CONTEMPORARY GALAXY FORMATION THEORY: Contemporary cosmological magnetohydrodynamical galaxy formation simulations take into account a wide range of physical processes, and use state-of-the-art numerical codes and take weeks to months to run on the largest supercomputers. They are incredibily sophisticated apparatus and allow us to gain deep insight into the physical processes that drive galaxy formation, including the energy connected to an accreting central SMBH. Naab and Ostriker (2017) present an up to date reivew of the major challenges for galaxy formation theory, including the desire to understand the underlying physical processes that regulate the structure of the interstellar medium, star formation, and the driving of galactic outflows.

Current state-of-the-art cosmological simulations, not limited to, but for example, the EAGLE Project (Schaye et al., 2015; Crain et al., 2015) and the IllustrisTNG Project (Pillepich et al., 2018) employ and track 10s of billions resolution elements across 100s of megaparsec-cubed volumes. For EAGLE (e.g. their L100N1504 simulation), the fundamental units of dimensions mass (M), length (L) and time (T, i.e. resolution) are $\sim 2\times10^5$ for initial baryonic particle mass, "softening lengths" of 0.35-0.7 pkpc; and and time-steps sampling $\sim$1000 years ($\sim 10^6$ time-steps across the age of the Universe) [2]. For the new IllustrisTNG "TNG100" model one has 1.4×10^6 for baryonic particle mass, and the Plummer-equivalent gravitational softening lengths $\approx$0.2-1 pkpc, and $8\times10^5 h^{-1}$ M$_\odot$ for the seed black hole mass. As such, these are extremely powerful for global galactic properties, but these simulations were never designed to explicitly address inner central engine physics.

Further powerful progress is made with the new high-resolution "zoom-in" galaxy simulations, e.g. Feedback In Realistic Environments (FIRE-2; Wetzel et al., 2016; Hopkins et al., 2017) or MUFASA (Davé et al., 2016). In FIRE-2 for example, Wetzel et al. (2016) run a cosmological scale dark-matter-only simulation is run to redshift $z=0$, an isolated DM halo is then selected, the particles are traced back to very high, $z=100$ redshift and the 'convex hull' is regenerated at high resolution (embedded within the full lower-resolution volume). The fiducial baryonic simulation contains dark matter, gas, and stars within the zoom-in region, comprising 140 million total particles, with $M_{\rm DM}=3.5\times10^4 M_\odot$ and $M_{\rm gas,initial}=7070 M_\odot$. The dark matter and stars have fixed gravitational softening lengths of 20pc and 4pc (Plummer equivalent), respectively. In these zoom-ins, particle time-stepping is fully adaptive and the shortest time step achieved is 180 years. As such, these 'zoom-in' simulations are very much on their way to resolving the scales, masses and cadences needed in order to successful model e.g. the "changing look" quasars.

However, what is remains very concerning is that even once the mass, length and timescales are computationally accessible, *we currently do not know what physical prescriptions should be directed for the central black hole and quasar engines to follow.*

For example and as described in detailed in Weinberger et al. (2017), modelling AGNs in cosmological simulations poses several fundamental challenges. First, the detailed physical mechanisms of both accretion on to SMBHs (Hopkins and Quataert, 2010, 2011; Anglés-Alcázar et al., 2013; Gaspari et al., 2013; Anglés-Alcázar et al., 2015, 2017; Curtis and Sijacki, 2015, 2016a,b; Emsellem et al., 2015; Rosas-Guevara et al., 2015) and the AGN-gas interaction (Huarte-Espinosa et al., 2011; Gaibler et al., 2012; Cielo et al., 2014; Costa et al., 2014; Roos et al., 2015; Hopkins et al., 2016; Bieri et al., 2017) are poorly understood, which makes it at present impossible to formulate a 'correct' treatment for simulations. The long-time standard physical mechanism of Bondi-Hoyle-Lyttleton accretion, i.e. that of spherical accretion onto a compact object traveling through the interstellar medium (Hoyle and Lyttleton, 1939; Bondi and Hoyle, 1944; Bondi, 1952) with the accretion rate given by $\dot{M}_{\rm Bondi}=\frac{\pi G^2 M_{\rm BH}^2 \rho}{c_s^3}$, *is known to be a considerable oversimplification.* (e.g., Edgar, 2004).

1.3 Upcoming Surveys, Instruments and Missions

Variability studies hold information on otherwise unresolvable regions in Active Galactic Nuclei (quasar). Population studies of large samples likewise have been very productive for our understanding of quasar (Lawrence,

[2] The times are spaced logarithmically in the expansion factor a such that $\Delta a = 0.005a$.