Where does observatory time come from?

Peter Mirtschin | Group Leader – NSW Observatory Operations
13 September 2018

CSIRO ASTRONOMY & SPACE SCIENCE
www.csiro.au

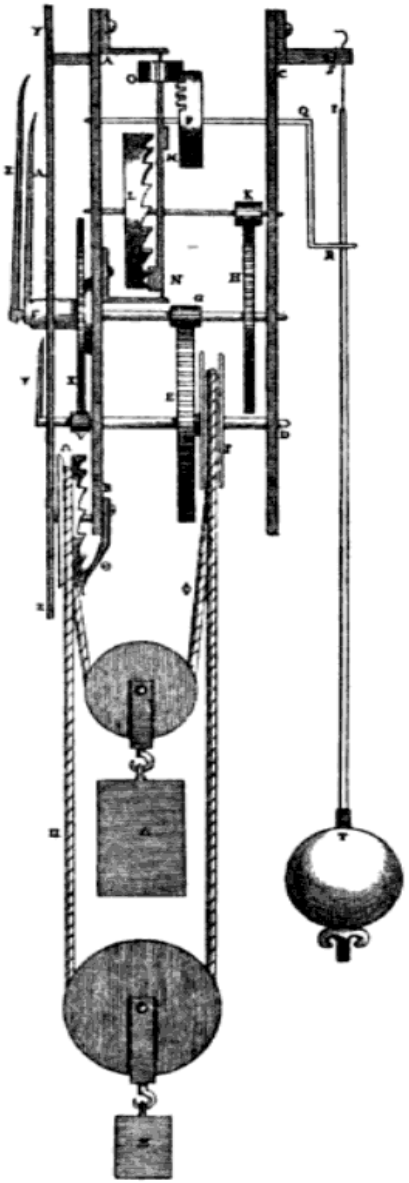
Overview

- What is “time” and how is it defined?
- Leap second & IERSA
- Observatory implementation
- Questions

What is time?

- **Christiaan Huygens – 1629-1695**
  - Dutch physicist, mathematician, astronomer and inventor
  - Studied Saturn's rings
  - Discovered Saturn's moon – Titan
  - Invented pendulum clock in 1656
  - Time standard until 1930's

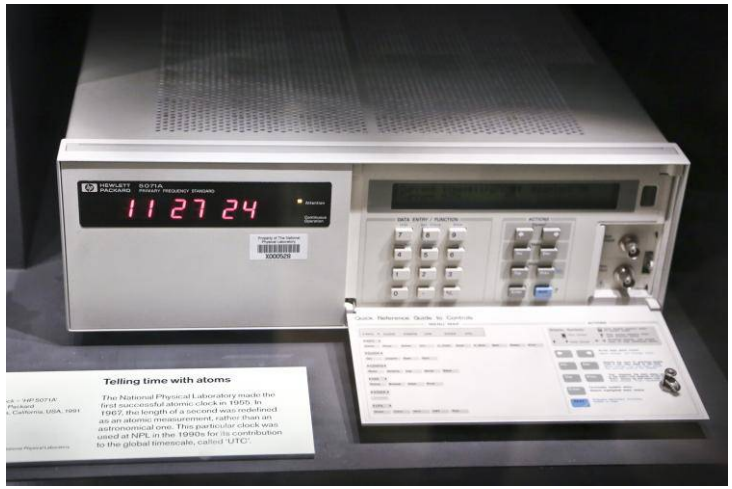
  - Definition: 86400 seconds in 1 rotation of earth on its axis
  - Universal Time (UT1), also known as Astronomical Time



What is time?

Atomic Time

- the time it takes a Cesium-133 atom at the ground state to oscillate precisely 9,192,631,770 times.
- Excellent long term stability
- A time scale that combines the output of some 200 highly precise atomic clocks worldwide, and provides the exact speed for our clocks to tick.
- International Atomic Time (TAI)



- A$70k

What is time?

Atomic Time Too Accurate

- The velocity of Earth's rotation around its own axis does not match the speed of atomic time. On average, it is a tiny bit too slow—and it is gradually slowing down, although very slightly. The slowing down is not consistent and varies on many factors.

- Atomic clocks, however, tick away at the same speed over millions of years. Compared to the Earth's rotation, atomic clocks are simply too consistent.

