

Astronomy 150: Killer Skies

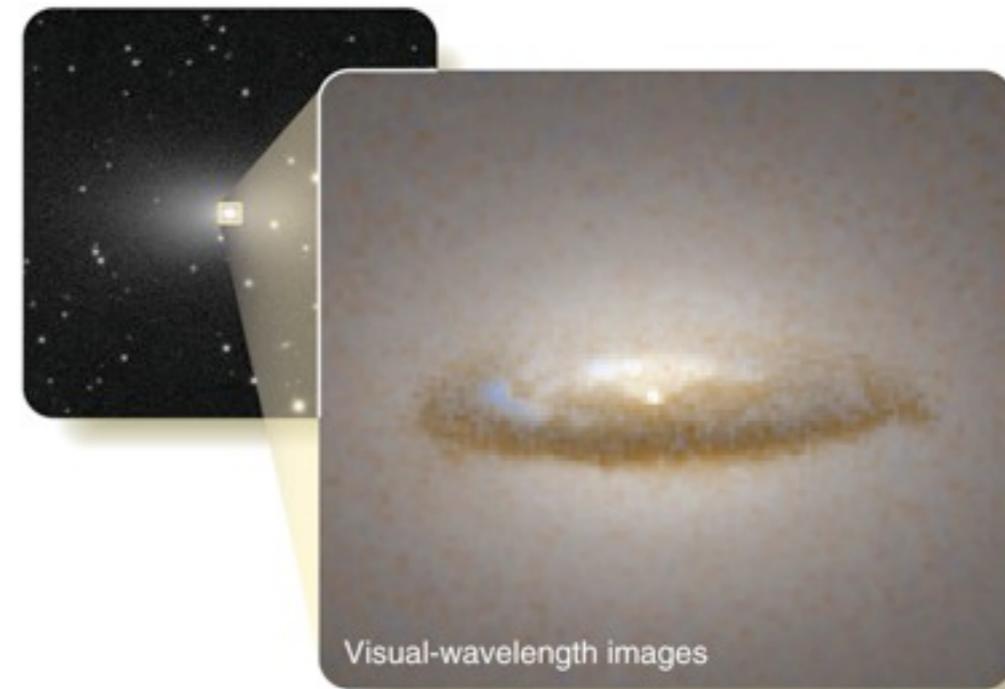
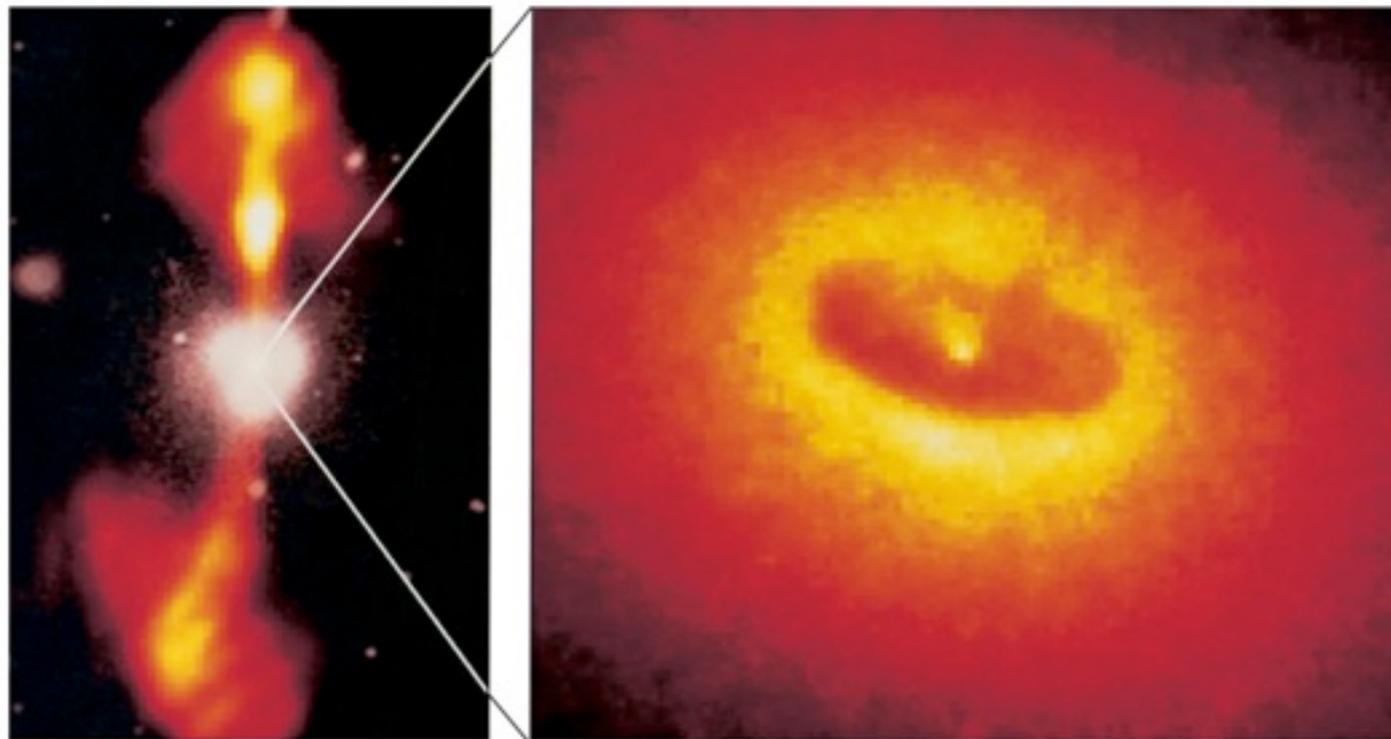
Lecture 32, April 13

Assignments:

- ▶ HW9 was due at start of class
- ▶ Solar Observing due now
- ▶ HW10 due next Friday
- ▶ Computer Lab 2 also due next Friday

Last time: Spaghettification

Today: **Cosmic Blowtorches**



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Computer Lab 2

Another chance to analyze real research-grade data and draw conclusions about the cosmos

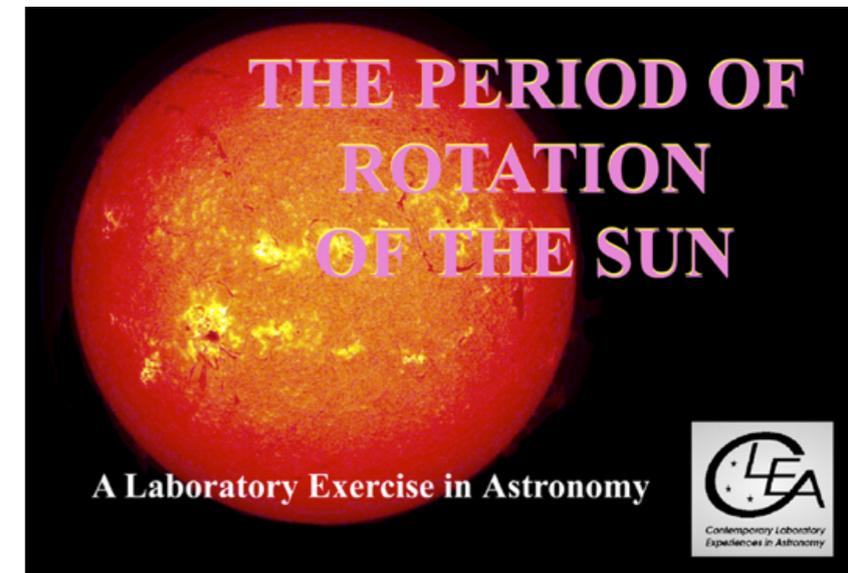
You can choose one of two:

- ▶ Solar Rotation
- ▶ Galaxy Zoo

details on course website

“Second Chance”: **If you do both labs** then

- ▶ higher score will count as your Lab 2 score
graded out of 100, counts for 50 points out of 1000 on final grade
- ▶ lower score will **replace up to 20 points** on final grade total for **one** low Homework, Observing, or Lab 1 score
not “extra” points on final point total, **only replaces one** existing low score
- ▶ in practice: **maybe worth doing if you have any** of these
 - a homework score < 20 out of 20
 - a Lab 1 score < 40 out of 100
 - an Observing or Planetarium score < 20 out of 25



Hour Exam 2

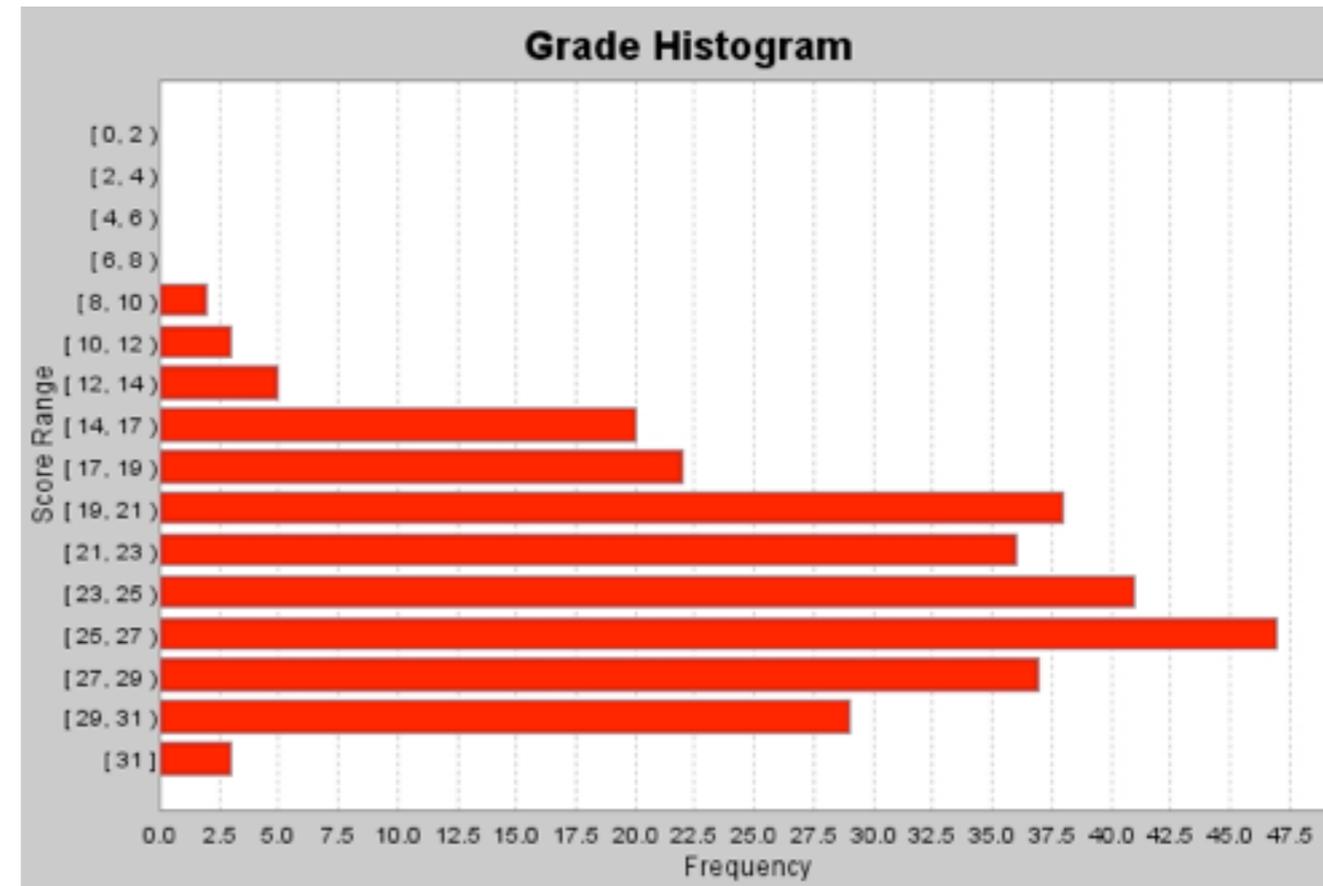
Scores posted on
Compass

- ▶ along with grade distribution

Bravo!

This was difficult
material!

