Discrete Gauge Symmetries, Chern Simons terms and Axion Monodromy

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c.f. Shiu's talk
Retolaza's parallel session talk

String Pheno 2014, Trieste

Plan

- Discrete gauge symmetries, Zn particles and strings
- String theory realizations
  - Torsion homology
  - Flux compactifications
- Gauge symmetries from 3- and 2-forms
  - Axion monodromy
- String theory realizations
  - Torsion homology
  - Flux compactifications
- Conclusions

Z_n discrete gauge symmetries

- Can realize Z_n as U(1) Higgssed by field of charge n

  4d Lagrangian for gauge field and phase ϕ of scalar field

$$|F_2|^2 + |d\phi - nA_1|^2$$

  Gauge transformation $$A_1 \to A_1 + d\lambda \quad ; \quad \phi \to \phi + n\lambda$$

- Can be dualized to 4d BF theory

  Banks, Seiberg

$$|H_3|^2 + nB_2 \wedge F_2 + |F_2|^2$$

  Zn symmetry read from coefficient of BF coupling

- Dualizing also gauge field to dual gauge potential, we get

$$|H_3|^2 + |dV_1 - nB_2|^2$$

  Gauge transformation $$B_2 \to B_2 + d\Lambda_1 \quad ; \quad V_1 \to V_1 + n\Lambda_1$$

Charged objects

- Relevant 4d fields: ϕ, A_1, B_2, V_1
- Particles and strings (Zn annihilation on instantons and junctions)

  - Strings defined by holonomy given by scalar field shift (and coupling to dual 2-form B_2)

  - Particles defined by integral of $*F_2$ on surrounding S^2 (and coupling to A_1)

$\mathcal{O}_{\text{particle}} \sim e^{2\pi i n \int_\gamma A}$ $\mathcal{O}_{\text{string}} \sim e^{2\pi i m \int_\Sigma B_2}$

$e^{-2\pi i \phi} e^{2\pi i k \int_\gamma A}$ $e^{-2\pi i \int_{\partial\Sigma} A} e^{2\pi i k \int_\Sigma B_2}$ $\exp\left[2\pi i \frac{nm}{k} L(\Sigma, \gamma)\right]$

Can generalize to arbitrary p-forms in arbitrary dimensions

Berasaluce-González, Ramírez, AU; also Quevedo, Trugenberger

Many (interrelated) stringy realizations

- Torsion homology

  Cámara, Ibáñez, Marchesano;
  Berasaluce-González, Cámara, Marchesano, Regalado, A.U.

- BF couplings on D-branes

  Rparity, Btriality in MSSM models

  Berasaluce-González, Ibáñez, Soler, A.U

- Discrete isometries & magnetized D-branes

  Non-abelian selection rules on Yukawas

  Berasaluce-González, Cámara, Marchesano, Regalado, A.U.

- Flux compactifications

  Berasaluce-González, Cámara, Marchesano, A.U.

- Supercritical strings

  Berasaluce-González, Montero, Retolaza, A.U.

c.f. Montero's parallel session talk

Many (interrelated) stringy realizations

Focus on...

- Torsion homology — Cámara, Ibáñez, Marchesano; Berasaluce-González, Cámara, Marchesano, Regalado, A.U.
- BF couplings on D-branes — Berasaluce-González, Ibáñez, Soler, A.U
  MSSM models
- Discrete isometries & magnetized D-branes
  Non-abelian selection rules on Yukawas — Berasaluce-González, Cámara, Marchesano, Regalado, A.U.
- Flux compactifications — Berasaluce-González, Cámara, Marchesano, A.U.
- Supercritical strings — Berasaluce-González, Montero, Retolaza, A.U.

