Title: Revisiting Scalar Collapase in AdS

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Abstract: TBA

# Revisiting Scalar Collapse in AdS

Perimeter Institute
Waterloo, Canada

Steve Liebling
*Collaborators**: Alex Buchel, Luis Lehner

Long Island University
New York, USA

*on sabbatical at*
Perimeter Institute
Waterloo, Canada

June 5, 2012

* very preliminary work...don't hold them responsible

# Previous work

- Bizoń & collaborators study the dynamics of a real scalar field in spherically symmetric AAdS [1104.3702]
    - Finds **any** initial scalar field eventually collapses to BH
    - Perturbation analysis reveals "weakly turbulent" instability
    - Finds same behavior in higher dimensions [1108.4539]

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  - Generically don't observe weak initial data forming a black hole
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  - Provide an example of a solution that bounces and ultimately forms a BH
- Pretorius & Choptuik study real scalar in 2+1 AAdS [gr-qc/0007008]
  - Asks: "will any distribution of energy that could conceivably form a black hole (i.e. with asymptotic mass $M > 0$) eventually do so if one waits long enough?"

# Motivation

- Reproduce Bizoń :
  - (Semi-)Independent confirmation of main result
  - Understand what this behavior looks like
  - Understand what numerical "tricks" it takes to make stable and convergent
  - Understand where AMR is required
  - Consider other initial data
  - Look at effects of changing dimension of the bulk
  - Extract boundary information
- Extend to complex scalar field
  - Conserved global $U(1)$ charge...any interesting dynamics?
  - Presence of *boson star solutions*:
    - Correspond to stationary state of boundary CFT
    - Alternative "path"...instead of thermalizing to a (large) BH
    - Late-time dynamics in boundary extraction...oscillating quantum operators
- Step towards future work

# The Model

- Spherically symmetric form of metric in dimension $d$ and $\ell^2 = -d\,(d-1)\,/\,(2\Lambda)$:

$$ds^2 = \frac{\ell^2}{\cos^2 x}\left[-Ae^{-2\delta}dt^2 + A^{-1}dx^2 + \left(\sin^2 x\right)\, d\Omega^2_{d-1}\right]$$

- Complex scalar field Klein-Gordon Equations ($i = 1, 2$):

$$\dot{\Phi}_i = \left(Ae^{-\delta}\Pi_i\right)' \quad \dot{\Pi}_i = \frac{1}{\tan^{d-1} x}\left(\tan^{d-1} x\; Ae^{-\delta}\Phi_i\right)' \quad \dot{\phi}_i = Ae^{-\delta}\Pi_i$$

- Metric component equations $\tan x \equiv r$:

$$A' = \frac{d-2+2\sin^2 x}{\sin x \cos x}\,(1-A) - \sin x \cos x\; A\left(\Phi_i^2 + \Pi_i^2\right)$$

$$\delta' = -\sin x \cos x\left(\Phi_i^2 + \Pi_i^2\right)$$

## *Modified Choptuik's* ad *1D AMR infrastructure:*

| | Original: | Modified to: |
|---|---|---|
| Evolution Scheme: | Iterative CN | RK3 MOL |
| AMR Boundary Treatment | Linear Interp. in time | Linear taper |
| Spatial Accuracy | Second Order | High-order |

# Boundary conditions: Origin

Enforcement of boundary conditions at origin:

$$\phi_i(t,x) = f_0(t) \quad \Pi_i(t,x) = g_0(t) \quad \Phi_i(t,x) = 0$$

$$A(t,x) = 1 \quad \delta(t,x) = \delta_0(t)$$

- Set $\phi_i(t,0)$ and $\Pi_i(t,0)$ via a quadratic fit using second and third points
- Set $\Phi_i(t,0) = 0$ and set first interior point via linear interpolation with first and third values
- Set $A(t,0) = 1$ and integrate outward
- No condition on $\delta$...integrate inwards

*...standard practice for s.s. codes*

# Boundary conditions: Outer Boundary

Enforcement of boundary conditions at outer boundary $\rho \equiv \frac{\pi}{2} - x$:

$$\phi_i(t,x) = f_d(t)\rho^d \quad \Pi_i(t,x) = g_d(t)\rho^d \quad \Phi_i(t,x) = h_d(t)\rho^{d-1}$$

$$A(t,x) = 1 - M\rho^d \quad \delta(t,x) = 0$$

set:

- Set $\phi_i(t,\rho=0) = 0$ and $\Pi_i(t,\rho=0) = 0 = \Phi_i(t,\rho=0)$
- Set $A(t,\rho=0) = 1$ though not necessary (integration outwards satisfies this)
- Set $\delta(t,\rho=0) = 0$ so that coordinate time $t$ is proper time on boundary
- Additionally: do power-law fit to first and second interior points from outer boundary using third interior point value *...just fitting one point not stable for $d > 3$*

# *Extracting Boundary Info*

- Usual practice: *extract boundary stress-energy tensor*
- Boundary stress-tensor is just $M$, the mass enclosed in the spacetime
- Asymptotic behavior of scalar field corresponds to CFT operator
- Use a least-squares, polynomial fit to outermost $n$-points

The Dynamics: Tests & How do things behave?

## *Surprised or not?*

The view from the **bulk**:

- If one starts with "small" pulse, it won't compress enough enough to form BH
- Then AAdS reflects the outgoing pulse back, don't see any (obvious) reason why it should compress anymore after any number of reflections
- In any case, Minkowski and dS are linearly stable...seems natural
- **Surprised!**

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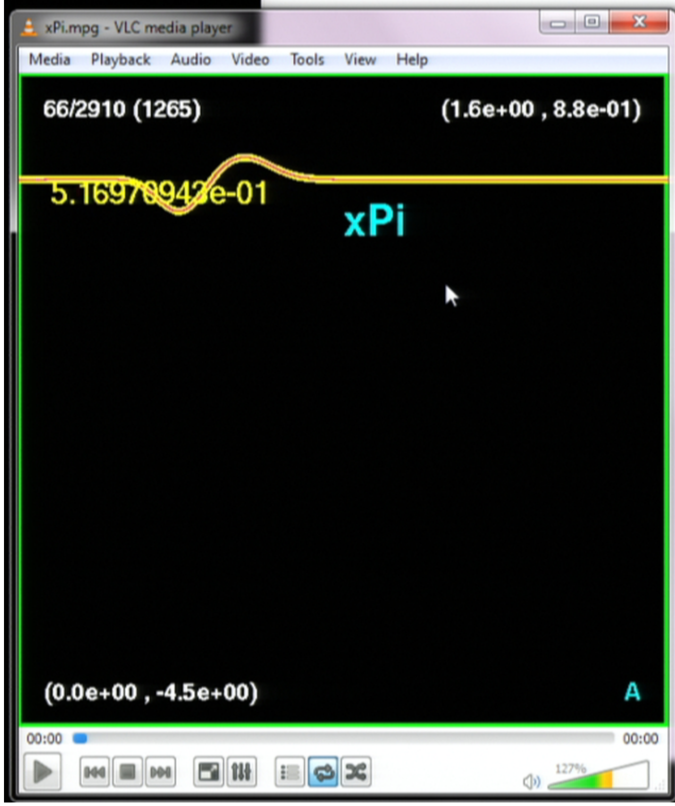
The view from the **boundary**:

- Everything needs to thermalize and so any initial energy should eventually settle into a black hole
- **Not surprised!**...*it had to be this way*

