Shi Shao

Curriculum Vitae

Institute for Computational Cosmology
Durham University
South Road, Durham DH1 3LE, UK

Tel: +44 749 079 81 60
E-mail: shi.shao@durham.ac.uk

RESEARCH PROFILE

I am a theoretical astrophysicist studying the interface of cosmological simulations, observations and advanced statistical tools. My PhD focused on small-scale structure formation and evolution, more specifically, the internal structure and the distribution of satellite galaxies around Milky Way. For my postdoctoral research, I expanded my area of expertise by studying the accretion history of satellite galaxies with a focus on galactic scale problems.

EDUCATION

2009 – 2016 **National Astronomical Observatories, Chinese Academic of Sciences, China**
Ph.D. in numerical cosmology under the supervision of Prof. Liang Gao
Thesis title: "Numerical Simulation of Cosmic Structure Formation"

2012 – 2014 **Max-Planck institute for Astrophysics, Germany**
Joint training doctoral student in astrophysics under the supervision of Prof. Simon White
Thesis title: "Disk Dynamics in Live Dark Matter Haloes"

2005 – 2009 **Nanjing University, China**
B.Sc. in astronomy. Graduated with a GPA of 4.0 (on a scale from 1.0 to 4.0).

RESEARCH EXPERIENCE

2015 – **Durham University, Durham, United Kingdom**
• Studying the accretion history of galactic satellites. – Postdoctoral Research Associate (2017–)
• Studying the spatial and kinematic distribution of satellite galaxies in the Local Group. – Visiting Ph.D student (2015–2016)

2012 – 2014 **Max-Planck institute for Astrophysics** – Joint training doctoral student
• Studying the interplay between central baryonic disc and dark matter haloes for MW sized galaxies.

2007 – 2009 **National Astronomical Observatories, CAS** – M.Sc. student
• Developed a analytic method of predicting the central phase space density of dwarf galaxies and performed a series of numerical experiments to test the model.

TECHNICAL SKILLS

- Multiple years of programming experience, among which 10 years of C/C++ Programming, 10 years of BASH, 8 years of parallel programming and 8 years of IDL.
- Eight years of experience in handling very large data sets and in efficiently analysing them using parallel codes.
- Experience with advanced statistical tools and visualization tools.

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List of Publications

REFEREED PUBLICATIONS

As of December 2017, my publication record contains 2 refereed publications with 72 citations and 1 paper that is being refereed at the moment.

2017 • **Shao, S.**, Cautun, M., Frenk, C. S., Grand, R. J.J., Gómez, F. A. and Marinacci F.; *"The multiplicity and anisotropy of galactic satellite accretion"*, submitted to MNRAS, arxiv:1712.05409

2016 • **Shao, S.**, Cautun, M., Frenk, C. S., Gao, L., Crain, R. A., Schaller, M., Schaye, J. and Theuns, T.; *"Alignments between galaxies, satellite systems and haloes"*, MNRAS, 460, 3772, arxiv:1605.01728 (11 citations)

2013 • **Shao, S.**, Gao, L., Frenk, C. S. and Theuns, T.; *"The phase-space density of fermionic dark matter haloes"*, MNRAS, 430, 2346, arxiv:1209.5563 (61 citations)

PUBLICATIONS IN PREPARATION

• Wang, P., Cai, Y., Kang, X. Peacock, J., Luo, Yu L., **Shao, S.**, Cautun, M.; *"The connection between fasting rotating galaxies and their environments"*,
Expected Submission Date: February 2018

RESEARCH STATEMENT

The main focus of my work is to study small-scale structure formation and evolution in its cosmological context and to understand the connection between central, satellite galaxies, and large-scale structure across cosmic time. During my PhD period, I have gained much experience in programming high performance computers and analyzing large cosmological simulation data sets. In the following, I outline the projects that I plan to do during my postdoctoral period. I also summarize my previous work in the Appendix.

