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Scanning Fabry-Perot interferometer in the extragalactic researches.

A.V. Moiseev and V.L Afanasiev

Special Astrophysical Observatory, Russian Academy of Sciences, 369167 Russia e-mail: moisav@sao.ru

Abstract. The scanning Fabry-Perot interferometer (IFP) is a powerful tool for investigation of kinematics of extended objects by the method of panoramic spectroscopy. In this review the opportunities of the IFP are illustrated on the observations recently obtained on the 6-m Russian telescope. We show some results concerning objects with complex ionized gas kinematics like an AGN, barred and spiral galaxies, polar-ring objects.

Key words. Instrumentation: panoramic spectroscopy – Galaxies: kinematics

1. Introduction: historical review

More then one century ago Fabry & Perot (1901) described "a new form of interferometer". Then Buisson et al. (1914) used FP etalon in their studding of Dopler velocities in the Orion nebulae from direct measurements of radii of interference rings on a photographic plates. Unfortunately, in following years this application was forgotten (first of all because technical reasons) and only on 1950-60 George Courtés revived this technique for observations of galactic HII-regions. For observations of galaxies, such a technique was first applied by Tully (1974) in studying the motions of ionized gas in M51. He constructed the first spectrophotometric data-cube. In this cube, X and Y ("spatial coordinates") correspond to the coordinates in the sky plane, while the wavelengths is a third "spectral coordinate". In the following two decades the systems with the scanning IFP were employed in observations at many large telescopes: the system TAURUS Atherton & Reay (1981), CIGALE Boulesteix et al. (1982), HIFI (Tully 1995) etc.

Now the scanning IFP is a highly efficient device for investigation of kinematics of extended objects. The data cube is generated by taking series of images of interference rings through IFP accompanied by gap changing between the parallel plates. There major advantages are a large field-of-view (typically $5-10''$) accompanied, high spectral resolution and large throughput. Today several scientific team present works based on IFP: in France (GASP project, first of all), in Mexico, and in Spain. Here we proved a short review of the results obtained recently with our F-P system on the 6-m Russian telescope.

2. IFP at the 6-m telescope.

The study of two-dimensional kinematics of galaxies at the 6-m telescope of SAO RAS with the scanning IFP was started by our colleagues from Marseille Observatoire in cooperation with SAO team in the first half of 1980s

