

Kinematics and ionization properties of gas outflows in nearby galaxies viewed with Fabry-Perot interferometry.

Alexei Moiseev^(1,2), Dmitry Oparin⁽¹⁾, Aleksander Perepelitsin⁽¹⁾ & William C. Keel⁽³⁾

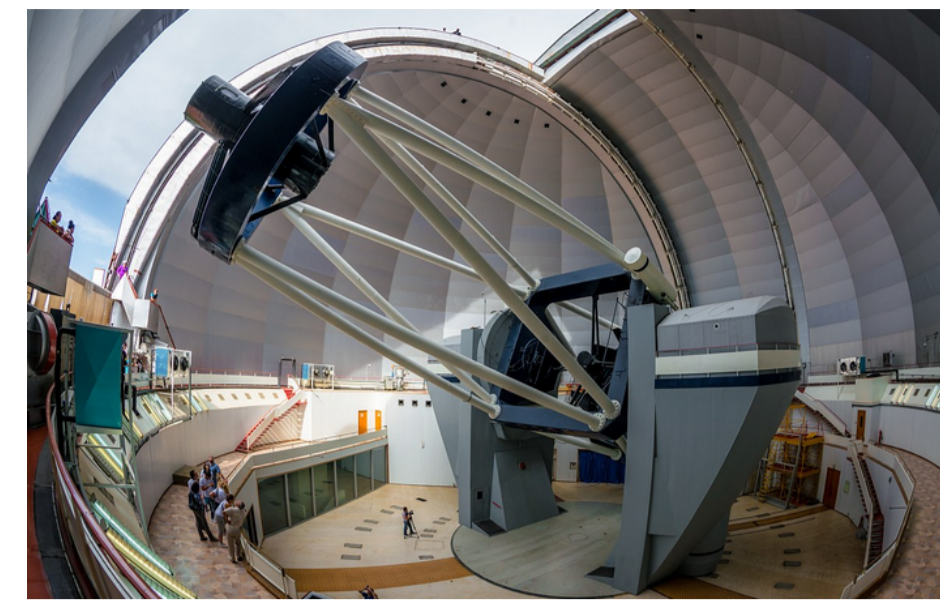
(1) Special Astrophysical Observatory, Russian Academy of Sciences, Nizhnij Arkhyz, Russia

(2) Sternberg Astronomical Institute of Lomonosov Moscow State University, Moscow, Russia

(3) Department of Physics and Astronomy, University of Alabama, Box 870324, Tuscaloosa, AL 35487, USA