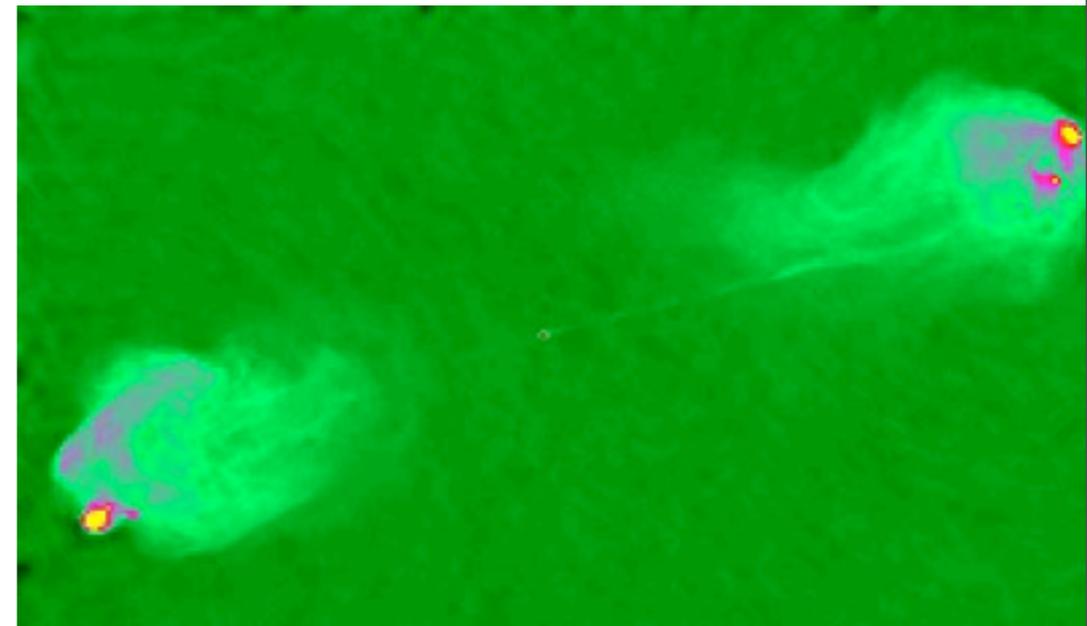
I am pleased with how
the class did



Supermassive Black Hole Jets

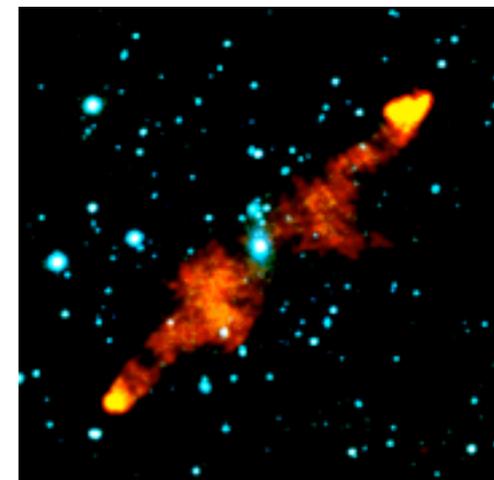
Every (?) galaxy has a supermassive black hole at its center

- ▶ most on a diet, not feeding, not dangerous (except nearby)
- ▶ when they do feed, not all matter falls in
- ▶ some matter ejected at speeds $>99\% c$
- ▶ forms back-to-back “jets”



Relativistic Jets from Active Galactic Nuclei

- ▶ stretch from black hole to far beyond the host galaxy
- ▶ Jets are among largest structures in the Universe
- ▶ carry enormous energy
- ▶ but many open questions are under study:
 - how exactly is the jet created by the BH?
 - what is the jet made of?
 - what determines the amount of time the jet is “on”?



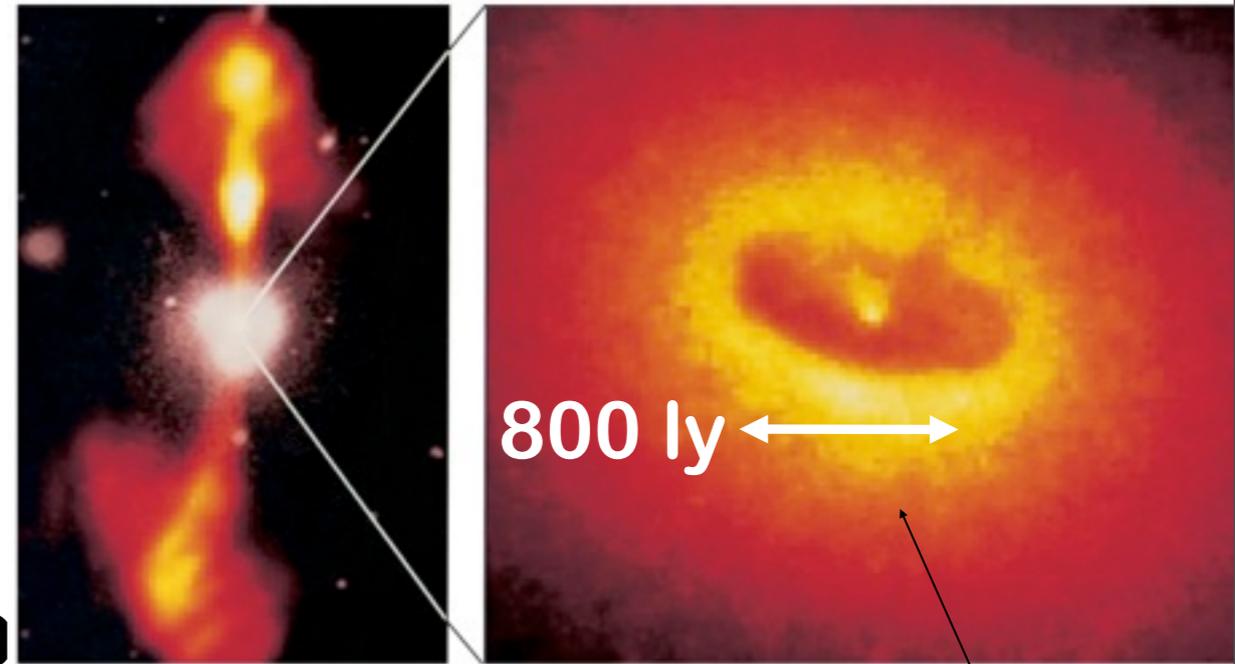
The Central Engine – Supermassive Black Holes

Supermassive black holes are energy source for active galaxies

- ▶ Only thing compact enough and energetic enough

Material falling into the black hole compresses and heats up

- ▶ Emits tremendous amounts of energy
- ▶ Some gas escapes via high-speed jets
- ▶ the more the black hole eats, the more powerful the jet
i.e., accretion rate sets jet power



NGC 4261 in the Virgo Cluster

**From velocities,
1.2 billion solar
masses!**

Supermassive Black Holes in Context

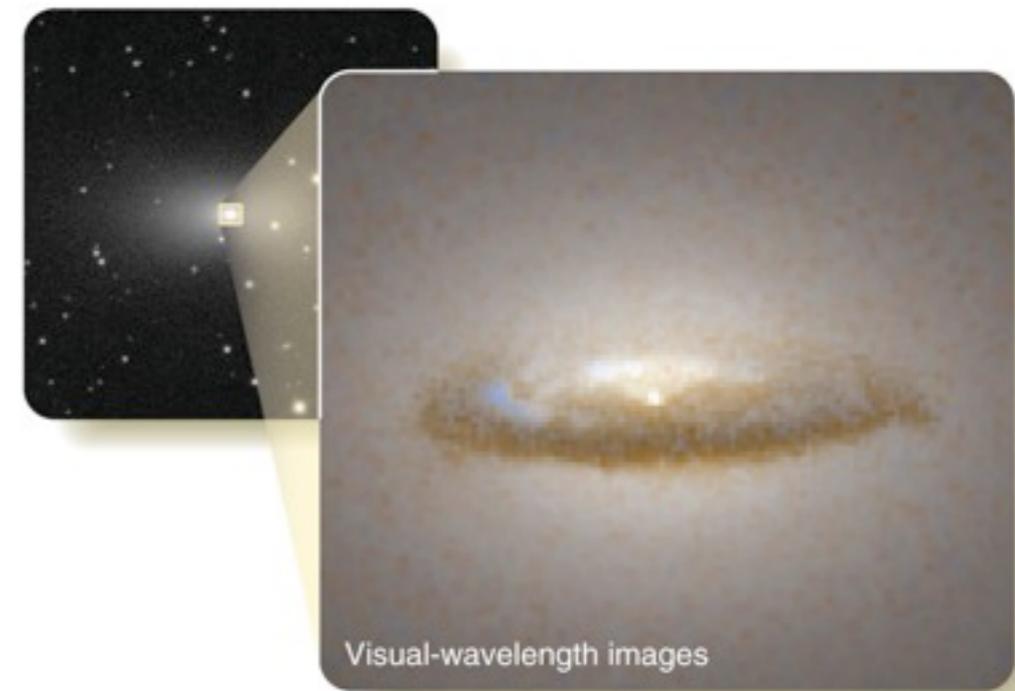
Supermassive black holes live in the centers of galaxies containing billions of stars (and other stuff)

And despite the impressive black hole masses, they are dwarfed by their host galaxies

- ▶ supermassive BH mass:
up to $10^9 M_{\text{sun}}$
- ▶ host galaxy mass:
up to $10^{13} M_{\text{sun}}$!
- ▶ supermassive BH size:
 R_{Sch} up to 100 AU or about 0.01 parsecs
- ▶ host galaxy size:
up to 20,000 parsecs!

Galaxy gravity drives black hole to center

Black hole gravity is **not** what holds galaxy together!



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Driving Active Galaxies: The Monster Within

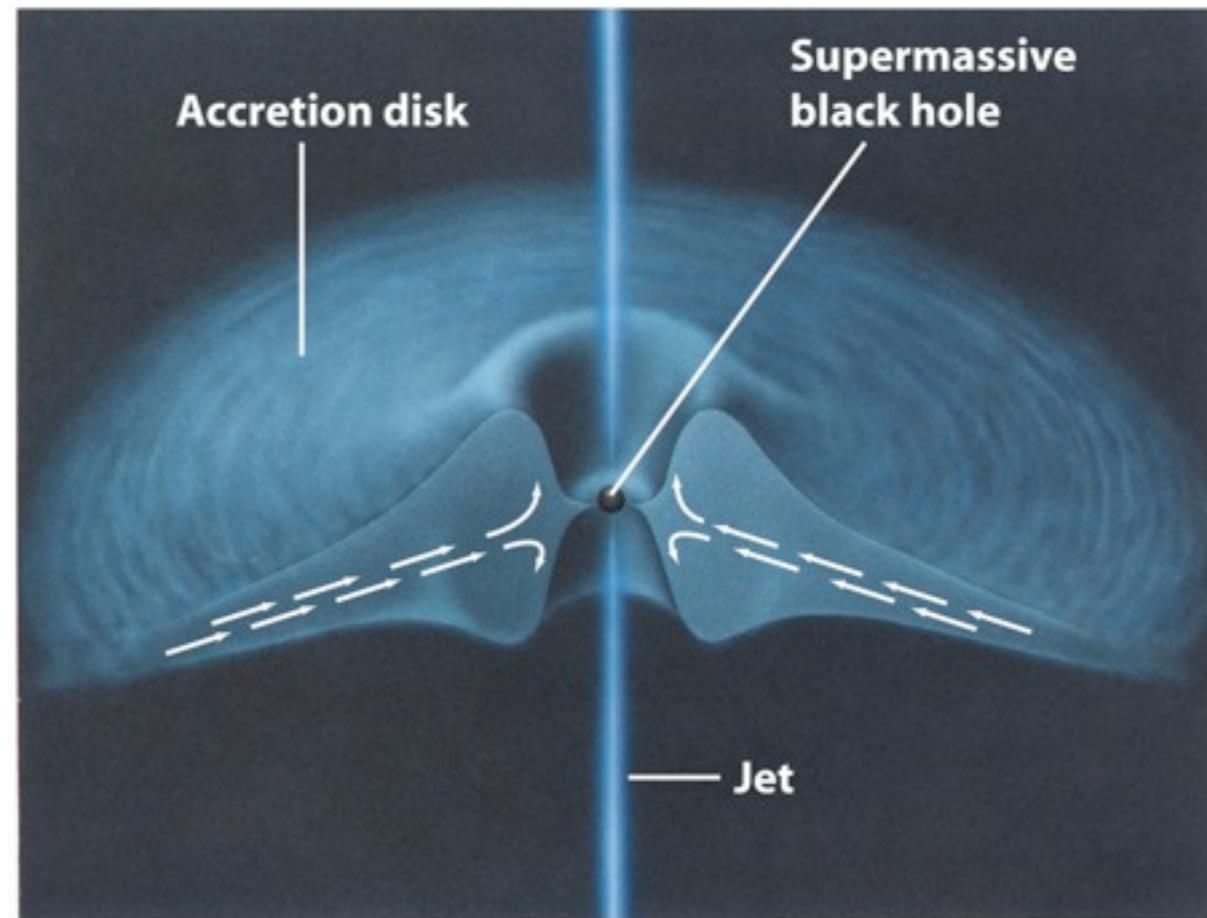
The jet energy source
is a supermassive
black hole

Accretion disk
emits tremendous
amounts of energy
as it falls onto the
black hole

**Jet is a beam
of death!**

But only dangerous if you are caught in the
beam

Crucial question: **where does the beam point?**



Pointing the Death Ray

When black hole feeds, **spins up**

- ▶ accretion disk determines equator of spin
- ▶ Jet ejected along **poles** of spin

