GLPA conference, 2015

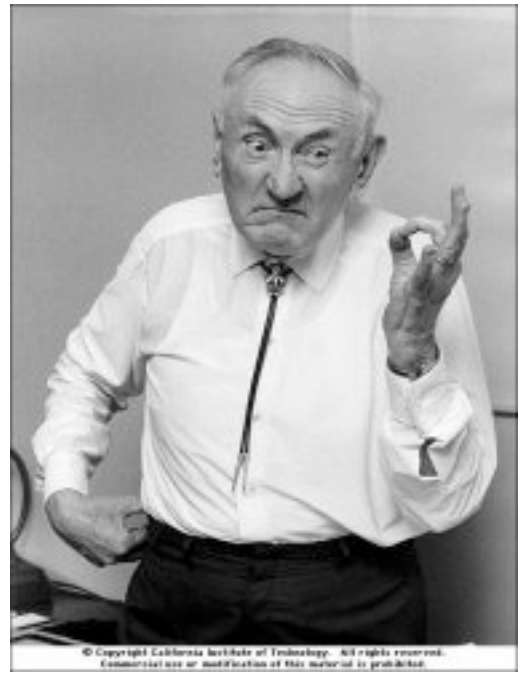
Dark Matter

Dragan Huterer,
Jacob Bourjaily, Ron Kaitchuck

Dark Matter!

Early History:

- Fritz Zwicky (1933) observed the motions of galaxies in the Coma cluster and
- Zwicky concluded that their trajectories cannot be supported by the visible matter (he used the so-called virial theorem to relate the velocities to the total mass)
- Therefore, some -- most -- matter in Coma must be dark



Fritz Zwicky
(Swiss,
prof at Caltech)


Coma cluster (100 Mpc away)

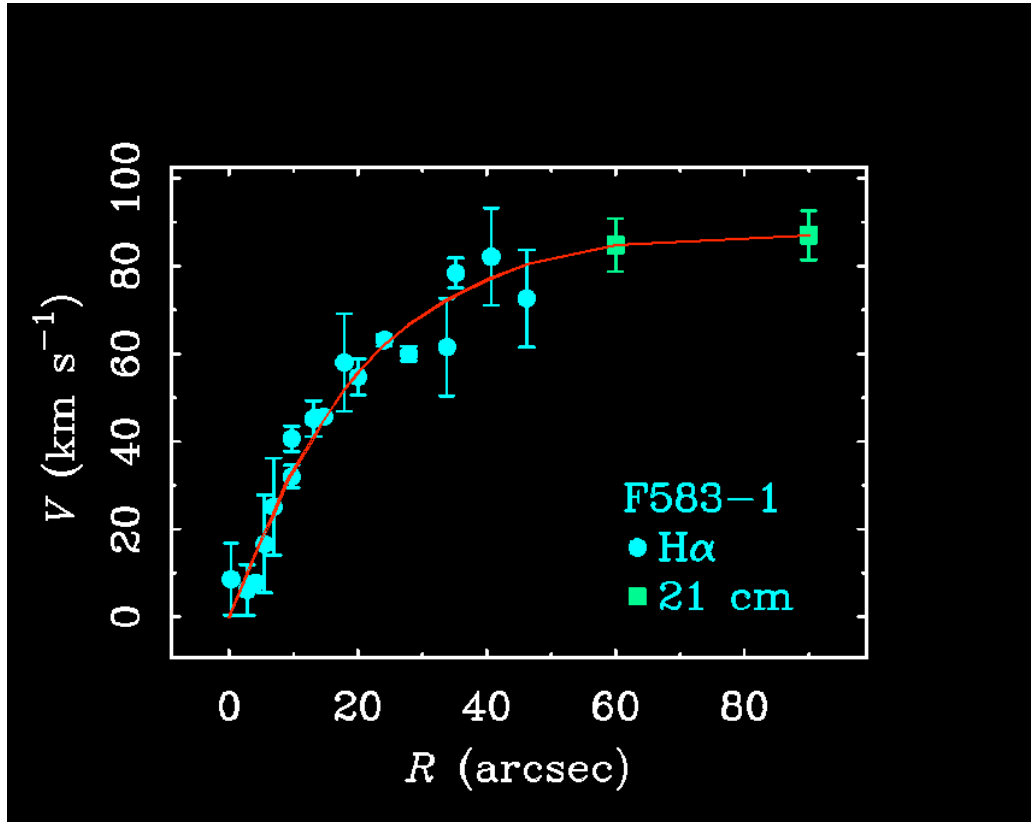
Flat rotation curves

- In the 1970s, Vera Rubin and collaborators clinch the evidence for DM by measuring rotation rate of stars in galaxies
- She found that rotation curves stay flat as you recede from the center of the galaxy
- Conclusion: the dark halo conspires to "kick in" where the luminous matter stops to make the total curve flat

Vera Rubin
(American,
shown measuring spectra)

