The Texas Dark Matter Project: Constraints on Dark Matter Axion Models from White Dwarf Evolution

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What Are White Dwarf Stars … and Why Should I Care?

- Stellar remnants of most low mass stars.
- Evolve by slowly radiating away residual thermal energy.

- They radiate that energy in the form of photons, neutrinos, and maybe other weakly-interacting particles such as axions, which are dark-matter candidates – and maybe other SUSY particls?

What are axions?

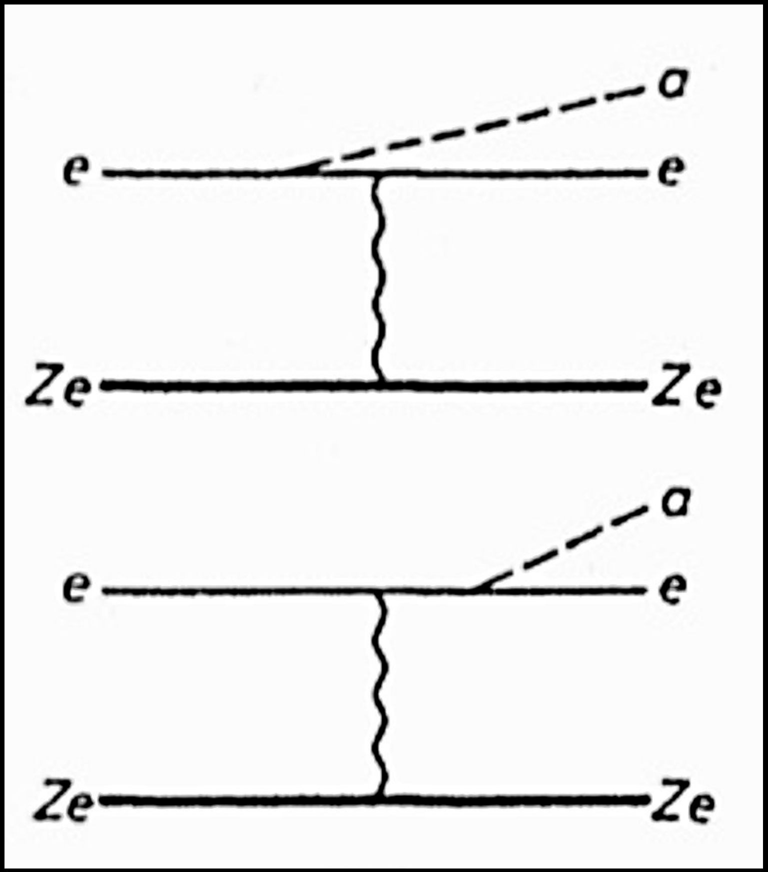
- Experimental fact: The neutron dipole moment is at least 10 orders of magnitudes smaller than that expected from the Standard Model of particle physics.
- A small dipole moment for the neutron means that Charge-Parity (CP) is perfectly conserved in strong interactions.
- In order to ensure CP conservation, a simple solution is to introduce an extra term in the Lagrangian of the fundamental interactions.
- This new term corresponds to a new symmetry, the Peccei-Quinn symmetry.
- The spontaneous breaking of this symmetry gives rise to axions.

Basic axion properties

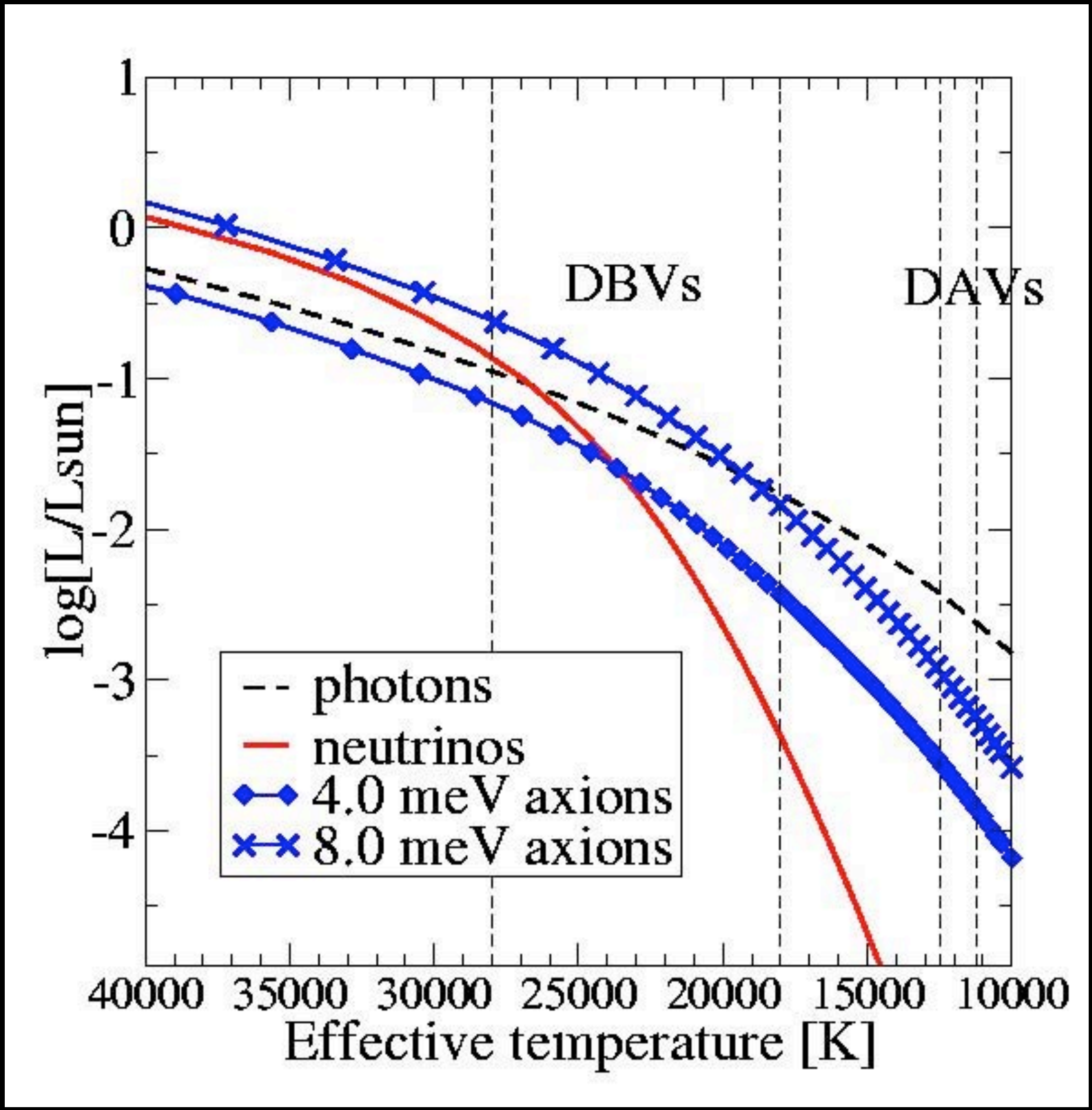
- Like neutrinos:
  - neutral
  - weakly interacting
  - low mass*
- Unlike neutrinos:
  - bosons
- The existence of axions has NOT been confirmed
- *The axion mass is not constrained by the theory. The only reason we think axions have (very) low mass is because if they did not, we would have found them by now.

