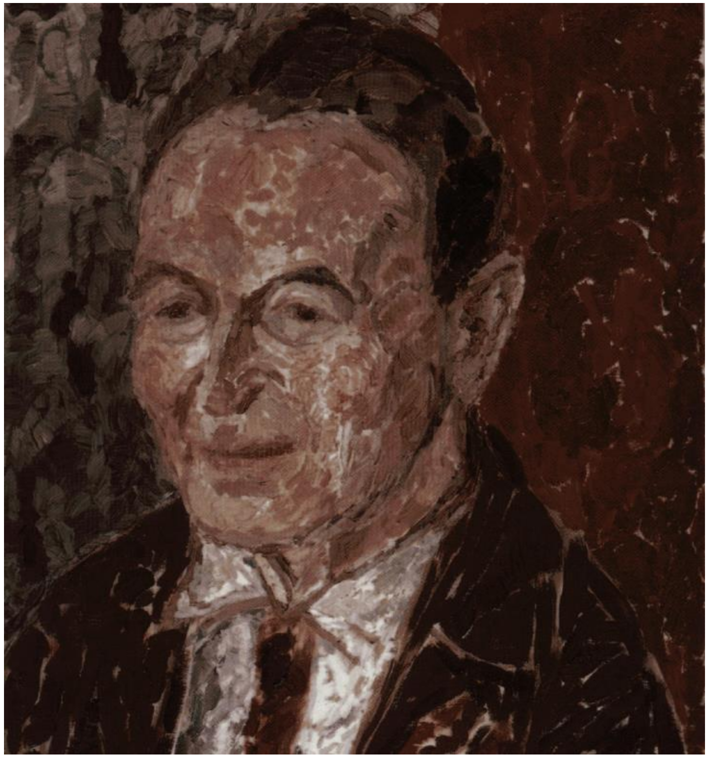
Klein Particles in the Universe



Oscar Klein Memorial Lecture
2008

Helen R. Quinn
SLAC

Klein and Dirac

Relativistic particle dynamics in the late 20's

Klein's equation (~1926)

worked for spinless particles-scalars

- but not for electrons (spin ½)

Dirac's (1928) got fermions right

--and fermions are the stuff of matter

But what about the scalars?

Klein's equation is as viable as Dirac's

Do we see any particles that obey it?

A overview of the role of scalars
in modern particle physics
and in the Universe and its history

Yukawa's scalar meson

Introduced to explain nuclear forces 1935

pion and, later, Kaon discovered

Now we know:

mesons are quark-antiquark composites

pseudoscalar –but still obey Klein's eqn

nuclear forces are quark-quark interactions

when nucleons overlap

mesons provide the long range tail of the effect

Are there any fundamental scalars?

No reason why not!

Play many useful roles in models,

but none so far observed directly!

Higgs particle

Supersymmetric partners to fermions

Axion

Inflaton

Higgs Scalar Field

In Standard Model
complex scalar weak doublet = 4 scalar fields

Spontaneous symmetry breaking
everywhere constant but non-zero Higgs field
gives quark and W and Z masses (removes 3 scalars)

Mass as potential energy due to interactions
with the Higgs field

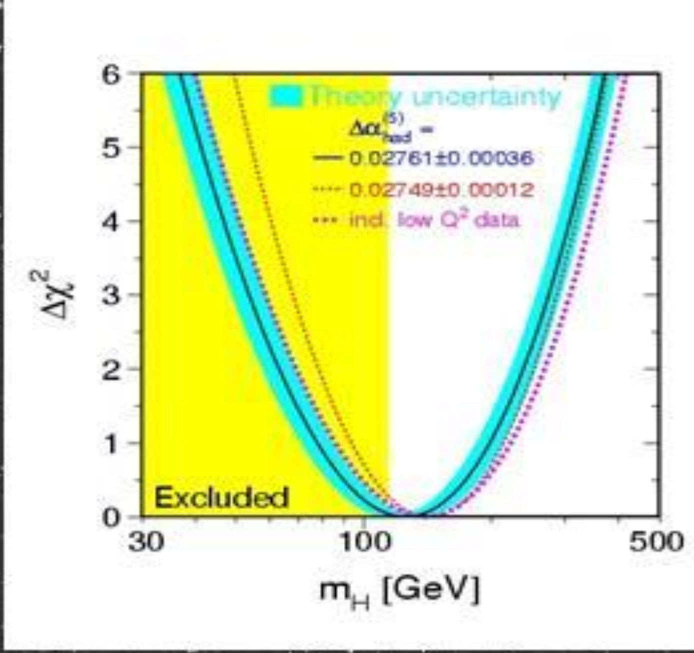
Fluctuations about constant Higgs field:
one remaining scalar particle – the Higgs boson

