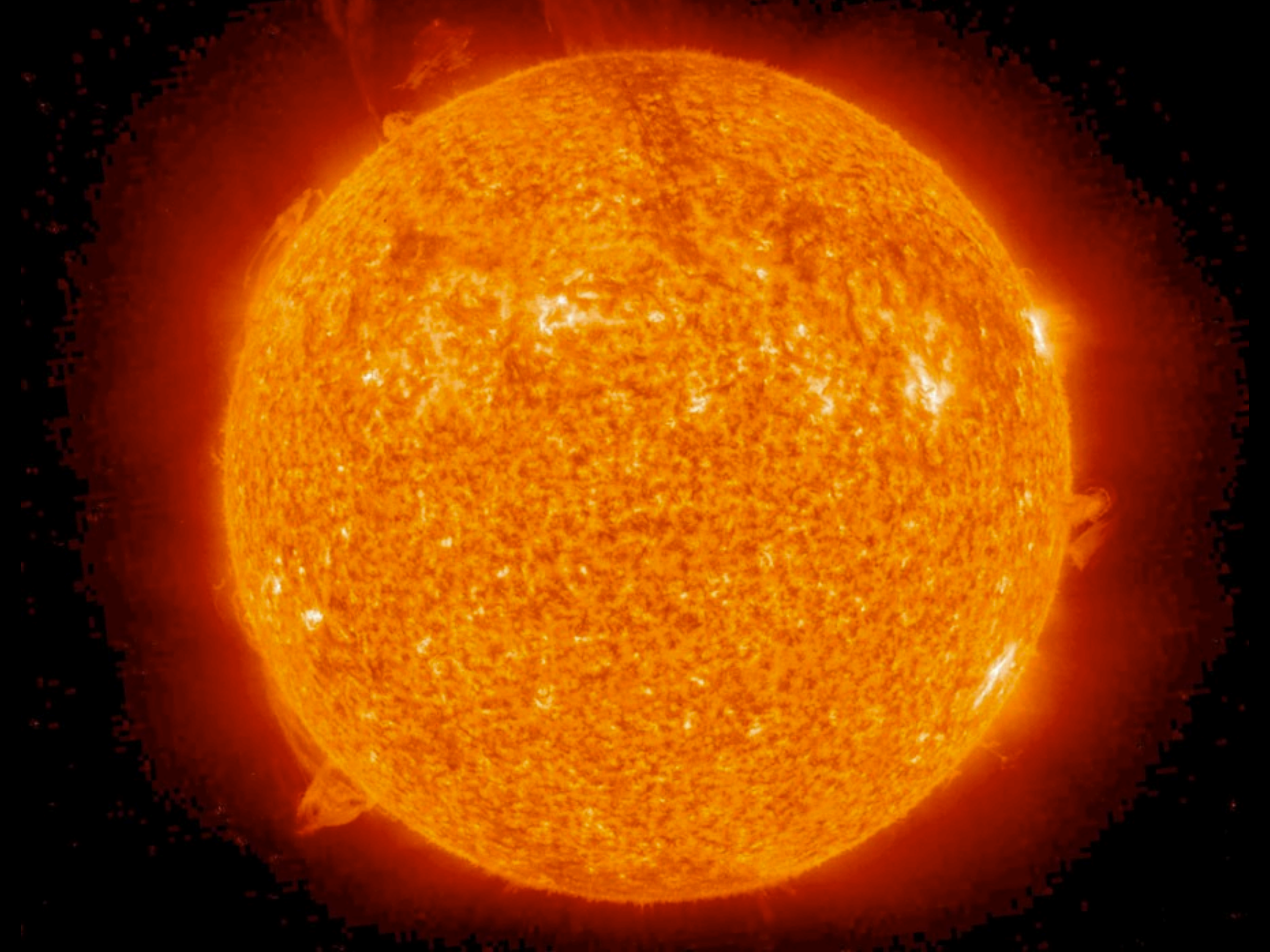
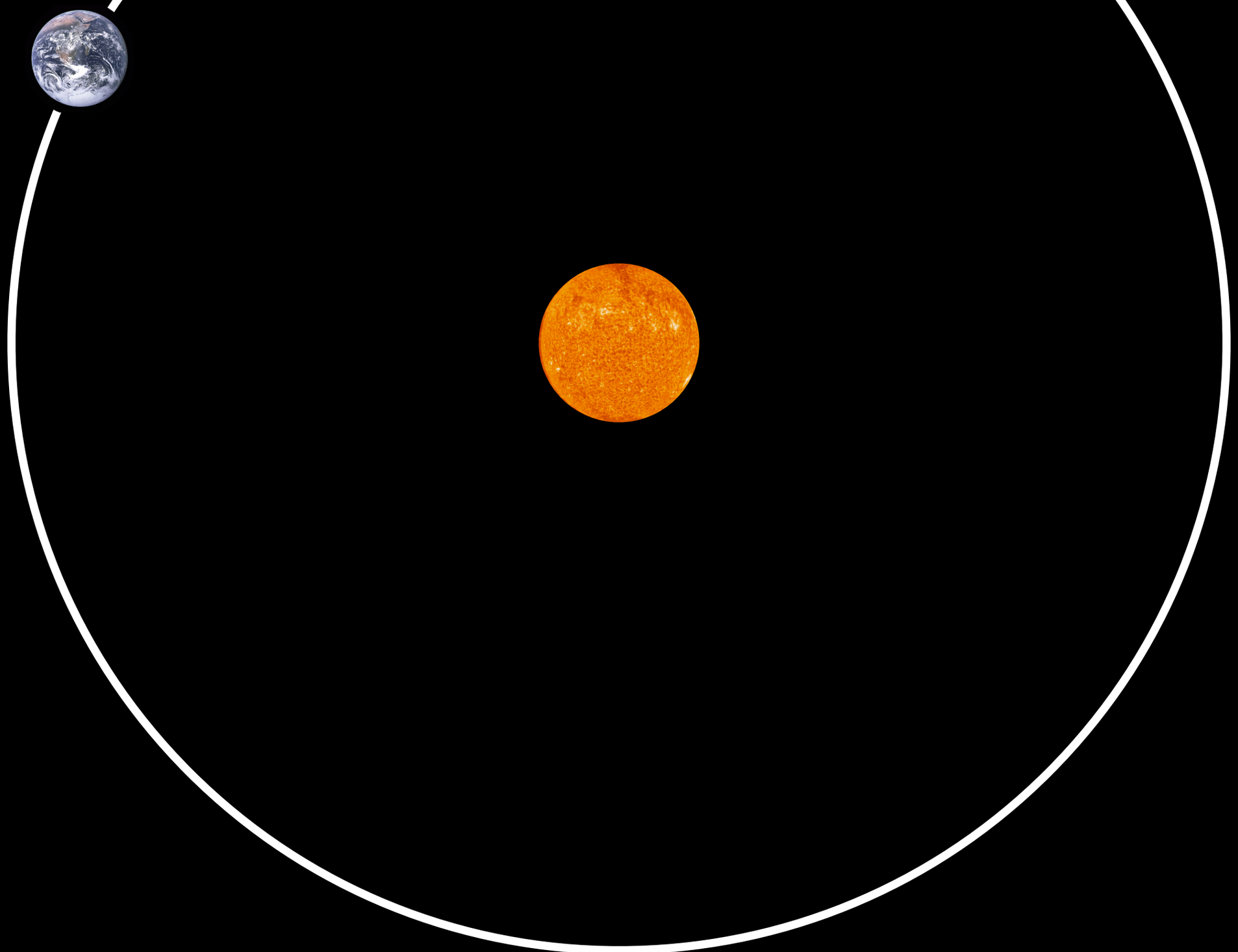
Weigh the Galaxy

