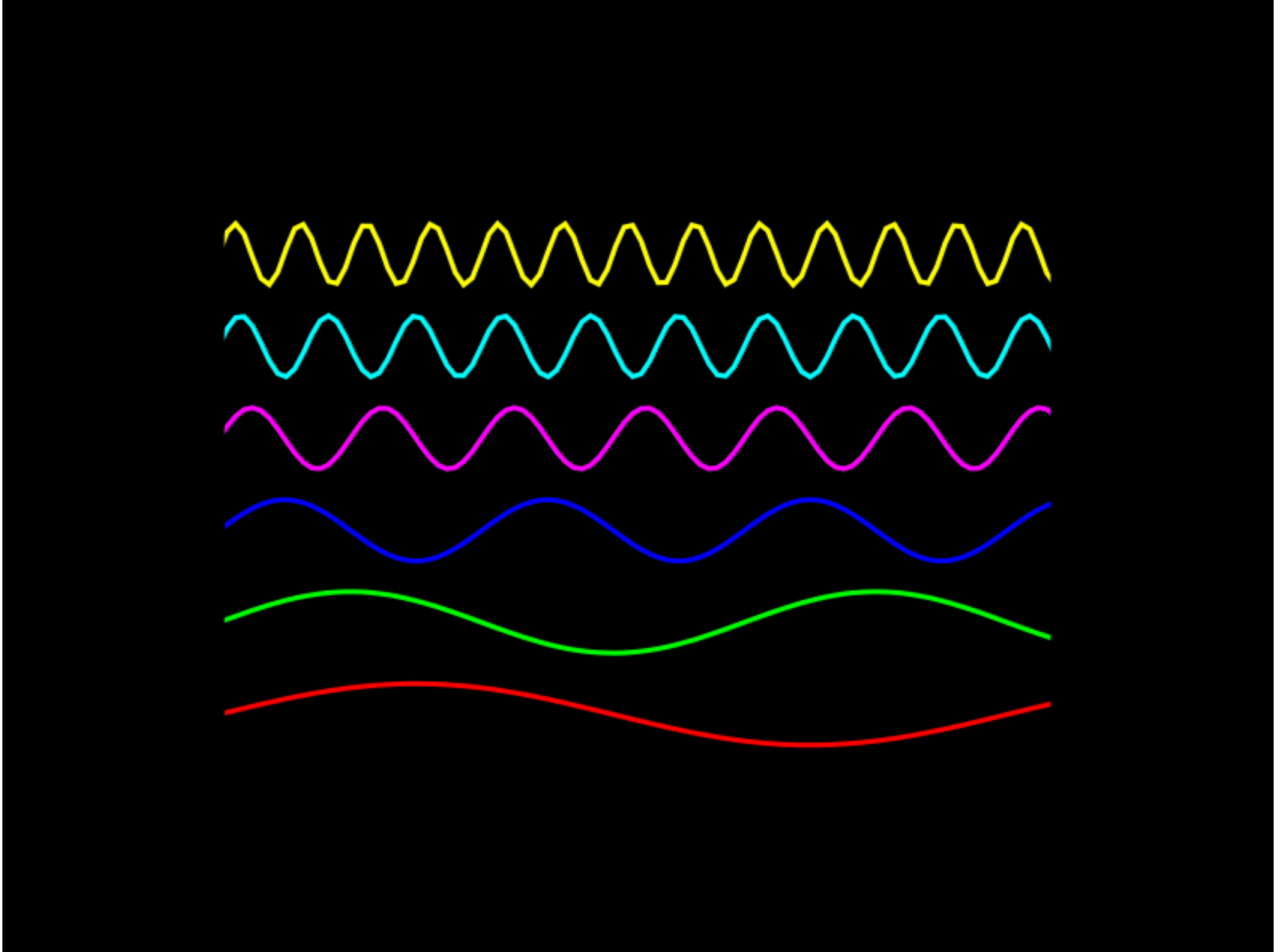
An Portán agus a Chairde

Evan Keane
SKAO

Birr Castle, I-LOFAR Talk
20/07/2017



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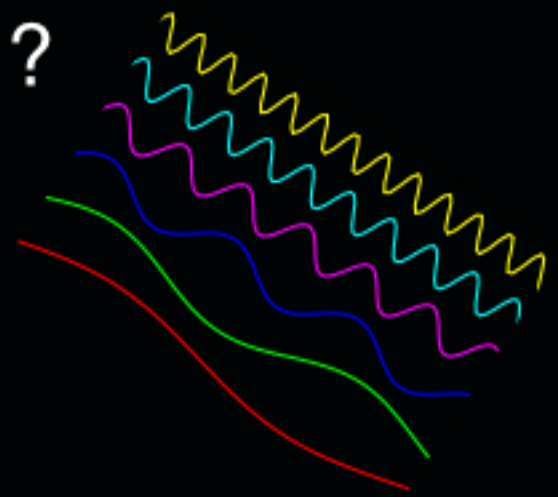

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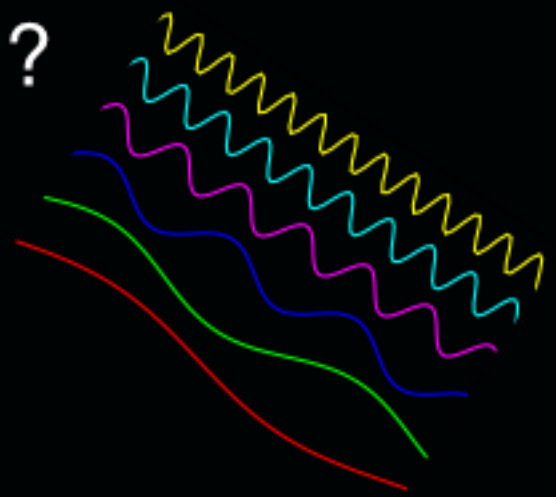

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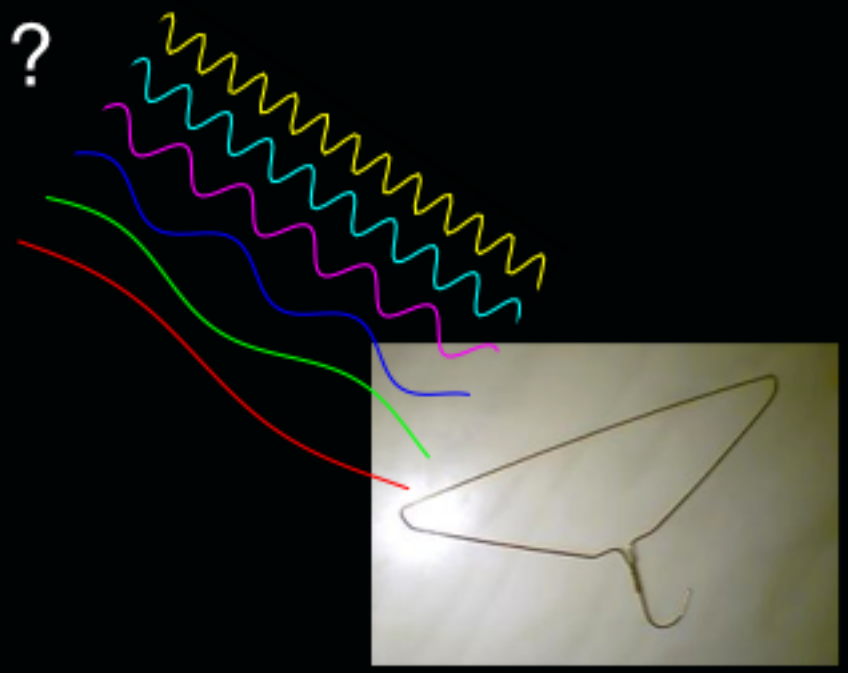

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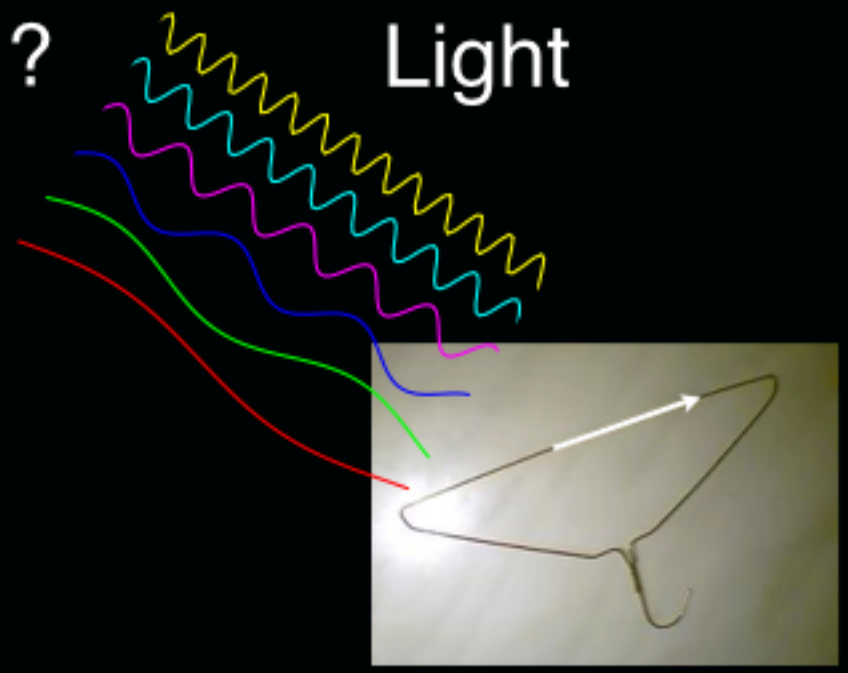

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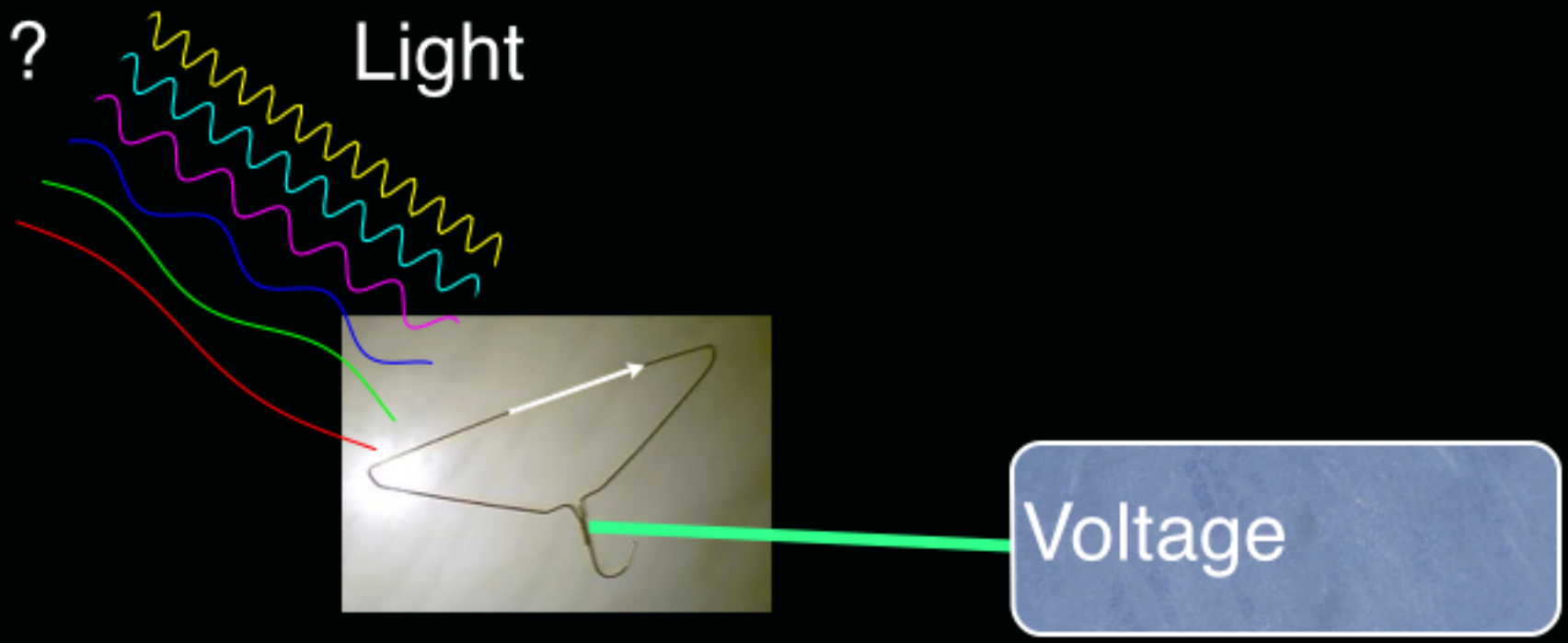

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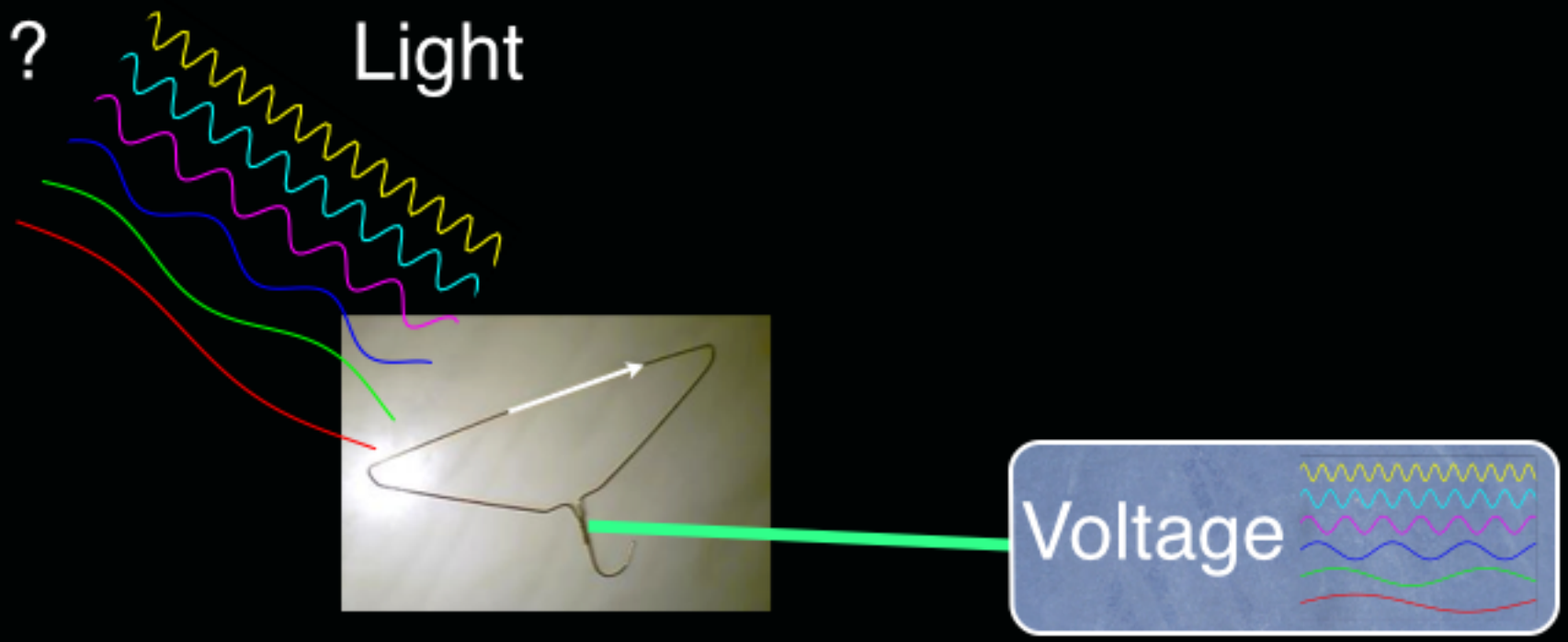
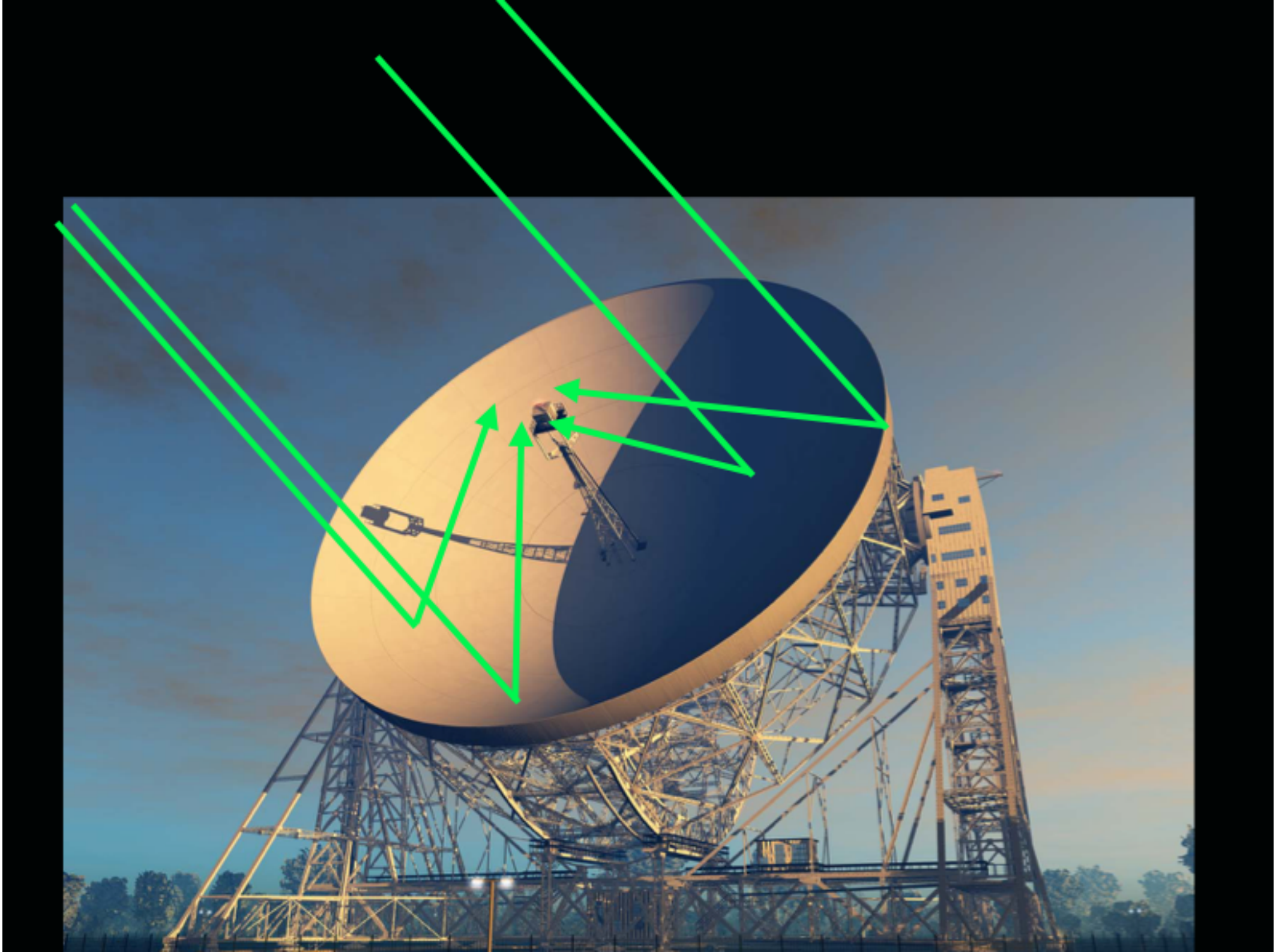
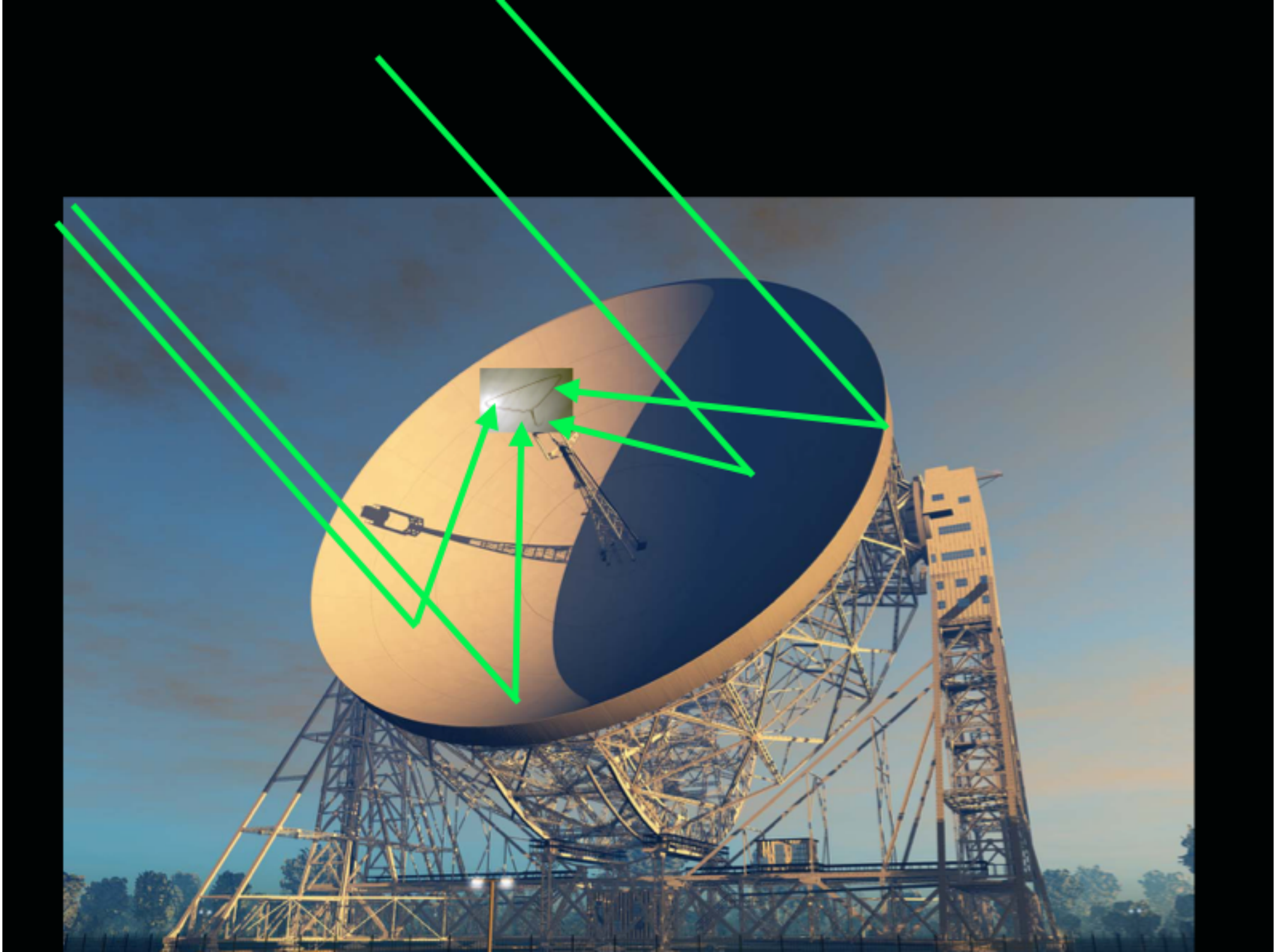
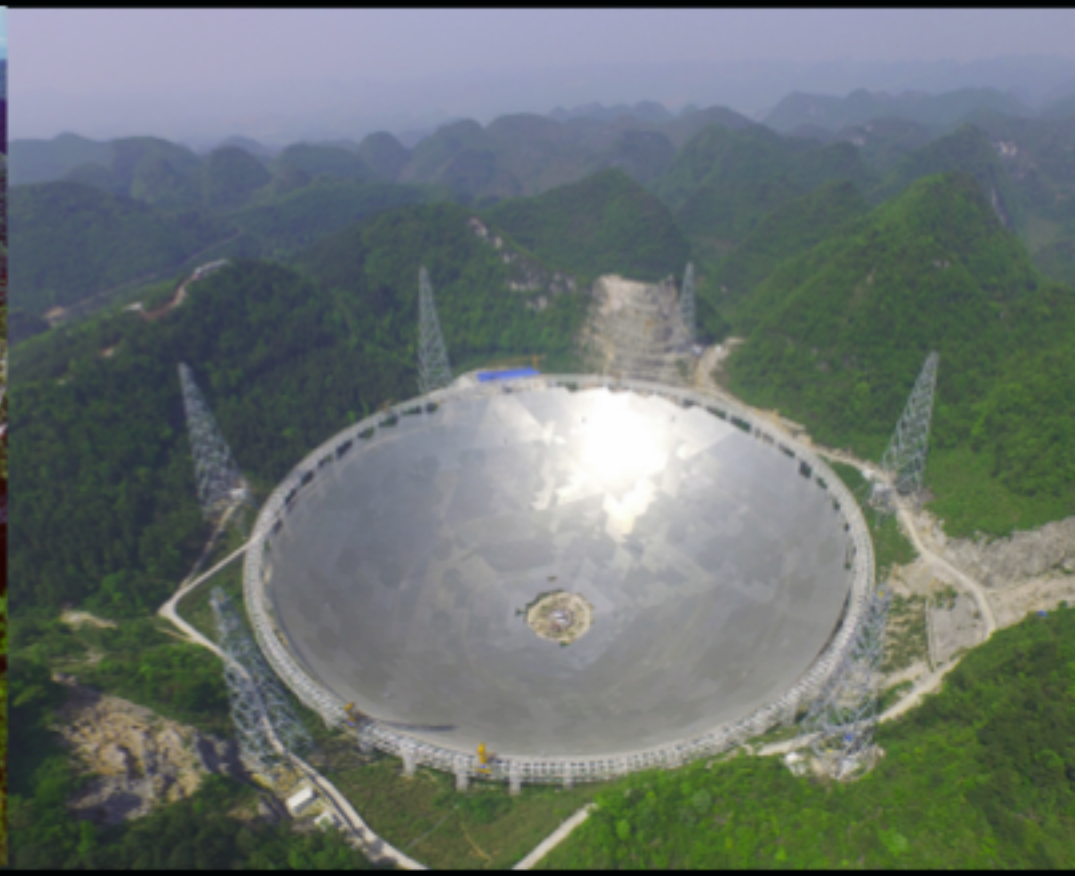