Leap second

- Atomic time – basis for measuring intervals of time accurately.
- Astronomical time – basis for orientation on the sky.

- Need a method of reconciling these differences between atomic and astronomical time – leap seconds.

- Upcoming leap seconds are announced by the International Earth Rotation and Reference Systems Service (IERS) in Paris, France.

- Before the difference between UTC and UT1 reaches 0.9 seconds, a leap second is added to UTC and to clocks worldwide. By adding an additional second to the time count, our wall clocks are effectively stopped for that second to give Earth rotation the opportunity to catch up.

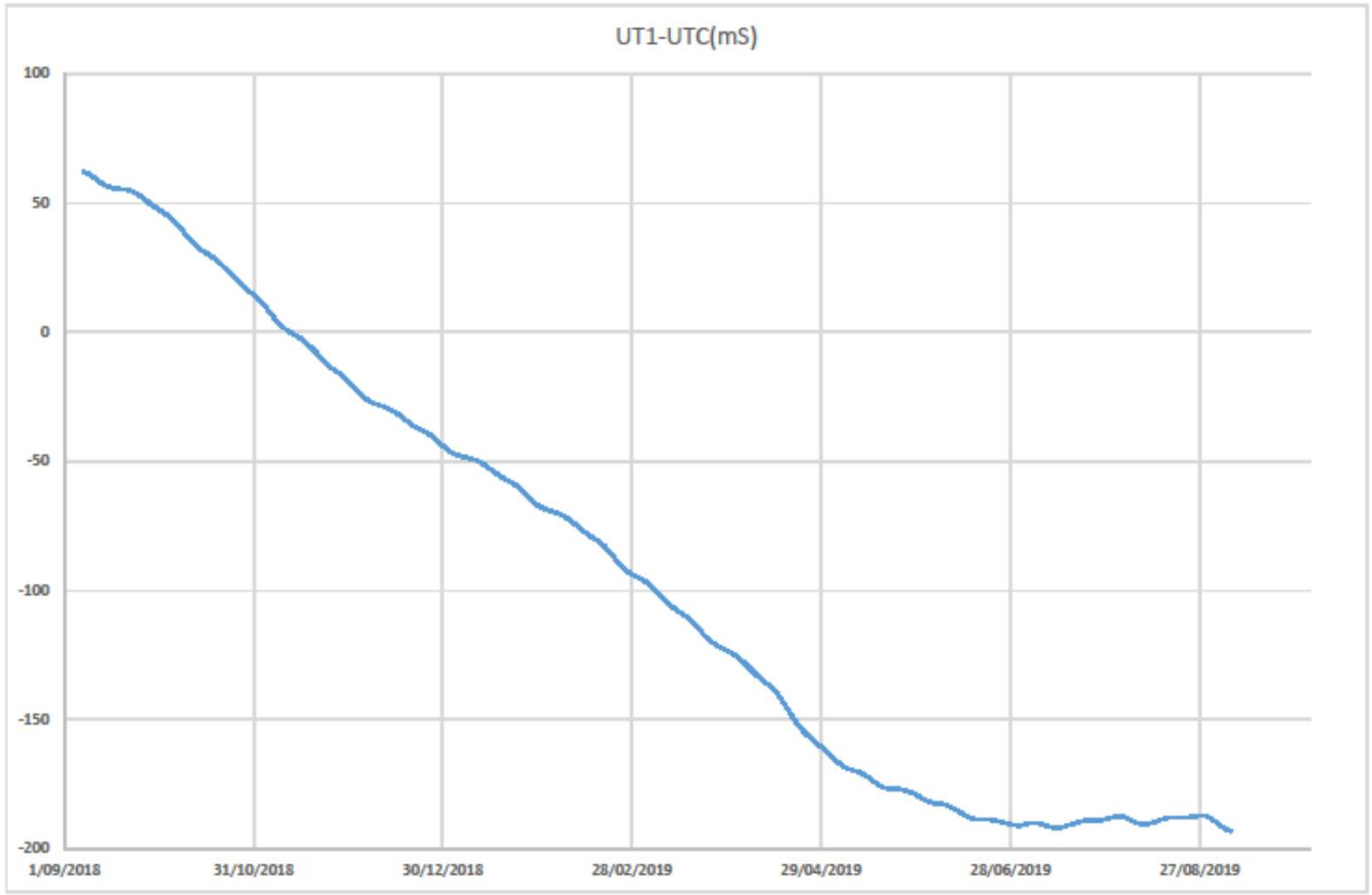
Leap second

- International Earth Rotation Service (**IERS**), produces and disseminates the IERS Bulletin A
- Commonly known as IERSA
- Prediction of the error between UTC & UT1.
- Two components:
  - DUTC (UT1 – UTC) in integer seconds
  - DUT1 (remainder in mS)
- Updated weekly on Friday mornings

