EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

ESF Exploratory Workshop

COSMOGONY of AGN:

Unifying approaches for the next decade

Brindisi, Italy, 31 August - 4 September 2010

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SCIENTIFIC REPORT

1. Executive Summary

The ESF exploratory workshop “Cosmogony of AGN: unifying approaches for the next decade” took place in Brindisi, Italy, from August 29th till September 4th, 2010. The exploratory workshop was attended by 29 participants from 9 European countries (Czech Republic, France, Germany, Greece, Italy, Poland, Spain, The Netherlands, United Kingdom), who gathered to discuss the current status of our understanding of Active Galactic Nuclei (AGN).

Active Galactic Nuclei are the signposts for growing supermassive black holes within galaxies. Observationally, they are defined as the compact, bright emission from the nuclear region of a galaxy that spans the entire electromagnetic spectrum, from the radio band to gamma-rays.

The workshop was organized following three guiding principles: i) to bring together scientists working on the same topic using different methods and observational techniques; ii) to focus on recent results and open key questions and iii) to map out the most effective observational and theoretical strategies needed to address the most fundamental open issues in the field.

The sessions were arranged according to an approximate order that proceeded from the study of the regions very close to the black hole to finish with an assessment of the role of AGN for their large-scale environment. We tackled the following topics:

- Probes of the inner regions of accretion discs
- Outer accretion discs, Broad Line Region, SgrA*
- AGN jets and jet-disc connection
- Obscured AGN and population synthesis
- Host galaxy-AGN connection
- The potential for future missions

Extended discussions were organized at the end of each session, which were all lively and productive. The set of key questions that were gathered before and during the workshop stands as an accurate picture of the state of the art of the field and as an indication of the probable directions of investigation in the near future. Furthermore, a few topical areas of intense debate were covered during the meeting. We summarize below the main results in these areas:

- We have identified the study of **black hole spin** distributions (both in stellar mass and supermassive black holes) as one of the main fields where we should concentrate the observational and theoretical activity in the near future. Improvement will be needed in sensitivity and calibration accuracy of the next generation of X-ray observatories, as well as, on the theoretical side, in the modeling of the often complex geometry of the inner regions of the accretion flows and the surrounding structures.
- Indeed, despite its many successes, the classical **theory of relativistic accretion discs** leaves open a few fundamental questions which were left unanswered in more than 30 years of X-ray astronomy, concerning the nature of the disc viscosity and the inner structure of the accretion flow. Numerical simulations have provided great insights into the nature of viscosity, but the interplay of the various instabilities in real flows is not clear yet. During the meeting we have discussed new methods to use the observed properties of variability from accreting black holes to constrain the physical state of the accretion disc.
- A large fraction of the discussions were focused on the role of AGN for the evolution of the galaxies they reside in. A great deal of activity has addressed the issue of the **obscured AGN population**. Unfortunately, the current census of obscured AGN is far from complete, and the various techniques devised in order to draw a more comprehensive picture of obscured AGN have been discussed during the workshop. Two

complementary approaches that cold potentially lead to a breakthrough in the field are observations in the hard-X-ray band with the upcoming satellites NuSTAR and Astro-H, and the search for outflowing molecular gas with ALMA.

- There are, however, also indirect probes of the role of black holes' growth for galaxy evolution. The most widely used is the study of the so-called **scaling relations**, and of their cosmological evolution. The commonly adopted assumption is that they represent a relic of an epoch of rapid black hole and galaxy assembly, and is the result of the feedback action induced by the copious energy release from the central AGN. During the workshop such a view has been challenged by new models and simulations that show instead how local scaling relations may just be the statistical outcome of the process of hierarchical merging of structure in a ΛCDM Universe. This may have far-reaching consequences for our understanding of the role of black holes in galaxy formation, which were discussed in detail during the meeting.

The meeting was deemed a great success by almost all the participants. We believe we succeeded in creating a network of European astronomers interested in the various facets of black hole astrophysics and ready to accept the importance of multi-wavelength, multi-method approaches to the study of these fascinating objects.

Follow-up activities have been broadly divided into three steps:

1) A **report** to the wider community of the large body of accumulated knowledge emerged from the workshop;
2) The production and **dissemination** of a pedagogical/explanatory tool in the form of a 3D interactive graphical model of the symbiotic AGN-galaxy system and finally
3) Future **action** in the form of coordinated multi-wavelength observational campaigns to be organized and carried out at the European level.

