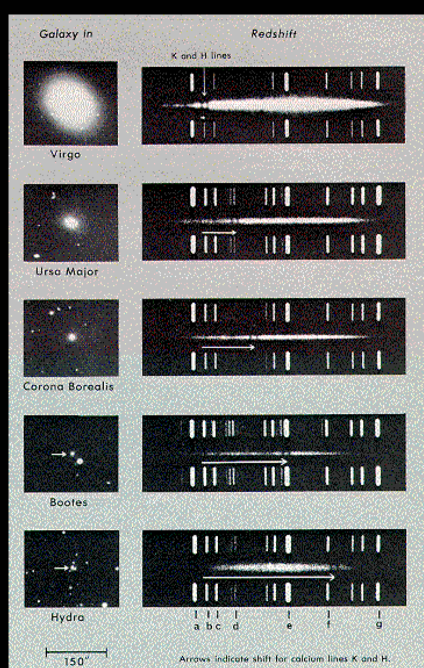
The Hubble Law and Quasars

Dorrit Hoffleit 1907-2007

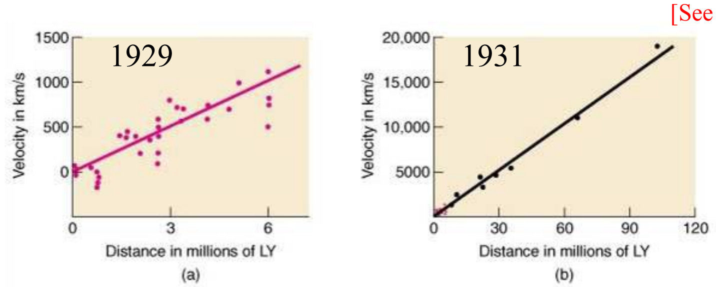
Clicker question: you measure the wavelength of an emission line of neutral hydrogen in a galaxy to be 24 cm. The lab wavelength is 21 cm. Which of the following statements are true?

- The line is blue-shifted and the galaxy is moving toward us
- The line is blue-shifted and the galaxy is moving away from us
- The line is red-shifted and the galaxy is moving toward us
- The line is red-shifted and the galaxy is moving away from us



Hubble's Law (1929)

[See Fig 15.15]

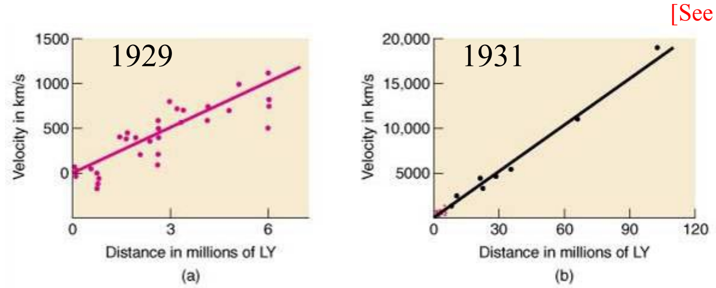


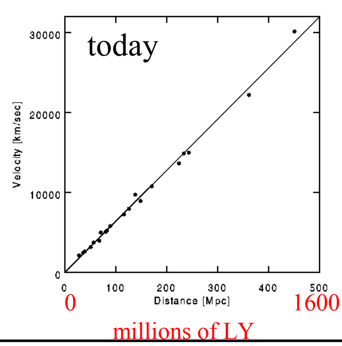
- Measure radial velocity v from Doppler shift.
- Hubble's Law:

  $v = H_o\, d$
- Proportionality constant H_o is called "Hubble constant"

Hubble's Law (1929)

[See Fig 15.15]





