BUBBLES

- As this expands and plows out a big sphere of space, it leaves a less-dense bubble behind
- Somewhat tamer bubbles are also made by bright hot stars and their strong stellar wind

Fig.15.5

BUBBLES POP

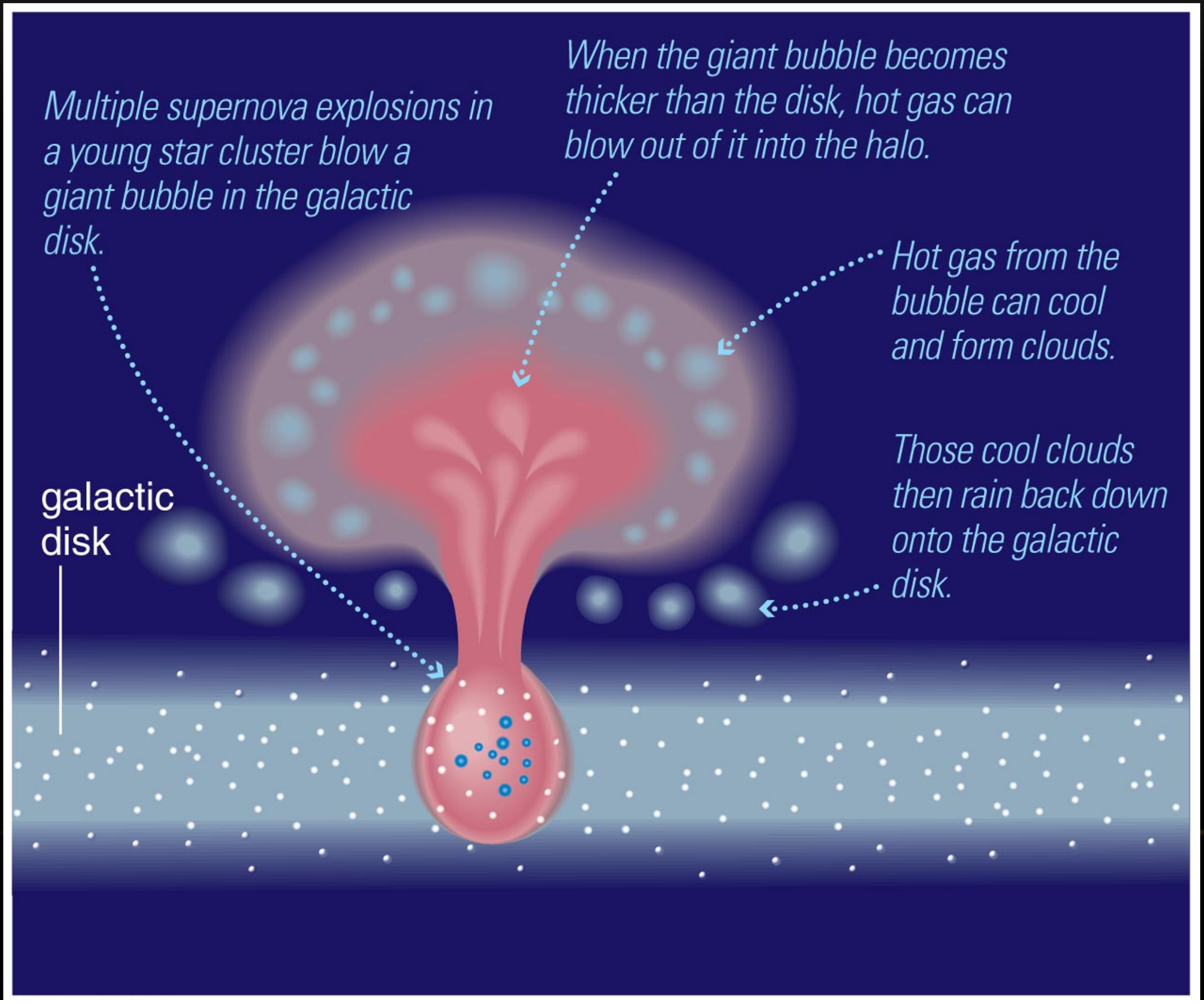


Fig.15.8

CLOUD FORMATION

- The gas cools
  - Molecular hydrogen (H_2) forms
  - Those Giant Molecular Clouds form from this
  - Including the dust etc (forming from the carbon compounds that come from the carbon made in the old stars)

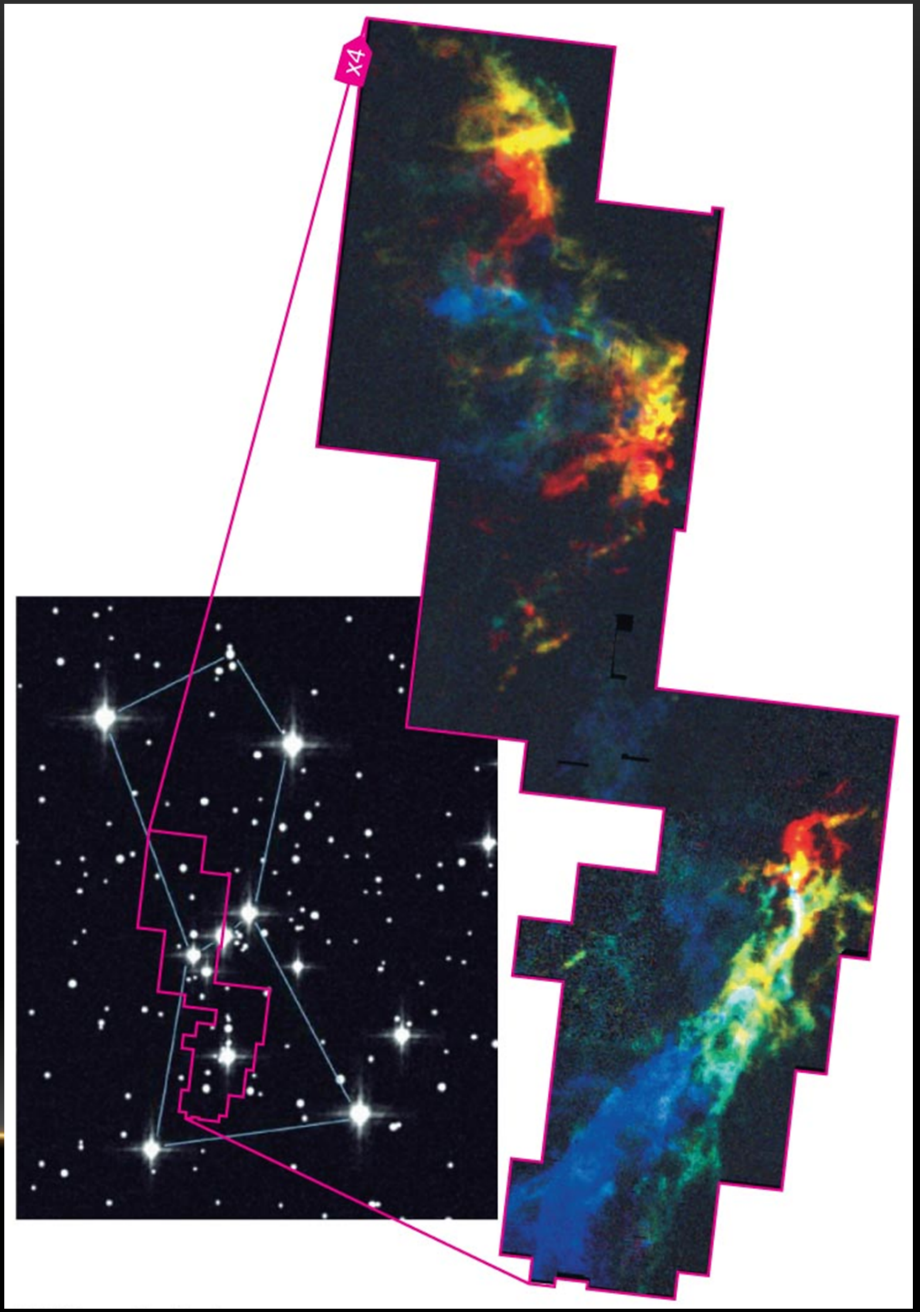


Fig.15.9

ORION'S BELT AND SWORD OVER THE CANARY ISLANDS

FROM WHICH STARS FORM

- Some of which are massive, hot, and erode the clouds
- This HST photo of the Carina Nebula is action packed

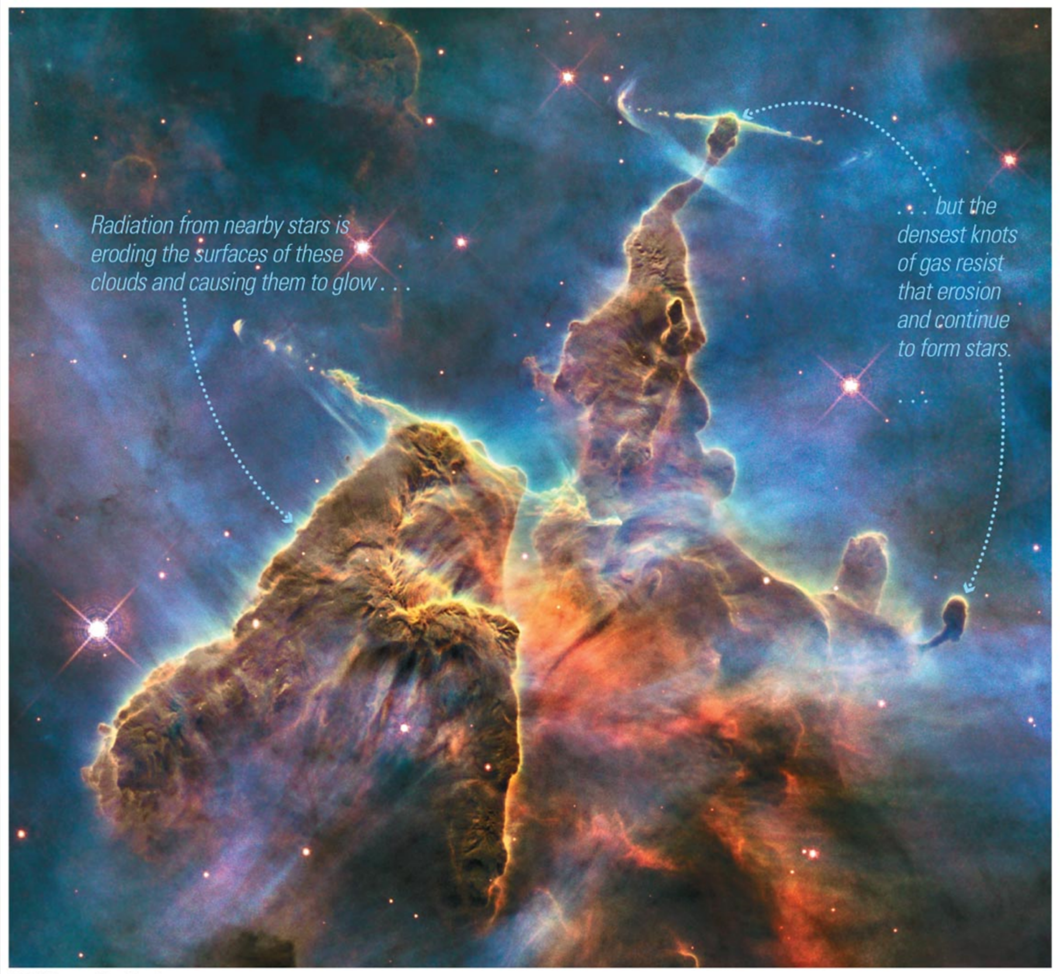
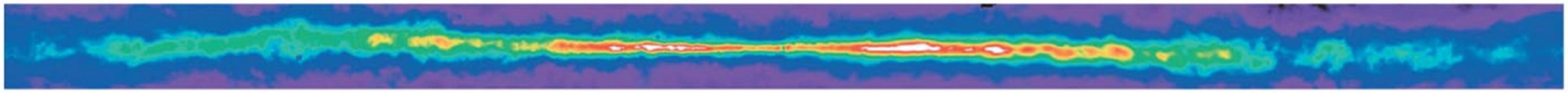


