How astronomers define our world view

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From pre-history to history:

Development of our concept of time and thus position in universe

Prehistory -- Antique :

movement of animals

mating and other ceremonies

administrative cycles

position of Sun : morning / midday / evening / seasons

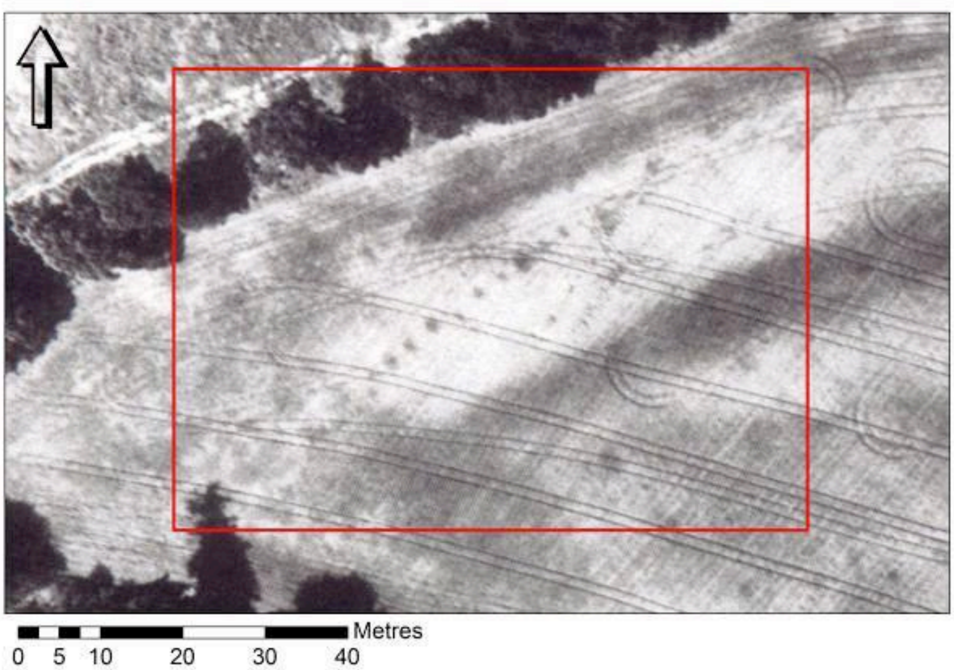
moonphases --> lunar calendar

yearly cycle of solar position :
summer / winter solstice / equinox

Development of our concept of time and thus position in universe

Prehistory -- Antique :

E.G: 8000 BC old remnants of time-keeping device in Scotland :



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sowing- and reaping times

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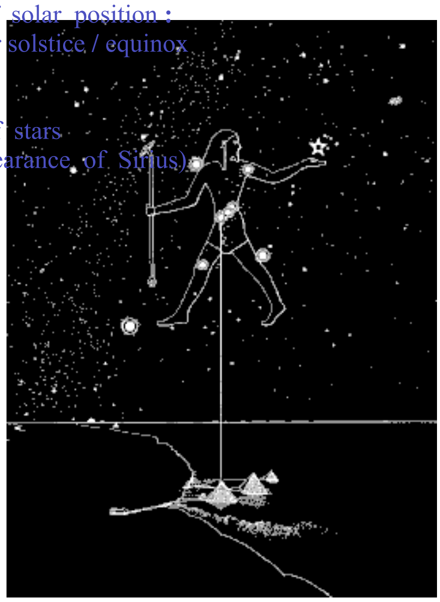
yearly cycle of solar position :
summer / winter solstice / equinox

yearly cycle of stars
(e.g.. first appearance of Sirius)



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yearly cycle of stars
(e.g.. first appearance of Sirius)

--> concept of time / supernatural phenomena

time keeping by priests / **astronomers**
good computational methods : Mesoamerikca (e.g. Maya) / China . . .

e.g.: Shang Dynasty in China (appros. 1600 - 1050 BC) :
"the year started with the first new moon after the winter solstice"

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Development of our concept of time and thus position in universe

A particularly relevant historical development :

*The concept of a **single God** - the discovery of monotheism*

Pharao Akhenaten / Echnaton / Amenhotep IV
-- pharao of the eighteenth dynasty and died about 1336 or 1334 BC --
abandoned Egyptian polytheism and declared *the Aten* (the disk of the Sun) as the sole god.
In his poem "Great Hymn to the Aten" he praises
Aten as the creator and giver of life.

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Akhenaten, Nefertiti and their daughters

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Development of our concept of time and thus position in universe

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In his poem "Great Hymn to the Aten" he praises
Aten as the creator and giver of life.

The following pharao, Horemhab, totally erased the cult of Aten.

It is thought that Moses (perhaps a high priest?) may have departed from Egypt at this time.

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Development of our concept of time and thus position in universe

A particularly relevant historical development :

It is thought that Moses may have departed from Egypt at this time.

The concept of a **single God**
--the discovery of monotheism--
may have been crucially important
in simplifying our world view.
It is an immense intellectual step towards abstractness.

From here on a person can try to come closer to God by studying and trying to understand the rules God made that govern our world . . .

Phenomena related to God are often associated
with astronomical / heavenly events.

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learning from experience

A historical perspective :

500 years ago

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Step I

A convincing, beautiful theory

About 500 years ago . . .

For more than a 1000 years
everyone

especially very clever people
with much influence

"knew" that . . .

"It was known" that . . .

The Earth is at the center of the universe.

The Sun, Moon, and all planets move on eternal circles about the Earth.

This *geocentric model* was *beautifully consistent* with Aristoteles' theory of motion **:**

The nature of Celestial objects is to move eternally on circles.

The nature of Earth objects is to come to rest.

And this was easy to prove by experiment.

And all of this was excellently consistent with the vast quantity of observational data and the cultural / religious understanding of the time.

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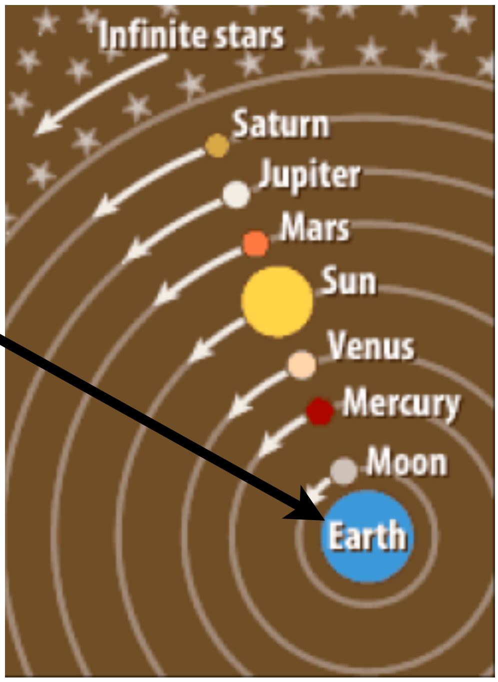
Thus, there was an *elegant theory*, with ***one center***, ***the Earth***, consistent with everything we knew, and with which *high-precision calculations* could be made

by adding epicycles onto epicycles.



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Step II

Making the theory fit

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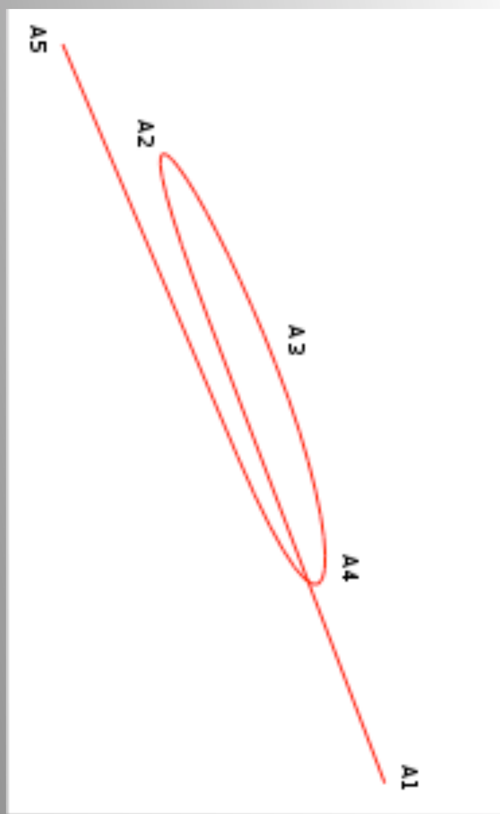
The simple geocentric model could not exactly account for the motions of the planets.



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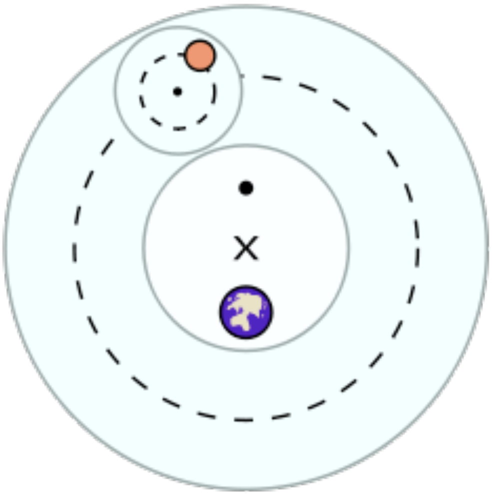


The geocentric model could not exactly account for the motions of the planets.

Remedy : add further epicycles, allow the Earth to be displaced from centre

==> the highly complicated Ptolomaic model

The Ptolomaic model
(Claudius Ptolomy : 2nd century AD)

The resultant system ended up being highly complicated :

each planet required an epicycle revolving on a deferent, offset by an equant which was different for each planet.

But it predicted various celestial motions well, including the beginnings and ends of retrograde motion.

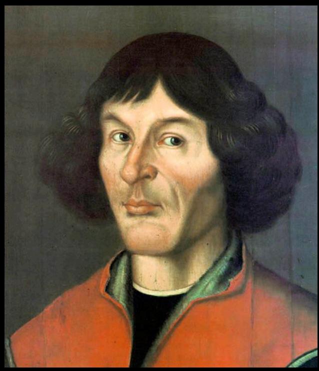
Step III

An alternative

First, in the 3rd century BC

(Aristarchus of Samos) and

then again, in 1543 . . .



. . . Copernicus suggested

a different model :

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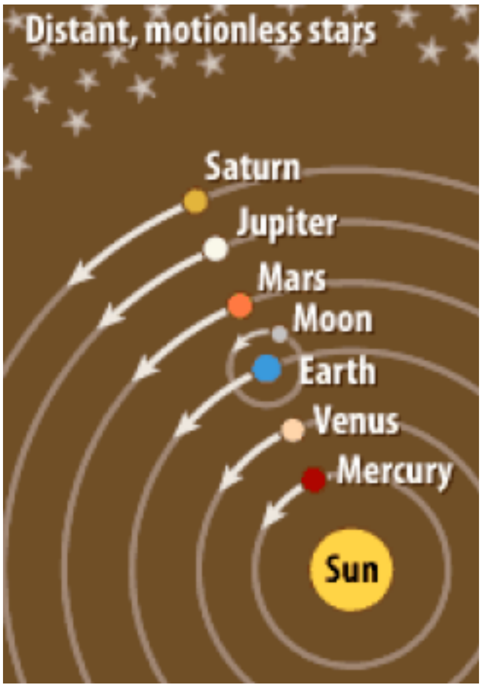
In this model, the
Sun is at the centre.



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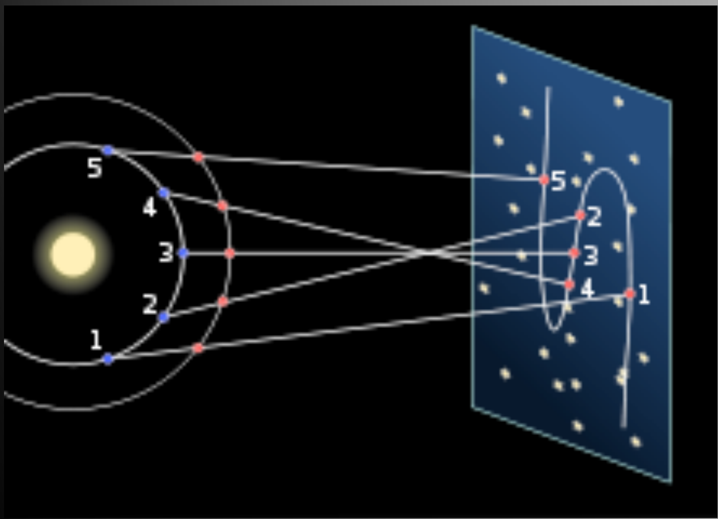
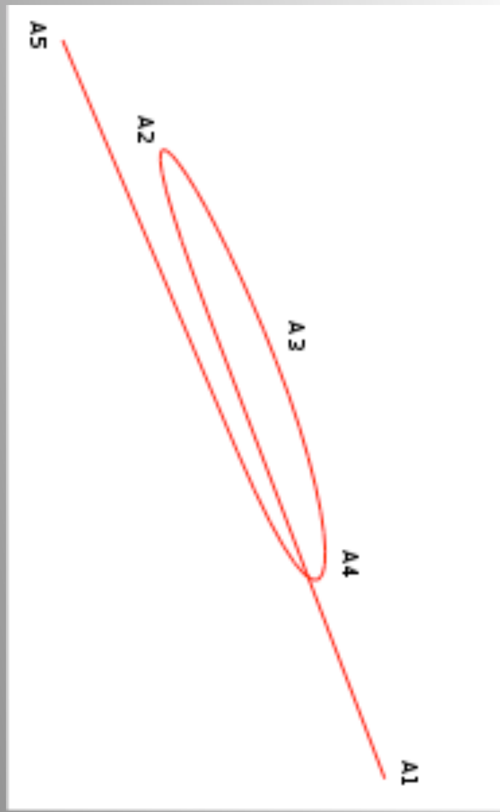
The periodic retrograde motions of the planets were accounted for naturally and simply





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In this model, the Sun is at the centre.

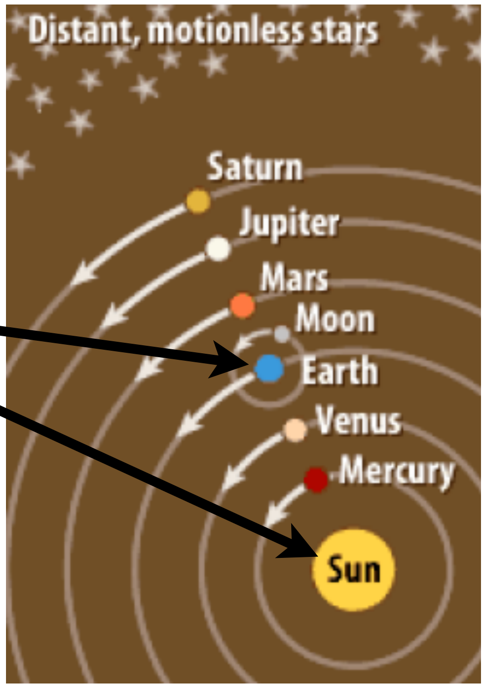
But this is more complicated:

It needs ***two centers***.
and it also needs a little epicycles

And, it is ***not consistent*** with cultural / religeous believes.

It is not convincing !

(It's beauty is hidden.)



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Thus 500 years ago there are two models for the world :

The Party Line !!

This is where ***resources*** flow (e.g. the King's Astrologer). This is what you do, if you do not want to be ***burned*** :

(I)

600 BC

The geocentric model

(the standard model)

- **Aristotele, Ptolomei** and many others

(II)

3rd century BC
1543 AD

The heliocentric model

(the exotic model)

- **Aristarchus, Copernicus**

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Step IV

Decision
made possible through
technological advance

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Technological advance :

stage I

Tycho & Kepler

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Tycho Brahe

(1546 - 1601)

observes

positions of stars and planets with unprecedented accuracy and precision

Johannes Kepler

(1571 - 1630)

derives

his three laws using Tysho's data

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Tycho Brahe
(1546 - 1601)

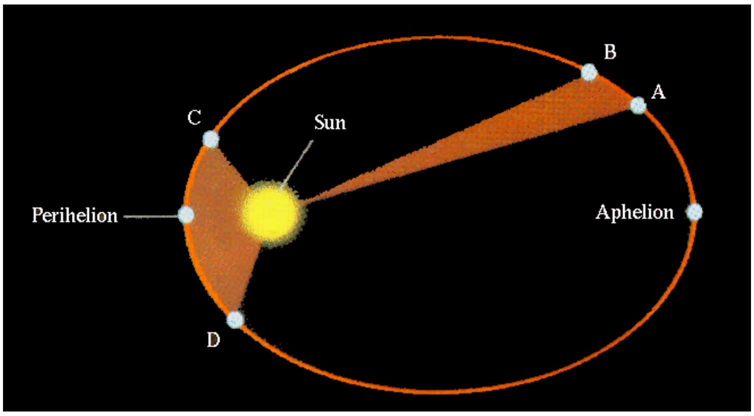
realized that progress needed systematic, rigorous observation and he improved and enlarged existing instruments, and built entirely new ones.

Mural quadrant (Tycho Brahe 1598)

Johannes Kepler
(1571 - 1630)

Kepler's laws are:

1. The orbit of every planet is an ellipse with the Sun at one of the two foci.
2. A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.[1]
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.



Kepler's laws were not accepted.

Several major figures such as *Galileo* and *René Descartes* completely ignored Kepler's publication. Many astronomers, including Kepler's teacher, *Michael Maestlin*, objected to Kepler's introduction of physics into his astronomy.