Bigger = More Light



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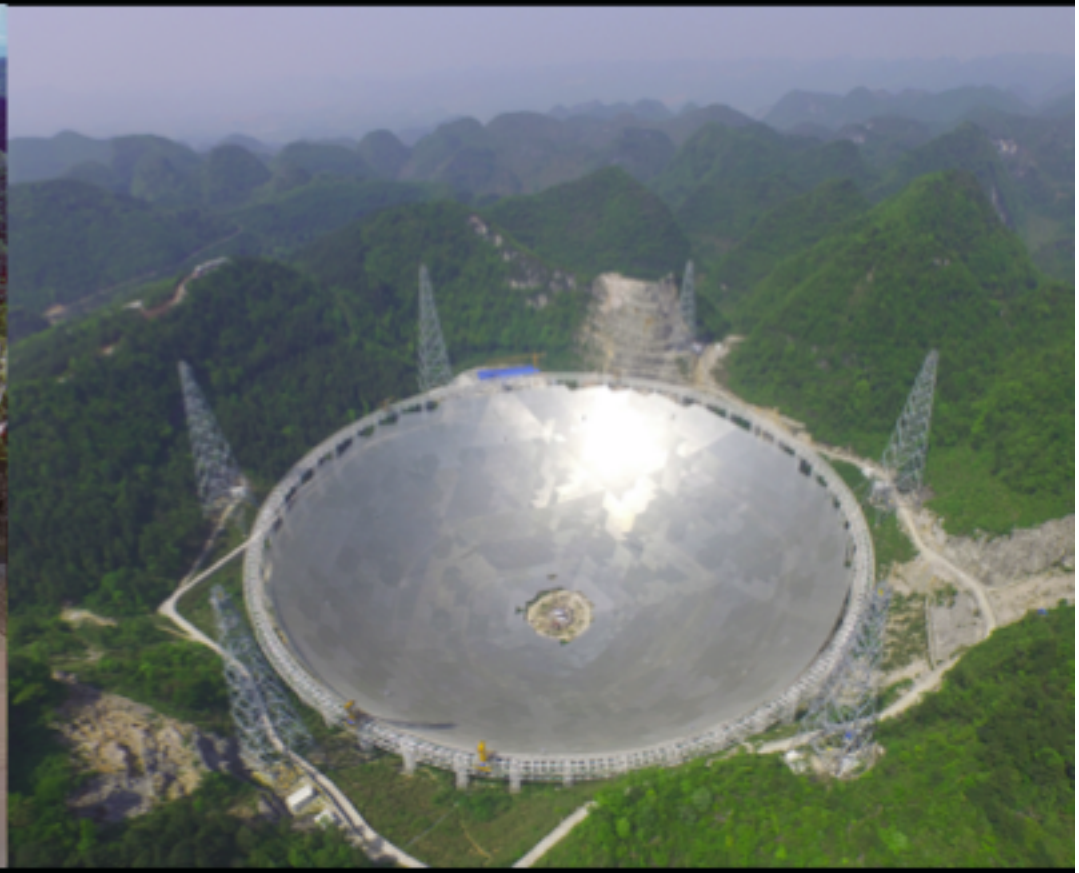

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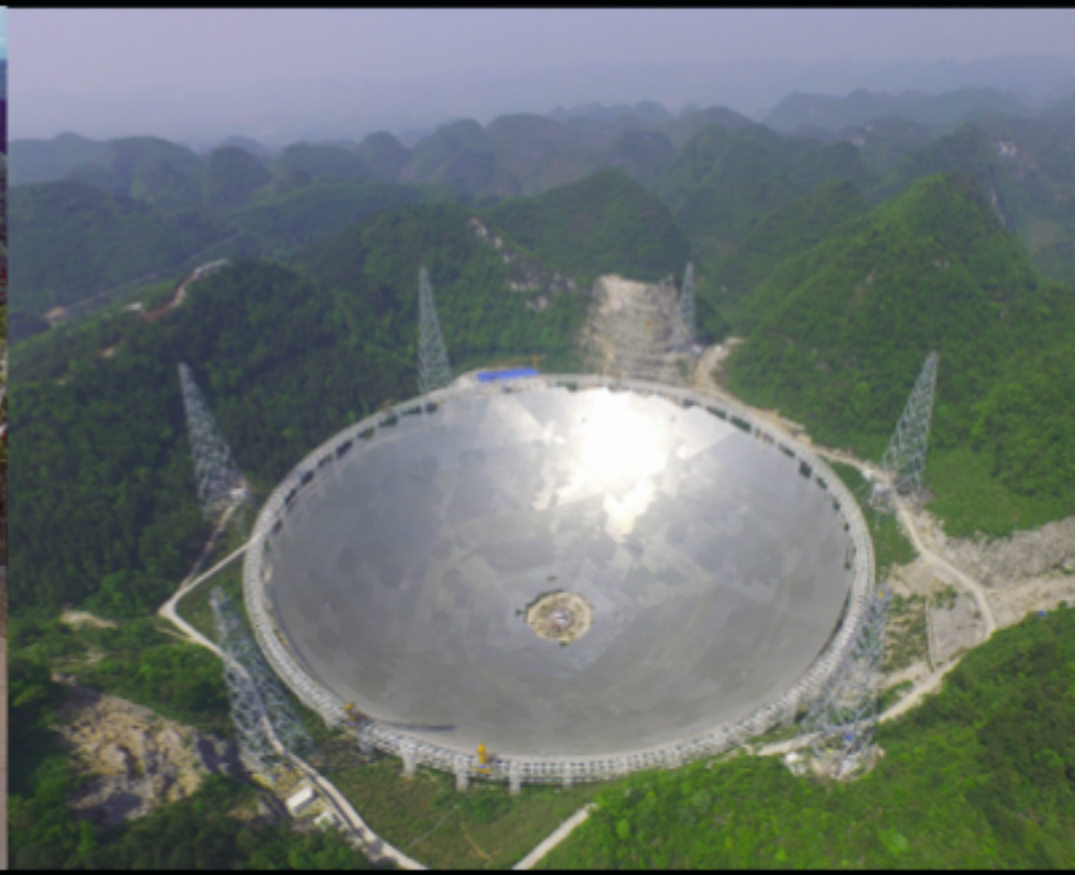

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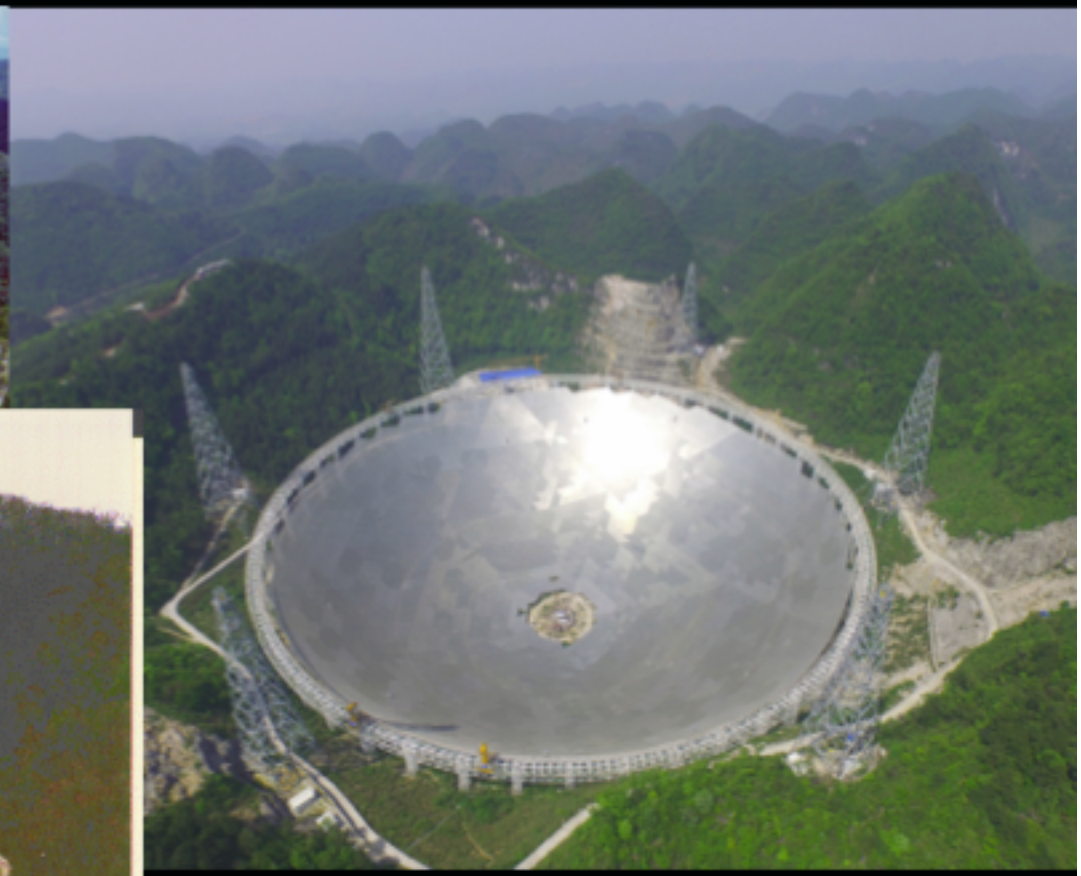

Bigger = More Light

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Headline Science with I-LOFAR

- LOFAR can do world-leading headline grabbing science!
- That goes for I-LOFAR alone
- Will talk about 2 examples
- Pulsars & Fast Radio Bursts

Birr Times

Saturday, September 1, 2018.

Pulsar-Black Hole Discovere

History was made this past weekend by a group of Irish astrophysicists using the Irish LOFAR station in the grounds of Birr Castle. The team, led by Prof. M. Mouse of the Google Institute for Technology in Clonmel, used the newly built radio telescope in combination with a supercomputer to identify a pulsar closely orbiting a black hole - the first such discoverey made by humanity. Both the pulsar and black hole are the 'dead' remnants of violent supernova explosions that occur when massive stars run out of nuclear fuel. Prof. P. Gallagher could not be reached for comment as he was busy running laps of joy around Trinity before being seen to disappear in the proximity of 'The Pav'. Astronomers will continue to study the system in order to test the 'black hole theorems' famously proposed last century.

2 Big Questions

- What is it?
- What is it good for?

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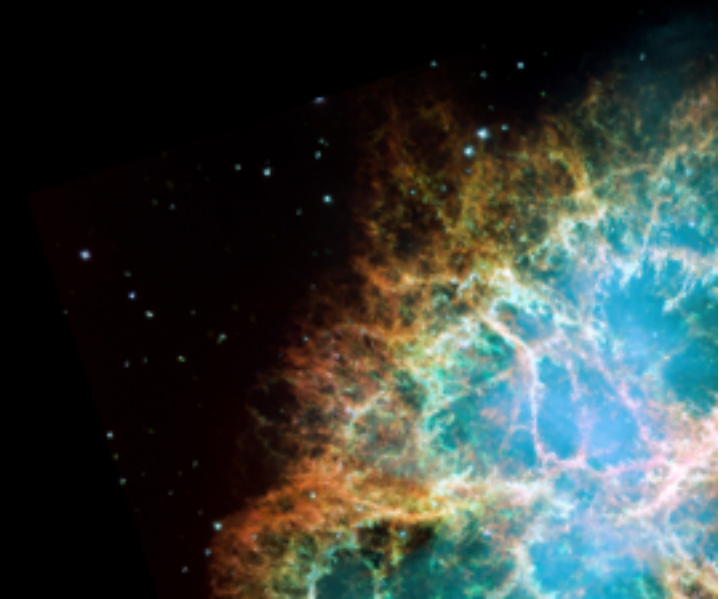
Pulsars



Pulsars

Pulsars

- A pulsar is a re-animated stellar corpse — a zombie star

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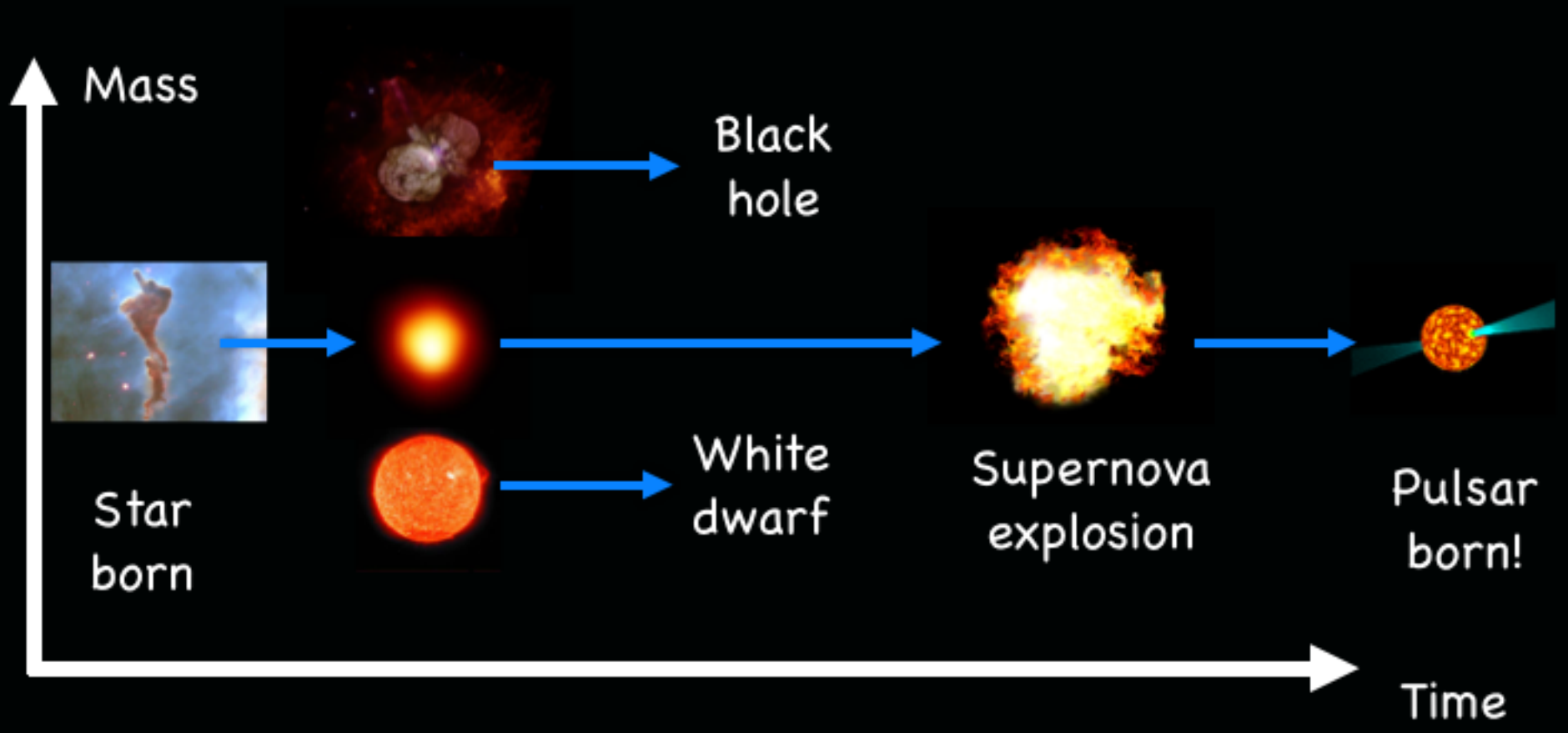
- They are also great clocks

Pulsars

- A pulsar is a re-animated stellar corpse — a zombie star
- They are also great clocks
- Actually they are really really great clocks

Zombie Stars

- When stars die there are 3 possibilities



The Crab

- Crab pulsar resides in the Crab Nebula (SN1054)
- Crab Nebula discovered with the Leviathan, named by 3rd Earl of Rosse

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Somerville, Observatory, 1988, **108**, p131

Crab

M1—THE IRISH NEBULA

By W. B. Somerville
Department of Physics and Astronomy, University Colleg, Lon 'on

It is suggested that The Crab Nebula is a poor name for an object that much more resembles a shaggy dog. The name The Irish Nebula is proposed instead, in honour of Lord Rosse.

In all the extensive and continuing discussion[1,2] of the object known as *The Crab Nebula*, one simple fact is rarely mentioned—in its appearance, the object does not remotely look like a crab. Moreover, unlike others such as the Orion nebula and the Andromeda nebula, the Crab nebula is not in the constellation of the same name, a potential cause of confusion. Taking these points together prompts the idea that a more suitable name should be found.

An obvious approach is to examine the appearance in modern photographs. Good high-resolution black-and-white photographs, showing the filaments, have always reminded me very much of the structure seen in very-short-exposure ($\sim 10^{-5}$ sec) spark photographs of the shattering of a jug of milk[3,4], consistent with the violent motions known to be present, although on a very different time-scale. A possible name might therefore be *The Spilt Milk Nebula*. The essential objection to such a name is that it is totally shapeless.

Not only does it not resemble a crab, the nebula also clearly does not resemble a pineapple[5]. It is possible, however, that the Birr Castle observers thought of their first drawing not as a pineapple but as some creature of the sea, perhaps even an elongated crustacean like a lobster or crayfish. In many of the old drawings of constellation figures[6], Cancer the Crab appears as a lobster.