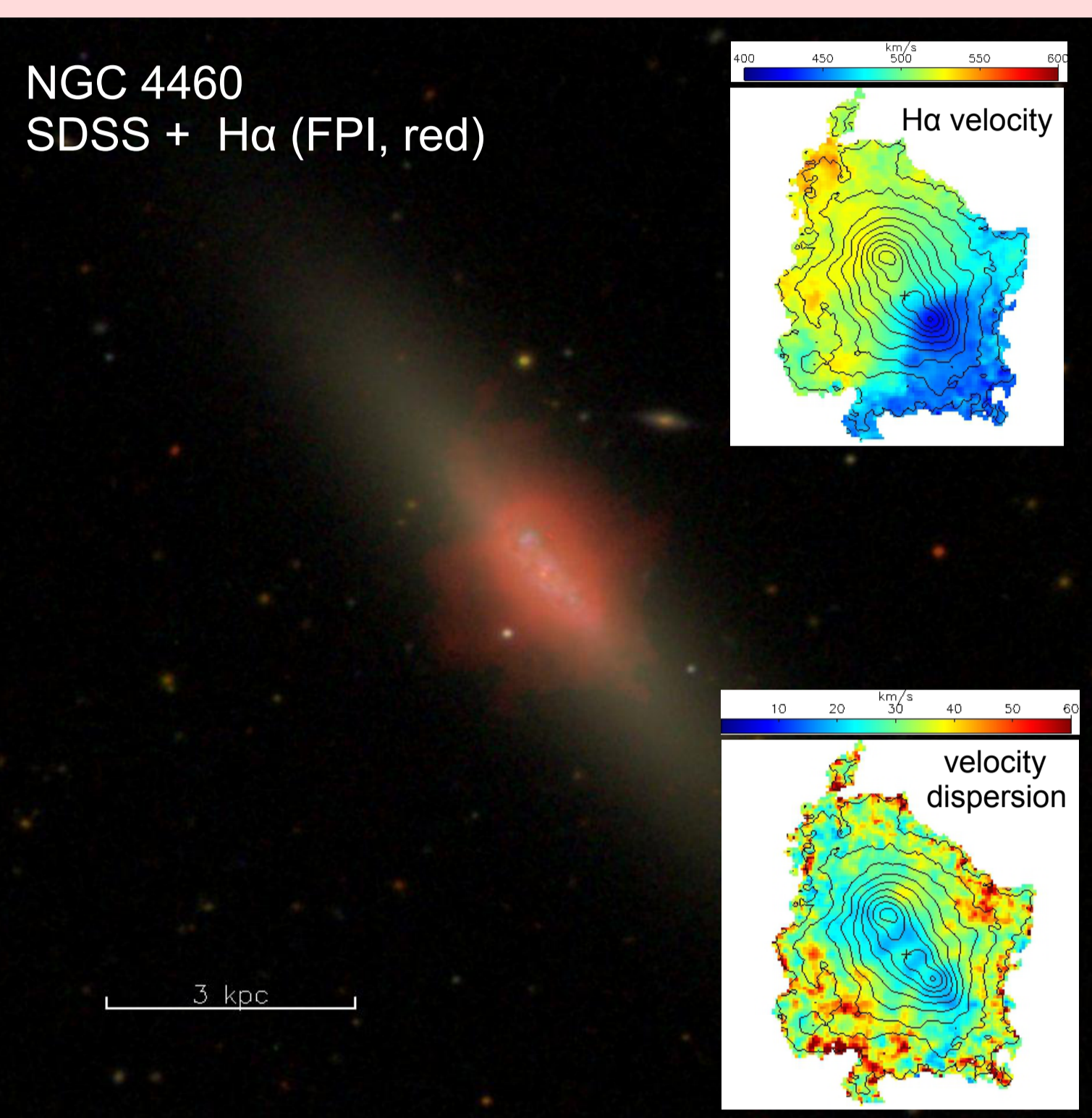


Even in the era of modern integral-field spectrographs, the Fabry-Perot interferometer (FPI) still provides a unique combination of a large field of view, high spectral resolution, and detailed image sampling that are important to study the ionized ISM among nearby star-forming galaxies and AGNs. We present some recent results (published as well under the current analysis) taken with high- and low- resolution FPIs at the 6-m telescope Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) and at the new 2.5-m telescope of the Caucasus Observatory of the Sternberg Astronomical Institute of Lomonosov Moscow State University (SAI MSU).



