STELLAR COUNTER-ROTATION IN DISK GALAXIES:

Separating kinematics and stellar populations of decoupled components

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Based on:
Coccato et al. 2011, MNRAS, 412, L113;
Coccato et al. 2012, A&A, in preparation

COUNTER-ROTATION IN GALAXIES

✓Stars rotating along opposite direction with respect to other stars and/or gas have been detected in several galaxies (Bertola & Corsini 1999 for a review).

✓Several types of counter-rotations: stars vs stars, stars vs gas, gas vs gas, kinematically decoupled cores.

✓The particular case of *extended counter-rotating stellar disks* is observed in few cases: NGC 4550 (Rubin et al. 1992), NGC 7217 (Merrifield & Kuijken 1994), NGC 3593 (Bertola et al. 1996), NGC 4138 (Jore et al. 1996), and NGC 5719 (Vergani et al. 2007). But large spectroscopic surveys are now identifying more candidates (e.g. Krajnovic et al. 2012).

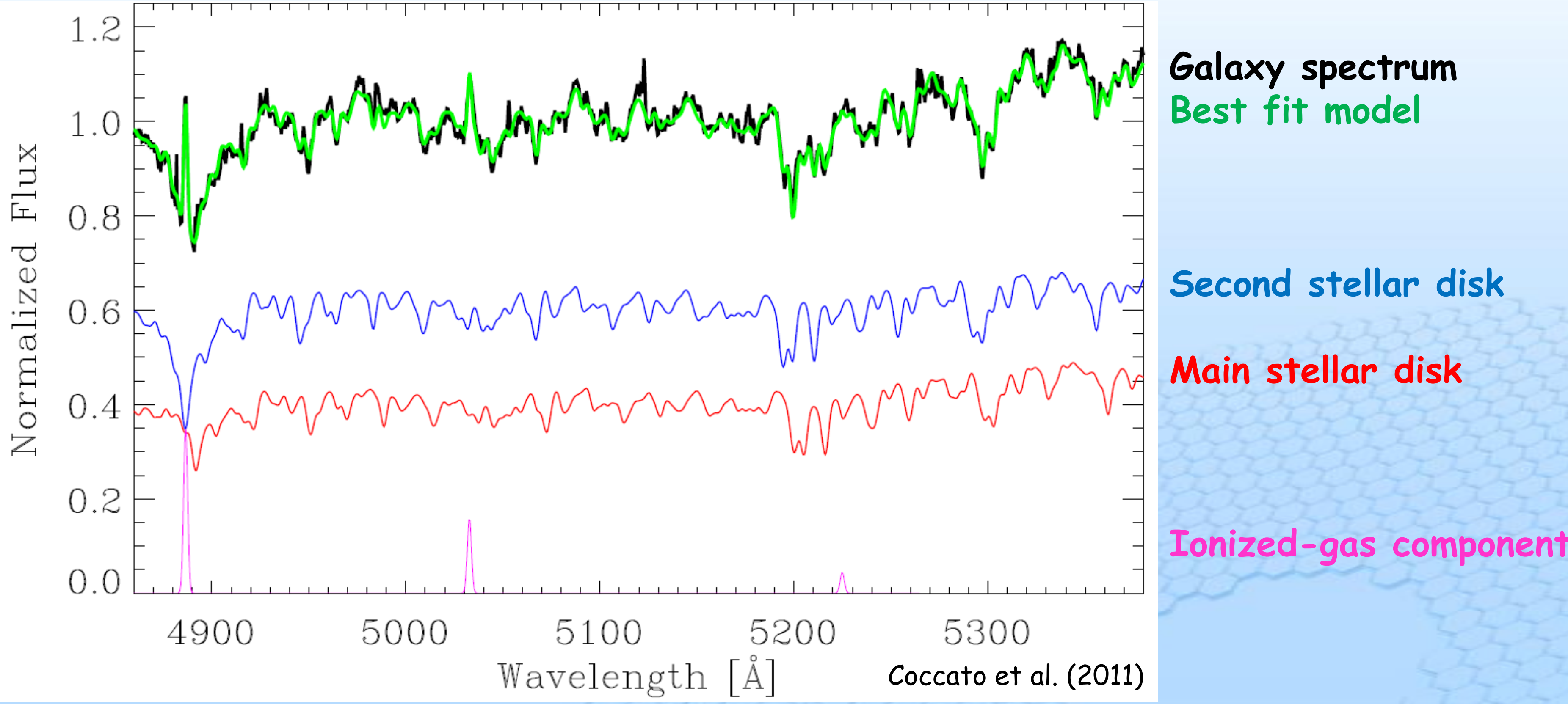
SCENARIOS:

1. **Accretion of gas** on retrograde orbits plus subsequent star formation (Lovelace & Chou 1996; Thakar & Ryden 1996; Pizzella et al. 2004)
   - Component associated with the gas: *always* younger.
   - The two stellar components can have different stellar populations properties [H/Z], [α/Fe].
2. **Binary mergers** between galaxies (gas+stars) (Balcells & Gonzalez 1998; Puerari & Pfenniger 2001; Crocker et al. 2009).
   - Component associated with the gas: younger in 50% of cases.
   - The two stellar components can have different SSP properties.
3. **Internal instabilities** (e.g dissolution of bars) (Evans & Collett 1994).
   - 50% of the stars are counter-rotating. Both components share the same SSP properties.

Stellar populations is the key!! We need to disentangle both kinematics & stellar population properties of the counter-rotating components.

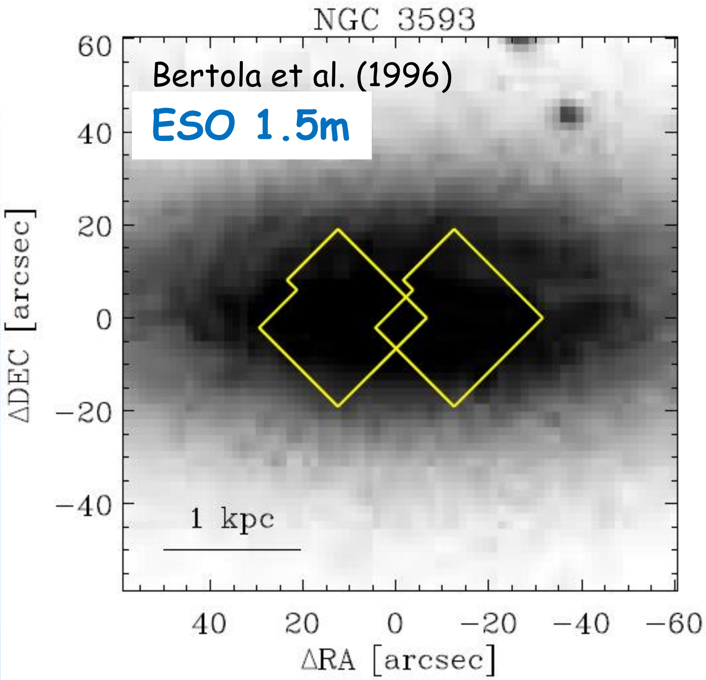
SPECTRAL DECOMPOSITION:

