Astrophysical Dynamics (ASTP-617) Notes

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Fall 2015

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Chapter 1

Introduction and Historical Overview

Chapter 2

Observations of Galactic Nuclei and Supermassive Black Holes

2.1 Structure of galaxies and galactic nuclei

2.1.1 Intensity profiles

Intensity profiles are functions used to describe the intensity of a galaxy as a function of distance from the center, $I(R)$.

The **Sérsic profile** is commonly used, as it is simple and effective. The general form is:

$$\ln I(R) = \ln I_e - b\,n\Big[\big(R/R_e\big)^{1/n} - 1\Big]. \qquad \text{(Merritt 2.3)}$$

The **Sérsic index**, n, characterizes the shape of the function, and in practice, $n \in [0.5, 8]$. b is typically chosen such that R_e, the **effective radius**, contains half of the total light. The effective intensity, I_e, is thus defined as $I_e \equiv I(R_e)$.

To make the function a little more intuitive, one may use differentiation to put it in the form:

$$\frac{\mathrm{d}\ln I}{\mathrm{d}\ln R} = -\frac{b}{n}\left(\frac{R}{R_e}\right)^{1/n} \qquad \text{(Merritt 2.4)}$$

This form illustrates the fact that the slope on a log–log plot of the intensity grows with R by $(R/R_e)^{1/n}$.

In many galaxies, within a radius R_b, there is a break in the intensity profile (shown in Merritt Figure 2.2). For this reason, it is necessary to define a **core-Sérsic profile**:

$$I(r) = \begin{cases} I_b\left(\dfrac{R_b}{R}\right)^{\Gamma}, & R \leqslant R_b, \\ I_b \exp\Big(b(R_b/R_e)^{1/n}\Big)\exp\Big(-b(R/R_e)^{1/n}\Big), & R > R_b. \end{cases} \qquad \text{(Merritt 2.8)}$$

2.2 Techniques for weighing black holes

2.3 Supermassive black holes in the Local Group

2.4 Phenomenology

2.5 Evidence for intermediate-mass black holes

2.6 Evidence for binary and multiple supermassive black holes

2.7 Gravitational waves

The amplitude, h, of a gravitational wave is a dimensionless quantity given by

$$h \approx \frac{G}{c^4}\frac{\ddot{Q}}{D} \approx \frac{GM_Q}{c^2 D}\frac{v^2}{c^2}, \tag{Merritt 2.55}$$

where v is the internal velocity of the source, M_Q is the portion of the source's mass (in units of mass, not just 0–1) participating in the quadrupolar motions, and D is the distance to the source.

To understand the detector size needed to observe a gravitational wave, consider the ideal case, where the entire mass is participating in quadrupolar motions ($M_Q = M_{12}$), and the binary is located at a distance D from the observer and a from each other. Then we have $v^2 \approx GM_{12}/a$, and from (Merritt 2.55) we have

$$\begin{aligned} h &\approx \frac{GM_{12}}{c^2 D}\frac{GM_{12}}{ac^2} \\ &\approx \frac{G^2}{c^4} M_{12}^2 a^{-1} D^{-1} \\ &\approx 2 \times 10^{-16} \left(\frac{M_{12}}{10^{-8} M_\odot}\right)^2 \left(\frac{a}{\text{mpc}}\right)^{-1} \left(\frac{D}{100\text{Mpc}}\right)^{-1} \end{aligned} \tag{Merritt 2.58}$$