FPI at the SAO RAS 6-m telescope

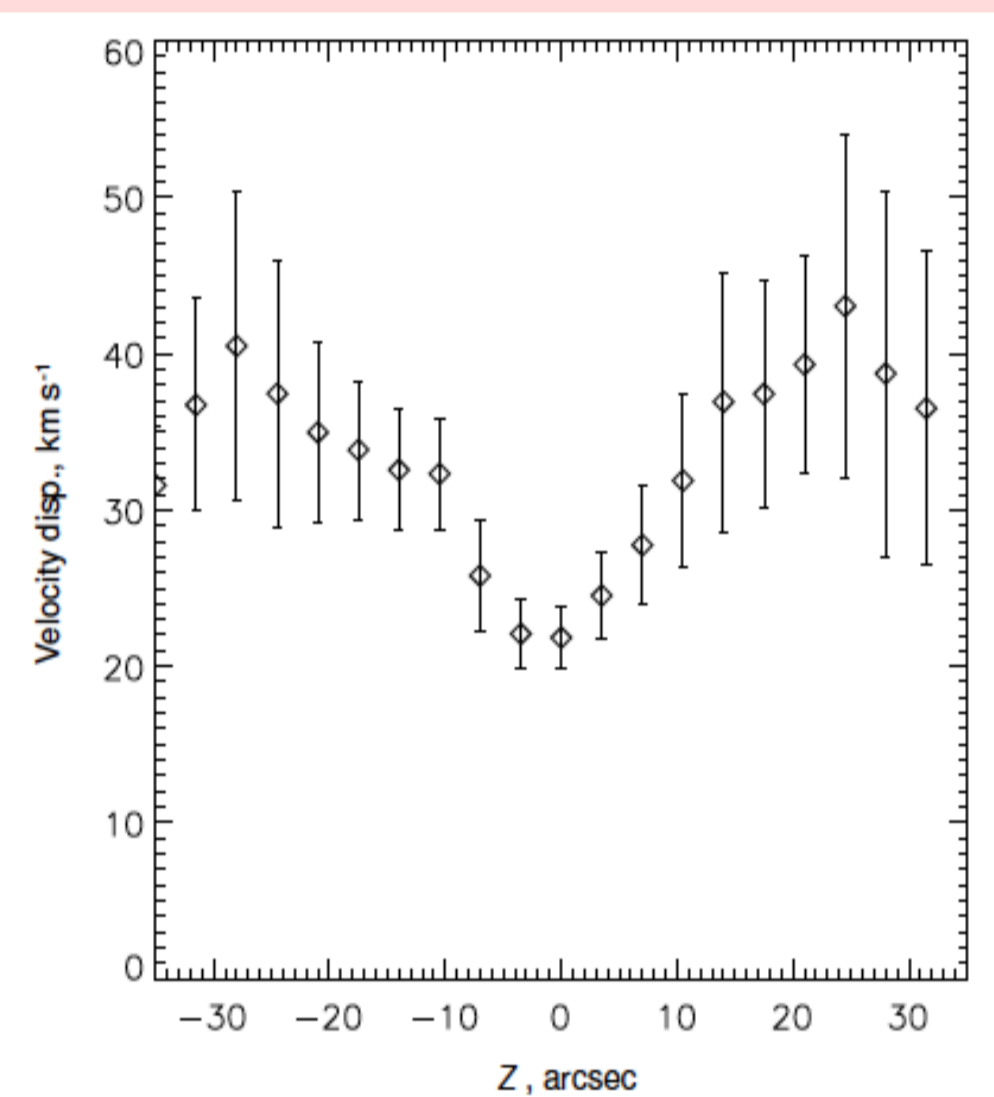
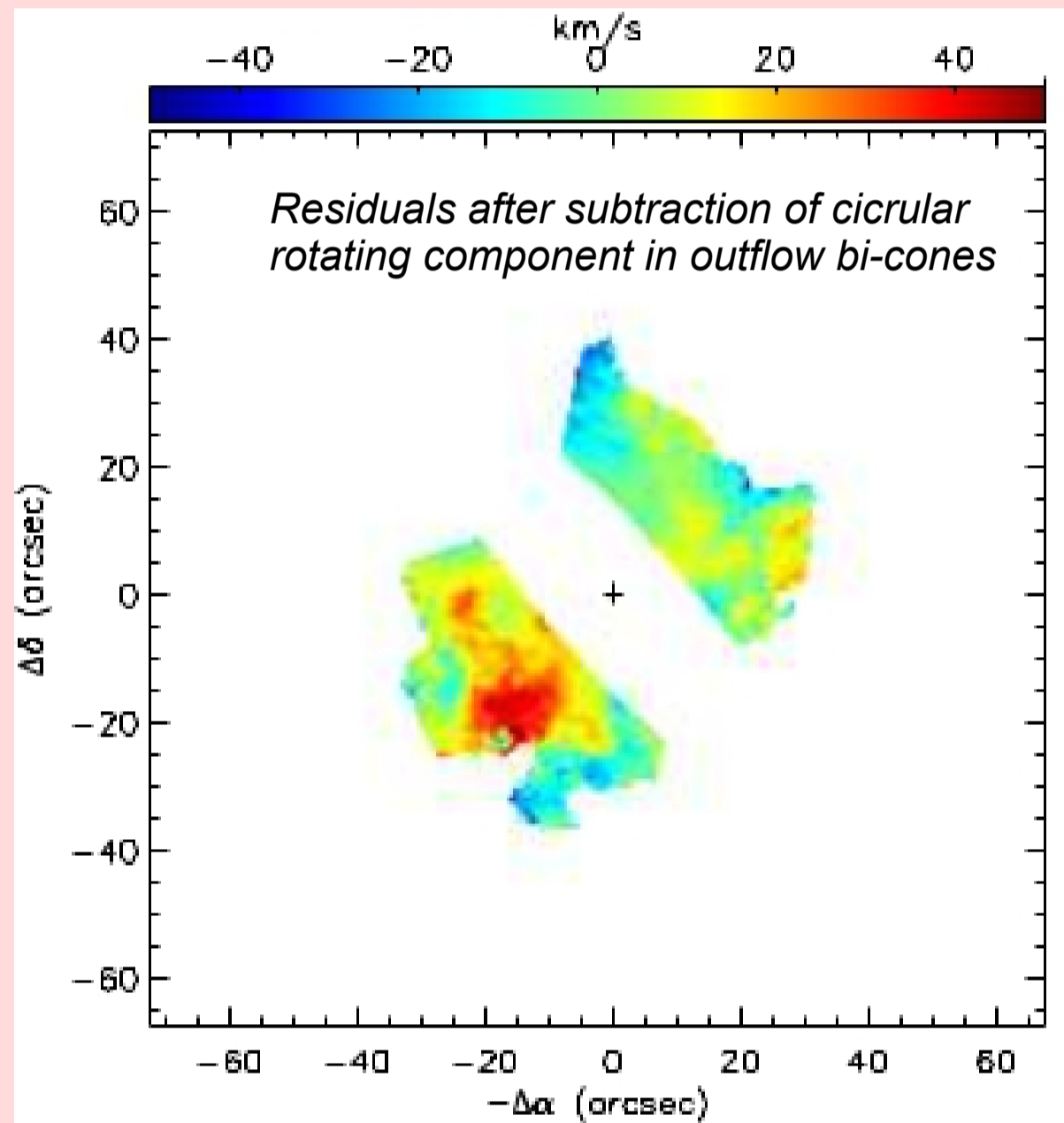
The SCORPIO-2 prime focus reducer (Afanasev & Moiseev, 2011) is equipped with FPIs providing the spectral resolution $\delta\lambda=0.4-2\text{\AA}$ ($\sigma=8-50$ km/s) for observations of the ionized gas in nearby galaxies in the H α , [OIII], [NII] and [SII] emission lines with 6 arcmin field of view (Moiseev, 2015).



Galactic-scale outflow in the lenticular galaxy NGC 4460

- Burst of starformation in the central kiloparsec with SFR=0.3 Mo/yr
- We constructed a geometrical model of the outflow, the NW cone is closer to us.
- The galactic wind parameters derived from FPI observations:
 - the outflow velocities: $V_{\text{out}}=30-80$ km/s
 - the mass of the ejected ionized gas: $M=1.7\times 10^9$ Mo
 - the dynamical age: $t=20-50$ Myr
 - the ionized gas kinetic energy: $E=(0.3-2.2)\times 10^{52}$ erg
- the velocities of outflows are below the escape velocities.