Some adopted compromise positions. *Ismael Boulliau* accepted elliptical orbits but replaced Kepler's area law with uniform motion with respect to the empty focus of the ellipse while *Seth Ward* used an elliptical orbit with motions defined by an equant

Johannes Kepler
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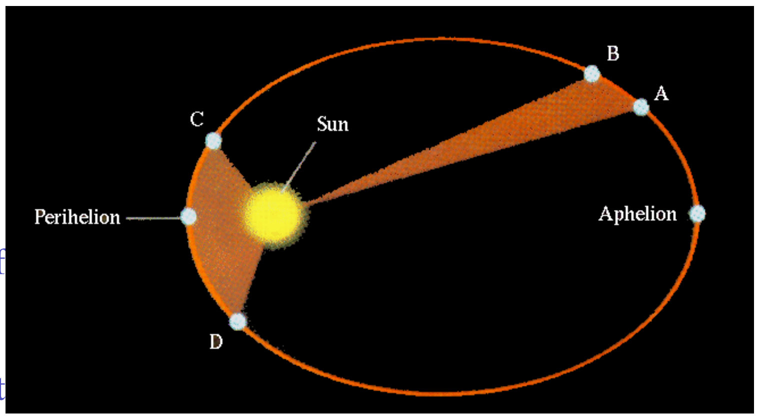

Technological advance :
stage II
Galileo

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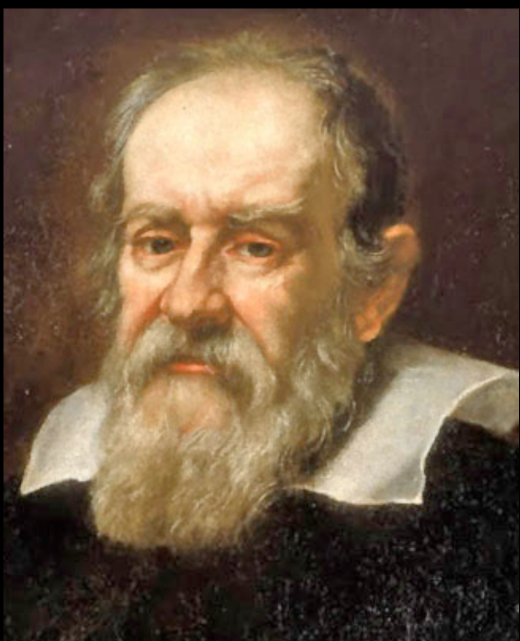
Galileo Galilei (1564 - 1642)

He observes
the Sun, the Moon, Venus and Jupiter
with a ***telescope***



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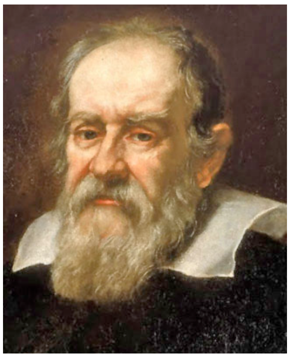

He observes
the Sun, the Moon, Venus and Jupiter
with a ***telescope***

Venus shows phases → Venus must *orbit the Sun* within Earth's orbit.

Jupiter has moons orbiting about it → There is *more than one center* !

The moon is cratered → Heavenly bodies are *not perfect crystal balls*

The Sun has spots and rotates → Heavenly bodies are not perfect and they *rotate*

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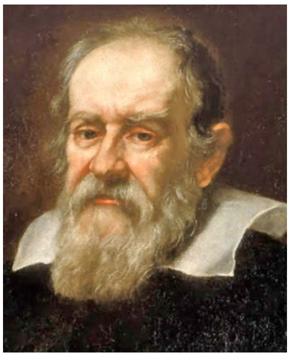

He observes
the Sun, the Moon, Venus and Jupiter
with a ***telescope***

Further, he

- developed the concept of motion in terms of velocity (speed and direction) through the use of inclined planes.
- developed the idea of force, as a cause for motion.
- determined that the natural state of an object is rest or uniform motion, i.e. objects always have a velocity, sometimes that velocity has a magnitude of zero = rest.
- objects resist change in motion, which is called inertia.

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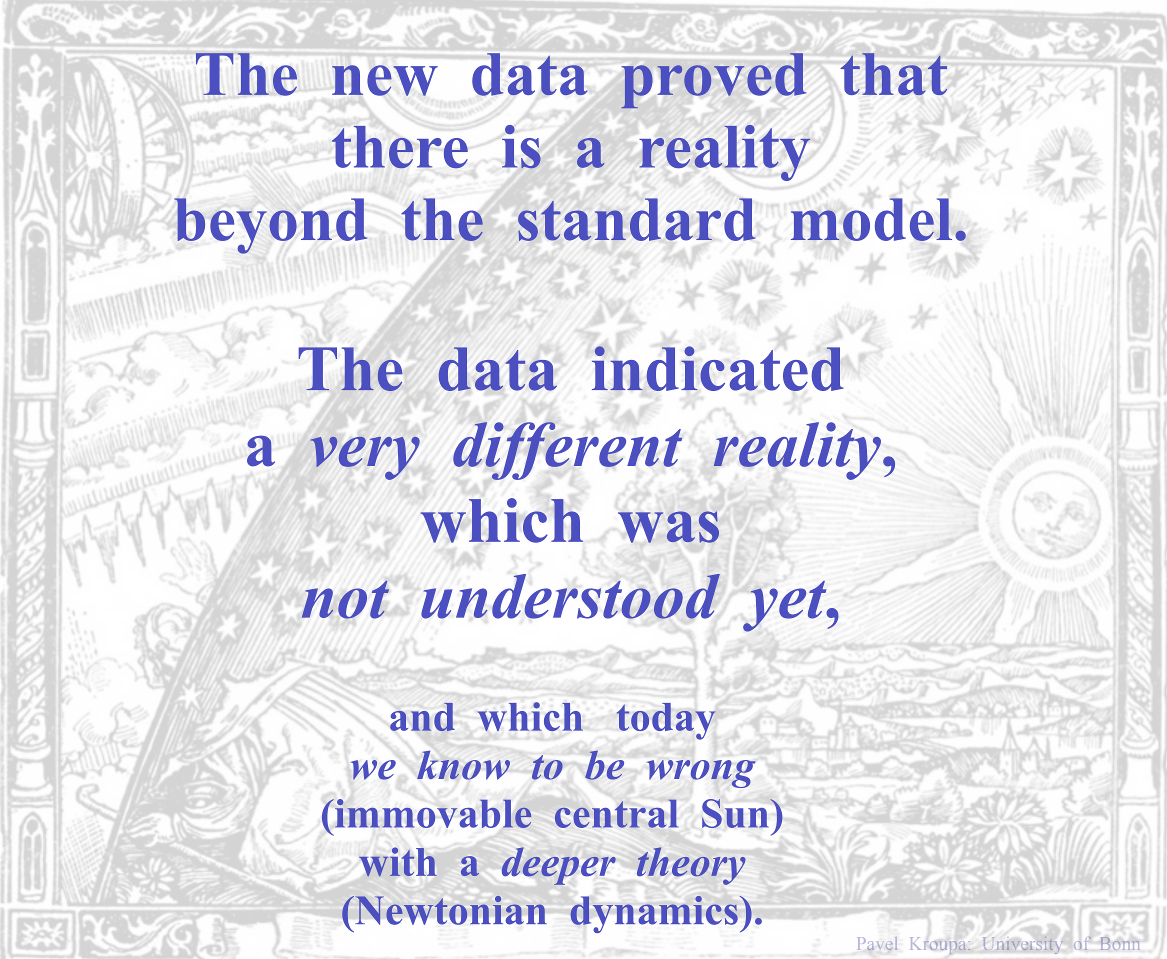

The new data proved that there is a reality beyond the standard model.

The data indicated a *very different reality*, which was *not understood yet*,

and which today *we know to be wrong* (immovable central Sun) with a *deeper theory* (Newtonian dynamics).

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Remember this slide ?

Thus 500 years ago there are two models for the world :

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Two models for the world :

With Galileo's observations the situation ought to have been crystal clear for any intelligent contemporary :

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But it took until after Newton (1643-1727),
i.e. about 100--200 more years,
until the
Heliocentric worldview
was
fully established.

In Summary

Step I : A convincing beautiful model (the standard model)

The *geocentric world* view by Aristoteles (about 4th century BC).

Step II : Making the theory fit

Add epicycles to achieve high precision (Claudius Ptolemaeus in the 2nd century AD)

==> ***excellent description of the data***.

many astronomers not happy as computational model complex

Step III : An alternative model (the exotic model)

The *heliocentric model* by Aristarchus (3rd century BC)
(and later Copernicus 1543).

Not accepted **:** more complex and unsatisfying.

It needs ***two centers*** and does ***not fit*** the data well.

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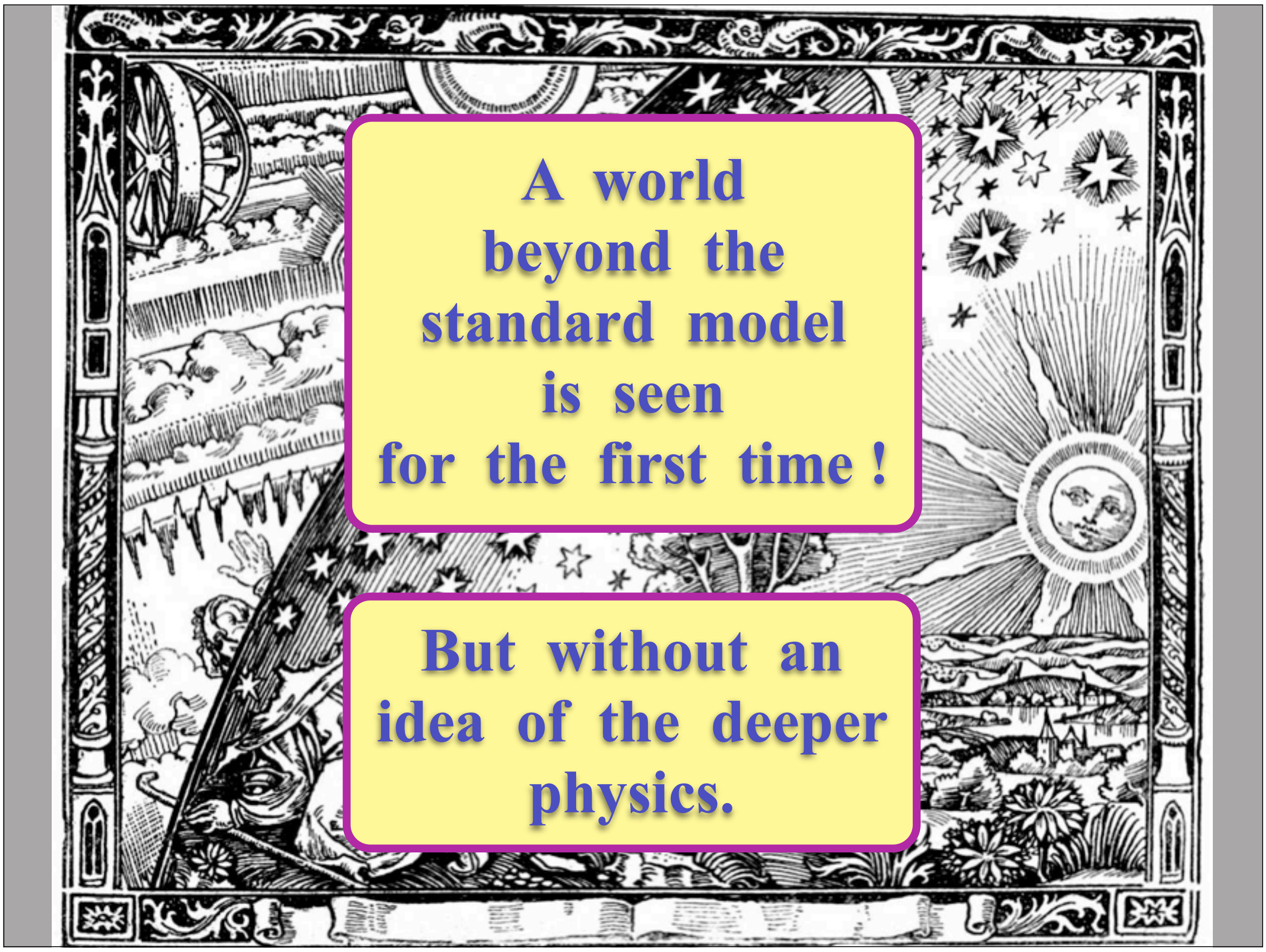

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Step V : Conclusions

It became irrelevant to debate whether the geocentric model fits any data. Beauty or even "high-precision" of a model can misguide.

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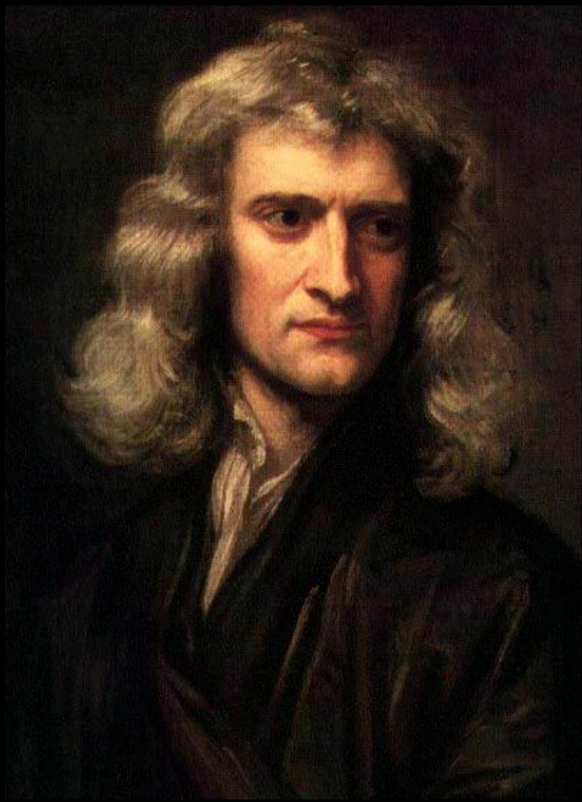
It took until Newton (1643-1727),
i.e. about 200 more years,
until the
Heliocentric worldview
was
fully established
and the deeper reality
--Newtonian dynamics--
was established



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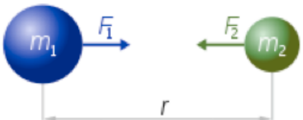
Isaac Newton (1643-1727) **:** 1665 **: the first formulation of mathematical physics,** based on Kepler & Galilei

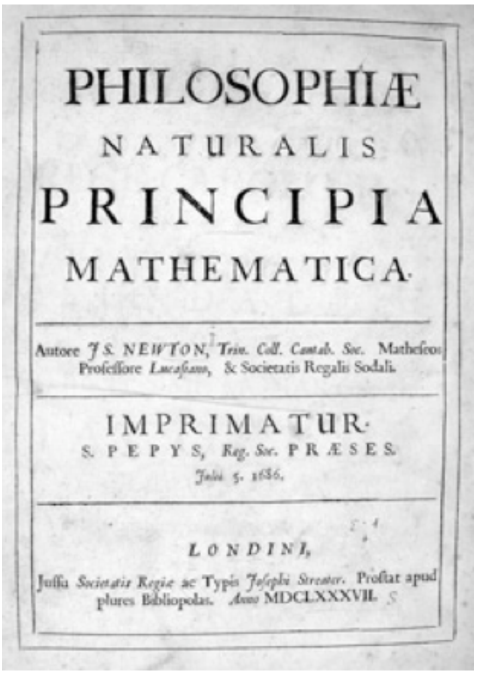
The first real unification theory :
Fall of the *Cambridge Apple* is unified with the observed *motion of the Moon* and of the planets - perhaps the most influencial scientific work ever written **:**
Philosophiæ Naturalis Principia Mathematica

1. **First law**: When viewed in an inertial reference frame, an object either is at rest or moves at a constant velocity, unless acted upon by a force.[2][3]
2. **Second law**: The acceleration of a body is directly proportional to, and in the same direction as, the net force acting on the body, and inversely proportional to its mass. Thus, **F** = m**a**, where **F** is the net force acting on the object, m is the mass of the object and **a** is the acceleration of the object.
3. **Third law**: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.

Law of universal gravitation :

$$F = G\frac{m_1 m_2}{r^2}$$





PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore J. S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Newton still assumes space and time are absolut and Euclidean, everywhere. Action at a distance.

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Step V

Conclusions

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The geocentric model is wrong.

The heliocentric model is correct
(but not complete)

But two intellectual steps were
needed at the same time :

- Sun at the centre
- non-circular orbits

It became irrelevant to ask if
some data are consistent with
the geocentric model
(there are such data !)

but instead,
the only issue of significance was
what the
deeper physical meaning
of the Heliocentric model might be.

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Appendix A

What stopped Aristarchus' heliocentrism being widely accepted, delaying progress for over 2000 years ?

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This is a fascinating, largely sociological, but also technological, problem

(and cannot be blamed only on the Church).

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Our current world view

Step I

A convincing, beautiful theory

Einstein (1879-1955) **:** Theory of General Relativity (1916)

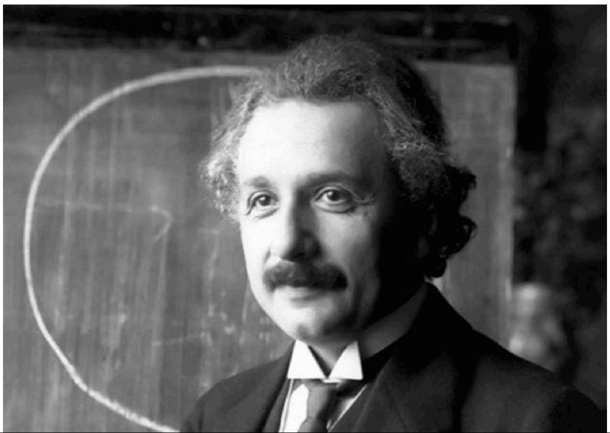
Brilliant new idea :
Gravitation is not a force but an effect of space-time geometry.

Space and time are curved by matter. The curvature tells matter how to move.