c.f. Montero’s parallel session talk

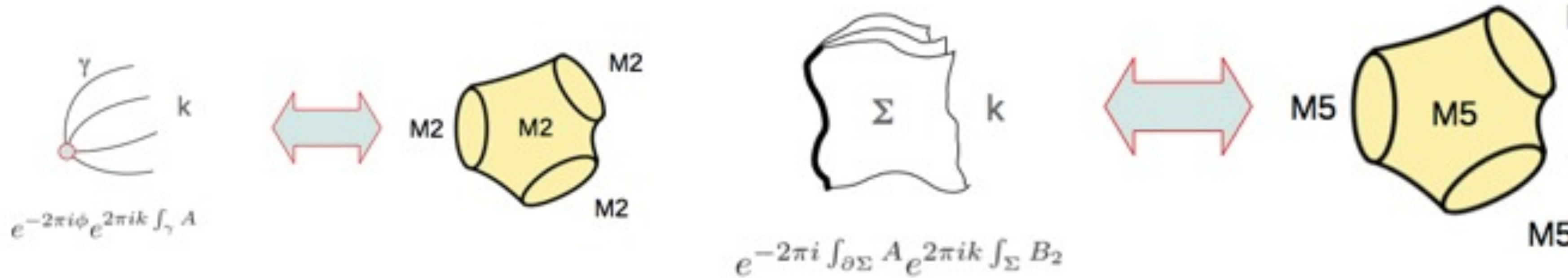
Zn symmetries from torsion p-forms

Compactifications of p-forms on spaces with torsion homology

- Ex: M-theory on 7d space (e.g. G2) X with $H_2(X,Z)=H_4(X,Z)=Z_n$

M2's on 2-cycles are Z_k particles
instantons are M2 on 3-chains,
emit torsion M2's

M5's on 4-cycles are Z_k strings
junctions are M5 on 5-chains,
emit torsion M5's



- Gauging manifest using non-harmonic forms (massive U(1))

Cámara, Ibáñez, Marchesano
cf. Ftheory talks

Ex: $d\eta_2 = n\,\omega_3$

KK reduction
$$C_3 = A_1(x^\mu)\wedge\eta_2(y^m) + \phi(x^\mu)\,\omega_3(y^m)$$
$$G_4 = (d\phi - n\,A_1)\wedge\eta_2 + \ldots$$

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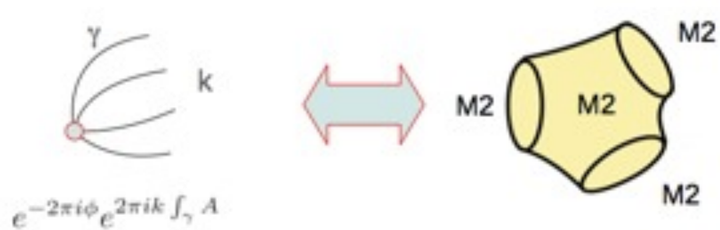
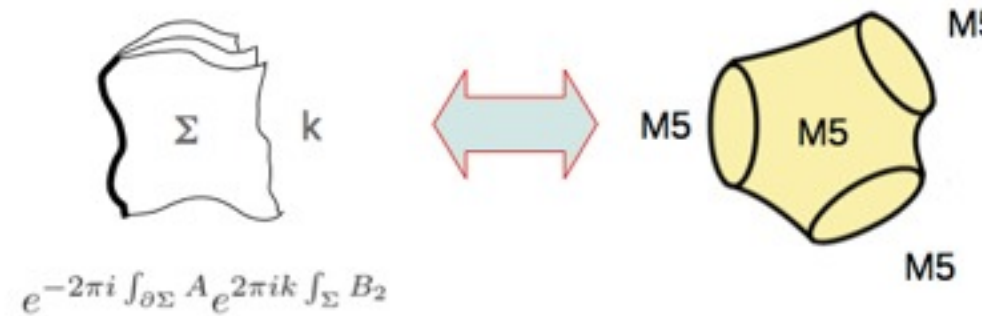




