Special Holonomy Metrics, Degenerate Limits and Intersecting Branes

Nipol Chaemjumrus and CH:

[arXiv:1907.04040] **Degenerations of K3, Orientifolds and Exotic Branes**

[arXiv:1908.04623] **Special Holonomy Manifolds, Domain Walls, Intersecting Branes and T-folds**

1. Degenerate Limit of K3
2. Gibbons-Hawking Metrics
3. Ooguri-Vafa Metrics
4. Special Holonomy Generalisations
5. Intersecting Brane Duals
6. Applications to String Theory and Dualities: Type I’ string, D8-branes and orientifolds

Degenerate Limit of K3

Hein, Sun, Viaclovsky and Zhang [HSVZ]

- Family of K3 Metrics g(t), limit t=0 is line interval
- Long Neck Region at small t
- Segment of neck is nilfold fibred over a line.
- Nilfold is S^1 bundle over T^2, with degree (Chern number) m. Different values of m in different segments.
- Jump in m: insertion of gravitational instanton (Kaluza Klein monopole)
- Ends of neck capped by Tian-Yau spaces: complete non-compact hyperkahler manifolds asymptotic to nilfold fibred over a line

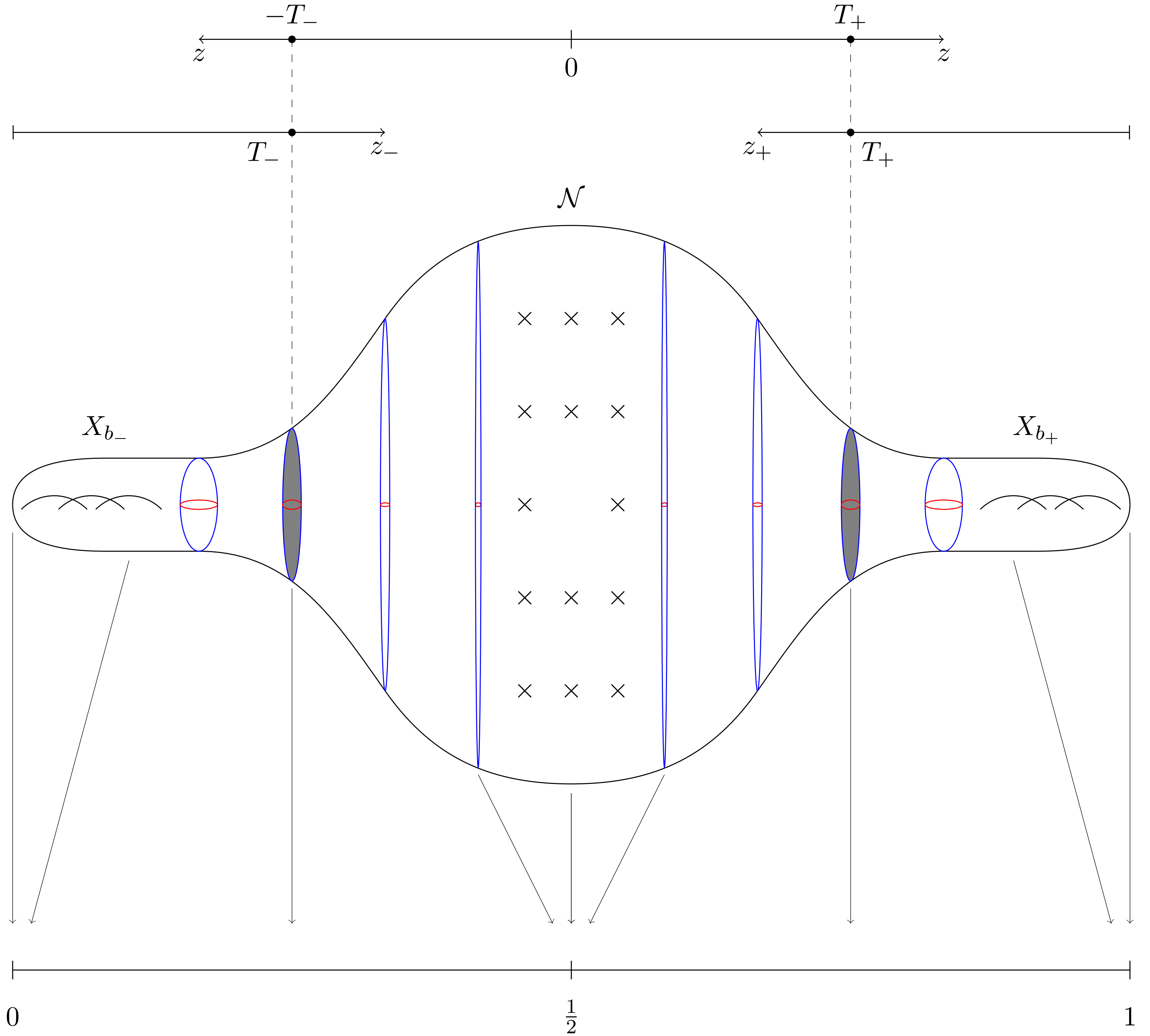


FIGURE 1. The vertical arrows represent collapsing to a one-dimensional interval. The red circles represent the S^1 fibers and the blue curves represent the base $\mathbb{T}^2$s of the nilmanifolds. The $\times$s are the monopole points in the neck region $\mathcal{N}$. The gray regions are in the "damage zones".

Gibbons-Hawking Metric

Hyperkahler metric with S^1 symmetry

$$g = V(d\tau^2 + dx^2 + dz^2) + V^{-1}(dy + \omega)^2$$

$V(\tau, x, z)$ a harmonic function on $\mathbb{R}^3$

$$\vec{\nabla} \times \vec{\omega} = \vec{\nabla} V$$

Delta-function sources at points (m an integer)

