Outer Starforming Rings in S0 – Growth by Accretion

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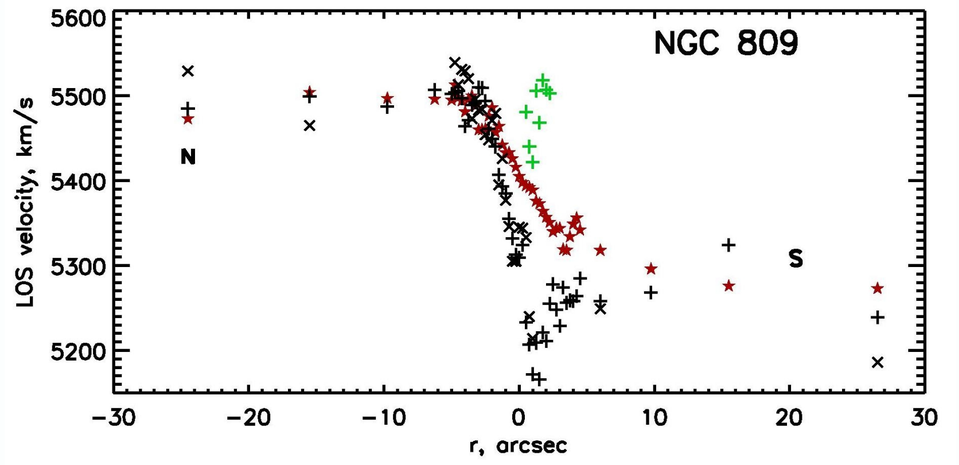
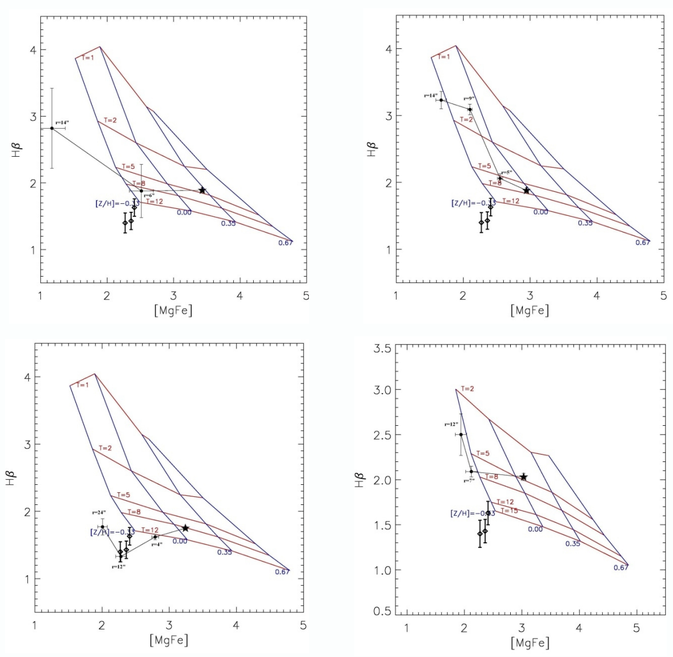
For a sample of the outer starforming rings in unbarred S0 galaxies we have obtained deep long-slit spectra at the 11m SALT telescope and have proved the gas excitation by young stars in the rings. We have measured stellar population properties - ages and metallicities - in the outer stellar disks and have estimated the ionized-gas metallicities in the outer rings by the strong-line method. While the outer stellar disks of the galaxies under consideration have appeared to be very metal-poor, the gas in the rings reveals solar metallicity. We suggest the origin of the starforming rings in the outer disks of nearby S0-galaxies by accretion of gas-rich satellites, rather massive with respect to their host galaxies.

An unique example of the galaxy with shock-like gas excitation in the ring: the two-peak profiles of the [NII] emission line give evidence for a hidden bar presence



Galaxy	Distance from center of the galaxy r, arcsec	Stellar metallicity, [Z/H]	Gaseous metallicity (related to solar value), 12+log(O/H)-8,66
PGC 48114	+11…+15,5	~ -1,35	+0,05±0,01
NGC 2697	-15…-10,5	~ -0,33	-0,03±0,01
	-10…-8	-0,33…0	0±0,01
	+7,5…10,5	-0,33…0	-0,01±0,01
	+11…+14	< -0,33	+0,02±0,01
	+14,5…+16,5	~ -0,33	-0,05±0,01
	+19…+22	< -0,33	-0,01±0,01
	+22,5…+27	-	-0,03±0,01
	+43,5…+48	-	-0,03±0,01
NGC 7808	-9,5…-14,5	< -0,33	+0,05±0,01
	-7…-9	< -0,33	+0,07±0,01
	+7,5…+9,5	< -0,33	+0,06±0,01
	+10…+15	~ -0,20	+0,04±0,01
NGC 4324	+93,5…+94	-	-0,08±0,01
	-24,5…-22,5	< -0,33	+0,03±0,01
	-67,5	< -0,33	+0,03±0,01

