Walking on quantum foundations

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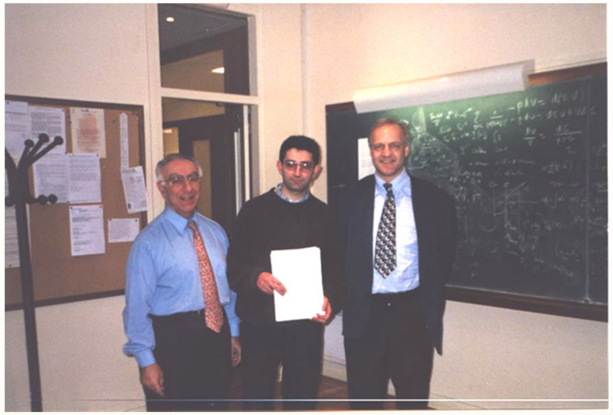


Emergent Quantum Mechanics 2015,
EmQM15, Vienna

Goal of the lecture

Thank the organizers

Round up the usual suspects:

Towards interpretations of QM
Ensemble interpretation of QM
Model of a Q measurement
Towards the measurement problem

EmQM: Stochastic Electrodynamics for the hydrogen atom

Neutrino mass from cluster lensing

Summary

Accidents along the road

To understand Nature we have become accustomed to inconceivable concepts …

Our task is to demystify physics

Towards interpretations of QM

Working with postulates is a "black box" approach; can give partial answers

The only point of contact between reality (in the lab) and Q theory
lies in Q measurements

Hence: *interpretation should be guided by realistic models for measurement*

"To leave out the apparatus from theoretical considerations
is as bad
as leaving it out in practice" *(ABN 2013)*

(Our) Ensemble interpretation

Density matrix $\hat{\mathcal{D}} = \sum_i p_i |\psi_i\rangle\langle\psi_i|$ describes *our knowledge* about an *ensemble* of identically prepared systems as in stat mech

Pure state $|\psi\rangle \mapsto \hat{\mathcal{D}} = |\psi\rangle\langle\psi|$ is limiting case: purified *ensemble*

Ensemble can be real (many particles: bundle at LHC during one season. a trapped ion in photon field, repeated excitation)
or virtual (as in stat mech) (e.g. universe)

QM = tool for making statistical statements from the density matrix

$$\langle\hat{A}\rangle = \langle\psi|\hat{A}|\psi\rangle \mapsto \mathrm{tr}(\hat{\mathcal{D}}\hat{A})$$

$\Rightarrow$ QM = about what we can measure, not about what is

epistemology	$\Leftrightarrow$	ontology
Bohr		Einstein

Quantum measurement theory describes an ensemble of measurements on an ensemble of systems

The Apparatus

- *has a macroscopic pointer, so it is macroscopic itself*
- *is coupled to a thermal bath to dump energy in*
- *is a many particle quantum system => Q statistical physics*

- *Q measurement: system S interacting with apparatus A*

The model for a Q measurement

The model to consider: “Curie-Weiss model for Q measurement”
S= spin ½, measure $s_z = \pm 1$

A = M+B
M = Ising magnet, starts as metastable paramagnet,
ends: magnetized, up or down
B = thermal bath

Post-measurement state

$$\hat{\mathcal{D}}(t_{\rm f}) = p_\uparrow\,|\!\uparrow\rangle\langle\uparrow\!|\otimes\hat{\mathcal{R}}_\Uparrow + p_\downarrow\,|\!\downarrow\rangle\langle\downarrow\!|\otimes\hat{\mathcal{R}}_\Downarrow = \sum_i p_i\hat{r}_i\otimes\hat{\mathcal{R}}_i$$

Tentative interpretation:
Magnet ends up in up/down ferromagnetic state
Sign of magnetization maximally correlated with sign of spin S
Prefactors satisfy Born rule $p_\uparrow = r_{\uparrow\uparrow}(0), \quad p_\downarrow = r_{\downarrow\downarrow}(0)$

Truncation: No Schrödinger cat terms $|\!\uparrow\rangle\langle\downarrow\!|, \quad |\!\downarrow\rangle\langle\uparrow\!|$
physical disappearance: sums of many oscillating terms vanish
despite mathematical survival: individual terms have fixed amplitude

Result is *thermodynamical:* $\hat{\mathcal{R}}_i$ is generalized Gibbs state
Conserved quantities: Energy, s_z

The quantum measurement problem

we have to split the *full ensemble*

$$\hat{\mathcal{D}}(t_{\rm f}) = p_{\uparrow}\,|\!\uparrow\rangle\langle\uparrow\!|\otimes\hat{\mathcal{R}}_{\Uparrow} \;+\; p_{\downarrow}\,|\!\downarrow\rangle\langle\downarrow\!|\otimes\hat{\mathcal{R}}_{\Downarrow}$$

into up-down *subensembles*. Classically trivial.

