Is Anybody Out There?

The Search for ET with help from 8 million volunteers

Dan Werthimer
University of California, Berkeley

http://seti.berkeley.edu

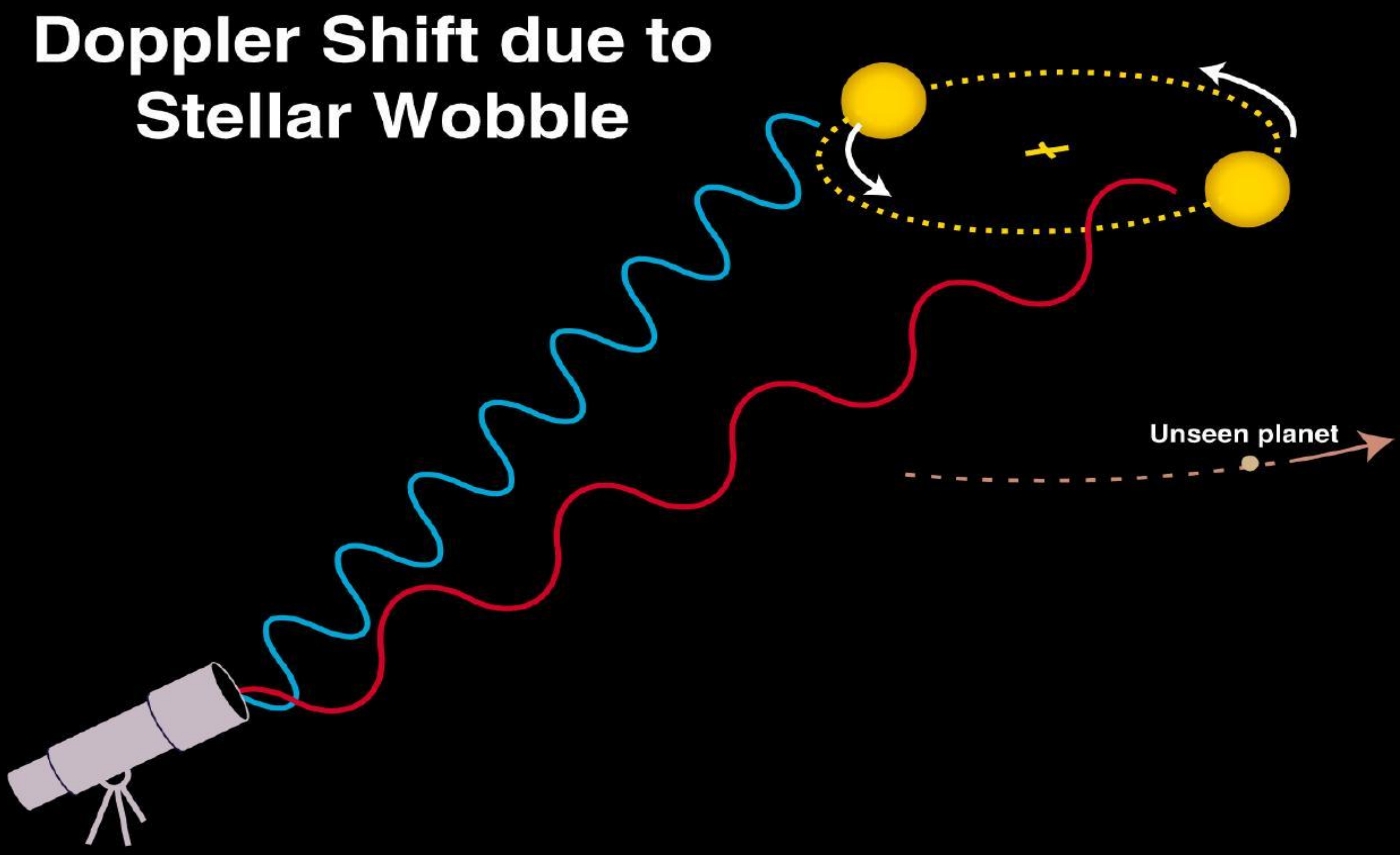
SETI@home
The Search for Extraterrestrial Intelligence

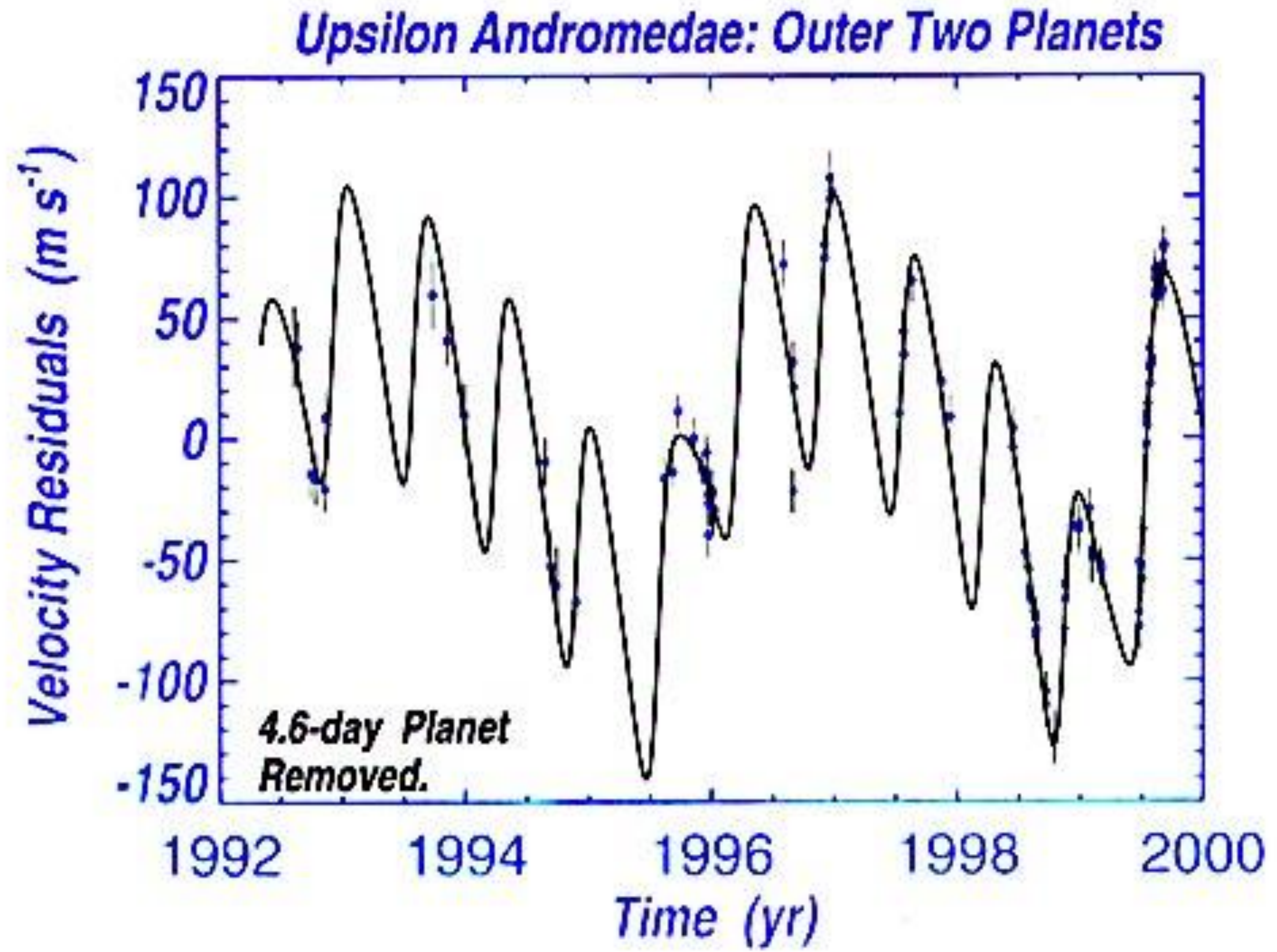
Drake Equation

$$N = R\, f_s\, f_p\, n_e\, f_l\, f_i\, f_c\, L$$

N = number of communicating civilizations in our galaxy

Planet Detection

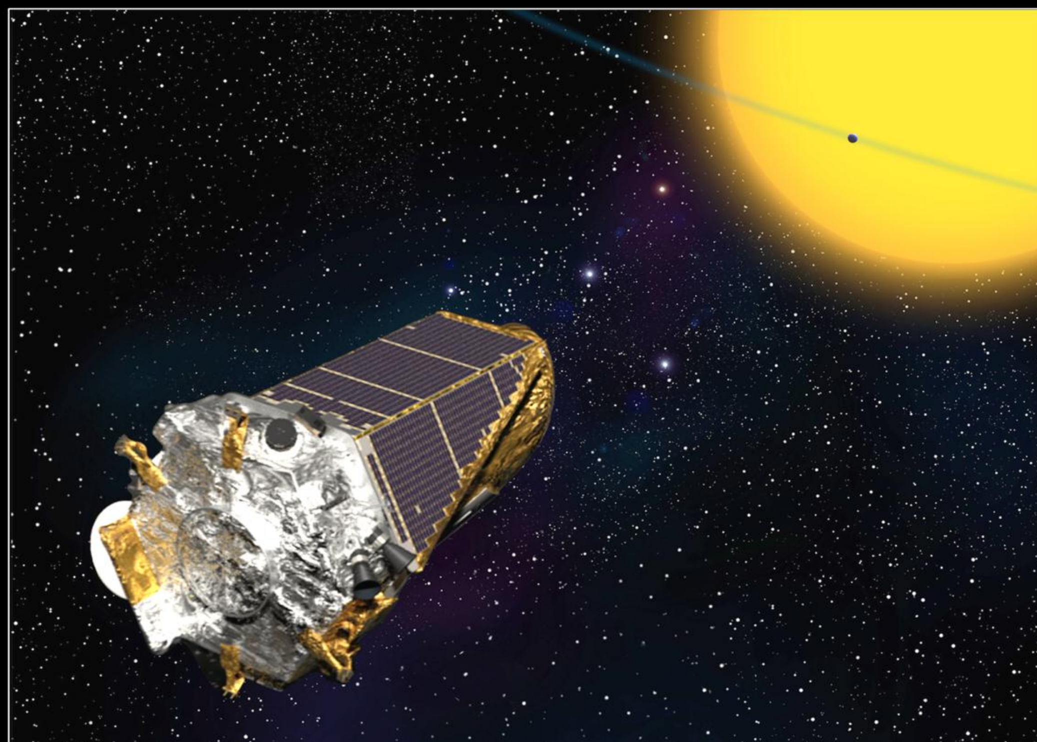


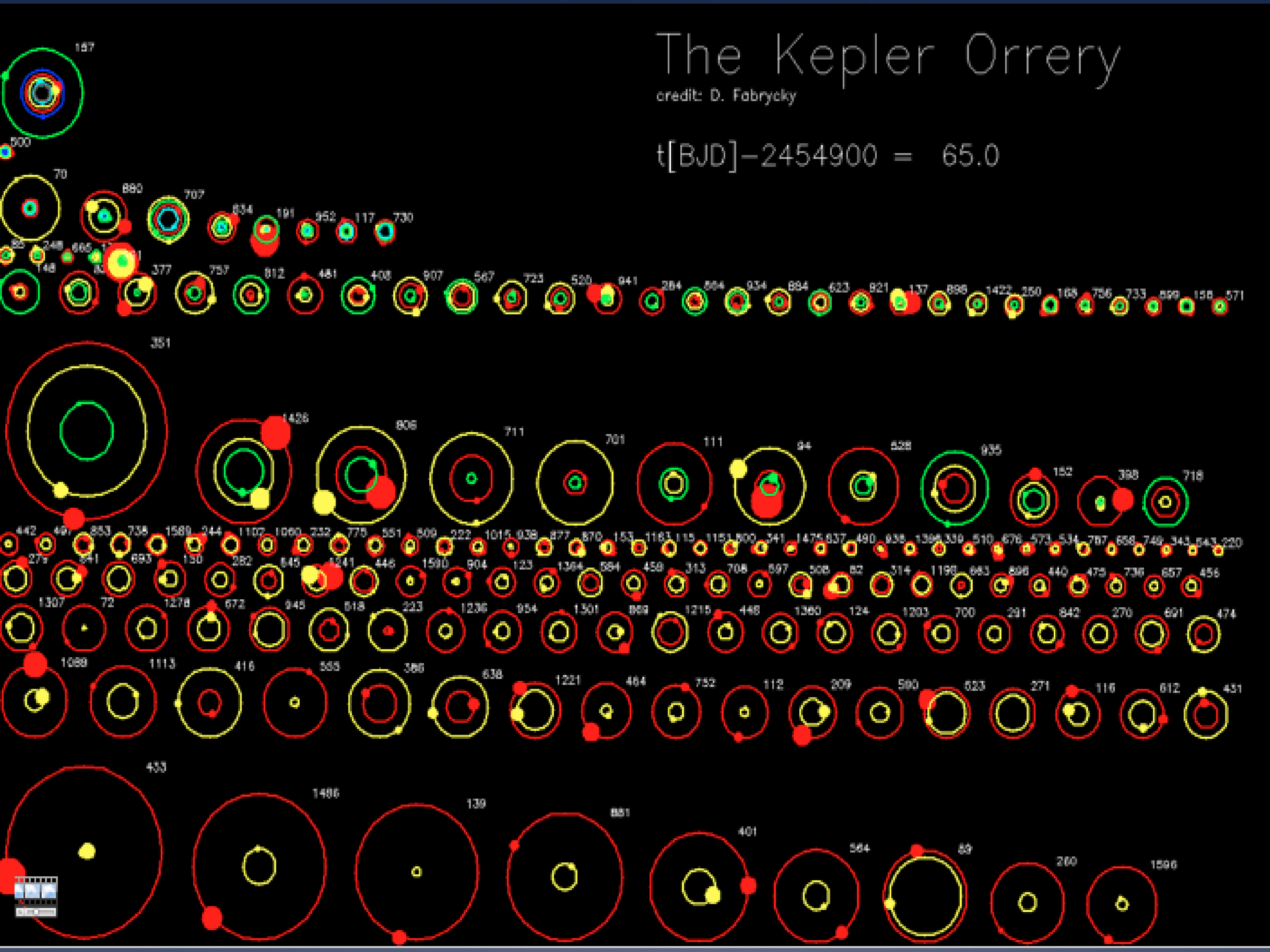

Upsilon Andromedae: Outer Two Planets
Velocity Residuals (m s-1)
150
100
50
0
-50
-100
-150
4.6-day Planet Removed.
1992
1994
1996
1998
2000
Time (yr)

NASA’s Kepler Mission

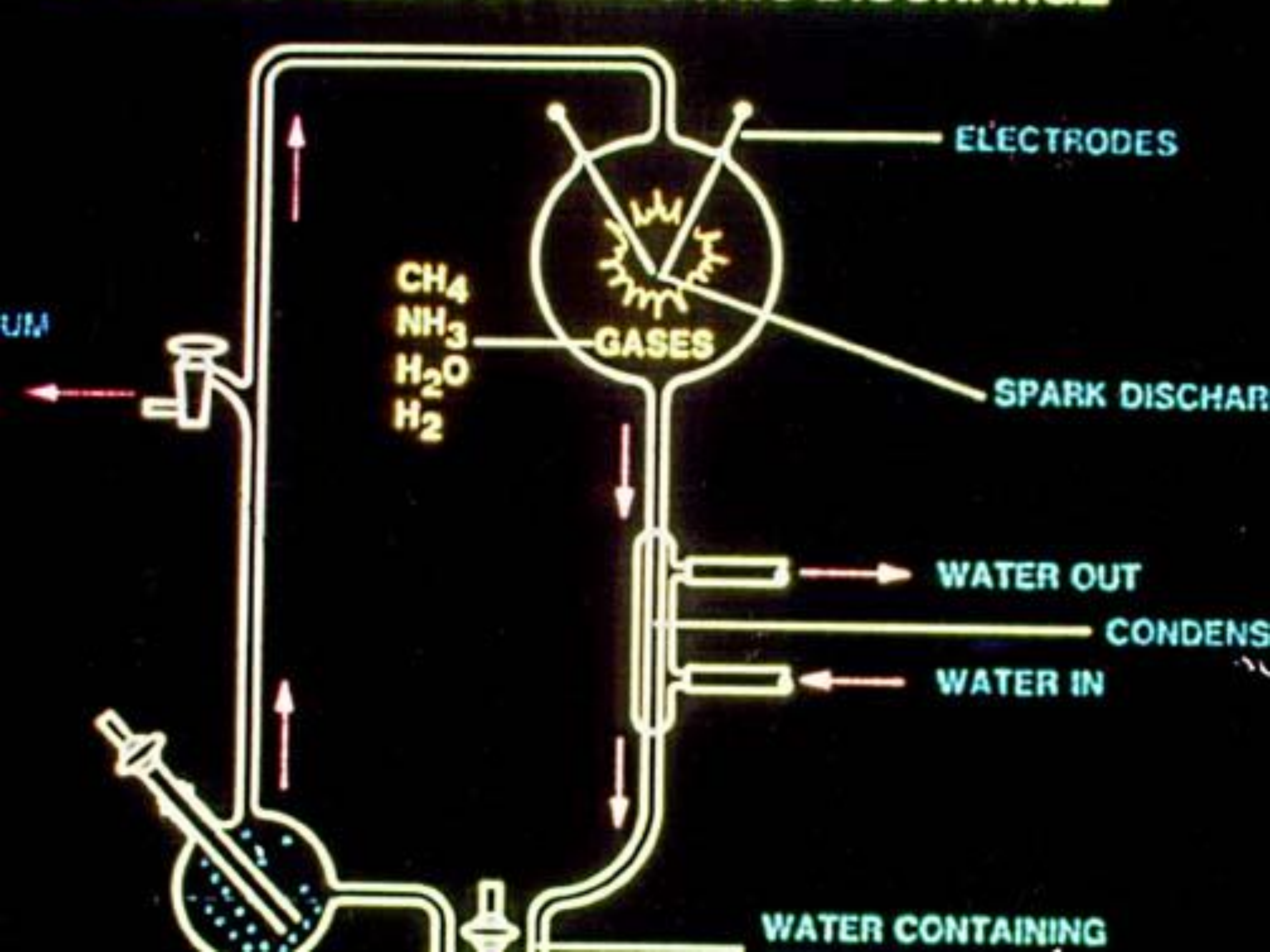
Survey 150,000 Stars
for Earth-size Planets

