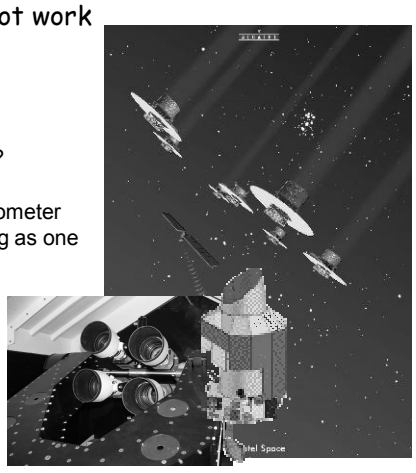
Planets and life

- Successful detections of extrasolar giant planets suggests that planetary systems may be fairly common
  - could we detect Earth-like planets?
  - is it likely that such planets would have life?
  - how would we know?

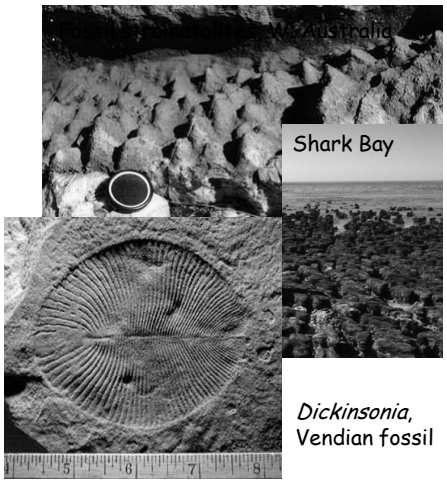
Detection of Earth-like planets

- Doppler shift technique will not work
- Two possible strategies
  - transit detection
    - WASP ground-based (now)
    - CoRoT space-based (now)
    - Kepler (NASA) within 5 years?
  - direct imaging
    - requires space-based interferometer
      - multiple telescopes acting as one
    - Darwin, TPF
    - >10 years
- One system of Earth-mass planets has been found
  - around a pulsar!
    - not well understood, but clearly not really "Earth-like"



Life on Earth: the fossil record

- Oldest rocks ~3.8 Gyr old
- Oldest fossils ~3.5 Gyr
  - bacteria
- Oldest eukaryotes (nucleated cells) ~2 Gyr
  - coincide with rise of atmospheric oxygen
- Oldest multicellular organisms ~550 Myr
- Early hominids ~5 Myr



Dickinsonia, Vendian fossil

Life on Earth: implications

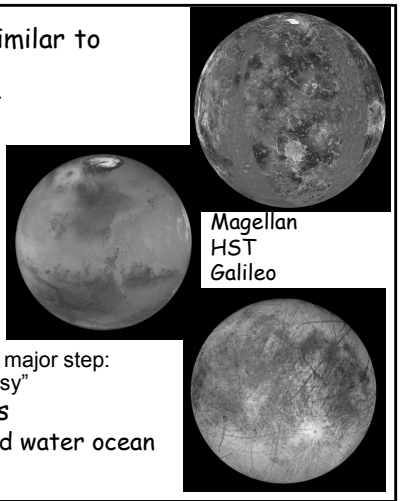
- Life appears very quickly
  - "easy" process?
- but >80% of history of life consists of single-celled organisms
  - becoming multicellular is "hard"?
  - on the other hand, it evolved several times...
- and intelligence appears only in last 0.001% of life's timeline
  - intelligence is "hard"?

- **Main elements used by life are very abundant**
- **"Organic" (carbon-based) compounds form easily in "early-Earth" conditions**
- **Route from there to DNA+protein organisms not well understood**
  - → **"RNA world" first?**
- **Liquid water looks essential**

Arguing from a single example is intrinsically unsafe — and there is clear selection bias (we exist!)

Life elsewhere: the solar system

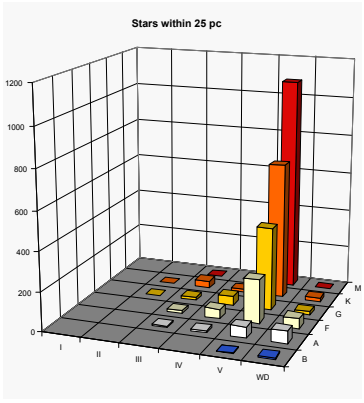
- Venus looks superficially very similar to Earth
  - but runaway greenhouse effect leads to surface temperature of 745 K (472°C)
- Mars is too small to keep its atmosphere
  - evidence for running water early in its history
  - life might have evolved, but not complex life
    - finding bacterial fossils would be major step: confirm that originating life is "easy"
- Europa is heated by tidal forces
  - icy crust probably overlies liquid water ocean



Magellan
HST
Galileo

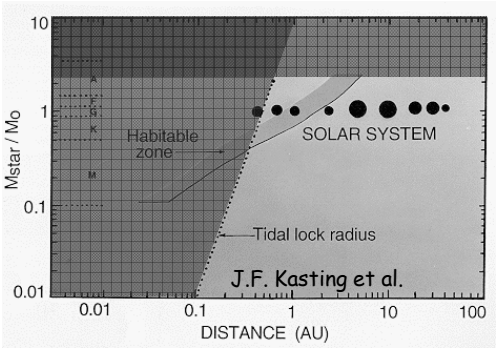
Life elsewhere: other stars

- Criteria for candidate stars:
  - long enough lifetime
    - life unlikely to evolve in 10-million-year lifetime of 10-solar-mass star
    - star of 1.7 M_{sun} has 2 Gyr main sequence lifetime
      - classes FGKM are OK
  - high heavy element content
    - evidence suggests this is required for planet formation
      - not stars in halo
  - stable star, stable orbits
      - not close binary?
      - not very low mass stars (often unstable flare stars)?
- Many stars satisfy these criteria



