Gas Kinematics In and Around Edge-on Galaxies from MaNGA Observations

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Mapping Nearby Galaxies at APO (MaNGA) is a massive Integral Field Unit survey of a large number of relatively nearby galaxies that started in 2014 as a part of SDSS-IV at the Apache Point Observatory. After the first year of observations MaNGA has obtained IFU spectra of about a thousand of objects, with several dozens of edge-on galaxies among them. The two-dimensional spectra help us constrain parameters of galactic components with superior rotation curves. There is a significant fraction of galaxies in which the extra-planar gas emission is confidently detected. The extra-planar gas velocity fields in several galaxies show signs of lagging rotation with respect to the gas motion close to the galactic plane. We show progress of MaNGA survey in observations of edge-on galaxies and discuss their impact on our understanding of gas kinematics in and around spiral galaxies after finishing the survey.

MaNGA at a glance

Mapping Nearby Galaxies at APO (Bundy et al, 2015, Drory et al. 2015)

- Lergest Integral Field Unit (IFU) survey
- 17 IFUs in the field (19 to 127 fibers)
- Well studied SDSS/BOSS spectrograph on the Sloan 2.5m telescope
- 3 degree FOV, 2" fibers,
- 56% filling factor, spatial dithering
- Median seeing at APO is ~1.4"
- R ~ 2000, covers 3600-10300A range
- 5% absolute accuracy of the flux calibration (Yan et al. 2016)
- Targets: galaxies at z ~ 0.03 (median)

The SDSS telescope at the Apache Point Observatory and a cartridge plugged with MaNGA IFUs.

A 127-fiber IFU (image credit: Niv Drory)

Edge-On Galaxies in MaNGA sample

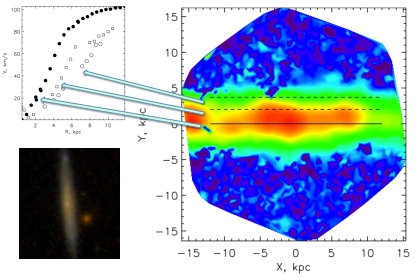
About 1400 galaxies observed in 2014-2015
67 edge-on galaxies identified in the sample:

- inspected SDSS images of all galaxies;
- dust lane is projected on the nucleus region
- no spiral arms, disk warps, or interacting companions

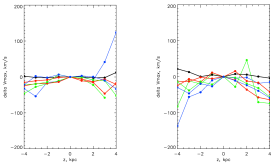
Data available from the Data Reduction / Data Analysis pipelines (Law et al, 2016, also Belfiore et al, 2015)

- Emission line spectrum corrected for underlying absorption
- Output: emission line flux, RV, QA flags

Lagging Rotation of Extra-planar Ionized gas
at high distance above the galactic midplane



Ha image of an edge-on galaxy from MaNGA sample with slower rotation of the extra-planar gas. The solid line designates the midplane profile (corresponds to the solid circles in the top-left panel), the dashed lines are at z=2.0 and 3.8 kpc above the galactic midplane (open symbols).



The observed radial velocity difference (with respect to the center) in the vertical profiles at the radial distance r=0 (black), 0.1 (red), 0.4 (green), and 0.7 (blue) of R_{max} where the R_{max} is the maximum radial extension of the galaxy in given IFU. There shouldn't be any gradient of the black line even in a case of a lagging rotation, so it indicates the accuracy level of the measurements (~ 10 km/s .)

Velocity Field from the Hα emission
In many edge-on galaxies sufficient Ha flux is detected at > 3 kpc above the galactic plane

Fraction of fibers with S/N (Ha) > 3 and good flags in the selected edge-on galaxies	IFU	spaxels with S/N>3
	19 :	83.5%
	37 :	66.4%
	61 :	45.9%
	91 :	38.8%
	127:	42.6%

Vertical lagging of the gas rotation
Model: cylindrical rotation of gas
Linear vertical lag of the rotation
V(r,z) = V(r) (1 - |z| *dV/dz)

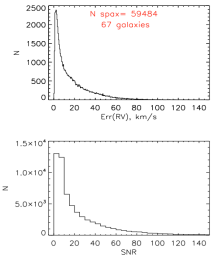
Projection effects : the observed V(x,y) is a result of projection, integrated along the line of sight.

Dust effects:
Dust disk (for the absorption) is embedded into the stellar disk

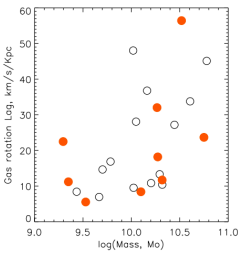
Free parameters of the model:
-parameters of the rotation curve
-ionized gas disk and dust disk parameters
-lag of the rotation (dV/dz)

Results:

- The vertical rotation lag is estimated in selected edge-on galaxies
- **28 out of 67 (42%) galaxies show systematic vertical lag of the ionized gas rotation.**
- Positive correlation of the lag with galactic mass (and Vmax).



Top panel: RV uncertainty in good spaxels in selected 67 edge-on galaxies
Bottom panel: S/N ratio in these spaxels



The lag of the extra-planar ionized gas rotation in selected edge-on galaxies. Positive correlation with the galactic mass can be seen. Red circles designate the galaxies with the most reliable fitting.

The gas rotation curve (RC) decomposition in edge-on galaxies using MaNGA data

* Pro: We can use the stellar disk thickness as a constraint for the RC decomposition
* Contra: dust extinction doesn't allow to see the whole galaxy, at least in the galactic midplane

Benefits from MaNGA: it samples regions above and below the galactic midplane, where the dust extinction is low.

We develop a constrained RC decomposition using the Ha kinematics. Only good data are used with S/N > 3 per spaxel.

Galactic components:
Exponential stellar disk, exponential or Sersic bulge, dark halo. The stellar disk thickness is constrained (but not fixed) by the dark halo-to-disk mass ratio (e.g. Khoperskov et al., 2010)

Additional data and constraints:
Near Infrared Photometry from NICPFS (3.5m at the Apache Point Observatory). We considered 4 galaxies as a test sample.

Constraints from the NIR
stellar disk parameters: exponential scale length, scale height, bulge parameters, bulge-to-disk luminosity ratio.

Free parameters: dark halo model (NFW or isothermal), dark mass and the spatial scale, dust amount, and the dust disk vertical scale height.

Results: with fewer model parameters, the dark matter scale length and mass are estimated reliably, especially in the case of "featureless" rotation curves.

Expected results at the end of MaNGA survey:

- 10,000 galaxies observed
- Some 400-500 true edge-on galaxies
- 150-200 galaxies with detected lag of the rotation in extra-planar gas
- Reliable parameters of the dark halo from the constrained decomposition for 500 galaxies

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