Probing Graviton Mass

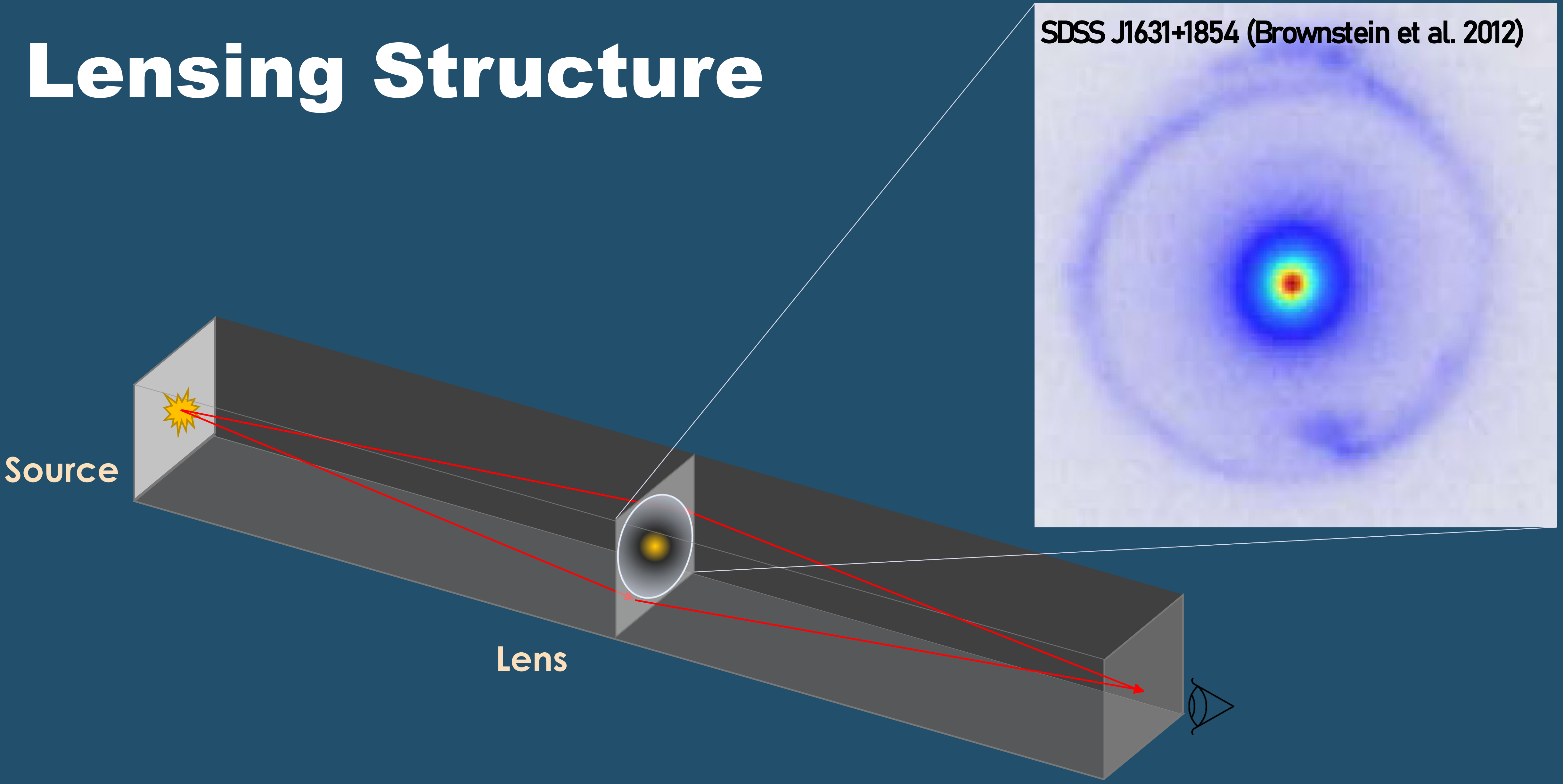
Through Strong Lensed Gravitational waves