Einstein (1879-1955) **:** Theory of General Relativity (1916)

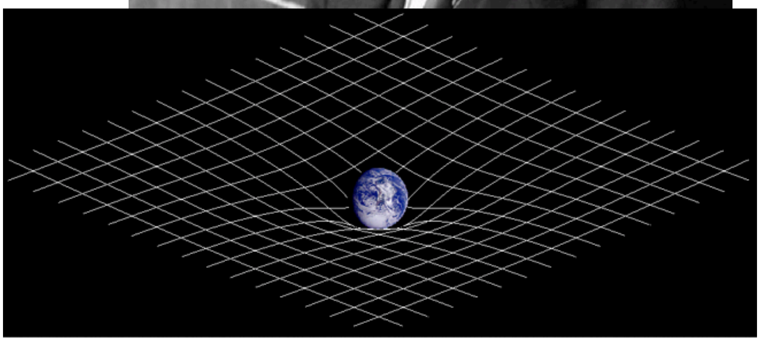
Einstein's field eqaution :

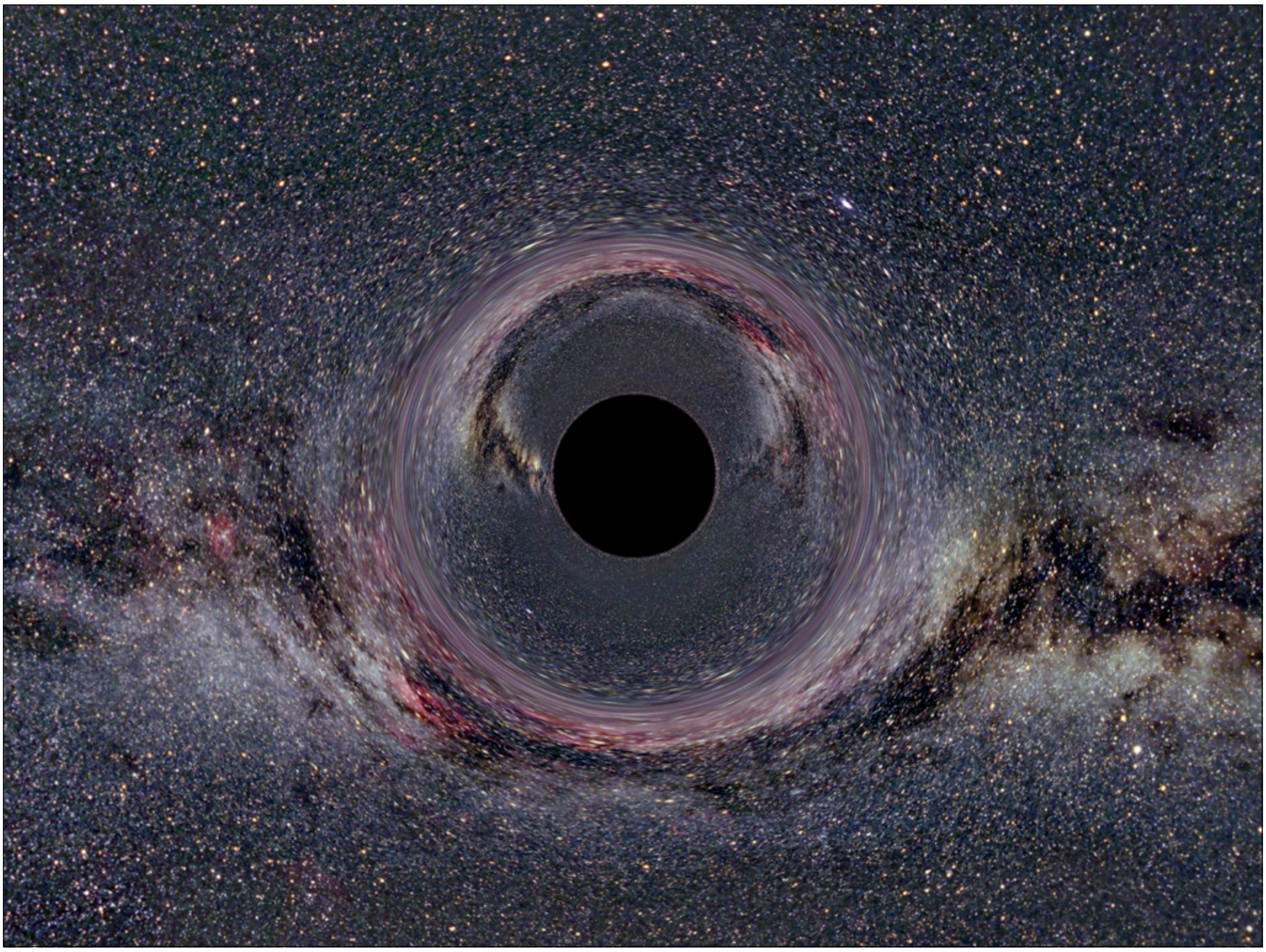
$$G_{\mu\nu} + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$



Space, time and mass are not separable anylonger.

Space and time are not absolute.





The Standard / Concordance Cosmological Model

LCDM = CCM

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Step IIa

Making the theory fit

Testing the model globally
(where astronomical data are difficult)

Standard model of cosmology :

Postulate I : Einstein's field equation is valid everywhere

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

where $R_{\mu\nu}$ is the Ricci curvature tensor, R the scalar curvature, $g_{\mu\nu}$ the metric tensor, Λ is the cosmological constant, G is Newton's gravitational constant, c the speed of light in vacuum, and $T_{\mu\nu}$ the stress–energy tensor.

Postulate II : Matter is conserved

Standard model of cosmology :

Assumptions are immediately falsified :

- Prediction of a highly curved highly inhomogeneous universe
- Prediction of falling *rotation curves* of galaxies and *structure formation* too slow

Solution:

- Postulate a mathematical trick (*inflation*) — not understood
- Postulate existence of unknown exotic matter (*dark matter*) — not found

But this also does not work:

- Universe expands today faster, than it should

Solution:

- Postulate a mathematical trick (*dark energy*) — not understood

Problem :

- Model (=*Standard Model of Cosmology* = *LCDM*) does **not conserve energy**

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The Standard / Concordance Cosmological Model

Problems

inflation :	the detailed particle physics mechanism responsible for inflation is not known
dark energy : 74 %	the implied dark energy density is so small that it is unstable to quantum correction (Dvali et al. 2002); not seen by WMAP (Sawangwit & Shanks); energy creation; may not be there at all (Wiltshire)
dark matter : 22 %	despite much search hitherto unknown stuff
baryons : 4 %	only 40% of these found - the *missing baryon problem*
dark force :	totally unknown (Peebles & Nusser 2010; Kroupa et al. 2010)

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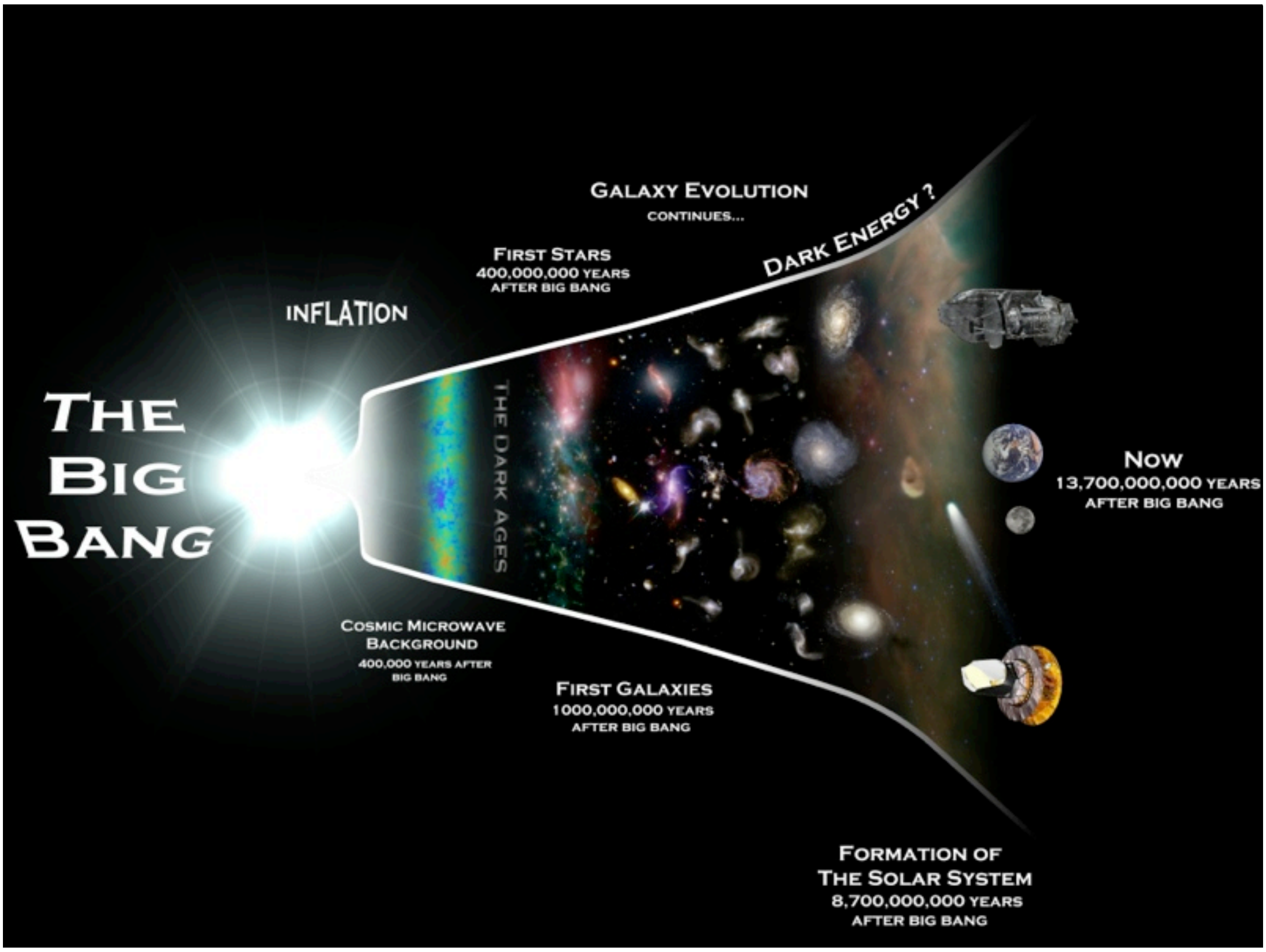
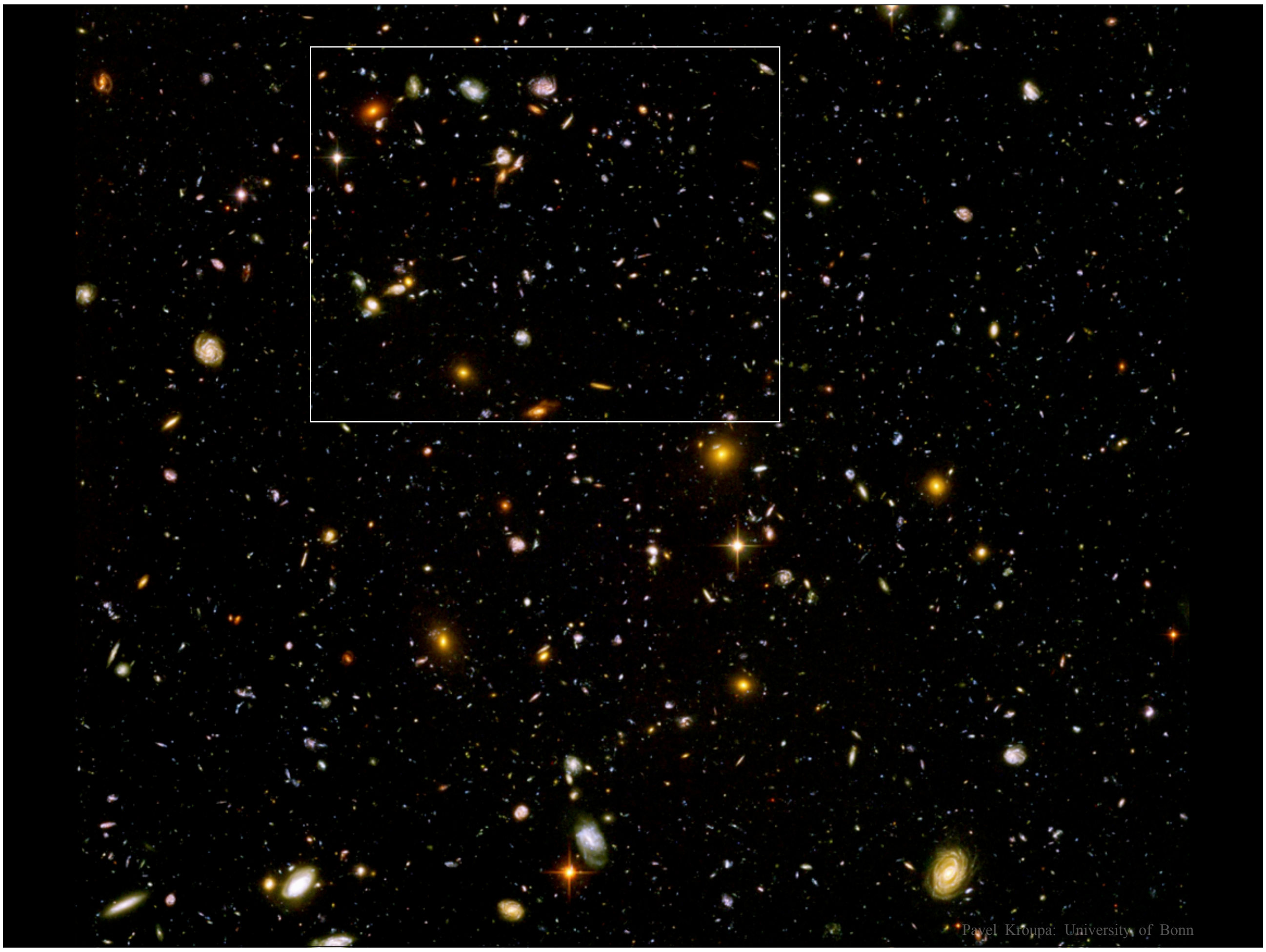
That is, we are trying to describe / model the universe with essentially unknown physics.

This is like trying to construct stellar models based to 95 % on completely unknown ingredients.

But, this statement does not falsify the model !!

According to the Standard model of Cosmology (the SMoC) . . .

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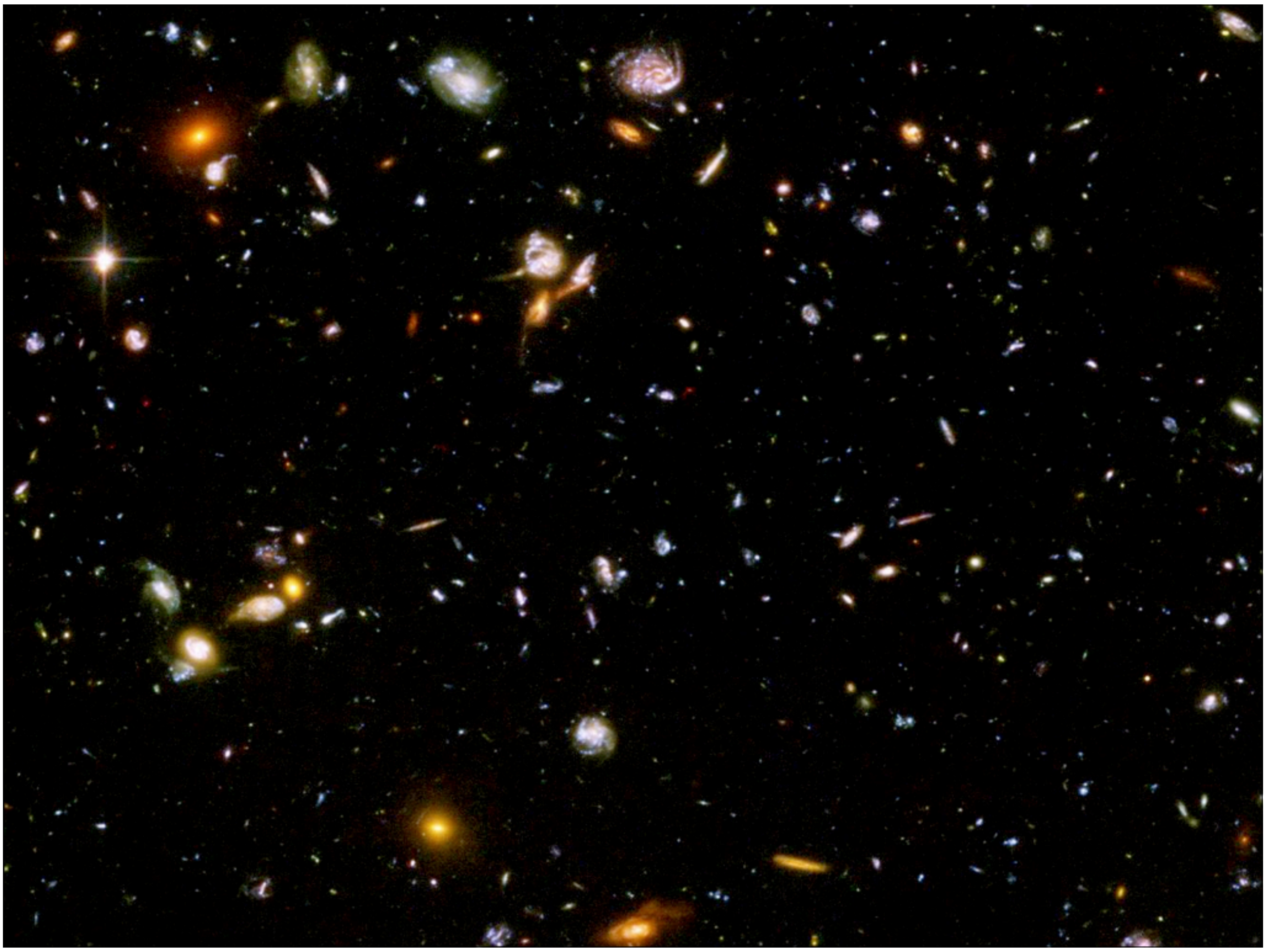
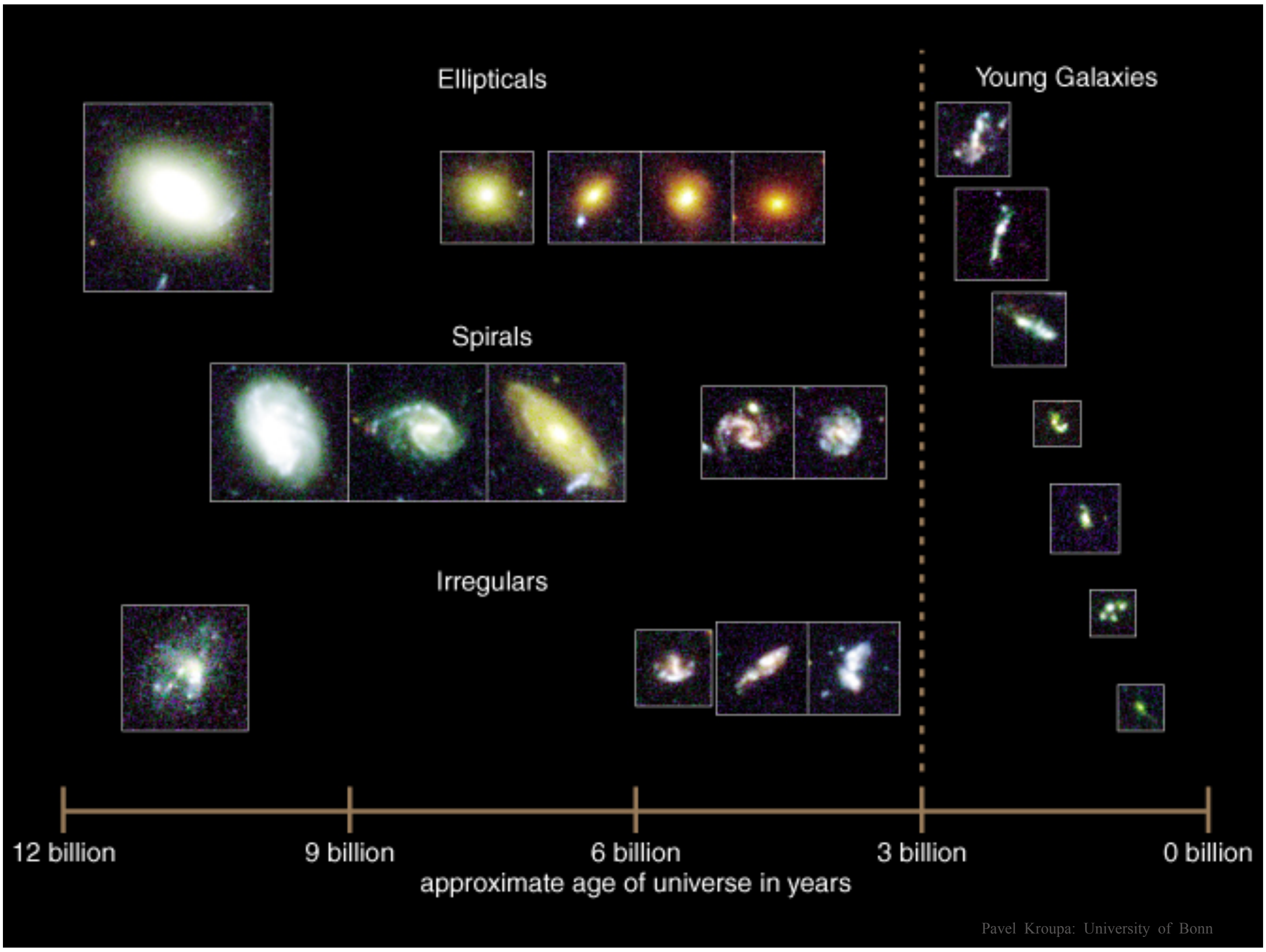