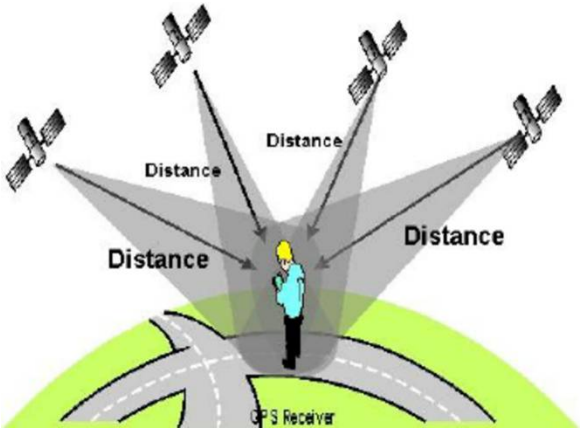
- Learn More: “The Future of Time: UTC and the Leap Second”
  - David Finkleman, Steve Allen, John H. Seago, Rob Seaman and P. Kenneth Seidelmann
  - https://arxiv.org/abs/1106.3141

IERS – Bulletin A - historical

IERS – Bulletin A - prediction



Obtain absolute time reference



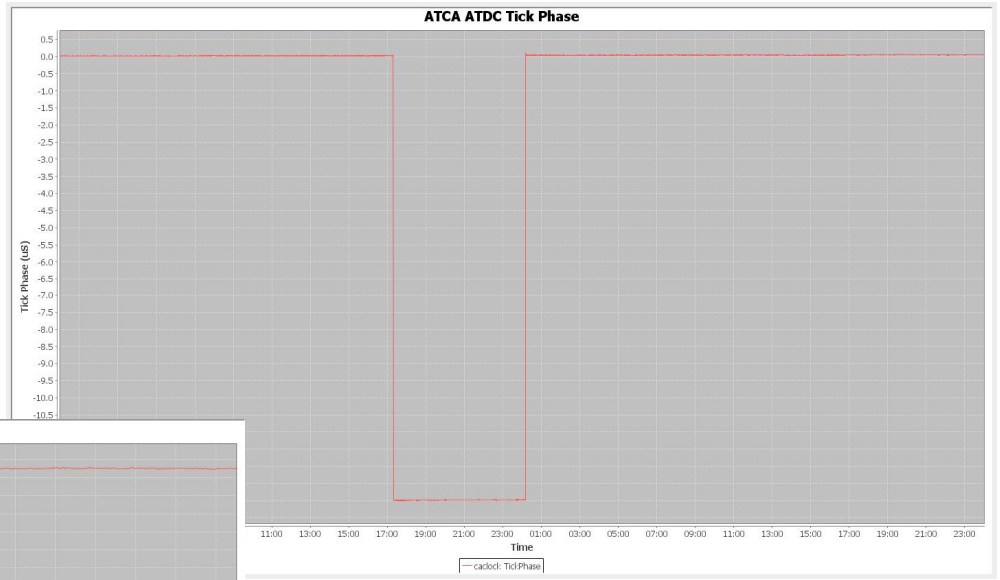
- **Global Positioning System** (**GPS**), is a satellite-based radionavigation system owned by the US government and operated by the US Air Force.
  - It provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.
  - Obstacles such as mountains and buildings block the weak GPS signals
  - Typical Error - TAI to GPS (Original Design 1µS -> 60nS)