Shuaibo Geng

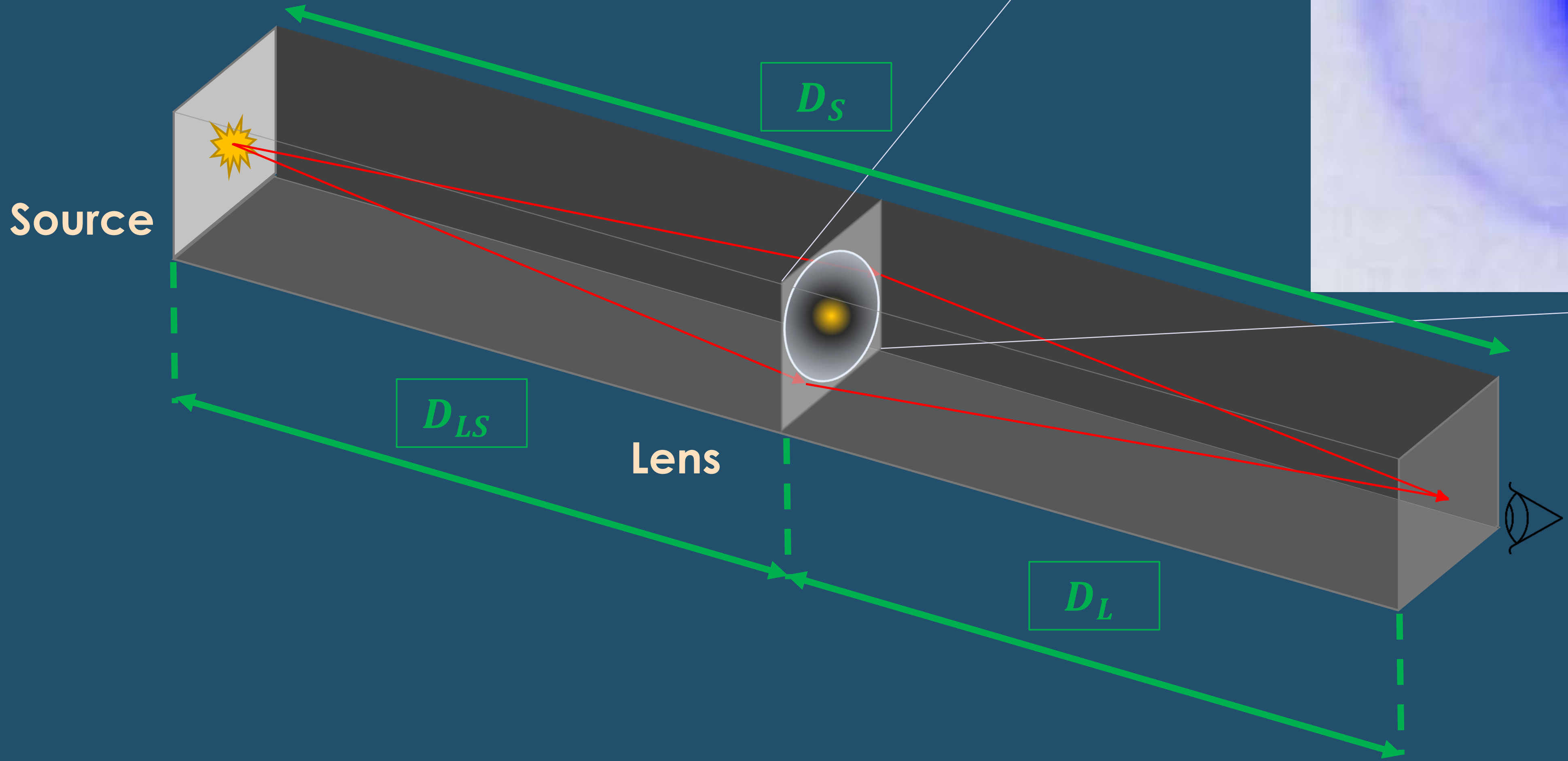
Collaborators : Sreekanth Harikumar, Marek Biesiada

