Stringy features

- M_s, $\ell_s \sim 1/M_s$, $g_s \ll 1$
- $M_{pl} = \dfrac{M_s}{g_s^{\frac{2}{D-2}}}$
- $R_s = \ell_s$ $\qquad \sqrt{S_*} = \dfrac{M_s}{g_s^2}$
- stringy in eff $\qquad \sqrt{S_{str}} > \dfrac{M_s}{g_s}$

* tidal effects $\quad b \gg \ell_s \quad$ (t-channel)

stringy eikonal. (ti

* s-channel production $\quad b \lesssim \ell_s \sqrt{\log \ell_s^2 s}$

tree-level

(transverse spreading)

Corr. to the phase shift

$$T(s,t) = 8\pi G_N \left(\frac{su}{t} + \frac{tu}{s} + \frac{st}{u} \right) \frac{\Gamma(1-\alpha' s)\,\Gamma(1-\alpha' t)\,\Gamma(1-\alpha' u)}{\Gamma(1+\alpha' s)\,\Gamma(1+\alpha' t)\,\Gamma(1+\alpha' u)}$$

$$s+t+u=0.$$

$$T(s,t) = -8\pi G_N \frac{s^2}{t}\left[s^{2\alpha' t} \frac{\Gamma(1-\alpha' t)}{\Gamma(1+\alpha' t)} 2^{-\alpha' t} e^{-i\pi\alpha' t} \right]$$

$\alpha' s \gg 1$

$$\underbrace{T(s,b)}_{2\delta(s,b)} = \frac{1}{2s}\int d^{D-2}\vec{q}\, e^{i\vec{b}\cdot\vec{q}}\, T(s,-\vec{q}^{\,2})$$

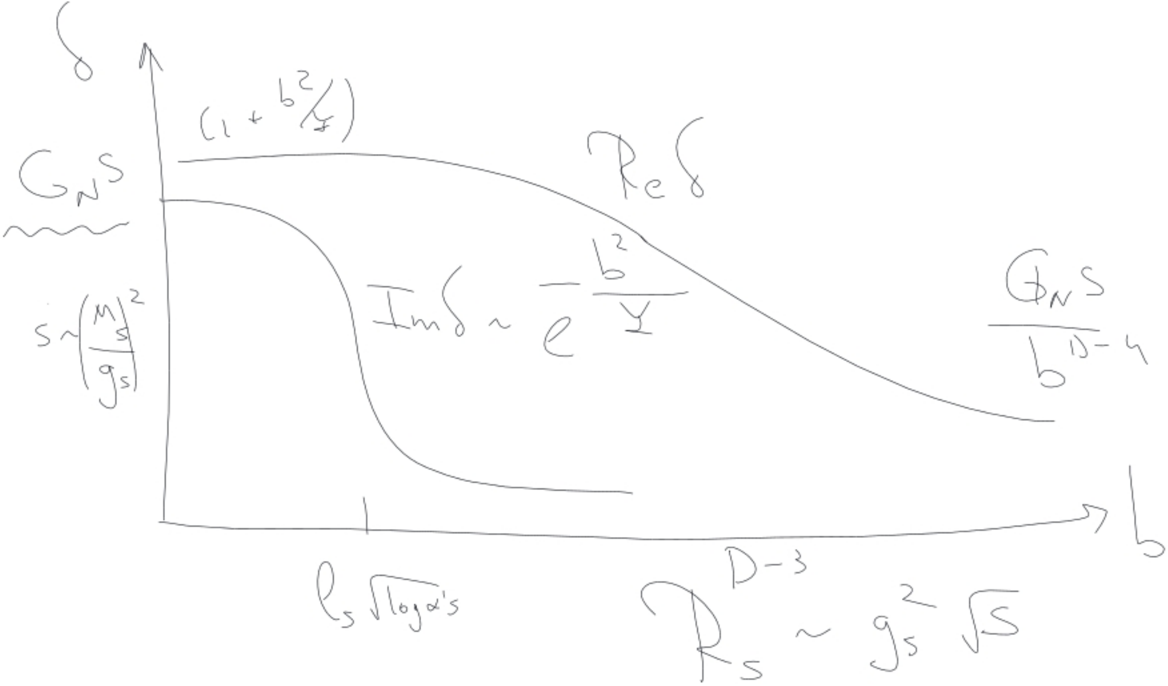
$$Y = s l_s^2 \log\left(-i s l_s^2 / 2\right) \sim l_s \sqrt{\log l_s^2 s}$$

