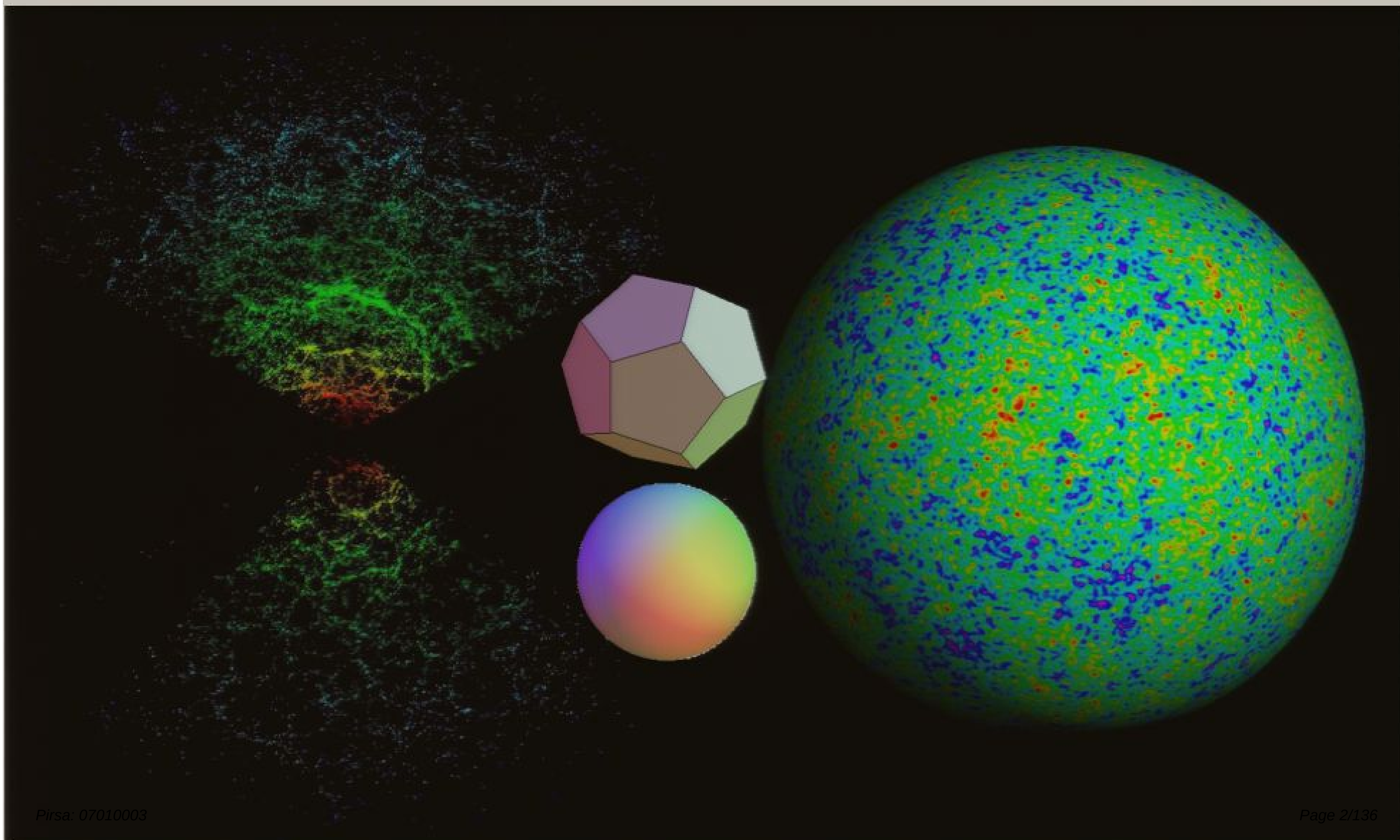
Title: The Mathematical Universe

Date: Jan 31, 2007 02:00 PM

URL: http://pirsa.org/07010003

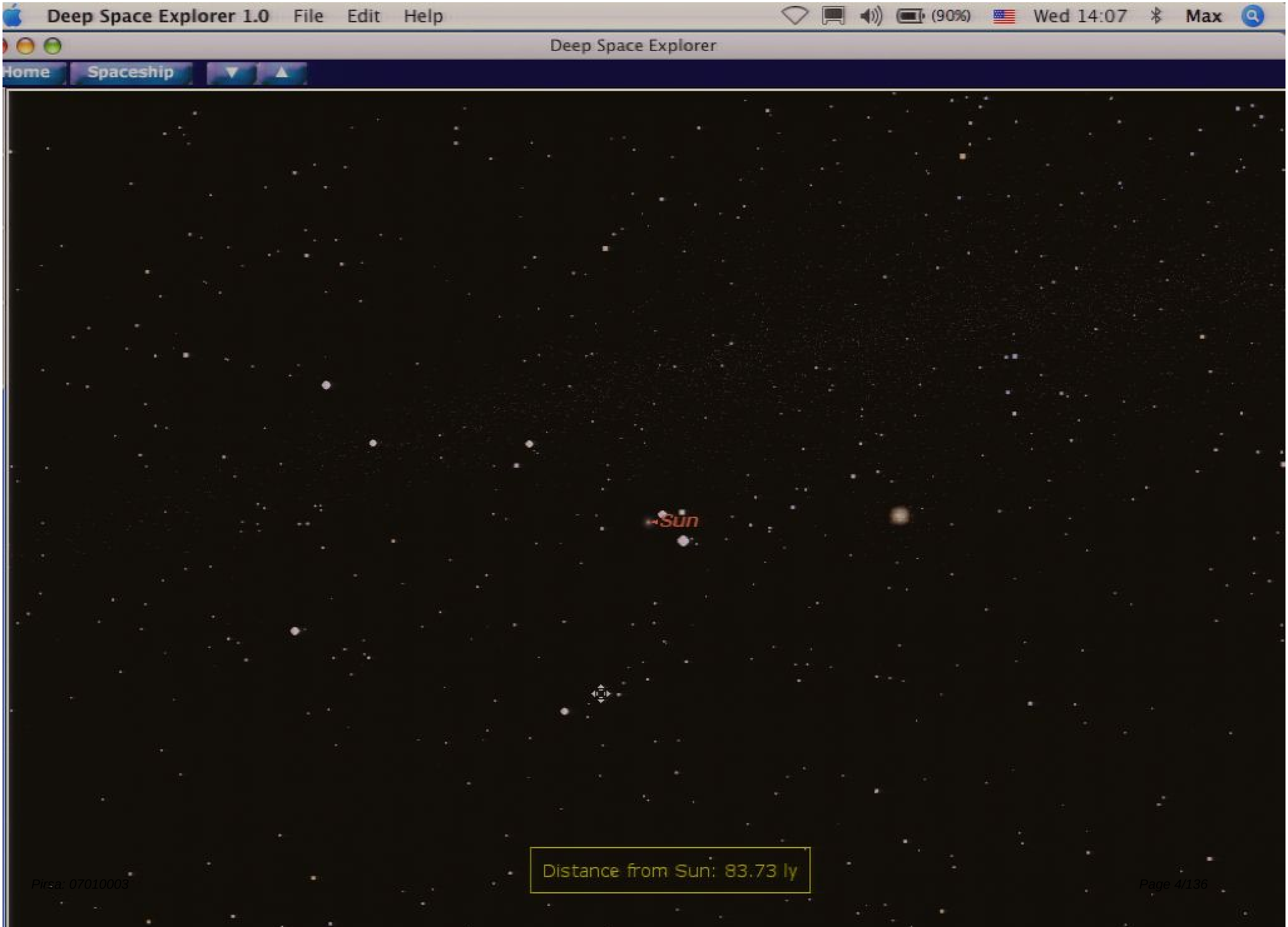
Abstract: With a cosmic flight simulator, we'll take a scenic journey through space and time. After exploring our local Galactic neighborhood, we'll travel back 13.7 billion years to explore the Big Bang itself and how state-of-the-art measurements are transforming our understanding of our cosmic origin and ultimate fate. We then turn to the question of whether this can all be described purely mathematically, and discuss implications ranging from standard physics topics like symmetries, irreducible representations, units, free parameters and initial conditions to broader issues like parallel universes, simulations and and Goedel incompleteness.

The Mathematical Universe



Max Tegmark, MIT

OUR PLACE IN SPACE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Deep Space Explorer
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Spaceship
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ptune
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Deep Space Explorer
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Spaceship
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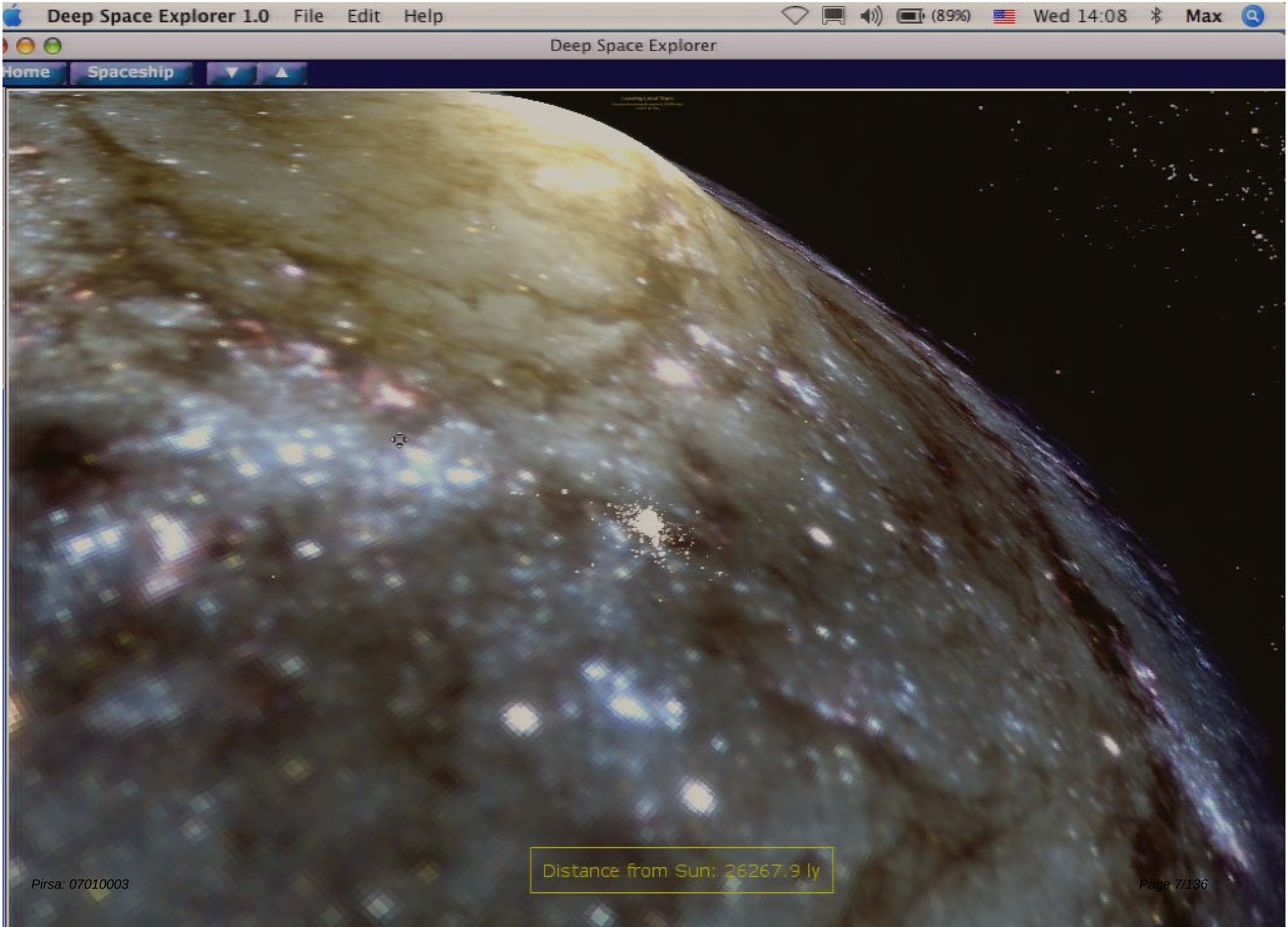
The catalog contains some 30,000 stars near the Sun.
Sun
Distance from Sun: 8.926 ly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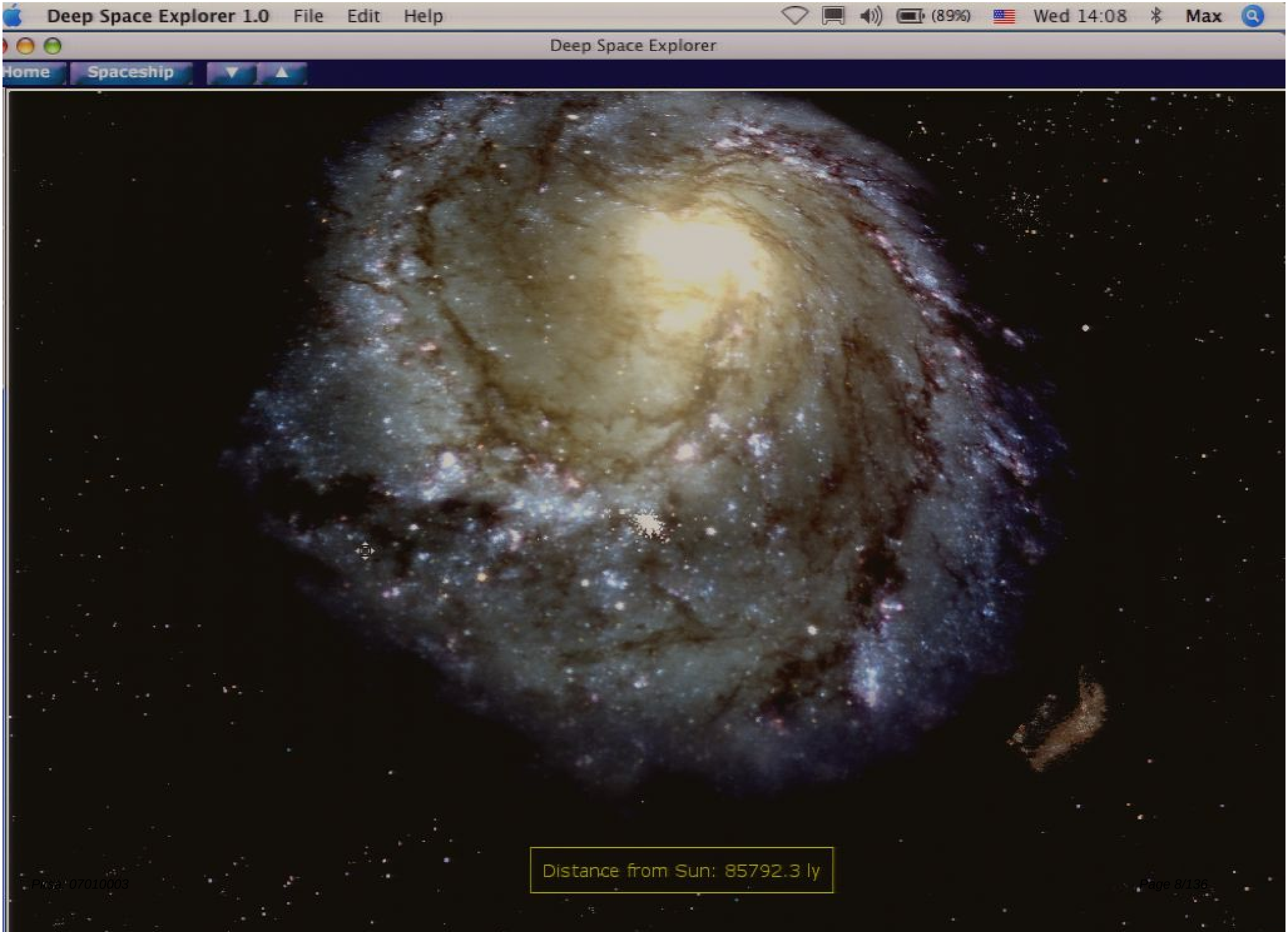
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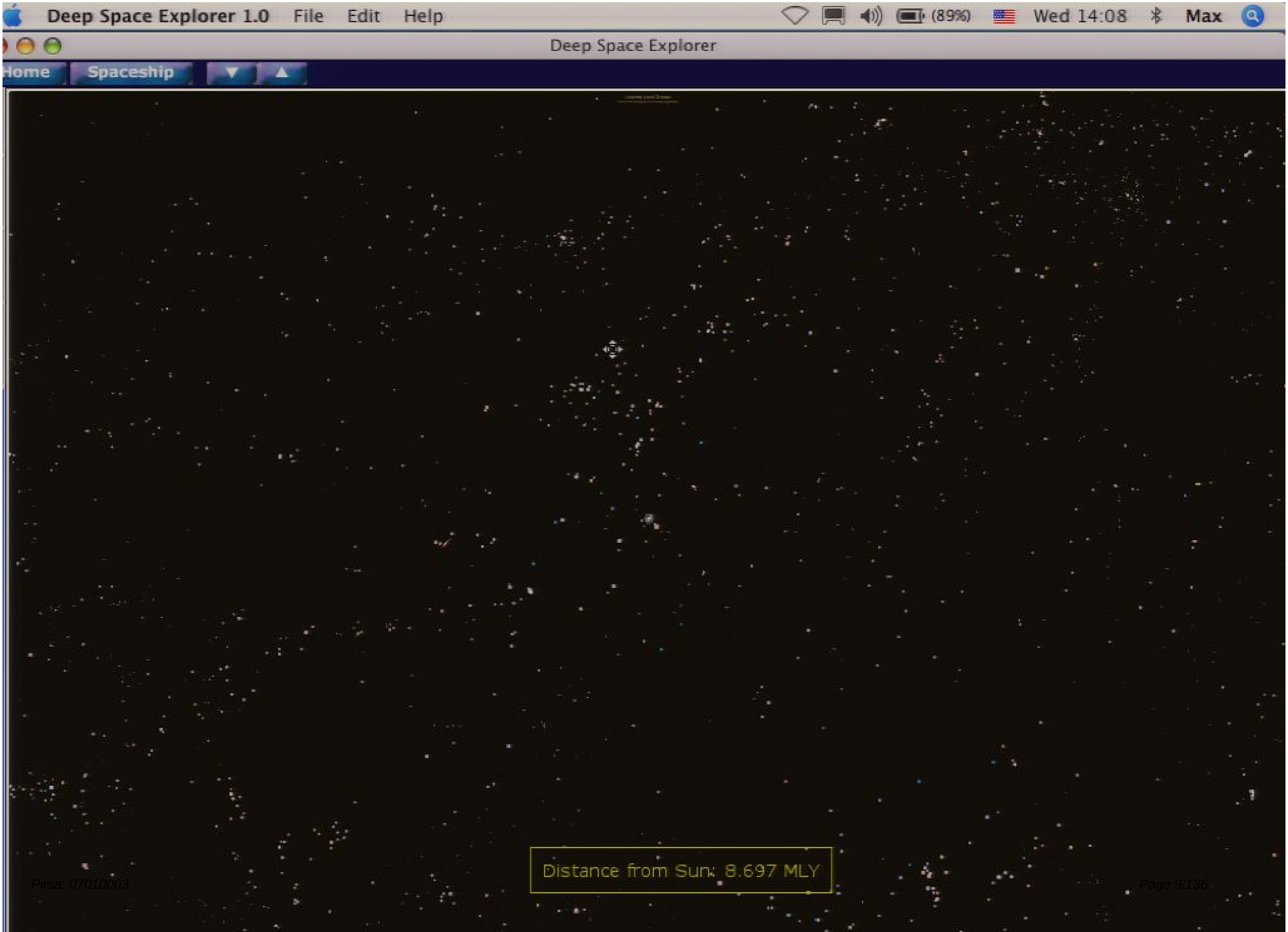
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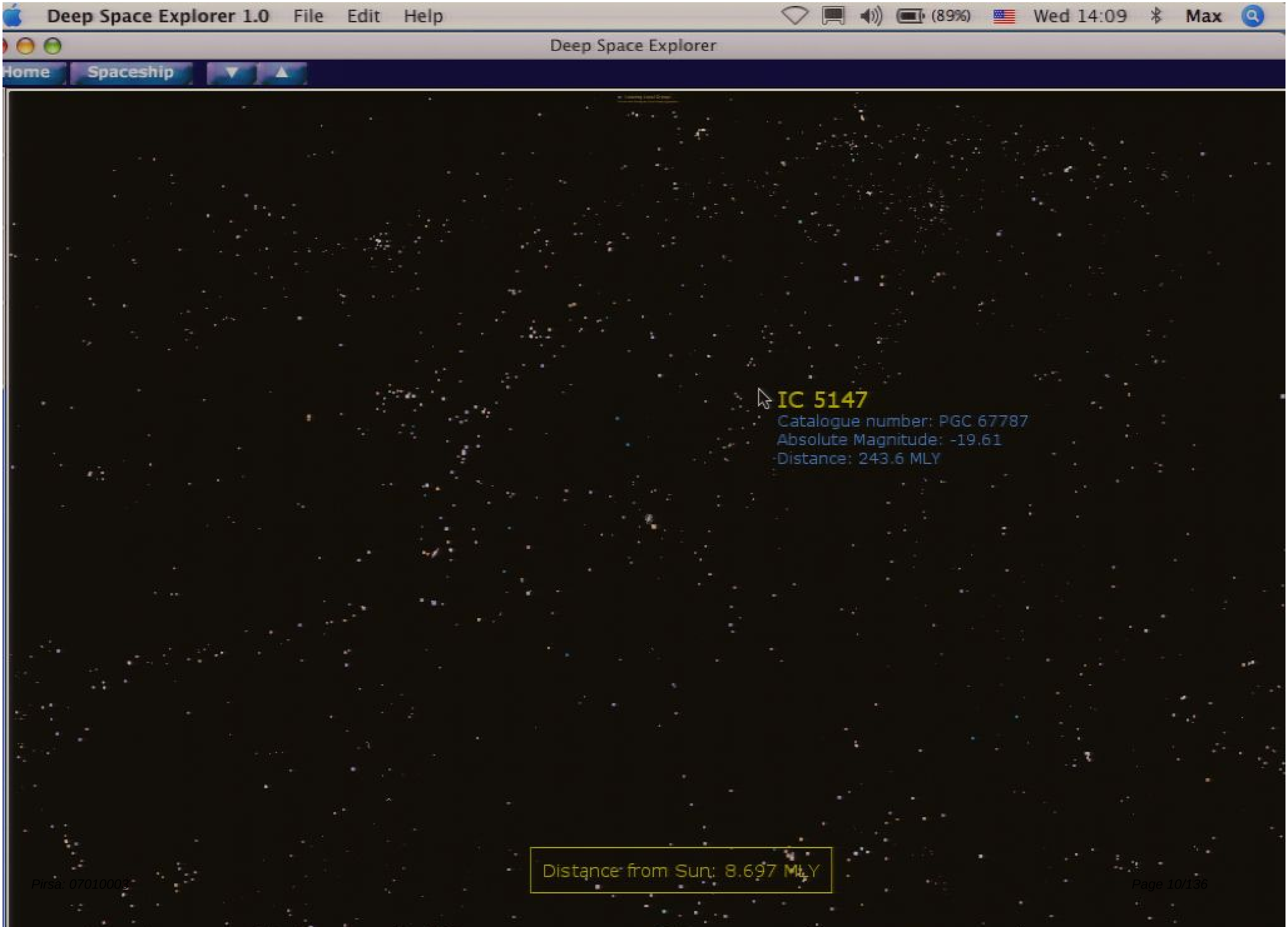
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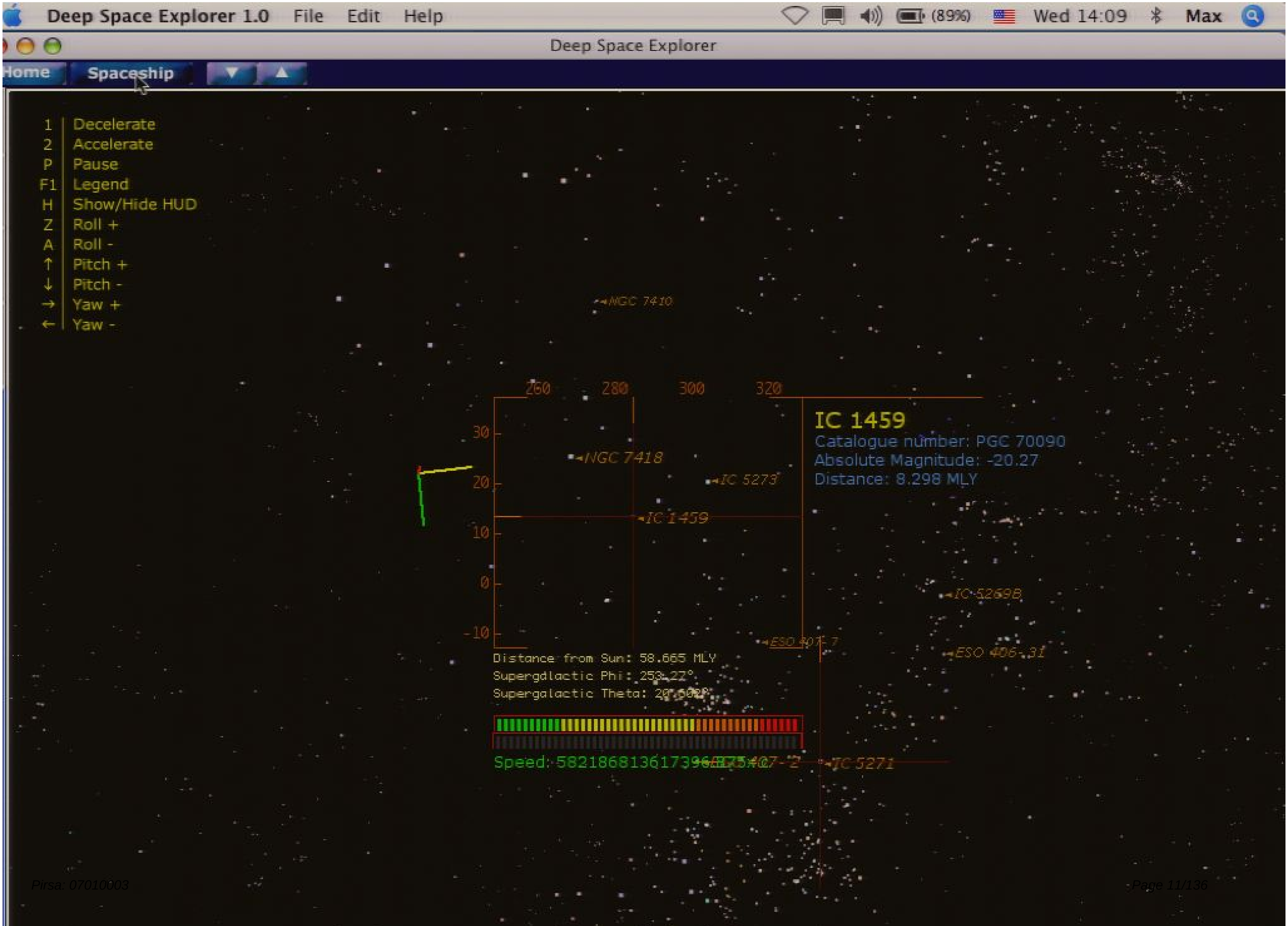
Absolute Magnitude: -19.61
Distance: 243.6 MLY
Distance from Sun: 8.697 MLY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Deep Space Explorer
Home
Spaceship
1 Decelerate
2 Accelerate
P Pause
F1 Legend
H Show/Hide HUD
Z Roll +
A Roll -
↑ Pitch +
↓ Pitch -
→ Yaw +
← Yaw -
NGC 7410
260 280 300 320
30
20
10
0
-10
NGC 7418
IC 5273
IC 1459
IC 1459
Catalogue number: PGC 70090
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ESO 406-31
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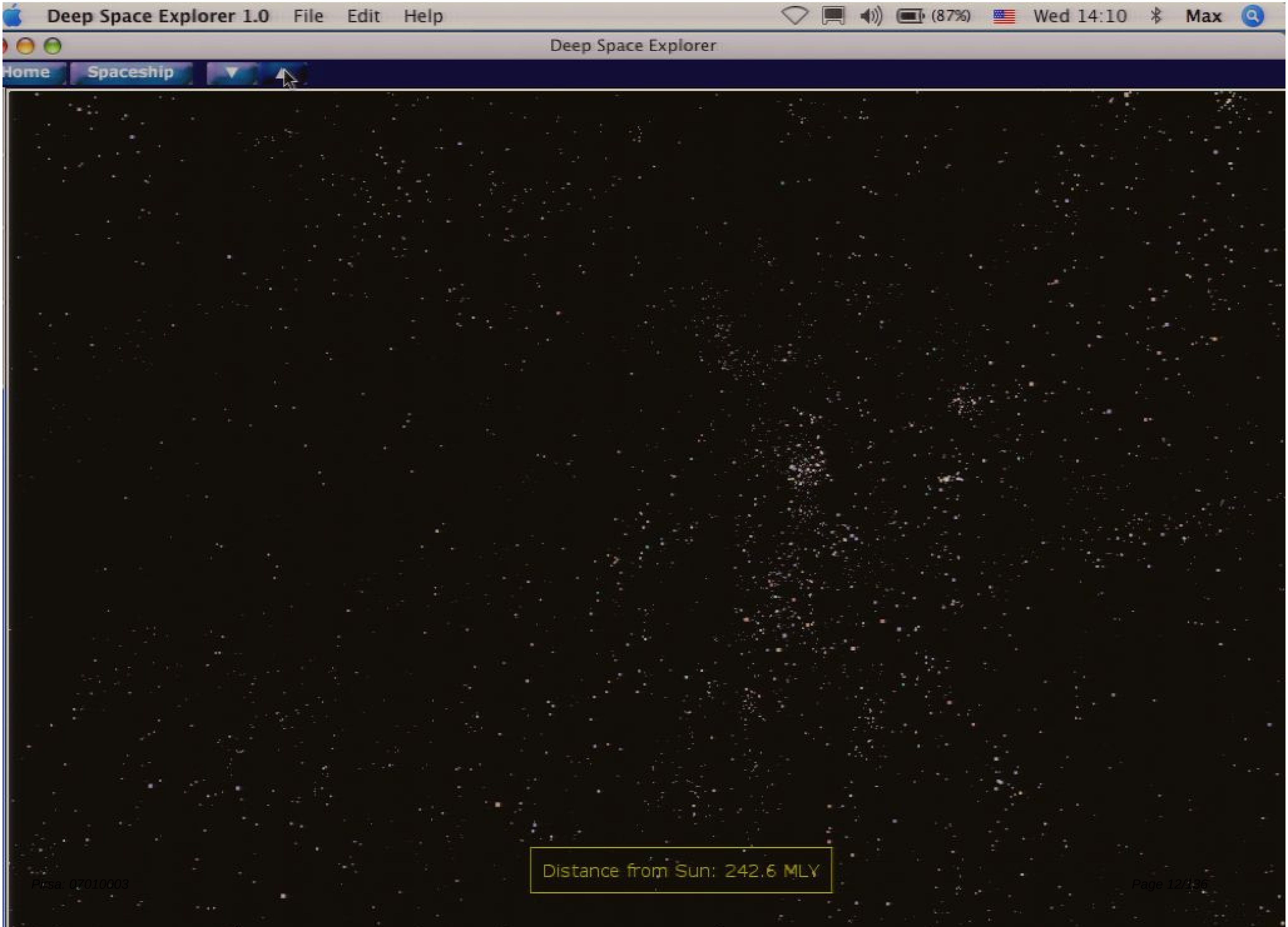
Distance from Sun: 58.665 MLY
Supergalactic Phi: 253.22°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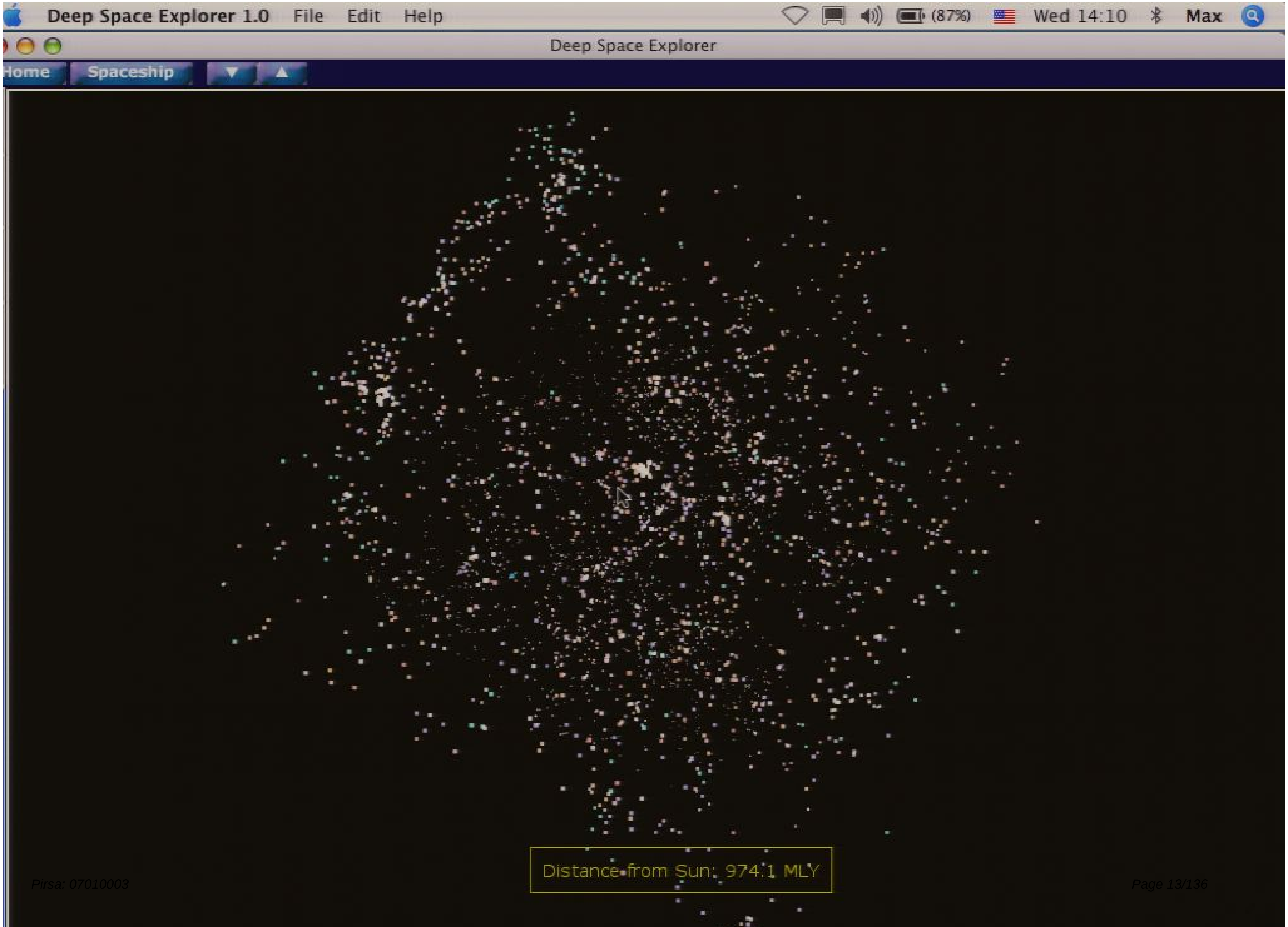
Deep Space Explorer
Home
Spaceship
Distance from Sun: 242.6 MLY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Deep Space Explorer
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Spaceship
Distance from Sun: 974.1 MLY

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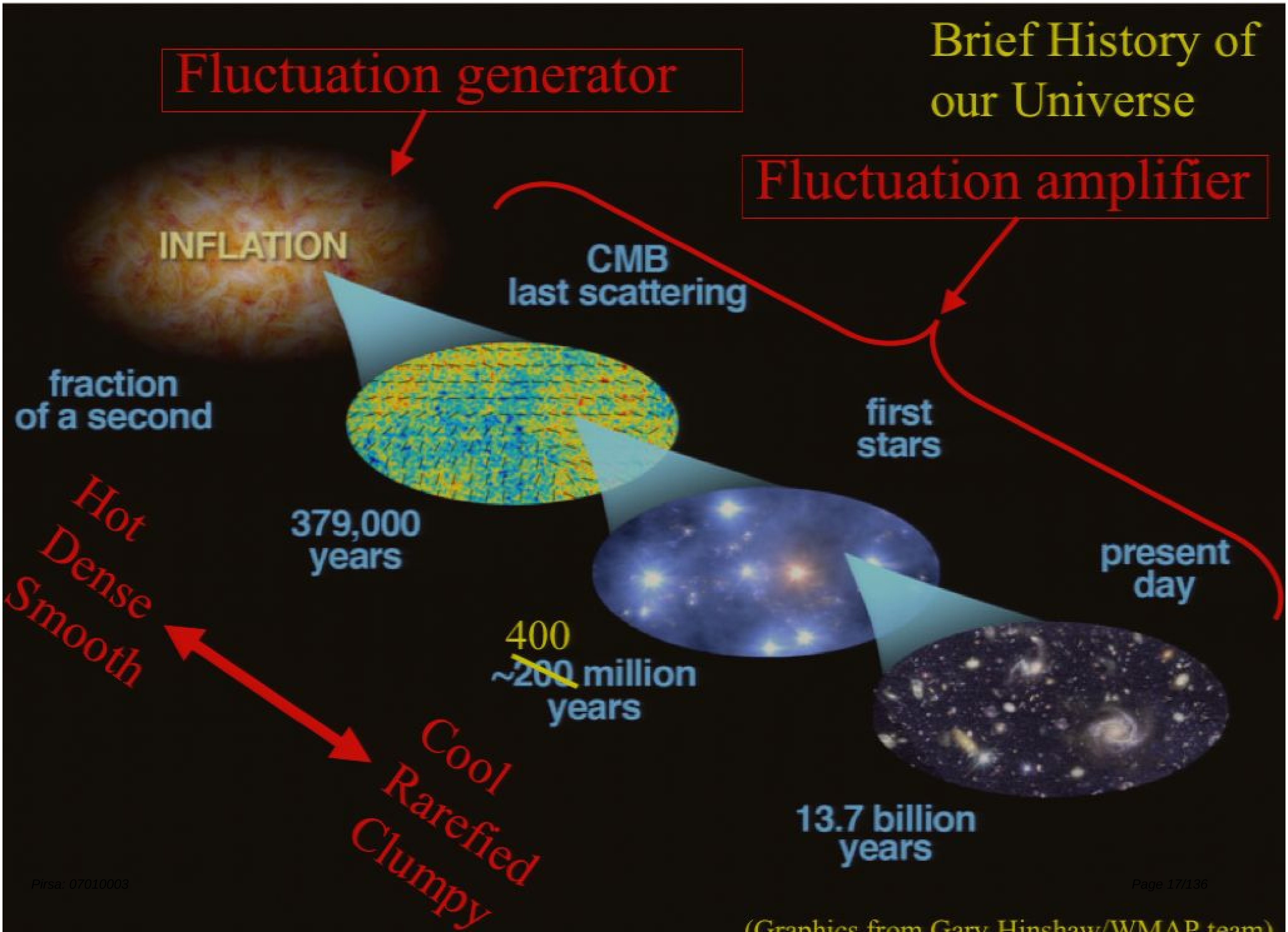
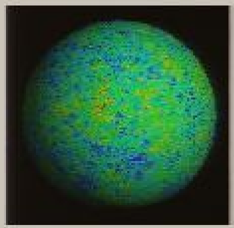
DSE

OUR PLACE IN TIME

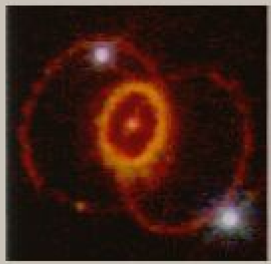
The sky as a time machine


Brief History of our Universe
Fluctuation generator
Fluctuation amplifier
INFLATION
CMB
last scattering
fraction
of a second
first
stars
Hot
Dense
Smooth
379,000
years
present
day
400
~~~200~~ million
years
Cool
Rarefied
Clumpy
13.7 billion
years
(Graphics from Gary Hinshaw/WMAP team)
~~~

