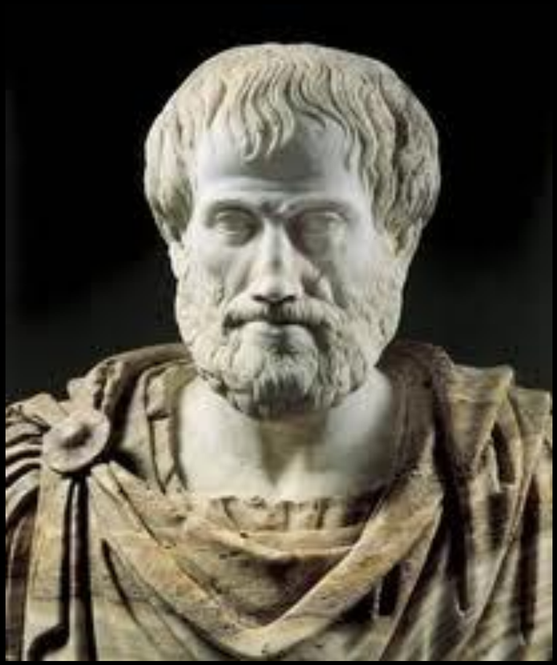
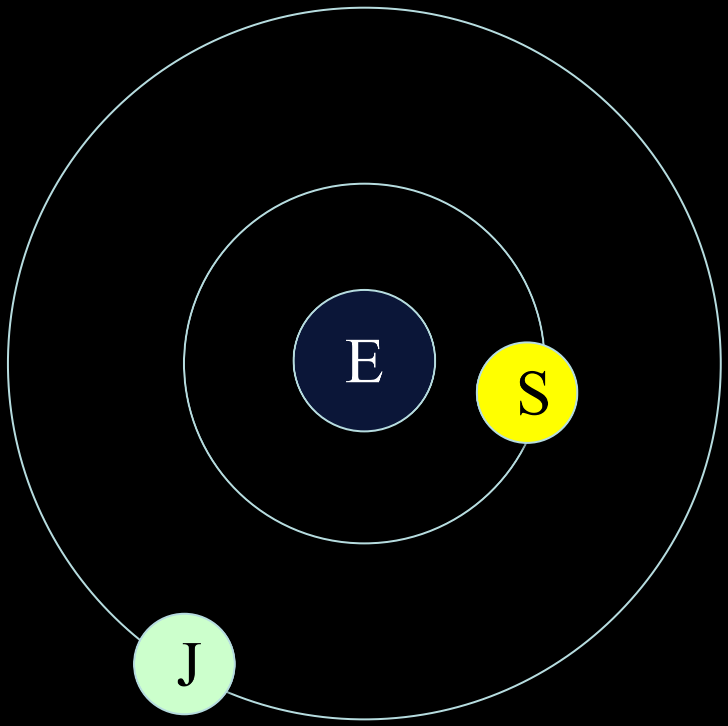
# Our Changing view of the Universe