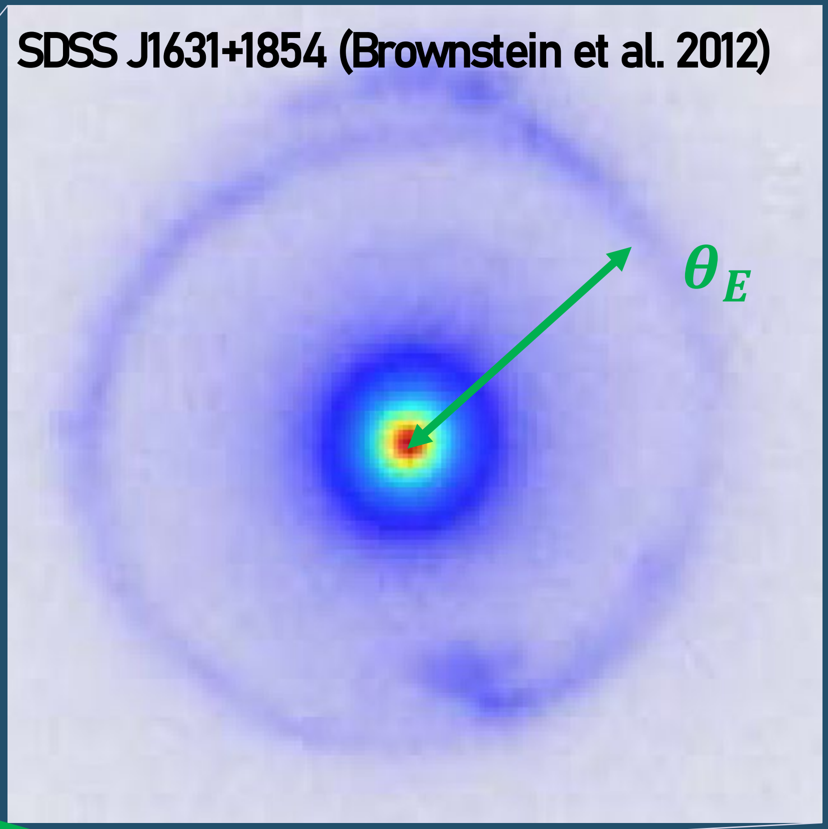
NCBJ PAiP-2025

Lensing Structure

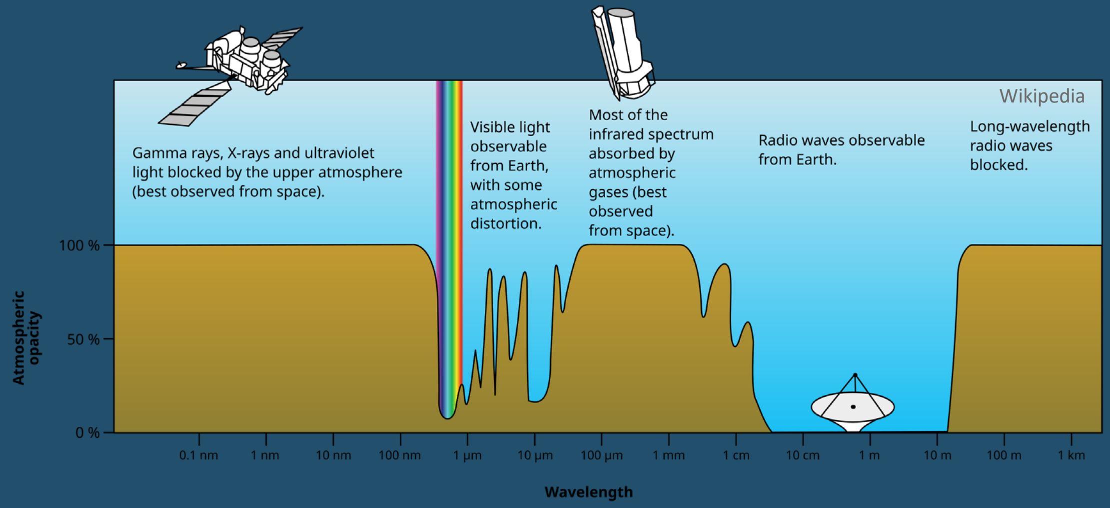


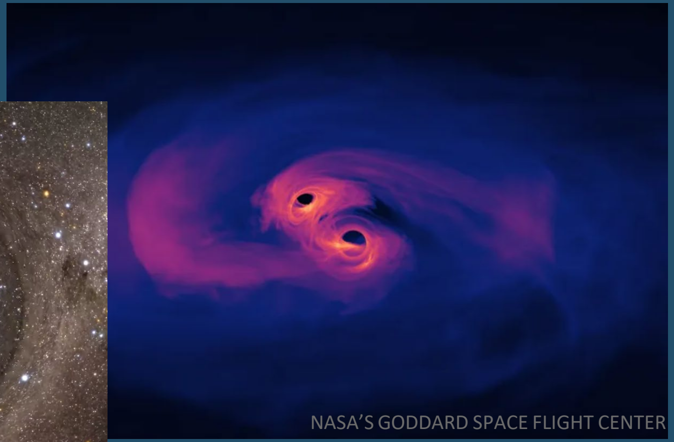
Lensing Structure

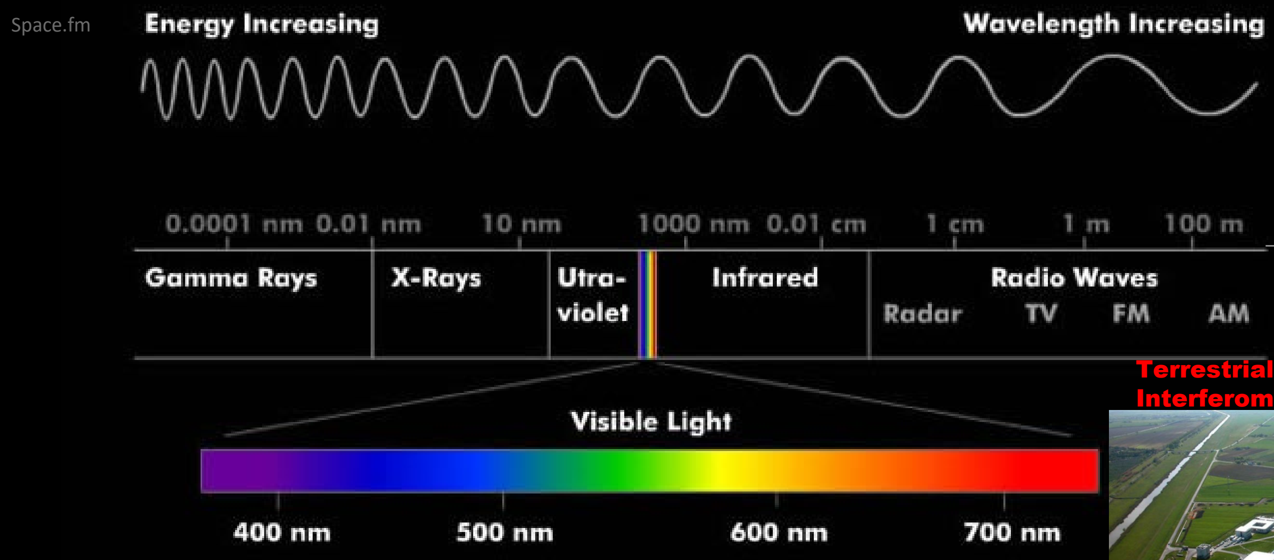


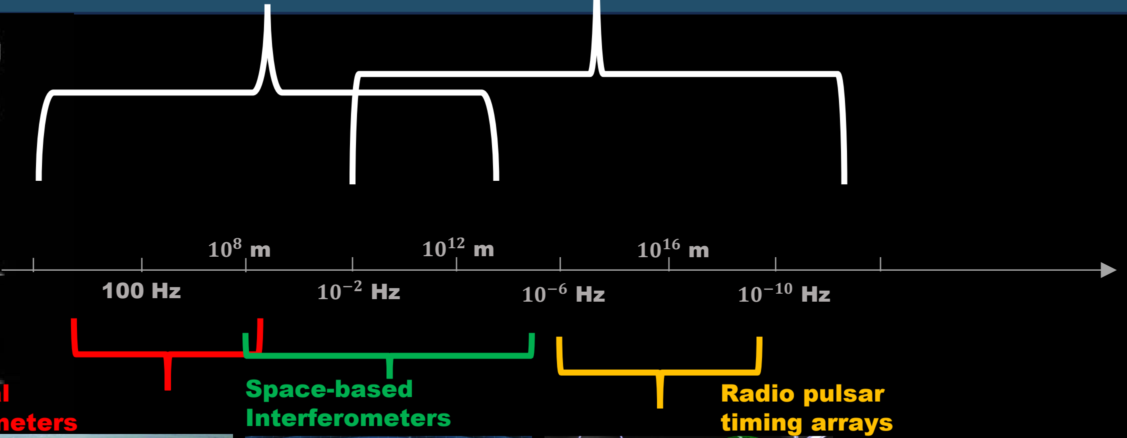


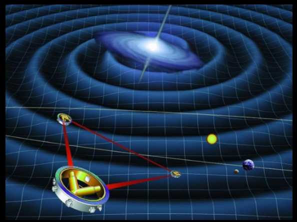
EM+GW spectrum

