BRST-BV treatment of Vasiliev's four-dimensional higher-spin gravity

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Outline

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- Adaptation to Vasiliev's HSGR
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Abstract

We provide Vasiliev's 4D HSGR with a classical Batalin – Vilkovisky (BV) master action using an adaptation of the Alexandrov – Kontsevich – Schwarz – Zaboronsky (AKSZ) implementation of the (BV) field-anti-field formalism to the case of differential algebras on non-commutative manifolds.

- Vasiliev's equations follow via the variational principle from a Poisson sigma model (PSM) on a non-commutative manifold (see talk by Nicolas Boulanger which we shall also review below)
- AKSZ procedure: classical PSM on commutative manifold is turned into BV action for "minimal" set of fields and anti-fields by substituting each classical differential form by a "vectorial superfield" of fixed total degree given by form degree plus ghost number
- Apply to Vasiliev's HSGR by adapting the AKSZ procedure to PSMs on non-commutative manifolds — part of a more general story!

Many motivations for HSGR

Existence of gauge theories are non-trivial facts, mathematically as well as physically once the dynamics is interpreted properly.

In the case of HSGR, a benchmark is set by Vasiliev's equations:

- AdS/CFT correspondence:
  - weak/weak-coupling approaches
  - physically realistic AdS/CMT dualities
  - anti-holographic duals of as. free QFTs
- formal developments of QFT:
  - unfolding
  - generally covariant quantization
  - twistorization
- co-existence of HSGR and string theory:
  - interesting for stringy de Sitter physics and cosmology
  - new phenomenologically viable windows to quantum gravity
  - new perspectives on the cosmological constant problem and long-distance gravity (*e.g.* dark matter vs scalar hairs)

Why the PSM off shell formulation

- Thinking of Vasiliev's 4D equations as "toy" for quantum gravity:
  - Many symmetries may suppress UV divergencies ...
  - ... but also introduce higher time derivatives already at the classical level
  - Find suitable generalization of canonical quantization?
- Perturbative expansion around AdS4:
  - Linearized spectrum $\sim$ square of free conformal scalar/fermion ....
  - ... suggests dual CFT3 $\sim$ large-N free field theory
  - No loop corrections at all! Tree-level exact or perfect cancellations?

Why 4D and not 3D?

The situation in 4D is cleaner than in 3D where the PSM formulation essentially amounts to BF-models in the case of HSCS theory and BFCG-models in the case of Prokushkin – Vasiliev HSGR — we shall not discuss the latter models any further here but they are for sure very interesting and actually in a certain sense more complicated than those arising for 4D HSGR.

Fradkin – Vasiliev cubic action

- Intrinsically 4D action $\sim$ free Fronsdal plus interactions:
  - Fradkin – Vasiliev cubic action $\sim$ free first-order action for Fronsdal fields plus cubic interactions ....
  - ... but it requires extra auxiliary fields to be eliminated via subsidiary constraints on extra linearized higher spin curvatures
  - Non-abelian higher spin connection and curvature

$$A \equiv A_{\rm dyn} + A_{\rm Extra}$$

$$F \equiv F_{\rm Fronsdal\,EoM} + F_{\rm Extra} + F_{\rm Weyl}$$

$$\delta S^{(2)}_{\rm FV} \propto F^{(1)}_{\rm Fronsdal\,EoM}\ , \qquad F^{(1)}_{\rm Extra} \propto A_{\rm Extra} + \nabla^{(0)} \cdots \nabla^{(0)} A_{\rm dyn}$$

$$F_{\rm Weyl} \propto J^{(1)}(e, e; \Phi)$$

  - Beyond cubic order, non-abelian corrections mix equations of motion with subsidiary constraints
  - Completion of Fradkin – Vasiliev action on shell as generating functional for tree diagrams?