# Geocentric Universe

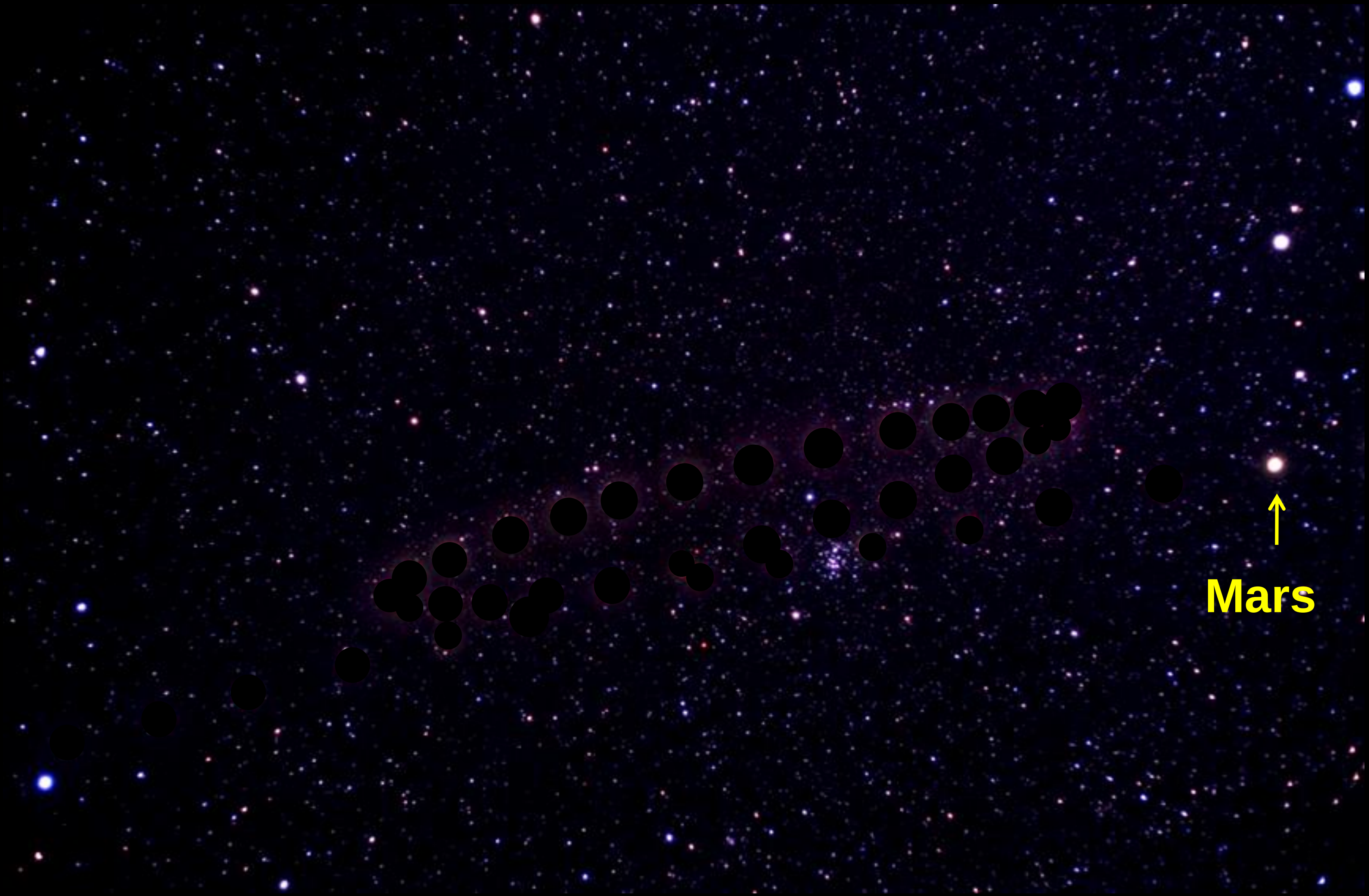


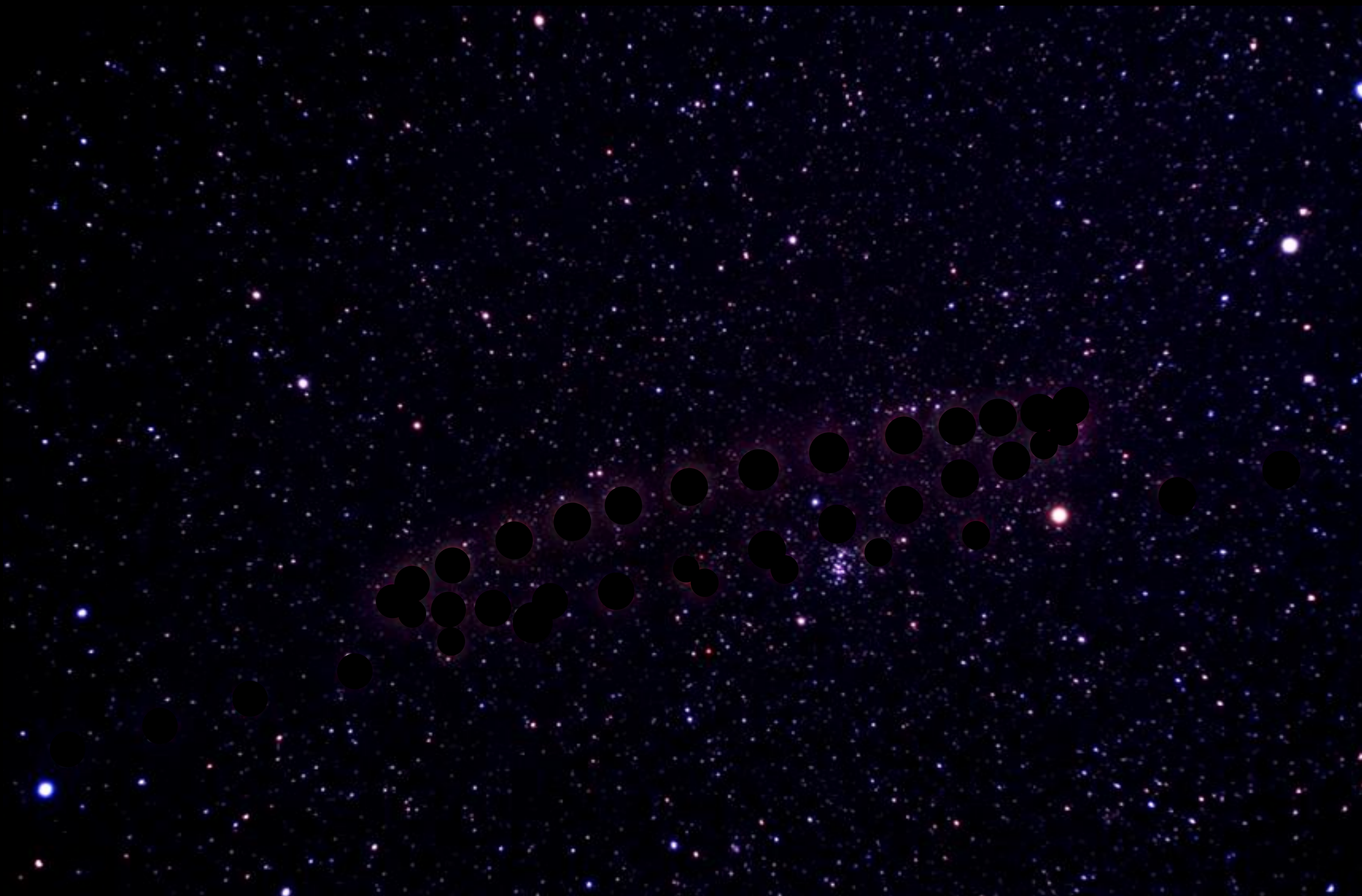
# Geocentric Universe

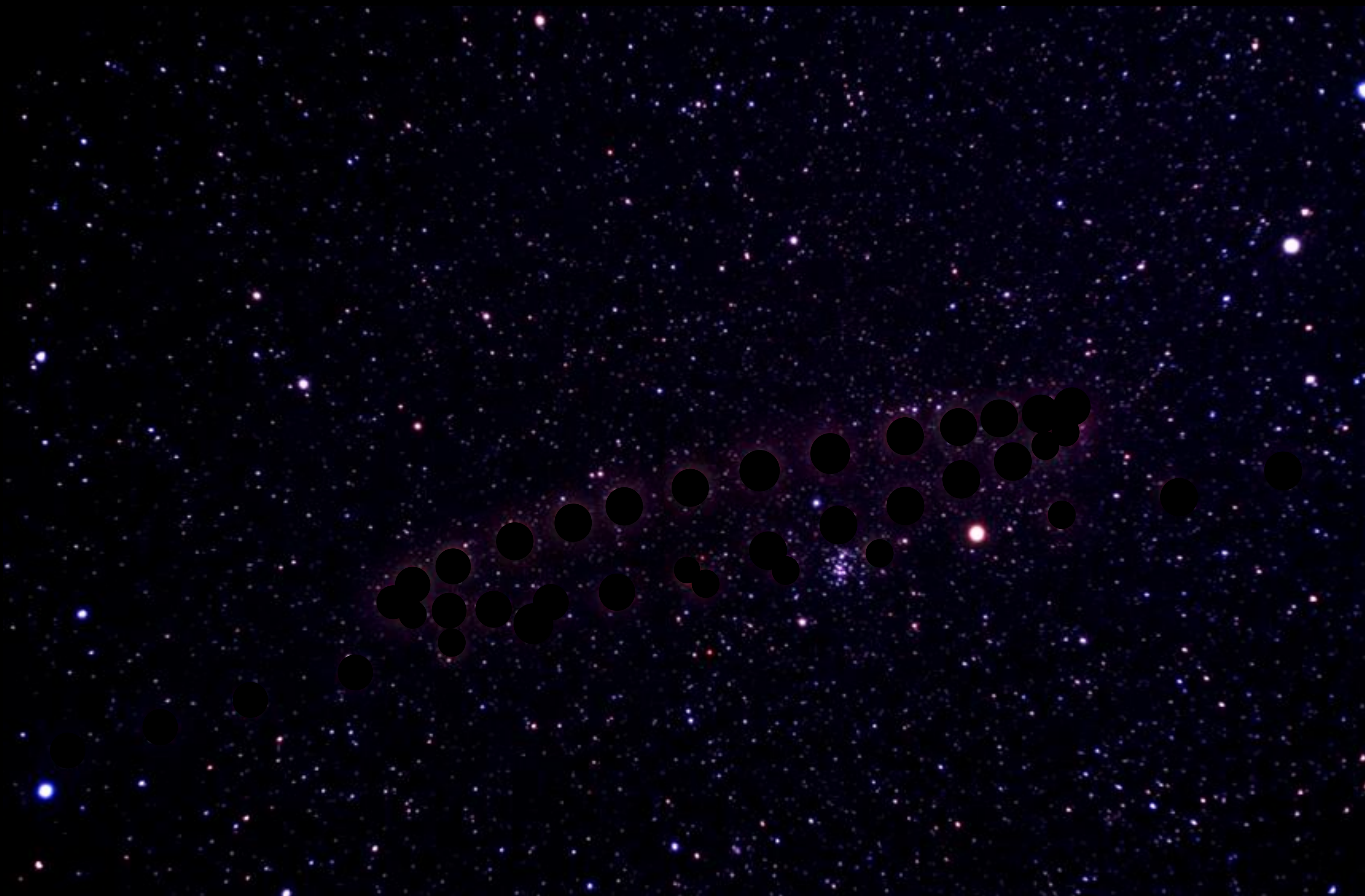


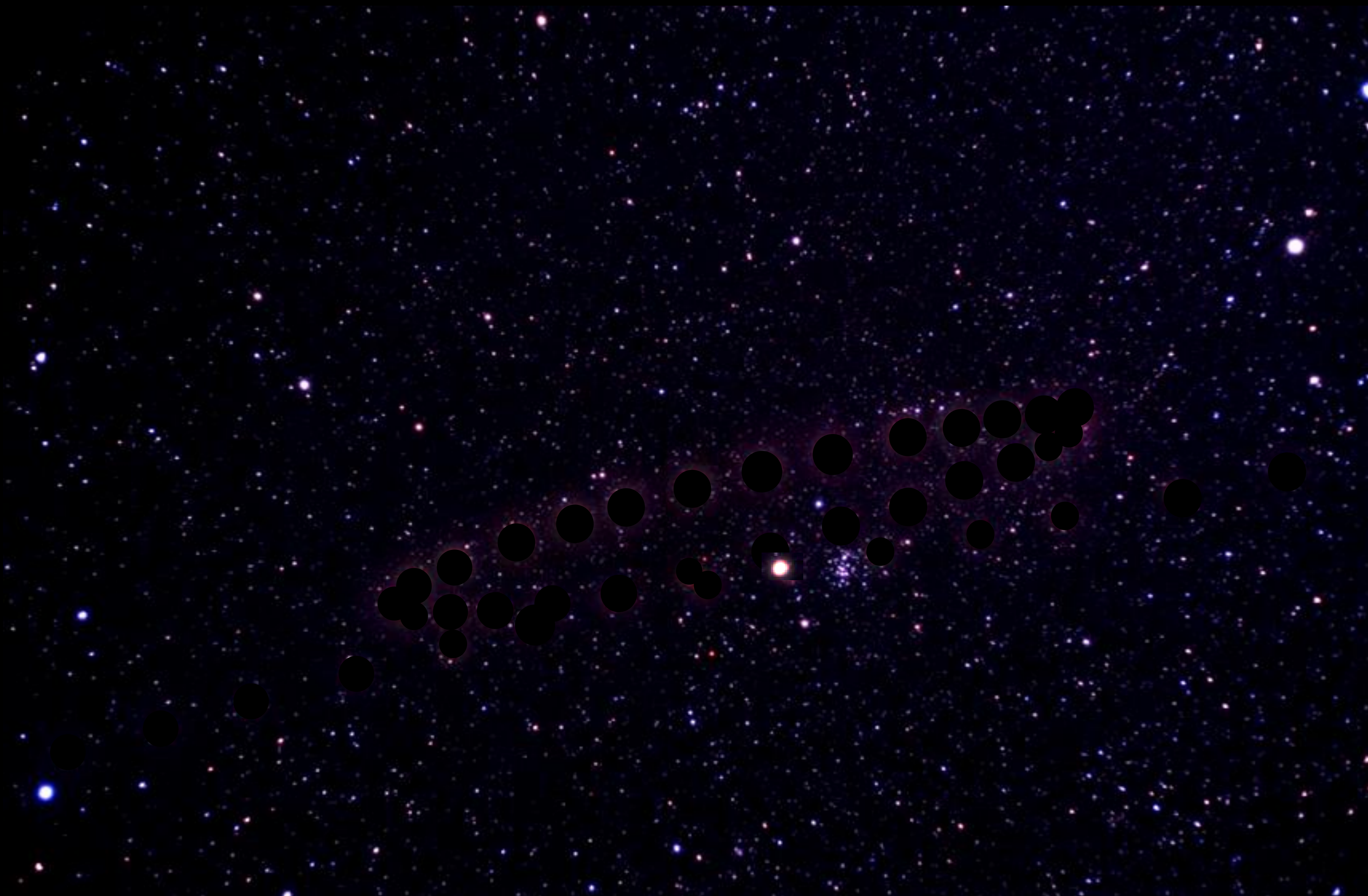

sun and planets move around Earth

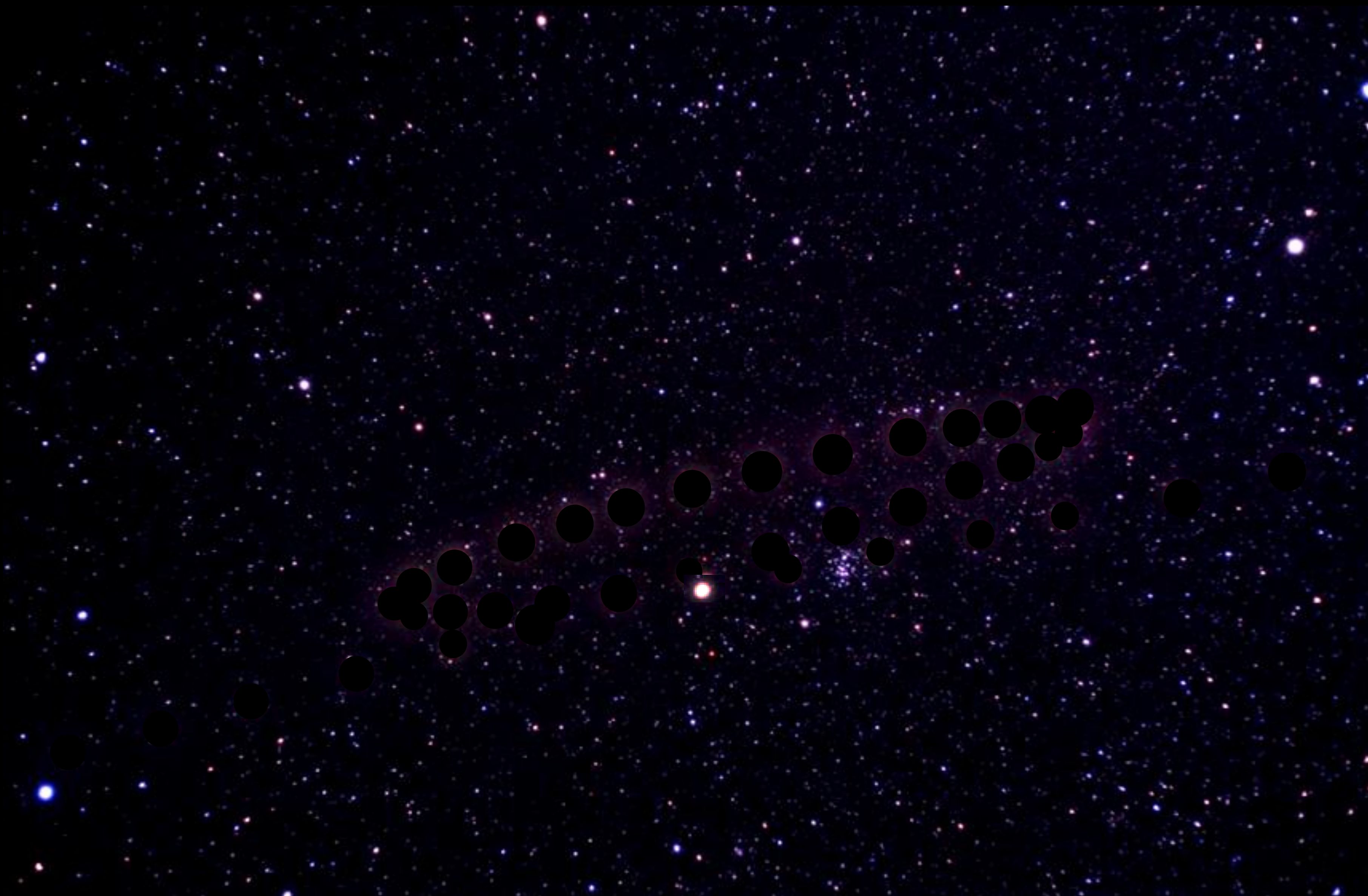
# Retrograde Motion of Mars

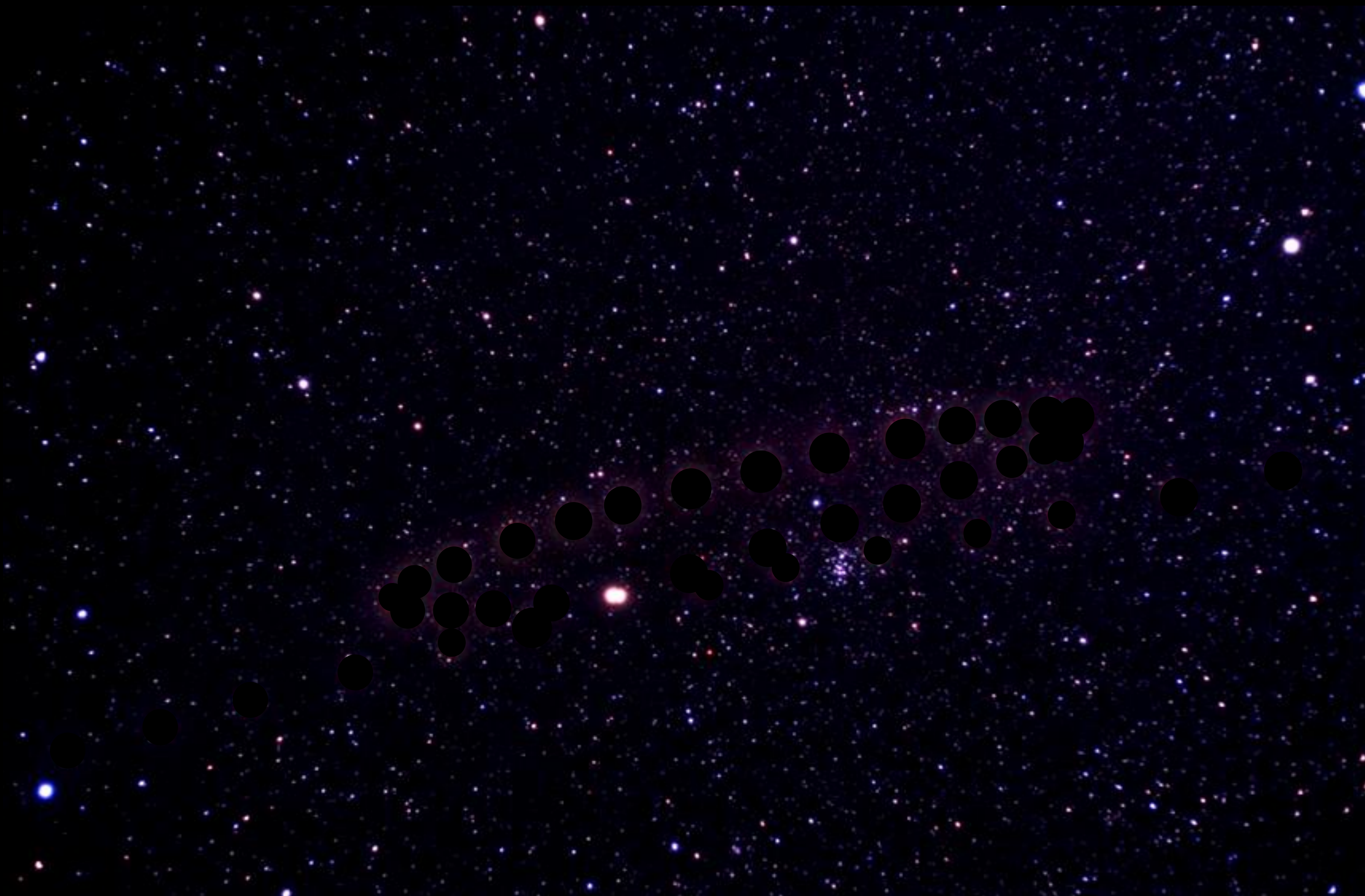


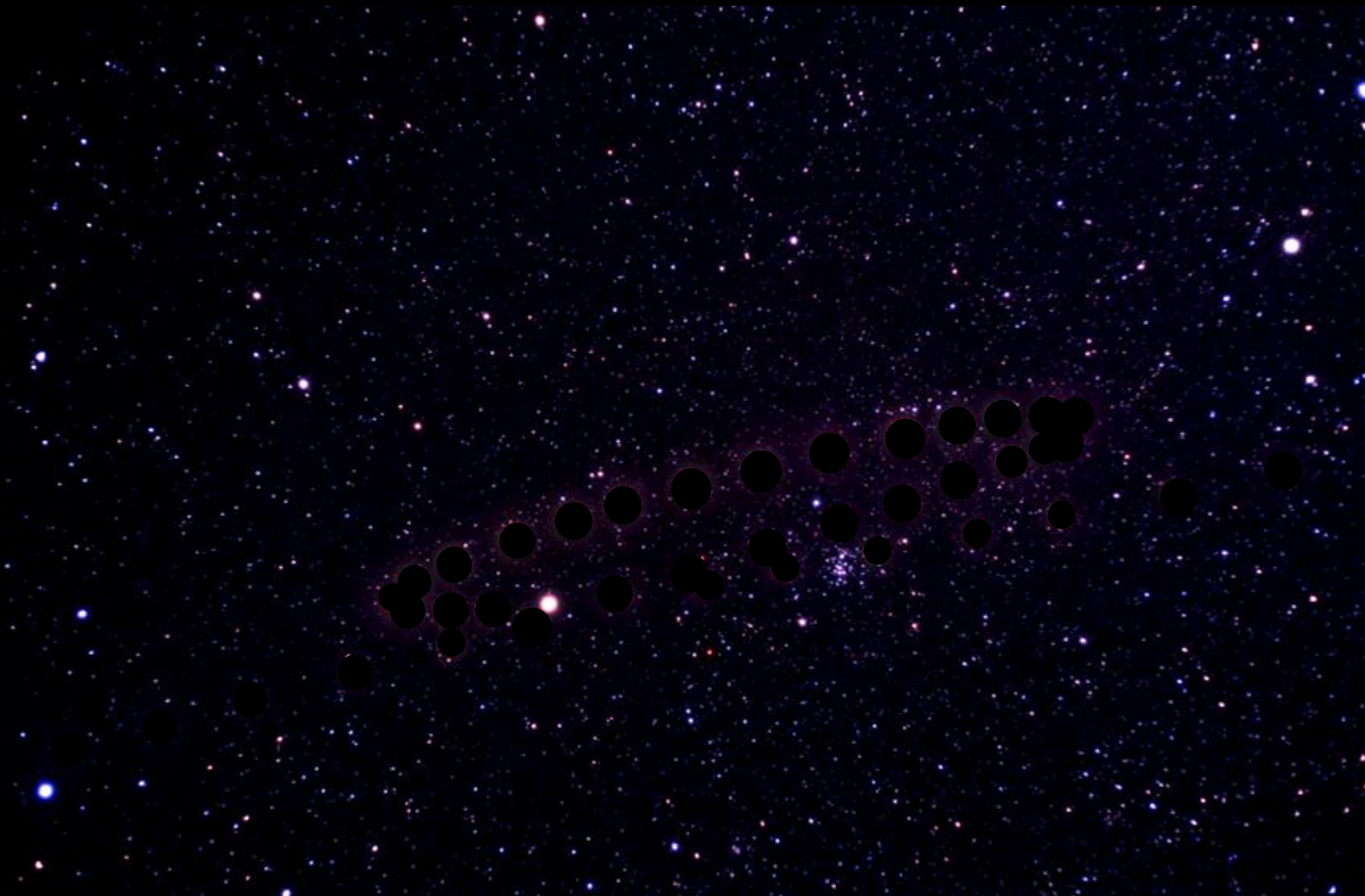


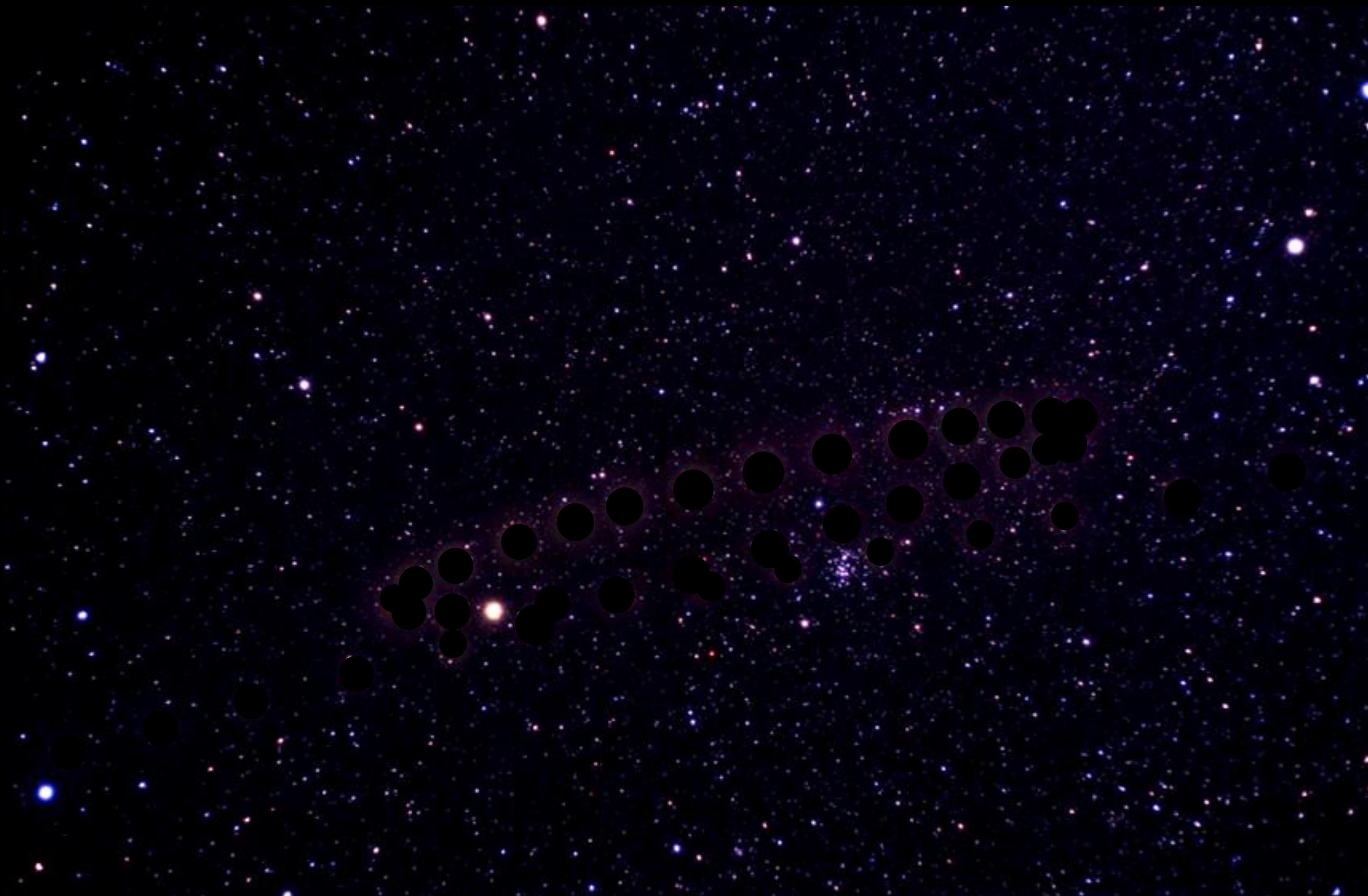


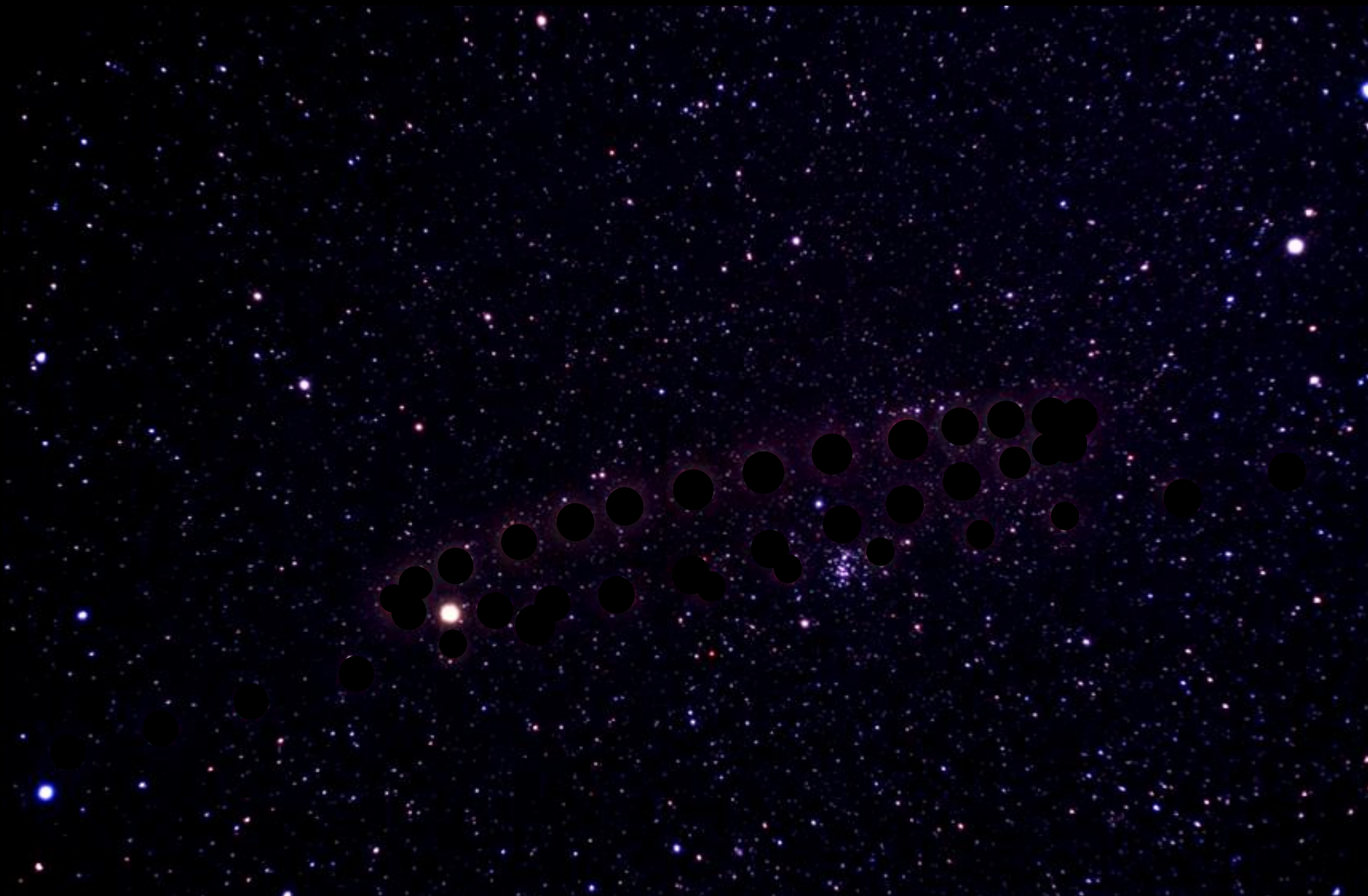


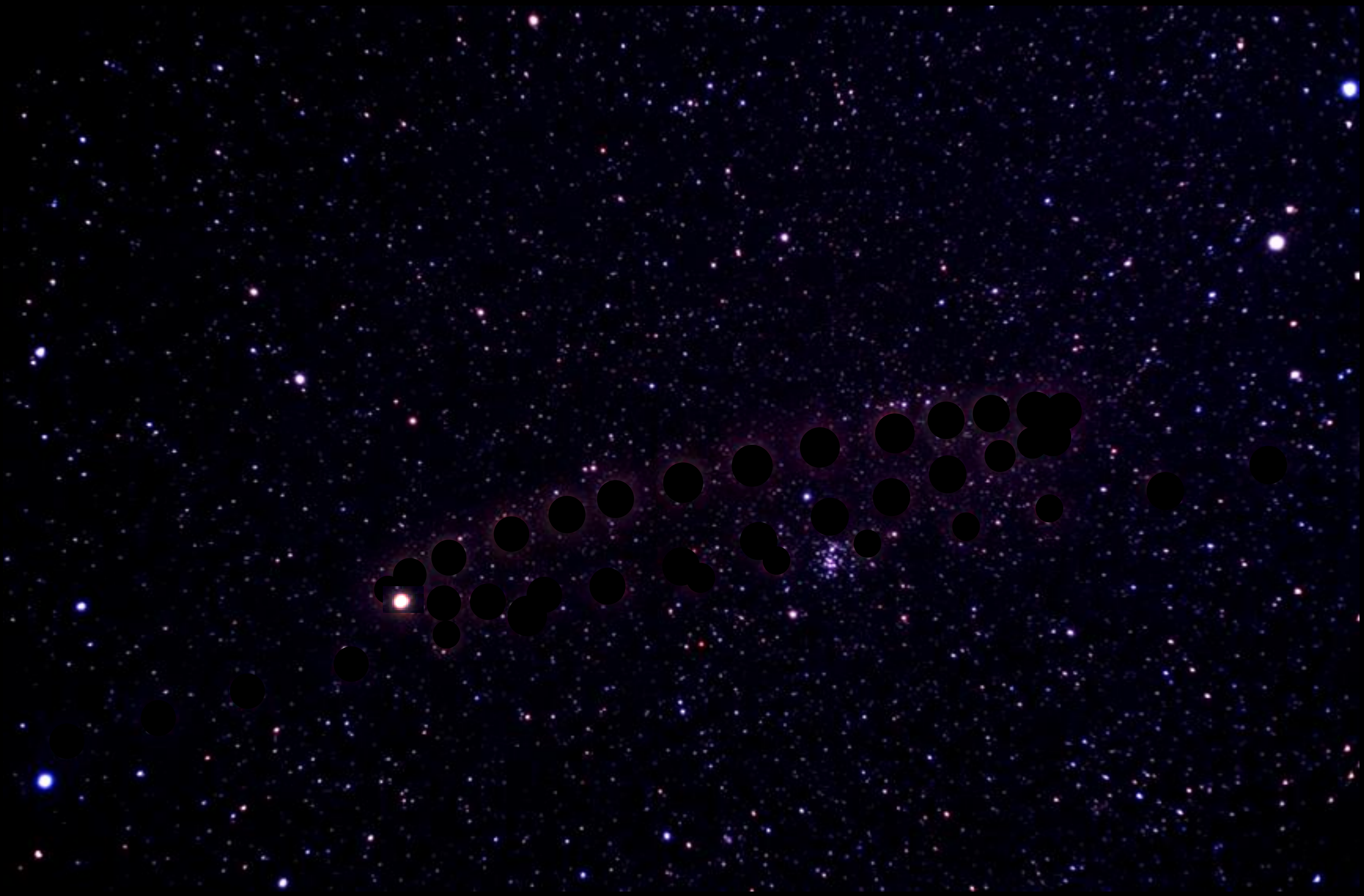


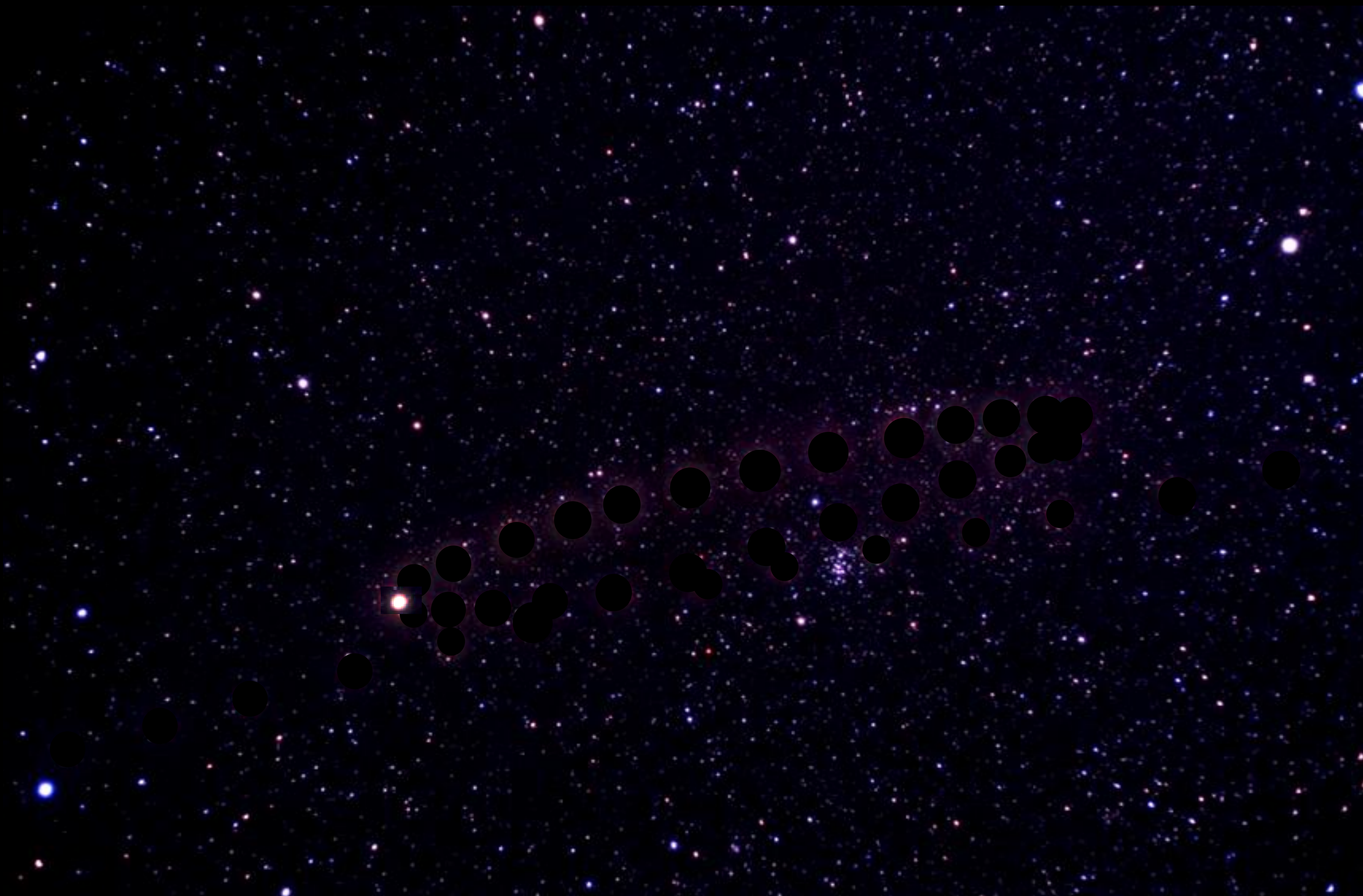


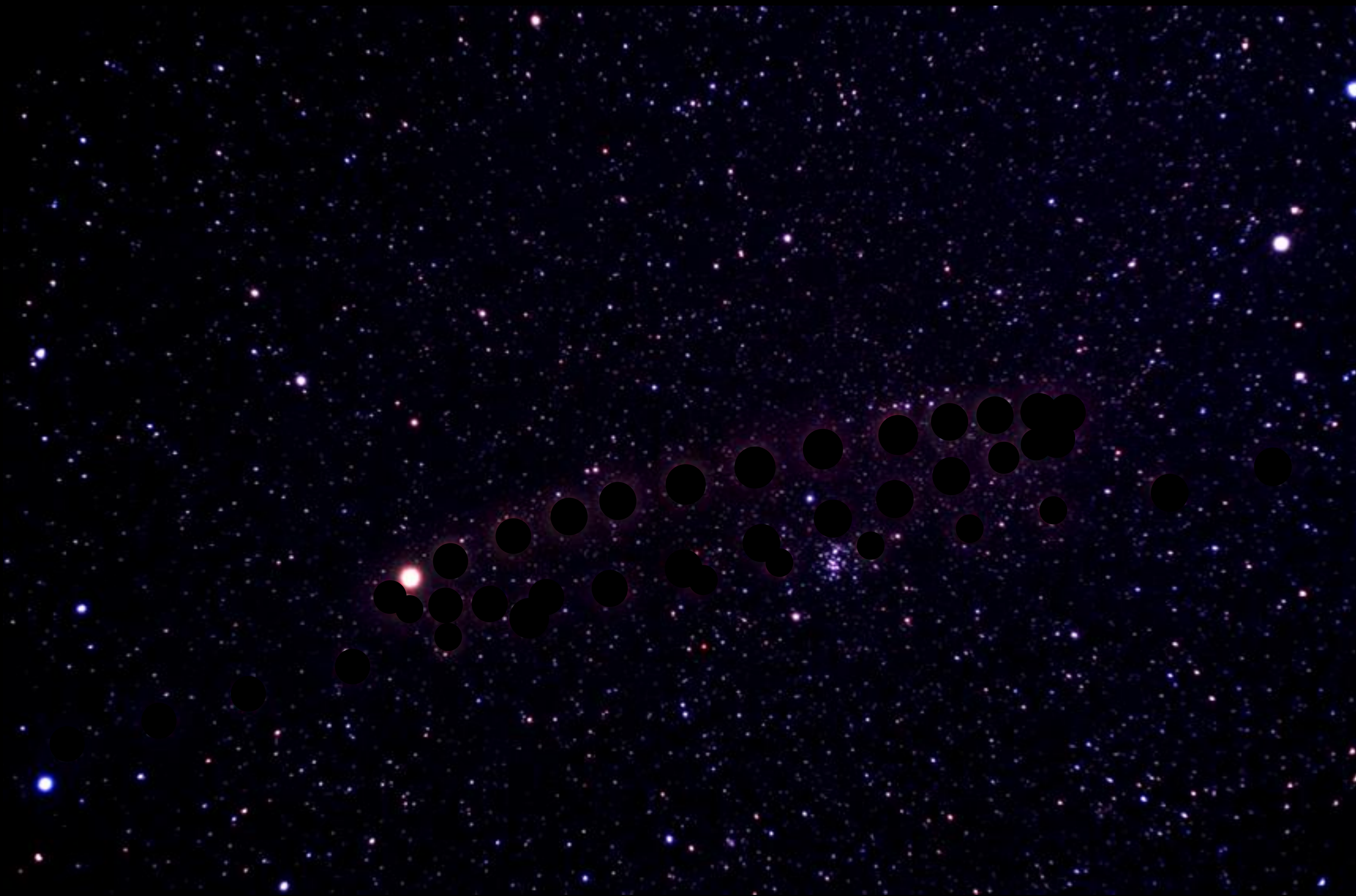


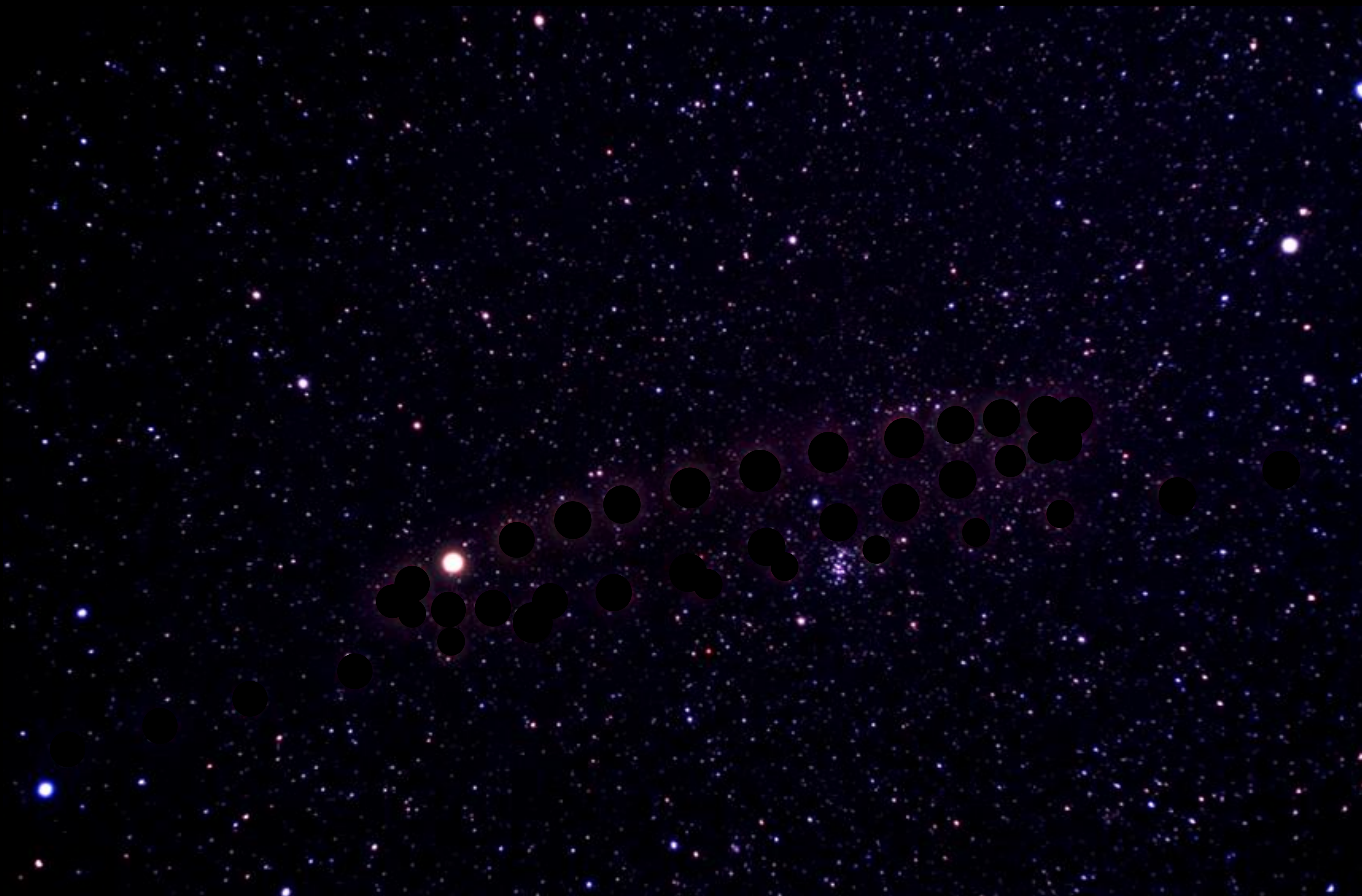


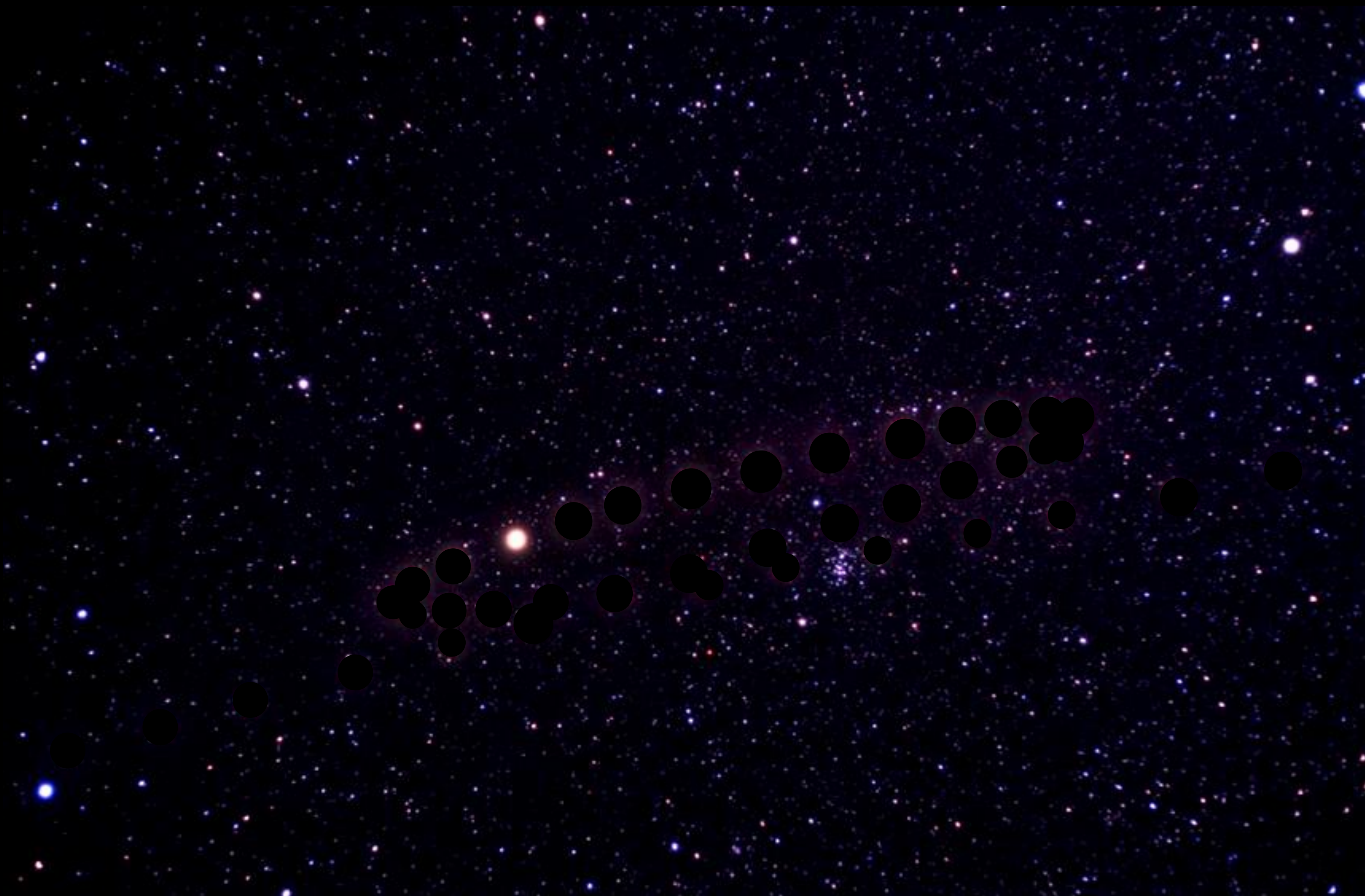


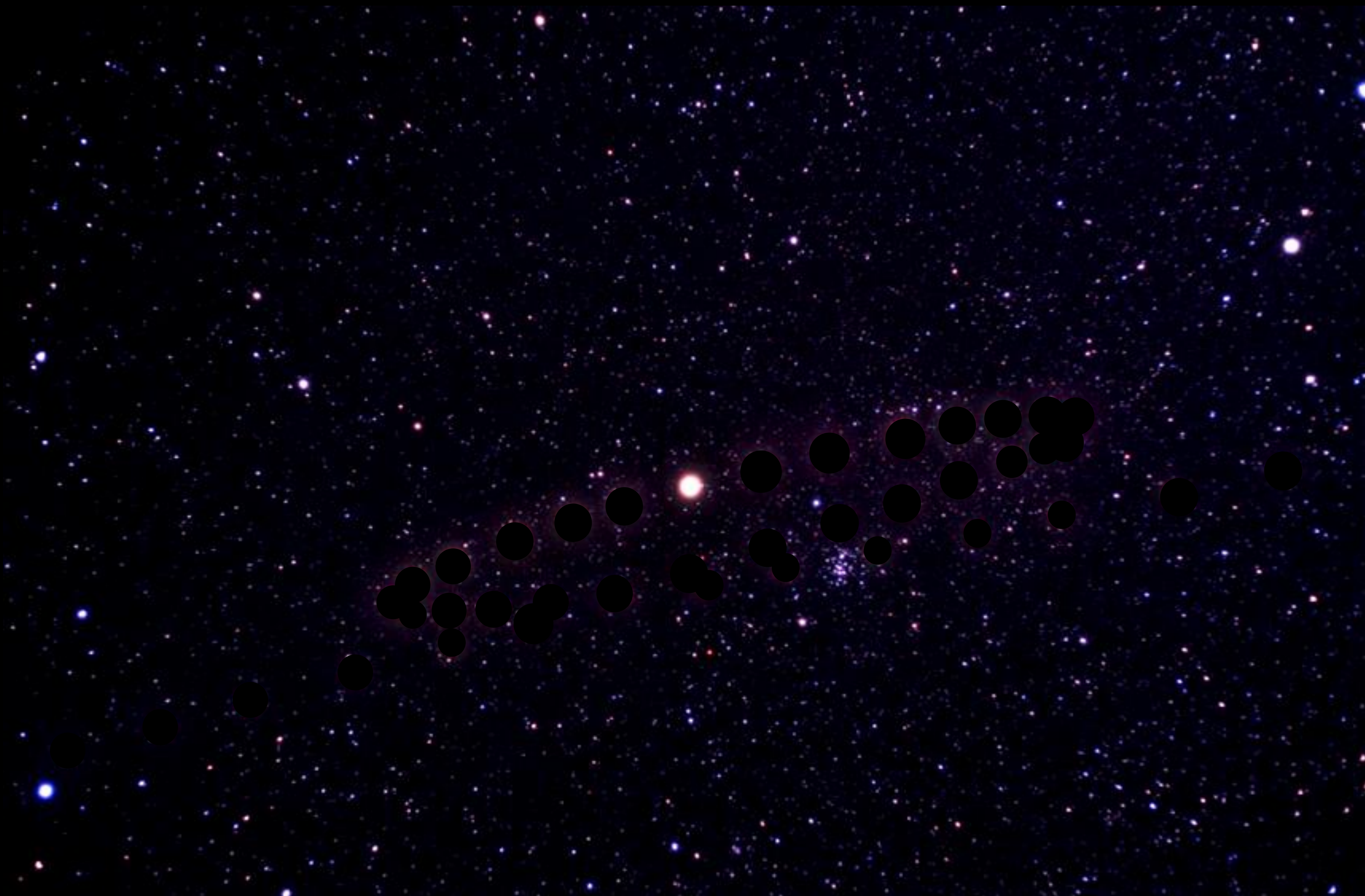


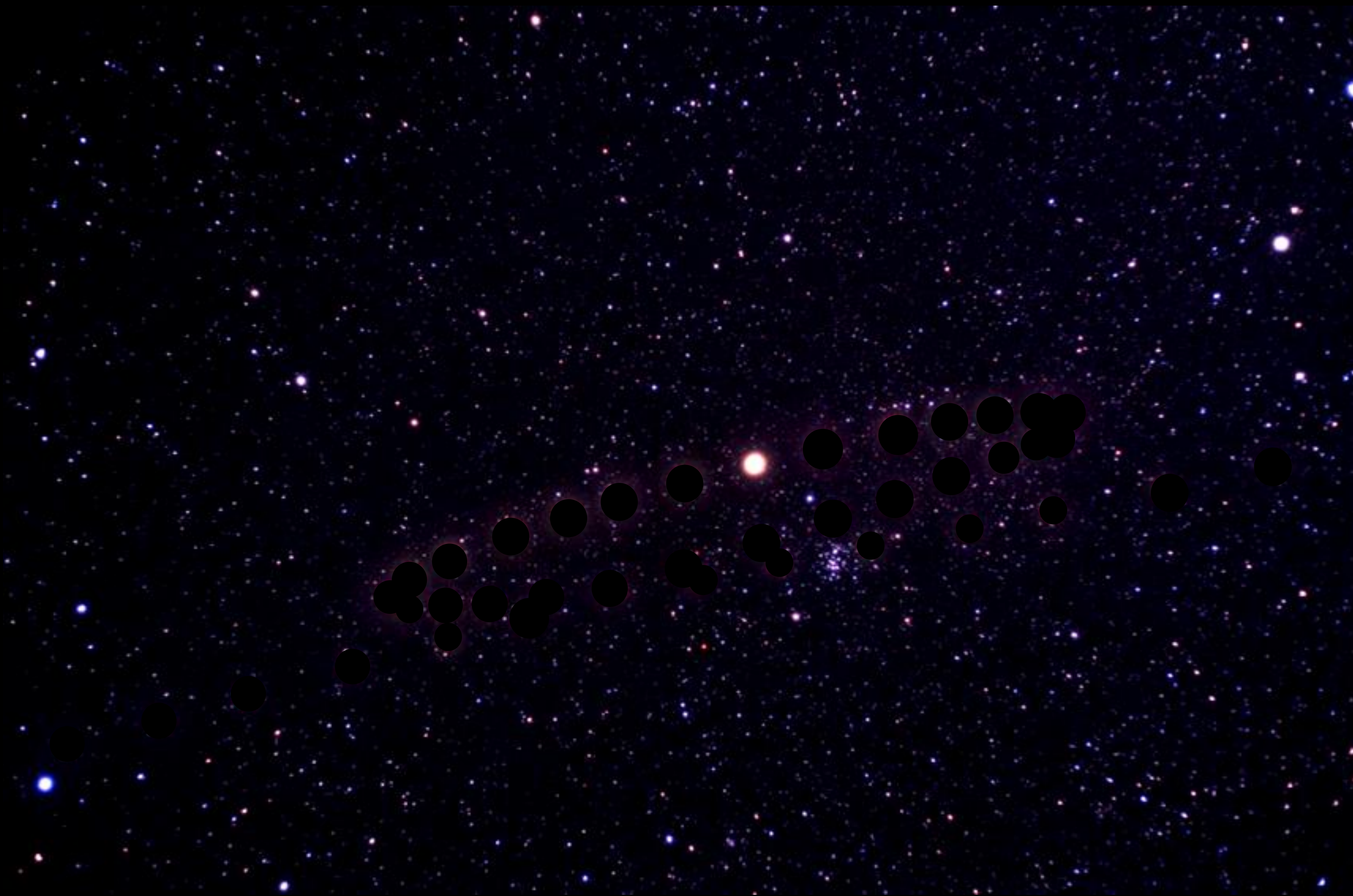