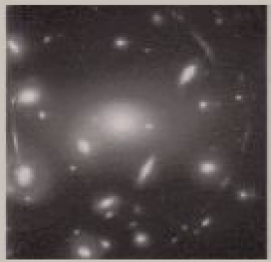


CMB

GALAXY SURVEYS

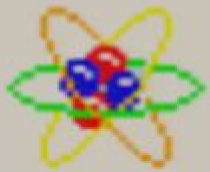


DISTANT SUPERNOVAE



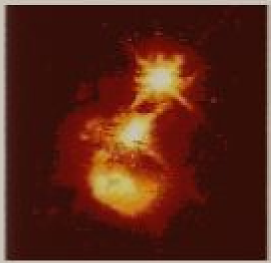
GRAVITATIONAL LENSING

THE COSMIC SMÖRGÅSBORD



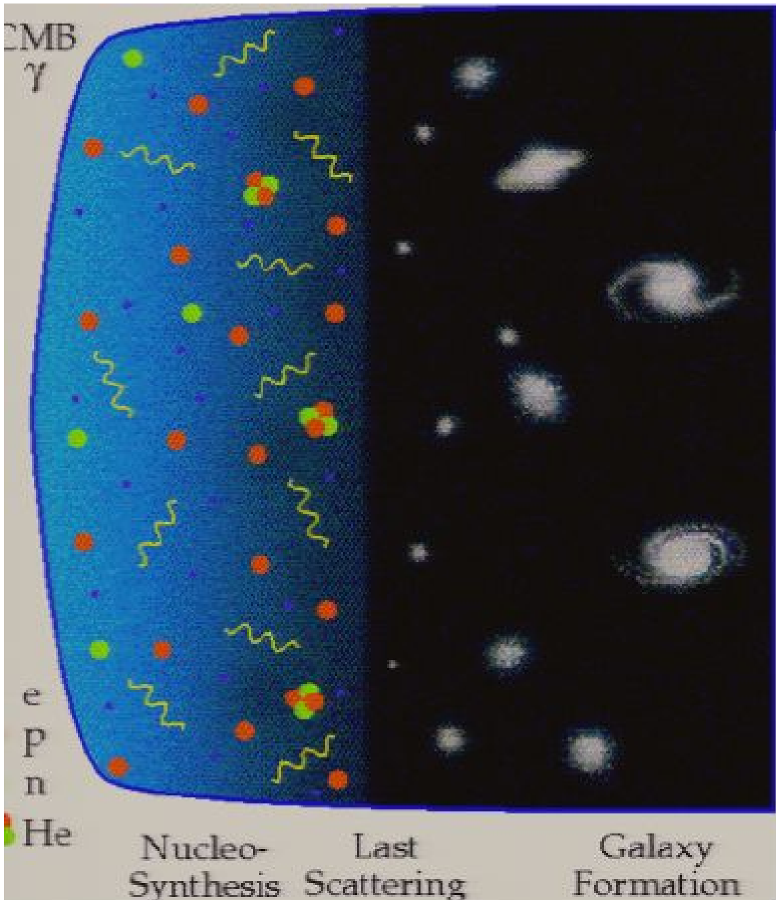
BIG BANG NUCLEOSYNTHESIS

GALAXY CLUSTERS



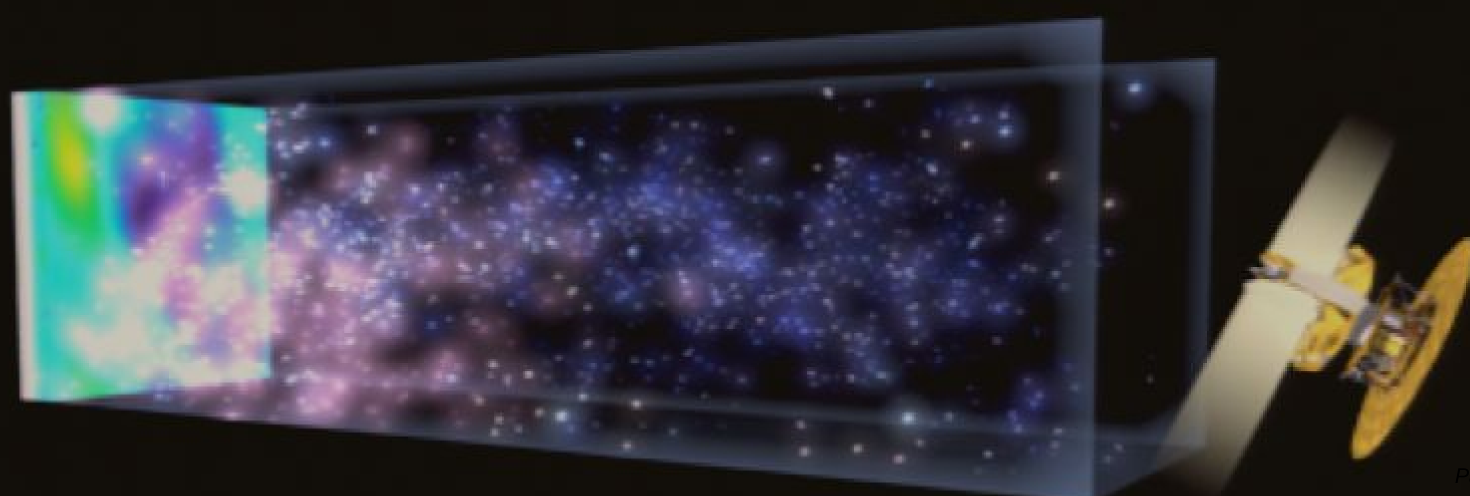
LYMAN ALPHA FOREST

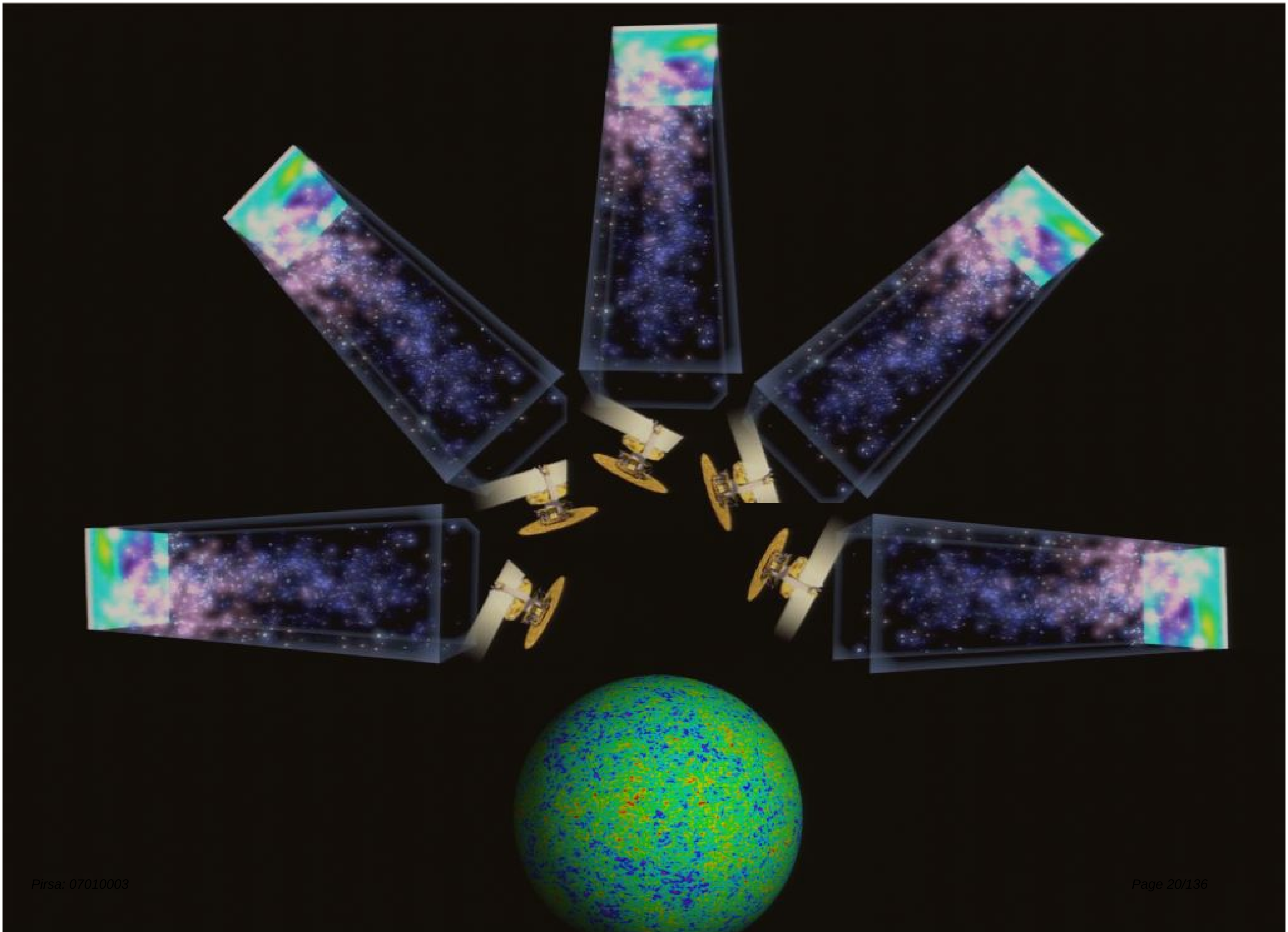
Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Perimeter Colloquium

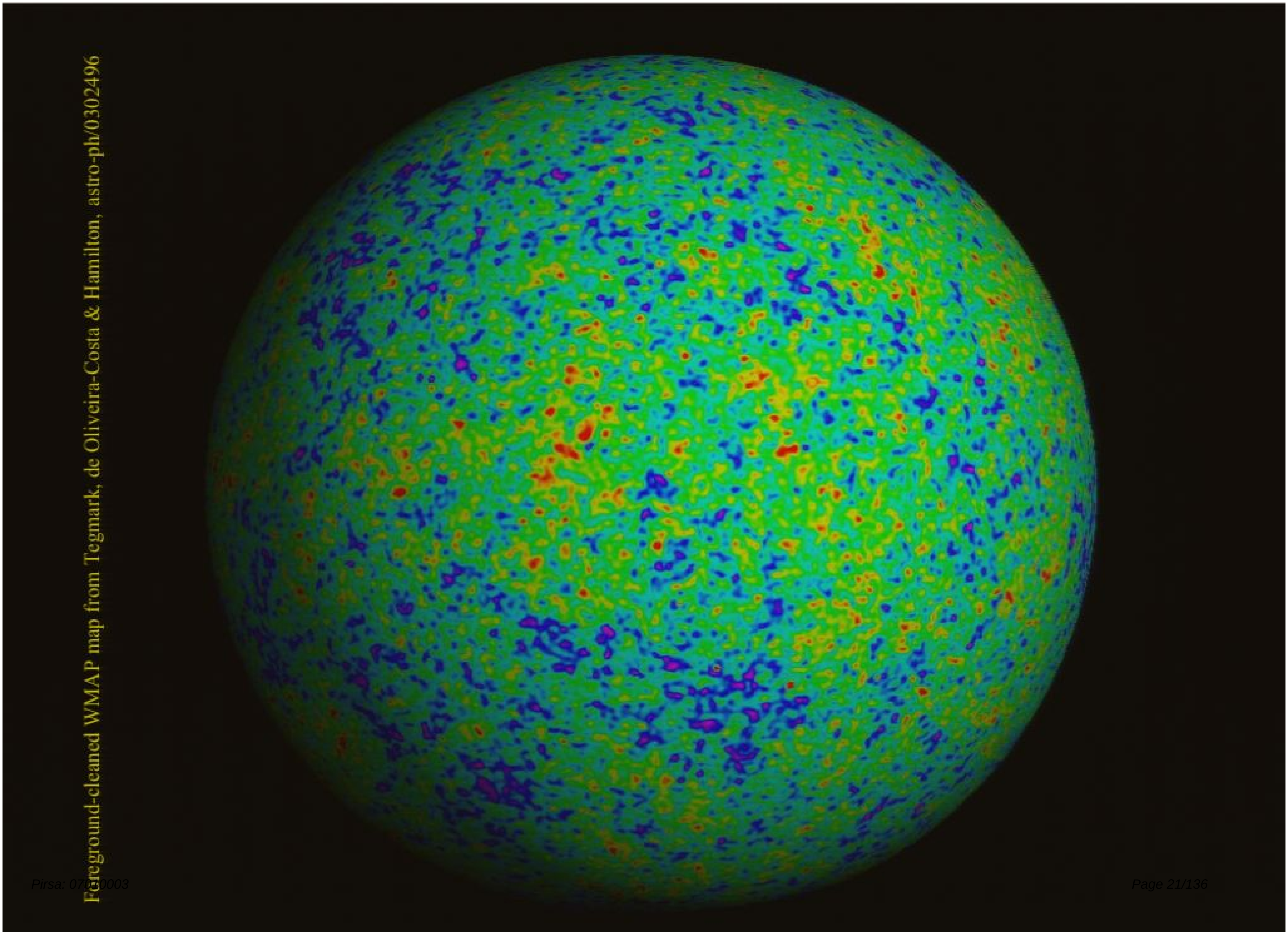


(Figure from Wayne Hu)

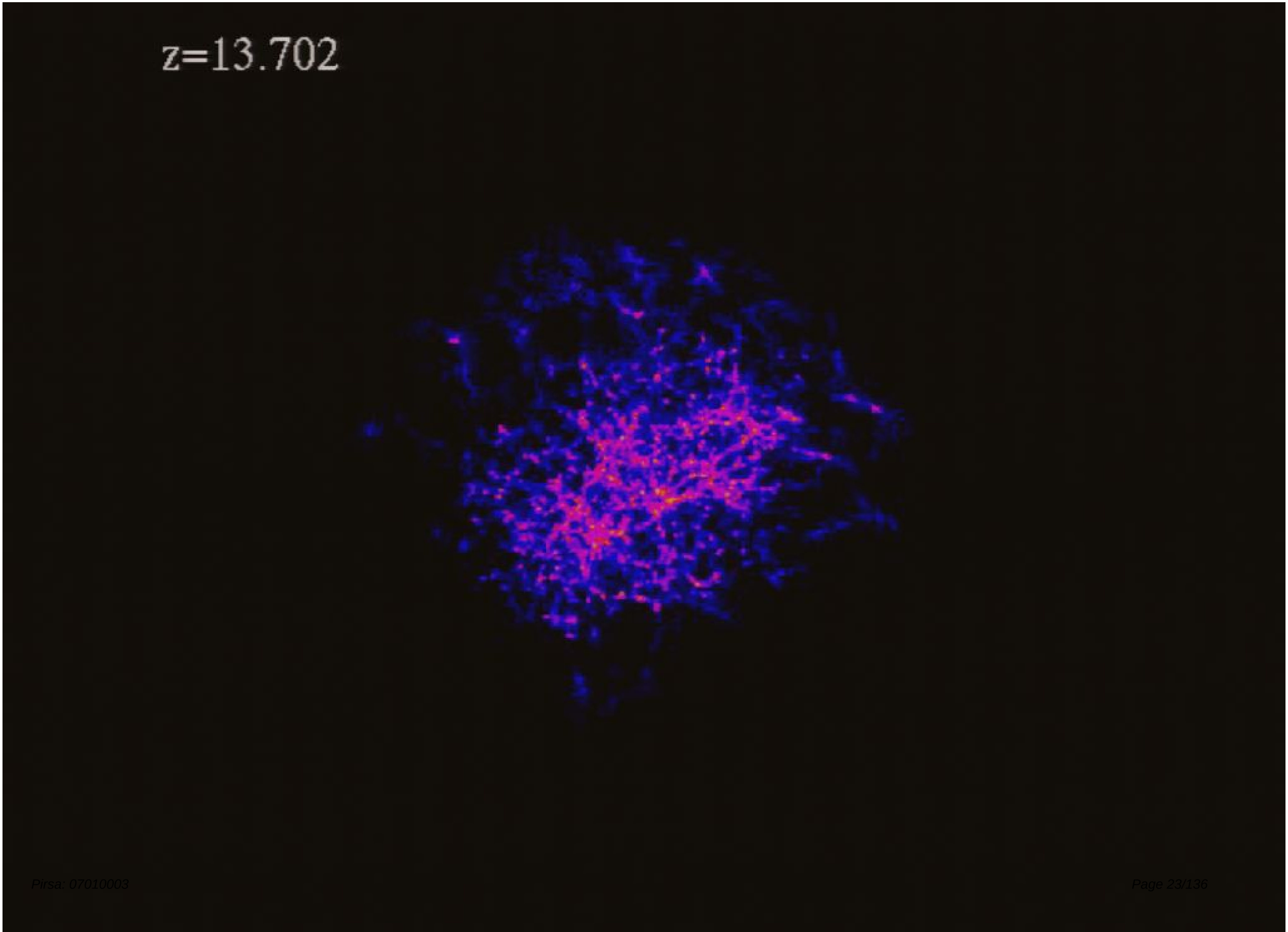
(Figure from WMAP team)






Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496

Formation movies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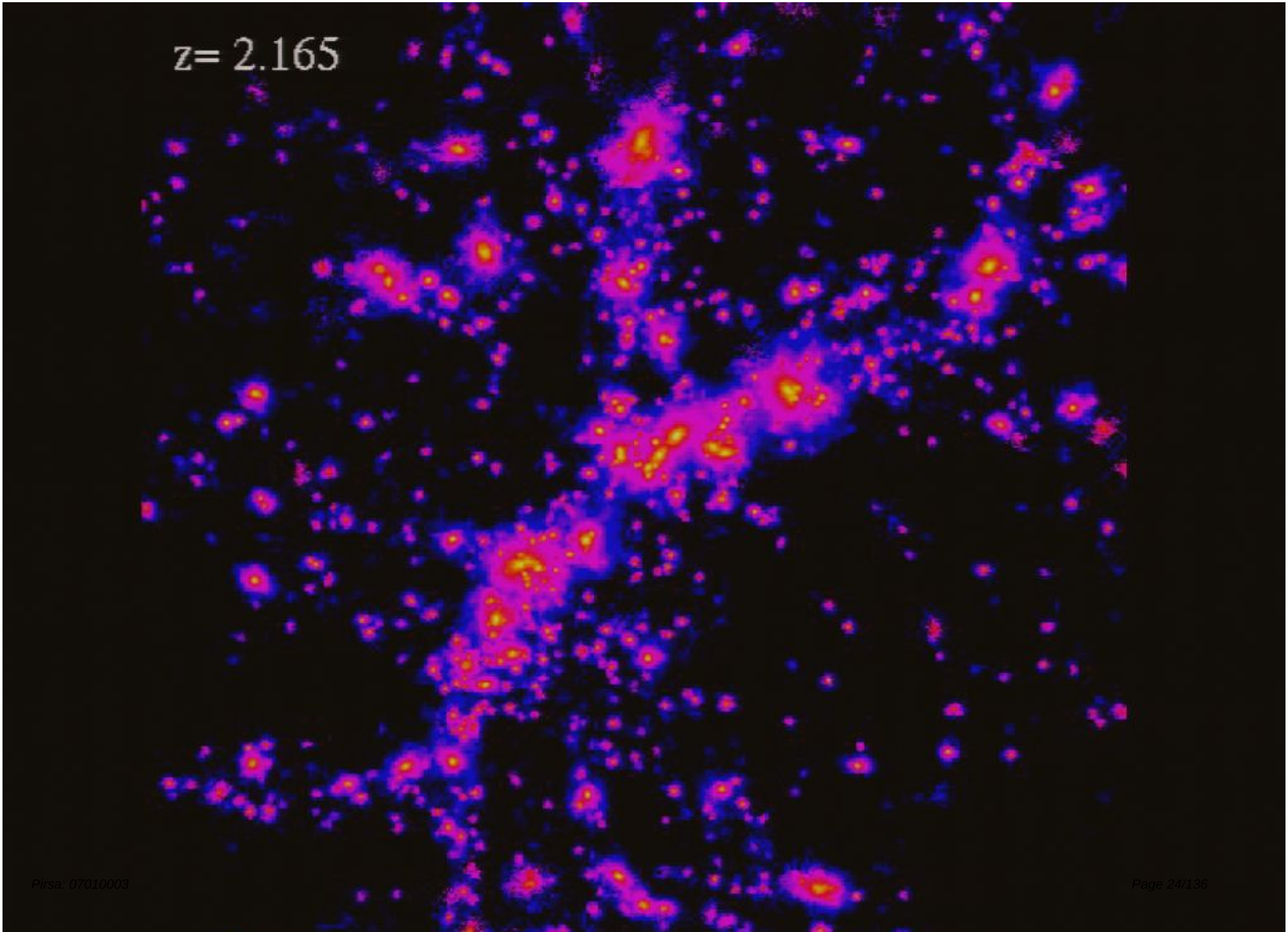
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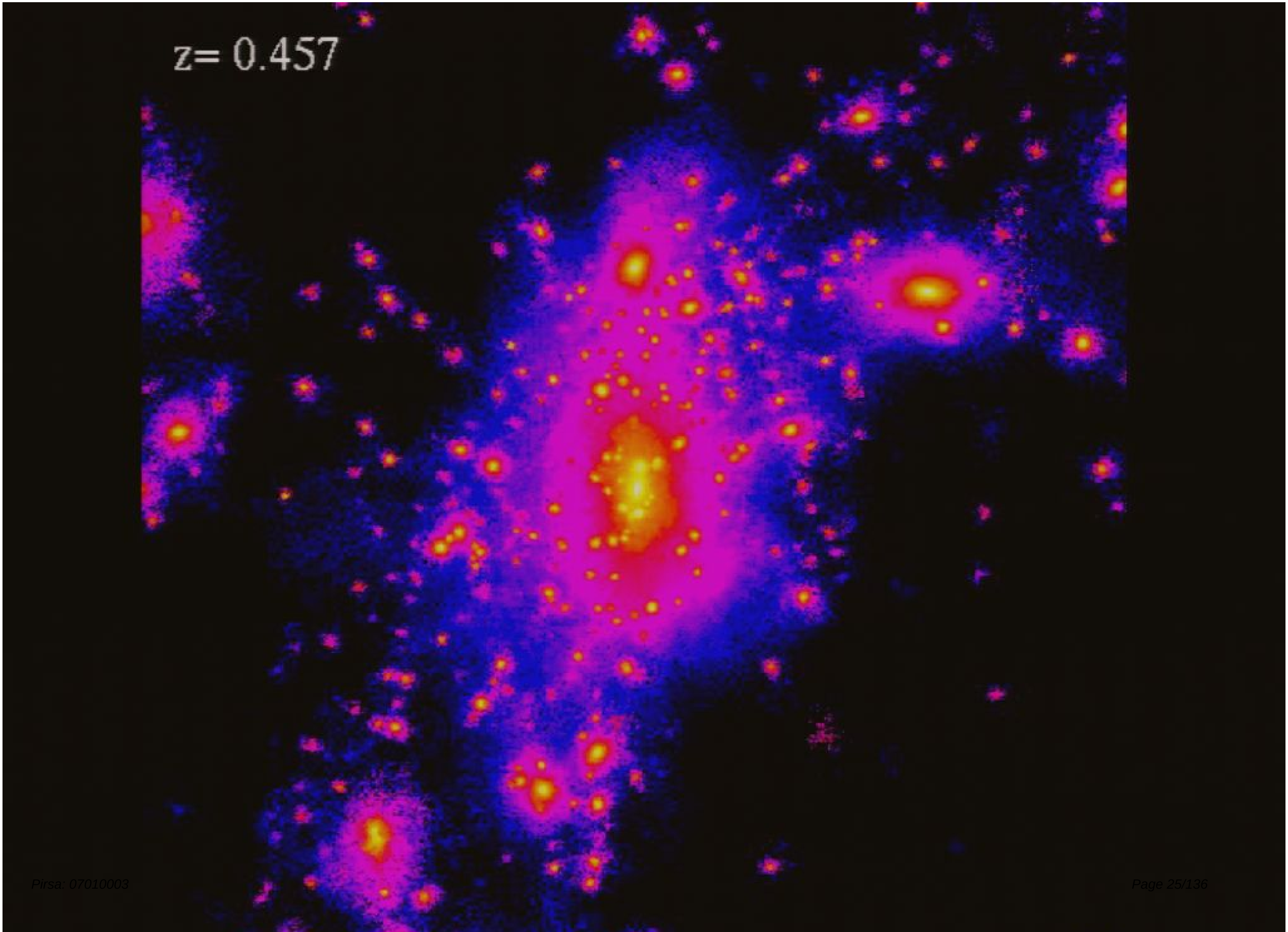
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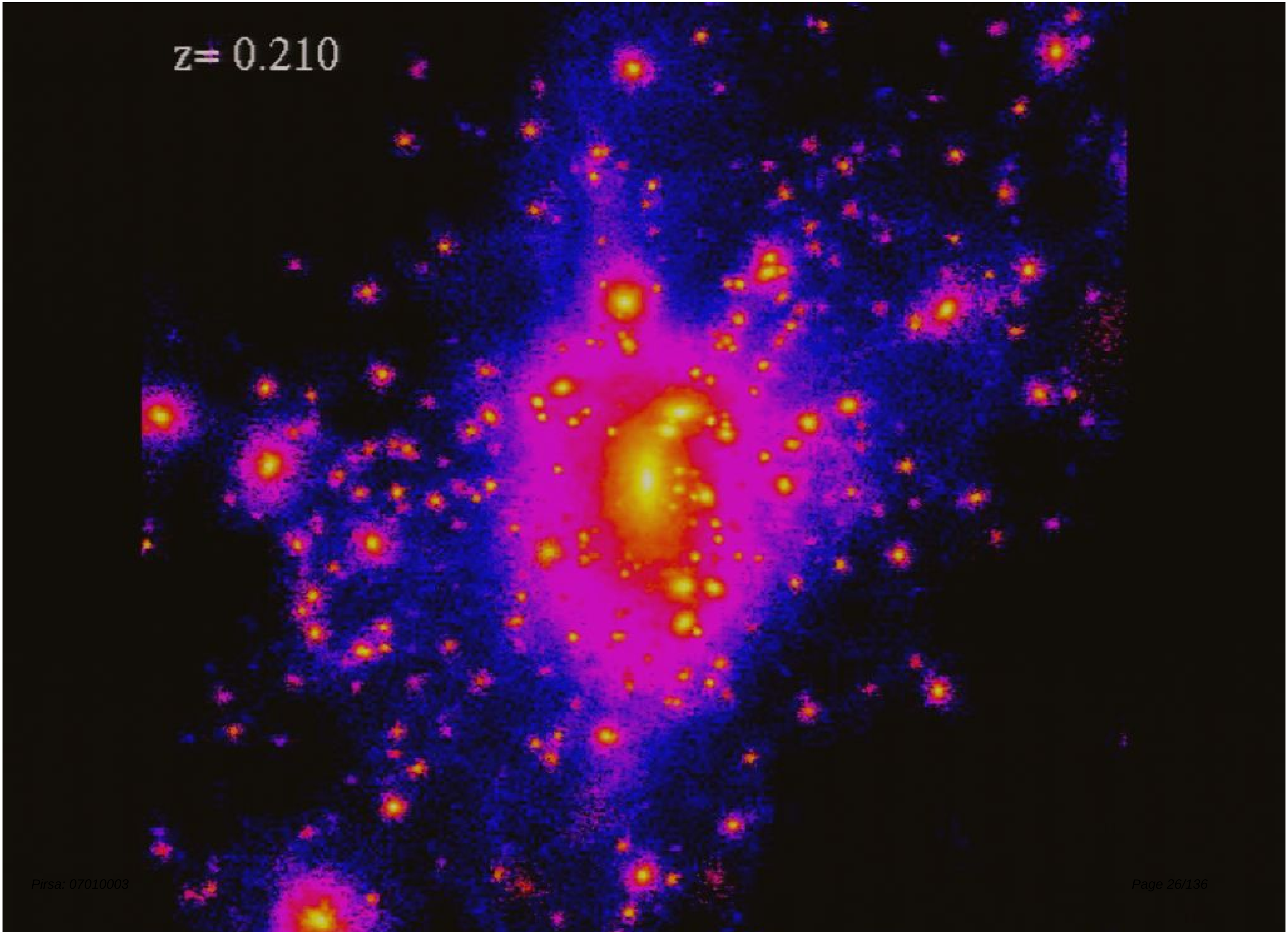
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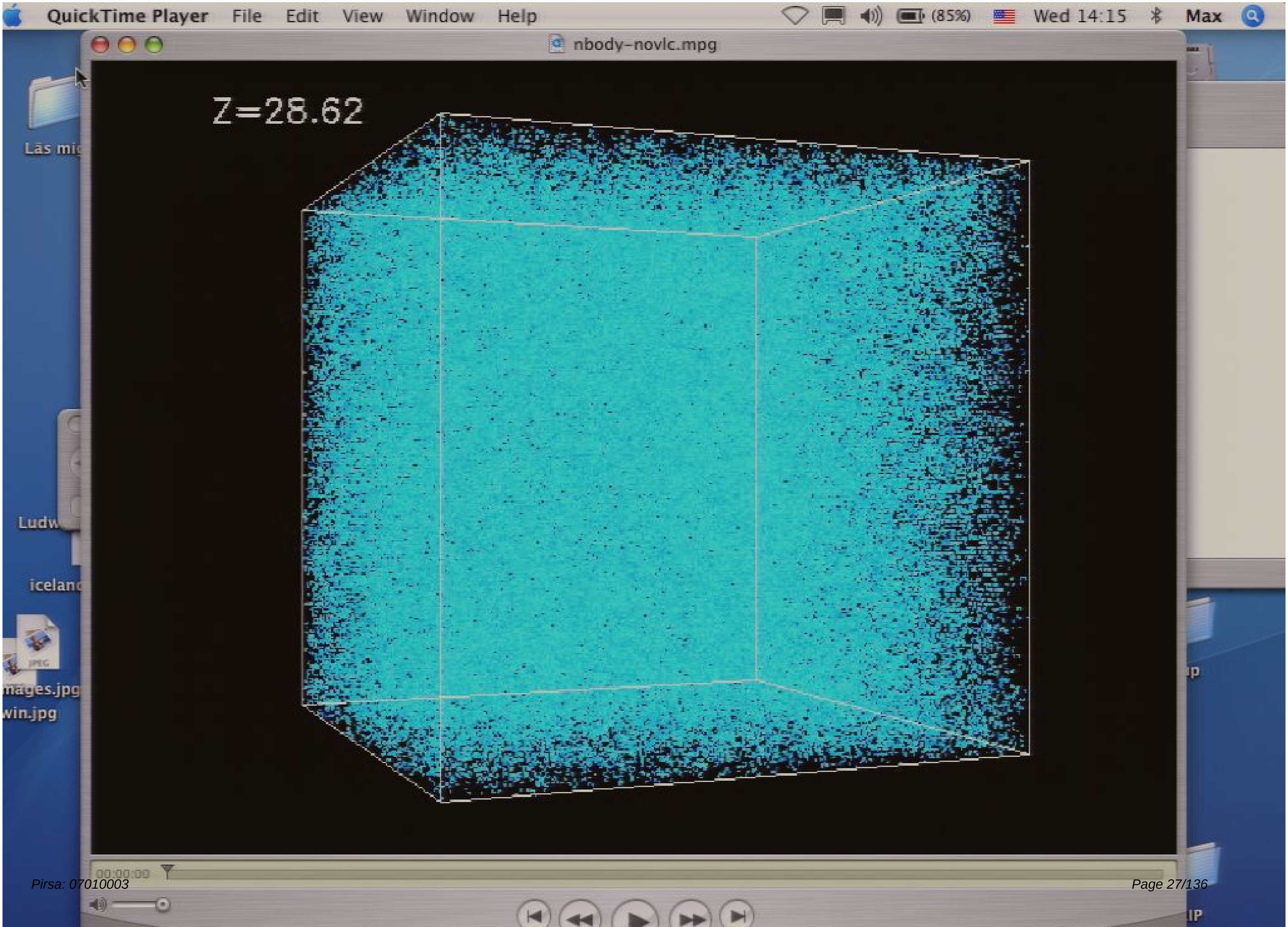
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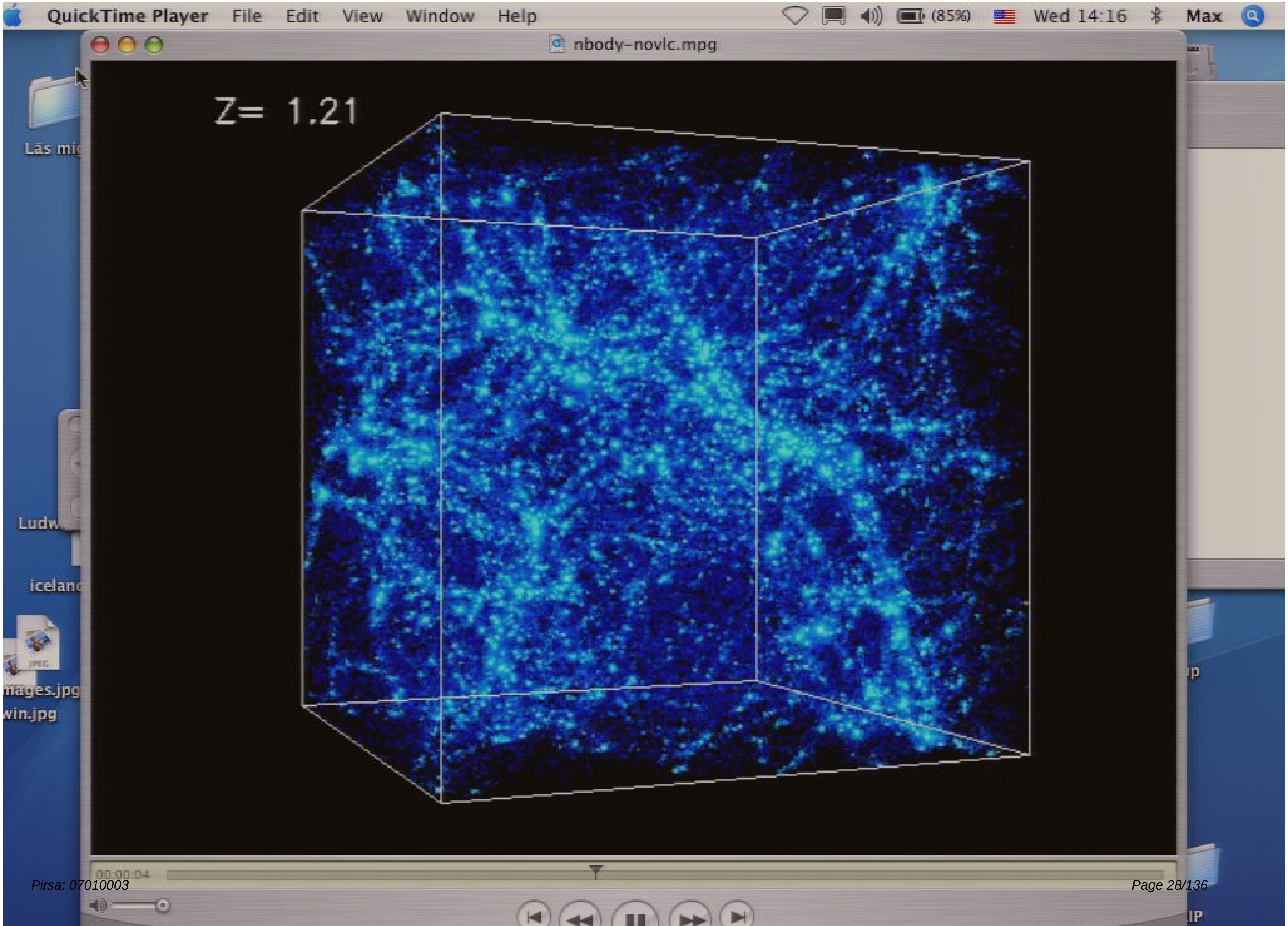
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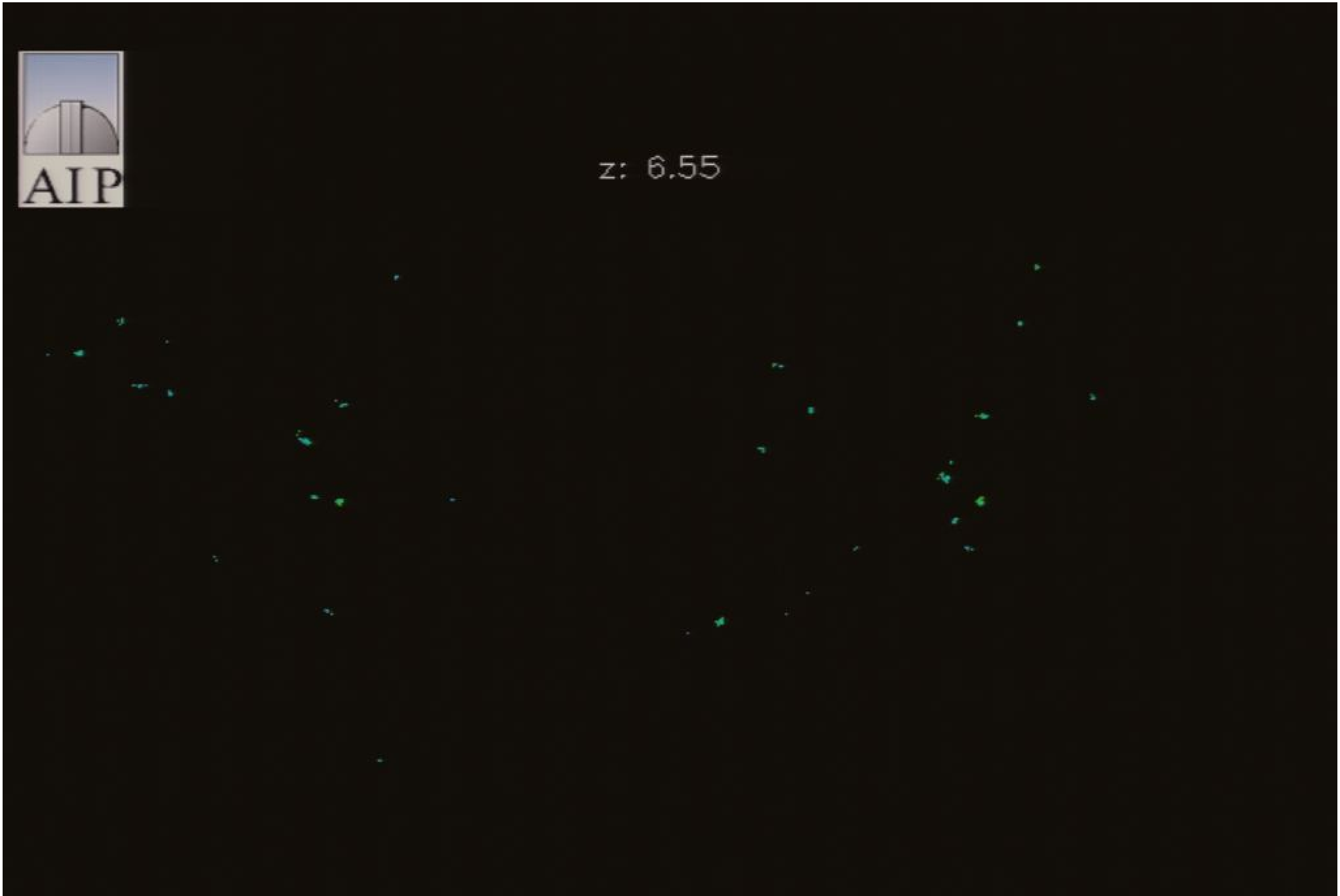
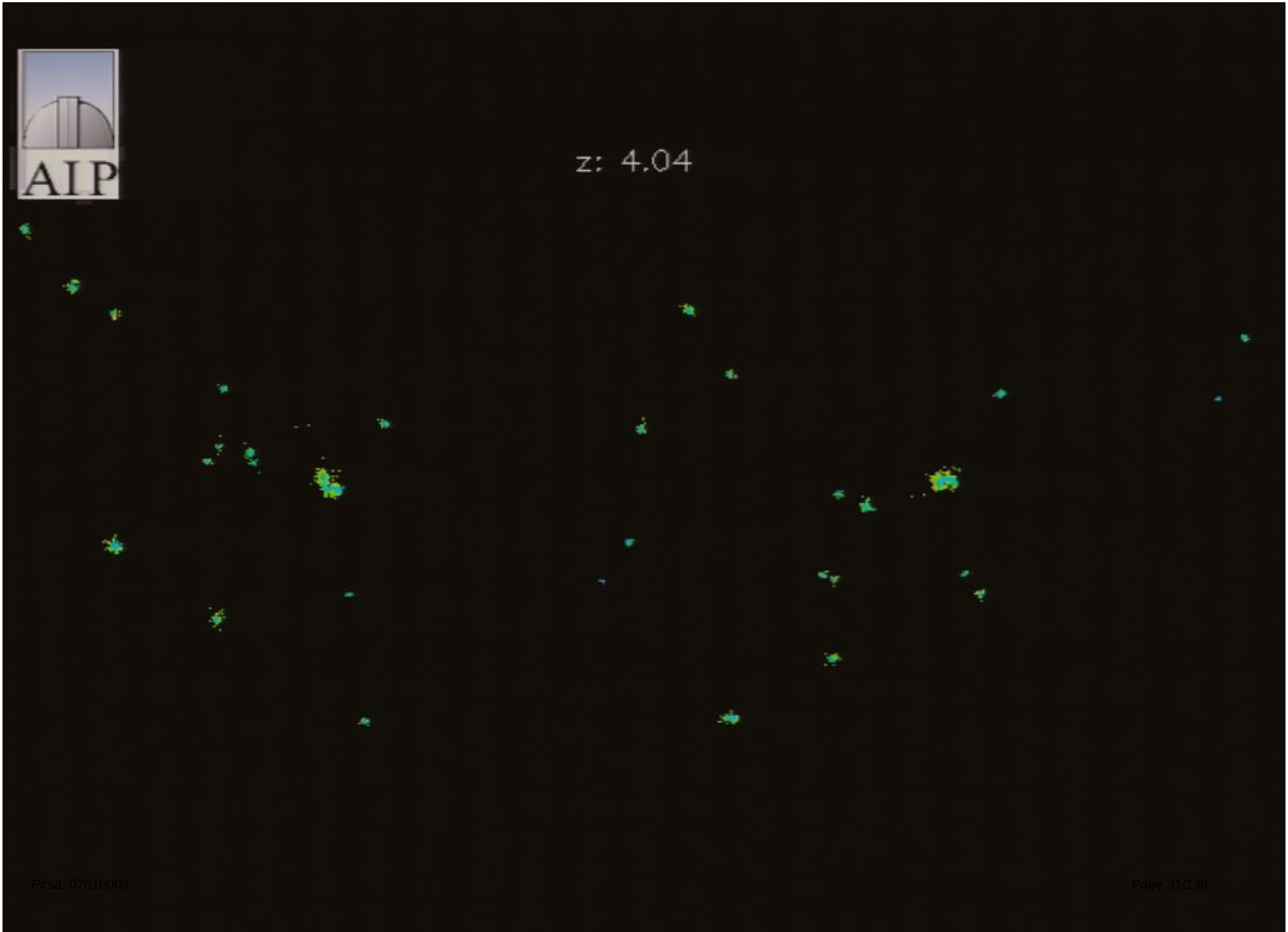
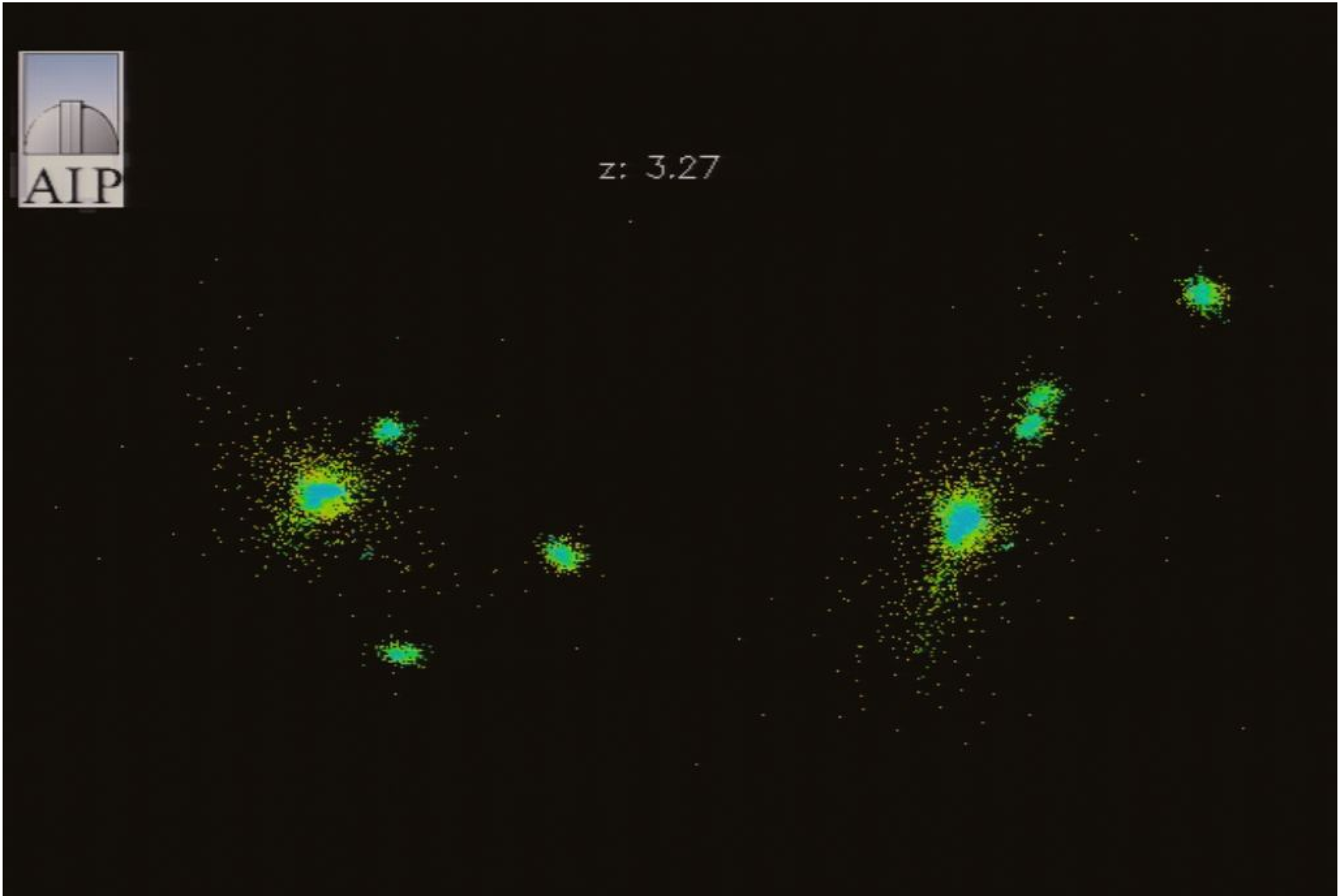
z: 16.9


