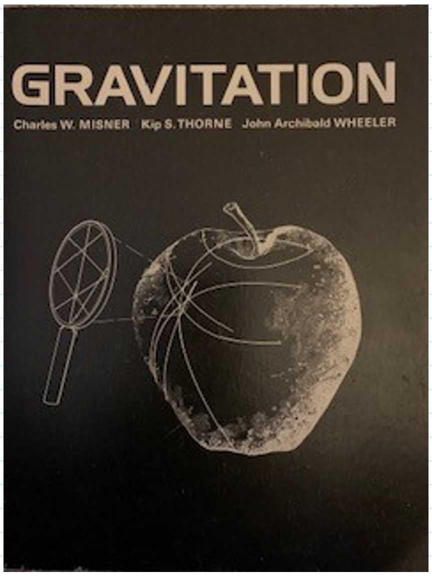
155 Lecture 17b

Sunday, March 1, 2020 7:14 PM

# The existence of BH's (history)

When I studied GR in 1978, we used this book ("MTW"):

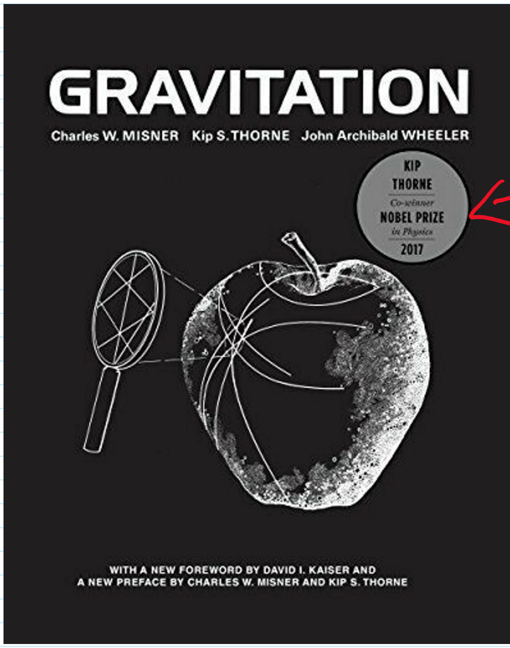



Which was completed in the early 1970's:

Copyright © 1970 and 1971 by Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler.

Copyright © 1973 by W. H. Freeman and Company.

(BTW today the cover looks like this:

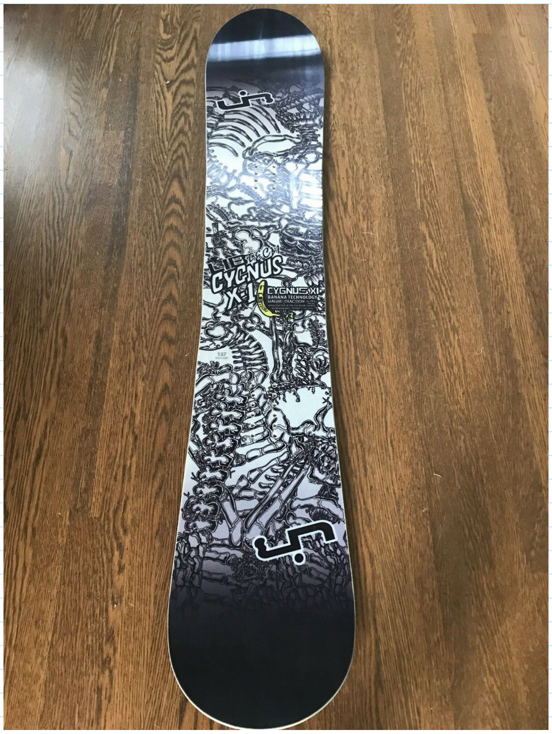



Here is what the 1973 copy had to say about the existence of BH's

of a star with a white-dwarf core. Today hope to discover the first black hole is not least among the forces propelling more than one research: How does rotation influence the properties of a black hole? What kind of pulse of gravitational radiation comes off when such an object is formed? What spectrum of x-rays emerges when gas from a companion star piles up on its way into a black hole?[5] All such investigations and more base themselves on Schwarzschild's standard 1916 static and spherically symmetric solution of Einstein's field equations, first really understood in the modern sense in 1960, and in 1963 generalized to a black hole endowed with angular momentum.