- Determine the size and orbital period distributions of planets

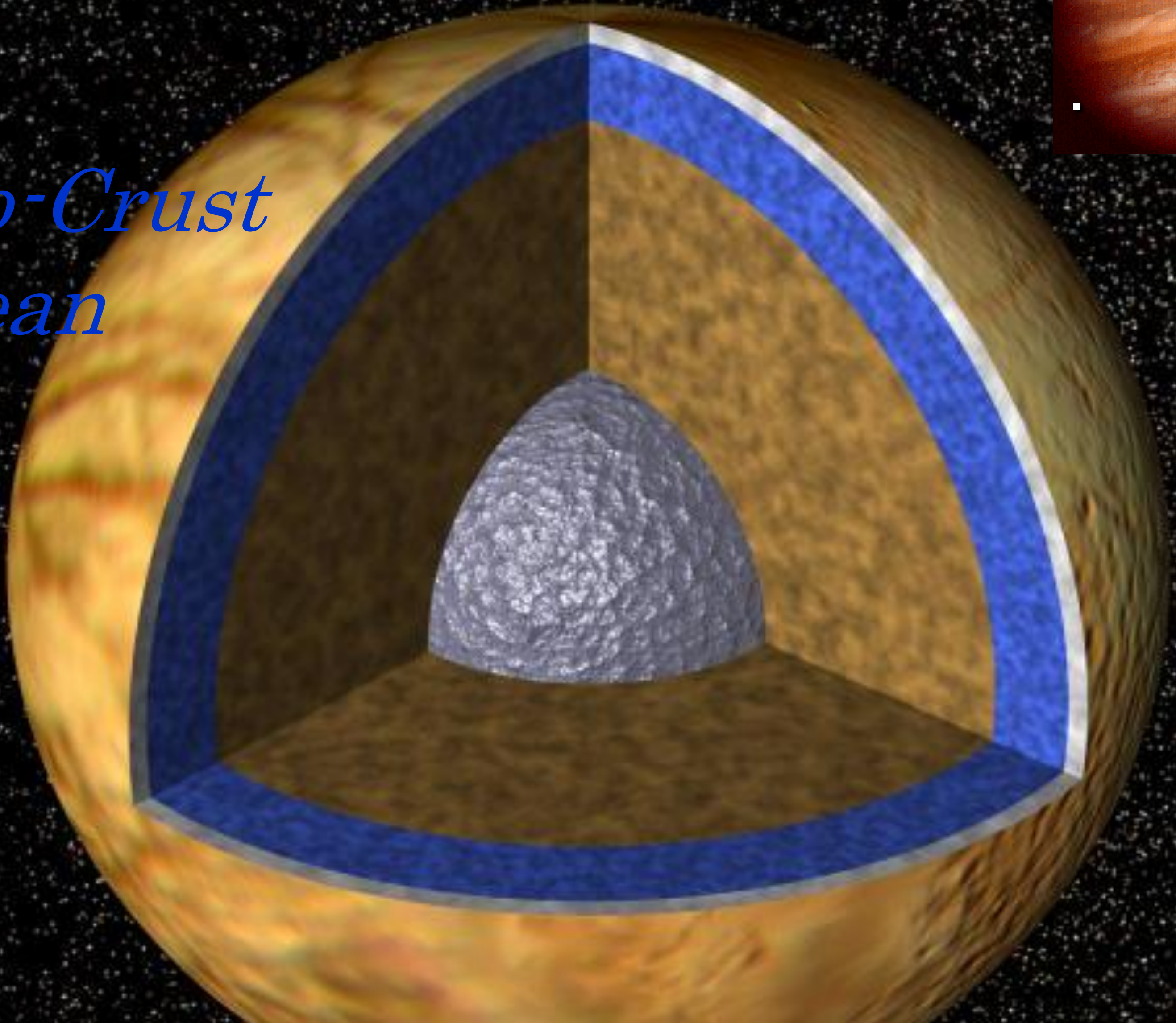


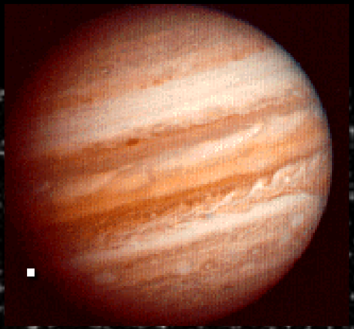

The Kepler Orrery
credit: D. Fabrycky
t[BJD]−2454900 = 65.0

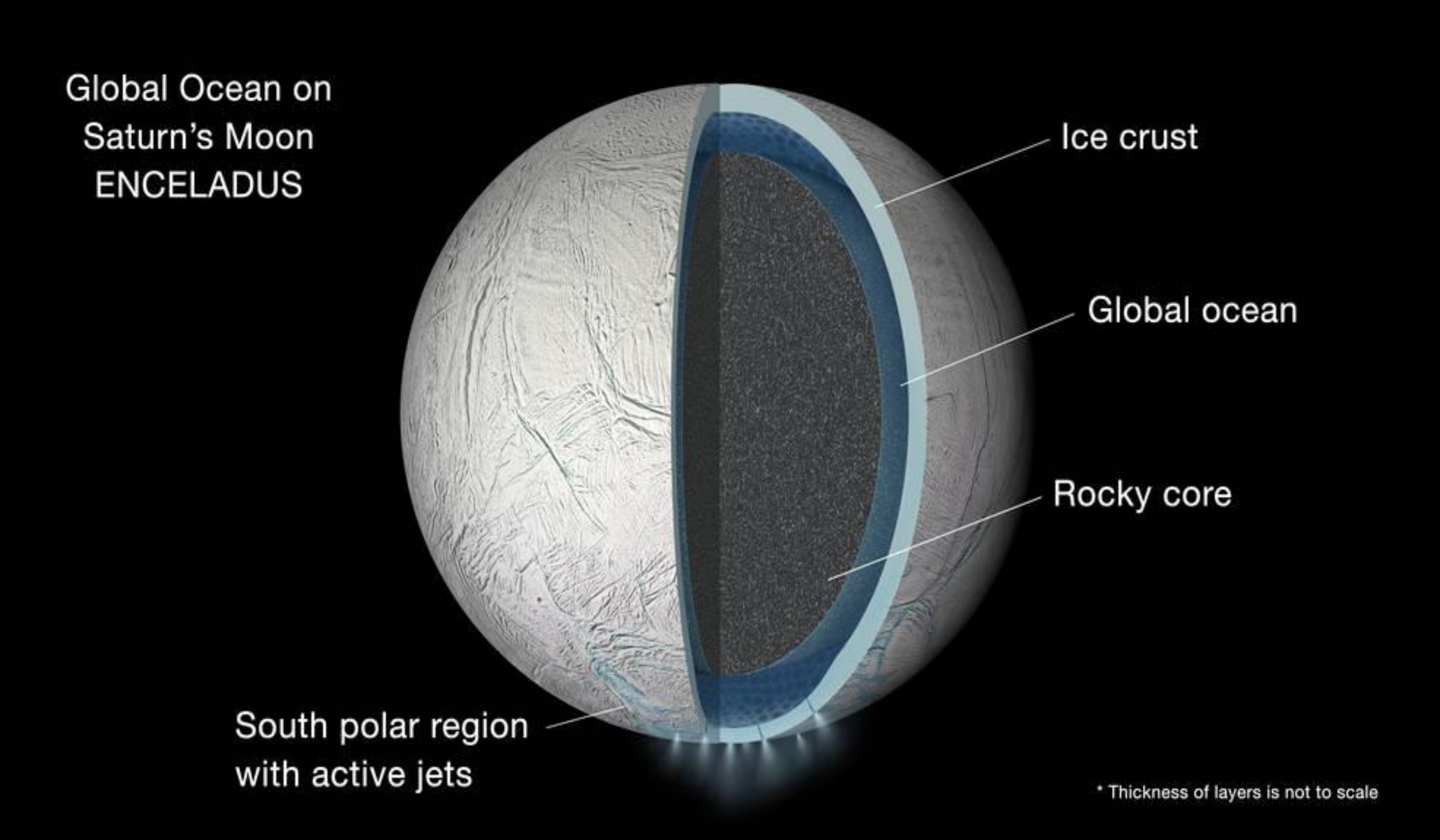

Campbell's
Primordial
SOUP


ELECTRODES
CH_4
NH_3
H_2O
H_2
GASES
UM
SPARK DISCHAR
WATER OUT
CONDENS
WATER IN
WATER CONTAINING

Jupiter's Moon: Europa



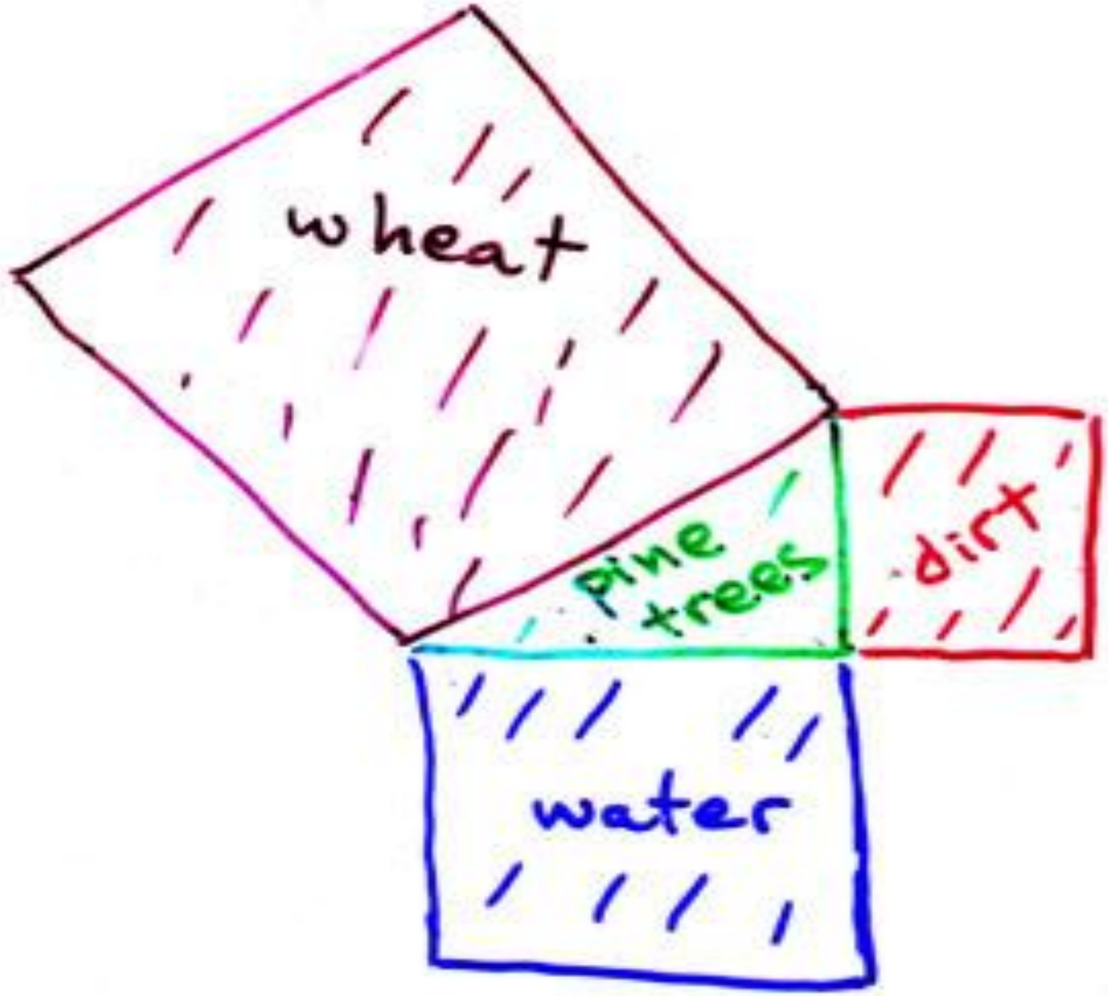



Global Ocean on
Saturn's Moon
ENCELADUS
Ice crust
Global ocean
Rocky core
South polar region
with active jets
* Thickness of layers is not to scale

SETI Before IEEE

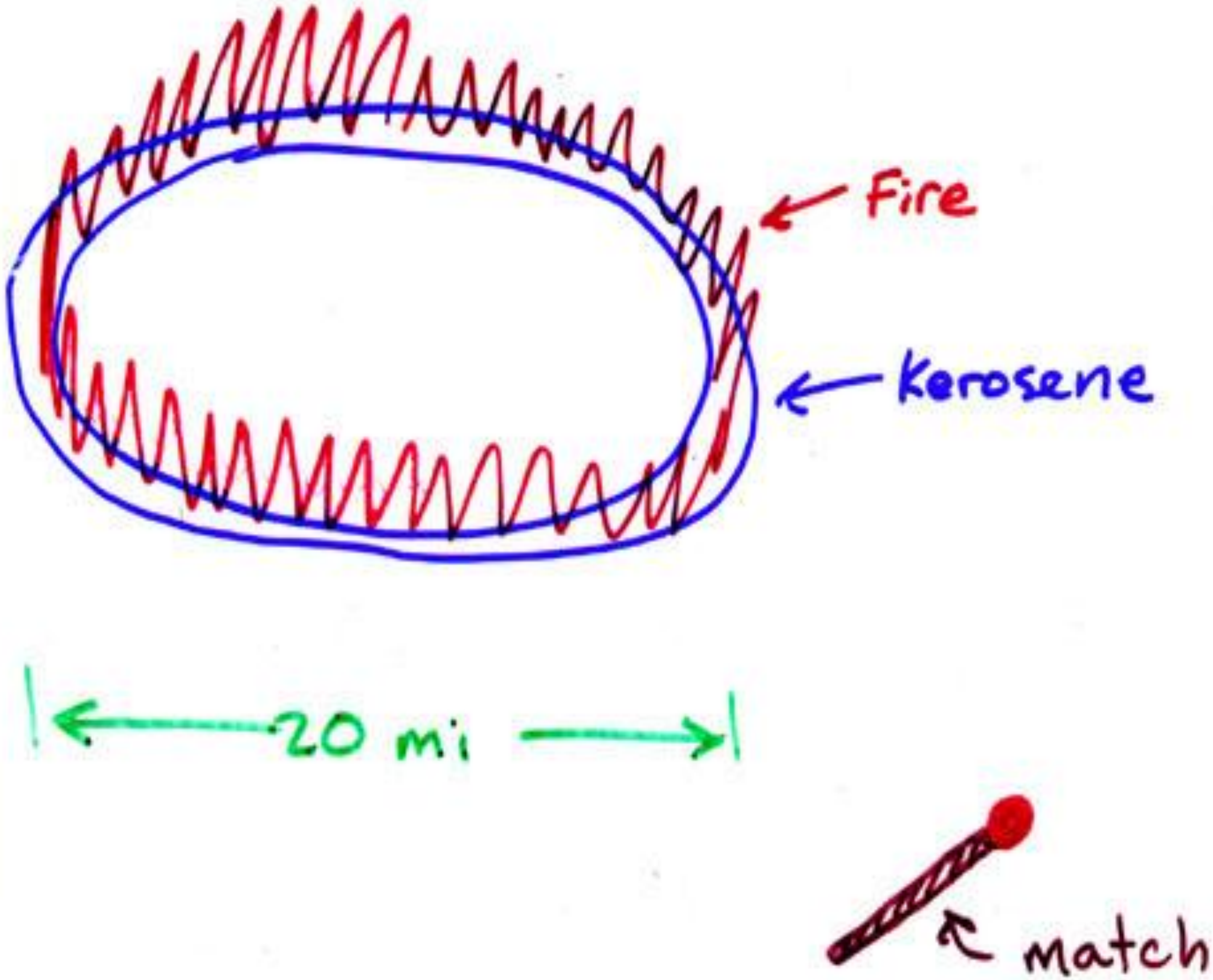
Signal Processing Society

Karl Gauss 1820



NOT FUNDED

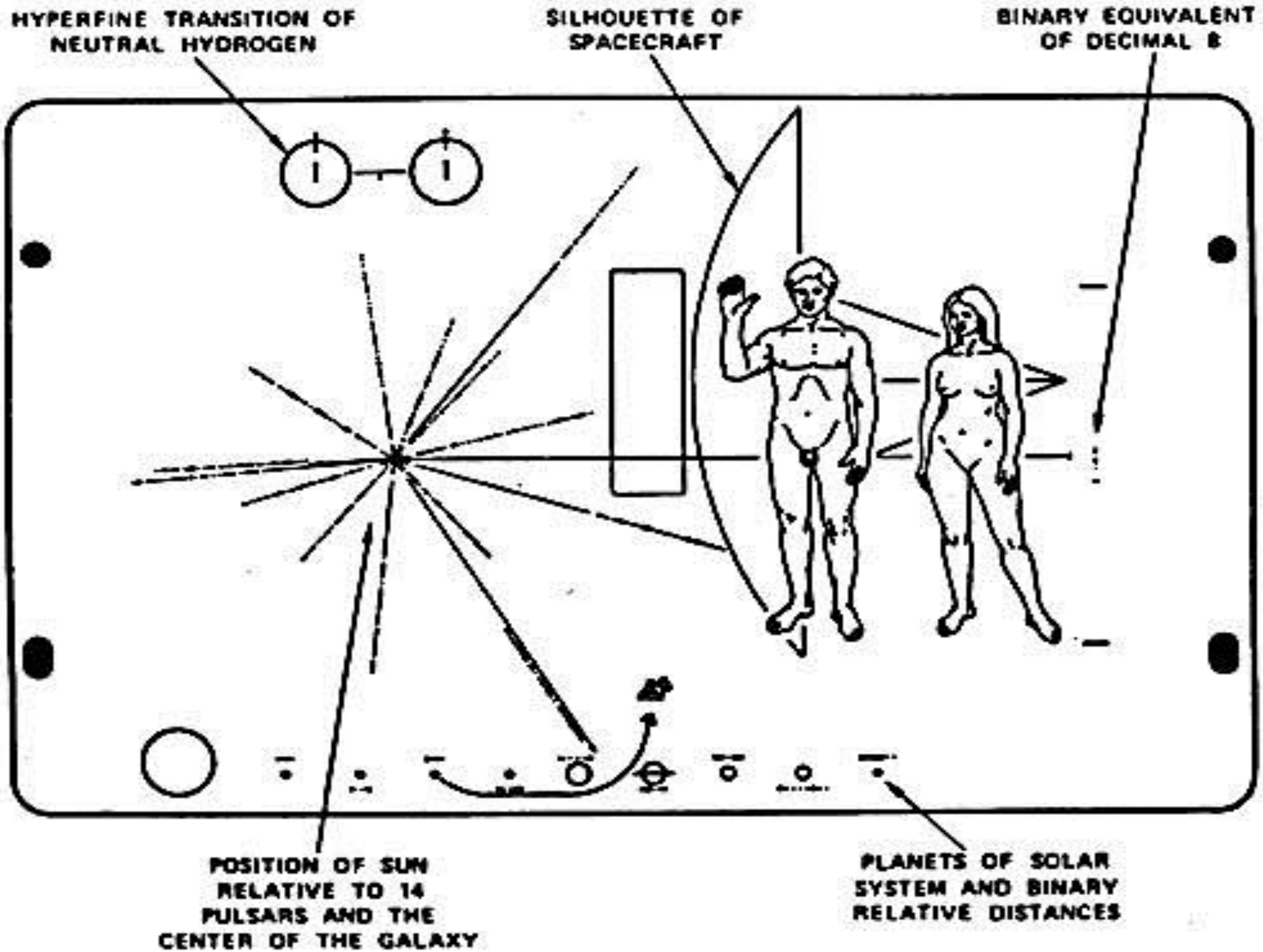
Joseph Von Littron ~1840



NOT FUNDED

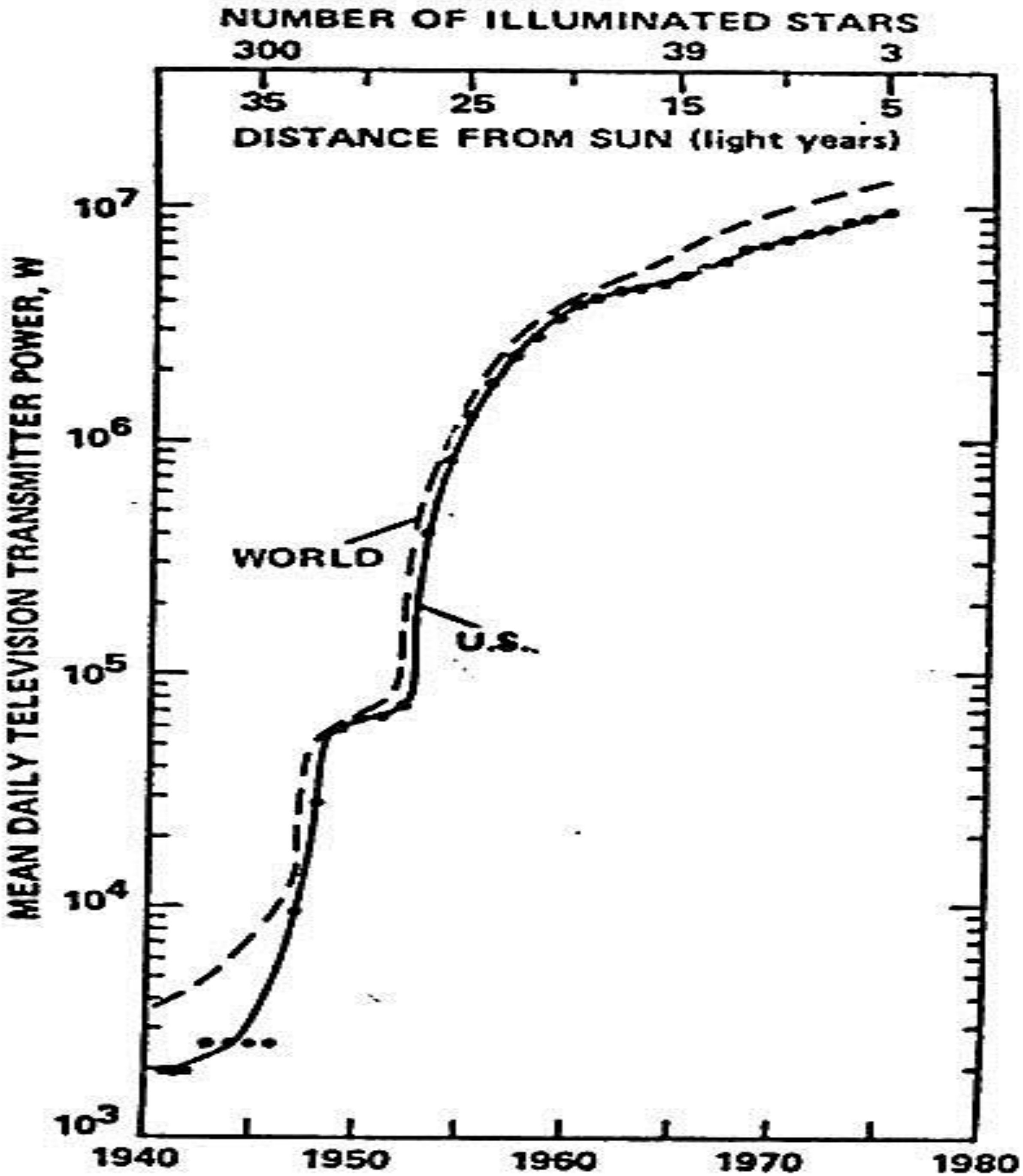
Charles Cros 1869

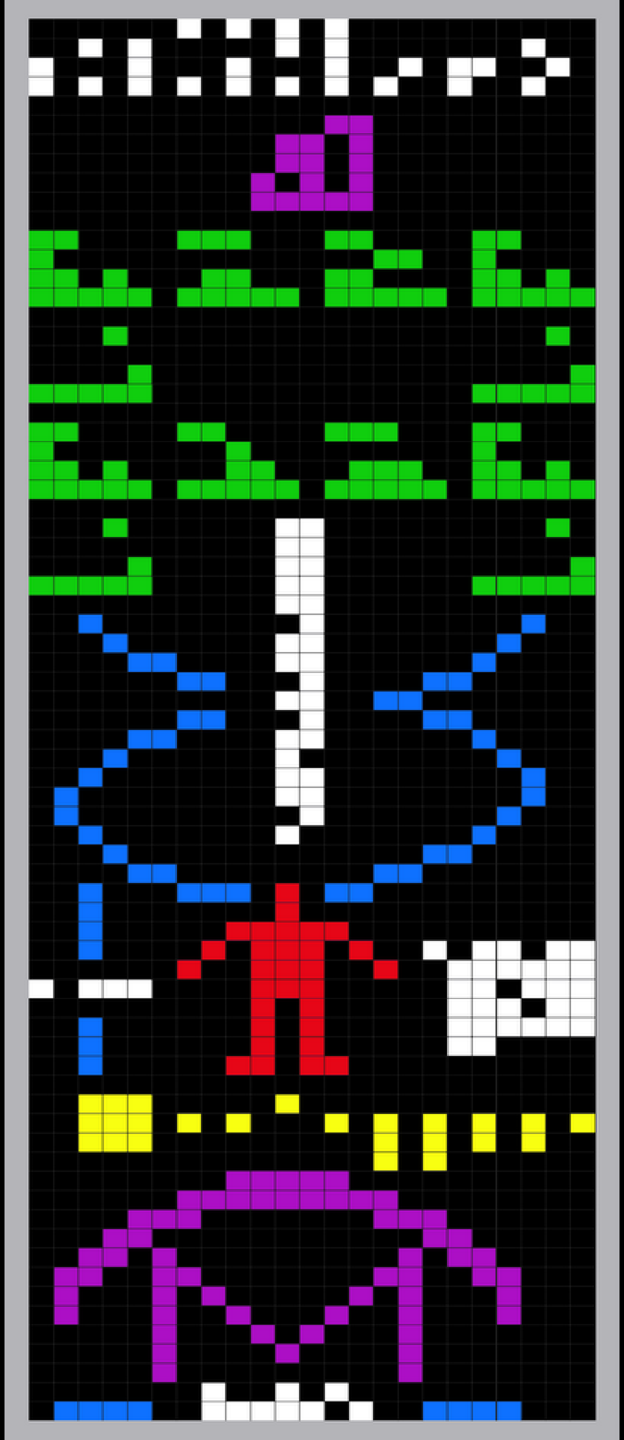
NOT FUNDED


HYPERFINE TRANSITION OF NEUTRAL HYDROGEN
SILHOUETTE OF SPACECRAFT
BINARY EQUIVALENT OF DECIMAL 8
POSITION OF SUN RELATIVE TO 14 PULSARS AND THE CENTER OF THE GALAXY
PLANETS OF SOLAR SYSTEM AND BINARY RELATIVE DISTANCES

Porno in space:

FUNDED!


