Introduction

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NORMAL GALACTIC NUCLEI: OUTSTANDING PROBLEMS

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1. Introduction

This symposium – only the sixth major international conference on the Galactic Center or other normal galactic nuclei[1] – is a timely opportunity to review the rapid progression of research which has taken place recently in this area. The pace has been driven by both instrumental advances and by the recognition that galactic nuclei display some of the more fascinating extremes of nature: high stellar densities, supermassive black holes, unparallelled gas concentrations, strong magnetic fields, unusual populations of stars, etc. It is also evident that normal galactic nuclei probably hold important clues for understanding galaxy evolution and active galactic nuclei.

Much of this subject (and much of this meeting) is focussed on the Milky Way's Galactic center because of the tremendous resolution advantage we have there (the next nearest disk galaxy nucleus, that of M31, is 90 times further away). One expects that the phenomenology of the Galactic center is largely generalizable to galactic nuclei elsewhere. However, we are also seeing that instruments such as the Hubble Space Telescope, VLBI telescopes, millimeter arrays, and the largest optical/IR telescopes used at their diffraction limit, are now capable of reaching out to other galaxies, and illuminating phenomena that were previously accessible only in our Galaxy.

The definition of a "galactic center" or "central region" is not well formulated. From a stellar perspective, it can include the bulge and a central stellar bar (for galaxies which have one), so the central region can extend out to several kiloparsecs. The perspective of those who study the interstellar medium, however, is usually oriented to the smaller scales of the gaseous

[1]The literature on previous meetings includes: Riegler & Blandford 1982, Backer 1987, Morris 1989, Genzel & Harris 1994, and Gredel 1996.

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reservoirs often found in the central 500 pc or so of a spiral galaxy. Sometimes, it is trained on the 0.5 to 100-pc scales of well-defined circumnuclear gas disks which are now being found in a number of galaxies. And the most interesting part of a central region is often regarded as the central parsec, where supermassive black holes lurk near the stellar density maxima.

2. Outstanding Questions in Research on Galactic Nuclei

Detailed summaries of past research on the central regions of our galaxy have appeared in several recent review articles (Genzel et al. 1994; Morris & Serabyn 1996; Mezger et al. 1996). Rather than revisiting the rich body of literature again here, I offer a list of current issues which define the frontiers of research in the subject of normal galactic nuclei. These issues have motivated much of the work described in this volume, and I believe they will continue to be drivers for research in years to come.

1. *What is the non-axisymmetric mass distribution, from the central black hole (in those apparently numerous galaxies which have one) out to several parsecs, where the strength of any existing bar may decline?* Using stellar orbits and velocity dispersions to infer mass distributions is straightforward in a spherical potential, but when the potential has higher order multipole moments (such as the m=2 bars and spiral arms or the m=1 offset, or "sloshing mode"), as most galaxies indeed appear to have when closely examined, then determination of the mass distribution from observations is a challenging enterprise. An important related question is how the various multipole moments in the mass distribution couple to each other, thereby exchanging energy and fostering the growth of particular modes.

2. *How does gas react to the gravitational potential?* That is, how can we understand the dynamics and distribution of molecular clouds near a galactic nucleus? Not only must one deal with orbital theory and, given the finite sizes of interstellar clouds, with tidal forces that can disrupt or deform clouds, but much of the behavior of gas clouds near a galactic nucleus is determined by the shocks they suffer. This is intimately linked to the next question:

3. *What is the dominant mode of star formation in a galactic nucleus, and what is the consequent initial mass function?* The tidal forces, large turbulent velocities and presumed large magnetic field strengths in the molecular medium of galactic nuclei might well favor massive stars, relative to gas in the disk. In particular how did stars form in the central parsec of our Galaxy, where these processes inhibiting star formation might be expected to have their greatest effect? If massive stars are favored, what happens to their compact remnants, or, given their unusually powerful and

prolonged winds, do massive stars even form such remnants?

4. *What is the nature of the relatively abundant helium emission-line stars in the central region of our Galaxy?* These luminous, windy objects resemble Wolf-Rayet stars, Ofpe stars, or LBV's, but they are far more abundant than one might expect from any ordinary mix of recently-formed stars. Can their properties be ascribed to an elevated metallicity, relative to solar? To what extent are such stars present in other galaxies? In particular, can such stars be called upon to account for the nuclear spectra of the so-called "Wolf-Rayet galaxies"?

5. *What produces the extremely hot, x-ray emitting coronal gas in our Galaxy, and does it imply a galactic wind emerging from the central few hundred parsecs?* Can such a coronal gas component be found in other galaxies with the next generation of high-energy observatories?

6. *As gas migrates into a galactic nucleus, what are the branching ratios for its various possible fates?* What fraction of the entering gas mass is channeled to star formation, to a galactic wind, or to accretion onto a compact central object? Current evidence suggests that the residence time of gas in a galactic nucleus is only a few $\times$ 10^8 years, so it is important to resolve this question of the mass budget.

7. *How does the gas inflow rate to a galactic nucleus and the size of the central mass concentration that results from it (be it in the form of gas or stars) depend on the strength of the bar?*

8. *What is the origin of the strong magnetic field in the Galactic center region?* Is such a field typical of all galaxies? How does this field affect cloud dynamics and star formation? A relatively straightforward prediction is that recently formed stars in the Galactic center are relatively highly magnetized.

9. *How do central black holes form, and once formed, how do they evolve as they interact with stars and gas?* How soon can we find irrefutable evidence for the apparently inevitable occurence of violent tidal disruption of stars by supermassive black holes? If the energy released by such events is anywhere near 10^{53} ergs, and if the time interval for such events is only $\sim 10^4$ years, as has been suggested, then we should probably see the "smoking gun" in a few nearby galaxies, if not in our own Galactic center.

10. *What are the mechanisms responsible for the nonthermal emission from compact objects in normal and moderately active galactic nuclei, and how do their luminosities and spectral energy distributions relate to the accretion rate?* These questions will be well constrained by the rapidly improving picture of the spectrum of the candidate supermassive black hole in the Milky Way, Sagittarius A*.

11. *Is the last step in the mass accretion process onto a galactic nucleus mediated by coherent circumnuclear gas disks of 1 to 100-pc scales?* The circumnuclear disk in our Galaxy, the disk revealed by H_2O megamasers in NGC4258, and several others observed recently by the HST or by VLBI networks all suggest that the centralmost gas has been drawn into a more or less continuous disk configuration. Does this process usually occur by quasi-steady-state accretion, or do such disks form when individual clouds wander close enough to the center to be tidally disrupted and quickly rearranged into a disk by shear and dissipative shocks?

12. *Is activity in a galactic nucleus cyclical or repetitive, with starbursts and accretion events occuring on time scales of 10^7 to 10^8 years?* This begs the related question of what distinguishes active and inactive galaxies. The reactive mix of a large quantity of gas and a massive compact central object is apparently present in a large fraction of galaxies, whether they are active or not. Is the process which initiates their violent interaction an inevitable and recurring one?

13. *Is there any evidence that dark matter is present in galactic nuclei, apart from central black holes?* The answer at present appears to be "no," but at a time when dark matter is recognized as the dominant constituent of the universe, and is evidenced on almost all larger scales than we are concerned with here, we should be mindful of the possibility that it might manifest itself in galactic nuclei as well.

This list obviously does not include all of the important questions, but when these 13 questions have been answered, the subject of "normal galactic nuclei" will then have matured. I congratulate the primary conference organizer, Dr. Yoshiaki Sofue, for his considerable success in assembling a group of active researchers who can best inform us on the progress which has been made in answering such questions.

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