Title: 13/14 PSI - Student Presentations - 2

Date: Aug 16, 2013 10:30 AM

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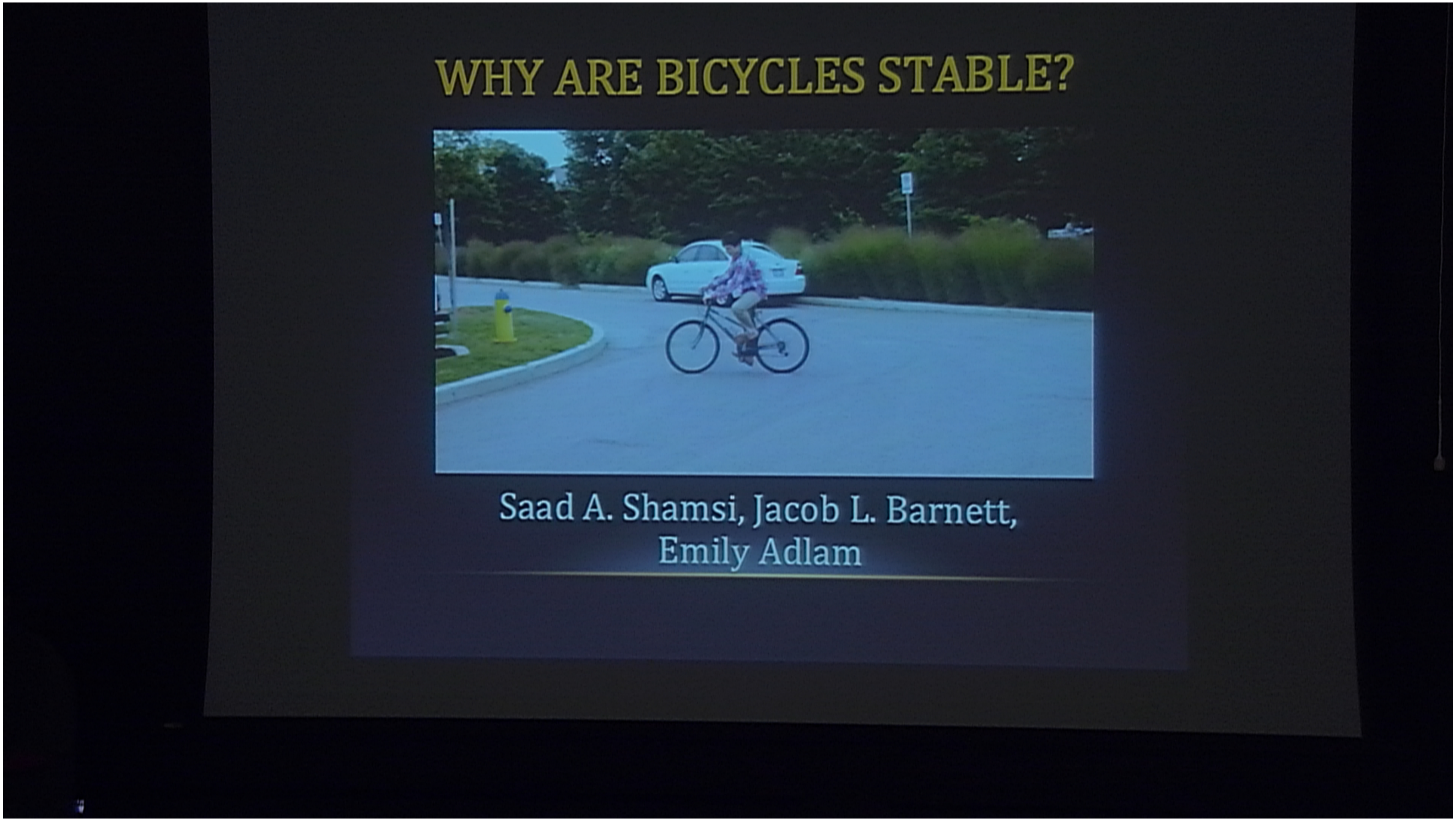
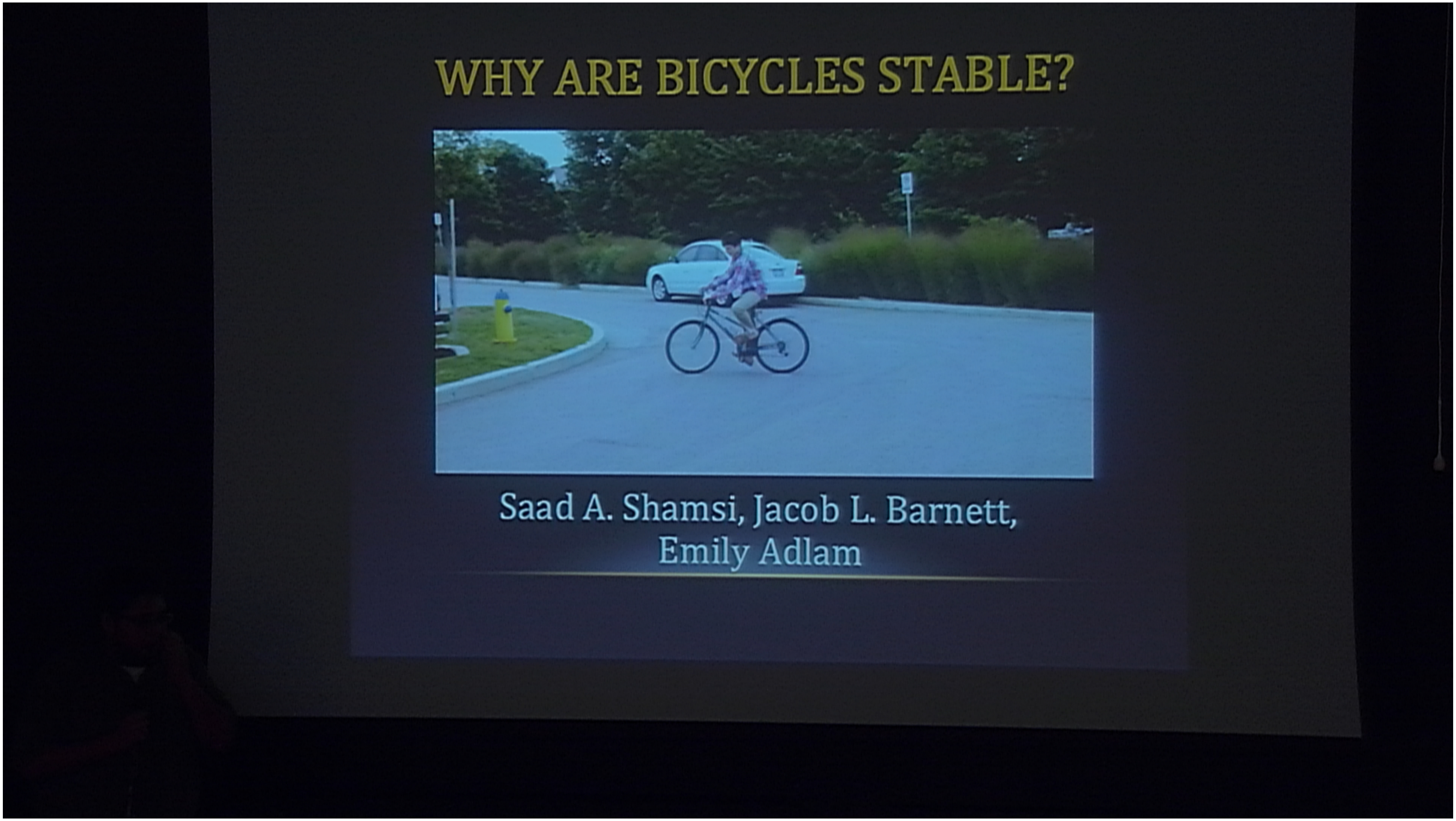
Abstract:


WHY ARE BICYCLES STABLE?
Saad A. Shamsi, Jacob L. Barnett,
Emily Adlam


WHY ARE BICYCLES STABLE?
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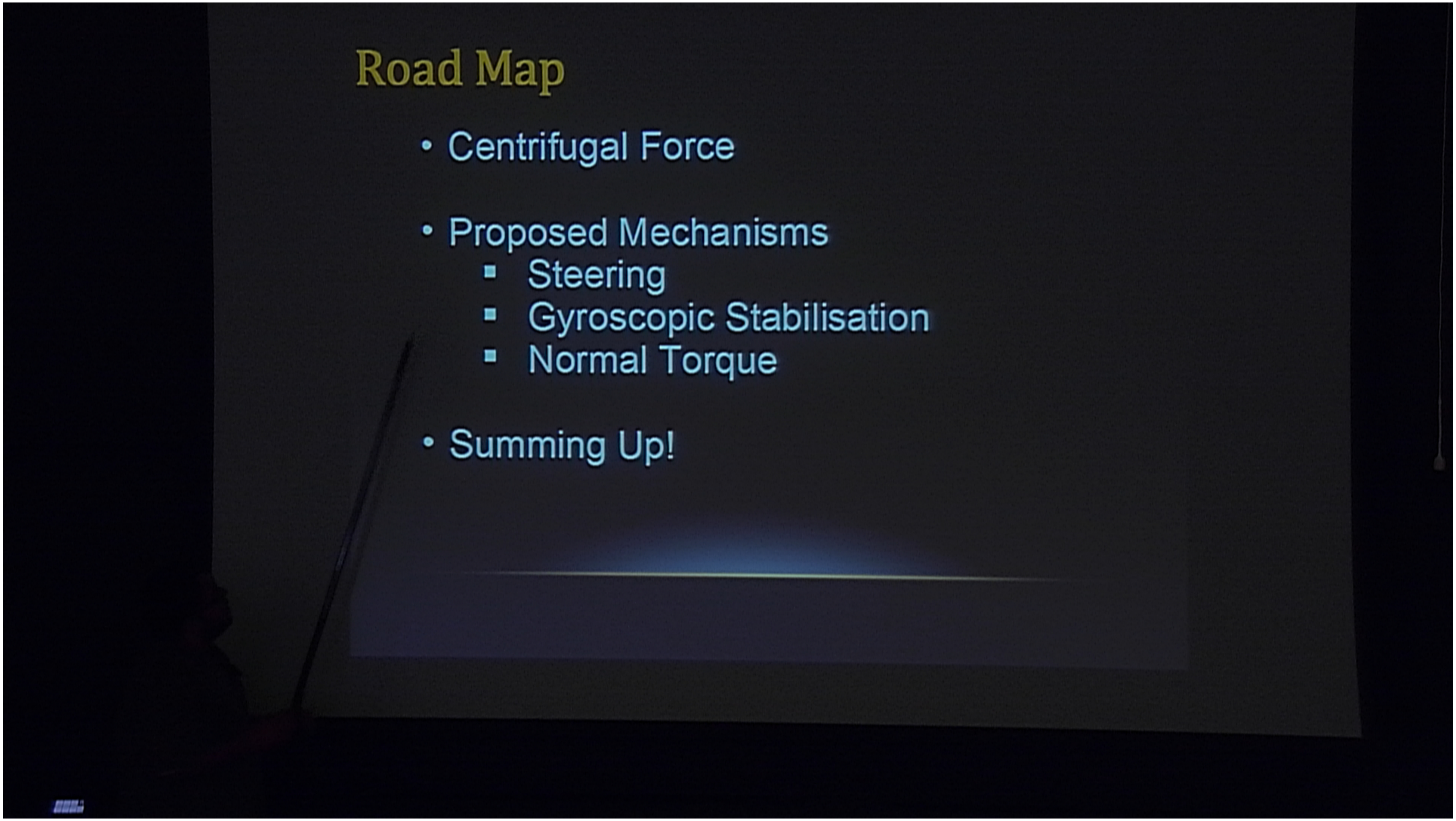
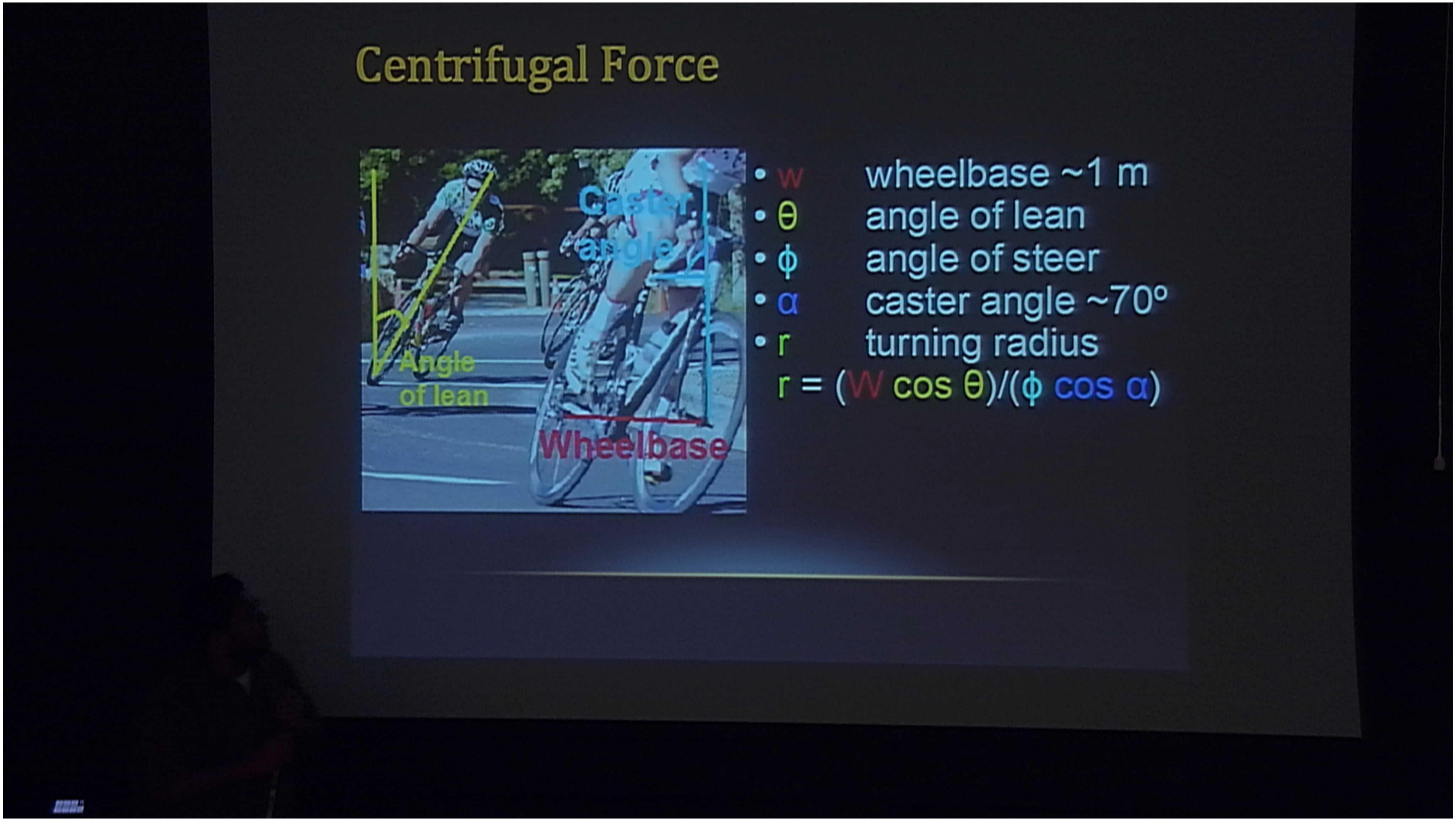
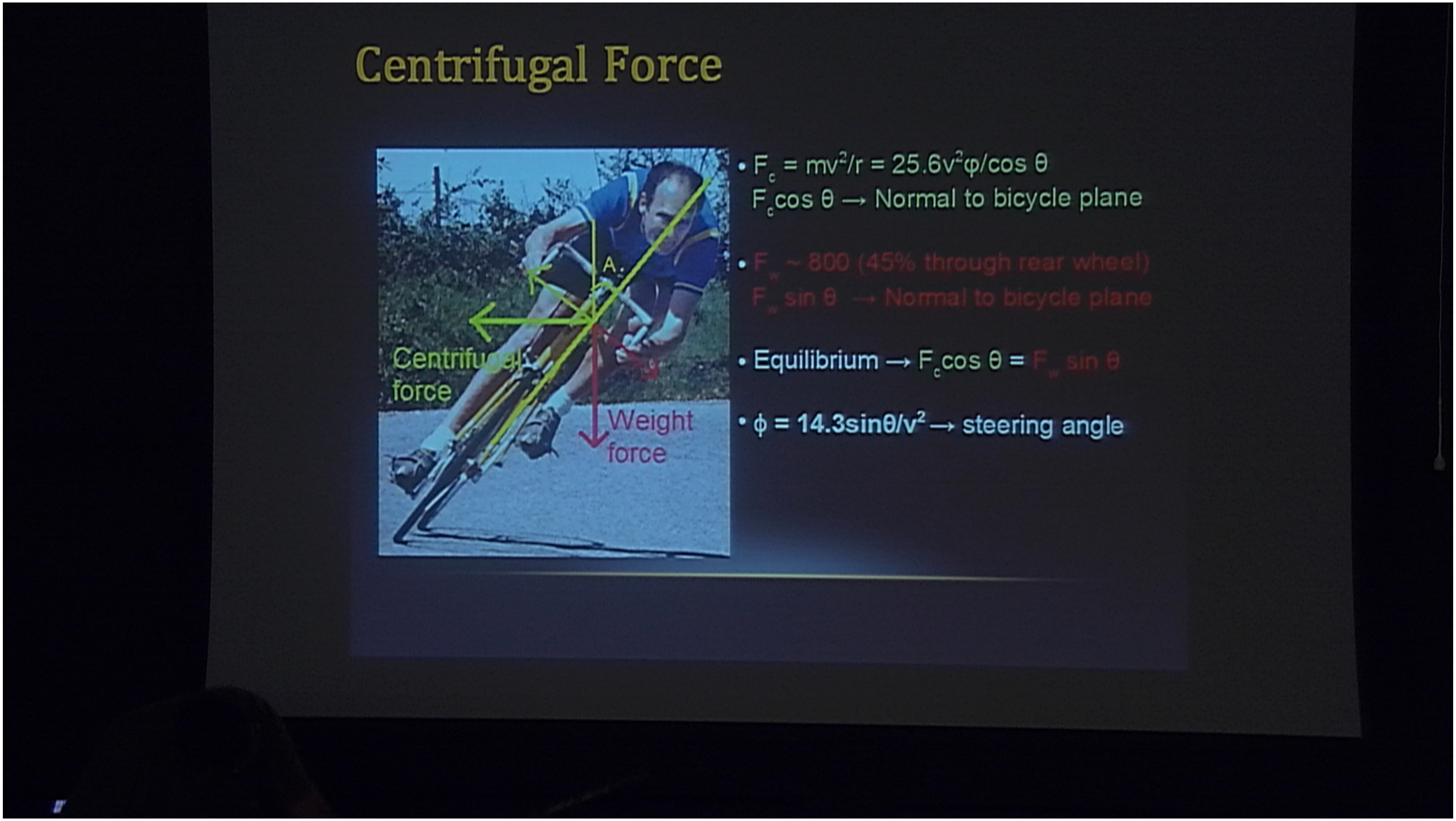
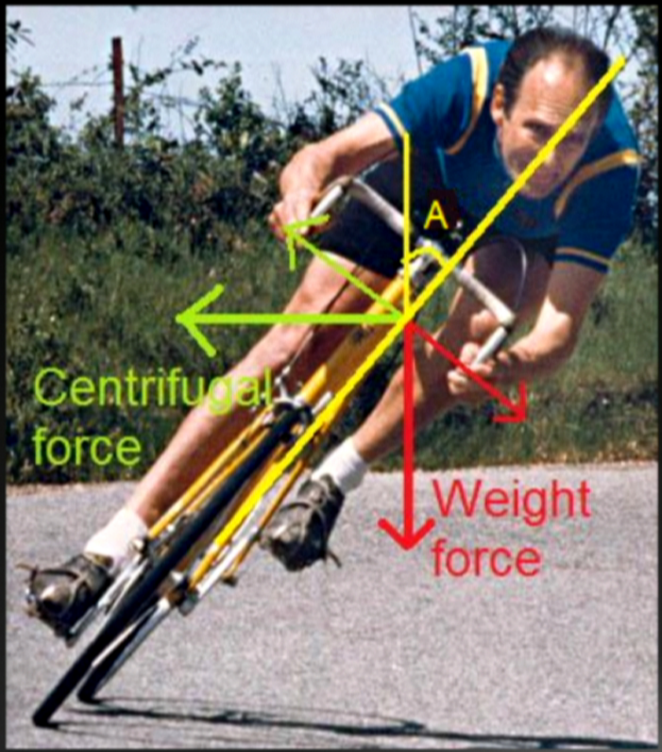

Road Map
• Centrifugal Force
• Proposed Mechanisms
▪ Steering
▪ Gyroscopic Stabilisation
▪ Normal Torque
• Summing Up!