$$g = \frac{GM}{R^2}$$

$$g = \frac{GM}{R^2}$$

$$M_{\oplus} \approx 6 \times 10^{24} kg$$



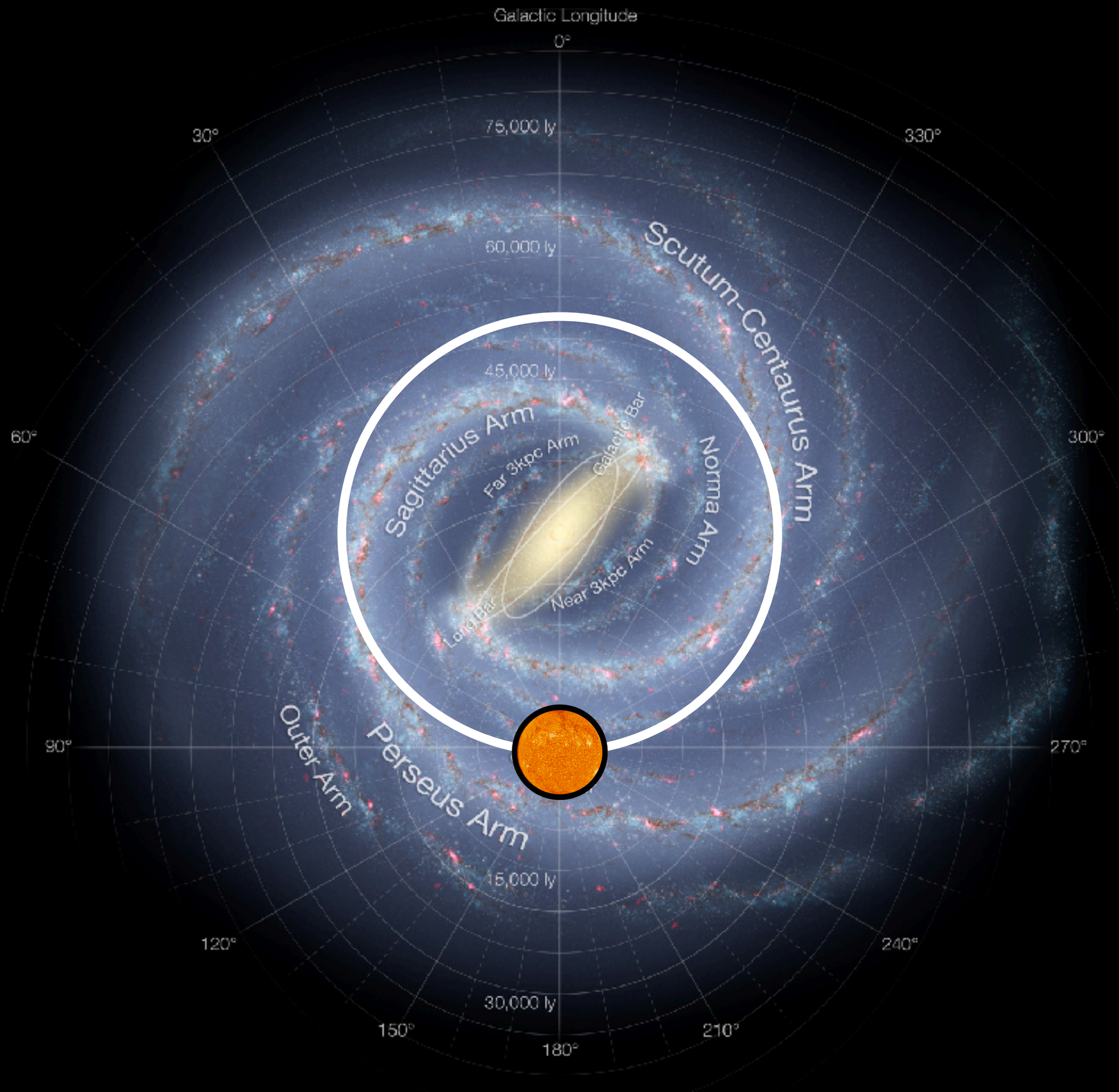


$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

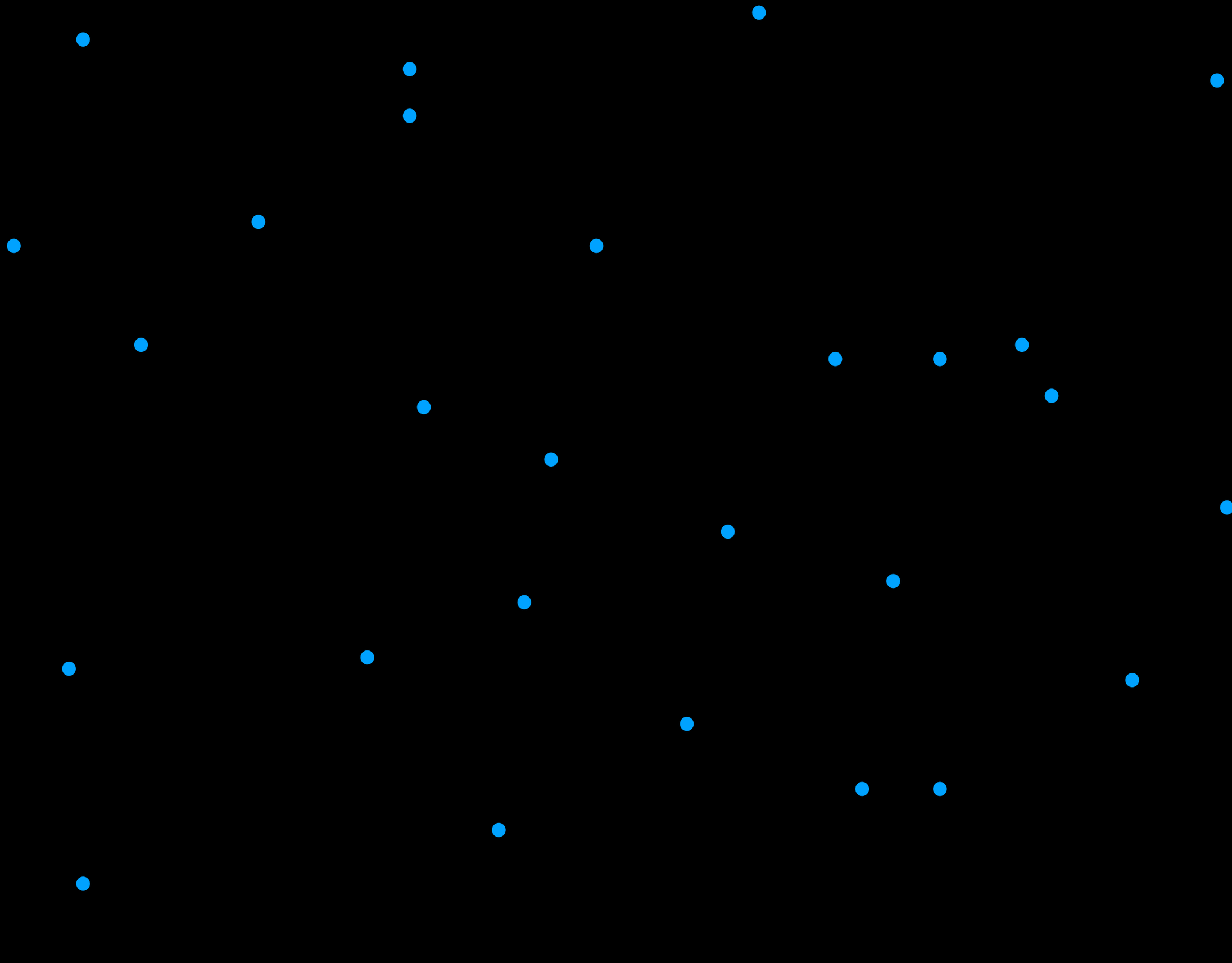
$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