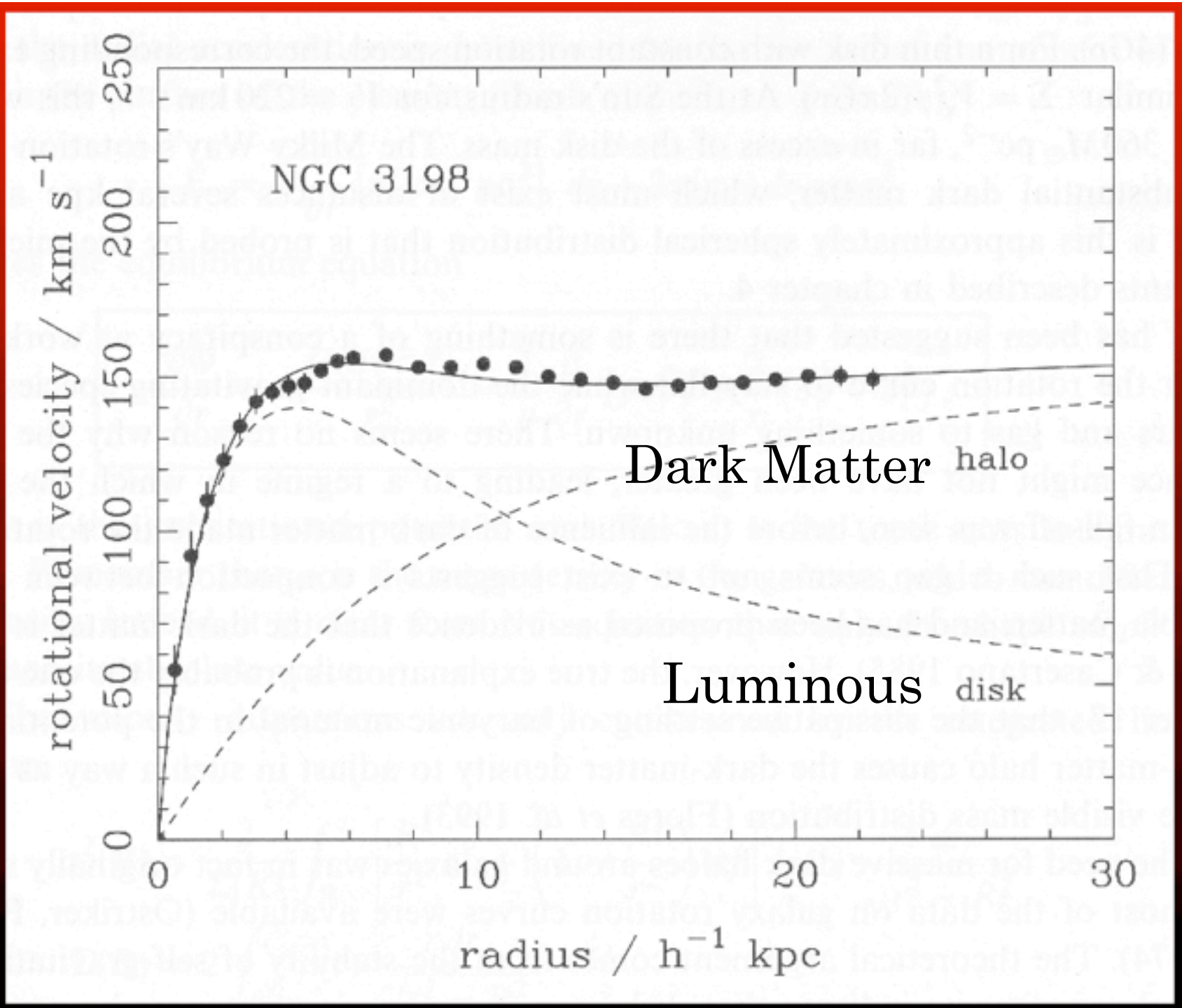
Measuring the rotation curve

- Galaxies (that is, gas, clouds and stars in them) rotate
- Rotation can only be supported by sufficient mass (see Newton's laws equation at right)
- Newton's laws predict that velocity should fall off with square root of radius
- Not observed - velocity stays constant with radius ⇒ "flat rotation curves"



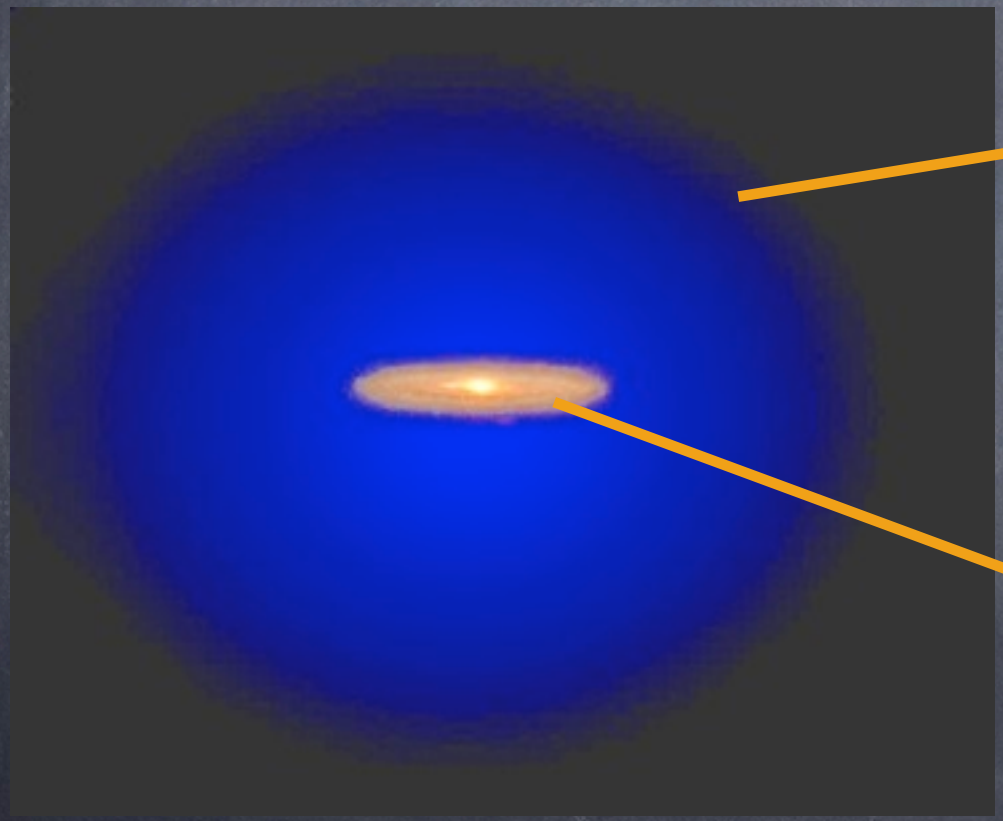
$$\frac{mv^2}{r} = \frac{GM_r m}{r^2} \Rightarrow v = \sqrt{\frac{GM_r}{r}}$$

A typical galaxy rotation curve



Dark Matter is in "halos" around galaxies

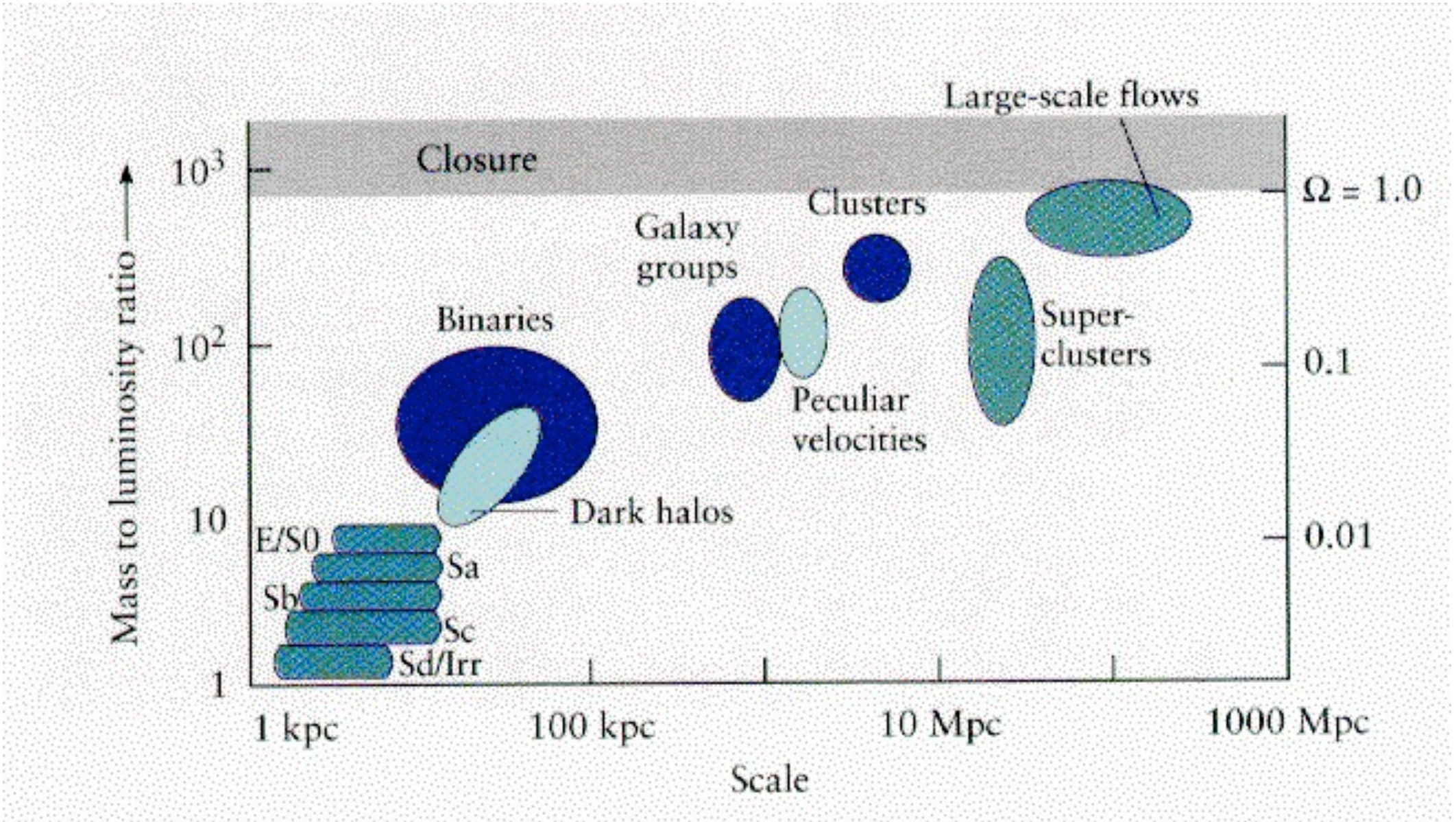
(and also around clusters)



