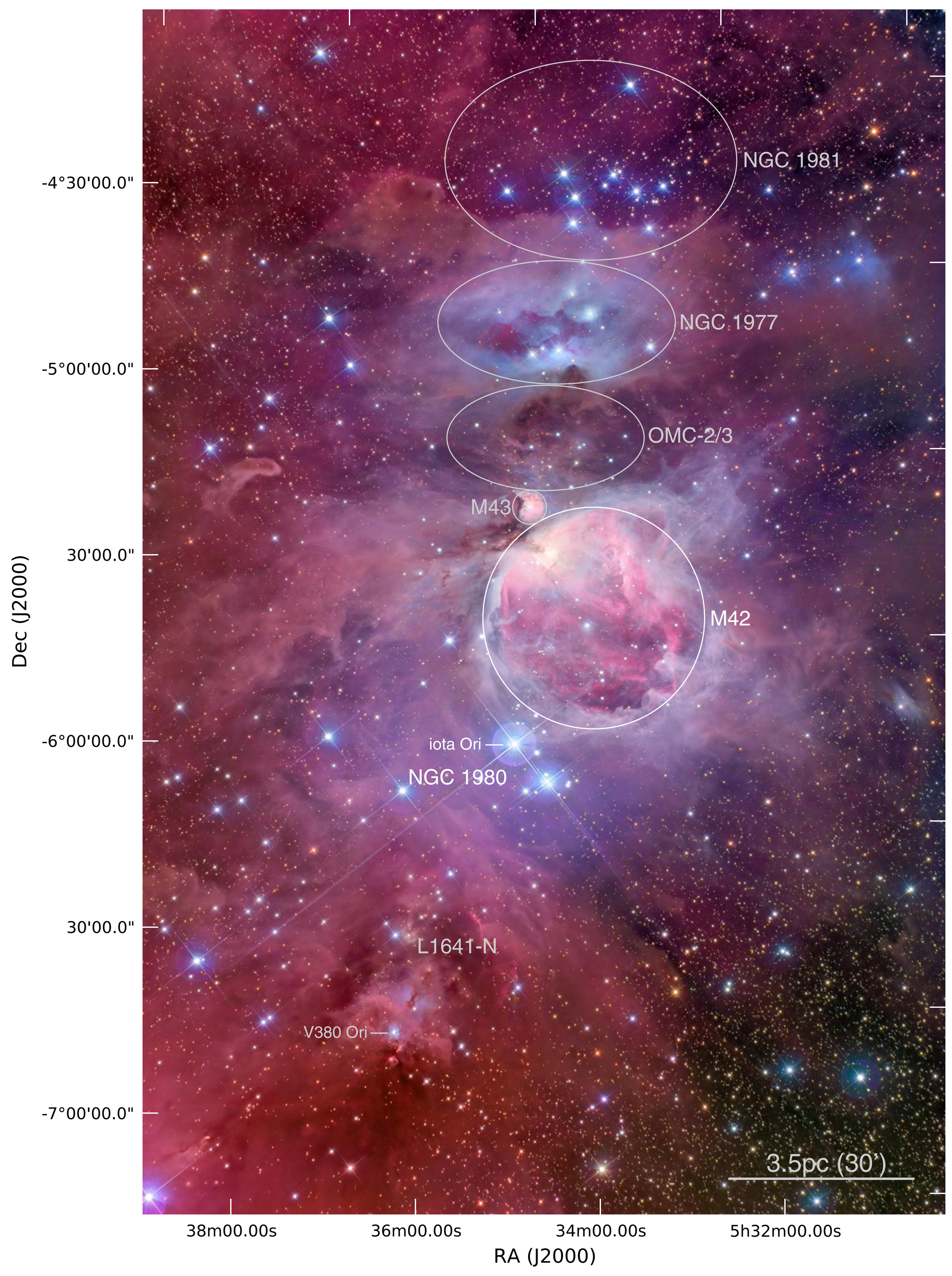

Figure 1: Optic photography of the region sorrounding the ON, where NGC 1981, NGC 1977, NGC 1980, M42 and other nearby populations are highlighted (Alves & Bouy 2012).

