PhD Project on The Origin of Supermassive Black Holes in the Early Universe

The unknown origin of supermassive, i.e., >10^5 $M_\odot$, black holes (SMBHs) that reside in the nuclei of most large galaxies (like M87) is one of the most intriguing frontier topics, involving both astrophysics and cosmology. The first (i.e., "Population III") stars in the universe, forming at z>20 in dark matter minihalos of ~10^6 $M_\odot$, have been considered as potential SMBH progenitors, especially if the stars form with very high masses ~10^5 $M_\odot$ (Banik, Tan & Monaco 2019). Alternative models involve formation at lower redshifts from more massive dark matter halos, i.e., the direct collapse scenario (e.g., Bromm & Loeb 2003).

Predicting the properties of SMBHs that form from Population III stars requires following: on the one hand the formation of minhalos as a result of the non-linear growth of primordial cosmic perturbations; and on the other the formation and death of Population III stars and growth of the SMBHs by continued accretion. In a previous paper (Banik, Tan & Monaco 2019) we generated dark matter minihalos using the code PINOCCHIO (PINpointing Orbit Crossing Collapsed HIerarchical Objects, Monaco et al. 2013), which is based on Lagrangian Perturbation Theory for the evolution of cosmic perturbations, and adopted a specific model where dark matter annihilation heating creates the conditions for Population III protostars to collapse into SMBHs. Models have been presented that allow sufficient numbers of SMBHs to form that can explain all the observed local z = 0 SMBHs by this single formation mechanism.

The objective of this PhD project is to investigate observational consequences of first star and SMBH formation scenarios, including predictions for very high-z quasar populations, which, along with the supermassive protostar precursors, may be detected by next generation telescopes like JWST, E-ELT, Euclid & ATHENA. Predictions will include the evolution of number counts from the highest redshift and clustering properties of SMBHs down to low redshifts, using available data to constrain models and optimize forecasts. Others steps will include predictions for the frequency of SMBH mergers that may be detected via gravitational waves, and use of state-of-the-art semi-analytic models of galaxy formation to connect these objects to the evolution of their host galaxies.

This PhD thesis is co-supervised by Prof. Pierluigi Monaco (Trieste) and Prof. Jonathan Tan (Chalmers University, Gothenburg, Sweden), with a research stay in Sweden of one year as a visiting student at Chalmers as part of the project. Interested students are warmly encouraged to contact the proponents, Prof. Monaco (pierluigi.monaco@inaf.it) and Prof. Tan (jonathan.tan@chalmers.se). A complete application must be received by **June 17th, 2020**. You can find further information about the application procedure here: http://web.units.it/dottorato/fisica/en/node/2753.

Banik, N., Tan, J. C. & Monaco, P. 2019, "The formation of supermassive black holes from Population III.1 seeds. I. Cosmic formation histories and clustering properties", MNRAS, 483, 3592

Bromm, V., & Loeb, A. 2003, "Formation of the First Supermassive Black Holes", ApJ, 596, 34

McKee, C. F. & Tan, J. C. 2008, "Formation of First Stars. II. Radiative Feedback Processes & Implications for IMF", ApJ, 681, 771

Monaco P., Sefusatti E. et al. 2013, "An accurate tool for the fast generation of dark matter halo catalogues", MNRAS, 433, 2389

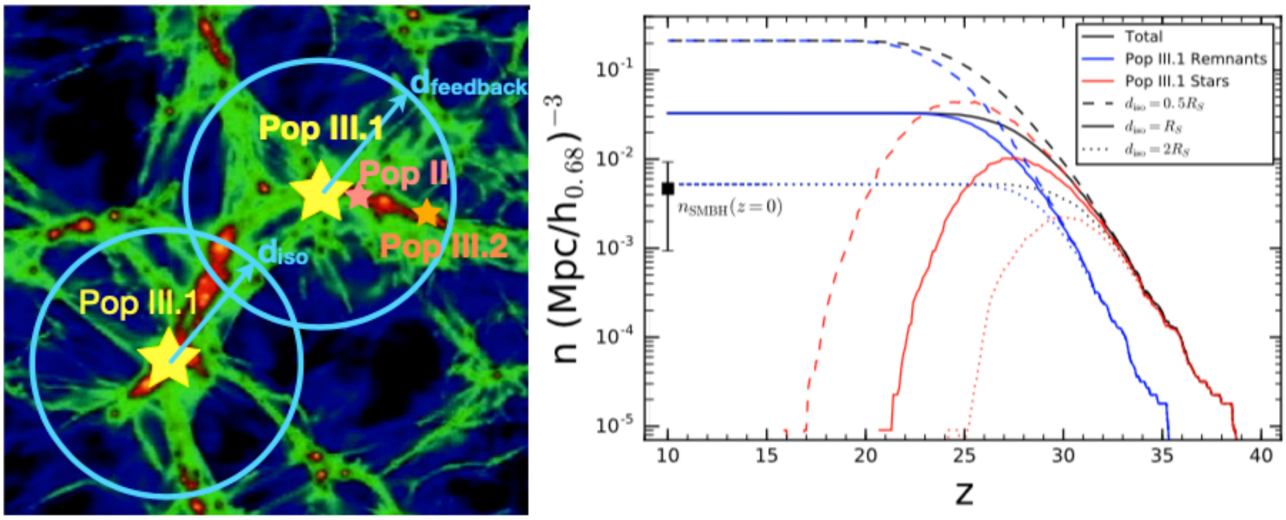

Figure 1: (a) Left: *Schematic illustrating definitions of Pop III.1 stars (McKee & Tan 2008), i.e., that are the first objects to form from metal-free gas in a local region of the universe, doing so in isolation from other astrophysical sources of feedback by a distance d_{iso}. Pop III.2 stars are also metal-free, but are affected by radiative feedback (e.g., FUV or EUV), e.g., from a Pop III.1 source that has feedback radius of $d_{feedback}$. Pop II stars are metal enriched by chemical feedback, forming in closer proximity to previous stellar generations.* ***(b) Right:*** *(from Banik, Tan & Monaco, in prep.) Evolution of the comoving number density of Pop III.1 stars and remnants for models with d_{iso} = (0.5, 1, 2)×R_S, where R_S is the Strömgren radius of a 10^5 solar mass main sequence star (given the mean density of the universe at a given redshift), here hypothesized to be the outcome of Pop III.1 star formation. The data point shows an estimate of the comoving number density of SMBHs in the local universe. This simple model can naturally explain the observed numbers of SMBHs with a single, physically-motivated formation mechanism. Such models will be used to make predictions for high z observations with, e.g., JWST, E-ELT, Euclid & ATHENA.*