Recent & Historical Geochronology Instrument Developments @ JPL

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Special thanks to J. P. Kirby

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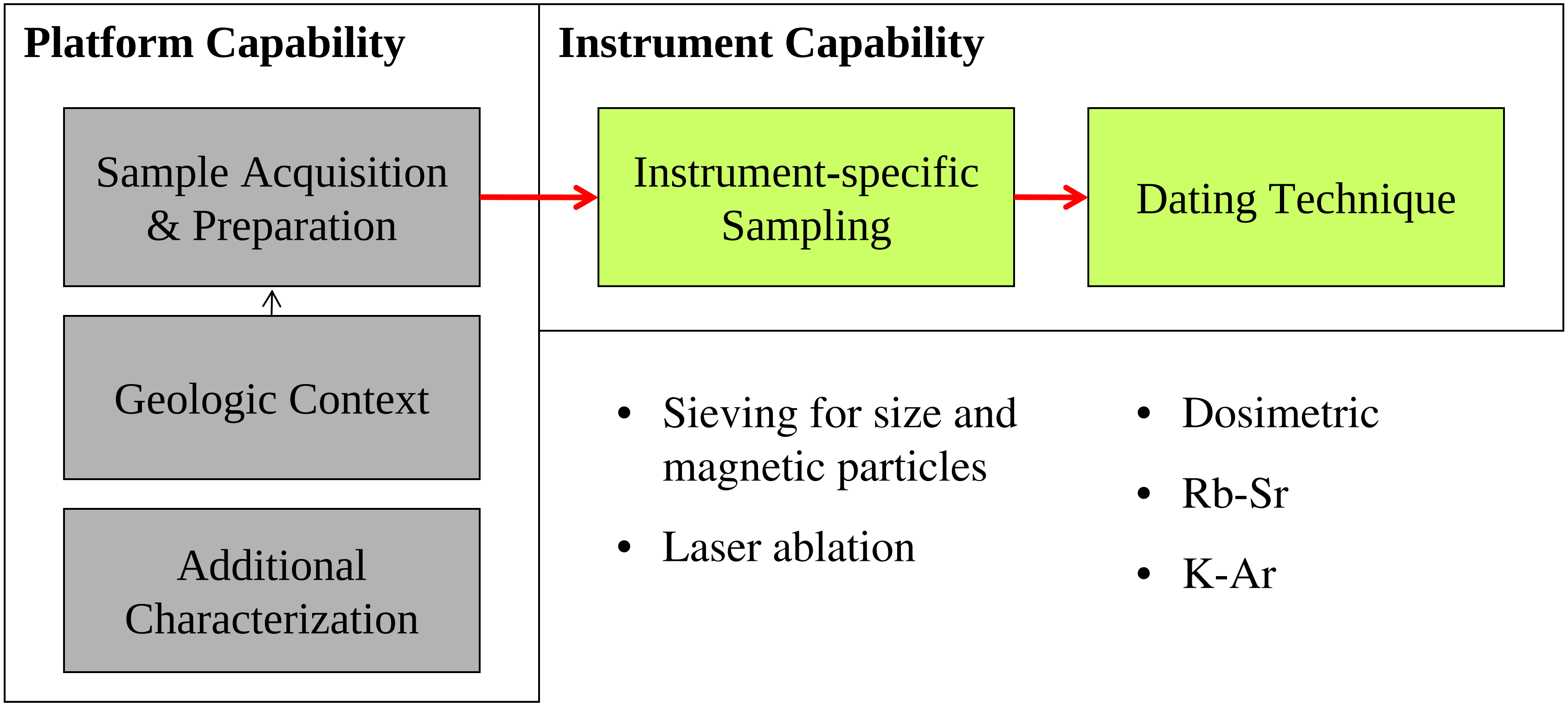
Topics

- What are the challenges for an *in situ* system?
- What approaches have been (or are being) tried?
  - Intent is to provide a sense of the development status of geochronology instrumentation
- What challenges do these developments face going forward to flight?



- Sieving for size and magnetic particles
- Laser ablation

- Dosimetric
- Rb-Sr
- K-Ar

- Chronological techniques not applicable to all rock types
- Sample must be free of post-crystallization disturbances
- Dust contamination
- As a minimum, expose fresh surface
- Desireable, pre-selection of grains

In Situ Geochronometer Developments

- **Luminescence/ESR technique**
  - JPL, Ulmer Systems, Oklahoma State U, McMaster U, LPI
- **^{87}Rb – ^{87}Sr decay**
  - JPL, U Pittsburgh ➔ Scott Anderson's talk
  - JPL, U. Wisconsin, Tangent Technologies, OI Analytical
- **^{40}K – ^{40}Ar decay & cosmogenic nucleotide buildup (^{3}He, ^{20,21,22}Ne, ^{36,38}Ar)**
  - UA, JPL, LANL ➔ Tim Swindle's talk

