The central kiloparsec of Seyfert galaxies: Integral-field spectroscopy with OASIS

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Narrow-line regions of Seyfert galaxies

In the classical paradigm of active galactic nuclei (AGN), the narrow-line regions (NLRs) of Seyfert galaxies consist of gas ionised by the AGN, which extends beyond the nuclear torus and reaches to kiloparsec distances (Fig. 1). These scales make the NLRs suitable for spatially resolved observations of the interplay between the AGN and their host galaxies, such as the transport of gas toward the galactic nucleus, the role of gravitational instabilities, the feedback of the nucleus including outflows, and the origin of gas in the central regions of active galaxies.

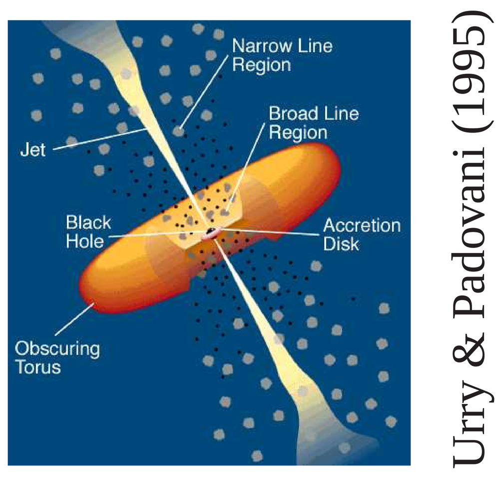

Fig. 1. Unified model of AGN. The size of the nuclear torus is on the scale of ~pc. The NLRs extend to ~ $10^2 - 10^3$ pc.

Observations and data analysis

We observed a sample of 16 nearby ($0.002 < z < 0.05$, i.e. $16 - 220$ Mpc) Seyfert galaxies with the use of the optical integral-field unit OASIS mounted at CFHT. We covered the central few kiloparsecs with the spatial sampling of $0.27'' - 0.41''$ and the spectral sampling ~ 1.9 Å. The observed spectral range contains Hα, Hβ, and the forbidden doublets of [N I], [N II], [S II], [O I], and [O III]. We derived fully 2D maps of physical quantities characterising the ionised gas, such as surface brightness, mean LOS velocities, LOS velocity dispersion, electron density, and interstellar reddening. We plot spatially resolved spectral diagnostic diagrams, which reflect the ionisation level, metallicity, temperature and density of the NLR gas. We performed stellar-population modelling with the use of the synthetic evolutionary library of Bruzual & Charlot (2003), and derived stellar velocities and the stellar-population ages. For details see Stoklasová et al. (2009).

