M SQUARED

HIGH POWER LASERS FOR STRONTIUM AI

DR JOSEPH THOM

QUANTUM TECHNOLOGY SCIENTIST

2006

Established
M Squared
in Glasgow.

100+

The number of people
we employ, over three
continents.

£18M +

Our turnover
in the last financial
year.

380+

Individual patents.

33

Number
of countries
in which we are active.

>162

Number
of partners
and customers.


THz
MIR
NIR
VIS
DUV
CW
ns
ps
fs

SOLSTIS

SOLSTIS SPECIFICATIONS

LARGE TUNING RANGE - 670 nm to 1050 nm

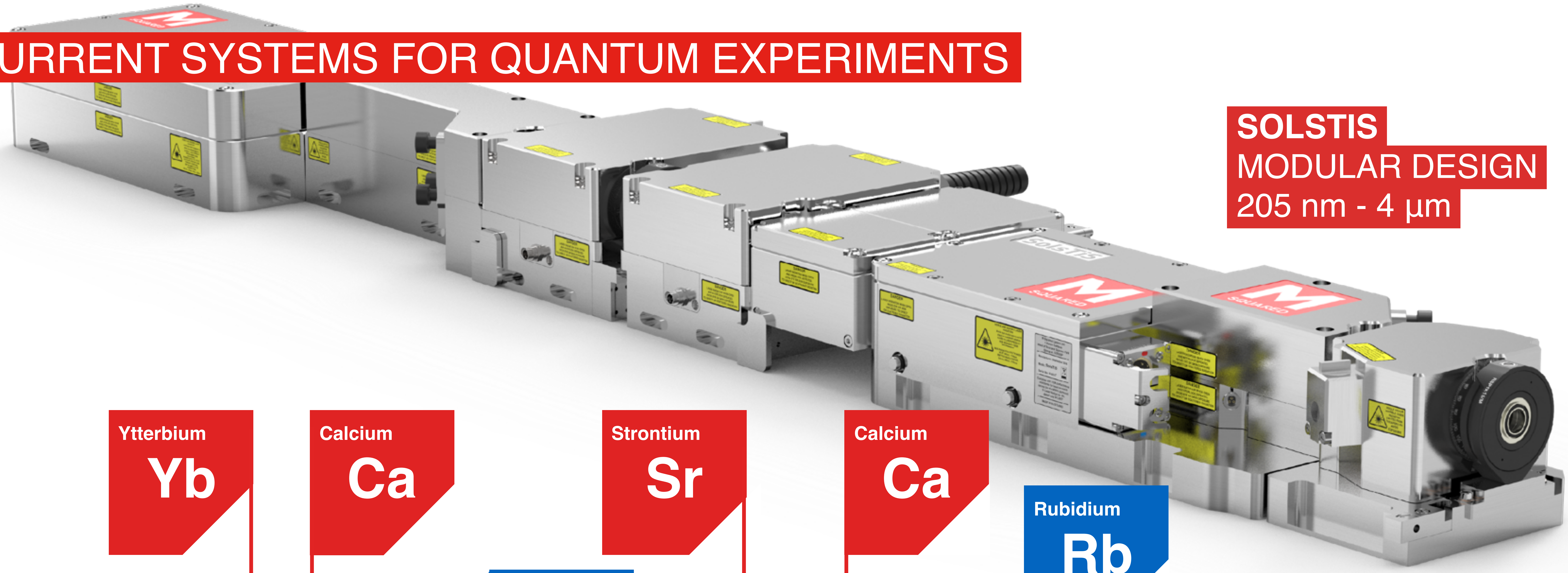
HIGH POWER - > 5 W at 780 nm

NARROW LINEWIDTH - < 50 KHz

LOW AMPLITUDE NOISE - < 0.075 % (10 Hz to 10 MHz)

CONTROL BY ETHERNET

CURRENT SYSTEMS FOR QUANTUM EXPERIMENTS



SOLSTIS
MODULAR DESIGN
205 nm - 4 µm

Ytterbium Yb
369 nm
Microwave qubit rotation

Calcium Ca
397 nm
Microwave qubit rotation

Caesium Cs
509 nm
Rydberg excitation

Strontium Sr
674 nm
Optical qubit rotation

Calcium Ca
729 nm
Optical qubit rotation

Rubidium Rb
780 nm
Laser cooling and Raman transitions

ion | neutral atom

200 300 400 500 600 700 800 900 1000 4000 nm

ECD-X-Q *(up to 200 mW)*
EMM *(up to 200 mW)*
ECD-X *(up to 2.5 W)*
EMM *(up to 1 W)*
SolsTiS *(up to 6 W)*
EMM *(up to 30 mW)*