Axions in white dwarfs

- In white dwarfs, axions may be produced by bremsstrahlung when an electron passes near a nucleus (the axion replaces the photon)



Sources of energy loss in WDs



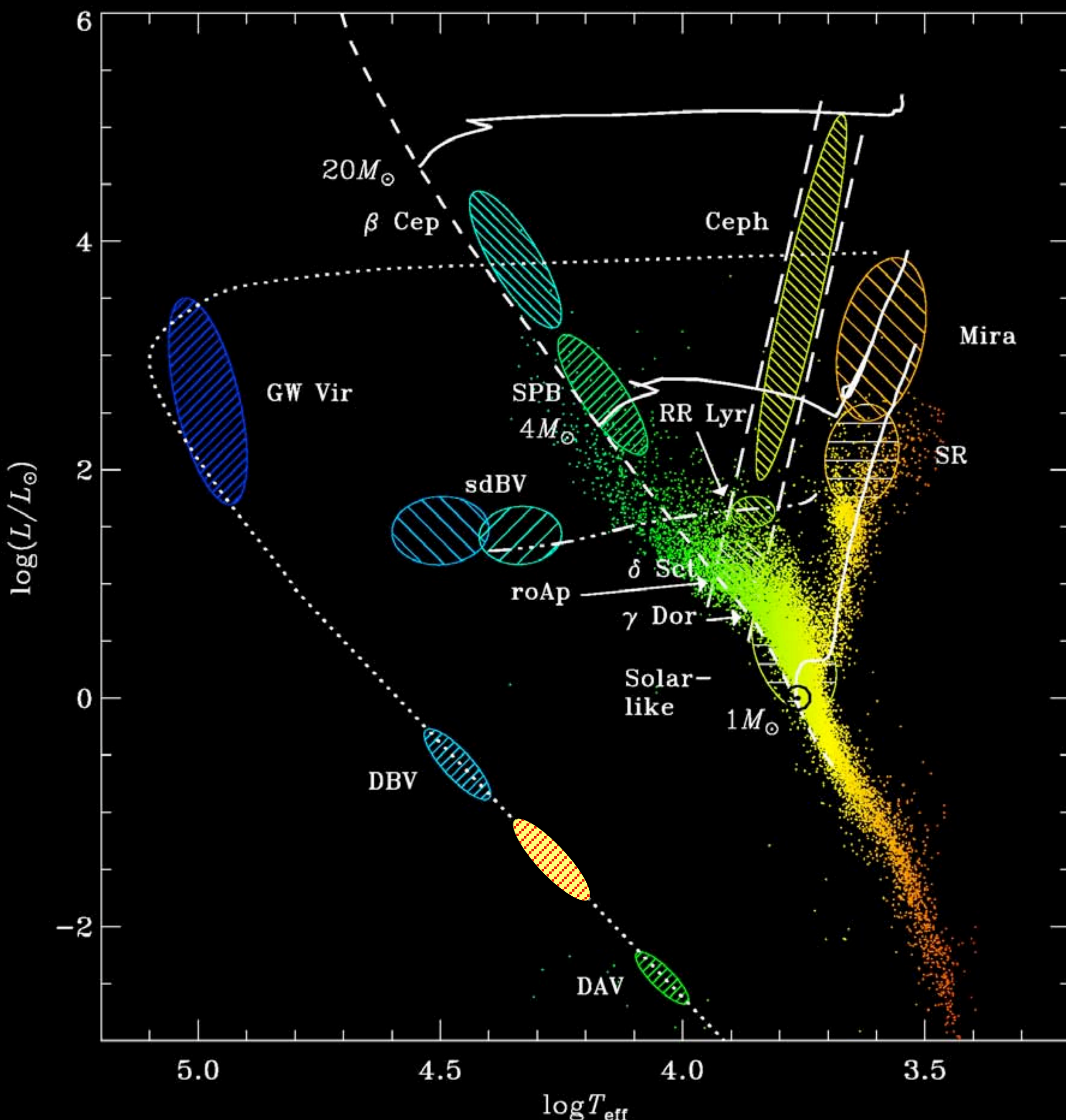
Are Effects of Plasmon Neutrinos or Axions Measurable Using the Techniques of Asteroseismology?

How do we test this?

- **Some white dwarfs pulsate and their pulsation periods slow down as a result of the loss of energy. Measuring the rate of period change, we can determine the *total* energy loss rate.**

- **This allows us to constrain the properties of plasmon neutrinos and axions.**

The first new class of pulsating white dwarf found in the last 25 years!



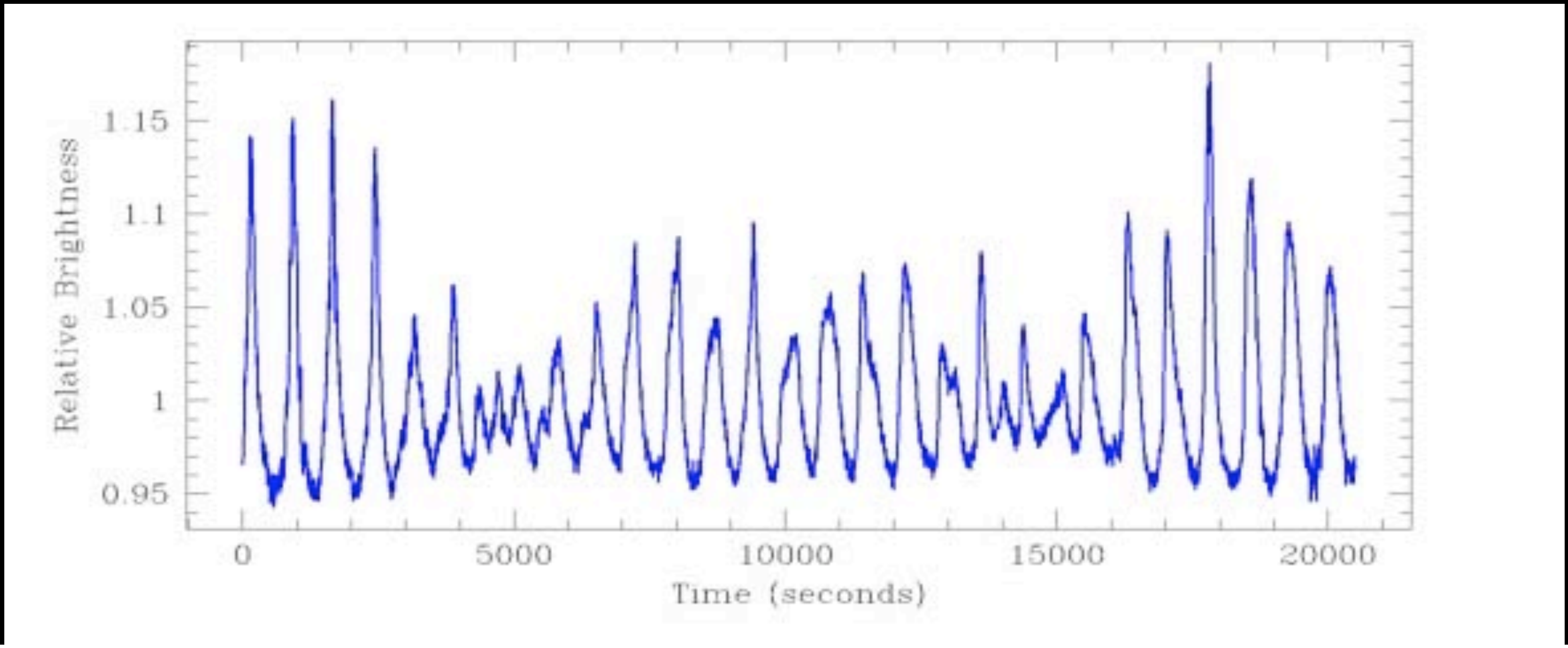
All four have been discovered at McDonald Observatory!

