

**Safran Timing Technologies**

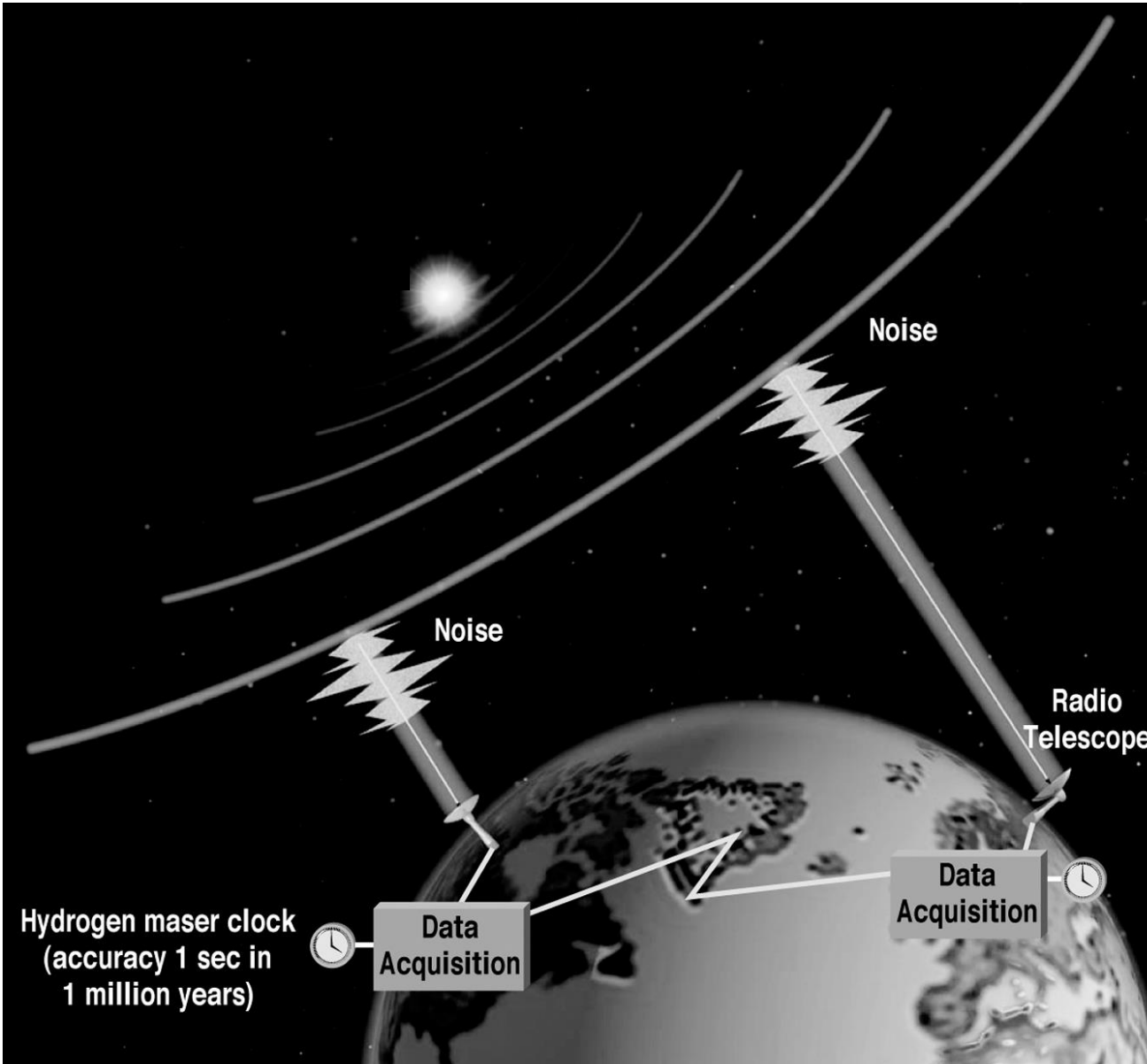
**State of the Art  
Time & Frequency  
References for  
SKA Low & SKA Mid**

