SCORPIO at the 6-m telecope:

current state and perspectivies for spectroscopy of galactic and extragalactic objects

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Special Astrophysical Observatory RAS,

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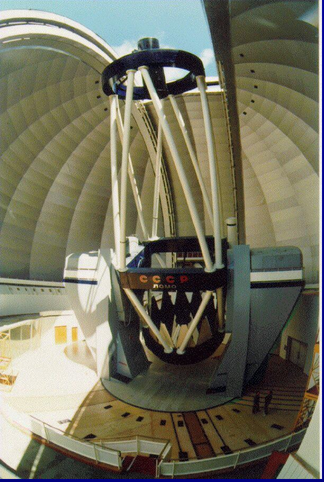
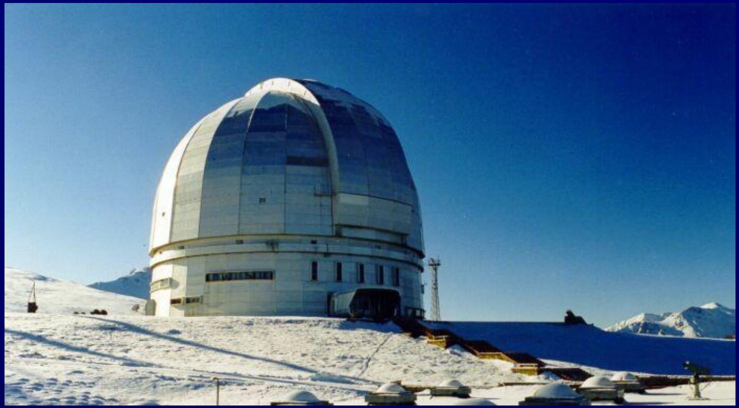


The 6m telescope BTA

Big Telescope Alt-azimuthal (BTA) is the principal instruments of the Special Astrophysical Observatory (SAO) Russian Academy of Sciences.

Main mirror diameter	6 m
Focal ratio	(F/4)
First light	1976
Location:	Northern Caucasus
Mean seeing:	1.5"



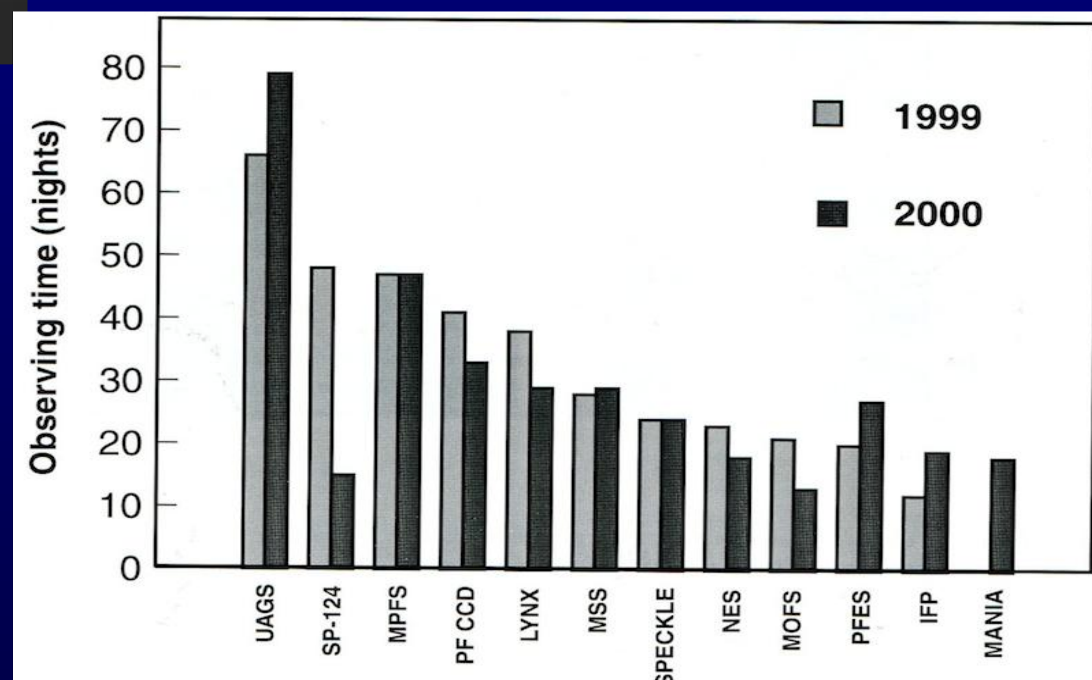
http://www.sao.ru

Typical distribution of the observing time:

SAO astronomers: ~40%
Other Russian institues: ~30%
Former USSR countries: ~10%
Other countries: ~20%

In 2000 we had 11 observational methods (8 in the prime focus).

A multi-mode instrument is necessary!



The family of 'faint objects cameras'

The idea of a focal reducer for a large telescope – Courtes (1960)

EFOCS/ESO 3.6 m (Buzoni et al., 1984) = 8(!) observing modes

ESO Faint Object Spectrograph and Camera,

- direct imaging,
- long-slit,
- slitless,
- echelle,
- imaging polarimetry,
- spectropolarimetry,
- coronography,
- Multiple Object Spectroscopy

The modern devices for 2-10 m telescopes:
AFOCS, DFOSC, FORS2, DOLLORES..

FORS2 (VLT 8.2m)

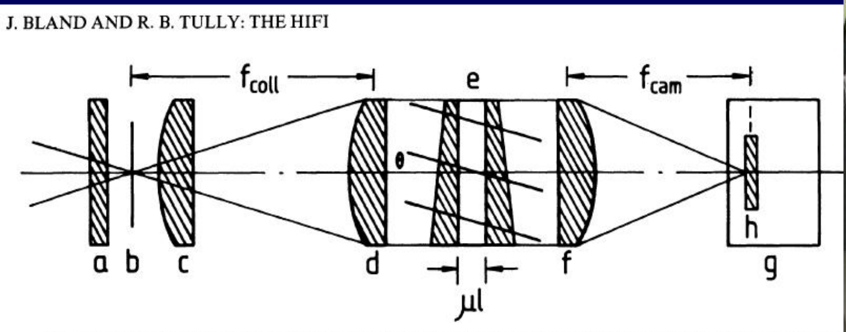


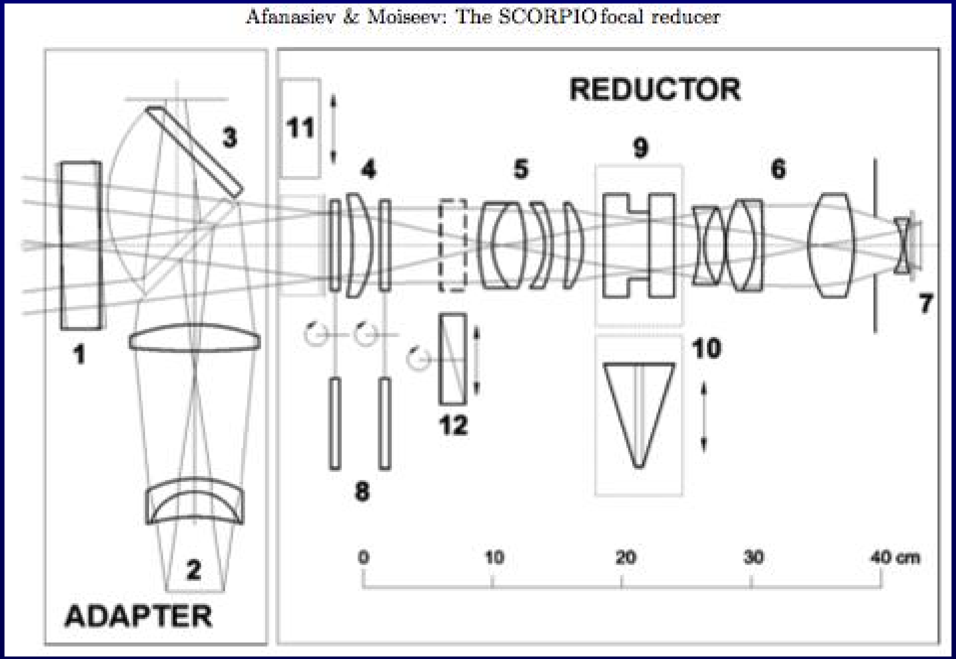
FIG. 1. Schematic drawing of an imaging Fabry–Perot interferometer comprising (a) interference filter, (b) focal plane, (c) field lens, (d) collimator lens, (e) Fabry–Perot etalon, (f) camera lens, (g) Dewar housing, (h) CCD.

AFOCS (Asiago 1.82m)

Spectral Camera with Optical Reducer for Photometric and Interferometric Observations

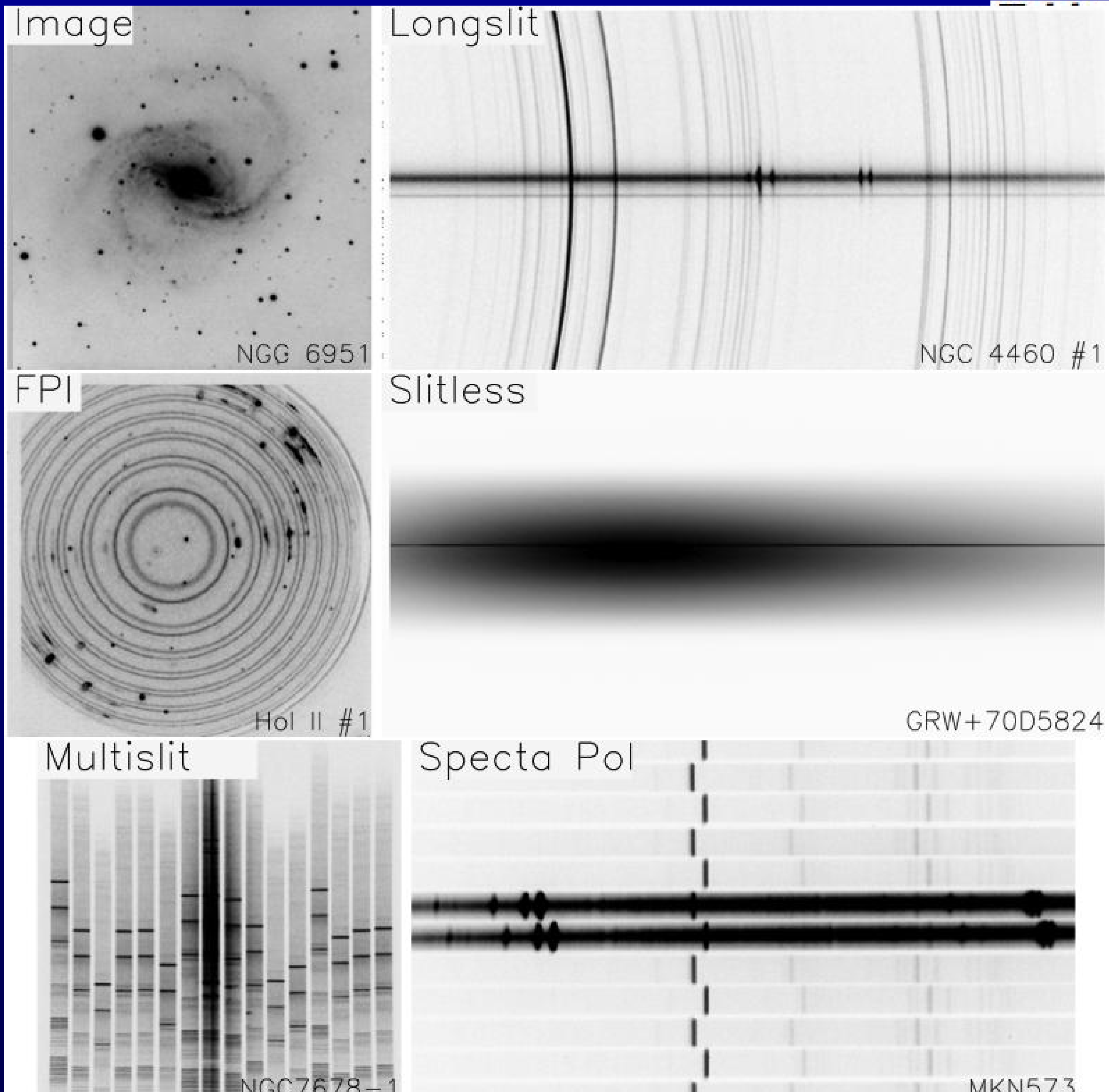
Observing modes in 6x6 arcmin field-of-view:

1. Direct imaging (broad-band and narrow-band filters).
2. Long-slit spectroscopy (δλ=2-8 Å)
3. Slitless spectroscopy
4. Multi-object spectroscopy (16 slits)
5. 3D spectroscopy with Fabry-Perot interferometer.
6. Spectropolarimetry.



The first light: September, 2000

SCORPIO observing modes



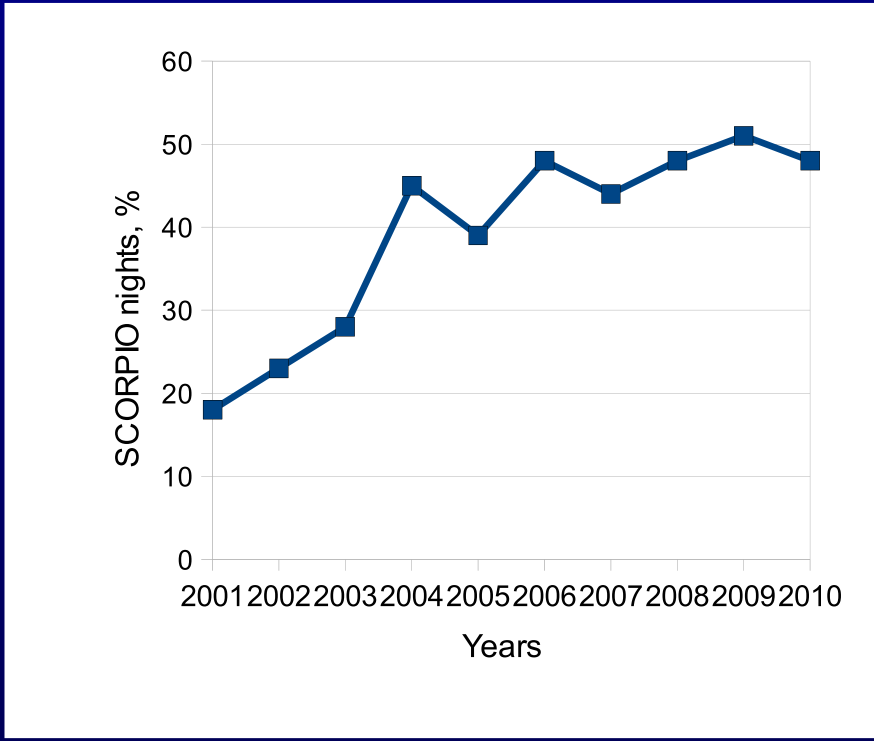
1. The main characteristics of SCORPIC

Total focal ration	$F/2.6$
Field of view:	
full	$6.1' \times 6.1'$
in mutlsilit mode	$2.9' \times 5.9'$
Image scale	$0.18''$/px
Spectral range	3 600 – 10 000Å
Spectral resolution	
with grisms	
(for slit width $1''$)	1.5 – 20Å
with Fabry-Perot	
interferometers	0.8 – 2.5Å
Maximal quantum efficiency (telescope+SCORPIO +CCD)	
Direct imaging	70%
Spectroscopy	40%
Observations with FPI	20%