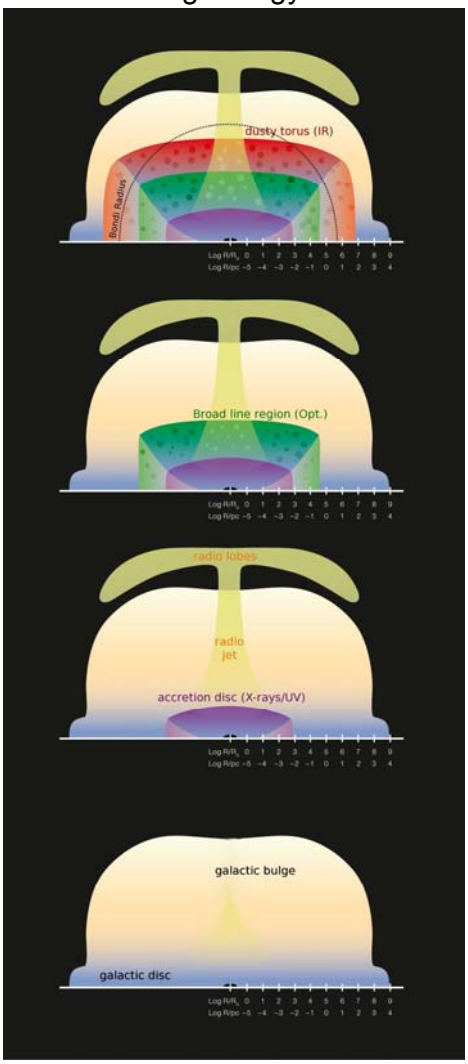
2. Scientific Report

2.1 Introduction

The fundamental paradigm established in the last two decades assumes that accretion of matter onto supermassive black holes (SMBHs) powers the strong energy release observed in Active Galactic Nuclei (AGN) and Quasars. Starting from this paradigm, the classical unification scheme relocates the various families/types of active galactic nuclei within a single scenario in which the orientation of the emitter-absorber-observer system is responsible for the different spectral properties exhibited.

In recent years the research on AGNs has undergone a veritable renaissance, since it was realized that the growth of black holes and the accompanying release of accretion energy are closely related to structure formation in the Universe. However, the classical unification scheme does not yet include any evolutionary aspects of AGNs. These start only to be addressed in so-called super-unification schemes. Such global models attempt to coherently explain accreting black holes over a broad range of masses and accretion rates. Within such schemes, distant Quasars, nearby AGNs, dormant SMBHs (like the one at the center of our Milky Way), and stellar mass galactic black holes (GBHs) are studied as members of a single class of astrophysical objects related through physical scaling relations and evolutionary tracks. The unifying physical ingredient of super-unification schemes is the mechanism of accretion onto a black hole in all its aspects.

The further development of super-unification schemes and their connection to the accretion process were the main motivation for the proposed workshop. We elaborated on the most promising observational approaches and the relevant theoretical studies that may shed light on the physical properties of AGNs at different spatial scales and at different stages during the growth of massive black holes in the Universe.



A series of schematic, logarithmic views of an AGN-galaxy system (Merloni, ESO graphics)

The meeting was organized into 5 scientific sessions, covering a broad range of topics, theoretical and observational. The various topics were broadly divided according to both the physical scale considered and the experimental techniques used to probe it.

2.2 Session1: Probing the inner regions of accretion discs

One of the main research goals in the field of accreting black holes is to characterize and understand the physical processes arising in the innermost regions of the accretion flow, where most of the radiative output is generated. Understanding the inner accretion flow geometry is mandatory if we want to determine the physical parameter of the system, and derive constraints on the properties of space-time in the strong gravitational field around a black hole. Of particular importance would be the possibility of measuring the spin magnitude and its direction with respect to that of the accretion flow. The meeting begun with a review of the current status of our understanding of the innermost regions of black hole accretion flows. **M. Guainazzi** (ESA, Spain) argued that the detection of Special and General Relativity effects through X-ray spectroscopy is an inescapable consequence of our AGN structure model and discussed to what extent this prediction is fulfilled once well-defined, unbiased and complete AGN samples are considered. Current X-ray telescopes have been pushed to their limits in terms of accuracy and sensitivity, but our ability to measure BH spin is still severely limited. This indicates clear directions to be followed by the next generation of instruments.

V. Karas and **M. Dovciak** (Academy of Science, Czech Republic) presented detailed theoretical models for the spectral line shape produced in relativistic accretion discs around black holes. They showed how the constraints on the physical parameters of any observed system (such as inclination to the line of sight, black hole spin, etc.) are affected by the angular distribution of the disc emission and on the actual geometry of the X-ray emitting 'corona'. Wide exploration of such, more realistic, models is therefore crucial for future "high-precision" X-ray spectrographs.

While the first few contributions focused on the powers of X-ray spectroscopy for testing General Relativistic effects in astrophysical black holes, **P. Uttley** (Univ. of Southampton, UK) and **I. Papadakis** (univ. of Crete, Greece) discussed the merit of combining spectral and timing studies of variable AGN. It is indeed the case that current X-ray telescopes are able to collect enough photons from bright, nearby active galactic nuclei to study the variability of the sources on dynamical timescales, or shorter. Studies of variability across the observed spectrum demonstrate that AGN show clear evidence of both intrinsic variability of the accretion disc (instabilities) *and* X-ray heating of the disc by the corona. In the case of black hole X-ray binaries, their 'hard state' discs appear unstable and may generate low-frequency (all) variability. This led Uttley to the following conjecture: in accreting black holes all continuum variability (including that from the jet) is caused by accretion disc instabilities. However, stellar mass black holes in their 'high-soft' states show very stable discs, differently from what observed in AGN. This may be a direct indication of mass-dependent physical instability in accretion flows, which were further discussed in session 2 (see below). The key issue of the "scalability" of accretion properties from stellar mass to supermassive black holes was also the subject of Papadakis presentation, where he presented preliminary (and, so far, inconclusive) searches for clear relativistic signals in the variability patterns of two bright AGN.