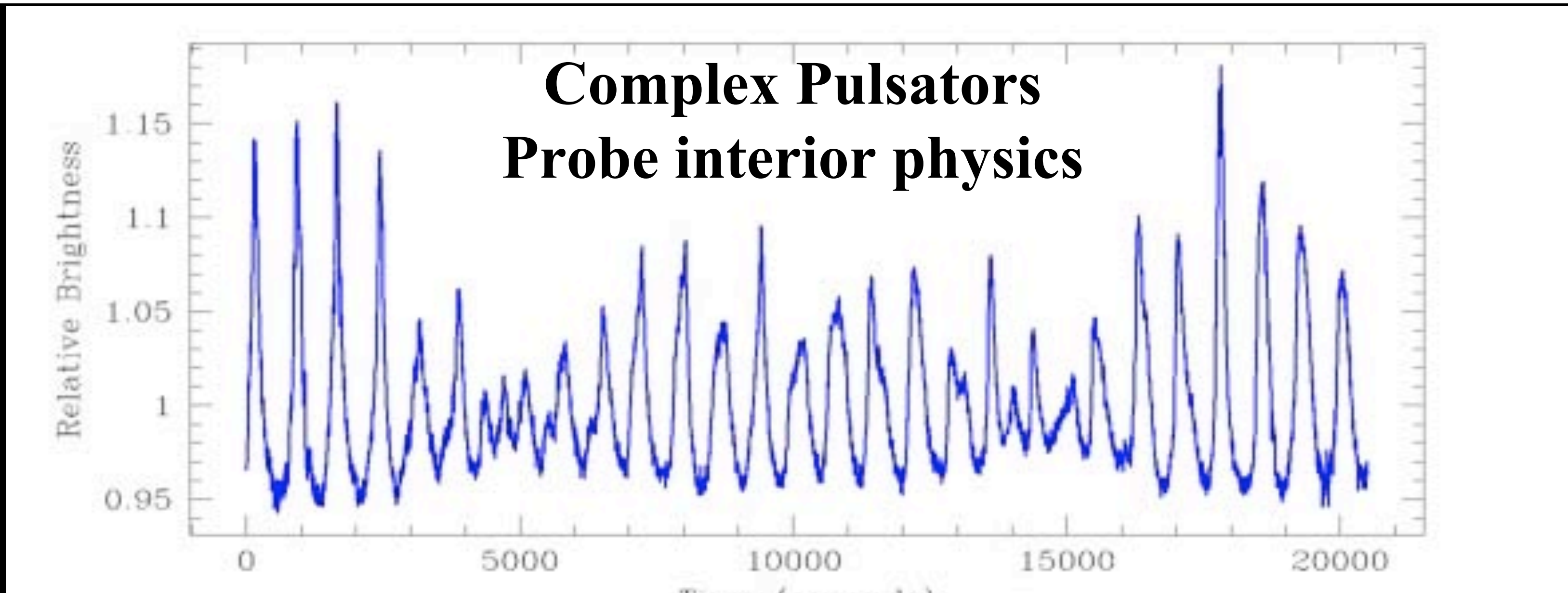
"One of the first tasks to be undertaken by the staff of the McDonald Observatory will be to investigate further the mysteries of the white dwarfs."

-- May 5th, 1939

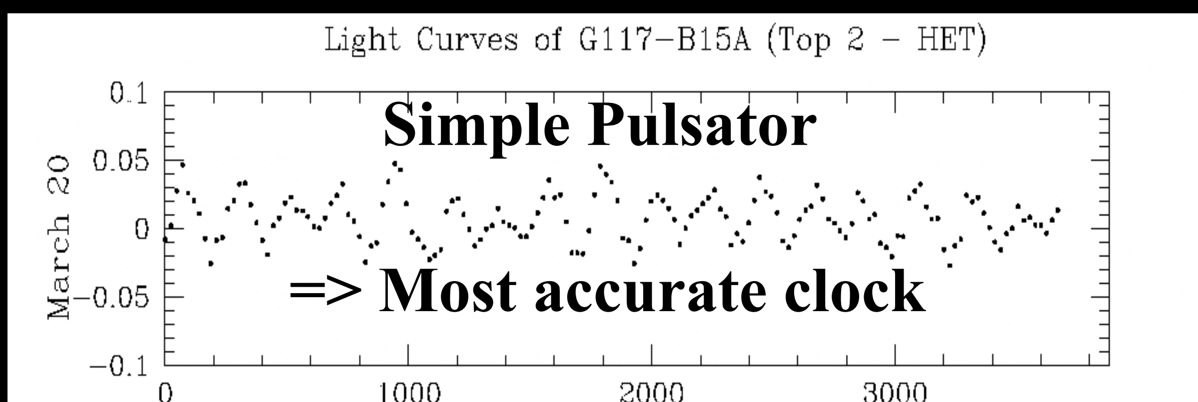
Mike Montgomery's light curve simulations for multimode pulsations in GD 358

gd358_new2.mov





Asteroseismology: Using normal modes of pulsating WDs to study extreme physics and time itself

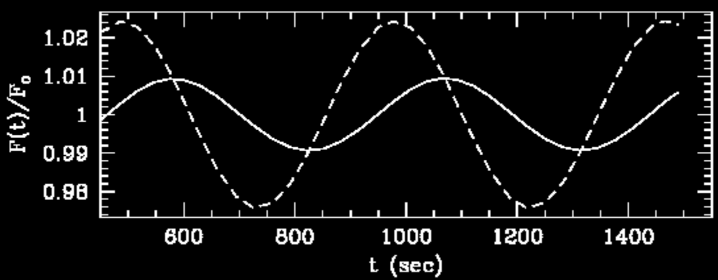


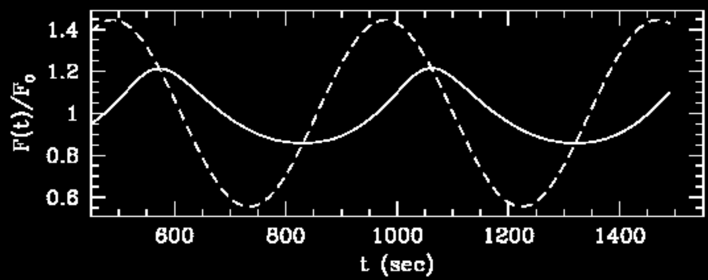
Non-radial Modes

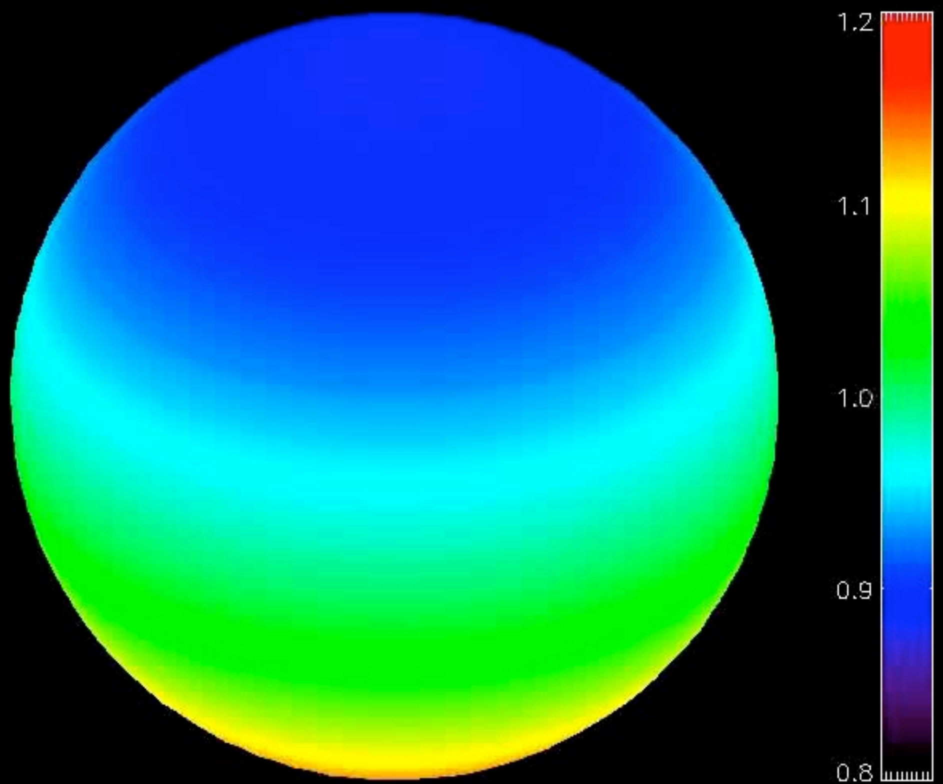
l=1,*m*=0

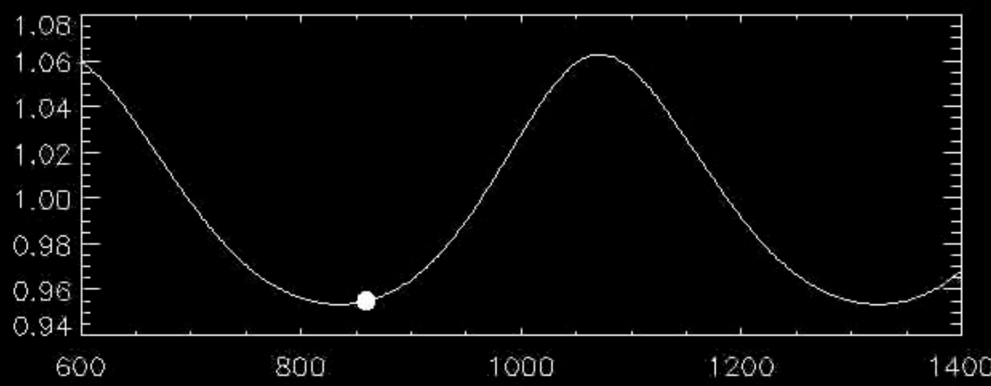
(standing wave)

