Outline

- Parent bodies
  - What meteorites/sample returns would we like to have?
- Volatiles
- Organic Matter
- Supporting facilities
- Convergent aims

Parent bodies

- Nature of parent bodies
- Size and distribution
  - Remote observations
- Composition
  - Asteroids
    - Meteorites
  - Extended stories
    - Laboratory chemical and physical manipulation

Image courtesy of NASA

Parent bodies

- What were they first made of?
  - Primary processes
  - Recipes for asteroids
- What did they turn into?
  - Secondary processes
  - Aqueous, thermal, oxidation , irradiation
- What events do they record?
  - Proxies
  - Relative orders
  - Absolute chronology

Murchison

Parent bodies

- Material transport
  - What processes induce movement in parent bodies?
  - Which parent bodies are disturbed by such processes?
  - What is the variation in such processes over time?
  - What parent bodies survive transport?

Image courtesy of NASA

Parent bodies

- Representative sampling
  - How representative is our current information on parent bodies?
  - Can we improve our understanding by assessing more *parts* of the parent body population?
  - Can we improve our understanding by assessing more *components* of the parent body population?

Image courtesy of NASA

Parent bodies

- Indications of gaps in our curated samples
- Hot and cold deserts
  - Large numbers
  - New types of meteorite
- Camera networks
  - Small numbers
  - Catalina Sky Survey
    - Almahata Sitta, first F-class meteorite (Jenniskens et al. 2009)
  - Desert Fireball Network
    - Bunburra rockhole, first Aten meteorite (Bland et al. 2009)

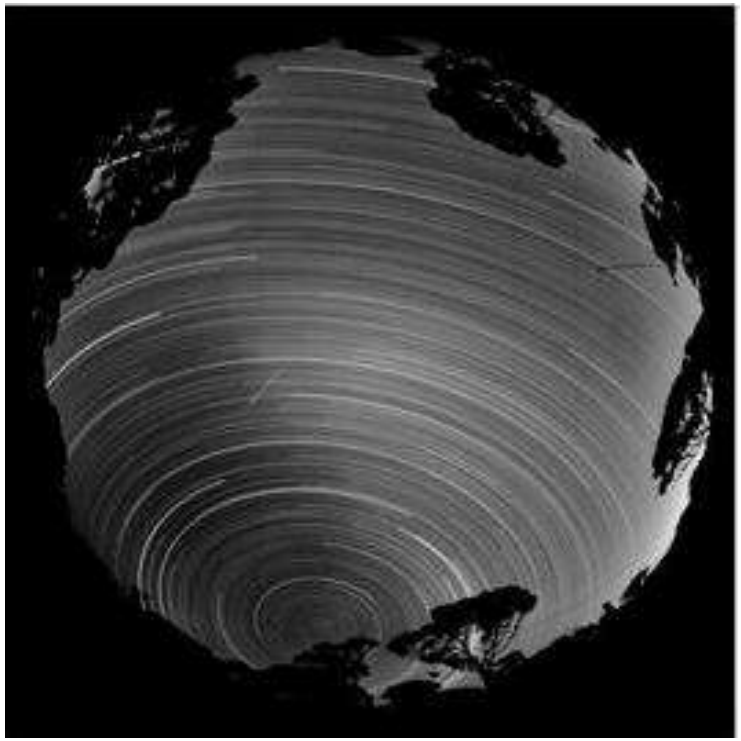


Image courtesy of DFN

Parent bodies

- Targeted sampling
  - What are the most ancient parent bodies and how do we recognise them?
    - Non-hydrous?
    - Volatile contents?
    - Isotopic enrichments?
    - Presolar materials?
  - Can we sample the most ancient parent bodies?
    - Can these materials survive passage to the Earth?
    - Do we need in situ analysis and/or sample return?
  - Answers will need analytical and engineering advances

