Conference Summary

Eric Charles
SLAC National Lab.

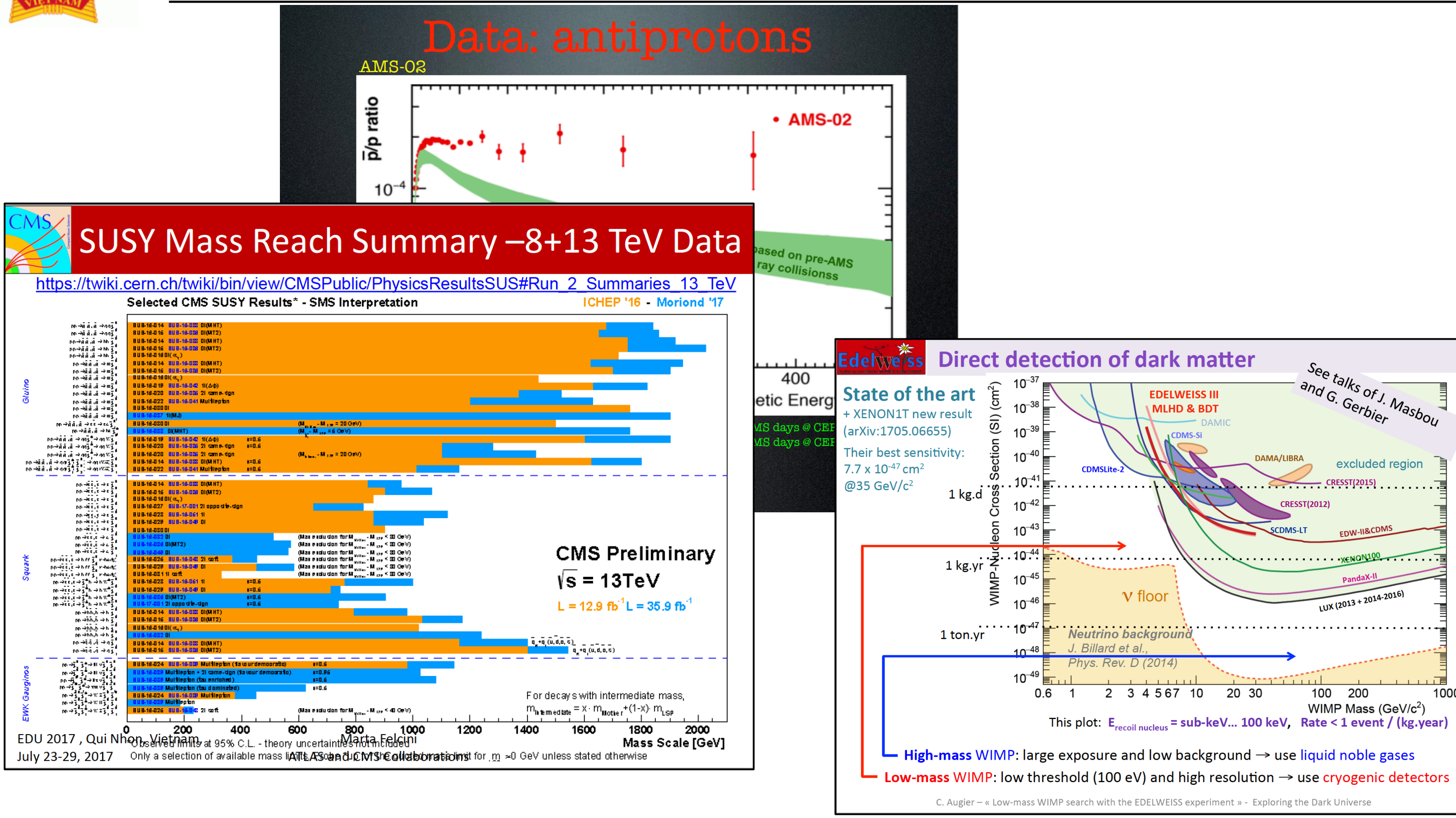
13eme Recontres de Vietnam:
“Exploring the Dark Universe”
29 July 2017, Quy Nhon, Vietnam

Outline

- Introduction
  - Theme I: new data / new models / new questions
  - Theme II: communication between communities
- A high level tour of science topics with various personal biases and a few random asides
- Meta Summary

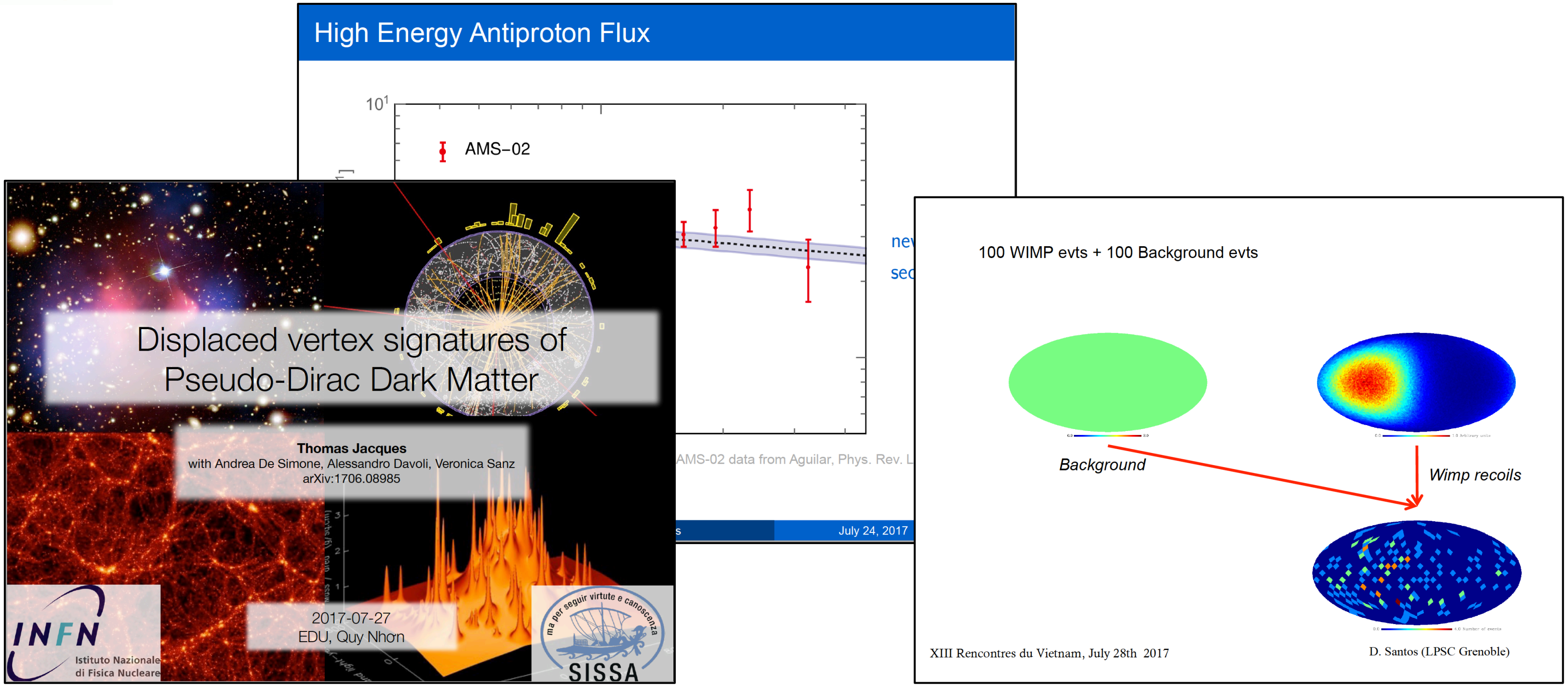
THEMES: NEW DATA / NEW MODELS / NEW QUESTIONS

New Data Tests Existing Models & Methods



Meta level: “WIMP ‘Miracle’ seems pretty compelling, lets start by going out and looking for 100 GeV WIMPs.”

New Data Push us to New Models & Methods



Meta level: “Well, none of use have found these 100 GeV WIMPs. How do we look for those XX you mentioned?”

Sterile ν

PeV DM

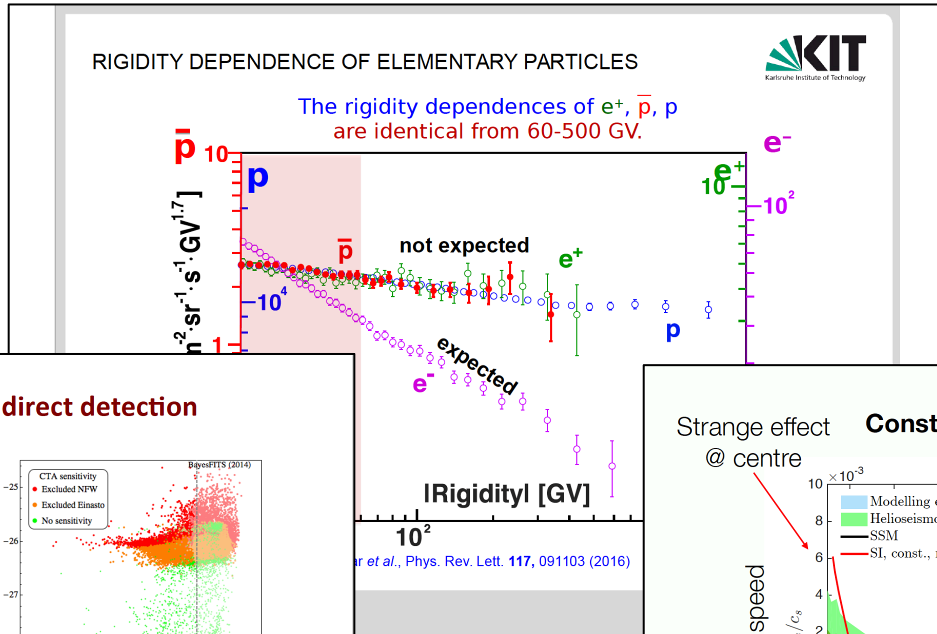
Primordial Black Holes

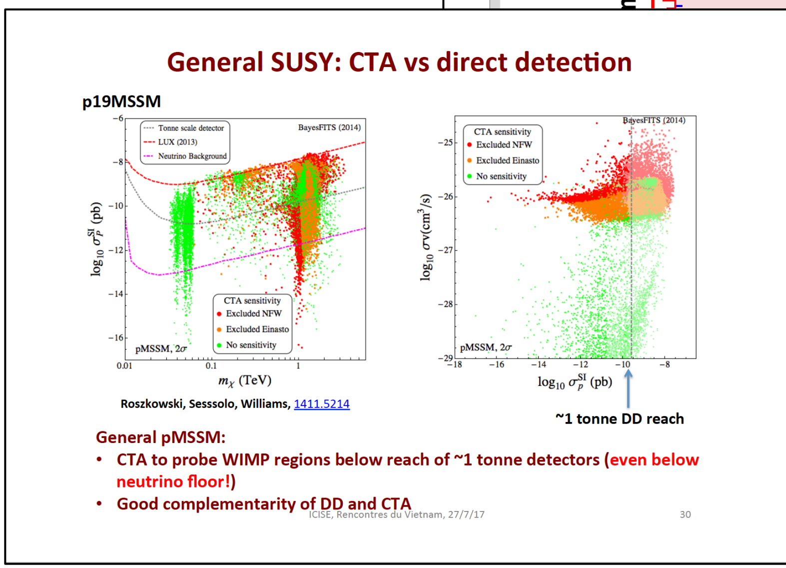
Axions & ALPS

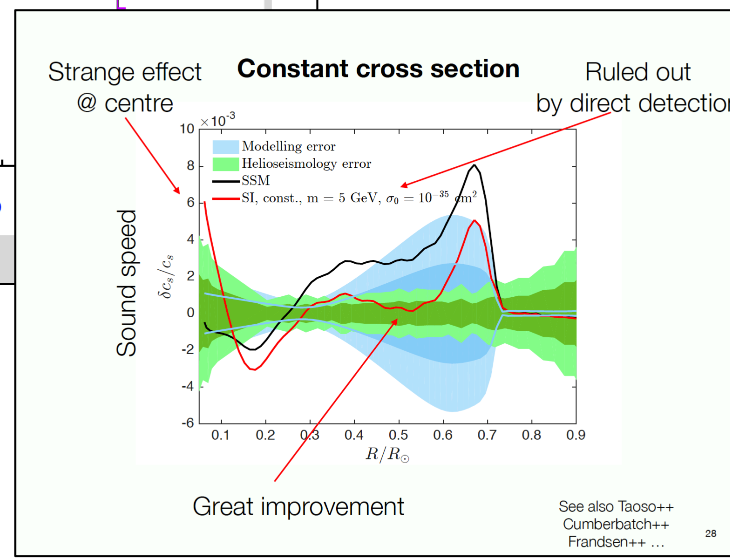
Spin-2 Fields

Asymmetric DM

New Models & Methods raises New Questions







Meta level: “Oh, XX is a rich model space, and in looking for it we are learning lots of new things”

Theme II: Communicating between Communities

- This conference brings together people for multiple communities:
  - Accelerator-based
  - Direct-detection
  - High-Energy Astronomy / Astrophysics
  - Cosmology
  - Particle Theory / phenomenology
- We all had to take a step back and focus on things that will be of interest to people outside our specific communities
  - I hope this talk follows in that spirit, i.e., I'm not going to be saying a lot about nano-Bq / kg, pseudo-rapidity cuts, or γ-ray telescope instrument response functions

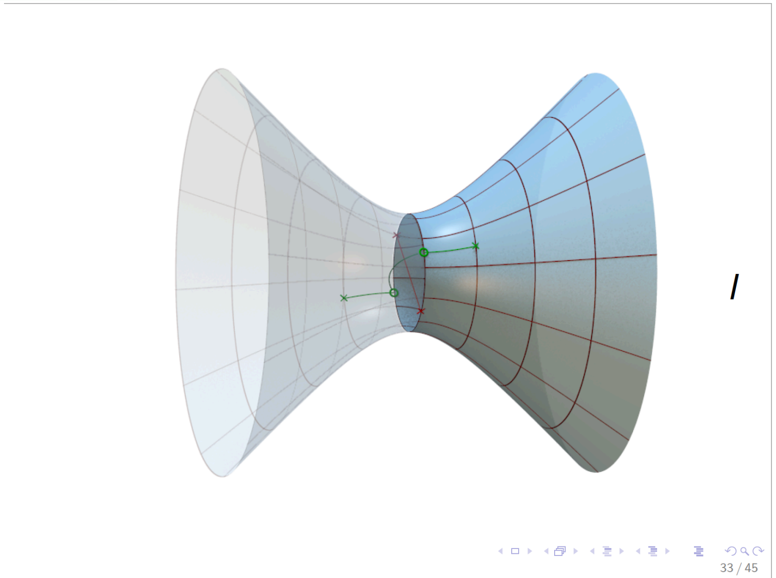
SCIENCE TOPICS

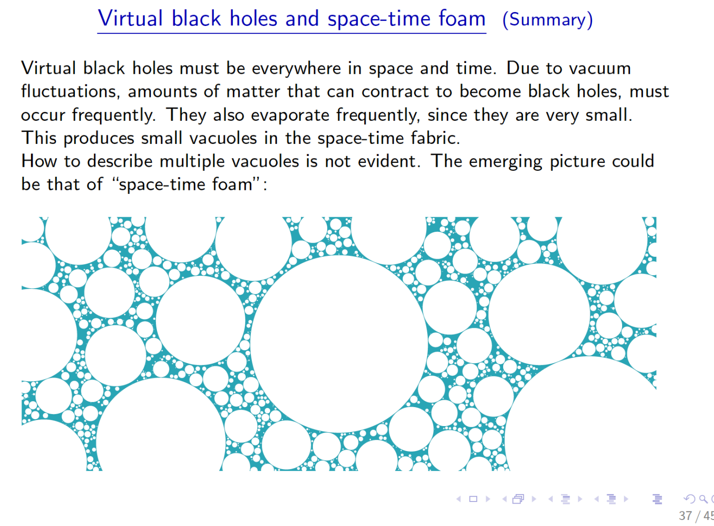
Topics Covered

- Intro & Keynote
- Dark matter theory
- Searches
  - Accelerator Searches
    - Light DM at e^+e^- colliders & fixed target experiments
    - Searches at the LHC
  - Direct detection:
    - Direct detection of WIMPs
    - Directional Detection
    - Direct detection of WISPs, ALPs & axions
  - Indirect detection:
    - Indirect detection with neutrinos
    - Indirect detection with γ rays
    - Indirect detection with charged particles
- Cosmology & Astrophysical Dark Matter

INTRO & KEYNOTE

Keynote Lecture by G. ‘t Hooft





- Explained motivation for fundamental new ingredients in quantum treatment of black holes: gravitational back reaction, spherical harmonics expansion of in-, out-going particles, antipodal identication.
- Some quotes:
  - “Space has become time, and time has become space”
  - “This is a pure state only if you combine universe 1 with universe 2”
  - “A time Mobius strip ... this rescues unitarity & causality."

Introduction

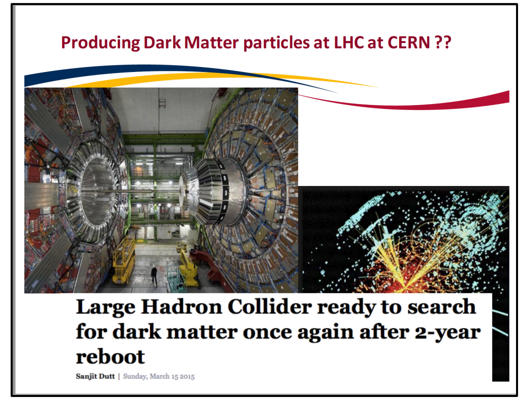
Gerbier

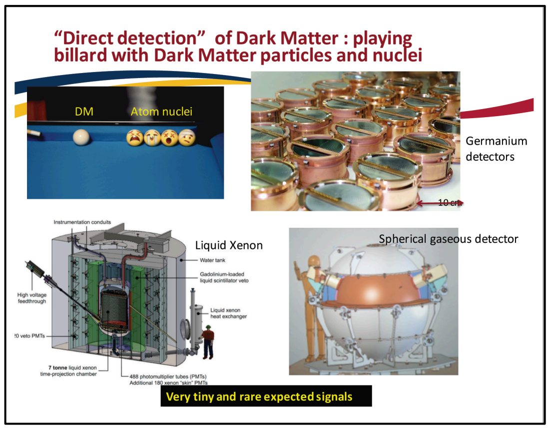
Will EDU2017 bring new lights on Dark Matter ?

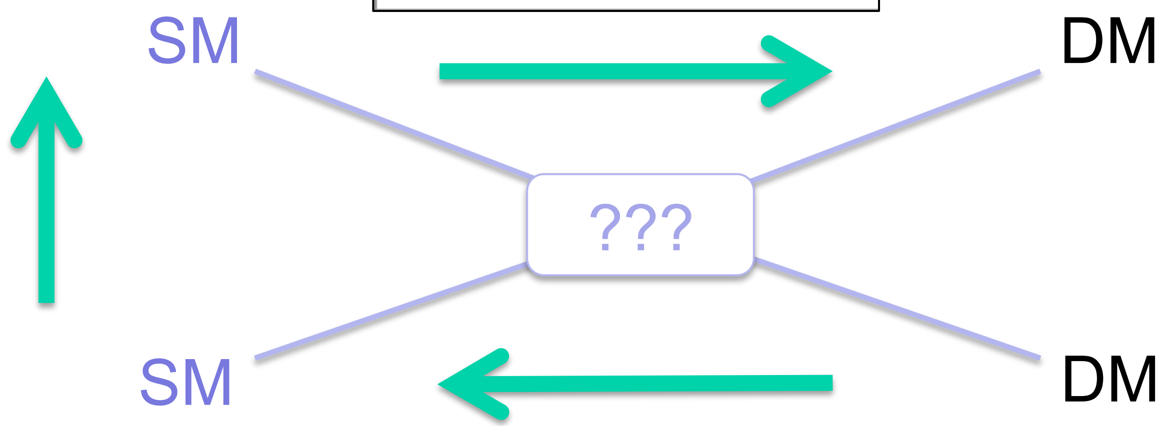
- Dark Matter has not yet been identified
- Here and now is EDU2017
- 75 participants
- 60 presentations on
  - Theories, models
  - Indirect detection of Dark Matter
  - Direct Detection of Dark Matter
  - Dark Matter production at accelerators (LHC, e+e-, fixed target…)
  - …
- We are going to learn …

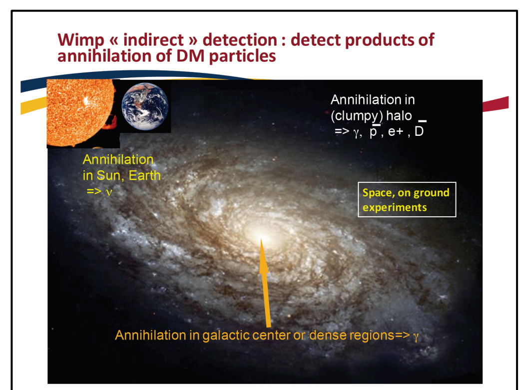
Direct, Indirect, Accelerator-based Searches

Gerbier





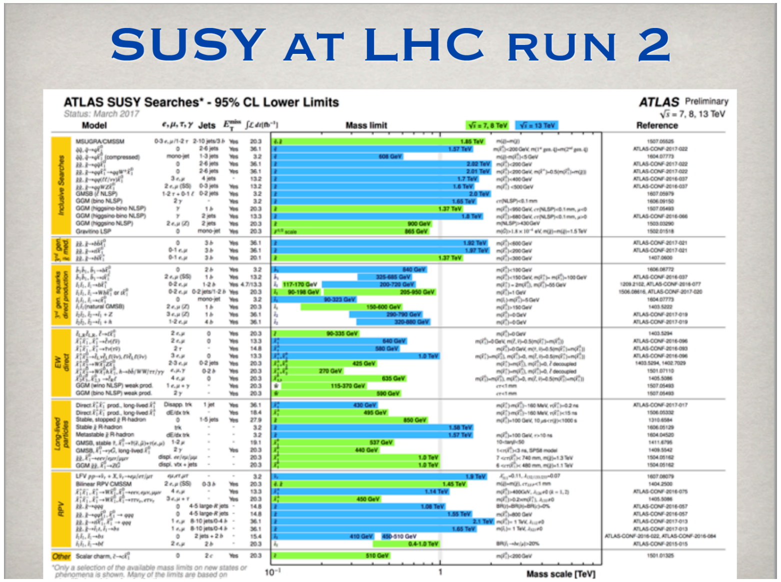


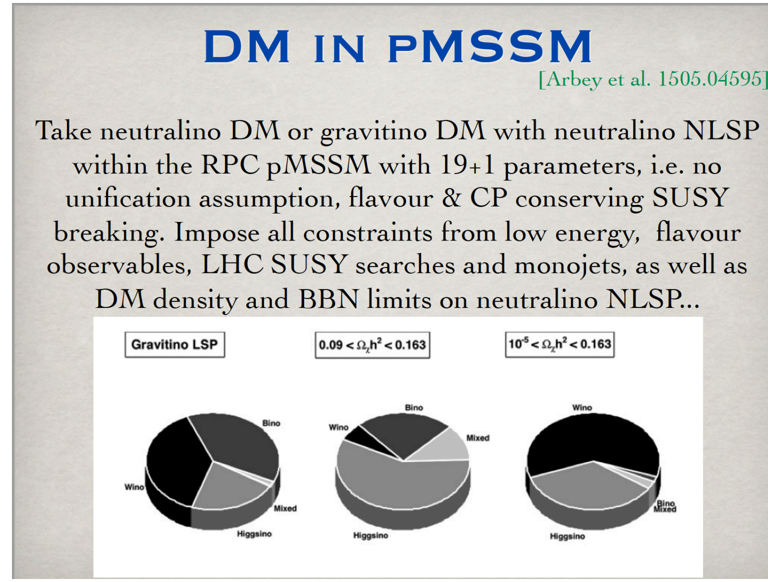


THEORY

SUSY Phenomenlogy

Covi





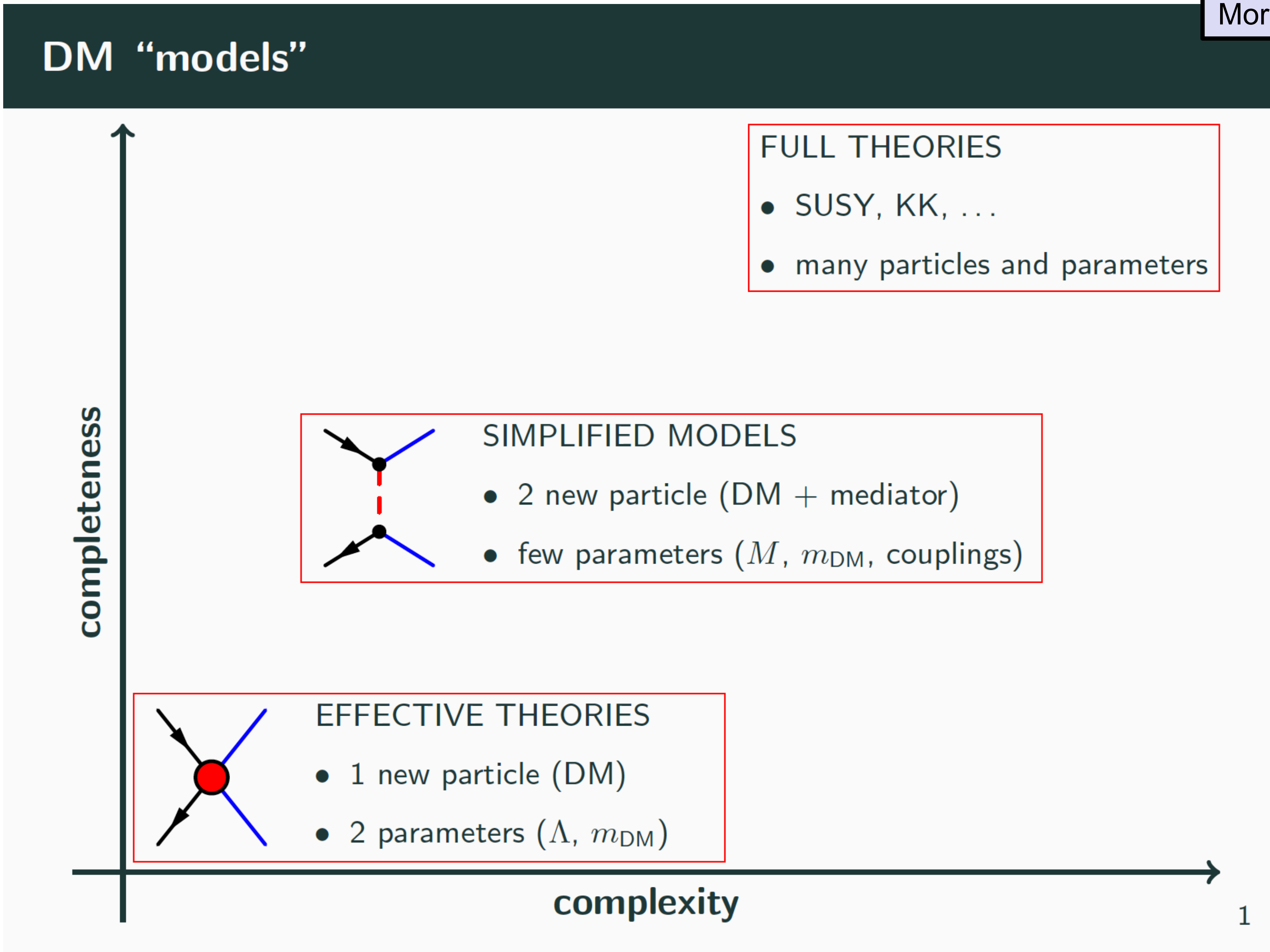
- Massive efforts underway to explore the massive SUSY parameter space
- Identify DM candidates (i.e., the lightest SUSY particle) for different scenarios
- Explore representative simplified models to probe SUSY space
- Combine LHC / direct detection / indirect detection / cosmological constraints (e.g., codes such as GAMBIT)