Quantum oddity: mixed states have infinity of decompositions, eg

$$\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix} = |\!\uparrow\rangle\langle\uparrow\!| + |\!\downarrow\rangle\langle\downarrow\!| = |\!\rightarrow\rangle\langle\rightarrow\!| + |\!\leftarrow\rangle\langle\leftarrow\!| = \dots$$

We can <u>not</u> interpret $\hat{\mathcal{D}}(t_{\rm f})$ *in terms of up/down subensembles*

Can the splitting of $\hat{\mathcal{D}}(t_{\rm f})$ nevertheless become unique?

New mechanism: ongoing dynamics in the *macroscopic* apparatus

The quantum measurement problem (2)

Final density matrix for *full ensemble* has thermodynamic form

$$\hat{\mathcal{D}}(t_{\rm f}) = \sum_i p_i \, \hat{r}_i \otimes \hat{\mathcal{R}}_i$$

But do arbitrary *subensembles* finally have this form,

$$\hat{\mathcal{D}}^{(k)}_{\rm sub}(t_{\rm f}) = \sum_i q_i^{(k)} \hat{r}_i \otimes \hat{\mathcal{R}}_i$$

with $0 \le q_i^{(k)} \le 1$???

Subensembles: same dynamics, unknown initial conditions

Subensemble relaxation due to small flip-flop terms in *H*

Assume *weak additional terms* in H_M with *flip-flops*, conserving *m*

At *t* large enough, so that registration will be established, cut coupling S-A.
Ongoing dynamics inside apparatus A.

Go to microcanonical ensemble, keep only states $m = \pm m_{\mathrm{F}}$

Consider at a time $t'_{\mathrm{f}} < t_{\mathrm{f}}$
any decomposition $\hat{\mathcal{D}} = \mu \hat{\mathcal{D}}^{(1)}_{\mathrm{dec}} + (1-\mu)\hat{\mathcal{D}}^{(2)}_{\mathrm{dec}}$ $\quad 0 < \mu < 1$

Ongoing ynamics indeed leads to generalized Gibbs state for each term

$$\hat{\mathcal{D}}^{(k)}_{\mathrm{dec}}(t_{\mathrm{f}}) = \sum_i q_i^{(k)} \hat{r}_i \otimes \hat{\mathcal{R}}_i$$

Mechanisms: 1) Random matrix theory ABN 2013, 2015
2) Collisional relaxation: repetitions of them

This new physical effect must be part of our interpretation of QM

Only now: Postulates *to connect to individual events* as weak as possible, dealing with apparatus A only

In $\hat{\mathcal{D}}_{\rm dec}^{(k)}(t_{\rm f}) = \sum_i q_i^{(k)} \hat{r}_i \otimes \hat{\mathcal{R}}_i$ the $q_i^{(k)}$ represent probabilities for pointer indications

Born rule understood as statement about pointer values,
for ideal measurements fully correlated with quantum variables.

Also $q_i^{(k)} = 1$ occurs => pure subensembles exist, $q_i^{(k)} = \delta_{i,j_k}$

For a pure subensemble all members give the same measurement outcome
Thus connection to individual events.
(measurement problem reduced to this weak hypothesis*)*

In QM these postulates are needed.
If the theory of EmQM is known, they can be read off from it

EmQM: Stochastic Electrodynamics ??

