Possible talk titles whilst awaiting LHC run II :

<u>WHAT NEXT</u>? – frequent talk title in past year, pessimistic

-- giving such a talk apparently requires no knowledge of LHC physics, Higgs physics, supersymmetry, phenomenology, etc – talks often negative

-- should not go unchallenged

<u>EXCITING STRING PHENOMENOLOGY</u> – Higgs, LHC physics and more

<u>TIP OF THE ICEBERG</u>? – maybe we already have the bottom!

-- in early 1970s the SM fell into place over 2-3 years

Gordy Kane, Michigan Center for Theoretical Physics

SUPERSYMMETRY 2013, Trieste, ICTP

Some of us should **venture to embark on a synthesis of facts and theories**, albeit with **secondhand and incomplete knowledge of some of them** – and **at the risk of making fools of ourselves.**”

Erwin Schrodinger

Wittgenstein (last words of Tractatus) “whereof one cannot speak, thereof one must be silent” – Schrodinger’s reply “***But it is only here that speaking becomes worthwhile”***

Need theoretical top down framework AND "bottom up" phenomenological constraints → *NUTCRACKER METHOD*

Oldest known nutcracker in museum in Taranto,Italy, ~200 BC, about when systematic science began

The Standard Model is an excellent example

PARTICLE PHYSICS HAS ENTERED A VERY EXCITING TIME, PARTICULARLY BECAUSE **DATA** FROM **CERN LHC**, AND FROM **DARK MATTER** SATELLITE AND LABORATORY DETECTION EXPERIMENTS, IS FINALLY BEGINNING TO EMERGE

THERE IS **ANOTHER, LESS APPRECIATED REASON** WHY WE ARE ENTERING AN **EXCITING TIME**! TODAY FOR THE FIRST TIME THERE ***IS*** A COHERENT, CONSTRAINED, CONSISTENT **THEORETICAL FRAMEWORK** TO ADDRESS ESSENTIALLY ALL THE BASIC QUESTIONS PHYSICISTS WANT TO ASK ABOUT THE PARTICLES AND FORCES THAT FORM OUR WORLD, HOW THEY FIT INTO A DEEPER AND BROADER FRAMEWORK, WHY THEY ARE WHAT THEY ARE – "M/STRING THEORY FRAMEWORK"

THE BOUNDARIES OF PHYSICS ARE CHANGING!

Compactified Extra Dimensions of Space!

Stabilizing the compactified region

Don’t have to know everything about string theory in order to know some important things about string theory and its connections to the real world

“The problem with making predictions is that people test them. This is a relatively new problem for string theorists…”Burgess Cicoli Quevedo `13

BUT:

1999, a well known string theorist: “string theorists have temporarily given up trying to make contact with the real world”

2013 Annual Strings meeting, Korea – over 40 plenary talks (only plenary) – none mentioned LHC or Higgs data substantively – David Gross (to his credit) lamented the trend

theory ↑, phenomenology ↓

Standard Model does not *address* Dark Matter at all

Supersymmetric SM does address the problem of dark matter (and more) – contains good candidate, and relic density can be right – *if we did not know about dark matter, supersymmetric SM would make us think of it and look for it (historically it did)* – the SSM "*addresses*" the problem of dark matter

If we did not know about gravity, or forces like QCD and the electroweak force, or quarks and leptons, or parity violation, or families of particles, or supersymmetry, string theory would make us think of them and look for them – *"addresses"* them

CAN "STRING THEORY" REALLY PROVIDE ANSWERS AND TESTABLE UNDERSTANDING?

Most books, blogs, etc very misleading

Don't have to be somewhere to test something there! Big Bang – can't go faster than speed of light – dinosaur extinction

String theory is too important to be left to string theorists ☺

Can you do anything you want with string theories?

No, string theories can make falsifiable predictions!

- **Compactify Heterotic string on Z_3 orbifolds -- does not lead to a correct neutrino mass spectrum**

- **Compactifying M theory on G_2 manifold with R-parity conservation leads to wino-like LSP Dark Matter with mass ~ 150 GeV – Fermi-LAT data has too few photons (and wrong spectrum) to agree with wino-like predictions!**

Shows that one has to go BEYOND the MSSM for compactification!, or that hidden sector content may be important!

