Session 7: Discussion - questions and answers

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Galaxy Evolution and Feedback across Different Environments
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Discussion Session

For this Session, Roderick Overzier invited everybody to submit questions relevant to the subject of the Symposium, that we then tried to answer during the Session. The questions and the corresponding answers - some discussed at the Symposium, and some sent by the participants after the Symposium - are listed below.

1. When and how do we expect to finally confirm what were the seed masses of supermassive black holes?

***Amirnezam Amiri*:** Understanding how super massive black holes' seeds distributed or evolved is one of the prominent keys in our knowledge in galaxy formation and evolution. There are different ways to create a super massive BH in the central galaxy region, for example: a) Direct matter collapsed on the halo when the baryonic and dark matter halo interact, gravitationally; b) Mass gathering (light elements, particularly hydrogen) as a function of time. Passing a criterion away, the mass gathered collapsed to a BH; c) Merging astrophysical BH together to make a SMBH. A good paper can be found here: https://iopscience.iop.org/article/10.1086/344675/pdf.

***Richard Bower*:** Ooooo! A tricky one: by looking for the remnants that failed to merge, but how would we find such objects? Possibly by extending the black hole mass function to lower masses, but the difficulty would be to distinguish low accretion rate objects from low mass objects. I think that the way we will make progress on this is through gravitational wave detections, particularly in the LISA era. That will be particularly well suited to answering this issue.

***Rainer Weinberger*:** Existence of specific channels: intermediate mass BHs (excluding: space based gravitational wave detectors). Excluding seed channels that produce higher mass seeds will be very difficult.

***Roderik Overzier*:** The combination of JWST and future X-ray telescopes Athena and Lynx should be able to detect the massive, direct-collapse seeds, if they exist. Shortly after their formation, accretion onto the massive seeds outshines any stellar emission from their hosts leading to strong infrared and X-ray emission. Not detecting any of such objects at very high redshifts should thus also be extremely insightful.

2. Should we believe SMBH masses at high redshift?

***Amirnezam Amiri*:** One of the highest SMBH is at redshift ∼7.5 with an 800 million solar mass (https://arxiv.org/abs/1712.01860). There are two scenarios, from my mind, to describe them: a) The available gas in the whole galaxy moves to central part as a function of short time (angular transportation or other mechanisms) and collapse to SMBH; b) Colliding or cannibalism of a satellite galaxy to central region. It seems possible we can detect more SMBHs based on their activities (∼quasars) at larger distances when our telescope facilities develop more.

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***Thaisa Storchi-Bergmann*:** One major caveat is the method used to measure these masses: scaling relations and the assumed virial equilibrium for the clouds of the Broad Line Region (BLR). It is not clear that these properties – derived for nearby targets – apply also at the early phases of the Universe. In particular, in these earlier phases, non-circular motions could be dominating the BLR kinematics, resulting in overestimated SBMH masses.

***Rainer Weinberger*:** The precise number may be uncertain, but as an order of magnitude estimate.

3. What processes may explain overmassive black holes with respect to their bulges?

***Richard Bower*:** When we see such objects in our simulations, they are the result of a more massive galaxy being stripped of their stellar mass. It is possible, however, that the black hole enters the rapid growth phase "prematurely" in a relatively low mass galaxy. While the growth of the central black hole seems supressed in most galaxies until $M^* \sim 10^{10.5}$ Msol due to the interaction with supernova-driven feedback, this suppression may sometimes fail leading to premature rapid BH growth. We need to understand this interaction better, and spotting these "exceptions" may help us do exactly that.

***Benjamin Davis*:** Sahu, Graham, & Davis (2019, ApJ, 887, 10) presented a separate, steeper central black hole mass – stellar velocity dispersion (M–sigma) relation for core-Sérsic galaxies. This substructure in the M–sigma relation reveals that dry mergers do not increase the velocity dispersion, relative to the increased black hole mass, at the pace followed by Sérsic galaxies (built through either gas-rich mergers or accretion of gas from their surroundings). Such distinctive coevolution is typically manifest in brightest cluster galaxies (BCGs) because they undergo multiple gas-poor (dry) mergers, resulting in over-massive black holes with only mildly increased velocity dispersions.