Stellar populations

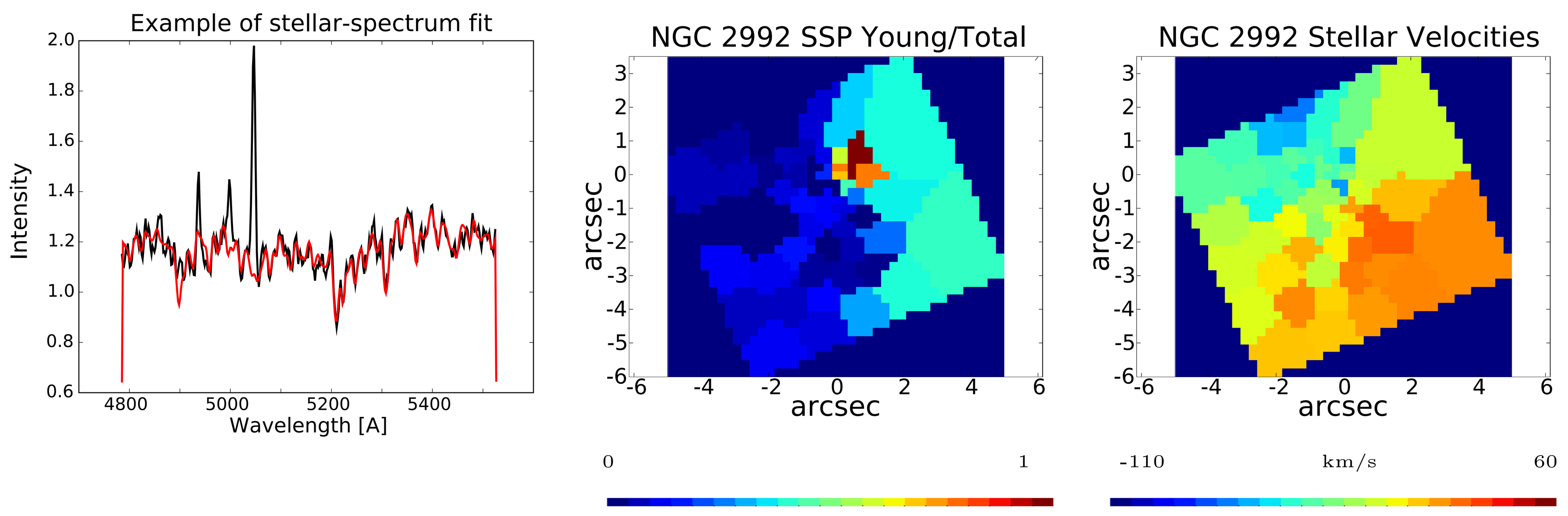

Fig. 2. Stellar-population modelling. Left: example of a stellar-population fit (red) to data (black). Middle: mass fractions of young (100 Myr) stellar populations in NGC 2992. Right: stellar velocities in NGC 2992.

S-shaped velocity fields of ionised gas

Most of the observed mean LOS velocity fields reveal departures from circular motions. 80% of the Seyfert 2 sample exhibit twisted (S-shaped) isocontours of mean LOS velocities of gas (Fig. 3), which do not have counterparts in the stellar velocities that we measure. In general, these are signatures of motion in a non-axisymmetric potential (spiral, bar, warp), or outflows from the galactic nucleus.

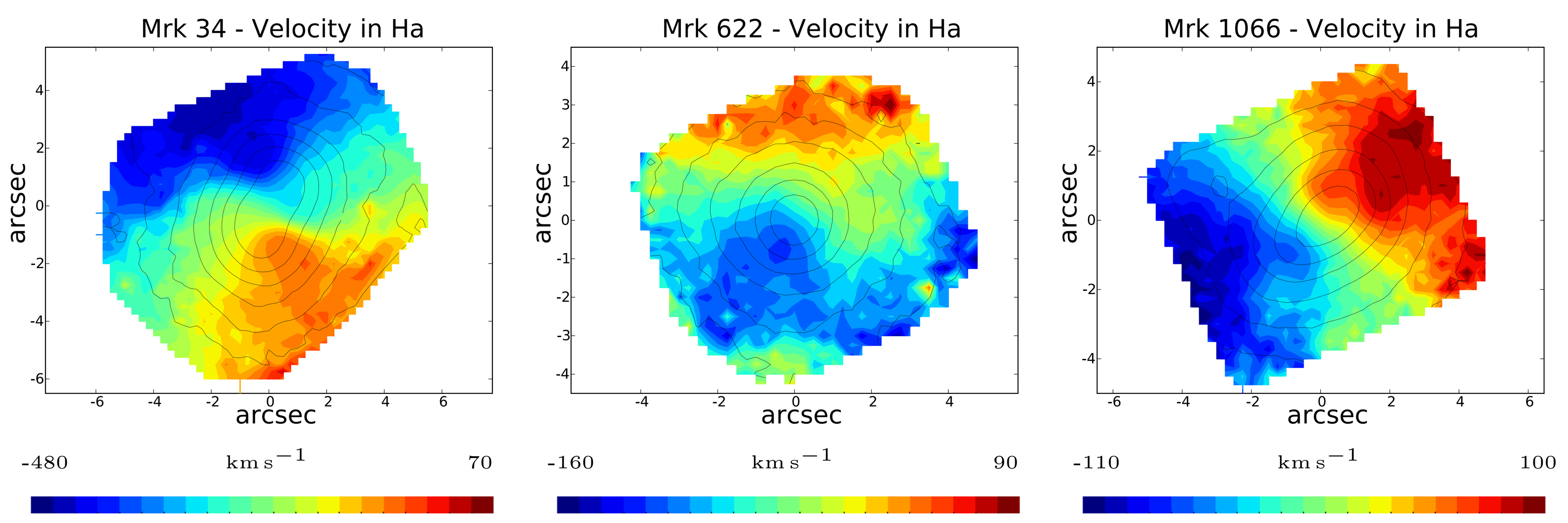

Fig. 3. S-shaped isocontours of mean LOS velocities. North is up, east to the left. The black contours represent surface brightness isocontours.

Outflow in NGC 4051

NGC 4051 has been suspected to have an outflow in [O III] lines. We trace its 2D properties with spatial resolution of 50 pc (Fig. 4), in surface brightness and in kinematics. The outflow reaches projected velocities of $\sim 550\ \mathrm{km\,s^{-1}}$ and is approximately parallel to the radio jet. It is not present in low-ionisation lines. Infrared data for NGC 4051 were interpreted as an inflow by Riffel et al. (2008), and therefore detailed modelling is necessary.