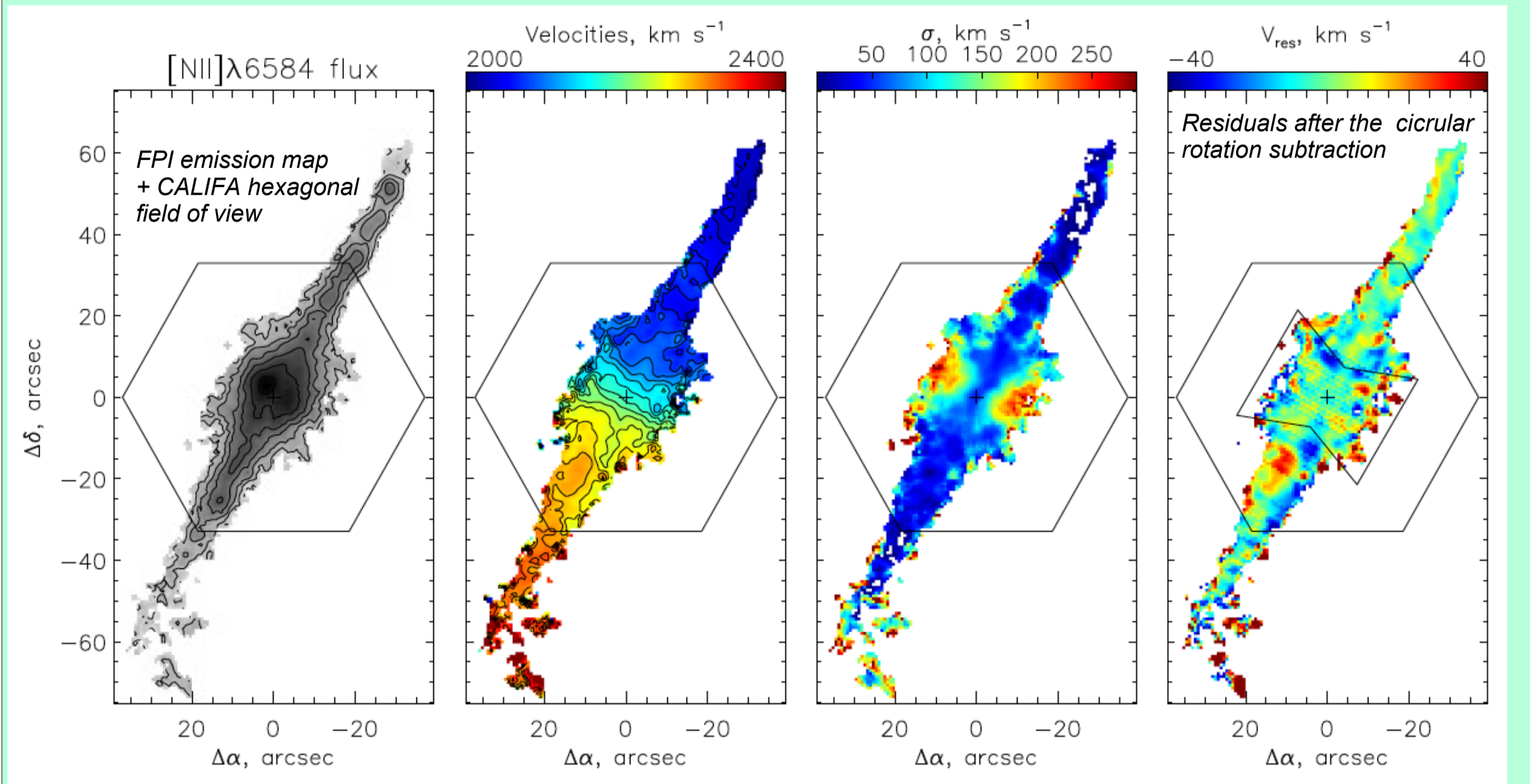
See details in Oparin & Moiseev (2015)