*What do things look like?*

show movie of bouncing scalar field, ultimately forming a BH

# *What do things look like?*

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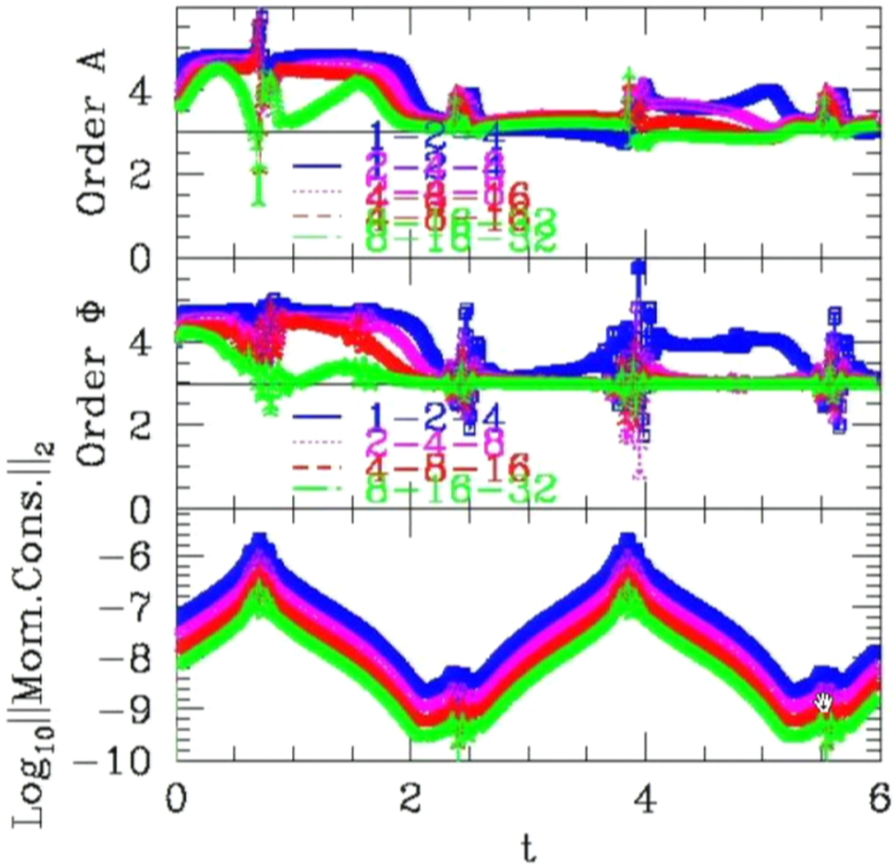
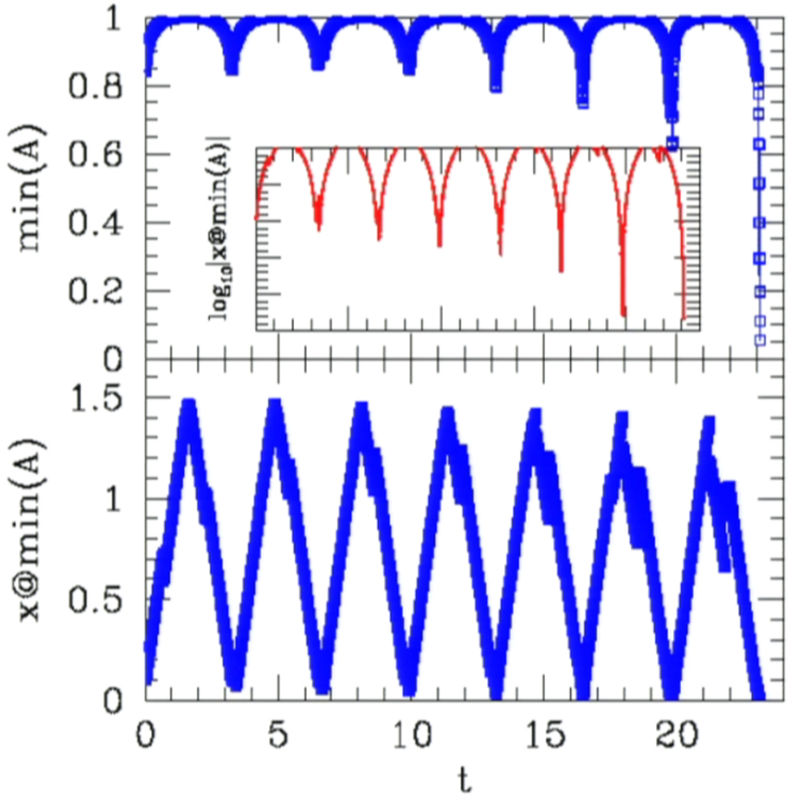
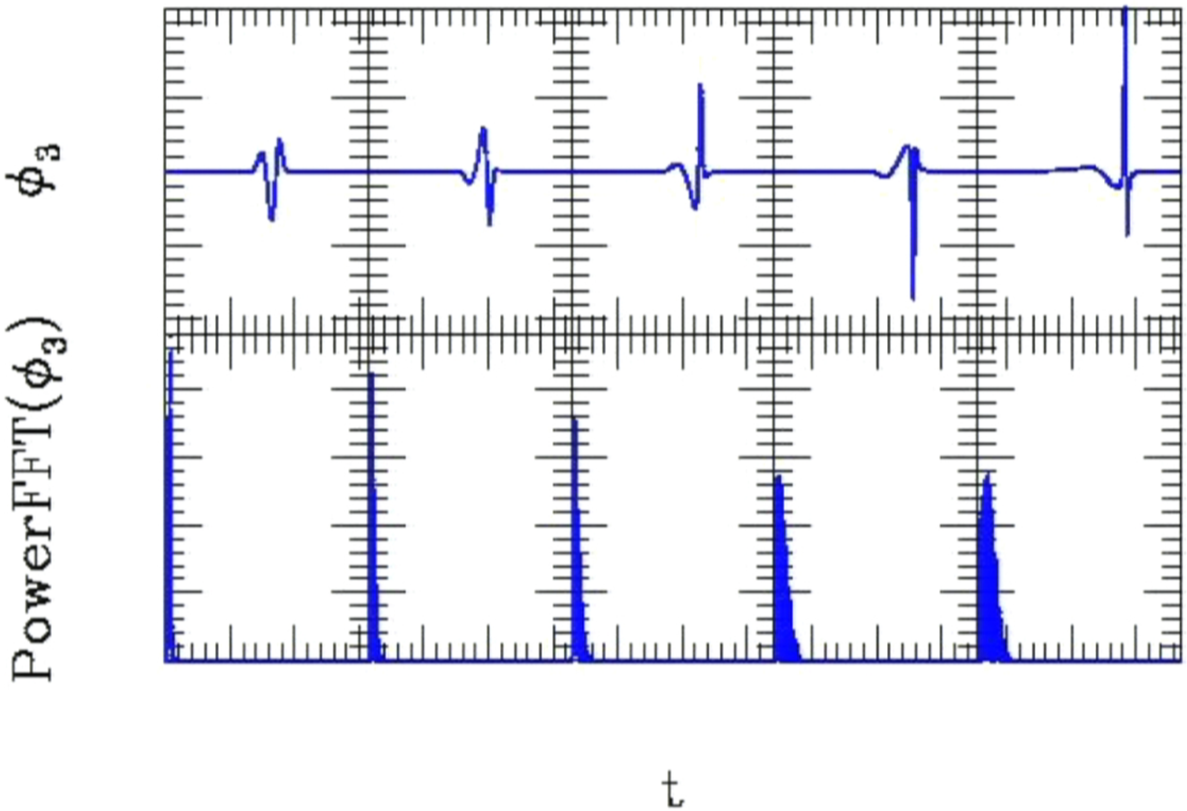
## Do things converge through the bounces?...*yes*