The session, like all those following during the meeting, was closed by an open discussion, which revolved round the few key open questions raised during the presentations. We list them below:

2.2.1 Key questions to session 1

- Do uncertainties in the line intrinsic emissivity influence significantly the current black hole spin estimates?
- Do timing properties simply map the geometry of the regions close to the black hole, or are we missing some important factors?
- Do we have compelling statistical evidence to modify our view of the accretion flow in the innermost 20 Schwarzschild radii around the black hole?
- How does the X-ray source operate, and can we see any evidence for General Relativistic effects in the X-ray flux variability light curves?
- What is the nature of the X-ray corona of accreting black holes?

2.3 Session 2: Outer accretion discs, broad line region, Sgr A*

The issue of variability from accreting black holes was further analyzed in the next session, following a more theoretical approach. **B. Czerny** (N. Copernicus Institute, Poland) gave an in-depth look onto the various instabilities predicted by the theory of accretion discs. If, on the one hand, it is now commonly accepted that the mechanism driving the viscous evolution of an accretion disc is the so-called “Magneto-Rotational Instability” (MRI), there are still uncertainties in the connection between the MRI-driven turbulence and the (lack of) variability in ‘high-soft’ state black holes, where the disc emission is most prominent in the observed spectra. Together (or sometimes in competition) with the MRI, different kinds of major instabilities are expected to work in accretion discs. In the innermost part, where radiation pressure dominates, a limit-cycle type of behavior is expected, depending on the exact nature of the viscous transport of angular momentum. In this context **A. Janiuk** (N. Copernicus Institute, Poland) presented current state-of-the-art models of slowly rotating accretion and ejection flows around SMBHs. She pointed out that such hydrodynamical flows can reveal the relevant instabilities, notably the radiation pressure instability. In the discussion following Janiuk's talk she emphasized that, while recent results are promising, further development of the dynamical modeling is necessary, notably to understand if instabilities can trigger limit-cycles of AGN activity. **A. Roszanska** (N. Copernicus Institute, Poland) focused on the constraints that can be put on AGN outflows either from variability studies or from spectral analysis and radiative transfer modeling. The field of UV/X-ray spectroscopy of AGN outflows suffers from the key problem that it is yet impossible to determine with enough precision either the overall geometry or the distance of the outflow material to the central source. Both of these issues complicate an estimation of the kinetic power in AGN winds and thereby the possible impact on the environment of the central engine. **R. Goosmann** (Strasbourg Observatory, France) gave an overview of what can be inferred from polarization observations of AGN. Pointing out that polarization is particularly sensitive to the emission and reprocessing geometry of the complex AGN environment he summarized past crucial results and gave an outlook on the prospects of upcoming X-ray polarimetry missions for AGN research. To fully benefit from the analytical power in polarimetry the further development of complex, time-dependent polarization models is necessary.

The session closed with two presentation on the SMBH at the center of our galaxy, Sgr A*. Although Sgr A* has a very low accretion rate, its proximity makes it a particularly suitable probe for accretion and ejection phenomena around SMBHs. **H. Falcke** (Radboud Univ. Nijmegen, The Netherlands) presented recent breakthroughs in measuring the size of Sgr A* at various radio frequencies using VLBI. The highest frequency measurements approach the expected size of the black hole shadow, while future sub-mm measurements

should be able to even measure the size of the black hole's event horizon. The radio observations reveal a systematic time lag between different radio frequencies. Combining size and timing techniques, it is thus possible to constrain flow speed and direction of magnetized plasma flows in the immediate environment of Sgr A*, i.e. on a scale of a few to tens of gravitational radii. The radio data are being confronted to GRMHD models and turn out to be consistent with an accelerated jet that is connected to an accretion flow. Moving towards the larger environment of Sgr A*, **G. Ponti** (Univ. of Southampton, UK) gave a presentation on the history of its activity over the past thousand years, a real 'tour de force' in archeo-astronomy! Analyzing the systematics of the X-ray reprocessing in different molecular clouds around Sgr A*, Ponti traces back past luminosity changes and concludes that Sgr A* was by a factor of 1000 brighter only 100 years ago, while it has never exceeded an Eddington accretion rate of ~2×10^{-4} during the second millennium.

2.3.1 Key questions to session 2

- Is the propagation model for disc variability correct? Are there observed counter-examples?
- Can we see radiation pressure instability at work in black holes accretion discs?
- What is the nature of the (giant or small) outburst of "dormant" SMBH? Do these events fit in the super-unification schemes?
- Can we develop geometrically and dynamically accurate, multi-wavelength models of AGN and can we evaluate them in a useful manner by past, current and near-future observations?