$$V = a + \sum_i \frac{m}{|\vec{r} - \vec{r}_i|}$$

S^1 Bundle on $\mathbb{R}^3$ - {points}

Regular at sources if m=1: multi-Taub-NUT

Orbifold singularities for m>1

Smeared GH Metrics

$V(\tau, x, z)$ a harmonic function on $\mathbb{R}^3$

"Smeared" solutions: V independent of one or more coordinates

Can then take those coordinates to be periodic
Metric typically singular

Smear on x,y: $V(\tau) = m\tau + c$

or
$$V(\tau) = \begin{cases} c + m'\tau, & \tau \le 0 \\ c + m\tau, & \tau > 0. \end{cases}$$

Singular at kink at $\tau = 0$

Domain wall: 2-plane dividing space into 2 parts

N=m-m': energy density (tension) of domain wall (2-brane)

Piecewise linear:

multi-wall solution with domain walls at $\tau = \tau_1, \tau_2, \ldots \tau_n$

$$V(\tau) = \begin{cases} c_1 + m_1\tau, & \tau \leq \tau_1 \\ c_2 + m_2\tau, & \tau_1 < \tau \leq \tau_2 \\ \vdots \\ c_n + m_n\tau, & \tau_{n-1} < \tau \leq \tau_n \\ c_{n+1} + m_{n+1}\tau, & \tau > \tau_n\,. \end{cases}$$

The charge of the domain wall at τ_r is the integer

$$N_r = m_{r+1} - m_r$$

$$ds^2 = V(\tau)(d\tau^2 + dx^2 + dz^2) + \frac{1}{V(\tau)}(dy + M(\tau)xdz)^2$$

$$M(\tau) \equiv V'(\tau)$$

Can take x,y,z periodic

Single-sided domain wall

$$V = c + m\,|\,\tau\,|$$

Quotient by reflection $\tau \to -\tau$ gives
"single-sided" wall at $\tau = 0$

$$V(\tau) = m\tau + c$$

$$ds^2 = V(\tau)(d\tau^2 + dx^2 + dz^2) + \frac{1}{V(\tau)}(dy + mxdz)^2$$

Take x,y,z periodic

Fixed τ: **nilfold**

$$ds^2_{\mathcal{N}} = dx^2 + (dy + mxdz)^2 + dz^2$$

S^1 Bundle over T^2

$$F = mdx \wedge dz$$

Quotient of the group manifold of the Heisenberg group by a cocompact discrete subgroup

