m33 x-7
a 15.65-Msun black hole
in an eclipsing binary

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outline

- black holes in theory
- black holes in fact
- m33 x-7

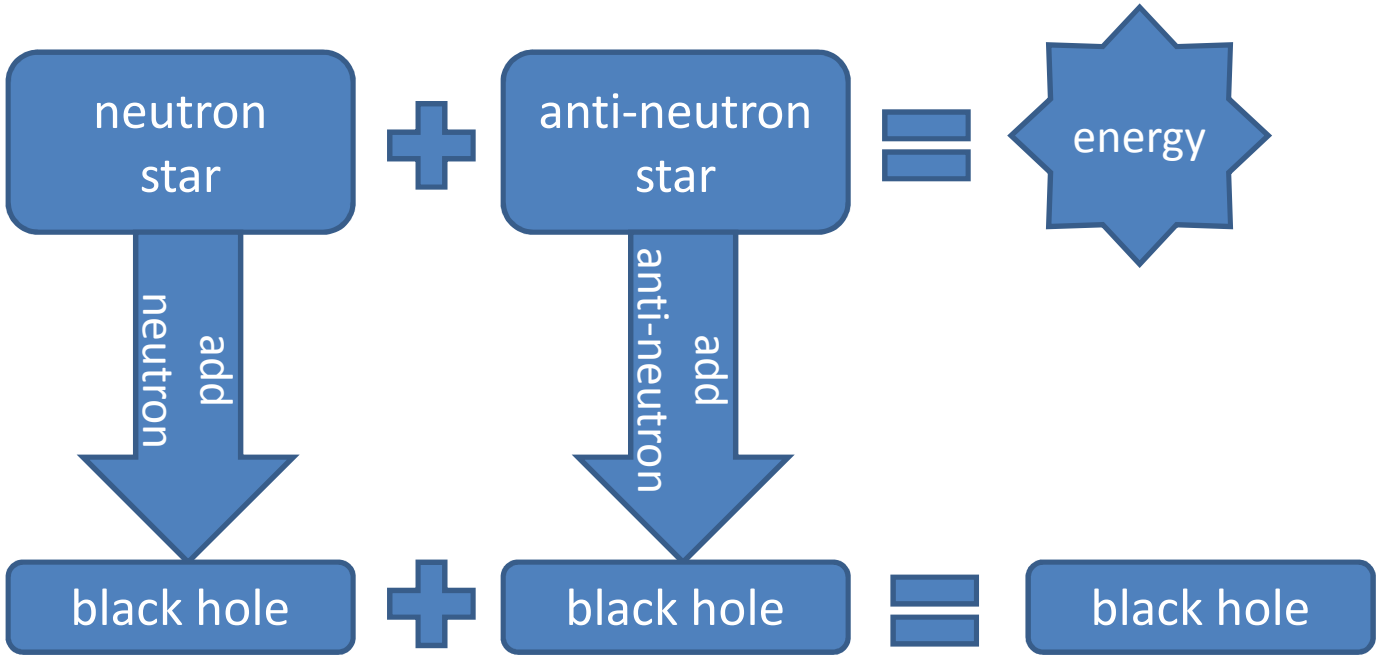
black holes

- internal structure from general theory
- very different from any stars

- event horizon
- time-like space
- singularity

black holes have no hair

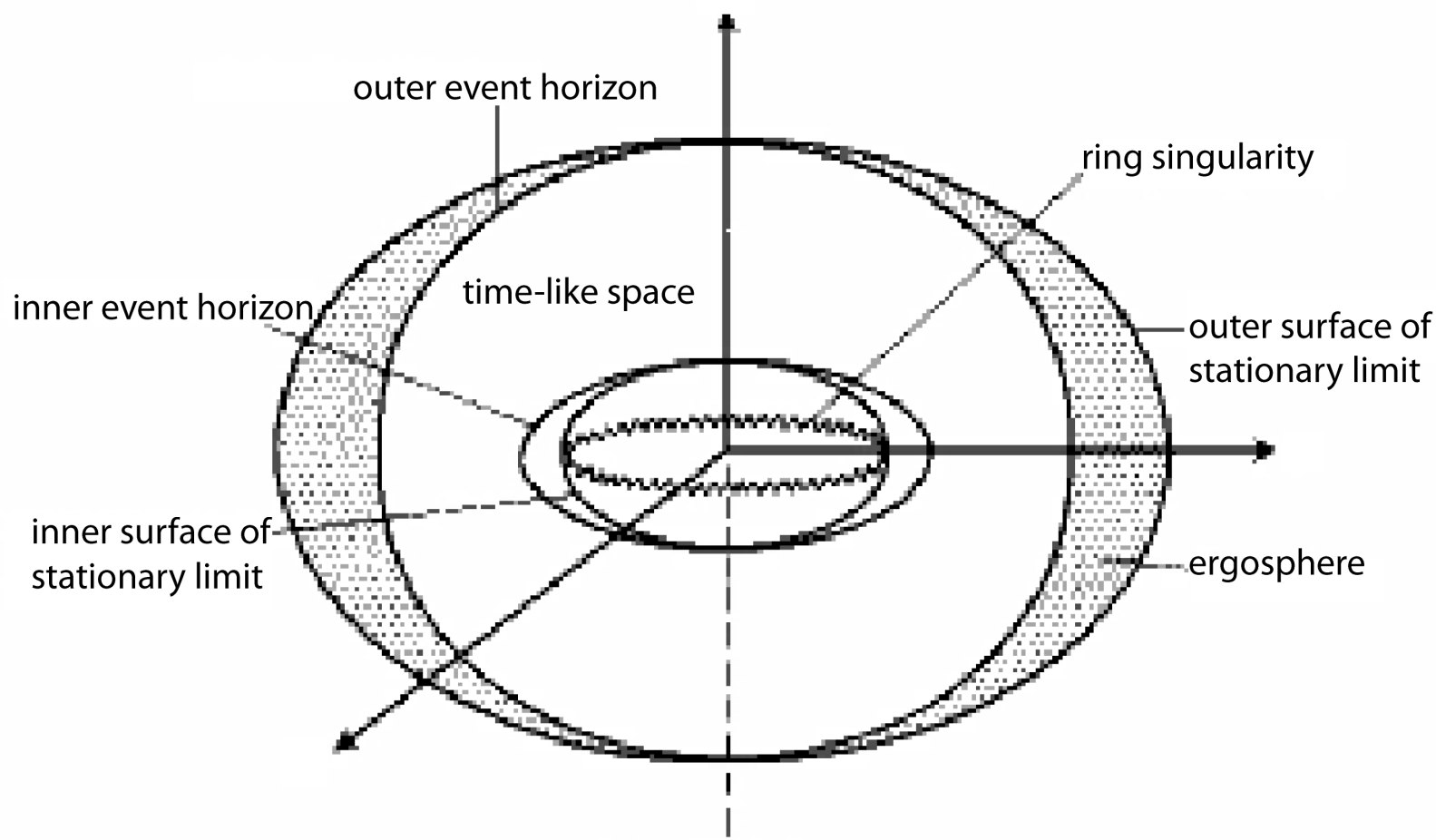
- 3 fundamental properties:
  mass, spin, electric charge



