Technologies and Improvement

SFI Technology Workshop

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Two questions

- How do technologies improve?
  - Obviously learning, better design, variation/selection, etc.
  - But want to look at improvement from inside perspective
- In particular, why do technologies become more complex?

A technology is an assemblage of parts
(or systems, stages, subroutines, components, etc.)

- Architected together for a particular purpose
- System quite hierarchical in structure
- Makes a technology highly changeable, very highly configurable (especially “in the wild”)

Two simple improvement mechanisms

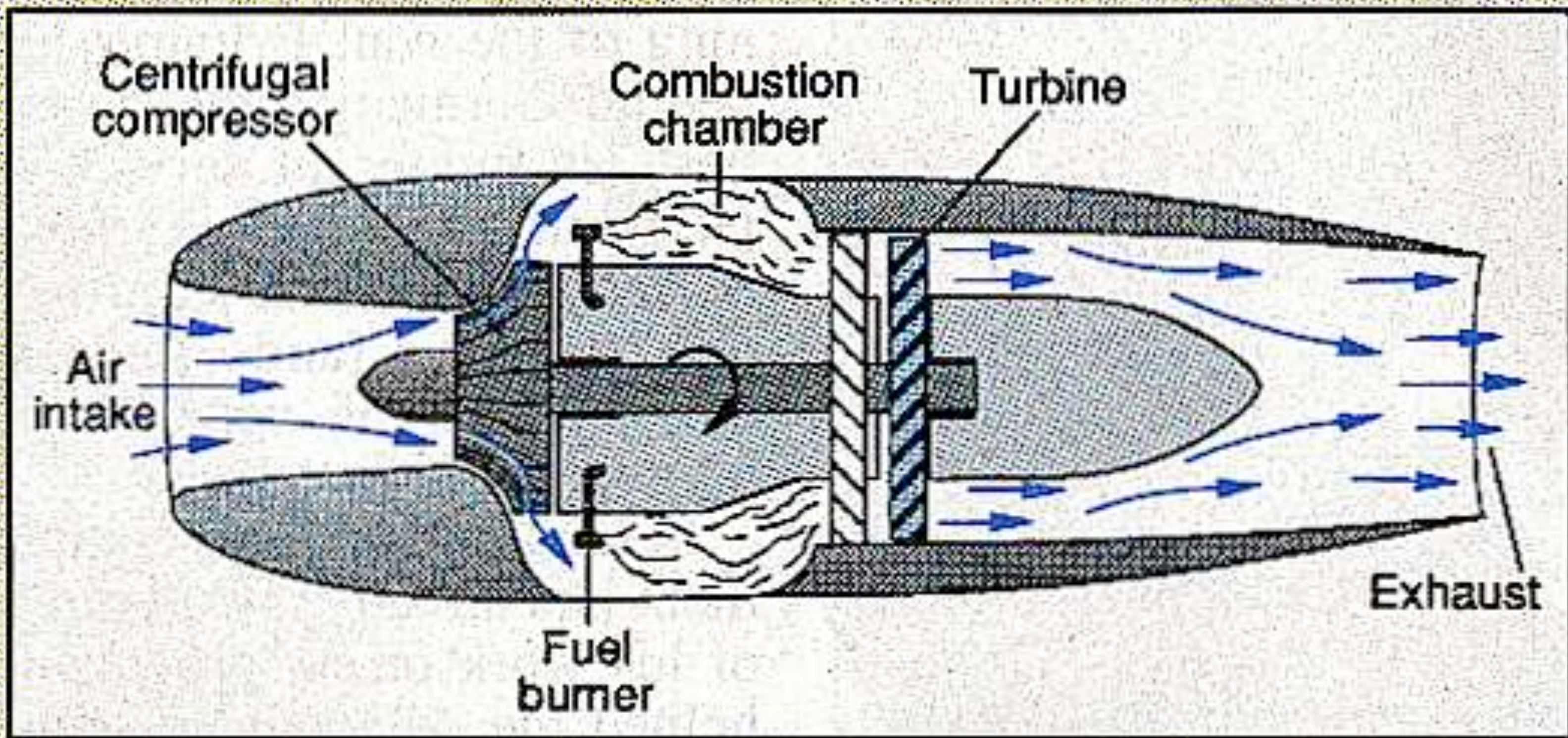
Technologies are "pushed" to perform better, and certain parts reach physical limits.