To be fair to the name, in the Palomar Sky Survey photographs the Crab does have some similarity to a crab, albeit rather a small one. However, the image there is heavily overexposed, so this doesn't count. In any case, it actually looks much more like a small spider, squashed onto the print. This would make for an unattractive name. The idea of something animate is appealing, however; and indeed a very good representation can be found without any difficulty. If in its photographs the nebula looks like any creature at all, it surely is a shaggy dog. This is seen particularly clearly in the well-known colour picture from the Hale Observatories[11], oriented to have East downwards. The dog even appears to be wearing a collar. I hesitate, however, to propose the name *The Shaggy Dog Nebula*, for fear that the suggestion might not be taken seriously.

Indeed, a better name can be found. The shape of the nebula M1 not only is like a shaggy dog, it also is very much like the map of Ireland. This comes about, of course, because Ireland itself is like a shaggy dog: with East upwards, Ulster is the head and Mayo and Kerry the feet. The fit of Ireland to the nebula M1 is remarkably good (with both oriented to have North upwards, which is satisfying, but with East and West reversed in accordance with the usual reproduction of astronomical photographs). The fit is at least as good as for the geographical or pictorial designations commonly used for many other nebulae. Even some details correspond. There is a bright star at about the position of Dublin, while Belfast is a knot in the tracery of orange filaments that overlies the more diffuse green. The pulsar, a source of strange radio emission, lies not very far from the location of Athlone.

There is a second good reason to favour the name, *The Irish Nebula*. Birr Castle, from where Lord Rosse made his celebrated observations of this object, is close to the very heart of Ireland. In fact, it is quite as near the pulsar as Athlone is. It would be a fitting tribute to a distinguished observer and his colleagues, and to a great telescope, if their best-known object of study were to be re-named in this way.

The resemblance of M1 to the map of Ireland suggests a search for other nebulae that may have local geographic shapes. Another is readily found. The central region of the Orion nebula (as photographed from Lick[15]) looks very closely like the map of Wales, even to having a representation of Anglesey. It is, however, coloured green[16]. A further complication is that in an infrared photograph[17] the Orion nebula actually looks rather like some sort of crab. But these are minor objections and we may therefore also contemplate *M42: The Great Welsh Nebula in Orion*.

Pulsars

- Pulsars are small (but deadly)— radius 10-15 km
- Pulsars are heavy — between 1.2 and 2.0 times the mass of the Sun
- Small + heavy = very strong gravity
- Also very strong magnets
  — about 1,000,000,000,000 stronger than Earth

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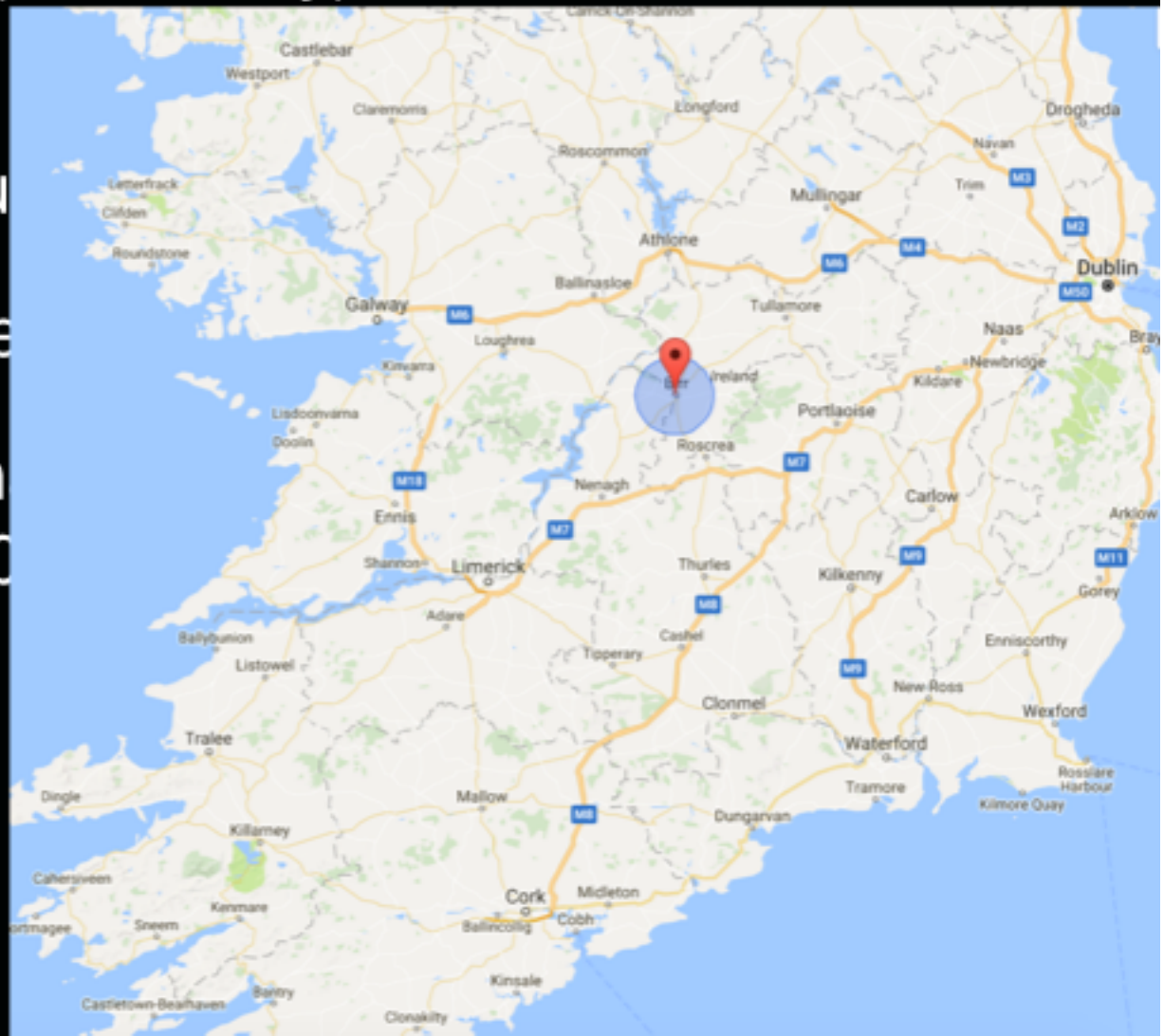

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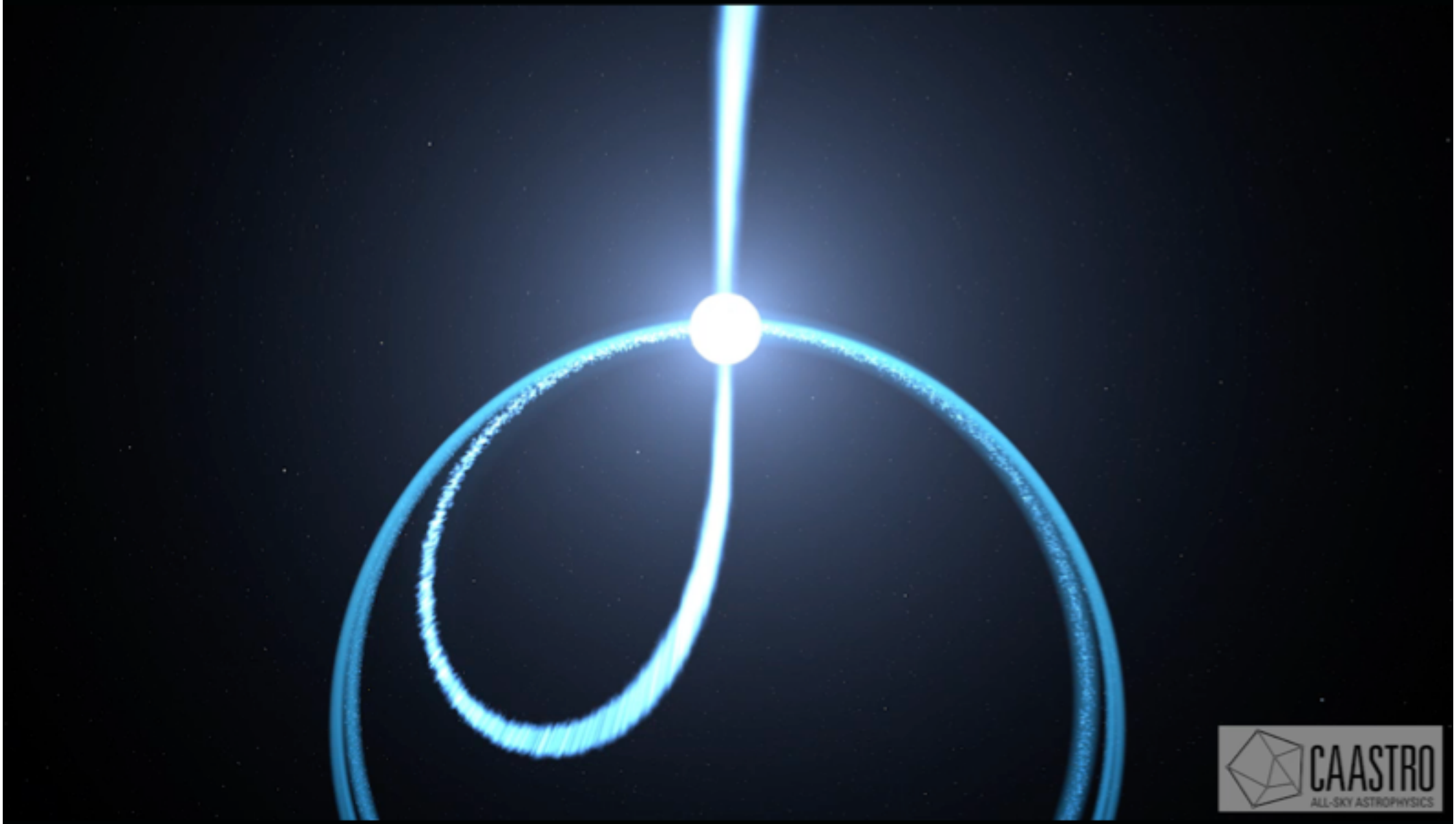
Pulsars

- Pulsars spin very fast, a pulsar ‘day’ can be as fast as 1.4 milliseconds, or as ‘slow’ as 8.5 seconds
- Pulsars emit lighthouse-like beacons of light

Pulsars



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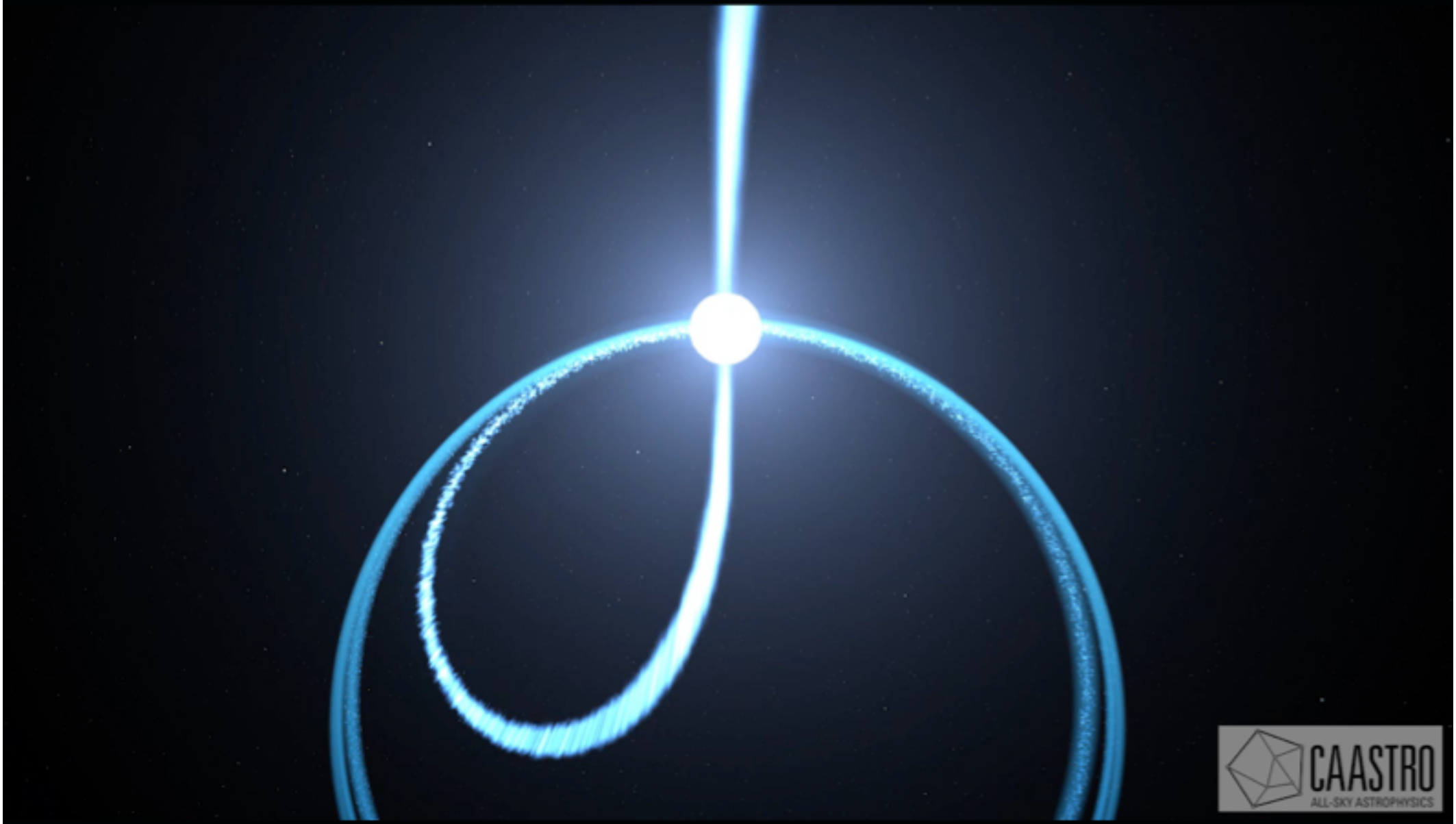
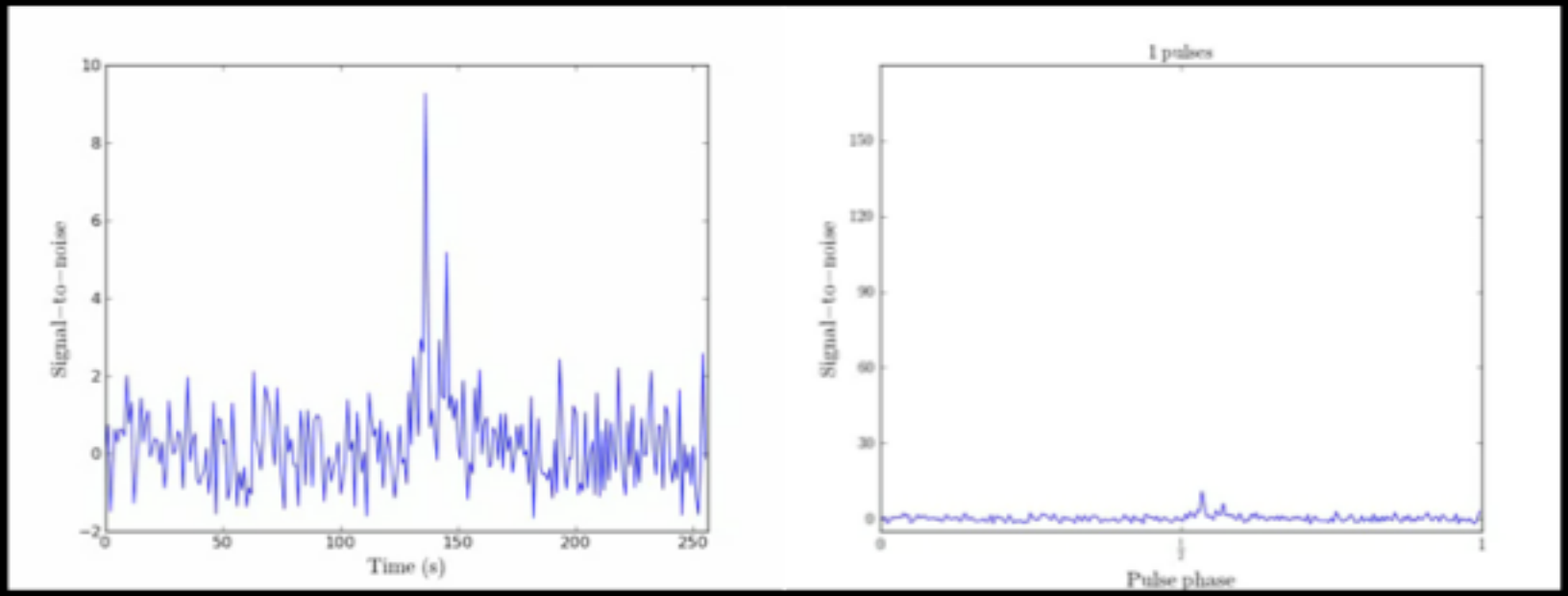


Super Clocks

- PSR timing clean and precise



Individual pulses

Integrated profile
—> VERY stable

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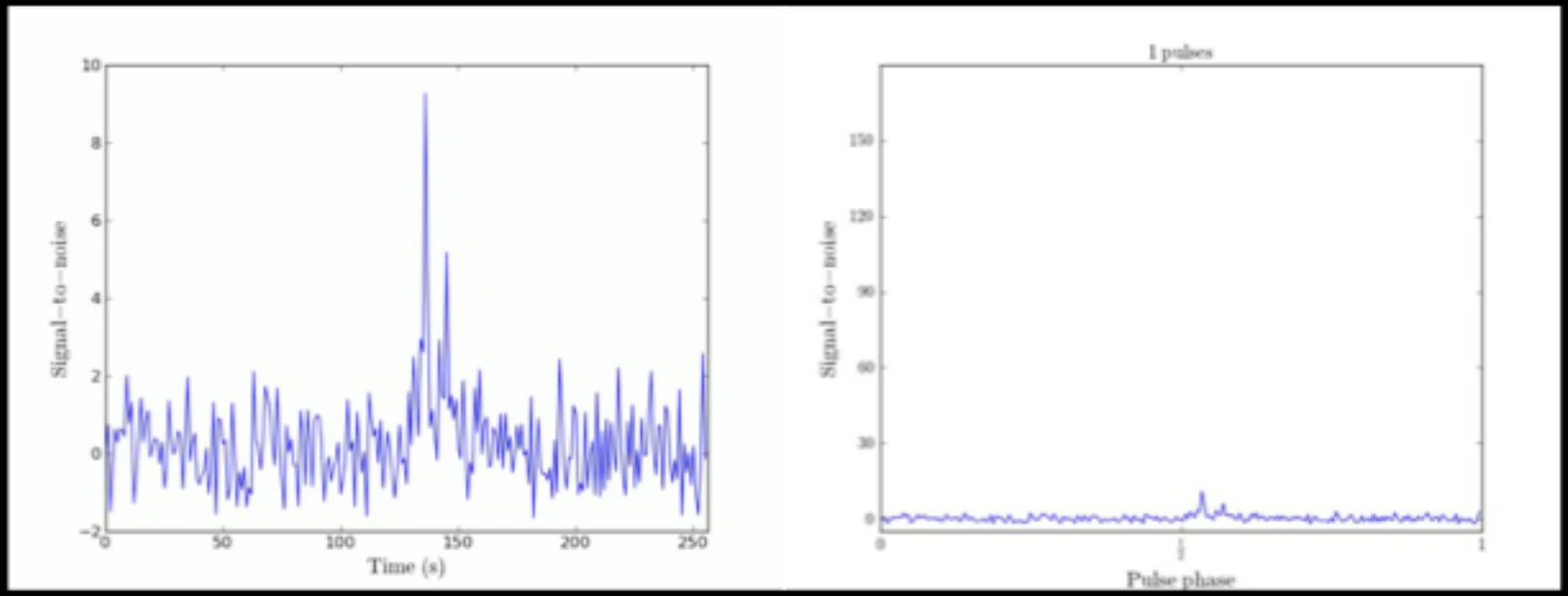

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Precision Astrophysics

Already today, we can do amazing measurements…

Spin parameters:

- Period: 5.757451924362137(2) ms (Verbiest et al. 2008) Note: 2 atto seconds uncertainty!

Astrometry:

- Distance: 157(1) pc (Verbiest et al. 2008)
- Proper motion: 140.915(1) mas/yr (Verbiest e t al. 2008)

Orbital parameters:

- Period: 0.102251562479(8) day (Kramer et al. in prep.)
- Projected semi-major axis: 31,656,123.76(15) km (Freire et al. 2012)
- Eccentricity: $3.5\ (1.1) \times 10^{-7}$ (Freire et al. 2012)

Masses:

- Masses of neutron stars: 1.33816(2) / 1.24891(2) $M_\odot$ (Kramer et al. in prep.)
- Mass of millisecond pulsar: 1.667(7) $M_\odot$ (Freire et al. 2012)
- Main sequence star companion: 1.029(3) $M_\odot$ (Freire et al. 2012)
- Mass of Jupiter and moons: $9.547921(2) \times 10^{-4}\ M_\odot$ (Champion et a. 2010)

Relativistic effects:

- Periastron advance: 4.226598(5) deg/yr (Weisberg et al. 2010)
- Einstein delay: 4.2992(8) ms (Weisberg et al. 2010)
- Orbital GW damping: 7.152(8) mm/day (Kramer et al. in prep)

Fundamental constants:

- Change in (dG/dt)/G: $(-0.6 \pm 1.1) \times 10{-}12\ \mathrm{yr}^{-1}$ (Zhu et al. 2015)

Gravitational wave detection:

- Change in relative distance: 100m / 1 lightyear (EPTA, NANOGrav, PPTA)

But with the SKA…we can do so much more!!