Ages and metallicitites of the stellar populations



RESULTS

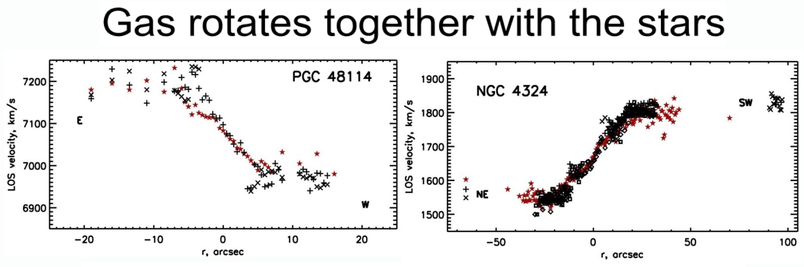
By using the long-slit spectra obtained, we have calculated Lick indices H-beta, Mgb, Fe5270, and Fe5335 along the radius for every galaxy, as well as the equivalent widths of the emission lines, mainly H-alpha and [NII]6583. For the latter task the Gauss-analysis of the four-line blends ([NII]6548+H-alpha emission+H-alpha absorption+[NII]6583) was applied. By tracing the emission-line ratio of [NII]/H-alpha, we have identified the regions where the ionized gas is excited by yound stars: the BPT criterium of [NII]/H-alpha<0.5 was used. In NGC 809 the emission lines detected along the radius have appeared to be excited by shock waves everywhere, and some signs of the nuclear bar are seen. In other four galaxies we have found the radially limited zones of the emission-line gas excited by young stars - these regions have appeared to be rings with the current star formation. We have measured the oxygen abundances in these regions by involving the method of strong lines and by using in particular the formula connecting the metallicity and the ratio of [NII]/H-alpha from Pettini and Pagel (2004). The metallicity of starforming gas in the rings has appeared to be nearly solar in all cases. The Lick index H-beta has been corrected for the emission-line contamination: in the rings we applied the well-modelled Balmer decrement H-alpha/H-beta=2.8 to calculated the equivalent width of the H-beta emission line which is exactly the correction to be added to the measured Lick index H-beta. After that we have confronted the measured Lick indices to the SSP models by Thomas et al. (2003) and have determined the mean ages and metallicities of the stellar populations along the radii – in the Figure above our measurements are compared to the Thomas' et al. models and to the data for the bulge globular clusters of our Galaxy (diamonds). While the mean ages of the stellar populations in the ring areas range between 2 and 12 Gyr, the mean stellar metallicities are everywhere strongly subsolar, [Z/H]<-0.3.

INTRODUCTION

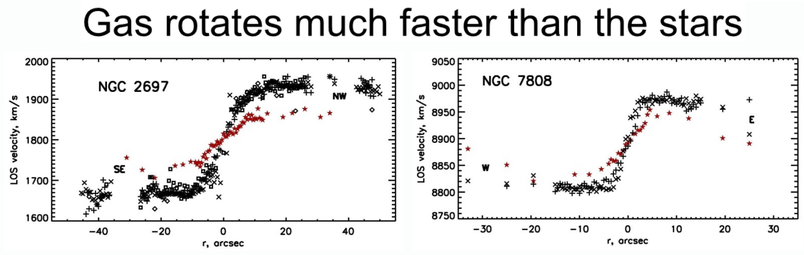
Lenticular galaxies are disc galaxies which differ from spirals by smooth appearance of their reddish large-scale stellar discs and by visible absence of spiral-like starforming sites. As a class, they belong to the red sequence and are usually characterized as `quiescent' galaxies. However, despite the absence of visible star formation, the discs of S0s contain often noticeable amounts of cold gas. Frequent decoupling between the gas and stellar kinematics in the S0 discs provoked a suggestion that the cold gas in S0s was mostly accreted from outside, and perhaps the conditions of such accretion - off-plane direction of infall and/or transmittent regime of inflow - were often unfavourable for star formation ignition. However, when ultraviolet space telescope GALEX had surveyed a large sample of nearby galaxies with a spatial resolution of a few arcsec, numerous UV-rings were found in optically red, `quiescent' lenticular galaxies (Gil de Paz et al. 2007). In general, outer stellar rings can be often met in S0 galaxies. According to the statistics of the recent catalogue of stellar rings ARRAKIS (Comeron et al. 2014) based on the data of the NIR survey of nearby galaxies S4G (Sheth et al. 2010), the occurence of outer stellar rings is maximal just among lenticular galaxies: up to 60% of S0 galaxies have outer stellar rings. Interestingly, while the fraction of outer rings rises toward the morphological type of S0, the fraction of strong bars diminishes (Buta et al. 2010). This fact puts into doubt a hypothesis that all the rings in disc galaxies have the resonance nature and consist of stars born after assembling the own gas of the galactic discs at certain resonance radii - at least as it concerns the rings in lenticular galaxies. The aim of our study of the outer rings in S0s is to look for the gas in these rings, to see if it is excited by young stars, and to suggest anything about the origin of the rings basing on the gas properties.