Scott

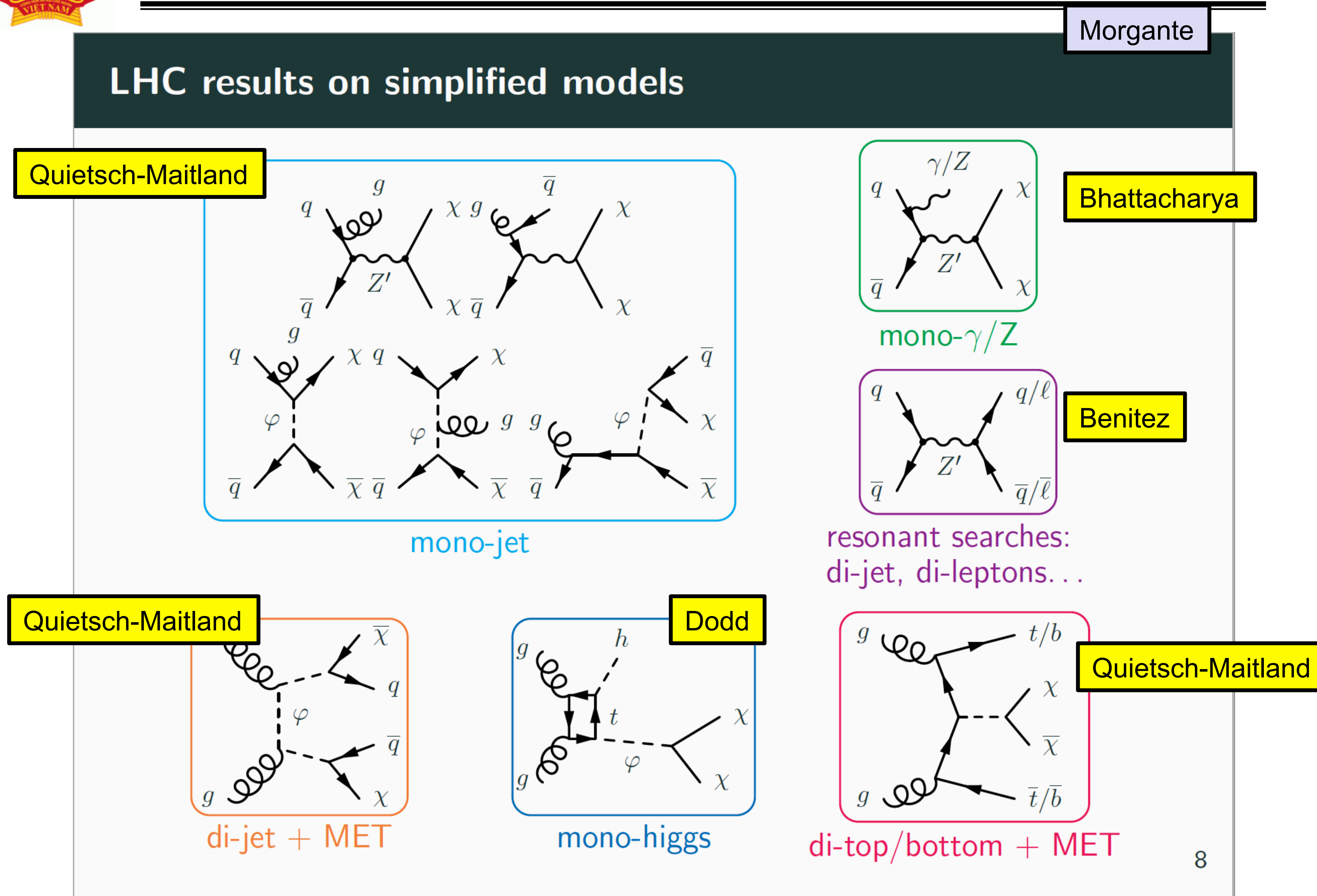
Felcini Morgante

Full Theories -> Simplified Models -> Effective Theories

Morgante



Simplified Models

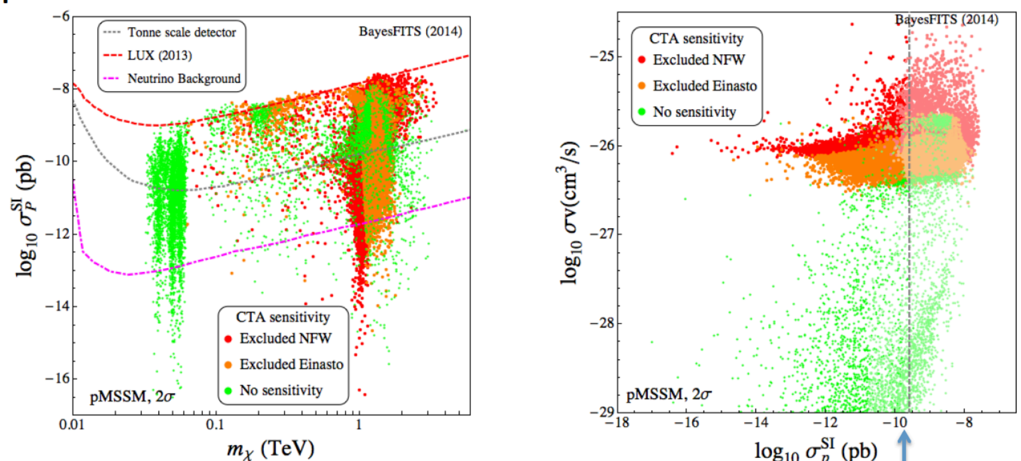


Light Higgs Favors High Mass SUSY

Roszkowski

General SUSY: CTA vs direct detection

p19MSSM



Roszkowski, Sesssolo, Williams, 1411.5214

~1 tonne DD reach

General pMSSM:

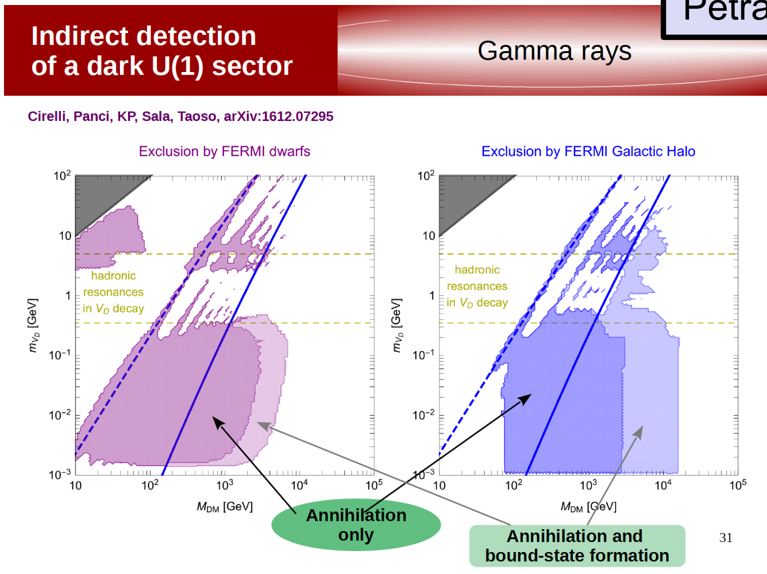
- CTA to probe WIMP regions below reach of ~1 tonne detectors (even below neutrino floor!)
- Good complementarity of DD and CTA

ICISE, Rencontres du Vietnam, 27/7/17 30

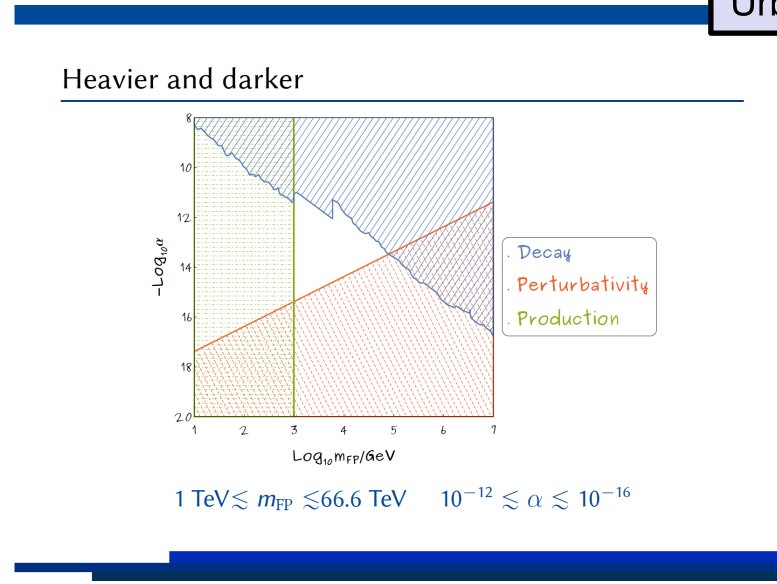
- For an optimistic, the low mass of the Higgs means that the favored SUSY mass scale is high, which helps to explain why we haven't seen it at LHC, and could be great news for Cerenkov Telescope Array (CTA)

Specific Theoretical Developments

Petraki



Urban



- Parts of parameters space for which DM interactions at LHC would be "long-range", implying bound states have important effect on phenomenology, boosting the LHC mass reach Petraki
- Self consistent solutions where spin 2 fields behave as DM. Available parameters space could be closed with factor of 100 improvement in limits on DM decay Urban
- PeV DM is feasible in rich dark sector theories and should be explored in more detail Sala

SEARCHES

DIRECT DETECTION

DM Scattering Produces Heat, Light & Ions

Masbou

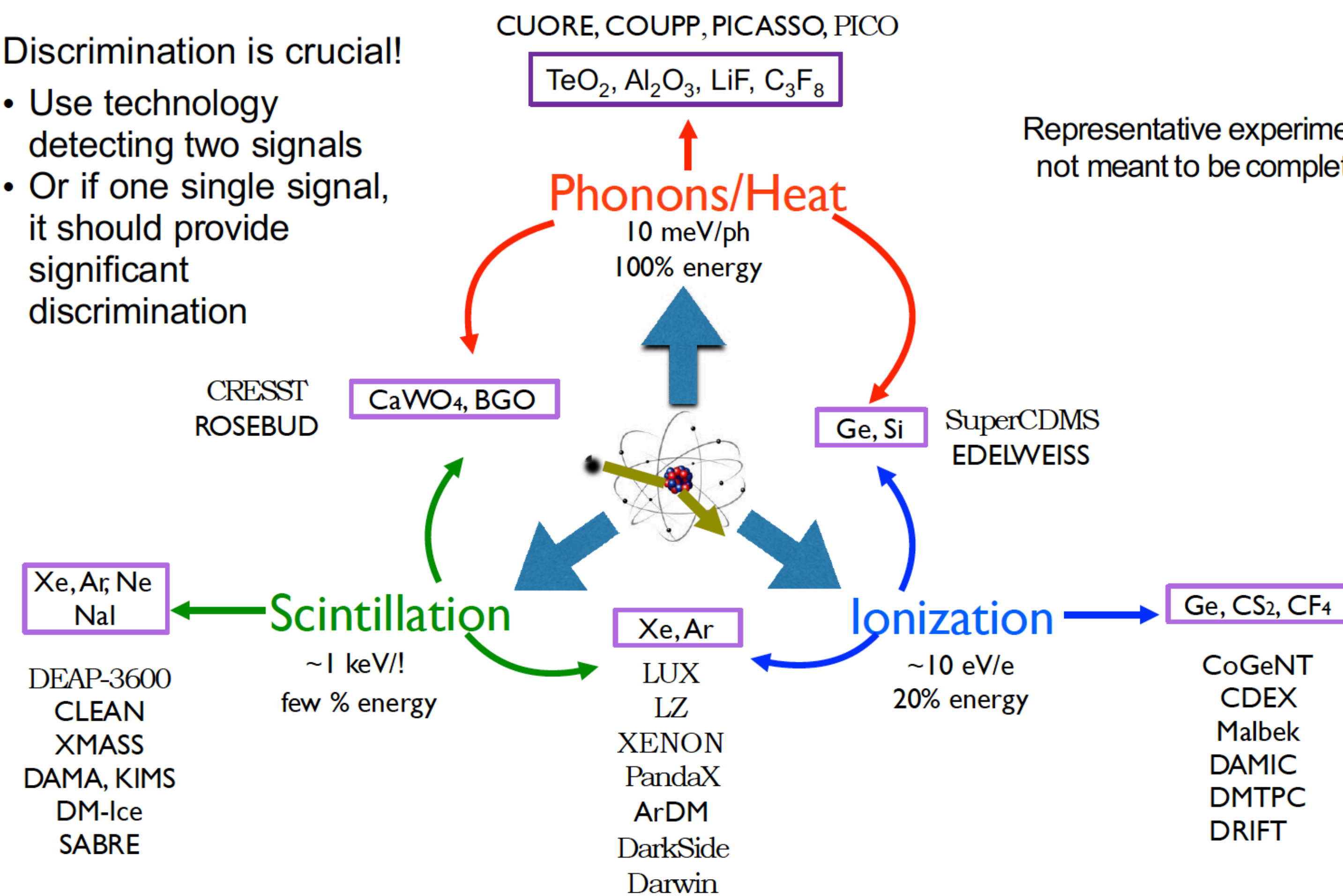
Direct Detection Techniques

from Carmen Carmona

Discrimination is crucial!

- Use technology detecting two signals
- Or if one single signal, it should provide significant discrimination

Representative experiments, not meant to be completed



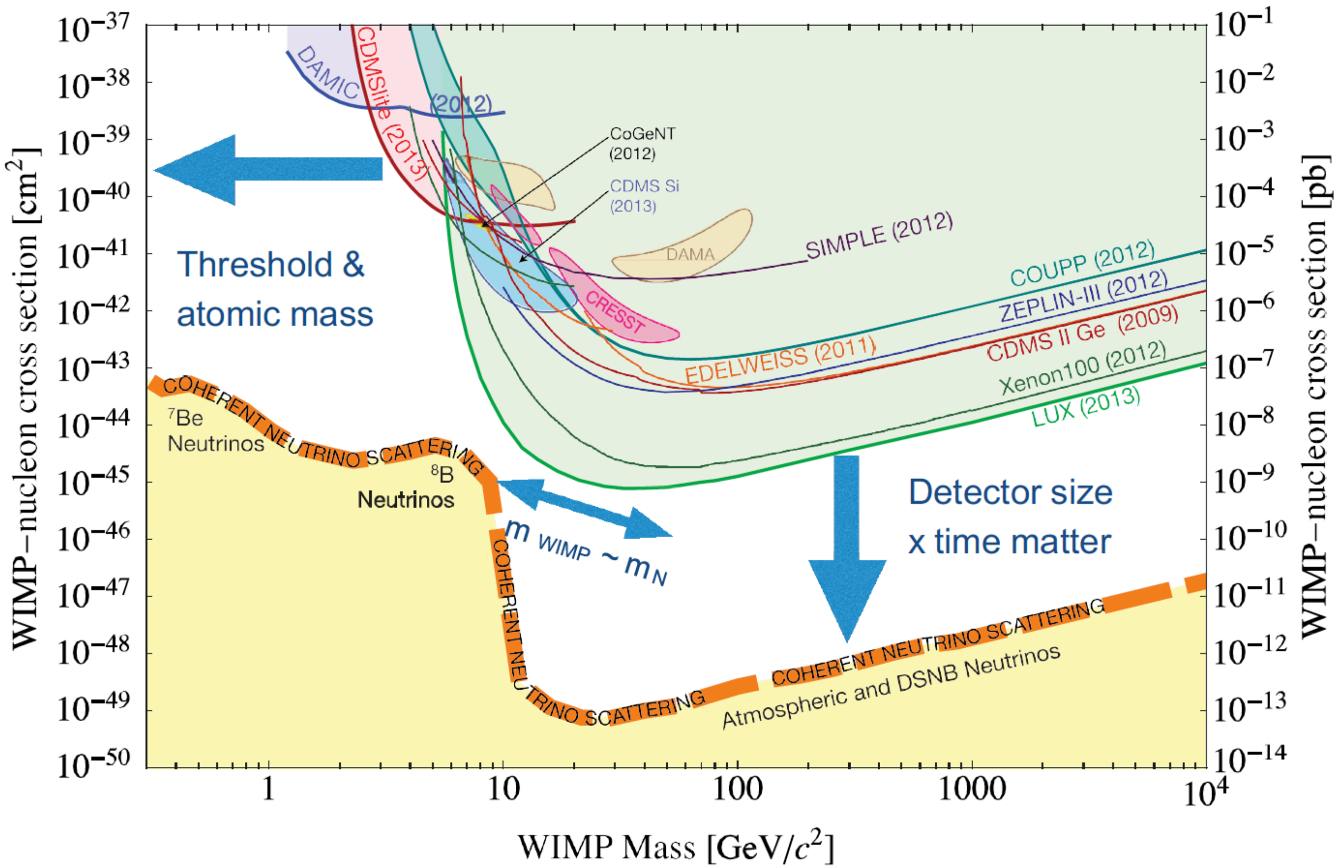
Julien Masbou, EDU 2017, Quy Nhon, 25th July 2017

Current Status of Direct Detection

Masbou

How is evolving the field of Direct Detection ?

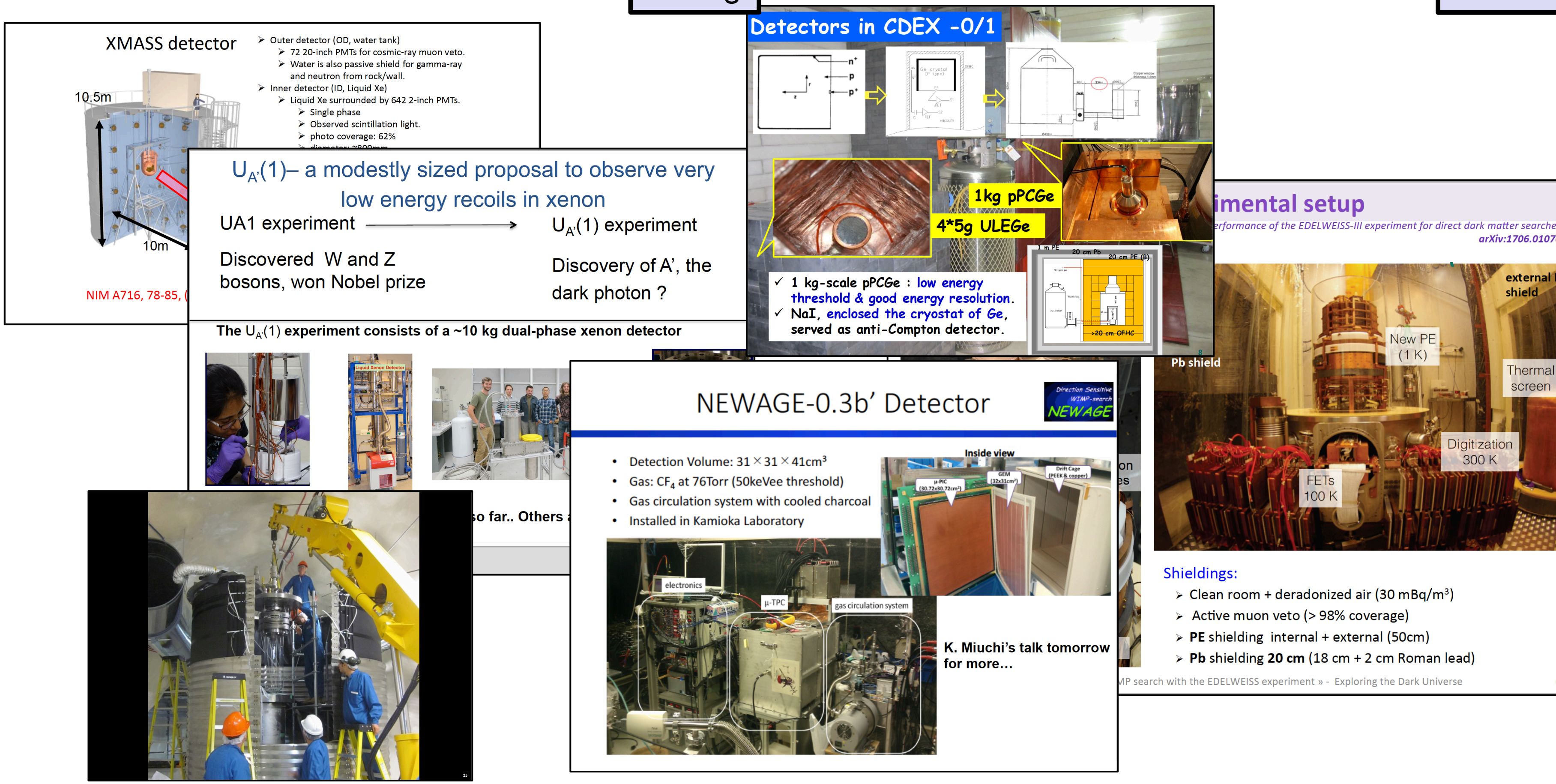
$$R \sim 0.13 \frac{\text{events}}{\text{kg . year}} \left[\frac{A}{100} \times \frac{\sigma_{\chi N}}{10^{-38}\ \text{cm}^2} \times \frac{\langle v \rangle}{220\ \text{km.s}^{-1}} \times \frac{\rho_\odot}{0.3\ \text{GeV.cm}^{-3}} \right]$$