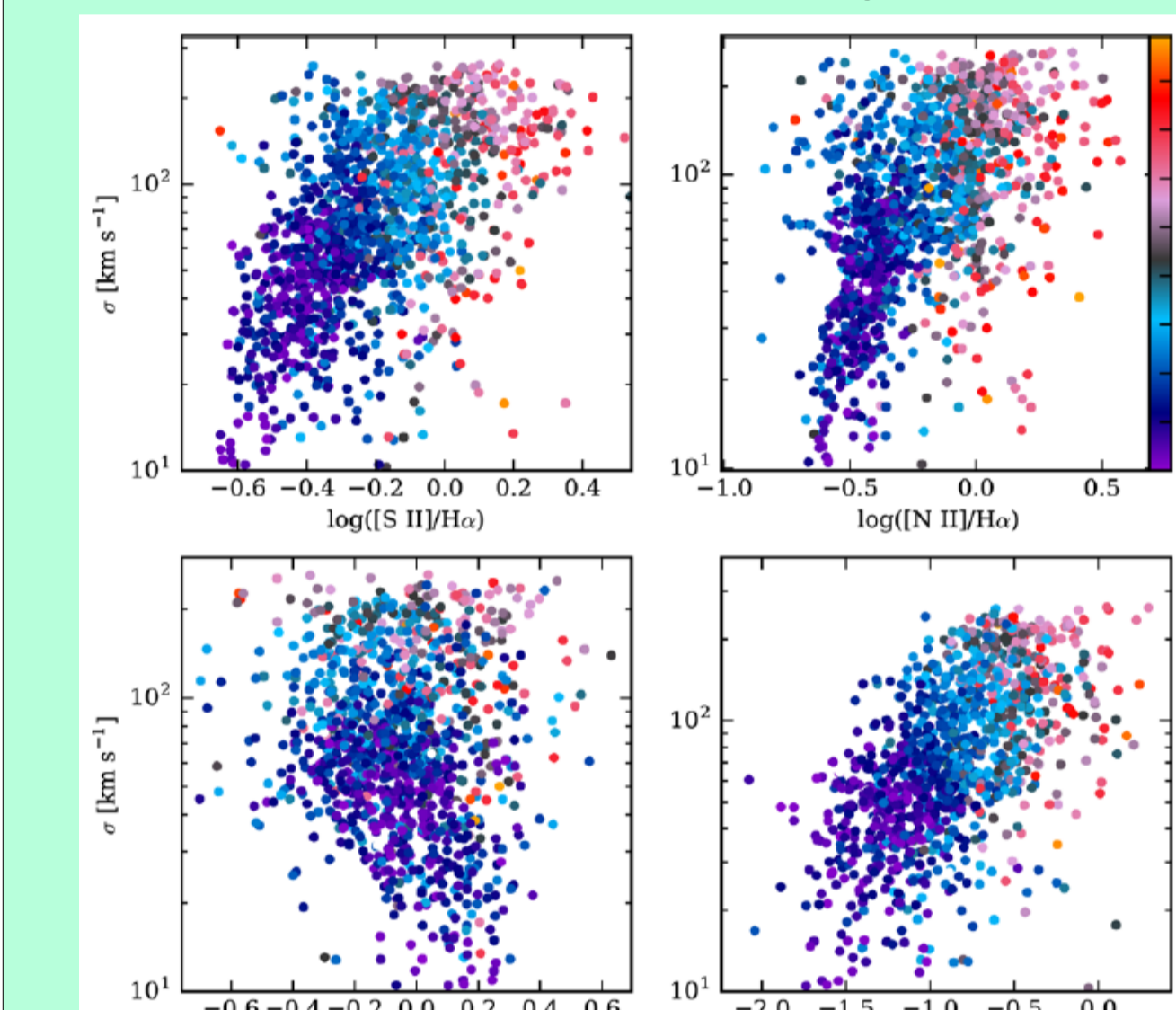
Dependence of the velocity dispersion on the extraplanar distance

The gas turbulent motions become substantial outside the bright dense regions: velocity dispersion values there are comparable to the V_{out} .

Star formation driven galactic winds in UGC 10043



Total SFR=0.3 Mo/yr



The diagrams line ratios — ionized gas velocity dispersion for the points having both FPI and CALIFA measurements. Colors correspond to extraplanar distance.

The deprojected outflow velocities $V_{\text{out}}=100-250$ km/s together with the velocity dispersion $\sigma<300$ km/s are in a good agreement with an estimation of shock velocities obtained from emission lines ratios in CALIFA spectra (100-400 km/s).