Really there are **two** back-to-back jets

- ▶ one from north pole, one from south

So accretion disk plane sets jet direction

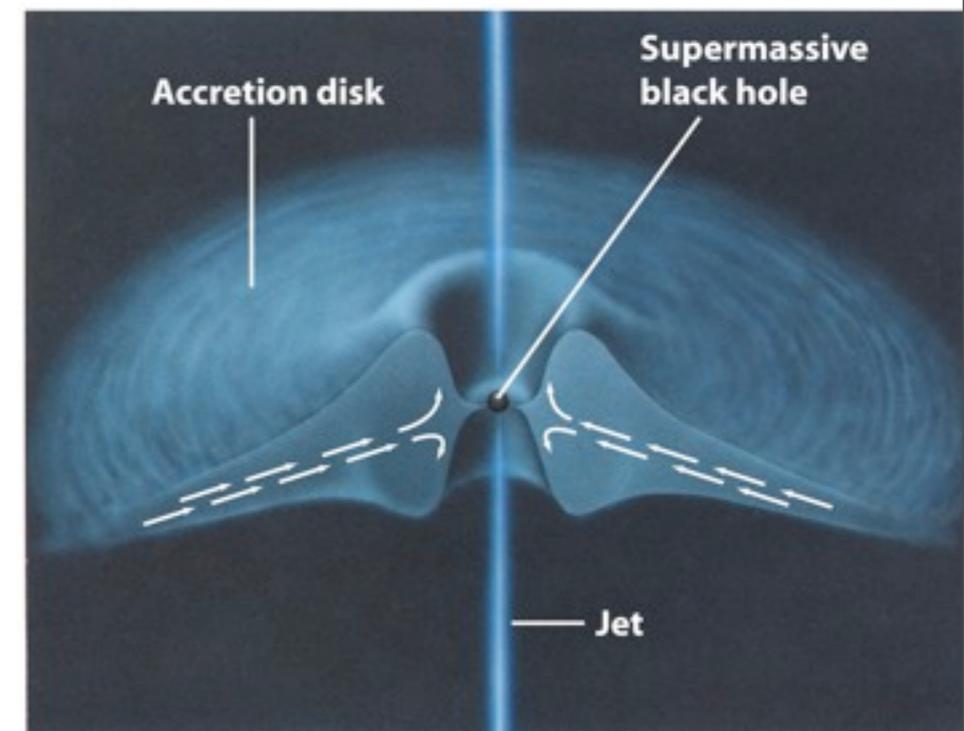
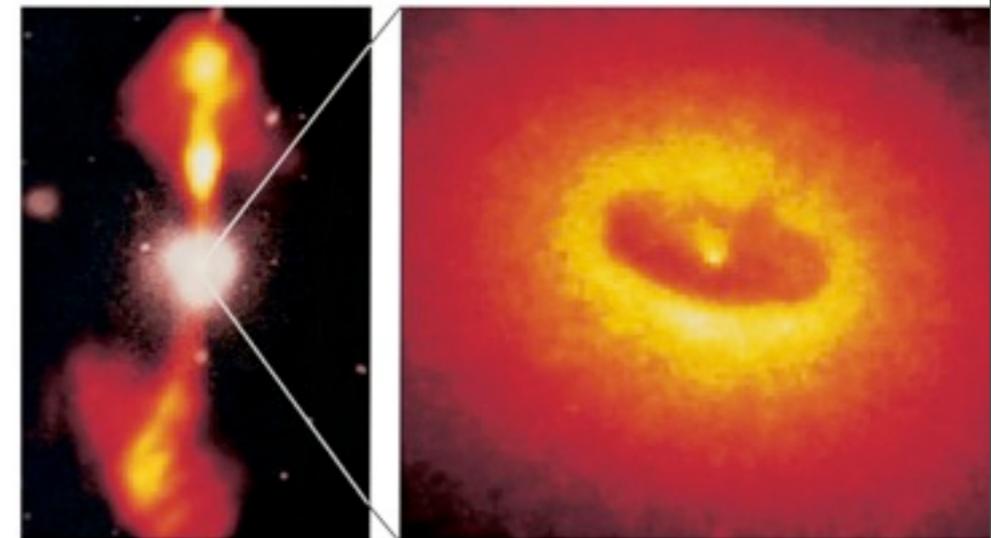
- ▶ **What sets disk plane?**

Orientation of infalling material

- ▶ but only accrete from region very near black hole
- ▶ direction of infalling matter depends on orbit directions of nearest stuff
- ▶ not clear what sets that,
but could very well be **random**

Bottom line: **disk and jet directions could well be “unaware” of nature of larger galaxy**

- ▶ if so: **jet direction cannot be predicted** by looking at host galaxy
- ▶ **jet direction could be random!**
- ▶ if so---nobody can feel safe!



Local Danger?

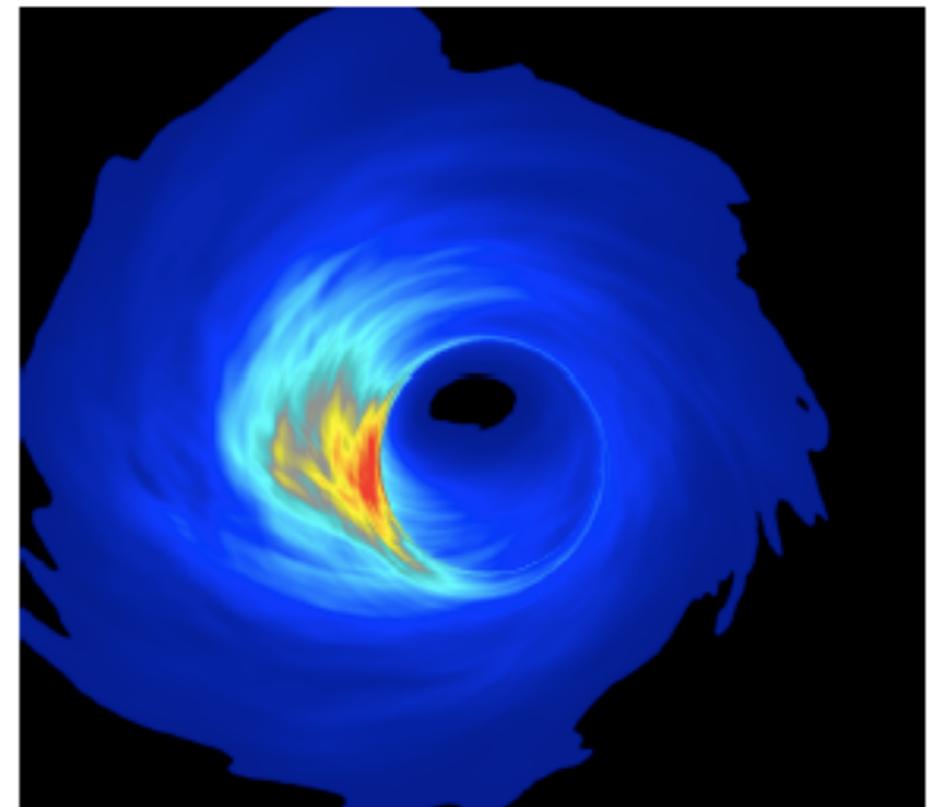
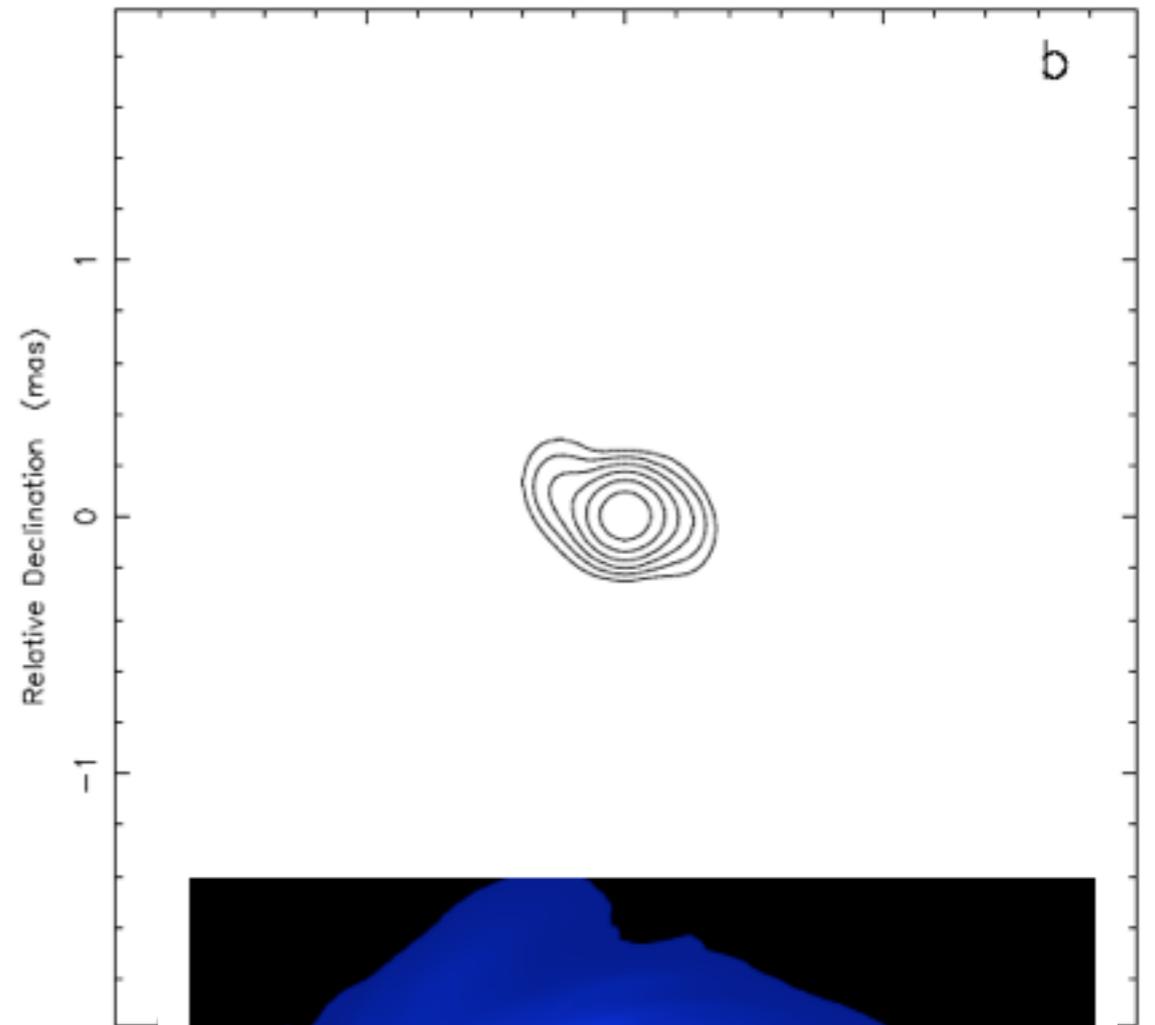
Our own Galaxy's supermassive black hole is Sagittarius A*

Today: Sgr A* has a very small accretion disk.

Not really feeding, very very light snacks at best.

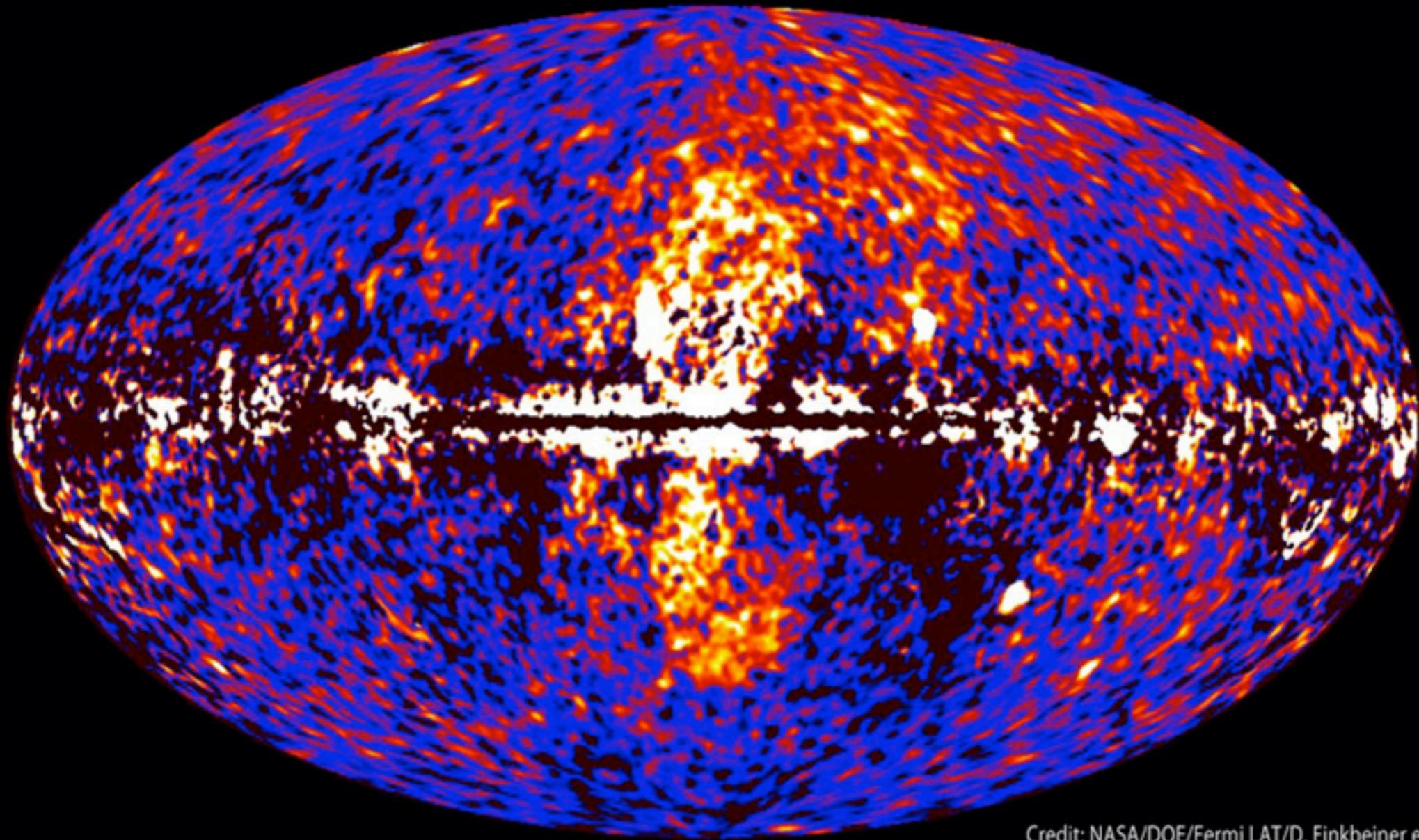
We do see occasional flares from the center, harmless.