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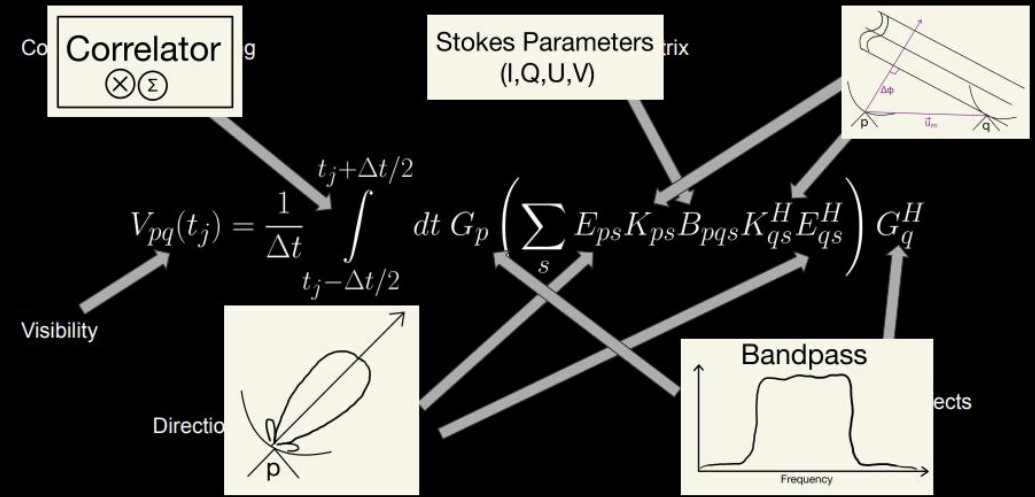


# Why Atomic Clock for SKAO ?



Source : Chris Finlay (UNIGE)

## Radio Interferometry Measurement Equation (RIME)



**Time is also a critical parameter**

# SKAO REQUIREMENTS



## SKA1 LEVEL 0 SCIENCE REQUIREMENTS

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## Frequency & Time Requirements

- **Frequency accuracy** is defined here as the fractional error in the frequency,  $\Delta\nu/\nu$ , relative to an adopted frequency standard over a specified time interval. One of the instances in which frequency accuracy is vital is in a measurement of the time evolution of cosmological red-shifts (as documented RD1) which yields a 0.1 Hz frequency shift at 1 GHz over 10 years.
- **Timing accuracy** is defined here as the time error,  $\Delta\tau$ , relative to an adopted time standard over an indicated time interval. Timing accuracy is of particular importance in the context of enabling precision pulsar timing.

- SCI\_REQ-14 SKA1-LOW shall provide frequency accuracy of at least  $10^{-11}$  over a 10 year interval. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted, but particularly a measurement of the time evolution of cosmological red-shifts (RD1).
- SCI\_REQ-15 SKA1-MID shall provide frequency accuracy of at least  $10^{-11}$  over a 10 year interval. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted, but particularly a measurement of the time evolution of cosmological red-shifts (RD1).
- SCI\_REQ-16 SKA1-LOW shall provide timing accuracy of at least 10 nsec over a 10 year time year interval to enable precision pulsar timing at 150 – 350 MHz (HPSO 5).
- SCI\_REQ-17 SKA1-MID shall provide timing accuracy of at least 10 nsec over a 10 year time year interval to enable precision pulsar timing at 950 – 1760 MHz (HPSO 5).



# Why Atomic Clocks are Critical to Fundamental Physics?

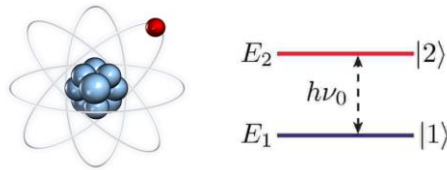
- Electro-magnetic energy is emitted in fixed «quanta» amounts (photons)
- Max Planck's Quantum Theory :
  - Energy =  $\hbar\nu = \hbar c/\lambda$
  - $\hbar$  = planck constant  $6.626 \cdot 10^{-34}$
  - $\nu$  = frequency (light color)
  - $c$  = light speed (celerity)
  - $\lambda$  = wavelength
- Therefore, energized electrons will always emit an exact frequency