Jodrell Bank Observatory

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Jodrell Bank Observatory

So What?

- Clocks behave differently depending on gravity
- Strong gravity —> clock slows down
- Gravitational wave passes by a pulsar/Earth —> pulsar signal earlier/later
- Observe the clock's behaviour
  —> learn about pulsars, black holes and how gravity really works

Gravitational Waves

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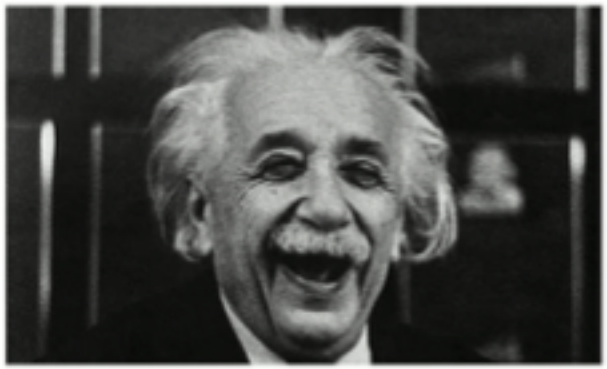
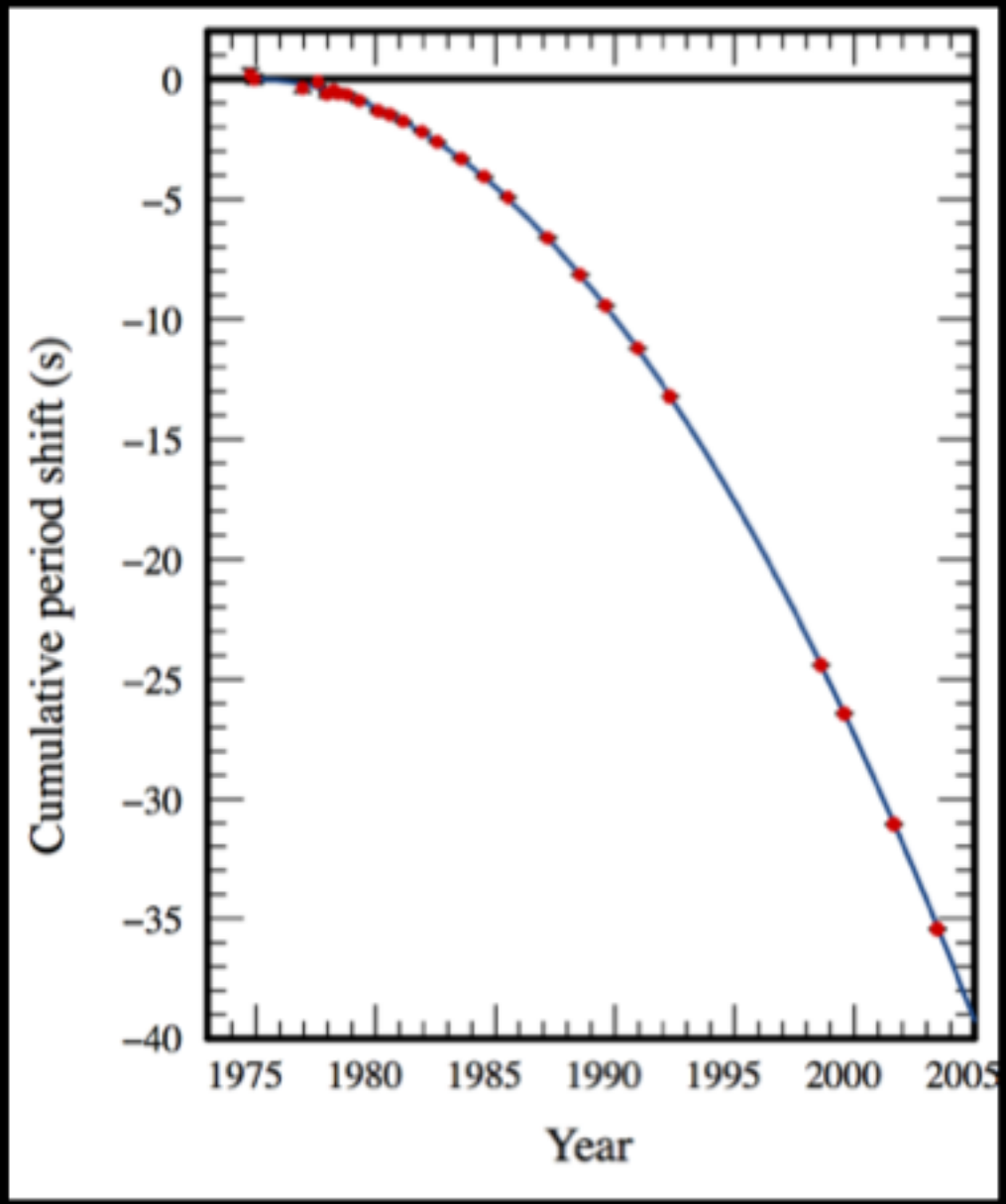
Credit: M. Purver



Gravitational Waves

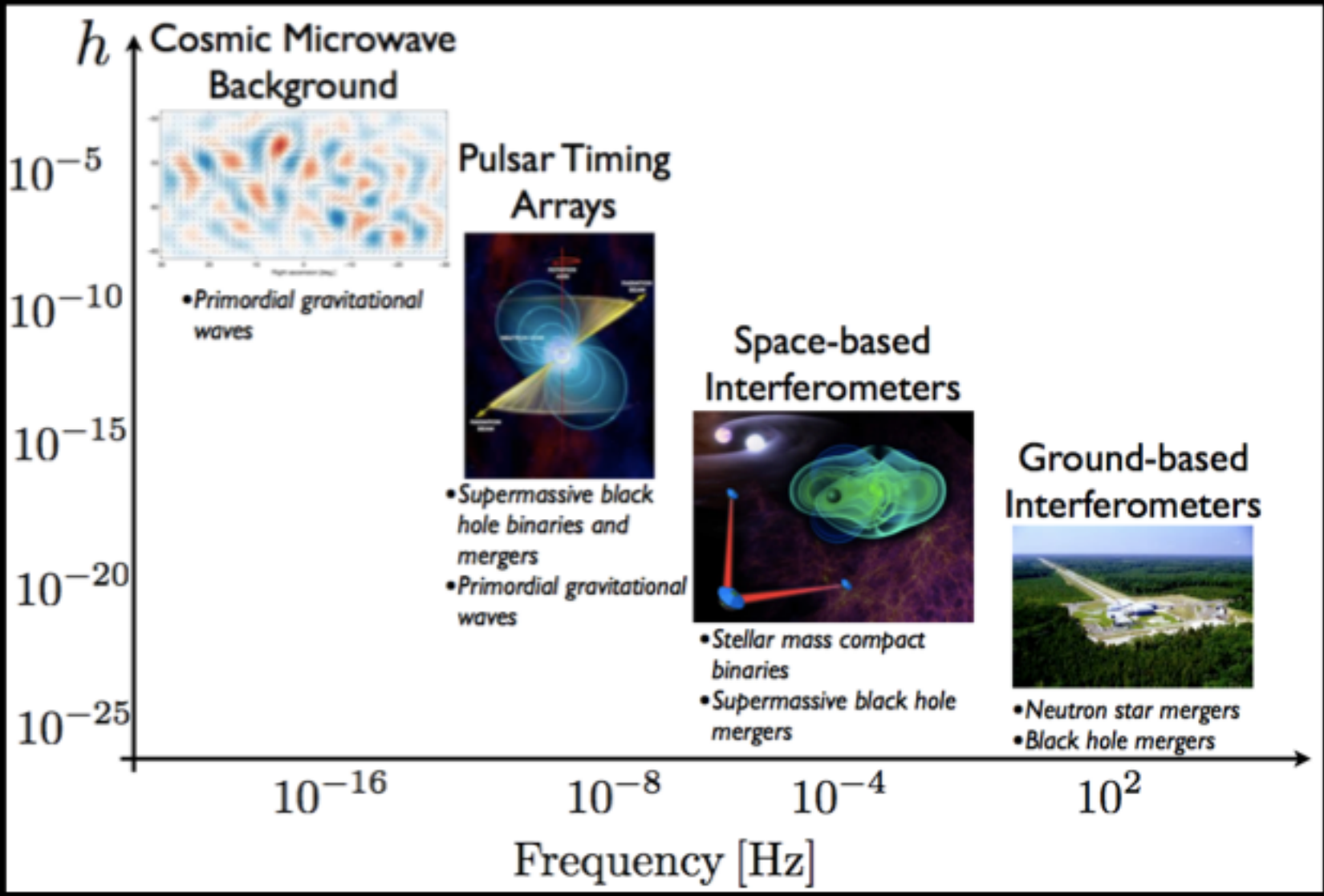
- PSR B1916+13 (Hulse-Taylor, Nobel Prize 1993)

Gravitational Waves



Nobel Prize 1993)

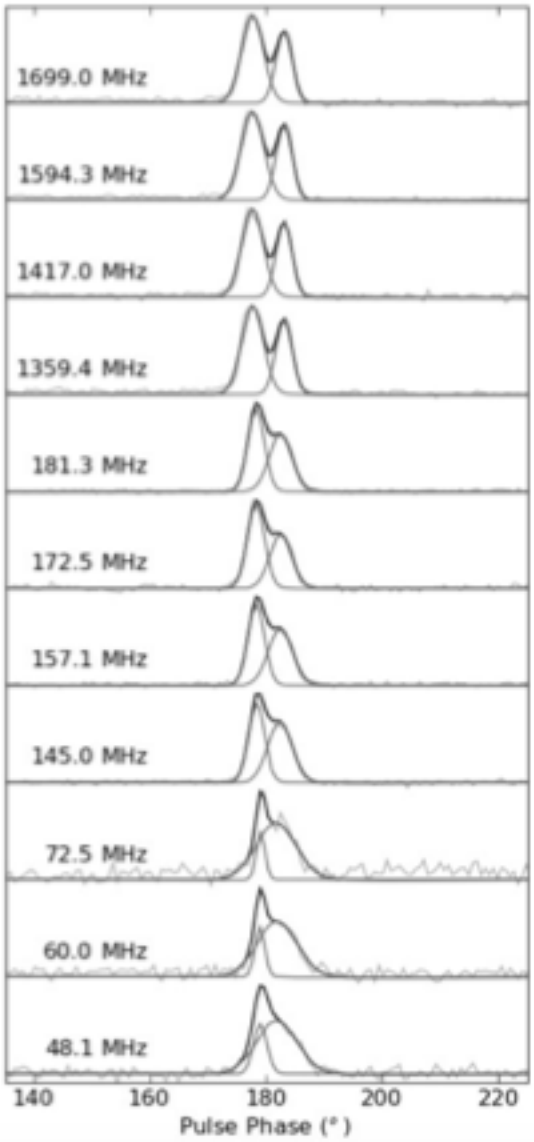
The GW Sky



Credit: G. Janssen

I-LOFAR's Role

- Impact of GWs on pulsar signal is small at ~100 ns
- Several 'interstellar weather' effects of order >~10 ns are larger at LOFAR freqs
- Profiles change with frequency, pronounced with LOFAR's fractional BW
- Measure with I-LOFAR and then apply to data @ ~10x higher frequency for even better timing
- I-LOFAR should spend ~1 day/week doing pulsars



Hassall et al. 2012

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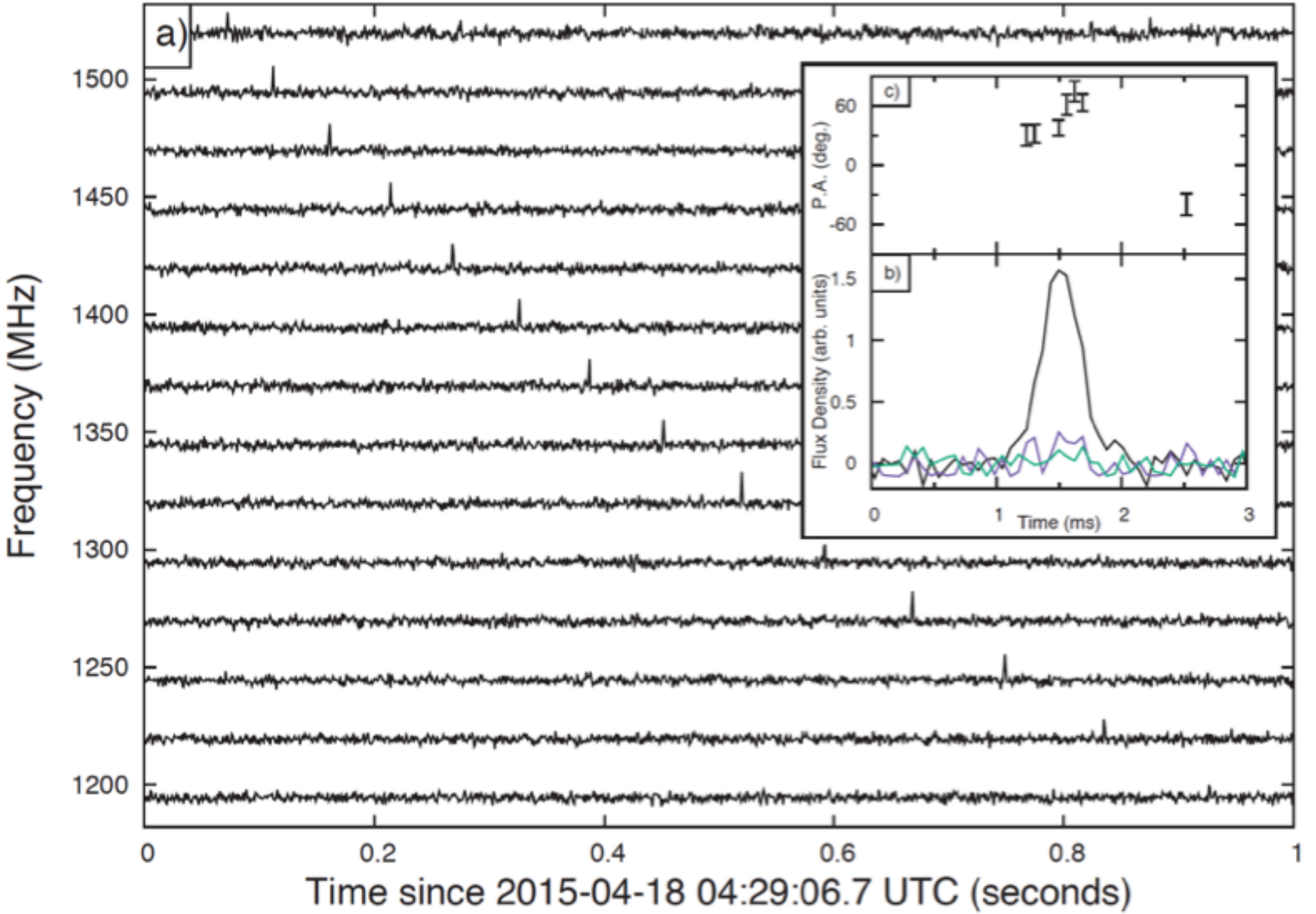
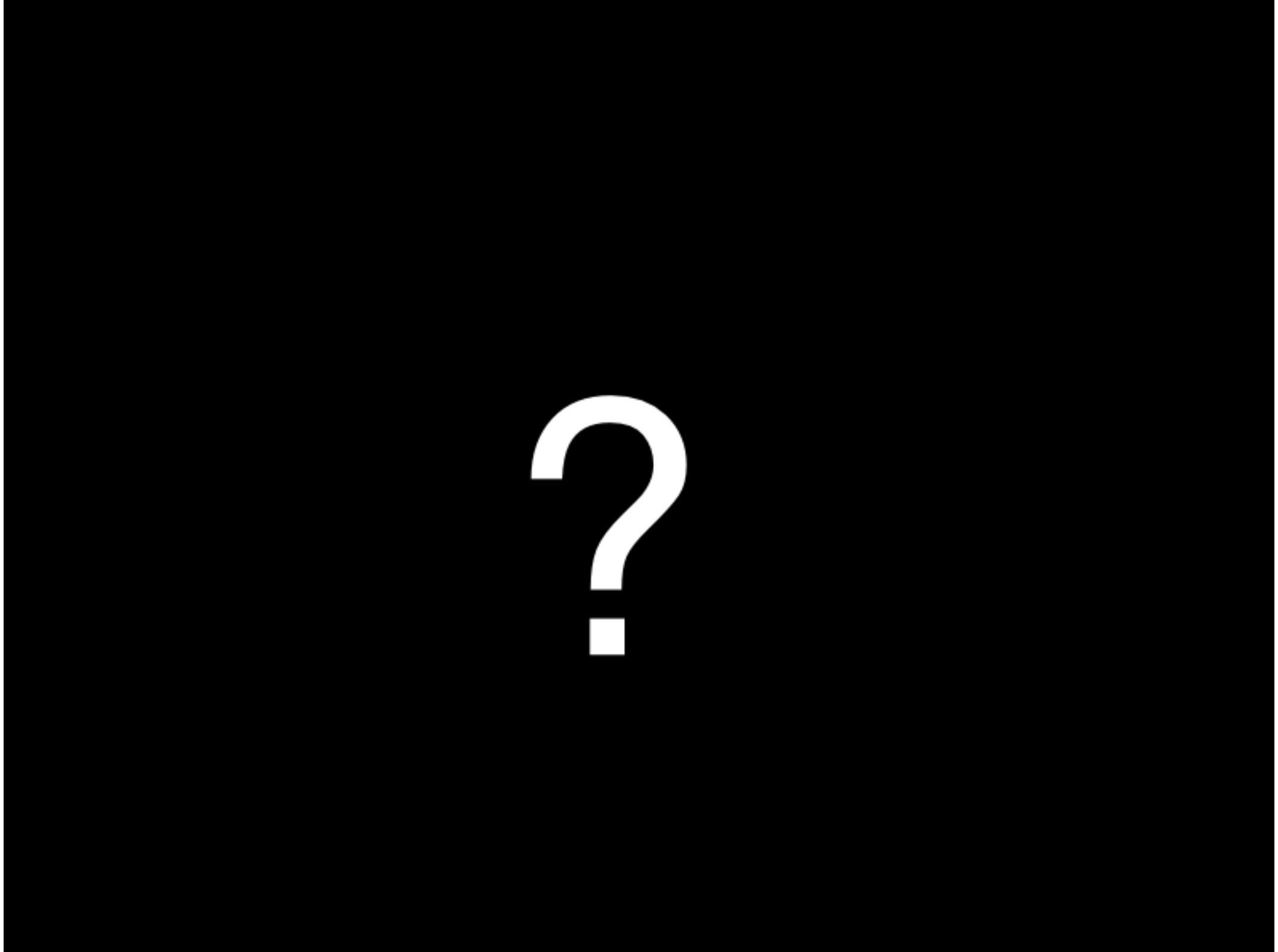
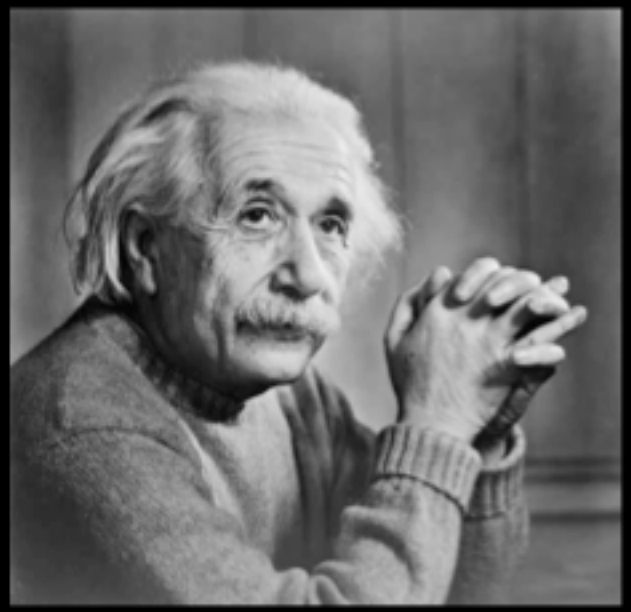
Fast Radio Bursts