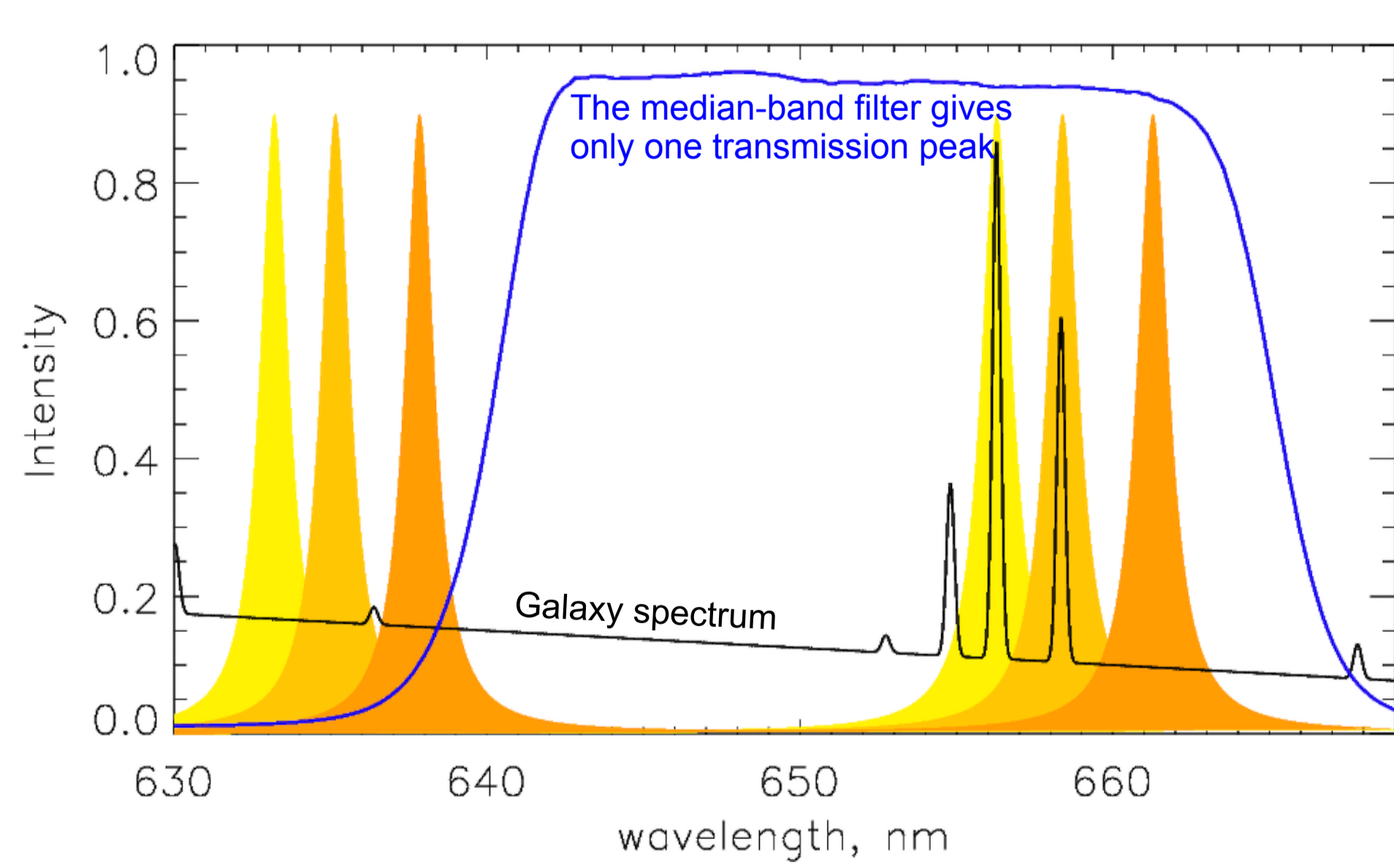
The observed correlation between forbidden-to-Balmer lines ratios and ionized gas velocity dispersion gives additional arguments in favour of the shock-wave excitation of the gas in wind nebulae.

For details see López-Cobá et al. (2017)

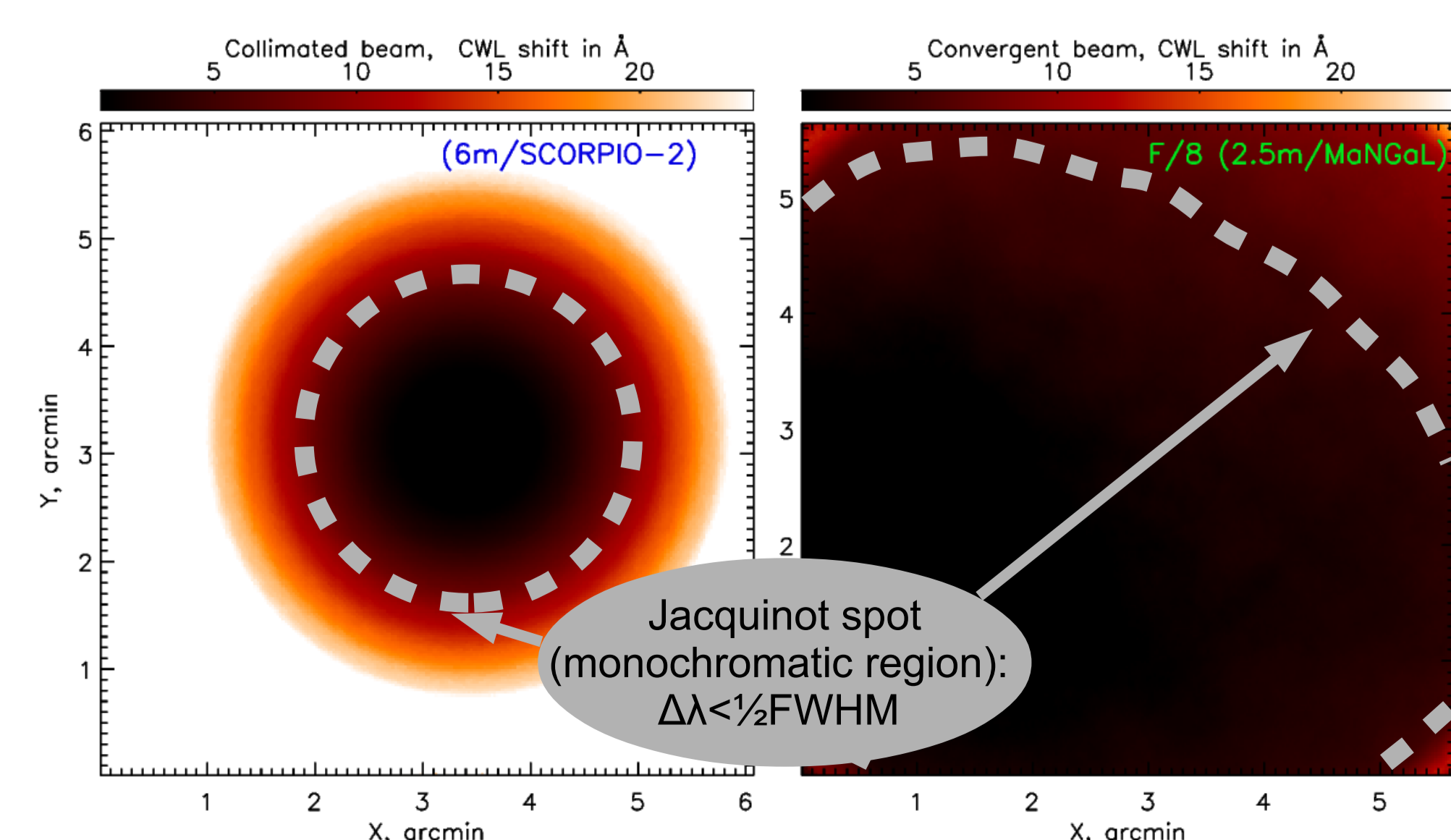
Tunable-filter at the 2.5-m SAI MSU telescope.