No jet, but it probably had one in the past!



Remember New Bubble?

Fermi data reveal giant gamma-ray bubbles



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

<http://antwrp.gsfc.nasa.gov/apod/ap101110.html>

In the Crosshairs?

There is a big molecular cloud nearby the center (390 lyrs), but currently in a stable orbit.

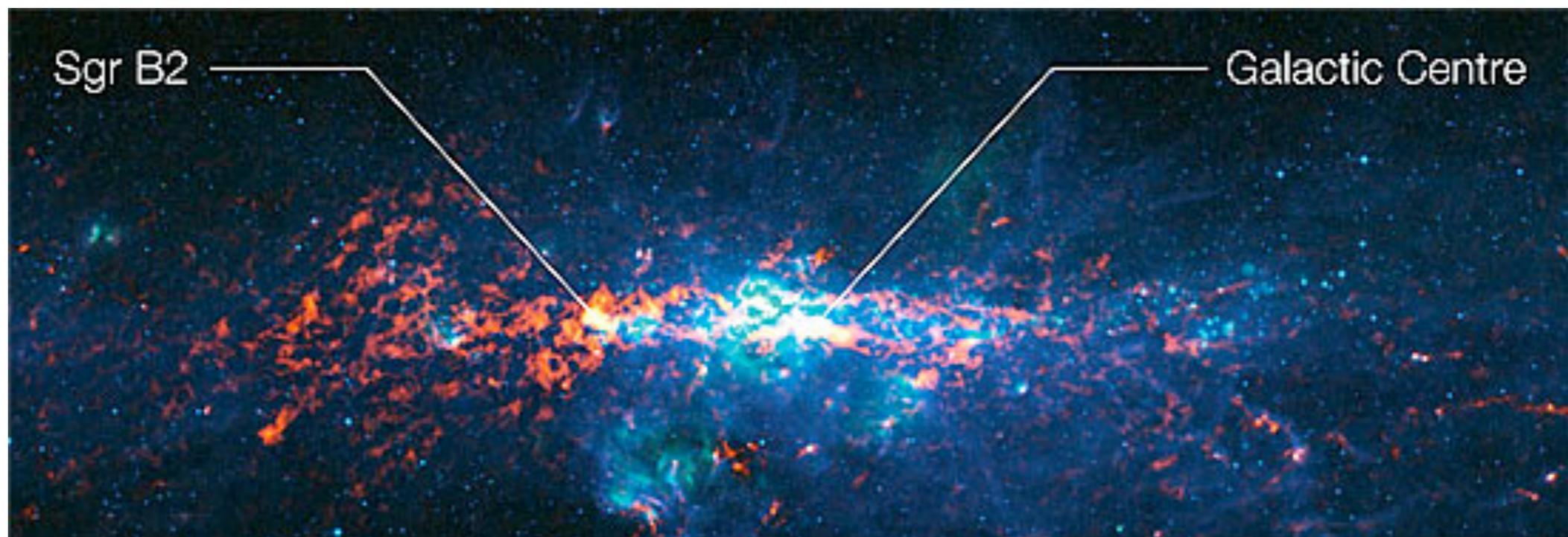
so no evidence right now that a harmful jet could happen soon but if the cloud fell in for some reason (cloud collisions?), we could easily create an accretion disk and jet.

The jet will be beamed, and could be randomly oriented

- ▶ If so, then no direction is safe for sure
- ▶ but like throwing one dart at dartboard:
 - most regions going to be missed
- ▶ probably at worst a 0.1% (1 in 1000) chance of being aimed at us

good odds...

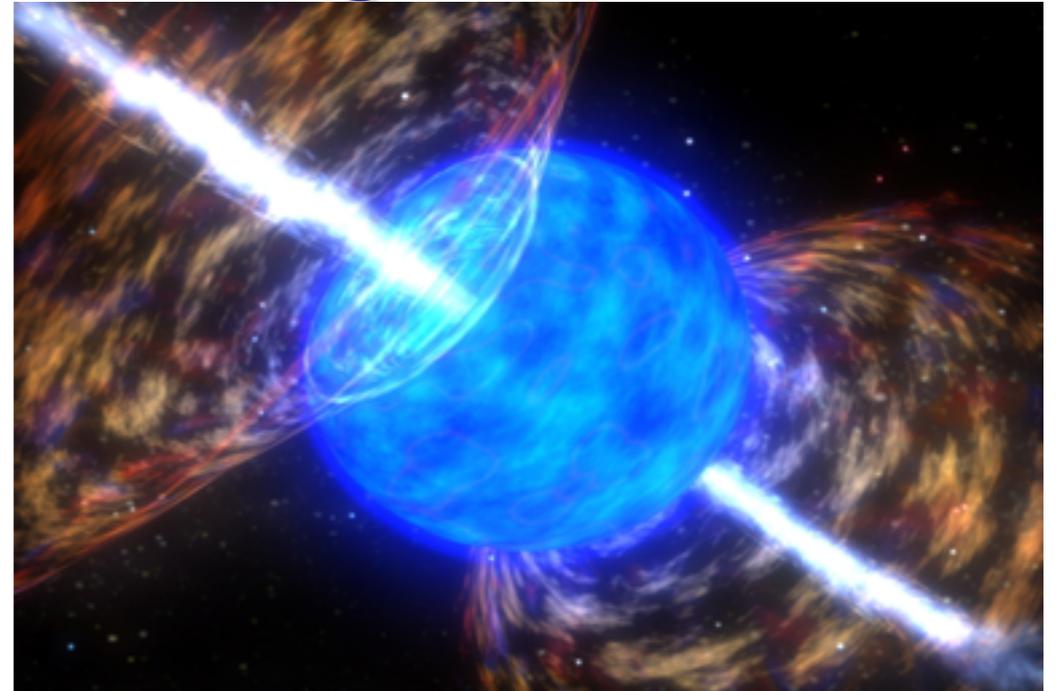
- ▶ but sort of disturbing given that we have no defense



AGN Jets vs Gamma-Ray Bursts

In many ways, **AGN jets are similar to GRBs**

- ▶ both are created by black holes
- ▶ both are material ejected at huge speeds
- ▶ both eject matter in a narrow beam
- ▶ both are directed along the poles of a spinning black hole
- ▶ both generate ionizing radiation which is very dangerous if you are in the beam



but note **important differences**

▶ **GRB outflows**

- created by stellar-mass black holes, say $1-10M_{\text{sun}}$
- ejected matter has small mass, $<M_{\text{earth}}$
- blast is very short-lived, dies off in days
- blast material stopped well within galaxy hosting the GRB

▶ **AGN outflows**

- created by supermassive black holes $>10^6M_{\text{sun}}$
- ejected material unknown, but carries huge energy
- though (much) less energy emitted per second than a GRB
- but: blast sustained for possibly millions of years
- blasts stretch far beyond host galaxy

Lesson: AGN jets are GRBs on steroids!



Jet Threat

Many **similarities** between active galaxy jets and gamma-ray burst properties

- ▶ particularly the emission of enormous amounts of **ionizing radiation** (X-ray, gamma-ray)

Threats are thus similar as well

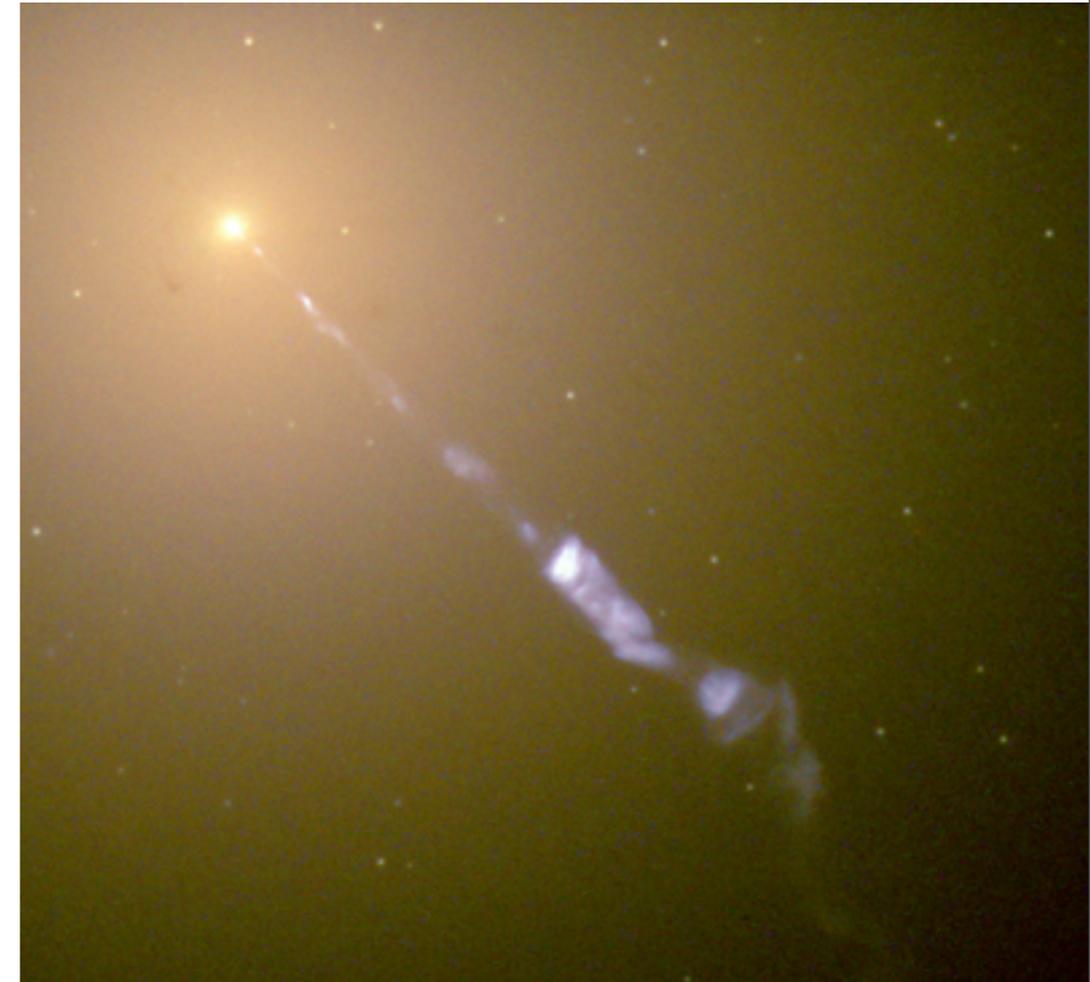
- ▶ ionizing radiation destroys Earth's ozone layer
- ▶ Sun's UV unfiltered, destroys food chain from bottom up

Good news:

- ▶ the GRB actually has a higher luminosity
- ▶ more energy emitted per second
- ▶ so initially the Sgr A* jet will be less harmful than a GRB

Bad news:

- ▶ the GRB lasts only seconds and then stops forever
- ▶ but the AGN goes on for millions of years!
- ▶ and worse: **Earth could be engulfed by the jet itself**
not sure what made of but likely highly energetic electrons and positrons



Jet in huge galaxy M87
>100 million stars are in the beam

Radiation and particles will continuously fry Earth's atmosphere

- ▶ ozone layer will be totally stripped clean
- ▶ if any life survives, it will have to be highly radiation resistant

