Title: The Outside Story: String spreading in the S-matrix and black holes

Date: May 02, 2015 09:00 AM

URL: http://pirsa.org/15050140

Abstract:

Gary has had an enormous impact on the field in general. For me personally his work has been a huge inspiration. First some great collaborations:

HEP | **4** records found | Search took 0.15 seconds.

1. **Inflation Physics from the Cosmic Microwave Background and Large Scale Structure**
K.N. Abazajian, K. Arnold, J. Austermann, B.A. Benson, C. Bischoff, J. Bock, J.R. Bond, J. Borrill, I. Buder, D.L. Burke (Chicago U., KICP) *et al.*. Sep 20, 2013. 11 pp.
Published in **Astropart.Phys. 63 (2015) 55-65**
FERMILAB-PUB-13-442-A
DOI: 10.1016/j.astropartphys.2014.05.013
e-Print: **arXiv:1309.5381 [astro-ph.CO] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Fermilab Library Server (fulltext available); Link to Fulltext
Detailed record - Cited by 31 records

$\langle \gamma\gamma \rangle$

GH: t-dep bckgrnd ⇒ cosmology

2. **Insightful D-branes**
Gary Horowitz (UC, Santa Barbara), Albion Lawrence (Brandeis U. & Santa Barbara, KITP), Eva Silverstein (SLAC & Stanford U., Phys. Dept. & Santa Barbara, KITP). Apr 2009. 30 pp.
Published in **JHEP 0907 (2009) 057**
NSF-KITP-09-53, SLAC-PUB-13584, SU-ITP-09-16, BRX-TH-607
DOI: 10.1088/1126-6708/2009/07/057
e-Print: **arXiv:0904.3922 [hep-th] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
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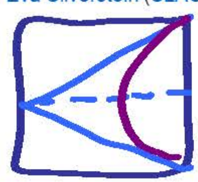

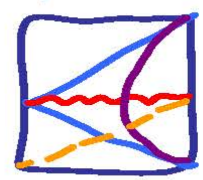

3. **The Inside story: Quasilocal tachyons and black holes**
Gary T. Horowitz (UC, Santa Barbara), Eva Silverstein (SLAC & Stanford U., Phys. Dept.). Jan 2006. 33 pp.
Published in **Phys.Rev. D73 (2006) 064016**
SLAC-PUB-11616, SU-ITP-06-01
DOI: 10.1103/PhysRevD.73.064016
e-Print: **hep-th/0601032 | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Phys. Rev. D Server; SLAC Document Server
Detailed record - Cited by 60 records 50+

4. **Clean time dependent string backgrounds from bubble baths**
Ofer Aharony (Weizmann Inst.), Michal Fabinger (Stanford U., Phys. Dept. & SLAC), Gary T. Horowitz (UC, Santa Barbara), Eva S
Published in **JHEP 0207 (2002) 007**
SLAC-PUB-9203, WIS-16-02-DPP
DOI: 10.1088/1126-6708/2002/07/007
e-Print: **hep-th/0204158 | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server ; ADS Abstract Service; JHEP Electronic Journal Server; SLAC Document Server
Detailed record - Cited by 120 records 100+

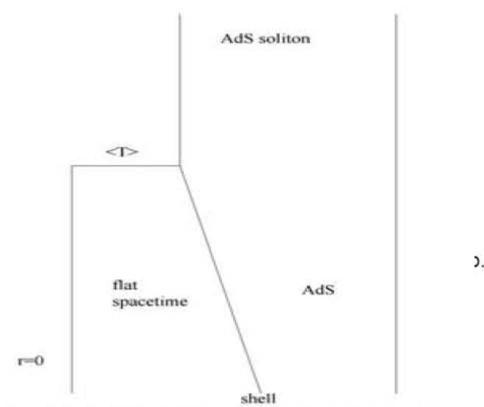

Fig. 1: A shell of D3-branes slowly contracts. The spacetime outside is approximately $AdS_5 \times S^5$, while the spacetime inside is approximately flat. The branes are wrapped around a Sherk-Schwarz circle, and when this circle reaches the string scale, the winding tachyons condense. The exterior geometry becomes a bubble which settles down to the AdS soliton (cross S^5). We will be interested in the fate of excitations in the $< T >$ region.

Gary's paradigms like Calabi-Yau compactification, singularity resolution (or not) in various contexts, holographic SC, etc. have been extraordinarily stimulating

Vacuum Configurations for Superstrings
P. Candelas (Texas U. & Santa Barbara, KITP), Gary T. Horowitz (UC, Santa Barbara), Andrew Strominger (Princeton, Inst. Advanced Study), Edward Witten (Princeton U.). Mar 1985. 28 pp.
Published in **Nucl.Phys. B258 (1985) 46-74**
NSF-ITP-84-170
DOI: 10.1016/0550-3213(85)90602-9
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server ; Science Direct

Special geometry

Lifshitz Singularities
Gary T. Horowitz, Benson Way (UC, Santa Barbara). Nov 2011. 14 pp.
Published in **Phys.Rev. D85 (2012) 046008**
DOI: 10.1103/PhysRevD.85.046008
e-Print: **arXiv:1111.1243 [hep-th] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server ; ADS Abstract Service