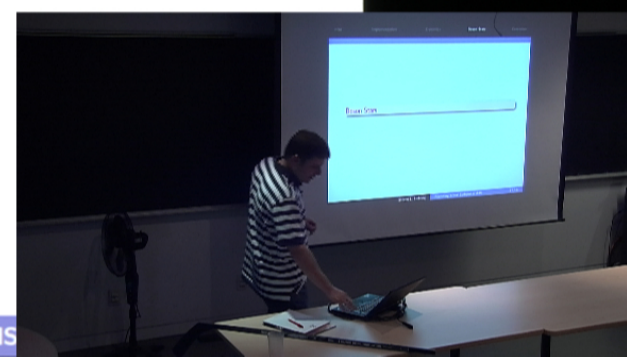
## *What's happening to the metric?*




## *What's compressing the pulse?*



# Boson Stars



# Boson Stars

- Search for stationary, gravitating soliton-like solutions w/ ansatz:

$$\phi(r,t) = \phi_0(r)e^{i\omega t}$$

- Usually include $V(\phi) = m^2|\phi|^2$ term for massive field (required in 3D asymp. Minkowski??) as in `[Astefanesei/Radu,gr-qc/0309131]`

  *...interestingly* `[Dias/Santos/Horowitz:1105.4167]` *considers rotating boson stars in AdS with no mass term*