Lagrange multipliers

- Introduce Weyl zero-form Φ and Lagrange multipliers V and U

$$S_{\rm tot} = \int \mathcal{V}_{\rm FV}[A,\Phi] + \int {\rm Tr}\left[V \star (F + J(A,A;\Phi)) + U \star (D\Phi + P(A;\Phi)\right]$$

assuming that (note direction of $\Rightarrow$)

$$\delta \int \mathcal{V}_{\rm FV} \approx 0 \quad \Leftarrow \quad F + J \approx 0\ , \quad D\Phi + P \approx 0$$

- Shortcomings:
  - Apparent "conflict of interest" between kinetic terms in $\mathcal{V}_{\rm FV}$ and in $\int {\rm Tr}\left[V \star dA + U \star d\Phi\right]$ — resolved in negative fashion as FV term can redefined away modulo total derivative!
  - The generation of quantum corrections to A and Φ becomes problematic

Higher dimensional “BF-like” models (first run)

Embed 4D spacetime into the boundary of higher dimensional “bulk” manifold $\mathcal{M}$:

- “duality extend” $(A, B; U, V)$ into all form degrees mod 2 and add bulk Hamiltonian $\mathcal{H}(B; U, V)$
- natural boundary conditions: $U|_{\partial M} \approx 0$ and $V|_{\partial \mathcal{M}} \approx 0$
- original equations of motion are recuperated on ∂M without need to fix any gauges (*N.B.* interpolations between inequivalent 4D configurations on different boundaries — *c.f.* Hawking's no-boundary proposal and transitions between complete 4D histories)
- perturb around free bulk theory $\rightsquigarrow$ correlators on $\partial\mathcal{M}$ restricted by conservation of form degree
- add “topological vertex operators” $\int_{\partial\mathcal{M}} \mathcal{V}[A, B; dA, dB]$ such that $\delta \int \mathcal{V}$ vanishes on the bulk shell $\rightsquigarrow$ more vertices $\rightsquigarrow$ additional loop corrections on $\partial\mathcal{M}$
- $\Rightarrow \int \mathcal{V}_{\mathrm{FV}}$ remains tree-level exact deformation

Poisson sigma models on commutative manifolds

- Topological models on manifolds $\mathcal{M}$, say of dimension $\hat{p}+1$.
- The fundamental fields are locally defined differential forms X^α (α label internal indices) and their canonical momenta P_α (non-linear Lagrange multipliers) obeying

$$\deg(X^\alpha)+\deg(P_\alpha) \;=\; \hat{p}$$

- Physical degrees of freedom are captured by topological vertex operators $\oint_{\mathcal{M}_i}\mathcal{V}[X,dX]$
- In particular, local degrees of freedom enter via X^α of degree zero and topologically broken gauge functions of degree zero, captured by
  - zero-form invariants which are topological vertex operators that can be inserted at points
  - topological vertex operators depending on the topologically broken gauge fields (generalized vielbeins)

Target space and generalized Hamiltonian

- Target space: phase space $T[\hat{p}]\mathcal{N}$ of graded Poisson manifold $\mathcal{N}$ equipped with:
  - a nilpotent vector field $Q \equiv \Pi_{(1)} = Q^{\alpha}(X)\partial_{\alpha}$ of degree 1
  - compatible multi-vector fields $\Pi_{(r)}$ of ranks r and degrees $1 + (1 - r)\hat{p}$

$$\{\Pi_{(r)}, \Pi_{(r')}\}_{\text{Schouten}} \equiv 0 \ .$$

- In canonical coordinates, the classical bulk Lagrangian is of the generalized Hamiltonian form

$$\mathcal{L}^{\text{cl}}_{\text{bulk}} = P_{\alpha} \wedge dX^{\alpha} - \mathcal{H}(P, X)$$

where $\mathcal{H} = \sum_r P_{\alpha_1} \cdots P_{\alpha_r} \Pi^{\alpha_1 \cdots \alpha_r}(X)$ obeys the structure equation

$$0 \equiv \{\mathcal{H}, \mathcal{H}\}_{\text{P.B.}} \sim \partial_{\alpha}\mathcal{H} \wedge \partial^{\alpha}\mathcal{H} \ .$$

Gauge invariance, structure group and topological symmetry breaking

- Structure equation $\Rightarrow$ under the gauge transformations

$$\delta_{\epsilon,\eta}(X^\alpha, P_\alpha) \ := \ d(\epsilon^\alpha, \eta_\alpha) + (\epsilon^\alpha \partial_\alpha + \eta_\alpha \partial^\alpha)(\partial^\alpha, \partial_\alpha)\mathcal{H} \ ,$$

the classical Lagrangian transforms into a total derivative, *viz.*

$$\delta_{\epsilon,\eta}\mathcal{L}^{\rm cl}_{\rm bulk} \ = \ d(\epsilon^\alpha \partial_\alpha (1 - P_\beta \partial^\beta)\mathcal{H} + \eta_\alpha (dX^\alpha - \partial^\alpha \mathcal{H}))$$

