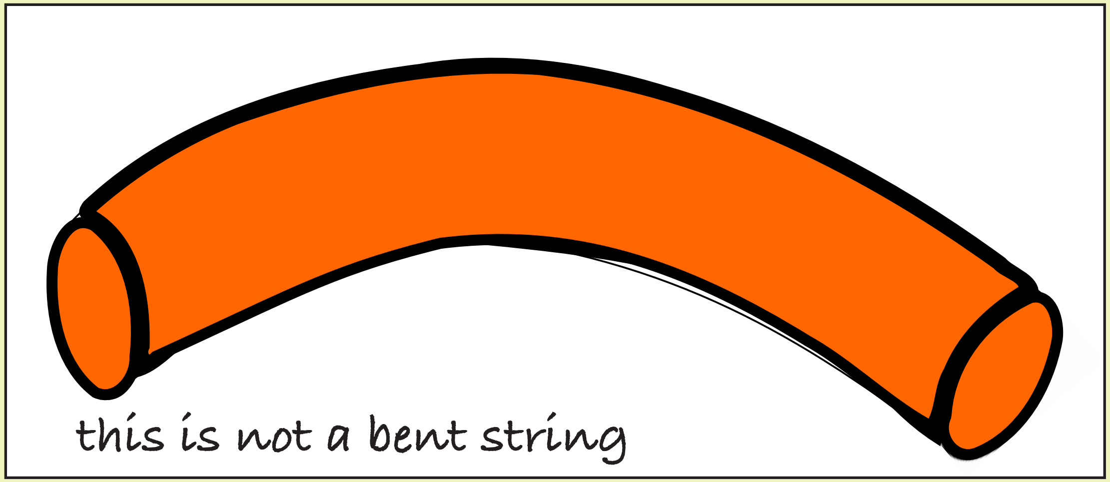
THE YOUNG MODULUS OF BLACK STRINGS



Jay Armas | NBI

BASED ON arXiv:1110.4835 J.Armas, J.Camps, T.Harmark, N.A.Obers

CHAPTER 1:

THE ART AND CRAFT OF BENDING BLACK BRANES

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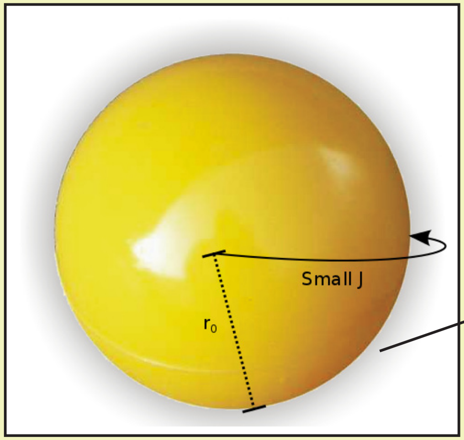
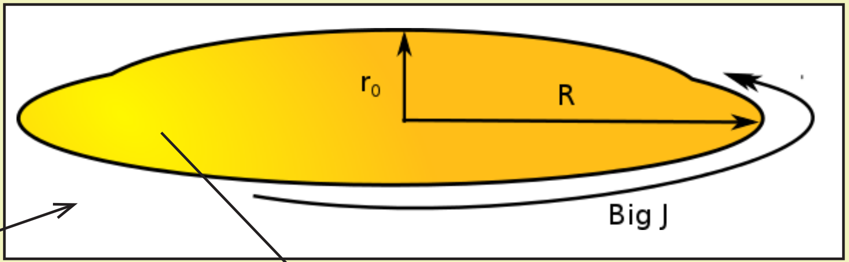
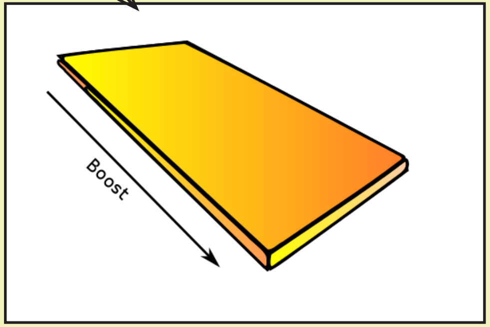
The Blackfold Approach (I): Myers Perry



