# ASTR 1120: Stars & Galaxies

*Eagle Nebula*

*Prof. Juri Toomre TA: Ben Brown*
Lecture 27 Mon 14 Mar 05
*zeus.colorado.edu/astr1120-toomre*

## Today's Joys

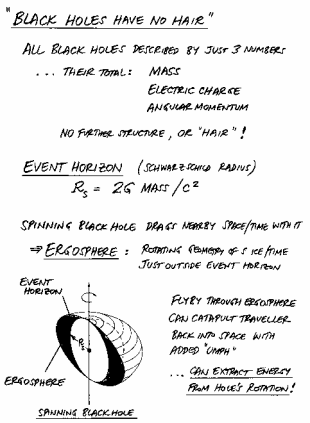
- How to *detect black holes*, (indirectly) even *supermassive* ones
- Mystery of fantastic explosions far away: *Gamma Ray Bursts (GRBs)*
- *Our Milky Way Galaxy* in overview, seeing various components of any *spiral galaxy* – and a fine *SONG*
- *Observatory Night # 6* tonight, by sign-up
- Read *Chap 19 Our Galaxy* with care

REMINDER

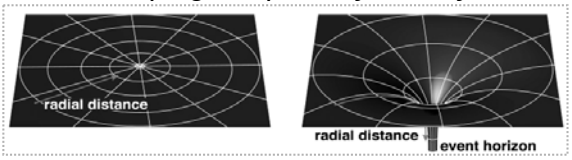
*"Black holes have no hair"*

*Only three numbers describe BH!*

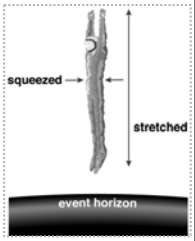
*Ergosphere: spinning BH drags nearby spacetime along*




## Warping of Space by Gravity

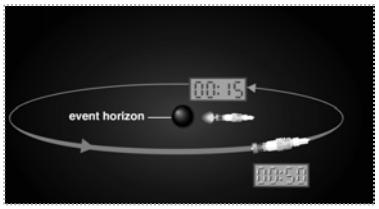



- *Gravity imposes curvature on space*
  - light's path through space will be "bent by gravity"
  - within the event horizon, it cannot climb out of the hole
- *As matter approaches event horizon…*
  - tidal forces are tremendous
  - object would be "spaghettified"



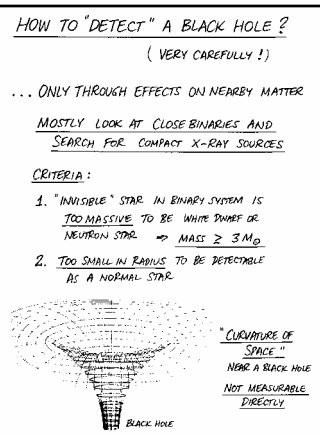

## Warping of Time by Gravity

- *If we launched a probe to a black hole, time slows down as it approaches the event horizon*
  - it may take 50 min of time on mother ship for 15 min to elapse on probe
  - from *mother ship's view*, the probe takes forever to reach event horizon
  - light from probe is redshifted more and more, eventually disappears as light from it is redshifted beyond radio




*From probe's view:*
- it heads straight into the black hole
- light from the mother ship is blueshifted

*How to "detect" a black hole*



## *Clicker – Size of Black Hole*

- *What does the Schwarzschild radius of a black hole (BH) depend on?*

*C.*

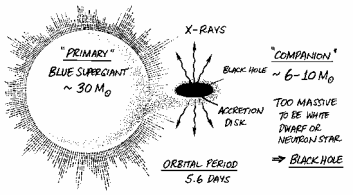
- *A.* Both mass and chemical composition of the BH
- *B.* Radius of BH, as measured by careful observations of its size
- *C.* Only the mass of BH
- *D.* Whether BH formed in massive star supernova or in some other way

*Observing a black hole:*

*Cygnus X-1*

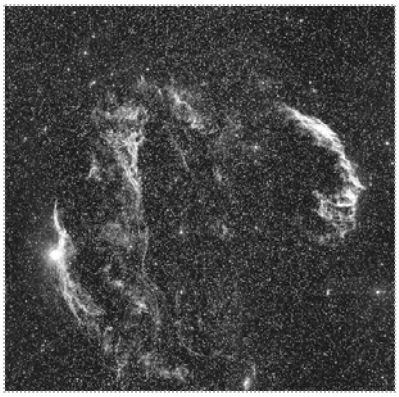

CYGNUS X-1 :
MOST VIABLE BLACK-HOLE CANDIDATE

- ECCLIPSING BINARY SYSTEM IN SN REMNANT (CYGNUS LOOP)
- STRONG X-RAY SOURCE, VERY RAPID FLUCTUATIONS
- DOPPLER VELOCITY VARIATIONS OF PRIMARY INDICATE MASSIVE COMPANION (NOT SEEN DIRECTLY)