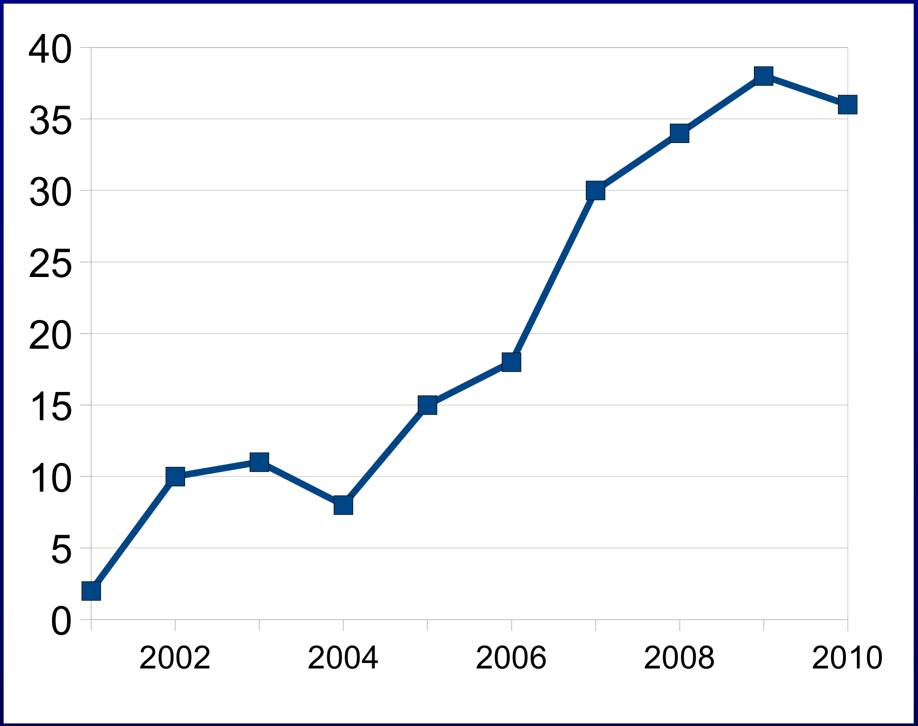
Afanasiev & Moiseev (2005)

The SCORPIO impact

The calendar time distributed for SCORPIO observations



The number of publications



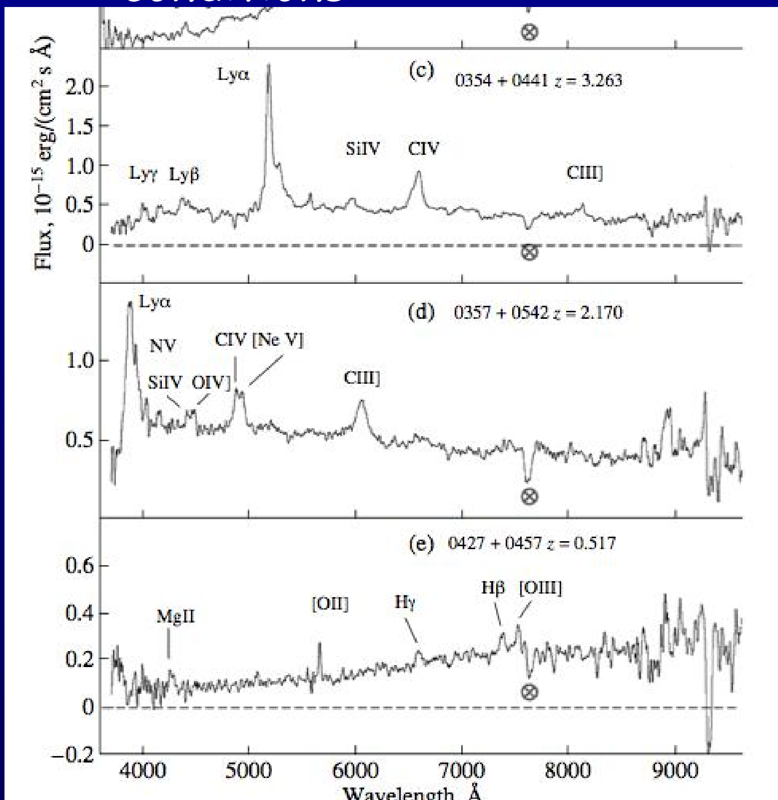
2001-2011: SCORPIO data were used in ~215 publications

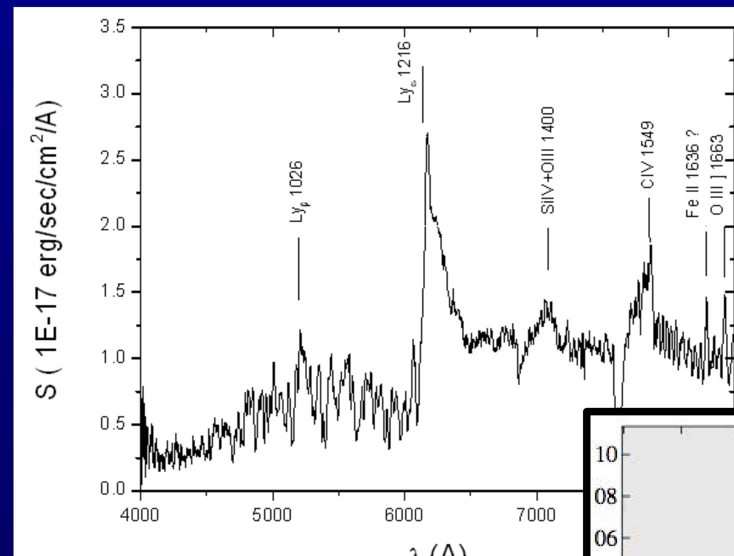
Spectral identification of radiosources

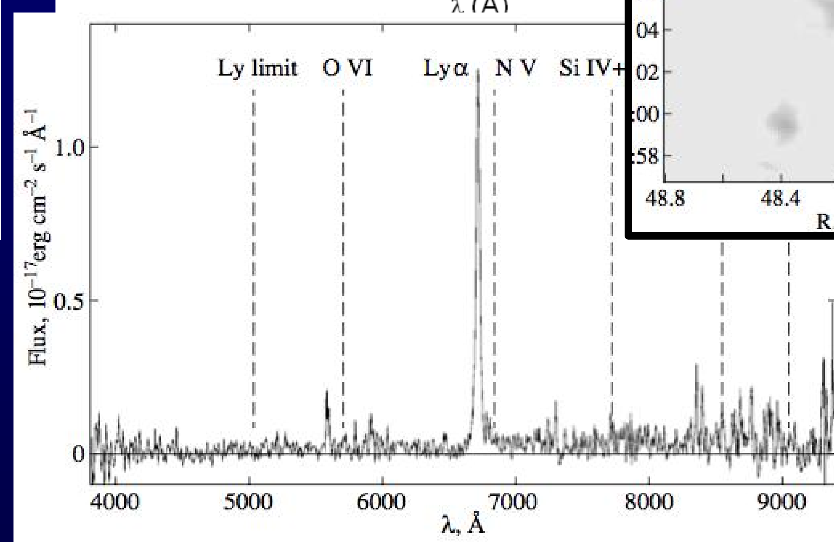
Spectroscopy of ~18-20^m in 'any' atmospheric conditions

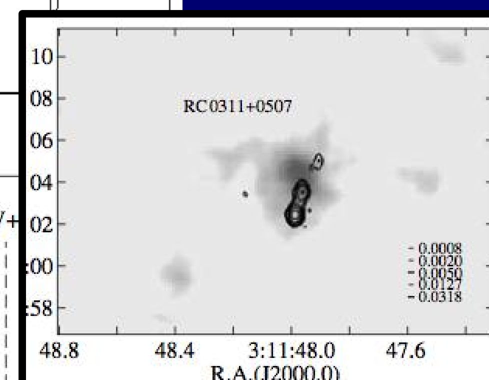
Very radio-loud galaxies/QSO at z=4-4.5

Need a SMBH with M>10^9Mo





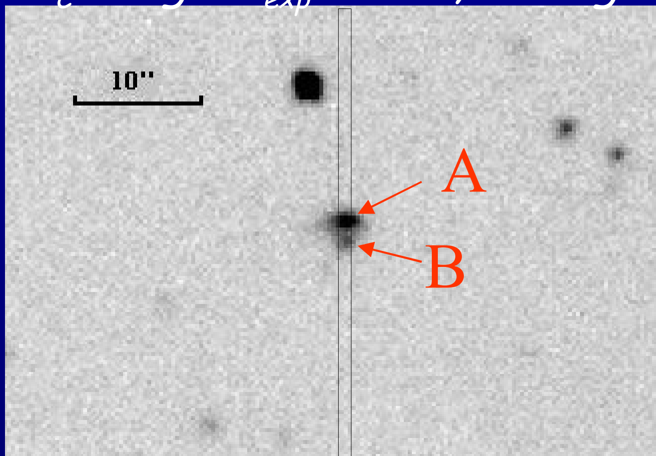




Afanaseiv et al (2003-2008)
Amirkhanian, Mikhailov (2006)
Kopylov et al (2006)
Parijskij et al (2010)

Faint objects spectroscopy (23-24 mag)

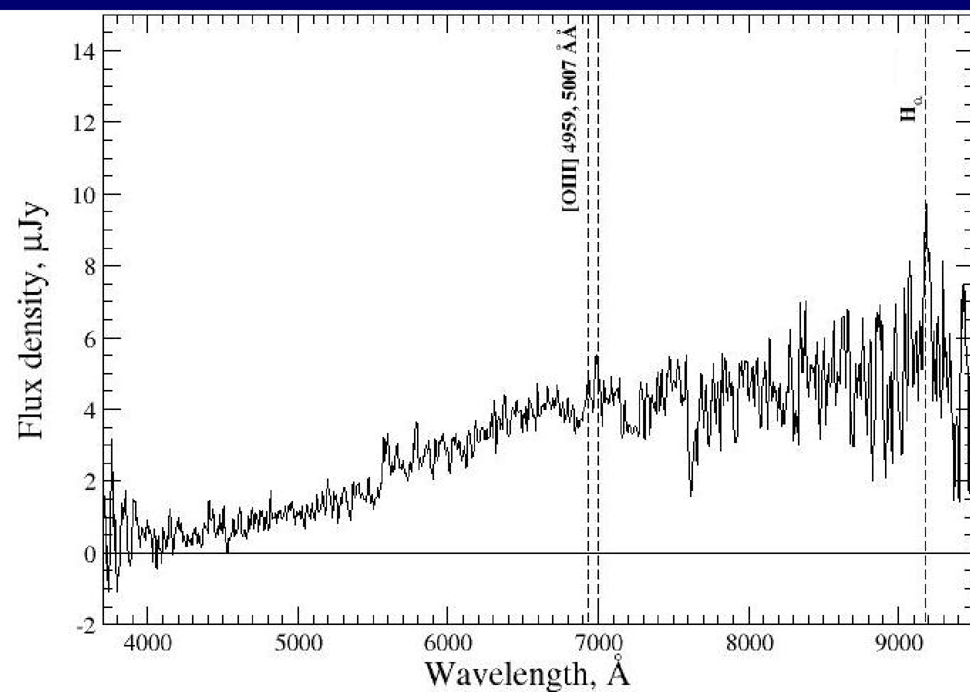
R_C image T_{exp}=180 s, seeing=1.3''



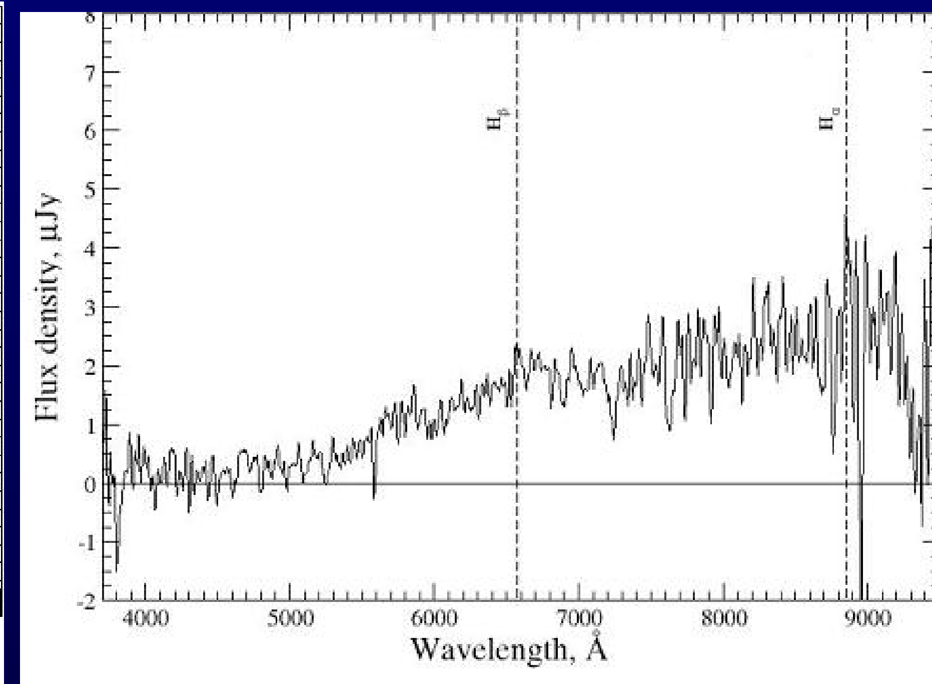
Host galaxy of the 'dark' gamma-ray burst GRB001109: T_{exp}=7200 s

(Fatkhullin, 2003)

Object A: R_C=22.5^m , z=0.40

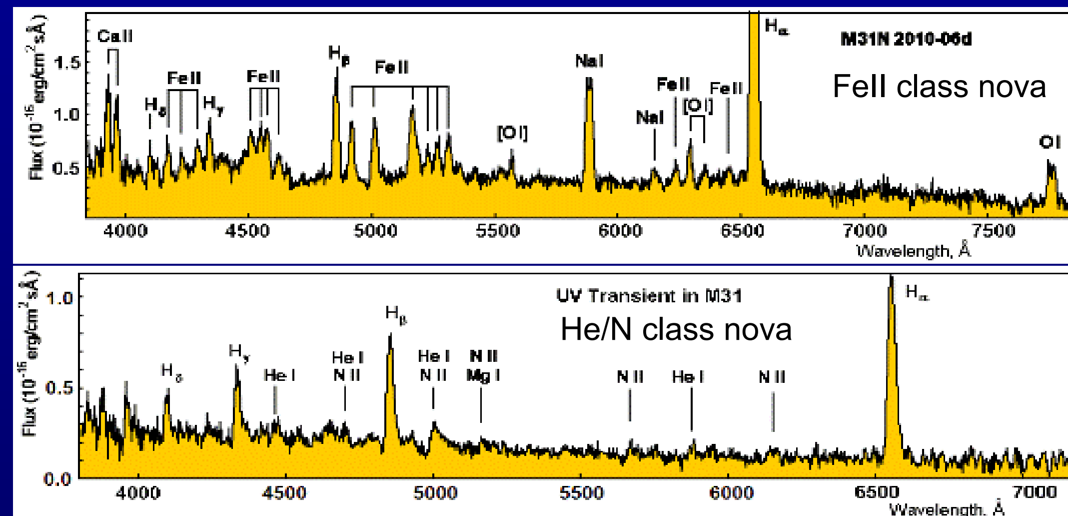


Object B: R_C=23.4^m , z=0.34



Transient objects

Novae in M31 (Pietsch et al. 2007-2011)