So …

1. New parts are substituted

2. New "workaround" assemblies are added

Whittle's engine



Whittle described his jet engine as beautifully simple

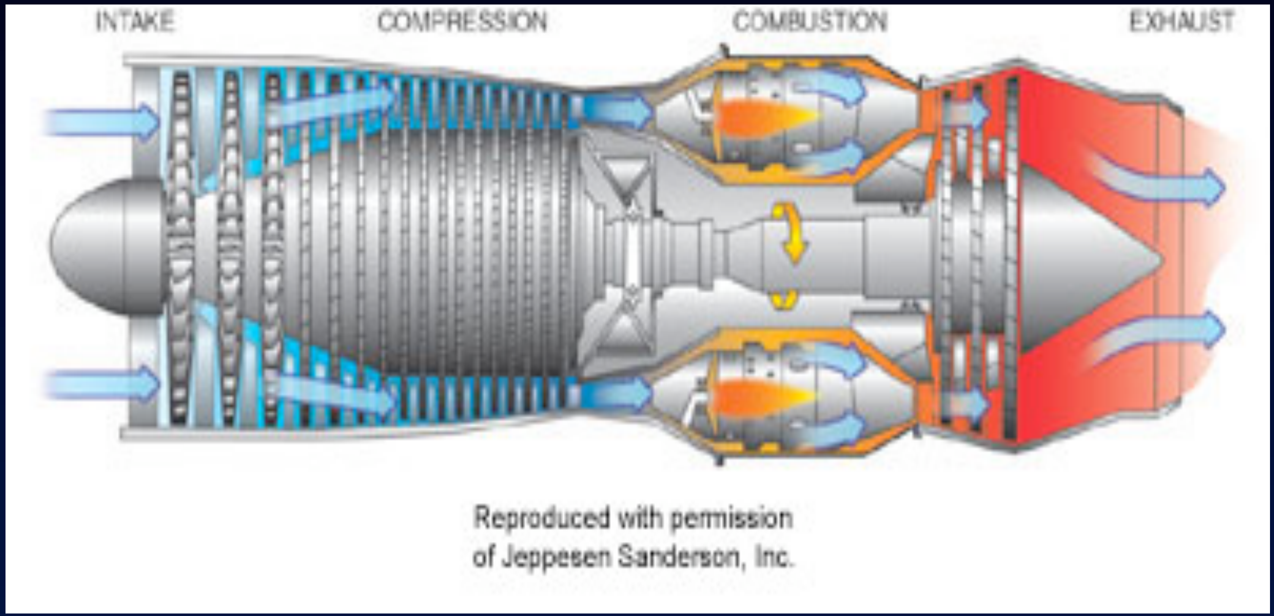
Early jet engine

- Superior parts were substituted in:

- Better materials
  - E.g. Combustion chamber

- Different design of parts
  - E.g. Shift from radial to axial compressors

Jet engine (GE J47)