In this work we study spectrally a small sample of five lenticular galaxies where the outer UV-bright rings are present. In NGC 809 and NGC 7808 the presence of the ultraviolet rings was reported by the GALEX team (Gil de Paz et al. 2007); for NGC 4324 a nice picture of the UV-ring is presented by Cortese and Hughes (2009). The distant S0 galaxy PGC 48114 was noted as a ring galaxy by Kostyuk (1975), and our inspection of the corresponding GALEX image has confirmed the presence of extended ring-like UV-signal in this object. Finally, NGC 2697 has been found by us occidentally and is confirmed to have a ring morphology in the GALEX maps by visual inspection. All the galaxies are unbarred S0s so we suppose that their rings have been formed as a result of outer cold-gas accretion with the subsequent star formation.

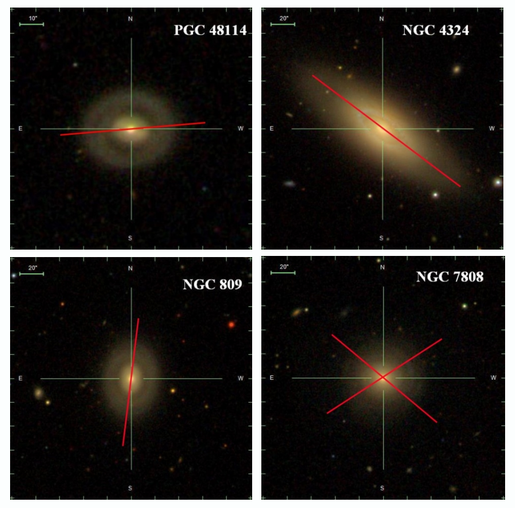
Gas rotates together with the stars



Gas rotates much faster than the stars



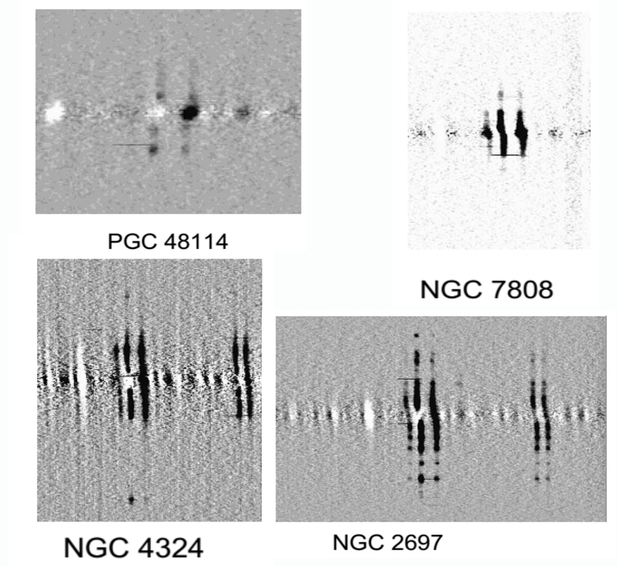
Starforming rings in S0 galaxies



SPECTRAL OBSERVATIONS

The long-slit spectroscopy has been made with the Robert Stobie Spectrograph (RSS) at the Southern African Large Telescope (SALT) by establishing a 1.25 arcsec slit width. The slit was aligned along the major axis for every galaxy except NGC 7808 which looks face-on, for which two slit orientations were probed. The slit positions are shown in the Figure above, overposed onto the SDSS images of the galaxies. The volume-phase grating PG0900 was used for our program to cover the spectral range of 3760-6860 AA with a final reciprocal dispersion of about 0.97 A per pixel and FWHM spectral resolution of 5.5 A. The seeing during observations was in the range of 1.5-3.0 arcsec. The RSS effective field of view is 8 arcmin along the slit. We used a binning factor of 2 or 4 to give final spatial sampling of 0.25 arcsec per pixel and 0.51 arcsec per pixel respectively. The spectrum of an Ar comparison arc was obtained to calibrate the wavelength scale every night after each galaxy observation as well as spectral flats were observed regularly to correct for pixel-to-pixel variations. Spectrophotometric standard stars were observed during twilights for the relative flux calibration. Primary data reduction was done with the SALT science pipeline. After that, the bias and gain corrected long-slit data were put onto a wavelength scale. The accuracy of the spectral linearization was checked using the sky lines; the rms scatter of the sky [OI]-line wavelength measurements along the slit is 0.04 A. Since the diameters of the galaxies under consideration do not exceed 3 arcmin, the sky spectra from the slit edges were used to estimate the background during the galaxy exposures and to subtract it.

Starforming rings in S0 galaxies



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