Readings for Lecture

From Gallaway "*An Introduction to Observational Astrophysics*":

PS#9 (Part I) is posted.   Part II will be posted next week.

Final Project Details

The final project (PS9) + final exam will be combined into a single Final Project.
This final project will be due at the end of finals period.

The final project grade will count as either 20% or 30% of your grade.
The midterm exam will count as either 30% or 20% of your grade.

I will take the higher of the two scores to count as 30%

The remaining 50% is from PS#1-8.

Summer 2017 Opportunity

Hi Marla,

I have a favor to ask... could you let your Astro 255 students know about the opportunity to work as a TA for the Yale Summer Program in Astrophysics:

yspa.yale.edu/employment

We are going to hire 3 Teaching Assistants this year. The pay is $3200 for four weeks (July 7 through August 6), plus room and board and travel expenses. They also, of course, get to participate in the fun activities and the research project, and it's a unique teaching opportunity for undergraduates.

thanks, Michael

Application deadline is Dec 31

Black Holes

Black Holes come in two varieties:

1. Massive BHs:

    Found at centers of galaxies, $M = 10^6$ to $10^9 M_{sun}$

2. Stellar mass BHs:

    Final state of massive stars, $M = 3\text{-}25\ M_{sun}$

Black Holes

Stellar mass black holes are created ‘naturally’ as the by-products of stellar evolution.

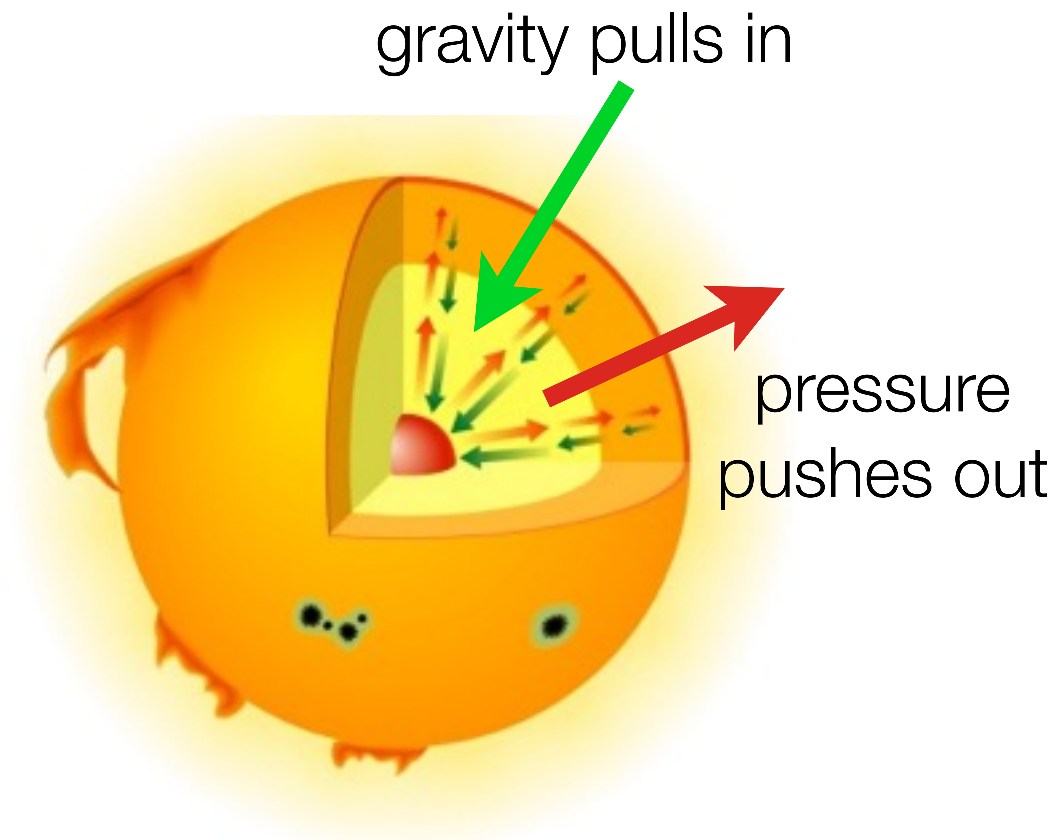
This is the only way we know how to make black holes!

So where do massive galactic black holes come from?

Can ‘grow’ black holes either by:

(1) merging two black holes together,
(2) accreting material or ‘feeding’ the black hole.

