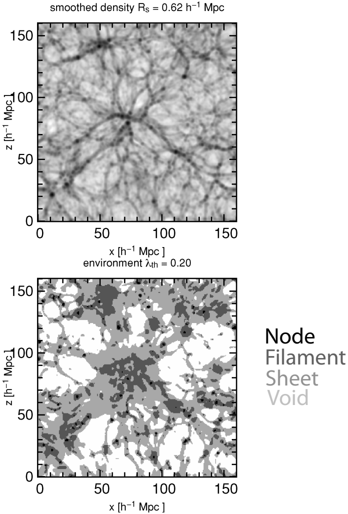
Measuring alignments between large-scale structure filaments and galaxy spins from integral-field spectroscopy

Alex Krolewski (UC Berkeley)
with Shirley Ho (CMU/LBL), Yen-Chi Chen (UW) and Ananth Tenneti (CMU)
Advances in Theoretical Cosmology in Light of Data, Nordita, Stockholm

July 25, 2017

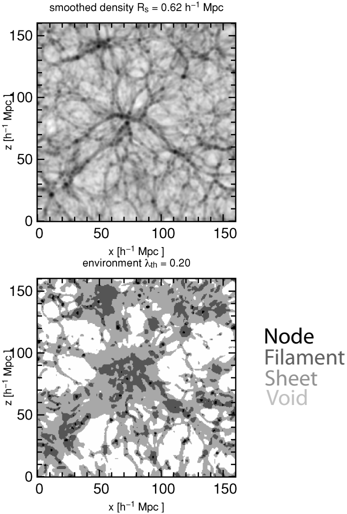
- Structure formation is anisotropic: sheets → filaments → nodes



Forero-Romero et al., 2009

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)



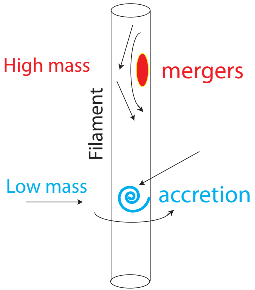
Forero-Romero et al., 2009

Cosmic web-driven alignments

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

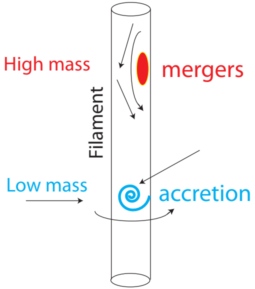
Cosmic web-driven alignments

- 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



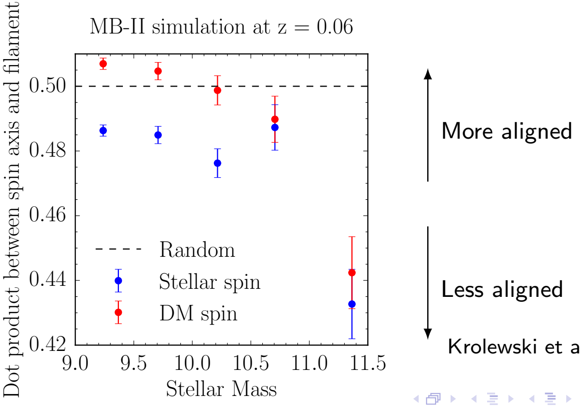
Cosmic web-driven alignments

- 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
- Mergers align high-mass galaxy spins perpendicular to filaments (see Aragon-Calvo et al. 2007, Hahn et al. 2007, Codis et al. 2012)



Cosmic web-driven alignments

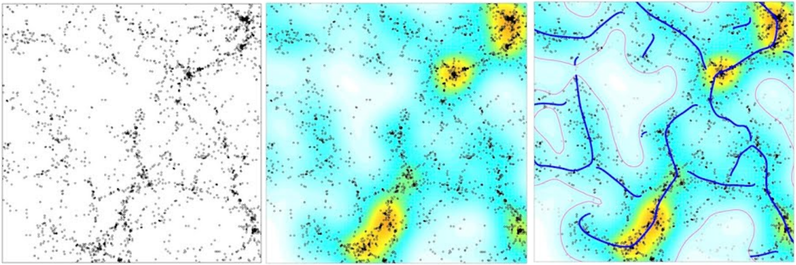
- Actually...results from hydro simulations are more complicated than this simple picture
- DM spins and stellar spins show different behaviors: accurate comparison to theory requires hydro sims!



