MULTI-SPIN COMPONENTS IN GALAXIES: Dissecting kinematics and stellar populations

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in collaboration with:
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Based on:
OUTLINE OF THE TALK


2. Presentation of a new method to study these systems: “spectral decomposition analysis”.

3. Results of spectral decomposition on some multi-spin galaxies.
MULTI-SPIN GALAXIES

✓ **Counter-rotations.** Stars rotating along opposite direction with respect to other stars and/or gas. (see Corsini 2014, arXiv: 1403.1263 for review). Different classes:
  - **Nature:** stars vs. stars, stars vs. gas, gas vs. gas, kinematically decoupled cores.
  - **Extension:** Kinematically decoupled cores (KDC); large-scale disks (e.g. NGC 4550).

✓ **Structural components.** Bulge/Disk. Nuclear stellar disks (same spin direction, but different amplitude).

✓ **Misaligned/Orthogonal structures.** Warps, Polar Ring Galaxies, Polar disk galaxies.
MULTI-SPIN GALAXIES

Counter-rotations: NGC 4550 (large scale counter-rotating stellar disks)

Rubin et al. (1992)
Counter-rotations: NGC 4550 (large scale counter-rotating stellar disks)
**MULTI-SPIN GALAXIES**

**Counter-rotations:** NGC 0128 Gas and stars counter-rotating

Bureau & Chung (2006)
Structural components: Kinematically Decoupled Cores

NGC 4365 (From SAURON)

Coccato et al. (2009)

NGC 4494 major axis

Central fast-rotating component

Main galaxy body
MULTI-SPIN SYSTEMS IN GALAXIES

Misaligned/Orthogonal structures

Warp: UGC 3697 (Integral galaxy)

Polar disk: NGC 4650A
**SCENARIOS**

Counter-rotating galaxies:

1. Accretion of gas on retrograde orbits plus subsequent star formation (Lovelace & Chou 1996; Thakar & Ryden 1996). *Secondary component is younger.*
   
   Accretion of gas along filaments (Algorry et al. 2014).
   
   Example: NGC 5719 direct observation of on-going gas accretion on a galaxy with stellar counter-rotation.

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*NGC 5719/5713*

*Vergani et al. (2007)*
SCENARIOS

Counter-rotating galaxies:

2. Galaxy binary mergers: The properties of the counter-rotating disks depend on the nature of the progenitors and star formation history. According to simulations, mergers of galaxies:

✓ do not play a significant role (Algorry et al. 2014).
✓ can explain the presence of 50% counter-rotating stars in NGC 4550 and the different flattening of the two counter-rotating disks (Crocker et al. 2009).
SCENARIOS

Polar rings/disks:

1. **Dissipative polar merger** of two disk galaxies with unequal mass (Bekki 1998; Bournaud & Combes 2003);

2. **Tidal accretion** of external material (gas and/or stars), captured by an early-type galaxy on a parabolic encounter (Reshetnikov & Sotnikova 1997; Bournaud & Combes 2003; Hancock et al. 2009);

3. **Cold accretion** of pristine gas along a filament (Macciò et al. 2006; Brook et al. 2008).
Counter-rotating bulge (NGC 524, Katkov+2011)

- **Velocity**: 
- **σ**: 
- **age**: 
- **[Z/H]**

Binary merger simulations from Balcells & Gonzalez (1998)

1. $M_2:M_1 = 1$
2. $M_2:M_1 = 2$
3. $M_2:M_1 = 3$

- □ Galaxy 1
- △ Galaxy 2
- ● Total

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MOTIVATIONS

To understand the properties and the formation mechanisms of multi-spin galaxies and their components we need to study the properties of both components:

1. Morphology (size, geometry)
2. Kinematics
3. Stellar population content (Age, metallicity...)

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**Aim:** Study the spectral (and morphological) properties of the structural components in a galaxy, separately. For example:

1. Date the formation of the counter-rotating disk.
2. Measure the metallicity and abundance ratio of the decoupled components.
3. Unveil the real extension of a KDC and its kinematic properties.
4. Study the stellar populations of bulges by removing the contamination from the stars in the disk.
5. Properties of the thick and thin disks in spirals.
6. ...

