Title: Renormalization Group Flow

Date: Sep 08, 2007 12:00 PM

URL: http://pirsa.org/07090014

Abstract: ABSTRACT: The asymptotic freedom conjecture for gravitation is explored in which strong renormalization effects (as in QCD) may occur at astrophysical distance scales larger than the solar system.
Nonperturbative renormalization group trajectories exhibiting such an infrared fixed point describe a theory of gravitation with a running gravitational coupling which grows at large distance. The concept that this extra gravity may provide the answer to the missing mass inherent in the dark matter paradigm is a natural suggestion. We provide the alternative of Modified Gravity to answer the problem of galaxy rotation curves from the smallest dwarf galaxies to the largest giant galaxies and to galaxy clusters including the Bullet Cluster.
The theory may also explain the apparent anomalous deceleration of the Pioneer 10 and 11 space probes, within solar system constraints.

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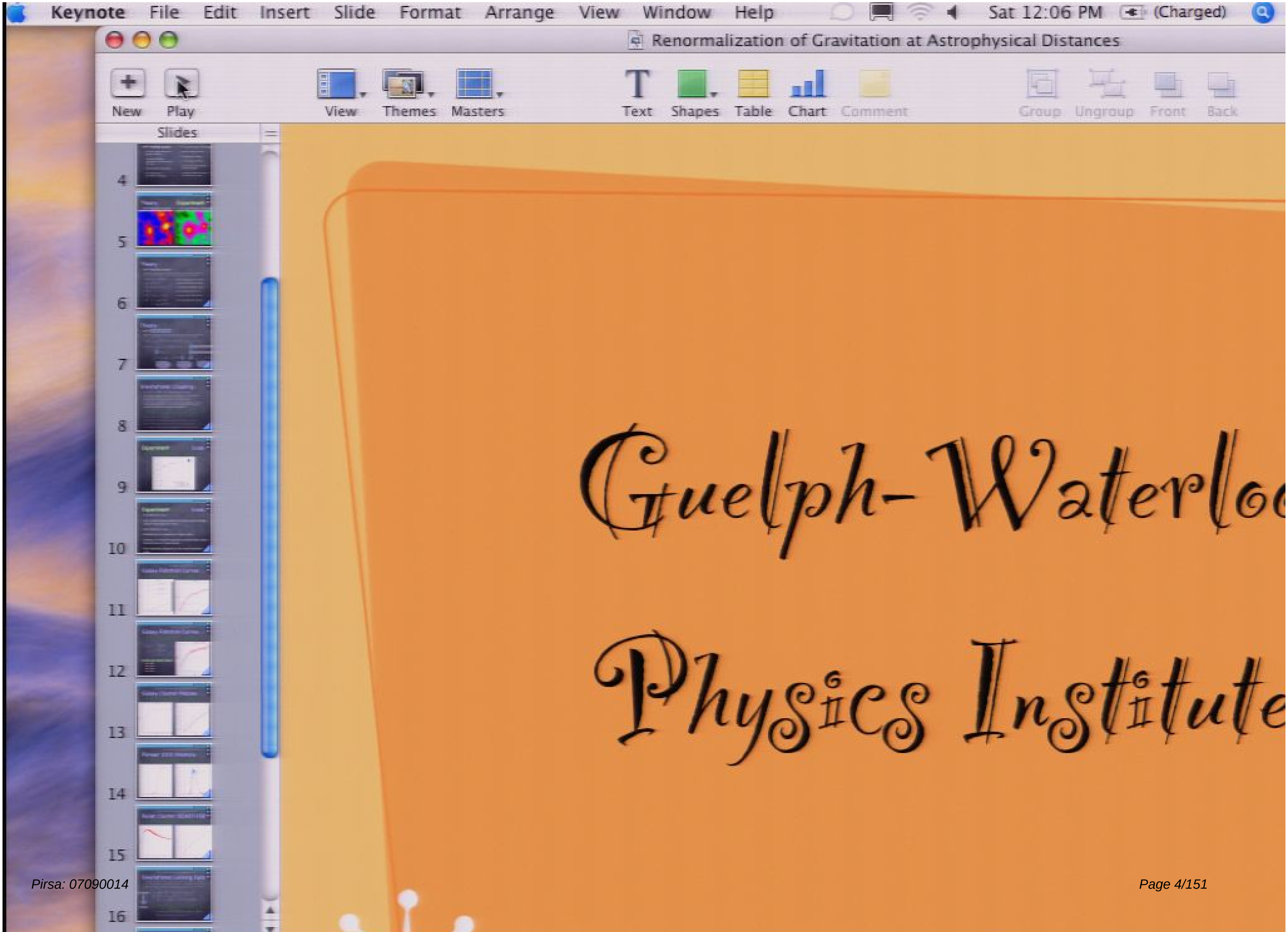
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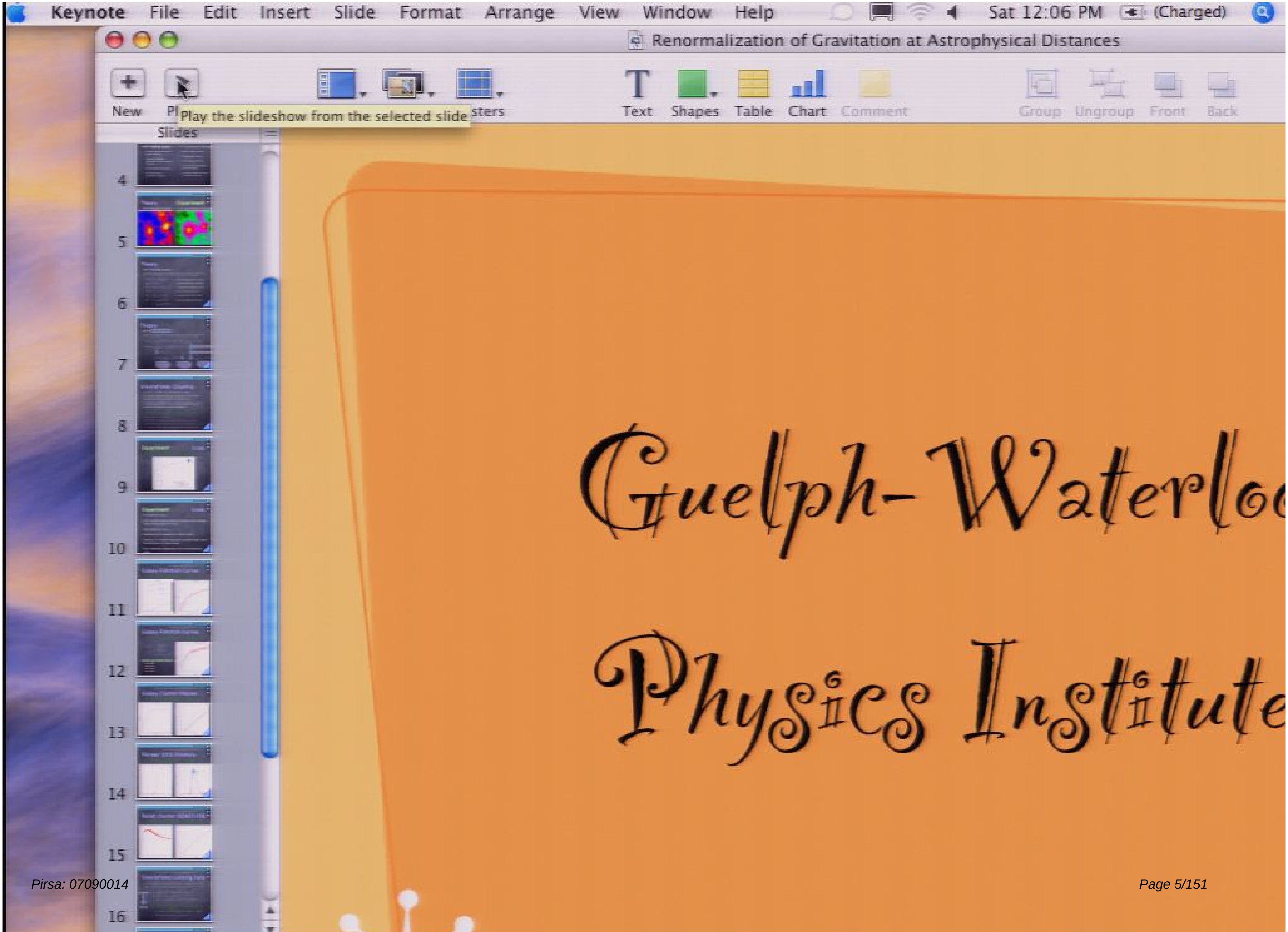
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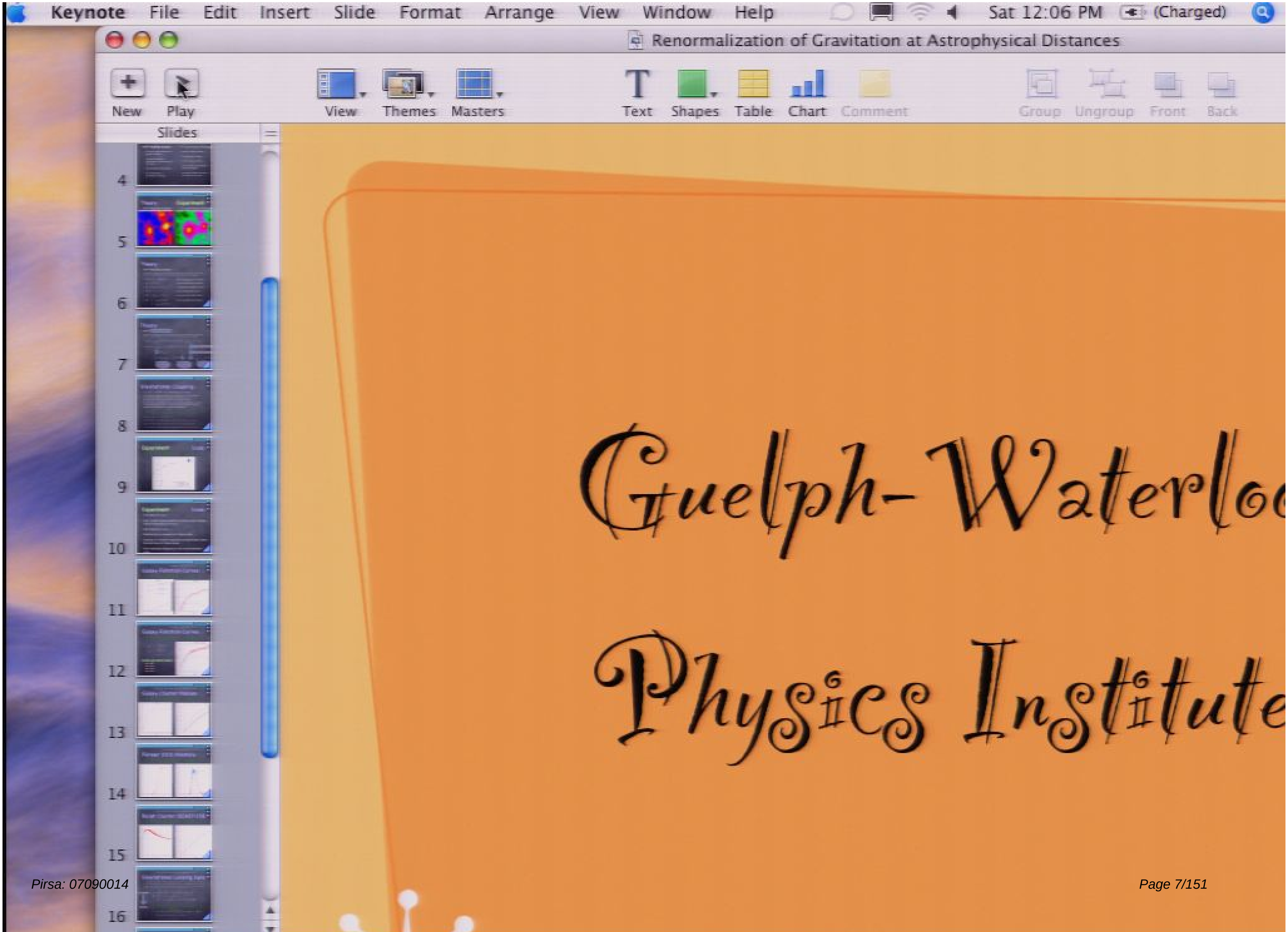
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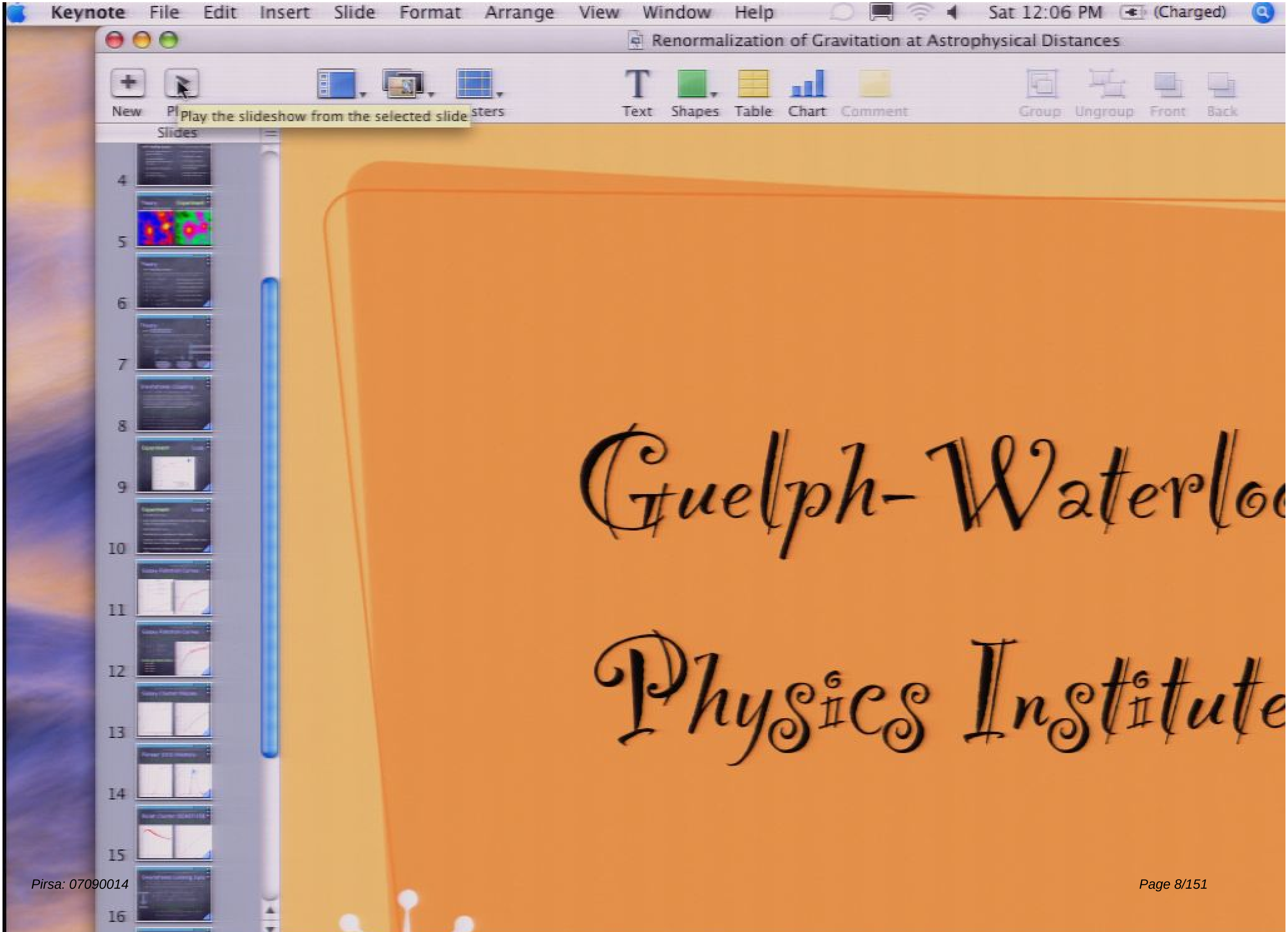
