RADIATOR DEVELOPMENT FOR OXYGEN STORAGE ON THE MOON

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Introduction, Motivation & Outline

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- Vision for Exploration includes "use of lunar resources to support sustained human space exploration…"
- In a favorable orbit, dark sky could be a valuable resource.
  - Provides economical cryogenics capability by radiative cooling.
  - Spitzer Space Telescope dewar shell maintained at 35 K.
- Lunar orbit is favorable.
- Design of radiator to specific lunar environment.
- Applications:
  - Zero-boil-off storage of oxygen and methane.
  - Air revitalization by freezing out CO_2 and other impurities.
  - Separation of lunar volatiles by selective distillation.
- Conclusion

Favorable Orbits

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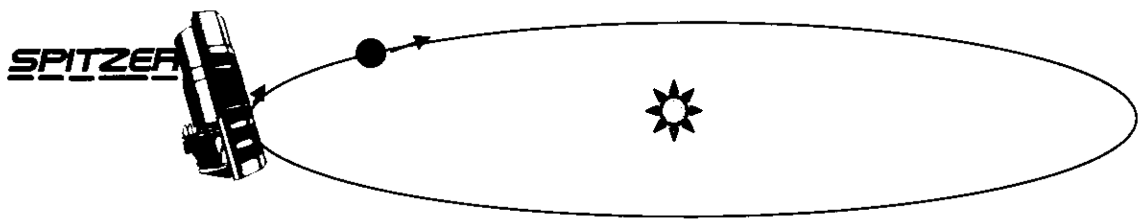
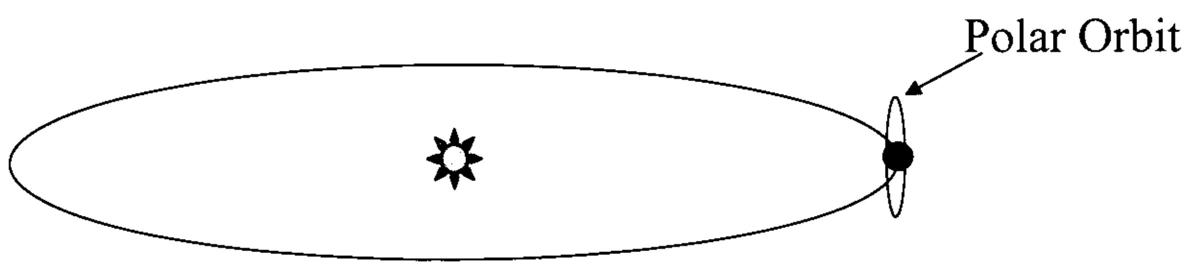
- Orbit of Spitzer Space Telescope – Earth trailing solar orbit.



- Near Earth orbits are not favorable except Polar orbit.



Lunar Obit Favors Radiative Cooling

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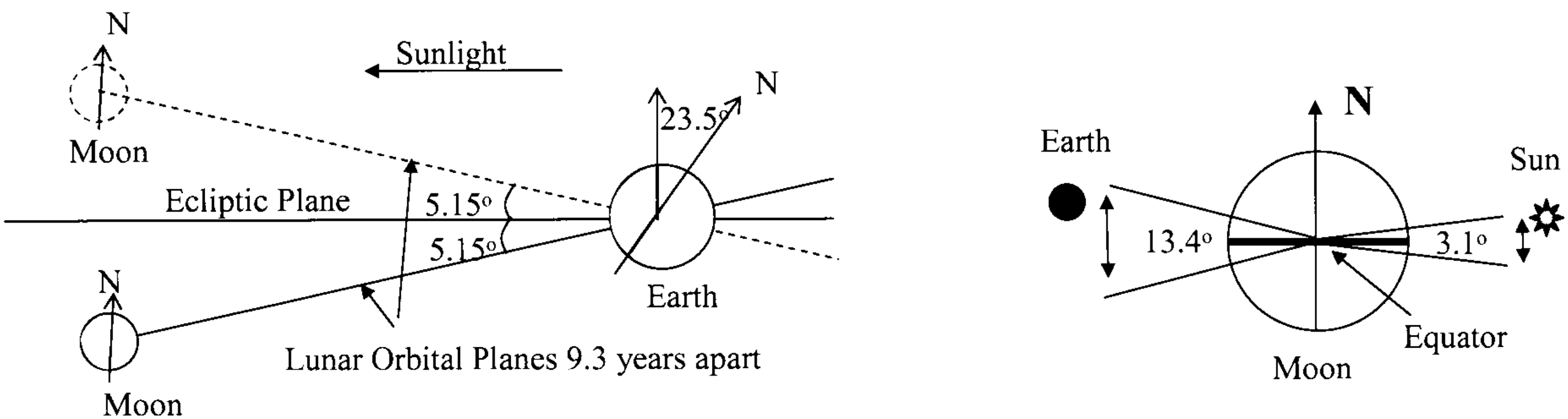