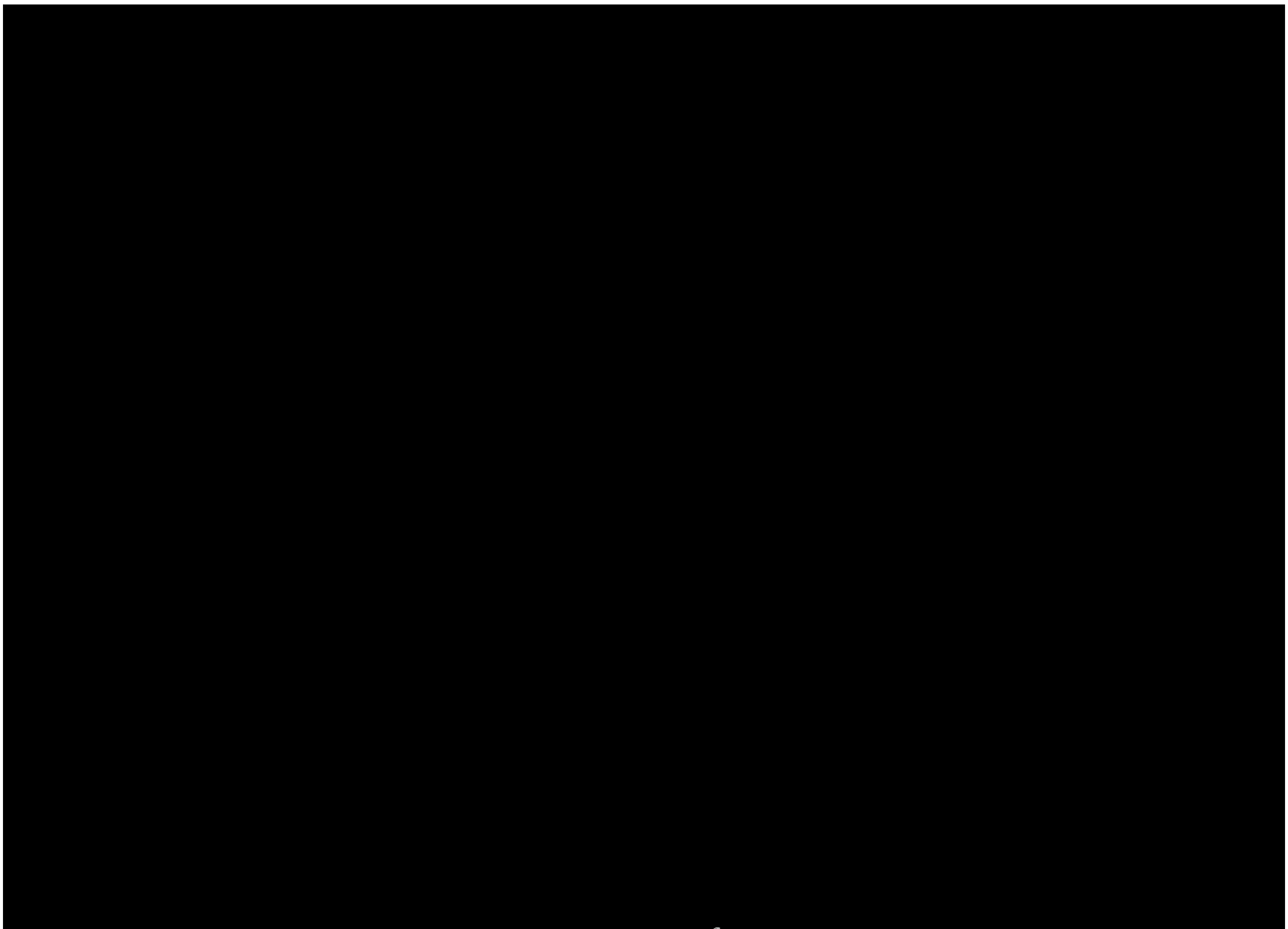
Cosmological structure formation

Film by John Dubinski and Kameel Farah (CITA)

(http://www.cita.utoronto.ca/~dubinski/nbody/)

64

Pavel Kroupa: University of Bonn

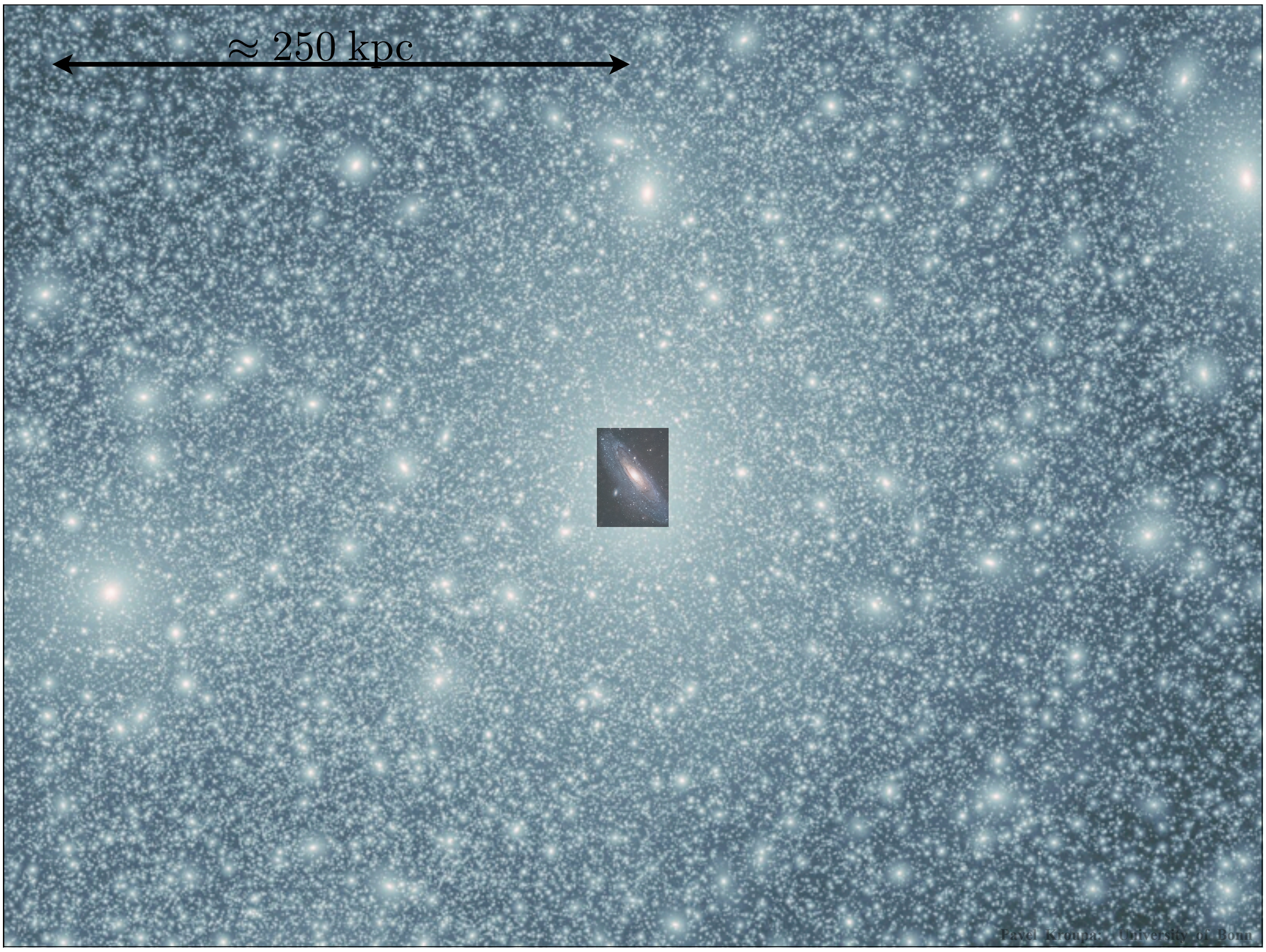


Cosmic structure formation

But the model fails . . .

I. The Dual Dwarf Galaxy Theorem is *falsified* by the observational data (Kroupa 2012).

II. The observed distribution of satellite galaxies around Andromeda and the Milky Way are incompatible with the model (Pawlowski, Kroupa et al. 2012):



Vast Polar Structure around the Milky Way

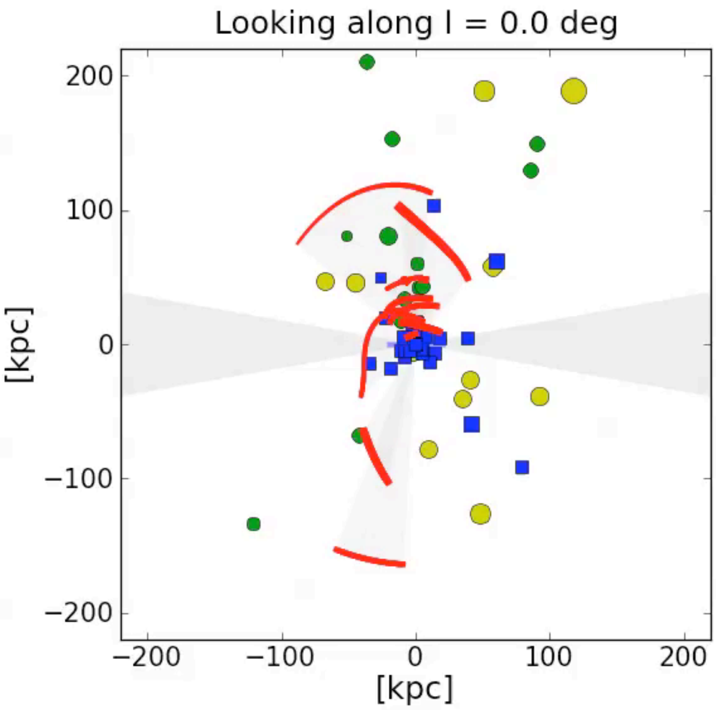
Pawlowski et al. 2012

YH globular clusters

dSph satellites

UFD satellites

streams

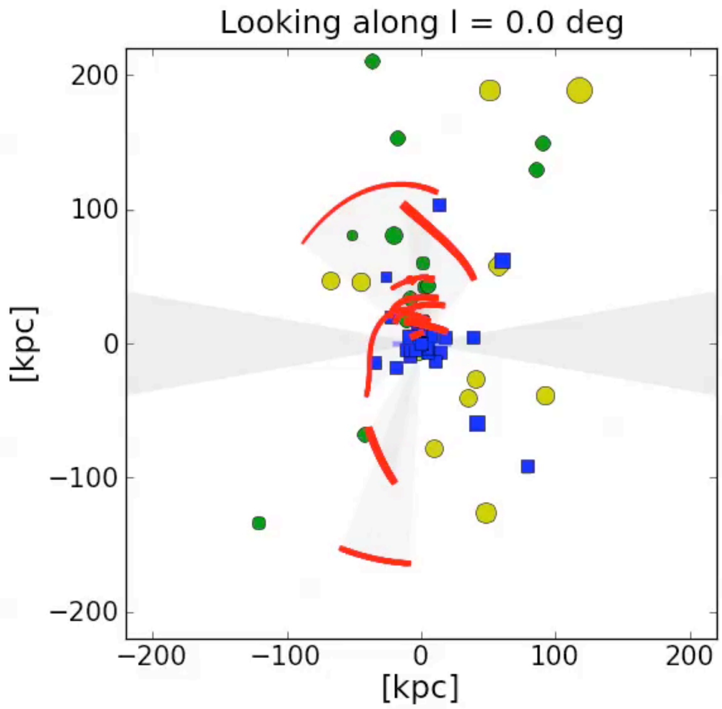


See also
YouTube video
"The Vast Polar Structure"

Pavel Kroupa: University of Bonn

Vast Polar Structure around the Milky Way

Pawlowski et al. 2012



YH globular clusters

dSph satellites

UFD satellites

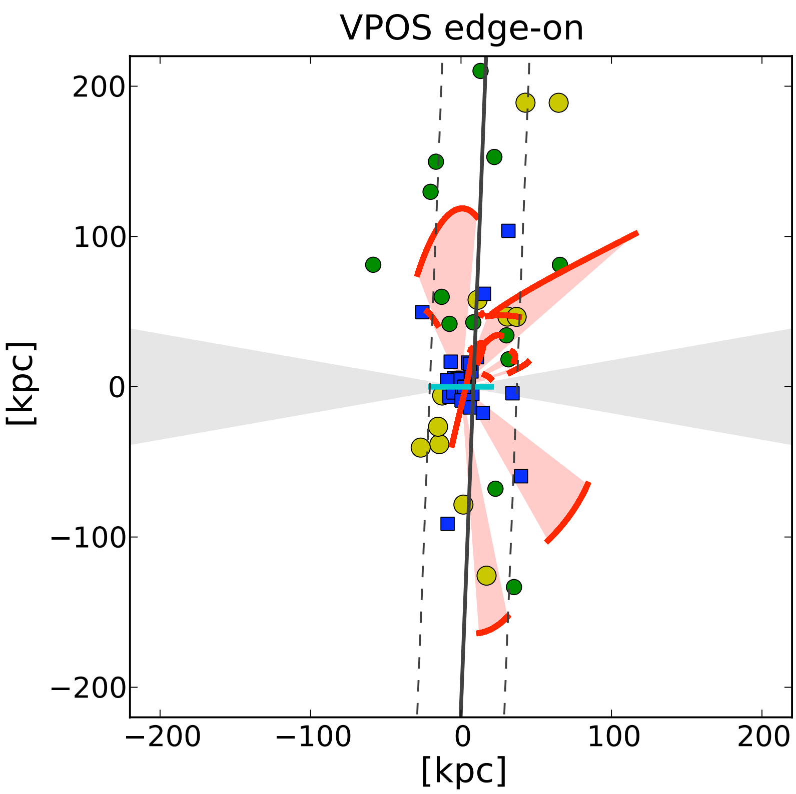
streams

See also *YouTube video* "The Vast Polar Structure"

Pavel Kroupa: University of Bonn

Vast Polar Structure around the MW

Pawlowski et al. 2012



Pavel Kroupa: University of Bonn

Step IIb

Making the theory fit

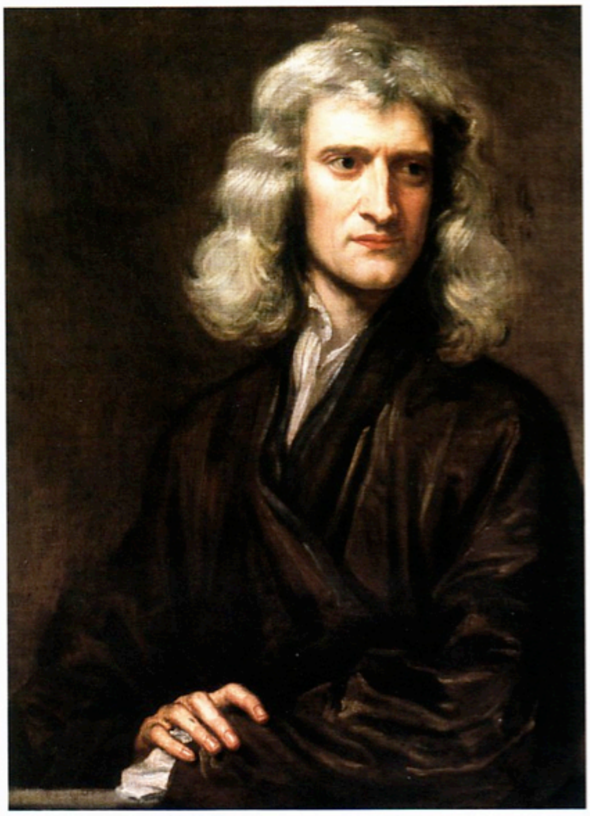
Lets consider the issue of
dark matter closer

Pavel Kroupa: University of Bonn

Return to the law of universal accelaration

Pavel Kroupa: University of Bonn

Sir Isaac Newton (1643 - 1727)