COHERENT COMBINATION SCHEME

SPECIFICATIONS

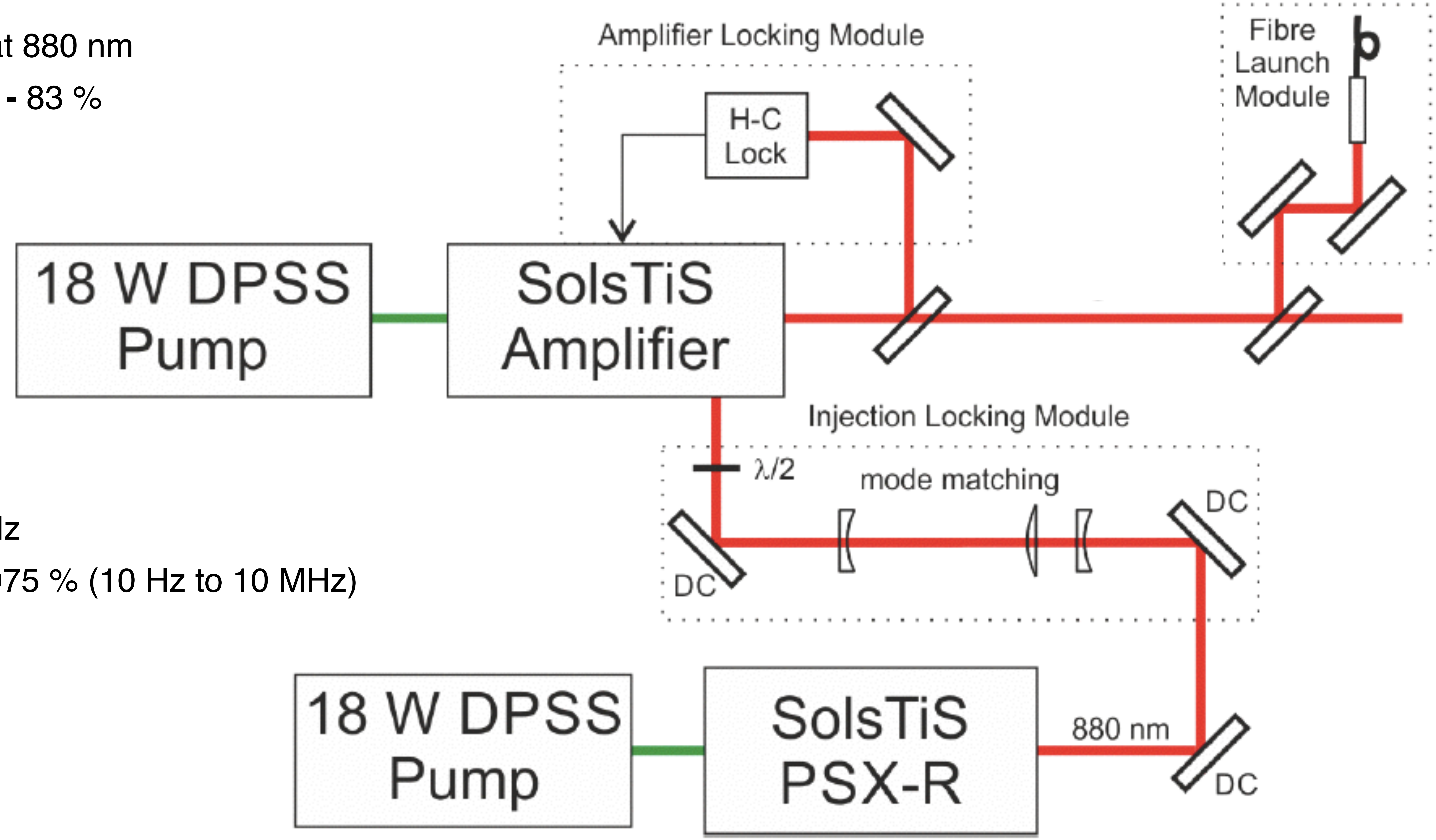
AMPLIFIER OUTPUT - > 10 W at 880 nm

FIBRE COUPLING EFFICIENCY - 83 %

M2 PARAMETER - < 1.01

NARROW LINEWIDTH - < 50 KHz

LOW AMPLITUDE NOISE - < 0.075 % (10 Hz to 10 MHz)



COHERENT COMBINATION SCHEME

SPECIFICATIONS

AMPLIFIER OUTPUT - > 10 W at 880 nm

FIBRE COUPLING EFFICIENCY - 83 %

M2 PARAMETER - < 1.01

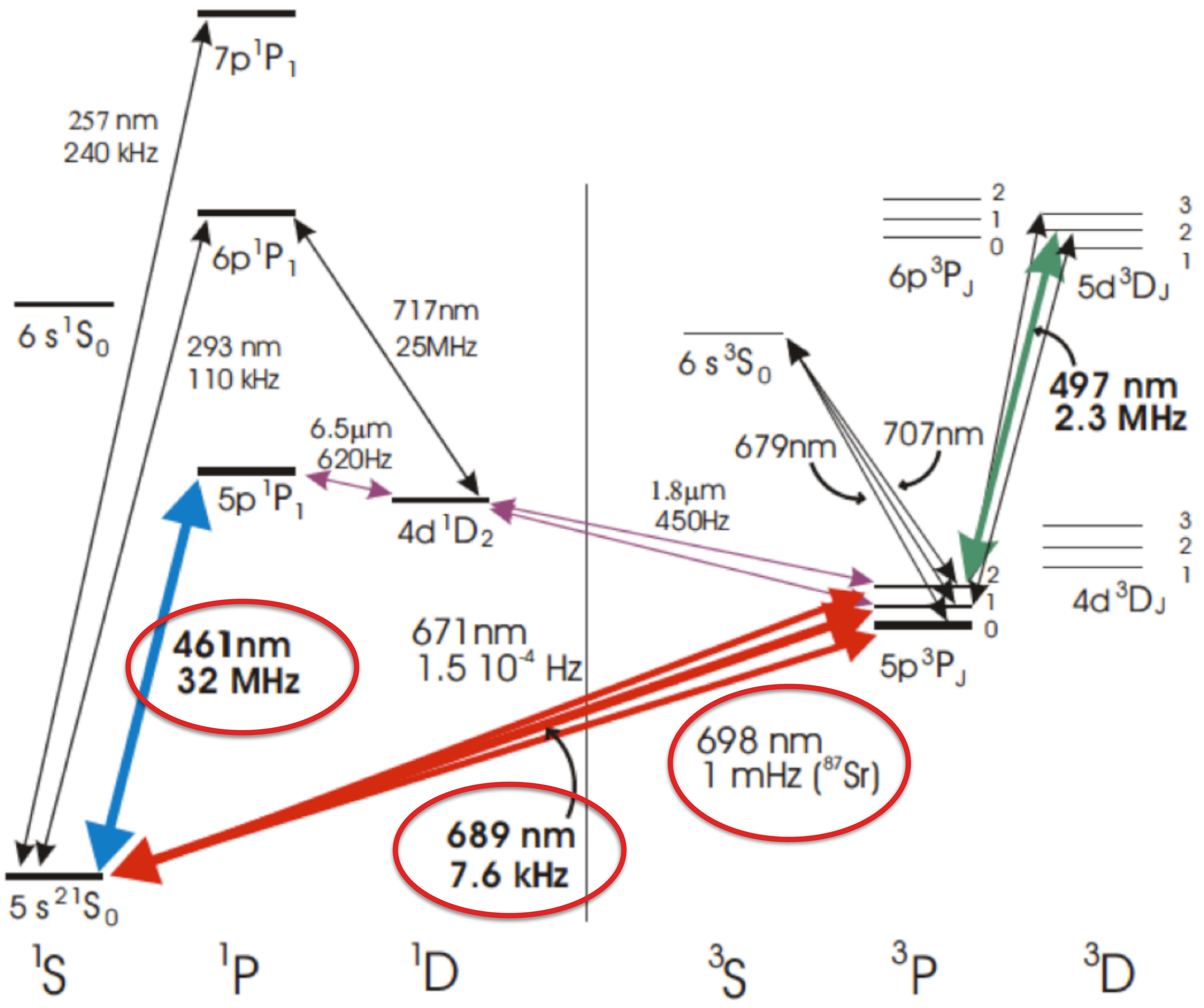
OUTPUT POWERS AT STRONTIUM WAVELENGTHS

461 nm - > 2 W (after SHG module)