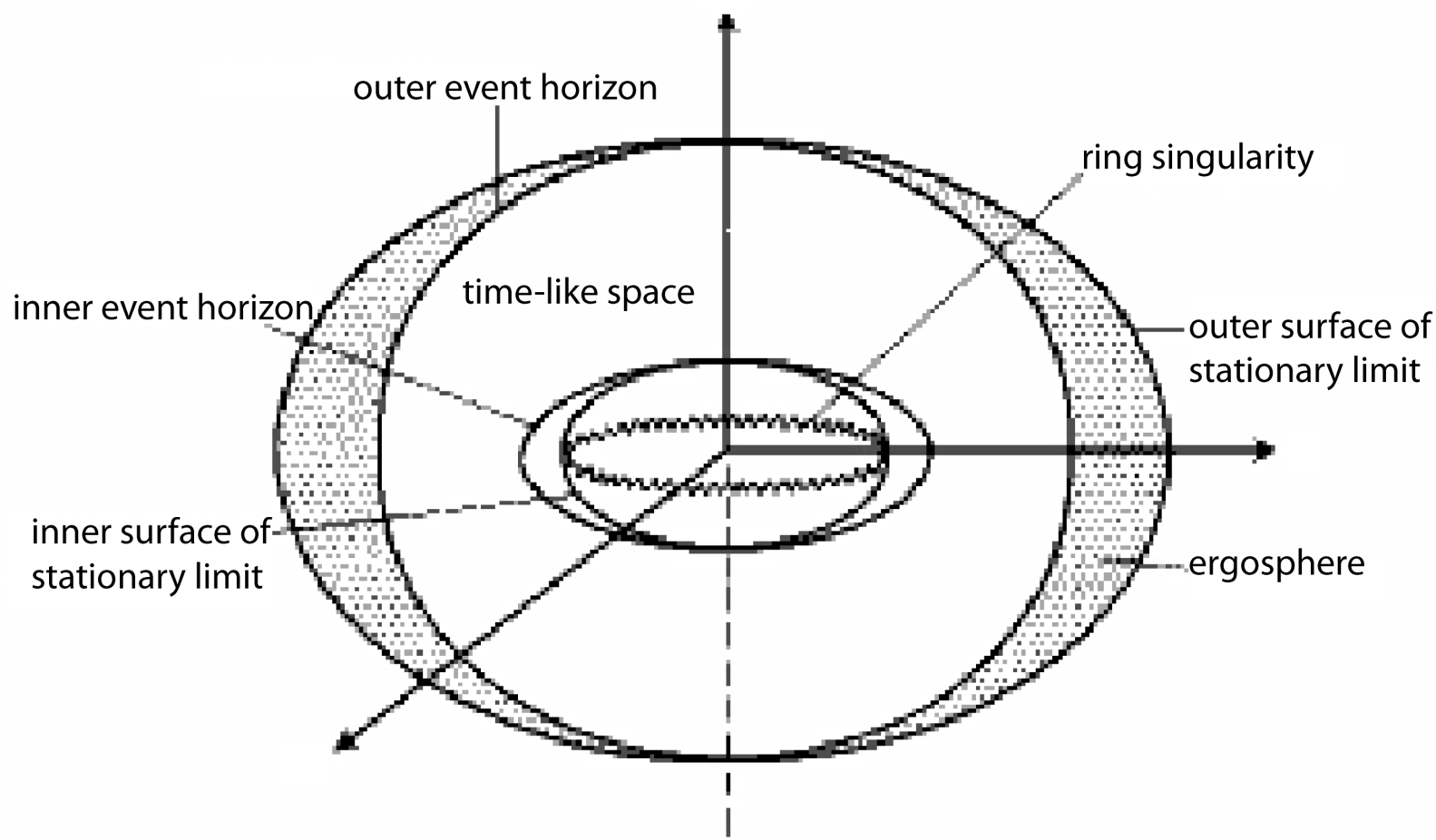
hawking radiation

- adding quantum process
- photons/antiphotons created
- location of event horizon fuzzy
- black holes evaporate
- temperature inversely proportional to mass

kerr (rotating) black hole



kerr (rotating) black hole



alternate theories

- frozars
  - cannot observe star collapse through event horizon
  - black hole form only when $t \rightarrow \infty$
- gravatars
  - quantum gravity
  - dense crust of ordinary matter enclosing “dark energy”

how to find a black hole?

- x-ray binaries:
  accreting compact object in binaries
- to distinguish from neutron stars
  - primarily mass
  - search for pulsars

cygnus x-1

- one of the first x-ray sources discovered
- ~10 Msun black hole
  ~30 Msun companion
- too massive to be a neutron star
- 1 Msun neutron star + 9 Msun star
  could masquerade as a black hole
- rate of this type of system: ~1 per galaxy

