Solving the DM problem with

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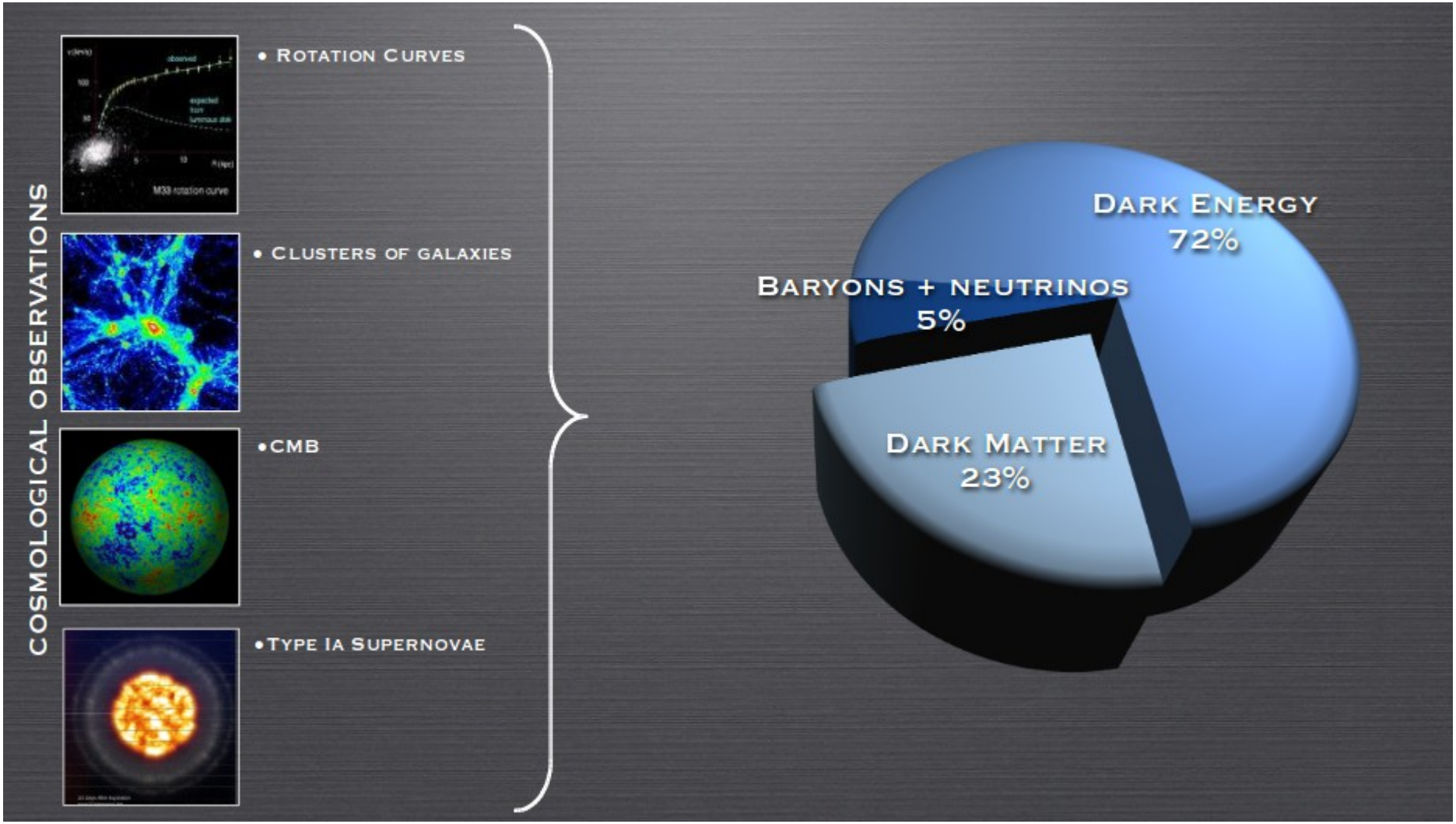
Abundance of evidence for DM gives few clues for its origin



- A particle origin is a very reasonable assumption, as is some coupling to SM matter

  - dark matter must somehow be produced in the early universe

Lots of options for dark matter

- Primordial black holes
- Weakly Interacting Massive Particles (WIMPs)
- Sterile Neutrinos
- Asymmetric dark matter
- Axions
- Wimpzillas!

