And Now For Something Completely Different……

Galactic Neutrino Communication & SETI

(SETI=Search for Extra-Terrestrial Intelligence)

John Learned

University of Hawaii

"Work" in collaboration with Sandip Pakvasa (UH), Walt Simmons (UH), Xerxes Tata (UH), Tony Zee (UCSB), Rolf-Peter Kudritzki (UH)

This work is NOT supported by: DOE, NSF, NASA, DOD, DARPA…….
Not even by the SETI Institute! But much beer was needed in production.

Long Distance Neutrino Communication is an old idea:

- H. Saenz et al., 1977
- J. Albers, P. Kotzer & D.Padgett, 1978
- M. Subotowicz, 1979
- J. Pasachoff & M. Kutner, 1979

They had the basic idea to use neutrino beams for interstellar and terrestrial communication based on the penetrating power of neutrinos…….

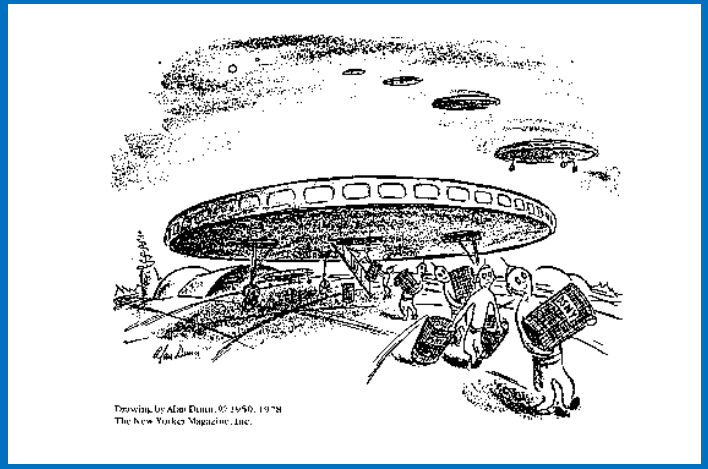
Also proposed use for communicating with submarines, getting the US Navy interested! (Needless to say, one way only!)

A recent proposal is to use neutrino beams from muon colliders: Z. Silagadze, arXiv:0803.0409(2008).
Idea of neutrino communication with submarines has been revived very recently: P. Huber, arXiv:0909.4554(2009).

SETI:
Search for Extra-Terrestrial Intelligence

- There should/might be many advanced civilizations(ETI) out there in the galaxy……
- Fermi's question(1950): "So, where are they?" Namely, if they are out there why haven't we seen or heard from them? Why are they not here?
- Maybe security concerns prevent them from revealing themselves?
- Maybe they would like to send info on a variety of topics…..?
- Too Many Possible Scenarios, no point in trying to guess, just look for signals…

History/origin of "The Fermi Question"

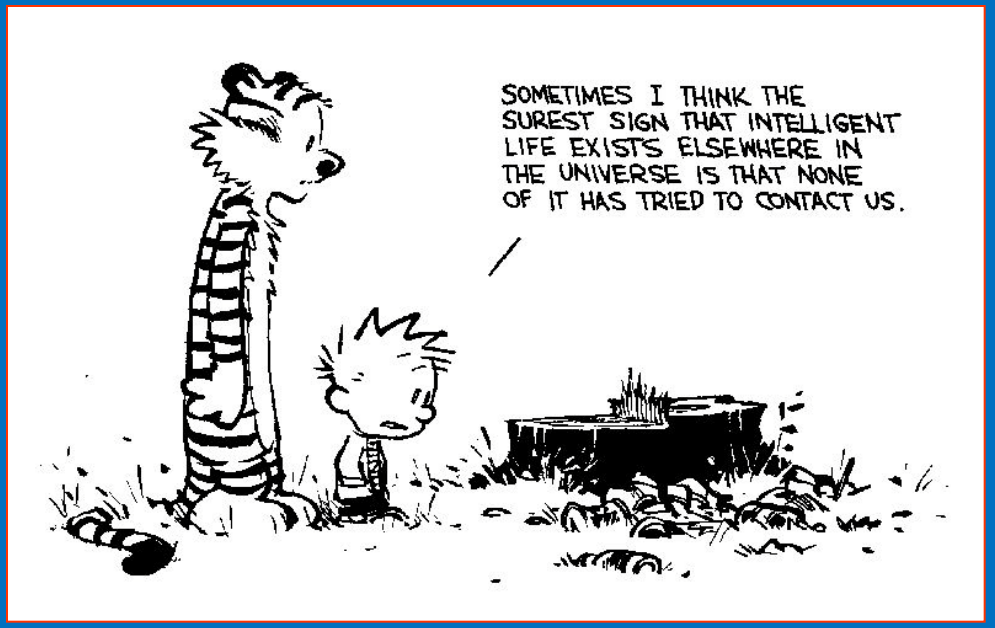


- 1950: Herb York, Edward Teller, Emil Konopinski and Enrico Fermi were meeting for lunch at the Los Alamos Laboratory. Before Fermi arrived, the talk was abut a recent cartoon in the New Yorker magazine about two recent headline making news-reports,
  - one on flying saucers and
  - the other on disappearing trash cans in NYC!

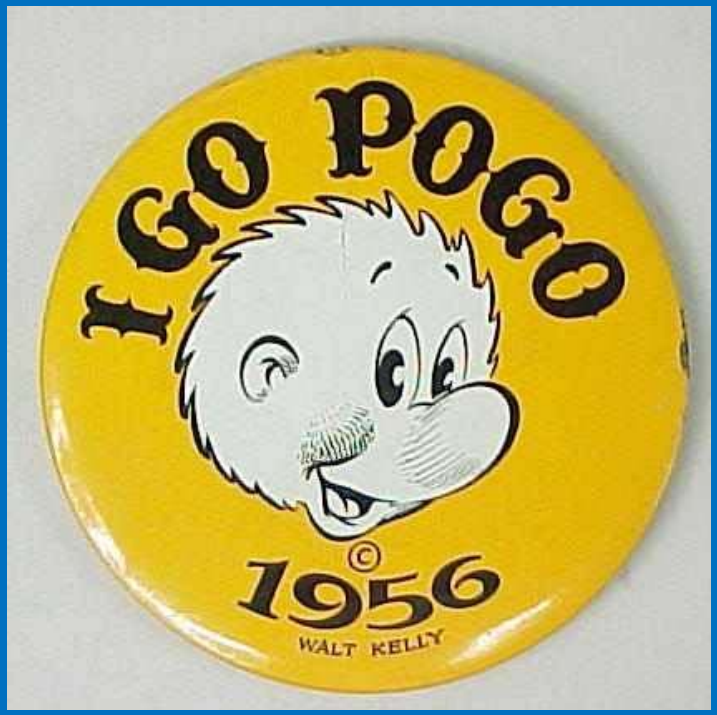
- On arrival, Fermi's reaction was that the the "model" in the cartoon was obviously correct as it explained TWO unrelated events!
- Later during the lunch, in the middle of a conversation about something else altogether, Fermi is reported to have exclaimed "So, where are they?"
- It was clear to the others what he had meant……..