Distant supernovae probably associated with gamma-ray bursts,
GRB host galaxies:
Moskvitin et al. (2010)
Roy et al. (2011, MNRAS)
Castro-Terado (2008, Nature)

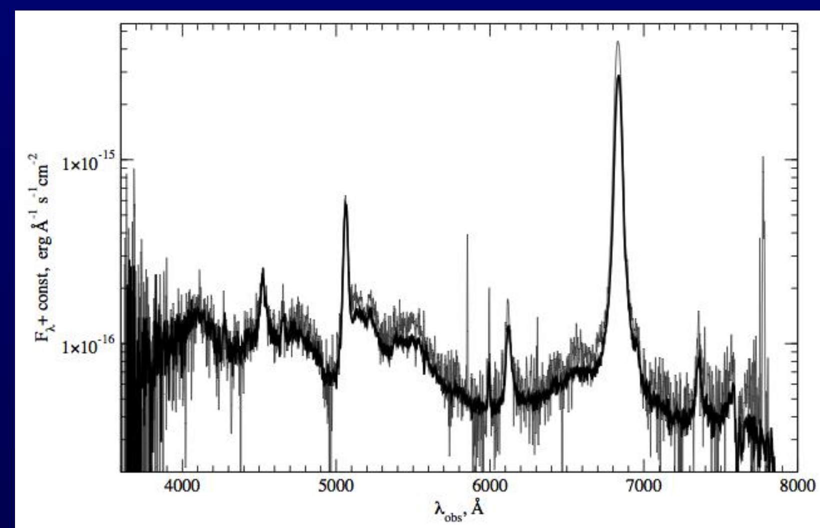
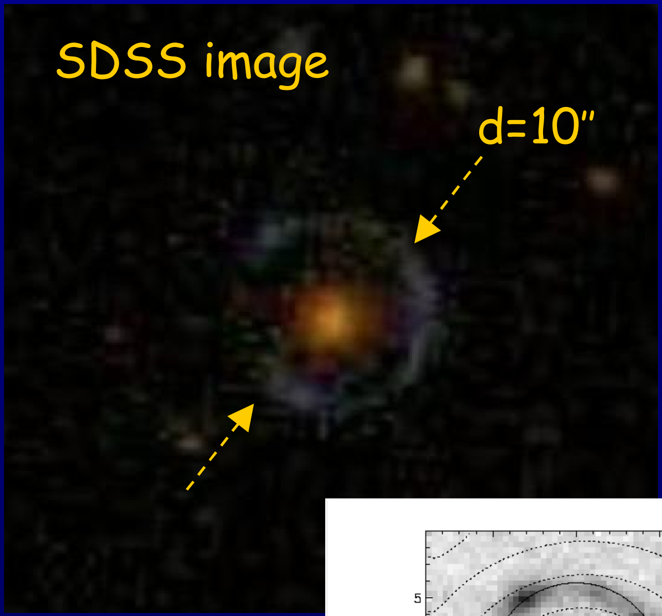
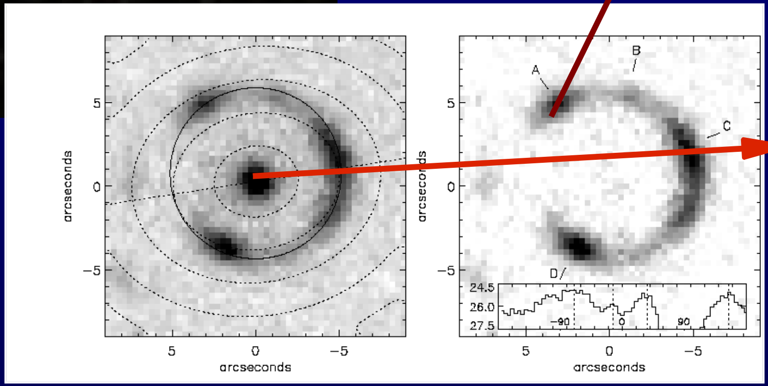


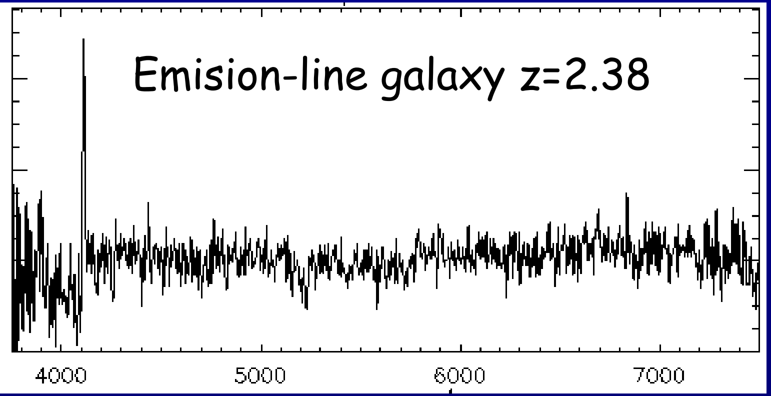
Figure 9. The spectra of SN 2008iy, obtained with the BTA+Scorpio on April 23 (the black line) and September 25 (the grey line), 2009. The object's redshift, measured from the BTA spectra $z = 0.041$ is

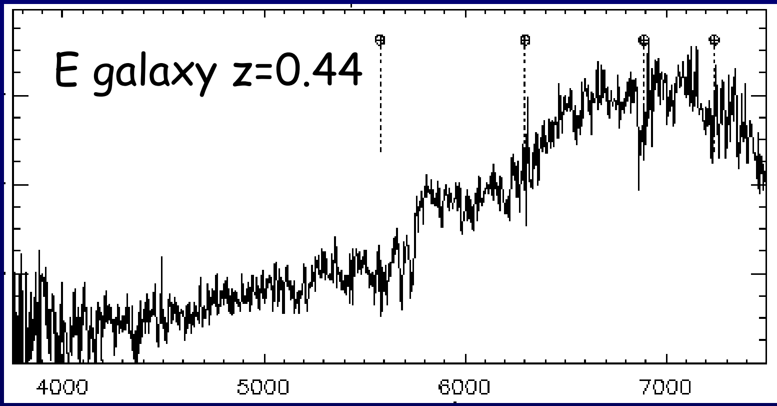
CAmbridge Sloan Survey Of Wide ARcs in the skY

The Cosmic Horseshoe (CASSOWARY #1)





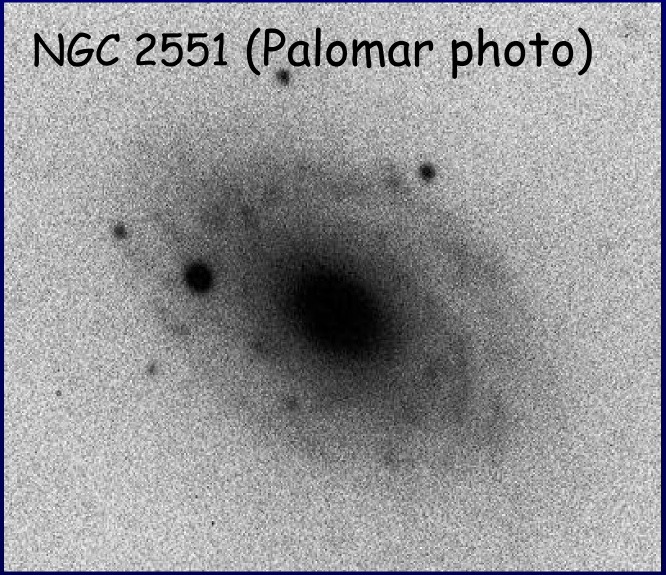




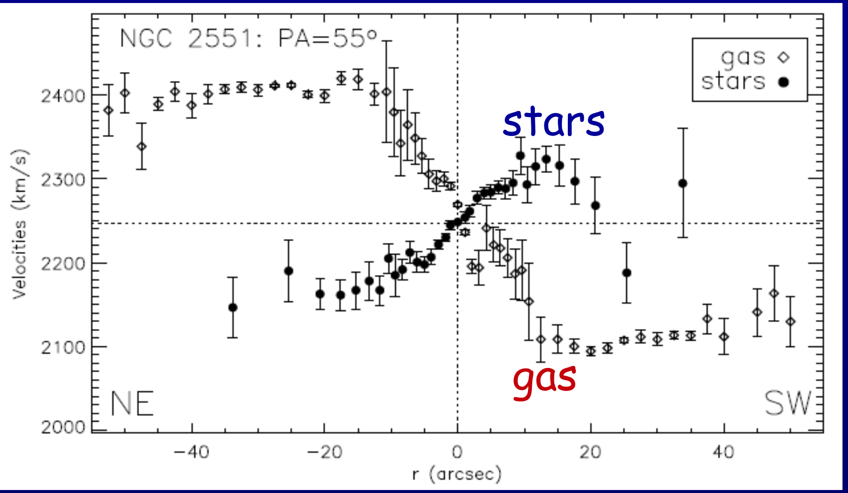
- Diameter of the Einstein ring: 10 arcsec
- Magnification factor: 25-35

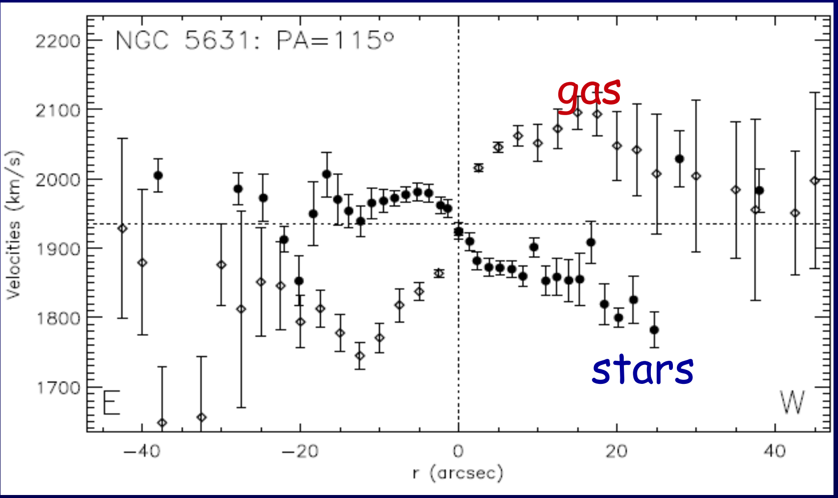
Belokurov et al (2007, ApJL)
More objects — Belokurov et al (2009)

Kinematics of stars and gas in S0 galaxies



The line-of-sight velocities (SCORPIO)

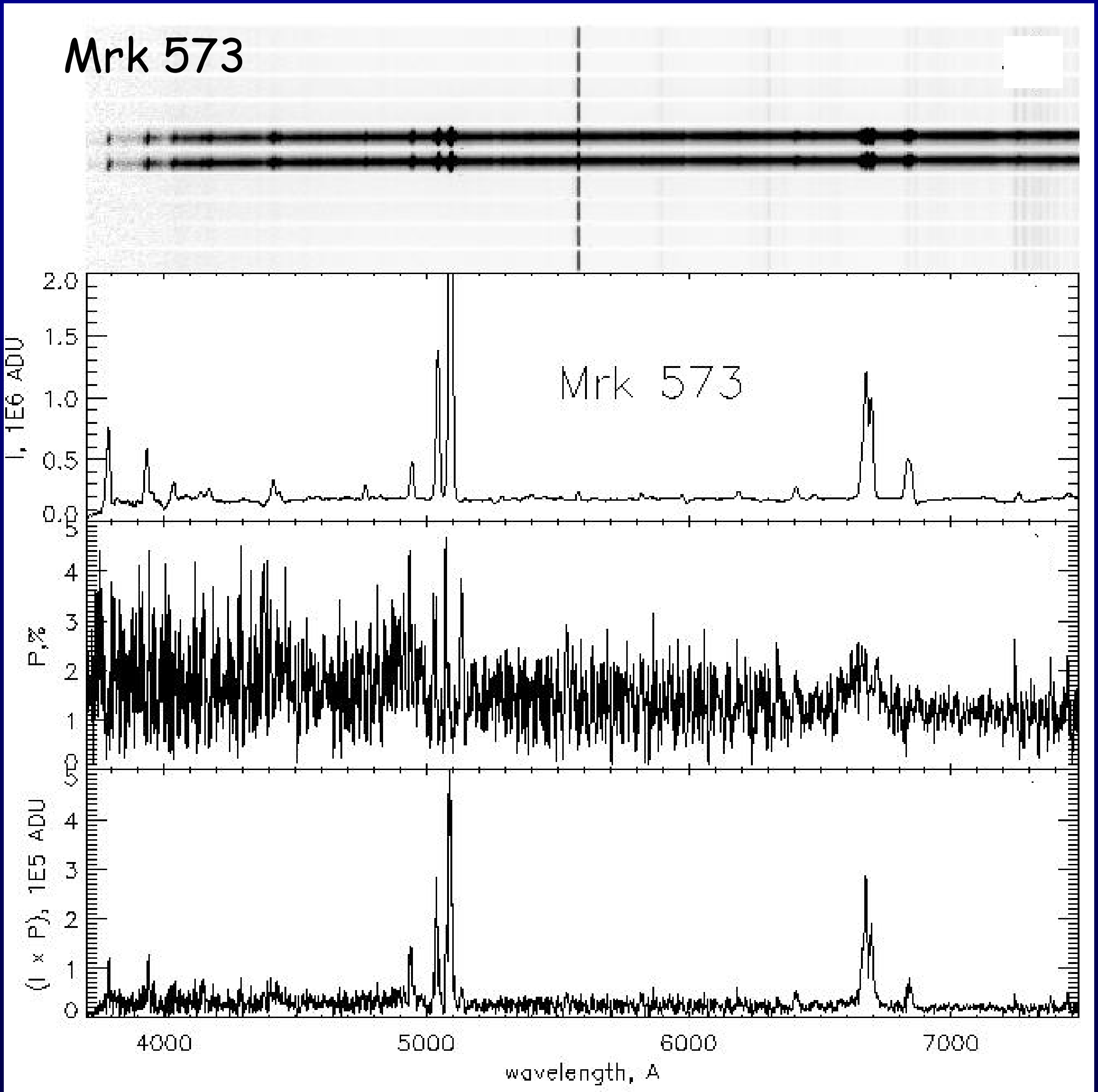




Large-scale (up to $0.8R_{25}$>5-7 kpc) counter-rotating ionized gas discs

Sil'chenko, Moiseev & Afanasiev (2009, ApJ)

