Counter-rotating stellar population in disc galaxies

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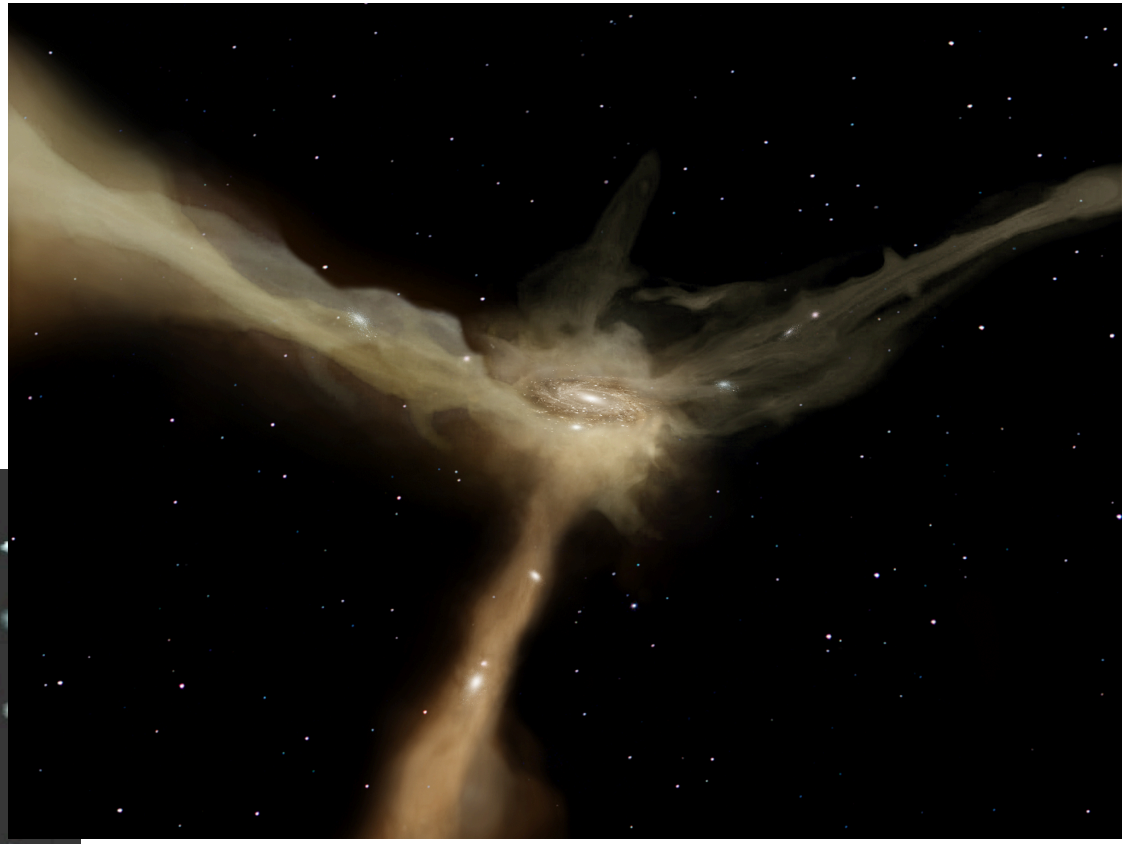
Special Astrophysical Observatory

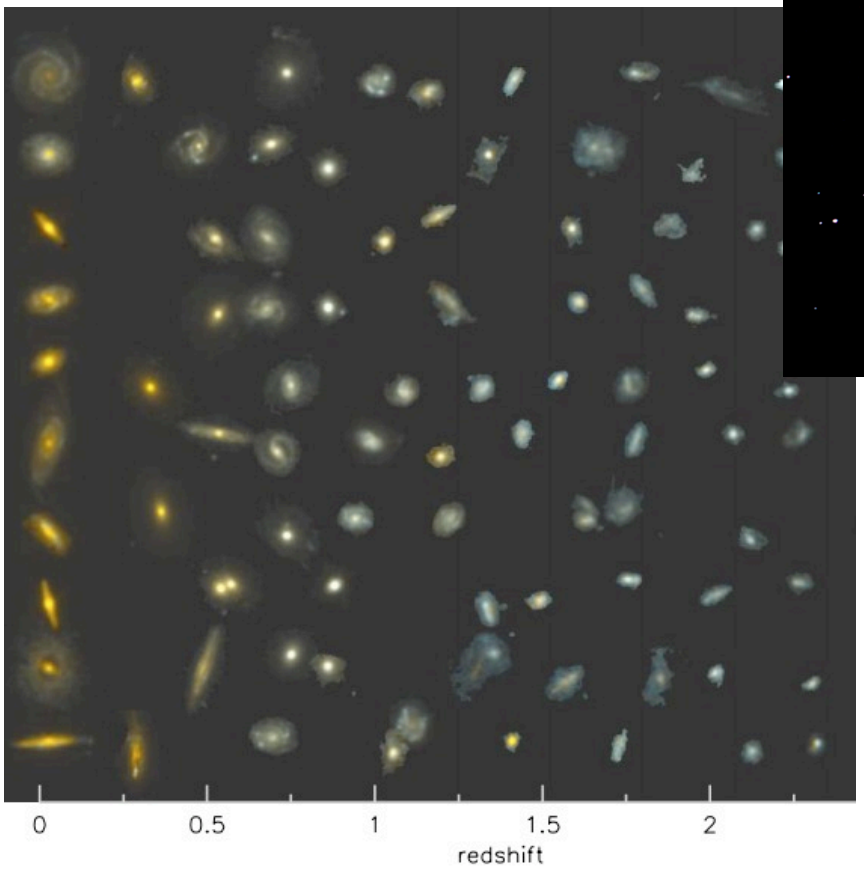
VOLGA
View On the Life of GAlaxies

Outline:

- Introduction
- Stellar population modeling
- Spectral decomposition
- Spectral vs. photometrical decompositions
- Summary

How do galaxies assembly and evolve?





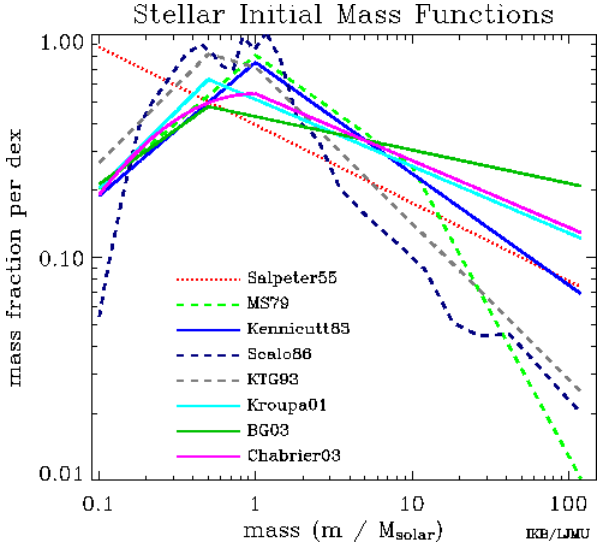
- Galaxy merging
- Accretion
- Internal secular evolution

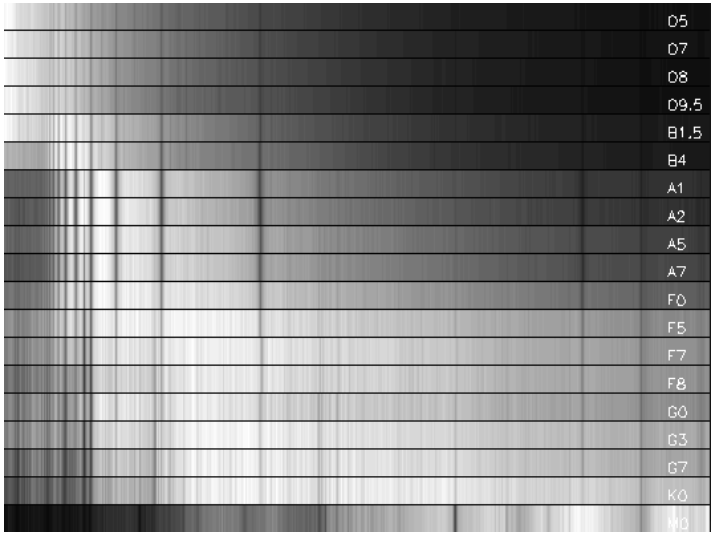
Stellar population

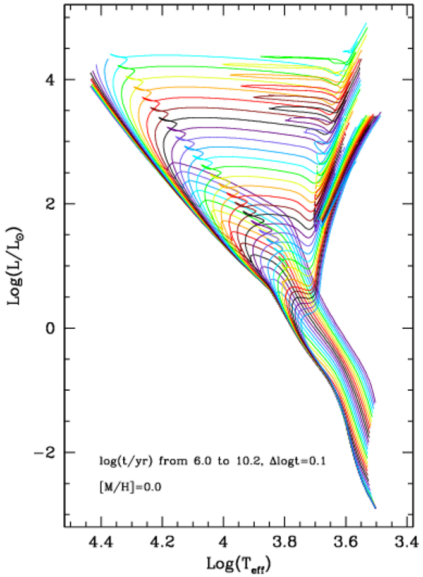
- *Stellar population* synthesis models are tools for interpreting the integrated galaxy light.
- *Stellar population* keep fossil record of star formation history.