Mitigation

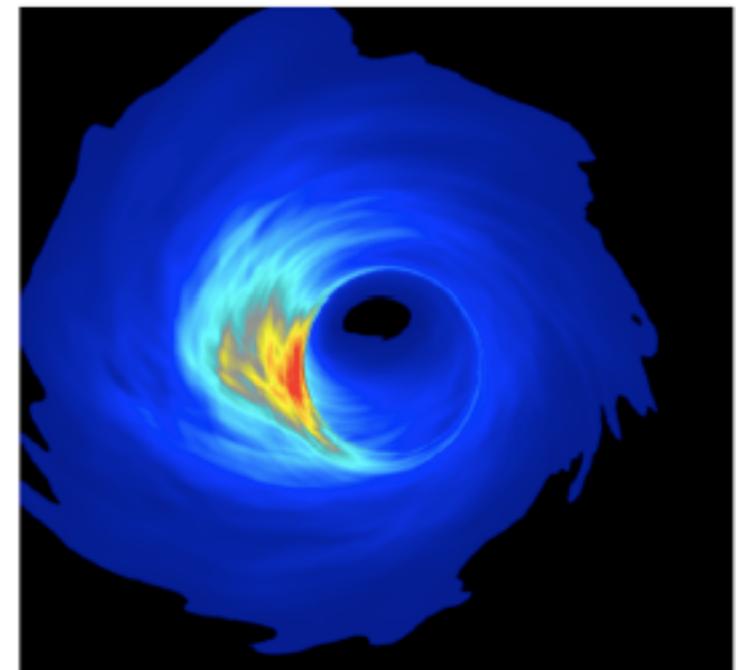
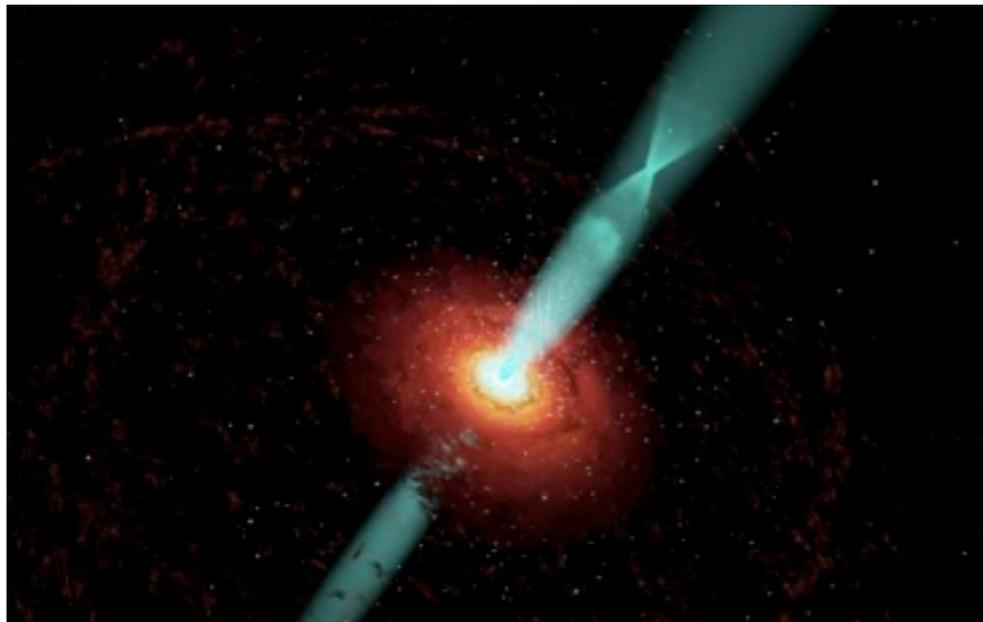
Nope!

Destruction on large scale of Galaxy.

No warning.

Human race gone...

...but beamed, so the odds of this happening are small



Imagine

Radio and X-ray astronomers notice something odd

Sagittarius A* is getting brighter

And bigger: appears as an expanding blob

High-energy gamma rays turn on next, along with high-energy neutrinos

The blob starts to appear in visible light

Doppler shifts show that it is made of matter travelling at huge speeds $>99\% c$

Eventually it fills half of the night sky

Imagine

The UV, X-rays and gamma-rays become ever more intense

The Earth's ozone layer is totally stripped clean

The Sun's UV rays destroy the food chain and initiate a mass extinction

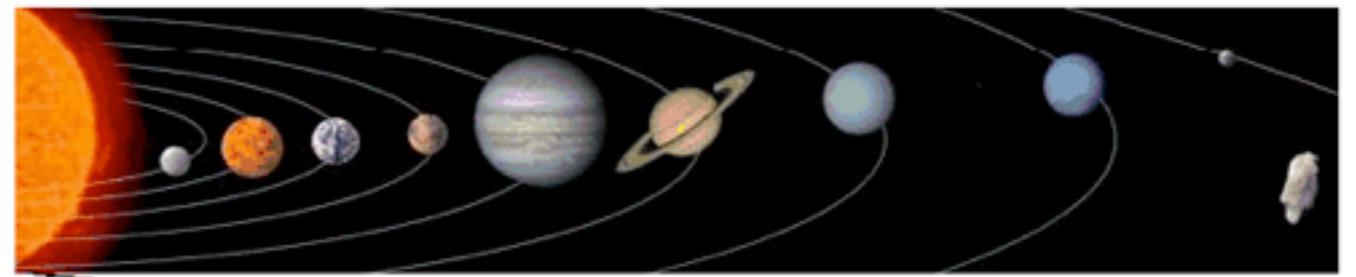
Finally, the solar system is engulfed in the blast of a plasma filled with positrons

The blast pushes back the solar wind, possibly inside 1 AU

The Earth will be bathed by intense cosmic rays for thousands of years

As you slather on Sunblock 2000, you wonder if this is what Brian meant by a relativistic jet

The Big Picture: On to Galaxies



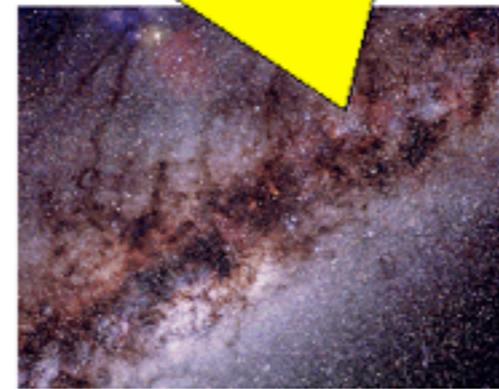
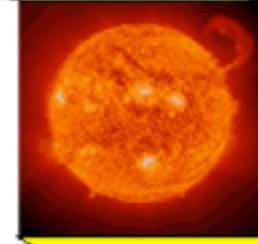
We've seen threats posed by

- ▶ the solar system
- ▶ the Sun, stars, and black holes

But stars and planetary systems are organized into **galaxies**

Can these too be dangerous?

Yes---eventually



Imagine

- ▶ **After getting flung 1 billion years into the future in a DeLorean, you notice that the sky is different.**
- ▶ **The sky is full of a galaxy, up close and personal.**
- ▶ **As you keep traveling into the future, you notice that it is changing position as it interacts with the Milky Way.**
- ▶ **You sigh in hope as you notice that the Earth and Sun are fine.**
- ▶ **Actually, the sky is prettier than before. This ain't so bad!**

Imagine

- ▶ **But, in a few million years you realize that the Solar System has been knocked out of its usual Galactic orbit.**
- ▶ **And the Solar System is headed straight for the center of the Galaxy..... And there are many dangers there..**
- ▶ **As you die from lethal amounts of UV radiation, you wonder why Brian didn't mention the beauty of the event.**

Top 10 Ways Astronomy Can Kill you or your Descendents

7. Galaxy Collisions.

Milky Way vs. Andromeda.

Our sibling galaxy Andromeda is heading right for us, on a collisions course at 120 miles/second! In about 2 billion years, they will collide. Train wreck!

Remember Galaxies mostly empty space, so stars will not impact.

<http://www.youtube.com/watch?v=dJRc37D2ZZY>

http://www.youtube.com/watch?v=jexMl2S06_I

iClicker Poll: Our Milky Way Galaxy

Milky Way to eye: irregular band of light

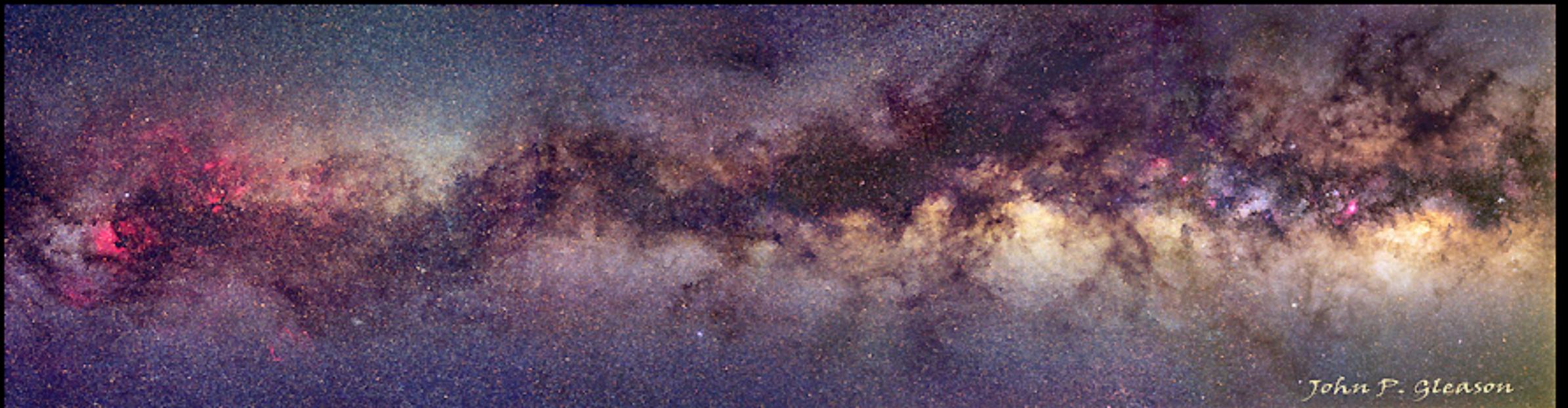
go see it!

need to drive a few miles out of town on a clear night

Vote your conscience!

What is the dominant Milky Way light source?

- (A) predominantly gas**
- (B) predominantly stars**
- (C) roughly equal mix**



M i l k y W a y G a l a x y

The Milky Way Revealed

Galileo's telescope showed:

- ▶ Milky Way made (mostly) of stars
- ▶ so numerous and distant their light smeared together to your eye

But indeed, there are also gas clouds and dark splotches and -- as well will see -- much more stuff than what meets the eye



What is the shape of the galaxy?

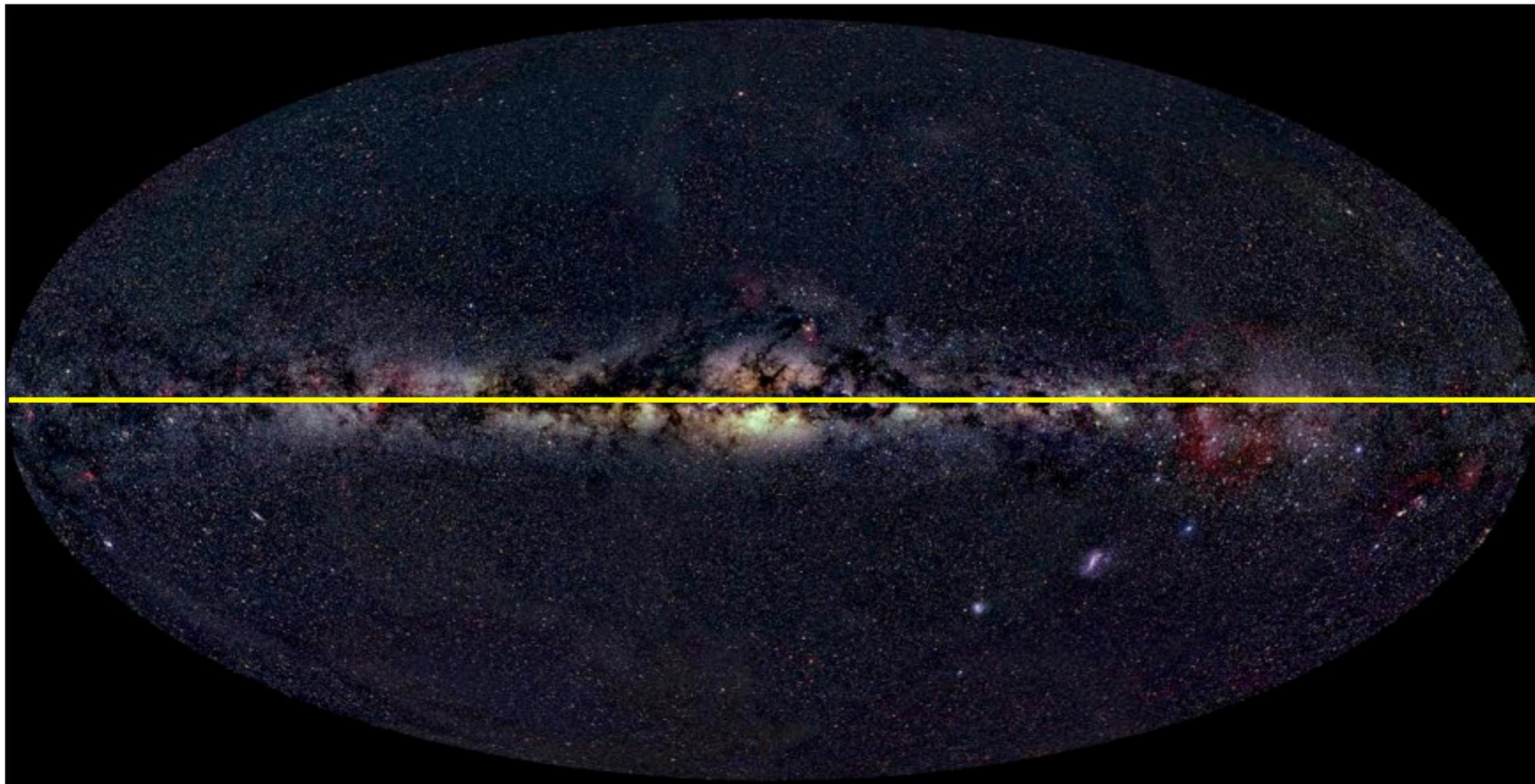
- ▶ Nearby stars are all over the sky
- ▶ Distant stars make a faint band of light circling the entire sky
 - ▶ **The Milky Way**
- ▶ **Q: if MW is circle on 2-D sky, how are stars arranged in 3-D space?**
- ▶ Suggests the overall population of stars is *disk-shaped*
 - ▶ *note similarity with Solar System planets lying in a plane*
- ▶ Population of stars called the **Galaxy**