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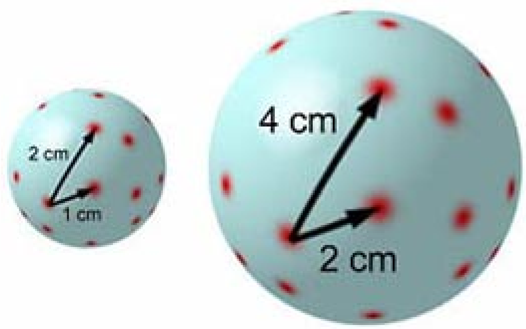
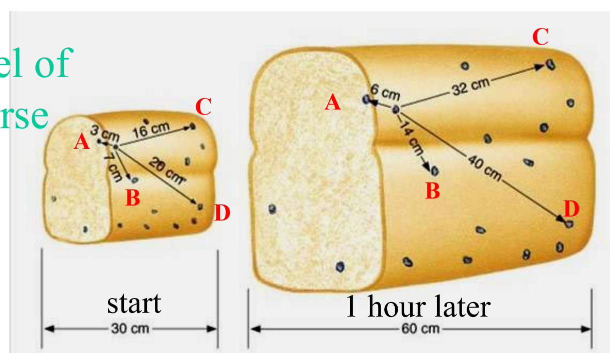
Are we particularly unpopular?



Raisin Bread Model of Expanding Universe

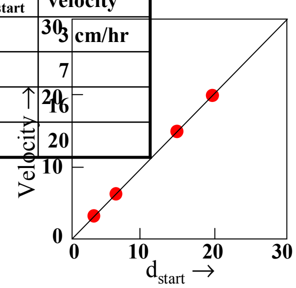
- Raisin-bread model shows V=H D
- Why do raisins move? Bread pushes them.

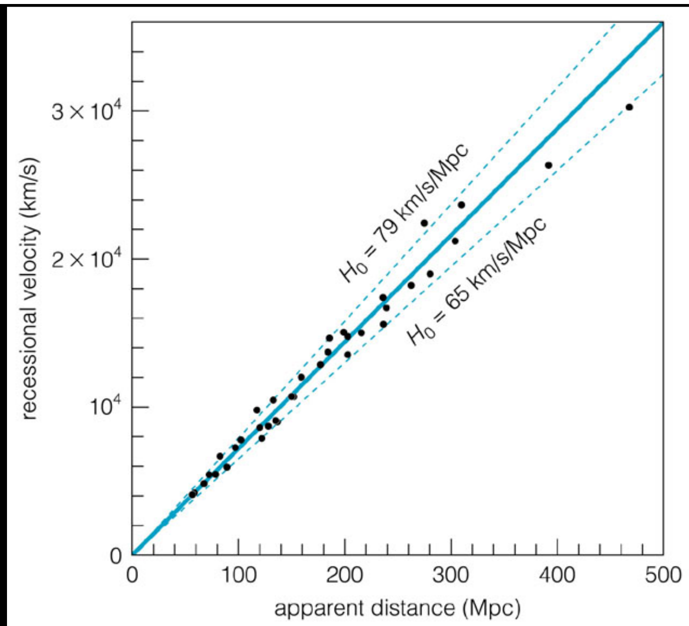
5. Why are galaxies moving?
   a. Space pushes galaxies.
   b. Big Bang set proto-galaxies in motion. Gravity slows (or accelerates) motion.



Galaxy	d_{start}	d_{end}	d_{end} - d_{start}	velocity
A	3 cm	6 cm	3 cm	3 cm/hr
B	7	14	7	7
C	16	32	16	16
D	20	40	20	20