Impressive Efforts to Address Instrumentation Challenges

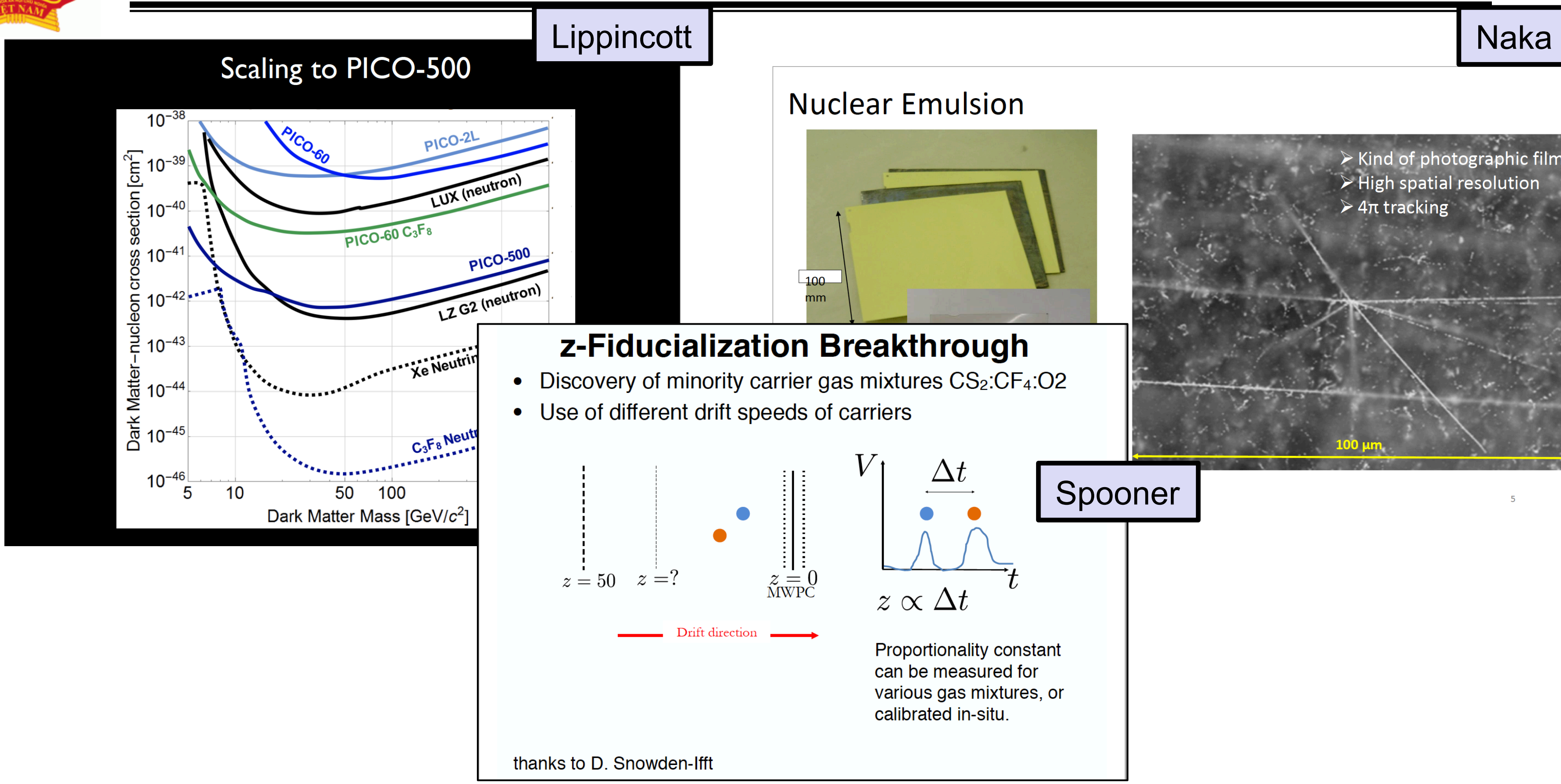
Chung

Oblath



- Common themes: reducing background radiation, thermal noise, increasing fiducial volume, mixing new and tested technologies

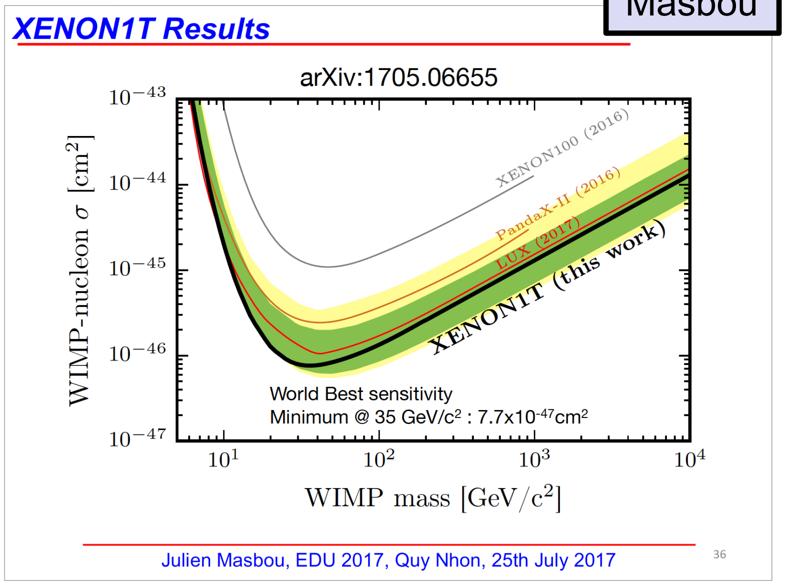
Some Developments that Stood Out (for me)



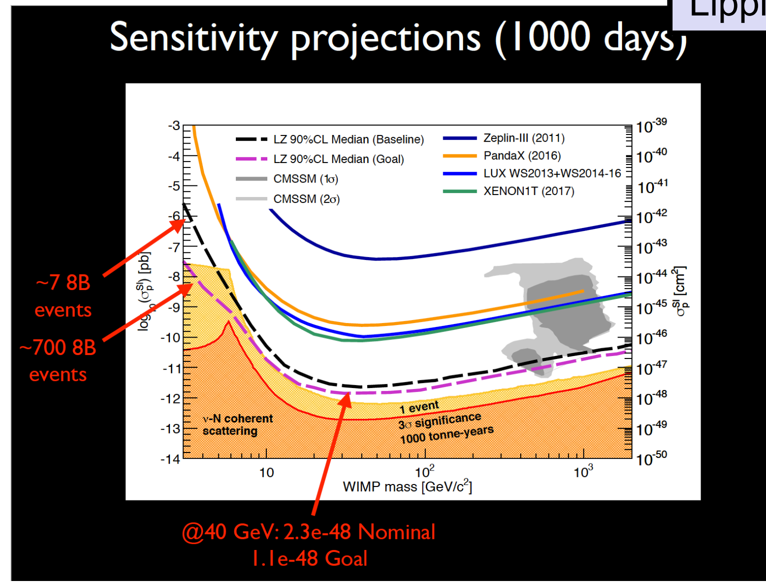
- ν-floor is much lower for C_3F_8 than for Xe
- Using resonance effect to go beyond diffractive limit in emulsion resolution
- Adding minority carriers to measure drift time start time (z-position)

Direct Detection: High-Mass WIMP Searches

Masbou



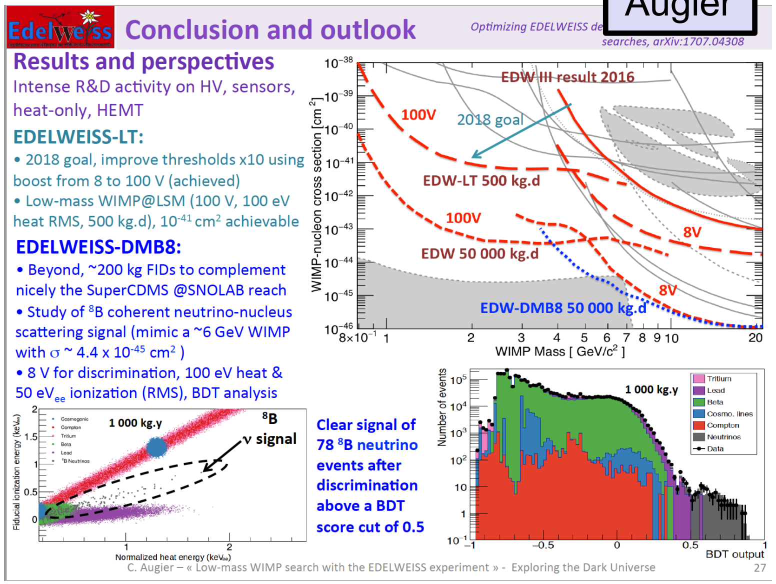
Lippincott



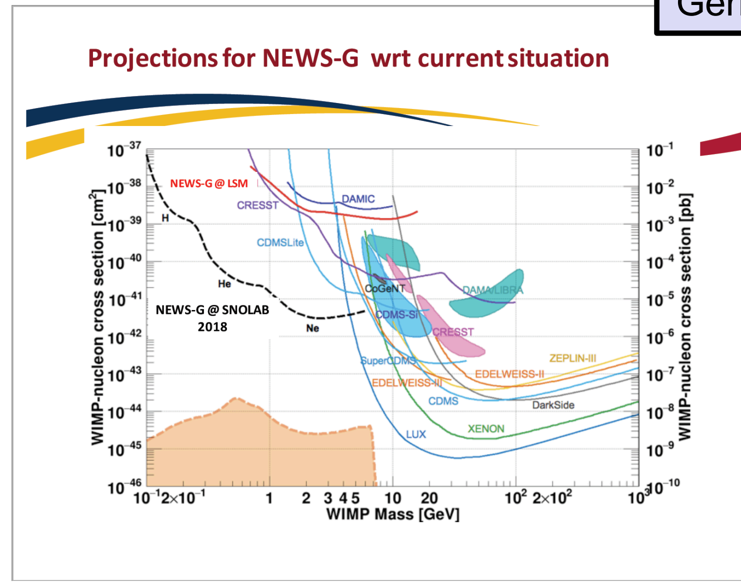
- Flagship liquid noble detectors continue to bravely push down to the neutrino floor
- Given the background level required, this is a truly impressive achievement

Direct Detection: Low-Mass WIMP Searches

Augier



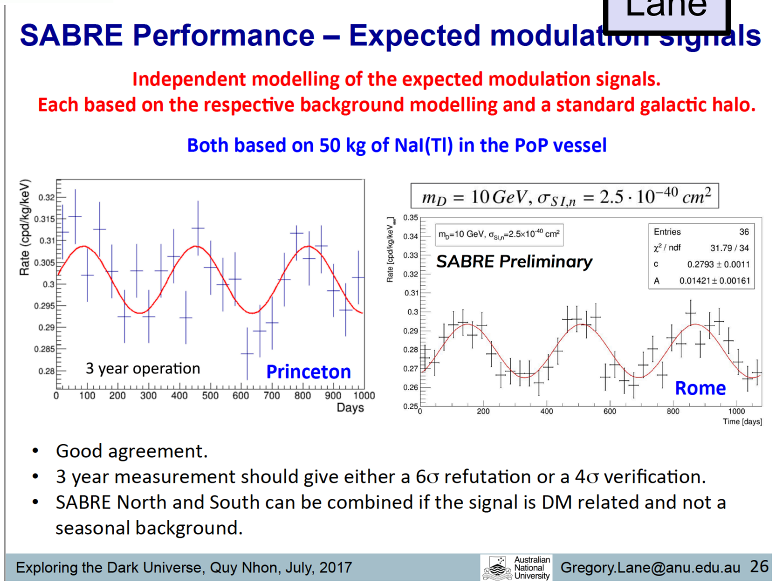
Gerbier



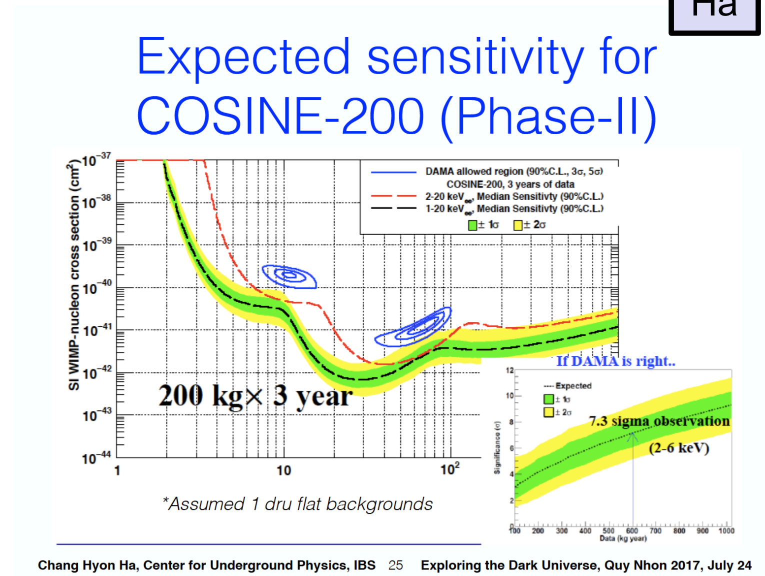
- For low-mass WIMP searches the main goal is to lower the threshold and push down to lower masses
- Technically, this means lowering the threshold for measuring ionization or heat deposition
- We expect orders of magnitude improvement in cross-section sensitivity in the 1-10 GeV mass range

Direct Detection: DAMA / LIBRA

Lane



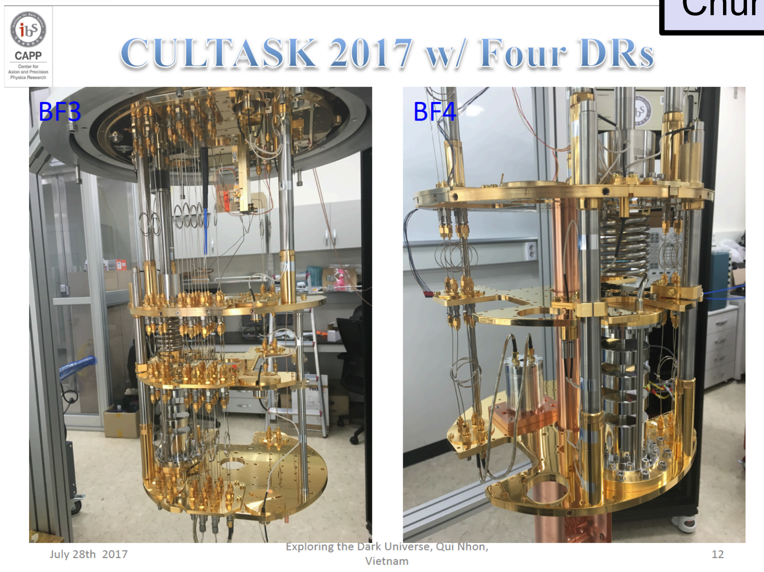
Ha



- Several experiments are reproducing DAMA / LIBRA scenario with increasing fidelity
- Expect to probe DAMA / LIBRA signal region with almost identical setup in next few year
    - This will test explanations offered for tension between DAMA / LIBRA signal region and exclusion regions of other experiments

Direct Detection: Axions & Axion Like Particles

Chung



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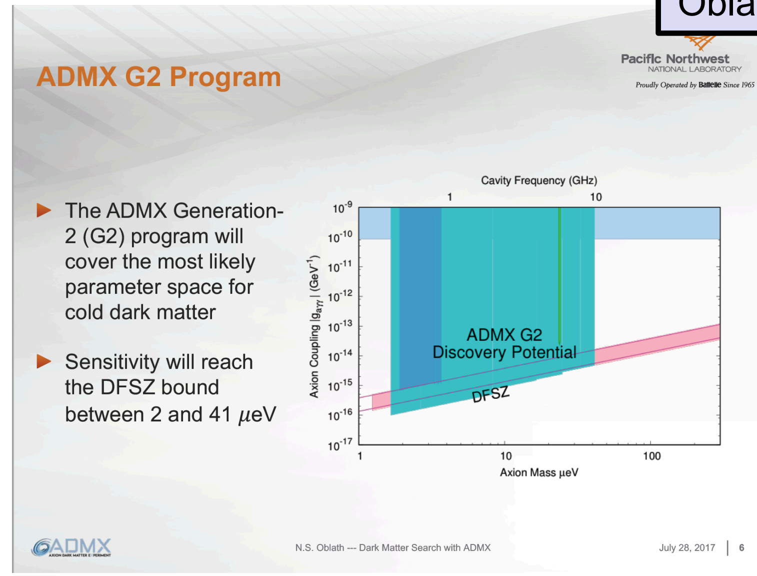


- Low-mass Axions (~μeV) more “field-like” that “particle-like”
- Haloscopes: couple to local axions or axion-like particles in Galactic halo using tunable microwave resonating cavities and magnetic fields
- ADMX-2 will probe coupling-mass plane in region that would produce DM at the relic density between 2 – 41 μeV

Direct Detection: Light Shining through a Wall

Ballou

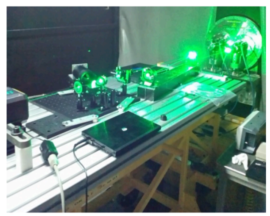
OSQAR LSW Experiment

Use of two standard spare magnets for LHC at the CERN SM18 magnet testing hall, where cryogenics for magnet cooling (1.9 K) and vacuum facilities are available and are provided. The 2 dipoles are aligned at warm conditions cooled down, cold tested and finally powered.

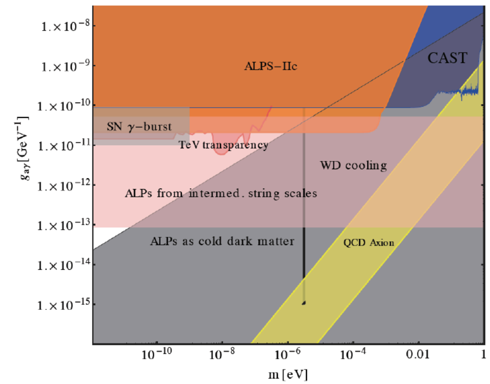
B = 9 T over effective **L = 14.3 m**

Photon Source: COHERENT Verdi V18 CW Laser
λ = **532 nm (2.3 eV)** - Optical power : **18.5 W**

Photon beam is linearly polarized with $\vec{E}_\gamma \parallel \vec{B}$
Search for pseudoscalar ALPs
Use of a $\lambda/2$ wave plate for polarization $\vec{E}_\gamma \perp \vec{B}$
Search for scalar ALPs
Use of beam expander telescope to reduce the Laser beam divergence.



Scientific impact of the expected sensitivity reach of the final stage of ALPS-II



ALPS-II will surpass CAST in the lower mass region.

ALPS-II will reach bounds set from astrophysical considerations (1987a super-nova gamma burst, TeV transparency of the universe, WD cooling, ...)

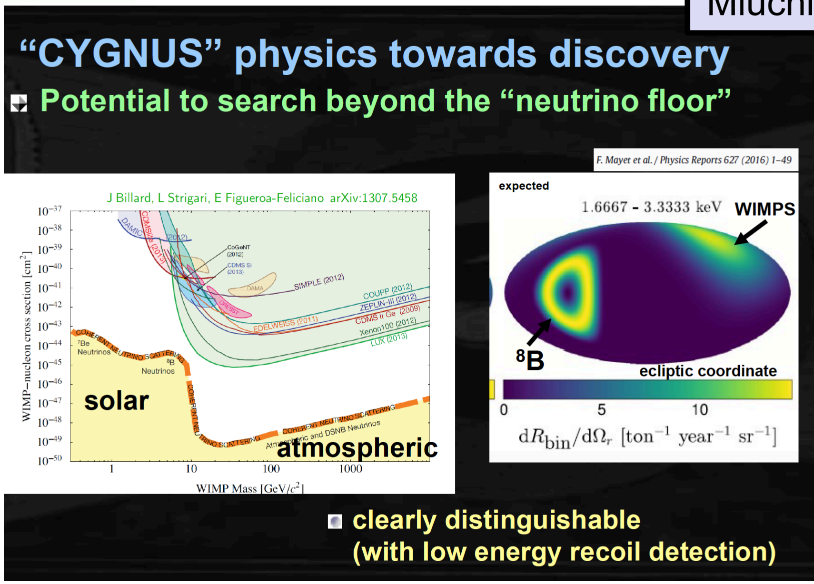
ALPS-II will tackle the un-colored and gray (DM) parameter region of ALPs predicted in string theory motivated SM extensions.

ALPS II Technical Design Report arXiv:1302.5647

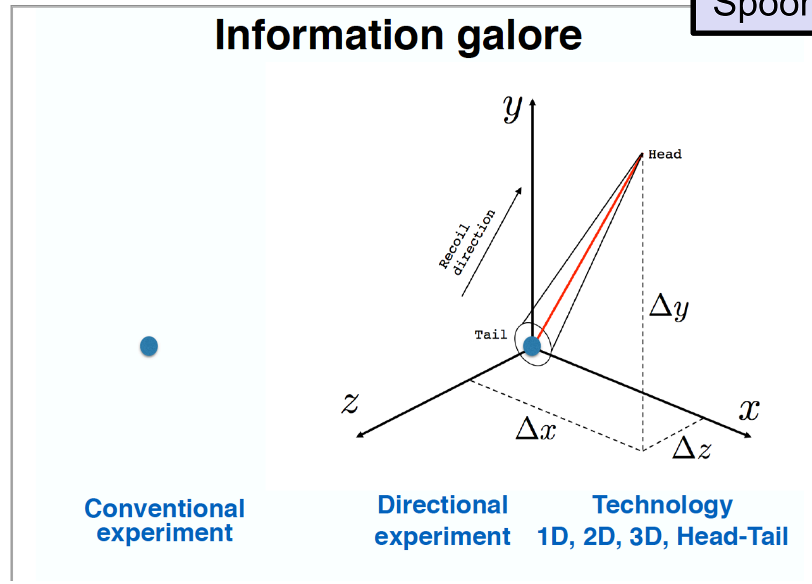
- Light Shining through a Wall: use powerful magnetic fields to convert photons to axions and back so that they can pass an optical barrier
- Current sensitivity not as good as Helioscopes (e.g., CAST), but ALPS-II upgrade would read CAST sensitivity as well as parts of cosmologically significant region

Direct Detection: Directional Detectors

Miuchi



Spooner

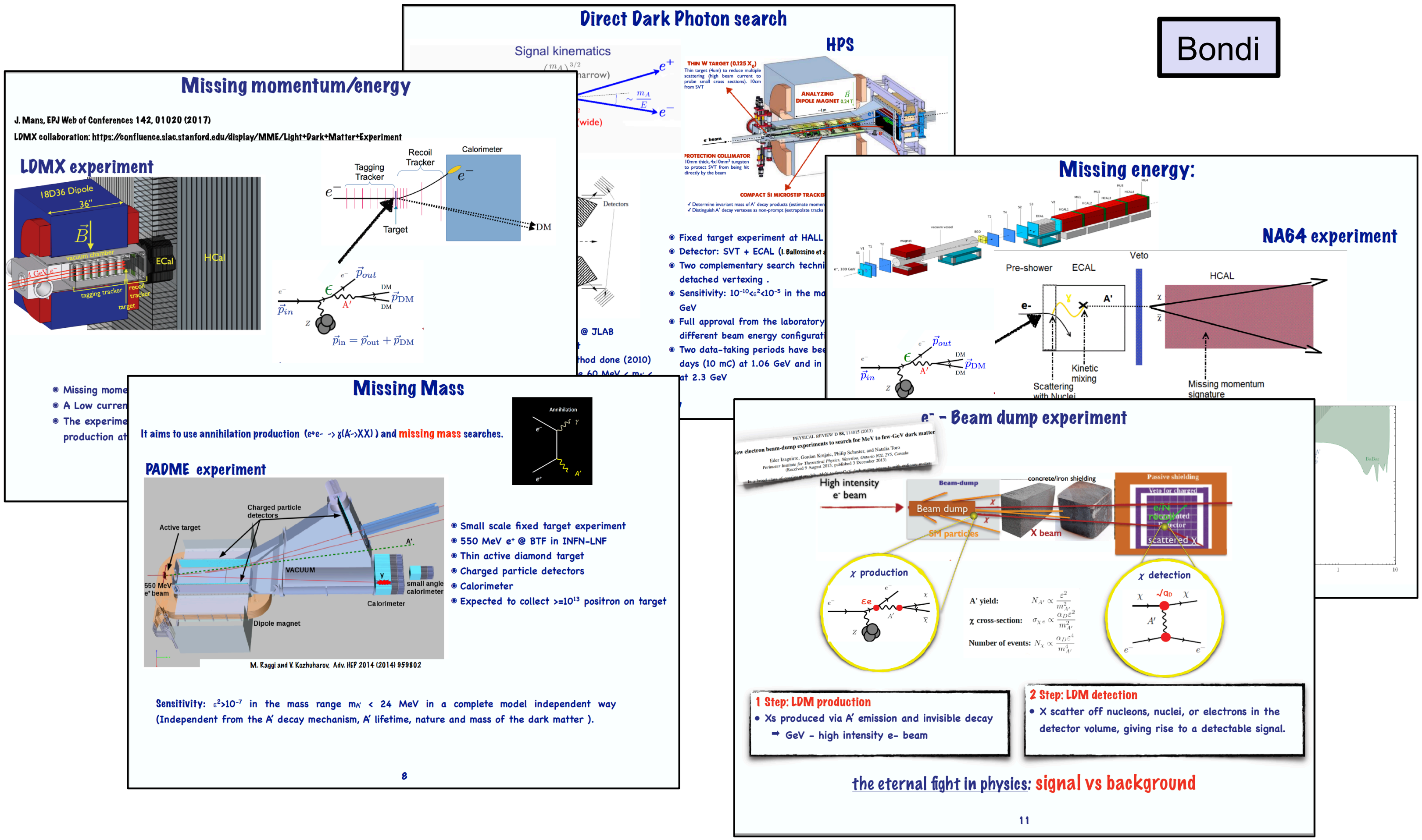


- Directional detection: measure direction of recoiling electon or neutron
- Fundament challenge: extracting enough information to estimate direction before recoil particle direction is randomized by multiple scattering
  - This gets harder as the recoil energy goes down
- Gas approach: decrease the density of the target
  - Works, but reduces the target mass tremendously
- Other approaches: increasing the tracking resolution
  - This is hard, we are already very good at tracking