The ancient Greeks named the band of light 'galaxies kuklos' - the 'milky circle'

The Milky Way

- Our galaxy is a collection of stars, nebulae, molecular clouds, and stellar remnants
 - ▶ All bound together by gravity
 - ▶ Connected by the stellar evolution cycle



Milky
Way

Map of the entire sky in visible light

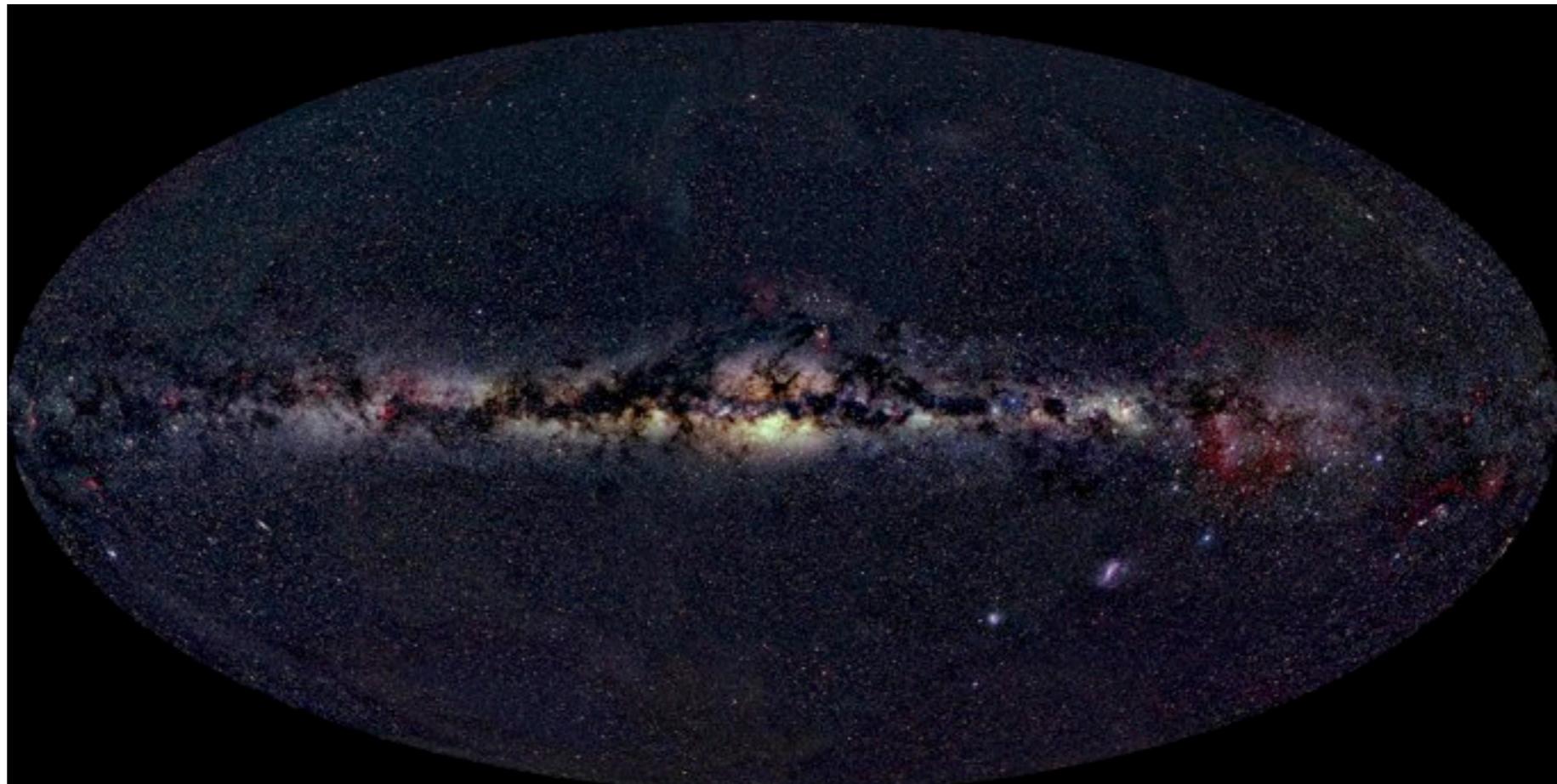
Where are we?

The Sun lies inside the Milky Way disk of stars

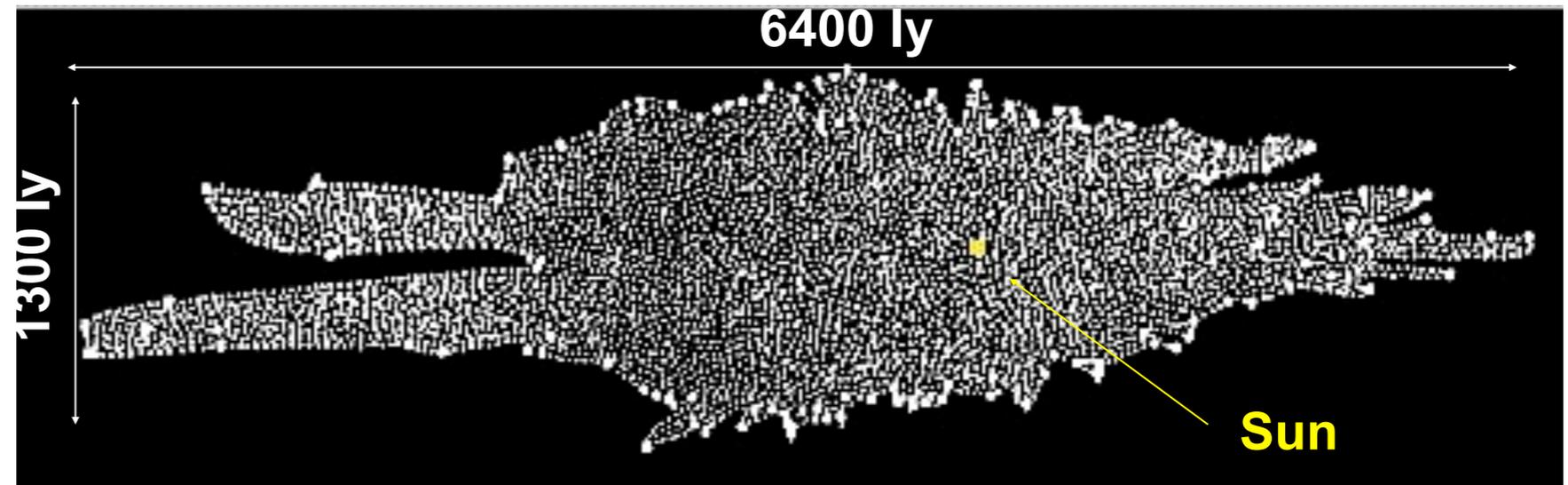
But where are we?

- ▶ near center?
- ▶ near edge?
- ▶ in between?

Note: in the sky, MW band is roughly same brightness in all along its circle



The Discovery of the Milky Way!



Herschel model for Milky Way
view looking down on disk plane

- The number of stars were counted in all directions from the Sun by William Herschel (the guy who discovered Uranus) and his sister Caroline
- They assumed that all stars have the same brightness – **Bad assumption!** and that space is completely transparent – **Nope!**
- They concluded that the Sun is at the center of the Universe

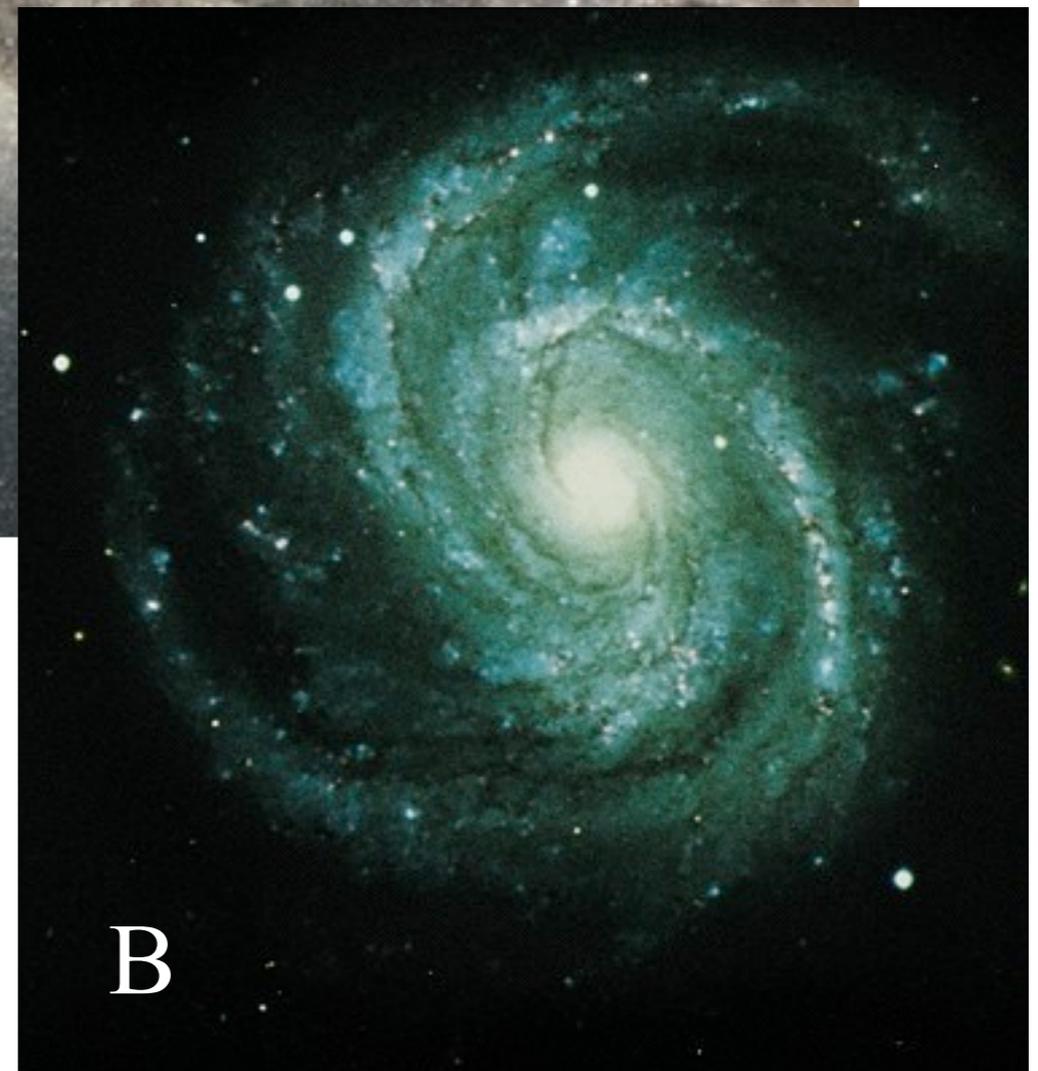
Which is a picture of the Milky Way?



A

A is what we see from Earth inside the Milky Way.

