The Gravitational-Wave Background

Anisotropies and Cosmic Strings

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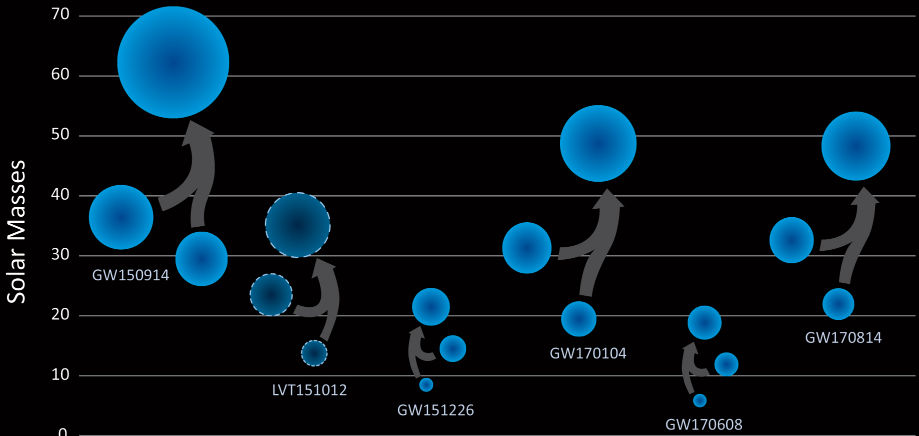
YTF10
12 January 2018

Black Holes of Known Mass



LIGO/VIRGO

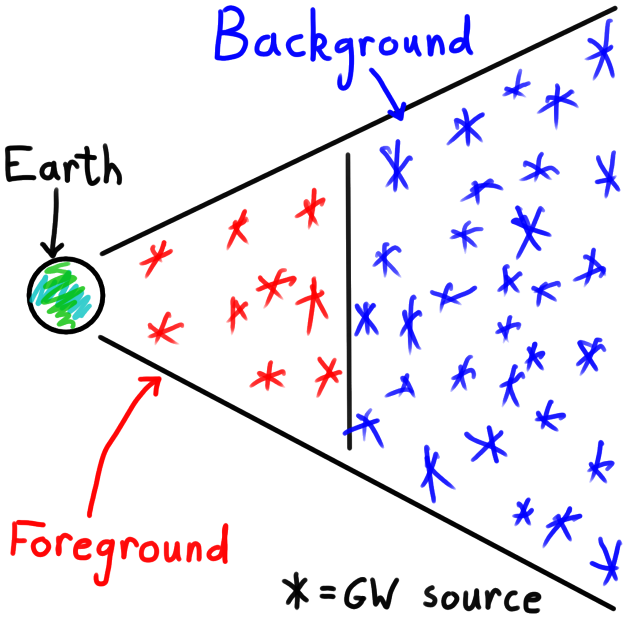
Astrophysics

- Black hole and neutron star populations
- Binary formation
- Gamma-ray burst physics
- Neutron star equation of state
- . . .

Gravity

- Graviton mass
- Lorentz invariance
- Equivalence principle
- . . .

Cosmology?



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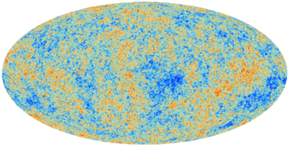
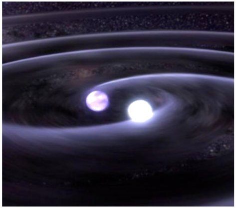
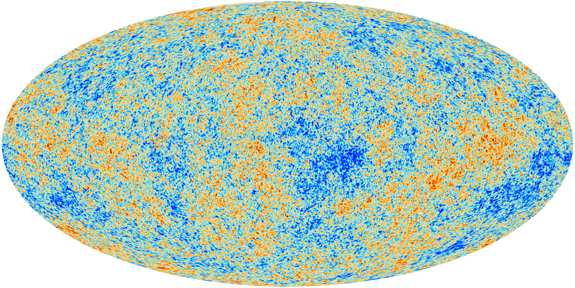
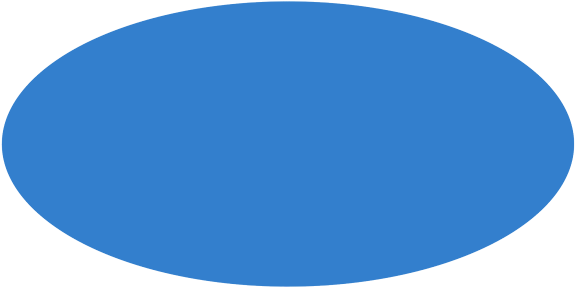
	Fore-ground	Back-ground
EM		
GW		SGWB?