AIP
z: 6.55


AIP
z: 4.04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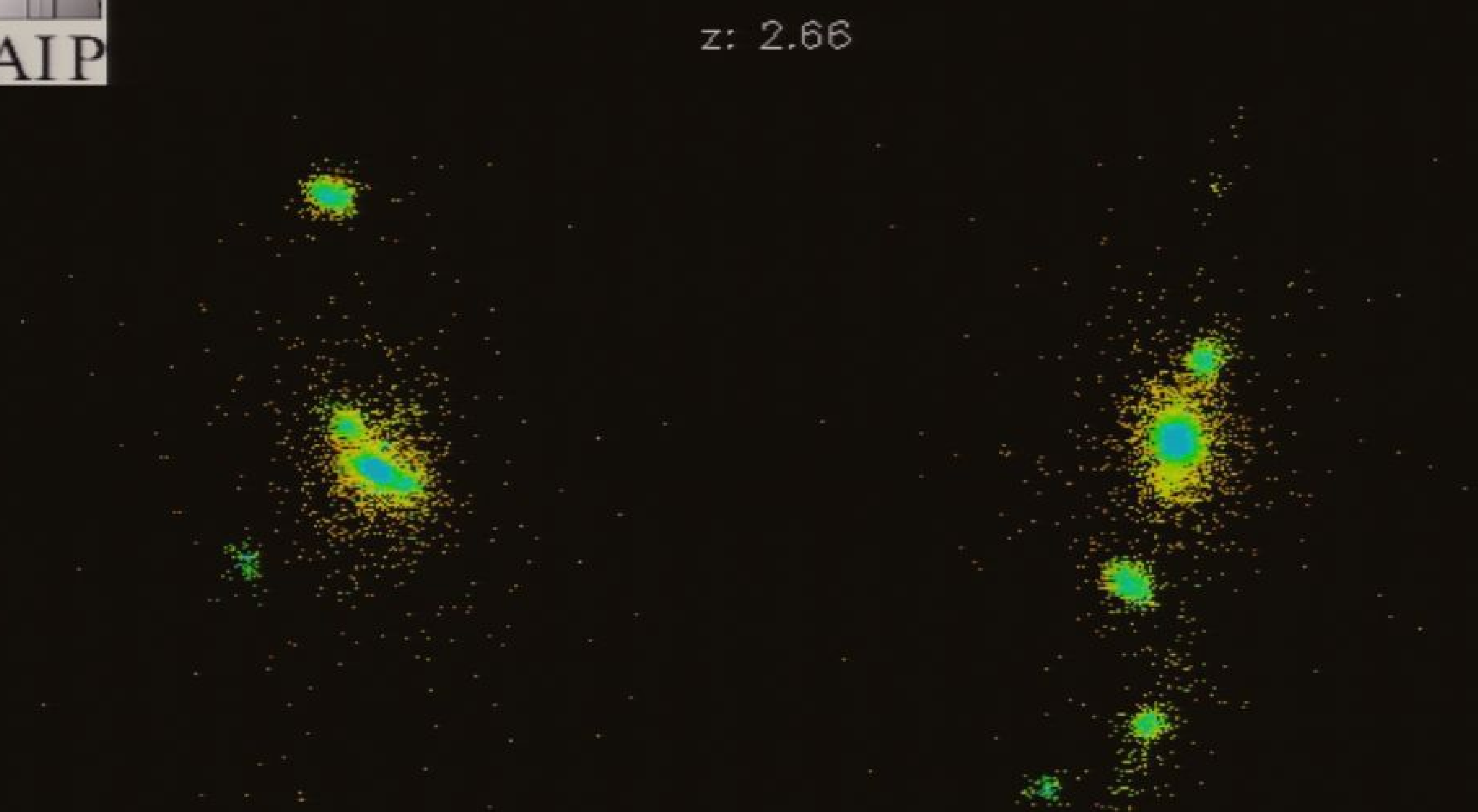
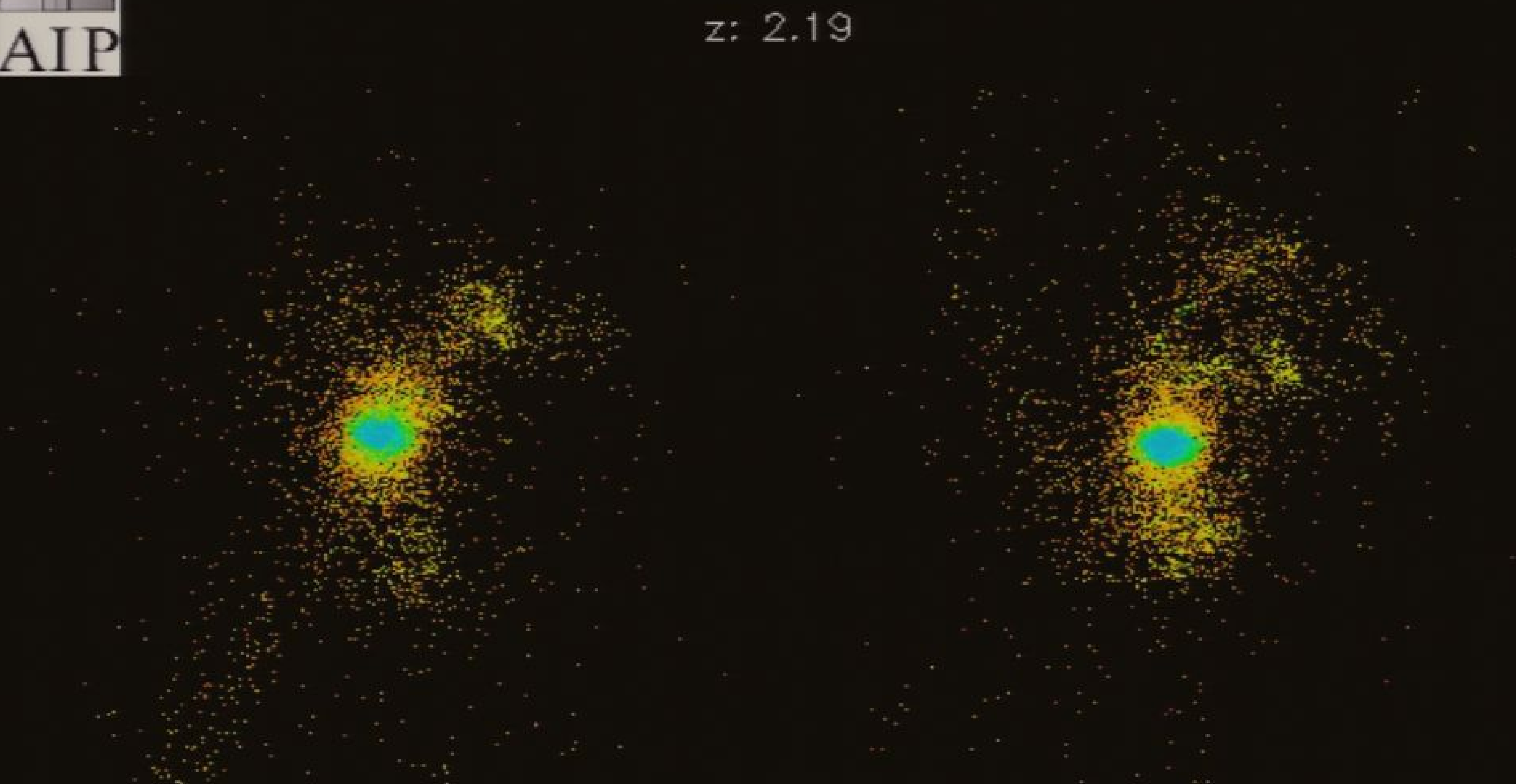
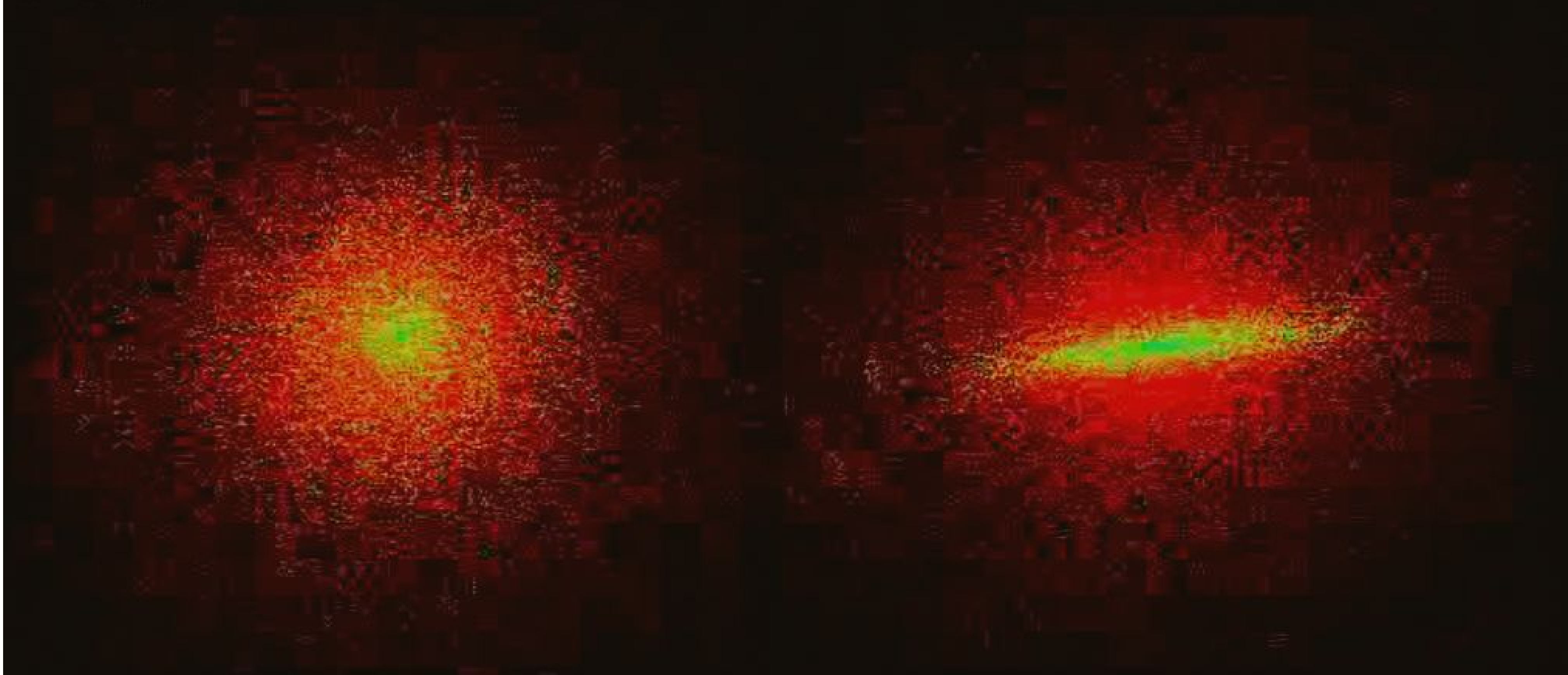
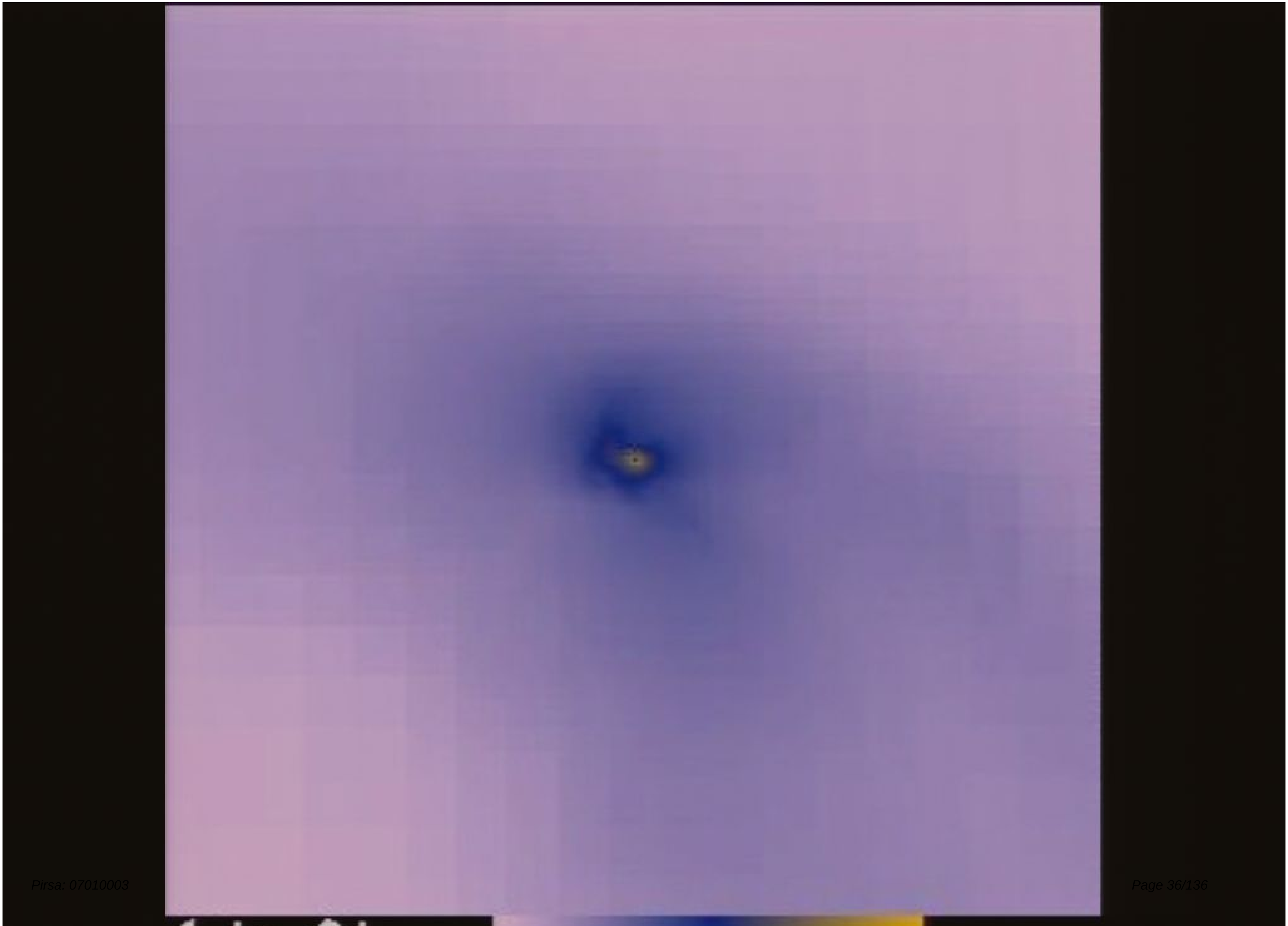
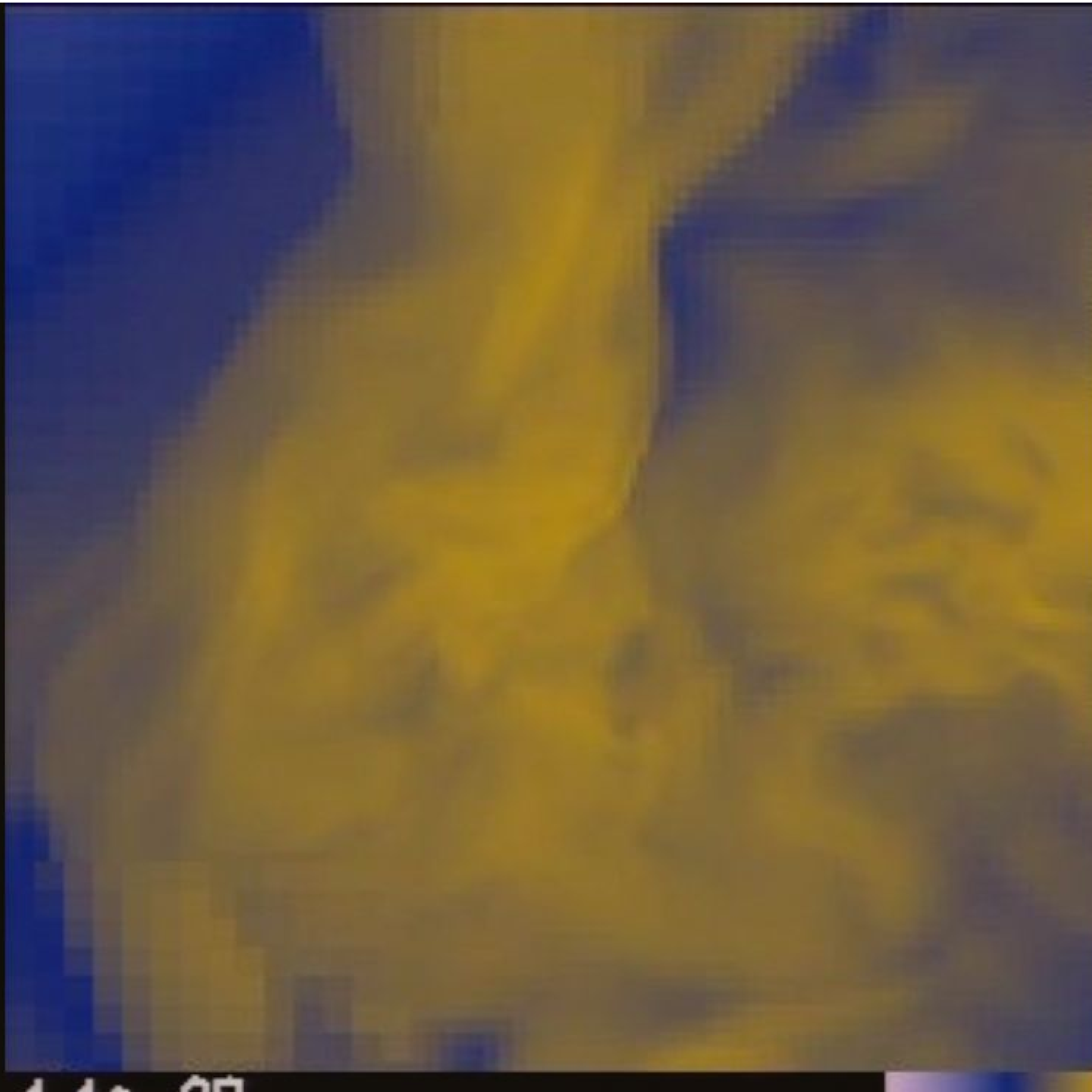

z: 2.66

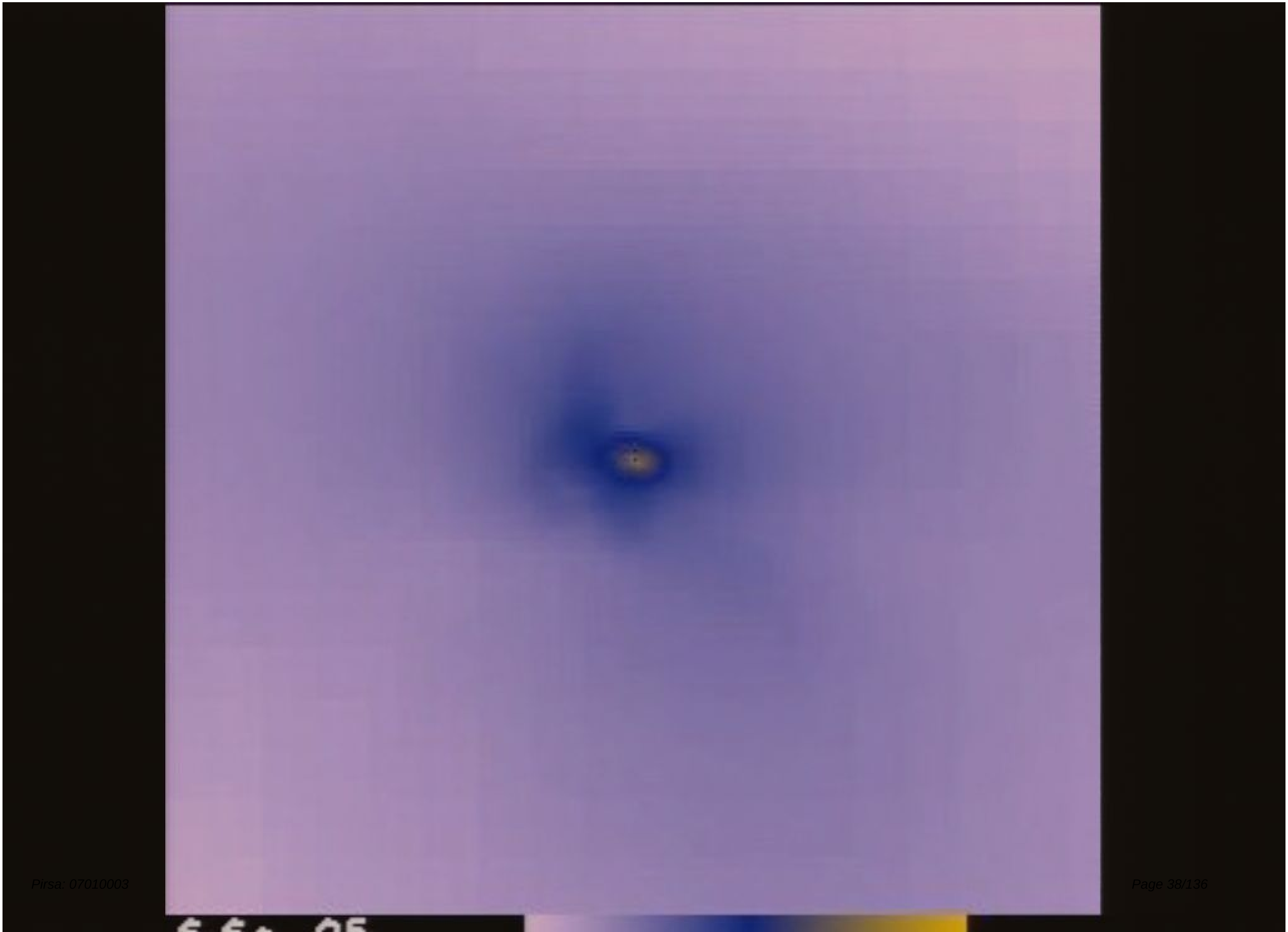

z: 2.19

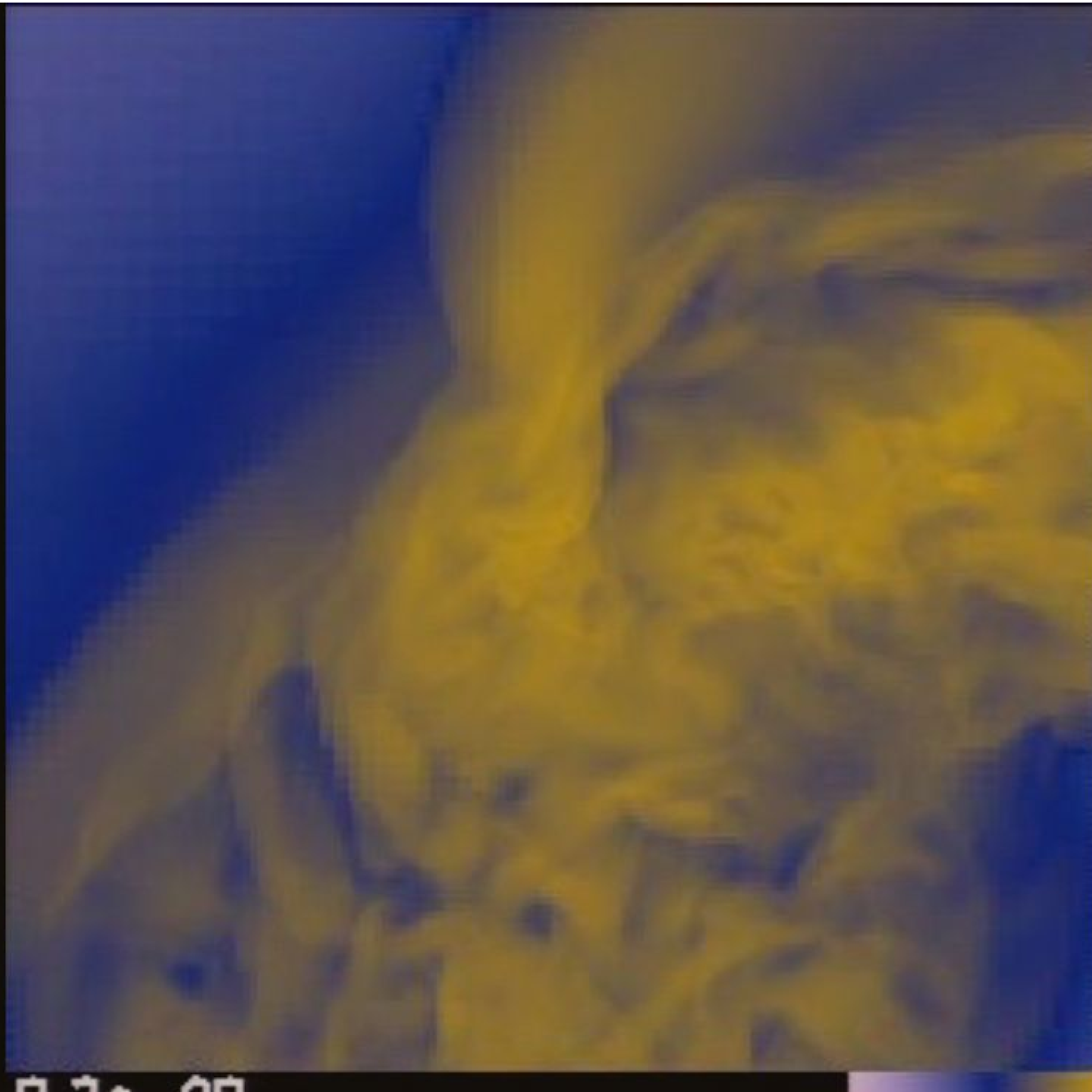
z: 0.37

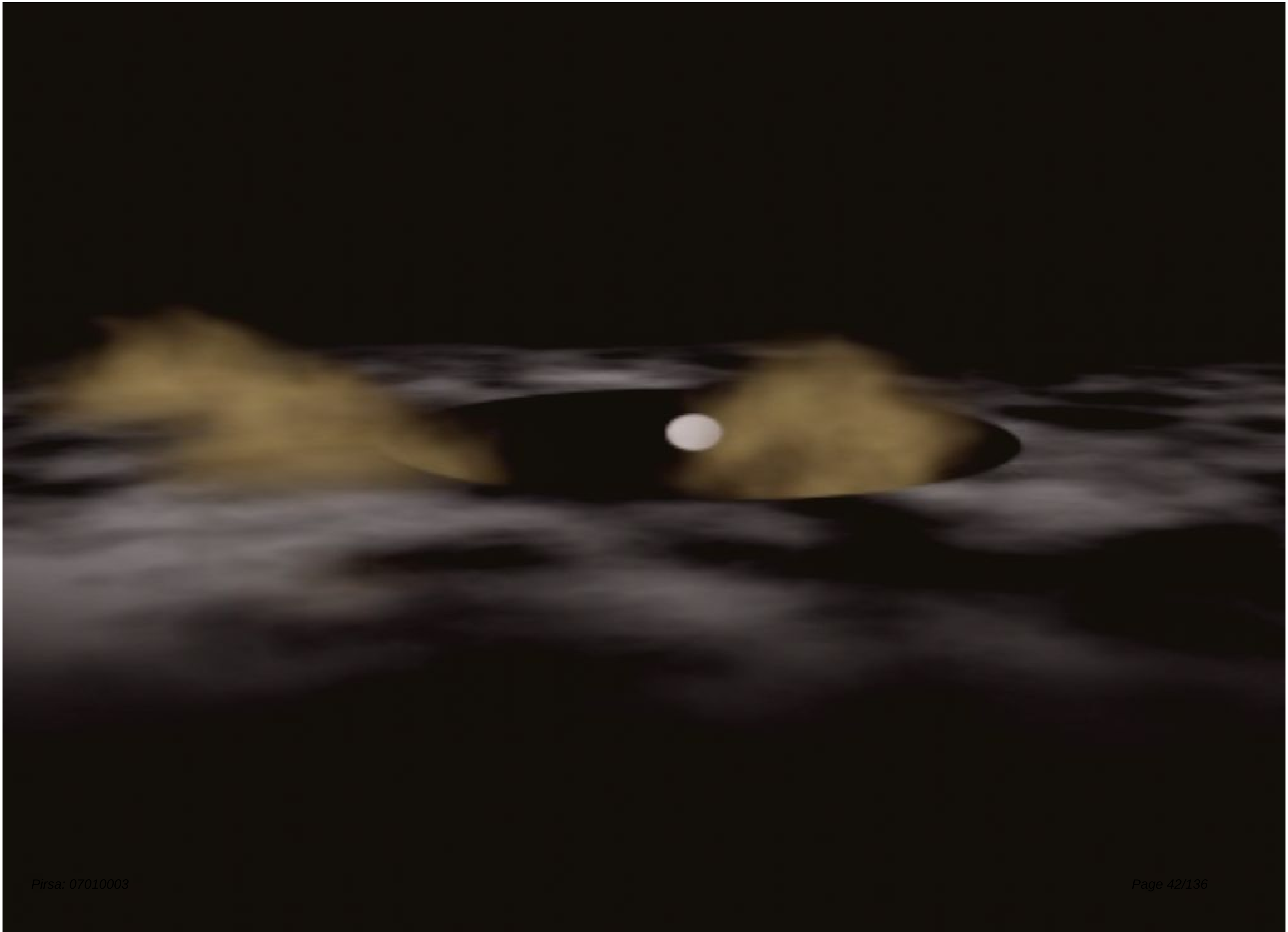


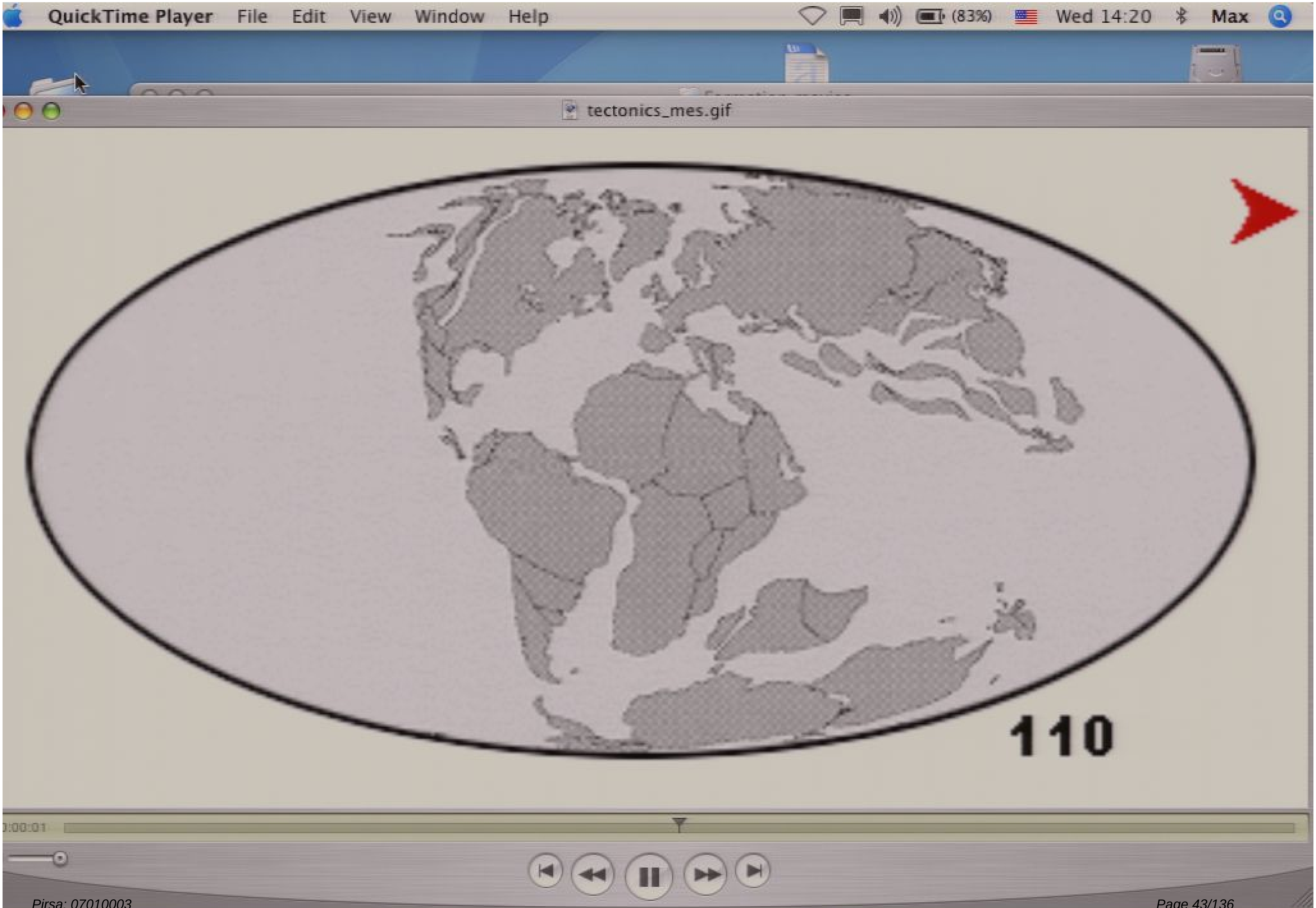








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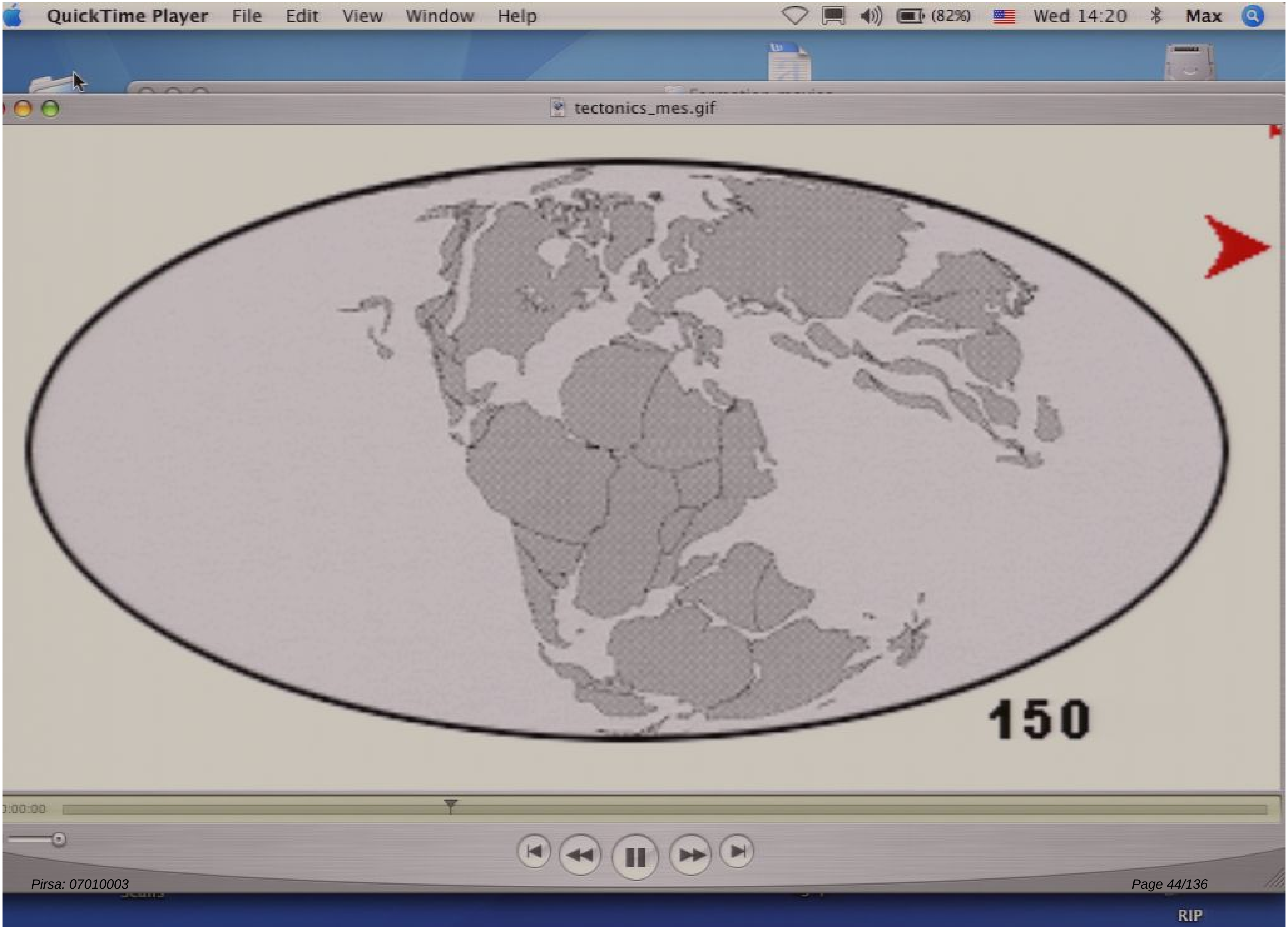
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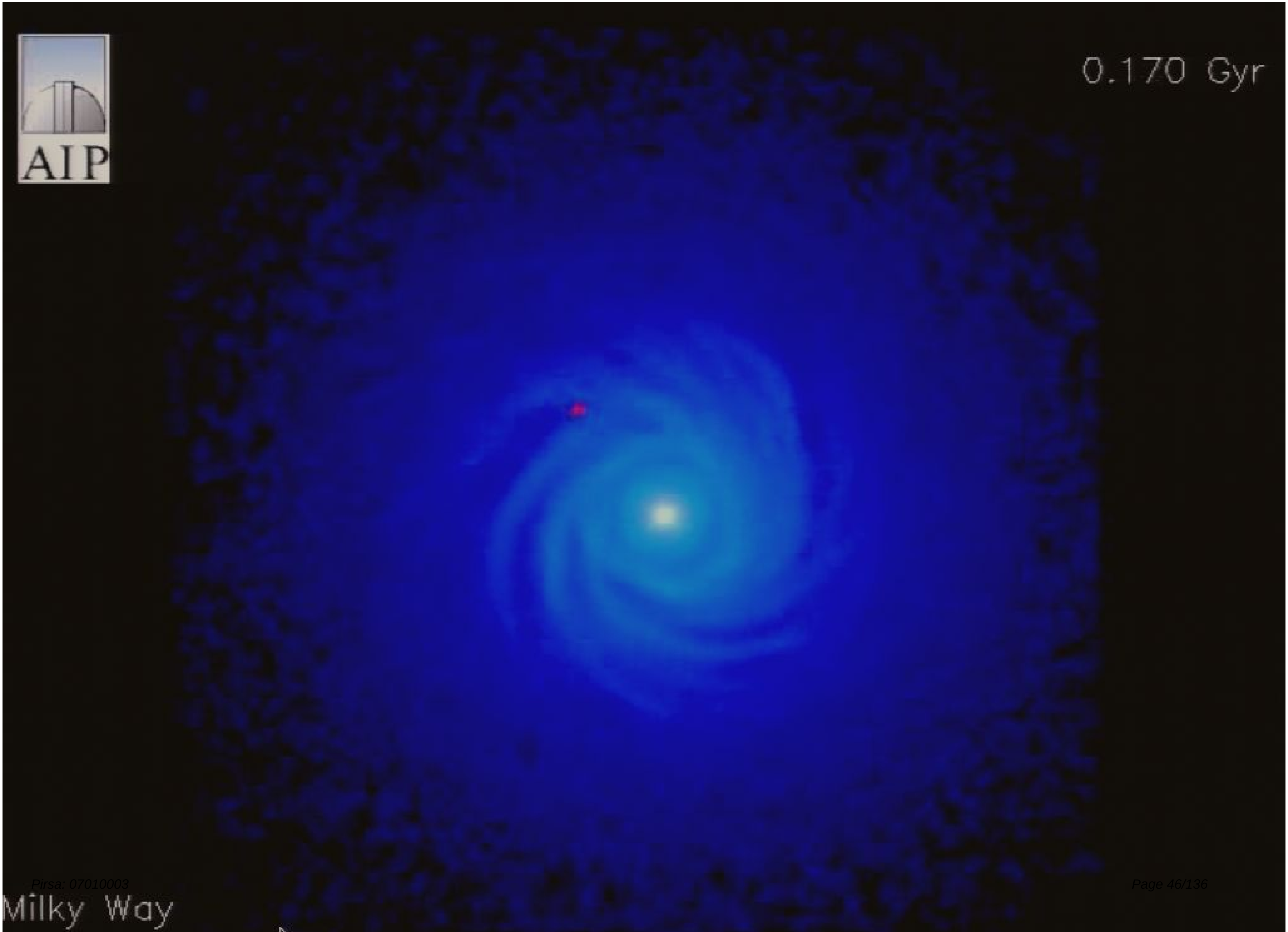
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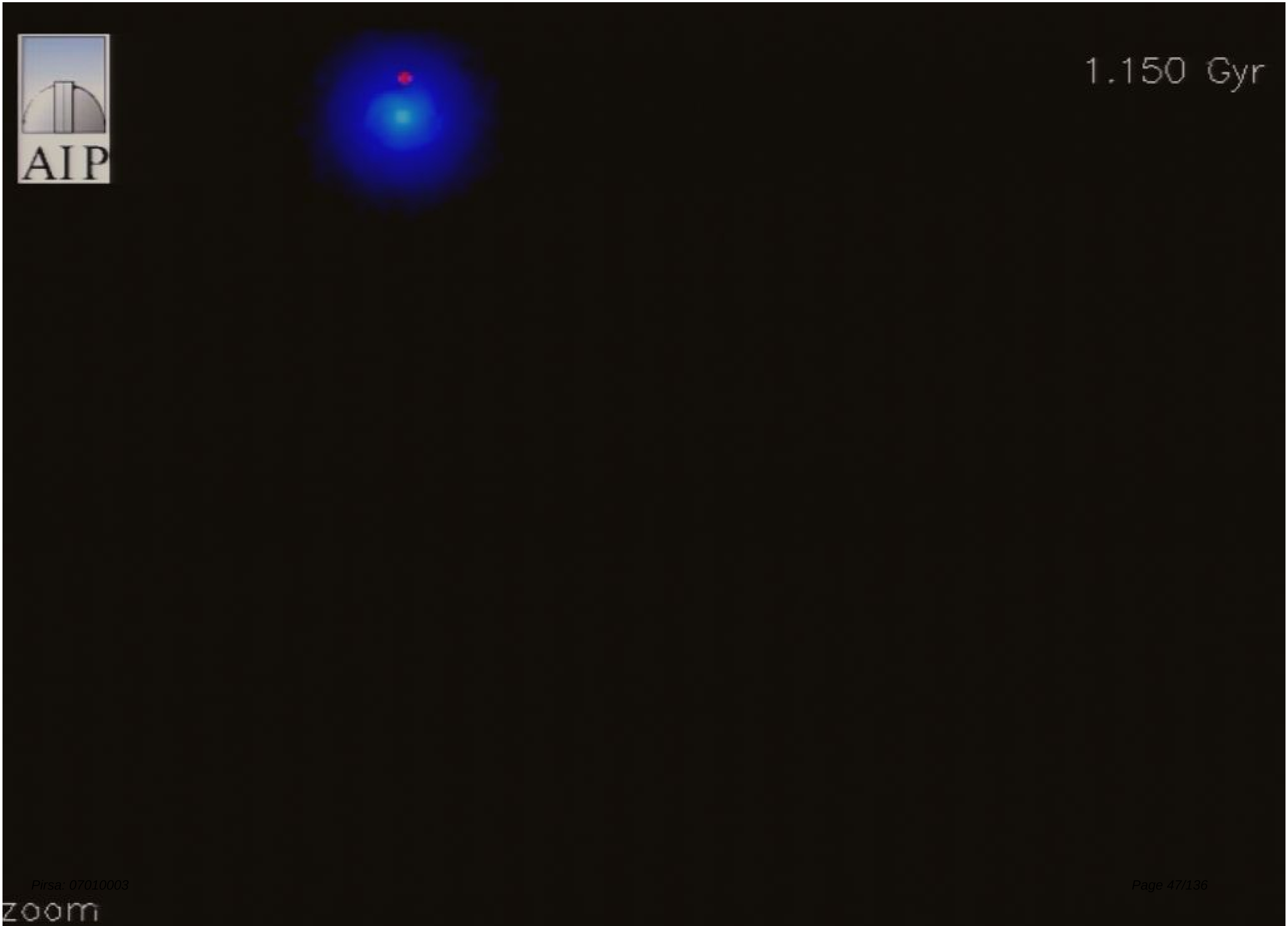
0.170 Gyr
Milky Way