Keane et al., 2016, Nature, 530, 453



Speed of Light: 300 km per millisecond



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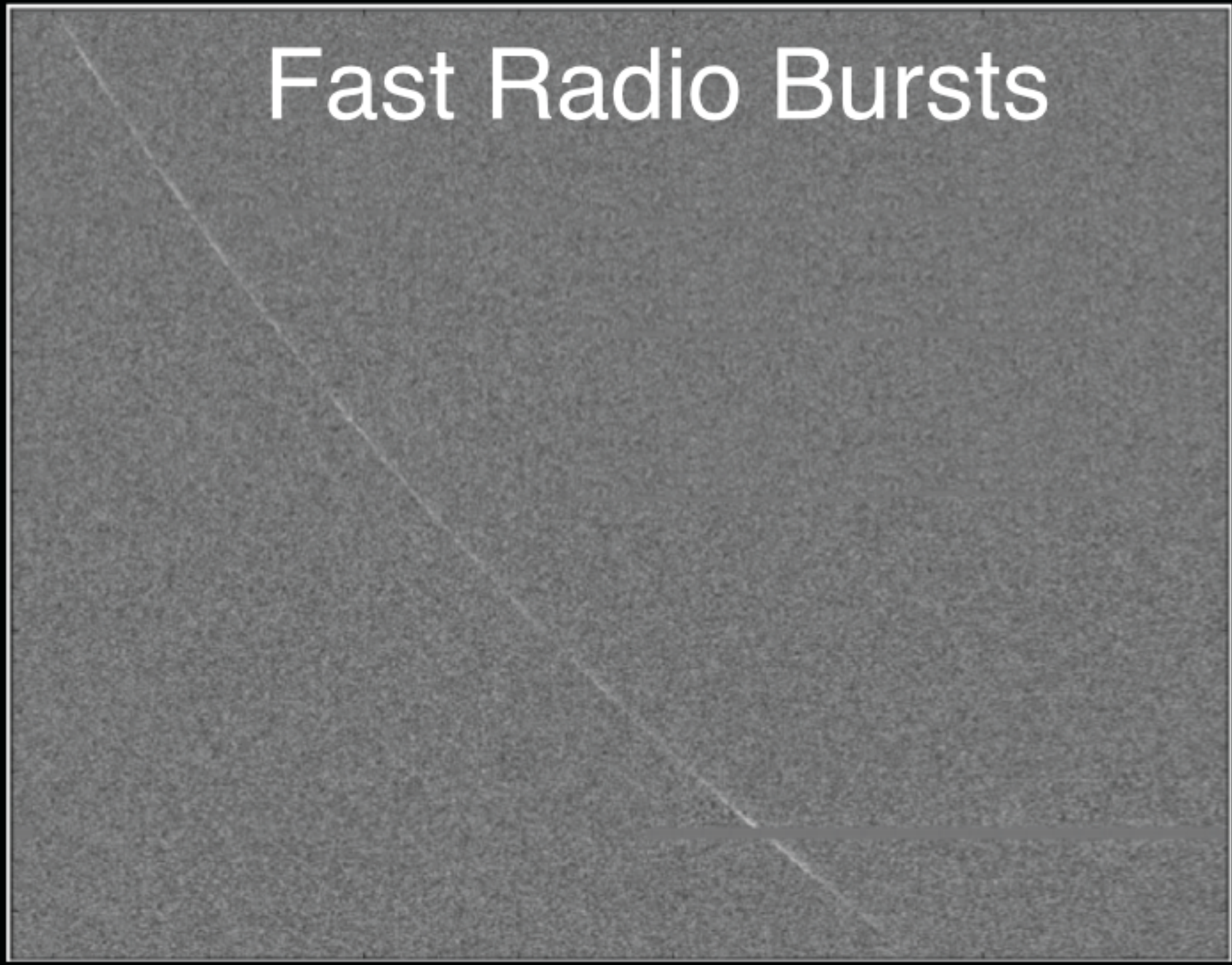
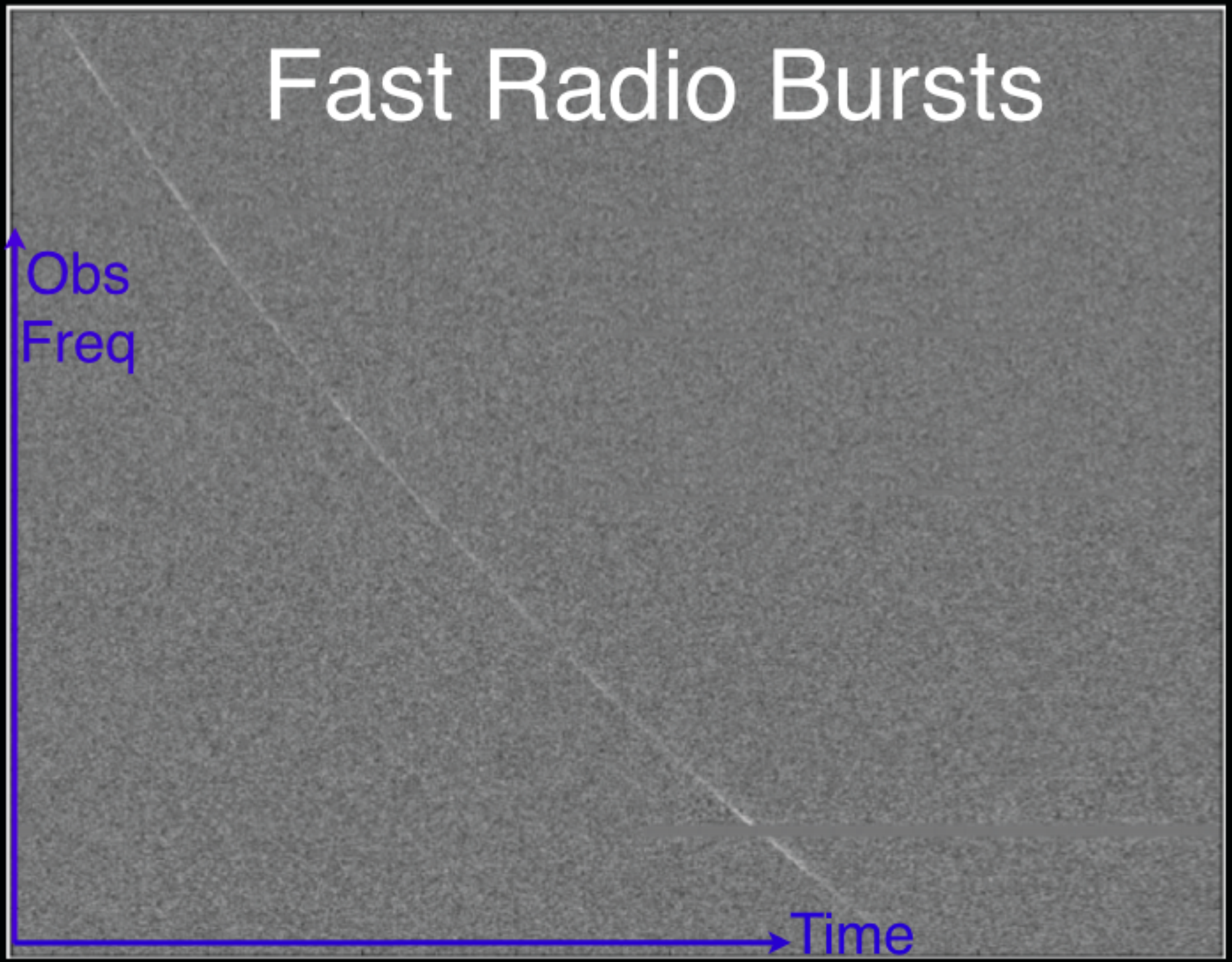



Fast Radio Bursts
Obs
Freq
Time

Fast Radio Bursts

Obs Freq

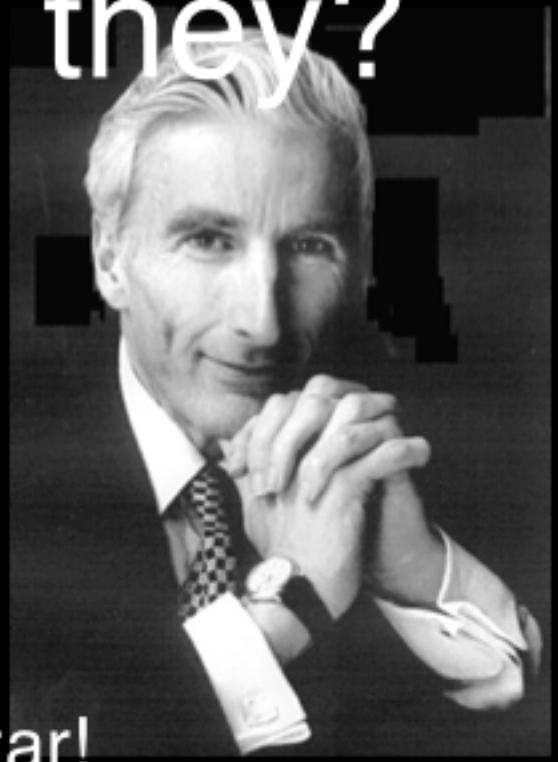
Time

Arrival time delay

$t_{delay} = 4.150 \text{ ms } (DM/f_{GHz}^2)$

$DM = \int n_e \, dl$

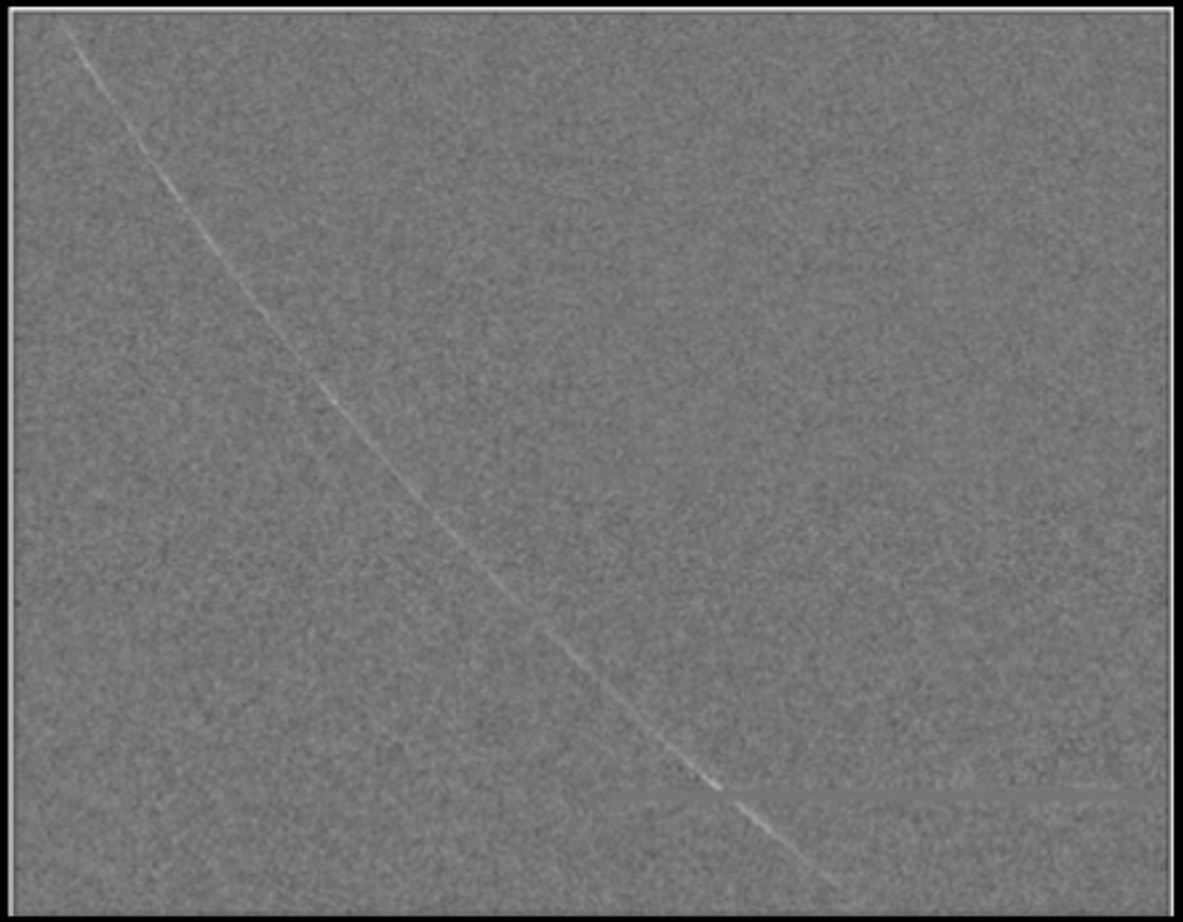
What are they?



- (Some seem to be from a) Blitzar!

A pulsar can become unstable as it spins slower
—> become a black hole
—> ejects its magnetosphere (hair)
—> “Reese fireball”

What are they good for?



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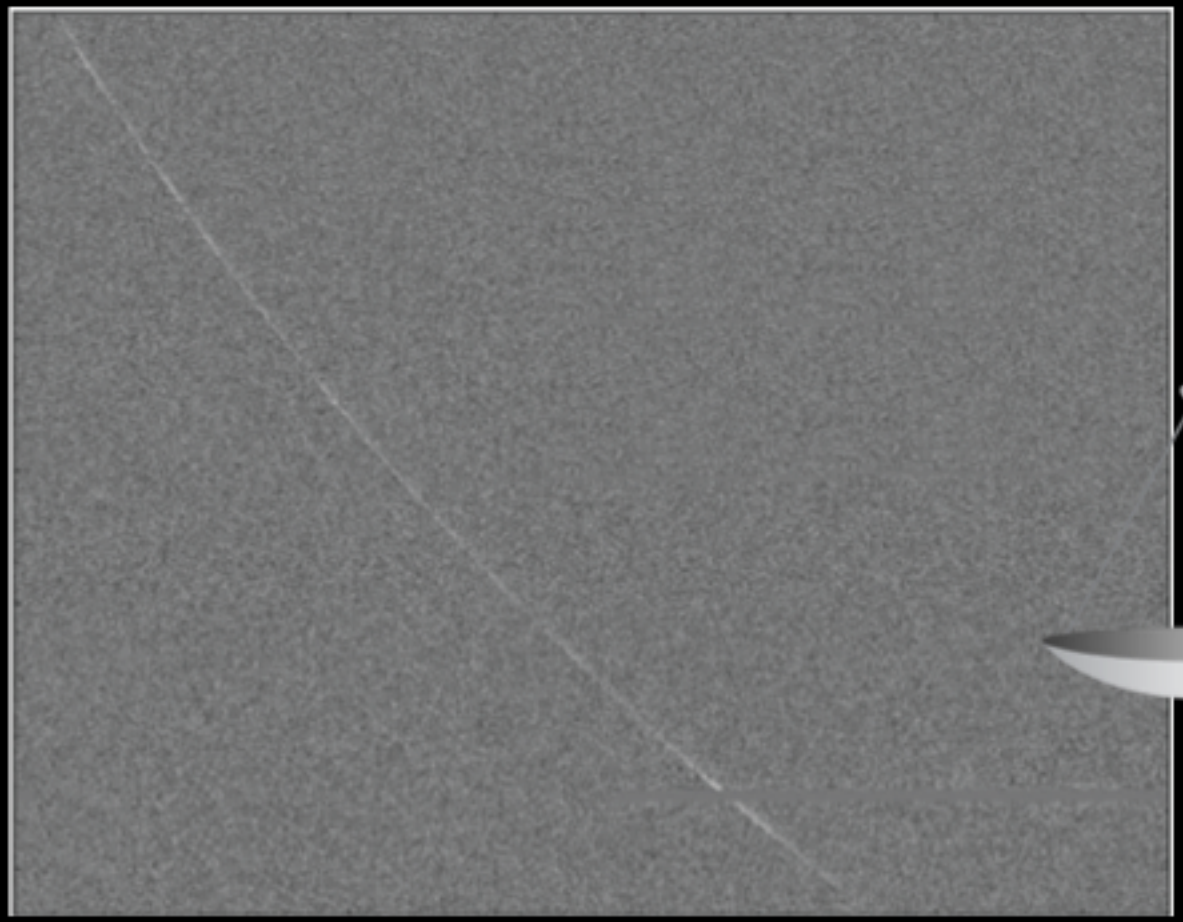

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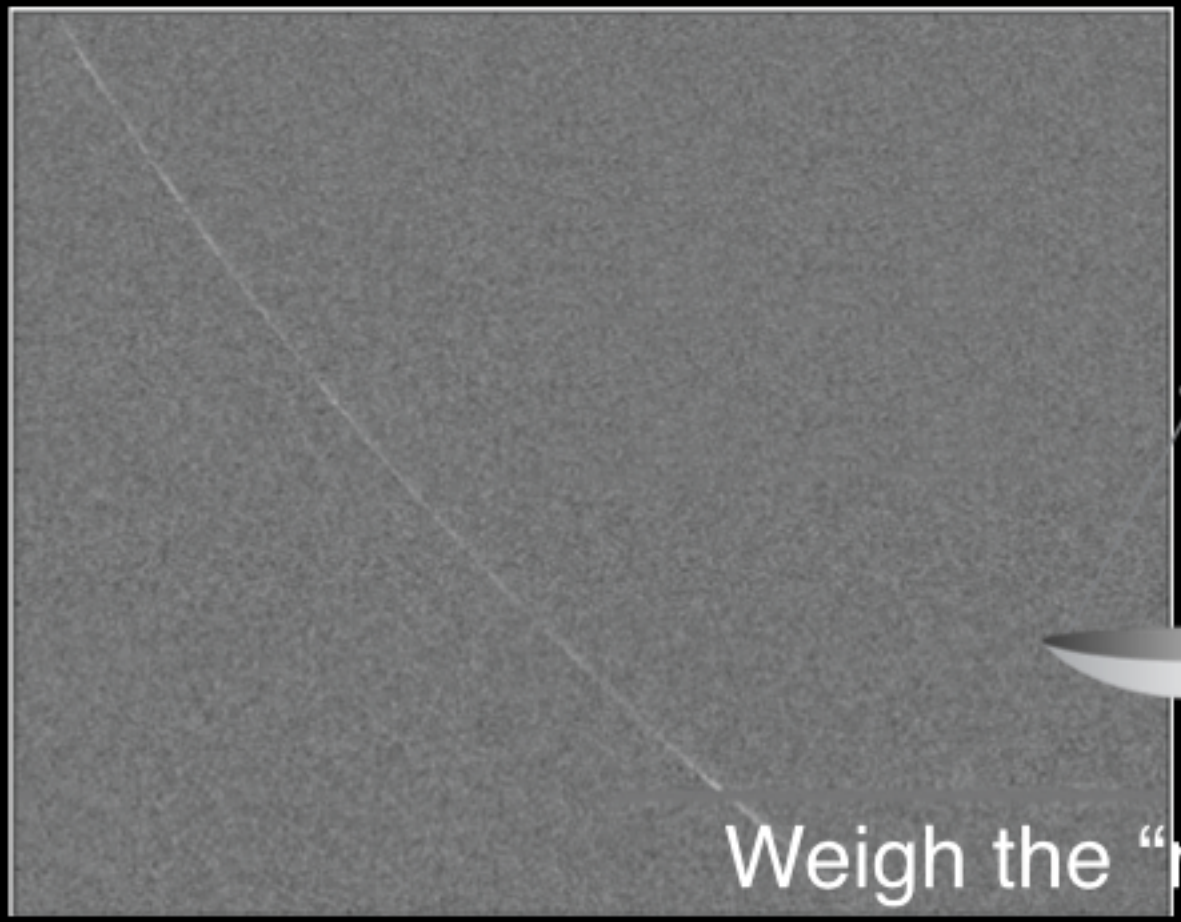
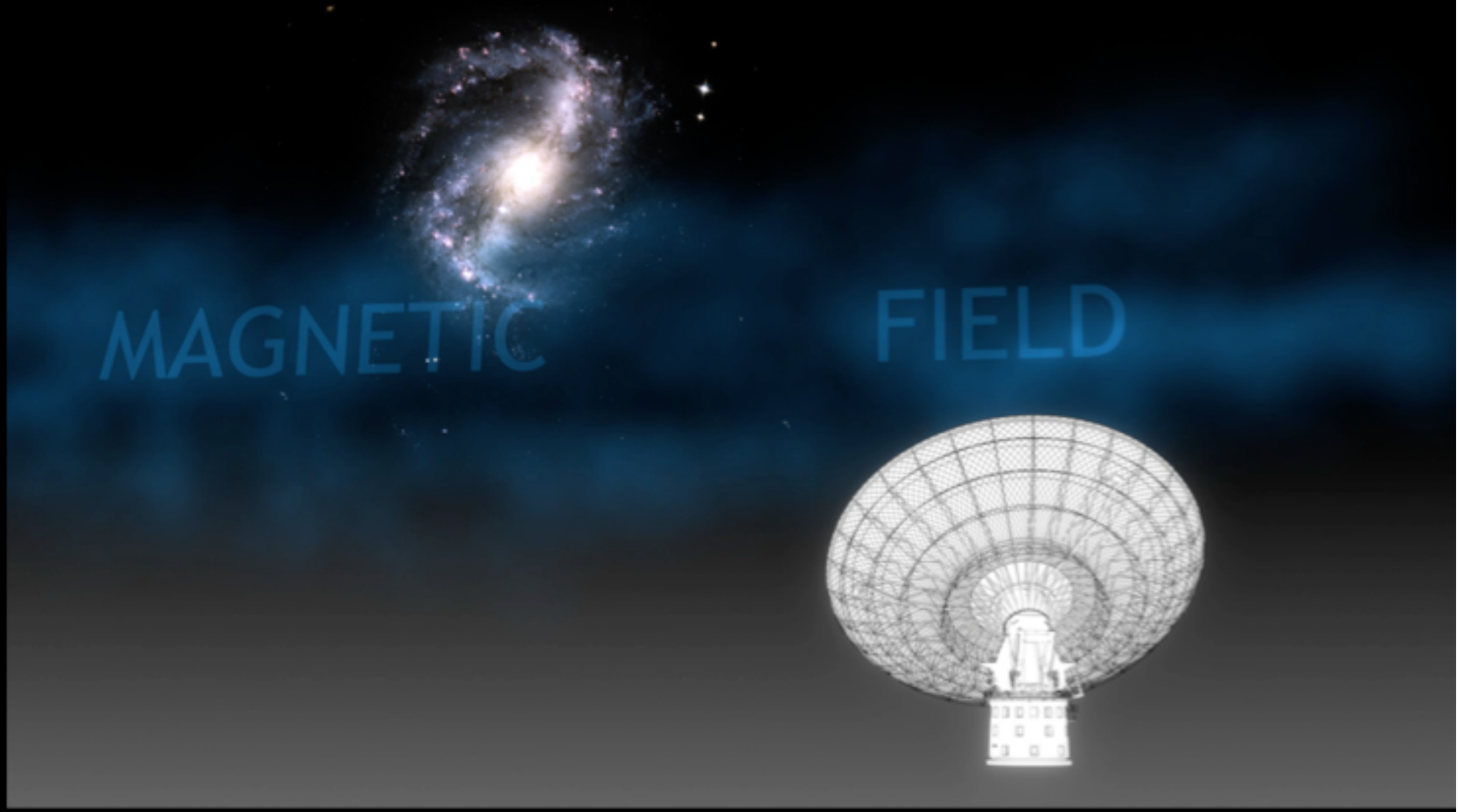


Weigh the “missing baryons”

What are they good for?



