Summary of key points/ Questions raised

- Session 1—Setting the stage
  - In the search for biosignatures, we must consider the origin of life, as well as the maintenance of life
    - Baross: Hydrothermal vents may have played a role in the origin, or at least early evolution, of life
    - *Serpentinization* is a key process for providing surface area/hydrogen/trace metals
  - Free energy is an important consideration
    - Hoehler: This is the most fundamental requirement for life
    - Smith: Free energy gradients are also an essential factor in some theories of the *origin* of life (metabolism first, as opposed to control first)
    - Hoehler: Life as we know it only uses *redox* chemistry (transfer of electrons), as opposed to other sources of free energy

- Our understanding of the evolutionary relationships between extant organisms is still changing
  - Baross: The rRNA tree may have a 2-domain structure rather than a 3-domain structure
  - This can have implications for the nature of the last common ancestor. Was LUCA a methanogen?
- Session 2—Habitable environments in the Solar System
  - Mars remains a likely abode for either extant or extinct life
    - Grotzinger: MSL has provided new evidence for repeated formation of long-lived lakes
    - Direct evidence for serpentinization from observations of clays and magnetite
    - More small rovers are needed to explore diverse environments
    - Me: Arguments continue as to how to explain prolonged periods of warmth on early Mars. Can we reach consensus on this question?

- Ocean worlds are another place where life might have originated and evolved
  - Europa and Enceladus are highest on the priority list
  - Hand: Detection of life on life on one of these worlds would almost certainly indicate an independent origin of life
  - Finding DNA-based life would therefore indicate *convergence* toward a universal type of biology
  - Many of the requirements for life are arguably present on these worlds (water, biologically important elements, water-rock interactions, hydrothermal vents?)
  - Free energy is still an important consideration
    - Reduced materials could be provided by the mantle
    - Oxidants could be provided by crustal overturn
    - Is the available free energy sufficient to create/sustain life?

- NASA has multiple different pathways that it might pursue to detect biosignatures
  - Stofan: Humans can play a key role in looking for life on Mars, e.g., by enabling deep drilling
  - Others have argued that we should delay human exploration of Mars, either for cost reasons or to avoid biological contamination until the planet has been better studied
- Session 3—Exoplanets
  - Remote detection of biosignature gases has been studied more and more intensively in recent years
    - Meadows: The simultaneous presence of O_2 and CH_4 (or N_2O) is still the best available remote biosignature
    - O_2 by itself is an ambiguous biosignature (but hopefully we can identify false positives from the planetary context)
    - Thermodynamic disequilibrium by itself is not necessarily a biosignature, as chemoautotrophic life (e.g., methanogens) would tend to drive an atmosphere *towards* equilibrium

- We should remain cognizant of the fact that nature may surprise us and that life on extrasolar planets may be different from what we know
  - Bains: Ammonia might be a possible biosignature on a hydrogen-rich super-Earth
  - Regardless of the merit of this particular suggestion, we need to approach this question with open minds, lest we be accused of looking for our keys under the lamppost
  - We want to study non-Earth-like worlds, anyway, for their own intrinsic interest
- Detection of life on exoplanets may start to become possible within the new few years
  - JWST may be able to do transit spectroscopy on an Earth-like planet around an M star (not discussed here)
  - Siegler: WFIRST will not find Earth-like planets, but it will find other non-transiting planets and test space-based coronagraphs
  - Brogi: Proxima Centauri b may be charactized from the ground, especially when new 30-40 m telescopes are constructed

- Session 5—Life detection techniques
  - NASA has been looking for extraterrestrial life for at least 4 decades
    - Clark: The Viking life detection experiments did not tell us what we had hoped to learn from them, but they nevertheless provided lots of useful information
    - Viking provides a cautionary tale about thinking carefully about 'false positives' before announcing any results
  - Looking for DNA-based life is relatively easy
    - Ruvkun: Send an Oxford Nanopore machine to Mars!
    - We have an *extraordinary* database on DNA-based life on Earth. This could enable us to discriminate between terrestrial contamination and alien life
    - Was life transferred from planet to planet? From star to star?
  - Many aspects of water-based life are likely to be replicated elsewhere, regardless of whether DNA is involved

    - Benner: Molecular systems cannot arise without life
        - Is this a challenge to the ‘metabolism first’ hypothesis for life’s origin promoted by Eric Smith?
    - Life in liquid water will be based on biopolymers with repeating charges, and hence should be easy to detect even if it is not DNA-based
    - Need *dry land* to allow for formation of borate evaporates $\Rightarrow$ Water Worlds may not be good places to search for life

- Session 6: Instrumentation
    - Detection of life in plumes (Cable)
        - Questions?
    - Detection of life on extrasolar planets using LUVOIR or HabEx (Domagal-Goldman)
        - Questions?
    - Detection of organics on Mars (Eigenbrode)
        - Questions?

Parting thoughts

- Many questions still remain concerning biosignature detection and interpretation
- The National Academy has two decadal surveys looming on the horizon
  - Astronomy and Astrophysics starting in 2018 (2019?)
  - Planetary Science starting roughly a year later
- It would be nice if the astrobiology community could organize itself ahead of these surveys and provide a coherent set of principles/suggestions to feed into both of them