- Globally defined classical topological field theory with graded structure group generated by gauge parameters $(t^\alpha, 0)$ obeying

$$t^\alpha \partial_\alpha (1 - P_\beta \partial^\beta)\mathcal{H} \ = \ 0$$

- Remaining gauge parameters and corresponding fields are glued together across chart boundaries by means of transitions from the structure group (*c.f.* separate treatment of local translations and Lorentz rotations in Einstein – Cartan gravity)

Boundary data and Cartan integrability

The degrees of freedom reside in the boundary data:

- if $\mathcal{H}|_{P=0} = 0$ the variational principle holds with $P_\alpha|_{\partial\mathcal{M}} = 0$ so P_α can be taken to vanish on-shell in the case of a single boundary component
- integration constants C^α for the X^α of degree zero
- values of topologically broken gauge functions, λ^α say, on boundaries of the boundary $\partial\mathcal{M}$ (noncompact)
- windings in transitions, monodromies etc

N.B. Given C^α and λ^α, the local field configuration on $\partial\mathcal{M}$ given on shell by Cartan's integration formula:

$$X^\alpha_{C,\lambda} \;\approx\; \left[\exp((d\lambda^\beta + \lambda^\gamma \partial_\gamma Q^\alpha)\partial_\beta) X^\alpha\right]\Big|_{X=C}$$

where we recall that $\mathcal{H} = P_\alpha Q^\alpha(X) + O(P^2)$

Intrinsically defined observables on shell versus topological vertex operators off shell

- Classically, the physical information in initial/boundary data is captured by various classes of intrinsically defined observables $\mathcal{O}[X]$ obeying

$$\delta_{t'}\mathcal{O} \equiv 0 \,, \qquad \delta_\epsilon \mathcal{O} \approx 0$$

  - t' parameters of chosen structure group (need not be same as t)
  - structure group not unique by any general means
  - larger/smaller structure group $\leftrightarrow$ fewer/more observables
  - notions of unbroken phase and various broken phases
  - topologically broken symmetries (incl. diffeos) resurface on shell
- Certain $\mathcal{O} \approx \oint \mathcal{V}$ with $\mathcal{V}[X, dX]$ being topological vertex operator defined off shell such that

$$\delta_{t'}\mathcal{V} \equiv 0 \,, \qquad \delta\mathcal{V} \approx 0$$

N.B. On shell $\oint \mathcal{V}$ only depends on the homotopy class of its cycle.

Total action

- PSM characterized by the total action

$$S^{\rm cl}_{\rm tot} \;=\; \int_{\mathcal{M}} (P_\alpha dX^\alpha - \mathcal{H}(X,P)) + \sum_i g_i \oint_{\mathcal{M}_i} \mathcal{V}^i(X,dX)$$

  - $\mathcal{H}$ breaks Cartan gauge algebra down to maximal structure group
  - topological vertex operators $\mathcal{V}^i$ (may) cause further breaking
  - all Cartan gauge symmetries restored on shell
  - the on shell values $\mathcal{V}^i$ identified as semi-classical generating functions for amplitudes
- for a field theory with an "ordinary" action principle $S_{\rm D}$ in D dimensions, one may choose $\mathcal{V} = S_{\rm D}$ — in general, the does *not* reproduce the standard S-matrix/holographic correlation functions
- in the case of HSGR, we propose to take $\mathcal{V}$ to be the yet-to-be found completion of $S_{\rm FV}$

Gauge fixing and Batalin–Vilkovisky field-anti-field formalism

The first step of the gauge fixing procedure is to exhibit all gauge-for-gauge symmetries:

extend the classical fields $(X^\alpha, P_\alpha) \equiv (X^{\alpha,\langle 0\rangle}_{[p_\alpha]}, P^{\langle 0\rangle}_{\alpha,[\hat{p}-p_\alpha]}) \longrightarrow$ finite towers of ghosts $(X^{\alpha,\langle q\rangle}_{[p_\alpha-q]}, P^{\langle q'\rangle}_{\alpha,[\hat{p}-p_\alpha-q']})$ with ghost numbers $q = 1,\dots,p_\alpha$ and $q' = 1,\dots,\hat{p}-p_\alpha$