$$F_{\mathrm{b}} \propto \mathrm{Re}\{e^{i\omega t} Y_{10}\}$$







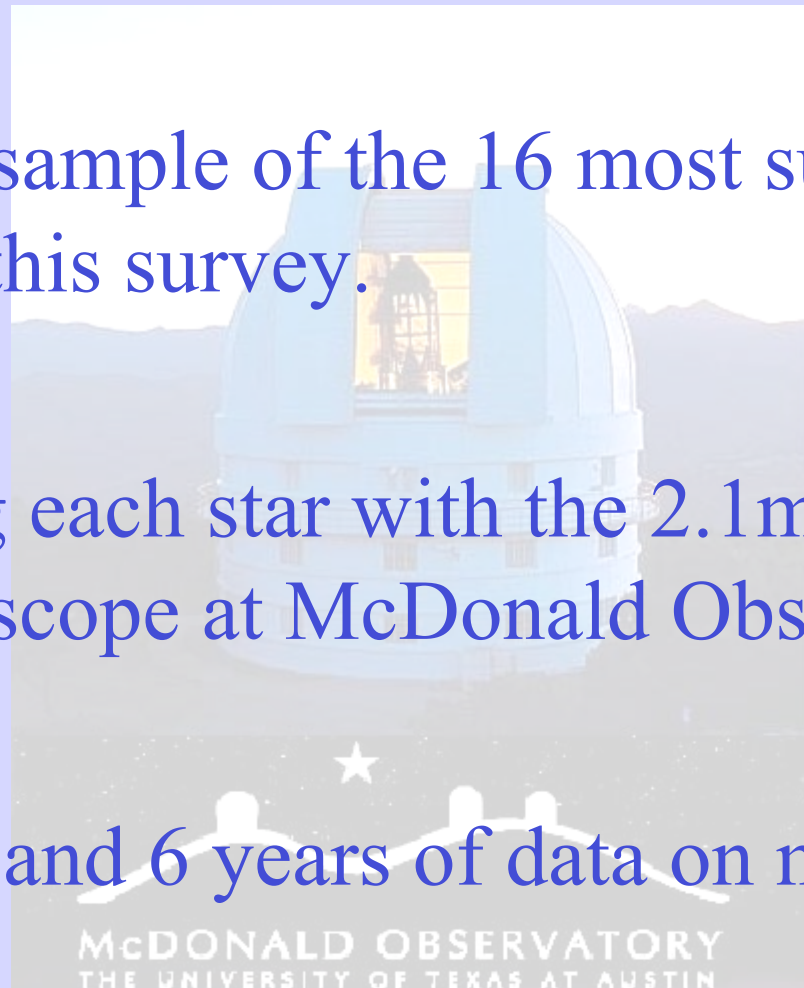


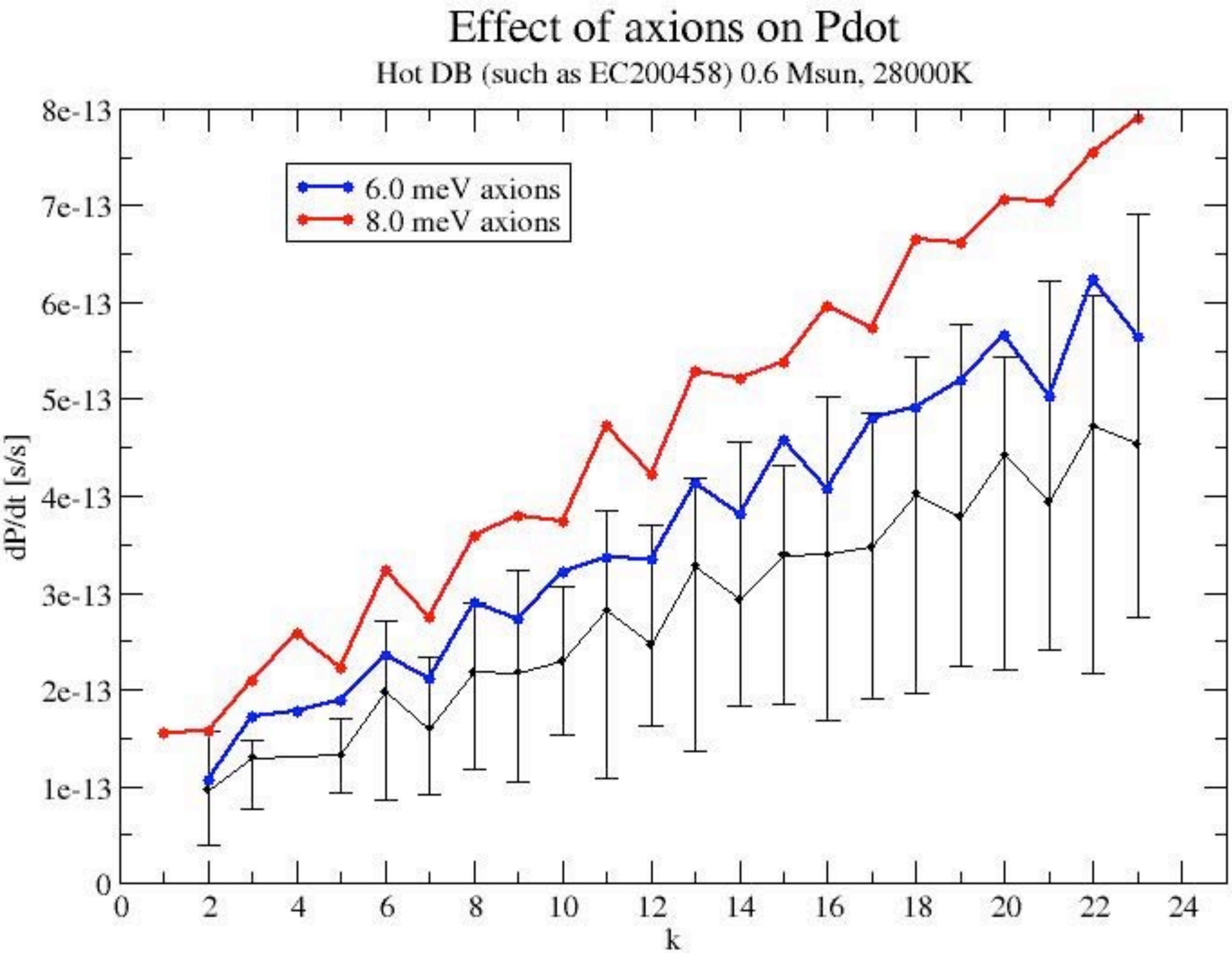
Extreme Stability Pulsators: **DBV** and **HDAV Stars**

- The most stable optical clocks—only a few millisecond pulsars are more stable (or are they …?)
- Stellar evolution becomes a spectator sport!
- Extreme Physics: Plasmons and axions