Fermi's Question has given rise to much discussion and attempts to answer it… including books..

- One implication was that since we have not seen/heard from them, there are no ETI: <u>there is no one out there.</u>
- One simple response is: <u>Absence of evidence is NOT evidence of absence</u>!
- An even simpler and telling one is due to Calvin and Hobbes: The fact that no one has tried to contact us IS Itself Proof of Extra terrestrial Intelligence!! (November 12, 2008).



Comment in the Walt Kelly Strip "Pogo Possum" by Porky Pine:



- "There's only two possibilities. There is life out there in the Universe that's smarter than we are, or we're the most intelligent life in the Universe. Either way, it's a mighty sobering thought."

Would Contact with Extraterrestrials Benefit or Harm Humanity? A Scenario Analysis

Seth D. Baum,[1] Jacob D. Haqq-Misra,[2] & Shawn D. Domagal-Goldman[3]

1. Department of Geography, Pennsylvania State University. E-mail: sbaum@psu.edu
2. Department of Meteorology, Pennsylvania State University
3. NASA Planetary Science Division

Acta Astronautica, 2011, 68(11-12): 2114-2129
This file version: 22 April 2011

Abstract

While humanity has not yet observed any extraterrestrial intelligence (ETI), contact with ETI remains possible. Contact could occur through a broad range of scenarios that have varying consequences for humanity. However, many discussions of this question assume that contact will follow a particular scenario that derives from the hopes and fears of the author. In this paper, we analyze a broad range of contact scenarios in terms of whether contact with ETI would benefit or harm humanity. This type of broad analysis can help us prepare for actual contact with ETI even if the details of contact do not fully resemble any specific scenario.

http://arxiv.org/ftp/arxiv/papers/1104/1104.4462.pdf

# These authors consider a number of scenarios ranging from optimistic to most pessimistic.

Beneficial

Mere detection

Philosophical implications

Cooperative extraterrestrials

Discussion of science and mathematics

Advice in avoiding global catastrophe

Solutions to problems on Earth

Uncooperative extraterrestrials

Humanity successfully overcomes a threat

Neutral

Invisible to us

Intentionally hiding

Unintentionally escape our notice
- Different form of existence
- No desire to communicate
- Too far away

Noticeable but indifferent

Uninteresting and non-useful

Mild nuisance

Harmful

Intentional harm

Selfish ETI
- ETI eat us
- ETI enslave us
- ETI attack us

Universalist ETI
- To improve galactic infrastructure
- To more efficiently use our resources
- If we are seen as a threat

Unintentional harm

Physical hazard
- Transmission of disease
- Invasive species
- Mechanical harm
- Act of incompetence
  - *unfriendly Artificial Intelligence*
  - *self-replicating probes*
  - *physics experiments*

Information hazard
- Computer virus
- Biological hazard
- Demoralizing cultural impact

Interesting Implications

- Many have warned about danger from contact (Carl Sagan, Jared Diamond, Martin Royle, Stephen Hawking…)… think of the history of humans!
- However, an exponentially expansive species (think movie "Alien") probably does not exist or they would be here now! Unless they collapsed….

- For decades (~ 50 years) Standard Searches for ETI have concentrated on radio (e.g. the 21 cm line), microwave or optical frequencies (all are photons)

- Photons can be obscured/attenuated as opposed to neutrinos; also scattered leading to jitter in time & direction.

- Less backgrounds and noise for a Neutrino signal, so….

Neutrinos & SETI: Obviously a very hot topic judging by citations:

- Walt Simmons, John Learned, Xerxes Tata, Sandip Pakvasa, *Q. J. Roy. Astro. Soc. (1994).*

  #Citations= 1

- John Learned, Tony Zee, Sandip Pakvasa, *Phys. Lett. B(2009).*

  #Citations = 3

- John Learned, Tony Zee, Rolf-Peter Kudritzki, Sandip Pakvasa, arXiv:0809.0339(rejected by Phys. Rev. Lett., in press Contemporary Physics).

  #Citations = 0

Although many in non-technical magazine e.g. The Economist etc……!

Good thing we have tenure.

"Talking to the neighbors"

SETI with Neutrinos

"A modest proposal for an interstellar communications network"

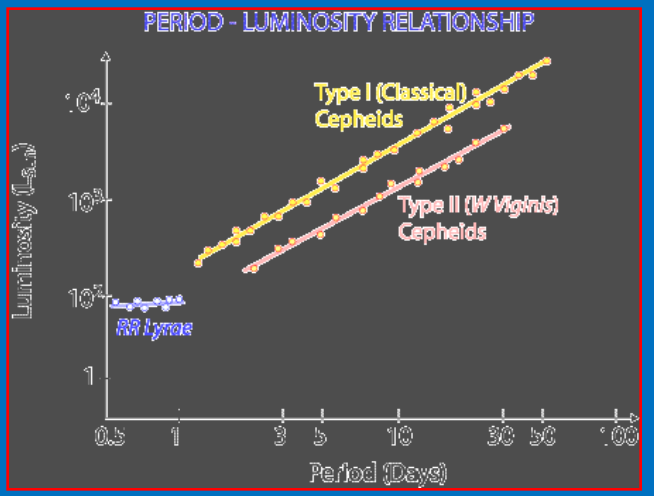
Economist, 7 April 2011

http://www.economist.com/PrinterFriendly.cfm?story_id=18526871

Three Possible Nu Scenarios to discuss

- Timing-Data Communication with neutrinos
- Sending a focused beam of neutrinos of a definite energy
- Disturbing a Cepheid variable star with a neutrino beam to modulate its period
  - → Will only cover the latter today…

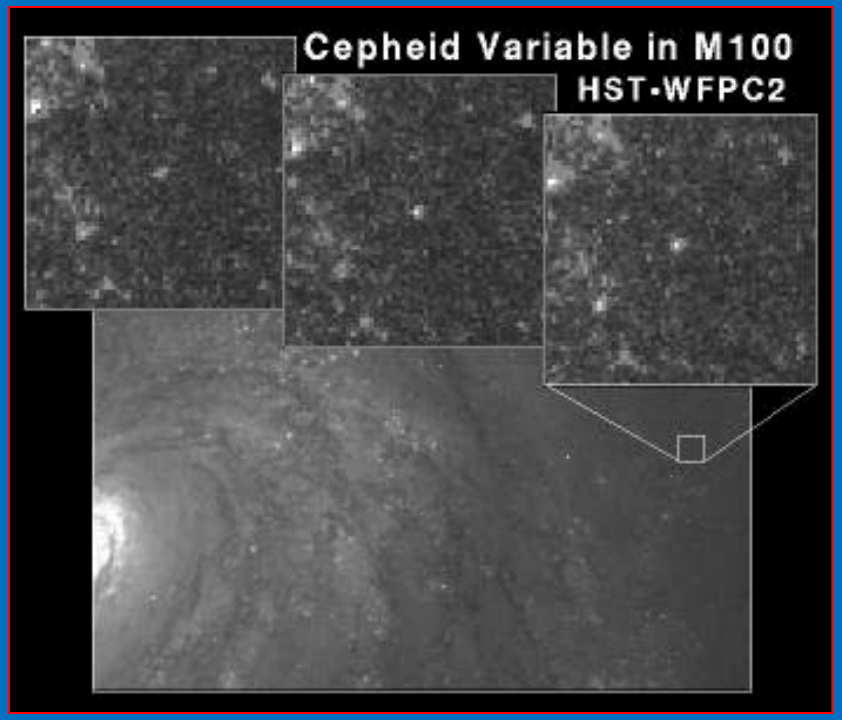
Cepheids variables and the cosmic distance ladder