Approach to make predictions, compute Higgs mass, gluino mass, properties, etc:

Divide all compactified M theories into two classes

- **Those that have softly-broken supersymmetry, TeV scale physics, Higgs mechanism, nucleosynthesis, etc**
- **The rest!**

Calculate M_h /M_{Z}, gluino mass, etc, for those solutions – test such predictions – did that for higgs mass and properties before data, works

The graviton has a superpartner, the *gravitino* , whose mass is determined by supersymmetry breaking. This sets the mass scale for the theory, for superpartners, for dark matter, for the Higgs sector

Studying the compactified theories led to a surprise:

Study the full moduli mass matrix (don't need to actually calculate it) -- it generically has smallest eigenvalue of order the gravitino mass!
(Three independent derivations)

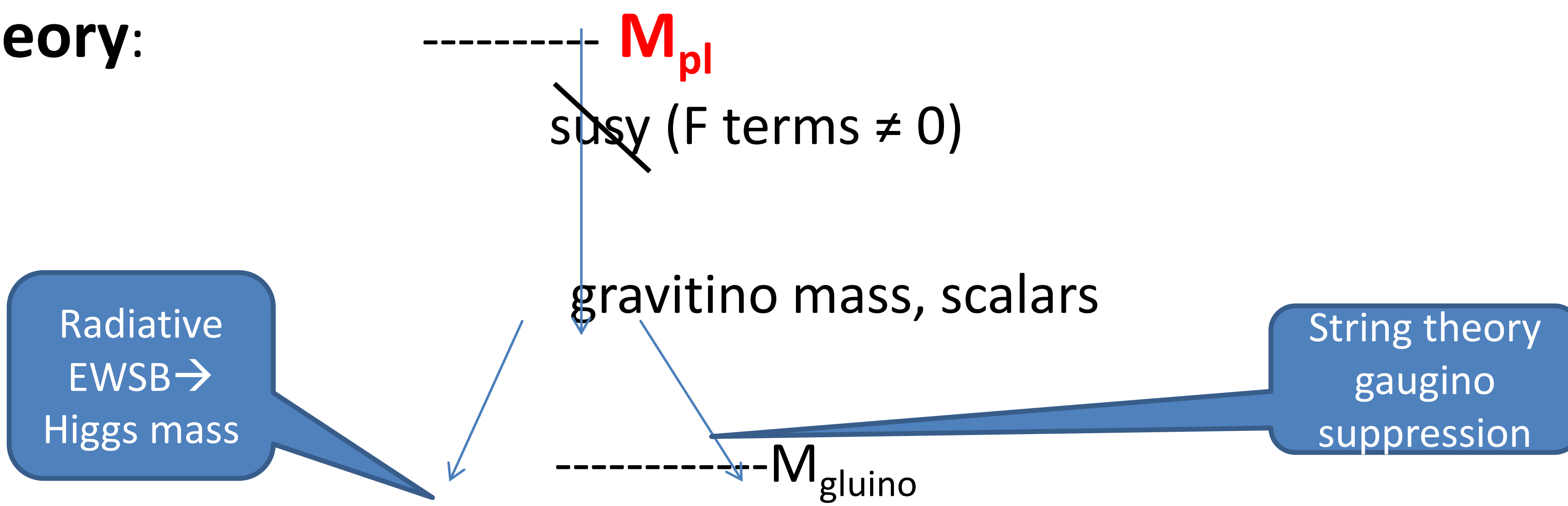
Ties moduli masses to gravitino masses! Moduli masses are strongly constrained by cosmology, e.g. nucleosynthesis → moduli masses $\gtrsim$ 30 TeV → gravitino mass $\gtrsim$ 30 TeV → automatically in decoupling sector of Higgs sector → why 126!

Naturalness? Fine-tuning?

Naturalness is what you think about when you don't have a theory – theory may be apparently unnatural, but of course isn't

ALL SCALES CALCULABLE

M theory:



- **Scalars ~ gravitino (too heavy to see at LHC), but gluinos suppressed to ~ TeV since no contribution to their masses from main source of supersymmetry breaking, so gluinos accessible at LHC!**

- **Actually still have naturalness in effective theories sense, because can study nature one segment at a time**

WHAT NEXT?

The future may be very bright:

we are poised to construct and test a theory of our physical universe that addresses most or all the issues together coherently, and has few inputs → *cautious excitement as phenomenologists become M/string phenomenologists, and as LHC and dark matter data emerge*

Too early? The Standard Model emerged over 3 year period in early 1970s – ingredients in place

Remember

“if people don’t want to come to the ballpark nobody’s going to stop them”

Yogi Berra