x-ray novae

- transient behaviour
- low mass, dim companions

- accretion disk goes through
  cool dim storage mode
  hot bright flushing mode

microquasars

- apparent superluminal behaviour
- analogies to quasars

intermediate mass black holes

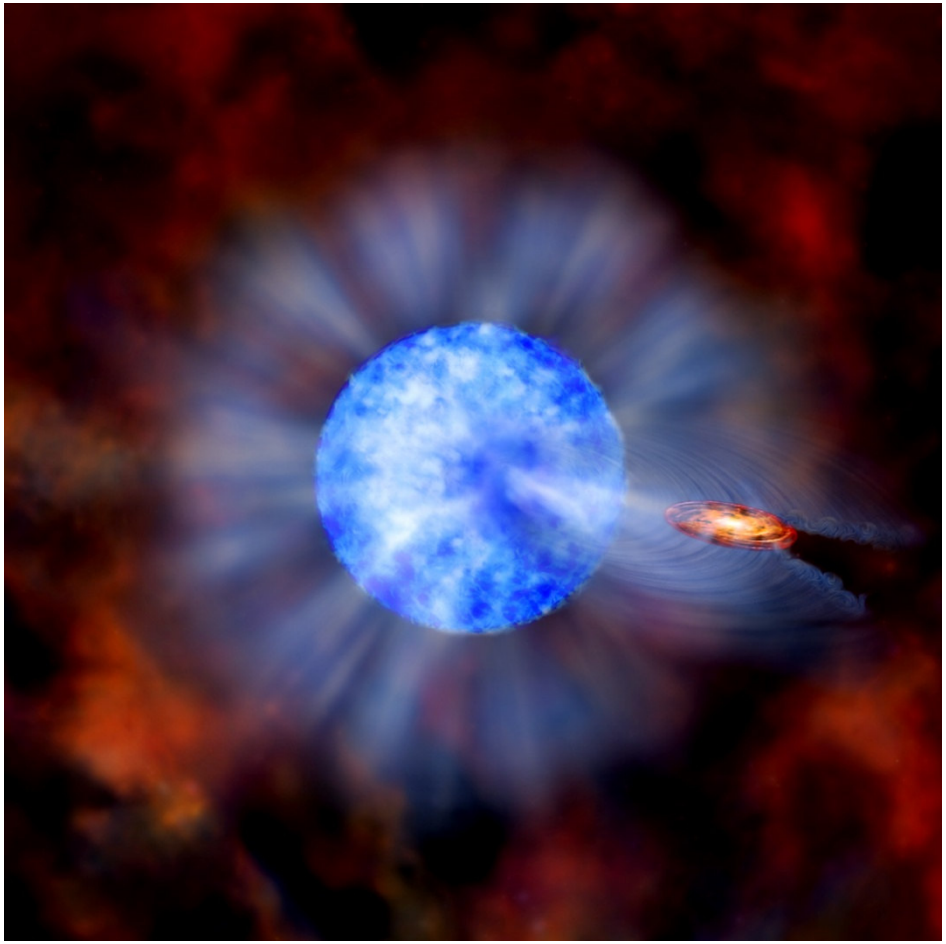
- ultra luminous x-ray sources (ULX)
- centres of globular clusters
- same mass ratio:
  star clusters to intermediate black holes
  galactic bulges to supermassive black holes

m33 x-7

History of m33 x-7

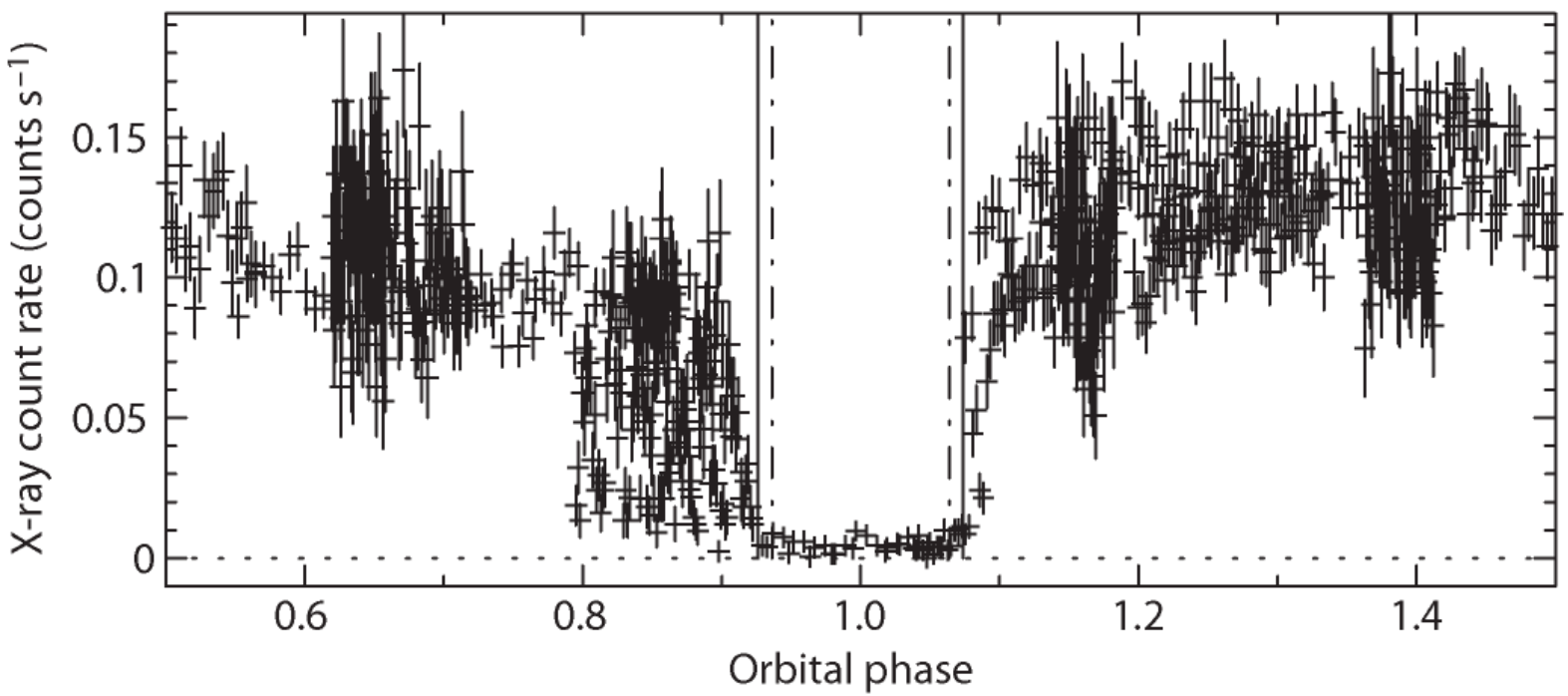
- 1981 detected as a variable x-ray source
- 1989 thought to be an eclipsing binary
- 1993 confirmed as an eclipsing binary
- 1997 period measured
- 2004 optical counterpart identified
- 2007 mass of black hole determined

what's so special about M33 X-7?