Anisotropies are important!





SGWB energy density

$$\Omega_{\mathrm{gw}}(\nu_{\mathrm{o}}, \hat{\mathbf{e}}_{\mathrm{o}}) \equiv \frac{1}{\rho_{\mathrm{c}}} \frac{\mathrm{d}^3 \rho_{\mathrm{gw}}}{\mathrm{d}(\ln \nu_{\mathrm{o}})\, \mathrm{d}^2 \sigma_{\mathrm{o}}}$$

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SGWB energy density

Observation direction

GW energy density

$$\Omega_{\rm gw}(\nu_{\rm o}, \hat{\mathbf{e}}_{\rm o}) \equiv \frac{1}{\rho_{\rm c}} \frac{\mathrm{d}^3 \rho_{\rm gw}}{\mathrm{d}(\ln \nu_{\rm o})\, \mathrm{d}^2 \sigma_{\rm o}}$$

Observed frequency

Critical density

Solid angle

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Main result

$$\Omega_{\mathrm{gw}} = \frac{\pi\nu_{\mathrm{o}}^3}{3H_{\mathrm{o}}^2}\int_0^{\eta_{\mathrm{o}}}\mathrm{d}\eta\, a^2\int\mathrm{d}\zeta\, nR(1+\hat{\boldsymbol{e}}_{\mathrm{o}}\cdot\boldsymbol{v}_{\mathrm{o}})\int_{S^2}\mathrm{d}^2\sigma_{\mathrm{s}}\, r_{\mathrm{s}}^2\tilde{h}^2$$

Developed from G. Cusin, C. Pitrou, & J.-P. Uzan; arXiv:1704.06184

Main result

$$\Omega_{\rm gw} = \frac{\pi \nu_{\rm o}^3}{3 H_{\rm o}^2} \underbrace{\int_0^{\eta_{\rm o}} \mathrm{d}\eta\, a^2}_{\text{Time integration}} \int \mathrm{d}\zeta\, nR(1 + \hat{\mathbf{e}}_{\rm o} \cdot \mathbf{v}_{\rm o}) \underbrace{\int_{S^2}}_{\text{Sphere around source}} \mathrm{d}^2\sigma_{\rm s}\, r_{\rm s}^2 \tilde{h}^2$$