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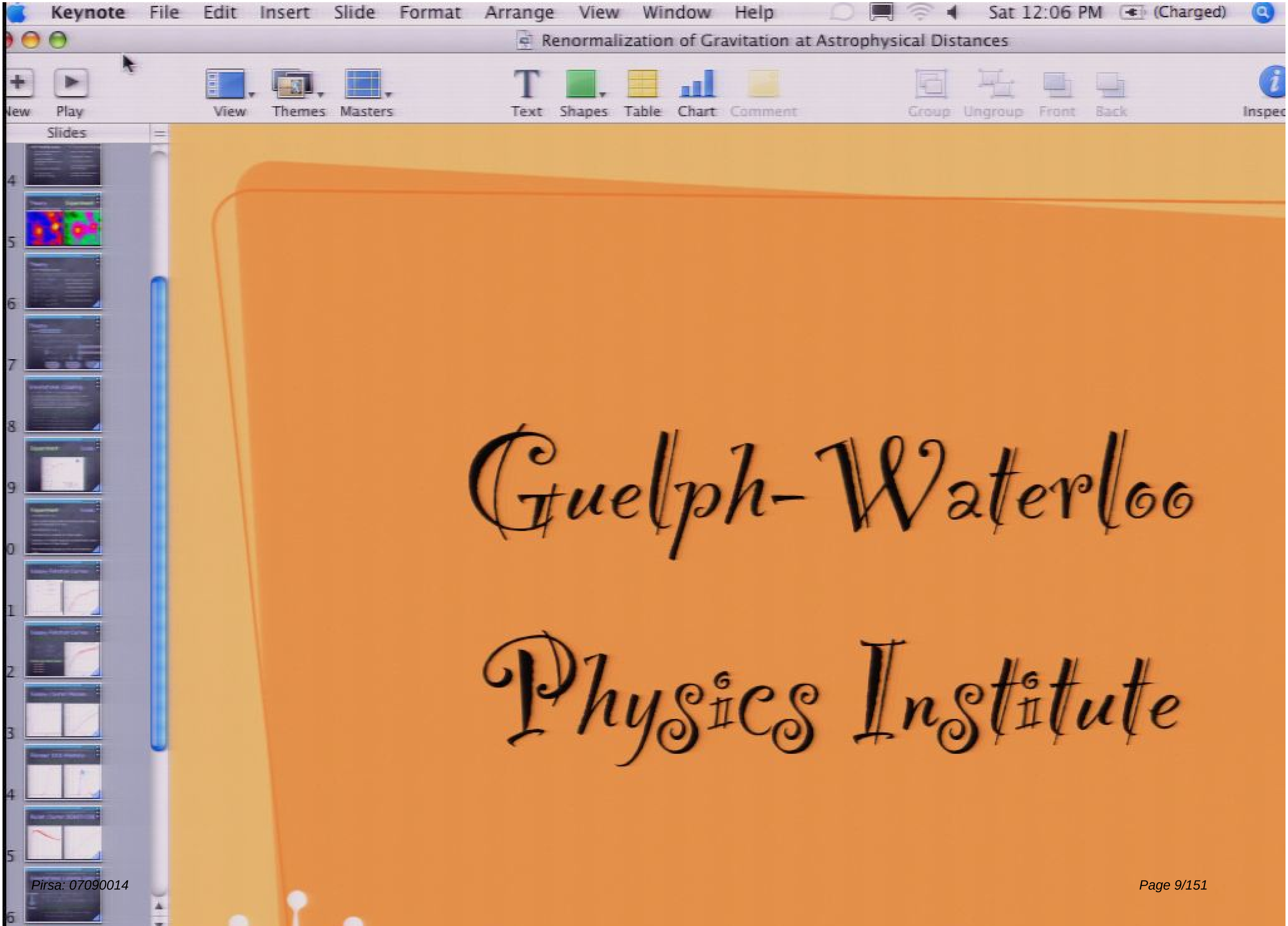
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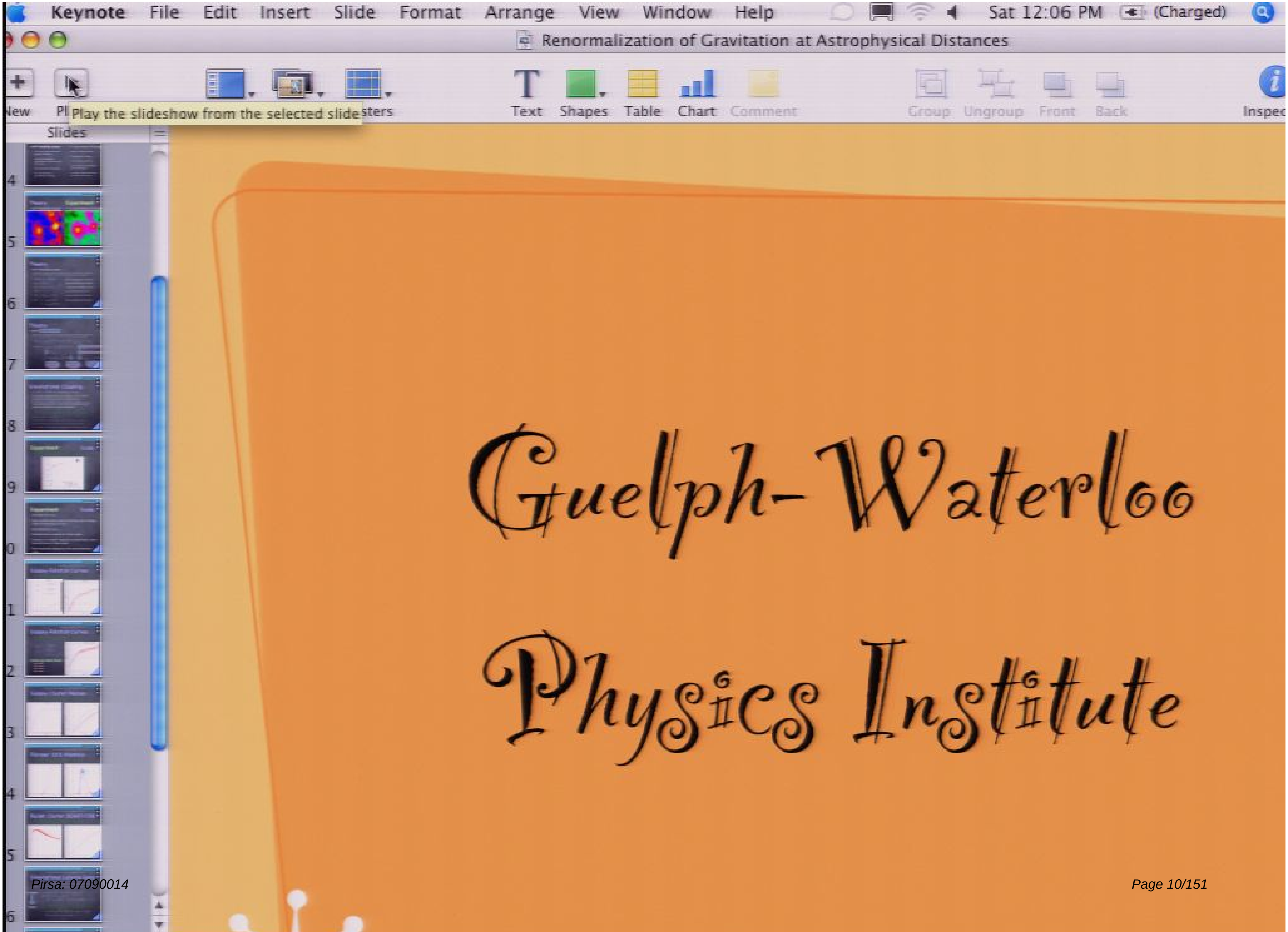
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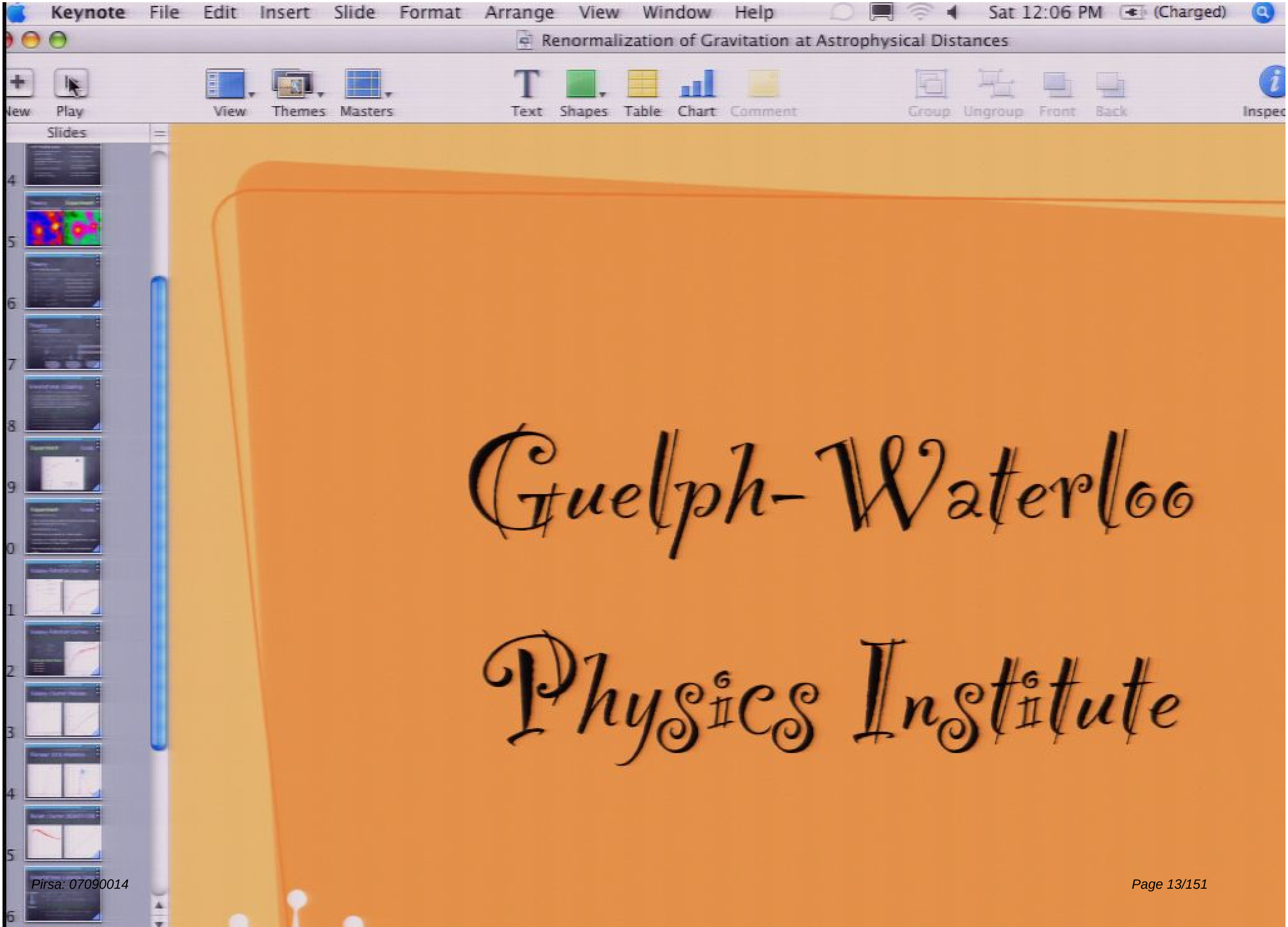
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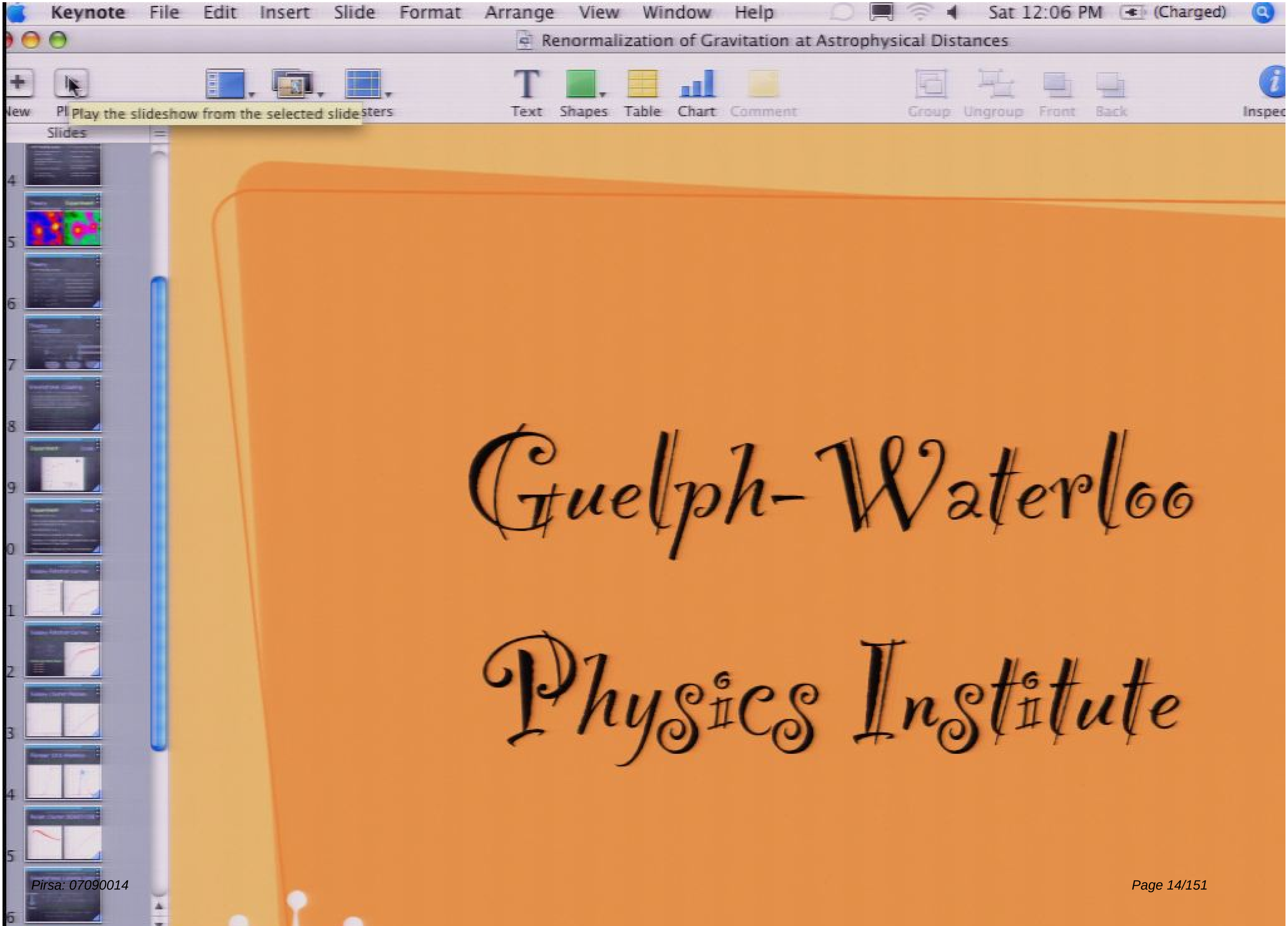
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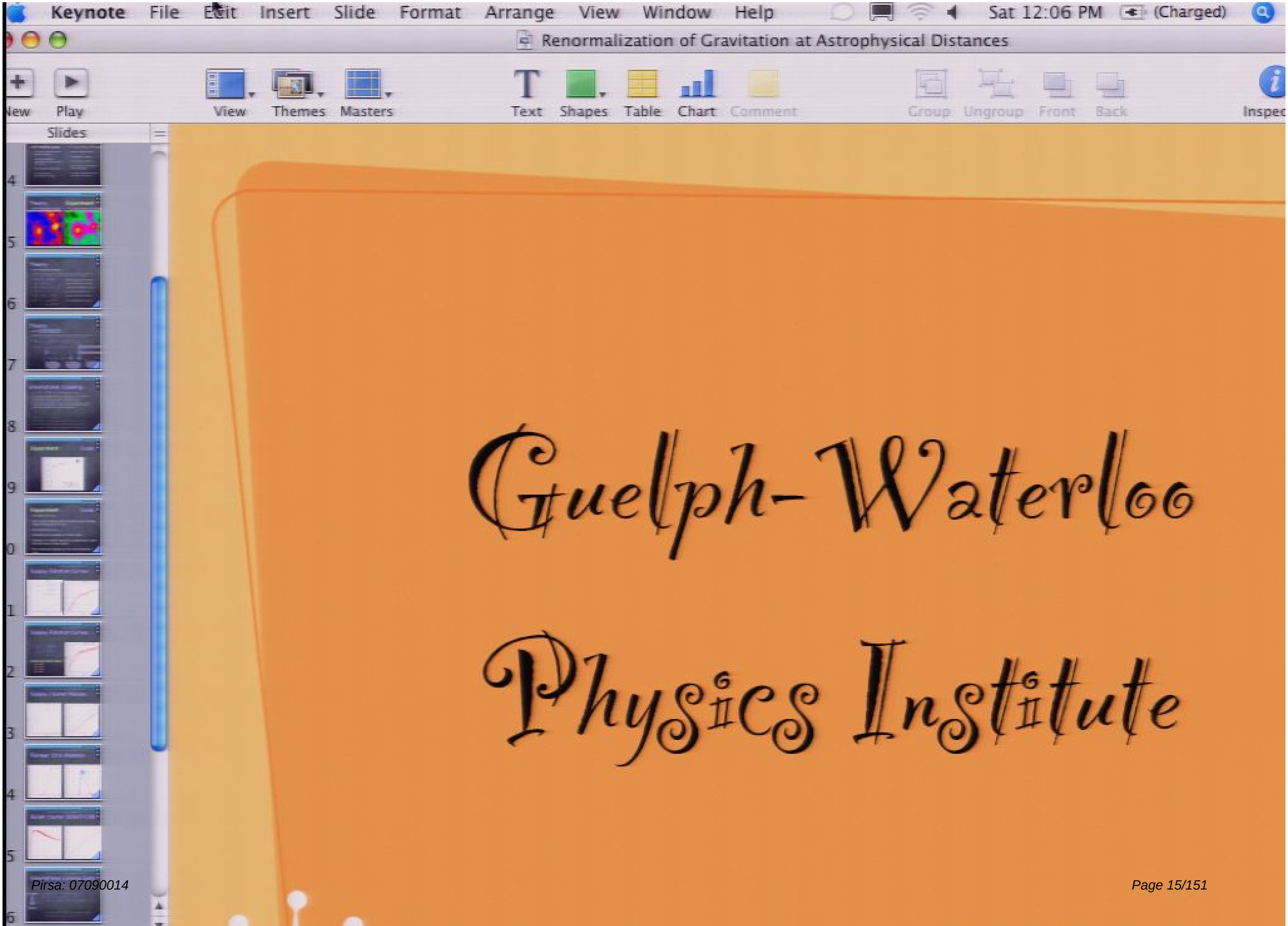
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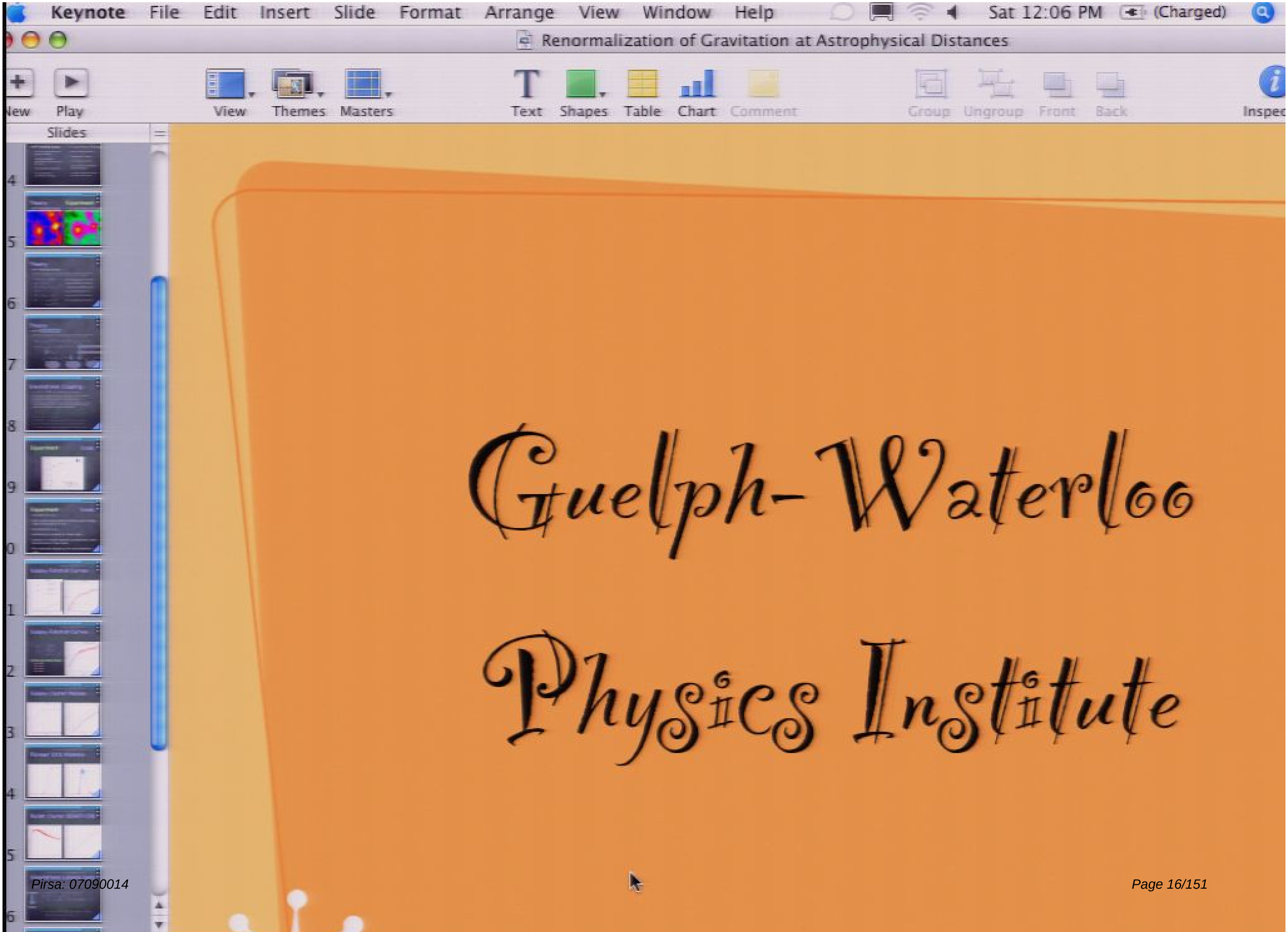
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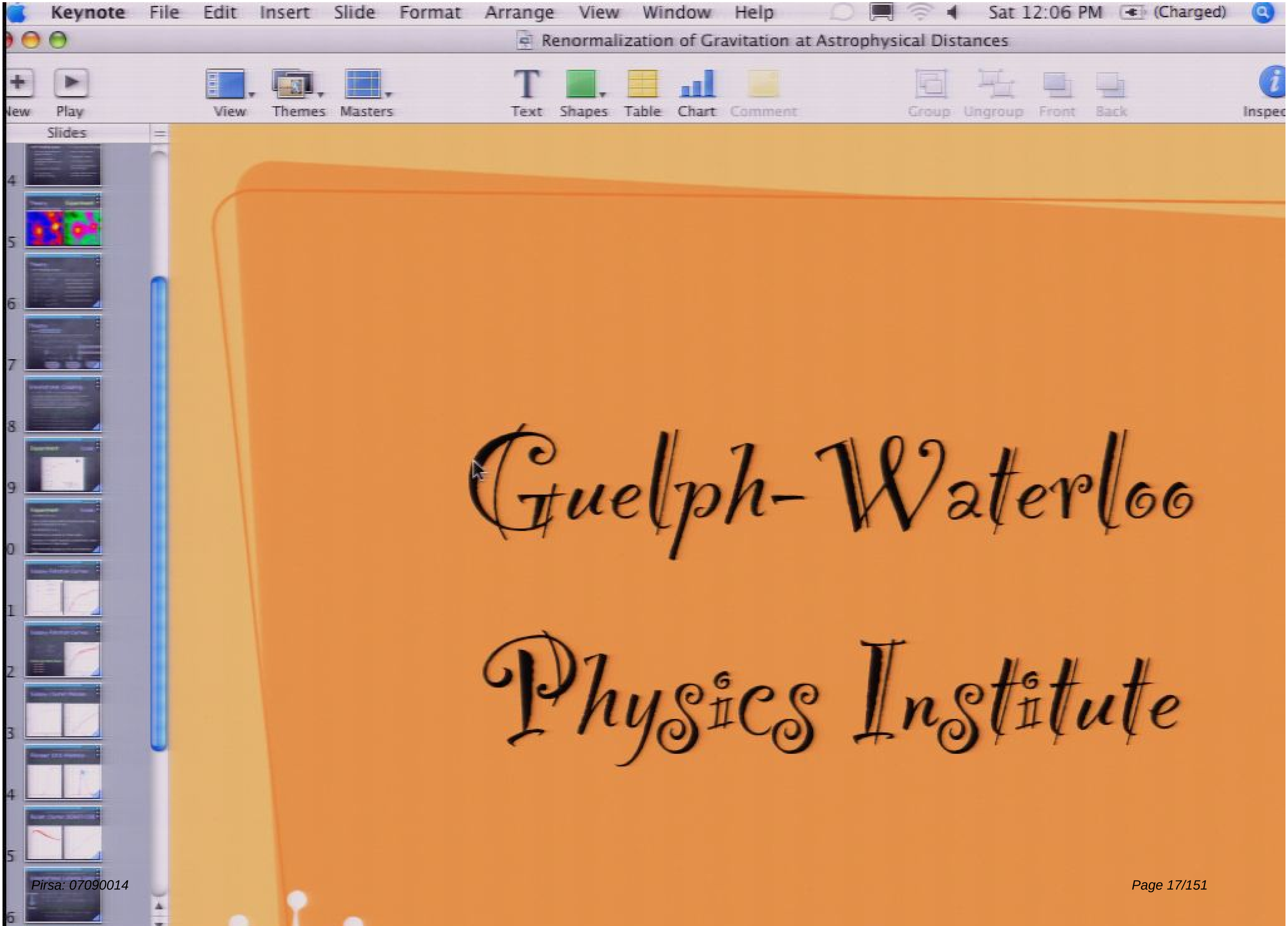
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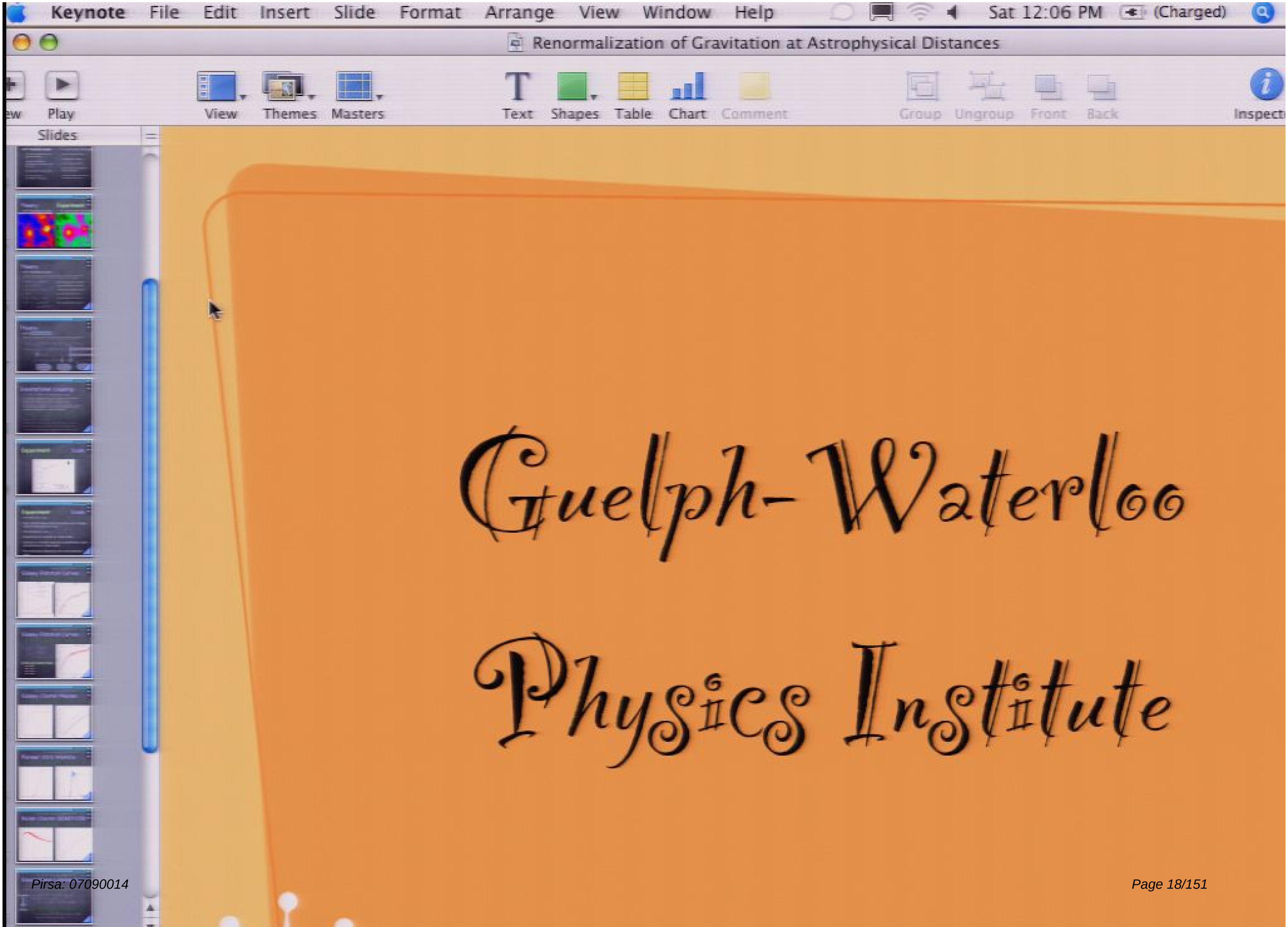
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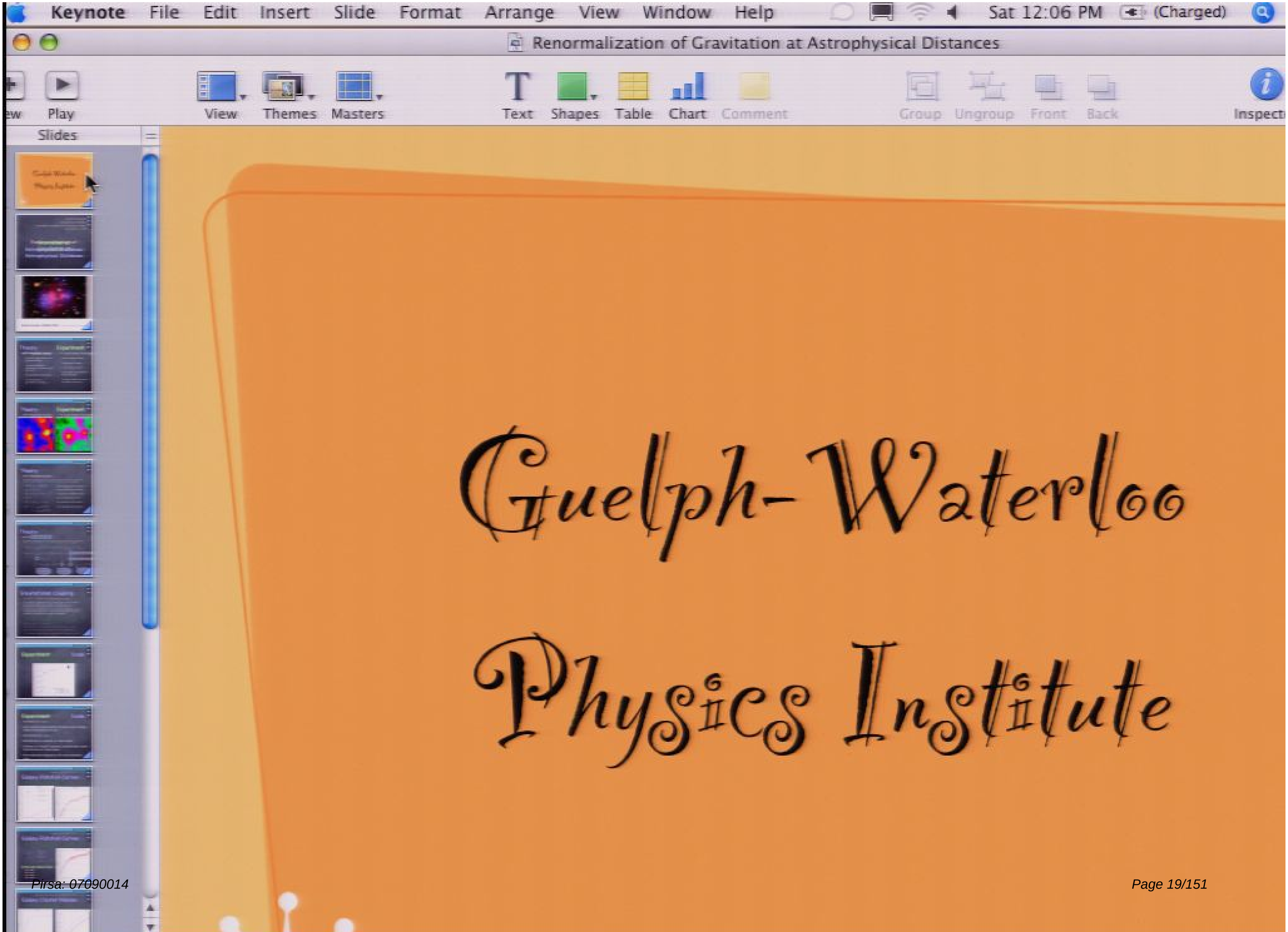
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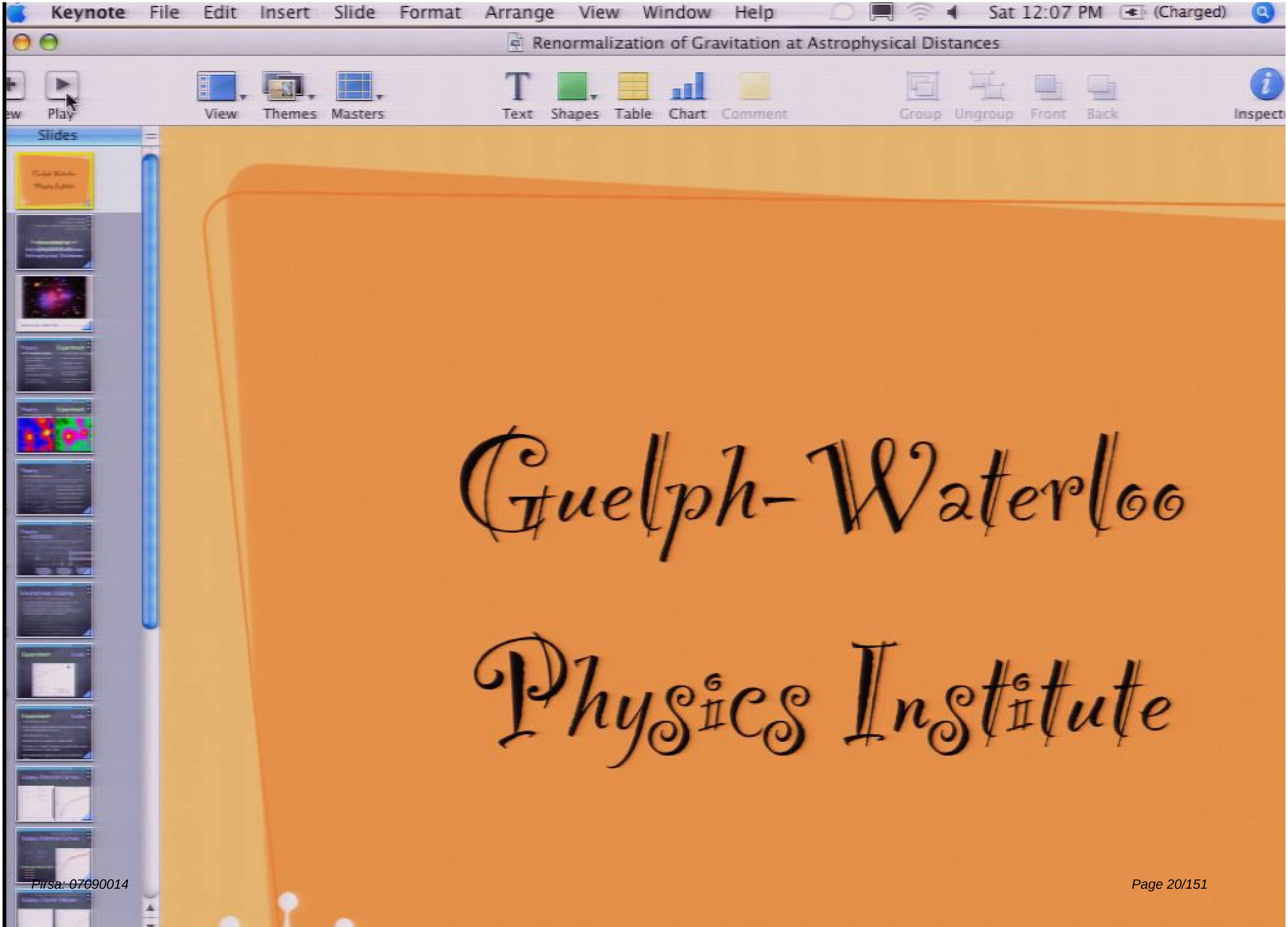
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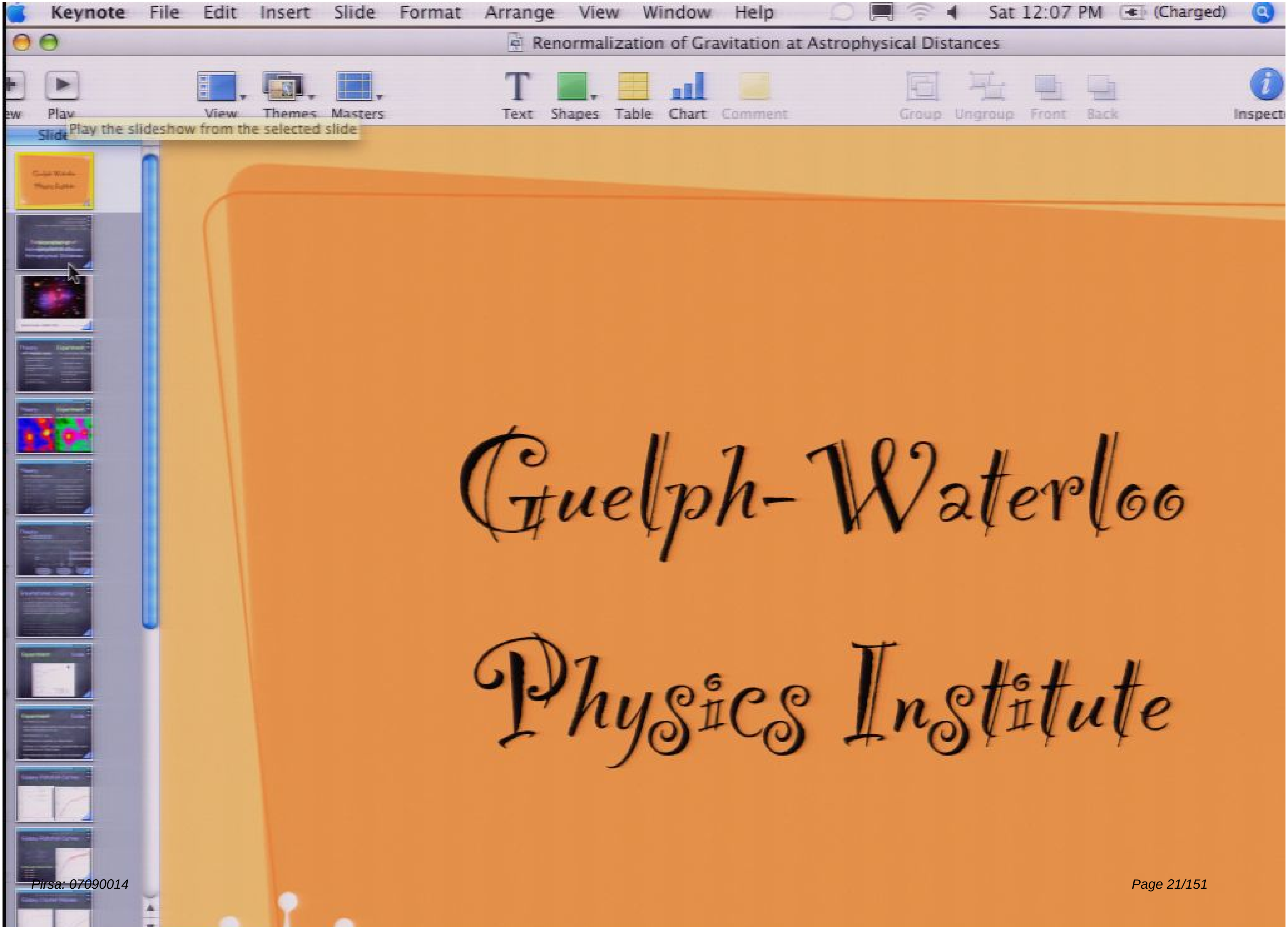
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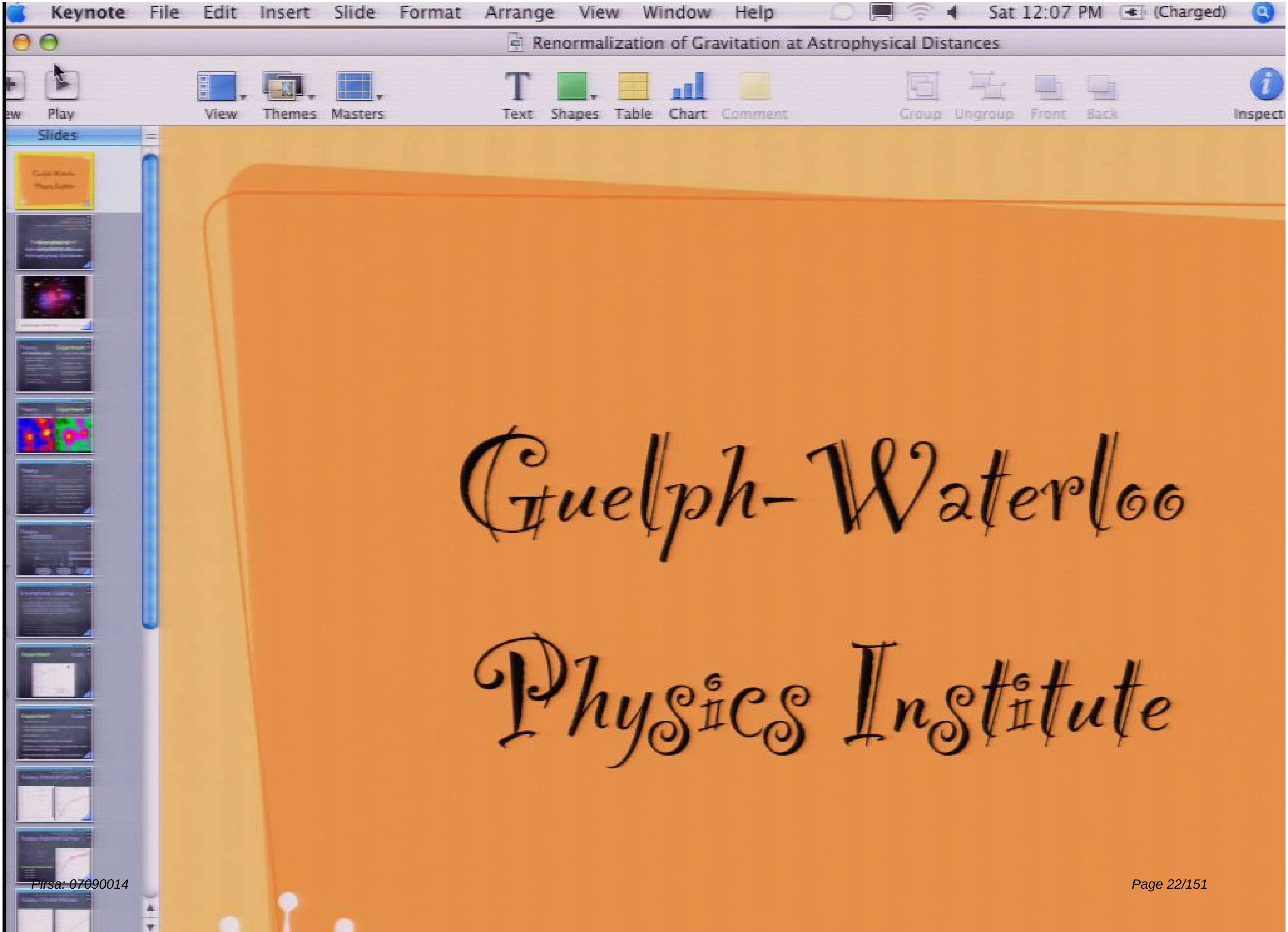
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Joel R. Brownstein
University of Waterloo
Perimeter Institute for Theoretical Physics
September 7, 2007.