Fields and anti-fields

As the Cartan gauge symmetries do not in general close off-shell, the BRST operator needs to be constructed via a "minimal" master action

$$S^{\mathrm{BV}}[\phi^i, \phi^*_i]$$

depending on

- "fields" ϕ^i comprising the classical fields and the ghost towers
- "anti-fields" ϕ^*_i obeying

$$\mathrm{gh}\phi^i + \mathrm{gh}\phi^*_i \ = \ -1 \ , \qquad \mathrm{deg}\phi^i + \mathrm{deg}\phi^*_i \ = \ \hat{p} + 1 \ .$$

BV bracket

The space of fields and anti-fields is equipped by a natural symplectic structure corresponding to the BV bracket

$$(A,B) \ := \ \int_{p\in\mathcal{M}} \delta_i(p) A\, \delta_*^i(p) B \ , \qquad \mathrm{gh}(\cdot,\cdot) \ = \ 1 \ ,$$

where $\delta_i(p)$ denotes the functional derivative with respect to ϕ^i at the point p *idem* $\delta_*^i(p)$.

Classical and quantum master equation

- If the anti-fields are eliminated by means of a canonical transformation then the path-integral over the remaining Lagrangian submanifold is does not depend on the c.t. provided that

$$(S,S)+\frac{i}{2}\hbar\Delta S \ \equiv\ 0\ ,$$

where the BV Laplacian Δ is the slightly singular operator defined by

$$\Delta\ :=\ \int_{p\in\mathcal{M}}\delta_i(p)\delta^i_\star(p)\ ,\qquad \mathrm{gh}\Delta\ =\ 1\ .$$

- Δ is formally nilpotent but does not act as a differential; rather

$$\Delta(AB)-\Delta(A)B-A\Delta(B)\ \equiv\ (A,B)\ .$$

- The nilpotent BRST differential s is given by

$$sA\ :=\ (S,A)\ .$$

- s is generated by a BRST current only if $\Delta S=0$.

AKSZ vectorial superfields

AKSZ: Minimal quantum master action of the PSM obtained by extending the classical differential forms into unconstrained vectorial superfields of fixed total degree p given by the sum of form degrees and ghost numbers as follows:

$$\mathbf{X}^{\alpha} = \underbrace{X^{\alpha\,\langle p_\alpha\rangle}_{[0]} + X^{\alpha\,\langle p_\alpha-1\rangle}_{[1]} + \ldots + X^{\alpha\,\langle 0\rangle}_{[p_\alpha]}}_{\textit{fields}} + \underbrace{X^{\alpha\,\langle -1\rangle}_{[p_\alpha+1]} + X^{\alpha\,\langle -2\rangle}_{[p_\alpha+2]} + \ldots + X^{\alpha\,\langle p_\alpha-\hat{p}-1\rangle}_{[\hat{p}+1]}}_{\textit{antifields}} \quad , \tag{1}$$

$$\mathbf{P}_{\alpha} = \underbrace{P^{\langle \hat{p}-p_\alpha\rangle}_{\alpha\;[0]} + P^{\langle \hat{p}-p_\alpha-1\rangle}_{\alpha\;[1]} + \ldots + P^{\langle 0\rangle}_{\alpha\;[\hat{p}-p_\alpha]}}_{\textit{fields}} + \underbrace{P^{\langle -1\rangle}_{\alpha\;[\hat{p}-p_\alpha+1]} + P^{\langle -2\rangle}_{\alpha\;[\hat{p}-p_\alpha+2]} + \ldots + P^{\langle -p_\alpha-1\rangle}_{\alpha\;[\hat{p}+1]}}_{\textit{antifields}} \quad , \tag{2}$$

AKSZ quantum master action

Ultra-local functionals $F = F(\mathbf{X}, \mathbf{P})$ and F' obey

$$(\int_{\mathcal{M}} \mathbf{P}_\alpha d\mathbf{X}^\alpha, F) \; = \; dF \;, \qquad (\int_{\mathcal{M}} F, F') \; = \; \{F, F'\}_{\mathrm{P.B.}} \;,$$

$$\Delta \int_{\mathcal{M}} F \; \equiv \; 0 \;.$$

Thus, since $\{\mathcal{H}, \mathcal{H}\}_{|rmP.B.} \equiv 0$, it follows that

$$S^{\mathrm{AKSZ}}_{\mathrm{bulk}} \; := \; \int_{\mathcal{M}} [\mathbf{P}_\alpha d\mathbf{X}^\alpha - \mathcal{H}(\mathbf{X}, \mathbf{P}))]$$