Luminescence and Electron-spin Resonance Dating

S. Kim (JPL), S. McKeever (Oklahoma State U), W. Rink (McMaster U),
S. Clifford, LPI, A. Yen (JPL)

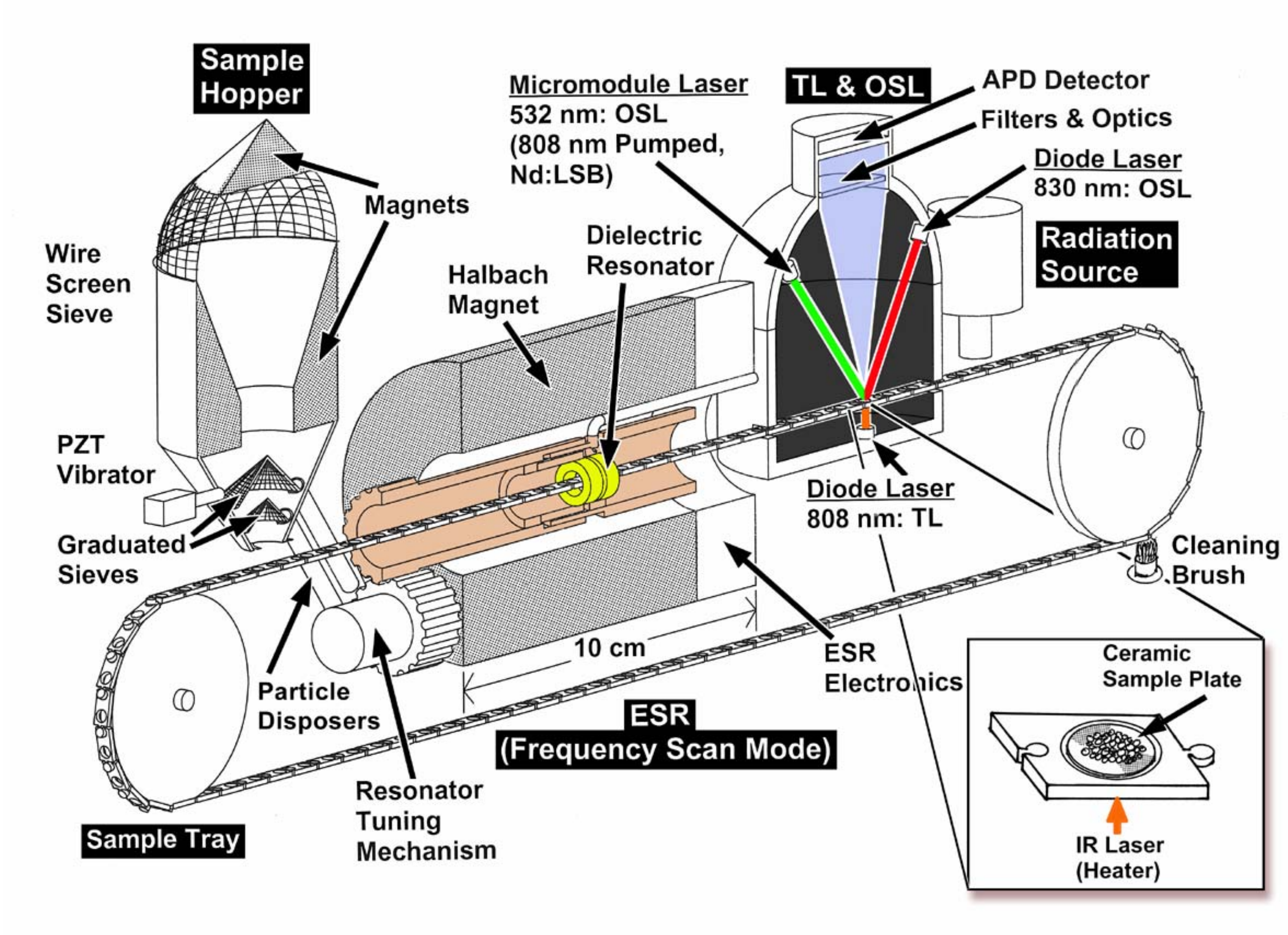
- Dosimetric approach that integrates TL, OSL, and ESR
- All 3 used for dating time since some dynamic geological resetting event
  - Time since last exposure to sunlight (solar reset) and thus burial ages of soils in sediments
  - Time since last thermal event such as volcanic heating, mechanical stresses
  - Measures the accumulation of absorbed radiation dose within mineral grains as f(time)
    - Ionizing radiation accumulates trapped charge in the mineral, which is depleted when exposed to solar radiation (resetting the clock)
    - Luminescence intensity α dose since last exposure to sunlight α depositional age
  - Utility: dating eolian, fluvial, periglacial, impact, volcanic processes spanning the past 100 ka – 1 Ma)