Krolewski et al., in prep

Measuring alignments in data

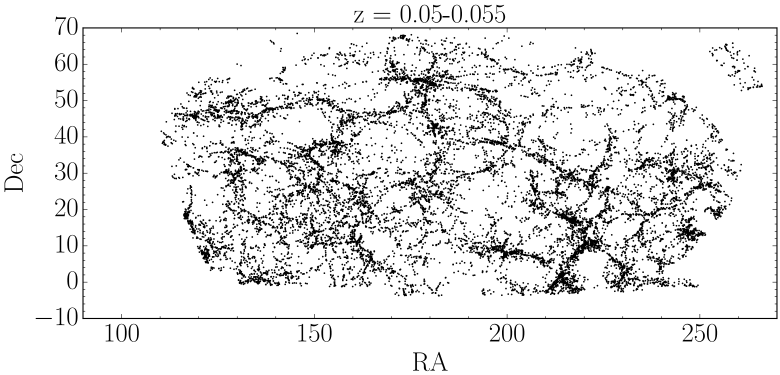
- Filaments can be identified with a dense spectroscopic survey
- We use *Cosmic Web Reconstruction* catalog of Chen et al. 2016
  - Filaments identified as ridges in density field



Galaxy Field KDE-smoothed density field Density ridges

Measuring alignments in data

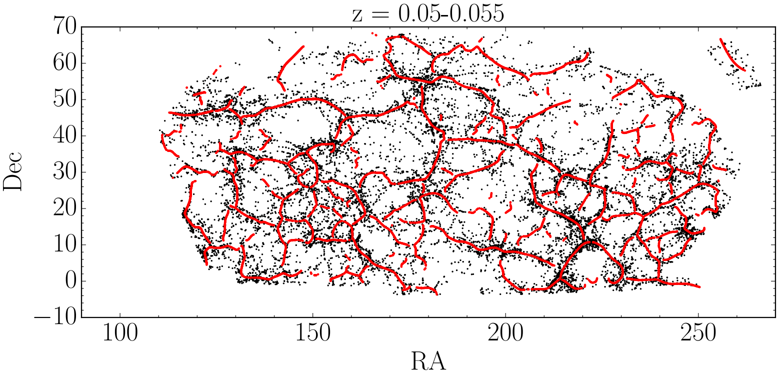
- Use SDSS Main Galaxy Sample to identify filaments
  - We use 2D slices of (RA,DEC) to find filaments ($\Delta z = 0.005$): reduces computational cost, eliminates redshift-space distortions, minimizes impact of redshift-dependent galaxy density



Chen, Ho, Mandelbaum et al., MNRAS 2015. 1509.06376

Measuring alignments in data

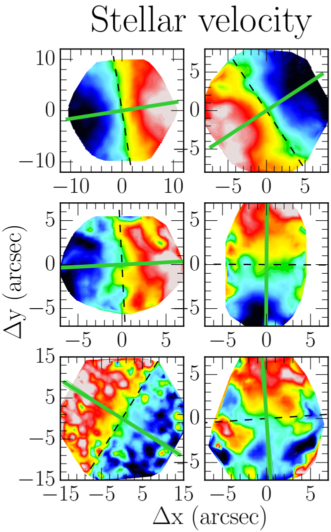
- Use SDSS Main Galaxy Sample to identify filaments
  - We use 2D slices of (RA,DEC) to find filaments ($\Delta z = 0.005$): reduces computational cost, eliminates redshift-space distortions, minimizes impact of redshift-dependent galaxy density



Chen, Ho, Mandelbaum et al., MNRAS 2015. 1509.06376

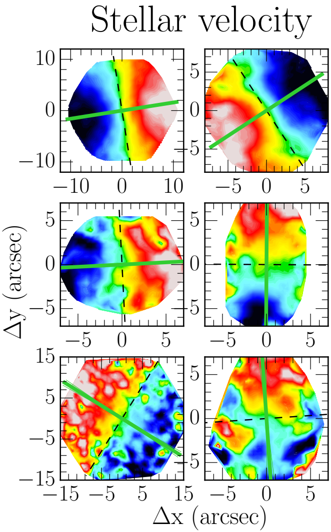
Measuring galaxy spin

- 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



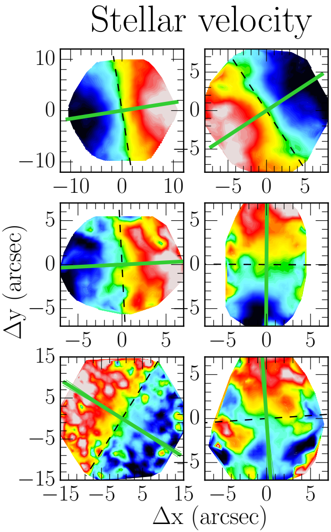
Measuring galaxy spin

- 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
- Create symmetric template for each galaxy's velocity map to find best-fit position angle (Krajnovic et al., 2006)



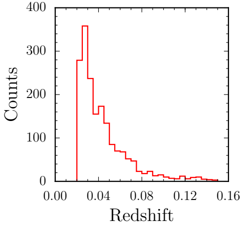
Measuring galaxy spin

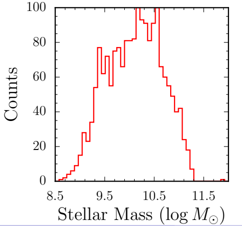
- We use stellar kinematics from the MaNGA integral field survey to estimate galaxy spin
- Integral field spectroscopy: 19-127 fibers per galaxy to create a resolved map of galaxy properties
- Advance over previous work: previous work used shapes to measure spin rather than kinematics
- Create symmetric 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.

