COUNTER-ROTATING DISKS IN GALAXIES: Dissecting kinematics and stellar populations with 3D spectroscopy

Lodovico Coccato (ESO)

in collaboration with:
L. Morelli; A. Pizzella; E. M. Corsini; E. Dalla Bonta' (University of Padova, Italy); M. Fabricius (MPE); Enrica Iodice (INAF-OAC); M. Arnaboldi (ESO)

More info in:

- Coccato et al. 2011, MNRAS, 412, L113;
- Coccato et al. 2013, A&A, 459, 3;
- Fabricius et al. 2014, MNRAS, 441, 2212 (→ talk)
- Coccato et al. 2014, A&A, submitted

COUNTER-ROTATION IN GALAXIES

✓Stars rotating along opposite direction with respect to other stars and/or gas have been detected in several galaxies (see Corsini 2014, arXiv: 1403.1263 for 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 the topic of this talk. NGC 4550 as prototype (Rubin et al. 1992). Few objects known so far, 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; Algorry et al. 2014). Example: NGC 5719 direct observation of on-going gas accretion on a galaxy with stellar counter-rotation (see poster by L. Morelli).

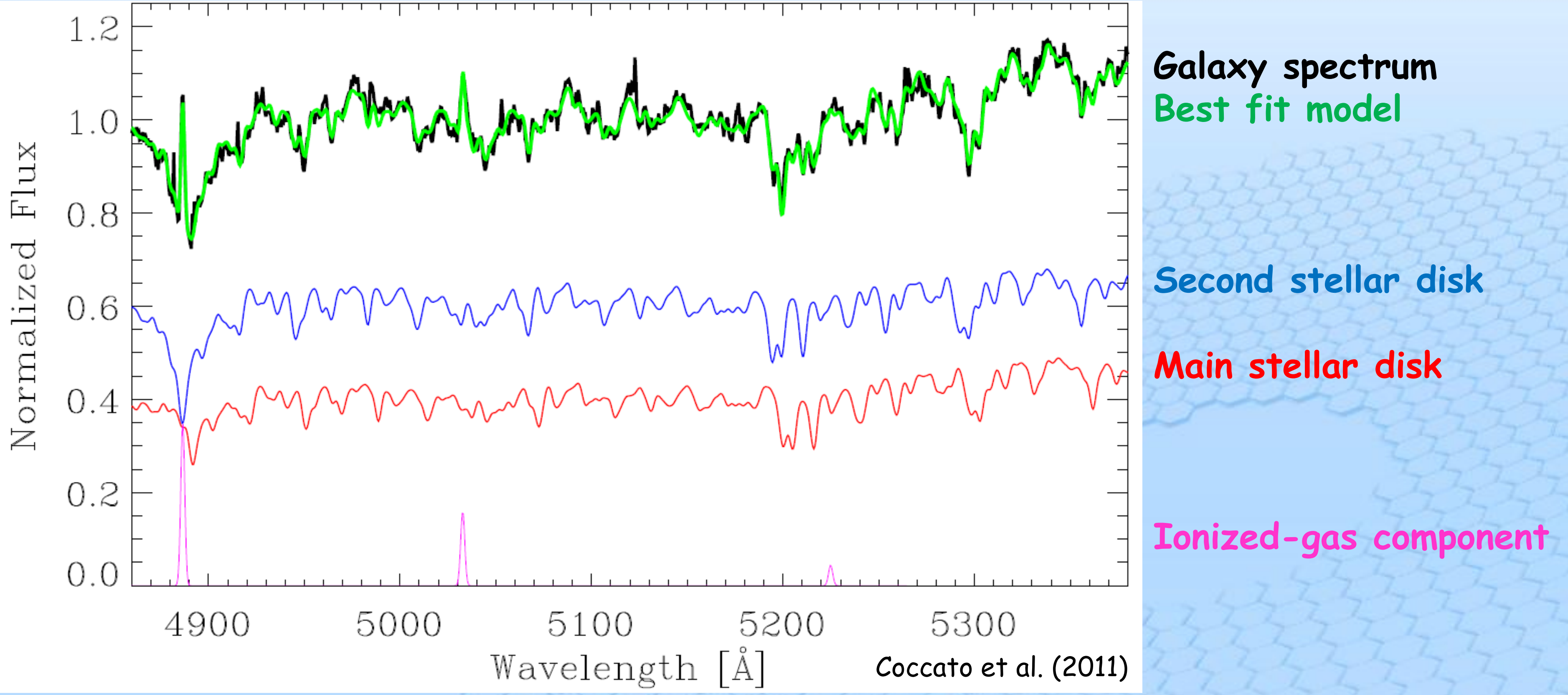
2. **Galaxy mergers**: The properties of the counter-rotating disks depend on the nature of the progenitors and star formation history. According to simulations:
   - Merger of galaxies play no significant role (Algorry et al. 2014).
   - Can explain the presence of 50% counter-rotating stars in NGC 4550 and the different flattening of the two counter-rotating disks (Crocker et al. 2009).

Aim: Study the properties of both the counter-rotating (CR) stellar disks.
Complication: the CR disks are co-spatial: the sum of their contributions is observed.
Challenge: Separate the two components and measure them independently.

SPECTRAL DECOMPOSITION:

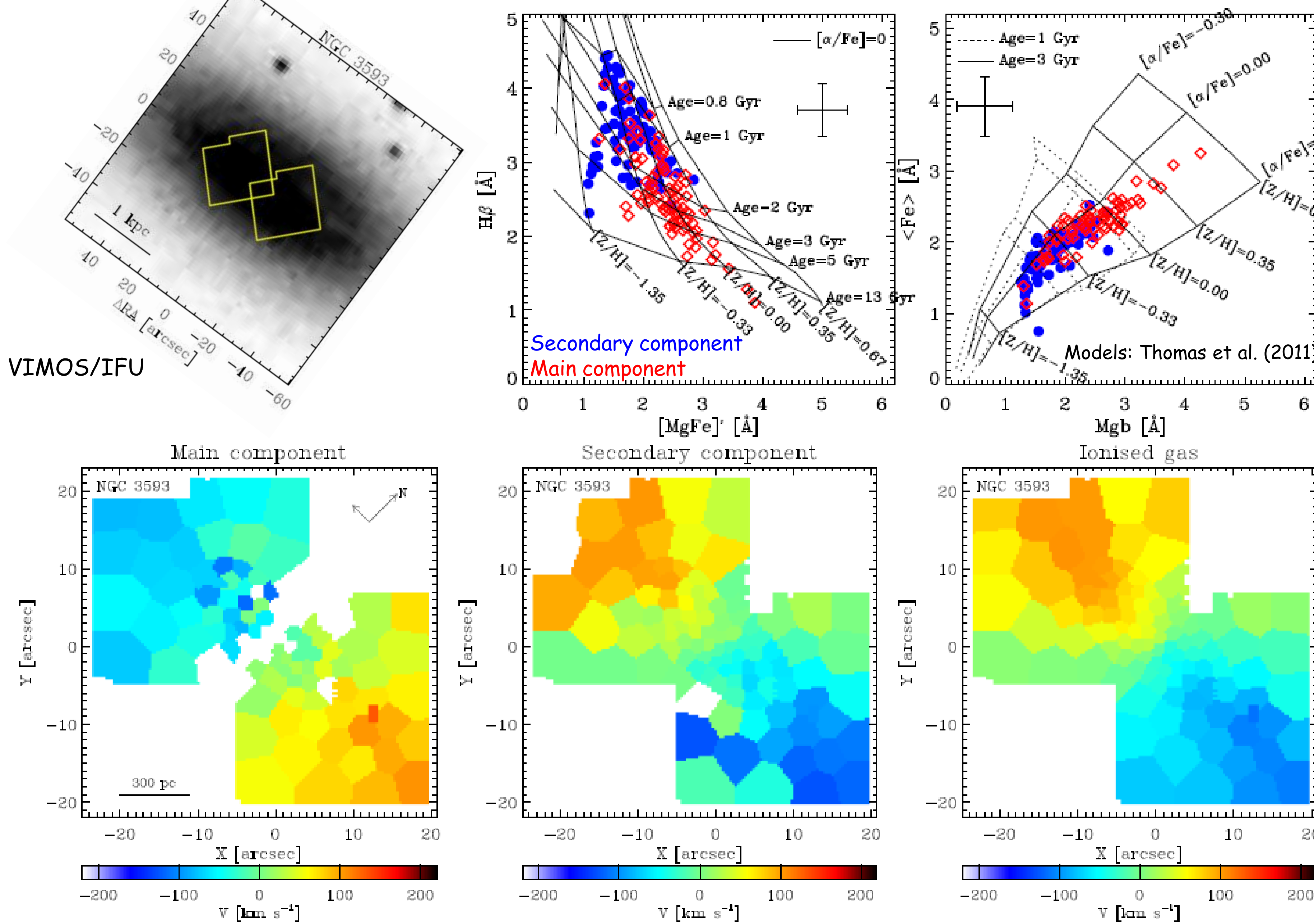
disentangling kinematics *and* stellar populations of the two CR disks