B is what the Milky Way “might” look like if we were far away looking back at our own galaxy from some other galaxy



B

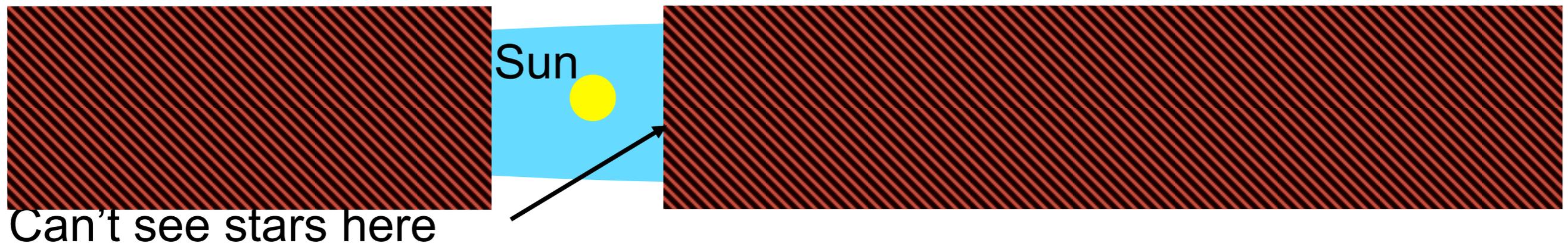
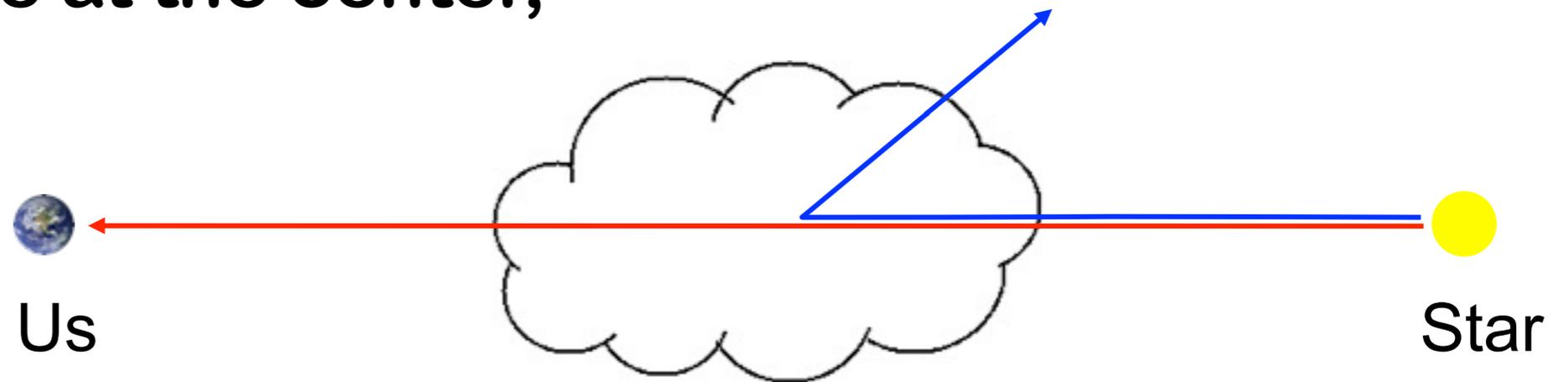
The Milky Way is made of all the stars in our galaxy– about **100 billion**. **All the stars you can see in the sky are in our Galaxy.**



Enormous clouds of dust obscure our view of most of the stars in our Galaxy

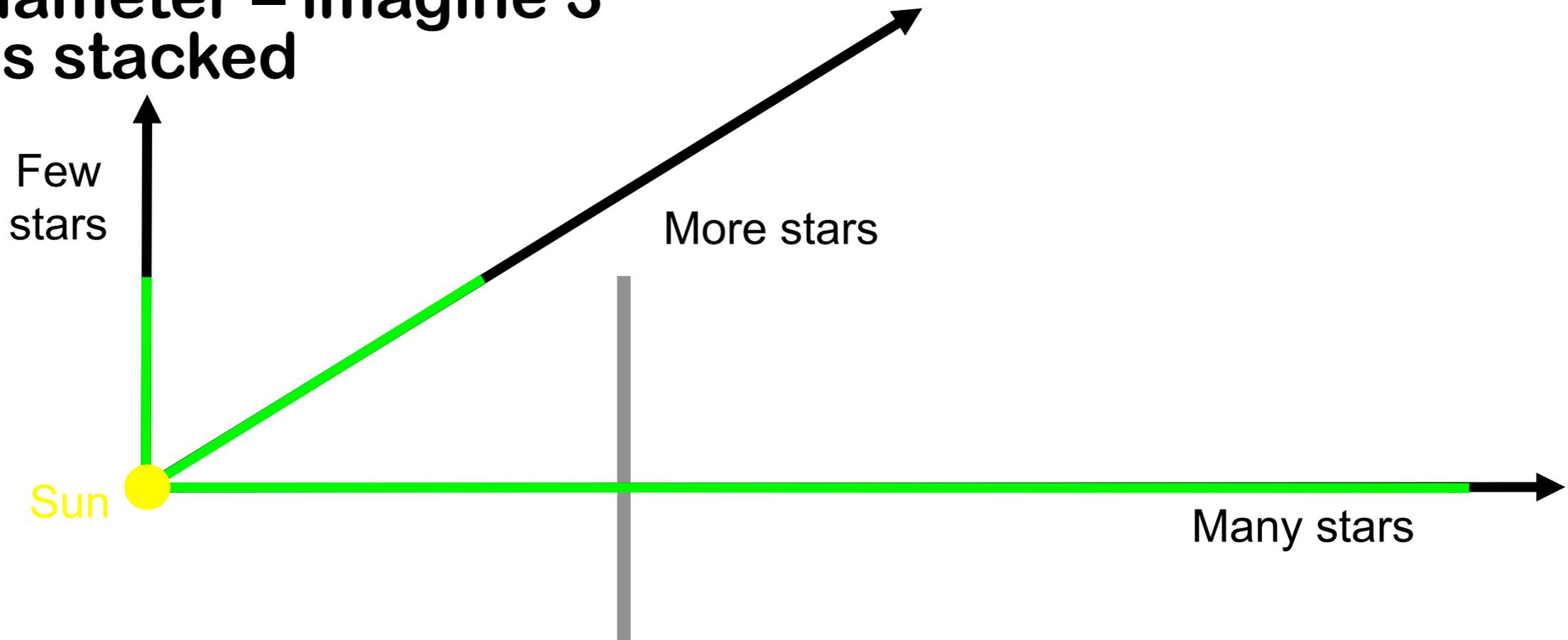
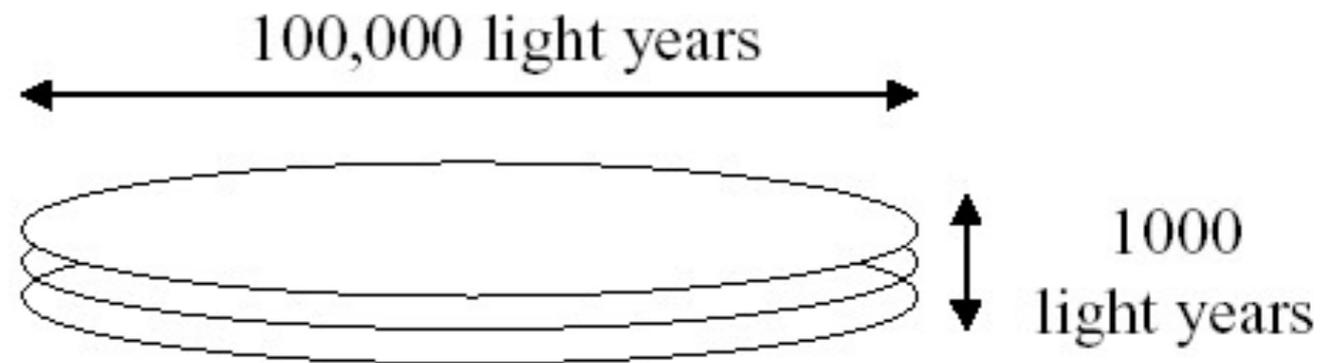
The Importance of Being Earnestly Dust

- There is clearly dust in the Milky Way disk. How does dust effect the measurement?
 - ▶ Makes stars dimmer and redder
- There is more dust toward Galaxy center.
- Consequence: Under-estimation in the number of stars in all directions
- We appear to be at the center, but we're not!



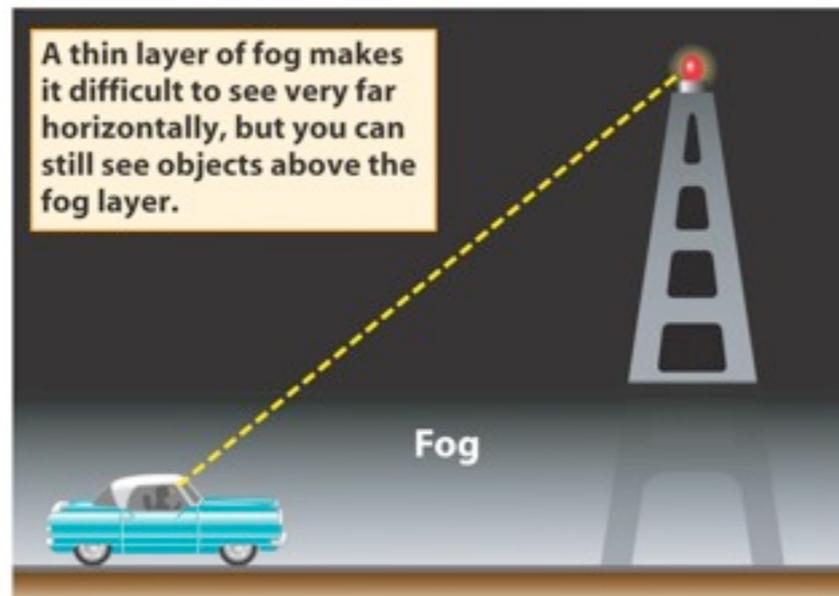
But, We Are in a Disk of Stars!

- But Herschels were correct in determining that the distribution of stars in the Milky Way is in a thin disk
- The Milky Way is very thin in comparison to its diameter – imagine 3 DVDs stacked



How Do We Find the Center?

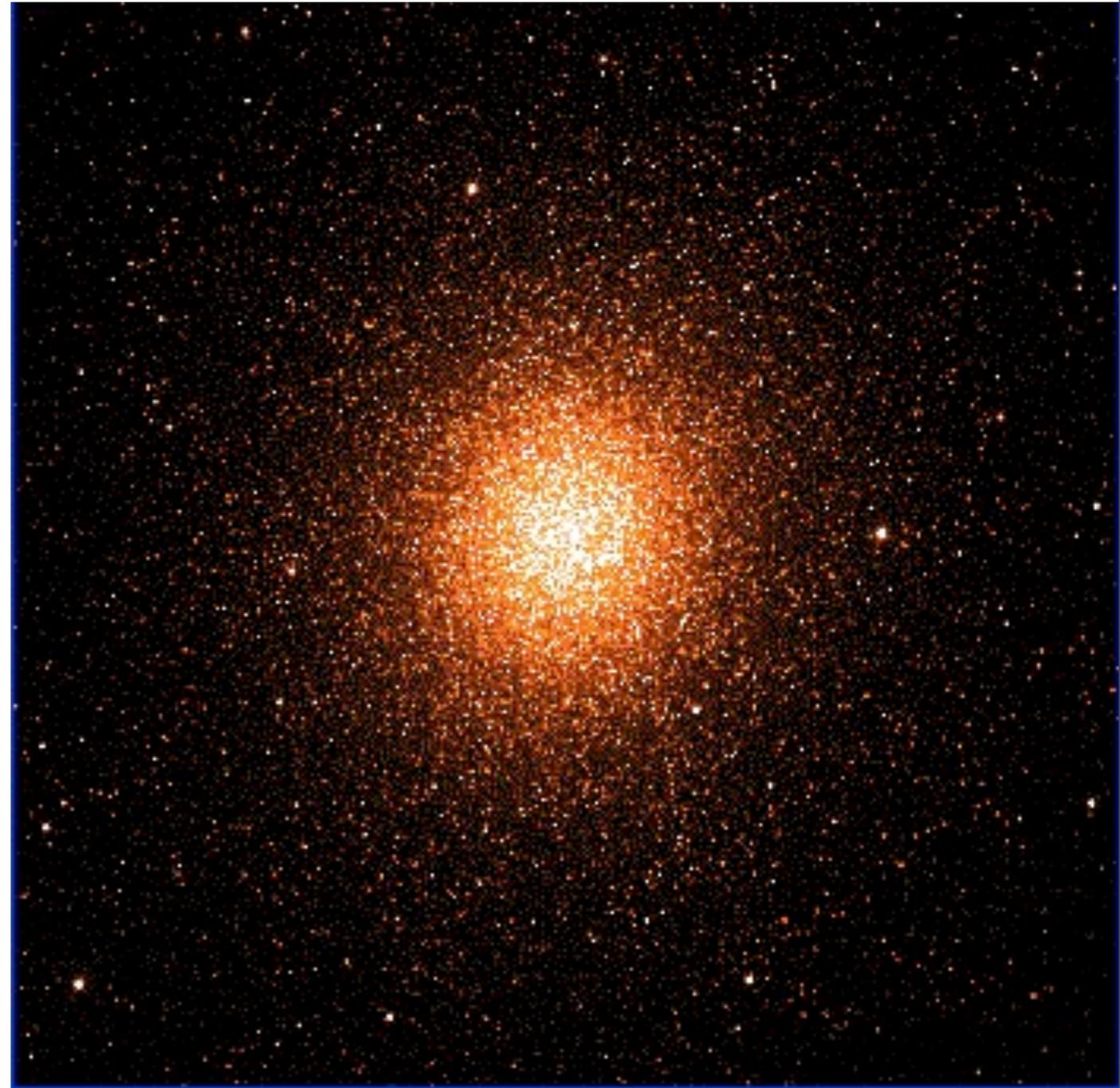
- If dust blocks our view, how do we find the center?
- We need to look outside of the disk!
 - ▶ Get around the dust
- A collection of relatively bright objects, outside the disk.