Stellar Evolution



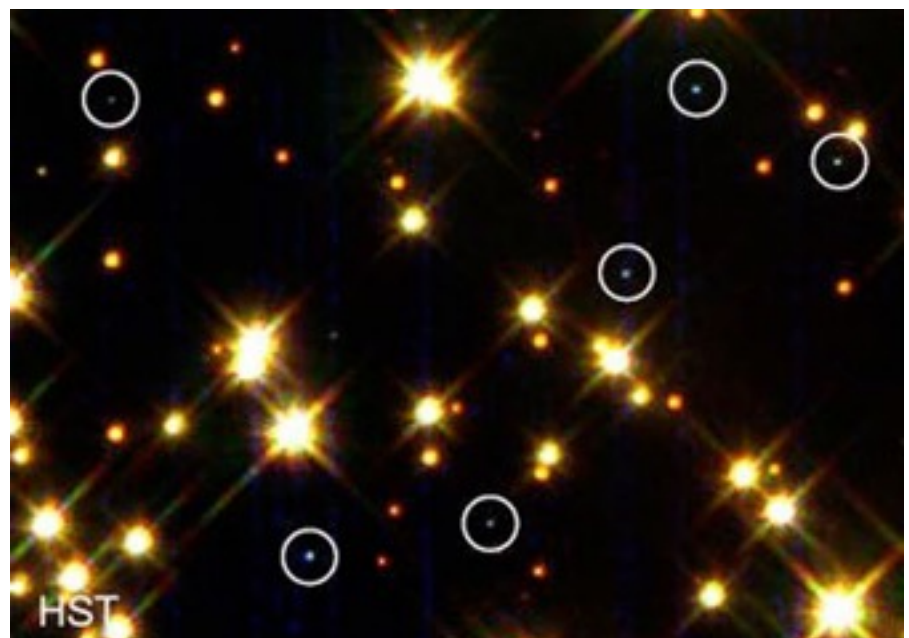
The Sun is in equilibrium, gravity balances pressure.

Pressure comes from heat generated by nuclear fusion in Sun’s core.

Hydrogen + Hydrogen = Helium + energy
(nuclear fusion)

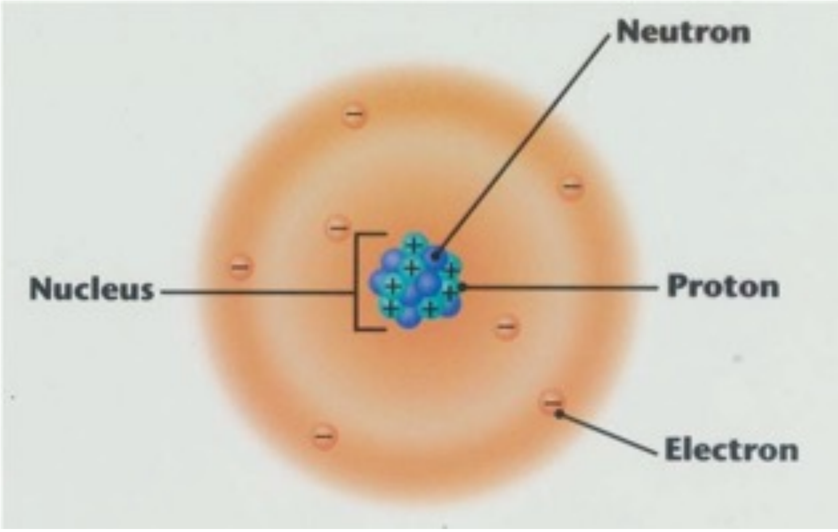
Stellar Evolution

When Sun's hydrogen fuel is expended, the outer parts expand and disappear. Inner core (white dwarf) is left behind.



Stellar evolution

What ‘holds up’ a White Dwarf remnant?



Gravity still pulls inward, but this time electron pressure pushes outward.

“Chandrasakhar limit”: A white dwarf more massive than 1.4 M_{sun} cannot be supported by electron pressure.

-> one teaspoon of white dwarf weights as much as an elephant.