NUMBER OF ILLUMINATED STARS
300
39
3
35
25
15
5
DISTANCE FROM SUN (light years)
MEAN DAILY TELEVISION TRANSMITTER POWER, W
10^7
10^6
10^5
10^4
10^3
WORLD
U.S.
1940
1950
1960
1970
1980



Signal Types

1. **Artifact** (radio, radar, ~TV, ????)
2. **Deliberate** (easy to decode, pictures, language lessons)

First civilization we contact is likely to be a billion years ahead of us. (ray norris, 2002)

First Radio SETI

- Nikola Tesla (1899)
  - Announces “coherent signals from Mars”
- Guglielmo Marconi (1920)
  - Strange signals from ET
- Frank Drake (1960)
  - Project Ozma
  - one channel, 1420-1420.4 MHz

BERKELEY SETI RESEARCH CENTER

BERKELEY **SETI**

SSL
UNIVERSITY OF CALIFORNIA
Berkeley

CASPER

BWRC

Berkeley
Astronomy
Department

Berkeley Lab

The University of California 1868
Let There Be Light

American Museum of Natural History

UW-La Crosse

Columbia University

NRAO

National Astronomy and Ionosphere Center — Arecibo Observatory

University of Toronto

SETI Institute

ASTRON

University of Hawai'i

LOFAR

Cornell University Founded A.D. 1865

Berkeley SETI Group

Zuhra Abdurashidova, David Anderson, Hong Chen, Jeff Cobb, Steve Croft, Matt Dexter, Walt Fitelson, Jack Hickish, Eric Korpela, Matt Lebofsky, Dave MacMahon, Eric Petigura, Chris Schodt, Sophia Shiek, Isaac Shivvers, Andrew Siemion, Nate Tellis, Ed Wishnow, Dan Werthimer

Breakthrough Prize Foundation, NSF , NASA, Donors

Keysight, Intel, Seagate, Xilinx

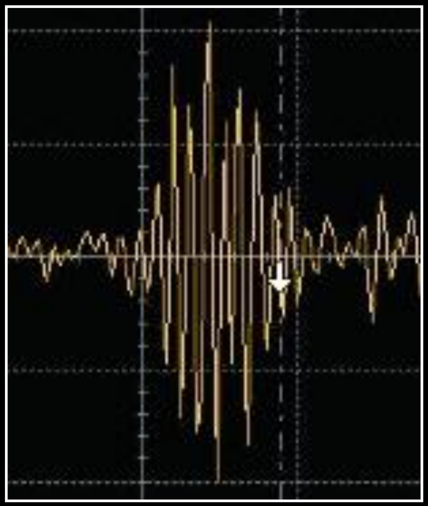
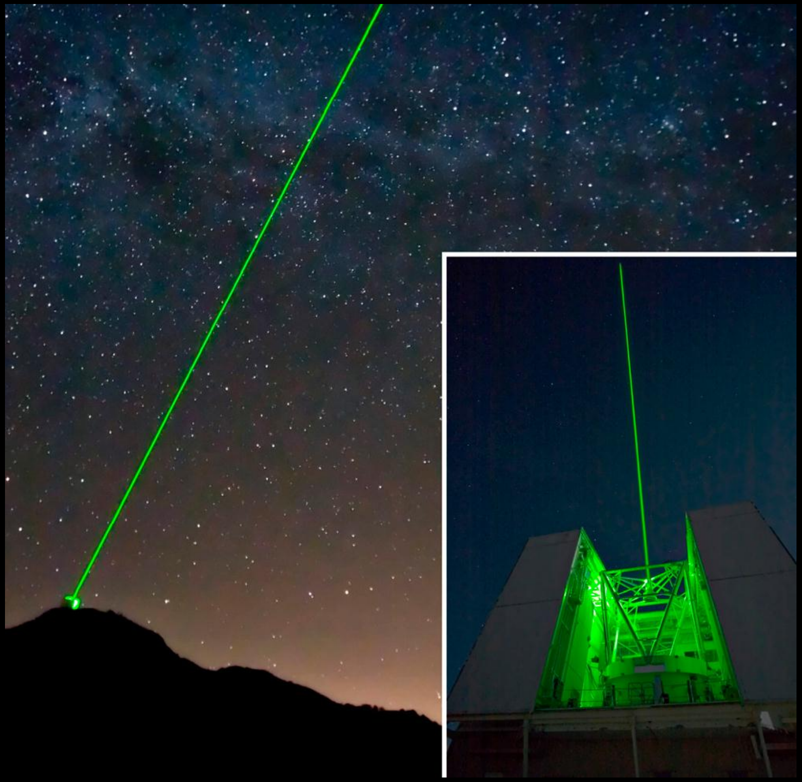
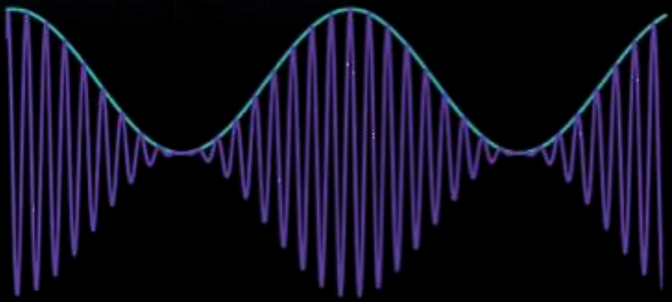
SETI@home

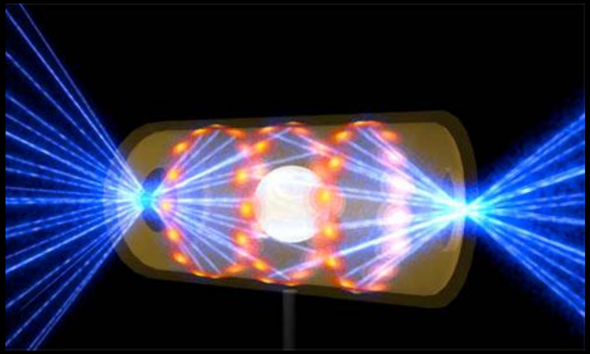
The Search for Extraterrestrial Intelligence

Berkeley SETI Research Center Experiments

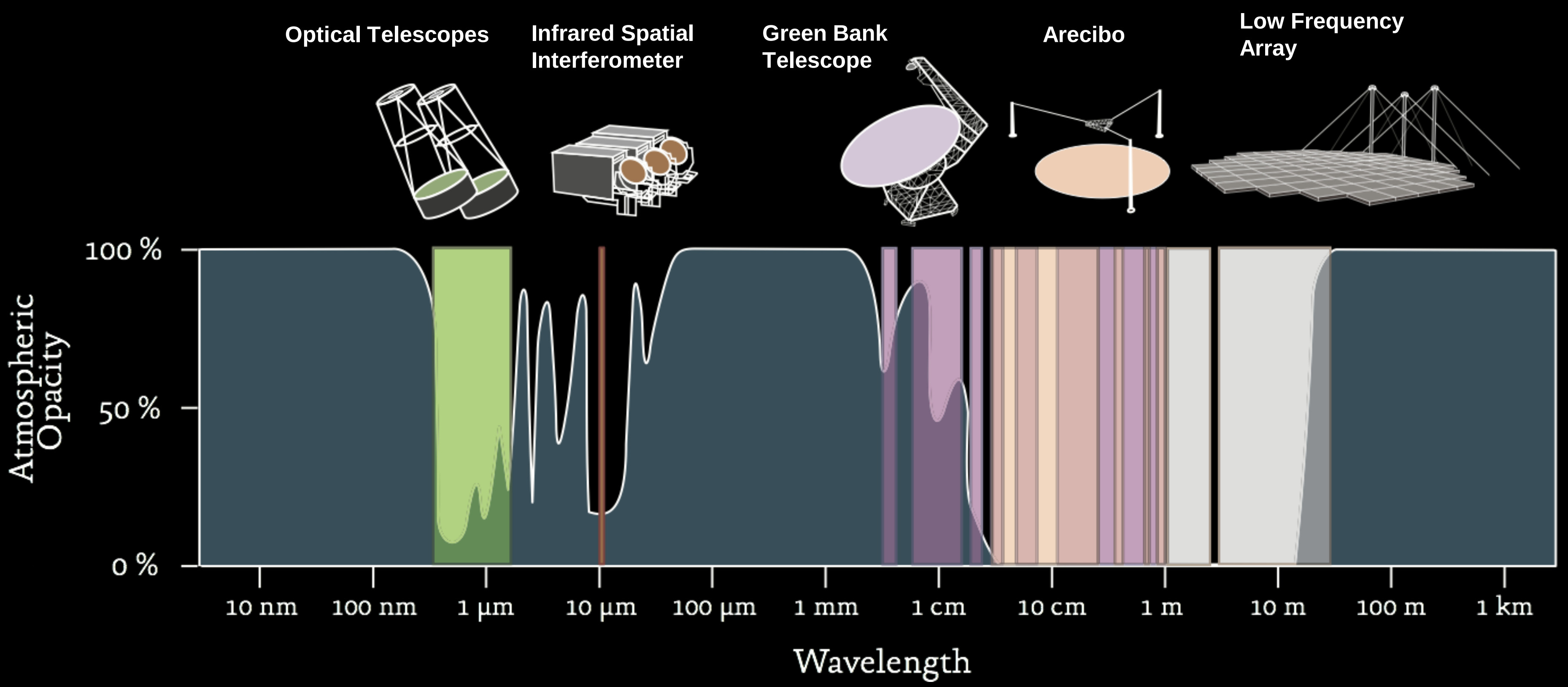
- Radio SETI
  - SERENDIP VI (Arecibo)
  - SERENDIP VI (Greenbank)
  - LOFAR SETI
  - GBT Targeted Time Domain SETI
  - SETI@home
  - Astropulse
- Optical/IR SETI
  - Spectral Search for Laser Lines from KOI
  - Searches for ET artifacts in light curves
  - IR SETI with the Infrared Spatial Interferometer
  - IR photodetector system
- Panchromatic SETI

Technosignatures…

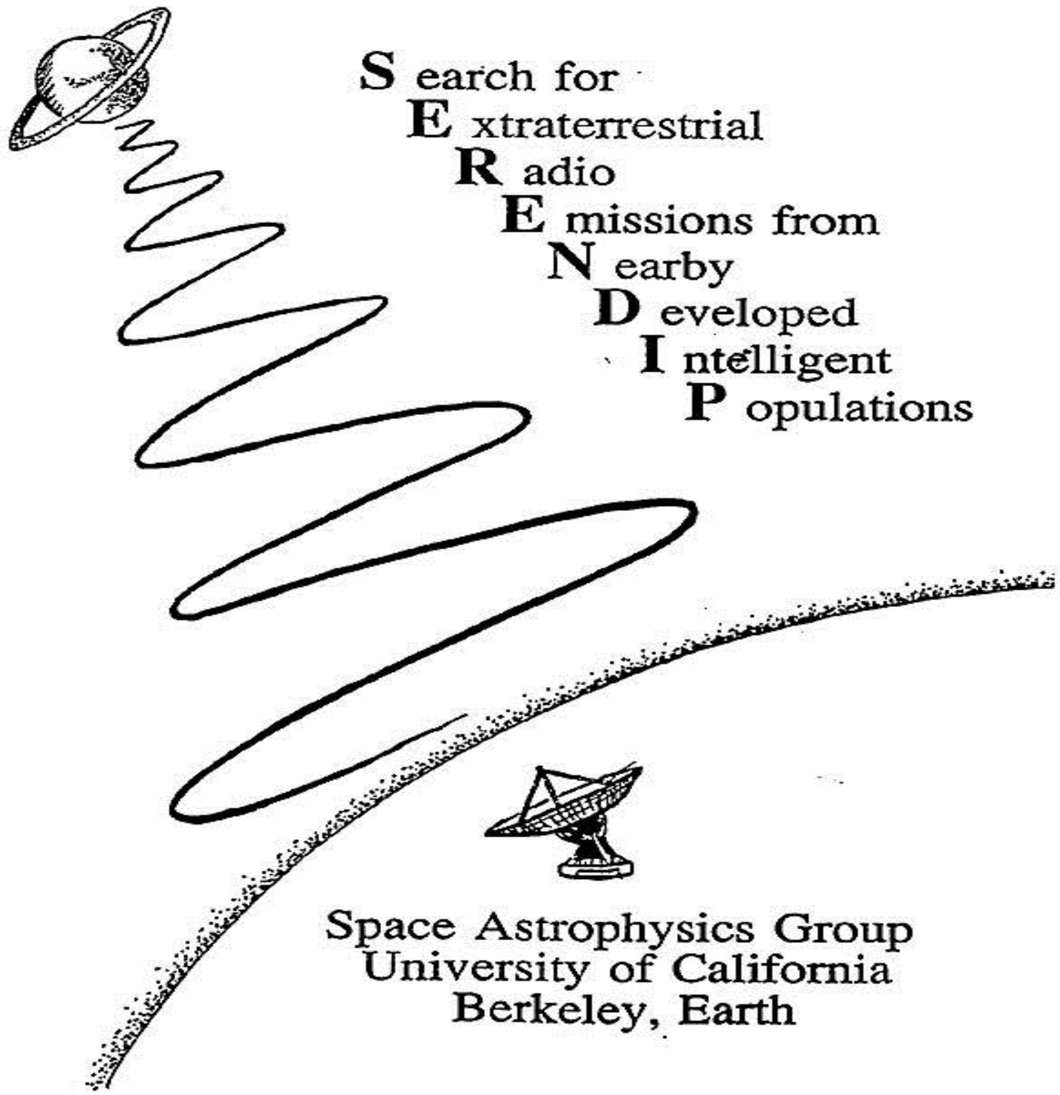


Searching Across the Electromagnetic Spectrum



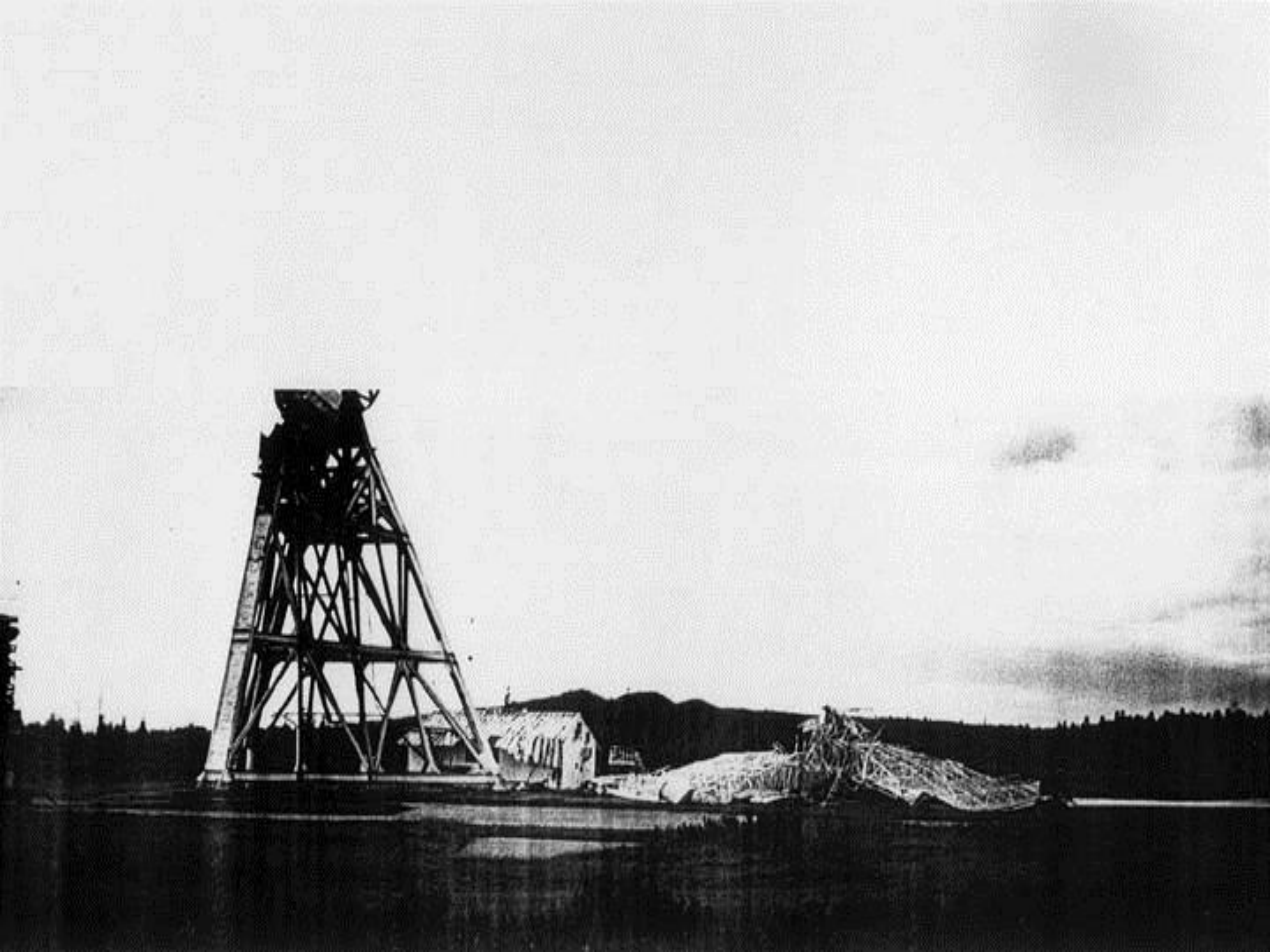
Using multiple telescopes, we can search across the electromagnetic spectrum for indicators of advanced technology.

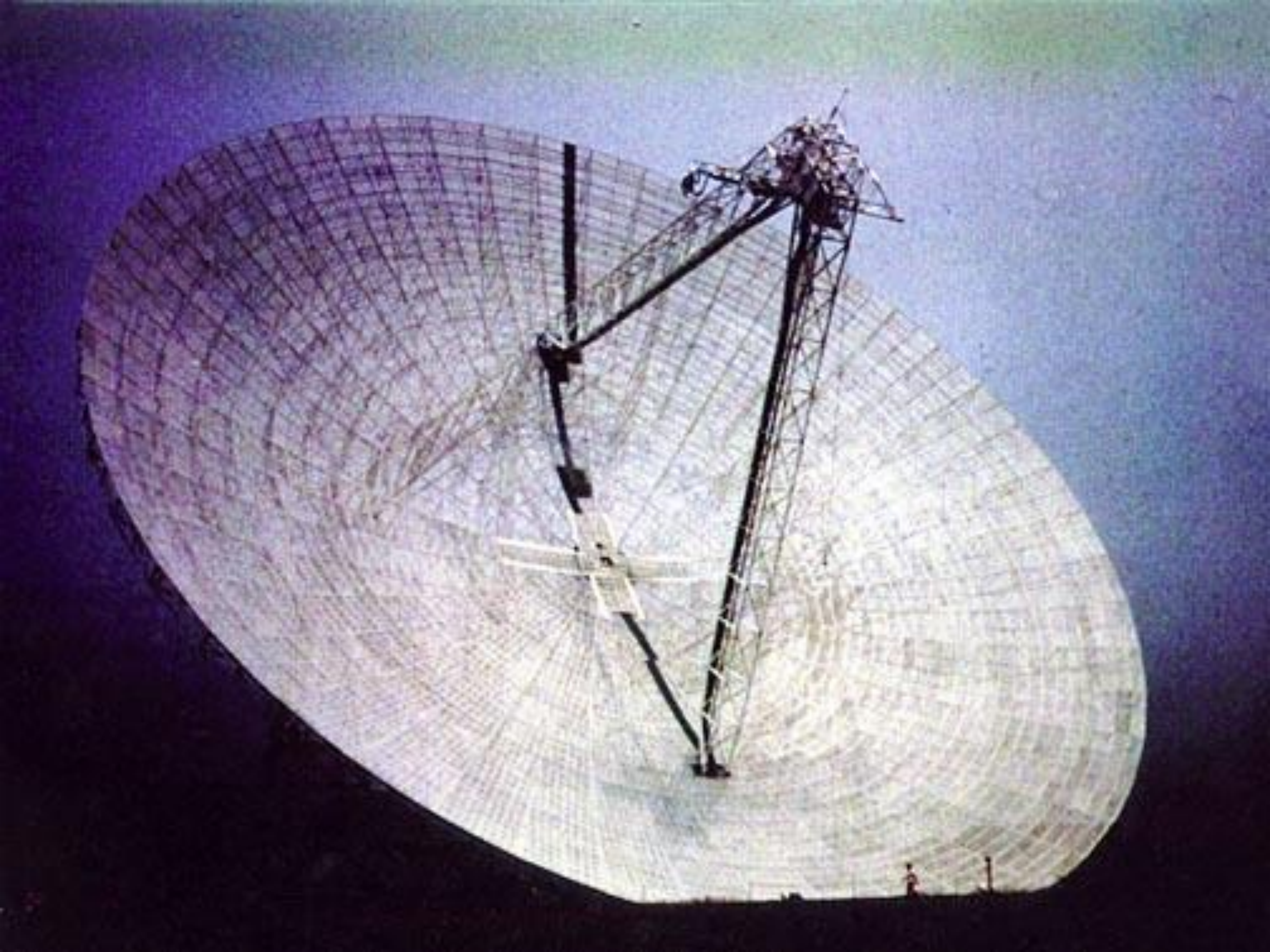
SERENDIP



S earch for
E xtraterrestrial
R adio
E missions from
N earby
D eveloped
I ntelligent
P opulations

Space Astrophysics Group
University of California
Berkeley, Earth



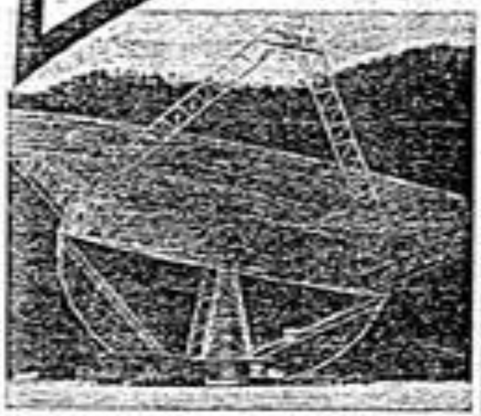


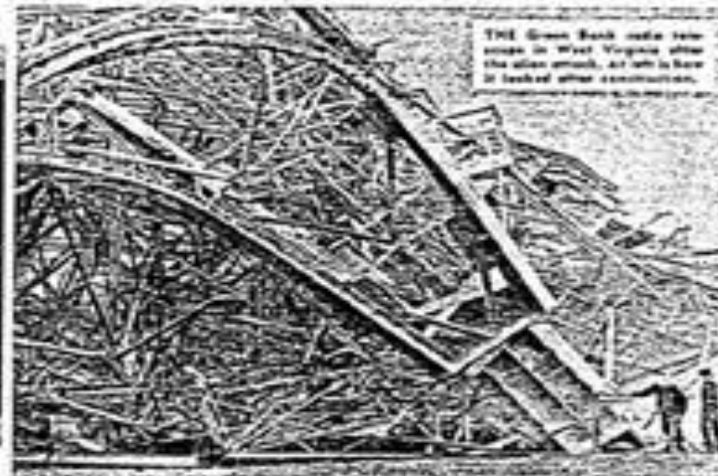
World Weekly News Jan. 31, 1989 p. 5

America's most powerful radio telescope IS . . .

ZAPPED!

. . . by hostile space aliens!





THE Green Bank radio telescope in West Virginia after the alien attack. At left is how it looked after construction.

BEFORE ▲ AFTER ▶

Space aliens zapped the enormous radio telescope at Green Bank, W. Va., with a powerful laser to keep scientists from monitoring their activities in the northern hemisphere!

That's the claim of Swiss astronomer Peter Vuisard, who says the destruction of the 300-foot instrument on November 15 qualifies as the boldest act of extraterrestrial aggression in the history of the world.

By KAGAN DUNN

"We know that extraterrestrials have shot down planes and abducted people but this is the first time they have been brazen enough to destroy a government research facility," the expert told newsmen in Geneva. "The Americans must have been learning too much about them," he continued. "There is no other rational explanation for such a strike as this. In some circles it might be considered an act of war."

Dr. Vuisard's report sent shockwaves throughout the world's scientific community. But the handful of men who can tell about the Green Bank disaster with authority refused to describe the incident as anything more than "a mystery."

There is no doubt that the instrument — which could detect objects almost two-thirds of the way to the edge of the visible universe — was essential to monitoring extraterrestrial activity in the northern skies.

And its devastation by a destructive beam stands as compelling proof that it was zapped by extraterrestrials who wanted to mask their activity from mankind, Dr. Vuisard said.

"Any other explanation defies logic," he continued. "The telescope had been in operation since 1962 and was solid as a rock.

"Suddenly it collapses in the dead of night. What are we supposed to think? That the telescope just fell apart?"

French radio astronomer [illegible] Kraemer was inclined to agree with Dr. Vuisard but warned against jumping to conclusions.

"I firmly believe that we can prove extraterrestrials zapped the telescope at Green Bank," he said. "But let's wait until all the evidence is in.

"Then we can take whatever steps are necessary to prevent things like this from happening in the future."

Brave dog

A German shepherd survived for three days after being buried by an avalanche near Berne, Switzerland.

When rescued by police the dog wagged its tail and appeared to be hungry but in good health.