Determining your position in the fog

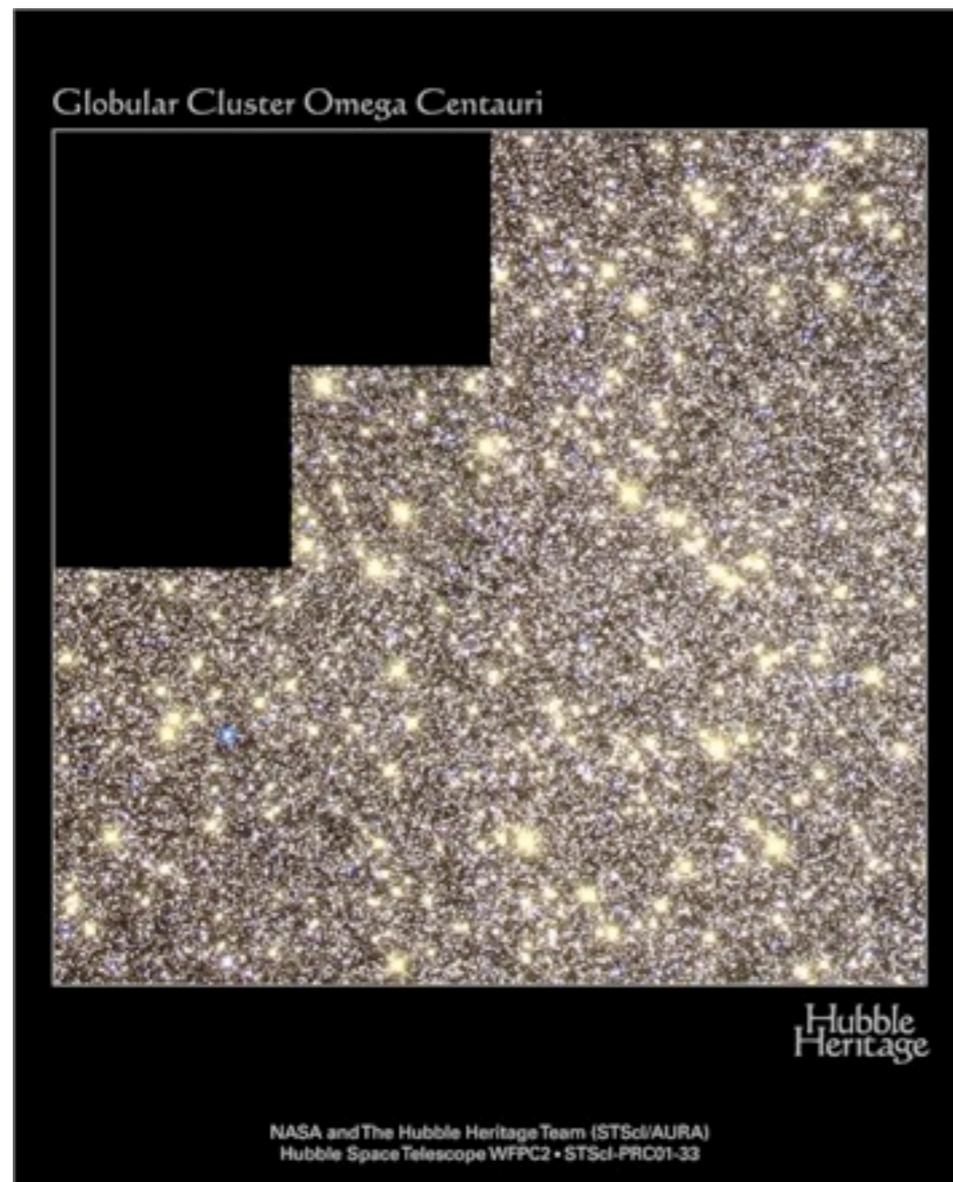
Globular Clusters

- Extremely regular, gravitationally bound groups of stars– very dense
- About 10^5 – 10^6 stars each
- HR diagram of these groups of stars show that they are very old– 10 billion years!
- Generally outside disk of the Galaxy.



Globular Clusters

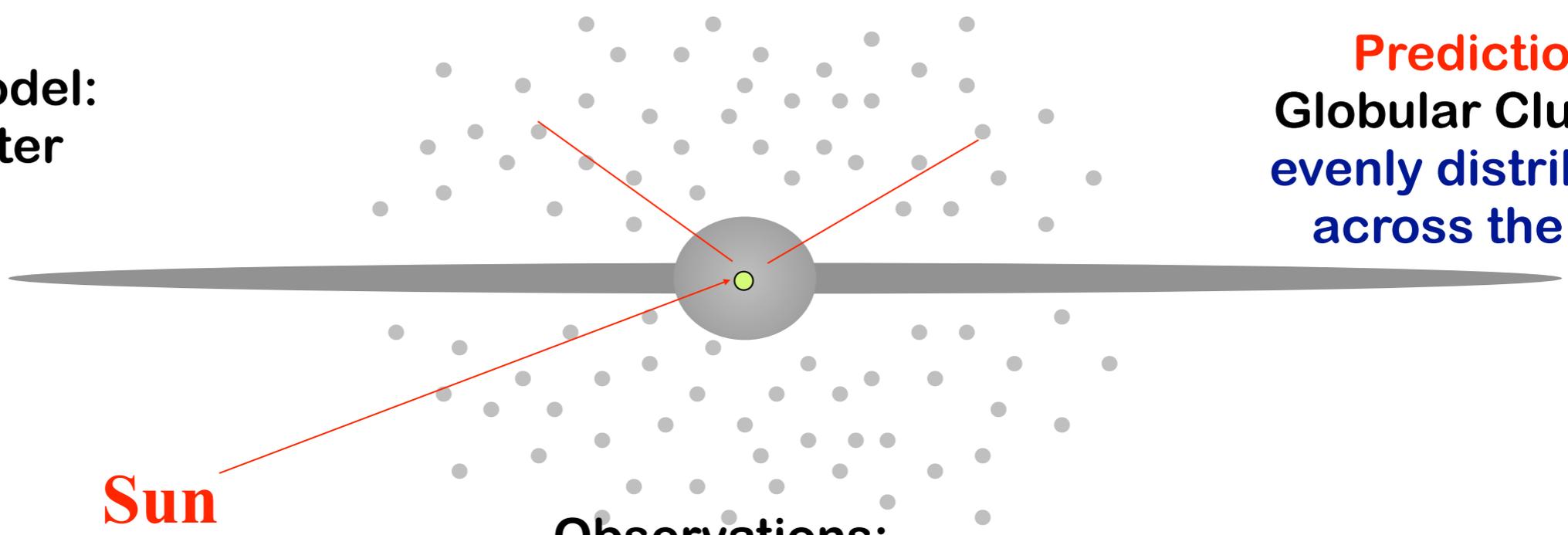
- Large groups of stars (about 150 in the MW)
- Old population of stars



Finding Our Place!

Herschel model:
Sun at center

Prediction:
Globular Clusters
evenly distributed
across the sky



Sun

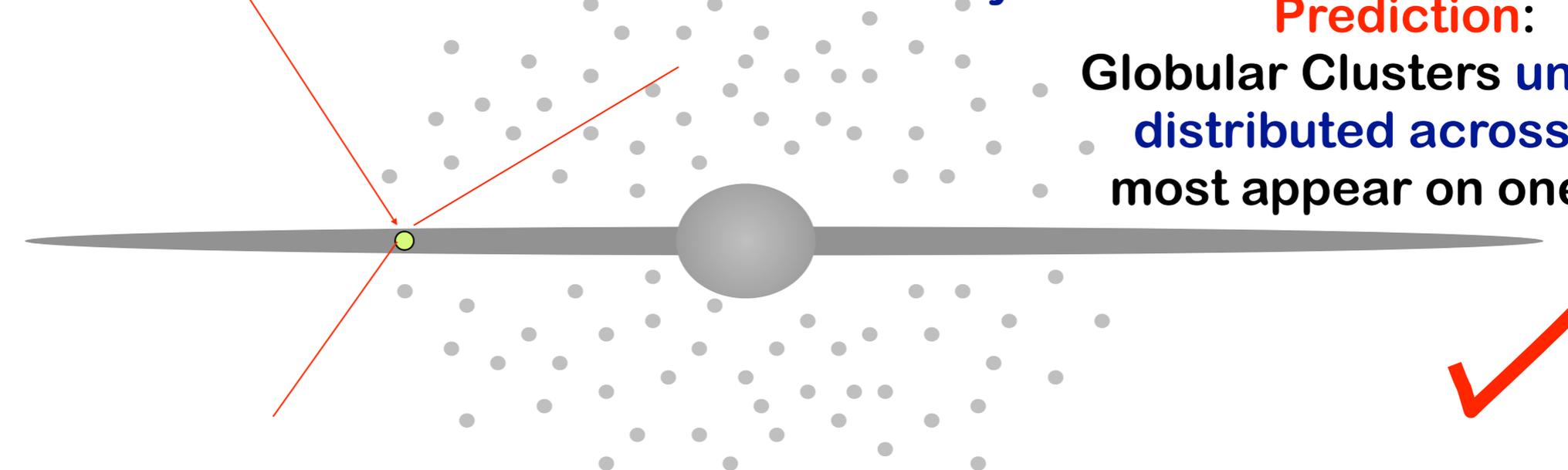
Observations:

Most GCs fill **half** the sky

Prediction:
Globular Clusters **unevenly**
distributed across sky,
most appear on one side



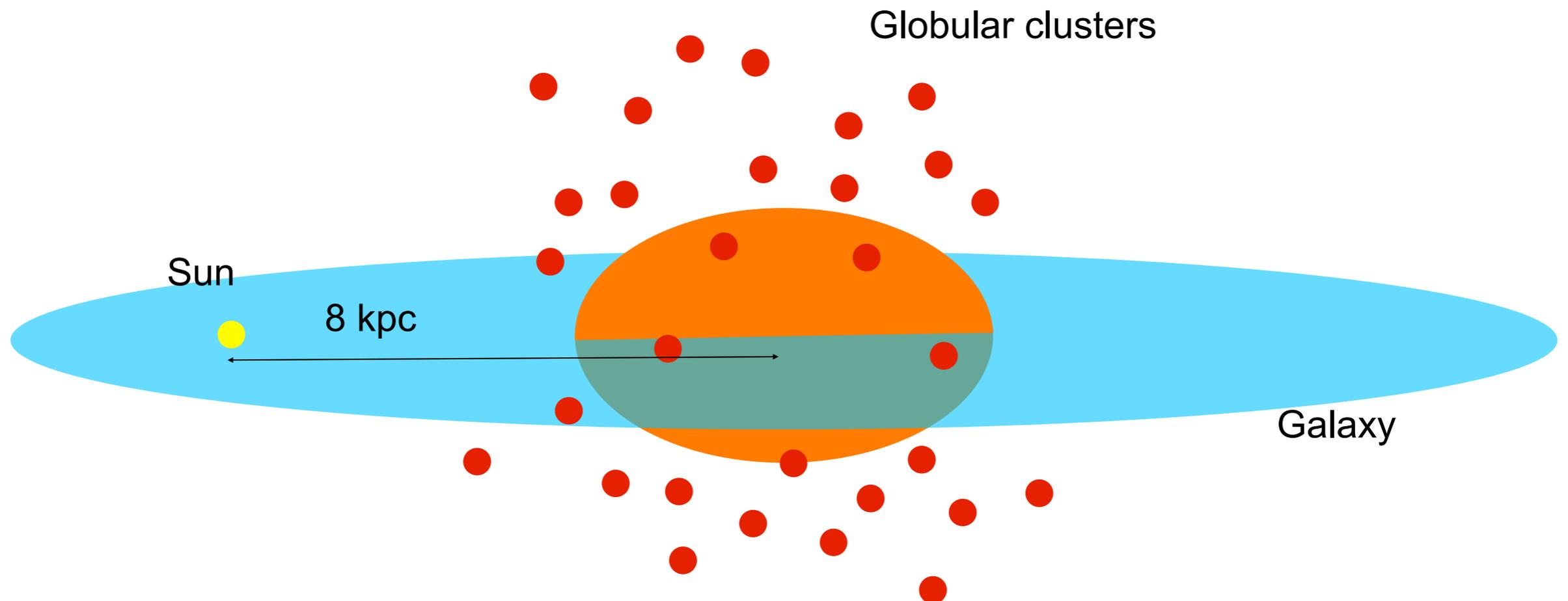
Harlow
Shapley



what if we're off-center?

Our Place

- Shapley showed that we are not the center of the Galaxy in the 1920s.
- All of the globular clusters are orbiting around a point in Sagittarius– 25,000 lyrs away.
- That must be the center of our Galaxy.



Copernican Revolution Revisited

Copernicus:

- ▶ the Earth goes around the Sun
- ▶ Earth is a typical planet among many
- ▶ not at center of Solar System

Shapley:

- ▶ the Sun is a typical star among many
- ▶ not at center of Galaxy

....more revolutions to come