1.150 Gyr
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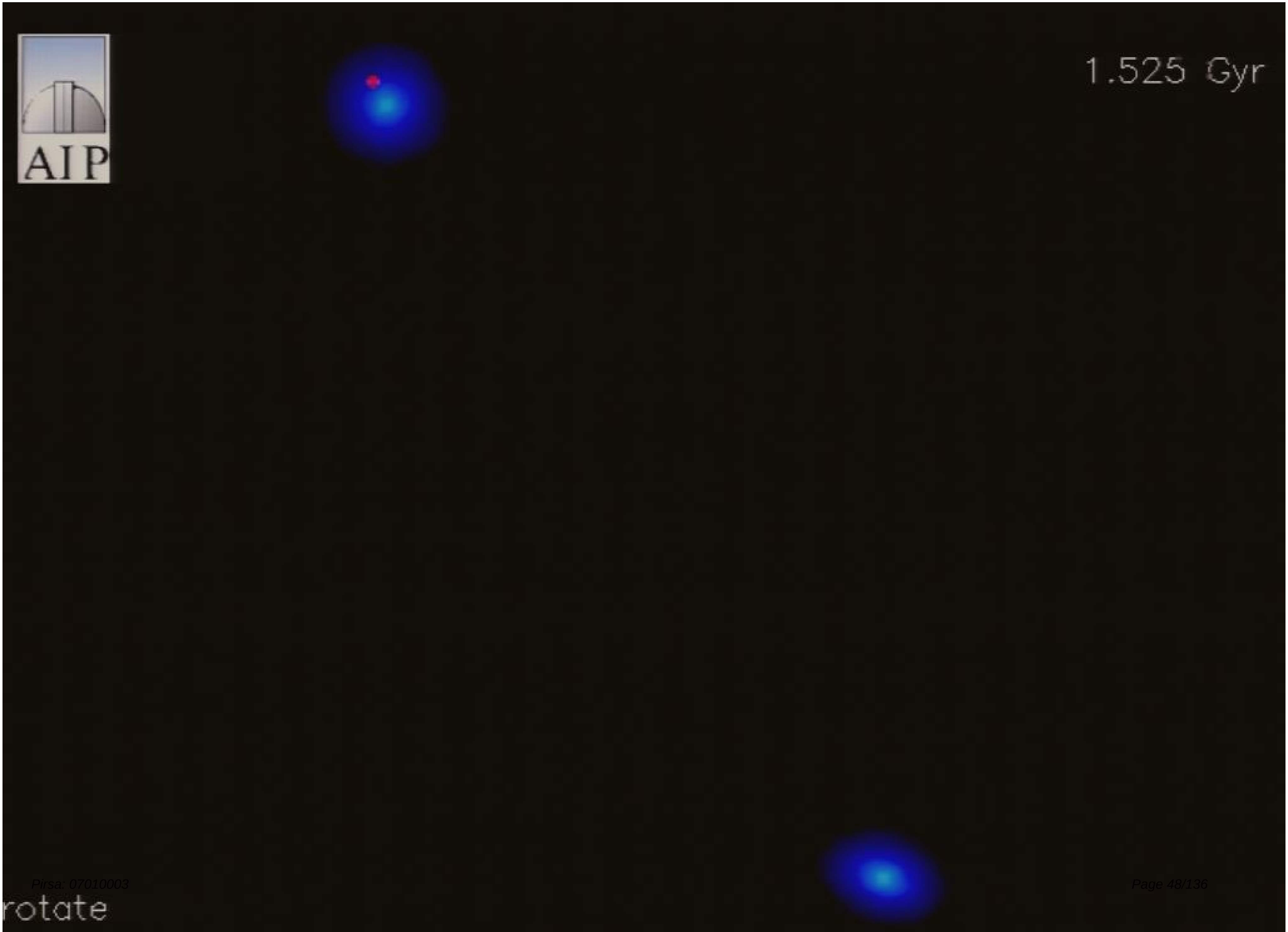
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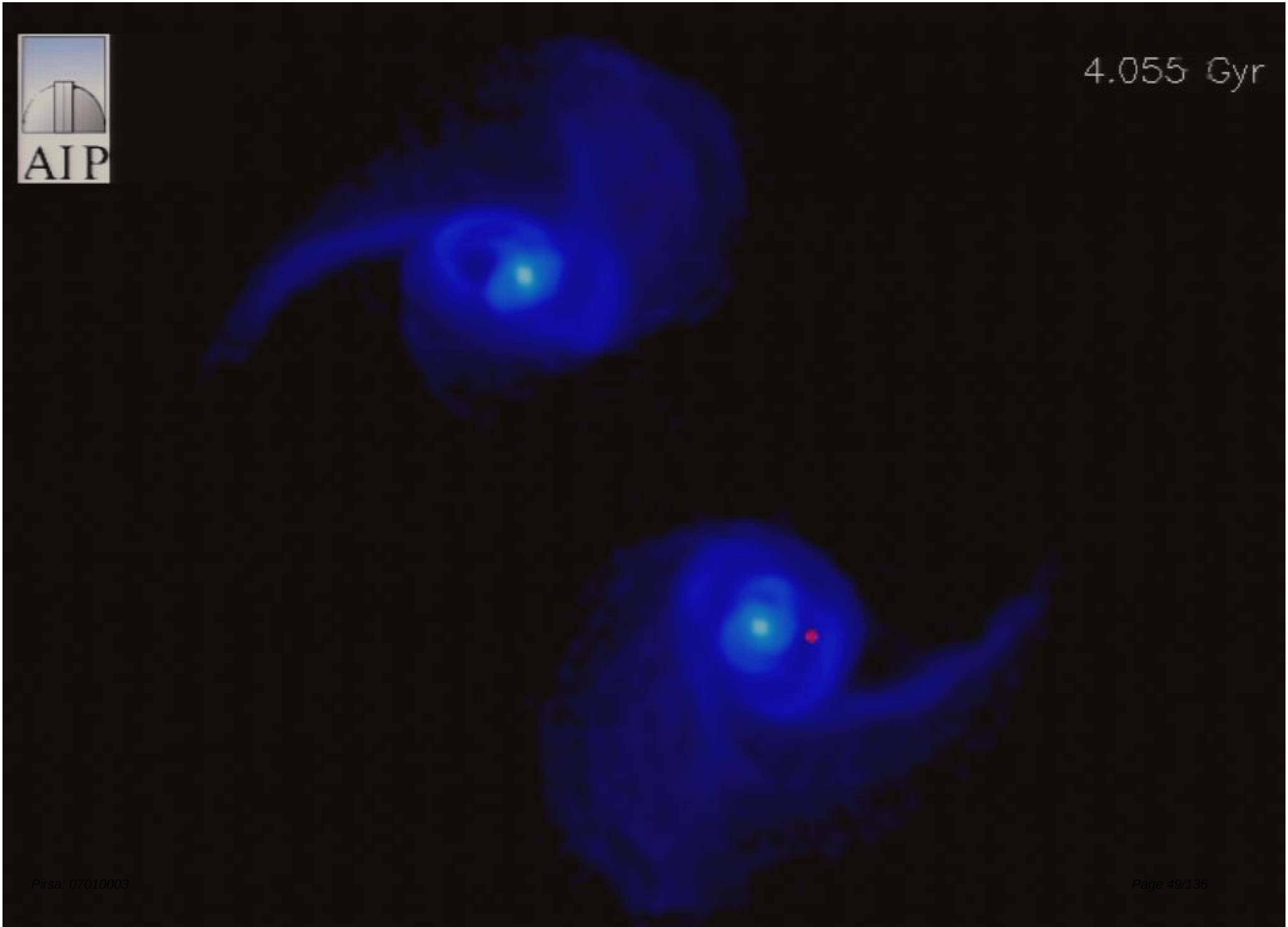
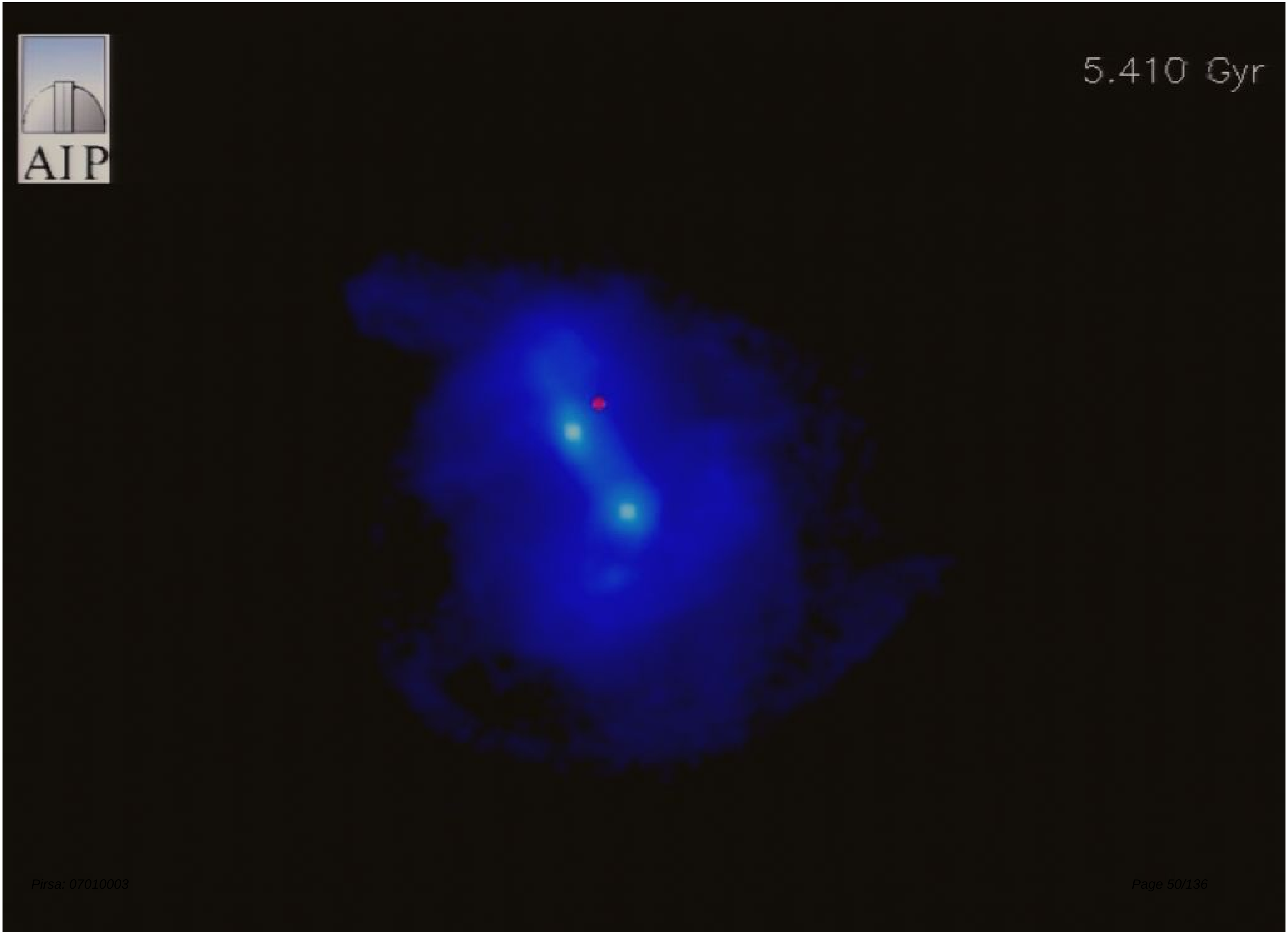

4.055 Gyr
AIP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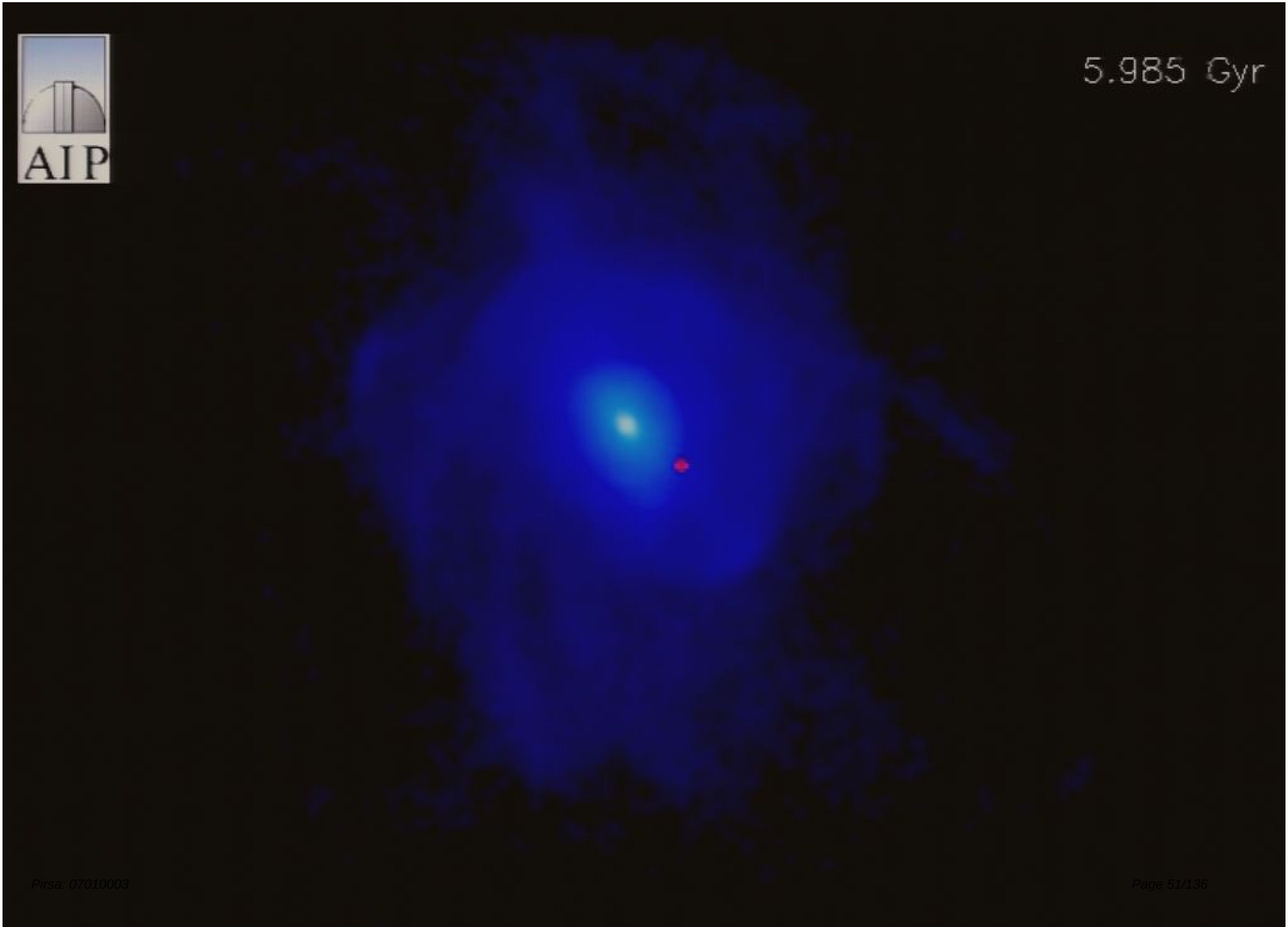
5.410 Gyr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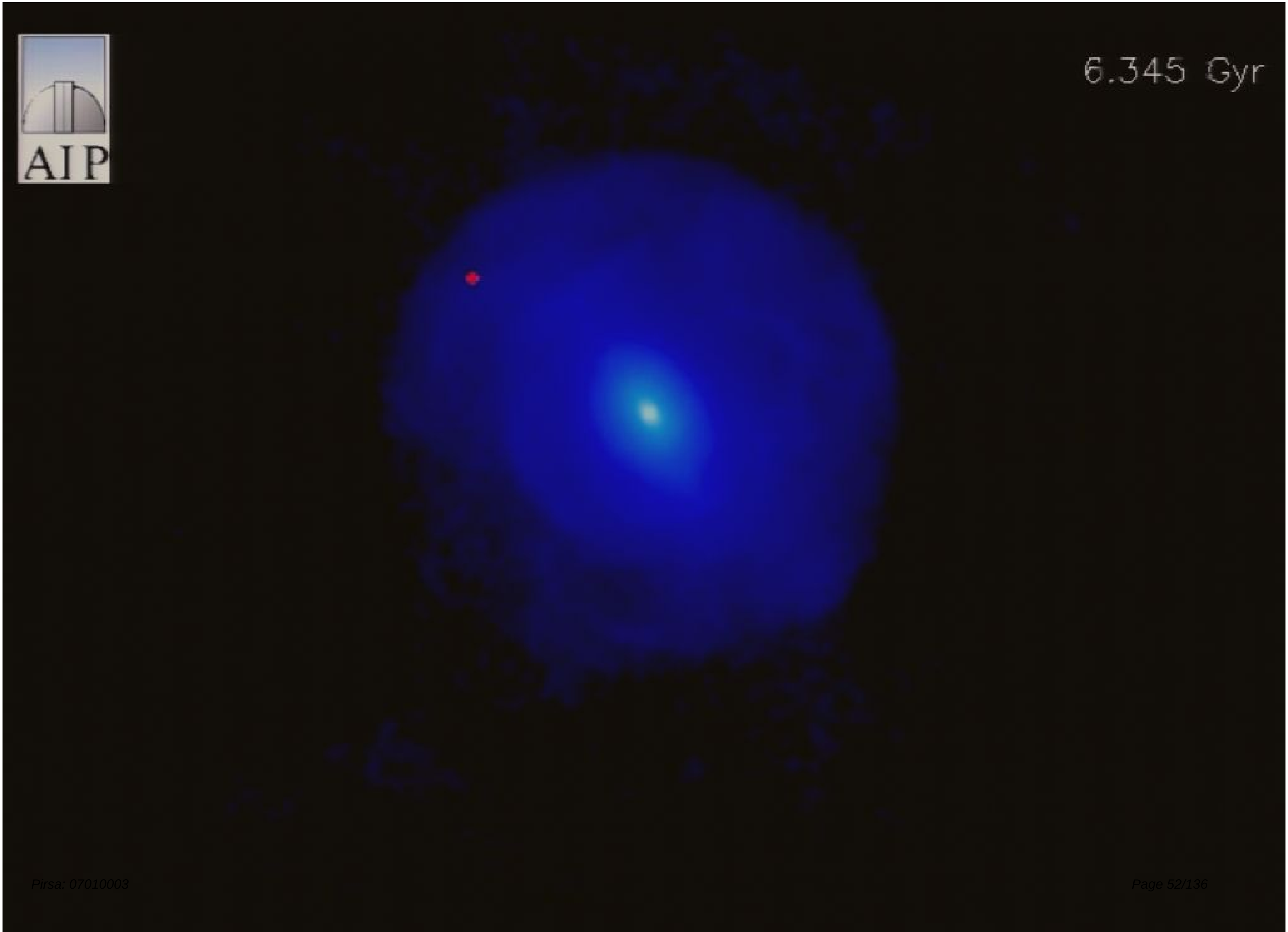
5.985 Gyr


6.345 Gyr

Formation movies

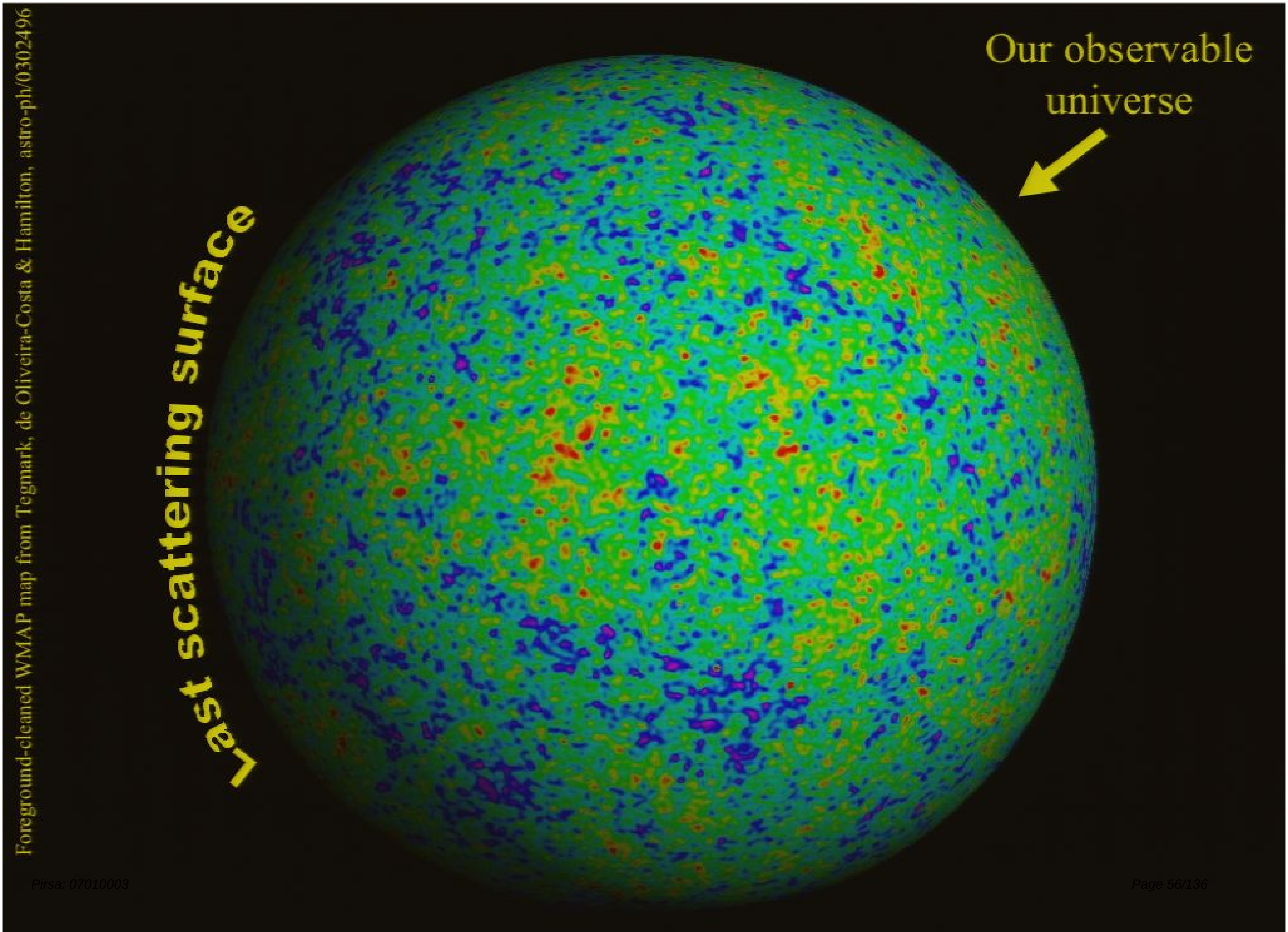
SDSS

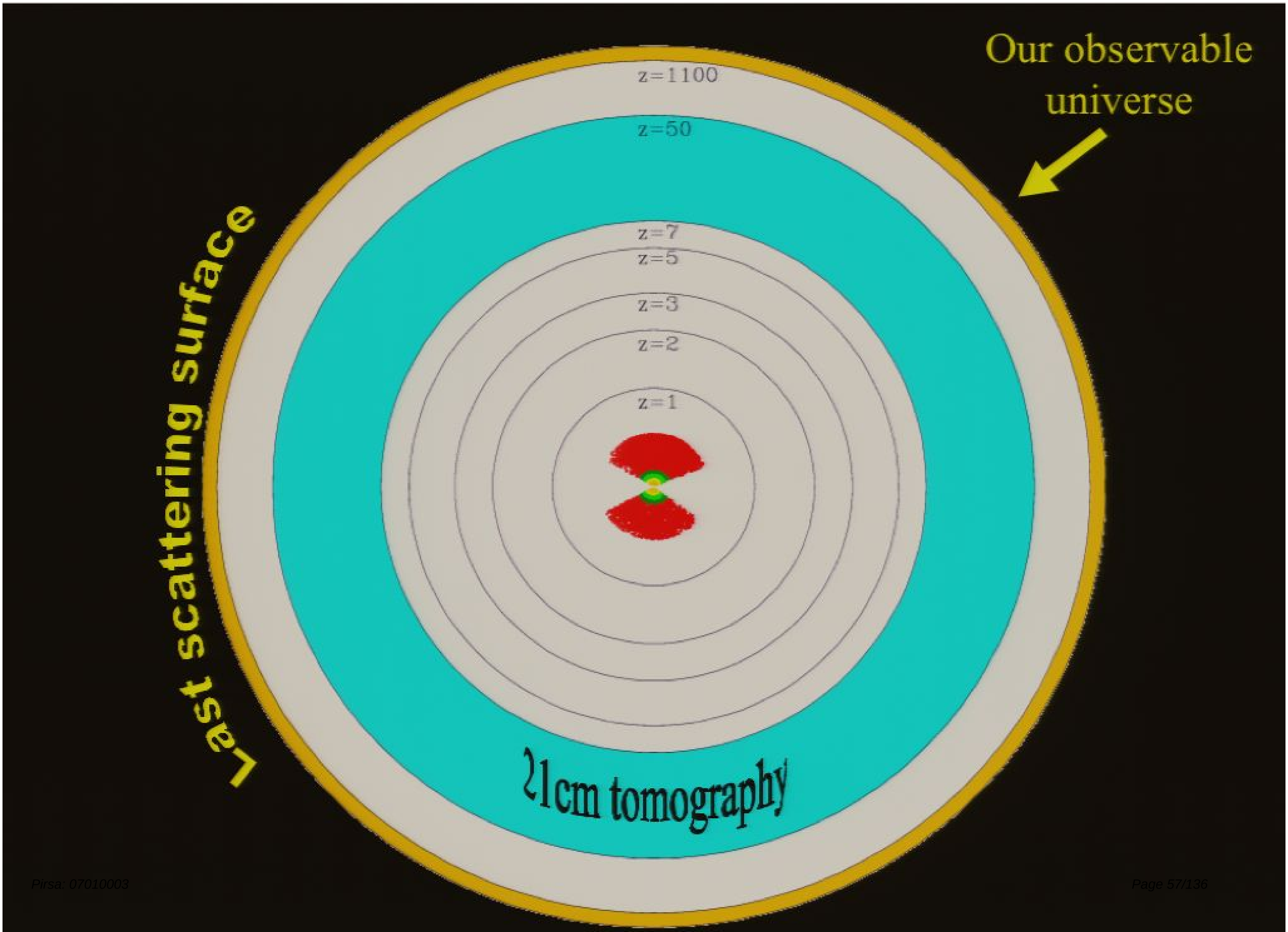
Cosmological Constraints from the SDSS Luminous Red Galaxies

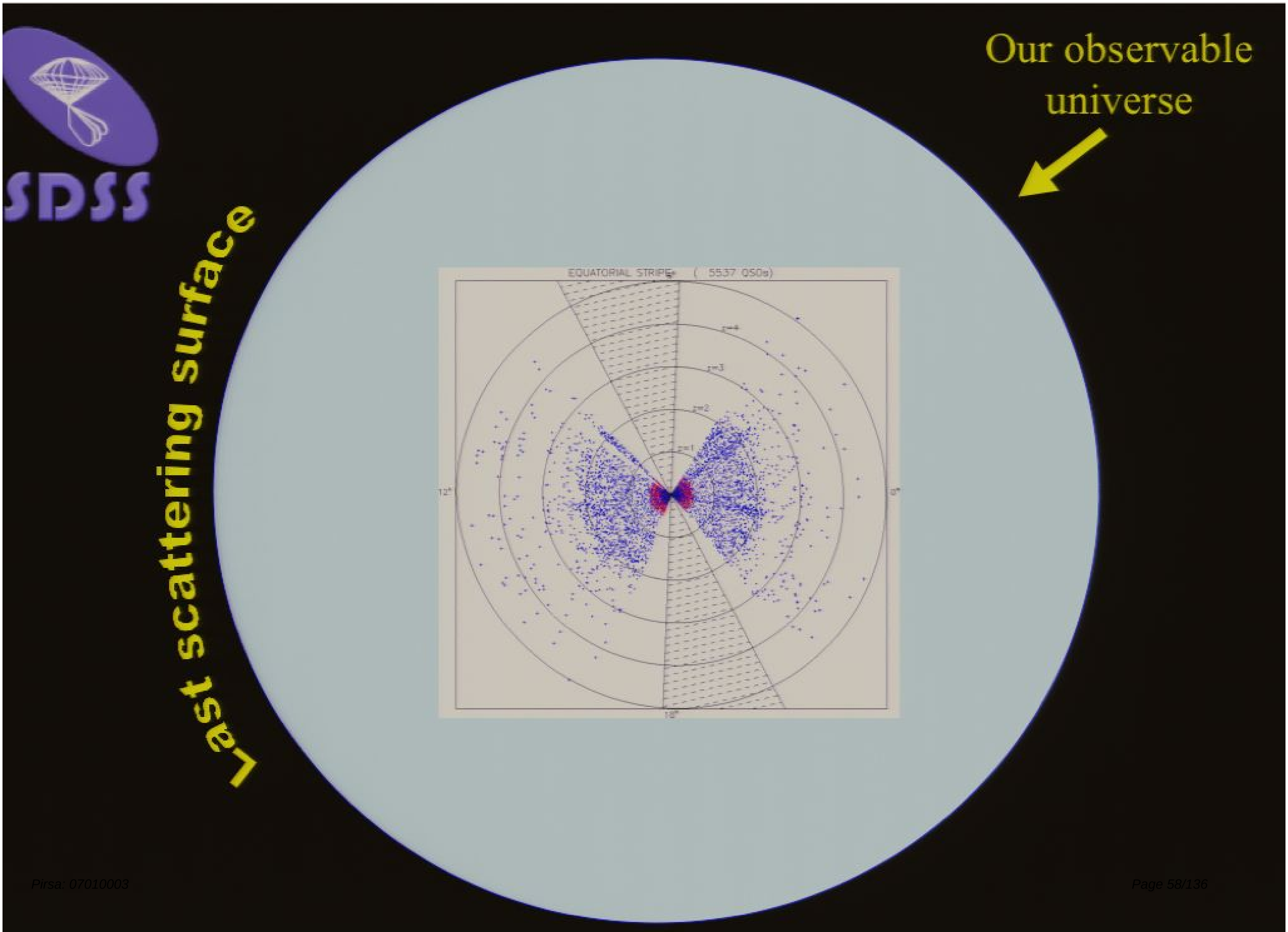
Max Tegmark[1], Daniel J. Eisenstein[2], Michael A. Strauss[3], David H. Weinberg[4], Michael R. Blanton[5], Joshua A. Frieman[6,7], Masataka Fukugita[8], James E. Gunn[3], Andrew J. S. Hamilton[9], Gillian R. Knapp[3], Robert C. Nichol[10], Jeremiah P. Ostriker[3], Nikhil Padmanabhan[11], Will J. Percival[10], David J. Schlegel[12], Donald P. Schneider[13], Roman Scoccimarro[5], Uroš Seljak[14,11], Hee-Jong Seo[2], Molly Swanson[1], Alexander S. Szalay[15], Michael S. Vogeley[16], Jaiyul Yoo[4], Idit Zehavi[17], Kevork Abazajian[18], Scott F. Anderson[19], James Annis[7], Neta A. Bahcall[3], Bruce Bassett[20,21], Andreas Berlind[5], Jon Brinkmann[22], Tamás Budavari[15], Francisco Castander[23], Andrew Connolly[24], Istvan Csabai[15], Mamoru Doi[25], Douglas P. Finkbeiner[3,26], Bruce Gillespie[22], Karl Glazebrook[15], Gregory S. Hennessy[27], David W. Hogg[5], Željko Ivezić[19,3], Bhuvnesh Jain[28], David Johnston[29,30], Stephen Kent[7], Donald Q. Lamb[6,31], Brian C. Lee[32,12], Huan Lin[7], Jon Loveday[33], Robert H. Lupton[3], Jeffrey A. Munn[27], Kaike Pan[22], Changbom Park[34], John Peoples[7], Jeffrey R. Pier[27], Adrian Pope[15], Michael Richmond[35], Constance Rockosi[6], Ryan Scranton[24], Ravi K. Sheth[28], Albert Stebbins[7], Christopher Stoughton[7], István Szapudi[36], Douglas L. Tucker[7], Daniel E. Vanden Berk[24], Brian Yanny[7], Donald G. York[6,31]

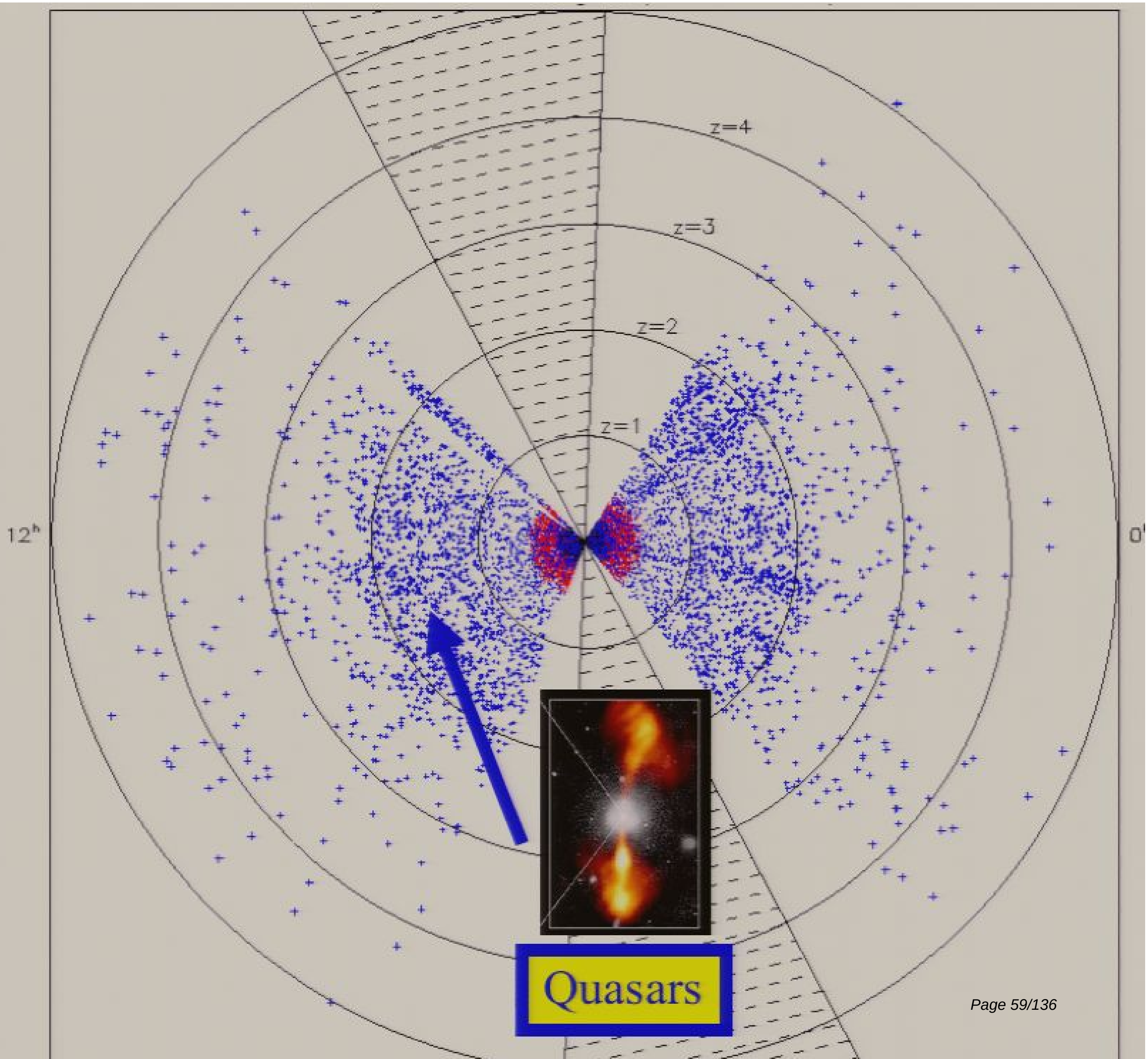
[1]Dept. of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA; [2]Department of Astronomy, University of Arizona, Tucson, AZ 85721, USA; [3]Princeton University Observatory, Princeton, NJ 08544, USA; [4]Dept. of Astronomy, Ohio State University, Columbus, OH 43210, USA; [5]Center for Cosmology and Particle Physics, Dept. of Physics, New York University, 4 Washington Pl., New York, NY 10003, USA; [6]Center for Cosmological Physics and Department of Astronomy & Astrophysics, Univ. of Chicago, Chicago, IL 60637, USA; [7]Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA; [8]Inst. for Cosmic Ray Research, Univ. of Tokyo, 5-1-5, Kashiwanoha, Kashiwa, Chiba, 277-8582, Japan; [9]JILA and Dept. of Astrophysical and Planetary Sciences, Univ. of Colorado, Boulder, CO 80309, USA; [10]Inst. of Cosmology & Gravitation, Univ. of Portsmouth, Portsmouth, P01 2EG, United Kingdom; [11]Dept. of Physics, Princeton University, Princeton, NJ 08544, USA; [12]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA; [13]Dept. of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA 16802, USA; [14]International Center for Theoretical Physics, Strada Costiera 11, 34014 Trieste, Italy; [15]Department of Physics and Astronomy, The Johns Hopkins University, 3701 San Martin Drive, Baltimore, MD 21218, USA; [16]Dept. of Physics, Drexel University, Philadelphia, PA 19104, USA; [17]Dept. of Astronomy, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106-7215; [18]Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA; [19]Dept. of Astronomy, Univ. of Washington, Box 351580, Seattle, WA 98195; [20]South African Astronomical Observatory, Cape Town, South Africa; [21]Applied Mathematics Dept., Univ. of Cape Town, Cape Town, South Africa; [22]Apache Point Observatory, 2001 Apache Point Rd, Sunspot, NM 88349-0059, USA; [23]Institut d'Estudis Espacials de Catalunya/CSIC, Campus UAB, 08034 Barcelona, Spain; [24]University of Pittsburgh, Department of Physics and Astronomy, 3941 O'Hara Street, Pittsburgh, PA 15260, USA; [25]Inst. of Astronomy, Univ. of Tokyo, Osawa 2-21-1, Mitaka, Tokyo, 181-0015, Japan; [26]Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, MS46, Cambridge, MA 02138; [27]U.S. Naval Observatory, Flagstaff Station, 10391 W. Naval Obs. Rd., Flagstaff, AZ 86001-8521, USA; [28]Department of Physics, University of Pennsylvania, Philadelphia, PA 19104, USA; [29]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena CA, 91109, USA; [30]California Inst. of Technology, 1200 East California Blvd., Pasadena, CA 91125, USA; [31]Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA; [32]Gatan Inc., Pleasanton, CA 94588; [33]Sussex Astronomy Centre, University of Sussex, Falmer, Brighton BN1 9QJ, UK; [34]Department of Astronomy, Seoul National University, 151-742, Korea; [35]Physics Dept., Rochester Inst. of Technology, 1 Lomb Memorial Dr, Rochester, NY 14623, USA; [36]Institute for Astronomy, University of Hawaii, 2680, Woodlawn Drive, Honolulu, HI 96822, USA;

(Dated: Submitted to Phys. Rev. D, August 22, 2006)


Our observable universe
Last scattering surface
Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496


Our observable
universe
z=1100
z=50
z=7
z=5
z=3
z=2
z=1
Last scattering surface
21cm tomography


SDSS
Our observable universe
Last scattering surface
EQUATORIAL STRIPE (5537 QSOs)
z=1
z=2
z=3
z=4



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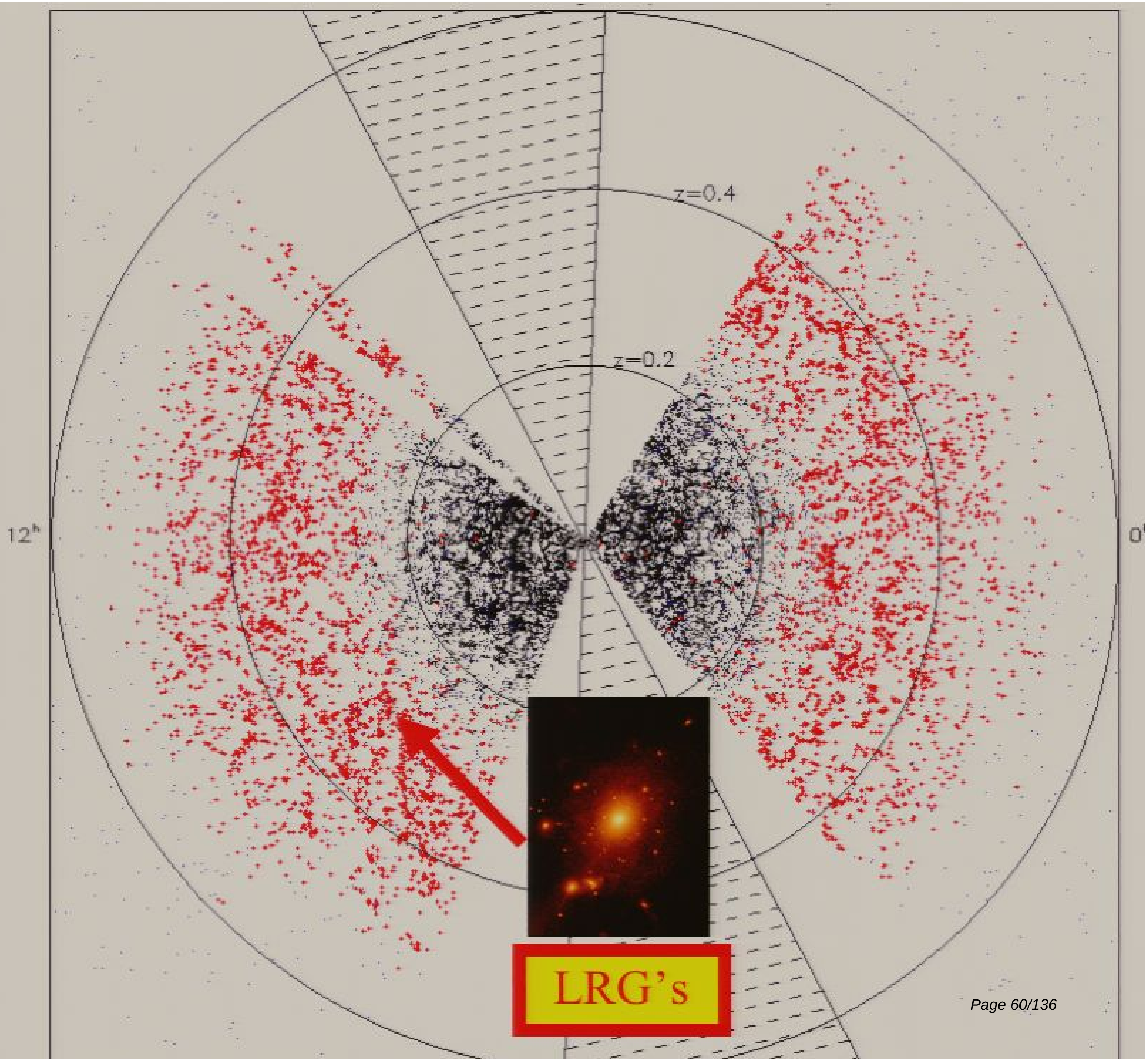