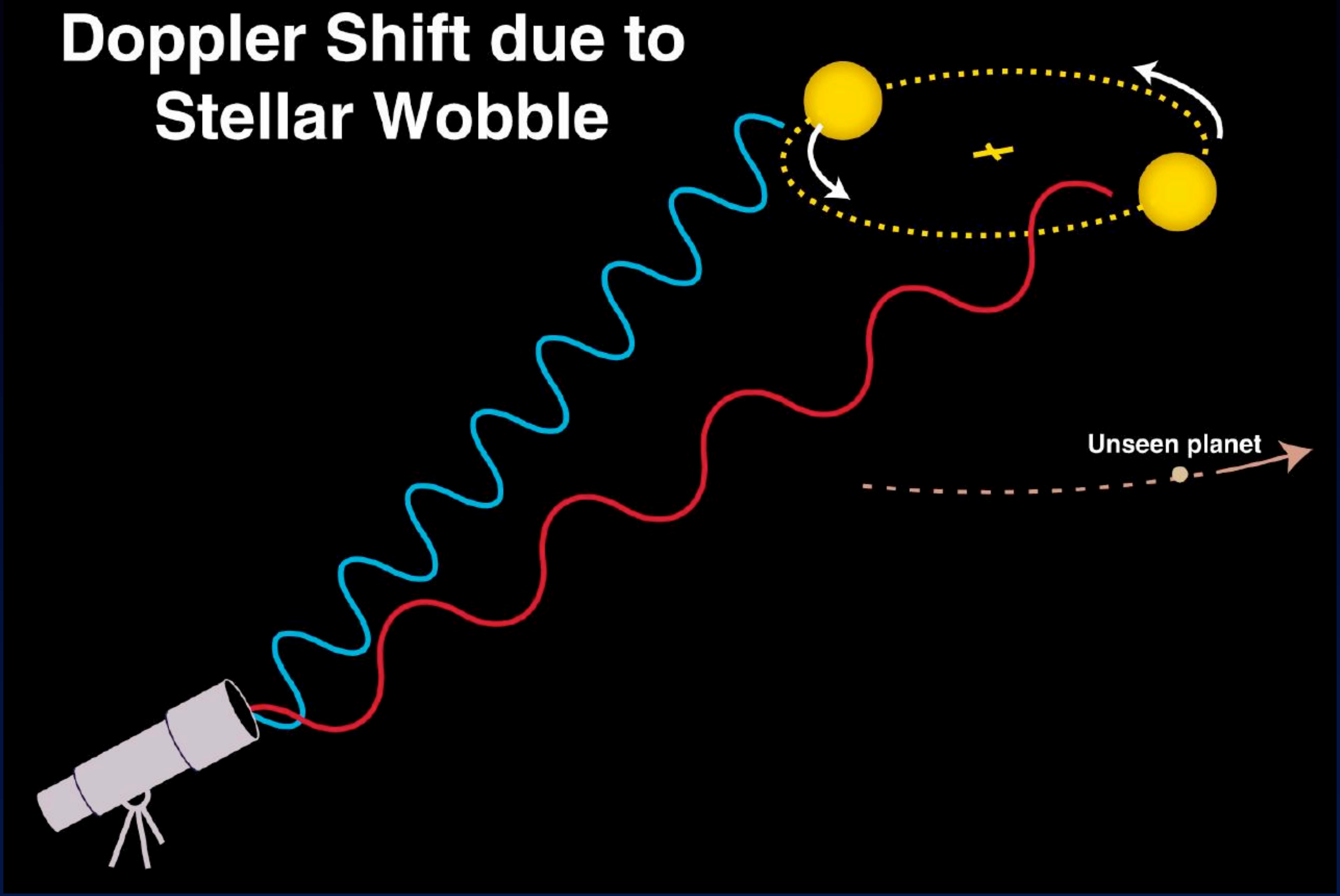


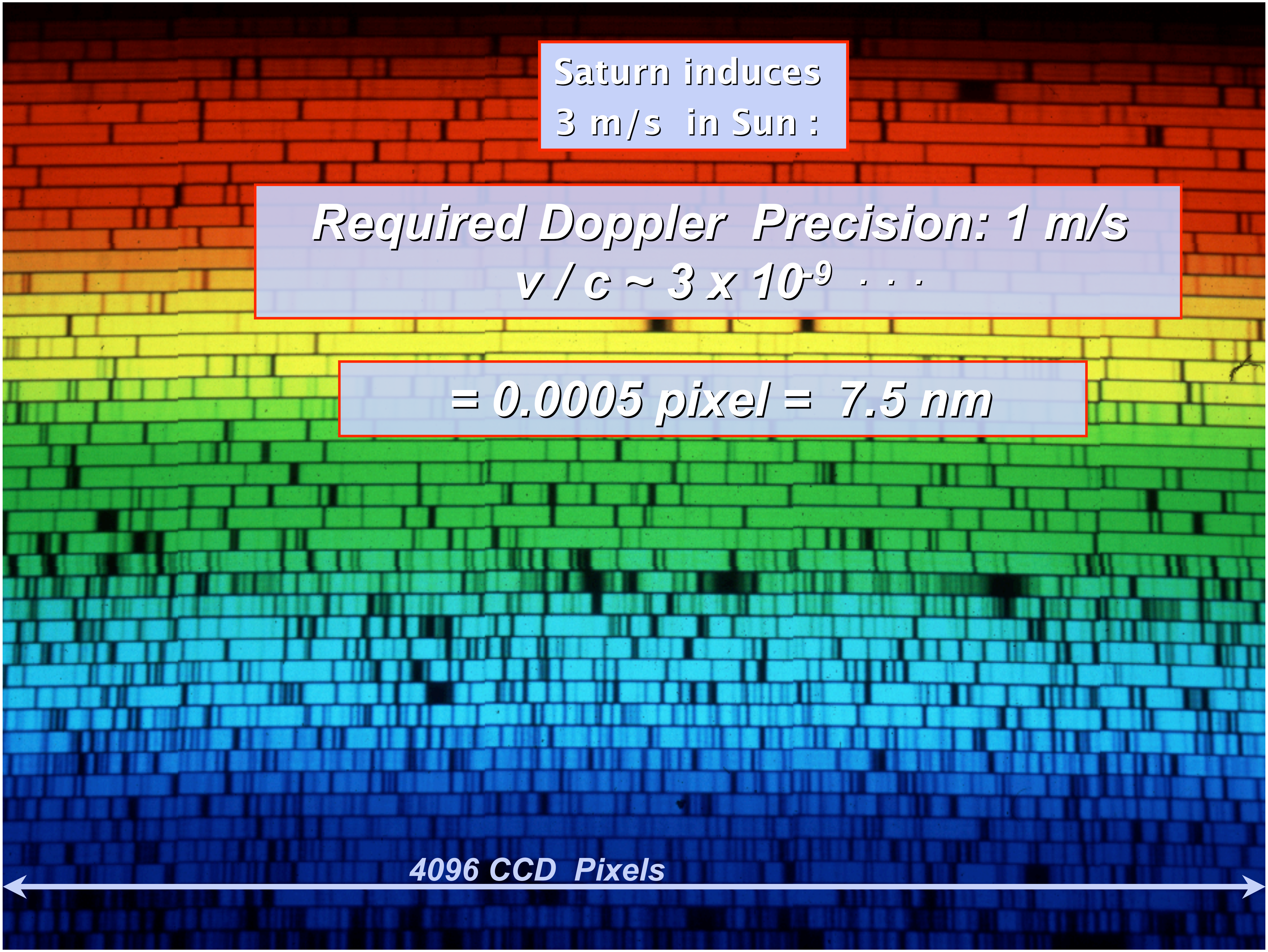
Looking at the process of improvement:

Exoplanet Detection

(developed by Geoff Marcy and Paul Butler, UC Berkeley)

