Measuring alignments between large-scale structure filaments and galaxy spins from integral-field spectroscopy

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Structure formation is anisotropic: sheets $\rightarrow$ filaments $\rightarrow$ nodes
Cosmic web

- Structure formation is anisotropic: sheets → filaments → nodes
- Galaxy properties depend on background density (e.g. Postman et al. 2006, Cappellari et al. 2011)
- Cosmic web geometry drives tides that may additionally affect galaxy properties (e.g. Darvish et al. 2016, Laigle et al. 2017)
Cosmic web-driven alignments

- Tides from large-scale structure align galaxy spins (e.g. Hirata and Seljak 2004)

Galaxy formation processes also drive alignments between galaxy spins and large-scale filaments. Accretion aligns low-mass galaxy spins with filaments, while mergers align high-mass galaxy spins perpendicular to filaments (see Aragon-Calvo et al. 2007, Hahn et al. 2007, Codis et al. 2012).
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Cosmic web-driven alignments

- Actually...results from hydro simulations are more complicated than this simple picture
- DM spins and stellar spins show different behaviors: accurate comparison to theory requires hydro sims!

\[
\begin{array}{c}
\text{Stellar Mass} \\
9.0 & 9.5 & 10.0 & 10.5 & 11.0 & 11.5 \\
\text{Dot product between spin axis and filament} \\
0.42 & 0.44 & 0.46 & 0.48 & 0.50
\end{array}
\]

MB-II simulation at z = 0.06

- More aligned
- Less aligned

Krolewski et al., in prep
Measuring alignments in data

- Filaments can be identified with a dense spectroscopic survey
- We use *Cosmic Web Reconstruction* catalog of Chen et al. 2016
  - Filaments identified as ridges in density field

Galaxy Field  KDE-smoothed density field  Density ridges
Measuring alignments in data

- Use SDSS Main Galaxy Sample to identify filaments
  - We use 2D slices of (RA,DEC) to find filaments ($\Delta z = 0.005$): reduces computational cost, eliminates redshift-space distortions, minimizes impact of redshift-dependent galaxy density

Chen, Ho, Mandelbaum et al., MNRAS 2015. 1509.06376
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Measuring galaxy spin

- We use stellar kinematics from the MaNGA integral field survey to estimate galaxy spin.
- Integral field spectroscopy: 19-127 fibers per galaxy to create a resolved map of galaxy properties.
- Advance over previous work: previous work used shapes to measure spin rather than kinematics.
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- Create symmetric template for each galaxy’s velocity map to find best-fit position angle (Krajnovic et al., 2006).
- Exclude poor fits, observations with multiple galaxies in IFU, etc.
Measuring galaxy spin

- Trimmed sample size: 1766 galaxies
- Final MaNGA sample will be $4 \times$ larger

Krolewski et al., in prep

Alex Krolewski  Spin-filament alignment  July 25, 2017
SDSS-MaNGA alignment results

- No significant deviation from random for entire sample:
  \[ \langle \cos \theta \rangle = 0.6412 \pm 0.0072 \] compared to \[ \langle \cos \theta \rangle = \frac{2}{\pi} = 0.6366 \] for random alignments
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  \[ \langle \cos \theta \rangle = \frac{2}{\pi} = 0.6366 \] for random alignments
- No/weak dependence on distance from filament, stellar mass, color, morphology

Krolewski et al., in prep
Comparison to MB-II hydro simulation

- From simulations we expect a mass-dependent alignment signal (e.g. Codis et al., 2012)
- Create mock filament catalog in MB-II by matching galaxy number density and projecting into 2D slices
- Ensure that we match the redshift distribution in each stellar-mass bin

![Graph showing dot product for different simulations and data sets.](image)
Gas kinematics

- Repeat fitting using gas kinematics (Hα line) rather than stellar continuum
Gas kinematics

- Repeat fitting using gas kinematics (Hα line) rather than stellar continuum
- Mass-dependent trend is similar to stellar kinematics: discrepancy between data and simulation remains
- Errors underestimated due to large error on filament measurement?
Future: alignment measurements at $z \sim 2$ with IGM tomography

- IGM tomography allows measurement of $z \sim 2$ cosmic web with similar fidelity to low-redshift surveys (Lee and White 2016): see KG Lee’s talk
- Alignment measurement is feasible with $\sim 10000$ coeval galaxies: will require larger-area surveys such as Subaru-PFS rather than pilot CLAMATO survey
Conclusions

- First measurement of galaxy-filament alignment using galaxy spins from kinematics rather than photometry.
- No detection of alignment in combined sample, but mass dependence of alignments does not agree with simulations.
- Future surveys will allow for better filament reconstructions, higher-S/N measurements, and extend these measurements to $z \sim 2$. 