Strings 2021, June 21

Discussion Session

High-Energy Limit of String Theory

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Very early days (1967...)

- Birth of string theory very much based on the high-energy (Regge) limit: Im $A^{(Regge)} \neq 0$!
- Duality bootstrap (except for the Pomeron!) => DRM (emphasis shifted on res/res duality, xing)
- Need for infinite number of resonances of unlimited mass and spin (linear traj.s => strings?)
- Exponential suppression @ high E & fixed θ => colliding objects are extended, soft (=> strings?)
- <u>One</u> reason why the NG string lost to QCD.
- Q: What's the Regge limit of (large-N) QCD?

20 years later (1987...)

- After 1984, attention in string theory shifted from hadronic physics to Q-gravity.
- Thought experiments conceived and efforts made to construct an S-matrix for gravitational scattering @ $E \gg M_P$, $b < R$ => "large"-BH formation ($R^{D-3} \sim GE$). Questions:
- Is quantum information preserved, and how?
- What's the form and role of the short-distance stringy modifications?
- N.B. Computations made in flat spacetime: an emergent effective geometry. What about AdS?

High-energy vs short-distance

Not the same even in QFT !

With gravity it's even more the case!

High-energy, large-distance
($b \gg R, l_s$)

- Typical grav.^{al} defl. angle is $\theta \sim R/b = GE/b$ (D=4)
- Scattering at high energy & fixed small θ probes $b \sim R/\theta > R$ & growing with energy!
- Contradiction w/ exchange of huge $Q = \theta E$? No!
- Large classical Q due to exchange of $O(Gs/h)$ soft ($q \sim h/b$) gravitons: t-channel "fractionation"
- Much used in amplitude approach to BH binaries
- θ known since ACV90 up to $O((R/b)^3)$, universal.

Lesson

To explore short-distances… go to short distances, to small b!

High-energy, short-distance in weak-coupling string theory

If $l_s \gg l_P$ there is room for a perturbative string-gravity regime:

$l_P \ll b, R \ll l_s$ (exp. par. $R/b \to R/l_s \ll 1$)

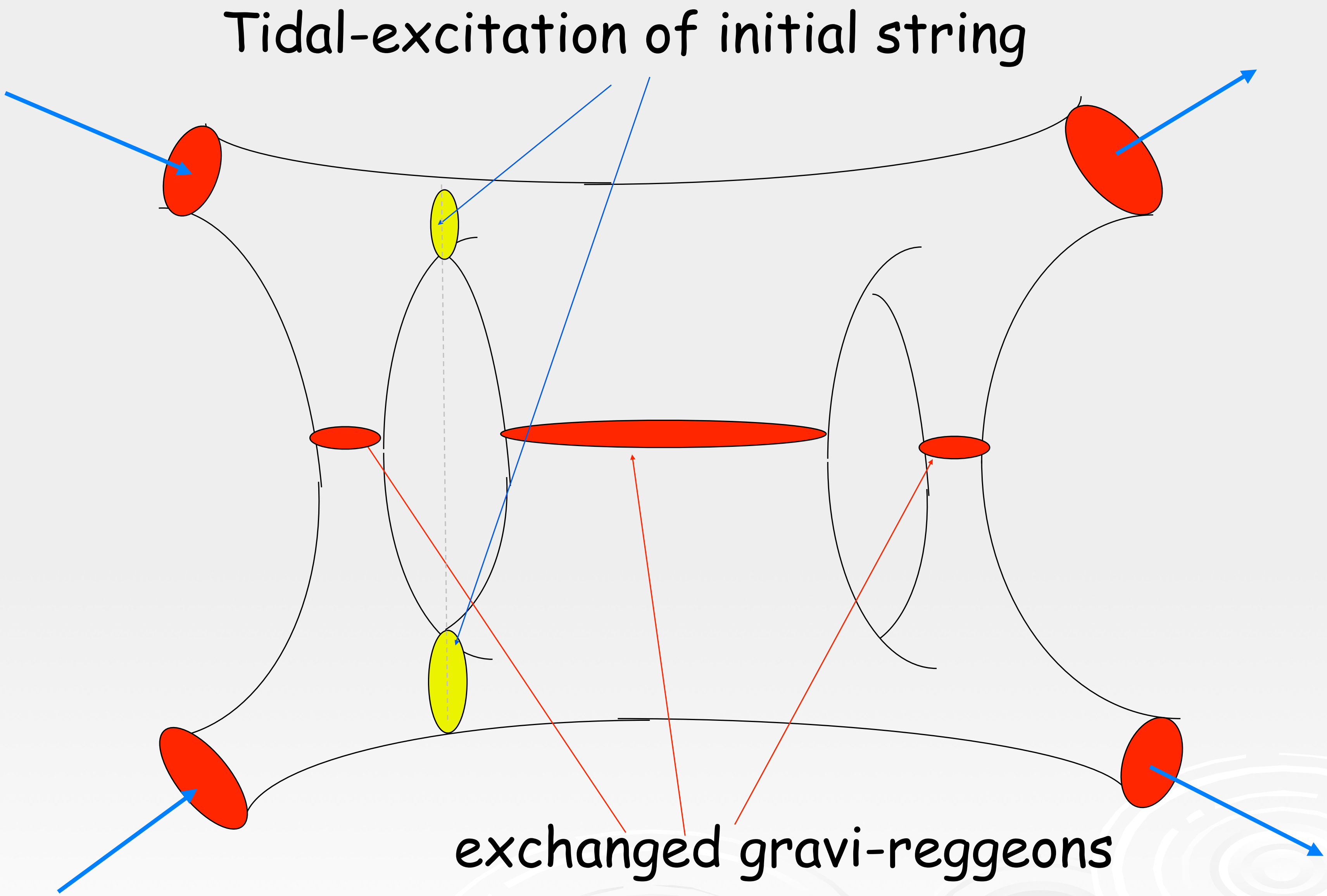
- Incidentally: finite size (tidal) effects kick in at