Centrifugal Force
Caster angle
Angle of lean
Wheelbase
• w wheelbase ~1 m
• θ angle of lean
• ϕ angle of steer
• α caster angle ~70º
• r turning radius
r = (W cos θ)/(ϕ cos α)


Centrifugal Force
• F_c = mv²/r = 25.6v²φ/cos θ
F_c cos θ → Normal to bicycle plane
• F_w ~ 800 (45% through rear wheel)
F_w sin θ → Normal to bicycle plane
• Equilibrium → F_c cos θ = F_w sin θ
• ϕ = 14.3sinθ/v² → steering angle
A
Centrifugal force
Weight force

Centrifugal Force



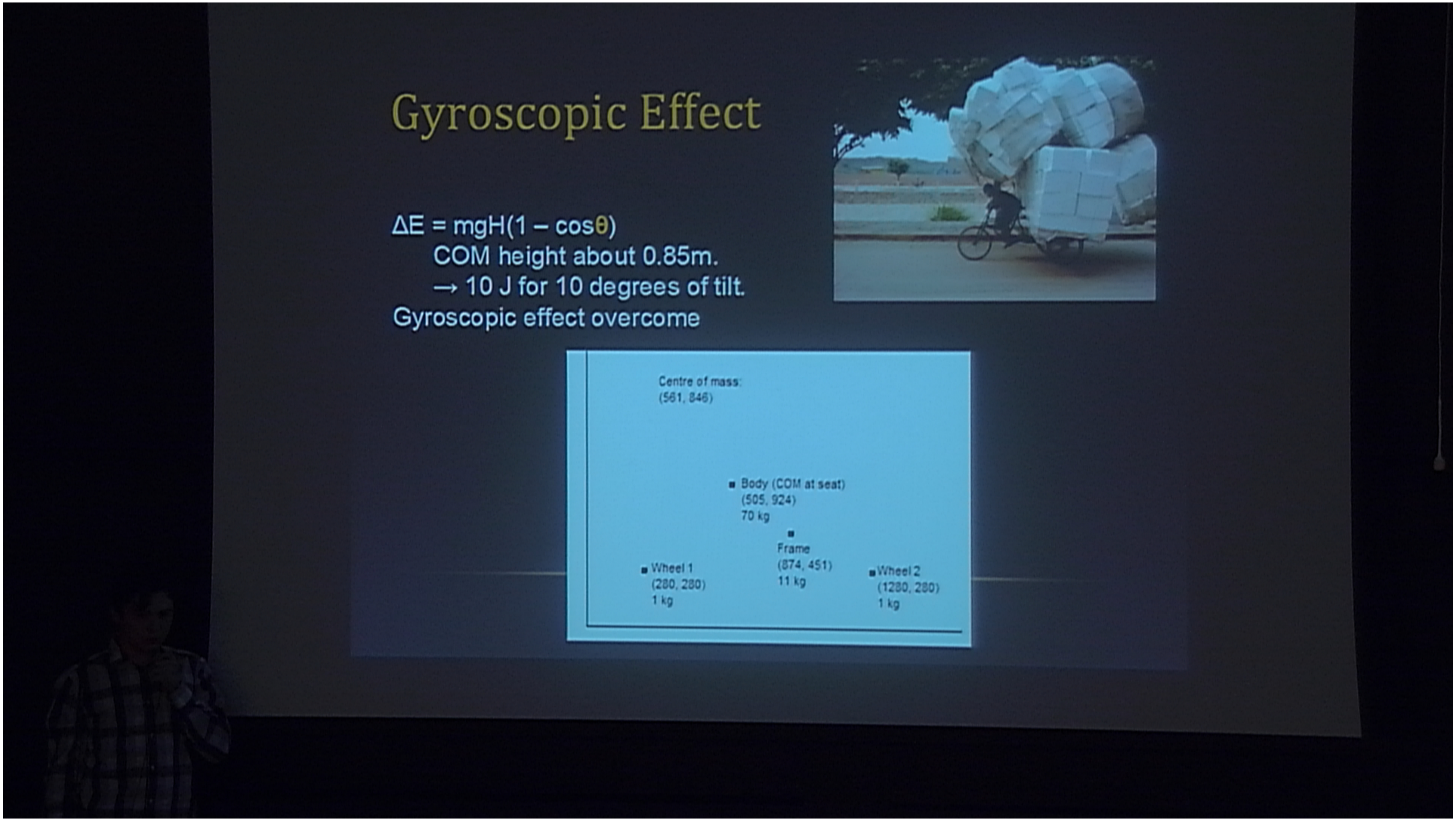
- $F_c = mv^2/r = 25.6v^2\varphi/\cos\theta$
  $F_c\cos\theta \rightarrow$ Normal to bicycle plane
- $F_w \sim 800$ (45% through rear wheel)
  $F_w \sin\theta \rightarrow$ Normal to bicycle plane
- Equilibrium $\rightarrow F_c\cos\theta = F_w\sin\theta$
- $\phi = \mathbf{14.3sin\theta/v^2} \rightarrow$ steering angle