Goals

- Determine the astrophysical parameters and evaluate the origin and connection of NGC 1977 and NGC 1981;
- Deepen the understanding of the star formation history of the clusters surrounding the ON;

Methodology

In order to characterize NGC 1977 and NGC 1981 we have performed the following steps:

Astrophysical Parameters Determination

- To separate the members of a clusters from the field stars we have used the data form Gaia DR3 (Gaia Collaboration et al. 2023) together with the decontamination method developed by our group, described in detail in Angelo et al. (2019) e Ferreira et al. (2020).

Structural Parameters

- We have performed a radial density profiles (RDP) analysis and the King's profile fit (King 1962) to determine the limit radii (R_{lim}), the core radius (R_c) and the central density (σ_0).

Spectroscopy Analysis

- The spectroscopic data of the brightest stars of NGC 1981, collected at CASLEO - Argentina (2015) and OPD - Brazil (2022), together with the spectra and the stellar parameters from the APOGEE data (Abdurro'uf et al. 2022) were used to analyze the radial velocity (V_{rad}) and metallicity ([Fe/H]).

Astrophysical and Structural Parameters

Table 1: Astrophysical parameters of NGC 1977 and NGC 1981.

	NGC 1977	NGC 1981
RA (°)	83.85	83.83
DEC (°)	-4.81	-4.35
μ_α (mas/yr)	1.40	1.2
μ_δ (mas/yr)	-0.75	0.6
ϖ (mas)	2.56	2.53
R_{lim} (")	1000 ± 57	1062 ± 57
E(B-V) (mag)	0.07 ± 0.04	0.03 ± 0.04
$(M\text{-}m)_o$ (pc)	417 ± 54	381 ± 50
Idade (Myrs)	4 ± 1	8 ± 1
[Fe/H] (dex)	0.04 ± 0.40	0.04 ± 0.57
V_{rad} (km s^{-1})	-	41.6 ± 8.3