Gravitation at Astrophysical Distances

Joel R. Brownstein
University of Waterloo
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September 7, 2007.

Renormalization of Gravitation at Astrophysical Distances

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University of Waterloo
Perimeter Institute for Theoretical Physics
September 7, 2007.

Renormalization of Gravitation at Astrophysical Distances

Bullet Cluster 1E0657-558

http://chandra.harvard.edu

Theory

Experiment

Theory

- NGT ↘ Modified Gravity

Experiment

Theory

- NGT ➘ <u>Modified Gravity</u>
  - relativistic generalization of general relativity
  - weak-field effective modifications to Newton's $1/r^2$ force law
  - Renormalization Group flow
  - The renormalized gravitational coupling

Experiment

- Galaxy Rotation Curves
- Gravitational Lensing
- X-ray galaxy clusters
- Solar System Constraints & Pioneer Anomaly
- Cosmology (CMB, Structure Formation).

Theory

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  - relativistic generalization of general relativity
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Experiment

- The Dark Matter Paradigm
  - Galaxy Rotation Curves
  - Gravitational Lensing
  - X-ray galaxy clusters
  - Solar System Constraints & Pioneer Anomaly
  - Cosmology (CMB, Structure Formation, and so on).

Theory

- NGT ➘ Modified Gravity

Experiment

- The Dark Matter Paradigm

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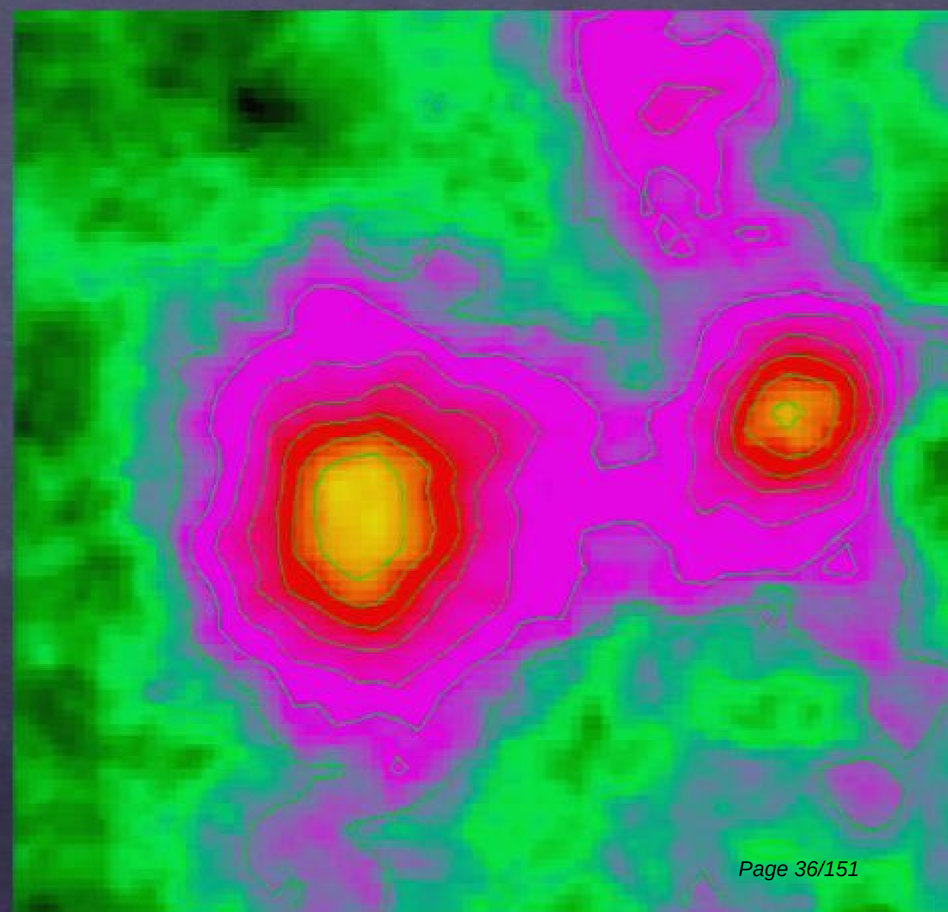

Theory

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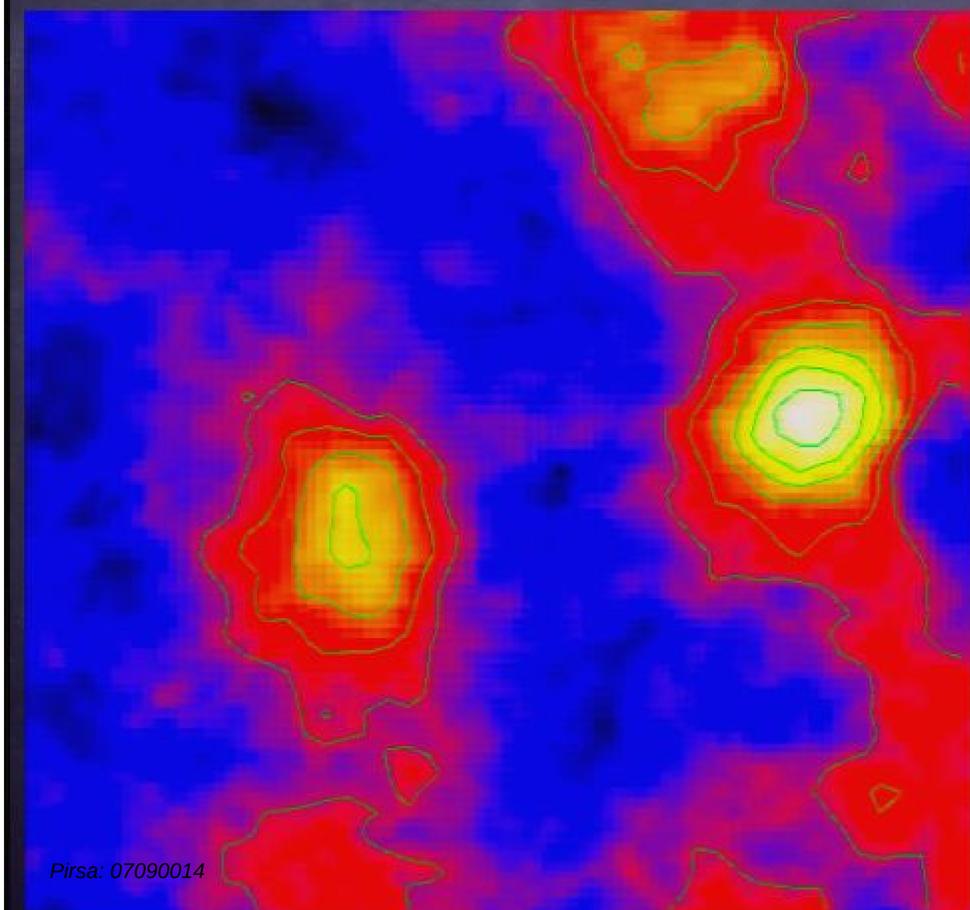
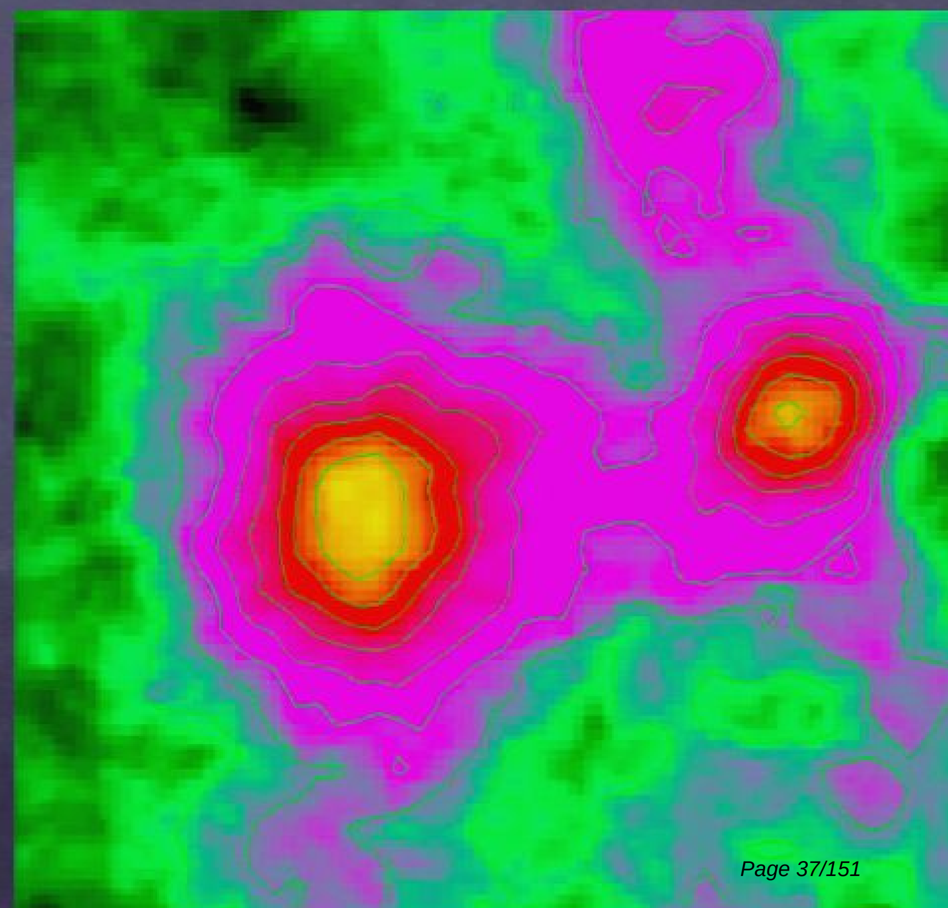


Experiment

- The Dark Matter Paradigm



Theory

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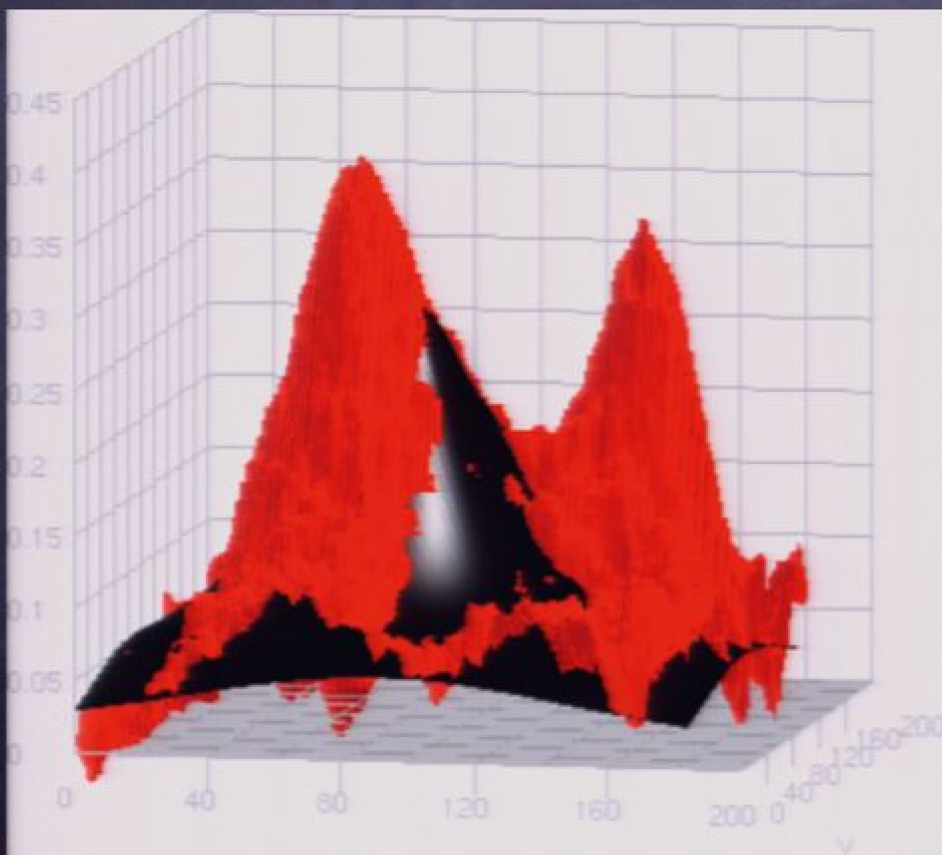

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Experiment

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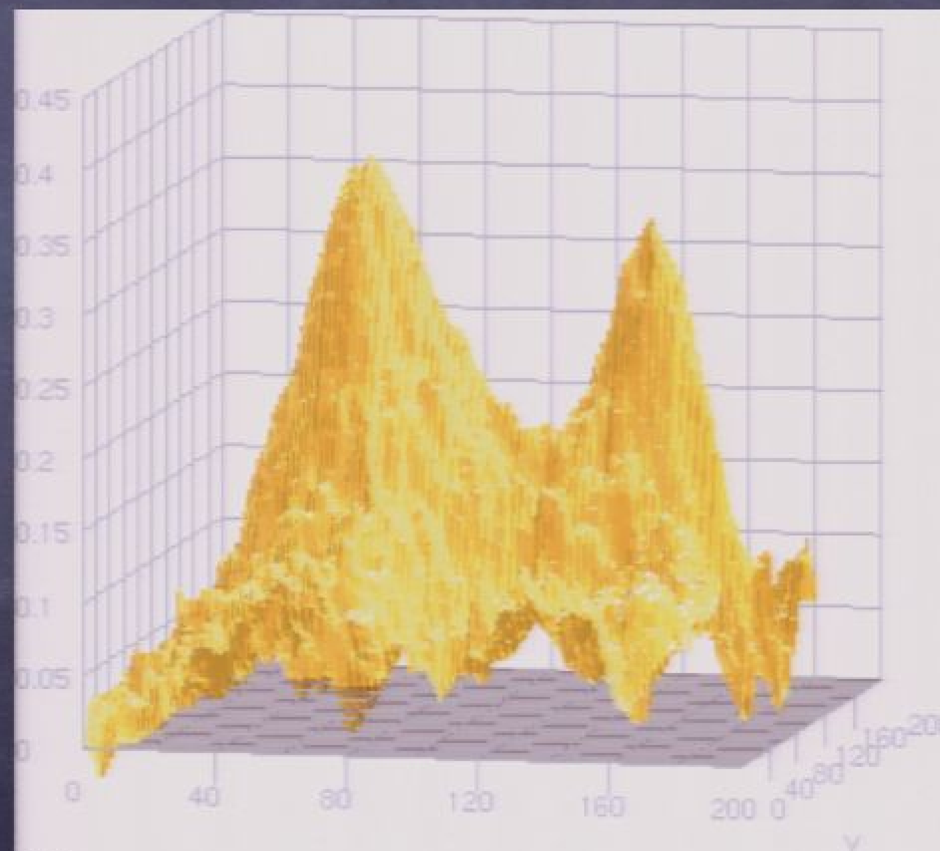

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Theory

- NGT ↘ Modified Gravity

Experiment

- The Dark Matter Paradigm

Theory

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Nonsymmetric Gravitation Theory [Moffat (1979-1995), R.B. Mann (1985), J. R. Brownstein (1991), M. C. Clayton (1995), N. J. Cornish (1996), and a host of graduate students.

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- $g_{\mu\nu} = g_{(\mu\nu)} + g_{[\mu\nu]}$ >16 degrees of freedom (d.o.f.)

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- $g_{[\mu\nu]}$ >spin-1 skewon with 6 d.o.f.

Theory

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- $w^{\lambda}_{\mu\nu} = w^{\lambda}_{(\mu\nu)} + w^{\lambda}_{[\mu\nu]}$

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- $w^{\lambda}_{\mu\nu} = w^{\lambda}_{(\mu\nu)} + w^{\lambda}_{[\mu\nu]}$ >spin connection with torsion

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- $w^{\lambda}_{\mu\nu} = w^{\lambda}_{(\mu\nu)} + w^{\lambda}_{[\mu\nu]}$ >spin connection with torsion
- $$\begin{aligned} ds^2 &= g_{\mu\nu} dx^{\mu} dx^{\nu} \\ &= g_{(\mu\nu)} dx^{\mu} dx^{\nu} \end{aligned}$$

Theory

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- $g_{[\mu\nu]}$ >spin-1 skewon with 6 d.o.f.
- $w^{\lambda}_{\mu\nu} = w^{\lambda}_{(\mu\nu)} + w^{\lambda}_{[\mu\nu]}$ >spin connection with torsion
- $$\begin{aligned} ds^2 &= g_{\mu\nu} dx^{\mu} dx^{\nu} \\ &= g_{(\mu\nu)} dx^{\mu} dx^{\nu} \end{aligned}$$ >spin-2 graviton with 10 d.o.f.

Theory

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Theory

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- $$L_{\rm EH} = \frac{c^3}{16\pi G}\sqrt{-g}\left[g^{\mu\nu}R_{\mu\nu}(\Gamma) - 2\Lambda\right] - \frac{c^3}{2G}\sqrt{-g}g^{\mu\nu}T_{\mu\nu}$$

Theory

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- $L_{\rm NGT} = \frac{c^3}{16\pi G}\sqrt{-g}\Big[g^{\mu\nu}R_{\mu\nu}(w) - 2\Lambda + \ldots\Big] - \frac{c^3}{2G}\sqrt{-g}g^{\mu\nu}T_{\mu\nu}$

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- $$L_{\mathrm{NGT}} = \frac{c^3}{16\pi G}\sqrt{-g}\Big[g^{\mu\nu}R_{\mu\nu}(w) - 2\Lambda - \frac{1}{4}\mu^2 g^{\mu\nu}g_{[\mu\nu]} + \ldots\Big] - \frac{c^3}{2G}\sqrt{-g}g^{\mu\nu}T_{\mu\nu}$$

EH extension

Theory

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EH extension

skewon mass, μ

Theory

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EH extension

skewon mass, μ

Theory

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EH extension

skewon mass, μ

connection compatibility

Joel R. Brownstei
Perimeter Institut

Theory

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EH extension

skewon mass, μ

connection compatibility

no ghosts constraint

Theory

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- $M(r)$ is the total (ordinary) mass enclosed in a sphere or radius, r.
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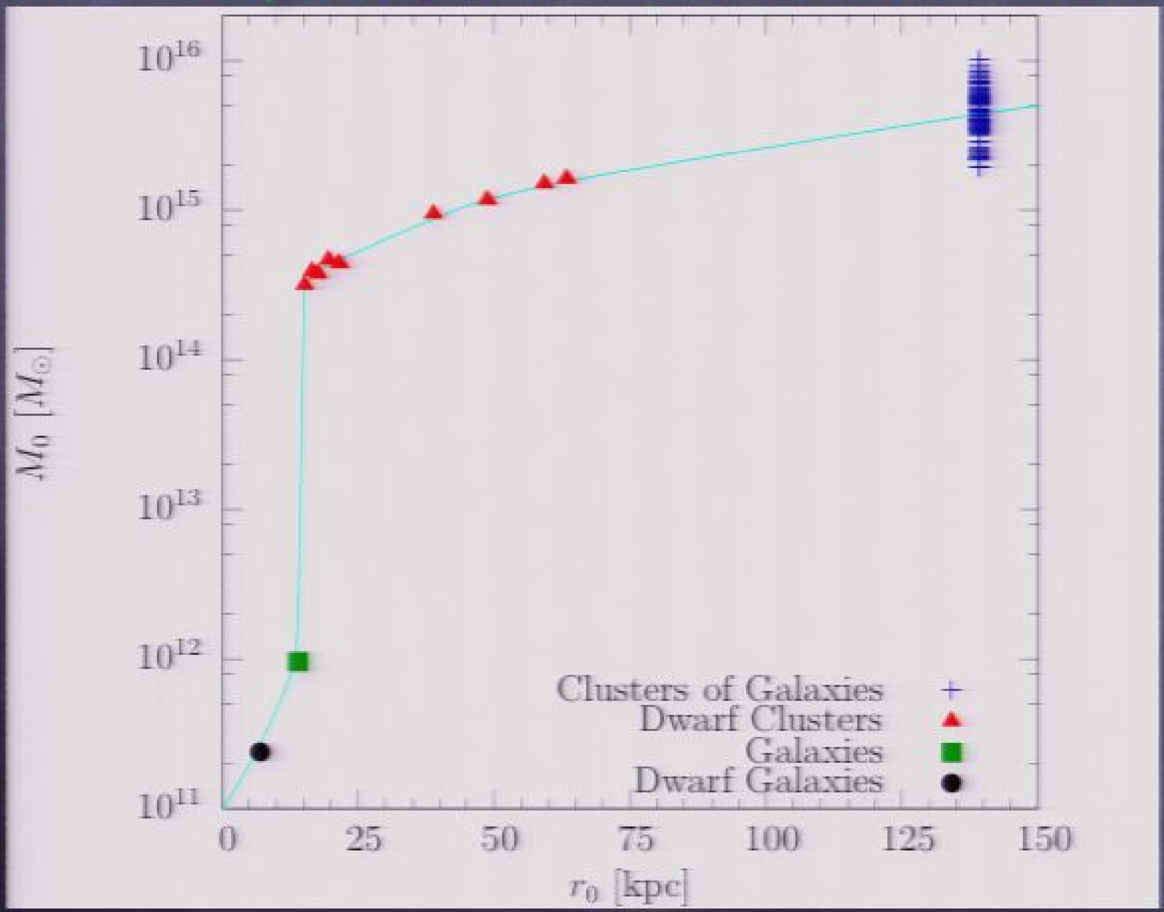

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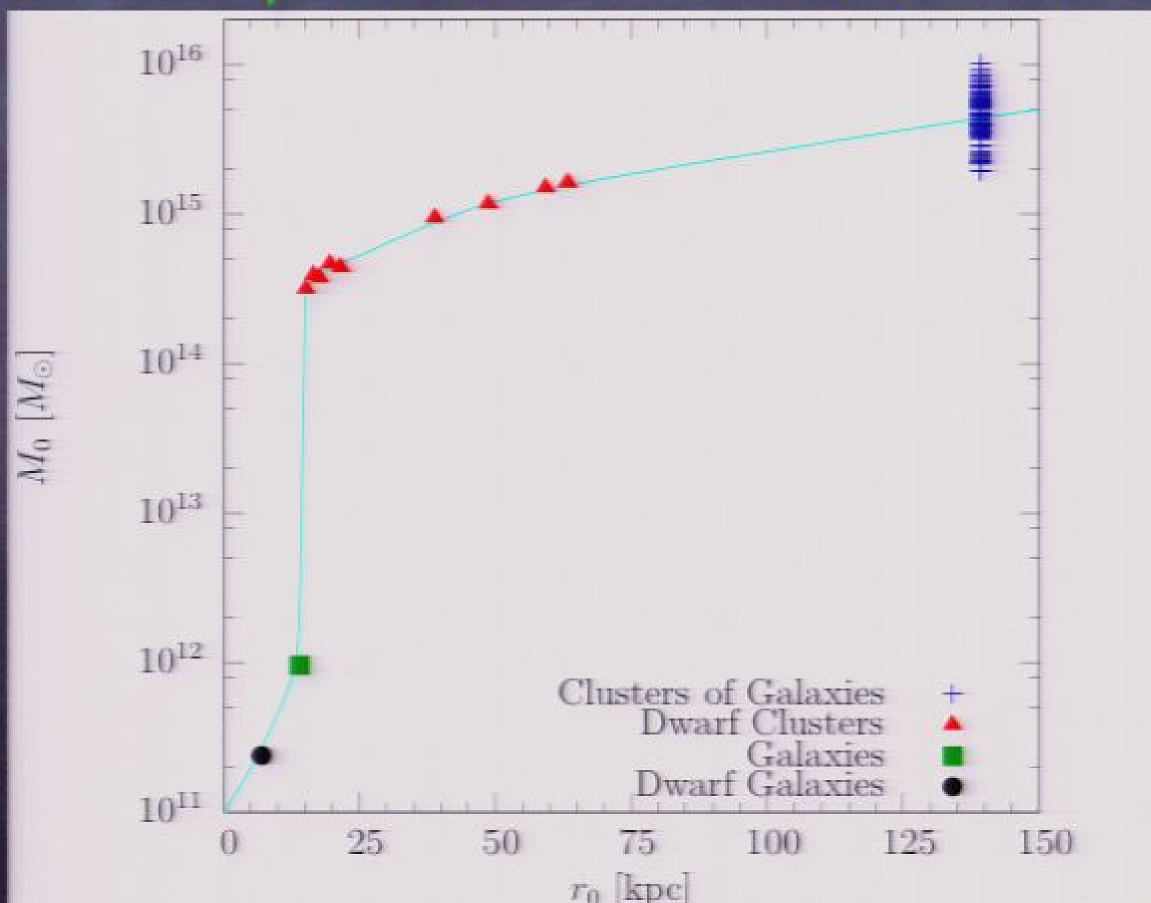

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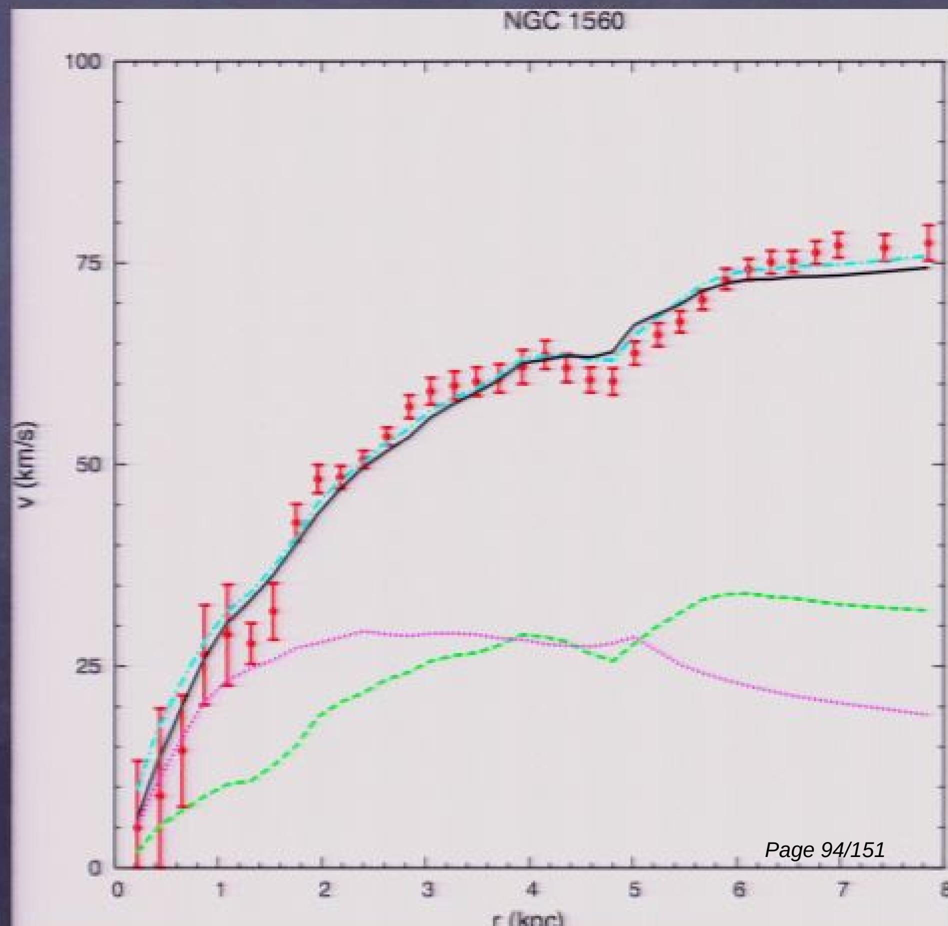