Construction of *2 independent synthetic templates* as linear combinations of stars from 2 spectral libraries (→ stellar populations). Convolution with *2 Gaussian LOSVDs* (→ kinematics). Iterative procedure (χ^2 minimization).

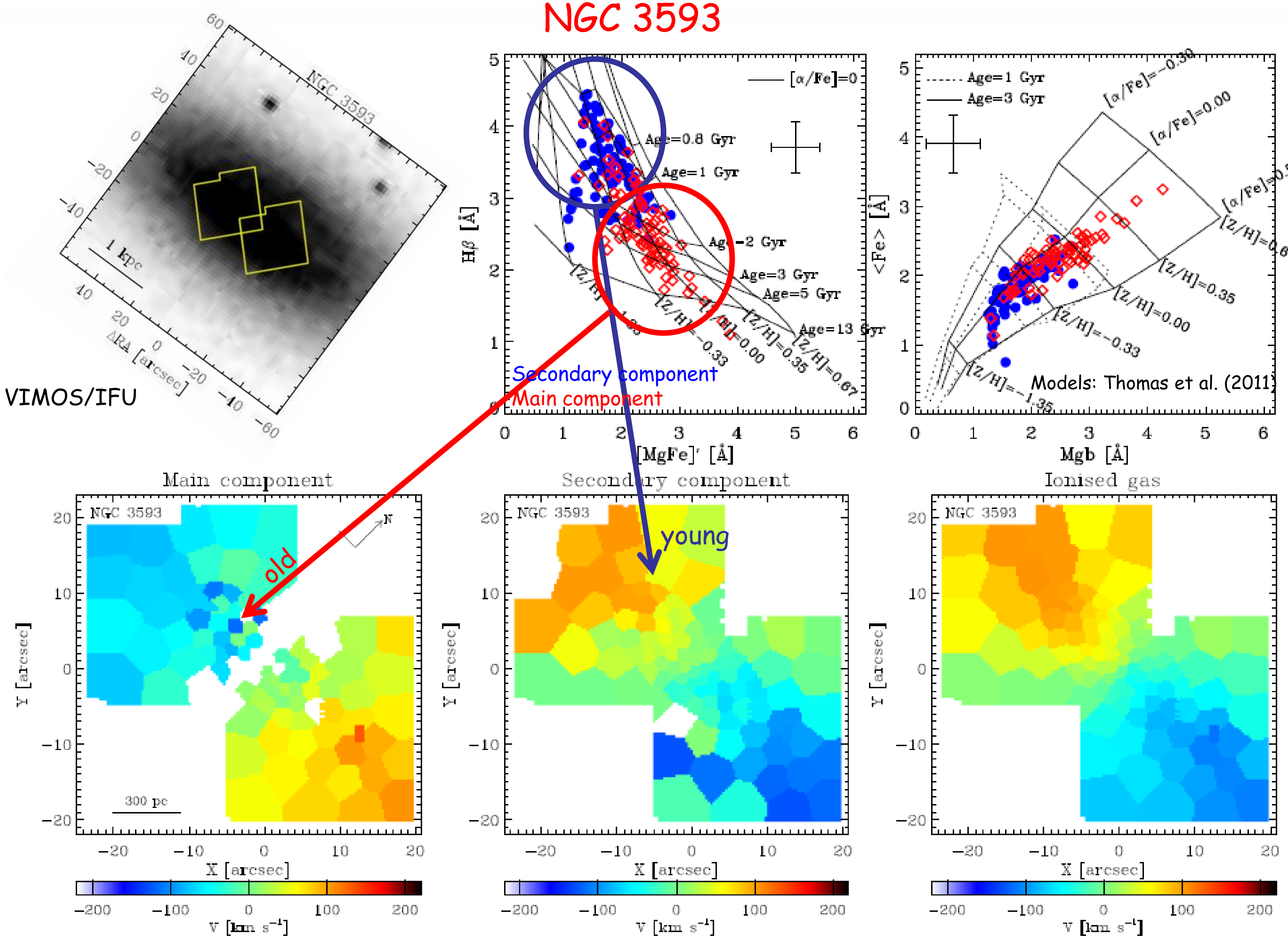


Differences in the position of absorption line features and in the Hβ equivalent widths between the two stellar components (→ different kinematics and stellar population content).