Applicability of techniques, as practiced on Earth

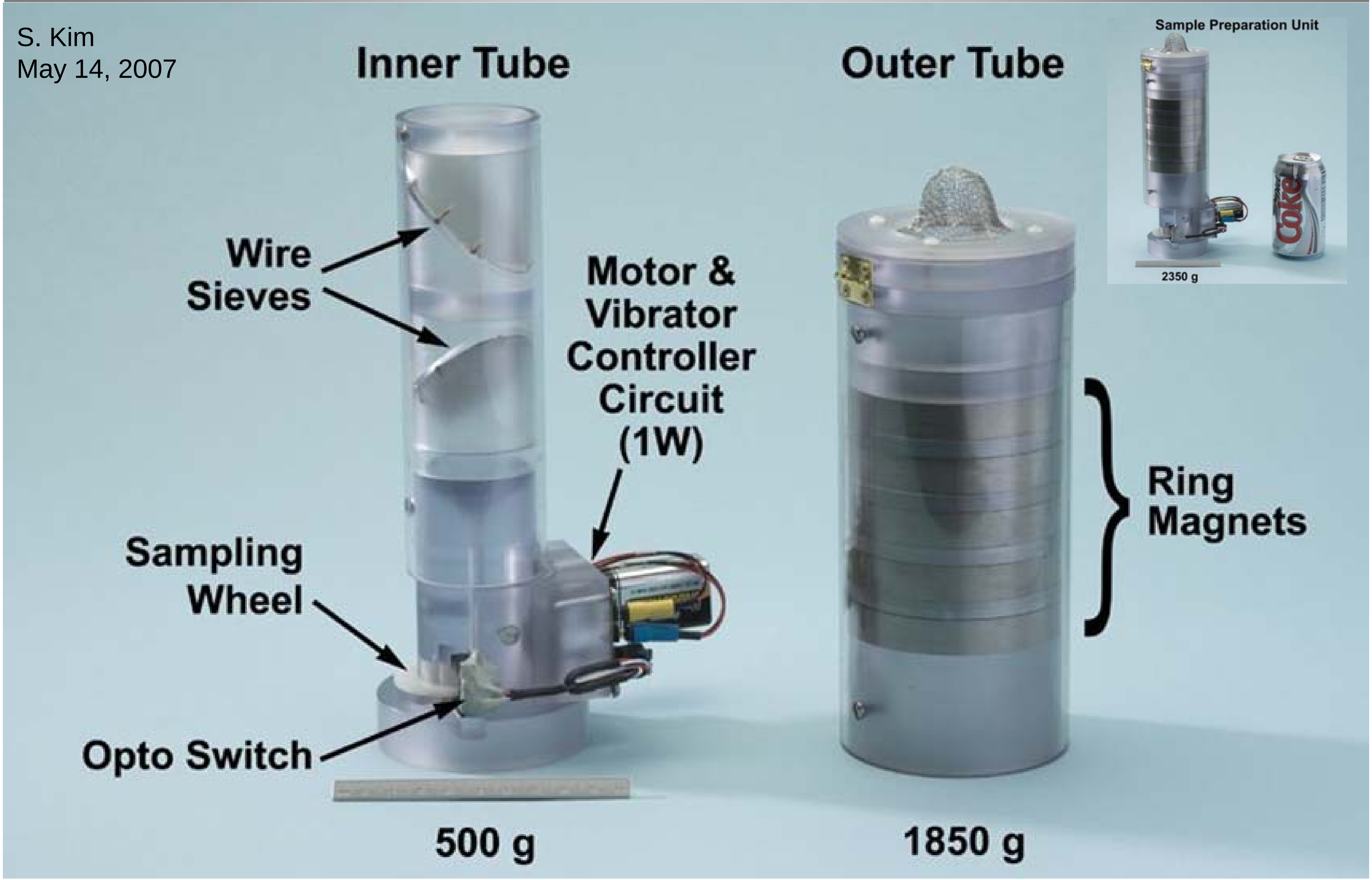
	TL	OSL	EPR
Eolian/Fluvial deposits (age of burial, solar reset)	M	H	L
Volcanic Rocks (crystallization age)	H	H	L
Sedimentary Volatile Deposits (age of crystallization of carbonates, sulfates)	L	L	H
Dust Particles in Polar Ice Caps (age of incorporation into ice)	L	H	L
Material characterization	L	L	H