1908:
Henrietta Leavitt's (Harvard Observatory) discovery of the luminosity-period relation allowed Hubble to make his discovery & made cosmology possible (see recent biography "Miss Leavitt's Stars")

Learned, Kudritzki, Pakvasa, & Zee

http://xxx.lanl.gov/PS_cache/arxiv/pdf/0809/0809.0339v2.pdf, in press Contemporary Physics



- A Cepheid variable is a member of a particular class of variable stars, notable for tight correlation between their period of variability and absolute luminosity.

- Namesake and prototype of these variables is the star Delta Cephei, discovered to be variable by John Goodricke in 1784.

- This correlation was discovered and stated by Henrietta Swan Leavitt in 1908 and given precise mathematical form by her in 1912.

- Period-luminosity relation can be calibrated with great precision using the nearest Cepheid stars.

- Distances found with this method are among the most accurate available.

- Leavitt, Henrietta S. "1777 Variables in the Magellanic Clouds". *of Harvard College Observatory*. LX(IV) (1908) 87-110.

- P C. "Periods of 25 Variable Stars in the SMC". *Harvard College Circular 173* (1912) 1-3.

The Cepheid variables proved very very useful:

Measure period and apparent magnitude (brightness),

Period -> Absolute magnitude

Distance = RefDist x sqrt(Absolute/Apparent)

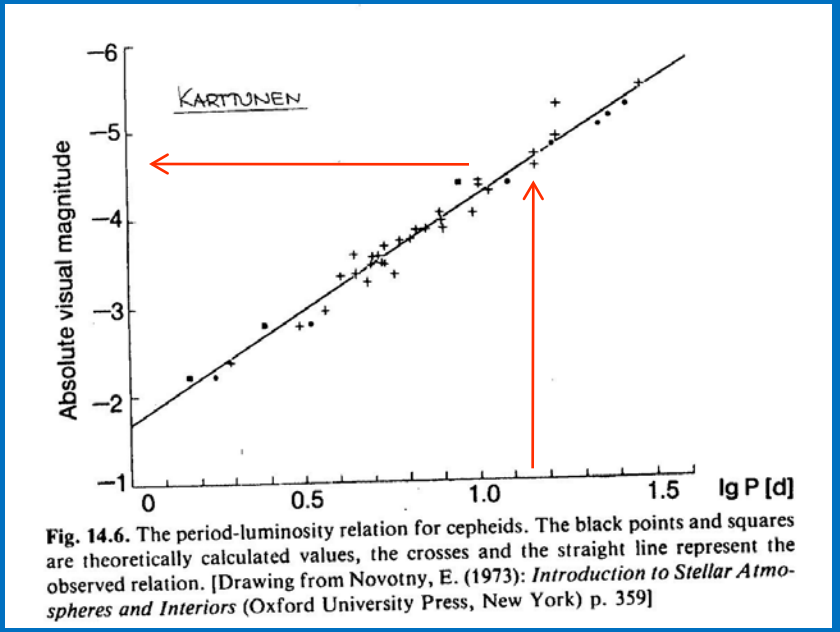


Fig. 14.6. The period-luminosity relation for cepheids. The black points and squares are theoretically calculated values, the crosses and the straight line represent the observed relation. [Drawing from Novotny, E. (1973): *Introduction to Stellar Atmospheres and Interiors* (Oxford University Press, New York) p. 359]

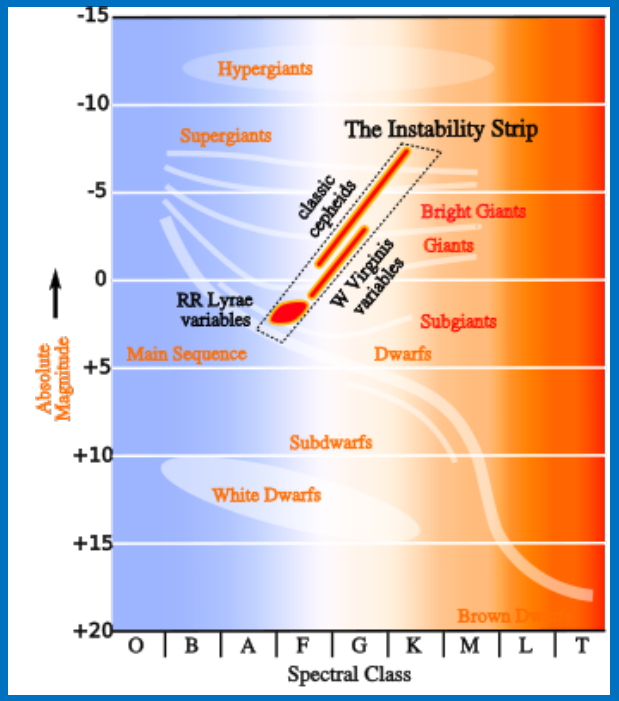
In 1915 they were used by Harlow Shapley to measure the size & shape of the milky way, and the location of the sun in it.

In 1924, Edwin Hubble used them to measure distance to the Andromeda galaxy and proved that it is not part of the milky way! (End of the Island Universe idea!)

In 1929, Humason and Hubble showed that the universe is expanding!

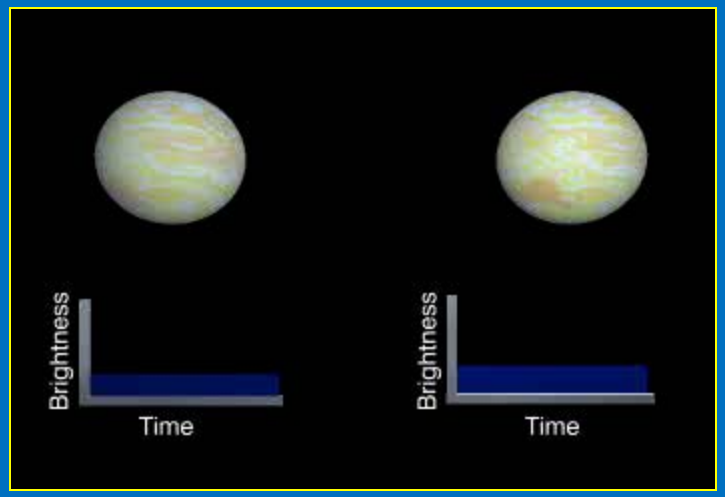
In mid -'40s, Baade showed that there are two different classes of Cepheid variables with differing velocity-luminosity relationship and thus revised the distance scale by about a factor of 2……(classical and type II).