Consider the hydrogen ground state

$$\ddot{\mathbf{r}} = -\frac{\mathbf{r}}{r^3} - \alpha^{3/2}\mathbf{E} + \frac{2}{3}\alpha^3\dddot{\mathbf{r}}$$

Stochastic field + damping

$$\mathcal{E} = \frac{1}{2}\dot{\mathbf{r}}^2 - \frac{1}{r}$$

$$\dot{\mathcal{E}} = -\alpha^{3/2}\dot{\mathbf{r}} \cdot \mathbf{E} + \frac{2}{3}\alpha^3\dot{\mathbf{r}} \cdot \dddot{\mathbf{r}}$$

Hal E Puthoff, 1987: *Ground state of hydrogen as a zero-point-fluctuation-determined state*

$$\mathcal{E} = -\frac{1}{2}k^2$$

$$\langle\dot{\mathcal{E}}\rangle = \alpha^3(\ k^9\ \ -\ \ k^8)$$

circular orbits
Stabilization at large k and at small k

Numerics: M. Liska 2014, 2015

Analytic tricks, Simulation with OpenCL using video cards

Curves from an Ansatz for the stationary state, in agreement with QM N 2005

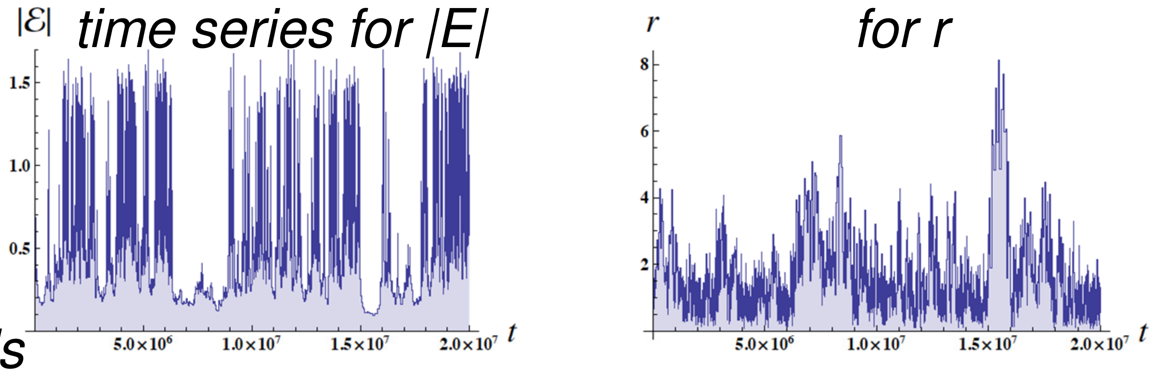


Fig. 3 a): Time series for the energy, in Bohr units. b): Time series for the radius.

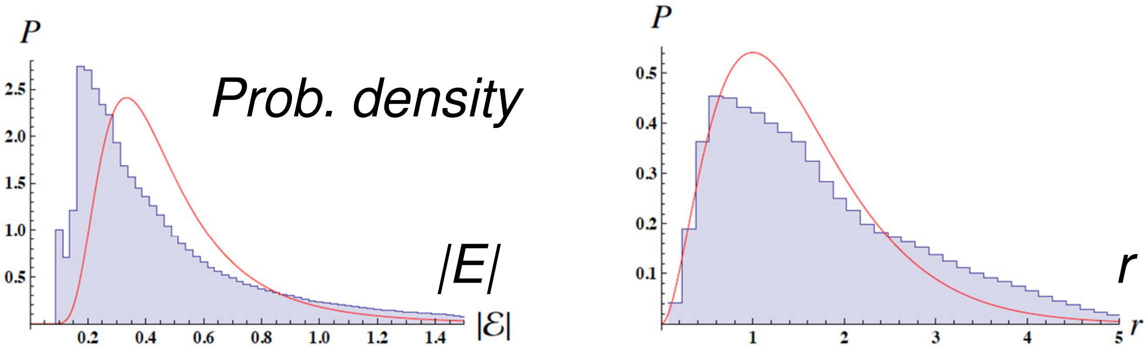


Fig. 4 a): Histogram for the energy data of Fig. 1a. The red curve is the conjecture. b): Histogram for the radius data of Fig. 1b. The red curve is the conjecture.