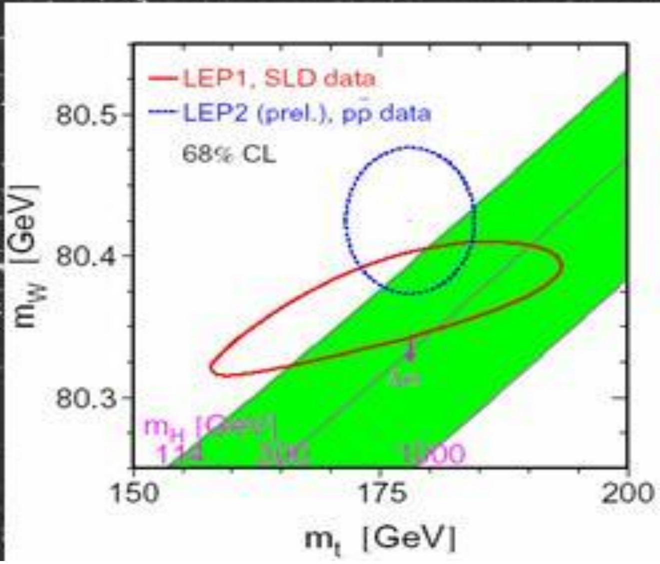
What we know about the Higgs

- Although they did not directly observe it, the LEP experiments have collected a wealth of information on the Higgs boson through comparisons of EW observables to EW theory + radiative corrections

- From theory we know its couplings, its decay modes, and how its mass impacts the W and top masses.
- If it exists, then we know its mass with about 60 GeV accuracy, and the direct search limit already cuts away a large part of the allowed mass region

- Latest LEP results: $M_H=126^{+73}_{-48}$ GeV, $M_H<280$ GeV @ 95% CL (Winter '05).





simplest SM version predictions –not yet seen

Slide copied from Tomasso Dorigo's blog
Plots commonly used without attribution

What if it is not seen at LHC?

Multi-Higgs models – more heavy scalars!

Supersymmetry models

–lots and lots of scalars

one for every known fermion!

Composite Higgs particle

– back to scalars made from fermions

Supersymmetry

Proposed symmetry between Dirac and Klein particles –fermions and bosons

For every known fermion postulates a scalar

For every known boson postulates a fermion

Why would you want to do that?

Symmetry must be badly broken

–we've seen none of the "superpartners"!

Why do particle physicists like SUSY?

Hierarchy “problem”

what sets Higgs boson mass scale?

why it is much below grand unification scale?

Grand Unification =

Strong, electromagnetic and weak couplings merge

Works better with SUSY (or other added particles)

Coupling unification

the weak get stronger and the strong get weaker!

- Grand Unified Theory (GUT)?

Hierarchy of scales?

Why is weak symmetry breaking scale
so much below symmetry breaking of GUT?

“Technically unnatural”
“fine tuning” to get high scale parameters
that give the right low-scale physics

Is this a problem?
SUSY reduces the need for fine tuning

If SUSY is right there are many scalars

"sfermions"

squark, selectron, sneutrino, ….

To fix "hierarchy problem"

some must have masses in LHC range (or lower)

Already experimental constraints are troubling

"the little hierarchy problem"

Other reasons for more scalars

Strong CP problem -- axion
+more heavy scalars

Inflation driver -- Inflaton

Matter-Antimatter symmetry of Strong Interactions (CP)

Almost exact!

strong experimental bounds on breaking

- neutron electric dipole moment.

But --once you have weak CP violation

it can infect the strong interactions

This is a high order effect in the SM,

extensions such as SUSY may make the problem worse.

Need a “protection mechanism” to keep the effect small enough to fit dipole moment data

Fixing strong CP
Peccei-Quinn "Symmetry"

Add more scalar fields to Standard Model

1 scalar weak doublet gives 4 more scalar particles

Add PQ symmetry to protect strong CP

Most of the new scalars are massive,

one, related to PQ symmetry, is very light –the axion

PQ "symmetry" is not quite a symmetry –broken by QCD

-- if it were exact the axion would be massless

Do axions exist?

Invisible axions

Original version of axion excluded by direct searches, red giant lifetimes, Supernova

Fix to get "invisible axion"

by adding more scalar fields

Invisible Axion

a scalar candidate for dark matter

Plus more heavy scalars

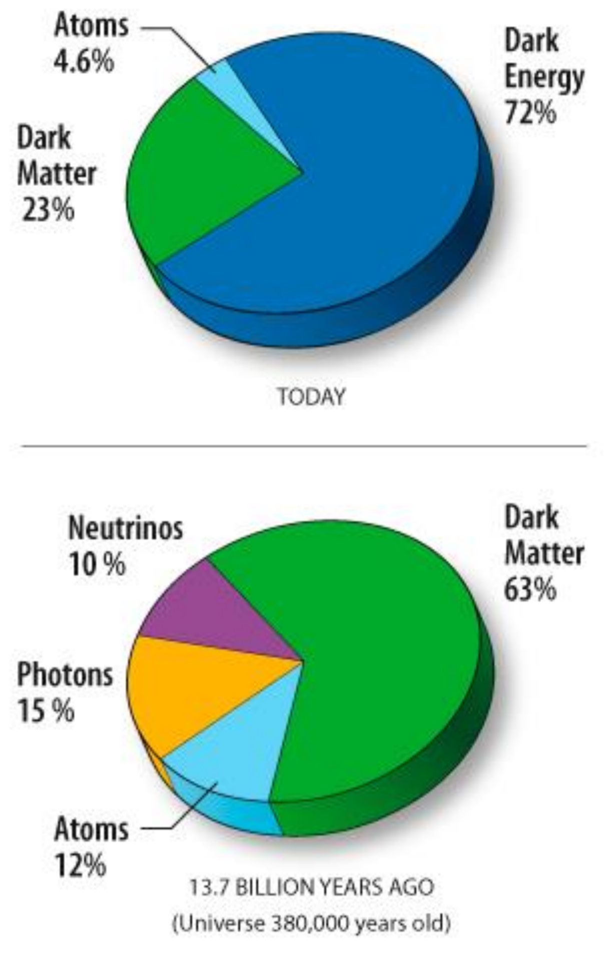
What do we know about "dark matter"?