689 nm - > 7 W

698 nm - > 8 W

(powers in standard configuration are approximately a factor of 2 less)



QUANTUM NAVIGATION

STATE OF THE ART

ACCELERATION MEASUREMENTS AT ~ 100 ng

LASER REQUIREMENTS

LOW PHASE NOISE - 25 mrad AT T = 25 ms

- HIGH SENSITIVITY INTERFEROMETER

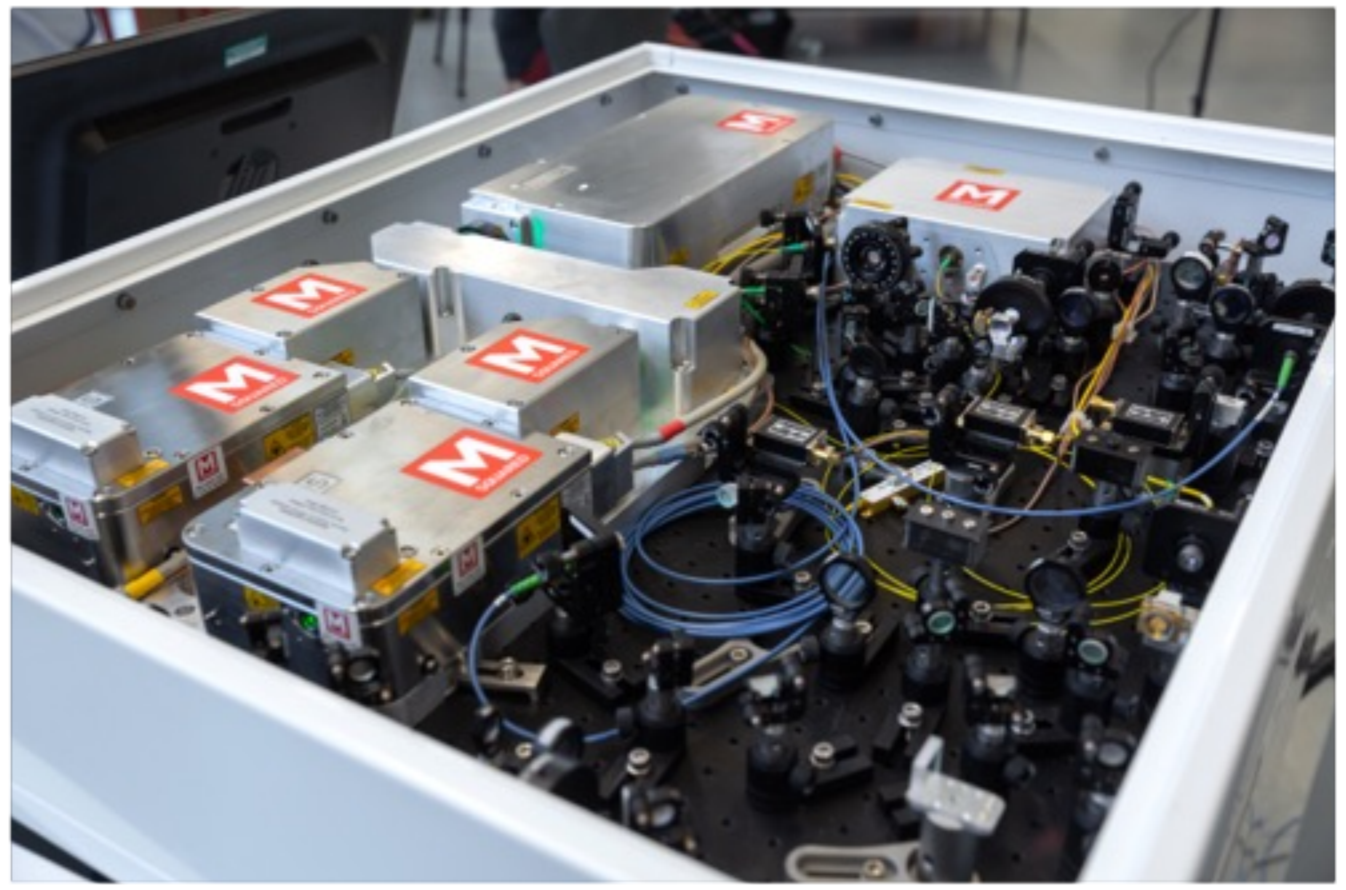
HIGH POWER - 6 W TOTAL POWER AT 780 nm

- LARGE RAMAN BEAMS AND SHORT PULSE DURATIONS

SYSTEM AGILITY - FINELY TUNED OPTICAL PULSES FOR LASER COOLING, STATE PREPARATION, RAMAN TRANSITIONS

Imperial College London

QUANTUM GRAVIMETRY



STATE OF THE ART

ACCELERATION MEASUREMENTS AT ~ 1 ng

LASER REQUIREMENTS

LOW PHASE NOISE - 25 mrad AT T = 25 ms

- HIGH SENSITIVITY INTERFEROMETER

HIGH POWER - 6 W TOTAL POWER AT 780 nm

- LARGE RAMAN BEAMS AND SHORT PULSE DURATIONS