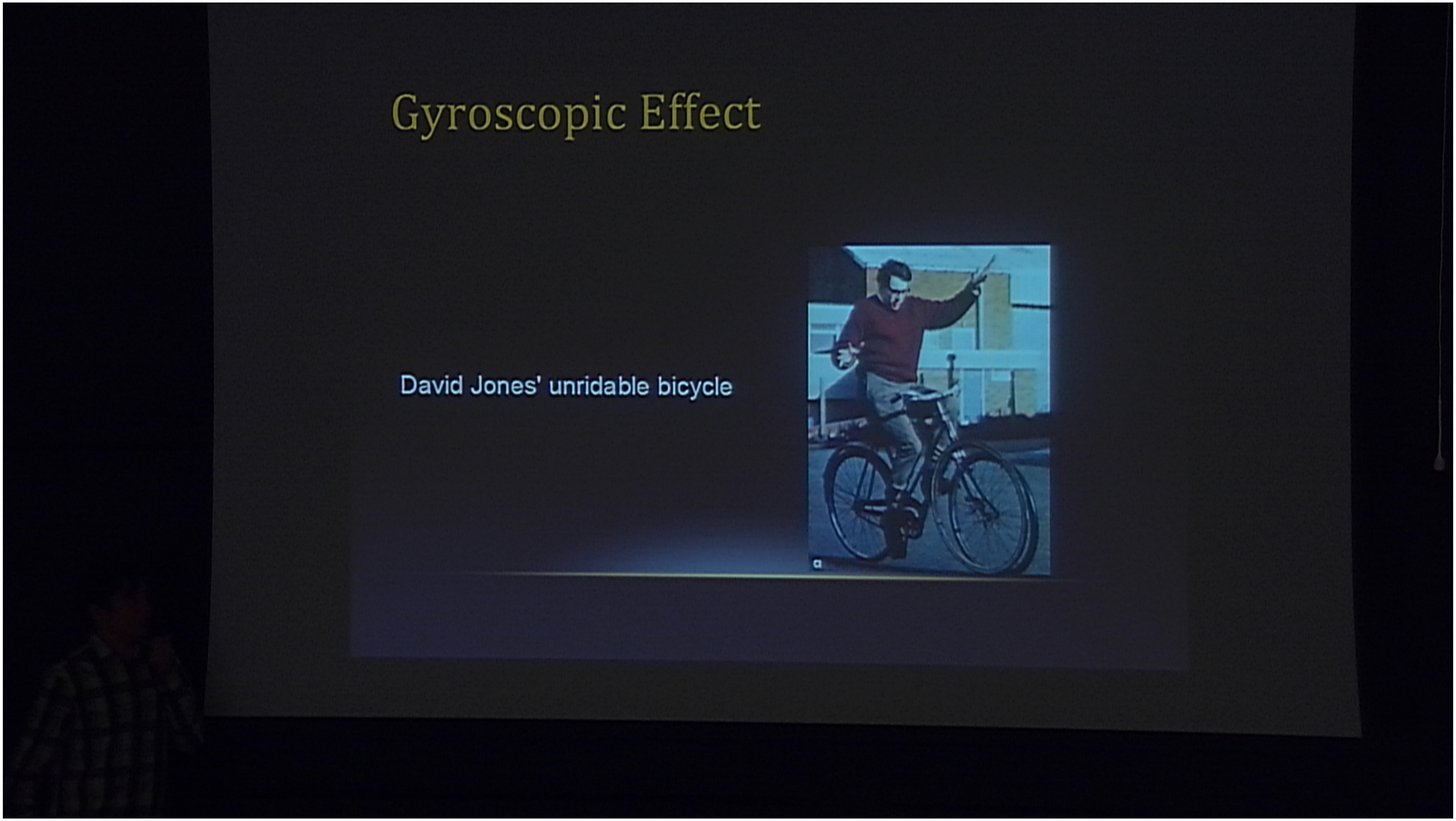
Manual Intervention

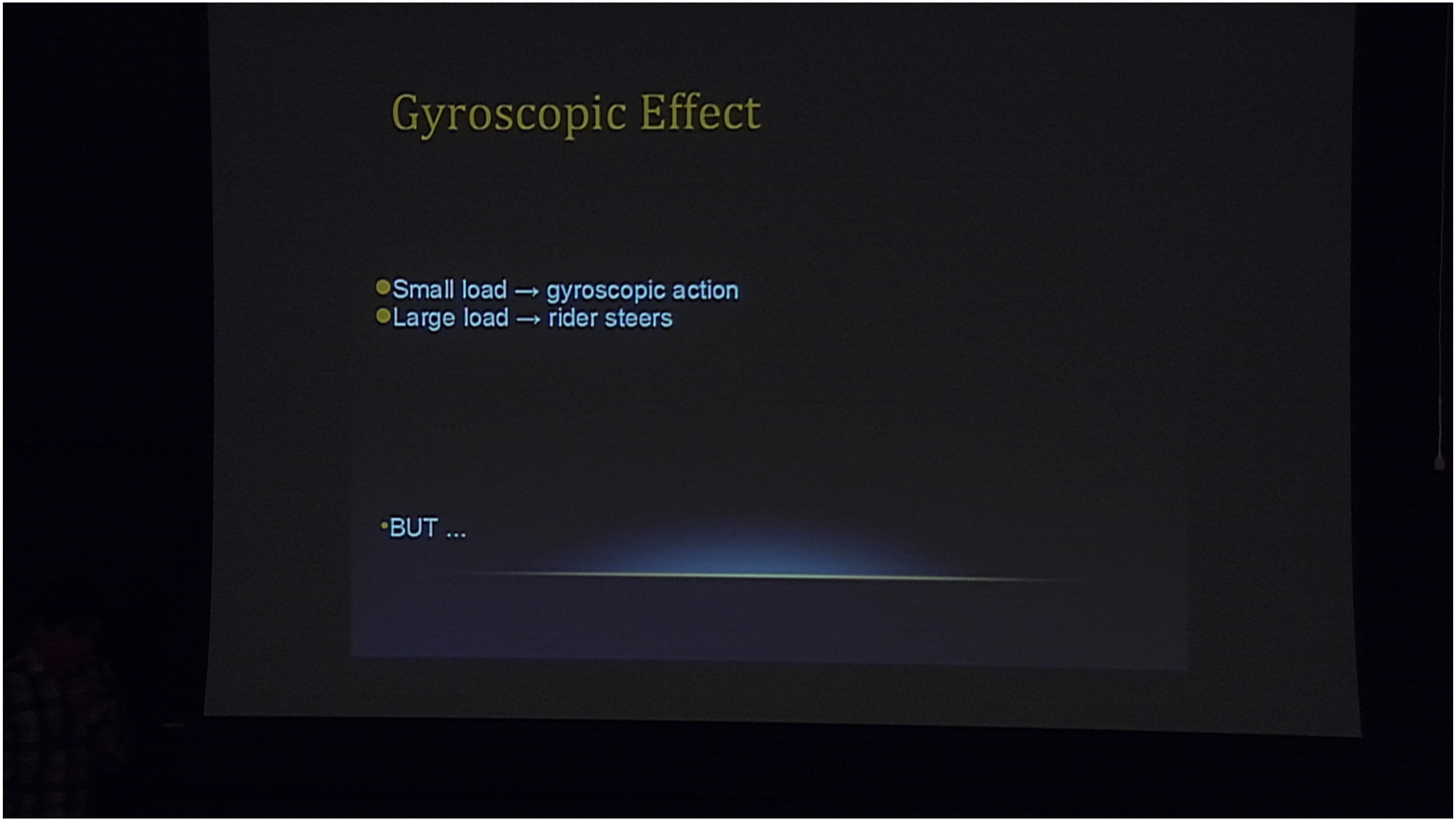
- Bicycle leans → rider steers in direction of lean → centrifugal force.

- BUT
  Moving riderless bicycle:
  - ~ twenty seconds to fall

  Stationary riderless bicycle:
  ~ two seconds to fall

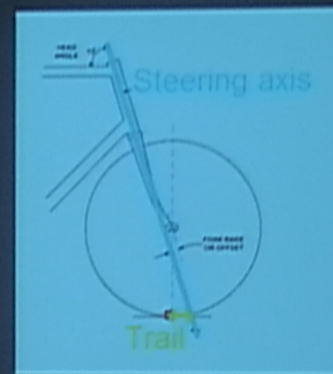

Gyroscopic Effect
ΔE = mgH(1 – cosθ)
COM height about 0.85m.
→ 10 J for 10 degrees of tilt.
Gyroscopic effect overcome
Centre of mass:
(561, 846)
Body (COM at seat)
(505, 924)
70 kg
Frame
(874, 451)
11 kg
Wheel 1
(280, 280)
1 kg
Wheel 2
(1280, 280)
1 kg

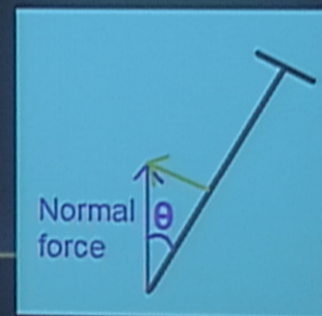

Gyroscopic Effect
David Jones' unridable bicycle

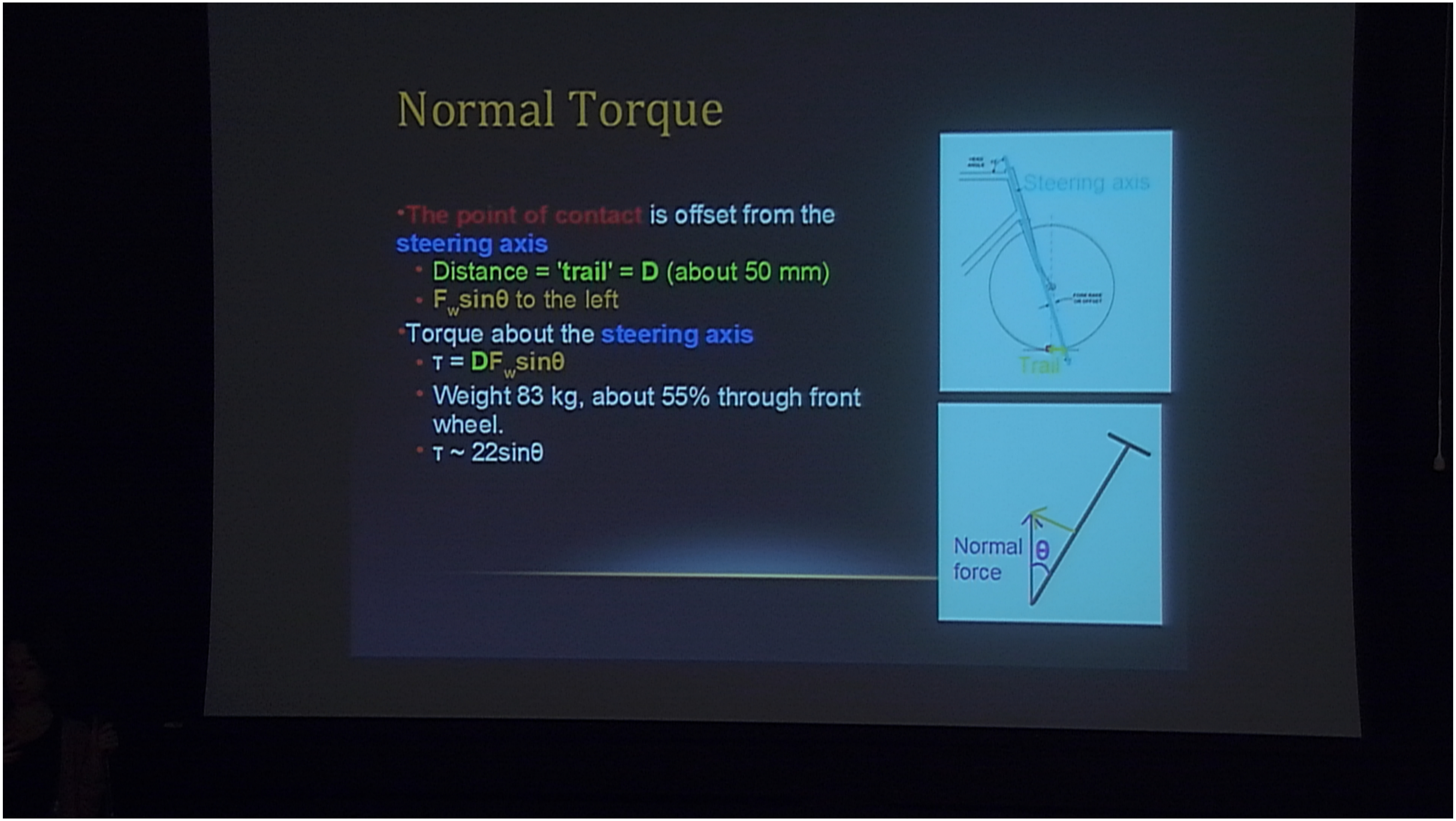

Gyroscopic Effect
Small load → gyroscopic action
Large load → rider steers
BUT ...

Normal Torque

- The point of contact is offset from the steering axis
  - Distance = 'trail' = D (about 50 mm)
  - $F_w \sin\theta$ to the left
- Torque about the steering axis
  - $\tau = DF_w \sin\theta$
  - Weight 83 kg, about 55% through front wheel.
  - $\tau \sim 22\sin\theta$

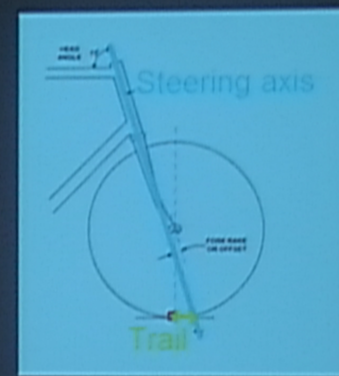


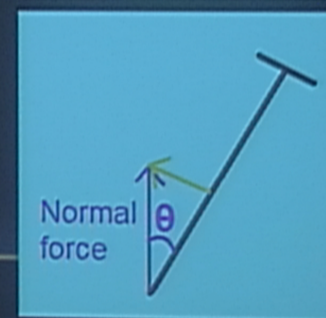



Normal Torque
•The point of contact is offset from the steering axis
• Distance = 'trail' = D (about 50 mm)
• F_w sinθ to the left
•Torque about the steering axis
• τ = DF_w sinθ
• Weight 83 kg, about 55% through front wheel.
• τ ~ 22sinθ
Steering axis
Trail
Normal force
θ

Normal Torque

- The point of contact is offset from the **steering axis**
  - Distance = **'trail'** = **D** (about 50 mm)
  - $F_w \sin\theta$ to the left
- Torque about the **steering axis**
  - $\tau = DF_w \sin\theta$
  - Weight 83 kg, about 55% through front wheel.
  - $\tau \sim 22\sin\theta$





Normal Torque

Torque from friction?