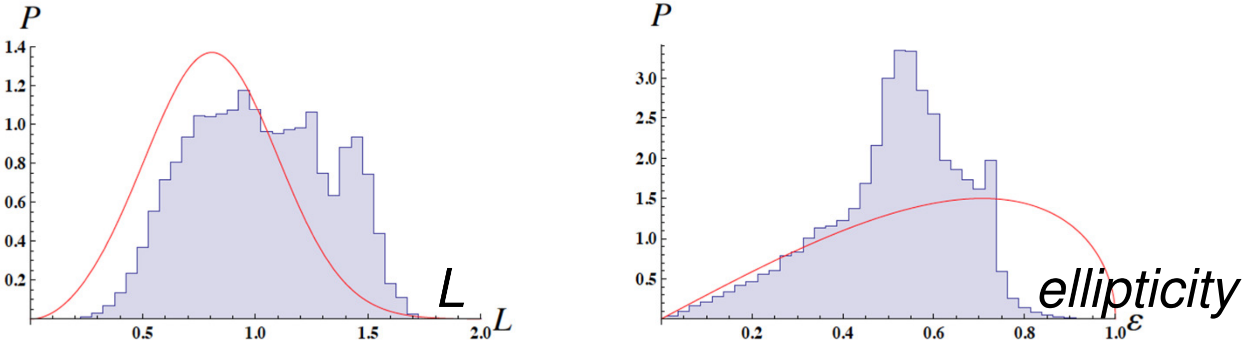


Fig. 5 a): Histogram for the angular momentum data. We see a clear discrepancy at lower L with the conjecture given in red. b): Histogram for the eccentricity data. We see a clear discrepancy at high ϵ with the conjecture given in red

Self-ionization occurs

Per orbit
for $\mathcal{E} \to 0$

$$\Delta\langle\mathcal{E}\rangle = \alpha^3 \frac{0.294 - L}{L^5}$$

Self ionization when for $\mathcal{E} \to 0$ orbit has $L < 0.294$

Relativistic corrections don't help (N+Liska 2015).

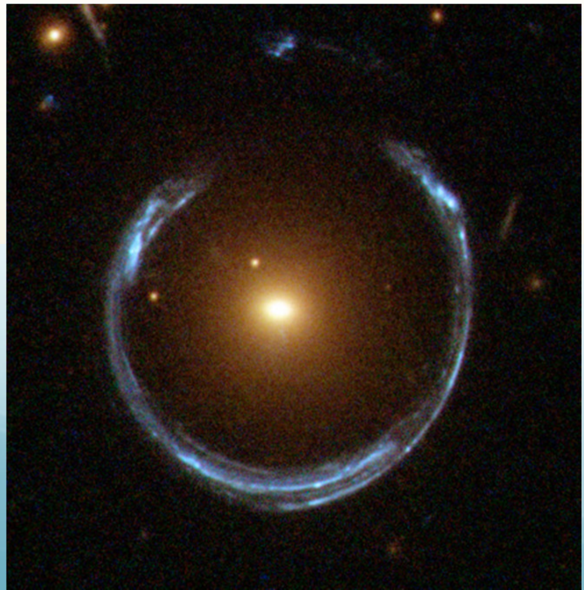
Is some physics overlooked, or the theory wrong ??

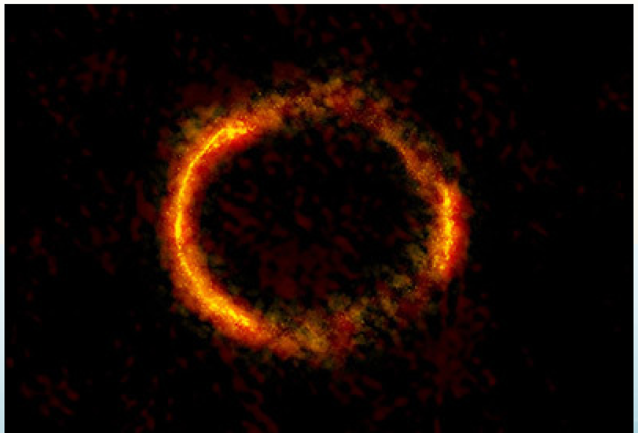
Cluster DM : Strong gravitational lensing

home

Mexico city

"Horse shoe" Einstein ring





***ALMA** infrared*

Gravitational lensing in galaxy cluster

Abell 1689

Components:

Galaxies

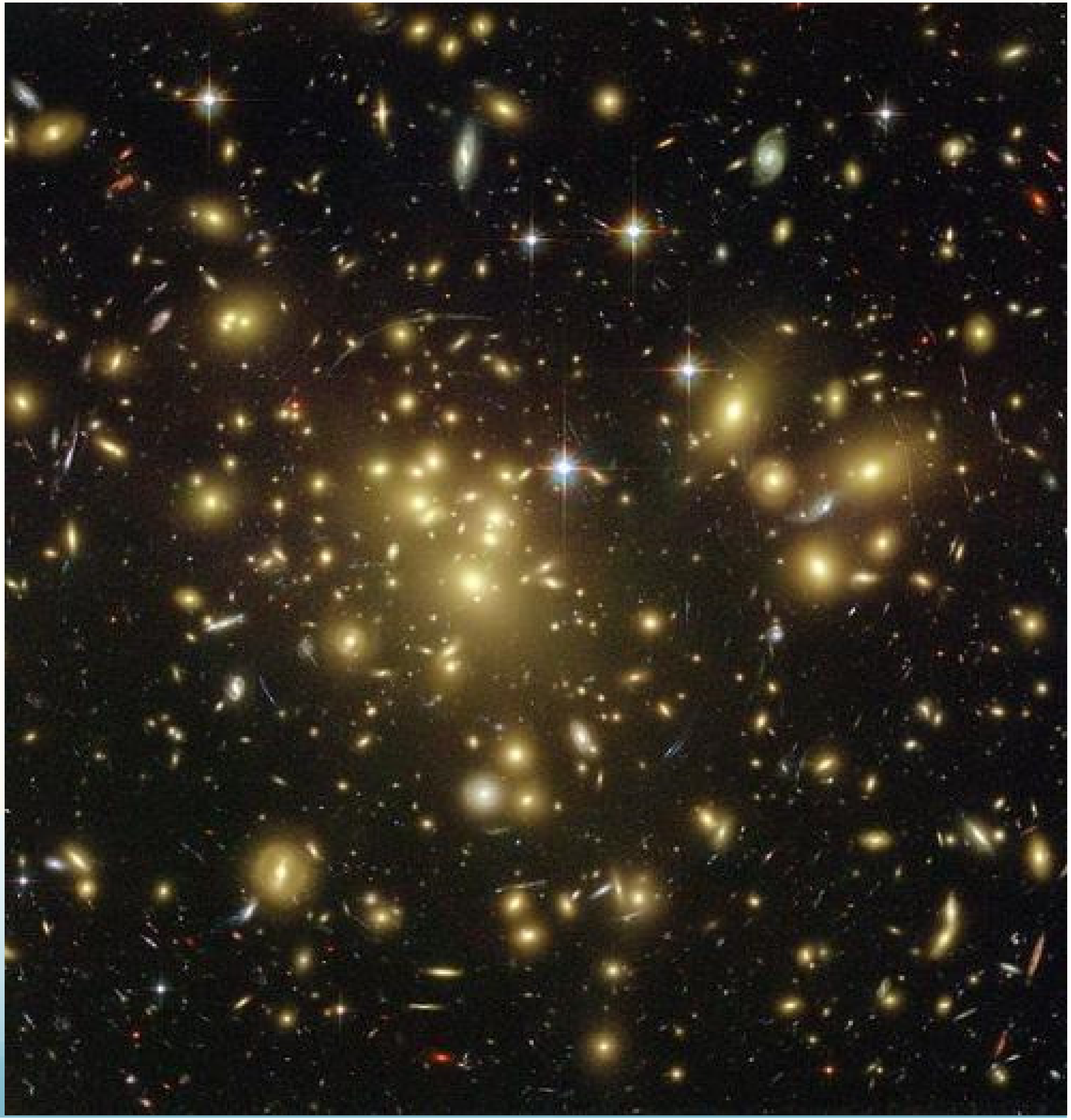
X-ray gas

Dark matter

Lensing observation:

Lensing arcs: Strong Lensing

Weak lensing



Gravitational lensing in galaxy cluster

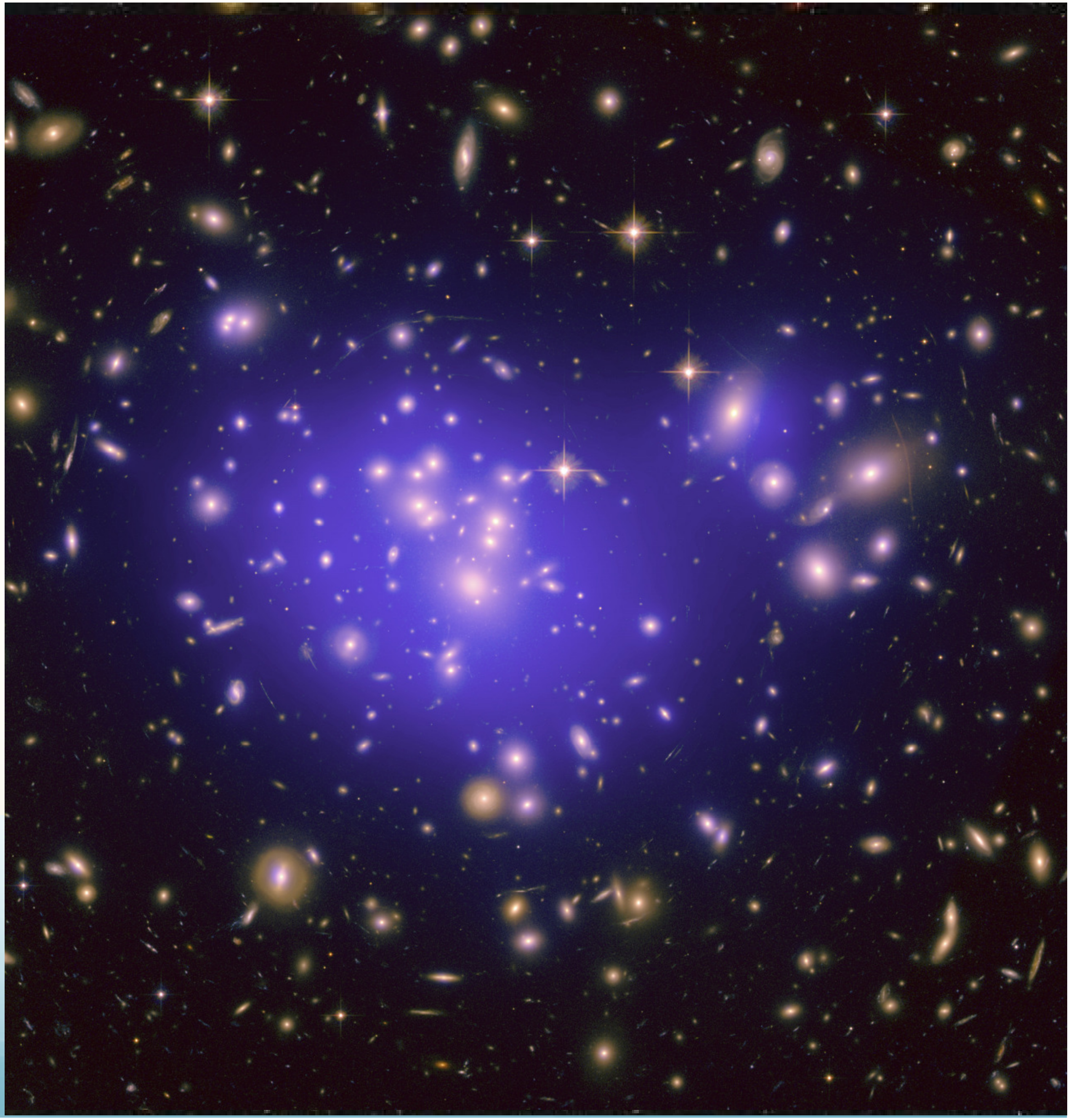
Abell 1689

Components:

- *Galaxies*
- *X-ray gas*
- *Dark matter*

Observations:

- *Galaxies*
- *Lensing arcs: Strong Lensing*
- *X-ray gas*
- *Weak lensing*



Modeling for A1689

1) X-ray gas density: observations up to 1 Mpc => fit shape

2) Central galaxy: mass density model $\frac{M(R_i + R_o)}{2\pi^2(r^2 + R_i^2)(r^2 + R_o^2)}$

3) Dark matter: Fermi gas of neutrinos at low T (quantum degenerate) in the gravitational potential $\varphi(r)$

$$\int \frac{\mathrm{d}^3 p}{(2\pi\hbar)^3} \frac{gm}{\exp\{[p^2/2m + m\varphi(r) - \mu]/T\} + 1}.$$