4-d space: nilfold fibred over a line

1st approximation to HSVZ K3

Interval $\tau \in [0,\pi]$
Multi-domain wall solution with domain walls at $\tau = \tau_1, \tau_2, \ldots \tau_n$
Single-sided domain walls at $\tau = 0,\pi$

$$ds^2 = V(\tau)(d\tau^2 + dx^2 + dz^2) + \frac{1}{V(\tau)}(dy + M(\tau)xdz)^2$$

$$V(\tau) = \begin{cases} c_1 + m_1\tau, & 0 \leq \tau \leq \tau_1 \\ c_2 + m_2\tau, & \tau_1 < \tau \leq \tau_2 \\ \vdots & \\ c_n + m_n\tau, & \tau_{n-1} < \tau \leq \tau_n \\ c_{n+1} + m_{n+1}\tau, & \tau_n < \tau \leq \pi \end{cases} \qquad M(\tau) \equiv V'(\tau)$$

<u>HSVZ resolve singularities:</u>

- Resolve domain walls with Ooguri-Vafa construction
- Resolve single-sided domain walls with Tian-Yau spaces

Ooguri-Vafa Metric

Want Gibbons-Hawking metric, $\mathbb{R}^3$ replaced with $\mathbb{R} \times T^2$
1st approximation: smear over T^2

<u>Ooguri-Vafa:</u>

- On $\mathbb{R}^3$, take periodic array of sources in (x,z) plane
- Regularised sum of potentials gives harmonic function
- Can now periodically identify x,z directions, to get single source on $\mathbb{R} \times T^2$.
- Near source, non-singular, looks like Taub-NUT
- Can then take superpositions to get multiple sources on $\mathbb{R} \times T^2$.
- Solutions regular on finite interval in $\mathbb{R}$

Resolve GH metric with

$$V(\tau) = \begin{cases} c + m'\tau, & \tau \leq 0 \\ c + m\tau, & \tau > 0. \end{cases}$$

Charge N=m-m'

by OV metric with V harmonic on $\mathbb{R} \times T^2$

Monopole charge N

Near sources, N-centre multi Taub-NUT, or one source of charge N, orbifold singularity: bubbling limit to Taub-NUT

For N sources, regular hyperkahler metric for some interval

$$-T < \tau < T'$$

Far enough away from $\tau = 0$, tends to GH with

$$V(\tau) = \begin{cases} c + m'\tau, & \tau \leq 0 \\ c + m\tau, & \tau > 0. \end{cases}$$

Tian-Yau Spaces

- Complete non-singular non-compact hyperkahler space
- Asymptotic to a nilfold bundle over a line.
- Of the form M \ D, where M is a del Pezzo surface, D ⊂ M is a smooth anti-canonical divisor
- Del Pezzo surfaces are complex surfaces classified by their degree b, where b = 1, 2, . . . , 9
- The del Pezzo surface of degree nine is CP^2
- A degree b del Pezzo surface can be constructed from blowing up 9 – b points in CP^2
- A 2nd del Pezzo surface of degree 8 is $CP^1 \times CP^1$
- The TY space M_b of degree b is constructed from del Pezzo of degree b
- M_b is asymptotic to GH metric on $N_b \times \mathbb{R}$ where N_b is nilfold of degree b
- Degree zero: Take M to be rational elliptic surface, $N_0 = T^3$, M_0 is ALH, asymptotic to cylinder given by $T^3 \times \mathbb{R}$

1st approximation to HSVZ K3

Interval $\tau \in [0,\pi]$

Multi-domain wall solution with domain walls at $\tau = \tau_1, \tau_2, \ldots \tau_n$

Single-sided domain walls at $\tau = 0,\pi$

$$ds^2 = V(\tau)(d\tau^2 + dx^2 + dz^2) + \frac{1}{V(\tau)}(dy + M(\tau)xdz)^2$$

$$V(\tau) = \begin{cases} c_1 + m_1\tau, & 0 \le \tau \le \tau_1 \\ c_2 + m_2\tau, & \tau_1 < \tau \le \tau_2 \\ \vdots & \\ c_n + m_n\tau, & \tau_{n-1} < \tau \le \tau_n \\ c_{n+1} + m_{n+1}\tau, & \tau_n < \tau \le \pi \end{cases} \qquad M(\tau) \equiv V'(\tau)$$

<u>HSVZ resolve singularities</u>:

Glue together Ooguri-Vafa spaces, Tian-Yau spaces to get complete K3 metric

Tian-Yau spaces of degree b_-, b_+

$$b_- = -m_1, b_+ = m_{n+1} \qquad 0 \le b_\pm \le 9$$

$$N_i = m_{i+1} - m_i$$

$$\sum_{i=1}^{n} N_i = b_- + b_+ \le 18$$

Special Holonomy Generalisations

- Replace 3-d nilfold with higher dim nilmanifold
- Quotient of nilpotent Lie group by discrete subgroup
- T^n bundle over T^m
- Special holonomy metrics on nilmanifold fibred over a line
  Gibbons, Lu, Pope and Stelle [GLPS]

Dimension	Nilmanifold: torus bundle over torus	Holonomy
4	S^1 over T^2	SU(2)
6	S^1 over T^4	SU(3)
6	T^2 over T^3	SU(3)
7	T^2 over T^4	G_2
7	T^3 over T^3	G_2
8	S^1 over T^6	SU(4)
8	T^3 over T^4	Spin(7)

Nilmanifold: S^1 bundle over T^4

5-dimensional nilpotent Lie algebra T_i

Only non-vanishing commutators are

$$[T_2, T_3] = mT_1, \qquad [T_4, T_5] = mT_1$$

Metric

$$ds^2 = \left(dz^1 + m(z^3dz^2 + z^5dz^4)\right)^2 + (dz^2)^2 + (dz^3)^2 + (dz^4)^2 + (dz^5)^2 \,.$$

Fibre coord: z^1

Nilmanifold fibred over line: SU(3) holonomy

$$ds^2 = V^2(\tau)(d\tau)^2 + V(\tau)\Big((dz^2)^2 + (dz^3)^2 + (dz^4)^2 + (dz^5)^2\Big)$$

$$+V^{-2}(\tau)\Big(dz^1 + M(\tau)(z^3dz^2 + z^5dz^4)\Big)^2$$

$$M(\tau) \equiv V'(\tau)$$

V Piecewise linear

Nilmanifold: T^3 bundle over T^4

7-dimensional nilpotent Lie algebra T_i

Only non-vanishing commutators are

$$[T_4, T_5] = mT_1, \qquad [T_6, T_7] = mT_1, \qquad [T_4, T_6] = mT_2$$

$$[T_5, T_7] = -mT_2, \qquad [T_4, T_7] = mT_3, \qquad [T_5, T_6] = mT_3$$

Metric

$$ds^2 = \Big(dz^1 + m(z^5dz^4 + z^7dz^6)\Big)^2 + \Big(dz^2 + m(z^6dz^4 - z^7dz^5)\Big)^2$$
$$+\Big(dz^3 + m(z^7dz^4 + z^6dz^5)\Big)^2 + (dz^4)^2 + (dz^5)^2 + (dz^6)^2 + (dz^7)^2$$

Fibre coords: z^1 z^2 z^3

Nilmanifold fibred over line: Spin(7) holonomy

$$ds^2 = V^6(\tau)(d\tau)^2 + V^3(\tau)\Big((dz^4)^2 + (dz^5)^2 + (dz^6)^2 + (dz^7)^2)\Big)$$
$$+V^{-2}(\tau)\Big(dz^1 + M(z^5dz^4 + z^7dz^6)\Big)^2$$
$$+V^{-2}(\tau)\Big(dz^2 + M(z^6dz^4 - z^7dz^5)\Big)^2 + V^{-2}(\tau)\Big(dz^3 + M(z^7dz^4 + z^6dz^5)\Big)^2$$