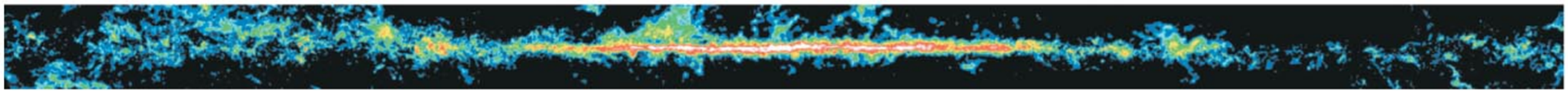
Fig.15.10

WHERE IN THE MILKY WAY?

Like Fig.15.11



a 21-centimeter radio emission from atomic hydrogen gas.



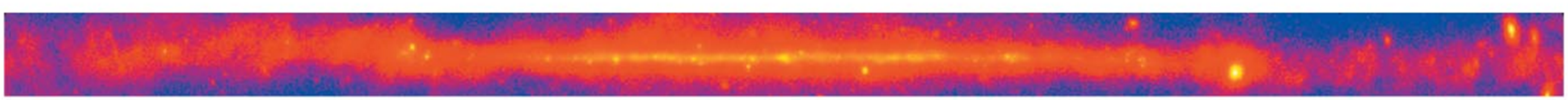
b Radio emission from carbon monoxide, revealing molecular clouds.

c Infrared (60–100 μm) emission from interstellar dust.

d Infrared (1–4 μm) emission from stars, which penetrates most interstellar material.

e Visible light emitted by stars, which is scattered and absorbed by dust.

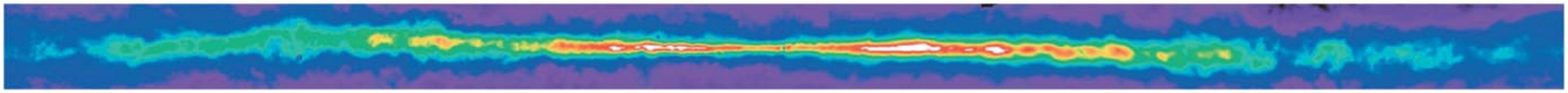
f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).



g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

ALL IN THE DISK

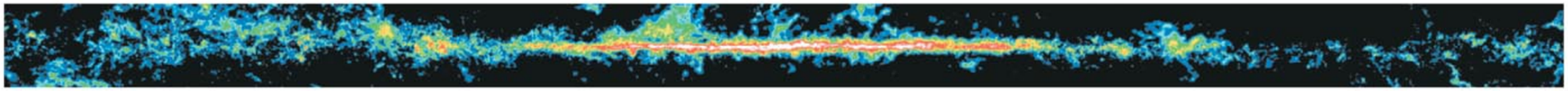
- Different wavelengths let us see different stuff
- For example, cold atomic hydrogen gas we see in 21cm radio waves:



a 21-centimeter radio emission from atomic hydrogen gas.

BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- Carbon monoxide traces the molecular clouds



b Radio emission from carbon monoxide, revealing molecular clouds.

BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- Dust shows up in the far infrared

c Infrared (60–100 μm) emission from interstellar dust.

BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- Cool starlight shows up in the near infrared
  - Which goes through gas, dust well: see far away!

d Infrared (1–4 μm) emission from stars, which penetrates most interstellar material.

BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- Visual light shows us what we see in the night sky (*with dust lanes in the foreground*)

e Visible light emitted by stars, which is scattered and absorbed by dust.

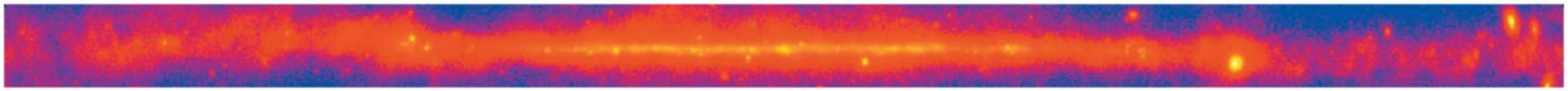
BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- X-rays show hot stuff
  - diffuse hot gas and points from compact objects

f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).

BUT DIFFERENT BITS

- Different wavelengths let us see different stuff
- Gamma rays show high energy particle interactions



g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

- Cosmic rays hitting gas, and a few particle sources (*the Crab is the bright spot*)

DISK VS. HALO

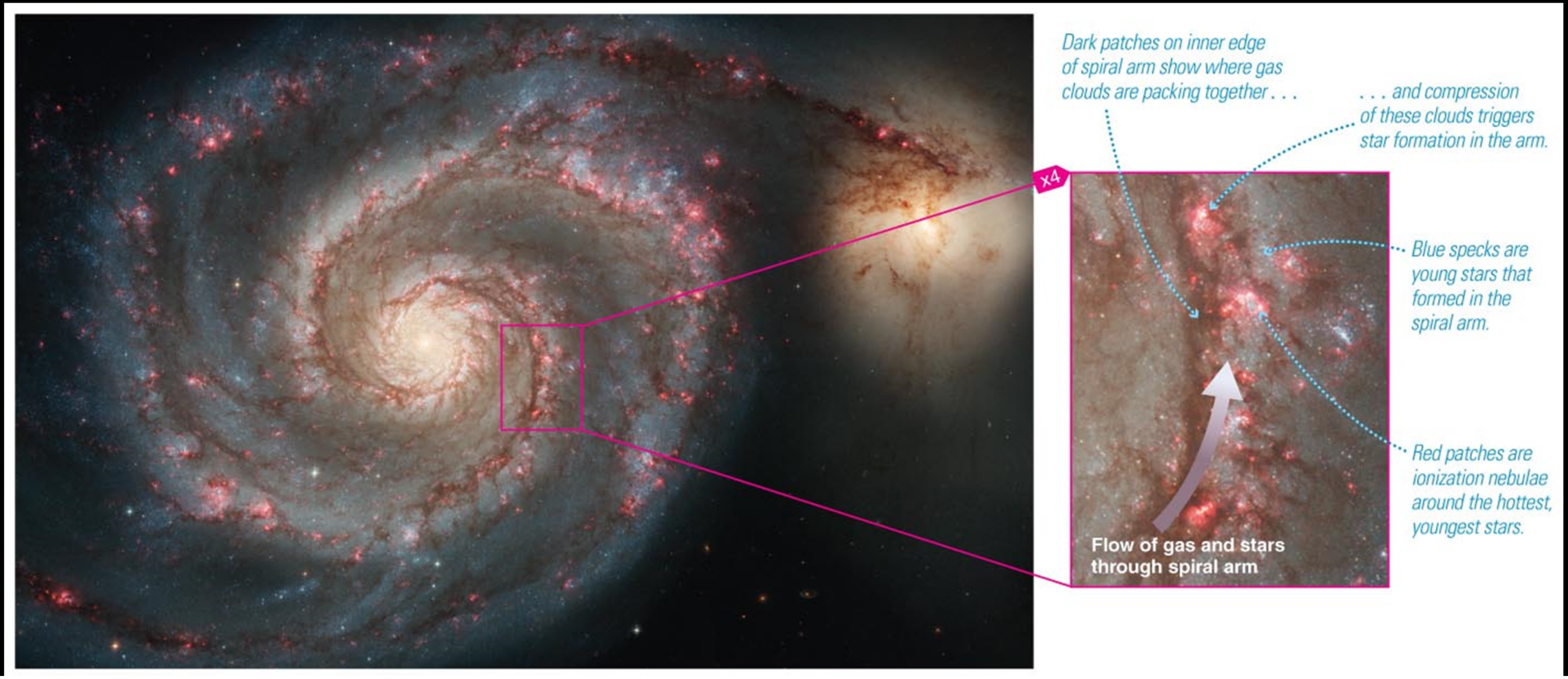
Halo: No ionization nebulae, no blue stars
$\Rightarrow$ no star formation