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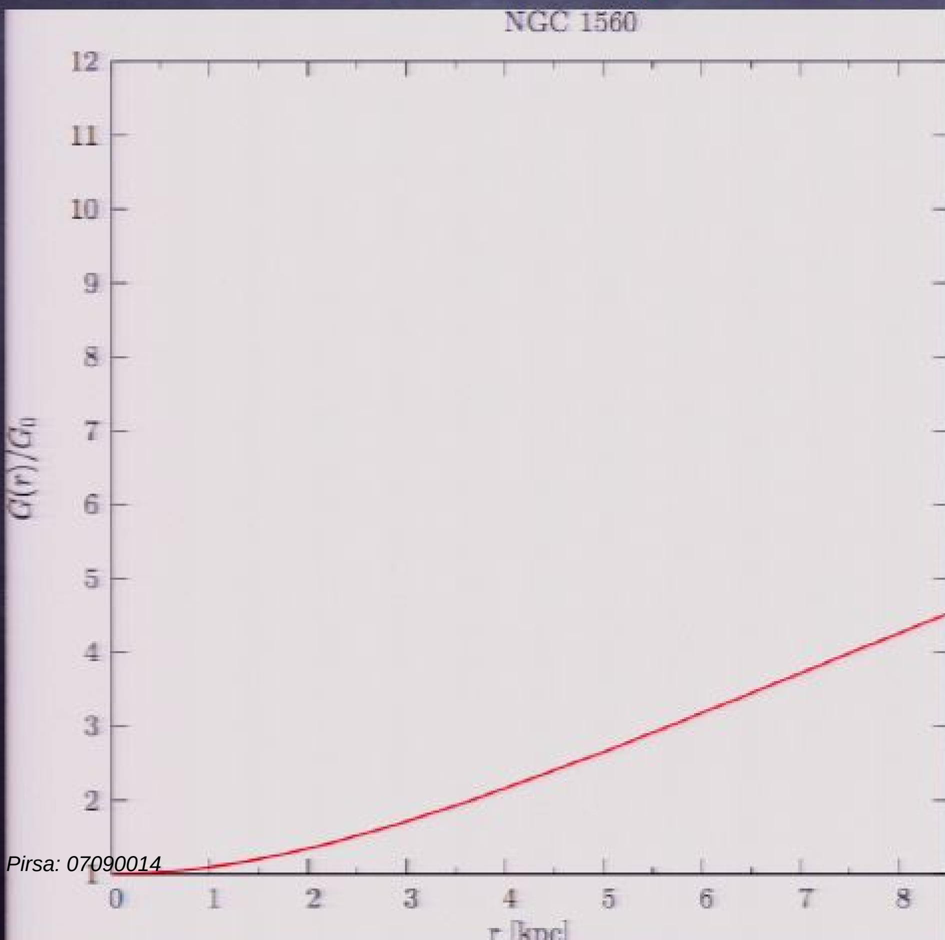

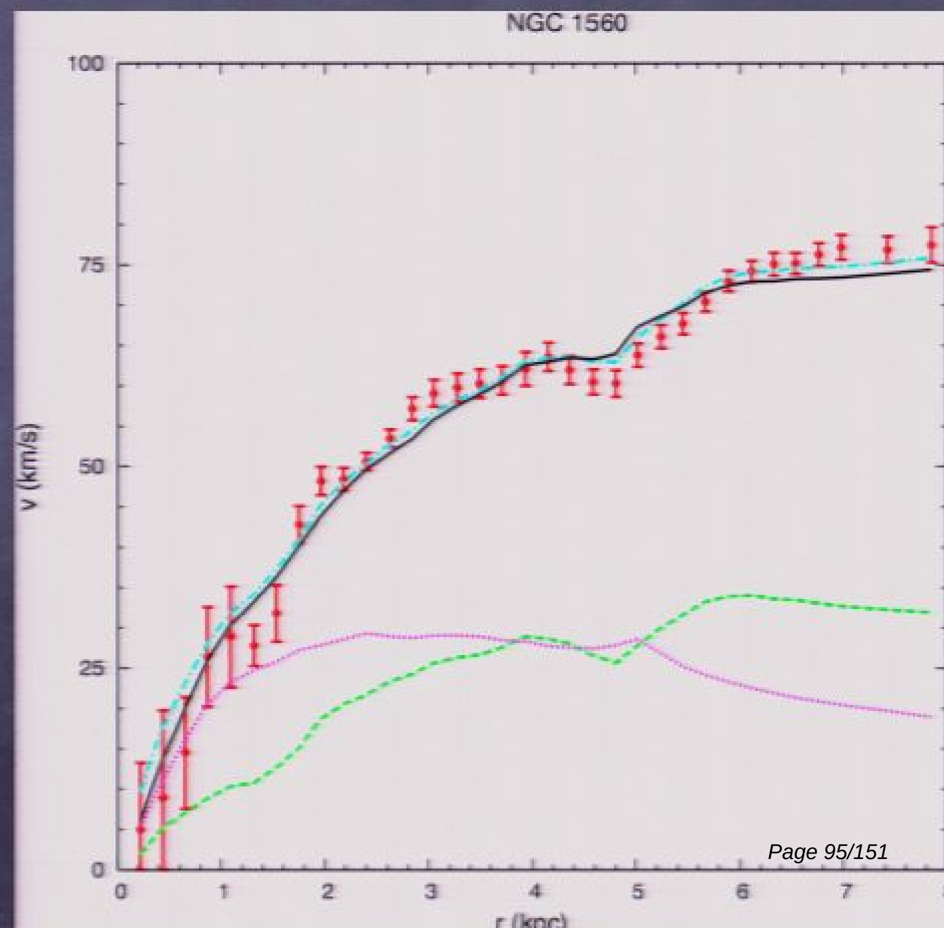

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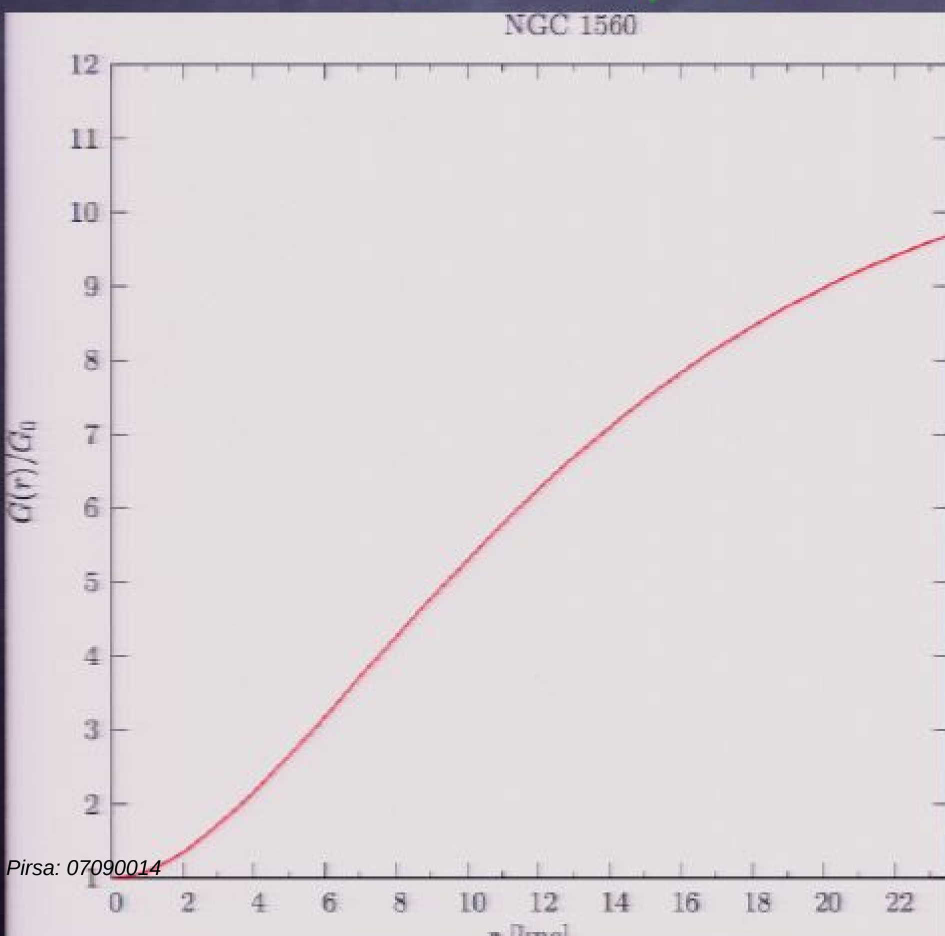

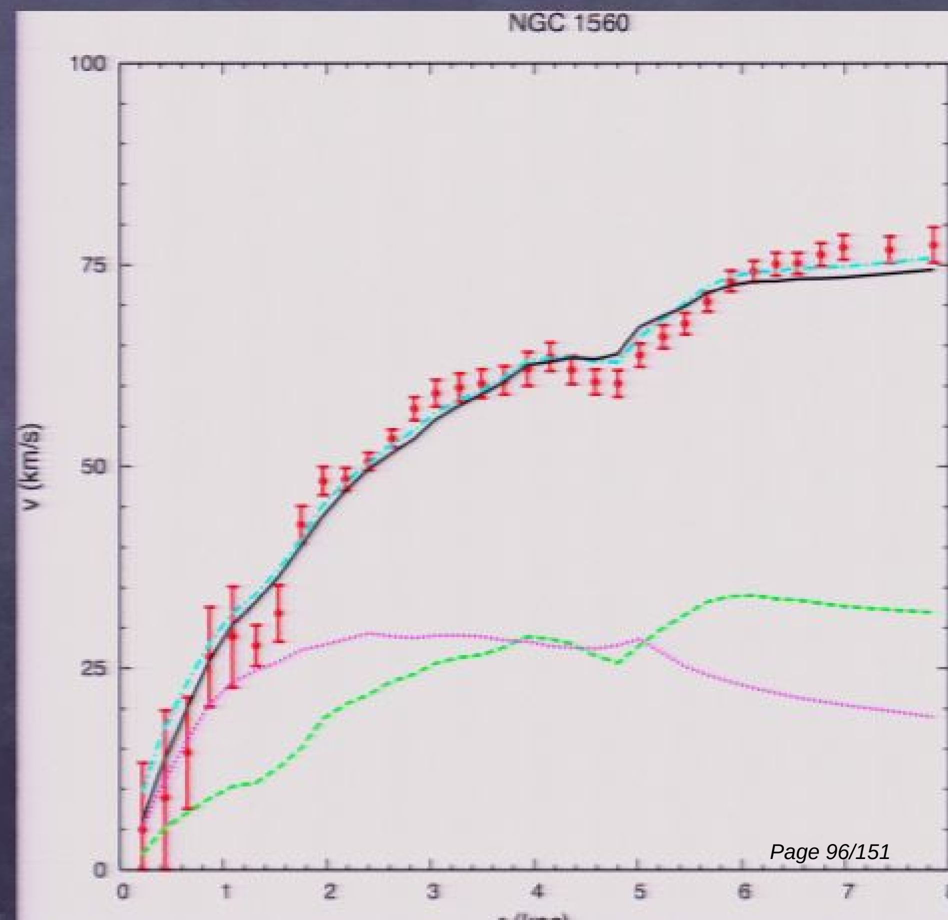

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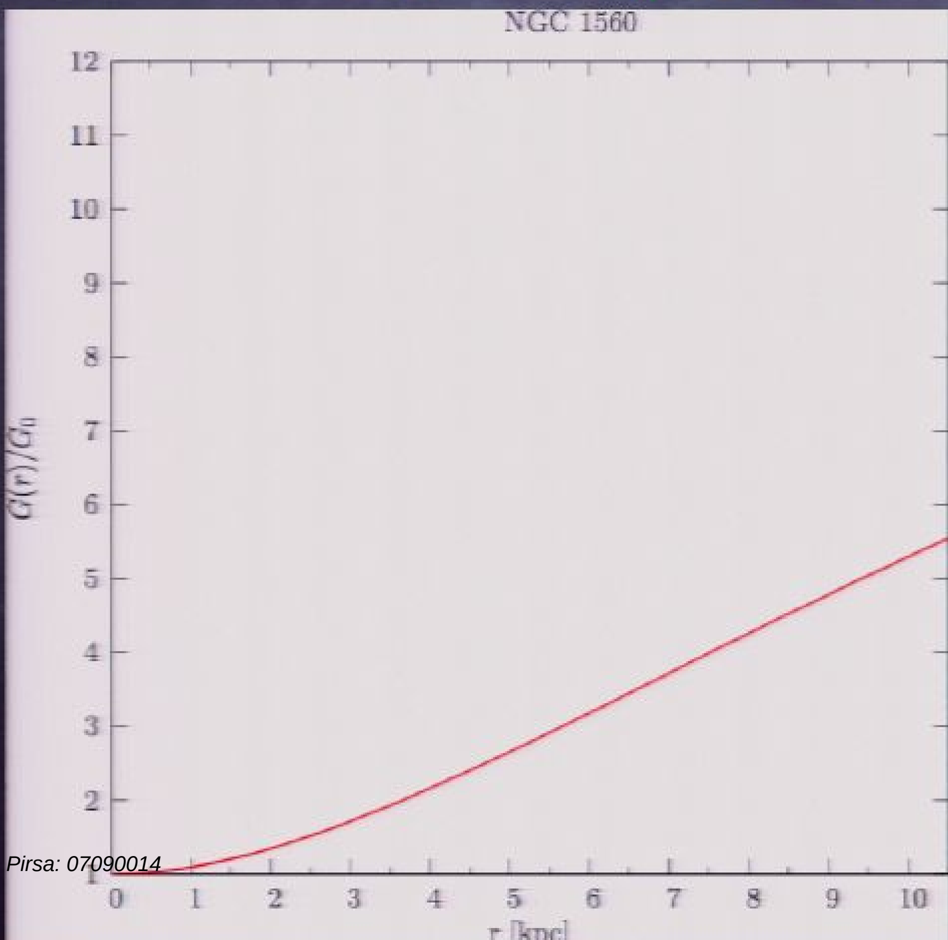

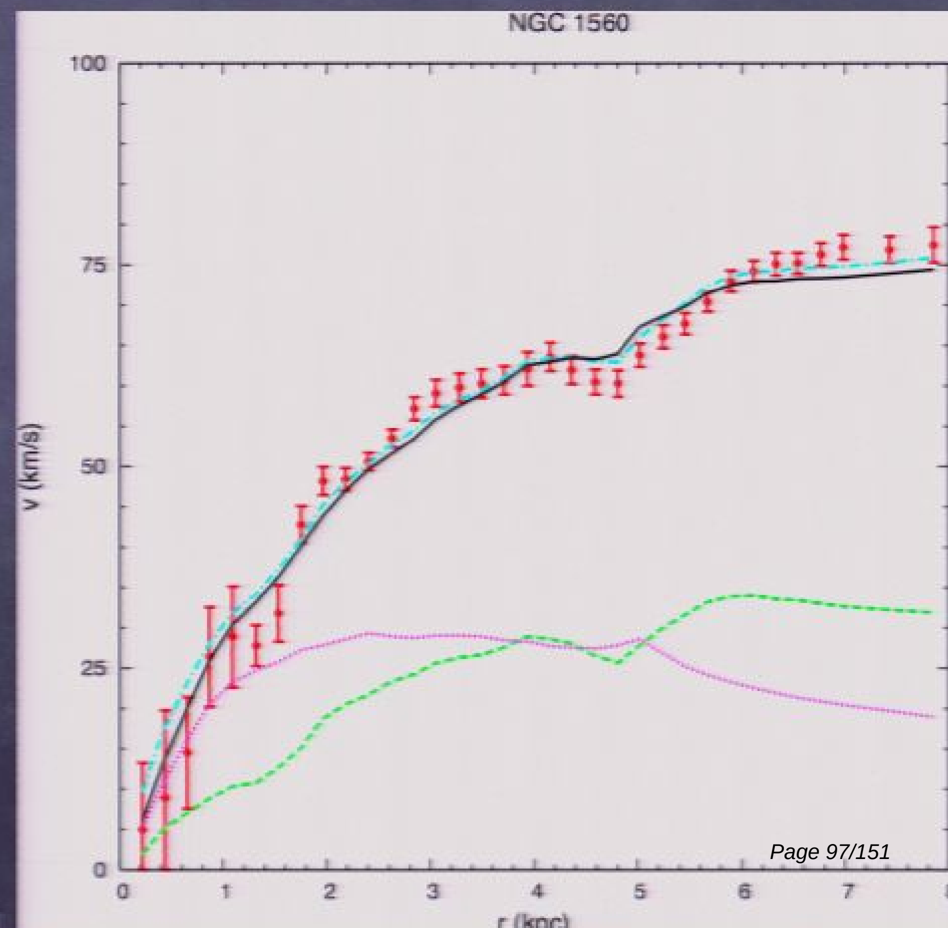

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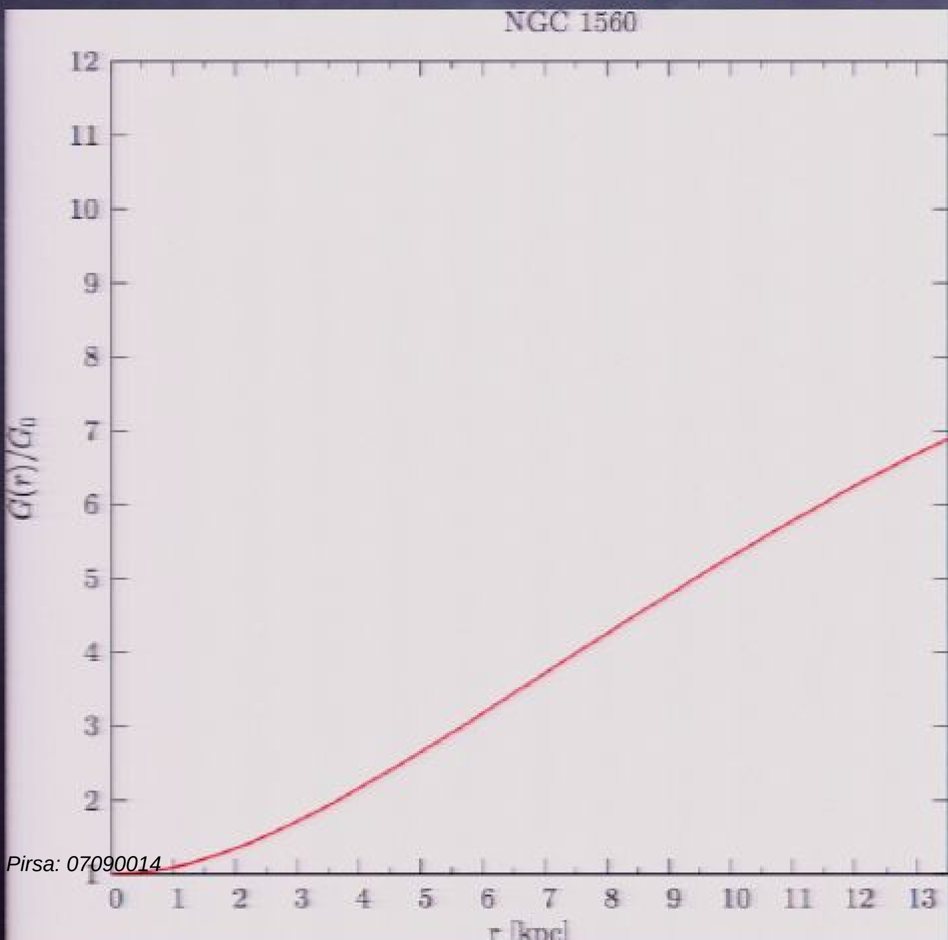

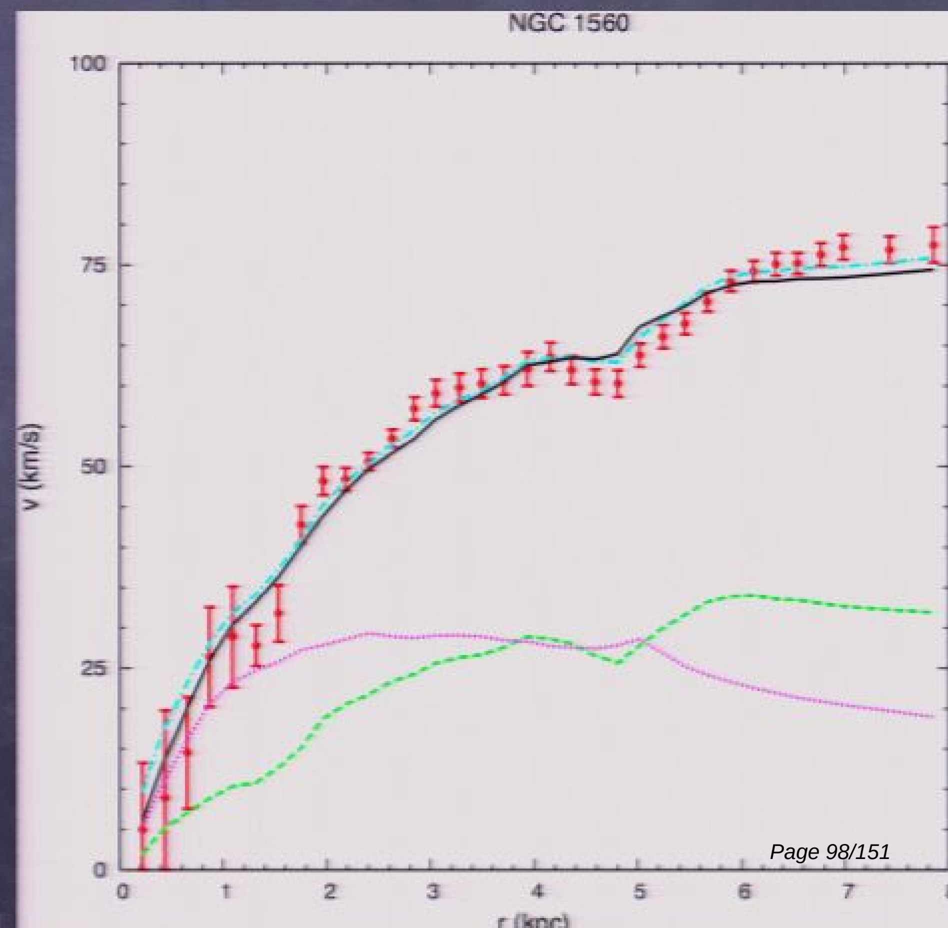

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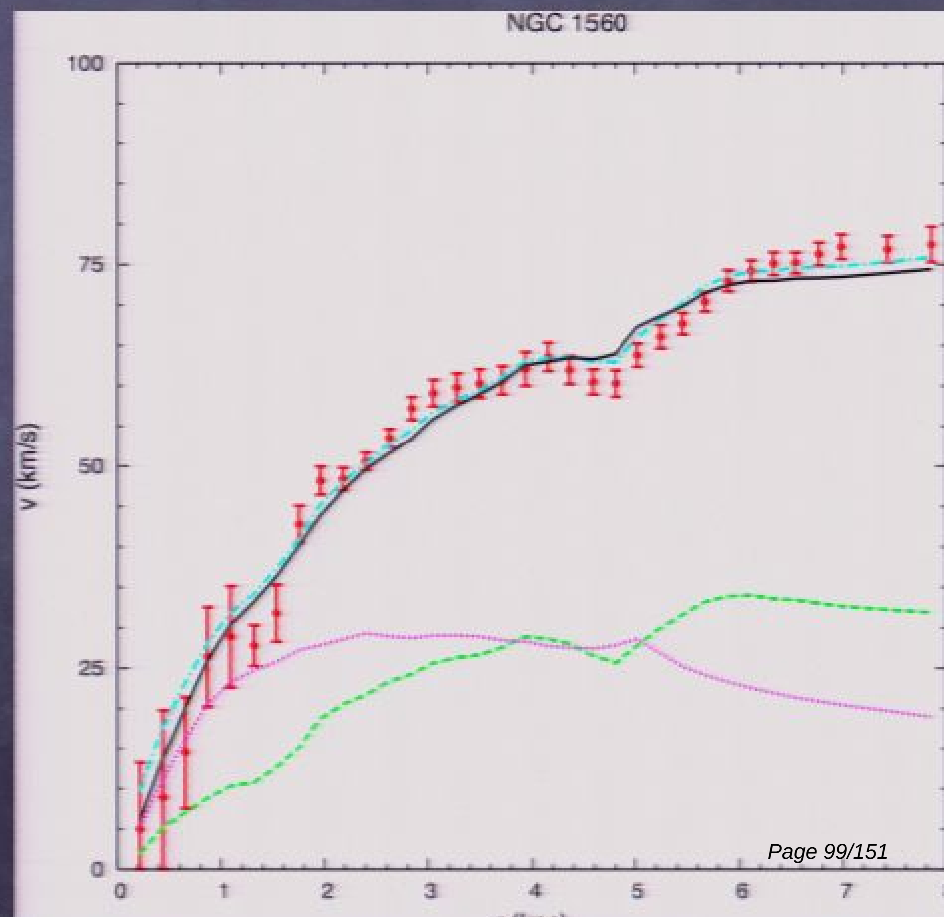

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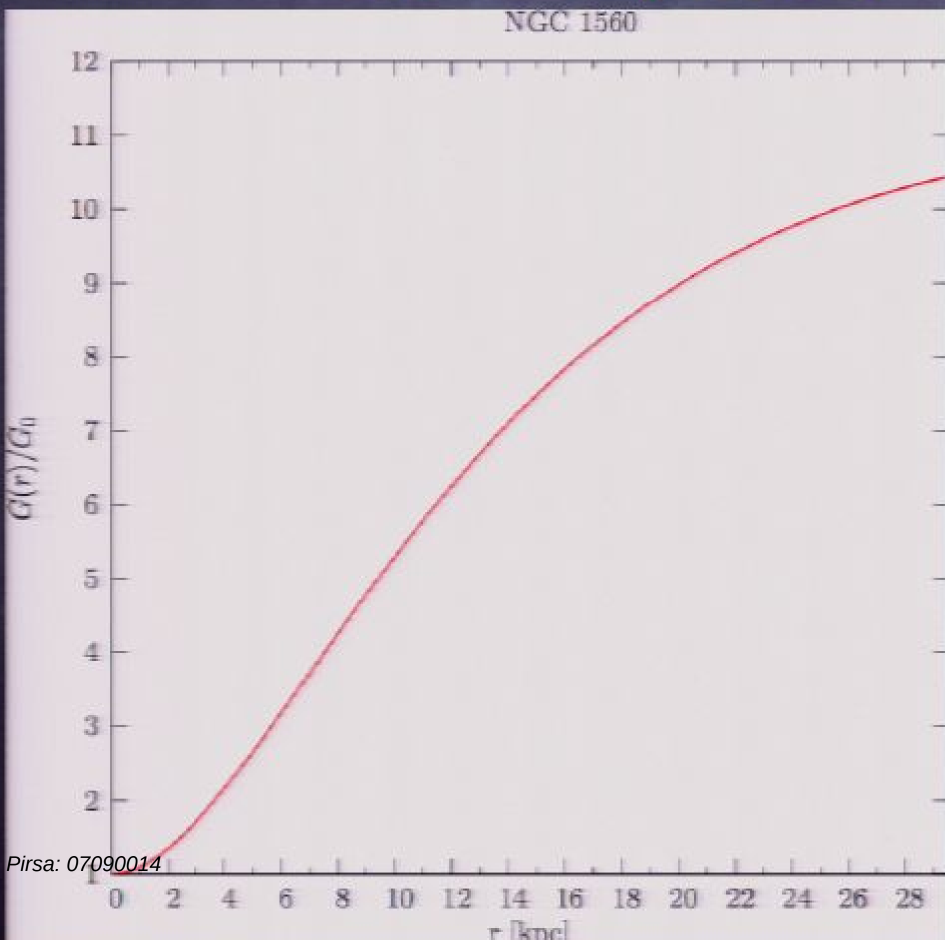

