Title: From Large N Double Scaling Limits to Non-Critical Superstrings

Date: Feb 19, 2008 11:00 AM

URL: http://pirsa.org/08020033

Abstract: We consider the large N limit of a class of fourdimensional supersymmetric theories in conjunction with a limit in their parameter space towards singular points where extra baryonic states become light, which causes the low-energy description to break down. However, this can be cured by defining a large N double scaling limit where one approaches the singularity by keeping the mass M of these states fixed. This limit has several interesting features. For example, the conventional \\\'t Hooft limit leads to a free theory of colour singlet states where all interactions are suppressed by powers of 1/N. In this case, the large N Hilbert space splits into two decoupled sectors, and one of them keeps residual interactions whose strength in inversely proportional to the mass M. We argue that for a class of these models the dynamics of this sector is dual to a non-critical superstring background, which is exactly solvable.

From Large N Double Scaling Limits to Non-Critical Superstrings

Gaetano Bertoldi

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- Work done in collaboration with Nick Dorey (DAMTP, Cambridge University), Tim Hollowood (Swansea University) and J. Luis Miramontes (University of Santiago de Compostela)
- Talk based on hep-th/0507075, 0603075, 0603122, 0611016

Outline

- Motivation and results
- 4d N=1 SUSY & Dijkgraaf-Vafa Matrix Model
- The large N Double scaling limit (DSL)
- Double scaled Little String Theory
- Duality proposal
- From Large N DSL to Matrix Model DSL
- Open problems

- ‘t Hooft: large N limit of Yang-Mills $g_{YM}^2 N$ fixed →
  String Theory: $g_s \sim 1/N$

  stable glueballs → excitations of the string

- AdS/CFT: examples of this scenario for confining models. Dual string theory is compactification of 10d critical superstring theory

- Problems: Ramond-Ramond flux, obstacle for quantization of the string;
- In the supergravity approximation only lightest glueball states survive
- Unwanted Kaluza-Klein states may not decouple

Results in brief

- We will propose large N limits of partially confining theories where the dual string theory has:
- No RR flux
- Exactly solvable worldsheet description
- String coupling can be made small
- This is achieved by a Large N Double scaling limit (DSL)
- This Large N DSL maps to a Matrix Model DSL
- Matrix Model DSL is analogous to ones considered in the study of $c \leq 1$ non-critical bosonic strings
- There is also a class of Large N DSL where "simple" dual string is not known

The Models

- 4d N=1 SUSY Yang-Mills U(N) + chiral adjoint field Φ + polynomial superpotential

$$W(\Phi) = \varepsilon Tr_N \left[\frac{\Phi^{m+1}}{m+1} - \sum_{l=1}^{m} g_l \frac{\Phi^l}{l} \right]$$

- Vacua:

$$U(N) \to \prod_{i=1}^{m} U(N_i) \to \hat{G} = U(1)^m$$

no mass gap but partial confinement

- Large N spectrum:
- conventional weakly interacting glueballs
- Magnetic/electric dibaryons with mass $\sim N$

- There are special vacua where the mass M of some dibaryons vanishes:

1. Conventional 1/N expansion breaks down
2. Glueball interactions are NOT suppressed

- In the DSL where N $\rightarrow \infty$, superpotential couplings $g_l \rightarrow g_{l,crit}$ but M is kept fixed a sector of the theory remains interacting

$$g_{eff} \sim 1/N_{eff} = \frac{\sqrt{T}}{M}$$

- Proposal: dynamics of this sector has a dual non-critical string description

$$R^{3,1} \times \left(\frac{SL(2)_k}{U(1)} \times LG(W) \right) / Z_m$$

Dijkgraaf-Vafa Matrix Model

- N=1 SUSY YM U(N) with adjoint Φ

$$W_{tree}(\Phi) \Rightarrow W_{eff} = \sum_l N_l \frac{\partial F_0}{\partial S_l} + 2\pi i(\tau_0 + b_l) S_l$$

- F_0 is free energy of an auxiliary complex one-matrix model in the planar limit

$$\exp \sum_{g=0}^{\infty} F_g g_s^{2g-2} = \int d\hat{\Phi} \exp\left(-g_s^{-1} \mathrm{Tr} W(\hat{\Phi})\right).$$

- Spectral curve: $y^2 = W'(x)^2 + f_{m-1}(x)$

$$S_l = \oint_{A_l} y dx \qquad \frac{\partial F_0}{\partial S_l} = \oint_{B_l} y dx$$