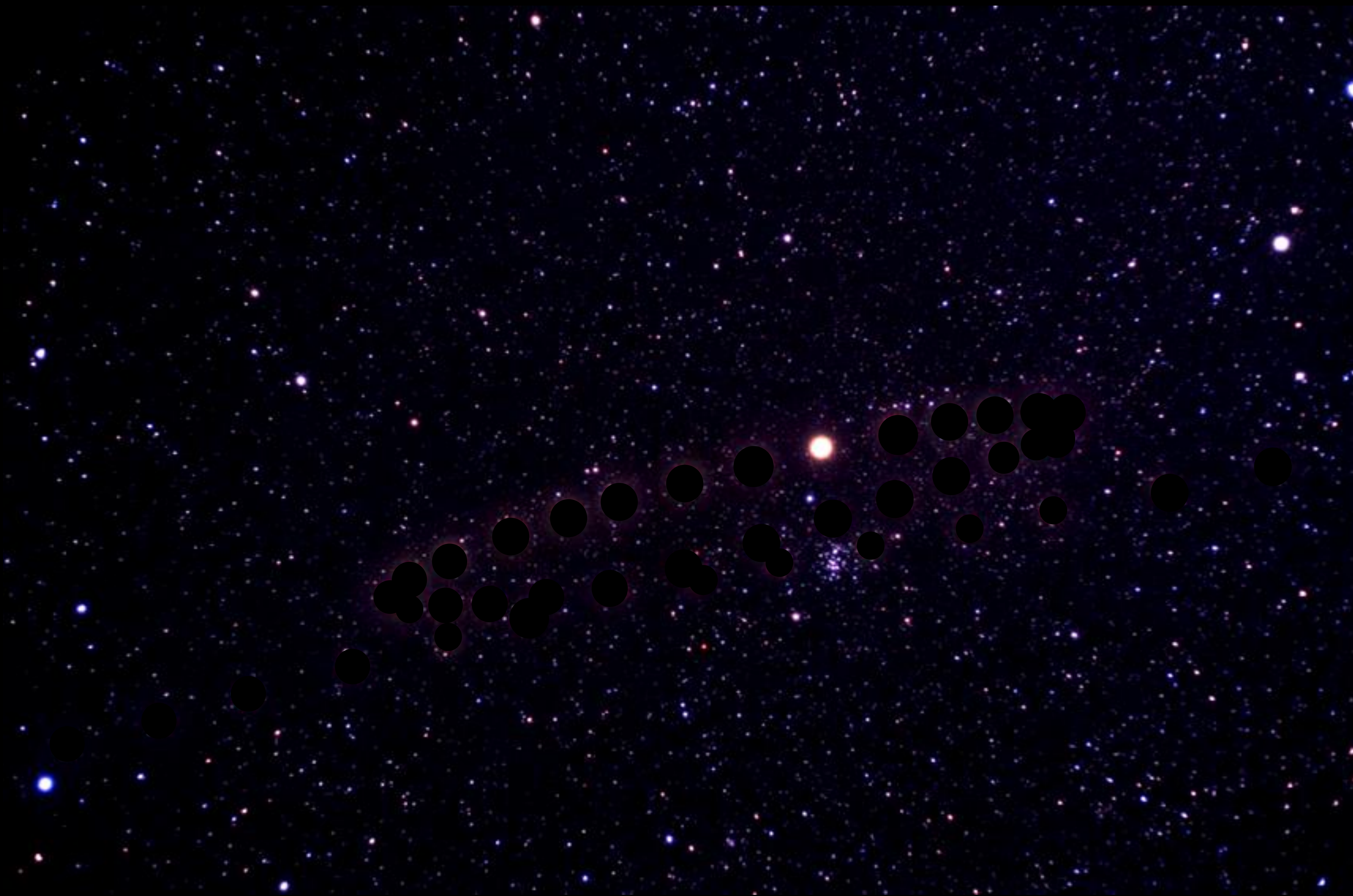


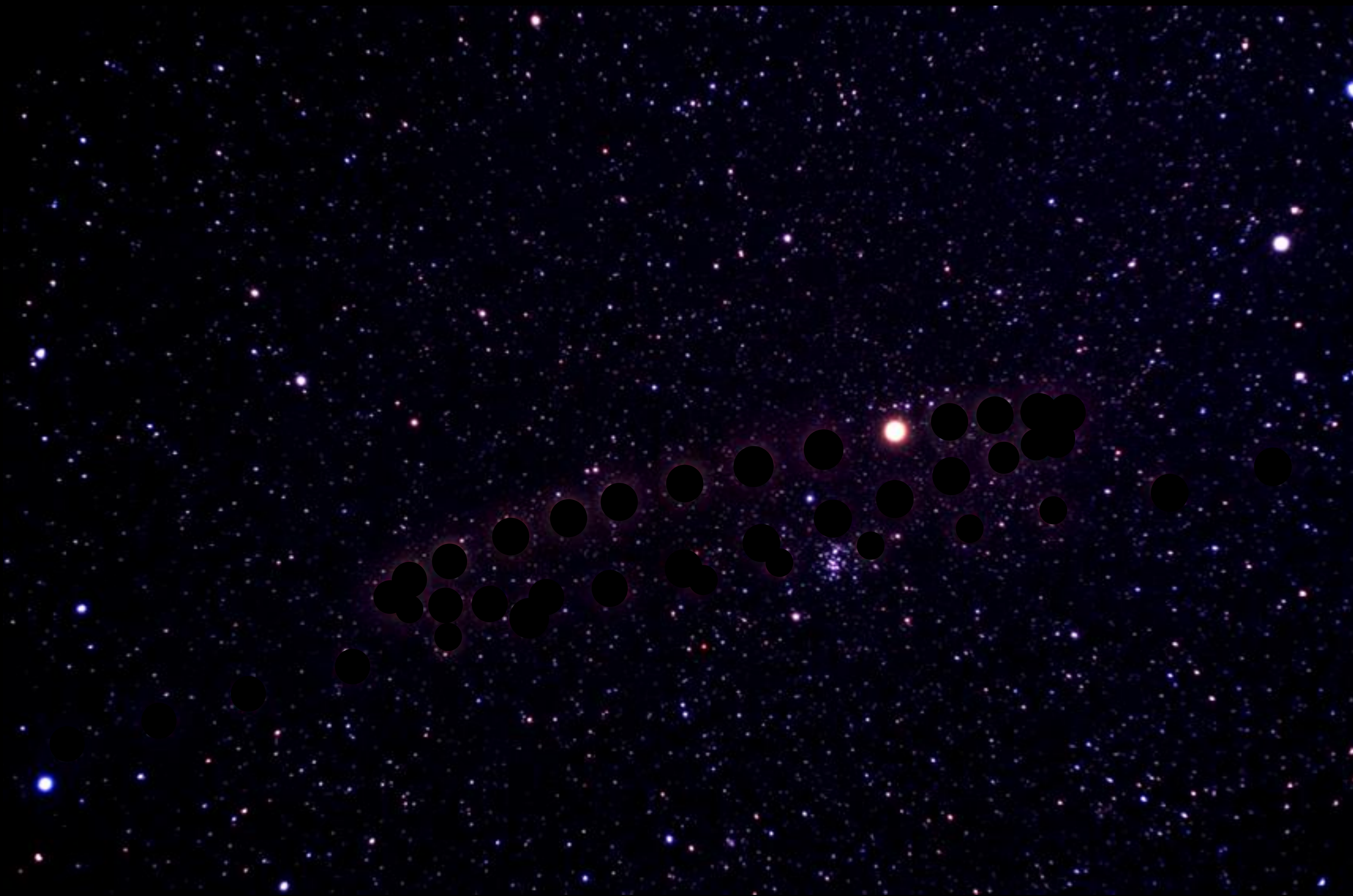


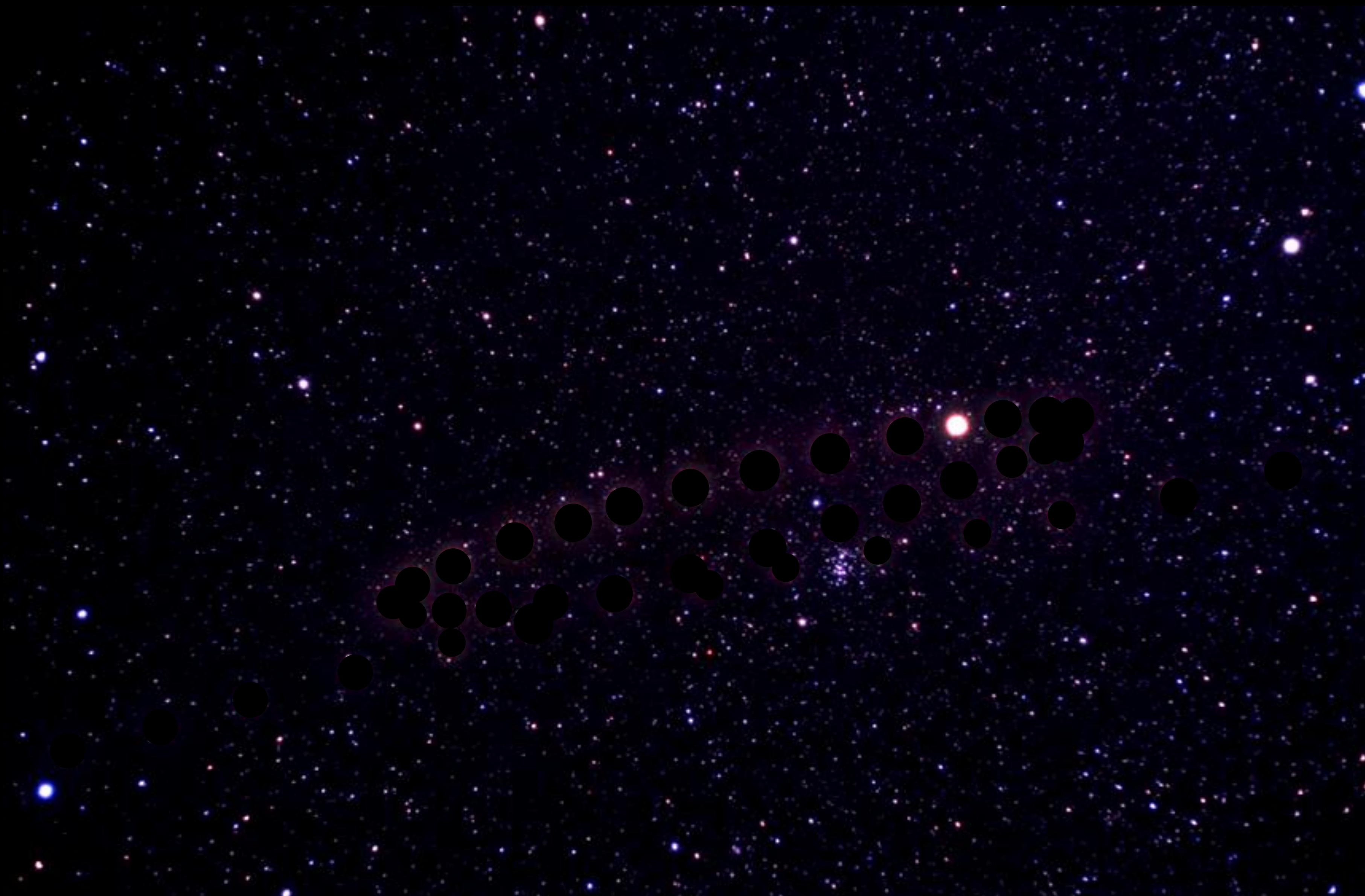


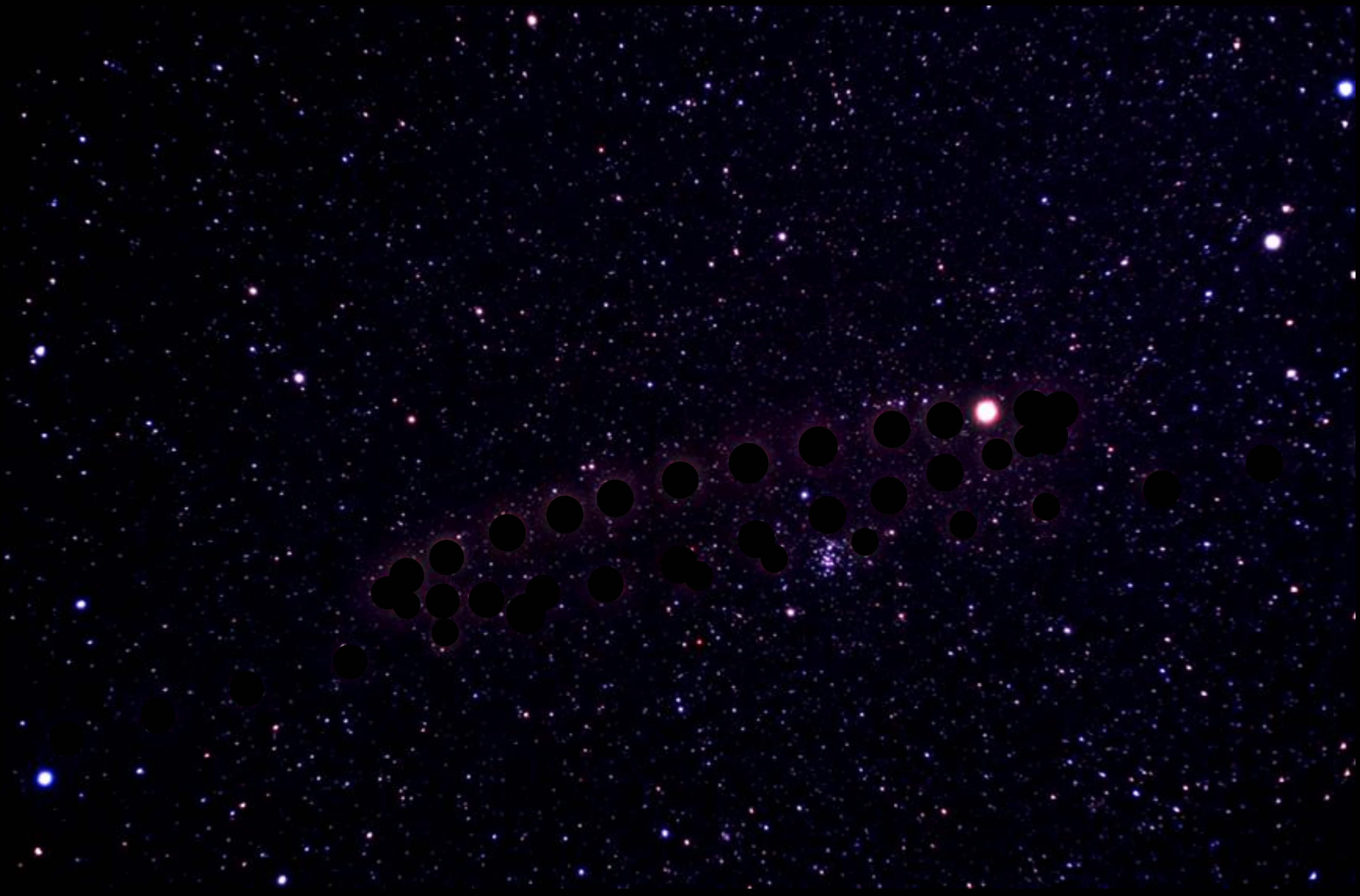


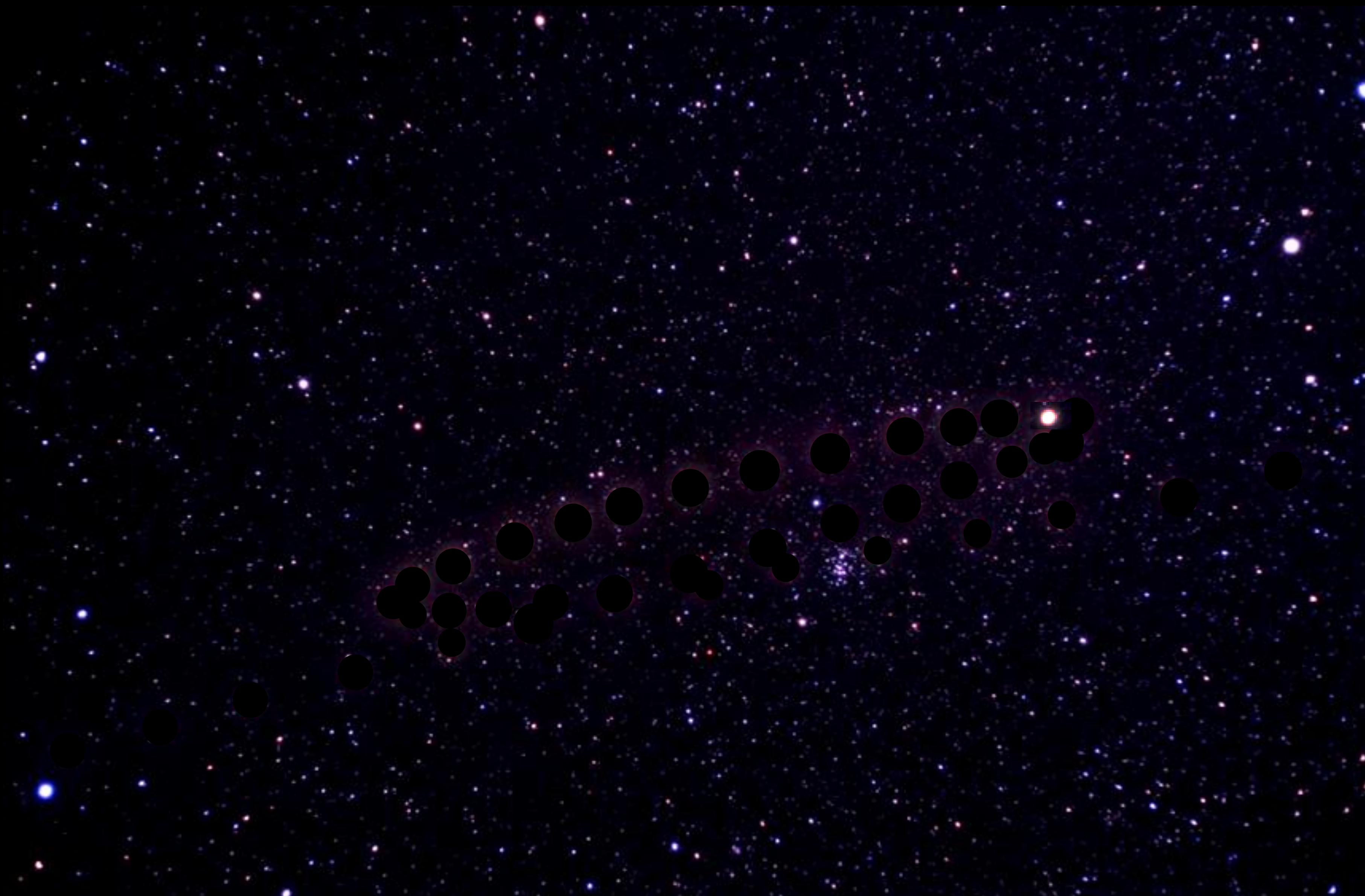


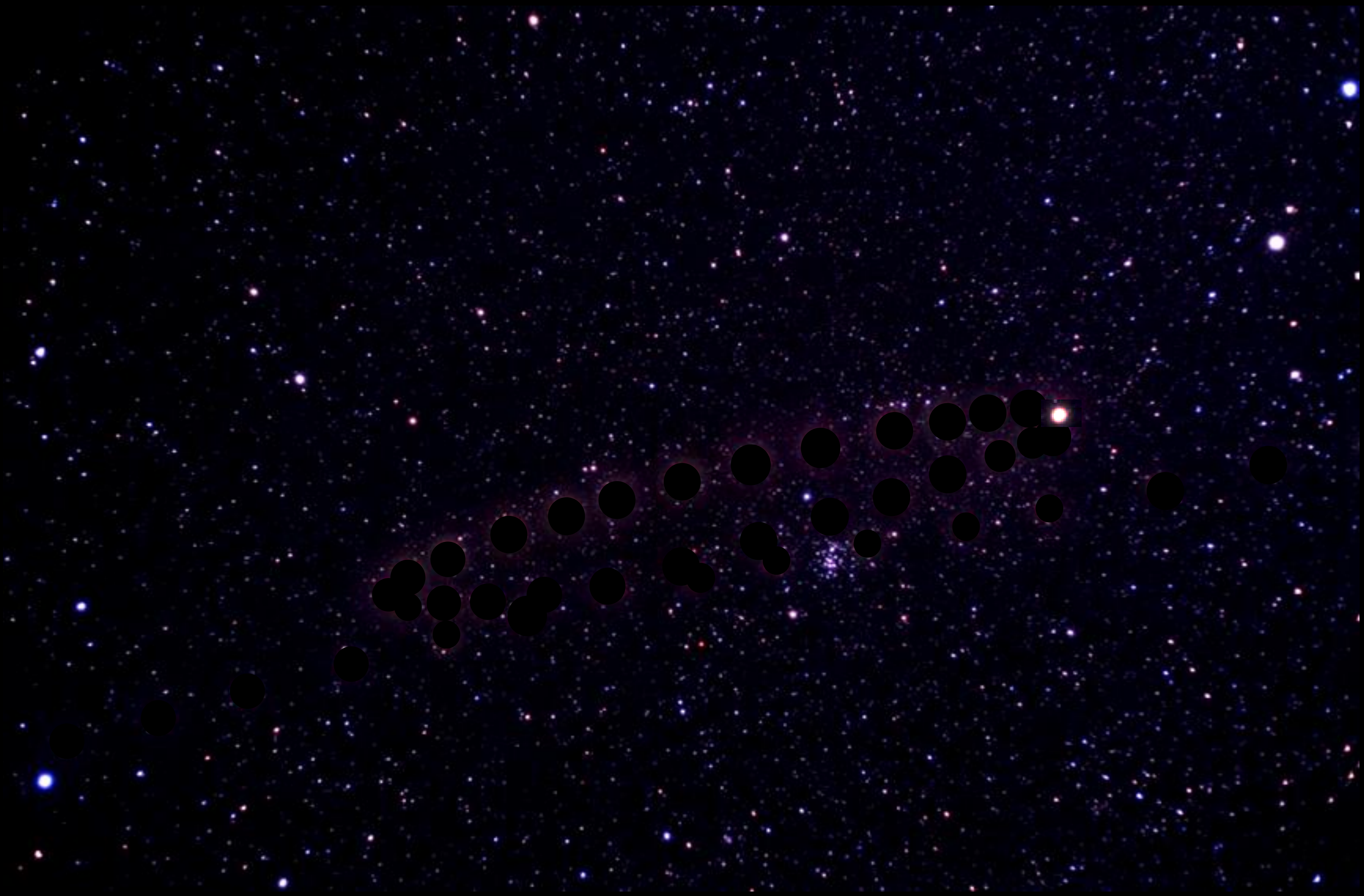


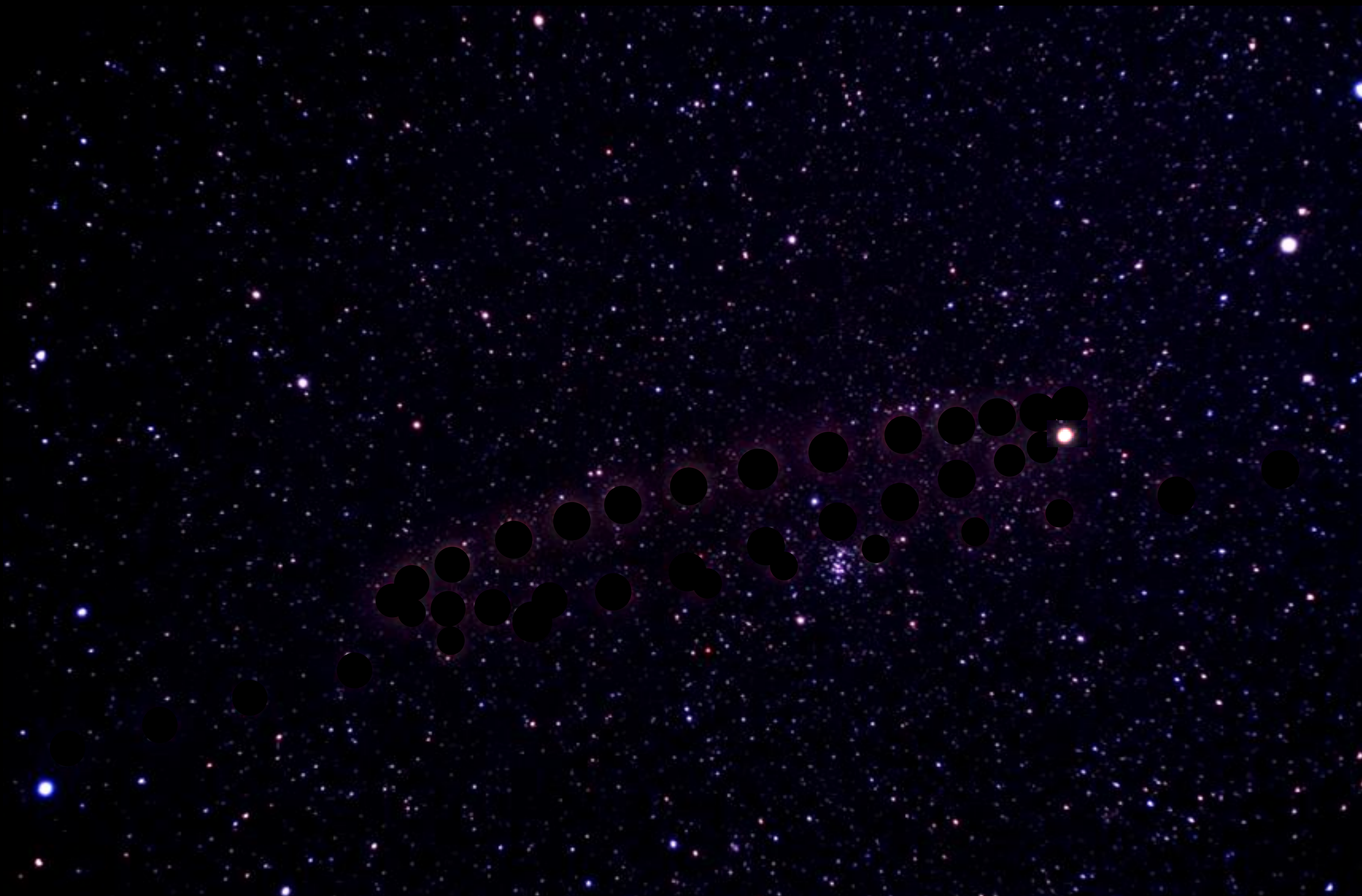


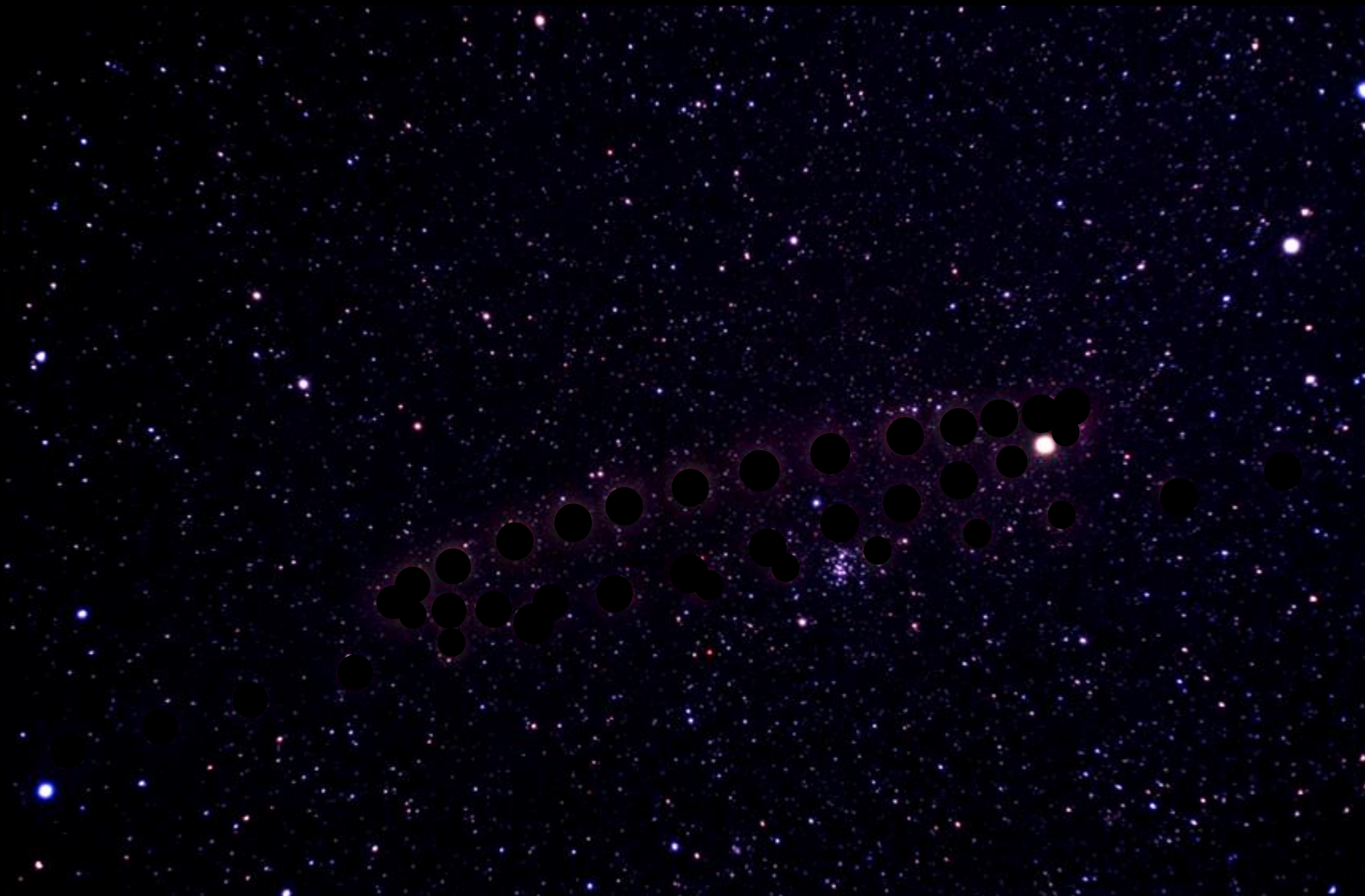


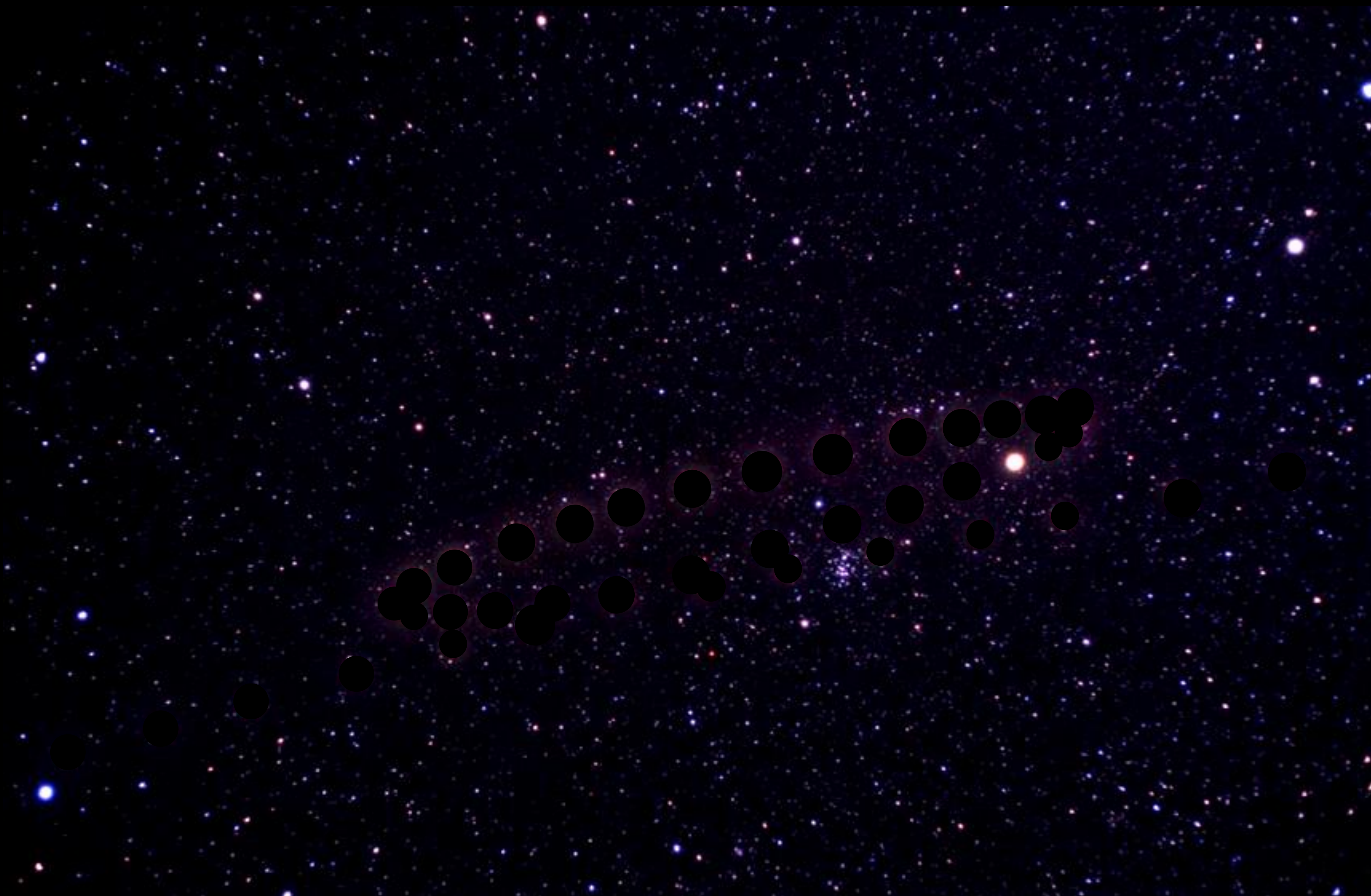


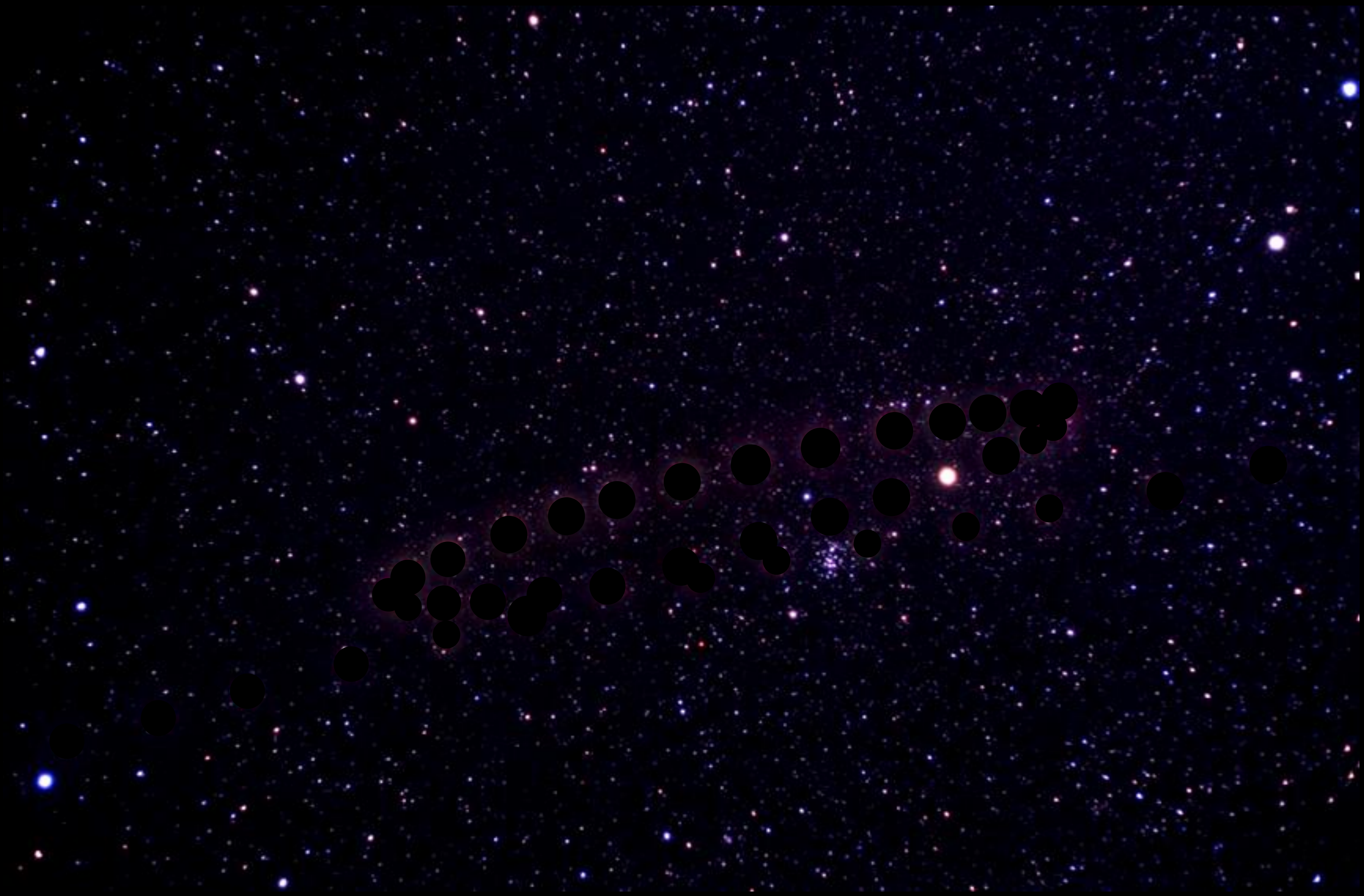


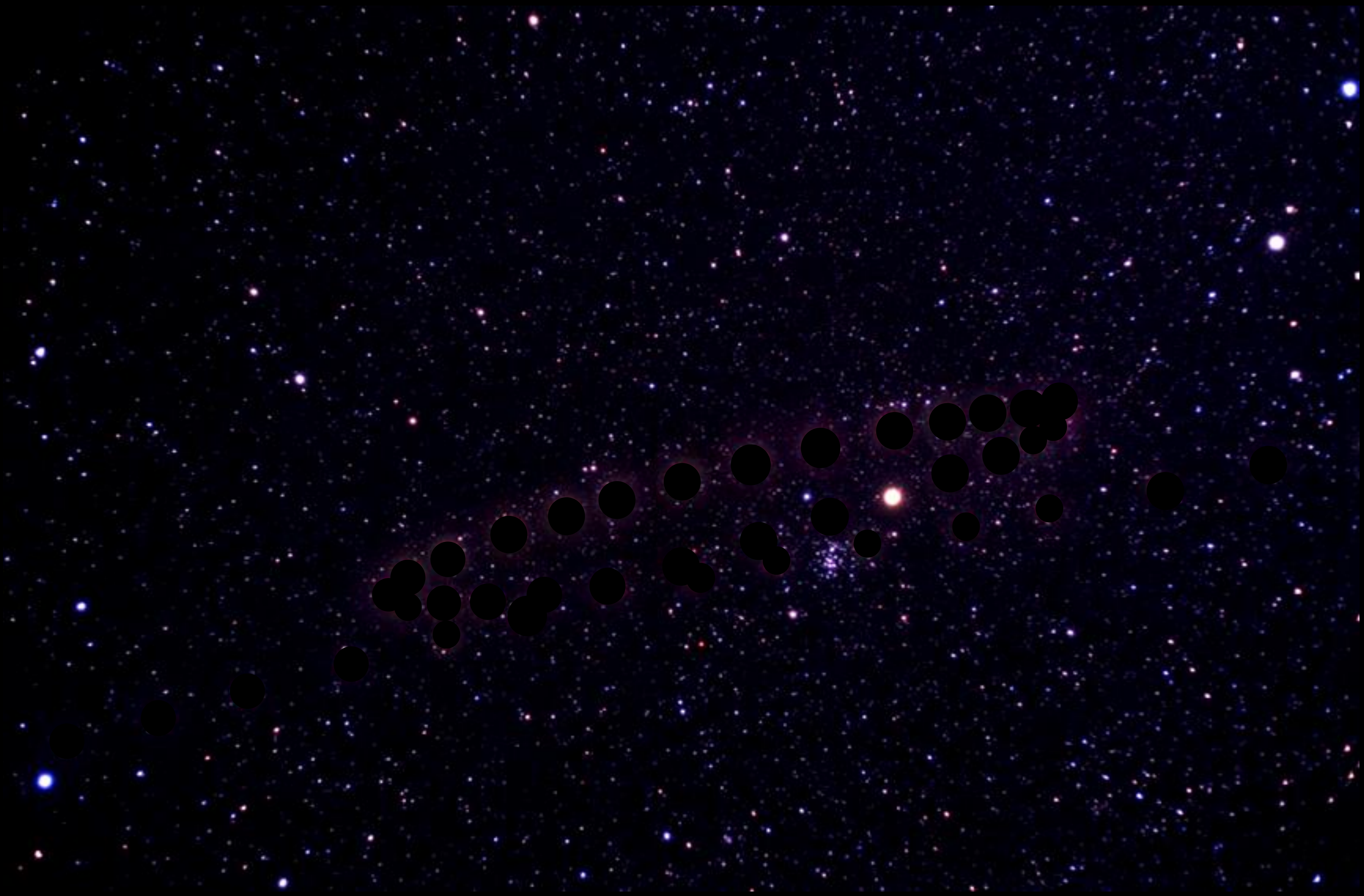


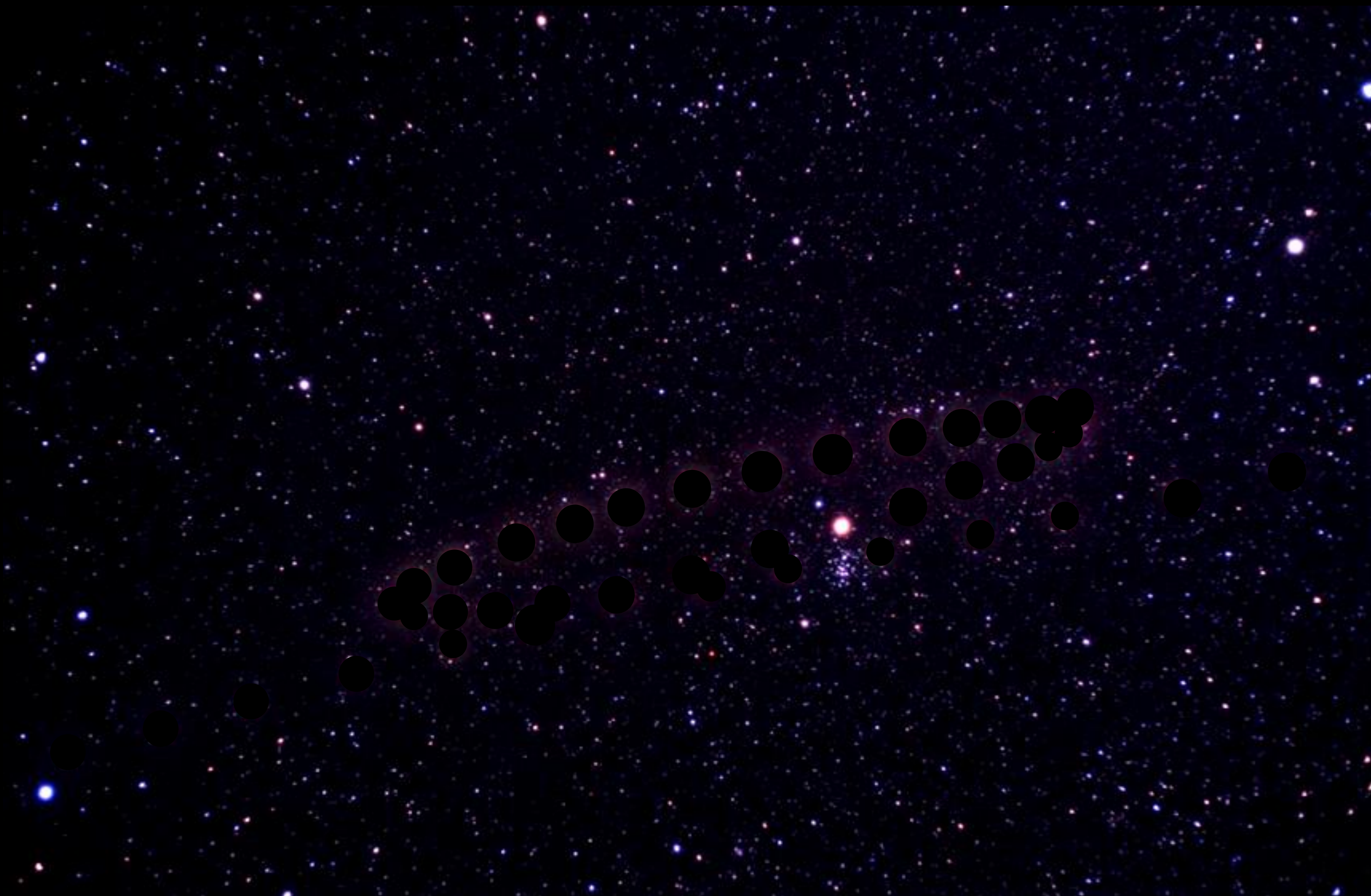


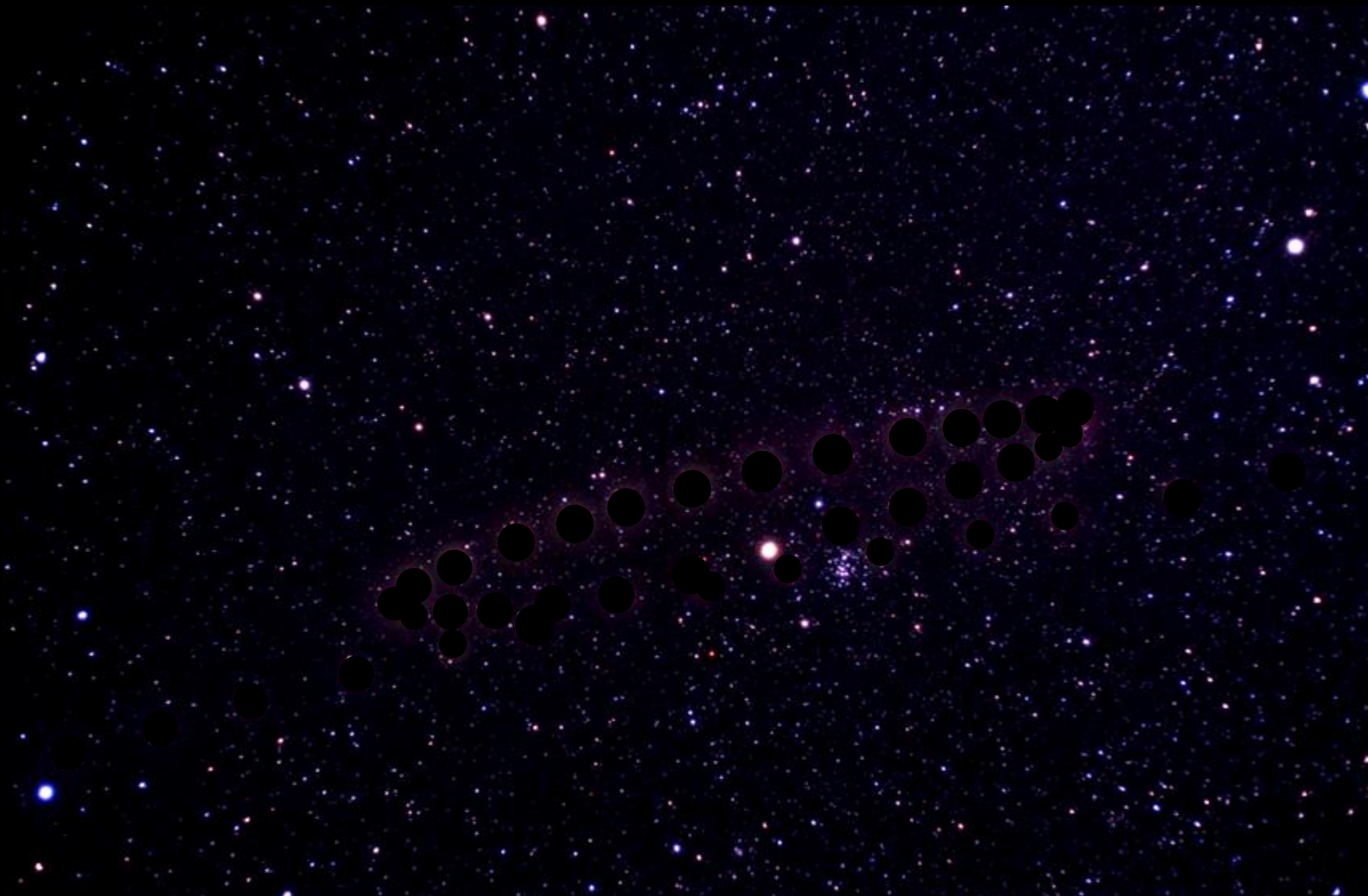


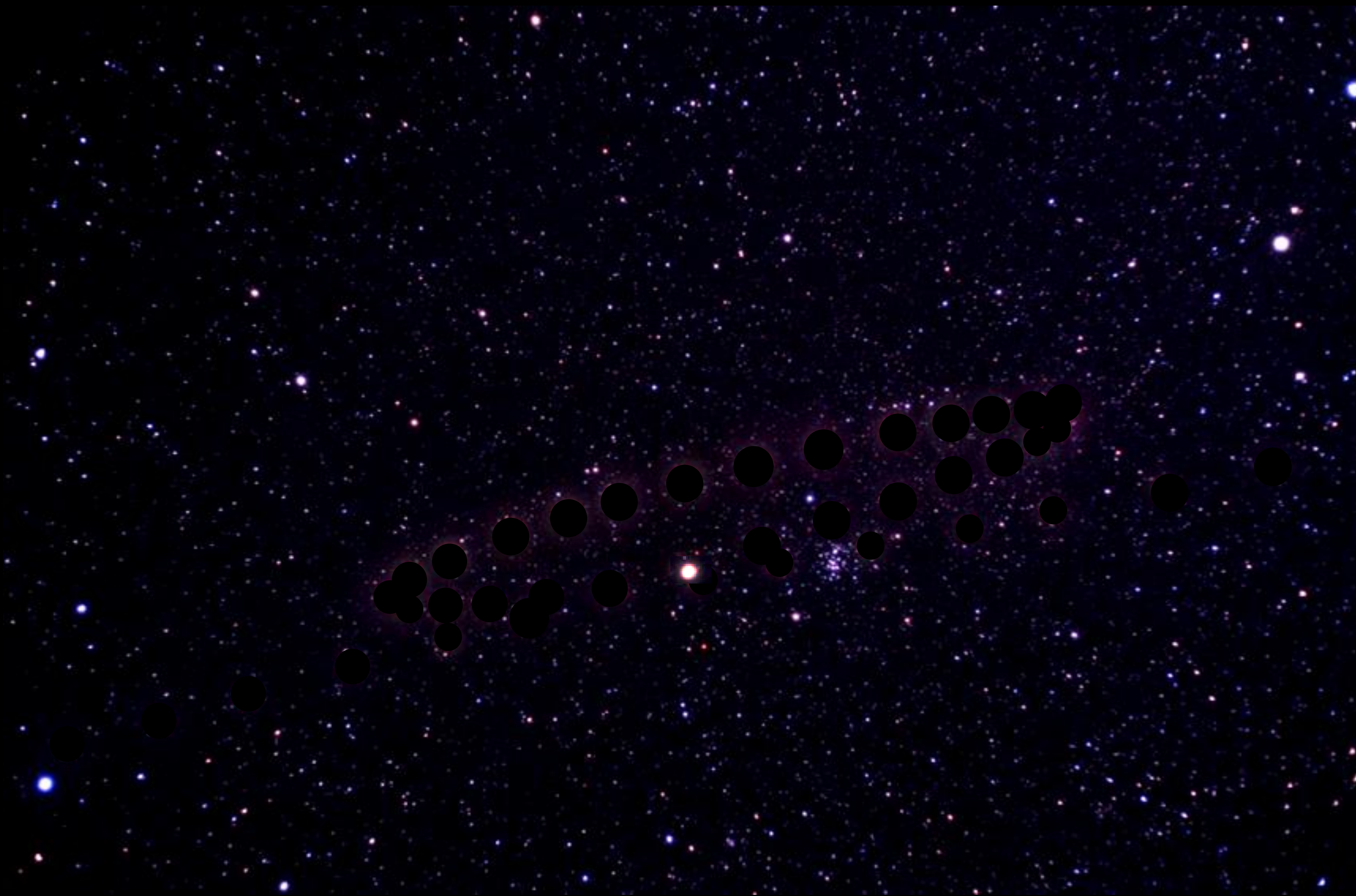


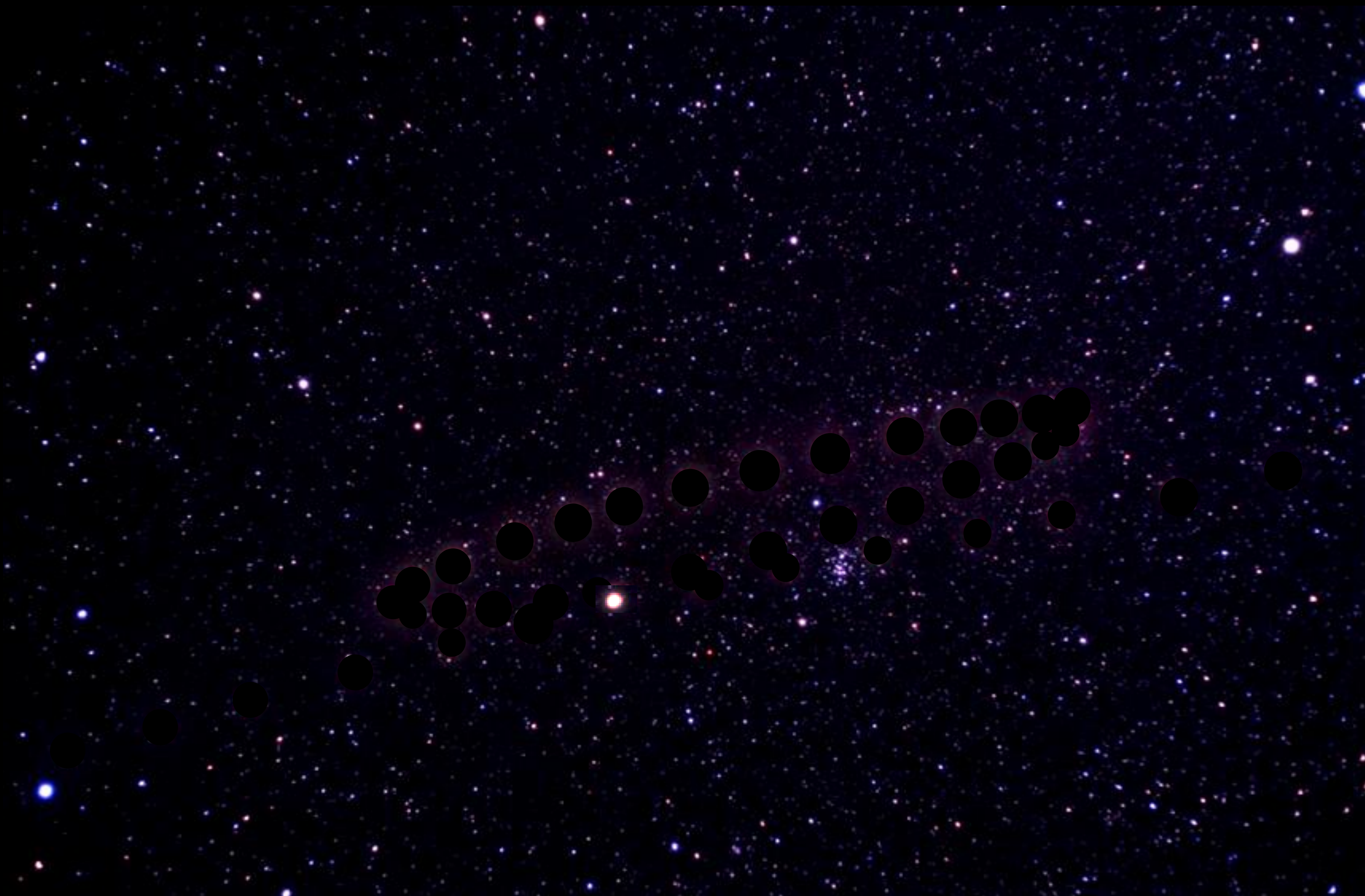


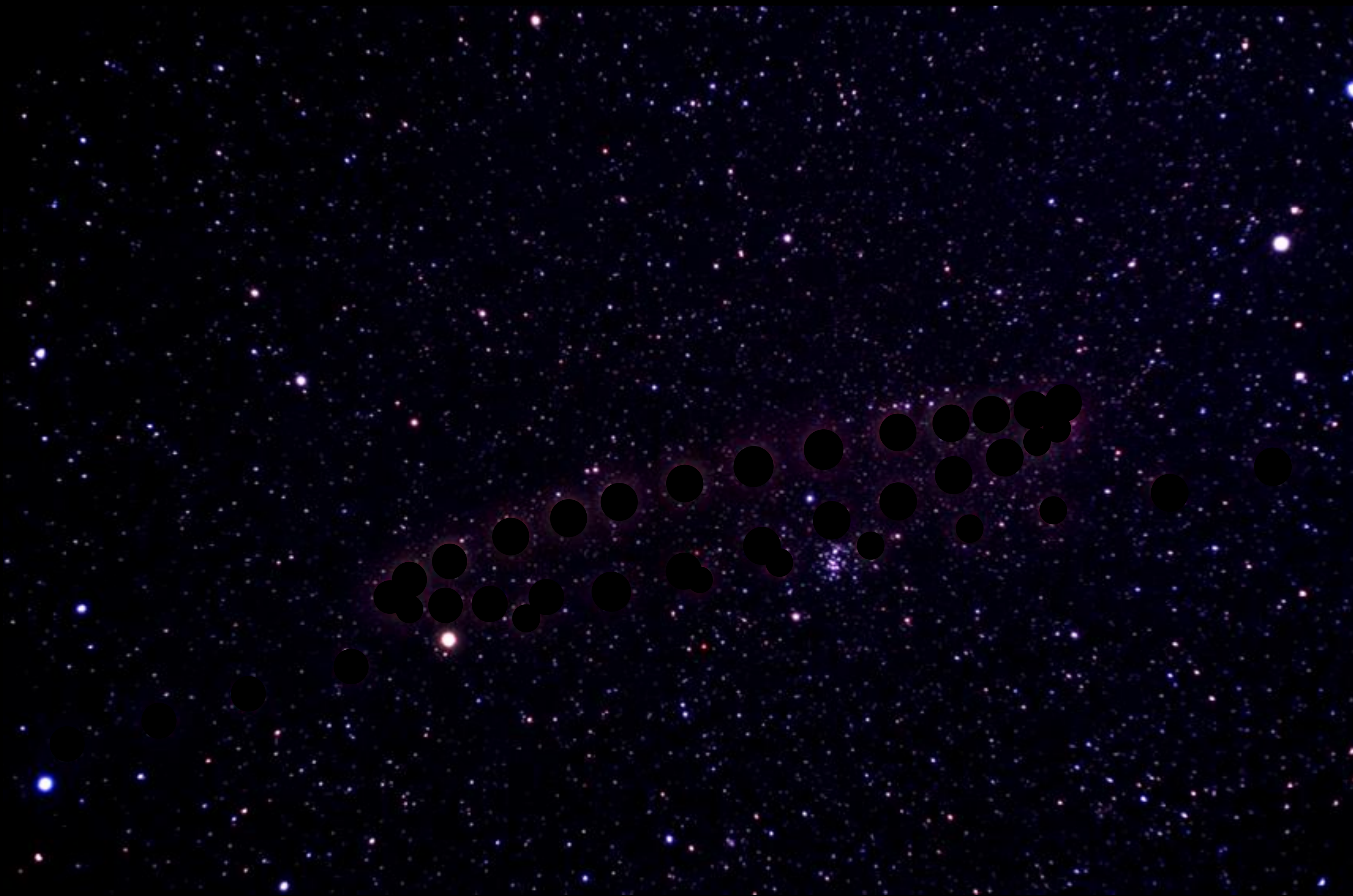


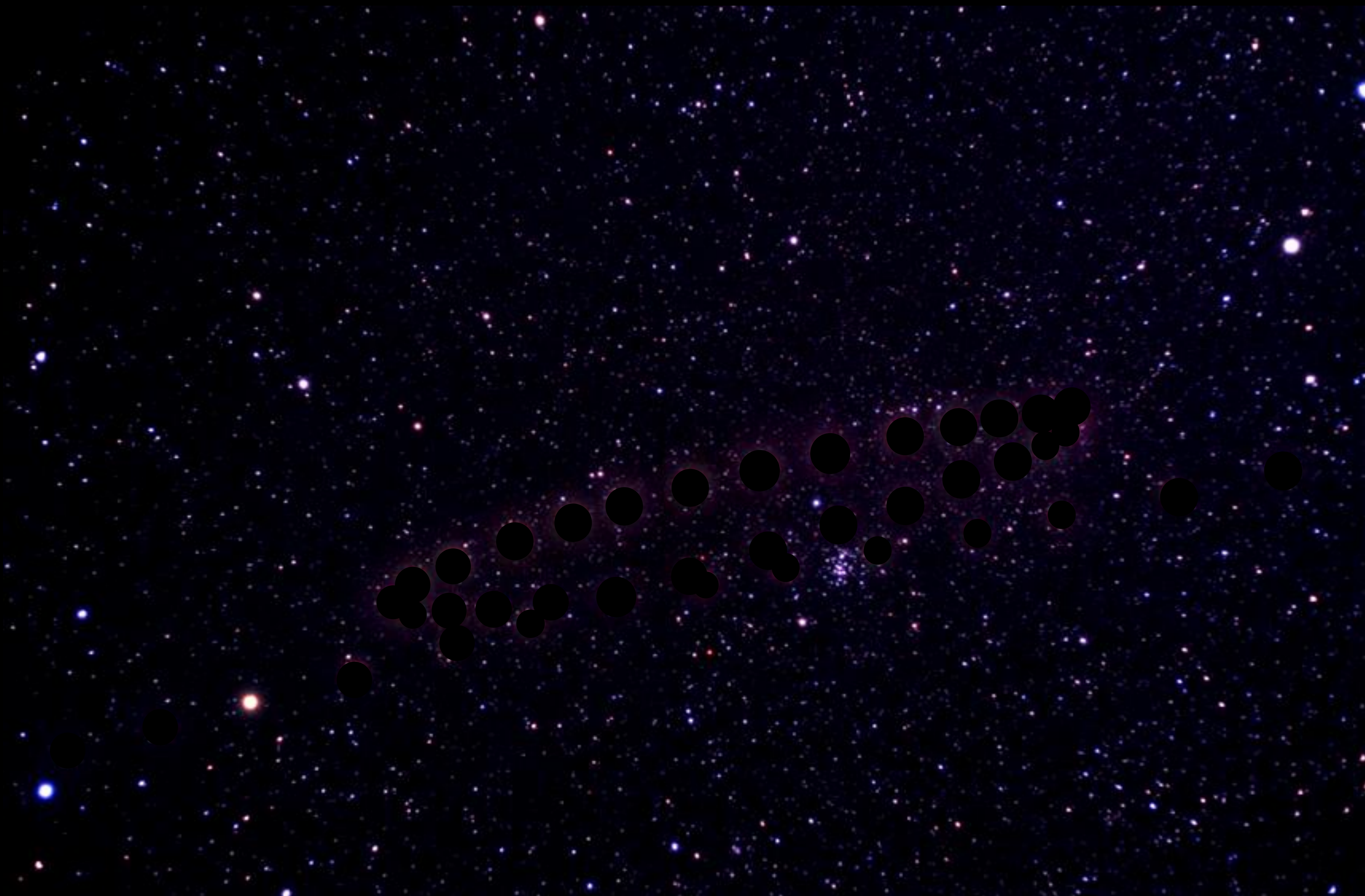




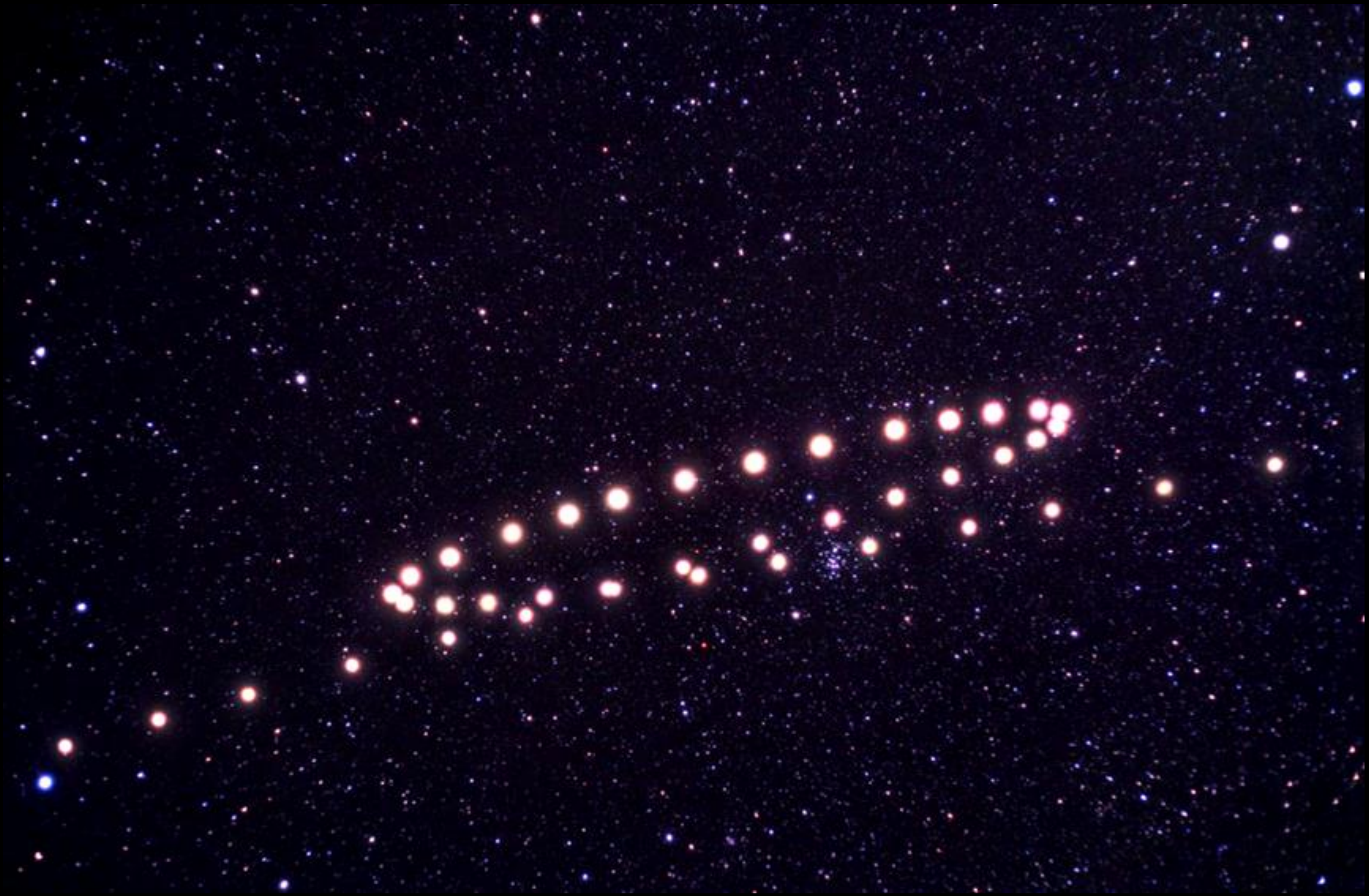