Cepheid Mechanism



Cepheid usually a population I giant yellow star, pulsing regularly by expanding and contracting, regular oscillation of its luminosity from 10^3 to 10^4 times L

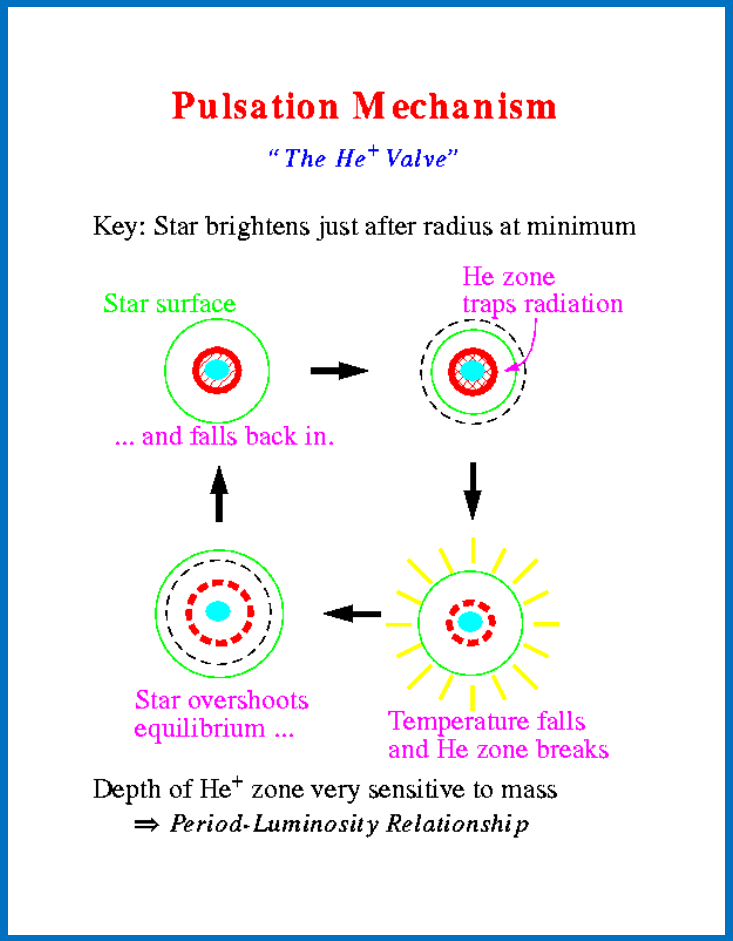
Cepheids, population I stars: "Type I Cepheids", Similar (population II) W Virginis: Type II Cepheids.



Luminosity variation due to cycle of ionization of helium in the star's atmosphere, followed by expansion and deionization. Key: ionized, the atmosphere more opaque to light.

Period equal to the star's dynamical time scale: gives information on the mean density and luminosity.

Model for Cepheid Variablity

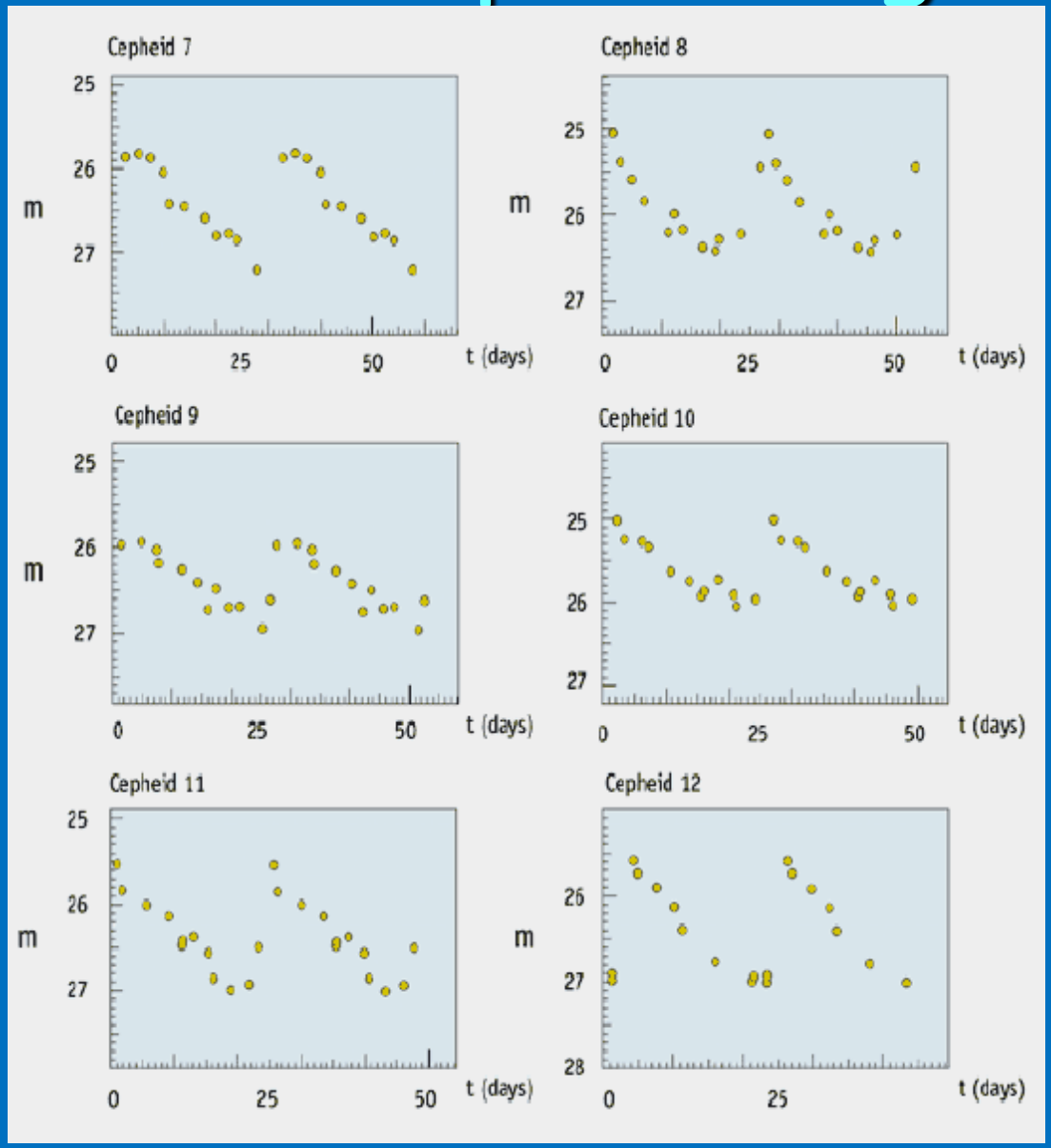


- Basic idea given by Eddington in 1917:

  Doubly ionized He is more opaque(than, say singly ionized He) At the dimmest point of the cycle, the gas is most opaque, and outermost layers heat and expand, as the gas expands, it begins to cool, so becomes less ionized and hence more transparent, radiation escapes. The expansion stops and star contracts due to gravity. And the process repeats.