$$M(\tau) \equiv V'(\tau)$$

Further Nilmanifolds

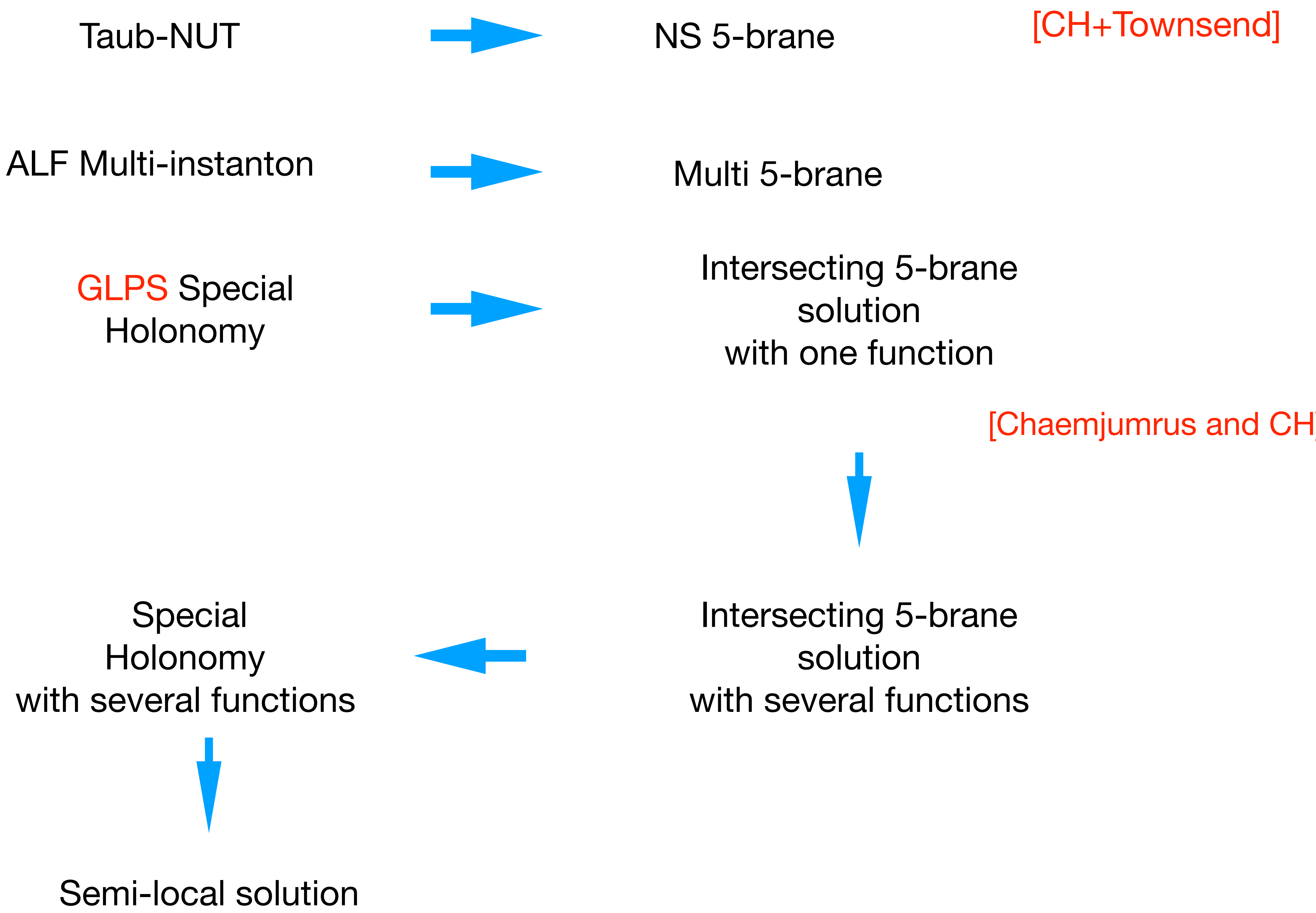
Extends to further examples with more general nilmanifolds.
The previous case are from 2-step nilpotent Lie groups giving a torus bundle over a torus

p-step nilpotent Lie groups
$[X_1, [X_2, [\cdots[X_p, Y]\cdots]] = 0$
Torus bundle over a torus bundle over a torus…..

Chiossi and Salamon:
For any 6-dimensional nilmanifold with half-flat SU(3) structure, fibration over a line interval gives a G_2 metric
24 cases.

SU(3) structure: almost complex 6-manifold,
with (1,1) form ω, (3,0) form Ω
Half-flat: $\omega \wedge d\omega$ and $Re(\Omega)$ closed

T-duality


Taub-NUT
NS 5-brane
[CH+Townsend]
ALF Multi-instanton
Multi 5-brane
GLPS Special Holonomy
Intersecting 5-brane solution with one function
[Chaemjumrus and CH]
Special Holonomy with several functions
Intersecting 5-brane solution with several functions
Semi-local solution

