Extreme Environment Technologies for Space Exploration

Extending the Temperature Range of Electronics for Spacecraft

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NASA/JPL

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Why are we here?

(Why are we having this meeting?)

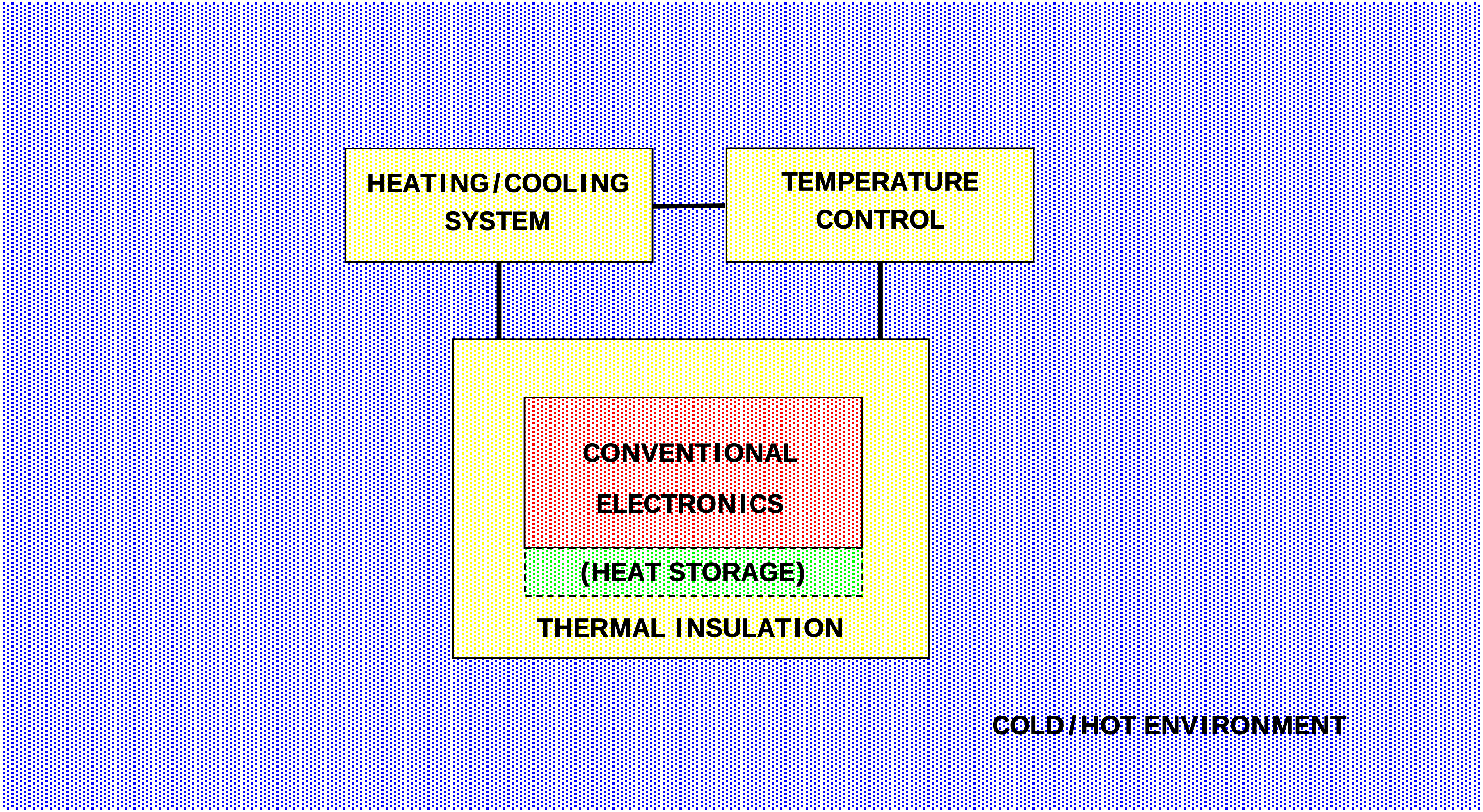
“Very Little of the Solar System (or the Universe) Is at Room Temperature.”

How do we approach this situation?