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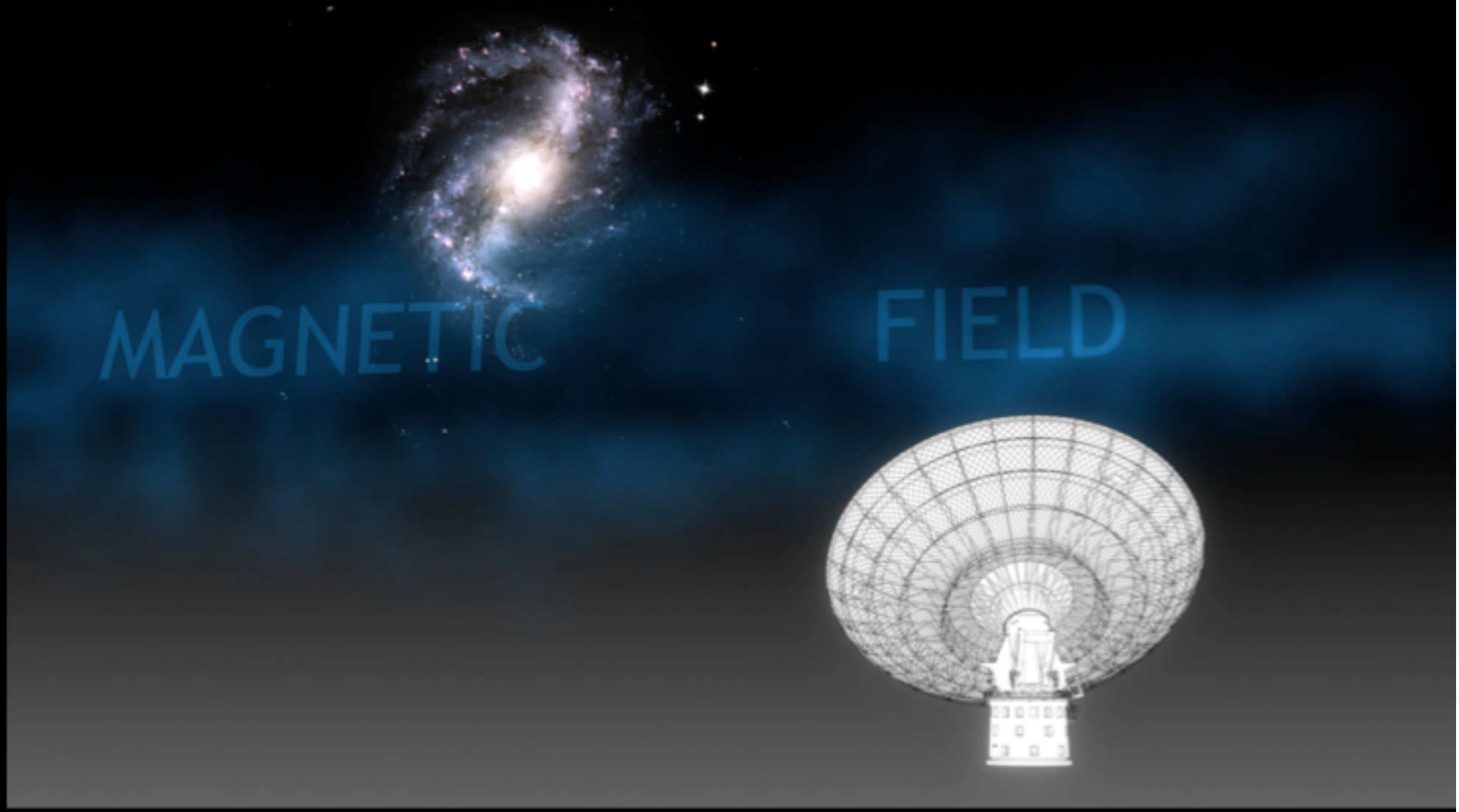


What are they good for?

Measure Dark Energy!

The Square Kilometre Array

SKA

SQUARE KILOMETRE ARRAY

SKA-MID

SKA1 MID - the SKA's mid-frequency instrument

The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

Location: South Africa

Frequency range: **350 MHz** to **14 GHz**

~200 dishes
(including 64 MeerKAT dishes)

Total collecting area: **33,000m²**

or **126 tennis courts**

Maximum distance between dishes: **150km**

SKA1 MID

Total raw data output:

2 terabytes per second

62 exabytes per year

x340,000

Enough to fill **340,000** average laptops with content **every day**

Compared to the JVLA, the current best similar instrument in the world:

4x the resolution

5x more sensitive

60x the survey speed

www.skatelescope.org Square Kilometre Array @SKA_telescope

SKA-LOW

SKA1 LOW - the SKA's low-frequency instrument

The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

Location: Australia

Frequency range:
50 MHz to **350 MHz**

~130,000
antennas spread between **500 stations**

Total collecting area:
0.4km²

Maximum distance between stations:
65km

SKA1 LOW

Total raw data output:
157 terabytes per second
4.9 zettabytes per year

Enough to fill up
35,000 DVDs
every second

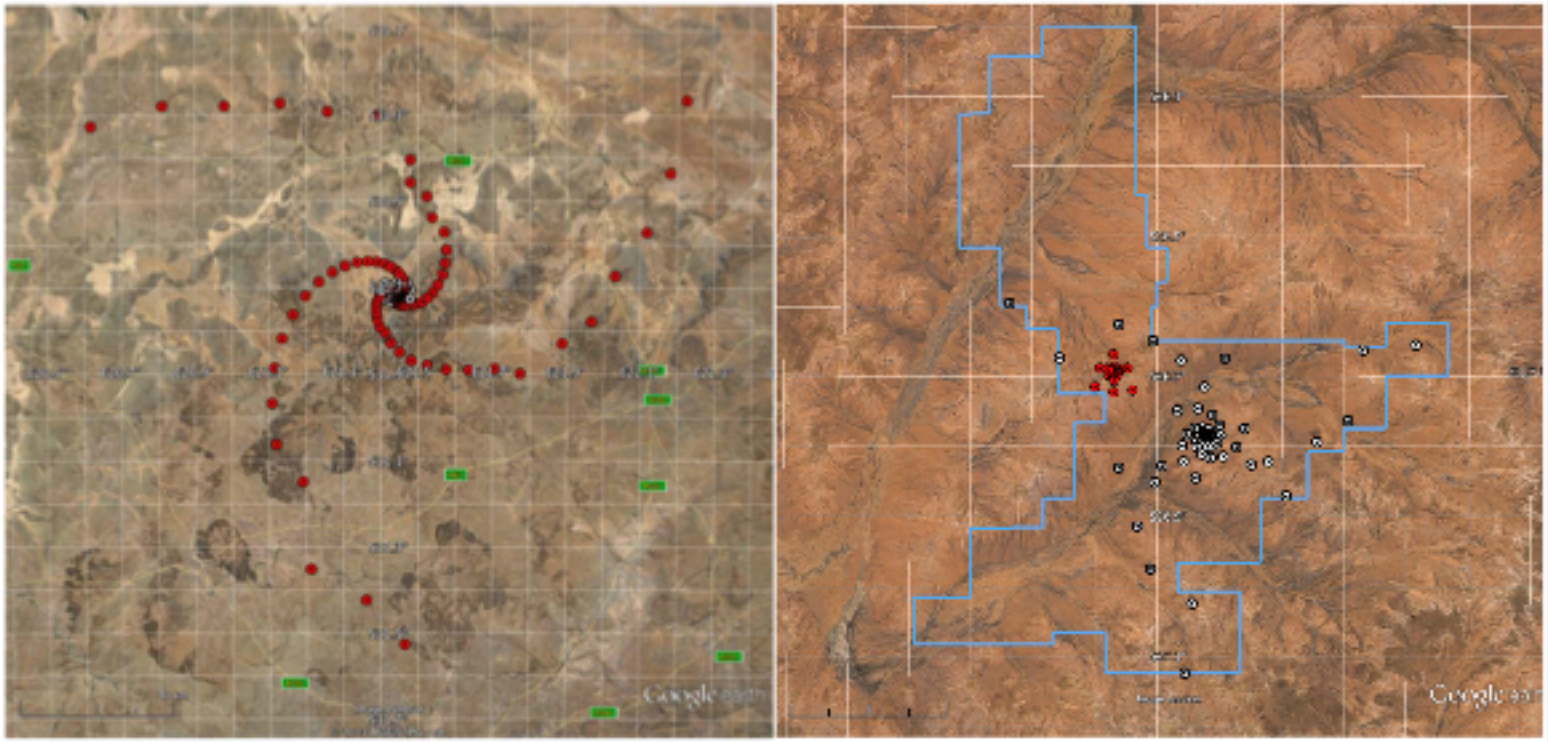
5x
the estimated global internet traffic in 2015
(source: Cisco)

Compared to LOFAR Netherlands, the current best similar instrument in the world

25% better resolution
8x more sensitive
135x the survey speed

Where is it?

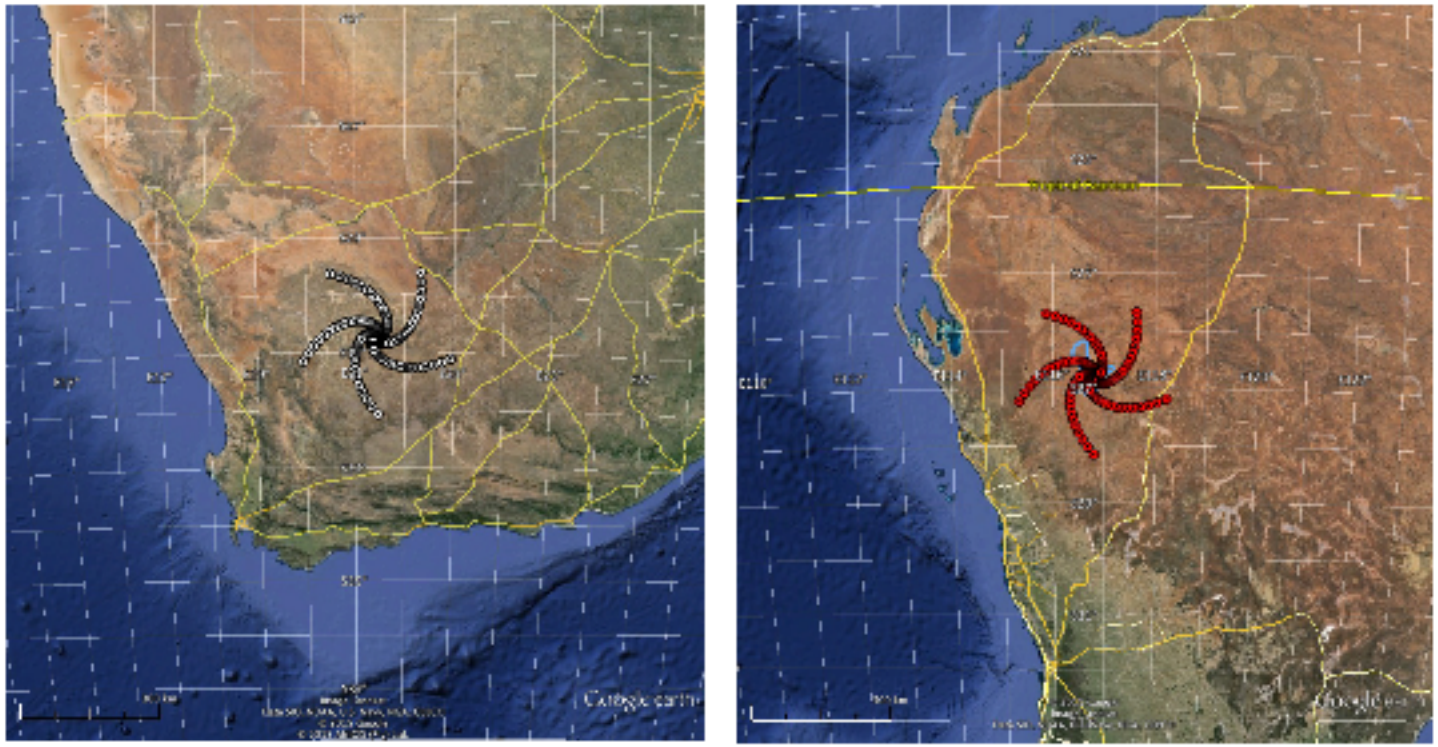
SKA1 Configurations



- SKA1–MID, –LOW: B_{Max} = 156, 65 km

Where is it?

SKA2 Configurations



- SKA2–Dish, –LOW: B_{max} ≈ 300 km “core”, ≈3000+ km remote

What is it good for?

What is it good for?

Science!

Science?

- Pulsars
- Cosmology
- “Epoch of Reionisation"
- “Cradle of Life”
- Transients & Searching the Unknown
- Magnetism
- Solar, Heliospheric & Ionospheric Physics

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Just some of the SKA science areas!

Searching the Unknown!

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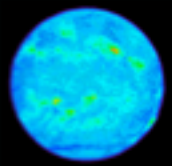
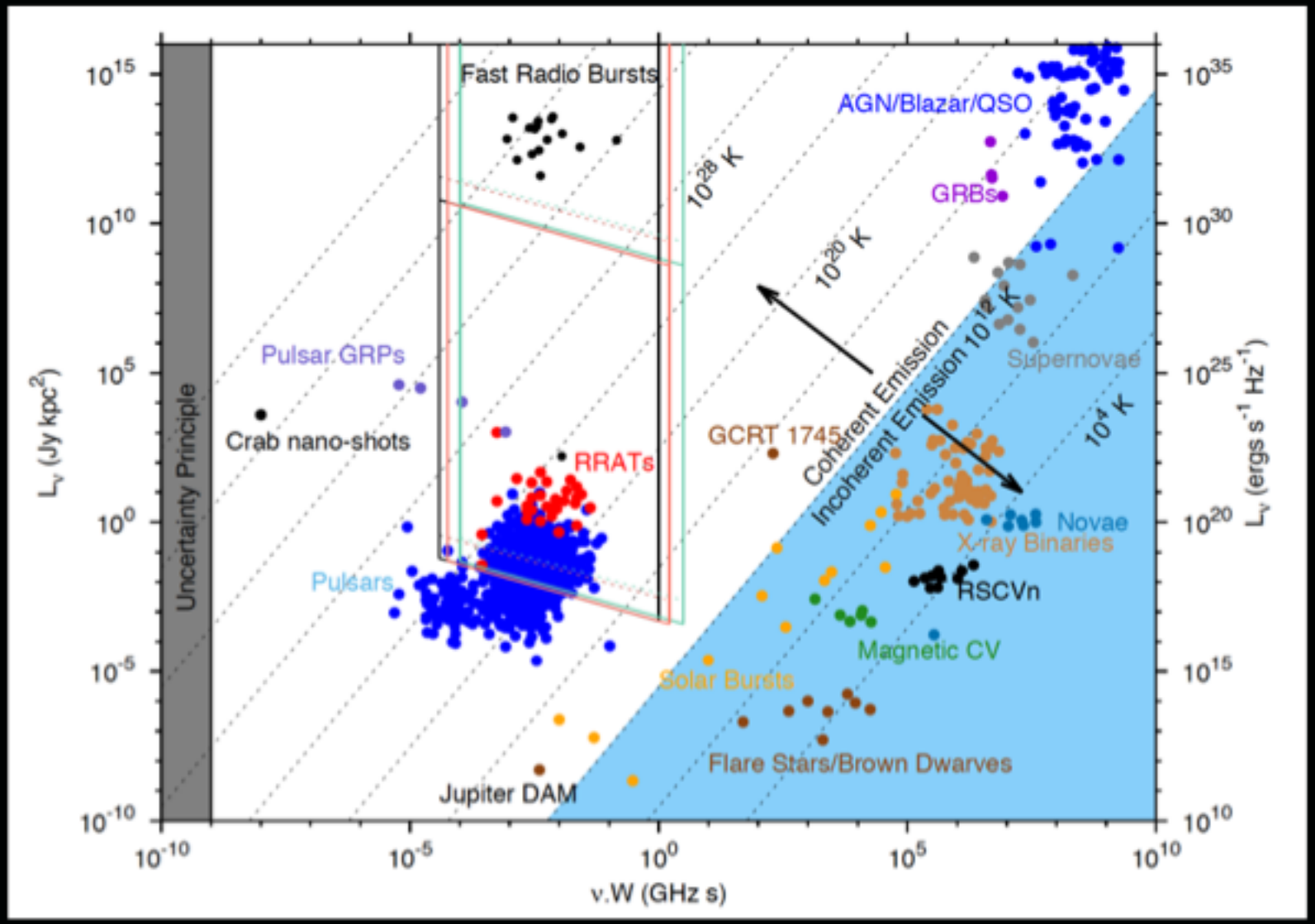
Searching the Unknown!



Transient Parameter Space

Bright



Faint

Fast

Slow

Take Home Points

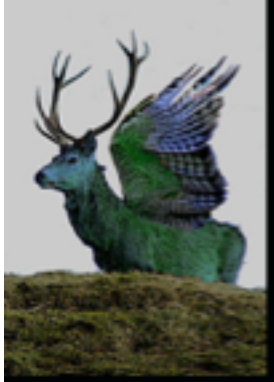
Pulsars
Super clocks revealing the true nature of gravity

Fast Radio Bursts
Violent explosions imprinted by “missing” mass, magnetic fields & dark energy en route to Earth

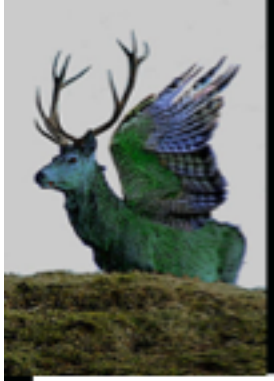
SKA
Will be the biggest telescope on the planet

Extra Slides

(For Best Questions)



SUPERB Discovery #2: Perytons



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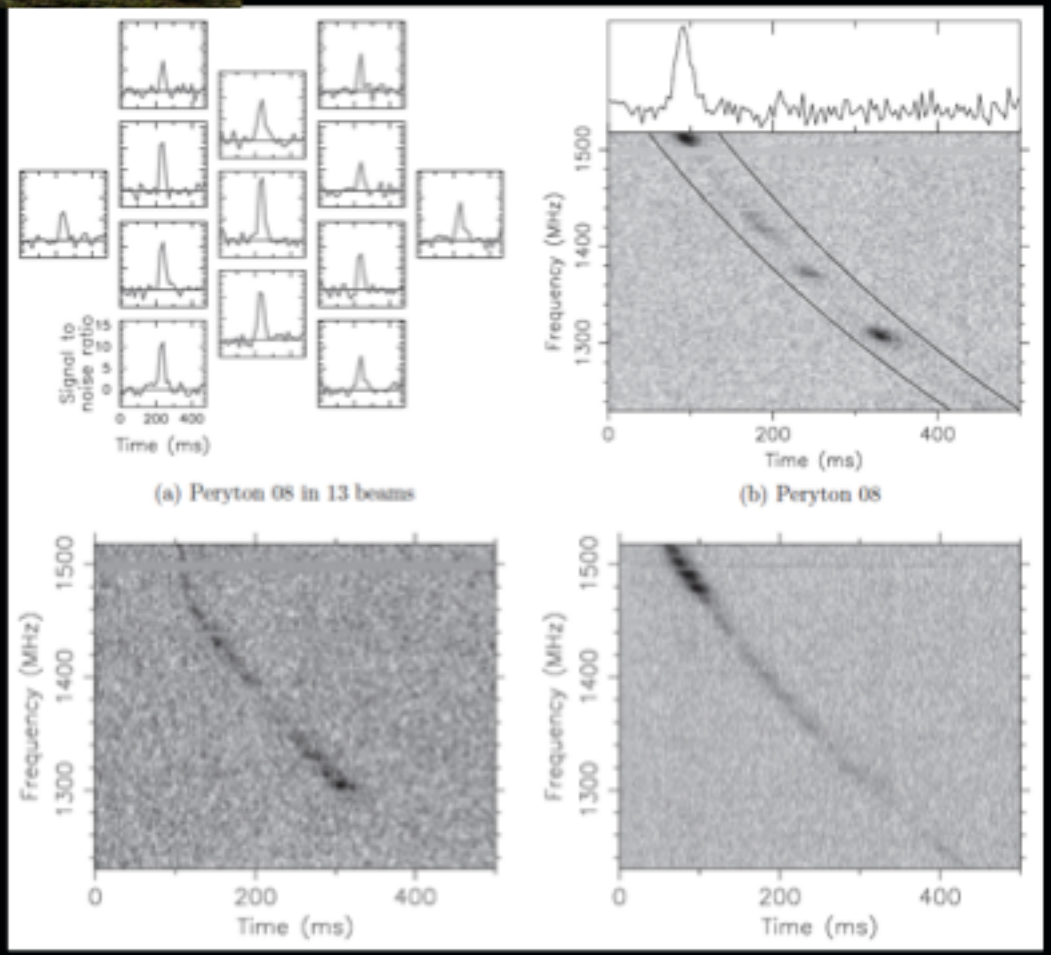
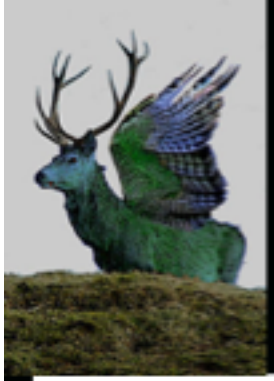