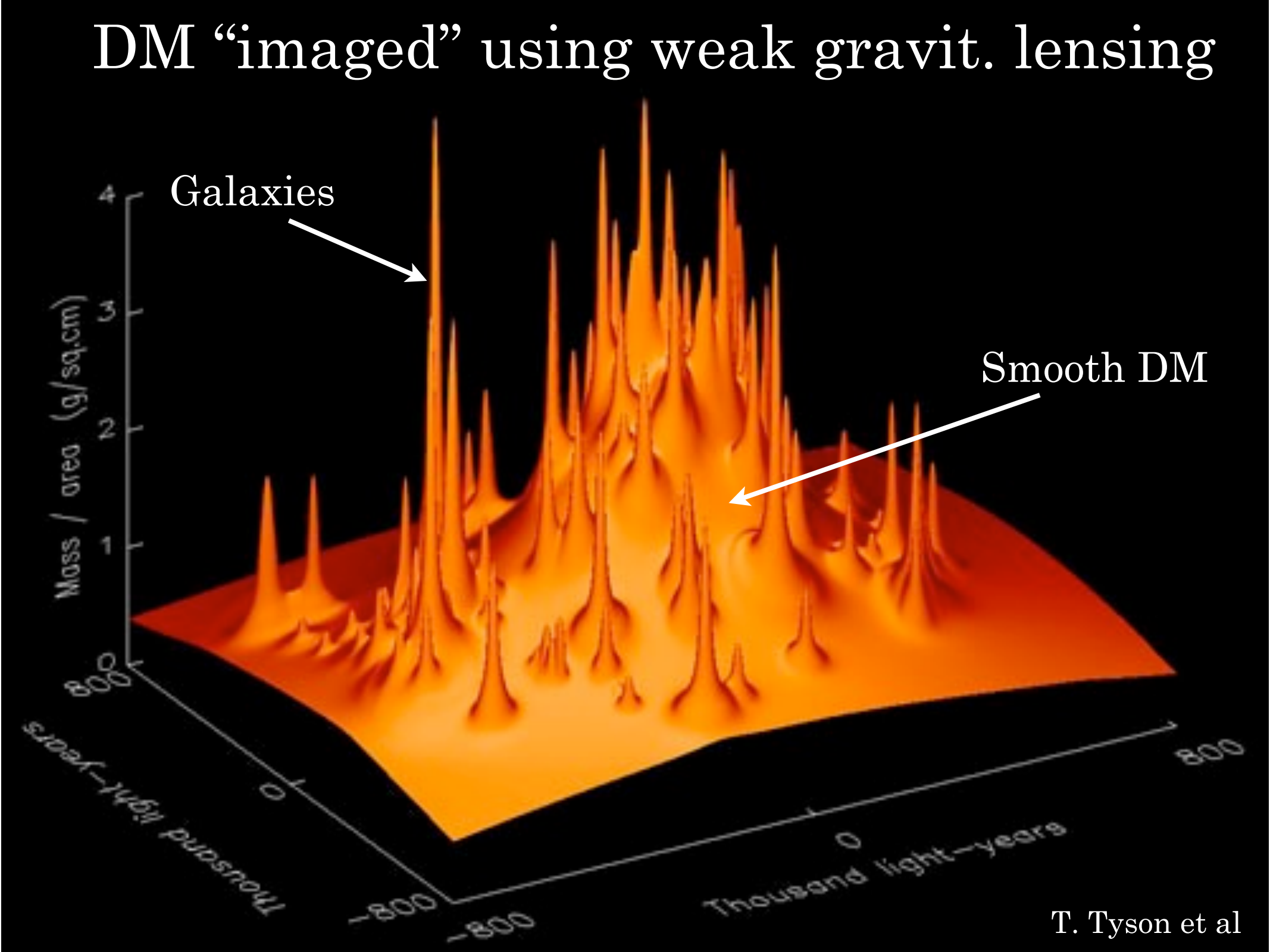
(invisible)
Dark Matter halo

(visible) light
from galaxy

"Mass-to-Light ratio" measurements indicate: the bigger the object is, the more DM-dominated it is