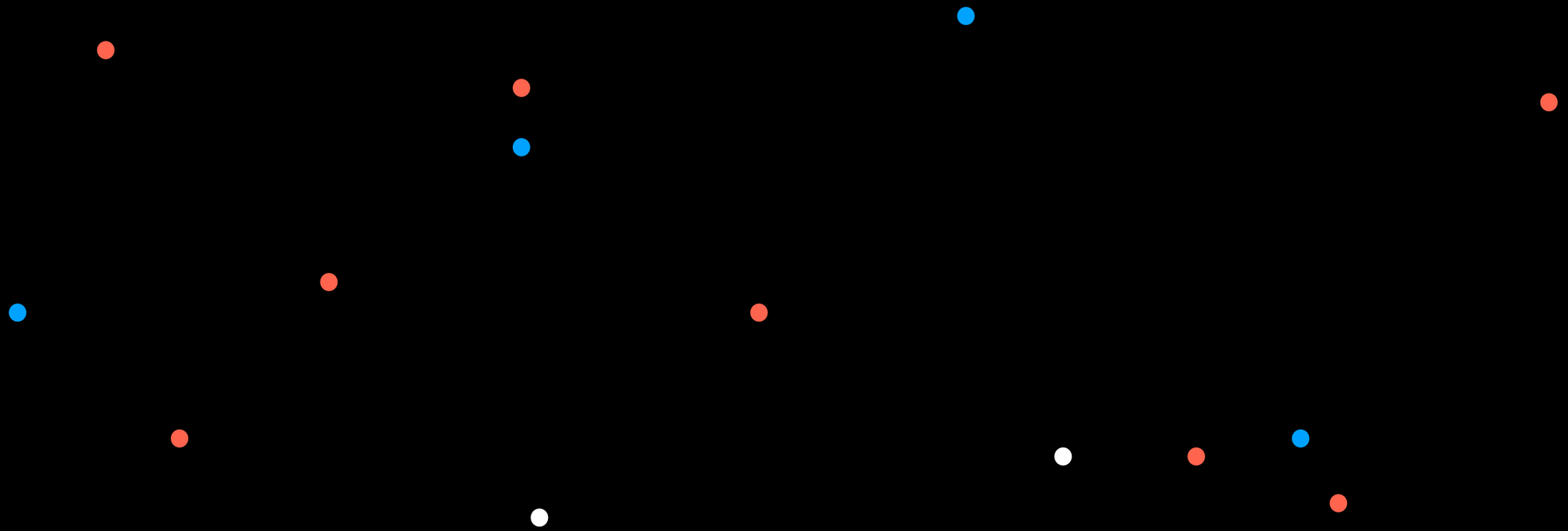
$$M_\odot \approx 2 \times 10^{30} kg$$

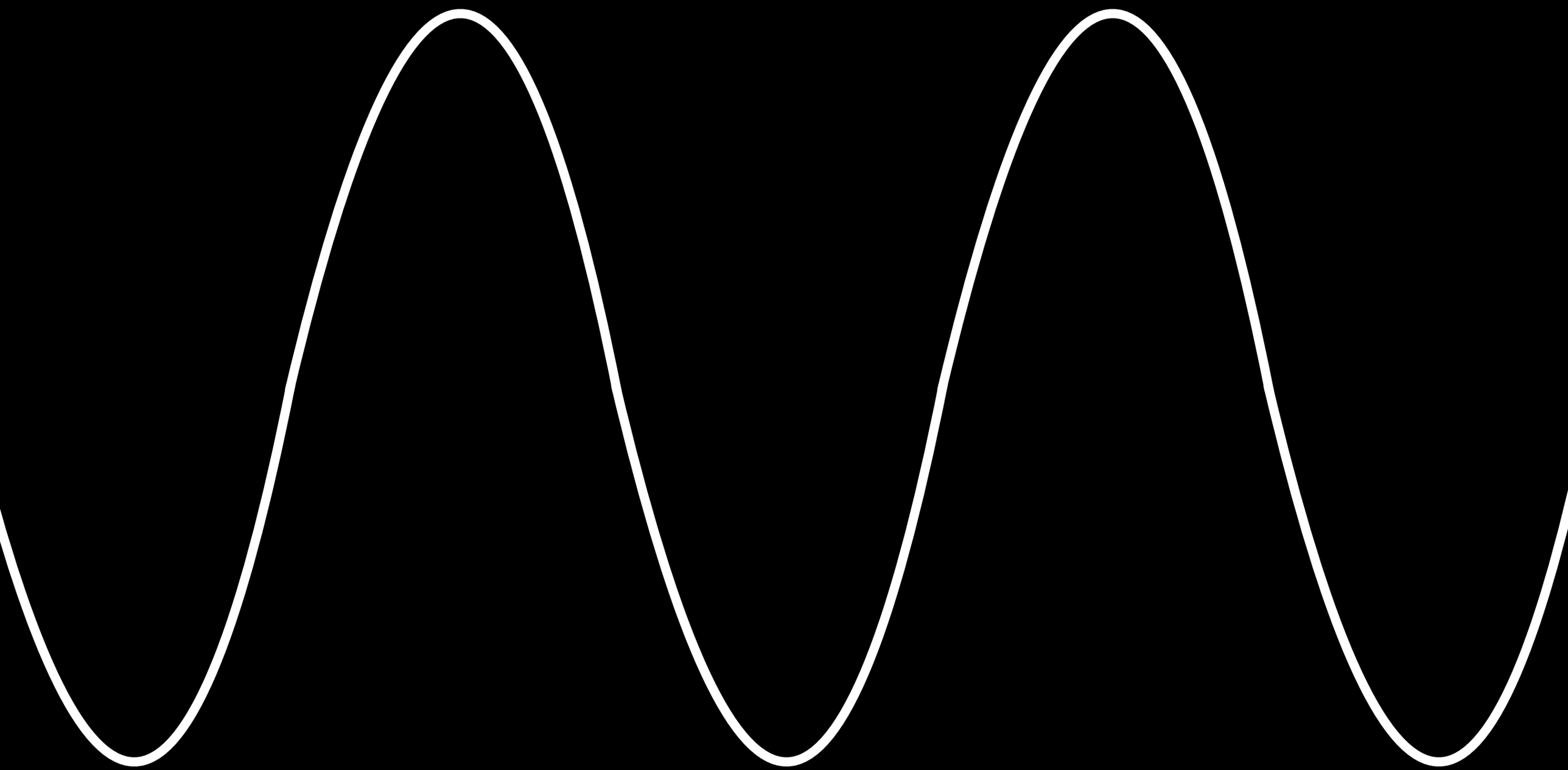
$$(\approx 3 \times 10^6 M_\oplus)$$

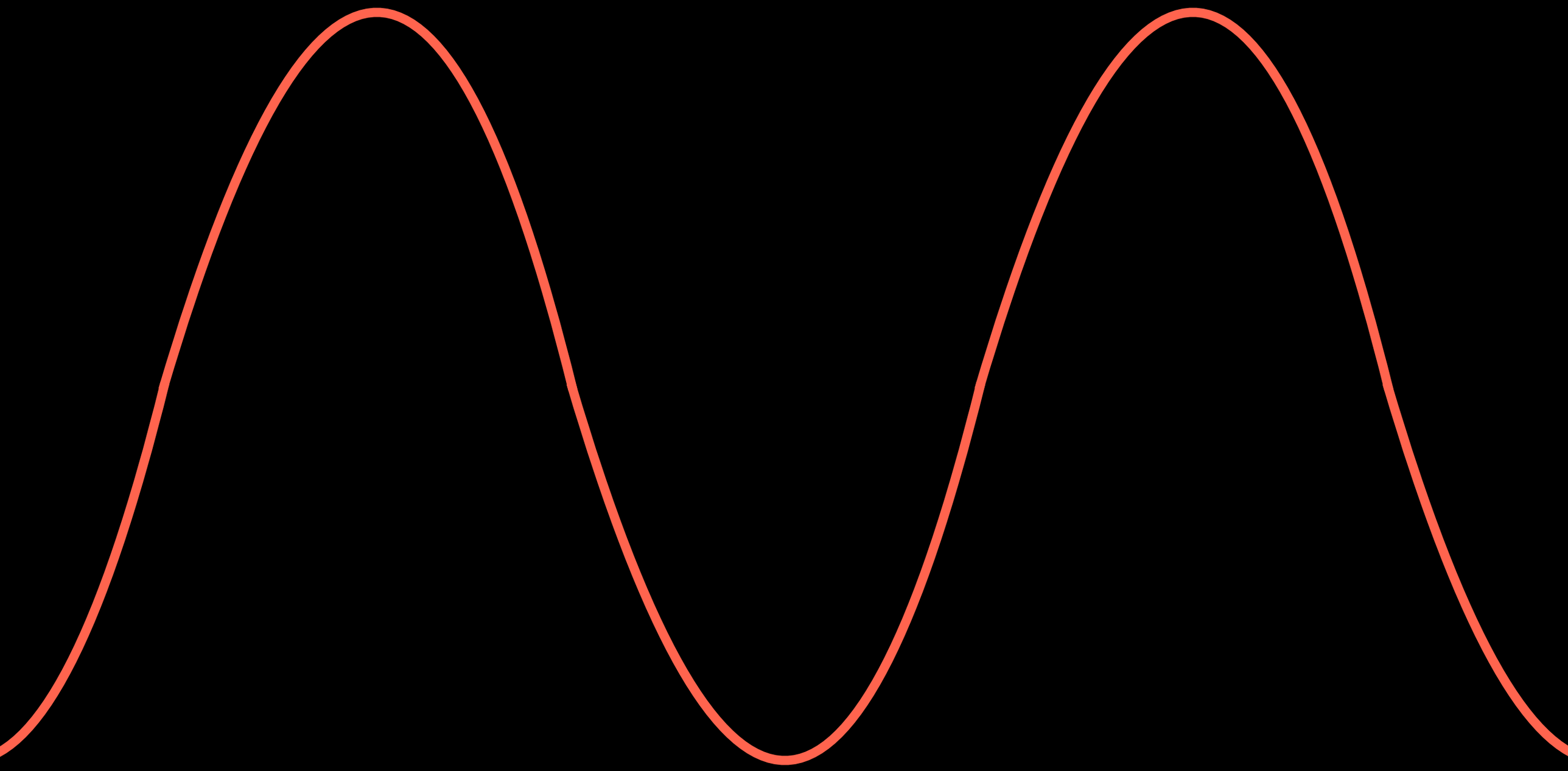

Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar

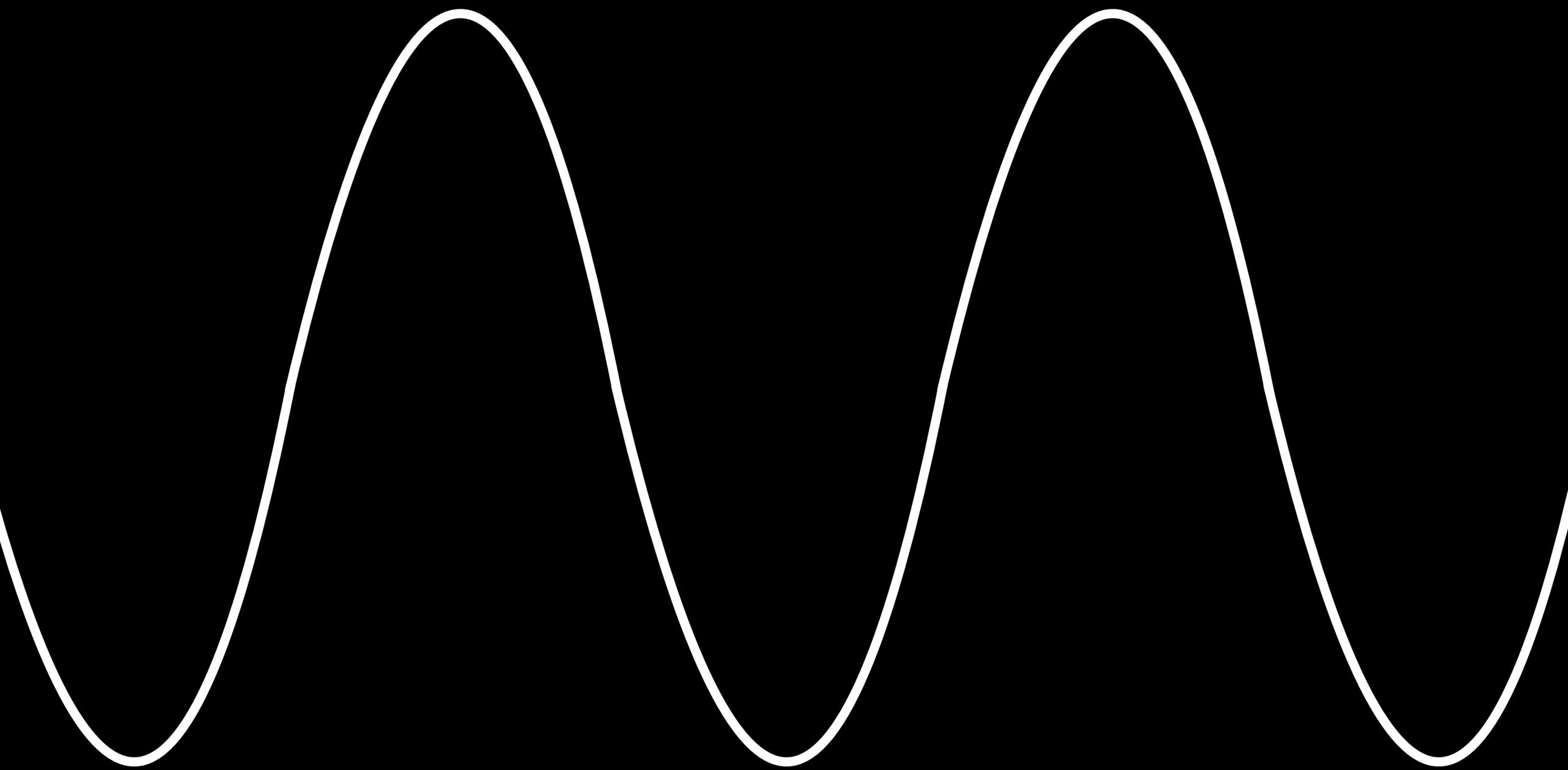
$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