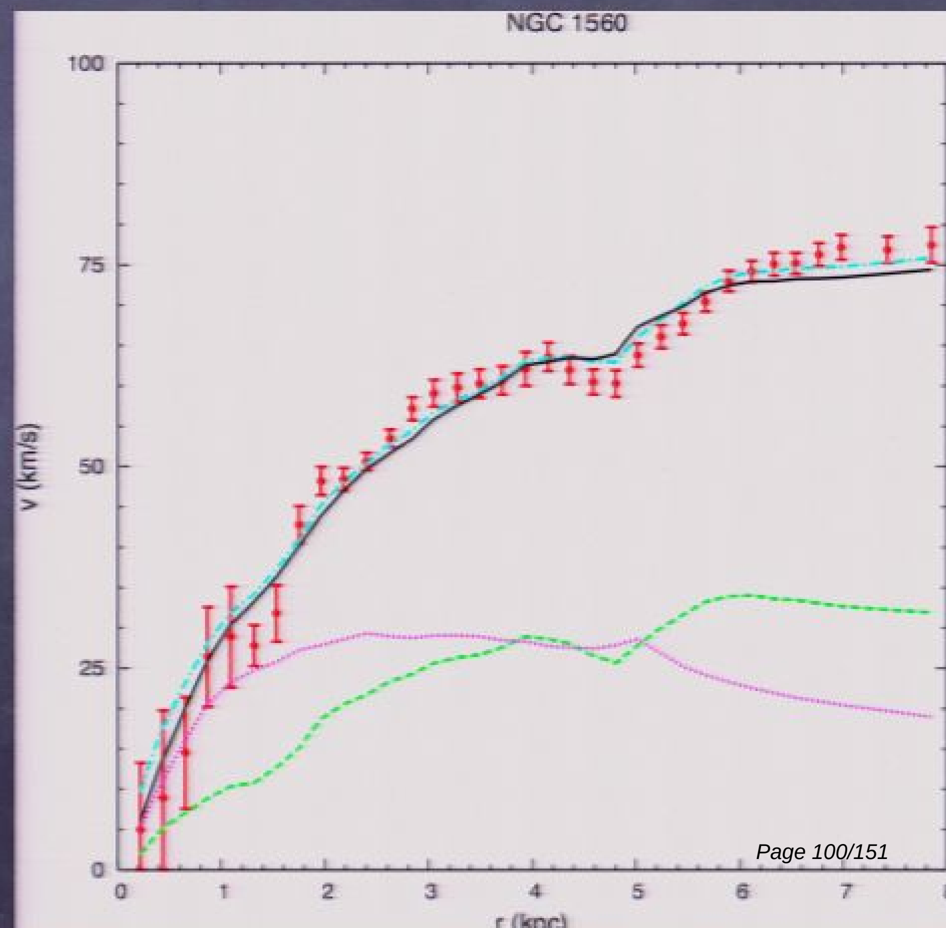

Astrophys. J. 636 (2006) 721-74 astro-ph/050637

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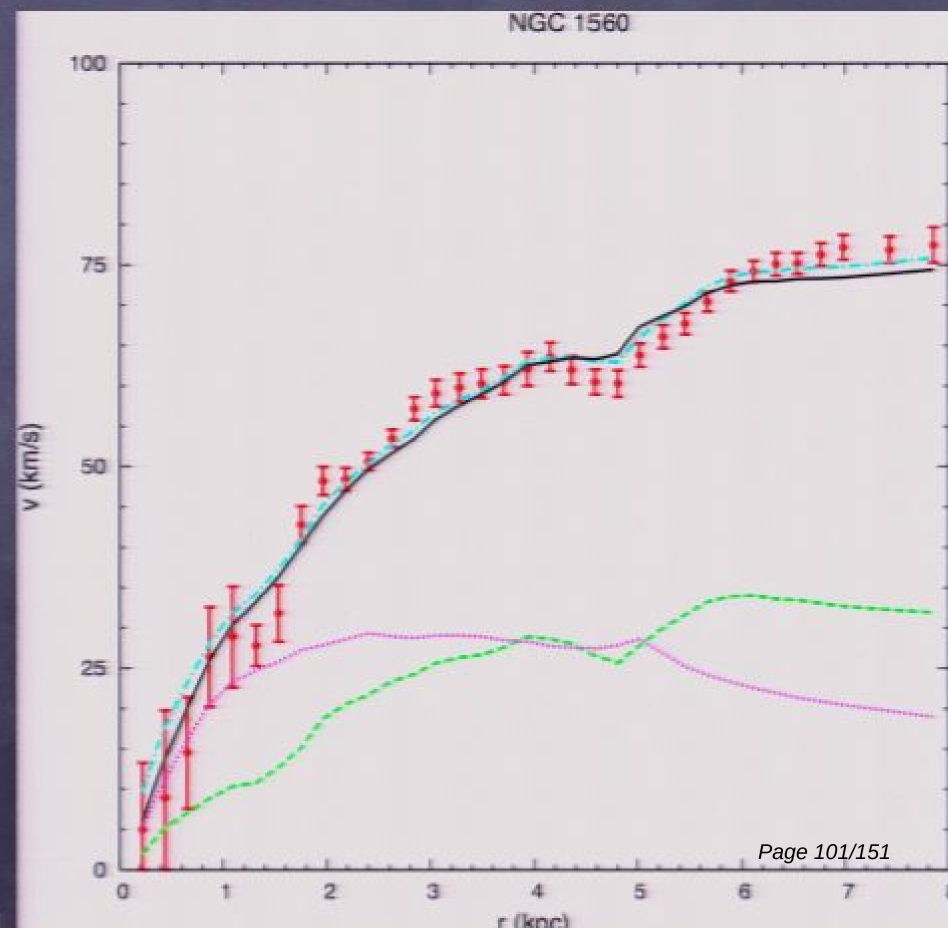

Astrophys. J. 636 (2006) 721-74 astro-ph/0506370

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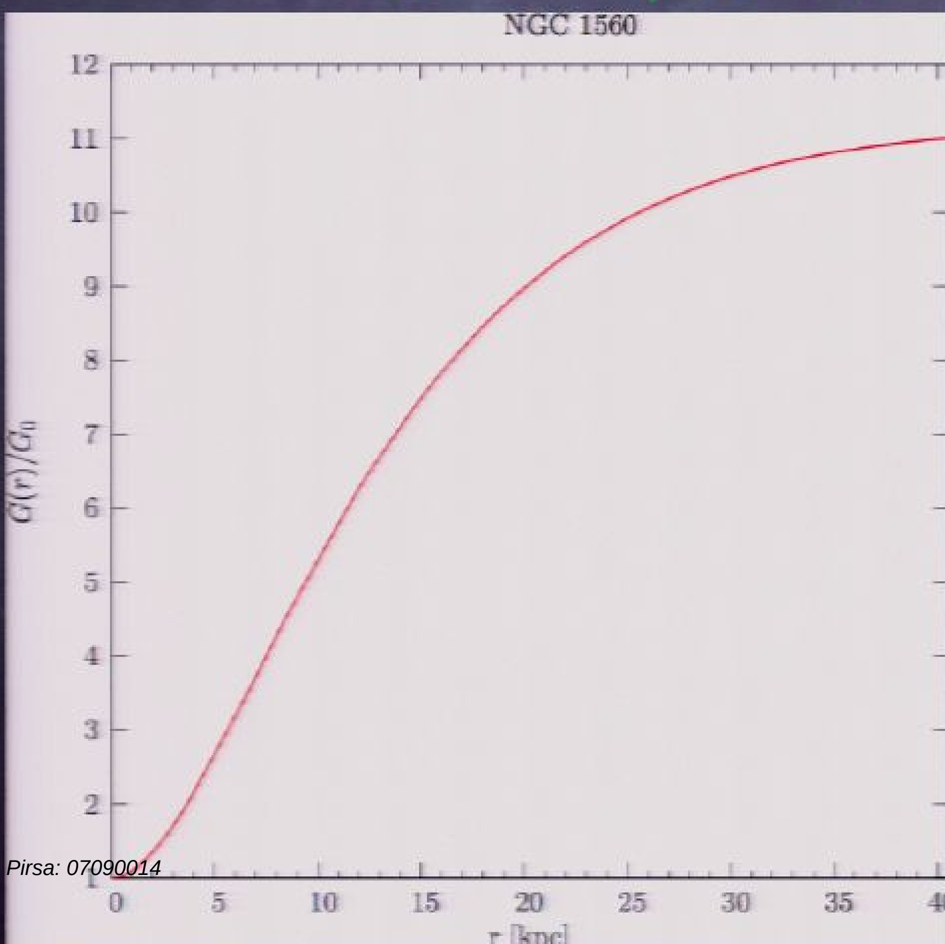

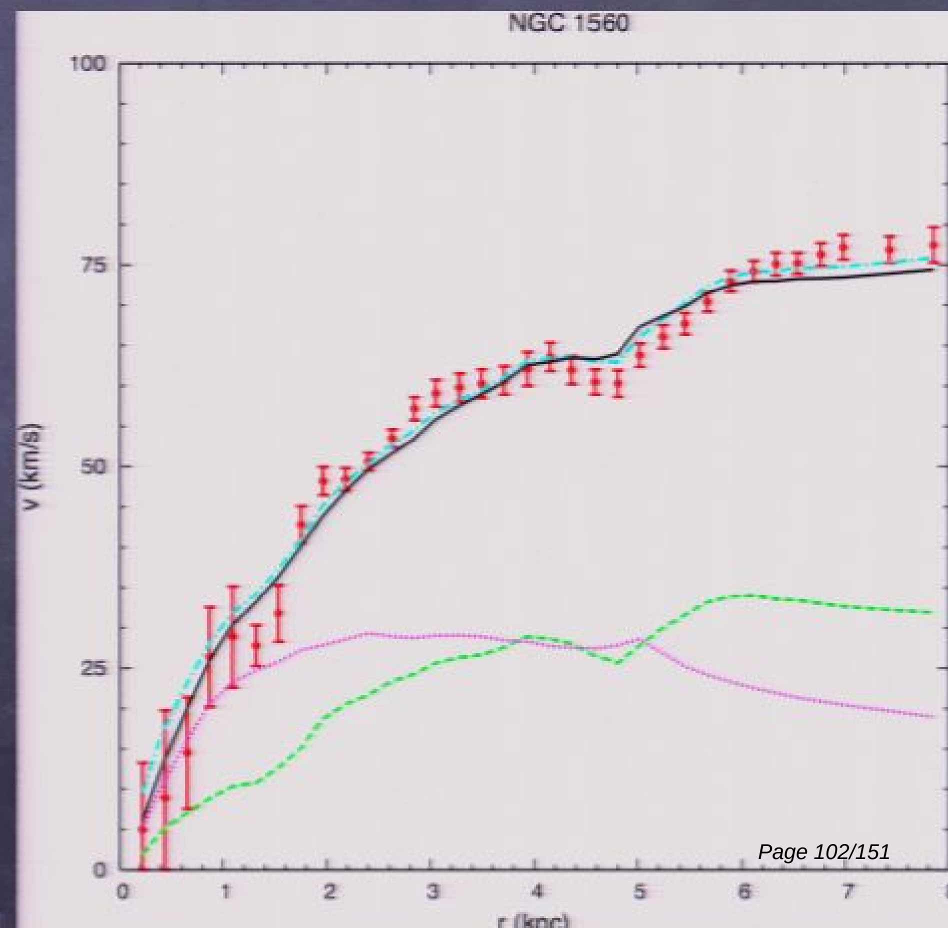

Joel R. Brownstein
Perimeter Institute

Astrophys. J. 636 (2006) 721-74 astro-ph/050637

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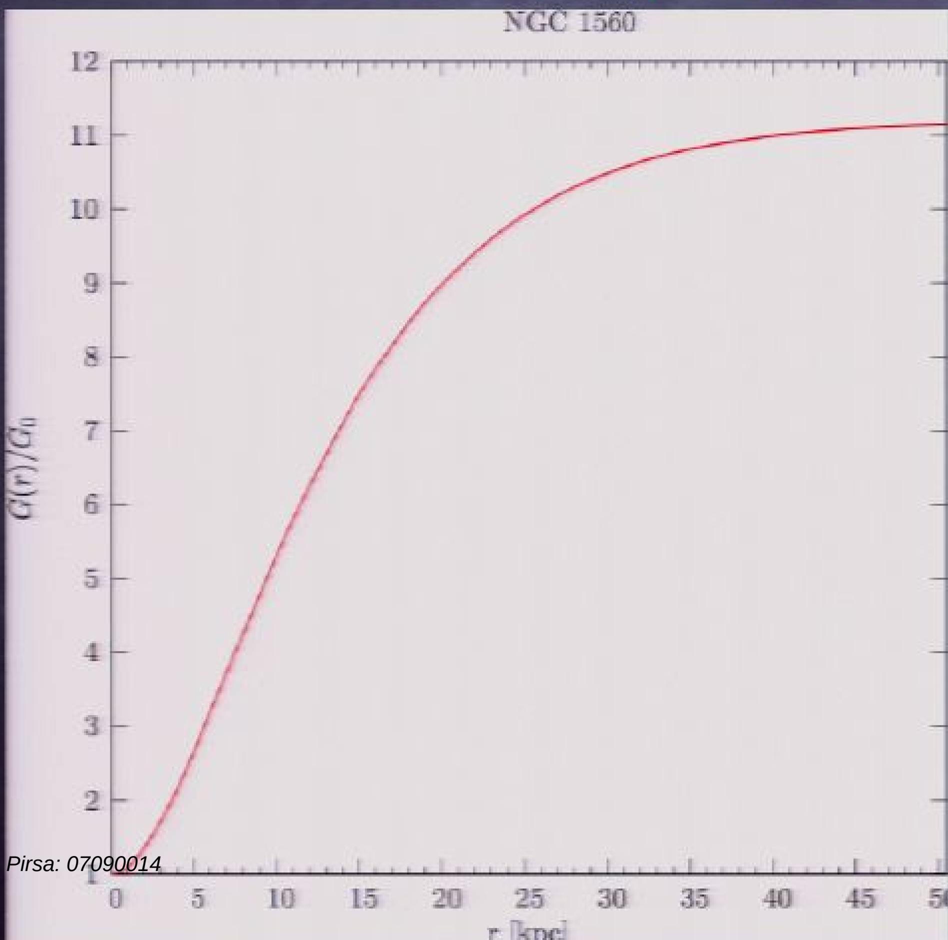

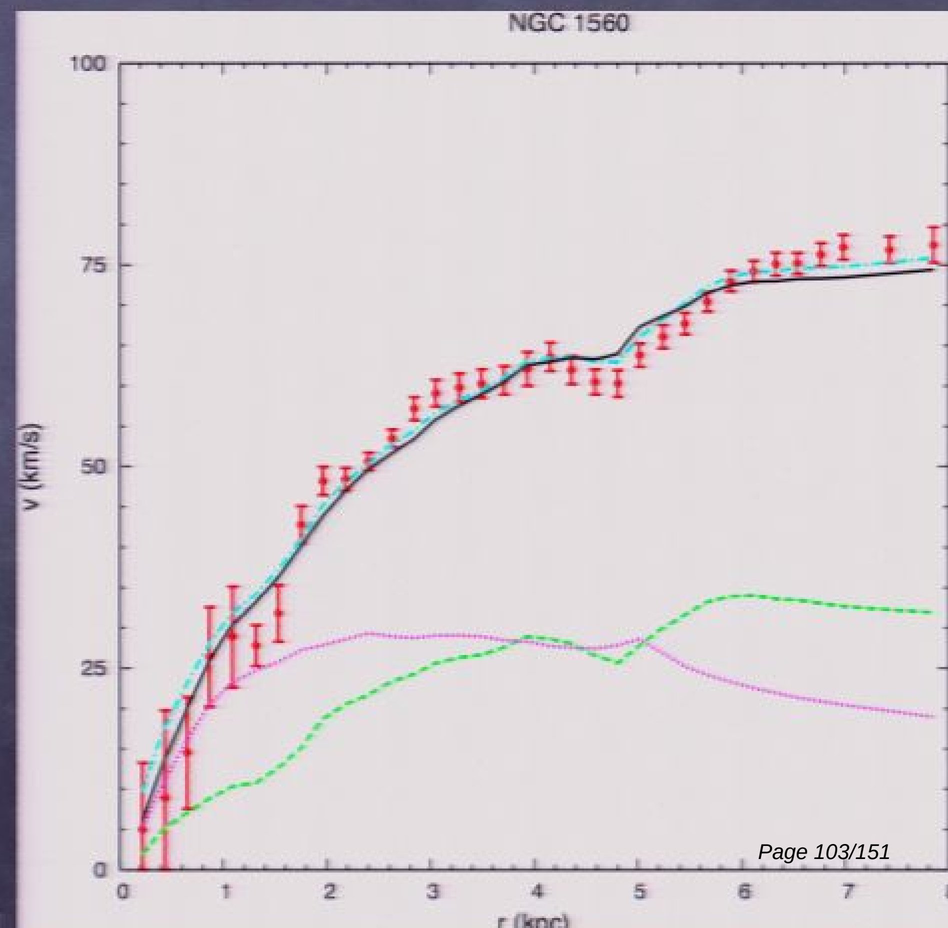

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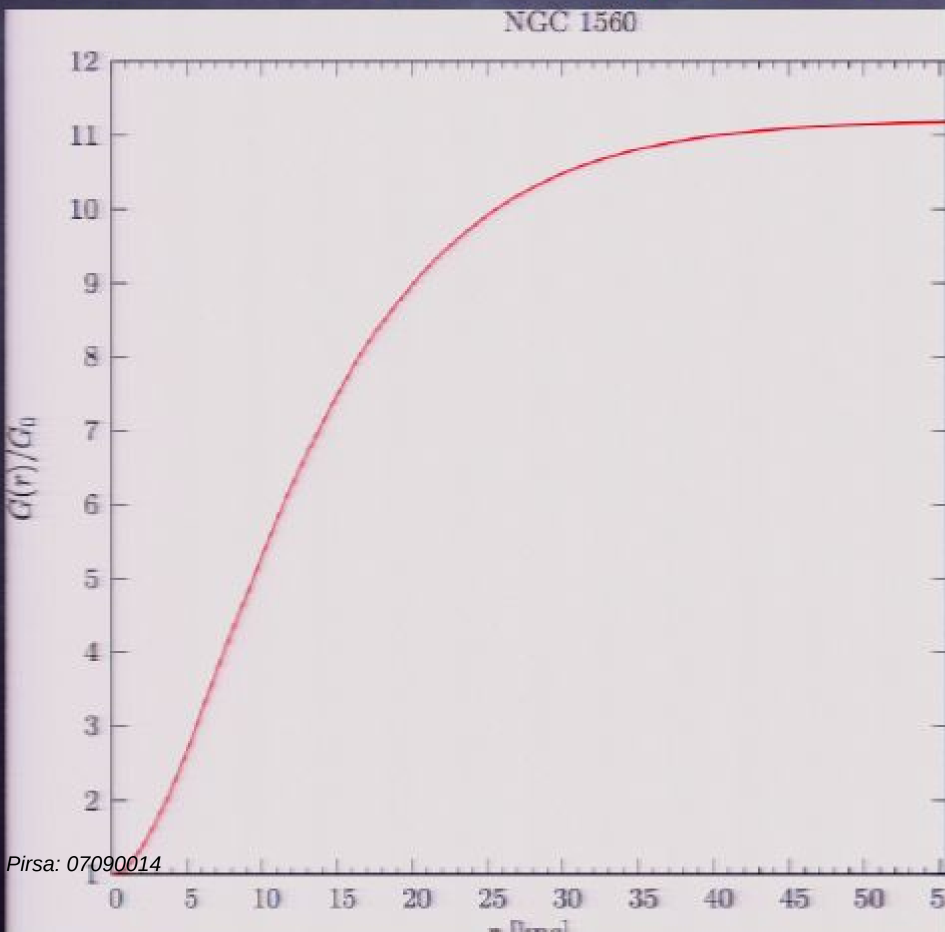

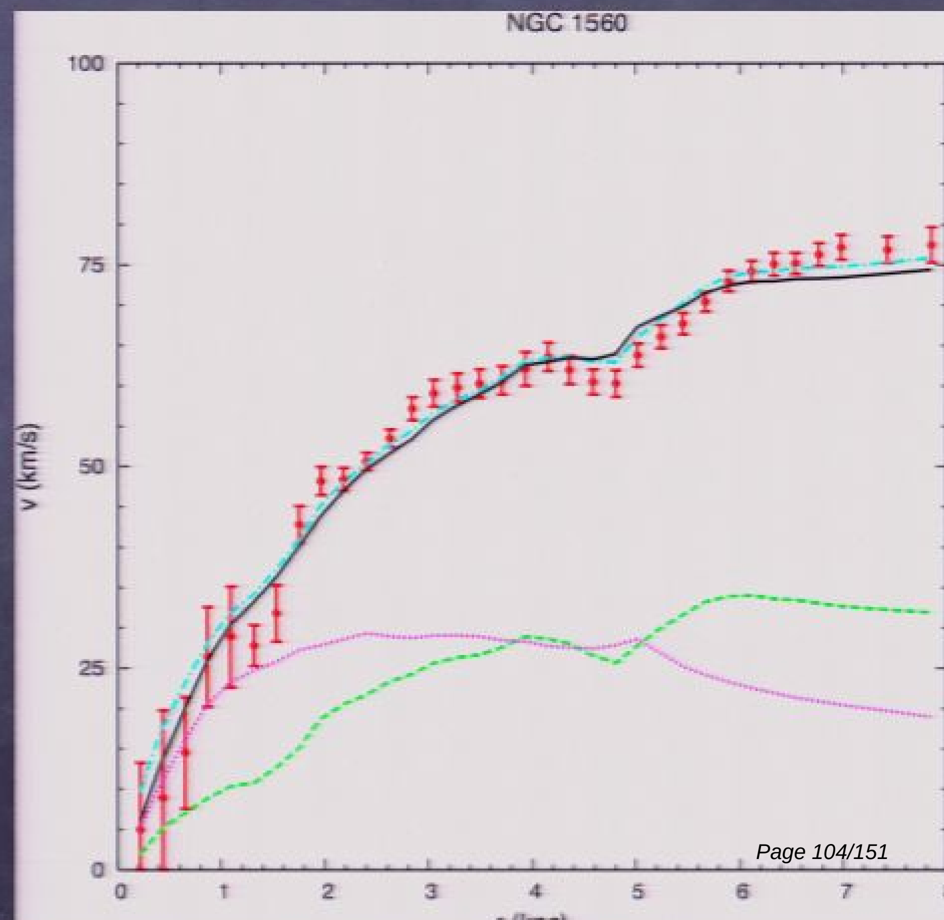

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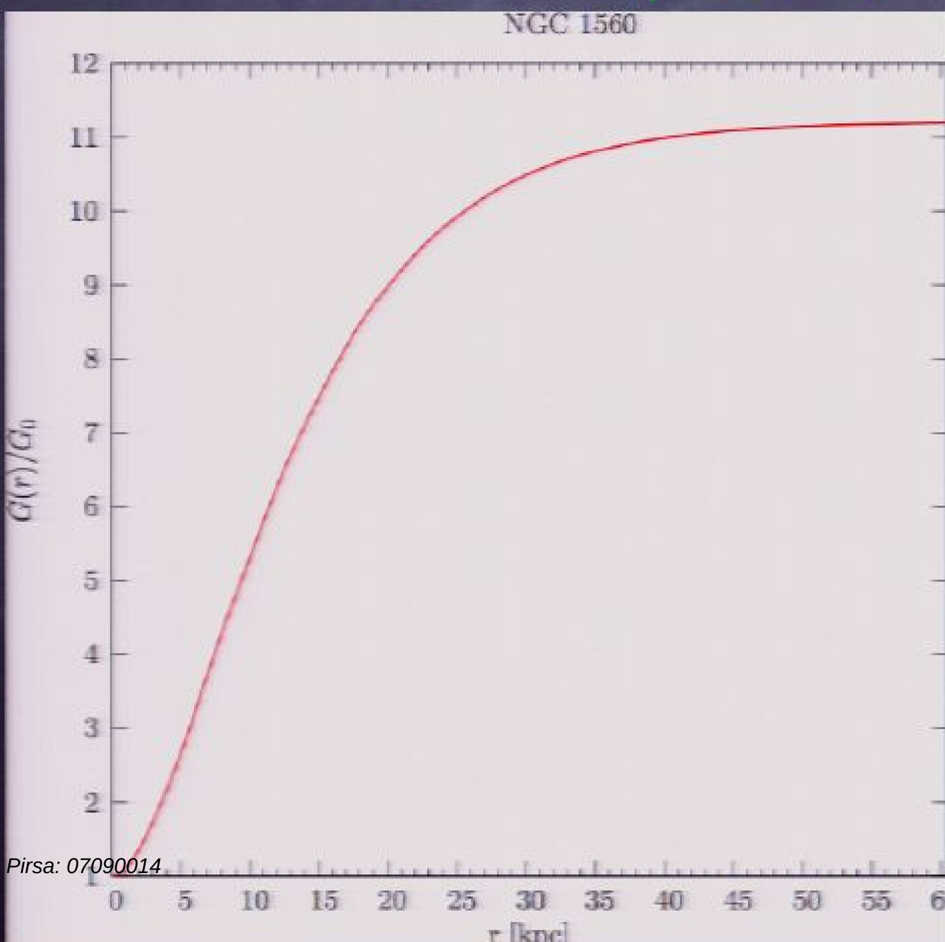

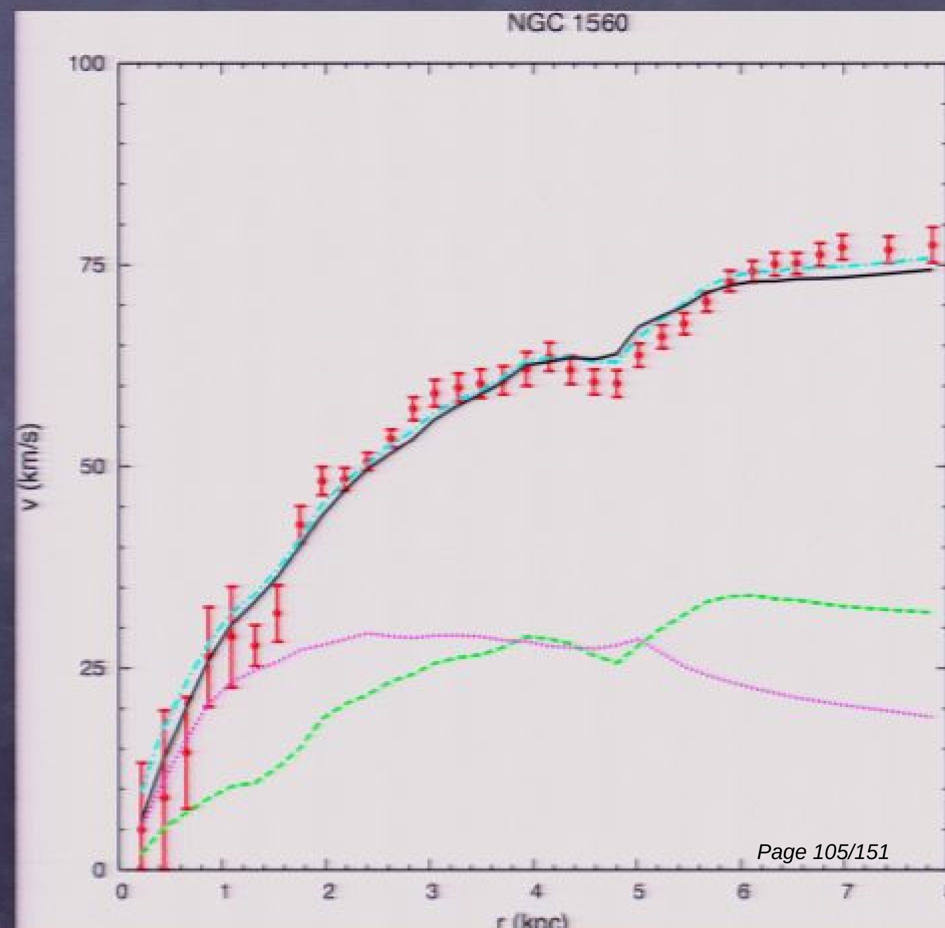

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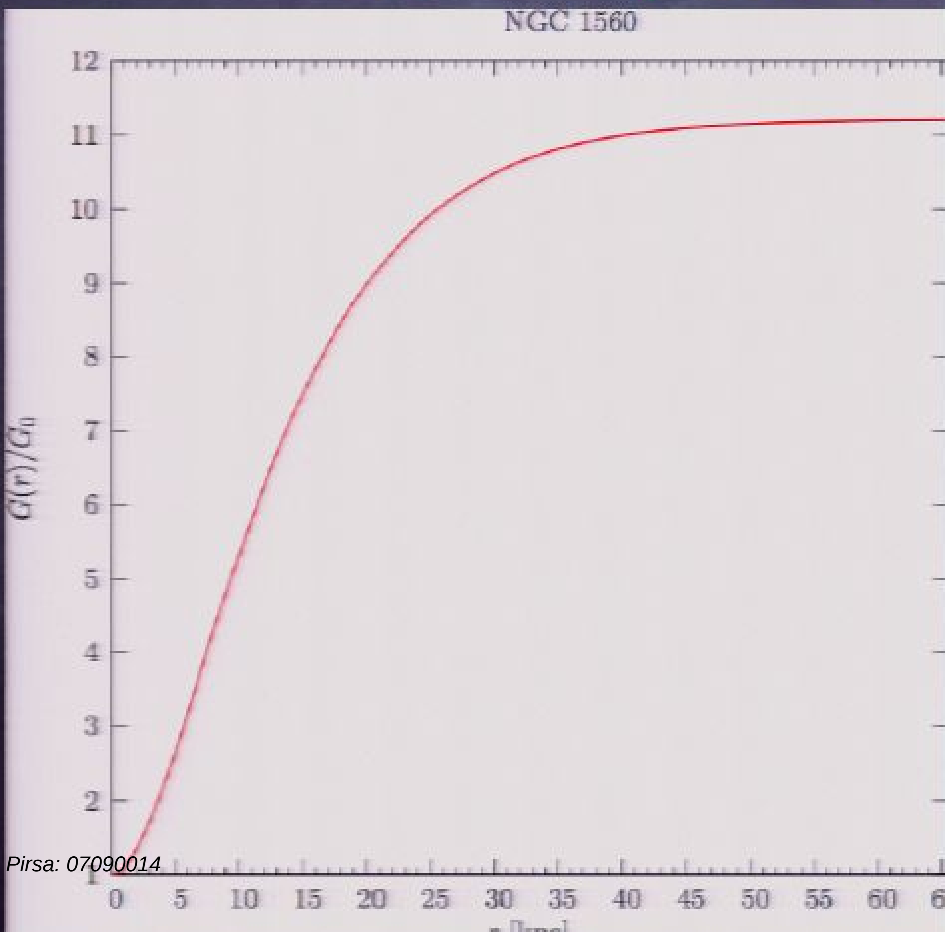