Disk: Ionization nebulae, blue stars $\Rightarrow$ star formation

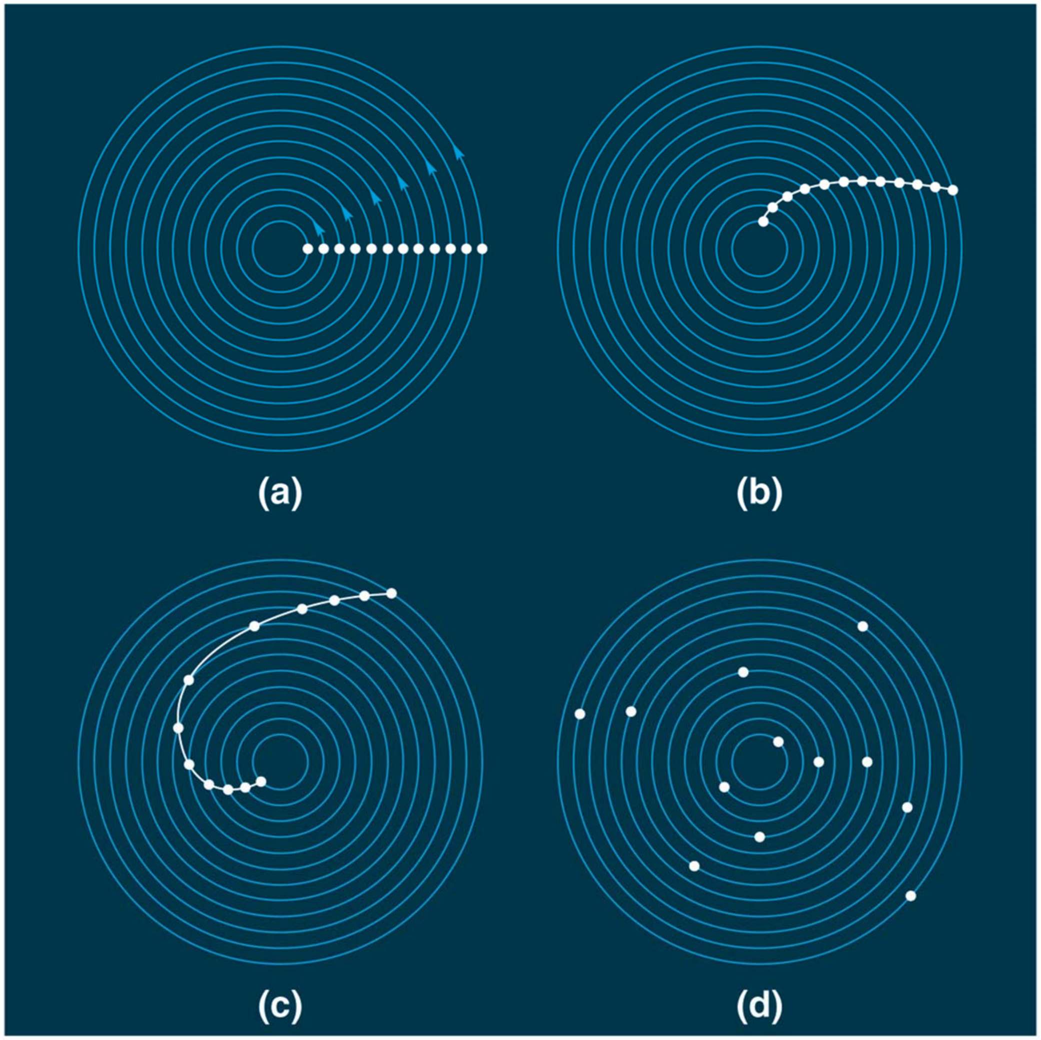
SEEN FACE ON

- We see lit up areas on the disk as "spiral arms"
  - Places where star formation is active, making stars, and the brightest stars don't last long

Fig.15.11



WHAT ARE THESE ARMS?



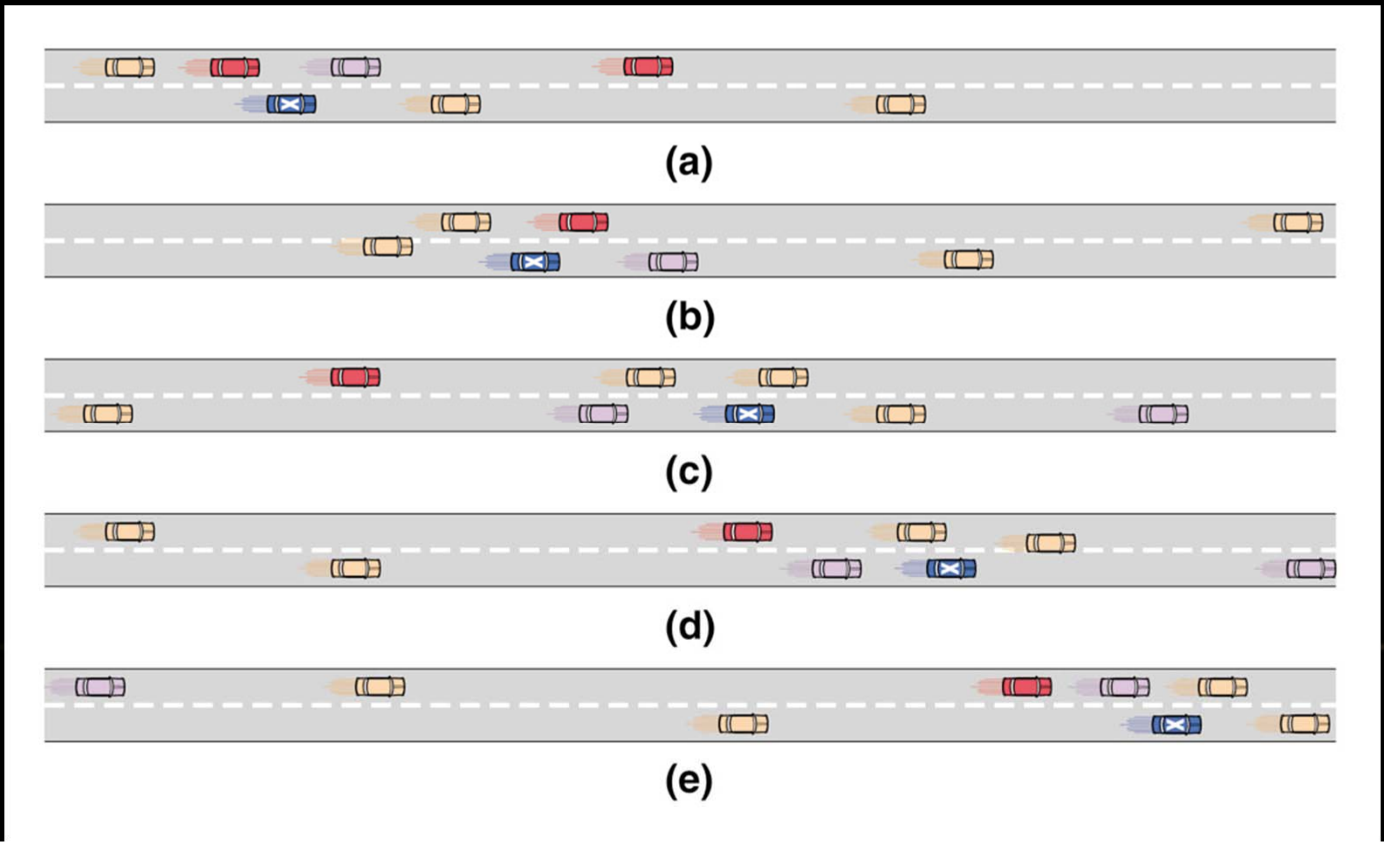
- Areas where there is more gas and star formation
  - New stars means bright ones haven't died yet!
- But a line orbiting doesn't stick together

TWO IDEAS

- Density Waves
- Self-Propagating Star Formation

DENSITY WAVES

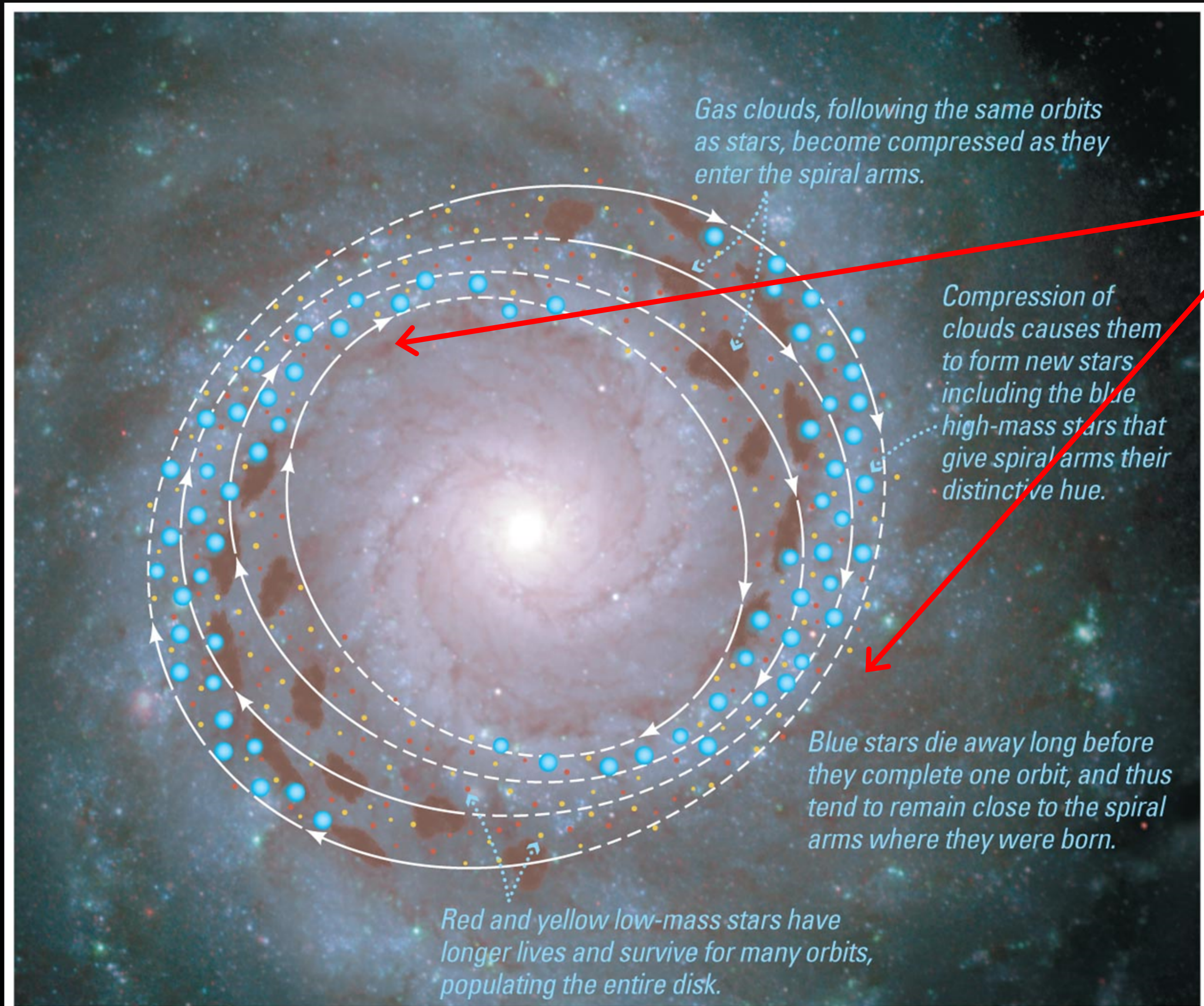
- Imagine a slow-moving highway patrol car
- Traffic clumps up, although different cars make up the clump



