SCORPIO at the 6-m telescope: current state and perspectives for spectroscopy of galactic and extragalactic objects

Victor Afanasiev & Alexei Moiseev
Special Astrophysical Observatory RAS,
N. Arkhyz, Russia
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
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)](image1)

![AFOCS (Asiago 1.82m)](image2)
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.

The first light: September, 2000
### SCORPIO observing modes

#### 1. The main characteristics of SCORPIO

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total focal ratio</td>
<td>$F/2.6$</td>
</tr>
<tr>
<td>Field of view:</td>
<td></td>
</tr>
<tr>
<td>full</td>
<td>$6.1' \times 6.1'$</td>
</tr>
<tr>
<td>in multislit mode</td>
<td>$2.9' \times 5.9'$</td>
</tr>
<tr>
<td>Image scale</td>
<td>$0.18''/\text{px}$</td>
</tr>
<tr>
<td>Spectral range</td>
<td>$3600 - 10000\text{Å}$</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td></td>
</tr>
<tr>
<td>with grisms</td>
<td>$1.5 - 20\text{Å}$</td>
</tr>
<tr>
<td>(for slit width $1''$)</td>
<td></td>
</tr>
<tr>
<td>with Fabry-Perot interferometers</td>
<td>$0.8 - 2.5\text{Å}$</td>
</tr>
<tr>
<td>Maximal quantum efficiency</td>
<td></td>
</tr>
<tr>
<td>(telescope+SCORPIO+CCD)</td>
<td></td>
</tr>
<tr>
<td>Direct imaging</td>
<td>70%</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>40%</td>
</tr>
<tr>
<td>Observations with FPI</td>
<td>20%</td>
</tr>
</tbody>
</table>

---

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 radio sources

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

Very radio-loud galaxies/QSO at z=4-4.5
Need a SMBH with $M > 10^9$ Mo

Amirkhanian, Mikhailov (2006)
Parijskij et al (2010)
Faint objects spectroscopy (23–24 mag)

$R_c$ image $T_{exp} = 180 \text{ s}, seeing = 1.3''$

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

(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)
The Cosmic Horseshoe (CASSOWARY #1)

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

Kinematics of stars and gas in SO galaxies

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

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)
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.
Multi-slit data: globular clusters in dwarf galaxies

Spectra of objects
V = 18-21m

"Ages, metallicities and [alpha/Fe] ratios of globular clusters in NGC 147, 185 and 205"
New compact elliptical galaxies

cE or 'M32-like galaxies:'
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.'
Star formation in the Local Volume (d<10 Mpc)

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

\(0.019 \pm 0.003\) Mo/yr/Mpc³

(Karachentsev & Kaisin, 2010, AJ)

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

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.
Ionized gas outflow (superwind) in NGC 4460

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 $V \geq 130$ km/s, SFR~0.3 $M_\odot$/yr (Moiseev, Karachentsev & Kaisin, 2010, MNRAS)
SCORPIO with a scanning Fabry-Perot interferometer

3D data cubes
Western filament of nebula W50 related with SS433

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

Abolmasov et al (2009)
Jets and outflows from young stellar objects

PV Cep

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 star formation in the dwarf irregular galaxy IC 1613: a complex of expanding shells:

• re-estimation ages of the bubbles
• comparison with SF models

(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.

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

Shalyapina et al. (2004)

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

SDSS image

A giant \( (D=48 \text{ kpc}) \) stellar-gaseous disk inclined at
\( \Delta i=73\pm12^\circ \) 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.
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
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
Thank you for attention!