# 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  $\gamma \rightarrow \rho$  or  $\pi \rightarrow 3\pi$  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:

 $\nu + A \rightarrow \nu + A$ 

In Standard Model (Dan Freedman 1974 [1])

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

Large, up to 10<sup>4</sup> 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  $\mu$  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

Mark W. Goodman and Edward Witten Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544 (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<sup>1</sup> 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,<sup>2</sup> and the same seems to be true for axions.<sup>3</sup> 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



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

#### First popular article (SZ 13 Jul 1987)

#### Moning.12.Jull 1957

#### FOR SCHUNG • WISSENSCHAFT • TECHNIK

#### Antien binden für der anterfahren der Das Rätter annen gebenschet, gie aus bilder für annen für der bei einer bilder für annen für der bei einer anter bilder für annen für der bei einer anter bilder für annen für der bei einer anter bilder für annen für der bilder für der bilder für der bilder für der bilder b

An die Instantisturgender tage und der Harryngenvon Mannelskrapen benn omn. Ober die Unterhährungende, als die Laues der Lätterhe dasse hanthermisikinger wirdelt, einfahren, Andersamhe hannen oder bärden Augen (die Lätter ein Veräusseurs) besichten, ywe die Erächter der Umann au einer der Lählte die Umpergen der Althöhren Hammen wirklen, dense nach eine sonderen, des muchklichen, Andrie Umbergehte.

Der ellerte Bisgeht berecht wir Bechniekungen der kertehn, ven Schlagischer. Der Alle der Meinsteinstetzen gels essen abgeste bilder beferende ist der Bestehltendigen der der Schwarter Schlacht der Schlacht auf Hittenden Berechnerste Bisselberen Berecht ist der Bestehlten der Ansten Erlachten Persen is dereichten zu sichlichen Meinder der Bergester Bilder, wenne Beitresse aus einderen. Meinder der Schlachtungen Beitressen auf der Bestehlung der Bestehlten und einer Berecht der Bestehlten der Bestehlung der Beltenden der Bestehlung (Baltwaren Beitressen Weinfeltung unserheit (Bertrechtung) der Bestehlung der Bestehlung unserheit (Bertrechtung) der Bestehlung der Bestehlung werderten Weinfeltung (Baltwaren Beitrechtung) beitre Bestehlung der Bestehlung der Bestehlung werderten Bestehlung (Baltwaren Bestehlung der Bestehlung Leinen, derschlacht Bestehlung aberteilten Erstehlung leinen Bestehlung beitrechtung der Bestehlung darten beit der Bestehlung Bestehlung beitrechtung darten beitre Bestehlung beitrechtung bereichtungen der Bestehlung beitrechten Bestehlung Bestehlung darten beit der Bestehlung beitrechtung beitrechtung darten beitre Bestehlung beitrechtung beitrechtung darten beit der Bestehlung beitrechtung beitrechtungen der Bestehlung beitrechtung beitrechtung beitrechtung der Bestehlung beitrechtung beitrechtung beitrechtungen der Bestehlung beitrechtung beitrechtungen beitrechtungen der Bestehlung beitrechtung beitrechtungen beitrechtungen der Bestehlung beitrechtungen beitrechtungen der Bestehlung beitrechtungen beitrechtungen der Bestehlung werte Bestehlung beitrechtungen gestehlungen beitrechtungen beitrechtungen der Bestehlung Feltungen beitrechtung, Weinbeger und Bestehlung beitrechtungen Schlächlungen beitrechtungen und Bestehlungen Bestehlungen Bestehlungen beitrechtungen beitrechtungen beitrechtungen Bestehlungen beitrechtungen und Bestehlungen Bestehlungen Bestehlungen beitrechtungen und Bestehlungen Bestehlungen Bestehlungen beitrechtungen beitrechtung

had, um van der beibeiteten biese preisehet au. gesten.

After rank terminative for and an affectionprincipality of forther of their of the affection of abundances which the technology of the state and the state of t Das Rätsel der dunklen Materie In Universitätigt ein unsettlichte Manne

> Actureurs, eds. ther? Incoheren. Bail for auton Lawlath a activation form the Law die Repaireur der Reig, det die ohiet bei Zechnen Reight von Ellerenzen, die ders. Bail der gudten gesten e oglehete Ohne besauflichen, dah der Statt, aus ders die gesande de Repairent der under det Schnatzer, das afgehabet.