Looks same from any raisin





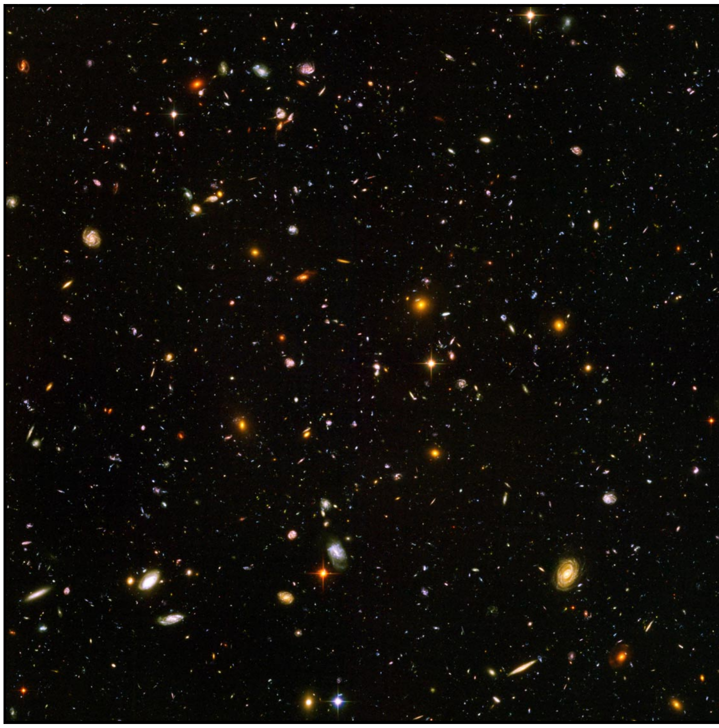
Hubble's Law: velocity = H_0 x distance

Clicker question

$v = H d$

Galaxy X is 10 million light years away. Galaxy Y is 20 million light years away. According to the Hubble Law, Galaxy Y will be

A. Moving away from us twice as fast as Galaxy X
B. Moving away from us half as fast as Galaxy X
C. Moving away from us with the same speed as Galaxy X

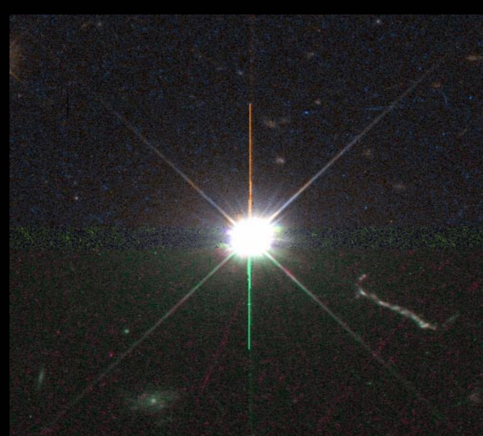


Distances of farthest galaxies measured from redshifts

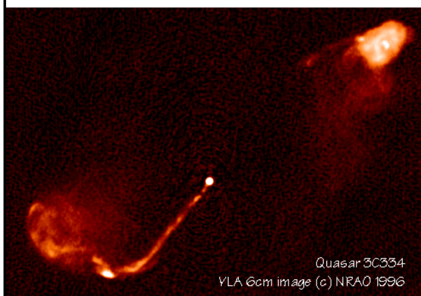
$D = v/H$

Discovery of quasars

Quasi-stellar object



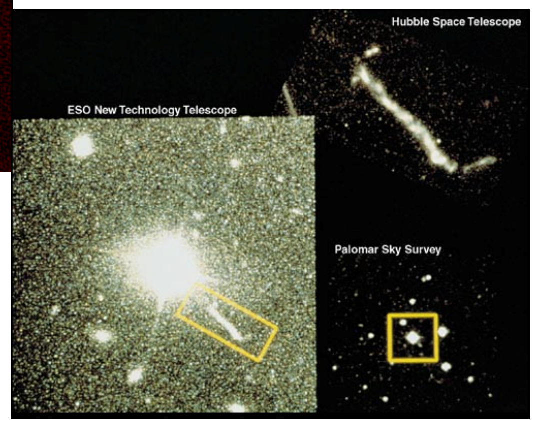
Quasars: Quasi-Stellar Radio Sources [26]



Radio image

- But most are *not* radio sources
  - Quasi-Stellar Objects (QSOs)

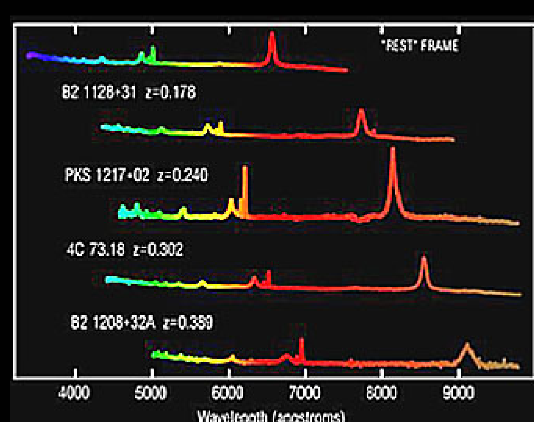
Optical image



[Fig 26.3]

The Mystery Deepens

- Quasars had weird spectra



What were they?