Matter in the Universe

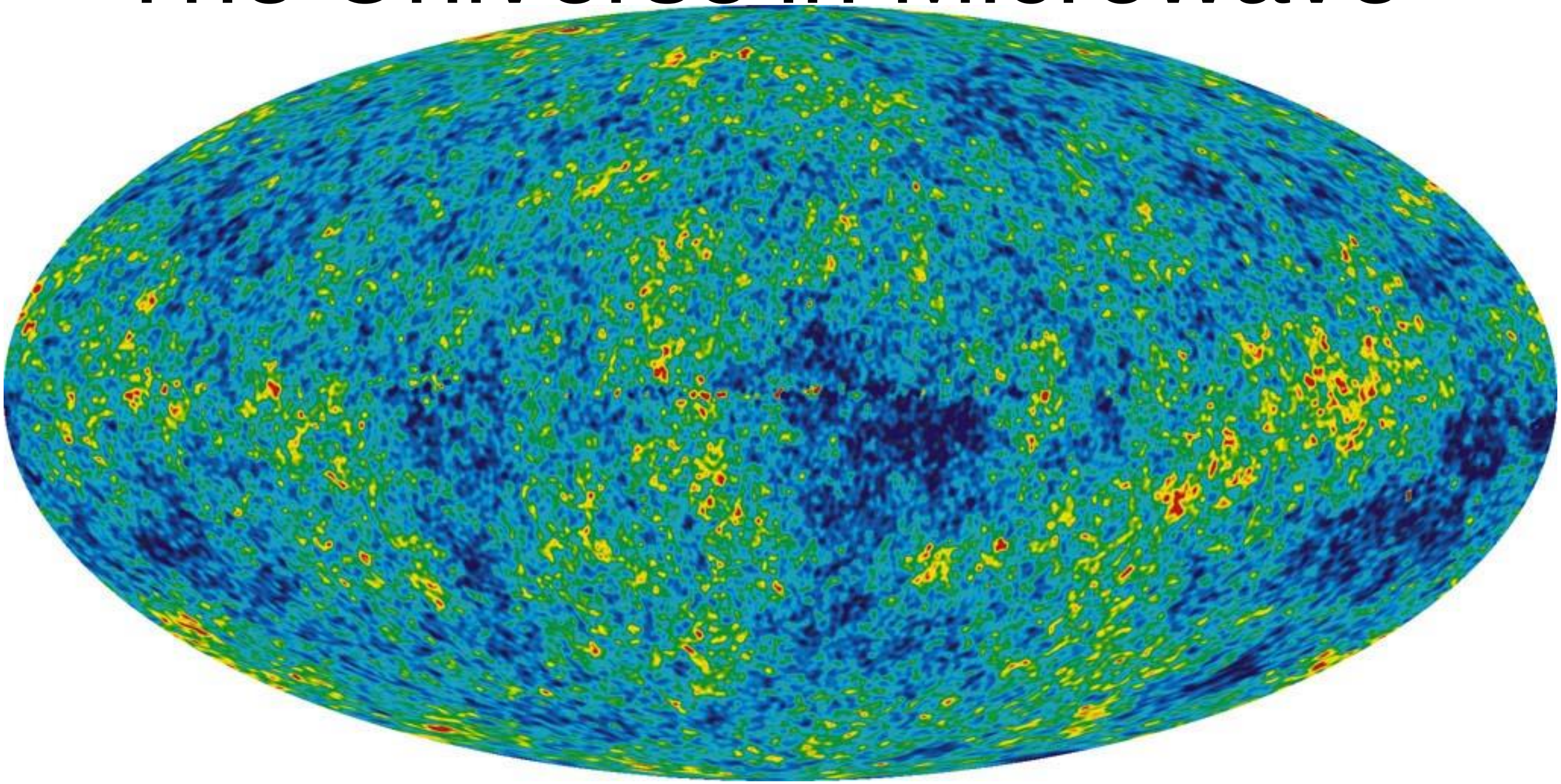
WMAP (+much else)