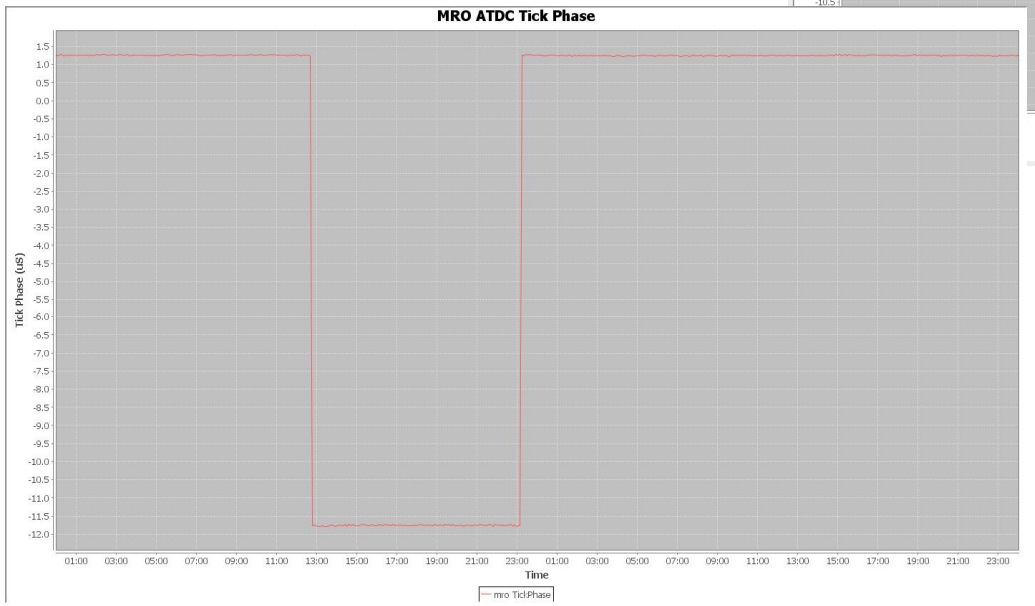
GPS Error

Even GPS can get it wrong!

By 13 µS

26 Jan 2016





Time standards

- Long term stability (> several hours) from GPS is excellent
- Short term stability (< several hours) from GPS is not good enough for radio astronomy
- Hydrogen Maser (Parkes & ATCA)
  - uses the intrinsic properties of the hydrogen atom to serve as a precision frequency reference:
    1,420,405,751.786 Hz
  - 21 cm line in hydrogen spectrum.

Time standards

- ASKAP's short term stability requirement is not quite as stringent

- GPS disciplined Rubidium oscillator is adequate
  - hyperfine transition of electrons (at 6.834682610904 GHz) in rubidium-87 atoms is used to control the output frequency.
  - Fine tuned (disciplined) by GPS for long term stability.

Time error

- Reference Oscillator (Maser or Rubidium) is the source of precision timing at each observatory.
- GPS 1pps is the common timing reference (absolute time)
- Difference between them provides a fine-grain measure of the absolute time error of the observatory clock.
- Result is referred to as ‘tickphase’

Binary Atomic Time (BAT)

- A 64 bit integer representing the count of microseconds since the epoch, MJD 0.0, i.e. 00:00hrs on Nov 17 1858.

- BAT is derived from the observatory time standard.
  - It is an approximation to International Atomic Time (IAT)
  - Where IAT = BAT + offset + rate $*$ ΔBAT
    - Rate is the error in the frequency of the reference oscillator
    - Offset is the tickphase.

Local Mean Sidereal Time (LMST)