Parameters → ζ

Burst rate → R

GW strain (Fourier) → $\tilde{h}$

Time integration

Source num. density → n

Our peculiar velocity → $\mathbf{v}_{\rm o}$

Sphere around source

Developed from G. Cusin, C. Pitrou, & J.-P. Uzan; arXiv:1704.06184

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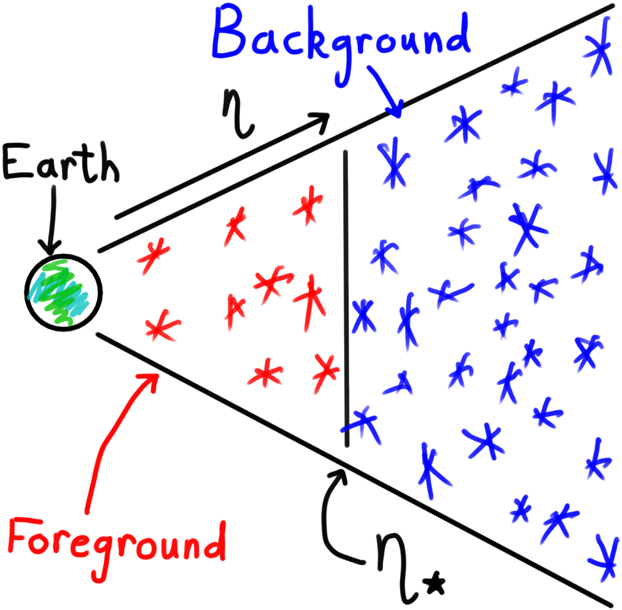
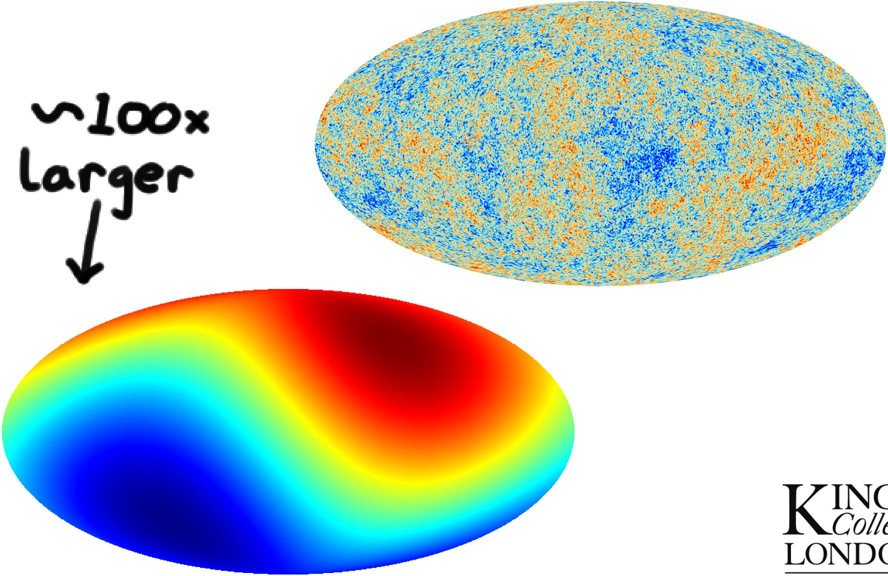
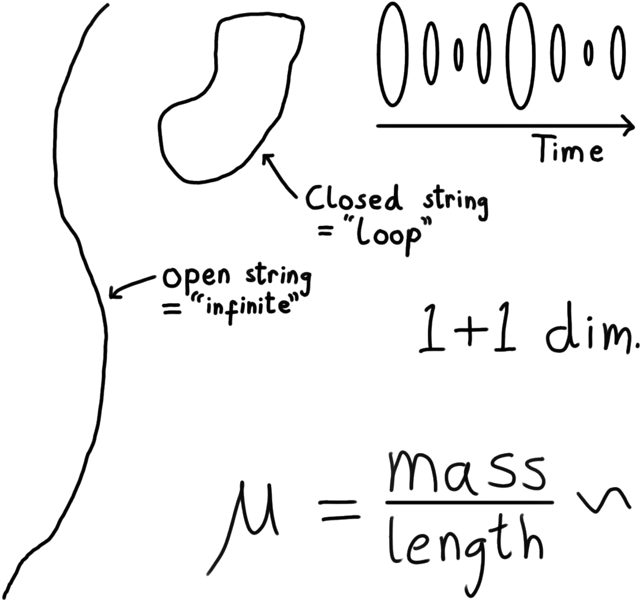