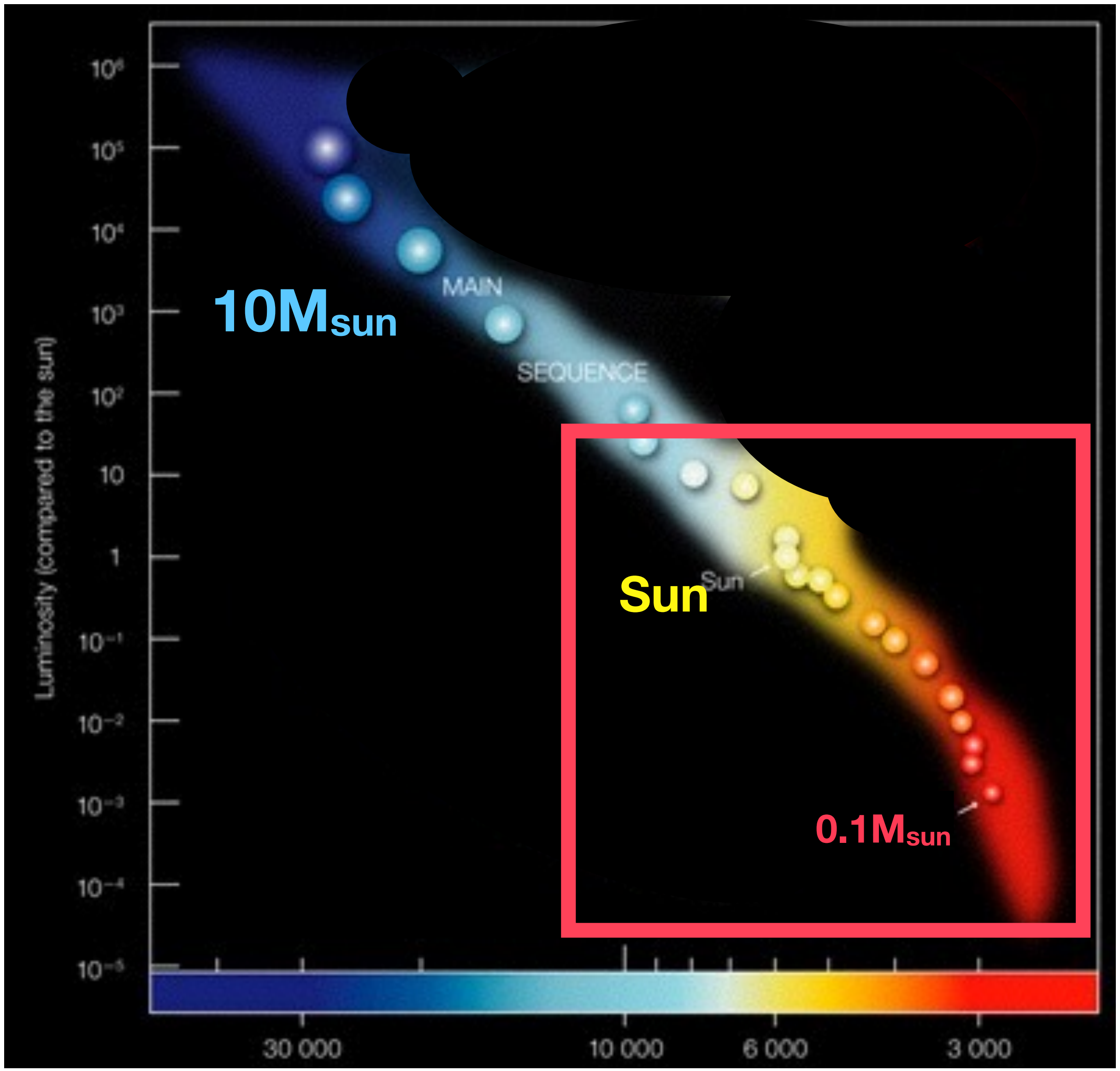
Stellar Evolution

Stars who end their lives more massive than the Chandrasakhar limit of 1.4 M_{sun} continue collapsing and become even more dense.

As a massive object collapses, pressure from the nucleus itself will stop the collapse => Neutron Star.

A star more massive than 3 M_{sun}, there is no sufficient source of pressure to halt the collapse => Black Hole.