Applicability H: High M: Medium L: low

Luminescence and Electron-spin Resonance Dating Breadboard Concept

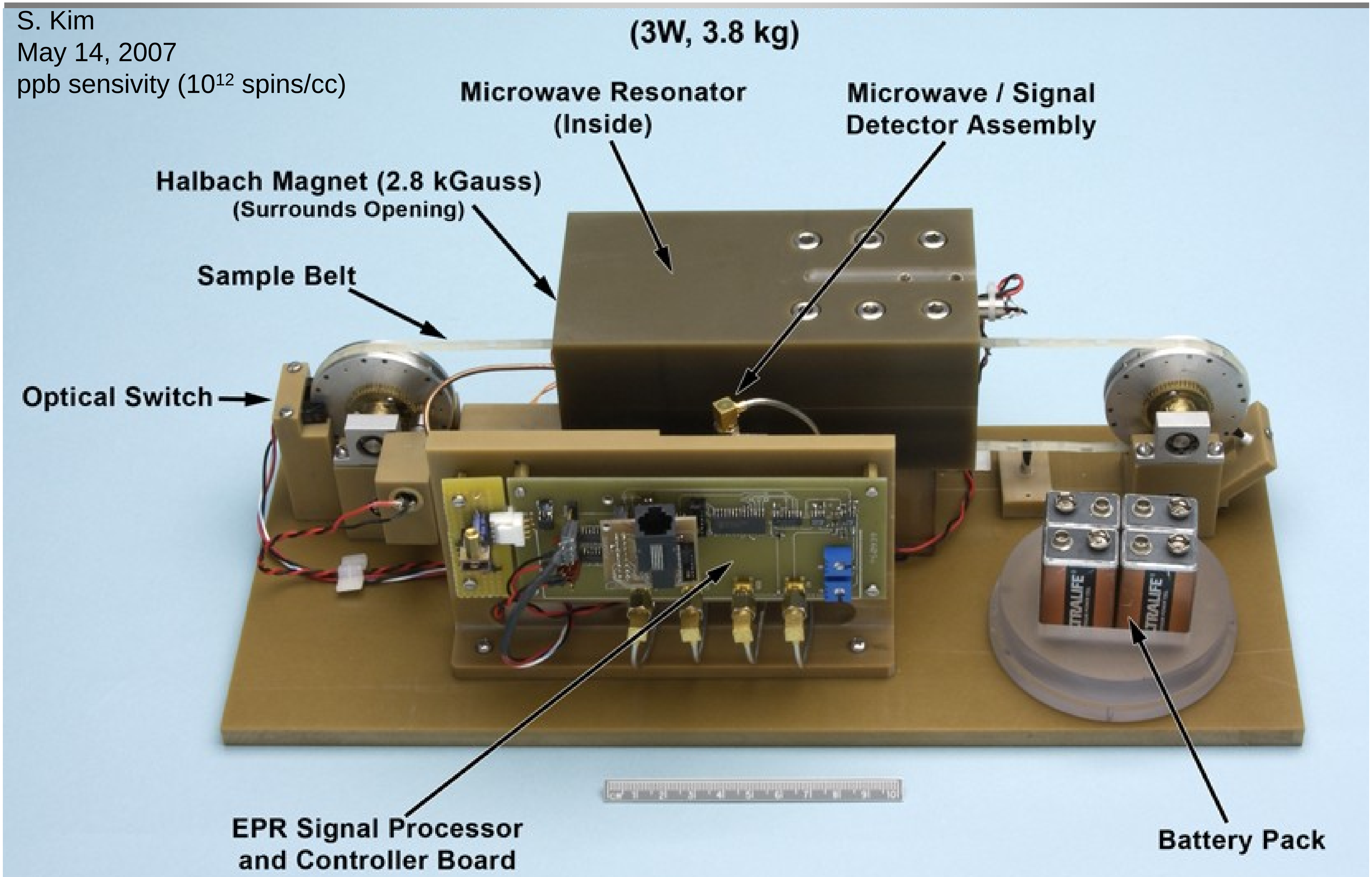


Luminescence and Electron-spin Resonance Dating Development Status—Sample Preparation Unit



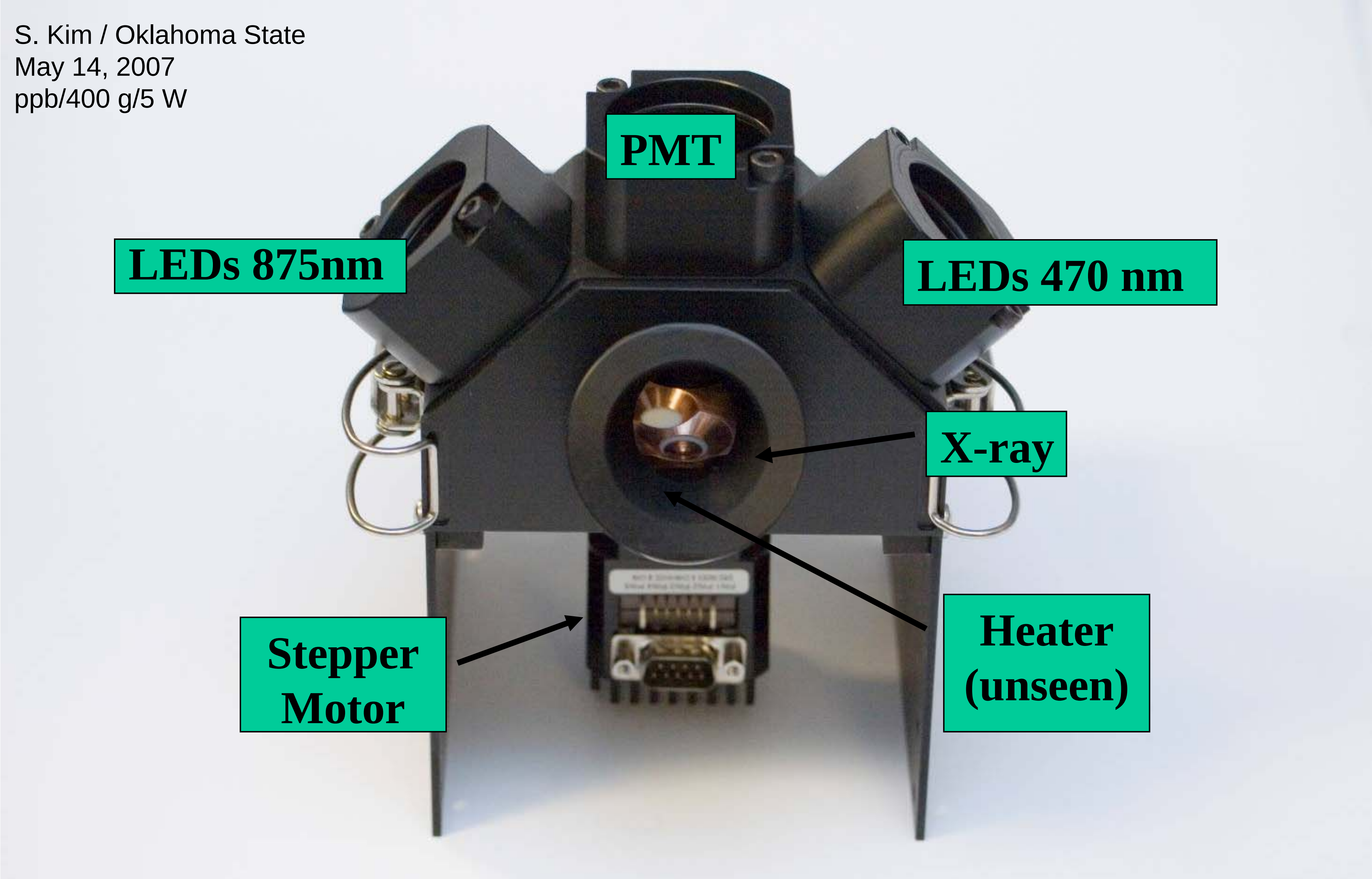
Luminescence and Electron-spin Resonance Dating Development Status—ESR Spectrometer subsystem

S. Kim
May 14, 2007
ppb sensivity (10^{12} spins/cc)



Luminescence and Electron-spin Resonance Dating Development Status— OSL and TL subsystem