Two matters for would-be tidal force singularity

• • •


THE NATURE OF SPACE AND TIME - PROFESSOR GARY T. HOROWITZ.
To se mi líbí
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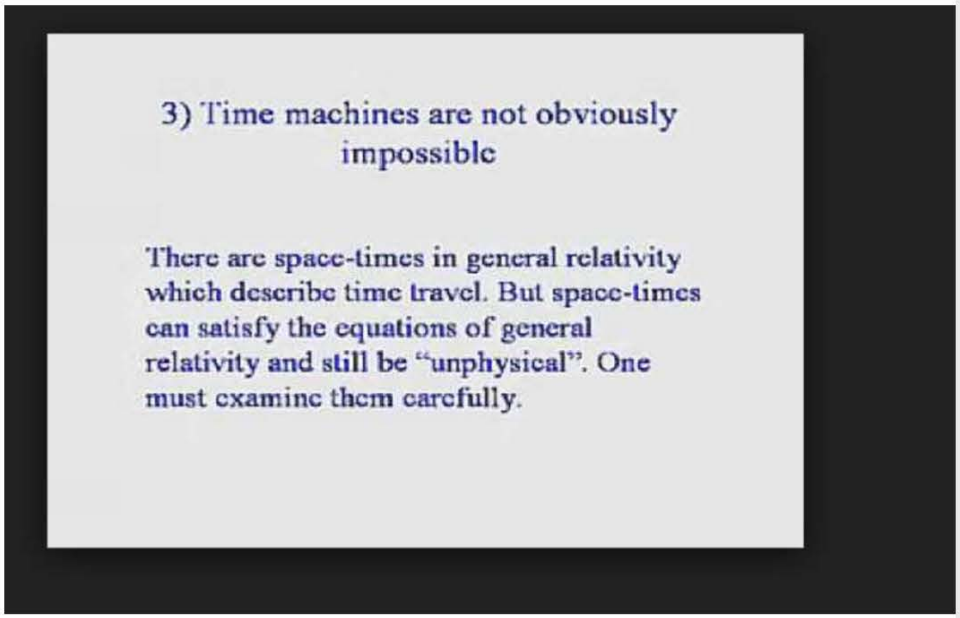
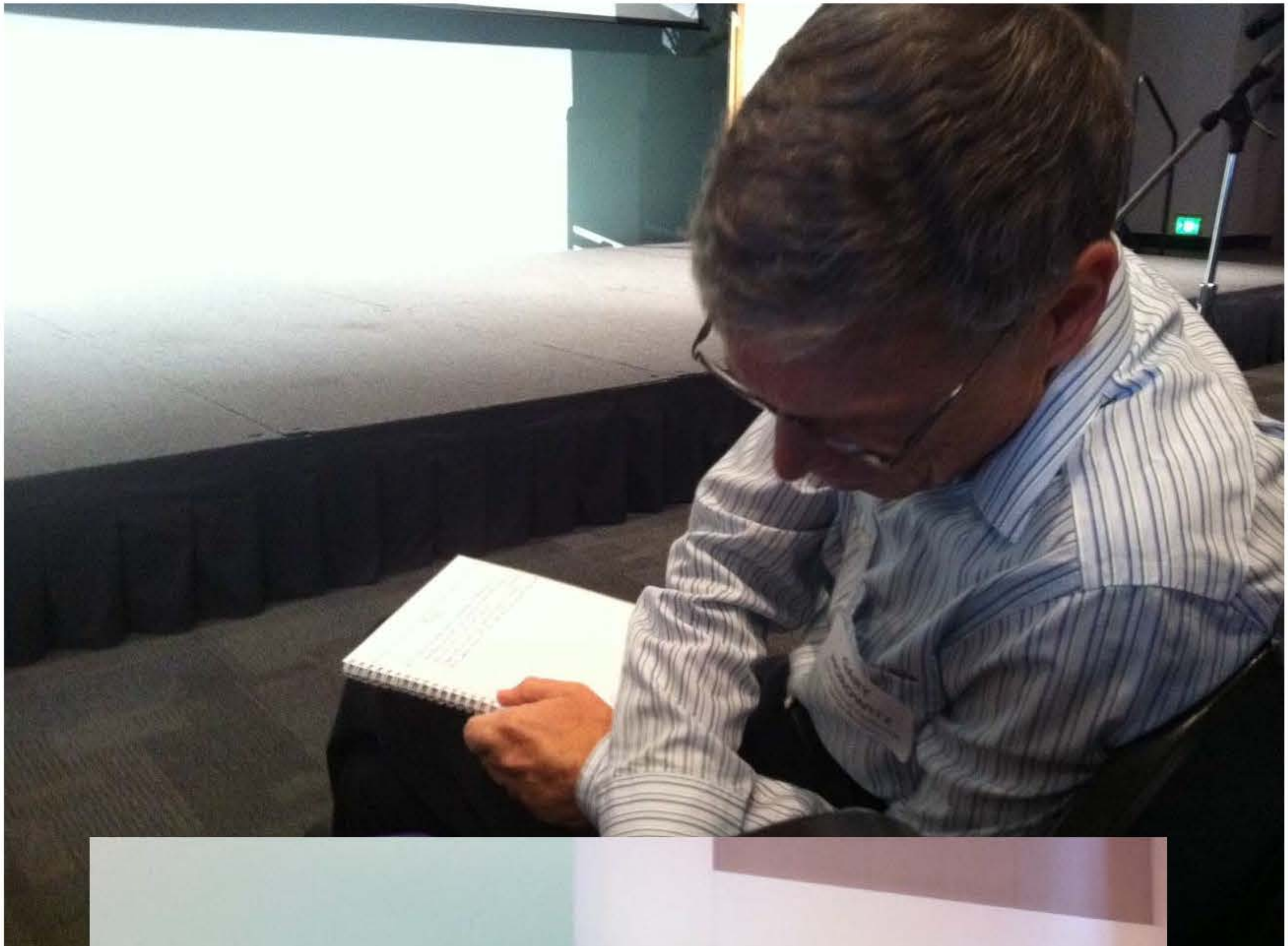
0:18 / 1:15

Of course Gary's main interest, now that he's 60, is:





I am <u>not</u> suggesting that Gary is a homocidal maniac. However:

Time travel need not cause paradoxes

Famous question: What if you travel into the past and kill your grandmother?