The Mapper of Narrow Galaxy Lines (MaNGaL*) was developed in 2017 in SAO RAS for observations at the 1-m SAO RAS and 2.5-m SAI MSU telescopes. The low-order scanning FPI works as a narrow (bandwidth $\sim 15\text{\AA}$) filter precisely positioned at the emission lines. In contrast with a 'classical' optical layout having a tunable-filter in the collimated beam (Jones et al 2002; Veilleux et al. 2010), MaNGaL is afocal reducer with the FPI in a convergent beam (see Courtes 1964). This arrangement provides a significantly larger size of a central monochromatic region that is crucial in studying of extended targets (see the figure below).

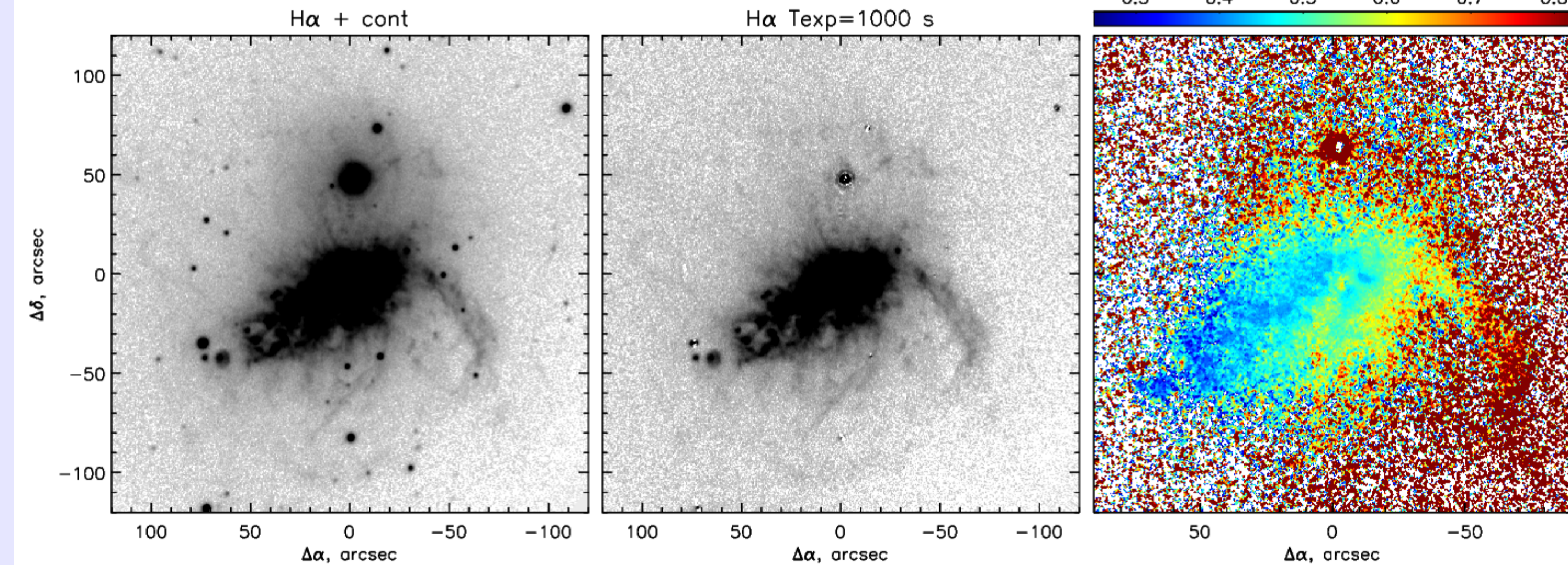
*'Mangal' is a Caucasian and Middle Eastern barbeque.



Tunable filter operating principle: the FPI transmission profiles tuned for observations in two emission lines and in the continuum (yellow-orange).