Stellar Evolution

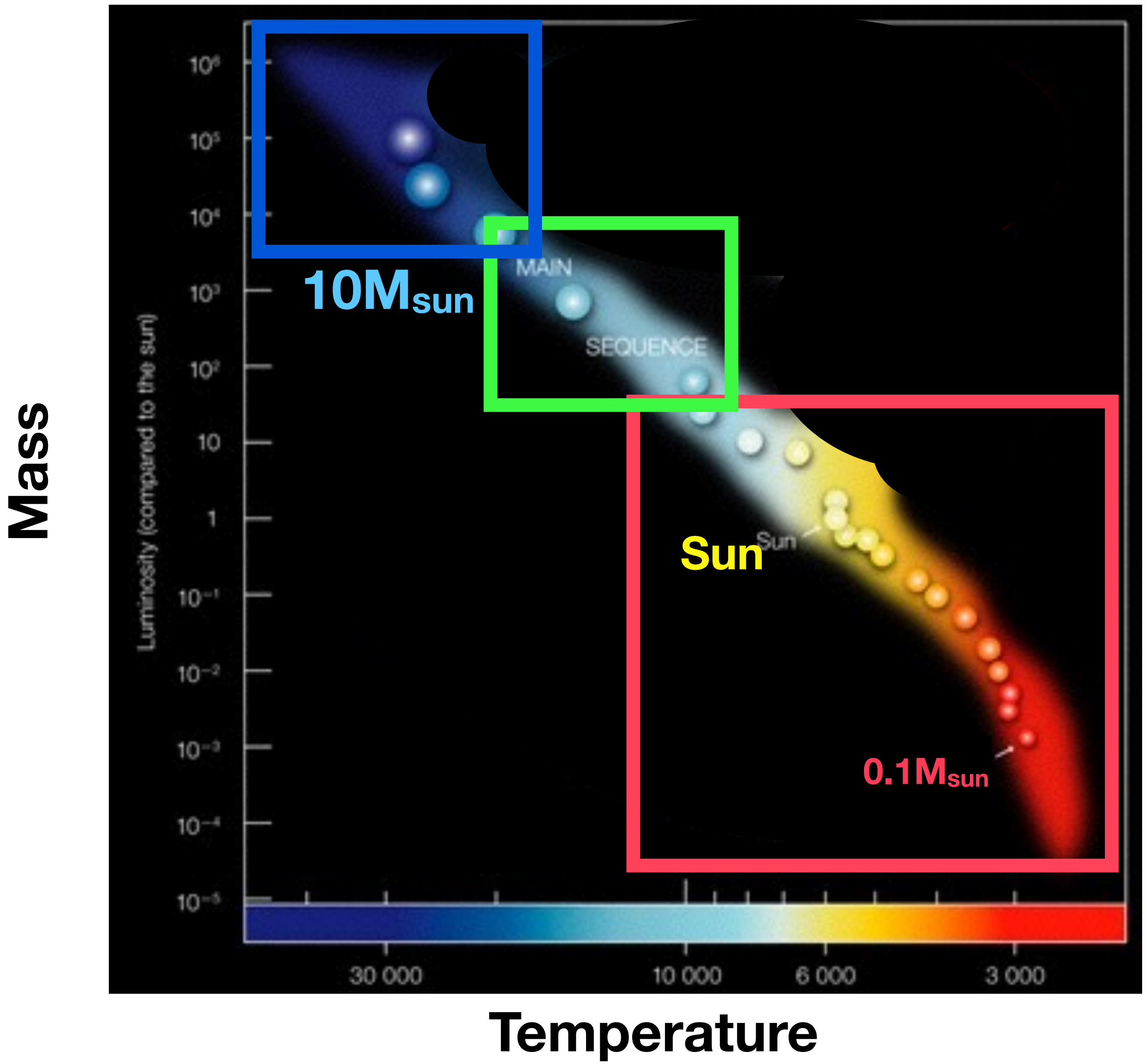


Mass

Temperature

White Dwarf remnant
$\rho = 1 \times 10^{9}\ \mathrm{kg/m^3}$

Stellar Evolution

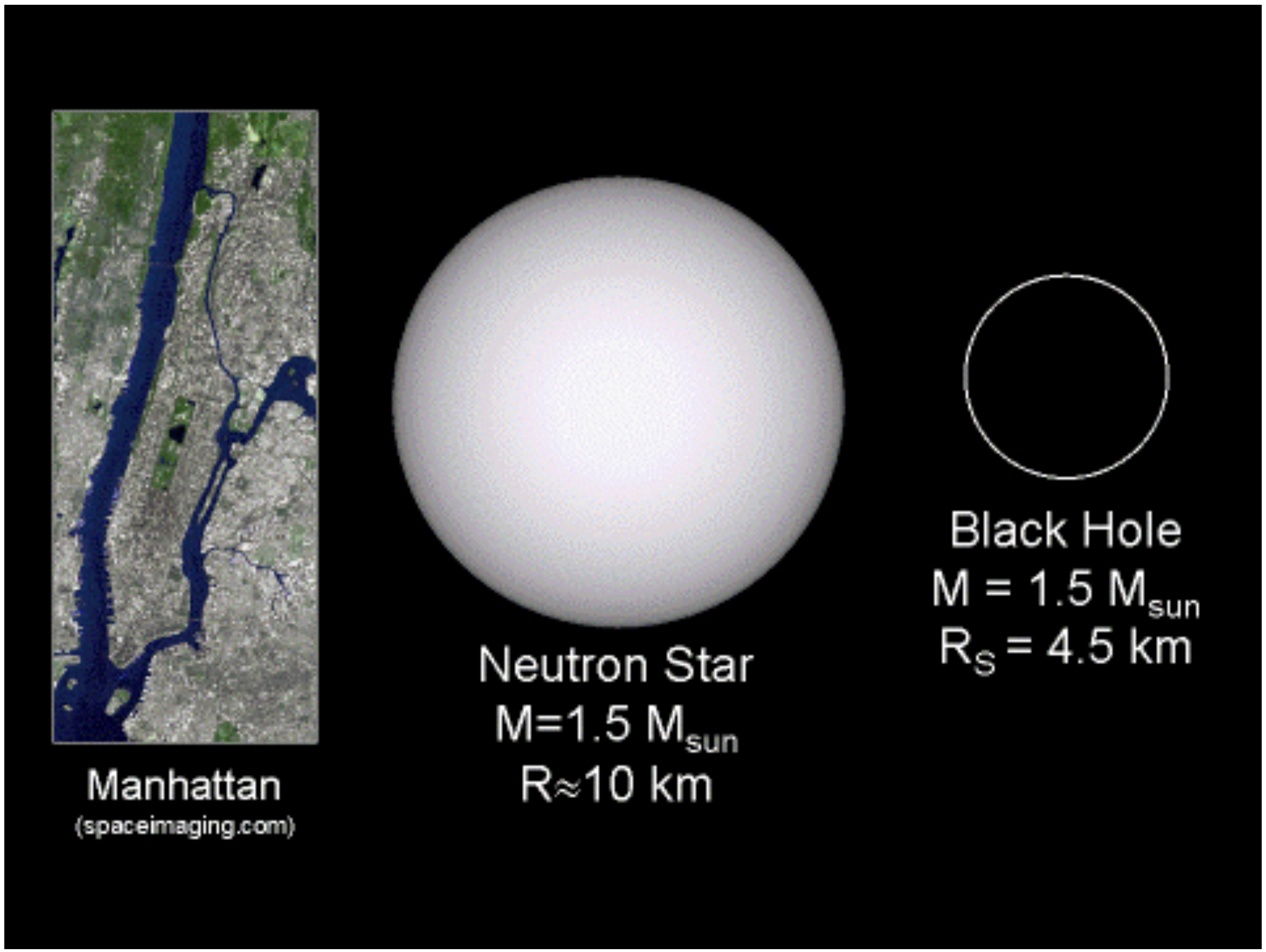


Black Hole remnant
ρ = ??? kg/m^3

Neutron Star remnant
$\rho = 1 \times 10^{17}$ kg/m^3

White Dwarf remnant
$\rho = 1 \times 10^{9}$ kg/m^3

Stellar Evolution



Neutron Stars:
1.4 to 3 M_{sun}

Black Hole
3 to 25 M_{sun}