Burke-Spolaor et al, 2011, ApJ, 727, 18



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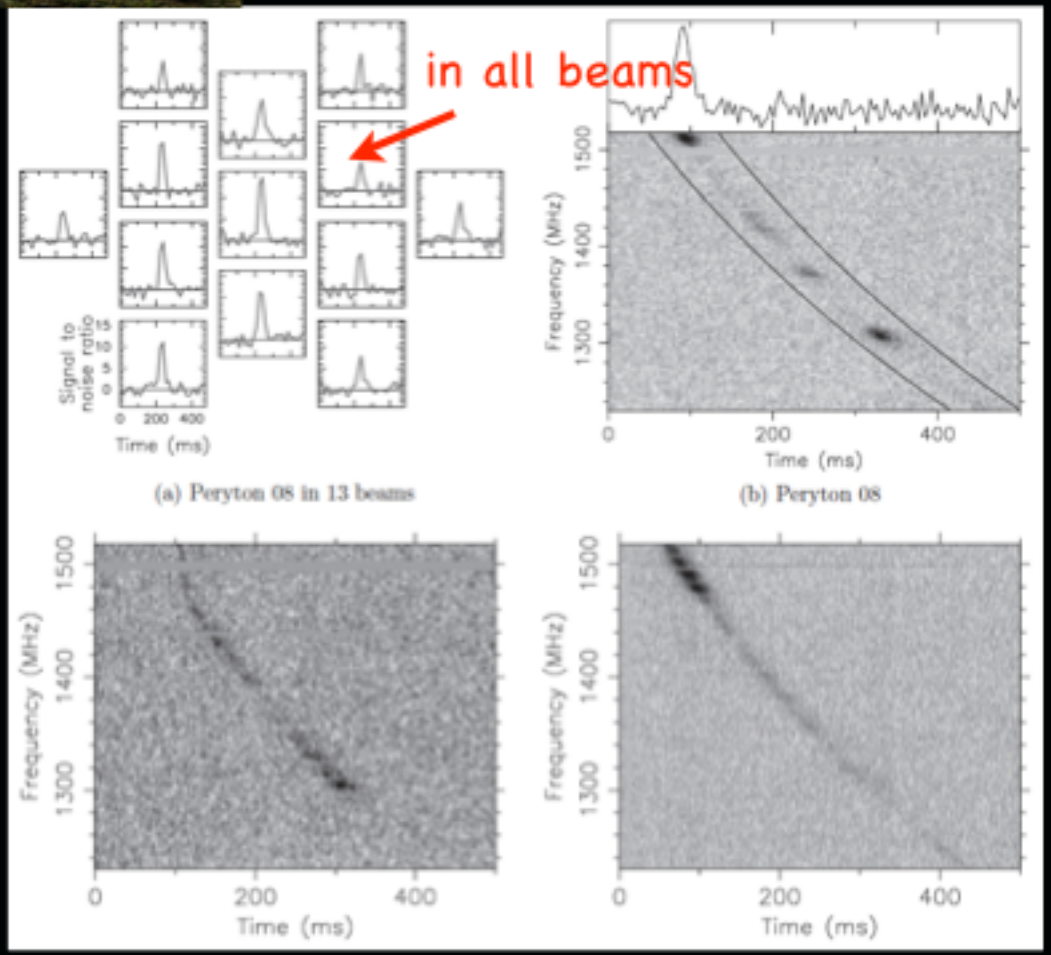

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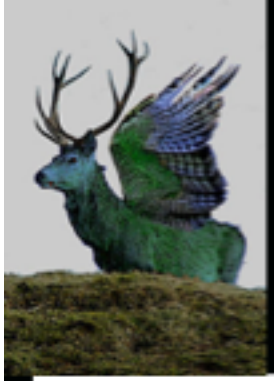

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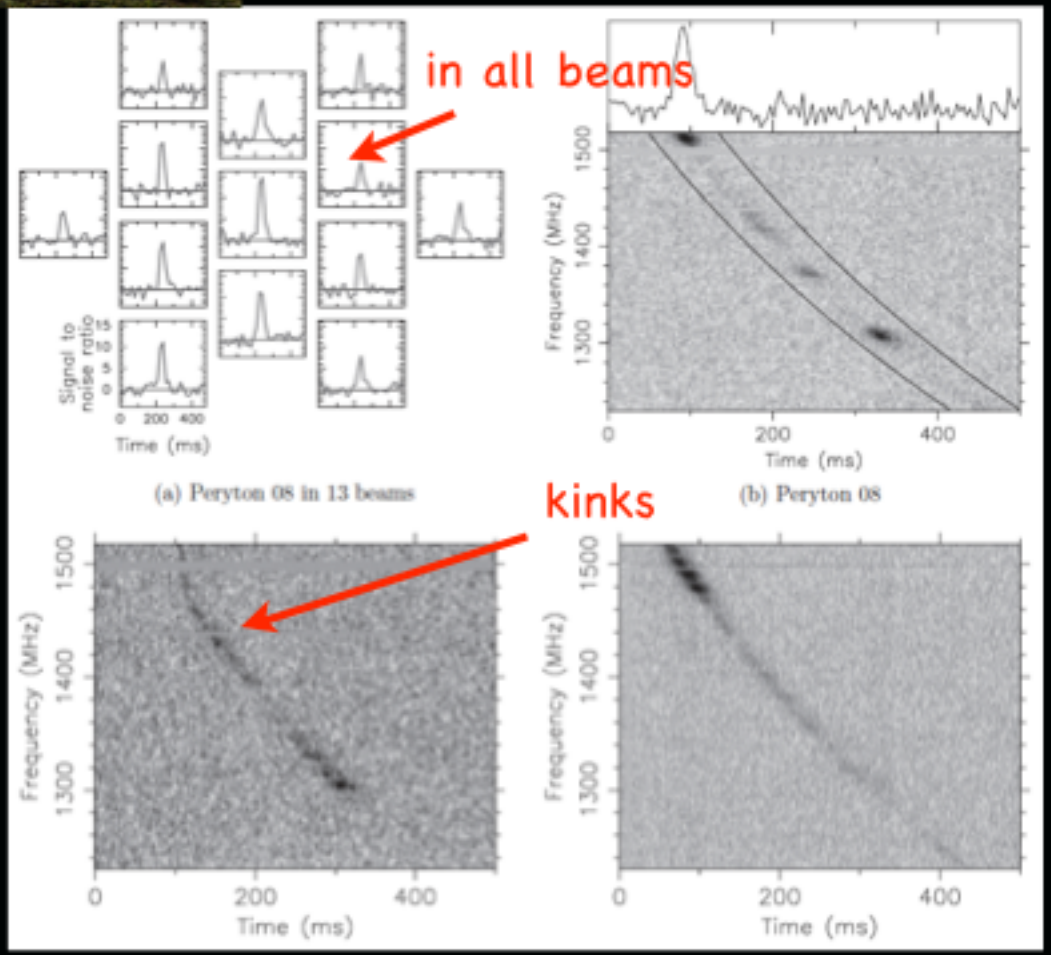

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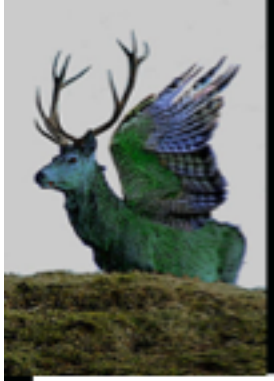

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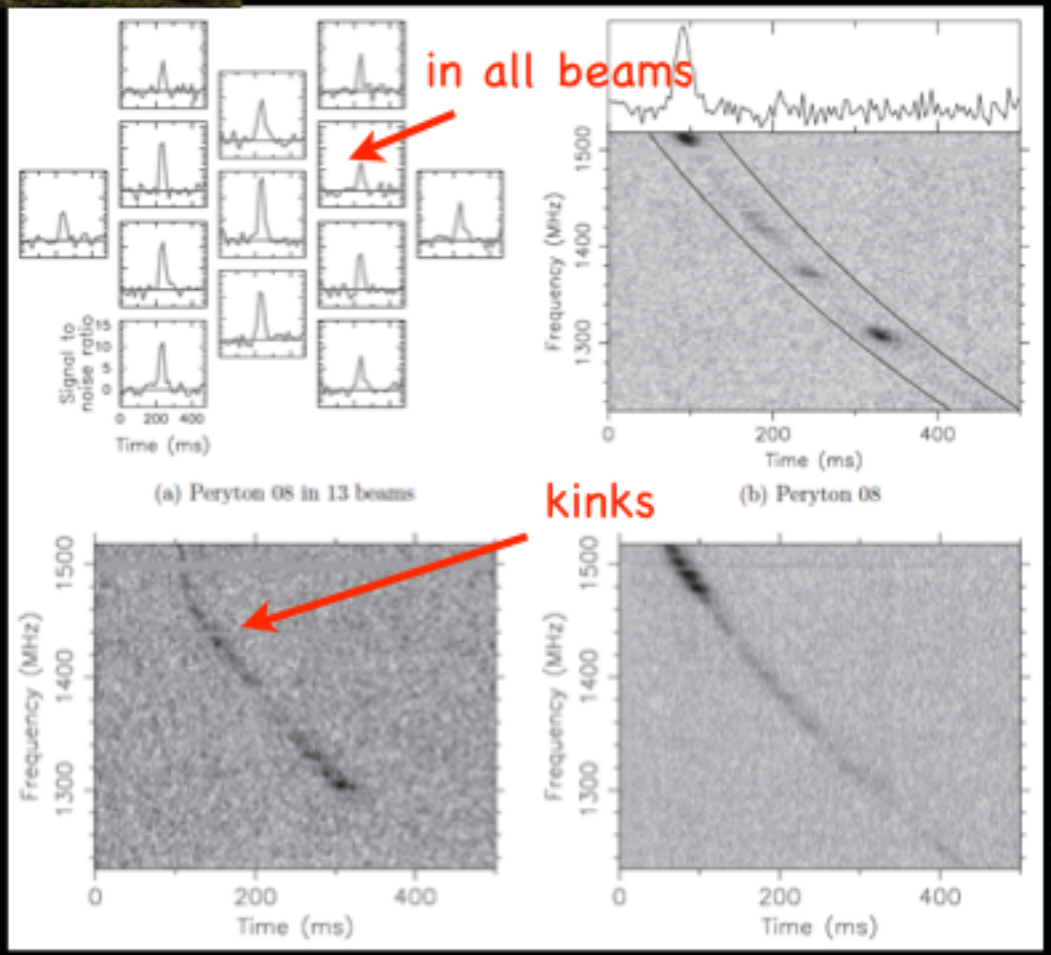

Burke-Spolaor et al, 2011, ApJ, 727, 18

- So what?
- Inferred "DM" close-ish to Lorimer Burst DM —> not really
- They occurred every N x 22.0 s
- Noticed in 2011, data from 1998!
- Clearly RFI of some sort …
- But peryton propaganda went viral

Perytons

Perytons

- Parkes L-band system ~1.15 to ~1.55 GHz
  Most likely sources of RFI would be most strongly emitting outside of this range

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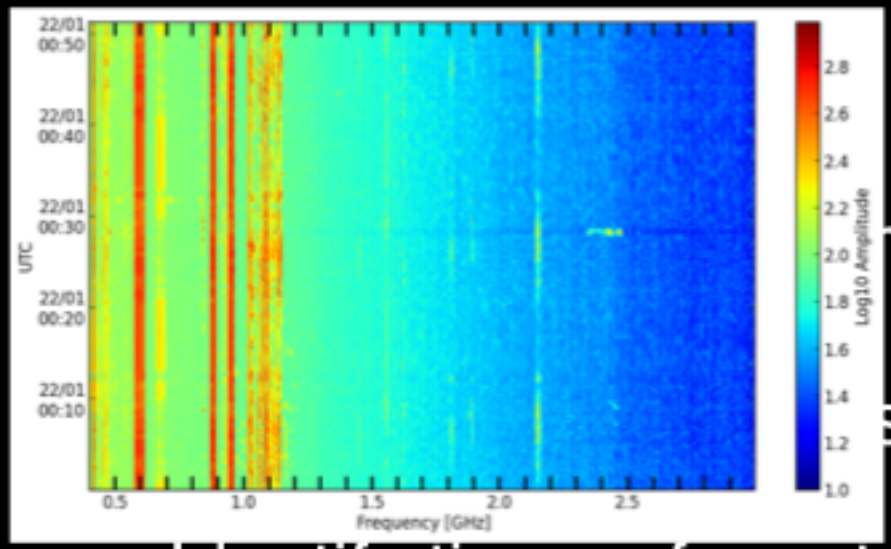
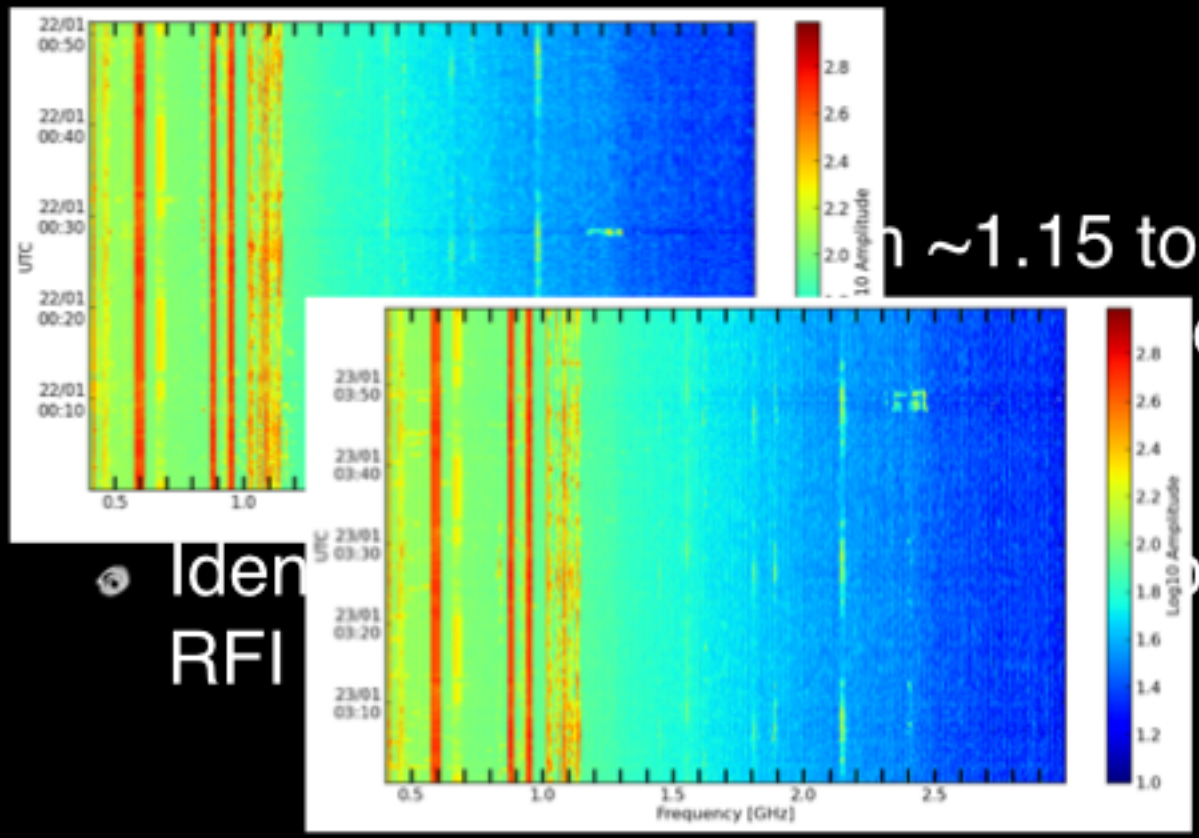
- Identify times of perytons at L-band —> what did the RFI monitor see?

Perytons



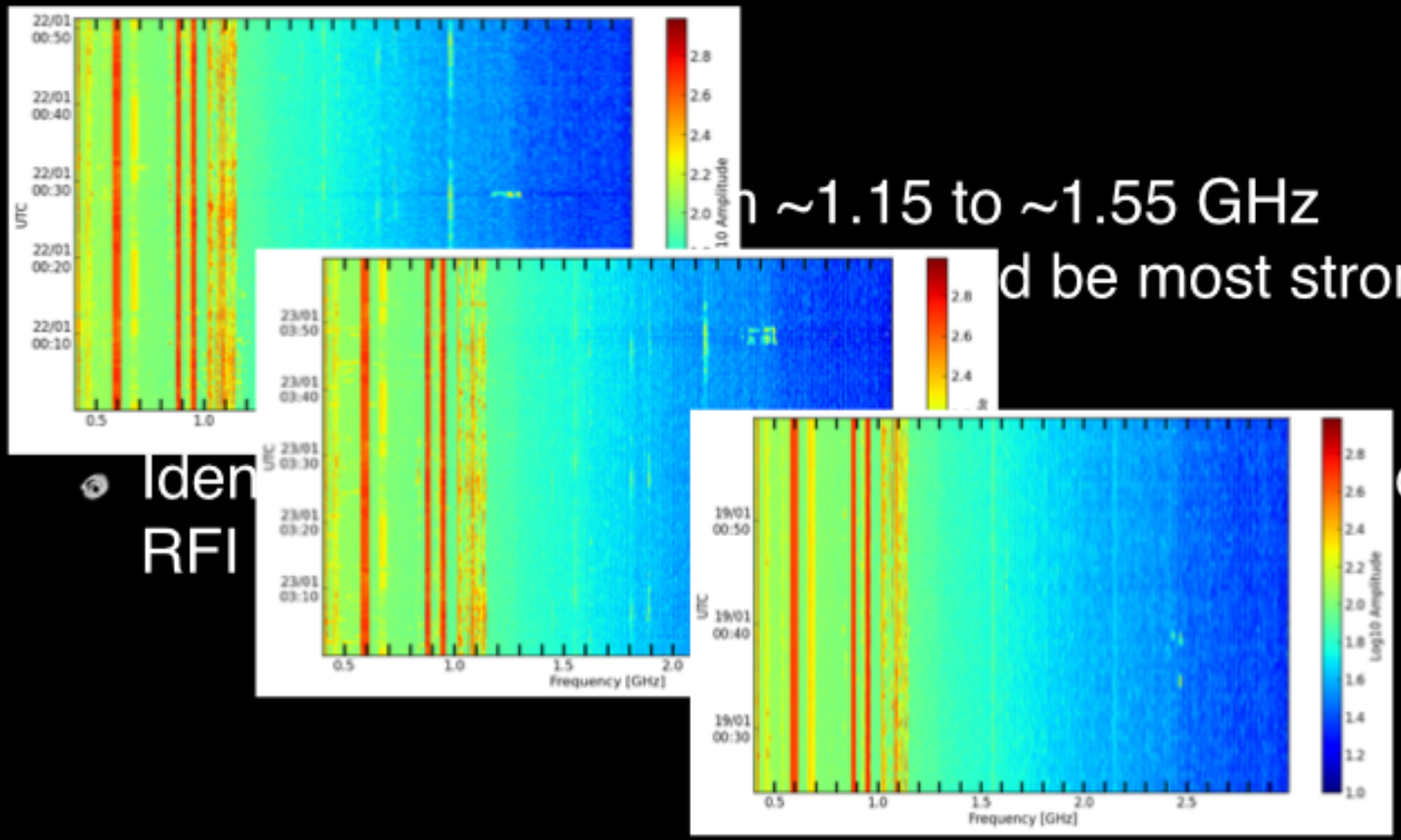
- …n ~1.15 to ~1.55 GHz
- … RFI would be most strongly
- …s range
- Identify times of perytons at L-band —> what did the RFI monitor see?