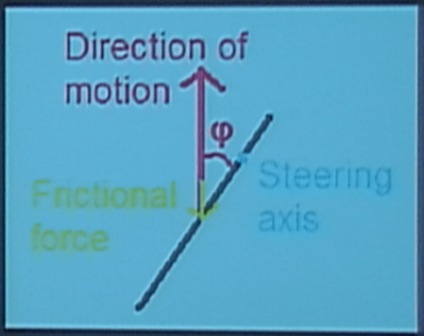
Component $F_f \sin\varphi$ acts to the right

→ torque $DF_f \sin\varphi$ about the steering axis

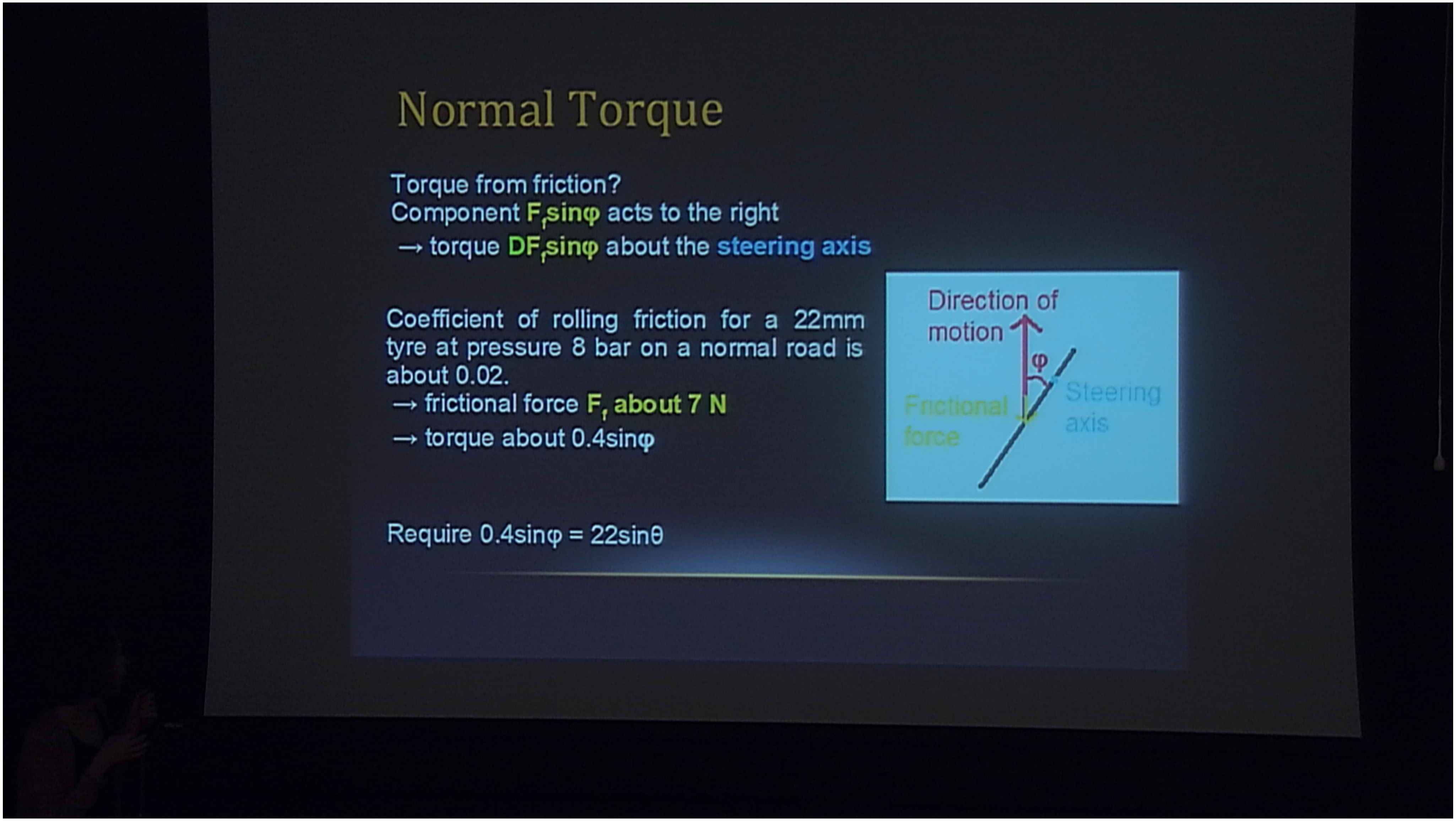
Coefficient of rolling friction for a 22mm tyre at pressure 8 bar on a normal road is about 0.02.

→ frictional force F_f about 7 N

→ torque about $0.4\sin\varphi$

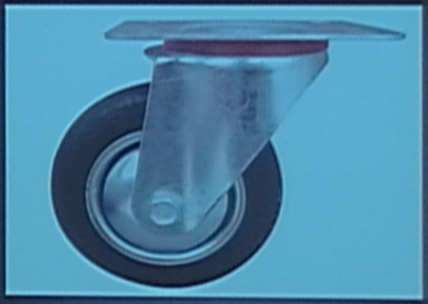


Require $0.4\sin\varphi = 22\sin\theta$


Normal Torque
Torque from friction?
Component $F_f\sin\varphi$ acts to the right
→ torque $DF_f\sin\varphi$ about the steering axis
Coefficient of rolling friction for a 22mm tyre at pressure 8 bar on a normal road is about 0.02.
→ frictional force F_f about 7 N
→ torque about $0.4\sin\varphi$
Require $0.4\sin\varphi = 22\sin\theta$
Direction of motion
φ
Steering axis
Frictional force

Normal Torque

- Two wheels converge.
- Front wheel travels in a plane, rest of the bike falls into line
- Back keeps front on track