NAIC Arecibo Observatory, Puerto Rico

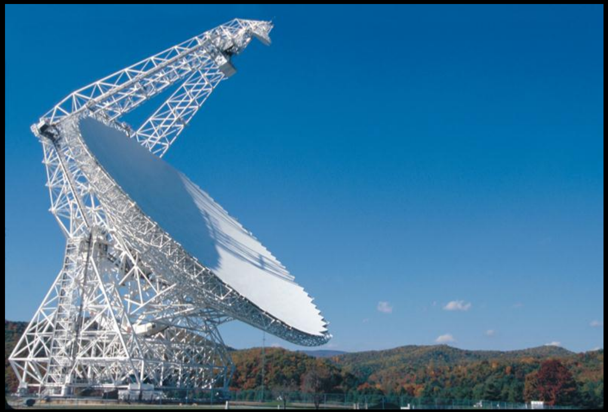
Breakthough Prize Foundation "LISTEN" SETI Project

- $100M over 10 years
- Starting with Green Bank and Parkes Radio Telescopes
- Lick Observatory (optical SETI)
- 1,000,000 stars; 1000 galaxies; galactic plane; all sky
- New instrumentation: 10 GHz bandwidth (20 billion channels)
- SETI@home participants will analyze interesting parts of data
- Open source data, hardware, software, gpuware, gateware

The Breakthrough Listen Initiative: Telescopes

Automated Planet Finder (Lick Observatory)

- Search for extremely narrow emission lines from artificial lasers
- Extremely high resolution "Levy Spectrometer" 374 - 950 nm, $\lambda/\Delta\lambda = 10^5$



Green Bank Telescope (Green Bank, WV)

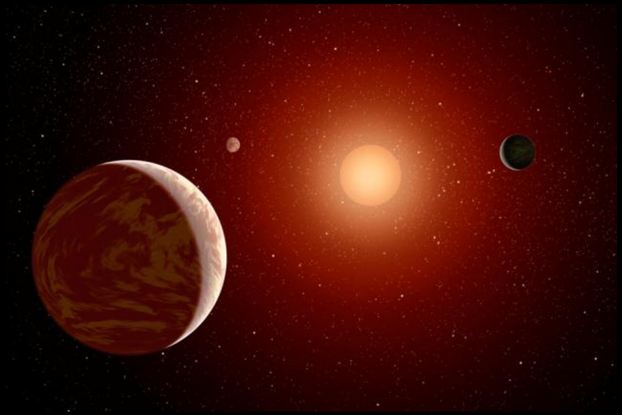
- Radio search focusing on targeted and raster observations
- Nearly continuous frequency coverage 300 MHz - 100 GHz
- Flexible IF system can deliver up to 10 GHz dual-pol analog bandwidth

Parkes Telescope (New South Wales, Australia)

- Radio search focusing on surveys
- Southern hemisphere location gives great access to galactic plane
- Multi-beam receiver allows very efficient L-band (1.2 - 1.5 GHz) sky surveys

The Breakthrough Listen Initiative:

10 years - 10^8 dollars



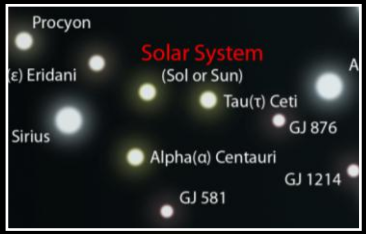
1 Million Stars

1000 Galaxies

1 day of Breakthrough Listen = 1 year of any previous search

http://breakthroughinitiatives.org

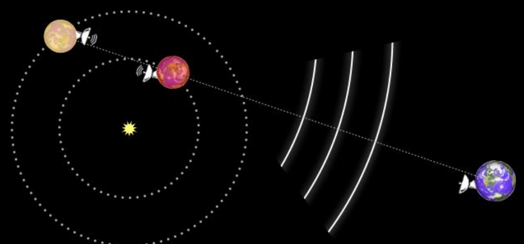
The Breakthrough Listen Initiative: Targets



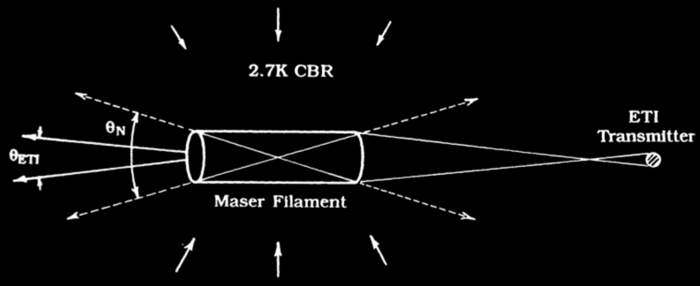
Nearby Stars

Sun-like Stars

Known Earth-like Exoplanets or Solar System-like Exoplanet Systems

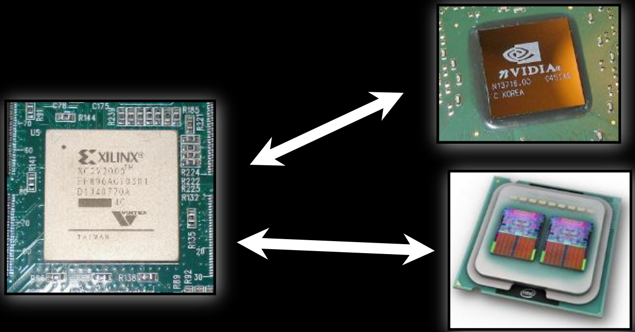


Serendipitous Alignments, e.g. multiple exoplanets in a single system along a line of sight to the Earth, “eavesdropping SETI”



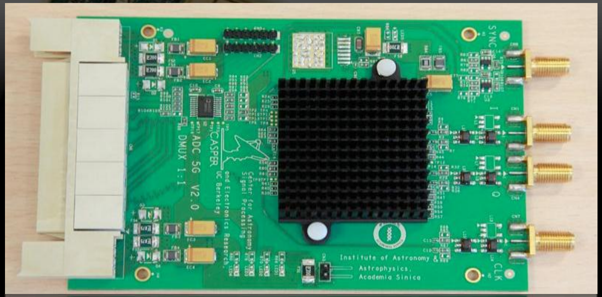
Exotica, e.g. natural amplifiers, astrophysical masers, a la Cordes, 1993

The Breakthrough Listen Initiative: Technology



Commodity Compute Elements

FPGA Computing Boards



High Speed Digitizers

Many-GHz processing capability

200 - 400 Gbps data recording

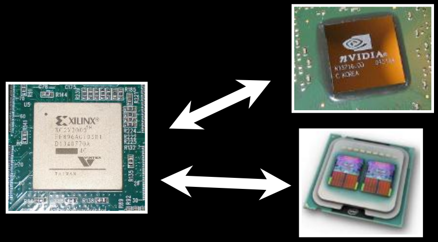
10^{10} channel spectroscopy

GPU-accelerated multi-parameter search pipeline (dispersion, Doppler effects)

Interference identification, classification

CASPER

The Breakthrough Listen Initiative: Timeline

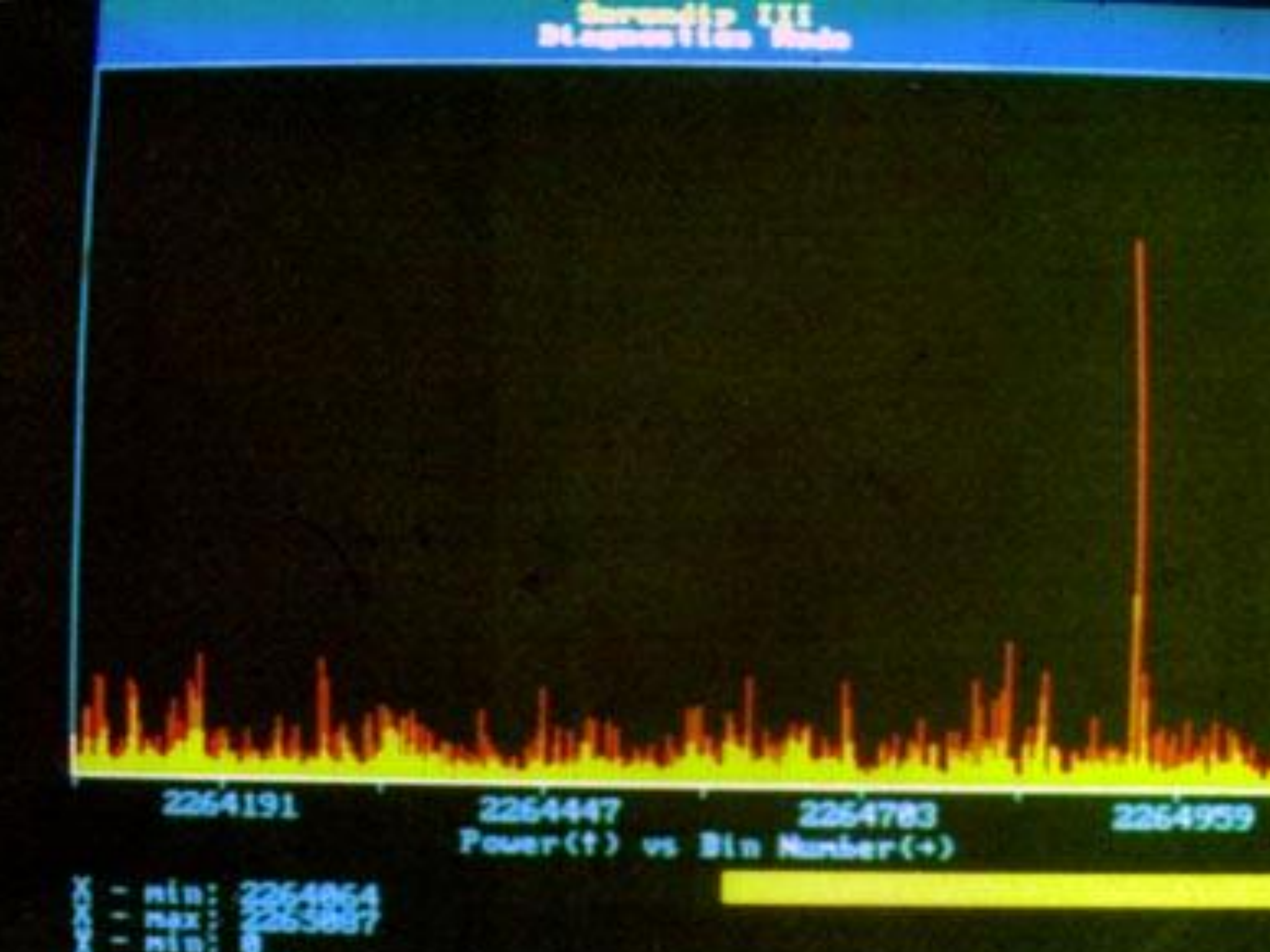


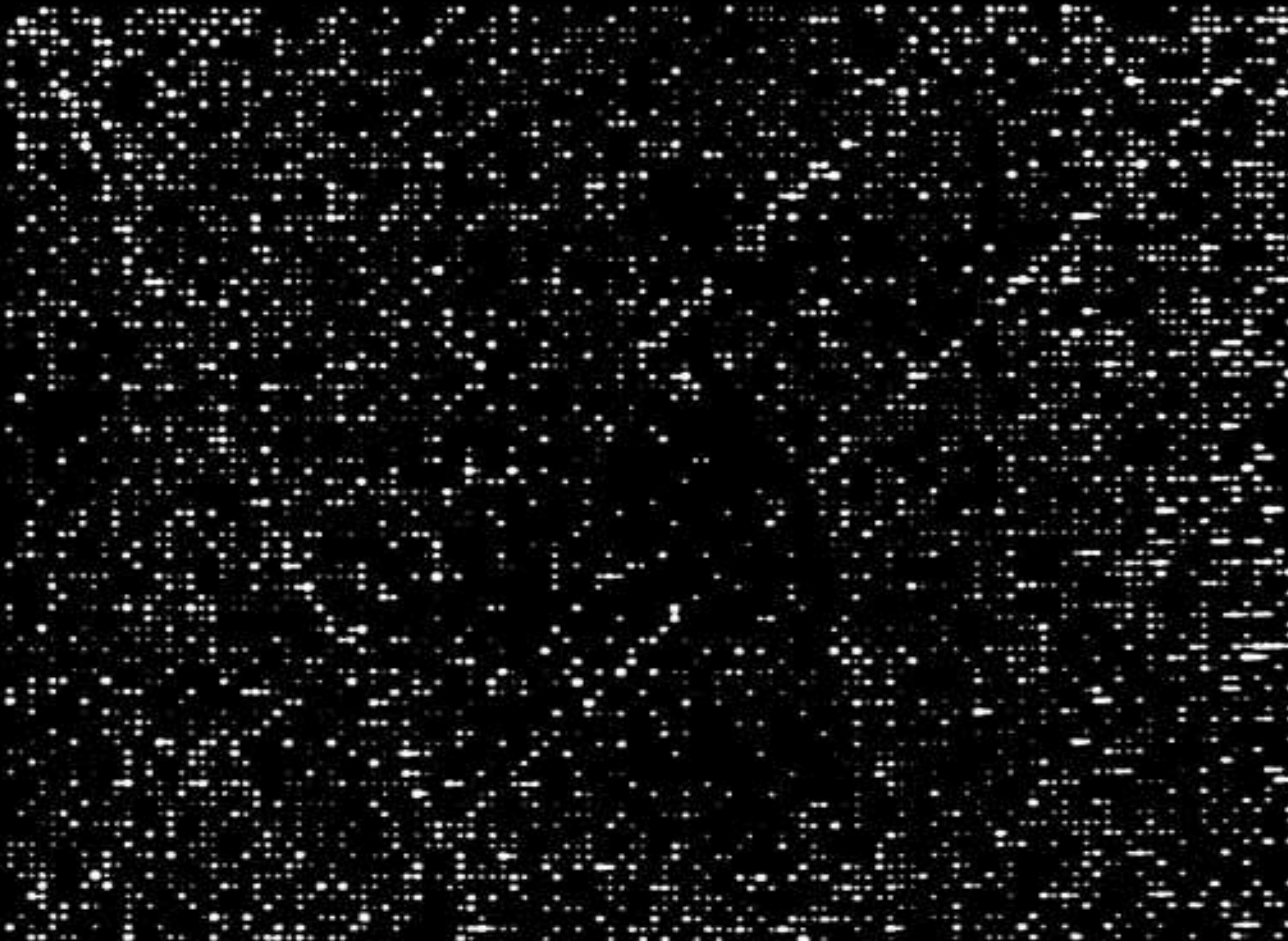
Fall 2015
Instrumentation development and
observation planning

January 2016
GBT Observations commence

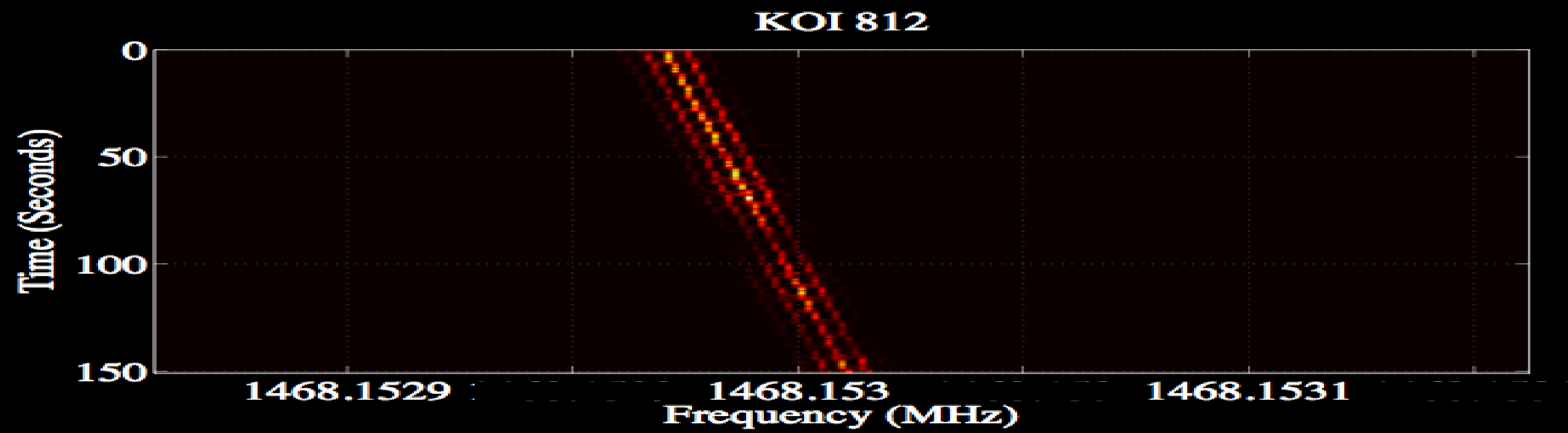
Early 2016
APF observations begin

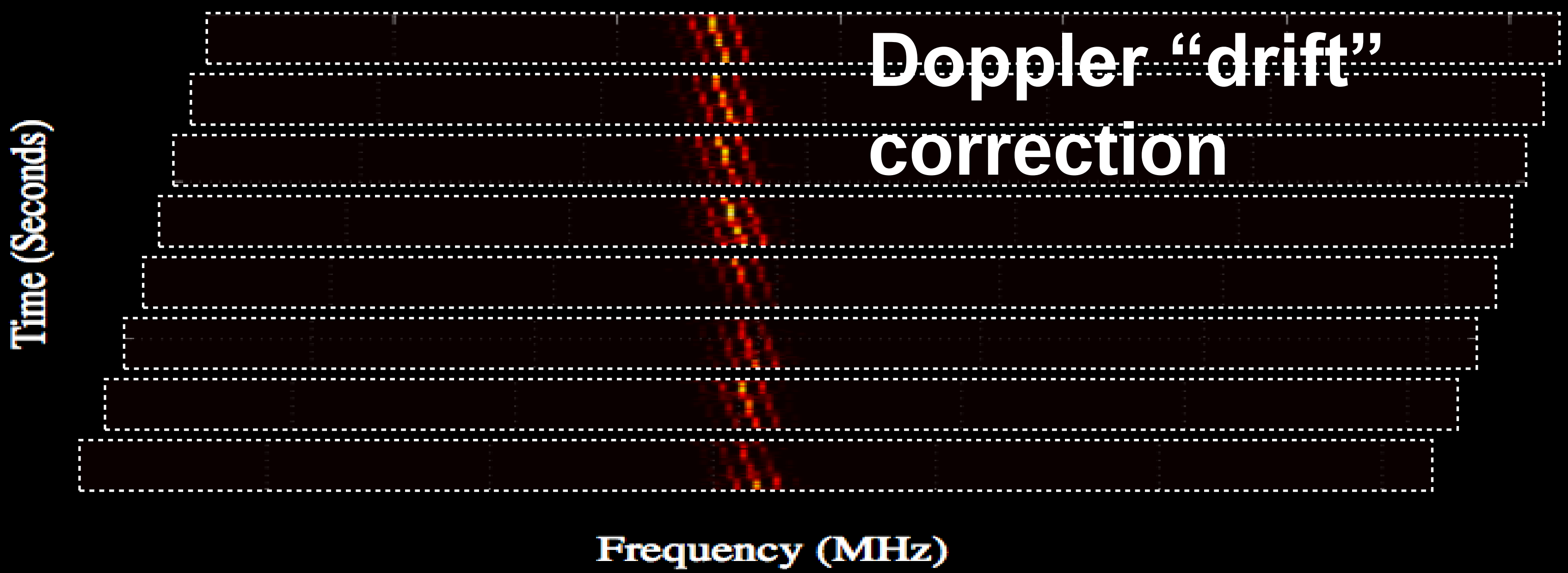
October 2016
Parkes observations begin

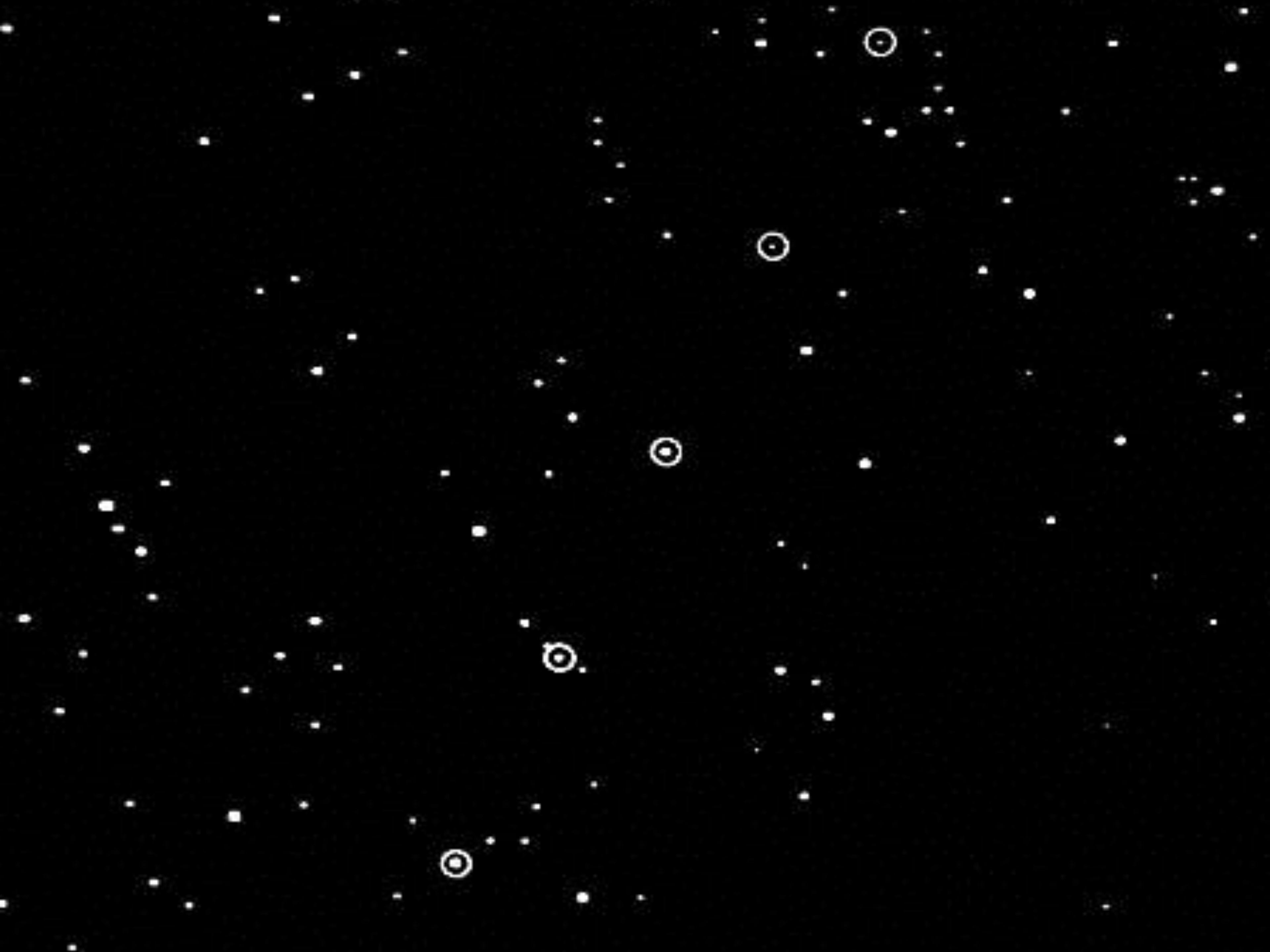

2264191
2264447
2264703
2264959
Power(↑) vs Bin Number(→)