Spectropolarimetric observations



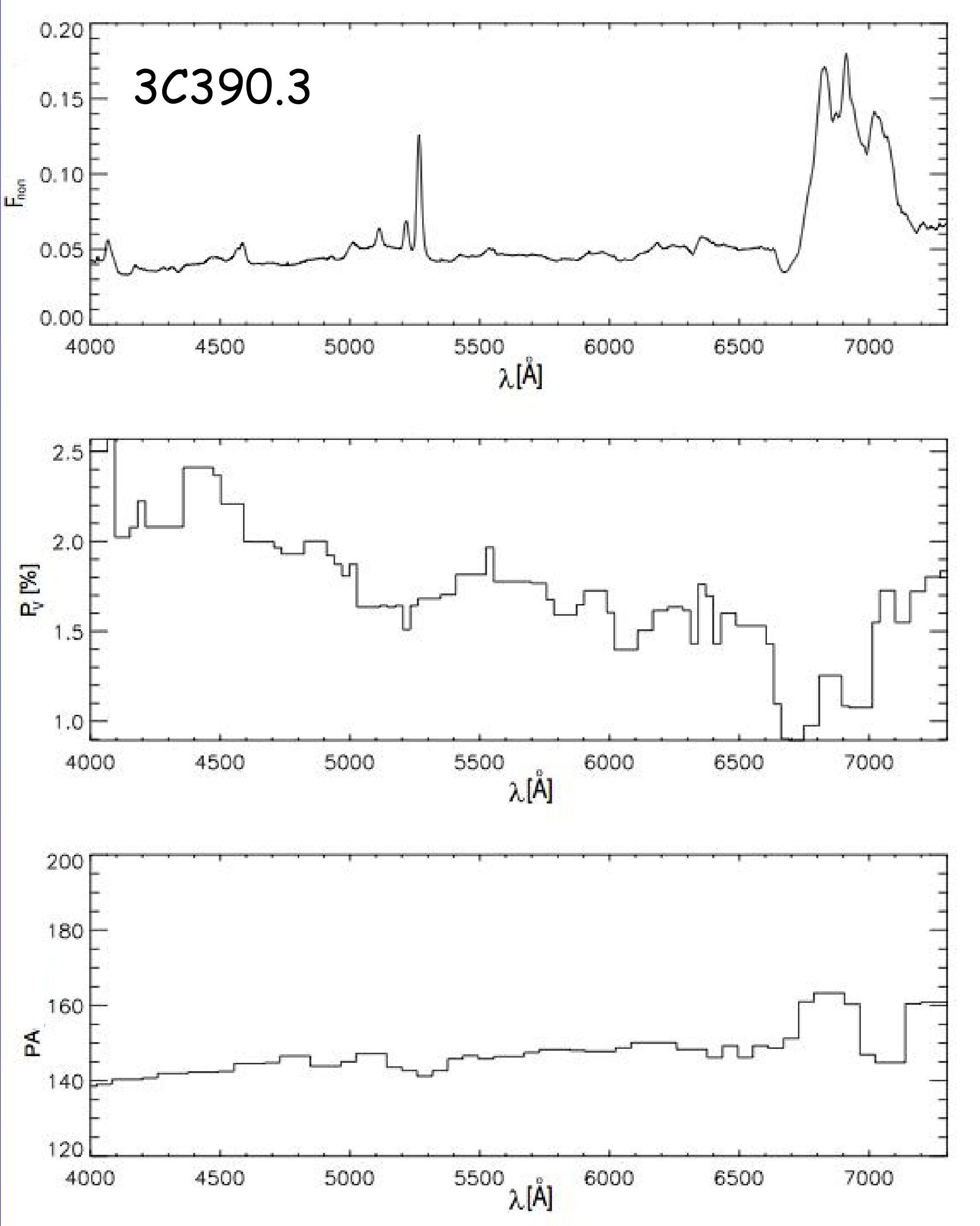
The original spectrum (Texp=2 h)

the integrated spectrum of the nucleus minus the spectrum of the surrounding galaxy

the degree of polarization

the spectrum of polarized emission

Afanasiev & Moiseev (2005)

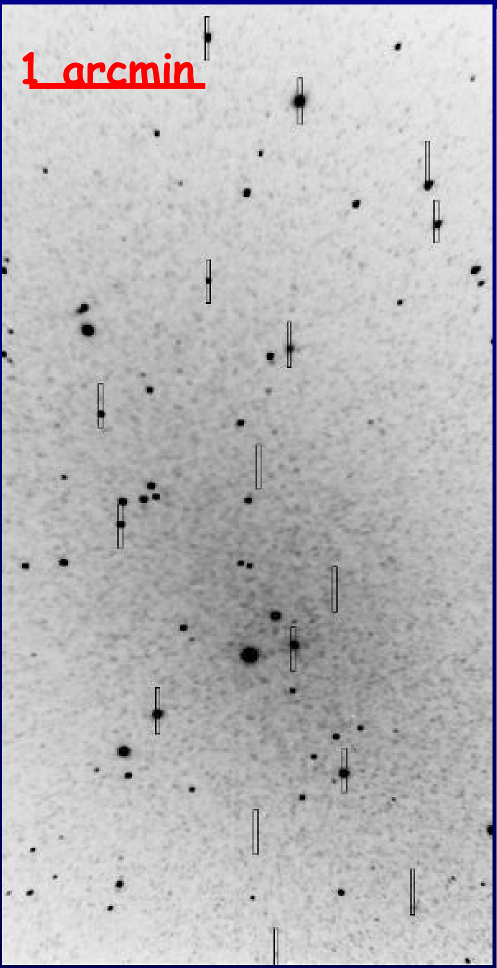


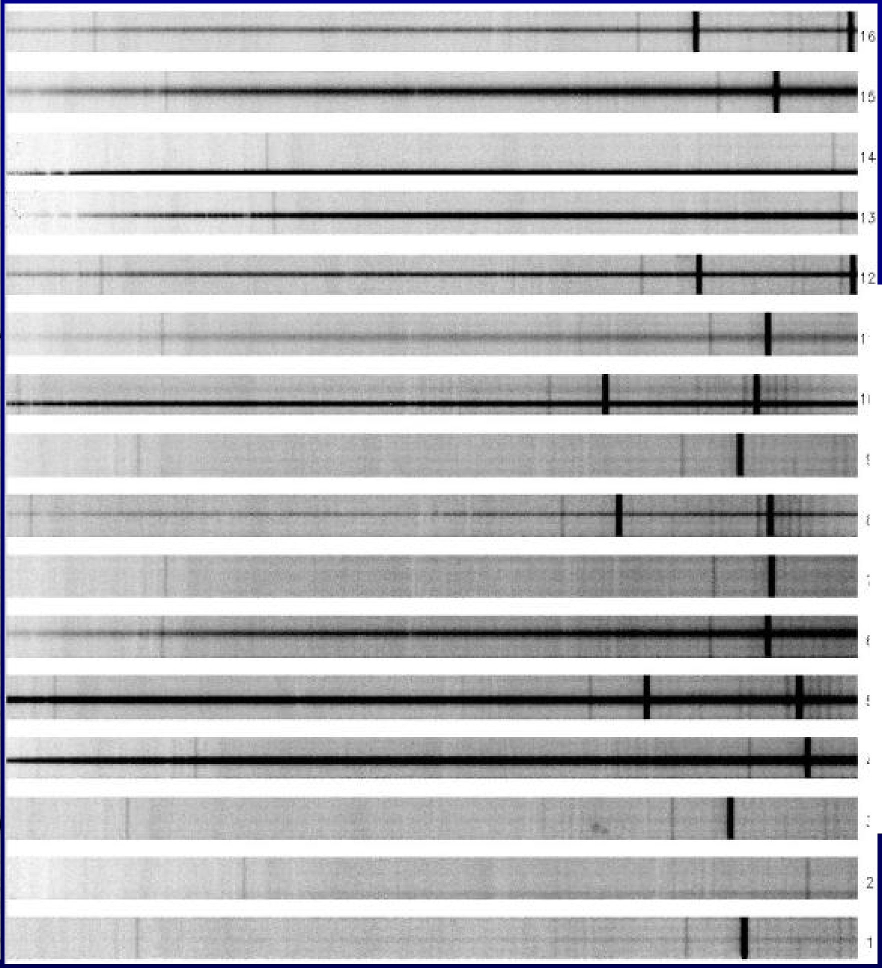
Object	p	s	$B(R_\lambda)$[G]
PG 0007+106	1/2	1	2.43
PG 0026+129	3/4	5/4	1
PG 0049+171	3/4	5/4	13
PG 0157+001	3/4	5/4	98
PG 0804+761	3/4	3/2	3.4
PG 0844+349	3/4	1	37
PG 0953+414	3/4	1	300
PG 1116+215	3/4	3/4	100
PG 2112+059	3/4	2	14.4
PG 2130+099	1/2	1	27
PG 2209+184	1/2	3/4	16
PG 2214+139	1/2	5/4	2.8
PG 2233+134	3/4	3/2	0.37
3C 390.3	3/4	1	6.4

The magnetic field strengths and radial distributions in an accretion disc around a supermassive black hole were evaluated within the framework of traditional accretion disc models

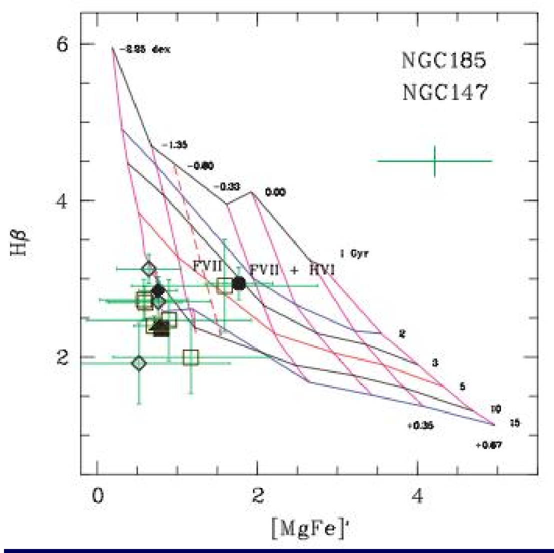
Afanasiev et al (2011)

Multi-slit data: globular clusters in dwarf galaxies



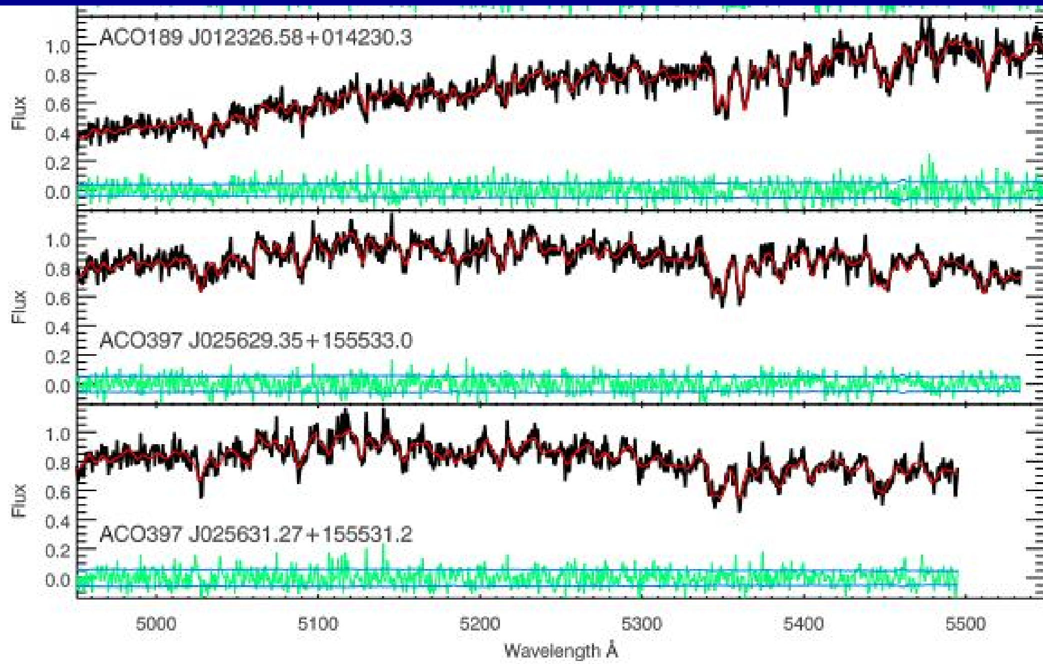


Spectra of objects
$V = 18\text{-}21^m$



Sharina, Afanasiev & Puzia(2006, MNRAS)
"Ages, metallicities and [alpha/Fe] ratios of globular clusters in NGC 147, 185 and 205"

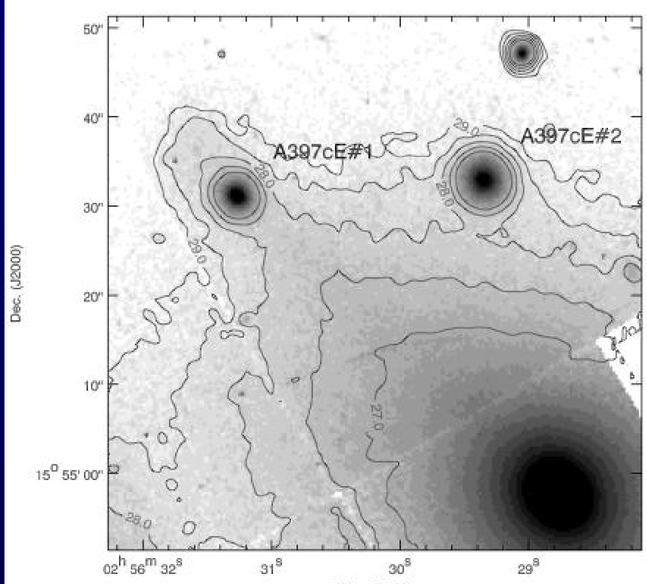
New compact elliptical galaxies



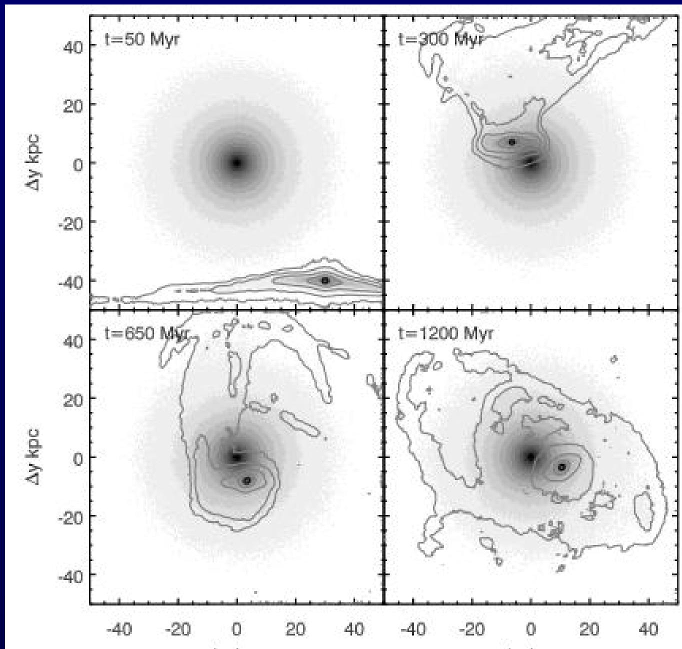
cE or 'M32-like galaxies:'

Chilingarian et al(2009, Science):
21 new cE galaxies were found.

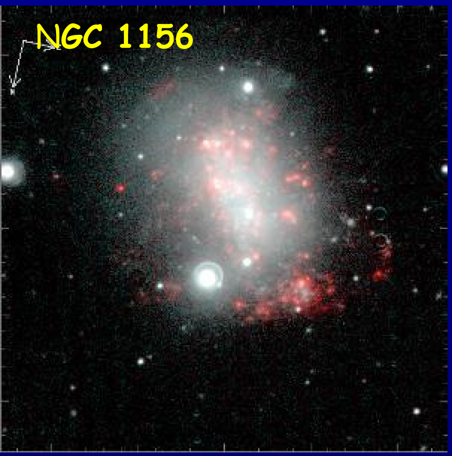
'..tidal stripping of the stellar component plays an important role in the morphological transformation of galaxies in dense environments..'