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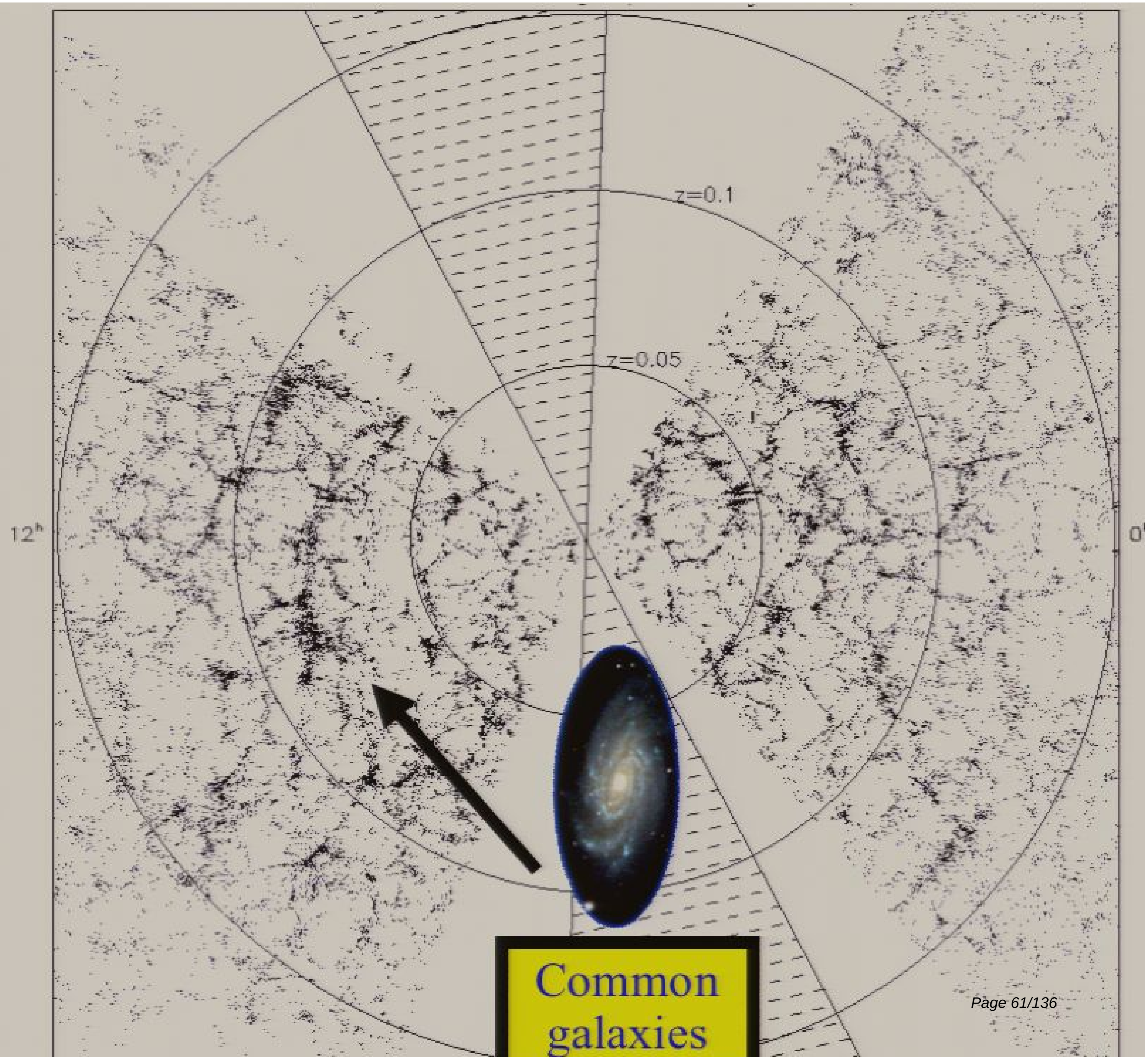

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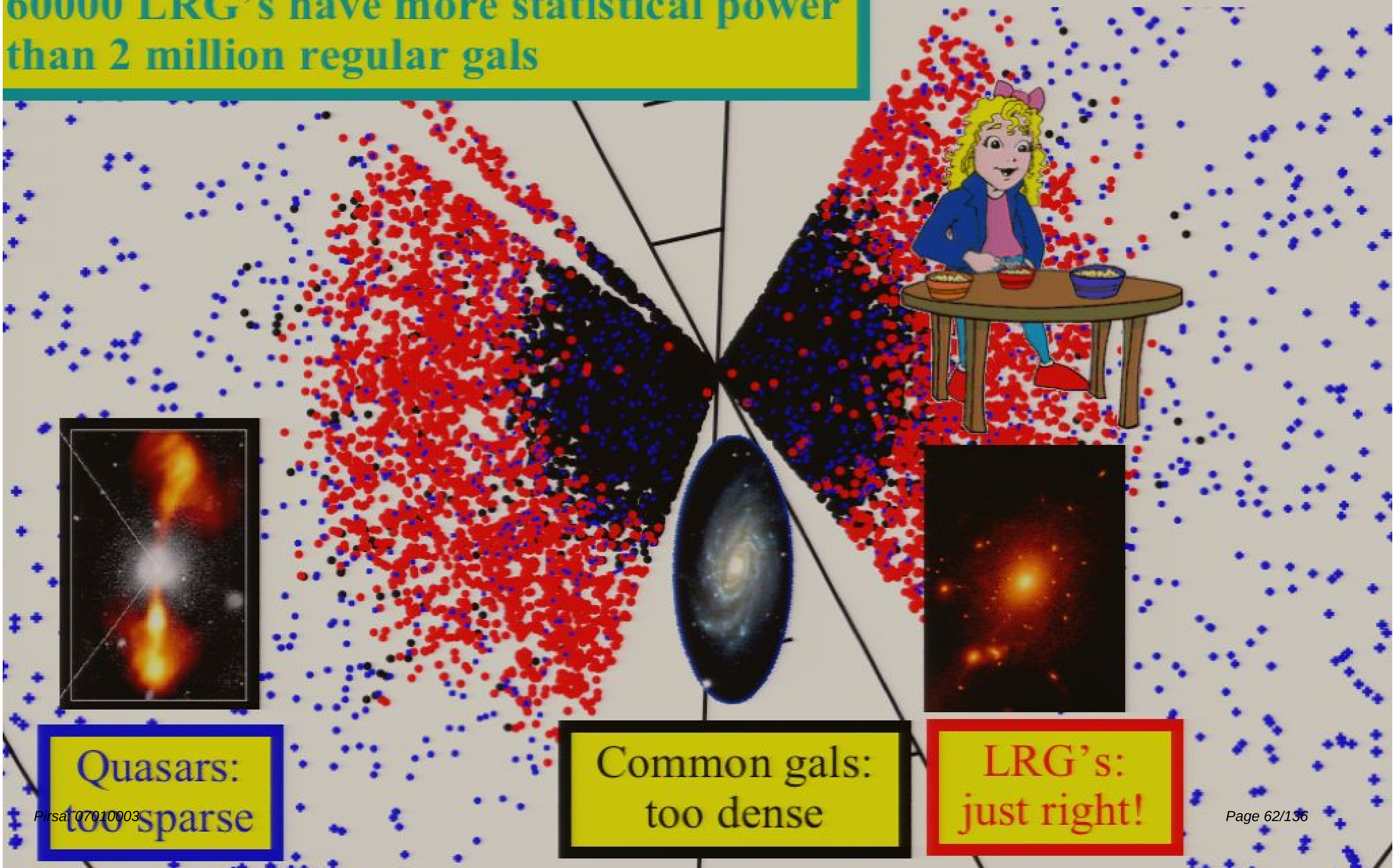
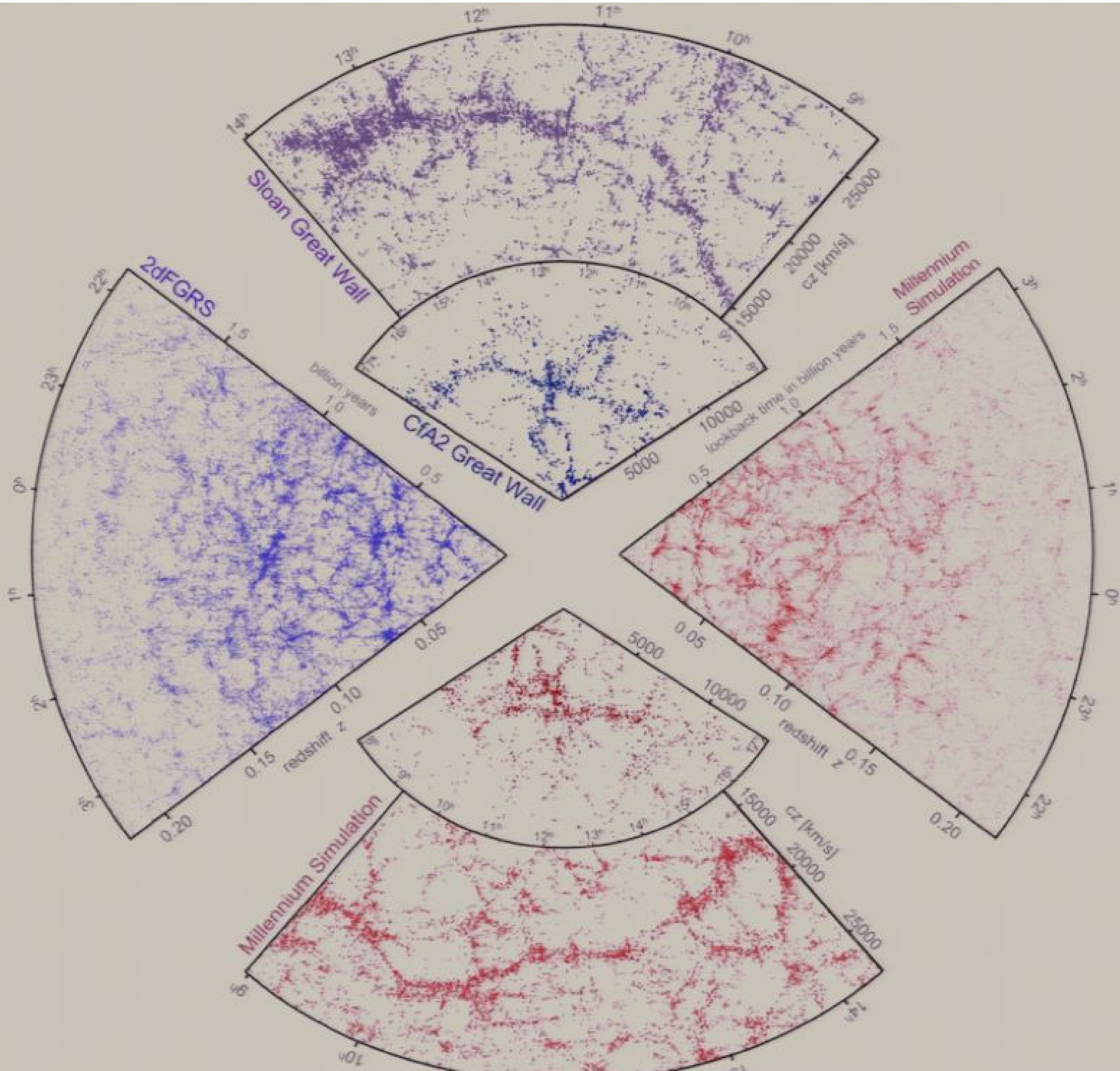
Why LRG's are "Goldilocks galaxies":

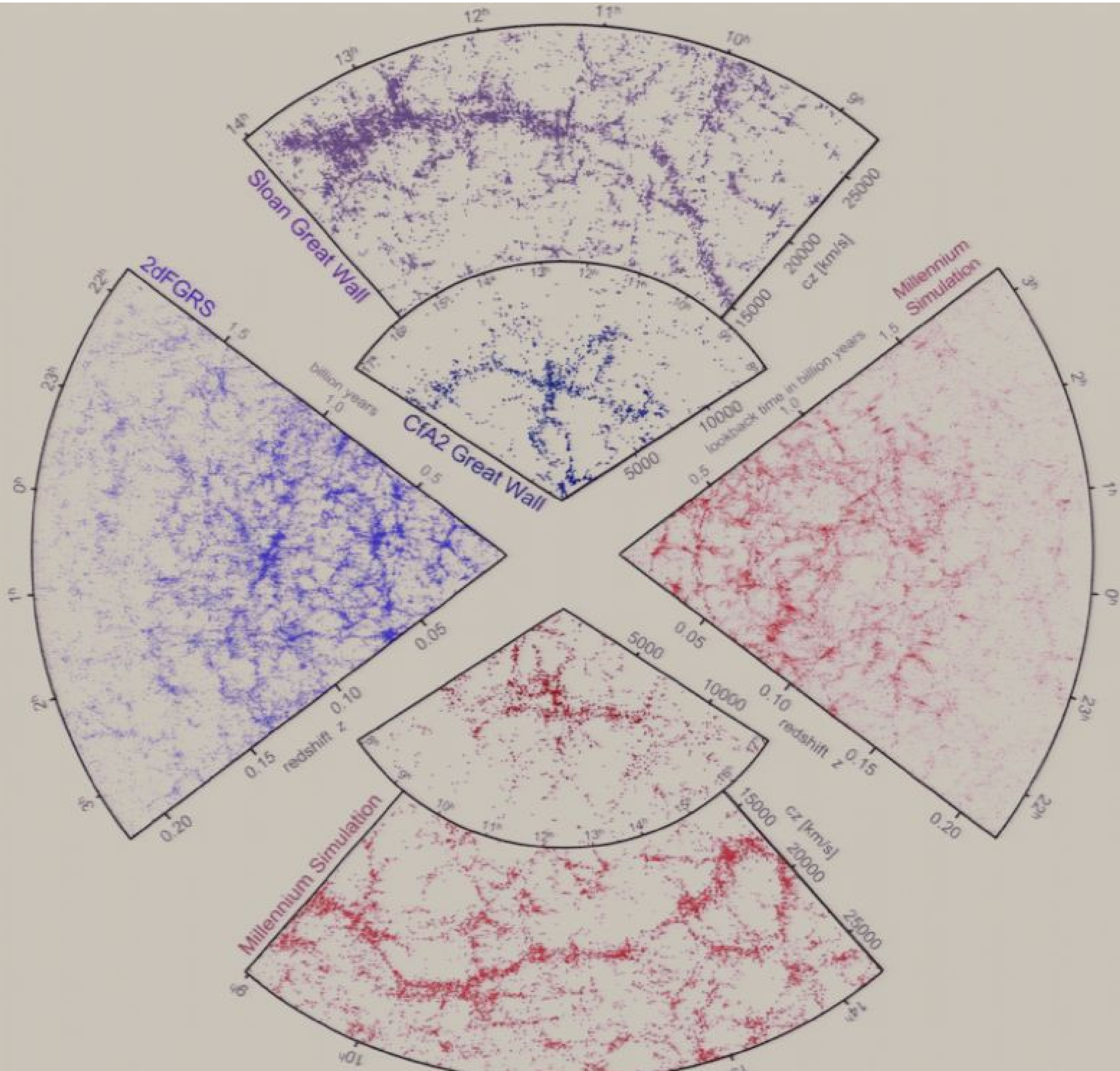
60000 LRG's have more statistical power than 2 million regular gals



Springel, Frenk & White 2006, Nature, 440, 11

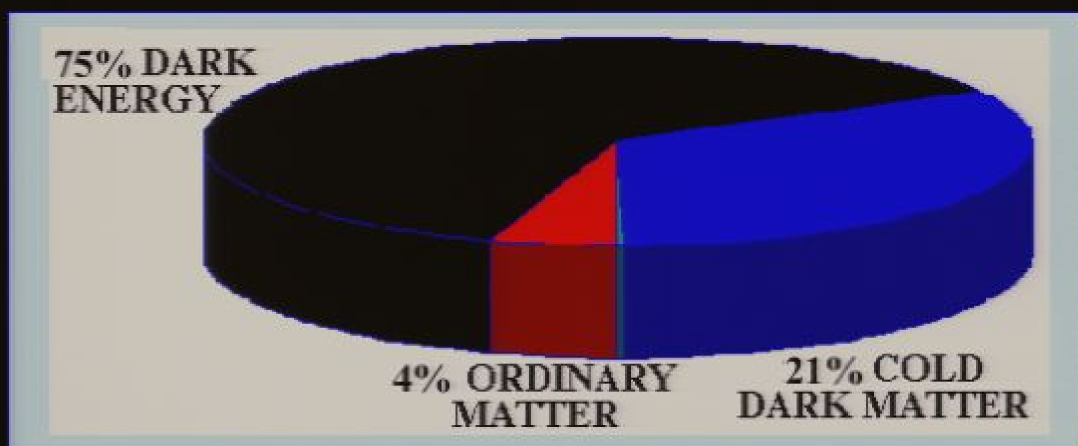


Springel, Frenk & White 2006, Nature, 440, 11

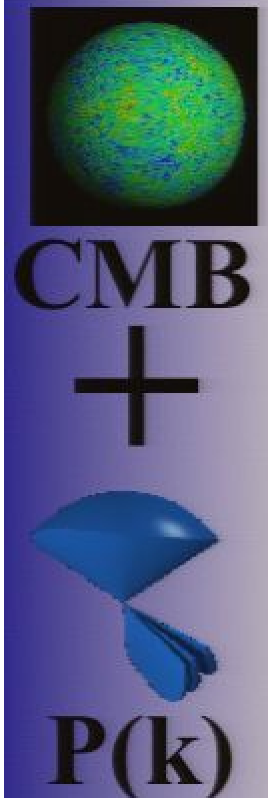


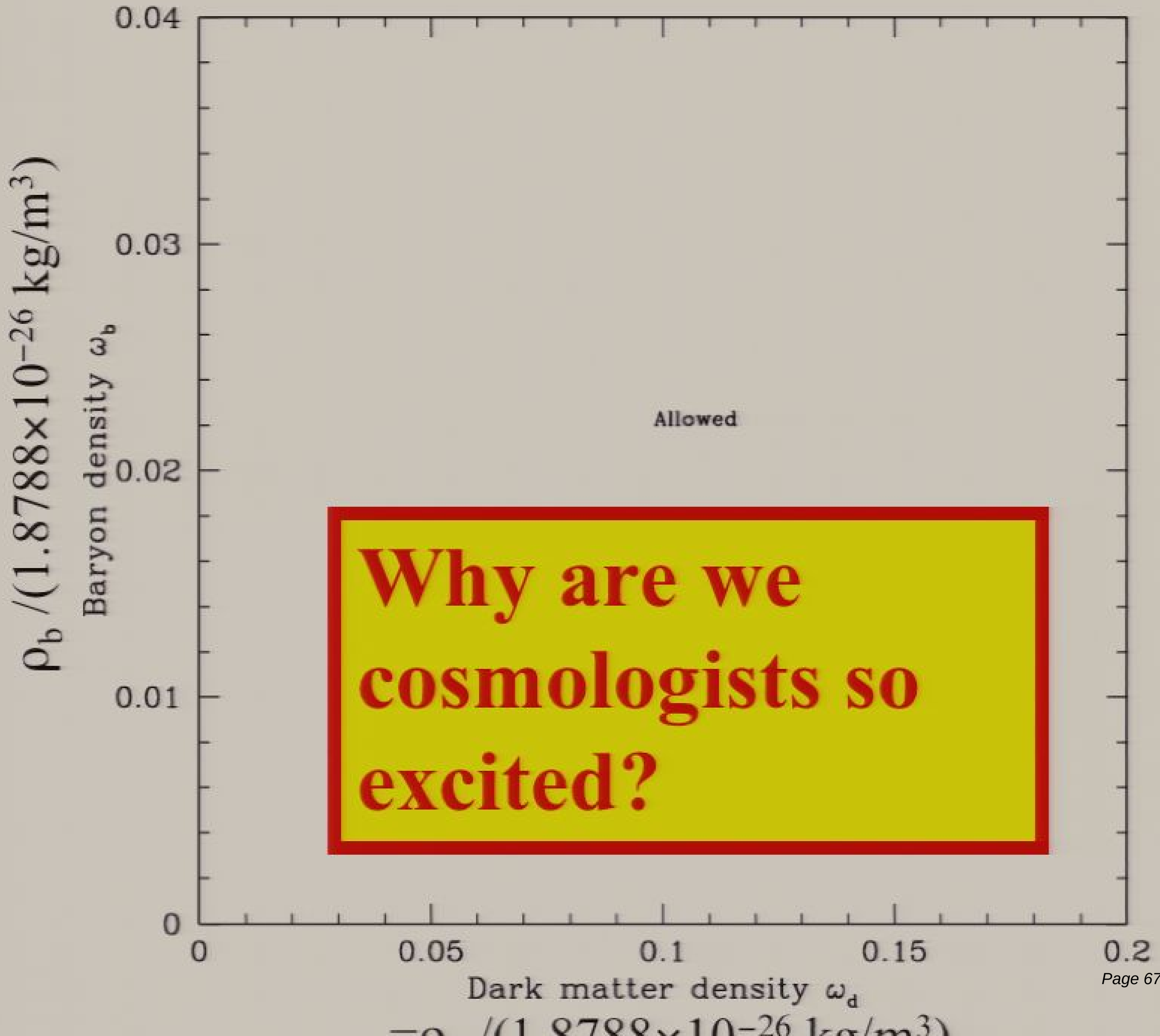
Measuring cosmological parameters

What's the matter?



How much dark matter is there?





Why are we cosmologists so excited?

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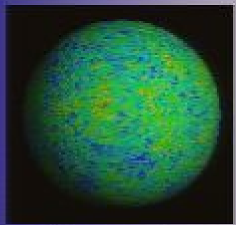
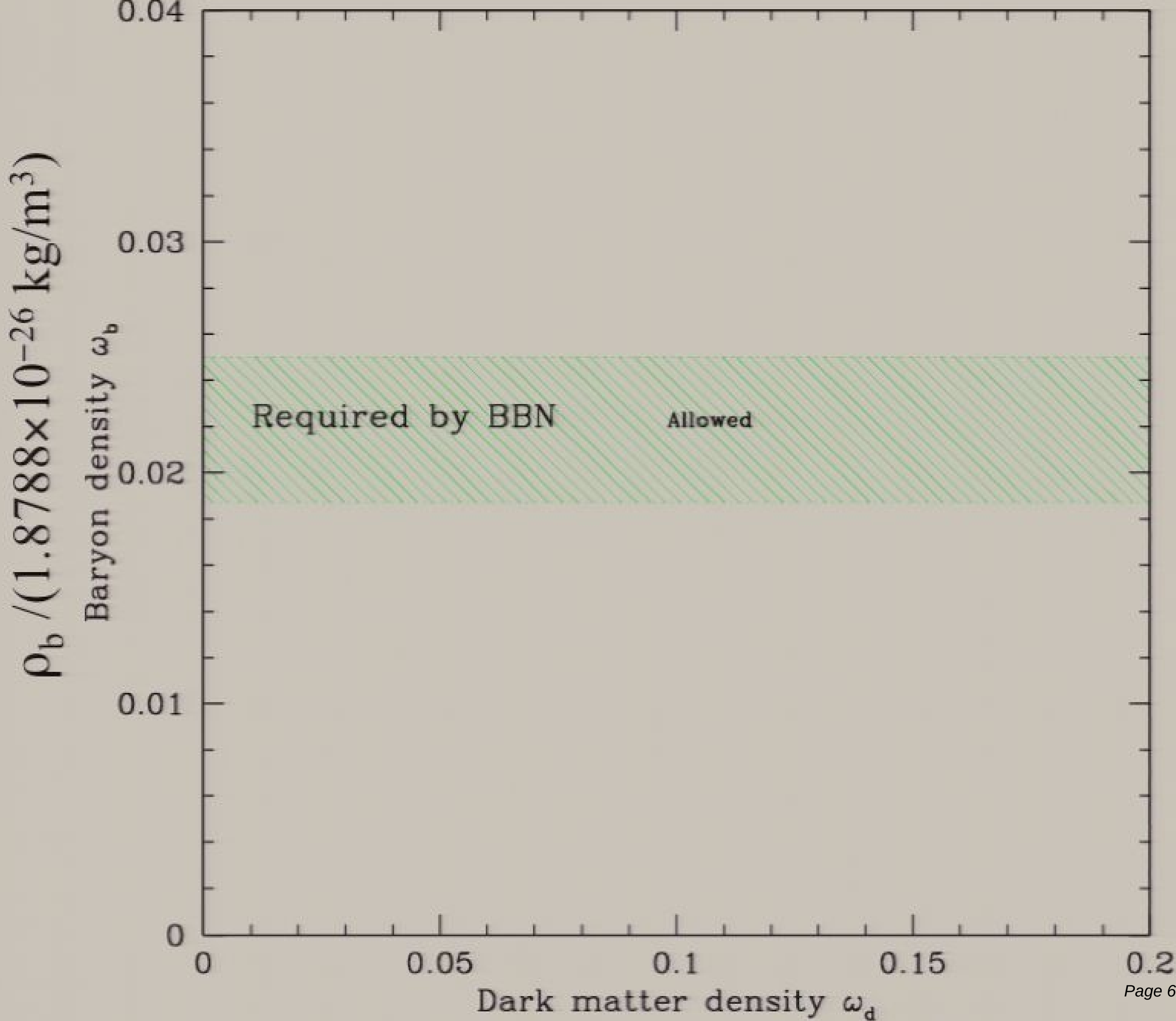


CMB

+

P(k)



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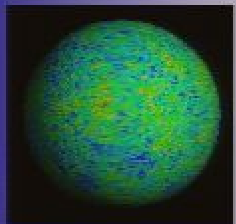
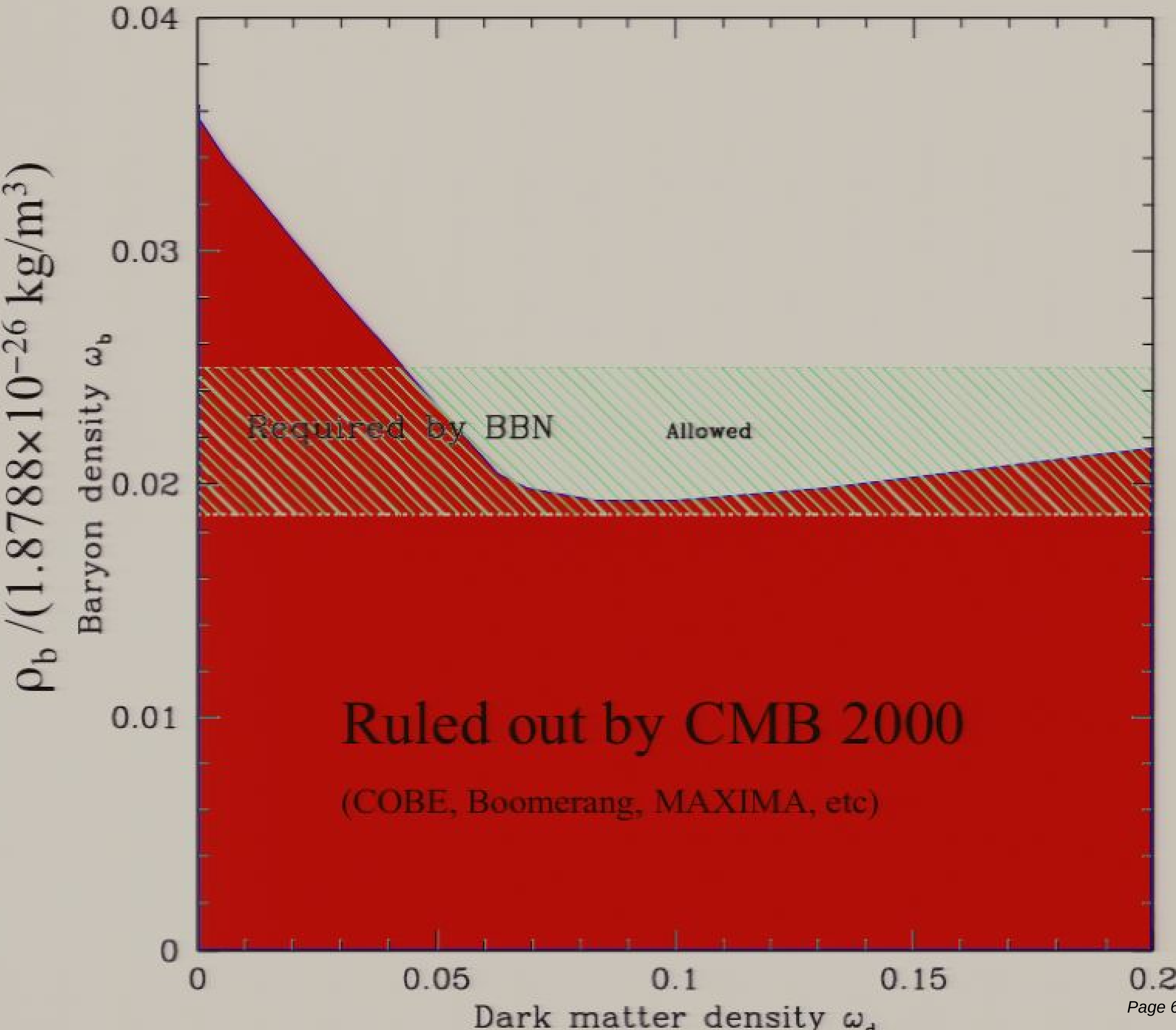


CMB

+

P(k)



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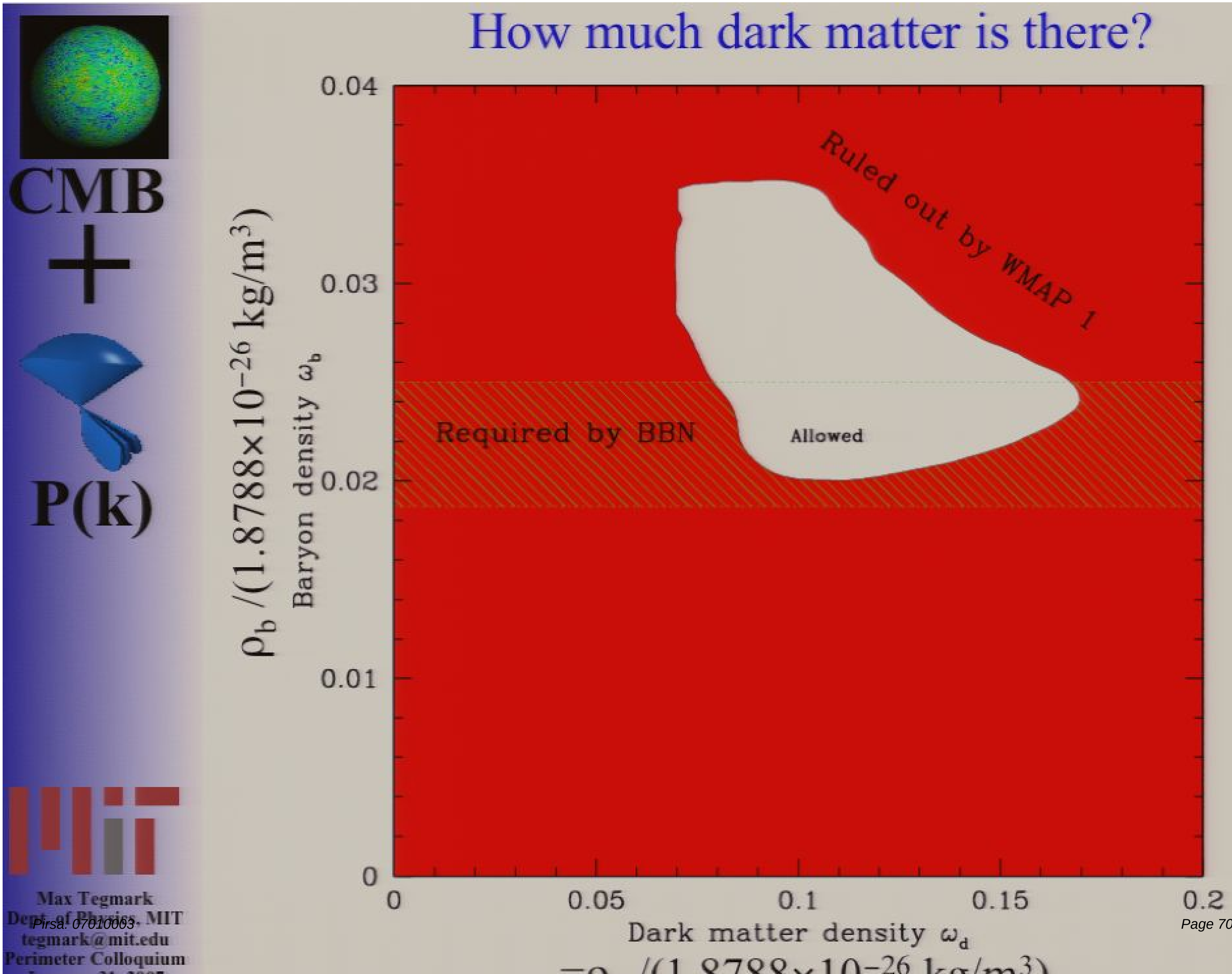

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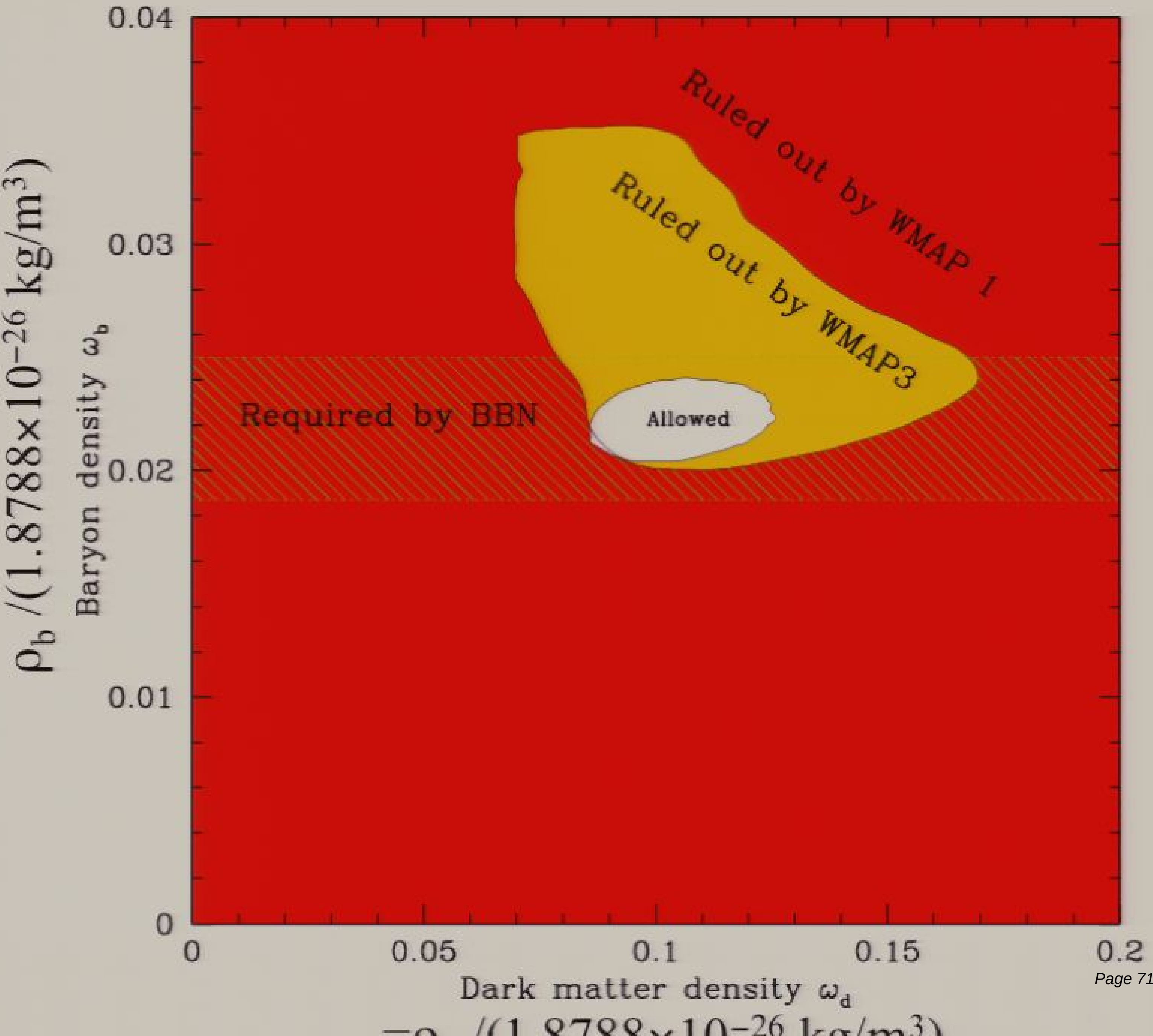

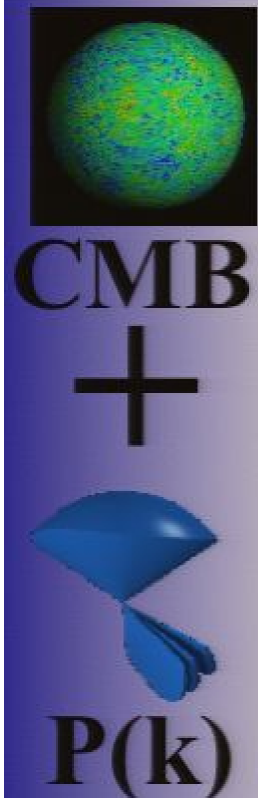

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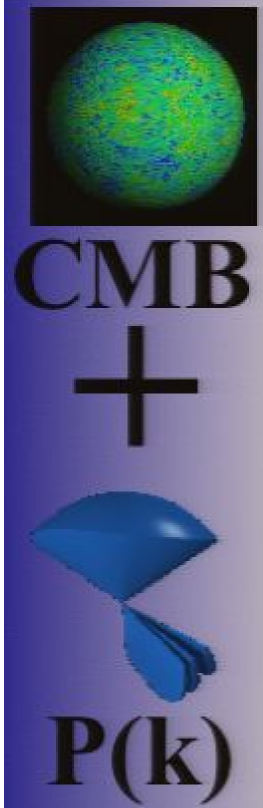

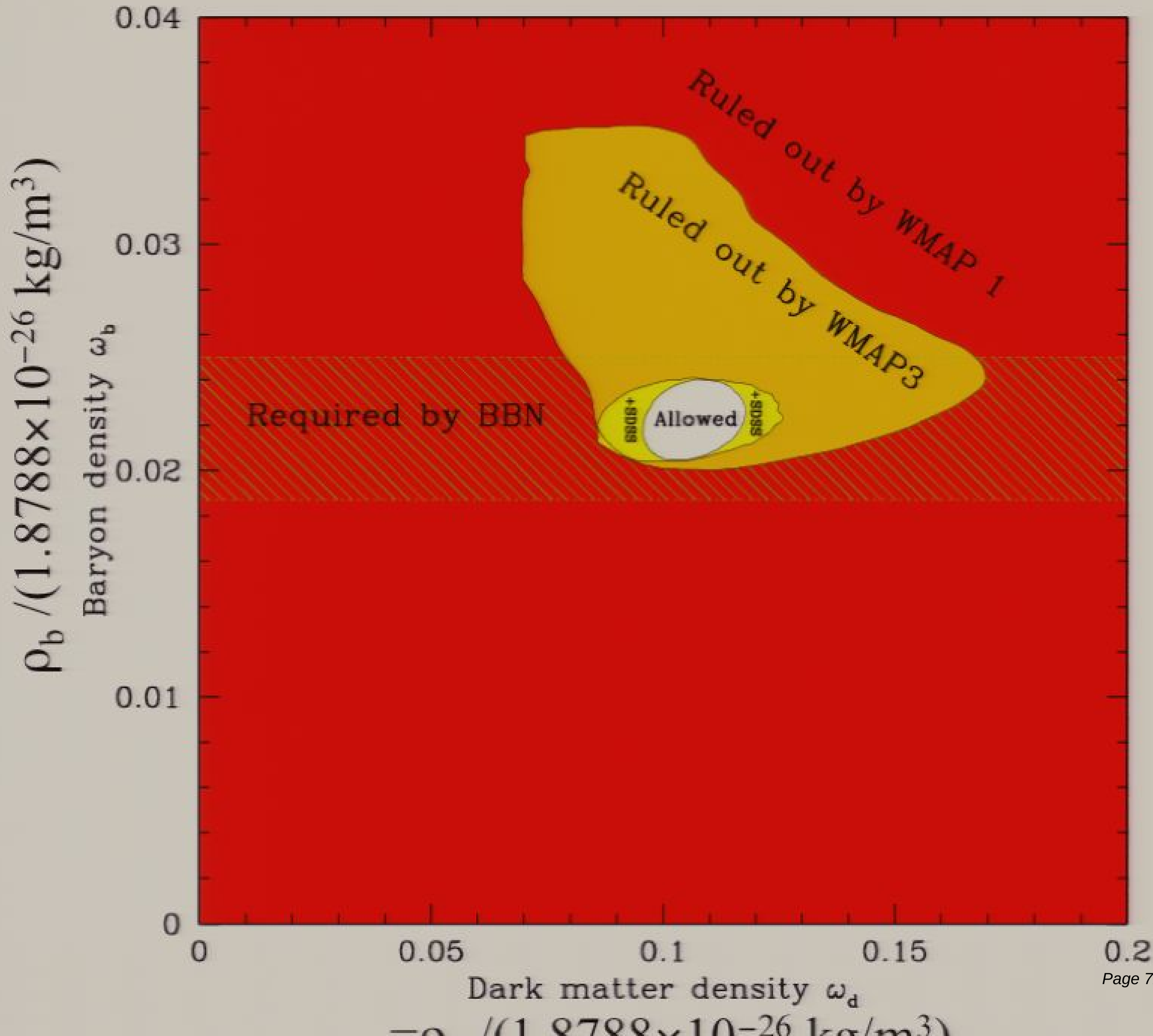

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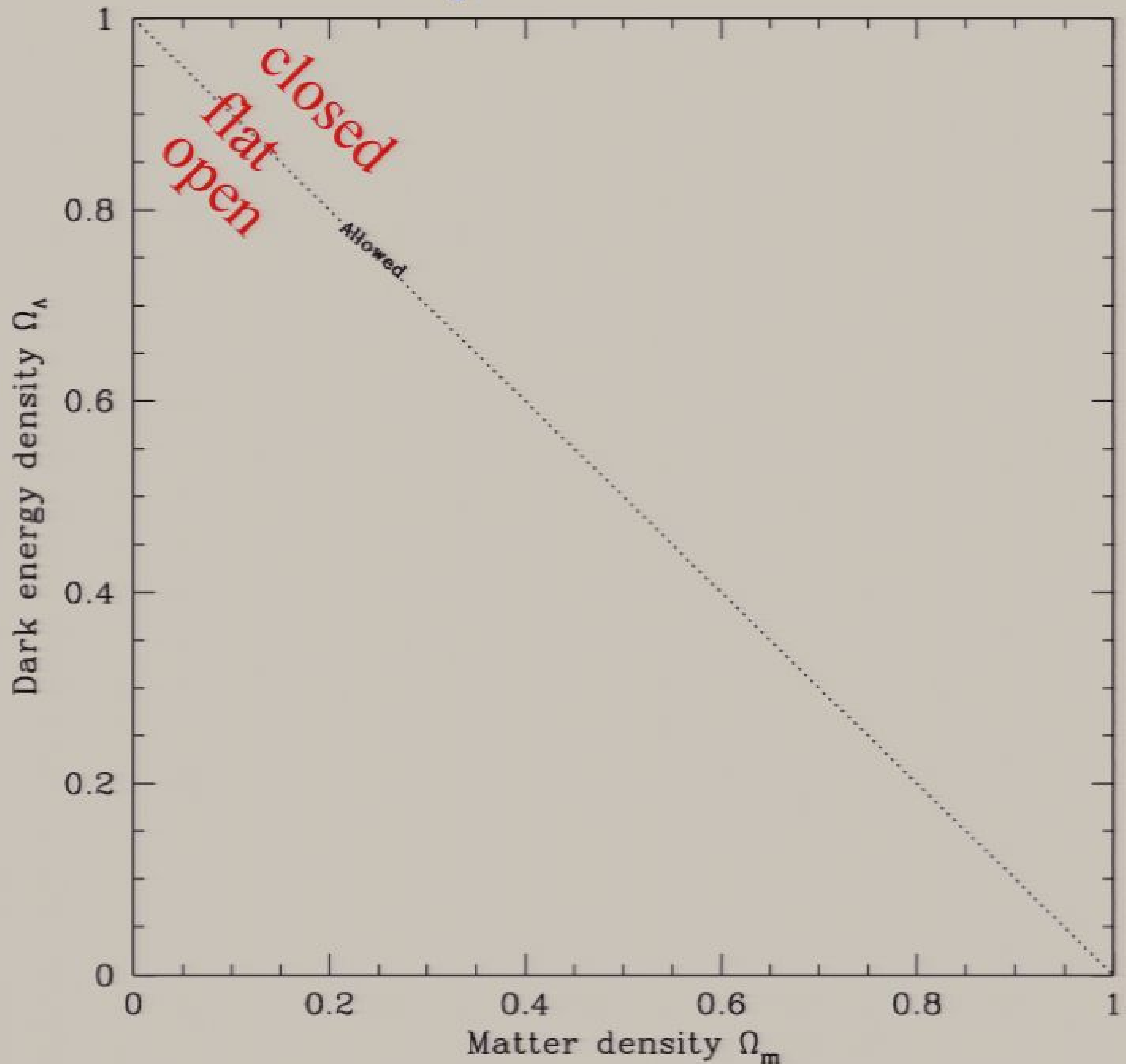
How flat is space?