(The identification of He was due to Zhevakin in 1953 . Extensive detailed modeling for the P and time variation of P exists in the literature.)

Cepheid Light Curves



Typical saw tooth pattern

Sample of data from Hubble Key project measured 800 Cepheids, out through Virgo Cluster

Period-luminosity relation

$$M_v = -2.81 log(P) - (1.43 \pm 0.1)$$

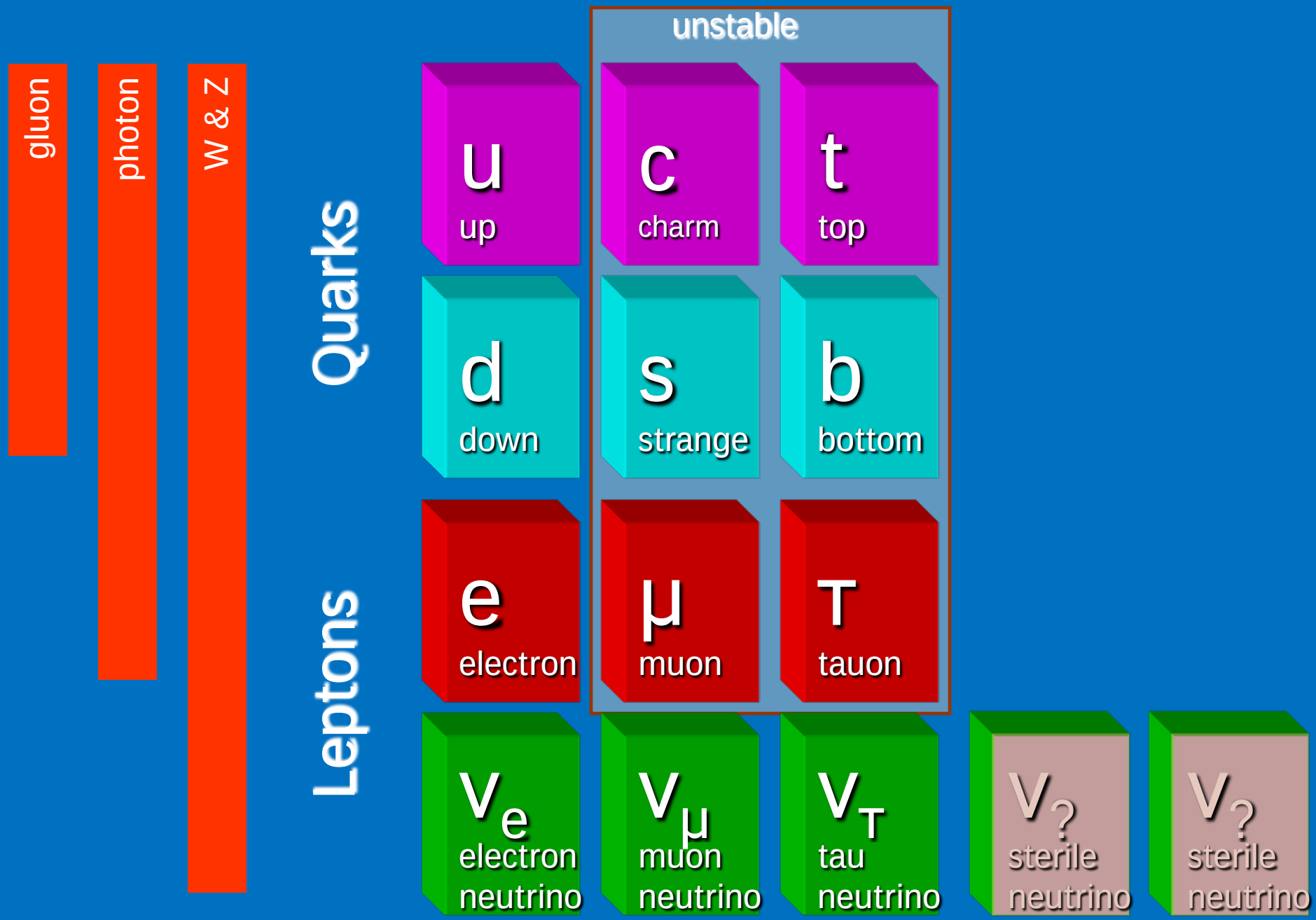
Feast & Catchpole, 1997

Interlude: What's a Neutrino?

Breakfast Nus?

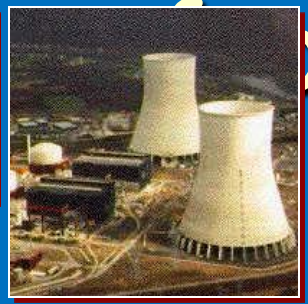
Neutrino Contents about
0.00000000000000002 kCal

Thanks Joshua Murillo


gluon
photon
W & Z
Quarks
Leptons
unstable
u
up
c
charm
t
top
d
down
s
strange
b
bottom
e
electron
μ
muon
τ
tauon
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
$\nu_?$
sterile neutrino
$\nu_?$
sterile neutrino

Where do Neutrinos come

✓ Nuclear Reactors (power stations, ships)

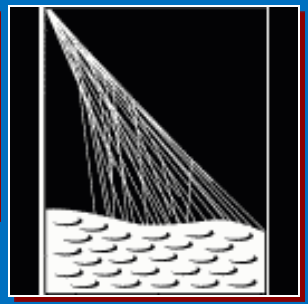


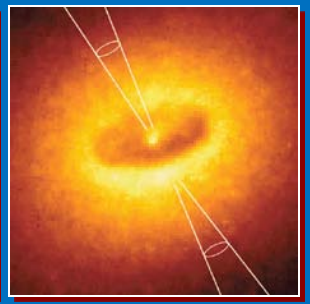
Sun ✓

✓ Particle Accelerator

Supernovae (star collapse)
SN 1987A ✓

✓ Earth's Atmosphere (Cosmic Rays)

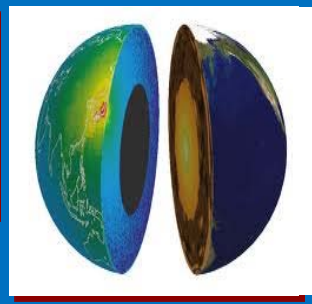


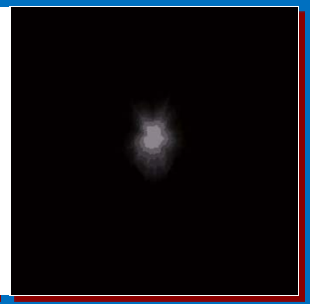


Astrophysical Sources

Soon ?