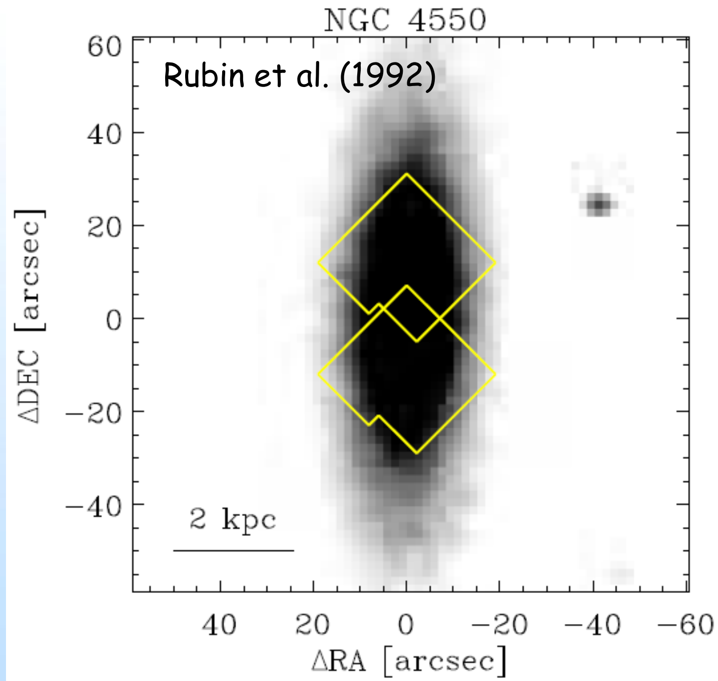
disentangling kinematics *and* stellar populations of the 2 disks



•The spectra of the stellar components are obtained convolving 2 synthetic templates with *2 best fitting LOSVDs*. Each synthetic template is an *independent* linear combination of stars from a spectral library.

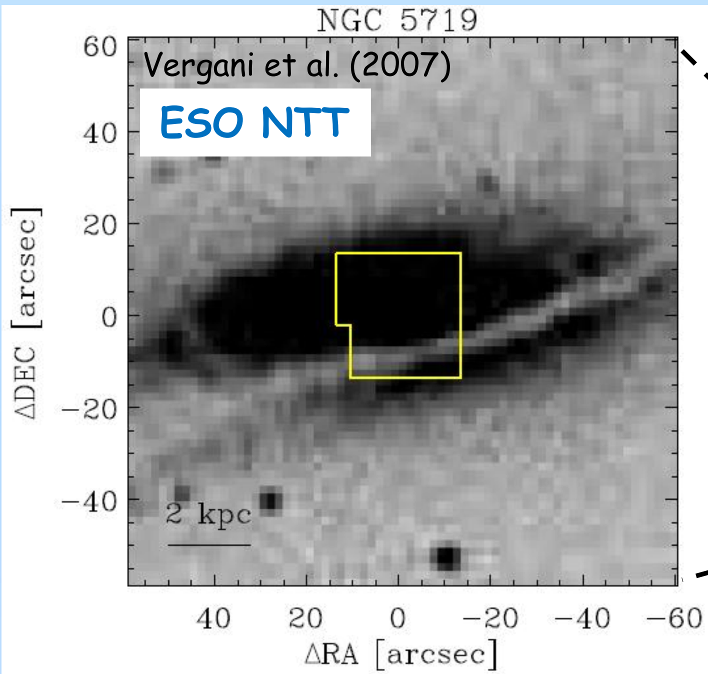
•Differences in the position of absorption line features and in the Hβ equivalent widths between the two stellar components (→ different kinematics and stellar population content).



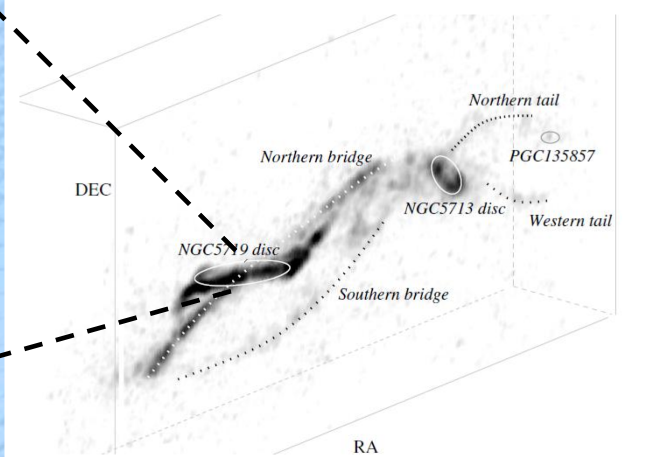


SAMPLE:

VIMOS
- Nice λ coverage 4200 - 6200
- Good spectral resolution (~50 km/sec)



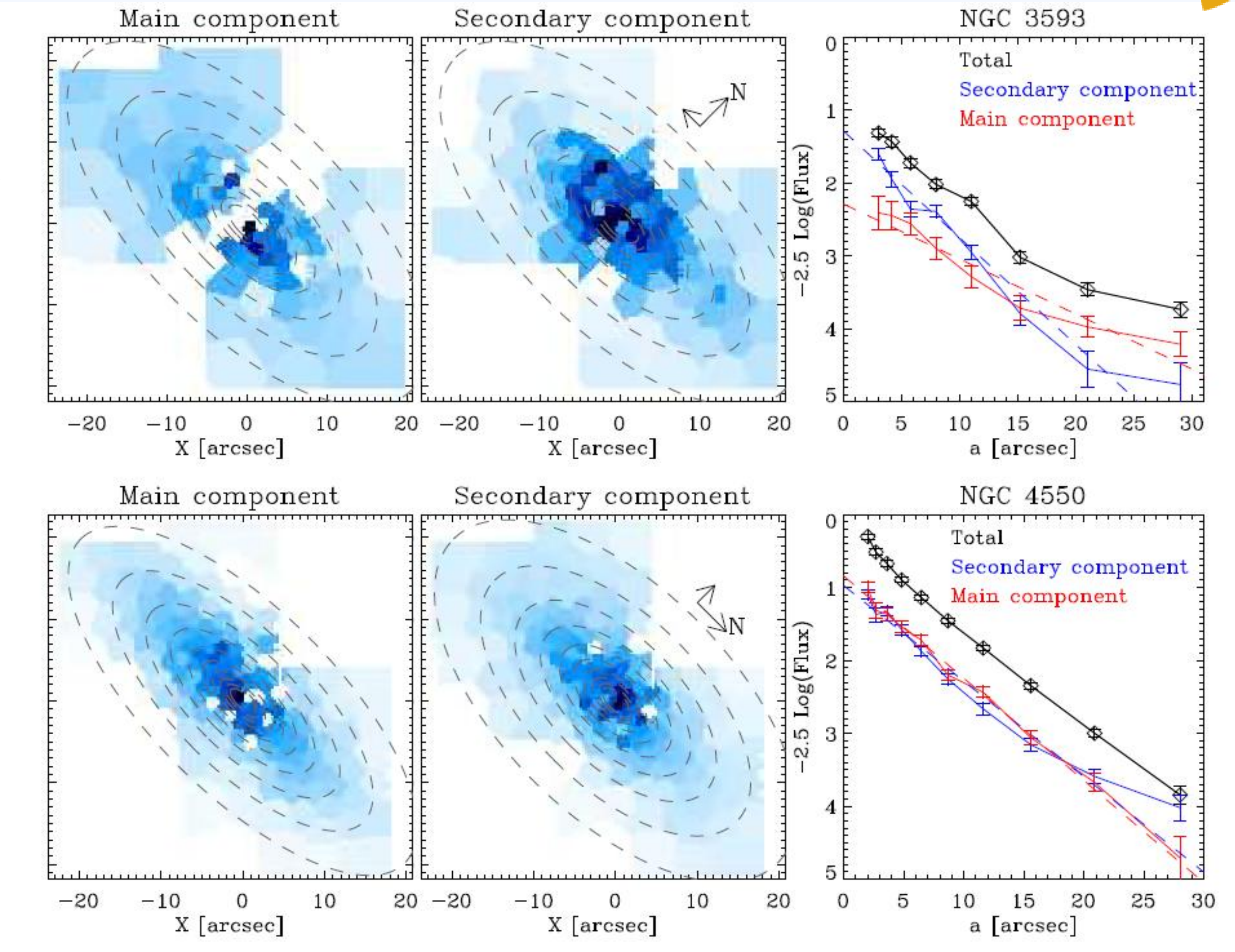
NGC 5719:
Gas acquisition from companion



