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SPACE TELESCOPE SEARCHES FOR BLACK HOLES IN GALACTIC NUCLEI

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ABSTRACT

The Hubble Space Telescope (HST) will allow astronomers to obtain luminosity profiles, rotation curves, and velocity dispersions at angular scales that are an order of magnitude superior to those obtained previously. This enhanced spatial resolution will greatly improve our sensitivity for detecting centrally condensed matter in nearby galactic nuclei including, possibly, black holes.

I. INTRODUCTION

The determination of the total masses and mass distributions of various types of galaxies has been an active area of astronomical research throughout the past approximately 15 years. Reviews by Faber and Gallagher (1979) and by Trimble (1987) summarize many of the results obtained from ground-based observations and their implications for the existence of black holes in the nuclei of some galaxies. Many of these observations concentrate on determining the mass content of galaxies out to large distances from their nuclei in order to estimate their total masses and its forms. However, other observations have been directed at determining the mass and luminosity distributions of galaxies as far toward their nuclei as practicable. Because they are so nearby, M31 and M32 have been especially good candidates for seeking black holes in their nuclei. Observations by Tonry (1987), Dressler and Richstone (1988), and Kormendy (1988) strongly suggest the possible presence of black holes in both these nearby galaxies.

The Hubble Space Telescope (HST) will routinely obtain images with spatial resolution of 10s of milliarcseconds throughout the UV to near-IR region Spectroscopy of regions through apertures as small as 0.1 arcseconds will also possible throughout most of the same spectral region. This increase in angu resolution will enable astronomers using the HST to obtain luminosity profi rotation curves, and velocity dispersion profiles of the central regions of gala with spatial resolution at least an order of magnitude improved over what has be possible to date from the ground. Limited angular resolution is the primary limiting factor for detecting the presence of centrally condensed matter in the nuclei of galaxies, so that the availability of the HST Observatory will greatly improve our sensitivity for detecting black holes in the nuclei of galaxies.

II. APPROACH

From images of a galaxy taken through one or more broad-band filters, along with certain assumptions about the galaxy's orientation and symmetry, one directly obtains the luminosity profile L(R). From these data and additional models of the fractions of stellar types, the luminosity distribution yields an estimate of that portion of the mass distribution due to stars. Non-uniqueness of the conversion from observed luminosities and spectra to stellar sources, and uncertainty in the true orientations and symmetry of the galaxy, produce rather large uncertainties in the determination of $M_{stellar}(R)$ for any particular galaxy.

The total mass distribution of the galaxy can be estimated from the effects of gravity acting on the luminous matter. Spatially-resolved spectra of spiral galaxies produce rotation curves, V(R), of the (line-of-sight) velocity of stars versus position in the galaxy. Because elliptical galaxies generally are not supported by rotation, one sees in their spectra primarily a dispersion, $\sigma_V(R)$, in the (line-of-sight) velocities with position. Within uncertainties set by unknown inclination effects, symmetry, and dominant orbit types (radial, circular, isotropic), one can obtain estimates of M(R), the total mass within radius R, for both spirals and ellipticals. (Note that the velocity dispersion, $\sigma_V(R)$, as R-->0 will provide useful information about the matter in both spiral and elliptical galaxy nuclei.)

The signature of a black hole in the nucleus of a galaxy will be a normal luminosity and a high value of mass as R-->0. If the inferred density of invisible material within the nucleus becomes great enough, it can be argued that the matter very probably has collapsed into a black hole simply because separate masses so closely crowded will not be stable against gravitational collapse. Such an argument is unlikely to be absolutely conclusive in any given case, but the likelihood of a black hole can become extremely high if one can detect the existence of substantial mass within a small enough volume. Thus, the measurements of L(R) and M(R), the latter through either V(R) or $\sigma_V(R)$, at small R are crucial for detecting any possible black holes in galactic nuclei.

III. SENSITIVITY OF HST FOR FINDING NUCLEAR BLACK HOLES

It is the factor-of-10 increase in angular, and therefore spatial, resolution that will make the HST a powerful tool for finding black holes (if they are there) in the nuclei of galaxies, or for setting improved upper limits to their presence. Two major reasons explain why increased spatial resolution enhance so dramatically our sensitivity for detecting black holes in galaxies:

(1) The measured spectral effects become stronger as R-->0 since both V(R) and $\sigma_V(R)$ scale as $(M/R)^{1/2}$, and

(2) Observations at smaller values of R enhance the intrinsic contrast between total mass M(R) and the mass $M_{stellar}(R)$ due to stars.