✓ Bulk Earth (U/Th Radioactivity)





Big Bang (here 330 ν/cm^3)
Indirect Evidence

What do we know well about neutrinos?

- No electric charge.
- Little or no electric/magnetic dipole moment.
- Essentially point particles.
- Very small mass compared to other fermions.
- Participates only in SM weak interaction.
- Falls under gravity (SN1987A).
- Produced in only left-handed helicity state (nubar = righthanded)
- Comes in three flavors, e, μ and τ
- Lepton number is conserved (but not lepton flavor)
- No known lifetime (but…).
- Has nothing to decay to amongst known particle zoo (but ν_m-> ν_n OK)
- SM processes produce neutrinos as superposition of mass states
- Mass states' relative phases change with flight time,
  producing morphing between interaction states ("ν oscillations").
- Three mass states explains all accepted data, but room for new things.
- *Almost* surely we are living in a bath of undetectable ~600nu/cm^3
  left from Big Bang, which travel ~300 km/s.

Back to Nu SETI

Main thing for present purposes:

We understand neutrinos rather well.

We know how to make beams of neutrinos.

They can penetrate even deep into stars.

When they do stop, they can deliver a lot of energy.

How to modulate the period and create a signal ?

- If the period can be modulated one can observe this signal over enormous distances --- intergalactic!
- This requires depositing energy deep inside the star so that the cycle ends earlier and the period is shortened….
- This is where neutrinos come in, as any other method will not reach deep inside the star…..

Neutrino Beam to Tickle a Star?

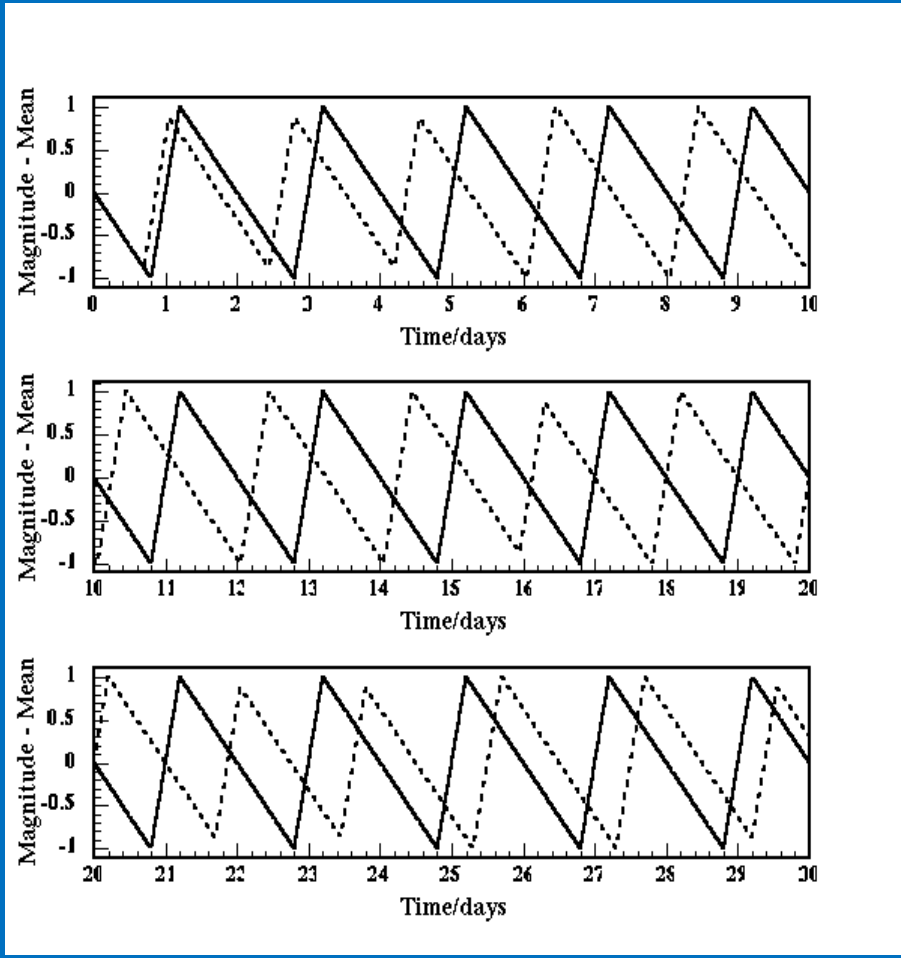
- Idea is to use neutrinos to deliver energy at controlled depth to star, as giant amplifier.
- Cepheids fill this need…. Bright pulsing stars with period of instability.
- Any civilization would monitor Cepheids as distance markers.
- Can be seen from distant galaxies (we see Cepheids in the Virgo cluster).

- Try to avoid details (which we cannot know) here, consider big picture.
- Guess at energy input: take deposition time of roughly speed of sound crossing nucleus (~0.1 s).
- Take power to be 10% of stellar core output.
- Need Pwr ~10^{-6} L_{ceph} . Few day Cepheid, would need 10^{28} J! But, NOT OUR PROBLEM!

Tickling a Cepheid….?

- Could be much less needed… have not done studies. Not useful for now.
- Not to melt, need accelerator at r>100 AU, capture radiation from area ~0.1AU^2
- Accelerators are efficient, well known physics at lower powers, but need large technology extrapolation.
- Want neutrinos of order 1 TeV to deposit energy deep inside star with exponentially increasing density (energy choice selects radius of deposition).
- Studies needed to determine how little one needs to jump start expansion. But we need not solve that problem for present purposes, simply aver that it is solvable and the ETI would do so.

Light Curve of Simulated Cepheid



- Ordinate is stellar magnitude relative to the mean, abscissa is time in days.