How to Find Stellar-Mass Black Holes?

Question:

If black holes don’t emit light by definition,

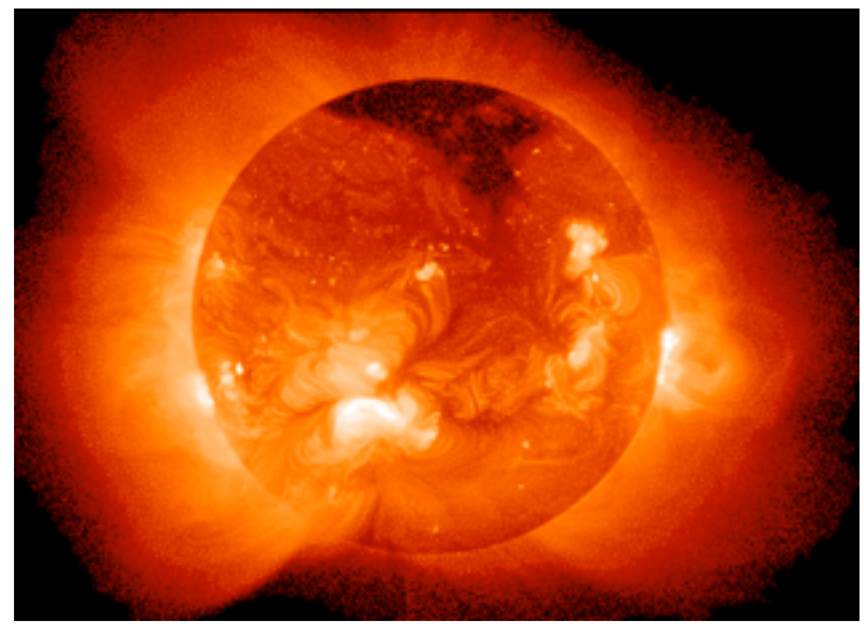
how can we hope to see them?

All of the known stellar mass black holes were discovered in the X-rays!

Where Do X-rays Come From?

X-rays are a very energetic form of light.

The Sun seen in X-rays

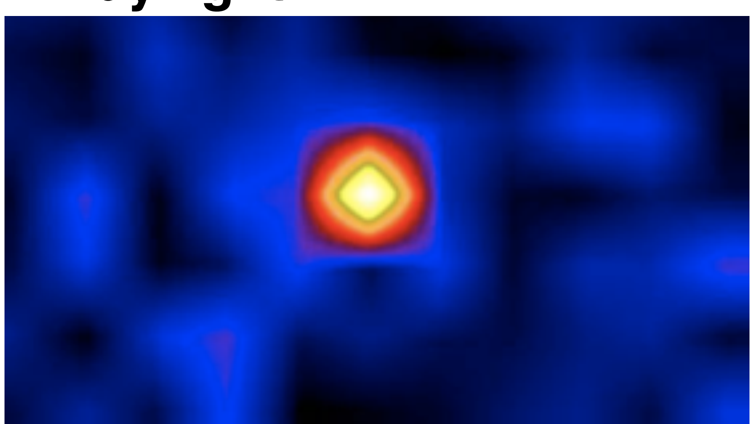


X-rays are emitted from material that is hot (millions of degrees).

