Searching for pulsars with Einstein@Home

David Keitel

(Albert Einstein Institute, Hannover, Germany)

for the LIGO scientific collaboration and Virgo collaboration

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http://www.einsteinathome.org/

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Einstein@Home Contributors

Bruce **Allen**
David **Anderson**
Stuart **Anderson**
Carsten **Aulbert**
Oliver **Bock**
Jim **Cordes**
Teviet **Creighton**
Julia **Deneva**
Irene **Di Palma**
Ralph **Eatough**
Heinz-Bernd **Eggenstein**
Henning **Fehrmann**
Akos **Fekete**

Steffen **Grunewald**
Lucas **Guillemot**
David **Hammer**
Jason **Hessels**
Mike **Hewson**
Yousuke **Itoh**
Evan **Keane**
David **Keitel**
Gaurav **Khanna**
Hunjoo **Kim**
Benjamin **Knispel**
Badri **Krishnan**
Paola **Leaci**
Bernd **Machenschalk**

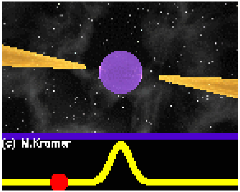
Kathryn **Marks**
Chris **Messenger**
Eric **Myers**
M.Alessandra **Papa**
Holger **Pletsch**
Reinhard **Prix**
Gary **Roberts**
Miroslav **Shaltev**
Peter **Shawhan**
Xavier **Siemens**
Alicia **Sintes**
Sinéad **Walsh**
Karl **Wette**
Graham **Woan**

Overview

1. Introduction - searching for pulsars
2. Einstein@Home
3. E@H GW searches
4. E@H radio searches
5. E@H gamma-ray searches
6. Ongoing E@H efforts

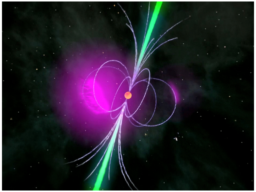
Intro - pulsars across the spectrum

radio



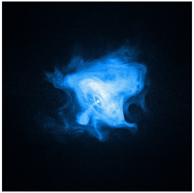
[M. Kramer, MPIfR]

gamma-rays



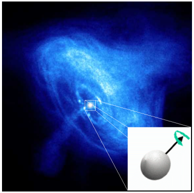
[NASA/Fermi/Cruz de Wilde]

X-rays



[NASA/CXC/SAO/F.Seward]

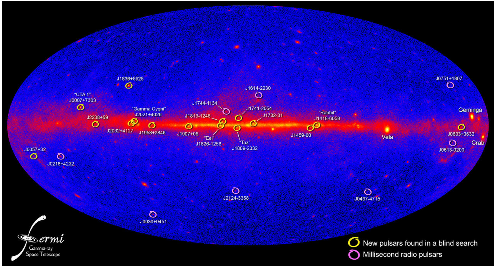
gravitational waves



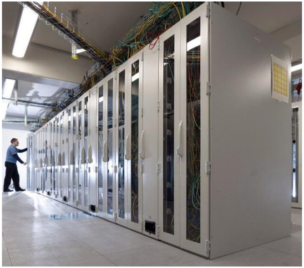
[Chandra/NASA, inset: R. Prix]

Intro - blind pulsar searches

- first radio pulsars were discovered serendipitously
- blind searches - both in radio and in new wavelength windows - have huge discovery potential
- blind searches $\Rightarrow$ huge parameter spaces $\Rightarrow$ high-performance computers, clusters, distributed computing



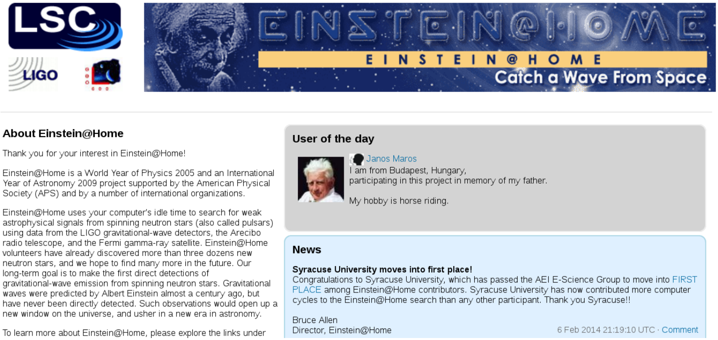
[NASA/DOE/Fermi LAT Collaboration]



[AEI/B.Allen]

Einstein@Home

- distributed volunteer computing project based on *Berkeley Open Infrastructure for Network Computing*
- divide parameter space into *workunits*
- send these out to *hosts*
- computations from spare cycles



