A Triangle of Traits:

Constraining Scattering Through IR Effects

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say you're interested in quantum gravity...

You have Einstein's field equations as a classical theory, know how they can come from a lagrangian, try to quantize by expanding perturbations about a flat metric, find a spin 2 graviton but run into the problem that the theory is non-renormalizable

- quantum effects take place at very short distances, the Planck scale, so one route is to look for a UV complete theory that contains a spin 2 graviton such as string theory.
- a rather different starting point is to hope that one can use symmetries to constrain / define a gravitational scattering matrix starting from **long distance, IR effects.**

More symmetries = more constraints

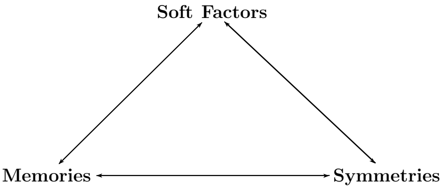
Noether's Theorem: continuous symmetries correspond to conservation laws

- translation invariance $\leftrightarrow$ conservation of momentum
- gauge 'symmetries' (eg redefining your coordinate system) are a redundancy in description of system, not physical propagating degrees of freedom
  - physical symmetries and non-trivial behavior at the boundary.
  - interesting that you can do better than translations: *angle dependent supertranslations*

With an eye towards QG look for extended symmetry group to constrain the $\mathcal{S}$-matrix.

There are three traits that accompany each other:

i) Weinberg – photon $\mathcal{O}(\frac{1}{\omega})$
ii) Weinberg – graviton $\mathcal{O}(\frac{1}{\omega})$
iii) Cachazo & Strominger – graviton $\mathcal{O}(1)$



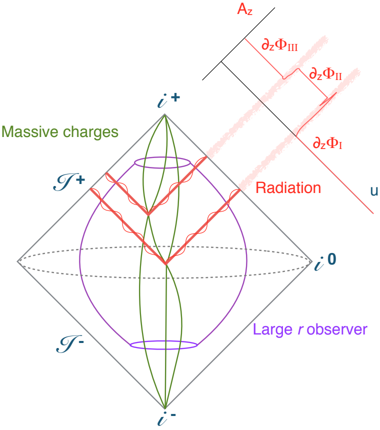
i) Liénard-Wiechert / Bieri & Garfinkle
ii) Zeldovich & Polnarev / Christodoulou
iii) Pasterski, Strominger, & Zhiboedov

(global)	(asymptotic)
i) e-charge	large U(1)
ii) p^μ	supertranslations
iii) $J^{\mu\nu}$	superrotations

Things simplify at large distances

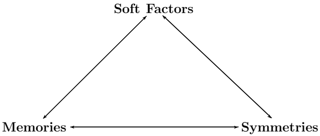
If you have a set of particles interacting over a small region but you send them in as plane wave packets, then far away they separate from one another.

- Describe incoming and outgoing particles in terms of their momenta, charges, spin, etc. This same data that you plug into your theory to compute the $\mathcal{S}$-matrix is also the data that tells you how the particles couple to gauge fields.

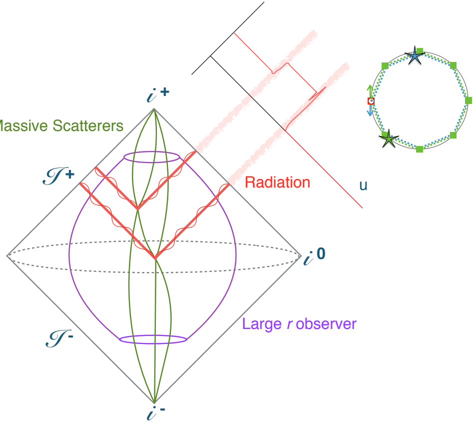


Accelerating masses or charges source radiation

- Can change the acceleration profile for a charge to reduce the power radiated, but if you specify the initial and final velocity of that charge there is some net radiation accompanying it. **This is a 'memory effect.'**
- Long time scales correspond to low energies. When computing an amplitude this measurement corresponds to what in field theory are known as **soft factors.**



Independent work by relativists and quantum field theorists from the 1960s combine together here, since the equations that come from these soft factors can be used to justify extending the symmetry group.



i.e. some coordinate transformations that one might have thought to consider pure gauge transformations don't fall off at the boundary. Formalize this boundary for flat space.

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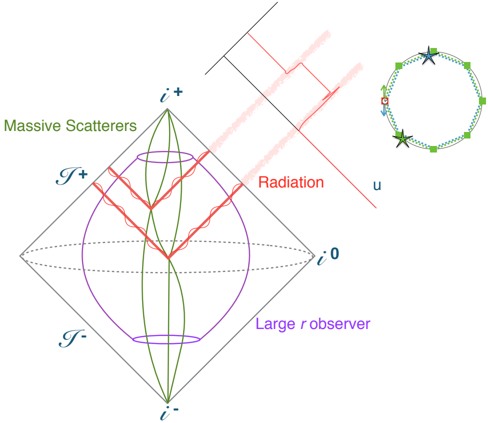

Once you are slightly away from flat the fact that scatterers couple to gravity implies that the metric will change in response.
Baseline shift symmetry versus radiation-induced transition memory effect.

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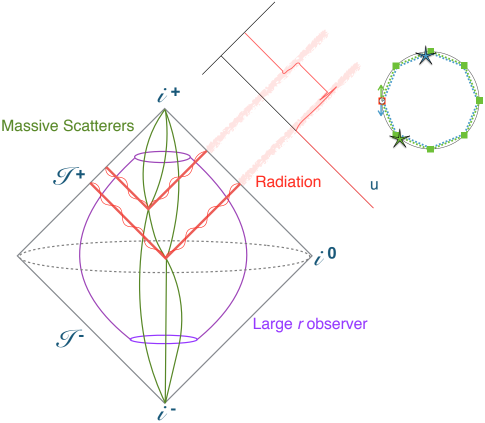

Set masses on sphere at fixed angles declare your coordinate system. When some scattering process occurs the masses shift, reset by profiles induced by shift is this additional vacuum ambiguity. Similar rotational effect for angular momentum flux.

Look at the triangle, realize you can do the same thing for angular momentum and you have an entire iteration that started a few years ago versus 1960s.

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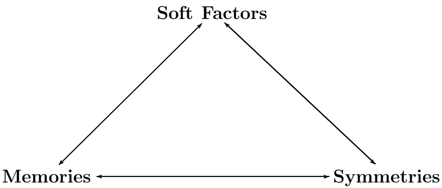

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The upshot is you have this universal triangle where you expect multiple traits to accompany each other.

Applications

- **Holography:** With spin memory and soft factor conformal symmetry can try to envision a holographic description for massless scattering.

- **Effective Field Theory:** Local boosts also similar to reparametrization invariance in SCET.

- **Black Holes:** Can ask what happens when horizons are present and what constraints can be placed on black hole evaporation.

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