ACCELERATOR SEARCHES

Low Mass DM Searches

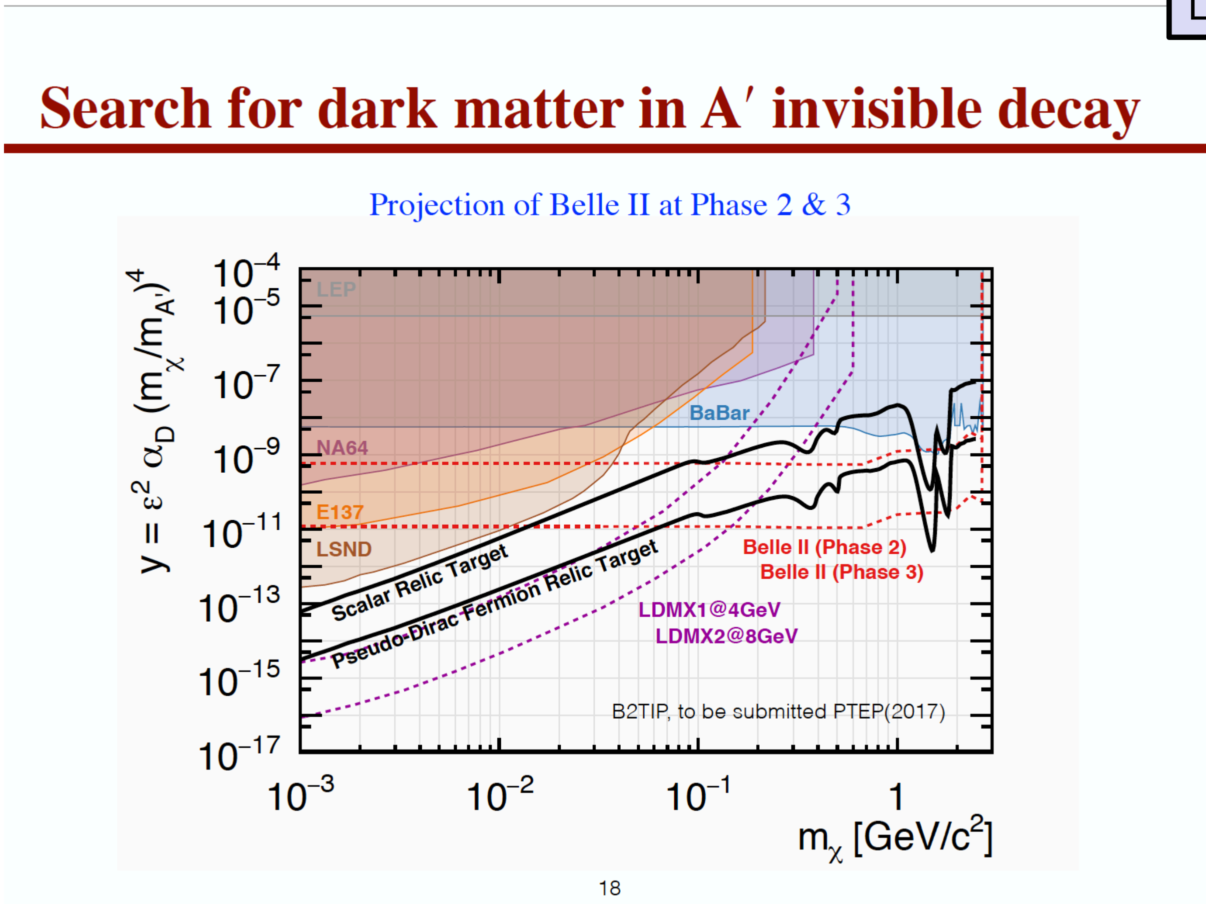
Bondi



- Very nice summary talk describing numerous accelerator-based low mass DM searches probing "Heavy Photon" at 1-1000 MeV scale
- Complementary approaches: missing mass, energy, momentum, direct search for dark photons

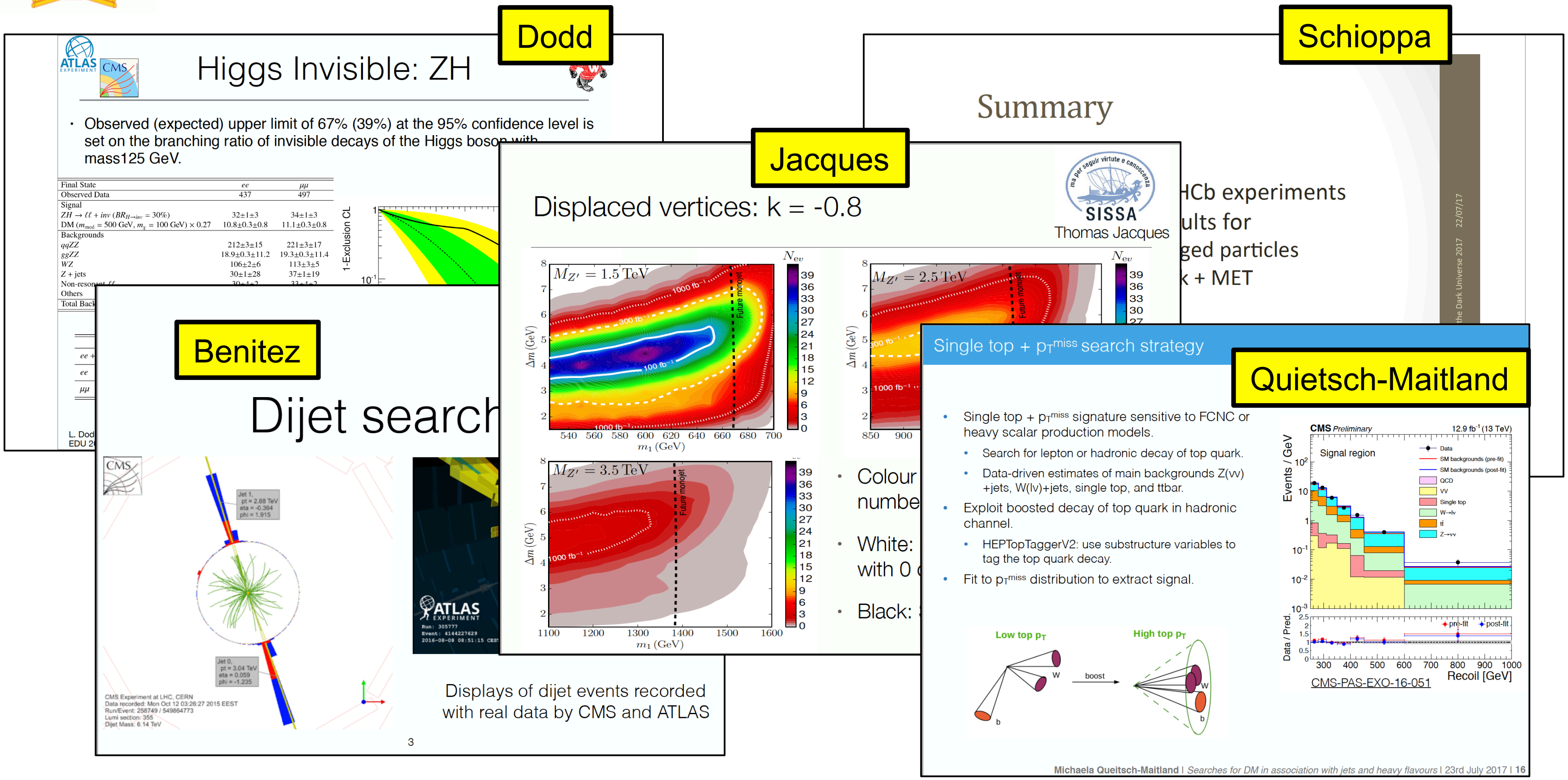
Light Dark Matter at e+e- Colliders

Li



- A’ invisible decay (search for bump in recoil mass spectrum)
- A’ decay to leptons (spectrum of γe^+e^-, $\gamma\mu^+\mu^-$ doesn’t match QED)
- Also sensitive to axions / axion like particles

DM / SUSY Searches at the LHC



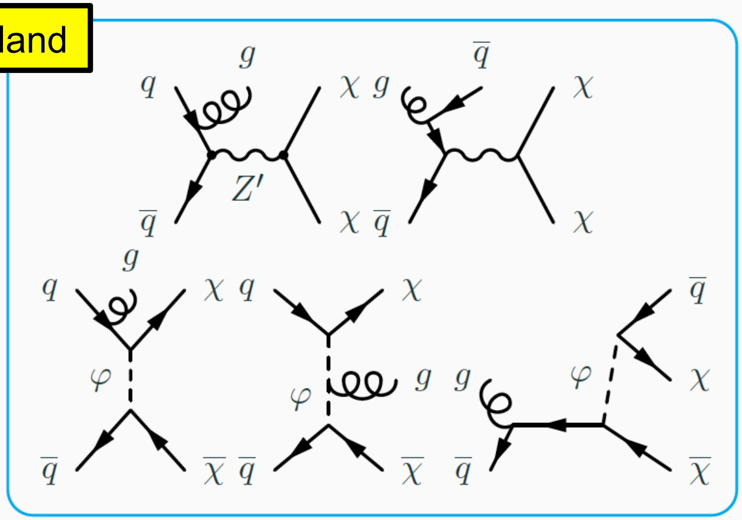
- Several talks about searches for different topological signatures at the LHC
- As an outsider, biggest questions are: how they all tie together, and what are the implications for WIMPs as DM

Simplified Models

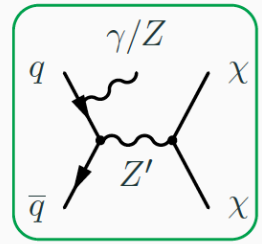
Morgante

LHC results on simplified models

Quietsch-Maitland

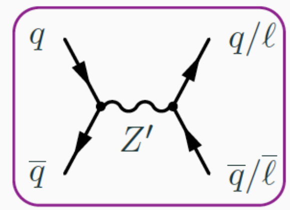


mono-jet



mono-γ/Z

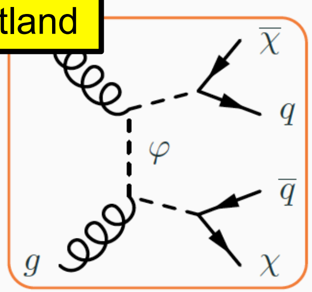
Bhattacharya



resonant searches:
di-jet, di-leptons. . .

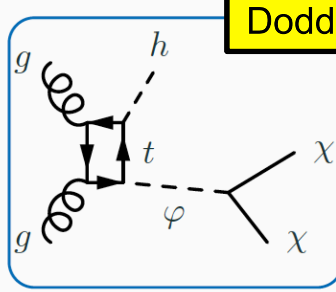
Benitez

Quietsch-Maitland

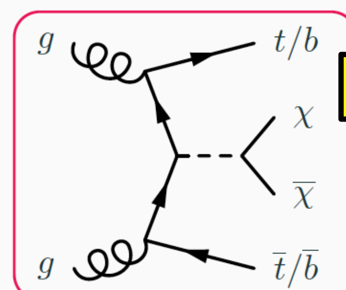


di-jet + MET

Dodd



mono-higgs



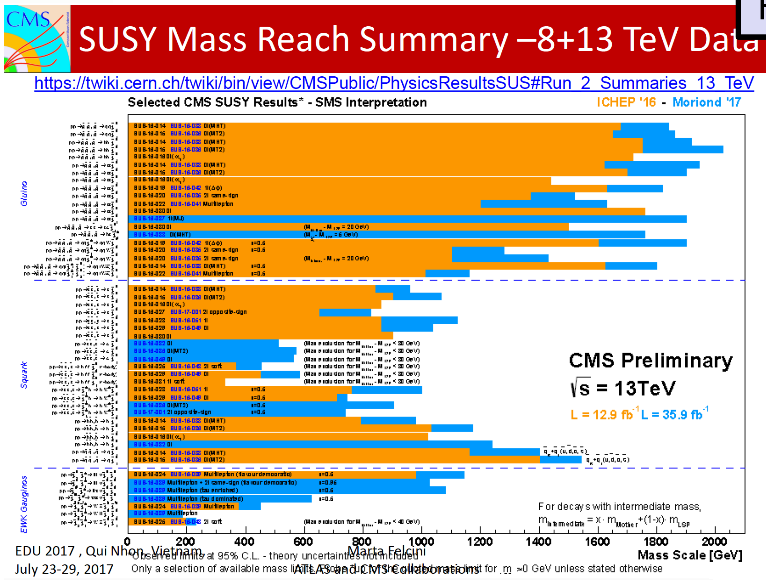
di-top/bottom + MET

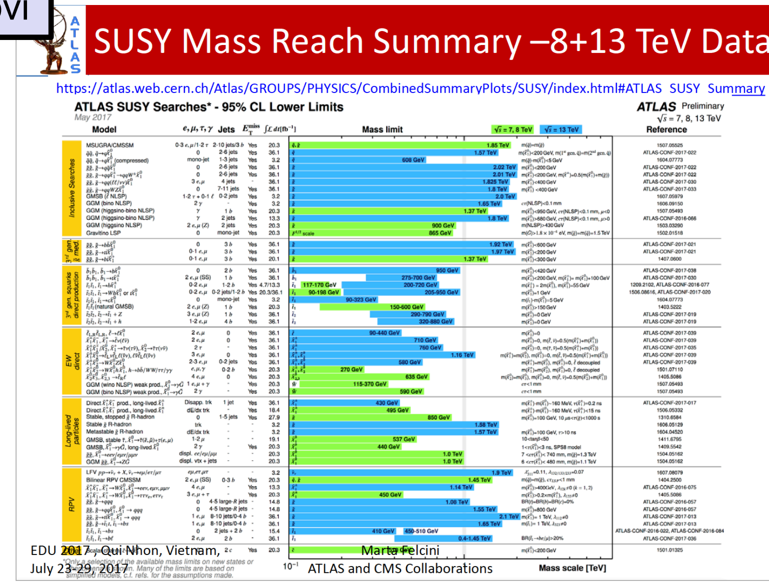
Quietsch-Maitland

8

Making Sense of all the LHC SUSY Searches

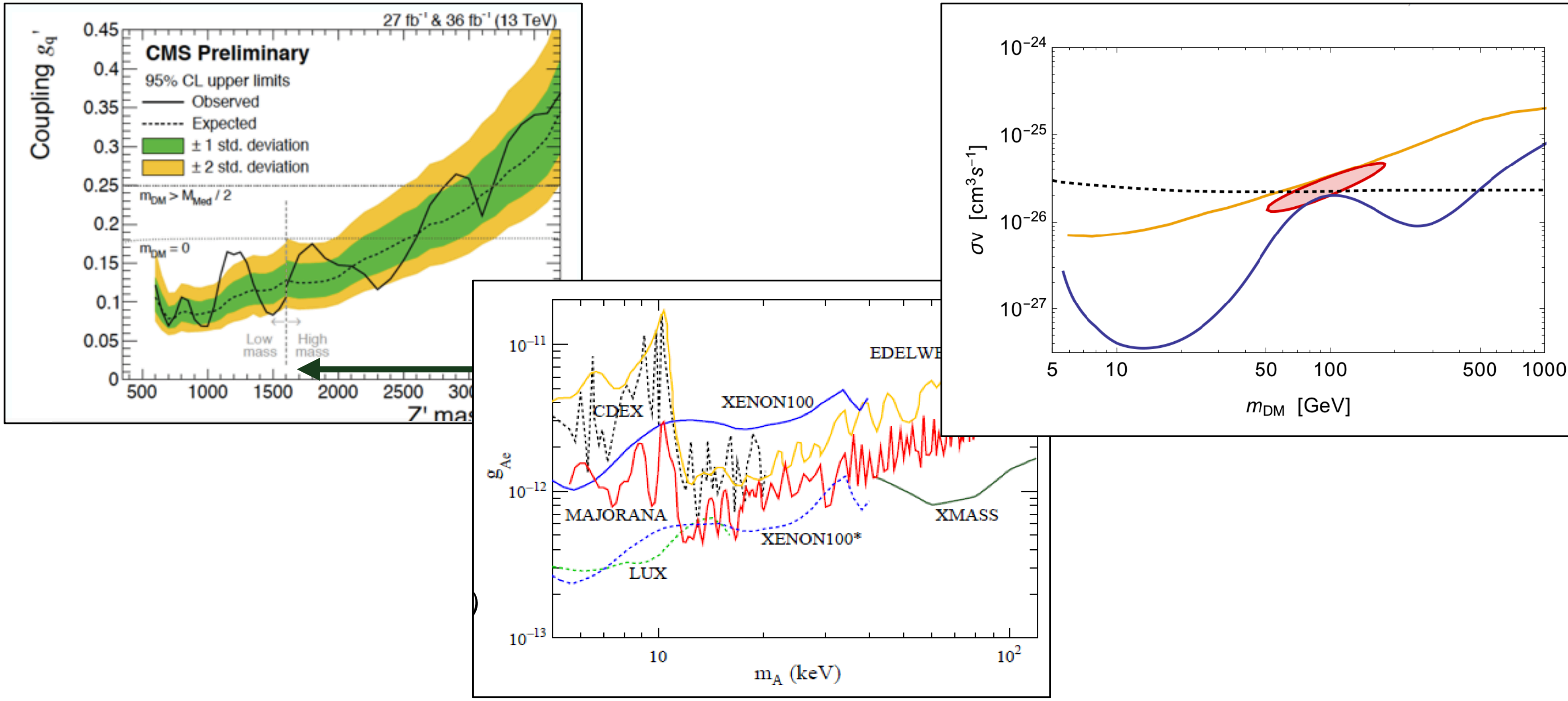
Felcini, Covi





- Complementary talks walking us through the implications of the numbers SUSY searches performed at the LHC:
  - From experimental perspective, in the simplified model space, looking for particular topological signatures **Felcini**
  - From the theoretical perspective, in SUSY parameters space, asking which particle is the LSP and hence the DM candidate **Covi**

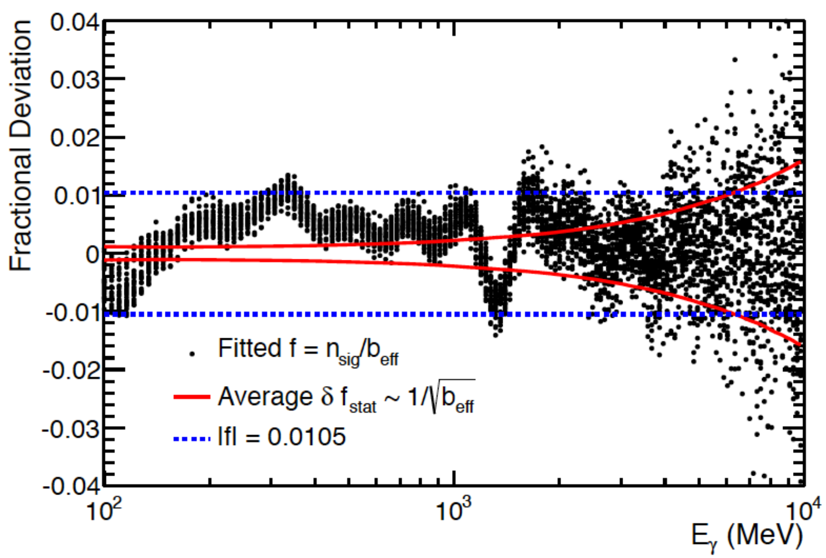
Aside: Spectral Features in Limit Curves

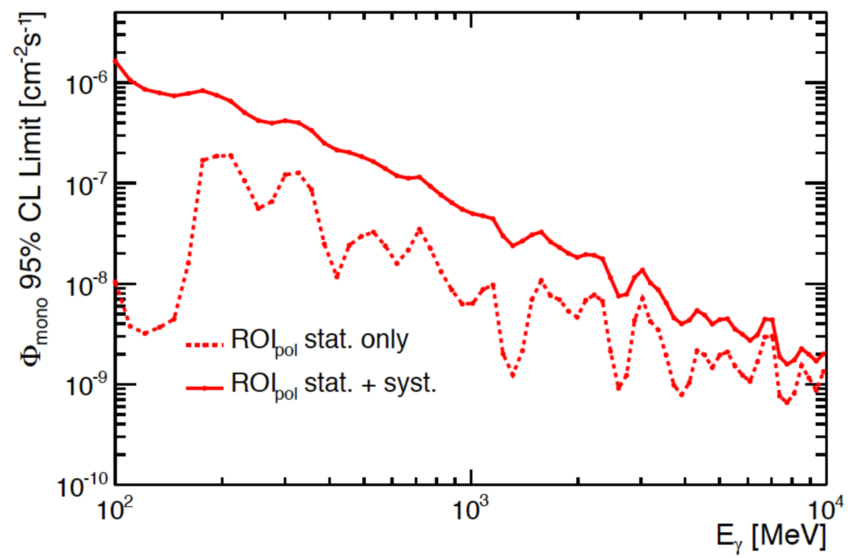


- Structured features in limit curves can indicate systematic limitations in the background modeling
- E.g., the background spectral model isn't quite right, or the empercially fit background model parameters are under-constrained & correlated with the signal

Aside: Spectral Features in Limit Curves

arXiv:1406.3430v1 (also: 1704.05458v1)





- Search for low-mass spectral lines with Fermi-LAT (in systematics dominated region)
- Use negative control, i.e., fits for signal in region where there should be no signal, to establish level at which model uncertainties can fake (or mask) a signal
- Apply this to constrain a nuisance "template" in the fitting procedure, reducing the significance of any signal at or below the systematic level

SUSY Status Update

Covi

OUTLOOK

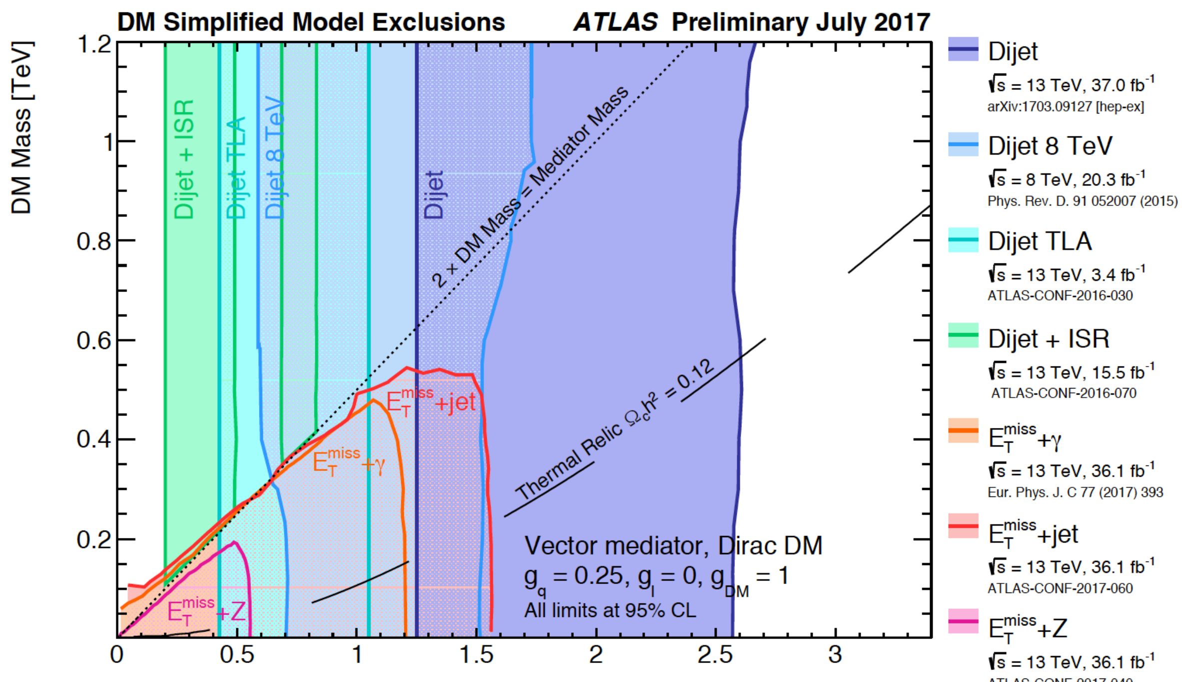
- Supersymmetry is too rich a theory to be easily excluded... Very different DM candidates are possible with various signatures !
- Nevertheless the simplest models of supersymmetric Dark Matter like Bino in the CMSSM are under siege and survive only in corners of the parameter space.
- On the other side Wino Dark Matter is also challenged by indirect detection thanks to the Sommerfeld enhancement.
- For gravitino Dark Matter a lot of parameter space is still viable, but the window for thermal leptogenesis may be closed soon by the LHC, if the gluino is not seen below ~2 TeV.
- Cosmologically though there are advantages to heavy SUSY, like scenarios for baryogenesis in RPV with gravitino DM !