Nilmanifold: S^1 bundle over T^4

Nilmanifold fibred over line: SU(3) holonomy

$$ds^2 = V^2(\tau)(d\tau)^2 + V(\tau)\Big((dz^2)^2 + (dz^3)^2 + (dz^4)^2 + (dz^5)^2\Big)$$

$$+V^{-2}(\tau)\Big(dz^1 + M(\tau)(z^3 dz^2 + z^5 dz^4)\Big)^2$$

$$M(\tau) \equiv V'(\tau)$$

2-function generalisation, SU(3) holonomy

$$ds^2 = V_1(\tau)V_2(\tau)d\tau^2 + \frac{1}{V_1(\tau)V_2(\tau)}\Big(dz^1 + M_1(\tau)z^3 dz^2 + M_2(\tau)z^5 dz^4\Big)^2$$

$$+V_1(\tau)\Big((dz^2)^2 + (dz^3)^2\Big) + V_2(\tau)\Big((dz^4)^2 + (dz^5)^2\Big)$$

Functions $V_1(\tau)$, $V_2(\tau)$ piecewise linear,
$M_1 = V_1$, $M_2 = V_2'$

[Chaemjumrus and CH]

Nilmanifold: T³ bundle over T⁴

Nilmanifold fibred over line: Spin(7) holonomy

$$ds^2 = V^6(\tau)(d\tau)^2 + V^3(\tau)\Big((dz^4)^2 + (dz^5)^2 + (dz^6)^2 + (dz^7)^2)\Big)$$
$$+V^{-2}(\tau)\Big(dz^1 + M(z^5dz^4 + z^7dz^6)\Big)^2$$
$$+V^{-2}(\tau)\Big(dz^2 + M(z^6dz^4 - z^7dz^5)\Big)^2 + V^{-2}(\tau)\Big(dz^3 + M(z^7dz^4 + z^6dz^5)\Big)^2$$

6-function generalisation, Spin(7) holonomy

$$ds^2 = V_1(\tau)V_2(\tau)V_3(\tau)V_4(\tau)V_5(\tau)V_6(\tau)d\tau^6 + \frac{1}{V_1(\tau)V_2(\tau)}\Big(dz^1 + M_1z^5dz^4 + M_2z^7dz^6\Big)^2$$

$$+\frac{1}{V_3(\tau)V_4(\tau)}\Big(dz^2 + M_3z^6dz^4 - M_4z^7dz^5\Big)^2 + \frac{1}{V_5(\tau)V_6(\tau)}\Big(dz^3 + M_5z^7dz^4 + M_6z^6dz^5\Big)^2$$

$$+V_1(\tau)V_3(\tau)V_5(\tau)(dz^4)^2 + V_1(\tau)V_4(\tau)V_6(\tau)(dz^5)^2$$

$$+V_2(\tau)V_3(\tau)V_6(\tau)(dz^6)^2 + V_2(\tau)V_4(\tau)V_5(\tau)(dz^7)^2$$

Functions $V_1(\tau), \cdots, V_6(\tau)$ piecewise linear,
$M_1 = V_1,\ M_2 = V_2', \ldots.$

[Chaemjumrus and CH]

Nilmanifold: S^1 bundle over T^4

2-function solution, SU(3) holonomy

$$ds^2 = V_1(\tau)V_2(\tau)d\tau^2 + \frac{1}{V_1(\tau)V_2(\tau)}\left(dz^1 + M_1(\tau)z^3dz^2 + M_2(\tau)z^5dz^4\right)^2$$

$$+V_1(\tau)\left((dz^2)^2 + (dz^3)^2\right) + V_2(\tau)\left((dz^4)^2 + (dz^5)^2\right)$$

If $V_2 = 1, M_2 = 0$, (Gibbons-Hawking)x$\mathbb{R}^2$
GH: τ, z^1, z^2, z^3 $\quad$ $\mathbb{R}^2 : z^4, z^5$

If $V_1 = 1, M_1 = 0$, (Gibbons-Hawking)x$\mathbb{R}^2$
GH: τ, z^1, z^4, z^5 $\quad$ $\mathbb{R}^2 : z^2, z^3$

“Overlap” or “intersection” of smeared Kaluza-Klein monopole solutions
Singular at kinks in $V_1(\tau), V_2(\tau)$
Can this be generalised to overlap of **localised** Kaluza-Klein monopole solutions?
Solution with functions on $\mathbb{R}^3$:

$$V_1(\tau, z^2, z^3) \qquad V_2(\tau, z^4, z^5)$$

Localised Solutions?