obeys

$$(S^{\mathrm{AKSZ}}_{\mathrm{bulk}}, S^{\mathrm{AKSZ}}_{\mathrm{bulk}}) \; = \; 0 \; = \; \Delta S^{\mathrm{AKSZ}}_{\mathrm{bulk}}$$

modulo boundary terms that vanish for suitable assignments of cross-chart transformation properties and boundary conditions (here the general theory involves sophisticated generalizations of bundle theory).

HSGR: non-commutative base and target spaces

- $\mathcal{M} \supset \partial\mathcal{M}$ (X and Z coordinates) and $T^*[\hat{p}]\mathcal{N}$ (spaces of functions of Y) non-commutative; denote the combined associative product by $\star$.
- The generalized Hamiltonian bulk action ($Z^i = (A, B, U, V)$)

$$S^{\rm cl}_{\rm bulk}[Z^i; J] \ = \ \int_{\mathcal{M}} \left[U \star DB + V \star \Big(F + \mathcal{F}(B; J) + \widetilde{\mathcal{F}}(U; J) \Big) \right] \ ,$$

  where $DB := dB + [A, B]_\star$, $F := dA + A \star A$ and J are d-closed central elements (of even form degrees).

- If $\hat{p} = 2n$, the fields decompose under form degree as follows:

$$A \ = \ A_{[1]} + A_{[3]} + \cdots + A_{[2n-1]} \ , \qquad B \ = \ B_{[0]} + B_{[2]} + \cdots + B_{[2n-2]} \ ,$$
$$U \ = \ U_{[2]} + U_{[4]} + \cdots + U_{[2n]} \ , \qquad V \ = \ V_{[1]} + V_{[3]} + \cdots + V_{[2n-1]} \ .$$

- Variational principle $\Rightarrow R^i := dZ^i + Q^i(Z^j) \approx 0$ and homogeneous boundary conditions on (U, V) such that on $\partial\mathcal{M}$

$$F + \mathcal{F} \ \approx \ 0 \ , \qquad DB \ \approx \ 0 \ .$$

Adaptation of BV to non-commutative setting

- $\star$-functional differentiation defined naturally via

$$\delta F[X,P] \;\equiv\; F[X+\delta X, P+\delta P] \;=:\; \int_{\mathcal{M}} (\delta X^\alpha \star \delta_\alpha F + \delta P_\alpha \star \delta^\alpha F) \; .$$

  N.B. The $\star$-functional derivatives act as differentials on ultra-local functionals and cyclic derivatives on local functionals. The former action induces a suitable non-commutative generalization of the Dirac delta function (which in a certain sense is less singular than the commuting ditto).

- Introduce fields and master fields; the gauge fixing procedure (independence of choice of Lagrangian submanifold) $\rightsquigarrow$ BV Laplacian given by double $\star$-functional derivatives of the above types.

Adaptation of AKSZ to non-commutative setting

- Extend $Z^i \to \mathbf{Z}^i = (\mathbf{A}, \mathbf{B}, \mathbf{U}, \mathbf{V})$
- The AKSZ action

$$S^{\rm AKSZ}_{\rm bulk}[\mathbf{Z}^i; J] \;=\; \sum_\xi \int_{\mathbf{M}_\xi} {\rm Tr}\left[\mathbf{U} \star D\mathbf{B} + \mathbf{V} \star \Big(\mathbf{F} + \mathcal{F}(\mathbf{B}; J) + \widetilde{\mathcal{F}}(\mathbf{U}; J)\Big)\right] ,$$

generates BRST transformations

$$(S^{\rm AKSZ}_{\rm bulk}, \mathbf{Z}^i) \;=\; \mathbf{R}^i \;:=\; d\mathbf{Z}^i + Q^i(\mathbf{Z}^j; J)$$

- It follows that the AKSZ action obeys the classical master equation

$$(S^{\rm AKSZ}_{\rm bulk}, S^{\rm AKSZ}_{\rm bulk}) \;=\; 0 \;,$$

modulo boundary terms that vanish if $(\mathbf{U}, \mathbf{V}) = 0$ on $\partial\mathcal{M}$ and $(\mathbf{U}, \mathbf{V})$ form sections with bold-faced transition functions from the unbroken gauge algebra associated to $(\mathbf{A}, \mathbf{B})$.