Increase angular momentum



Zoom into horizon



$$ds^2 = -f(r)dt^2 + f(r)^{-1}dr^2 + r^2 d\Omega^2_{D-4} + (d\sigma^2 + \sigma^2 d\phi^2)$$

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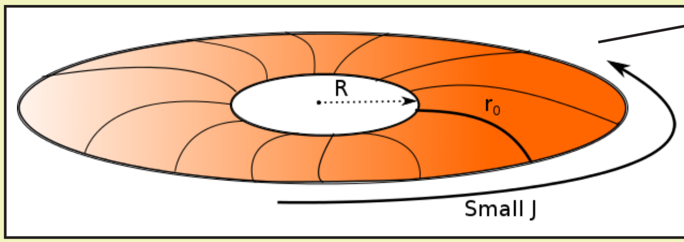
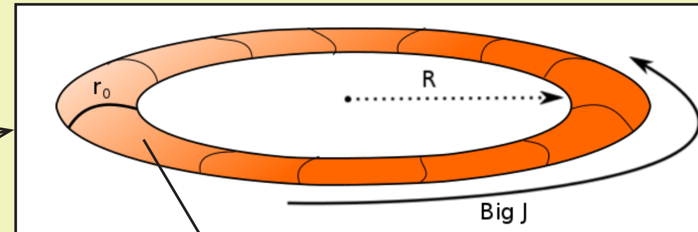
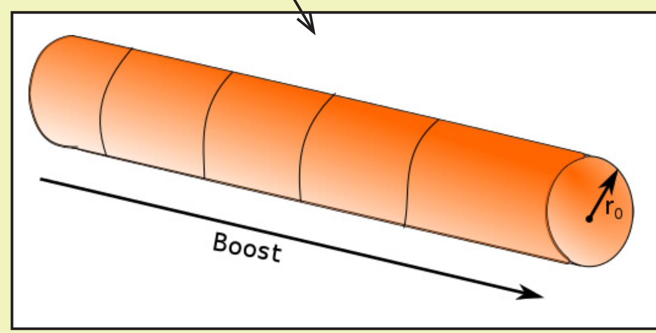
The Blackfold Approach (II): Black Ring



Increase angular momentum



Zoom into horizon



$$ds^2 = -f(r)dt^2 + f(r)^{-1}dr^2 + r^2 d\Omega^2_{D-3} + dz^2$$

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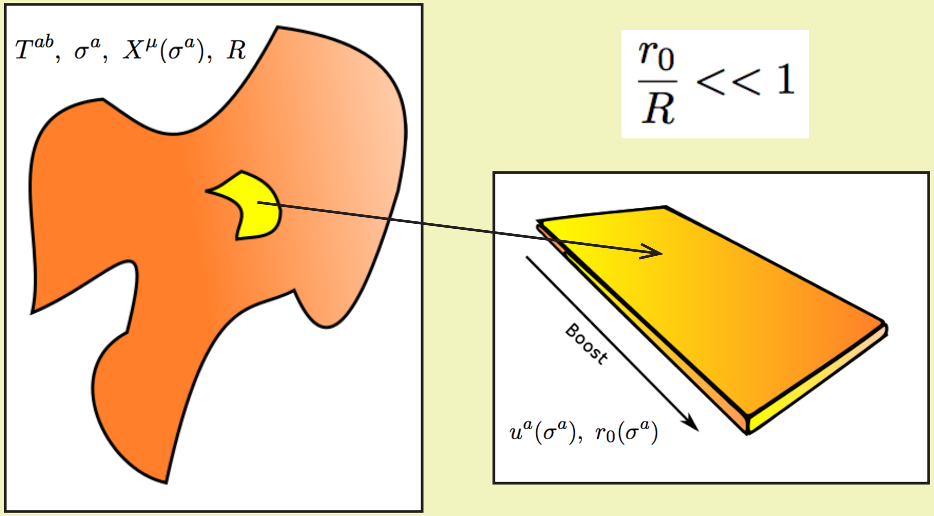
The Blackfold Approach (III): Observation

WE HAVE ABSOLUTELY NO IDEA OF WHAT KIND OF HIGHER DIMENSIONAL BLACK HOLES ARE OUT THERE BUT IT SEEMS TO BE A GENERAL FEATURE TO EXHIBIT A LIMIT WHERE THEY BECOME LOCALLY BLACK BRANES.