Background
η
Earth
Foreground
η_*

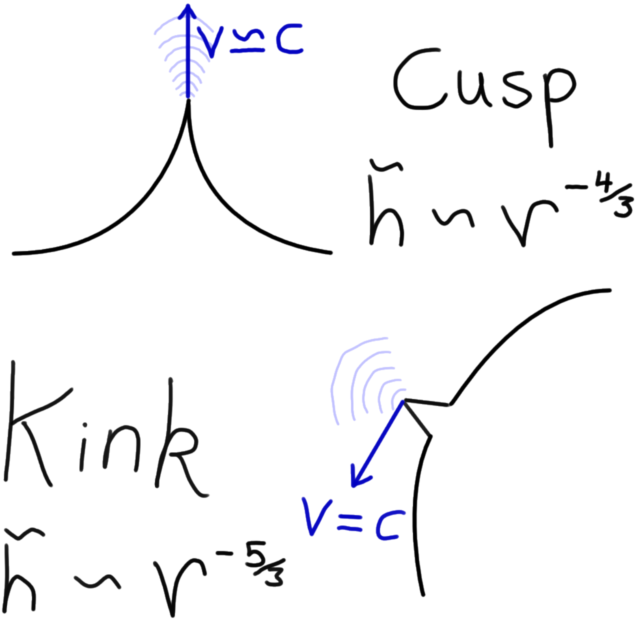
Kinematic dipole



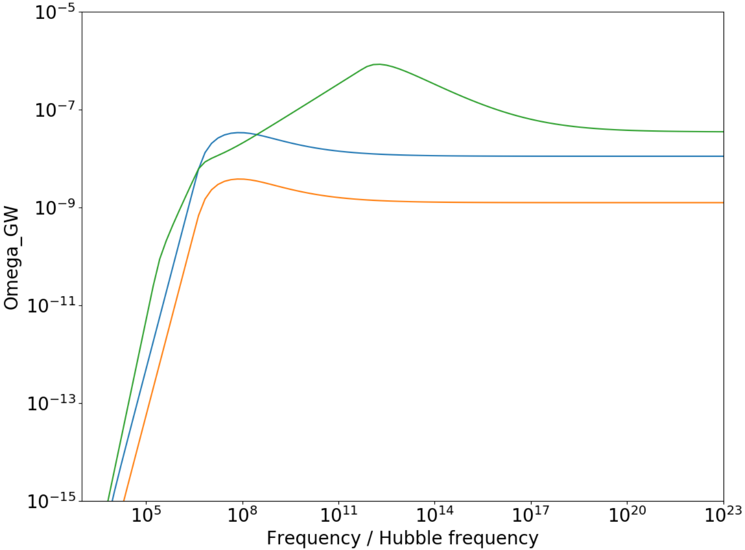


1+1 dim.

$$\mu = \frac{\text{mass}}{\text{length}} \sim E^2$$


v ≃ c
Cusp
$\tilde{h} \sim \nu^{-4/3}$
Kink
$\tilde{h} \sim \nu^{-5/3}$
v = c

The Homogeneous Background



Summary

- GW background anisotropies are important
- Powerful new analytical framework
- Important constraints for cosmic strings
- Much more on the way!

Thanks for listening!

Characterising the anisotropies

$$\delta_{\mathrm{gw}} = \delta_{\mathrm{gw}}^{(\mathrm{s})} + \mathcal{D}_{\mathcal{F}}\, \hat{\boldsymbol{e}}_{\mathrm{o}} \cdot \boldsymbol{v}_{\mathrm{o}}$$

$$C_{\mathrm{gw}}(\theta_{\mathrm{o}}, \nu_{\mathrm{o}}) \equiv \left\langle \delta_{\mathrm{gw}}^{(\mathrm{s})} \delta_{\mathrm{gw}}^{(\mathrm{s})} \right\rangle$$

Characterising the anisotropies

Source anisotropies

Dipole factor

$$\delta_{\rm gw} = \delta^{(\rm s)}_{\rm gw} + \mathcal{D}_{\mathcal{F}}\, \hat{\mathbf{e}}_{\rm o} \cdot \boldsymbol{v}_{\rm o}$$

$$C_{\rm gw}(\theta_{\rm o}, \nu_{\rm o}) \equiv \underbrace{\left\langle \delta^{(\rm s)}_{\rm gw} \delta^{(\rm s)}_{\rm gw} \right\rangle}_{\text{Avg. over sky}}$$

Angle of separation