- String dual picture: Calabi-Yau geometry

$$W'(x)^2 + f_{m-1}(x) + y^2 + z^2 + w^2 = 0$$

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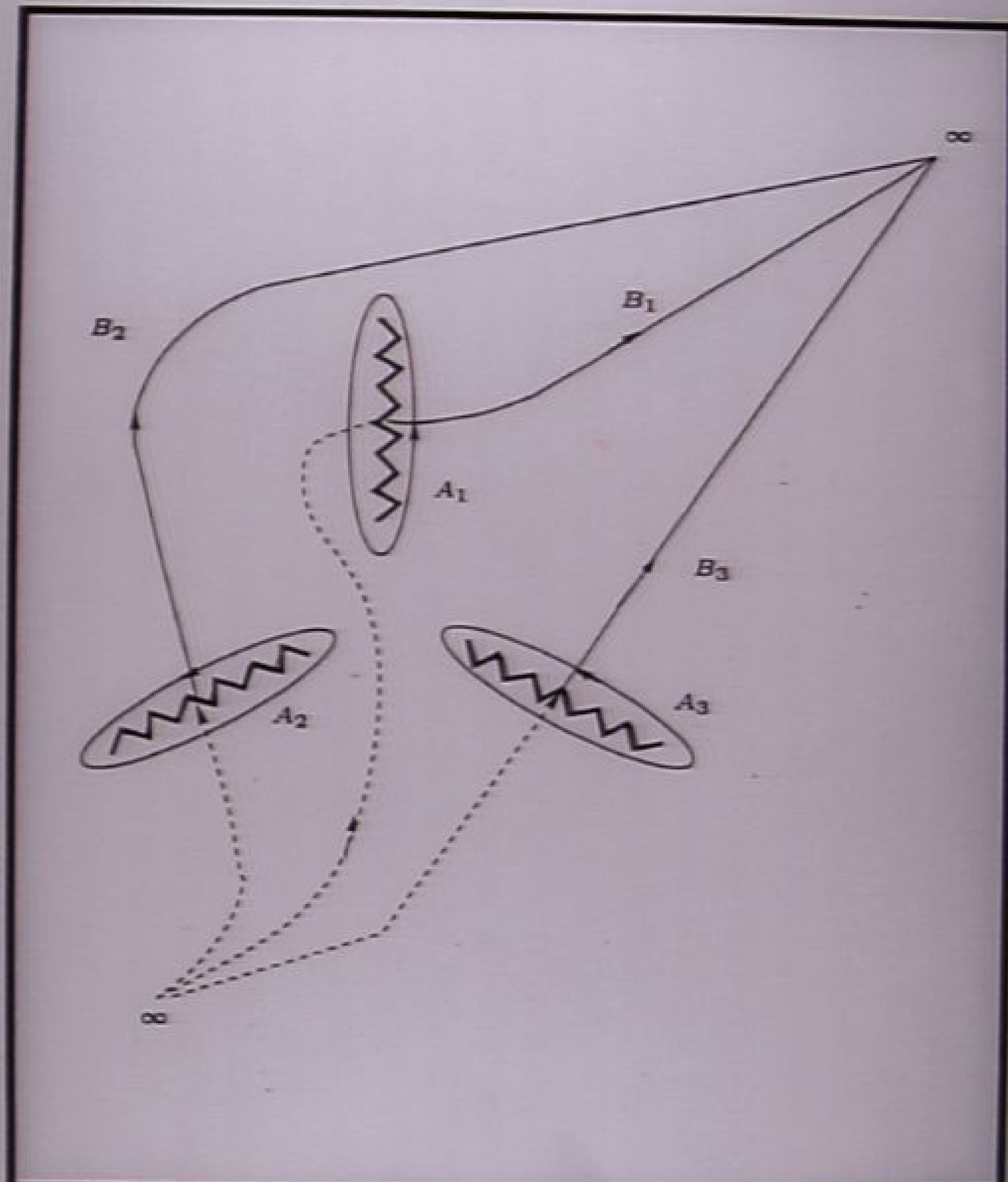
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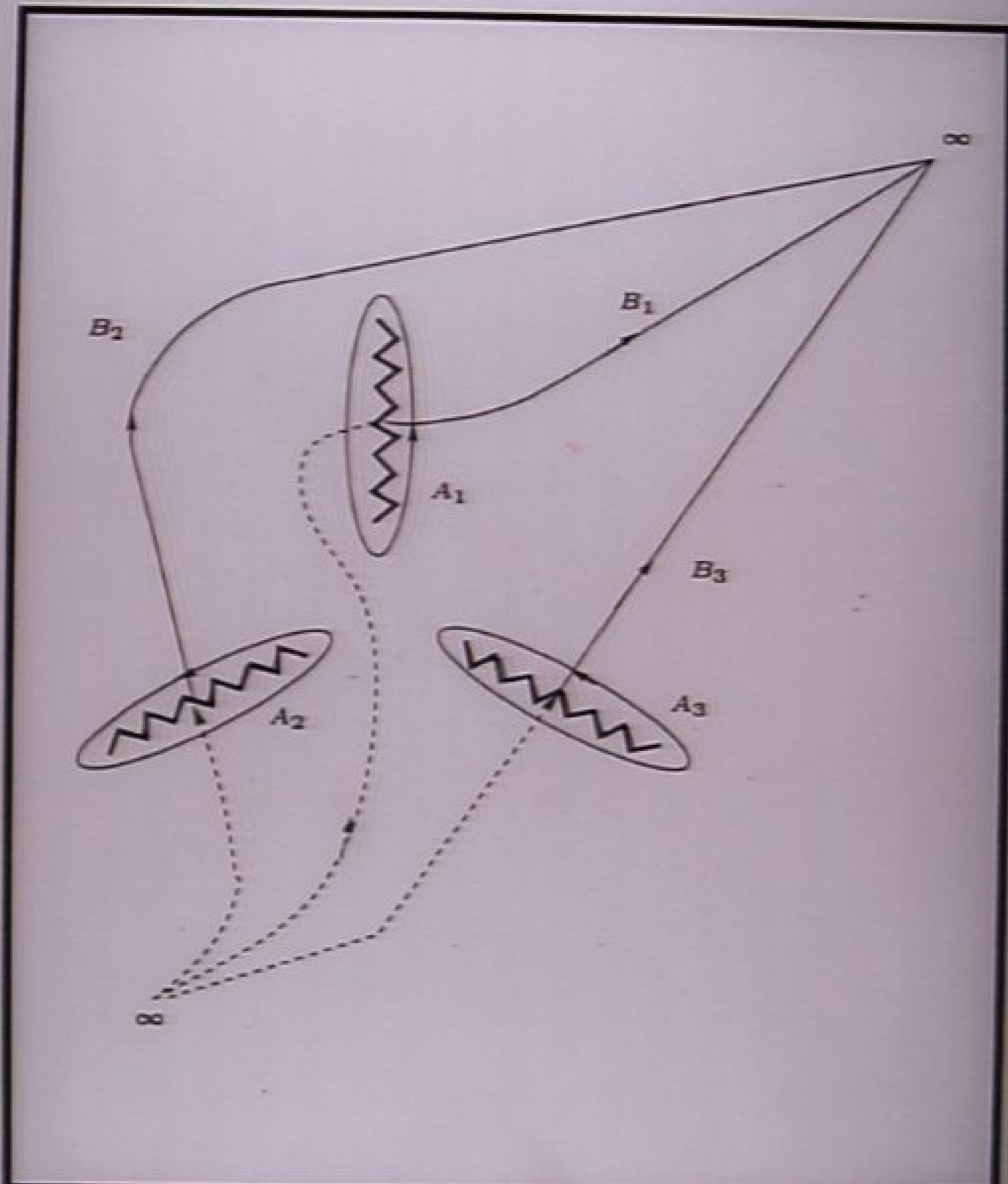