Black Hole in Cygnus X-1

Optical light

X-ray light



First (and best) case for a black hole M_{BH} = 7-13 M_{sun}.

Discovered in 1973 in X-rays

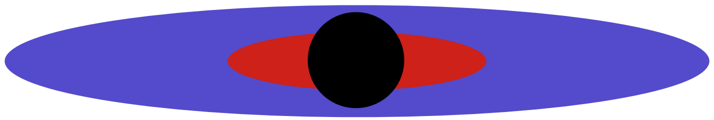
Bright star is observed to orbit around an unseen companion with 5.6 day period.

Cygnus X-1 is bright in X-rays, which implies hot gas in the system.

Where Do X-rays Come From?

Suppose there was a disk of gas in orbit around a black hole:

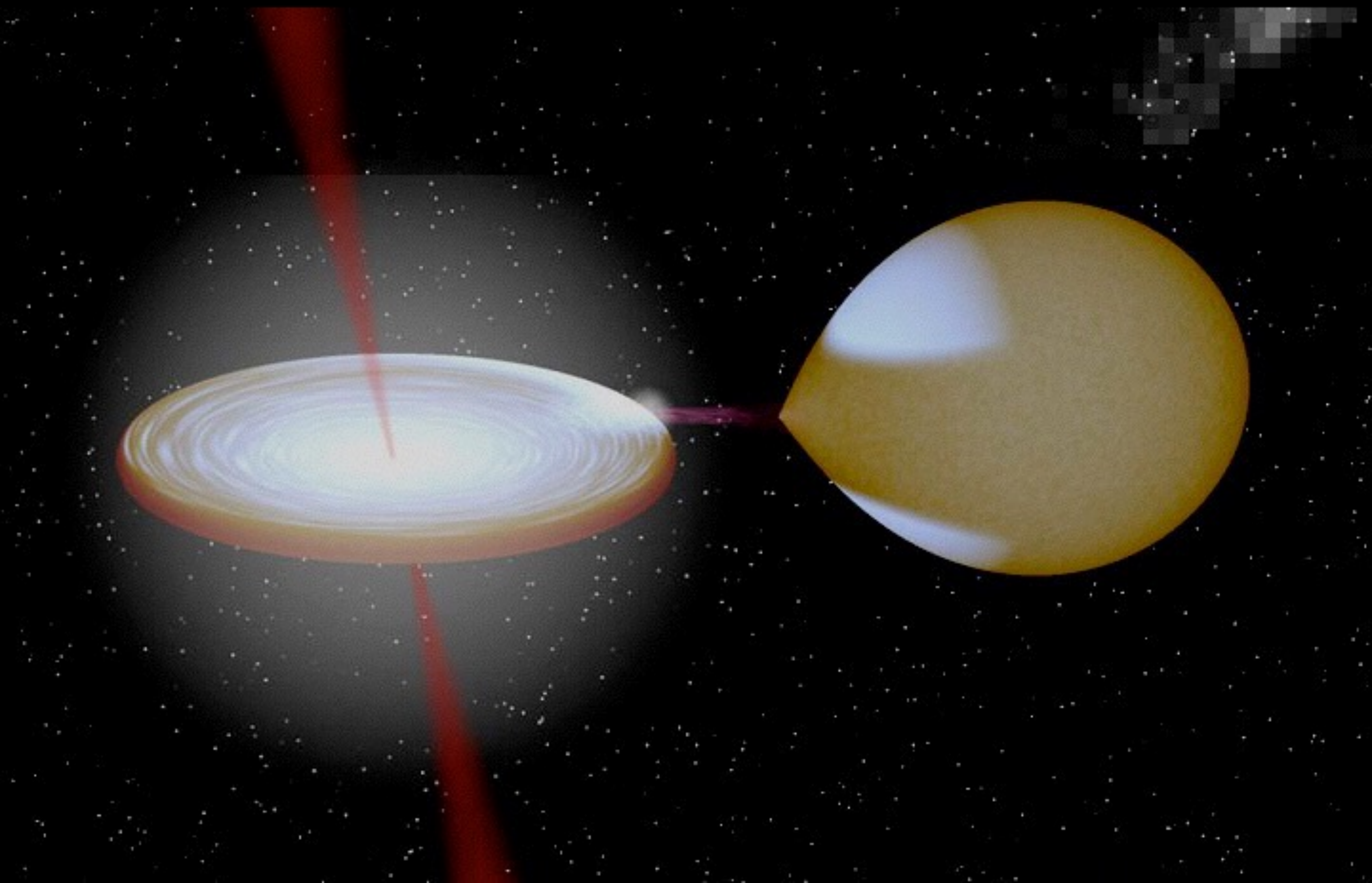
Black Hole



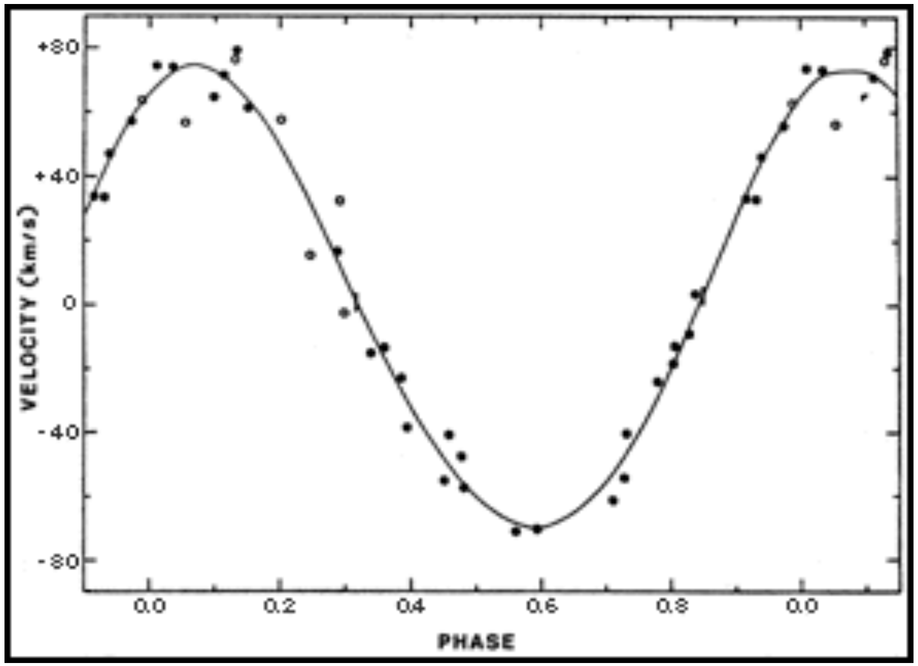