$g = 6$ *standard ("active") neutrinos* $\nu_e \, \bar{\nu}_e, \, \nu_\mu \, \bar{\nu}_\mu, \, \nu_\tau \, \bar{\nu}_\tau$

$g = 12$ *if also righthanded* ν_i, *lefthanded* $\bar{\nu}_i$ *exist*

4) Solve Poisson eqn $\varphi''(r) + \frac{2}{r}\varphi'(r) = 4\pi G[\rho_\nu(r) + \rho_G(r) + \rho_g(r)]$

5) χ^2 *fit of Strong & Weak Lensing data*

Prediction for the neutrino mass and signature

Abell 1689: $m_\nu = 1.90^{+0.12}_{-0.15} \left(\frac{12}{g}\right)^{1/4} \frac{\text{eV}}{c^2}$

If active and sterile ν *have thermal occupation then*
cosmic fraction: $\Omega_\nu h^2 = (g/12)^{3/4}(0.121 \pm 0.008) h_{70}^{1/2}$
Planck Cold Dark Matter $\Omega_c h^2 = 0.1188 \pm 0.0010$

g =12 can explain all data: 3 active + 3 sterile neutrinos
CMB data => m = 1.861±0.014 $(0.7/h)^2$ *eV/*c^2

Neutrinoless double β *decay:* $m^{0\nu}_{\beta\beta} \geq 0.33 m_\nu = 0.61\,\text{eV}/c^2$
Experiments exclude this (not 5 σ), hence "it does not occur"

But then Dirac type, not Majorana type: ν *are chargeless* $e^\pm$

Summary

The measurement problem elucidated

QM is like Stat Mech: describes our best knowledge about ensembles
Measurement theory defined only in a given context (detectors, mirrors, …)
Subensemble relaxation: decomposition into subensembles
also thermodynamic

Individual outcomes due to new mechanism and weak postulates
Frequency interpretation of Born probabilities for pointer indications
The Ensemble Interpretation is minimal. Why not teach it?

Hydrogen atom in Stochastic Electrodynamics is self-ionizing

Cluster lensing leads to neutrino mass of 1.9 eV; Dirac nature
In conflict with standard model of cosmology Λ-cold dark matter
KATRIN: test neutrino mass from tritium decay. Starts 2016-2017.

Accidents along the road

A macroscopic system can not be in a pure state
Schrödinger cat paradox: meaningless
Information paradox of macroscopic black holes: meaningless
Wavefunction of the Universe: meaningless
Pointer must be macroscopic and in mixed state

Measurement outcomes are only defined within a given context (detectors, beam splitters, mirrors, …)
Counterfactuals are meaningless.
Flaw: Bell inequalities combine different contexts => no say on local realism.
The contextuality loophole can not be closed. (EmQM-11)

Quantum probabilities ($|\psi_i|^2,\ q_i^{(k)}$) are not real probabilities,
unless they can be connected to macroscopic pointer outcomes
Many worlds interpretation: over-interpretation
Nonlinear collapse models: over-interpretation; not needed
Connections to brains: over-interpretation
Schrödinger cats: dead & alive = over-interpretation
The wavefunction is epistemic

Majority view:

Nature is nonlocal

and Bell is our prophet

Physics is left in a psychiatric state

Minority view:

Nature is just local and Bell is a false prophet

CHSH: 2 detector locations at A, 2 at B => 4 different contexts

Different contexts can NOT be combined, Bell inequality can NOT be derived
This *contextuality loophole* is a theoretical problem, it cannot be closed

The only conclusion is that QM works.
Not any implication on locality or realism.

N'11

Un(??)finished business:
“*The*” interpretation of QM

Copenhagen: measurements via Born and collapse postulate
Many worlds/relative state: no collapse; infinite branching
Wigner’s friend/mind-body: observation finishes the measurement
Decoherence: the environment does it all
Bohmian mechanics: Bohm particles and their guiding field
Nonlinear collapse models: QM should be extended in nonlinear way
Consistent histories: doing away with measurements
Modal interpretation
Real ensemble: elsewhere in the Universe the same events happen
Gravitation is needed to understand collapse

Why not teach the Ensemble Interpretation ??

Quantum Mechanics
is a theory

that describes
the statistics
of outcomes
of experiments

It cannot and should not describe individual experiments
(otherwise than in a probablistic sense)