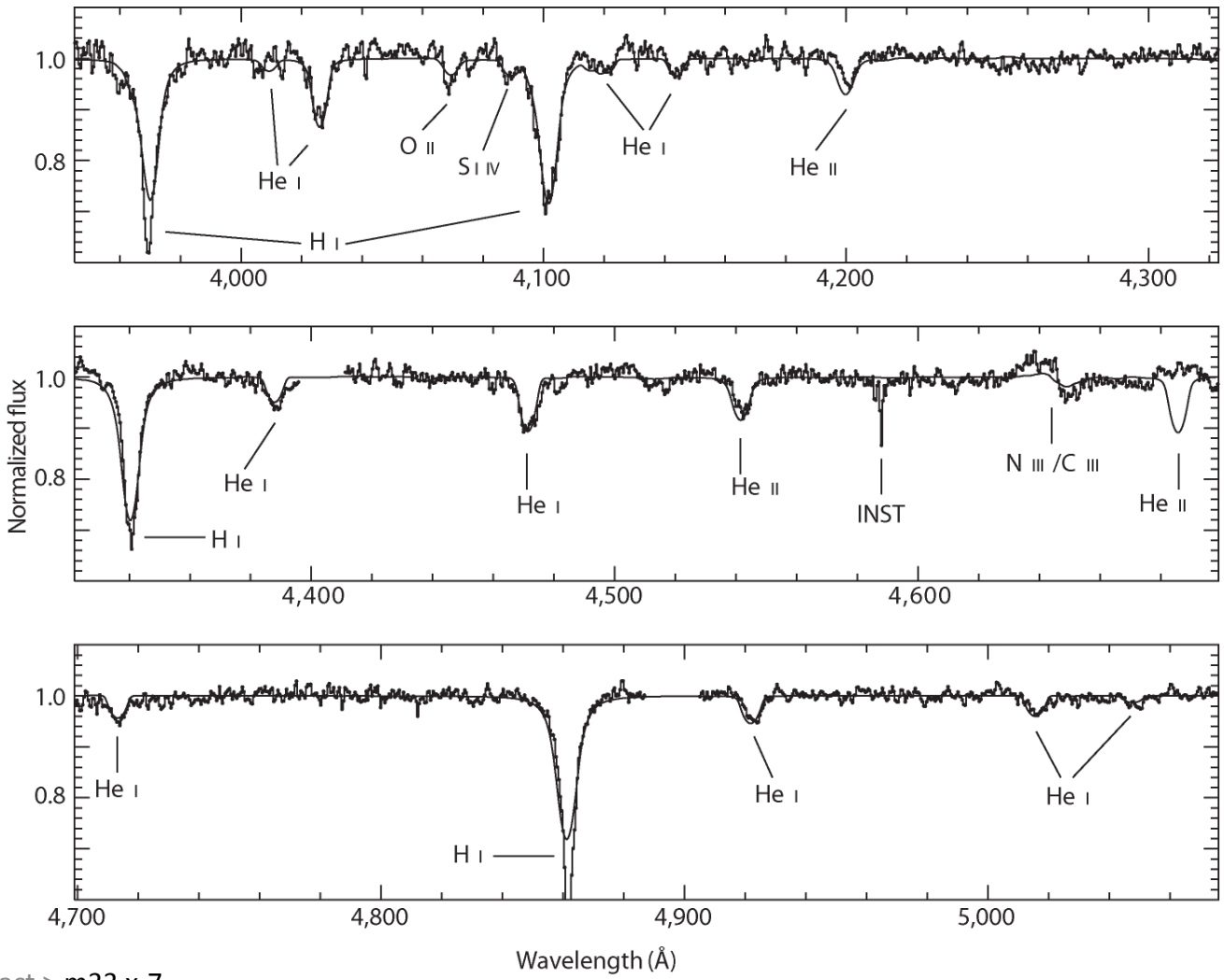


- only known black hole in eclipsing binary
- most massive stellar black hole?

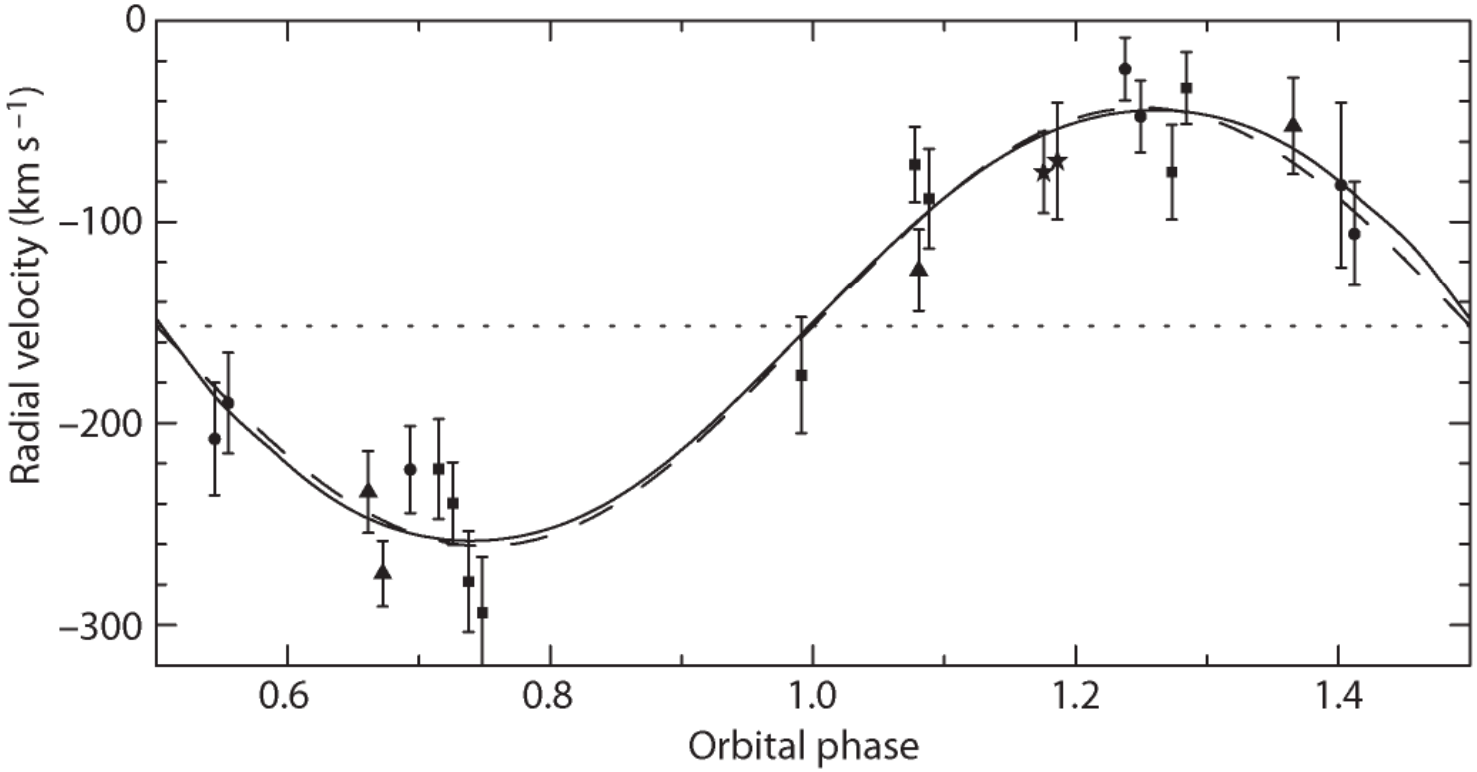
x-ray light curve (chandra)