JEREMY WHITAKER / TRUSTEES OF THE PORTSMOUTH ESTATES

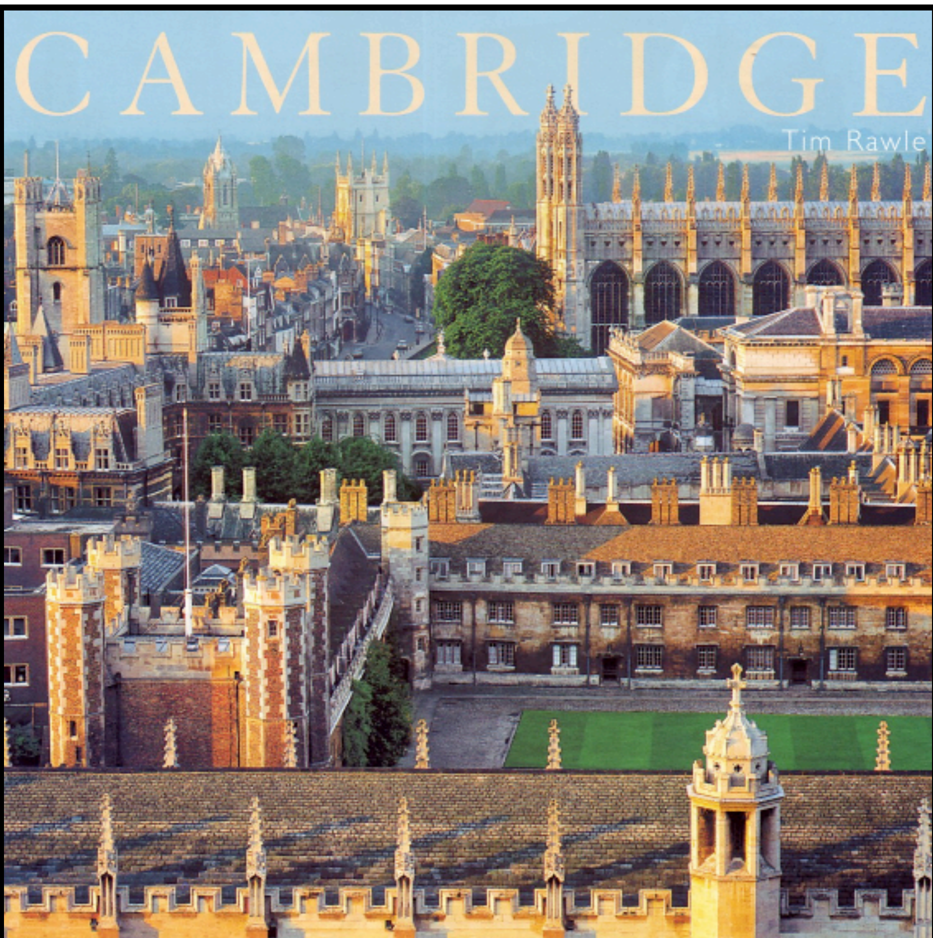
By Godfrey Kneller, 1689. Painted when Newton was 46 and one of the University's two members of parliament. He kept this portrait in his possession to the end of his life. Notice the artist's interest in Newton's delicate fingers

By Godfrey Kneller, 1702, as President of the Royal Society when Newton was 59

NATIONAL PORTRAIT GALLERY

By John Vanderbank, 1726, when Newton was 83. Presented to Trinity College, 1766

TRINITY COLLEGE, CAMBRIDGE



Pavel Kroupa: University of Bonn

Pavel Kroupa: University of Bonn

Isaac Newton (1643 - 1727)

The force, with which *body 2* is attracted to *body 1* :

= −

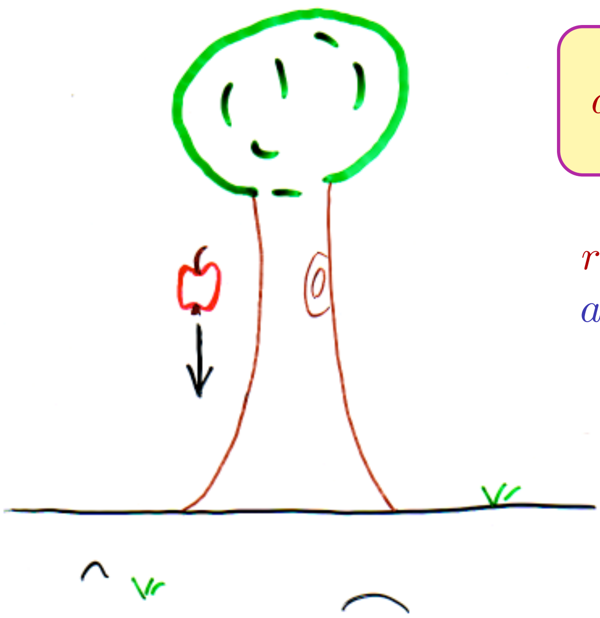
The force, with which *body 1* is attacted to *body 2* :

$$F_{12} = m_2\, a_2 = m_2 \frac{G\, M_1}{r_{12}^2} = M_1 \frac{G\, m_2}{r_{21}^2} = M_1\, a_1 = -F_{21}$$

$$\not{m}_2\, a_2 = \not{m}_2 \frac{G\, M_1}{r_{12}^2}$$

$$a_2 = \frac{G\, M_1}{r_{12}^2}$$

Falling apple



$$a_2 = \frac{G\, M_1}{r_{12}^2}$$

$r_{12} = R_{\rm Earth} = 6400$ km

$a_2 = g =$ Earth's surface gravity

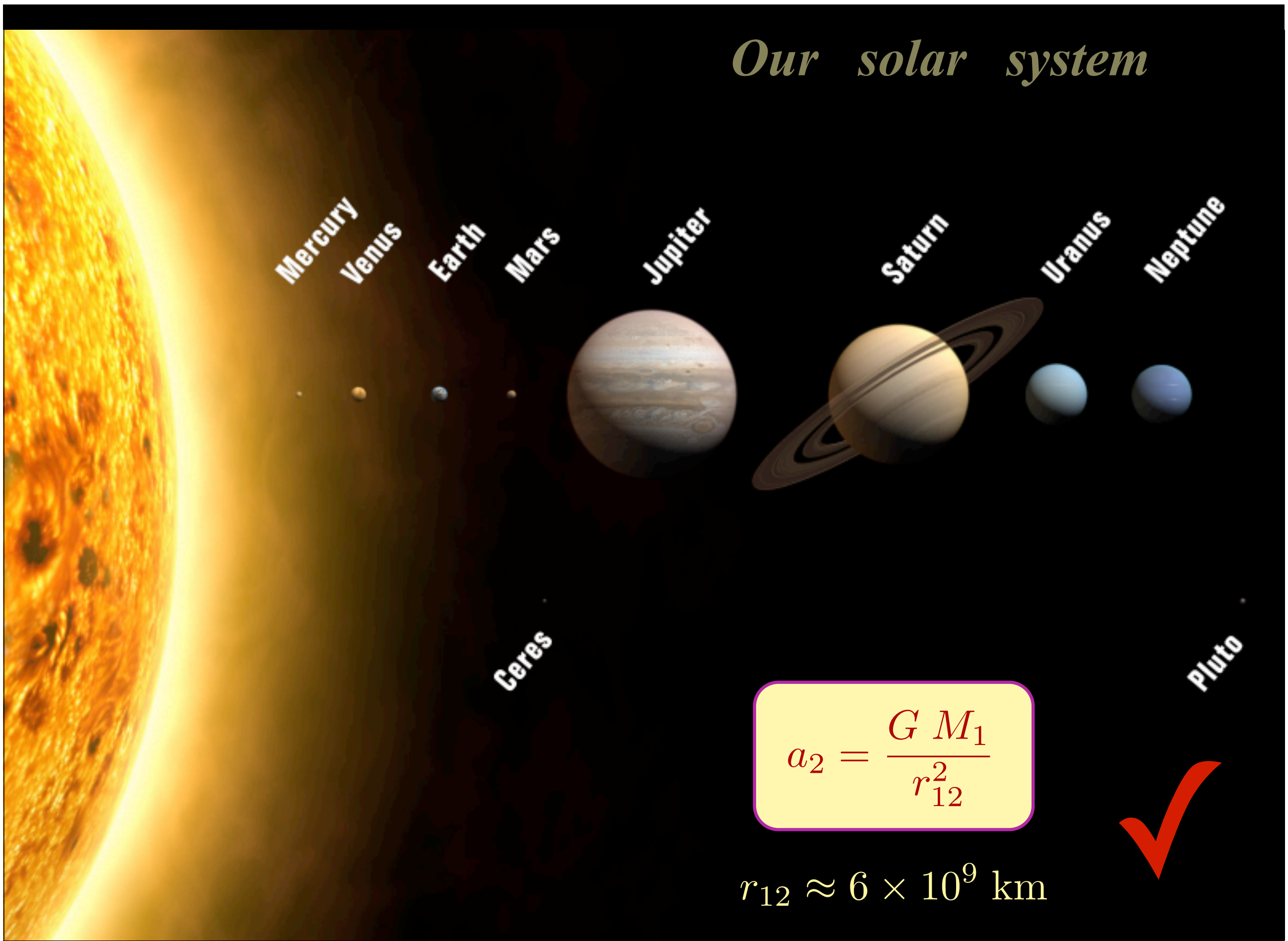
✓

Moon's orbit about the Earth

$$a_2 = \frac{G\,M_1}{r_{12}^2}$$

$r_{12} = 380\,000$ km

Our solar system



$$a_2 = \frac{G\,M_1}{r_{12}^2}$$

$r_{12} \approx 6 \times 10^9$ km

Newton works over length-scales typical for the solar system.

This is not surprising because Newton's law was empirically formulated over exactly these length scales.

Now we will apply Newton's force law to an extended length scale … ***star clusters***.

This corresponds to an ***extrapolation*** of the length scale by a factor of 10^5.

Q **:** Should such a (fantastic) *extrapolation of an empirical law* work out **?**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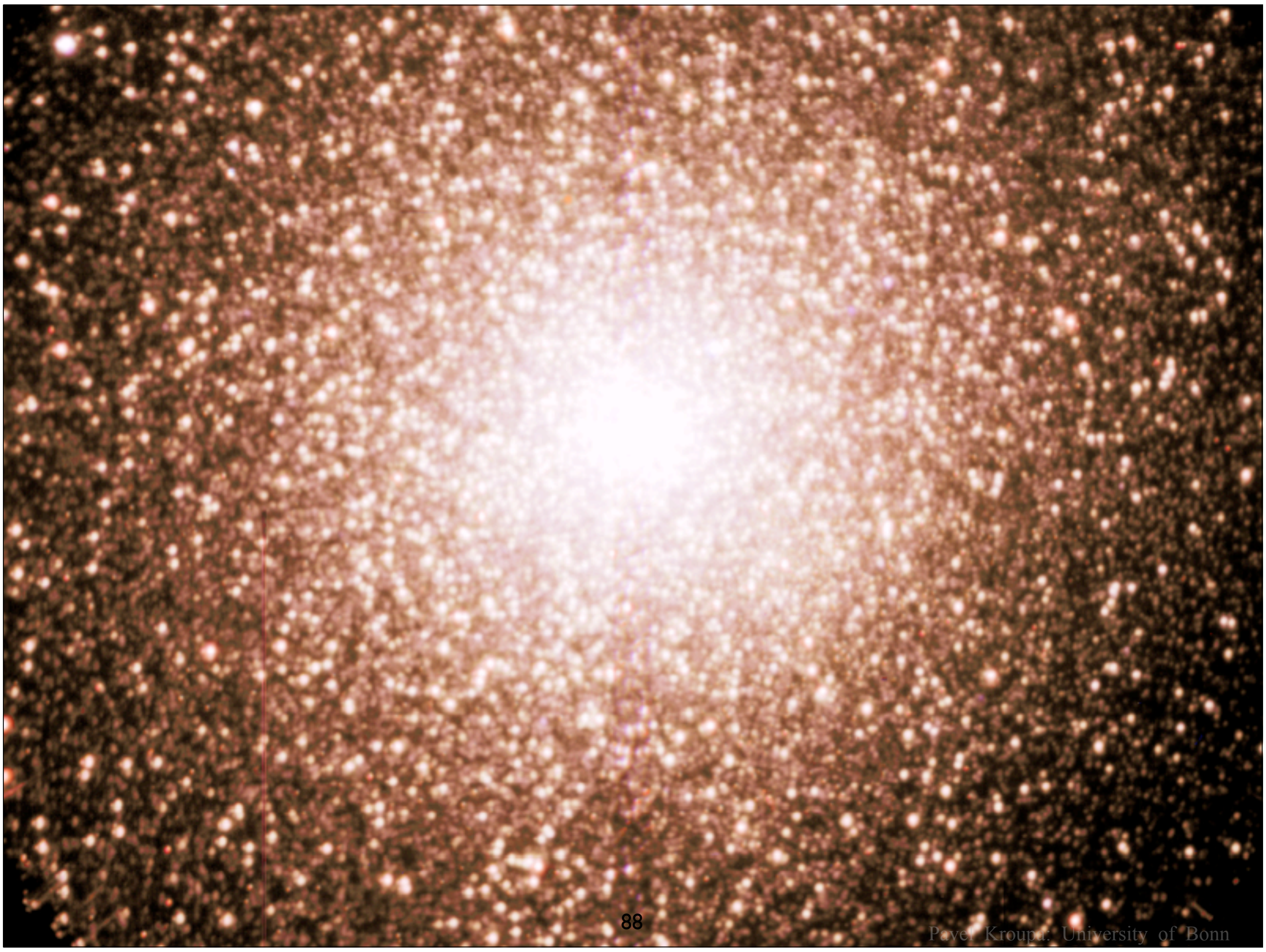
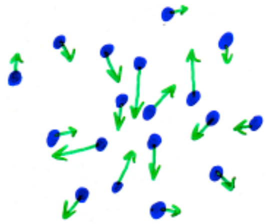

88
Pavel Kroupa: University of Bonn

Star clusters



velocity dispersion
σ [km/s]

theory in excellent
agreement with observations

$$a_2 = \frac{G\,M_1}{r_{12}^2}$$

$r_{12} \approx 3.8 \times 10^{24}$ km (40 ly)

So, this worked out, at least in a statistical sense.

But lets ***extrapolate*** Newton to an even larger length scale … ***galaxies***.

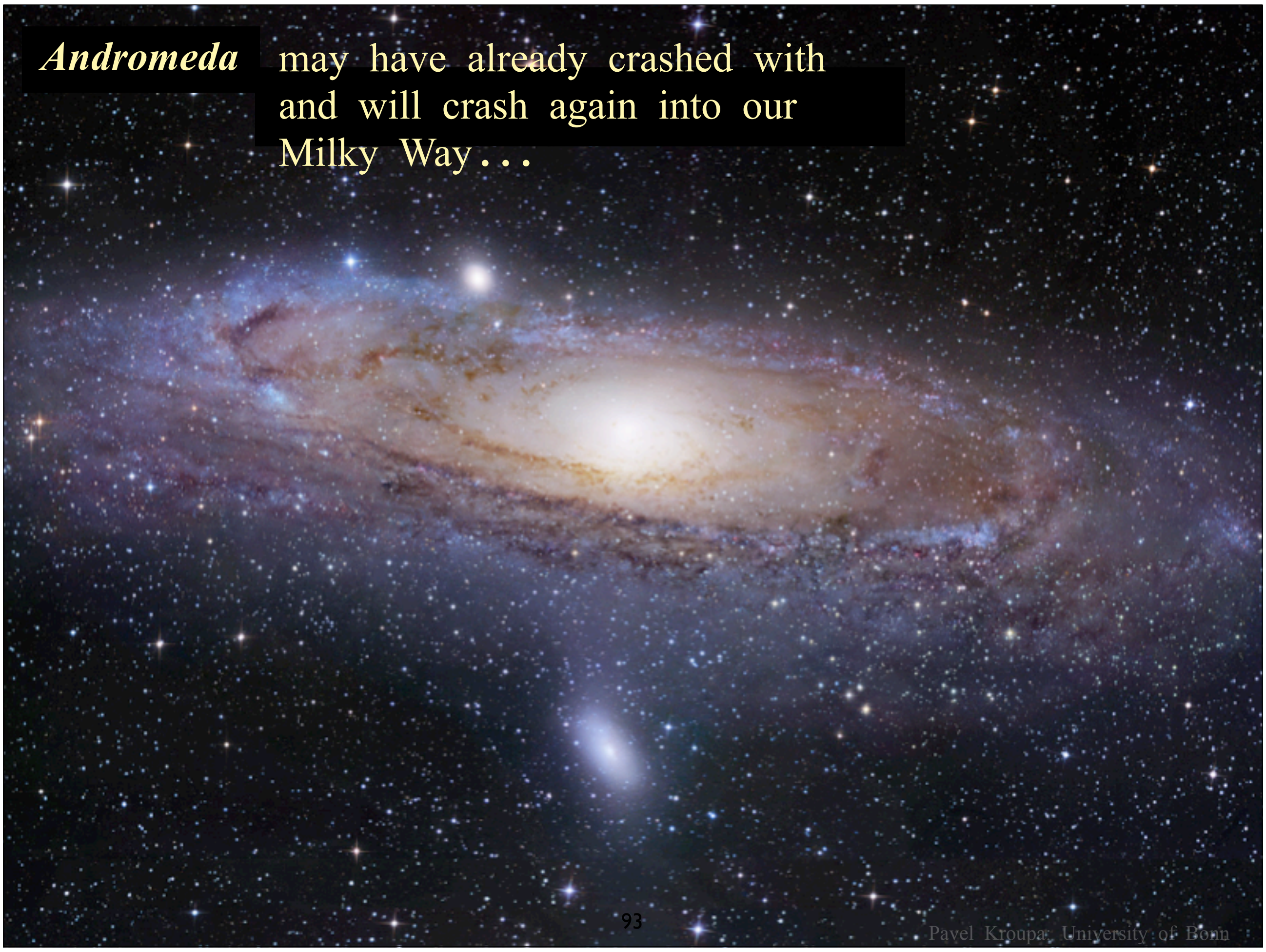
This corresponds to a further ***extrapolation*** by a factor 1000 .

[**Note:** Neither *Newton* (1687: Principia) nor *Einstein* (1915: GRT) new about the existence of galaxies nor about cosmological scales - this issue was discussed in the *Great Shapley-Curtis Debate* in 1920.]

Q **:** Should this extrapolation work **?**


Galaxies
91
Pavel Kroupa: University of Bonn


92
Pavel Kroupa: University of Bonn



Two colliding disk galaxies ⟶ E galaxy

Two movies by John Dubinski and Kameel Farah (CITA) of the ***Andromeda galaxy*** and the ***MW*** merging in about 3Gyr and forming an E galaxy.