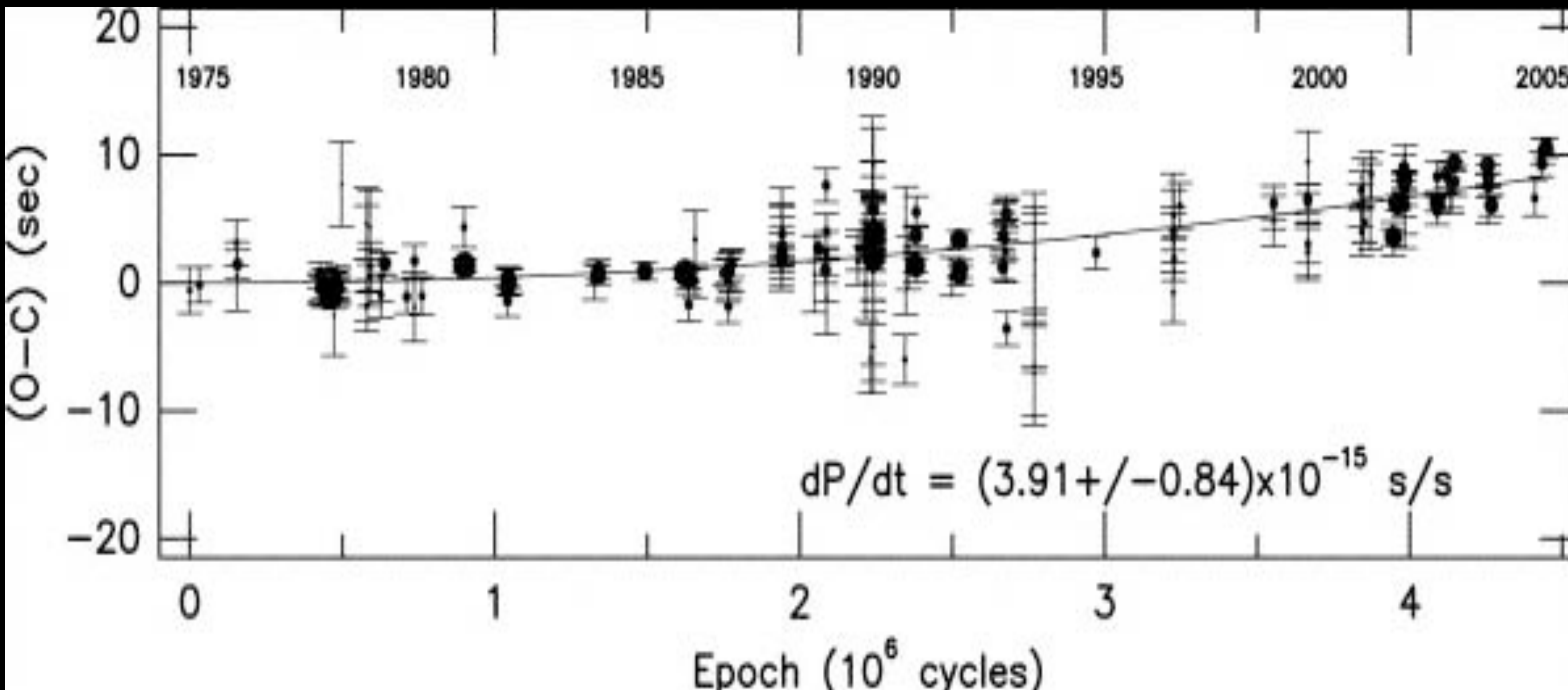
Our Survey

- Selected a sample of the 16 most suitable DAVs for this survey.
- Monitoring each star with the 2.1m Otto Struve telescope at McDonald Observatory
- Between 5 and 6 years of data on most stars.





Effect of axions on Pdot
Hot DB (such as EC200458) 0.6 Msun, 28000K
6.0 meV axions
8.0 meV axions
dP/dt [s/s]
k
8e-13
7e-13
6e-13
5e-13
4e-13
3e-13
2e-13
1e-13
0
0 2 4 6 8 10 12 14 16 18 20 22 24



20
10
0
−10
−20
(O−C) (sec)
1975
1980
1985
1990
1995
2000
2005
dP/dt = (3.91+/−0.84)x10^−15 s/s
0
1
2
3
4
Epoch (10^6 cycles)

Axion models

- E/N is a parameter also essentially unconstrained by the theory, though usually, it is taken to be of order 1. The value of E/N depends on the axion model one adopts.
- For KFSZ axions, E/N = 0
- For DFSZ axions, E/N = 8/3

Physical nature of pulsations and effect of cooling

- Non-radial g-modes driven in the partial ionization zone.
- Restoring force is buoyancy
- The frequency at which a region displaced slightly from equilibrium oscillates is N, the Brunt-Vaisala frequency. N is strongly sensitive to composition transition zones and changes in density. N (along with another frequency – the Lamb frequency) dictates the periods of the modes.
- Pulsation periods get longer and longer as the star cools.

Axions and the missing universe

- Axions would constitute cold dark matter and if they exist and have the right mass, could account for it.
- 2 classes of cosmological models:
  - thermal axions
  - quantum misalignment

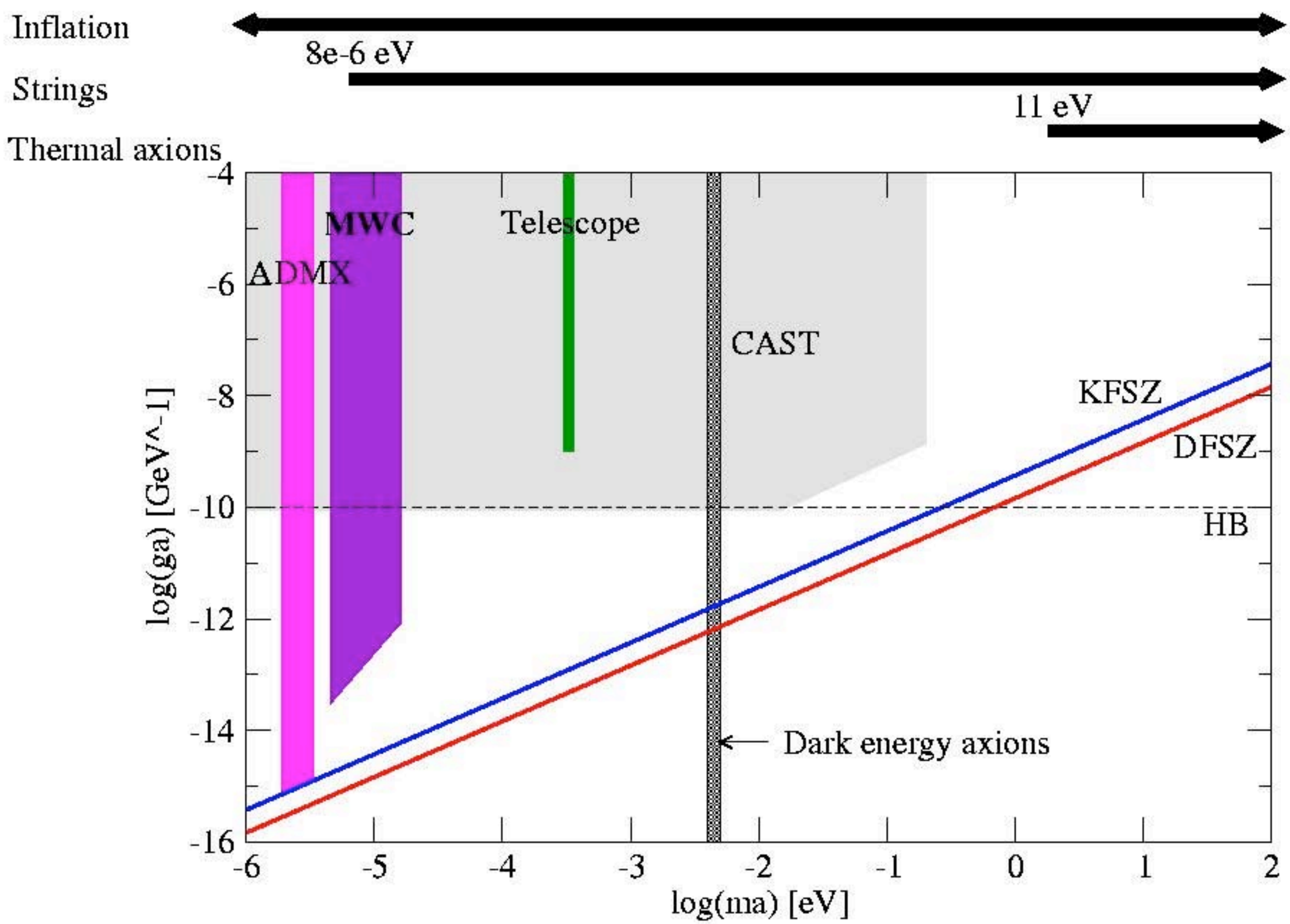
More controversial: dark energy

- Recent data suggests that the cosmological constant is indeed a constant and dark energy may be due to a quantum vacuum of light particles.
- The corresponding real particle should:
  - be stable over the lifetime of the universe
  - interact weakly with the matter we know
  - have a mass between 4 and 5 meV