SYSTEM AGILITY - FINELY TUNED OPTICAL PULSES FOR LASER COOLING, STATE PREPARATION, RAMAN TRANSITIONS

ION TRAP MICROWAVE QUBIT

UNIVERSITY OF OXFORD

STATE OF THE ART

~ 99.9 % TWO QUBIT FIDELITY

~ 99.99 % SINGLE QUBIT

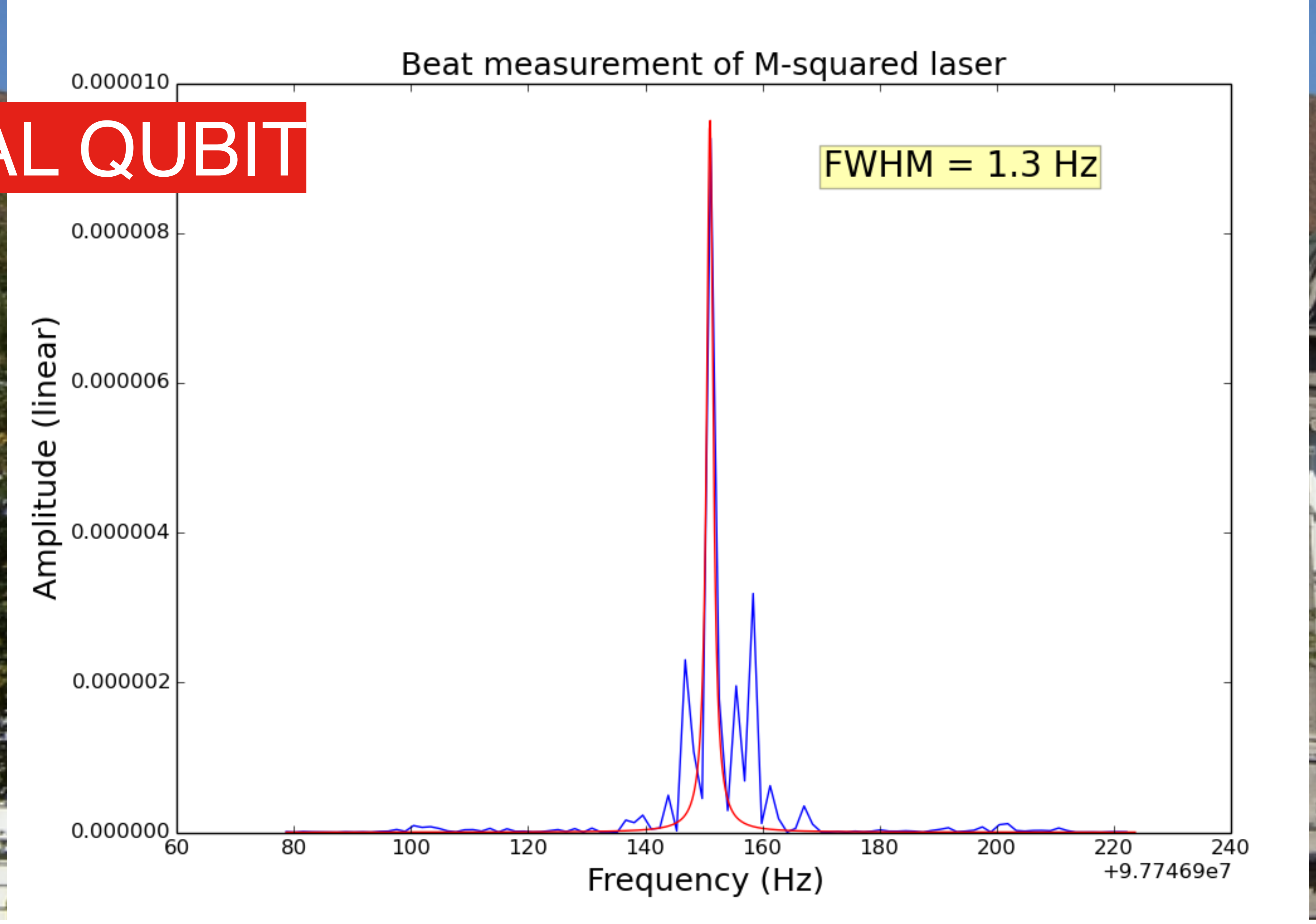
(LUCAS, OXFORD)

LASER REQUIREMENTS

PHASE LOCKED LASERS FOR STIMULATED RAMAN TRANSITIONS:

- **LOW PHASE NOISE -** 5 mrad BETWEEN 1 kHz -1 MHz FOR 3.2 GHz GIVES ACCURATE QUBIT ROTATIONS
- **HIGH POWER -** LARGE DETUNING FROM ATOMIC RESONANCE
- **HIGH POWER -** INTENSE LASER FIELD AT MULTIPLE IONS PERMITS FAST GATE ROTATIONS

ION TRAP OPTICAL QUBIT



STATE OF THE ART

> 99.9% TWO QUBIT FIDELITY

> 99.9 % SINGLE QUBIT FIDELITY

(BLATT, INNSBRUCK)

LASER REQUIREMENTS

NARROW LINEWIDTH - LONG COHERENCE TIMES (~1s)