2.4 Session 3: AGN jets and jet-disc connection

Although black holes are very simple mathematical entities, they come observationally in a large variety of flavors, especially in the family of AGN. Many scientists are currently working to test the possibility of generalizing mathematical mass-scaling relations to the accretion/jet physics, in order to allow a direct comparison between stellar mass and supermassive black holes. In session 3 we discussed the scaling analogy between GBH and AGN in detail. The session started with a quick introduction to the distinct accretion states of black hole X-ray binaries (XRBs) by **E. Koerding** (CEA Saclay and Univ. Paris VII, France) and the claim that also AGN should present transitions from a state to another depending on their accretion rate, but given the impossibility to observe it directly as in XRB (an outburst in AGN would last millions of years), the use of scaling relations is fundamental. Indeed, for objects of different black hole mass, it is possible to connect XRBs to AGN and other accreting objects, via scaling observables properties with the mass of the object, the liberated power in the accretion flow and the accretion state. The correlations between the radio and X-ray emission in hard state XRBs and AGN have led to the discovery of the Fundamental Plane (FP) of black hole accretion, linking accretion-driven radiative attributes to black hole mass. However, it has been shown that different objects follow different FP relations, suggesting that the global physical picture is still unknown. In her contribution, **S. Markoff** (Univ. of Amsterdam, The Netherlands) stressed again the similarity between XRBs and AGN, supported by the analysis of their spectral energy distribution for which the same models can be applied to the two class of accreting objects. From a theoretical point of view, magneto-hydrodynamical (MHD) models are necessary in order to explore the relationship between accretion inflow, jet launching and particle acceleration. Moreover, it was suggested that a derivation of models of hard state coronae should contain strong magnetic fields and bulk motion. An alternative approach has been presented

by **J. Malzac** (CESR Toulouse, France), which uses the wealth of accurate data of one of the best studied black hole in the universe, Cygnus X-1, to constrain the models of black hole accretion and ejection. In particular, the modeling of high-energy radiation processes allows to constrain important physical parameters of the corona, such as the strength of magnetic field, or the temperature of the ions, values which appear to challenge current accretion models. The jet properties and contribution to the X-ray spectrum were also discussed, suggesting that the bulk of the X-ray emission is not produced in the jet while the jet could contribute at higher energy (e.g., TeV). The relationship between the jet power and BH spin in XRBs was discussed by **R. Fender** (Univ. of Southampton, UK) and no evidence for any correlation between the properties of the jets and the (few) reported spin measurements was found. This is an important, albeit still preliminary, result, as many theoretical models invoke extraction of rotational (spin) energy from a black hole as the main mechanism responsible for relativistic jet acceleration. If we then believe in the analogy between XRB and AGN, Fender concluded that the spin cannot be the only driving parameter for the origin of a jet from a supermassive black hole, and the consequent radio-loud AGN appearance.

The strongest radio-emitting AGN can indeed be studied at very high angular resolution, to better understand the physical properties of their jets. Radio interferometric observations of AGNs, with particular emphasis on the Very-Long-Baseline Interferometry (VLBI) observations, have made possible significant advances in jet astrophysics as reported by **M. Perez-Torres** (Inst. Astrofisico de Andalucia, Granada, Spain) who extensively summarized our knowledge of AGN jets at high (milliarcsecond) resolution. The quest for higher sensitivity of high-resolution radio telescopes will undoubtedly bring new insights into the physics of particle acceleration close to a black hole. Improved future radio and mm-VLBI facilities will allow meaningful statistical studies of AGNs, yet many advances will come from very deep observations of the best targets.

The capabilities of VLBI observations applied to AGN studies were further discussed by **C. Mundell** (Liverpool John Moores Univ., UK) and **F. Panessa** (INAF-IASF, Rome, Italy). Mundell showed that radio observations of nearby AGN taken at two epochs reveals possible variation in the nuclear radio flux density, suggesting that all Seyfert galaxies (i.e. nearby AGN of moderate power) may exhibit variation in their nuclear radio flux density and may experience intermittent periods of quiescence and nuclear outburst. Radio emission is detected at any level in local AGN, as presented by Panessa, even in the faintest local nuclei, displaying different radio properties, from flat to steep or inverted spectra, low and high brightness temperature, suggesting different physical processes acting in their sub-pc scale regions.

The session was closed by an intense discussion related to the accretion efficiency in hard states XRB, the cause of the substructure in the fundamental plane and the jet and X-ray corona relation; we summarize below the most pressing questions emerged from the discussion.

2.4.1 Key questions to session 3

- What is the role of the Black Holes' spin?
- Is there really a radio loud/radio quiet divide/dichotomy in AGN or is it all just an illusion?
- Is there really any evidence for spin-powering of jets, and if NO is a serious possibility, then are all the numerical simulations going down the wrong path?
- What is the nature of the jet-disc connection?
- What can VLBI do for you in AGN/jet related studies?

- To what extent does mass-scaling hold in accretion physics, in the face of clear environmental differences?