NARROW-BAND SIGNAL DETECTION

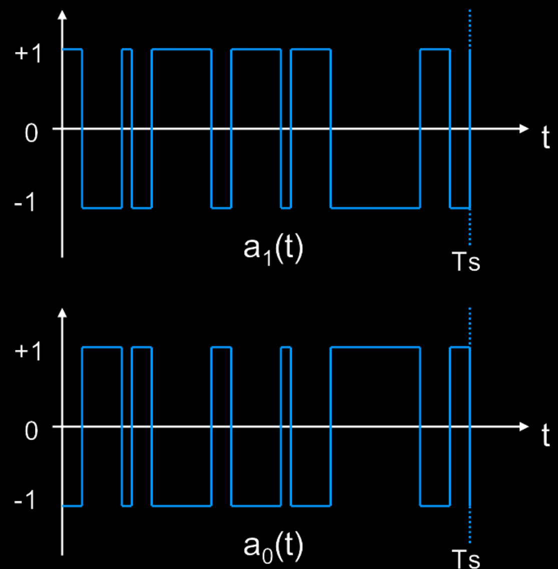




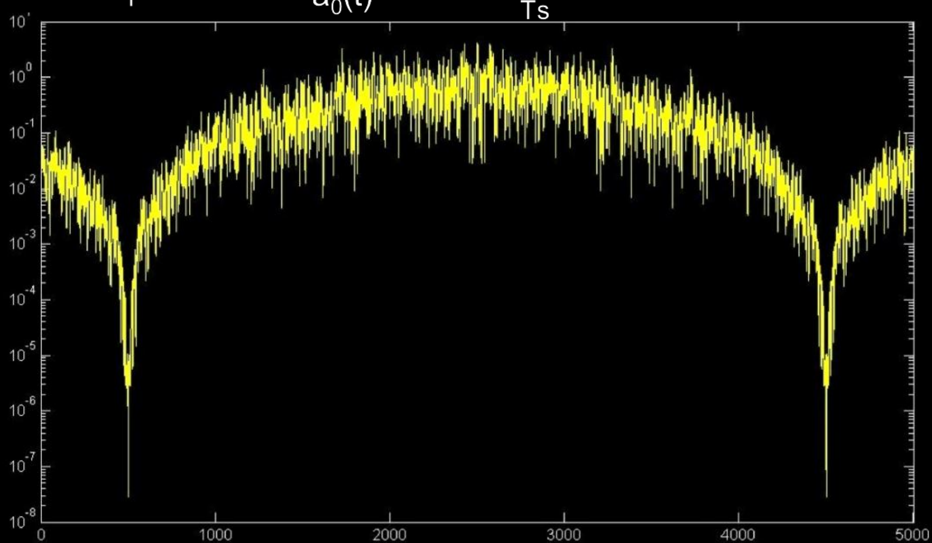


Broadband Emission

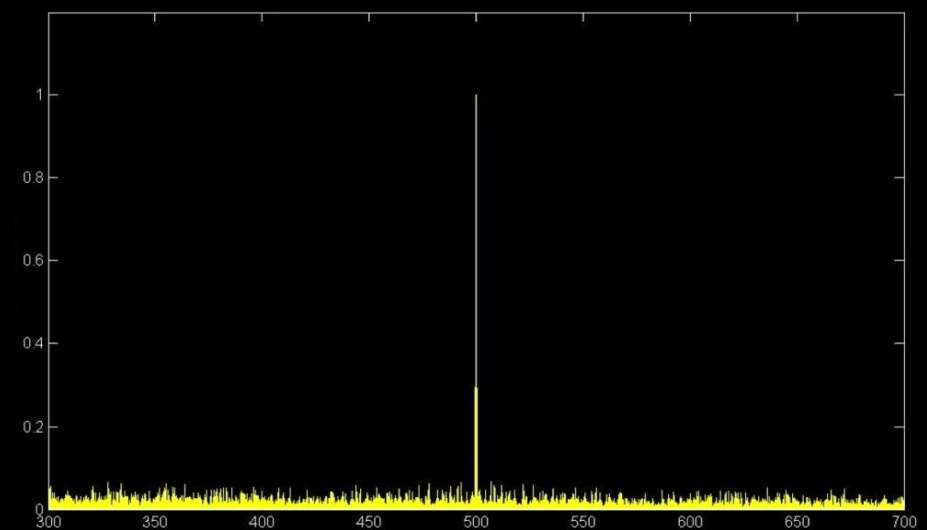
An example… Binary Phase Shift Keying (BPSK)



- **Modern radio communication largely broadband**
- **Wide bandwidths permit rich information content**



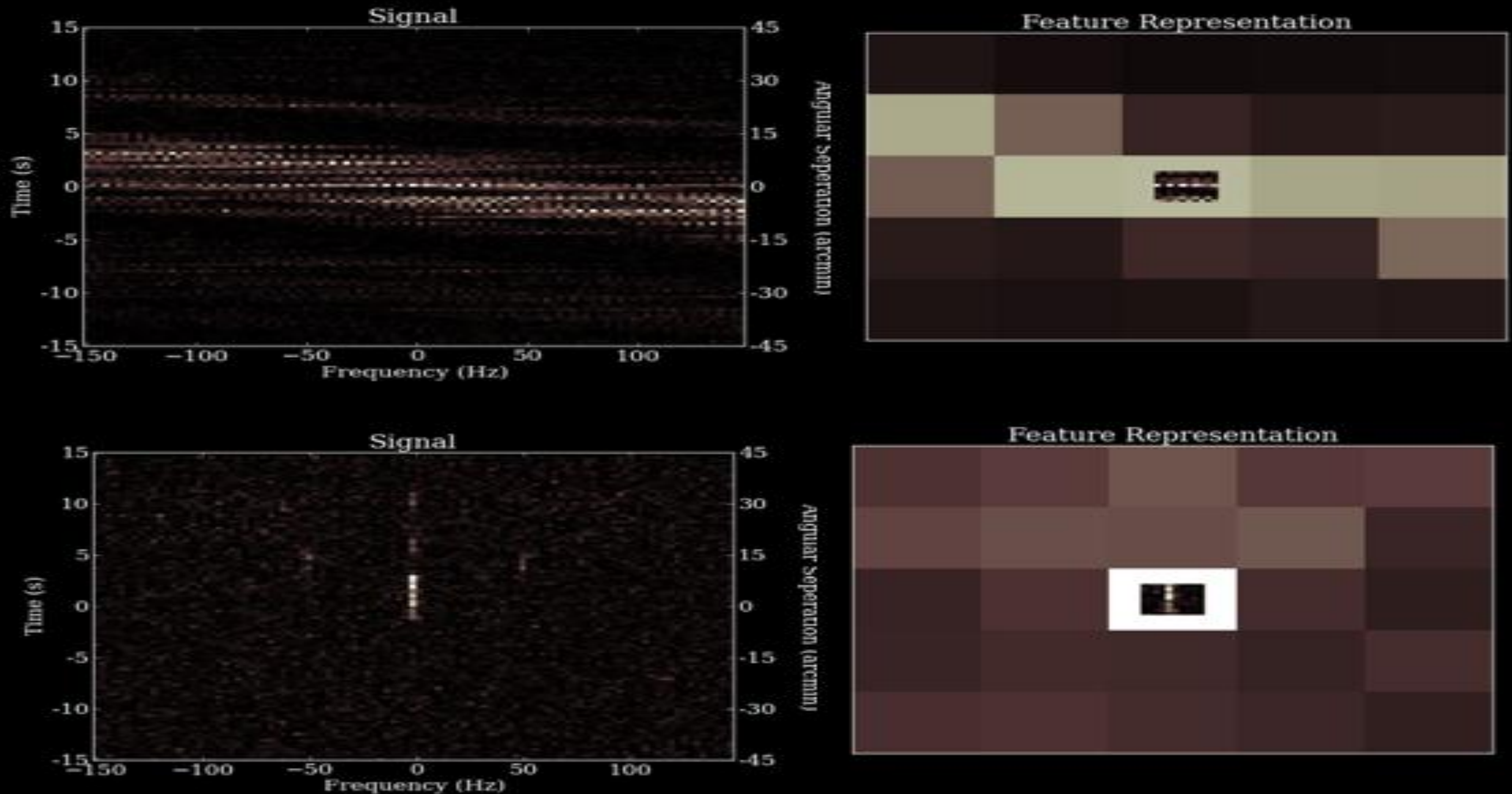
Power Spectrum

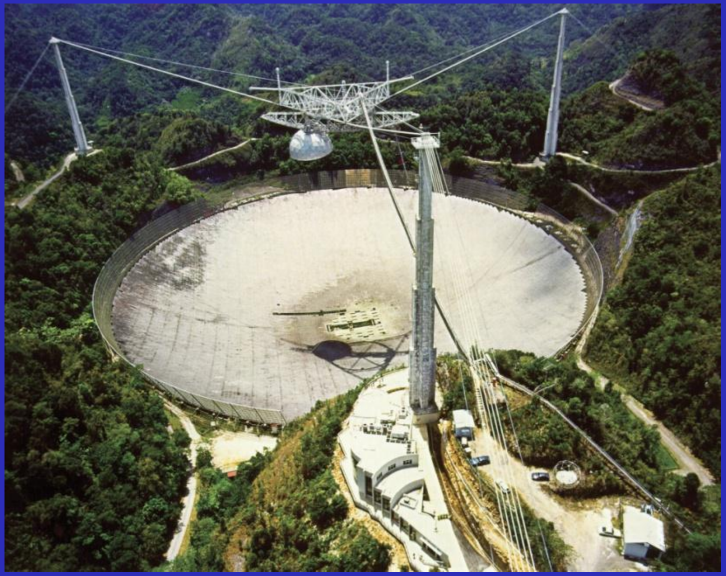


Auto Correlation

MACHINE LEARNING-BASED SEARCHES

- **Local Outlier Factor (LOF) ranking approach**
- **Find isolated signals in feature space**

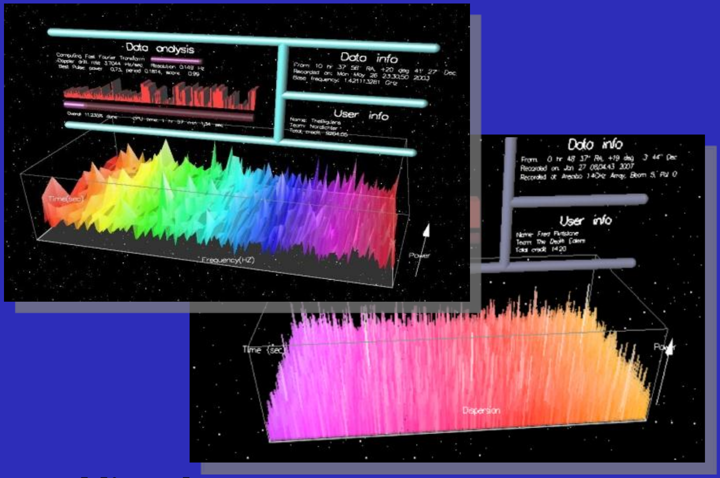




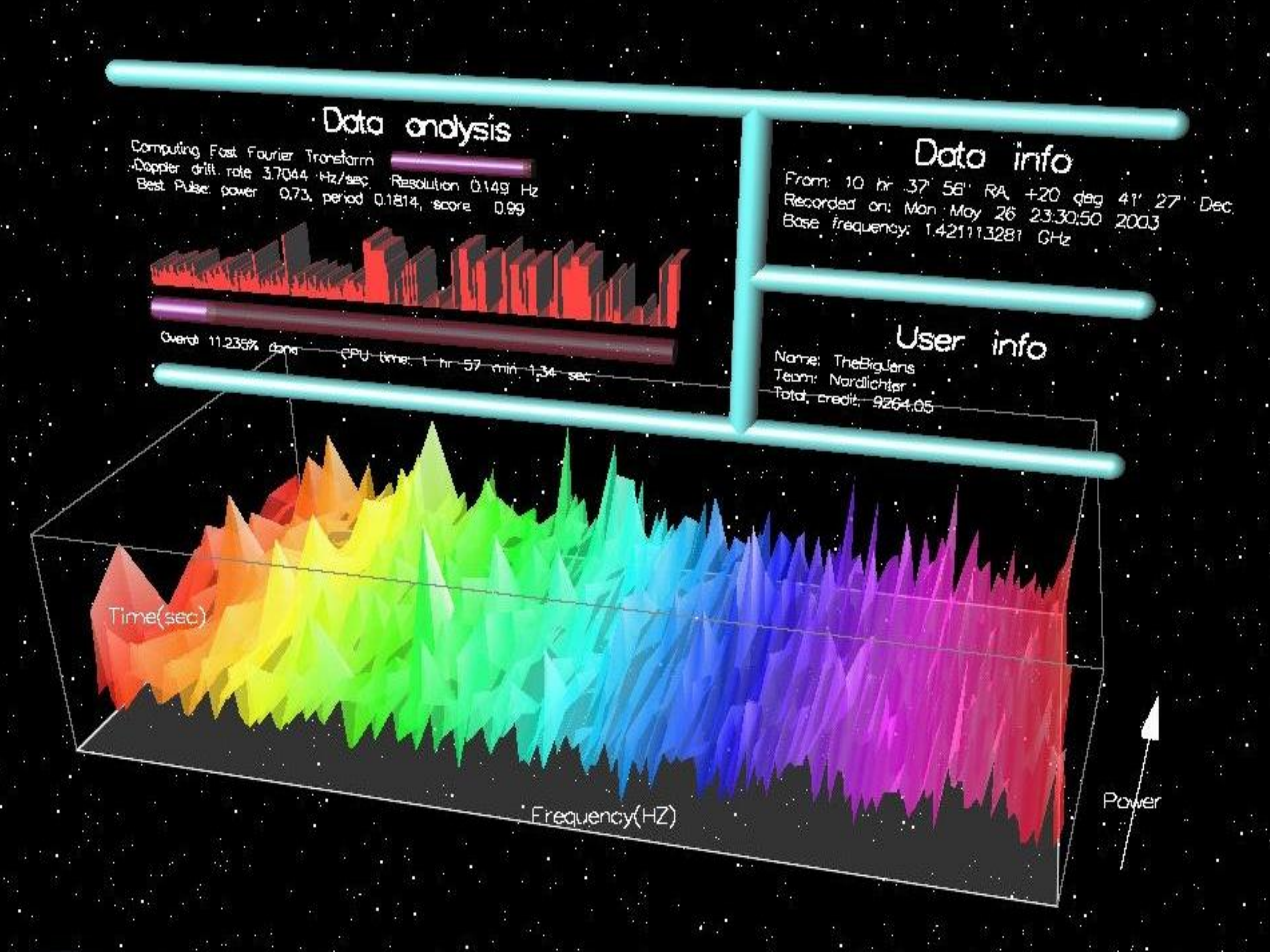
Arecibo Observatory

High performance data storage silo

UC Berkeley Space Sciences Lab



Public Volunteers


Data analysis
Computing Fast Fourier Transform
Doppler drift rate 3.7044 Hz/sec, Resolution 0.149 Hz
Best Pulse: power 0.73, period 0.1814, score 0.99
Overall 11.235% done
CPU time: 1 hr 57 min 1.34 sec
Data info
From: 10 hr 37' 56" RA, +20 deg 41' 27" Dec
Recorded on: Mon May 26 23:30:50 2003
Base frequency: 1.421113281 GHz
User info
Name: TheBigJens
Team: Nordlichter
Total credit: 9264.05
Time(sec)
Frequency(HZ)
Power

SETI@home Statistics

TOTAL	RATE
8,464,550 participants (in 226 countries)	2,000 per day
3 million years computer time	1,000 years per day
$3*10^{23}$ operations	1,000 Tera-flops

- Primary Schools
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Secondary Schools
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Junior Colleges
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Universities and Departments
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Small Companies (< 50 employees)
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Medium Companies (50-1000 employees)
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Large Companies (> 1000 employees)
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Clubs
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4
- Government Agencies
  - Top 200
  - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4

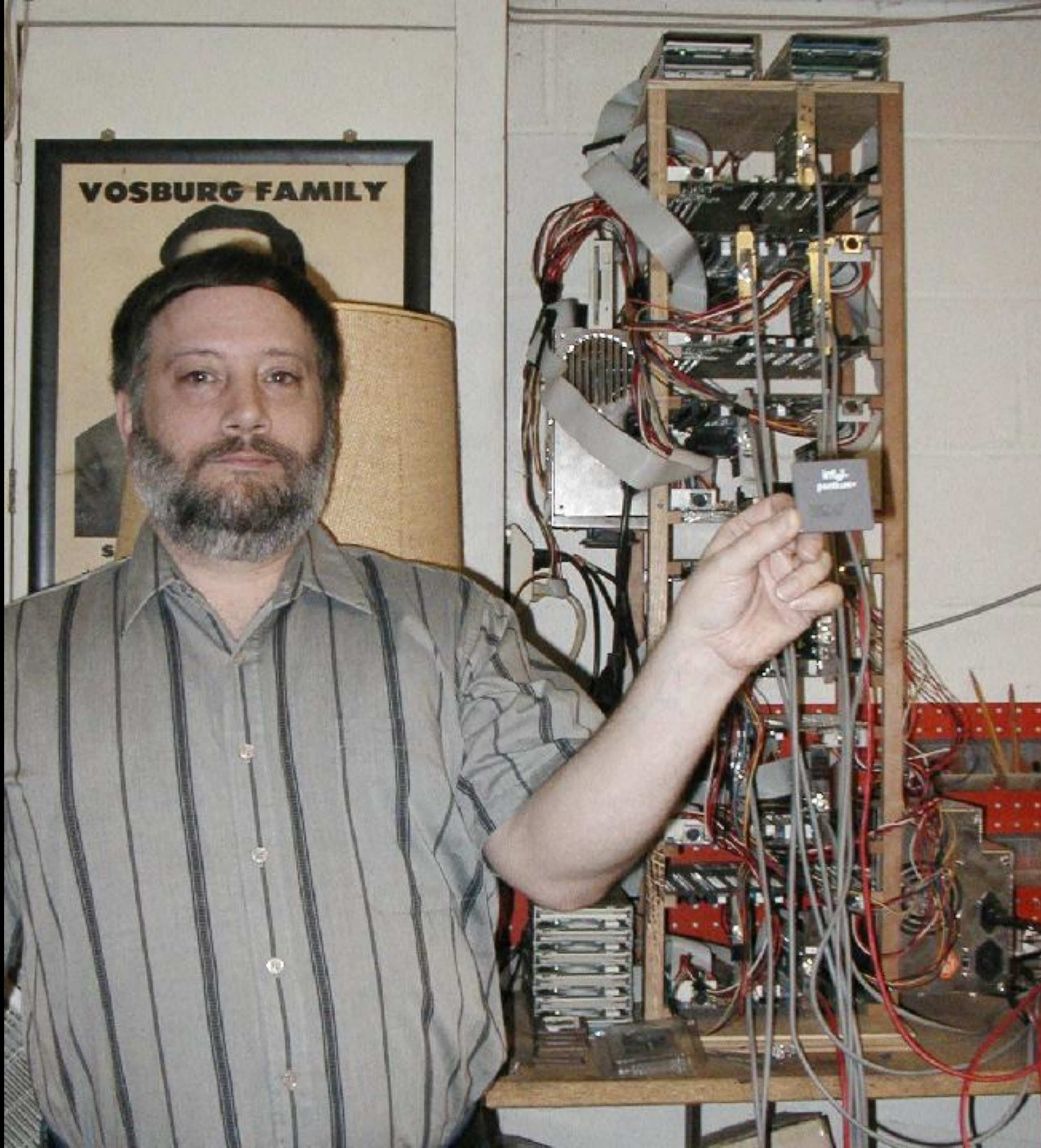
SETI@home

The Search for Extraterrestrial Intelligence

Large Company Teams

Last updated: Mon Apr 29 13:43:25 2002 UTC

Name	Members	Results received	Total CPU time	Average per w
1) Compaq Computer Corporation	790	3558699	3186.750 years	7 hr 50 m
2) Sun Microsystems	476	3332359	3466.458 years	9 hr 06 m
3) SGI SETI	390	3093165	2162.647 years	6 hr 07 m
4) IBM	1078	1675466	2844.529 years	14 hr 52
5) Microsoft	1208	1605938	2037.371 years	11 hr 06
6) Intel® Corporation	475	1595846	1388.653 years	7 hr 37 m
7) Hewlett-Packard	610	1265982	1764.556 years	12 hr 12
8) Apple Computer, Inc.	714	841045	1381.364 years	14 hr 23


VOSBURG FAMILY

Web site: 2 million hits/day

200,000 visitors/day

(stats & games popular; science less popular)

100,000 children, families

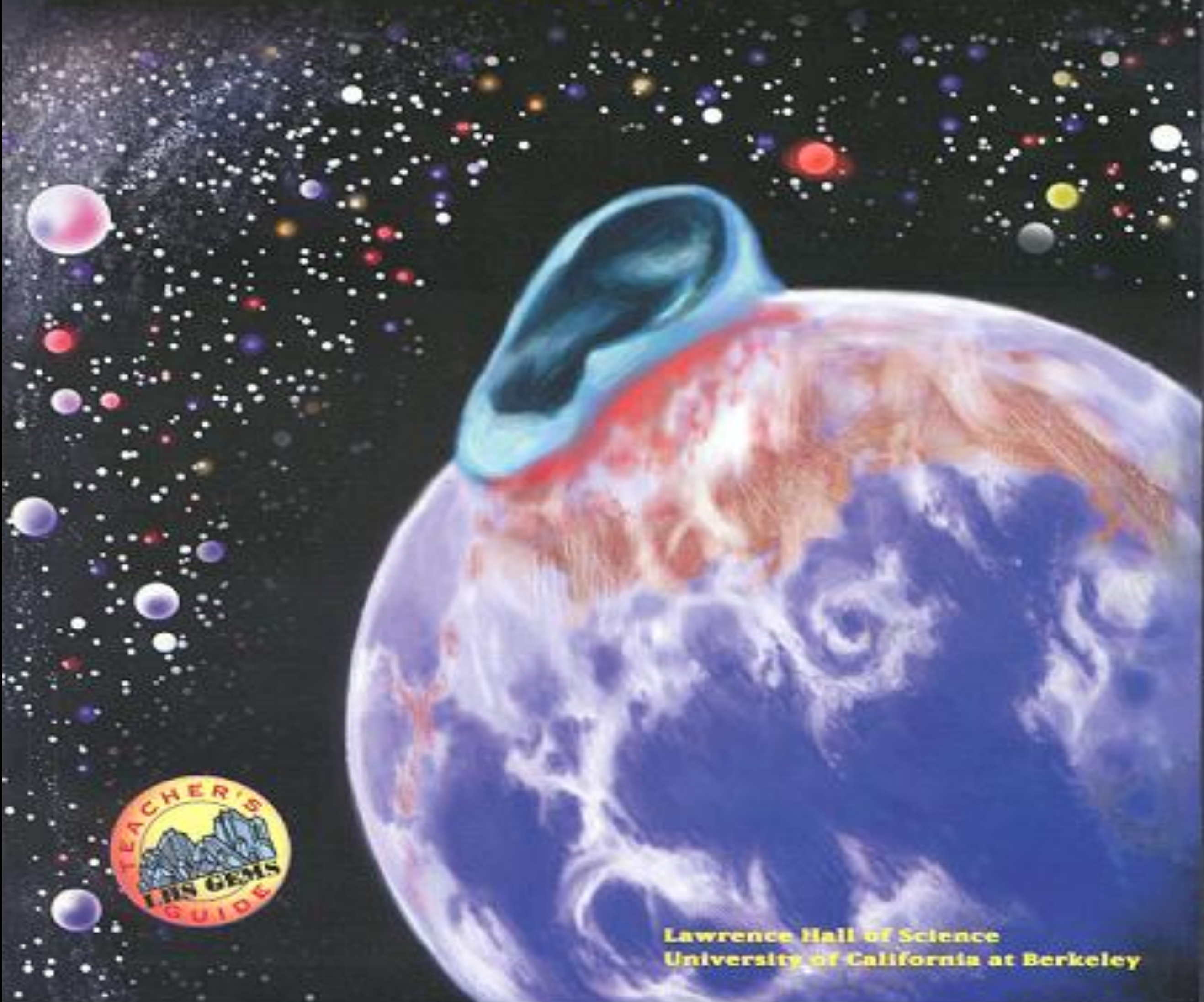
(including congress members and their kids)

> 7,000 schools

Messages from Space:

The Solar System and Beyond

Grades 5–8



Lawrence Hall of Science
University of California at Berkeley

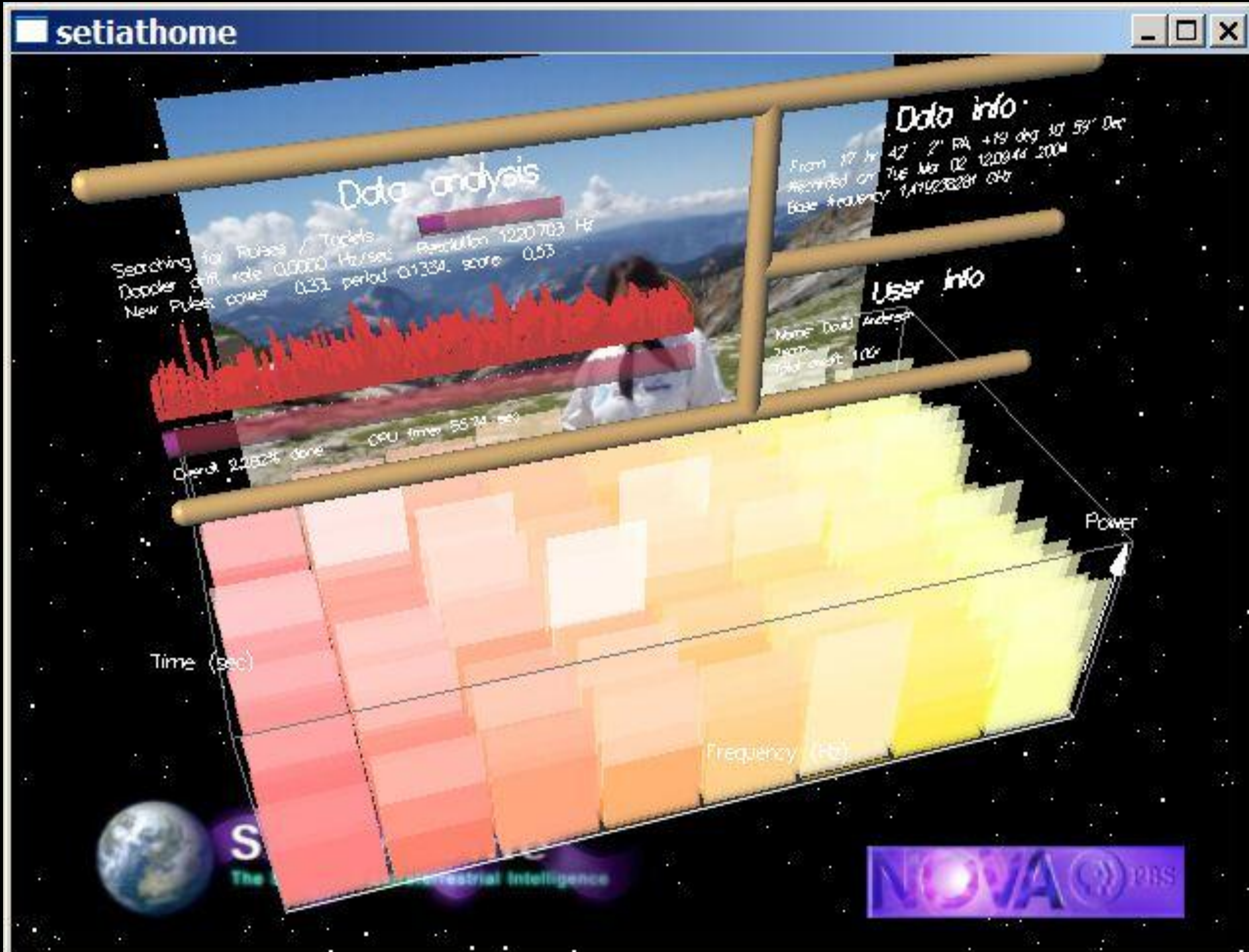
Public Participation Scientific Supercomputing

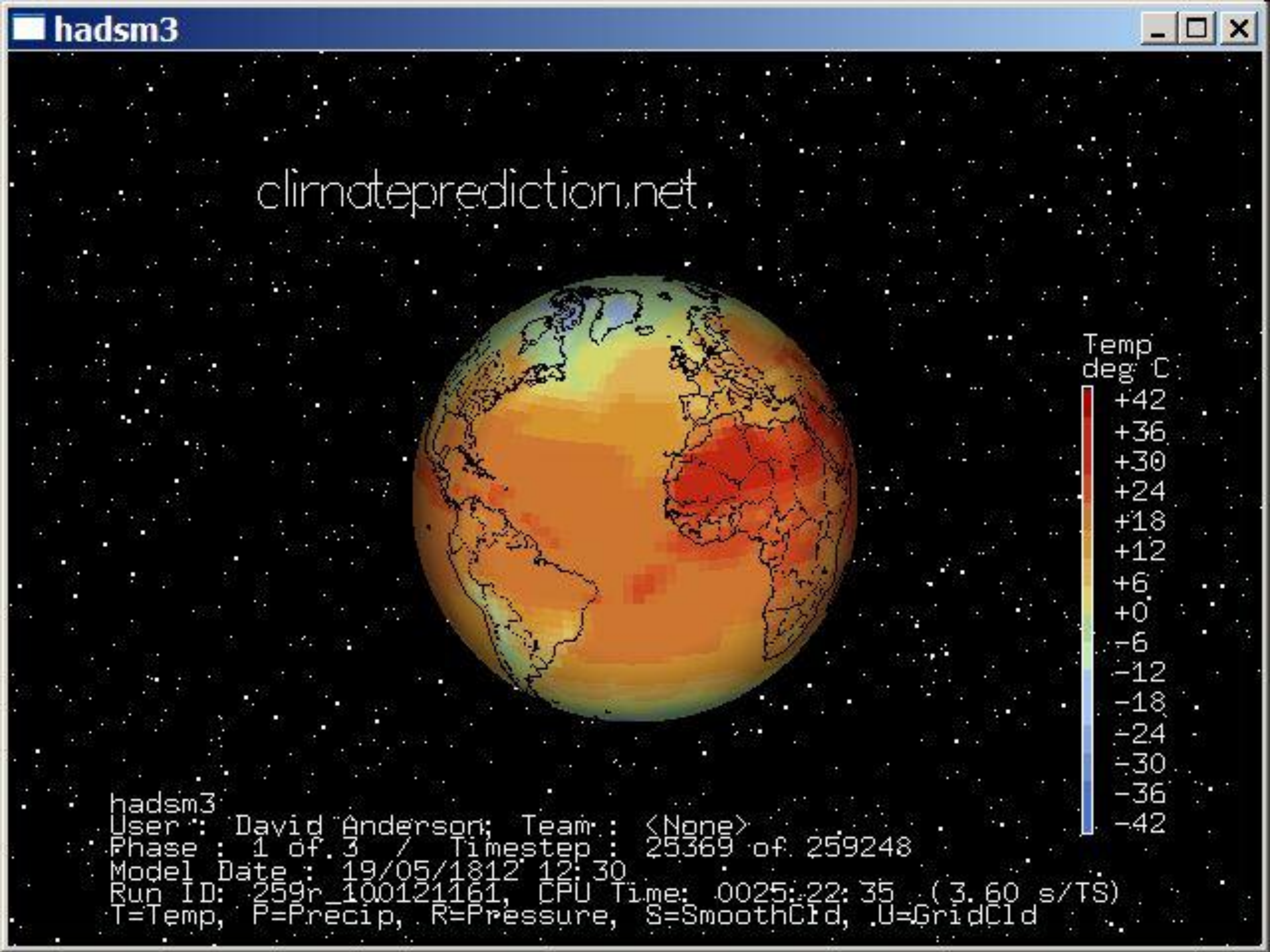
aka “Distributed Computing”

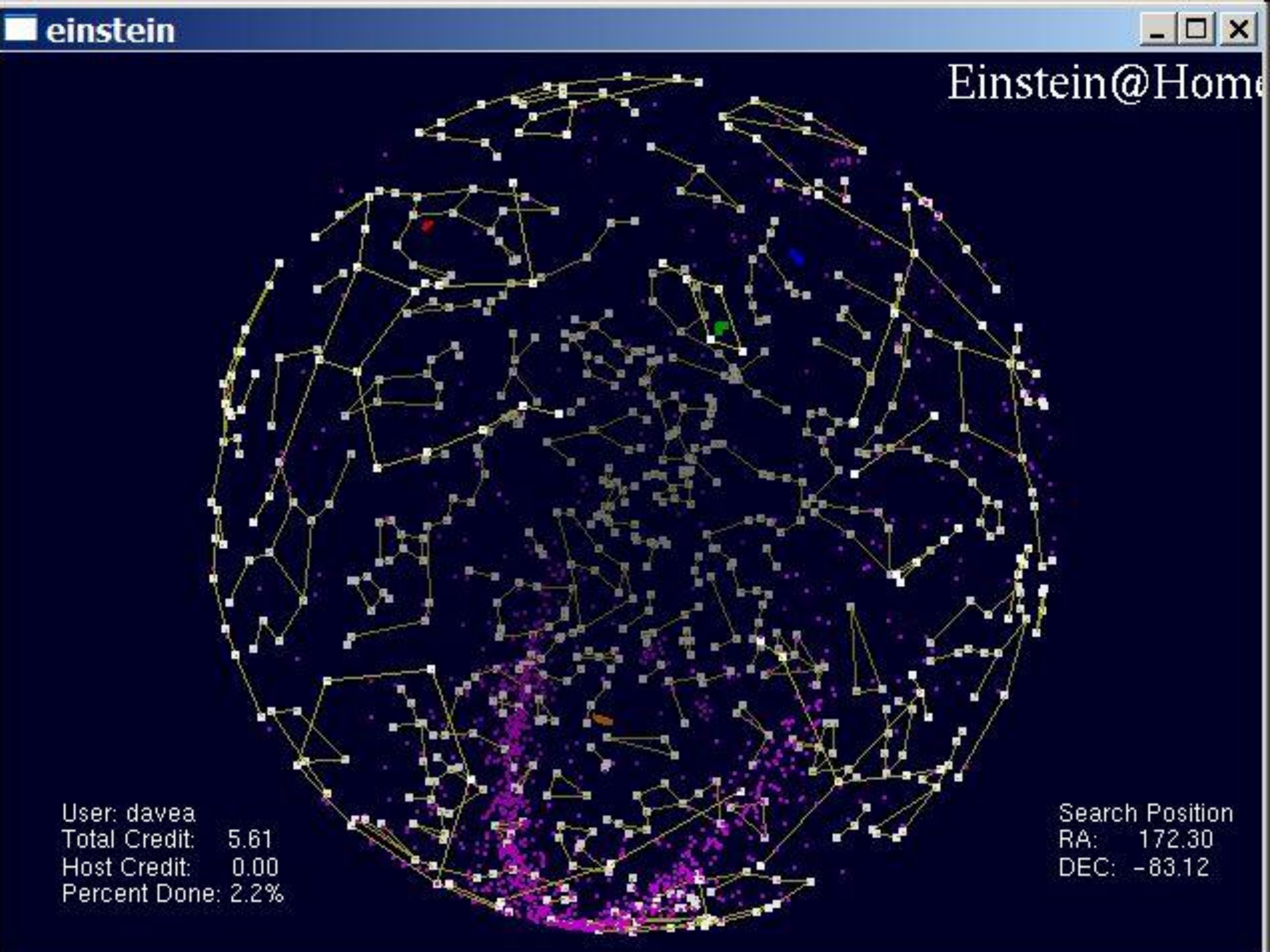
aka “edge resource aggregation”

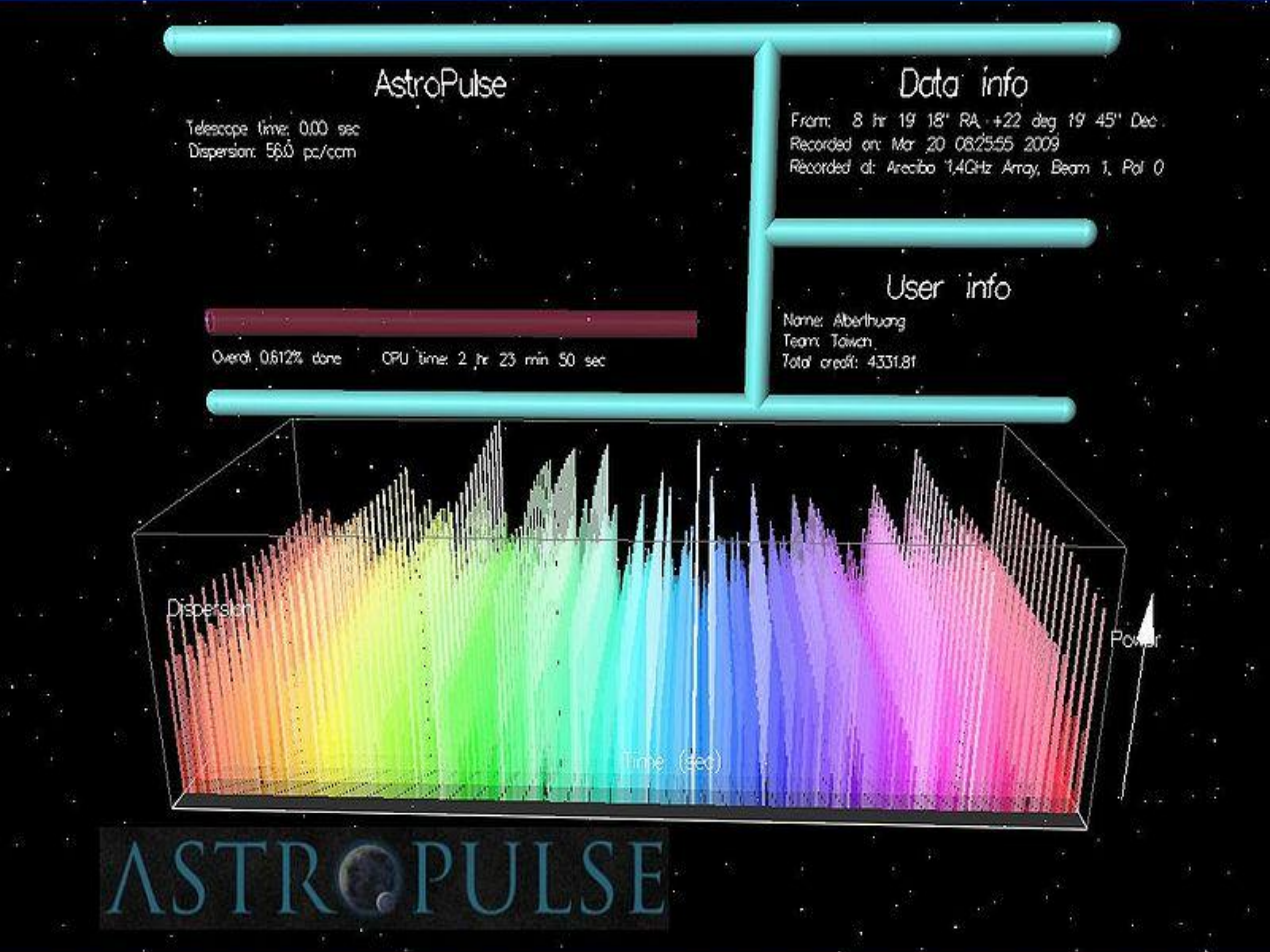
Projects

- Astronomy
  - SETI@home (Berkeley)
  - Astropulse (Berkeley)
  - Einstein@home: gravitational pulsar search (Caltech,…)
  - PlanetQuest (SETI Institute)
  - Stardust@home (Berkeley, Univ. Washinton,…)
- Earth science
  - Climateprediction.net (Oxford)
- Biology/Medicine
  - Folding@home, Predictor@home (Stanford, Scripts)
  - FightAIDSathome: virtual drug discovery
- Physics
  - LHC@home (Cern)
- Other
  - Web indexing/search
  - Internet Resource mapping (UC Berkeley)

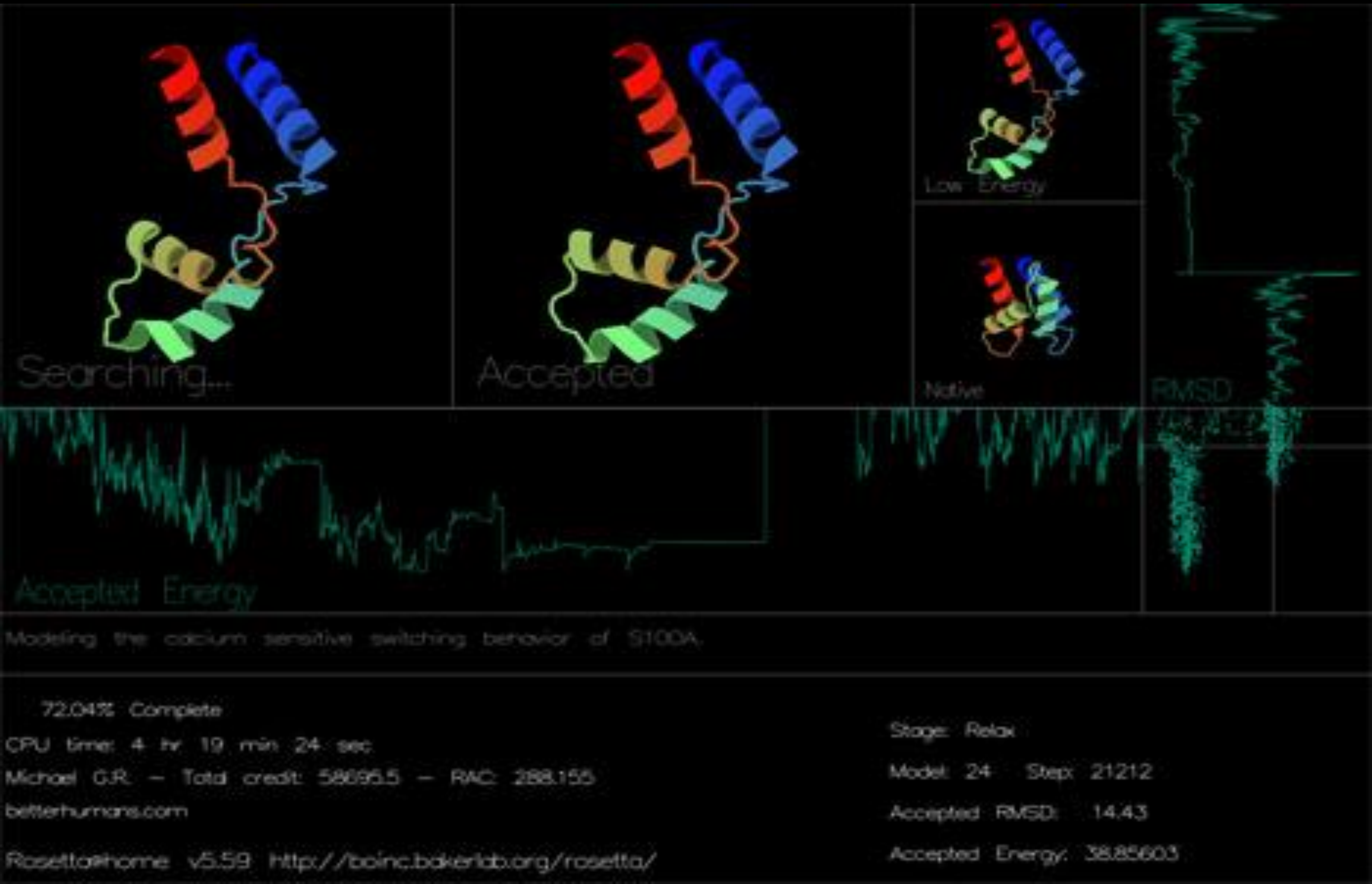

setiathome
Data analysis
Searching for Pulses / Triplets
Resolution 1220.703 Hz
New Pulses power
Data info
User info
Time (sec)
Frequency (Hz)
Power


hadsm3
climateprediction.net
Temp
deg C
+42
+36
+30
+24
+18
+12
+6
+0
-6
-12
-18
-24
-30
-36
-42
hadsm3
User : David Anderson; Team : <None>
Phase : 1 of 3 / Timestep : 25369 of 259248
Model Date : 19/05/1812 12:30
Run ID: 259r_100121161, CPU Time: 0025:22:35 (3.60 s/TS)
T=Temp, P=Precip, R=Pressure, S=SmoothCld, U=GridCld

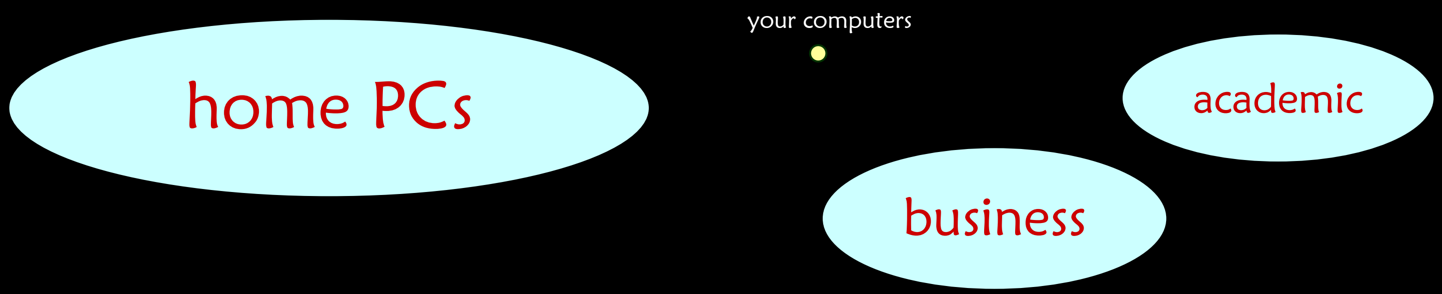

einstein
Einstein@Home
User: davea
Total Credit: 5.61
Host Credit: 0.00
Percent Done: 2.2%
Search Position
RA: 172.30
DEC: -83.12


AstroPulse
Telescope time: 0.00 sec
Dispersion: 56.0 pc/ccm
Overall 0.612% done
CPU time: 2 hr 23 min 50 sec
Data info
From: 8 hr 19' 18" RA, +22 deg 19' 45" Dec
Recorded on: Mar 20 08:25:55 2009
Recorded at: Arecibo 1.4GHz Array, Beam 1, Pol 0
User info
Name: Alberthuang
Team: Taiwan
Total credit: 4331.81
Dispersion
Time (sec)
Power
ASTROPULSE

Rosetta Screensaver



Where's the computing power?



2010: 1 billion Internet-connected PCs

55% privately owned

If 100M participate:

- 100 PetaFLOPs, 1 Exabyte (10^18) storage

Thinking@Home

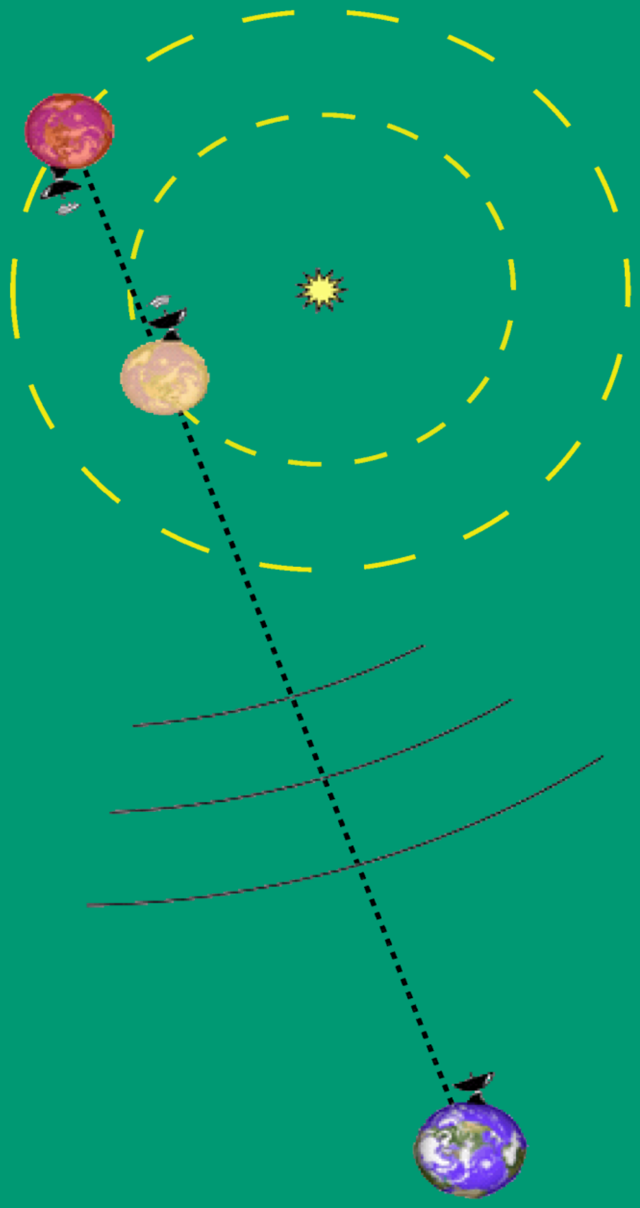
Stardust@home...