$$E = h\nu$$

$$E = \frac{hc}{\lambda}$$

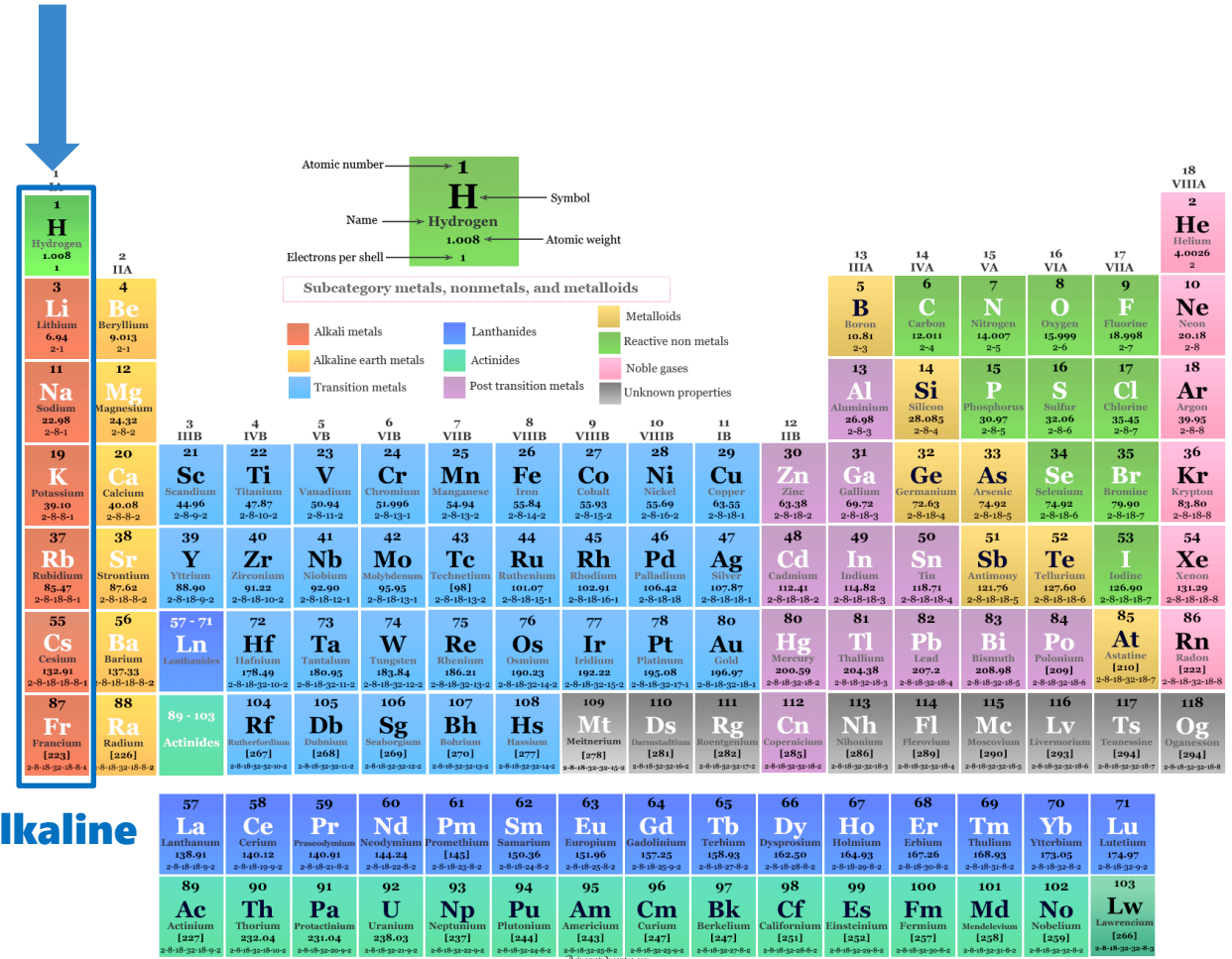
$$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$$