Surface brightness

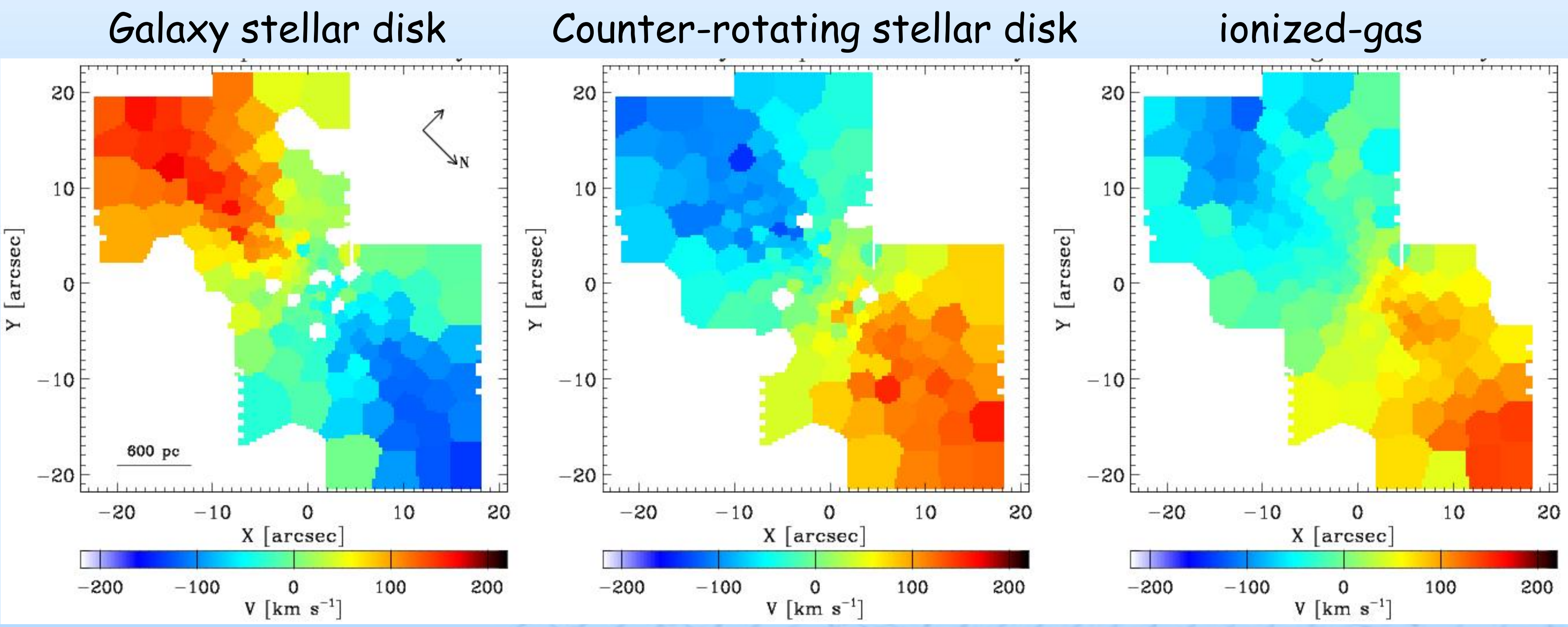
NGC 3593

NGC 4550



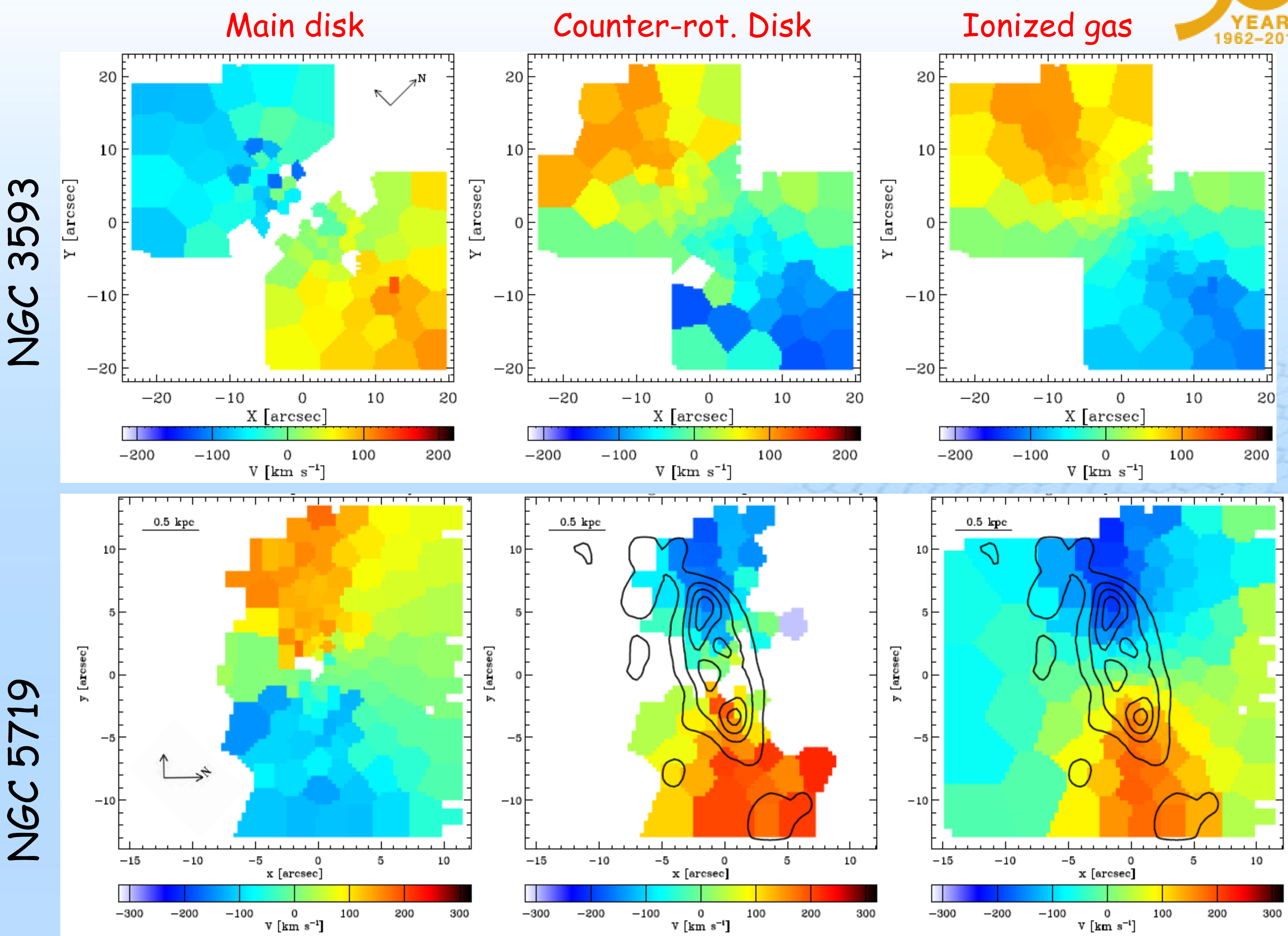
Velocity fields

NGC 4550



The procedure works very well in separating the kinematics of various components.