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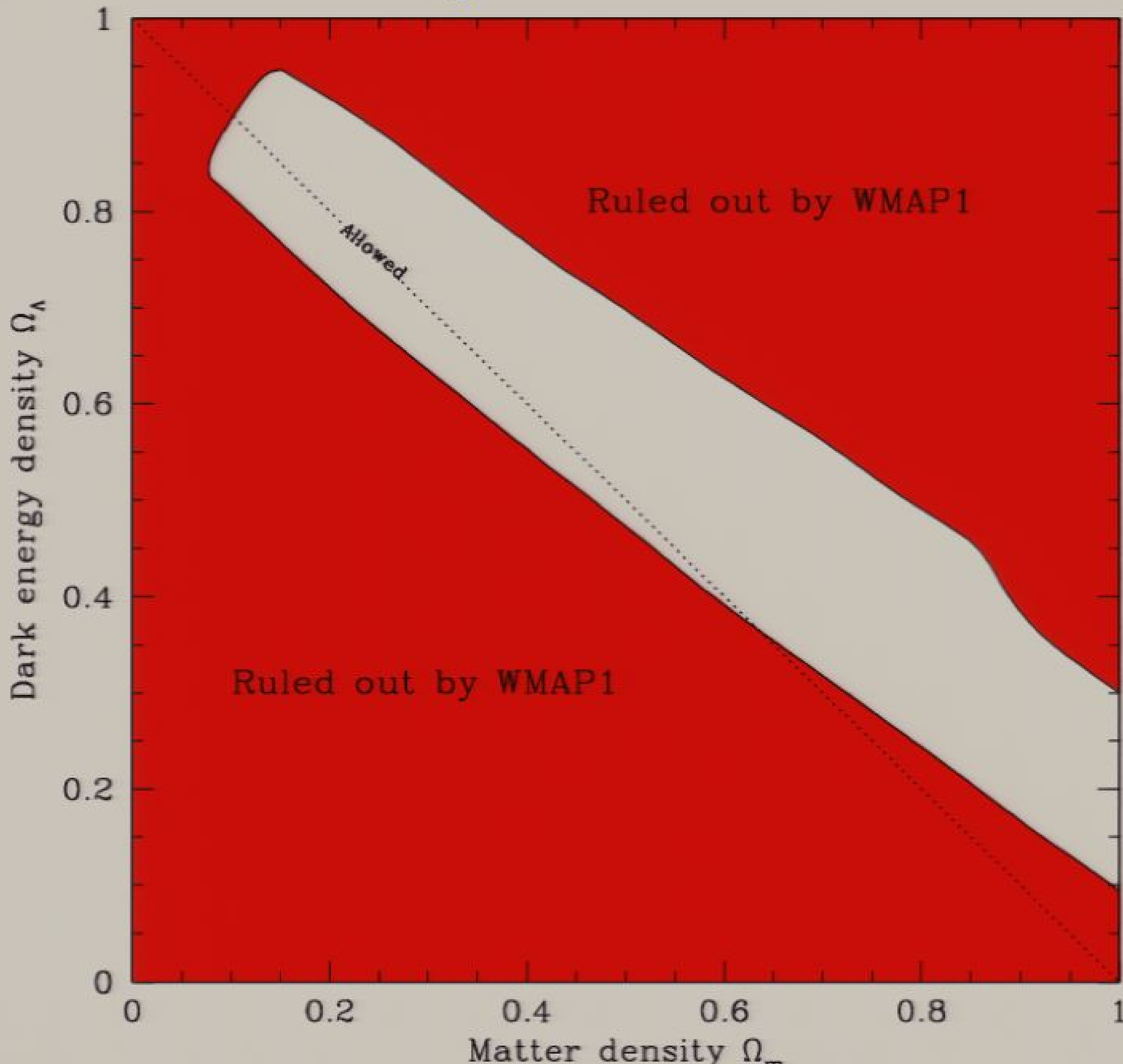

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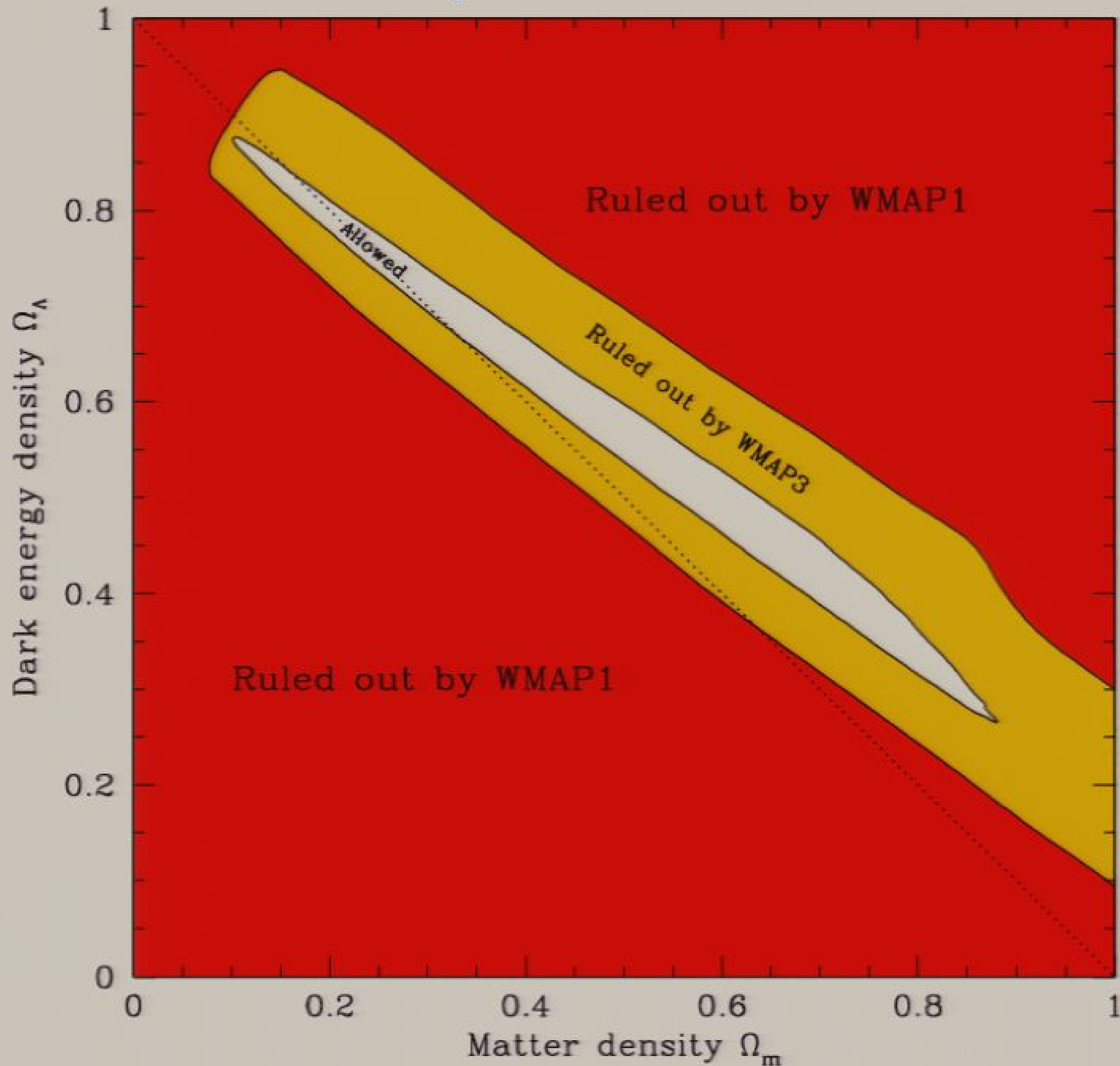
How flat is space? Somewhat.



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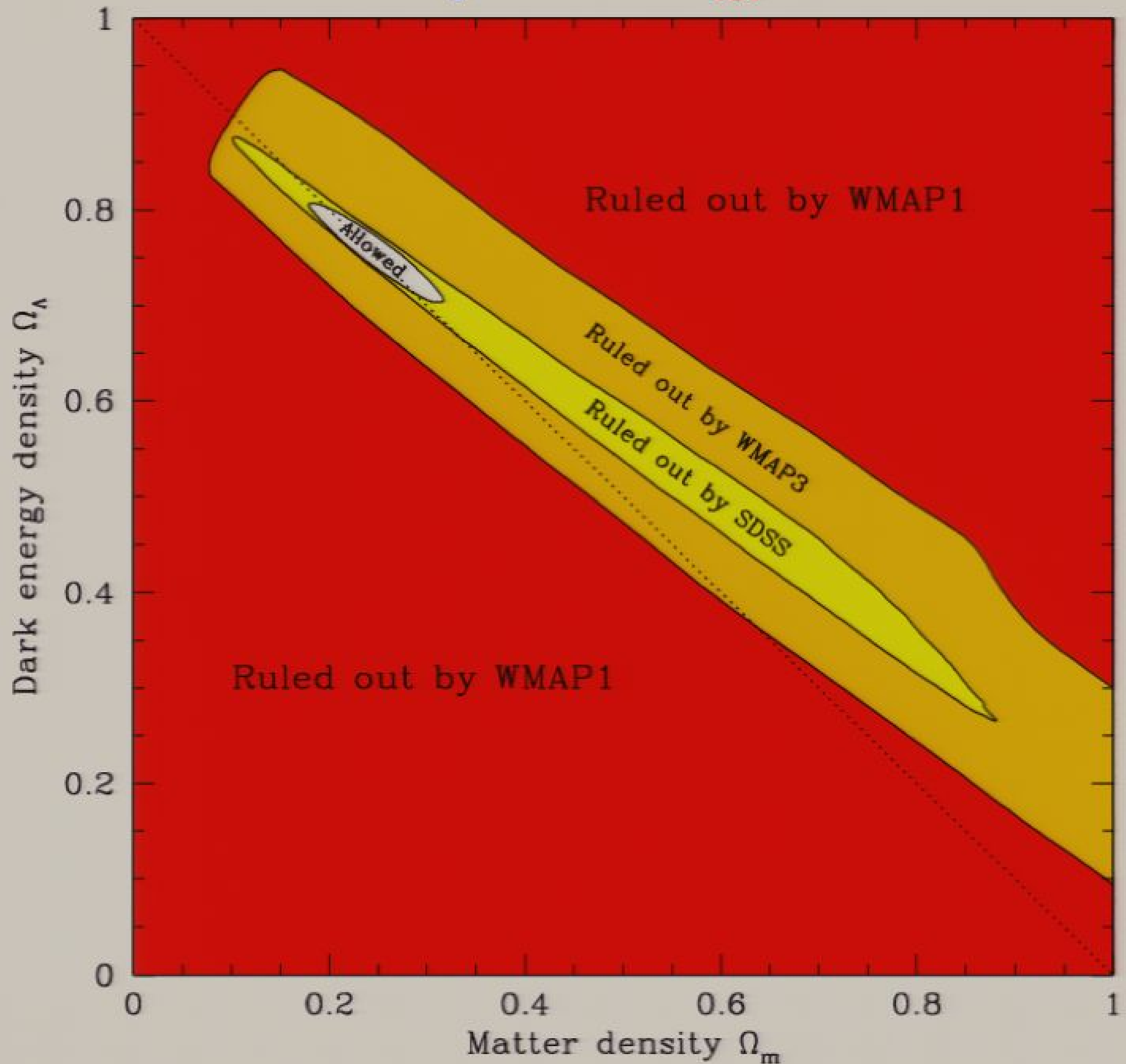
How flat is space? Ω_{tot}=1.003±0.010



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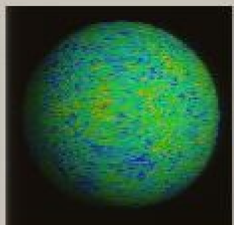


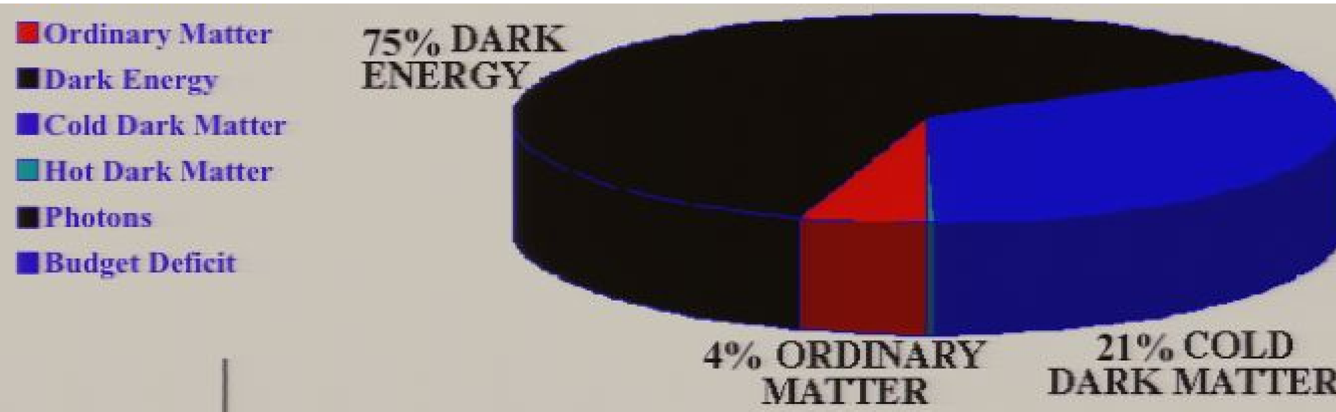
CMB

+

LSS

Parameter	Value	Meaning	Definition
Matter budget parameters:			
Ω_{tot}	$1.003^{+0.010}_{-0.009}$	Total density/critical density	$\Omega_{tot} = \Omega_m + \Omega_\Lambda = 1 - \Omega_k$
Ω_Λ	$0.761^{+0.017}_{-0.018}$	Dark energy density parameter	[illegible]
ω_b	$0.0222^{+0.0007}_{-0.0007}$	Baryon density	[illegible]
ω_c	$0.1050^{+0.0041}_{-0.0040}$	Cold dark matter density	[illegible]
ω_ν	< 0.010 (95%)	Massive neutrino density	[illegible]
w	$-0.941^{+0.087}_{-0.101}$	Dark energy equation of state	[illegible]
Seed fluctuation parameters:			
A_s	[illegible]	Scalar fluctuation amplitude	Primordial scalar power at k = 0.05/Mpc
r	< 0.30 (95%)	Tensor-to-scalar ratio	Tensor-to-scalar power ratio at k = 0.05/Mpc
n_s	[illegible]	Scalar spectral index	Primordial spectral index at k = 0.05/Mpc
$n_t + 1$	[illegible]	Tensor spectral index	[illegible]
α	[illegible]	Running of spectral index	[illegible]
Nuisance parameters:			
τ	[illegible]	Reionization optical depth	
b	[illegible]	Galaxy bias factor	[illegible]
Q_{nl}	[illegible]	Nonlinear correction parameter	[illegible]
Other popular parameters (determined by those above):			
h	[illegible]	Hubble parameter	[illegible]
Ω_m	[illegible]	Matter density/critical density	$\Omega_m = \Omega_{tot} - \Omega_\Lambda$
Ω_b	[illegible]	Baryon density/critical density	$\Omega_b = \omega_b/h^2$
Ω_c	[illegible]	CDM density/critical density	$\Omega_c = \omega_c/h^2$
Ω_ν	[illegible]	Neutrino density/critical density	$\Omega_\nu = \omega_\nu/h^2$
Ω_k	[illegible]	Spatial curvature	$\Omega_k = 1 - \Omega_{tot}$
ω_m	[illegible]	Matter density	[illegible]
f_ν	[illegible]	Dark matter neutrino fraction	[illegible]
A_t	[illegible]	Tensor fluctuation amplitude	[illegible]
M_ν	[illegible]	Sum of neutrino masses	[illegible]
$A_{.002}$	[illegible]	WMAP3 normalization parameter	[illegible]
$r_{.002}$	[illegible]	Tensor-to-scalar ratio (WMAP3)	[illegible]
σ_8	[illegible]	Density fluctuation amplitude	[illegible]
[illegible]	[illegible]	Velocity fluctuation amplitude	
Cosmic history parameters:			
z_{eq}	[illegible]	Matter-radiation Equality redshift	[illegible]
z_{rec}	[illegible]	Recombination redshift	[illegible]
z_{ion}	[illegible]	Reionization redshift (abrupt)	[illegible]
z_{acc}	[illegible]	Acceleration redshift	[illegible]
t_{eq}	[illegible]	Matter-radiation Equality time	[illegible]
t_{rec}	[illegible]	Recombination time	[illegible]
t_{ion}	[illegible]	Reionization time	[illegible]
t_{acc}	[illegible]	Acceleration time	[illegible]
t_{now}	[illegible]	Age of Universe now	[illegible]
Fundamental parameters (independent of observing epoch):			
Q	[illegible]	Primordial fluctuation amplitude	[illegible]
κ	[illegible]	Dimensionless spatial curvature	[illegible]
ρ_Λ	[illegible]	Dark energy density	[illegible]
ρ_{halo}	[illegible]	Halo formation density	[illegible]
ξ	[illegible]	Matter mass per photon	[illegible]
ξ_b	[illegible]	Baryon mass per photon	[illegible]
ξ_c	[illegible]	CDM mass per photon	[illegible]
ξ_ν	[illegible]	Neutrino mass per photon	[illegible]
η	[illegible]	Baryon/photon ratio	[illegible]
A_Λ	[illegible]	Expansion during matter domination	[illegible]
[illegible]	[illegible]	Seed amplitude on galaxy scale	[illegible]
CMB phenomenology parameters:			
A_{peak}	[illegible]	Amplitude on CMB peak scales	[illegible]
A_{pivot}	[illegible]	Amplitude at pivot point	[illegible]
H_1	[illegible]	1st CMB peak ratio	[illegible]
H_2	[illegible]	2nd to 1st CMB peak ratio	[illegible]
H_3	[illegible]	3rd to 1st CMB peak ratio	[illegible]
$d_A(z_{rec})$	[illegible]	Comoving angular diameter distance to CMB	[illegible]
$r_s(z_{rec})$	[illegible]	Comoving sound horizon scale	[illegible]
r_{damp}	[illegible]	Comoving acoustic damping scale	[illegible]
Θ_s	[illegible]	CMB acoustic angular scale fit (degrees)	[illegible]
ℓ_A	[illegible]	CMB acoustic angular scale	[illegible]

Using WMAP3 + SDSS LRGs:



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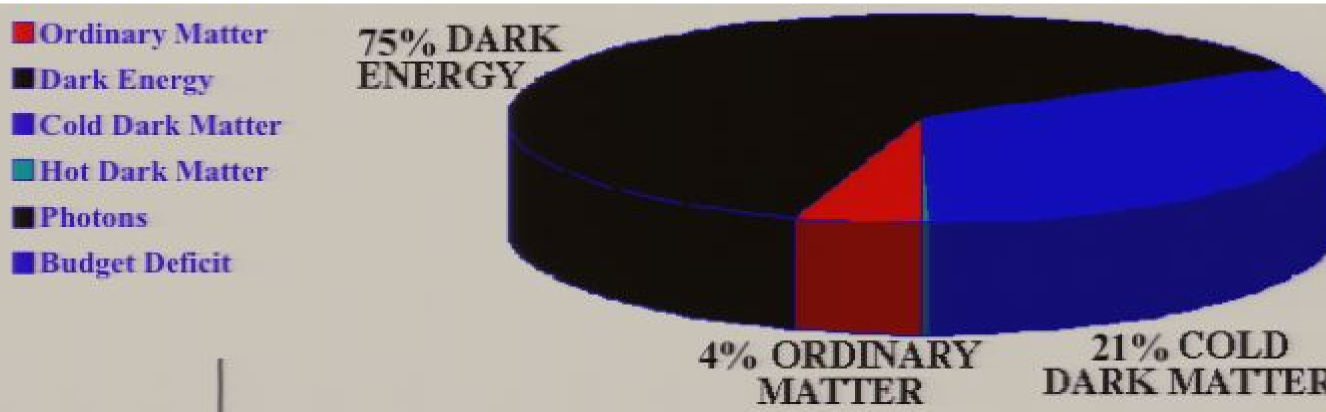
Seed fluctuation parameters:		
A_s	$0.690^{+0.045}_{-0.044}$	Scalar fluctuation amplitude
r	< 0.30 (95%)	Tensor-to-scalar ratio
n_s	$0.953^{+0.016}_{-0.016}$	Scalar spectral index
$n_t + 1$	$0.9861^{+0.0096}_{-0.0142}$	Tensor spectral index
α	$-0.040^{+0.027}_{-0.027}$	Running of spectral index

Using WMAP3 + SDSS LRGs:



Parameter	Value	
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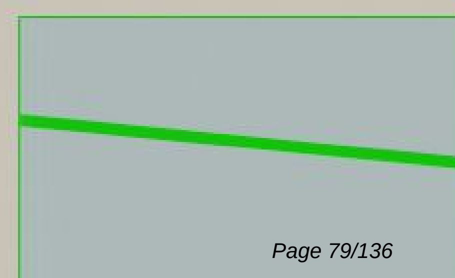
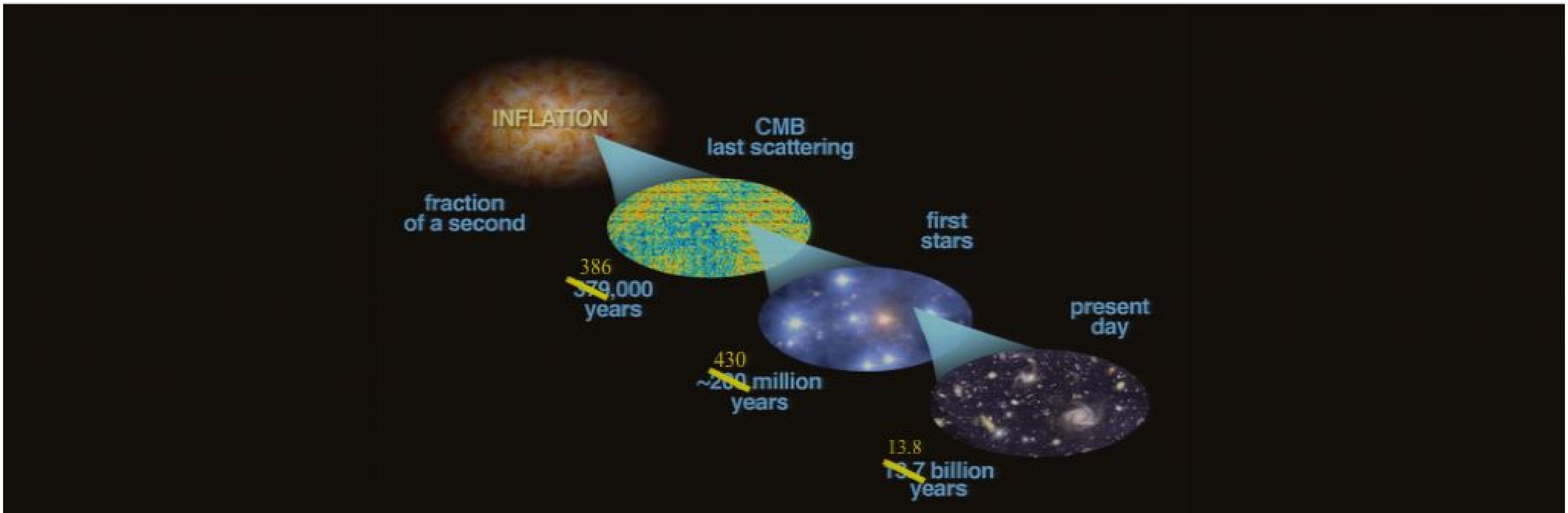
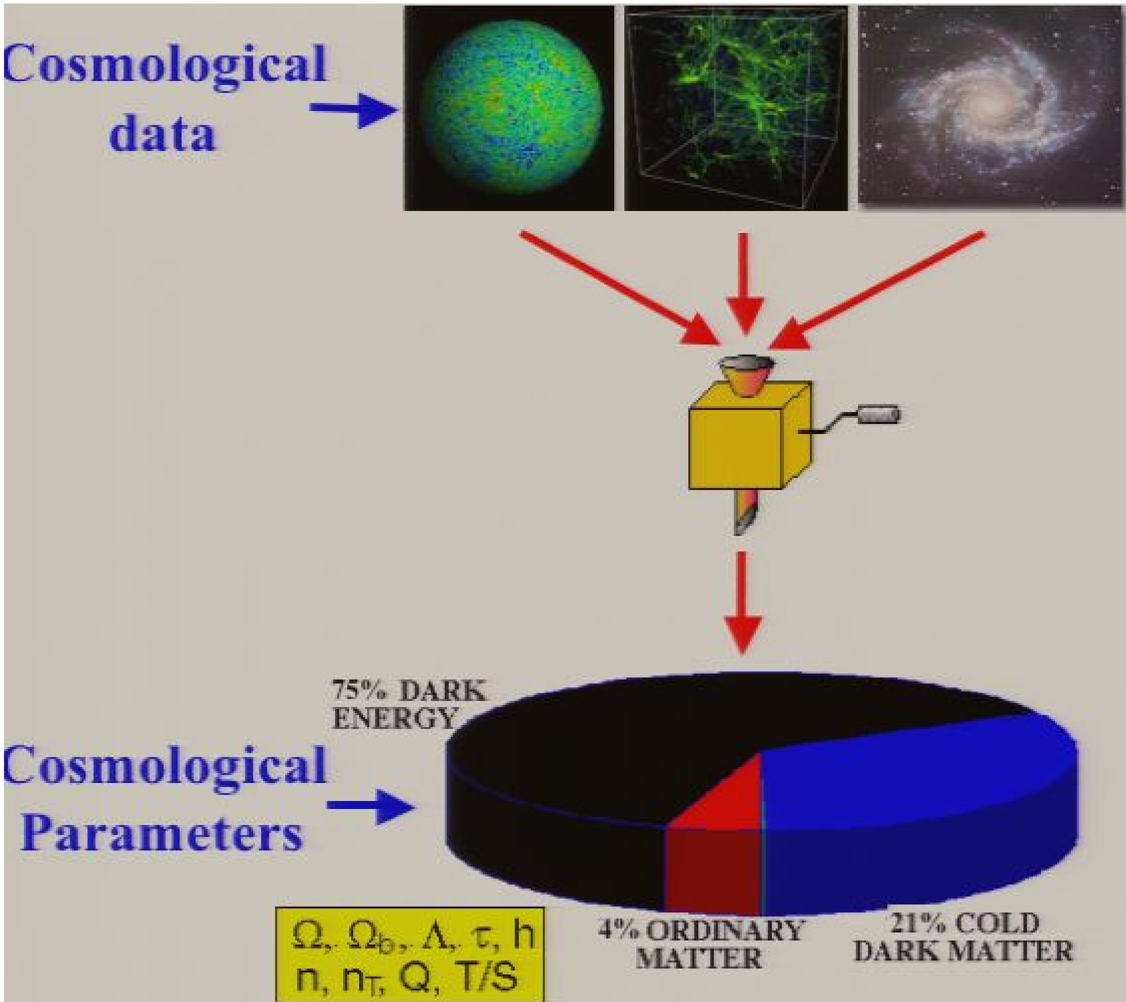
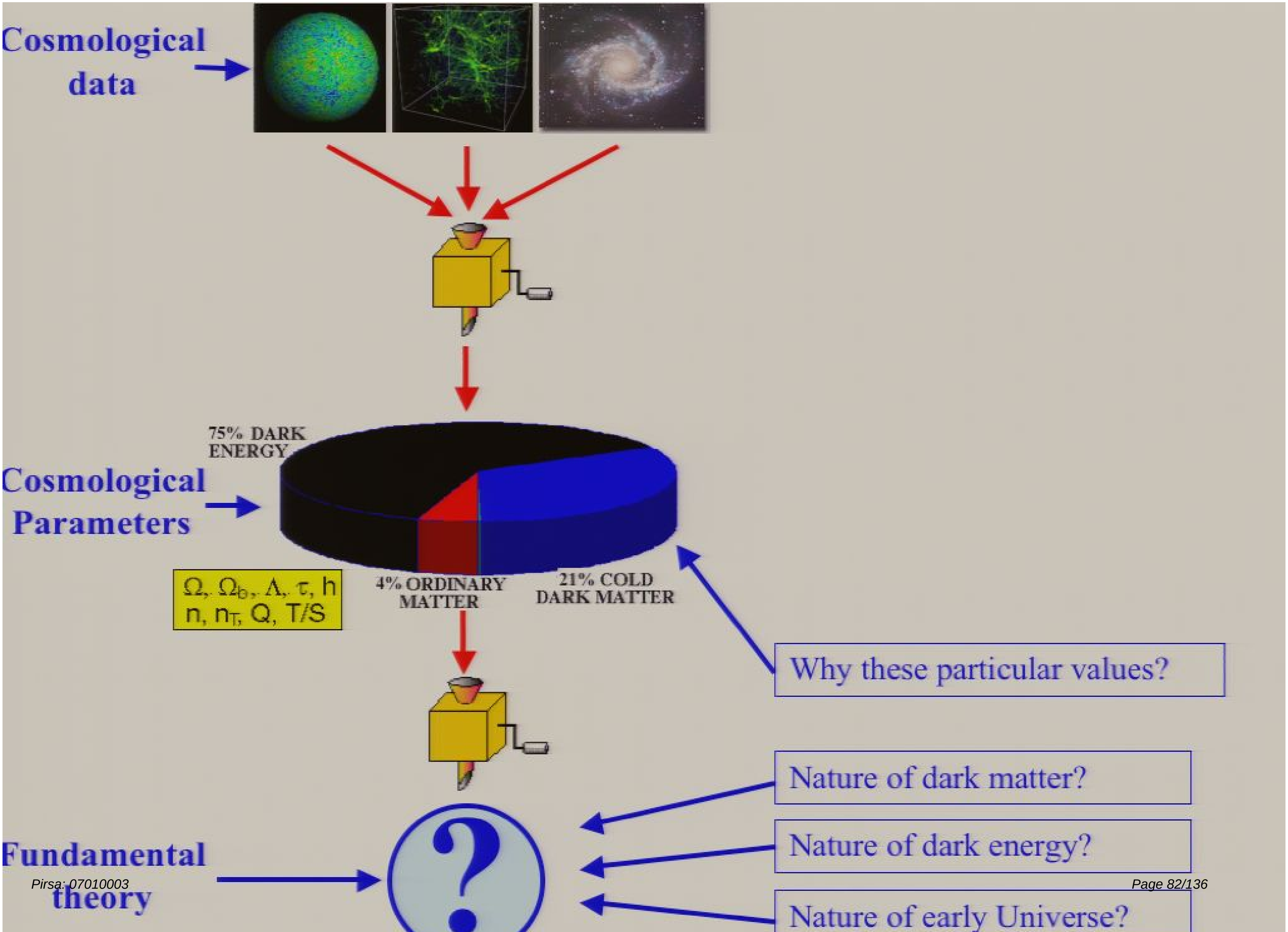
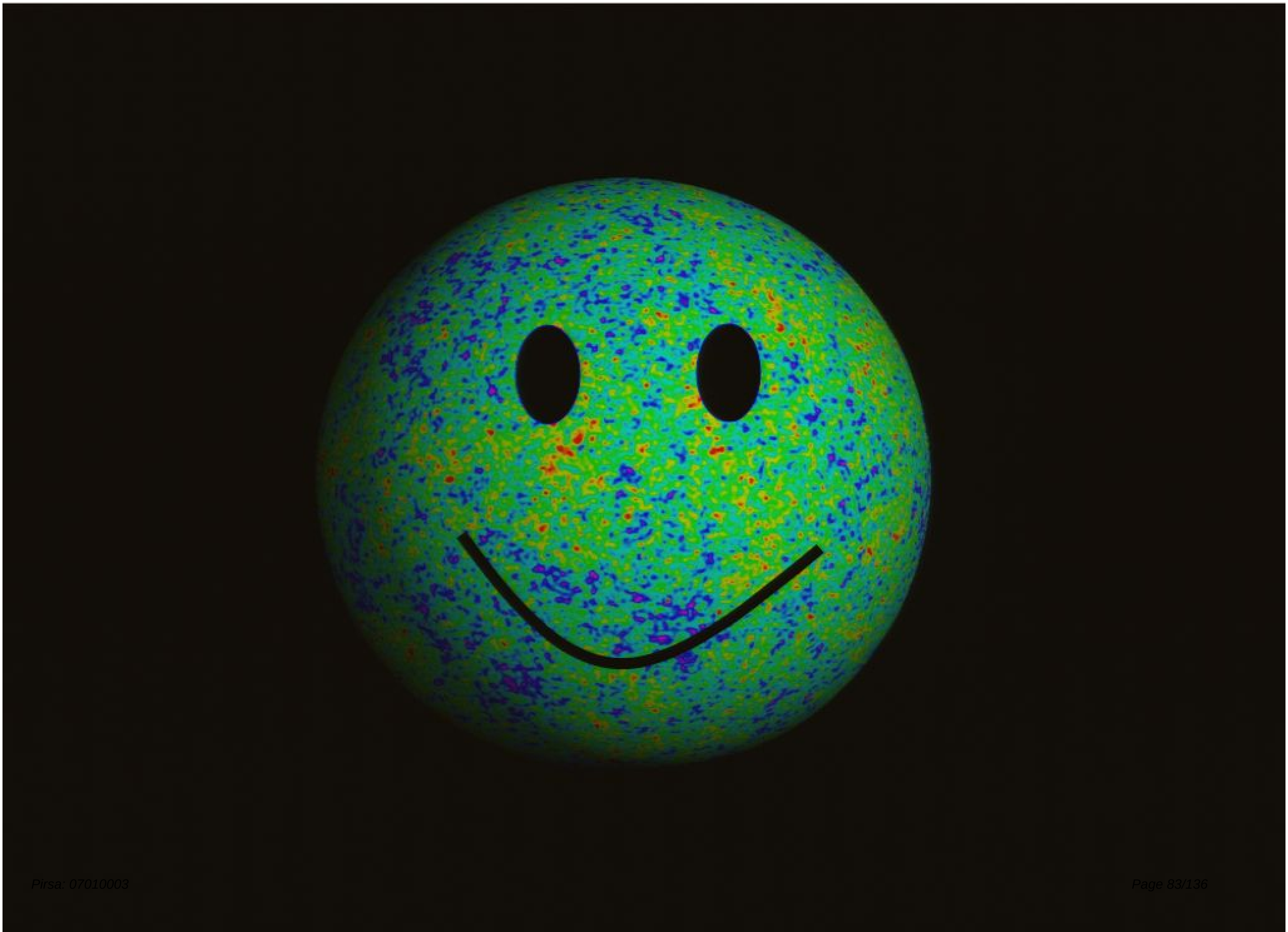




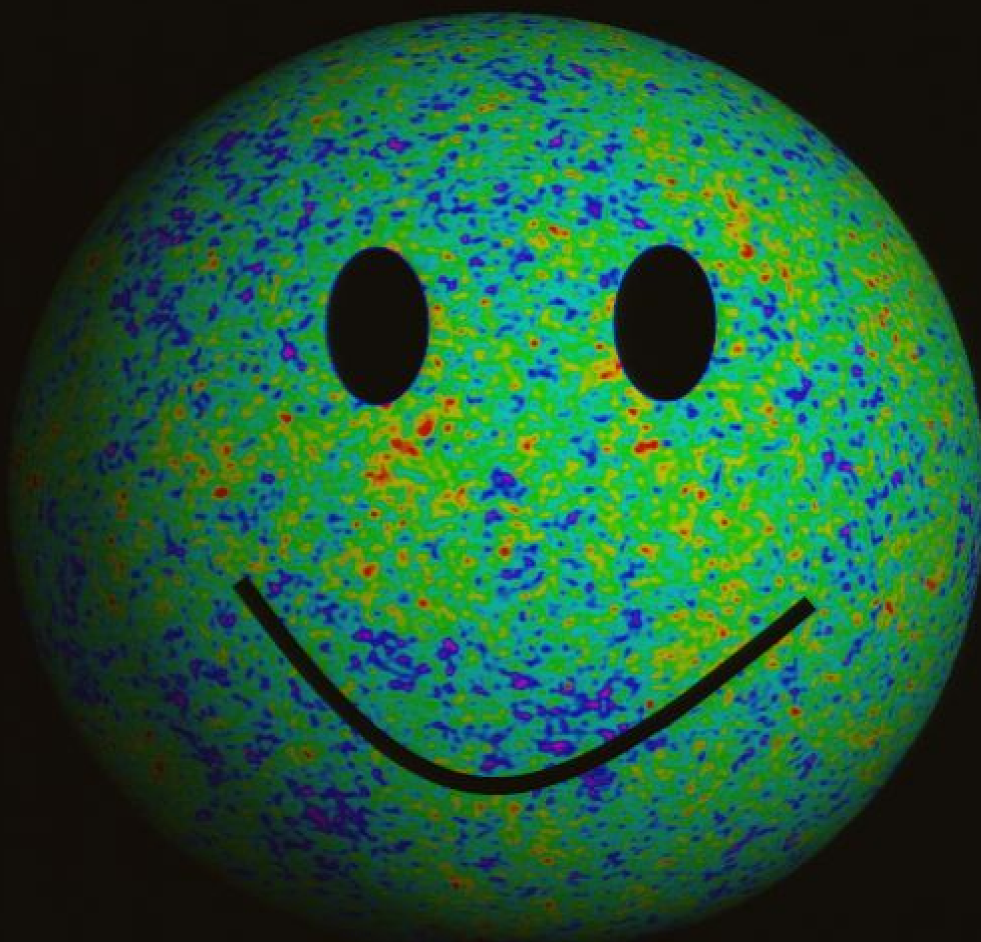
Cosmic history parameters:		
z_{eq}	3057^{+105}_{-102}	Matter-radiation Equality redshift
z_{rec}	$1090.25^{+0.93}_{-0.91}$	Recombination redshift
z_{ion}	$11.1^{+2.2}_{-2.7}$	Reionization redshift (abrupt)
z_{acc}	$0.855^{+0.059}_{-0.059}$	Acceleration redshift
t_{eq}	$0.0634^{+0.0045}_{-0.0041}$ Myr	Matter-radiation Equality time
t_{rec}	$0.3856^{+0.0040}_{-0.0040}$ Myr	Recombination time
t_{ion}	$0.43^{+0.20}_{-0.10}$ Gyr	Reionization time
t_{acc}	$6.74^{+0.25}_{-0.24}$ Gyr	Acceleration time
t	$13.76^{+0.15}$ Gyr	Age of Universe now


Cosmological data
Cosmological Parameters
75% DARK ENERGY
4% ORDINARY MATTER
21% COLD DARK MATTER
Ω, Ω_b, Λ, τ, h
n, n_T, Q, T/S


Cosmological data
75% DARK ENERGY
Cosmological Parameters
Ω, Ω_b, Λ, τ, h
n, n_T, Q, T/S
4% ORDINARY MATTER
21% COLD DARK MATTER
Why these particular values?
Nature of dark matter?
Nature of dark energy?
Fundamental theory
Nature of early Universe?



But can we understand all this in terms of a fundamental "theory of everything"?



gr-qc/9704009

hep-th/0702???

Can we describe reality purely mathematically?

External Reality Hypothesis (ERH):

There exists an external physical reality completely independent of us humans.

Mathematical Universe Hypothesis (MUH):

Or external physical reality is a mathematical structure.

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TOE

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TOE

For this description of the external physical reality to be *complete*, it must be devoid of human “baggage”.