The Outside Story: string spreading in the S-matrix and black holes

with M. Dodelson
2015 thought-expt data release
I. Longitudinal nonlocality in the string S-matrix
II. String spreading and

Outline

I. Intro
- Black Hole as accelerator
- string spreading — Susskind '94; Brower Polchinski Strassler Tan '06

II. Longitudinal Nonlocality in tree-level string amplitudes from phases & trajectories in {Veneziano, Bardakci-Ruegg}

III. Quantitative estimates for

Black Holes: conflict between EFT and Quantum Mechanics

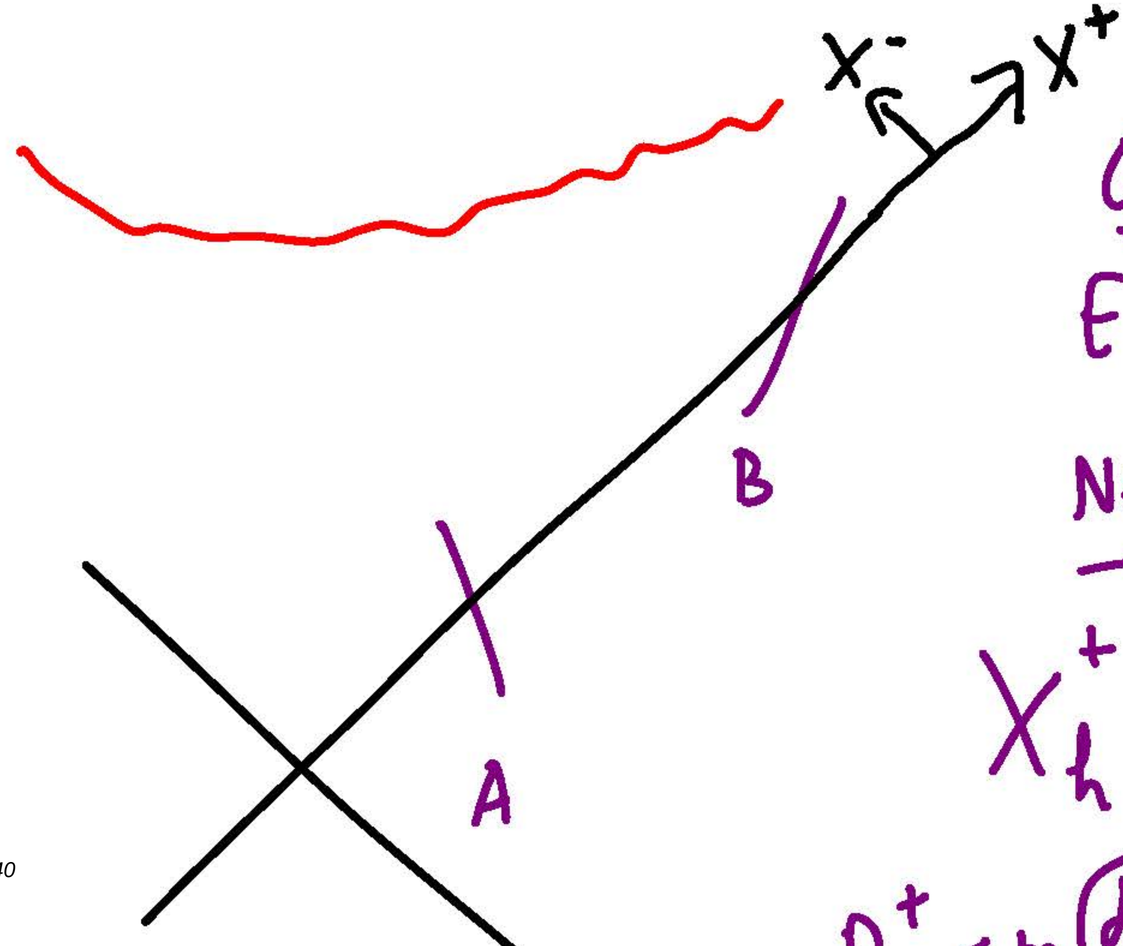
... Hawking ... Mathur ... AMPS ...

↓

single observer can see the conflict

→ Check level of violations of EFT in string theory, with

$$ds^2 = \frac{-2r_s}{r} e^{1-\frac{r}{r_s}} dX^+ dX^- + r^2 d\Omega^2$$



Outside:

E, m fixed

Near Horizon:

$$X_h^+ = 2 r_s \sqrt{e}\, \frac{E}{m}\, e^{\eta}$$

$$p^+ = m \left(\frac{dX^+}{\ldots}\right)\Big| = m e^{\eta}$$

Near horizon: huge Energy, but separated along X^+.

String Spreading

- Susskind '94
- Brown Polchinski Strassler Tan '06

Light Cone gauge $X^- \sim p^- \tau$,

Constraint determines X^+ in terms of $X^\perp$

n_{max}

- Apparent asymmetry between $\dot{X}_\perp$ and $X^\pm$ directions?

No: the RMS longitudinal spreading is detectable for

$X^\pm \approx$ direction of relative motion

More precisely: Brick Wall frame

Light cone time resolution:

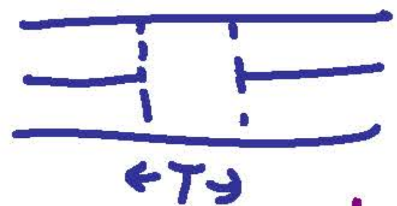
$$\Delta X^- \sim \frac{1}{P^+_{detector}} \qquad n_{max} \sim \frac{g'}{\Delta\tau} \qquad \tau \sim \frac{x^-}{p_s^-}$$

$$\Rightarrow \quad n_{max} \sim p_s^- \, p_d^+$$

$$\left(\text{for } t \sim -k_\perp^2 \sim \mathcal{O}\left(\frac{1}{g'}\right) \right)$$

More generally,

☆ This physical idea is confirmed **explicitly** in BPST '06 calculation of 4-point Regge amplitude in light-cone gauge.



in brick wall frame: $p_{\perp r} \sim \frac{k_\perp}{2}$, $m \simeq 0$

Note that the fact that X^+ is constrained in terms of $X_\perp$ does not make it unphysical, there are many familiar examples (perhaps most basic being the expansion of the universe, in spacetime or on a string worldsheet)