***Storchi-Bergmann*:** What about loss of mass of the galaxy outskirts due to tidal striping or harassment?

***Weinberger*:** From a simulation perspective, the only thing that happens is stripping of the host halo (reduction of stellar mass). However, I could imagine that the coupling efficiency related to AGN feedback is low in some systems, which could allow over-massive BHs. In simulations, this efficiency is postulated to be constant.

4. Does AGN feedback play an important role on shaping the SMBH mass-galaxy (or halo) mass relation or not?

***Richard Bower*:** At high galaxy/halo masses this is certainly the case: the growth of the black hole will be curtailed when the energy injection rate becomes comparable to the cooling rate of the halo.

At lower masses, below the mass of the MilkyWay, I'd say no! the effect is the other way around and the growth of the black hole is controlled by the effectiveness of the supernova-driven feedback. Just above the mass of the Milky Way, the supernova regulation breaks down and the black hole grows rapidly until its growth is curtailed by the halo mass.

The thing I like about this scenario, is that it simulataneously explains the transition in galaxy properties from late to early type and the appearance of hot X-ray corona.

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Montserrat Villar Martin**:** We do not know. The scenario is very promising and attractive. It is successful from the theoretical point of view, but the observational evidence is controversial. The lack of solid alternative explanations for several open issues related to galaxy formation and evolution (including the relation between the SMBH mass and some large scale galaxy properties) strengthens the AGN feedback scenario even more. At the same time, I have the impression that this has led to the assumption that it is the only option (at least in massive galaxies) and that if we look hard enough, we will find definite evidence for the impact of AGN feedback in galaxy evolution. Currently, theory and observations leave sufficiently broad room for interpretation to reconcile the data with this scenario (and with the opposite!). Clearly, this does not mean that it has been corroborated (anyway the goal is not to accommodate the data to the scenario we like). It is essential to constrain much better the triggering mechanism and outflow properties (masses, energies, mass outflow rates, sizes, geometries. . .) and effects to evaluate the true impact of AGN feedback in galaxy evolution in general. It is also essential to advance on the treatment of feedback in numerical simulations so that they can be compared with the observations.

Weinberger**:** It seems so, though how much is unclear.

5. What is the role of the hot halo in AGN feedback? Is it important in objects that are not part of groups/clusters?

Richard Bower**:** In the group/cluster regime, AGN feedback plays a key role as the question suggests. At lower masses, there is no hot halo for the black hole to heat (and the black hole does not undergo a sustained period of (close-to) Eddington limited accretion). Is there no hot halo because the BH haloes has limited accretion though? I'd argue that it is the other way around, and that the longer cooling times in groups/clusters allow for the creation of the hot halo that leads to a reduction in the effectiveness of SN feedback and to sustained high BH accretion rates.

Bianca Maria Poggianti**:** There is recent evidence that when a galaxy infalls into a cluster and moves at high speed within the hot intracluster medium filling the cluster, the ram pressure may cause the galaxy interstellar medium to flow towards the center, thus triggering the AGN activity. As a result, the fraction of AGN among galaxies with long extraplanar tails of stripped gas is unusually high, compared to both field and general cluster samples of galaxies. The ram pressure-triggered AGN, in turn, provides feedback that can impact a large fraction of the stellar disk: visible effects are a sharp decrease of the molecular gas content and the star formation activity, like a "cavity" that can extend for several kpc (see my contribution in these proceedings).

On the other hand, the large amount of energy injected by the AGN into the interstellar medium, decreasing its binding energy, can increase the efficiency of ram pressure stripping, possibly helping producing the striking tails of stripped gas that are observed in clusters. Of these two effects (the ram pressure causing the AGN, and the viceversa), the first one seems the dominant effect. This conclusion is reached observing that the triggering of the AGN is strongly linked with the velocity and position of the galaxy with respect to the cluster center, hence to the conditions for ram pressure stripping. This clearly does not exclude the possibility that the energy injected by the AGN contributes to efficient gas loss.

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***Weinberger*:** Many small-scale simulations show that the hot halo is the medium into which most of the AGN energy is transferred to. Thus, its existence might be crucial, not just for groups and clusters, but also in Milky-Way mass systems.