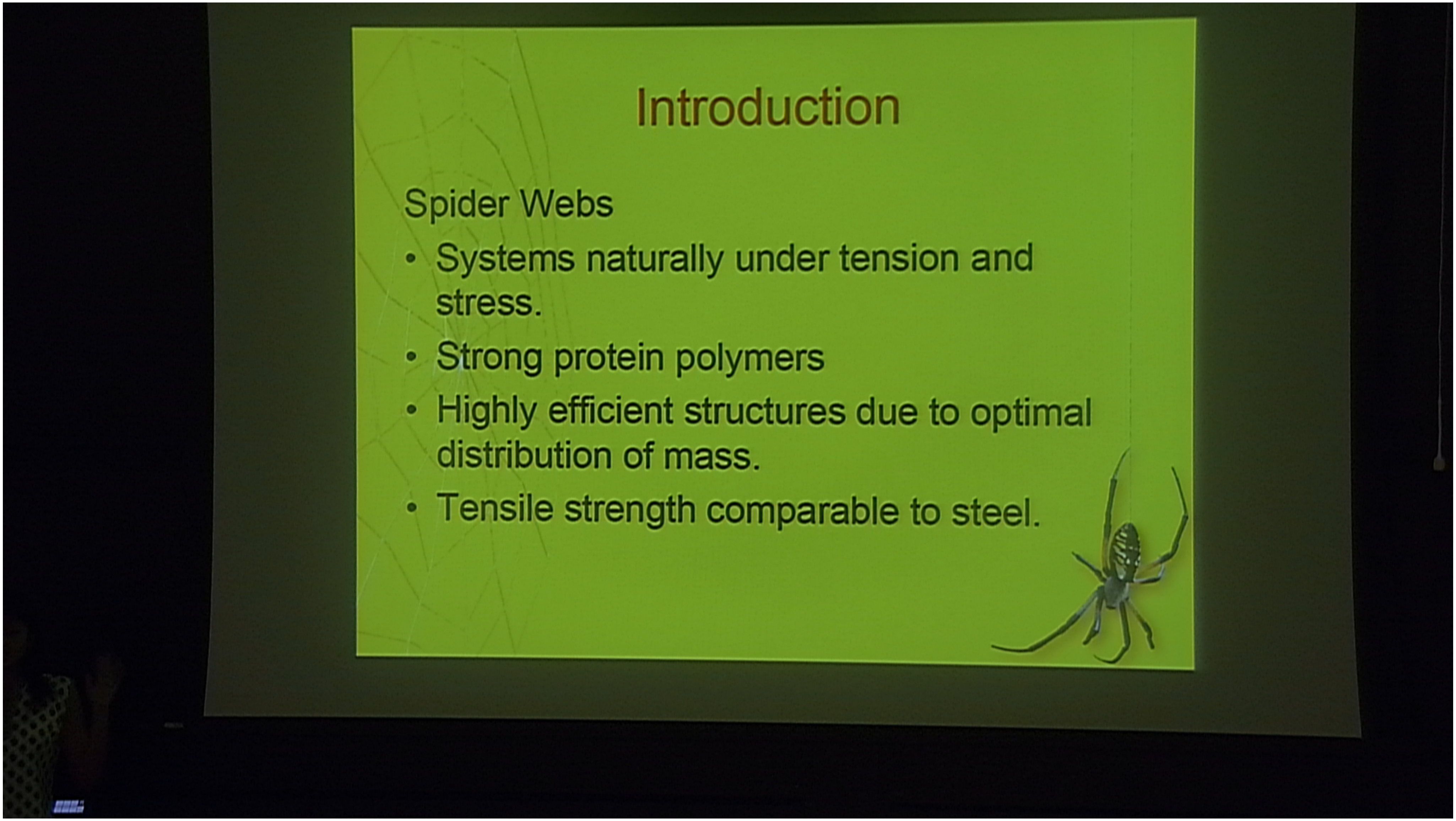
Conclusion

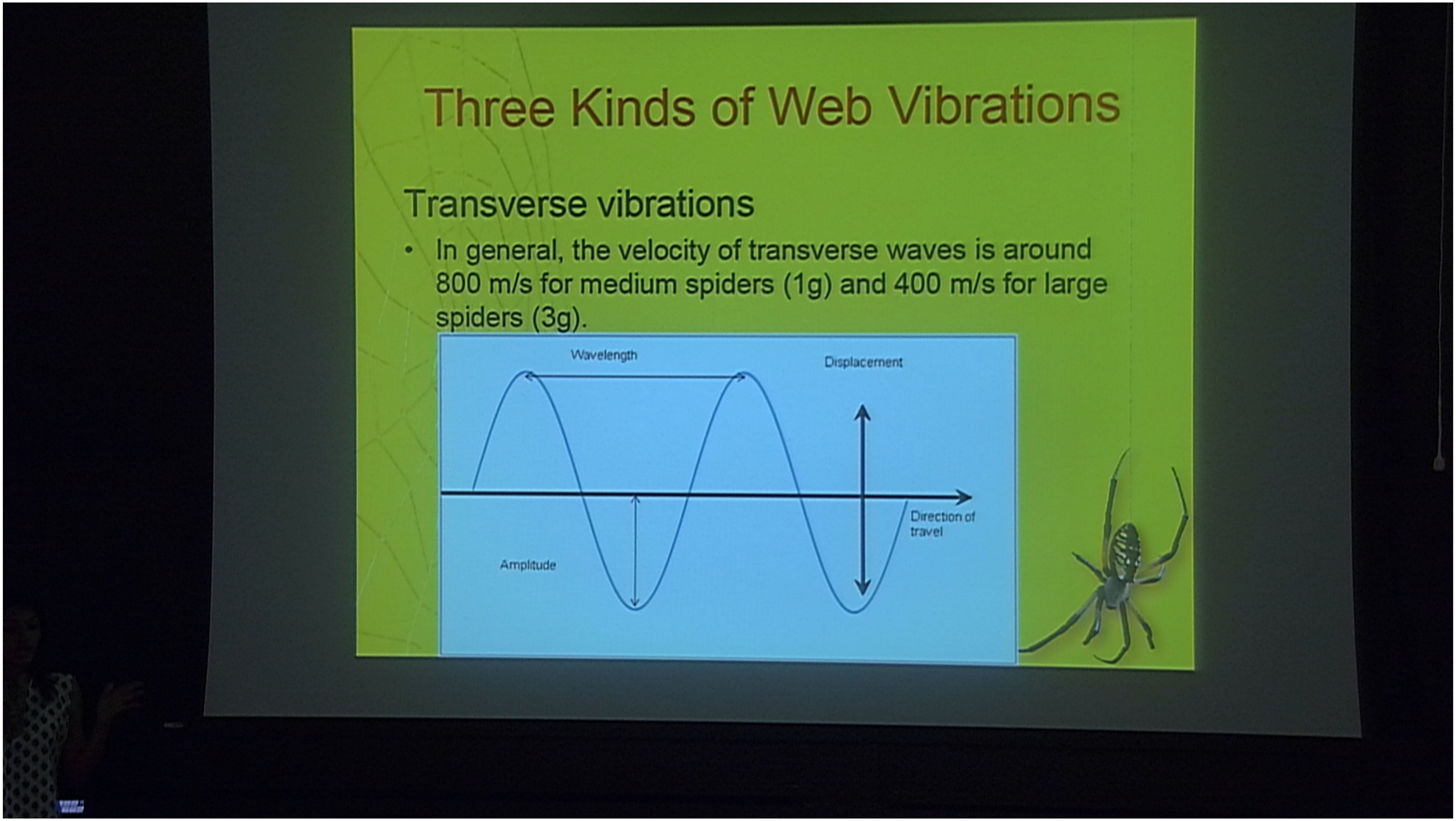
Small load:

- Normal force small → normal torque negligible
- Gyroscopic action important

Heavy load:

- Gyroscopic forces insignificant
- Normal torque important

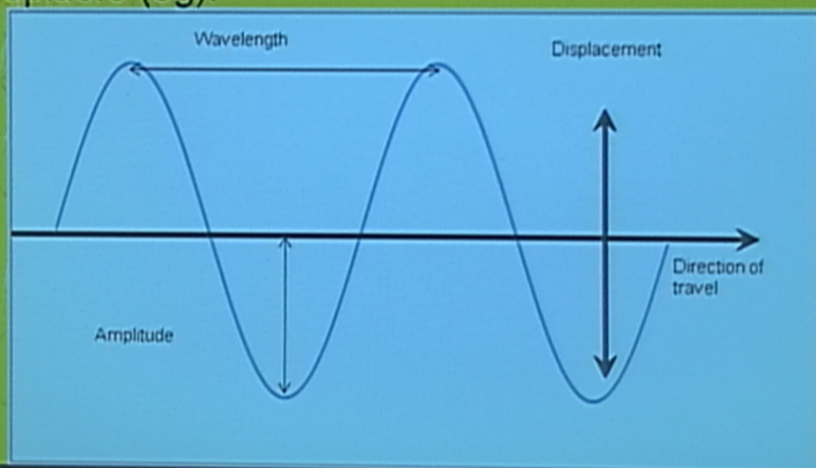

Introduction
Spider Webs
• Systems naturally under tension and stress.
• Strong protein polymers
• Highly efficient structures due to optimal distribution of mass.
• Tensile strength comparable to steel.

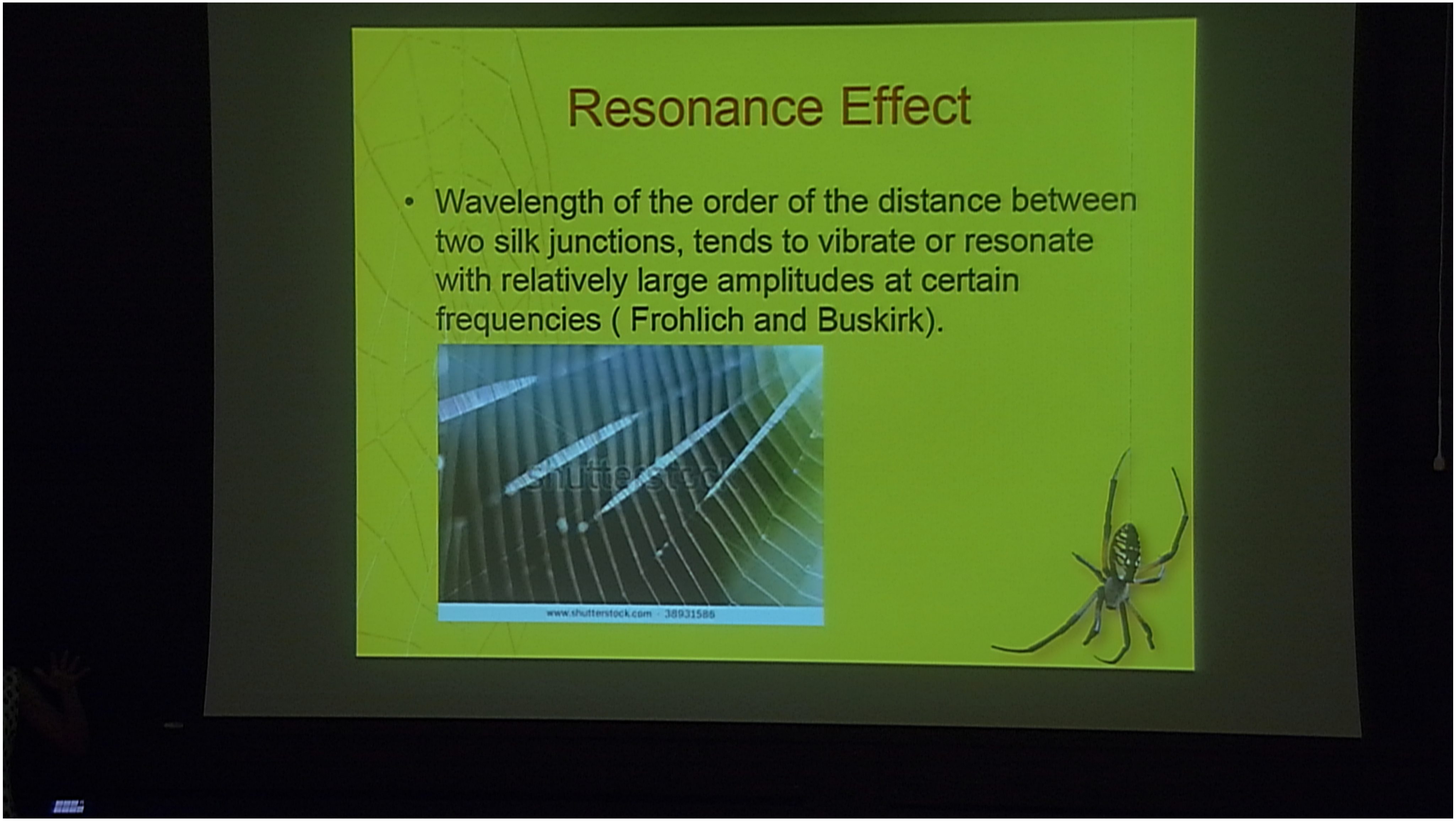

Three Kinds of Web Vibrations
Transverse vibrations
• In general, the velocity of transverse waves is around 800 m/s for medium spiders (1g) and 400 m/s for large spiders (3g).
Wavelength
Displacement
Direction of travel
Amplitude

Three Kinds of Web Vibrations

Transverse vibrations

- In general, the velocity of transverse waves is around 800 m/s for medium spiders (1g) and 400 m/s for large spiders (3g).