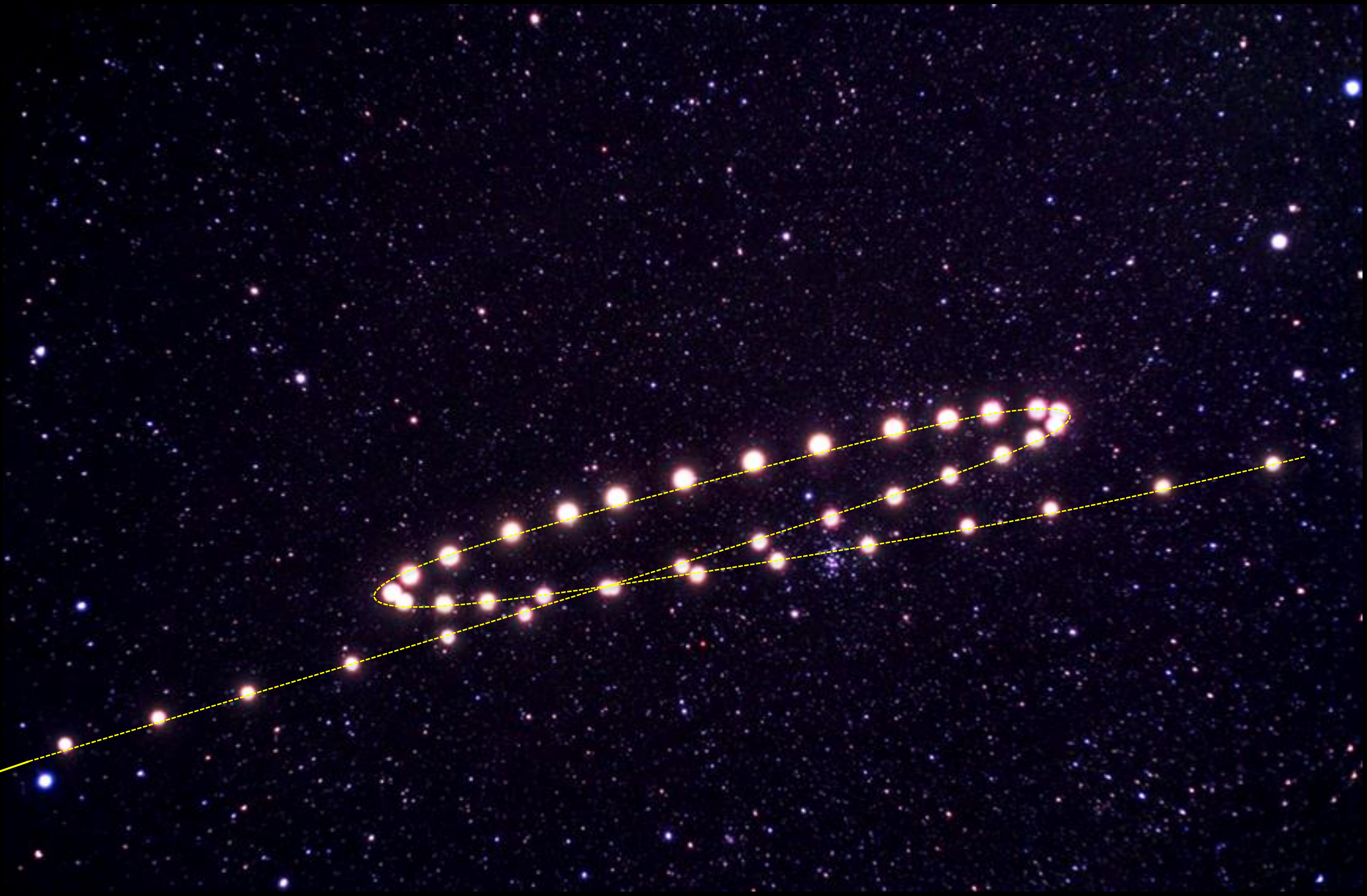




Video: https://vimeo.com/298439756



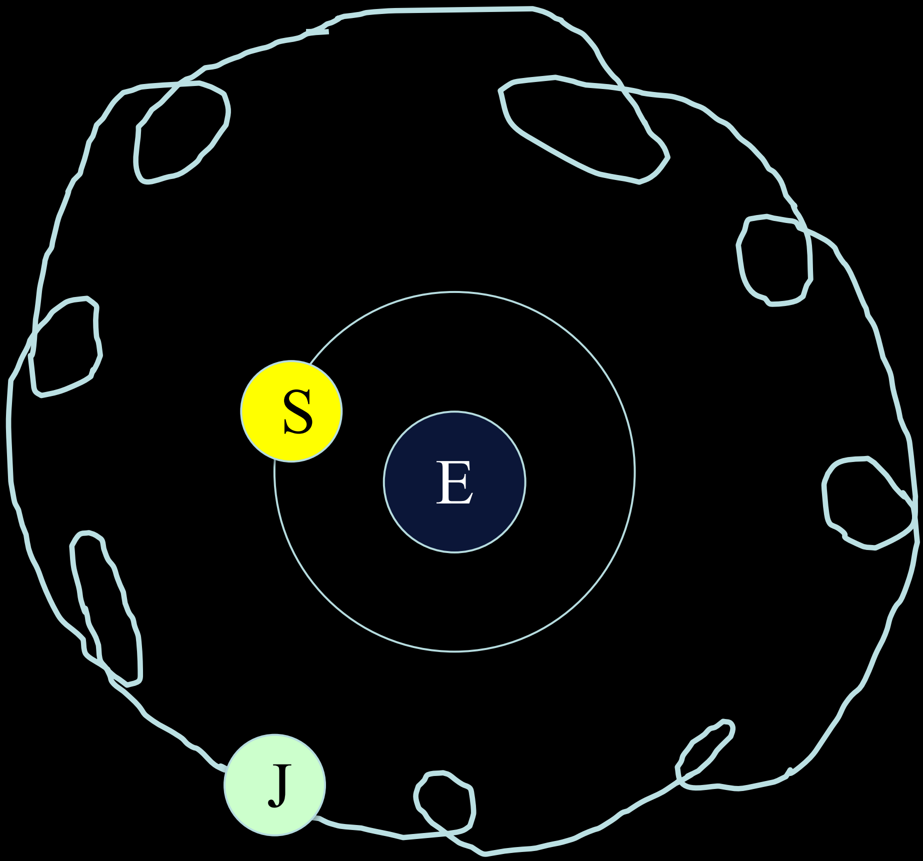
Time-lapse



retrograde

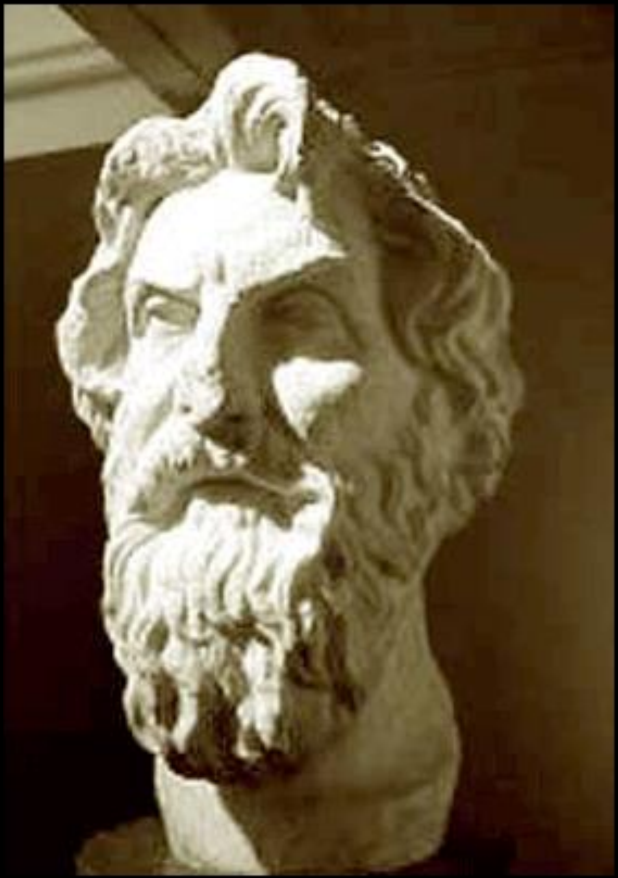
# Geocentric Universe

In a geocentric universe, retrograde motion of a planet implies that the orbit of the planet follows the irregular path below:



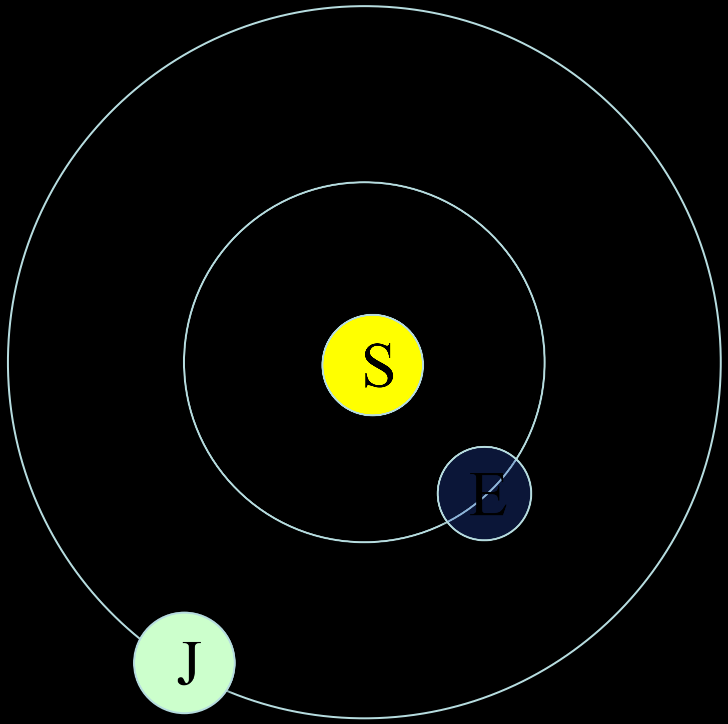

This deduction is inconsistent with the concepts of motion in orbiting paths

# Heliocentric Universe



# Heliocentric Universe

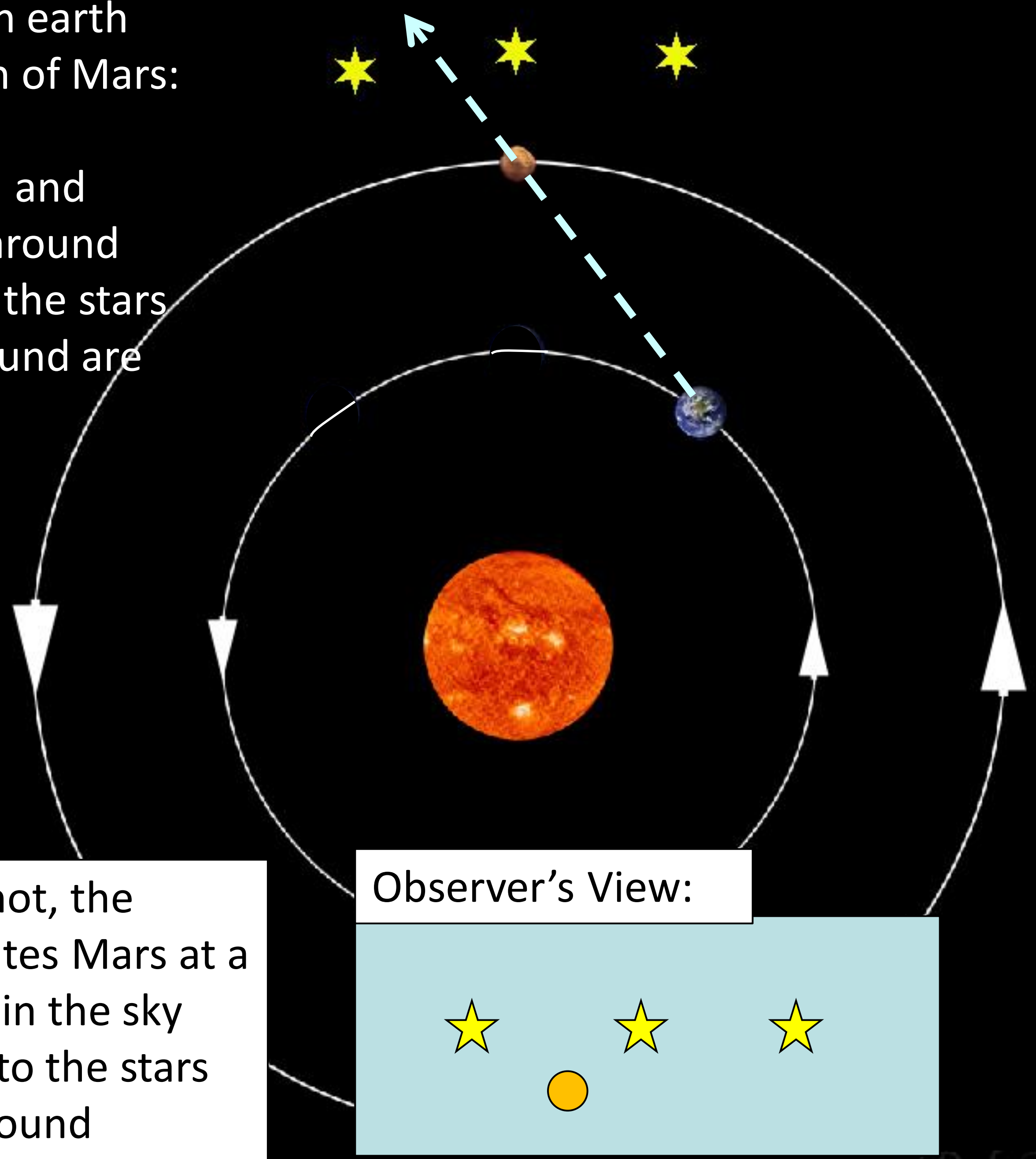
In a heliocentric universe, retrograde motion of a planet can be explained by using circular planetary orbits and the concept of earth revolving around the sun:



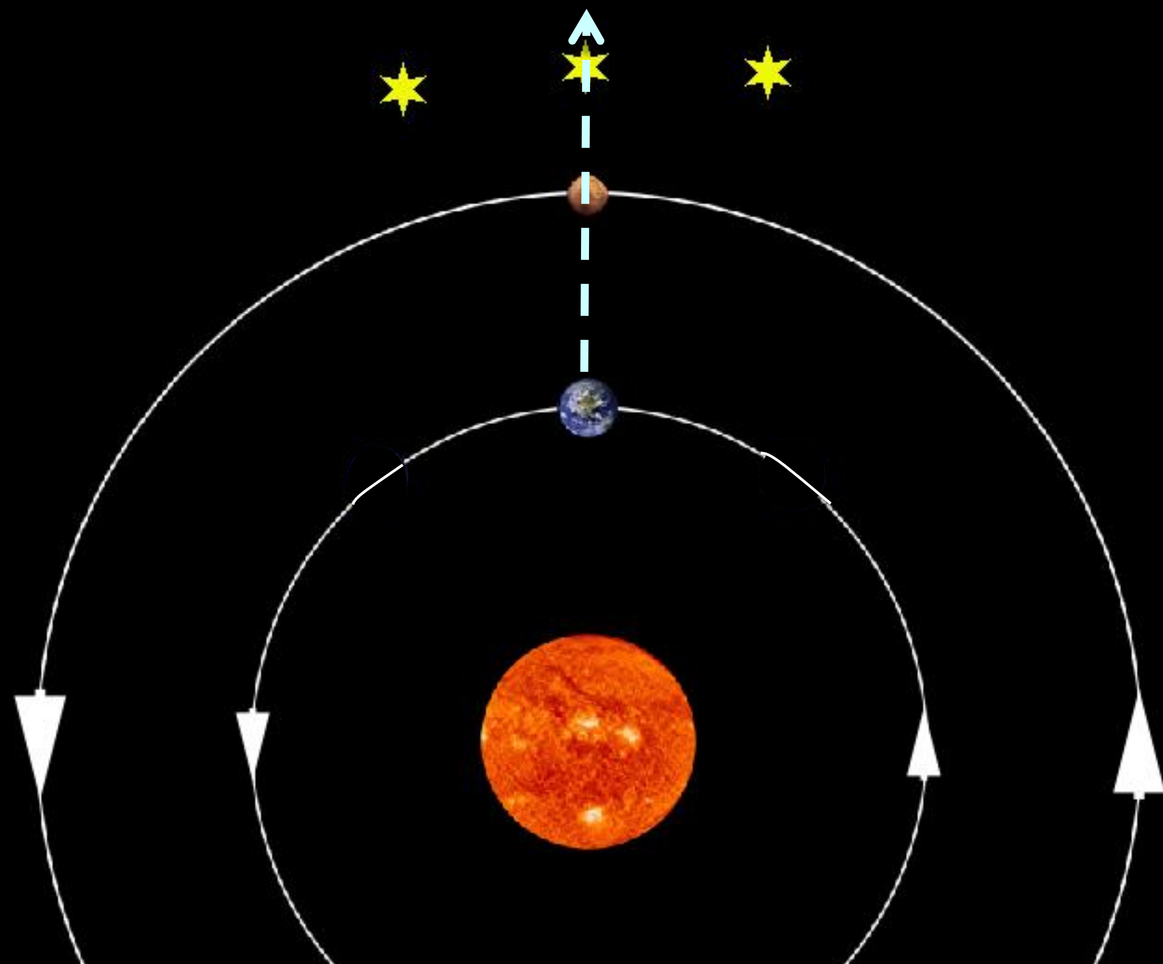