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- RR and NS fluxes

$$W_{eff} = \int_{CY} (H_{RR} + \tau H_{NS}) \wedge \Omega$$

$$\Omega \to y dx \qquad (H_{RR} + \tau H_{NS}) \to T dx$$

$$N_i = \oint_{A_i} T dx \qquad b_i = \oint_{B_i} T dx$$

- Massless Dibaryons → singular spectral curve, vanishing cycles

$$M \sim \int_{3-cycle} \Omega \to \int_{1-cycle} y dx$$

- Example of singularity: m branch points colliding

$$y^2 \approx x^m$$

The Exact F-term effective action

- F-term effective action $$L_F = \int d^2\theta \left[W_{eff}^{(0)} + W_{eff}^{(2)}\right]$$

$$W_{eff}^{(2)} = \frac{1}{2}\sum_l \frac{\partial F_0}{\partial S_l \partial S_k} w_{\alpha,l} w_k^{\alpha} \qquad W_{eff}^{(0)} = \sum_l N_l \frac{\partial F_0}{\partial S_l} + 2\pi i(\tau_0 + b_l) S_l$$

- In terms of the glueball superfields

$$S_l = -\frac{1}{32\pi^2} Tr_{N_l}[W_{\alpha,l} W_l^{\alpha}] = s_l + \theta_\alpha \chi_l^{\alpha} + \dots ,$$

$$w_{\alpha,l} = \frac{1}{4\pi} Tr_{N_l}[W_{\alpha,l}] = \lambda_{\alpha l} + \theta_\beta f_{\alpha l}^{\beta} + \dots$$

$$L_F \supset V_{ij}^{(2)} f_{\alpha\beta}^{i} f^{\alpha\beta j} + V_{ijk}^{(3)} \chi_\alpha^i f^{\alpha\beta j} \lambda_\beta^k + \dots \qquad L_F \supset H_{ij} \chi_\alpha^i \chi^{\alpha j}$$

L-point vertex

$$V_{i_1 \dots i_L}^{(L)} = \langle \frac{\partial^L F_0}{\partial S_1 \dots \partial S_L} \rangle$$

"Mass" matrix

$$H_{ij} = \langle \frac{\partial^2 W^{(0)}}{\partial S_i \partial S_j} \rangle$$

Breakdown of the 1/N expansion

- In the 't Hooft large N limit $\quad \varepsilon \sim N,\ g_l \sim N^0$

$$\langle S_l \rangle \sim N \qquad V^{(L)} \sim N^{2-L} \qquad H_{ij} \sim N^0$$

- At singularity $\quad y^2 = x^m - \delta,\ \delta \to 0$

$$V^{(3)}_{ijk} \sim \frac{1}{S - S_{crit}} \sim \frac{1}{N\delta^{\frac{m+2}{2m}}}$$

- Define the double scaling limit

$$N \to \infty,\ \varepsilon \sim N,\ \Lambda \sim const, \quad \delta \to 0$$

where $\quad \Delta \equiv \varepsilon\, \delta^{\frac{m+2}{2m}} \quad$ is kept fixed