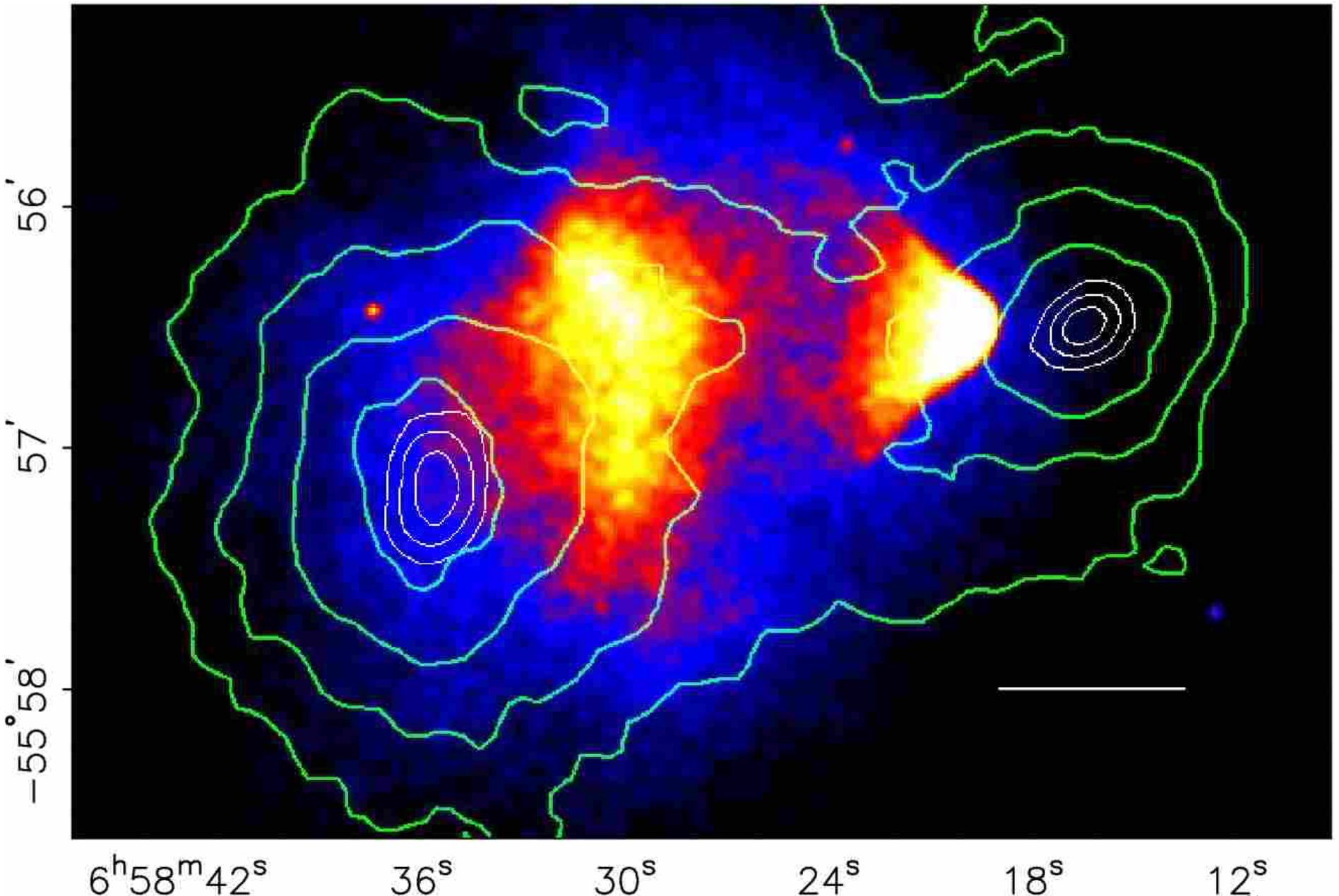


DM "imaged" using weak gravit. lensing



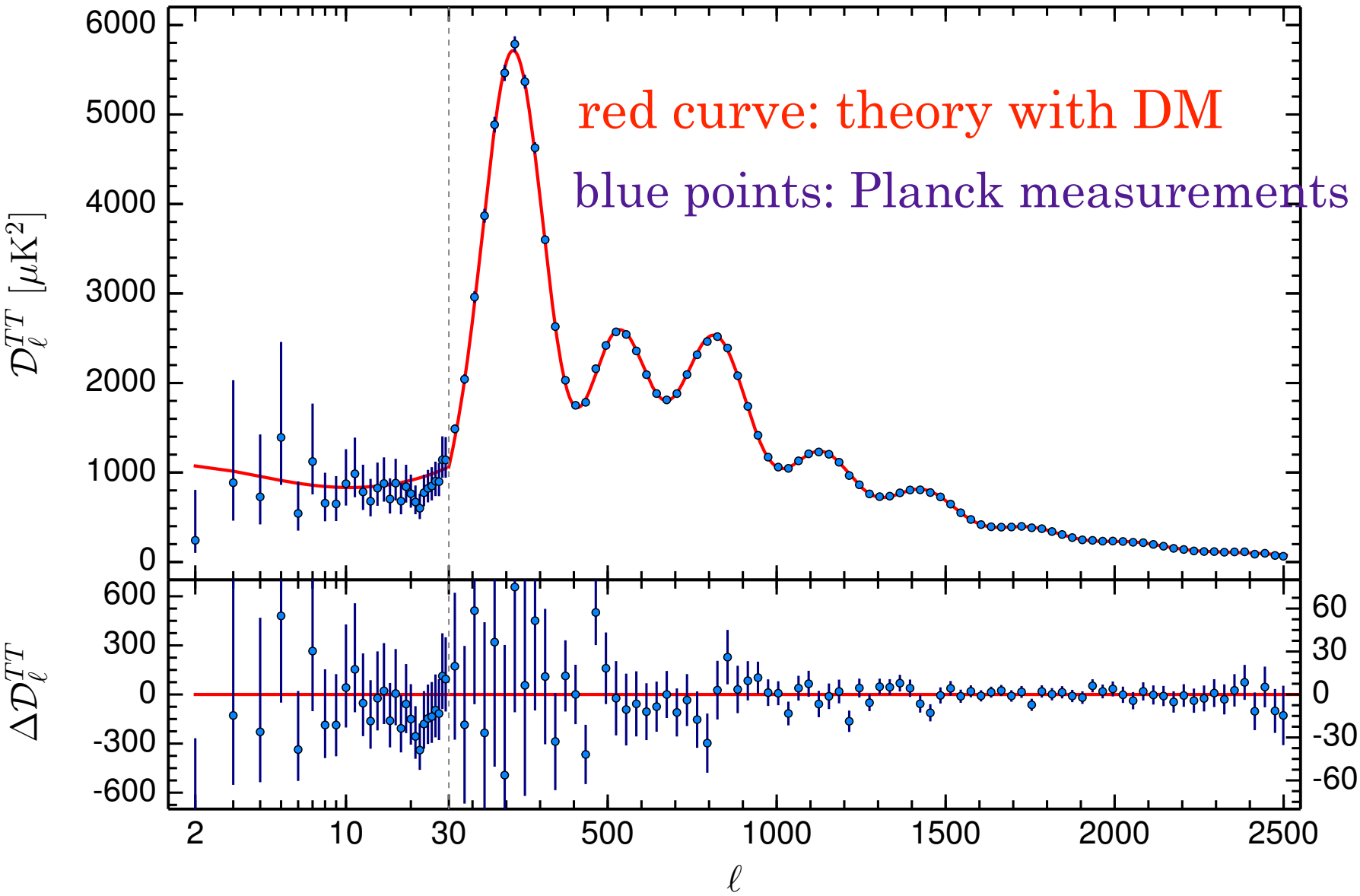
T. Tyson et al

Bullet cluster: mass and light do not overlap!



D. Clowe et al.

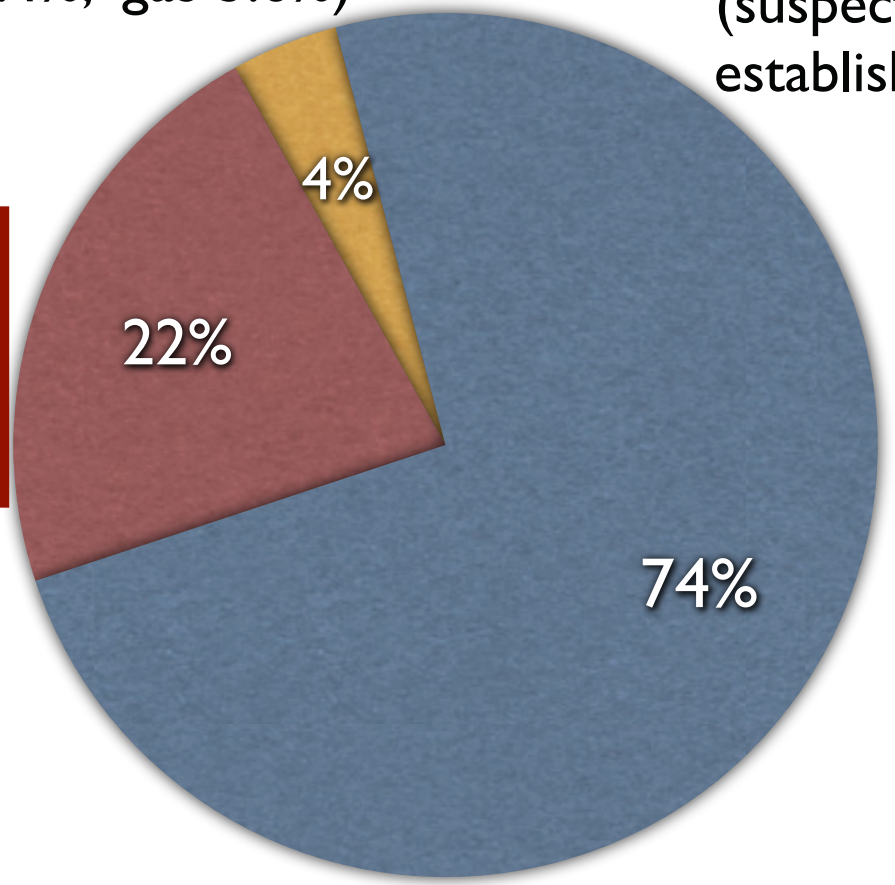
Best evidence for DM: fluctuations in the cosmic microwave background (CMB)



Makeup of universe today

Visible Matter
(stars 0.4%, gas 3.6%)

Dark Energy
(suspected since 1980s
established since 1998)