  $s/M_P^2 \, (l_s/b)^2 = O(1)$!

- and for heavy, long strings they would come up at

  $s/M_P^2 \, (L/b)^2 = O(1)$!

Described by a unitary (inelastic) S-matrix!



String gravity regime ($b, R < l_s$)

(NB: no BH formation expected!)

- String softening of quantum gravity @ small b: solving a causality problem (Edelstein et al.)
- Maximal classical $\theta \sim R/l_s$. At larger θ exp. fall off, agreement w/ Gross-Mende-Ooguri (in a finite energy range)
- Effective "Generalized Uncertainty Principle"

$$\Delta x \geq \frac{\hbar}{\Delta p} + \alpha' \Delta p \geq l_s$$

- s-channel "fractionation" and black-hole-like behavior: $\langle E_{final} \rangle \sim h/(G\, E_{initial})$ from $\langle N \rangle \sim Gs/h$.

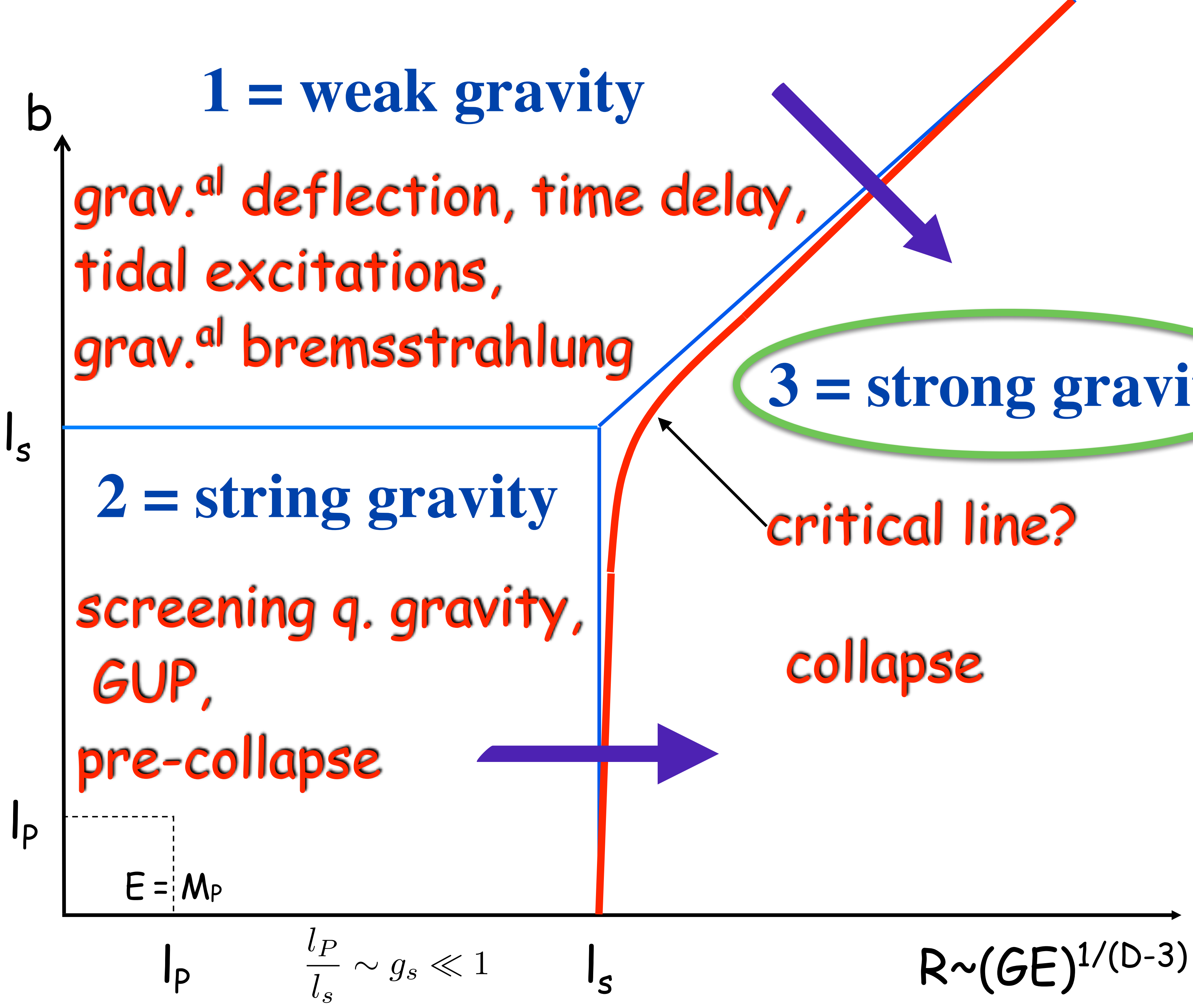
Recent developments/applications
(no strings attached, sorry)

- Two loop ACV90 result on θ inconsistent with HE limit of Bern et al.'s two-loop result (1901.04424).

  Solution (2008.12743, …): need to add radiation-reaction contributions -> smooth result all the way from deep NR to UR.

- Gravitational rad. from HE scattering @ small R/b: $dE^{GW}/d\omega$ has a bump at $\omega \sim 1/b$ (just confirmed in 2105.08739) and a "knee" around the Hawking scale $\omega \sim 1/R$ (1409.4555, 1812.08137)

  Another example of "fractionation"?



1 = weak gravity
b
grav.al deflection, time delay,
tidal excitations,
grav.al bremsstrahlung
l_s