- On the Moon, the Sun is always within 1.55° from its equatorial plane.
- The Earth is always within 6.7° from its equatorial plane.
- A large patch of sky is permanently dark regardless of location on the Moon.

Advantages of Radiative Cooling

- No need of electric power.
- Operates better during lunar night.
  - Solar powered cooler would not work at night.
- Reliable and un-interrupted cooling.
- Requires initial pointing at deployment. No adjustment need afterward.

Preliminary Radiator Design

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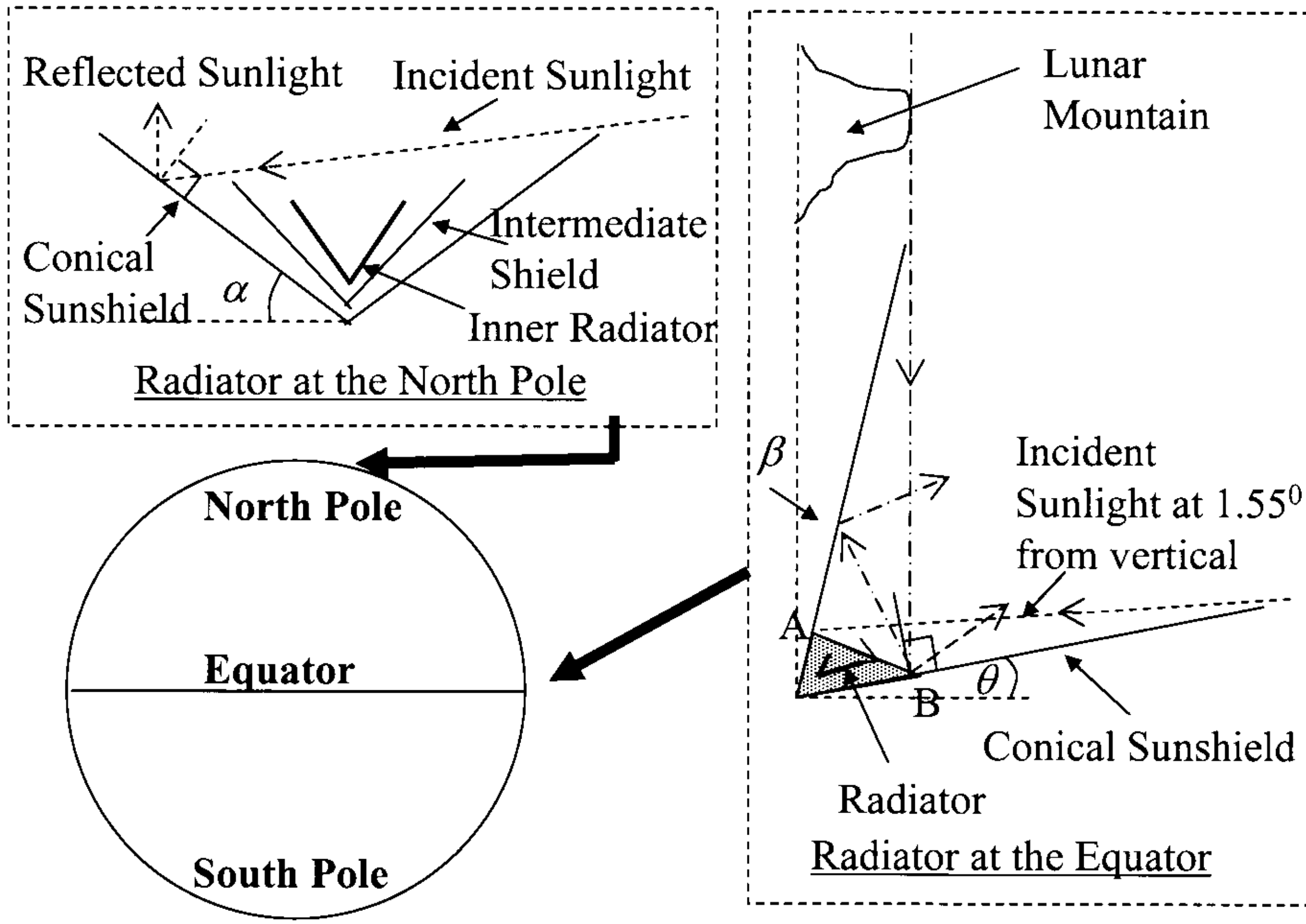
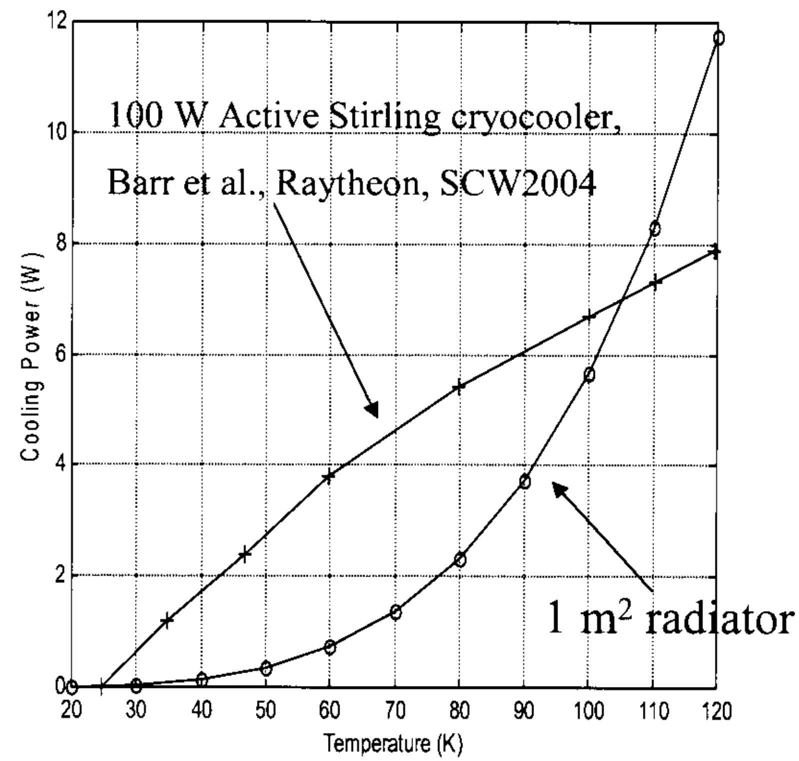