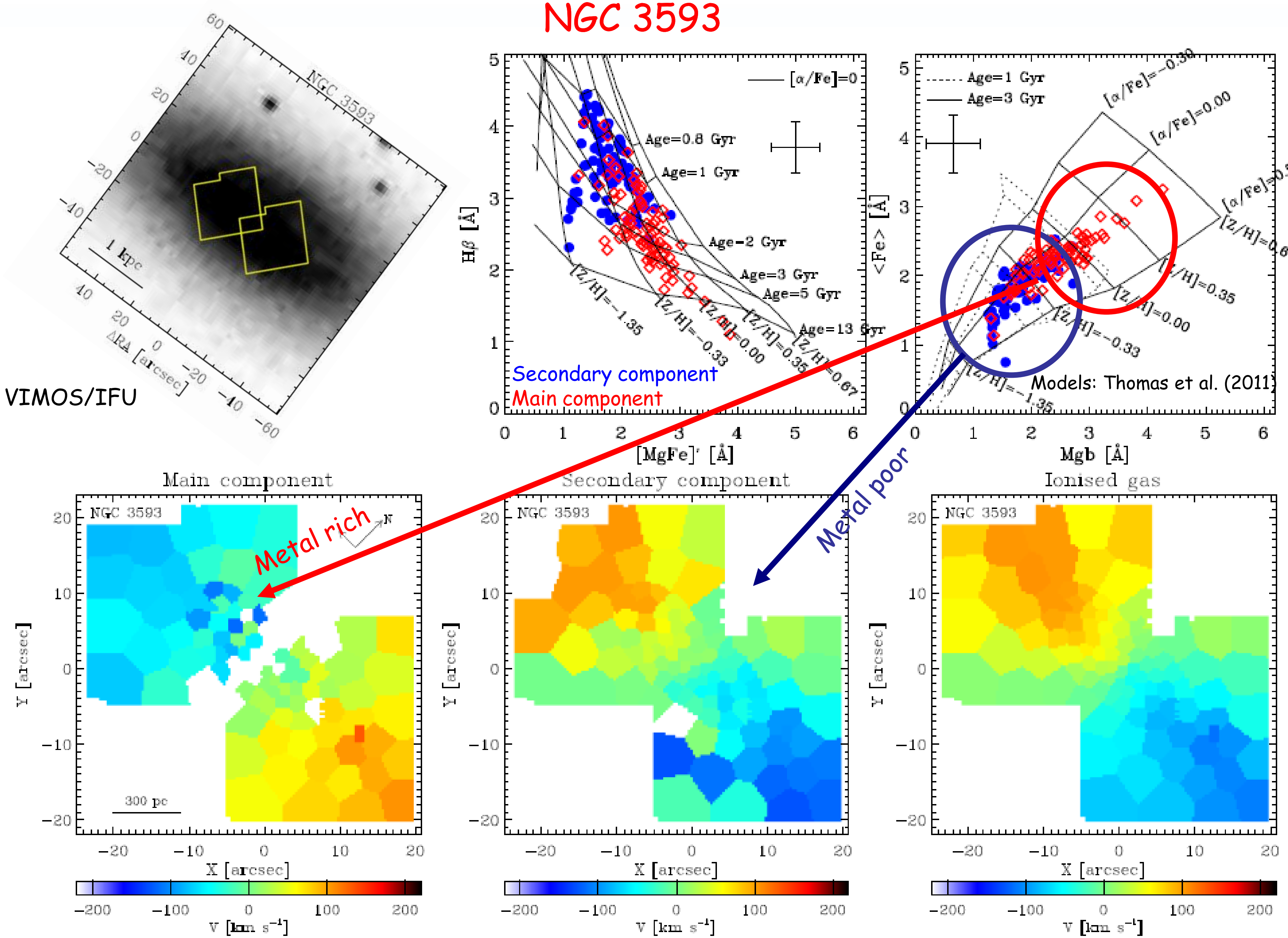
NGC 3593


NGC 3593
1 kpc
ΔRA [arcsec]
VIMOS/IFU
[α/Fe]=0
Age=0.8 Gyr
Age=1 Gyr
Age=2 Gyr
Age=3 Gyr
Age=5 Gyr
Age=13 Gyr
[Z/H]=−1.35
[Z/H]=−0.33
[Z/H]=0.00
[Z/H]=0.35
[Z/H]=0.67
Hβ [Å]
[MgFe]' [Å]
Secondary component
Main component
Age=1 Gyr
Age=3 Gyr
[α/Fe]=−0.30
[α/Fe]=0.00
[α/Fe]=0.50
<Fe> [Å]
Mgb [Å]
Models: Thomas et al. (2011)
Main component
Secondary component
Ionised gas
N
300 pc
Y [arcsec]
X [arcsec]
V [km s⁻¹]

NGC 3593

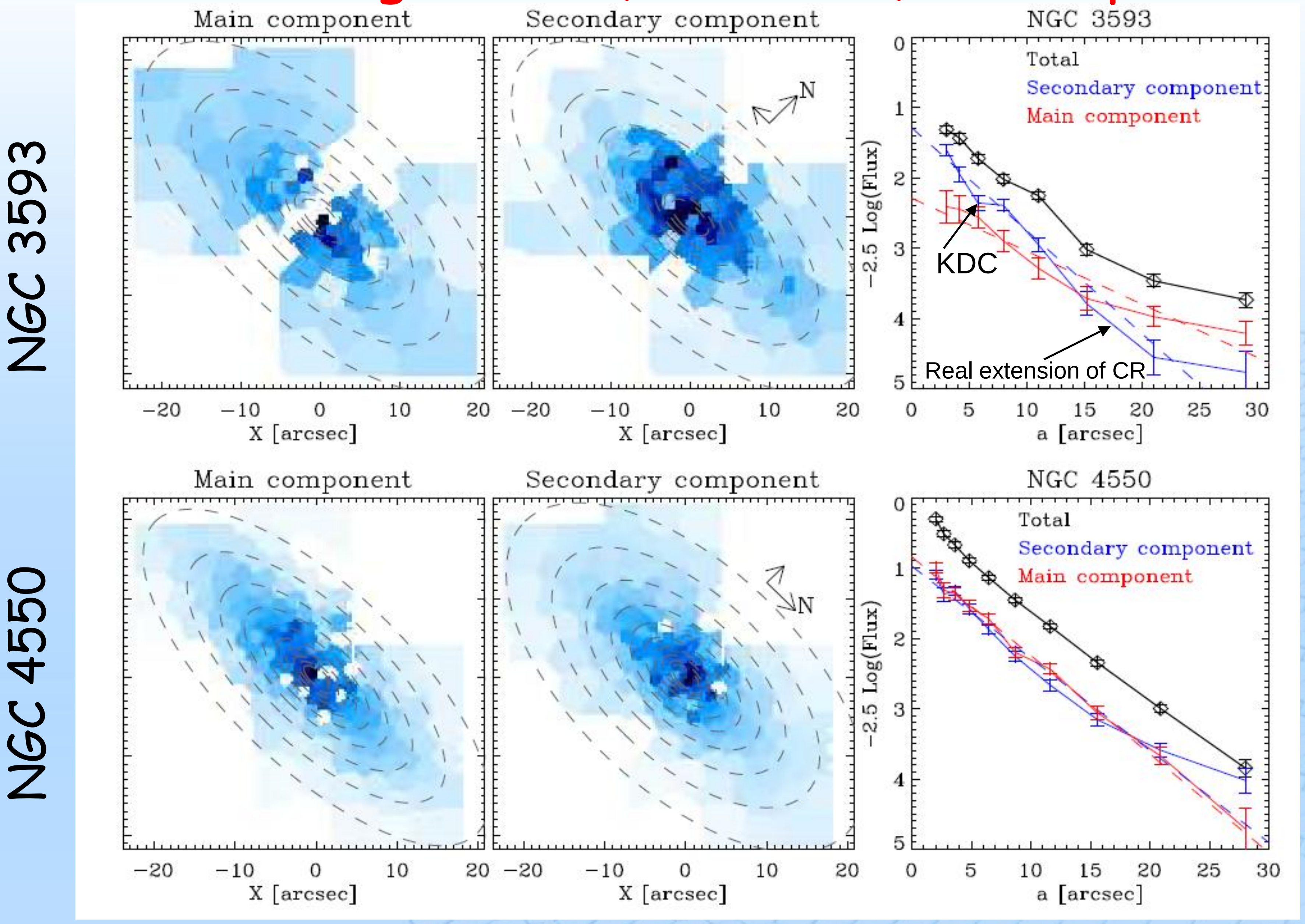

NGC 3593
1 kpc
ΔRA [arcsec]
VIMOS/IFU
[α/Fe]=0
Age=0.8 Gyr
Age=1 Gyr
Age=2 Gyr
Age=3 Gyr
Age=5 Gyr
Age=13 Gyr
[Z/H]=-0.33
[Z/H]=0.00
[Z/H]=0.35
[Z/H]=0.67
Hβ [Å]
[MgFe]' [Å]
Secondary component
Main component
Age=1 Gyr
Age=3 Gyr
[α/Fe]=-0.30
[α/Fe]=0.00
[α/Fe]=0.50
[Z/H]=0.67
[Z/H]=0.35
[Z/H]=0.00
[Z/H]=-0.33
[Z/H]=-1.35
<Fe> [Å]
Mgb [Å]
Models: Thomas et al. (2011)
Main component
Secondary component
Ionised gas
old
young
N
300 pc
Y [arcsec]
X [arcsec]
V [km s⁻¹]