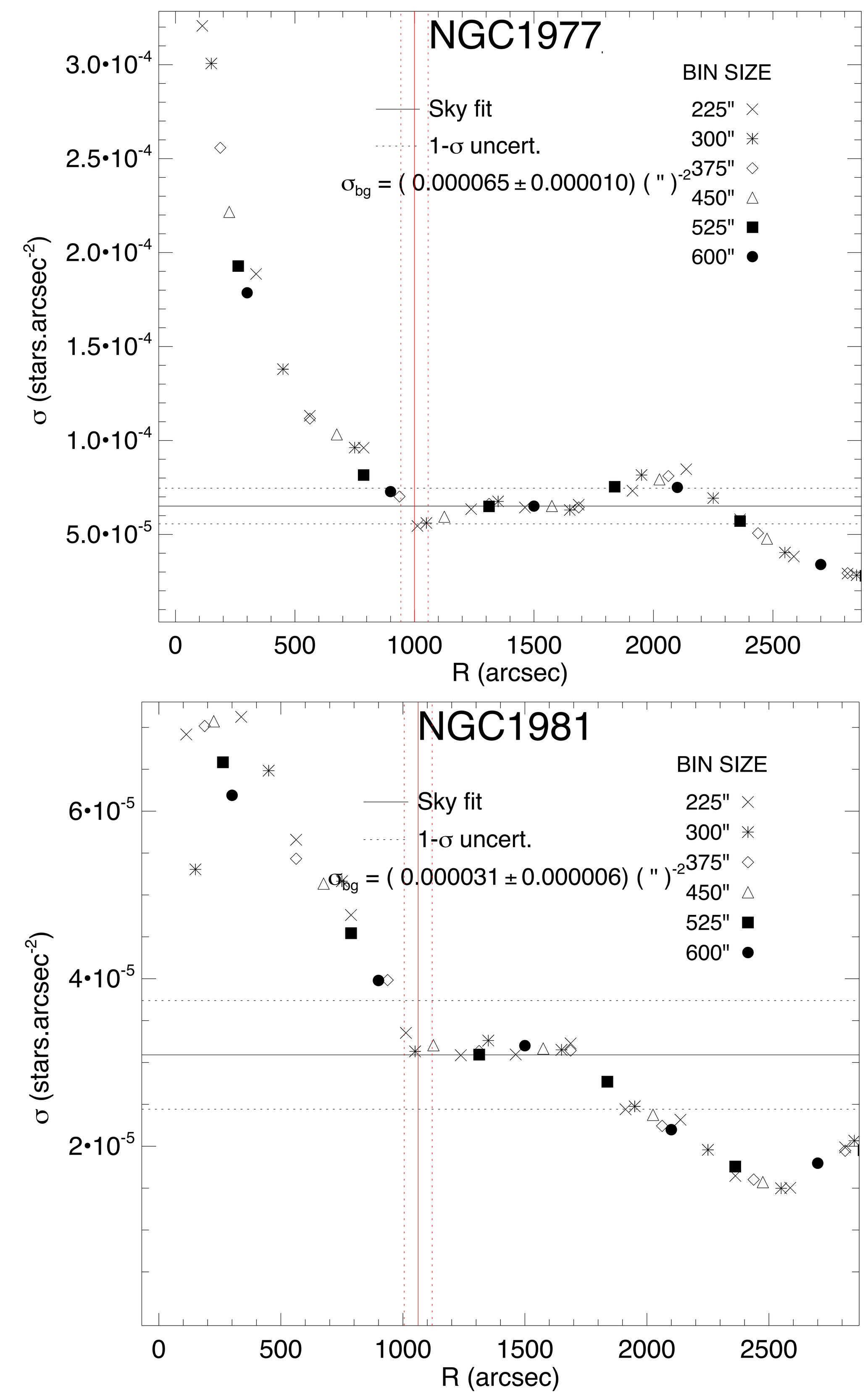

Figure 2: RDP of NGC 1977 (top panel) and NGC 1981 (bottom panel). The bins used on the fit are shown in arcsec on the panel. The limit radii (R_{lim}) and its error are represented by the solid and dashed vertical lines, respectively.

The RDPs and King's profile present fluctuations in the stellar density due the contamination of NGC 1977 in NGC 1981 and due the presence of the ON cloud. Both clusters present a large R_c, because they do not have a concentration of stars near the centre of the cluster, making difficult to properly fit the King's profile.