$$c = 3.0 \times 10^8 \text{ m/s}$$



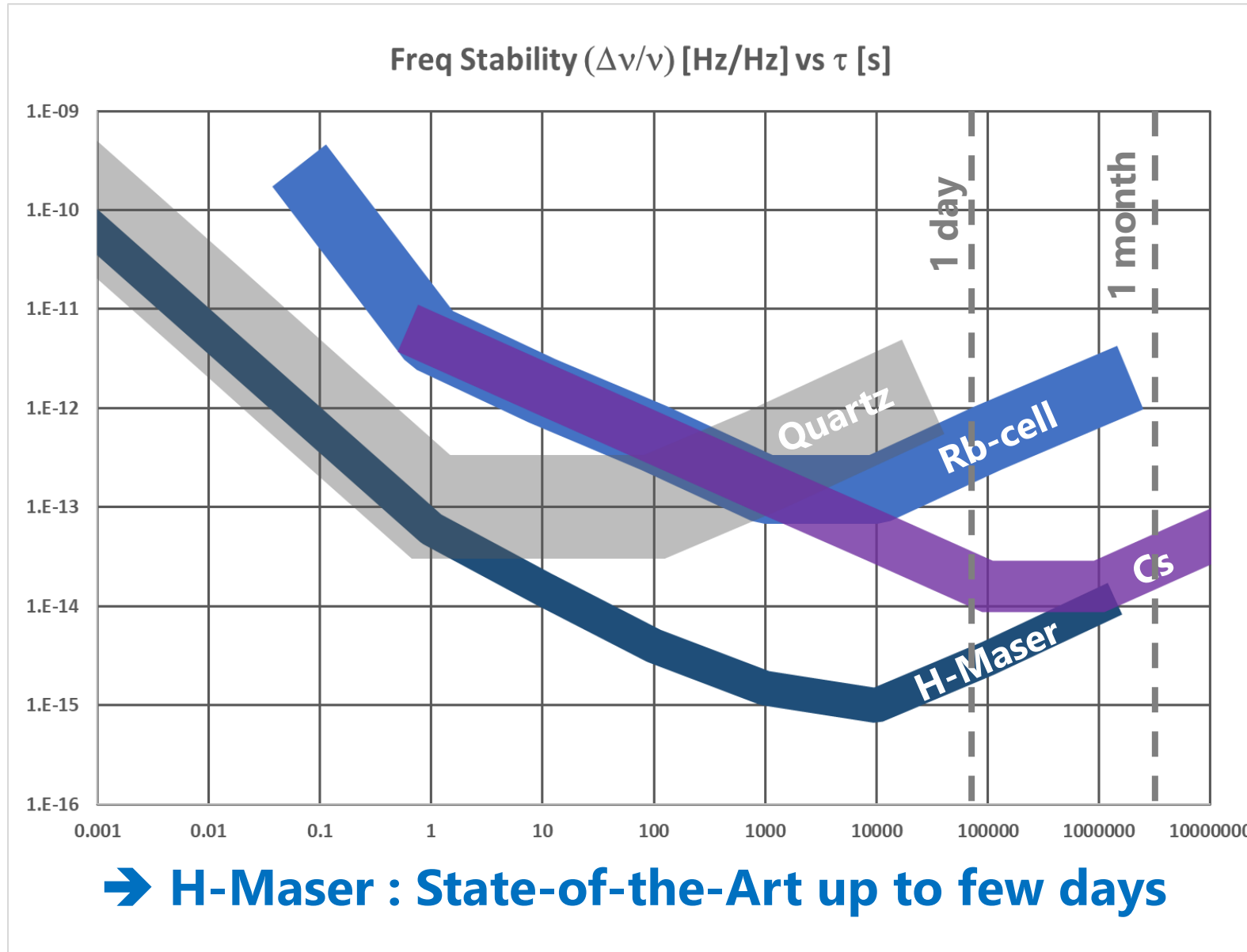
- Atomic clocks generate an exact frequency :
  - Cs : 9 192 631 770 Hz
  - Rb : 6 834 682 611 Hz
  - H : 1 420 405 752 Hz

*If fundamental constants change due to various "new physics", atomic clocks will be able to detect it*



**Alkaline**

# Which Atomic Clock for SKAO ?

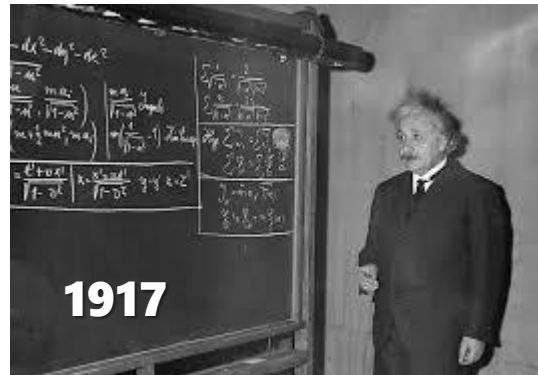


# The MASER Theory

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## MASER

Microwave **A**mplification by **S**timulated **E**mission of **R**adiation



# The MASER Technology

## The Nobel Prize in Physics 1964



Photo from the Nobel Foundation archive.  
**Charles Hard Townes**  
Prize share: 1/2