The visible sector is very complicated

We should probably expect the dark sector to be very complicated

- We should aim to determine how much DM is represented by each component
- This requires:

  1) distinct experimental handles on different DM sources

  2) sophisticated ways of combining measurements from ***many*** different sources

One example: WIMP dark matter

- There is no shortage of WIMP theories

  - can either take a top-down or bottom up approach
  - we all have our favourites

- Any WIMP theory could show up in lots of places

  - Higgs and supersymmetry searches at the LHC and its predecessors
  - low-energy accelerators
  - measurements of the magnetic moment of the muon
  - beam dump/fixed target
  - electroweak precision tests
  - dark matter direct detection experiments
  - searches for antimatter in cosmic rays
  - nuclear cosmic ray ratios
  - radio data
  - effects of dark matter on reionisation, recombination and helioseismology
  - the observed dark matter cosmological abundance
  - neutrino masses and mixings
  - gamma ray searches (e.g. FERMI-LAT, HESS, CTA, etc)

To confirm or refute a given WIMP theory

- Need to perform a global statistical fit

  - i.e. map out likelihood (Frequentist) or posterior PDF (Bayesian) in the model space
  - can repeat for different models for model comparison
  - many examples exist in particle physics, astrophysics and cosmology

- Require:

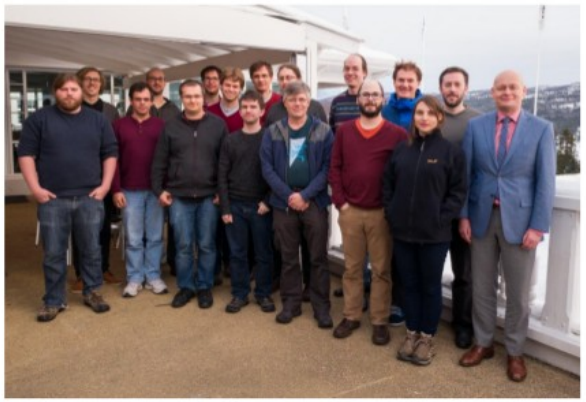
  - efficient exploration of large parameter spaces
  - fast predictions of experimental signatures
  - accurate likelihood calculations (including systematic effects)
  - a model independent framework that can cope with new ideas

GAMBIT: General tool for new physics exploration

GAMBIT: The Global And Modular BSM Inference Tool

- Fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source

ATLAS	A. Buckley, P. Jackson, C. Rogan, M. White,
LHCb	M. Chrząszcz, N. Serra
Belle-II	F. Bernlochner, P. Jackson
Fermi-LAT	J. Conrad, J. Edsjö, G. Martinez, P. Scott
CTA	C. Balázs, T. Bringmann, J. Conrad, M. White
HESS	J. Conrad
IceCube	J. Edsjö, P. Scott
XENON/DARWIN	J. Conrad, R. Trotta
Theory	P. Athron, C. Balázs, T. Bringmann, J. Cornell, J. Edsjö, B. Farmer, T. Gonzalo, S. Hoof, F. Kahlhoefer, A. Krislock, A. Kvellestad, M. Pato, F. Mahmoudi, J. McKay, A. Raklev, R. Ruiz, P. Scott, R. Trotta, C. Weniger, M. White



27 Members, 9 Experiments, 4 major theory codes, 10 countries

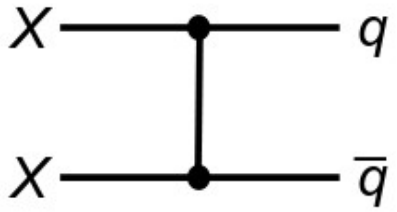
- Not just WIMP DM (axions coming soon), not just particle physics, not just astrophysics!

To confirm or refute the WIMP hypothesis

- WIMP miracle rests on the fact:

  - relic density for dark matter magically pops out for thermal relic with weak annihilation cross-section

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$



- For m_X ~ 100 GeV and typical couplings, get correct relic abundance

- Need to measure $\langle \sigma v \rangle$ to rule out WIMP hypothesis

  We need to measure this to rule out the WIMP hypothesis → need indirect detection experiments

  - LHC only probes interactions with quarks
  - same applies for direct detection experiments

Science with the Cherenkov Telescope Array (CTA)

CTA design goals:

- 10-fold increase in sensitivity over current VHE Υ-ray instruments
- energy range of ~30 GeV - 100 TeV
- large (~8º) field of view for surveys
- improved angular and energy resolution
- operate as an open observatory

CTA science goals:

- understanding where and how the bulk of CR particles are accelerated
- what makes black holes of all sizes such efficient particle accelerators
- the nature of dark matter
- Υ-ray probe for the fundamental laws of physics

www.cta-observatory.org
B.S. Acharya et al. 2013, APh, 43, 3

Australian CTA involvement

CTA – Australia

U. Adelaide
G. Rowell, B. Dawson, R. Clay, P. Veitch, D. Ottaway, M. White, V. Stamatescu, L. Bowman, A. Malouf, N. Wild

UNSW
M. Burton, M. Ashley, C. Braiding, N. Maxted

WSU
M. Filipovic, N. Tothill

ANU
G. Bicknell, R. Crocker

Monash
C. Balazs, D. Galloway

U. Syd
A. Green

Funding

ARC LIEF (hardware/commissioning)

NCRIS/AAL (travel, meetings, CTAO membership)

Summary

- GAMBIT is a new, open source tool for exploring generic models of dark matter

  - lots of WIMP calculations in place
  - axion calculations coming soon
  - cosmology offshoot is in the planning stage
  - we would love to hear from users interested in other studies

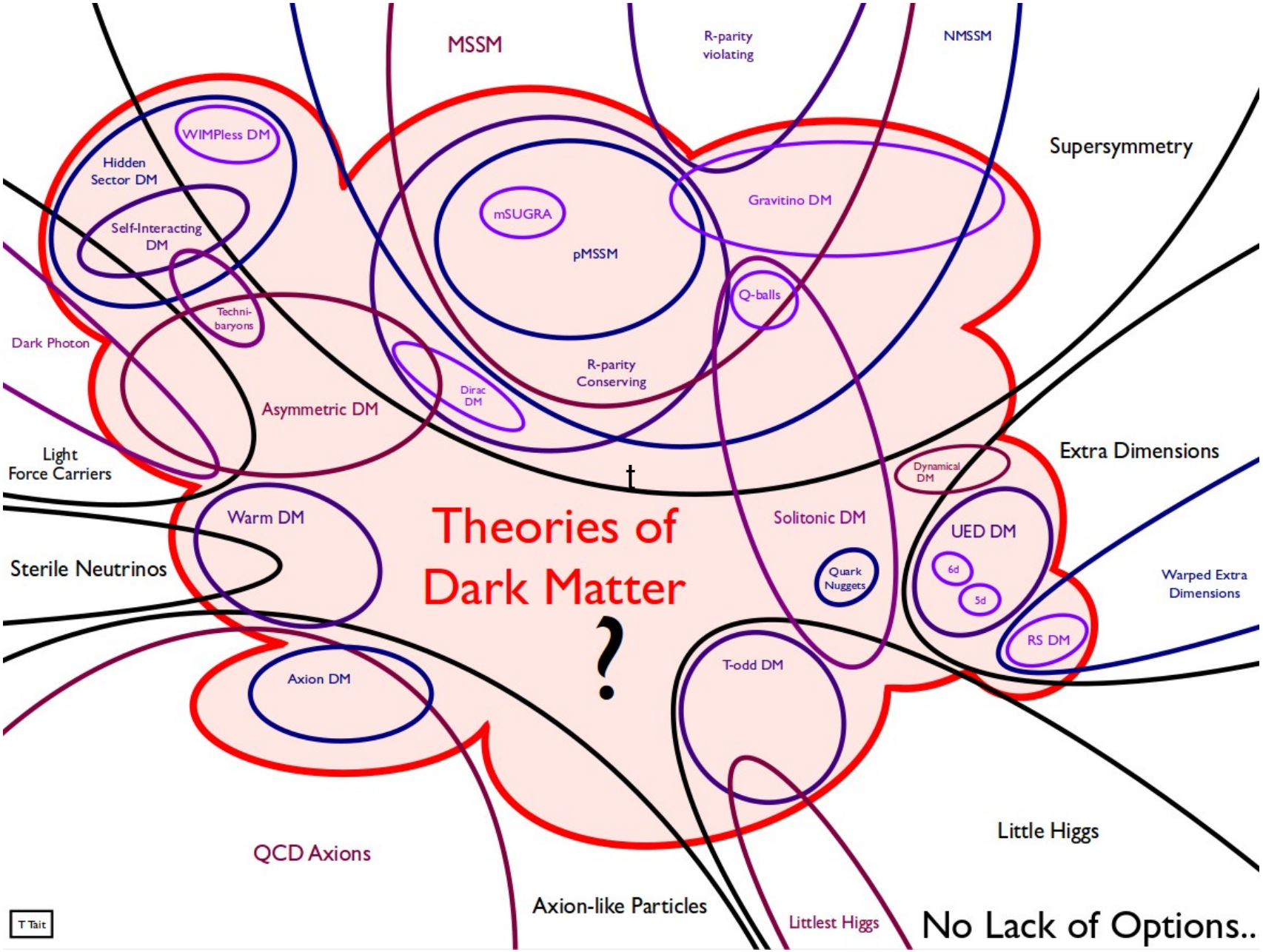
- The Cherenkov Telescope Array now has Australian involvement