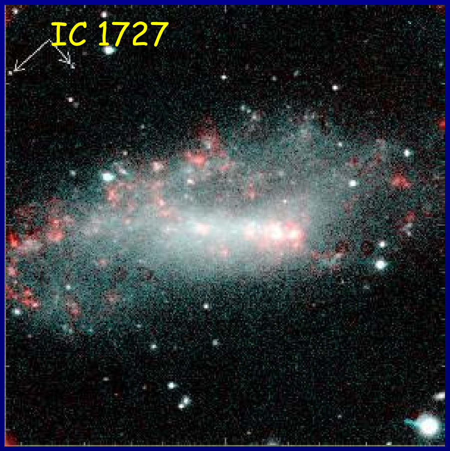


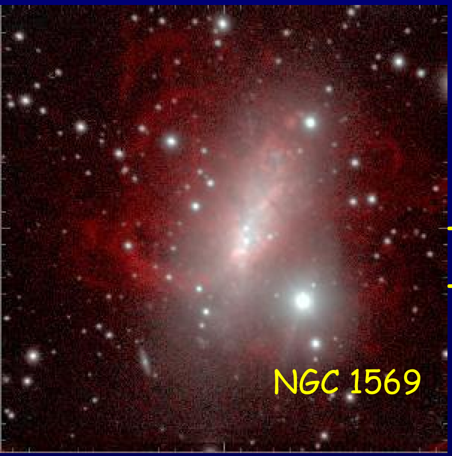
Abell 189, and Abell 397. The best-
ıd green solid lines respectively. Flux



Star formation in the Local Volume (d<10 Mpc)







Ha images of 161 Galaxies (37% of all data for LV):

- Star formation rate
- Gas consumption time

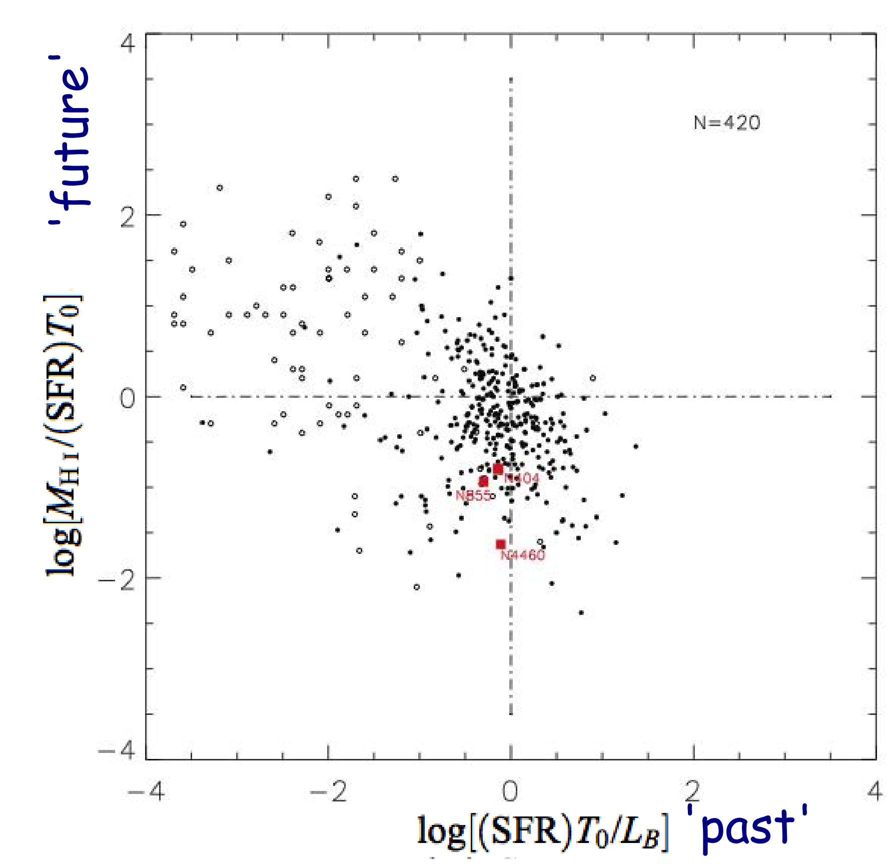


Figure 7. Evolutionary plane 'past–future' for 420 LV galaxies (Karachentsev & Kaisin 2010). The galaxies observed and detected in Hα

Karachentsev & Kaisin (2010, 2007)
Kaisin & Karachentsev (2008)
Karachentsev et al (2005)

The total SFR density in the local (z=0) universe:

(0.019±0.003) Mo/yr/Mpc^3

(Karachentsev & Kaisin, 2010, AJ)

Ionized gas outflow (superwind) in NGC 4460

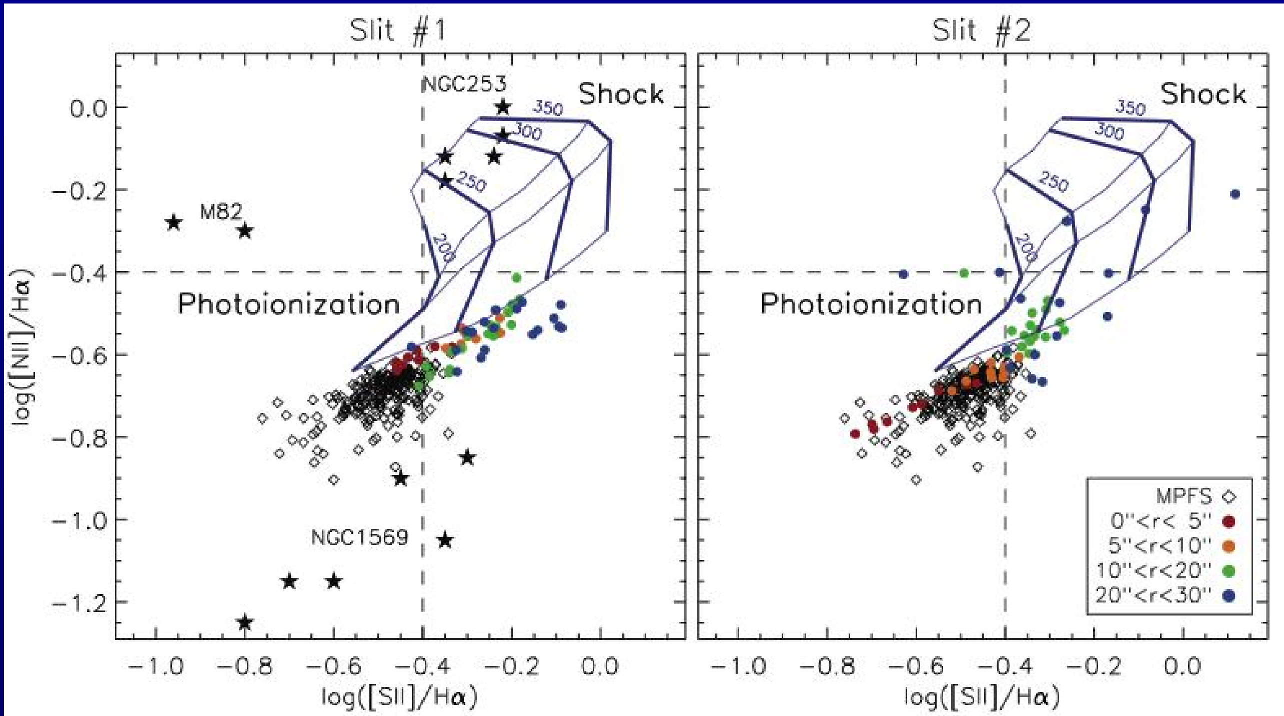
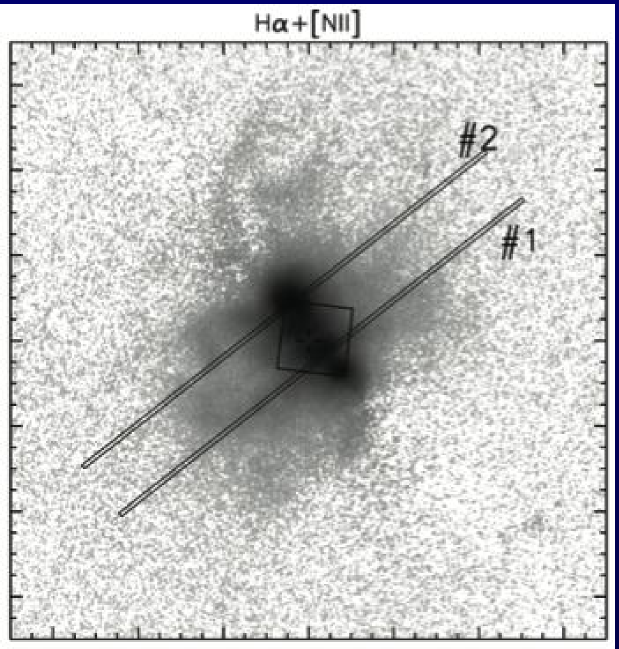


Figure 5. Diagram of the [N II]/Hα versus [S II]/Hα flux ratios. The dashed line separates domains with different ionization mechanisms. The blue lines show the grid of shock + precursor ionization models according to Allen et al. (2008) for $n = 1$ cm^{-3} and solar elemental abundances. The thin and bold blue lines mark the contours of the constant magnetic parameter 0.001, 0.5, 1 and 5 μG cm$^{2/3}$ (from bottom to top) and the contours of constant shock velocity (labelled

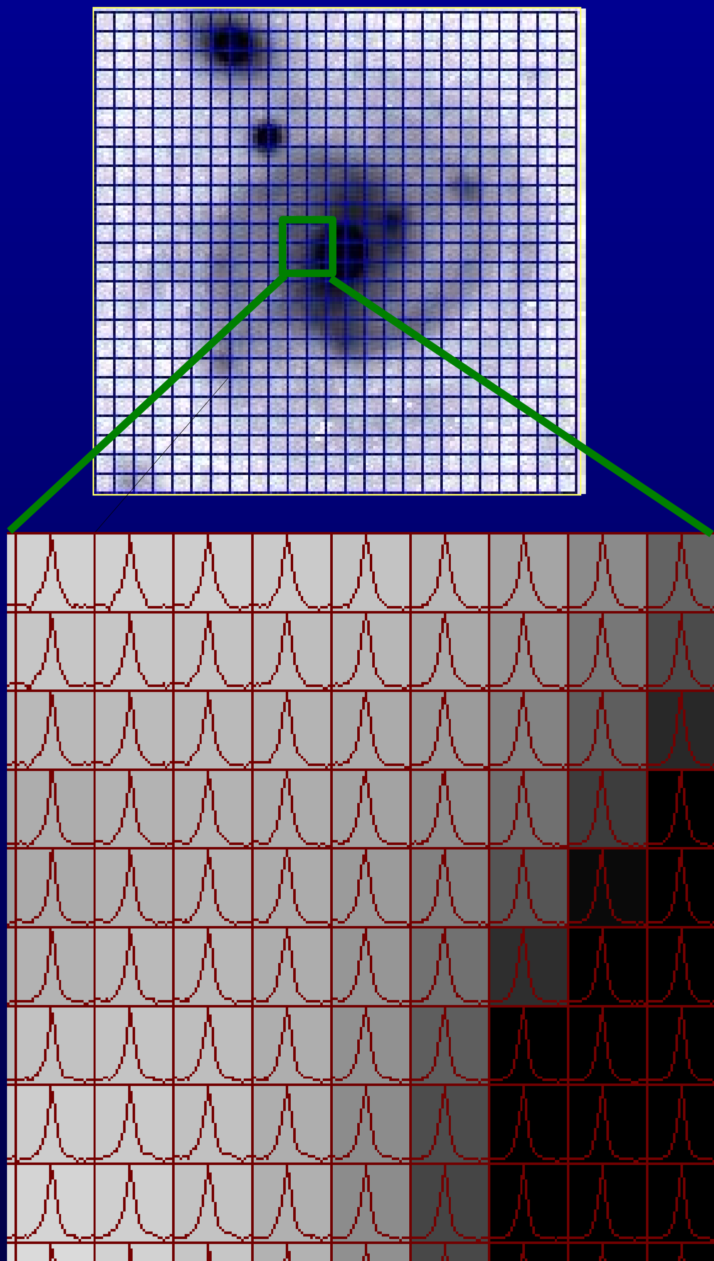


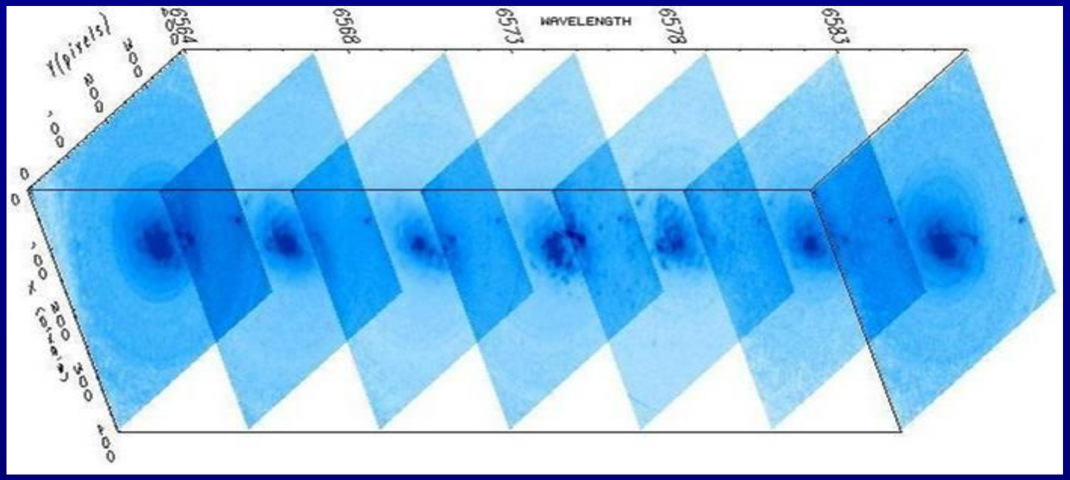
Whereas gas in the circumnuclear disc is photoionized by radiation of young stars, the external regions of the Hα nebulosity are ionized by shocks.