$$ds^2 = V_1 V_2 d\tau^2 + \frac{1}{V_1 V_2}\Big(dz + \omega\Big)^2$$

$$+V_1\Big((dx^1)^2 + (dx^2)^2\Big) + V_2\Big((dy^1)^2 + (dy^2)^2\Big)$$

Solution with local functions?

$$V_1(\tau, x^1, x^2),\ V_2(\tau, y^1, y^2)$$

T-dualise semi-local brane intersection solutions
OR Special case of equations of Pederesen and Poon, and Zharkov

$$\partial_\tau^2 V_1 + V_2(\partial_{x^1}^2 + \partial_{x^2}^2)V_1 = 0$$

$$\partial_\tau^2 V_2 + V_1(\partial_{y^1}^2 + \partial_{y^2}^2)V_2 = 0$$

Localised Solutions?

$$ds^2 = V_1 V_2 d\tau^2 + \frac{1}{V_1 V_2}\Big(dz + \omega\Big)^2$$

$$+V_1\Big((dx^1)^2 + (dx^2)^2\Big) + V_2\Big((dy^1)^2 + (dy^2)^2\Big)$$

Solution with local functions?

$$V_1(\tau, x^1, x^2),\ V_2(\tau, y^1, y^2)$$

T-dualise semi-local brane intersection solutions
OR Special case of equations of Pederesen and Poon, and Zharkov

$$\partial_\tau^2 V_1 + V_2(\partial_{x^1}^2 + \partial_{x^2}^2)V_1 = 0$$

$$\partial_\tau^2 V_2 + V_1(\partial_{y^1}^2 + \partial_{y^2}^2)V_2 = 0$$

Unfortunately, also

$$\partial_{x^i} V_1\, \partial_{y^i} V_2 = 0$$

Either V_1 independent of x^i or V_2 independent of y^i

Semi-Localised Solutions

$$ds^2 = V_1 V_2 d\tau^2 + \frac{1}{V_1 V_2}\Big(dz + \omega\Big)^2 + V_1\Big((dx^1)^2 + (dx^2)^2\Big) + V_2\Big((dy^1)^2 + (dy^2)^2\Big)$$

Solution with <u>semi-local functions</u> $V_1(\tau, x^1, x^2),\ V_2(\tau)$

$$\partial_\tau^2 V_1 + V_2(\partial_{x^1}^2 + \partial_{x^2}^2)V_1 = 0 \qquad \partial_\tau^2 V_2 = 0$$

<u>Solution</u>

$$V_2 = a + m\tau \qquad V_1 = b + \frac{q}{\left(3m^2\mathbf{x}^2 + (a + m\tau)^3\right)^{2/3}}$$

$\mathbf{x}^2 = (x^1)^2 + (x^2)^2$

V_1 localised in τ, x^1, x^2
Near origin: Cone over squashed sphere
SU(3) holonomy
Can add to V_1: linear $f(\tau)$ or harmonic $h(x^1, x^2)$
Generalise to piecewise linear V_2, superposition of sources for V_1

Localised Solutions and Degenerate Limits

- Are there fully localised non-singular solutions?
- Use duality to intersecting branes, brane webs to motivate ansatz
- Are these part of neck region of some compact special holonomy space, just as the hyperkahler metrics were model metrics for part of degenerate limit of K3?
- Relation to other configurations via string dualities?

T-Duality

Nilmanifold: T^n bundle over T^m Curvature 2-forms F_a, a=1,..,n

T-duality untwists bundle to T^{n+m}

3-form H, dH=0

$$H = dy^a \wedge F_a$$

Nilfold: S^1 Bundle over T^2 → T^3 with H-flux

$$ds^2_{T^3} = dx^2 + dy^2 + dz^2 \qquad H = m\,dx \wedge dy \wedge dz$$

GH Metric: Nilfold fibred over a line →

$$ds^2 = V(\tau)(d\tau^2 + dx^2 + dy^2 + dz^2) \qquad H = M(\tau)dx \wedge dy \wedge dz$$

Product with 6-d Minkowski space: **NS5-brane**
smeared over 3 directions and wrapped on T^3