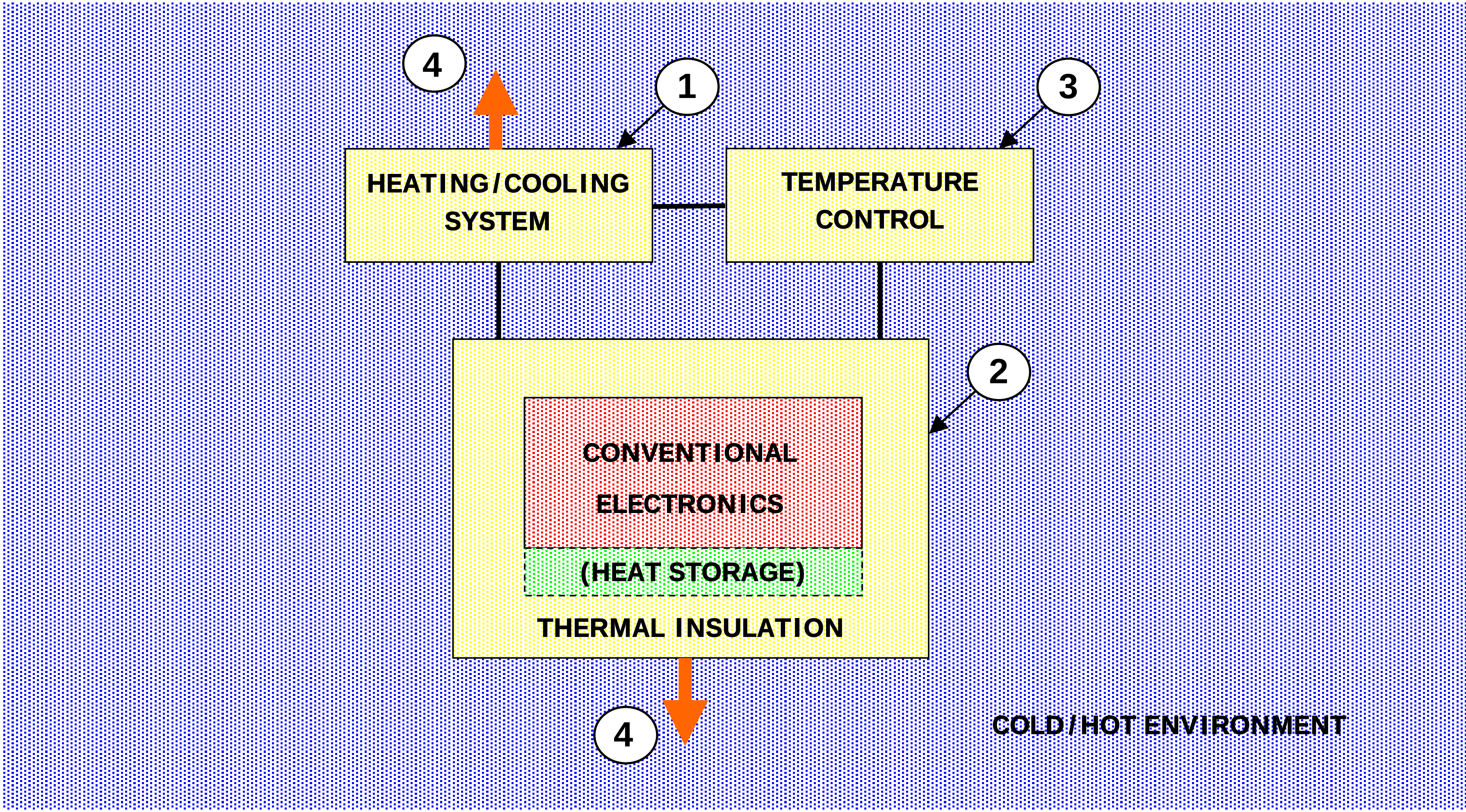
Traditional approach:

Send “room-temperature” to the remote site for the electronics.

Spacecraft


HEATING/COOLING SYSTEM
TEMPERATURE CONTROL
CONVENTIONAL ELECTRONICS
(HEAT STORAGE)
THERMAL INSULATION
COLD/HOT ENVIRONMENT

Spacecraft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1
3
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TEMPERATURE CONTROL
2
CONVENTIONAL ELECTRONICS
(HEAT STORAGE)
THERMAL INSULATION
4
COLD / HOT ENVIRONMENT