Radiator Versus Cryocooler

- **Radiator – cooling power limited by radiator surface area.**
- **Passive radiative cooler for low cooling power applications above 60 K.**
  - Zero-boil-off storage tank for oxygen and nitrogen.
  - Air revitalization by freezing out impurities.
- **Active cryocooler for higher cooling power applications and lower temperature applications.**
  - Storage & liquid fraction of H_2.
  - Large scale liquid fraction of O_2
- **Both technologies used together increases efficiency.**



Design Concept of a 1-m^2 Radiator for Purifying O_2.

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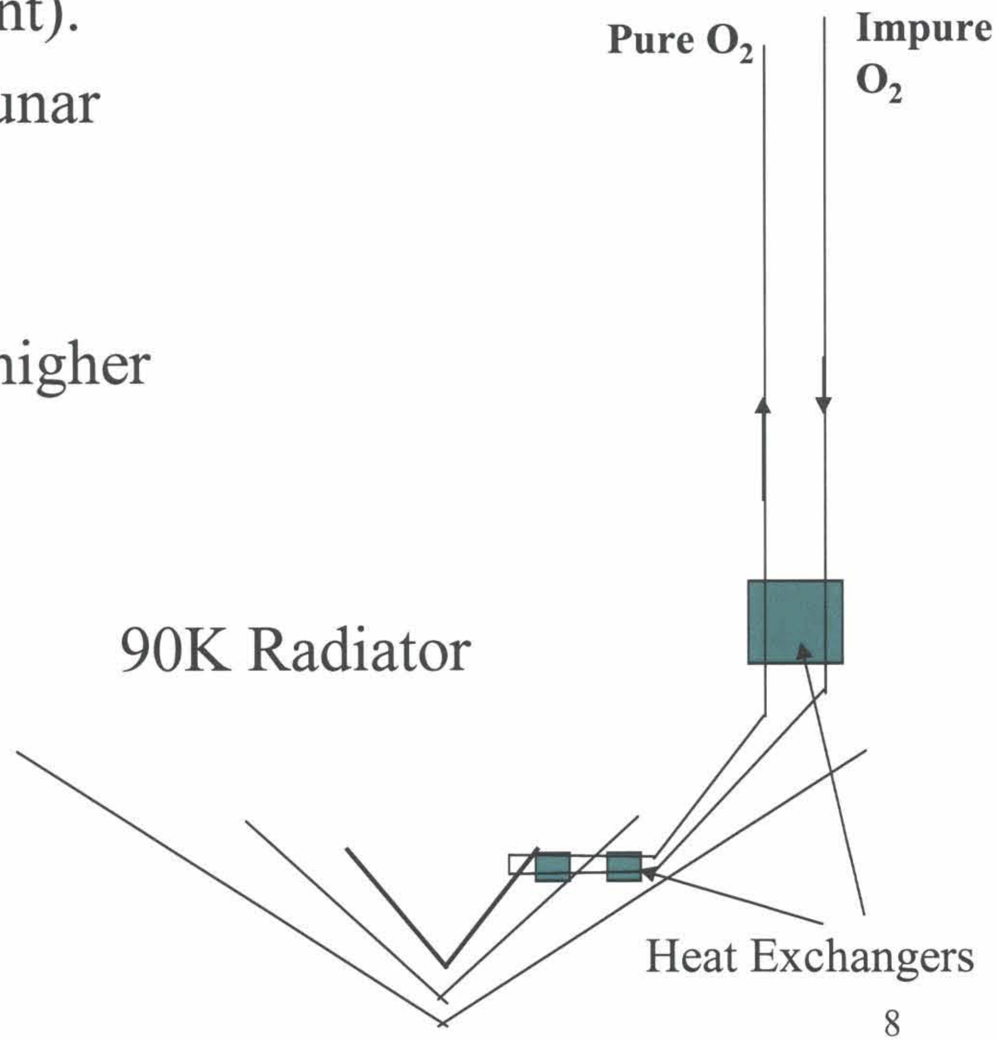
- Cool air to 90K (boiling point).
- Condense impure O_2 from lunar O_2 factory.
- Evaporate O_2 at 90K.
- Impurities that condense at higher temperatures are frozen.



Thermal Design of 1-m^2 Radiator for Purifying O_2.

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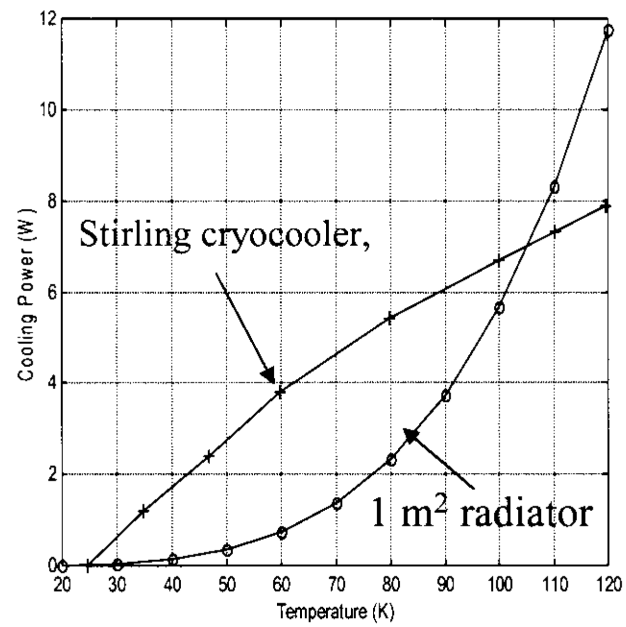
- 1 human converts 0.85 kg/day of O_2 to CO_2.
- Latent heat of $O_2 = 2.13 \times 10^5$ J/kg.
- Need 2 W to condense 0.85 kg/day of O_2.
- Need 2 W to cool O_2 from 300 K to 90 K.
- 4 W total. With 80% heat recovery by heat exchanger, 0.8 W cooling power needed.
- 1-m^2 radiator, cooling power = 3.75 W.
- 0.5 W heat loss to outer radiators.
- 3.25 W power available.
- Can support 4 astronauts continuously.
- Can use adsorber to increase temp. of operation and thus efficiency.