- Here, no such potential term, still find solutions

# *Boson Stars*

- Read stationary solutions into code...inherent numerical noise serves as perturbation
- Apparently stable for $t < 30\pi$
- **Question:** can they truly be stable?
- **Expectation:**
  - any perturbation "lives" forever and so to settle down, the solution must either collapse or form more massive BS
  - In language of `[Dias/Horowitz/Santos 1109.1825]`: any perturbation allows the mass to explore all possibilities (with same mass and charge)

show movie of metric function for boson star

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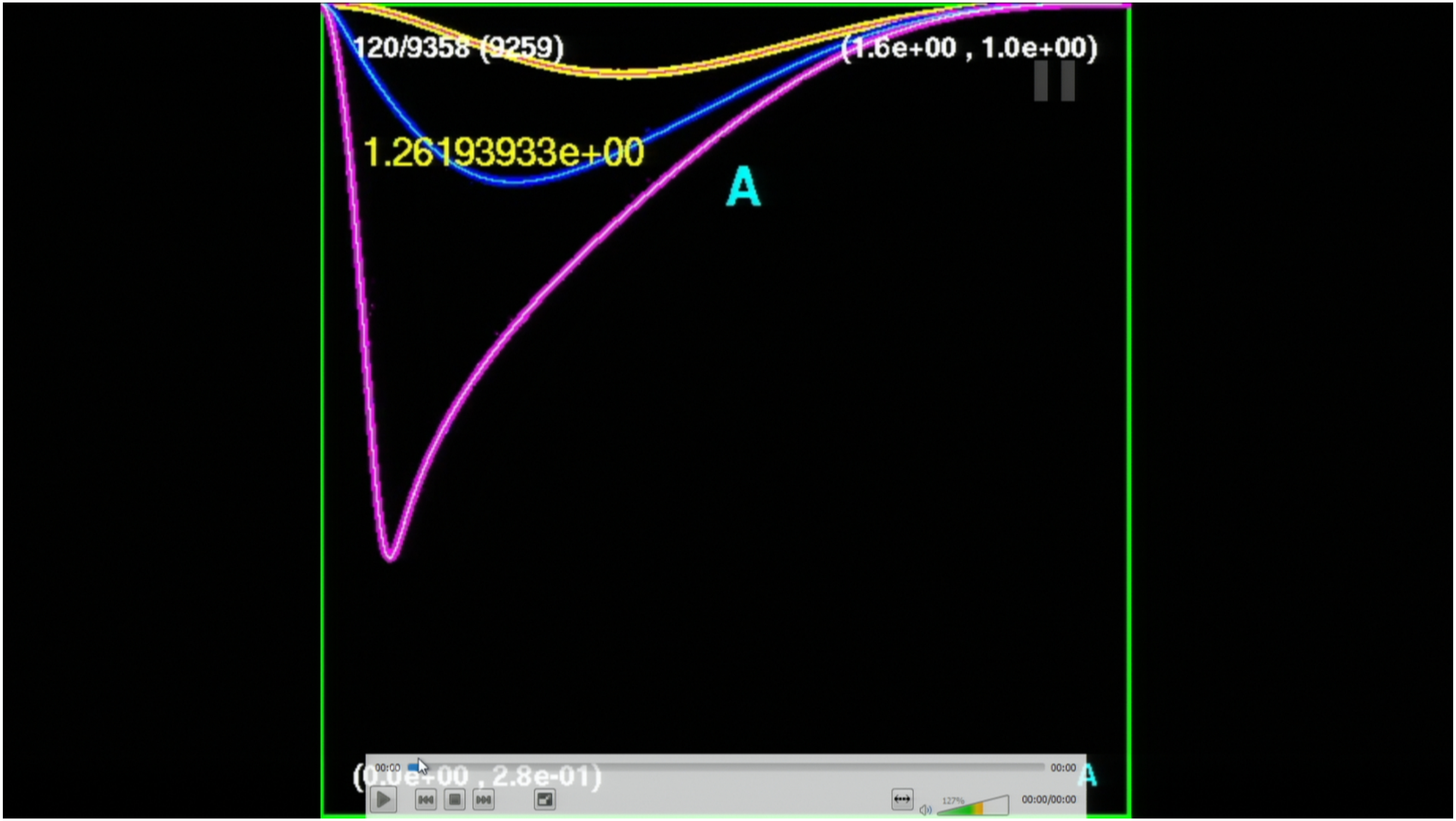