Ingredients of *stellar population* models:

- Star formation history (SFH)
- Metallicity enrichment history and abundance pattern
- Initial mass function (IMF)
- Stellar evolution tracks → stellar isochrones
- Stellar library







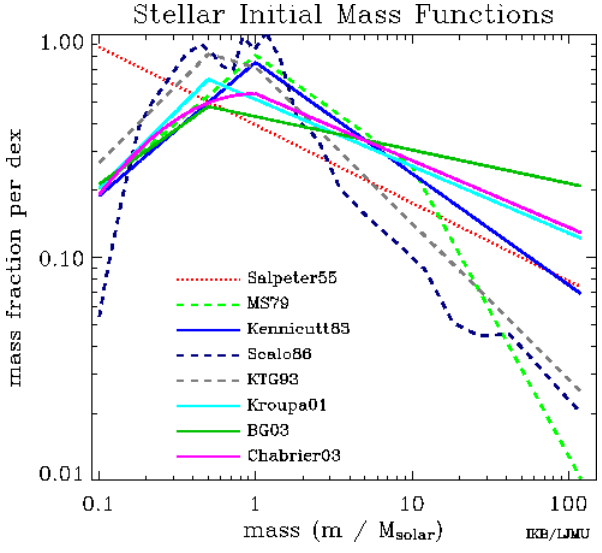
Stellar population

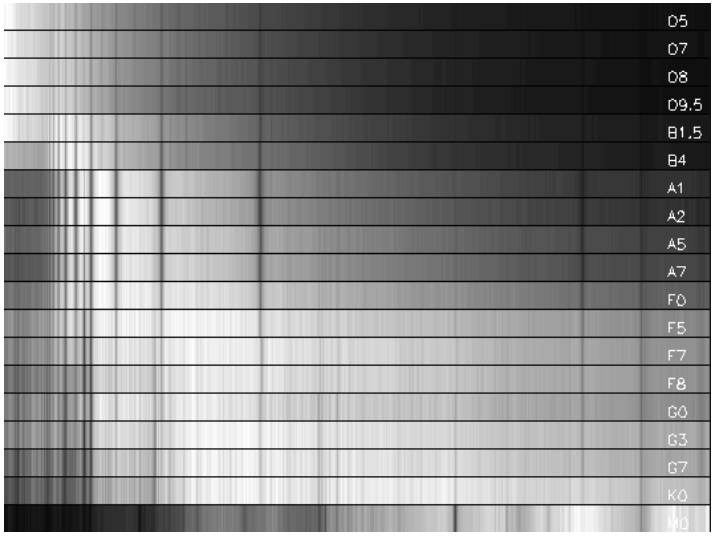
- Single/Simple Stellar population

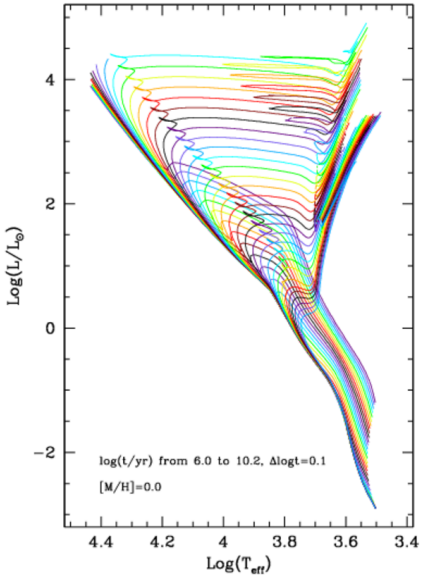
$$SSP(t,Z) = \int_{M_1}^{M_2} IMF(m_i) S[L(m_i)|_{t,Z}, T(m_i)|_{t,Z}] dm_i$$

- Composite Stellar population (CSP)

$$CSP(t,Z) = \int_0^t SFR(t-t') SSP(t',Z) dt'$$

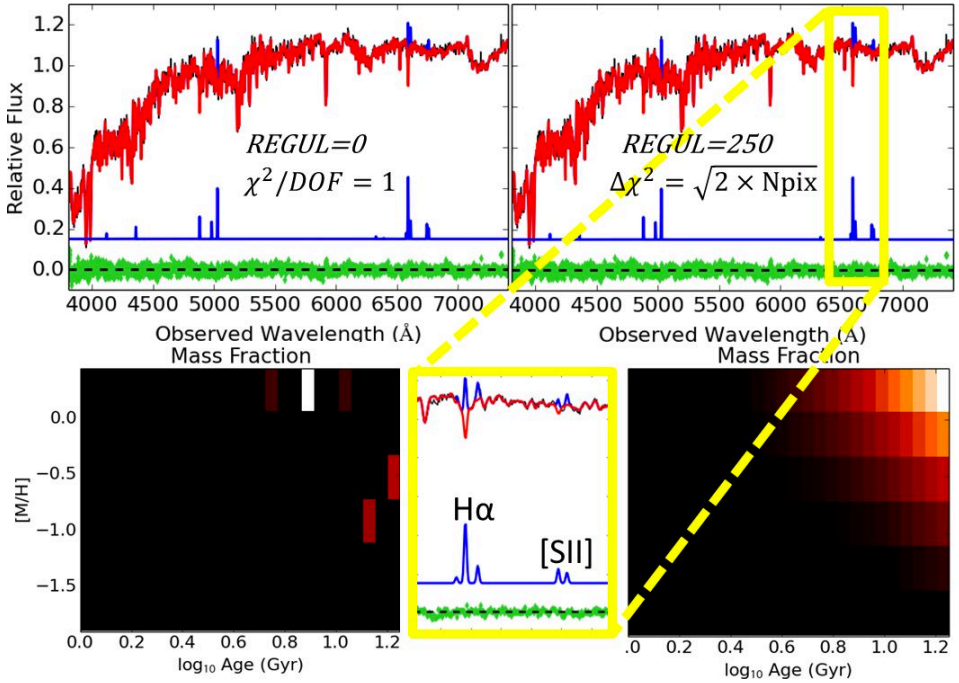






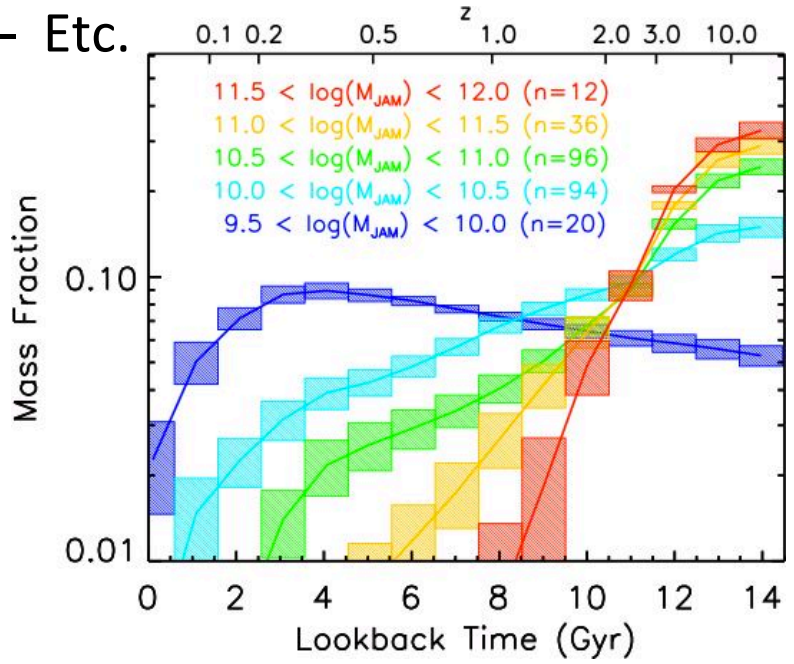
SFH recovery

- Pameterized SFH (SSP or exp-SFH)
  - ULySS (Koleva+08)
  - NBursts (Chilingarian+07)
  - Etc.



Cappellari's web page

- Non-parametrically
  - STECKMAP/STECMAP (Ocvirk +06)
  - Starlight (Cid Fernandes+05)
  - Updated PPXF (Cappellari+04)
  - Etc.



McDermid+15

SFH recovery

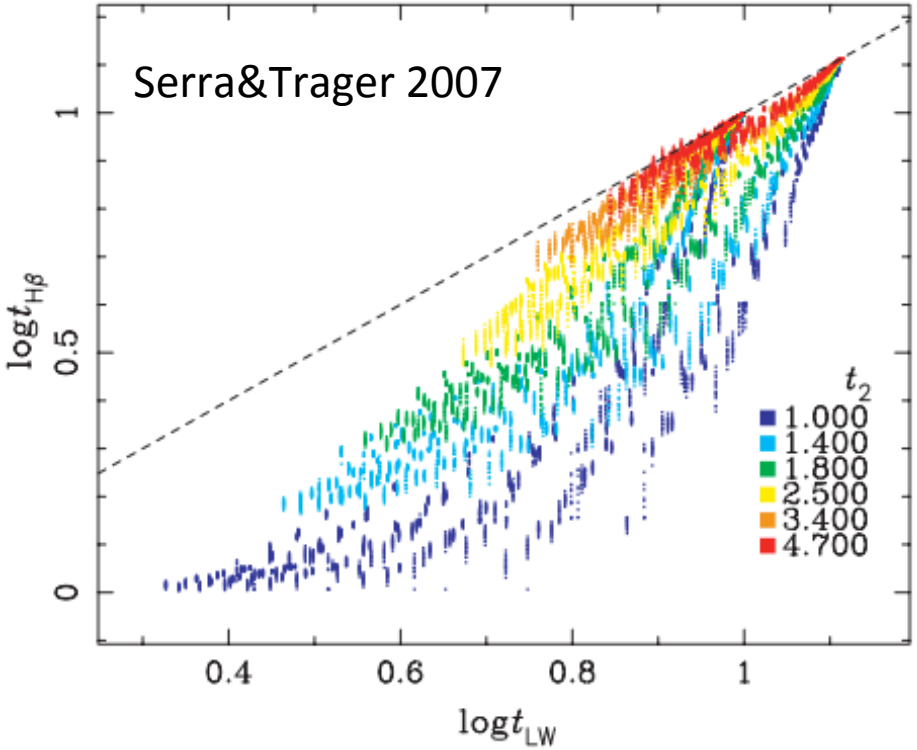
- Ill-posed inverse problem!!!
  - Etc

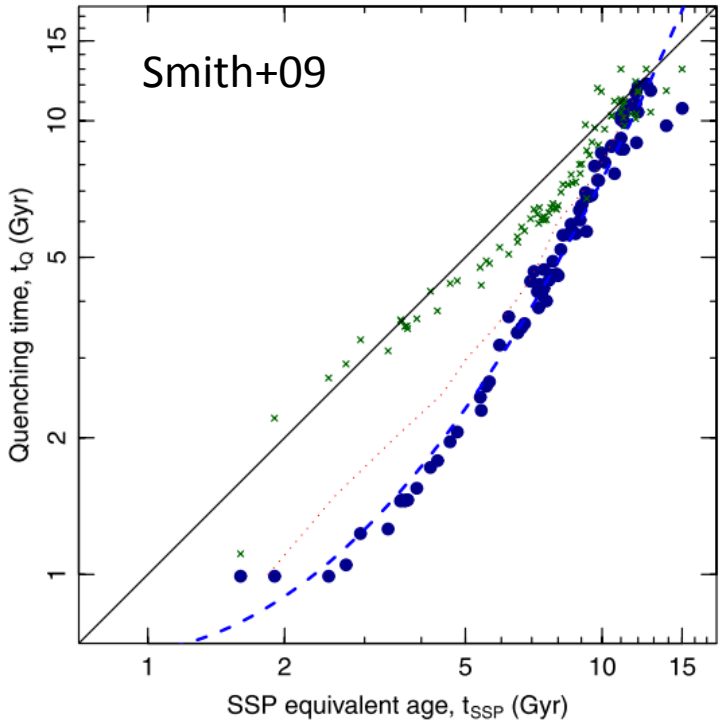
Required SN > 100!!!
(Ocvirk et al. 2006)