  - we are starting to become involved in dark matter searches
  - nascent effort involving Australian gamma ray community plus particle experimentalists and theorists, plus astrophysics theorists
  - exciting physics to come, starting in ~2019

Lots of options for dark matter

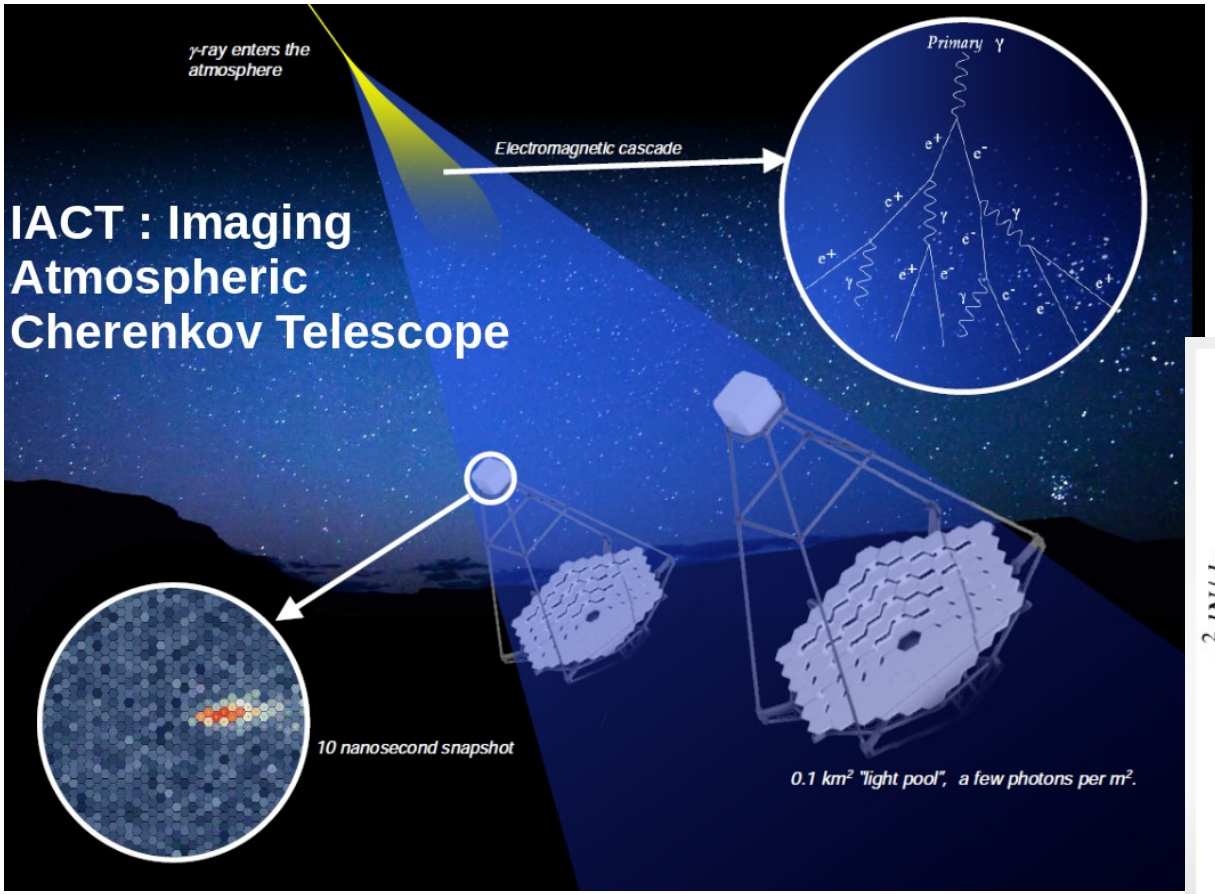
- Primordial black holes
  - lots of mechanisms for creation / most of the mass range is ruled out (grav. lensing)
- Weakly Interacting Massive Particles (WIMPs)
  - expected in many BSM physics theories / small scale structure might be difficult to obtain
- Sterile Neutrinos
  - favoured way to get neutrino masses? / minimal model is disfavoured
- Asymmetric dark matter
  - improved structure formation / potentially reduced observational options
- Axions
  - very strong theoretical motivation (strong CP problem) / minimal model is ruled out
- Wimpzillas!
  - lots of theoretical options / strong constraints from e.g. Pierre Auger (UHECR)