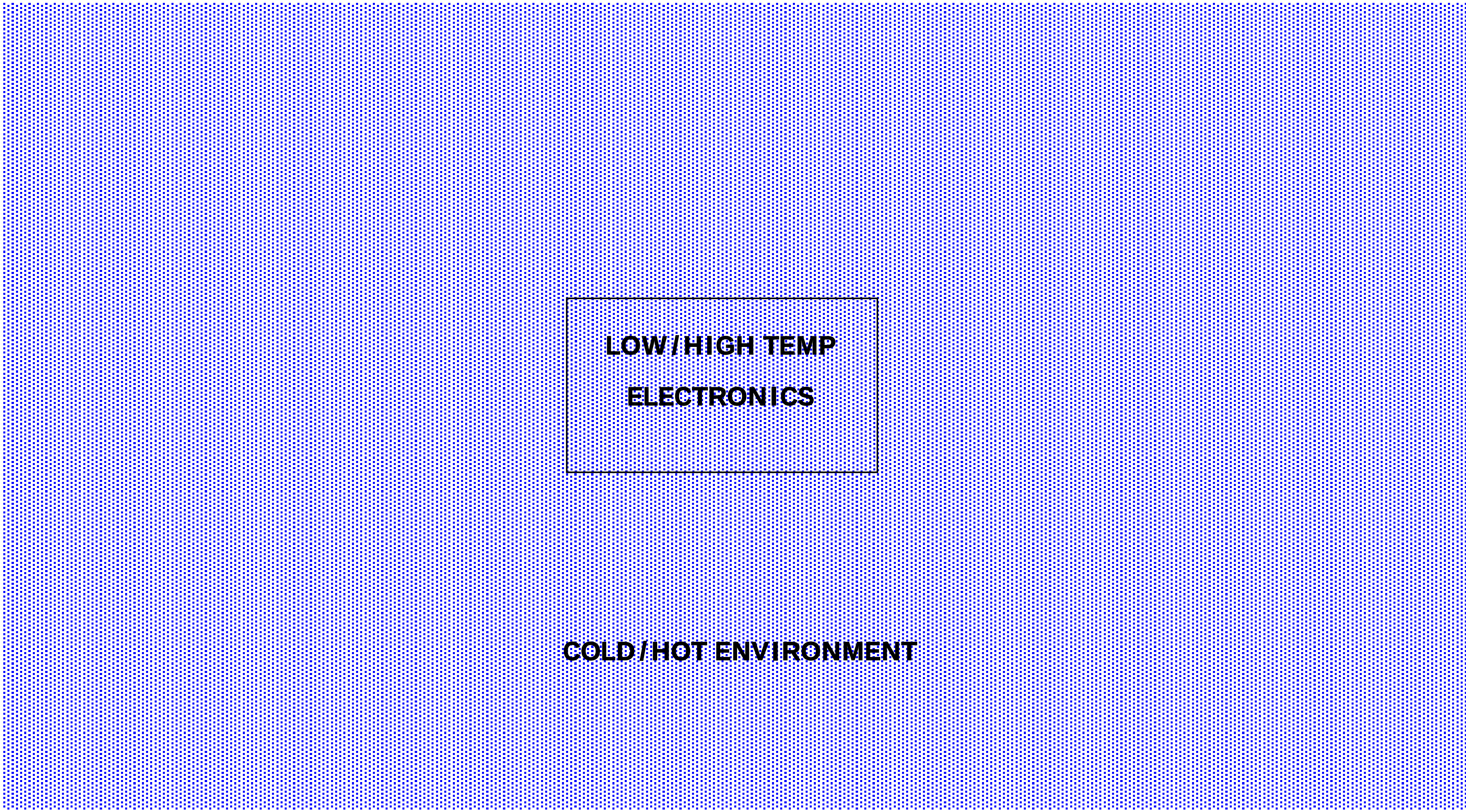
Drawbacks of Using Conventional Electronics

- Insulation
  - adds volume and weight
  - reduces maneuverability
  - limits operating time (passive)
- Heating/cooling (active)
  - uses large amount of power
  - adds control complexity
  - disturbs environment
  - reduces reliability
- Sometimes impractical

Another approach:

Let the spacecraft electronics operate at the temperature of the remote environment.