Resonance Effect
• Wavelength of the order of the distance between two silk junctions, tends to vibrate or resonate with relatively large amplitudes at certain frequencies (Frohlich and Buskirk).
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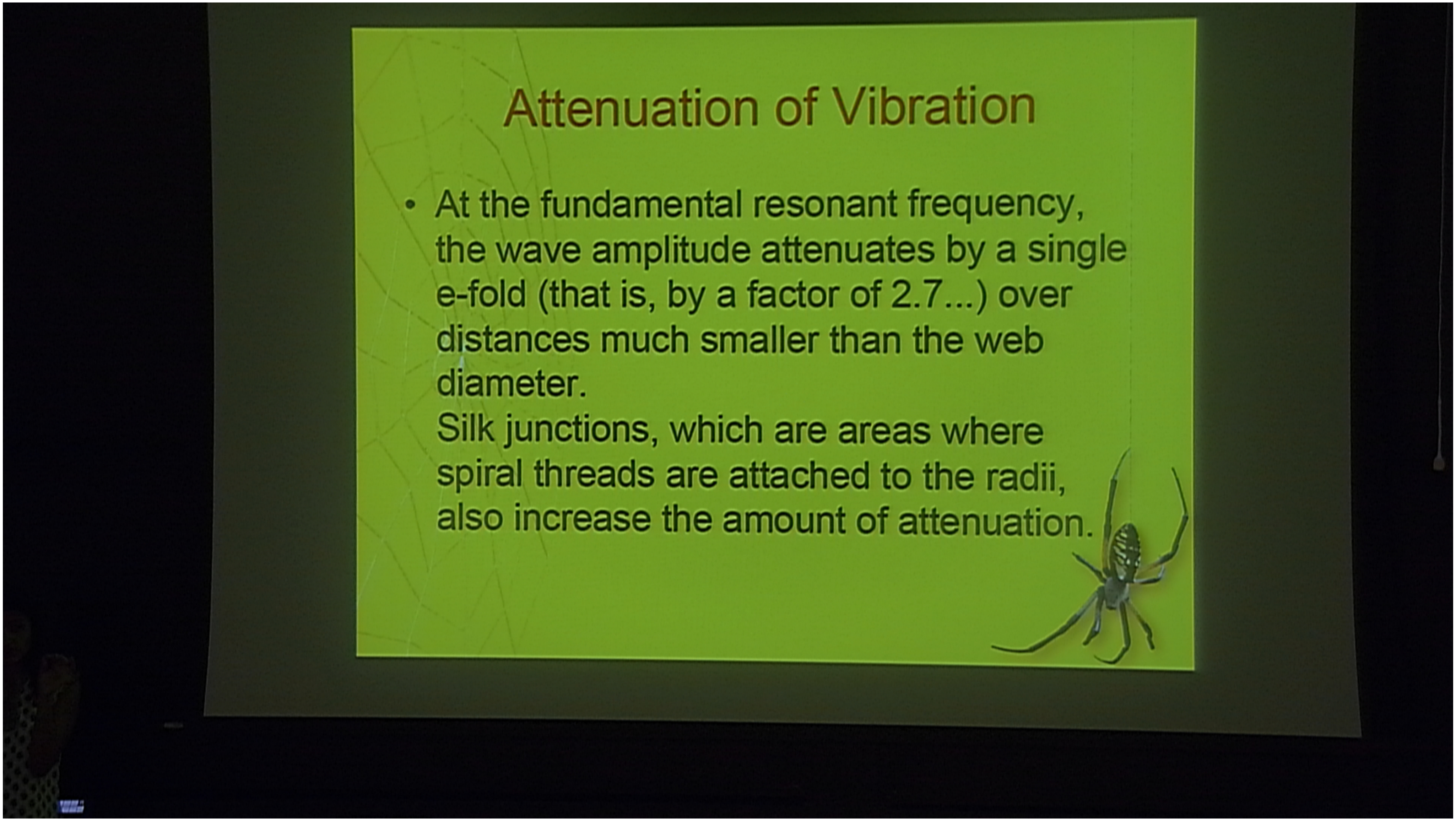

Attenuation of Vibration
• At the fundamental resonant frequency, the wave amplitude attenuates by a single e-fold (that is, by a factor of 2.7...) over distances much smaller than the web diameter.
Silk junctions, which are areas where spiral threads are attached to the radii, also increase the amount of attenuation.