Kahler → Generalised Kahler

Gates, CH, Rocek

2 complex structures $J^{\pm}$, g bihermitian

Connections with torsion $\nabla^{\pm} = \nabla_{Levi-Civita} \pm g^{-1}H$

Local Product structure: complex coordinates z^a, w^i

$$ds^2 = g_{a\bar{b}} dz^a d\bar{z}^{\bar{b}} + g_{i\bar{j}} dw^i d\bar{w}^{\bar{j}}$$

Generalised Kahler potential $K(z, \bar{z}, w, \bar{w})$

$$g_{a\bar{b}} = K_{,a\bar{b}} \,, \quad g_{i\bar{j}} = -K_{,i\bar{j}}$$

Holonomy $Hol(\nabla^{\pm}) \subseteq U(r)$

CY, Monge Ampere → Generalised Kahler

Generalised Monge Ampere

$$det(K,_{a\bar{b}}) = det(-K,_{i\bar{j}})$$

Buscher; CH; Rocek

Holonomy $Hol(\nabla^{\pm}) \subseteq SU(r)$

CH

T-dualising Generalised Monge Ampere gives equations of

Pederesen and Poon, and Zharkov

Further Dualities

Smeared KK Monopole

↓

NS5-brane Smeared on T^3

↓

D8-brane Wrapped on T^3

D8-brane: domain wall in 9+1 dimensions

Type I' String Theory

Interval x $\mathbb{R}^{1,8}$

16 D8-branes of charge 1: N_i branes at points τ_i on interval

Orientifold 8-planes of charge -8 at end-points $\tau = 0,\pi$

$$ds^2 = V^{-1/2} ds^2(\mathbb{R}^{1,8}) + V^{1/2} d\tau^2 \qquad V(\tau) = \begin{cases} c_1 + m_1\tau, & 0 \le \tau \le \tau_1 \\ c_2 + m_2\tau, & \tau_1 < \tau \le \tau_2 \\ \vdots & \\ c_n + m_n\tau, & \tau_{n-1} < \tau \le \tau_n \\ c_{n+1} + m_{n+1}\tau, & \tau_n < \tau \le \pi \end{cases}$$

$$N_i = m_{i+1} - m_i \qquad \sum_{i=1}^{n} N_i = 16$$

Or, if at $\tau = 0$ there are N_- branes giving charge $b_- = -8 + N_-$
and at $\tau = \pi$ there are N_+ branes giving charge $b_+ = -8 + N_+$

$$b_- = -m_1, b_+ = m_{n+1} \qquad 0 \le b_\pm \le 8$$

$$\sum_{i=1}^{n} N_i = b_- + b_+ \le 16$$

Like K3 story, but 16, not 18!

This is correct story for *perturbative* type I' theory

At *strong coupling*, O8 plane can emit one D8 brane to leave

O8* plane of charge -9 Morrison and Seiberg

Then O8* planes at either end and 18 D8-branes on interval

If at $\tau = 0$ there are N_- branes giving charge $b_- = -9 + N_-$

and at $\tau = \pi$ there are N_+ branes giving charge $b_+ = -9 + N_+$

$$b_- = -m_1, b_+ = m_{n+1}$$

$$\sum_{i=1}^{n} N_i = b_- + b_+ \leq 18$$

Same equations as for degenerate K3

String Dualities

IIA string on K3 dual to Heterotic string on T^4 [CH+Townsend]

→

IIA string on K3 dual to Type I' string on (Interval) x T^3

- Strong coupling in type I' mapped to weak coupling in type IIA, so dual gives insight into mysterious I' strong coupling regime
- KK monopoles dual to D8-branes wrapped on T^3
- Tian-Yau end caps dual to orientifold planes
- Moduli space of type I' mapped to *subspace* of moduli space of IIA on K3

- D8 branes and O8 planes on interval give fully consistent background for type I’ string theory.

- Singularities of metric reflect presence of physical objects (branes)

- Dual configurations also fully consistent

- Duality taking D8-branes wrapped on T^4 to KK monopoles takes type I’ on T^3 to type IIA on K3.

- *Predicts(!)* region of K3 moduli space in which K3 looks like HSVZ

- Dualities take intersecting branes to special holonomy metrics

- Intersecting branes part of consistent string backgrounds

- *Predicts(!?)* consistent background incorporating the special holonomy solutions as part of a compact complete special holonomy space.