2.5 Session 4: Obscured AGN and population synthesis

One of the main causes of the baffling diversity of observational characteristics in AGN is the presence and properties of obscuring material along the line of sight. **S. Bianchi** (Univ. Roma 3, Italy) summarized the fundamental ingredients of so-called Unified Models of AGN, according to which most of the observed differences are due to the orientation with respect to the line of sight of an axisymmetric obscuring structure (a 'torus') surrounding the nucleus. Such orientation effects are still considered to be important, however the obscuring medium can be placed at different scales (dust lanes, torus, BLR) in different objects. The classical torus is required in many sources, but its covering factor likely depends on luminosity. Overall, the BLR and the torus are likely part of a smooth continuum of cold matter, with the sublimation radius separating an inner dust-free from an outer dusty region. At low Eddington ratios, such matter may disappear altogether, producing the so-called 'true' or 'naked' type 2 objects. The role of absorption is also fundamental in AGN evolution as discussed by **E. Piconcelli** (INAF-Osservatorio di Roma, Italy). Indeed, an early dust-enshrouded phase of quasar activity is invoked by the most popular models of SMBH/galaxy co-evolution. In this contribution, three different observational evidences in favor of this expected AGN phase are proposed: (i) the discovery of obscured AGN pairs in merging systems, since galaxy mergers are key driving factors of galaxy evolution in hierarchical models; (ii) the existence of buried luminous quasars in high-z dust-obscured galaxies; and (iii) evidence of AGN feedback on host galaxy properties of nearby, powerful obscured quasars, through the detection of giant molecular outflows in AGN. **D. Alexander** (Durham Univ., UK) pointed out that X-ray surveys often miss the most heavily obscured systems and that, in general, the process of AGN identification remains a considerable challenge, as significant absorption can come from both the host galaxy and the AGN itself. He suggested that new surveys with the recently launched *Herschel* FIR observatory, combined with *Spitzer* data can significantly improve the accuracy of AGN and star-formation decomposition in the infrared band, allowing the AGN component to be isolated in a large number of IR-selected galaxies. Closing on a bright note for X-ray astronomy, Alexander reminded that the improved sensitivity of the upcoming *NuSTAR* satellite should provide a significant leap forward in obscured AGN detection (see also Session 6). The role of the high-redshift (z>3) AGN, discovered by multi-wavelength identification campaigns from medium-deep and deep X-ray surveys, has been discussed by **M. Brusa** (MPE Garching, Germany) within the framework of X-ray Background synthesis models and semi-analytic models of galaxy formation. She has shown that, for the first time, it is possible to provide sizable samples of z~3-4 X-ray selected Quasars. Because there are strong differences in the predictions of the expected numbers of very high-redshift AGN in the existing cosmological models, future X-ray missions and multi-wavelength campaigns will be able to properly sample this population and test current galaxy formation models. The session ended with a contribution from **X. Barcons** (Inst. de Fisica Cantabria, Santander, Spain) who summarized our knowledge about XRB and SMBH growth models, pointing out that, despite the many on-going efforts to search for it, there is currently no clear evidence of merger-driven AGN activity, and that our uncertainties in high-z AGN and SMBH seeds are still huge. The future IXO mission would significantly increase the number of z=6-10 AGN, trace the spin evolution and characterize the feedback process at early epochs.

2.5.1 Key questions to session 4

- Can we put observational constraints on the formation (and growth) of the first black holes?
- Is the kinetic energy output of radio AGN an important source of feedback in galaxy formation? For which galaxies and at which cosmic epochs is it most relevant?
- Can the observed AGN population produce the feedback required in galaxy evolution models?

2.6 Session 5: Host galaxy AGN connection

The final session focused on AGN evolution and the relation between active nuclei and their host galaxies on cosmological time scales. An important discovery was made about 10 years ago, when a firm relation between the mass of central SMBHs, M_{BH}, and the velocity dispersion σ, of the stellar bulge population in their host galaxies could be established. We now know that such a M_{BH} - σ relation goes along with other scaling relations between black hole mass and properties of the host galaxies and that these relations could evolve over cosmological time scales. **S. Komossa** (MPE Garching, Germany) compared the properties of rapidly growing SMBHs of high- and low-redshift AGN, showing that they populate different regions in the M_{BH} - σ plane. Another manifestation of the evolving scaling relations over cosmological time is given by a relative lack of type-2 (obscured) objects at high redshift, i.e. in the younger universe. In this context, Komossa pointed out the possibility of gravitational recoil following black hole mergers. If a SMBH is subject of gravitational recoil it might move out of the funnel of the obscuring torus, but still carrying its broad line region with it. When this happens, a formerly type-2 object can transform into a type-1 (unobscured) AGN, independently of the viewing angle towards the object. **K. Jahnke** (MPIA Heidelberg, Germany) presented results of cosmological LCDM models that do not confirm any causal relation between M_{BH} and the mass of the stellar bulge. While such a relation is observed, the ΛCDM models suggest that it is rather a statistical outcome that does not point out any intrinsic co-evolution of SMBHs and stellar bulges. According to Jahnke's models, subsequent dark halo and galaxy mergers can produce the observed relation between M_{BH} and galaxy bulge mass for a vast range of initial model conditions at early cosmic times. If this is true, the observed M_{BH} – bulge relation does not constrain the physics of AGN-galaxy co-evolution, as previously thought. On the other hand, it is expected that AGN feedback on the host galaxies and the intergalactic medium is an important, yet not understood element in the co-evolution of SMBHs and their host galaxies. Such feedback may appear as kinetic energy output in strong AGN winds or as radiative feedback. As for the kinetic component, **E. Costantini** (SRON Utrecht, The Netherlands) reviewed the observational constraints on the efficiency of AGN winds. She concludes that current knowledge on the geometry and structure of the winds is too poor to put any reliable constraints on AGN feedback. Properties of the wind like its density structure; location, geometry and covering factor can only be determined indirectly and thus also depend on an underlying radiative transfer model. Costantini suggests conducting long-term, multi-wavelength observations of AGN warm absorbers in order to overcome the current uncertainties.