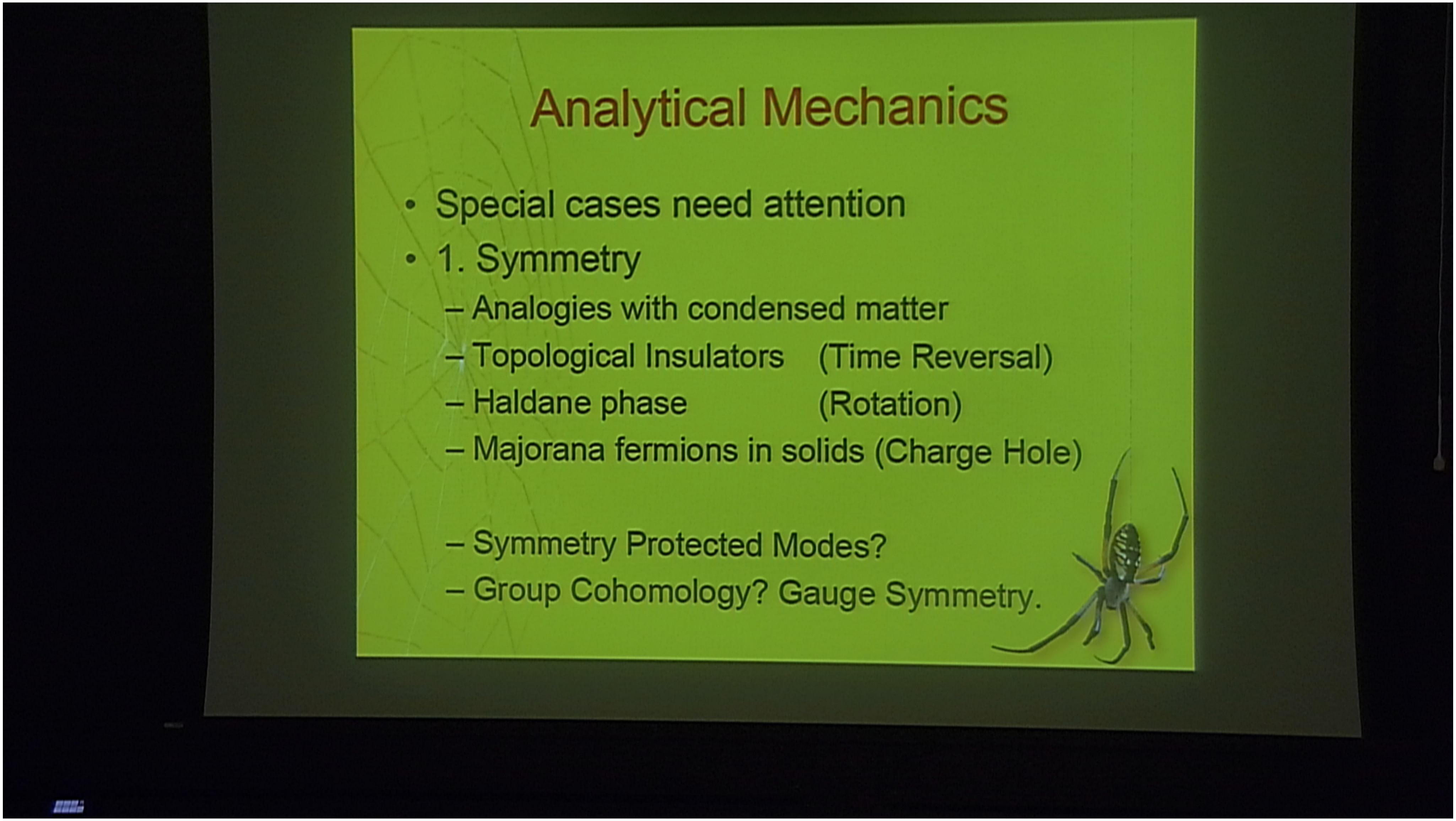
Analytical Mechanics

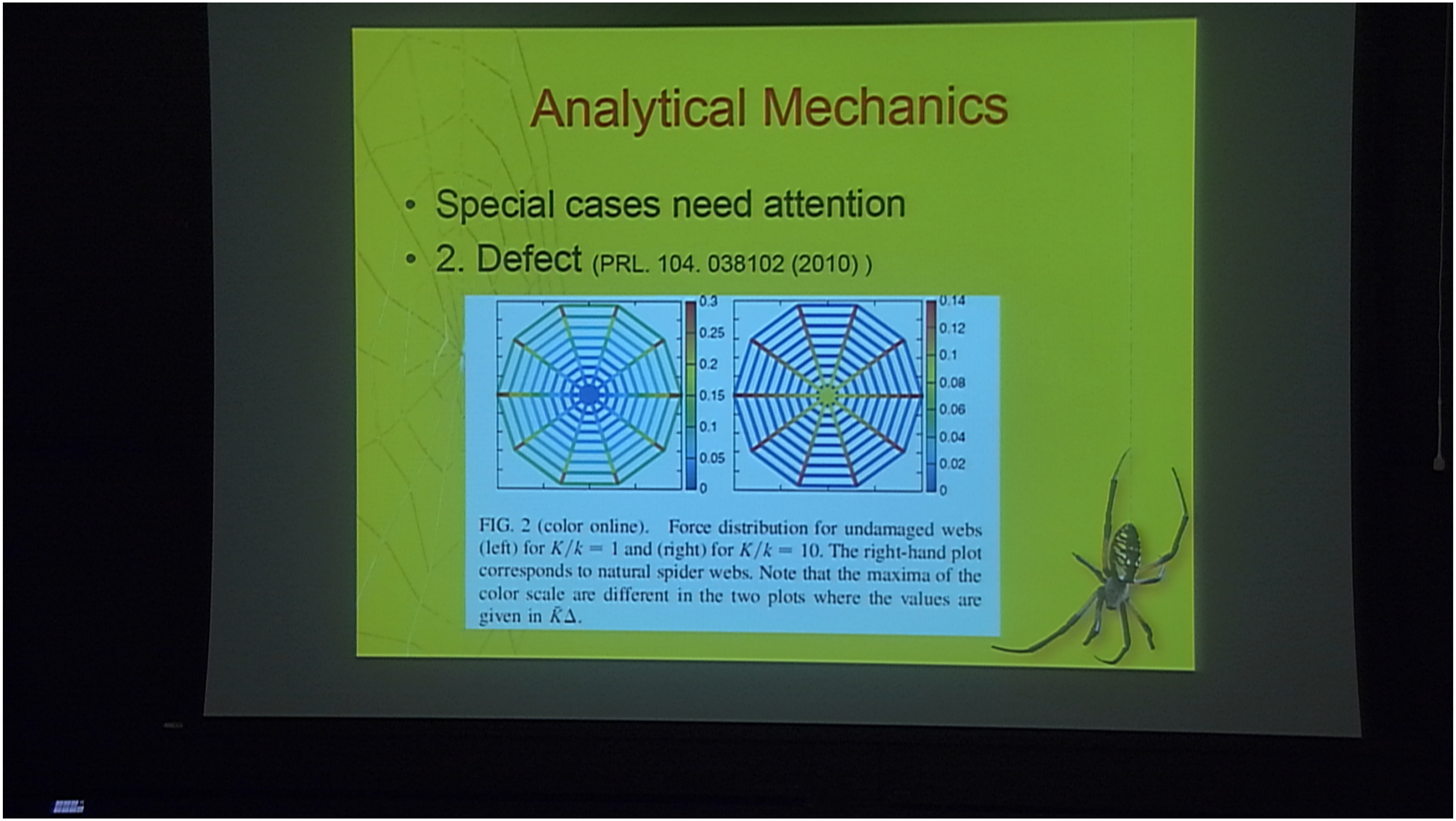
- Euler-Lagrange EQ ➔

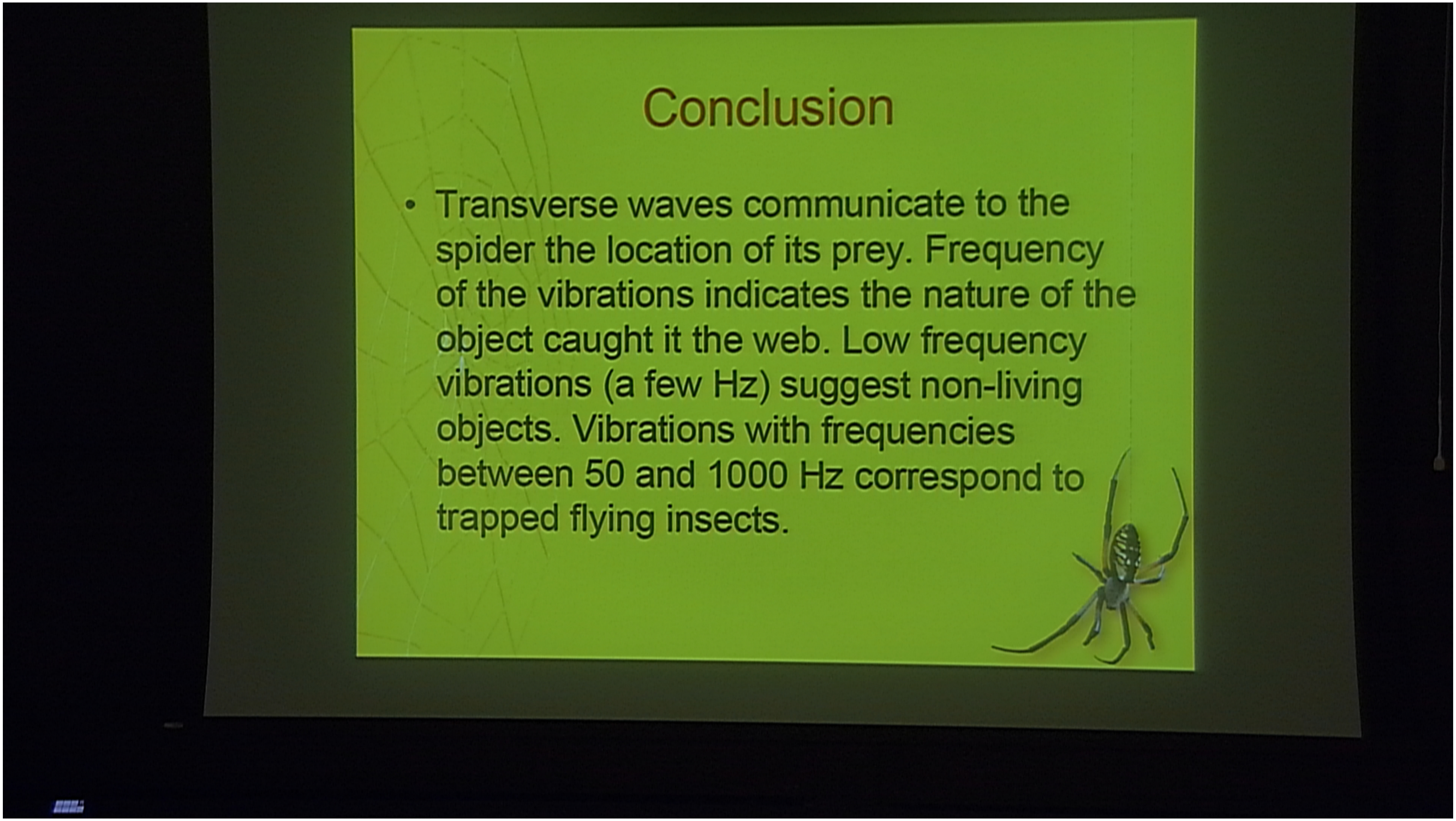
$$M_{ab}(\vec{x},\vec{y})\ddot{\phi}_b(\vec{y},t) + K_{ab}(\vec{x},\vec{y})\phi_b(\vec{y},t) = 0$$

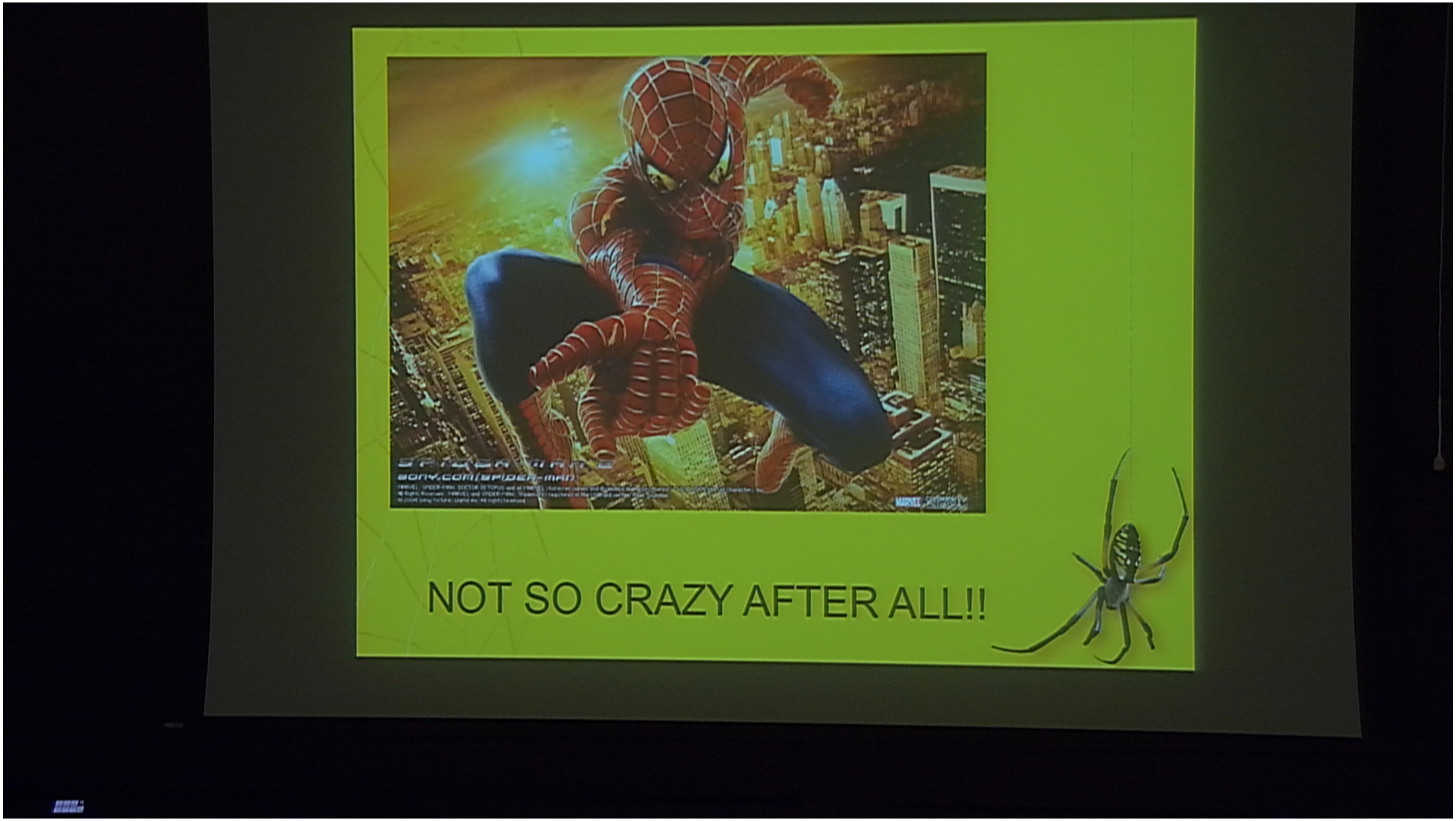
Quasi-Quantum Equation (Q.Q.)

- How to solve it analytically?
- Forget about it.
- Also Forget about Numerics


Analytical Mechanics
Special cases need attention
1. Symmetry
– Analogies with condensed matter
– Topological Insulators (Time Reversal)
– Haldane phase (Rotation)
– Majorana fermions in solids (Charge Hole)
– Symmetry Protected Modes?
– Group Cohomology? Gauge Symmetry.


Analytical Mechanics
• Special cases need attention
• 2. Defect (PRL. 104. 038102 (2010))
0.3
0.25
0.2
0.15
0.1
0.05
0
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
FIG. 2 (color online). Force distribution for undamaged webs (left) for $K/k = 1$ and (right) for $K/k = 10$. The right-hand plot corresponds to natural spider webs. Note that the maxima of the color scale are different in the two plots where the values are given in $\bar{K}\Delta$.


Conclusion
• Transverse waves communicate to the spider the location of its prey. Frequency of the vibrations indicates the nature of the object caught it the web. Low frequency vibrations (a few Hz) suggest non-living objects. Vibrations with frequencies between 50 and 1000 Hz correspond to trapped flying insects.


NOT SO CRAZY AFTER ALL!!