The Blackfold Approach (IV): The Method

$$\frac{r_0}{R} << 1$$



$$T^{ab} = \Big((\epsilon + P)u^a u^b + P\gamma^{ab}\Big)\,\delta_\perp^{n+2}(x^\rho - X^\rho(\sigma^a))$$

$$\epsilon = -(n+1)P$$

If the object acts as a source to Einstein's equations then it must satisfy:

$$\nabla_\mu T^{\mu\nu} = 0$$

Projecting this in directions parallel and orthogonal to the worldvolume leads to:

$$D_a T^{ab} = 0$$

$$T^{ab} K_{ab}{}^{\rho} = 0$$

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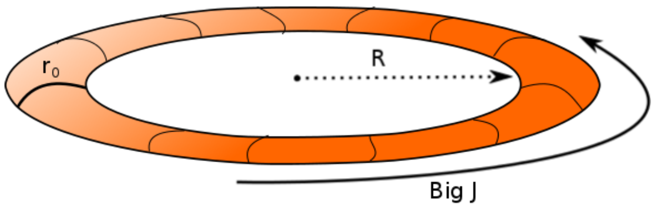
The Blackfold Approach (V): An Example



The equilibrium condition is simply:

$$\Omega = \frac{1}{\sqrt{n+1}}\frac{1}{R}$$

The object is described by the mapping functions:

$$X^t = \tau, \ X^z = R\phi$$

with intrinsic metric:

$$\gamma_{ab} d\sigma^a d\sigma^b = -d\tau^2 + R^2 d\phi^2$$

and Killing vector:

$$k^a \partial_a = \partial_\tau + \Omega \partial_\phi$$

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CHAPTER 2:

BLACK BRANES AS VISCOUS FLUIDS AND ELASTIC SOLIDS

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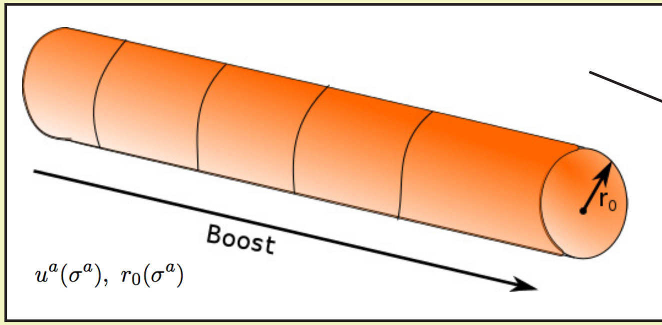
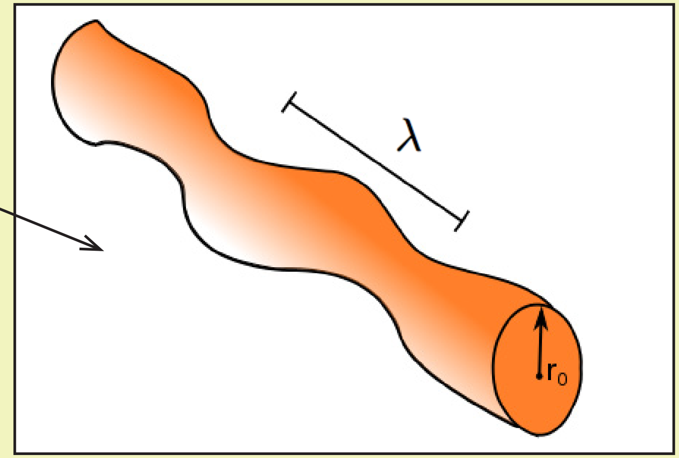
Transport/Response Coefficients (I): Viscosities