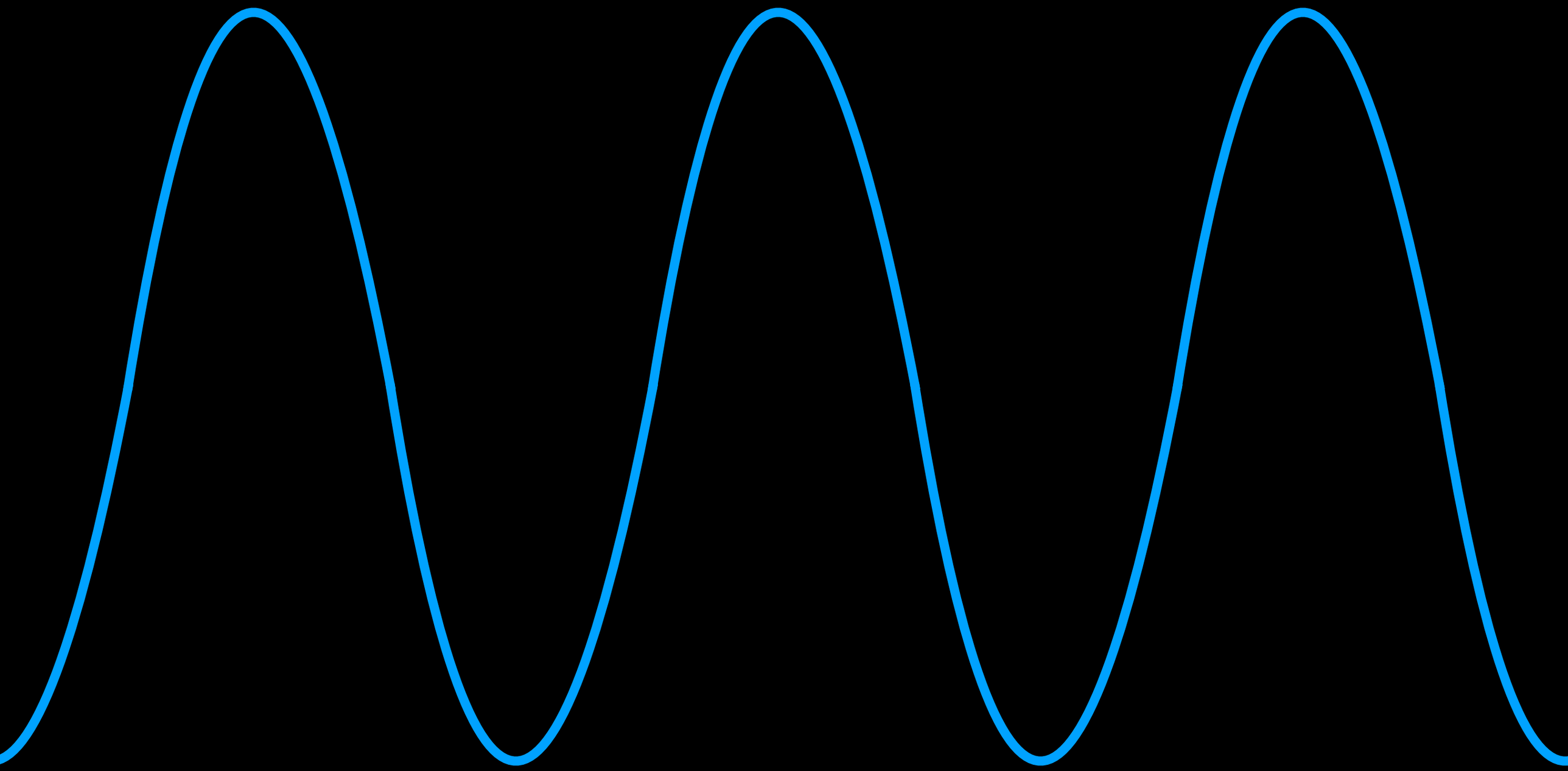






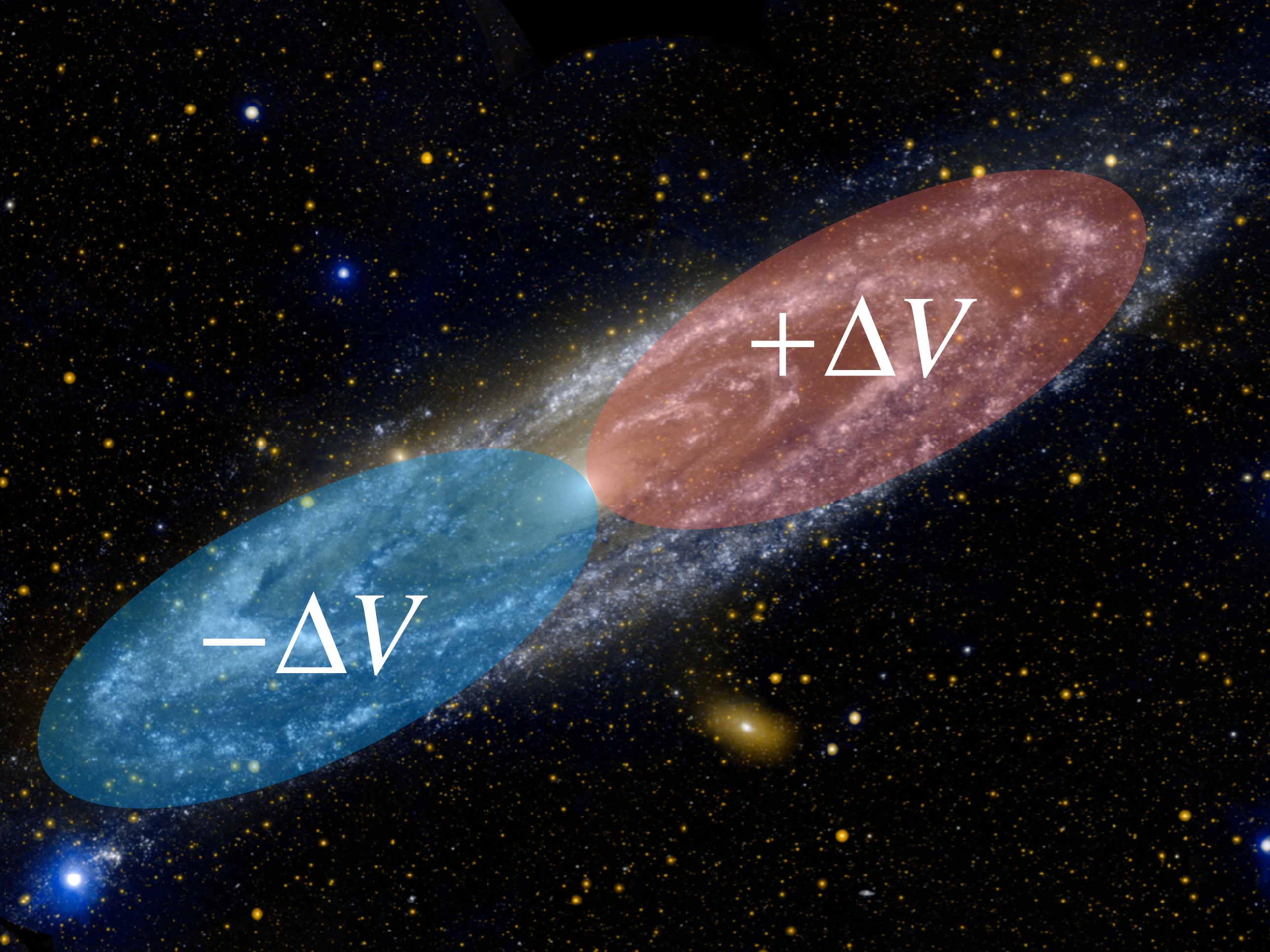


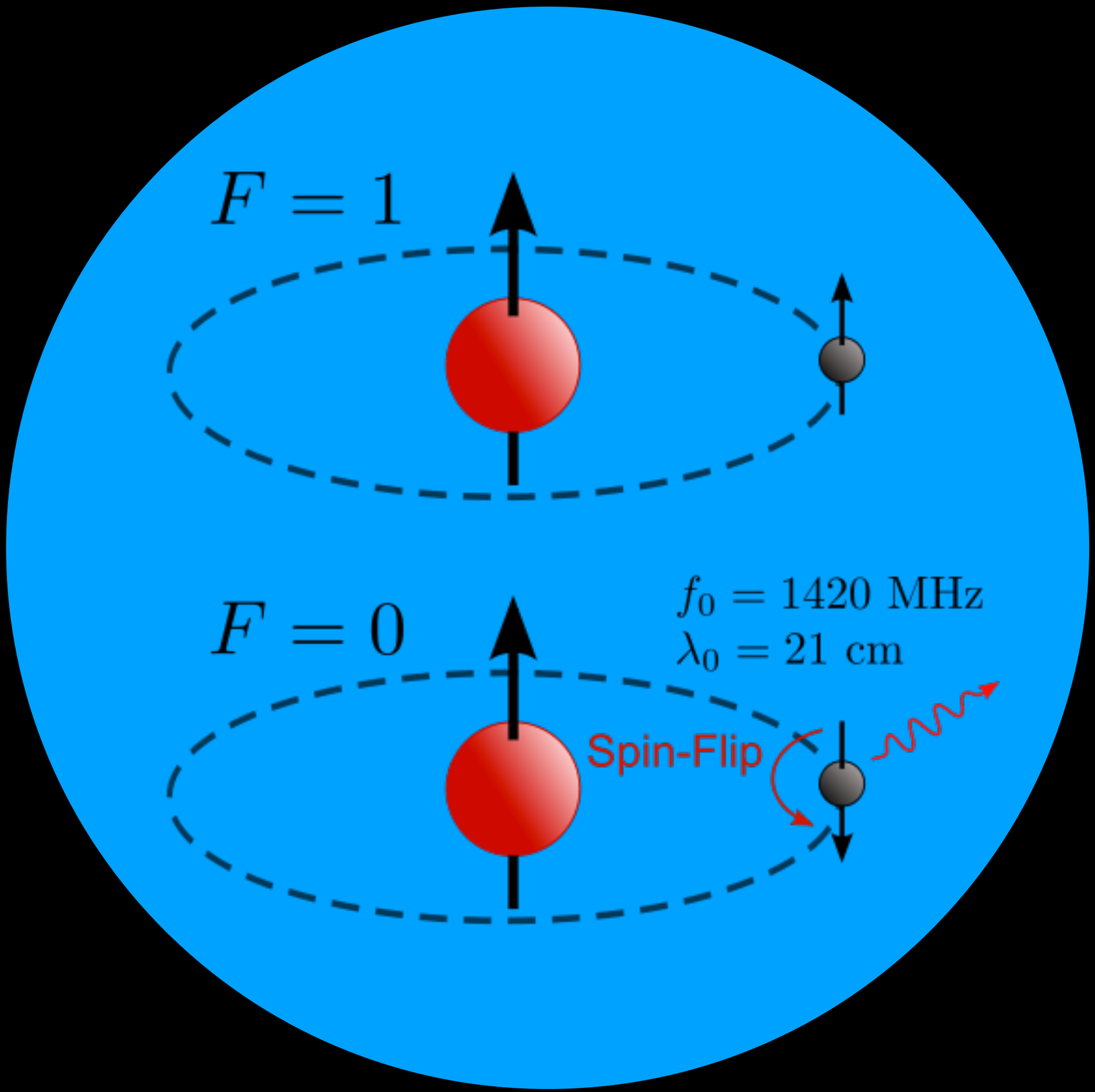


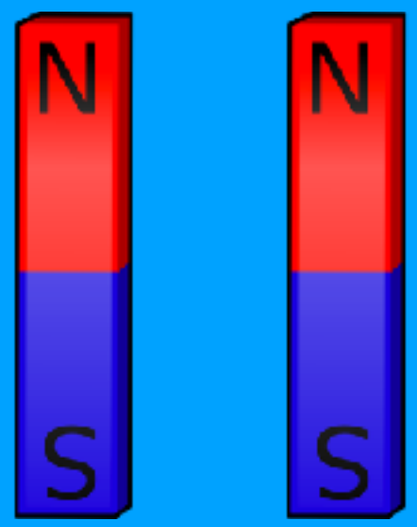