COMMON DENSITY WAVES

- Sound is a density wave
  - Wave moves faster than the actual air molecules
  - In a galaxy, stars orbit faster than the wave
- Computer simulations show that this could work for a galaxy
  - Driven by gravity from asymmetric shape of galaxy
- One problem – they eventually die out

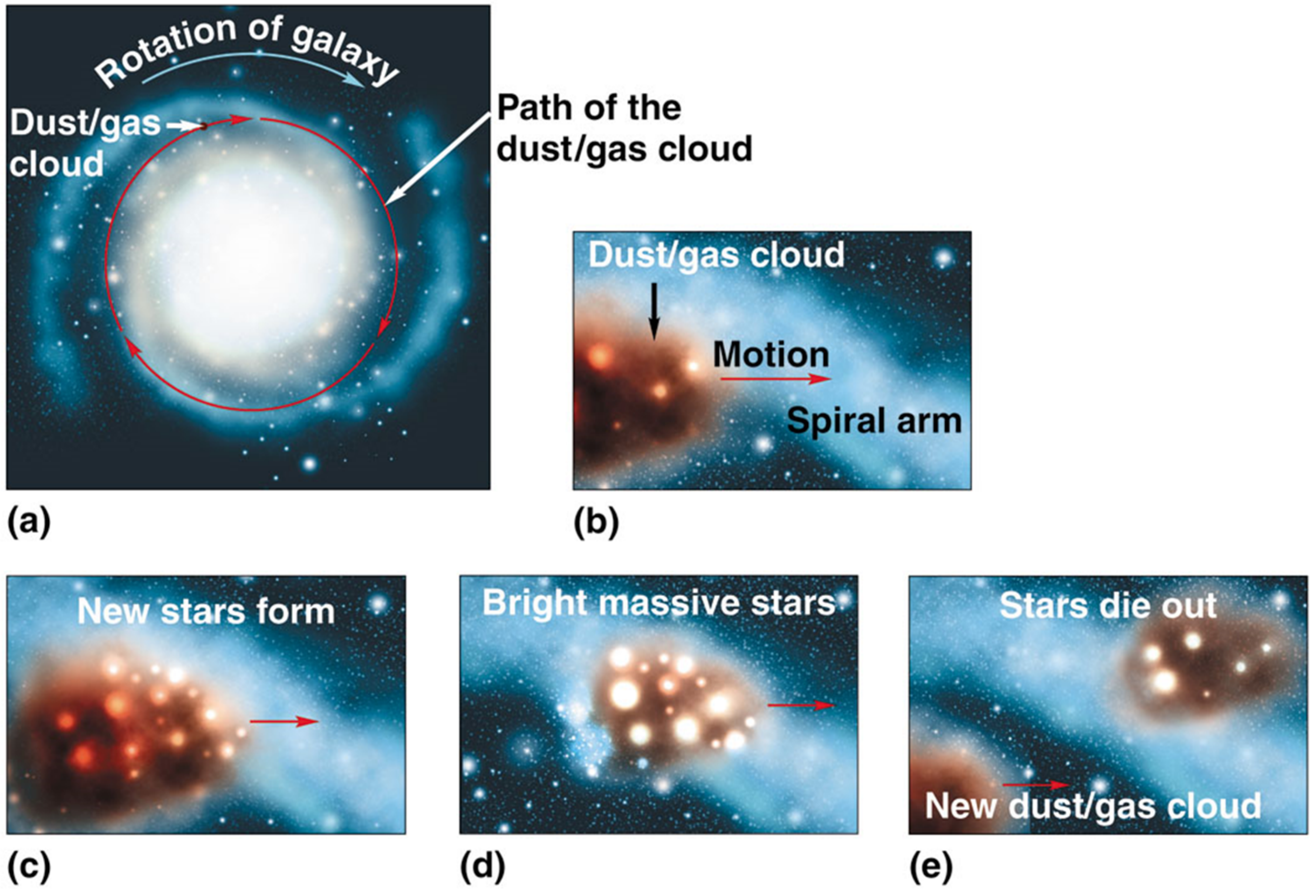
DENSITY WAVES IN A GALAXY



- Here, there are two “bottlenecks”
- As clouds orbit into one, they get squeezed a bit and star formation starts

Fig.15.17

SELF-PROPAGATING STAR FORMATION



- Spiral arms host star formation
- Star formation means Supernovae
- Supernovae shocks collapse the next gas cloud along

Like a forest fire!

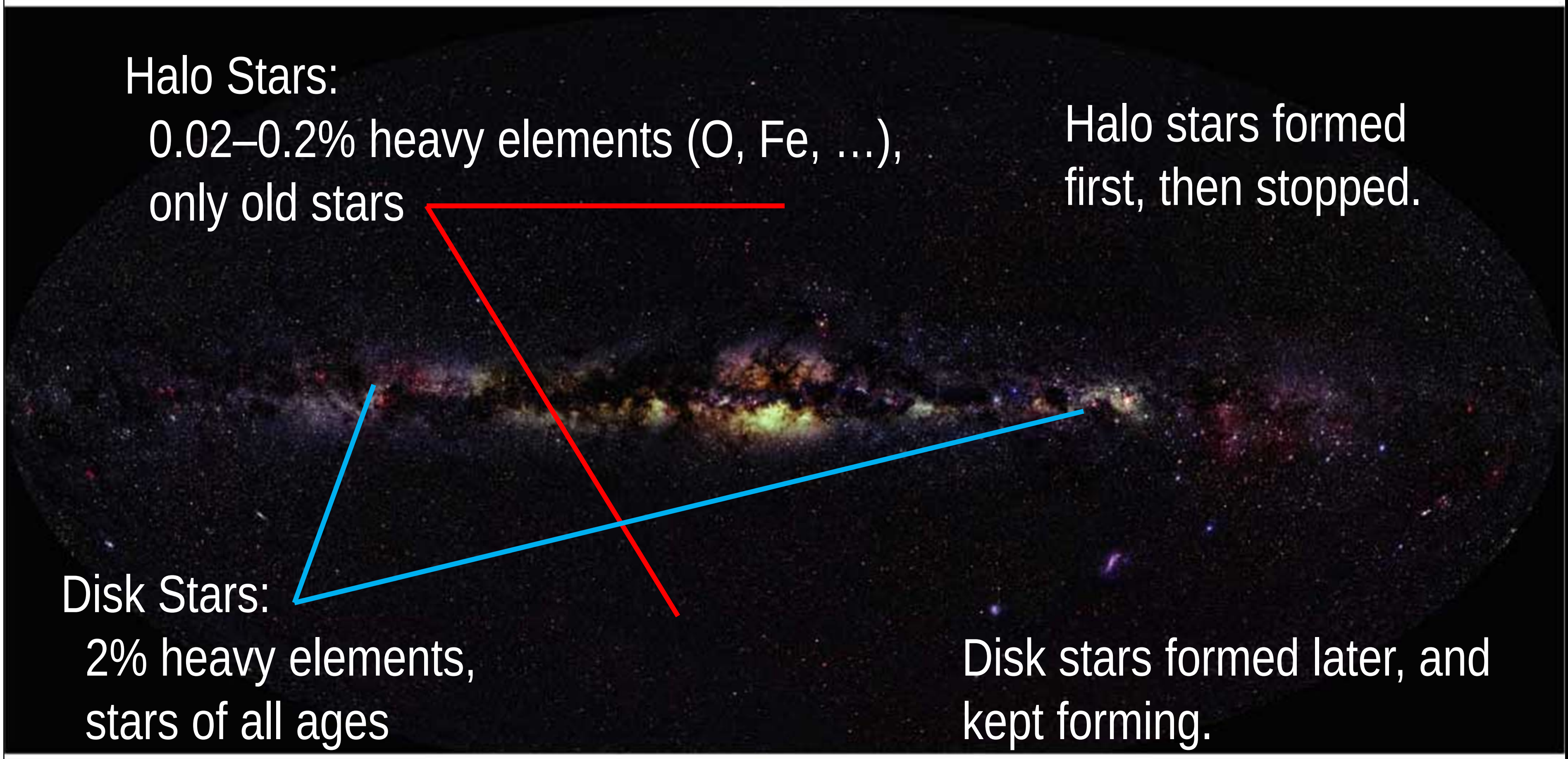
LIKELY A COMBINATION

- A density wave could also trigger collapse of gas clouds and star formation
- Some galaxies look more like one thing is happening than the other, or a combination of both