Photo from the Nobel Foundation archive.  
**Nicolay Gennadiyevich Basov**  
Prize share: 1/4



Photo from the Nobel Foundation archive.  
**Aleksandr Mikhailovich Prokhorov**  
Prize share: 1/4

## $\text{NH}_3^*$ -MASER - 1953

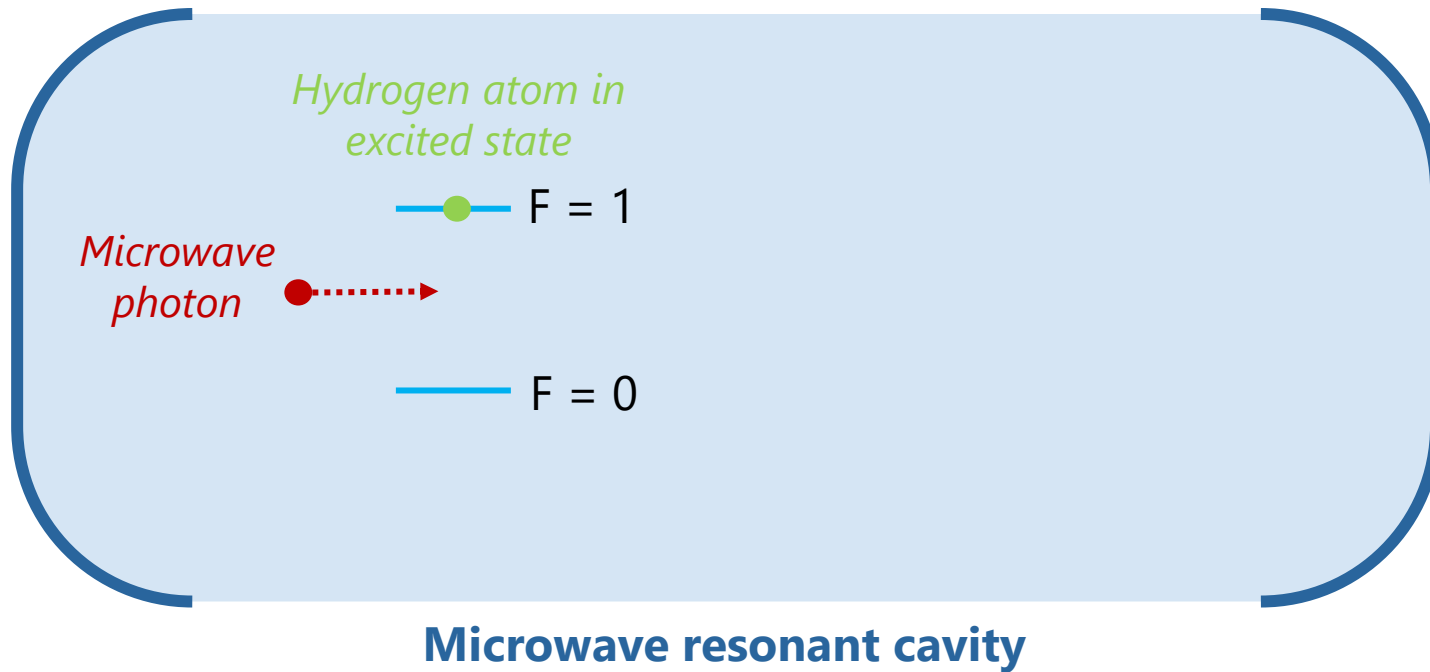


\* $\text{NH}_3$  : ammonia

*The Nobel Prize in Physics 1964. NobelPrize.org. Nobel Prize Outreach AB 2022. Tue, 1 Nov 2022.  
<<https://www.nobelprize.org/prizes/physics/1964/summary/>>*