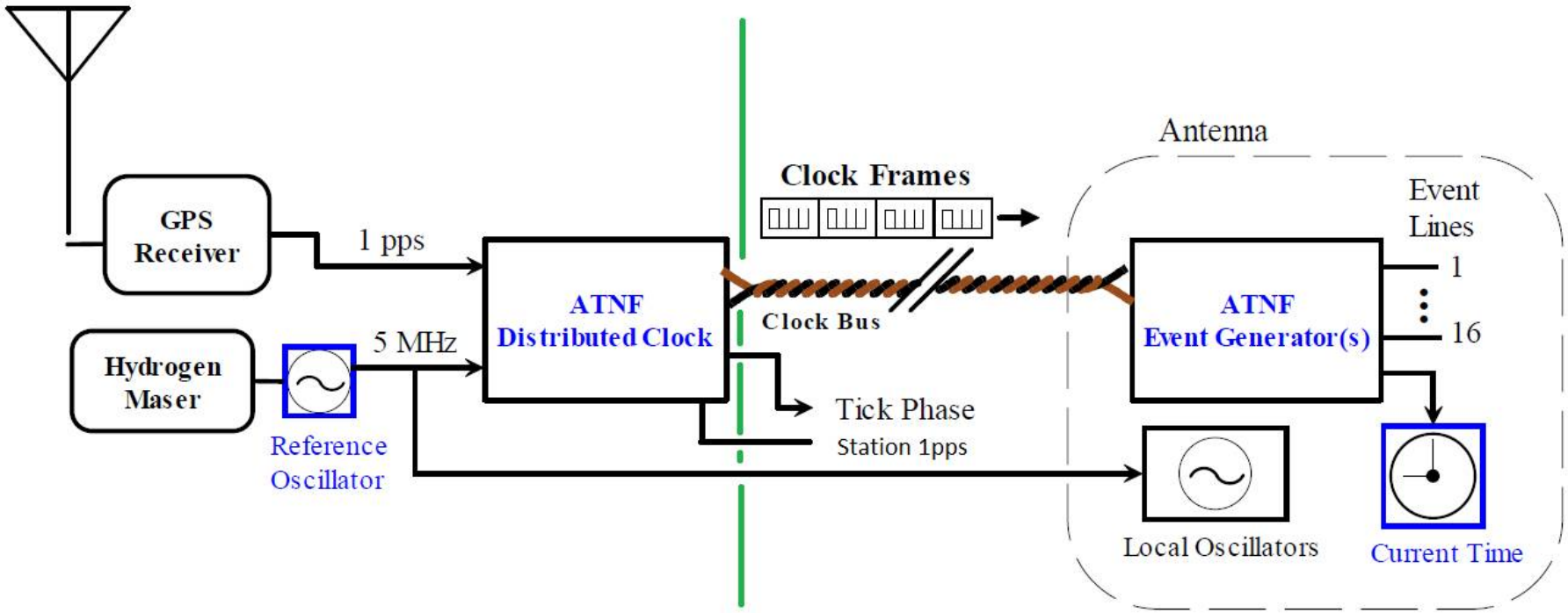
- LMST is the right ascension (RA, an equatorial coordinate) of a star on the observer's meridian. One sidereal day corresponds to the time taken for the Earth to rotate once with respect to the stars and lasts approximately 23hrs 56min.

- LMST is a direct indication of whether a celestial object of known right ascension is observable at that instant.

- The meridian (longitude) of an observatory is required to calculate LMST for that location.

ATNF Distributed Clock (ATDC)

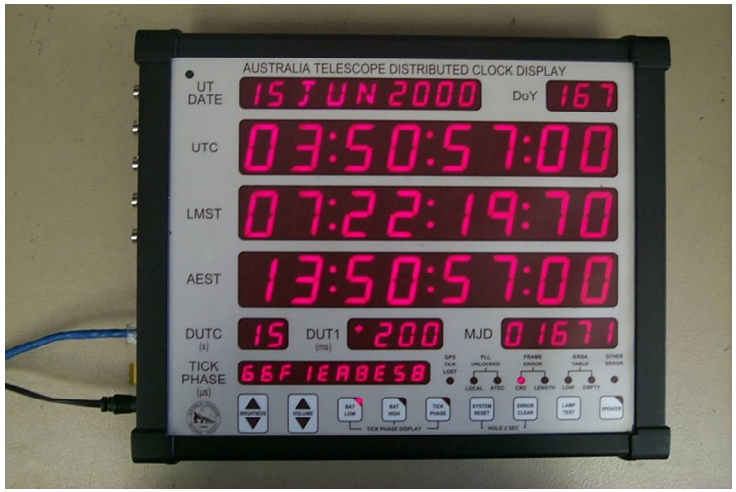
- Measures tickphase
- Generates time coded signals for time dependent equipment
- Signal contains BAT, UTC, UT1, Local Time, LMST, Tick Phase, DUTC.

