

# Exploring the Nonlinear Universe with the Galaxy Clustering and the Intensity Mapping

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## 1. Background and Goal of the project

The ultimate goal of cosmological observations is to deepen our knowledge of fundamental physics. All the ongoing and future cosmological observations are designed to achieve key science goals such as revealing the origin of the cosmic acceleration or weighing the neutrino masses. One powerful way is to map out spatial distribution of galaxies in three dimensions, which traces the large-scale structure of the Universe, over the entire cosmic history. Galaxy clustering or intensity mapping is a technique to probe the spatial distribution from such gigantic maps. I am heavily involved in galaxy surveys such as HETDEX, while Dr. Maartens and Dr. Santos are playing leading roles in MeerKAT and the SKA.

One of the open questions we have in common is how to accurately model nonlinear and non-Gaussian distribution of galaxy clustering or intensity mapping and how to extract full cosmological information from them. A straightforward and rigorous approach is to model and adopt the three-point correlation function or the bispectrum in Fourier space. I am currently pursuing this direction with other collaborators [[Sugiyama, Saito, Butler, Seo, 2018, 2019, 2020](#)]. The main purpose of this project is to share and discuss these progresses with Dr. Maartens, Dr. Santos, and their group members at UWC, and to pursue a further collaboration along this line.

It is worth pointing out that there had been no recent close relationship between the physics departments at Missouri S&T and at UWC. It is a unique and exciting opportunity to establish a new relationship between the two departments through our new astrophysics group and this UMSAEP program. Thus, another goal of this UMSAEP

project is to initiate such a relationship and then to collaborate together towards a longer-term relationship.

## 2. Saito's Visit at UWC in February 2020

Following the proposed plan, I visited Dr. Maartens and Dr. Santos at Physics Department at University of the Western Cape from late January through mid February in 2020 with my postdoc, Dr. Gurung-Lopez. My travel was partially supported by the UMSAEP program, while the local expense of Dr. Gurung-Lopez was fully supported by UWC.

Looking back our travel, it was one of the toughest and the most challenging business trips in my entire professional career mainly due to two main unexpected accidents. First, there were occasional electric power failures planned by the city, which prevented us from continuously working on computers at both the department and the accommodation almost throughout our stay in Cape Town. Second, there were some protests performing march and blocking the campus entrance. We had to evacuate from the campus twice, and were not able to enter the campus once. In contrast to the people at the department who gave us a warm welcome, these unwelcome but unavoidable accidents definitely had a notable impact on our visit plan.

We nonetheless had as many meetings as possible to discuss our project. Dr. Maartens, his student Mr. Viljoen, and I discussed the impact of nonlinear Redshift-Space Distortion on the two-point projected clustering [[Saito, MPA Lecture on RSD in 2016](#)]. Dr. Maartens, his postdoc Mr. Karagiannis, and I discussed the bispectrum analysis in general [[Maartens et al. 2020](#)]. Dr. Santos, Dr. Gurung-Lopez and I shared the progress of the intensity mapping analysis, and discussed a way to incorporate Dr. Gurung-Lopez's semi-analytical Lyman-alpha emitter simulation into Dr. Molaro's reionization simulation [[Molaro et al. 2019](#)].

We also had a chance to make a research presentation on our project (see Fig. 1). I gave a seminar talk on the aforementioned new development of the bispectrum analysis, while Dr. Gurung-Lopez talked about his PhD work on cosmological simulation of Lyman-alpha emitters [[Gurung-Lopez et al., 2019, 2020](#)]. We had many questions and comments from the audience including postdocs and graduate students. In addition, Dr. Santos kindly invited us to visit South African Radio Astronomy Observatory which locates in center of the city. He gave us a brief tour on the MeerKAT observation control system (see Fig. 2).

Overall, I would conclude that our visit to UWC was successful despite of the unexpected accidents mentioned earlier. When we left Cape Town, we did know how next a few years would look like. It was about the time when the pandemic started...



Fig 1: I (left) and Dr. Gurung-Lopez (right) gave a seminar talk in Dr. Maartens' and Dr. Santos' group at UWC.



Fig 2: Dr. Santos (left) is explaining a remote observation system of MeerKAT to myself (center) at South African Radio Astronomy Observatory.

### **3. Santos's Colloquium Talk at S&T in April 2021**

In our original plan, we anticipated Dr. Santos's visit at Missouri S&T in May 2020. The pandemic inevitably forced us to change the plan. We kept seeking for a possibility to realize Dr. Santos's physical visit at Rolla, but the situation was not improved at all. Thus, we decided to invite Dr. Santos to give an online colloquium talk at Physics Department at Missouri S&T, and he kindly accepted our invitation.

Dr. Santos's colloquium talk was scheduled at noon in CDT on April 22nd in 2021. Because of the time difference, we had to schedule his talk during lunch time. Nonetheless, his talk attracted more than twenty participants (about the average number of participants in our physics colloquium). I am sure that his talk would have attracted more audience if the talk was given in person in a regular colloquium schedule.

Dr. Santos gave a colloquium talk entitled "Cosmology with MeerKAT and the SKA." He briefly overviewed the 21cm measurements from neutral hydrogen in the Universe and exciting science cases with two ongoing and upcoming surveys, MeerKAT and the SKA. Galaxy clustering and Intensity mapping are ones of the main techniques to measure cosmological signal in both surveys, and hence the talk is aligned with the main subject of this project. We had several questions from the audience and insightful answers from Dr. Santos at the end of his talk. The students at our astrophysics group were certainly impressed by the talk, and I heard several positive feedback on excellence on his talk. Thus, I conclude that the talk went successfully.



Fig. 3: Dr. Santos's online zoom colloquium talk at Missouri S&T in April 2021.

## 4. Summary and Future Prospects

The main goal of this UMSAEP project is to initiate a long-term relationship between newly established astrophysics group at Missouri S&T and strong astrophysics group at UWC, and then to promote the collaboration on the proposed research projects. I believe that we have successfully achieved the first part of the goal. My visit and research activities with the local researchers at UWC were well accepted and went well despite of various disturbances such as power failure and protest march. I would think that we were even fortunate to be able to visit them right before the pandemic started. My travel to

South Africa is still the last international travel I made. Also, our relationship does continue, which is proven by Dr. Santos's colloquium talk at S&T in April 2021.

However, it was unfortunate that our collaboration did not go as smoothly as we had anticipated when I visited UWC. The main reason was the pandemic. Everyone including Dr. Maartens, Dr. Santos and myself were forced to get used to new research, education and teaching activities, working from home and taking care of families. After all, it was extremely hard and challenging for everyone to find sufficient time and room to pursue a collaborative project further. Nonetheless, Dr. Maartens and I have kept discussing to improve the treatment of nonlinear Redshift-Space Distortion onto the projected angular clustering and its impact on cosmology inference. I hope to publish at least one publication along this line in the near future.

Looking ahead towards the future, I would like to retain and further develop the relationship we have initiated through this UMSAEP program. This is not only to work on a collaborative research project, but also to have a common activity such as summer internship and/or exchange program for students. Such an innovative activity would attract more students to bachelor and graduate programs both to S&T and UWC.