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VGS31b: a highly inclined ring along a filament in a void. Implication for the cold accretion

Formation of Polar Ring Galaxies (PRGs)

Aim of the work

Properties of VGS31b

Photometric analysis

Chemical abundances

Results

Conclusions

Status of the project
Formation of Polar Ring Galaxies (PRGs)

The two possible formation scenarios for PRGs, proposed till some years ago, involve the interaction of two galaxies (Bekki 1998; Bournaud & Combes 2003)

- Tidal accretion of gas from outside
- Polar merging of two disk galaxies
Formation of Polar Ring Galaxies (PRGs)

Both scenarios are able to account for

☆ the main morphologies observed for PRGs
☆ a central HG similar to an early-type system

BUT

☆ The accretion scenario fails in reproducing extended disk-like polar structures with a total baryonic mass comparable with (or even larger!) that in the HG.

☆ The merging scenario fails to form massive polar disk around an HG with rotation velocities as large as observed along the HG major axis.
Formation of Polar Ring Galaxies (PRGs)

PRGs can be formed through cold gas accretion along a filament, extended for ~1Mpc, into the virialized dark matter halo (Macciò et al. 2006)

If the polar disk forms by accretion from cosmic web filaments of external cold gas, we expect metallicities similar to those of same-mass late-type galaxies.
Aim of the work

Recent observational studies on PRGs (Iodice et al. 2006; Spavone et al. 2010, 2011) single out the critical physical parameters that allow us to disentangle among the formation scenarios. They are:

(1) the total baryonic mass of the polar structure versus that of central spheroid;

(2) the kinematics along both the equatorial and meridian planes;

(3) the metallicity and SFR in the polar structure

Main aim of this work is to address the most reliable formation scenario for VGS31b, by comparing the observed properties with the theoretical predictions.
Properties of VGS31b

VGS31 is a system of three aligned galaxies embedded in a common HI envelope, belonging to a multiwavelength survey of 60 void galaxies, called “The Void Galaxy Survey (VGS)”, conducted by Kreckel et al. (2012)

One sided tail, curved towards north-east, kinematically connected to the central early-type disc galaxy (HG)

Highly-inclined ring-like structure around the HG (~70°).

VGS31b = MRK1477
D = 84 Mpc (H₀=75 km s⁻¹ Mpc⁻¹)  d(HG) ~ 41″ (~16 kpc)

GEE3
Padova, November 13th
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Photometric analysis

We used Sloan Digital Sky Survey (SDSS) images of VGS31 observed in the $u, g, r, i, z$ bands. The ring-like structure of the galaxy is clearly visible in the $g, r$ and $i$ bands, while it disappears in the $u$ and $z$ bands.

From the un-sharp masked image, the complex structure of this galaxy, even in the very central regions, stands out very clear:

- Two very luminous blobs observed in the NE and SW sides of the bar
- Luminous bar-like structure at P.A~230°
- Two inner arcs connecting the above features to the galaxy centre, tracing a 'spiral-like' pattern
- Two arms of the ring, having as starting points the two bright blobs
Photometric analysis

Since we aim to derive an average estimate of the metallicity ($Z$) for the ring component, we modelled the underlying light distribution of the HG, in order to obtain the range of radii where the ring dominates with respect to the HG and derive the average value for $Z$. 

GEE3 Padova, November 13th Marilena Spavone
Photometric analysis

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Photometric analysis

We derived integrated colors and magnitudes for different regions of VGS31b:

<table>
<thead>
<tr>
<th>Component</th>
<th>Region</th>
<th>$m_g$(mag)±0.01</th>
<th>$m_r$(mag)±0.01</th>
<th>$m_i$(mag)±0.01</th>
<th>$g - r$±0.02</th>
<th>$g - i$±0.02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tail</td>
<td>NE</td>
<td>18.12</td>
<td>17.57</td>
<td>16.32</td>
<td>0.55</td>
<td>1.8</td>
</tr>
<tr>
<td>Ring</td>
<td>N</td>
<td>18.12</td>
<td>17.20</td>
<td>16.19</td>
<td>0.92</td>
<td>1.9</td>
</tr>
<tr>
<td>Ring</td>
<td>S</td>
<td>18.10</td>
<td>17.53</td>
<td>16.60</td>
<td>0.57</td>
<td>1.5</td>
</tr>
</tbody>
</table>

The stellar population synthesis model by Bruzual & Charlot (2003) were used to reproduce the integrated colours in the selected regions, in order to estimate the average stellar mass in the tail and in the ring-like structure of VGS31b.