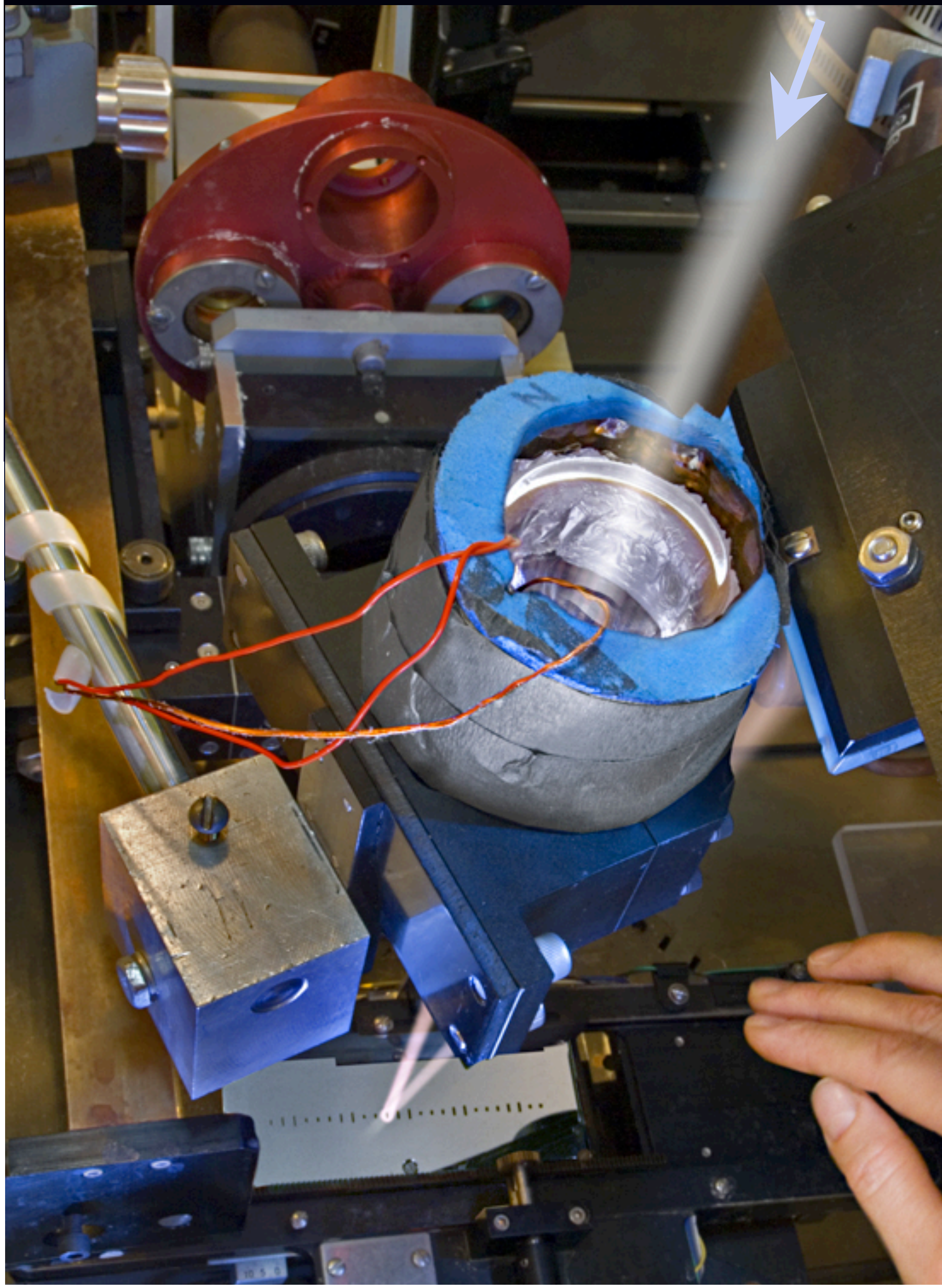
Exoplanet Detection




Saturn induces
3 m/s in Sun :
Required Doppler Precision: 1 m/s
v / c ~ 3 x 10-9 . . .
= 0.0005 pixel = 7.5 nm
4096 CCD Pixels

Challenges and limitations

- Shift in frequency that needs to be detected compares to 10^{-8} of shift from C to C-sharp
- Solution: Use an iodine absorption spectrum as benchmark



Telescope focal plane:

Keys to Doppler Precision:

- Wavelength Calibration

Send Starlight through
Iodine Cell

Challenges

- The earth itself is moving through space
- Solution: Use NASA data and develop correction algorithm

Challenges/limitations

- The iodine chamber can drift in temperature
- Solution: Add a temperature stabilizing system