The Large N DSL

- Hilbert space splits into 2 decoupled sectors
- One sector becomes free in the DSL, while the other has finite interactions weighted by

$$1/N_{eff} \sim 1/\Delta \sim \sqrt{T}/M$$

- Spectrum and interactions of the latter sector compatible with N=2 SUSY
- How is this possible given the presence of RR flux in initial geometry?
- More general singularities: the above picture partially holds: 1) Large N DSL is well-defined 2) no SUSY enhancement in general

$$y^2 \rightarrow Z_m(x)^2 B_n(x)$$

The field theory DSL

- there are two sectors $\mathcal{H}_\pm$ in the Hilbert space which decouple in the large N DSL.
- $\mathcal{H}_-$ contains $p = \frac{m-1}{2}$ $U(1)$ $\mathcal{N}=1$ vector multiplets, $\tilde{w}_{\alpha I}$ together with p neutral chiral multiplets S_I. These chiral multiplets become massless in the DSL
- interactions between colour-singlet states in $\mathcal{H}_-$ are controlled by

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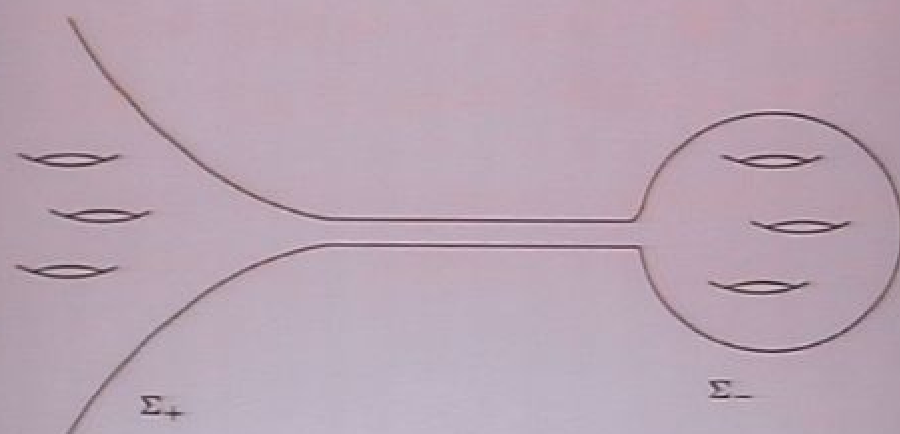

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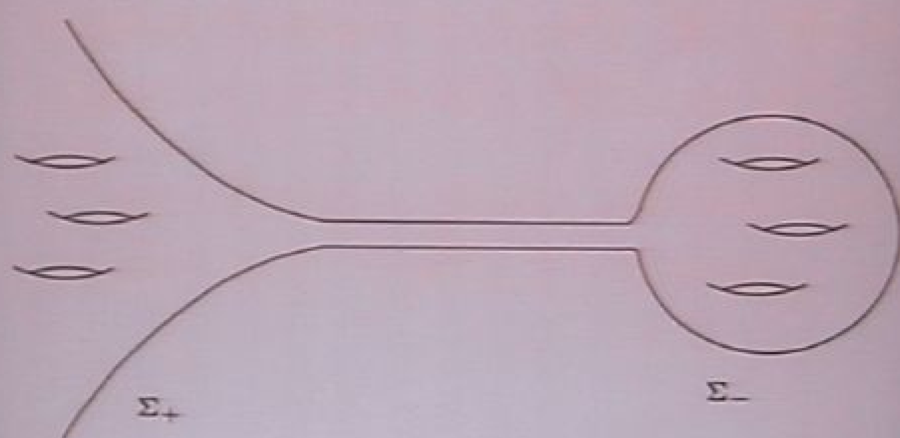

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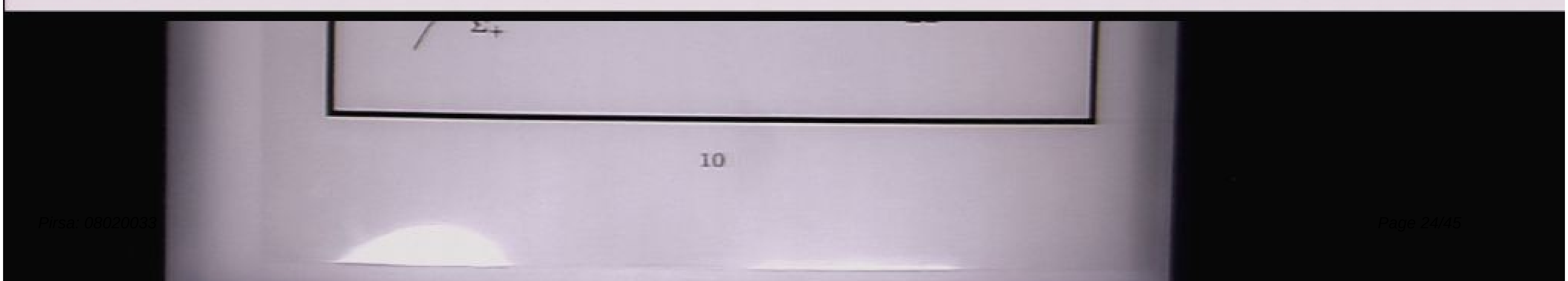

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Little String Theory

- How does the non-critical superstring emerge? String Theory in the proximity of certain CY singularities
- Consider CY in IIB with no fluxes

$$z^2 + w^2 + y^2 + x^m = \mu$$

- At $\mu = 0$ singularity → D3-branes wrapping shrinking cycles → massless states → singular string amplitudes
- Target space → Throat with linear dilaton

$$g_s = g_0 \exp\langle\phi\rangle \to \infty$$

- In the limit $g_0 \to 0$ states localized at singularity decouple from bulk 10d modes BUT maintain non-trivial interactions