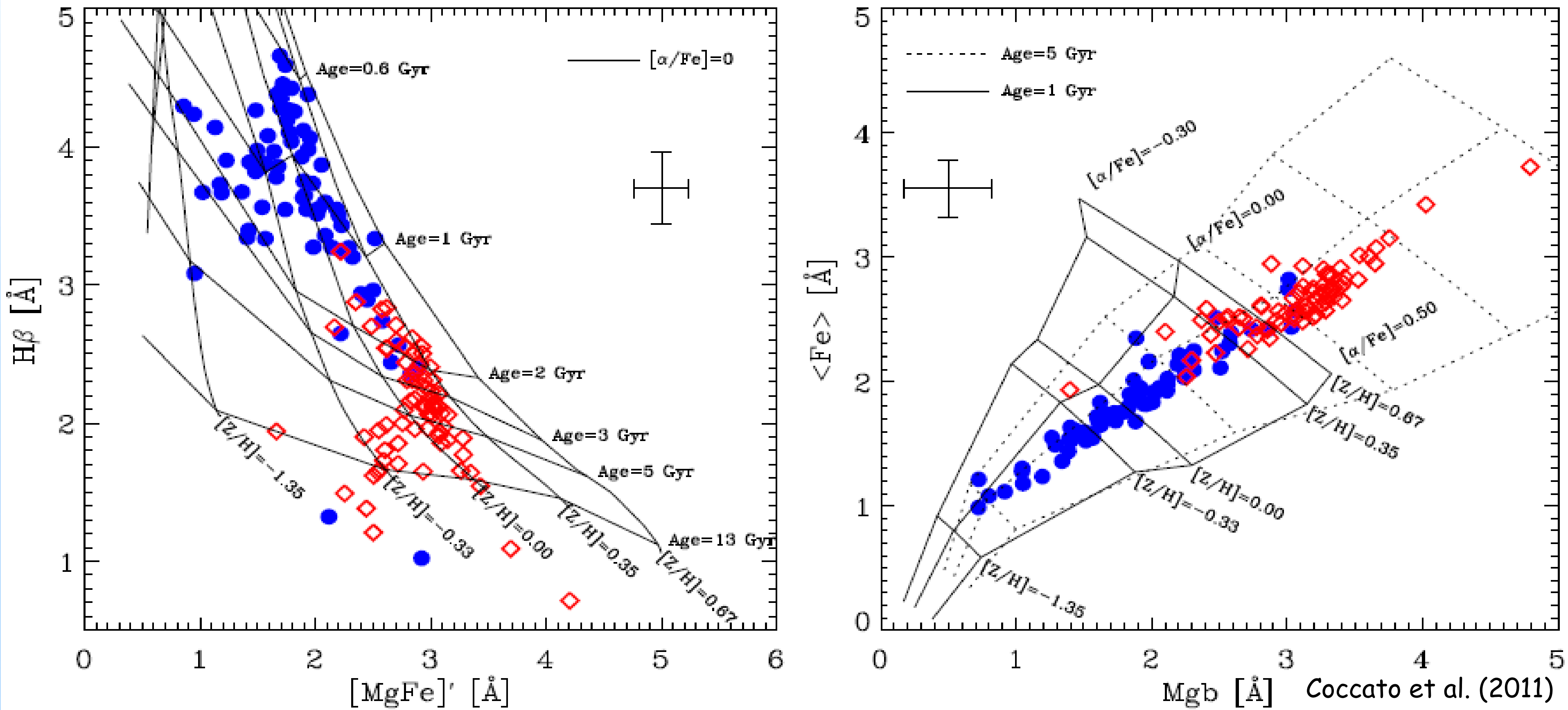
Velocity fields



L. Coccato – 05 Sept. 2012

LICK INDICES

NGC 5719



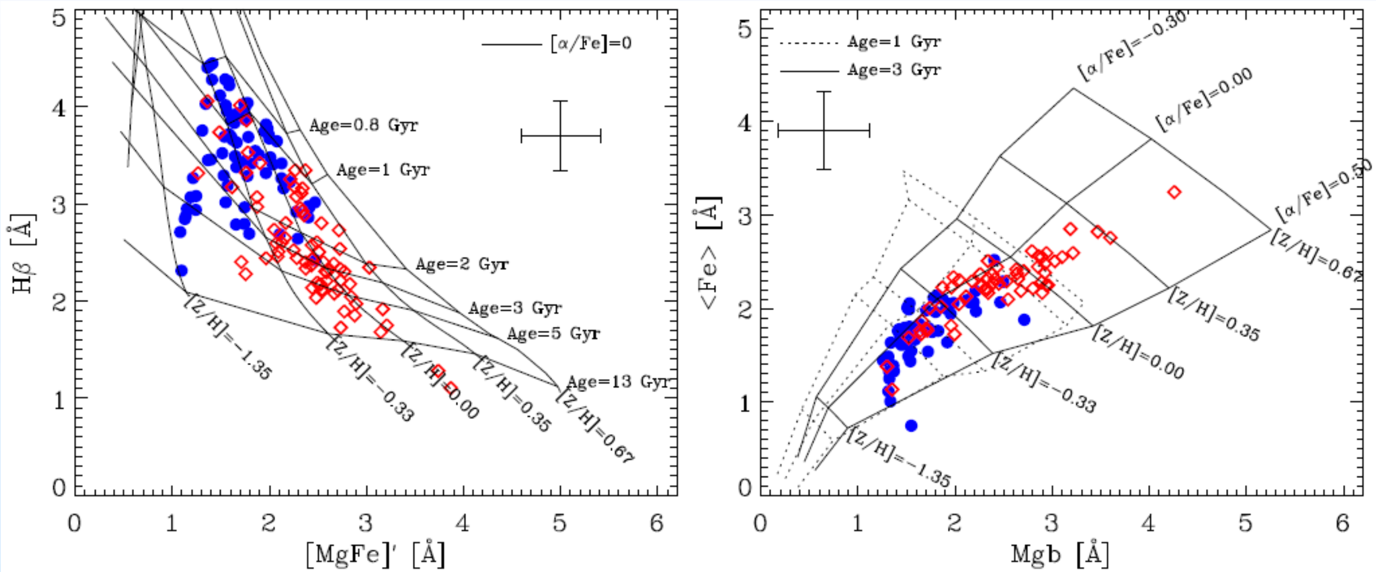
Coccato et al. (2011)