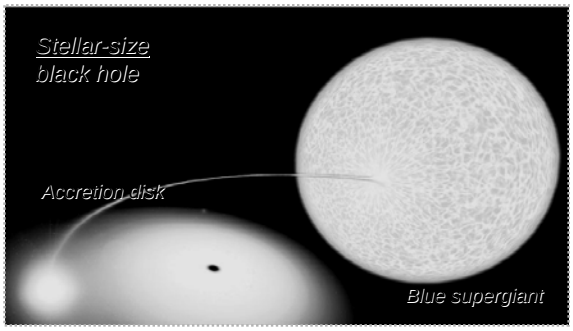



- STELLAR WIND POURS MATTER ONTO HUGE ACCRETION DISK
- INFALLING GAS HEATED AS SPIRALS INWARD, GETS SO HOT THAT EMITS X-RAYS AT INNER EDGE OF DISK

## *Cygnus Loop SNR – Home of Cyg X-1*



*Cygnus X-1: Blue supergiant (strong winds) pours H + He onto accretion disk of black hole*



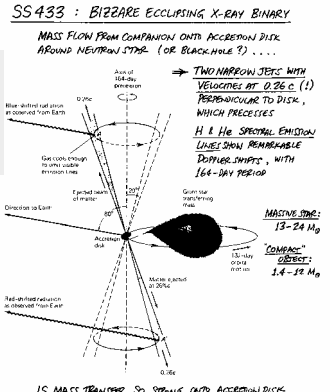

*SS 433*

*top candidate for wild object!*

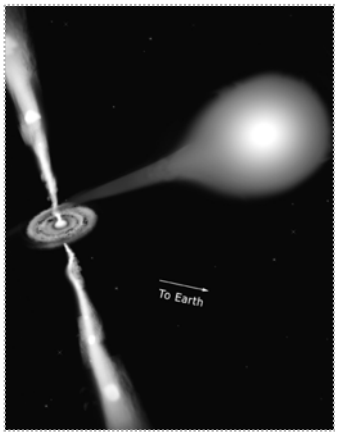
*another stellar-size black hole*

SS 433 : BIZZARE ECCLIPSING X-RAY BINARY

MASS FLOW FROM COMPANION ONTO ACCRETION DISK AROUND NEUTRON STAR (OR BLACK HOLE?) . . . .



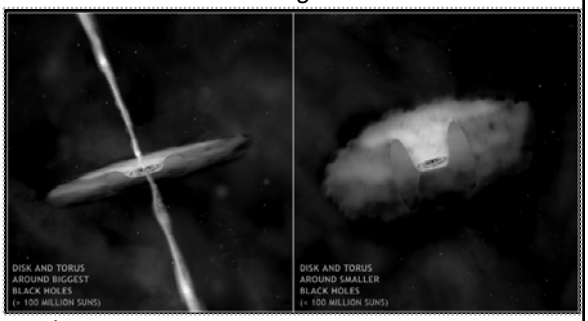

IS MASS TRANSFER SO STRONG ONTO ACCRETION DISK THAT ONLY WAY OUT IS ALONG ROTATION AXIS ?




*SS 443*

*BH + jets*

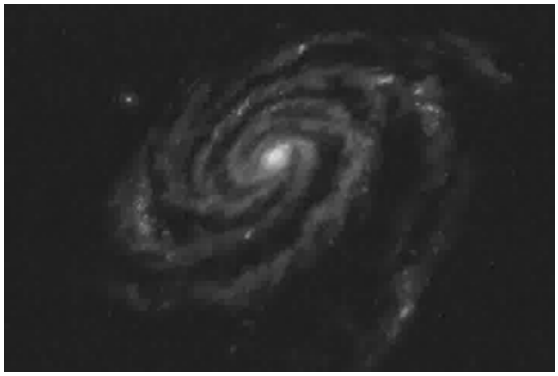
## *Super-massive black holes (BH) near centers of galaxies*



