Search for Dark Matter in the Lab.

A personal bit of history

OR

from

Dark Matter–What's that??

to

Dark Matter–What is it??

Transition was not easy

Until mid-80's particle physicists
never heard of DM—and couldn't care less

Dealing with DM was an eccentric occupation

Nowadays Used to justify big accelerator projects...
Ha Ha

How did this come about?

Well...

Coherent processes are fascinating, seem to combine the mysterious of quantum mechanics with the useful

.

Earlier had dealt with 'inelastic coherence' like $\gamma \to \rho$ or $\pi \to 3\pi$ on nucleus A.

Always a big question:How to observe the small nuclear recoil.

Uncertainty principle $\Delta \sim 1/R_A$.
Recoil Energy $E_R = \Delta^2/2M_A$
Much too small for usual particle detectors, especially for large A.

Particularly simple but interesting coherent process:

$$\nu + A \to \nu + A$$

In Standard Model (Dan Freedman 1974 [1])

$$\sigma \sim (Neutron\, number)^2 \sim G_{fermi}^2 N^2 E^2$$

Large, up to 10^4 enhancement

- Neutrino experiments with kilos instead of tons![2]
- Neutrino technologies...?[3]
- ......

Only the small recoil to look at. How to detect??

At this point Andre Drukier came around. From tests of G-L theory on small superconducting grains, He had suggested using the grains as particle detectors.

So I says if your detector is so great let's see if we could detect

the nuclear recoil in $\nu + A \rightarrow \nu + A$

I was skeptical.

——SURPRISE !———

At low enough Temperature a microscopic energy can change the state of a macroscopic body!

$$\Delta T = \Delta E/C$$

Example: At 300 mK a 10 μ tin sphere can be flipped from the superconducting to the normal state by 14 eV! [4] ——C is very small. An eV is hot (12,000 K).

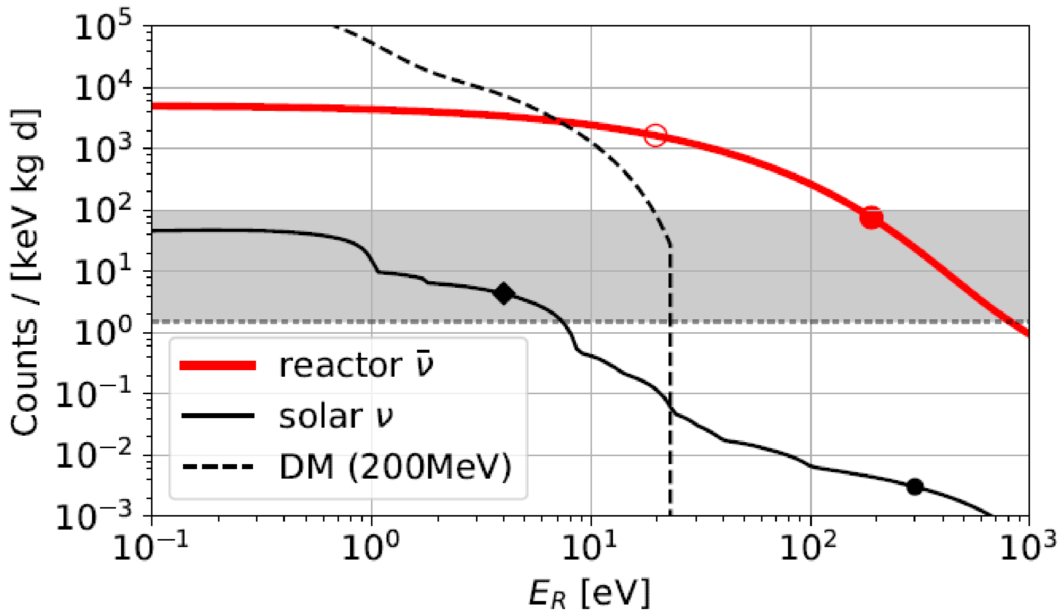
So we wrote a paper about a new 'Neutral Current Detector' using the N^2 enhancement and low temperature [2].

Since then a flurry of various ideas using Low T. Many new and intriguing ideas. (LTD Conference series, started here. LTD "0" in Waysand's office)

Significant recent realization concerning basic principle: Work [5] lead by Raimund Strauss using CRESST detectors (superconducting films). To go lower don't necessarily need smaller objects or lower T.