STELLAR POPULATIONS

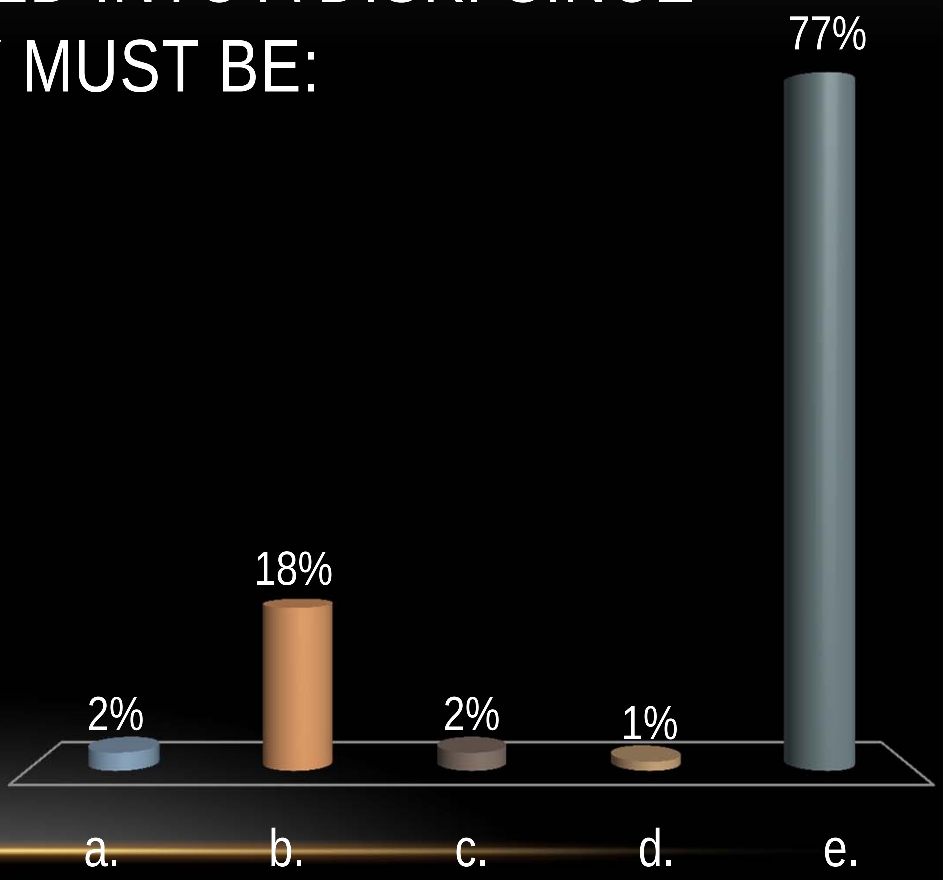
- Population I
  - Younger stars, found in the disk
    - more metals
    - includes bluer spectral types which don’t last long
- Population II
  - Older stars, found in the halo
    - Fewer metals
    - Redder, smaller stars that last a while

WHAT DO HALO STARS TELL US ABOUT OUR GALAXY'S HISTORY?



STARS WE SEE IN THE HALO OF OUR GALAXY (OR IN GLOBULAR CLUSTERS) FORMED EVEN BEFORE THE MILKY WAY COLLAPSED INTO A DISK. SINCE WE SEE THEM NOW, THEY MUST BE:

a. Young
b. Old
c. Low-mass
d. High-mass
✔ e. B and C



HOW DID OUR GALAXY FORM?

Fig.15.18

OUR GALAXY PROBABLY FORMED FROM A GIANT GAS CLOUD.

Fig.15.18

HALO STARS FORMED FIRST AS GRAVITY CAUSED THE CLOUD TO CONTRACT.

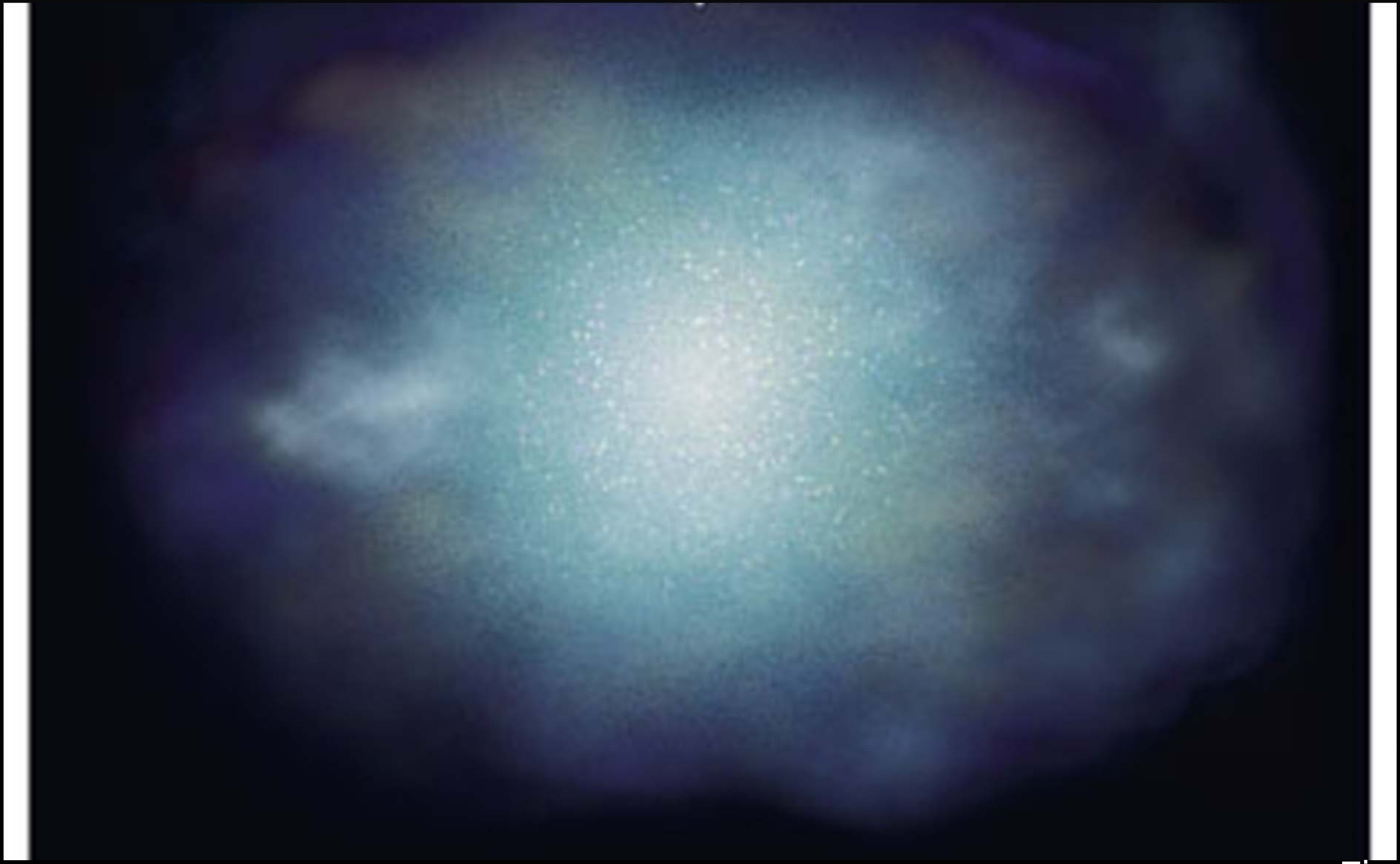


Fig.15.18

THE REMAINING GAS SETTLED INTO A SPINNING DISK.

Fig.15.18

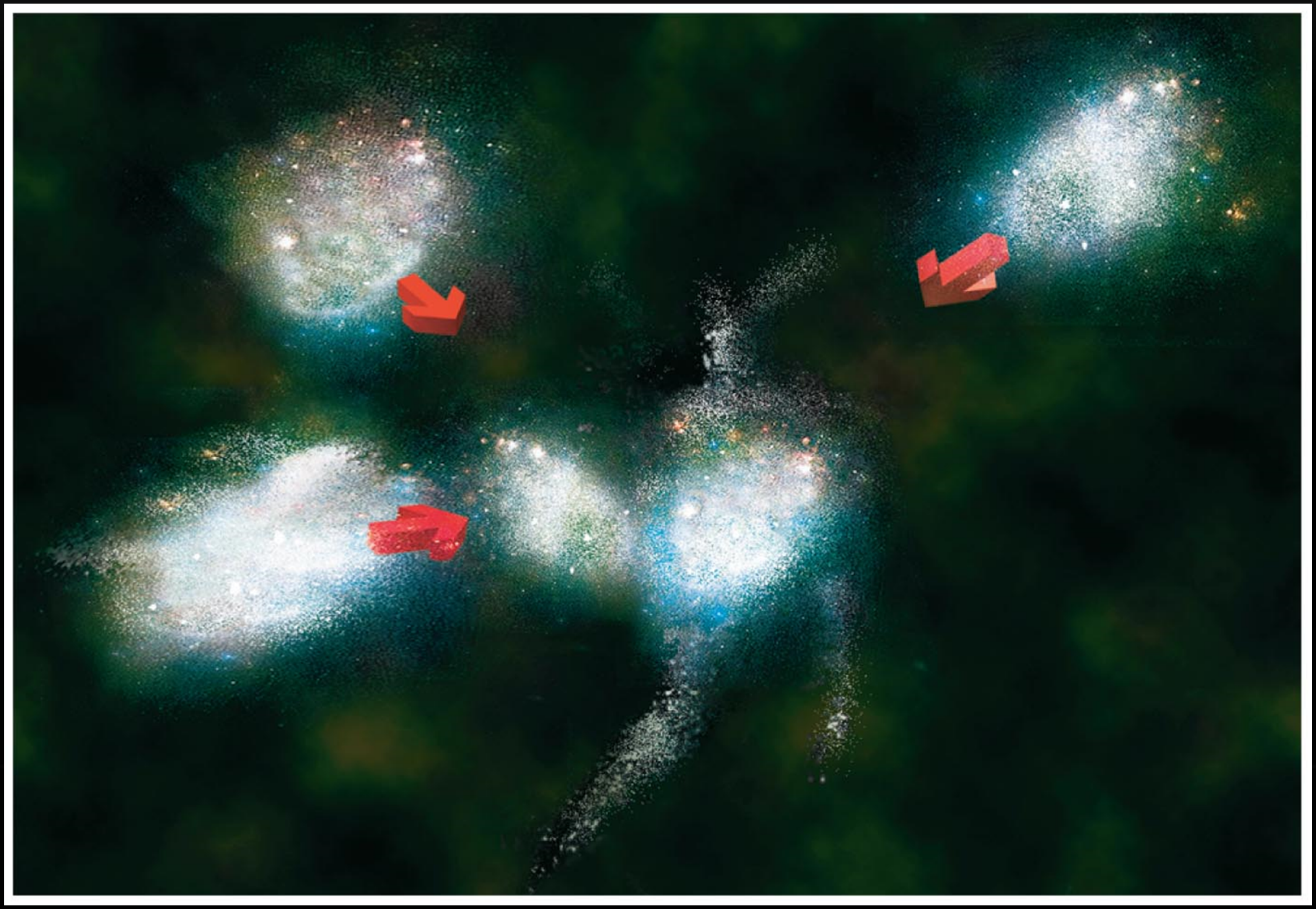
STARS CONTINUOUSLY FORM IN THE DISK AS THE GALAXY GROWS OLDER.