Stardust (NASA)

Citizen Science Projects

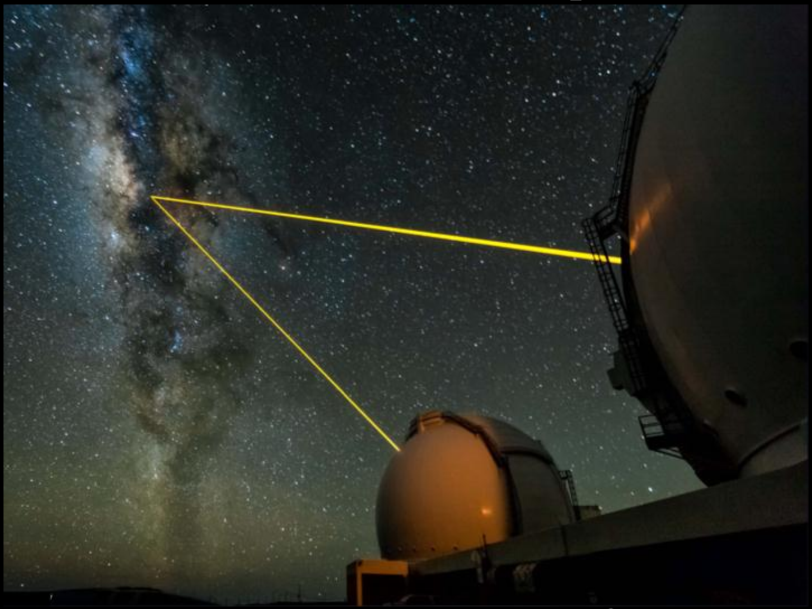
- SETI@home and Astropulse (UC Berkeley)
- Stardust@home (UC Berkeley)
- SetiQuest (Seti Institute)
- Galaxy Zoo (Galaxy Classification)
- Audubon Society's Christmas Bird Count (1900)
- Community Collaborative Rain, Hail & Snow Monitor Network
- Clickworkers (mars crater identficiation - NASA)
- Ebird, NestWatch, FeederWatch, Urban Birds (Cornell Univ.)
- ParkScan (monitor San Francisco Parks)
- ScienceForCitizens.net
- ENERGY@home

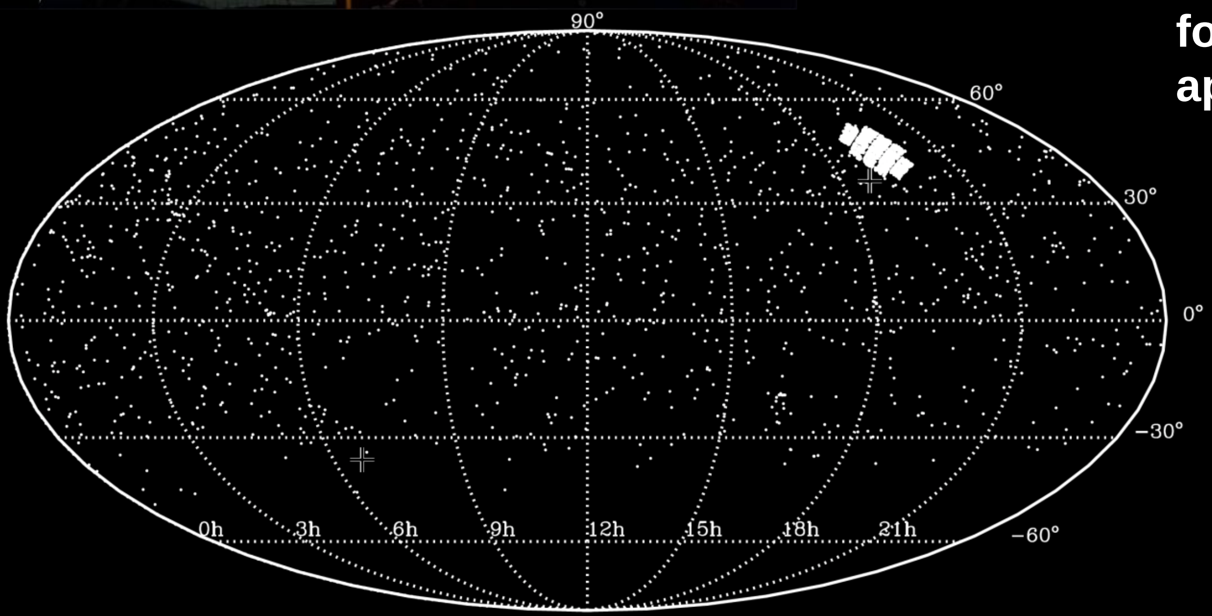
Interplanetary evesdropping



- Kepler has found numerous multiple planet systems
- When planets are in conjunction with Earth the more distant planet is beaming its signals at us, giving us an opportunity to catch spillover.
- Given the number of exoplanet systems, these conjunctions are frequent
- 5-10 minute obs (per band)
  - 1.1-1.9 GHz
  - 1.8-3.0 GHz
  - 7.8-11.0 GHz
- total of about 30 hours thus far

A Search for Optical Laser Emission Using Keck Telescope HIRES Spectrometer





- Survey of 2796 stars for narrow emission lines from artificial lasers.
- No detections of lasers brighter than 1000W focused with a 10m aperture

Infrared Spatial Interferometer
heterodyne detection at 27 THz w/ CO_2 laser LOs

Mt. Wilson, CA

3 telescope system 4,8,12m early 2006

Currently ~35m triangular baselines

SETI SPIN OFFS

CASPER

Collaboration for Radio Astronomy Signal Processing and Electronics Research

Collaborators

Xilinx, Intel, Fujitsu, HP, Sun/Oracle, Nvidia, NSF, NASA, NRAO, NAIC, CFA (Havard/Smithsonian), Haystack (MIT), Caltech, Cornell, CSIRO/ATNF, JPL/DSN, South Africa KAT, Manchester/Jodrell Bank, GMRT (India), Oxford, Bologna, Metsahovi Observatory/Helsinki University, University of California, Berkeley; Swinburne University (Australia), Seti Institute, University of California, Santa Barbara; University of California, Los Angeles; CNRS (France), University of Maryland Nancay Observatory, Univerity of Cape Town (South Africa), ASTRON (Netherlands), Academica Sinica (Taiwan), Cambridge, Brigham Young University, Rhodes University (South Africa)

Diamond Planet: Matthew Bailes et al

4 September 2008 | www.nature.com/nature | £10

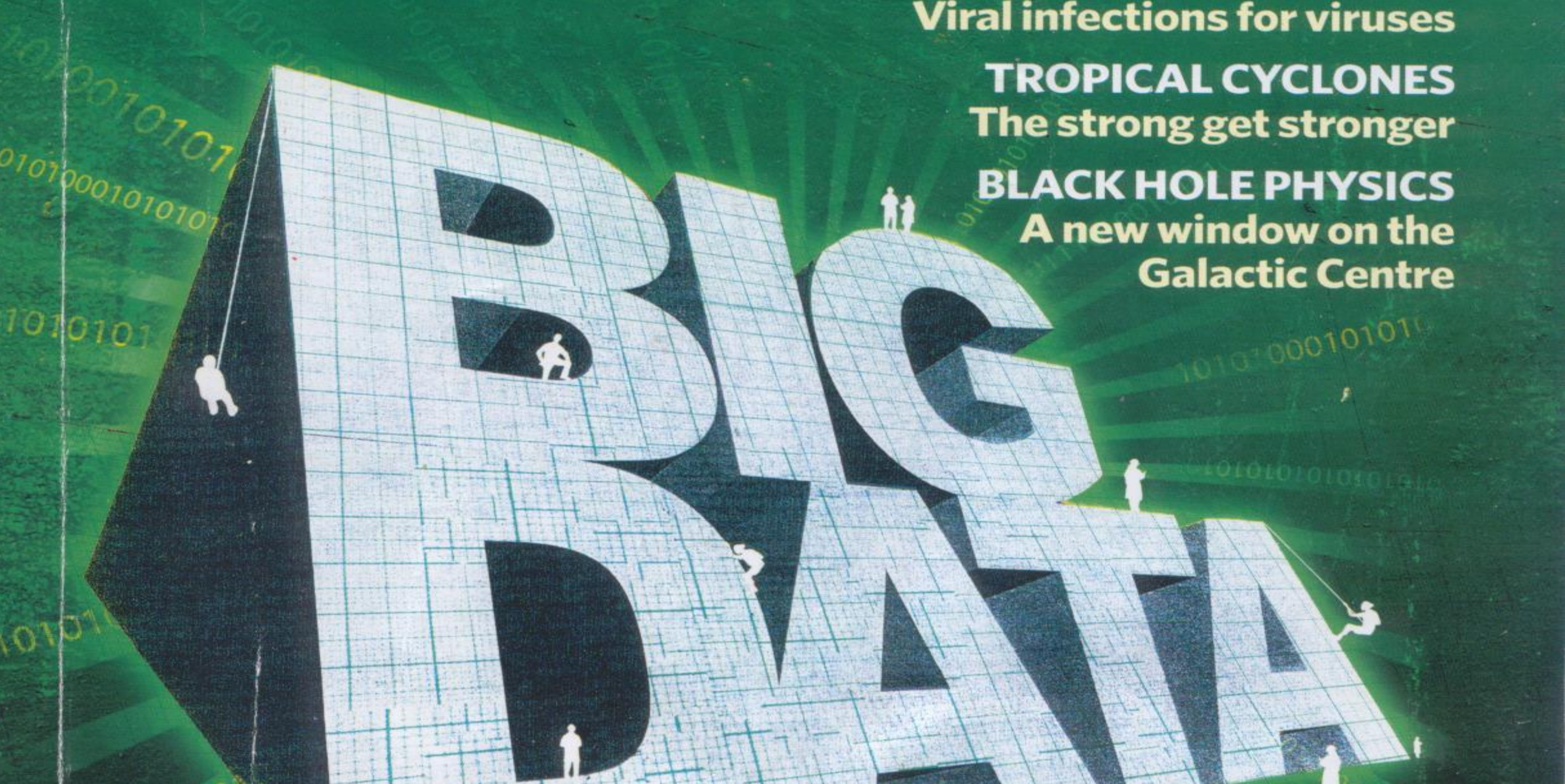
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

nature

THE BITER BIT
Viral infections for viruses

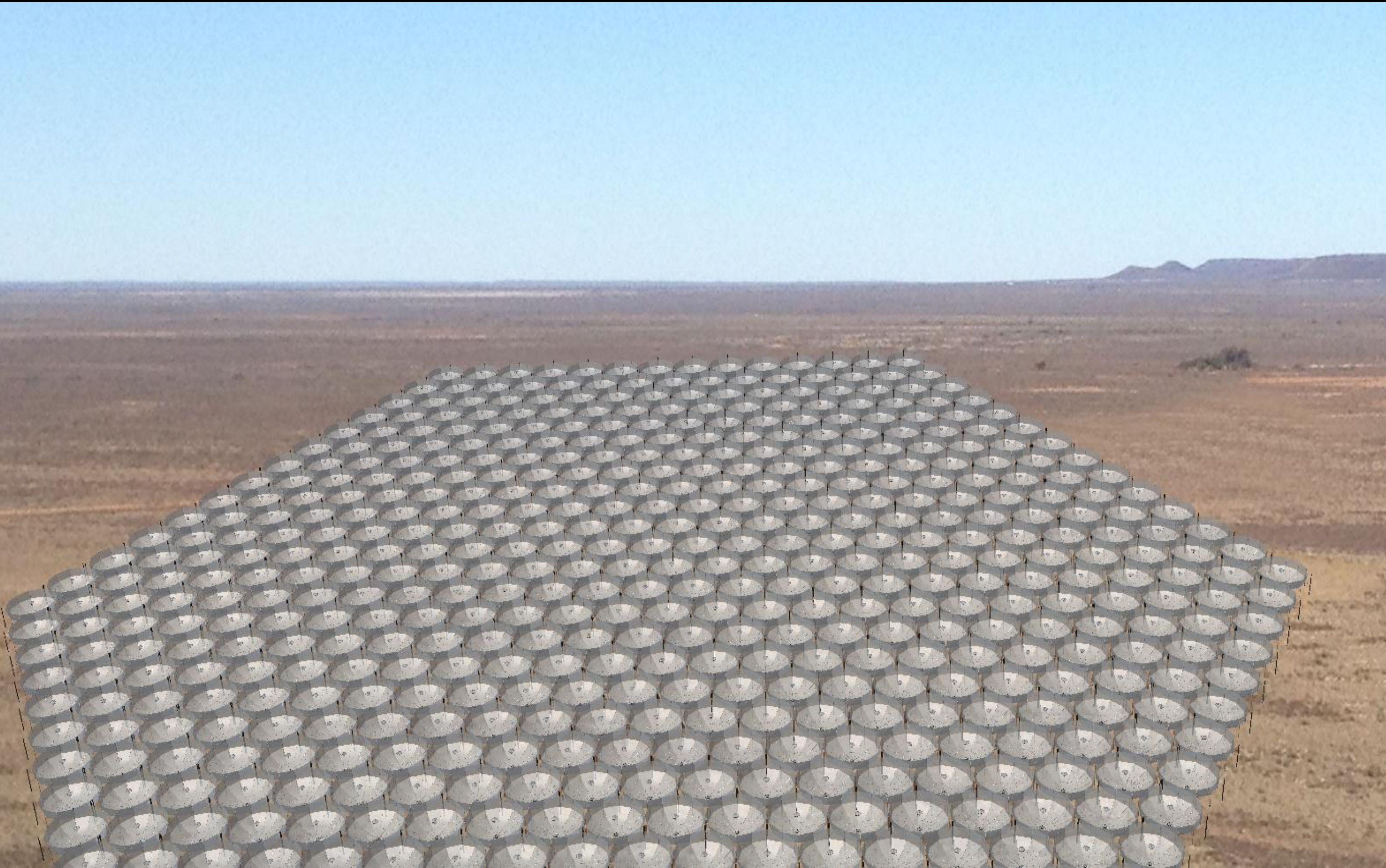
TROPICAL CYCLONES
The strong get stronger

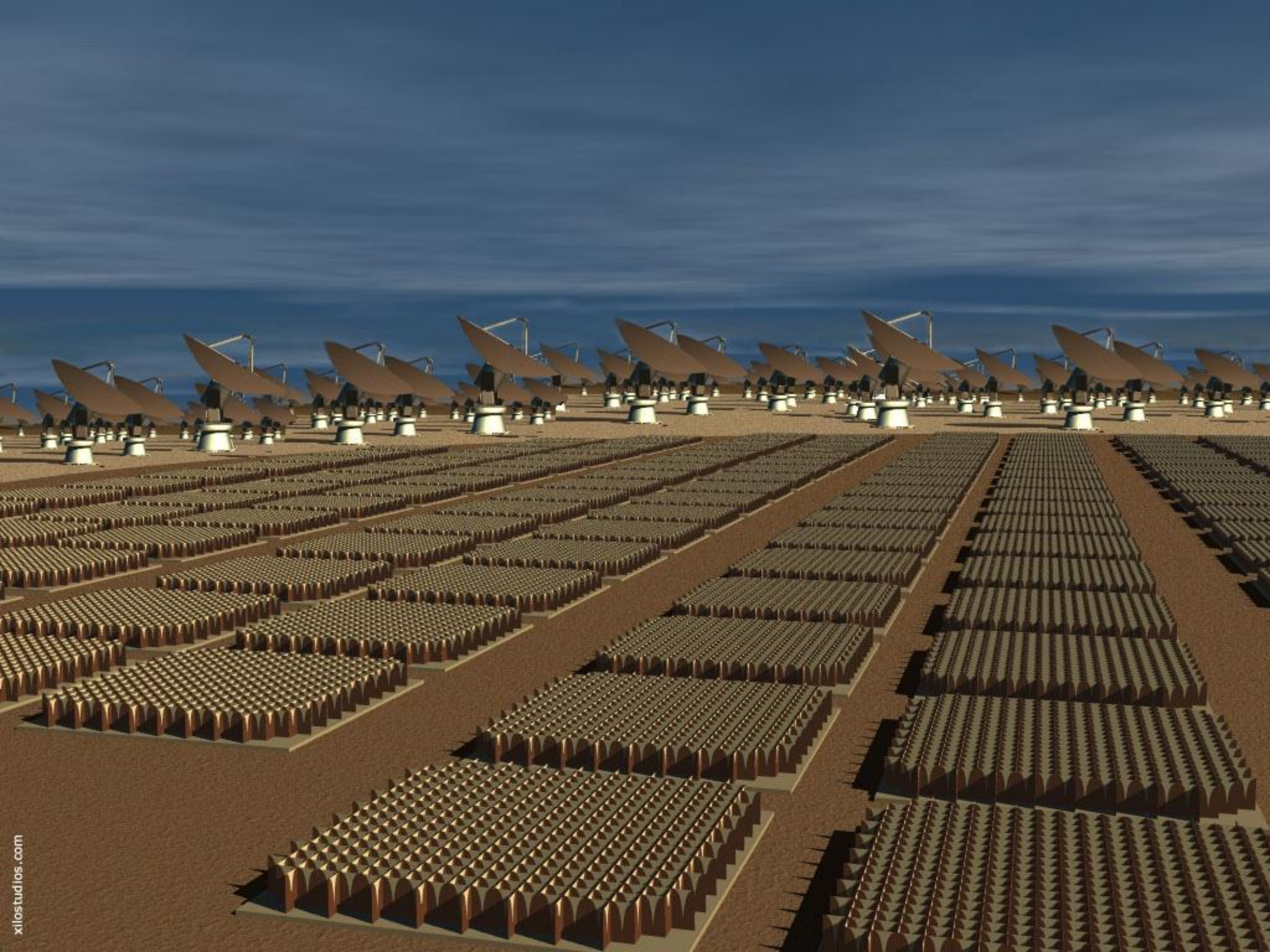
BLACK HOLE PHYSICS
A new window on the Galactic Centre