Achieved 20 eV thld. with 0.5 gm detector—understand by theory developed with Franz Proebst et al.[6]

Importance of lowering threshold



Dark Matter and WIMPs

The DM problem had been around for many decades..gradually becoming more convincing.

Particularly striking is the 'WIMP miracle': 'Freezeout' of a particle with G_{fermi} interactions conspires with the Hubble constant H, (h) to give about the correct amount of DM at the present time.

$$\Omega h^2 \approx \frac{10^{-37}\mathrm{cm}^2}{\langle \sigma_{ann} v \rangle}$$

How the devil does H know about G_{fermi}???

A natural suggestion was the neutrino...

But $\nu' s$ must have $m = 30eV$. So something new!

A new, missing, neutral, weakly interacting particle??

WIMP=Weakly Interacting Massive Particle

Around this time R. S. Raghavan moved from Garching to Bell Labs. when Ed Witten came to visit, he gave him a copy of our long-delayed paper.

I received a request to referee this:

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

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(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

Dark galactic halos[1] may be clouds of elementary particles so weakly interacting or so few and massive that they are not conspicuous. Many dark-matter candidates have been proposed. Magnetic monopoles are one dark-matter candidate accessible to experimental search,[2] and the same seems to be true for axions.[3] On the other hand, massive neutrinos are a popular dark-matter candidate which made in Ref. 5.

Let us first discuss the lower limit on detectable masses. If a halo particle of mass m and velocity v scatters from a target nucleus of mass M, the recoil momentum is at most $2mv$ and the recoil kinetic energy is at most $\epsilon=(2mv)^2/2M$. A reasonable value of v is $v=200$ km/sec. The lightest nucleus considered in Ref. 5 is

Must be wrong!!–rates of $10^4/kg-day$ (SNeutrino)

While we got at best $few/kg-day$???

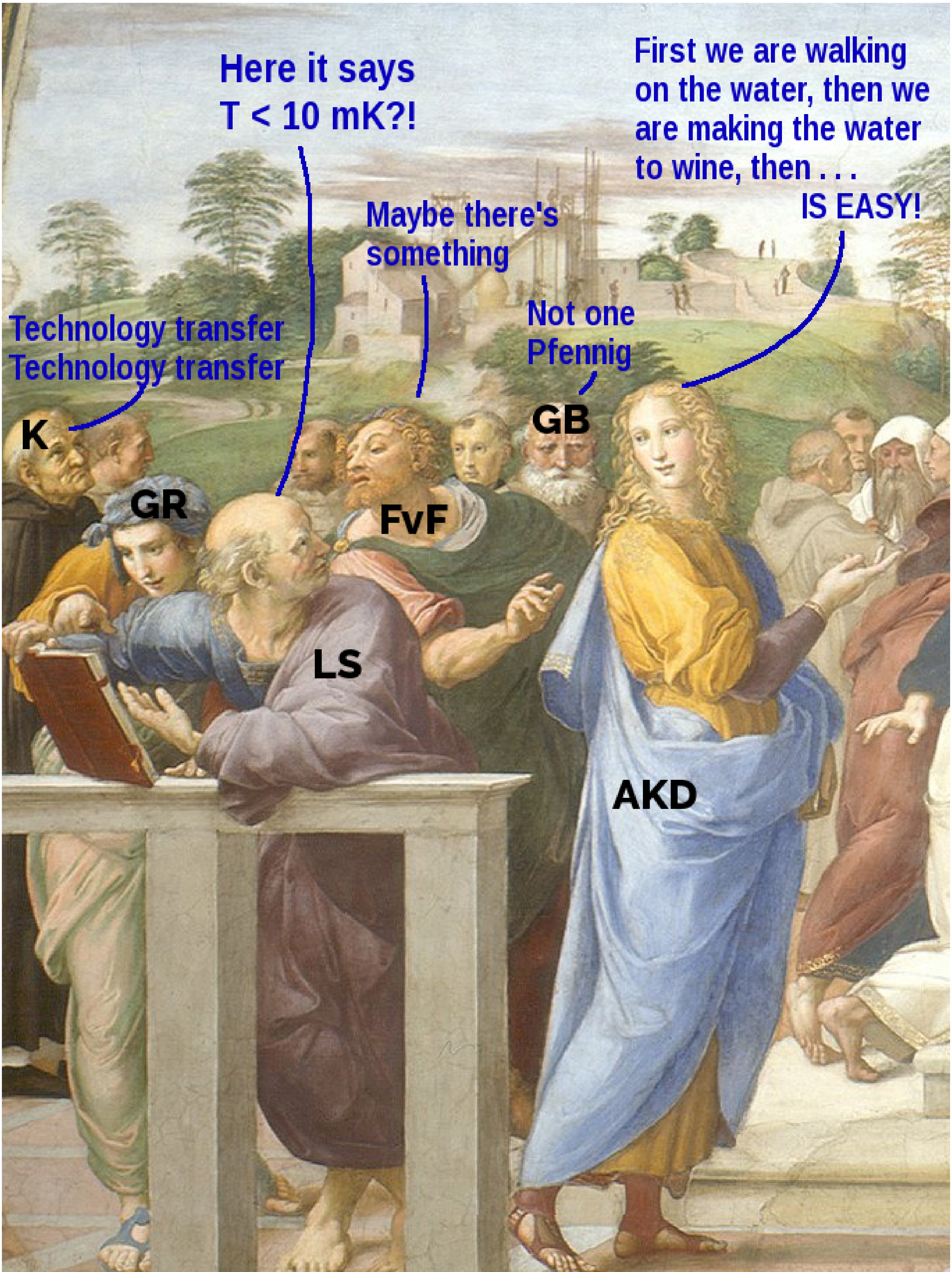
But: $G^2_{fermi}(...)(E_{neutrino})^2 \rightarrow G^2_{fermi}(...)(M_{WIMP})^2$