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$$\begin{tikzcd} \text{Nonrelativistic Quantum Mechanics} \arrow[d, "h\to 0"] \\ \text{Classical Mechanics} \end{tikzcd}$$

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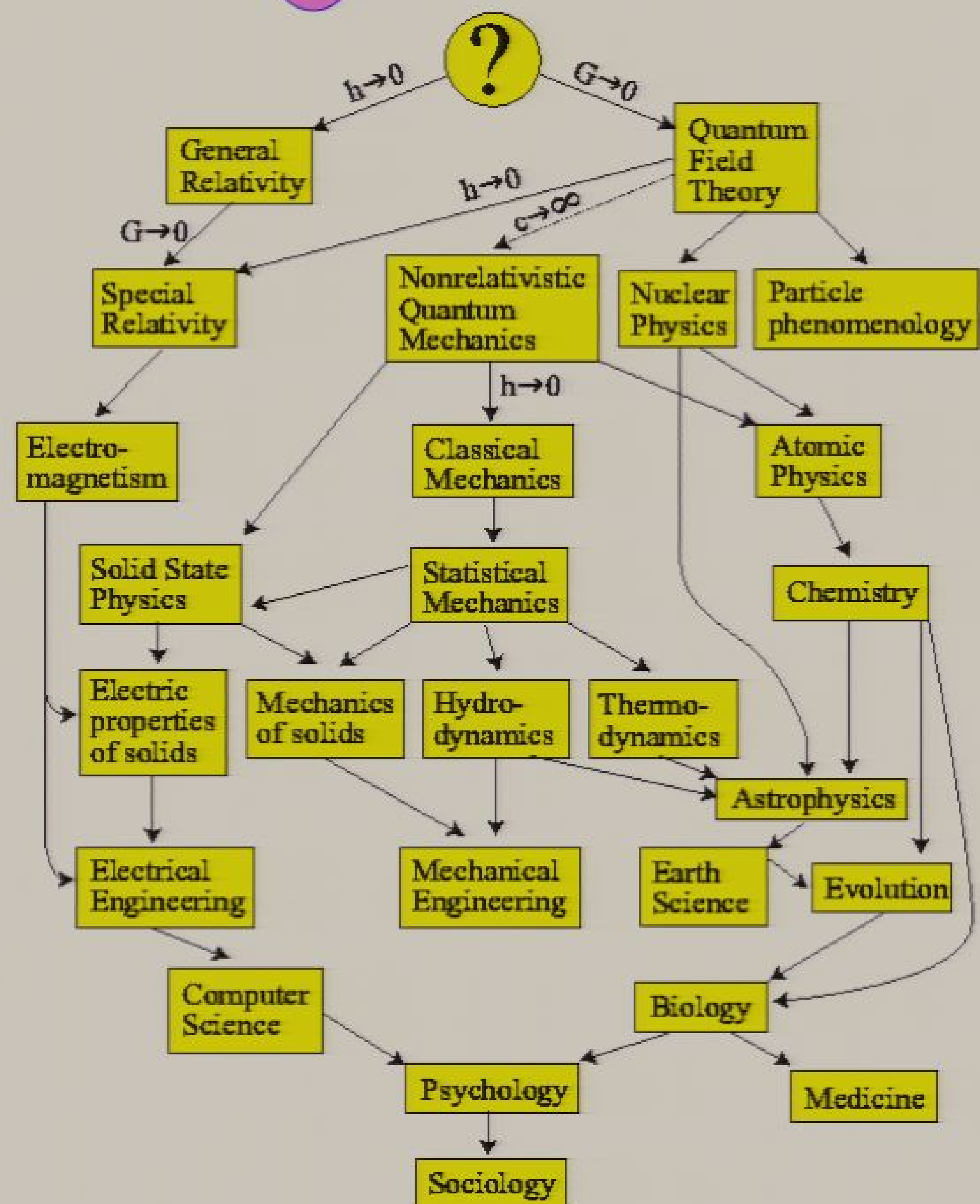
Tegmark & Wheeler 2001, quant-ph/0101077



Less baggage

More baggage

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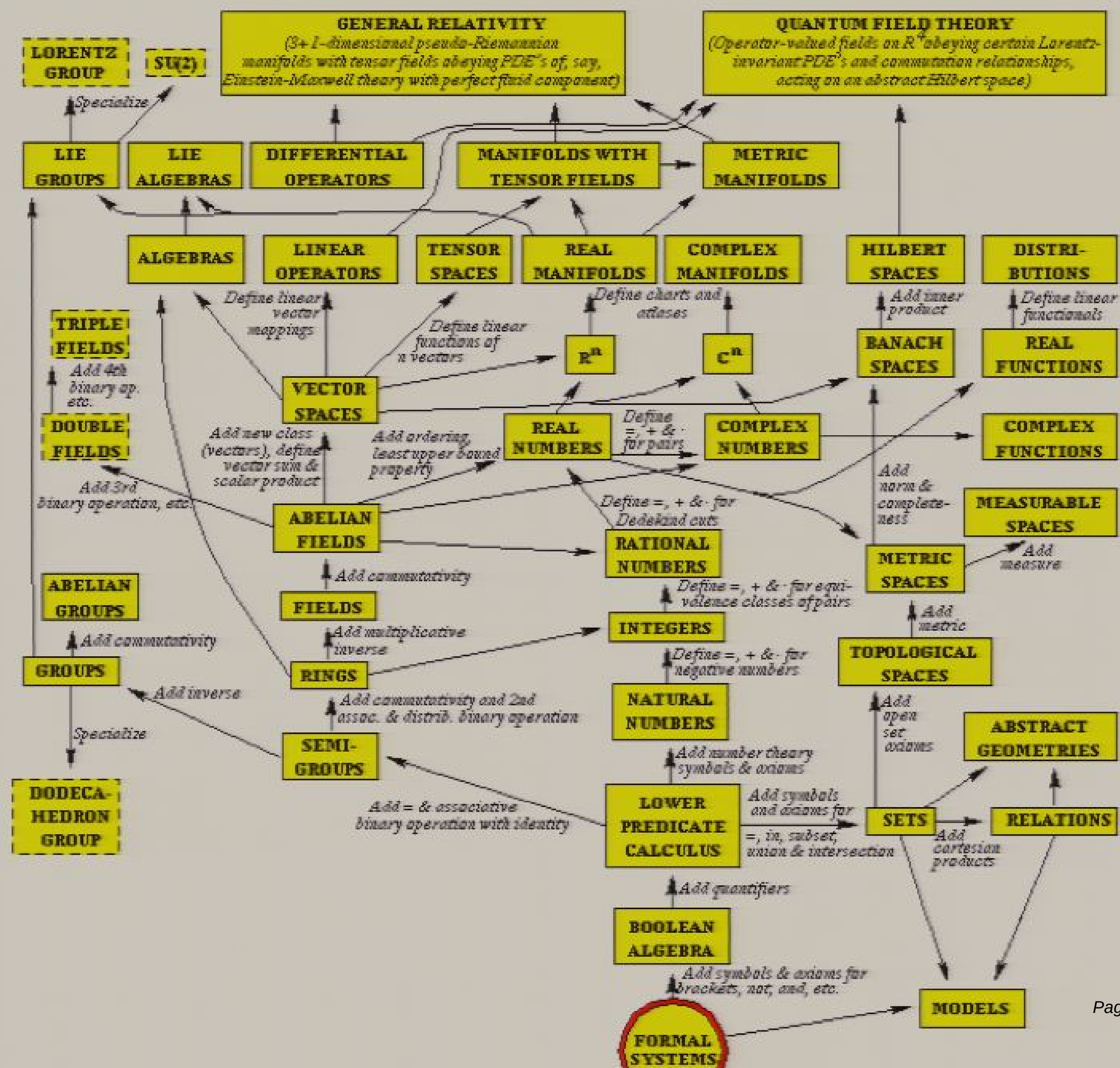
A mathematical structure: *abstract entities with relations between them*



Tegmark 1997, gr-qc/9704009, Ann. Phys, 270, 151

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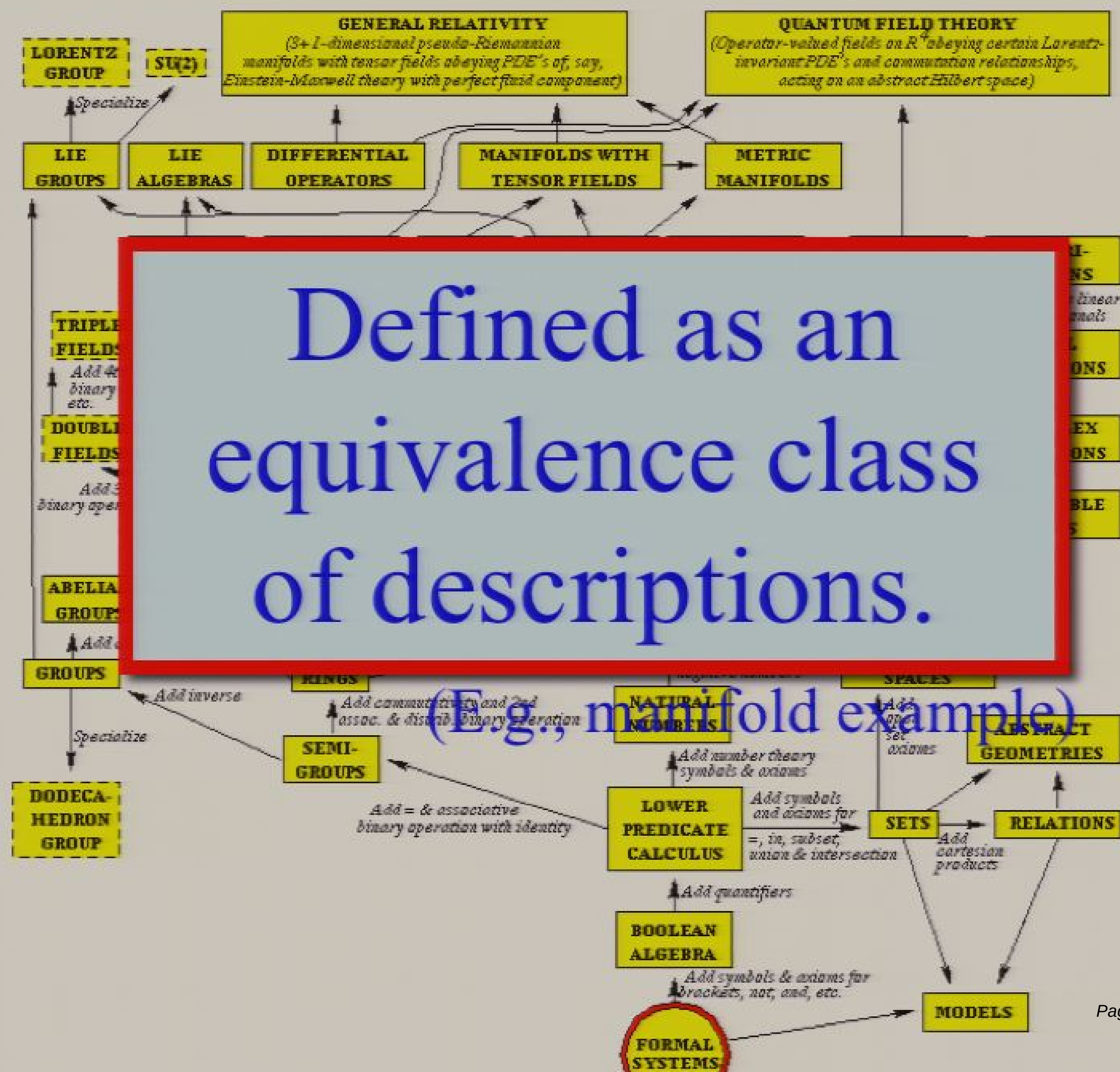
A mathematical structure: *abstract entities with relations between them*

Defined as an equivalence class of descriptions.

(E.g., manifold example)



Tegmark 1997, gr-qc/9704009, Ann. Phys. 270, 151

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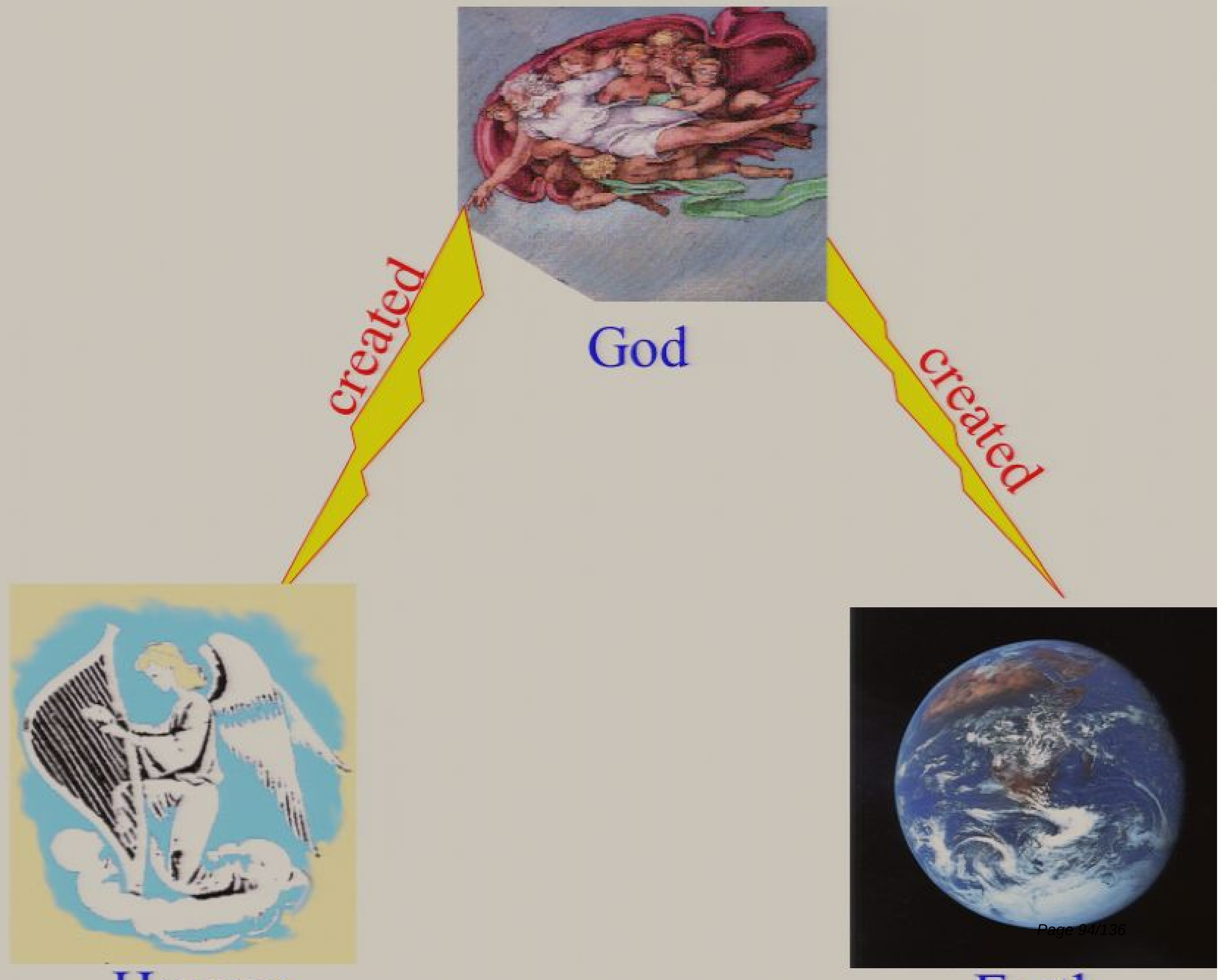
So is *"God created Heaven and Earth"* a mathematical structure?



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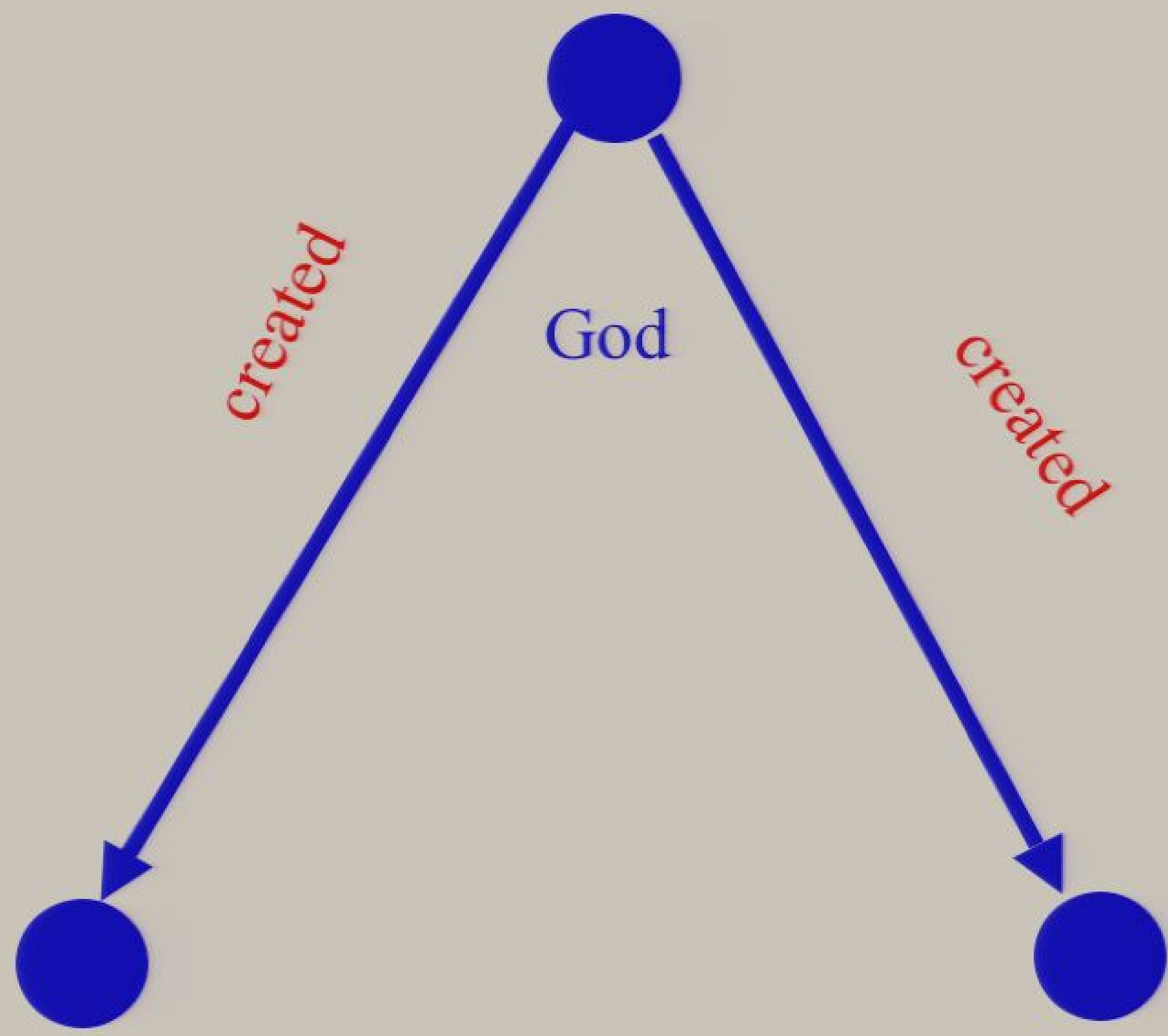
“God created Heaven and Earth”:



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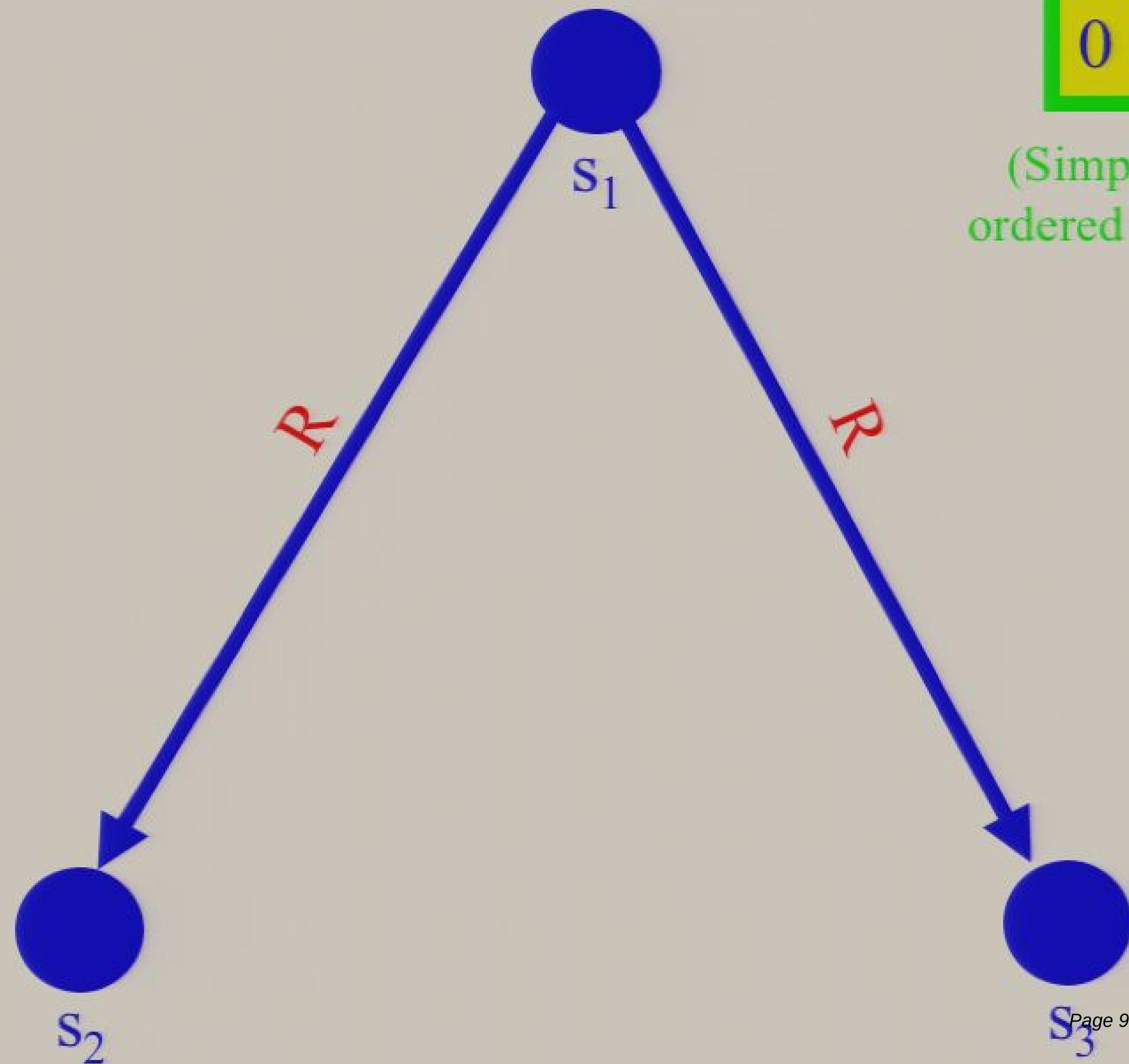
"s_1 R s_2 & s_1 R s_3":

$$\boxed{\begin{matrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix}}$$

(Simply an ordered graph)



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↓

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Phenomenology implications

External Reality Hypothesis (ERH):

There exists an external physical reality completely independent of us humans.

↓

Mathematical Universe Hypothesis (MUH):

Or external physical reality is a mathematical structure.

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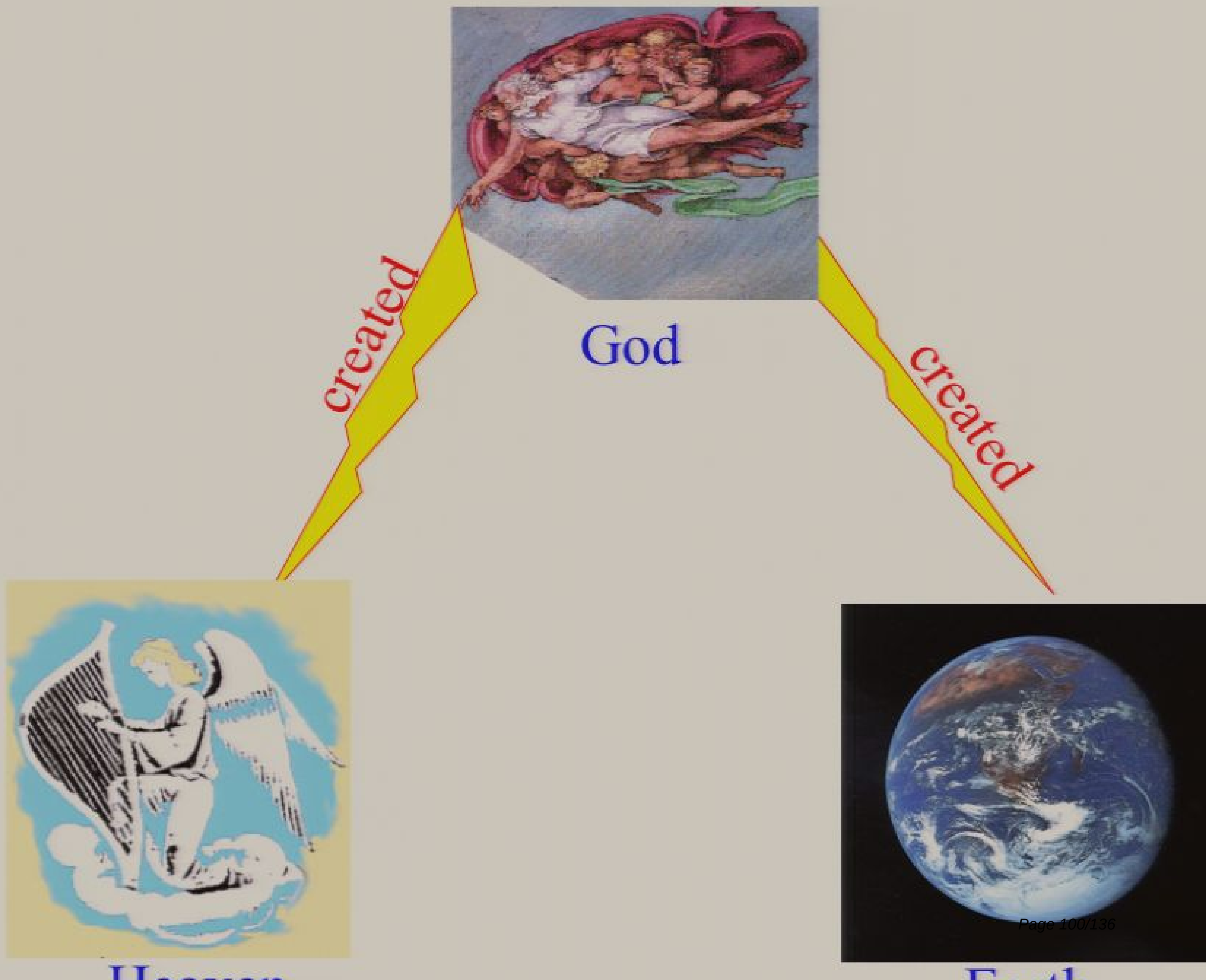
So is *"God created Heaven and Earth"* a mathematical structure?



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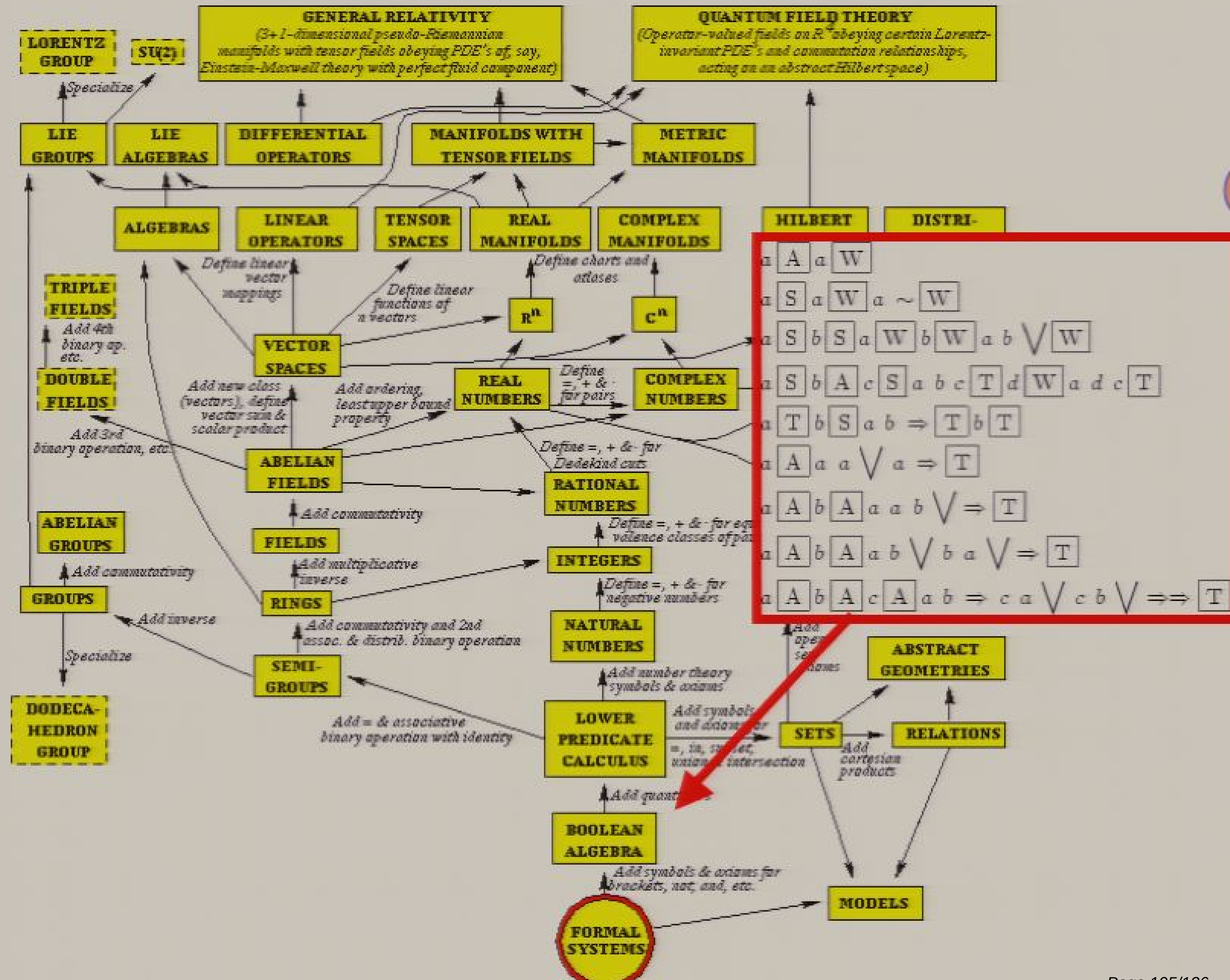

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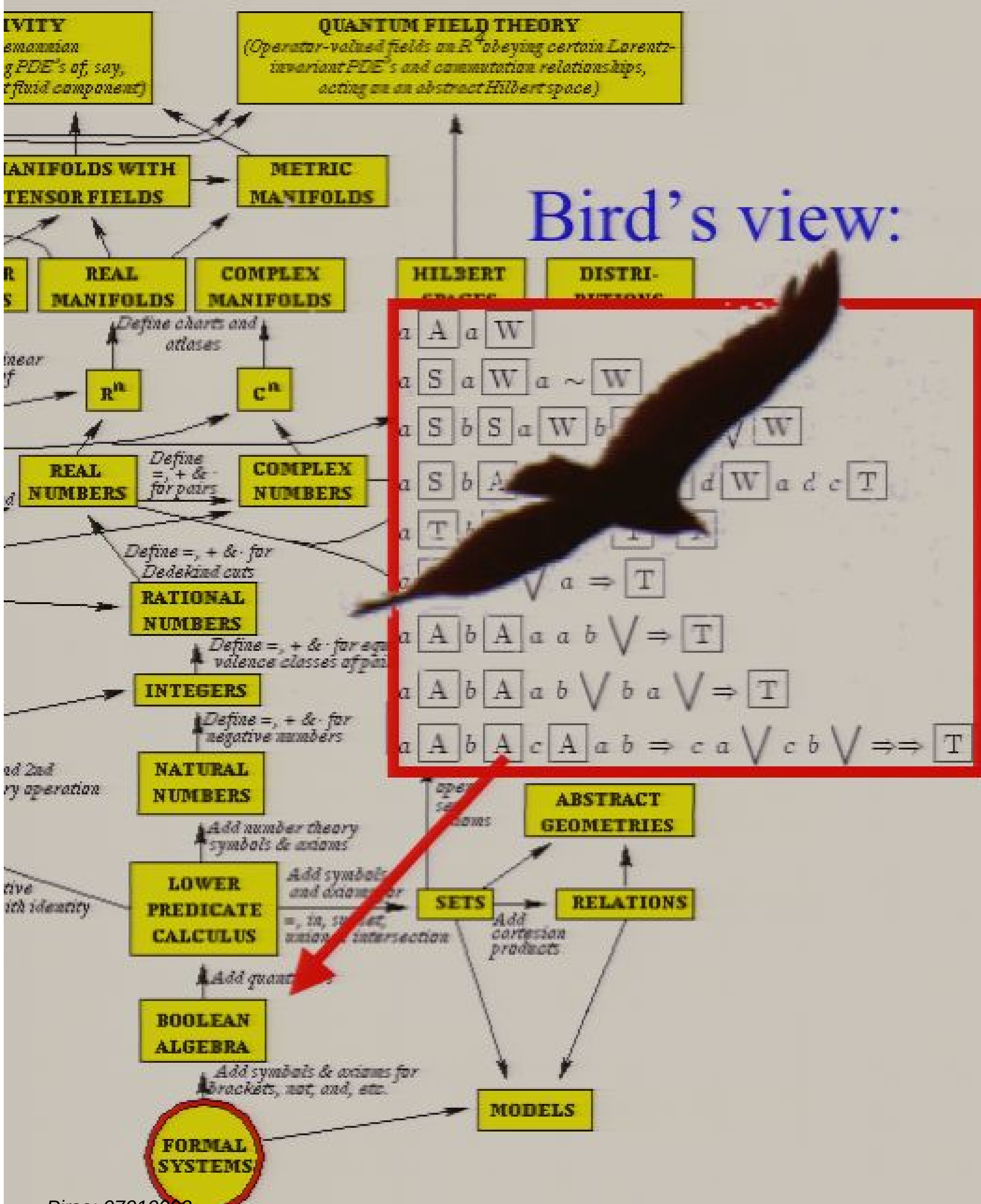
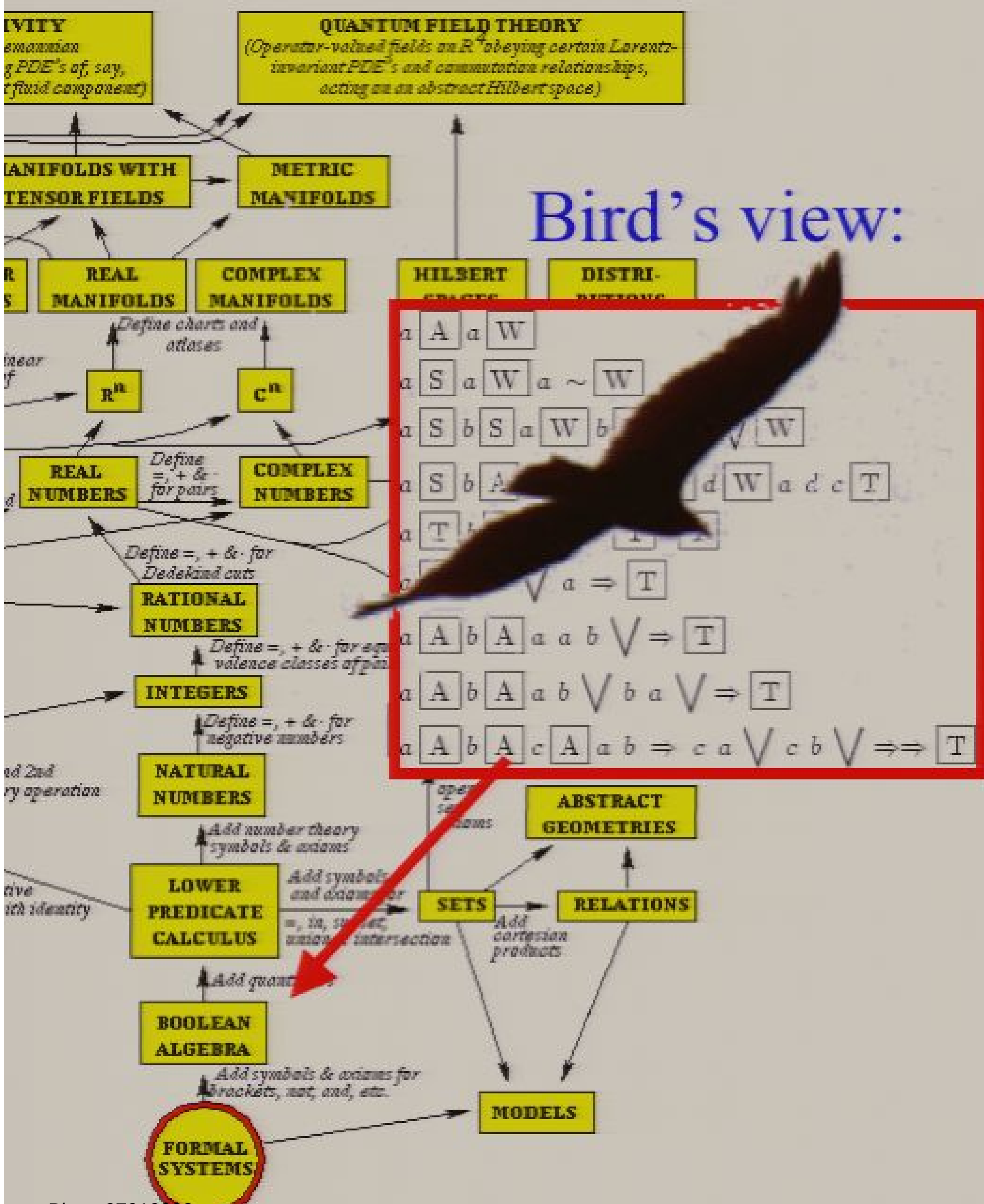
Bird's view:



Frog's view:

k 1997, gr-qc/9704009, Ann. Phys. 270, 151

Bird's view:



Frog's view:

Emergence implications

•Is it really possibly to derive "physics from scratch", i.e., frog's view from bird's view?

• How would physics emerge from the mathematical structure?

• Promising 1st steps: automorphism group, symmetries, irracs & irreps, etc.

• Gödel completeness/Church-Turing computability may help explain why our universe is so simple.

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Parallel universe mplications

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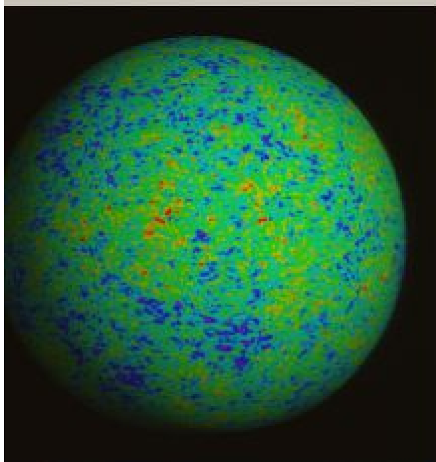
Parallel universe implications


This isn't science!
It's inevitable


Makes sense!
Why not?
I hate it!
AVON


Party on!

If our frog's view of our observable universe…



…requires more bits to describe than…

10^{100} bits?

10^{3} bits?

…the bird's view of our mathematical structure…

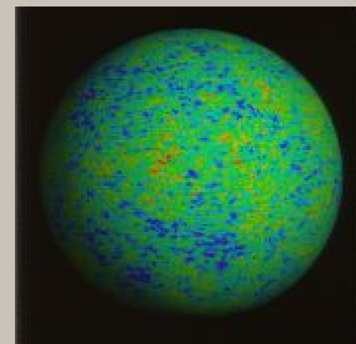
$$a\ \boxed{\mathrm{A}}\ a\ \boxed{\mathrm{W}}$$
$$a\ \boxed{\mathrm{S}}\ a\ \boxed{\mathrm{W}}\ a\ \sim\ \boxed{\mathrm{W}}$$
$$a\ \boxed{\mathrm{S}}\ b\ \boxed{\mathrm{S}}\ a\ \boxed{\mathrm{W}}\ b\ \boxed{\mathrm{W}}\ a\ b\ \bigvee\ \boxed{\mathrm{W}}$$
$$a\ \boxed{\mathrm{S}}\ b\ \boxed{\mathrm{A}}\ c\ \boxed{\mathrm{S}}\ a\ b\ c\ \boxed{\mathrm{T}}\ d\ \boxed{\mathrm{W}}\ a\ d\ c\ \boxed{\mathrm{T}}$$
$$a\ \boxed{\mathrm{T}}\ b\ \boxed{\mathrm{S}}\ a\ b\ \Rightarrow\ \boxed{\mathrm{T}}\ b\ \boxed{\mathrm{T}}$$
$$a\ \boxed{\mathrm{A}}\ a\ a\ \bigvee\ a\ \Rightarrow\ \boxed{\mathrm{T}}$$
$$a\ \boxed{\mathrm{A}}\ b\ \boxed{\mathrm{A}}\ a\ a\ b\ \bigvee\ \Rightarrow\ \boxed{\mathrm{T}}$$
$$a\ \boxed{\mathrm{A}}\ b\ \boxed{\mathrm{A}}\ a\ b\ \bigvee\ b\ a\ \bigvee\ \Rightarrow\ \boxed{\mathrm{T}}$$
$$a\ \boxed{\mathrm{A}}\ b\ \boxed{\mathrm{A}}\ c\ \boxed{\mathrm{A}}\ a\ b\ \Rightarrow\ c\ a\ \bigvee\ c\ b\ \bigvee\ \Rightarrow\Rightarrow\ \boxed{\mathrm{T}}$$

…then we're in a multiverse!

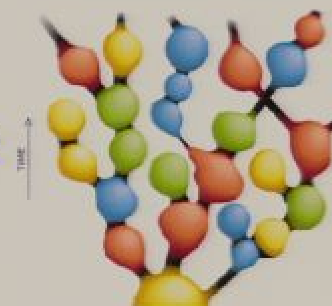
So if you're looking for a simple mathematical TOE, you're looking for a

Where are the parallel universes?

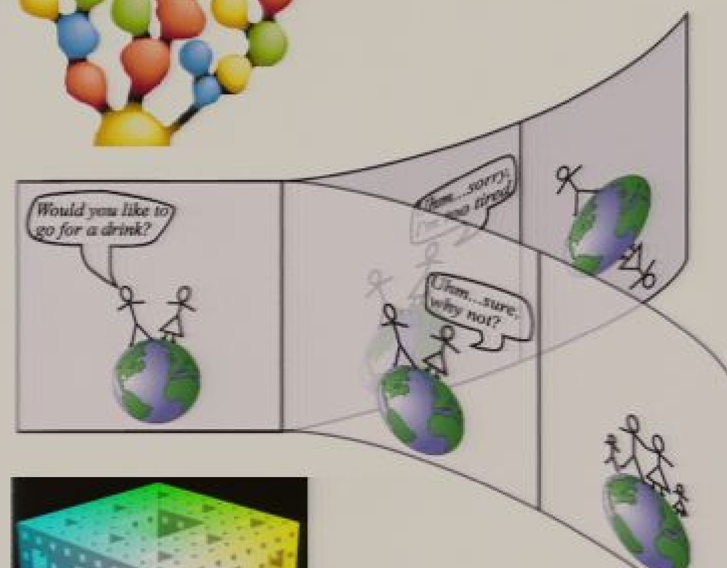
1) Far away in space



2) Infinitely far away in space



3) Elsewhere in Hilbert space



4) Elsewhere in "math space"

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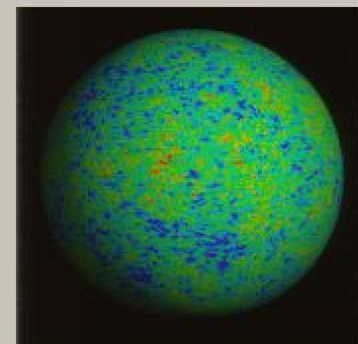
What are the 4 multiverse levels like?

10^{100} bits?



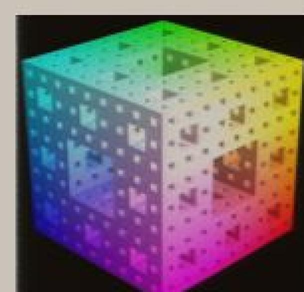
1) Same effective laws of physics, different initial conditions

10^3 bits?

2) Same fundamental laws of physics, different effective laws ("bylaws")

10^2 bits?