(http://www.cita.utoronto.ca/~dubinski/nbody/)

⟶ The *first movie* shows the interaction from very far away.

The *second movie* shows the interaction from the Sun. The Sun orbits the MW but is then ejected outwards onto radial orbit through the centre of the MW.

Two colliding disk galaxies → E galaxy

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(http://www.cita.utoronto.ca/~dubinski/nbody/)

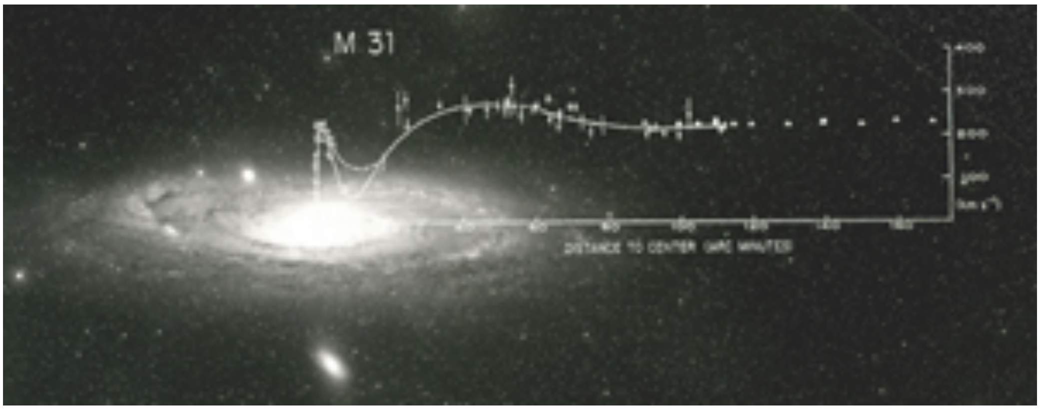
The *first movie* shows the interaction from very far away. ✓

→ The *second movie* shows the interaction from the Sun. The Sun orbits the MW but is then ejcted outwards onto radial orbit through the centre of the MW.

Collision between Andromeda and our Galaxy viewed from the Sun

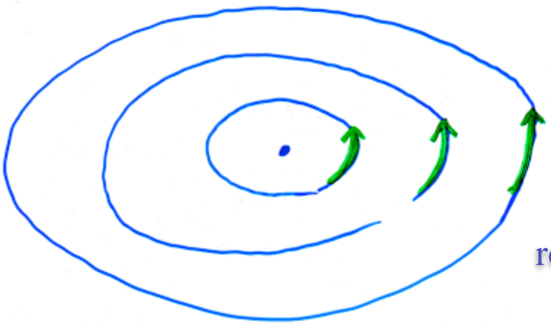
Vera Rubin
& Kent Ford 1970

Discover the flat rotation curve of Andromeda.



Pavel Kroupa: AIfA, University of Bonn

A spiral galaxy



rotational velocity
V_C [km/s]

$$a_2 = \frac{G\,M_1}{r_{12}^2}$$

$r_{12} \approx 40\,000$ ly

100

Pavel Kroupa: University of Bonn

Newton fails on galaxy scales !!

What about even larger length scales ?
… ***clusters of galaxies***.

This corresponds to a further ***extrapolation*** by a factor of 100 .

Q **:** Could this extrapolation of Newton's law work ?

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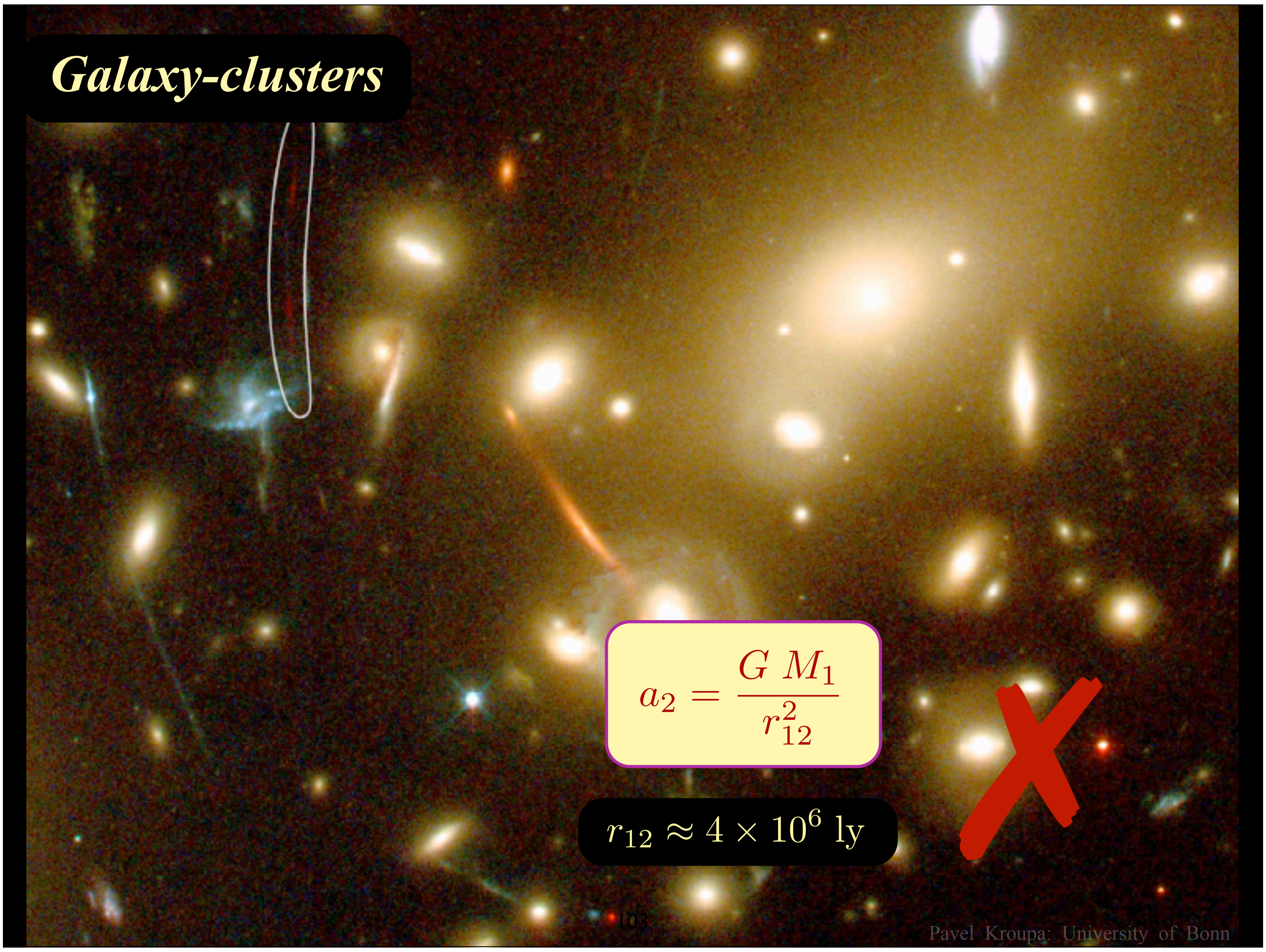
Pavel Kroupa: University of Bonn



Summary

Pavel Kroupa: University of Bonn

Summary:

	scale	factor	*Newton*?
Earth (apple)	$r_{12} = 6\,400$ km		✓
Moon around Earth	$r_{12} = 380\,000$ km		✓
solar system	$r_{12} \approx 40$ AU	1	✓
star clusters	$r_{12} \approx 40$ ly	63000	✓

$1\ \mathrm{AU} = 150 \times 10^6\ \mathrm{km}$ Earth – Sun

$1\ \mathrm{ly} = 9400 \times 10^9\ \mathrm{km}$

105

Summary:

	scale	factor	*Newton*?
Earth (apple)	$r_{12} = 6\,400$ km		✓
Moon around Earth	$r_{12} = 380\,000$ km		✓
solar system	$r_{12} \approx 40$ AU	1	✓
star clusters	$r_{12} \approx 40$ ly	63000	✓
galaxies	$r_{12} \approx 40\,000$ ly	6.3×10^7	✗
galaxy-clusters	$r_{12} \approx 4 \times 10^6$ ly	6.3×10^9	✗

$1\ \mathrm{AU} = 150 \times 10^6\ \mathrm{km}$ Earth – Sun

$1\ \mathrm{ly} = 9400 \times 10^9\ \mathrm{km}$

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Solution ?

→ **Certainly new physics :**

A. Newton is *wrong*. We need *new / modified dynamics*.

B. Newton is *right*.

→ Dark (invisible) matter must be postulated :

$$a_2 = \frac{G\,M_1}{r_{12}^2} \qquad \textbf{But} \qquad a_{\rm observed} > a_{\rm Newton}$$

$$\rightarrow \quad \frac{G\,(M_1 + \mathcal{M})}{r_{12}^2} > \frac{G\,M_1}{r_{12}^2}$$

≈ 90 % of the universe would consist of dark matter **!**

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Pavel Kroupa: University of Bonn

Today we have two models for the world :

Einsteinian / Newtonian

(I)

1982
Suggestion of massive, weakly interacting dark matter particles and their role in structure formation

Cold/Warm Dark Matter

non-Einsteinian / non-Newtonian

(II)

1983
Suggestion of a modification of Newton's force law

-Bond, Szalay & Turner 1982, Phys. Rev. Lett.
-Blumenthal, Pagels & Primack 1982, Nature
-Peebles 1982, ApJL
-Blumenthal, Faber, Primack, Rees, 1984, Nature

-Milgrom 1983, ApJ
-Moffat 2005, JCAP

Pavel Kroupa: AIfA, University of Bonn

The Party Line !!

This is where ***resources*** flow.
This is what you do, if you want a ***job*** :

(I)

1982
Suggestion of massive, weakly interacting dark matter particles and their role in structure formation

Cold/Warm Dark Matter

-Bond, Szalay & Turner 1982, Phys. Rev. Lett.
-Blumenthal, Pagels & Primack 1982, Nature
-Peebles 1982, ApJL
-Blumenthal, Faber, Primack, Rees, 1984, Nature

No Go !!

(II)

1983
Suggestion of a modification of Newton's force law

-Milgrom 1983, ApJ
-Moffat 2005, JCAP

Progress is always linked to

cultural pre-disposition

and

Sociology

→ Fanelli D. (2010) Do Pressures to Publish Increase Scientists' Bias? An Empirical Support from US States Data. PLoS ONE 5(4): e10271. doi:10.1371/journal.pone.0010271

Today and in the past young researchers are

1. afraid
2. discouraged to try alternatives

Some personal examples - statements by *well-known* and *very influential* scientists :

"In 1997 you have written that paper on *dSph satellites without dark matter* - you are *unhirable*." (about 2004)

"It is not worth reading those papers on satellite galaxies" (2009)

"But *everyone* knows that *MOND is crap*!" (at STScI May, 2010)

"*I would be scared* (mostly because I am still in search of a permanent post) of being labelled once and for all as a "*hardcore-MONDian*" person." (July 2010)

. . . as if being labeled a "*hardcore-LCDM*" person were acceptable . . . (my own note added Nov. 2010).

"I can't do any MOND work - the director would not appreciate it" (Garching, August, 2010).

Pavel Kroupa: AIfA, University of Bonn

Step III

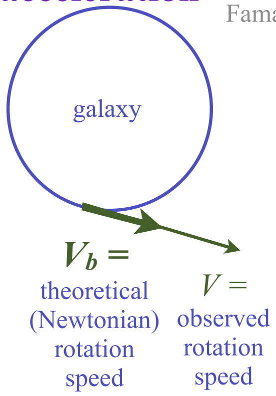
(the alternative)

Lets consider
the observational data
in a little detail . . .

Pavel Kroupa: University of Bonn

Mass-Discrepancy correlation with acceleration

McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012



Mass-Discrepancy correlation with acceleration

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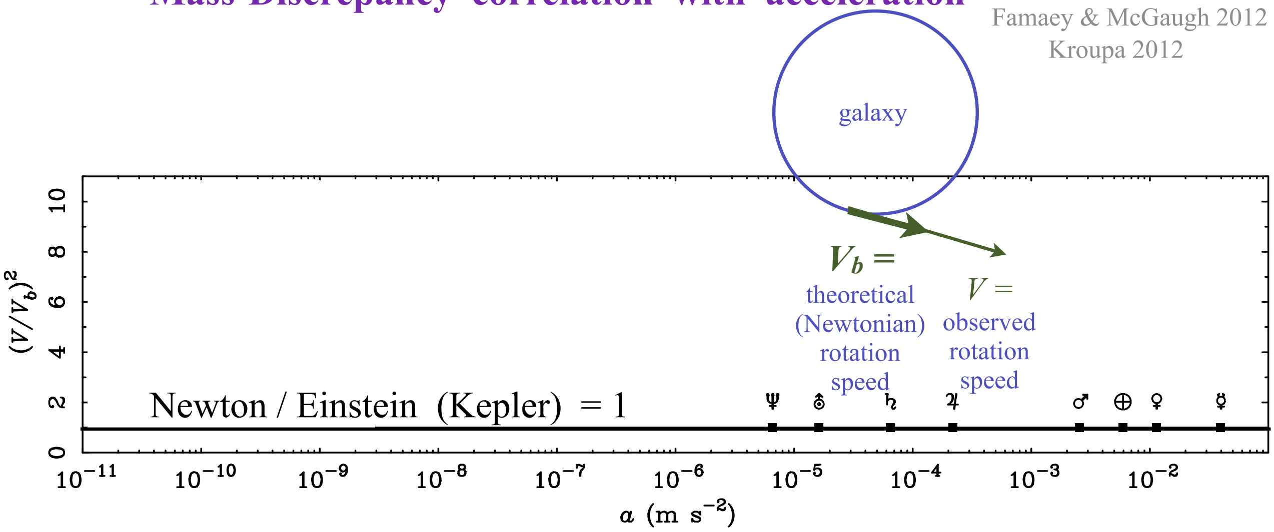

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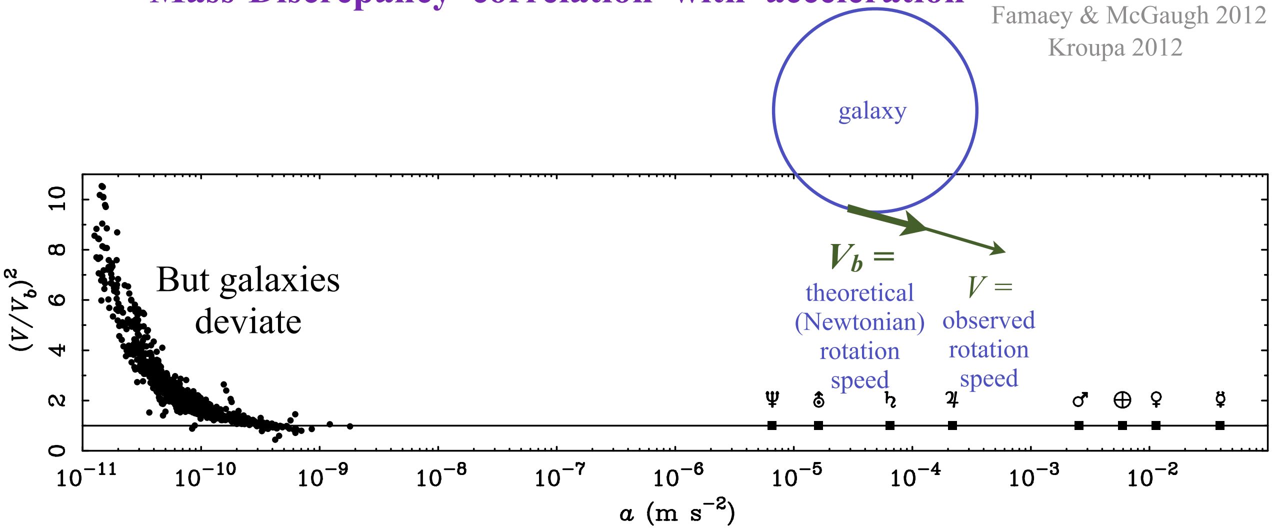

Pavel Kroupa: University of Bonn

Mass-Discrepancy correlation with acceleration

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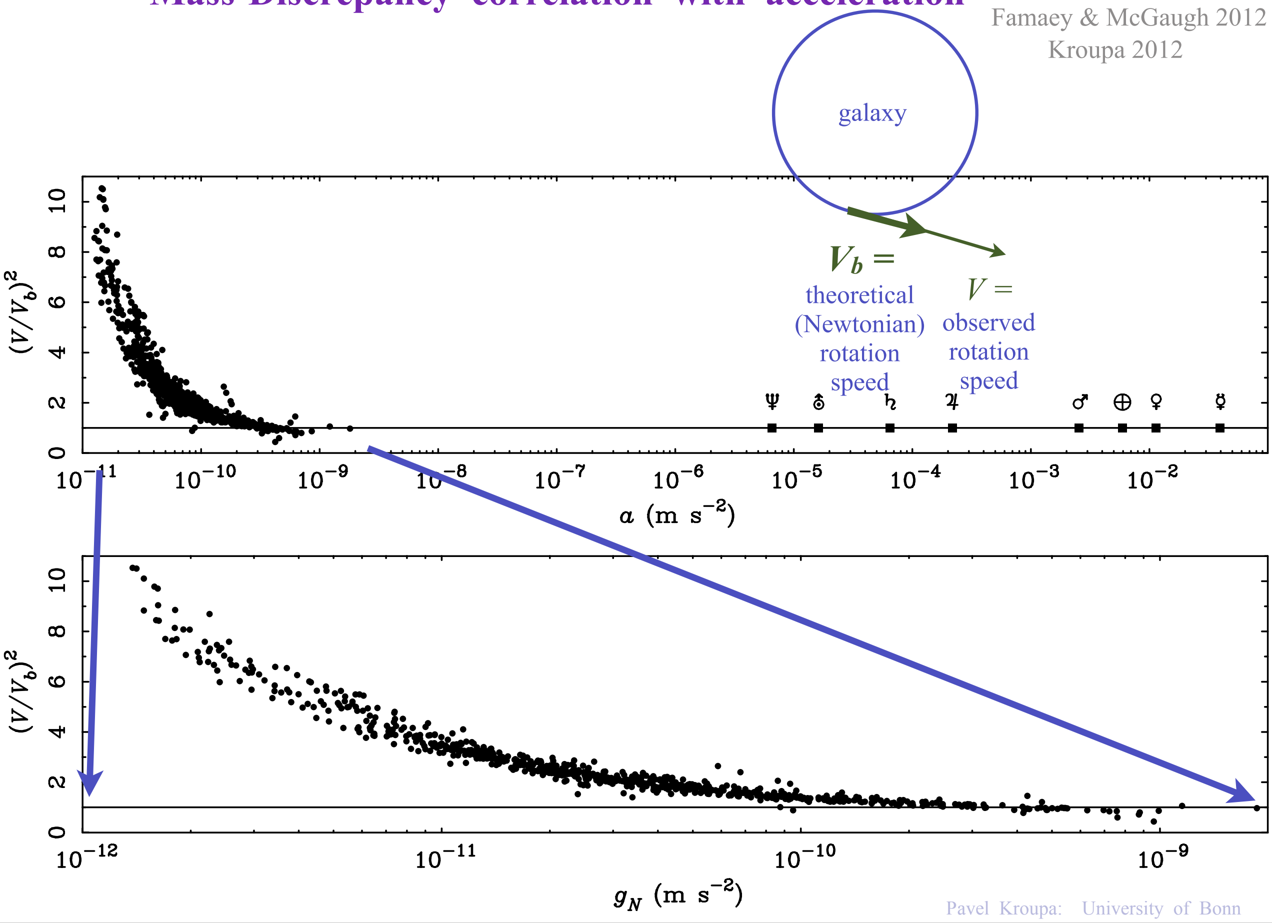

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This
systematic deviation
from the Einsteinian / Newtonian
expectation
cannot
be understood in terms of
dark matter particles.