- Secondary stellar component (rotating with the gas)
- Main stellar component

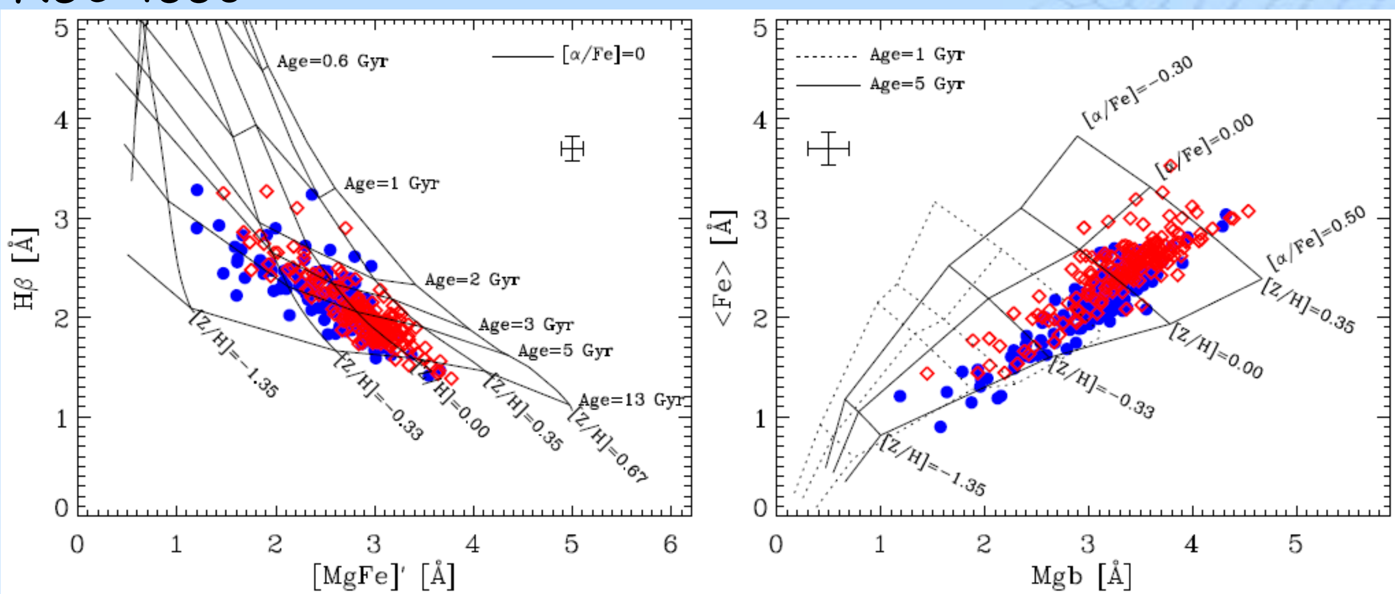
The procedure works well in separating the spectral indices of the various components.