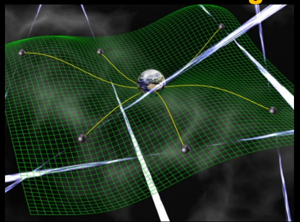




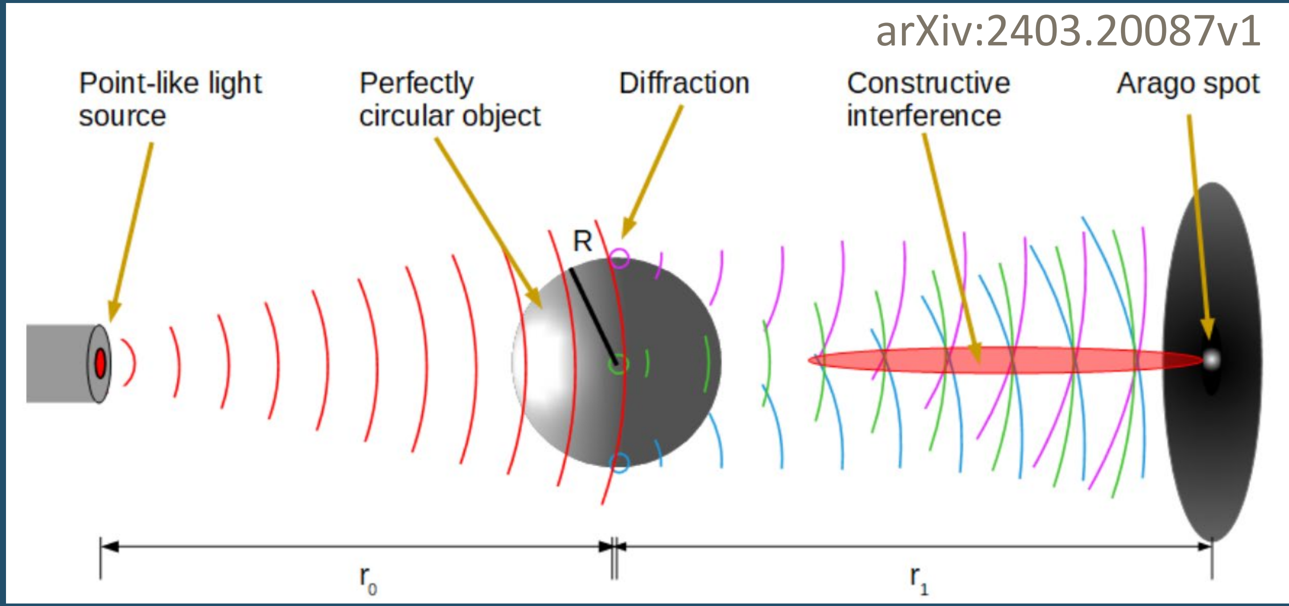


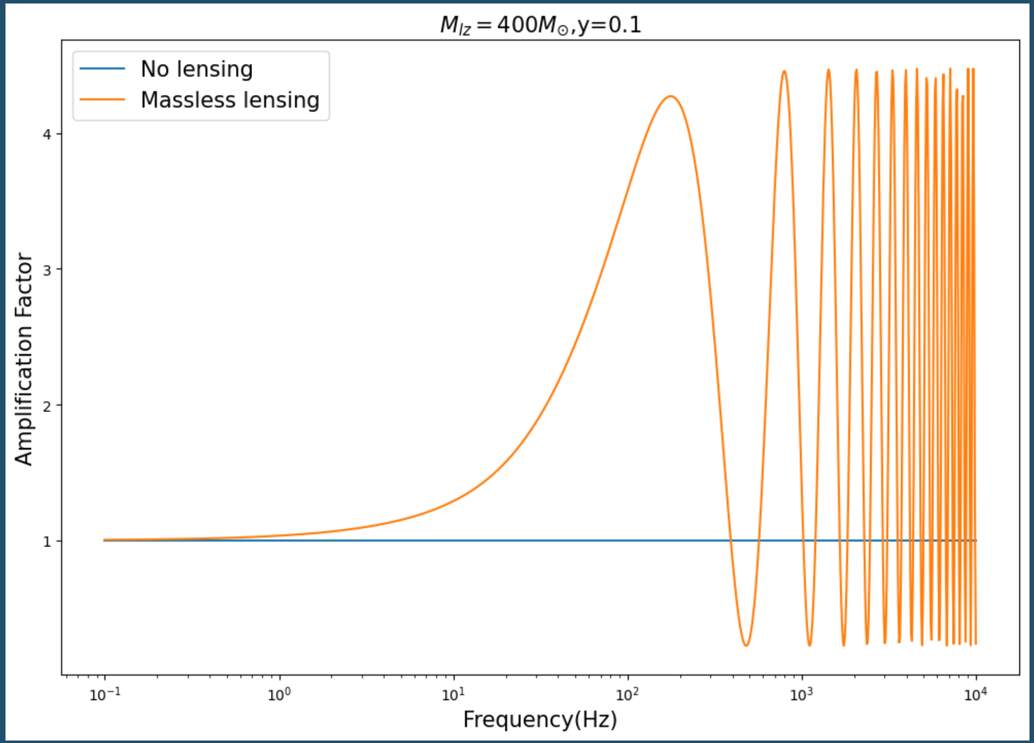






Wave optics effect





Amplification Factor

$$F(\omega) = \frac{h^L}{h} = \frac{w}{2\pi i}\iint_{\Sigma} e^{iwT(\vec{x},\vec{y})} dx^2$$

$$T(\vec{x},\vec{y}) = \left[\frac{(\vec{x}-\vec{