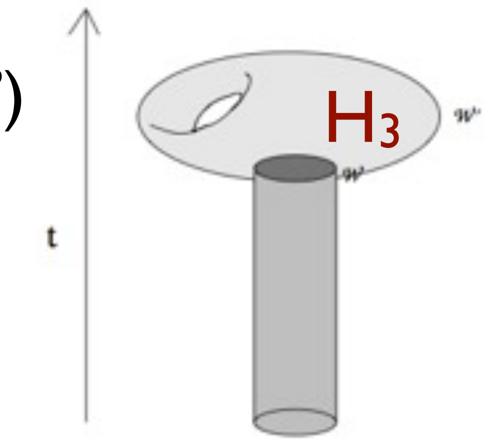
- Incidentally, three comments:
  - M-theory lift of Zn symmetries from D6-brane U(1)'s
  - Can get non-abelian symmetries
  - For later, useful to think about torsion as a 'geometric flux' (as in twisted tori)

Discrete symmetries from 'flux cathalysis'

- D-branes Z-valued in homology but Zn-valued in K-theory

  D-branes can decay in the presence of NSNS 3-form flux   ("""Freed-Witten anomaly""")

  Maldacena, Moore, Seiberg



- General branes and fluxes (beyond Ktheory)

  Berasaluce-González, Cámara, Marchesano, AU

  Discrete gauge symmetries from flux cathalysis

  4d BF coupling from 10d Chern-Simons term

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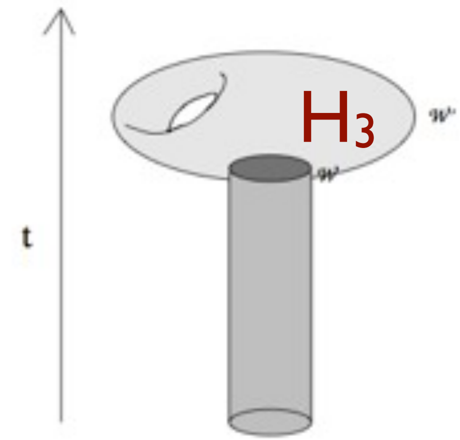

- General branes and fluxes (beyond Ktheory)

Berasaluce-González, Cámara, Marchesano, AU

Discrete gauge symmetries from flux cathalysis

4d BF coupling from 10d Chern-Simons term

Ex: IIA Freund-Rubin

$$\int_{4d\times X_6} \overline{F}_6 \wedge B_2 \wedge F_2 \rightarrow \int_{4d} n\, B_2 \wedge F_2$$

Zn particles are D0s, annihilate on NS5 on X6

Zn strings are F1s, annihilate on D6 on X6

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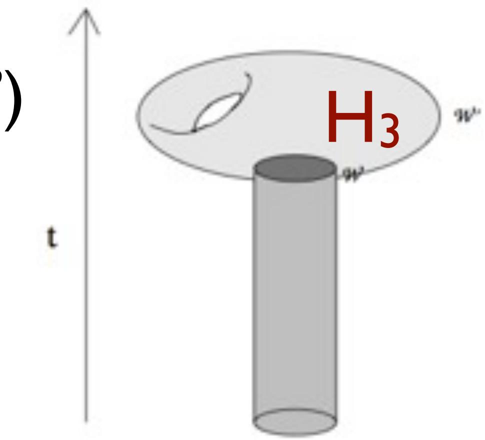

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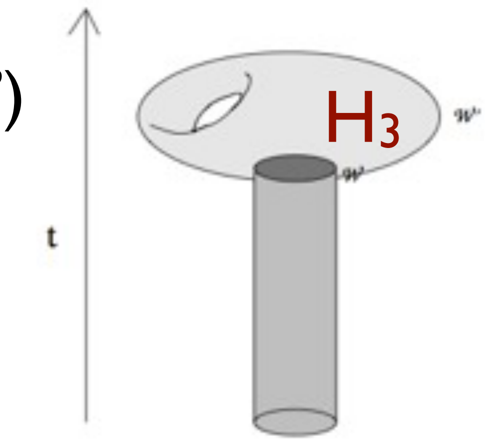

- General branes and fluxes (beyond Ktheory)

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Discrete gauge symmetries from flux cathalysis

4d BF coupling from 10d Chern-Simons term

Ex: IIB with NSNS flux on A-cycle $$\int_{4d\times X_6} \overline{H}_3 \wedge C_2 \wedge F_5 \;\to\; \int_{4d} n\, C_2 \wedge F_2$$