Send offprint requests to: A. Moiseev

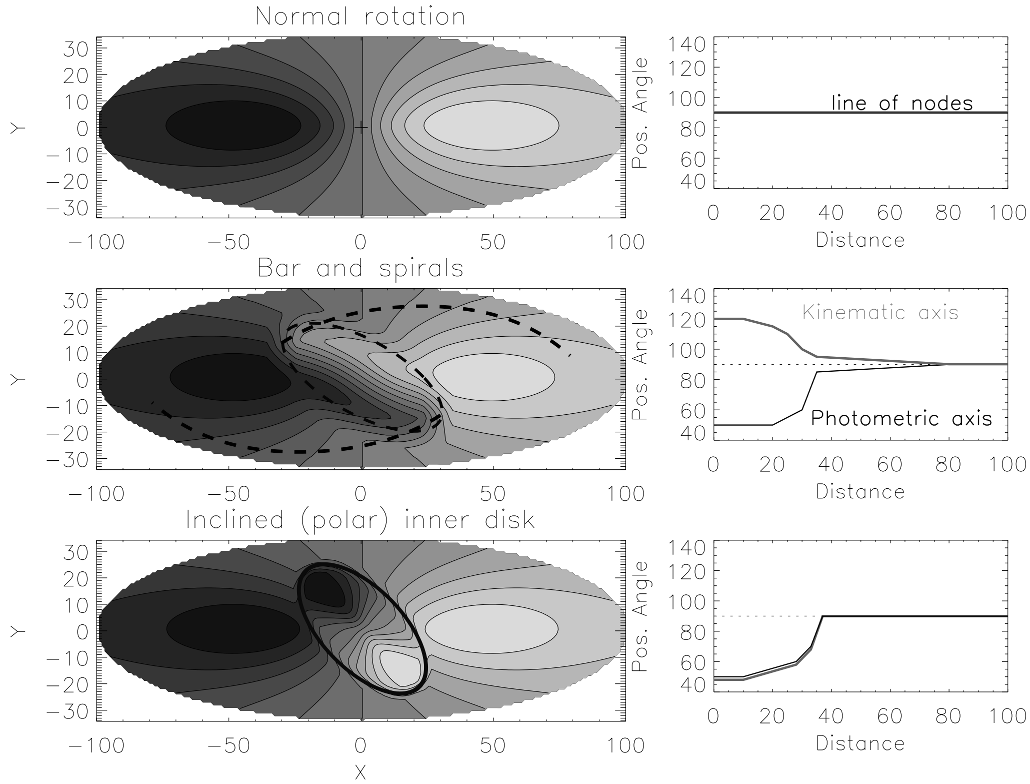

Fig. 1. The examples of model of line-of-sight velocity fields of rotated inclined galactic disk: purely circular rotation (top), bar with spirals (middle), inner polar disk (bottom). The mutual behaviour of the photometric and the kinematic axes is shown on the right panels.

Boulesteix et al. (1982). The observations were made with the system CIGALE (a focal reducer with IFP and photon counter IPCS as a detector). Then the IPCS was replaced by a CCD and in 2000 the first observations with a new multimode focal reducer SCORPIO Afanasiev & Moiseev (2005) are carried out. Today SCORPIO+IFP provides $6' \times 6'$ field of view with spectral resolution $1-2.5$Å in the H_α, [NII], [SII] and [OIII] emission lines. So, using data cubes we can create monochromatic images as well as fields of line-of-sight velocities in these lines.

3. Ionized gas kinematics in galaxies

Velocity fields contain a new additional information (comparing with long-slit data) about non-circular motions in a galactic disk. Indeed, in the case of purely circular rotation the observable velocities are fully determined only by a rotation curve; the position angle of the line of largest velocity gradient (PA_{kin}, "kinematic" axis) will be coincide with orientation of the major-axis of elliptical isophotes ("photometric axis"). The PA_{kin} deviation from the line-of-nodes of the whole disk is used to characterize the type of non-circular motions (oval distortion, polar disk). A general approach is quite simple (fFig 1).

Both the models of gas dynamics in a barred potential and the observations of barred galaxies show that isovelocity contours in the vicinity of a bar tend to turn along the major bar axis (because significant radial motions, see Moiseev et al. (2004) and references therein). Hence, photometric and kinematic obtained position angles of the major

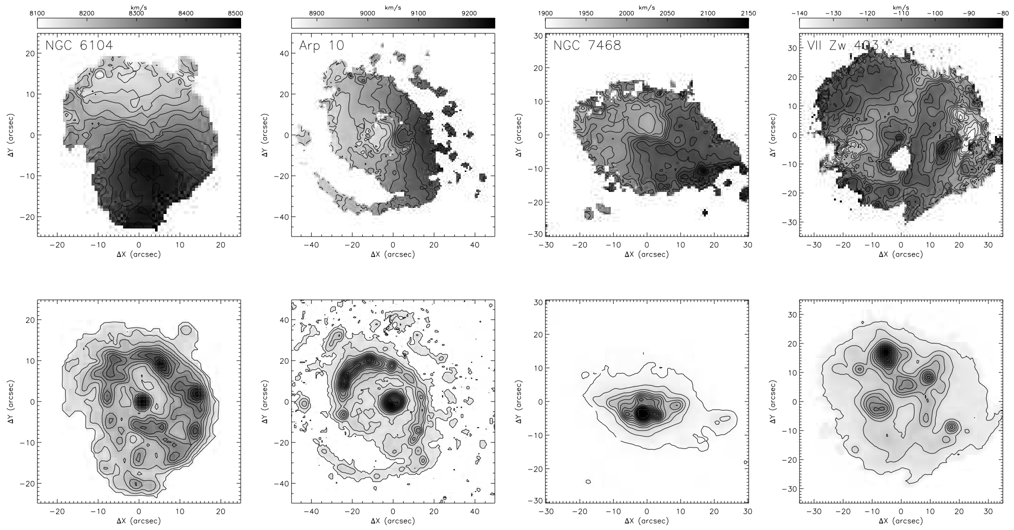

Fig. 2. SCORPIO-IFP velocity fields of ionizing gas (top) and H_α images (bottom) for different galaxies: Sy galaxy NGC 6104 with strong radial motions along bar Smirova et al. (2005); collisional expanding ring in Arp 10; inner polar ring in NGC 7468; dwarf starforming galaxy VIIZw403 (Lozinskaya et al. 2005).

axes change in a different way, turning in the opposite directions. In the second case of a circular rotation in a warped (polar, inclined) inner disk, the kinematic axis must follow the photometric one (see Fig. 1, bottom).