- → non-critical 4d string theory without gravity dubbed Little String Theory
- LST has N=2 SUSY in 4d. Below the string scale it reduces to an Argyres-Douglas SCFT

Double Scaled LST

- LST has a holographic dual description in terms of a linear dilaton background corresponding to the infinite throat region

  Problem: the string coupling diverges
- Giveon and Kutasov considered the double scaling limit

$$g_0 \to 0,\ \mu \to 0, \qquad \kappa^{-1} = \frac{\mu^{\frac{m+2}{2m}}}{g_0} \quad fixed$$

The singularity is cured by giving a mass to the wrapped D3-brane states. The string dual to DSLST is now given by

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$$\kappa \sim 1/M_{D3}\sqrt{\alpha'}$$

- The semi-infinite "cigar" geometry of SL(2)/U(1) replaces the linear dilaton throat. The string coupling has an upper bound

Proposal and Checks

- The Double Scaling Limit of LST maps to the field theory large N DSL. The above models in the large N DSL have a dual string description given by non-critical susy backgrounds

$$\kappa = \frac{\Lambda^{3-m/2}}{\Delta} F_1\left(\frac{\varepsilon}{N}, \Lambda, M_{UV}\right) \qquad \alpha' = \frac{1}{\Lambda^2} F_2\left(\frac{\varepsilon}{N}, \Lambda, M_{UV}\right)$$

- Puzzle: DSLST has N=2 SUSY (no RR flux) vs N=1 (RR flux not zero)

- Massless spectrum and F-term interactions are the same as DSLST

- Fact that degrees of freedom of interacting sector in field theory become exactly massless in the large N DSL and that their superpotential vanishes is strong indication of SUSY enhancement from N=1 to N=2

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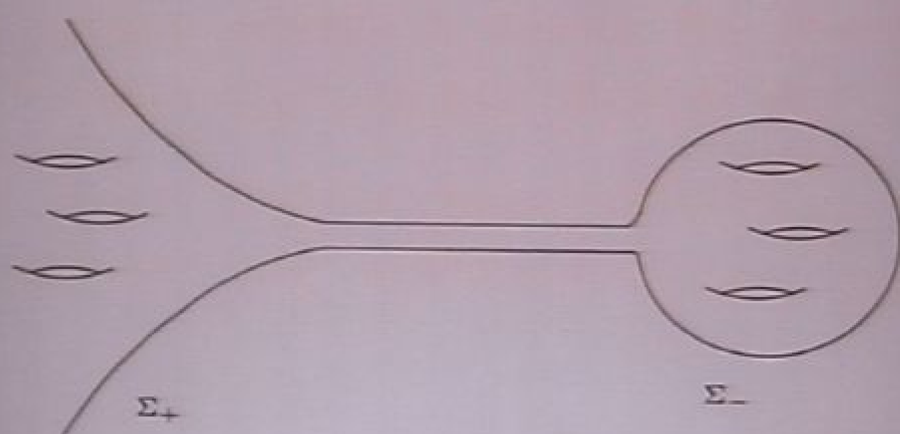

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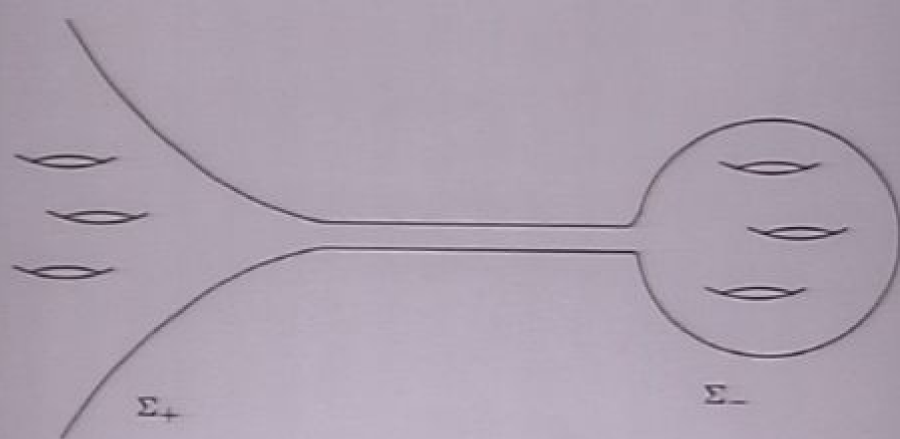

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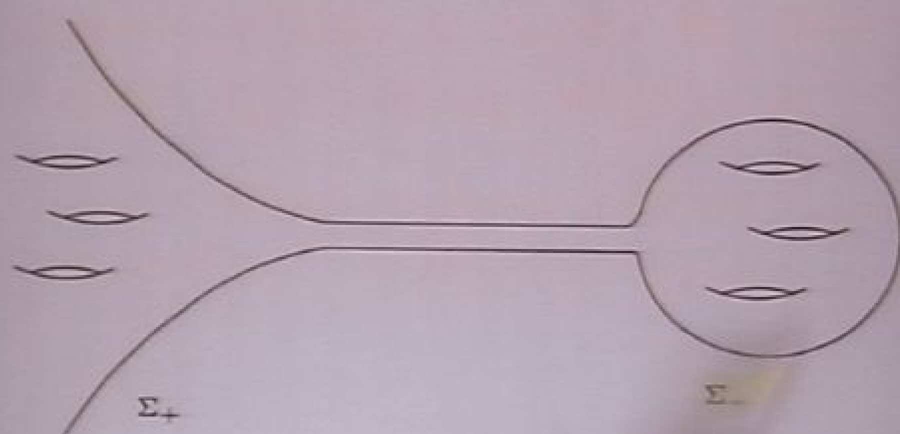