Zn particles are D3s on B-cycle, annihilate on D5 on X6

Zn strings are D1s, annihilate on D3 on A-cycle

Zn domain walls and gauge symmetries

Berasaluce-González, Cámara, Marchesano, AU
Shiu, Marchesano, AU

- Can consider other Zn charged objects in 4d

Lagrangian for 3-form eating up a 2-form — Dvali et al; Quevedo, Trugenberger

$$|F_4|^2 + |dC_2 - nC_3|^2$$

Gauge transformation $$C_3 \to C_3 + d\Lambda_2 \quad ; \quad C_2 \to C_2 + n\Lambda_2$$

- Can be dualized to Φ F4 theory

$$|F_4|^2 + n\,\phi F_4 + |d\phi|^2$$

Kaloper, Sorbo, Lawrence

- Dualizing also 3-form (to "(-1)form"), we get

$$|d\phi|^2 + \phi^2$$

Chaotic inflation model

No gauge invariance manifest in axion language

Corrections constrained to powers of F4 due to dual gauge inv.

Zn domain walls and gauge symmetries

Berasaluce-González, Cámara, Marchesano, AU
Shiu, Marchesano, AU

- Axion, because of discrete periodicity of full theory

- Implemented by the presence of Zn domain walls

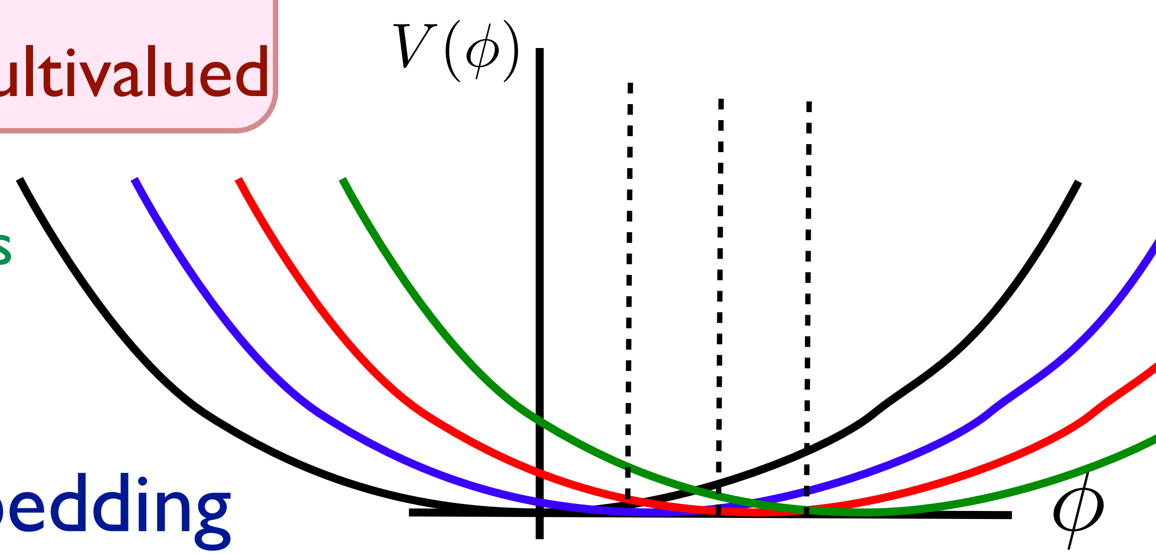
  Charged under C3, across a wall, $\phi \to \phi + 1/n \quad ; \quad F_4 \to F_4 + 1$