S. Kim / Oklahoma State
May 14, 2007
ppb/400 g/5 W



Luminescence and Electron-spin Resonance Dating
Challenges Going Forward

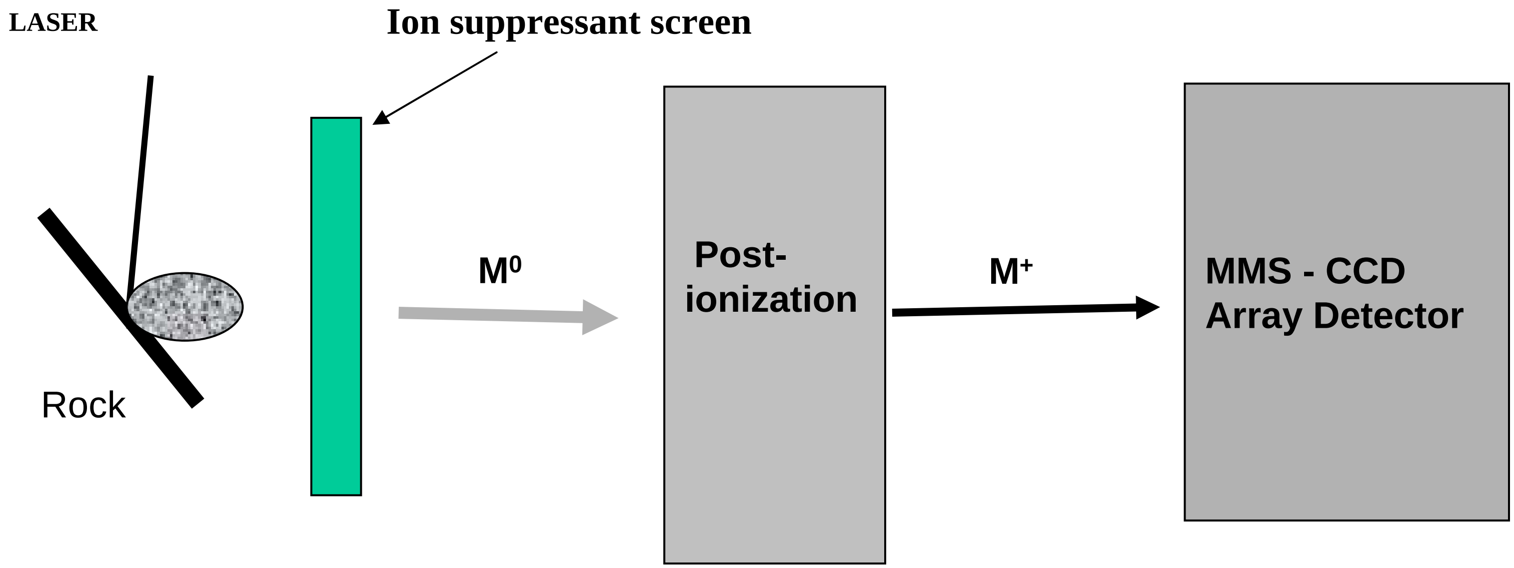
- No currently funded task
  - JPL PI submitted PIDDP on a different topic because geochronology not a priority in the NRA
- Science— Do we understand dosimetry on Mars well enough?
  - On Earth, use mineral separates; on Mars likely polymineralic
  - On Mars, lower natural dose rate but 1000x higher cosmic ray flux
  - Necessitates need to know burial rate
  - Gradual accumulation over time => variable dose rate
  - Efficiency of solar bleaching in low T of Mars

Rb-Sr Geochronology

- A few reminders about the technique
  - ^{87}Rb to ^{87}Sr by β^- decay
  - $(^{87}Sr/^{86}Sr)_i = 0$ not valid nor is it possible to estimate. So ratio is calculated by measuring 2 or more minerals in same rock with spread in Rb/Sr ratios
  - Measurement masses are 85, 86, 87. Use fact that $^{87}Rb/^{85}Rb$ is constant in all SS materials to derive desired D_r/D_s and P/D_s for isochrons

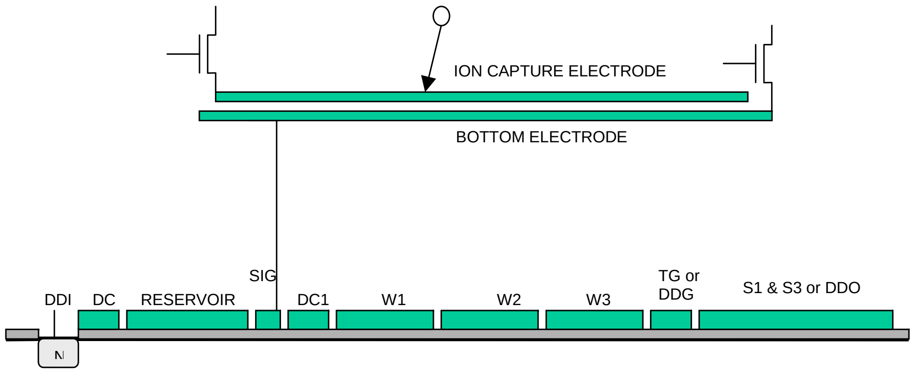
Laser Ablated – Electron Impact Ionization – MS for Geochronology (Rb-Sr)