At last scattering

- Dark matter 63%
- Neutrinos 10%
- Atoms 12%



The Universe in Microwave



WMAP data -- Temperature Fluctuations

=>Density fluctuations at “last scattering”

variation is a few parts in a million

Structure

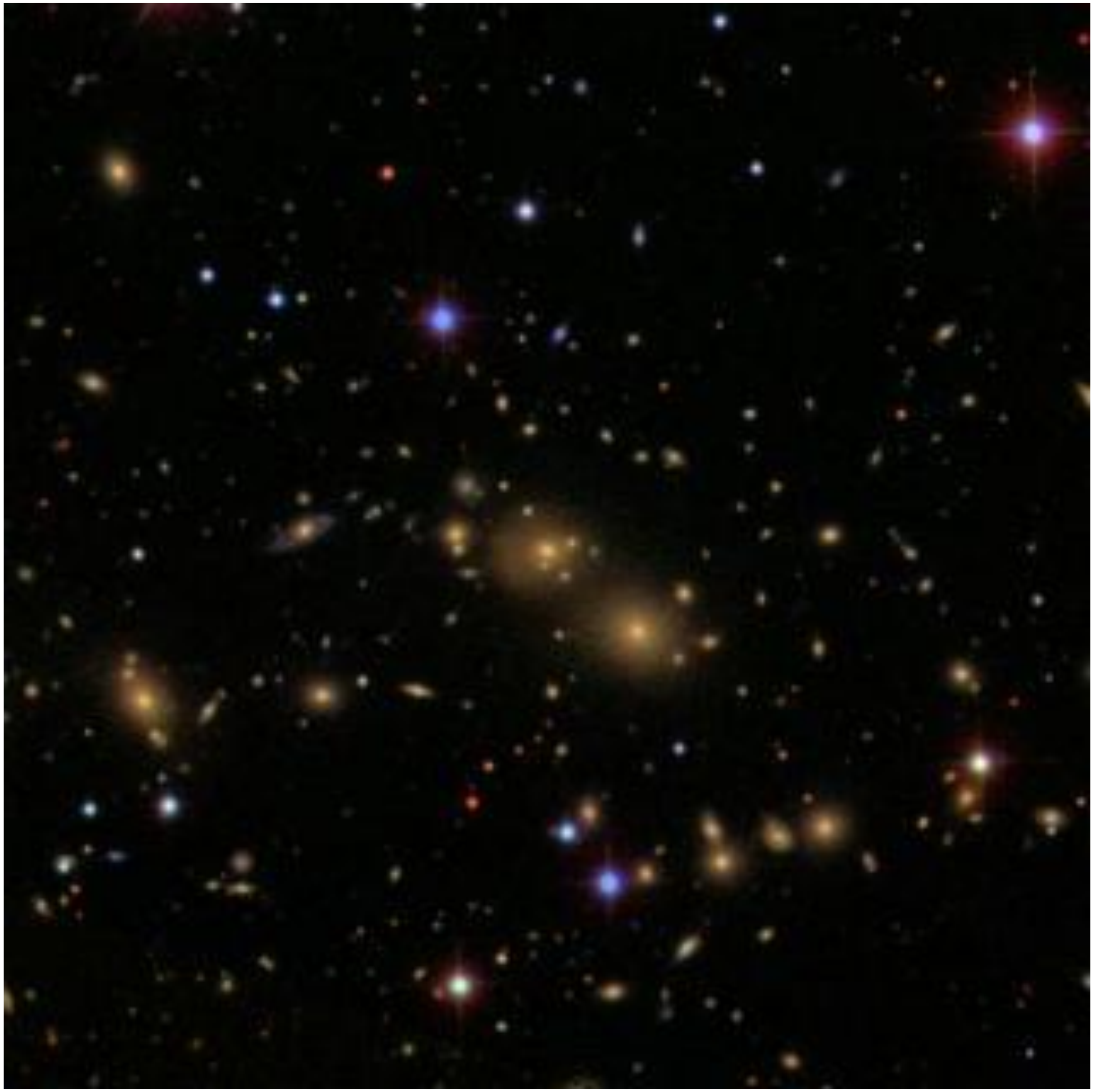
today

Lots of it!

Abell 2255

Sloan Digital

Sky Survey



Evolution of structure

Starting from microwave fluctuations

can models get observed structures today?

Requires “cold” dark matter

particles moving at non-relativistic speeds

very little interaction with ordinary matter

Implies either

heavy particles =WIMPS

or an axion-like mechanism

(light particles whose production is not thermal)

Axionic dark matter?

See e.g. P. Sikivie –Axion cosmology -astro-ph/0610440

Cold axions descended from primeval coherent axion field must dominate over thermal axions

Number density calculable from axion model parameters –can get plausible densities for dark matter consistent with limits

Can we see dark matter axions?