(*this model is oversimplified: Dark Matter, for example, supplies most of the gravity*)

Fig.15.18

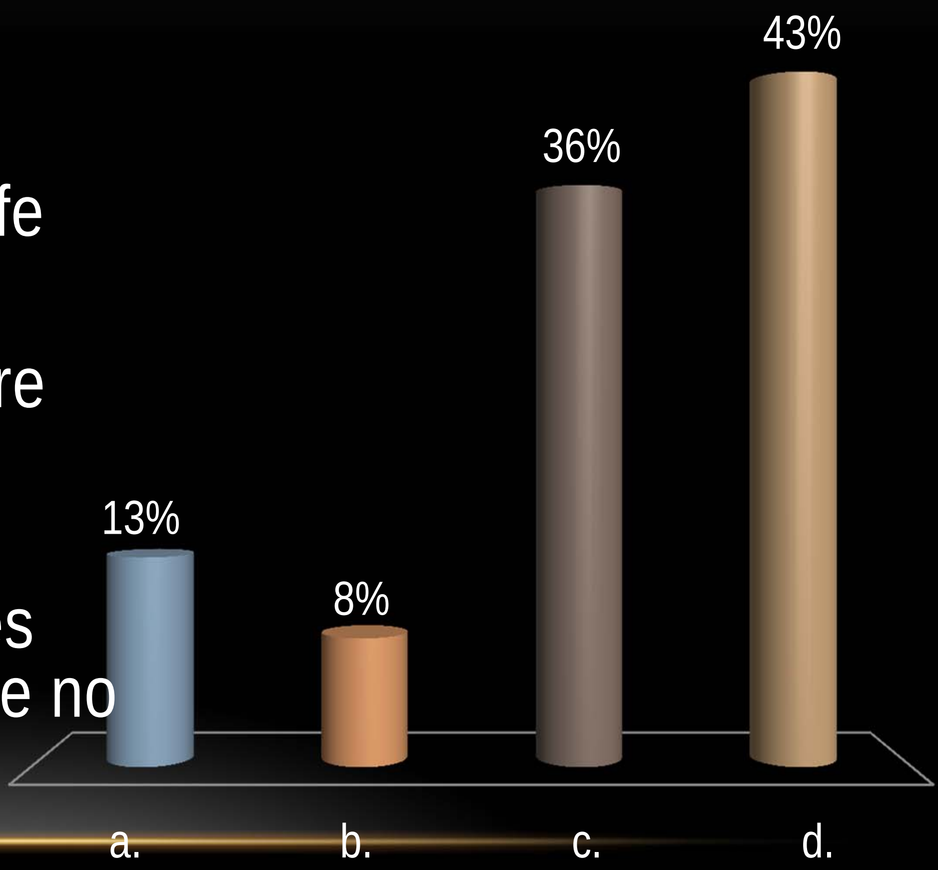
DETAILED STUDIES: HALO STARS FORMED IN CLUMPS THAT LATER MERGED.

Fig.15.19



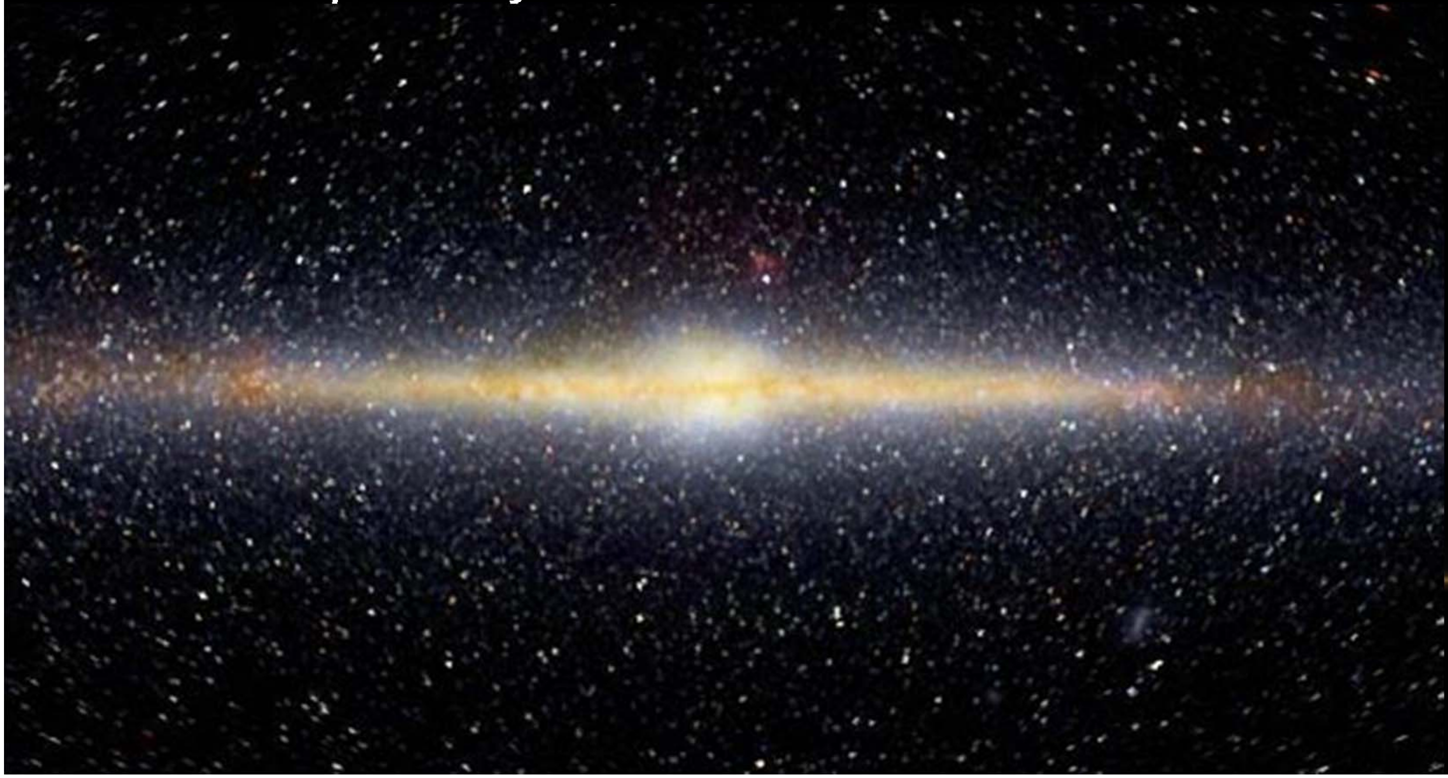
WHY DO STARS IN THE HALO OF THE GALAXY HAVE LITTLE OF THE COMMON ELEMENTS SUCH AS CARBON, NITROGEN, AND OXYGEN?

a. Those elements have been used up in halo stars.
b. C, N, and O are biological elements, and there is no life out there to make them.
c. The halo stars formed before those elements were made. ✓
d. Making C, N, and O requires massive stars, and there are no massive stars in the halo.



GALACTIC NUCLEUS

- The “Bulge” corresponds to a spherical core of stars in the center of the galaxy
- Especially visible in the infra-red



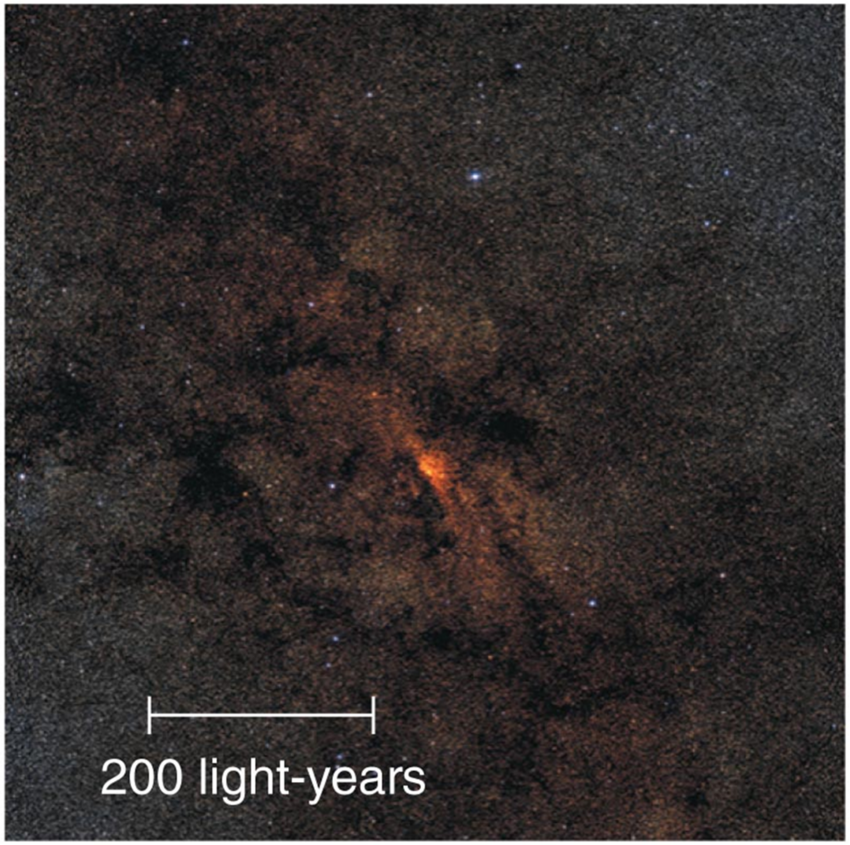
IR image of
Milky Way’s center
By E.L. Wright and
the COBE team

MANY STARS

- Infra-red lets us see closer to center
- There are really a lot of stars packed in there

2MASS
IR image

ZOOM IN: INFRARED

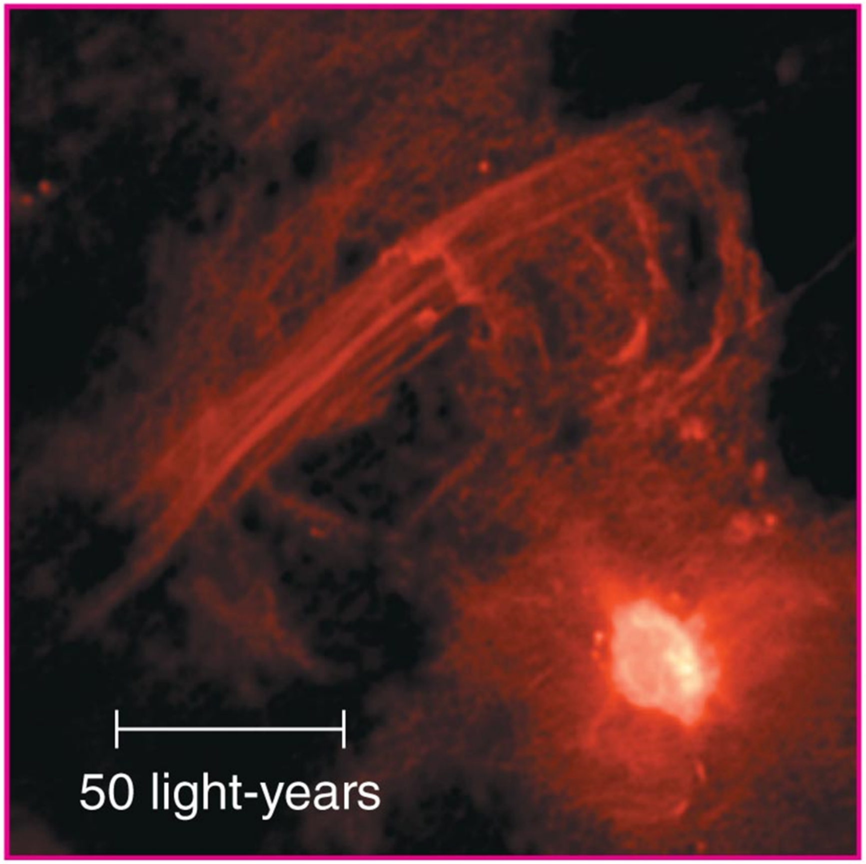


a This infrared image shows stars and gas clouds within 1000 light-years of the center of the Milky Way.