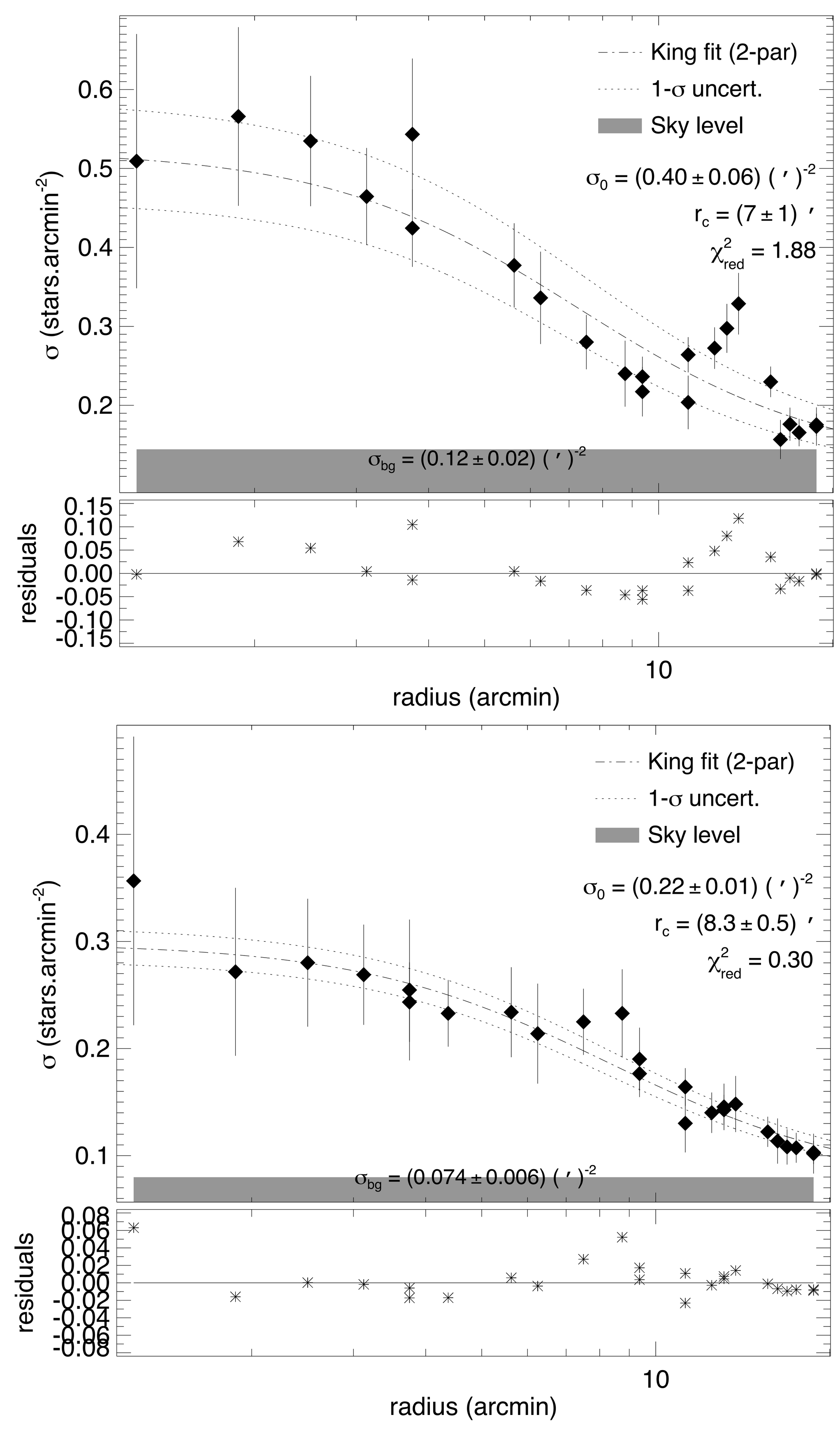

Figure 3: King's profile of NGC 1977 (top panel) and NGC 1981 (bottom panel). The King's fit and its error are represented by the solid and dashed lines, respectively. The core radius (R_c) and the central density (σ_0) are shown in figure.

Spectroscopy Analysis

Due the bad weather conditions, we were able only to determine the radial velocity (V_{rad}) from the CASELO and OPD spectra, because the poor S/N were insufficient to determine the [Fe/H]. The great dispersion seen in Figs 4 and 5 for the brightest star of NGC 1981 in the astrometric data may be suggesting that NGC 1981 is undergoing some disruptive process.

