- $\ell_{d}^{d-2} = \ell_{D}^{d-2}\left(\frac{\ell_D}{\ell_{KK}}\right)^{D-d}$ $\qquad D \to d$

- high energies $\gg 1$

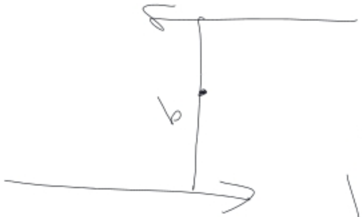
- $D > 4$, $\qquad \hat{S} \to$ string theory

  $\hat{S} \to$ flat space AdS/CFT

  $\hat{S} \to \lim_{N\to\infty} S_N$

$2 \to 2$ <u>Two variables</u> energy s

- $T(s,t)$, $t<0$ t - fixed
- $T(s,\theta)$, $t = -\frac{s}{2}(1-\cos\theta)$
- $T(s,b)$



$$J = \frac{\sqrt{s}\,b}{2}$$

b_J

Basic quantities: $c = \hbar = 1$

* $G_N = \dfrac{1}{m_p^{D-2}} = \ell_p^{D-2}$

* $R_S^{D-3} = \dfrac{16\pi G_N \sqrt{s}}{(D-2)\,\Omega_{D-2}}$

(strong) $b \lesssim R_S$

* $S_{BH} = \frac{\text{Area}}{4G_N} = \frac{4\pi}{D-2}\sqrt{s}\,R_s \sim \left(\sqrt{s}\right)^{1+\frac{1}{D-3}}$

* $b > \frac{1}{\sqrt{s}}\,, \quad s b^2 \gg 1\,.$

Massless pole

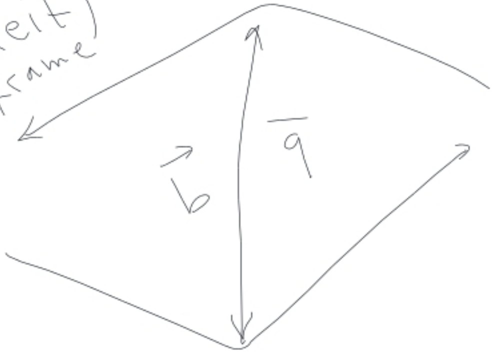
$$T(s,t) = -\frac{8\pi G_N s^2}{t}\left(1+O(\hbar)\right), \quad \begin{array}{l} s-\text{fixed} \\ t \to 0 \end{array}$$

- $D=4$ $\quad \left(\frac{x}{t}\right)^{-iG_N s}$
- $D>4$ $\quad \boxed{\Lambda = G_N s\,(-t)^{\frac{D-4}{2}}}$

$$T(s,b) = \frac{1}{2s}\int d^{D-2}\bar{q}\; T(s,-\bar{q}^2)\, e^{i\bar{b}\cdot\bar{q}}$$