**Complication:** the different structural components (i.e. counter-rotating disks, bulge/disks) are *co-spatial*: the sum of their contributions is observed.

**Challenge:** Separate the two components and measure them independently.
We construct 2 independent synthetic templates as linear combinations of stars from 2 spectral libraries (→ stellar populations). Convolution with 2 Gaussian LOSVDs (→ kinematics). Iterative procedure (χ² minimization).

Differences in the position of absorption line features and in the Hβ equivalent widths between the two stellar components (→ different kinematics and stellar populations).
PARAMETERS IN THE CODE:

\( F_1 \): Mean flux of first component.
\( F_2 = 1 - F_1 \): mean flux of the second component.

\( V_1, \sigma_1 \): kinematics of the first component.
\( V_2, \sigma_2 \): kinematics of the second component.

\( \text{SPC}(\lambda)_1 \): best fitting linear combination of stellar templates of the first component.

\( \text{SPC}(\lambda)_2 \): best fitting linear combination of stellar templates of the second component.

All are free parameters in the code; but, if required: \( F \) can be fixed via photometric decomposition; \( \text{SPC}(\lambda) \) can be constrained from regions where the other component is absent; kinematics can be constrained by independent methods.
SPECTRAL DECOMPOSITION:

Errors on kinematics (simulations)

Errors on SSP (simulations)

\[ \Delta V > 150 \text{ km/sec} : \text{rms} = 0.005 \]

\[ \Delta V < 150 \text{ km/sec} : \text{rms} = 0.05 \]

\[ s/n = 90 \quad \text{rms} = 0.005 \]

\[ s/n = 20 \quad \text{rms} = 0.050 \]
SPECTRAL DECOMPOSITION:
First application: large-scale counter-rotating stellar disks

NGC 5719
NGC 3593
NGC 4550
L. Coccato: Multi-spin components in galaxies
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NGC 5719

Secondary component
Main component

[α/Fe] = 0
Age = 0.8 Gyr
Age = 1 Gyr
Age = 2 Gyr
Age = 3 Gyr
Age = 5 Gyr

[Fe/H] = 0.00
[Fe/H] = -0.33
[Fe/H] = -0.35

Metal rich
Metal poor

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NGC 3593

Secondary component
Main component

Models: Thomas et al. (2011)

VIMOS/IFU
NGC 4550

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Stellar populations: Age, [Z/H], [α/Fe]

NGC 3593

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Stellar populations: Age, [Z/H], [α/Fe]

NGC 4550

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Surface brightness (kinematic) decomposition

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Although it dominates the light in the central regions, “KDC” in NGC 3593 is less massive than the stars in the galaxy.

The counter-rotating disks in NGC 4550 have the same luminosity, but different mass profiles.
Secondary disk: Same direction of rotation as the ionized gas. Younger, less massive, different metal content, more $\alpha$–enhanced than then main disk. $\rightarrow$ Supporting the gas accretion + star formation scenario.
But more statistics is needed (upcoming IFU surveys).

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Date the formation of the counter-rotating stellar disk

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>Formation of secondary comp.</th>
<th>After formation of main galaxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 3593</td>
<td>~2 Gyr</td>
<td>1.6 ± 0.8 Gyr</td>
</tr>
<tr>
<td>NGC 4550</td>
<td>~7 Gyr</td>
<td>&lt; 1 Gyr</td>
</tr>
<tr>
<td>NGC 5719</td>
<td>~1.3 Gyr</td>
<td>2.7 ± 0.9 Gyr</td>
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</table>
SUMMARY 1

Spectral decomposition technique that allows to separate the spectra of two kinematically distinct components in a galaxy.

1. It works on counter-rotating systems NGC 3593, NGC 4550, NGC 5179.

2. It allows to measure kinematics and stellar populations of both stellar components (plus ionized gas); morphologies, mass distributions of both components can be studied.

3. Secondary stellar component rotates in the same direction as the ionized gas.

4. Secondary components are always younger and have different [Z/H] than the main stellar components, and are more [α/Fe]. In agreement with the gas accretion plus star formation. Date the accretion event: ~2Gyr (NGC 3593, ΔT~1.6±0.8 Gyr), ~7Gyr (NGC 4550, ΔT<1Gyr), 1.3Gyr (NGC 5719, ΔT ~2.7±0.9 Gyr).