Let us take as given the <u>transverse</u> spreading

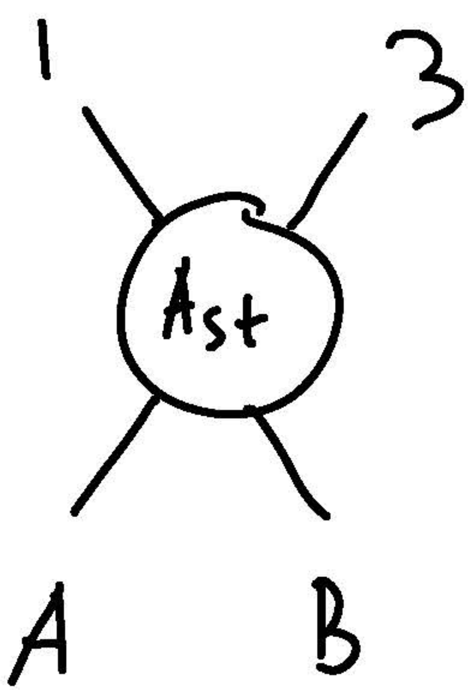
$$\Delta X_{\perp} \sim \sqrt{\alpha'} \log n_{max}$$

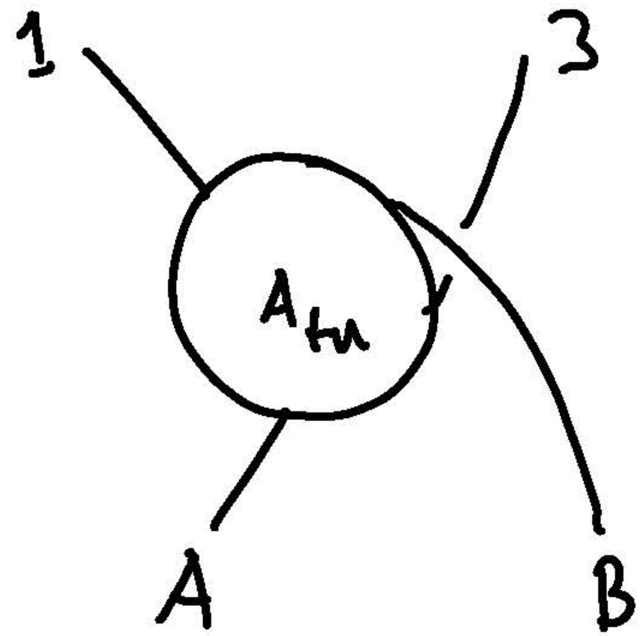
$$\sim \sqrt{\alpha'} \log \frac{s}{-t}$$

- Can be seen from impact parameter transform in forward scattering
- well-established in BPST

4pt)

Veneziano





5pt)