6. Does the environment play a role in shaping galaxies that are not part of a group or cluster?

***Amirnezam Amiri*:** Role of environment on galaxy evolution is an exciting topic. We can generally divide galaxies in two environments: High-density regions (cluster or groups of galaxies) and low-density regions (Isolated/void galaxies). It is well known the stellar parameters (such as star formation rate, stellar age, surface gas density) in void galaxies (or isolated galaxies) are younger than the galaxies in the crowded regions (e.g. https://arxiv.org/abs/1601.08228, https://arxiv.org/abs/1601.04092). The secular evolution can go ahead quietly and in this case the evolution of galaxies can be different. We should be aware that all void galaxies were not isolated at all. From some aspects of galaxy structure and formation at high redshift (the structure formation based on non-linearity regions) most of galaxies can interact together in time. Their evolution as a function of redshift (from dark energy effect at $z \sim 1$ to fly-by galaxy evolution) can exclude them into a low-density region.

***Richard Bower*:** An interesting question. In simulations, we certainly see galaxies that briefly interact with groups and clusters and then separate from them again. These are rare, however.

***Francoise Combes*:** Yes, this is a domain in which much work has been done in the recent years, both from observations and simulations. Simulations for instance by Bahe *et al.* (2013) show that the environment plays a role, much farther the virial radius of a cluster. Galaxies are pre-processed in cosmic filaments, before entering a group or cluster. Spiral galaxies flow along filaments towards each other to merge and form an elliptical, and the orientation of their spin is specific (Codis *et al.* 2015). We have observed galaxies in filaments around intermediate redshift clusters with ALMA, and it appears that the gas content of these galaxies reveal their environment (Sperone-Longin *et al.* 2020), We have also observed with IRAM the molecular content of galaxies around Virgo, at about 5-7 Virial radii, and there exist already significant environmental effects (Castignani *et al.* 2020).

***Weinberger*:** To some degree, though the underlying mechanism is gravity not hydrodynamics.

7. How much do you really believe the outflow rates (ionised, neutral, molecular) we estimate?

***Santiago Garcia Burillo*:** Mass outflow rates as well as momentum and energy rates suffer from large uncertainties due to inaccurate estimates of the masses, sizes and velocities of the outflowing components in all tracers. In particular, conversion factors between luminosities and masses plague the estimates of the molecular gas masses in outflows. While we normally accept the use of standard (Milky-way or ULIRG-like) CO-to-H2 conversion factors, typical of optically thick gas, when deriving masses of molecular outflows, there is now growing evidence that lower conversion factors may be more appropriate in some systems where the outflowing molecular gas is optically thin in CO lines. If this is the rule, numbers may change dramatically.

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Ric Davies: There are significant uncertainties in all aspects of the derivation of outflow rates, from the estimation of the speed itself (the maximum measured velocity in a line is taken to represent the outflow speed of all the gas), to the calculation of the mass (for ionised outflows the adopted density has a major impact; for molecular outflows the equivalent is the CO luminosity-to-mass conversion factor), to the outflow model itself (the two main classes of models differ by a factor 3 in outflow rate). Estimates of outflow rate that are based on integrated properties - as most are - have additional uncertainties, since one might expect, for example, outflow speed and gas density to vary with distance from the AGN. As such, one should treat any calculation of outflow rate as, at best, an order of magnitude estimation.

Steven Kraemer: Those based on spatially-resolved spectra are reliable, within a factor of a few. The global estimates have much larger uncertainties. However, the optical/resolved studies only sample a portion of the outflows. The largest reservoir for mass outflow may be in the form of X-ray emitting gas. But the lack of spatially resolved X-ray spectra make it difficult to determine the X-ray outflow rates. So, we have estimates of varying reliability and we are not getting a comprehensive view of the outflows.

Giacomo Venturi: I believe that they should be handled carefully, since the uncertainties on their estimation are several (arising e.g. from the density estimation, the CO-to-H2 conversion factor, the lack of spatial information) and the methods to obtain such quantities are really variable depending on the given work. For example, in Venturi *et al.* (2018) we found that by determining the mass outflow rate of the same object first from spatially resolved data and then by using the integrated information and a different recipe for calculating the mass outflow rate, the results changed by a factor of 20 between the two cases.

Weinberger: Not much.

8. What would it take to reduce outflow rate uncertainties by a factor of 10?

Santiago Garcia Burillo: High-spatial resolution combined with IFUs to build-up 3D models used to fit these observations. In molecular gas, use several lines to derive physical conditions and constrain conversion factors.