Image courtesy of NASA

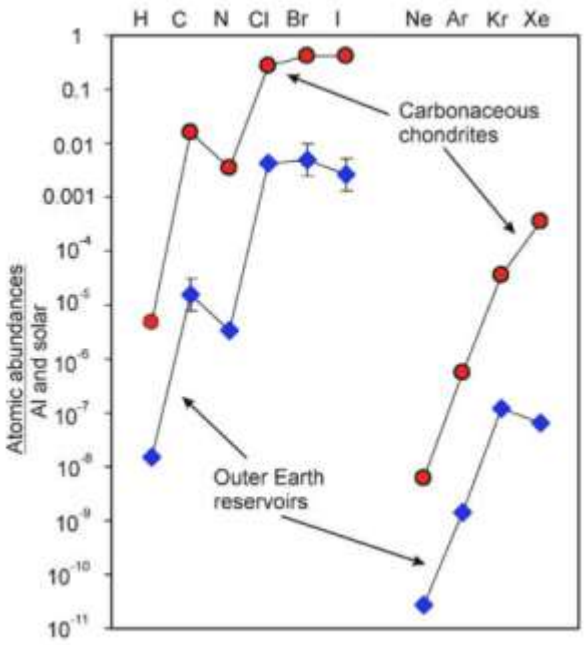
Parent bodies

- The benefits of new samples
  - New samples provide new understanding
  - Often paradigm shifts
- Sample examples
  - Fall of Murchison meteorite
    - Indigeneity of extraterrestrial amino acids (Kvenvolden et al. 1970)
  - Lunar sample return
    - Origin of moon (Hartmann & Davis 1975)

Volatiles

- Primary volatiles
  - Proto-habitability
  - Atmospheres are products of accretion
  - Delivery and loss relevant
  - Composition of primitive bodies as volatile carriers
  - Isotopic studies suggest that chondritic materials were major contributors

Kramers 2003



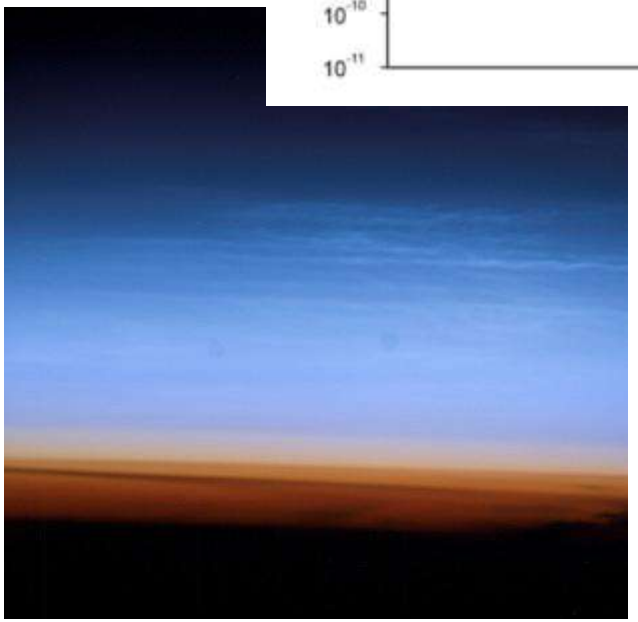


Image courtesy of NASA

Volatiles

- Volatile carriers
  - Compositional variations
- First order variability
  - Chondrites
  - Comets
- Second order variability
  - Petrographic type
- Composition of volatile carriers key
  - Can we understand how they vary?
  - Can we understand why they vary?
- Provide proxies/astrobiology

Volatiles

- Secondary volatiles
  - Delivery mechanism
    - Heating, vaporization, shock
    - Secondary volatiles generated
    - Quantitatively important (e.g. Court & Sephton 2009)
  - Post-accretion processes
    - Degassing
    - Interaction with cosmic phenomena
  - Fate of volatiles important
    - Duration of effects

Volatiles

- How to access primary volatiles?
  - Terrestrially ephemeral materials
  - Lost in the atmosphere
  - Ices, gases easily disperse
  - In situ or sample return
  - Technical challenges
  - Dedicated analytical procedures