Cappellari's web page

SSP model

- A widely adopted procedure is to fit stellar population by single age SSPs
- The SSP-equivalent chemical composition tracks quite closely the V-band luminosity-weighted one, while the SSP-equivalent age is strongly biased towards the age of the young population. (Serra & Trager 2007)

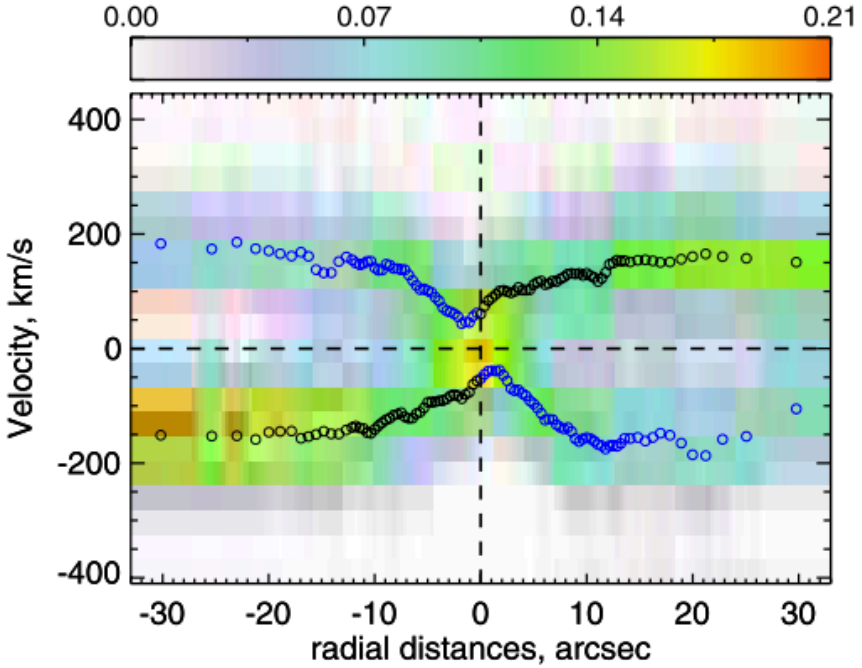


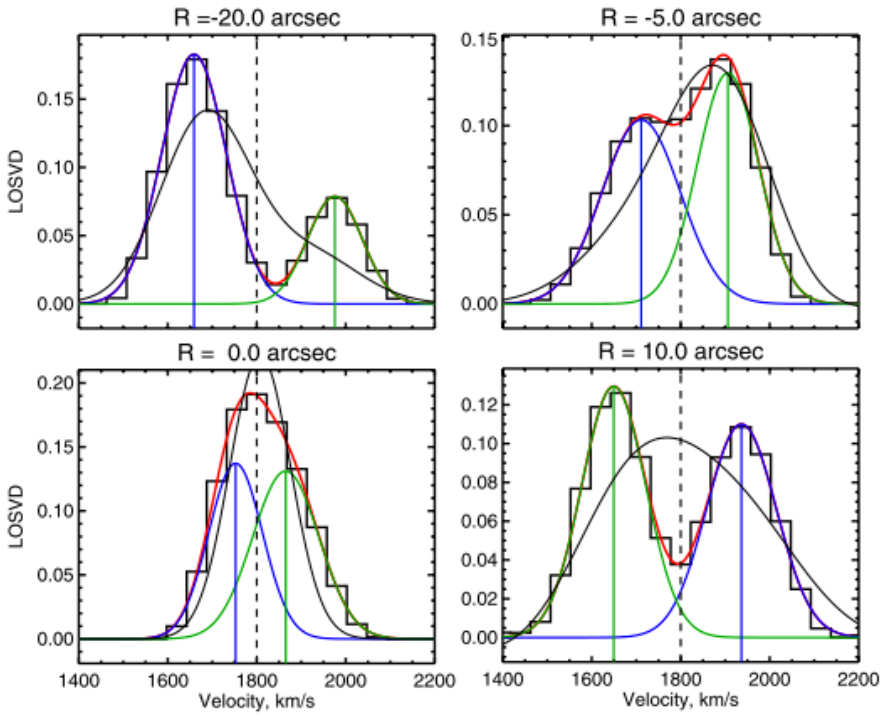


Stellar counter-rotation in IC 719

Kinematical separation helps to disentangle contribution of stellar population components and decompose theirs properties.

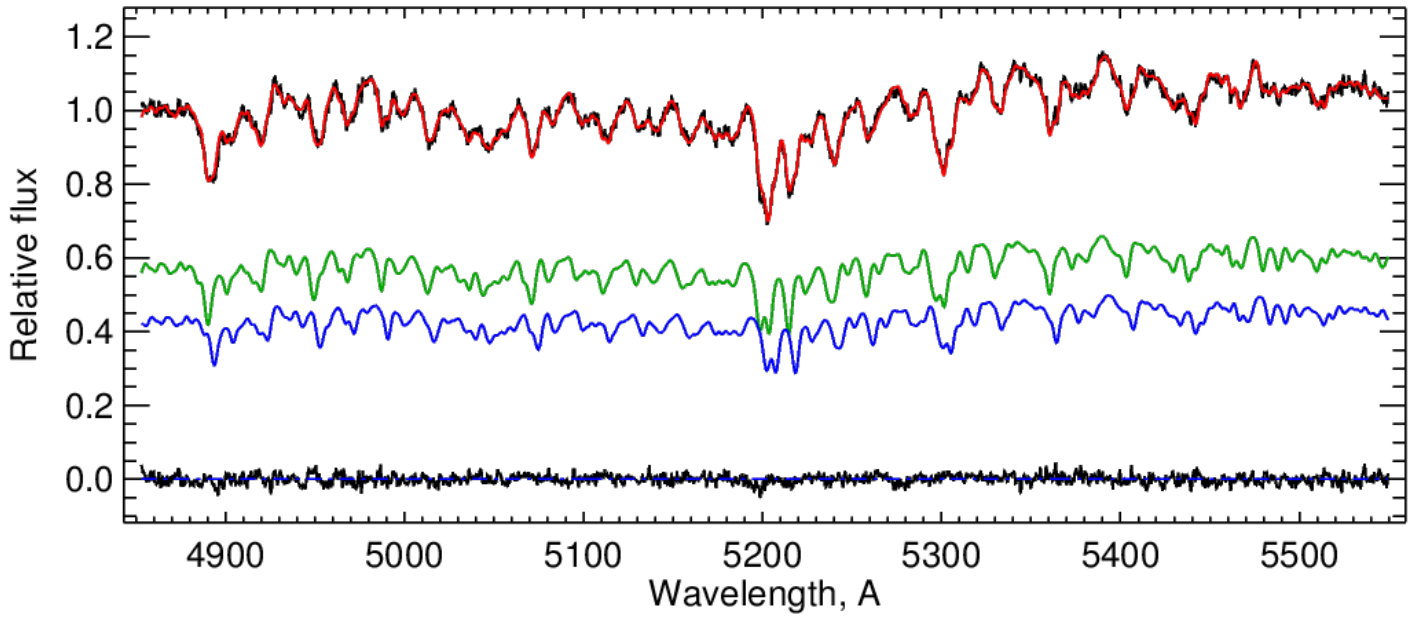
Katkov, Sil'chenko & Afanasiev ApJ 769, 105 (2013)





Spectral decomposition approach

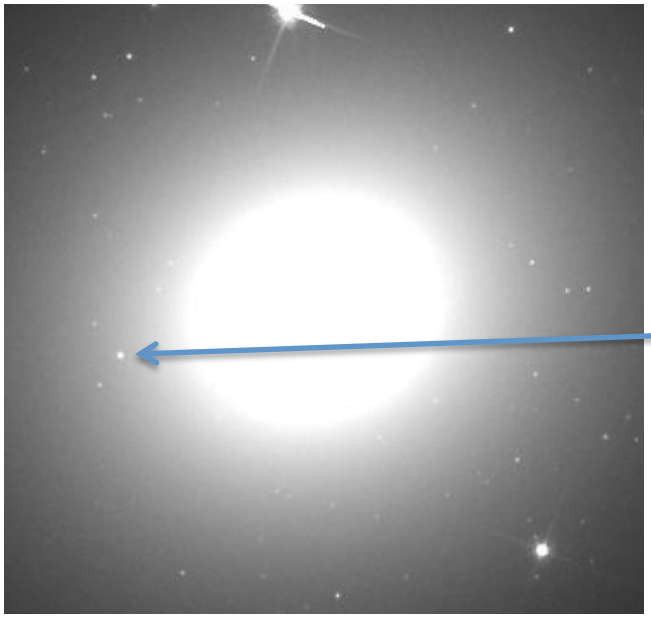
- Based on full spectral fitting techniques
- Main formula: $S_{models} = W_1(L(v_1,\sigma_1) * T_1) + W_2(L(v_2,\sigma_2) * T_2)$



- T_i=SSP(age_i,Z_i), -- SSP templates

Spectral decomposition approach

Chilingarian+2011



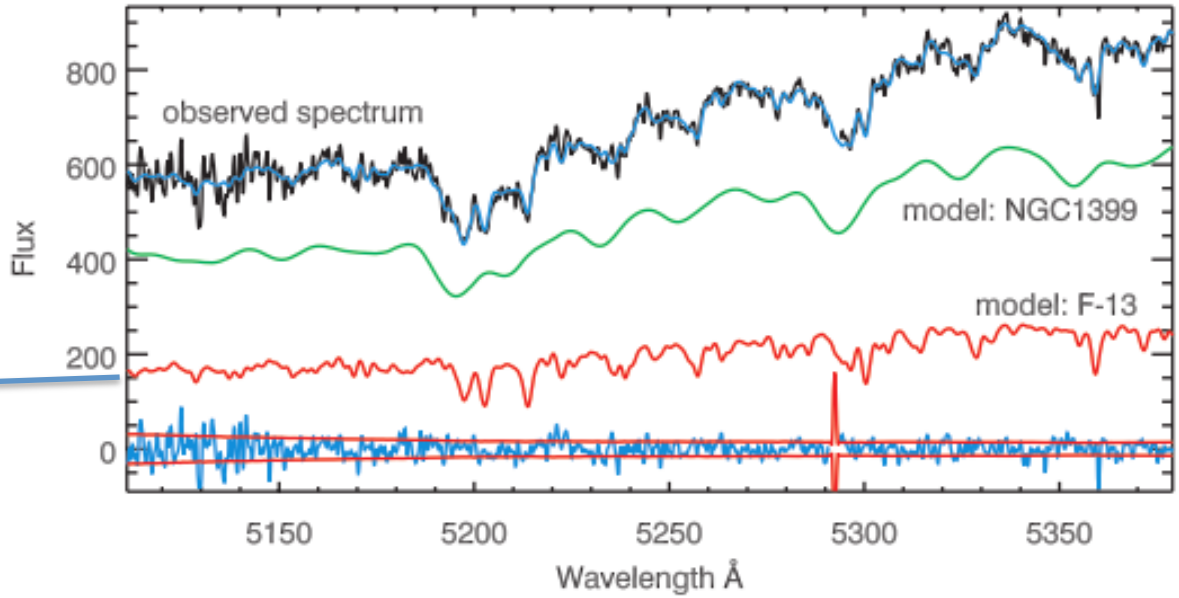


Figure 2. Two-component stellar population fitting of the *F*-13 spectrum. The observed spectrum is shown together with its best-fitting template and its decomposition into two components, NGC 1399 (green) and a UCD (red).