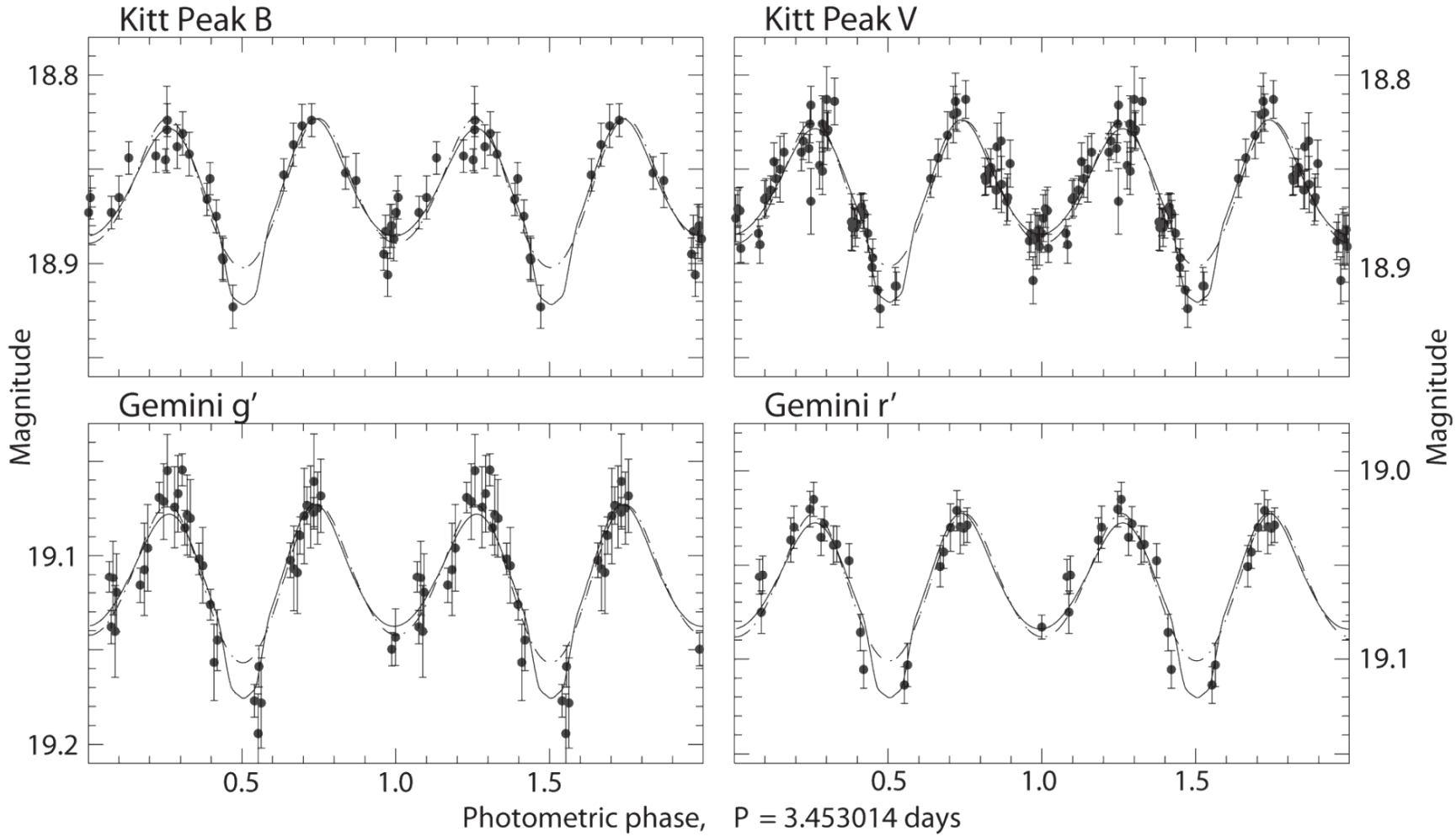
optical spectra (gemini)