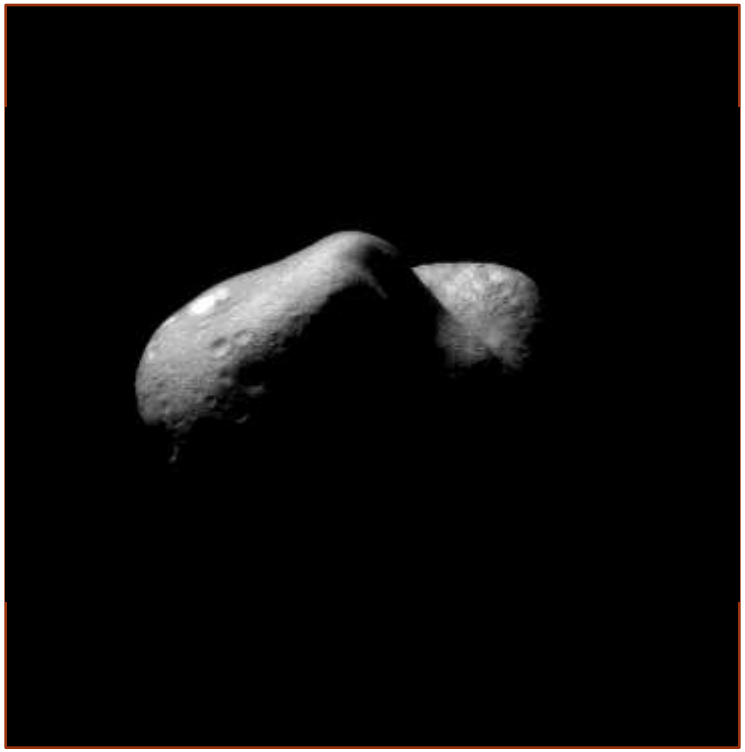


Image courtesy of NASA

Volatiles

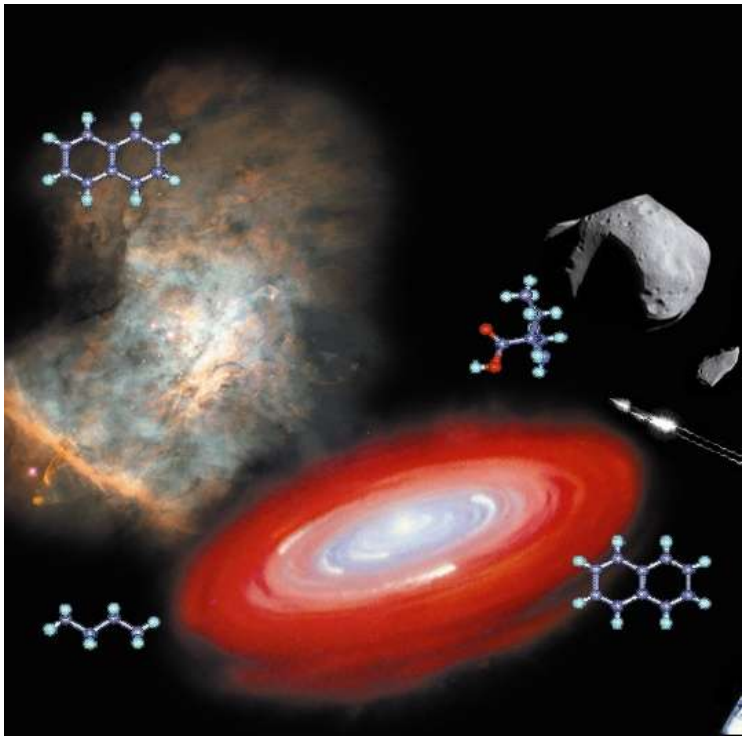
- How to understand the composition and contribution of secondary volatiles?
  - Laboratory experiments
  - Computer modelling
  - Observations

Organic matter

- Meteorites and their parent bodies host bona fide prebiotic material
- Record of chemical evolution in the early Solar System
- Only partially sampled by meteorites that fall to Earth