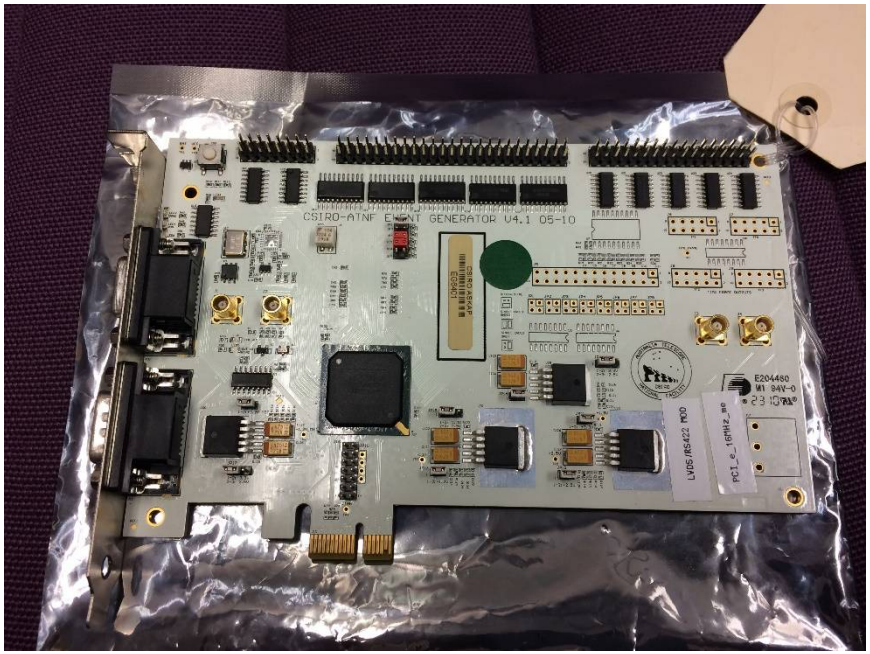


Fundamental observatory time components

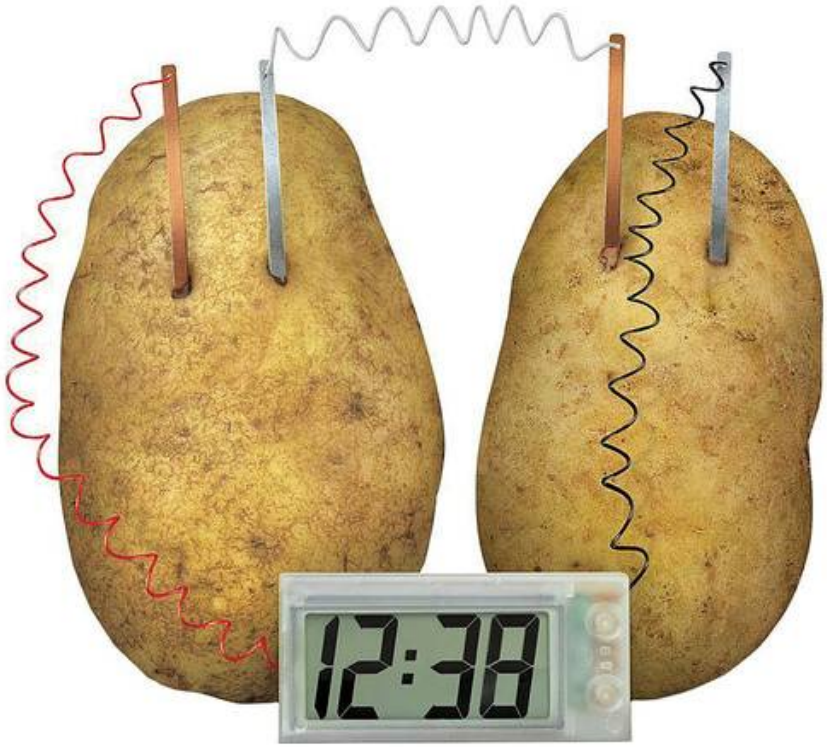
- Derived from local standard – Maser or Rubidium
- All other timing signals are derived from one or a combination:

- 10MHz (or 5MHz)
- 1pps
- timeframe (clockbus)





Questions?



Reference

S.A. Hoyle, P.L. Mirtschin, "Timing Systems for ATNF Telescopes", in *Proc. 15th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'15)*, Melbourne, Australia, October 2015, paper WEM301, pp. 660-663, ISBN: 978-3-95450-148-9, doi:10.18429/JACoW-ICALEPCS2015-WEM301, http://jacow.org/icalepcs2015/papers/wem301.pdf, 2015.

Thank you

CSIRO Astronomy & Space Science
Peter Mirtschin
Group Leader – Observatory Operations East

t +61 2 6790 4058
e peter.mirtschin@csiro.au