$$\frac{r_0}{\lambda} << 1$$

Small perturbation of intrinsic parameters



To first order in a derivative expansion:

$$T^{ab} = \left(\epsilon u^a u^b + P P^{ab} - 2\eta\sigma_{ab} - \zeta\vartheta P^{ab}\right)\delta^{n+2}(x^\rho - X^\rho)$$

$$\eta = \frac{\Omega_{(n+1)} r_0^{n+1}}{16\pi G},\ \zeta = 2\eta\left(\frac{1}{p} + \frac{1}{n+1}\right)$$

The perturbed brane must satisfy:

$$D_a T^{ab} = 0$$

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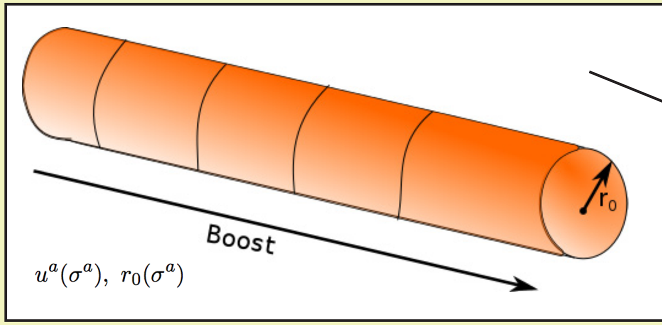
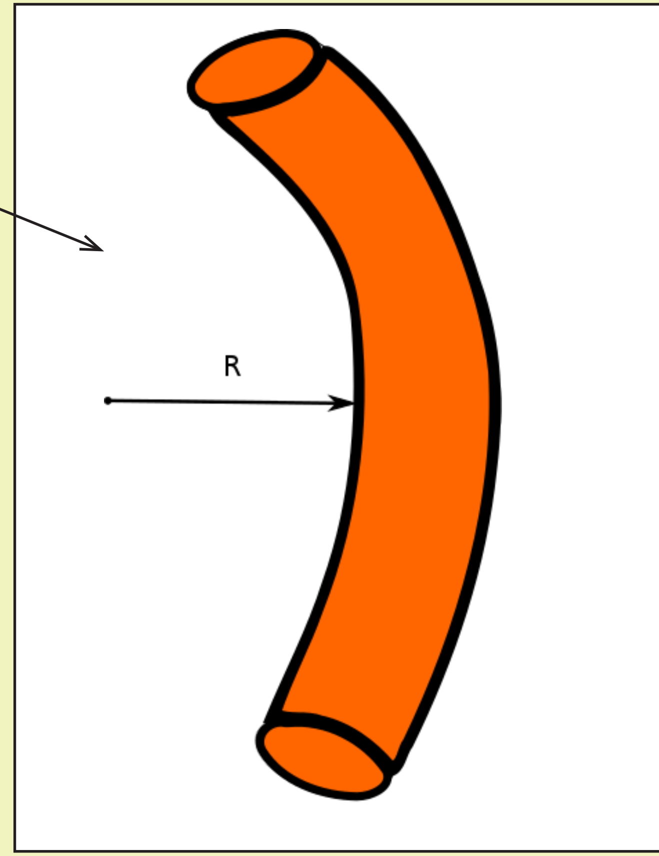
Transport/Response Coefficients (II): Young Modulus



$$\frac{r_0}{R} << 1$$

Small perturbation
of extrinsic
parameters



The equations of motion are modified to:

$$D_a T^{ab} = K_c{}^b{}_\mu \nabla_a d^{ac\mu}$$

$$T^{ab} K^{\rho}_{ab} = -K_{ac}{}^{\rho} K^{(c}{}_{b\lambda} d^{a)b\lambda} - \perp^{\rho}{}_{\sigma} \nabla_b \nabla_a d^{ab\sigma}$$