1) Red satellite galaxies fraction in MW mass halo

Observationally, the fraction of red satellite galaxies increases with host halo mass. This indicate that the intrinsic properties of satellite galaxies are primarily determined by their host halo mass. Various physical effects that lead to the reddening of satellite galaxies especially for massive hosts have been broadly studied in both theoretical models and simulations. However, the importance of the transition mass scale for host halo between 10^{12} and 10^{13} $M_\odot$ has been largely overlooked. Especially for 10^{12} $M_\odot$ host halo, within which the number of blue satellites become more pronounced than red ones according to SDSS observational data, whereas semi-analytic model fails to predict this trend (Wang et al., 2014). Although Sales et al. (2015) claim that they have found a better agreement between ILLUSTRIS hydro-dynamic simulation and observations, the overall mass function of ILLUSTRIS is about one order of magnitude higher than the observed mass function. While EAGLE simulation did better at this point, from my recent study, EAGLE simulations can predict more blue satellites than red satellites for the host halo at transition mass and it consists with observations. It might be interesting to further study the mechanism of how satellite get reddened and give the physical explanation on the fact that EAGLE can produce the good agreement between theory and observations whereas SAM or ILLUSTRIS fails. More specifically, I will study the evolution of satellites in terms of their gas fraction, color, and orbit at their infall time. The result may also be able to constrain the environmental effect on the reddening, mass-loss, and morphological transformations of satellites.

2) Counter-rotating gas in EAGLE galaxies

In about 10% of nearby red galaxies with little star formation, gas and stars are counter-rotating. However, Chen et al. (2016) has recently found 5% blue star forming galaxies are also counter-rotators, and this result offers observational evidence that the acquisition of external gas in blue galaxies is possible. External processes, mergers and gas accretion, could bring gas which is counter-rotating with pre-existing stars into the central. To understand the influence of gas accretion on the evolution of star forming galaxies, I plan to study the counter-rotators analogous to that in observation with stellar mass above 10^9 $M_\odot$ in EAGLE simulations. More specifically, I will study the shape and angular momentum of galaxies as a function of redshift, which I have gained a lot of working experience from my previous studies (Shao et al. 2016 and Shao et al. 2018). I will then investigate the evolution of surrounding gas and also the massive gas clumps at different epoch. If most of the counter-rotating gas turns out to be late-time accretion and could trigger star formation, this could indicate the interaction with pre-existing gas funnels the gas into central to form new stars.

3) Filling the gap of gravity test on scale of Local Universe

General relativity (GR) has been well established in our Solar system, and in recent years extensively tested on cosmological scales. Testing gravity on galactic scales, however, is still largely an unexplored area, even though preliminary studies Jain et al. (2013) indicate that this regime could provide much stronger constraints on deviations from GR. Built on my experience in working on the Local Group and the expertise on modified gravity (MG) at the ICC, I propose to fill this gap with two projects. First, I will study what constraint can be placed on leading MG models, such as $f(R)$ gravity, by requiring that the theory is close to GR in our Galaxy. This will be done by computing the gravity field in systems that closely mimic the Local Group, by running a MG code from collaborators at the ICC on the APOSTLE suite of zoom-in simulations. I will then extend this study to the Local Universe ($\sim$ 300 Mpc/h), for which the dark matter field can be accurately mapped using density reconstruction techniques (Wang et al., 2016). Collaborating with Wang, I will first reconstruct the density field in the Local Universe from SDSS galaxies, and then run a MG code to calculate, for a given model, in which regions do we expect to see deviations from GR. These projects will use the best-available information to provide detailed and precise 'screening maps' of the behaviour of gravity in the nearby universe, which will enable a range of accurate and strong astrophysical tests of GR for the first time.

References

Chen, Y.-M., Shi, Y., Tremonti, C. A., et al. 2016, Nature Communications, 7, 13269

Jain, B., Vikram, V., & Sakstein, J. 2013, ApJ, 779, 39

Sales, L. V., Vogelsberger, M., Genel, S., et al. 2015, MNRAS, 447, L6

Wang, H., Mo, H. J., Yang, X., et al. 2016, ApJ, 831, 164

Wang, W., Sales, L. V., Henriques, B. M. B., & White, S. D. M. 2014, MNRAS, 442, 1363