$$\cdot\ b \gg \sqrt{Y} \qquad\qquad -\frac{b^2}{Y}$$

$$T(s,b) = T_{GR}(s,b) + \frac{G_N s}{b^{D-4}} e$$

- $b \ll \sqrt{Y}$

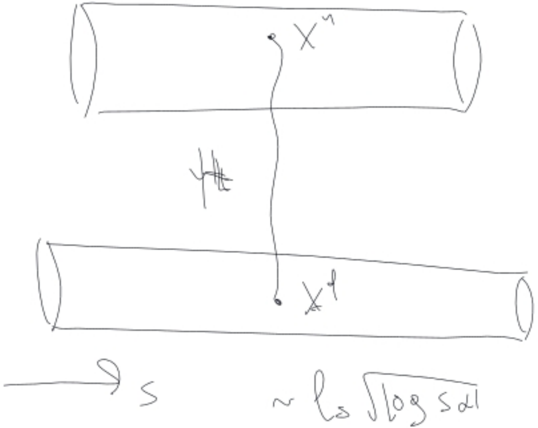
$$T(s,b) = \frac{2 G_N s}{\left(\sqrt{Y}\right)^{D-4}} \left(\frac{1}{D-4} - \frac{1}{D-2} \frac{b^2}{4Y} + \right)$$

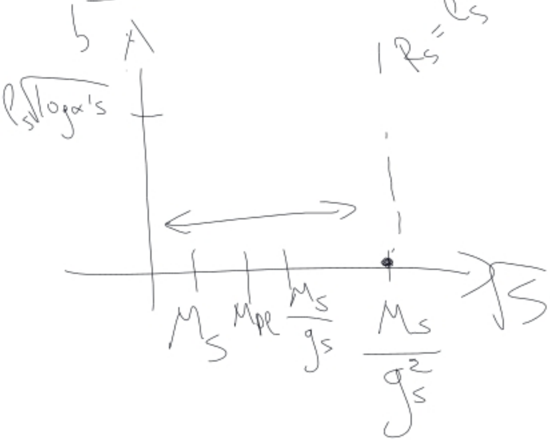


δ
$(1 + b^2/Y)$
$G_N s$
$s \sim \left(\frac{M_s}{g_s}\right)^2$
$\mathrm{Re}\,\delta$
$\mathrm{Im}\,\delta \sim e^{-\frac{b^2}{Y}}$
$\frac{G_N s}{b^{D-4}}$
b
$l_s \sqrt{\log \alpha' s}$
$R_s^{D-3} \sim g_s^2 \sqrt{s}$

$$\boxed{R_s \ll \ell_s}$$

$$\begin{cases} (G_N\sqrt{s})^{\frac{1}{D-3}} \ll \ell_s \\ s\alpha' \gg 1 \end{cases}$$





String prop. through the shockwave

$$ds^2 = -dx^- dx^+ + \frac{4G_N P_-}{|b_\perp|^{D-4}}\delta(x^-)(dx^-)^2 + \sum_{i=1}^{D-2}(dx^i)^2$$

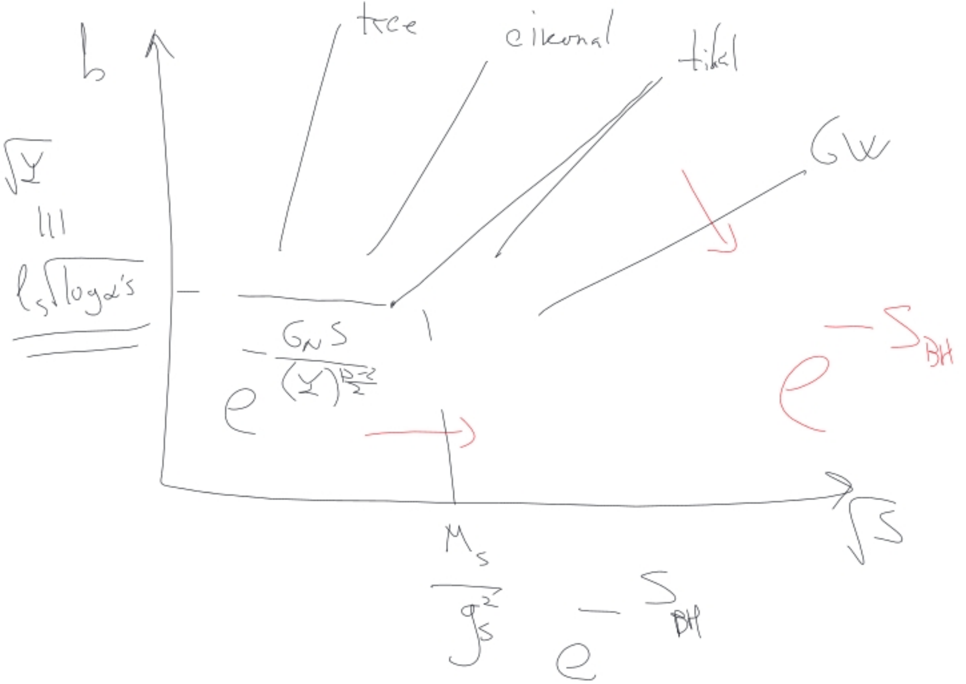
$$\hat{S}_{shock} = e^{i\, 4G_N S \int_0^{\pi} d\sigma \frac{1}{|\vec{X}(0,\sigma)|^{D-4}}}$$