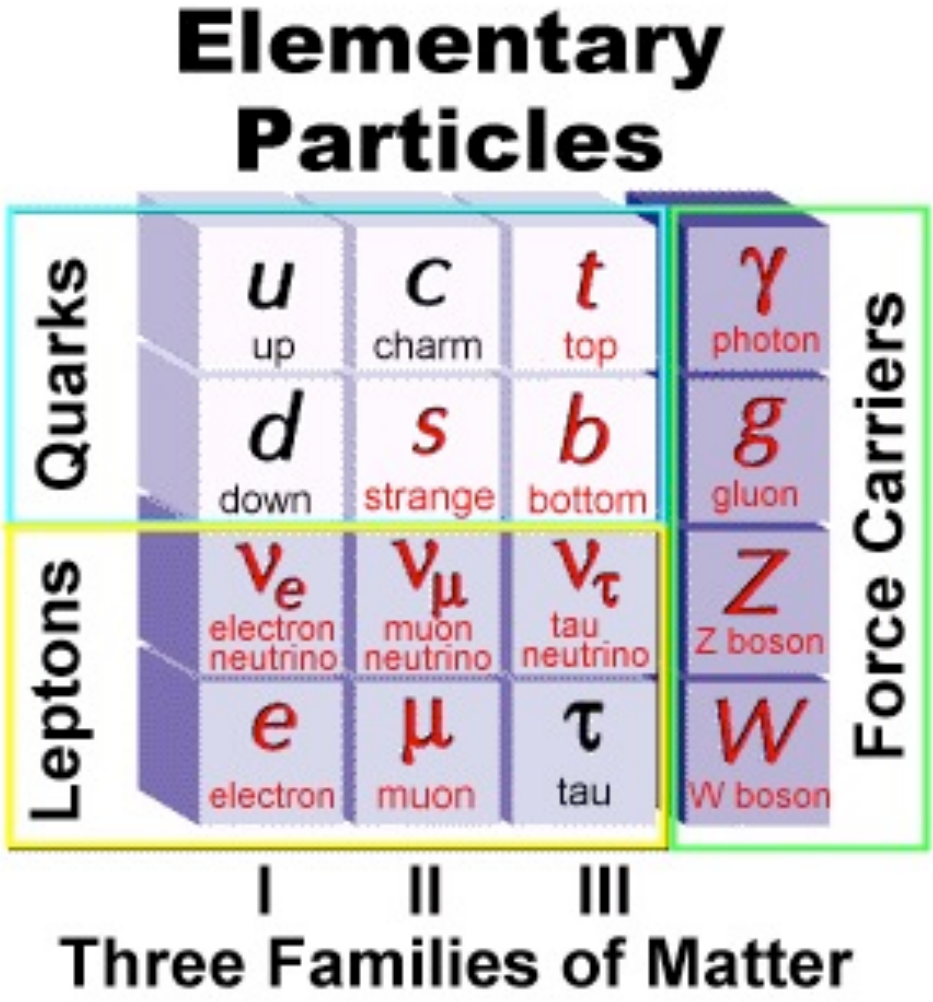


Dark Matter
(suspected since 1930s
established since 1970s)

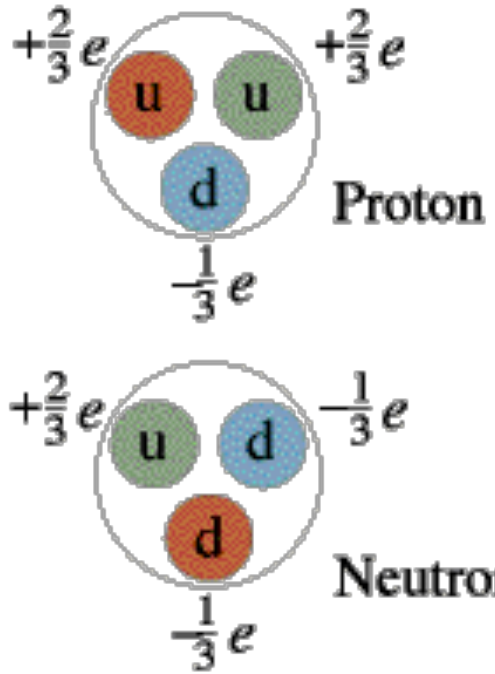
Also:
radiation (0.01%)

Simulation movie

DM **cannot** be one of these!

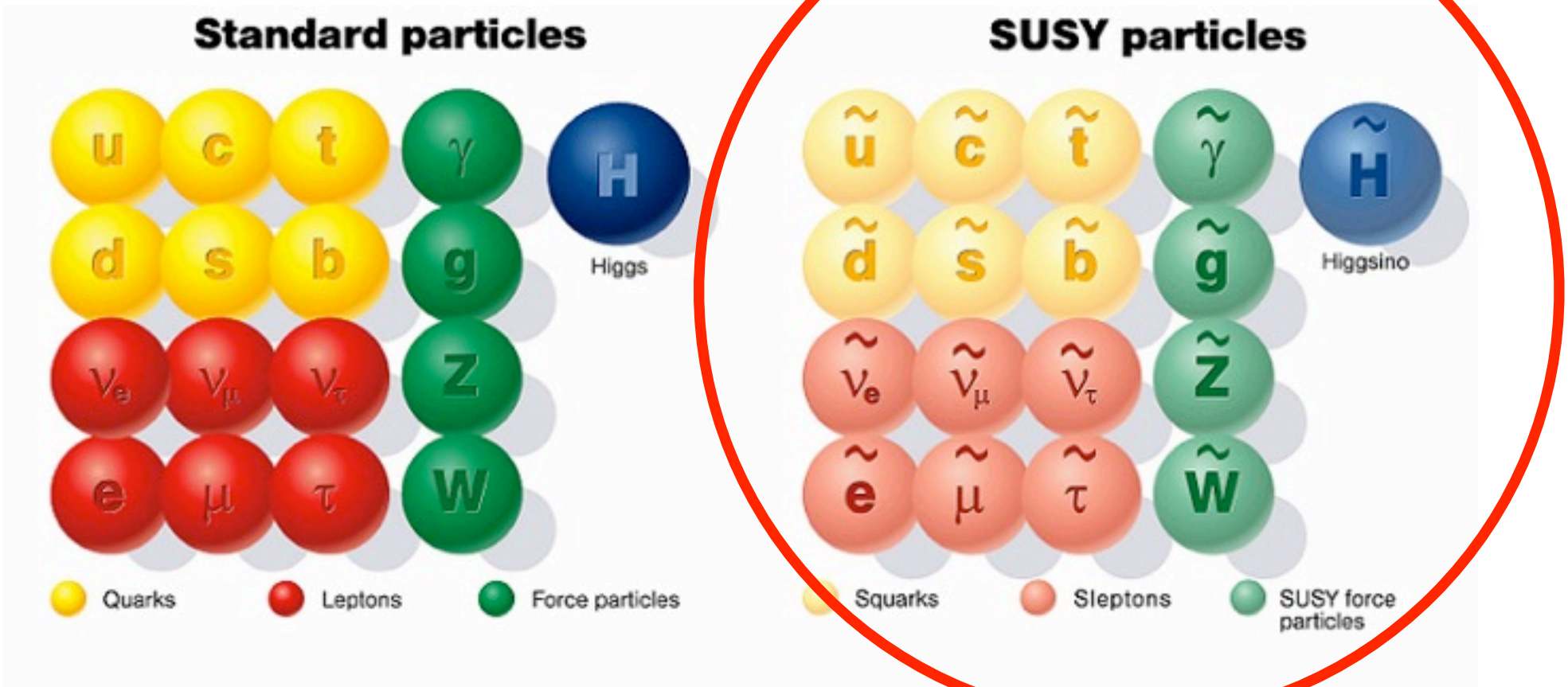


Examples:



- Hadrons: particle made of quarks
  - baryons: 3 quarks
  - mesons: 2 quarks
- Leptons and force carries are not made of quarks