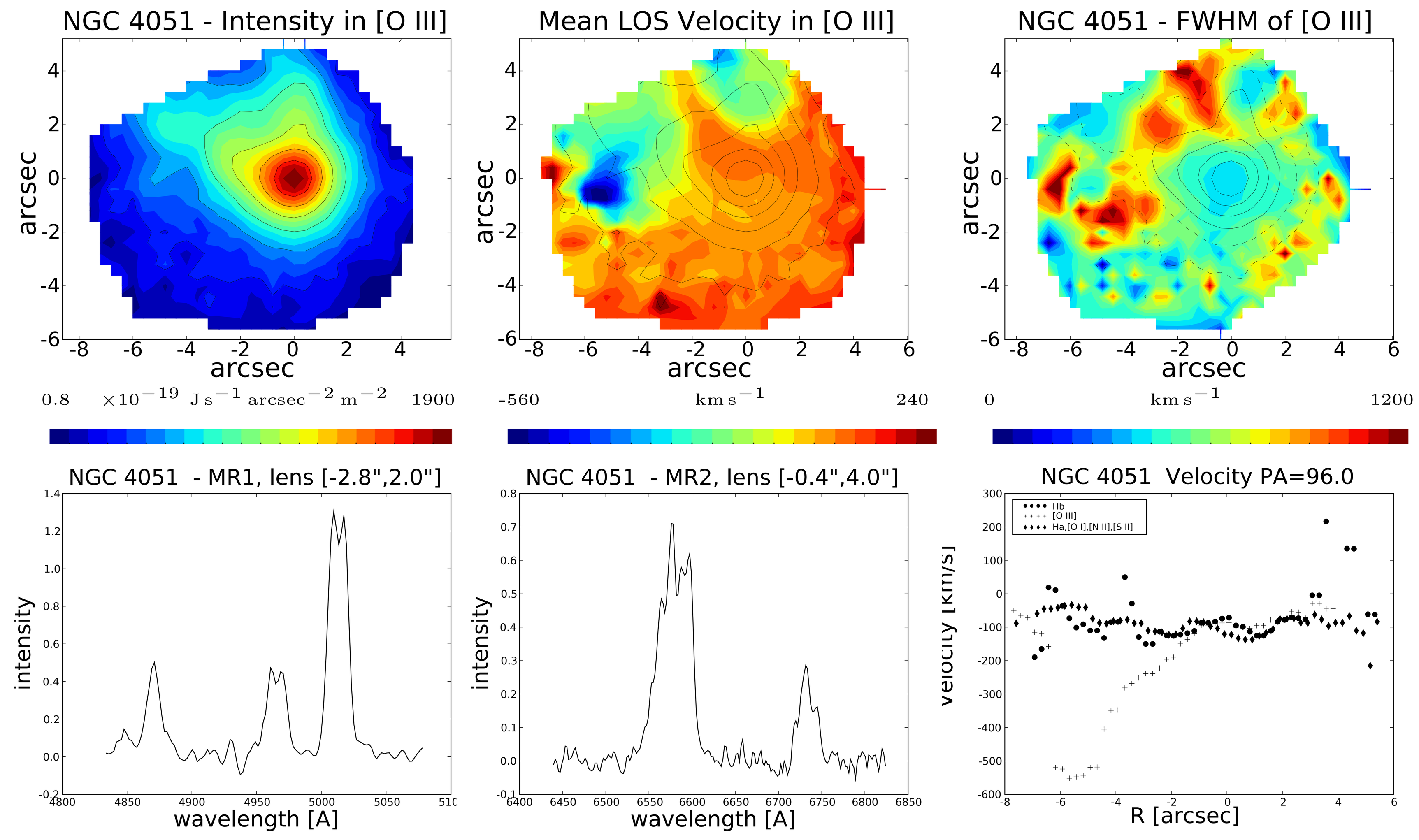

Fig. 4. NGC 4051. Outflow in NGC 4051 – maps of surface brightness and the kinematical fields in [O III]. Examples of multi-component profiles of emission lines. Comparison of a velocity profile in [O III] and in low-ionisation lines.

Rings

Rings usually provide evidence of non-axisymmetric gravitational potentials. We detect part of a ring in NGC 5728 which is present only in low-ionisation lines and not in [O III] and is characterised by high reddening (Fig. 5).

We have discovered a ring in Mrk 348 (previously unknown), based on kinematical study (Fig. 5). The two spots in the velocity map have no counterparts in the surface brightness (black contours). The galaxy disc is almost face-on, therefore we interpret the velocity pattern as a ring tilted out of the galactic plane.