[5] As of April 1973, there are significant indications that Cygnus X-1 and other compact x-ray sources may be black holes.

Today if you google Cygnus X-1 you get…




And from Wikipedia:

**Cygnus X-1** (abbreviated **Cyg X-1**)[11] is a galactic X-ray source in the constellation Cygnus, and the first such source widely accepted to be a black hole.[12][13] It was discovered in 1964 during a rocket flight and is one of the strongest X-ray sources seen from Earth, producing a peak X-ray flux density of $2.3 \times 10^{-23}$ $Wm^{-2}$ $Hz^{-1}$ ($2.3 \times 10^{3}$ Jansky).[14][15] It remains among the most studied astronomical objects in its class. The compact object is now estimated to have a mass about 14.8 times the mass of the Sun[6] and has been shown to be too small to be any known kind of normal star, or other likely object besides a black hole.[16] If so, the radius of its event horizon has 300 km "as upper bound to the linear dimension of the source region" of occasional X-ray bursts lasting only for about 1 ms.[17]

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Cygnus X-1 was the subject of a friendly scientific wager between physicists Stephen Hawking and Kip Thorne in 1974, with Hawking betting that it was not a black hole. He conceded the bet in 1990 after observational data had strengthened the case that there was indeed a black hole in the system. This hypothesis lacks direct empirical evidence but has generally been accepted from indirect evidence.[23]

Also, compare with:

## Observations from O1 and O2/2015-2017 [ edit ]

List of binary merger events[7][8]