  n walls annihilate on string, charged under C2

  Periodicity under $\phi \to \phi + 1 \quad (\text{and } F_4 \to F_4 + n)$

Axion monodromy:
Potential is periodic but multivalued

cf Westphal, Shiu, Hebecker's talks



- Easy to give string embedding

Many (interrelated) stringy realizations

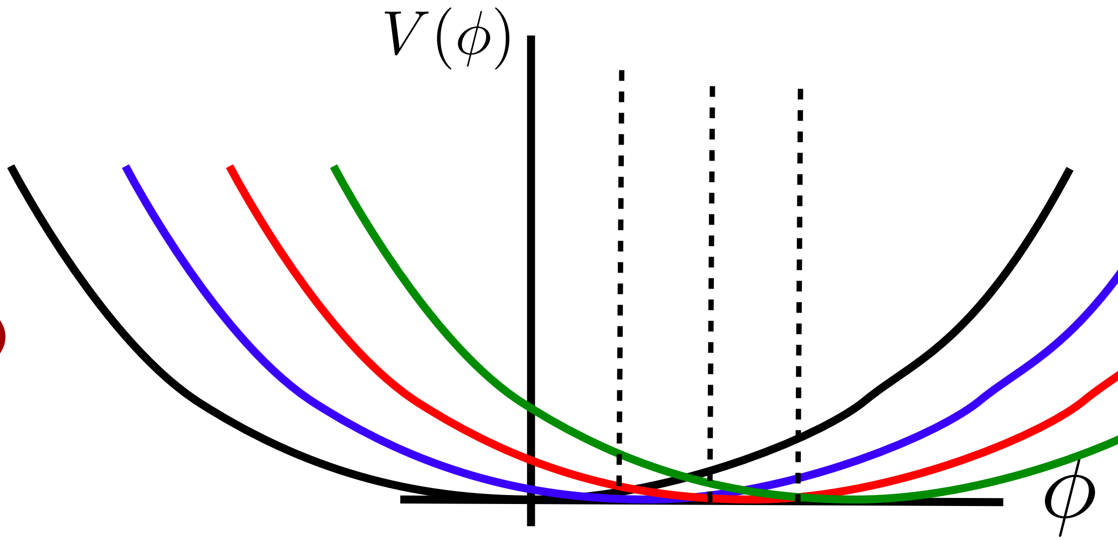
- Torsion homology

Berasaluce-González, Cámara, Marchesano, AU
Shiu, Marchesano, AU

related: Hebecker, Kraus, Witkowski;
Blumenhagen, Plauschinn;
McAllister, Silverstein, Westphal;
...

Focus on...

- Flux compactifications



- Backreaction, transitions by DW nucleation, computable

OBS: 4d instanton leads to cosine modulation, not to jump across branches

“Massive Wilson lines” (torsion p-forms)

Compactifications of 1-forms on cycles with torsion 1-homology

- Ex: D6 on 3cycle space Π with $H_1(\Pi,Z)=Z_n$

  axion Φ is gauge field on torsion 1-cycle (massive)

  4d domain wall is monopole (D4 ending on D6) wrapped on 1-cycle

  4d string is monopole (D4 ending on D6) wrapped on 2-chain

  4d instanton (cosine modulation) is F1 worldsheet on 2-chain

- 3- and 2-form from dual gauge potential and non-harmonic forms

  Ex: $d\eta_1 = n\,\omega_2$

  KK reduction $A_4 = C_3(x^\mu)\wedge\eta_1(y^m) + C_2(x^\mu)\wedge\omega_2(y^m)$

  $$F_5 = (dC_2 - nC_3)\wedge\omega_2 + \ldots$$

- In axion language

  WL Φ not a modulus: $A_1 = \phi\,\eta_1 \quad F_2 = \phi\,n\,\omega_2$

  F2 kinetic terms implies quadratic growth of energy with Φ

“Massive Wilson lines” (torsion p-forms)