NGC 3593

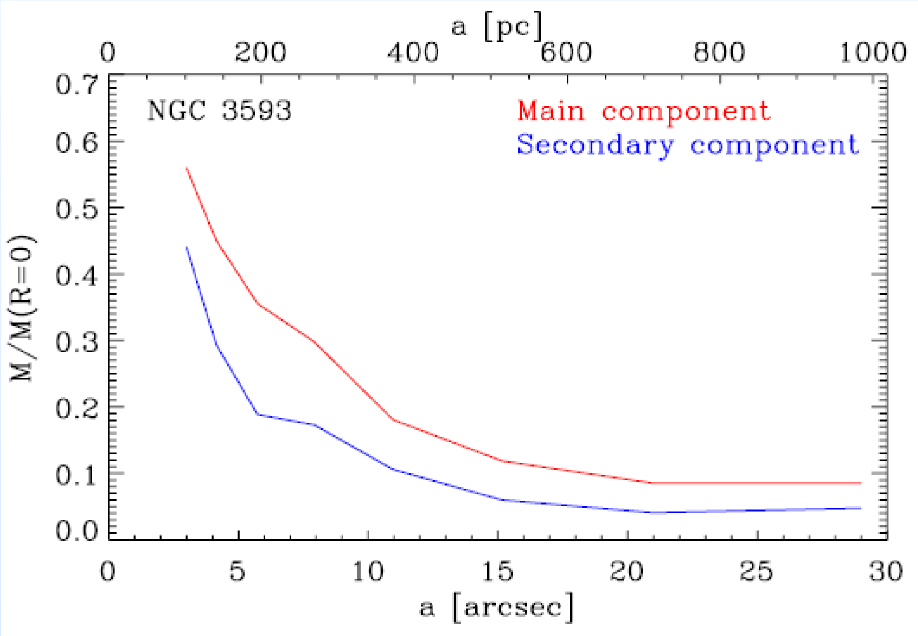


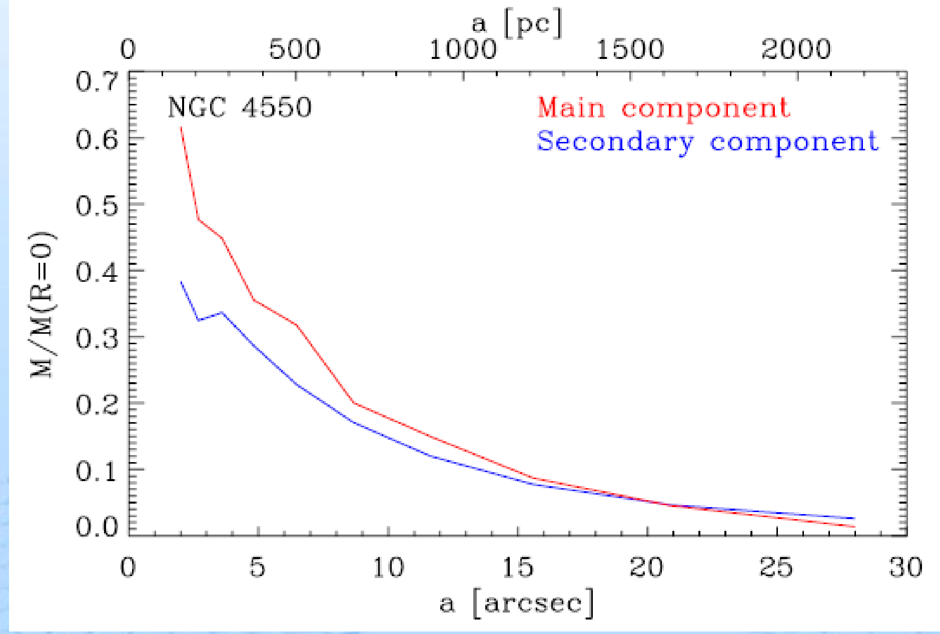
NGC 3593
1 kpc
ΔRA [arcsec]
VIMOS/IFU
[α/Fe]=0
Age=0.8 Gyr
Age=1 Gyr
Age=2 Gyr
Age=3 Gyr
Age=5 Gyr
Age=13 Gyr
[Z/H]=-1.35
[Z/H]=-0.33
[Z/H]=0.00
[Z/H]=0.35
[Z/H]=0.67
Hβ [Å]
[MgFe]' [Å]
Secondary component
Main component
Age=1 Gyr
Age=3 Gyr
[α/Fe]=-0.30
[α/Fe]=0.00
[α/Fe]=0.50
<Fe> [Å]
Mgb [Å]
Models: Thomas et al. (2011)
Metal rich
Metal poor
Main component
Secondary component
Ionised gas
300 pc
N
X [arcsec]
Y [arcsec]
V [km s^{-1}]

Surface brightness (kinematic) decomposition



STELLAR MASS PROFILE





Younger component, rotating as the ionized gas: less massive

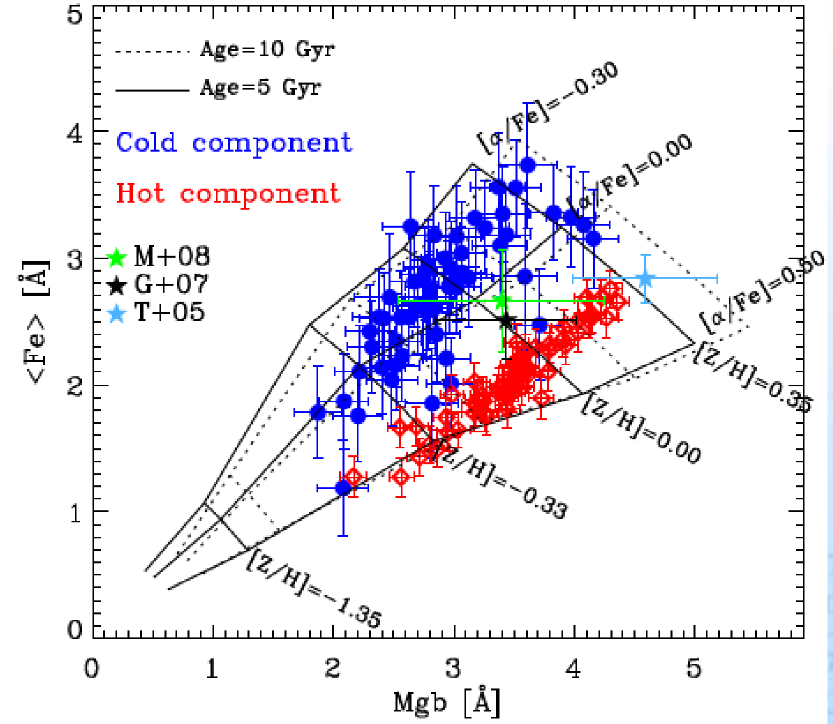
Other applications:

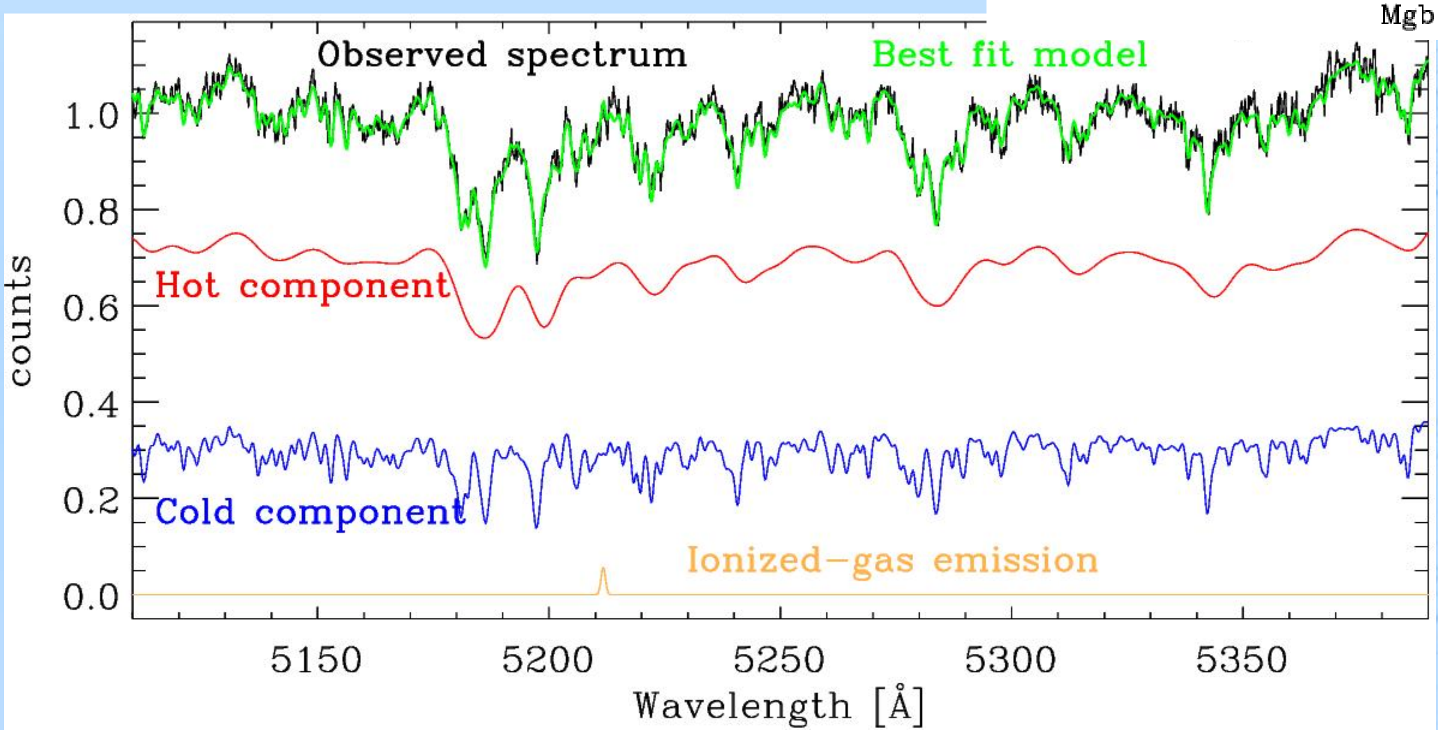
"Bulge" / "Disk" kinematic decomposition

NGC 7217

See Fabricius's talk

Data from Virus-W;
(Fabricius et al. 2014, MNRAS, 441, 2212)





NGC 4650A

Coccato et al. 2014, A&A submitted

Kinematics

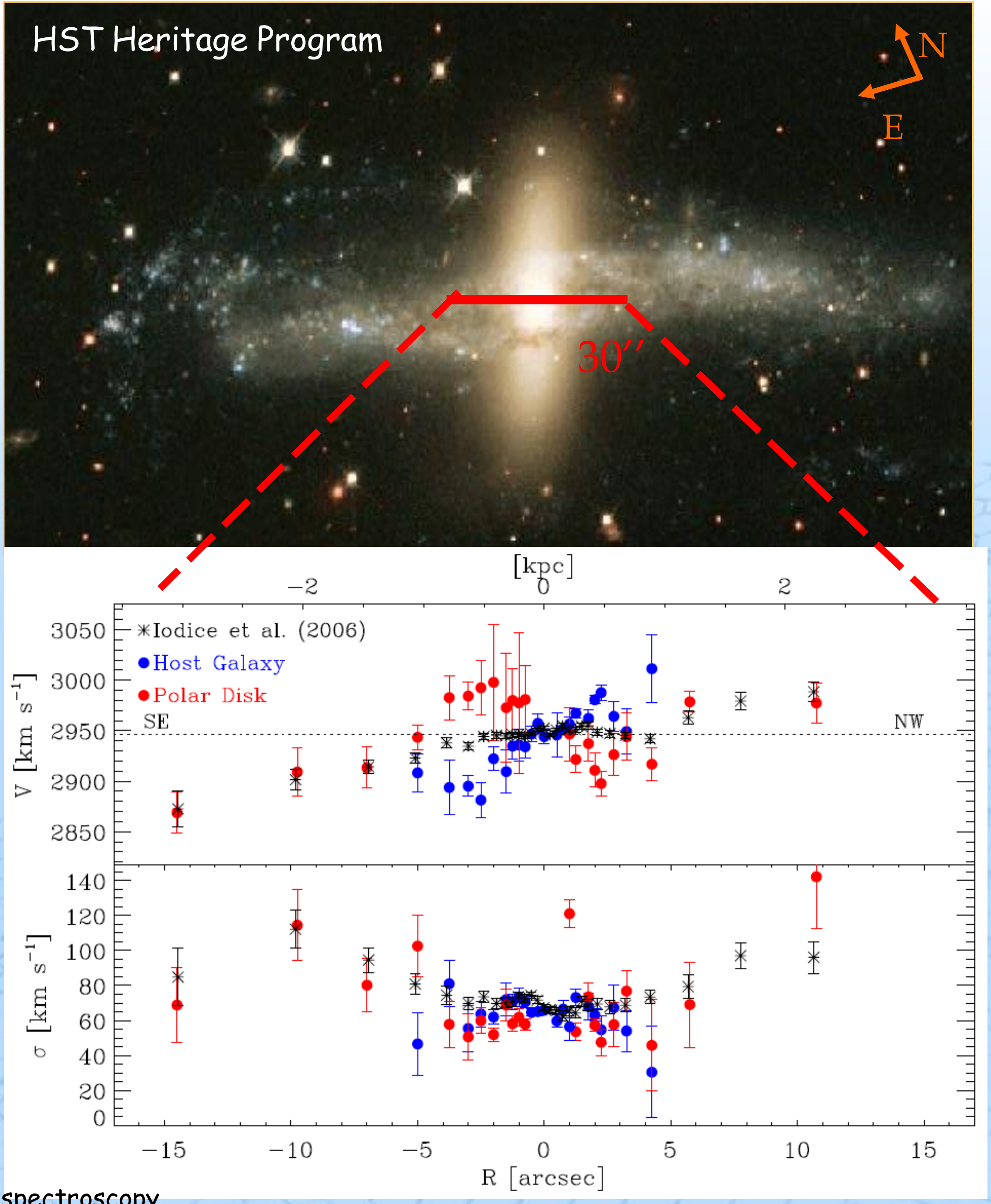
Rotation of host galaxy along the minor axis → **non axisymmetric potential.**

Counter-rotation of polar disk → **multiple accretion formation episode.**

Stellar content:

Spheroid: GIII (~50%) and KIII (~35%) plus contamination from young A,O,B stars (~15%).
NO RADIAL GRADIENT.

Disk: GIII (~45%) and KIII (~35%) plus contamination from young A,O,B stars (~20%).
RADIAL GRADIENT:
Young star fraction from 10% (R<1.5kpc) to 30% (R>1.5 kpc)
→ outer disk formed later?