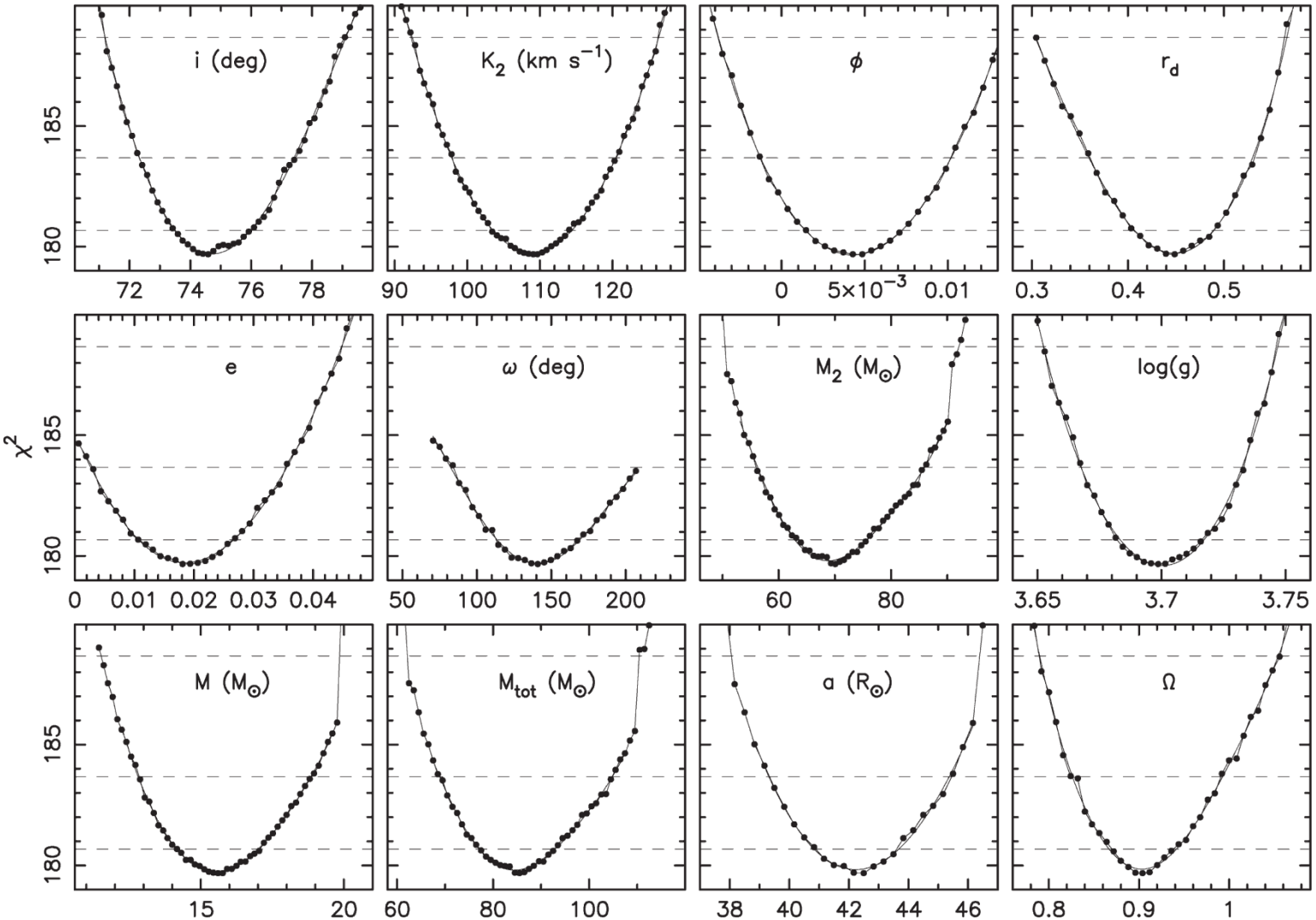
radial velocity curve (gemini)



optical light curve (gemini/wiyn)



chi^2 of parameter fits



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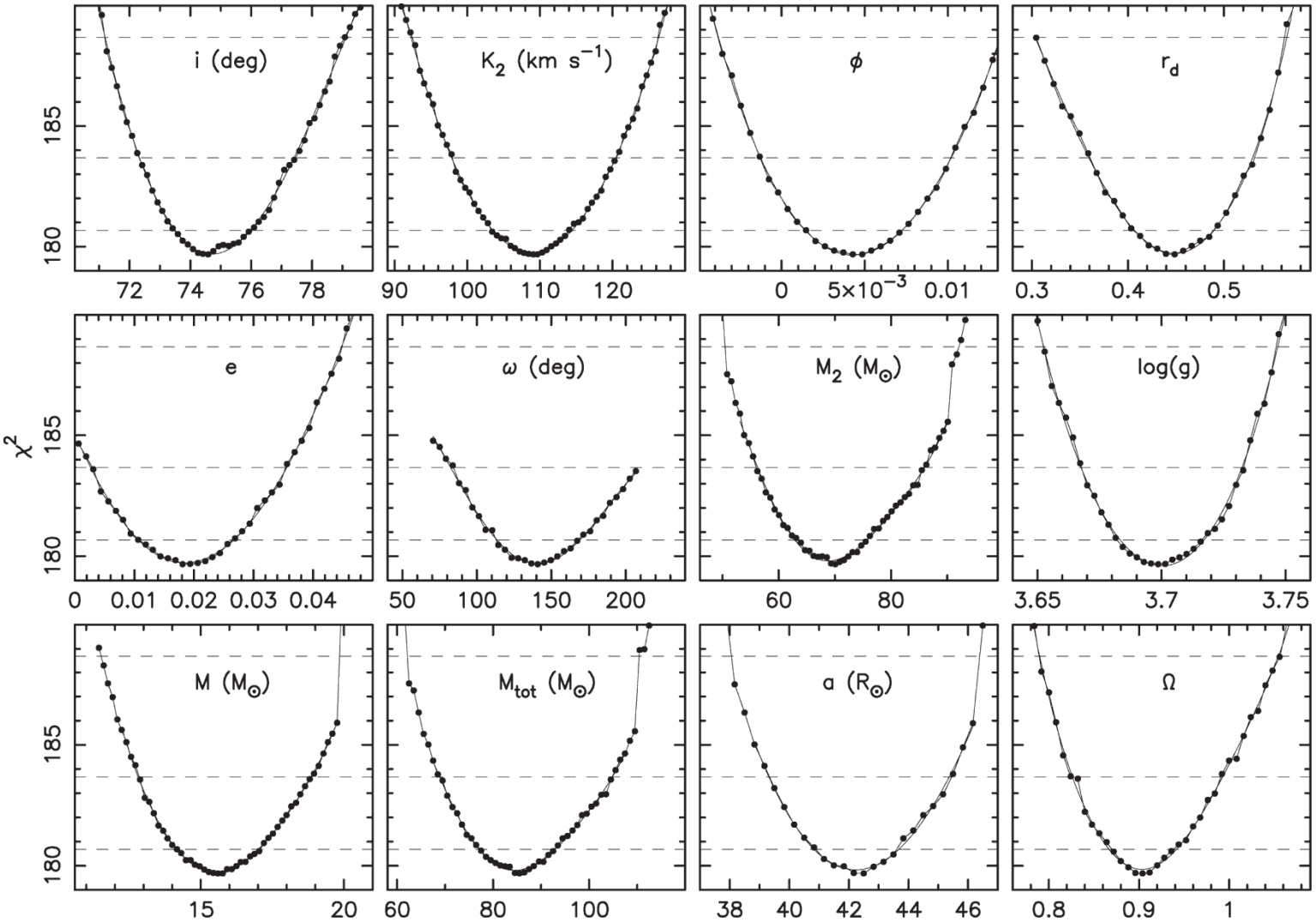