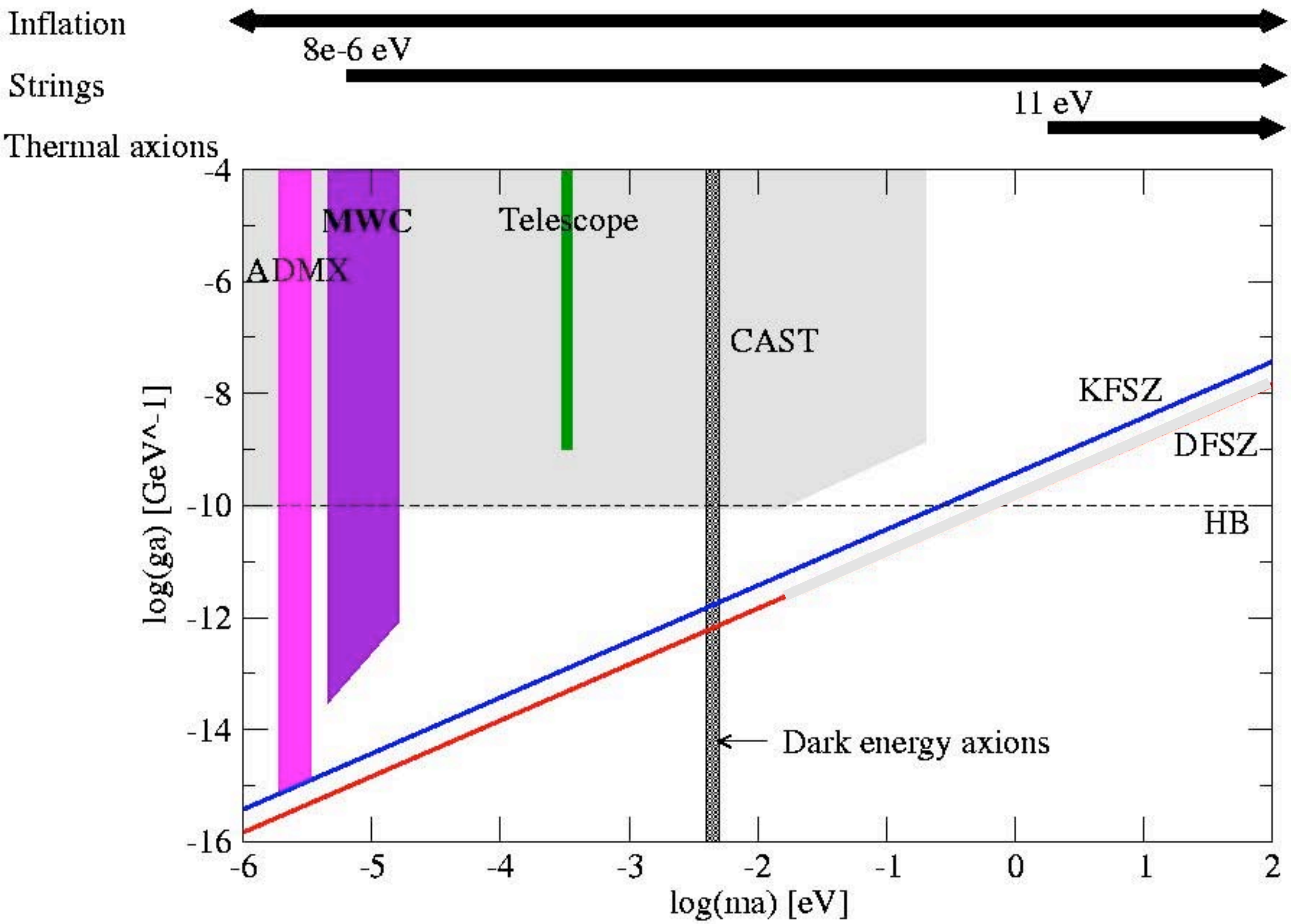
Axion interactions and axion models

- In theory, axions can interact with
  - photons
  - leptons (e.g. electrons)
  - baryons (e.g. protons and neutrons)
- Each interaction can be non-existent to strong (up to our detection limit). This gives rise to a continuum of axion models. Two particular models:
  - KFSZ axions interact only with photons
  - DFSZ axions interact both with photons and leptons
- The more massive the axion, the stronger those interactions.

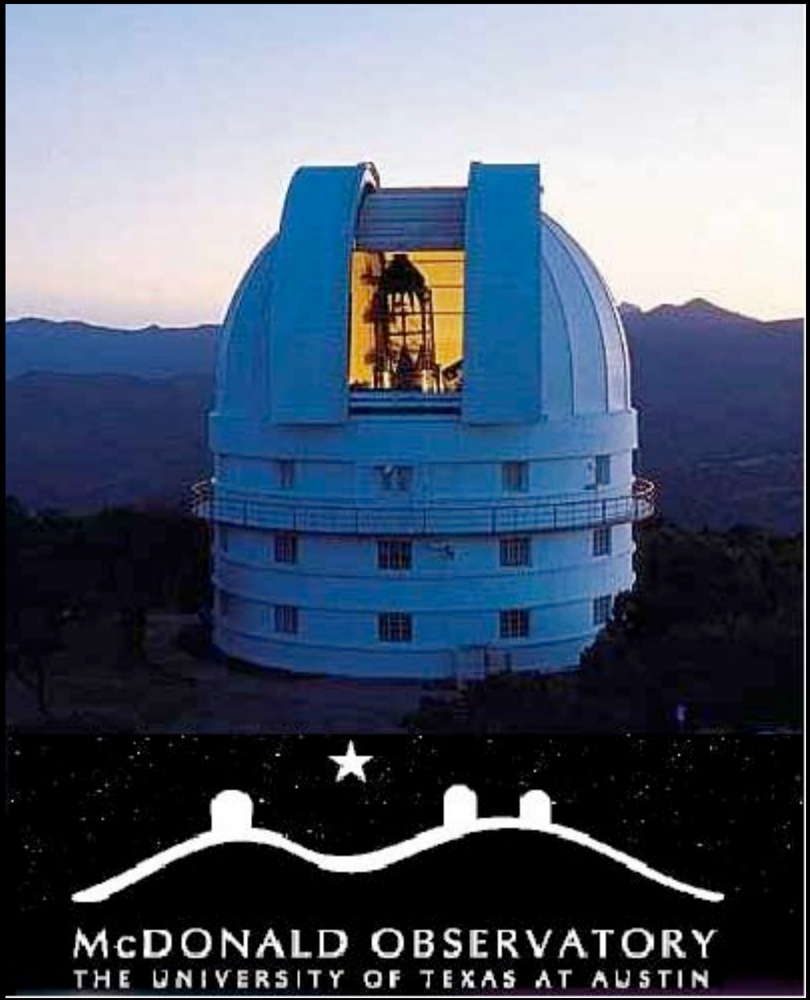
Axion-photon coupling constraints



Axion-photon coupling constraints



How useful will these constraints be for DM axions or other SUSY particles?