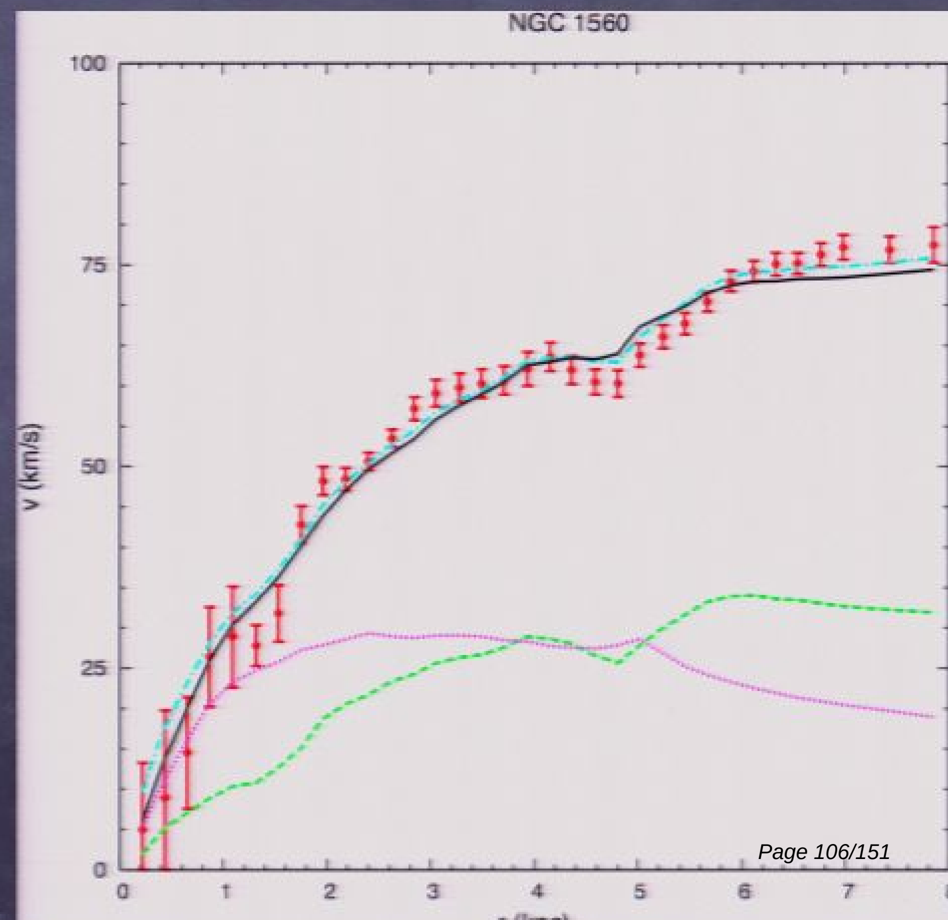

Astrophys. J. 636 (2006) 721-74 astro-ph/0506370

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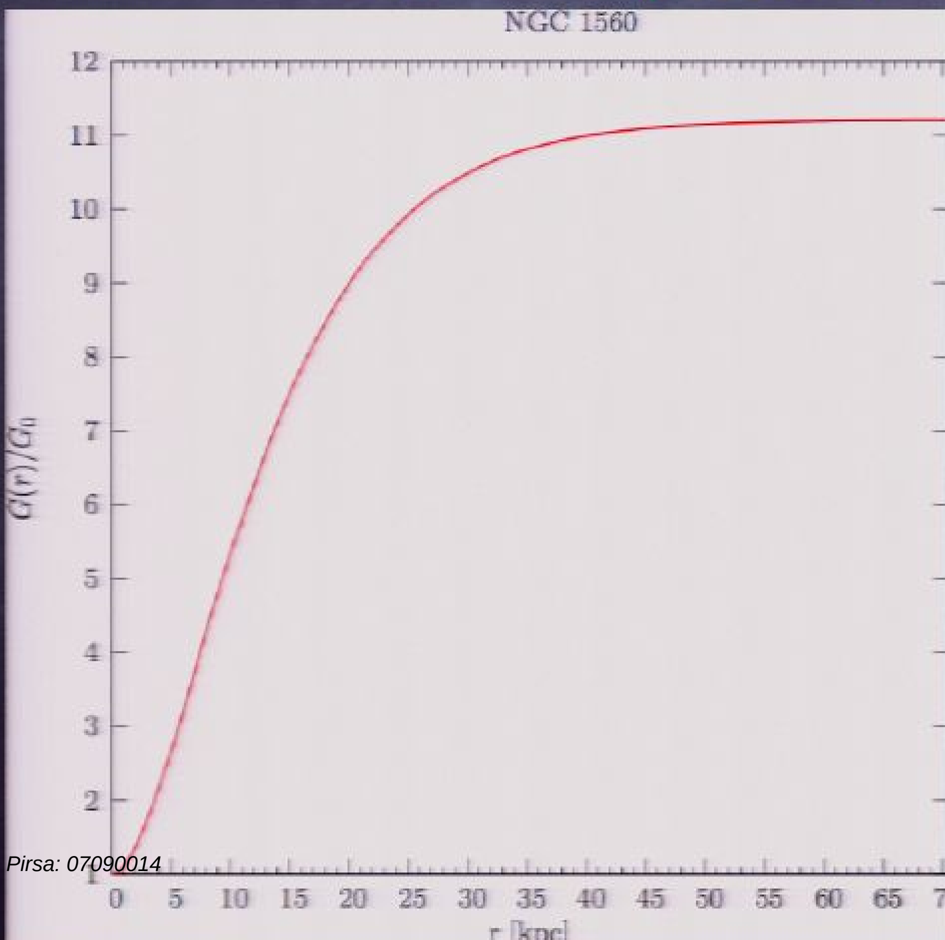

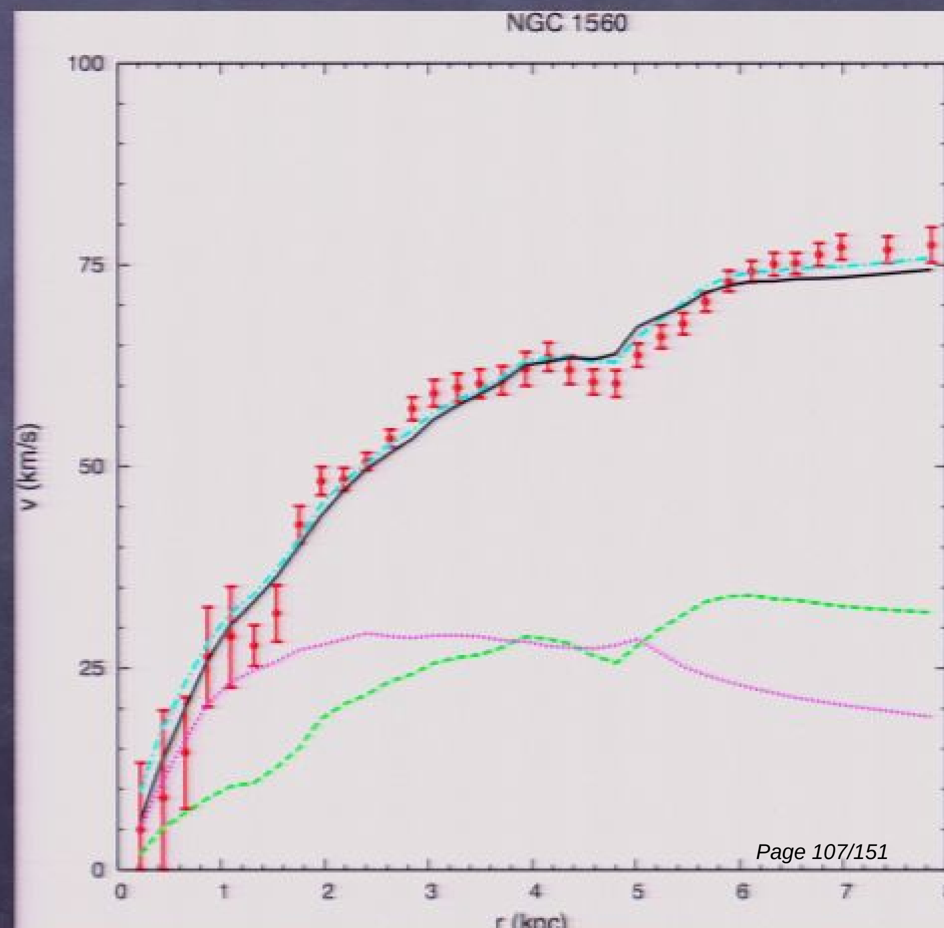

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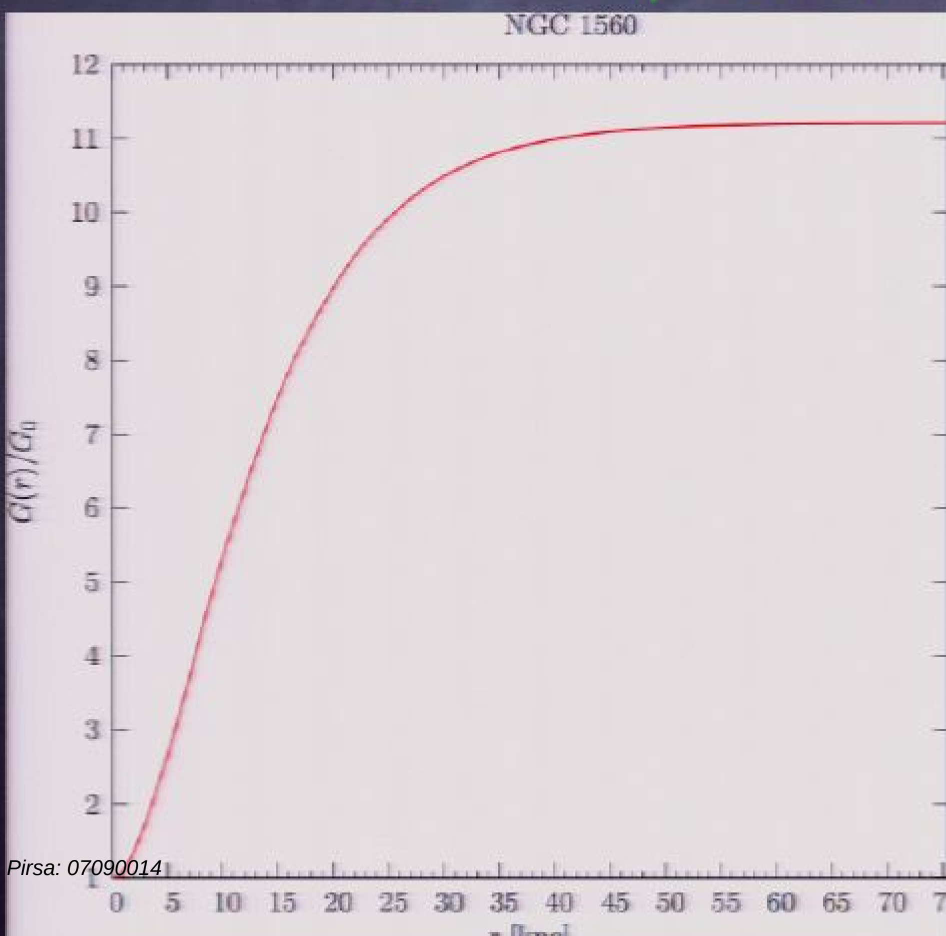

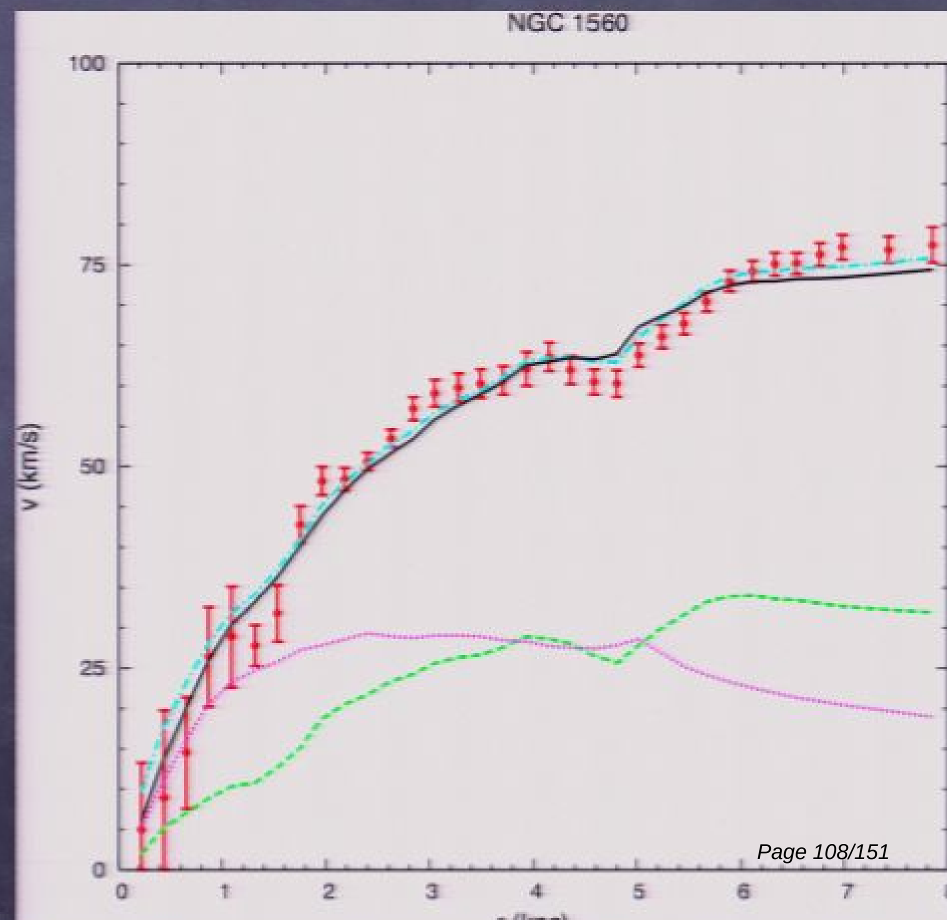

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- Astrophys. J. 636 (2006) 721-74 astro-ph/0506370

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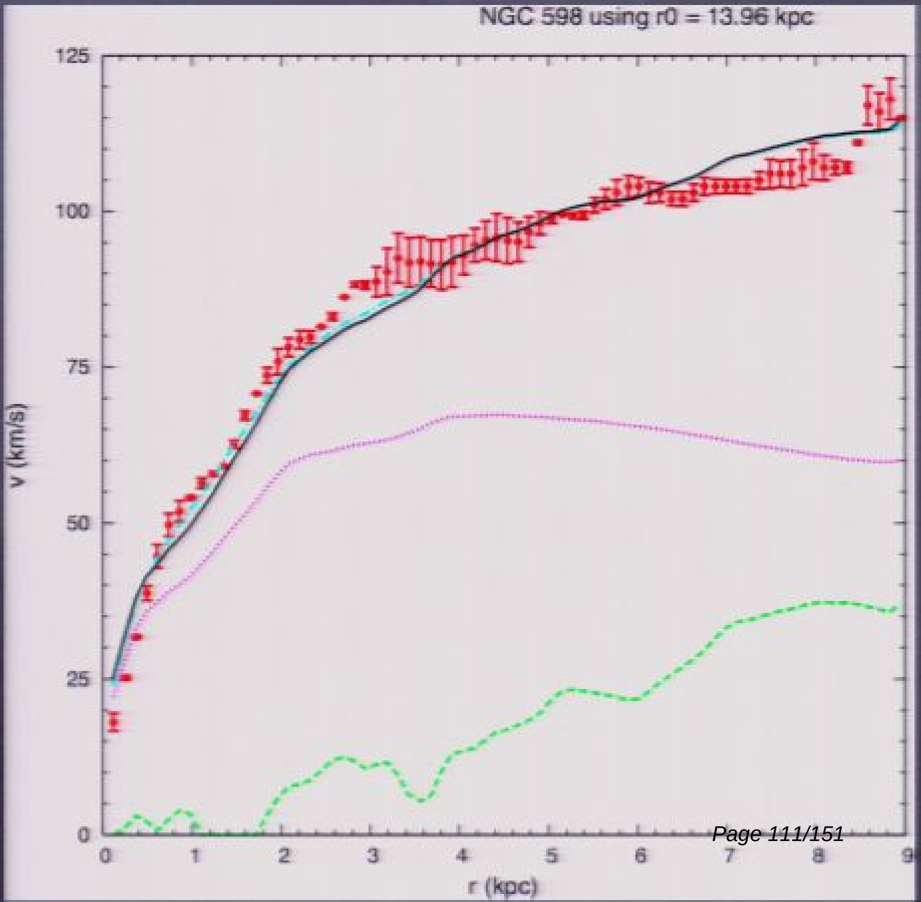

Astrophys. J. 636 (2006) 721-74 astro-ph/0506370

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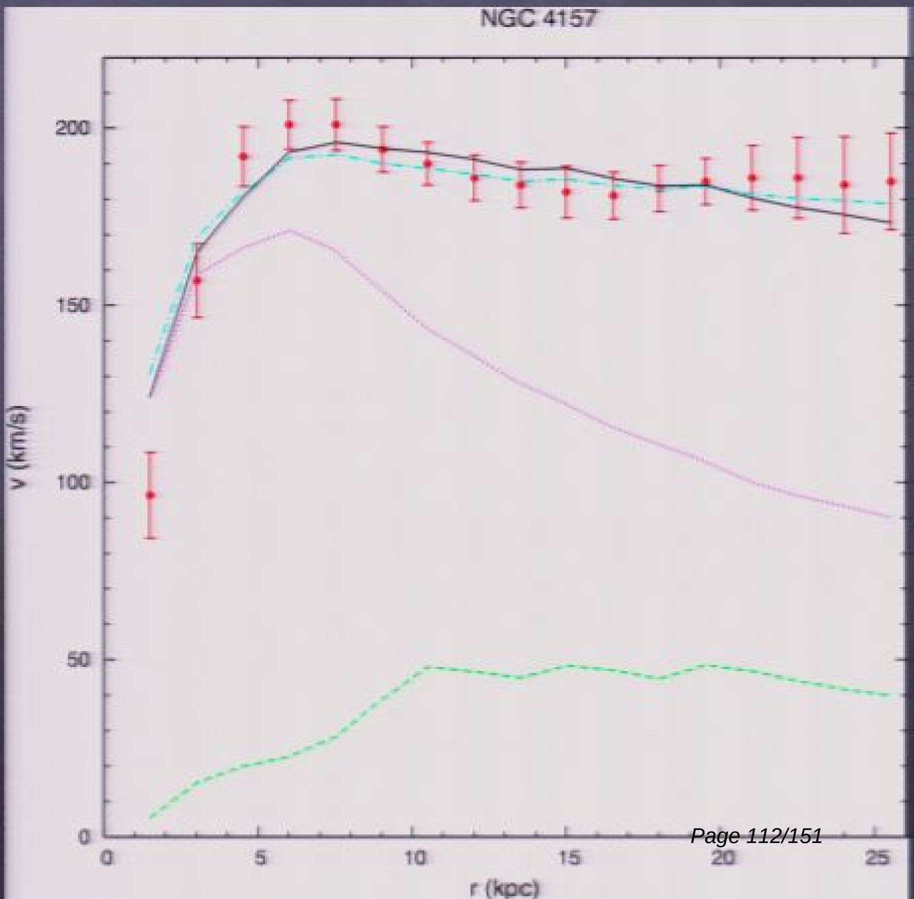

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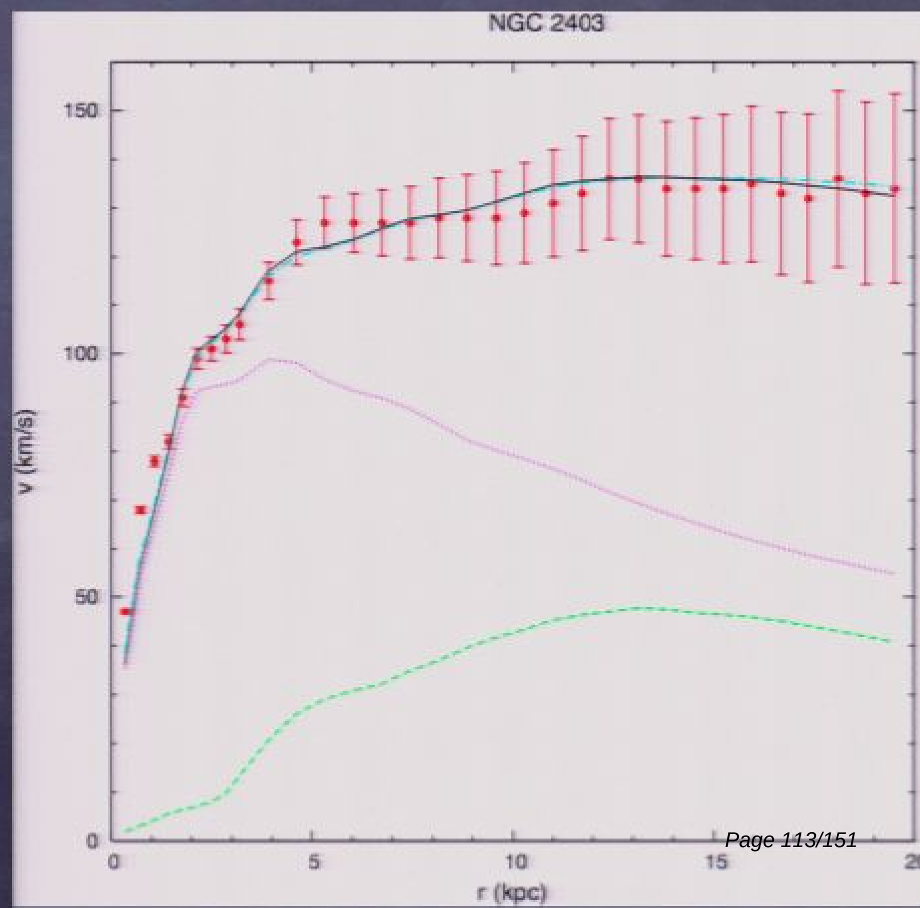

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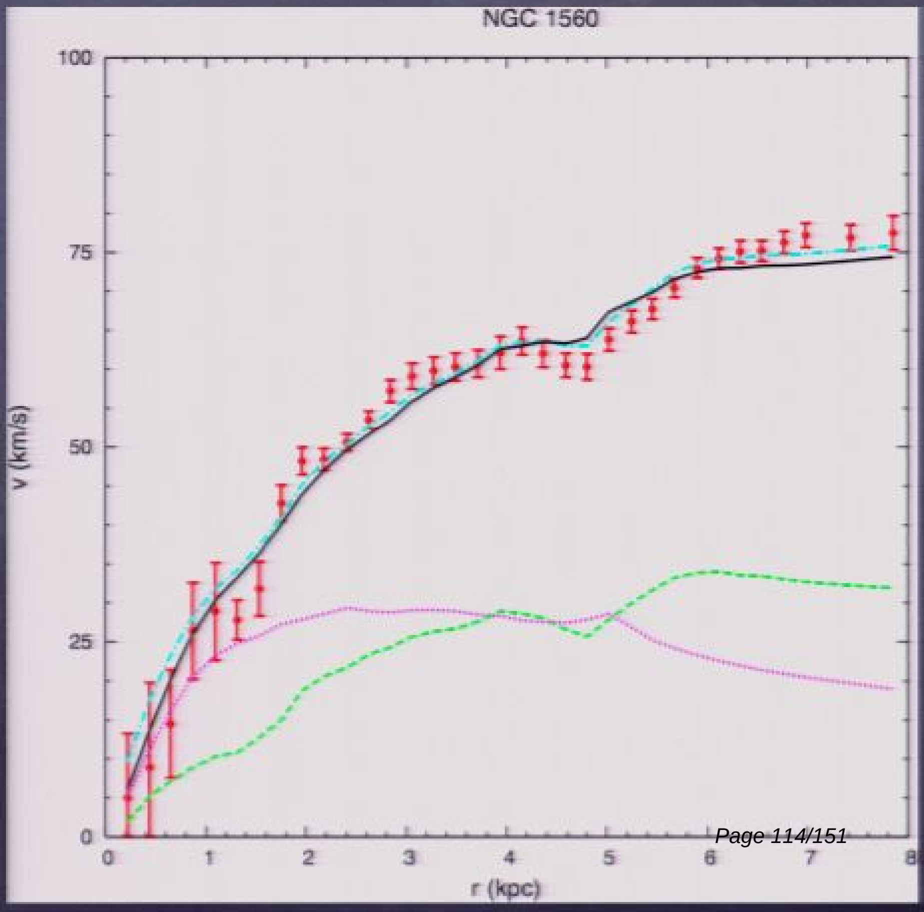

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Galaxy Cluster Masses

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Mon. Not. Roy. Astron. Soc. 367 (2006) 527-540 astro-ph/050722

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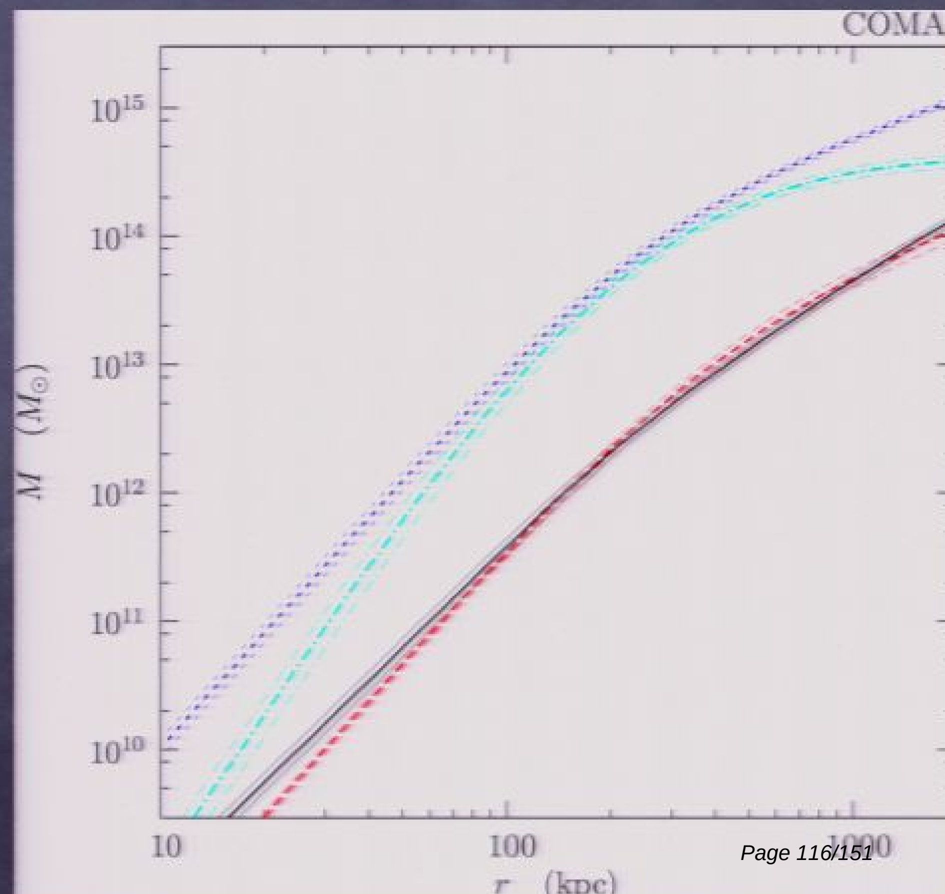

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Mon. Not. Roy. Astron. Soc. 367 (2006) 527-540 astro-ph/050722

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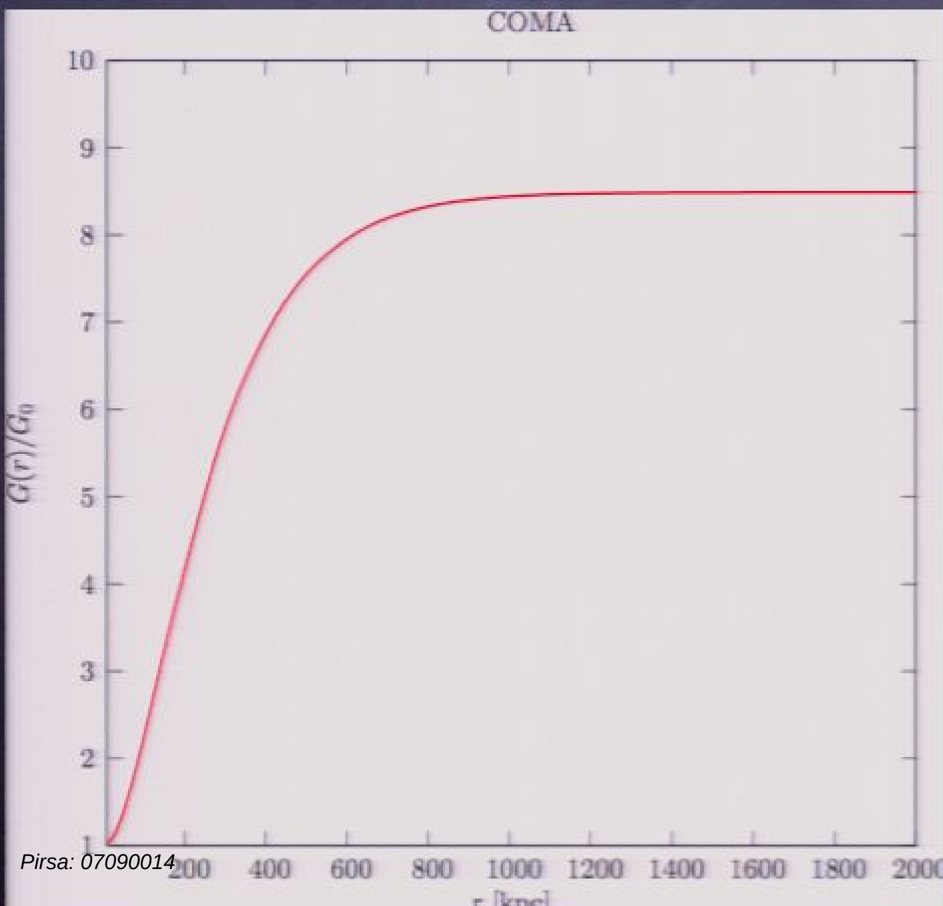