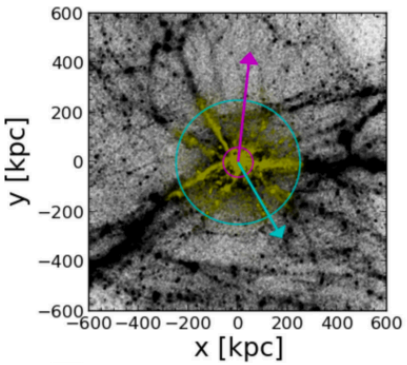
Spectral decomposition approach

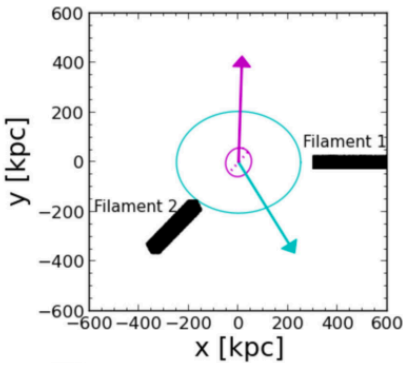
MC – main stellar disc component
CR – counter-rotating

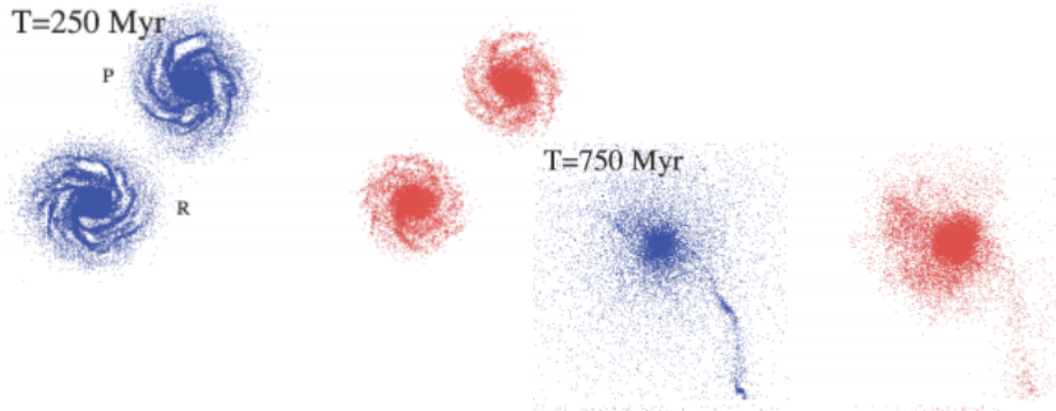
Name	Authors	Ages	Metallicities	Alpha elements
N5719	Coccato et al. 2011	CR < MC	CR << MC	CR >≈ MC
N3593	Coccato et al. 2013	CR < MC	CR < MC	CR≈MC
N4550	Coccato et al. 2013 Johnson et al. 2013	CR < MC (at some radii the same)	CR ≈ MC	CR ≈ MC
IC719	Katkov et al. 2013	CR < MC	CR > MC	
N4138	Pizzella et al. 2014	CR < MC	CR < MC	CR < NC
N4191	Coccato et al. 2015	CR < MC (negative gradient)	CR ≈ MC	CR ≈ MC
N448	Katkov et al. 2016	CR<≈MC (probably negative gradient in CR)	CR >≈ MC	

Scenarios of counter-rotation material acquisition

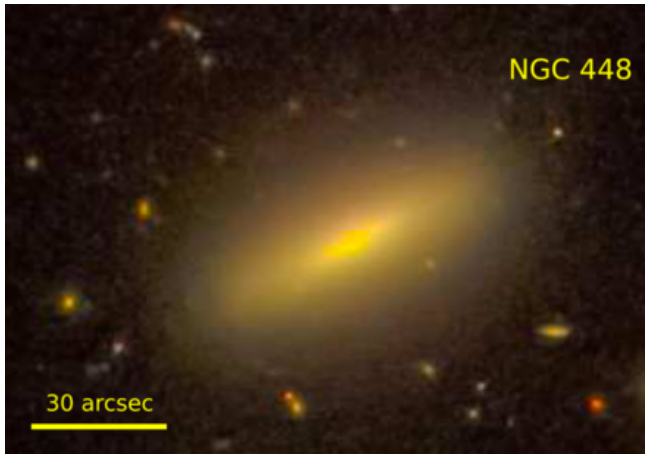
- Thakar & Ryden (1996, 1998) – episodic or prolonged accretion of gas from environment or merging with a gas-rich dwarf companion (many parameters)
- Puerari & Pfenniger (1998), Crocker et al. (2009) - strictly coplanar merger of two gas-rich giant progenitor galaxies is able to build up a massive counter-rotating disc
- Algory et al. (2014) – consequence of gas accretion from two distinct filamentary structures
- Evans & Collett (1994) - the bar dissolution process (sep-aratrix crossing)

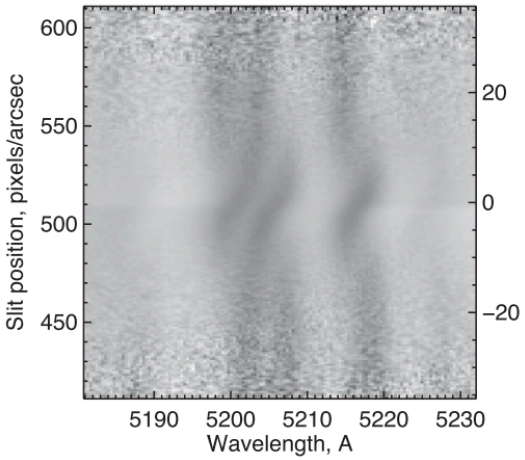




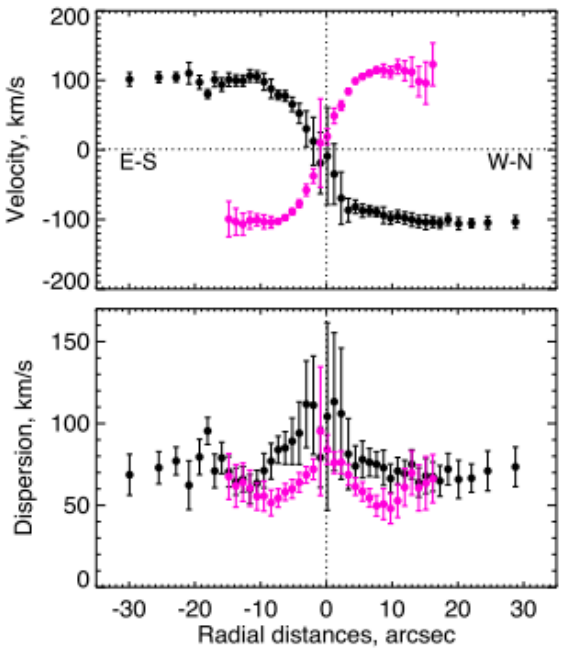


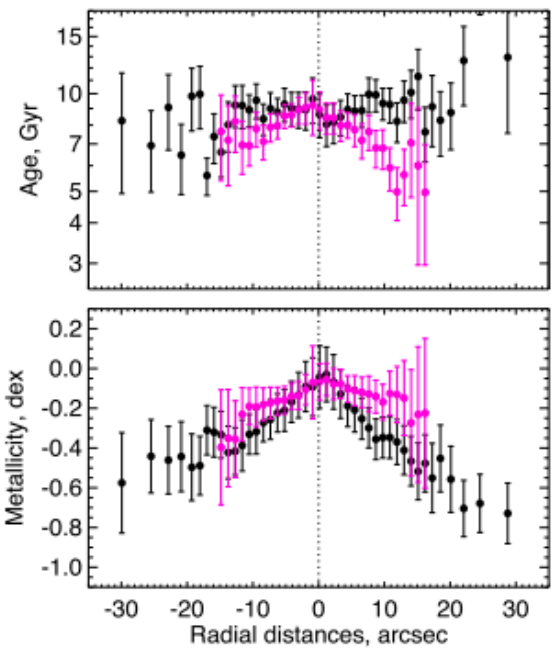
Spectroscopic and photometric decomposition