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SPECTRAL DECOMPOSITION:

Next applications:

1. **Bulge – disk decomposition**
   - remove the bulge (disk) contamination from the bulge (disk) light (NGC 7217, Fabricius et al. 2014)

2. **Host galaxy – polar disk decomposition**
   - remove the polar disk contamination from the host galaxy (NGC 4650A)
NGC 7217

VIRUS-W
Range: 4880 - 5480 Å
$\sigma_{\text{INSTR}}=15$ km/sec
FOV: 105" x 55"
Sampl= 0.19 Å/pxl
Filling factor: 1/3
Exp. per fibre: 1.5 hrs
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NGC 7217 Non parametric recovery of LOSVD

Problems: Short wavelength region, Low kinematic separation
- Large errors (esp. in the SSP recovery)

Solution: Use an independent routine to get the kinematics.
- Extension of Maximum Penalized Likelihood Method plus kinematic double-Gaussian decomposition
NGC 7217: Non parametric recovery of LOSVD

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NGC 7217: spectral decomposition

The kinematics are constrained from the non parametric approach, and used as input in the spectral decomposition.
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The central regions of the “bulge” have values more consistent with those of the central regions of ETGs (T+05), rather than those of bulges of spirals (G+07, M+08).

→ formation through a major merger?
NGC 7217: spectral decomposition

The kinematics are constrained from the non parametric approach, and used as input in the spectral decomposition

Mgb and <Fe> offset: passive evolution of a single stellar population, which gradually builds up both $\alpha$-elements and other metals over time.

The formation of the stars in the disk may have restarted at much lower <Fe> than the spheroid → accretion of primordial gas

(see Fabricius+2014 for further details)
NGC 7217: Conclusions

The kinematics are constrained from the non parametric approach, and used as input in the spectral decomposition.

Suggested formation scenario:

The spheroidal component of NGC 7217, formed through a major merger. Properties more similar to those of an elliptical galaxy than to those of the bulges of spirals.

The disk component formed after the merger, primordial gas accretion followed by star formation.
Central spheroid and polar disk co-exist

Problems: Short wavelength region, Low kinematic separation --> large errors

Solution:

I. Get the SSP from the spheroid from disk-free regions
II. Constrain the flux ratio of spheroid and polar disk
NGC 4650A (Polar Disk galaxy)

Problems: Short wavelength region, Low kinematic separation--> large errors

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DISK-FREE region, get the spheroid best template from there
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Parametric recovery of LOSVD
NGC 4650A
Polar disk / spheroid decomposition

Coccato et al. (2014) A&A submitted

Photometric decomposition along the slit profile to constrain $F_1$ and $F_2$ in the spectroscopic decomposition.
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Parametric recovery of LOSVD
**NGC 4650A**

**Kinematics**
Rotation of host galaxy along the minor axis $\rightarrow$ non axisymmetric potential.

Counter-rotation of polar disk $\rightarrow$ multiple accretion formation episode.

**Stellar content:**
Spheroid: GIII ($\sim$50%) and KIII ($\sim$35%) plus contamination from young A,O,B stars ($\sim$15%). NON GRADIENTS.

Disk: GIII ($\sim$45%) and KIII ($\sim$35%) plus contamination from young A,O,B stars ($\sim$20%). GRADIENT:
Young star fraction from 10% (R<1.5kpc) to 30% (R>1.5 kpc) $\rightarrow$ outer disk formed later?
The spectral decomposition technique works also in more difficult cases, with small kinematic separation and short wavelength region.

- **NGC 7217 (Bulge plus disk)**
  - Get the kinematics from an independent method.
  - Hints for formation mechanism: re-growing of a disk and a merger remnant.

- **NGC 4650A (spheroid plus polar disk)**
  - Get the spheroid population ($SPC(\lambda)_2$) from disk-free regions.
  - Get $F1$ and $F1$ from photometric decomposition of the slit profile.
  - Counter-rotation of the polar disk, multiple accretion.
  - Non axisymmetric potential.
The secondary component associated to the ionized gas is the youngest in all the 5 studied galaxies.