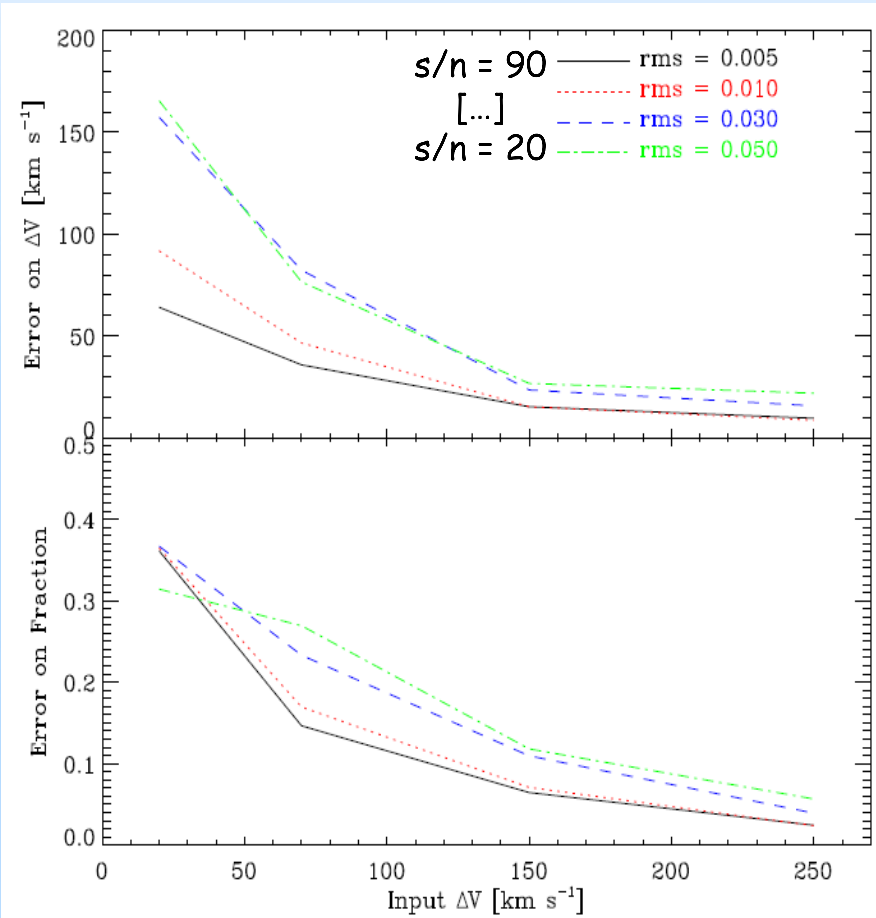
SUMMARY

We developed a spectroscopic decomposition technique (but see also other techniques: e.g. Katkov+ 2013; Johnston+13)

1. It has been successfully applied to:
   - counter-rotating disk galaxies (NGC 3593, NGC 4550, NGC 5179).
   - Bulge /disk decomposition (i.e. NGC 7217→ see Fabricius's talk).
   - Polar disk / host spheroid recovery (i.e. NGC 4650A).
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 components are always younger and have different [Z/H] than the main stellar components. In agreement with the gas accretion plus star formation. Date the accretion event: ~2Gyr (NGC 3593, ΔT~1.6$\pm$0.8 Gyr), ~7Gyr (NGC 4550, ΔT<1Gyr), 1.3Gyr (NGC 5719, ΔT ~2.7$\pm$0.9 Gyr).
4. *→ Larger statistics are needed to constrain the formation process(es) of counter-rotating disks (e.g. MANGA, VIMOS, MUSE, Virus-W surveys)*

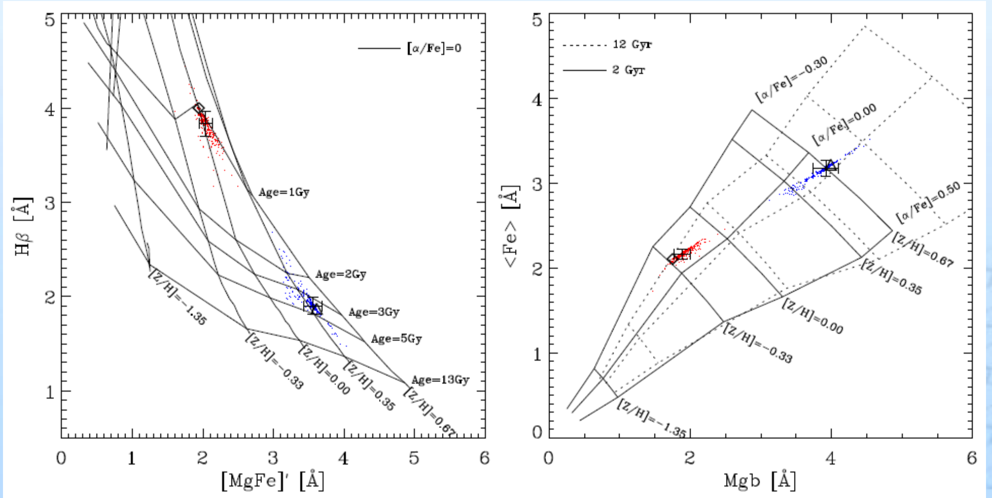
SPECTRAL DECOMPOSITION:

Errors on kinematics (simulations)

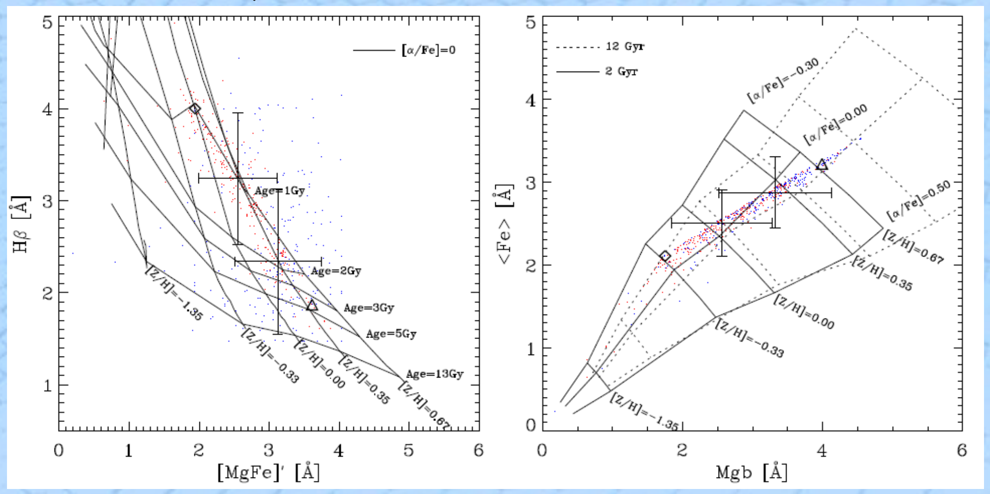


Errors on SSP (simulations)