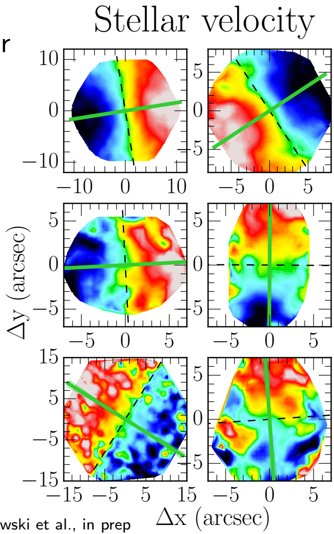


Measuring galaxy spin

- Trimmed sample size: 1766 galaxies
- Final MaNGA sample will be 4 × larger







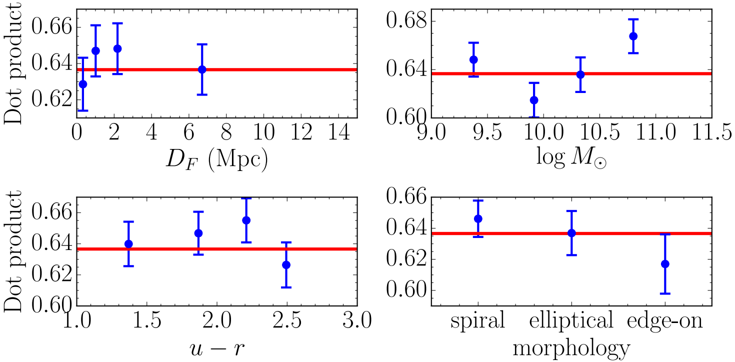
Krolewski et al., in prep

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

SDSS-MaNGA alignment results

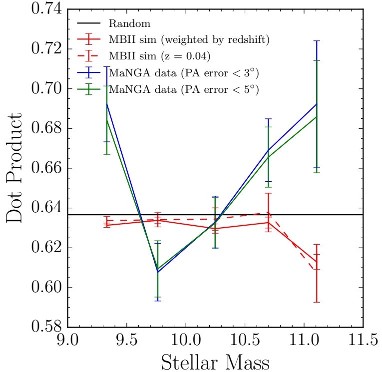
- No significant deviation from random for entire sample: $\langle \cos\theta \rangle = 0.6412 \pm 0.0072$ compared to $\langle \cos\theta \rangle = \frac{2}{\pi} = 0.6366$ for random alignments
- No/weak dependence on distance from filament, stellar mass, color, morphology



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



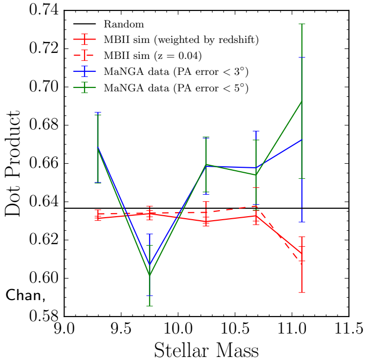
Krolewski et al., in prep

Gas kinematics

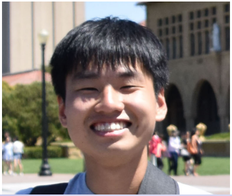
- Repeat fitting using gas kinematics (Hα line) rather than stellar continuum

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?

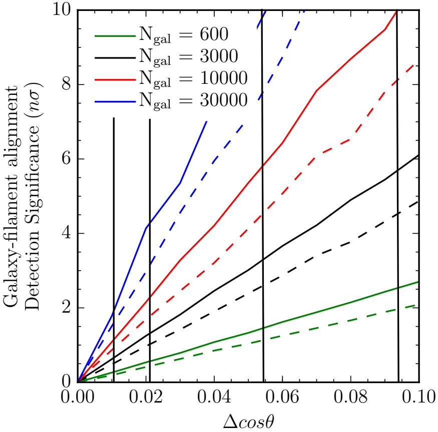


Work by Pok Fung (Sunny) Chan, undergrad at CUHK



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 ~ 10000 coeval galaxies: will require larger-area surveys such as Subaru-PFS rather than pilot CLAMATO survey



Krolewski et al., 2017, 1612.00067

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 $z \sim 2$