Ric Davies: Several things would help considerably: (i) using spectral and/or spatial information to constrain the outflow geometry, and hence how the measured maximum velocity relates to the actual outflow speed; (ii) for ionized outflows, a reliable way to estimate gas density is essential, and ideally one would know how the density varies with distance from the AGN; (iii) a better understanding of how outflows evolve over time (e.g. whether the outflow rate decreases with time or remains constant).

9. Is it important to have the exact feedback recipes (radiative, mechanical) in simulations of galaxy formation or only the global energy?

Richard Bower: The main challenge is to ensure that the energy that is put into the simulation is not immediately radiated. This happens because the limited resolution that we need to work at cannot reliably model the multiphase nature of the ISM. In reality, the cooling rate of hot (supernova-heated) gas can be much lower than you'd estimate from the average temperature density of a >100pc patch. Given this uncertainty, the exact

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recipe for heating is much less important than calibrating the net effective heating rate in some way.

Similar issues exist for the BH feedback, so I would optimistically think that the key is to heat the correct volume of gas by the correct change in entropy/energy. Hopefully the details of how this is done are not so important. Whether my optimism is well found is still an open question, however!

***Santiago Garcia Burillo*:** I think the effects of the various feedback recipes is expected to be dissimilar on the different ISM phases. In particular, momentum and energy is injected differently in molecular gas and this can tested observationally. The net efficiency of feedback on molecular gas may change depending on the feedback recipe.

***Weinberger*:** Energy + post-injection temperature and its timing are the key aspects to get global (integrated) galaxy properties correct; however, it is likely that internal galaxy properties are more sensitive to the exact mechanism. This needs to be explored further.

10. What quantities should be compared between observations and simulations? Wind velocity, outflow rate, kinetic energy?

***Weinberger*:** The velocity PDF might be quite helpful to determine underlying mechanisms, but it is hard to see how this alone helps to determine its impact on the galaxy. In the latter case, an energy estimate might be required.

***Storchi-Bergmann*:** From the physics point of view, the energy deposited on the galaxy should be the most important parameter. But observations are usually done for one gas phase, due to instrument constraints. Observations with multiple instruments, covering different wavelength ranges and gas phases are necessary to account for the energy deposited by outflows on the host galaxy.

11. How can <sub-pc scale simulations help to improve feedback prescriptions in large simulations?

***Weinberger*:** The main problem with feedback models on kpc scales is that it is not even clear what exactly they should produce. Small scale simulation, capturing the necessary physics should ideally be able to provide this information.

12. What kind of AGN feedback has a bigger impact on galaxy evolution in general; radiative or mechanical?

***Richard Bower*:** If my optimism truns out to be correct, this doesn't matter too much. The mechanical energy input will get converted into heat and the two schemes will look much the same, especially if they are both calibrated to match a subset of the observational data (eg., the entropy porofile of galaxy groups).

***Montserrat Villar Martin*:** This question takes for granted that AGN feedback has a significant impact in galaxy evolution which remains to be demonstrated. On the other hand, it is of course very relevant to discern the precise action of the different modes of feedback. This question poses a major challenge to understand the connection between galaxy evolution and AGN physics. At the moment, there is little observational direct evidence for AGN driven outflows to affect star formation activity in galaxies (and,

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consequently, their evolution) even for the most extreme outflows. The lack of evidence, of course, is not evidence of lack. Multiple questions need to be answered: How do AGN (and starburst!!) driven outflows affect the different gas phases in galaxies? (ALMA has been wonderful on this regard to discover and parametrize molecular outflows!) What are the precise masses, mass outflow rates, energy injection rates? What are the geometries, sizes? What are the time scales in relation to the star formation episodes? How much gas can escape the galaxy? Are we missing most of the gas affected by the outflows due to its undetectability with current technology? How frequent are radio jets in active galaxies? Do these provide an efficient feedback mechanism ?

***Weinberger*:** Mechanical feedback seems to have a substantially higher coupling efficiency.

***Storchi-Bergmann*:** From the observational point-of-view, one measures higher velocities and mass-outflow rates in the vicinity of the AGN in radiation-driven outflows occurring in gas-rich galaxies. Thus radiative feedback seems to have a larger impact in the vicinity of the AGN in such objects. Mechanical feedback, that occurs in radio galaxies, seem to have higher impact outside the galaxy, as observed via X-ray cavities produced by radio jets in galaxy clusters.