y})^2}{2} - \psi(\vec{x}) + \phi_m(\vec{y})\right],$$

$$w = 2\pi f \frac{1+z_l}{c}\frac{D_L D_S}{D_{LS}}\theta_{\rm Ein}^2$$

Probe graviton mass

Do gravitational waves propagate at the speed of light?
What if the graviton has mass?

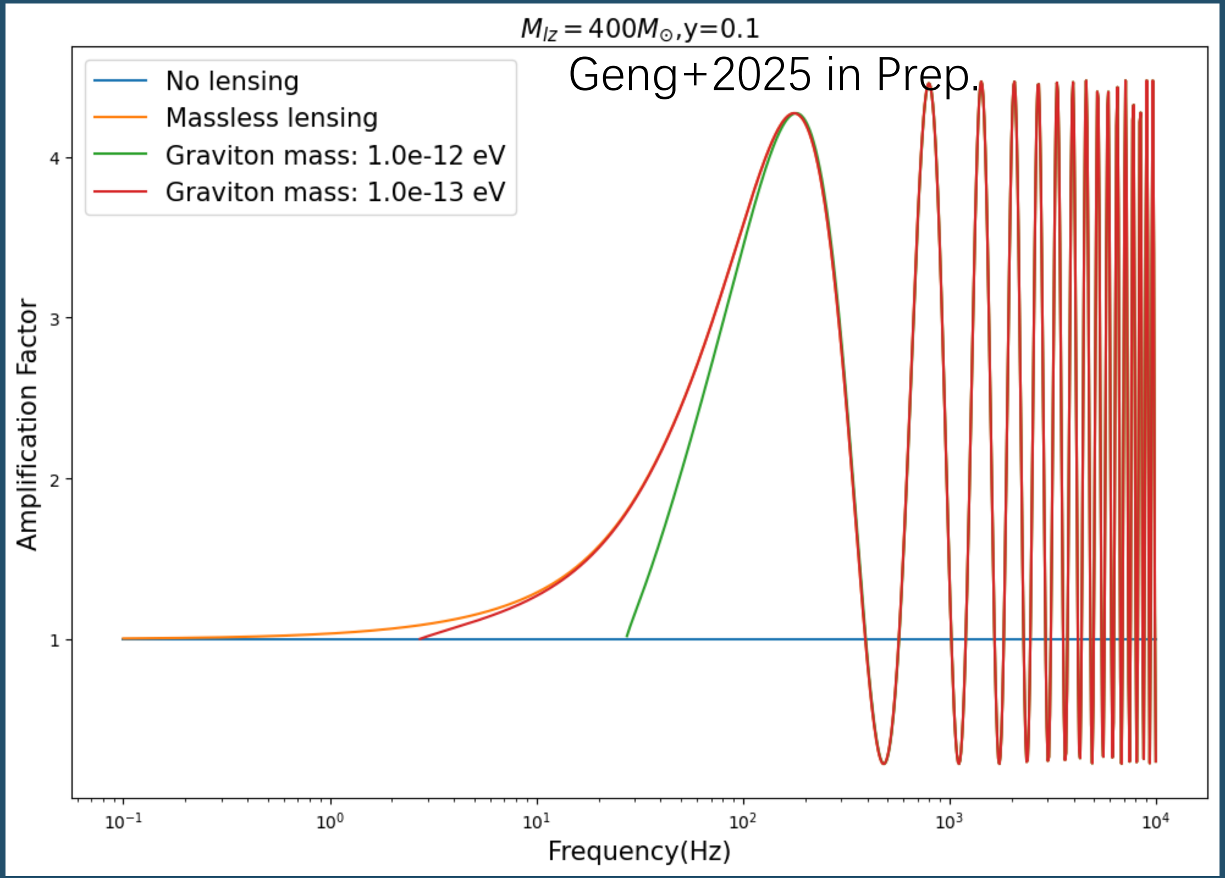
$$m^2c^4 = \hbar^2\omega^2 - \hbar^2k^2c^2$$