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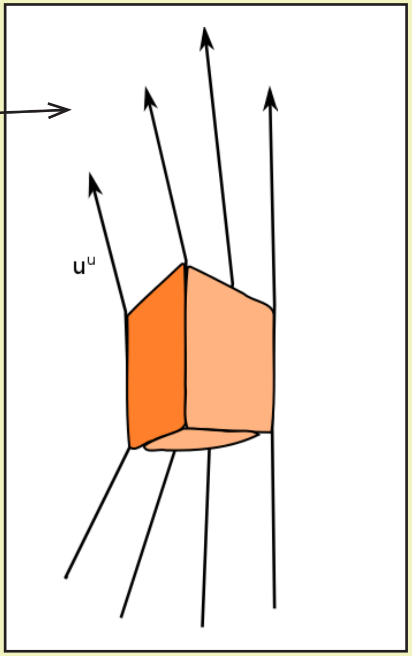
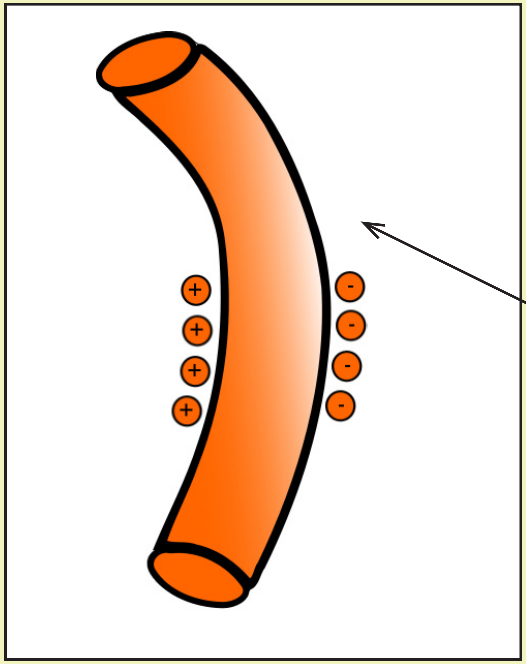
Transport/Response Coefficients (III): Young Modulus

A real 4D material can be described by a local particle density:

$$T^{\mu\nu} = \epsilon u^\mu u^\nu + P^{\mu\nu}$$





On the other hand, a p-brane develops dipoles of stress and requires a orthogonal component of the stress-energy tensor, a dipole contribution:

$$\hat{T}^{\mu\nu} = \int_{\mathcal{W}_{p+1}} d^{p+1}\sigma \left(T^{\mu\nu}\delta^D(x^\mu - X^\mu) + \nabla_\rho (d^{ab\rho} u_a^\mu u_b^\nu \delta^D(x^\mu - X^\mu)) \right)$$

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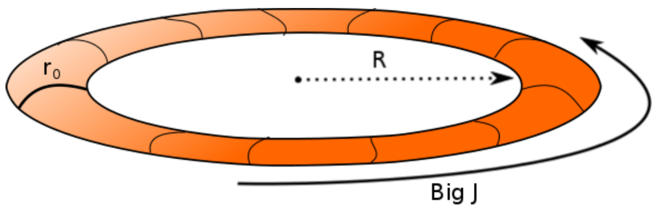
Transport/Response Coefficients (IV): Young Modulus



The Young Modulus for Black Strings is:

$$Y^{ttzz} = Y^{zztt} = -\frac{\Omega_{(n)}(n+2)}{16\pi G r_0^2}(n^2+3n+4)\xi(n)$$

$$Y^{tztt} = Y^{tzzz} = 0$$

$$Y^{tttt} = Y^{zzzz} = \frac{\Omega_{(n)}(n+2)(n+4)}{16\pi G r_0^2}(3n+4)\xi(n)$$

We can measure the dipole from an approximate analytic solution, in general we find the relation between stress and strain (Hookean Idealization):

$$d_{ab}{}^{\hat{\rho}} = \mathcal{C}(n) Y_{ab}{}^{cd} K_{cd}{}^{\hat{\rho}}$$

which can be measured in the linearized gravity regime far away from the source:

$$\bar{h}^{(D)}_{\mu\nu} = \frac{16\pi G \cos\theta}{\Omega_{(n+1)} r^{n+1}} d_{\mu\nu}{}^{\hat{\rho}}$$