$$\hat{X}^i = b^i + \text{stringy oscill.}$$

$$|\Psi_{out}\rangle = \hat{S}\,|\Psi_{in}\rangle$$

$$|\langle 0|\hat{S}|0\rangle| \sim e^{-2\pi(D-3)\underbrace{\frac{G_N s}{b^{D-2}}\ell_s^2}}$$

$$\frac{G_N s}{b^{D-2}}\ell_s^2 \sim O(1)$$



b
tree
eikonal
tidal
GW
$\sqrt{Y}$
$\geq$
$l_s\sqrt{\log \alpha's}$
$e^{-\frac{G_N s}{(Y)^{\frac{D-2}{2}}}}$
$e^{-S_{BH}}$
$\sqrt{s}$
M_s
$\frac{}{g_s^2}$
$e^{-S_{BH}}$

$$\hat{S}_{ACV} = e^{i \int \frac{d\sigma_u \, d\sigma_d}{\pi^2} \hat{\delta}_{tree}(s, \hat{X}'_u - \hat{X}'_d)}$$

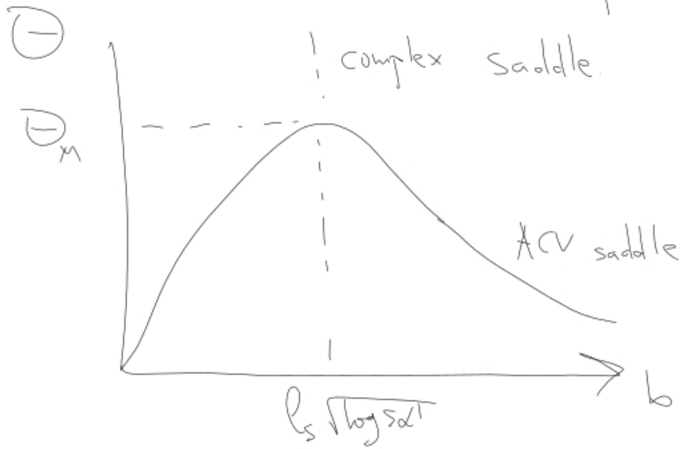
$$\delta_{tree} = -\frac{b^2}{\log \nu} \; ie + \frac{G_N s}{|X_u - X_d|^{D-4}}$$

$$\langle 0 | \hat{S}_{ACV} | 0 \rangle$$

- $\mathrm{Im}\, \delta_{tree} \neq 0$
- $[C, C^\dagger] = 1$

Fixed angles

$T(s,t) \qquad t = -q^2 \qquad q \simeq \frac{\partial \delta}{\partial b}$



$$\Theta_M \simeq \left(\frac{R_s}{l_s\sqrt{\log \alpha' s}}\right)^{D-3}$$

$$|T(s,\theta)| \sim e^{-(\sqrt{s})^{1-\frac{1}{D-3}}\,\theta^{\frac{D-2}{D-3}}}$$

$\Theta \gg \Theta_M$ complex saddle in b-space

(GMO)

$|T| \sim e^{-\sqrt{s}\log s}$ #

- $|b_s| > l_s \sqrt{\log \alpha' s}$

(GUP)

$\Delta X \gtrsim \frac{1}{\Delta P} + \alpha' \Delta P$

Graviton pole

$$T_s^{\text{tree}}(s,-q^2) = \frac{G_N}{\alpha'}(s\alpha')^{2-\alpha' q^2}$$

$$\int_{s_0}^{\infty} \frac{ds}{s'^3} T_s \sim \frac{8\pi G_N}{t}$$

$$s_* = \frac{1}{\alpha'} e^{\frac{1}{\alpha'|t|}}$$

$$\Lambda = G_N s_* |t|^{\frac{d-4}{2}} \ll 1.$$

$$\frac{1}{\log \frac{1}{g_s^2}} \ll \alpha' t \ll 1 \rightarrow \frac{1}{t} \text{ from tree}$$

$$t \rightarrow 0 \qquad \text{eikonal.}$$

Black hole ansatz: $\quad S_J(s) \simeq e^{-S_{BH}} \quad J \lesssim J^*_{\text{collapse}}$

$$H_2 \to gg \qquad 1,2 \to 3,4$$

$$\operatorname{Im} f_J = \sum_n \langle 1,2 | n \rangle \langle n | 3,4 \rangle$$