enormous difference $(GeVs/MeVs)^2$

There followed an enormous, still continuing, ''Gold Rush''

Now-a-days practically everybody is doing DM.

At MPI we started slowly. The early situation was like this


Here it says
T < 10 mK?!
First we are walking
on the water, then we
are making the water
to wine, then . . .
IS EASY!
Maybe there's
something
Not one
Pfennig
Technology transfer
Technology transfer
K
GB
GR
FvF
LS
AKD

Then we got serious. With Klaus Pretzl, further on grains.

First popular article (SZ 13 Jul 1987)

Montag, 13. Juli 1987 FORSCHUNG · WISSENSCHAFT · TECHNIK Süddeutsche Zeitung Nr. 157 G Seite 27

Das Rätsel der dunklen Materie

Im Universum gibt es unerklärlich viel Masse

Started the CRESST project–superconducting thermometer

or TES (Seidl thesis with Feiitzsch) Can measure micro, nano Kelvin T changes

Susan Cooper, Wolfgang Seidl, (Spokespersons)

Outstanding leadership of Franz Proebst

At present a group of dynamic young people.
Expanded colloboration MPI, Garching, Tuebingen, Vienna, Gran Sasso
(Federica Petricca, Spokesperson)

Situation Now

- Coherent Scattering of neutrinos has recently been detected [7] (J. Collar, K. Scholberg...)