Planets move around sun

An observer on earth tracks the path of Mars:

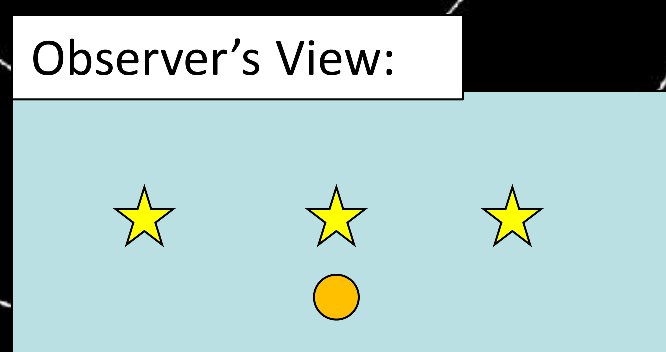
Both the earth and Mars revolve around the sun, while the stars in the background are stationary

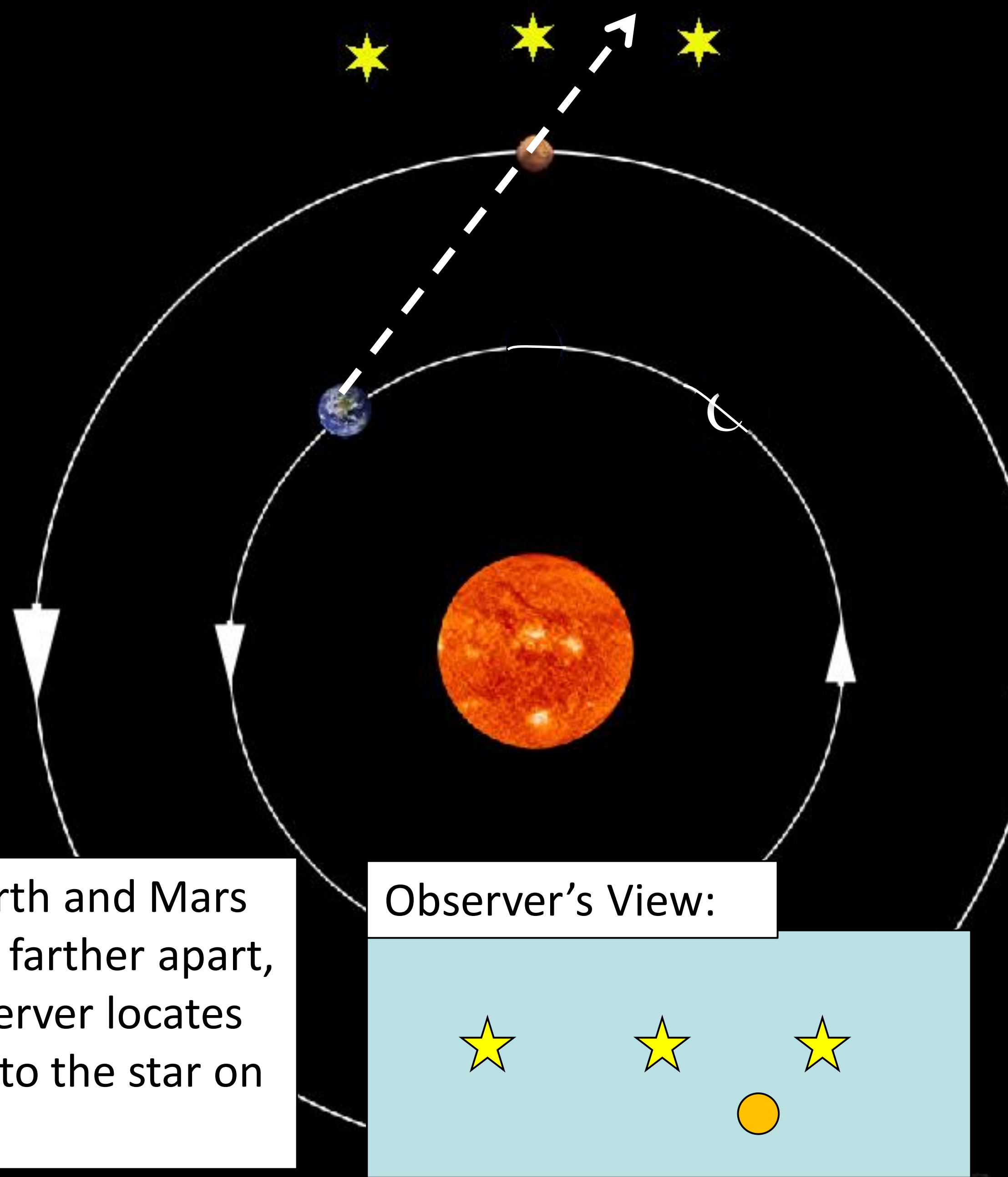



In this snapshot, the observer locates Mars at a certain point in the sky with respect to the stars in the background



Here, the earth has moved closer to Mars and the observer locates Mars at a different point in the sky aligned closer to the middle star



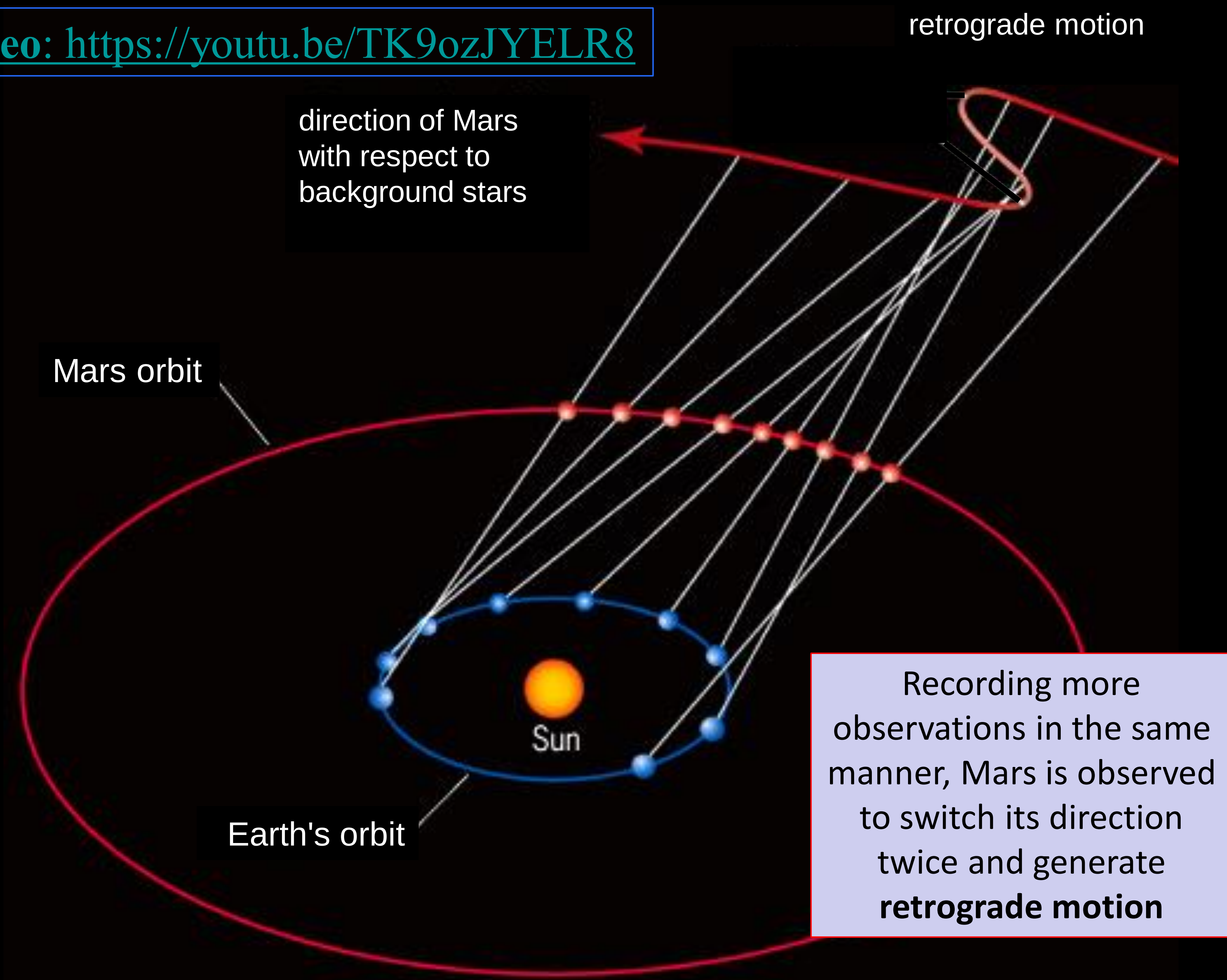



Now, the earth and Mars have moved farther apart, and the observer locates Mars closer to the star on the right.

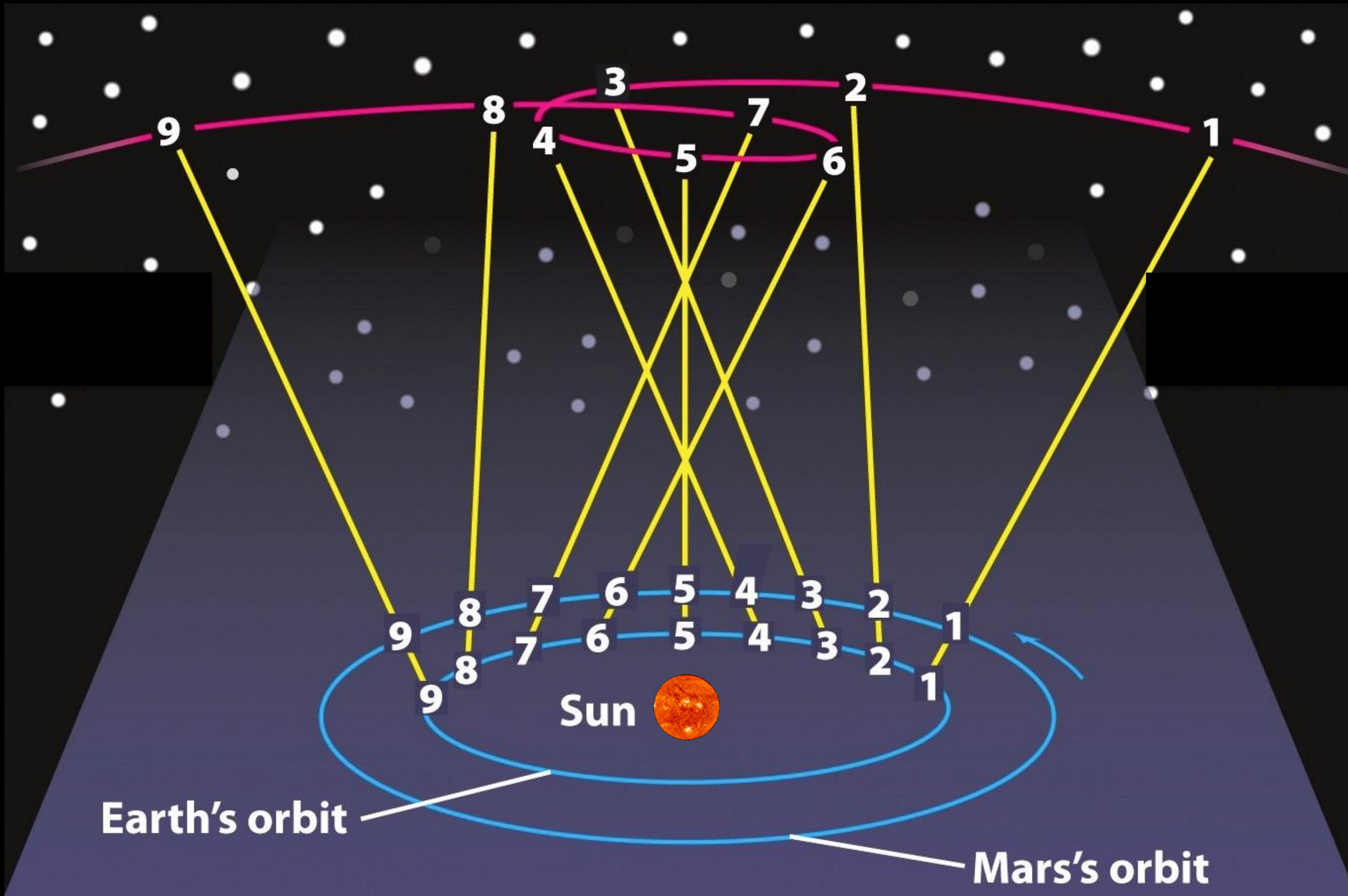
These three images of Mars indicate that it is moving to the **right**.