Appendix: Finished Works

A1: Baryonic effects on dark matter haloes
On scales of dwarf galaxies in our Milky Way, there is no strong evidence to support the standard cold dark matter model (CDM). There are, however, models of particle physics that predict lighter particles, such as sterile neutrinos, that would behave as warm dark matter (WDM). In WMD scenario, dark matter particles decouple as thermal relics or form from non-equilibrium decay, such that they acquire initial velocities whose amplitude depends on the particles mass. In the study of Shao et al. 2013 (MNRAS, 430, 2346), I have performed a series of numerical experiments to investigate how the primordial thermal velocities of fermionic dark matter particles affect the physical and phase space density profiles of the dark matter haloes into which they collect. The initial particle velocities induce central cores in both profiles, which can be understood in the framework of phase space density theory. I find that the maximum coarse-grained phase space density of the simulated haloes is very close to the theoretical fine-grained upper bound. The density in the inner regions of the simulated haloes is well described by a pseudo-isothermal profile with a core. I have developed a new analytical model based on this profile which, given the observed surface brightness profile of a galaxy and its central velocity dispersion, accurately predicts its central phase space density.

A2: Connection between galaxies and their surrounding cosmic structures
To understand the origin of the spatial distribution of the satellite populations of the Milky Way and Andromeda, in Shao et al. 2016 (MNRAS, 460, 3772), I have studied the alignment of the central galaxy, satellite system and dark matter halo in the largest of the Evolution and Assembly of GaLaxies and their Environments(EAGLE) simulation. I find that centrals and their satellite systems tend to be well aligned with their haloes, with a median misalignment angle of 33 in both cases. While the centrals are better aligned with the inner 10 kpc halo, the satellite systems are better aligned with the entire halo indicating that satellites preferentially trace the outer halo. The centralsatellite alignment is weak (median misalignment angle of 52) and I find that around 20% of systems have a misalignment angle larger than 78, which is the value for the Milky Way. The centralsatellite alignment is a consequence of the tendency of both components to align with the dark matter halo. As a consequence, when the central is parallel to the satellite system, it also tends to be parallel to the halo. In contrast, if the central is perpendicular to the satellite system, as in the case of the Milky Way and Andromeda, then the centralhalo alignment is much weaker. Dispersion-dominated (spheroidal) centrals have a stronger alignment with both their halo and their satellites than rotation-dominated (disc) centrals.

A3: Disk dynamics in live dark matter haloes
I have investigated the interactions between stellar discs and their dark matter haloes, using four LCDM haloes similar in mass to that of the Milky Way taken from the Aquarius Project. I find that the potential of the central disc strongly affects the shape of inner halo ($10 \leq$ kpc) and reconstructs its minor axis to be well aligned with the disc normal. As a consequence, tidal torque generated

by the misalignment in between inner and outer halo transfers its energy into the disc and makes the disc reoriented gradually. Discs underwent large orientation develop an integral-sign warp that is comparable in amplitude to observed warps. Disc warp is a long-term phenomenon which can only be continuously generated by misaligned halo, and it would disappear when the differential precession of the disc is gone. Methodology in this work has been also implemented in Shao et al. 2016 and Shao et al. 2018, and this work will be furthuer studied as a part of the project of my second proposal, in which I will study the counter-rotating gas in galaxies.

A4: Satellite galaxies group accretions

In arXiv:1712.05409, I studied the incidence of group and filamentary dwarf galaxy accretion into Milky Way (MW) mass haloes using two types of hydrodynamical simulations: EAGLE, which resolves a large cosmological volume, and the AURIGA suite, which are very high resolution zoom-in simulations of individual MW-sized haloes. The present-day 11 most massive satellites are predominantly (75%) accreted in single events, 14% in pairs and 6% in triplets, with higher group multiplicities being unlikely. Group accretion becomes more common for fainter satellites, with 60% of the top 50 satellites accreted singly, 12% in pairs, and 28% in richer groups. A group similar in stellar mass to the Large Magellanic Cloud (LMC) would bring on average 15 members with stellar mass larger than 10^4 $M_\odot$. Half of the top 11 satellites are accreted along the two richest filaments. The accretion of dwarf galaxies is highly anisotropic, taking place preferentially perpendicular to the halo minor axis, and, within this plane, preferentially along the halo major axis. The satellite entry points tend to be aligned with the present-day central galaxy disc and satellite plane, but to a lesser extent than with the halo shape. Dwarfs accreted in groups or along the richest filament have entry points that show an even larger degree of alignment with the host halo than the full satellite population. We also find that having most satellites accreted as a single group or along a single filament is unlikely to explain the MW disc of satellites.