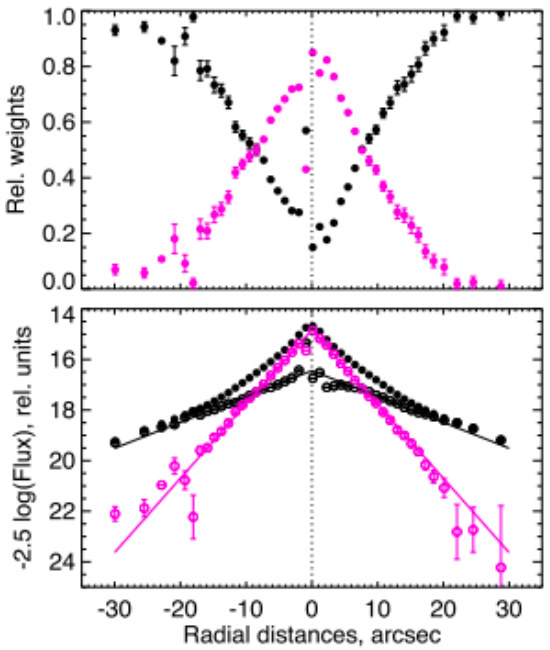




- CR contributes 30% to the galaxy light.
- CR mass of $9 \times 10^9 M_{sun}$



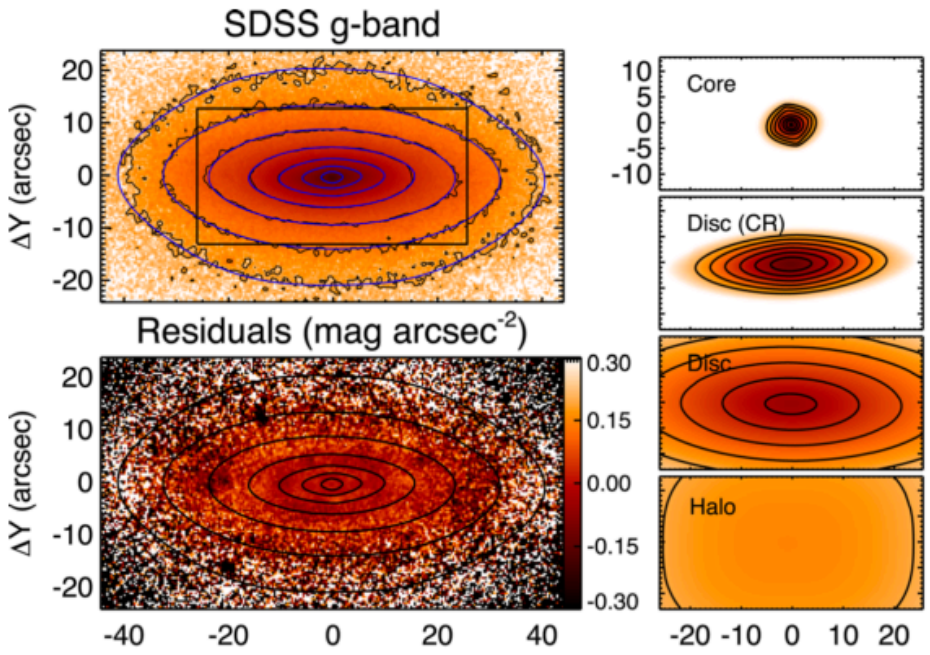


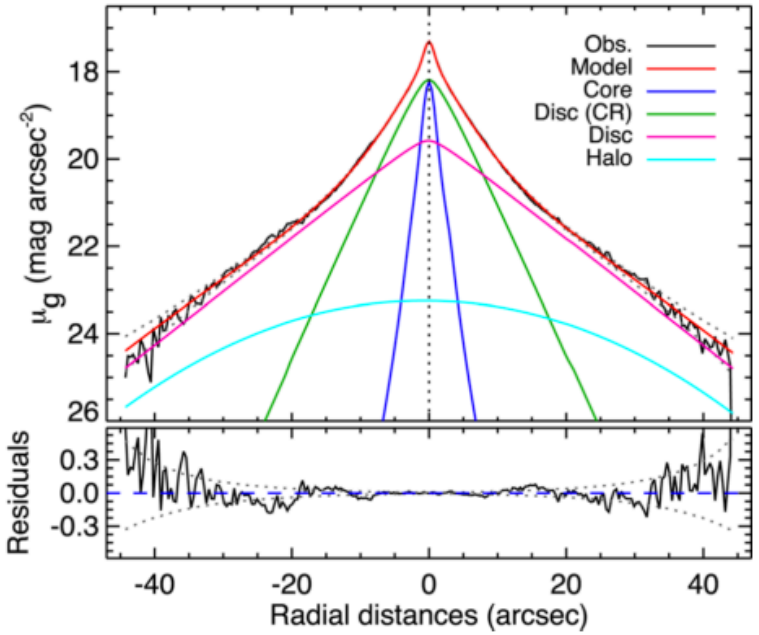


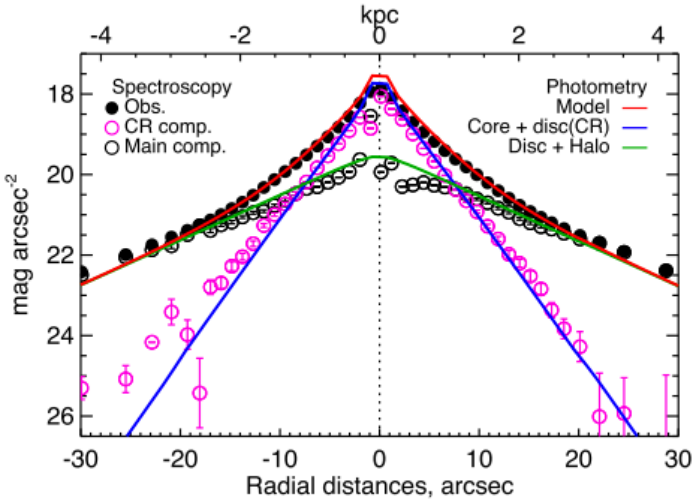
Katkov, Sil'chenko, Chilingarian, Uklein & Egorov, MNRAS 461, 2068 (2016)

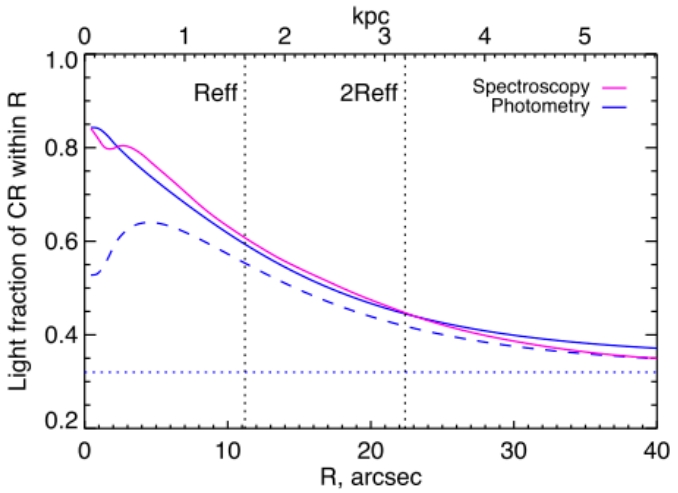
Only 5 slides separate you from lunch ☺

Spectroscopic and photometric decomposition





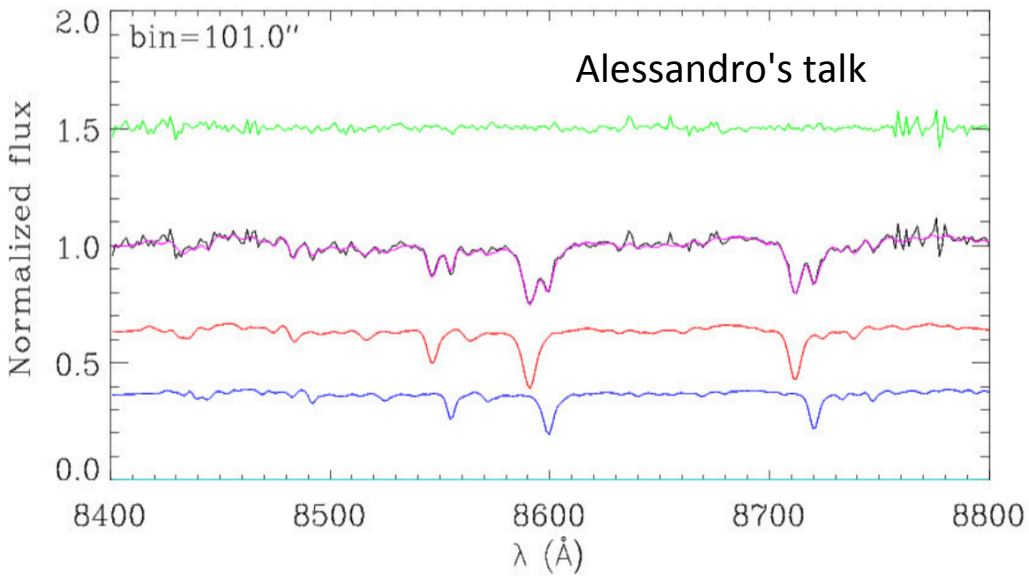


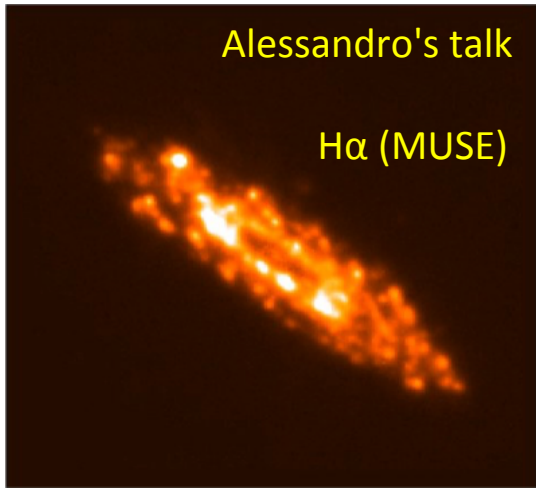


Katkov, Sil'chenko, Chilingarian, Uklein & Egorov, MNRAS 461, 2068 (2016)

Spectroscopic and photometric decomposition

IC 719: Ca Triplet region





How can be explained ring-like counter-rotating structure from the dynamical point of view?