- Stars, gas, dust

Fig.15.20a

ZOOM IN: RADIO

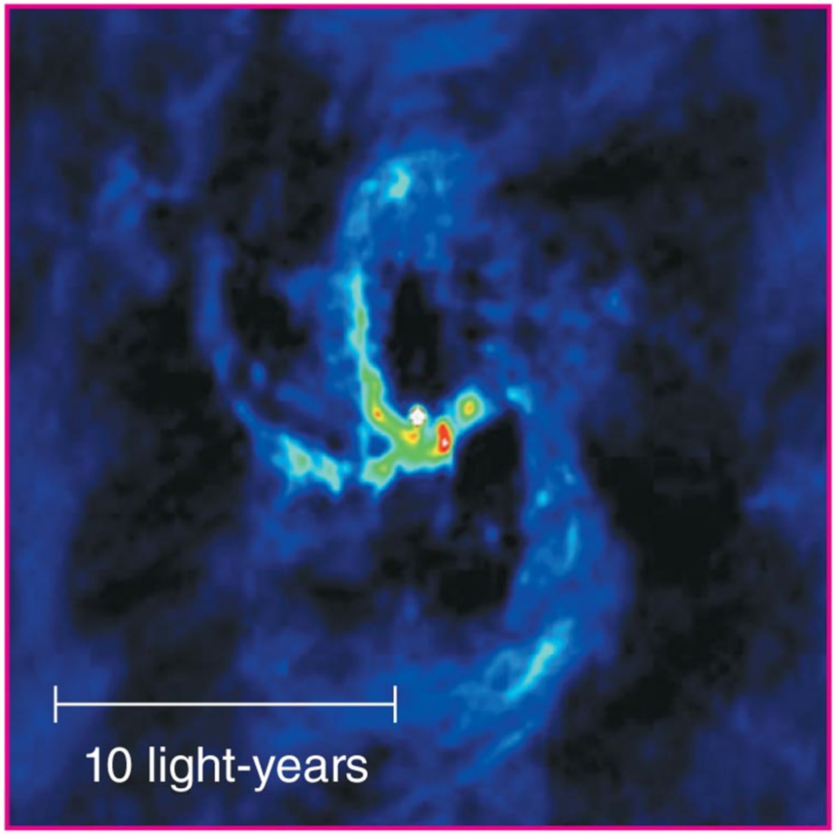


b This radio image shows vast threads of emission tracing magnetic field lines near the galactic center.

- Ions looping around in magnetic fields emit radio waves

Fig.15.20b

ZOOM IN: RADIO

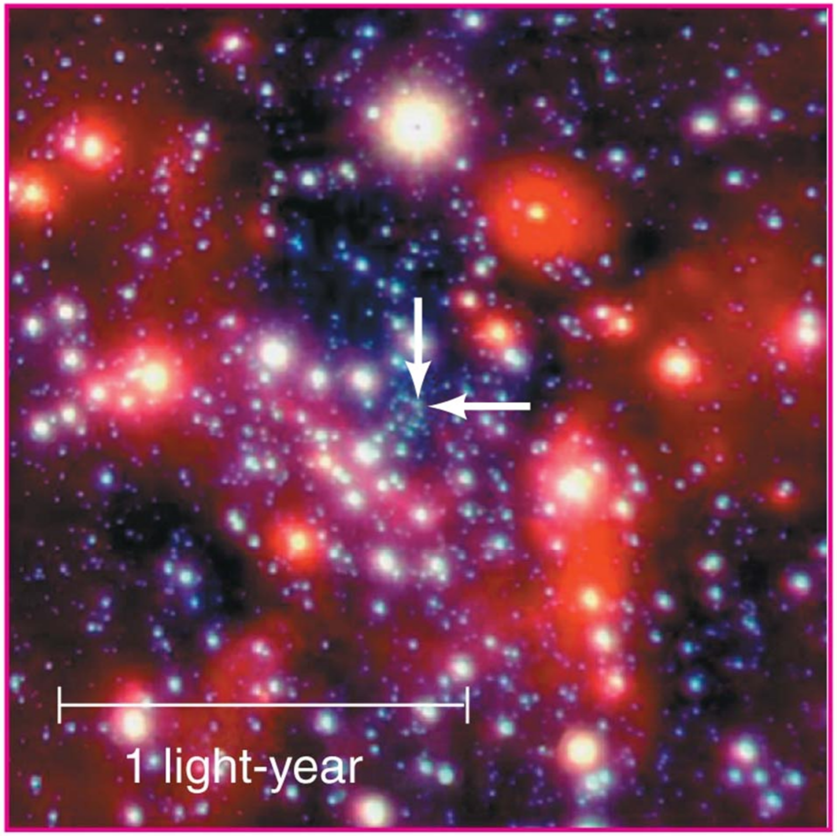


c This radio image zooms in on gas swirling around the radio source Sgr A* (marked by the white dot), suspected to contain a very massive black hole.

- Loop then around faster in larger magnetic fields in smaller spaces, get more radio
- This bright radio source is named "Sagittarius A"

Fig.15.20c

ZOOM IN: INFRARED

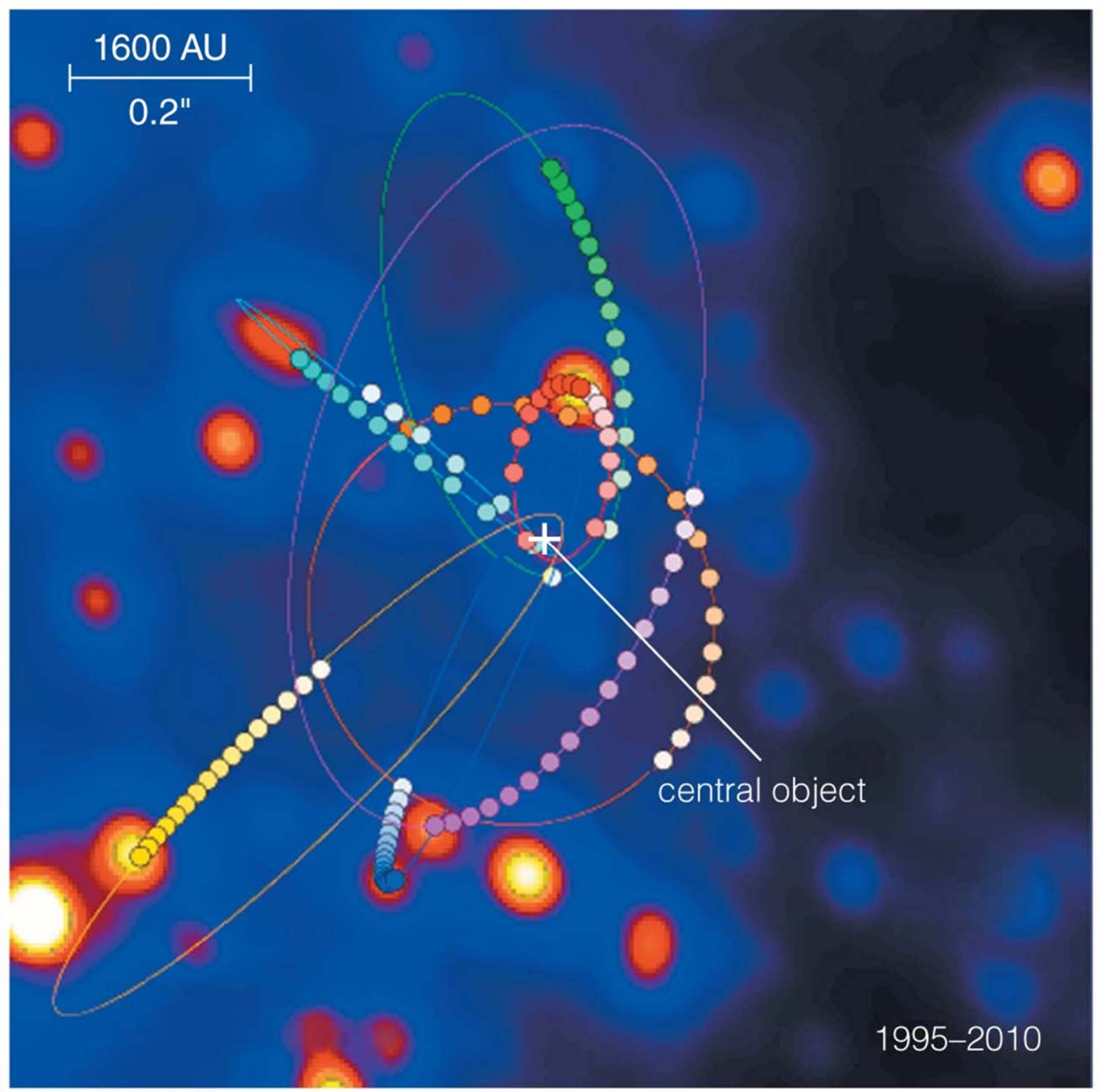


d This infrared image shows stars within about 1 light-year of Sgr A*. The two arrows point to the precise location of Sgr A*.