$$k^2 = \frac{\omega^2}{c^2} - \frac{m^2c^2}{\hbar^2} = (1 - \frac{m^2c^4}{h^2f^2})\frac{\omega^2}{c^2}$$

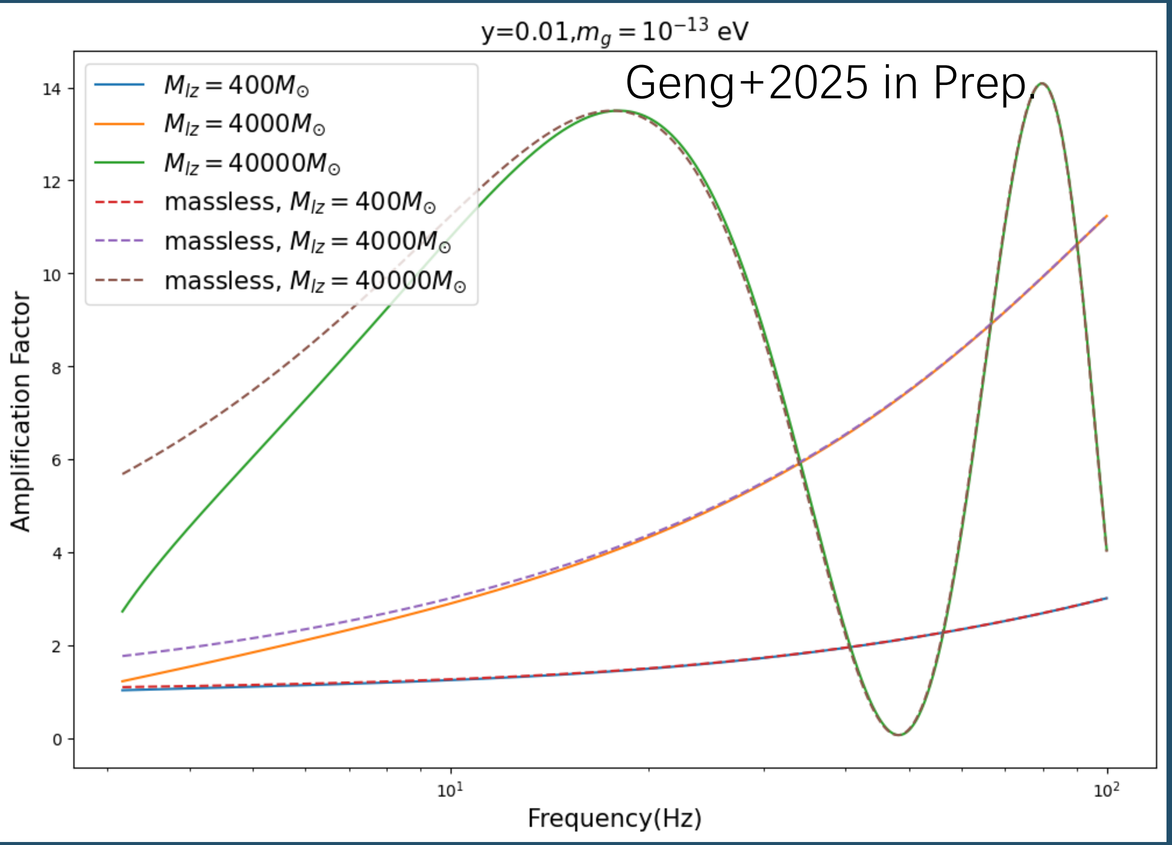
$$|k| \simeq (1 - \frac{m^2c^4}{2\hbar^2\omega^2})\frac{\omega}{c} = \frac{\omega}{c} - \frac{m^2c^4}{2c\hbar^2\omega}$$