M. Sinha (JPL), B. Beard (U WI), M. Wadsworth (Tangent), OI Analytica

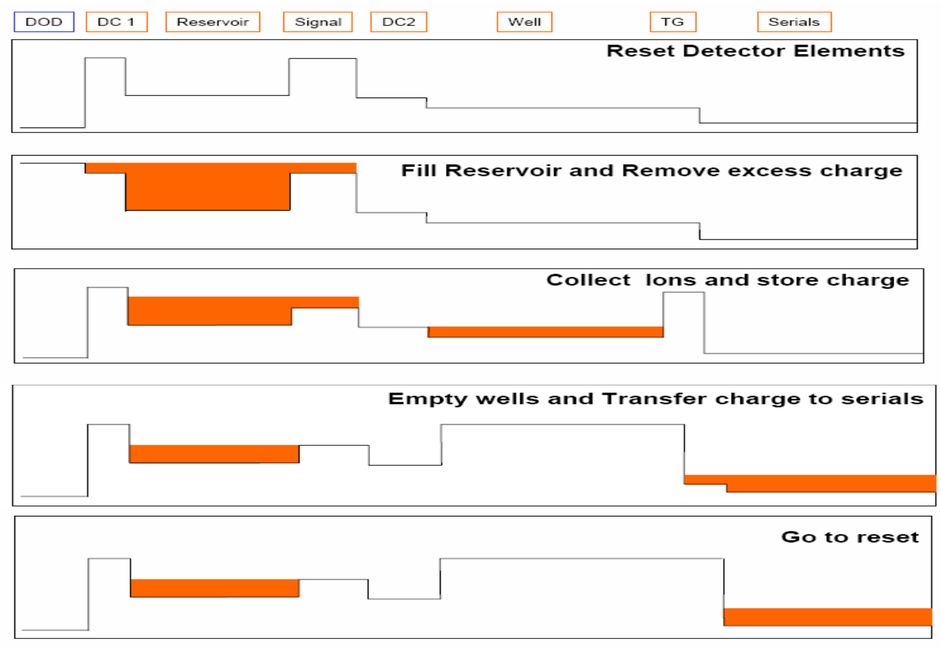


- Laser-ablation and sampling of neutrals only
  - Potential for cleaner mineral separates & better understanding of internal isochrons
  - 10^2–10^6 more neutrals than ions; may better represent elemental abundance
- Electron impact ionization of neutrals creates 100–1000 µs ion pulse
- Non-scanning magnetic sector MS with custom focal plane array detector integrates entire ion pulse simultaneously
- Estimated precision of age dating: 95% confidence of ±150 Ma for a 500 Ma rock

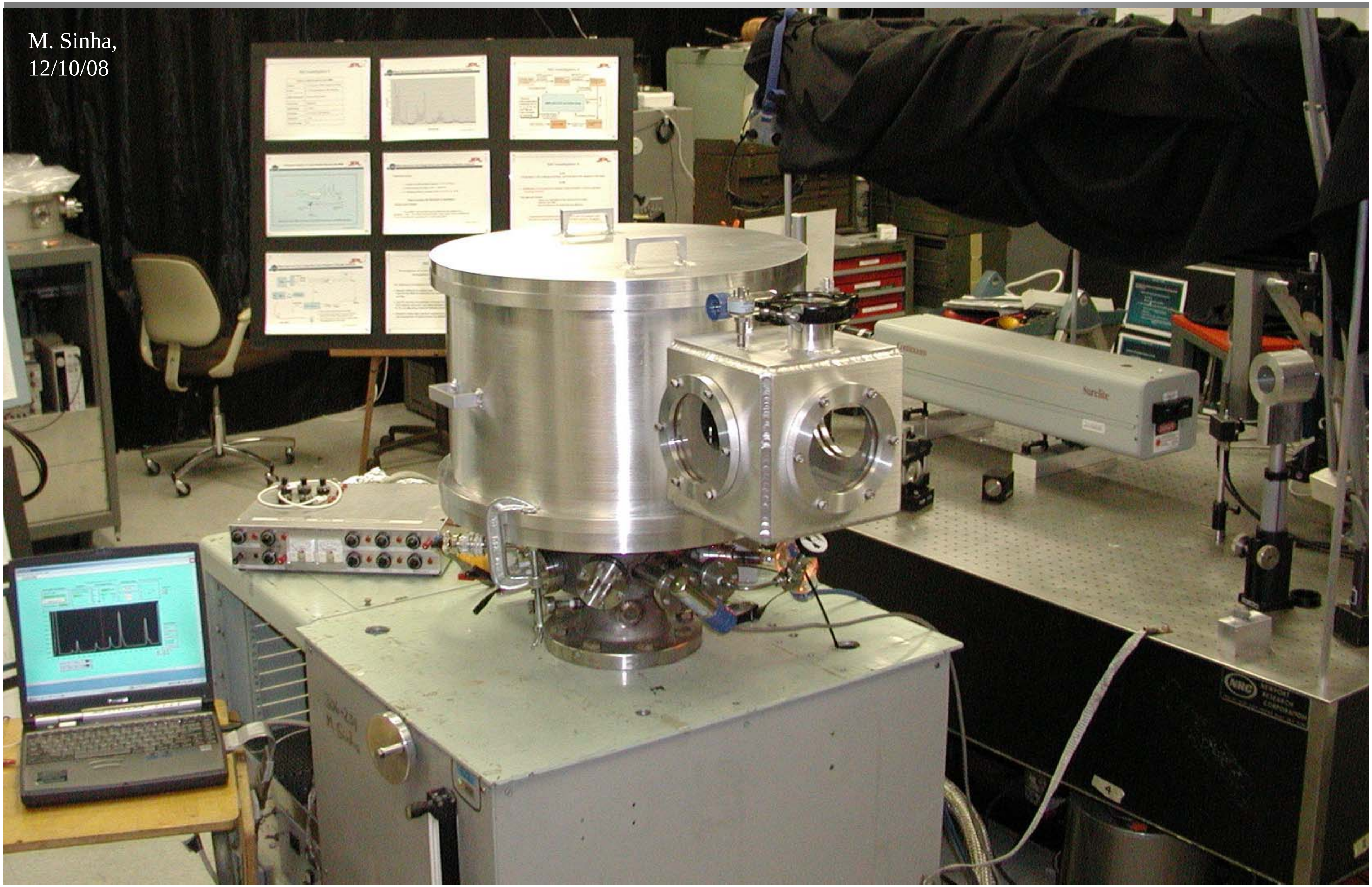
Direct Ion Detection with a Modified CCD Focal Plane Array