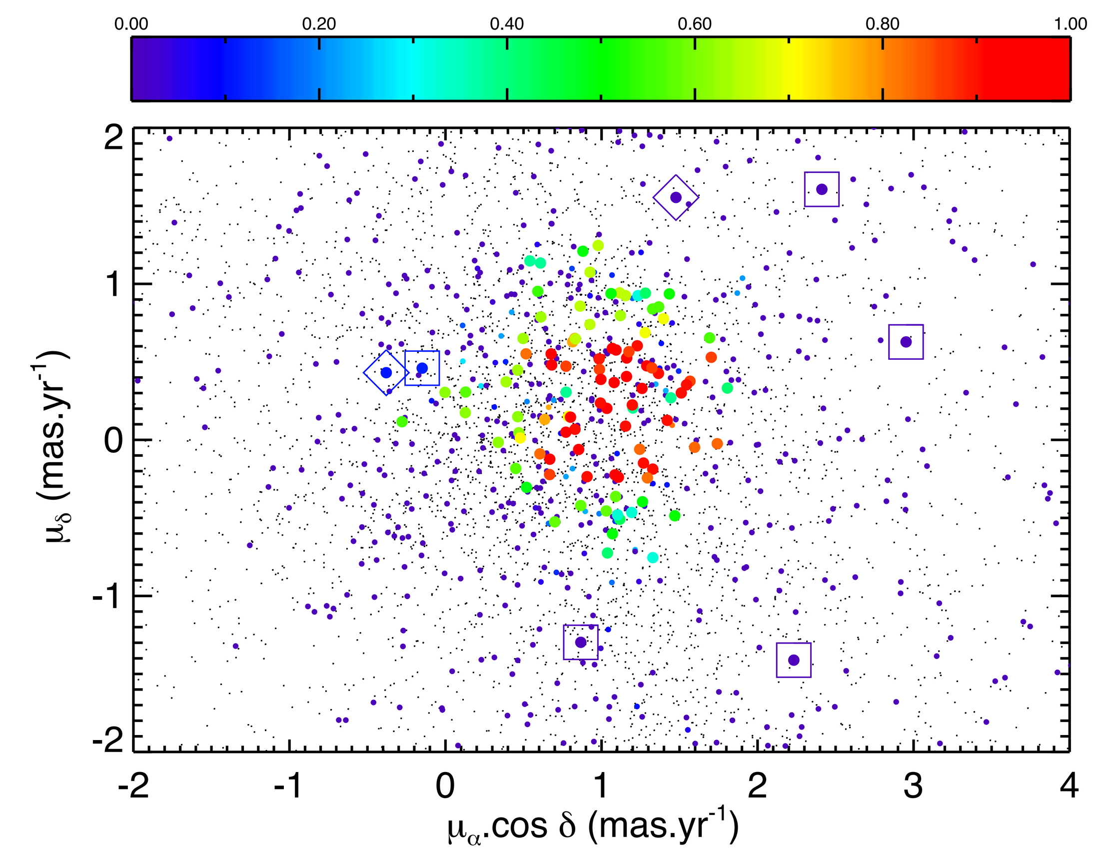

Figure 4: VPD of the stars member of NGC 1981. The larger filled symbols identify the cluster members, while the small purple and black dots represent field stars. The squares identify the brightest member stars according to Maia et al. (2010) and the diamonds identify the cluster members according to the analysis based on radial velocity dispersion. The symbol colours follow the membership probability scale according to the colour bar.

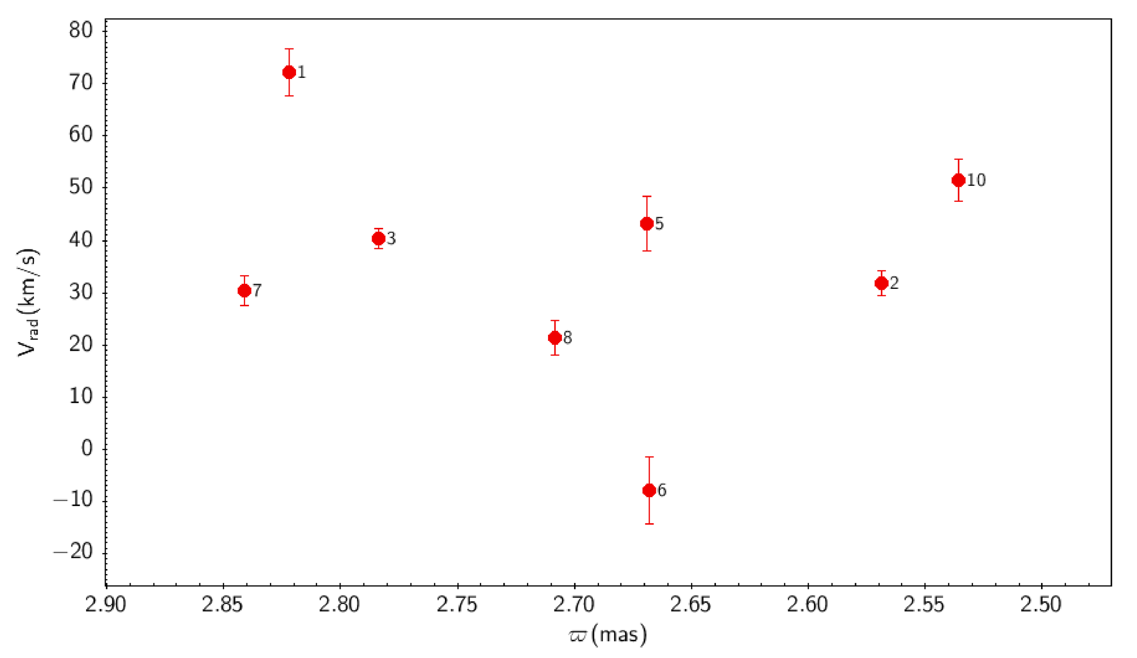

Figure 5: Diagram of the V_{rad} x ϖ for the stars observed spectroscopically at CASLEO and OPD of NGC 1981.

Crossmatching the data between our membership list and the APOGEE data we find that for NGC 1981 $\mathbf{V_{rad,NGC\,1981} = 35.94 \pm 9.34}$ **km s^{-1}** and **$\mathbf{[Fe/H]_{NGC\,1981} = -0.94 \pm 0.59}$ dex** and for NGC 1977 $\mathbf{V_{rad,NGC\,1977} = 37.76 \pm 6.92}$ **km s^{-1}** and **$\mathbf{[Fe/H]_{NGC\,1977} = -0.84 \pm 0.18}$ dex**.