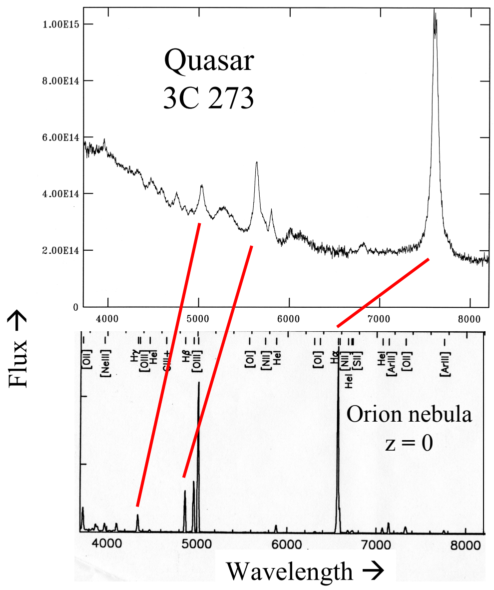
- One idea was that they were some kind of weird star within the Milky Way Galaxy

Maarten Schmidt realizes quasars have big redshifts

According to the Hubble Law, the quasars would be very far away

D = v/H

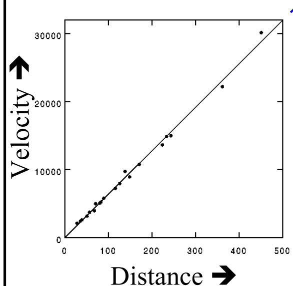
Large redshifts



- Measure Doppler shift from emission or absorption lines:

Redshift $z = \Delta\lambda/\lambda = v/c$

Largest known QSO redshift: z = 6



Redshift $z = \Delta\lambda/\lambda = v/c$ → $v = 6\,c$

Special relativity:

$$z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + v_{radial}/c}{1 - v_{radial}/c}} - 1$$ → $v = 0.96\,c$

→ Distance = 13 billion light years.
Light travel time = 13 billion years.

If quasars are far away, the must be very luminous

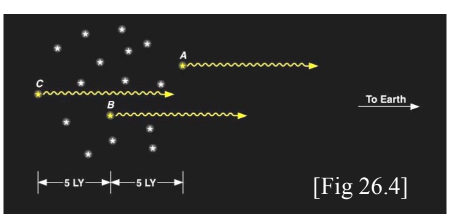
- What could provide so much luminosity, arising from such a small space?

Quasars & Active Galaxies

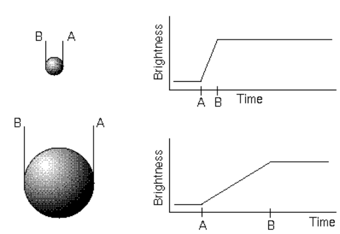
- Large redshift ➔ large distance

$$F = L/4\pi d^2$$
$$4\pi d^2 F = L$$

- Measured flux + distance ➔ huge luminosity
  - Up to 1000 x luminosity of an entire galaxy of stars.
- Rapid flux variability ➔ small volume.



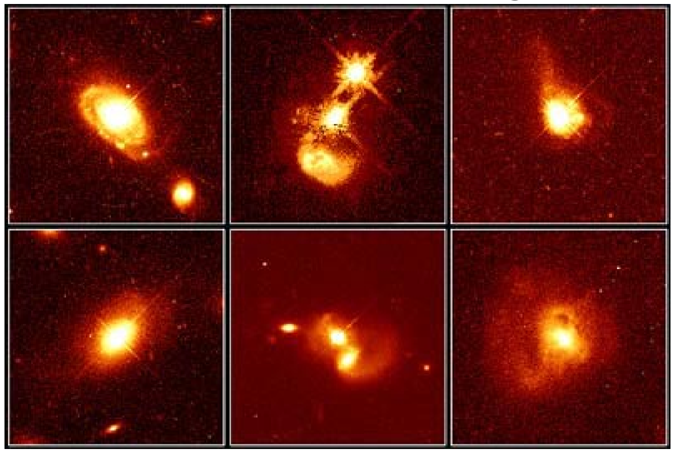
[Fig 26.4]



Some luminous quasars vary in *few days* ➔ same size as solar system.

Quasars: events in centers of galaxies

[Fig. 26.6]



- Hubble Space Telescope images.
  - bright star-like objects at centers of faint galaxies.