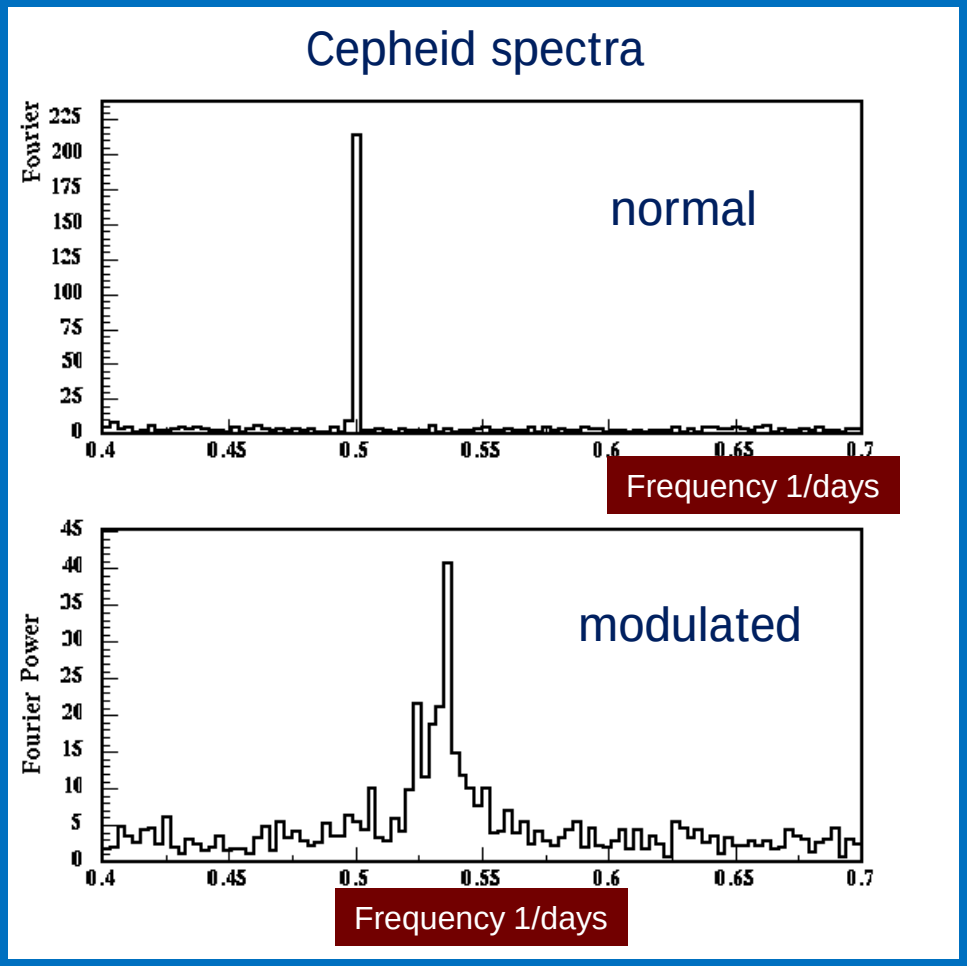
- Solid curve: unmodulated (idealized) Cepheid with 2 day period and 2 magnitude luminosity excursion, with expansion taking 0.4 days.

- Dashed curve: arbitrarily modulated light curve with triggered phase advance of 0.1 day (0.05 cycle) (Data = 1110000010100110).

- Units arbitrary but representative of real data.

- The sharpness of the transitions does not matter for the present discussions.

Fourier Transforms



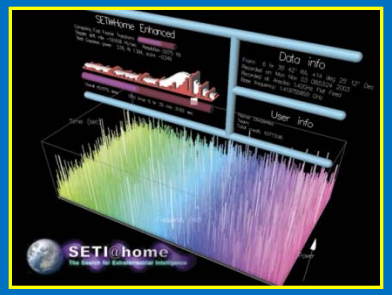
Abscissa is frequency, 1/days.

Ordinate is the Lomb-Scargle parameter, similar to chi squared;

• Fourier spectra of simulated observations of a regular periodic Cepheid variable and one with binary phase modulation.

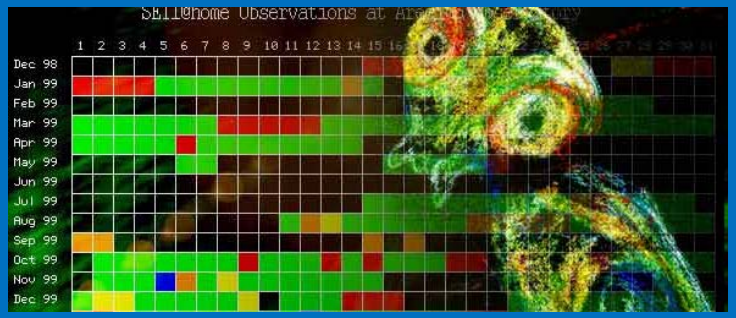
• More complicated structure of the modulated case is not so obviously different from a noisy spectrum: one could not immediately discern that the latter case was not ``natural''.

How to recognize an ETI Signal?



- Information theory says maximally compact data is indistinguishable from noise.
- Interesting question: how can one tell for sure when a signal is not `random'? Or can we tell a ETI signal from a hole in the ground? (to quote John Ellis)
- ETI signal should have inexplicable regularities: repeated sequences, letters, frames, apparent structures…. (Applies to all SETI).
- Who knows how they might encode?
- Hopefully we will know it when we see it!

Outlook



- Unstable stellar systems such as the Cepheids can serve as gigantic signal amplifiers visible across the universe.
- Assume a sufficiently advanced civilization
  - able to tickle stars (?)
  - find it worthwhile (???).
- Signatures of ETI communication may be available in data already recorded, and that a search of Cepheid (and perhaps other variable star, such as Lyrae) records may reveal an entre' into the galactic 'telegraph'!
- Certainly a long shot, but should it be correct, the payoff would be immeasurable for humanity.
- Many possibilities for ETI communication: try all practical ones.
- The beauty of this suggestion: data already exists, and we need only look at it in a new way.

Clarification

We are NOT proposing to attempt building the neutrino beams nor try to tickle the nearest cepheid variable star*.

Our proposals are much more modest:
Assuming that there may be some ETI much more advanced technologically than us, and that they may be sending such signals (for whatever reasons of their own), we merely propose that we should:

*Nearest Cepheid is Polestar at 143 parsecs.

Summary: Action Items

Not discussed here.

- Look for 45.5 GeV neutrino signal in KM3
- Look for 6.3 PeV anti-electron-neutrinos in KM3 via Glashow Resonance

- Analyze Cepheid Data to look for modulation: Signals are spectacular and the searches are practically free……

Large scale neutrino detectors……."build them and they will come" !

Timing Data Communications & SETI (1994)

- Currently our time standards based on Cs Fountain Clocks, accuracy 1 part in 10^{16}, Josephson junctions can potentially go to 10^{19}.

- Due to chaos and GR corrections, need synchronization signals to keep accurate time, not necessarily frequent, e.g. VLBI will need accurate timing data over huge distances. Local clocks need to exchange timing data to remain synchronized.

- Hence need stable clocks of highest precision->fast processes for transmitting and receiving markers & form of radiation to convey faithfully data over enormous distances.

- A very advanced ETI would presumably need ever more accurate timing eventually physics limit timing.

- Shortest time interval known today is the Z lifetime about 10^{-25} sec.

This suggests use of neutrinos from the decay of Z as an ideal carrier. (open problem: how to make Z-clocks!)
We imagine that an ETI is doing just that at distances of order of kiloparsecs in the galaxy for its own spread out outposts...
We expect to see neutrinos of energy of about 45.5 GeV.
To get a few events per year in a KM3 detector, we estimate power requirement at the source to be enormous: about solar luminosity!
Such an ETI source would look like a “Dyson shell”!
Who knows, after all there are over 50,000 IR sources Identified by IRAS.....In any case this is not OUR problem. (this will be my Mantra). All we need to do is wait and look for the neutrino signal at half the Z mass, clean with no backgrounds. ICECUBE is waiting....