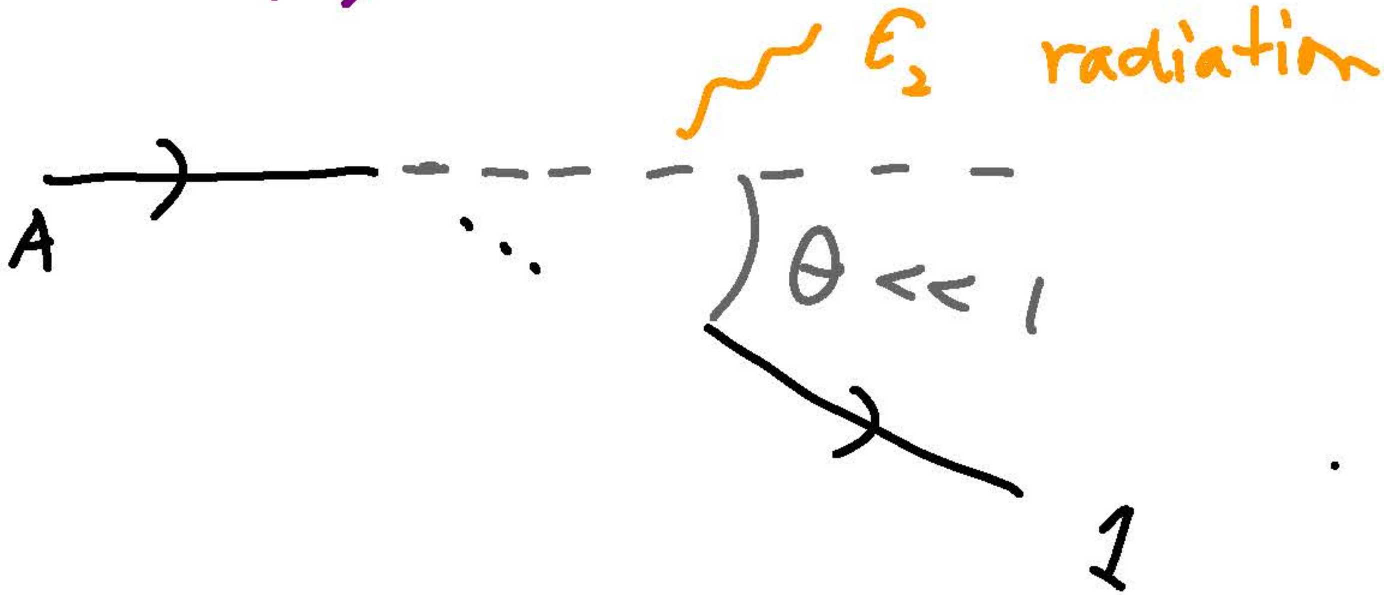
Bardakci - Ruegg

Bialas - Pokorski

S-matrix 'data' analysis

- Work in Regge or double Regge

  $E\theta_1 \, , \, E_2 \ll E$



(1) Keep track of <u>phases</u> in amplitudes

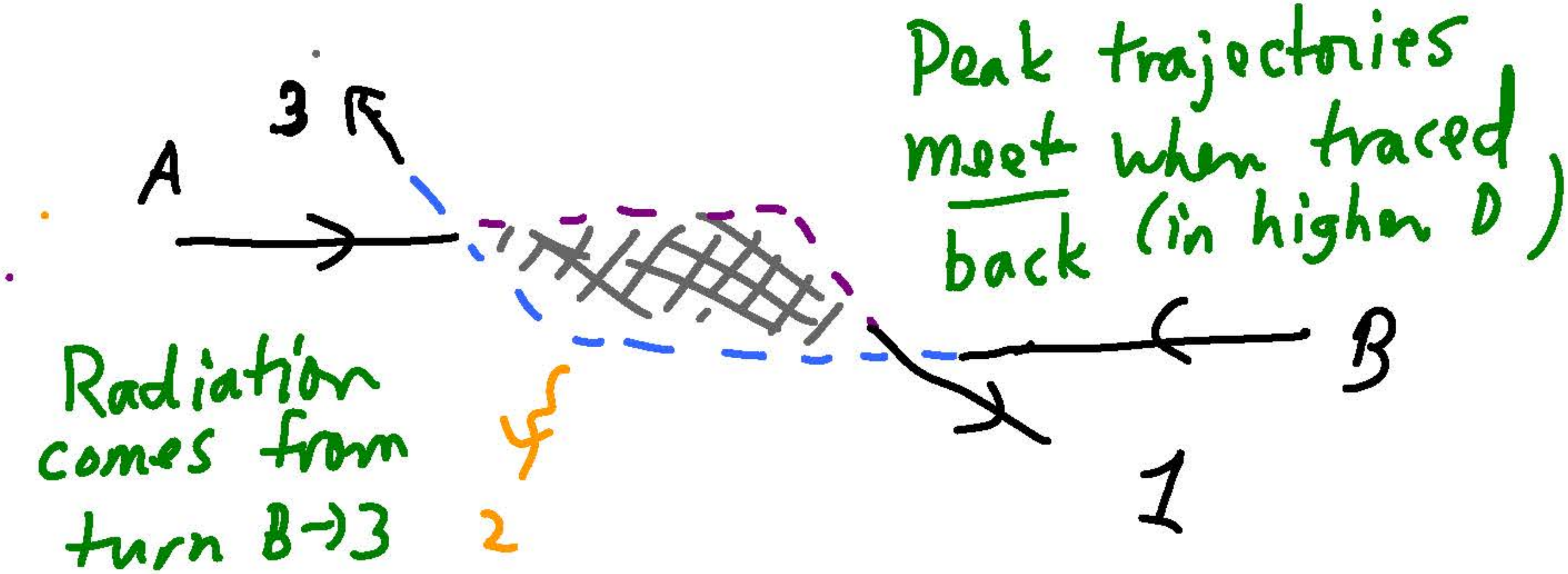
$$A \sim e^{i\delta(k_I \cdot k_J)} \hat{A}_{slow}$$

in tractable regime, and

(2) convolve with wavepackets to determine peak trajectories

peak impact parameter b_{AB}

time delays/advances T



(3) Explicit & simple string solutions for intermediate S-channel states ↔ imag. parts
* quantitative agreement with peak b & T

limited ⊥

2 Main examples: 4 point:

$$A_{st} \sim g_0^2\, \Gamma(-1-\alpha' t)\,(\alpha' s)^{1+\alpha' t}\, e^{-i\pi t} + \dots$$

$e^{\alpha' t}\left(\frac{-s}{t}\right)^{\alpha' t}$

$\frac{\sin(\pi\alpha'(s+t))}{\sin(\pi\alpha' s)}$

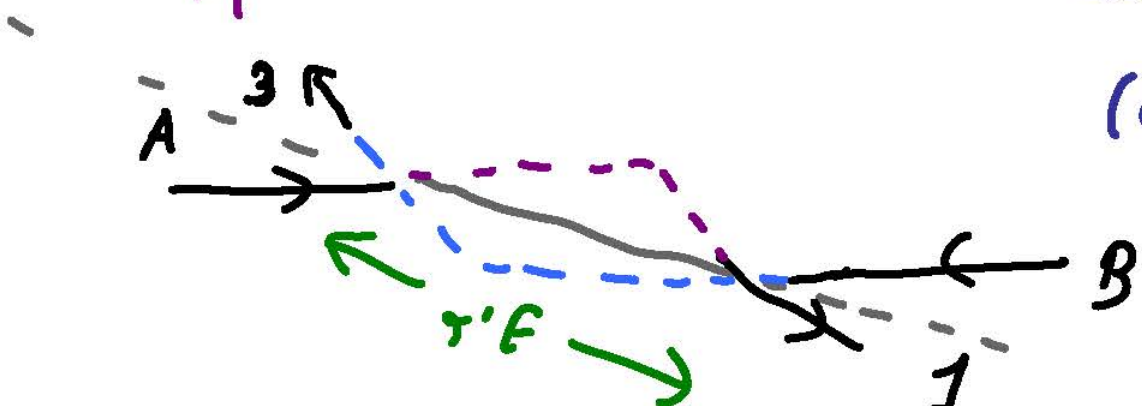
phase

→ Peak trajectories

$$b_{AB} = -2\pi\alpha' E\sin\theta_1 \neq 0 \;!$$

$$T_1 = 2\pi\alpha' E(1-\cos\theta_1) \simeq \pi E\theta_1^2\alpha'$$

time delay (cf attractive potential)



The interaction timescale* from BPST/GM is $\Delta X^-_{int} \sim -\frac{\alpha' t}{P_A^+}$

During this time, A travels along X^+ a distance

$$\Delta X^+ \sim \Delta X^- P_A^{+2} \sim \Delta X^- P^{+2} \sim \alpha' P^+$$

Alternate transverse effect?

(see appendix D)

Fourier transform

$$\int dq_\perp \, s^{-\alpha' q_\perp^2} e^{i\pi\alpha' q_\perp^2} e^{iq_\perp b} = \frac{\exp\left(-\frac{b^2}{4\alpha'(\log s - i\pi)}\right)}{\sqrt{\frac{\log s}{\pi} - i}},$$

- Not a real density

cf $A(\vec{q}) = A_{pt}(\vec{q})\, F(\vec{q})$

source $\rho(\vec{r}) = |\psi_s(\vec{r})|^2$

$F(\vec{q}) = \int d\vec{r}\, e^{i\vec{q}\cdot\vec{r}} \underbrace{\rho(\vec{r})}_{\text{real}}$

all directions

Interpret Fourier transform as wave function?