DM Implications of LHC Searches

ALL LHC Talks

Summary vector mediator

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults



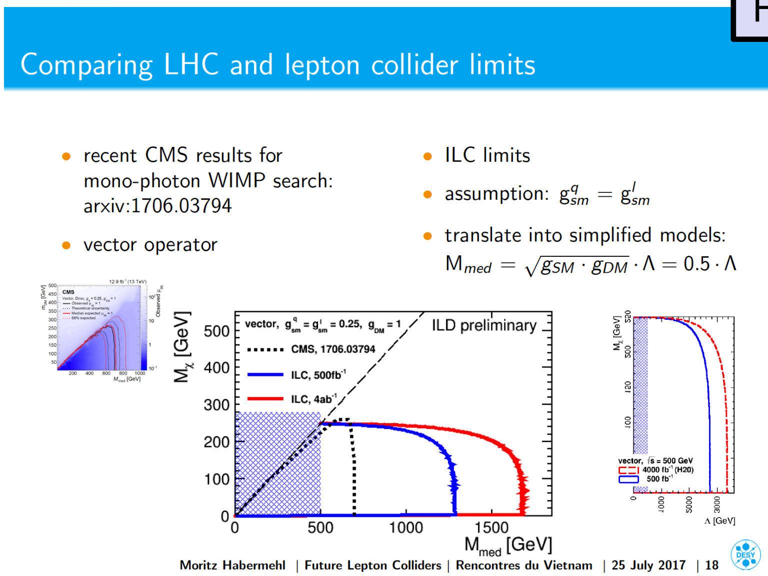
Note: Interplay of analysis sensitivity very model dependent

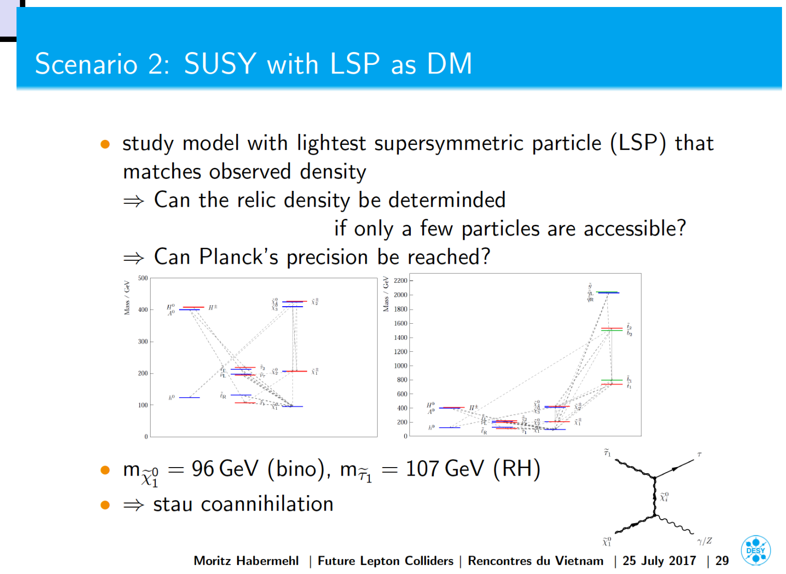
Michaela Queitsch-Maitland | *Searches for DM in association with jets and heavy flavours* | 23rd July 2017 | **21**

- Mono-jet search (red) looks for missing transverse energy from DM particle but is limited high missing energy cut need to reduce background
- Di-jet search (blue) looks for DM mediator particle producing pairs of SM particles and can reach higher energies

DM at future e$^+$e$^-$ colliders

Habermehl



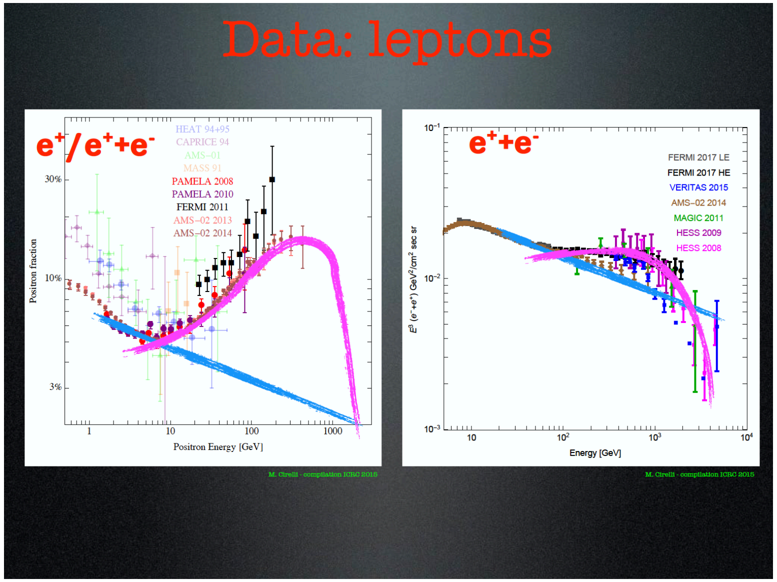


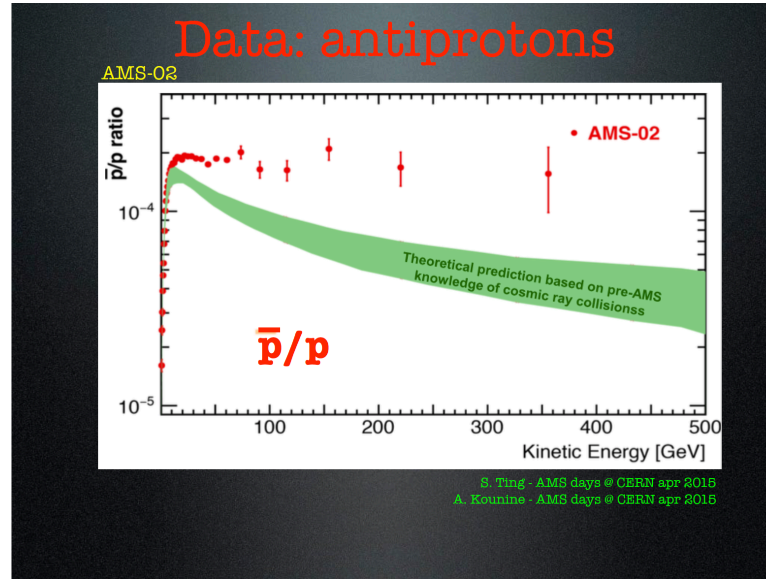
- Study covered 4 different e$^+$e$^-$ collider scenarios, 2 storage rings and 2 linear colliders
- Test coupling to leptons
  - complementary to LHC and direct detection searches
- In event of SUSY discovery we can expect to determine relic density with few percent precision (similar to Planck)

INDIRECT DETECTION

Indirect Detection with Charged Particles

Cirelli



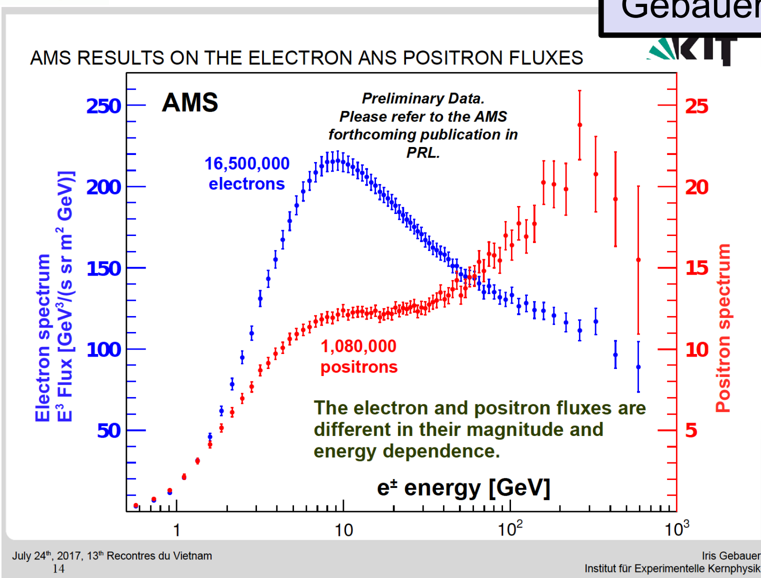


- Two spectral features that have generated excitement as potential dark matter signals:
  - Increase of positron fraction / spectral bump in total $e^+ + e^-$ spectrum above 10 GeV up to ~TeV Gebauer, Boudaud
  - Flatness of anti-proton to proton ratio above the geomagnetic cutoff

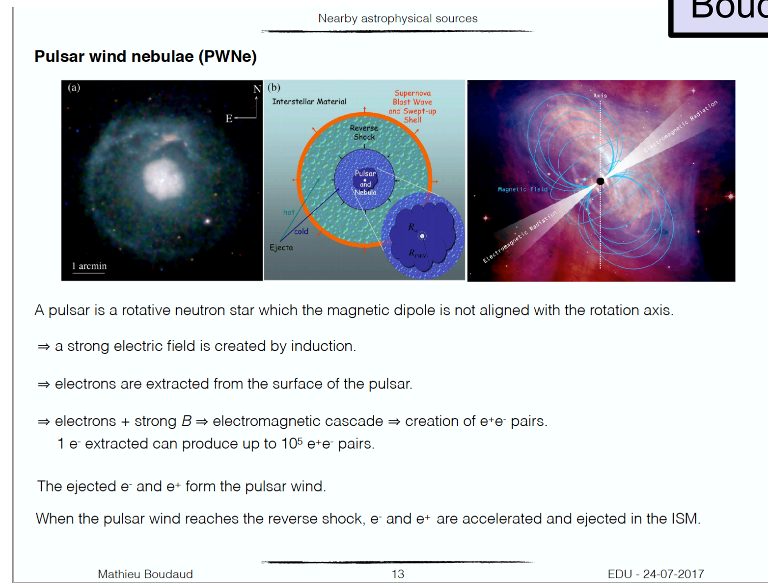
Gebauer, Winkler

Interpretations of Positron Fraction

Gebauer



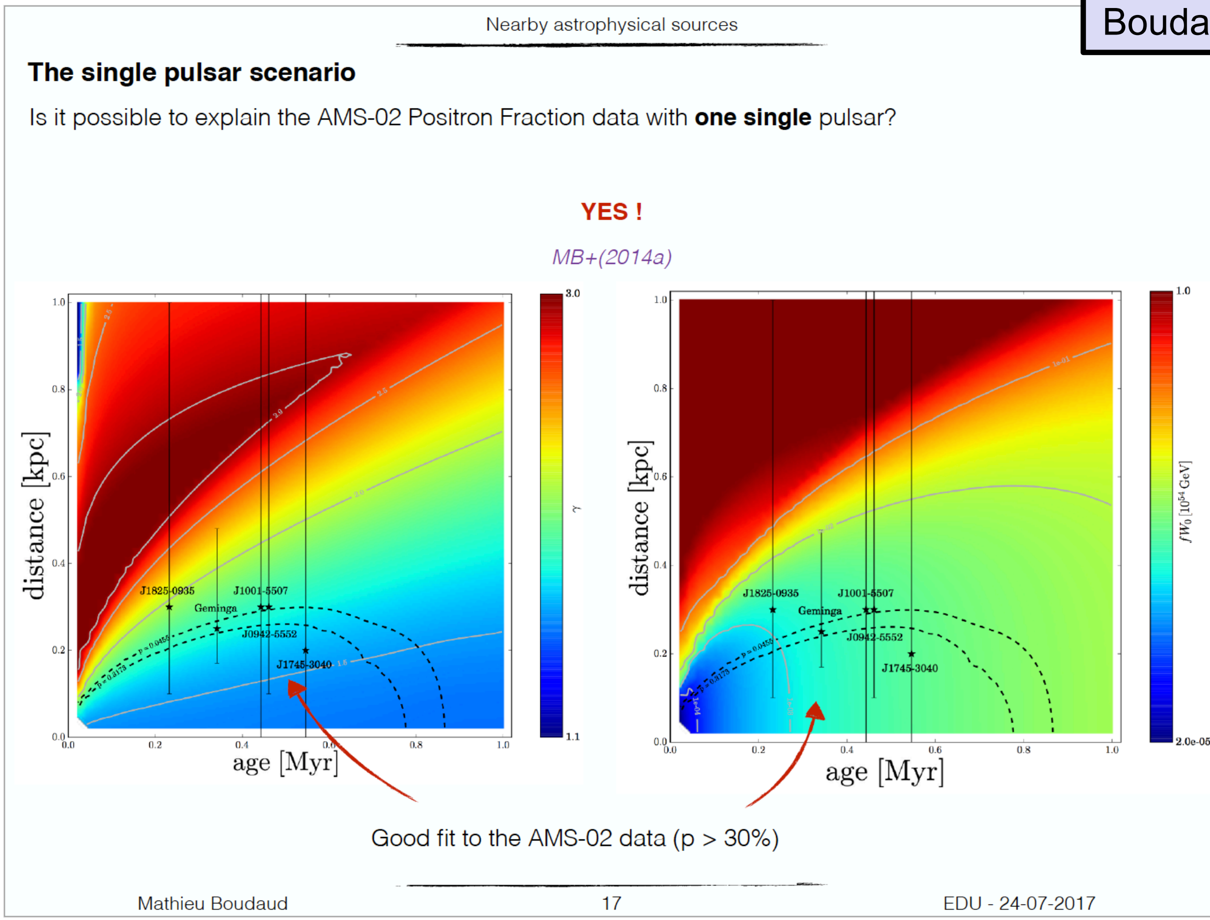
Boudaud



- Increase in the positron to electron ratio from 10 GeV up to > 100 GeV
  - Caveat: both spectra are steeply falling (note factor of E^3 in left-hand plot), the positron spectrum is just falling less steeply than the electron spectrum
  - This implies some source of large number of electron / positron pairs at high energy
- Favored interpretations: dark matter or pulsar wind nebulae (PWNe)

PWNe can *Easily* Explain Positron Spectrum

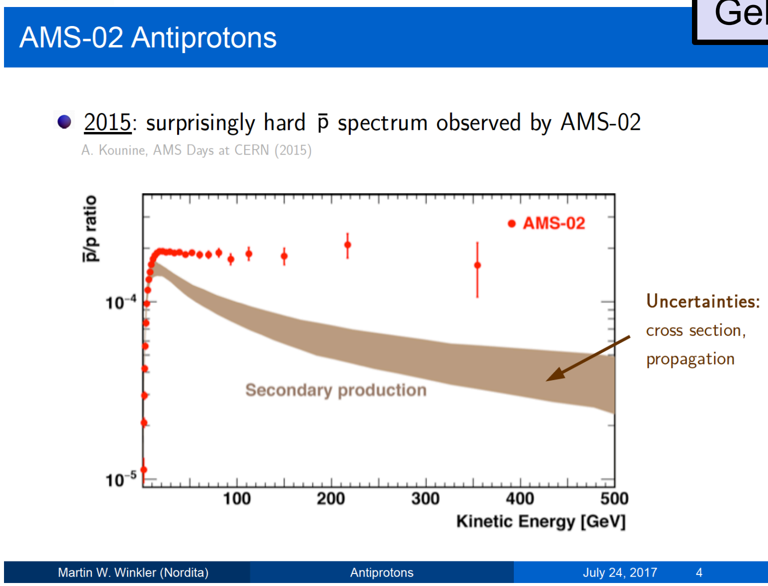
Boudaud

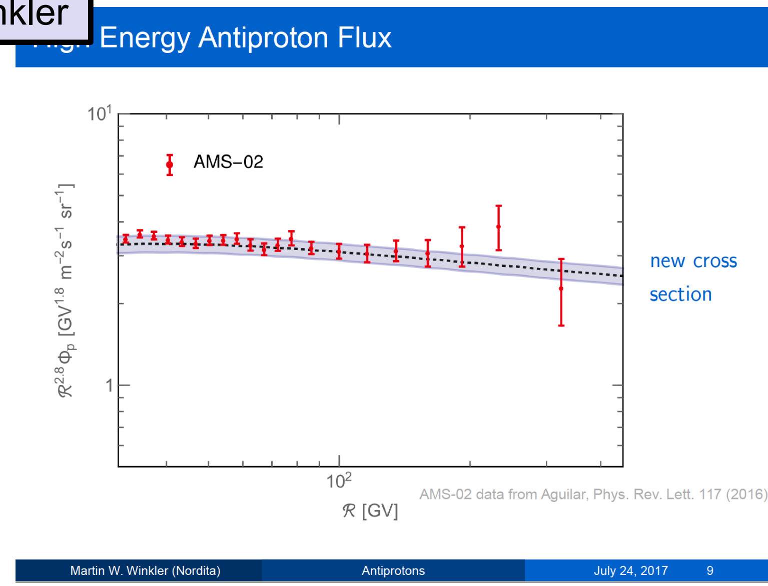


- At least five PWNe are close enough and young enough (high spin-down power) to produce the positron spectrum assuming reasonable efficiency for e^+e^- pairs

Interpretation of Proton Spectrum

Gebauer, Winkler

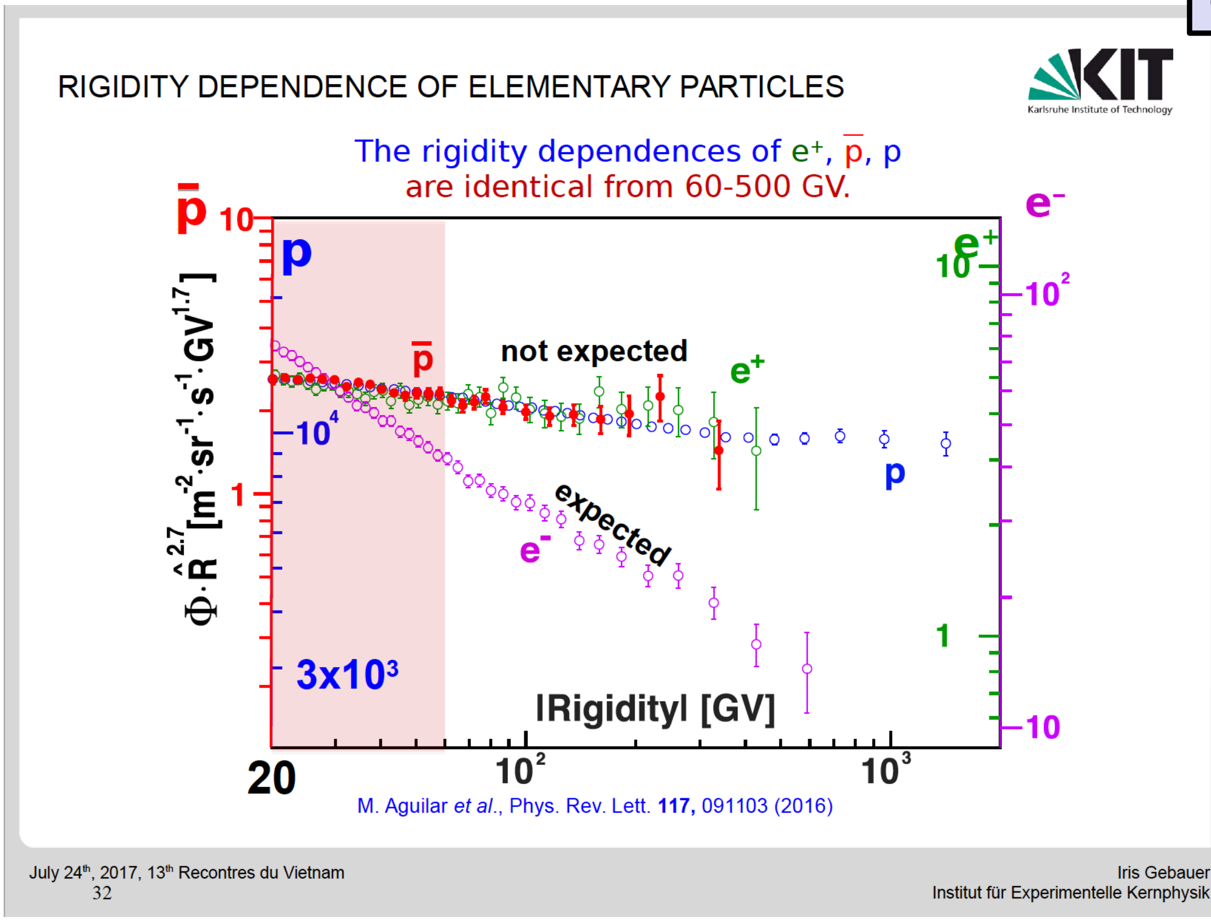




- Flatness of anti-proton to proton ratio was unexpected in 2015
  - "If anti-p are secondaries, their rigidity dependence should be different from p" Gebauer
- Boron/Carbon ratio measure by AMS-02 suggest propagation parameters should be updated, leading to flatter expected anti-p spectrum Winkler
- Updated measurements of cross-sections also lead to flatter expected anti-p spectrun

Comparison of Rigidity Spectra Presents Interesting Puzzle

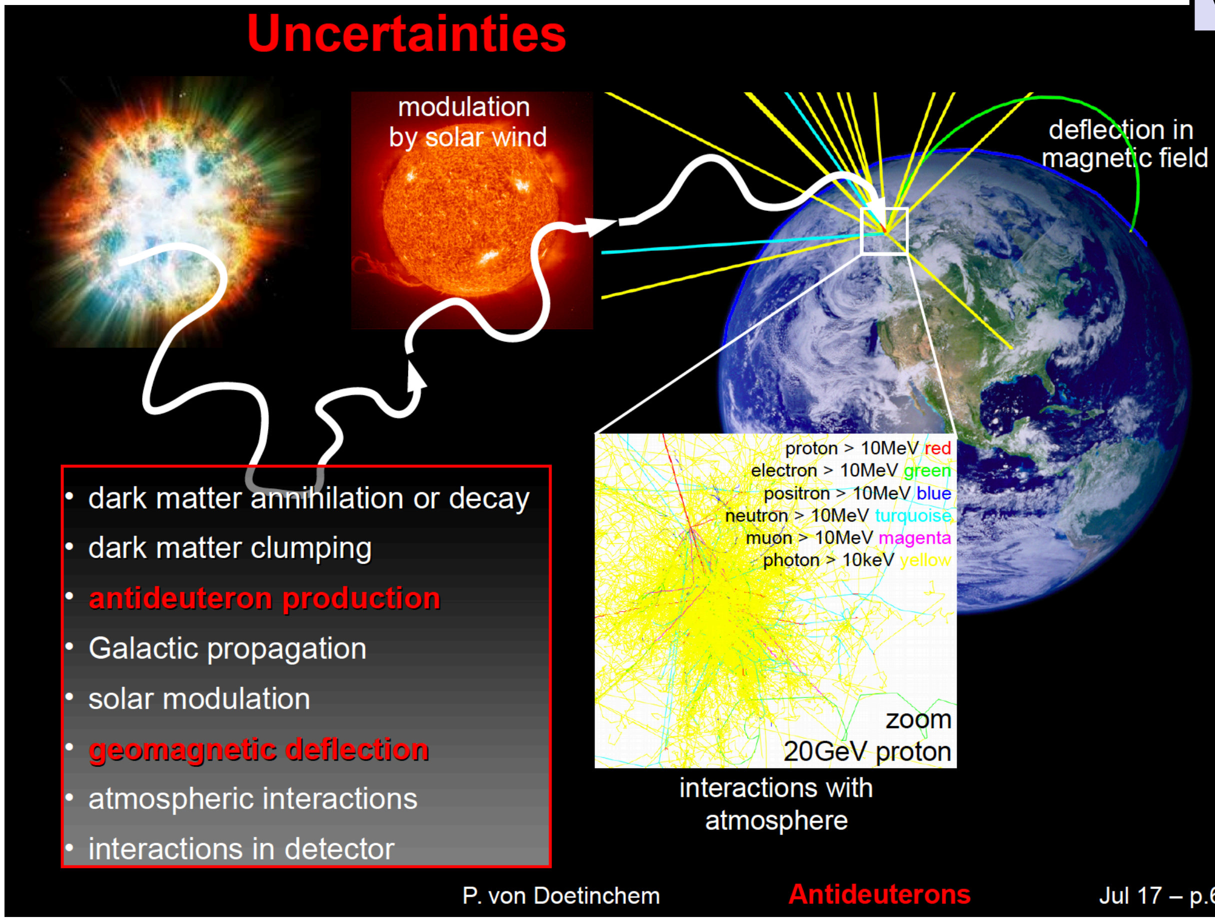
Gebauer



- We expect secondaries (such as anti-p) to have softer spectra than primaries (p) because of their spectra steepens after they are produced, as the highest energies ones are more likely to escape the Galaxy
- We expect electron spectra to soften because of radiative energy losses

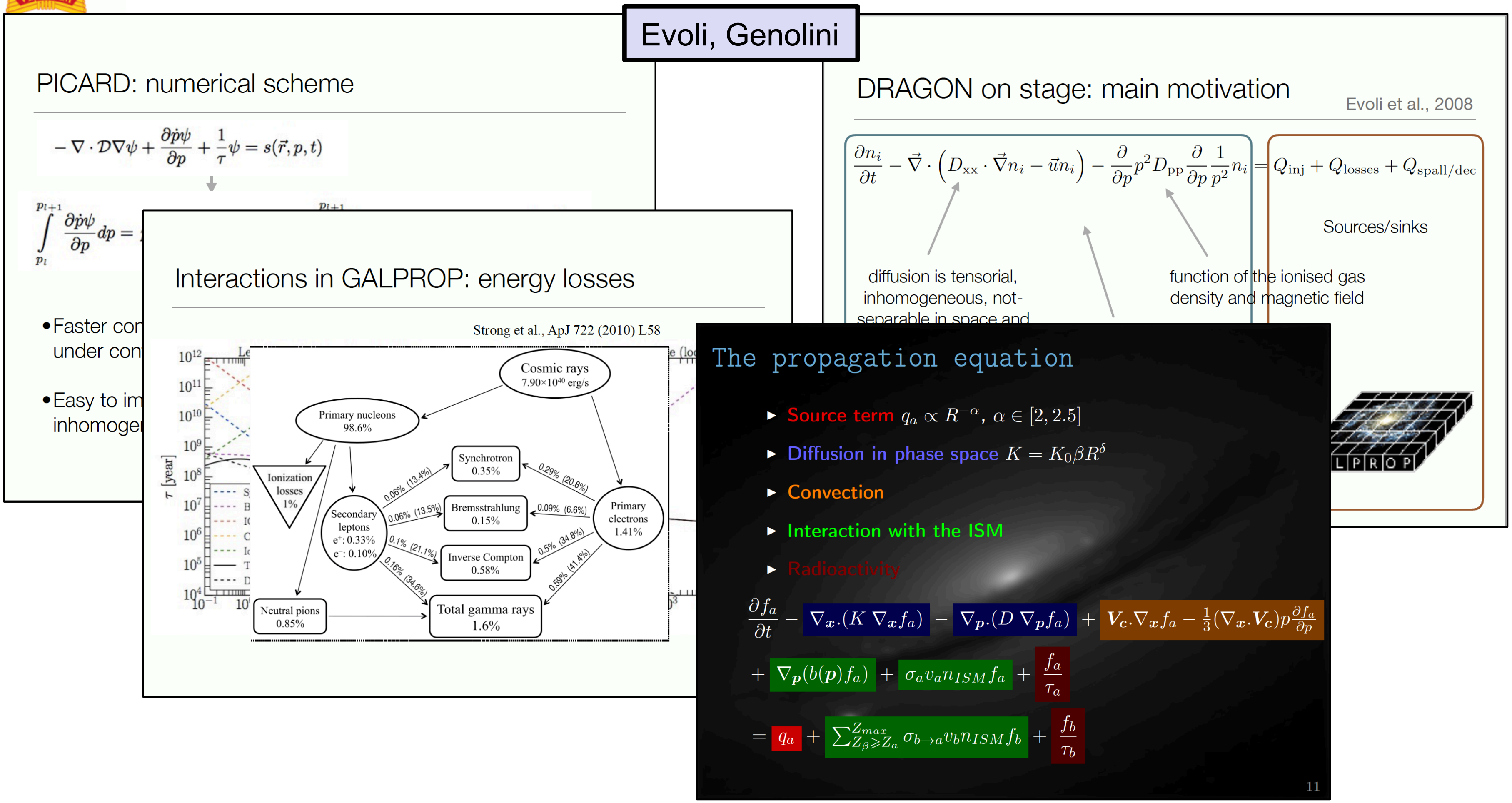
Other Developments (antideuterons & friends)

von Doetinchem



- Antideuterons are potentially good channel to look for DM signals, but must address geomagnetic deflection and uncertainties in production cross sections.