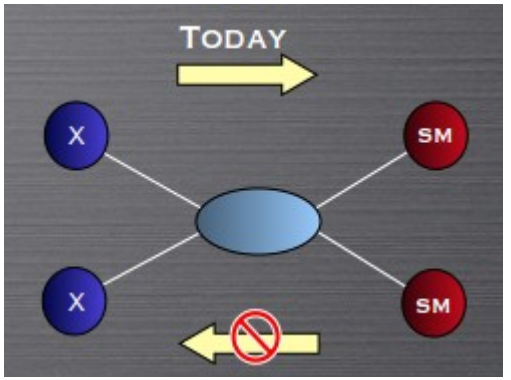
These categories are not always mutually exclusive

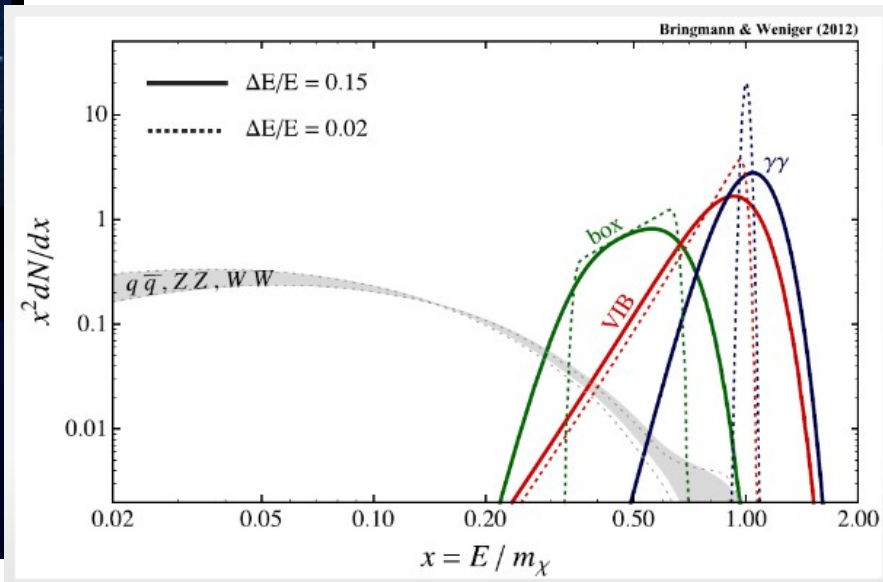


Tim Tait

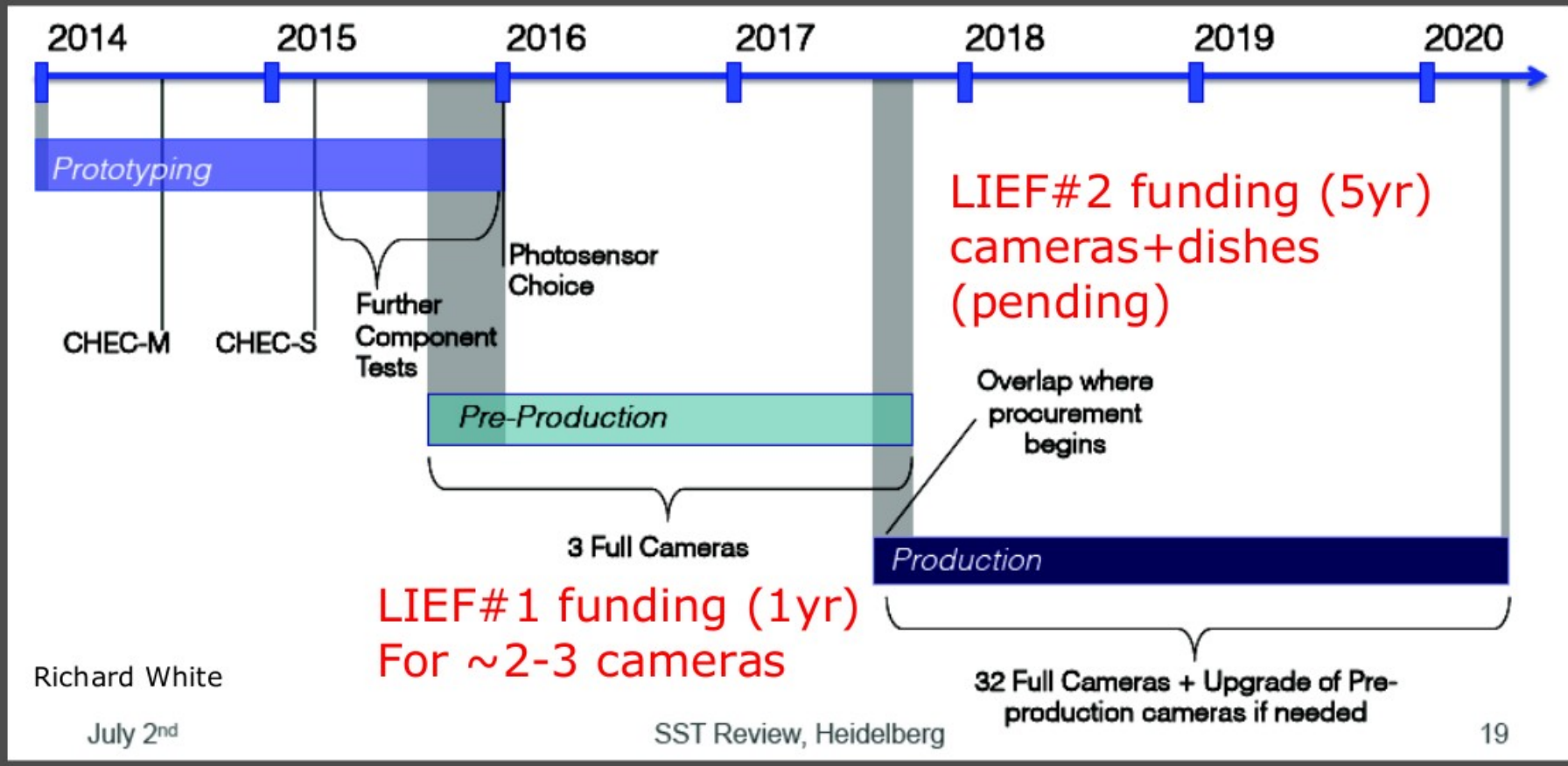
$$\frac{\mathrm{d}\Phi_\gamma(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m^2} \sum_i BR_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma}}_{Particle\ Physics} \times \underbrace{\int_{\Delta\Omega}\int_{LOS} \rho(r[s])^2 ds\, d\Omega}_{Astrophysics},$$







Timeline for CTA Small Size Telescopes (SST-GCT) Sub-consortium (aim 35 telescopes)



Timeline for all other aspects of CTA v. similar..

CTA sites


CTA sites selected 16 July 2015
Ground breaking Oct. 9, 2015
San Pedro Mártir, Mexico
La Palma, Canary Islands, Spain
Paranal, Chile
Aar, Namibia
Northern Hemisphere
Southern Hemisphere
Chosen sites
Backup sites

CTA Australian involvement

Australia's Roles in CTA:

CTA Hardware & Array Design

- Telescope hardware & commissioning (ARC LIEF funding)
- Atmospheric characterisation (LIDAR, cloud monitoring)
- Analysis techniques & effect of clouds on Cherenkov images

Multi-wavelength/messenger strengths

- ISM surveys/studies (Mopra, ATCA, ASKAP, SKA)
  (sub)arcmin surveys vital for CTA's Galactic science
  see **Poster #17, #33, A. Walsh talk**
- Radio continuum: transients/steady (ATCA, MWA, UTMOST, ASKAP, SKA)
- X-ray astronomy (e-ROSITA, XMM-Newton, Chandra)

Theory Strengths

- Theoretical high energy astrophysics (e.g. Galactic Centre, jets/outflows)
- Astro-particle physics – Dark matter properties

Great potential to link with....

- Optical (Halpha, GALAH, Skymapper)
- Cosmic-rays (Pierre Auger Obs.)
- Grav. Waves (A/LIGO)
- Neutrinos (IceCube)
- HP Computing (Pawsey....) transients, MWL features,, local data centre