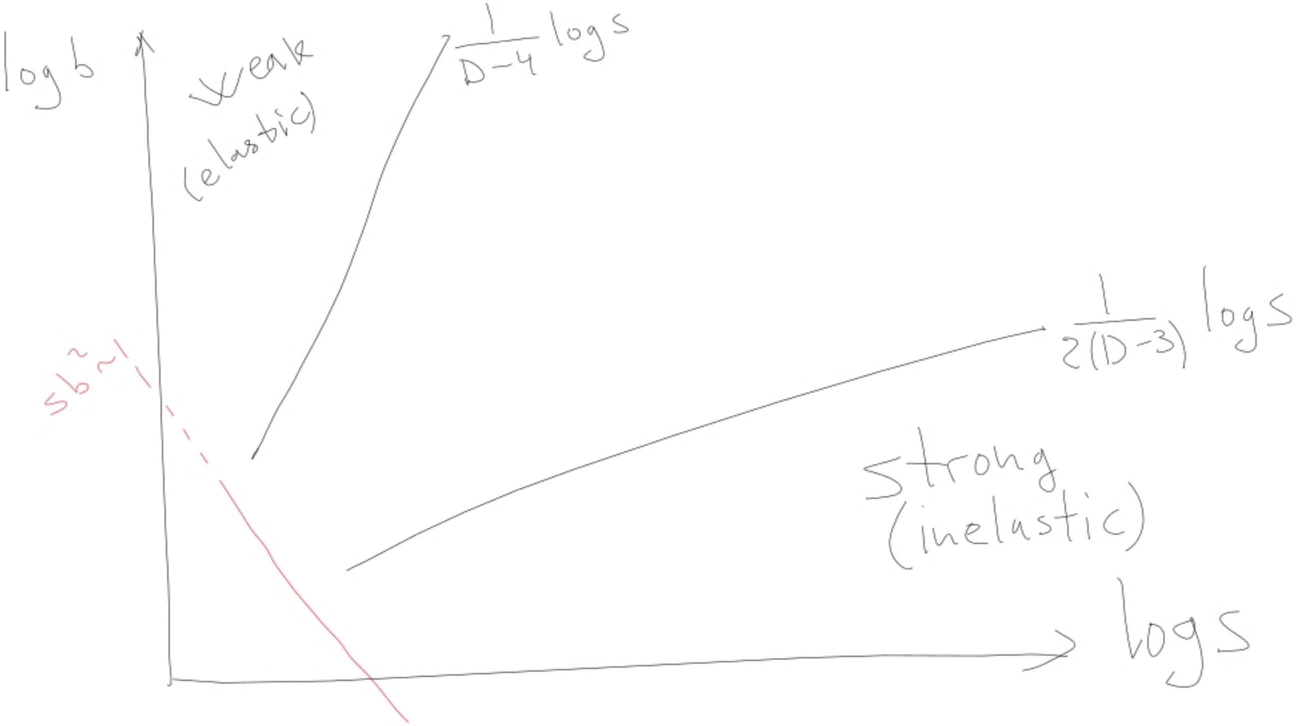
$$= \frac{\Gamma\left(\frac{D-4}{2}\right) G_N s}{\pi^{(D-4)/2}\, b^{D-4}} \ll 1$$

(Breit frame)



$$= \underbrace{(\sqrt{s}\, b)}_{\gg 1} \underbrace{\left(\frac{R_S}{b}\right)^{D-3}}_{\ll 1}$$

$b_J =$



$\log b$
weak (elastic)
$\frac{1}{D-4}\log s$
$\frac{1}{2(D-3)}\log s$
$s\tilde{b}\sim 1$
strong (inelastic)
$\log s$

Eikonal scattering

$$2\delta_{tree} = T_{tree}(s,b)$$

$$T_{tree}(s,b) \gg 1$$

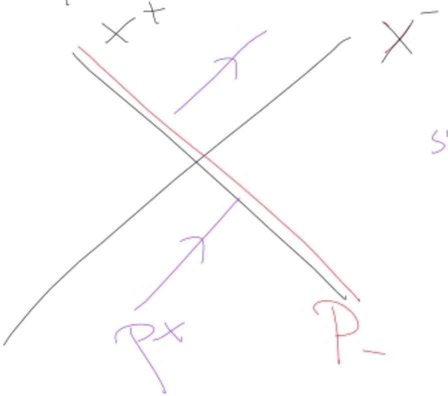
$$T_{eik}(s,t) = 2is \int d^{D-2}b \, e^{-i\vec{q}\vec{b}} \left(1 - e^{2i\delta_{tree}}\right)$$

$$2i\delta_{tree} \ll 1 \; ?$$

$\rightarrow$ propagation through the shockwave

$$T_{--} = -P_- \delta(x^-)\, \delta^{D-2}(\vec{x}) \qquad b = \sqrt{\sum_{i=1}^{D-2} (x^i)^2}$$

$$ds^2 = -dx^+ dx^- - 4\,\frac{\Gamma\left(\frac{D-4}{2}\right) G_N P_-}{\pi^{\frac{D-4}{2}}\, b^{D-4}}\, \delta(x^-)(dx^-)^2 + \sum_{i=1}^{D-2} (dx^i)^2$$