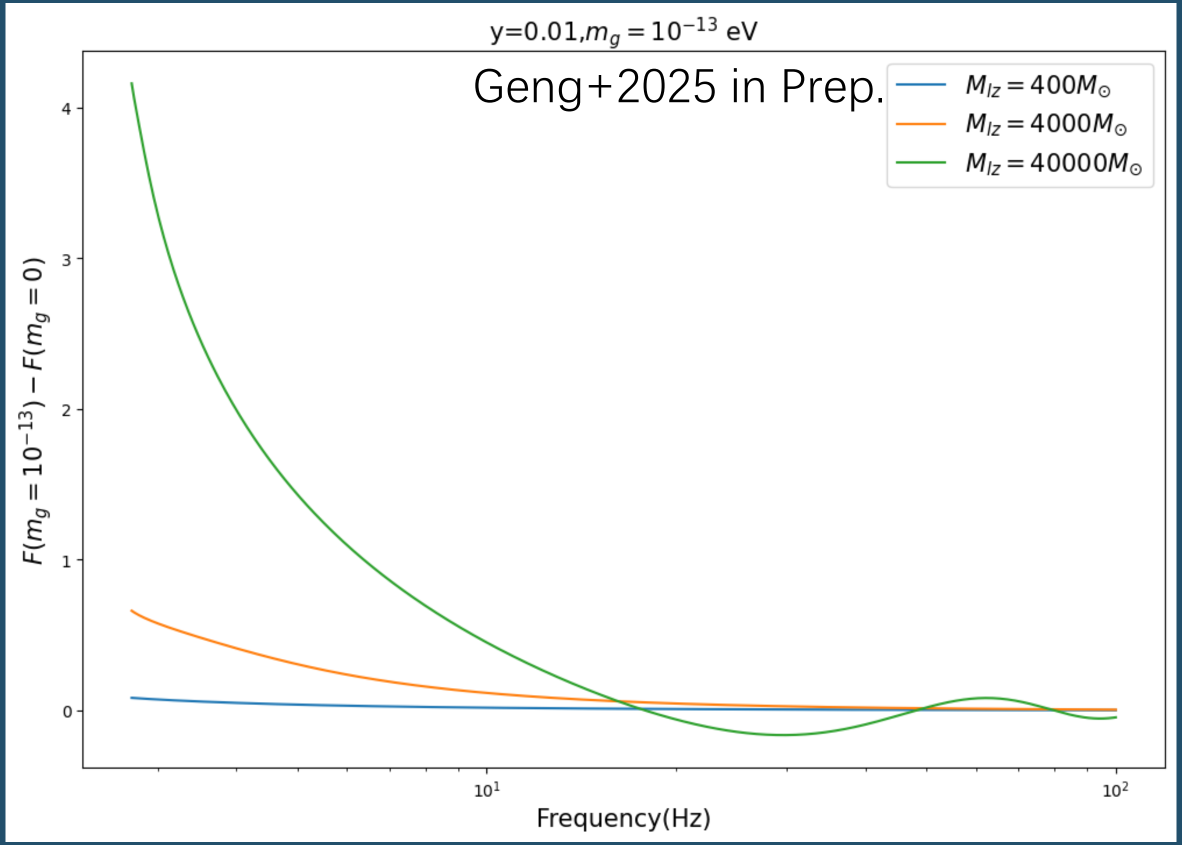
$$g(\omega, \mathbf{r}) = h(\omega, \mathbf{r})\, e^{-iar/\omega}$$