- Linear array of CCD pixels
- Photodiode replaced by a capacitive sensing element that serves as ion detector
- Capacitive element is coupled to CCD shift register and creates a packet of signal charge proportional to the charge on the capacitor
- 2nd generation CCD improves sensitivity, reduces noise, increases dynamic range and resolution



Laser Ablated – Electron Impact Ionization – MS for Geochronology
Sinha, et al



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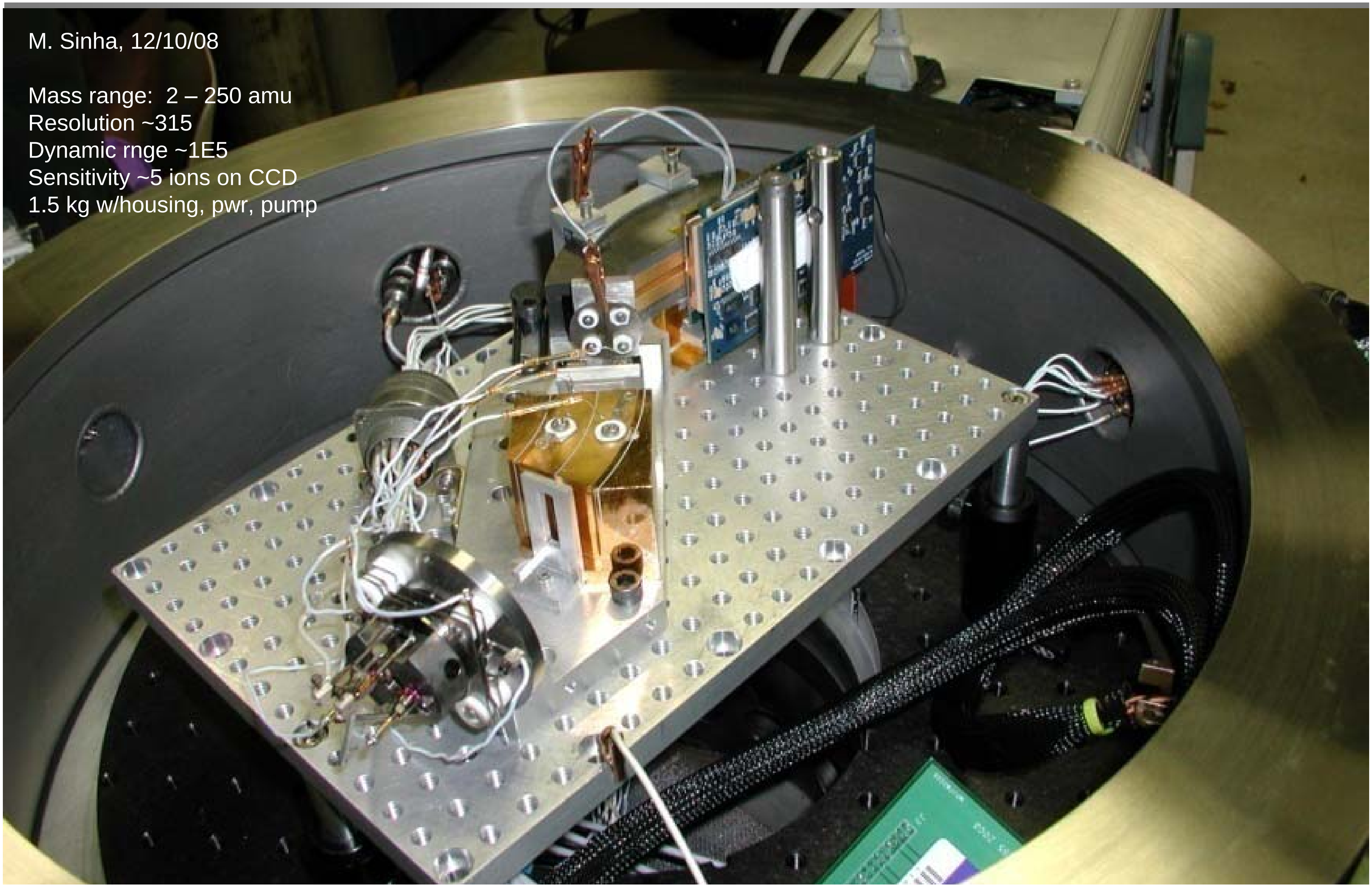
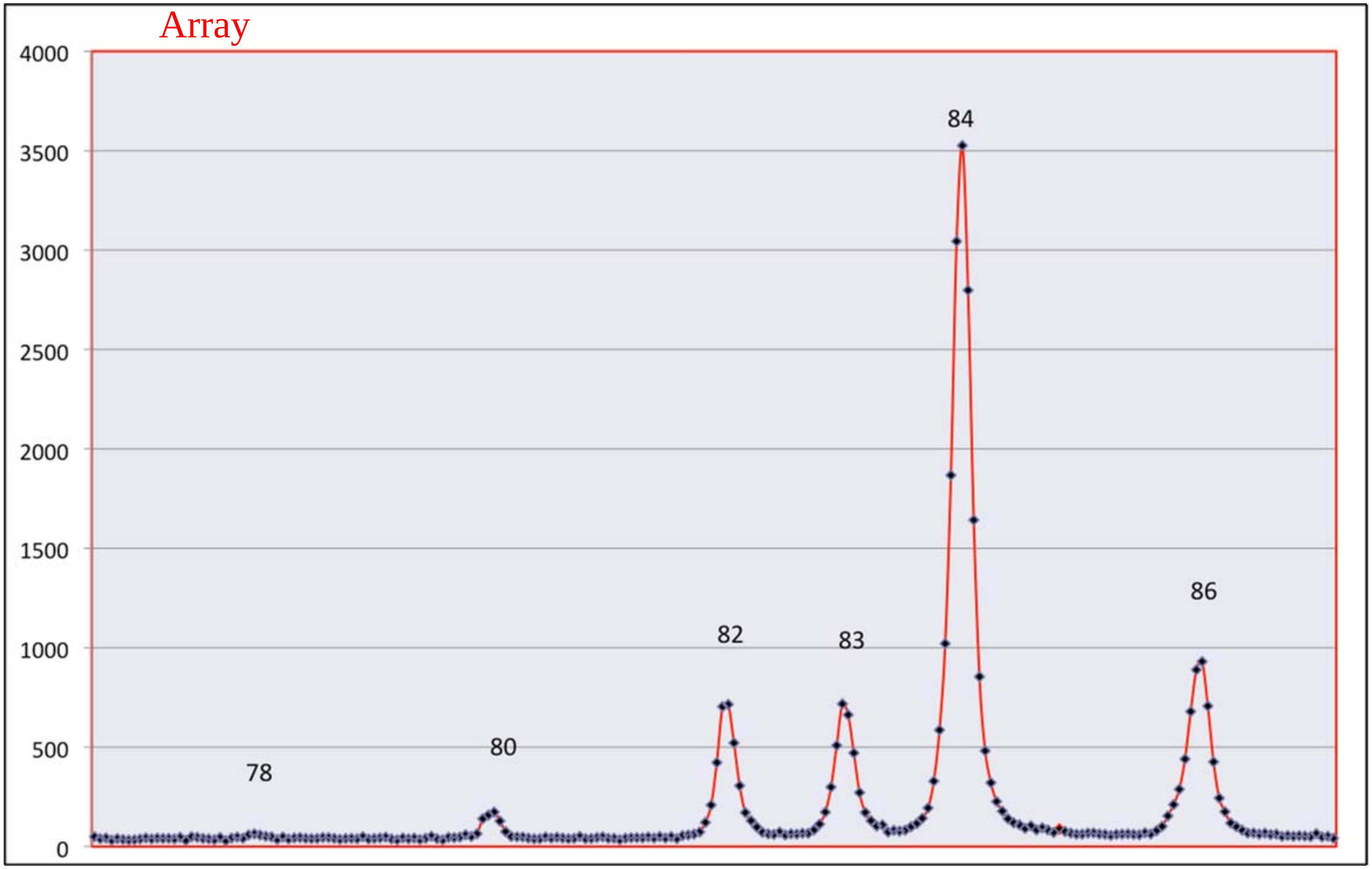