LICK INDICES

NGC 3593



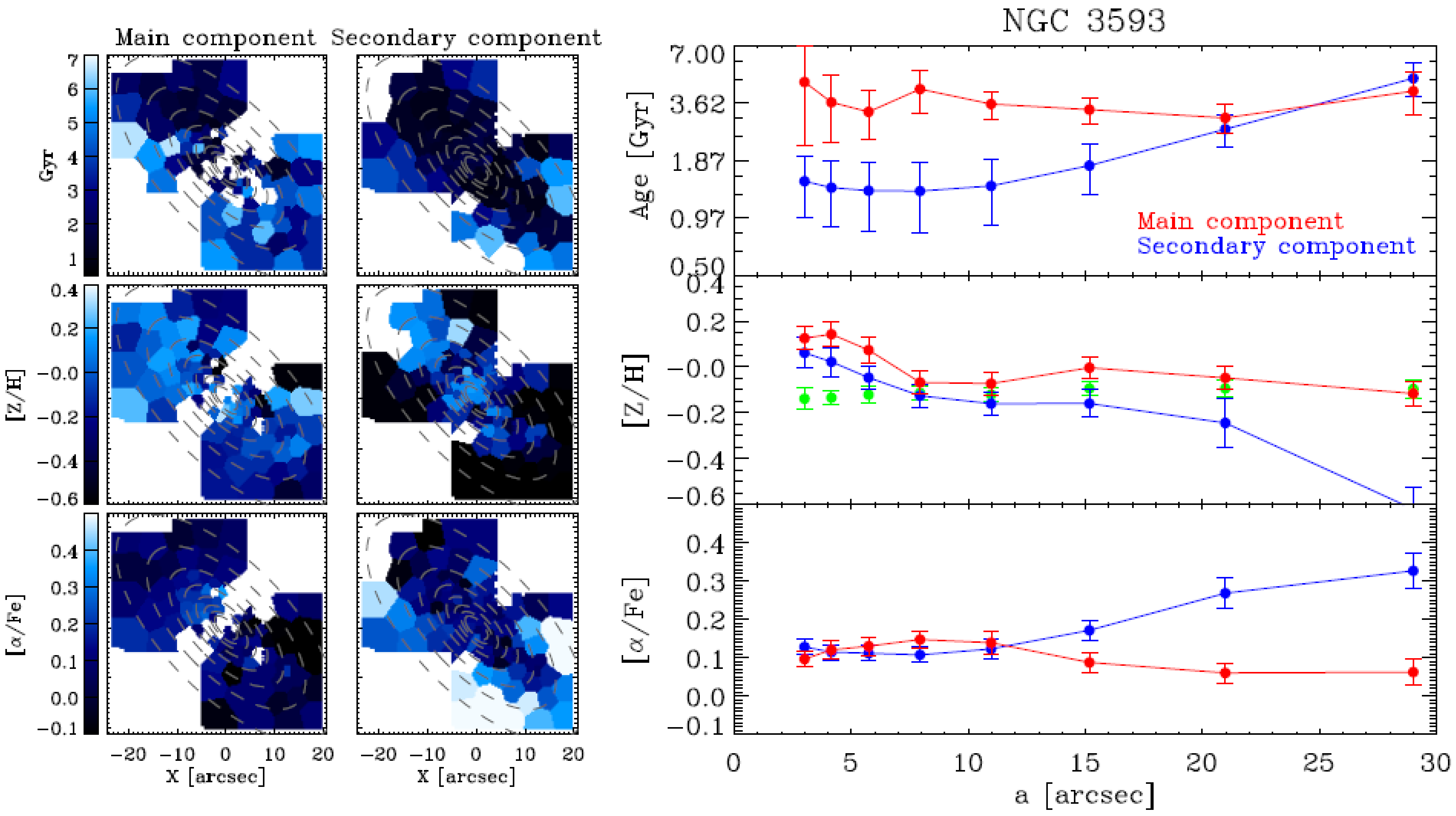
NGC 4550



- Secondary stellar component (rotating with the gas)
- Main stellar component

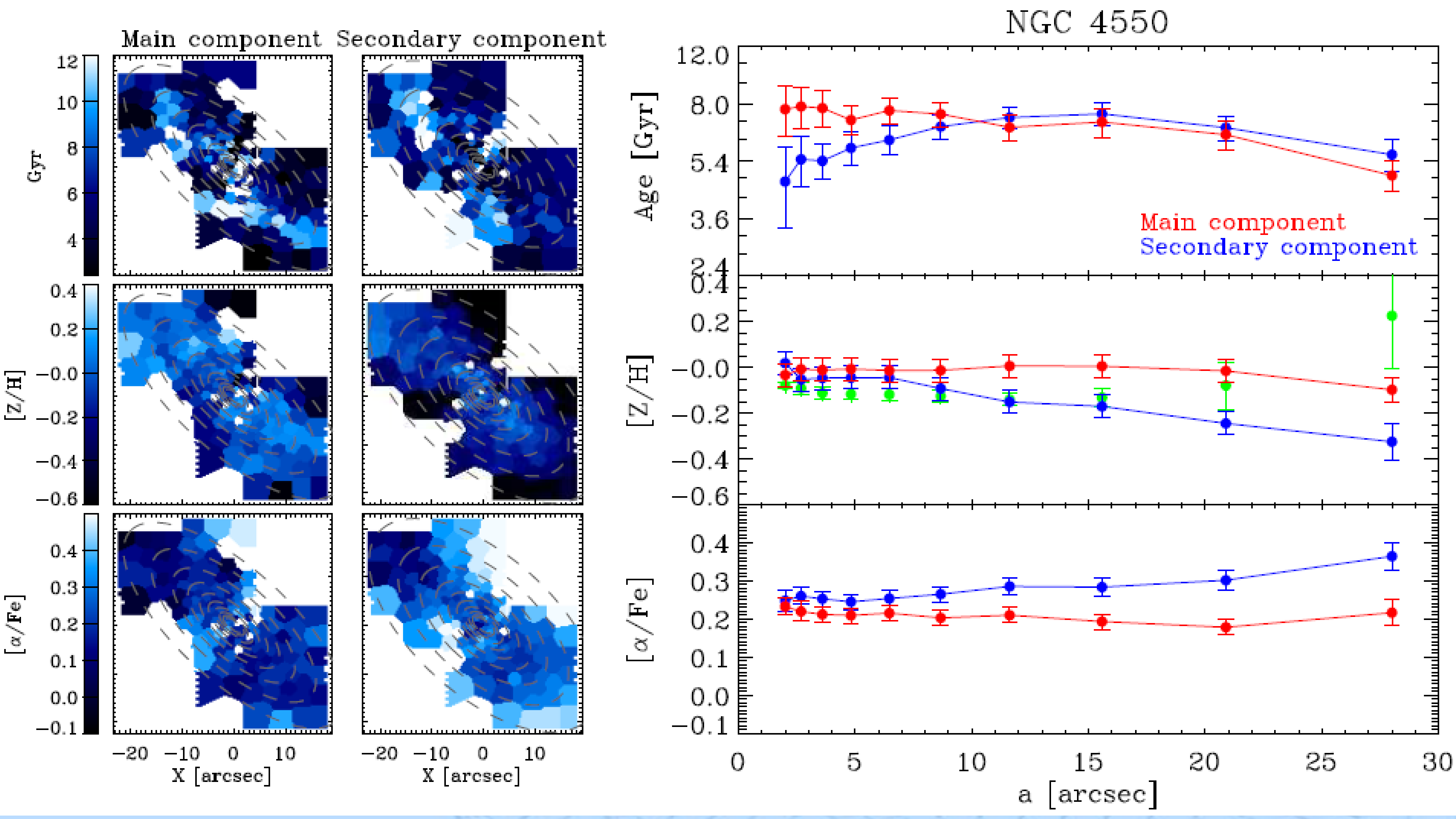
Stellar populations: Age, [Z/H], [α/Fe]

NGC 3593



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

NGC 4550



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

NGC 5719

Main disk

<Ages> = 4 Gyr
(2-13)

<[Z/H]> =0.08
Stddev ~0.2

<[α/Fe]> =0.1
Stddev~0.1

Counter-rot. disk

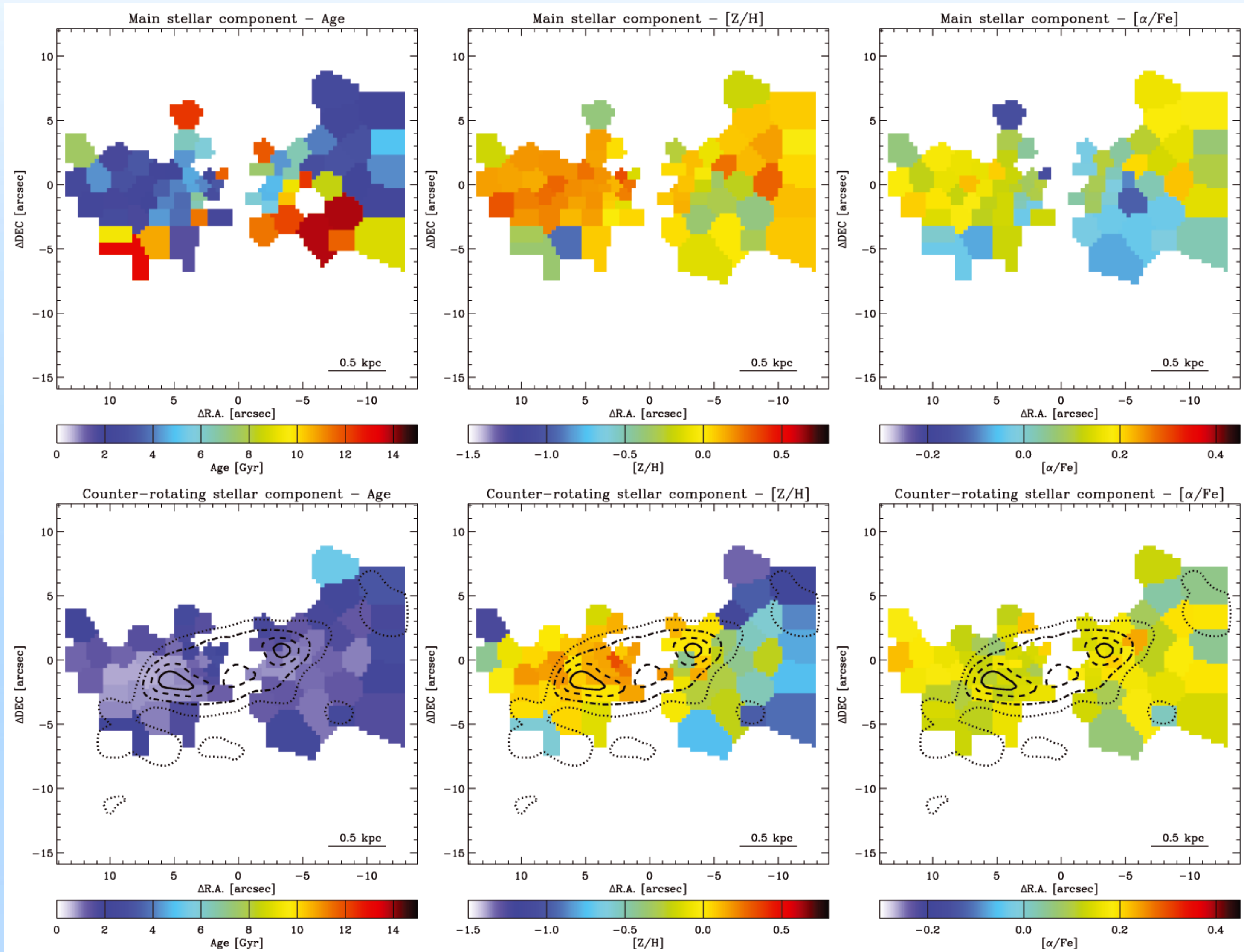
<Age> = 1.3 Gyr
(0.7 - 2)