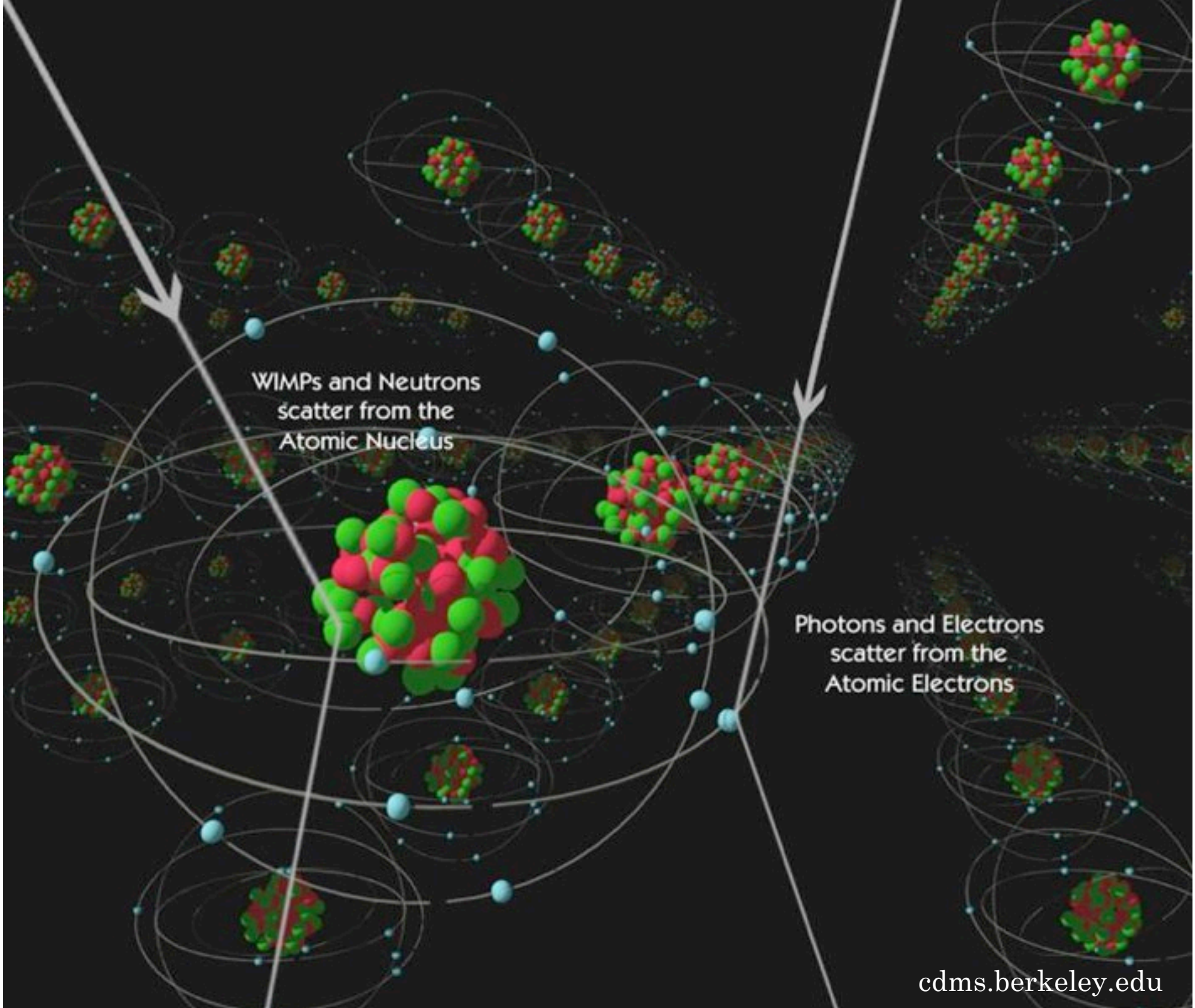
DM *could* be one of these supersymmetric particles
(there are other possibilities too...)

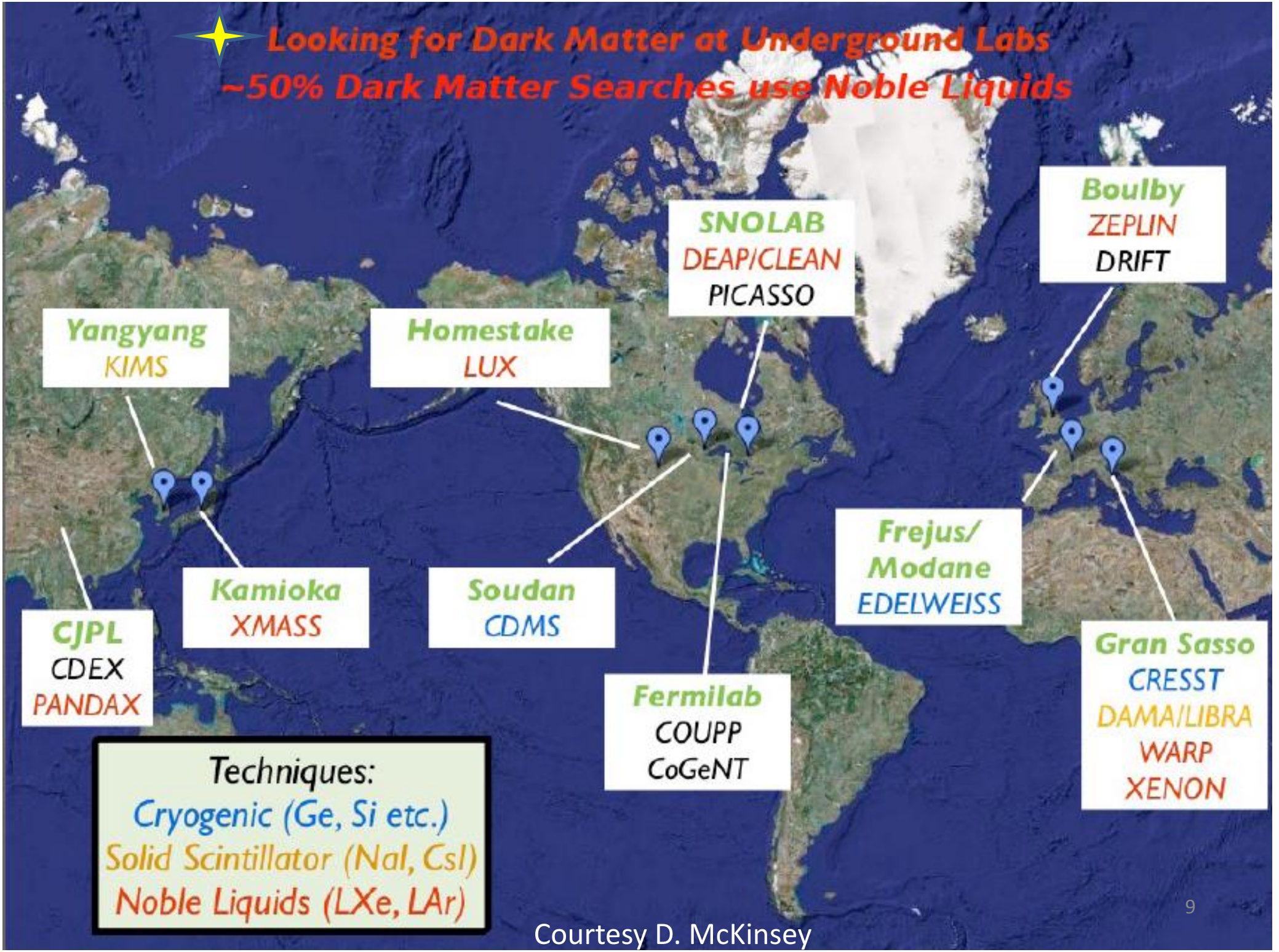


Direct and Indirect Searches for Dark Matter:

Direct detection - wait for WIMP to scatter off of nuclei in underground detectors