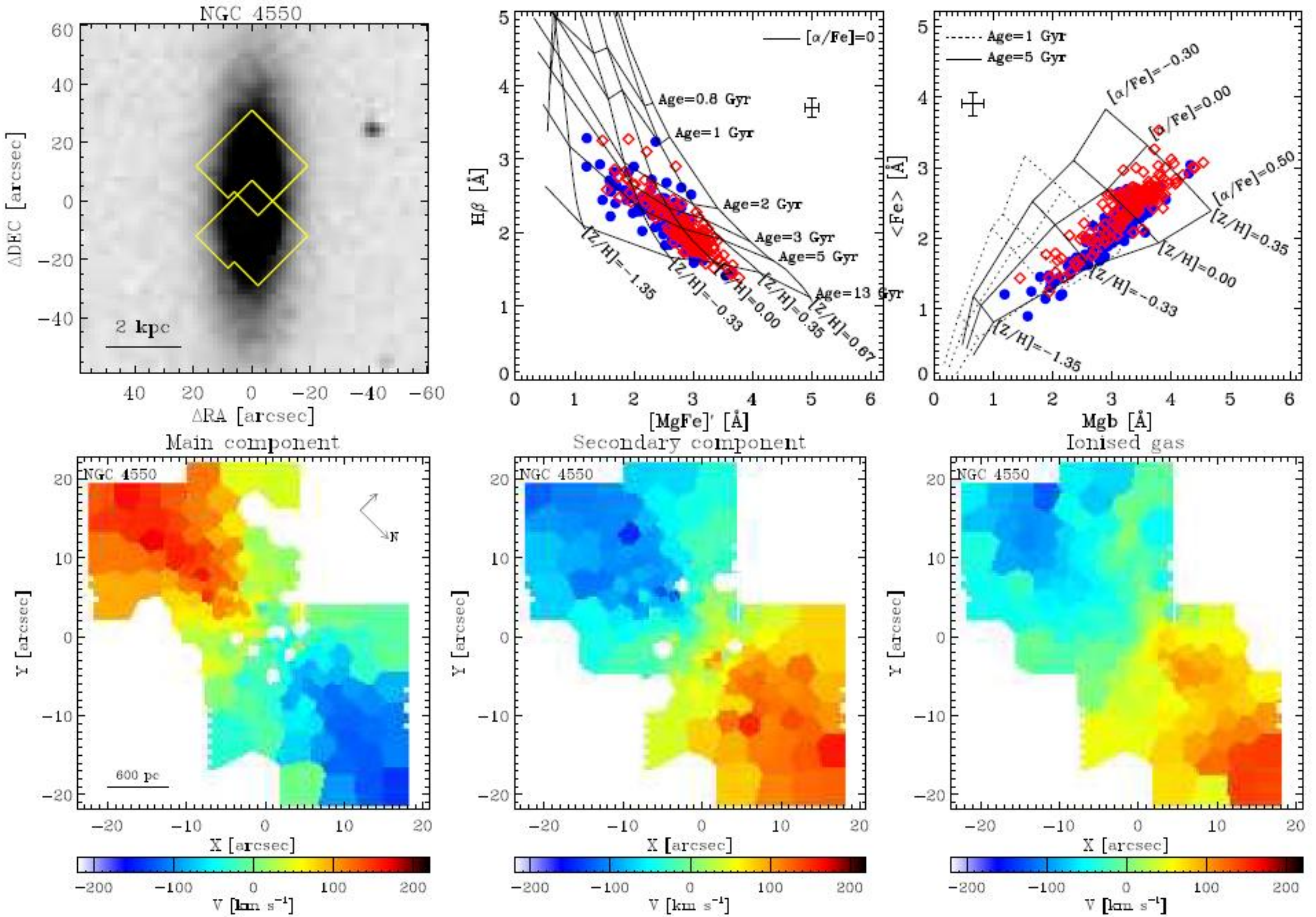
ΔV > 150 km/sec ; rms = 0.005



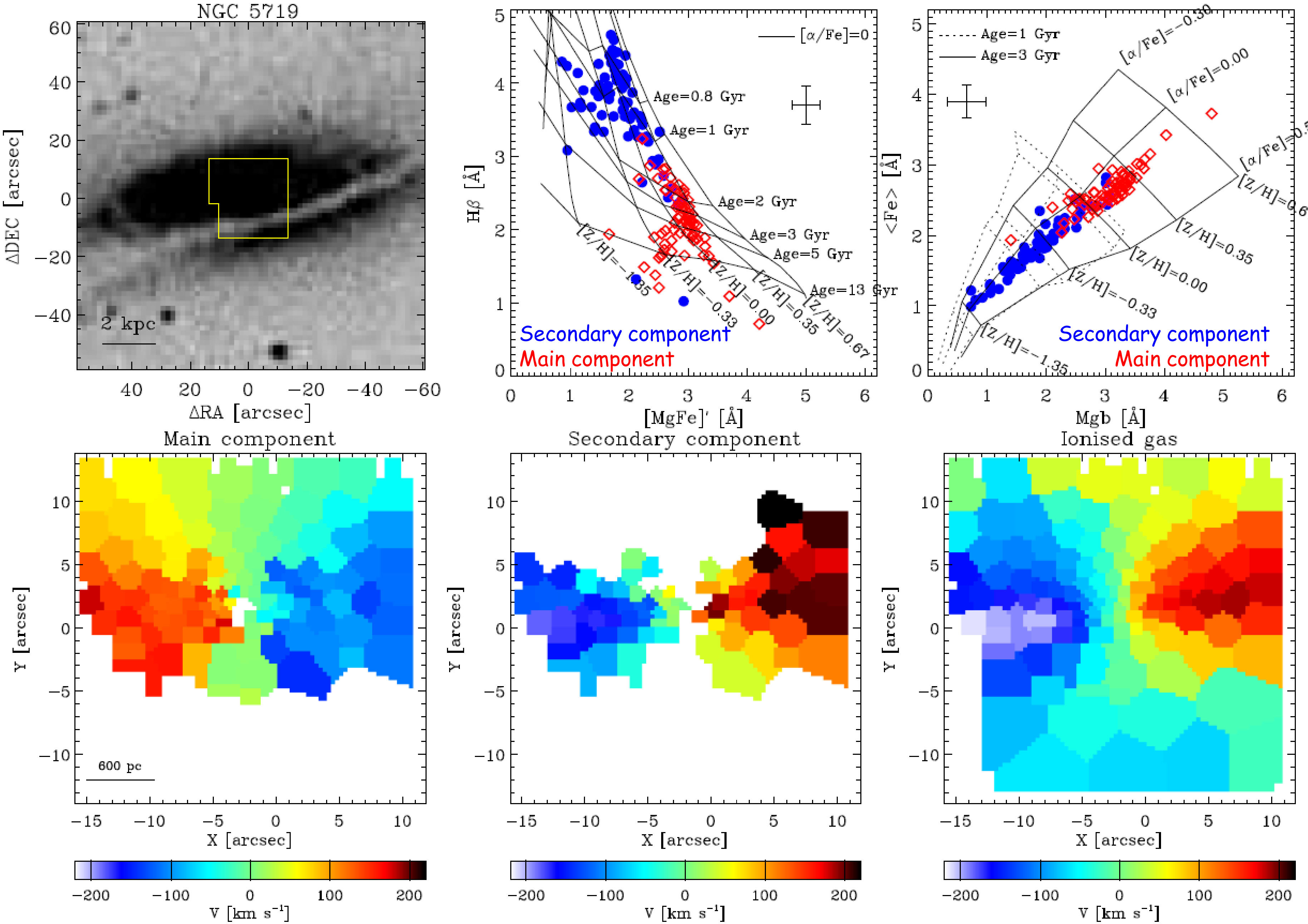
ΔV < 150 km/sec ; rms = 0.05



NGC 4550


NGC 4550
ΔDEC [arcsec]
ΔRA [arcsec]
2 kpc
[α/Fe]=0
Age=0.8 Gyr
Age=1 Gyr
Age=2 Gyr
Age=3 Gyr
Age=5 Gyr
Age=13 Gyr
[Z/H]=-1.35
[Z/H]=-0.33
[Z/H]=0.00
[Z/H]=0.35
[Z/H]=0.67
Hβ [Å]
[MgFe]' [Å]
Age=1 Gyr
Age=5 Gyr
[α/Fe]=-0.30
[α/Fe]=0.00
[α/Fe]=0.50
[Z/H]=0.35
[Z/H]=0.00
[Z/H]=-0.33
[Z/H]=-1.35
<Fe> [Å]
Mgb [Å]
Main component
Secondary component
Ionised gas
NGC 4550
N
600 pc
Y [arcsec]
X [arcsec]
V [km s^{-1}]