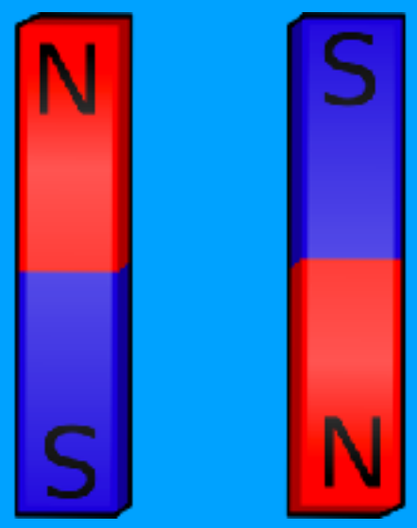
$$\frac{\Delta f}{f} = \frac{\Delta V}{c}$$

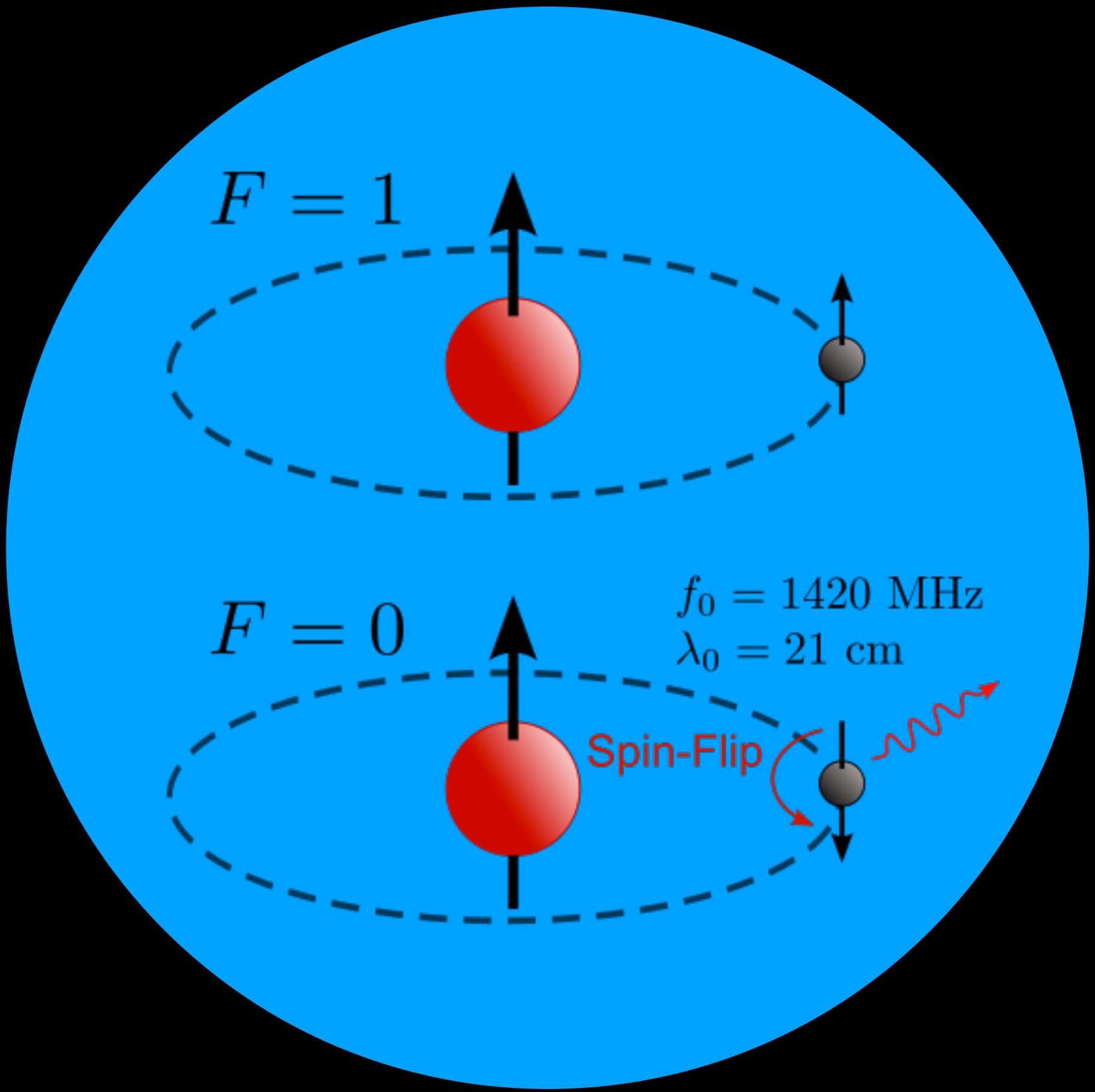
$$\frac{\Delta f}{f} = \frac{\Delta V}{c}$$