However, in the next snapshot, earth and Mars will get even farther apart, and Mars will appear to be located closer to the middle star, i.e. it will appear to have moved to the **left**

**Video**: https://youtu.be/TK9ozJYELR8

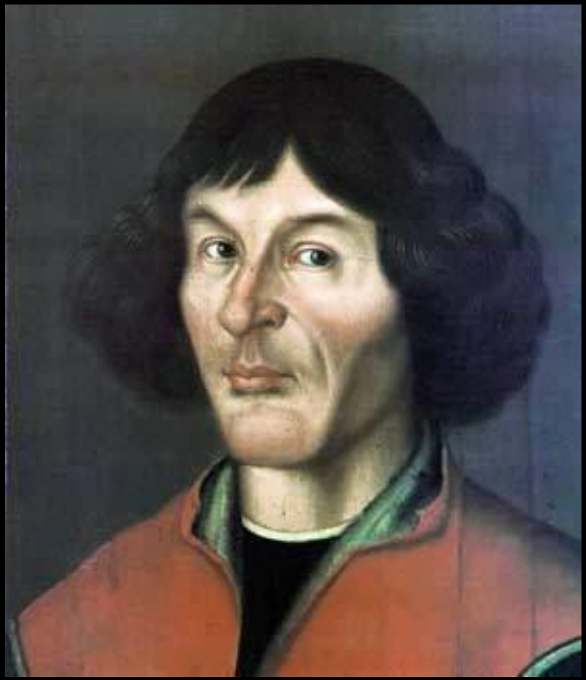



Recording more observations in the same manner, Mars is observed to switch its direction twice and generate **retrograde motion**

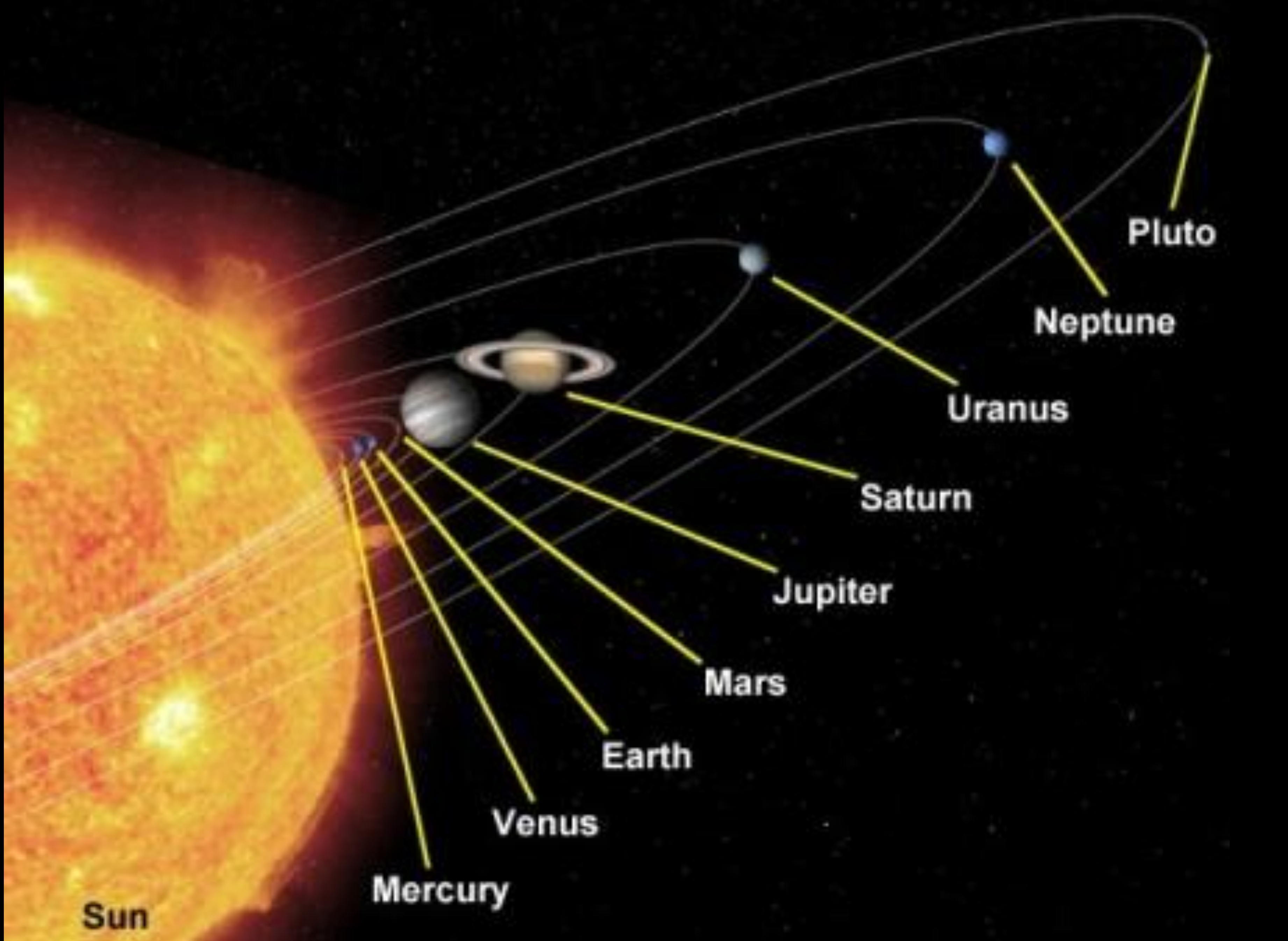


Sun
Earth’s orbit
Mars’s orbit

# Heliocentric Universe

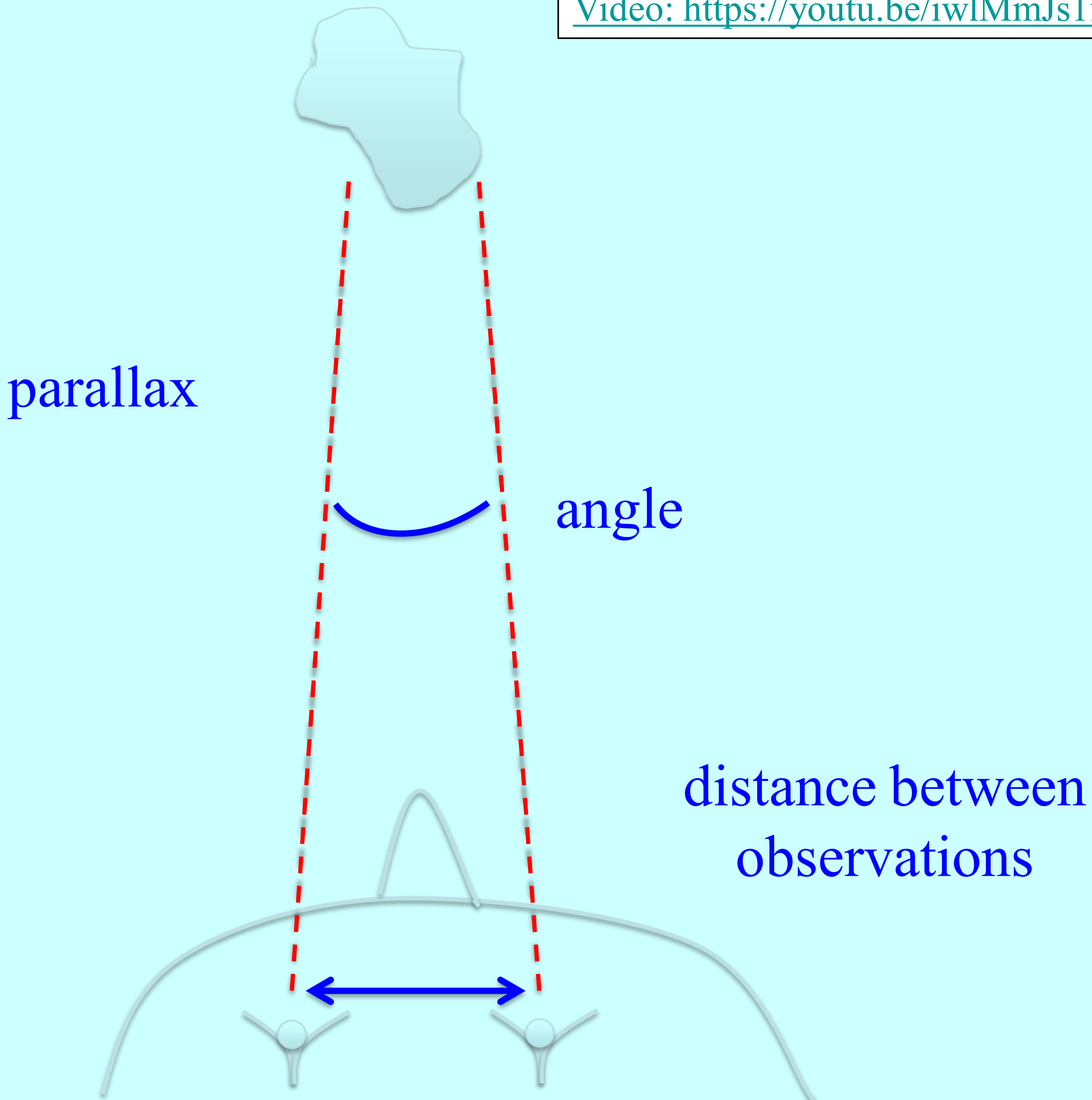


Mathematical basis


Pluto
Neptune
Uranus
Saturn
Jupiter
Mars
Earth
Venus
Mercury
Sun

# Tycho Brahe

Video: https://youtu.be/iwlMmJs1f5o




Each eye see’s a slightly different image, due to parallax, since there is about 2 inches separating your eyes

faraway ship

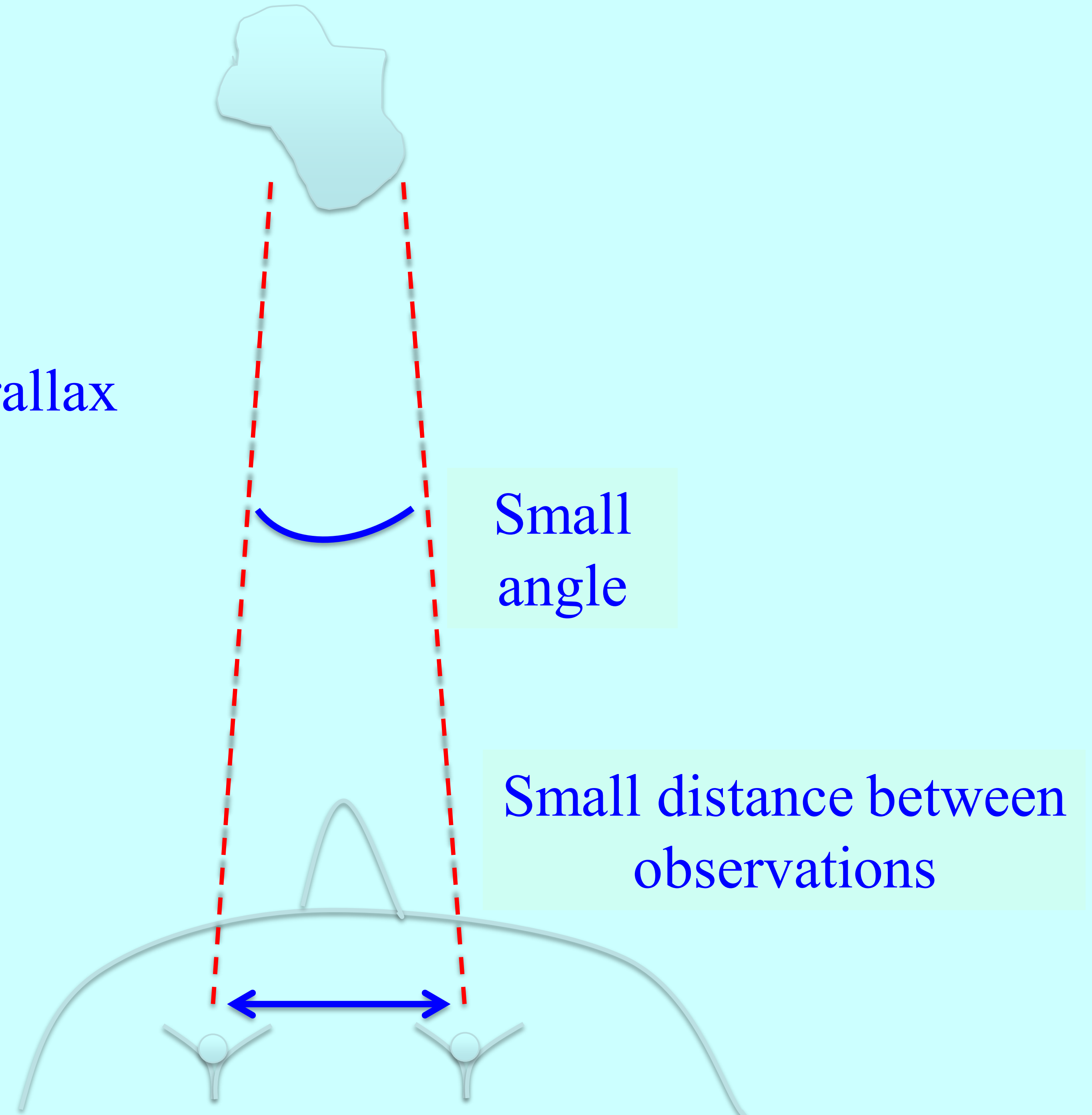
RIGHT
eye

Each eye see’s a slightly different image, due to parallax, since there is about 2 inches separating your eyes

Each eye see’s a slightly different image, due to parallax, since there is about 2 inches separating your eyes

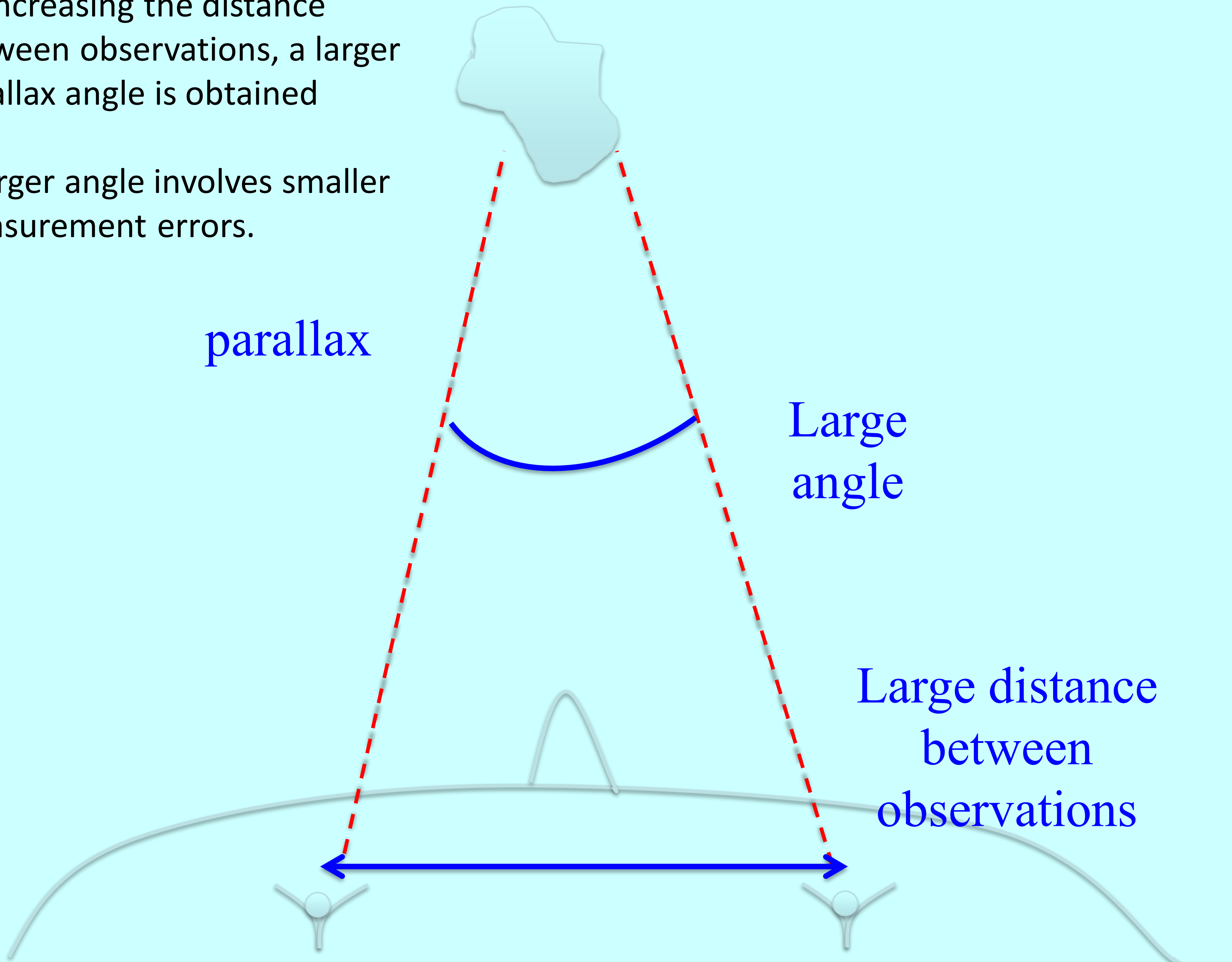
Your brain does the math and makes the images come together so that you see depth within about 20 ft.  Stare at this picture on the next page and let your eyes relax and you'll see 3-D.

parallax

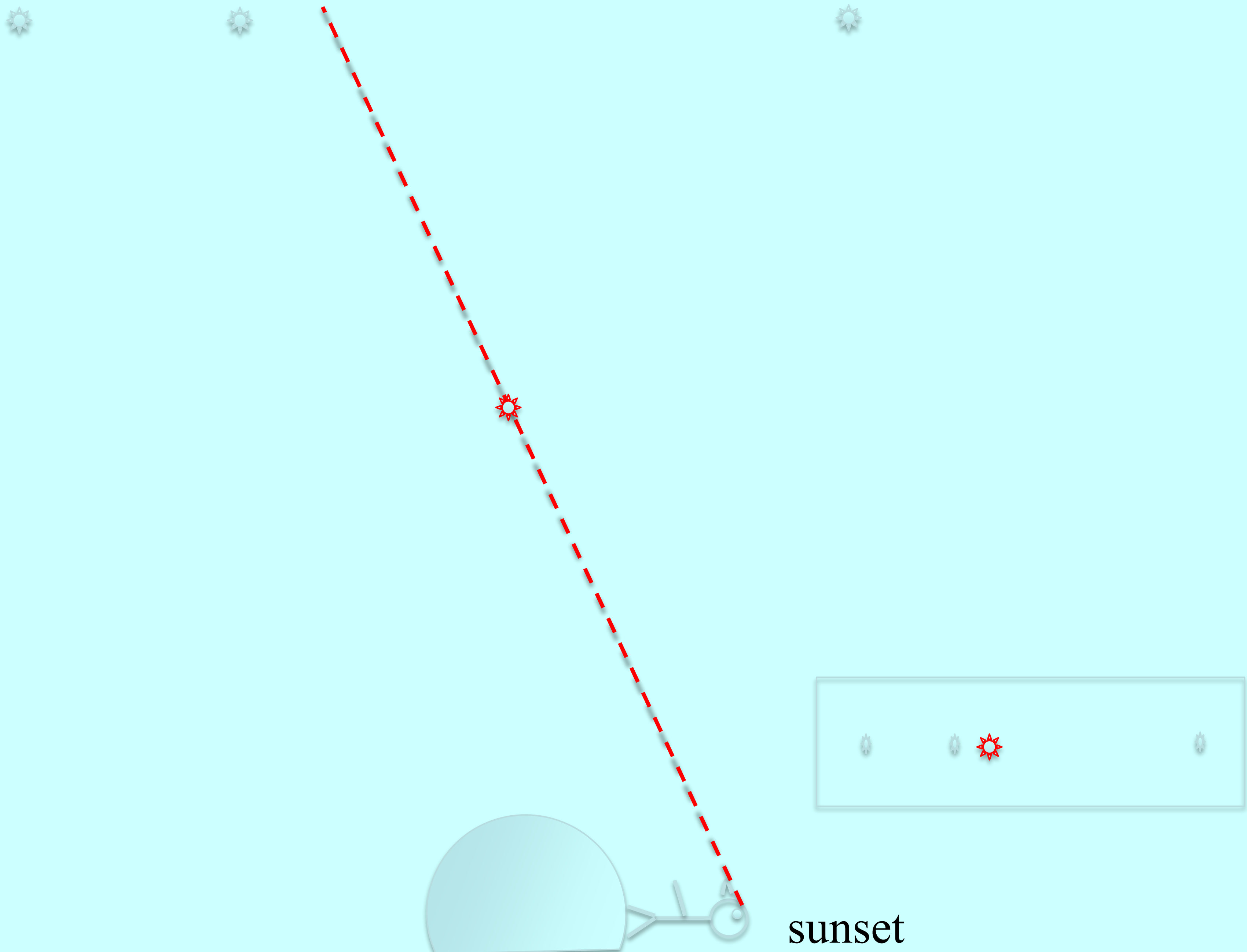


By increasing the distance between observations, a larger parallax angle is obtained

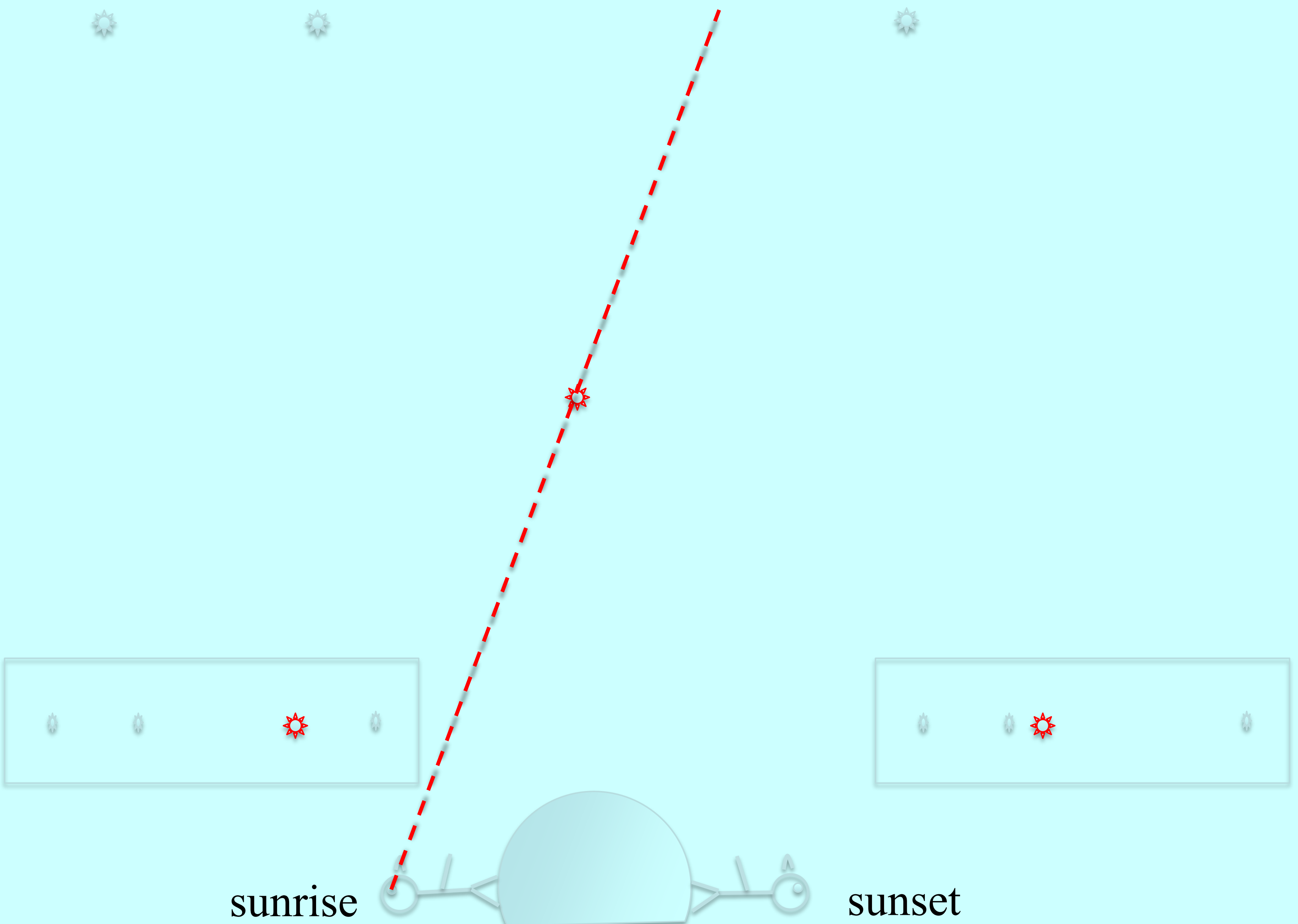
A larger angle involves smaller measurement errors.