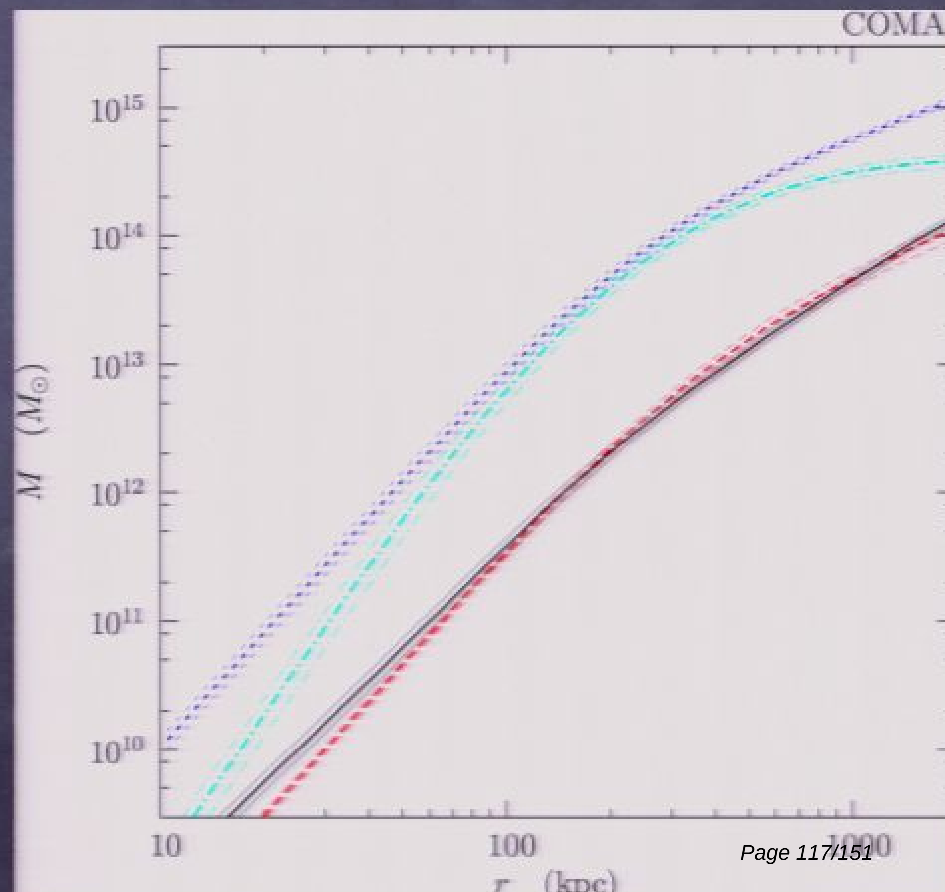

Pioneer 10/11 Anomaly

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Class. Quantum Grav. 23 (2006) 3427-3436 gr-qc/0511026

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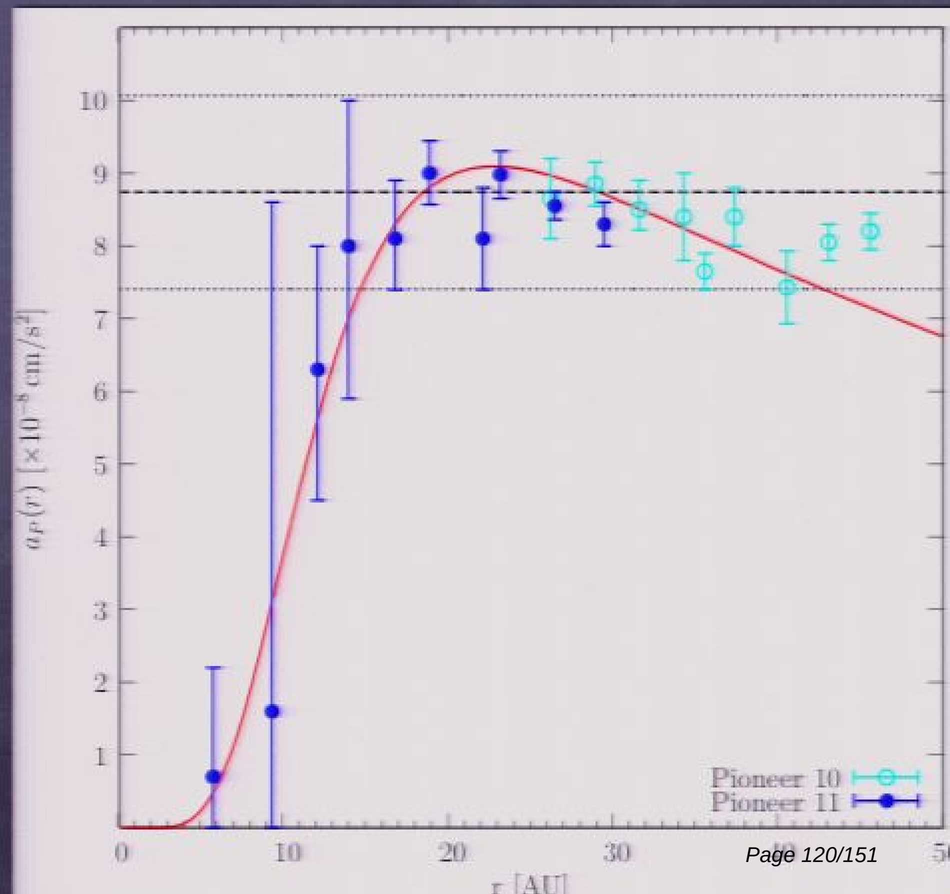

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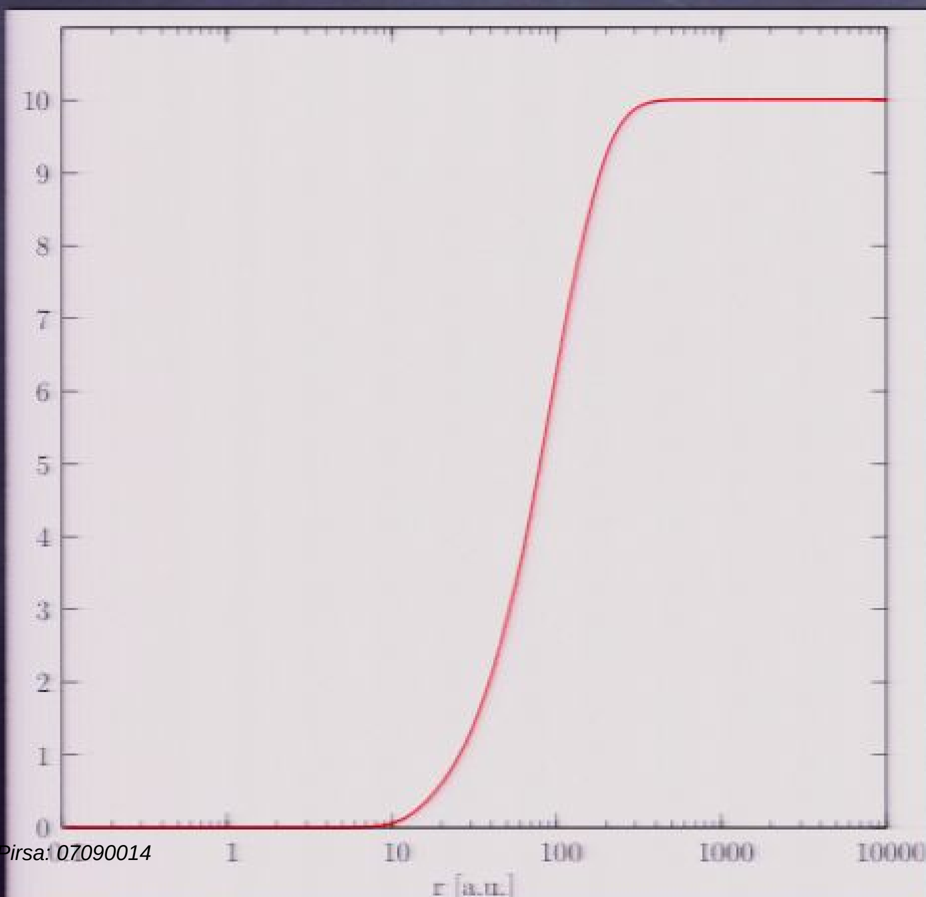

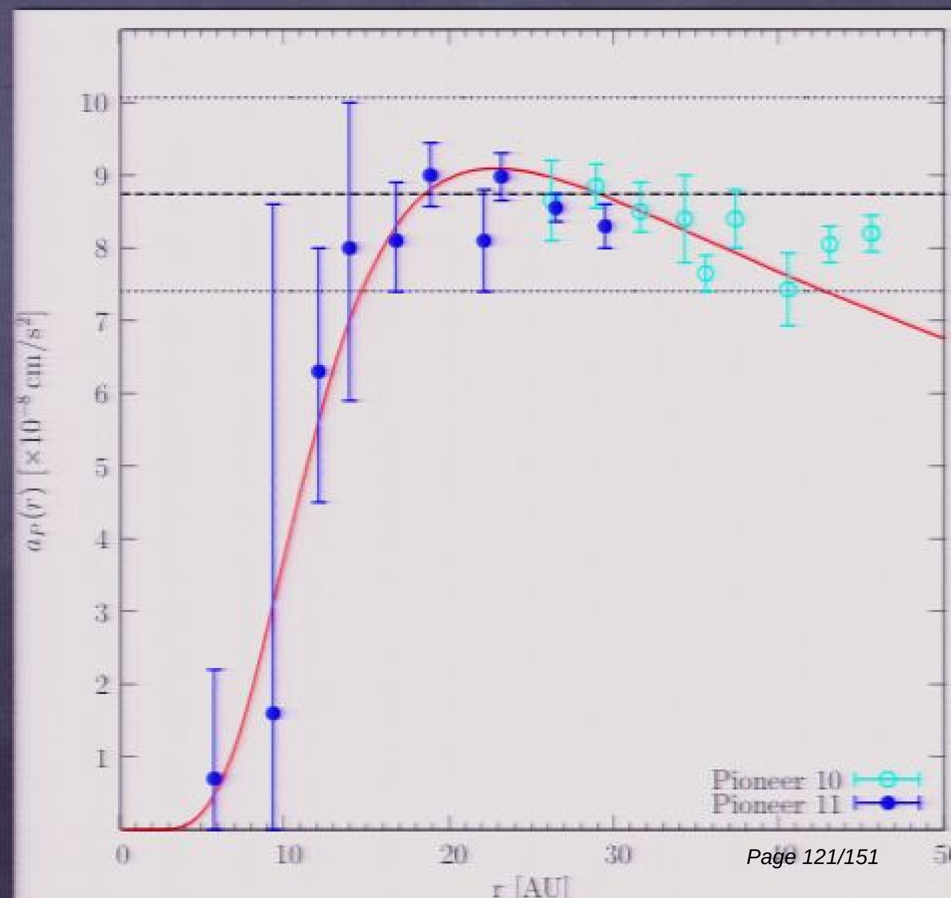

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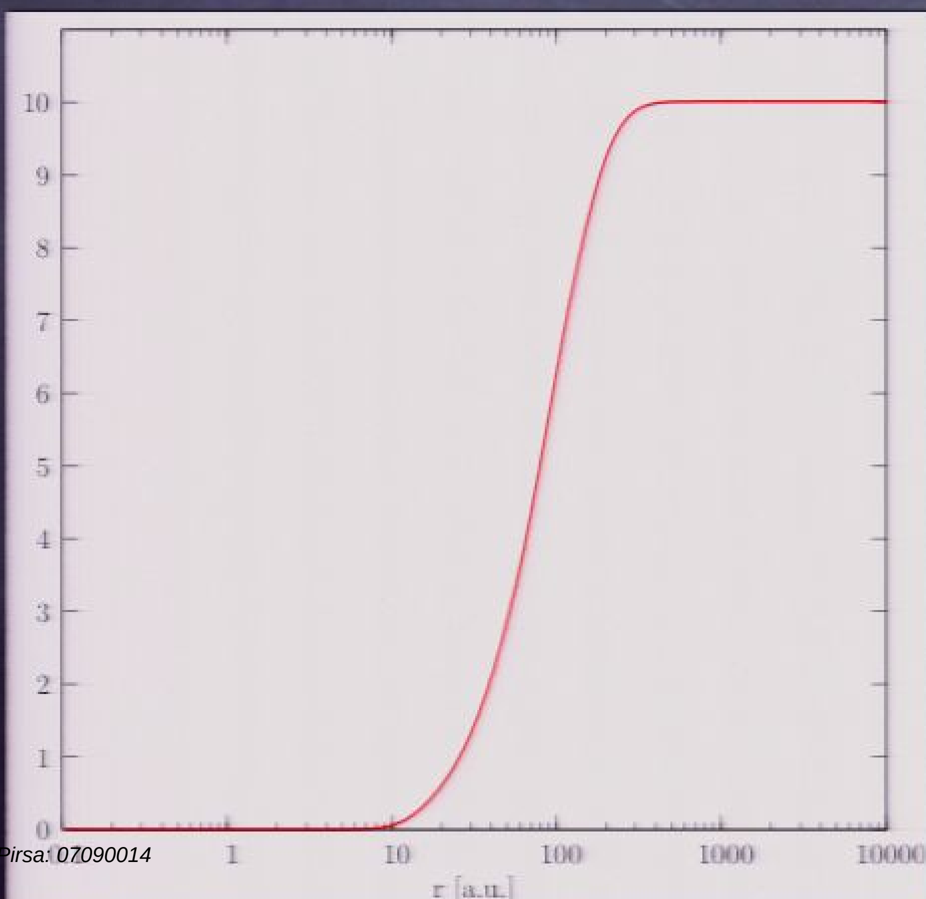

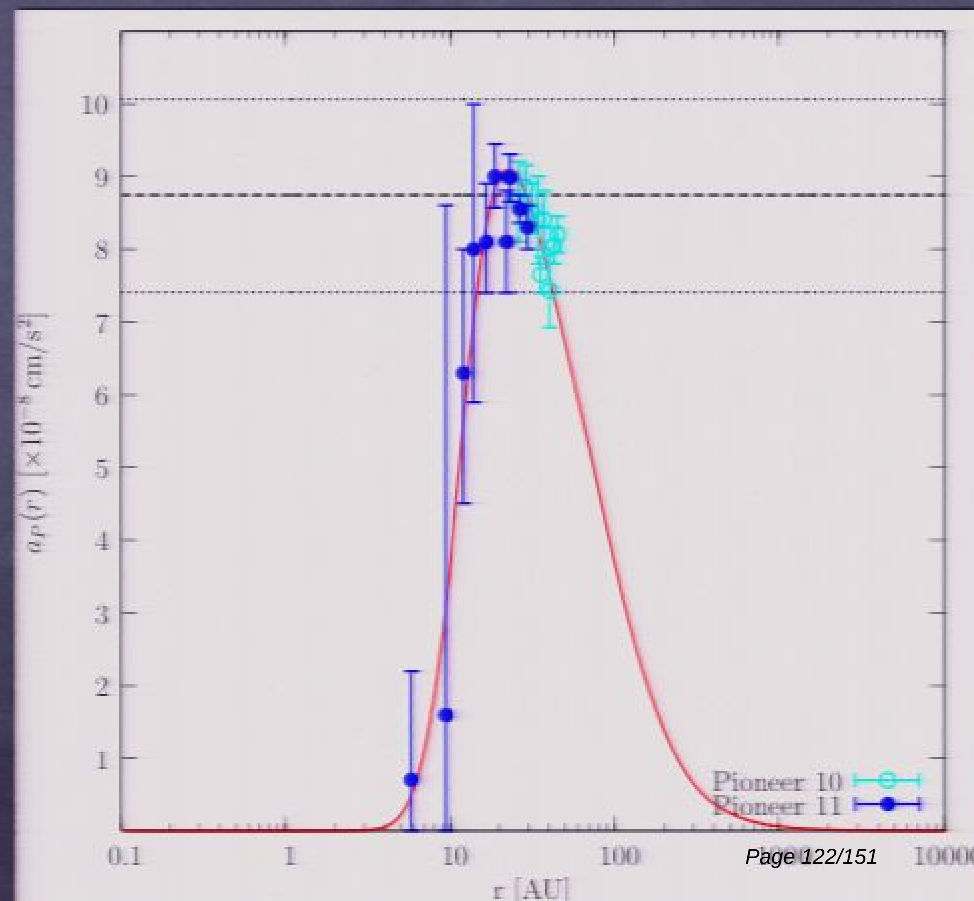

Bullet Cluster 1E0657-558

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- Mon. Not. Roy. Astron. Soc. accepted July 2007 astro-ph/0702146

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- Mon. Not. Roy. Astron. Soc. accepted July 2007 astro-ph/070214

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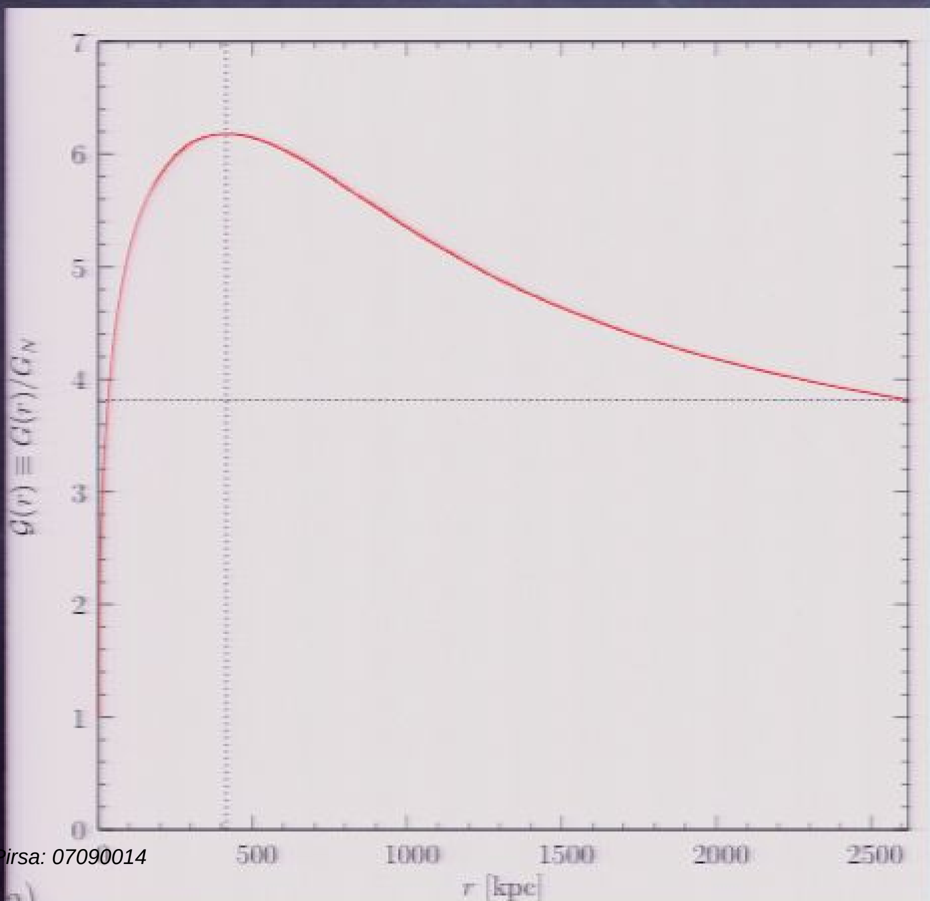

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- Mon. Not. Roy. Astron. Soc. accepted July 2007 astro-ph/070214

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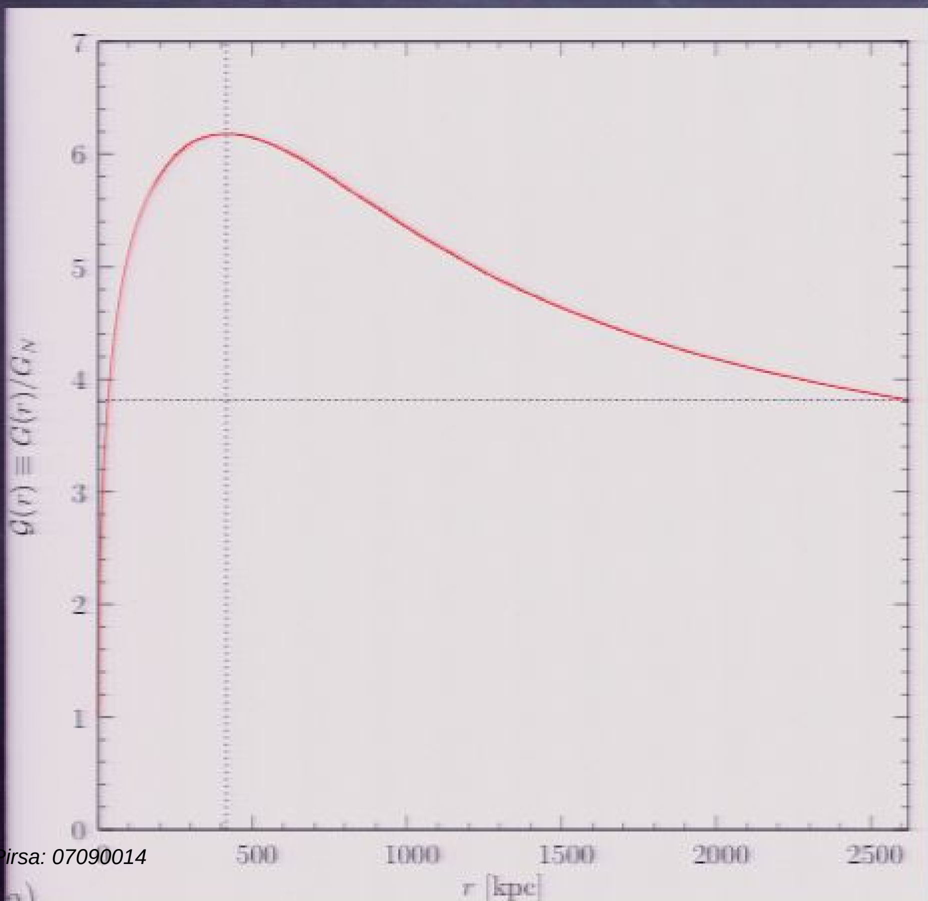

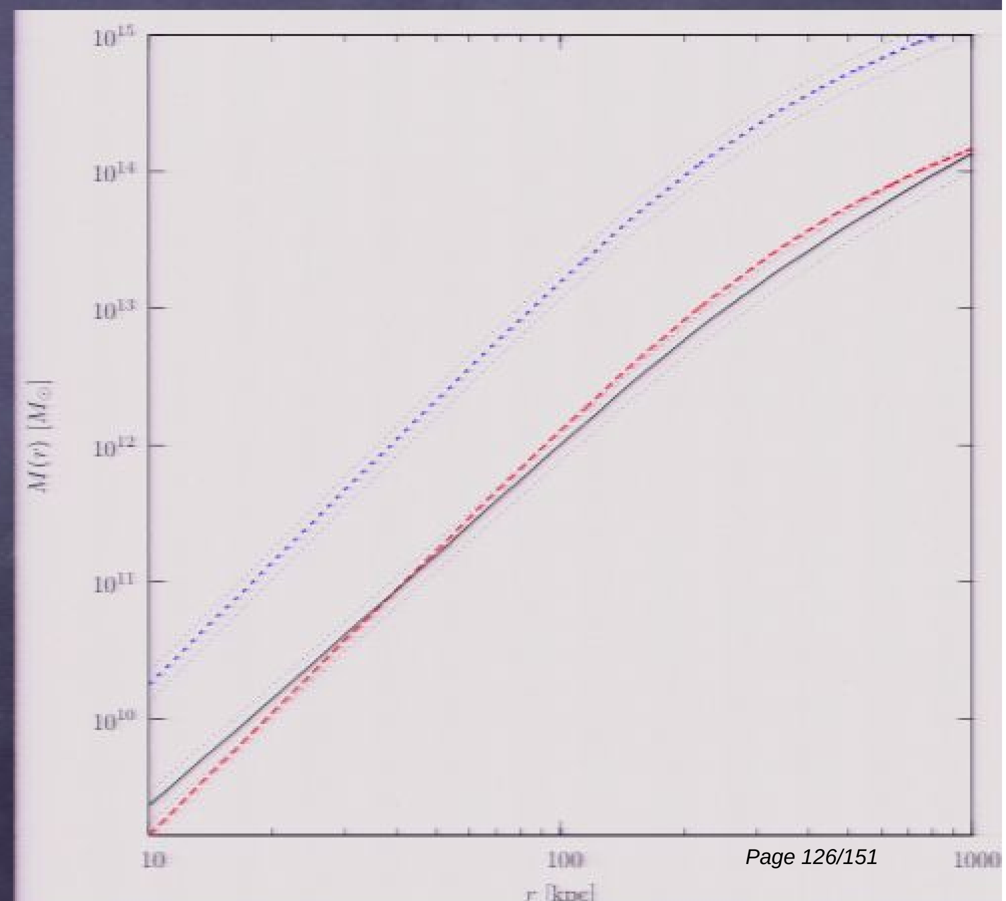

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Mon. Not. Roy. Astron. Soc. accepted July 2007 astro-ph/070214

Gravitational Lensing Eqns

In Einstein's general relativity, the local curvature is related to the distribution of mass/energy, as it is in MOG. In Newtonian gravity theory the relationship between the κ-map and the surface mass density becomes very simple, allowing one to refer to κ as the scaled surface mass density:

$$\kappa(x, y) = \int \frac{4\pi G_N}{c^2} \frac{D_{\rm l} D_{\rm ls}}{D_{\rm s}} \rho(x, y, z) dz \equiv \frac{\Sigma}{\Sigma_c},$$
$$\Sigma(x, y) = \int \rho(x, y, z) dz,$$
$$\Sigma_c = \frac{c^2}{4\pi G_N} \frac{D_{\rm s}}{D_{\rm l} D_{\rm ls}} \approx 3.1 \times 10^9 \; M_\odot/{\rm kpc}^2$$

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Einstein → MOG

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$$\bar{\Sigma}(x,y) = \int \mathcal{G}(r)\rho(x,y,z)dz,$$

Conclusions

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- The halo, the CMB and the emergence of dark energy.

Conclusions

Observations (Analytic and Computations)

- The closer we get to undertanding the data, the more likely it seems that the dark matter question may be resolved dynamically (extra gravity).

Hypothesis

- Dominant non-baryonic dark matter is dynamically generated by gravitational degrees of freedom. Whereas dark matter is predicted by Newtonian gravity applied to galaxies and clusters, it may not be a non-baryonic source. The alternative of modified gravity (MOG) is a very successful phenomenology and may lead to a paradigm shift in the understanding of the contents and evolution of the Cosmos.

Implications and further predictions

- The halo, the CMB and the emergence of dark energy.