HIGH POWER STABILITY - ACCURATE QUBIT ROTATIONS

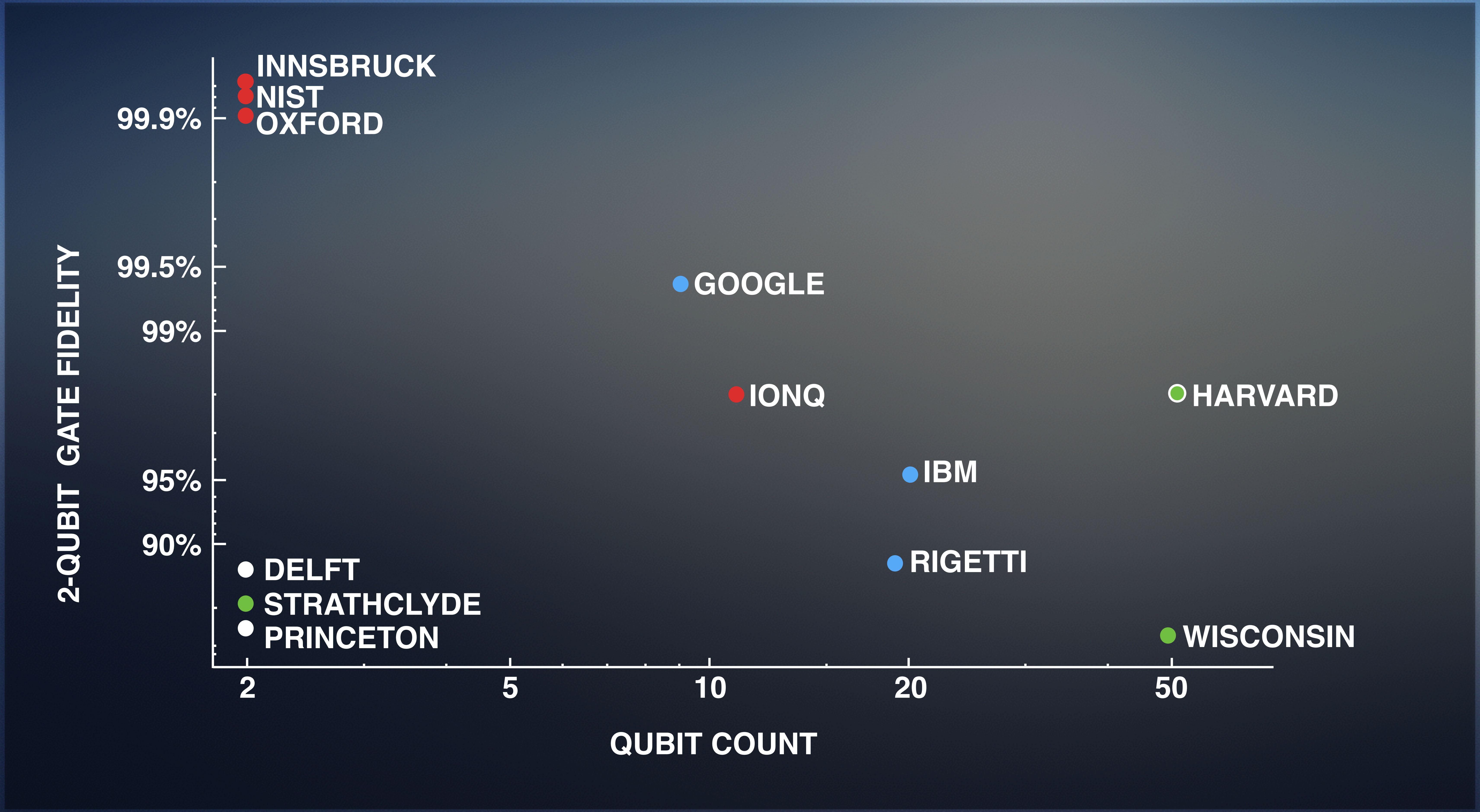
LOW AMPLIFIED SPONTANEOUS EMISSION

STATE OF THE ART IN QUANTUM COMPUTING

Ion based devices show highest gate fidelities at > 99.9%.

Advantageous when scaling quantum computers since less qubits are needed to form logical qubits.

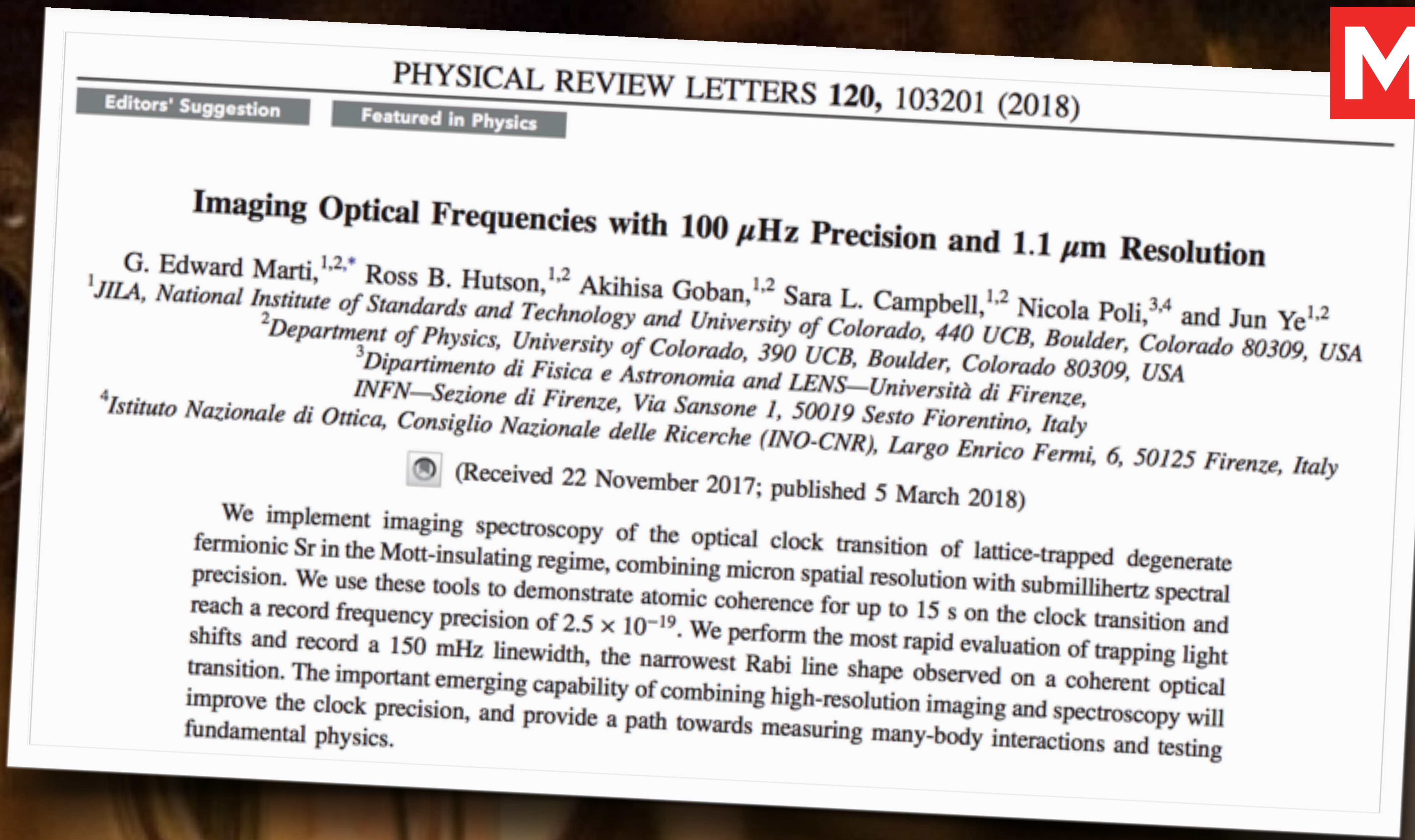
Ultra-stable and powerful lasers are key to achieving the highest fidelities.