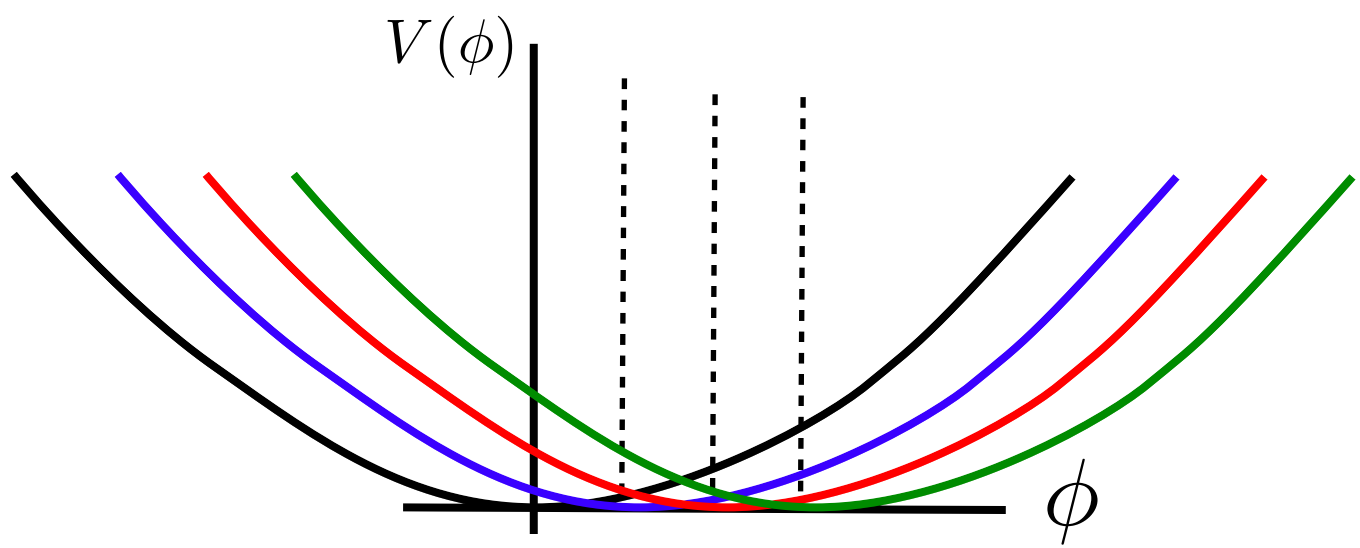
Compactifications of 1-forms on cycles with torsion 1-homology

- Ex: D6 on 3cycle space Π with $H_1(\Pi,Z)=Z_n$
- In geometric terms

  WL Φ not a modulus, turns on F2 flux on 2-chain of torsion 1-cycle

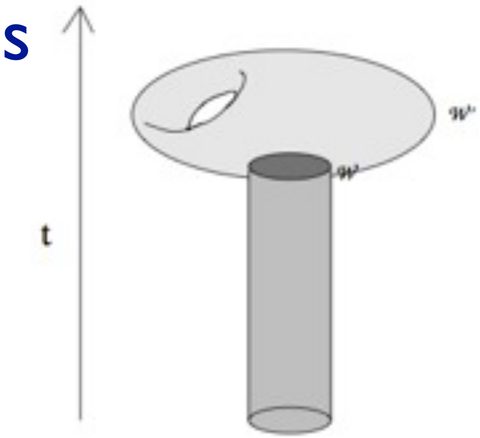
  F2 kinetic terms implies quadratic growth of energy with Φ
- UV completion allows discussing backreaction

  For large F2, change Maxwell to DBI: potential becomes linear



Fluxed axion monodromy

- Use 10d Chern-Simons terms to get 4d ΦF4 term, equiv use flux cathalisis to get Zn domain walls



Ex: IIB with NSNS flux on A-cycle

$$F_4 = \int_B F_7 \quad ; \quad \int_A H_3 = n$$

$$\int_{4d\times X_6} \overline{H}_3 C_0 F_7 \to \int_{4d} n\, C_0\, F_4$$

10d IIB axion has a monodromy. Origin of energetic cost?

GVW supo $\quad W = \int_{X_6} (F_3 - \tau \overline{H}_3) \wedge \Omega$

Period of C0 changes n units of F3 flux on A

4d Domain Wall is D5 on B (also from origin of F4)

4d instanton is D(-1) (cosine modulation)

- UV completion, backreaction:

10 periods require O(10) units of flux. Expect GVW remain good approx.