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Transport/Response Coefficients (V): Electric Susceptibility

Charged bent strings develop a polarization vector in transverse directions to the worldvolume. We can captured this by introducing a dipole correction to the current:

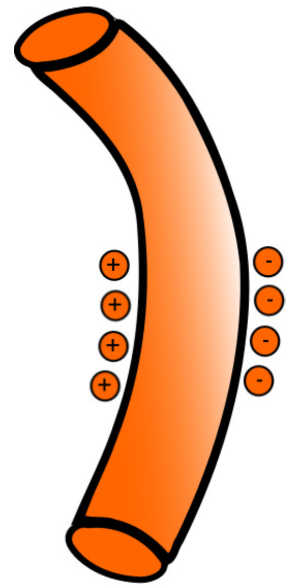
$$\hat{J}^{\mu\nu} = \int_{\mathcal{W}_{p+1}} d^{p+1}\sigma \left(J^{\mu\nu}\delta^D(x^\mu - X^\mu) + \nabla_\rho(\mathcal{M}^{ab\rho}u_a^\mu u_b^\nu \delta^D(x^\mu - X^\mu)) \right)$$

which can be measured using:

$$\nabla_\lambda F^{\lambda\mu\nu} = \hat{J}^{\mu\nu}$$

and hence the eletric susceptibility:

$$\mathcal{M}^{ab\hat{\rho}} = {\chi_e}^{ab\hat{\rho}}{}_{\mu\nu} E^{\mu\nu}$$



Measurement on its way!

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CHAPTER 3:

THE END

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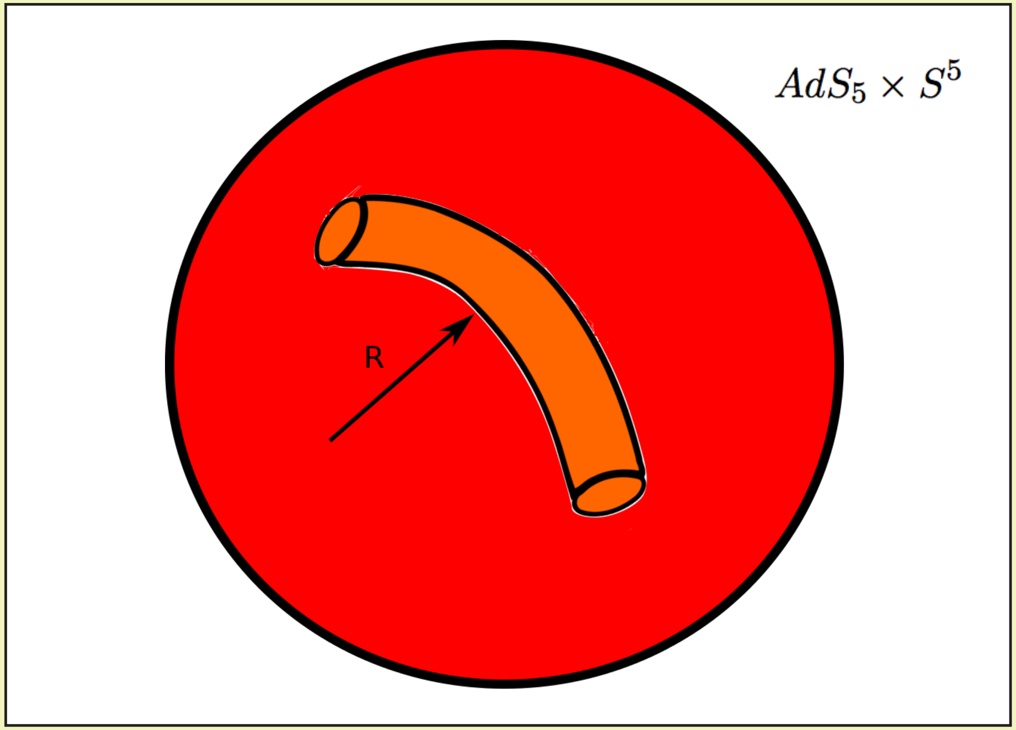
A Comment and food for thought

- A rather unusual use of jargon when speaking about black hole physics : elasticity, young modulus, stress, strain, susceptibility, etc.



