New polar ring galaxies catalogue.

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A photographic atlas of 157 polar ring galaxies, Whitmore et al (1990):

- **PRC-A (6 galaxies):** Kinematically confirmed

  - A-5

- **PRC-B (27 galaxies):** Good candidates

  - B-17

- **PRC-B (73 galaxies):** Possible candidates

  - C-43

- **PRC-D (51 galaxies):** Related objects

  - D-15

- Studying a role of merging and interactions in galaxy evolution (disc and bulge formation, star formation, etc.)

- Implication for dark matter contents: $M/L > 20 - 50$

- Probe to the 3D shapes of dark matter halo

- “Cold” gas accretion for galaxies masses assembly?
Formation of polar rings: simulations

1) The major merging scenario:

- A head-on collision between two orthogonal spiral galaxies (Bekki, 1998; Bournaud & Combes, 2003)

2) The accretion scenario:

- Tidal accretion of the polar material from a gas-rich donor galaxy (Schweizer et al. 1983; Reshetnikov & Sotnikova 1997)

- the disruption of a small companion on a polar orbit

- accretion of gas infalling from extragalactic cosmic filaments (Maccio et al., 2006)
20 years looking in Polar Rings Catalogue...

see Combes (2005), Iodice et al. (2003), Sparke (2002) ...

- A host galaxy like S0 or E, the polar component is like spirals or irregular galaxies (gas-rich and bluer)
- Not only narrow annuli, but also extended disc-like rings
- Warped and inclined rings

Only 20 large-scale polar rings + 6 inner rings were kinematically confirmed from the Whitmore et al. list:

- HI maps (Cox et al.; Sparke et al.)
- optical-long slit spectroscopy (Reshetnikov et al.)
- optical 3D spectroscopy (Spalyapina et al., Brosch et al.)
SDSS-based Polar Ring Catalogue (=SPRC)

14 already have kinematic confirmation

Results of original Galaxy Zoo project:
- GalZoo ring galaxies internet-forum
- Visual inspection of 41958 SDSS DR7 images

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<tr>
<th>Class</th>
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<th>Description</th>
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<tr>
<td>1</td>
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<td>Elliptical galaxy</td>
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<td>2</td>
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<td>Clockwise/Z-wise spiral galaxy</td>
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<td>3</td>
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<td>Anti-clockwise/S-wise spiral galaxy</td>
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<td>4</td>
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<td>Spiral galaxy other (eg. edge on)</td>
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<td>5</td>
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<td>Star or Don't Know (eg. artefact)</td>
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<td>6</td>
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<td>Merger</td>
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Table 1. Galaxy Zoo classification categories showing schematic symbols

$EDGE \geq 0.1, MG \geq 0.05, DK \geq 0.05$
New catalogue — SPRC: 275 candidates (185 — “the best” + “good”)

The BEST Candidates (70)

GOOD Candidates (115)

RELATED Objects (53)

FACE ON Rings (37)
SDSS-based Polar Ring Catalogue

Figure 2. Apparent distribution of PRG candidates in the sky in equatorial coordinates. The gray shaded area marks the Galaxy Zoo region. Blue dots are the objects from Whitmore et al. (1990), red dots are the galaxies from the new catalogue.

Figure 7. Histograms of the distribution of PRG candidates by redshift for the Whitmore et al. (1990) catalogue and the new list.
In references: 5 confirmed polar rings (including SPRC-7 observed at the 6 m telescope
2010: 5 confirmed polar rings, 1 case of overlap
2011: + 4 confirmed polar rings
“The best” objects with known gas/stars kinematics
What is the true shape of dark matter halo?

**Theory and simulations:**
A flattening should be depend from the origin (Combes, 2005):
- Accretion: \( c/a < 1 \)
- Merging: \( c/a \approx 1 \)
- Triaxial CDM halo: \( c/a = 0.5 - 0.7 \)

**Observations:**
- T-F relation (Iodice et al 2003; Reshetnikov 2004): flattened halo along polar plane
- Iodice et al (2009): new dynamical model for NGC4450A constrains very flat halo with \( c/a = 0.3 \)
- Strongly tilted rings would survive preferentially in roundest halos:
  - NGC 2685 (Josza et al, 2009),
  - NGC 3718 (Sparke et al, 2009),
  - NGC 4753 (Steiman-Cameron, 1993)

We need more spatial resolved 2D kinematics + detailed modeling of the 3D gravitational potential distribution
3D dark halo shape: simulations vs. observations:

1) Slightly triaxial halo \((c/b=0.95 \ a/b=1.1\) 
2) Evolved spiral structure in the polar ring 
(Khoperskov et al, poster on the SpS 3)
New examples of extended massive rings

- Discs rather than rings...
- How did they acquire a mass equal with their hosts?
- Fast rotation of central galaxies contradicts with a major merging scenario

Cold gas accretion along misalignment filaments?
Gas accretion from cosmic filaments

Macci et al (2006): gas infalling from cosmic filaments, with inclined angular momentum

Brook et al (2008): Simulated object similar with NGC 4650A

Iodice et al (2010): low metallicity (Z=0.2 Zsun) in the polar disk of NGC 4650 implies a cold accretion scenario?
Molecular gas observations

21 galaxies observed
12 Candidate PRG
P13  P15  P17  P24  P29  P31
P42  P47  P48  P52  P56  P61

9 Confirmed PRG
PC7  PC10  PC14  PC33  PC39  PC60
PC67  PC69  PC260

Double-horn profiles ➔ Rotating disks

Typical masses
$2 \times 10^9 \, \text{Mo}$
Molecular gas observations

**CO(1-0) and CO(2-1)**
- Simultaneously observed with IRAM-30m
- 24% detection rate
- About the same as in ATLAS³D nearby early-types galaxies
  (22%, Young et al, 2011)

**CO(2-1)/CO(1-0) ratio typical of dense galaxy discs or nuclei**
**Conclusion**

Sloan-based Polar Rings Catalogue contains 275 galaxies. It significantly (in 3 times) increases a number of genuine PRG candidates and may serve as a good basis both for the further detailed study of individual galaxies, and for the statistical analysis of PRGs as a separate class of objects.

14 SPRC galaxies already have a kinematic confirmation

The most interesting items related with further studying of SPRC:

- 3D dark halo shape

- Statistic of an external gas accretion, including a cold accretion along filaments

The deep HI observations are strongly needed!
Thank you for your attention!