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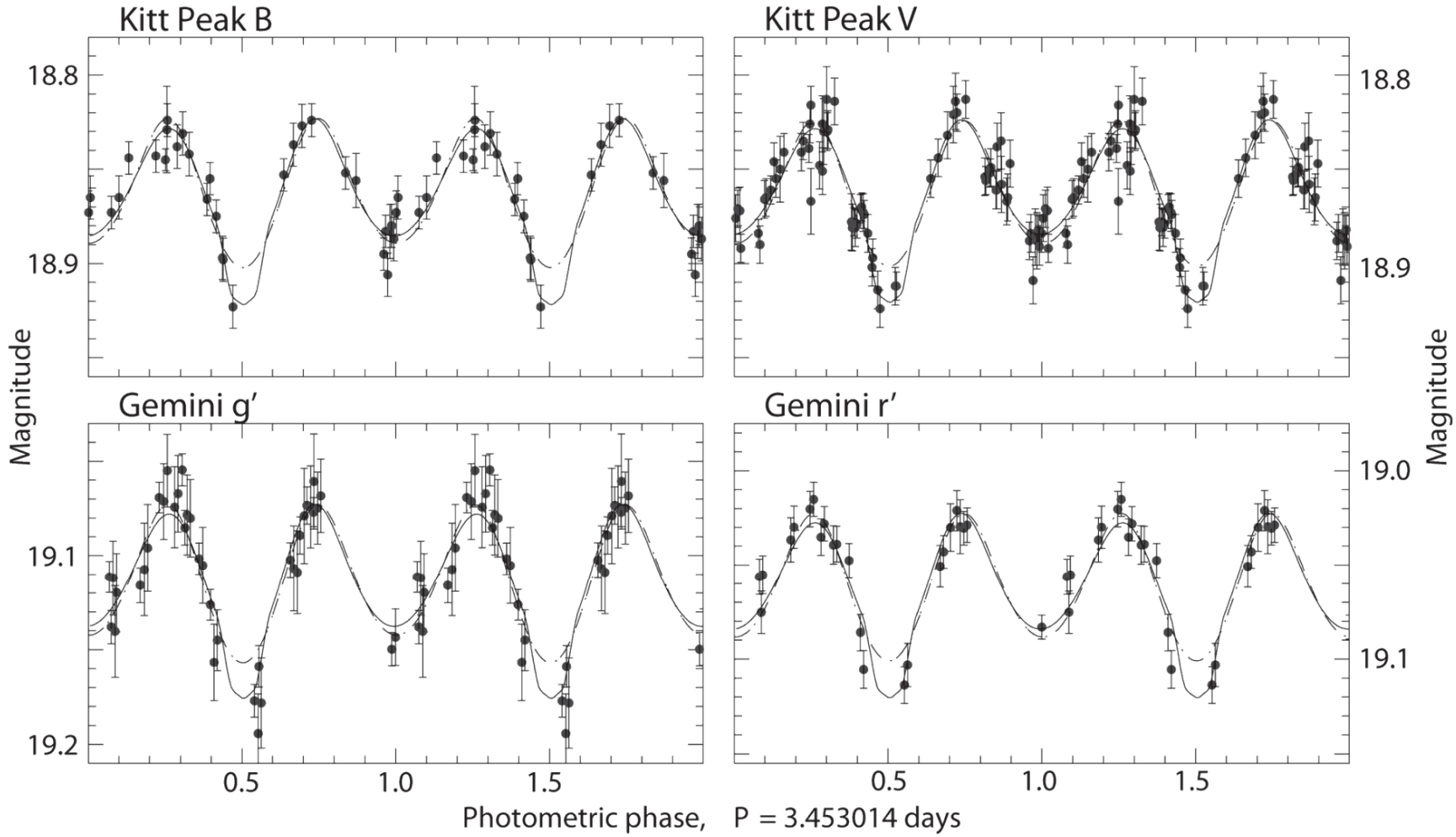
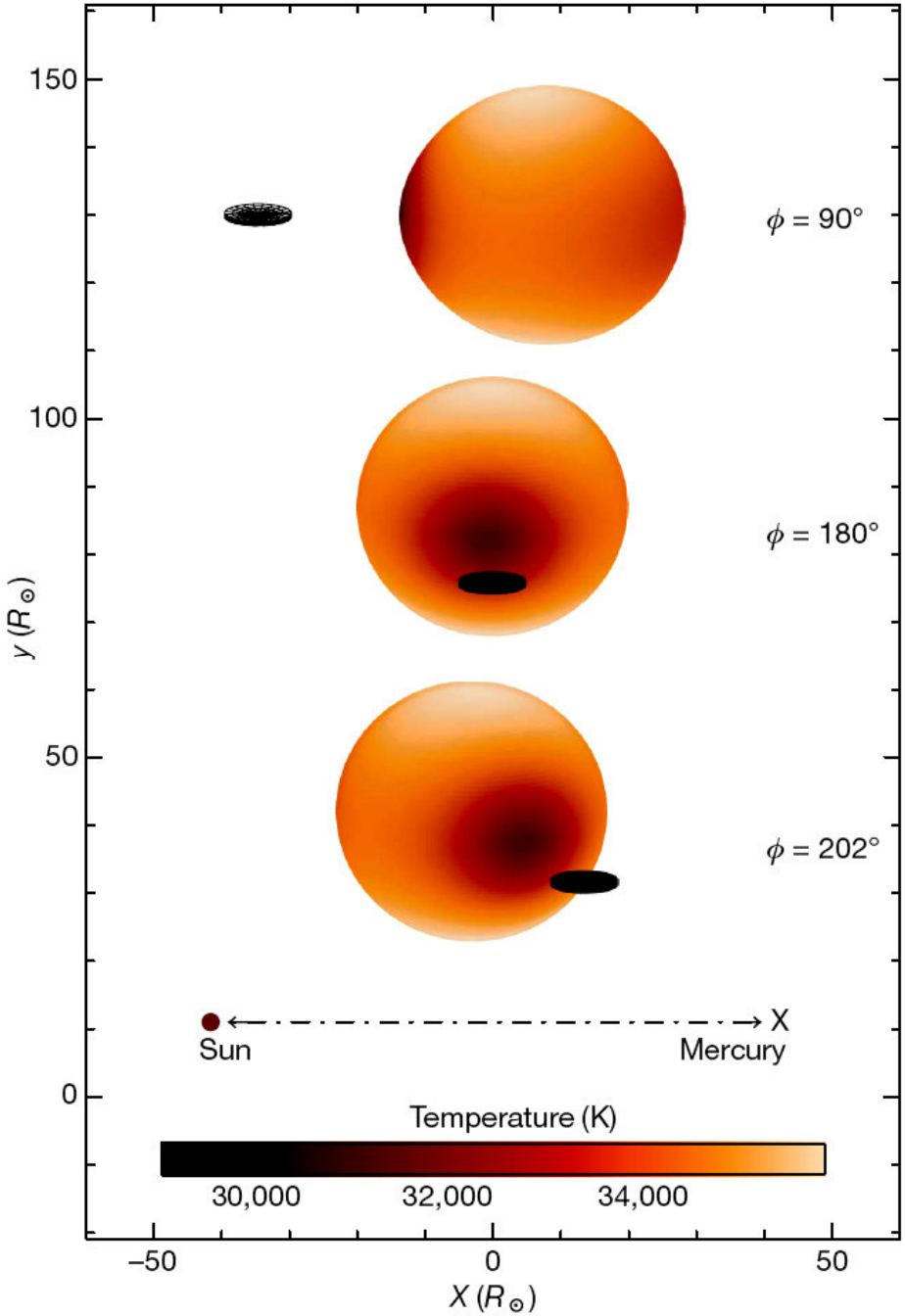
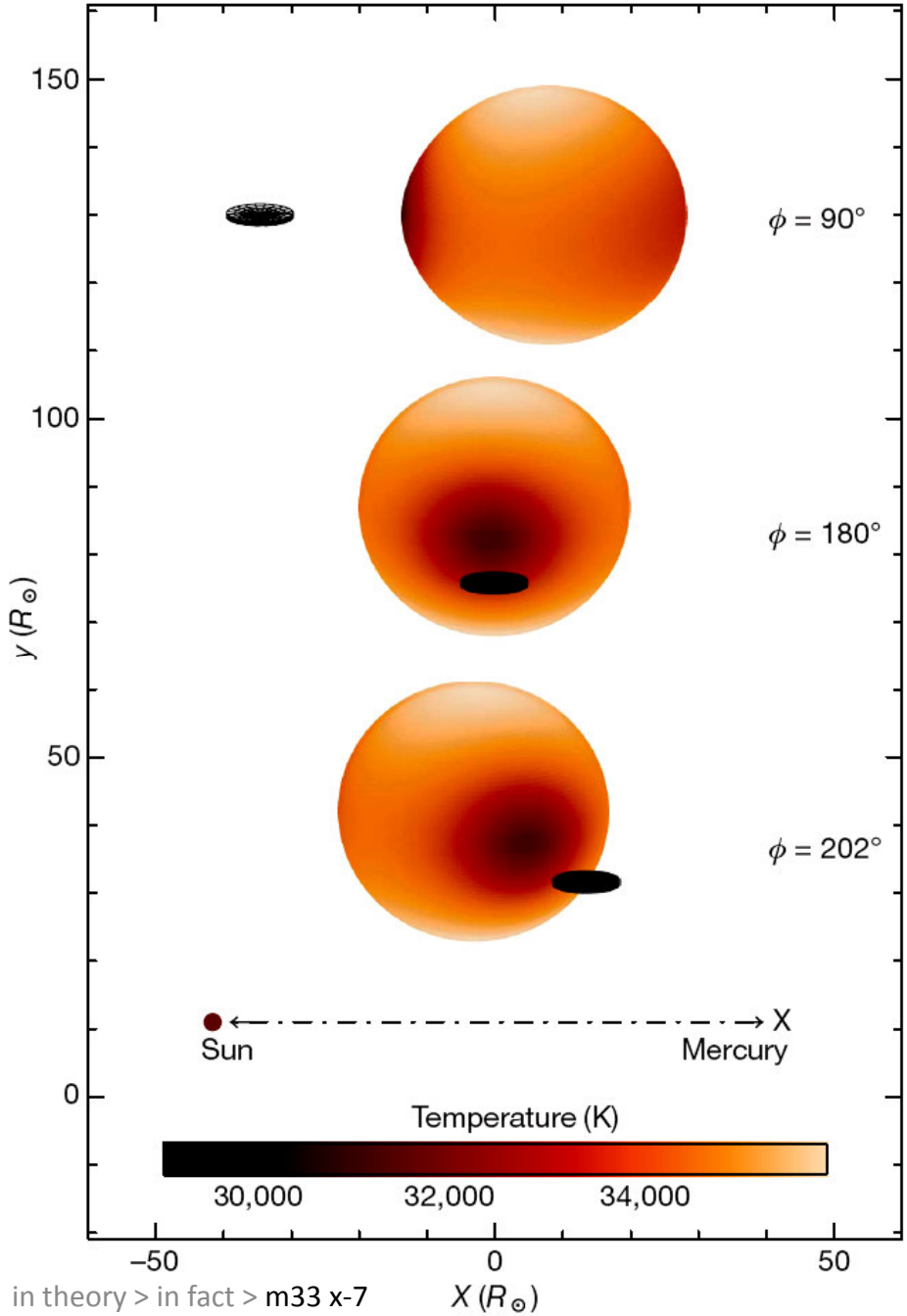



150
100
50
0
y (R⊙)
ϕ = 90°
ϕ = 180°
ϕ = 202°
Sun
Mercury
X
Temperature (K)
30,000
32,000
34,000
–50
0
50
X (R⊙)

most massive stellar black hole?

x-ray source	black hole mass	companion mass
M33 X-7	15.65 ± 1.45	70.0 ± 6.9
GRS 1915+105	14.0 ± 4.4	0.81 ± 0.53
gs 2023+338	12 ± 2	0.6
A 0620-00	10 ± 5	0.6
GS 2000+25	10 ± 4	0.5
XTE J1550-564	9.6 ± 1.2	NA
4U 1543-47	9.4 ± 1.1	2.5
Cygnus X-1	~10	~30



M1 = 16 Msun

M2 = 70 Msun

R2 = 20 Rsun

a = 42 Rsun

puzzles

- small present day separation implies
  a common envelope phase
- massive black hole implies
  common envelope began after core He burning
- requires progenitor to be
  1.2x more massive than companion
- companion star initial mass ~80Msun
  progenitor initial mass ~96Msun
- progenitor has to lose an order of magnitude less
  mass than predicted by evolutionary models
  before common envelope phase