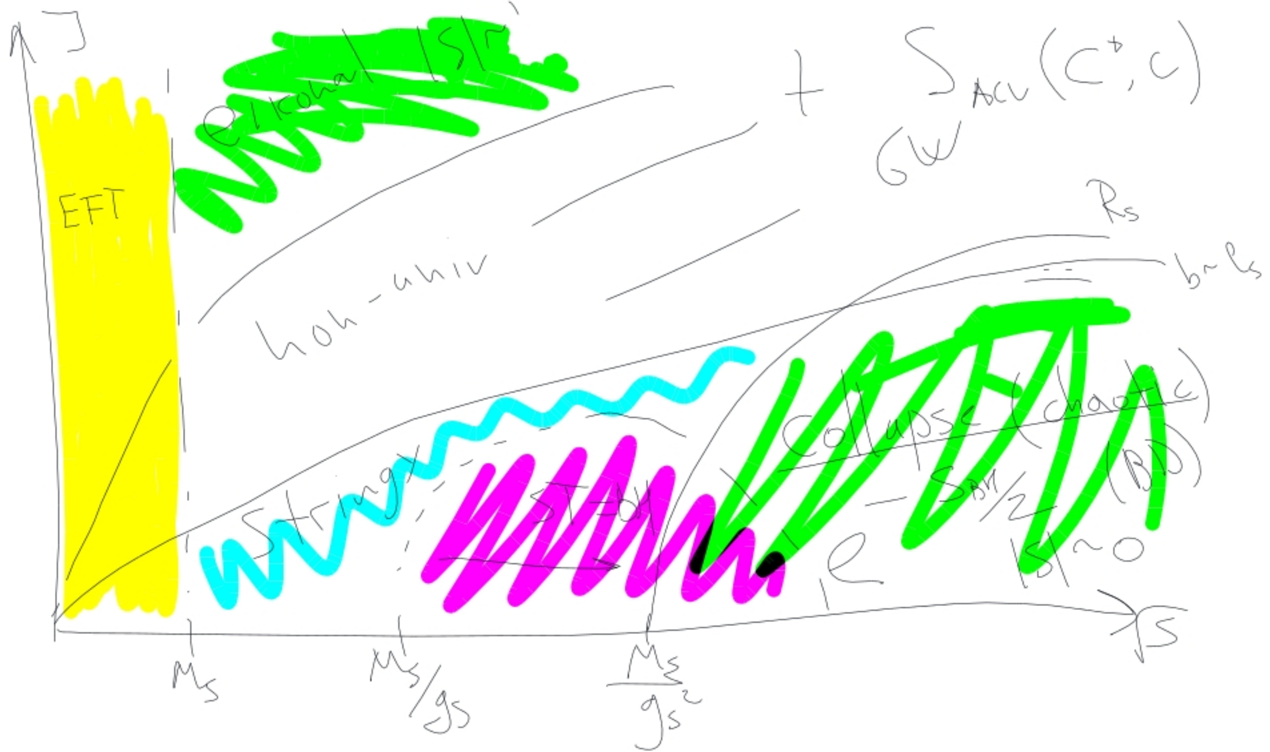
$$\mathrm{Im}\, f_J^{1,2\to 3,4} = \sum_{i=1}^{e^{S_{BH}}} \langle 1,2 | i \rangle \langle i | 3,4 \rangle \sim e^{-S_{BH}/2}$$

$$\sum_{i=1}^{e^{S_{BH}}} \left| \langle 1,2 | BH \rangle \right|^2 \simeq 1$$

$$\langle 1,2 | BH \rangle \simeq e^{-S_{BH}/2} e^{i\varphi_I}$$

$$\int_{L_{BH}}^{\infty} ds' \, e^{-S_{BH}/2} \simeq e^{-S_{BH}(M^*)/2}$$

$$C_n \sim e^{-S_{BH}(M^*)/2}$$


J
EFT
Eikonal |S|~1
+ S_ACU(C*, C)
GW
R_S
b~R_S
non-univ
String
ST=BH
Collapse (chaotic)
(BH)
e^{-S_BH/2}
|S|~0
√s
M_S
M_S/g_S
M_S/g_S^2