Spacecraft



Benefits of LT or HT Electronics

- Reduce mass & volume
- Reduce power requirements, increase efficiency
- (Improve performance)
- Reduce complexity
- Increase mission lifetime
- Improve maneuverability
- Increase *overall* reliability
- Less disruption of environment
  (size and waste heat)
- Enable missions

Difficulties of LT or HT Electronics

- Relatively unknown and unproven technologies
- Limited experience
- Limited background information
- New effects
- *Electronics* may be less reliable (esp. HT)
- Need more extensive qualification
- More difficult design
- Reduced performance (esp. HT)
- Lack of specified components
- Complete range of components not available

Alternative Approaches

- Part extreme temp &
  part conventional Temp
  (temperature partition)

- Intermediate temperature

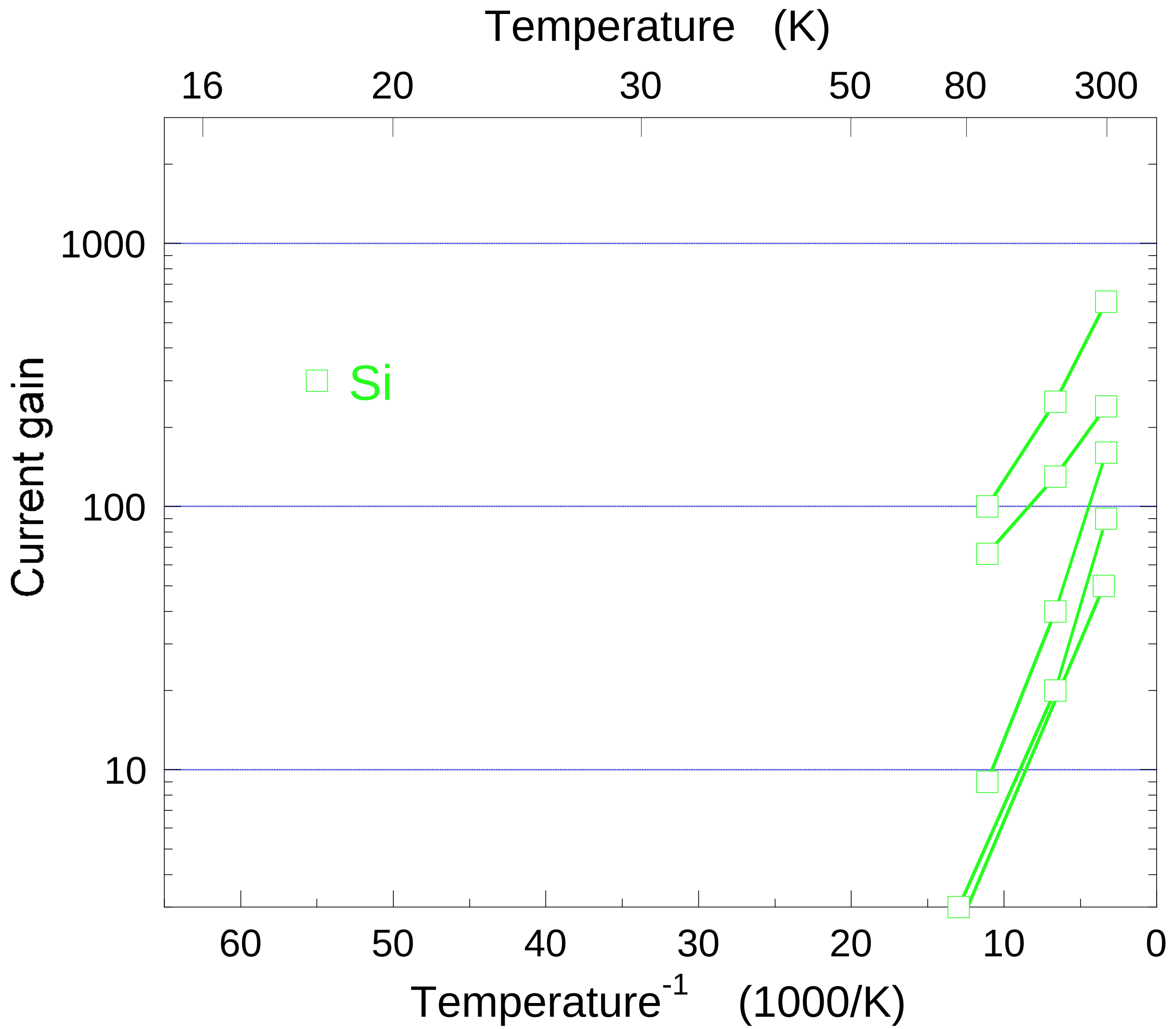
Low T or High T Electronics:
What Is Possible
and
What Is Practical?