The outflow velocity is V≥ 130 km/s, SFR~0.3 Mo/yr

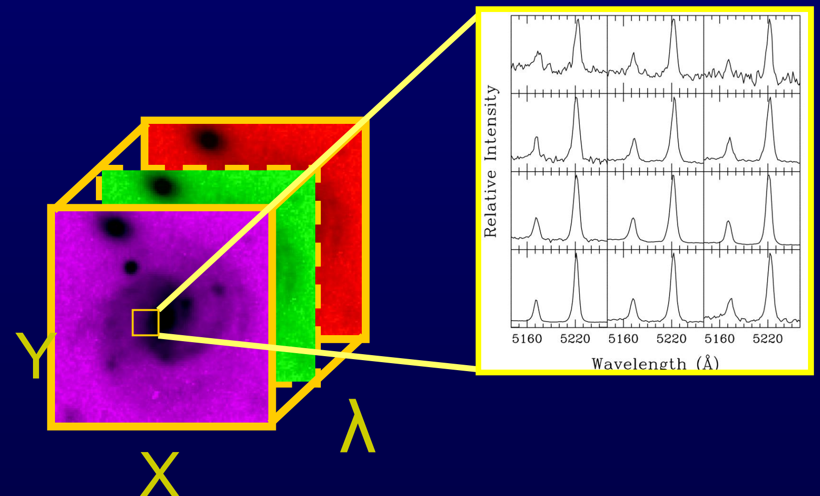
(Moiseev, Karachentsev & Kaisin, 2010, MNRAS)

SCORPIO with a scanning Fabry-Perot interferometer

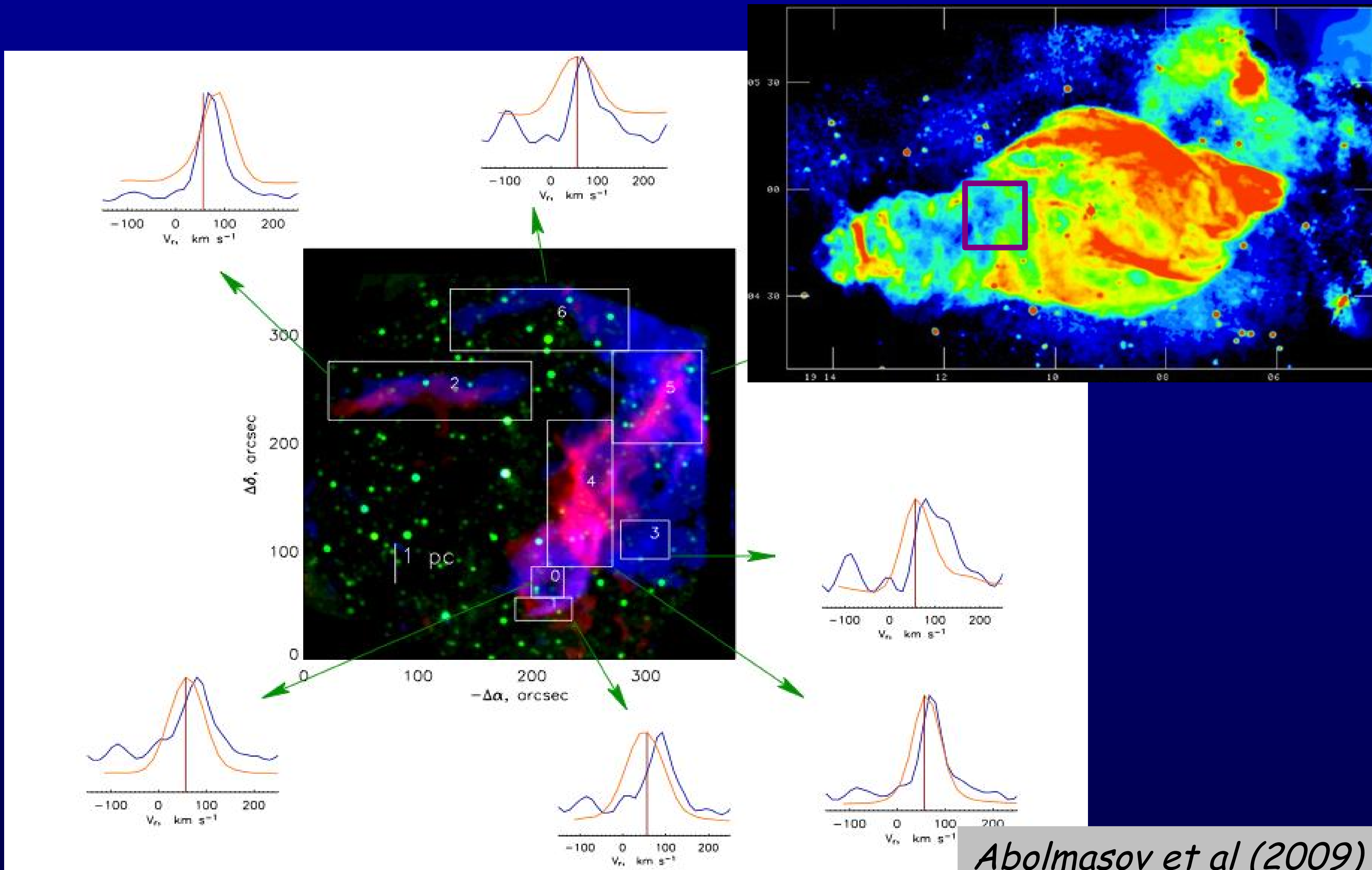




3D data cubes



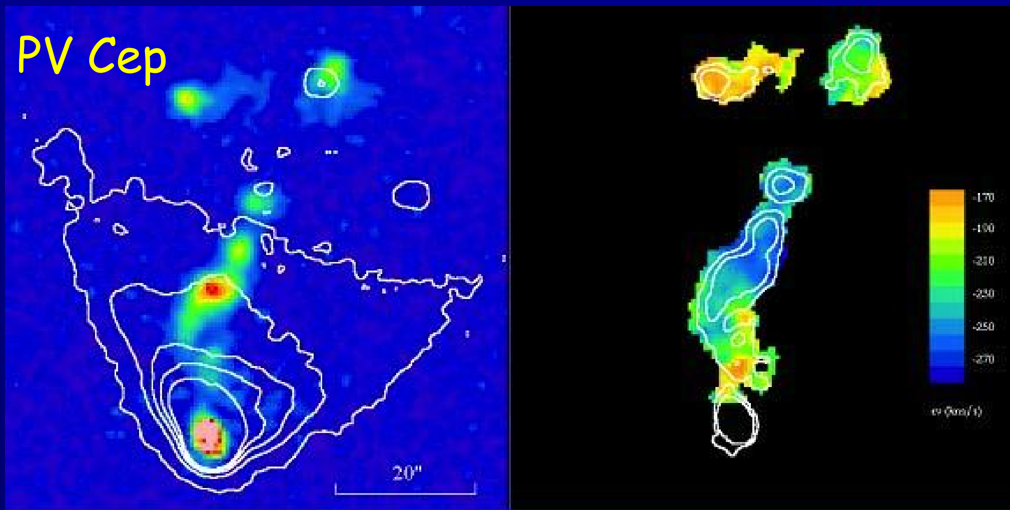
Western filament of nebula W50 related with SS433

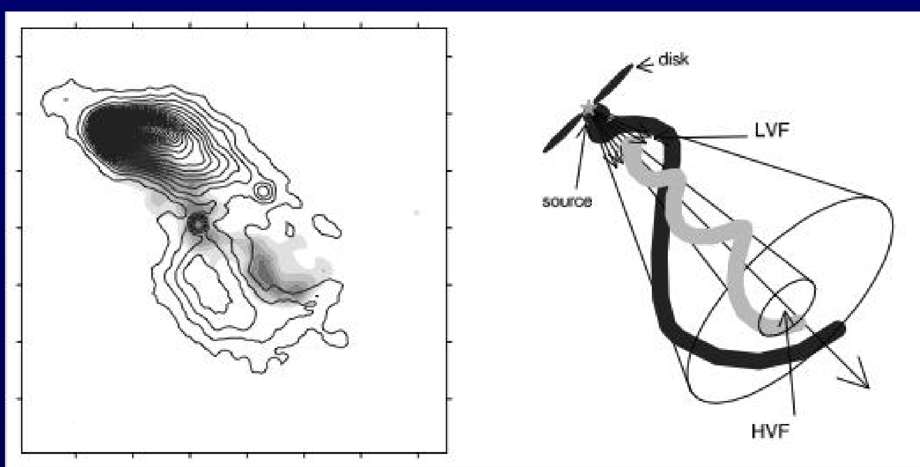


Abolmasov et al (2009)

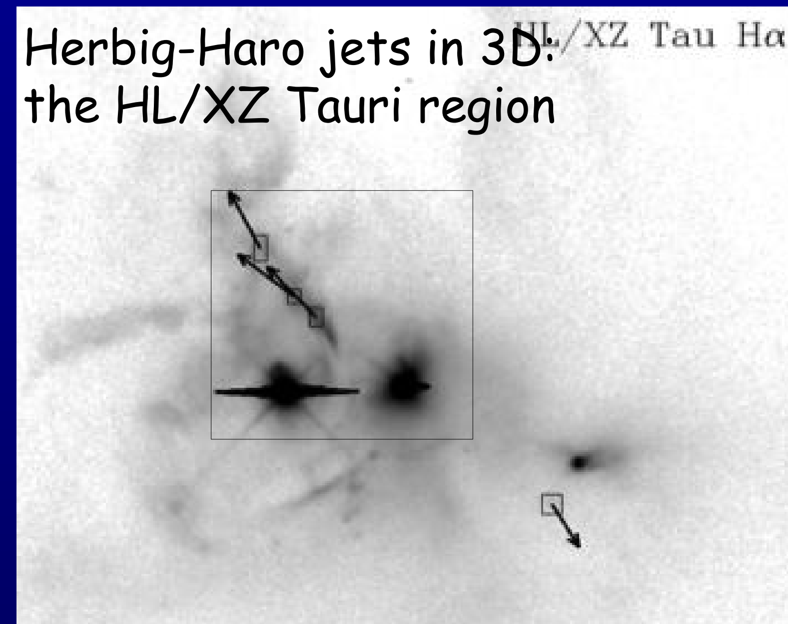
Fig. 3 The two intensity maps overlapped. [S II]λ6717 intensity is shown by red, [O III]λ5007 by blue (grayscale and

Jets and outflows from young stellar objects

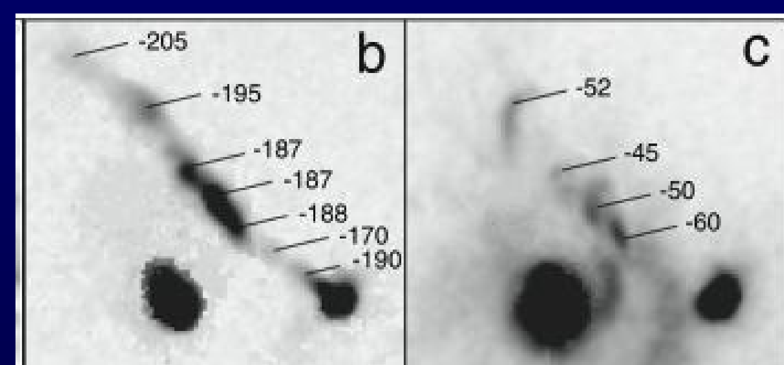




Movsessain et al (2006-2009)



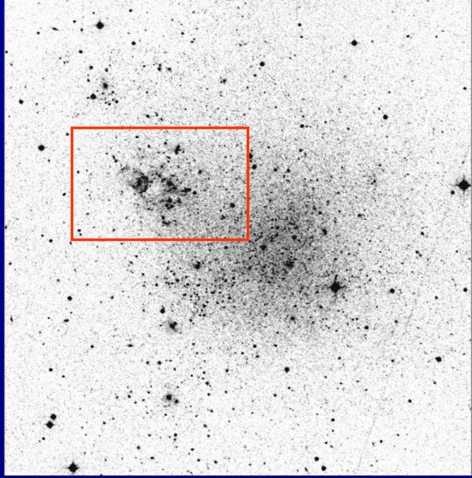
Herbig-Haro jets in 3D:
the HL/XZ Tauri region

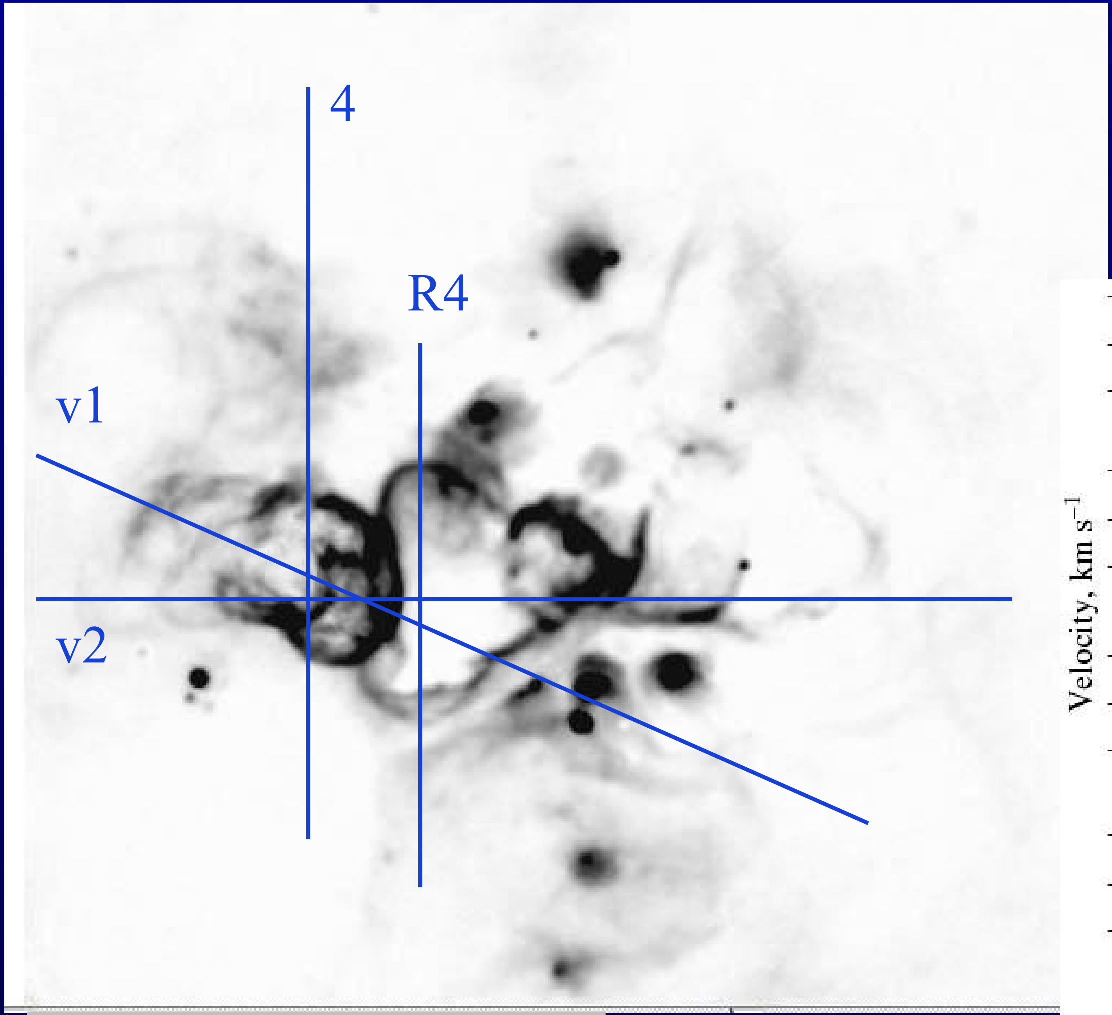


high (b) and low (c) velocity components

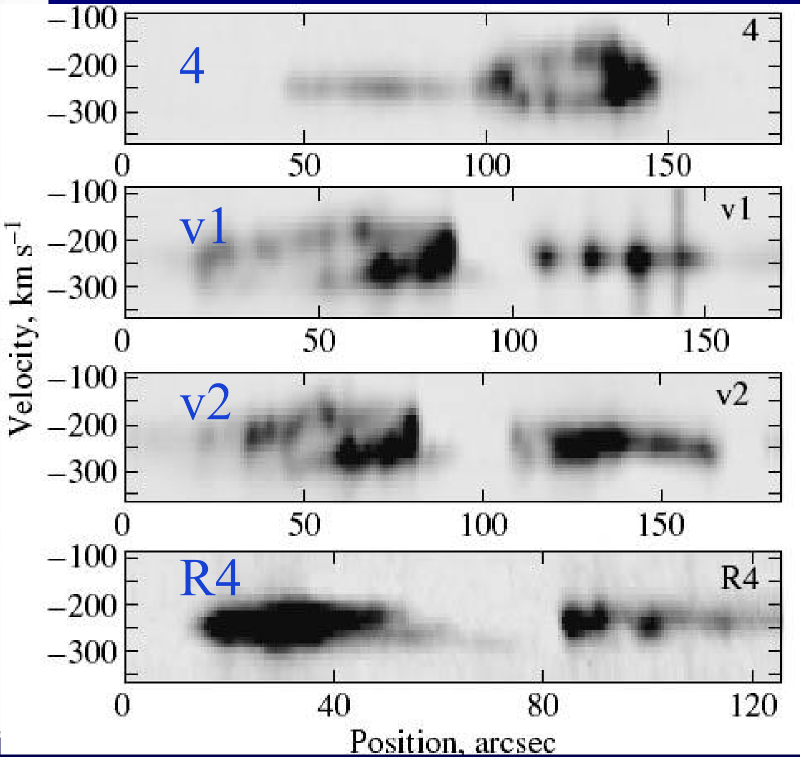
H II kinematics in the region of ongoing starformation in the dwarf irregular galaxy IC 1613: a complex of expanding shells:

- re-estimation ages of the bubles
- comparision with SF models



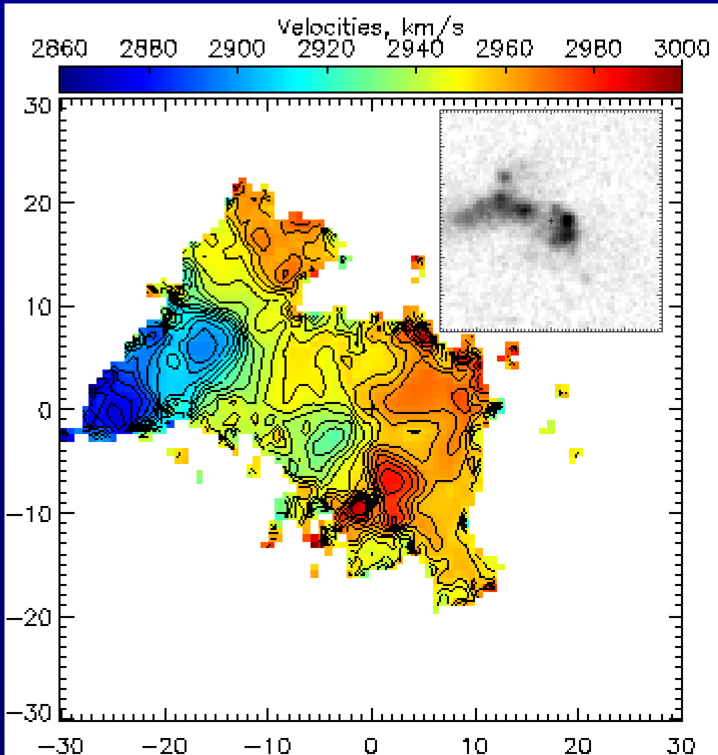


PV diagrams for ionized shells :

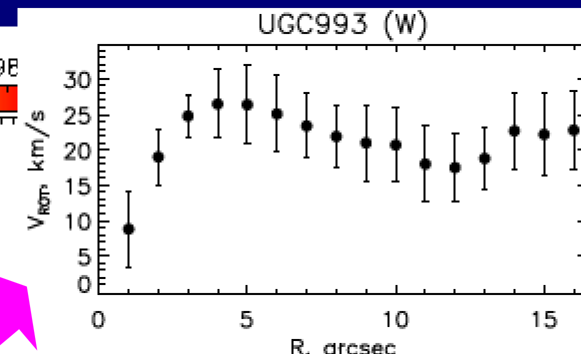


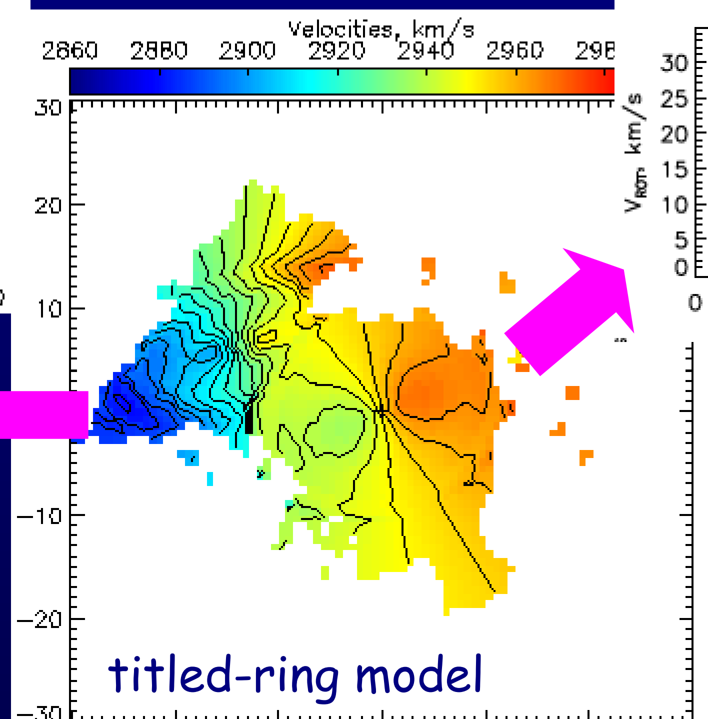
(Lozinskaya et al, 2003)

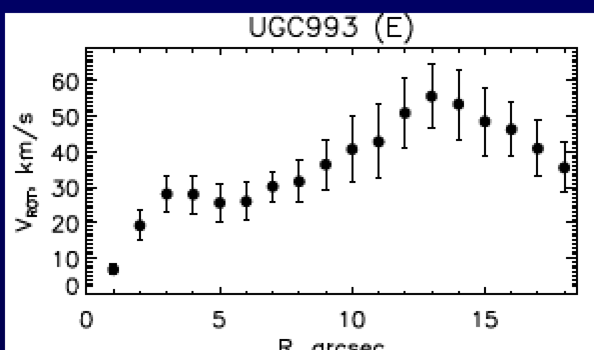
UGC 993: Merging of two dwarf discs



A detailed analysis of ionized gas morphology and kinematics in nine such galaxies shows the important role of recent interactions and mergers in the triggering of their star formation

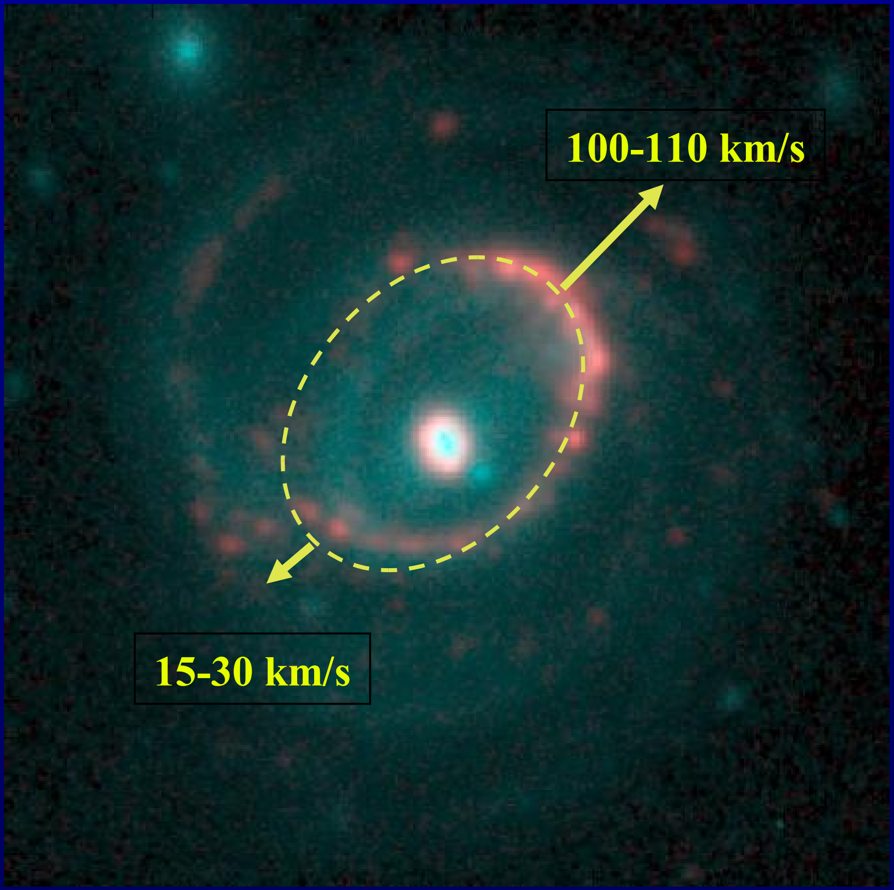


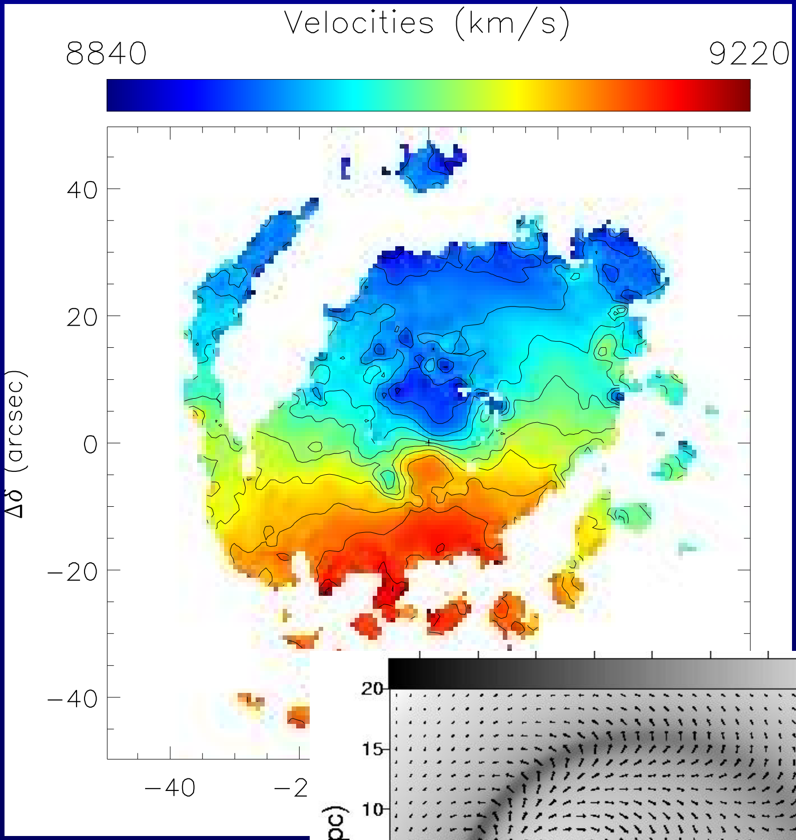


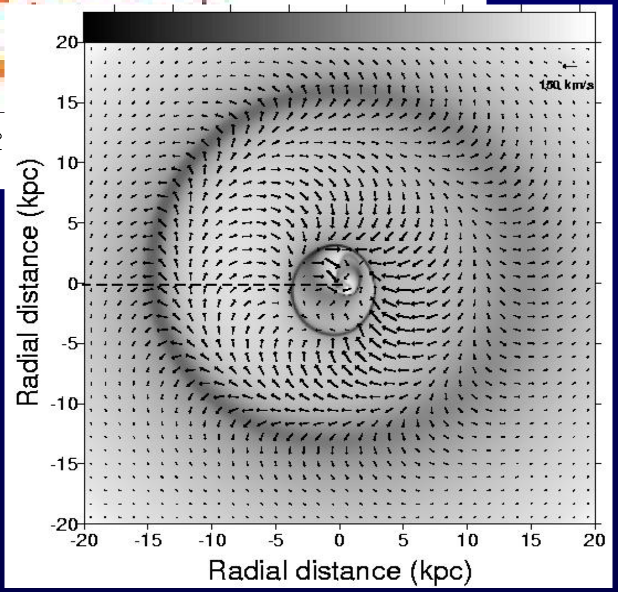


Moiseev, Pustilnik & Kniazev (2010, MNRAS)

Arp 10: colliding rings in a spiral galaxy



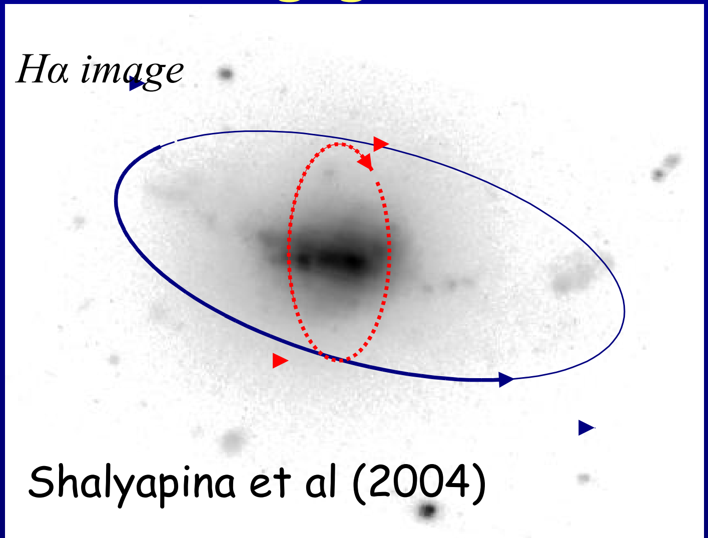


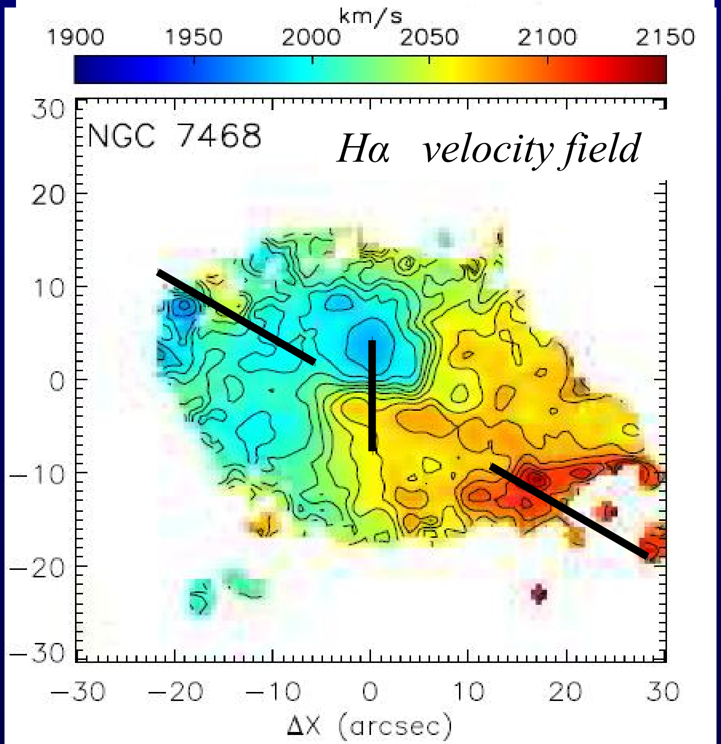


Dynamical age of the external ring: 0.15-0.20 Gyr

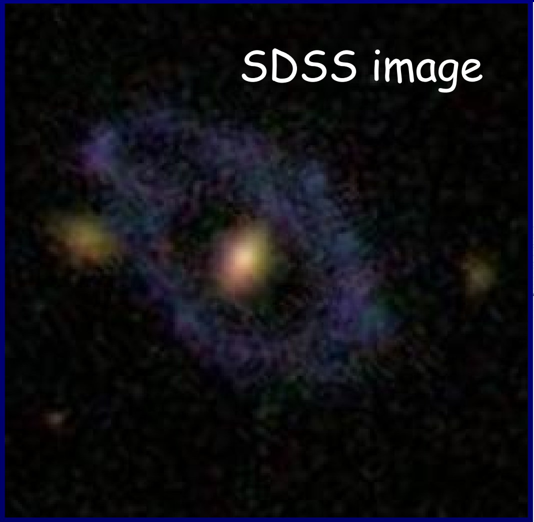
Numerical simulations of the circular density waves in Arp10 (Bizyaev, Moiseev & Vorobyov 2007)