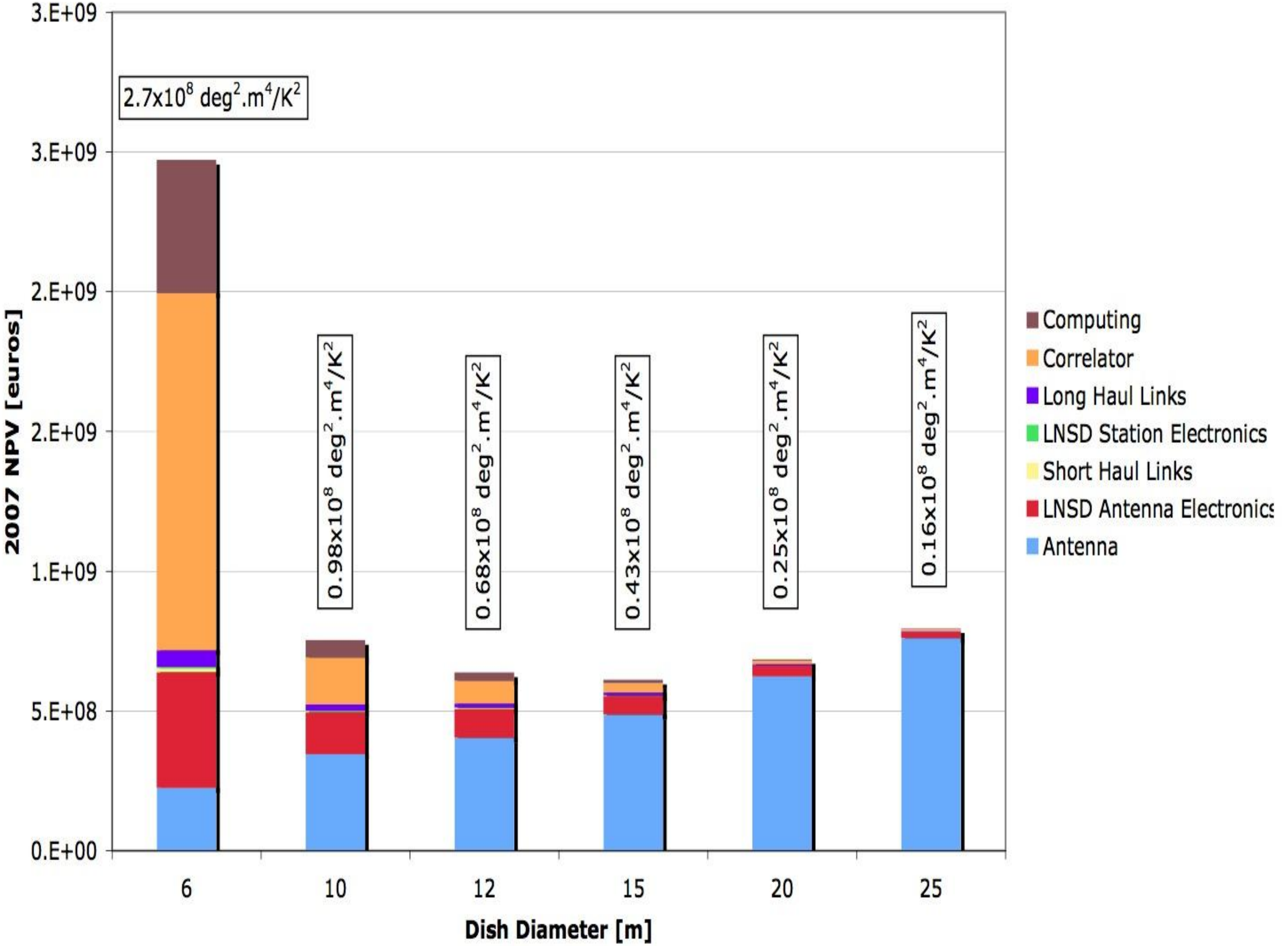


FAST 500 meter telescope

HERA Array   352 x 14 meter dishes

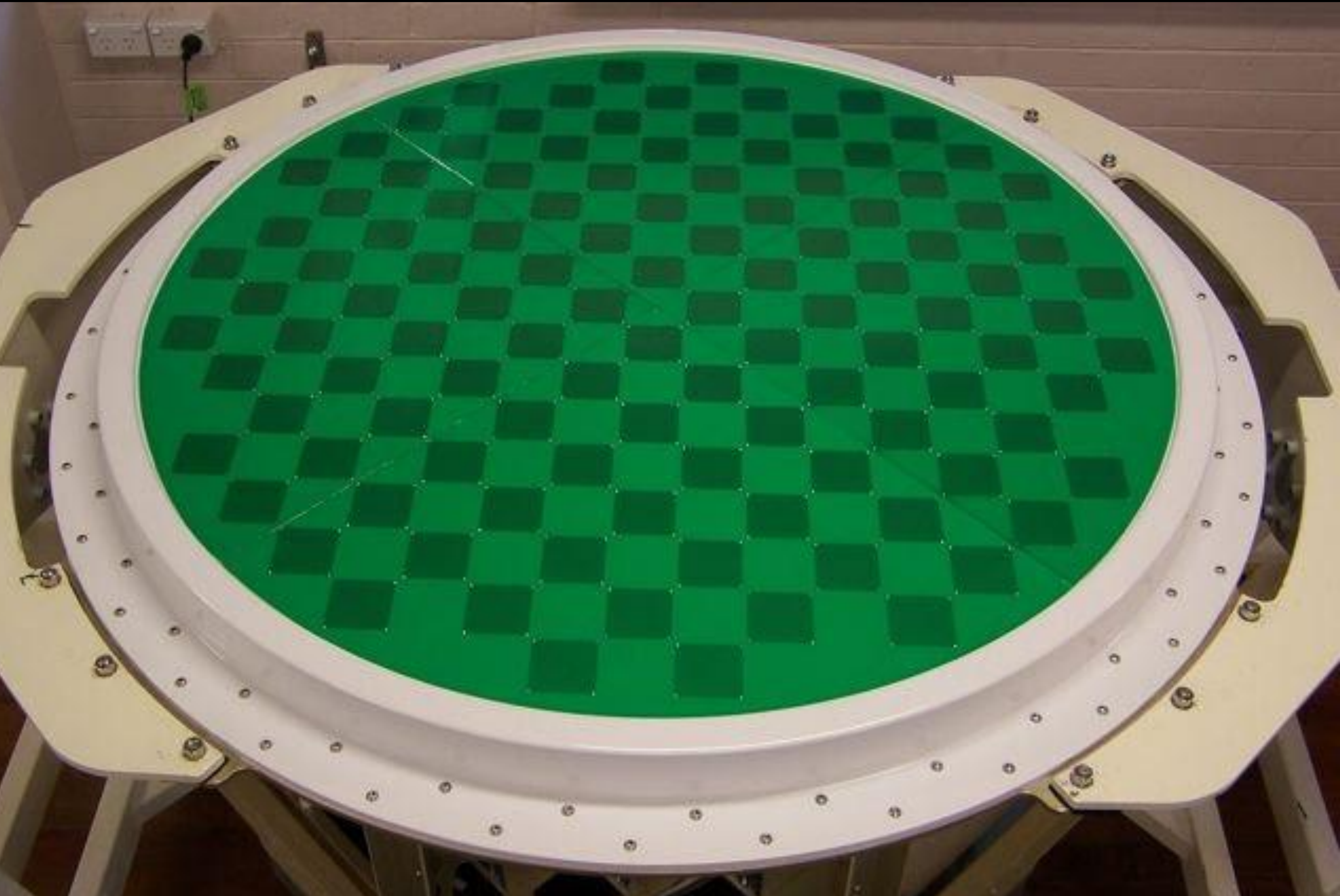



xilostudios.com

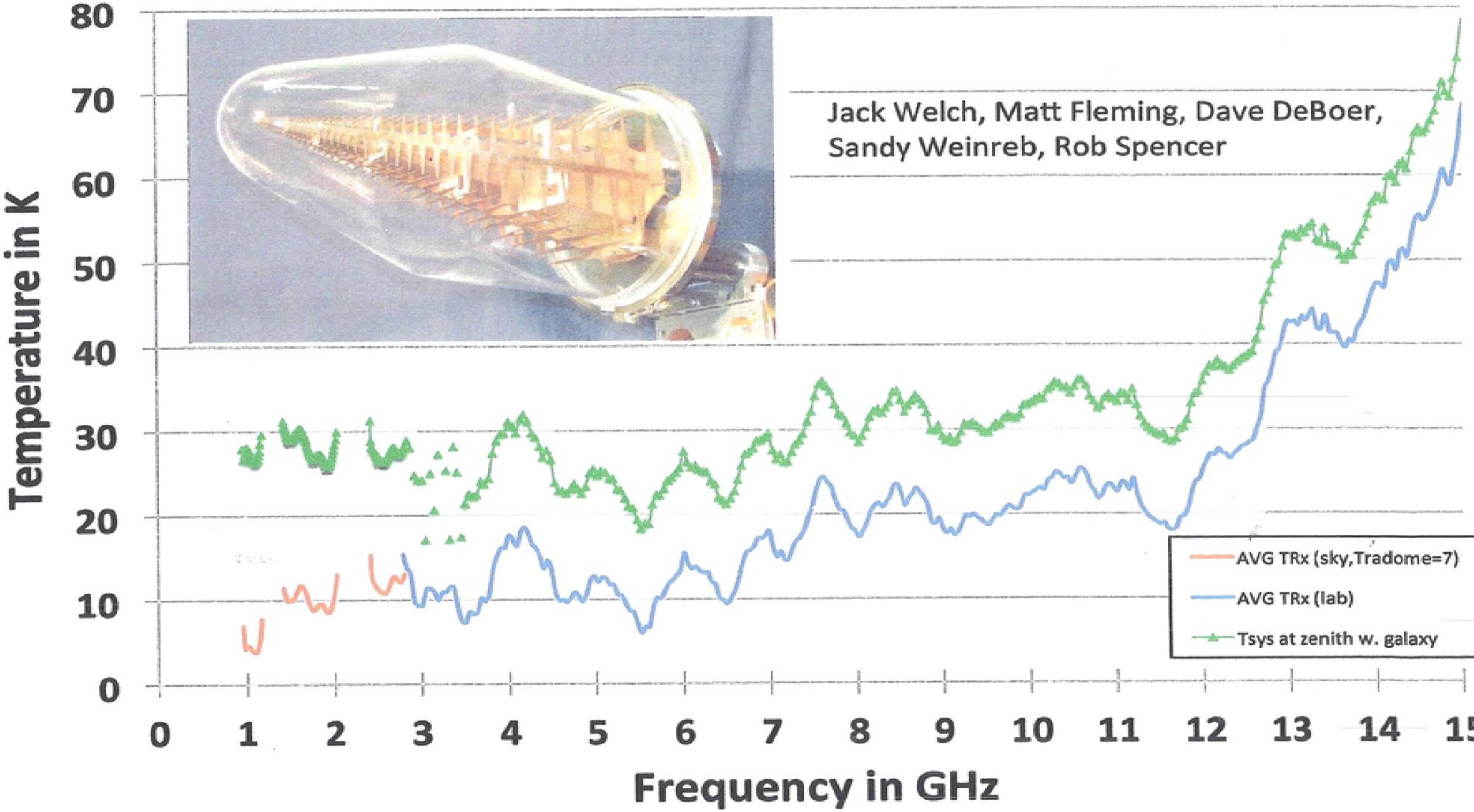


3.E+09
3.E+09
2.E+09
2.E+09
1.E+09
5.E+08
0.E+00
2007 NPV [euros]
2.7x10^8 deg^2.m^4/K^2
0.98x10^8 deg^2.m^4/K^2
0.68x10^8 deg^2.m^4/K^2
0.43x10^8 deg^2.m^4/K^2
0.25x10^8 deg^2.m^4/K^2
0.16x10^8 deg^2.m^4/K^2
6
10
12
15
20
25
Dish Diameter [m]
Computing
Correlator
Long Haul Links
LNSD Station Electronics
Short Haul Links
LNSD Antenna Electronics
Antenna

Phased Array Feed – 64 beams

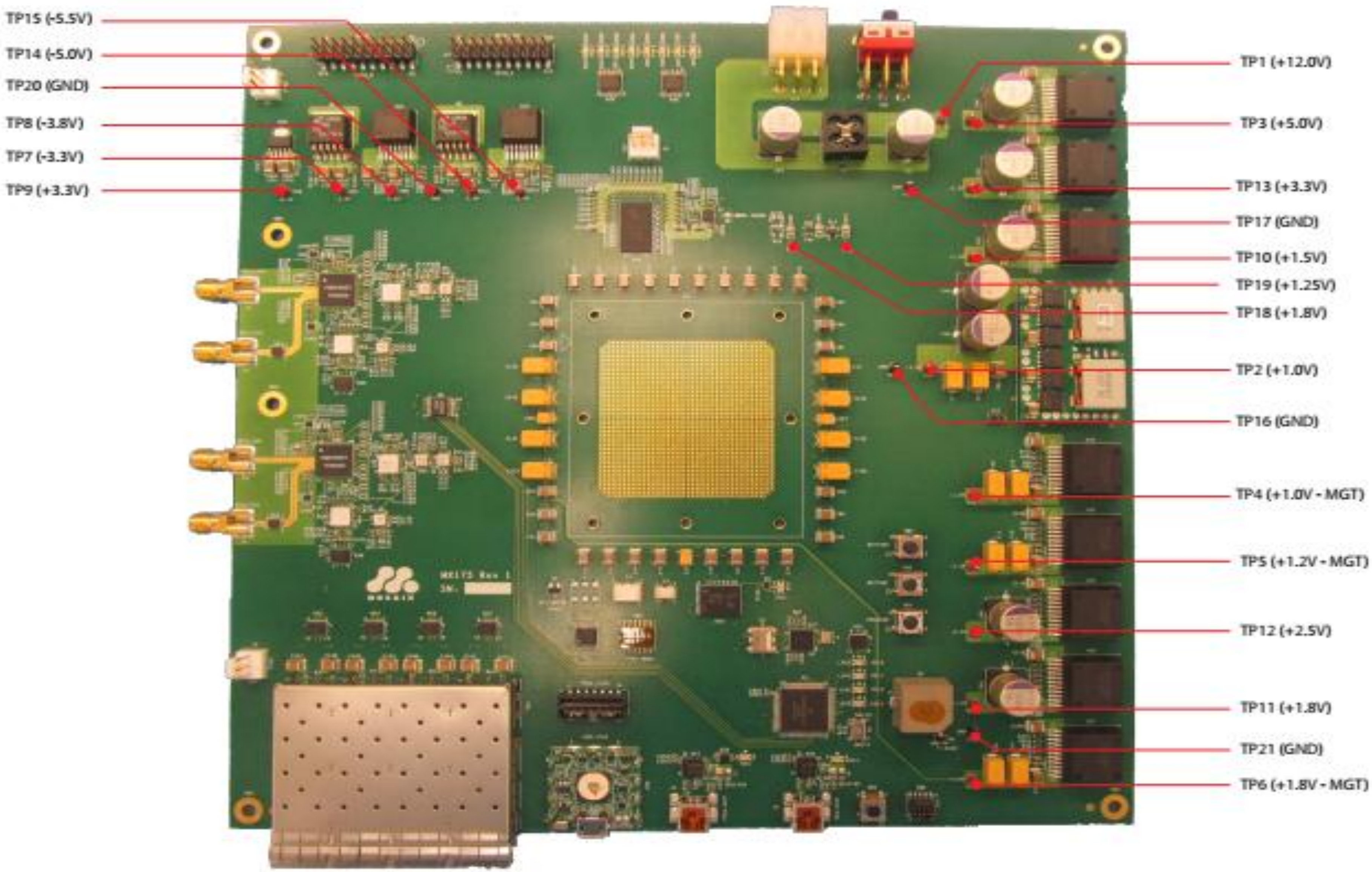


Measured Receiver Temperature & Tsys at Zenith
Cooled ATA Feed



Dual 26 Gsps ADC and FPGA board

MX175R1 TESTPOINTS

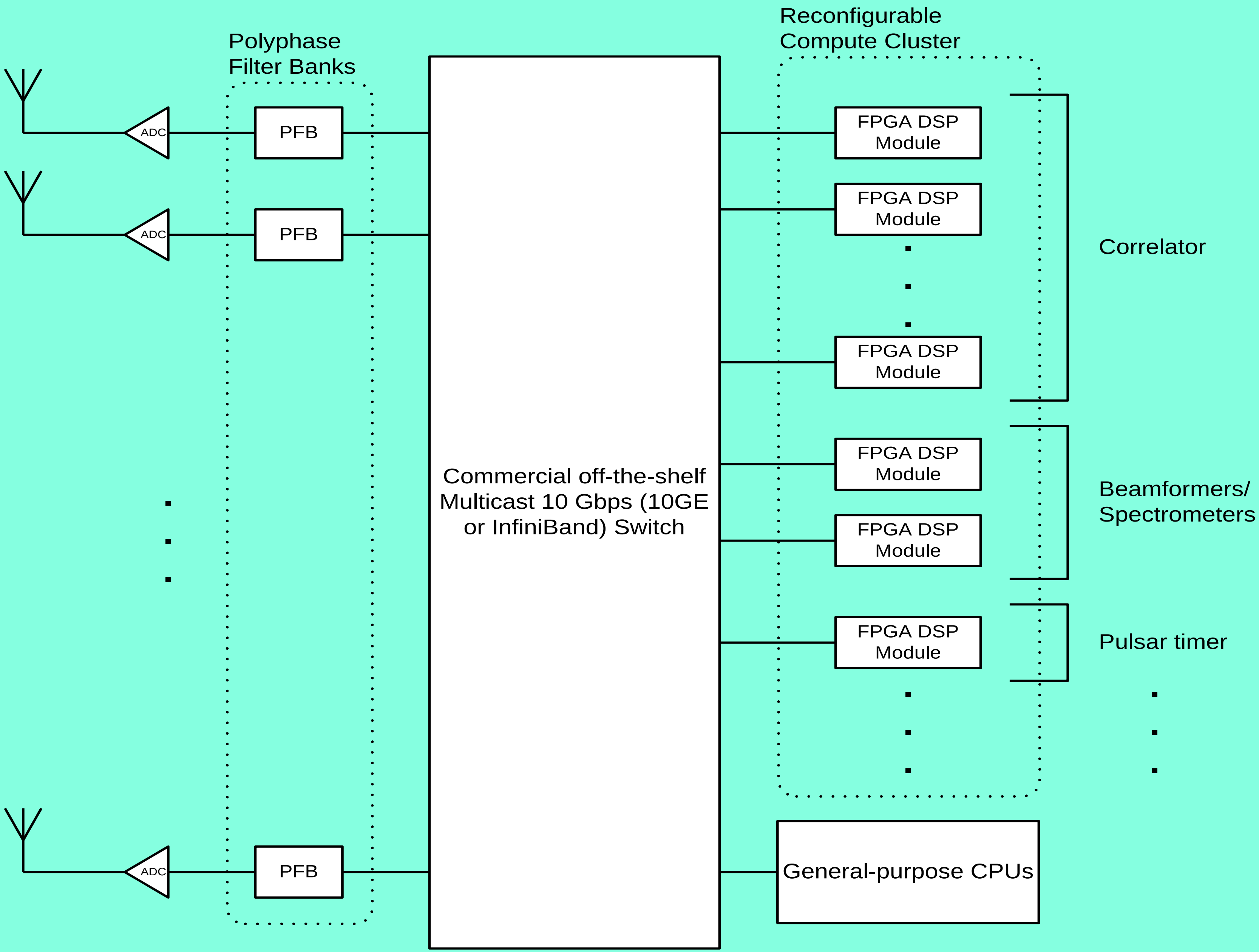


ADC's

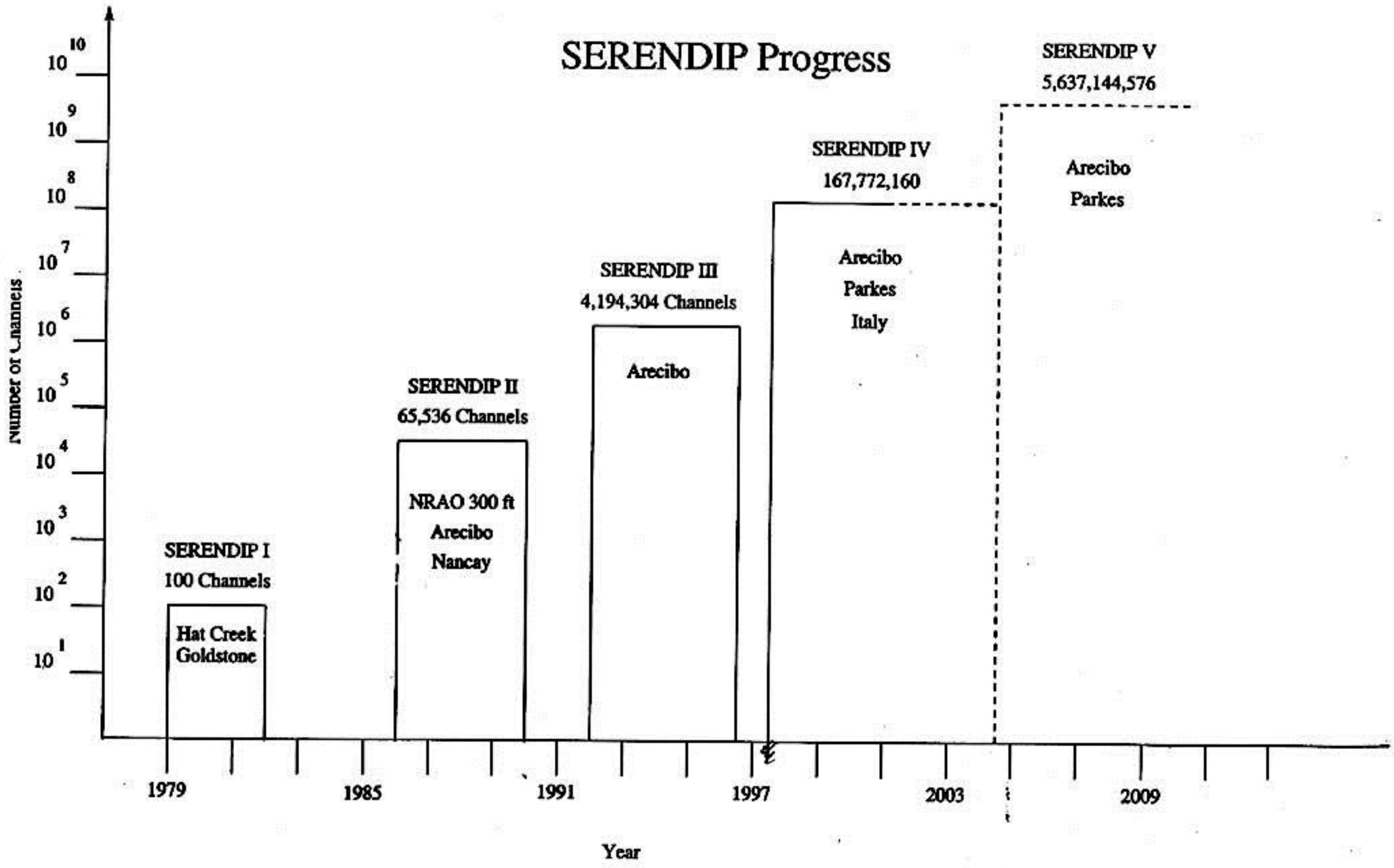
26 Gsps	3.5 bit	Hittite
55 Gsps	8 bit	Fujitsu
80 Gsps	8 bit	Berkeley
160 Gsps	8 bit	Keysight
240 Gsps	8 bit	Teledyne Lecroy

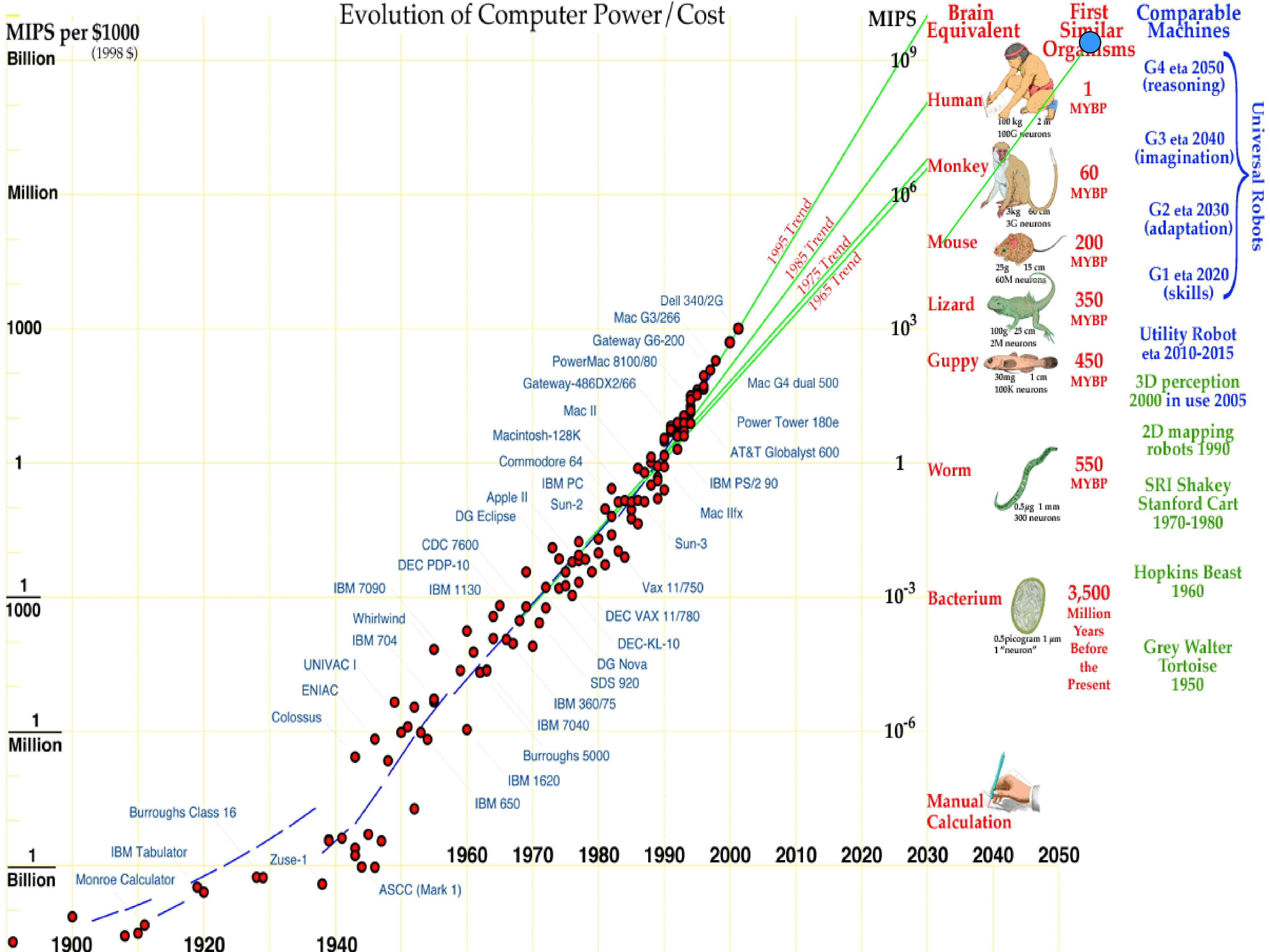
CASPER General Purpose Architechture

Dynamic Allocation of Resources, need not be FPGA based



Moores Law – Instruments using FPGA's: 2X per year (1,000,000 over 20 years)




Evolution of Computer Power/Cost
MIPS per $1000 (1998 $)
Billion
Million
1000
1
1/1000
1/Million
1/Billion
MIPS
10^9
10^6
10^3
1
10^{-3}
10^{-6}
1900
1920
1940
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
1995 Trend
1985 Trend
1975 Trend
1965 Trend
Dell 340/2G
Mac G3/266
Gateway G6-200
PowerMac 8100/80
Gateway-486DX2/66
Mac II
Macintosh-128K
Commodore 64
IBM PC
Apple II
Sun-2
DG Eclipse
CDC 7600
DEC PDP-10
IBM 7090
IBM 1130
Whirlwind
IBM 704
UNIVAC I
ENIAC
Colossus
Burroughs Class 16
IBM Tabulator
Zuse-1
Monroe Calculator
ASCC (Mark 1)
Mac G4 dual 500
Power Tower 180e
AT&T Globalyst 600
IBM PS/2 90
Mac IIfx
Sun-3
Vax 11/750
DEC VAX 11/780
DEC-KL-10
DG Nova
SDS 920
IBM 360/75
IBM 7040
Burroughs 5000
IBM 1620
IBM 650
Brain Equivalent
Human
100 kg 2 m
100G neurons
Monkey
3kg 60 cm
3G neurons
Mouse
25g 15 cm
60M neurons
Lizard
100g 25 cm
2M neurons
Guppy
30mg 1 cm
100K neurons
Worm
0.5μg 1 mm
300 neurons
Bacterium
0.5picogram 1 μm
1 "neuron"
Manual Calculation
First Similar Organisms
1 MYBP
60 MYBP
200 MYBP
350 MYBP
450 MYBP
550 MYBP
3,500 Million Years Before the Present
Comparable Machines
G4 eta 2050 (reasoning)
G3 eta 2040 (imagination)
G2 eta 2030 (adaptation)
G1 eta 2020 (skills)
Universal Robots
Utility Robot eta 2010-2015
3D perception 2000 in use 2005
2D mapping robots 1990
SRI Shakey Stanford Cart 1970-1980
Hopkins Beast 1960
Grey Walter Tortoise 1950

Use Sun As Gravitational Lens

Place camera at focus 100 billion km

Read License Plates on Extrasolar Planet

Summary and Conclusion

No ET so far

Still working on it

SETI HAIKU

Searching for life
Answers are revealed
About ourselves

Paula Cook, Duke University

One million earthlings
Bounded by optimism
Leave their PC's on

Dan Seidner