CFT

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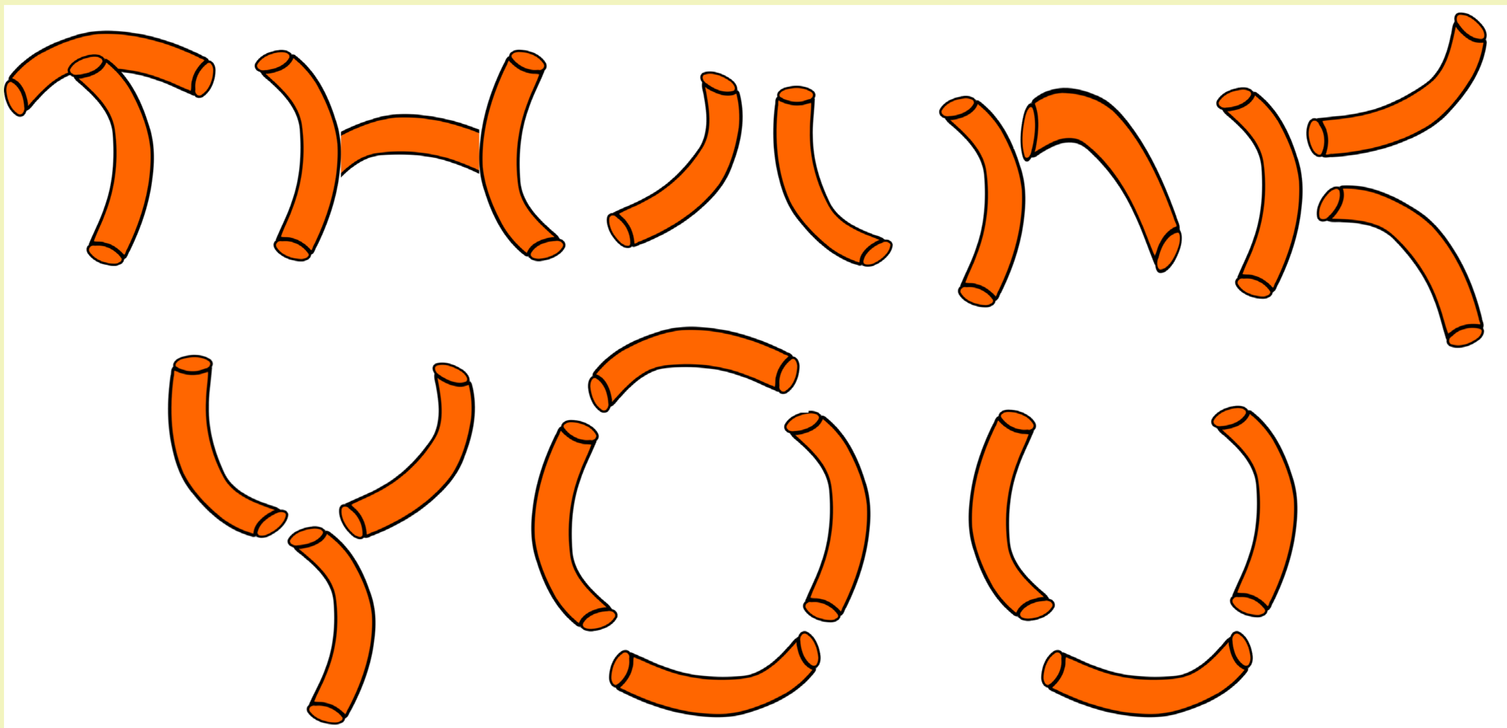
THANK YOU