3.1. Barred and spiral galaxies

Using this formalism we can detected a non-axisymmetrical structures nested in the circumnuclear regions and masked by a complex spatial distribution of dust and starforming regions. The spectacular example is a "dusty" NGC 972 where we have found bar-like kinematics Fridman et al. (2005), but bar are absent on optical images. However, near-infrared images reveal a prominent two-armed spiral pattern and a small bar.

We have observed a sample of candidate double-barred galaxies and suggest that these objects are, in fact, galaxies with very different circumnuclear structure (Moiseev et al. 2004). The majority of the observed morphological and kinematic features in the sample may be explained without the secondary bar hypothesis. Three cases of inner polar disks, one counter-rotating gaseous disk and seven nuclear disks nested in large-scale bars were found in this work.

For velocity fields of spiral galaxies a method of Fourer-series expansion of the azimuthal distributions of the line-of-sight velocities at different distances from the galactic center can be formulated (Lyakhovich et al. 1997). As it may be shown, all three components of the real spatial velocities connect with some combinations of harmonics, if a theory of spiral structure will be taken into account. Using this method a true picture of gas motions in spiral arms could be restored Fridman et al. (2001).

3.2. Collisional rings

Collisional ring galaxies represent a class of objects in which nearly symmetrical density waves are driven into a disk as a result of an almost face-on collision with another galaxy. We have observed a pecular galaxy Arp 10, which has two rings (the inner and outer one), and extended outer arc. The ionized gas velocity field constructed with IFP shows evidence for significant radial motions in both outer and inner galactic rings. We fit a model velocity field taking into account the regular rotation and projection effects. The expansion velocity of the NW part of the outer ring exceeds 100 $\mathrm{km\,s^{-1}}$, whereas it attain only 30 $\mathrm{km\,s^{-1}}$ at the SE part Moiseev et al. (2005). Therefore, the asymmetric shape of the outer ring (fig. 2) may be caused by a systematic difference in the ring expansion velocity and collisional origin of the rings is a proven fact.

3.3. Polar rings

Recently the team in St.Petersburg university (Hagen-Thorn, Shalyapina et al.) attempt to observe with IFP a gas kinematics in candidate polar-ring galaxies. The interesting results were already obtained. For example, they detected an inner gaseous disk whose rotation plane is almost perpendicular to the plane of the "main" galactic disk in dwarf galaxy NGC 7648 Shalyapina et al. (2004). The Fig. 2 shows the sharp turn of isovelocities in the circumnuclear region of the galaxy. The central collision of NGC 7468 with a gas-rich dwarf galaxy and their subsequent merging seem to be responsible for the formation of the disk.

3.4. Seyfert galaxies

The numerous emission line images of Seyfert galaxies show a existence of a cone-like narrow-line regions (NLR). Also these galaxies has high-collimated elongated radio structures coinciding with the cones axis . A ordered Z-shaped emission pattern is a frequently features in the NLRs. A sample of galaxies with Z-shaped NLRs were observed at the 6m telescope (Moiseev et al. 2002). Based on this data we have developed (in colloboration with team from Volgograd State University) a nonlinear model of the Z-shaped filaments formation. We suggest that these structures in NLRs have a wave origin and generated by the hydrodynamic instability on the velocity break between a galactic instellar medium and a outflowing gas from the AGN Afanasiev et al. (2005).

3.5. Violent starformation

A burst of starformation also produces noncircular gas motions triggered by the combined effect of stellar winds and supernova explosions in rich stellar groupings. In dwarf galaxies the formation of giant multi-shell complexes around stellar groupings can proceed unhindered. See, for example, IFP-observations of the nearby irregular galaxy IC1613 Lozinskaya et al. (2003): the authors refined the expansion velocities of individual shell of the ionized and neutral gas. In such galaxies the main part of line-of-sight velocities connect with HII regions expansion, frequently without any rotation (see blue compact dwarf galaxy VIIZw403 on fig. 2)

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