13. Why does AGN feedback always have to be so negative? Could it also, in cases, promote star formation?

***Giacomo Venturi*:** Models actually predict that AGN can also promote star formation, indeed, and in two different forms:

a) AGN outflows or jets, by compressing the molecular gas in the interstellar medium (ISM), would be able to trigger star formation (so-called "positive" feedback; see e.g. Silk & Norman 2009, Nayakshin & Zubovas 2012, Silk 2013, Zubovas *et al.* 2013, Nayakshin 2014). Observational evidence for AGN jets triggering star formation in companion galaxies was found for instance by Croft *et al.* (2006), Feain *et al.* (2007), Elbaz *et al.* (2009). Jet-induced star formation has also been observed by Crockett *et al.* (2012) and Santoro *et al.* (2015, 2016), who found star-forming clumps triggered by jet compression around Centaurus A. Observational evidence of positive feedback by AGN outflows has been found both at high and low redshift by Cresci *et al.* (2015a) and (2015b), respectively. So far, evidence of positive feedback is episodic and further observational effort is needed to assess its importance in galaxy formation and evolution, mostly by taking advantage of spatially resolved observations to uncover such outflow-ISM interactions.

b) Models predict that stars may be able to form even within the outflowing gas itself, by the effect of gas cooling and fragmentation (e.g. Ishibashi & Fabian 2012, 2014, 2017, Ishibashi *et al.* 2013, Zubovas *et al.* 2013a, Zubovas & King 2014), with potentially important implication on structural and chemical formation and evolution of the spheroidal component of galaxies and on the chemically enrichment of the circum-galactic and inter-galactic medium as well as on its re-ionization during the early Universe. Large quantities of dense and clumpy molecular gas, having the physical conditions of giant molecular clouds in which stars normally form, are indeed observed in outflows (e.g. Cicone *et al.* 2014, Aalto *et al.* 2015, Pereira-Santaella *et al.* 2016, Fluetsch *et al.* 2019). Finally, Maiolino *et al.* (2017) found first observational evidence of this new in-outflow star formation mode, by detecting the presence of outflowing gas ionised in situ by young stars and of a young stellar population with kinematics consistent with stars formed at high velocity in the inner region of the outflowing gas and then decelerated by the gravitational potential of the galaxy. Further studies (Gallagher *et al.* 2019, Rodríguez del

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Pino *et al.* 2019) have shown that such mechanism could be quite common in the local AGN population, but tricky to uncover. So, further focused observational effort through detailed observations is needed in this case as well.

***Weinberger*:** There is certainly a possibility for enhanced star formation due to increased pressure. This does not mean that the net long term effect is an increase, though.

14. Are we focusing too much on outflows in bright and rare quasars? Are these common enough to relate to every quenched galaxy?

***Montserrat Villar Martin*:** Regarding the first question, not really. The most extreme outflows are expected for AGN powers in the quasar regime. They often attract a lot of attention because sometimes they are indeed spectacular. Apart from this, I think that quasars are very relevant to understand the AGN feedback phenomenon in galaxies in general. Both theory and observations indicate that the more powerful the AGN is, the more extreme the outflows are (higher mas outflow rates, energy injection rates, etc). Thus, it is natural to expect that the most dramatic impact of AGN feedback on the host galaxies occurs in the most powerful AGN: QSOs. Let's imagine that observations contradict this and QSO outflows have little or no impact: this would question the efficiency of AGN feedback in less powerful active galaxies in general.

There are many exciting ongoing projects that cover a broad range of galaxy types, from statistical studies of very large samples to detailed studies of individual sources. This is, of course, essential since most galaxies will never go through an active phase as extreme as that of quasars. I find very interesting, for instance, the growing number of works focusing on the role of AGN feedback in low mass galaxies (<1e9 Msun), a regime that has been largely unexplored.

***Giacomo Venturi*:** Powerful outflows in bright quasars are considered the best candidates to seek the "smoking gun" of AGN feedback and study its properties. However, eventually, statistical studies involving the most common types of objects are required to determine the impact on the bulk of the galaxy population.

***Weinberger*:** They are certainly helpful to understand underlying mechanisms, but the question of abundance should always be considered when talking about galaxy populations.