The functional dependence of the spectral signature strength, proportional to $(M/R)^{1/2}$ (Item 1), suggests that the HST will be about 10 times more sensitive than a ground-based telescope for detecting a black hole in a particular galactic nucleus. However, it is the contrast enhancement (Item 2) arising from the ability to "home in" more sharply on the central region of the galaxy that really increases our sensitivity to a central black hole. Sampling R 10 times closer reduces the contribution to M(R) from stars by a factor of 1,000 if the central stars are uniformly distributed, and even more if (as is likely) their density increases toward the center of the galaxy.

Table 1 provides examples of the spatial resolution which will become possible with the HST. Images sampled on an angular scale as fine as 7 milliarcseconds will be possible, while spectra will be obtained through apertures as small as 0.1 arcseconds in diameter. Spectra taken from the HST will allow determination of V(R) and $\sigma_V(R)$ to at least 100 km/sec accuracy. Table 2 illustrates typical masses of black holes which will be detectable with the HST at various distances.

TABLE 1

SPATIAL SAMPLING IN PARSECS FOR VARIOUS BLACK HOLE DOMICILES

RESOLUTION (arcsec)	RESOLUTION (pc) ON CERTAIN TARGETS			AVAILABLE INSTRUMENTS
	M31 AND M32 D ≈ 0.35 Mpc	M87 9 Mpc	NGC 6251 70 Mpc	
0.007	0.03	0.6	5	FOC
0.022	0.08	2	15	FOC
0.044	0.15	4	31	FOC,WF/PC
0.10	0.35	9	70	FOC,WF/PC,FOS
0.2	0.88	23	175	FOC,WF/PC,FOS,GHRS
1.0	3.5	90	700	HST and GROUND-BASED

FOC = Faint Object Camera (on HST)
WF/PC = Wide-Field/Planetary Camera (on HST)
FOS = Faint Object Spectrograph (on HST)
GHRS = Goddard High Resolution Spectrograph (on HST)

TABLE 2

HST CAPABILITY FOR DETECTING BLACK HOLES IN GALAXIES AT VARIOUS RANGES

DISTANCE (Mpc)	RV^2/G ≈ MIN DETECTABLE BH ($M_\odot$)
0.35	$8 * 10^5$
9	$2 * 10^7$
70	$2 * 10^8$

For M31 and M32, we will be sensitive to black holes of the size (≈ 10^6 $M_\odot$) suspected to exist at the nucleus of our own galaxy [see, for example, Serabyn and Lacy (1985)]. The HST observations will be able to prove conclusively the presence or absence of black holes in M31 and M32 of the masses ($10^{6.5-8.0}$ $M_\odot$) suggested by the observations of Tonry (1987), Dressler and Richstone (1988), and Kormendy (1988).

IV. CONCLUSIONS

The HST will provide a powerful tool for finding black holes in the nucleus of nearby galaxies. The factor-of-10 increase in angular resolution of the HST, compared to ground-based telescopes, will increase our sensitivity to detect black holes in galactic nuclei by factors of 10 to 1,000. For the neighboring galaxies M31 and M32, we will be able to detect black holes of the same size (≈10^6 $M_\odot$) as may exist in our own Milky Way Galaxy, and will conclusively confirm or refute the presence of M ≈ $10^{6.5-8.0}$ $M_\odot$ black holes hinted at by current ground-based data.

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DISCUSSION

SONNABEND: Will HST give sufficient resolution at, say, the center of M31 to see individual high-velocity stars (if they exist), and thus provide a better test for a central black hole than just the velocity curve?

HARMS: Very high velocity stars (projected) near galactic nuclei would be very good indicators of condensed central matter which might be black holes, so we will certainly be looking for them. The cameras on the HST will provide images with spatial resolutions ranging from 7 to 44 milliarcseconds per pixel. At the distance of M31, this corresponds to spatial sampling on a scale of 0.03 parsecs to 0.15 parsecs, assuming a distance to M31 of 0.7 Mpc. Spectroscopy throughout a broad wavelength region from the UV through the near-IR is possible on a spatial scale of 100 milliarcseconds, corresponding to 0.35 parsecs at M31. While HST will not truly resolve individual stars in M31, individual bright stars near the nucleus may dominate the light emission in a given spatial sample, which would allow us to measure velocities of individual stars. If these stars show high velocity dispersions, this would provide strong evidence for centrally condensed matter in the galactic nucleus. The images from HST will allow us to determine whether such central matter is luminous or not with spatial resolution generally even better than will be attainable for spectra.