$+\Delta V$
$-\Delta V$


$F = 1$
$F = 0$
$f_0 = 1420$ MHz
$\lambda_0 = 21$ cm
Spin-Flip


N
S
N
S


N
S
S
N


$F = 1$
$F = 0$
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Spin-Flip

Galactic Longitude

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Scutum-Centaurus Arm

Sagittarius Arm

Norma Arm

Perseus Arm

Outer Arm

Far 3kpc Arm

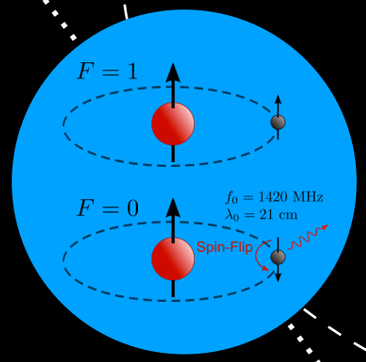
Near 3kpc Arm

Galactic Bar

Long Bar

Line of Sight

GC



Line of Sight

V_2

GC

$F = 1$

$F = 0$

$f_0 = 1420$ MHz

$\lambda_0 = 21$ cm

Spin-Flip

V_1

Line of Sight

V_2

γ

GC

V_1

Line of Sight

V_2

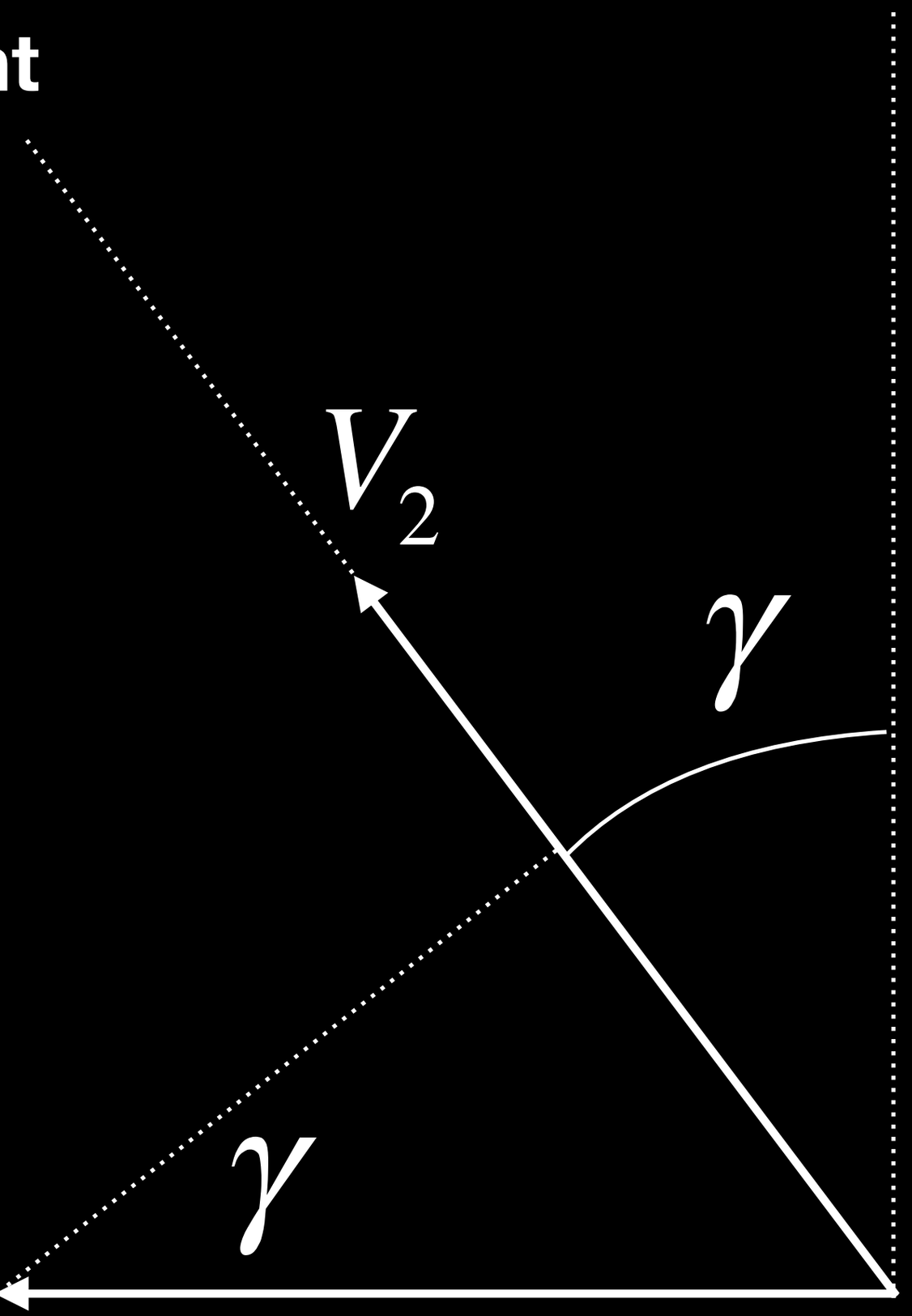
γ

γ

V_1

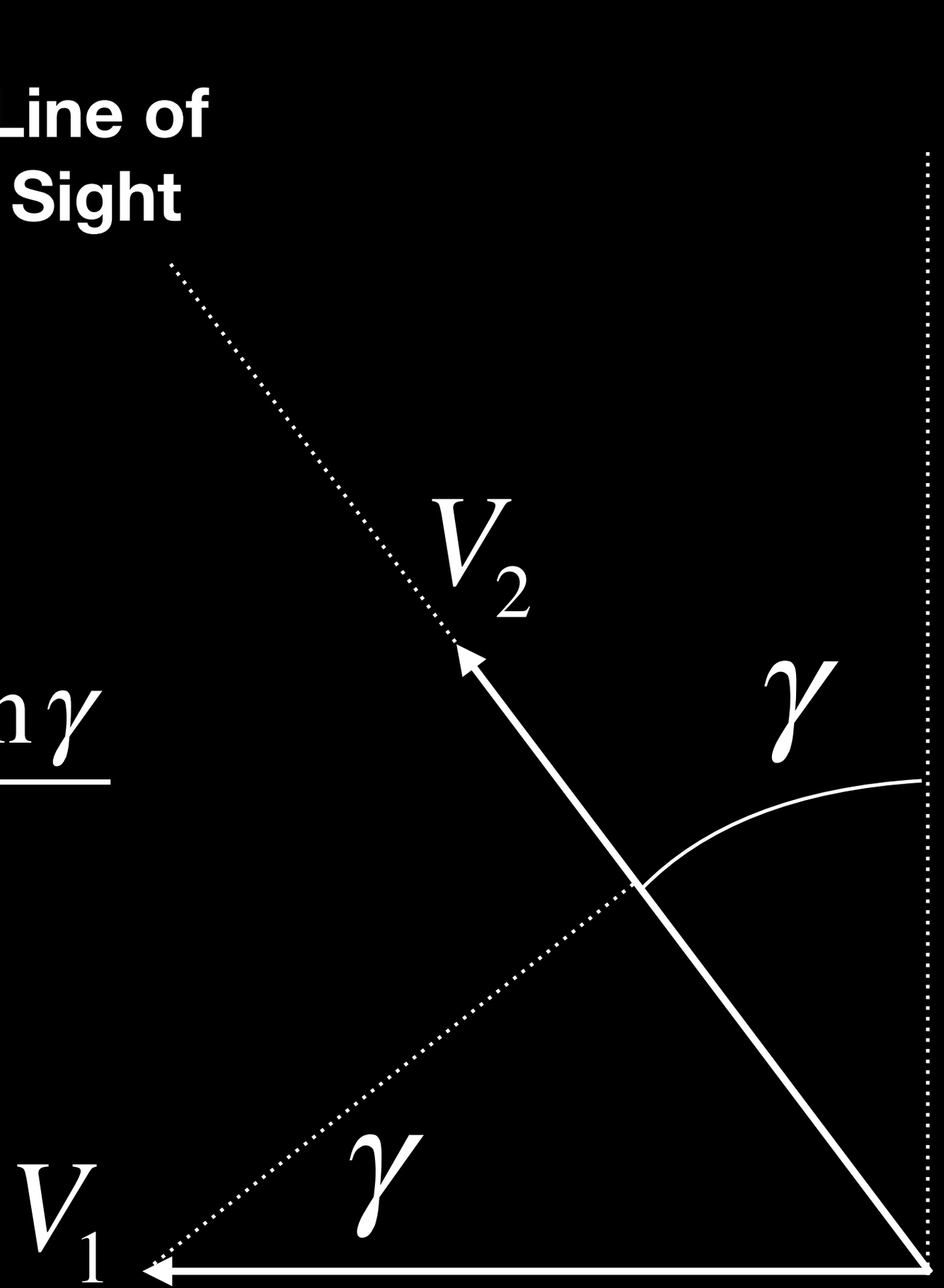
Line of Sight

$$\Delta V = V_2 - V_1 \sin\gamma$$



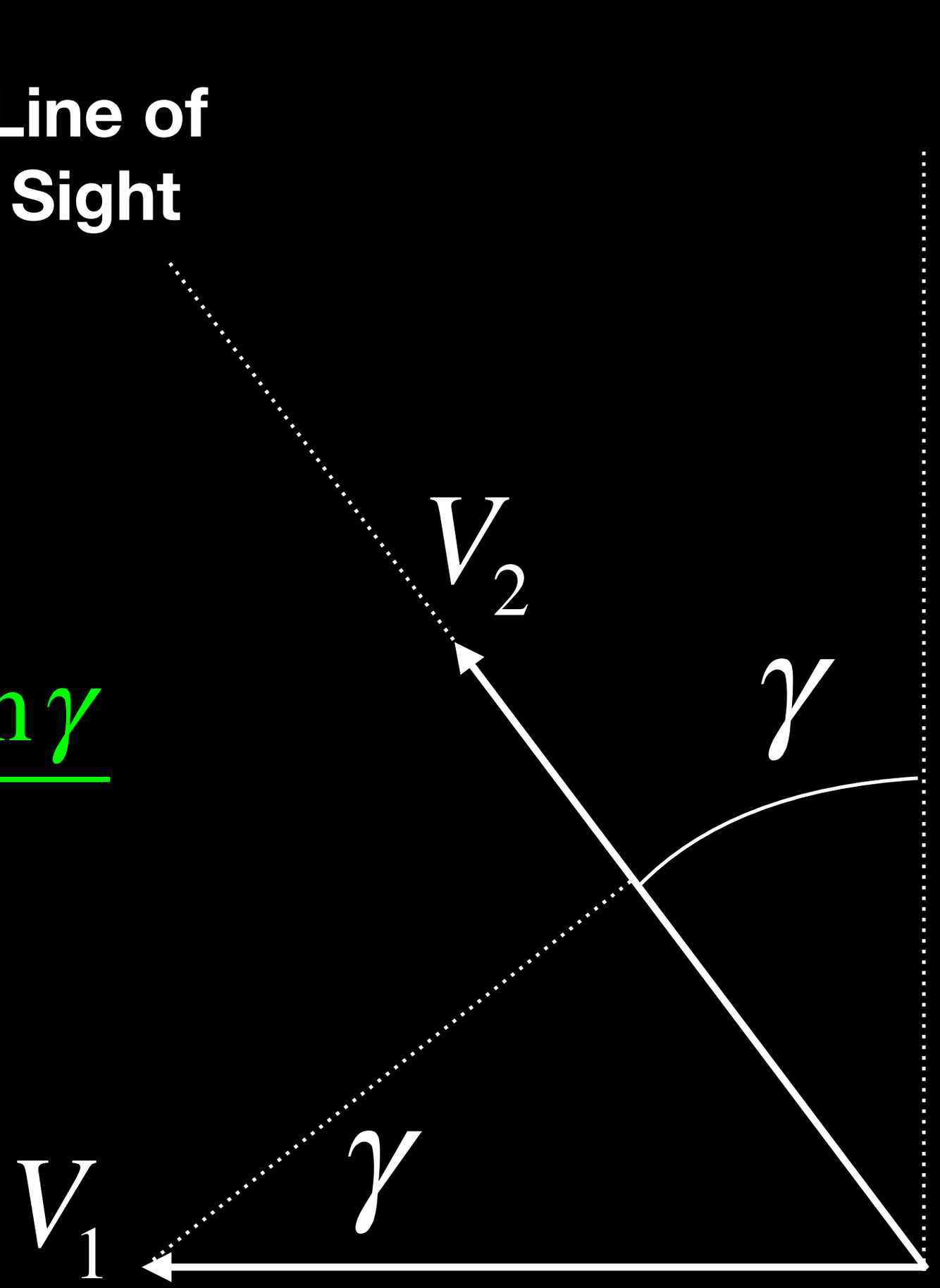
Line of Sight