15. How much should we believe the merger - ULIRG - blowout - quasar - elliptical cartoon? Are there other routes?

***Ric Davies*:** This scenario is entirely believable, but it is certainly only one possible evolutionary route. There is plenty of evidence that in the local universe, secular fuelling of AGN is the dominant mode (even if not the most spectacular); and there is evidence that this is also the case at high redshift. It is important to take into acount the differences between, for example, what causes the most luminous AGN, what generates the strongest feedback, what is the most common mode of fuelling, and what leads to the most black hole growth.

***Andrew Newman*:** I interpret this question to ask whether there are other routes to form ellipticals. While dry major mergers lead to formation of ellipticals, simulations show

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that this is not necessarily the outcome of a major merger when the merging galaxies' gas fraction is high. Thus, when considering massive galaxies that quenched early, there is reason to suspect that even if they experience a major merger that triggers a quasar phase and ends star formation, the end product may still be disk-dominated. There is support for this observationally: the ellipticity distribution of quiescent galaxies shifts to flatter values at high redshifts, suggesting a larger population of disks. The stellar-to-dynamical mass ratio in $z \sim 2$ quiescent galaxies correlates with ellipticity in the manner expected when viewing rotating disky galaxies at various inclinations. And the four $z > 2$ quiescent galaxies with spatially resolved kinematics are all disk-dominated "fast rotators" with V/sigma values 5-10x higher than classical ellipticals. All these observations suggest that quenching and elliptical formation are disconnected processes, at least in the gas-rich high-z universe, and that morphological transformation comes later. Most likely it occurs gradually through the same series of minor mergers that are commonly invoked to explain galaxies' evolution in size after quenching.

***Weinberger*:** It still is a possible idea, but I would consider it quite plausible that there are other routes to form quiescent galaxies. It is also likely that there exists quasar activity without quenching.

16. We have seen that outflows can originate from the accretion disk, or by the radiation pressure on the galaxy gas disk. How do we reconcile the two?

***Weinberger*:** These are not contradicting each other, but one has to be careful how to interpret outflows at different scales.

17. How do we reconcile massive molecular outflows observed on large scales with the less massive ionized flows on small scales?

***Santiago Garcia Burillo*:** The AGN winds are less massive than molecular outflows, but their typical velocities are much higher (by roughly an order of magnitude). The ionized winds are nevertheless the key actors by being powerful enough to launch more massive molecular outflows due to radiation and/or thermal pressure.

***Weinberger*:** A very dynamic multi-phase gas with a lot of entrainment. Maybe metal abundances can help with the interpretation.

18. Is AGN feedback sufficient to quench all star formation in massive galaxies at high redshift, or do we need other ingredients?

***Giacomo Venturi*:** So far, observational evidence from individual objects seems to show that outflow can be capable of shutting down star formation locally, but the overall SFR in the rest of the host galaxy remains still high. Clearest observational evidence for the impact of AGN feedback in single objects comes in the local Universe in the steadier "kinetic" mode through the action of jets which heat the gas halo around massive red galaxies at the centre of galaxy clusters, preventing gas cooling and re-accretion on the galaxy, and thus further star formation. Results from statistical studies are controversial, but clear and conclusive evidence that AGN feedback is able to shut down star formation is still missing. However, for instance, the feedback mechanism might act on different timescales than those on which we observe strong AGN activity and powerful outflows,

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with star formation resulting to be shut down only at later times, with a "delayed" feedback mechanism.

***Weinberger*:** It seems sufficient. At least I am not aware of any massive inconsistency in the simulated AGN population in simulations that rely on AGN feedback only.

19. How exactly do we define an "outflow" and how do we measure the effect it has on star formation?

***Giacomo Venturi*:** This is a debated topic. Some people define as outflow a motion which does not follow rotation in the galaxy disk and moves outward from the galaxy, and is not either in inflow or belonging to tidal tails or to stripped material (which can be tricky to distinguish observationally if good spatial information is lacking). Some define a velocity threshold with respect to systemic above which the gas is considered as in outflow and/or define a velocity dispersion threshold above which the emission in line profiles is considered as stemming from an outflow. Other even define as outflow only material moving outwards from the galaxy which has a velocity higher than the escape velocity from the galaxy (or galaxy halo) gravitational potential, which narrows down a lot the outflow candidates. The effect of outflows on star formation can be seek in different ways. Either in a direct way, e.g. by searching for regions of the galaxy where star formation appears damped in spatial correspondence with outflowing material, or through statistical studies investigating if star formation in the host (in the form of SFR, sSFR, SFE etc...) appears to be lowered in presence of outflows compared to cases without outflows. However, finding clear evidence may be tricky if the process of star formation quenching by outflows acts on different timescales than those in which outflows and intense star formation co-exist ("delayed" feedback) or if it operates on longer timescales through many outflow episodes with at a steadier and less intense pace, rather than through a single really intense blow-out phase.