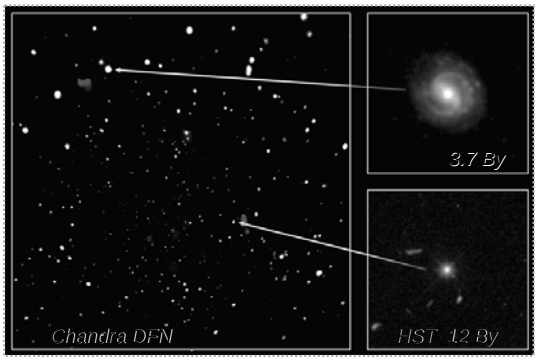

*Biggest BH – greater than 100 million $M_{SUN}$*

*Smaller BH*

## *Fly-In to Black Hole*



## *Super-massive BHs in very distant galaxies revealed by Chandra X-ray imaging*



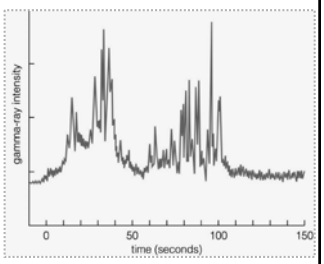

## *Gamma Ray Bursts (GRB)*

- *Cosmic gamma-rays must be observed from above our atmosphere*
  - *in 1960s, satellites saw very strong bursts of gamma-rays*
  - *occur daily, for a few minutes*
  - *gamma-rays are hard to focus, so determining their direction is tough – now feasible*
- *Since 1997, have detected GRB afterglows at other wavelengths*
  - *can pinpoint sources to very distant galaxies*
  - *must be vastly energetic!*

*GRB afterglow in very distant galaxy – Hubble optical image*

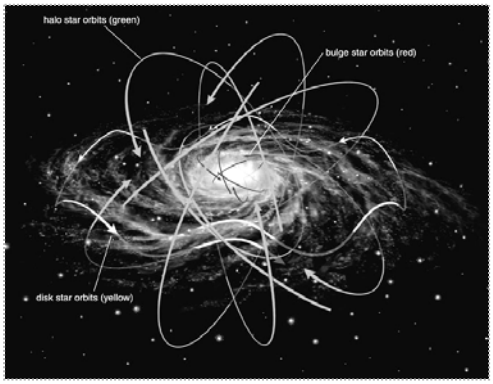
## *GRBs – puzzle, maybe explained*

- *Best theory suggests "hypernovae": giant super novae (from 30 to 100 $M_{solar}$) that form black holes*
- *Or might be two neutron stars falling together*
- *Or neutron star spiralling into black hole -- but energy release must be biggest thing around!*




*Short GR burst (~3 minutes), long optical afterglow (days)*

## *Now we turn to Our Milky Way Galaxy*



## *Stars and gas are all moving!*


*Sing our way to the Milky Way*

*THE GALAXY -- LIGHTEN UP*

Whenever life gets you down, Mrs. Brown,
And things are hard and tough,
And people are stupid, obnoxious and down,
And you feel that you've had quite enough...

Just remember that you're standing on a planet that's evolving
And revolving at 900 miles an hour.
It's orbiting at 90 miles a second, so it's reckoned,
From the sun that is the source for all our power.
The sun and you and me and all the stars that we can see
Are moving at a million miles a day
In an outer spiral arm at 40 thousand miles an hour
In the Galaxy we call the Milky Way.

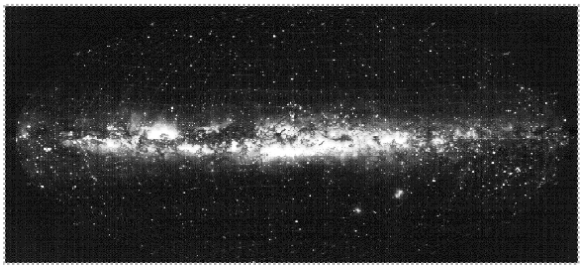
Now the Galaxy itself contains a hundred billion stars.
It's a hundred thousand light-years side from side.
It bulges in the middle 16 thousand light-years thick,
But out by us it's just 3 thousand light-years wide.
We're 30 thousand light-years from galactic central point.
It'll go round every 200 million years.
And our galaxy is only one of millions and billions
In this amazing and expanding Universe.

Now the Universe itself is still expanding and expanding
In every direction it could wish
As fast as it can go, the speed of light we know,
12 million miles a minute and that's the fastest speed there is.
So remember when you're feeling very small and insecure
How amazingly unlikely was your birth,
And pray that there is intelligent life somewhere up above,
For there isn't any down here on Earth.

