In watching you fall into Sun
and your light is bending

Who says I'm falling
I feel no forces and light moves straight
according to me

\[ \Delta y \approx \frac{1}{2} gt^2 \]

Sun Center
Estimate:

\[ \frac{1}{2} g_{\text{sun}} \Delta t^2 \{ \Delta \theta/2 \} \]

\[ c \Delta t \sim R \]

Range over which the sun's gravitational pull is large.

Now use:

1. \( g_{\text{sun}}(R) \sim \frac{GM_0}{R^2} \)

2. The time over which the sun's gravity bends the light is \( c \Delta t \sim R \).

When \( c \Delta t \) is much larger than \( R \), the gravity is weak.

3. \( R \sim R_0 \), our light rays skim the sun.

So...
\[ \Theta \sim \frac{1}{2} \frac{g_{\text{sun}}(R)}{c^2} \Delta t^2 \]

\[ \Theta \sim \frac{G M_0}{c R^2} \cdot \frac{R}{c} \]

\[ \Theta \sim \frac{G M_0}{c^2 R} \]

Taking
\[ G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg s}^2 \]
\[ M_0 = 2 \times 10^{30} \text{ kg} \]
\[ R_0 = 700,000 \text{ km} \]
So
\[ \Theta \approx 0.43'' \text{ arcsec} \]

A proper General Relativistic treatment gives
\[ \Theta \approx 1.75 \text{ arcsec} \]

Incidentally, Einstein originally predicted
\[ \Theta \approx 0.87 \text{ arcsec} \] well
But corrected the result later (Before the experiment in 1919)
and at night at a different time of the year

Compare angles between the stars during a solar eclipse.

Measure the deflection of starsight as it goes near the sun.

Measuring the bending of light
The men of the 1919 measurement – Einstein, Eddington, Dyson
Eddington and Dyson travel to the tropics at Sobral and Princeipe
...And set up telescopes in the Tropics and at Cambridge...
London (Courtesy of the Science Museum, 1979) during the 1979 eclipse. The mirror on the left was the chief suspect in the poor quality of the plates. The plates during an exposure were at the same position on images taken by a mechanical mirror that are driven by a mechanism. The field of view is in the circular tube on the right and the astrograph lens is in the square tube. The 4-inch lens is in the square.

The photographic plate

Record image on plate.
The experimental result agrees with Einstein's prediction of 1.7 arcsec.
Gravitational lensing in observational astronomy

Light from distant quasars bends around intermediate galaxy

Earth

Quasar Image

Quasar Image

Quasar Image

Galaxy

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Black Holes

Imagine you could contract the sun to a small point.

\[ \Delta \theta \]
\[ \Delta \theta \]
\[ \Delta \theta \]

Then, as Newton taught us, the force is the same.

Further, the deflection of light at a given radius is the same.

But, you can send the light much closer to the force center.

The angle gets larger. Eventually, when the radius is smaller than a certain radius \( R_{SCH} = \text{Schwarzschild Radius} \), the angle becomes of order \( 90^\circ \) and the light doesn't escape.
$R_{\text{sch}}$, light cannot escape from this inner circle.

Let's estimate the Schwarzschild radius.

From before:

$$\Delta \theta \sim \frac{G M}{c^2 r}$$

Deflection $\Delta \theta$ for how close we get to the sun.

We can estimate the Schwarzschild radius by setting the angle to

$$90^\circ = \frac{\pi}{2} \text{ rad}$$

So,

$$\frac{\pi}{2} \sim \frac{G M}{c^2 R_{\text{sch}}}$$

$$R_{\text{sch}} \sim \frac{G M}{c^2 \left(\frac{\pi}{2}\right)}$$

Actual General Relativistic Corrections show that

$$R_{\text{sch}} = \frac{2 G M}{c^2}$$