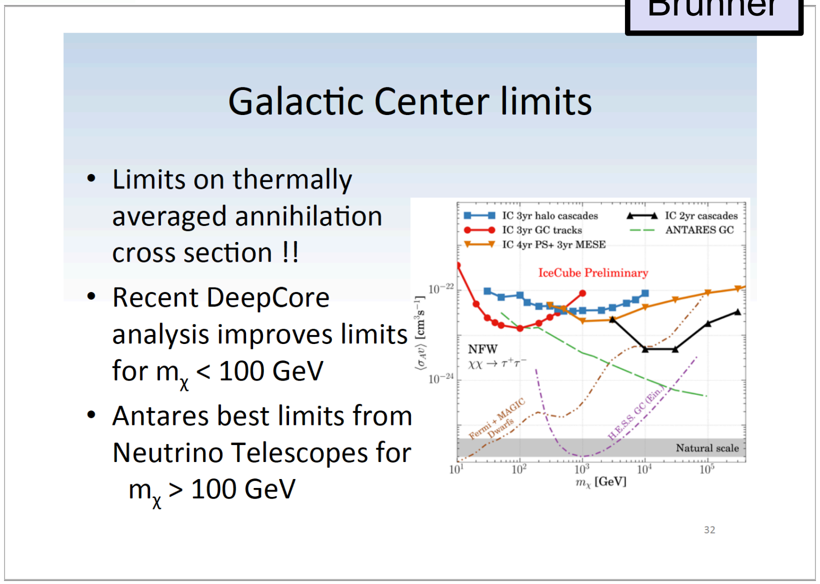
Galactic Particle Propagation Codes



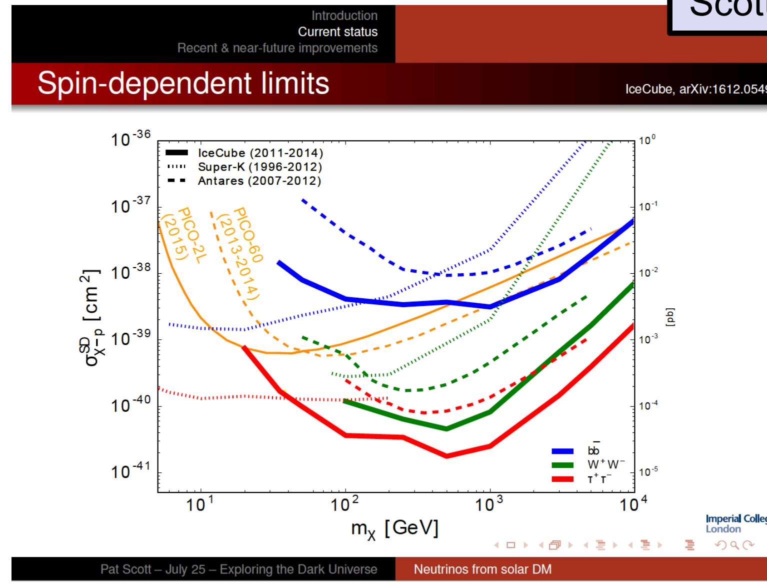
- Comparison of features, approximations, philosophy of existing Galactic particle propagation codes: GALPROP, PICARD, DRAGON, USINE

Indirect Detection with Neutrinos

Brunner



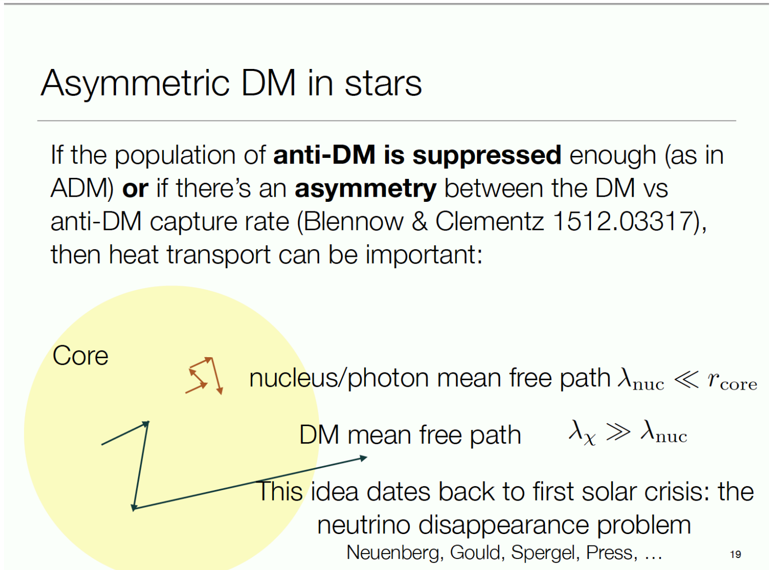
Scott

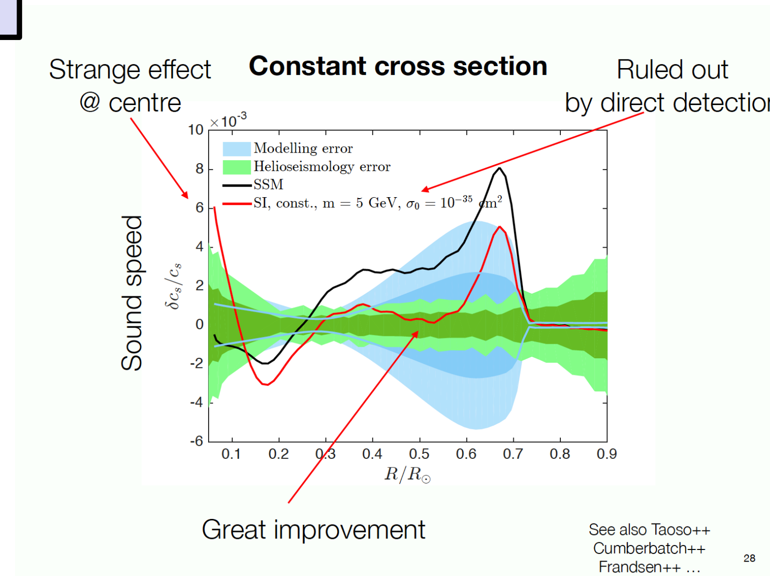


- Searches for high-energy ν from Galactic Center sensitive to annihilation cross section
  - Strongest limits in some channels above ~30 TeV
- Searches for high-energy ν from Sun sensitive to scattering cross section (in conjunction with annihilation cross section)

Solar Physics Probing Asymmetric DM

Vincent

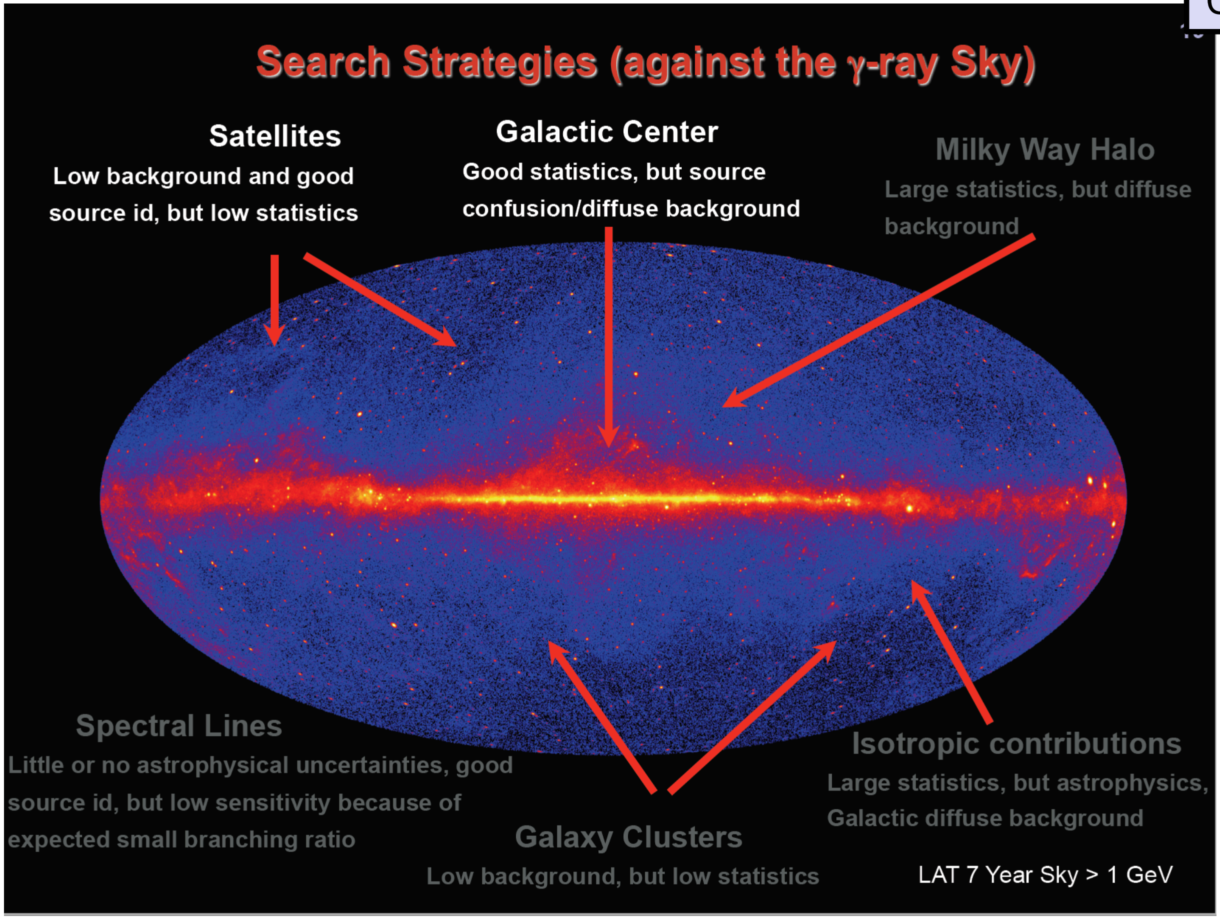




- Since asymmetric DM suppresses annihilation rate, the DM density of the sun can be much larger than it would be if the annihilation and capture rates were in equilibrium
- In this case the DM can affect the stellar heat transport, which can be probed, e.g., by helio-siesmology

Indirect Detection with γ Rays

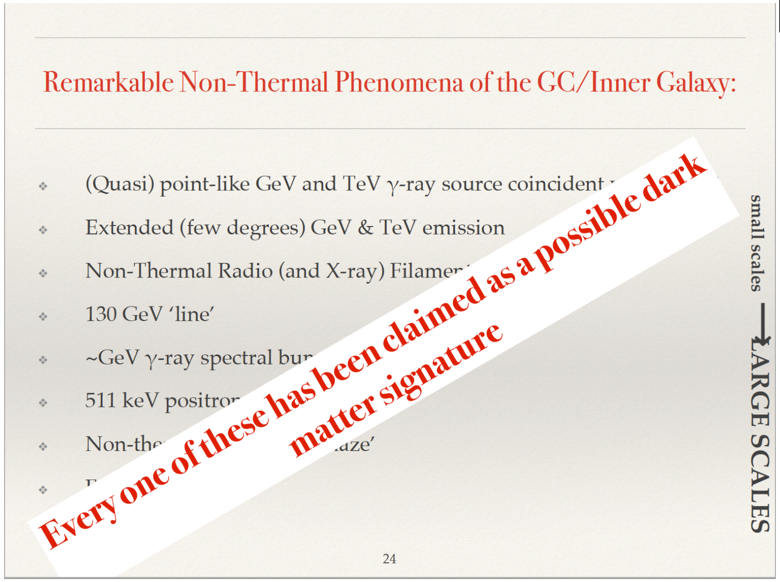
Charles

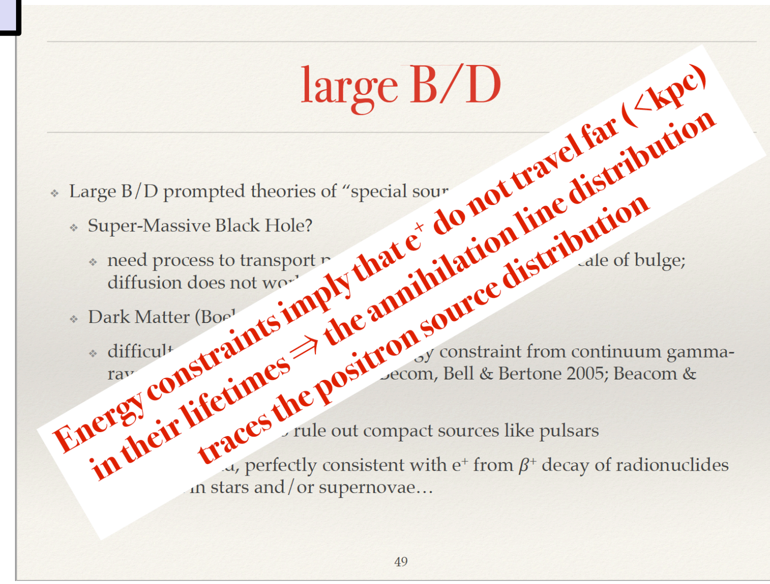


- Many targets for indirect searches with γ rays, but here we focused on the Galactic center (where there is an excess w.r.t. diffuse emission models) and the dwarf spheroidal galaxies (which set the strongest constraints)

Astrophysics of the Galactic Center

Crocker



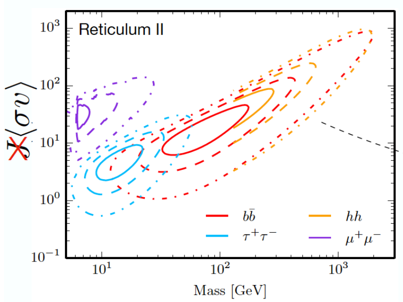


- Galactic center is a very complicated astrophysical region
- Many phenomena that have been interpreted as potential DM signals
- For example, the 511 keV line seen at the Galactic center:
  - However, the GC 511 keV line seems to come from bound-state positronium, implying the positrons are produced at low energies (i.e., not from DM or pulsars)

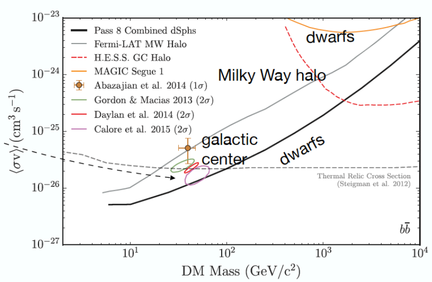
Measuring J-factors in Dwarf Galaxies

Geringer-Sameth

Everything* in these plots requires a *J* value and dynamical modeling is always involved



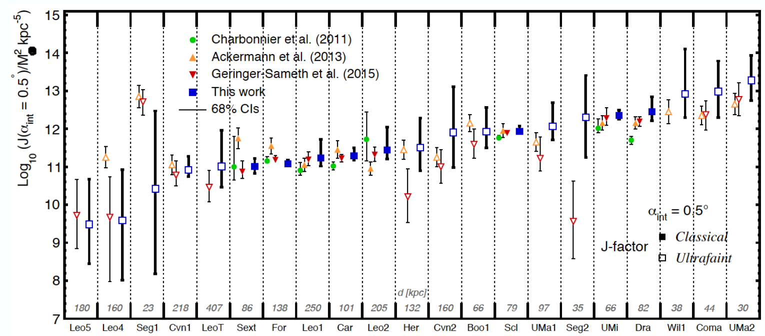
AGS et. al. 1503.02320 (PRL)



Fermi collab 1503.02641 (PRL)

Bayesian exploration of possible dark matter density profiles

Velocity anisotropy, light profile, truncation, priors



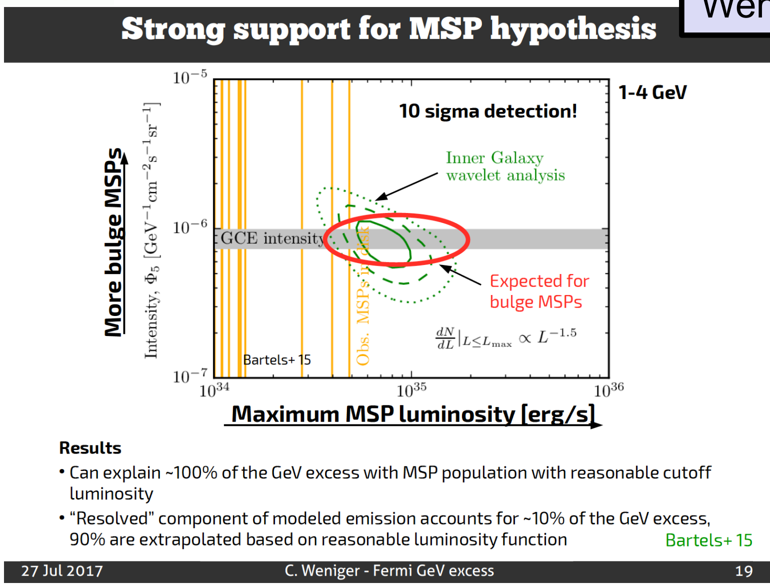
Bonnivard+ 1504.02048 (MNRAS)

see also Charbonnier+ 1104.0412 (MNRAS), Martinez 1309.2641 (MNRAS), Geringer-Sameth+1408.0002 (ApJ), Hayashi+ 1603.08046 (MNRAS)

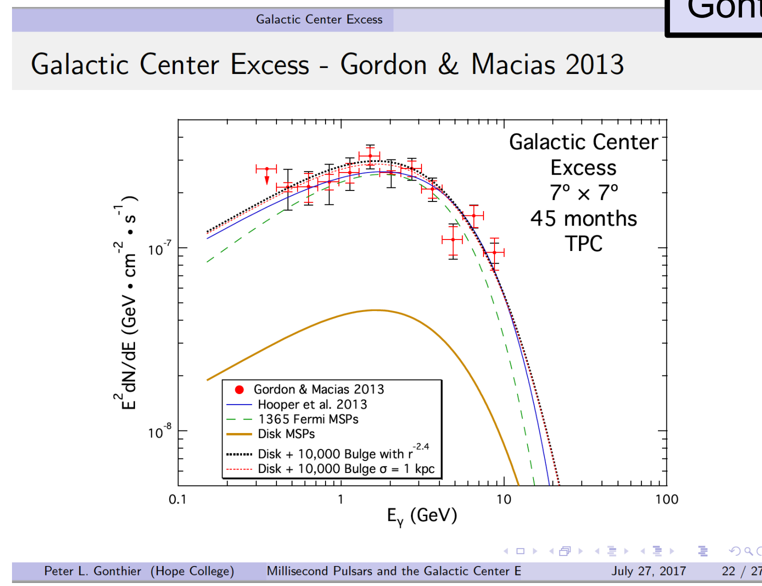
- Moving from flux measurement to discuss of DM annihilation cross section depends on J-factors
- Many uncertainties in estimating the astrophysical J-factors of Dwarf Spheroidal (dSph) galaxies: velocity anisotropy, galaxy membership, light profile, region of integration

GeV Galactic Center Excess is Probably Pulsars

Weniger



Gonthier

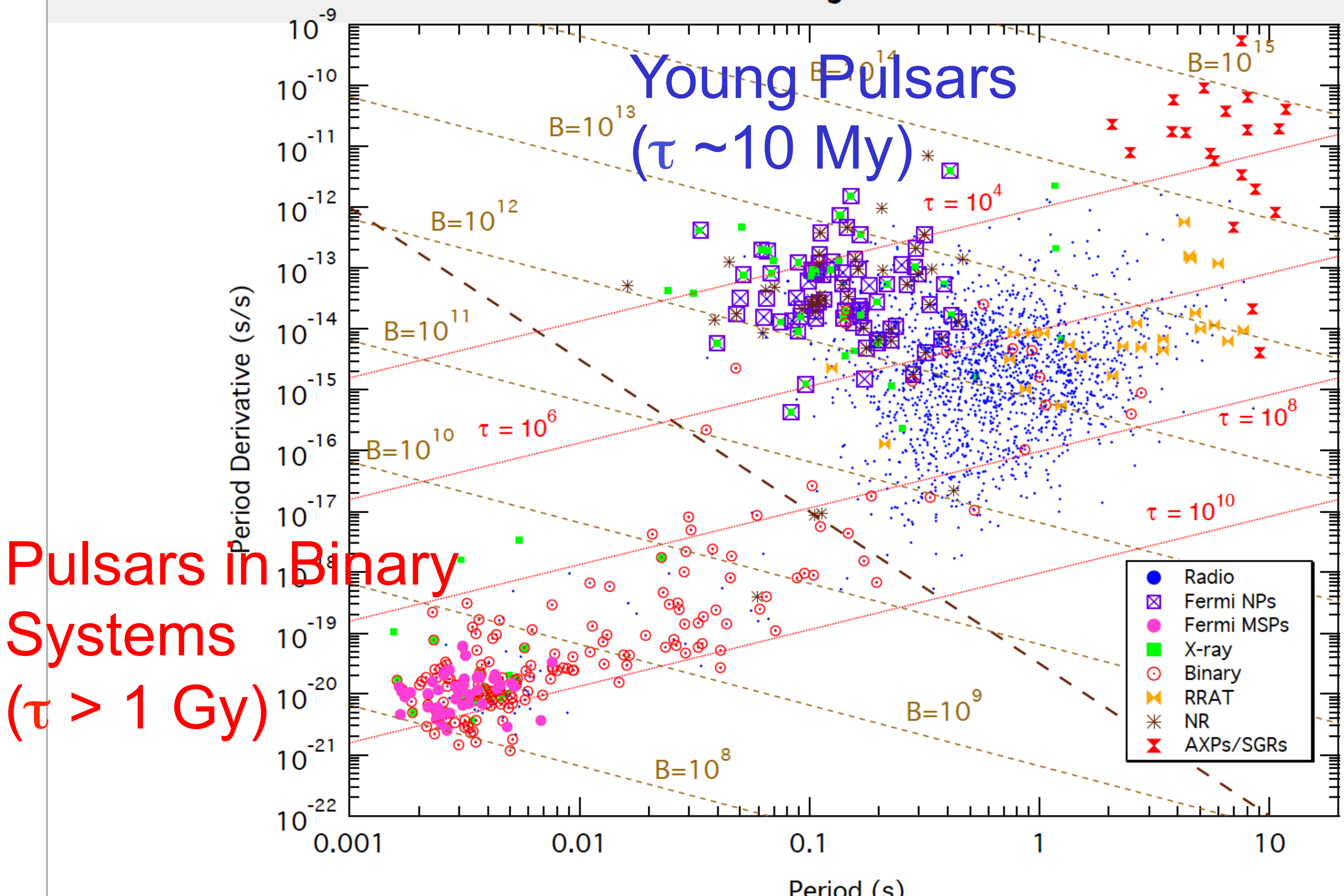


- "Best candidates [to explain the Galactic center GeV excess] are arguably millisecond pulsars in the Galactic bulge" Weniger
  - Highly significant (7-10σ with three complementary methods) observation that data favor a population of point sources with pulsar-like spectra
  - Population for ~10,000 millisecond pulsars in the bulge would give the flux needed to make the excess Gonthier