"Dyson Shell"

- Dyson shell is a name for stars which are being harnessed by advanced civilizations and have energy being expended to sustain them, using up most of the radiation energy by having a bunch of absorbers around the star. Dyson first discussed them(1960) and pointed out that they would be sources of intense infra-red radiation due to the thermal energy output.

Focused/Directed beam of neutrinos

- Why would ETI want to send us a focused beam?
- Don't know and don't care! Maybe they want to get our attention and then send us information (e.g. "Beware string theory!") Due to long time scales, may remain monologue for a while.
- Many different possibilities: intercept signals sent by ETI to their "military" outposts, we just happen to intercept them.....

- Sending a focused beam has the advantage of not being seen by all, and would be less "dangerous", perhaps an advanced ETI wants to transmit to a TES(Technologically Emergent Society) like ourselves.

- Perhaps they have been tracking us and know that we as a TES are ready to receive neutrino signals with large KM3 detectors?
- Beam choice: electron antineutrinos of energy 6.3 PeV. The cross-section on electrons in detectors is large and characteristic of the Glashow Resonance (produce on-shell W with a resultant shower). No BG and a unique characteristic energy.
- Range in Water at this energy ~ 100 km planned detectors will catch ~ 1 % of the flux (down-going and horizontal).

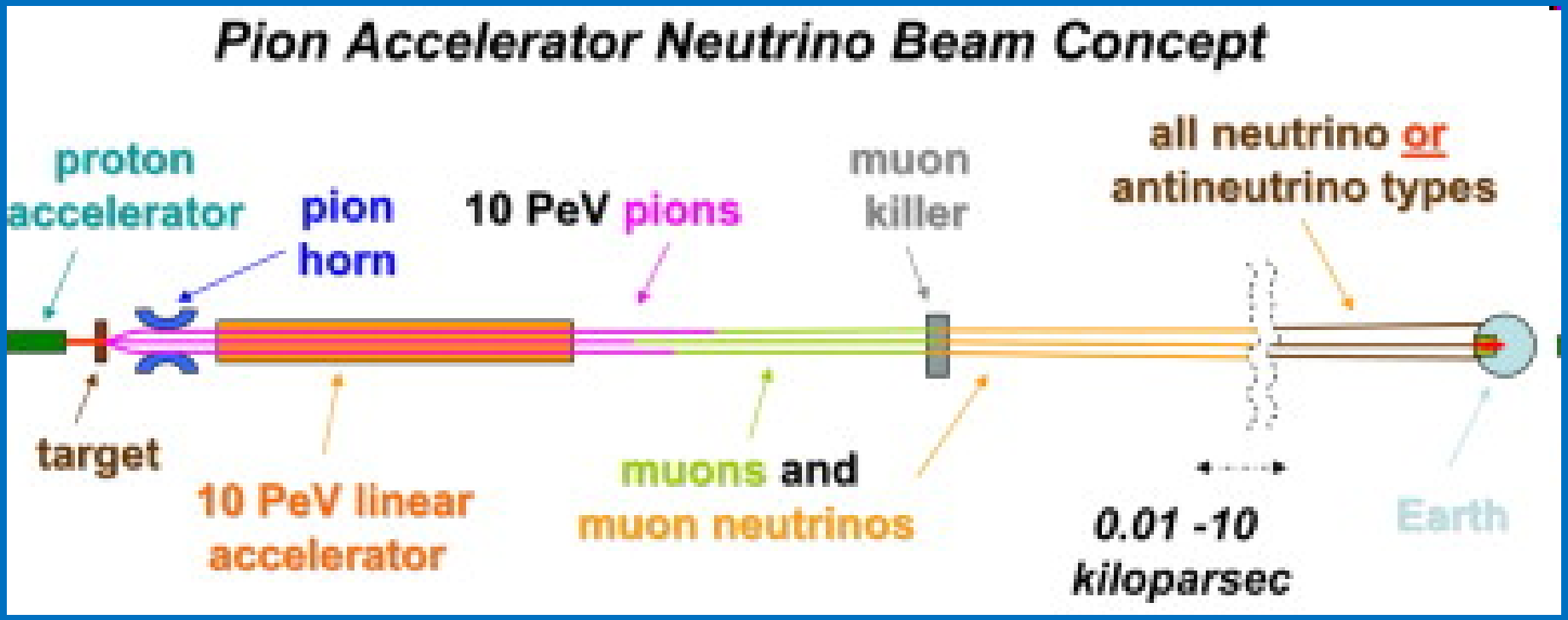
Glashow Resonance

- When a anti-ν_e hits an electron in the target at an energy of 6.3 PeV(10^6 GeV), the total energy in c.m. is just enuf to produce a W^-. At this resonant energy the cross-section is high and the signal due to the shower of the decay of the W is clear……

Such a resonance was first discussed by Glashow in 1960.

- A possible way to make such neutrinos is an e^+-e^- Collider in a boosted frame with e^- overtaking the e^+, making Z's of high energy…..
- From 1 kpc away this beam would be 3000 AU across, for a pulse of 100 neutrinos, need 10^{26} neutrinos in the beam! Again NOT OUR PROBLEM!
- A much better choice is a pion accelerator….see e.g. next slide.

Learned, Pakvasa & Zee, Phys. Lett. B 671, 15(2009),arXiv:0805.2429.



Artist's conception

- Protons hitting a target at ~30 PeV, switchable between π^+ and π-, decaying into μ and ν_μ or their antiparticles. Muons are removed as in usual beam dumps…A pure ν_μ beam, after a few light-days becomes a flavor mixture with $\nu_e:\nu_\mu:\nu_\tau = 4:7:7$.
- Encoding in a variety of ways: switching back and forth between neutrinos and antineutrinos, i.e. absence or presence of the Glashow Resonance, in addition to other signals(muons etc). One can also use timing/pulsing.
- Neutrino angle small ~ from 3 kpc, about 0.01 AU, much narrower than from Z decay.

AGAIN ALL WE HAVE TO DO IS SIT BACK AND WAIT

FOR SIGNAL OF 6.3 PEV ELECTRON ANTINEUTRINOS

Neutrinos mix and oscillate.

At large distances, oscillations average out and the only effect is mixing. The propagation matrix is such that an initially

pure ν_μ beam becomes a mixture

given by $\nu_e:\nu_\mu:\nu_\tau = 4:7:7$

Also a beam of ν_μ produces NO antineutrinos needed for the Glashow resonance.

Extra Slides

- More on Fermi Question:
- Many books and articles on this. For example: Stephen Webb, "Where is everybody?", Praxis Publishing, 2002.

  Here are listed over 50 proposals for "solving" the Puzzle listed along with counter-arguments.

Classes of solutions proposed:

(1) They are already here!

e.g. They are Us, we ARE the aliens!

(2) They exist but have not yet communicated…..or don't want to!

(3) They do not exist!?