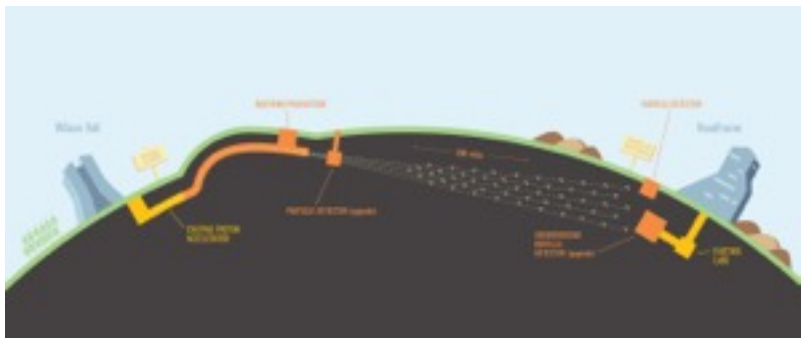
Indirect detection: detect products - "normal" particles - of WIMP annihilation in the center of Galaxy (or other galaxies)

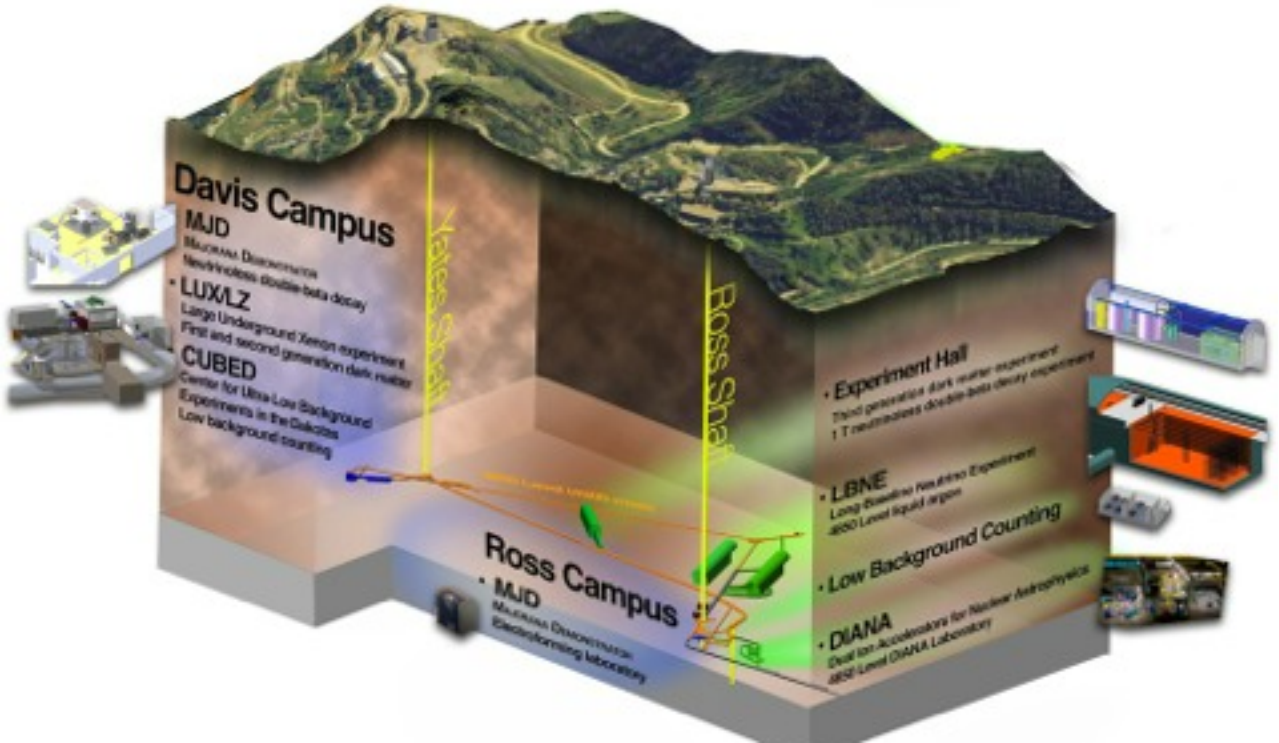

WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons
cdms.berkeley.edu



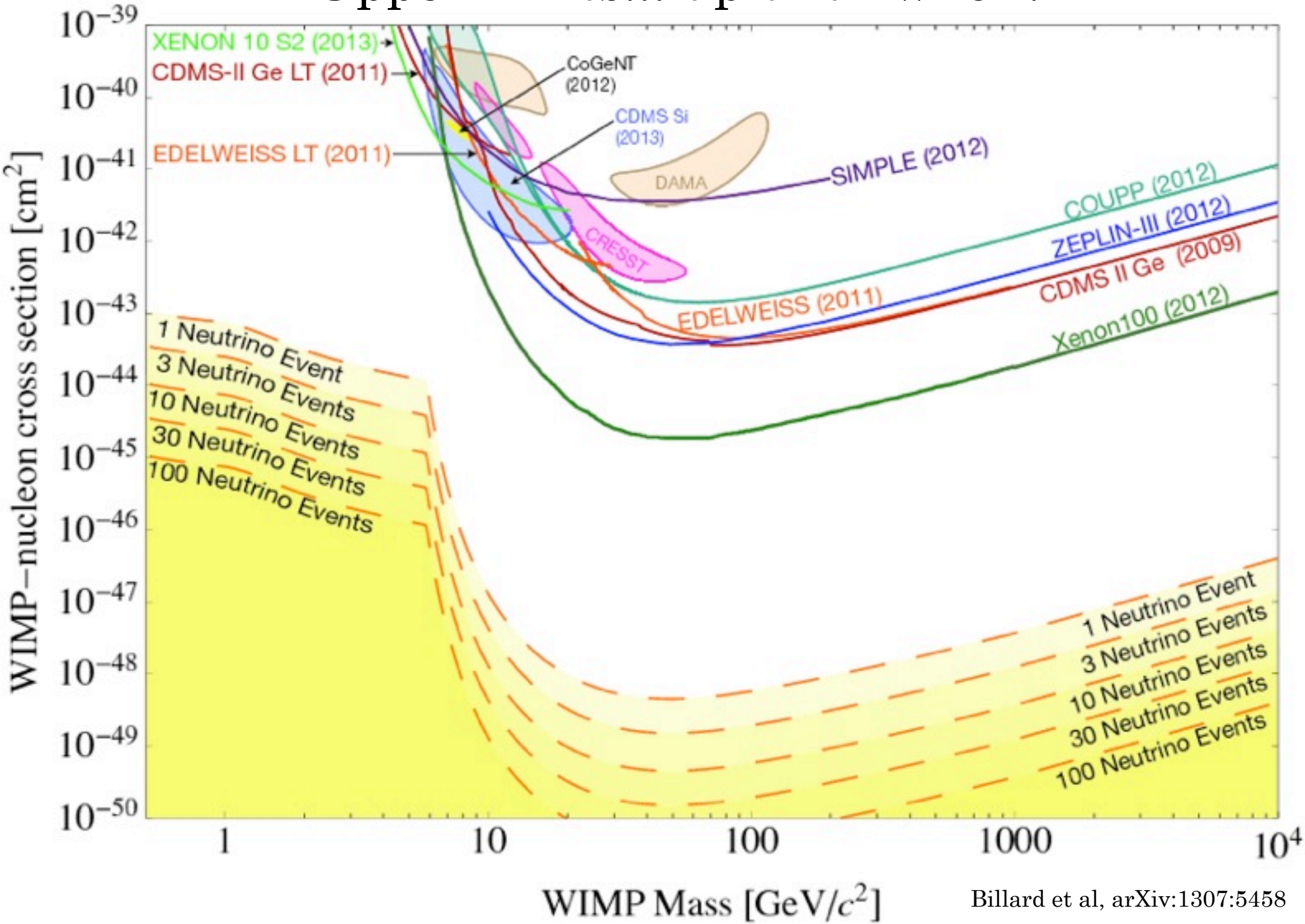
Courtesy D. McKinsey

Sanford Underground Research Facility (SD)