`http://www.einsteinathome.org/`

E@H history

- started in 2005 by Bruce Allen
- administration: AEI Hannover and U Wisconsin, Milwaukee
- original aim: discovery of continuous gravitational waves
- since 2009: also radio searches,
  first discovery: Knispel et al., Science (2010)
- since 2011: also gamma-ray searches,
  first discoveries: Pletsch et al., ApJL (2013)


LIGO Livingston


[NOAO/AURA/NSF]


[NASA/Fermilab]

E@H technology

- Windows, Linux, Mac, Android
- modest hardware requirements
- radio and γ searches also use GPUs

[Nvidia]

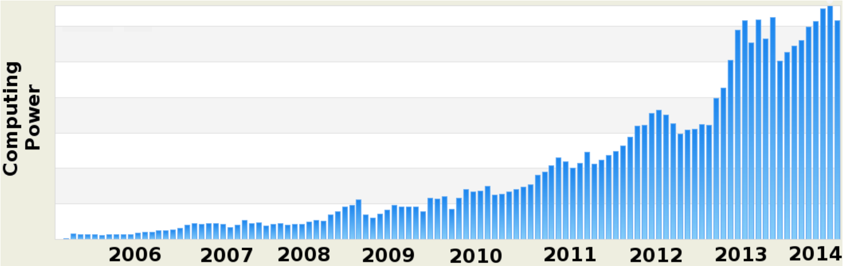
- validation: results from at least two volunteers' hosts per workunit
- post-processing: mostly on ATLAS computing cluster at AEI

[AEI/B.Knispel/NASA]

E@H community

- total participants:
  360k volunteers, 3.4 million hosts
- current participants (past 2 weeks):
  42k volunteers, 190k hosts
- average computing power: 1150 TFLOPS
- discoverers: certificates and acknowledgements in publications

[H.P.Tobler]



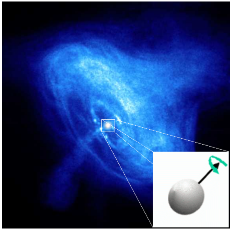
[boincstats.com]

E@H and Gravitational Wave pulsars

- GW: deformations of space-time travelling at speed of light
- simplest mechanism for *continuous waves* (CWs): small "mountain" on a rotating NS
- extremely weak signals:

$$h_0 \sim \frac{\Delta L}{L} \lesssim 10^{-24}$$

- detectors: laser interferometers
- e.g. LIGO: arm-length $L = 4\,\text{km}$



[Chandra/NASA, inset: R. Prix]

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E@H GW searches: S5

- fifth LIGO science run S5: from 2005 to 2007

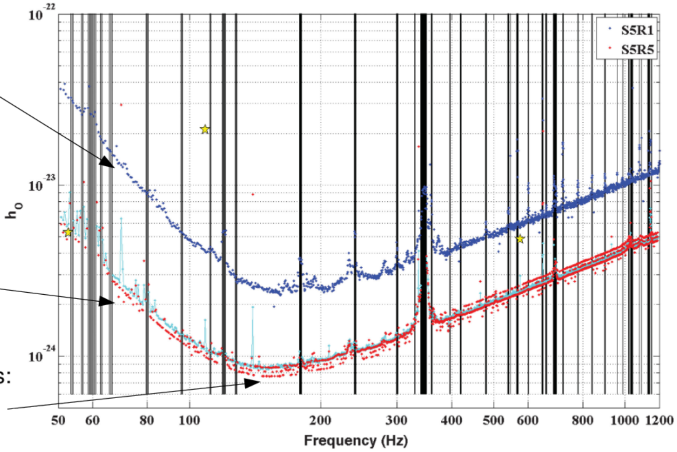
search over first 2 months

[Abbot et al. 2009]

search over 2 years of data

[Aasi et al. 2013]

best upper limits:
$h_0 \leq 7.6 \cdot 10^{-25}$



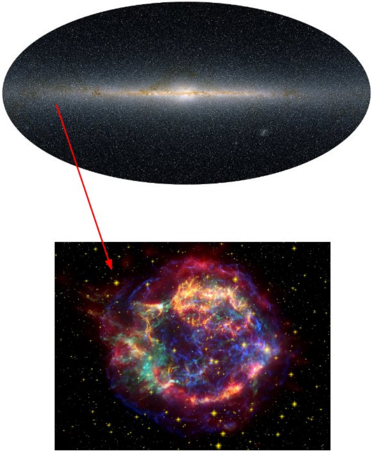
- more stringent than any other all-sky CW search