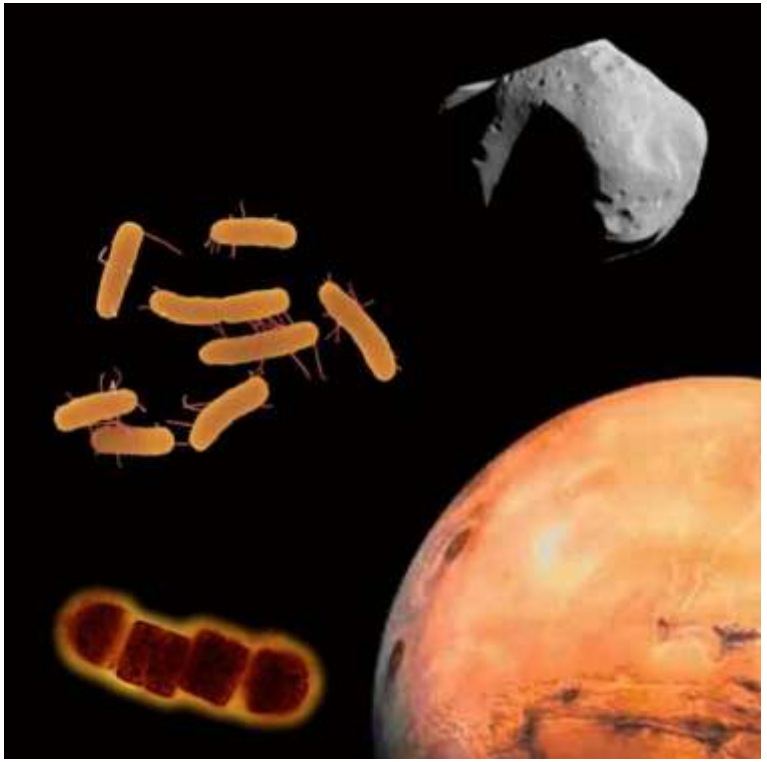
Organic matter

- What is the origin of organic matter?
  - Interstellar
  - Protoplanetary disk
  - Parent body processes
- How do we recognise the contributions of these different environments?
  - What features are characteristic?
  - Which tools are relevant?



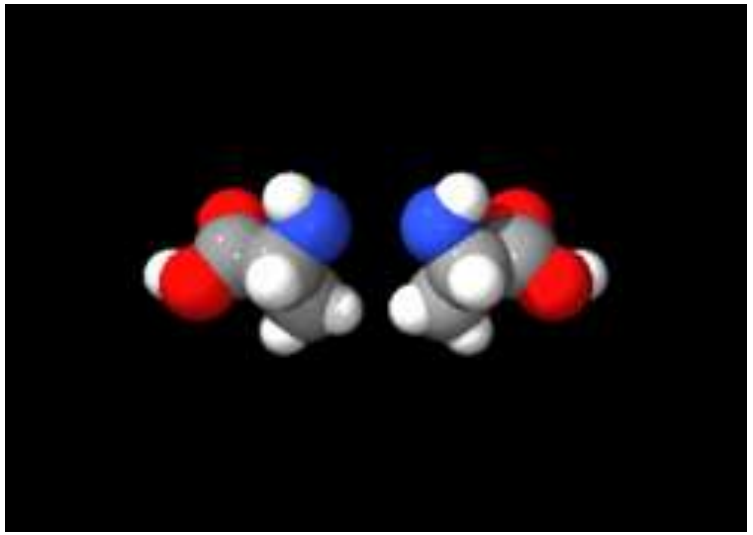
Organic matter

- What components of life exist?
  - Which biologically-relevant organic matter classes are present?
  - Which biologically-relevant organic structures are present?
  - What components are absent and how may they form?