★ Linearly declining SFR
★ Z=0.008 and Z=0.0004

TAIL ~ $10^8 M_\odot$
RING ~ $4 \times 10^8 M_\odot$
Chemical abundances

\[ R_{23} = \frac{[OII] \lambda 3727 + [OIII] \lambda 4959 + \lambda 5007}{H \beta} \quad (\text{Pagel et al. 1979}) \]

\[ R_3 = \frac{[OIII] \lambda 4959 + \lambda 5007}{H \beta} \]

\[ P = \frac{R_3}{R_{23}} \]

\[ 12 + \log \left( \frac{O}{H} \right)_P = \frac{R_{23} + 54.2 + 59.45 P + 7.31 P^2}{6.07 + 6.71 P + 0.371 P^2 + 0.243 R_{23}} \quad (\text{Pilyugin 2001}) \]
Chemical abundances

\[ 12 + \log (O/H)_P \approx 8.37 \pm 0.57 = A_{VGS31b} \]

\[ 12 + \log (O/H)_{sun} = 8.83 = A_{sun} \quad Z_{sun} = 0.02 \]

Given that:

\[ Z_{VGS31b} \approx K Z_{sun} \]

and

\[ K = 10^{A_{VGS31b} - A_{sun}} \]

\[ Z \approx 0.35 Z_{sun} \]
Chemical abundances

VGS31b has metallicity (Z = 0.35 Z⊙) lower than spiral galaxy disks of the same total luminosity!

SFR = 7.9×10^{-42} L(Hα) ~ 0.02 M⊙/yr

Expected metallicities:

0.2 Z⊙ ≤ Z ≤ 0.5 Z⊙
Results

The structure of VGS31b resembles that of forming highly inclined ring galaxy (~70°)
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Most of the light comes from the central spheroidal component, while the ring-like structure and the tail become very faint towards longer wavelengths, suggesting a very young stellar population for this component.
Results

★ The structure of VGS31b resembles that of forming highly inclined ring galaxy (~70°)
★ Most of the light comes from the central spheroidal component, while the ring-like structure and the tail become very faint towards longer wavelengths, suggesting a very young stellar population for this component
★ The ring seems to reach the galaxy centre tracing a ‘spiral-like’ pattern, where the ring's arms are connected to the two bright blobs at the ends of the bar-like structure and to the two inner arcs
Results

*g – r and g – i colours show that the inner regions of the HG are characterized by several areas of very blue colours, which suggest the presence of star-forming regions, while both the ring-like structure and the tail lack of these features
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- The ring-like structure of VGS31b has an average metallicity of $Z = 0.3 \ Z_\odot$, which is lower with respect to that of same-luminosity spiral discs, but it turns to be consistent with the values derived for other PRGs.
**Results**

★ $g - r$ and $g - i$ colours show that the inner regions of the HG are characterized by several areas of very blue colours, which suggest the presence of star-forming regions, while both the ring-like structure and the tail lack of these features.

★ The ring-like structure of VGS31b has an average metallicity of $Z = 0.3 \, Z_\odot$, which is lower with respect to that of same-luminosity spiral discs, but it turns to be consistent with the values derived for other PRGs.

★ The tail has integrated magnitudes corresponding to stellar masses of the order of $10^8 \, M_\odot$. 
Conclusions

Tidal accretion of gas from the close companion VGS31a?

As the mass ratio between VGS31b and VGS31a is 3:1, a tidal interaction would damage the discs and produce more prominent tails!
Conclusions

Disruption of a dwarf galaxy?

From the stellar population synthesis models (Bruzual & Charlot 2003) we derived a stellar mass of the order of $10^8 \, M_\odot$ for the tail, which turns to be higher than the typical masses of dwarf galaxies ($10^3 \, M_\odot \leq M_* \leq 10^7 \, M_\odot$, Sawala et al. 2011)
Conclusions

Polar major merging between two disc galaxies already present in the filament?

According to Bournaud & Combes (2003), to form a ring with a diameter of about 24 kpc, as observed in this object, the stellar mass of the victim disc, which will form the ring, should be of the order of $10^{10} \, M_\odot$. The value for the mass of the ring estimated by the integrated colours is about $4 \times 10^8 \, M_\odot$, which is two order of magnitude lower than that requested in the simulation to form an extended ring as observed in VGS31b.
Conclusions

Cold gas accretion from cosmic web filaments?

Beygu et al. (2013) suggested that the large HI amounts and its distribution lets VGS31b to be a good candidate for a ring formation through the cold accretion of gas along the filament where this galaxy and its companions are embedded in.

The new result of this work, which reinforces this view, is the low metallicity measured for the ring in VGS31b, i.e. $Z = 0.3 \ Z_\odot$, that remains almost constant along the whole extension!

Simulations by Snaith et al. (2012), suggest that the typical metallicity for a polar disc formed through the cold accretion of gas along a filament is about $Z = 0.2 \ Z_\odot$ and any significant gradient is measured along the polar structure.
Status of the project

- NGC4650A (VLT data-P.I. Iodice): Spavone et al. 2010, APJ, 714, 1081
- A0136, NGC660, SPRC241 (NOT data-P.I. Spavone): work in progress
Thank you for your attention!!!