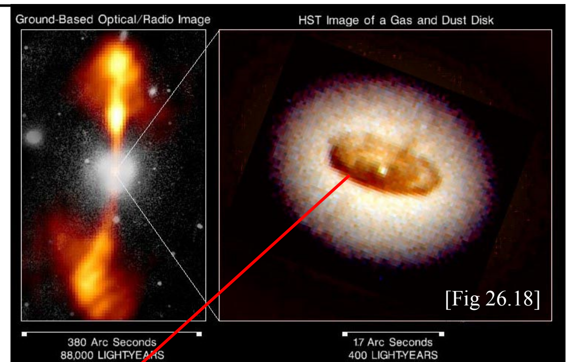
Black Holes in binary star systems

[Fig 23.14]

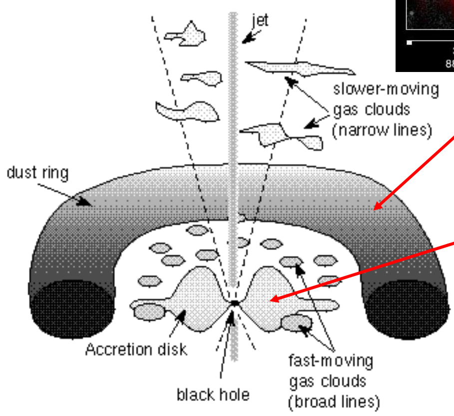
- Could black holes be the ultimate energy source in quasars? But black holes much more massive than those in binary stars?

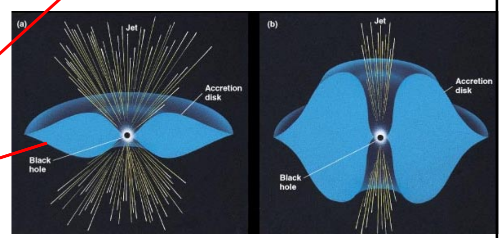
Energy Source:

- Gas, stars fall into $10^8 M_\odot$ black hole.
- Gravitational potential energy ➔ thermal energy ➔ light



[Fig 26.18]





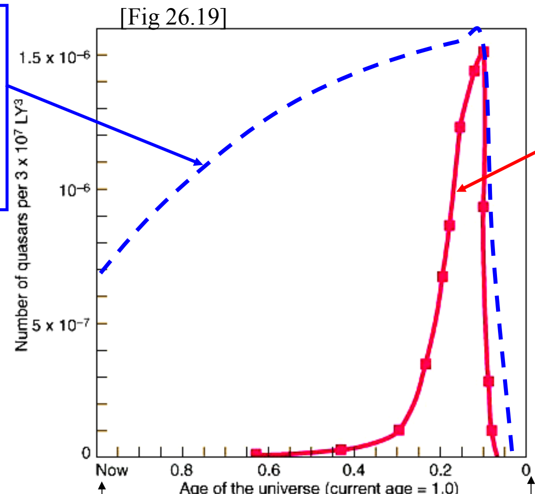
[Fig 26.17]

Accretion disk + Black Hole + Jets

Most Quasars Lived and Died Long Ago

Rate at which stars are formed in galaxies.

[Fig 26.19]



Number of Quasars per unit volume

Conclusion:
Quasars are events in young galaxies.

Strobel's QSO in spiral galaxy

Now
= 14 billion yrs

← time

Formation of universe

Why don't we see so many quasars today?

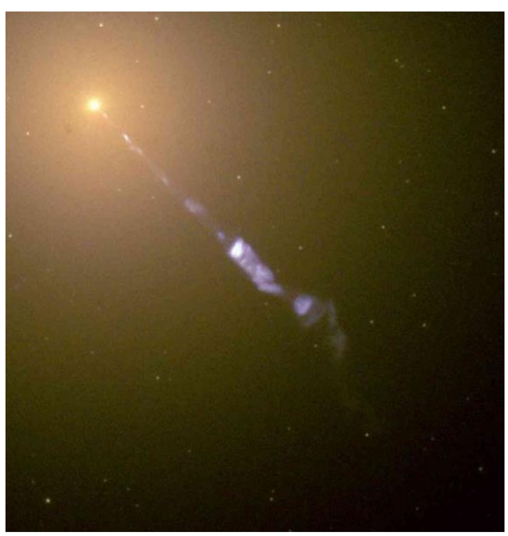
Did the black holes vanish?