- What's in there right in the middle? Use IR to see past gas
- "Sagittarius A*" is the thing at the heart of the radio blobs

Fig.15.20d

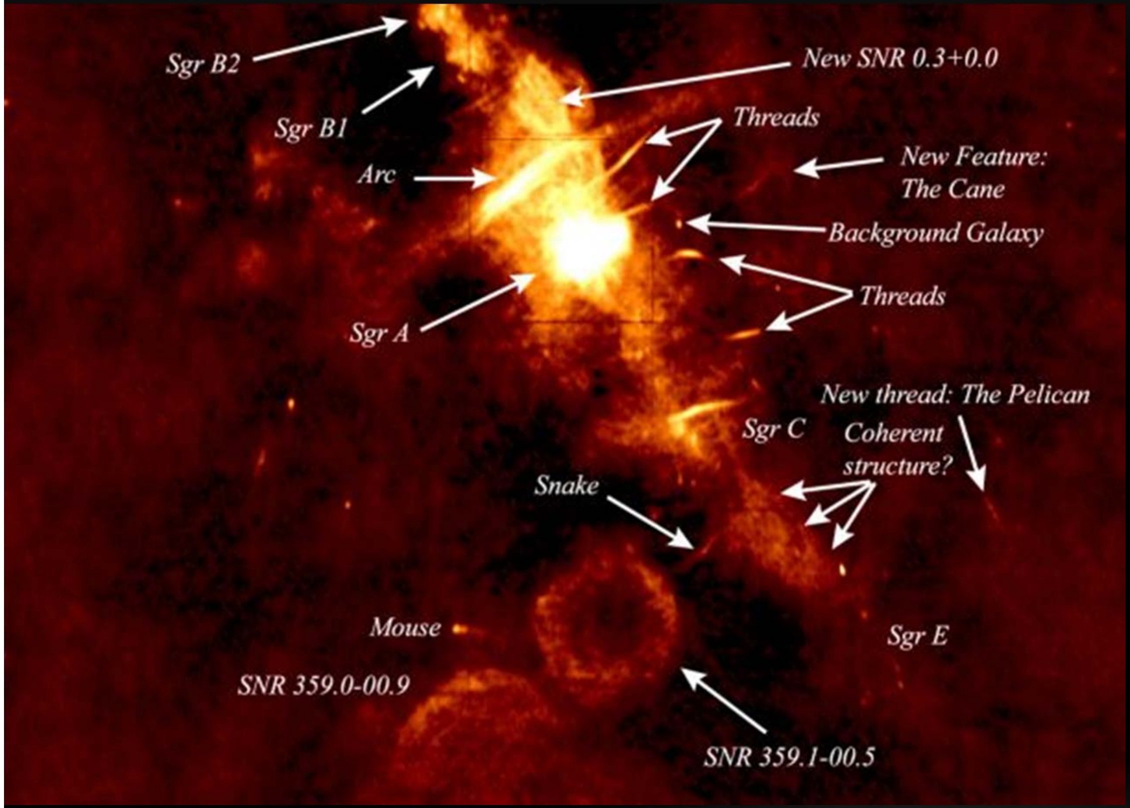
WATCH THINGS OVER TIME



- Even over 15 years, we see stars orbiting a large mass – *fast!*
- They are close to it, and there is a lot of gravity
  - About 4 million $M_\odot$
  - In a solar-system sized volume

Fig.15.21

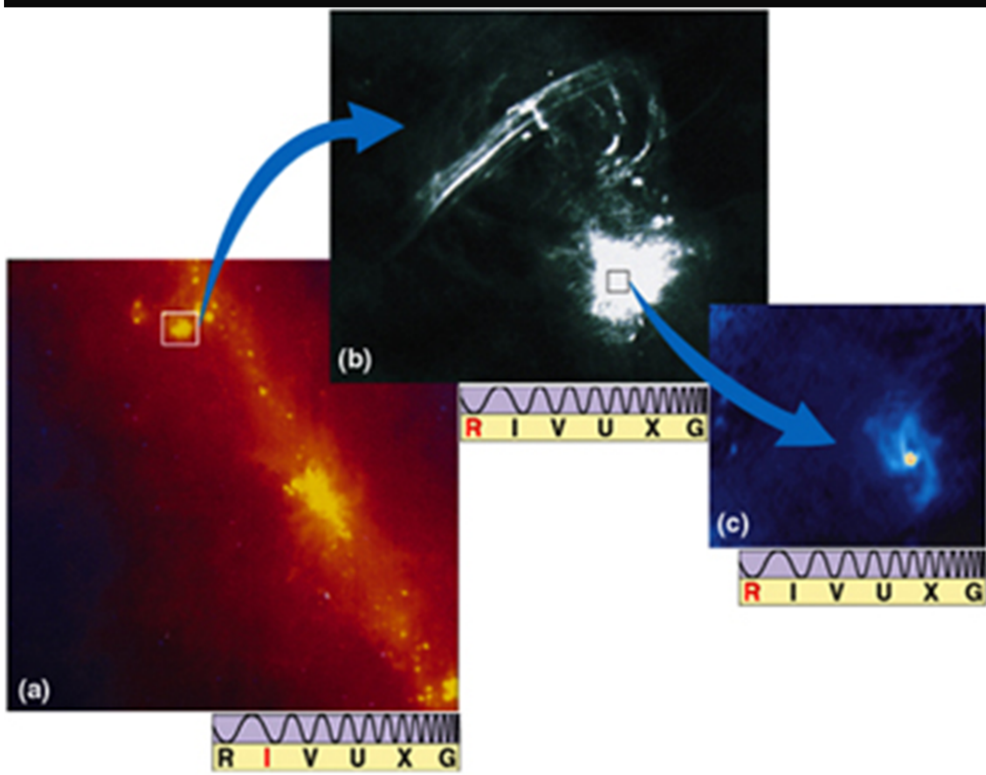
A BUSY PLACE



- This view is of the inner 60 pc
- The bright blob is “SgrA”, the very middle of the galaxy
- Much gas churned about, supernovae remnants
- High-energy emission and fast orbital motions suggest a massive (4 million of $M_{\odot}$) black hole

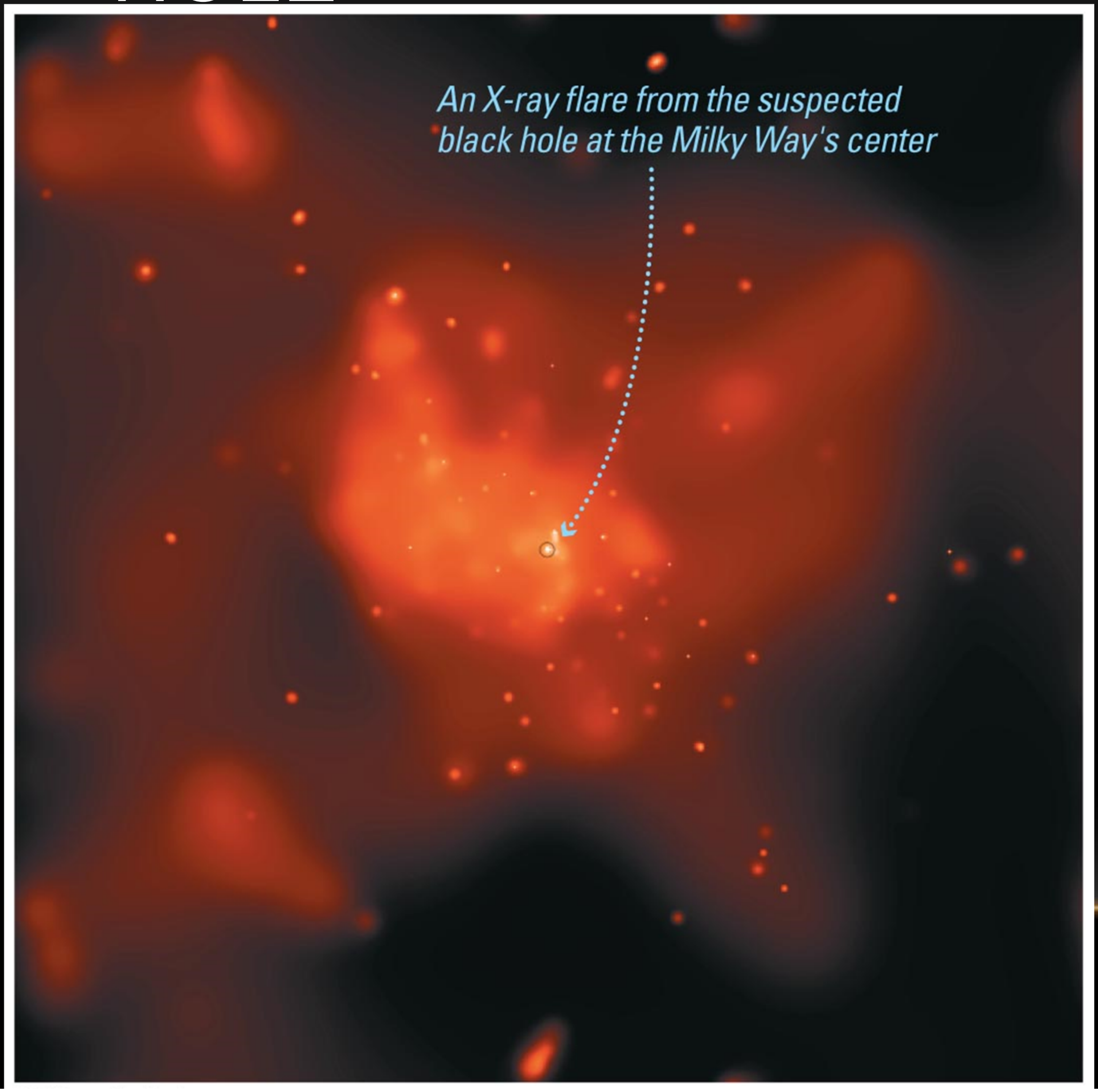
1m radio image by Kassim, Briggs, Lazio, LaRosa, Imamura

A BLACK HOLE?



- Use Doppler shifts to measure orbital velocity of stuff near center of SgrA*
- Use Kepler's Laws to find mass of thing it's orbiting around
- That much mass in such a small space must be a black hole

STUFF COLLIDES WITH BLACK HOLE



- X-ray flares from galactic center suggest that tidal forces of suspected black hole occasionally tear apart chunks of matter about to fall onto accretion disk

Fig.15.22