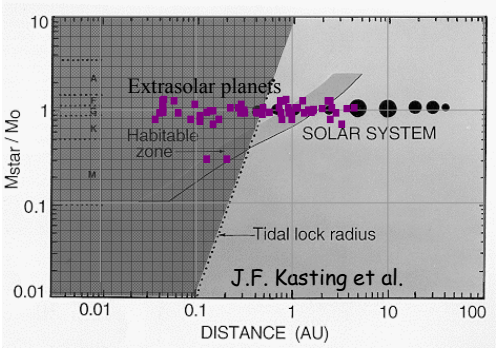
Habitable zones

- Liquid water probably essential for life
  - candidate planets must be in appropriate temperature range
  - temperature basically determined by distance from star
  - ***habitable zone***
    - should allow for stellar evolution
    - *continuously habitable zone*
    - also affected by size of planet
  - problem for low mass stars: tidal locking
    - planets face star
    - extremes of temperature



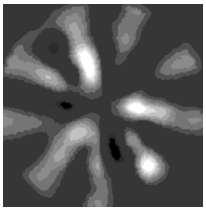
Planets in habitable zones

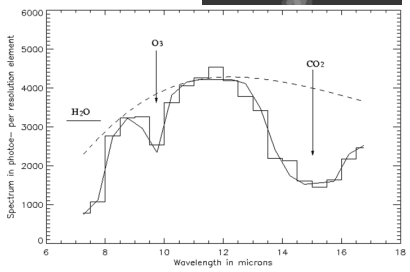
- Some observed extrasolar planets are in habitable zone
  - remember these are (probably gas) giants
  - remember detection method biased in favour of planets near stars
    - certainly no evidence against habitable planets
    - also possibility of rocky satellites of gas giants (Ganymede, Callisto and Titan are Mercury-sized)



Signs of life

- Oxygen is highly reactive
  - not stable in atmosphere: maintained by plants
  - earliest fossils already photosynthesising
    - oxygen in atmosphere good indicator of life even in early stages
  - spectroscopic detection possible
    - in infra-red to reduce background from star
    - good for 3-atom molecules
    - detect CO_2 (atmosphere), H_2O (oceans), O_3 (life)





Simulated image and spectrum from DARWIN homepage

Life like us?

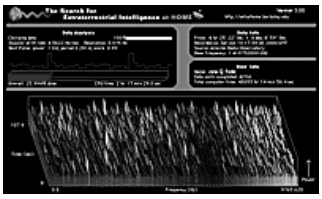
- How probable is evolution of intelligent organisms with technological civilisation?
  - Drake equation (Frank Drake, SETI pioneer)
    - Number of communicating civilisations
      = rate of formation of suitable stars ☑
      x fraction of these stars with planets ☑
      x number of Earth-like planets per system ☑
      x fraction of such planets which develop life ☑
      x fraction of life-bearing planets evolving intelligence
      x fraction of intelligent species developing technology
      x average lifetime of such a civilisation
  - information obtainable on factors marked ☑
    - last three very difficult to estimate
    - rough guess: assume 10 stars/year and all fractions = 0.1; then number of civilisations = average lifetime/10000

known
high?
?
high?
controversial
?
????

Search for Extra-Terrestrial Intelligence

- Drake equation suggests other civilisations may exist
  - only way to confirm this is direct detection
  - obvious method of communication is radio
    - galaxy fairly transparent to appropriate wavelengths
    - travels at speed of light
    - fairly easy to send and detect
  - "radio" covers a wide wavelength range!
    - need to guess appropriate wavelength
      - 21 cm? (hydrogen)
      - microwaves? (cosmic background)
  - would we recognise a signal?
    - probably: information-carrying signal very different from natural sources
  - would we be able to decode it?
    - much more problematic

SETI@home: Berkeley programme using Arecibo telescope at 21 cm



What if….

- Conversations with alien intelligence requires patience!
  - disc of Milky Way is ~40000 light years in radius
    - optimistically suppose 1000 civilisations
    - nearest one, on average, 2000 light years away
      - wait 4000 years for answer: not very practical…
      - so, don't converse, just send Encyclopaedia Britannica and assume they will too
      - advantage: will also take 4000 years for their invasion fleet to get here…..
- They're not there because they're not here?
  - unmanned (unaliened?) probes could in principle colonise Galaxy
    - fact that this has not happened suggests no advanced civilisations?
      - advanced civilisations are all eco-warriors, robot probes environmentally unfriendly?

Conclusions

- Evidence from history of life on Earth is that origin of life may be easy
  - evidence of past existence of life on Mars would be strong confirmation of this
- Basic criteria for stars "suitable" for life are not too difficult to satisfy
  - detection of Earth-like planets around nearby stars possible on 10-20 year timescale
    - spectroscopy could provide evidence for life on these planets
- Other technological civilisations might exist
  - probability depends on hard-to-estimate factors
  - radio searches so far found nothing, but you never know…
    - even if they do exist, United Federation of Planets probably precluded by large distances (at least on basis of current physics)