Not detectable in usual “wimp’ searches

too light = too little energy deposition

Axion searches with highly tuned cavity

— LLNL (van Bibber et al)

reaching interesting region

if our galaxy’s halo dark matter

is dominantly cold “invisible” axions

Axion search experiments

KSVZ and DFSZ

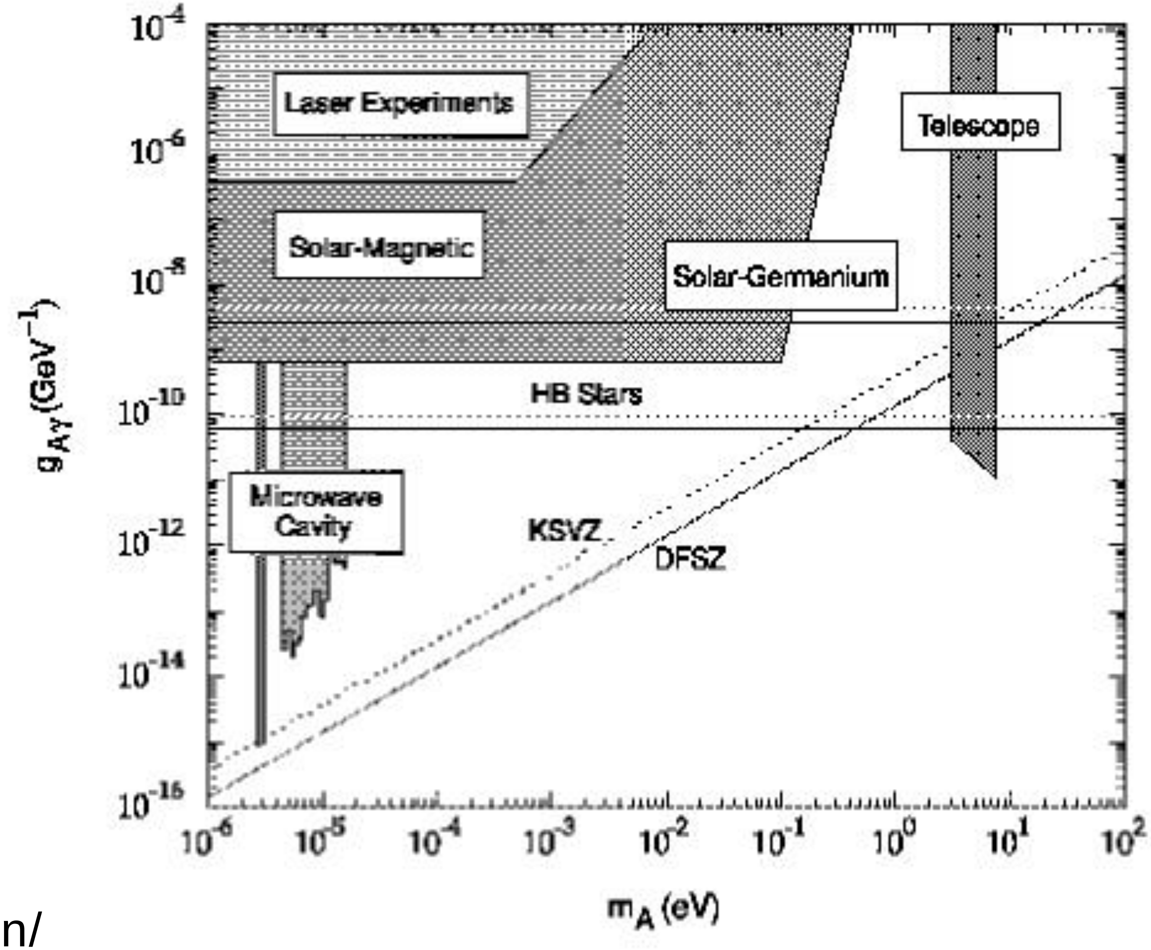
Invisible Axion
At halo density

Couples to photons

Exist as dark matter?

Produced in sun

www.phys.ufl.edu/~axion/



Is dark matter made of axions?

Or is it the lightest superpartner?