$$\frac{\Delta f}{f} = \frac{V_2 - V_1 \sin\gamma}{c}$$



Line of Sight

$$\frac{\Delta f}{f} = \frac{V_2 - V_1 \sin\gamma}{c}$$

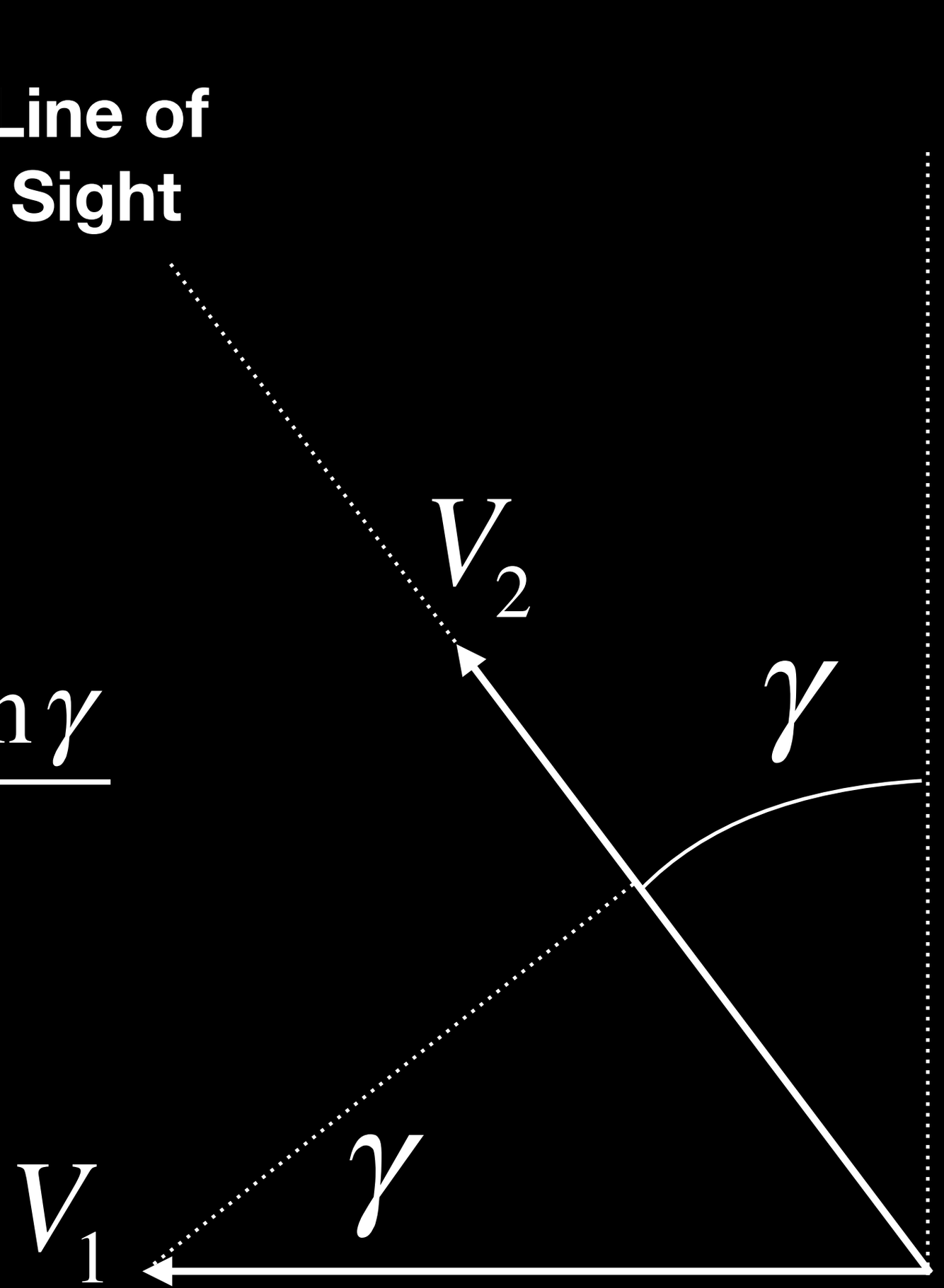


$$V(R) \approx \text{Constant}$$

$$V_1 \approx V_2$$

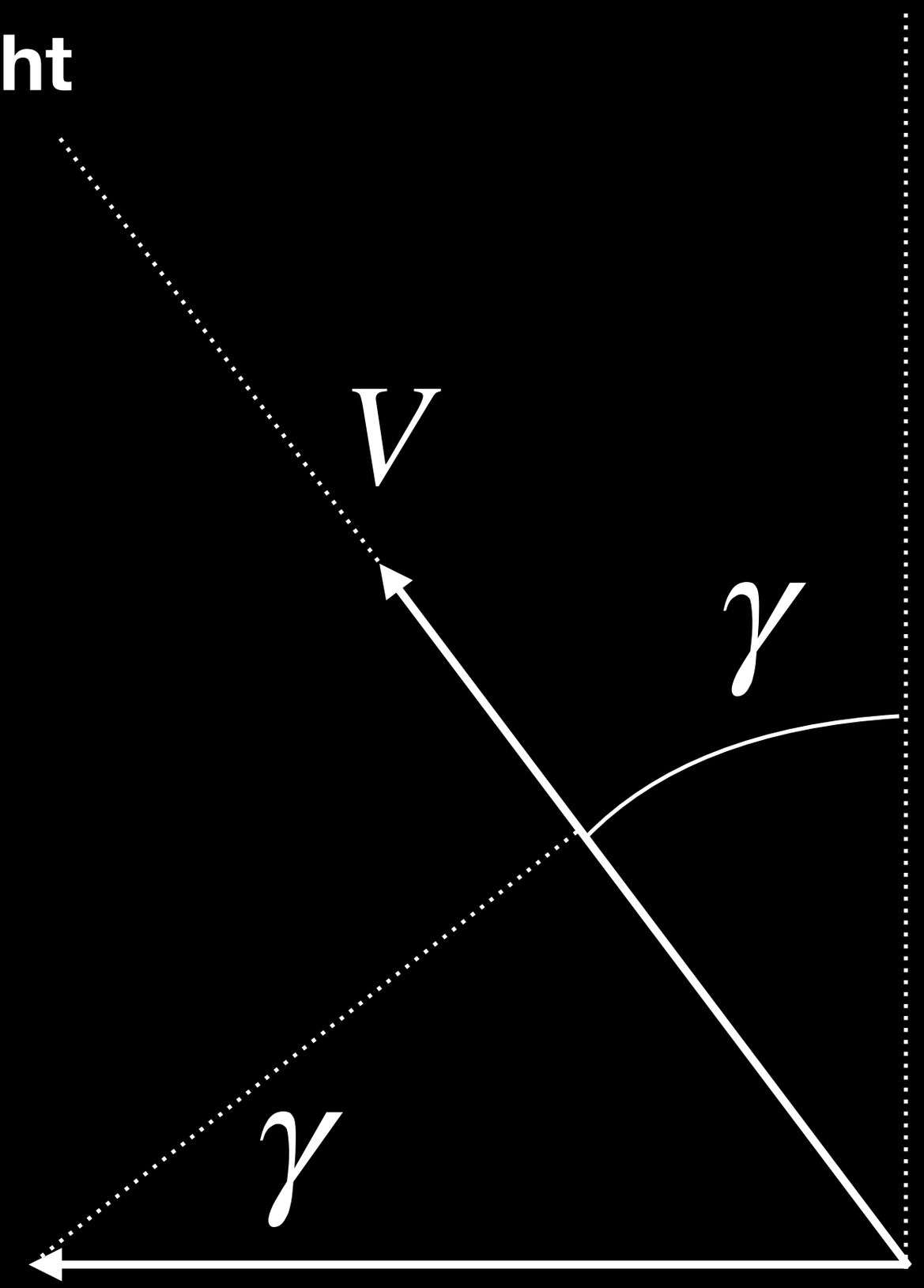
Line of Sight

$$\frac{\Delta f}{f} = \frac{V_2 - V_1 \sin\gamma}{c}$$



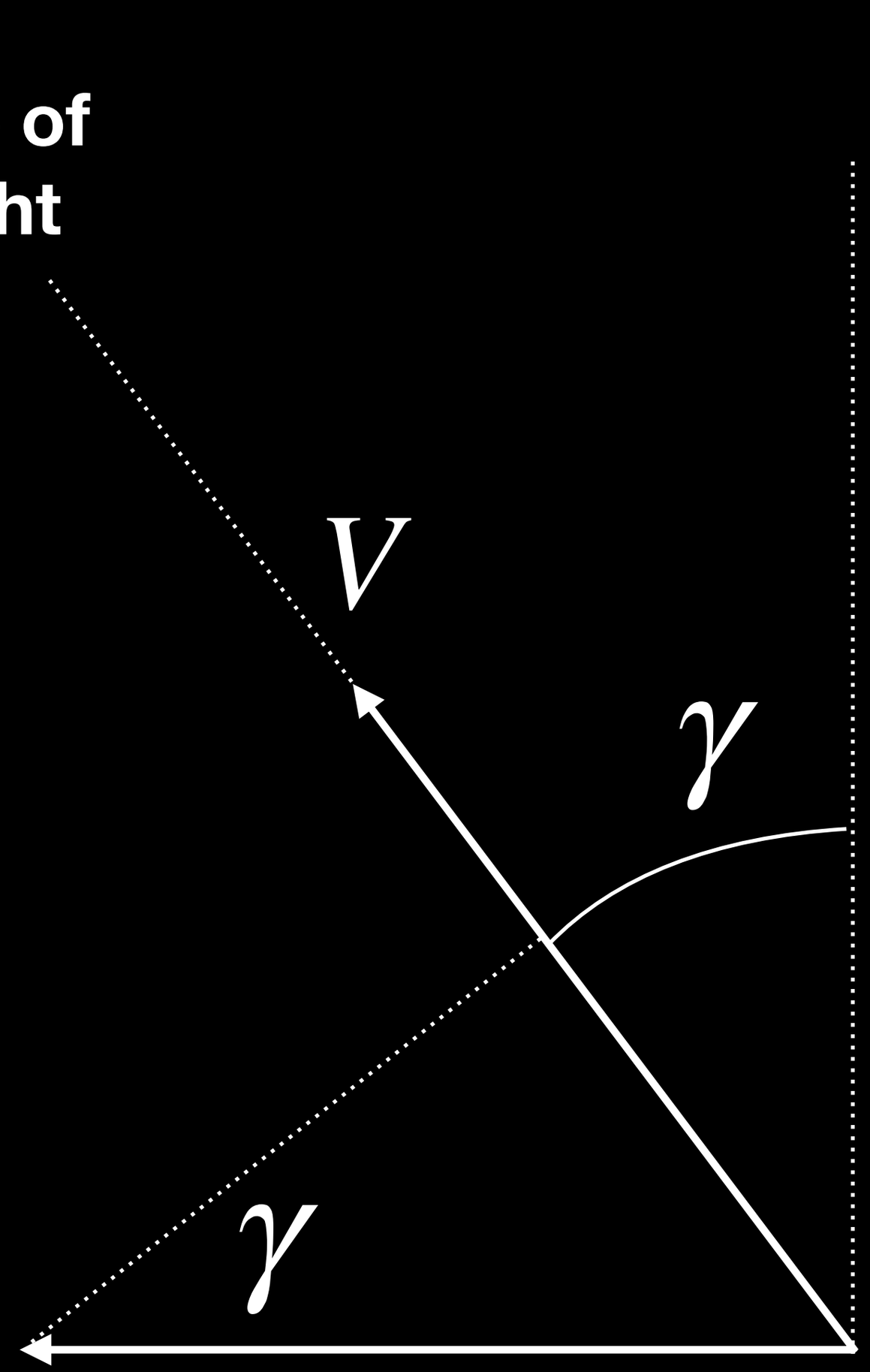
Line of Sight

$$\frac{\Delta f}{f} = \frac{V(1-\sin\gamma)}{c}$$



Line of Sight

$$\frac{\Delta f}{f} = \frac{V(1-\sin\gamma)}{c}$$



$$V^2 = \frac{GM}{R}$$

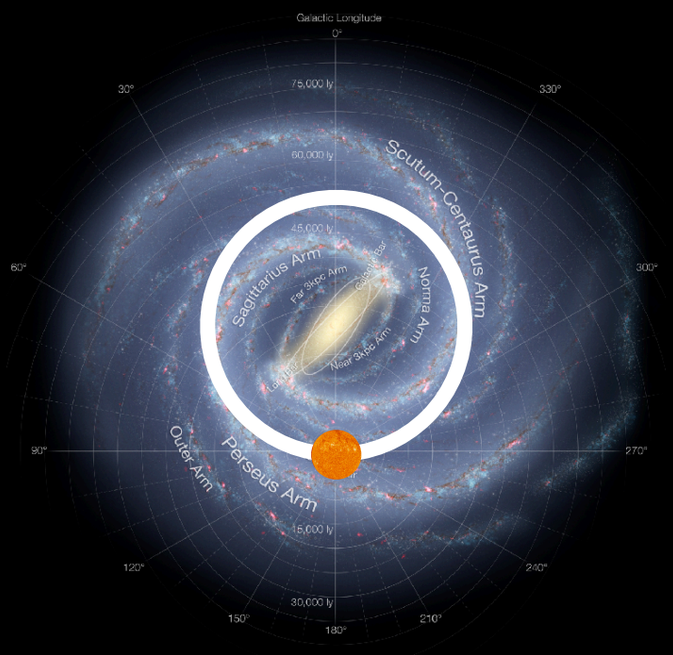
$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

$$\frac{\Delta f}{f} = -\frac{\Delta V}{c}$$

$$\frac{\Delta f}{f} = \frac{V(1-\sin\gamma)}{c}$$

$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$



$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

$$V \approx 200\,km/s$$

$$G \approx 4 \times 10^{-6}\,kpc M_{\odot}^{-1} (km/s)^2$$

$$R \approx 8\,kpc$$

$$M_{Gal} \approx ??$$

$$a_c = \frac{V^2}{R} = \frac{GM}{R^2}$$

$$V \approx 200\,km/s$$

$$G \approx 4 \times 10^{-6}\,kpc M_\odot^{-1} (km/s)^2$$

$$R \approx 8\,kpc$$

$$M_{Gal} \approx 10^{11} M_\odot$$

$$M_{Gal} \approx 10^{11} M_{\odot}$$

$$M_{*} \approx 2-10 \times \text{Smaller}$$

Evidence for Dark Matter!

Concepts

Doppler Shift:
How fast is the sun moving?
What is a “Galactic Year”?

Centripetal Acceleration:
How massive is the galaxy?
Dark Matter!

Extensions

Multiple Galactic longitudes:
Provide evidence for V(R)=Constant
(“flat rotation curve”)
Also evidence for Dark Matter

Many more physics concepts.