3 = strong gravity
2 = string gravity
critical line?
screening q. gravity,
GUP,
pre-collapse
collapse
l_P
E = M_P
l_P
$\frac{l_P}{l_s} \sim g_s \ll 1$
l_s
$R \sim (GE)^{1/(D-3)}$

Strong gravity regime ($R > b, l_s$)

- Can one go to $R > l_s > b$? Easier than $R > b > l_s$?
- In latter case semiclassical contributions come from (effective) tree-amplitudes, resummed in a 2-d EFT (crude) approximation (Lipatov->ACV07).
- Emergence of critical points for a unitary description (agreement w/ collapse criteria!)
- Q: Unitarity beyond critical point/line?
- Q_1: Is a semiclassical approximation sufficient?
- Q_2: Is string's UV completion necessary/sufficient?
- Q_3: Is the dispersion => collapse transition smoothed out by quantum/string effects?

Large Mass ?

- Large mass strings may correspond to collapsed objects if their Schw. radius exceeds their size.
- This needs $M > g_s^{-2} M_s$ meaning that self-gravity effects become $O(1)$ or larger. Non perturbative regime.
- (at $M < g_s^{-2} M_s$ string entropy beats BH entropy. We don't expect BH's of radius smaller than l_s to exist)

- At $M \sim g_s^{-2} M_s$ evidence in favor of a string-black hole correspondence ($T_{Haw} \sim T_{Hag}$, $S_s \sim S_{BH} \sim g_s^{-2}$ ...)
- Q: Are NP self-gravity effects just right to make BH & string entropy agree for $M \gg g_s^{-2} M_s$?

- Not clear. My own feeling: "fractionation" is once more the key...