***Weinberger*:** Not sure the effect on star formation is 'measurable' on an individual galaxy.

20. Is it necessary for feedback to expel the gas from a galaxy/halo for it to have an effect on the host galaxy?

***Richard Bower*:** I think the dominant effect is to cut off the supply of further cold gas by disrupting the cold stream as they pass through the hot halo of the galaxy. Supernova feedback is able to quickly heat/expel the gas that remains in the galaxy.

***Santiago Garcia Burillo*:** Not necessarily. Feedback can stabilise molecular gas by injecting kinetic energy that is eventually converted into turbulence. This will inhibit star formation for a while. A significant delay of the star formation process in the system, without having to resort to expelling the gas, is another form of feedback.

***Weinberger*:** Depends on mass of the galaxy/halo.

21. At what redshifts or in what environments does radio lobe-Xray cavity interaction become important?

***Weinberger*:** Might be as low as Milky-Way mass. Future soft X-ray observations will hopefully tell.

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22. How common are the small scale radio jets in QSOs or galaxies in general?

***Montserrat Villar Martin*:** There is evidence for a compact relativistic jet in the Milky Way. This opens the possibility that SMBH driven jets exist in many galaxies, even with such low levels of nuclear activity that we consider them "inactive".

Different studies have shown since the 1980's that Seyfert galaxies and LINERs often host compact (∼10−100 pc, sometimes larger) jets. We do not know whether this is the case for QSOs also. The nature of the radio emission in radio quiet quasars (RQQ, ∼90% of all QSO) is still a matter of debate. It is not clear whether it is dominated by star formation in the host galaxy or by non thermal emission due to processes related to the nuclear activity. Some works suggest that the relative contribution of AGN related processes (including jets) to the radio emission in RQQ increases with radio luminosity. Even when the radio emission has a clear AGN origin, it is often difficult to discern the precise mechanism that produces it (e.g. jets/lobes/hot spots vs. relativistic electrons in wide angle quasar outflows). Moreover, the fact that the radio emission is consistent with star formation does not exclude the existence of jets.

***Giacomo Venturi*:** While jets in historically known as "radio quiet" sources were usually considered not being capable of affecting their host galaxies, as opposed to the much more powerful and extended jets in "radio loud" objects, recently this paradigm has been challenged, with the discovery of low power jets in radio quiet sources driving outflows and interacting with the ISM of the galaxy in more and more objects (e.g. Combes *et al.* 2013, García-Burillo *et al.* 2014, Morganti *et al.* 2015, Oosterloo *et al.* 2017, Jarvis *et al.* 2019). Discriminating if a "radio quiet" source actually hosts a small-scale jet or not requires high spatial resolution observations to resolve the small scales. Complete high-resolution studies of galaxy samples are thus necessary to determine how common these small-scale low-power jets are. Moreover, though synergies with observations in other bands revealed that they seem to be able to drive outflows or turbulence throughout the host galaxy, so far it is still not clear at which extent they are capable of affecting the gas reservoir in the host and its star formation processes. Being a recent topic, more of such multi-band detailed works are necessary to better investigate the phenomenon and assess its role.

***Weinberger*:** Seem very abundant.

23. Is the small-scale feedback they drive enough to disrupt growth?

***Weinberger*:** Might certainly limit it to a certain degree.

24. Do we worry enough about the importance of AGN variability?

***Santiago Garcia Burillo*:** We should worry. Outflows may sometimes mimic the AGN variability or the duration of a complete 'AGN cycle' to some extent. Some relic outflows are being discovered in systems with no current AGN activity. Different regions in spatially extended outflows do have different associated time-scales and they can reflect different stages of the AGN activity.