Electronics Temperature Capabilities

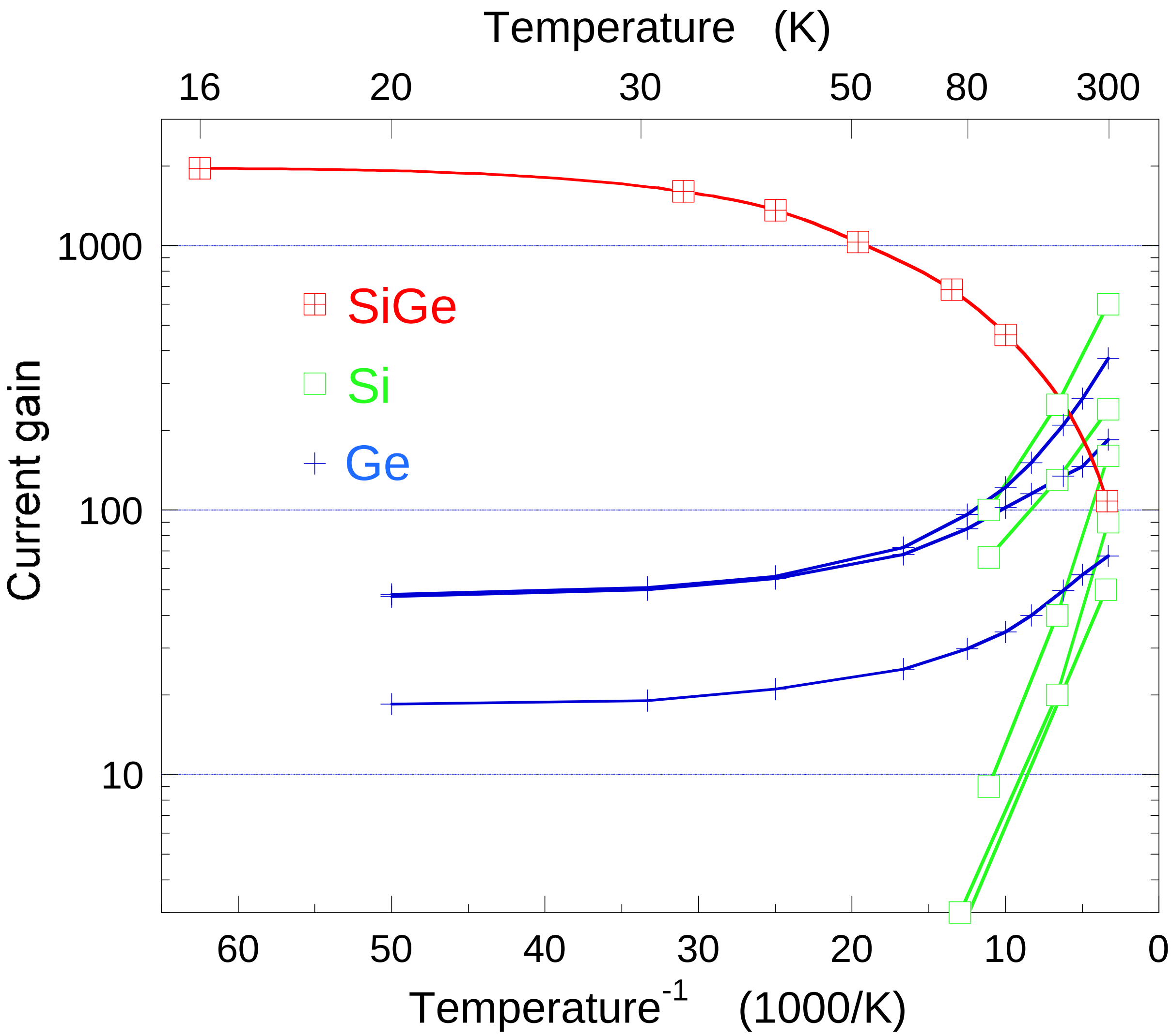
- Active devices (usually semiconductor)
- Passive components
- Power sources (especially batteries)
- Assembly & packaging (putting it all together)