-1.0 <[Z/H]<0.3

<[α/Fe]>=0.14
Stddev~0.05

Timescale: 2Gyr

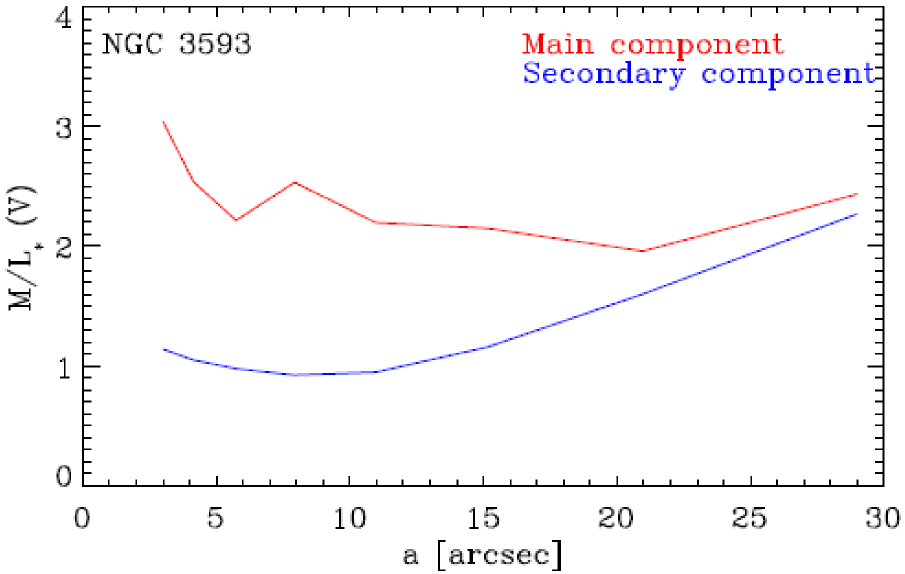
Age | [Z/H] | [α/Fe]

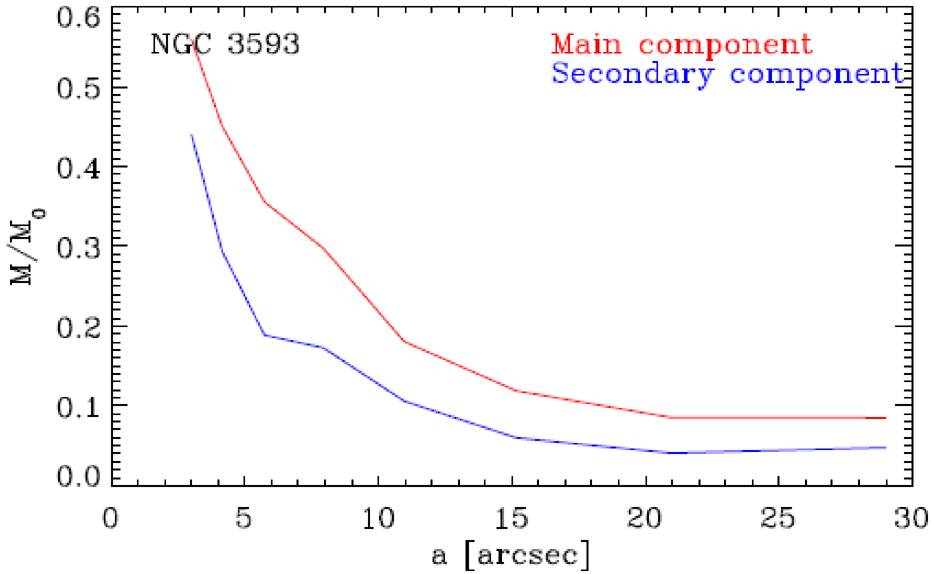


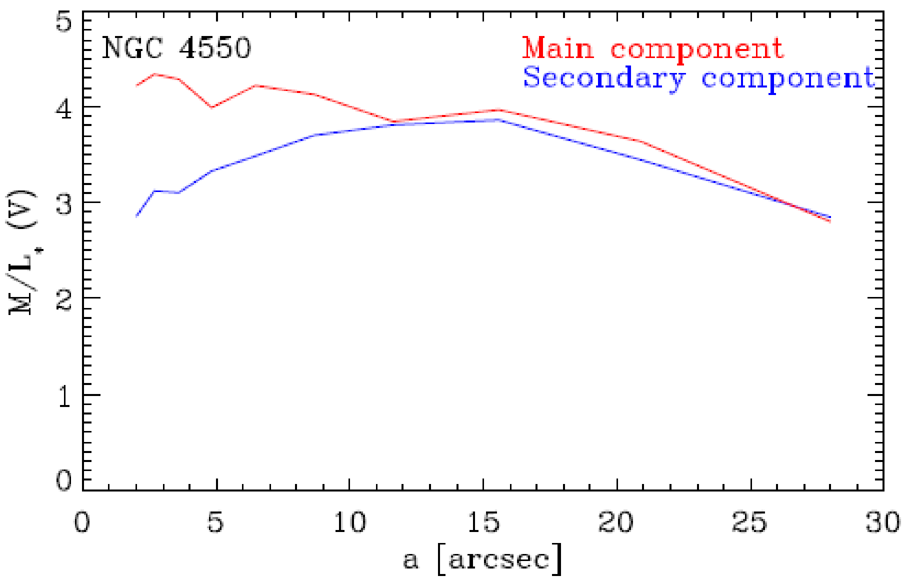
Coccato et al. (2011)