Aside: Pulsar Populations

Gonthier

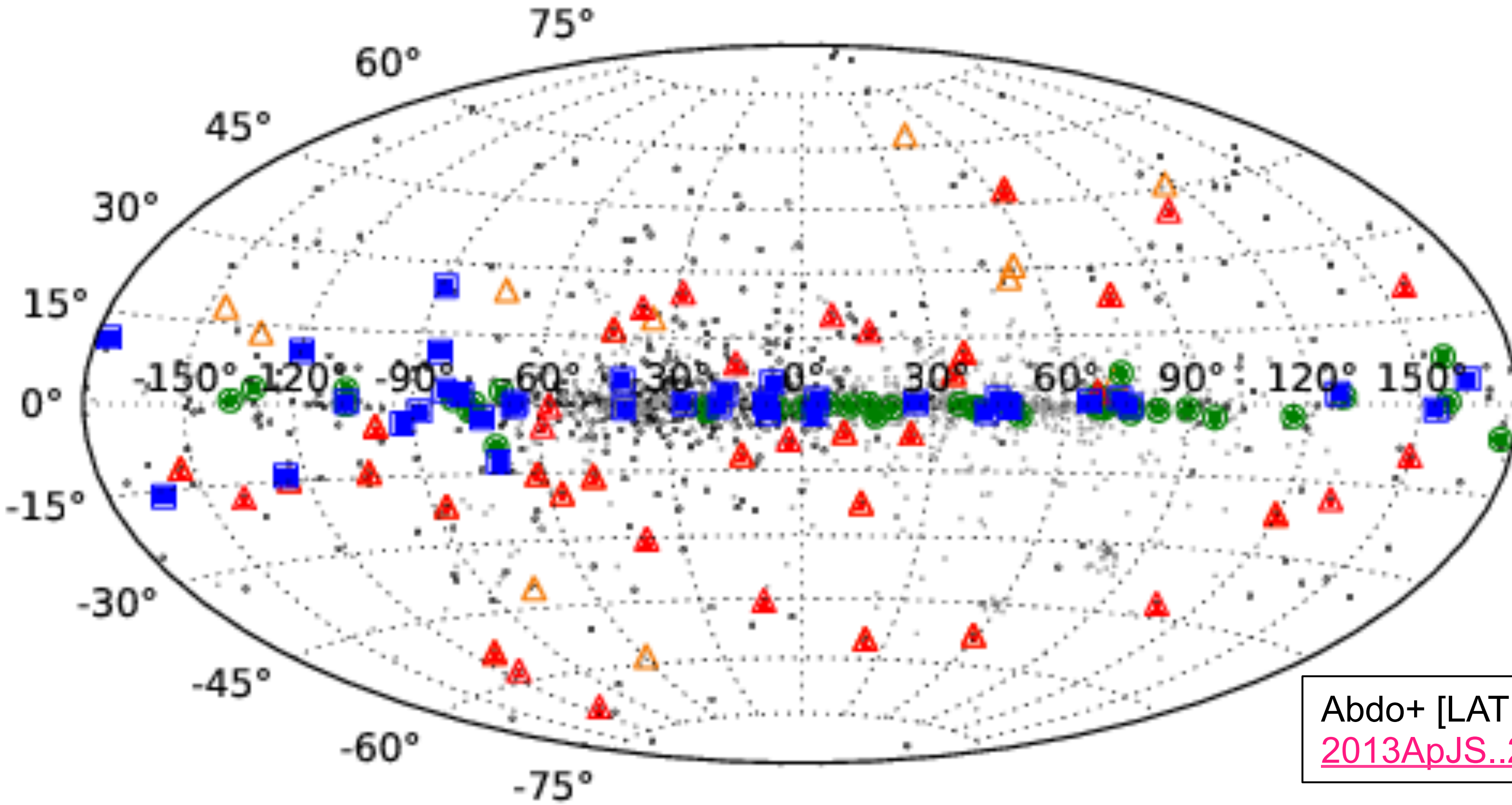
Pulsar Zoo with over 2530 subjects



ATNF - `http://www.atnf.csiro.au/research/pulsar/psrcat`

Aside: Two Pulsar populations

Position in Galactic Coordinates of All Known Pulsars (LAT-detected pulsars highlighted)

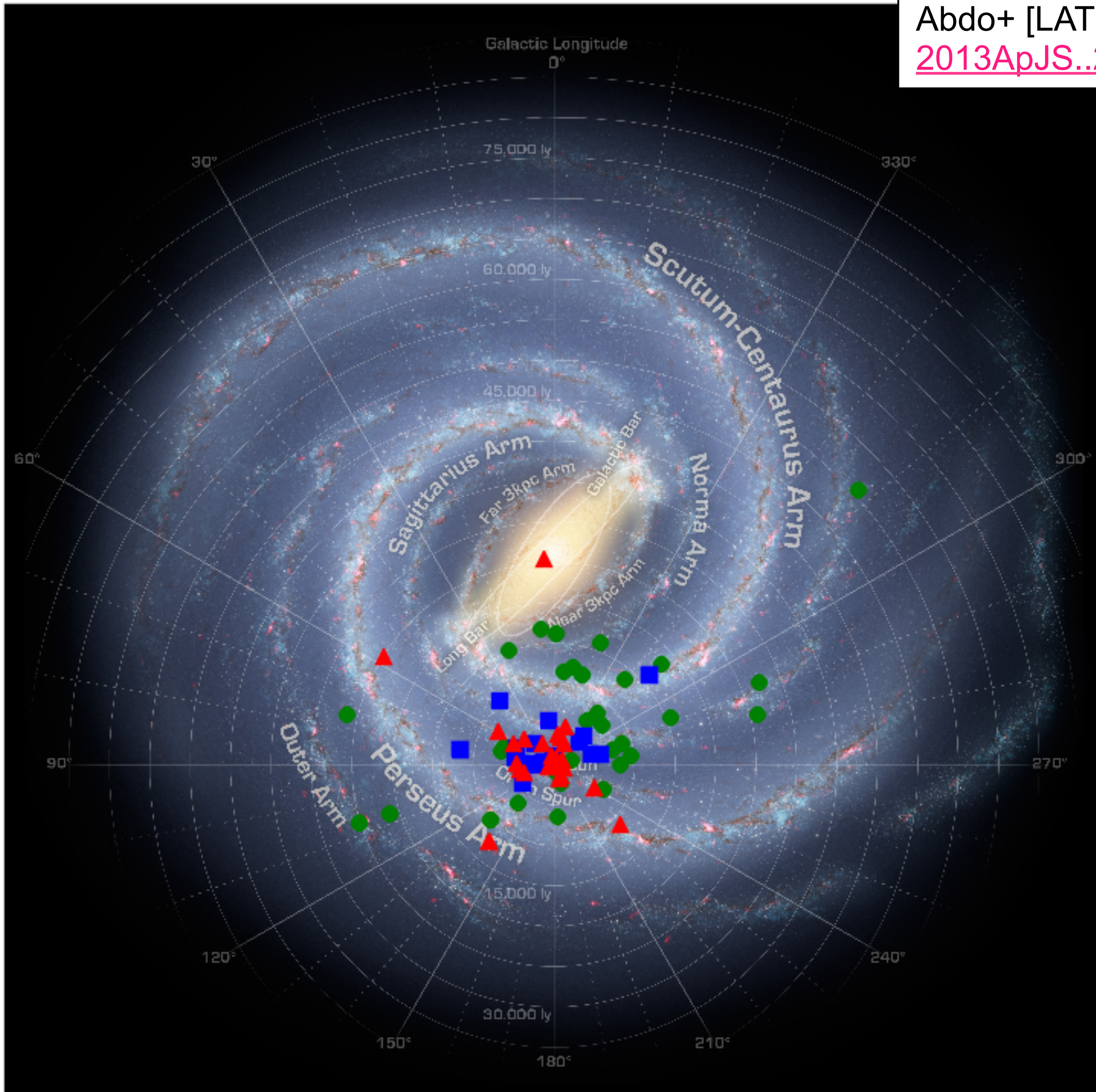


Abdo+ [LAT Clb]
2013ApJS..208...17A

- Young pulsars are found closer to Galactic plane
- Millisecond pulsar are more isotropically distributed

Observational Horizon for Pulsars

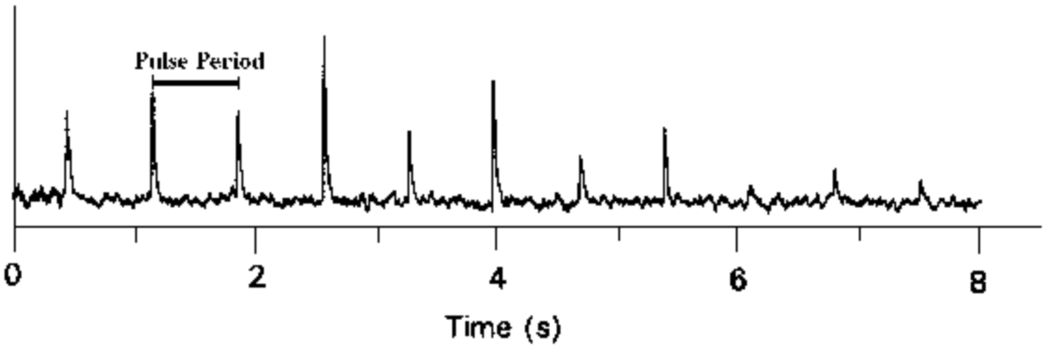
Abdo+ [LAT Clb]
2013ApJS..208...17A



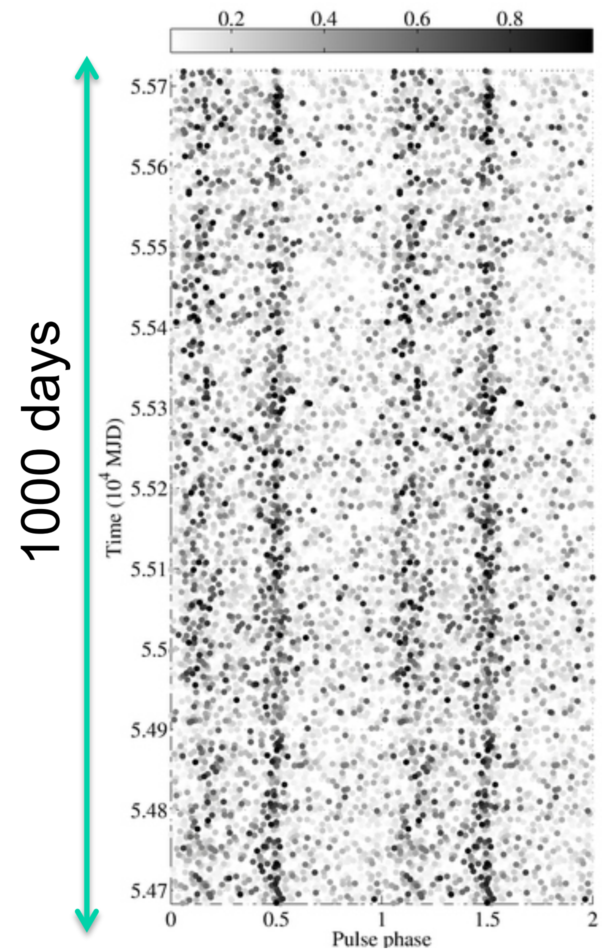
- Most γ-ray detected pulsars are within 2 kpc
  - Even less for ms pulsars
  - GC at 8.5 kpc

Detecting Pulsars

Radio Detection in Intensity Time Series



γ-ray Detection: 1000 days of weighted photons phase-folded against timing solution



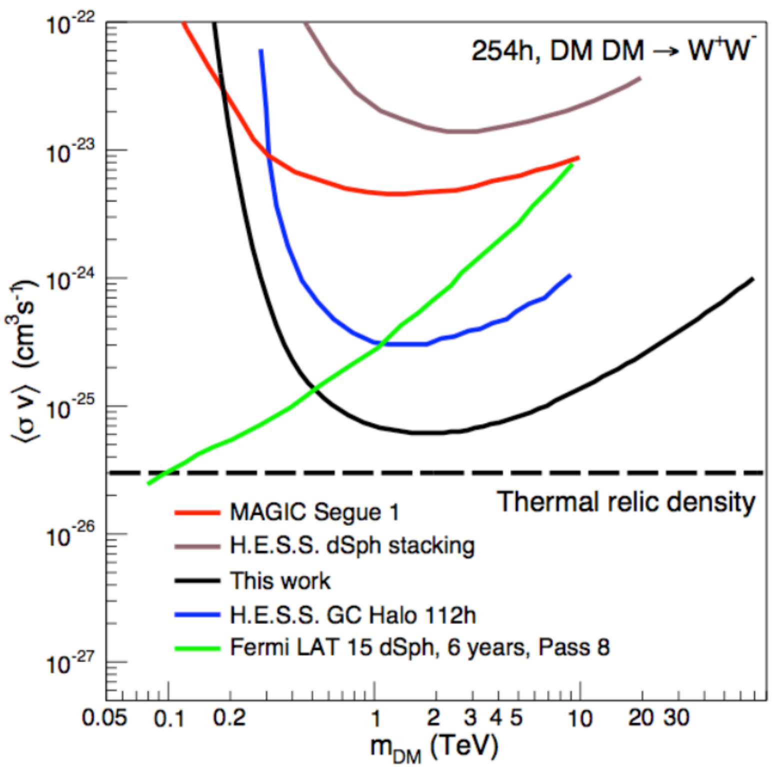
- Pulsars are detected primarily in radio and γ-ray searches
- Radio searches: point radio array at pulsar, look for pulses
  - Weak towards galactic center where free electrons disperse pulse profile
- γ-ray searches:
  - Weak for binary searches where orbital motion modulates timing solultion

DM Limits from HESS Observations of GC

Moulin

Constraints on the DM continuum signal

H.E.S.S. Collaboration, Phys. Rev. Lett. 117, 111301 (2016)



- For the Einasto profile, strongest limits so far in the TeV mass range:

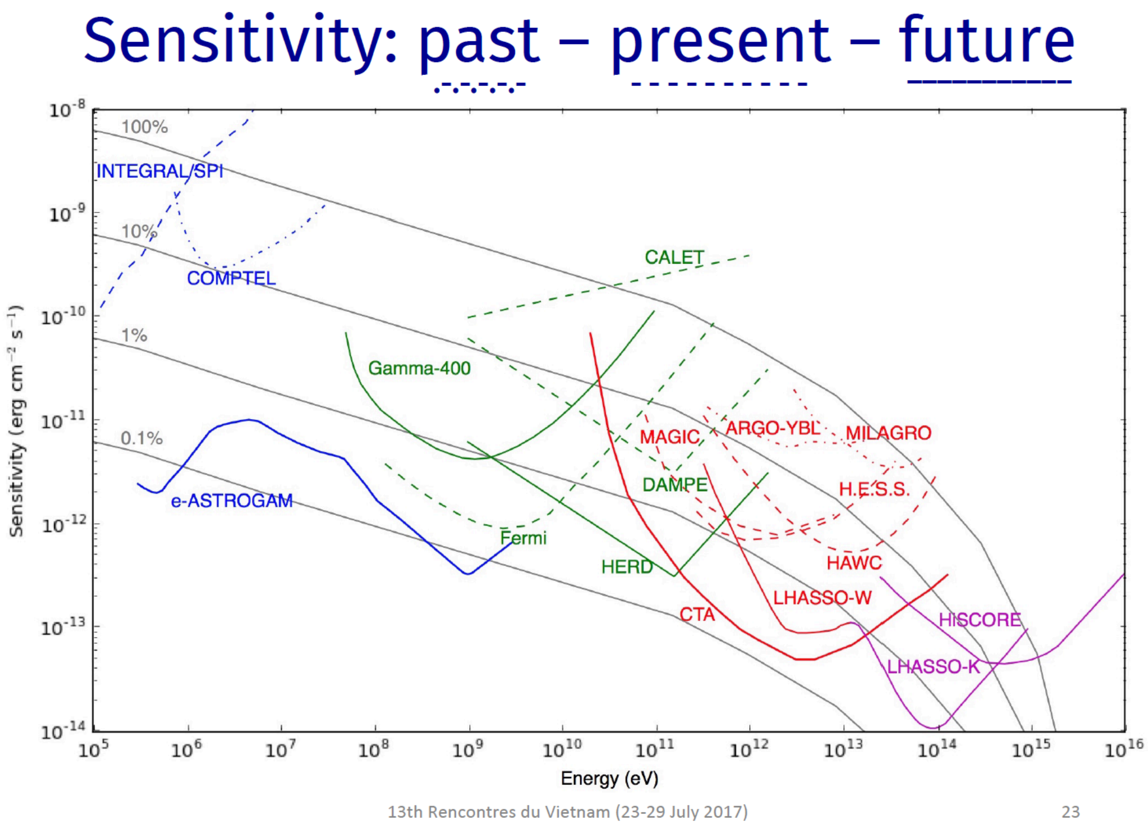
  → in the W^+W^- channel: 6×10^{-26} cm^3 s^{-1} at 1.5 TeV

- They well complement the Fermi-LAT limits down to about 300 GeV

- *Full H.E.S.S.-II array observations within the inner Galaxy Survey programme with pointings up to 3° in Galactic latitudes started in 2015*

New Eyes on the γ-ray Skies

Knoedlseder

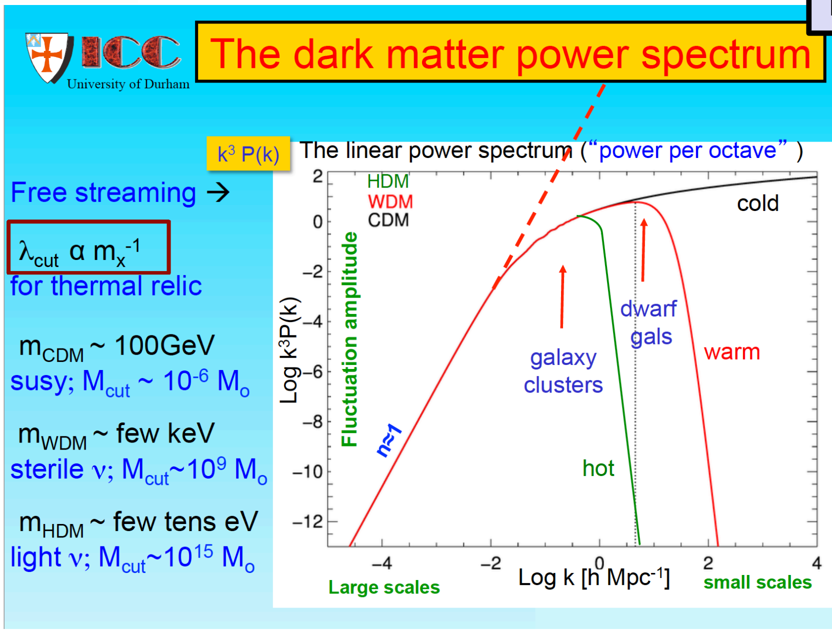


- Significant bands (~1MeV, ~few TeV, > PeV) where upcoming instruments will improve sensitivity by over an order of magnitude
- This will result in over 30 times more detected sources in those bands

COSMOLOGY & ASTROPHYSICAL DARK MATTER

Subhalo Structure Mass Function

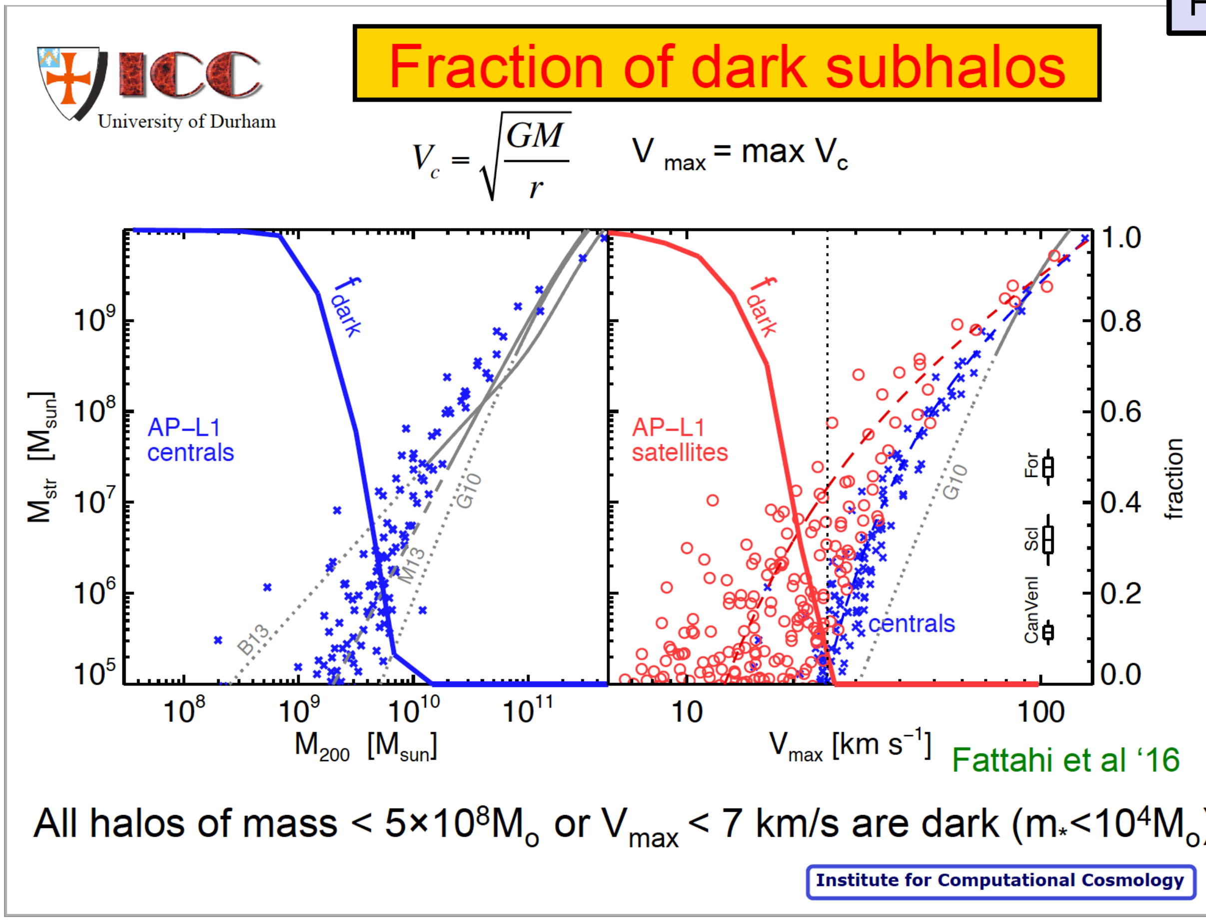
Frenk



- Both Cold and Warm DM are compatible with CMB & galaxy clustering
- Kinetic energy (temperature) of DM can suppress structure formation at small scales
- If we could see the dark matter directly, it would be very easy to distinguish Cold DM from Warm DM

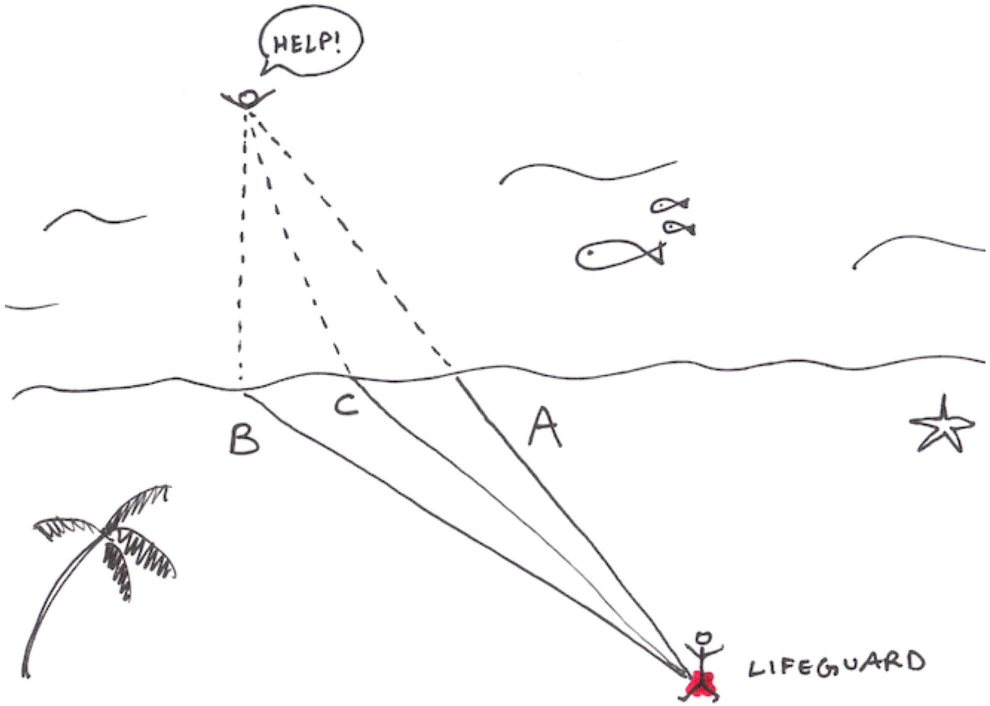
Distinguishing Cold v. Warm DM

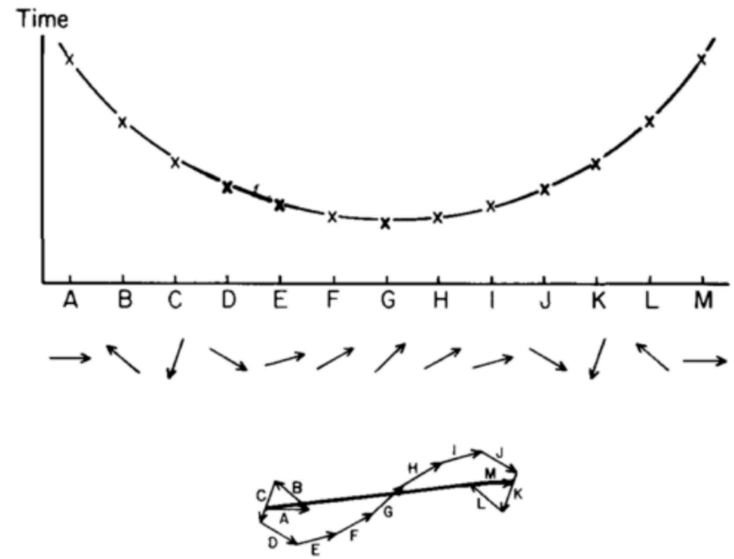
Frenk



- EAGLE (?) Simulations tell us that the fraction of sub-halos that are "dark" goes from ~1 at $10^9\ M_\odot$ to ~0 at $10^{10} M_\odot$
- This reduces the statistics in counting satellites, leaving ambiguity between WDM and CDM