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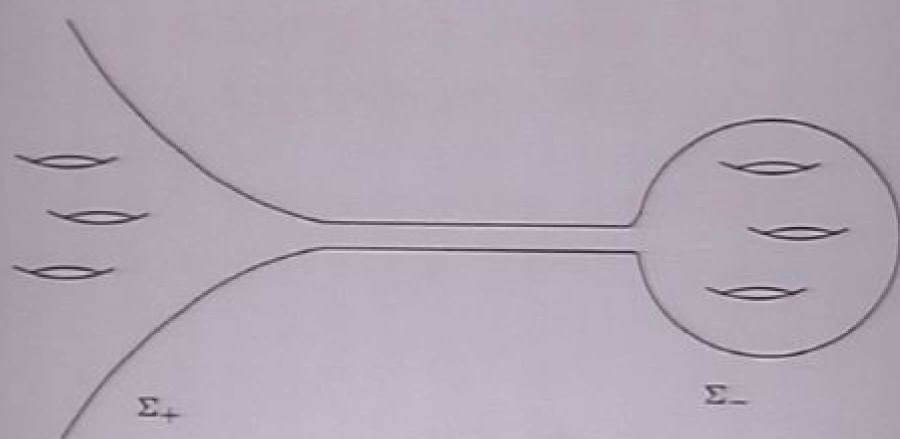

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Summary

- Novel example of duality between a SUSY field theory in a large N limit and a string background.
- Field Theory is in a partially confined phase. String background is non-critical and exactly solvable in α'. We can go beyond the supergravity approximation and there is no RR flux.
- The large N DSLs of these 4d SUSY theories map to DSLs of the auxiliary Dijkgraaf-Vafa Matrix Model. In particular they are well-defined in higher genus as well.
- The non-critical $c \leq 1$ bosonic string associated to MM DSL should correspond to a topological twist of the dual non-critical superstring background.
- Can define large N DSLs where there is no SUSY enhancement. In these cases dual string background is not known.

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Open problems

- Determine the non-critical bosonic string dual to MM DSL and compare with the topologically twisted superstring background. This would be a non-trivial "topological" test of the above duality proposal
- Complicated problem: near-critical spectral curve has in general genus ≥ 1 .
- Is the dual to generalized large N DSL with N=1 SUSY still simple?
- Explicit evaluation of higher genus free energy F_g and its asymptotic behaviour for large g . Perturbative series is not expected to be convergent $\rightarrow$ non-perturbative D-brane effects?

DSLs from Matrix Model point of view

- The Large N DSLs map to Matrix Model DSLs
- "New" universality classes → "near-critical" spectral curve

$$\Sigma: \quad y^2 = Z_m(x)^2 \sigma_{2s}(x) \to C\, Z_m(x)^2 B_n(x)$$

$$z_j, b_i \to x_0, \quad x = a\tilde{x},\ z_i = a\tilde{z}_i,\ b_j = a\tilde{b}_j \quad a \to 0$$

$$\Sigma_-: \quad y_-^2 = \tilde{Z}_m(\tilde{x})^2 \tilde{B}_n(\tilde{x}) \ .$$

- Scaling of Matrix Model free energy

$$F_g(\Sigma) \to (N a^{m+n/2+1})^{2-2g} F_g(\Sigma_-)$$

- Non-critical bosonic string dual to MM DSL? Topological twist of Non-critical superstring background
- Explicit check for simplest singularity (n=2, conifold) related to c=1 non-critical bosonic string