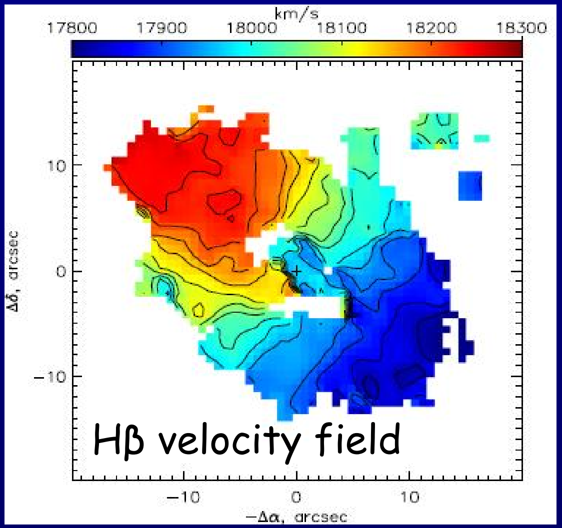
Polar ring galaxies





SDSS J075234.33+292049.8
the distant PRC z=0.06 (Brosh et al 2010)

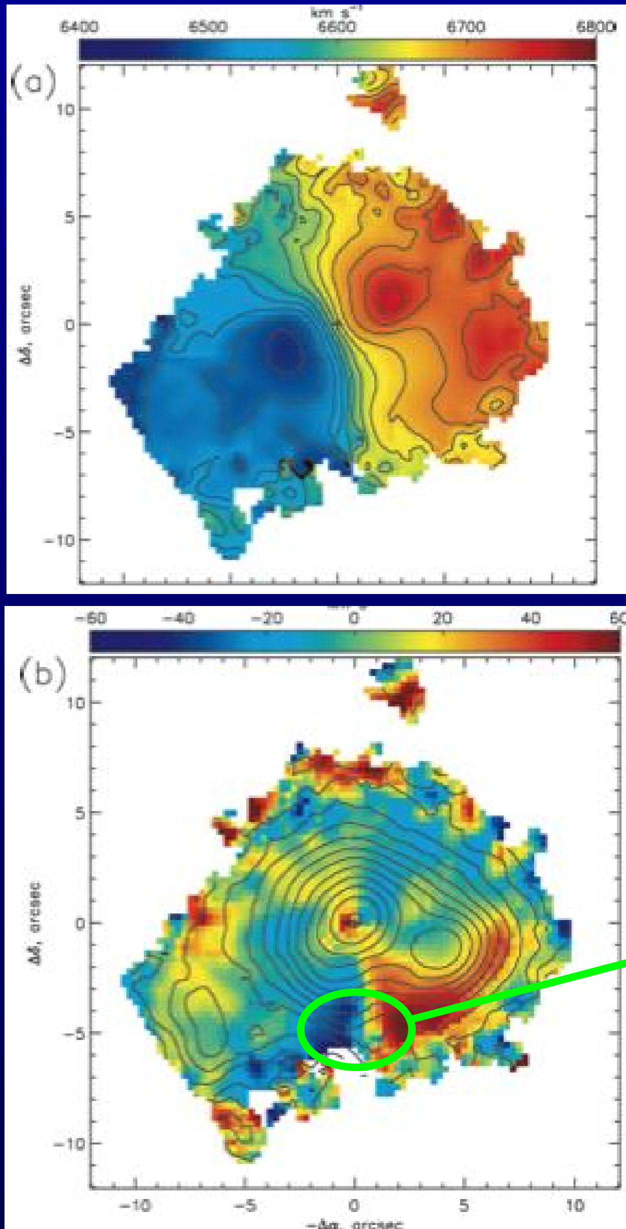




A giant (D=48 kpc) stellar-gaseous disk inlcined at $\Delta i = 73 \pm 12°$ to the central S0-galaxy

A significant amount of a dark matter: M/L=20

3D spectroscopy of merger Seyfert galaxy Mrk 334: nuclear starburst, superwind and the circumnuclear cavern



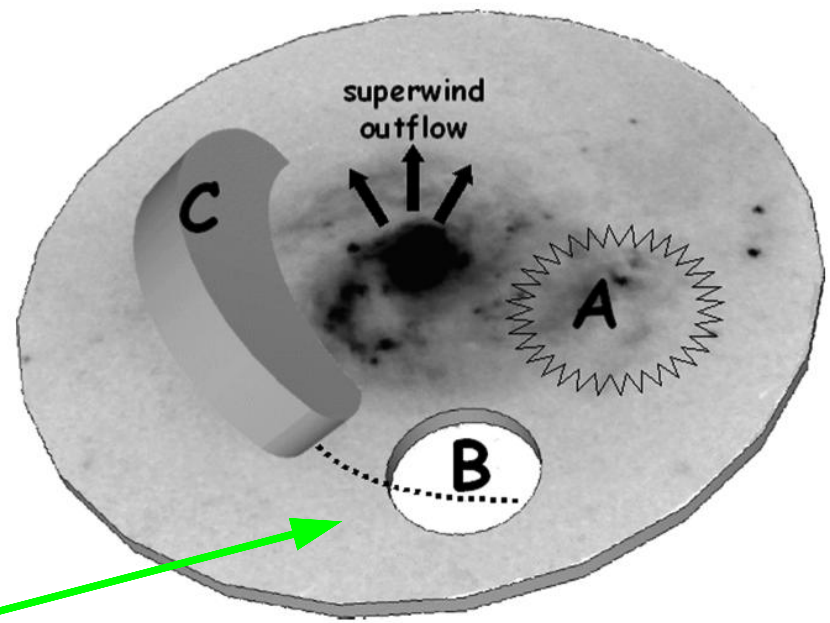


Figure 13. Sketch of the proposed model describing the spatial structure of the inner ($r < 5$ kpc) region of Mrk 334. The *HST* image from Fig. 5 is projected on to the plane of the galactic disc.

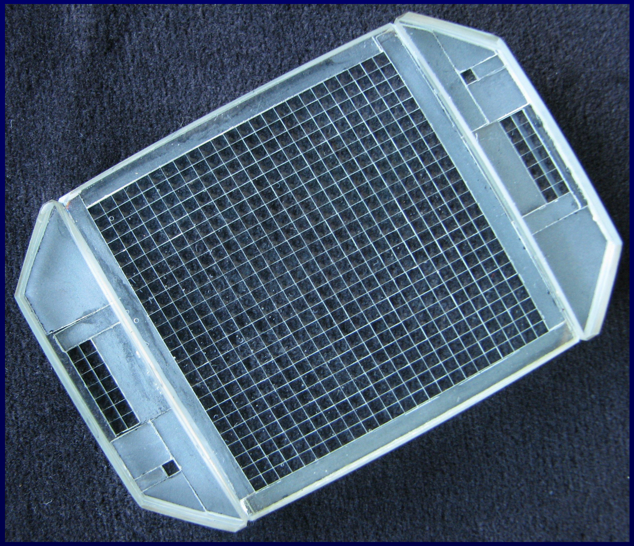
Smirnova & Moiseev (2010, MNRAS)

SCORPIO-2: what is new?

1. The device is specially designed to work under remote control from the Institute building (under the mountain where the telescope is sited): 27 filters, 9 VPH gratings

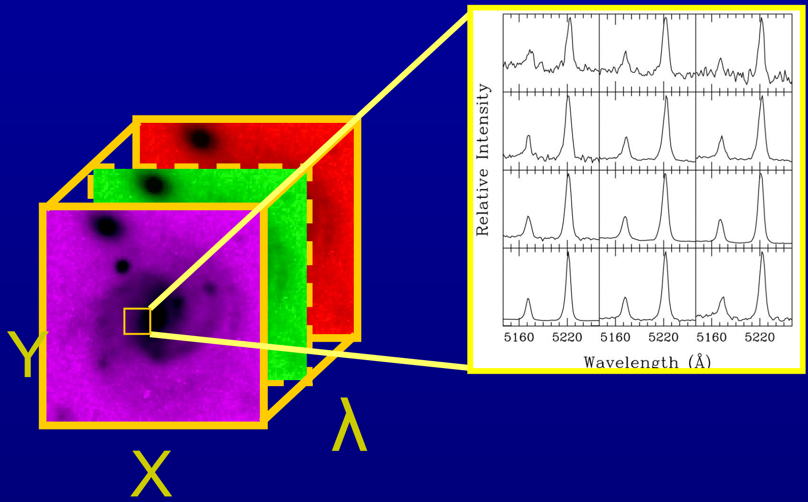
2.The opportunities for polarimetry (spectra and images) are greatly expanded.

3. New optics for large-format (CCD 2Kx 4.6K), the value of off-axis optical aberration are significantly decreased.

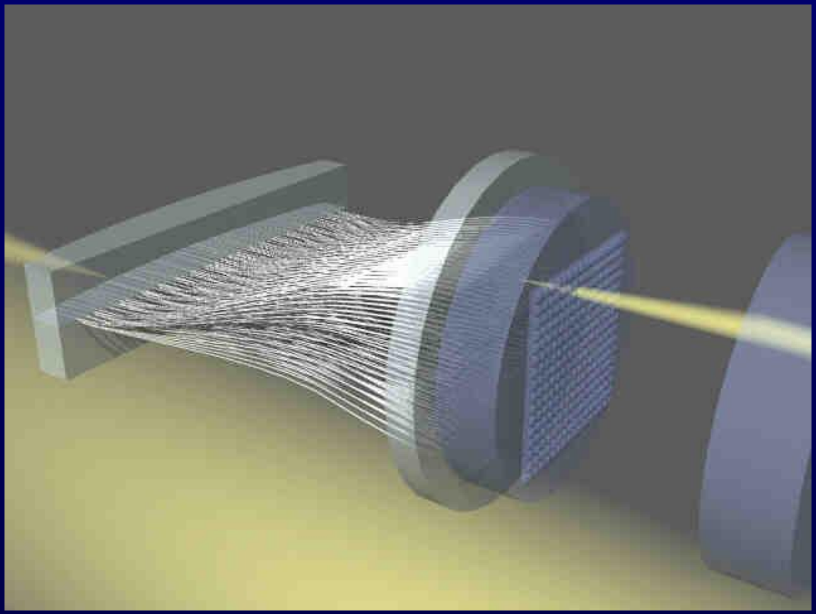


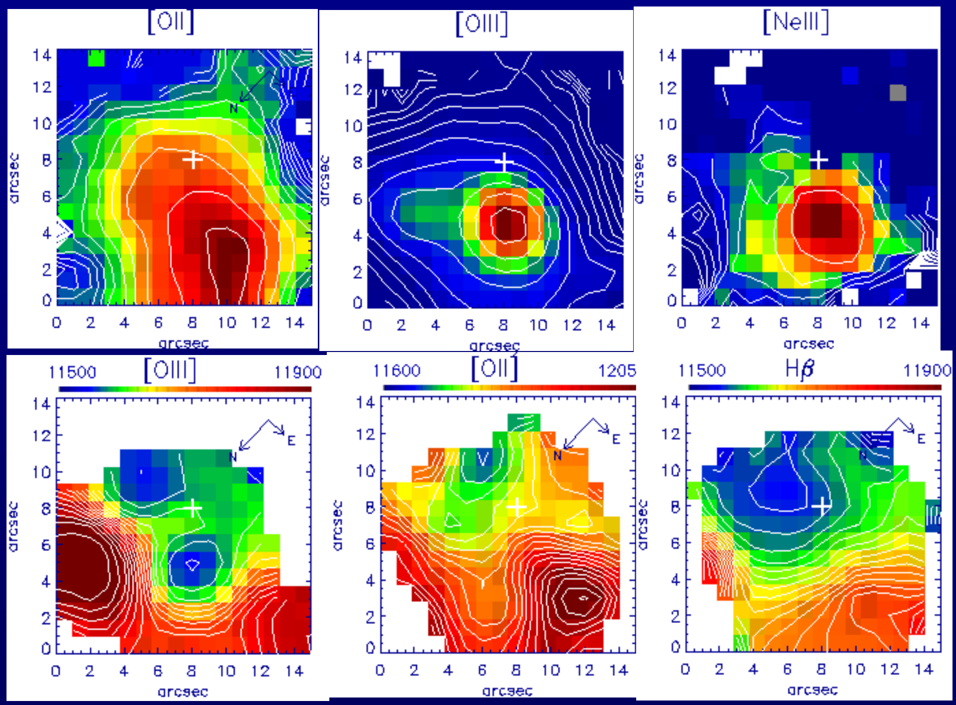
4. 3D integral-field unit: 24x24 lens array + fibers

SCORPIO-2/integral-field unit



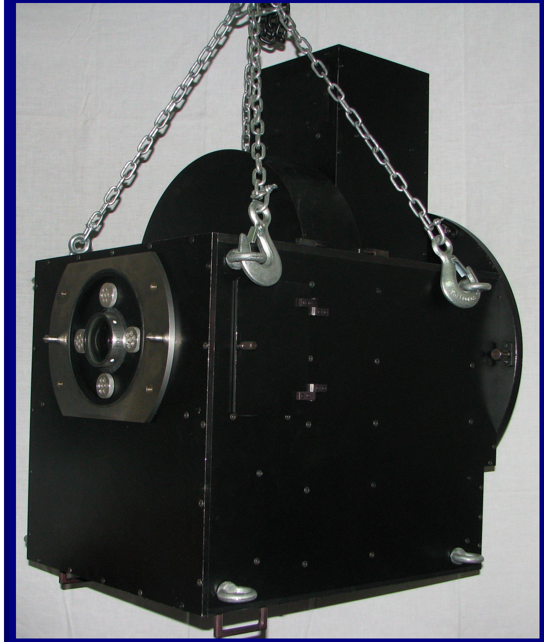
The idea - Georg Courtes (1982)
The first realization:
MPFS at the 6-m telescope
(Afanasiev et al., 1990, 2001).





Mrk 315 (Ciroi et al., 2005, MNRAS)

The first light (spectra/images/FPI): June, 2010



2011 - test observations, software, integral-field and multislit units
2012 - regular observations at the telescope

IC 1613
SCORPIO
Zeiss-1000