Low Temperature

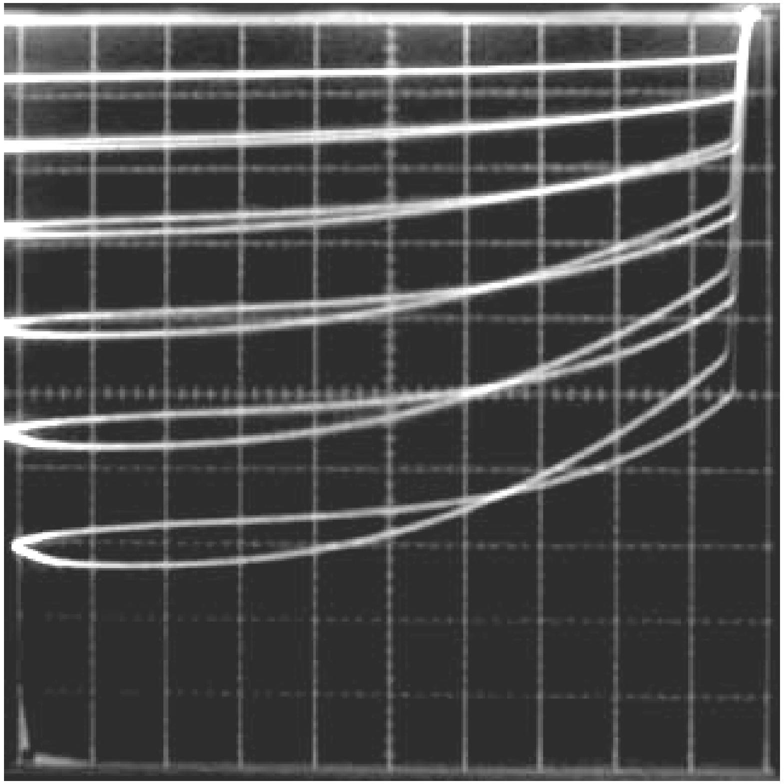
Si Bipolars: BJTs



Bipolars: Si BJTs, Ge BJTs, SiGe HBTs



Ge BJT: –269°C (4 K)



PNP; horiz: 0.5 V/div; vert: 1 mA/div; base current step: 0.1 mA (liquid helium); beta ~ 15 (RT beta ~ 70).

R. R. Ward, unpublished data.

Low-Temp Electronics in Spacecraft

Satellite	Launch date
IRAS (Infrared Astronomical Satellite)	1/83
COBE (Cosmic Background Explorer)	11/89
IRTS (Infrared Telescope in Space)	3/95
ISO (Infrared Space Observatory)	11/95
CHANRDA/AXAF (Advanced X-ray Astrophysics Facility)	7/99
GP-B/RM (Gravity Probe B/Relativity Mission)	(6/03)
SIRTF (Space Infrared Telescope Facility)	(8/03)
ASTRO-F/IRIS (Infrared Imaging Surveyor)	(2/04)
ASTRO-E2	(2/05)
Herschel Space Telescope	(07)

High Temperature

Passives and Packaging

- Low temperature
  - relatively easy
  - with care in materials selection and design can go to ~0 K
- High temperature
  - more difficult
  - melting, decomposition, interactions
  - depends on packaging “level,” component types, . . .
  - ~200–500°C
- Low or high temperature
  - *primary difficulties are large-value capacitors (electrolytic, ceramic) and batteries*
- Depends on requirements
  - allowable TCR, TCC, . . .
  - aging, lifetime

The Overall Picture

- Temperature is not the only factor/stress
- Examples of additional factors
  - Time
  - Radiation
  - Acceleration, vibration, shock
  - Pressure
  - Corrosive ambients
- Temperature does no act in isolation
- Interaction between temperature and other factors is often complex