$\vec{x}_\perp$

$$\Box \varphi = 0$$

$$\Psi \xrightarrow{\text{shock}} \underbrace{e^{-i\Delta X^+ p_+}}_{e^{i\delta_{\text{tree}}}} \Psi$$

- $\Lambda \to 0$ (pole)

$$\Lambda = G_N s (-t)^{\frac{D-4}{2}}$$

- eikonal saddle $\Lambda \to \infty$

$$|T_{eik}(s,t)| \sim s^{2-\frac{D-4}{2(D-3)}}$$

$$\sqrt{-t} = |\vec{q}| = \frac{G_N s}{b^{D-3}}$$

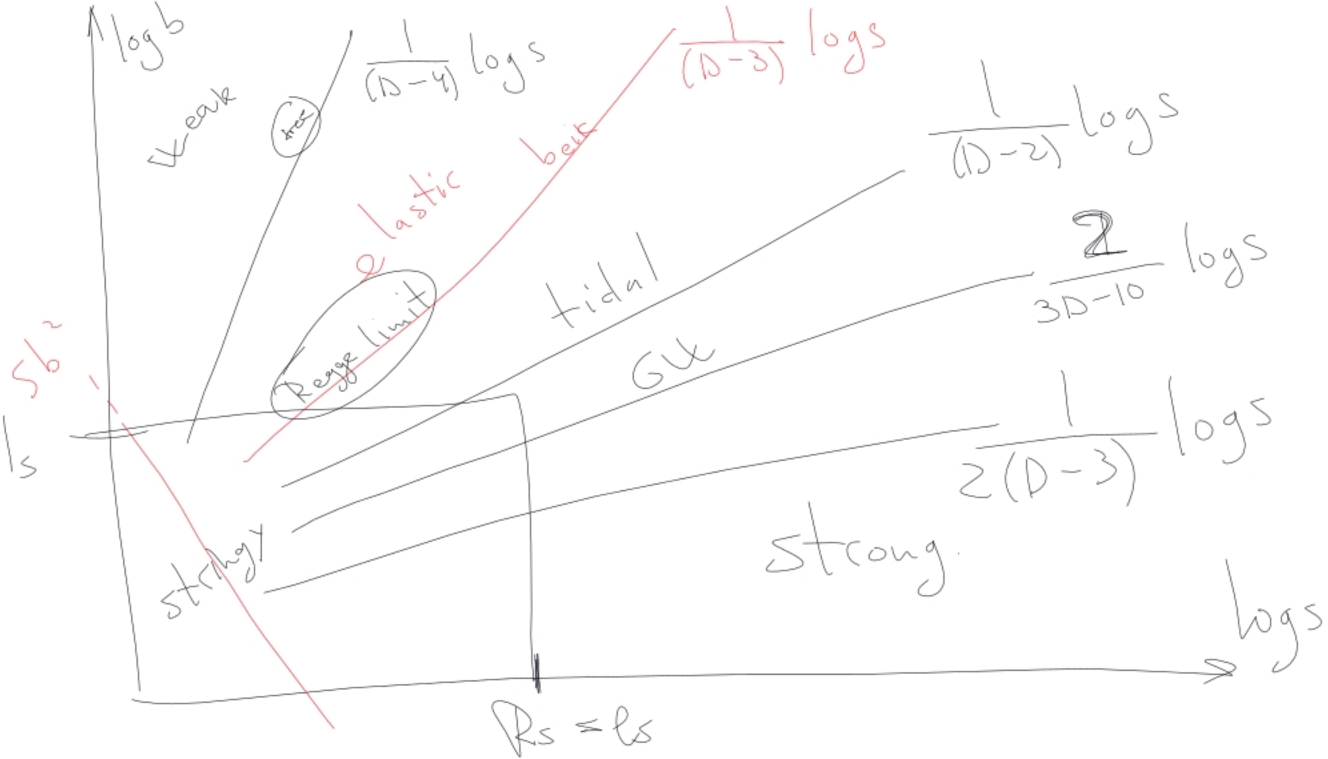
$$T_{eik} \sim \left(e^{2i\delta_{tree}} - 1\right)$$