Challenges and limitations

- The angle of observation changes as the star moves across the telescope
- The star's spectrum gets smeared out very slightly inside the spectrometer
- Fixes: Benchmark comparisons. De-convolution of the point spread function (PSF)

Further limitations

- Pixel brightness shift remains very small and hard to detect

- Fix: Sophisticated statistical methods to detect changes in pixel brightness

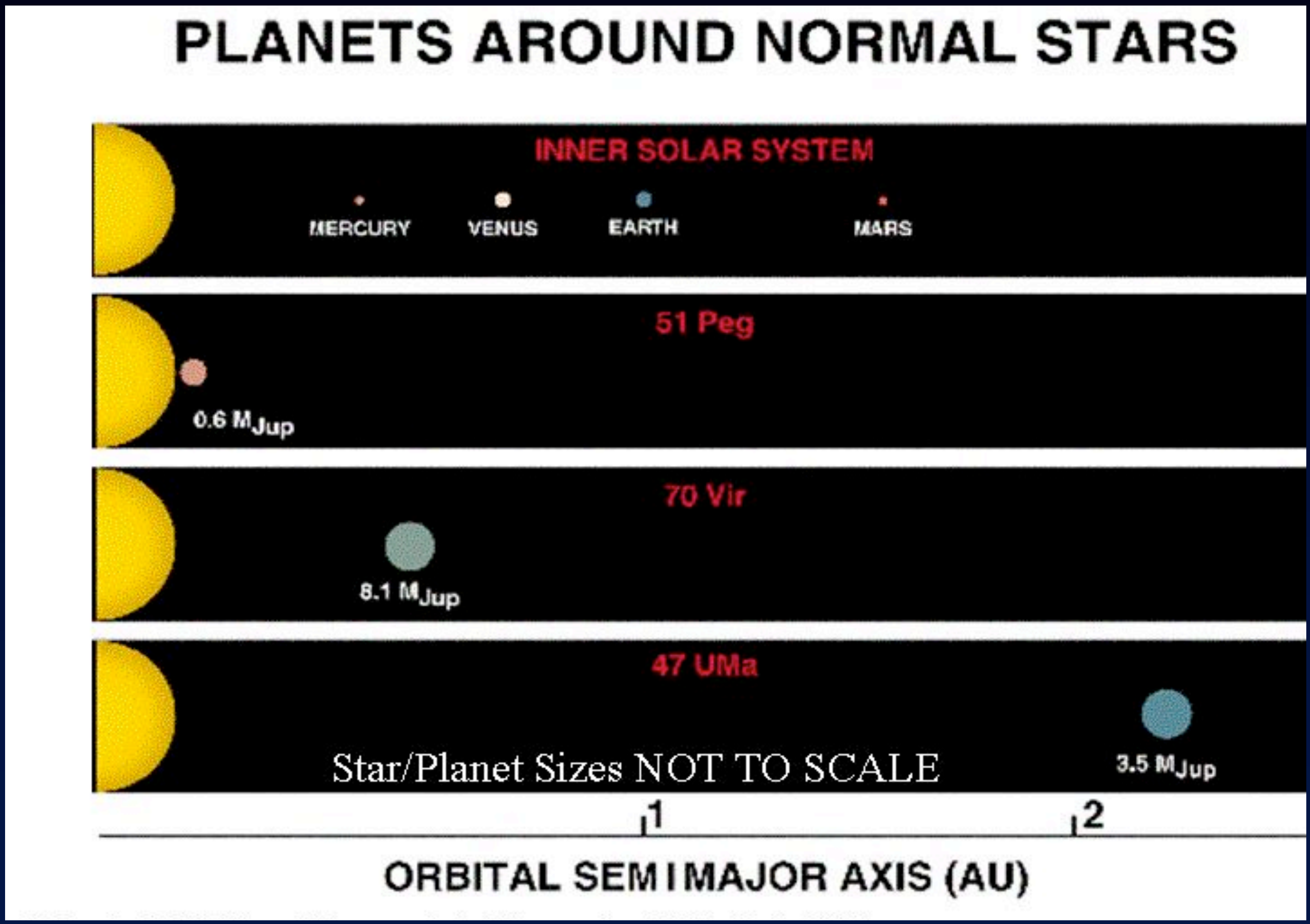
(See paper Attaining Doppler Precision of 3msec^{-1}, by Butler et al, 1996)