Perytons



- Iden band —> what did the RFI

Perytons



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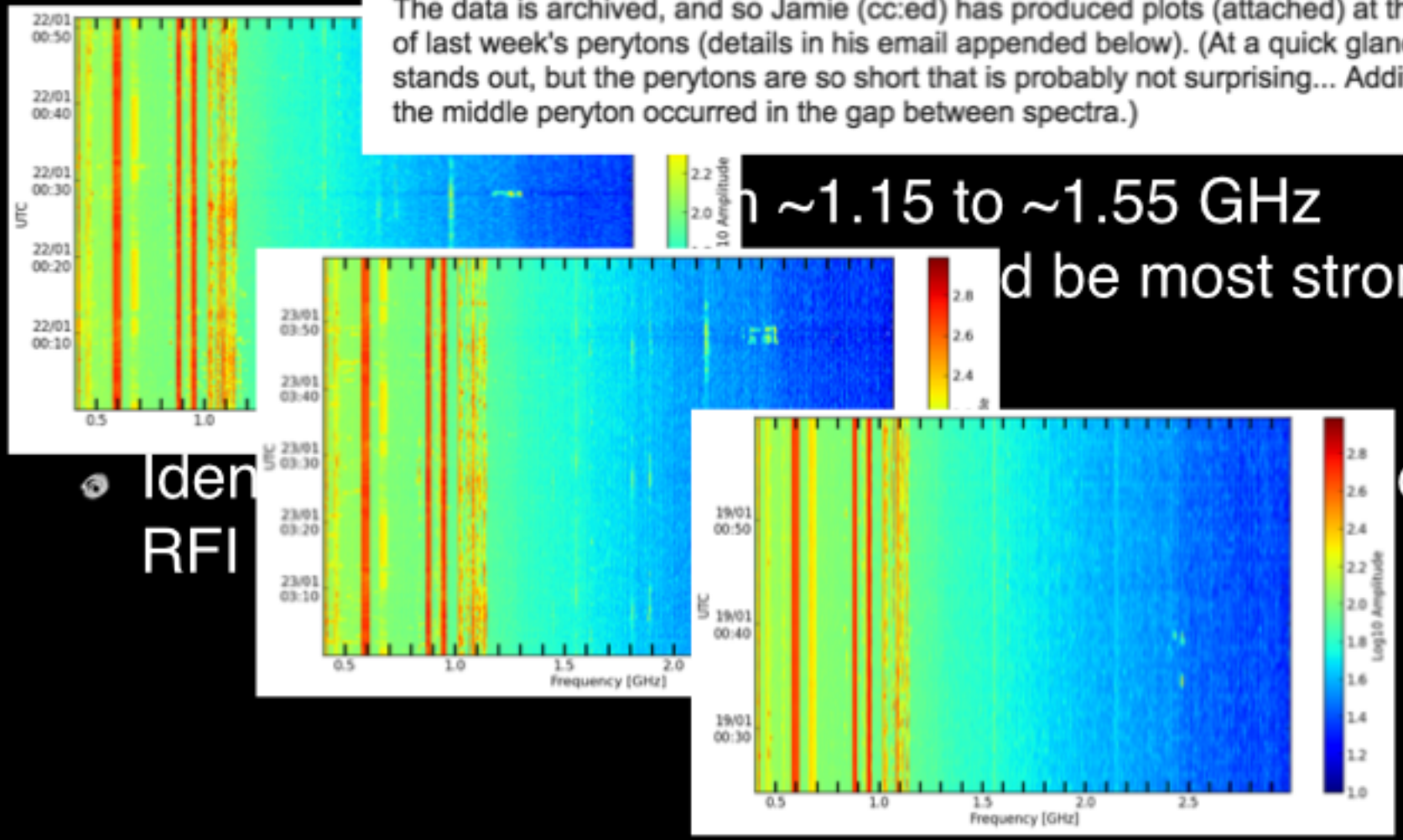

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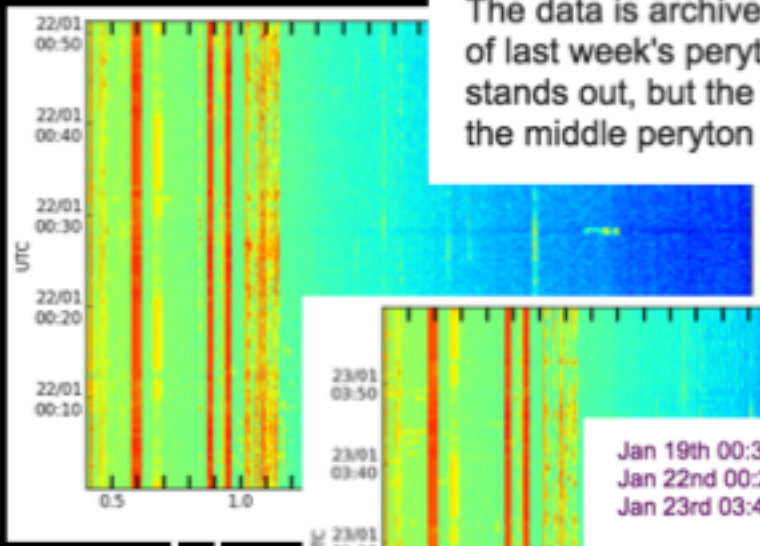

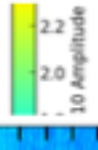

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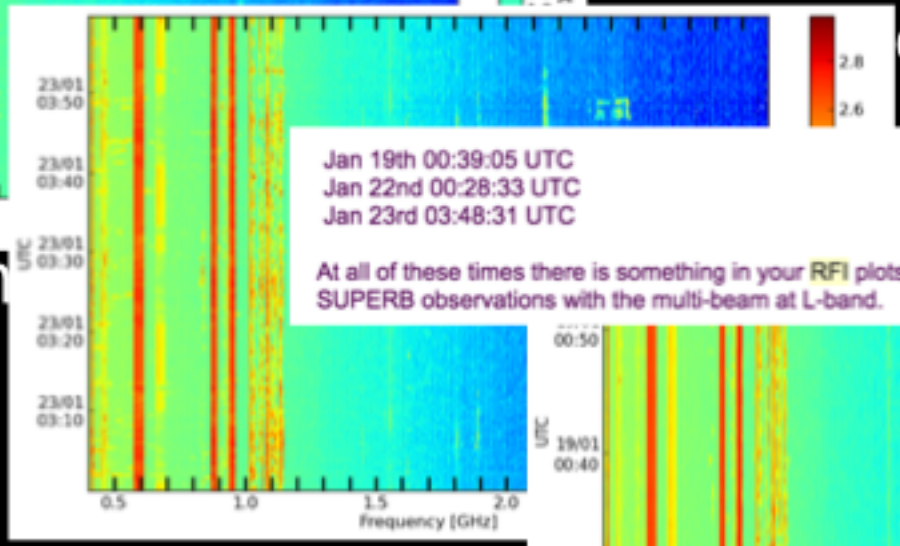
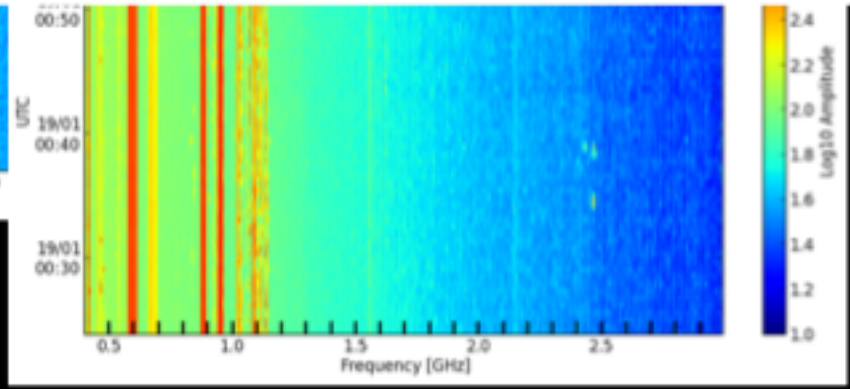


Jan 19th 00:39:05 UTC
Jan 22nd 00:28:33 UTC
Jan 23rd 03:48:31 UTC

At all of these times there is something in your RFI plots at between 2.3 and 2.5 GHz. This is of course out of our band for the SUPERB observations with the multi-beam at L-band.



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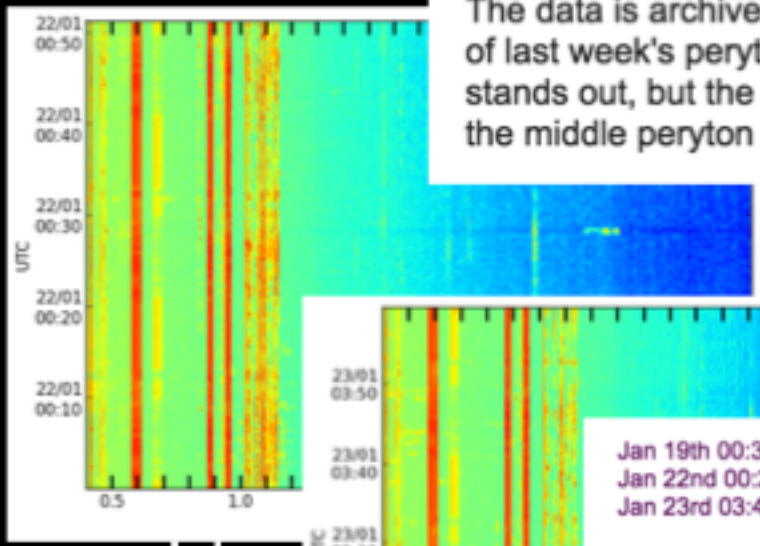

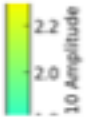

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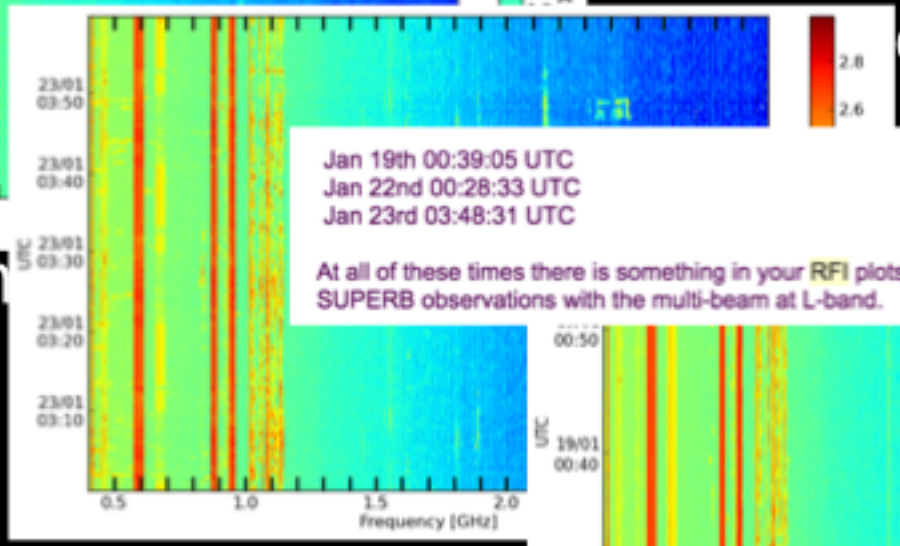

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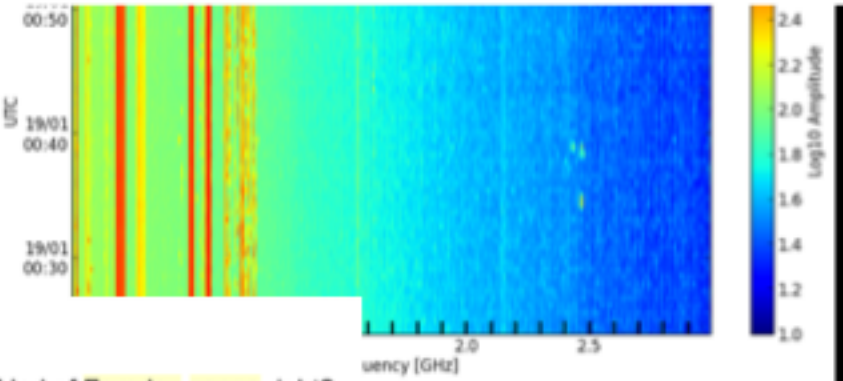

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Quick question: these microwave ovens around the site are in some kind of Faraday cages right?

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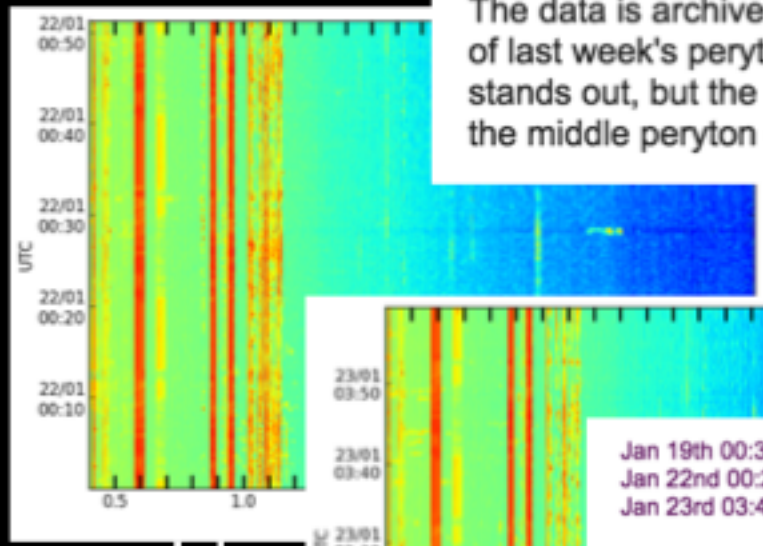

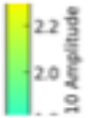

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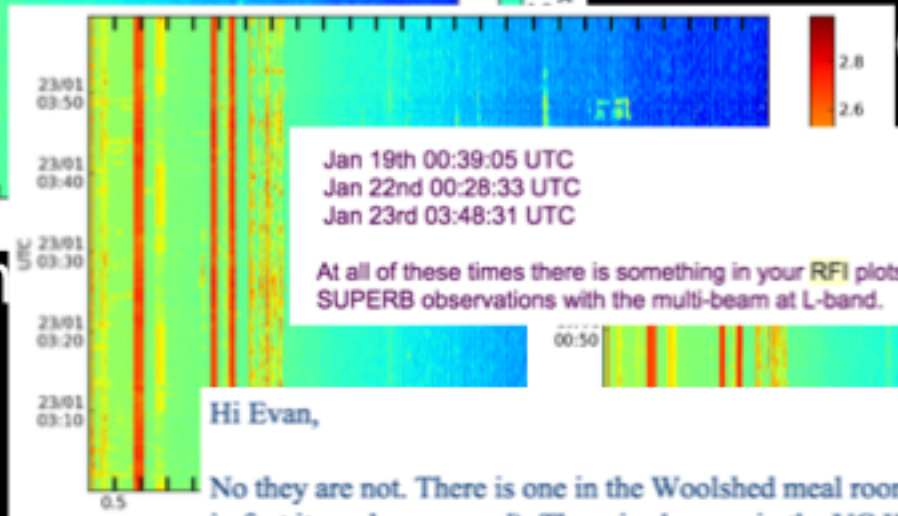

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RFI

Hi Evan,

No they are not. There is one in the Woolshed meal room, and one in the base of the tower (which gets little or no use now, in fact it can be removed). There is also one in the VC Kitchen area. I have one at my house, and so does the other resident, in their house.

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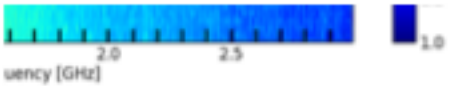
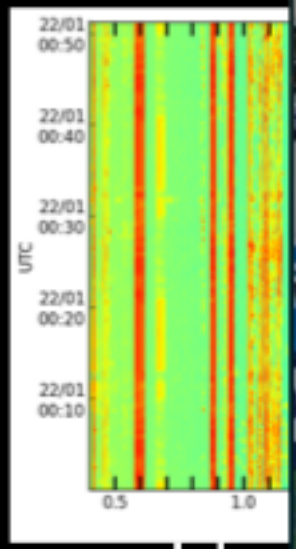


Perytons

Petroff et al, 2015, MNRAS, 451, 3933



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This is the microwave oven Faraday cage at @jodrellbank. It's a beast.

16 9

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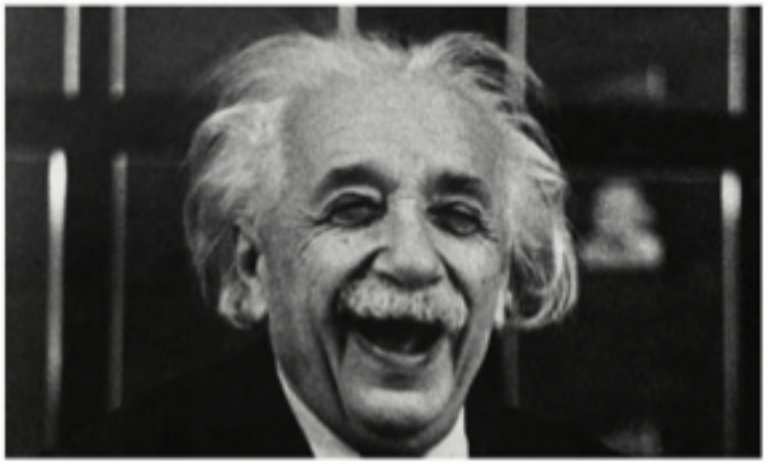
Gravitational Waves

- Hulse-Taylor Indirect
  —> Want direct detection
- GWs passing by PSR and/or Earth effects observed TOAs
- TOAs earlier/later by ~100 ns or less
- Sensitive to waves of frequency ~1/(10 years) to ~1/(1 week)
  —> nanohertz gravitational waves



Credit: M. Purver

Observing cadence

Observing baseline: Keeps getting better

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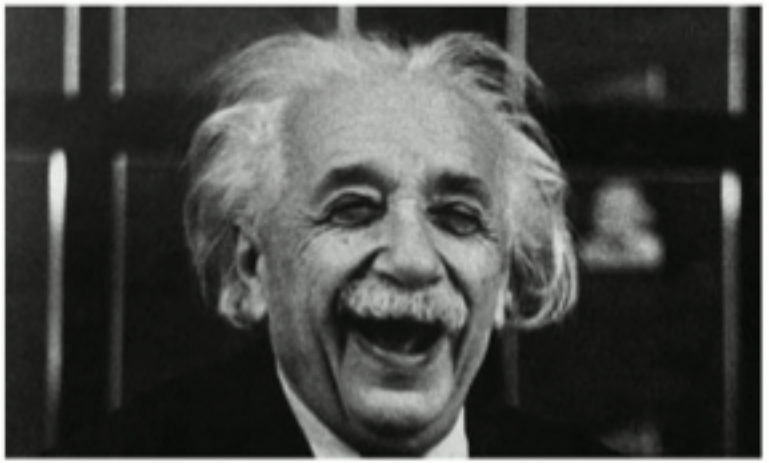

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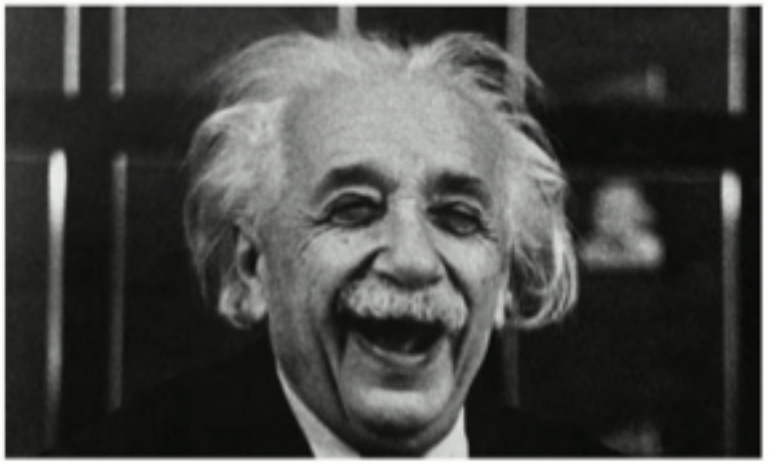

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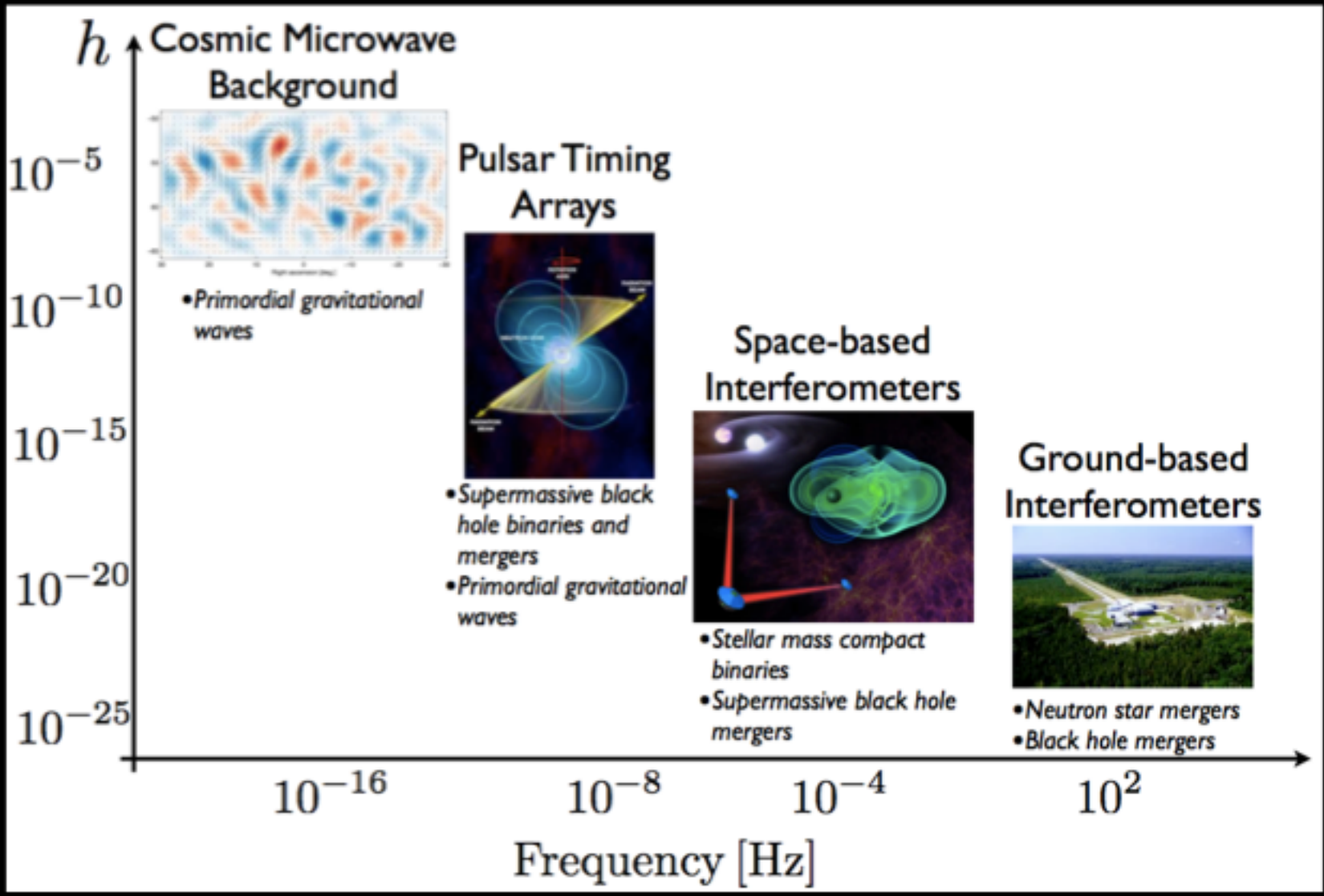
The GW Sky



Credit: G. Janssen

SKA Status

- SKA currently has 10 member countries
  AUS, ZA, UK, IT, NL, CN, IN, CA, SW, NZ
- IGO Treaty set to be ‘initialed’ in coming months
  —> then treaty to be ratified by parliaments
- Design CDRs by this time next year
- Shovels in the ground 2018
- Phase 1 construction 2018-2023
- Early science 2020