?

Pavel Kroupa: University of Bonn

Consider ***space-time scale invariance*** :

(Milgrom 2009; Kroupa, Pawlowski & Milgrom 2012)

If $(t,x,y,z) \longrightarrow \lambda(t,x,y,z)$ (the coordinates of a point in Minkowski space)

then, the Newtonian gravitational acceleration, $g_N \propto GM/r^2$,
scales as $g_N \longrightarrow \lambda^{-2} g_N$

while the kinematical acceleration, g , scales as $g \longrightarrow \lambda^{-1} g$ $\left[\frac{d\dot{x}}{dt}\right]$

For gravitational and kinematical acceleration to also be scale invariant we thus need g to scale as $g_N^{1/2}$

i.e. $g \propto (a_o g_N)^{1/2}$

$g^2 = a_o g_N$ or $a^2 = a_o g_N$

i.e. $\frac{a}{a_o} a = g_N$

Pavel Kroupa: University of Bonn

space-time scale invariance (from above) :

i.e. $\frac{a}{a_o} a = g_N$, thus $a = \frac{\sqrt{GM}}{r}\sqrt{a_0}$

centrifugal acceleration = centripetal acceleration

$$a = \frac{V^2}{r} = \frac{\sqrt{GMa_0}}{r} \qquad (V \equiv V_c)$$

$$V = (GMa_0)^{\frac{1}{4}}$$

the ***Tully-Fisher relation !***

and ***flat rotation curves !***

Consider *space-time scale invariance* :

(Milgrom 2009; Kroupa, Pawlowski & Milgrom 2012)

If $(t, x, y, z) \rightarrow \lambda(t, x, y, z)$

$g^2 = a_o g_N$ or $a^2 = a_o g_N$

i.e. $\frac{a}{a_o} a = g_N$

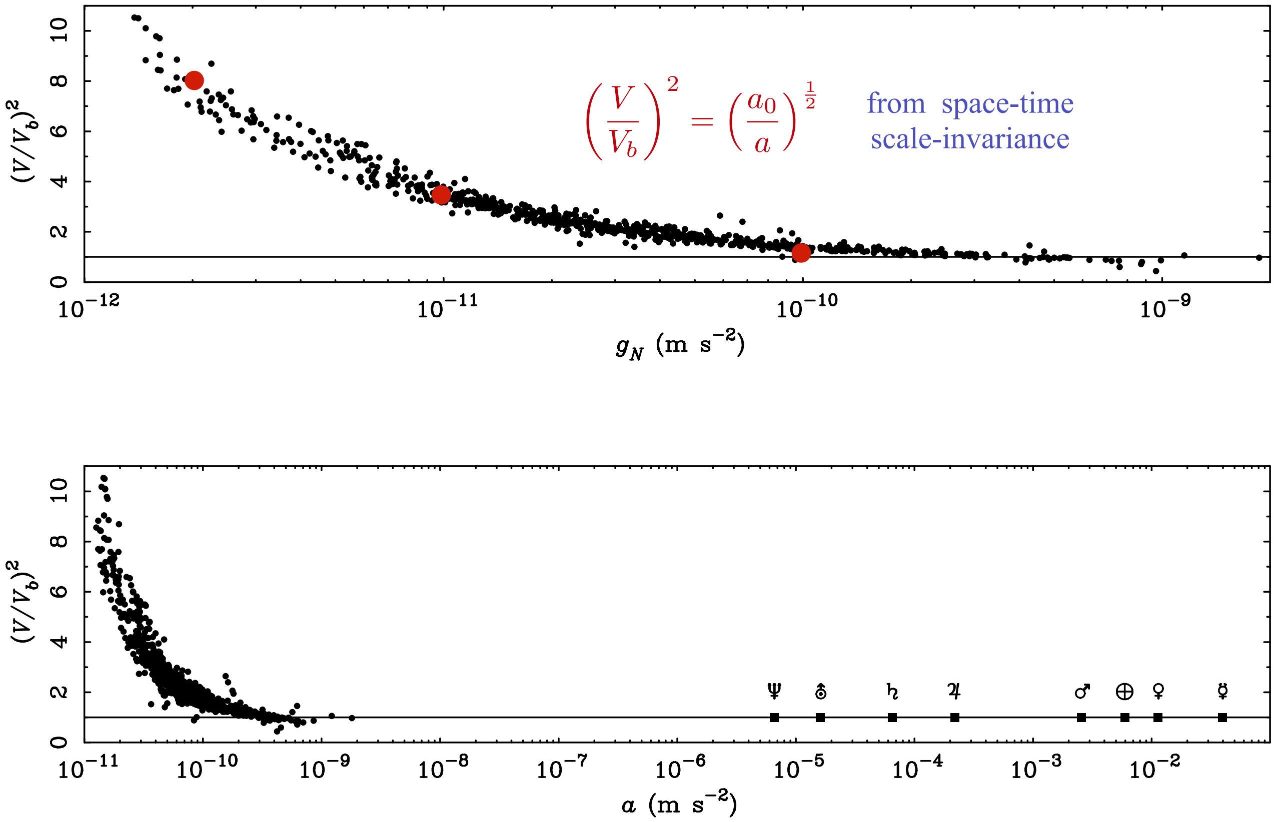
Since $V^2 = (Ga_0 M)^{\frac{1}{2}}$

$$V_b^2 = \frac{GM}{r}$$

$$\left(\frac{V}{V_b}\right)^2 = \frac{(Ga_0M)^{\frac{1}{2}}}{r\frac{GM}{r^2}} = \frac{(Ga_0M)^{\frac{1}{2}}}{ra} = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$$

i.e. $\left(\frac{V}{V_b}\right)^2 = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$

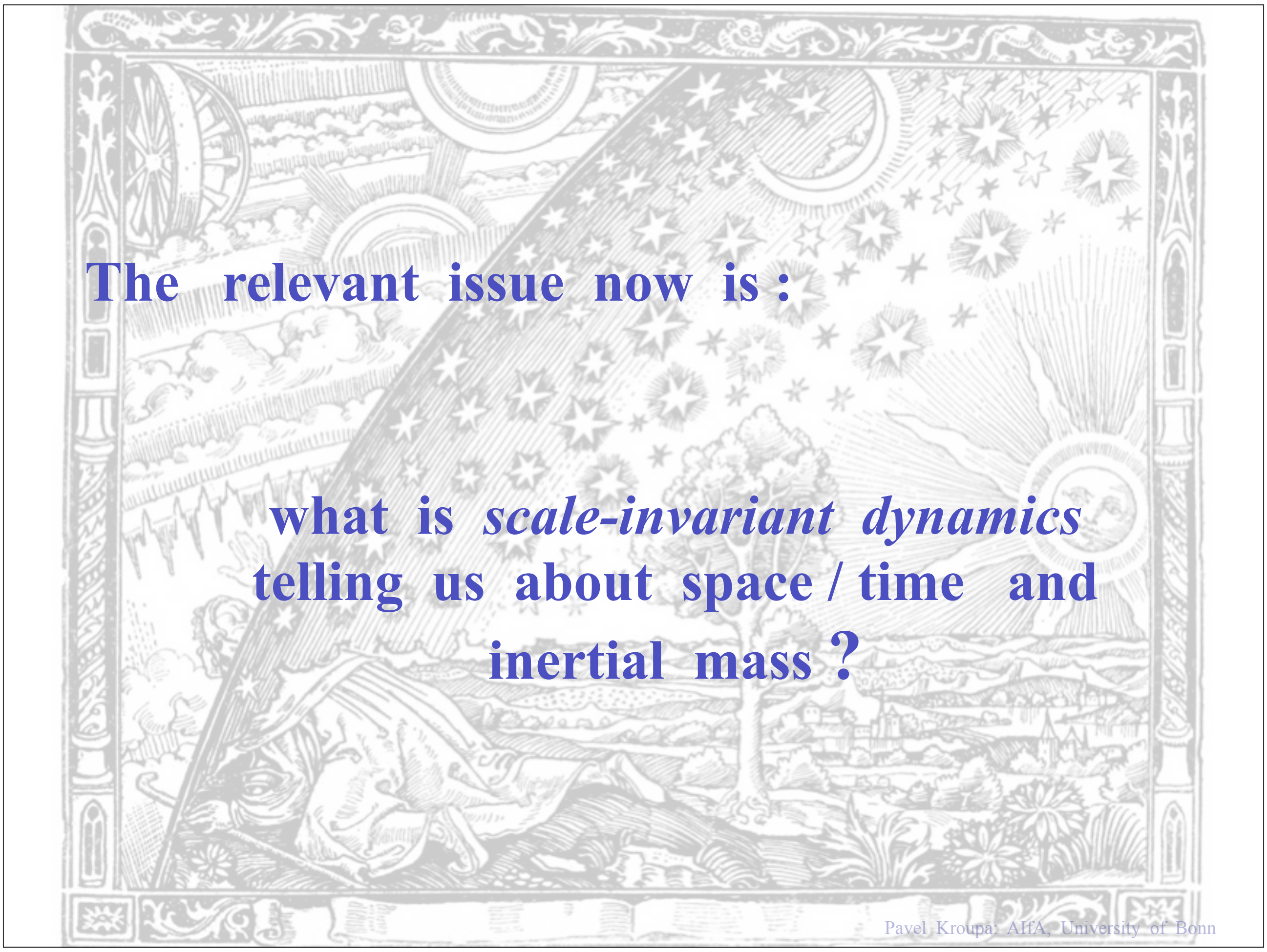
Mass-Discrepancy correlation with acceleration

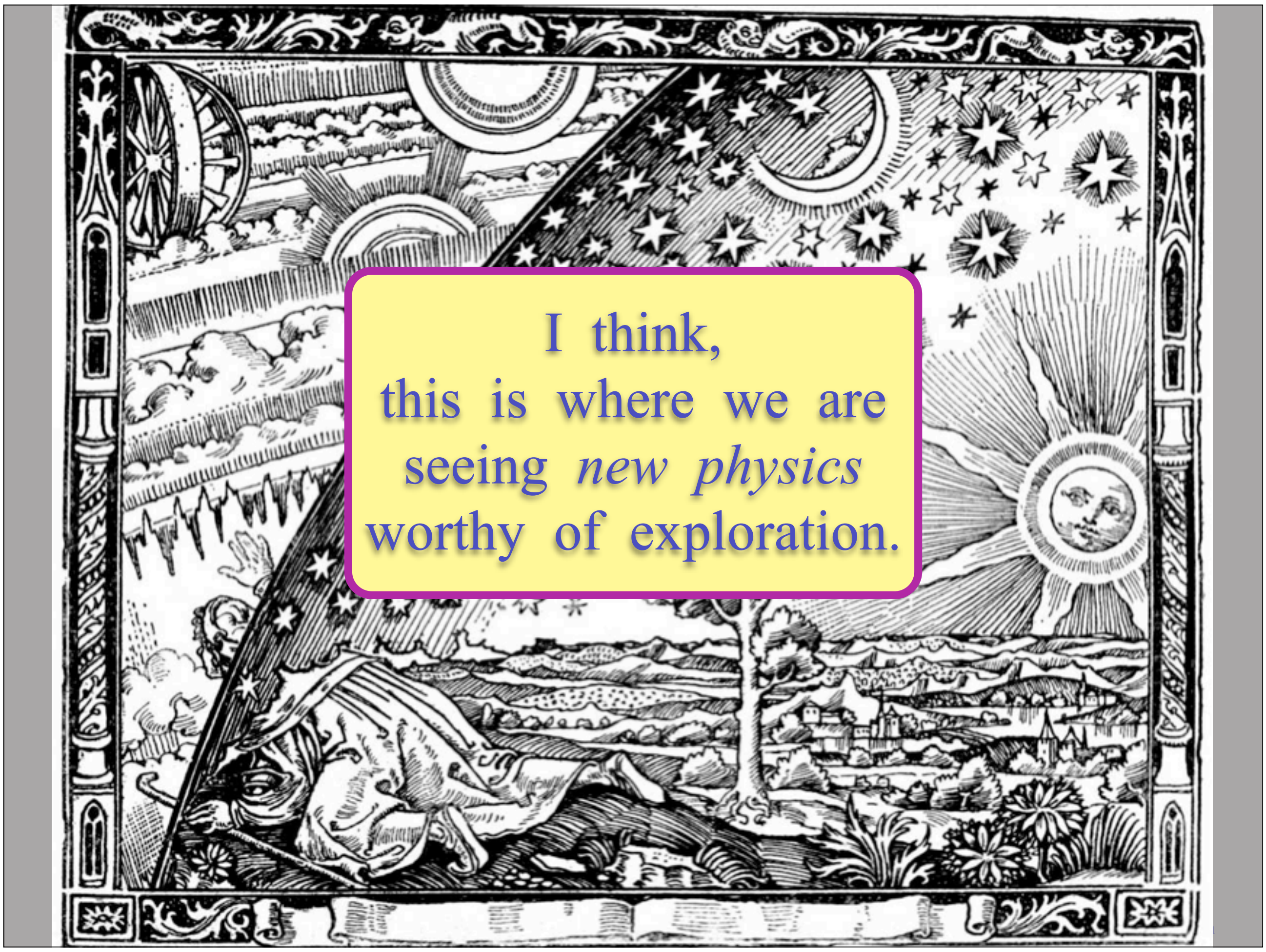


Milgromian Dynamics
from quantum mechanical processes in the vacuum

Kroupa et al. (2010), Appendix A:

"... an accelerated observer in a de Sitter universe (curved with a positive cosmological constant Λ) sees a non-linear combination of the Unruh (1975) vacuum radiation and of the Gibbons & Hawking (1977) radiation due to the cosmological horizon in the presence of a positive Λ. Milgrom (1999) then defines inertia as a force driving such an observer back to equilibrium as regards the vacuum radiation (i.e. experiencing only the Gibbons-Hawking radiation seen by a non-accelerated observer).
Observers experiencing *a very small acceleration* would thus see an Unruh radiation with a low temperature close to the Gibbons-Hawking one, meaning that *the inertial resistance defined by the difference between the two radiation temperatures would be smaller than in Newtonian dynamics, and thus the corresponding acceleration would be larger*. This is given precisely by the formula of Milgrom (1983) with a well-defined transition-function $\mu(x)$, and $a_0 = c\,(\Lambda/3)^{1/2}$. Unfortunately, no covariant version (if at all possible) of this approach has been developed yet."


The relevant issue now is :
what is *scale-invariant dynamics*
telling us about space / time and
inertial mass ?
Pavel Kroupa: AIfA, University of Bonn


I think,
this is where we are
seeing *new physics*
worthy of exploration.

. . .

Milgromian Dynamics (current best bet)

. . .

Mordehai (Moti) Milgrom
(Weizmann Institute, Rehovot)

Pavel Kroupa: University of Bonn

Milgromian Dynamics

Ansatz : (Milgrom 1983, ApJ, 270, 371)

$$\mu\left(\frac{a}{a_0}\right)\vec{a} = \vec{g_\mathrm{N}} \quad \begin{cases} \mu(x) = 1 \text{ if } |x| \gg 1 \\ \mu(x) = x \text{ if } |x| \ll 1 \end{cases} \quad \text{i.e. } \vec{a} = \vec{g_\mathrm{N}}\,\mu^{-1} \geq \vec{g_\mathrm{N}}$$

What is the interpretation ?

Milgromian dynamics can be understood to be

a different effective Law of Gravity
through a different "Poisson" equation

$$\vec{\nabla}\cdot\left[\mu\left(\frac{|\vec{\nabla}\phi|}{a_0}\right)\vec{\nabla}\phi\right] = 4\,\pi\,G\,\rho$$

giving the Milgromian potential

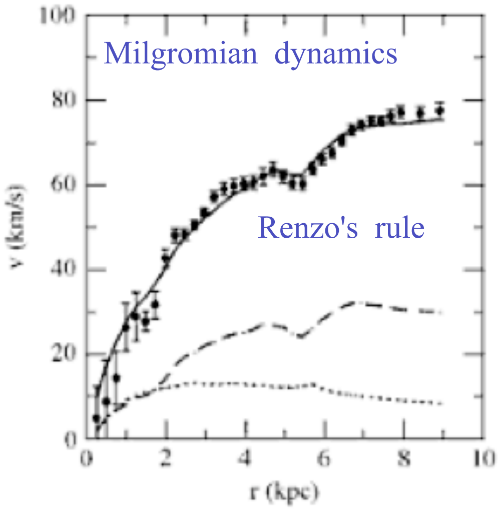
a modification of the Law of Inertia
through the breaking of the equivalence of inertial and gravitating mass

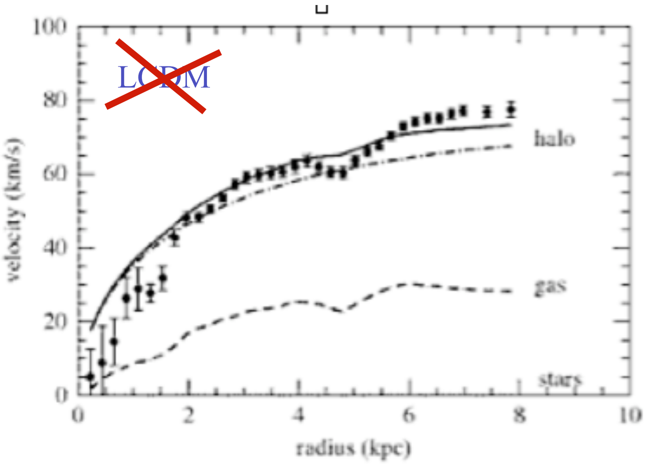
$$\vec{a} = \vec{F}\left[m\,\mu\left(\frac{|\vec{\nabla}\phi|}{a_0}\right)\right]^{-1}$$

where $\vec{F} = m\,\vec{g_\mathrm{N}}$ for gravity

Pavel Kroupa: University of Bonn

From Robert Sanders' Book
on
"*The Dark Matter Problem*",
Cambridge University Press, 2010





Remember this slide ?