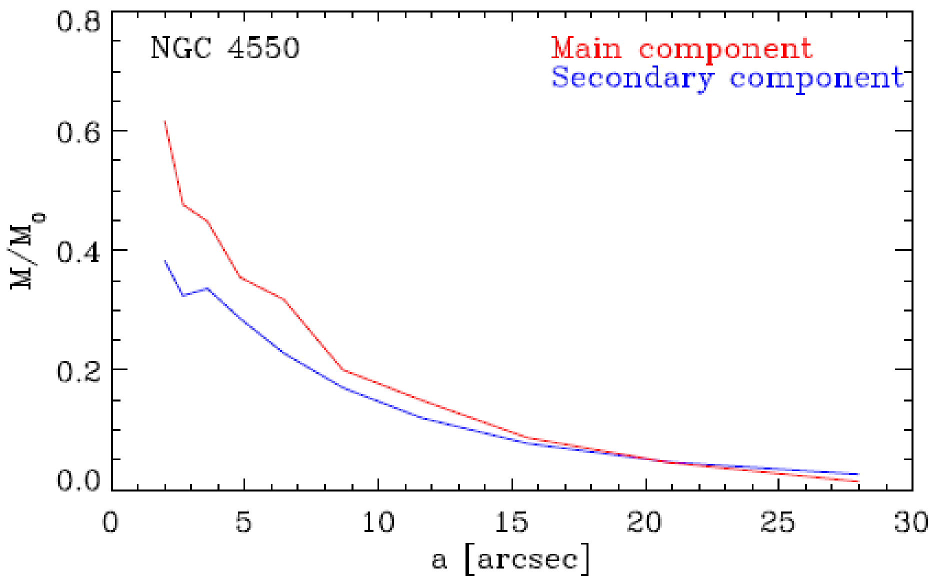
STELLAR *M/L*

STELLAR MASS







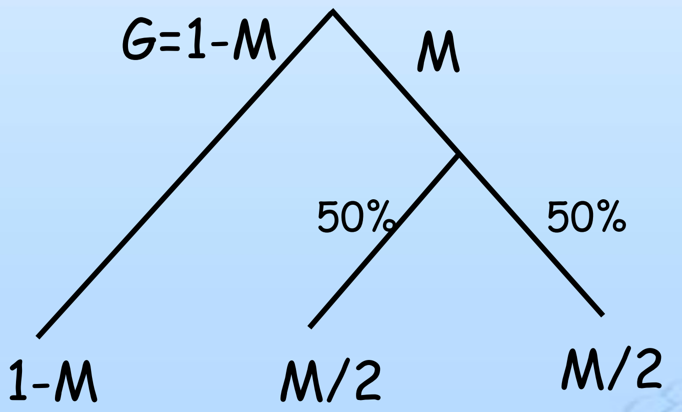


CONCLUSIONS

1. New spectroscopic decomposition technique: kinematics and stellar population. It works!!!
   - Decoupled structures (counter-rotating disks)
   - Spectroscopic Disk/Bulge decomposition (in progress)
2. All studied galaxies host a secondary stellar disk and a ionized gas disk that are counter-rotating with respect the main body of the galaxy. The secondary disks have **sizes comparable** with those of the main galaxy disks.
3. Stars in the counter-rotating stellar disks are on average **YOUNGER** than the stars in the main galaxy disk. They are also less rich in metals, more (or equally) α-enhanced and less massive.
4. Results support **gas accretion followed by star formation**. Date the accretion event: ~2Gyr (NGC 3593, ΔT~1.6 Gyr), ~7Gyr (NGC 4550, ΔT<1Gyr), 1.3Gyr (NGC 5719, +ΔT ~2.7$\pm$0.9 Gyr)
5. Bar dissolution scenario is ruled out.
6. Binary galaxy mergers cannot ruled out: M fraction < 38% (1 sigma).

How to disentangle scenarios using Age separation

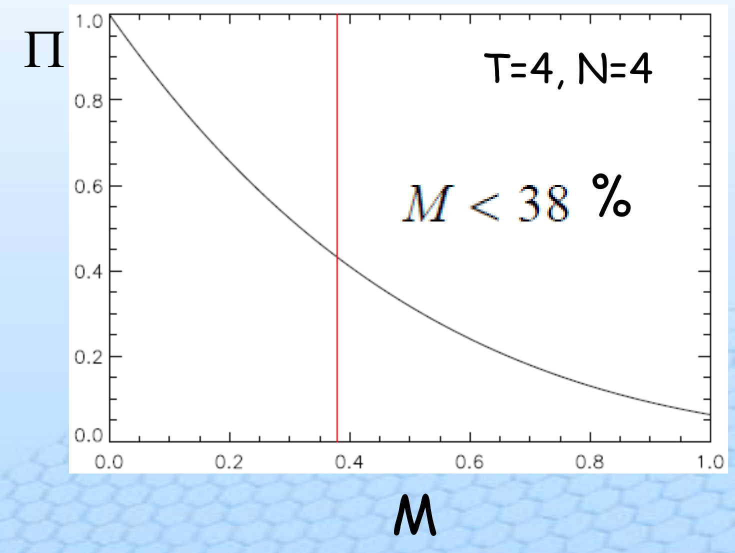
G: Fraction of counter-rotating galaxies generated by gas accretion.
M: Fraction of counter-rotating galaxies generated by binary mergers.
N = galaxies with 2nd component younger than the 1st
T = Total galaxies with counter-rotating disk.

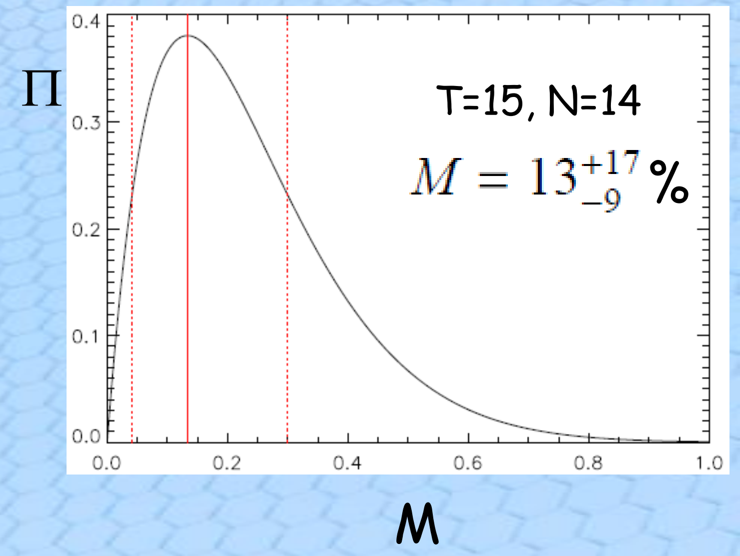


$$P(M) = 1 - M + M/2 = 1 - M/2$$

$$\Pi(N,T,P) = \binom{T}{N} P^N (1-P)^{T-N}$$

$$\int_{M^-}^{M^+} \Pi(N,T,P(x))dx = 0.67 \cdot \int_{-\infty}^{\infty} \Pi(N,T,P(x))dx$$





SUMMARY

Spectroscopic decomposition in counter-rotating galaxies that exploits the resolution and wavelength coverage of IFU like VIMOS@VLT:

1. It works!! NGC 3593, NGC 4550, NGC 5179 (+NGC 524 from literature, Katkov et al. 2011).

2. It allows to measure kinematics and stellar populations of ***both*** stellar components.

3. Secondary components are always younger (and have different [Z/H] and [α/Fe]) than the main components: favored scenario gas accretion on retrograde orbits followed by star formation.

4. Upper limit to the fraction of galaxies with large scale counter-rotating stellar disks produced by binary mergers (M<38%).