Aside: Fermat's Principle and Lensing





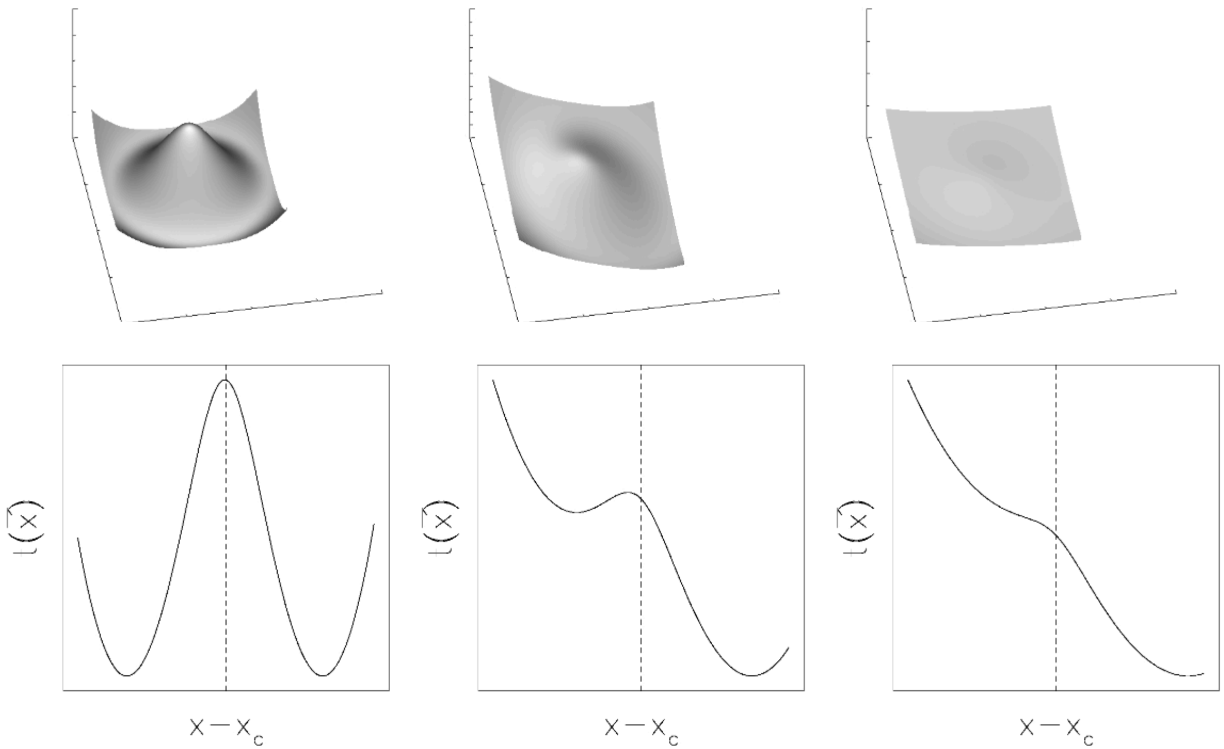
Fermat's principle as a variational principle: paths near the path of least time to add constructively.

Aside: Gravitational Lensing

ESA/Hubble & NASA
(Astronomy Picture of the Day 2011-12-21)

Gravitational time dilation means that light from lensed galaxy (behind) reaches us more quickly by travelling around the lensing galaxy (in front).

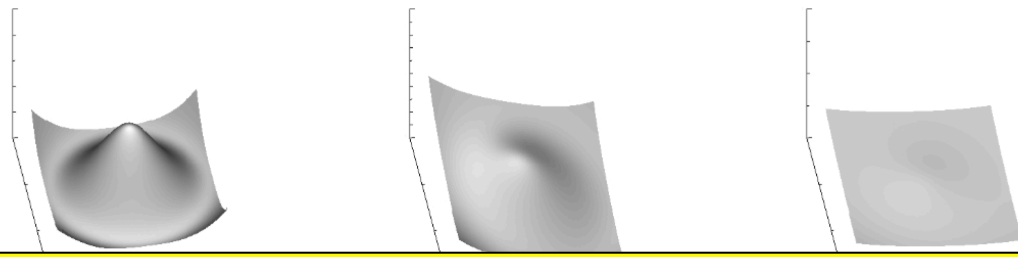
Aside: Strong Lensing



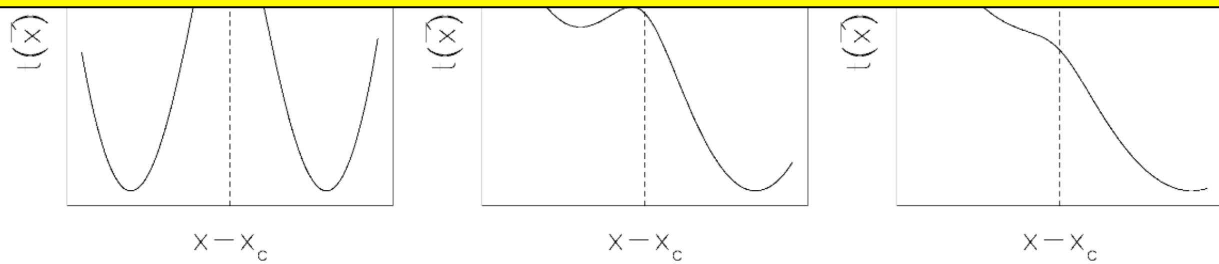
Einstein Ring | Einstein Cross | Weak Lensing

Light will appear for lines of sight where the gradient of the travel time is small: This includes minima, maxima and saddle points.

Aside: Strong Lensing



Key point for us: a strong lens creates a number of directions where the light travel time surface is flat: our sensitivity to lensing from sub-halos along these lines of sight is vastly improved



Einstein Ring Einstein Cross Weak Lensing

Light will appear for lines of sight where the gradient of the travel time is small: This includes minima, maxima and saddle points.

Measuring Strong Lensing Substructure Will Resolve CDM v. WDM

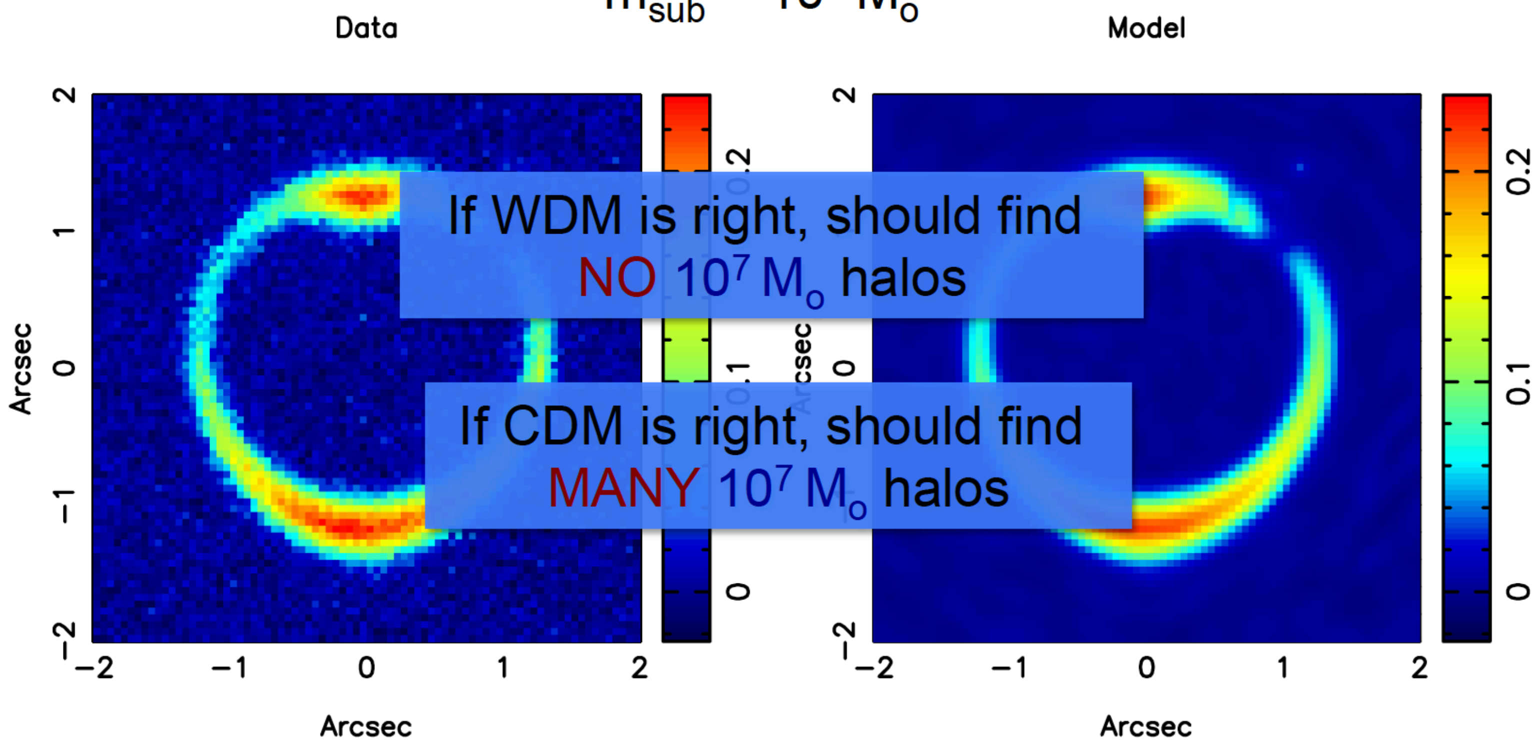
Frenk

University of Durham

Detecting substructures with strong lensing

Vegetti & Koopmans '09

$m_{sub} = 10^8\, M_o$



If WDM is right, should find NO $10^7\, M_o$ halos

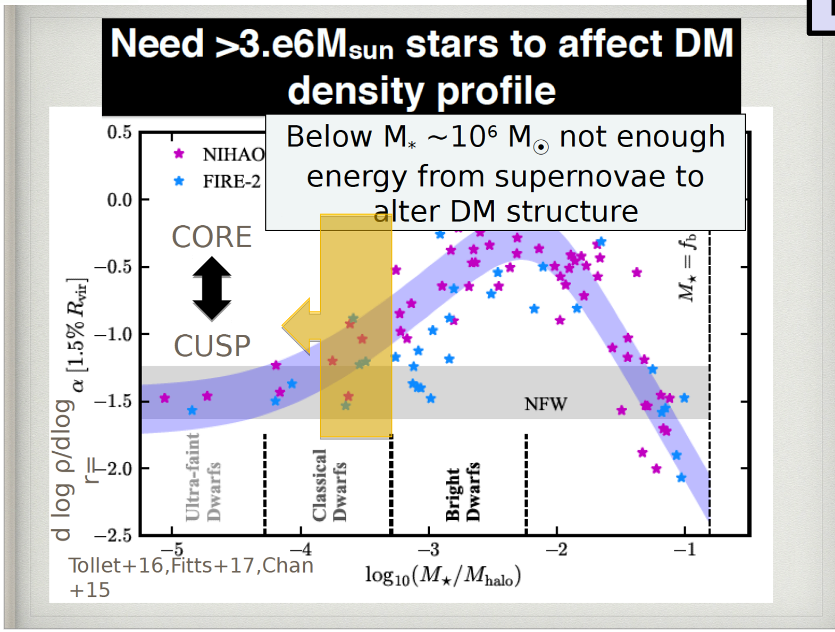
If CDM is right, should find MANY $10^7\, M_o$ halos

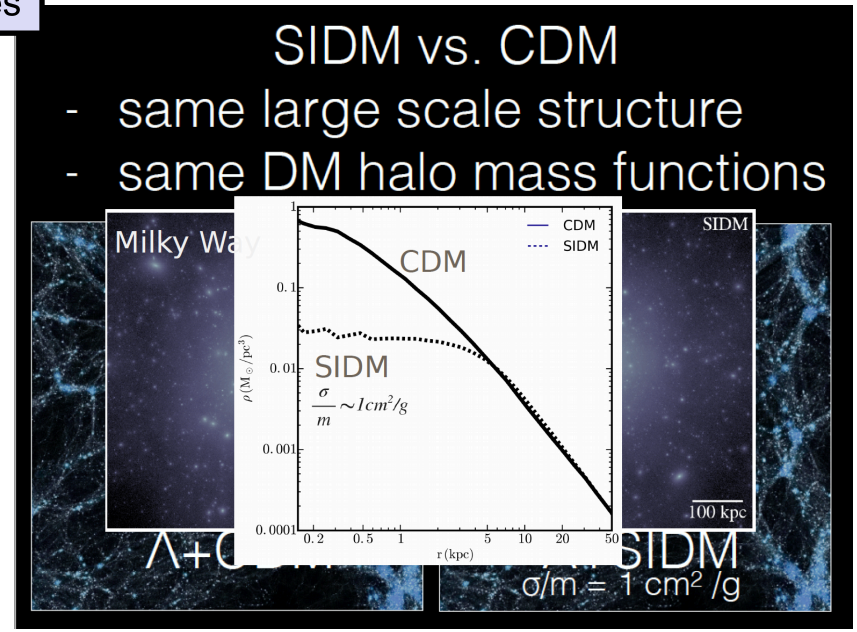
Can detect subhalos as small as $10^7\, M_o$

Institute for Computational Cosmology

Self-interacting DM and Baryonic Feedback

Robles

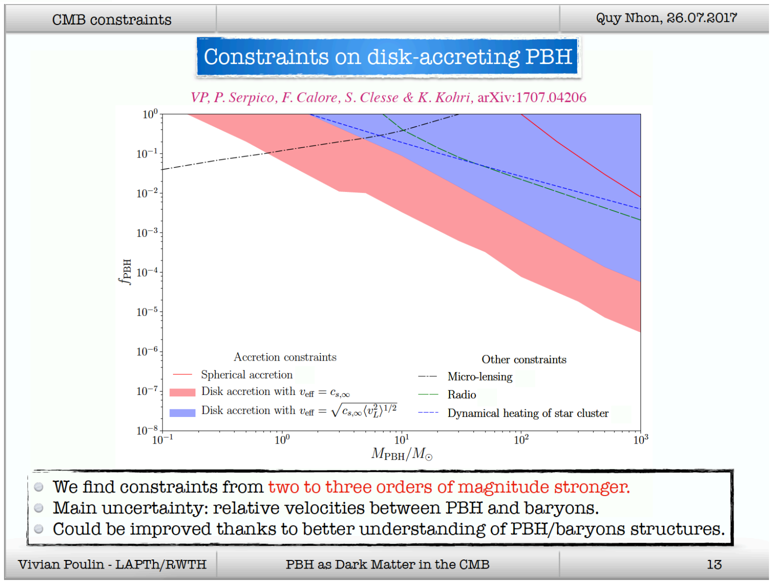


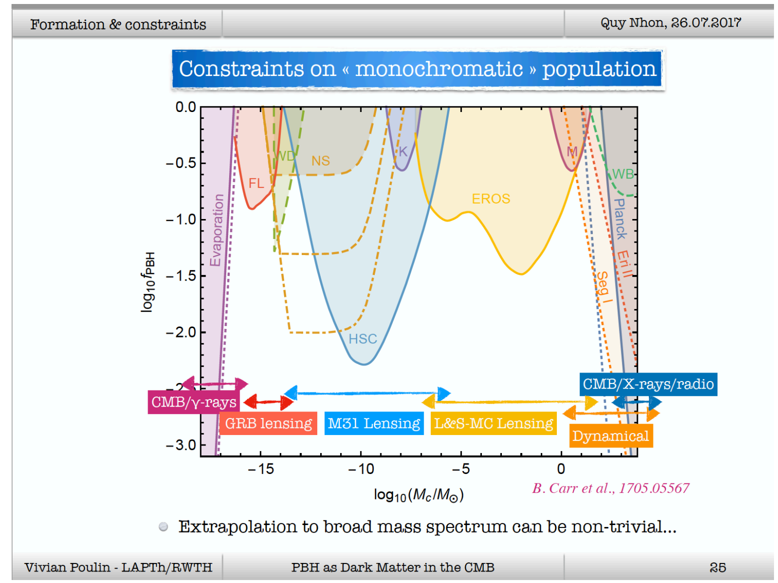


- Simulations including realistic feedback from baryonic processes (e.g., star formation, supernovae) used to explore case for self-interacting DM (SIDM)
- With SIDM, Dwarf Galaxies are much less sensitive to feedback

Primordial Black Holes

Poulin

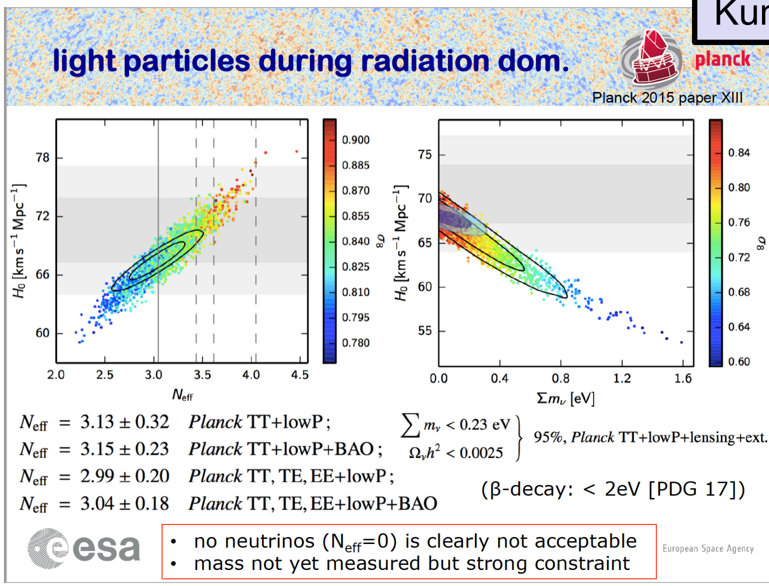




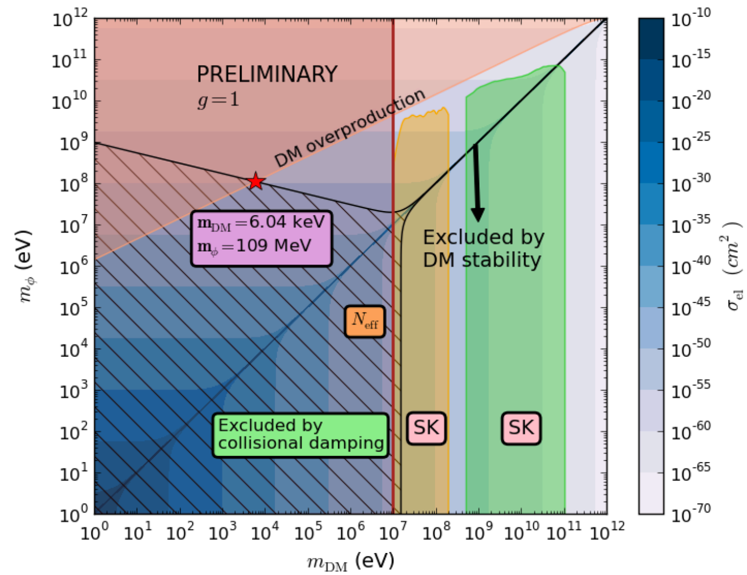
- Unexpected large rate & mass of black holes in LIGO gravity wave detections lead to question: what fraction of DM is attributable to high-mass primodial black holes
  - < 10-15 $M_\odot$: evaporation emits γ rays and puts energy back into CMB
  - 10^{-15} – 10^2 $M_\odot$: various lensing studies
  - > 2$M_\odot$: emission from accretion

Neutrinos & Cosmology

Kunz



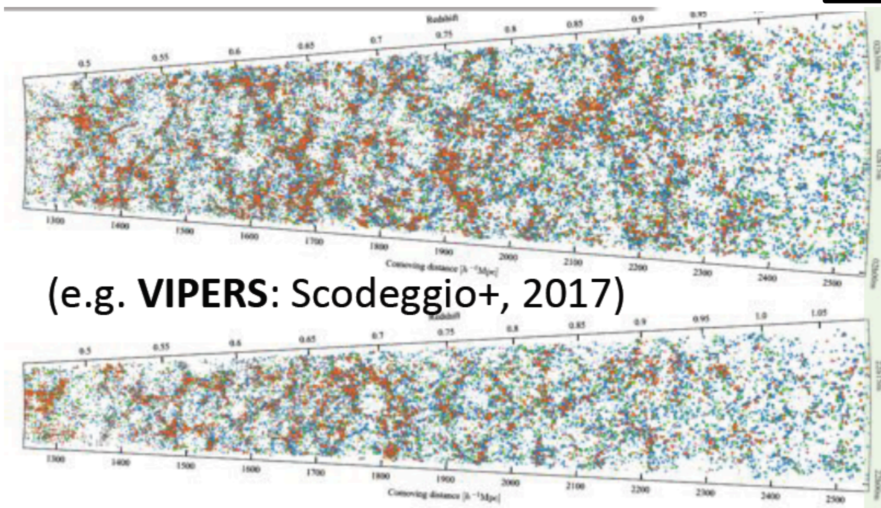
Olivares del Campo



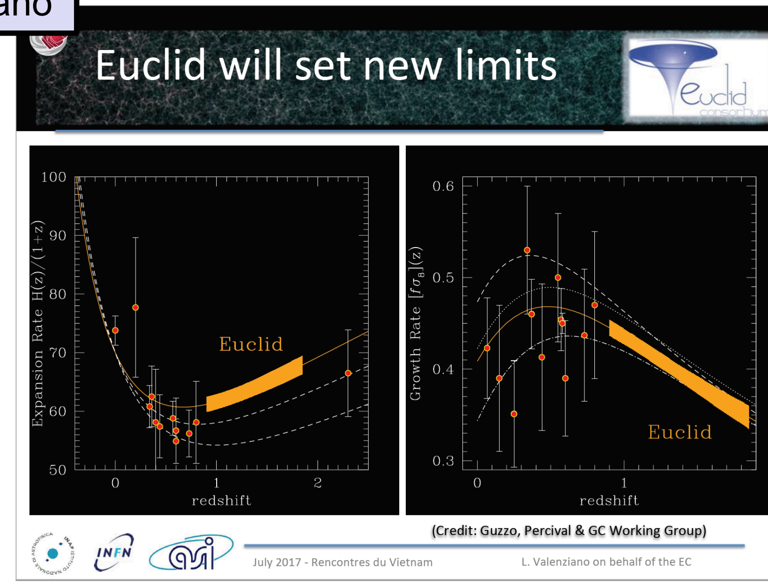
- The CMB sees the neutrino background
- Future large surveys should be able to detect the neutrino mass and strongly constrain WDM properties / see CDM velocity dispersion
- For MeV WDM cross section for annihilation to νν sets relic abundance

Euclid is Sensitive to Warm Dark Matter

Valenziano



(e.g. **VIPERS**: Scodeggio+, 2017)



- Euclid will greatly extend galaxy surveys for redshifts 1-2 (7-10 Gyr ago)
- This will improve constraints on structure growth rate and cosmic expansion
  - Could constrain m_{WDM}<2 keV

META SUMMARY

The Good News

- No convincing (or even particularly compelling) DM signals in any searches: be they direct, indirect or accelerator-based
  - Some things that have been interpreted as signals are now strongly disfavored by other measurements (e.g., DAMA/LIBRA) or face strong competing hypotheses (e.g., positron fraction, Galactic center GeV excess)
  - Some interesting observations that merit careful follow up: (Helioseismology anomoly, particle rigidities)
- This is a great application of the scientific method: we are finding ways of testing (and falsifying) hypotheses & developing new hypotheses
- Dark matter is more interesting that a simple ~100 GeV thermal relic WIMP

The Even Better News

- Many impressive efforts are underway:
  - to understand what the astrophysical data are telling us about the nature of dark matter
  - to continue to test the dominant WIMP paradigm by building more sensitive experiments and better understanding backgrounds
  - to develop ways to test other types of DM candidates
- This is a great application of the scientific method: we are finding ways of testing (and falsifying) hypotheses & developing new hypotheses
- We know that dark matter exists, perhaps we might be very lucky the discover that its particle nature is more interesting than, say, a ~100 GeV thermal relic WIMP from one of the simpler SUSY models

THANK YOU