The Overall Picture

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Aging Rates

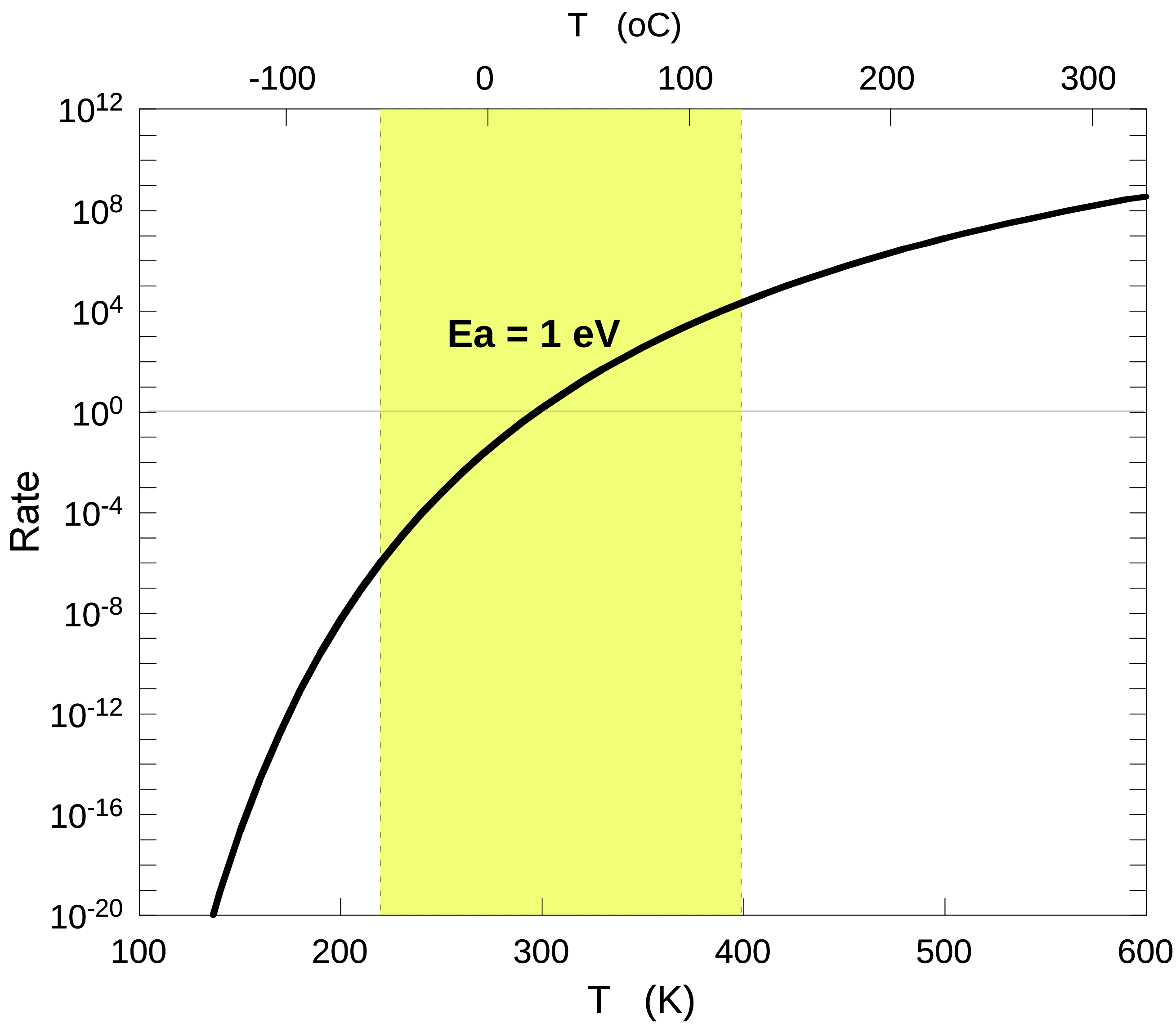
Arrhenius relation: Rate $\propto \exp(-E_a/kT)$