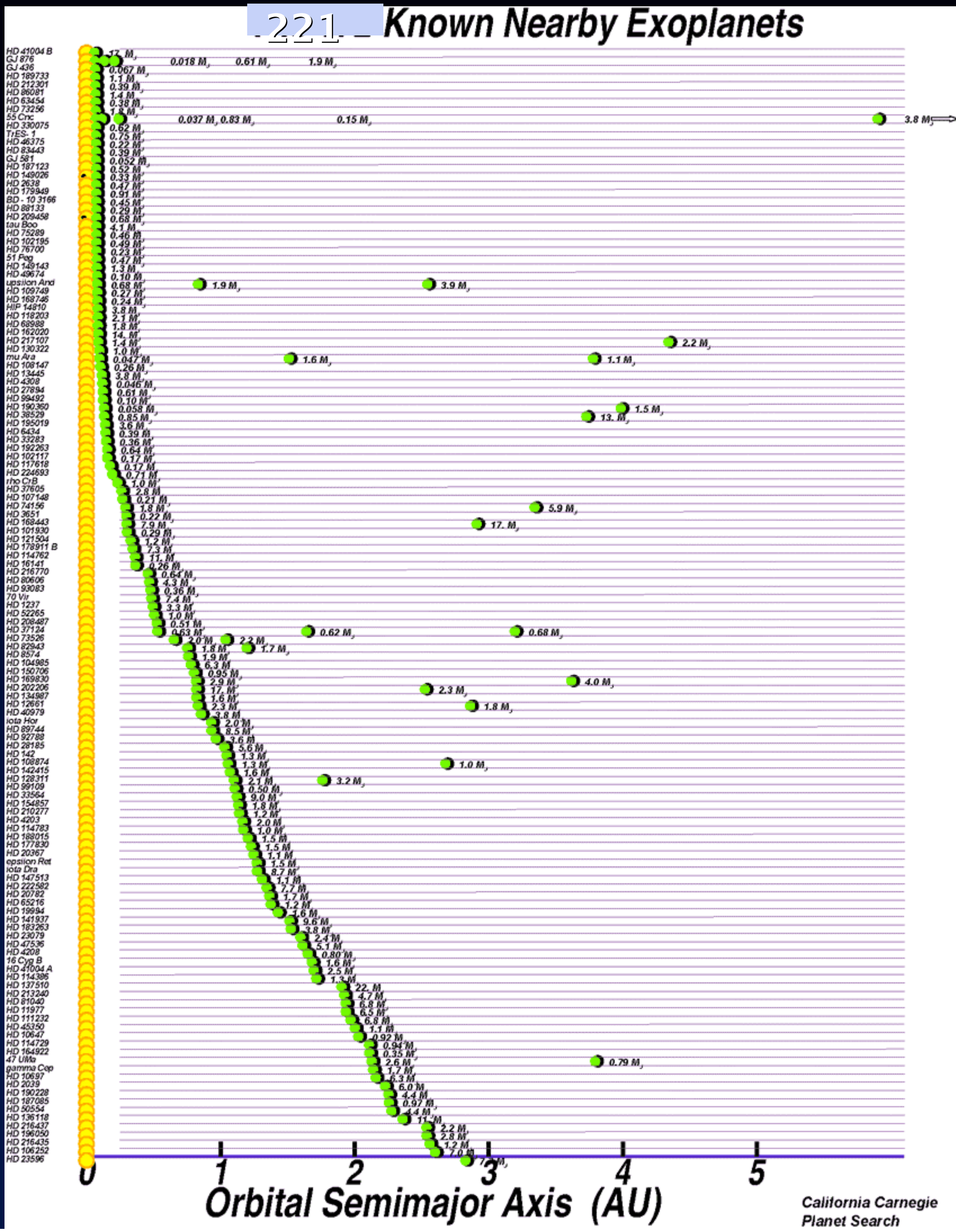
Notice …

- Locus of limitations keeps shifting. Several (functions) can be improved, but these change
- Could plot a learning curve, from about 50m/sec to about 1m/sec since 1990
- But this doesn’t tell us how it was reached