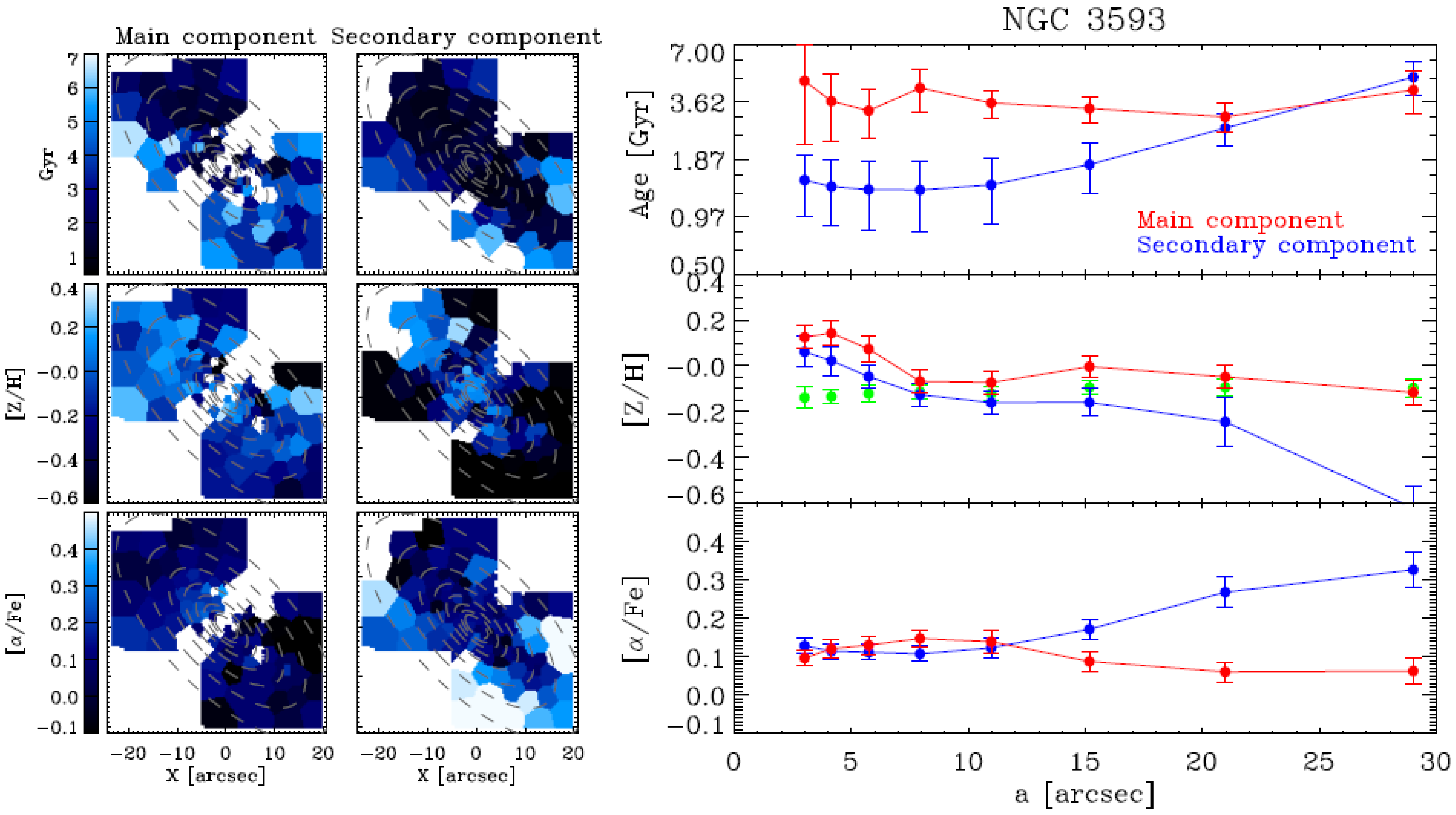
NGC 5719



See poster by L. Morelli

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

NGC 3593



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

NGC 4550

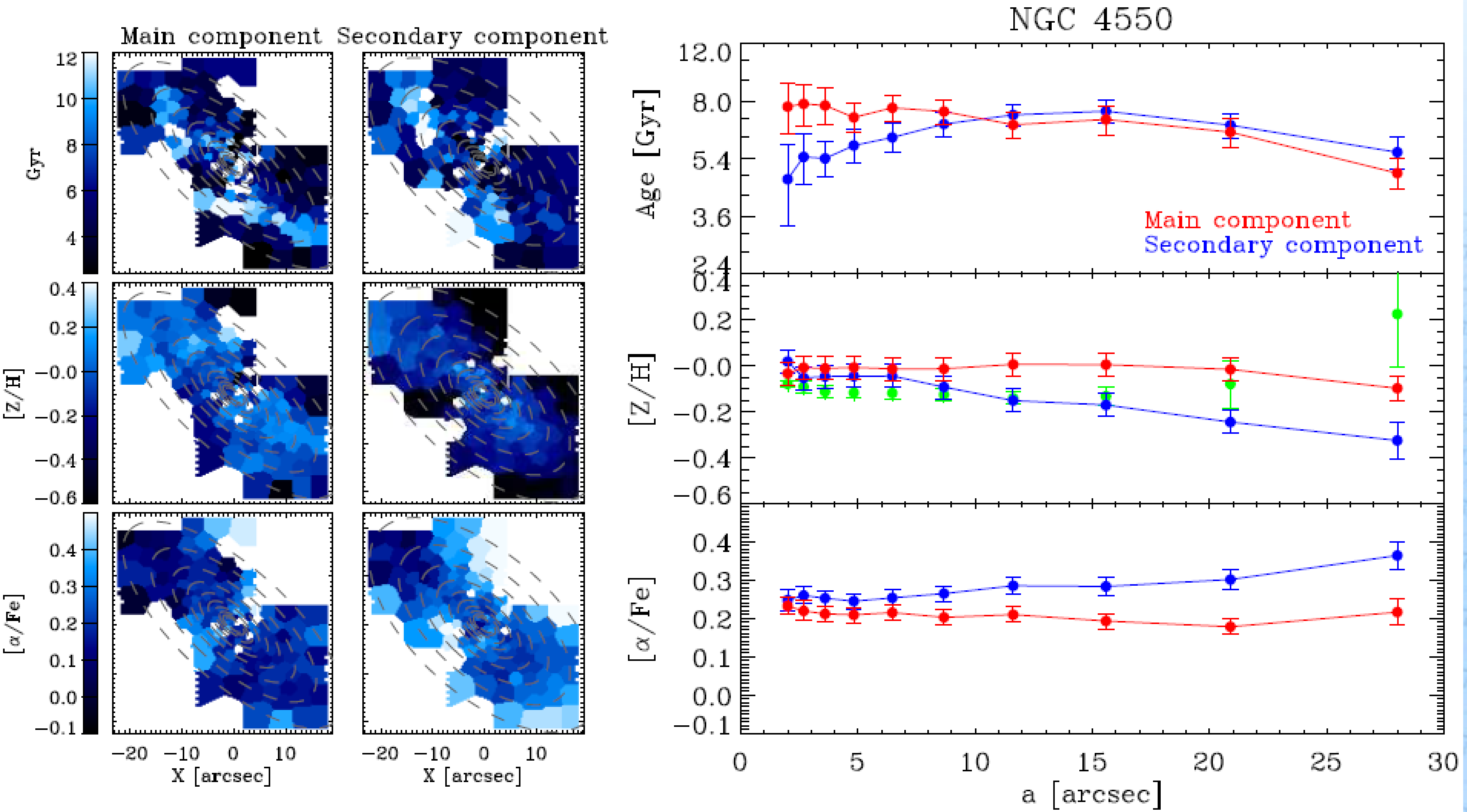


Table 1: Luminosity-weighted values for the stellar population parameters of the stellar discs in NGC 3593, NGC 4550, and NGC 5719.

	$\overline{\text{Age}}$ [Gyr]	$\overline{[\text{Z/H}]}$	$\overline{[\alpha/\text{Fe}]}$
NGC 3593			
Main:	3.6 ± 0.6	-0.04 ± 0.03	0.09 ± 0.02
Secondary:	2.0 ± 0.5	-0.15 ± 0.07	0.18 ± 0.03
NGC 4550			
Main:	6.9 ± 0.6	-0.01 ± 0.03	0.20 ± 0.02
Secondary:	6.5 ± 0.5	-0.13 ± 0.04	0.28 ± 0.02
NGC 5719			
Main:	4.0 ± 0.9	0.08 ± 0.02	0.10 ± 0.02
Secondary:	1.3 ± 0.2	0.3 ± 0.02	0.14 ± 0.02

Notes– $\overline{[\text{Z/H}]}$ and $\overline{[\alpha/\text{Fe}]}$ are given in logarithms of solar units. Errors are computed as the standard deviation of the measurements divided by the square root of the number of spatial bins.