Laser Ablated – Electron Impact Ionization – MS for Geochronology
Sinha, et al

Krypton Isotope Measurement with CCD Direct-Ion-Detector Array



Pixel Number

M. Sinha, 12/10/08

Error Estimates for Rb-Sr ratios

	Plagioclase	Clinopyroxene	Ortho-pyroxene	Olivine	
Sr ppm	100	10	3	1.5	
$^{87}Sr/^{86}Sr$ and % error	0.70537 ± 0.0793 %	0.70990 ± 0.1770 %	0.71134 ± 0.5499 %	0.70836 ± 0.5869 %	yesterday ±1%
$^{87}Rb/^{86}Sr$ and % error	0.0513 ± 1.277 %	0.687 ± 0.349 %	0.8901 ± 0.5869 %	0.4717 ± 1.203 %	±10%

- Assumes $1x10^6$ atoms/laser shot, 10% of atoms delivered to ion source, 1 in 1000 atoms ionized, 20% of ions arrive at detector, ions accumulated for 100 shots, all minerals had $(^{87}Sr/^{86}Sr)^i$ of 0.705 and are 500 Ma old
- For a 4-mineral isochron using the above estimates, 95% confidence of age error ± 140 Ma for 500 Ma rock

Challenges Going Forward for Both Rb-Sr Systems

- Rb and Sr must be ionized in direct proportion to their abundance in the sample
- Laser ablation for sampling
- Potential for cleaner mineral separates & better understanding of internal isochrons
- Both techniques sample neutrals, not ions; 10^2–10^6 more neutrals than ions; may better represent elemental abundance
- But, laser ablation (w/ICPMS) has shown significant elemental fractionation for elements of different volatility. Neutral generation is thermal.
    - Rb (688 ˚C) and Sr (1382 ˚C) have very different melting points
    - The extent of elemental fractionation must be characterized for different minerals
- Ionization efficiencies must be understood. In this respect, electron impact is more commonly used and may be better understood than resonant ionization (but, heck, I'm not sure)
- Resonant ionization is highly sensitive for ionization and highly selective. Electron impact is not selective and can, therefore, be used to characterize other neutral species.
- Both approaches must develop differentially pumped systems to keep sample outside (or bring the sample inside and pump down each time)

Summary

- There are several age dating systems operating at TRL 4 with potential to meet performance requirements
- None of these systems have yet demonstrated they can delivery the performance demanded
  - Elemental sampling and/or ionization bias effects need to be examined
  - H/W needs miniaturization & subsystems
- KISS should identify the tall tent poles that may not be funded under existing PIDDP/MIDP/etc funds
- To paraphrase Gregg, development needs to proceed *tout de suite*