QUBIT TYPE: ION TRAP; SUPERCONDUCTING; SILICON; NEUTRAL ATOM; NEUTRAL ATOM (GROUND-RYDBERG FIDELITY)

QUANTUM TIMEKEEPING

- **Optical lattice clocks require spectral purity**
- **Solstis targets the ‘magic wavelength’ to create a 3D strontium lattice.**



PHYSICAL REVIEW LETTERS **120**, 103201 (2018)

Editors' Suggestion | Featured in Physics

Imaging Optical Frequencies with 100 μHz Precision and 1.1 μm Resolution

G. Edward Marti,[1,2,*] Ross B. Hutson,[1,2] Akihisa Goban,[1,2] Sara L. Campbell,[1,2] Nicola Poli,[3,4] and Jun Ye[1,2]

[1]*JILA, National Institute of Standards and Technology and University of Colorado, 440 UCB, Boulder, Colorado 80309, USA*
[2]*Department of Physics, University of Colorado, 390 UCB, Boulder, Colorado 80309, USA*
[3]*Dipartimento di Fisica e Astronomia and LENS—Università di Firenze, INFN—Sezione di Firenze, Via Sansone 1, 50019 Sesto Fiorentino, Italy*
[4]*Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche (INO-CNR), Largo Enrico Fermi, 6, 50125 Firenze, Italy*

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We implement imaging spectroscopy of the optical clock transition of lattice-trapped degenerate fermionic Sr in the Mott-insulating regime, combining micron spatial resolution with submillihertz spectral precision. We use these tools to demonstrate atomic coherence for up to 15 s on the clock transition and reach a record frequency precision of 2.5×10^{-19}. We perform the most rapid evaluation of trapping light shifts and record a 150 mHz linewidth, the narrowest Rabi line shape observed on a coherent optical transition. The important emerging capability of combining high-resolution imaging and spectroscopy will improve the clock precision, and provide a path towards measuring many-body interactions and testing fundamental physics.

STATE OF THE ART

1 PART IN 10^{-19} MEASUREMENTS OF OPTICAL FREQUENCY

LASER REQUIREMENTS

HIGH POWER - LATTICE WITH MANY DEEP TRAPPING SITES

LOW POWER NOISE - MINIMAL ‘SHAKING’ OF LATTICE TO PREVENT ATOM HEATING

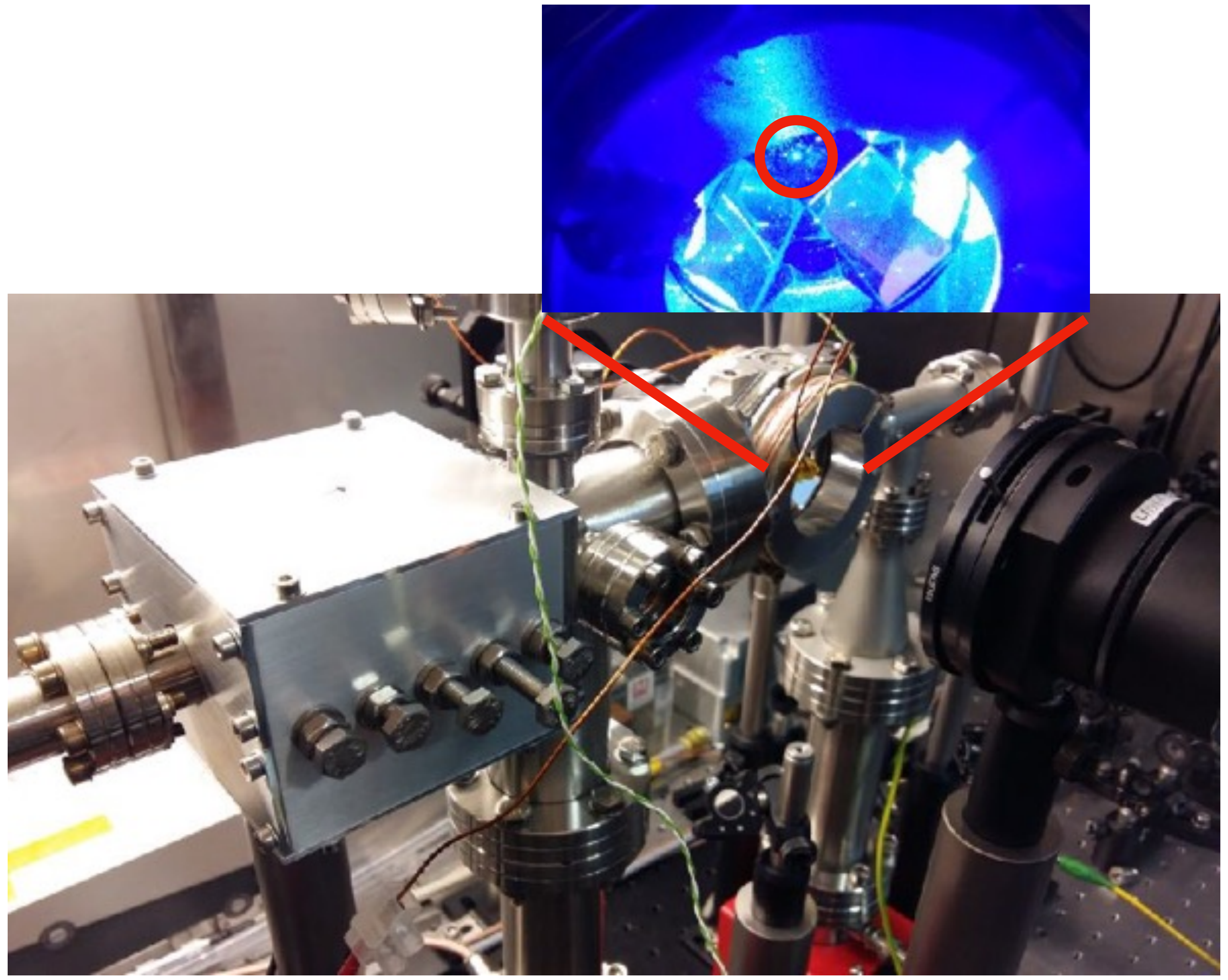
NIST (USA)	JILA (USA)	SYRTE (FRANCE)	PTB (GERMANY)
RIKEN (JAPAN)	NPL (UK)	INRIM (ITALY)	ECNU (CHINA)