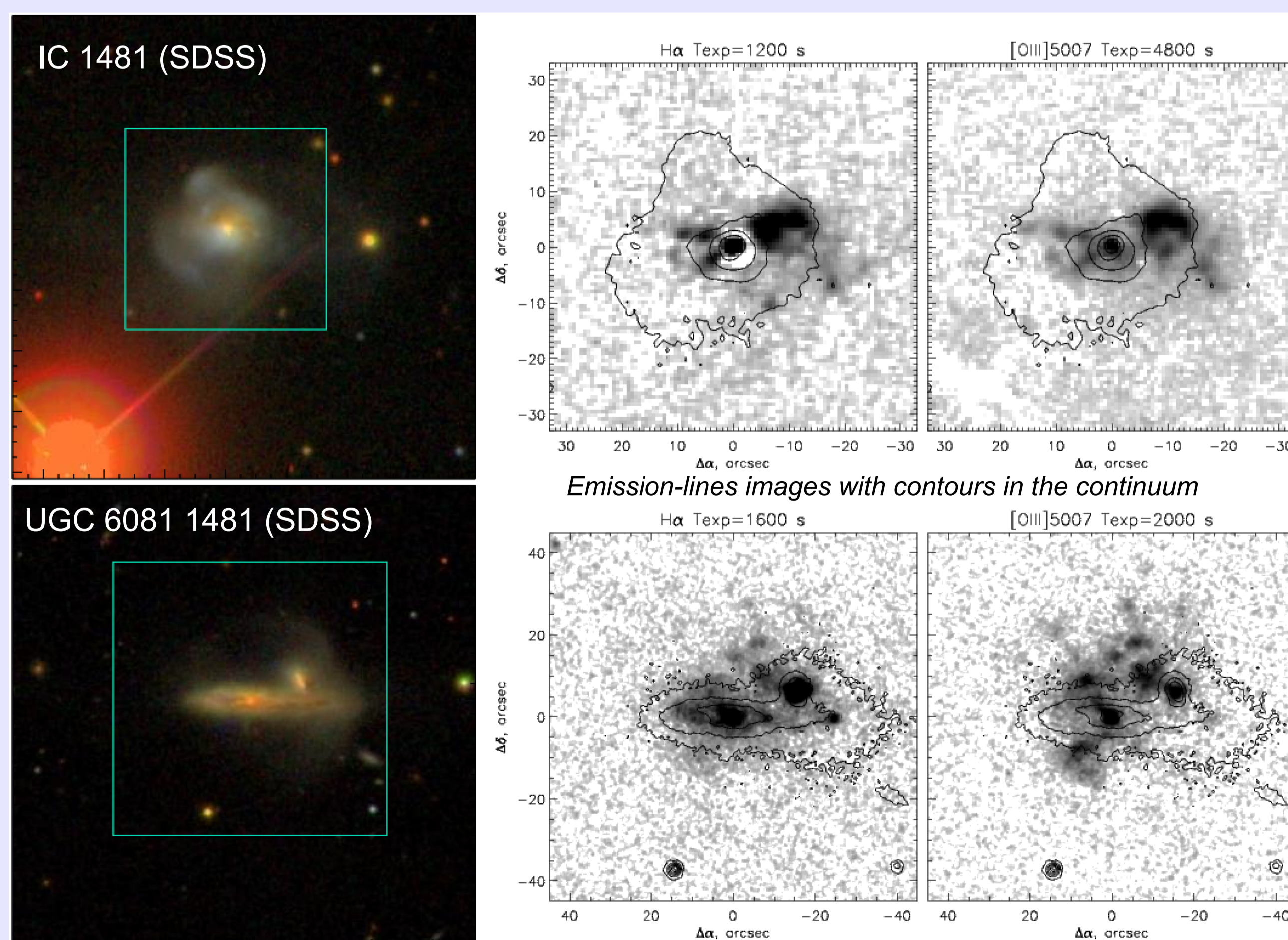


MaNGaL first light: wind outflow in NGC 1569 dwarf galaxy



The low [NII]/H α ratio corresponds to the HII regions in the galaxy disc, whereas the high value of this ratio in the diffuse gas and wind filaments indicates the increasing of shock contribution to gas ionization.

The confirmation of new ionization cones in Seyfert galaxies (AGN illuminates the intergalactic and external gas).



The emission-line region in IC 1481 extended at a projected distance of ~ 8 kpc seems to be similar to structures observed in the sample of faded AGN (Keel et al. 2015, 2017).

The galaxy UGC 6081 is a new interesting example of dual-AGN in a pair of galaxies with cross-ionization of gas in both companions (see details in Keel et al. 2018)

References

- Afanasev V. L. & Moiseev A. V., 2011, *Balt. Ast.*, 20, 363
 Courtes G., 1964, *AJ*, 69, 325
 Jones D.H. et al., 2002, *MNRAS*, 329, 759
 Keel W.C., et al., 2015, *AJ*, 149, 155
 Keel W.C., et al., 2017, *ApJ*, 835, 256

- Keel W.C., et al., 2018, *MNRAS* accepted, arXiv 1711.09936
 Lintott C. J. et al., 2009, *MNRAS*, 399, 129
 Lopez-Coba C. et al., 2017, *MNRAS*, 467, 4951
 Moiseev A.V., 2015, *Astroph. Bull.*, 70, 494
 Oparin D.V. & Moiseev A.V., 2015, *Astroph. Bull.*, 70, 392
 Veilleux S. et al., 2010, *AJ*, 139, 145