Recent Publications

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  J. R. Brownstein and J. W. Moffat, Class. Quantum Grav. 23 (2006) 3427-3436

  Galaxy Cluster Masses Without Non- Baryonic Dark Matter,
  J. R. Brownstein and J. W. Moffat, Mon. Not. Roy. Astron. Soc. 367 (2006) 527-540

- Galaxy Rotation Curves Without Non-Baryonic Dark Matter,
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- Galaxy Cluster Masses Without Non- Baryonic Dark Matter, J. R. Brownstein and J. W. Moffat, Mon. Not. Roy. Astron. Soc. 367 (2006) 527-540 astro-ph/0507222
- Galaxy Rotation Curves Without Non-Baryonic Dark Matter, J. R. Brownstein and J. W. Moffat, Astrophys. J. 636 (2006) 721-74 astro-ph/0506370

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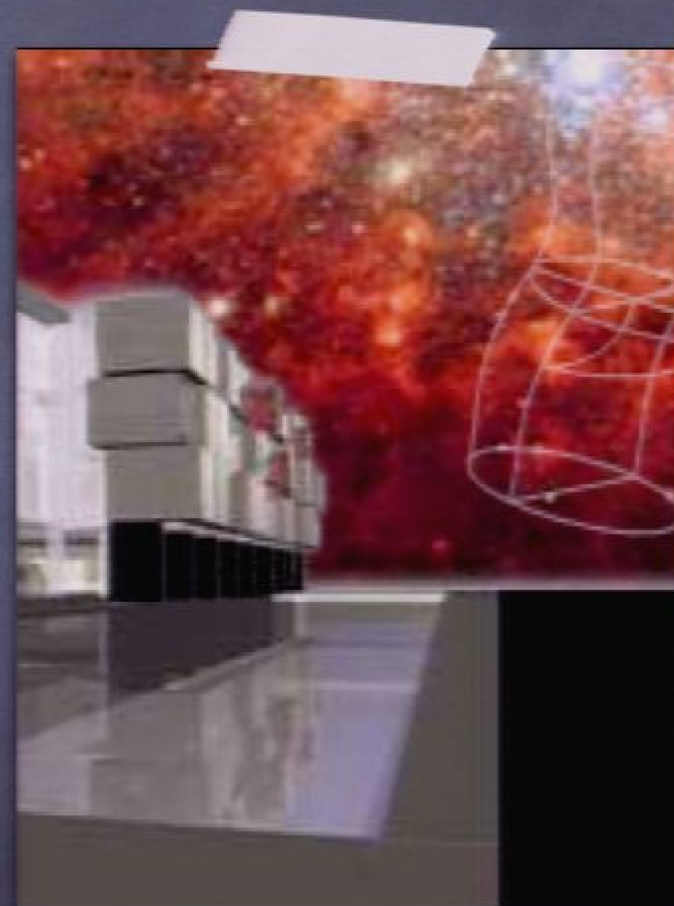

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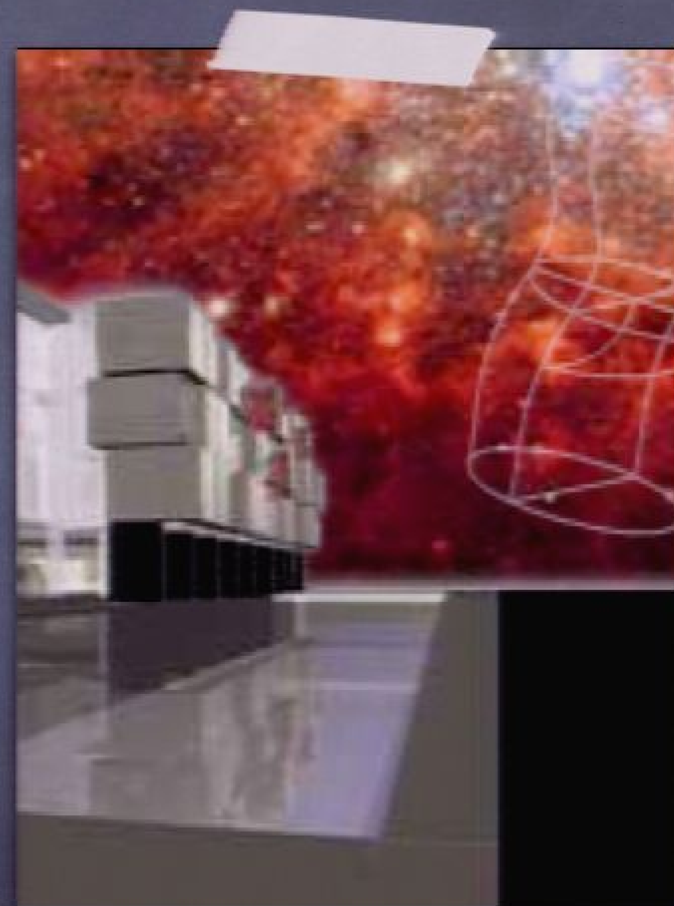

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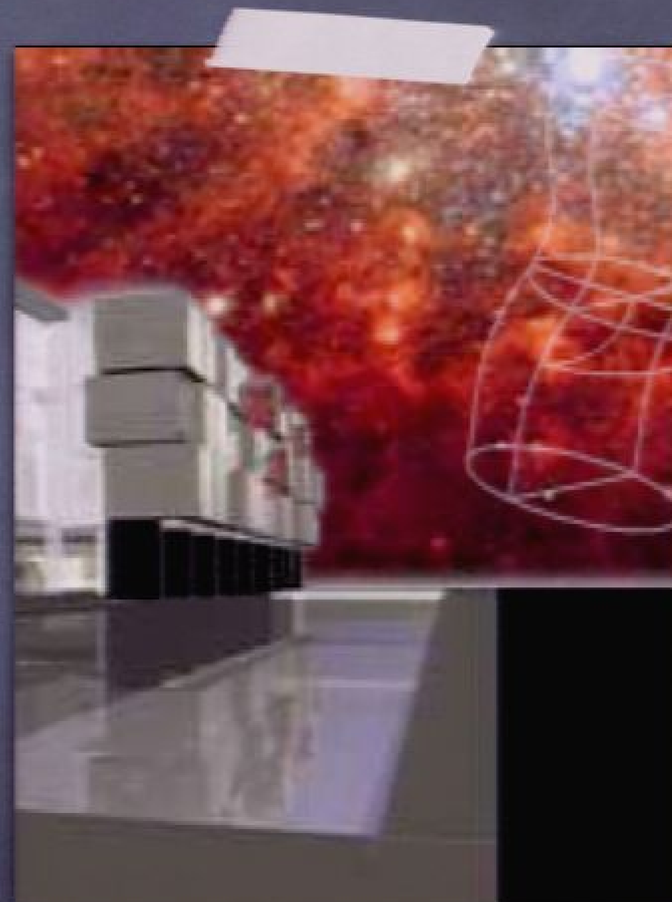

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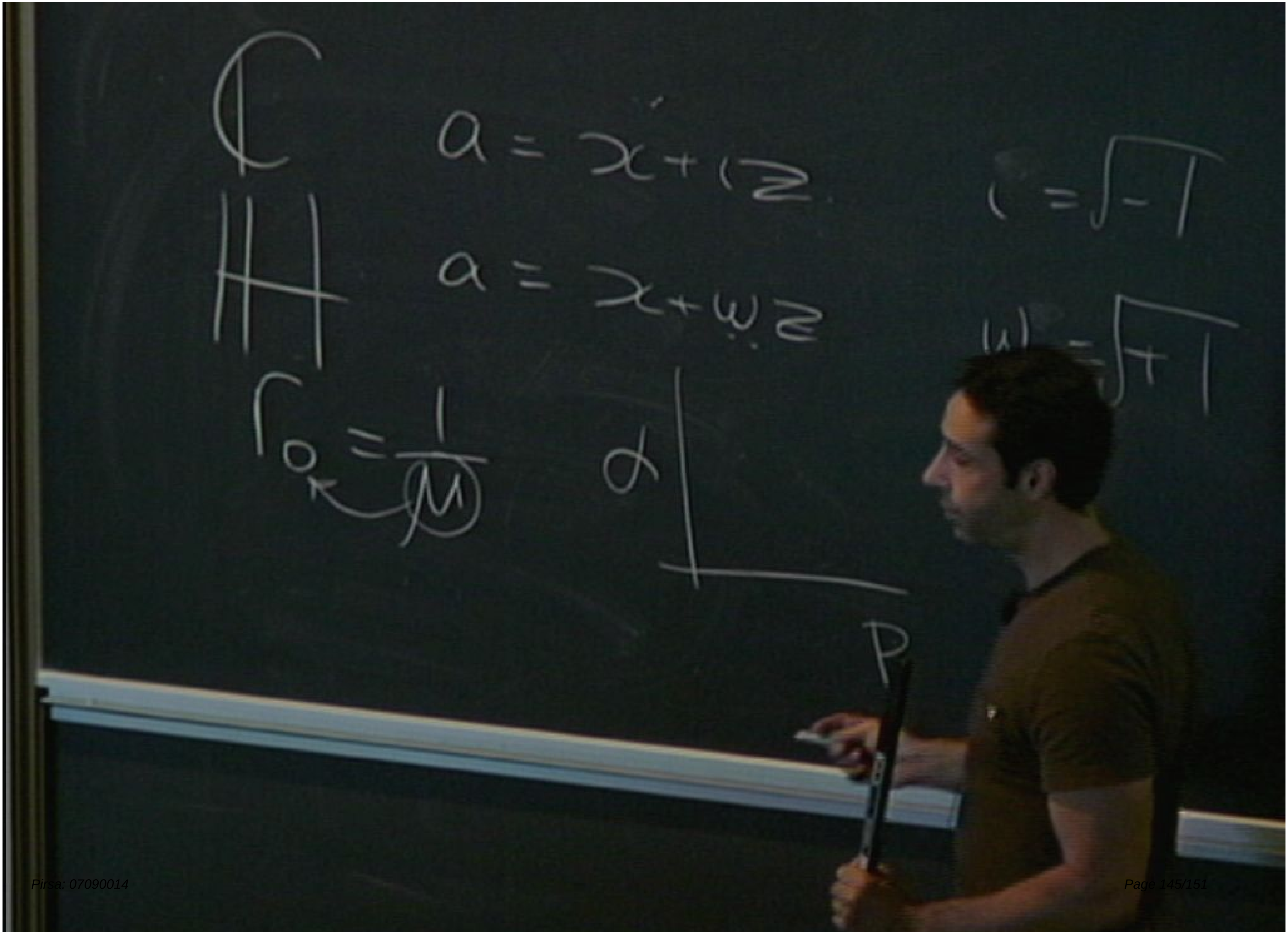
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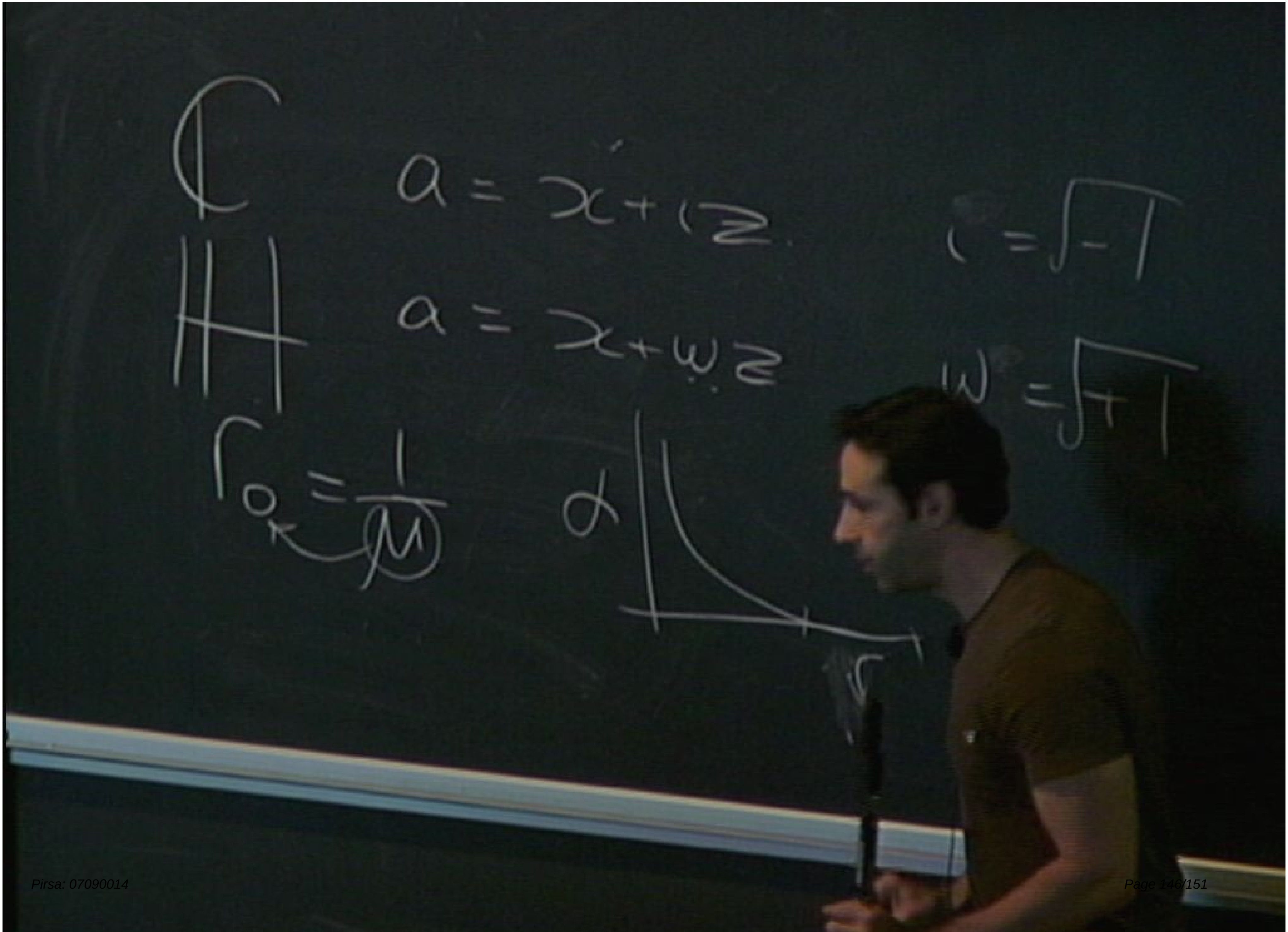
ℍ a = x + ωz
ω = √+1
r₀ = 1/M
α
P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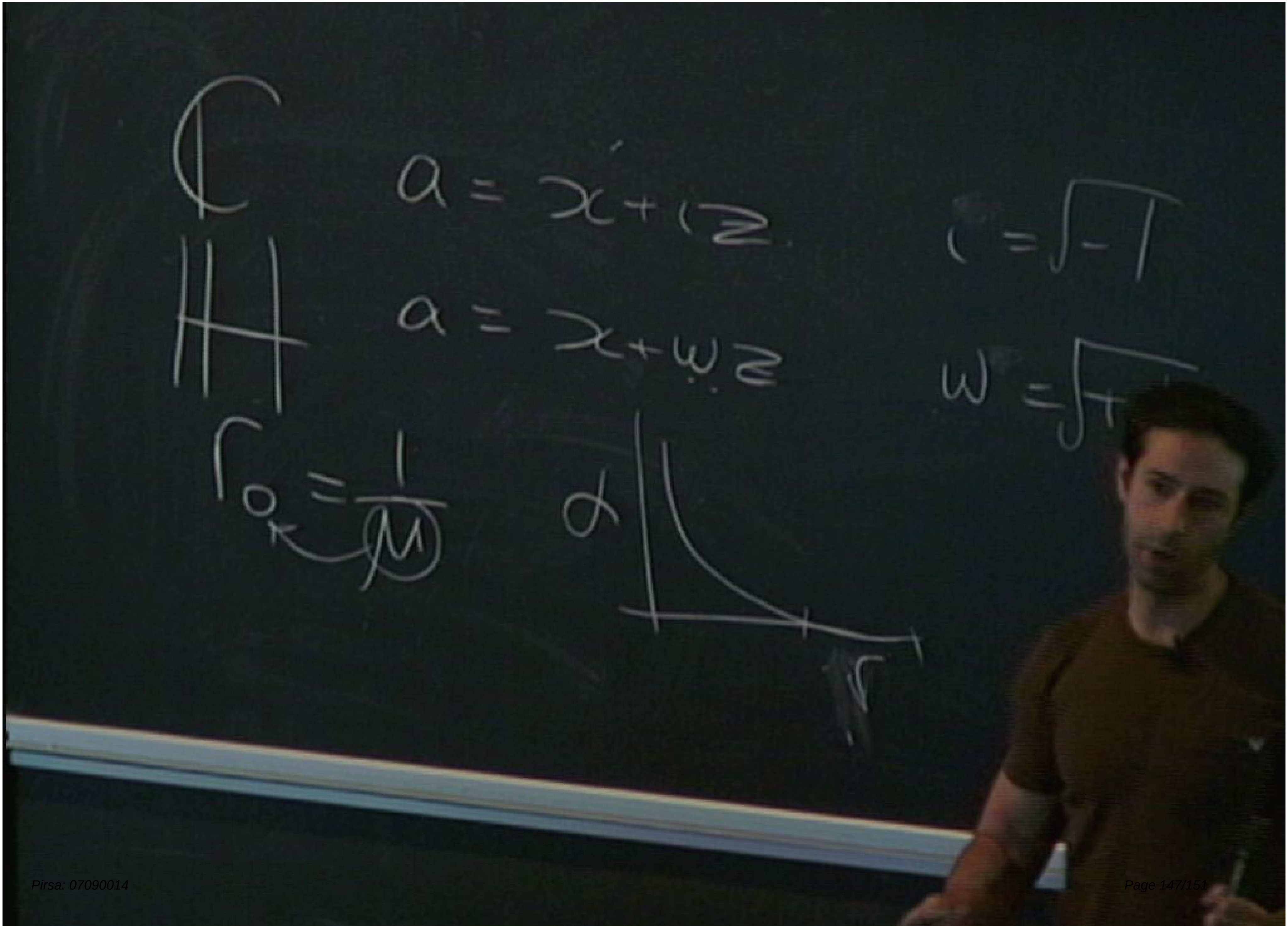
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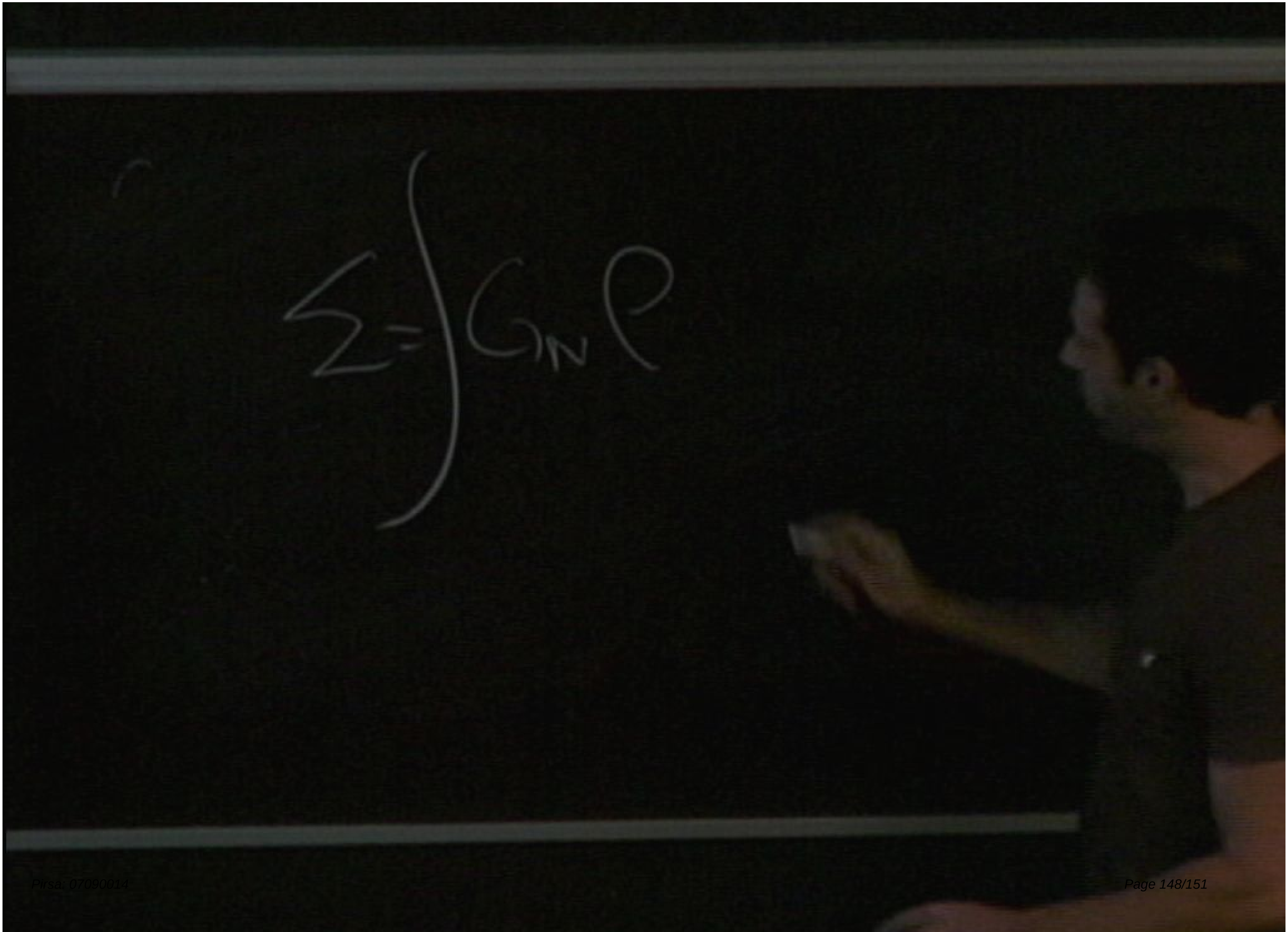
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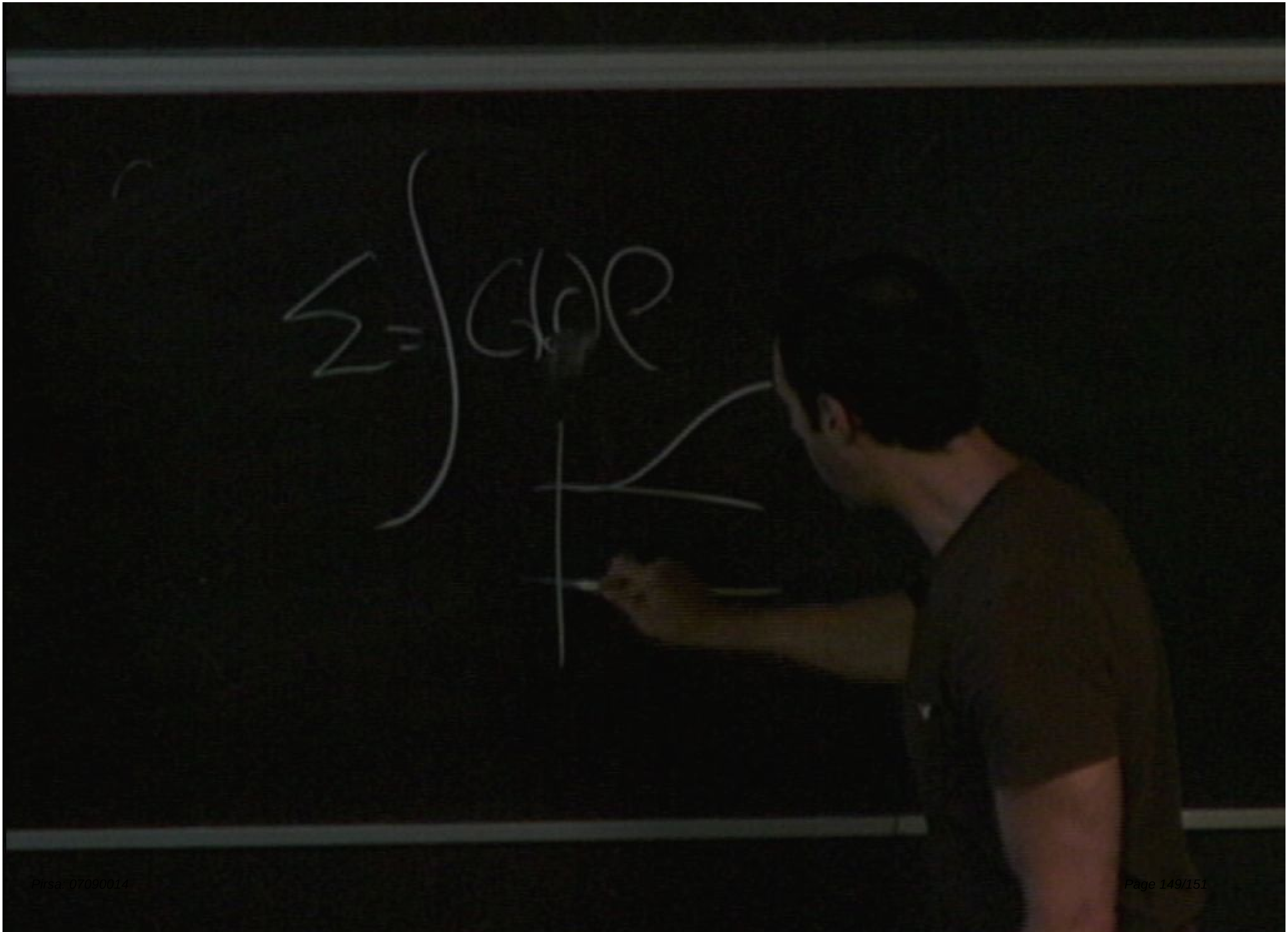
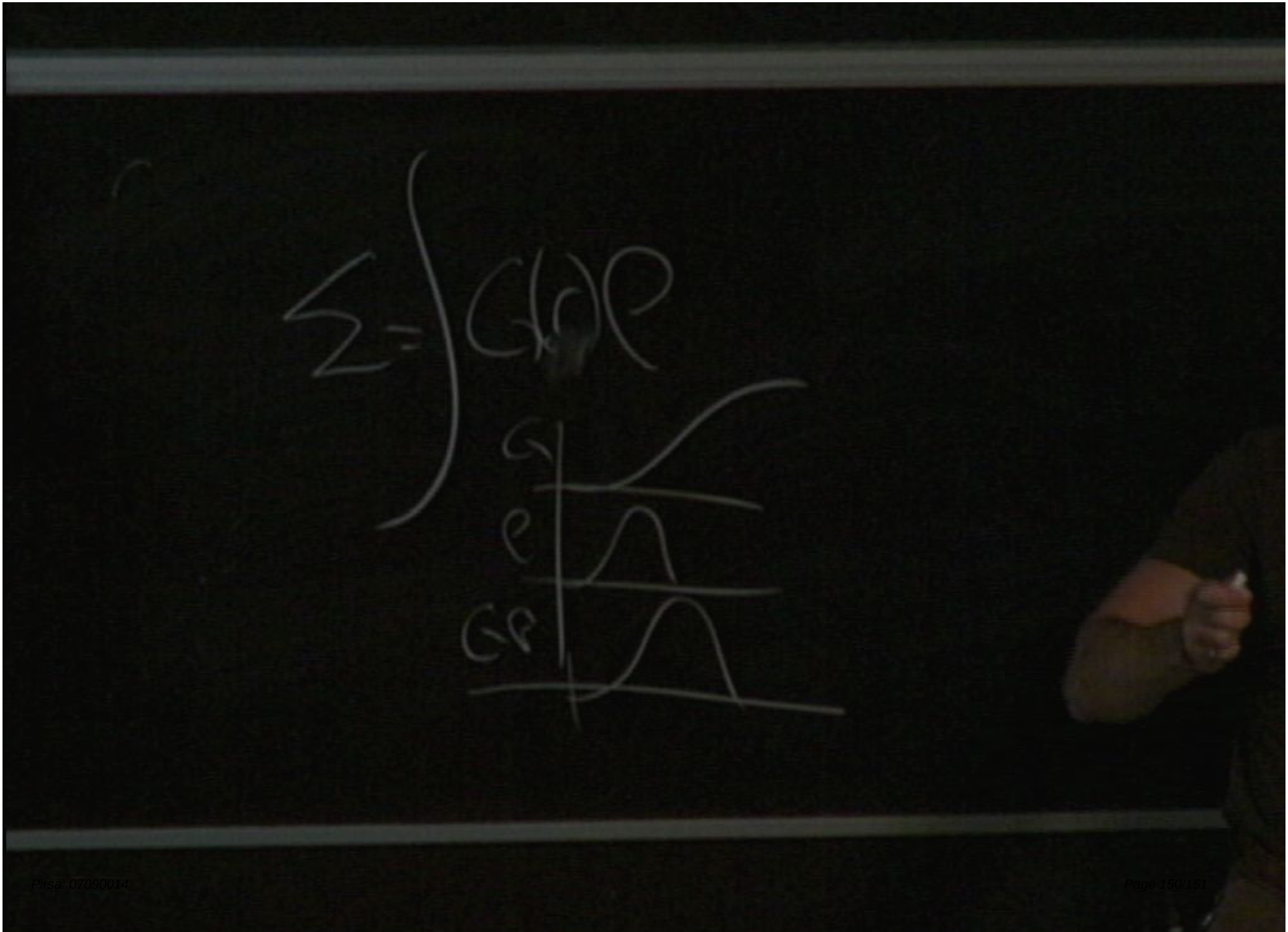
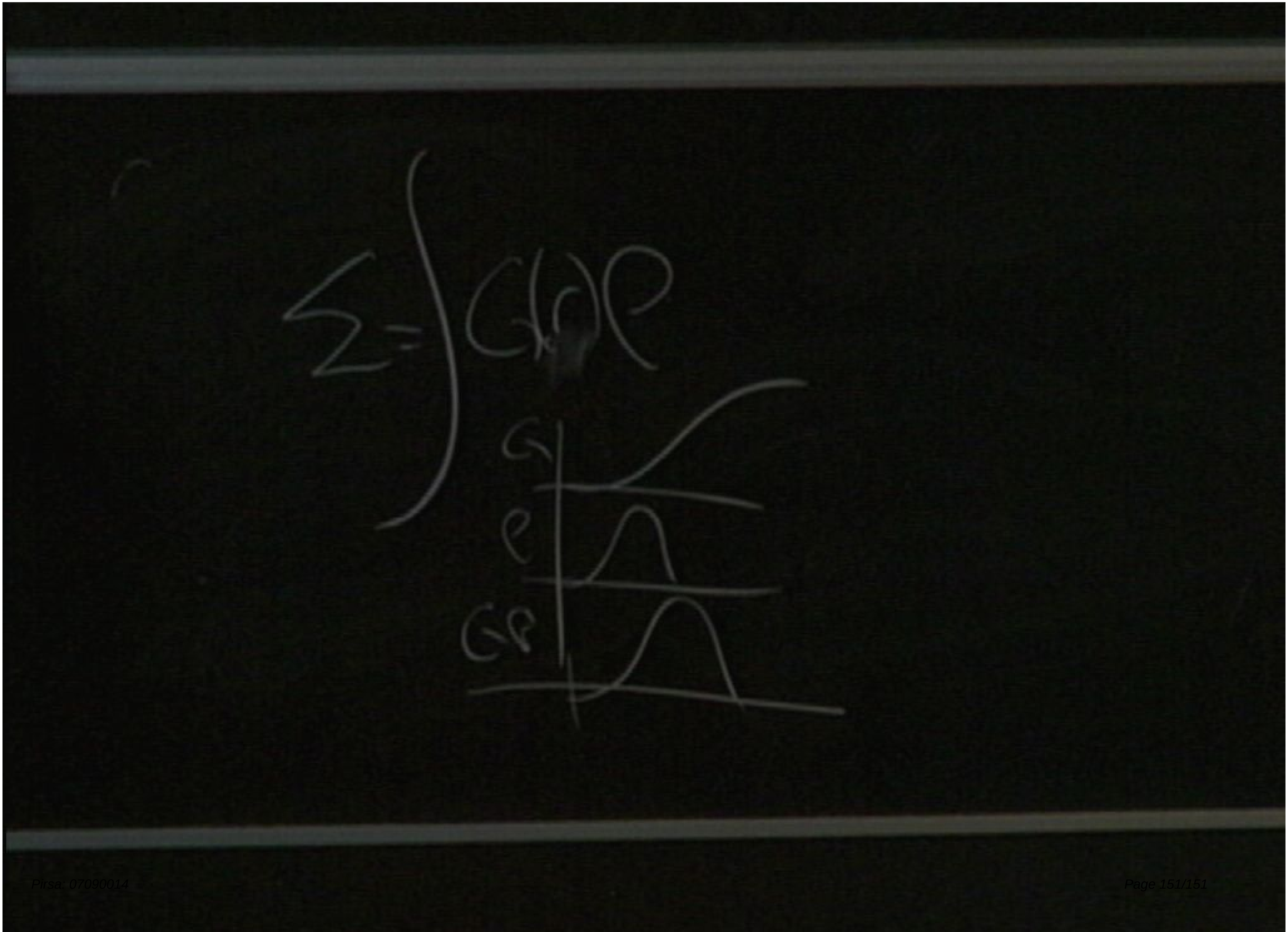



Z = ∫ G(x)P
G
P
GP


Σ = ∫ G(k) P
G
P
GP