1. Gas moves at different speeds depending on its orbit.
2. Friction heats gas up, emits light.
3. Gas losses energy, moves closer to black hole.
4. Repeat.

=> For a black hole, gas can heat up hot enough to emit X-rays

X-RAY BINARY



Black Hole in Cygnus X-1



First (and best) case for a black hole M_{BH} = 7-13 M_{sun}.

Radial velocity curve of bright star in Cygnus X-1.

No companion observed.

Stellar-Mass Black Holes in Our Galaxy

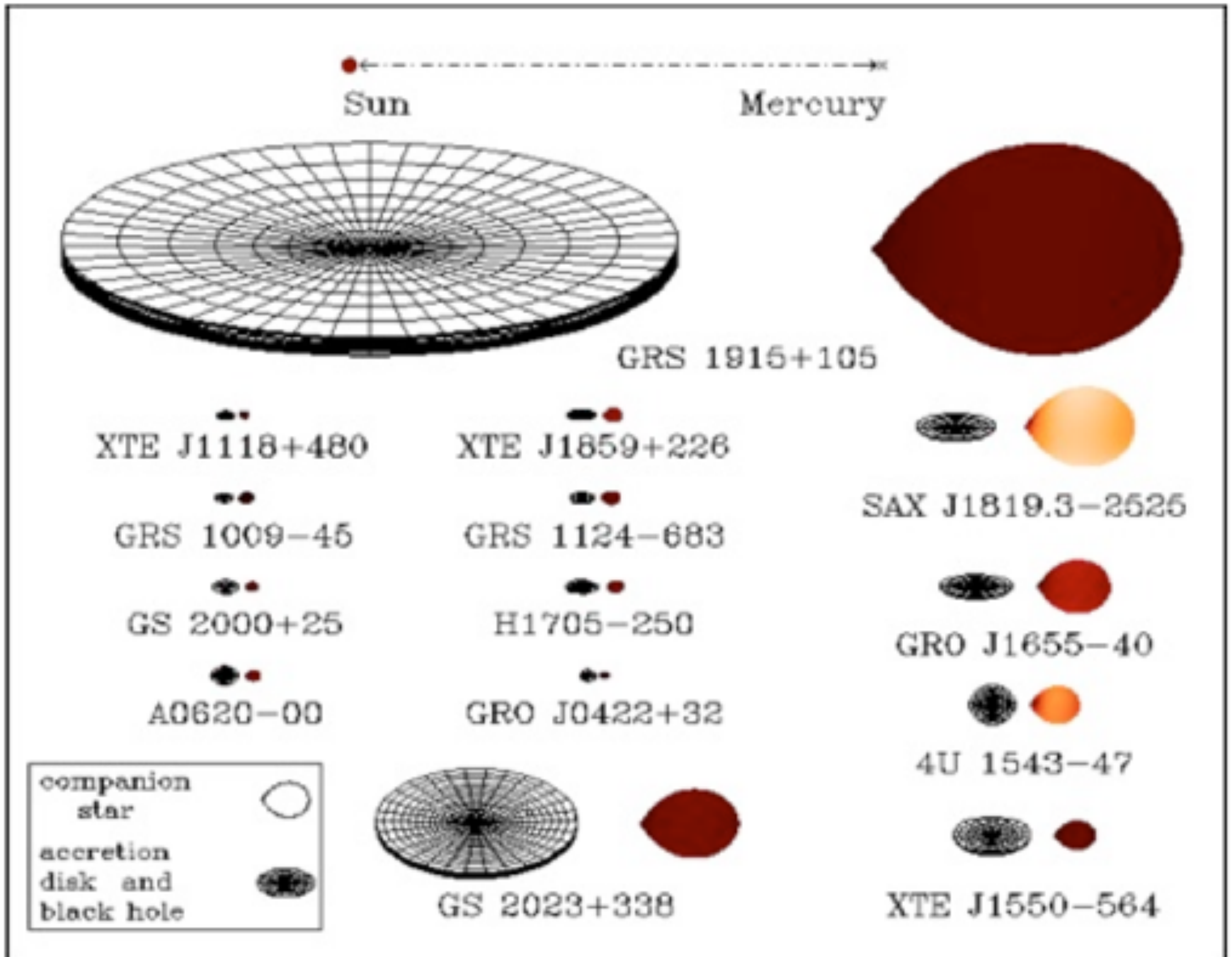
Currently 20 confirmed black hole candidates in our Galaxy:

--- First was Cygnus X-1: $M = 7\text{-}13\ M_{sun}$

--- Largest is GRS1915+105: $M = 10\text{-}18\ M_{sun}$

--- Most are in the range $4\text{-}10\ M_{sun}$

Stellar-Mass Black Holes in Our Galaxy



How many black holes are we missing?

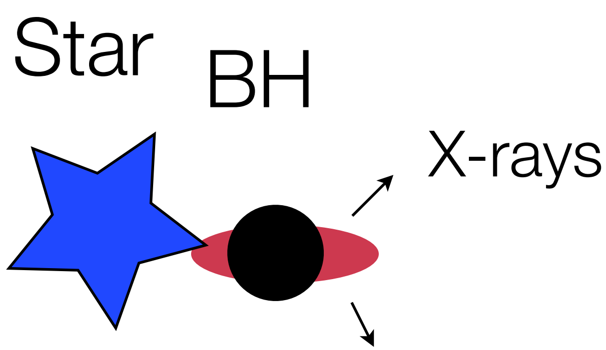
How Many BHs in the Milky Way?

Given the number of low mass stars we see in the Milky Way...

...we can estimate the number of high mass stars formed that have died and created a BH.

0.5% of all stars ever formed in the Milky Way are massive enough to form a BH.

X-ray Binary System



<u>Close separation binary</u>

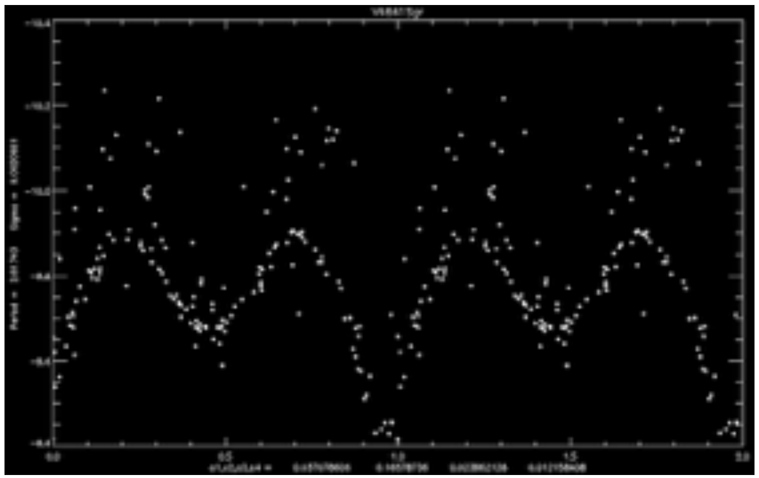
Tides are strong.
Gas surrounding black hole.
X-rays emitted as gas heats.
Black hole is discovered.

<u>Wide separation binary</u>

Tides are weak.
No gas surrounding black hole.
No X-rays.
Black hole cannot be ‘seen’.

Black Hole Binary Candidates

The 20 known stellar mass black holes in the Milky Way have been discovered at X-ray wavelengths. X-rays are emitted as a secondary star donates mass to its black hole companion.



0 1 2

Phase

The optical light curve of one X-ray discovered BH

No stellar mass black hole has been detected based on its optical lightcurve alone.

A goal of this project is improve the estimate for the number of stellar mass black holes in the Milky Way.