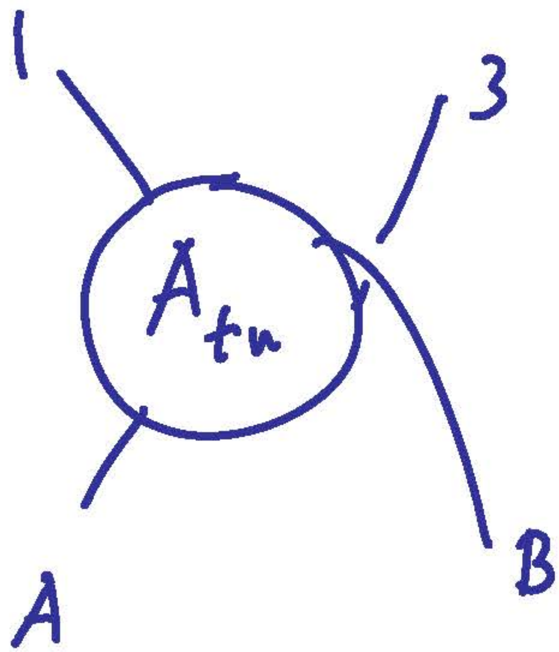
- Known ground state wave function

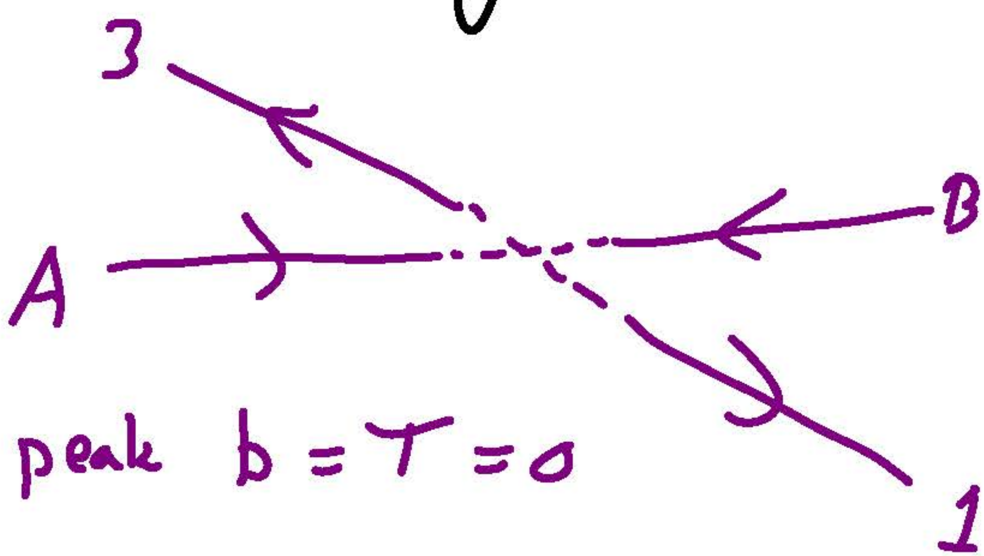
$$\Psi_0(\Delta y) = N_0\, e^{\frac{-(\Delta y)^2}{\sigma' \log \frac{n_{max}}{n_0}}}$$

- Alternate hypothesis:

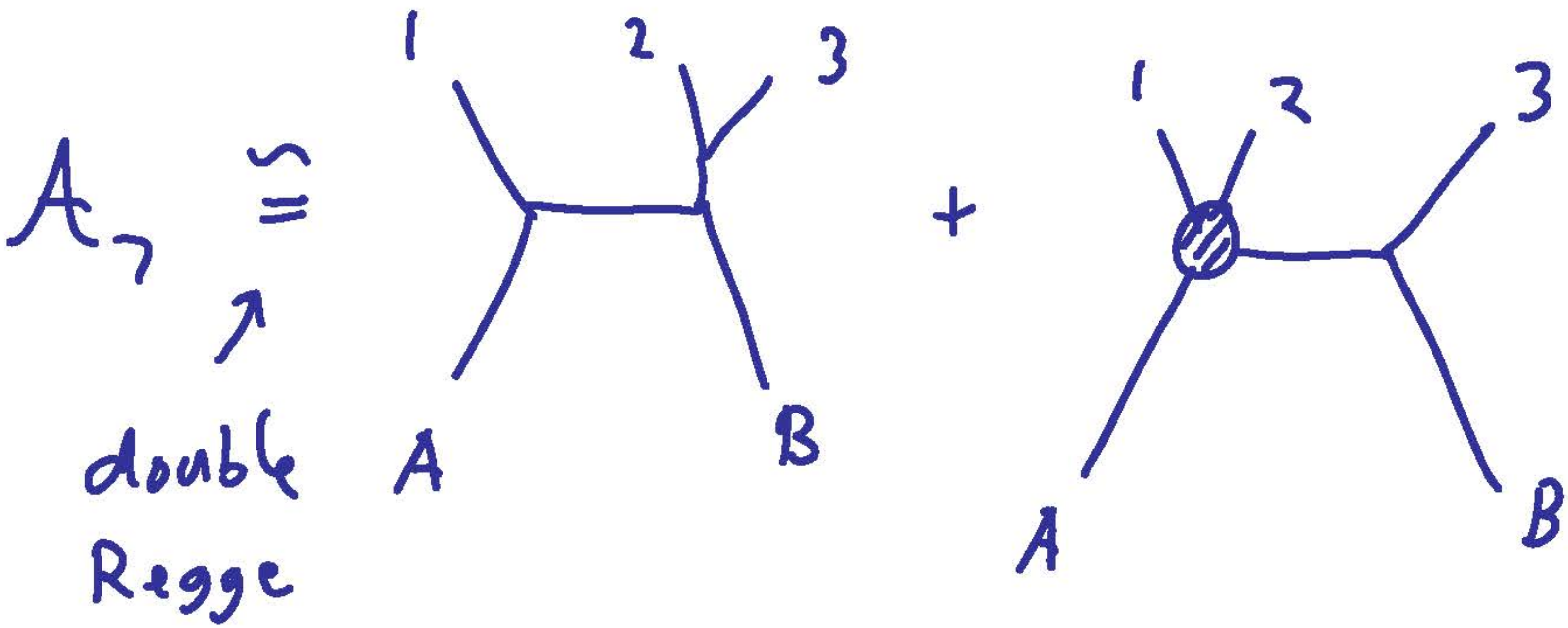
$$\Psi_\pi(\Delta y) = N_\pi\, e^{\frac{-(\Delta y)^2}{\sigma'(\log n_{max} - i\pi)}}$$