Lightest SUSY particle as dark matter

Need neutral stable particle – at ~ TeV mass scale

If scalar = sneutrino

viable in models with Right Handed neutrinos

If fermion = neutralino

mix of partners to Higgs and Z boson

Most “popular” dark matter candidate

Viable for some choices of SUSY parameters

Experimental WIMP searches

DAMA

– annual modulations due to motion through halo

CDMS, XENON

-search for individual events due to single particle impact

Results are contradictory –or at least hard to reconcile

WIMP

Dark

Matter

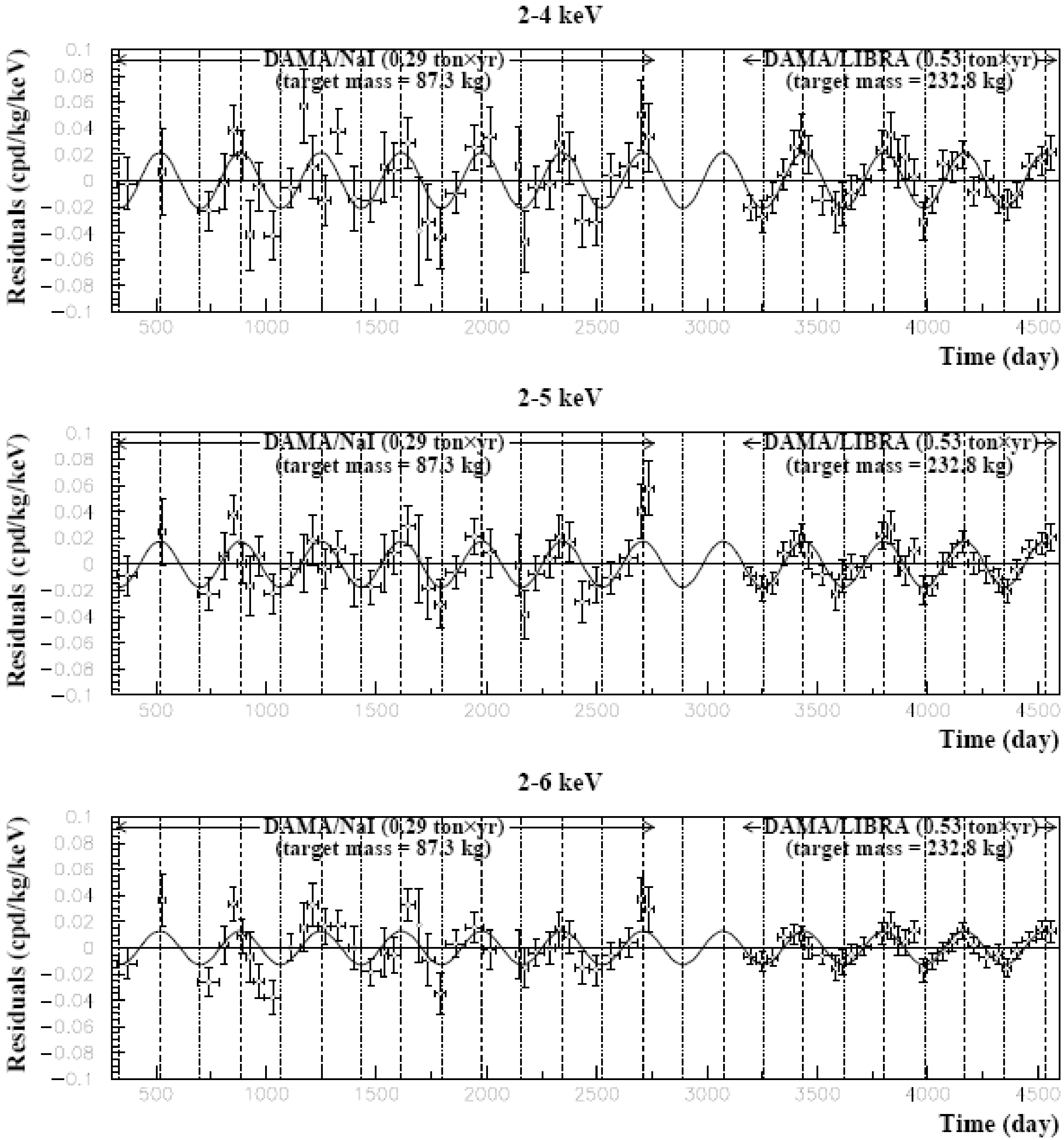
Search

Observed

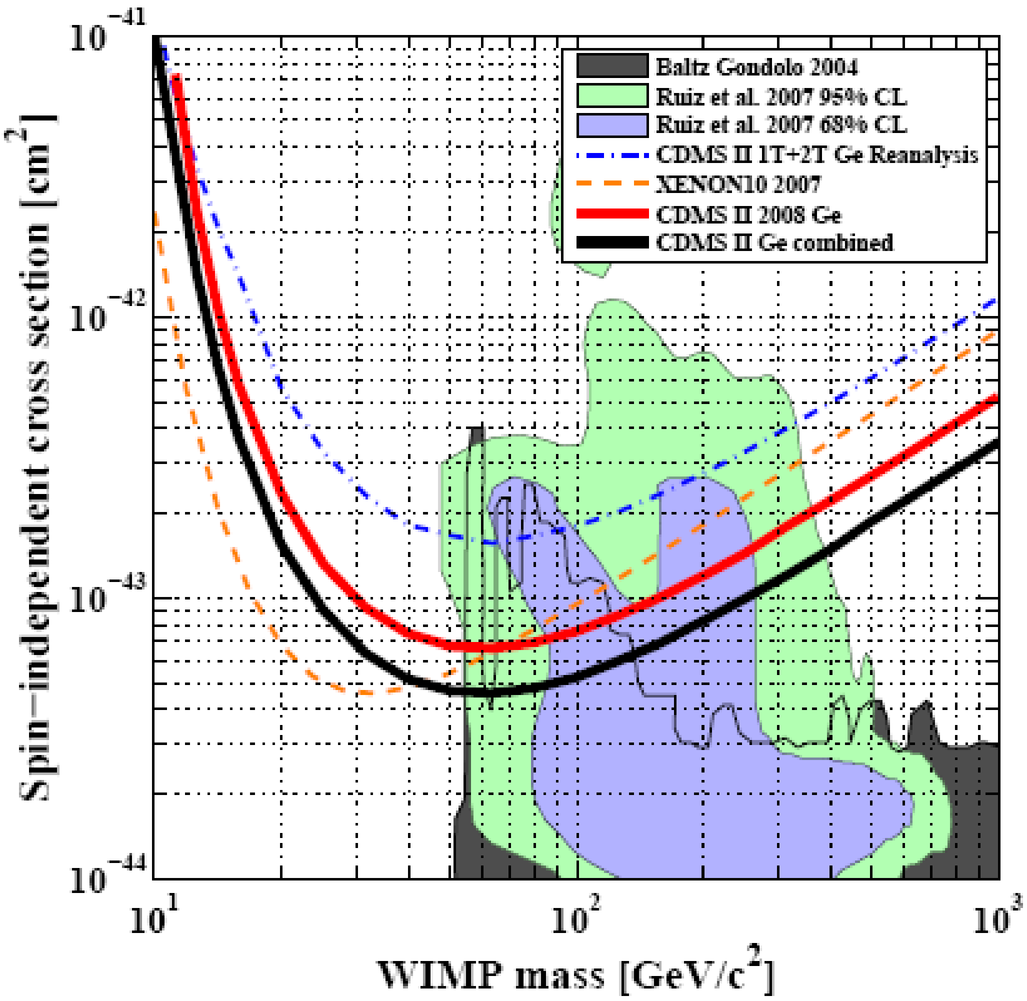
Annual

Modulation

DAMA



Excluded WIMP parameters



cdms.berkeley.edu/conference_talks_links/CDMS_5Tpreprint_080222.pdf

Scalar WIMP Dark Matter?