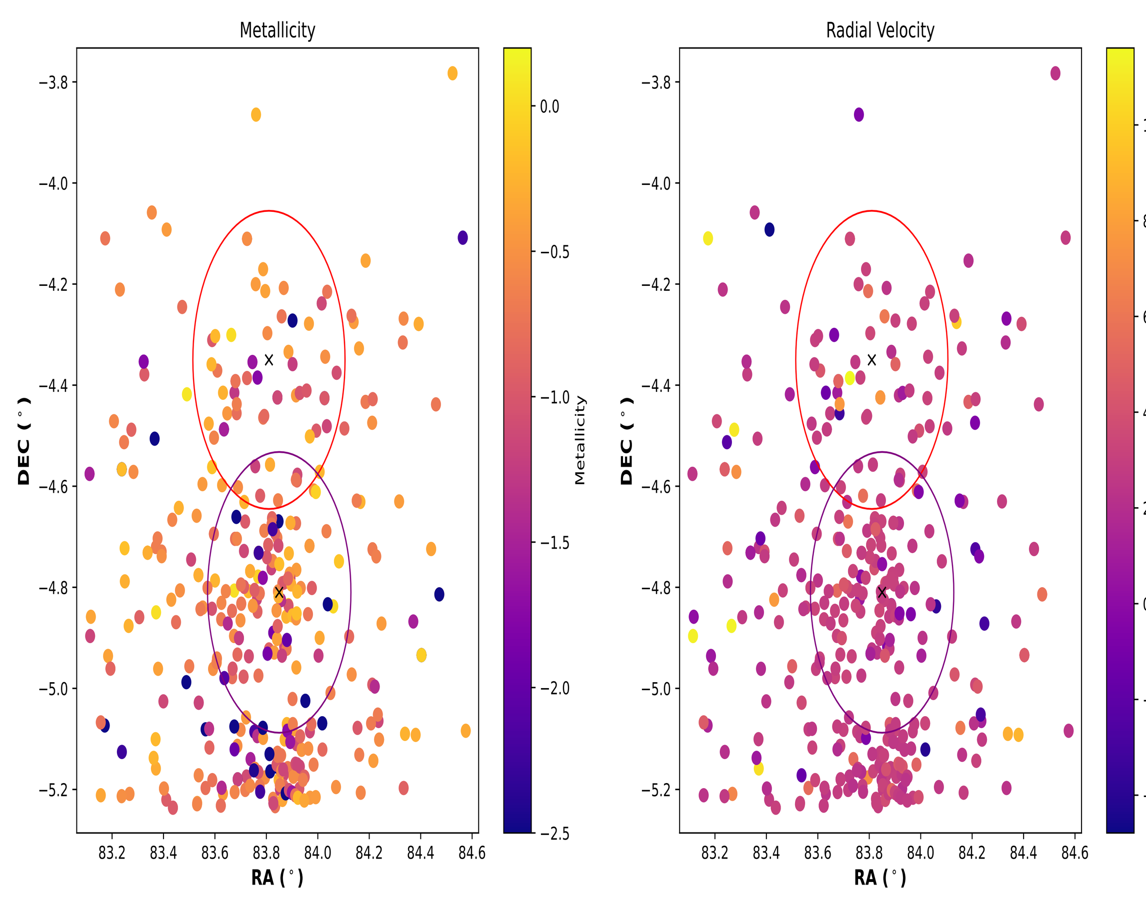

Figure 6: Skymap of APOGEE data of stars within 45' of the centre of NGC 1981. The symbol colours follow the [Fe/H] (left panel) or V_{rad} (right panel) scale according to the colour bar on the side. The red and purple circle represents the R_{lim} of NGC 1981 and NGC 1977, respectevely.

Conclusion

With our decontamination method and performing a study with Gaia DR3 and spectroscopic data, we could notice that:

- NGC 1977 and NGC 1981 present great similarity in their parameters, being hard to distinguish between their members;
- Both clusters present large R_c, suggesting that they have a more sparse distribution of its stellar content;
- No clear difference can be seen in the V_{rad}, but NGC 1977 is slightly more metallic than NGC 1981.
- The characteristics of NGC 1981 may be suggesting that it is undergoing some disruptive process.

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