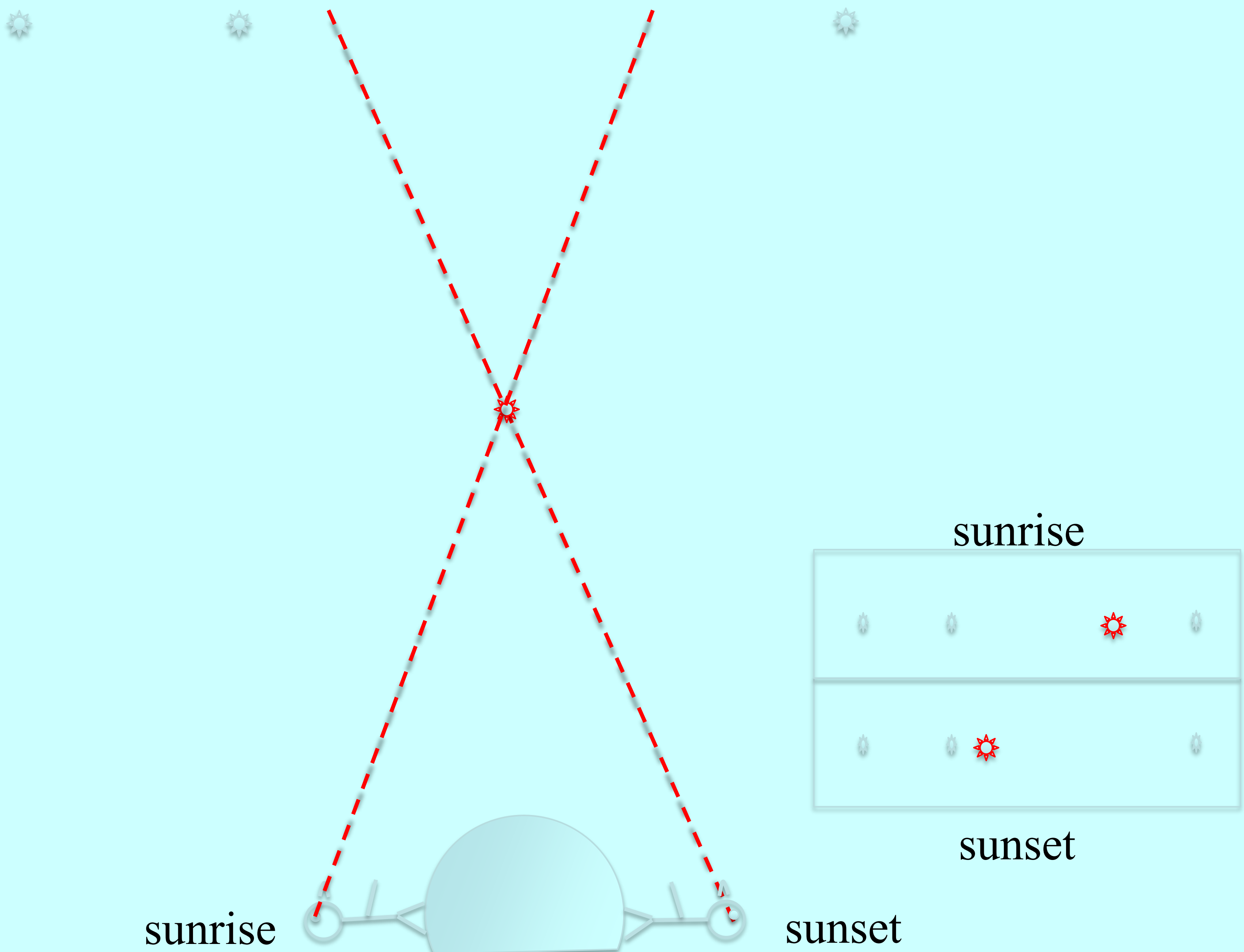


# Increasing distance between observations: sunset and sunrise

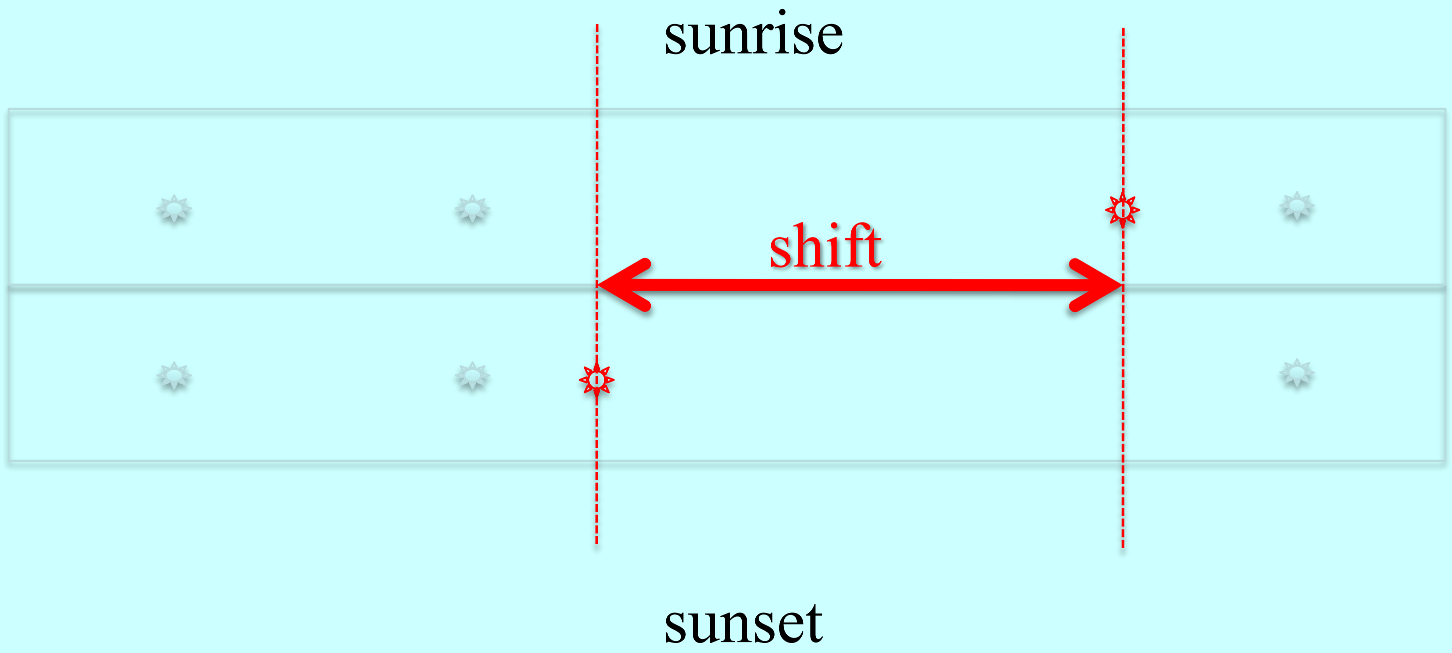


sunset


sunrise
sunset

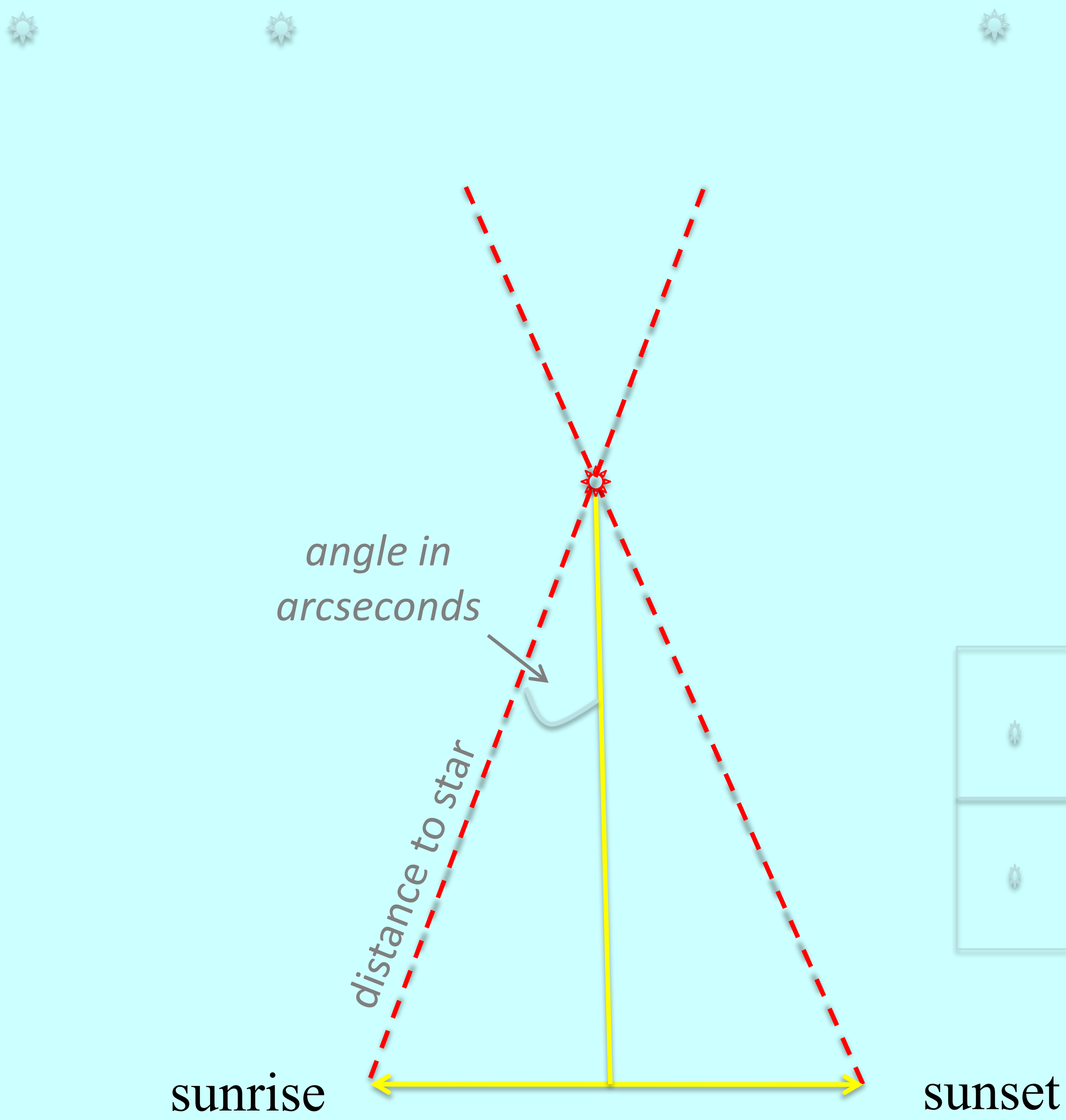


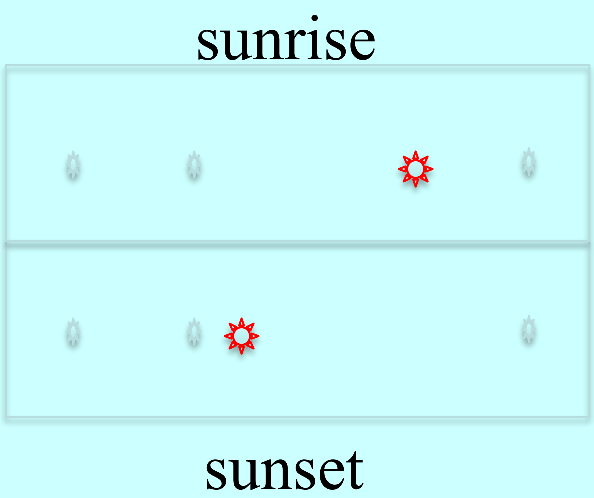
sunrise
sunset
sunrise
sunset



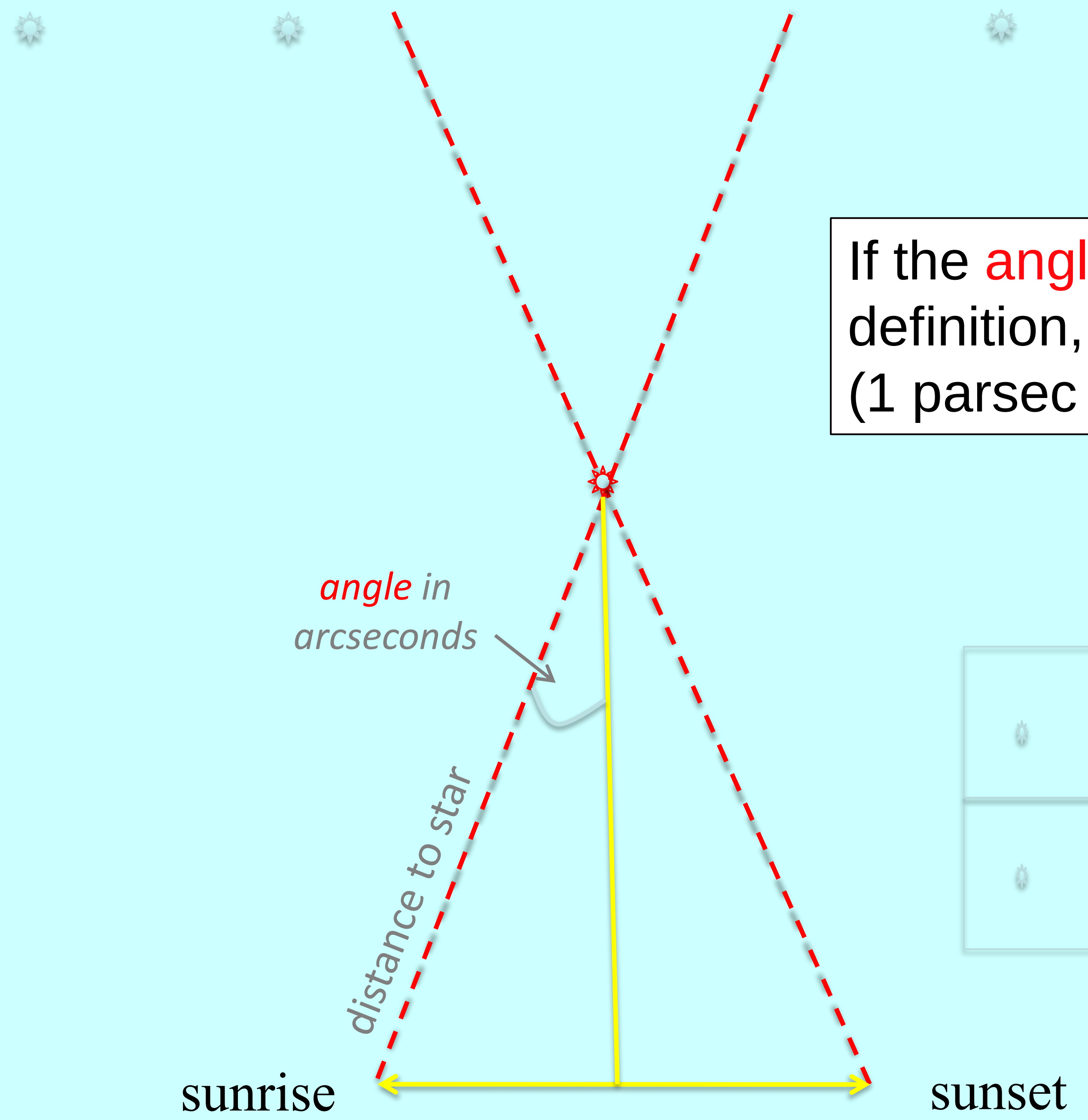

How do we get distance from this?

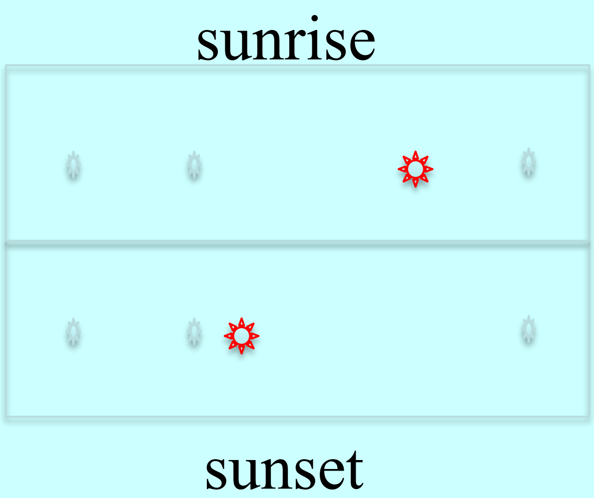
# Create a Triangle:



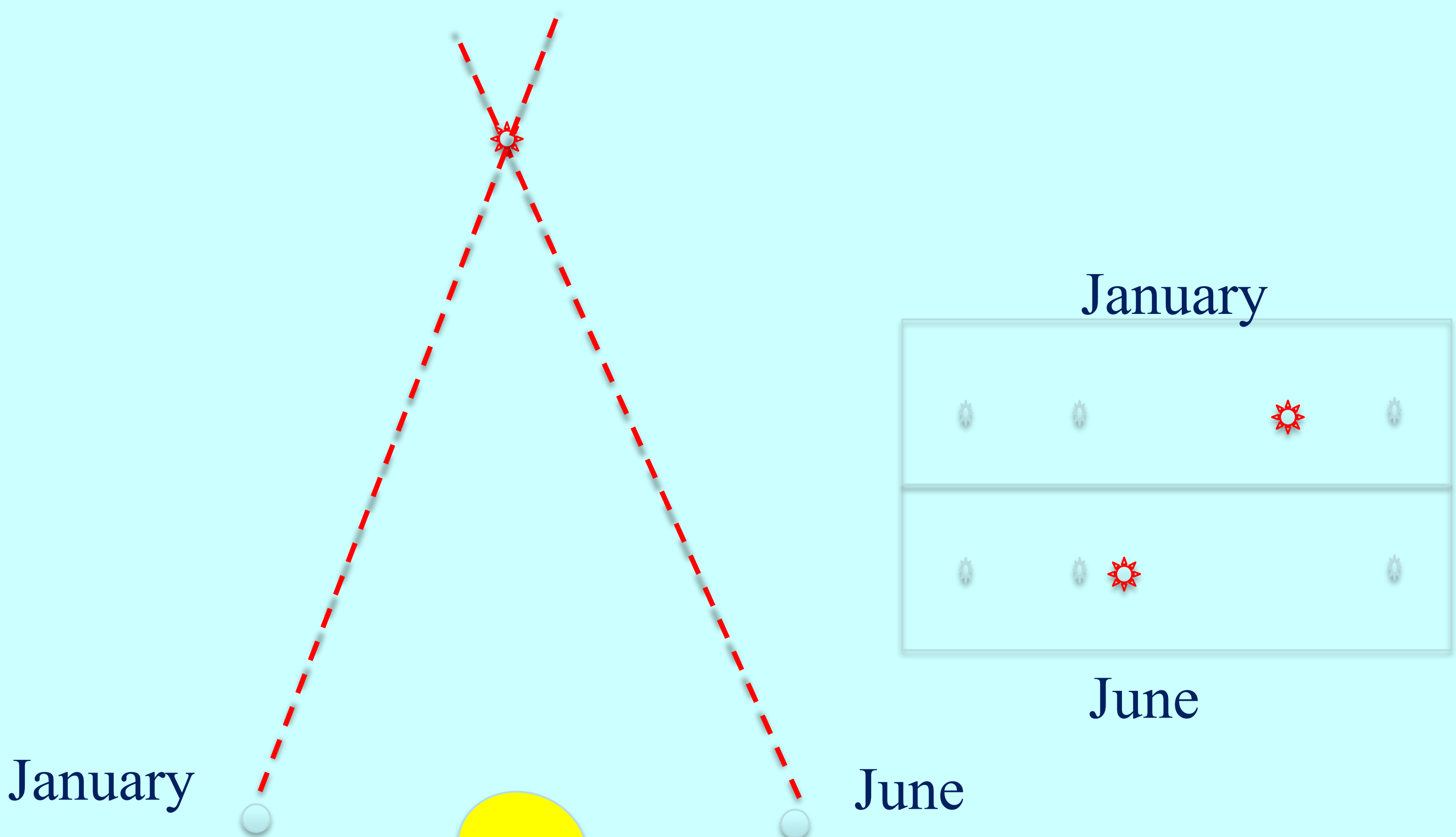



If the angle is 1" then by definition, the star is 1 pc (1 parsec = 3.26 l-yr)

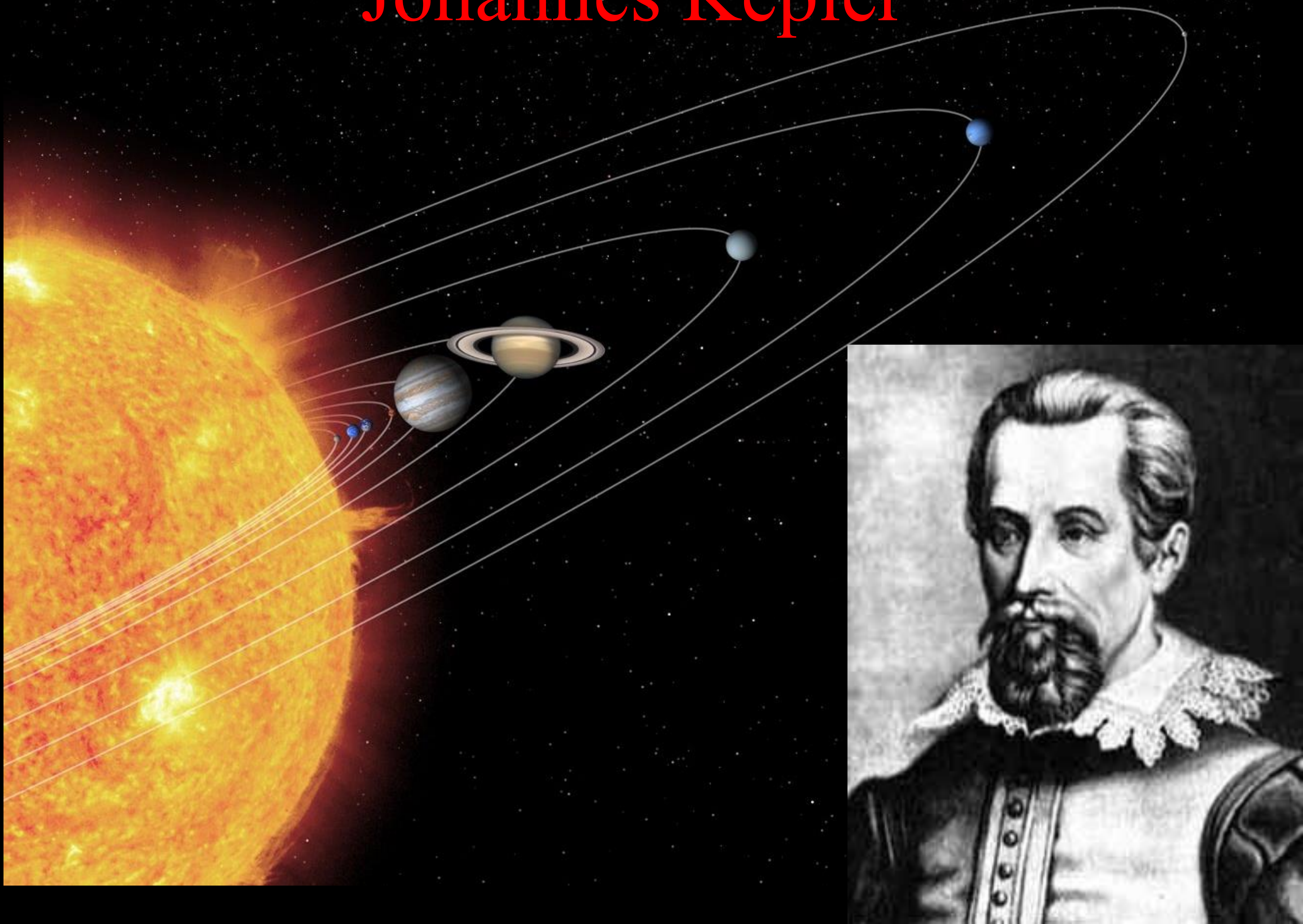


If the distance between the observations is larger, then we can detect farther stars— so let's use the size of earth's **orbit around the sun**

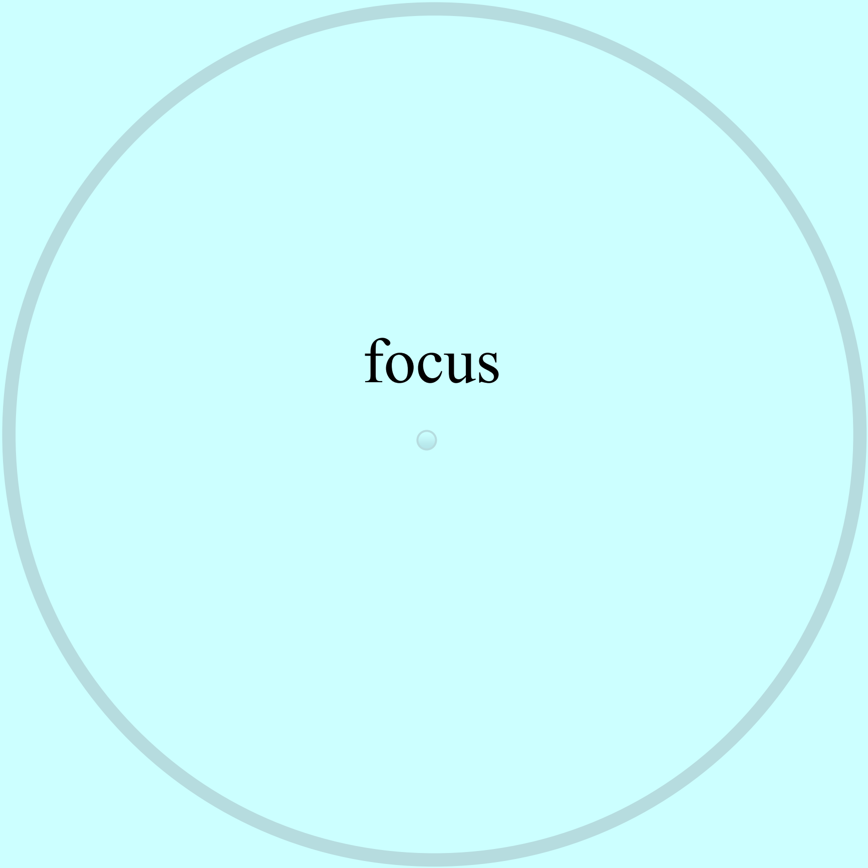


# Johannes Kepler

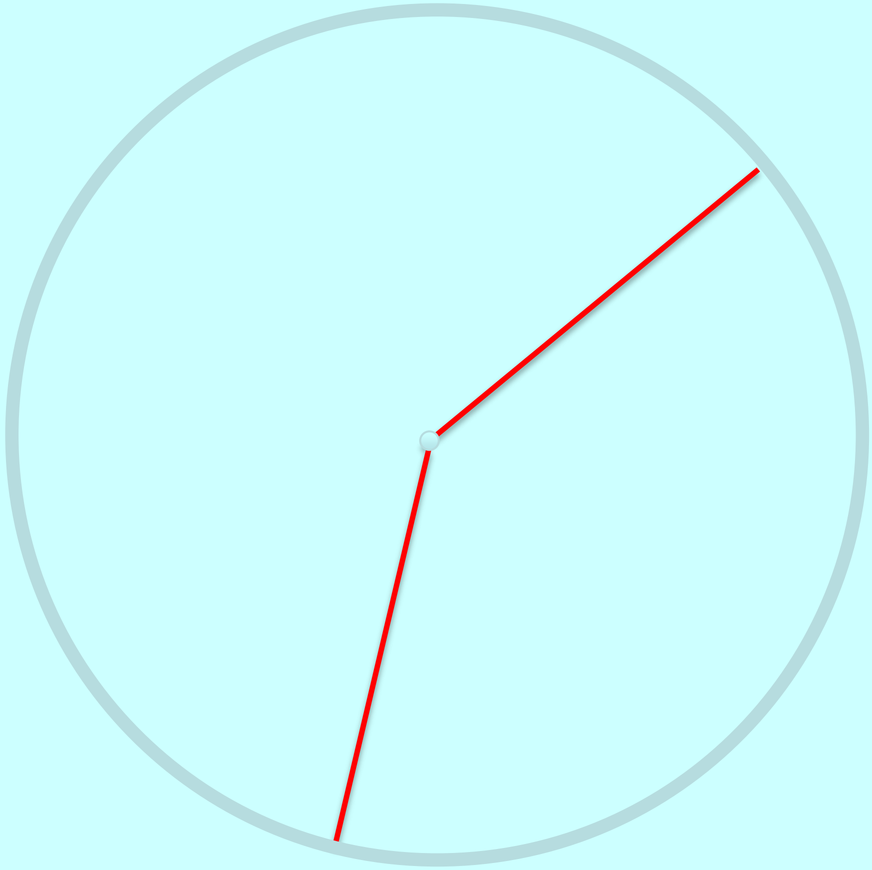


# Kepler's Law #1:

The planets do not move in perfect circles around the Sun.  They move in ELLIPSES with the Sun at one focus point.

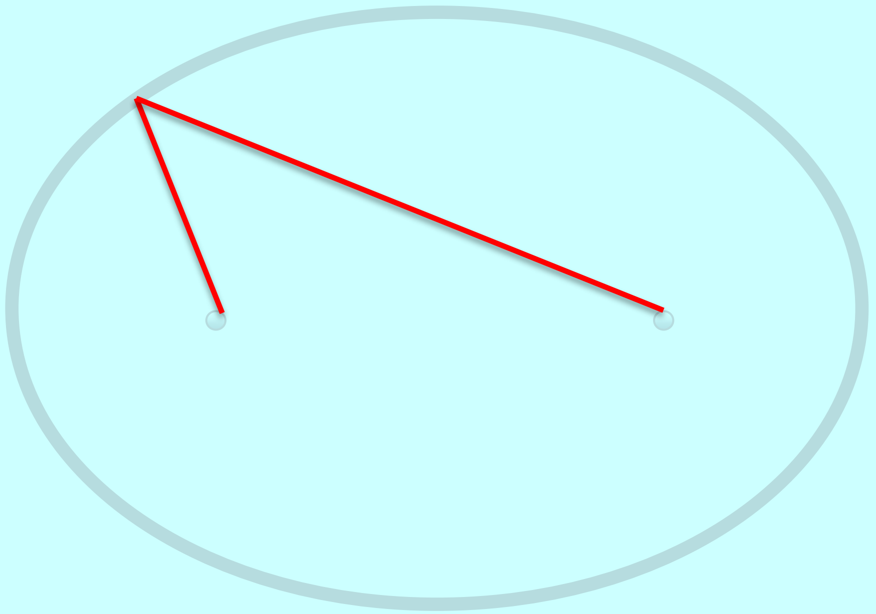

focus

Circle — distance to rim always the same (radius)

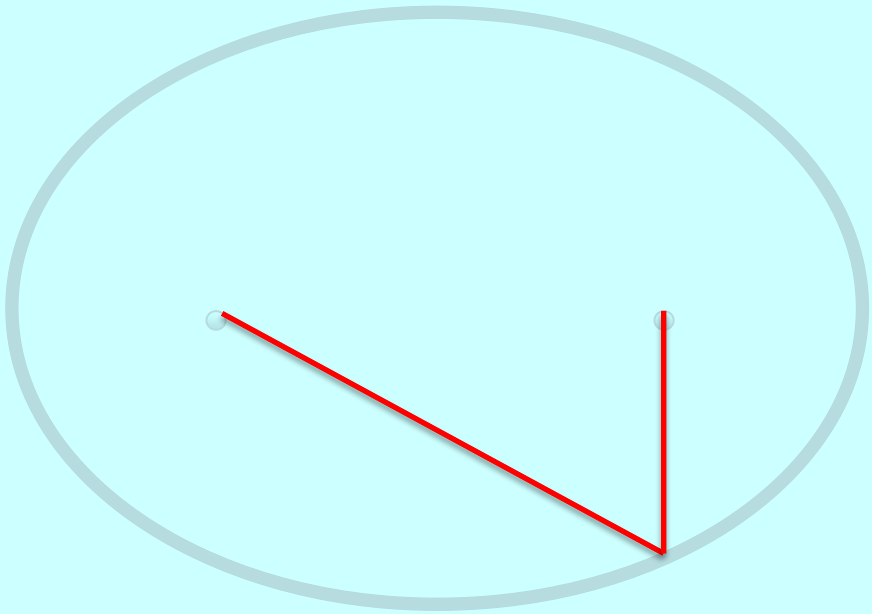


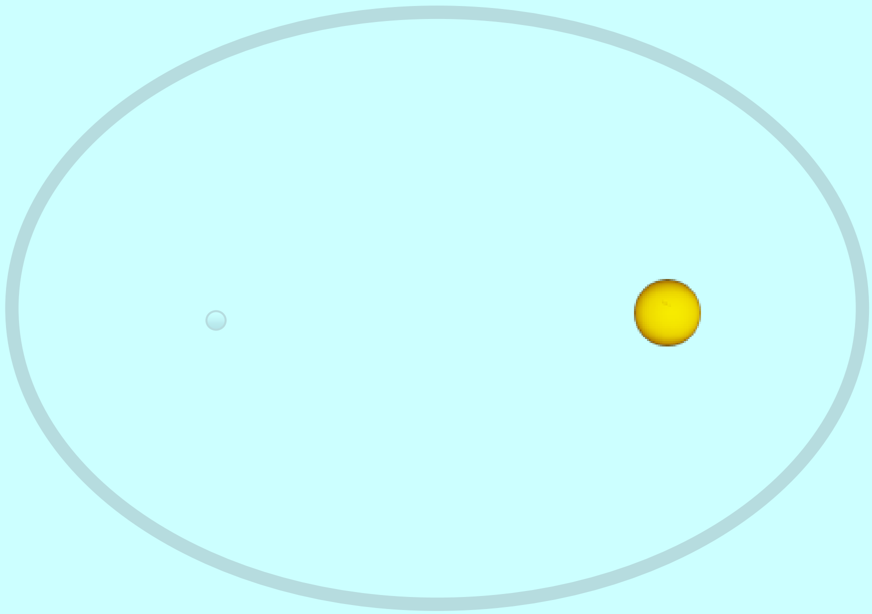
Ellipse — 2 focal points (foci)

Ellipse — sum of each line from the foci to the rim is the same



Ellipse — sum of each line from the foci to the rim is the same

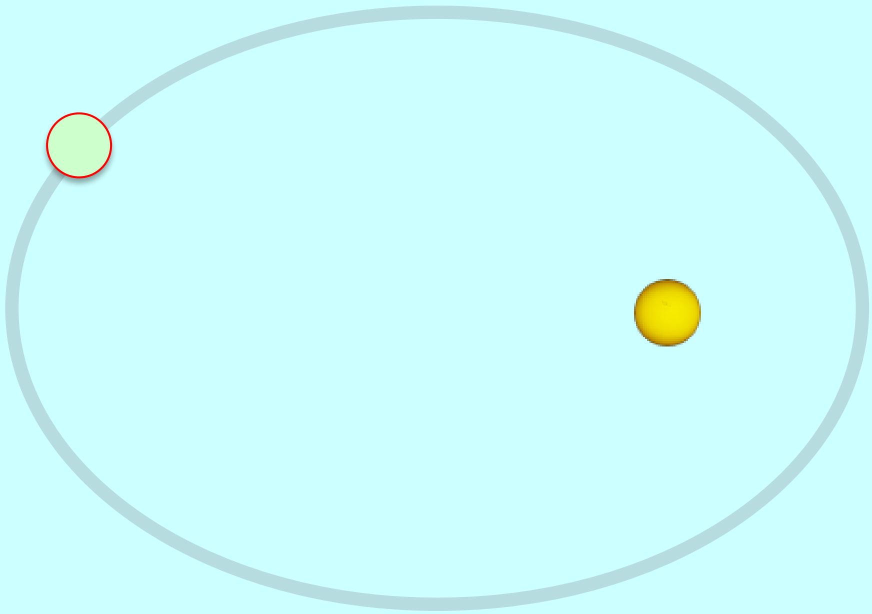




Planetary orbit with Sun at one focus

Kepler's Law #2:

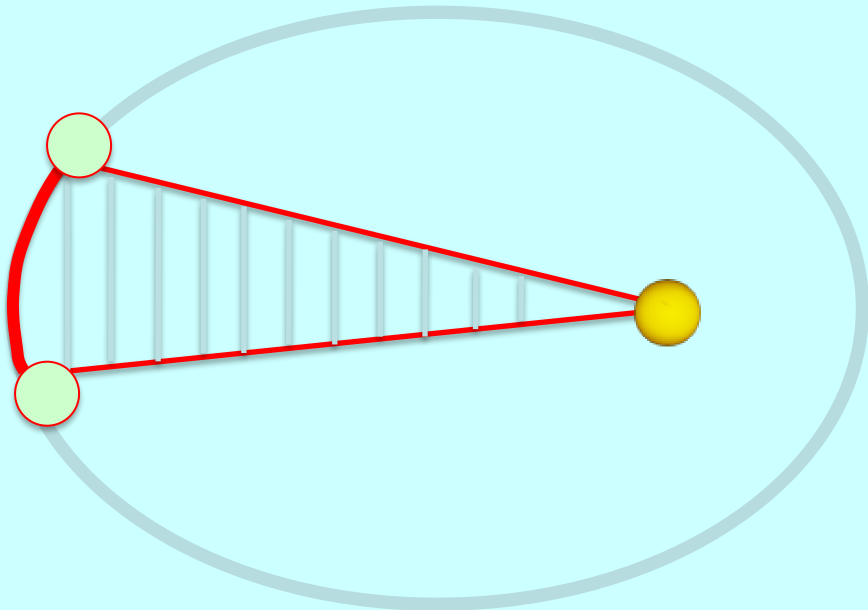
The closer the planet is to the Sun in its orbit, the faster it goes.