The relation between AGN activity and starbursts in the circum-nuclear environment of the host galaxy was investigated by **G. Risaliti** (INAF-Osservatorio di Arcetri, Italy) who argued that extensive star formation takes place only in high accretion AGN. Observationally, starbursts and AGN are particularly difficult to disentangle in ultraluminous infrared galaxies, but it turns out that hidden active nuclei are only found when the starburst compo-

nent is not dominating. This suggests that the AGN may be responsible for 'cleaning' its environment and thus reduce the obscuration at the highest luminosities. The distinction between obscured and unobscured AGN was also discussed by **R. Hickox** (Durham Univ., UK) who presented a systematic analysis of one large multi-wavelength survey, the Bootes field. The results give statistical constraints on how SMBHs, their host galaxies and dark matter halos evolve together. They reveal that evolution of an AGN over cosmic time is strongly dependent on the mass of the initial dark matter halo they reside in.

2.6.1 Key questions to session 5

- Which observations (current, or future) provide the tightest constraints on the origin of the BH-host scaling relations?
- Is AGN feedback needed in galaxy evolution? If so, for which galaxies? Any need for radiatively efficient feedback (the so-called quasar mode)?
- Can Gravitational Wave recoil naturally explain some, so far, unsolved puzzles in galaxy evolution and AGN phenomenology? Or, vice versa, can we use current observations to set tight constraints on the frequency of kicks and super-kicks?

2.7 Session 6: Overview of future facilities and prospects for AGN research

We closed the meeting with an extended discussion, structured around an overview of future instruments and facilities that will be available in the next few years to investigators of AGN and black holes. By doing so, we made an attempt to clarify which tools are needed and which observational campaigns should be carried out in order to be able to answer to the proposed key questions during the workshop.

We began with a presentation by **S. Markoff** of LOFAR (www.lofar.nl) the new international low-frequency (meter wavelength) telescope that is currently being built and commissioned in the Netherlands and throughout Europe. LOFAR will be the first of a new generation of radio telescopes heavily relying on super-computing facilities to bring together the signals from a large number of affordable, low-tech antennas.

The future of the radio astronomy at cm-mm wavelengths has been illustrated by **M. Perez-Torres**: the E-VLA (www.aoc.nrao.edu/evla), e-MERLIN (www.e-merlin.ac.uk), (e)VLBI (www.evlbi.org) and SKA (www.skatelescope.org) have been compared in terms of sensitivity and angular resolution. This comparison was followed by an overview given by **G. Risaliti** of the recently launched IR satellite HERSCHEL (www.esa.int/herschel).

X. Barcons then presented an overview of three major future observatories. ALMA (www.almaobservatory.org) is a large sub-millimeter observatory in construction phase (Atacama desert, Chile). Through its superb angular resolution and sensitivity it will allow the study of two main themes: the formation and origin of high-z galaxies and the birth of stars and planetary systems. The European Extremely Large Telescope (E-ELT, www.eso.org/public/teles-instr/e-elt.html) is a 42-meter aperture telescope, IR-optimized, with an Adaptive Optics built-in telescope designed to study several astrophysical issues related to planets, stars, galaxy and cosmology. The International X-ray Observatory (IXO; constellation.gsfc.nasa.gov) is a 20-m focal length, multi-instrument facility designed to explore, among other, the SMBH and galaxies co-evolution process and the conditions of matter under strong gravitational fields.

M. Brusa illustrated in great detail the common scientific goals of e-ROSITA (www.mpe.mpg.de/heg/www/Projects/EROSITA/main.html) and of the Wide Field X-ray Telescope (WFXT; wfxt.pha.jhu.edu), two instruments thought and designed to perform all extragalactic sky X-ray surveys and will study the growth and evolution of AGN up to z=6. Moving up

in energies, a comparison in terms of the different capabilities between a few hard X-ray future missions have been made by **F. Panessa**. NuSTAR (www.nustar.caltech.edu) and Astro-H (astro-h.isas.jaxa.jp) will be launched on 2012 and 2013, respectively; the former is the first focusing hard X-ray satellite reaching 80 keV and the latter will carry two main instruments, the Soft X-ray Spectrometer (for high resolution X-ray spectrography) and the Hard X-ray Imager up to 80 keV, both with the objective of resolving most of the XRB emission at its peak. Under study is also the New Hard X-ray Imaging and Polarimetric Mission (NHXM; www.brera.inaf.it/NHXM), carrying four high quality mirrors with multilayer coatings to allow a very broad spectral response (0.2-80 keV) and one telescope module dedicated to imaging polarimetry. Finally, **E. Koerding** summarized the current results in the TeV sky with Cherenkov Telescopes. The future Cherenkov Telescope Array (CTA; www.cta-observatory.org) will be 10 times more sensitive and with 10 times improved angular resolution, with the scope of understanding the origin of cosmic rays and their role in the Universe, understanding the nature and variety of particle acceleration around black holes and searching for the ultimate nature of matter and physics beyond the Standard Model.

3. Assessment of the results, contribution to the future direction of the field

The general consensus among the participants was that the workshop fulfilled its promises of creating a vibrant forum open to discussion and exploration of new ideas. In this respect, one particular aspect should be emphasized: throughout the meeting we have been able to foster interaction among scientists usually working on related topics with very diverse techniques. A common problem in Astrophysics is indeed the difficulty of bridging “cultural” gaps between communities which arise, on the one hand, from the high level of specialization of astronomers, and, on the other, on the wide variety of means (observation in different wavelengths, numerical simulations, analytic modeling) used by the various parts of the community. In line with a general trend in modern astrophysics, during the workshop it emerged the necessity of designing new observational programs with a clear multi-wavelength character.