Summary

- We have much more data then we use!
- Self-consisted view on *photometric and spectroscopic* decompositions helps to learn details of galaxy components formation.
- 2d view is much more useful for this aim
  - 2d spectroscopy (MUSE, MPFS, MANGA, SAMI et al.)
  - 2d photometric decomposition

Festival of «Circle of Light 2016», Moscow University building few days ago

Supplemental material

Spectral decomposition approach

MC – main stellar disc component
CR – counter-rotating

Name	Authors	Ages, Gyr	Metallicities, dex	Alpha elements
NGC 5197	Coccato et al. 2011	MC: 4.0 CR: 1.3	MC: 0.1 CR: -1.0	MC: 0.1 CR: 0.14
NGC 3593	Coccato et al. 2013	MC: 4.0 CR: 1.4	MC: -0.04 CR: -0.12	MC: 0.15 CR: 0.15
NGC 4550	Coccato et al. 2013	MC: 8.0 CR: 6.0	MC: -0.1 CR: -0.1	MC: 0.25 CR: 0.2

Outline:

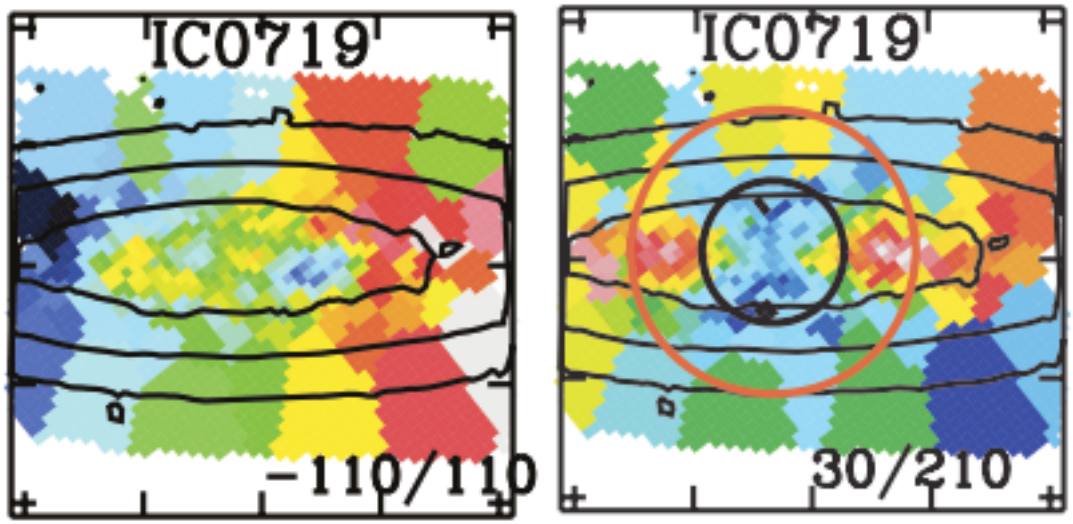
- Introduction
- Spectral decomposition
  - Technique basics
  - IC 719
  - NGC 448
- Dynamical evolution of counter-rotating discs

IC 719

Global Parameters of the Galaxies

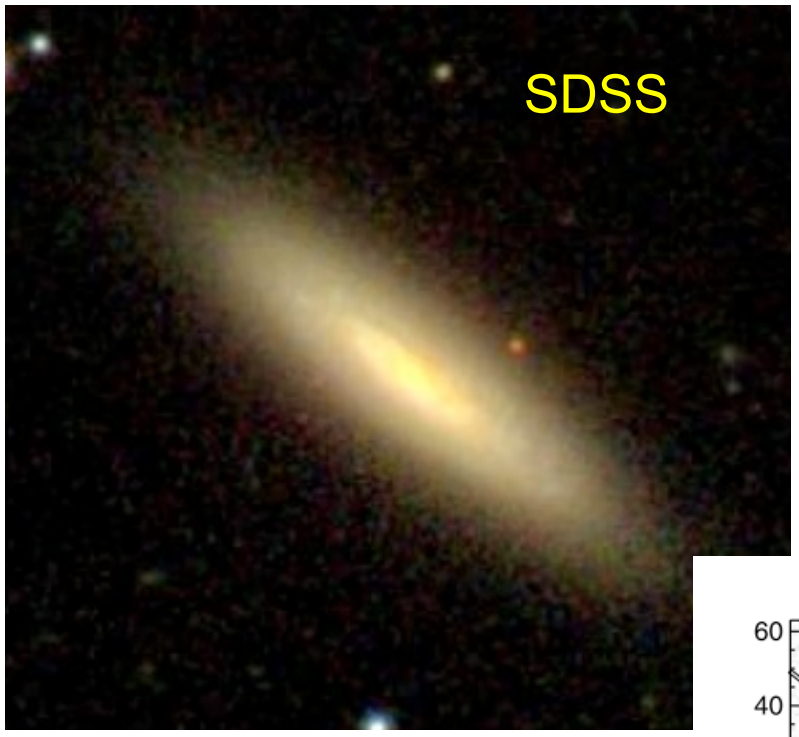
Galaxy	IC 719
Type (NED[a])	S0?
R_{25}, kpc (NED+RC3[b])	5.5
B_T^0 (LEDA[c])	13.66
M_B (LEDA)	−18.6
M_K (ATLAS-3D)	−22.7
V_r (NED)	1860 km s^{-1}
Distance, Mpc (ATLAS-3D)	29.4
Inclination (LEDA)	90°
$PA_{\rm phot}$ (LEDA)	52°
$V_{\rm rot} \sin i$, km s^{-1}, (LEDA, H I)	114.4 ± 6.6
σ_*, km s^{-1}, (LEDA)	121
$M_{\rm H\,I}$, 10^9 $M_\odot$[d]	0.54
$M_{\rm H_2}$, 10^8 $M_\odot$[e]	1.8

- Non-regular rotator
- 2sigma peaks



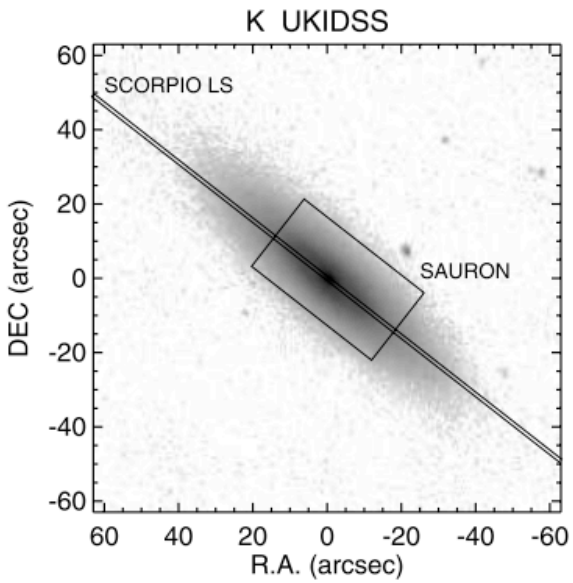
Krajnovic et al. (2011)

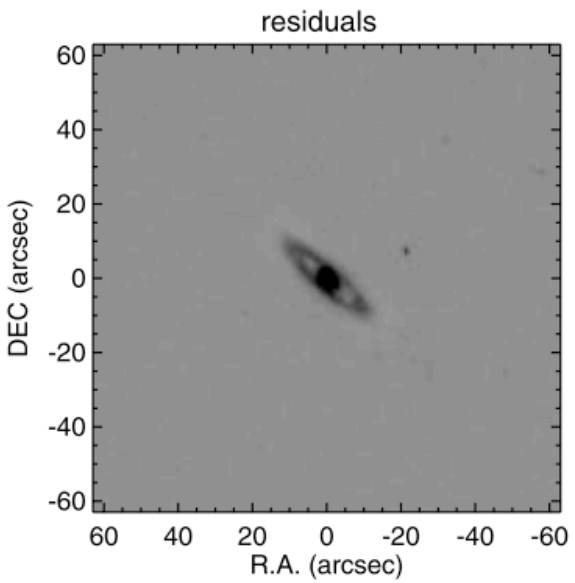
IC 719



- 1” long-slit mode
- 4300-7300 AA
- Sp. Resolution~3.5 A
- σ_{inst}~90 km/s
- T_{exp}~2.5^{h}