# The MASER Effect

## Physical Package - Microwave Cavity:



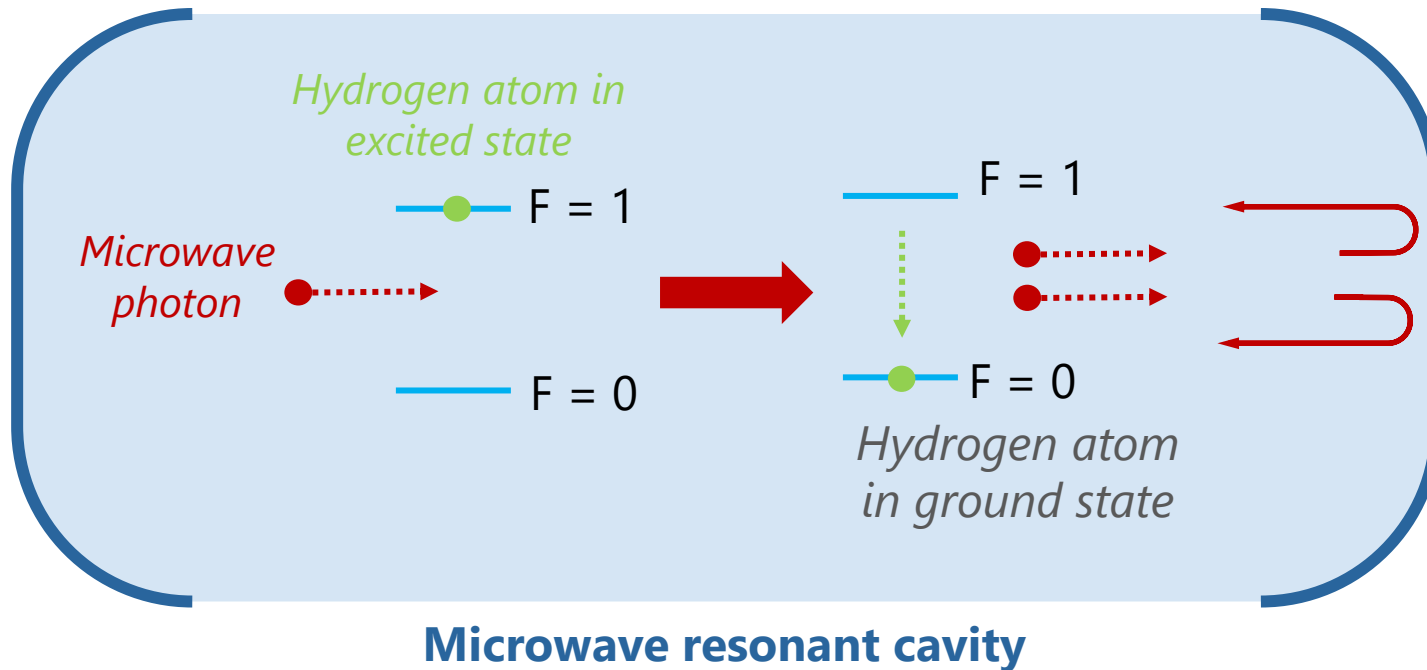
- **Resonant cavity**
  - ✓ Resonance mode of the cavity