Probably not, we don't know how we could make a supermassive black hole vanish

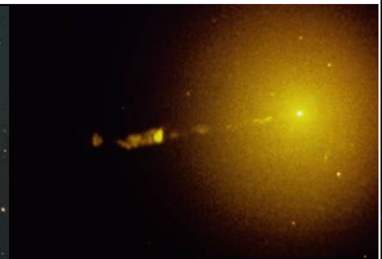
Did stuff stop falling into the black holes so much?

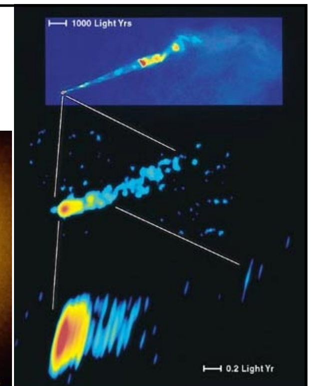
This may be more plausible

Jet from the Center of M87

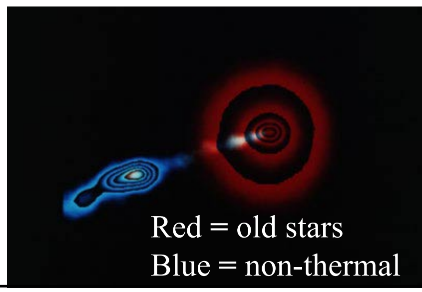


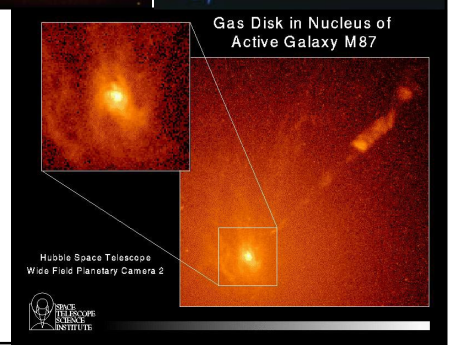
The Leftovers:
The Active Galaxy M87

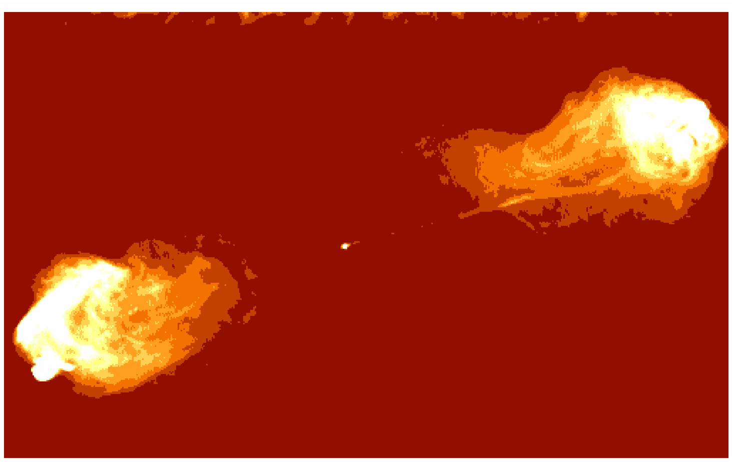




[see 26.2]

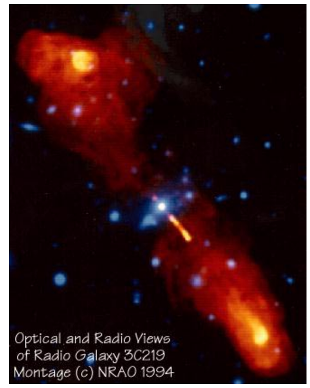


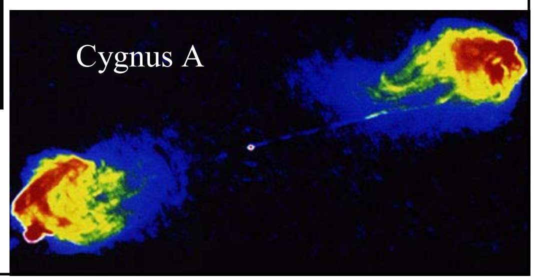




The Radio Galaxy Cygnus A

Some other Active Galaxies





These Radio Galaxies are E galaxies.

Also… Seyfert Galaxies = spirals with very low-luminosity QSO at center.