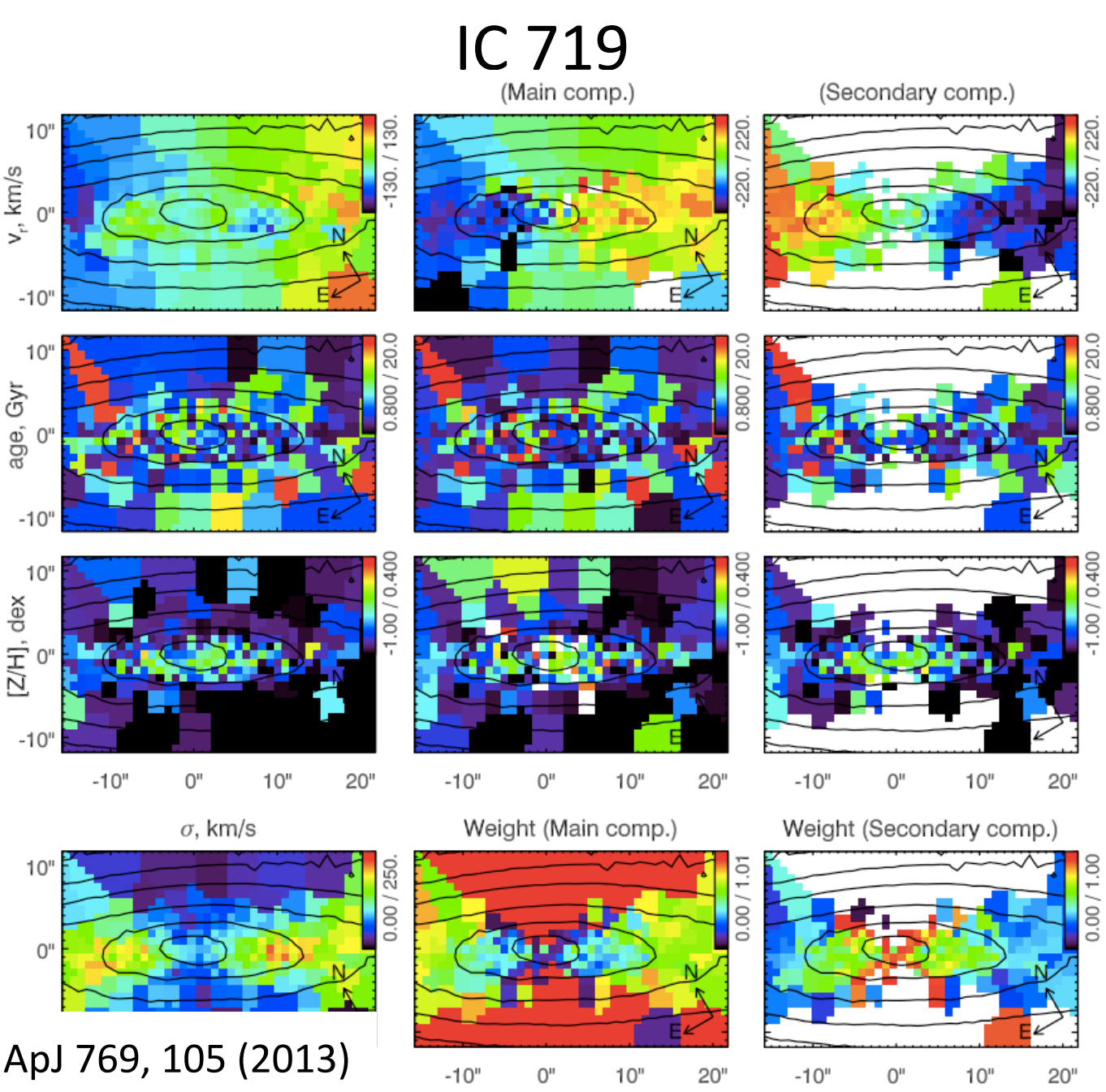
Atlas3D data with SAURON spectrograph





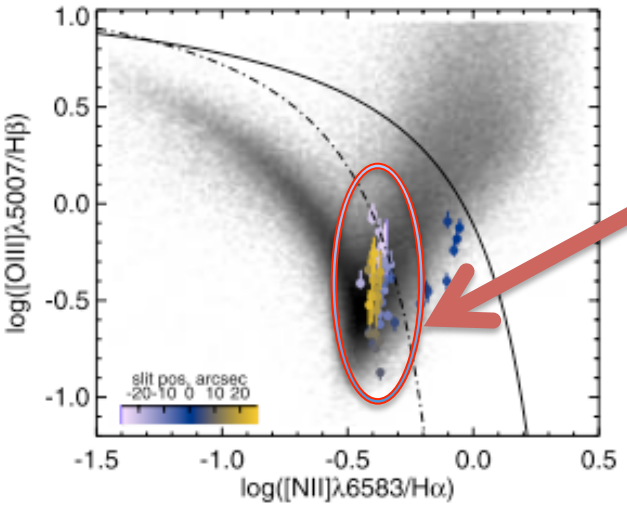
Katkov et al. ApJ 769, 105 (2013)

SAURON
IFU data



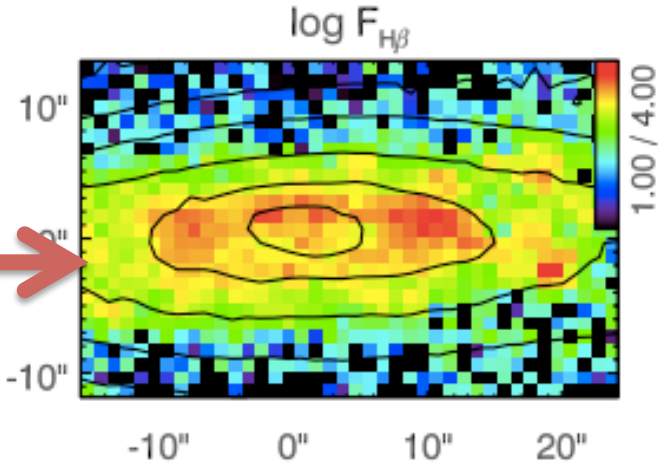
Katkov et al. ApJ 769, 105 (2013)

IC 719

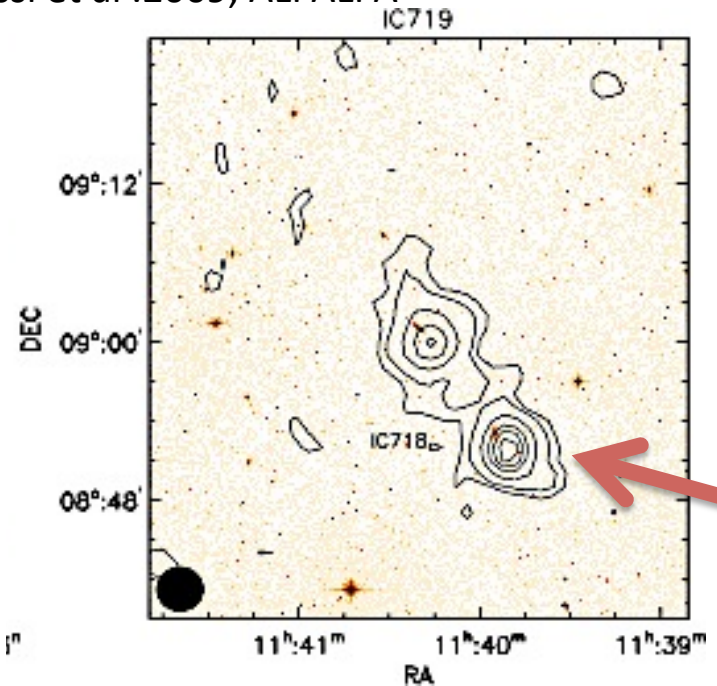


Grossi et al .2009, ALFALFA

Star-forming ring



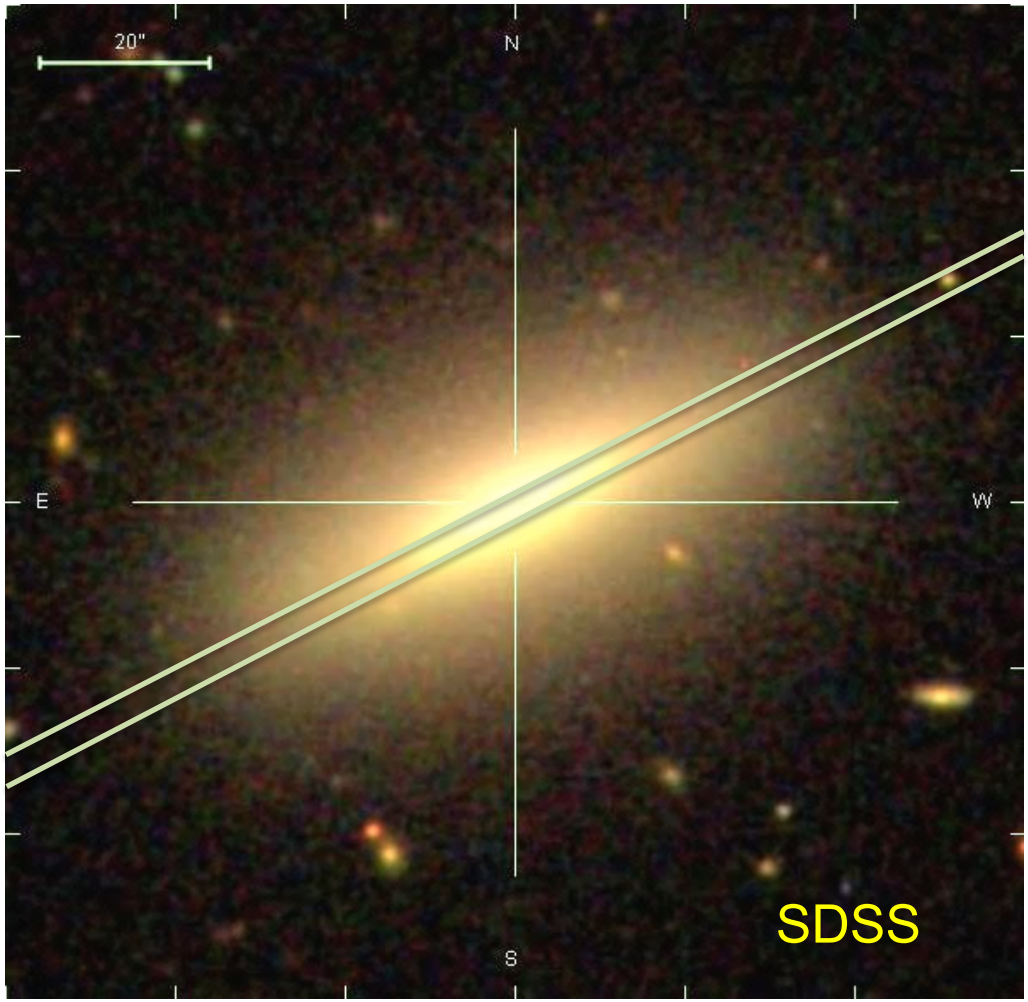
$Z_{main} < Z_{gas} < Z_{second}$



Accretion history consist of two accretion events

IC718 – gas reach dwarf satellite which can be source of external materials with decoupled angular momentum.

NGC 448

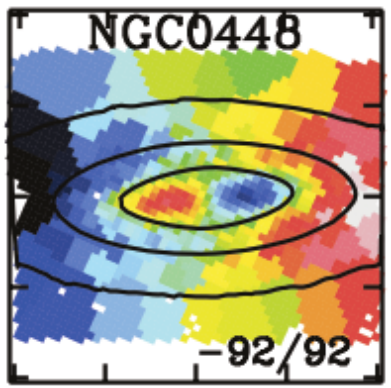


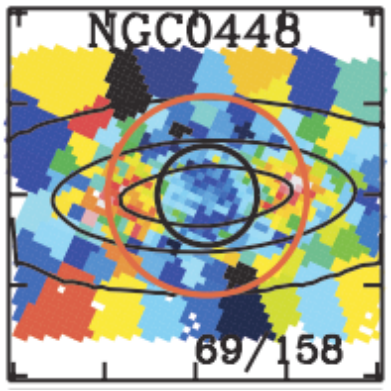
- 1” long-slit mode
- 4800-5550 AA
- Sp. Resolution~2.3 A
- σ_{inst}~60 km/s
- T_{exp}~3^h

Atlas3D data with SAURON spectrograph

Krajnovic et al. (2011)