# Kepler's Law #2:

A mathematical way to say this is:  a planet will sweep out equal areas in equal times

a month to travel
this distance
going slowly



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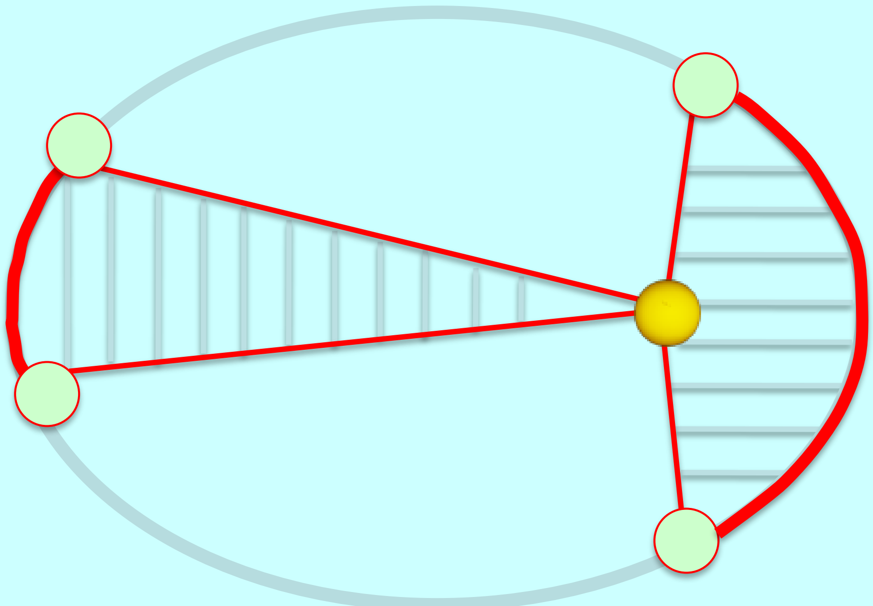
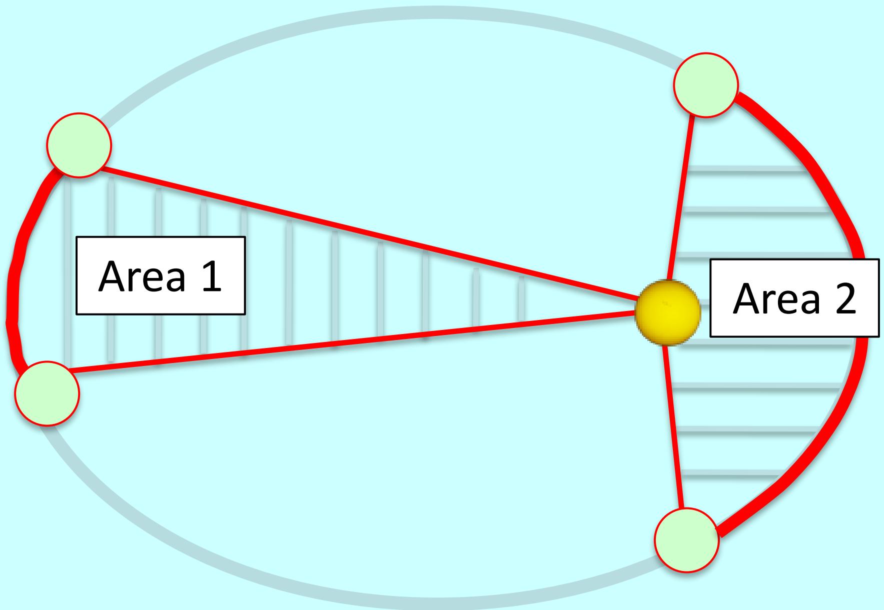


a month to travel this distance going fast

# Kepler's Law #2:

A mathematical way to say this is:  a planet will sweep out equal areas in equal times

a month to travel this distance going slowly

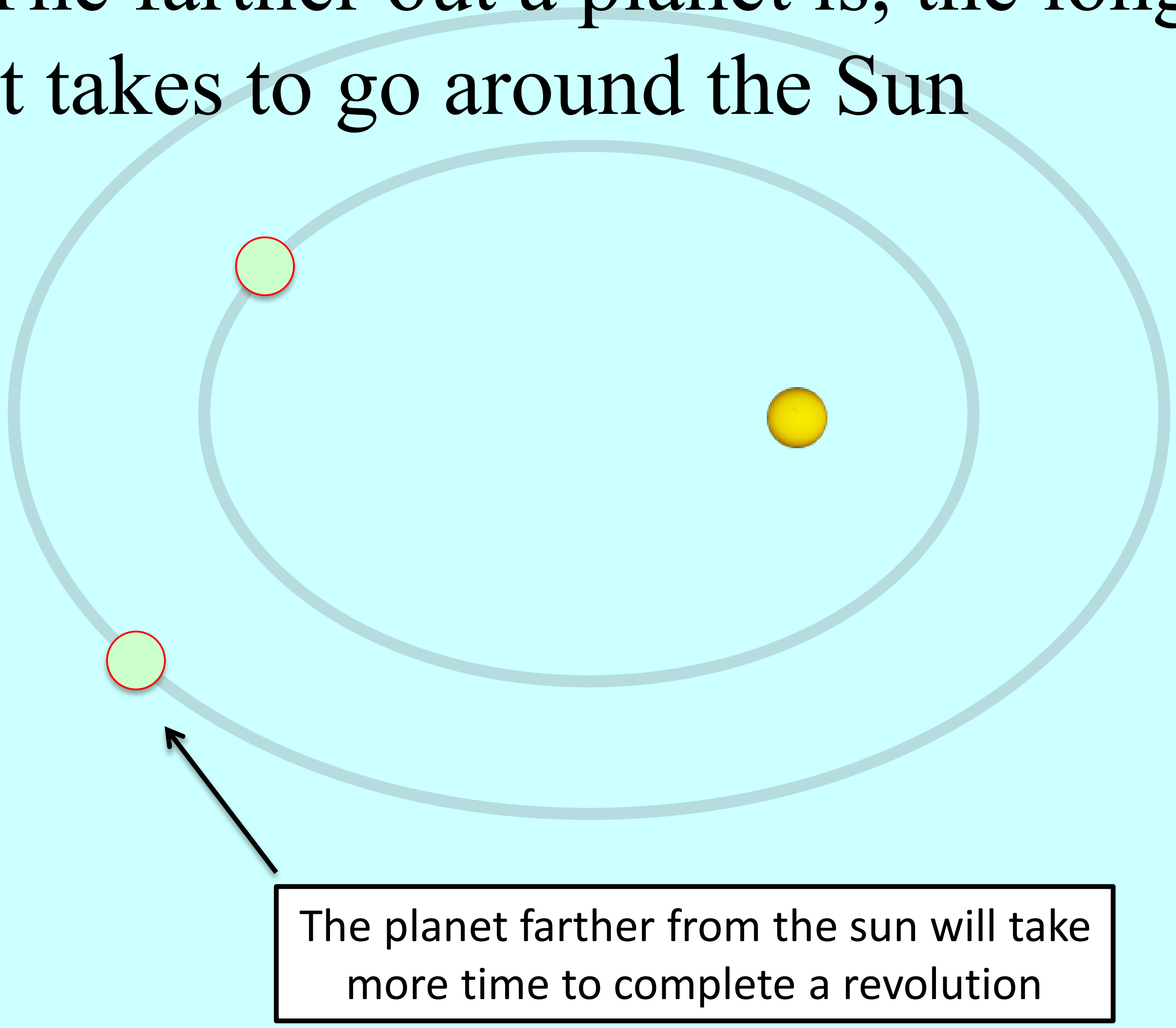



a month to travel this distance going fast

According to Kepler's 2nd Law:  **Area 1 = Area 2**

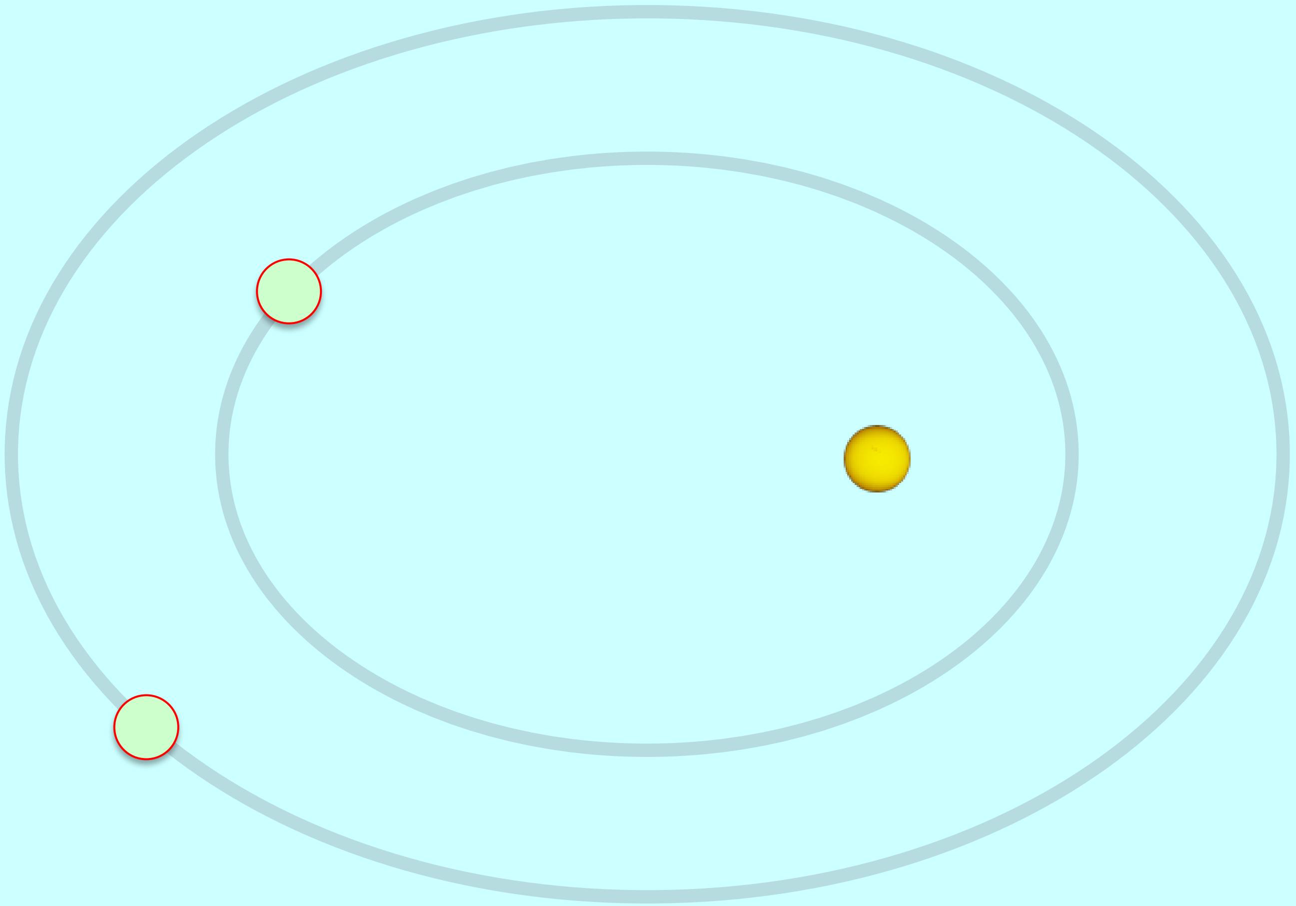
# Kepler's Law #3:

The farther out a planet is, the longer it takes to go around the Sun



# Kepler's Law #3:

$$P^2_{yr} = D^3_{AU}$$

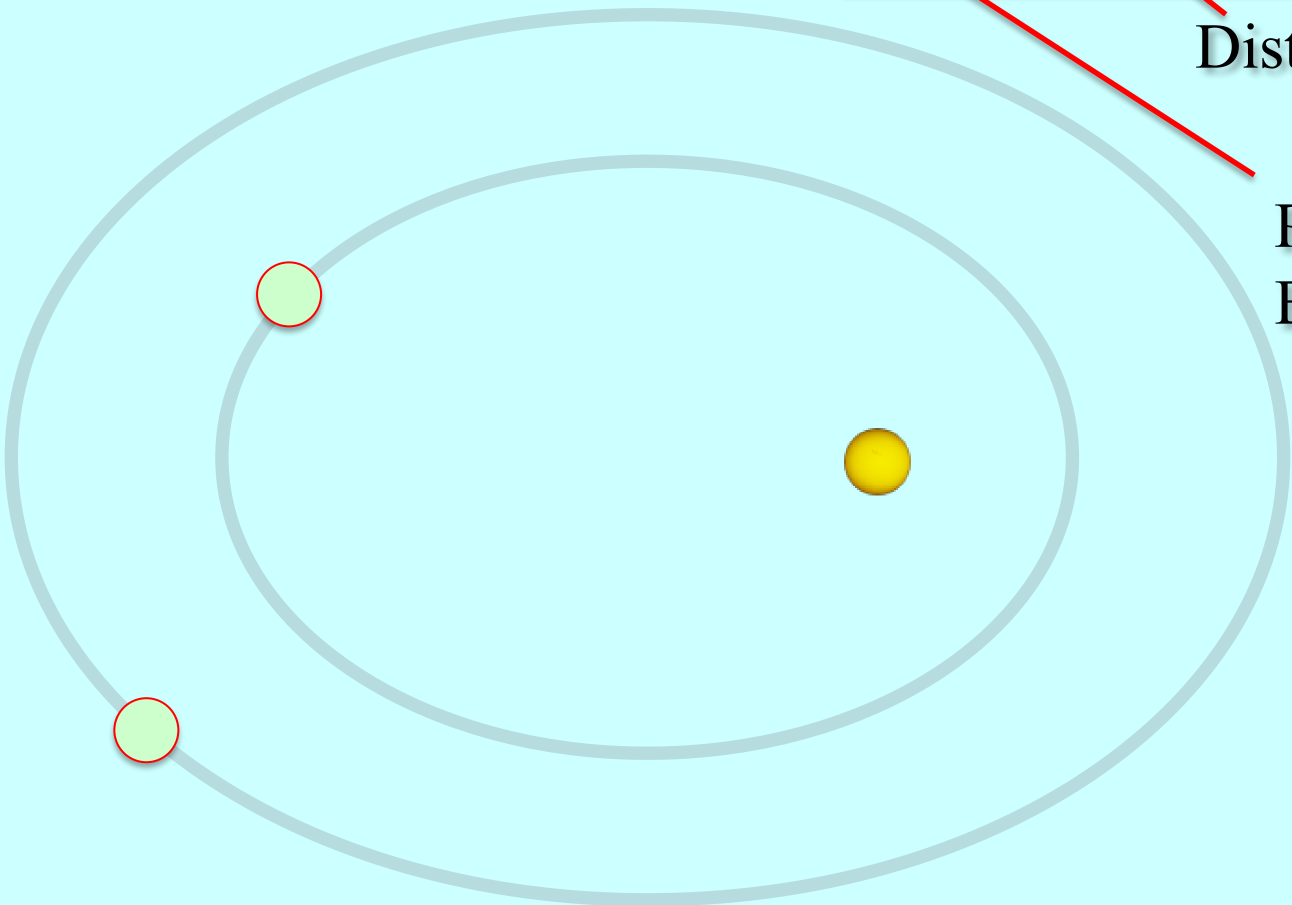


# Kepler's Law #3:

$$P^2_{yr} = D^3_{AU}$$

Distance in AU

Period in Earth-years



$$P_{yr}^{2} = D_{AU}^{3}$$

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If we want the PERIOD of a planet

(time it takes to orbit the Sun)

$$\sqrt{P_{yr}^{2}} = \sqrt{D_{AU}^{3}}$$

If we want the PERIOD of a planet

(time it takes to orbit the Sun)

$$P_{yr} = \sqrt{D_{AU}^3}$$

$$P_{mars} = \sqrt{D_{mars}^3}$$

$$\mathbf{P}_{mars} = \sqrt{(1.6\ \mathrm{AU})^3} = \boxed{2.02\ \mathrm{yr}}$$

$$P_{yr}^2 = D_{AU}^3$$

If we want the DISTANCE to a planet

(in AU from the Sun)

$$\sqrt[3]{P_{yr}^2} = D_{AU}$$

If we want the DISTANCE to a planet

(in AU from the Sun)

$$\sqrt[3]{P_{yr}^2 = D_{AU}}$$

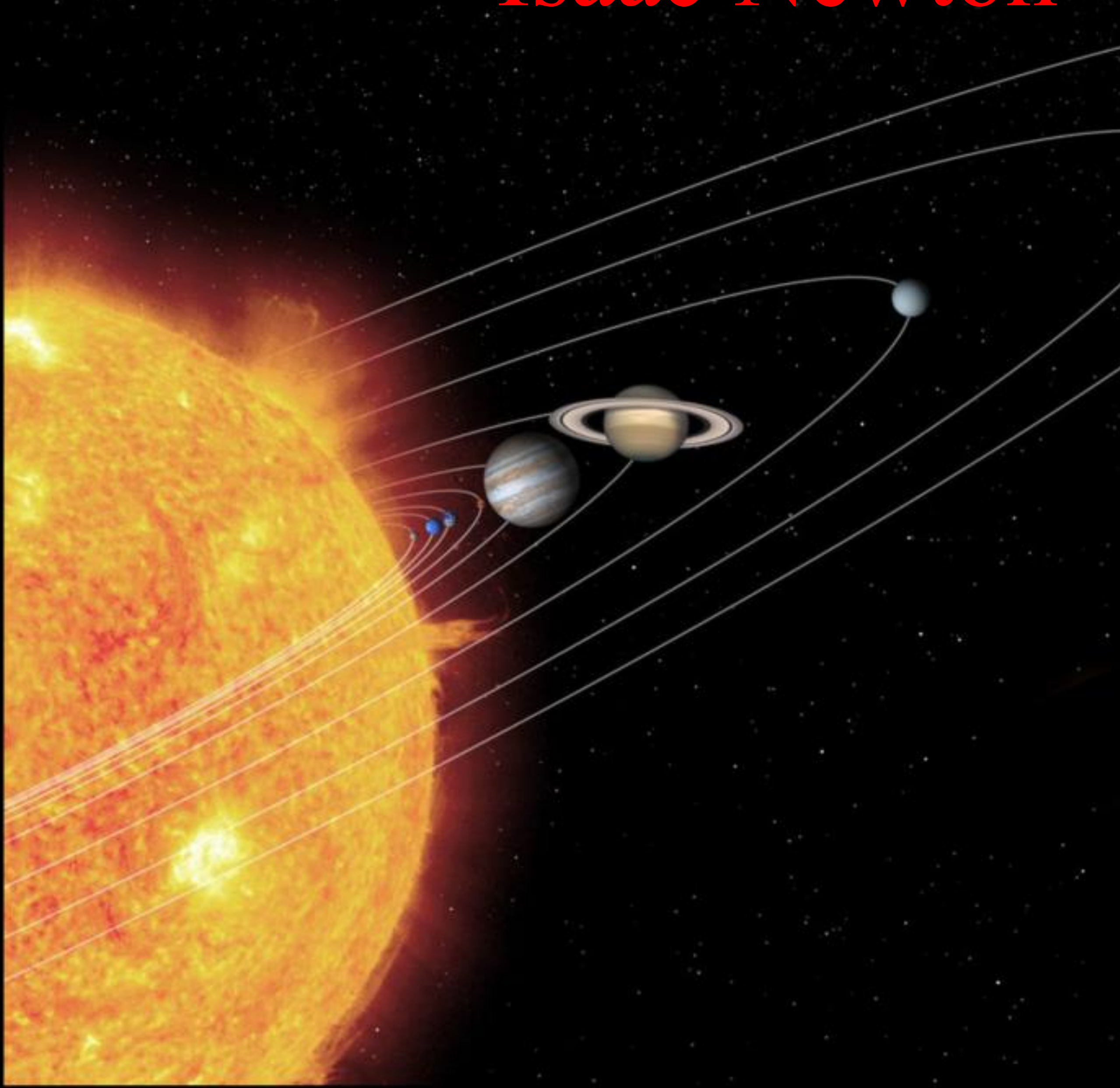
$$D = \sqrt[3]{P_{jupiter}^2}$$

$$\mathbf{D}_{jupiter} = \sqrt[3]{(12\ \mathrm{yrs})^2} = 5.3\ \mathrm{AU}$$

# Let’s Practice

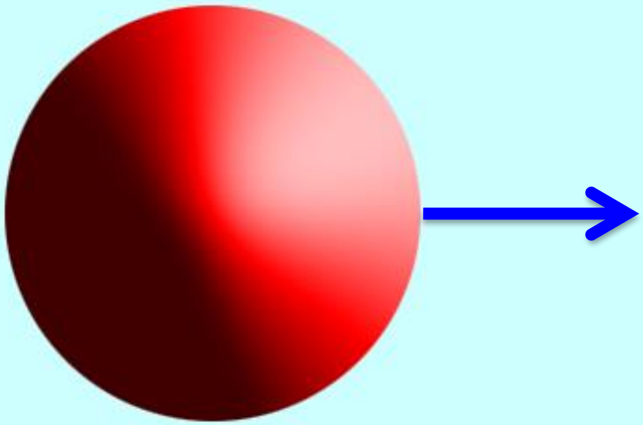
- The period of Saturn is 29.46 Earth years. How far is Saturn from the sun?
- Venus is 0.723 AU from the Sun.  What is the period of the planet Venus?
- The asteroid Vesta 4 has an orbital period of 3.63 Earth years.  How far is it from the sun?
- If Ceres’ period is 1.4 times longer then Vesta 4, how far is Ceres from the sun?

# Isaac Newton

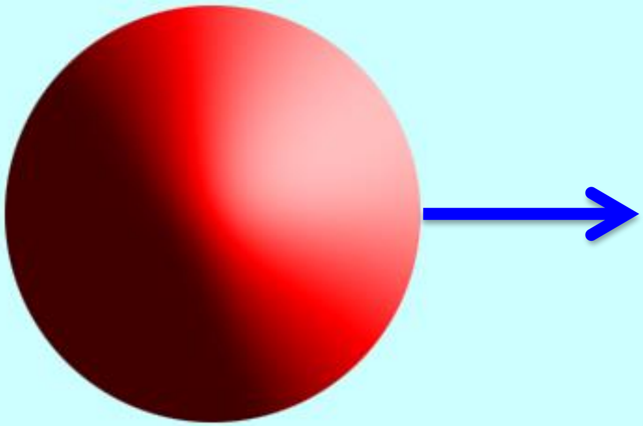


## Newton's 1st Law:

Objects will keep moving at constant velocity.



Newton's 1st Law:
Objects will keep moving at constant velocity.



or

anything with mass has inertia.

## some definitions:

**velocity = speed and direction**

**inertia = the ability to resist a force**

some definitions:

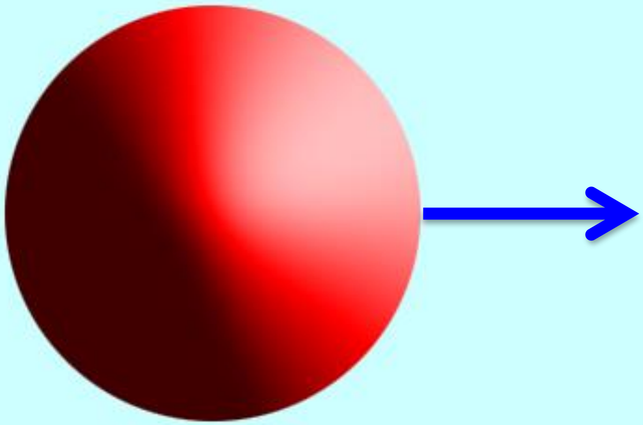
**velocity = speed and direction**

**inertia = the ability to resist a force**

ability of MASS to resist a change in its motion

# Newton's 1st Law:

Objects will keep moving at constant velocity.



What is the kind of PATH an object with CONSTANT velocity takes?

**Newton's 1st Law:**

*Objects will keep moving at constant velocity.*

What is the kind of PATH an object with CONSTANT velocity takes?

STRAIGHT LINE!!

some definitions:

***velocity = speed and direction***

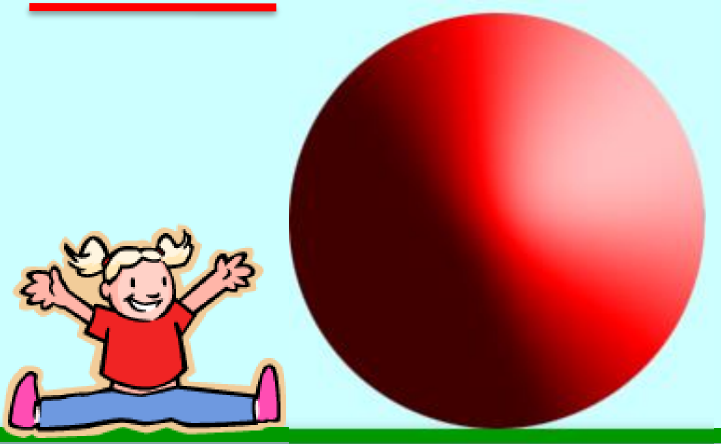
***acceleration = a change in velocity***

some definitions:

**velocity = speed and direction**

**acceleration = a change in velocity**

***Force provides acceleration***



## Newton's 2nd Law:

A force will change an object's velocity, and its acceleration is related to its mass:

$$F = ma$$

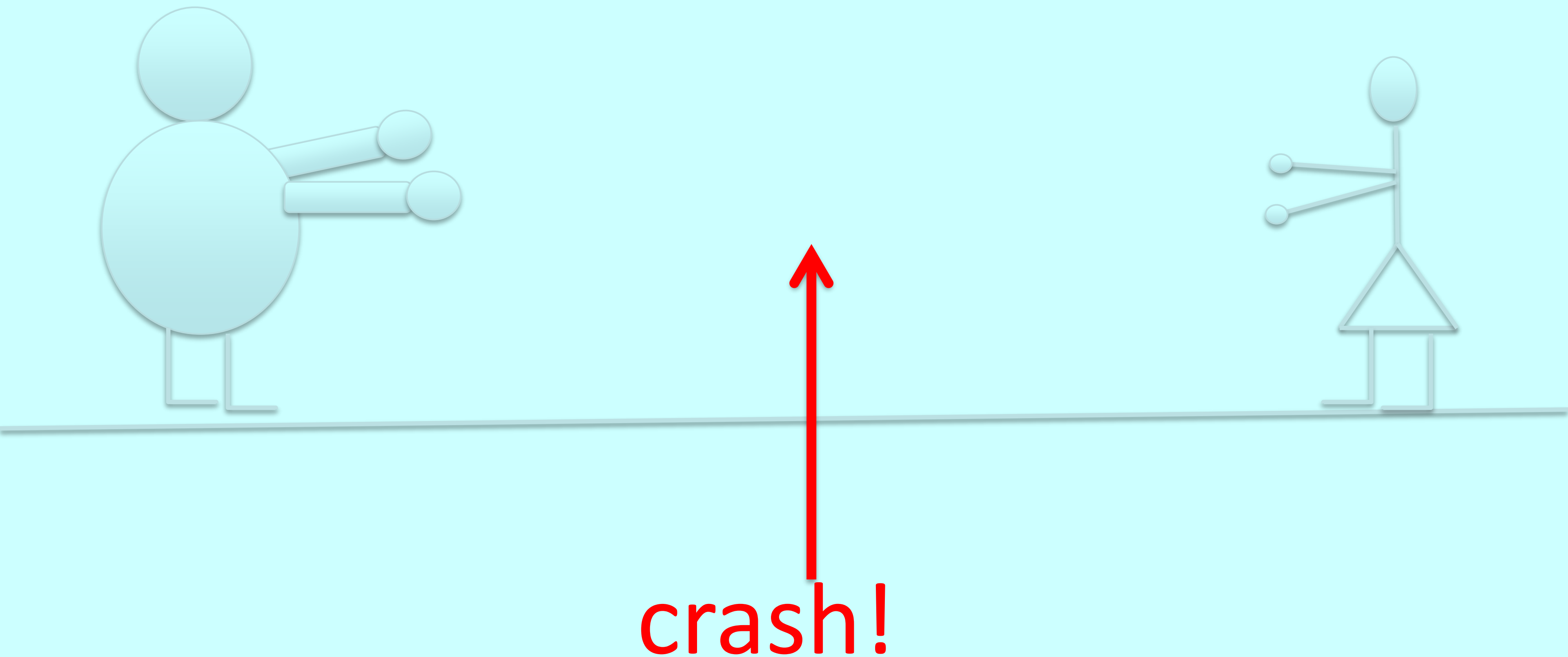
# Newton's 3rd Law:

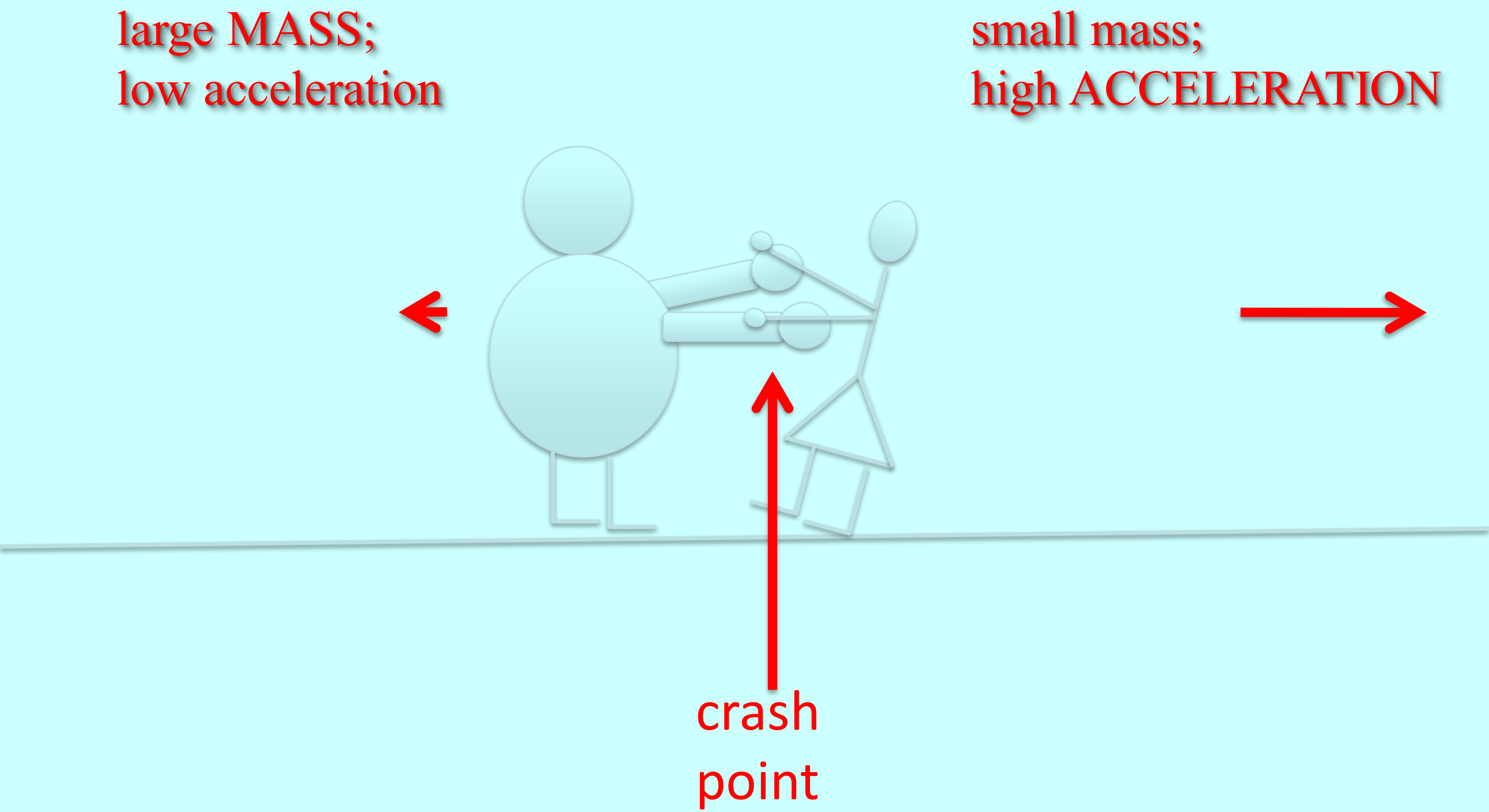
→ Forces don't act in isolation.


Bob
Sue

Force on Bob = Force on Sue

$$M_{Bob}\ a_{Bob} = m_{Sue}\ a_{Sue}$$





large MASS;
low acceleration
small mass;
high ACCELERATION
crash
point

# Force of Gravity between

# the Earth and Sue

$F_{\text{of earth on Sue}} = m_S a_S$

$$F_{\text{of earth on Sue}} = m_S a_S = M_e a_e = F_{\text{of Sue on earth}}$$

$$F_{\substack{\text{of earth}\\\text{on}\\\text{Sue}}} = \boxed{m_S}\, a_S = \boxed{M_e}\, a_e = F_{\substack{\text{of Sue}\\\text{on}\\\text{earth}}}$$

$$F = m_S a_S = M_e a_e = F$$

of earth on Sue

of Sue on earth