$$R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \ll \frac{1}{l_{pe}^4}$$

$$R_{uiju} \sim \partial_b^2 \delta \, \delta(u)$$

$$l_{pe}^4 \left(\frac{G_N s}{b^{D-2}} \right)^2 s \ll 1$$

$$\boxed{\frac{\delta_{tree}^{D/2}}{s b^2} \ll 1} \quad , \; b \gg R_s$$



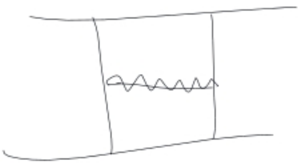
log b
weak
tree
$\frac{1}{(D-4)}$ log s
$\frac{1}{(D-3)}$ log s
elastic
belt
$\frac{1}{(D-2)}$ log s
$\frac{2}{3D-10}$ log s
tidal
Regge limit
GW
$s b^2$
l_s
$\frac{1}{2(D-3)}$ log s
stringy
strong
log s
$R_s = l_s$

- $R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \simeq M_*^4$

$$\delta_{\text{tidal}} = i \frac{G_N s}{M_*^2 b^{D-2}}$$

- Λ_{QCD} pp
- M_s strings

- Produce GW



$$\delta_{GW} = i \frac{G_N^3 s^2}{b^{3D-10}} = \delta_{\text{tree}} \left(\frac{R_s}{b}\right)^{2(D-3)}$$

logs $\xrightarrow{\text{conj}}$ $\log R_s/b$

$$T_{\Delta s}(s,b) = \int \frac{ds'}{\sqrt{2\pi}\,\Delta s} e^{-(s'-s)^2/(\Delta s)^2}\, T(s',b)$$

$$\Rightarrow \quad \ell_{pl}^{4} \left(\frac{G_N s}{b^{D-2}}\right)^2 \Delta s \ll 1$$

$$\frac{\lambda_s^2}{b^2}\,,\ \left(\frac{R_s}{b}\right)^{D-3},\ \ldots$$

$$\lim_{s \to \infty} \frac{T(s,t)}{T_{eik}(s,t)} = 1$$

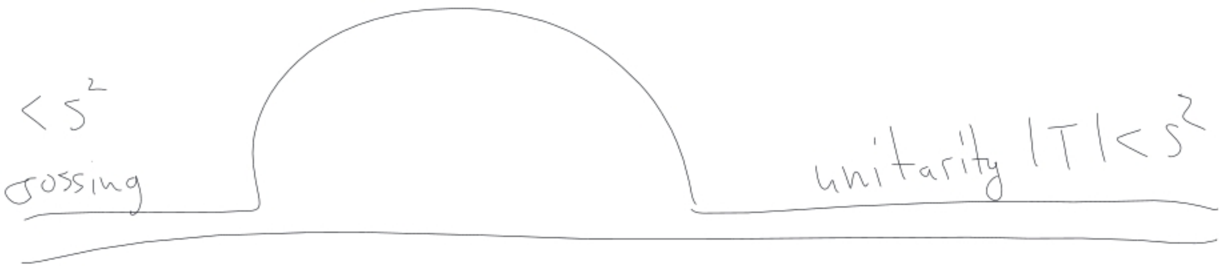
Regge limit is IR

QRG why

$$R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \Big|_{A\alpha} \to 0$$

<u>Ass:</u> $|T| < e^{s^\beta}$ $\beta < 1$ LS ACU

$$\lim_{s \to \infty} \frac{|T(s,t)|}{s^2} = 0 \Rightarrow \text{TSDR}$$



The ACV saddle: $\sqrt{-t} = \frac{G_N s}{b_*^{D-3}}$

$$R_s \sim s^{\frac{1}{2(D-3)}}, \quad b_* \sim s^{\frac{1}{(D-3)}}$$

$$b_* \gg R_s$$

$\underline{s \to \infty:}$

$$T_{eik}(s,t) = s(-t)^{\frac{2-D}{2}} \left(G_N s (-t)^{\frac{D-4}{2}} \right)^{\frac{D-2}{2(D-3)}} e^{i \Lambda \frac{D-3}{D-4}}$$

$t<0$ fixed