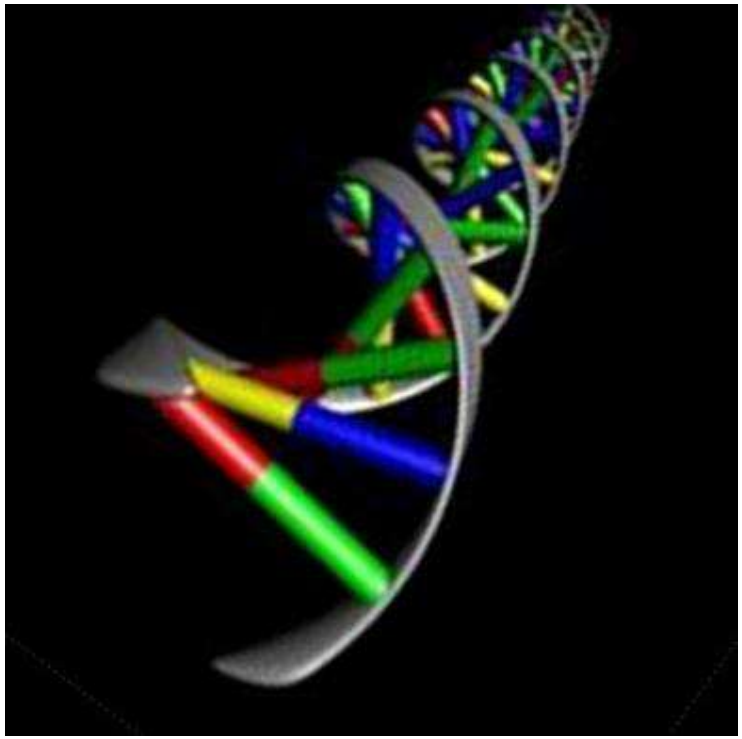
Organic matter

- What evidence is there for the early machinery of life?
  - What associations of biologically-relevant organic compounds occur in prebiotic settings?
  - What selection and concentration mechanisms are evident?
  - What processes facilitate selection or concentration?



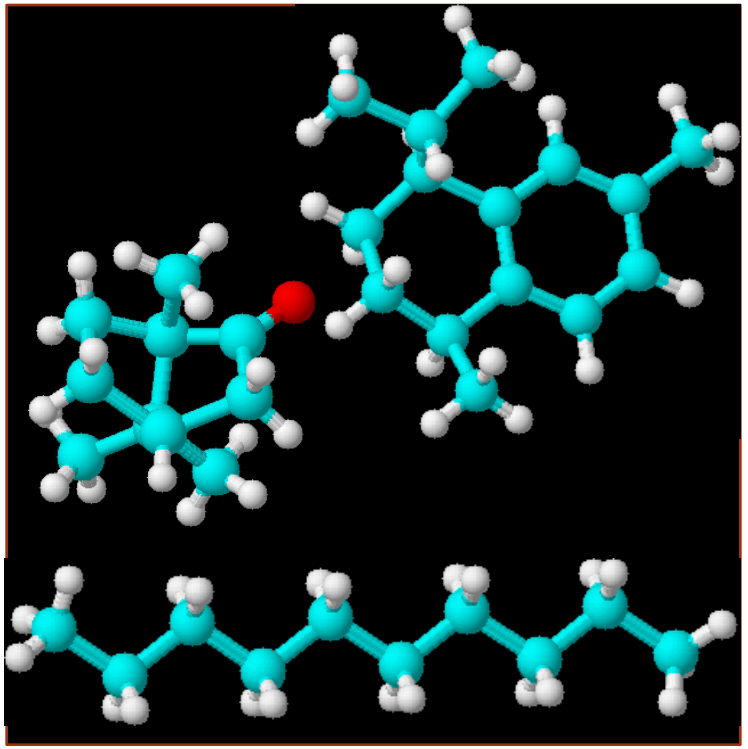
Organic matter

- How would we recognise the products of nascent life?
  - Secondary metabolites
  - Primitive biogeochemical cycles
  - Do we need planets?
- Organic and inorganic proxies
  - On what scales would we look?



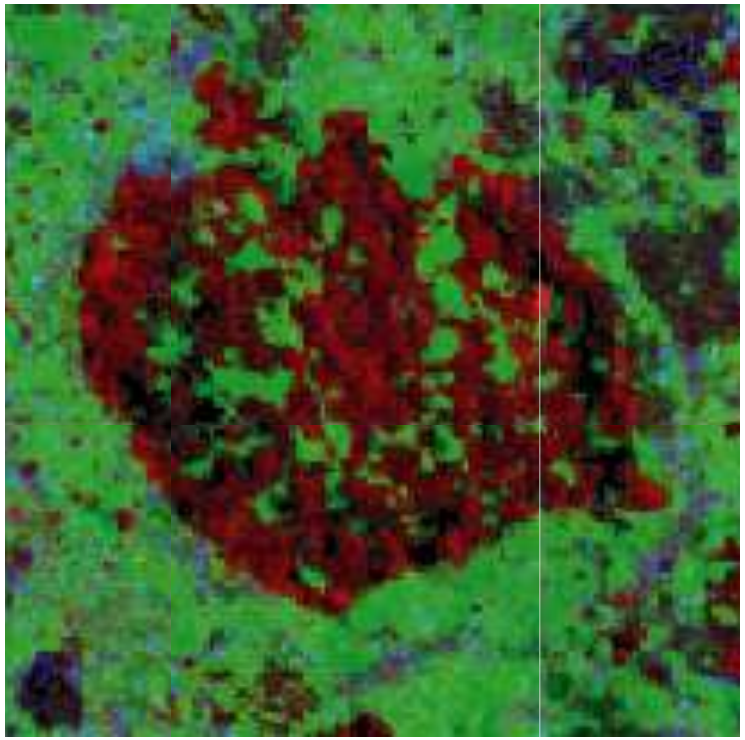
Organic matter

- Primary Processes
  - How does organic matter from different locations achieve co-location?
  - Is there a preservation bias during transport?
  - Is there a preservation bias during accretion?