# The MASER Effect

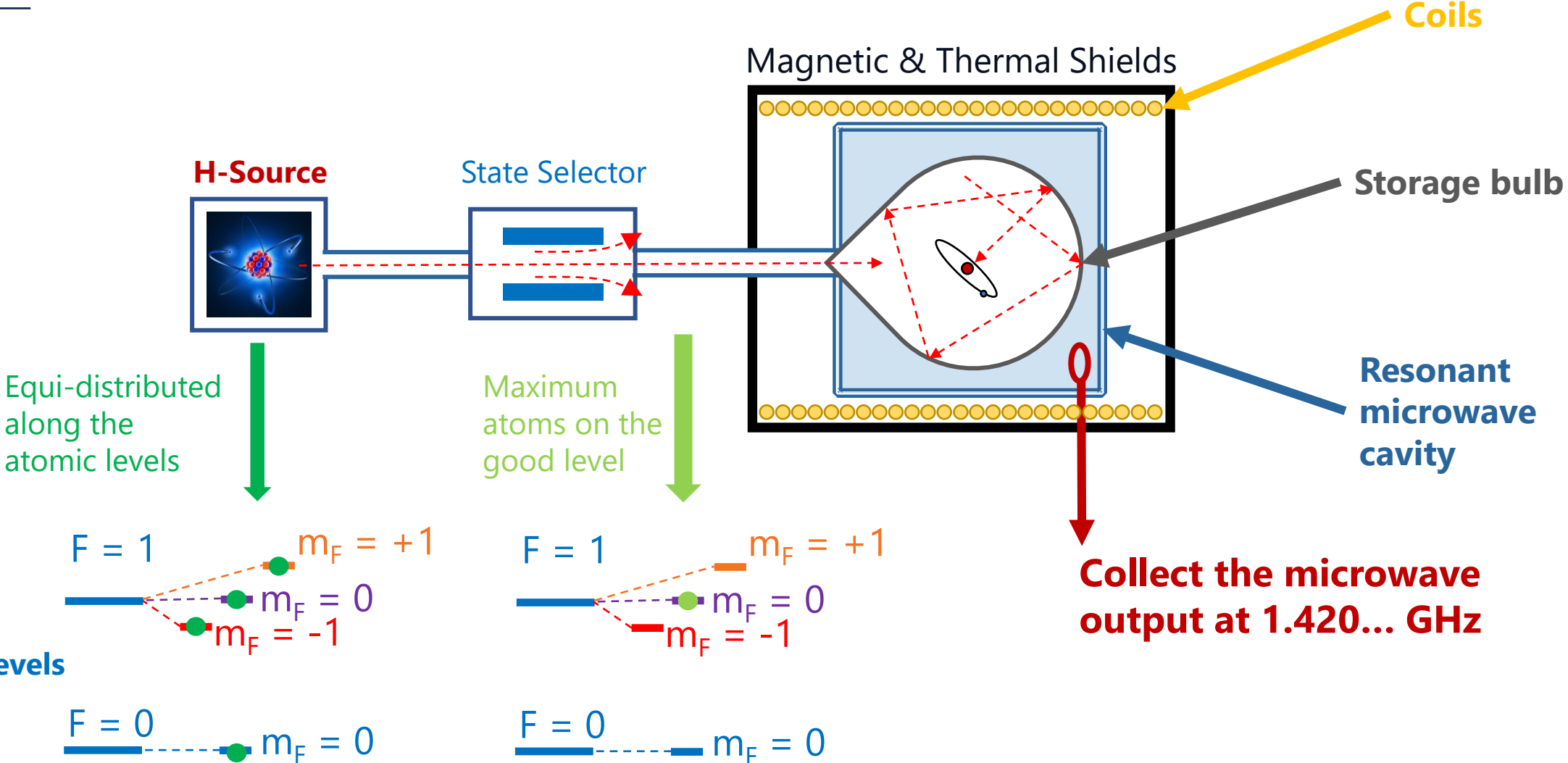
## Physical Package - Microwave Cavity

### MASER Effect → Stimulated Emission & Amplification



- **Stimulated emission**
  - ✓ Coherent emission of microwave photon
- **Resonant cavity**
  - ✓ Resonance mode of the cavity
- **Population inversion**
  - ✓ Need more atoms in excited state than in ground state

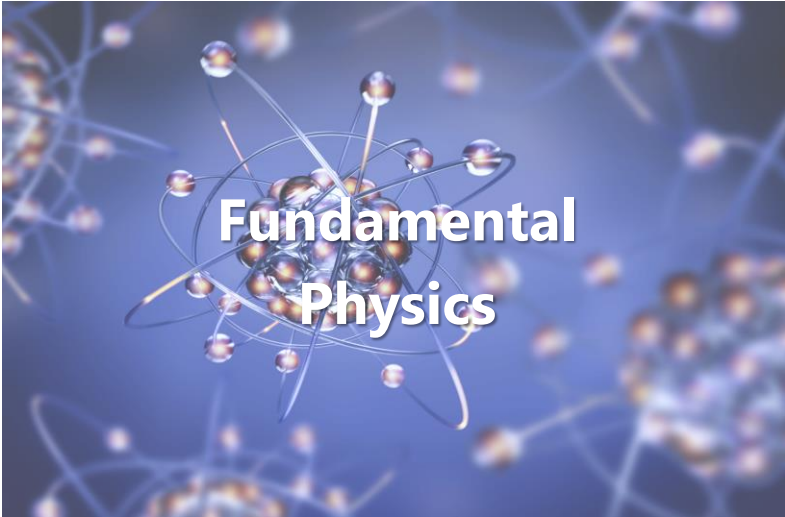
# MASER Atomic Clock







# Use Cases





# Safran MASER...



# ... around the world !




# New MASERs for SKAO



**iM174 : october 2024**  
**+**  
**iM107 : already on-site**  
**iM108 : already on-site**

Panorama of the Karoo near the SKA site in South Africa. Credit: Rob Millenaar (ASTRON)



**iM175 : end of 2025**  
**iM176 : end of 2025**  
**iM177 : end of 2025**

Panorama of the Murchison from the SKA site in Australia. Credit: CSIRO



Thank you for your attention

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