For Removing CO_2 from Air

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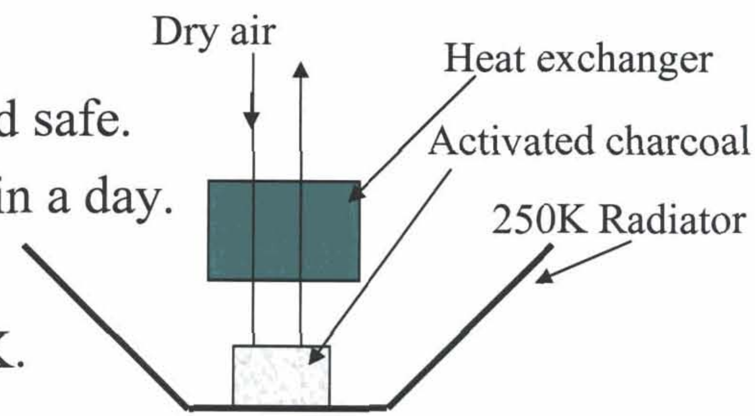
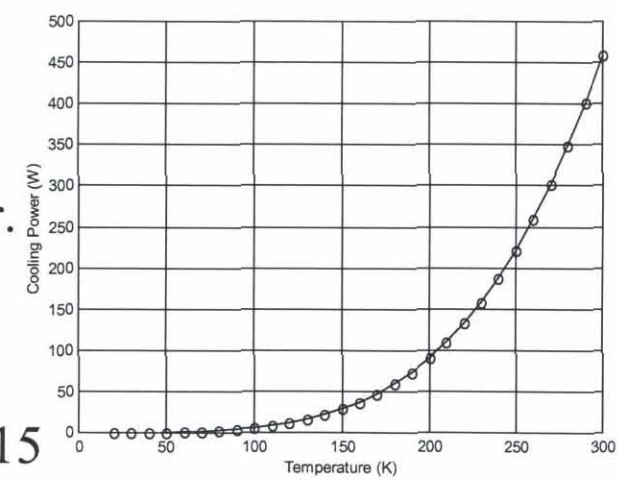
- 1 human produces 649 liter of CO_2 in a day.
- 5 cm^3 of CO_2/ liter (0.5%) of air is considered safe.
- 1.3×10^5 L of air (5300 mole) to be scrubbed in a day.
- Freezing point of CO_2 = 195 K.
- Removed CO_2 by activated charcoal at 250 K.
- $\Delta T = 300 - 250 = 50$ K.
- $C_P = 5R/2 = 20.8$ J/mole.
- Cooling power = (5300 mole) x C_P x ΔT / 3600
  = 1500 W.
- Requires 150 W with 90% efficient heat exchanger.
- 1-m^2 radiator, cooling power = 220 W @ 200K.
- Recover CO_2 by heating charcoal absorber.
- Latent heat = 571 kJ/kg. Turn 1 kW heater on for 15 minutes every day to reactivate charcoal.





Effects of Moon Dust

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- Micron-size dust are pervasion on the Moon.
- Reduces radiator efficiency.
- Effects needs to be characterized.

Conclusion

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- Lunar orbit is favorable for radiative cooling.
- A large patch of lunar sky is permanently dark.
- Radiator provides reliable and un-interrupted cooling.
- Applications:
  - Zero-boil-off cryogen storage.
  - Separation of lunar volatiles for resource utilization.
  - Purify oxygen for astronauts.
  - Scrub air for habitation.