$$y^2 = x^2 - \delta$$

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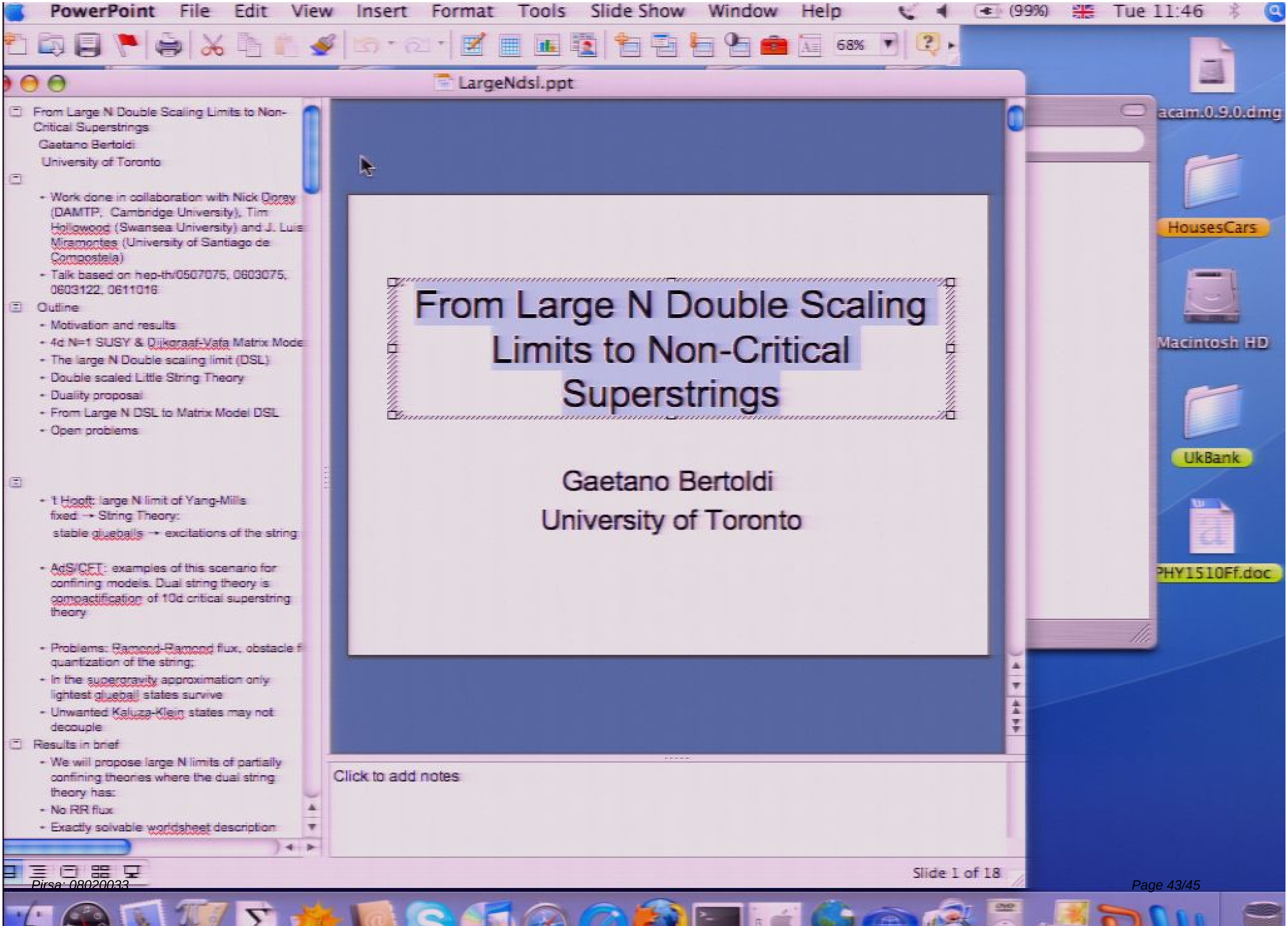
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