3) Nothing qualitatively new



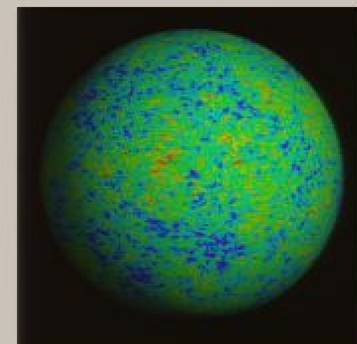
4) Different fundamental laws of physics

0 bits!

The bigger the multiverse, the simpler the theory

What are the 4 multiverse levels like?

10^{100} bits?



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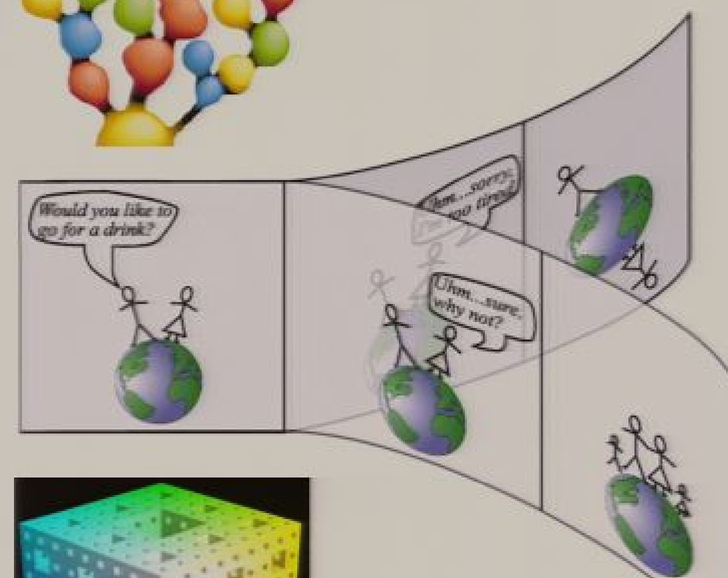

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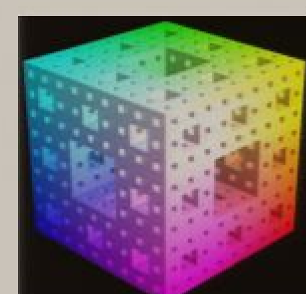

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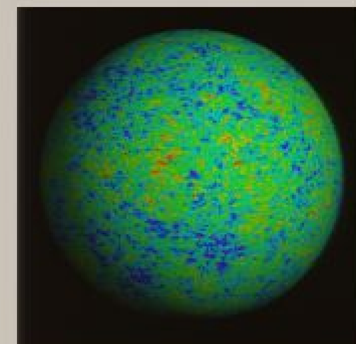
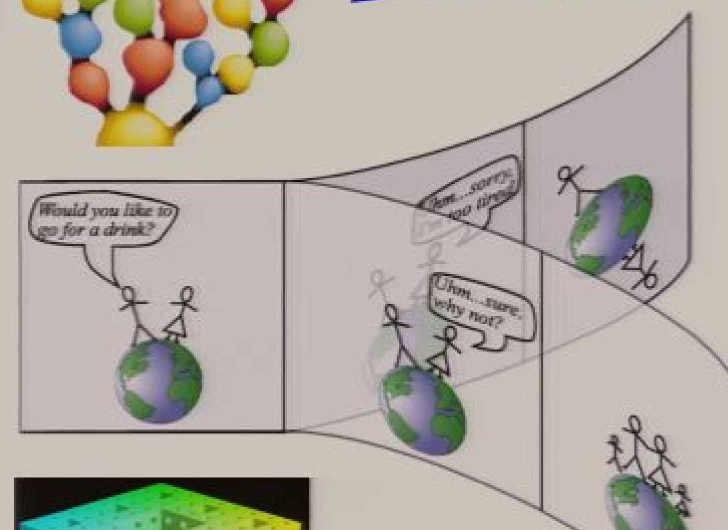


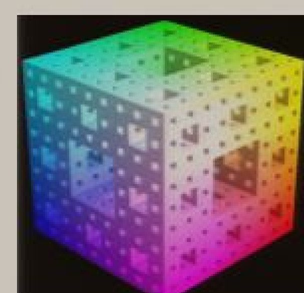
2) Same fundamental laws of physics, different effective laws

2a
2b
2c
2d

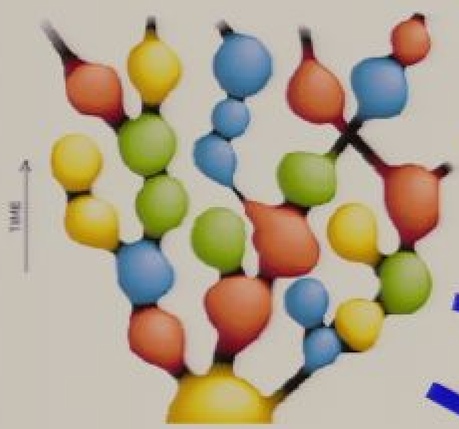
3) Nothing qualitatively new



4) Different fundamental laws of physics



Level II sublevels in string landscape:



2a) Same effective laws of physics (same minimum), different post-inflationary region

2b) Different minimum in effective supergravity potential

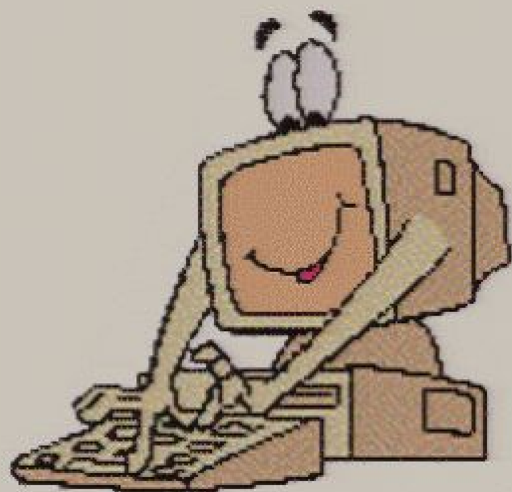
2c) Different fluxes

2d) Different compactifications

Same fundamental laws of physics (same mathematical structure), but different effective laws in b, c & d

Simulation hypothesis implications

Do we live in a simulation? (The Matrix, Tipler, Bostrom, Schmidthuber, Lloyd…)



- McCabe, Penrose: no, at least not a digital one
- Involves measure problem

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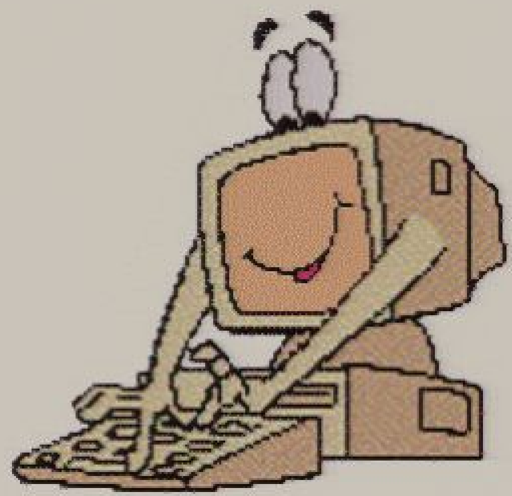
Do we live in a simulation? *(The Matrix, Tipler, Bostrom, Schmidthuber, Lloyd…)*



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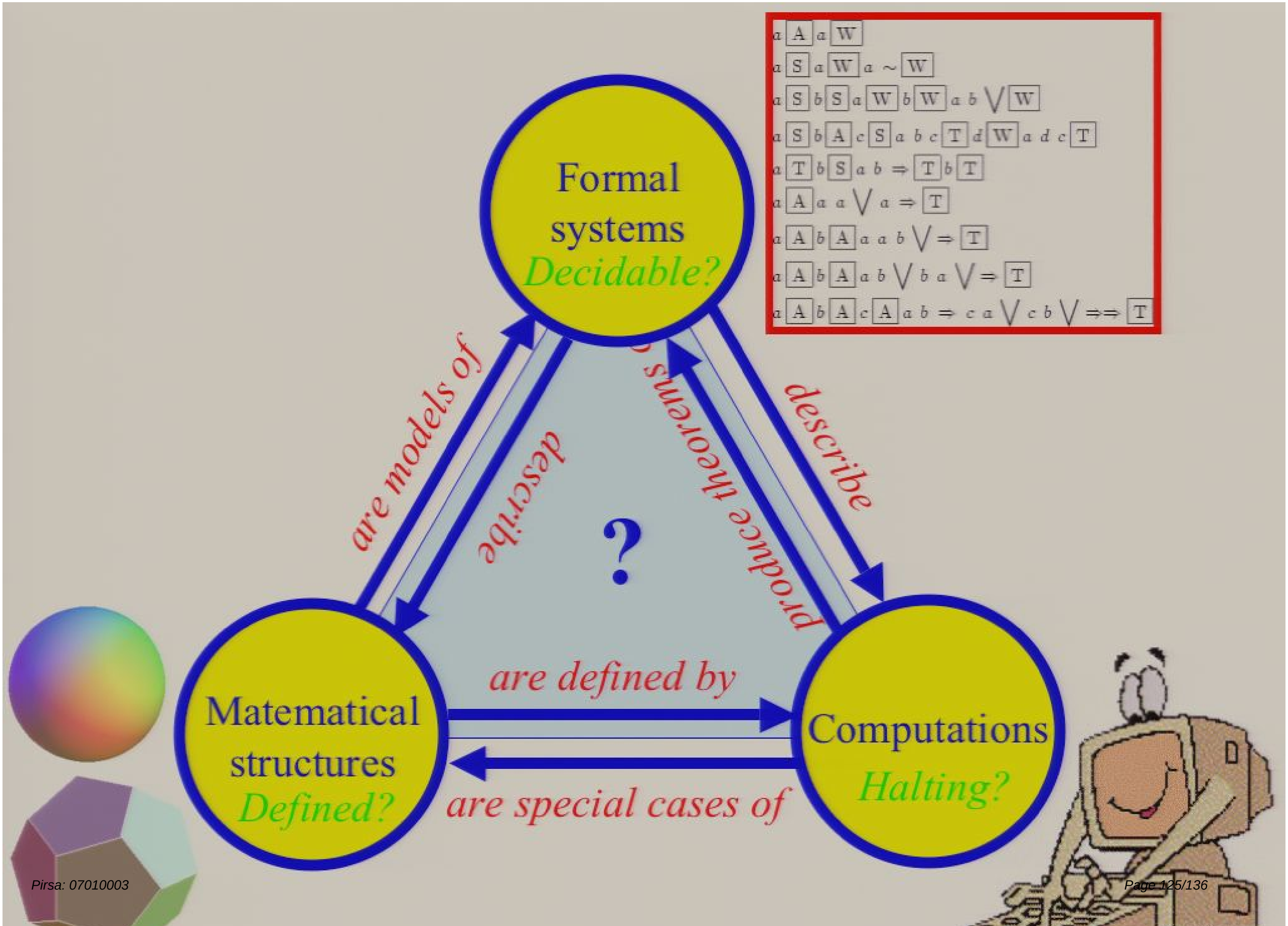

$a\ \boxed{A}\ a\ \boxed{W}$
$a\ \boxed{S}\ a\ \boxed{W}\ a \sim \boxed{W}$
$a\ \boxed{S}\ b\ \boxed{S}\ a\ \boxed{W}\ b\ \boxed{W}\ a\ b \bigvee \boxed{W}$
$a\ \boxed{S}\ b\ \boxed{A}\ c\ \boxed{S}\ a\ b\ c\ \boxed{T}\ d\ \boxed{W}\ a\ d\ c\ \boxed{T}$
$a\ \boxed{T}\ b\ \boxed{S}\ a\ b \Rightarrow \boxed{T}\ b\ \boxed{T}$
$a\ \boxed{A}\ a\ a \bigvee a \Rightarrow \boxed{T}$
$a\ \boxed{A}\ b\ \boxed{A}\ a\ a\ b \bigvee \Rightarrow \boxed{T}$
$a\ \boxed{A}\ b\ \boxed{A}\ a\ b \bigvee b\ a \bigvee \Rightarrow \boxed{T}$
$a\ \boxed{A}\ b\ \boxed{A}\ c\ \boxed{A}\ a\ b \Rightarrow c\ a \bigvee c\ b \bigvee \Rightarrow\Rightarrow \boxed{T}$
Formal systems
Decidable?
are models of
describe
produce theorems
describe
?
Matematical structures
Defined?
are defined by
are special cases of
Computations
Halting?

Do we live in a simulation? *(The Matrix, Tipler, Bostrom, Schmidthuber, Lloyd…)*

- McCabe: no, at least not a digital one
- Involves measure problem

- Unjustified to identify the 1D computational sequence with our 1D time
- Little said about how to identify the GR quantum universe with an evolving bit string.
- The "computer" doesn't need to *evolve* the universe, merely *specify* it.

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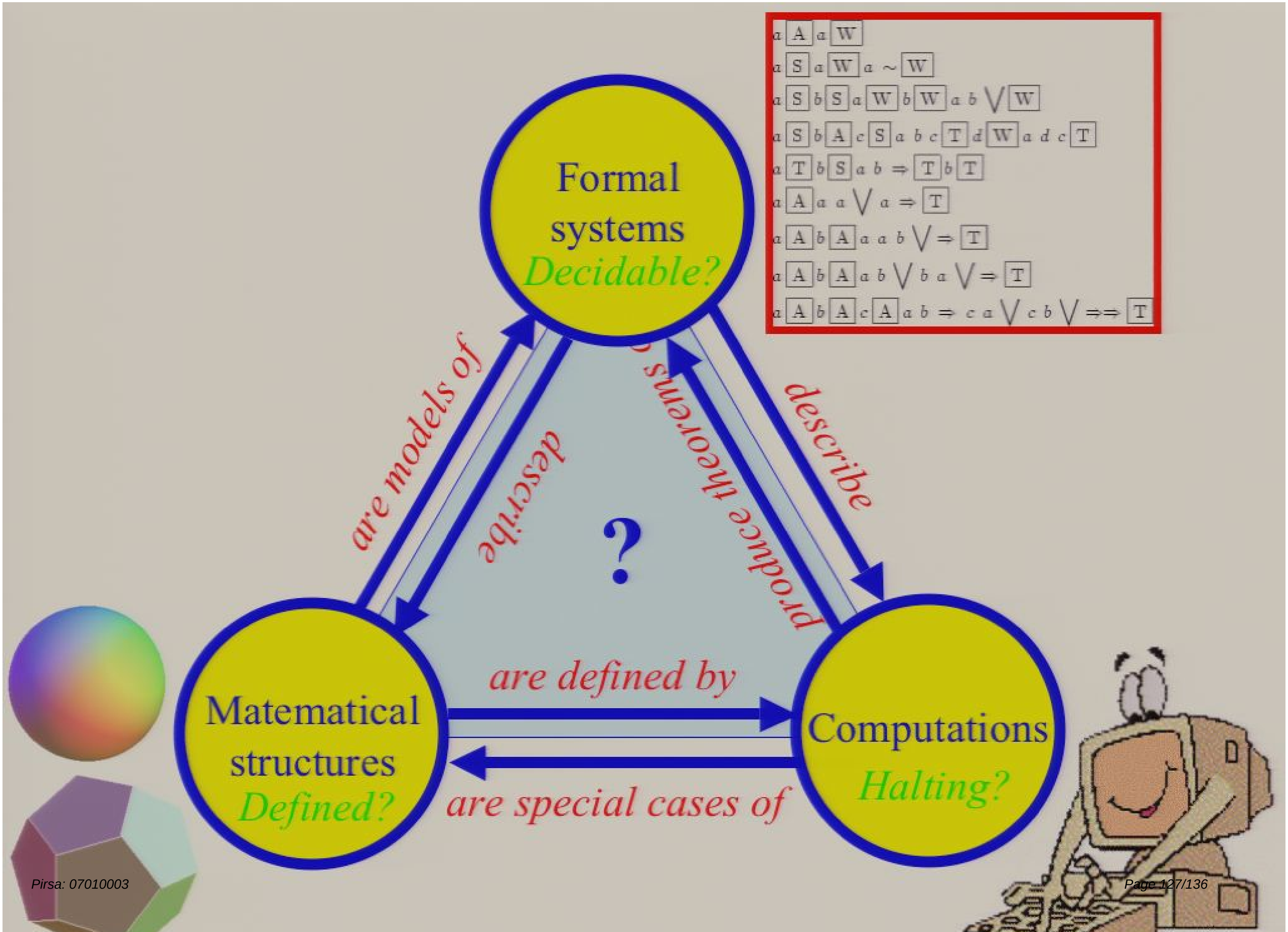
a A a W
a S a W a ~ W
a S b S a W b W a b ⋁ W
a S b A c S a b c T d W a d c T
a T b S a b ⇒ T b T
a A a a ⋁ a ⇒ T
a A b A a a b ⋁ ⇒ T
a A b A a b ⋁ b a ⋁ ⇒ T
a A b A c A a b ⇒ c a ⋁ c b ⋁ ⇒⇒ T
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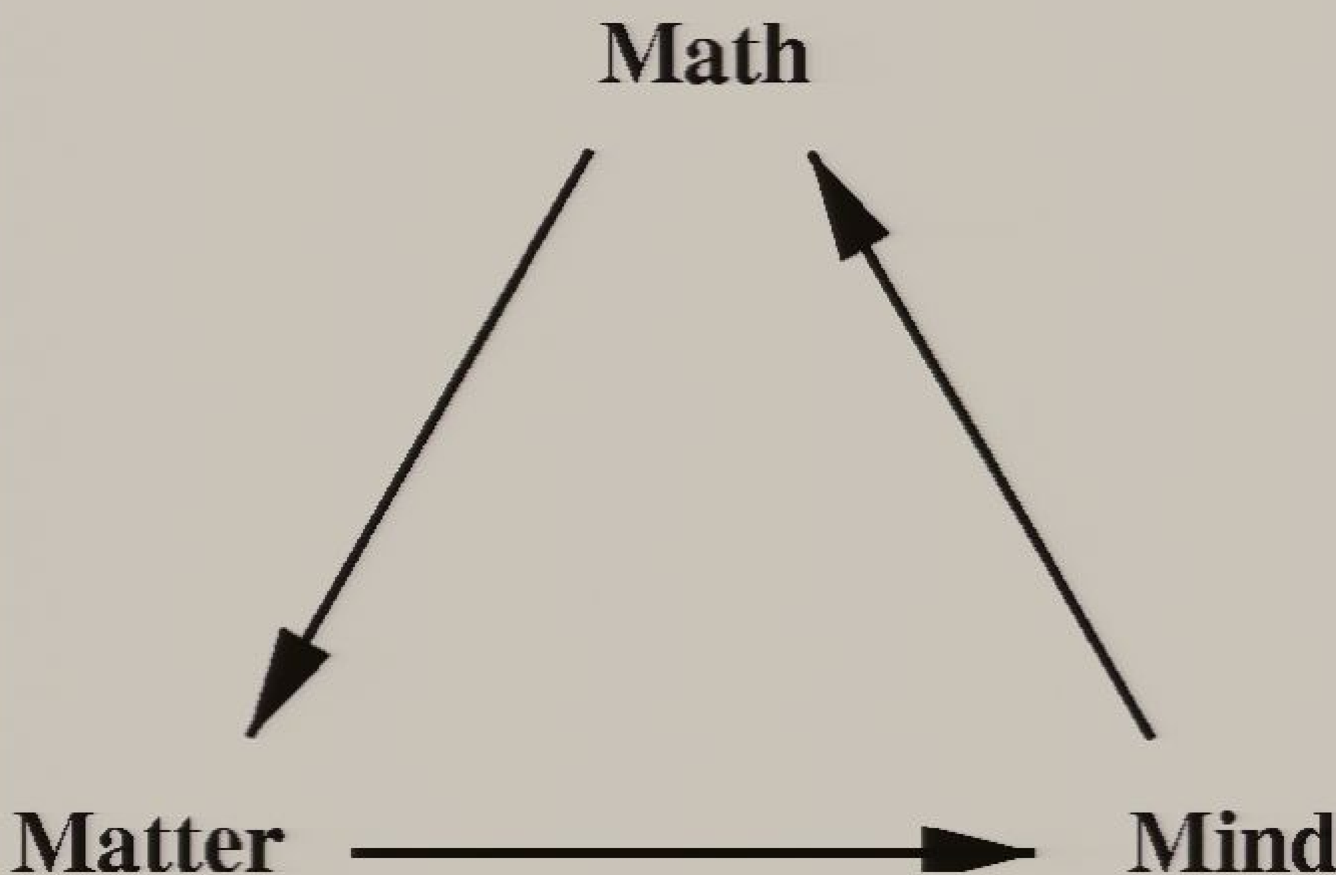
Penrose's Bermuda triangle:



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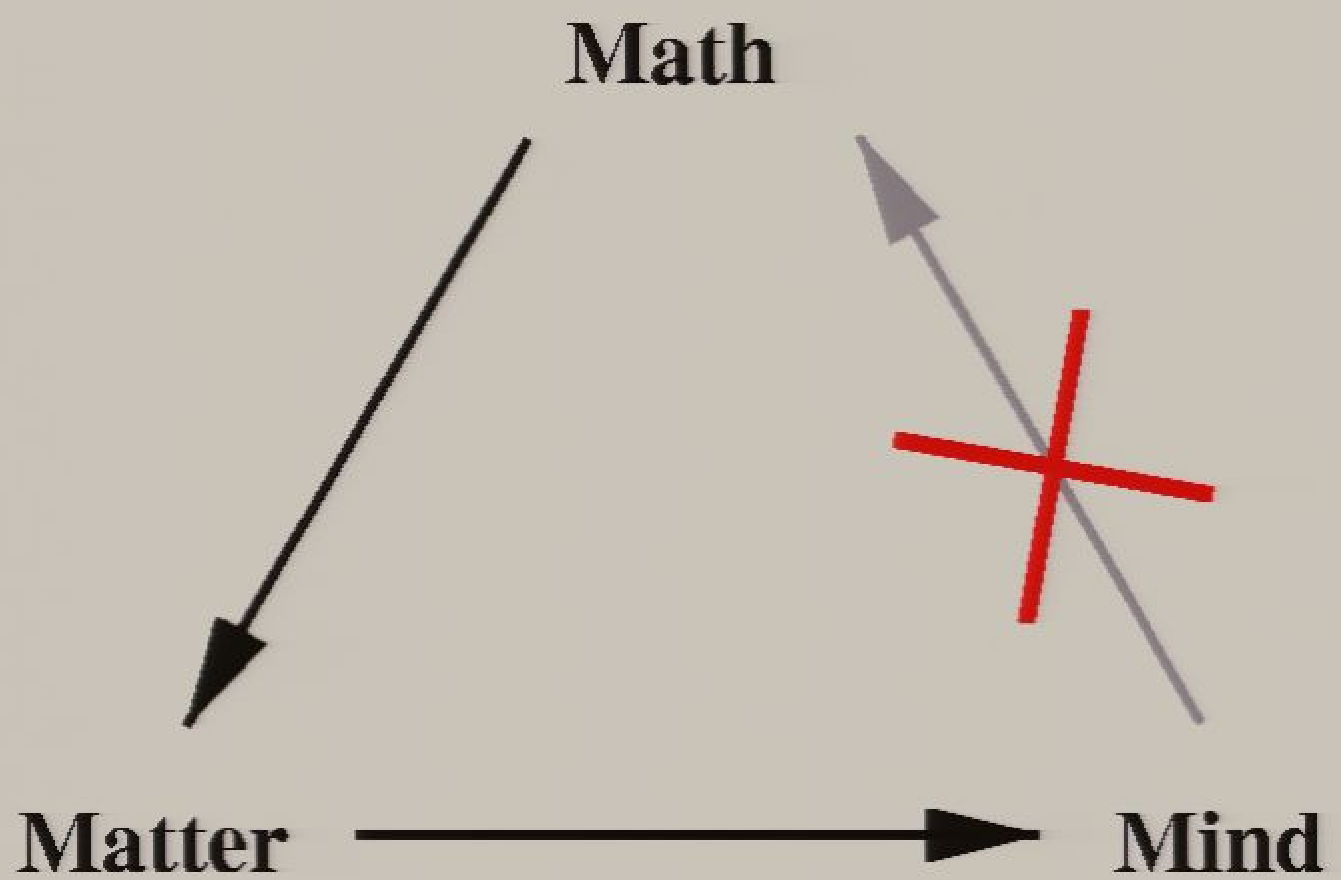
My guess:



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More MUH support

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Conclusions:

*** Cosmological data avalanche**

*** ERH => MUH => implications for physics:**

- ***Emergence***: symmetries, irreps, etc.
- "Initial conditions" banished: simple mathematical TOE => ***multiverse***
- ***Simulation argument***: computation doesn't need to *evolve* the mathematical structure, merely *specify* it
- Gödel completeness/Church-Turing computability may help explain why universe is so simple.

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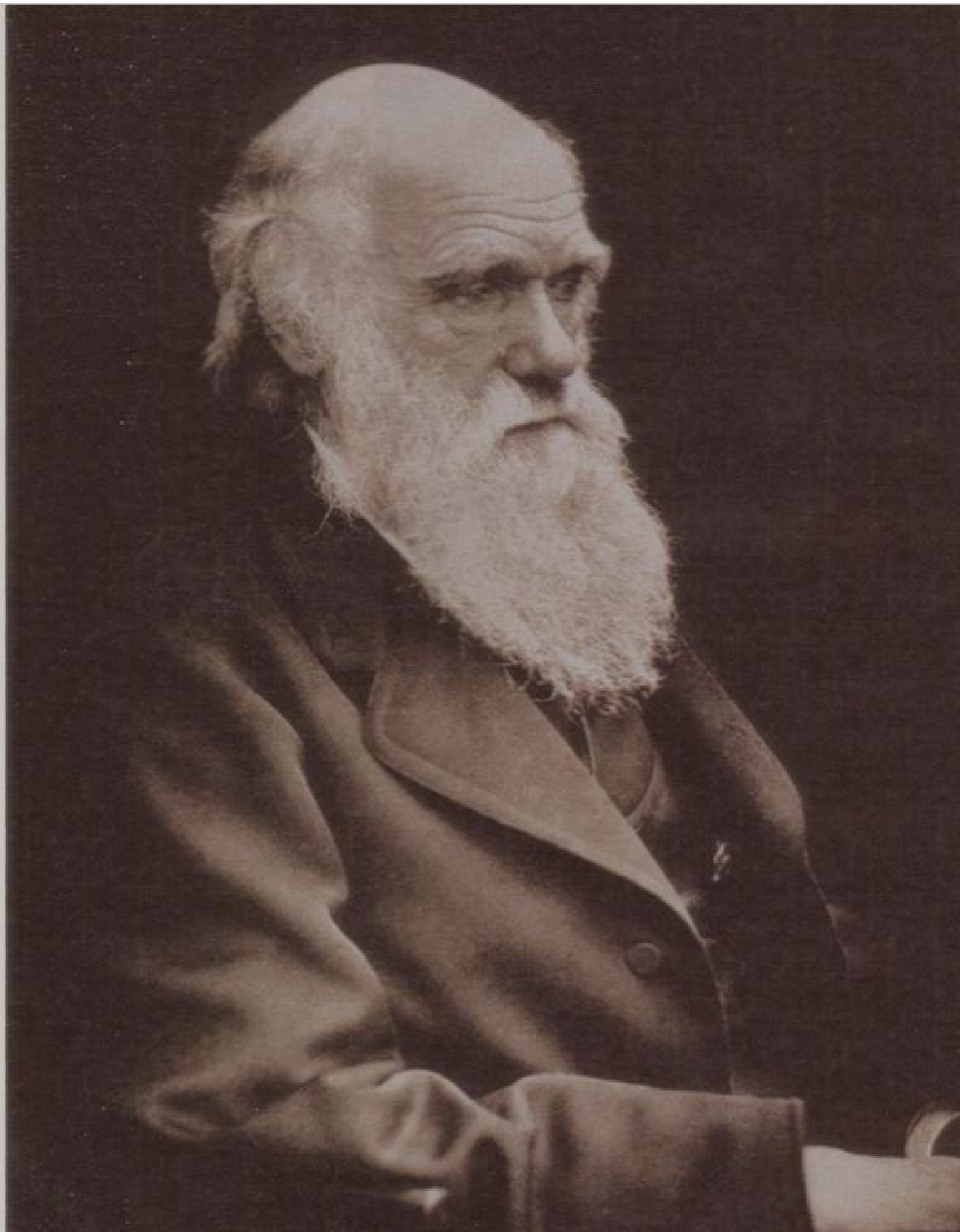

We’re not taking this guy seriously enough!

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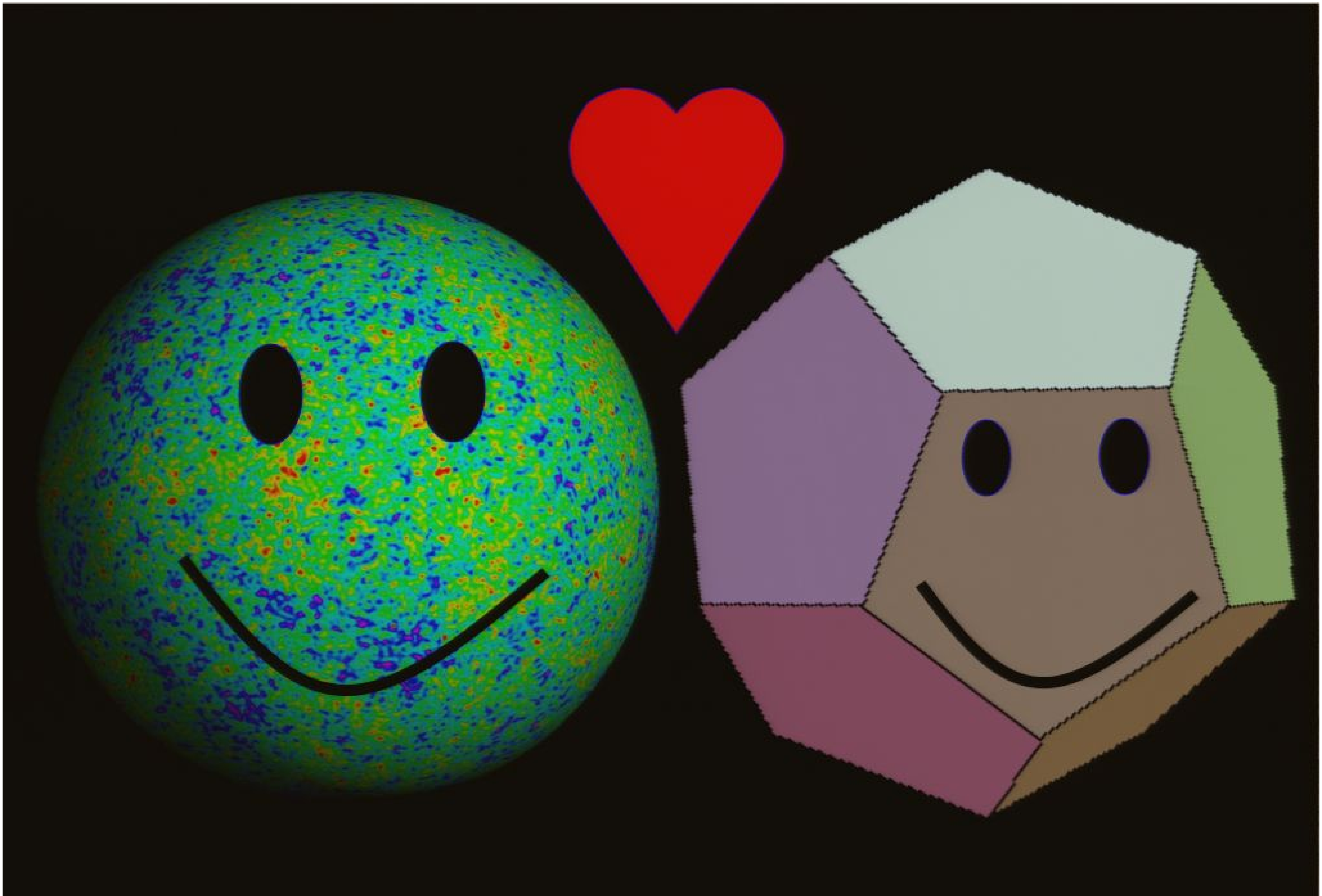

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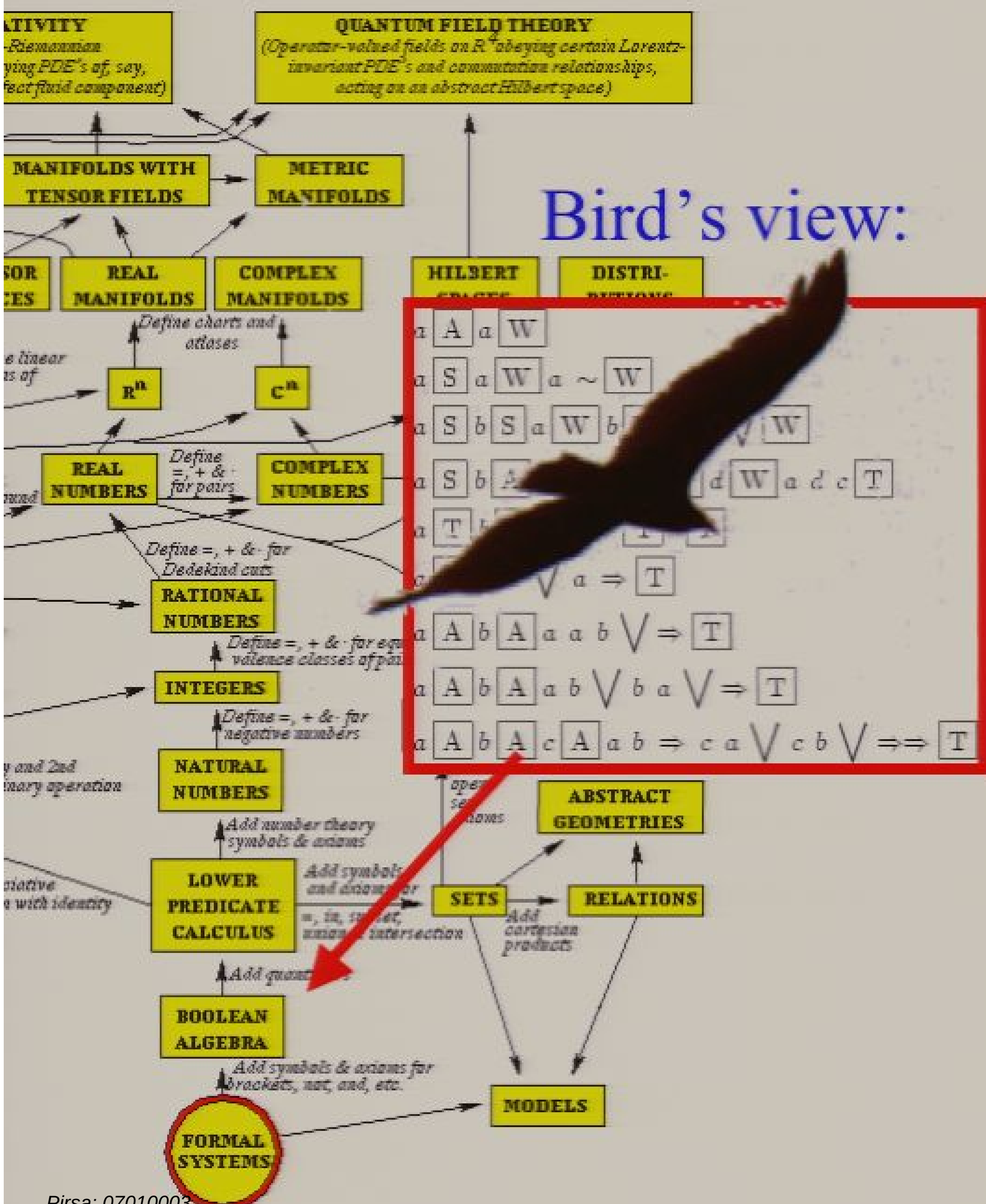
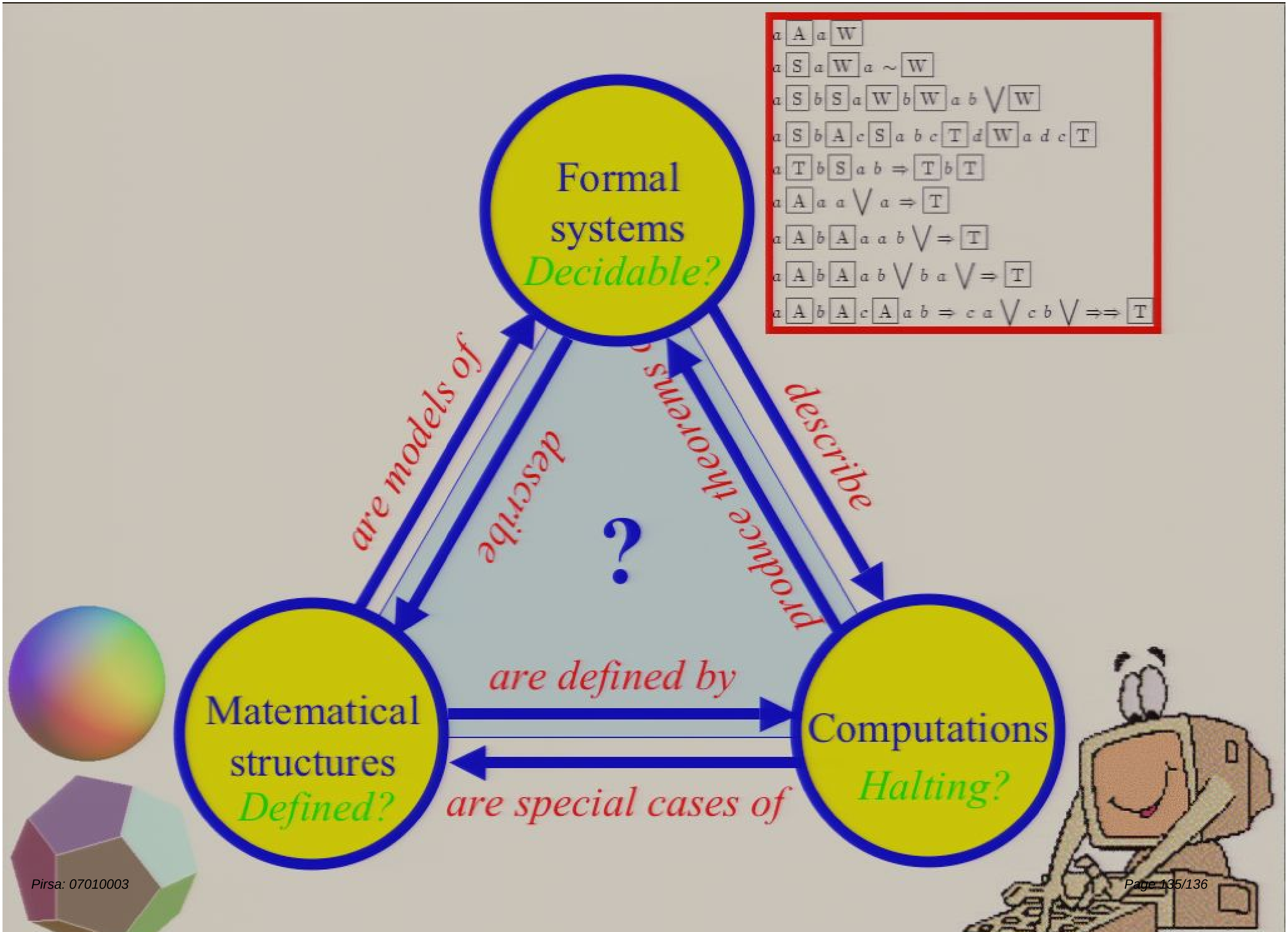


Bird's view:

Frog's view:


a A a W
a S a W a ~ W
a S b S a W b W a b ⋁ W
a S b A c S a b c T d W a d c T
a T b S a b ⇒ T b T
a A a a ⋁ a ⇒ T
a A b A a a b ⋁ ⇒ T
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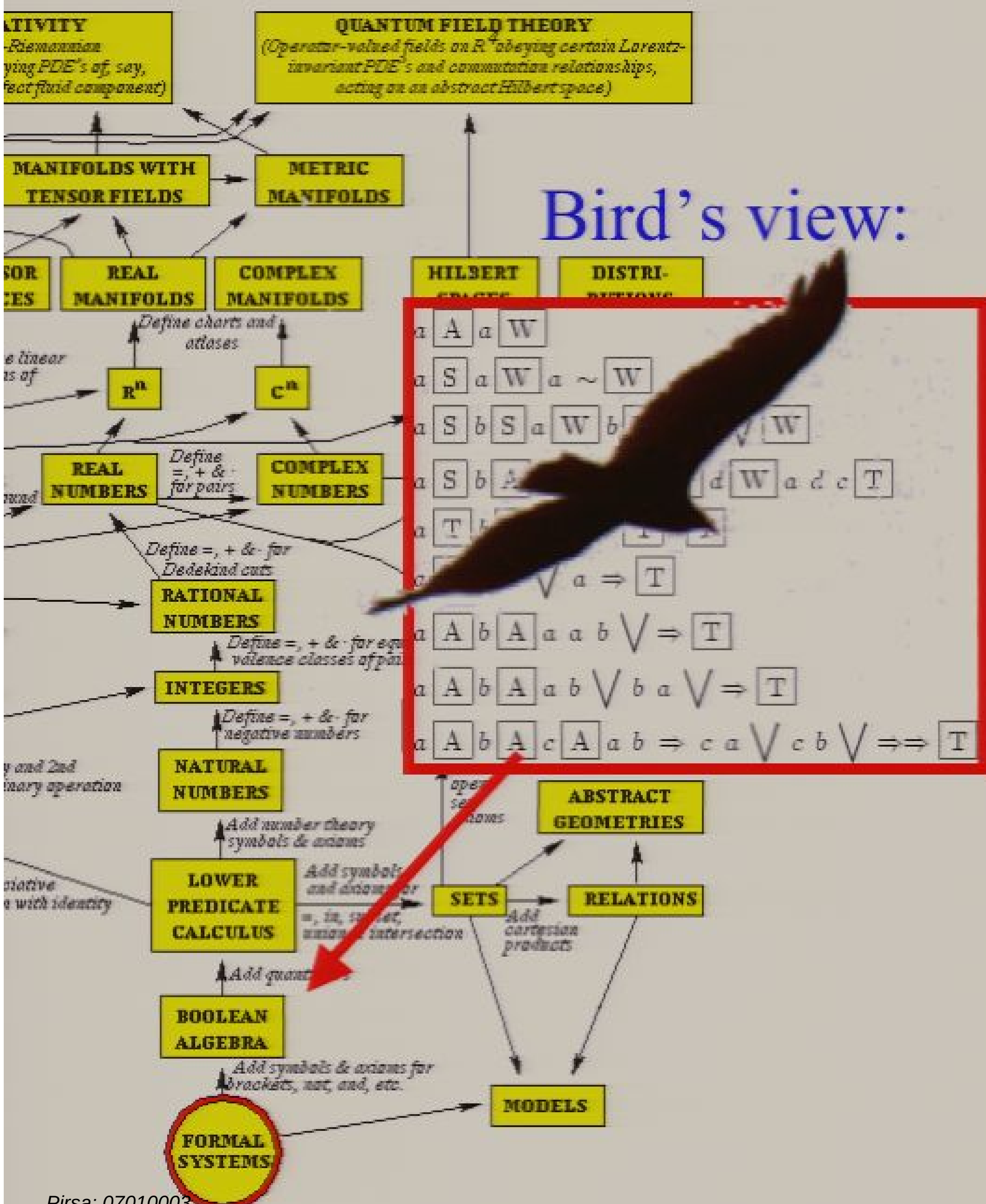

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