The set of key questions that were gathered before and during the workshop stands as an accurate picture of the state of the art of the field and as an indication of the probable directions of investigation in the near future.

A few topical areas of intense debate were covered during the meeting. Let us summarize the main results in these areas:

- Our ability to measure reliably **black hole spin** is still limited by the combination of insufficient sensitivity and calibration accuracy of the present generation of X-ray telescopes. The restrictions in currently available radiative transfer models further complicate the problem. Yet, the role of BH spin may be crucial for explaining some of the most dramatic manifestations of relativistic jets from AGN, with potentially a great impact on the properties of the structures that hosts them. The very first, sparse and incomplete, statistical analysis of spin distributions in galactic black holes seems to challenge the current interpretation of theoretical models of jet acceleration. In summary, we have identified the study of black hole spin distributions (both in stellar mass and supermassive black holes) as one of the main fields where we should concentrate the observational and theoretical activity in the near future.
- Despite its many successes, the classical **theory of relativistic accretion discs** leaves open a few fundamental questions, which were left unanswered in more than 30 years of X-ray astronomy. The main ones concern a) the physical nature of the viscous stresses and their scaling with local quantities within the disc (pressure, density); b) the

exact vertical structure of the disc and the height where most of the dissipation takes place and c) the nature of the inner boundary condition. Numerical simulations of MRI-unstable discs have provided great insights into the nature of viscosity, but the interplay of the various instabilities in accretion flows is not clear yet. During the meeting we have discussed new methods to use the observed properties of variability from accreting black holes to constrain the physical state of the accretion disc.

- A large fraction of the discussions were focused on the role of AGN for the evolution of the galaxies they reside in. There is a clear relationship between the ability of an AGN to affect the star-forming properties of its host galaxy and the amount of cold obscuring gas that may hide the view of a galactic nucleus. For this reason, a lot of activity has recently focused on the **obscured AGN population**. Unfortunately, the current census of obscured AGN is far from complete, and the various techniques devised in order to draw a more comprehensive picture of obscured AGN have been discussed during the workshop. Two complementary approaches that cold potentially lead to a breakthrough in the field are observations in the hard-X-ray band with the upcoming satellites NuSTAR and Astro-H, and the search for outflowing molecular gas with ALMA.
- There are, however, also indirect probes of the role of black holes' growth for galaxy evolution. The most widely used is the study of the so-called **scaling relations** (see section 2.6 above), and of their cosmological evolution. The commonly adopted assumption is that they represent a relic of an epoch of rapid black hole and galaxy assembly, and is the result of the feedback action induced by the copious energy release from the central AGN. During the workshop such a view has been challenged by new models and simulations that show instead how local scaling relations may just be the statistical outcome of the process of hierarchical merging of structure in a ΛCDM Universe. This may have far-reaching consequences for our understanding of the role of black holes in galaxy formation, which were discussed in detail during the meeting.

During the final discussion session, we have laid the ground for a series of follow-up actions to be carried out within the next few months. Following the ESF Exploratory Workshop, we would like to present to the scientific community an updated, and commented view of the observational appearance of AGN, of their evolution in time and of their theoretical understanding as it is today. This new AGN scheme should state the results that are currently confirmed, the points that are still controversial, as well as important tracks in future observational and theoretical AGN research. In more detail, we are planning the following actions:

- We will write an extensive version of the scientific report currently prepared for the ESF, which is meant as a scientific review paper addressed to the whole astronomical community. The three convenors of the ESF Exploratory Workshop are in the process of preparing a draft of this paper that then will be circulated among the workshop participants and finalized by January 2011.

- We want to develop an interactive, electronic image featuring the geometry and evolution of AGN according to our current understanding, updating and expanding the one shown in section 2.1 of this report. This electronic tool, from which also paper versions can be printed, is not only meant to be used by the scientific community but also in astronomy education anywhere in Europe or the world.

- We will apply for funding for a larger ESF conference to further develop the work that has begun with the ESF workshop. In the future, it will become more and more

important to coordinate multi-wavelength observing campaigns as well as interdisciplinary theoretical efforts. Therefore, we want to have the larger scientific community to take part in our discussions about AGN unification schemes and the planning of the next research steps.

4. Final List of Participants

Name	Institution	email
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5. Statistical information on participants

5.1 Age structure

We do not have exact information on the age of the participants. We instead divided them into “junior” and “senior” scientists following the ESF guidelines.