$$a = \frac{m_g^2c^4}{2\hbar^2(1+z)}$$



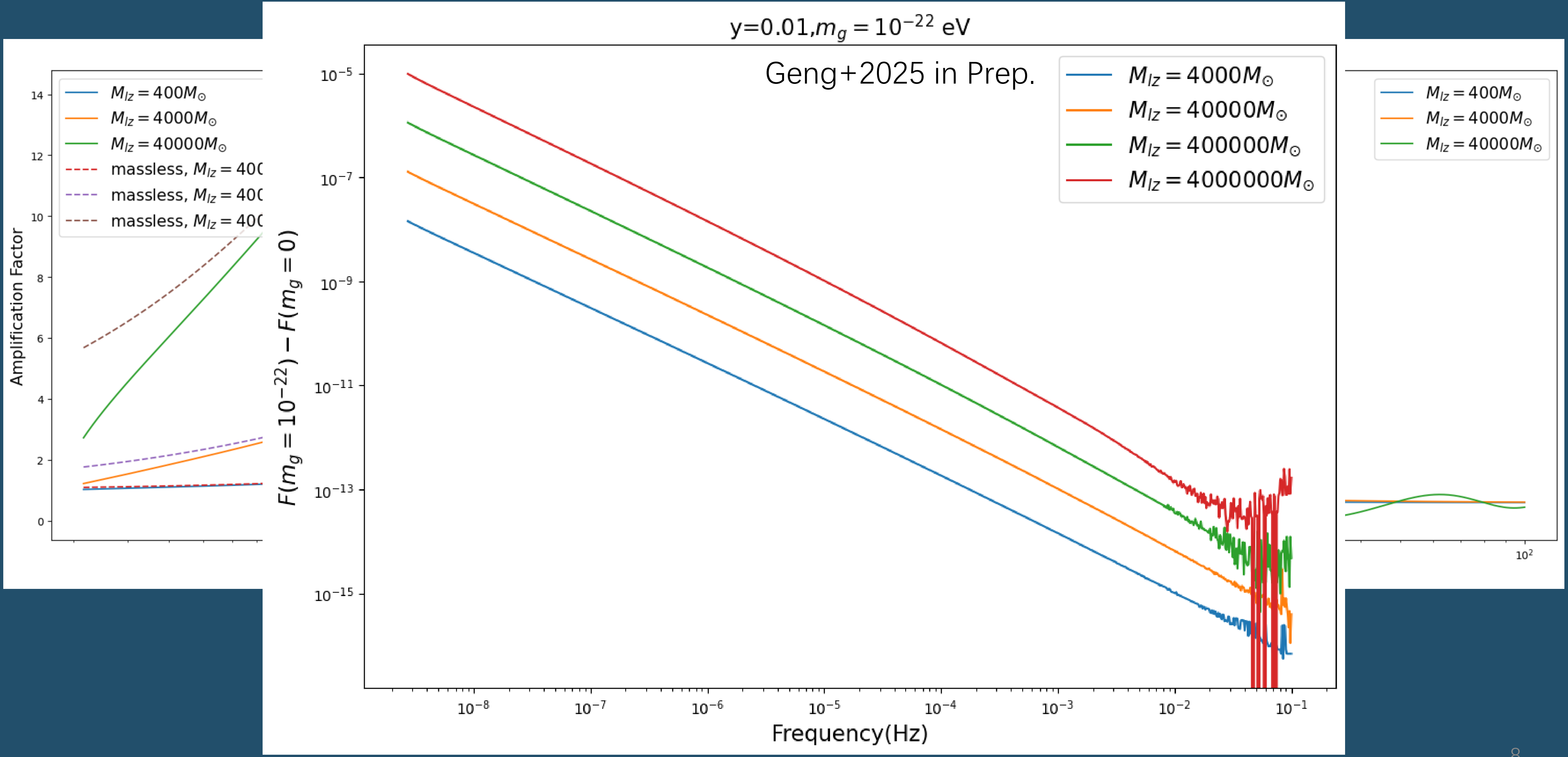
Lensed massive GW





$$M_{lz}=(1+z)M_{lens}$$

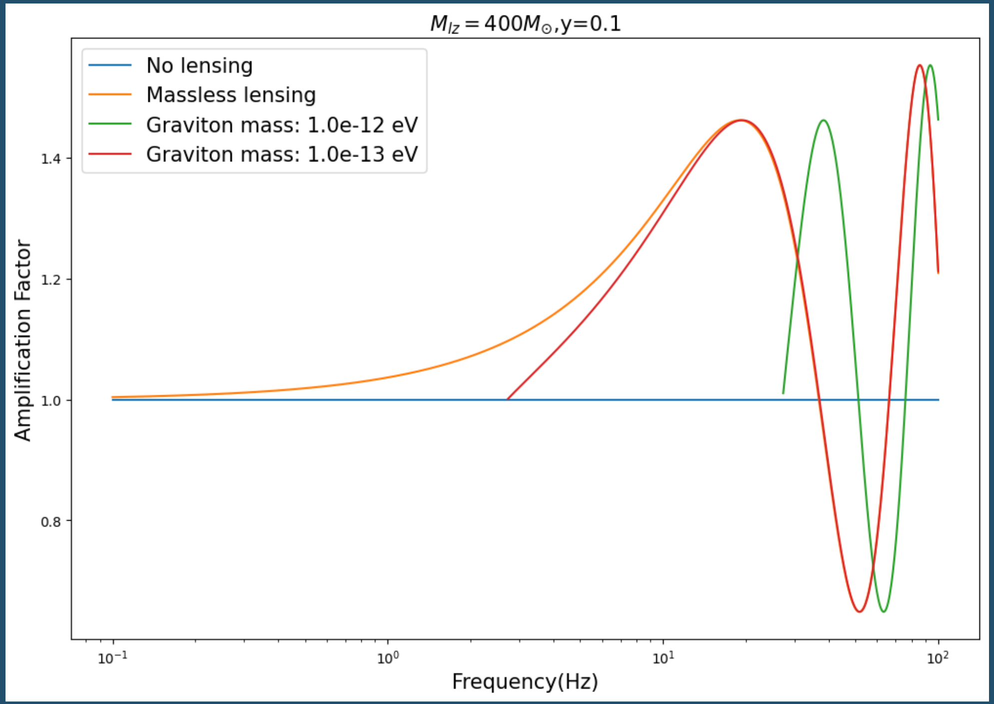
Lensed massive GW



Take-home message

Take-home message

- **Massive lensing:**
  Oscillation + Strain difference
- **Why lensing?**
  No lensing, no strain difference
- **How to detect lower mass graviton?**
  Lower frequency source
  More massive lens
  More sensitive detector



Take-home message

- **Massive lensing:**
  Oscillation + Strain difference
- **Why lensing?**
  No lensing, no strain difference
- **How to detect lower mass graviton?**
  Lower frequency source
  More massive lens
  More sensitive detector

$$g(\omega, \mathbf{r}) = h(\omega, \mathbf{r})\, e^{-iar/\omega}$$

$$a = \frac{m_g^2 c^4}{2\hbar^2(1+z)}$$

Take-home message

- **Massive lensing:**
  Oscillation + Strain difference
- **Why lensing?**
  No lensing, no strain difference
- **How to detect lower mass graviton?**
  Lower frequency source
  More massive lens
  More sensitive detectors