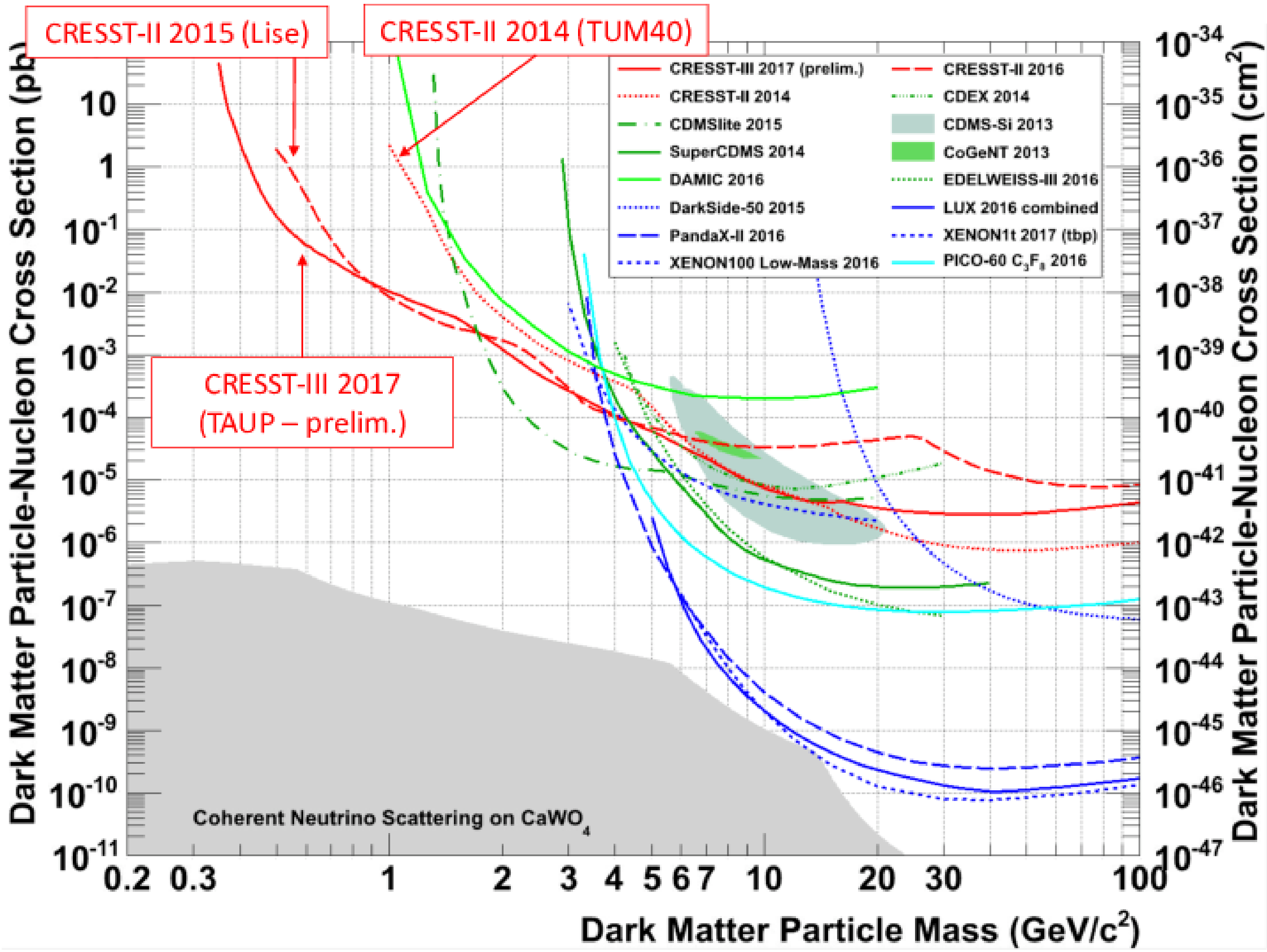
Unsurprising but gratifying

- CRESST and other groups continually improving limits

–Spectacular reduction of background (two-channel readouts [8])

- Several different and novel technologies. Heavy liquids, XENON...

- CRESST, because of cryo-technology very good for light ($\leq 1\,GeV$) WIMPs (small recoils)[9]



- Cosmological evidence for DM much
  strengthened in last decades.
  Era of ‘Precision Cosmmology’.

Open Questions

in ‘Instrumental Cosmology’[10]

- Detection of Relic Neutrinos

Exist two not-wrong ideas, but not very practical

- Detect Dark Energy

???? Nothing at all

- DM (and dark energy) Greatest, present-day, challanges for experimental and theoretical physics.

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2. A.K. Drukier and L. Stodolsky, Principles of a Neutral Current Detector for Neutrino Physics and Astronomy, MPI-PAE/PTh 36/82 Phys. Rev. **D30** (1984)2295.

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4. L. Stodolsky, Neutrino and Dark Matter Detection at Low Temperature, *Physics Today*, August, 1991.

5. R. Strauss, et al, Gram-scale cyogenic calorimeters for rare-event searches, arXiv:1704.04317; Phys. Rev.**D 96**,022009 (2017)

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8. P.Meunier et al., Discrimination between nuclear recoils and electron recoils by simultaneous detection of phonons and scintillation light, Applied Physics Letters **75**, 1335-1337 (1999)

9. F. Petricca, Talk at TAUP 2017

10. For an overview of some of the issues see, L. Stodolsky, 'Questions in the Detection of Very Low Energy Intertactions', *TAUP 89* A. Bottino and P. Monacelli eds. Editions Frontières, Gif-sur-Yvette (1989)