E@H GW searches: S6

- sixth LIGO science run S6:
  July 2009 to October 2010
- in post-processing:
  all-sky search
  in [50, 510] Hz range
- currently on hosts:
  directed search for CasA,
  1st + 2nd spindown,
  [50, 1000] Hz
- “global correlations” method

  [Pletsch 2008, Pletsch & Allen 2009]
- line-robust statistics

  [Keitel, Prix, Papa, Leaci, Siddiqi 2014]

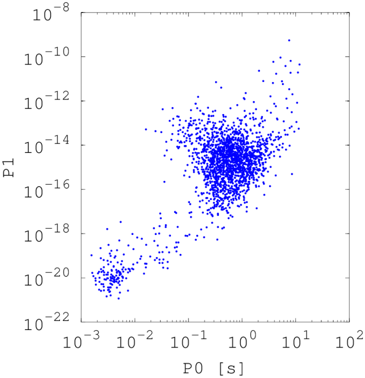


[2MASS] / [NASA/JPL-Caltech]

E@H and radio pulsars

- over 2300 known

  [ATNF catalogue / Manchester et al. 2006]
- ms pulsars in binary systems: especially interesting for testing fundamental physics (GR, QCD)
- E@H searches for shorter orbital periods



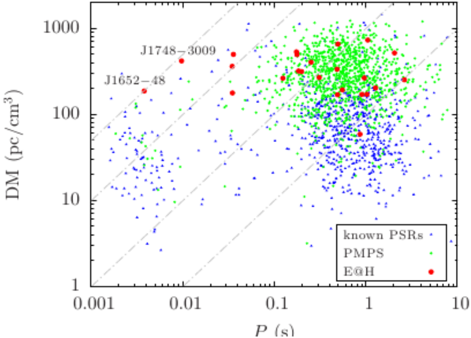
[ATNF]

E@H radio discoveries

- 24 pulsars from PALFA survey (Arecibo)

  [Cordes et al. 2006 / Knispel et al. 2010, 2011]
- 24 pulsars from PMPS survey (Parkes)

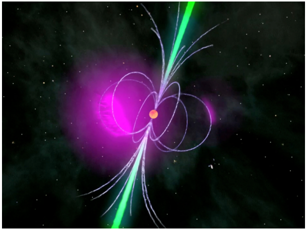
  [Manchester et al. 2001 / Knispel et al. 2013]
- including a BNS, two intermediate-mass binary pulsars



E@H and γ-ray pulsars

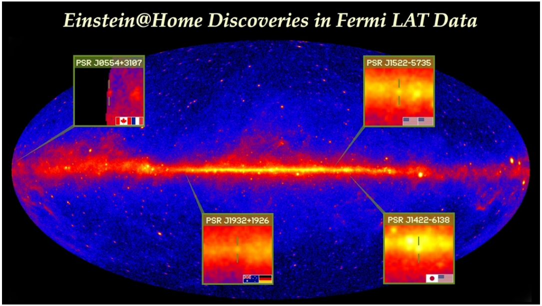
- Large Area Telescope (LAT) onboard Fermi, sensitive range: 20 MeV to 300 GeV
- Fermi LAT helped locate over 100 γ-ray pulsars [Abdo et al. 2013]
- 26 + 15 found blindly, mostly radio-quiet
- 15 with GW-derived methods at AEI - ATLAS and E@H [Pletsch et al.]
- detection of individual photons
- 4 years of data, $\sim 10^9$ rotations, $\sim$ 1000 photons


[NASA/Fermilab]


[NASA/Fermi/Cruz de Wilde]

E@H γ-ray discoveries

- pipeline moved from ATLAS cluster to Einstein@Home
- found 4 young γ-pulsars [Pletsch et al. 2013, ApJL]



[Knispel/Pletsch/AEI/NASA/DOE/Fermi LAT Collaboration]

- young and nearby pulsars $\Rightarrow$ interesting GW targets

Ongoing E@H efforts

- GW: post-processing of S6 all-sky run,
  searches for CasA and further supernova remnants
- radio: continuing Arecibo survey,
  Perseus Arm Pulsar Survey (Parkes)
- γ-rays: $\sim$ 100 pulsar-like unassociated Fermi sources left,
  isolated NS search ongoing,
  binary NS search in preparation

Conclusions

- Einstein@Home: world's largest computing resource for pulsar searches
- similar methods in GW, radio and γ windows
- many new pulsars found in "old" radio and γ data
- GW community still waiting for first detection, and for advanced LIGO
- you - and your university network? - can contribute, too!

Conclusions

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Thank you for your attention...

...any questions?

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