120/9358 (9259)
(1.6e+00 , 1.0e+00)
1.26193933e+00
A
(0.0e+00 , 2.8e-01)
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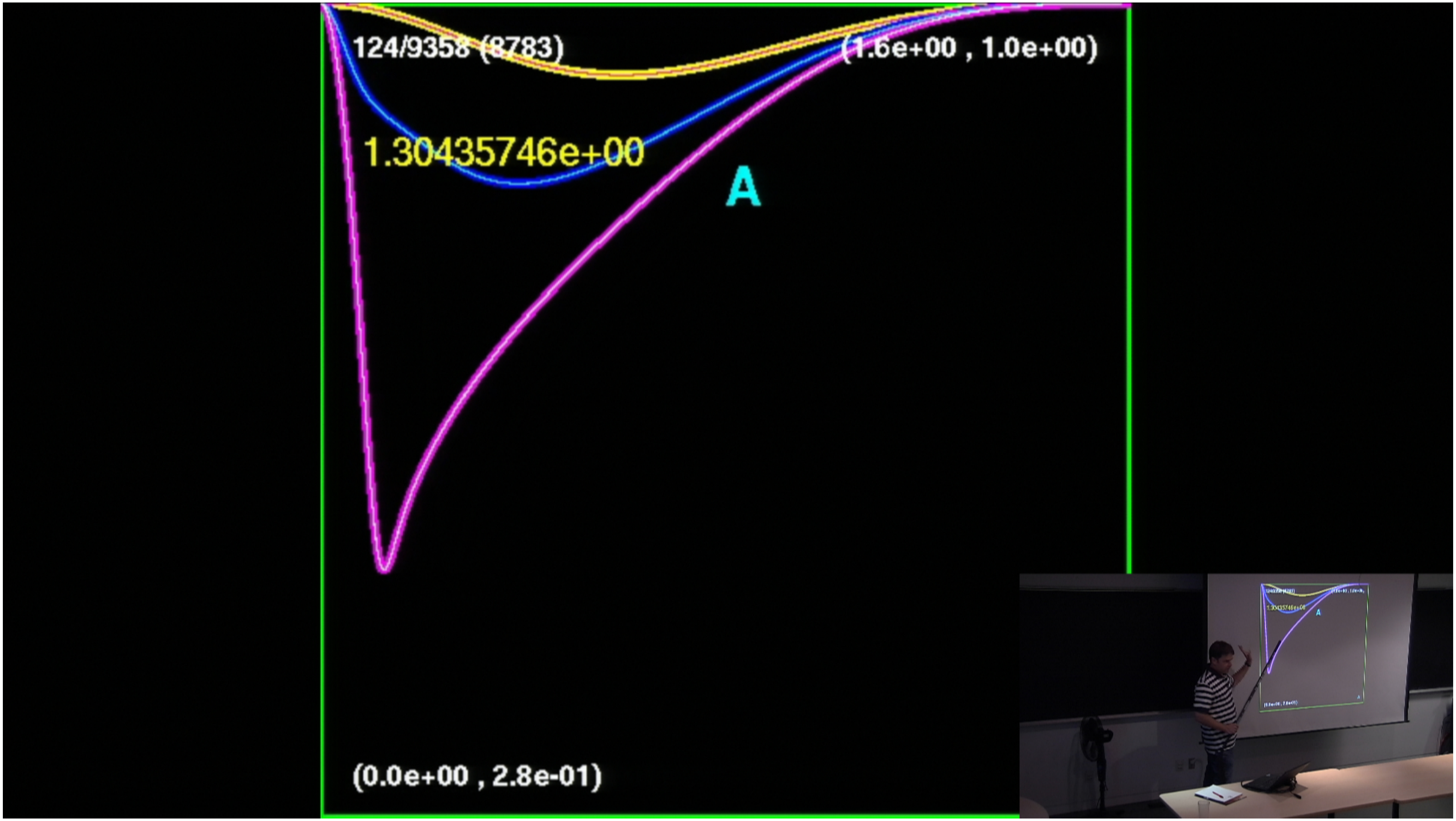
124/9358 (8783)
(1.6e+00 , 1.0e+00)
1.30435746e+00
A
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# *Conclusion*

- Single scalar field:
  - Bizoń 's work **reproducible**
  - Can achieve stable and **convergent**, higher order solutions (even through bounce)
- Complex scalar field:
  - Additional conserved, quantity...charge
  - "Massless" boson stars exist and appear "stable" in the linear sense
  - Nonlinear stability of boson stars...still investigating