Remember this slide ?

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Pavel Kroupa: AIfA, University of Bonn

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(II)

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Pavel Kroupa: AIfA, University of Bonn

Step V

Conclusions
with some history

Pavel Kroupa: AIfA, University of Bonn

Step I : A convincing beautiful model (the standard model)

The *geocentric world* view by Aristoteles (about 4th century BC).

Step II : Making the theory fit

Add epicycles to achieve high precision (Claudius Ptolemaeus in the 2nd century AD)

==> ***excellent description of the data.***

many astronomers not happy as computational model complex

Step III : An alternative model (the exotic model)

The *heliocentric model* by Aristarchus (3rd century BC)
(and later Copernicus 1543).

Not accepted **:** more complex and unsatisfying.
It needs ***two centers*** and does ***not fit*** the data well.

Step IV : Decision by technological advance

Galileo's ***solar system telescope data disprove the standard model***,
but are consistent with the Heliocentric model.

Step V : Conclusions

It is irrelevant to debate whether the geocentric model fits any data.
Beauty or even "high-precision" of a model can misguide.

Pavel Kroupa: AIfA, University of Bonn

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The *LCDM* model based on Einstein (1915).

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Pavel Kroupa: AIfA, University of Bonn

Step I : A convincing beautiful model (the standard model)

The *LCDM* model based on Einstein (1915).

Step II : Making the theory fit

Add *inflation*, *DM*, *DE*, *DF* to achieve high precision

==> ***excellent description of the data.***

many astronomers not happy as computational model complex

Step III : An alternative model (the exotic model)

The *heliocentric model* by Aristarchus (3rd century BC) (and later Copernicus 1543).

Not accepted **:** more complex and unsatisfying.

It needs ***two centers*** and does ***not fit*** the data well.

Step IV : Decision by technological advance

Galileo's ***solar system telescope data disprove the standard model***, but are consistent with the Heliocentric model.

Step V : Conclusions

It is irrelevant to debate whether the geocentric model fits any data.
Beauty or even "high-precision" of a model can misguide.

Pavel Kroupa: AIfA, University of Bonn

Step I : A convincing beautiful model (the standard model)

The *LCDM* model based on Einstein (1915).

Step II : Making the theory fit

Add *inflation*, *DM*, *DE, DF* to achieve high precision

==> ***excellent description of the data.***

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Scale-invariant dynamics (SID) by Milgrom (1983)

Not accepted **:** more complex and unsatisfying.

SID perhaps needs ***hot dark matter***.

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Conclusions

--Ekhenaton / Moses -- introduction and discovery of a single God
may have been crucial for developing our mathematical ansatz to the natural world

--Jesus / Paulus -- Encoding of equality of all humans in front of the one God
may have been important for establishing a large enough intellectual community for the scientific method to boom

--Aristoteles / Ptolomaei vs Aristarchus / Copernicus
(geocentric model vs heliocentric model)
established the position of humans in the world order

--Tycho Brahe and Johannes Kepler
High-tech observations imply a break-down of the geocentric model and lead to a massive mathematical simplification of the Solar system.

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--Albert Einstein
High-tech observations imply a break-down of Newtonian dynamics (bending of light, Mercury) . Gravitation not a force ! Reinterpretation as a geometrical effect.

Present-day :

High-tech observations of galaxies imply break-down of Einsteinian / Newtonian gravitation

Discovery of scale-invariant dynamics and development of first general relativistic formulation of it (Mordehai Milgrom and Jacob Bekenstein).

. . . to be continued . . .

Pavel Kroupa: *University of Bonn*

To finish :

Quoting my friend *Theo Nieuwenhuizen*
from Amsterdam :

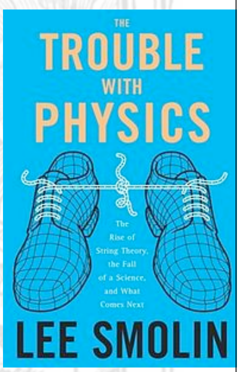
"The universe will be doing fine, but the
troubles are on this Earth"

Troubles on Earth :

Cosmology is in an absolute mess !

Pavel Kroupa, 2012, "The Dark Matter Crisis: Falsification of the Current Standard Model of Cosmology"
[http://www.publish.csiro.au/paper/AS12005.htm]

Modern cosmology is largely based on beliefs
(Inflation, C/WDM, DE) with a mathematical model that requires fixing with nearly every new observation (e.g. WMAP-->Planck).

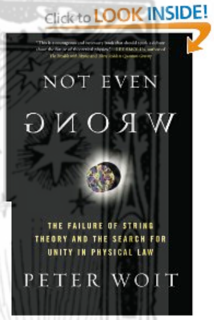


Theoretical physics is also in a serious crisis !

Lee Smolin, 2006, "The Trouble with Physics" discusses the role of controversy and diversity of approaches in scientific processes and ethics.

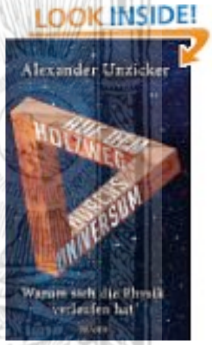
Troubles on Earth :

Peter Woit, 2006, "Not even wrong" discusses that string theory is not just going in the wrong direction, its not even science.

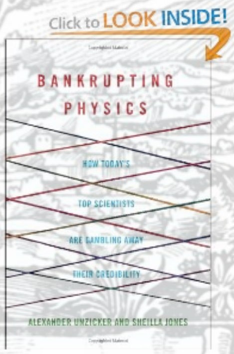


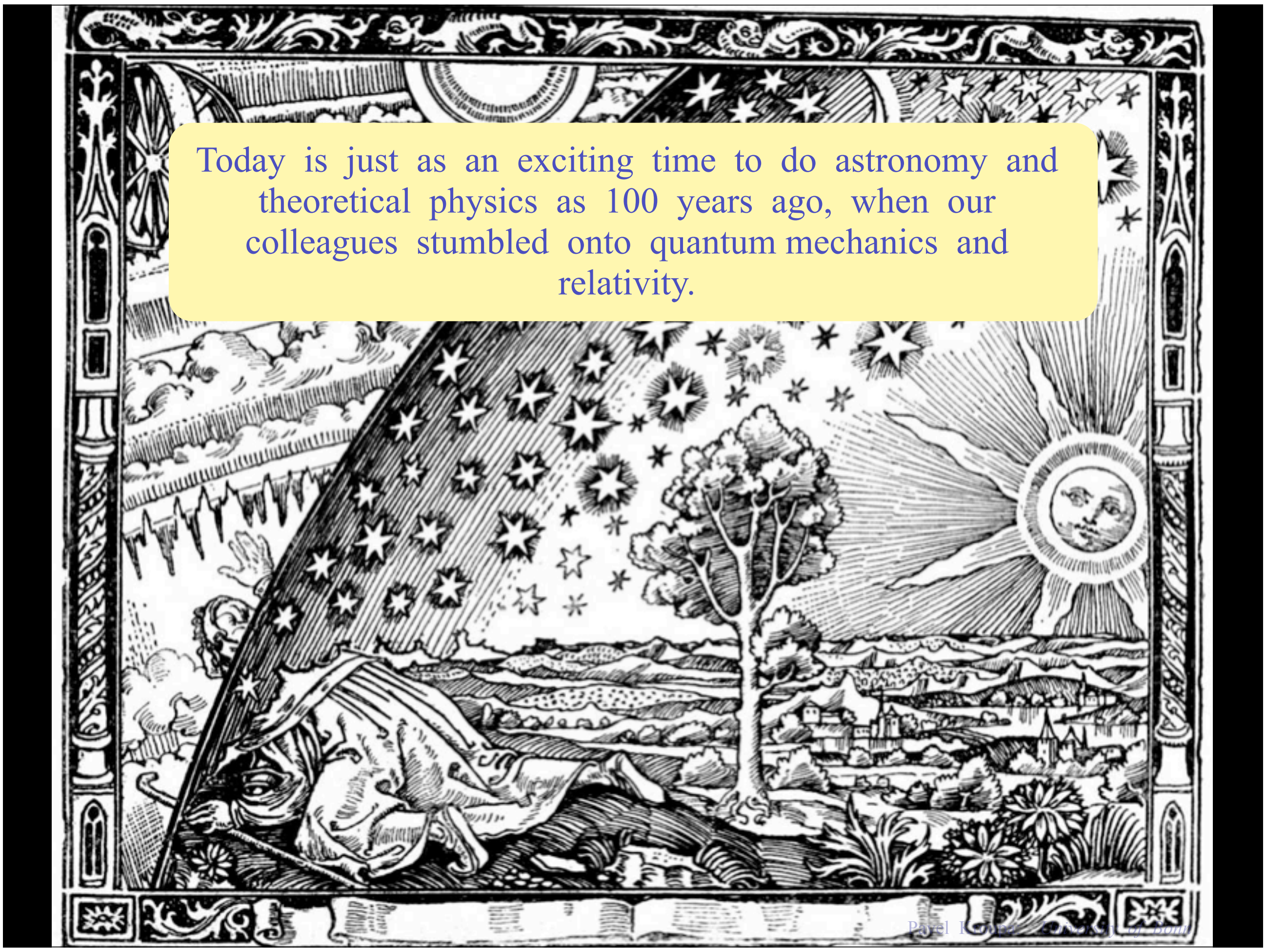
Alexander Unzicker, 2010, "Vom Urknall zum Durchknall"

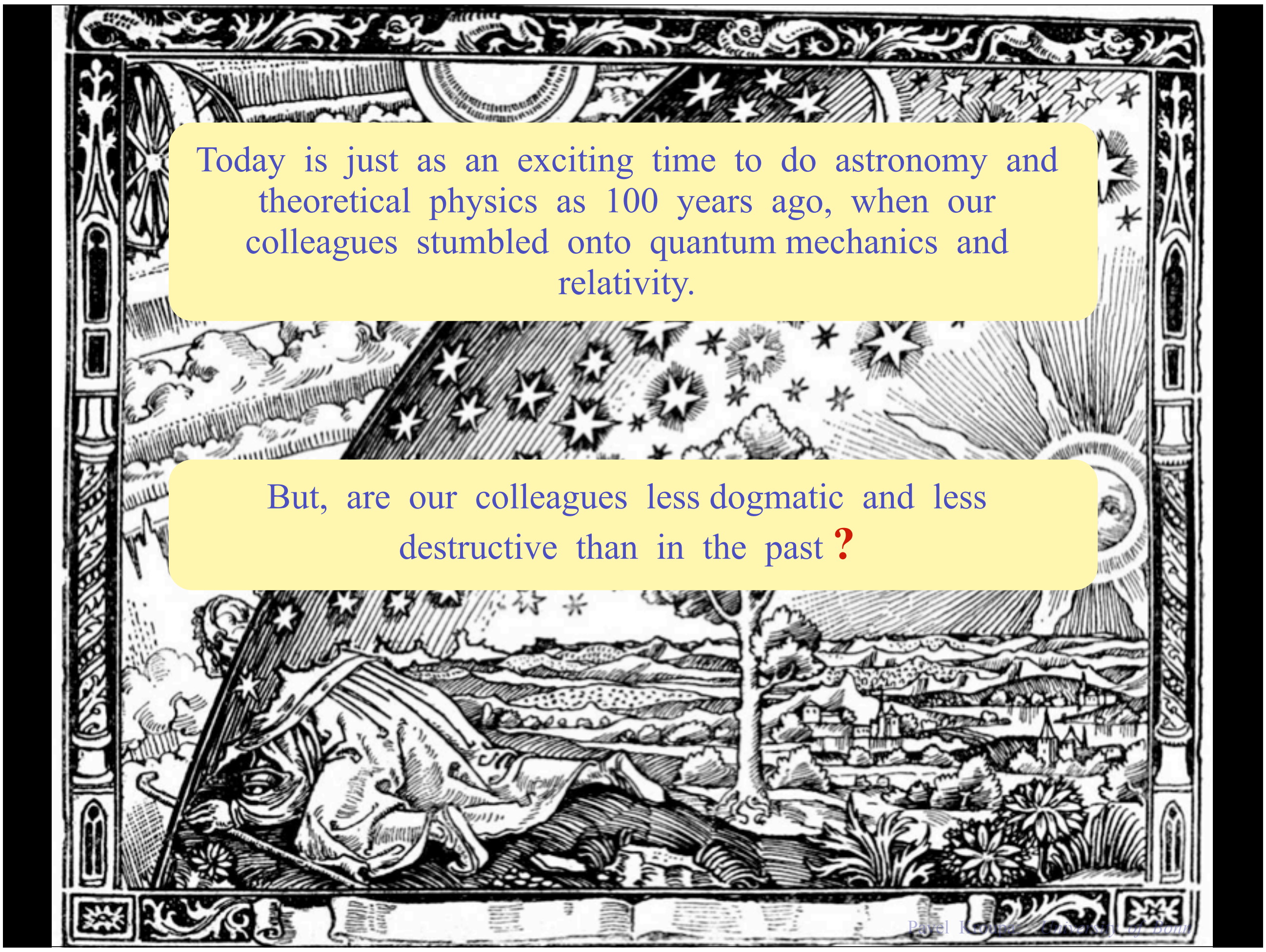
Alexander Unzicker, 2012, "Auf dem Holzweg durchs Universum"

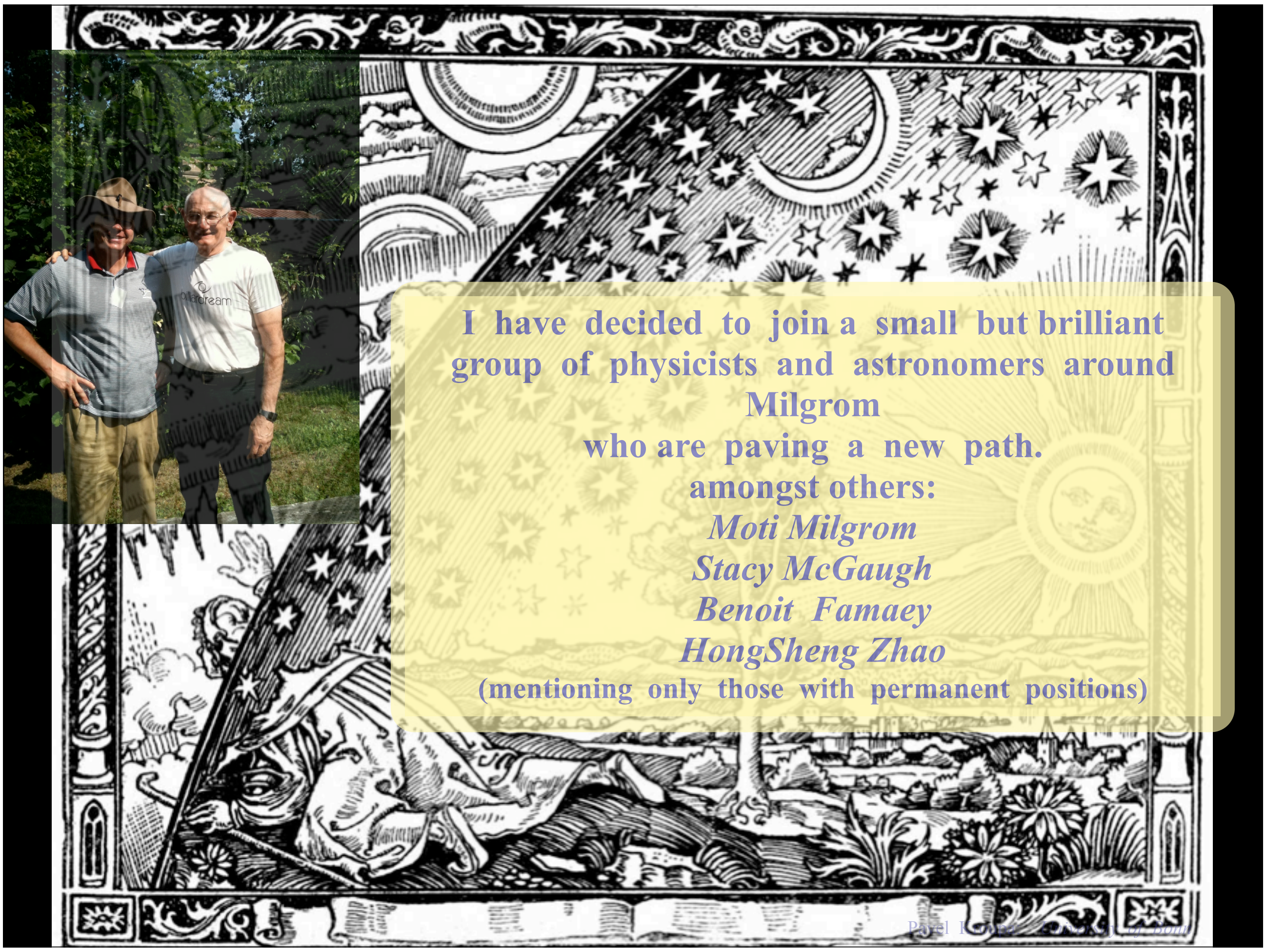


Alexander Unzicker, 2013, "Bankrupting physics: How Today's Top Scientists are Gambling Away Their Credibility"






Today is just as an exciting time to do astronomy and theoretical physics as 100 years ago, when our colleagues stumbled onto quantum mechanics and relativity.
But, are our colleagues less dogmatic and less destructive than in the past ?


I have decided to join a small but brilliant group of physicists and astronomers around Milgrom
who are paving a new path.
amongst others:
Moti Milgrom
Stacy McGaugh
Benoit Famaey
HongSheng Zhao
(mentioning only those with permanent positions)

Conclusions

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THE END