Corotation Resonance of Nonbarred Spiral Galaxies

A Research work

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with
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(Research advisor)
Outline

- Motivation / Objective
- Introduction
  - Density Wave Theory
  - Corotation Resonance
- Method
  - Multi-band Photometry Method
- Results and Discussion
- Conclusion
Structure of a Spiral Galaxy

Image courtesy of ESA/NASA and Hubble
Motivation

- To understand about density wave theory
- To know about corotation resonance and its importance in the disk galaxies
- To learn the method of determining the location of corotation resonance
What is Winding Problem?

- Differential rotation of materials such as gas, dust, cloud etc in the galactic disk
- Tightening of spiral arms due to decrease in the pitch angle of the spiral arms
- Destruction of the spiral arm structure causing the galaxy to lose the shape of spiral arms
Real images of some galaxies

After some rotations
Density Wave Theory

**Introduction**
- Proposed by two astronomers, Lin and Shu in 1964
- Introduced the concept of quasi-static density waves

**Assumptions**
- Presence of long lived quasi-static density wave
- Constant pattern speed of spiral arm and differential rotation of material

https://www.astronomynotes.com/ismnotes/s8.htm
http://ircamera.as.arizona.edu/NatSci102/NatSci/lectures/spiralarms.htm
Corotation Resonance

Plot of angular speed as a function of radius

Angular velocity (km/s/kpc)

\( \Omega(R) \)

Radius (kpc)

\( \Omega_{gp} \)

CR
Description of Data Sample

- Data sample were taken from the Carnegie-Irvine Galaxies Survey (CGS; Ho et al. 2011)
- Optical images were observed on the 2.5 m du Pont Telescope at the Las Campanas Observatory in Chile in between 2003 and 2007 with the Direct CCD Camera during dark time
- The galaxy images were taken in four different bands (B,V,R,I)

Blue  Violet  Red  Green+Yellow
Method

- **Multiband Photometry Method**
  
  - Developed by Puerari and Dottori in 1997
  - Photometric analysis of existing images
  - Images are analyzed using different routines within PyRAF
  - Images are processed through **3 major steps**

  They are:

  1. Foreground star subtraction
  2. Image deprojection
  3. Fourier transformation
Foreground Star Subtraction

- PyRAF **daofind** task is used to determine the co-ordinates of all foreground stars present in the image.
- PyRAF **psf** task is run to select those stars which were needed to be removed from the image.
- PyRAF **substar** task is run to subtract those fitted stars from the image.
The galaxy image is rotated by an angle equal to PA using PyRAF `rotate` task.

The rotated image is magnified along x-axis by an amount equal to its axis ratio using PyRAF `magnify` task.

PyRAF `ellipse` task is used to fit elliptical isophotes over the images.
Fourier Transformation

- Creating azimuthal and radial profiles
  Each galaxy image is divided into **360 azimuthal sections**, each of 1 degree wide and **120 radial sections**, each 1 of pixel wide

- Applying Fourier transformation

\[
F_2 (r) = \int_{-\pi}^{\pi} I_r (\theta) e^{-2i\theta} d\theta
\]

The phase angle can be obtained as

\[
\theta (r) = \tan^{-1} \frac{Re [F_2 (r)]}{Im [F_2 (r)]}
\]

Here, Re and Im mean the real and imaginary parts of the complex Fourier coefficient
Phase Angle vs Radius Plot

Presence of azimuthal age gradient (color gradient)

CR

Phase angle (radians)

Radius (arcsec)

Rotation

Dust lanes, shock

Corotation circle

Red

Blue
Some Examples

This galaxy has a single phase crossing which represents the location of corotation radius

IC 2627

CR = 12.28 ± 0.04
This galaxy has more than one phase crossing (within the range of 5 arc-seconds) which represents the location of corotation range / region.
# Data Results

<table>
<thead>
<tr>
<th>Galaxy name</th>
<th>P.A  (deg)</th>
<th>Axis ratio (a/b)</th>
<th>Ellipticity [1 - (b/a)]</th>
<th>Corotation radius (arcsec)</th>
<th>Corotation radius (pix)</th>
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</thead>
<tbody>
<tr>
<td>IC 2627</td>
<td>20</td>
<td>1.3</td>
<td>0.22</td>
<td>12.28±0.04</td>
<td>47.30±0.15</td>
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<td>IC 5332</td>
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<td>49.65±1.27</td>
<td>191.70±4.90</td>
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<td><strong>NGC 895</strong></td>
<td>-60</td>
<td>1.6</td>
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<td>61.09±1.29</td>
<td>235.877±4.98</td>
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<td>NGC 908</td>
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<td>NGC 2280</td>
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<td>127.03±3.17</td>
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<td><strong>NGC 2417</strong></td>
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<td>1.4</td>
<td>0.28</td>
<td>52.60±1.06</td>
<td>203.09±4.09</td>
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<td>NGC 3223</td>
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<td>1.8</td>
<td>0.45</td>
<td>56.26±0.38</td>
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<td>32.14±1.56</td>
<td>124.09±6.02</td>
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Continue,

<table>
<thead>
<tr>
<th>Galaxy name</th>
<th>P.A (deg)</th>
<th>Axis ratio (a/b)</th>
<th>Ellipticity [1 - (b/a)]</th>
<th>Corotation radius (arcsec)</th>
<th>Corotation radius (pix)</th>
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<td>60.65±0.97</td>
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<td>58.66±2.03</td>
<td>226.49±7.84</td>
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</table>
Conclusion

- We were successful to find the location of CR on those spiral galaxies
- We used multi-band photometry method to determine the location of CR in a sample of 19 non-barred spiral galaxies
- Out of 19 galaxies, 15 galaxies were found to have a single phase crossing while remaining 4 galaxies had more than one phase crossing
- We were unable to compare the results with any other method’s results