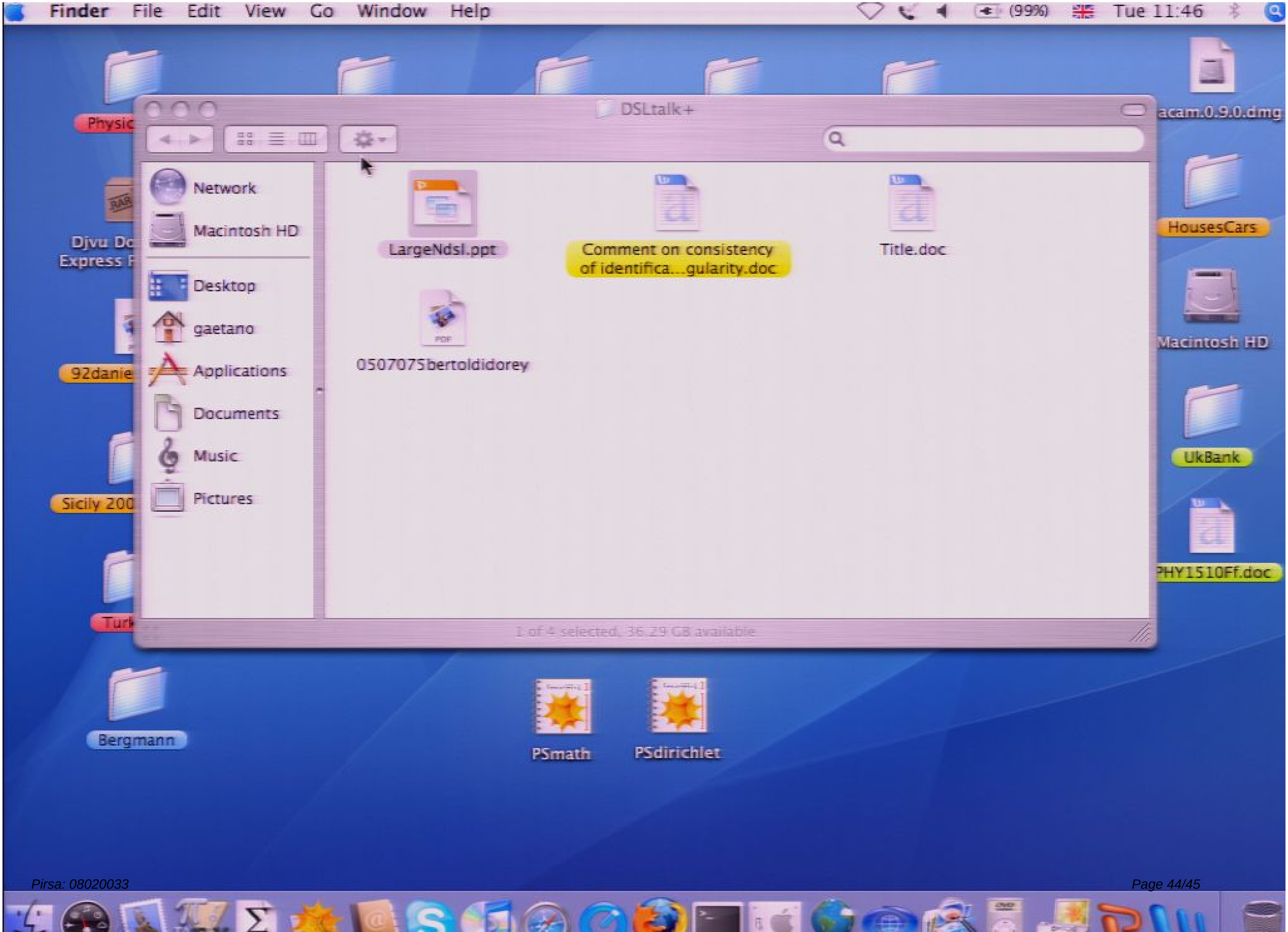
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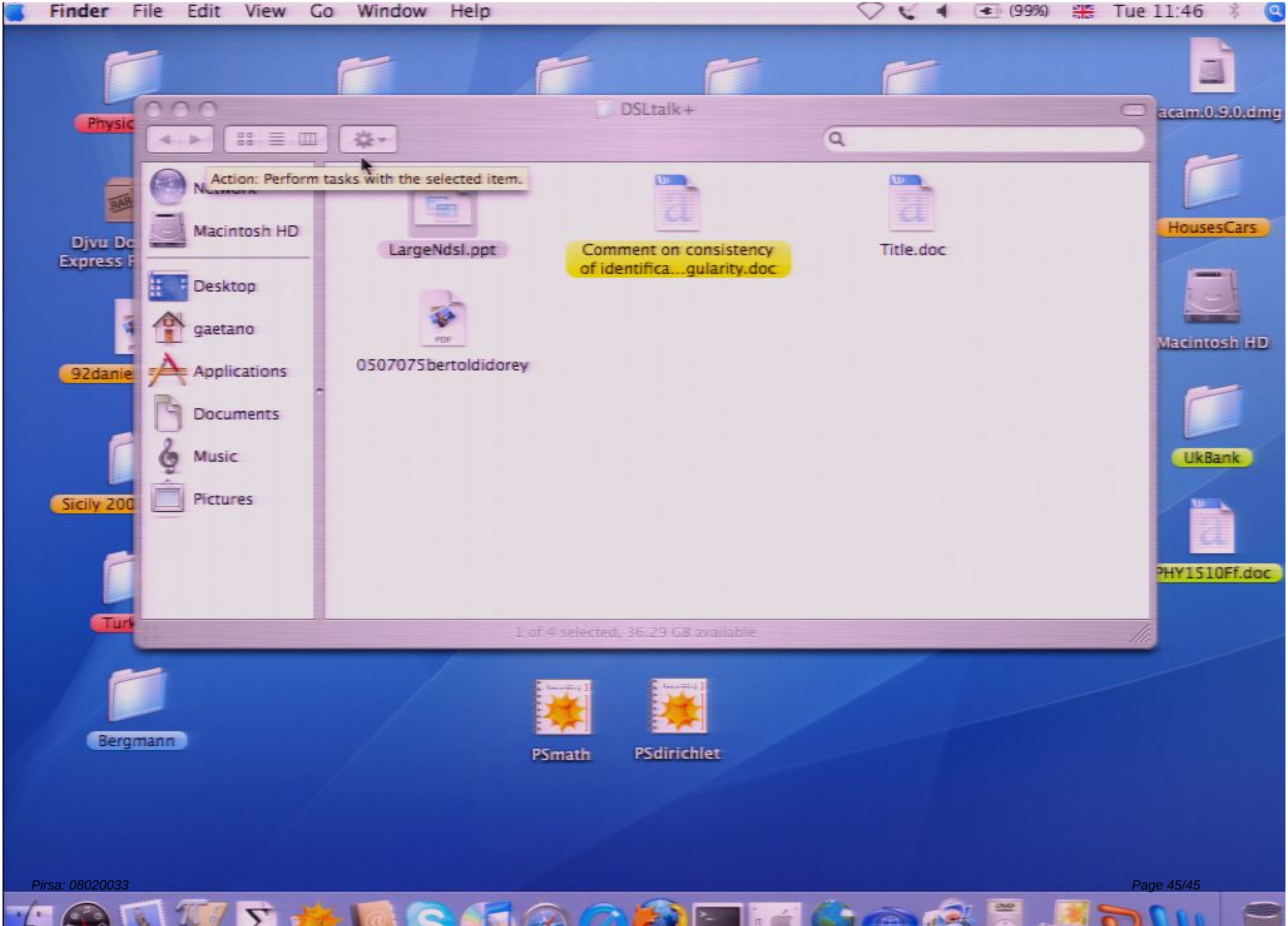
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