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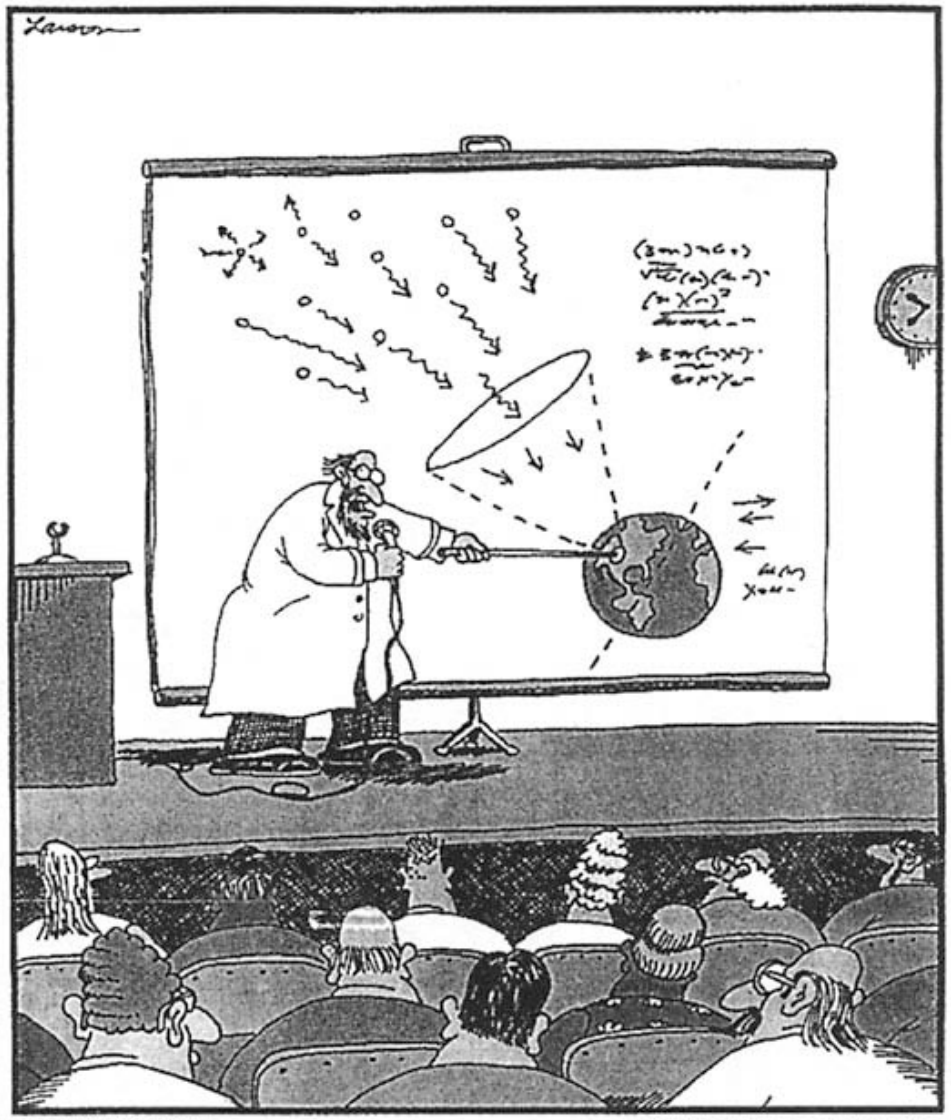
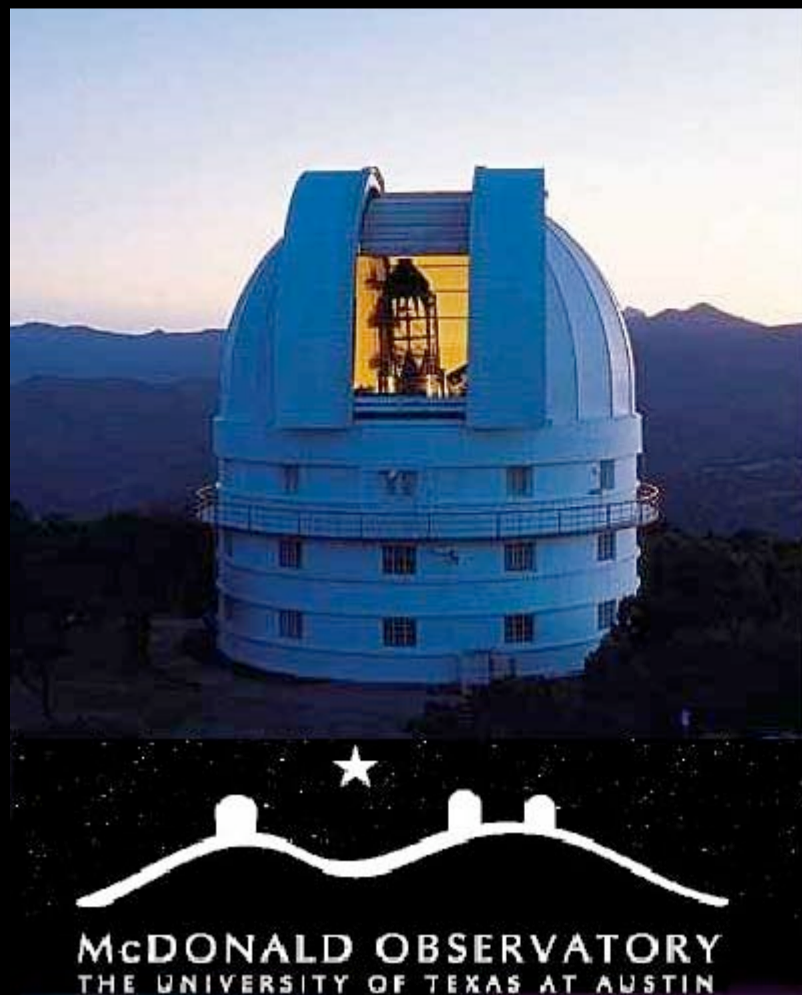
THE FAR SIDE OF SCIENCE

GARY LARSON

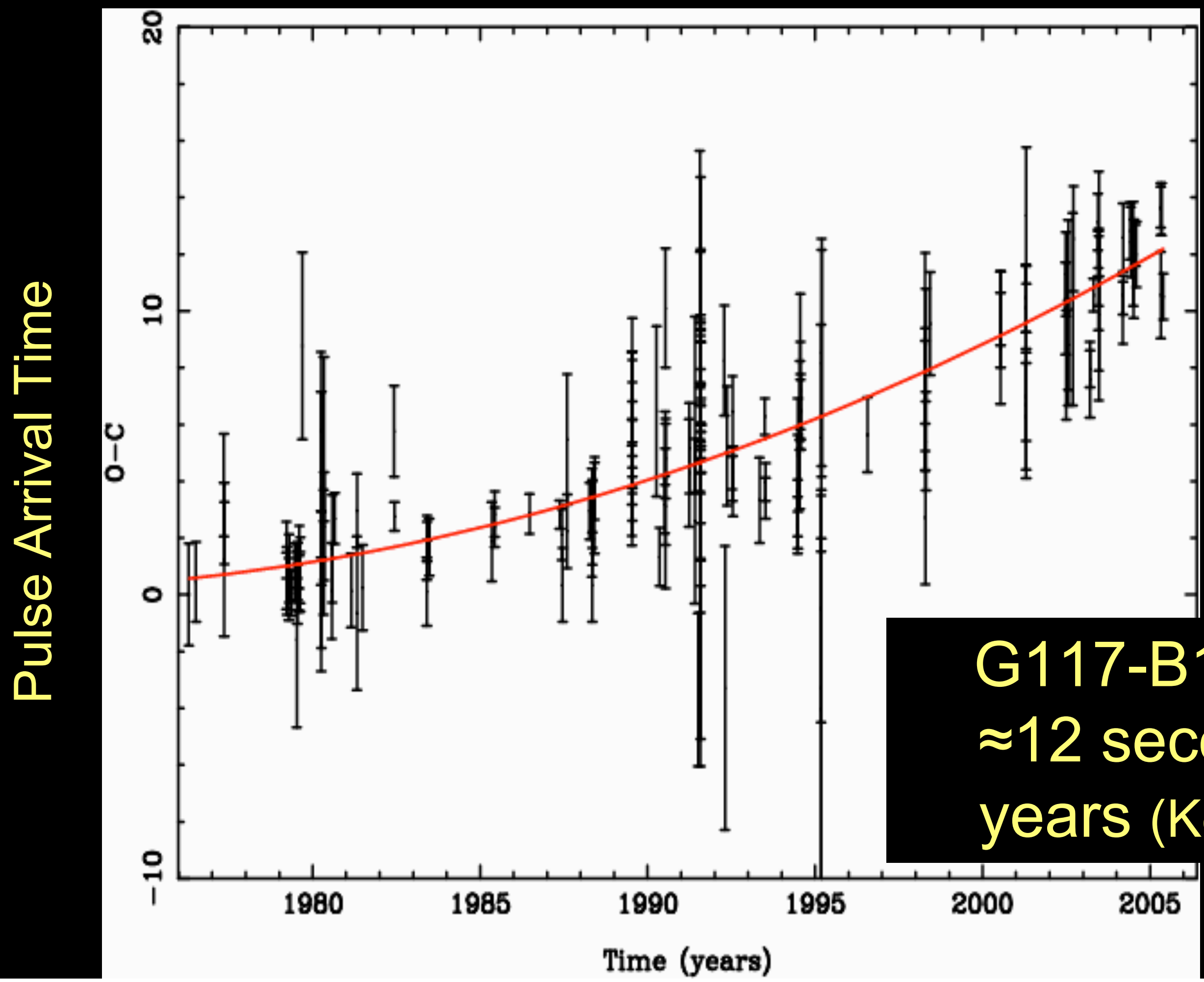


For The New York Times

"So, in the general relativistic sense, we find that the dynamic friction of the tensor light cone is actually negative, creating a local convergence of photons which causes the stars at night to be big and bright . . . especially here, deep in the heart of Texas."