Conclusions

- Discrete gauge symmetries everywhere
- Zn charged particles and strings

  Pretty well explored, motivate study of topological couplings in setups like torsion, fluxes, ...

- Zn charged domain walls

  'Exotic' gauge symmetries (3- and 2-forms)

  Monodromic axions, with controlled potential

  String constructions UV complete 4d Kaloper-Sorbo

- Applications to inflation

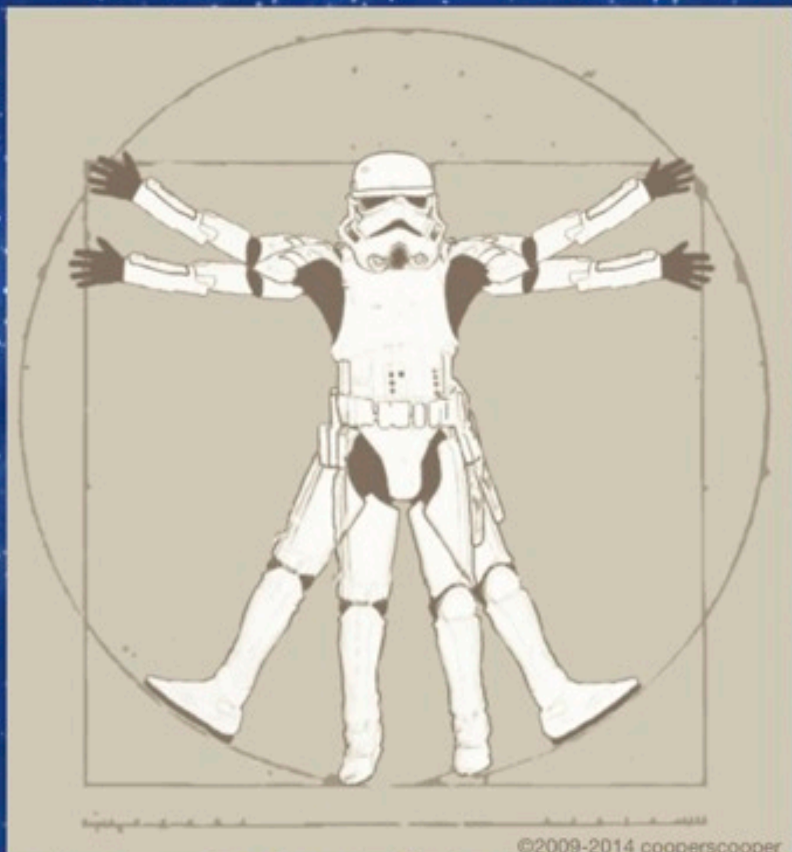
  ⇒Gary Shiu's talk

  Topological structure of monodromy in axion field space

  Natural interplay with flux moduli stabilization

  Need mechanisms for scales e.g. warping. A. Retolaza's talk

Fine-tuning, Anthropics and the String Landscape



Instituto de Física Teórica UAM-CSIC
Madrid, 8-10 October 2014
http://workshops.ift.uam-csic.es/ws/anthropic

Speakers:

- T. Banks (Santa Cruz & Rutgers U.)
- I. Bena (CEA Saclay)
- J.J. Blanco-Pillado (UPV)
- R. Bousso (Berkeley U.)
- A.R. Brown (Stanford U.)
- U. Danielsson (Uppsala U.)
- F. Denef (Columbia U.)
- J.F. Donoghue (Massachusetts U.)
- B. Freivogel (Amsterdam U.)
- B. Greene* (Columbia U.)
- A.H. Guth (MIT)
- L.J. Hall (Berkeley U.)
- C.J. Hogan (Chicago U. & Fermilab)
- M. Kleban (New York U.)
- U. Meissner (Bonn U.)
- L. McAllister (Cornell U.)
- F. Quevedo (ICTP)
- L. Randall (Harvard U.)
- S. Sethi (Chicago U.)
- A. Vilenkin (Tufts U.)
- A. Westphal (DESY)

* To be confirmed

Organizers:

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Thank you!