Organic matter

- Secondary Processes
  - How are organic compounds altered by aqueous, thermal and radiation processing?
  - Does secondary processing account for variation in organic matter between meteorite petrographic types?



Murchison from Pearson et al. (2002)

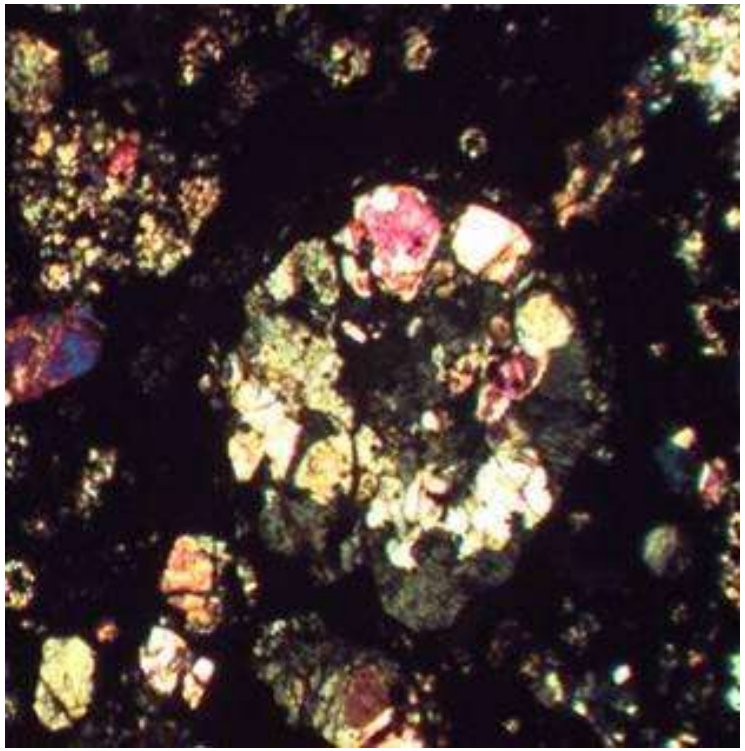
Organic matter

- Representative sampling
  - What is the context of meteoritic organic matter?
  - Which asteroids provide carbonaceous chondrites?
  - What is the variation in abundance of organic matter in asteroids?
  - What is the variation in chemistry of organic matter within and between asteroids?

Image courtesy of NASA

Organic matter

- Targeted sampling
  - The most ancient materials
  - Alteration sequences
  - Facilitate chemical evolution
- Uncontaminated material
  - In situ and sample return



DaG186

Organic matter

- Keep it clean
  - Decades have been lost by studying contamination
- Contamination control
  - Protect new samples
  - Detect contaminated samples
- Maximise the science
  - Focusing pre-terrestrial material
  - Synergies with space mission objectives
    - Planetary protection
    - Life vs non-life

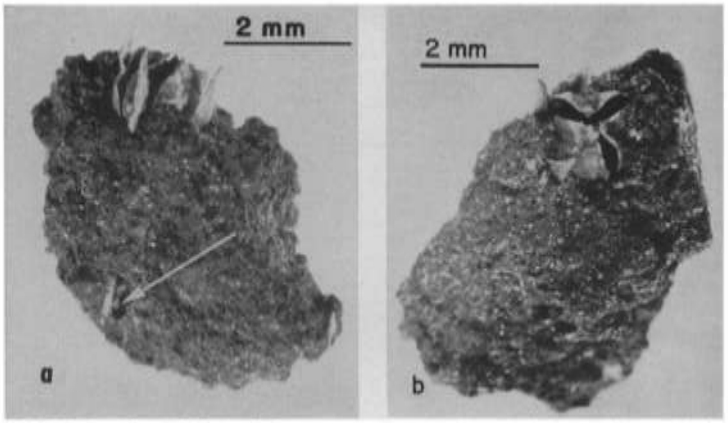


Fig. 3. (a) Seed capsule embedded in meteorite fragment. Arrow points to protruding stem. (b) The same fragment, end view.