Lighten up, there are stars in the sky,
Lighten up, it's a good question why,
But you don't know the answer and neither do I,
So meanwhile let's just all lighten up.

And remember that you're standing on a planet that's evolving ...

## *<u>The Milky Way</u> (fuzzy ribbon of light across the sky)*



## *Clicker – Where are we?*

- *Why was it so difficult to figure out <u>where in the Milky Way</u> are the Sun and Earth located, and if ours is the only "nebula" (galaxy) ?*

*D.*

- *A.* We are immersed in a soup of stars, gas and dust, so hard to see far
- *B.* In a middle of city of stars, hard to figure shape of overall `metropolitan area'
- *C.* Gas and dust can absorb light, making distance estimates uncertain
- *D.* All of the above

## *Size of Milky Way*

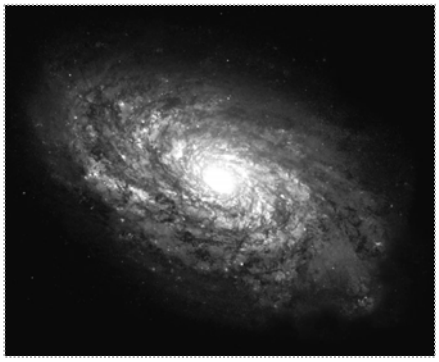
- *100-400 <u>billion</u> stars*
- *100,000 light years in <u>diameter</u>, or*

*~ 30,000 pc = 30 Kpc (kilo-parsecs)*

- *<u>Sun</u> is located about 8.5 kpc from center, in the `Orion Arm'*

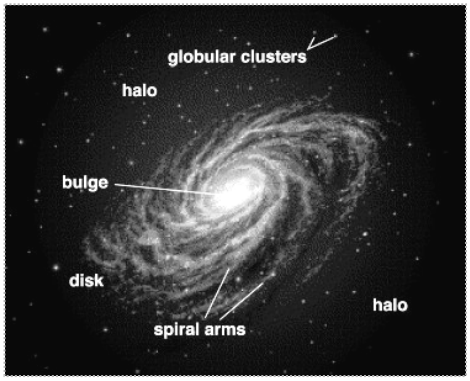
*Artist's sketch!*

## *What Milky Way might look like!*



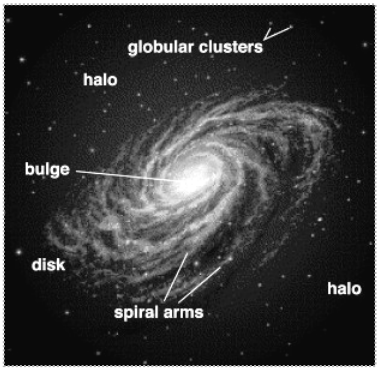
*Spiral Sb galaxy NGC 4414*

## *Milky Way <u>Anatomy</u> – Spiral Galaxy*

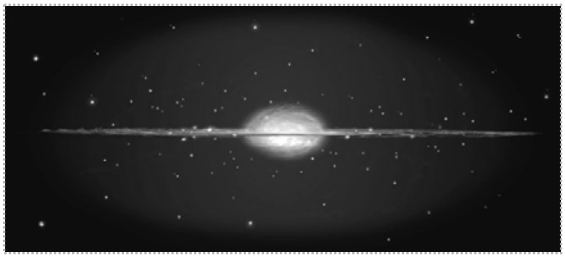



## *Disk, Bulge & Halo*

- *<u>Disk</u>: includes <u>spiral arms</u> -- young, new star formation*
- *<u>Bulge & Halo</u>: older stars, globular clusters*




## *Disk is very thin!*

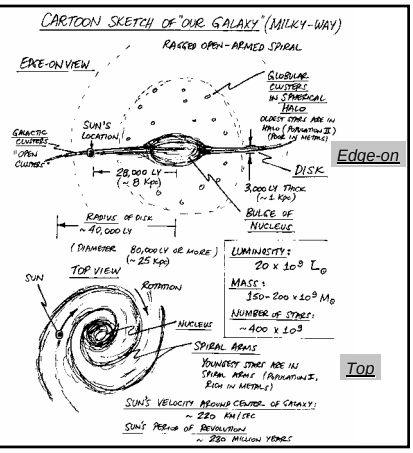


*Artist's edge-on view*

## *Spiral galaxy NGC 891 – nearly edge-on*

*<u>One-pager:</u>*
*ALL about us!*

*Cartoon sketch of Milky Way*




*Inventory of "stuff" making up our galaxy*