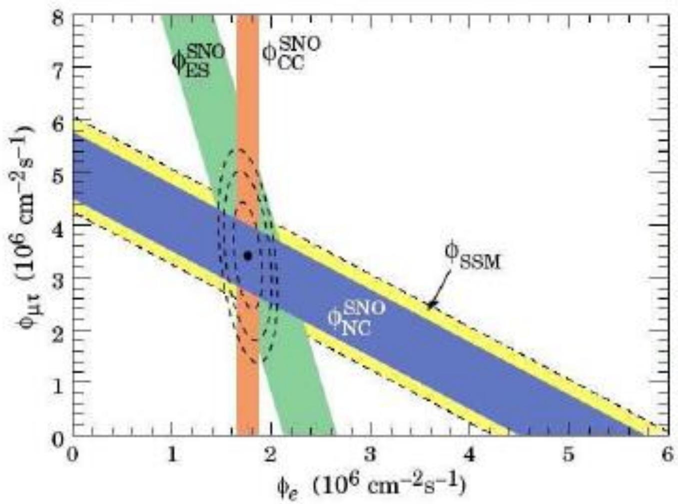
Left handed neutrinos only

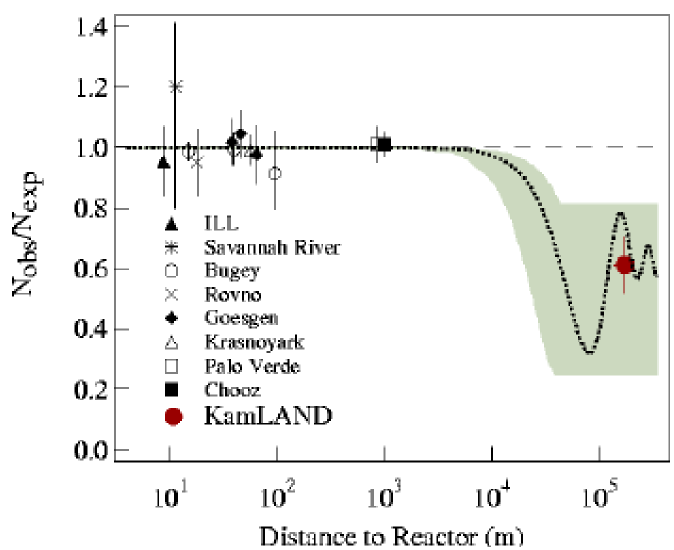
-- sneutrino parameters excluded

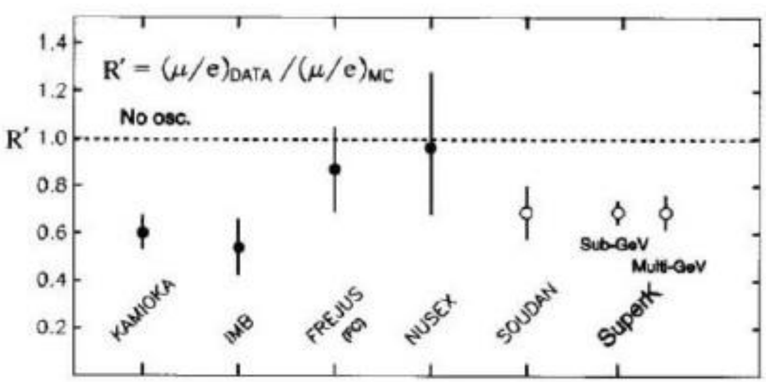
But evidence for neutrino mass

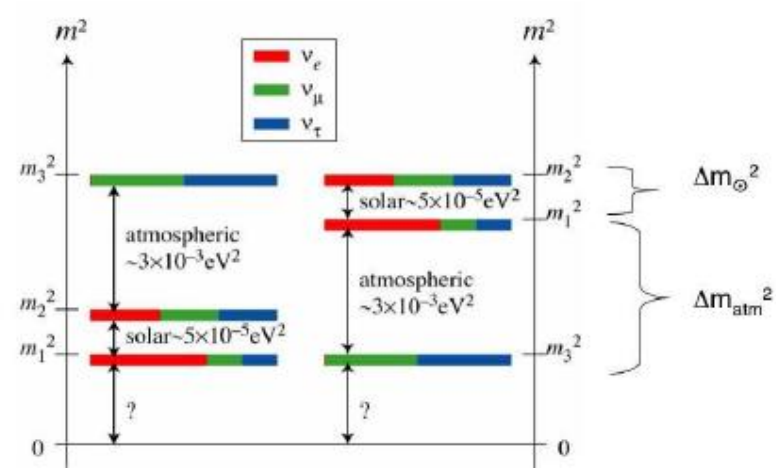
implies also right handed neutrinos

Evidence for Neutrino mass Implies "Right Handed neutrinos"









arXiv:hep-ex/0412032v2

Are there scalar wimps?

DAMA and CDMS may be consistent

if WIMP is (mostly "RH") sneutrino

Claim is that one can find allowed parameter ranges for this case in SUSY models too

I'm not sure

– have not checked for recent DAMA results

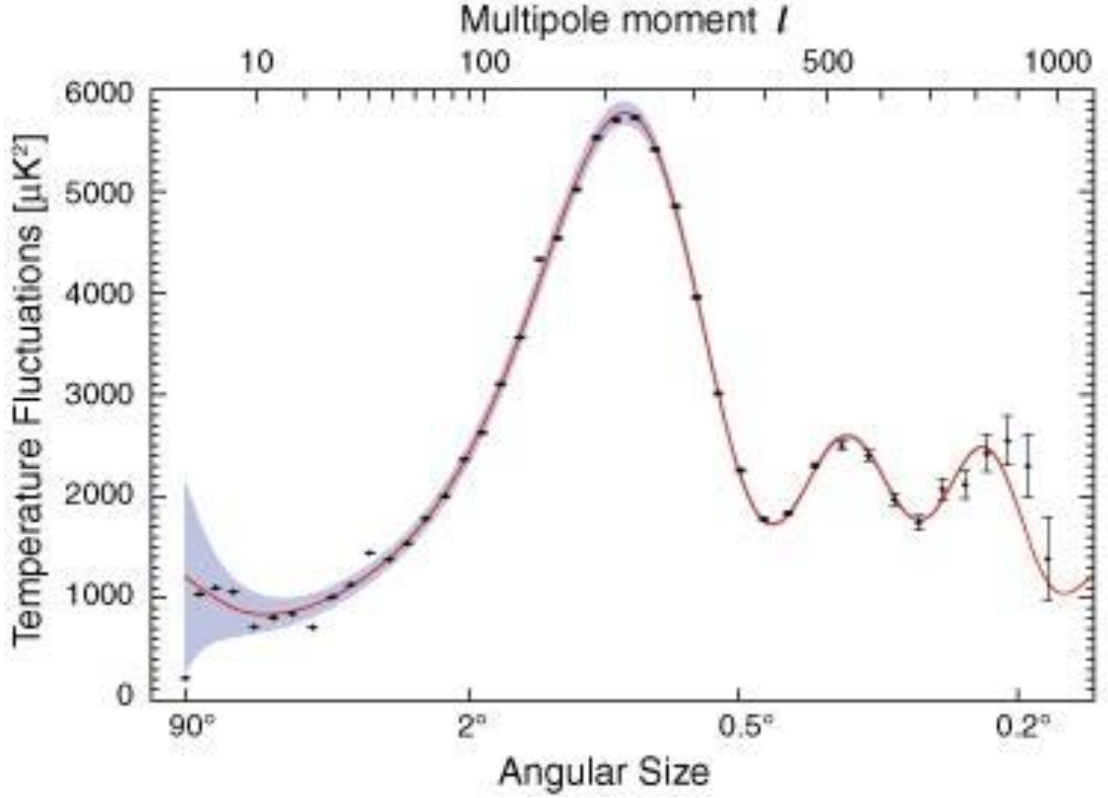
Inflation

Universe began with a period of exponentially rapid growth

What drove that growth?

Evidence for Inflation

WMAP (+much else)



What causes Inflation?

Typical theory –Linde's chaotic inflation

Inflation driven by

a scalar field –the "inflaton field"

Is there an inflaton particle?

Yes –but you'll never see it

Low mass and couples only to gravity,

During inflation energy density is in inflaton field
vacuum value --acts like a large cosmological constant

At end of inflation this energy is converted (reheating)
to produce particles and antiparticles
from then on the inflaton is mostly irrelevant

Are there any fundamental scalars?

My best guess - probably

My favorite candidates

- Higgs bosons (more than one type)

  - and the axion

My hope

- LHC will see evidence for Higgs particles

My dream

- axion evidence at LLNL or next generation searches