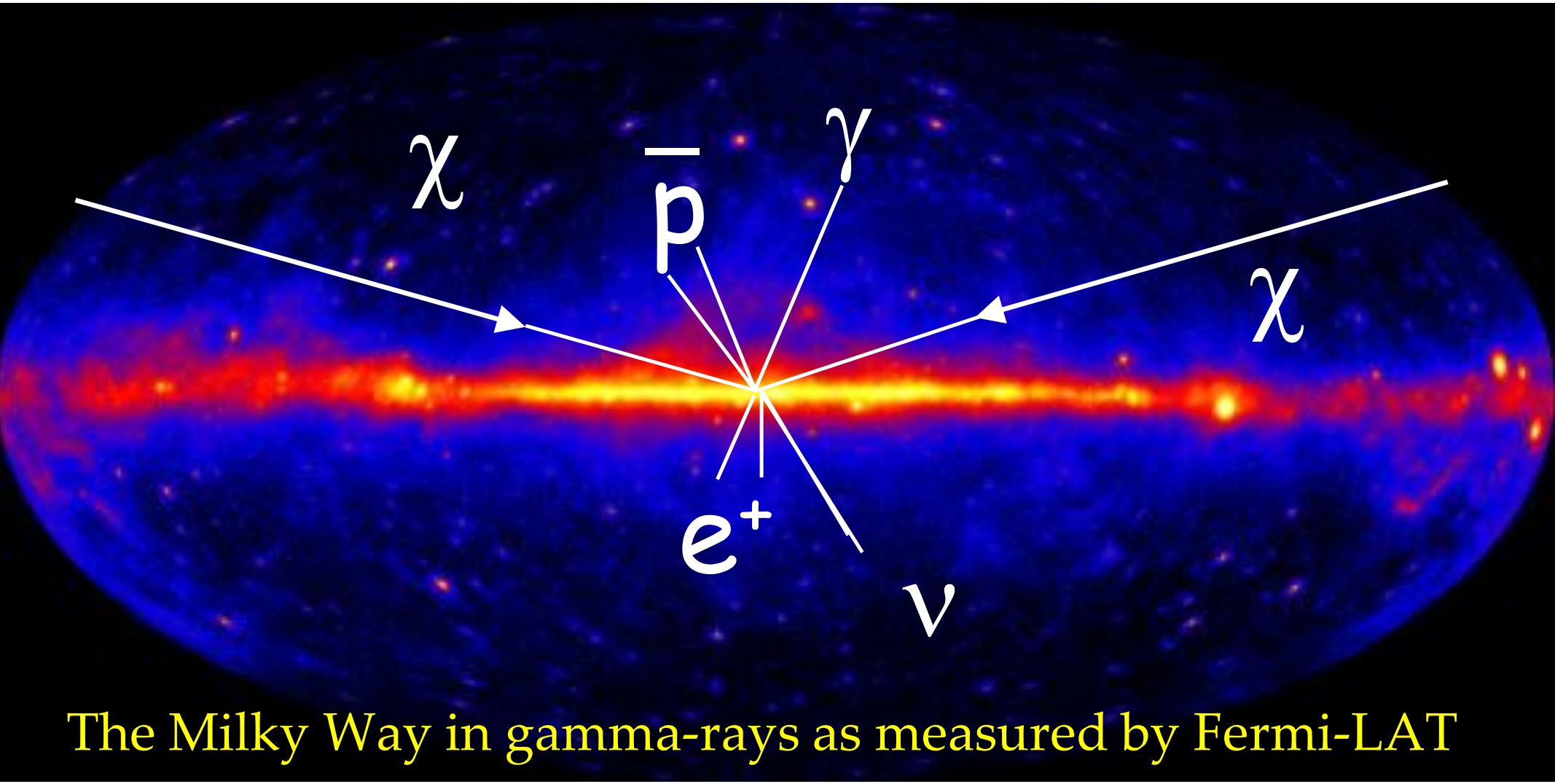


Upper limits... up until when?



Billard et al, arXiv:1307:5458

Indirect detection



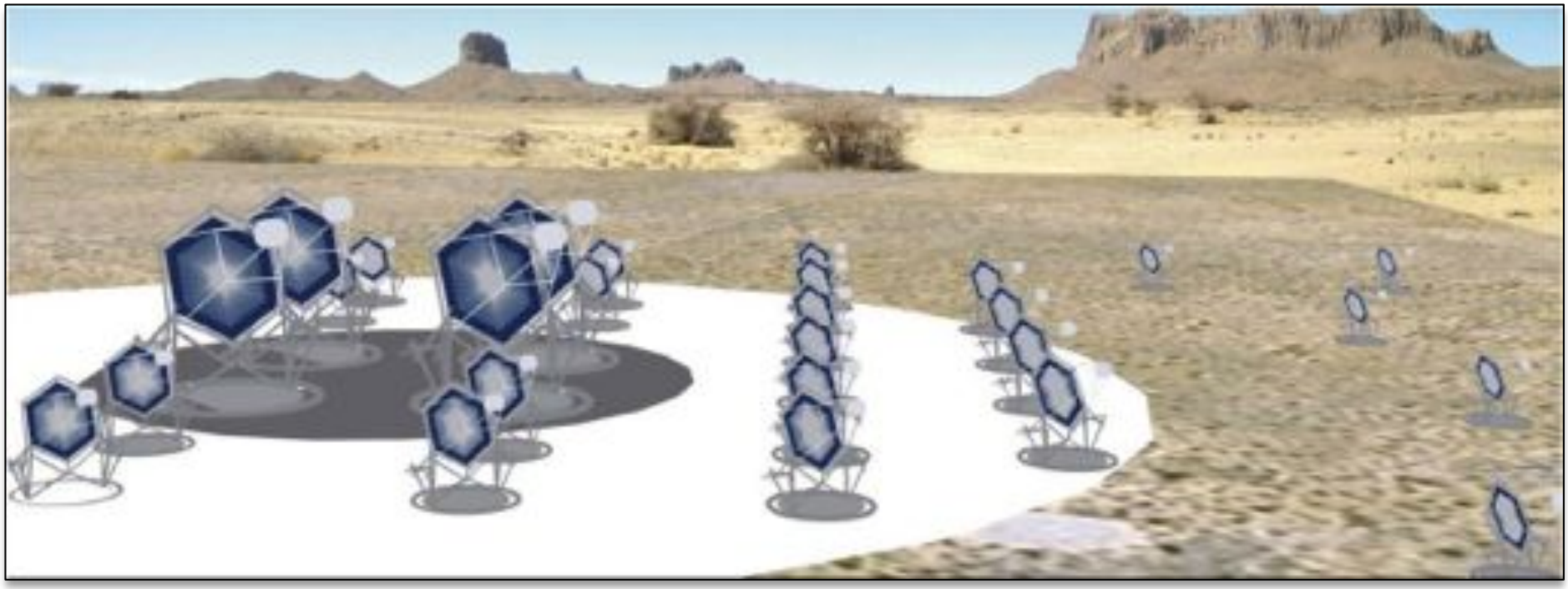
Lars Bergstrom

Indirect detection through γ-rays from DM annihilation

Fermi-LAT (Fermi Large Area Telescope)

H.E.S.S. & H.E.S.S.-2

VERITAS



CTA (Cherenkov Telescope Array)

Big Questions

1. How sure are we about the evidence for DM?

2. Is DM made up of as-yet undiscovered particles (Weakly Interacting Massive Particles, "WIMPS")?
   [as opposed to e.g. modifications of gravity]

3. Will we find the DM?
   When? How sure will we be we found it?

4. When we find DM, then what?