One of the 4 pt diagrams has <u>zero</u> time delay/advance

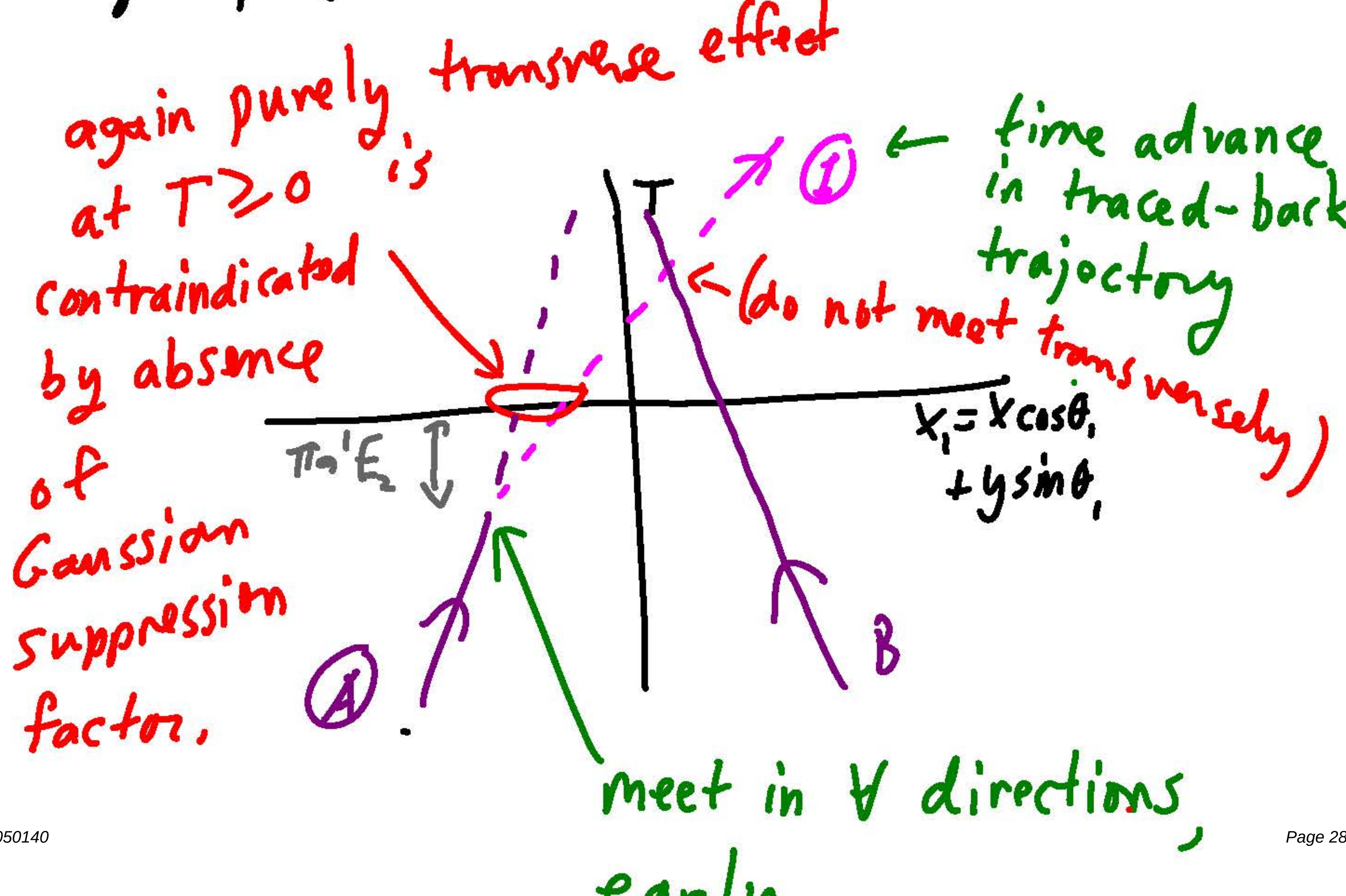




In this one, when we upgrade



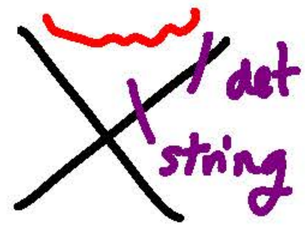
In a concrete regime with $A_7 \cong e^{i\pi(k_{B3} - k_{A1})} \hat{A}_{slow}$, peak trajectories, traced back, e.g. projected to 1+1 dimensions



Remarks

- These S-matrix amplitudes admit a simple interpretation terms of long. spreading; not captured by $\rho(X_\perp)$.
- However, BH problem has additional complications: (weak) curvature; strings appear in near-horizon

Horizon physics



- In Schwarzschild BH, find (including decays/secondary probes)

$$\Delta X^+ \sim p^+_{detector}\, \alpha' \Rightarrow \text{detectable}$$

spreading for $m_{det} > \frac{r_s}{\alpha'} \frac{E_{det}}{m}$

$\rightarrow$ breakdown of EFT for late infalling detector given

Remarks

☆ despite $R_g' \ll 1$, BH accelerates trajectories to generate large near-horizon relative boost

(Not simply Minkowski/Rindler dynamics)

- Causal (source string always spread, detector develops the

- relative boost sets in <u>outside</u> horizon; neither strict 'firewall' (AMPS) nor low-energy 'non violent nonlocality' (Giddings) but has elements of each.