***Ric Davies*:** Not enough by far. There have been important papers published about this topic. But still any comparison of active and inactive galaxies needs to allow for the fact that an inactive galaxy might be in a short 'off' phase during a longer period of

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stronger activity, or it might have been in a low activity phase for a long period. In the former case, other aspects of the galaxy may still be very similar to an AGN; while in the latter case they may be quite different. One should also consider whether the fuelling path (via secular evolution or minor/major merger, etc) and environment (which might help or hinder these fuelling paths, or have little impact) has an impact on long vs short term variability.

***Weinberger*:** In the context of interpretation of AGN luminosities, it is likely very important. With regard to AGN feedback and large-scale outflows not that much.

25. Do observations of luminous AGN with massive star formation imply that AGN feedback is not so important?

***Giacomo Venturi*:** Not necessarily. First, more than focusing only on the absolute SFR, it is important to also consider for instance the specific SFR (sSFR), its efficiency (SFE) or the departure of the source from the star formation main sequence. In some case also, AGN triggering may be associated with large quantities of material being funnelled to the galaxy centre and gas mixing (e.g. by merging processes), leading in parallel to strong star formation processes as well. Moreover, the fact that current star formation seems to be unaffected by AGN does not necessarily mean that they are not important, as their feedback effect might arise at later times, through a "delayed" feedback mechanism, or on longer and steadier timescales rather than in a fast and intense phase, maybe through the cumulative effect of multiple AGN episodes and outflow events, thereby with mechanisms more difficult to detect observationally.

***Weinberger*:** No.

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Roderik Overzier


Tiago Ricci and Ana L. Chies-Santos

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Travis Fischer

Montserrat Villar Martin

Cristina Ramos Almeida

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Poster-Sessions Photos

Santiago Garcia-Burillo, Francoise Combes and Keiichi Wada

Anelise Audibert, Miriani Pastoriza and Natacha Dametto

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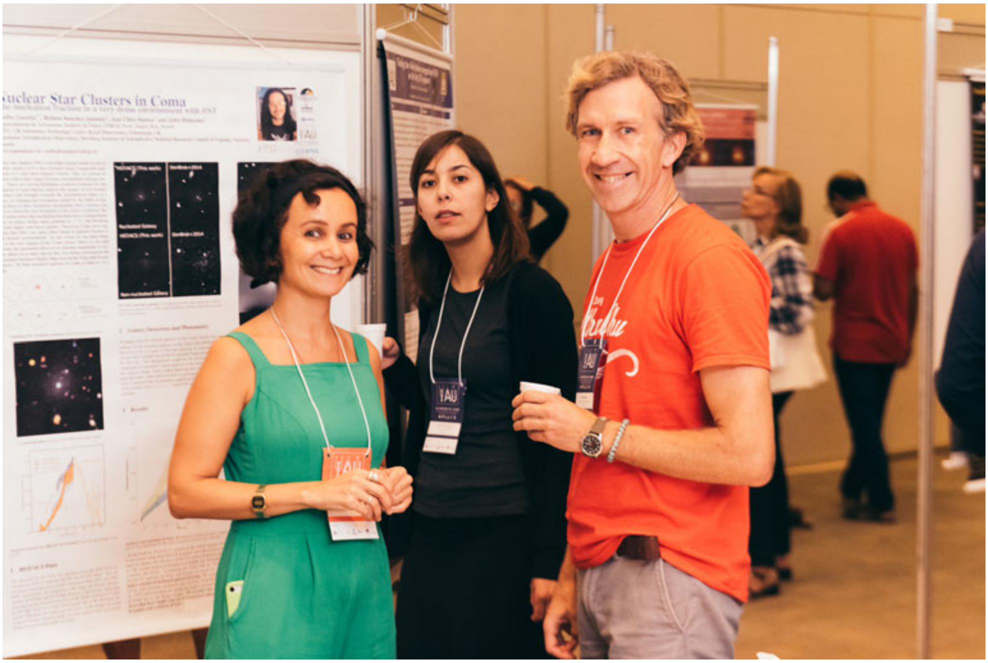

Ana L. Chies-Santos, Sandra Raimundo and Michael Beasley

Thaisa with Miriani Pastoriza and Eduardo Telles: Miriani was Thaisa's PhD advisor and to this date a guide and mentor for the Astronomy Department of IF-UFRGS.

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