Contaminated Meteorite
Author(s): Edward Anders, Eugene R. DuFresne, Ryoichi Hayatsu, Albert Cavaillé, Ann DuFresne, Frank W. Fitch
Source: *Science*, New Series, Vol. 146, No. 3648 (Nov. 27, 1964), pp. 1157-1161

Supporting facilities

- Analytical advances
  - Chronology of meteorite research aligns with technique development
  - Important test beds for analytical progress
- Objective
  - More diagnostic information not just more information
  - Single point diagnostic information particularly necessary for in situ studies
  - New techniques needed
  - New proxies required

Supporting facilities

- Stable isotope example
  - First stable isotopes of organic matter proves indigeneity (Briggs 1963)
  - First individual molecule measured reveals synthetic pathway (Yuen et al. 1984)
  - First measurement of free and macromolecular unit reveals alteration relationship (Sephton et al. 1998)
  - First dual isotope measurement (C&H) of meteorite molecule indicates cosmic origin (Butterworth et al. 2004)
- Future examples
  - Multiple isotopic measurements?
  - Intramolecular isotopic measurements?

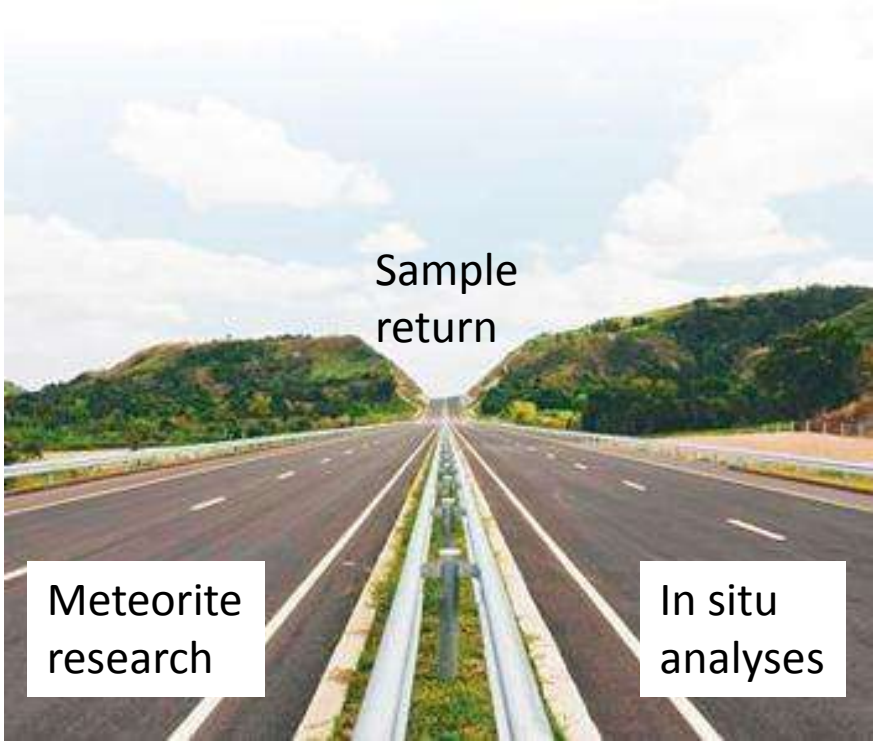
Discovery & New Frontiers

- Related Missions
  - Asteroid Rover/Sample Return (especially if modified to access alteration sequence)
  - Trojan/Centaur Reconnaissance
- Supporting facilities
  - Rapid meteorite recovery
  - Single point diagnostic techniques
  - Contamination control

Image courtesy of NASA

Convergent aims

- Ground based research
  - maximise information
- In situ analyses
  - target key data
- Sample return
  - Benefits from advances in both of above areas



Meteorites and astrobiology

- Alan Bennett
  British playwright (1934-present)
- "Life, you know, is rather like opening a tin of sardines. We are all of us looking for the key "