E_a = Activation energy

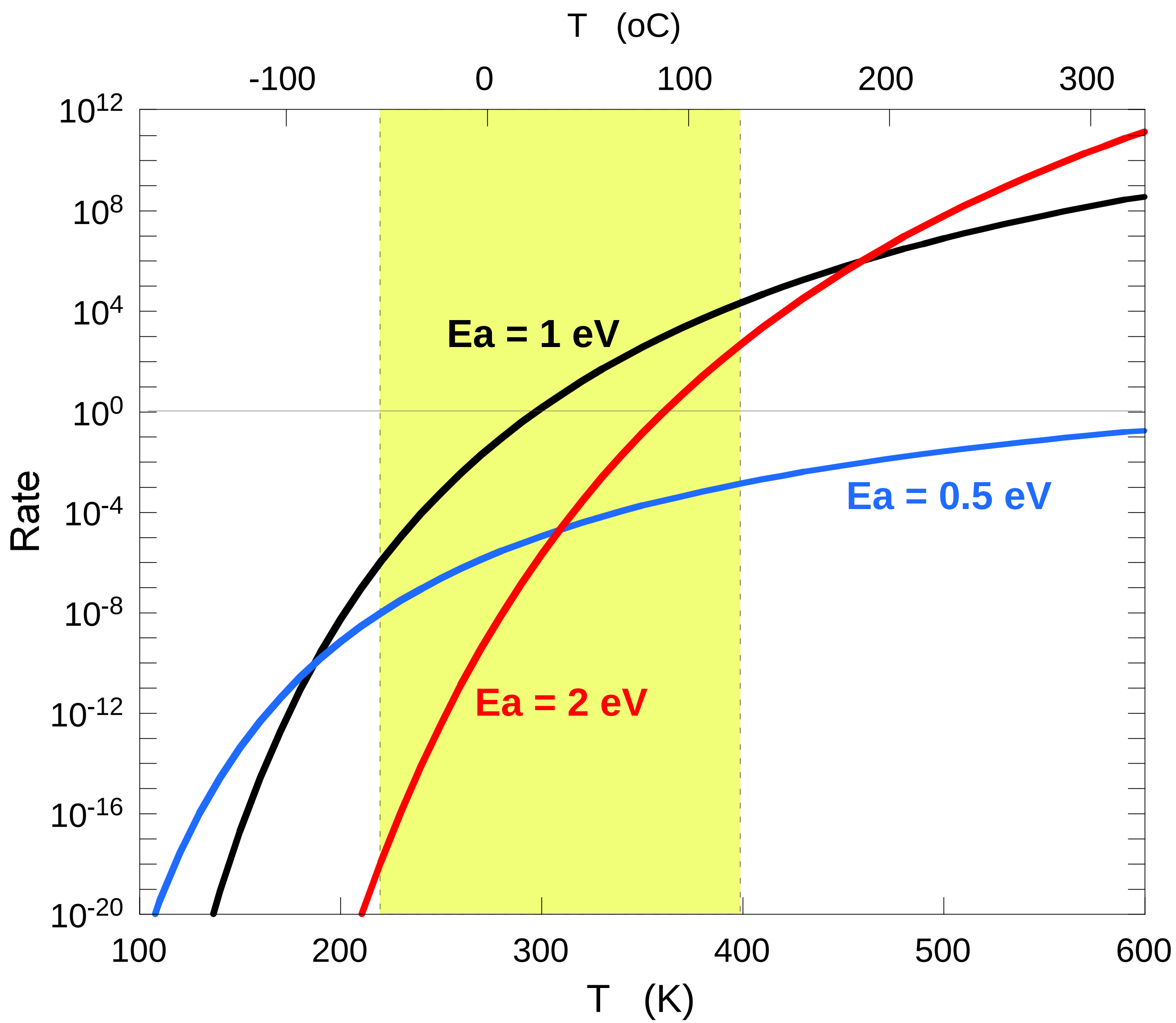
k = Boltzmann's constant

T = absolute temperature

Arrhenius - One Process



Arrhenius - Three Processes



- Extrapolation (or Interpolation) - risky
- Assumptions:
  - Dominant mechanism remains so for all temperatures
  - Dominant mechanism remains so for all times

Degradation at Low Temperature?

Degradation at Low Temperature

- Most processes are thermally activated, essentially absent
  - Corrosion, electromigration, interdiffusion, ...
- Charge trapping
  - High electric field
  - Radiation
  - Can be reversible
  - Warming can de-trap (“anneal”)

Temperature Effects

- Too much thermal energy (HT)
  - Decomposition, corrosion, electromigration, interactions, interdiffusion, restructuring, . . .
  - Excessive leakage currents
- Too little thermal energy (LT)
  - Freeze-out (semiconductor devices, capacitors, batteries)
  - Charge trapping

"Often temperature (thermal energy) works against you, but sometimes it works for you."

Summary/Conclusions

- Extending the temperature range of electronics has benefits for spacecraft
- Electronics is capable of operation at extreme temperatures in practice as well as in principle
- In designing electronics, all the factors need to be taken into account (time, radiation, . . .)
- The interaction of temperature with other factors (e.g. time) can be complicated
- Thermal energy can work for us or against us

EEE Meetings

- This meeting - future?
- NEPP usually yearly
- ECS LTE usually odd years (October 2003 in Florida)
- WOLTE even years (June 2004 in Netherlands)
- HITEN usually odd years (July 2003 in Oxford)
- HiTEC usually even years (2004?)
- ISAS yearly (Spring in Japan)

⇨ Check The ETE Web Site

www.ExtremeTemperatureElectronics.com