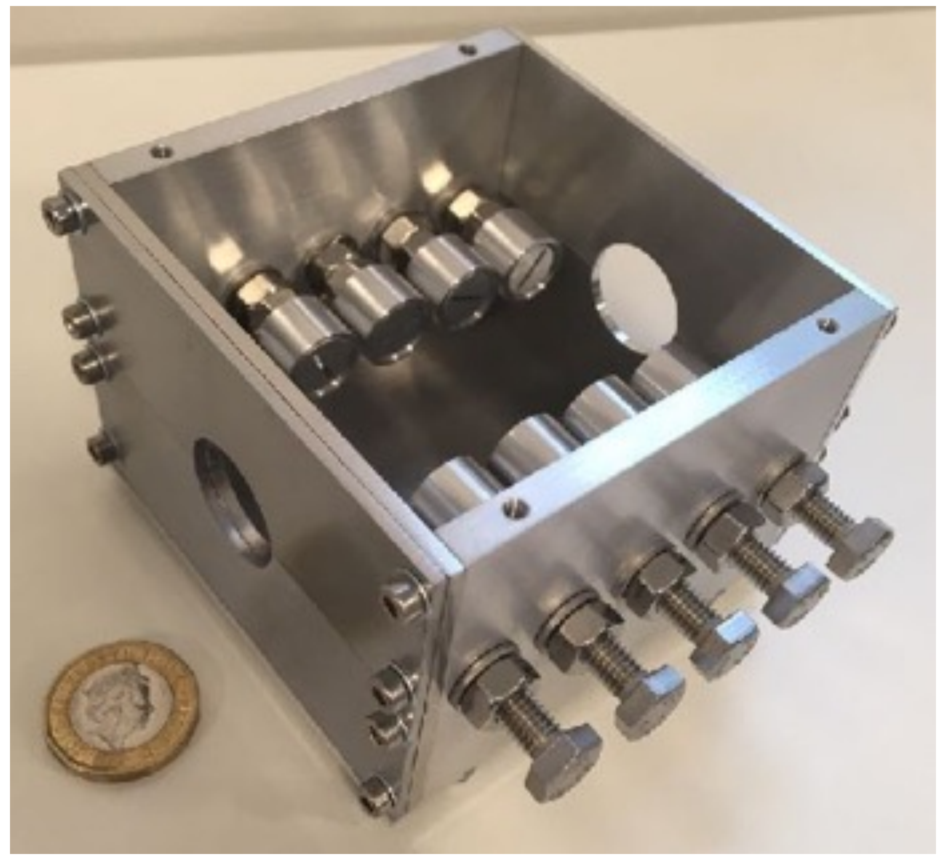
COMMERCIALISING ATOMIC CLOCKS AT M SQUARED

UNIVERSITY OF BIRMINGHAM

M SQUARED

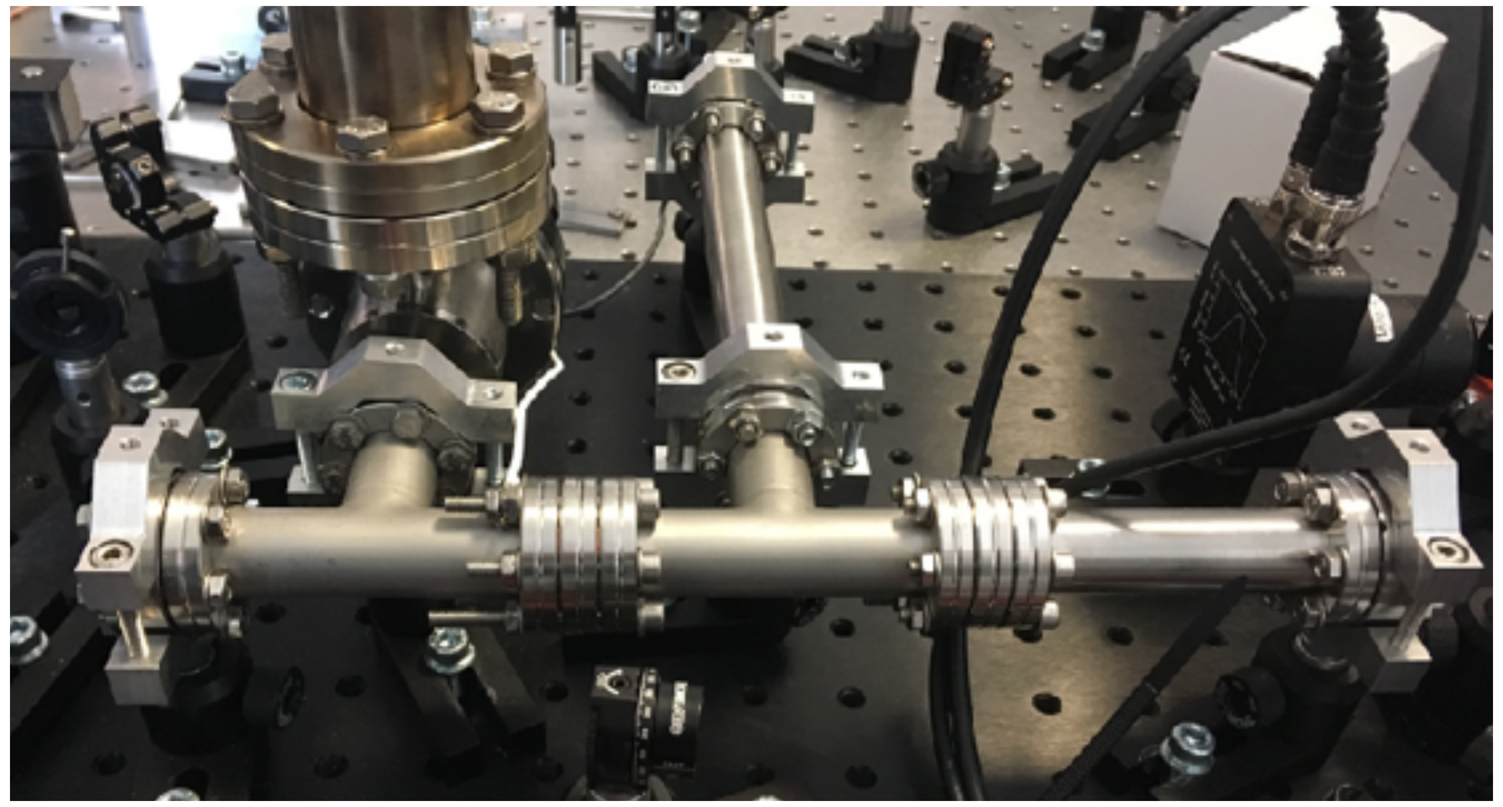
Single-beam MOT for the first commercial ^{87}Sr optical lattice clock