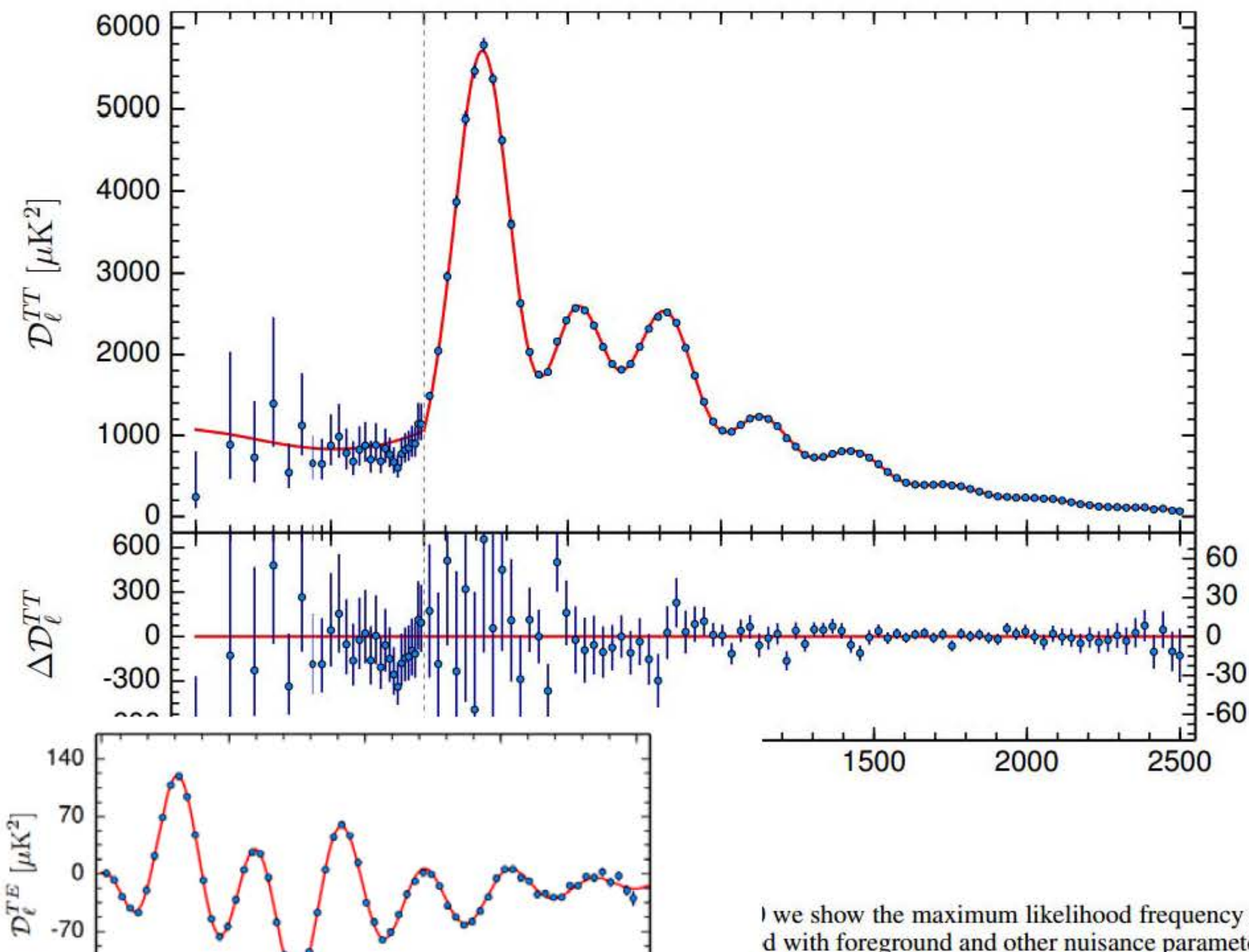
Also timescale $\Delta t \gtrsim 2 r_s$ short compared to Page time

- Observational tests ??

Cosmological Horizons?

observer-dependent
...

Planck Collaboration: Cosmological parameters



) we show the maximum likelihood frequency averaged
d with foreground and other nuisance parameters deter-

Cosmological horizons

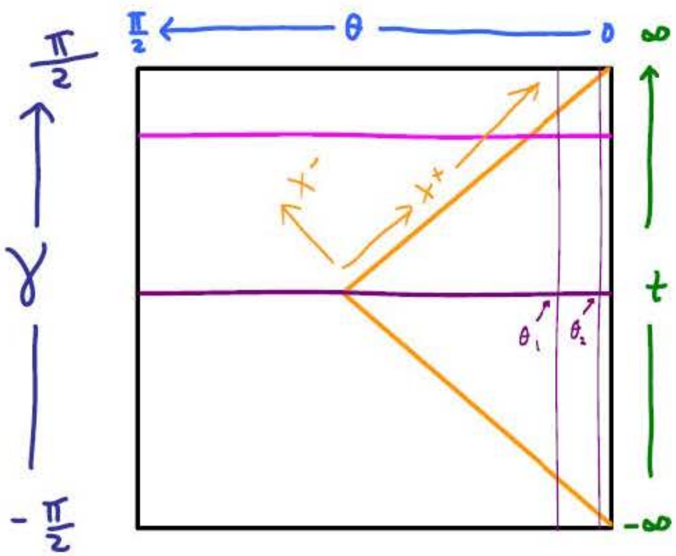


Figure 6: Trajectories 1 and 2 in the late de Sitter universe, as described in the text. For small values of the global spatial coordinate θ, the trajectories fall across the indicated observer horizon at a late global time, so that the spatial slices are nearly flat as in our observed universe. Within that regime, the hierarchy $\frac{\theta_2}{\theta_1} \ll 1$ leads to a large relative boost at the horizon, generated by the cosmological background.

Future directions

- Other regimes of string and QG effects, e.g. single-Regge, 6-pt, ...
- background fields (linear dilaton, tachyon wall, AdS,* electromagnetic flds, etc.) may further help tease out/test the longitudinal nonlocality

· 5-pt function cf Shenker-Stanford

Happy Birthday Gary!