> > ven mar sym Ling in term at all and the sym i thin in symp. We litter is a particular fund to be a super we litter is a superior for the symp. I Veniting its de mandale de duite fuit site anna au des Jan ven hade at initiates. De s venuets financialites aim is de symbol a be think extension aim is de symbol initiates.

t Calybilag és Chivauan yézsékékék is és A szarosztát megetőkékesekékékék



ALD DEN BENTEOLINGEN վեր տեղինել որ հել ու ին հայ եր հատ էս, ու ի մի կել էր կել էր կել էր հրապեսը մի ինչ հեր հերիսությունը հեն հել՝ որպելիցի են ինքեստեղ ազիննելը, մի ն ես ըստել եկ չն եր էս եր հերակերնելու, էրերին հերակեր՝ էր, Make է ցրենսը ու չեն, մի ստեղել ընդհնալու, նայց միր, անը հերավի որ գենի գոլ հել ստեղել էրեն հրանն Արժ հերակեր՝ եր հեկ պետո

American and density in the second se

e en vennete, derbe tienere bidfen viele – Ebe ged he. den den Estatischerven bert eine entyphen ististe Bides der deröhn tienkelte te onnen Energien, i L. den styn de. Wannschiftlichen pro biskelitig neter etitisken. hete genanden, die Tählen, der deröhen en biske,

Matche Rost auf des State submitteden, die belft, eben 1 Gesteher en bewen, der dies Weiden ist verfahlige al opplichens bezu. Die ich bestehen der die die Fernischgebeitung und ist state dass, dies Auf die Naturchenien Taulite, imp Wesperiten Diestehen der Begestehen auf Diek Matter auf Statel Mitgeitung wiegenen saht Gegehebet von Mate-Fausk-tablikkt (die 19 die Felgehebet von Mate-Fausk-tablikkt (die 19 die Felgehebet von Mate-Fausk-tablikkt

the Peristana dan Kjuringdan wara Mantehan wal dine Unterla dari wanyarak tik Man, dat mandarida melawini darit adari

contequine, size original, pero case, sub- thistotrangine, do a Marchae Marine Mandala. Babadaka, contequines forcias. How Receive a un procession, additionals force-solid cut histo, case its interactions. Origina das Militarappite de contextuarios das das forces data printe data de contextuarios contextuarios de la categori, da for taxione observationes das relations printes data das terminas contextualism. Polinies Lines. Chao spiteiro ada dassa admensionalism. Polinies Lines. Chao da for taxiones bia mice bian. Respectance.

Süddeling in Zaliting Nr. 157 G Salia

On these their protection is an expected by set inserpictup by the actuate a solitor for physics, thereare a soliton the largest, the actuate a solitor for physics thereare a transmission of the soliton is an excession, which is taken the properties of the Toppi way are not also a sharp the solution of the Toppi way are not also being the solution of the taken is the soliton of the taken the solution of the taken is the solution of the taken the solution of the taken is the solution of the taken the taken and the solution of the solution of the taken taken the solution of the solution of the taken taken the solution of the solution of the taken taken the solution of the solution of the taken and the taken as a solution of the solution of the physics the taken as a solution of the taken and the taken and the taken as a solution of the taken and the taken, the astronome ballow from the participal means, as for this as a solution.

Venetistation totistation abst decision: these by donado spectrism under during terrebuildings beingen Ronghologuis also kisken, appelationelle Rogal was alsons suppositionelles. Roberto (cales databate Withouterst) on during Royal and the shipping Withouterst) on during terrebuilding and the shipping Withouterstory (the section 2016) and the shipping Rometenson (the lowerster with theoris was hitten Rometenson (the order databate shipping).

Special be bandweither: them only active Verbein andress mityleing size with weaponized, and yok an der Tagang en Bergineng einigstelle yorde, werde wenthelsen Erstylnikungen, und Verbeiner dass Generalise untersteit. 2022 Statistich werde Weiter Haust en der Teinstellens Orderseitet und um 100 Ker Haust dass werde beiter ein der Statistichen der Statistichen der statistichen Understellt und um 100 Ker Haust dass werde beiter ein der Statistichen der Statistichen der statistichen Probenditie und num beiter der Statissten der statistichen Statistichen der Statistichen der Statistichen der statistichen Statistichen der Stati

## 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 (≤ 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.

### REFERENCES

1.D. Z. Freedman, "Coherent neutrino nucleus scattering as a probe of the weak neutral current," Phys. Rev. D **9**, 1389 (1974). doi:10.1103/PhysRevD.9.1389

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.

3. See European patent appl. 82107203.0 (1982)

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)

6. Pröbst et al., Model for Cryogenic Particle Detectors with Superconducting Phase Transition Thermometers, Jnl. Low Temp. Physics **100** 69 (1995)

7. D. Akimov *et al.*, [COHERENT Collaboration], Observation of Coherent Elastic Neutrino-Nucleus Scattering, Science (2017) doi:10.1126/science.aao0990 [arXiv:1708.01294 [nucl-ex]]

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)