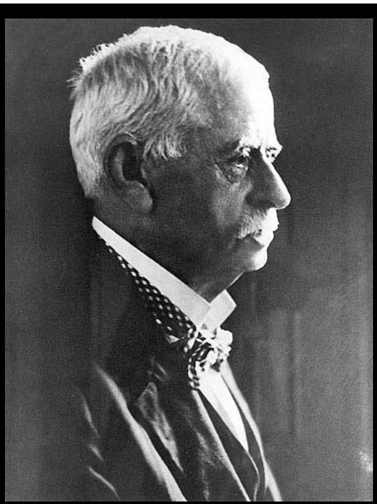

McDONALD OBSERVATORY
THE UNIVERSITY OF TEXAS AT AUSTIN

DAV pulsations are **very** stable



G117-B15A has lost ≈12 seconds in 30 years (Kepler 2005)


The Competitive Edge …



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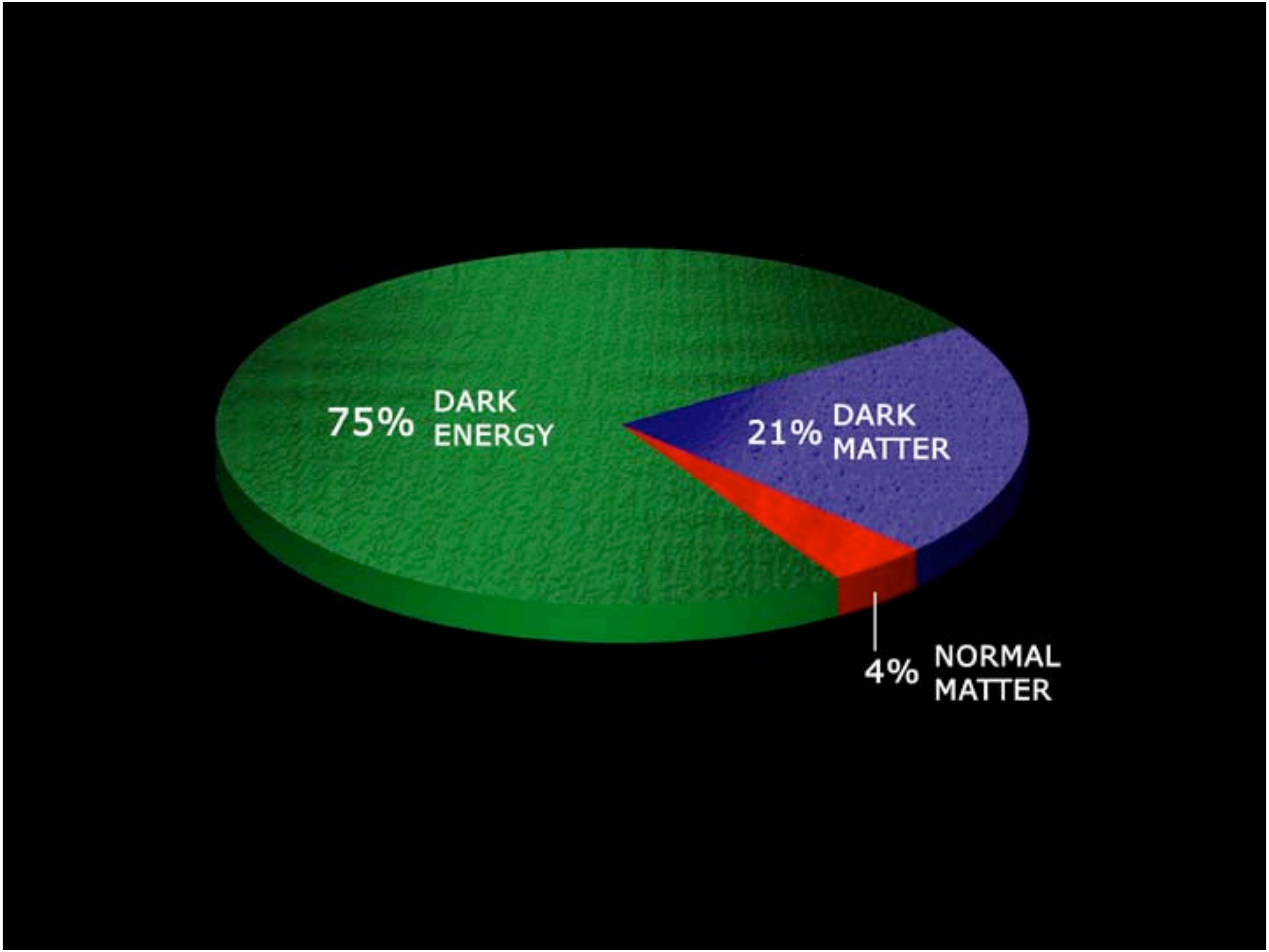
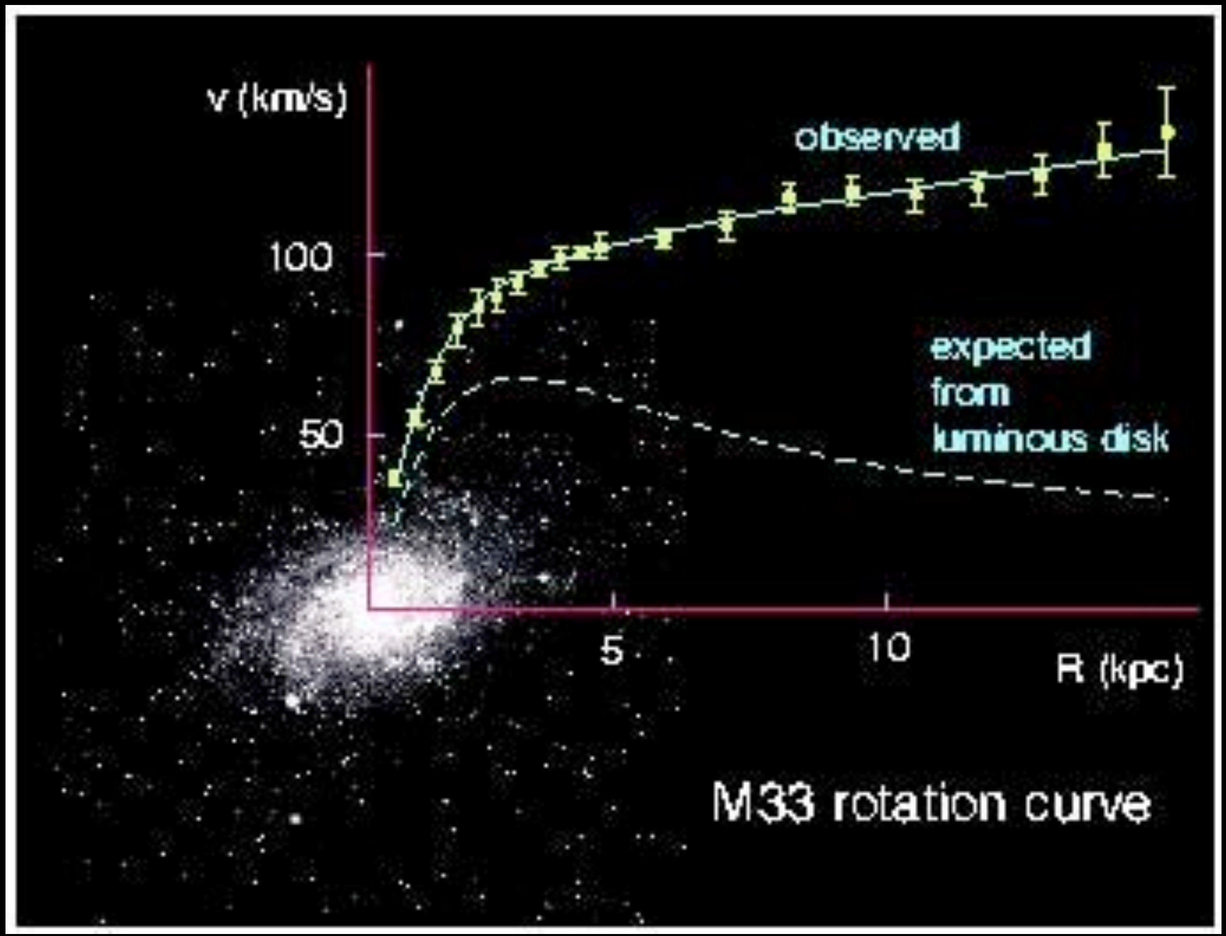

75% DARK ENERGY
21% DARK MATTER
4% NORMAL MATTER



Bergstroem, L. 2000