Quantum master action and deformations

- Whether the bulk action also obeys the quantum master equation is under investigation.
- As is well-known from ordinary topological field theories, gauge fixing actually requires "non-minimal" extensions of the AKSZ action $\rightsquigarrow$ cancellation of all vacuum bubbles (modulo topological terms) $\rightsquigarrow$ bulk partition function as sum over topologies.
- There exists various topological impurities $\mathcal{V}[\mathbf{X}, d\mathbf{X}; J]$ obeying $(S, \mathcal{V}) = 0 = (\mathcal{V}, \mathcal{V})$ and $\Delta\mathcal{V} = 0$.
- In particular, in certain broken phase there exist a topological two-form (surface operator) and four-form; the relation between the latter and the on shell FV action is under investigation.

Correspondence with free $O(N)$ vector model

- Integrate out Vasiliev's Z-variables $\rightsquigarrow$ classical formulation on commutative $\mathcal{M}$ times internal Y-space with perturbatively defined Q-structure
- Duality extend $B = B_{[0]} + B_{[2]}$; $A = A_{[1]} + A_{[3]}$; $U = U_{[2]} + U_{[4]}$ and $V = V_{[1]} + V_{[3]}$
- for any $\mathcal{H}(U, V; B)$ the boundary correlators $\langle B_{[0]}(p_1) \cdots B_{[p_n]} A_{[1]}(p_{n+1}) \cdots A_{[1]}(p_{n+m}) \rangle|_{p_i \in \partial\mathcal{M}}$ are given by their semi-classical limits (assume vacuum bubbles cancel)
- assume the existence of a perturbative completion $\int_{\partial\mathcal{M}} \mathcal{V}_{\rm FV}(B_{[0]}, dB_{[0]}; A_{[1]}, dA_{[1]})$ of Fradkin – Vasiliev action; add it as deformation to be treated as vertices (including kinetic terms!)
- $\rightsquigarrow \langle \exp(g \int_{\partial\mathcal{M}} \mathcal{V}_{\rm FV}) \rangle$ tree-level exact which matches the ultra-violet fixed point of the $O(N)$-vector model
- Still miss correspondence at the level of the vacuum value of the on shell action (free energy)

1/N corrections from $\Delta = 2$ boundary conditions?

- Klebanov – Polyakov: infra-red fixed point of double-trace deformation $\leftrightarrow$ bulk theory with $\Delta = 2$ boundary conditions
- add Gibbons-Hawking term $\int_{\partial^2\mathcal{M}} \phi\partial_n\phi$ and treat as extra vertex:
  - Giombi – Yin: Modified scalar two-point functions

$$G_{\Delta=1}(p;r,r') + |p| K_{\Delta=1}(p;r) K_{\Delta=1}(p;r') \equiv G_{\Delta=2}(p;r,r')$$

  - Sew together pairs of external scalar legs of $\Delta = 1$ tree diagrams $\rightsquigarrow$ scalar loops touching the boundary
  - HS completion of the GH term $\rightsquigarrow$ HS fields starts running in loops touching the boundary?

Broken higher spin gauge symmetries and flat limit?

- Girardello – Porrati – Zaffaroni: spin-(s-1) Goldstone modes for $s = 4, 6, \ldots$ identified as scalar-spin-(s-2) composite
- multi-particle states start behaving as "fundamentals" $\rightsquigarrow$ stringy spectrum with many trajectories but problem with large-N normalization of higher-point functions (impose connectedness?)
- flat double-scaling limit: $\Lambda \to 0$ and N small but not really a limit as N quantized

Conclusions

- Quantize 4D HS fields via topological Poisson sigma models in higher dimensions
- 4D spacetime meant to arise as submanifold where on shell action a lá Fradkin – Vasiliev can be added as a deformation.
- Assumptions of the structure of the FV action imply that holographic correlators with $\Delta = 1$ BC agree with free O(N) vector model but free energy problematic still ....
- Assumptions on the Gibbons – Hawking terms imply qualitative fitting to the interacting O(N) vector model

Thanks for your attention!

As far as Schrödinger's cat is concerned, I was thinking of something funny to say but then I thought that I better leave it to the audience :)