- regular rotator
- 2sigma peaks

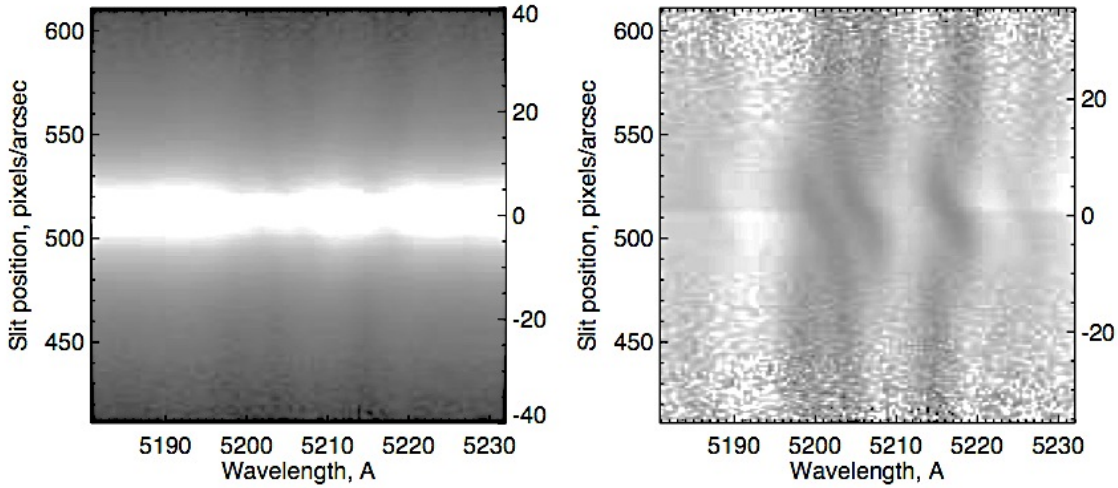


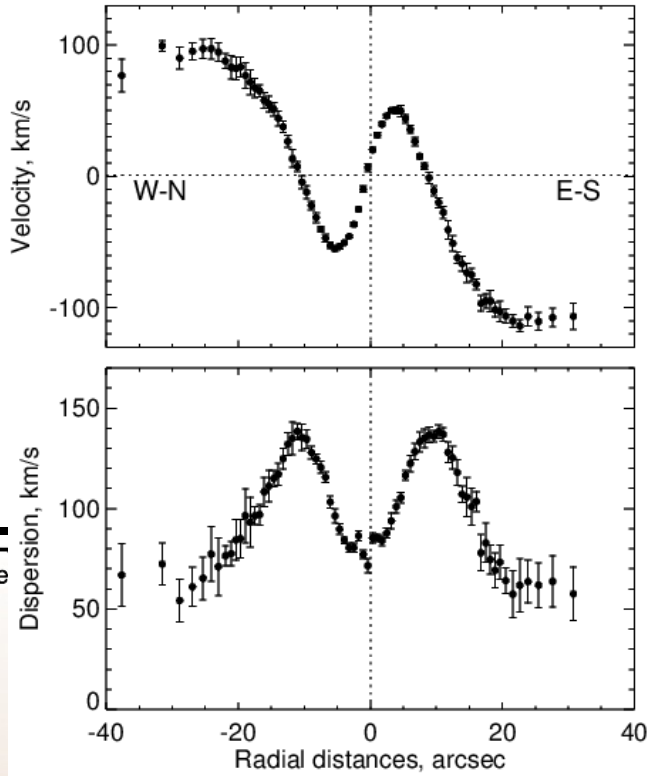


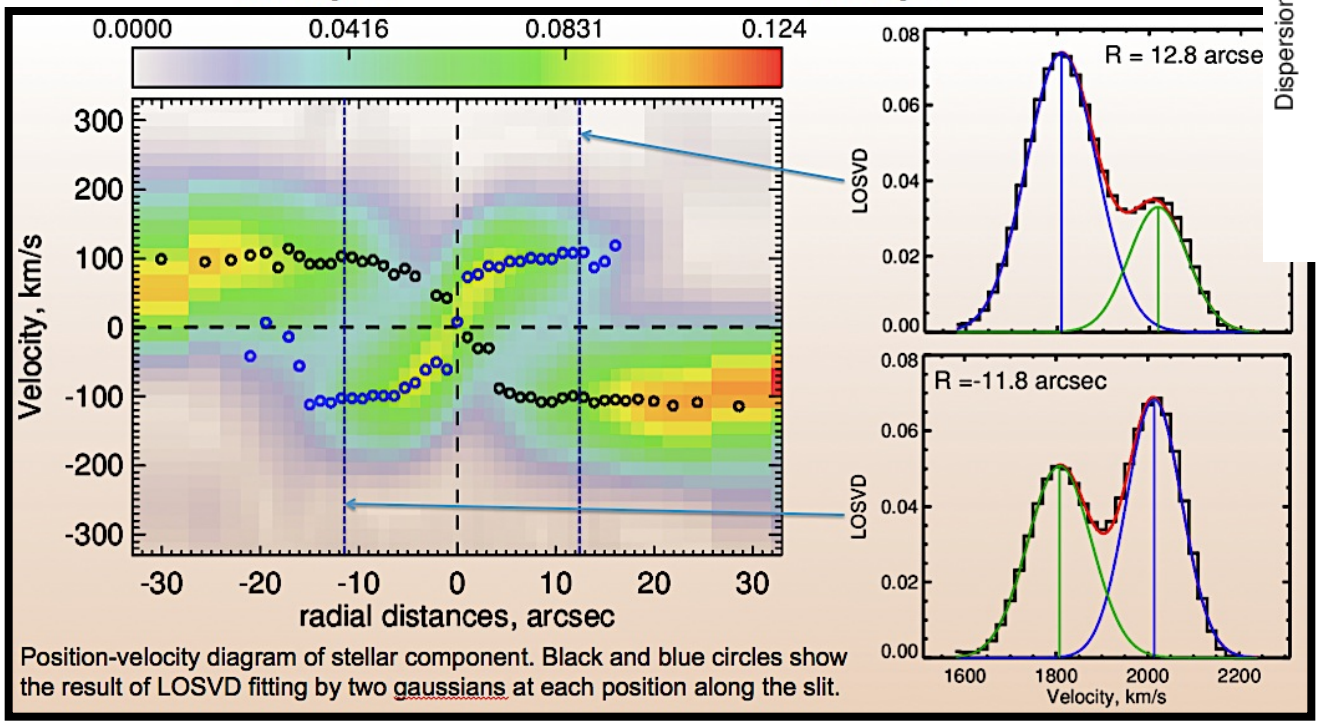
M_B=-19.2^m

NGC 448

SCORPIO long-slit data





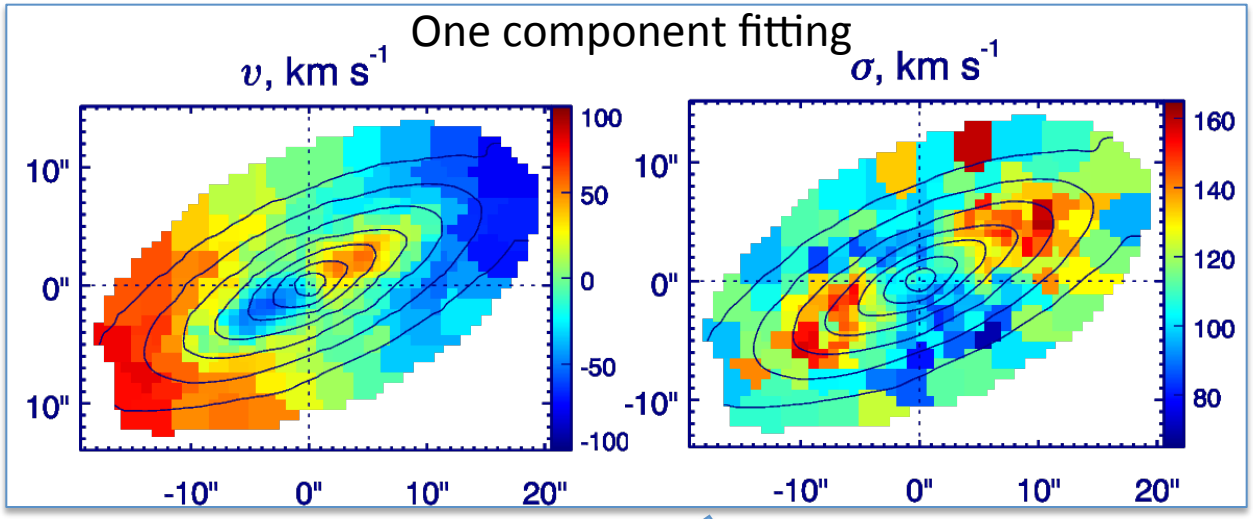


Position-velocity diagram of stellar component. Black and blue circles show the result of LOSVD fitting by two gaussians at each position along the slit.

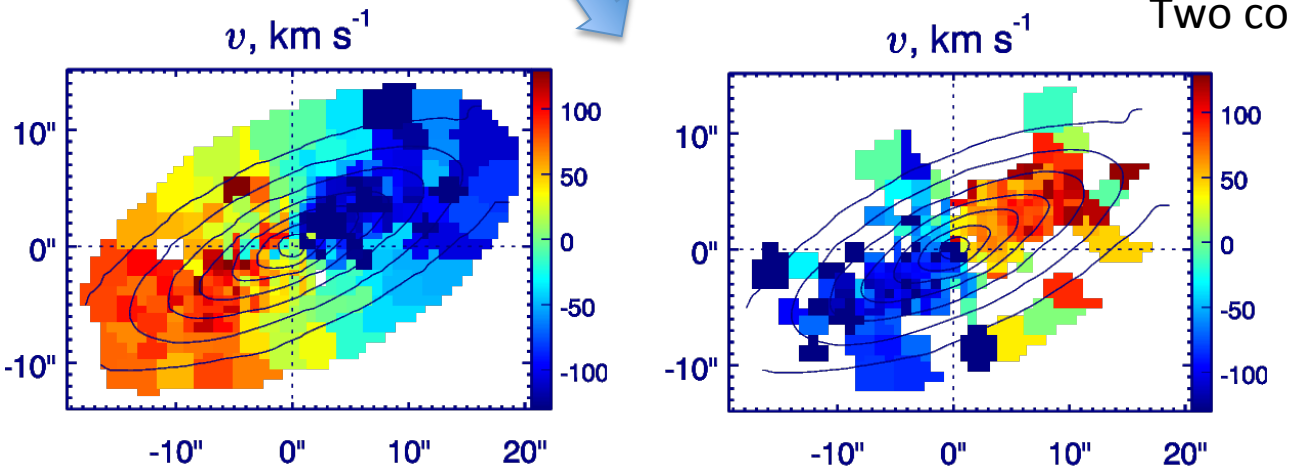
Katkov et al. in prep

SAURON long-slit data

NGC 448



Decomposition of SAURON data is more complicated due to lower spectral resolution. In order to stabilize solution we fixed velocity dispersion on 70 km/s.



Two component fitting

Katkov et al. in prep

Summary

- The counter-rotating stellar populations provide possibility to explore the history of accretion processes which is thought to be one of the main galaxy evolution driver
- The detection of counter-rotating galaxies is rare but the phenomena can be much more common.
- High quality spectroscopic data is needed.
  - High S/N is crucial for detection and decomposition of CR
  - High velocity dispersion is important for detection as well as extraction of dynamical structure of CR discs
  - 3D view is important for comprehensive view of knowingly 3D phenomena

Thank for your attention!