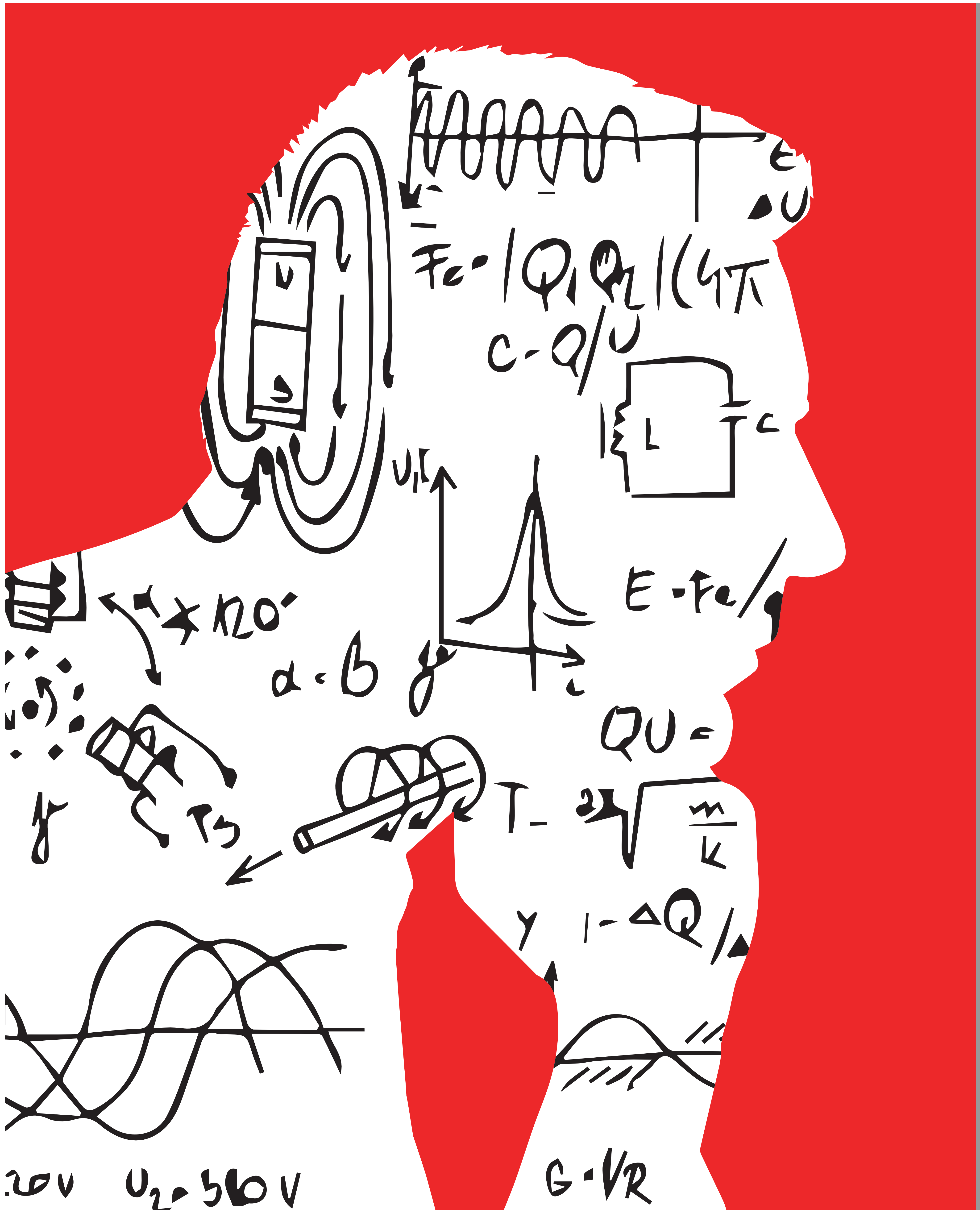




Compact permanent magnet Zeeman slower

Sr spectroscopy vapour cell





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THE SUNDAY TIMES SME EXPORT TRACK 100 2017 — LLOYDS BANK

THE QUEEN'S AWARDS FOR ENTERPRISE: INTERNATIONAL TRADE 2017

IOP INNOVATION AWARDS WINNER 2015 — IOP Institute of Physics

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2016

THE SUNDAY TIMES TECH TRACK 100 2016 — HISCOX

GROWING BUSINESS awards — amazon — WINNER 2016 INNOVATOR OF THE YEAR M SQUARED