Junior Scientists: 16
Senior Scientists: 13

5.2 Gender repartition

Male: 20
Female: 9

5.3 Countries of origin

Czech Republic: 2
France: 3
Germany: 4
Greece: 1
Italy: 4
Poland: 3
Spain: 3
The Netherlands: 3
United Kingdom: 6

6. Final Programme

Tuesday, August 31, 2010

Time	Event
18:30.	Welcome Reception, Grande Albergo Internazionale
20:30.	Dinner at “Da Mario” Restaurant

Wednesday, September 1, 2010

Location: Conference Hall, Grande Albergo Internazionale

Time	Title	Presenter
8:30 - 9:00	Registration	
9:00 - 9:15	Welcome	Convenors (Goosmann, Merloni, Panessa)
9:15 - 9:30	Presentation of the European Science Foundation	Morris Aizenman
Session 1: **Probing the inner regions of accretion disks**		
9:30 - 9:55	Living dangerously: astronomy close to black hole event horizons	Matteo Guainazzi
9:55 - 10:20	AGN as relativistic machines: to what extent?	Matteo Guainazzi
10:20 - 10:45	Role of emission angular directionality in spin determination of accreting black holes with broad iron line spectroscopy	Vladimir Karas
Coffee Break		
11:15 - 11:40	Reflection in lamp-post scheme of the illuminated black hole accretion disk	Michal Dovciak
11:40 - 12:05	Mapping accretion flows in strong gravity with X-ray time-lags	Phil Uttley
12:05 - 12:30	The study of the timing-luminosity relation in AGN	Iosif Papadakis
12:30 -13:00	**Open discussion 1: Broad Iron lines, GR effects, variability**	
Lunch Break		
Session 2: **Outer accretion discs, Broad Line Region, SgrA***		
14:30 - 14:55	Variability of radio-quiet AGN across the spectrum: facts and ideas	Bozena Czerny
14:55 - 15:20	2D and 3D hydro simulations of accretion flows	Agnieszka Janiuk

Time	Title	Presenter
15:20 - 15:45	Photoionization modeling of AGN outflows	Agata Roszanska
Coffee Break		
16:15 - 16:40	The power of multiwavelength polarimetry in AGN research	Rene Goosmann
16:40 - 17:05	Imaging the Event Horizon and MHD in strong gravity: the case of the Galactic Center black hole Sgr A*	Heino Falcke
17:05 - 17:30	Discovery of a superluminal Fe K echo at the Galactic Center: The glorious (or in-glorious) past of Sgr A* preserved by molecular clouds	Gabriele Ponti
17:30 -18:00	**Open discussion 2: Progress in analytic and numerical models of accretion flows, Sgr A***	
Dinner at “L’araba fenice” Restaurant		

Thursday, September 2, 2010

Location: Conference Hall, Grande Albergo Internazionale

Time	Title	Presenter
Session 3: **AGN Jets and jet-disc connection**		
9:00 - 9:25	Connecting accreting sources on all scales	Elmar Koerding
9:25 - 9:50	Fitting across the fundamental plane: new clues about jet-disk coupling	Sera Markoff
9:50 - 10:15	The X-ray corona and jets of BH: the case of Cygnus X-1	Julien Malzac
10:15 - 10:40	Spin powering of jets - is there really any evidence?	Rob Fender
Coffee Break		
11:10 - 11:35	Radio interferometric observations of AGNs	Miguel Perez-Torres
11:35 - 12:00	A new observational dimension - radio quiet AGN in the time domain	Carole Mundell
12:00 - 12:25	Radio emission in radio quiet AGN	Francesca Panessa
12:25 -13:00	**Open discussion 3: AGN jets, radio loud vs. radio quiet dichotomy, the role of spin**	
Lunch Break		
Session 2: **Obscured AGN and population synthesis**		
14:30 - 14:55	Beyond the standard unification model in AGN	Stefano Bianchi
14:55 - 15:20	Witnessing the obscured phase of quasar evolution	Enrico Piconcelli

Time	Title	Presenter
15:20 - 15:45	Identification of the most heavily obscured AGN	David Alexander
Coffee Break		
16:15 - 16:40	The highest redshift AGN	Marcella Brusa
16:40 - 17:05	The search for young growing BHs	Xavier Barcons
17:05 -17:35	**Open discussion 4: Unified model, origin of obscuration, AGN surveys, missing populations**	
Dinner at “Marco Aurelio” Restaurant		

Friday, September 3, 2010

Location: Conference Hall, Grande Albergo Internazionale

Time	Title	Presenter
Session 5: **Host galaxy AGN connection**		
9:00 - 9:25	Scaling relations and GW recoil	Stefanie Komossa
9:25 - 9:50	The non-causal origin of the black hole - galaxy scaling relation	Knud Jahnke
9:50 - 10:15	The interplay between star formation and nuclear activity in ULIRGs	Guido Risaliti
10:15 - 10:40	Radiative vs. kinetic energy feedback and AGN evolution	Andrea Merloni
Coffee Break		
11:10 - 11:35	Feedback from ionized gas	Elisa Costantini
11:35 - 12:00	Black Holes in the cosmic web: host galaxies and large-scale environments of AGN	Ryan Hickox
12:00 -12:30	**Open discussion 5: Origin and evolution of scaling relations, constraints on AGN feedback**	
Lunch Break		
Session 6: **The potential of future missions**		
14:00 - 16:00	LOFAR	Markoff
	EVLA, eMERLIN, eVLBI, SKA	Perez-Torres
	HERSCHEL and future IR mission	Risaliti
	ALMA and E-ELT	Barcons
	IXO	Barcons

Time	Title	Presenter
	eROSITA and WFXT	Brusa
	nuSTAR, Astro-H and future hard X-rays missions	Panessa
	CTA and Cerenkov telescopes	Koerding
16:00 -17:30	**Final discussion and Conclusions**	

Saturday, September 4, 2010

Departure