| GW event and time (UTC)[n 2] | Date published | Location area[n 3] ($deg^2$) | Luminosity distance (Mpc)[n 4] | Energy radiated ($c^2 M_{\odot}$) [n 5] | Chirp mass ($M_{\odot}$) [n 6] | Effective spin[n 7] | Primary | | Secondary | | Remnant | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Type | Mass ($M_{\odot}$) | Type | Mass ($M_{\odot}$) | Type | Mass ($M_{\odot}$) | Spin[n 8] | |
| GW150914 09:50:45 | 2016-02-11 | 179; mostly to the south | $430^{+150}_{-170}$ | $3.1^{+0.4}_{-0.4}$ | $28.6^{+1.6}_{-1.5}$ | $-0.01^{+0.12}_{-0.13}$ | BH [n 9] | $35.6^{+4.8}_{-3.0}$ | BH [n 10] | $30.6^{+3.0}_{-4.4}$ | BH | $63.1^{+3.3}_{-3.0}$ | $0.69^{+0.05}_{-0.04}$ | First GW detection; first BH merger observed |
| GW151012 [fr] 09:54:43 | 2016-06-15 | 1555 | $1060^{+540}_{-480}$ | $1.5^{+0.5}_{-0.5}$ | $15.2^{+2.0}_{-1.1}$ | $0.04^{+0.28}_{-0.19}$ | BH | $23.3^{+14.0}_{-5.5}$ | BH | $13.6^{+4.1}_{-4.8}$ | BH | $35.7^{+9.9}_{-3.8}$ | $0.67^{+0.13}_{-0.11}$ | Formerly candidate LVT151012; accepted as astrophysical since February 2019 |
| GW151226 03:38:53 | 2016-06-15 | 1033 | $440^{+180}_{-190}$ | $1.0^{+0.1}_{-0.2}$ | $8.9^{+0.3}_{-0.3}$ | $0.18^{+0.20}_{-0.12}$ | BH | $13.7^{+8.8}_{-3.2}$ | BH | $7.7^{+2.2}_{-2.6}$ | BH | $20.5^{+6.4}_{-1.5}$ | $0.74^{+0.07}_{-0.05}$ | |
| GW170104 10:11:58 | 2017-06-01 | 924 | $960^{+430}_{-410}$ | $2.2^{+0.5}_{-0.5}$ | $21.5^{+2.1}_{-1.7}$ | $-0.04^{+0.17}_{-0.20}$ | BH | $31.0^{+7.2}_{-5.6}$ | BH | $20.1^{+4.9}_{-4.5}$ | BH | $49.1^{+5.2}_{-3.5}$ | $0.66^{+0.08}_{-0.10}$ | |
| GW170608 02:01:16 | 2017-11-16 | 396; to the north | $320^{+120}_{-110}$ | $0.9^{+0.0}_{-0.1}$ | $7.9^{+0.2}_{-0.2}$ | $0.03^{+0.19}_{-0.07}$ | BH | $10.9^{+5.3}_{-1.7}$ | BH | $7.6^{+1.3}_{-2.1}$ | BH | $17.8^{+3.2}_{-0.7}$ | $0.69^{+0.04}_{-0.04}$ | Smallest BH progenitor masses to date |
| GW170729 18:56:29 | 2018-11-30 | 1033 | $2750^{+1350}_{-1320}$ | $4.8^{+1.7}_{-1.7}$ | $35.7^{+6.5}_{-4.7}$ | $0.36^{+0.21}_{-0.25}$ | BH | $50.6^{+16.6}_{-10.2}$ | BH | $34.3^{+9.1}_{-10.1}$ | BH | $80.3^{+14.6}_{-10.2}$ | $0.81^{+0.07}_{-0.13}$ | Largest progenitor masses to date |
| GW170809 08:28:21 | 2018-11-30 | 340; towards Cetus | $990^{+320}_{-380}$ | $2.7^{+0.6}_{-0.6}$ | $25.0^{+2.1}_{-1.6}$ | $0.07^{+0.16}_{-0.16}$ | BH | $35.2^{+8.3}_{-6.0}$ | BH | $23.8^{+5.2}_{-5.1}$ | BH | $56.4^{+5.2}_{-3.7}$ | $0.70^{+0.08}_{-0.09}$ | |
| GW170814 10:30:43 | 2017-09-27 | 87; towards Eridanus | $580^{+160}_{-210}$ | $2.7^{+0.4}_{-0.3}$ | $24.2^{+1.4}_{-1.1}$ | $0.07^{+0.12}_{-0.11}$ | BH | $30.7^{+5.7}_{-3.0}$ | BH | $25.3^{+2.9}_{-4.1}$ | BH | $53.4^{+3.2}_{-2.4}$ | $0.72^{+0.07}_{-0.05}$ | First announced detection by three observatories; first polarization measurement |
| GW170817 12:41:04 | 2017-10-16 | 16; NGC 4993 | $40 \pm 10$ | $\geq 0.04$ | $1.186^{+0.001}_{-0.001}$ | $0.00^{+0.02}_{-0.01}$ | NS | $1.46^{+0.12}_{-0.10}$ | NS | $1.27^{+0.09}_{-0.09}$ | NS [n 11] | $\leq 2.8$[n 12] | $\leq 0.89$ | First NS merger observed in GW; first detection of EM counterpart (GRB 170817A; AT 2017gfo); nearest event to date |
| GW170818 02:25:09 | 2018-11-30 | 39; towards Pegasus | $1020^{+430}_{-360}$ | $2.7^{+0.5}_{-0.5}$ | $26.7^{+2.1}_{-1.7}$ | $-0.09^{+0.18}_{-0.21}$ | BH | $35.5^{+7.5}_{-4.7}$ | BH | $26.8^{+4.3}_{-5.2}$ | BH | $59.8^{+4.8}_{-3.8}$ | $0.67^{+0.07}_{-0.08}$ | |
| GW170823 13:13:58 | 2018-11-30 | 1651 | $1850 \pm 840$ | $3.3^{+0.9}_{-0.8}$ | $29.3^{+4.2}_{-3.2}$ | $0.08^{+0.20}_{-0.22}$ | BH | $39.6^{+10.0}_{-6.6}$ | BH | $29.4^{+6.3}_{-7.1}$ | BH | $65.6^{+9.4}_{-6.6}$ | $0.71^{+0.08}_{-0.10}$ | |

https://en.wikipedia.org/wiki/List_of_gravitational_wave_observations