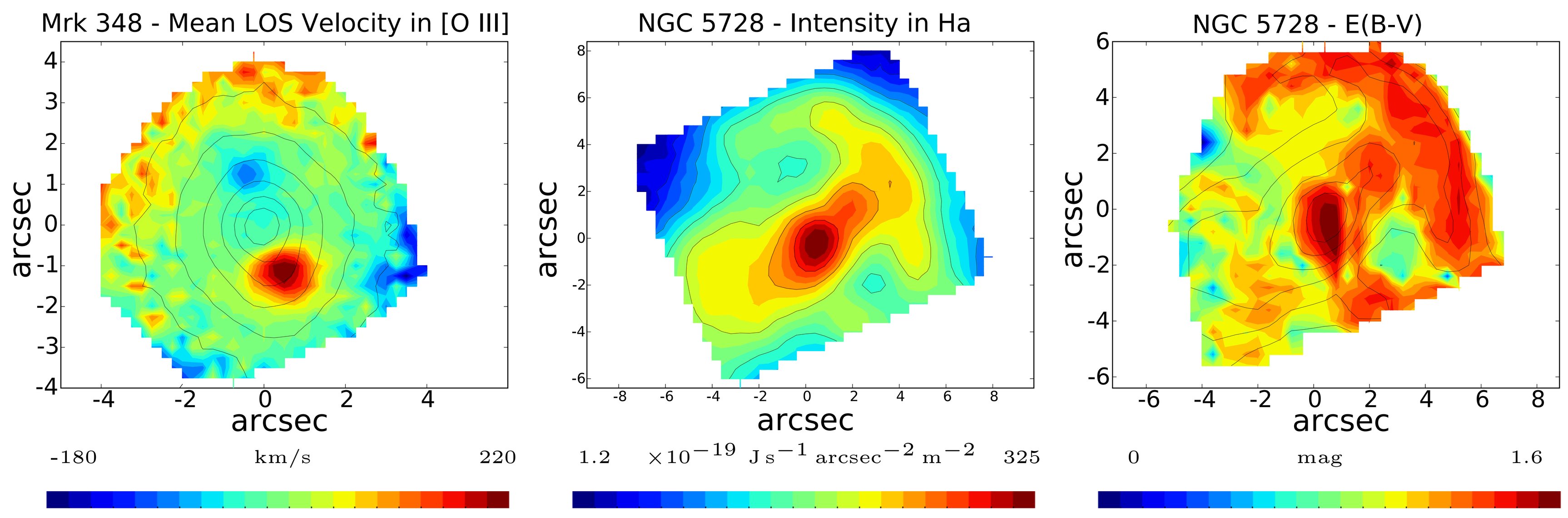

Fig. 5. Rings in Mrk 348 (mean LOS velocity map) and NGC 5728 (surface brightness and interstellar reddening maps).

Discussion

We develop models to interpret the observed non-circular velocity fields and to discriminate between gravitational and non-gravitational effects. The presence of S-shaped isovelocity contours in a majority of our sample may indicate the necessity of non-axisymmetric gravitational potentials for the transport of gas to the galactic centre and for the fuelling of the AGN. A comparison of active and quiescent spiral galaxies performed by Dumas et al. (2007) suggests that the S-shapes are more common in galaxies hosting an active nucleus. However, larger samples of data are needed to test this hypothesis. At the same time, detailed modelling of the kinematics is necessary to understand the true 3D nature of the observed features. We are testing models and studying the degeneracy of the interpretation, with the use of the wealth of information contained in the datacubes, including "tomography" in the velocity space, i.e. velocity channel maps. In case that the S-shapes are not of gravitational nature and are a result of outflows from the AGN, our data will contribute to the development of the AGN paradigm.

References

Bruzual, G. & Charlot, S. 2003, MNRAS, 344, 1000
Dumas, G. et al. 2007, MNRAS, 379, 1249
Riffel, R. A. et al. 2008, MNRAS, 385, 1129
Stoklasová, I. et al. 2009, A&A in press
Urry, C. M. & Padovani, P. 1995, PASP, 107, 803

Acknowledgements. The work has been supported by the Centre for Theoretical Astrophysics (LC06014) of the Ministry of Education of the Czech Republic, by the Institutional Research Plan No. AV0Z10030501 of the Academy of Sciences of the Czech Republic, by the grant No. 205/03/H144/2003/02 of the Czech Science Foundation and by a PhD fellowship provided by the French government for I.S.

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