Known Exoplanets

Jan 1996





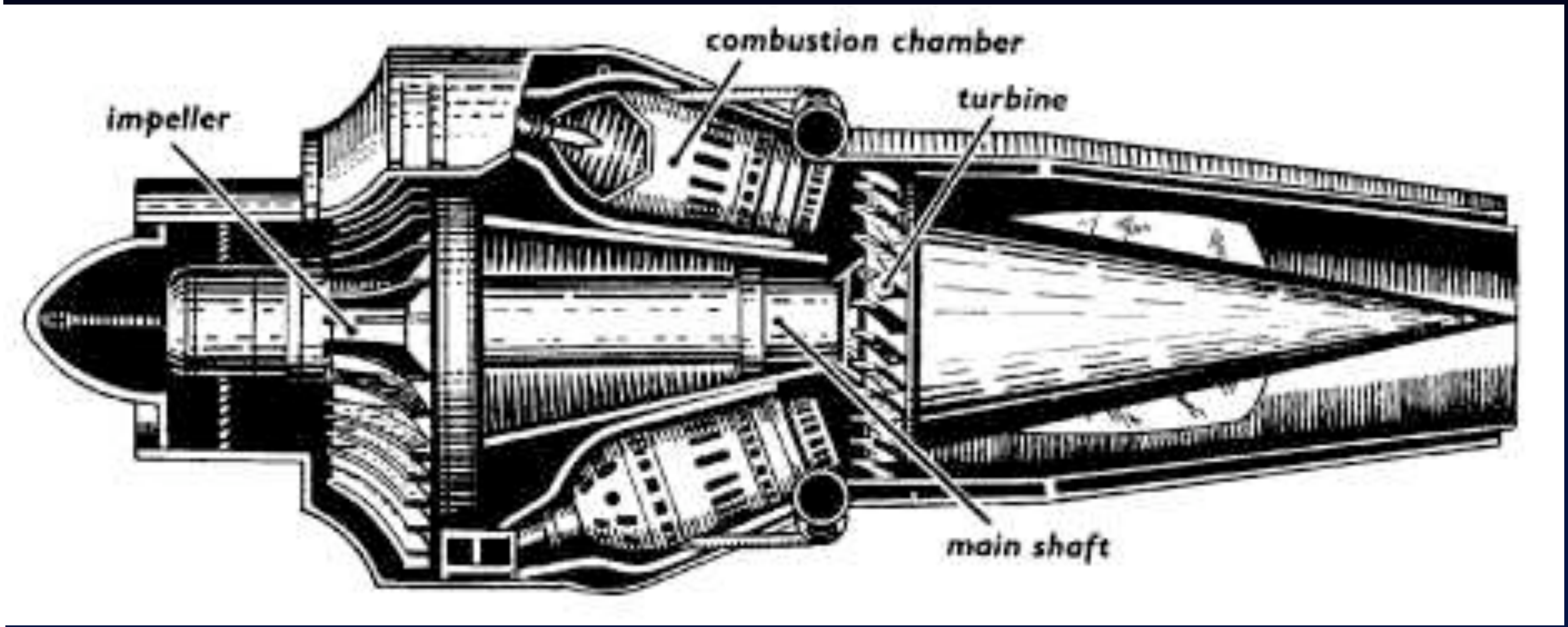
- a = 0 - 6 AU
- M sin*i* = 0.05-15 M_{JUP}
- 25 Multiple Planets

- Nearly half found by:
  - Swiss team
    - (Mayor et al.)
  - Harvard teams
    - (Noyes, Latham, et al.
  - Texas teams
    - (Cochran, Hatzes, Endl)

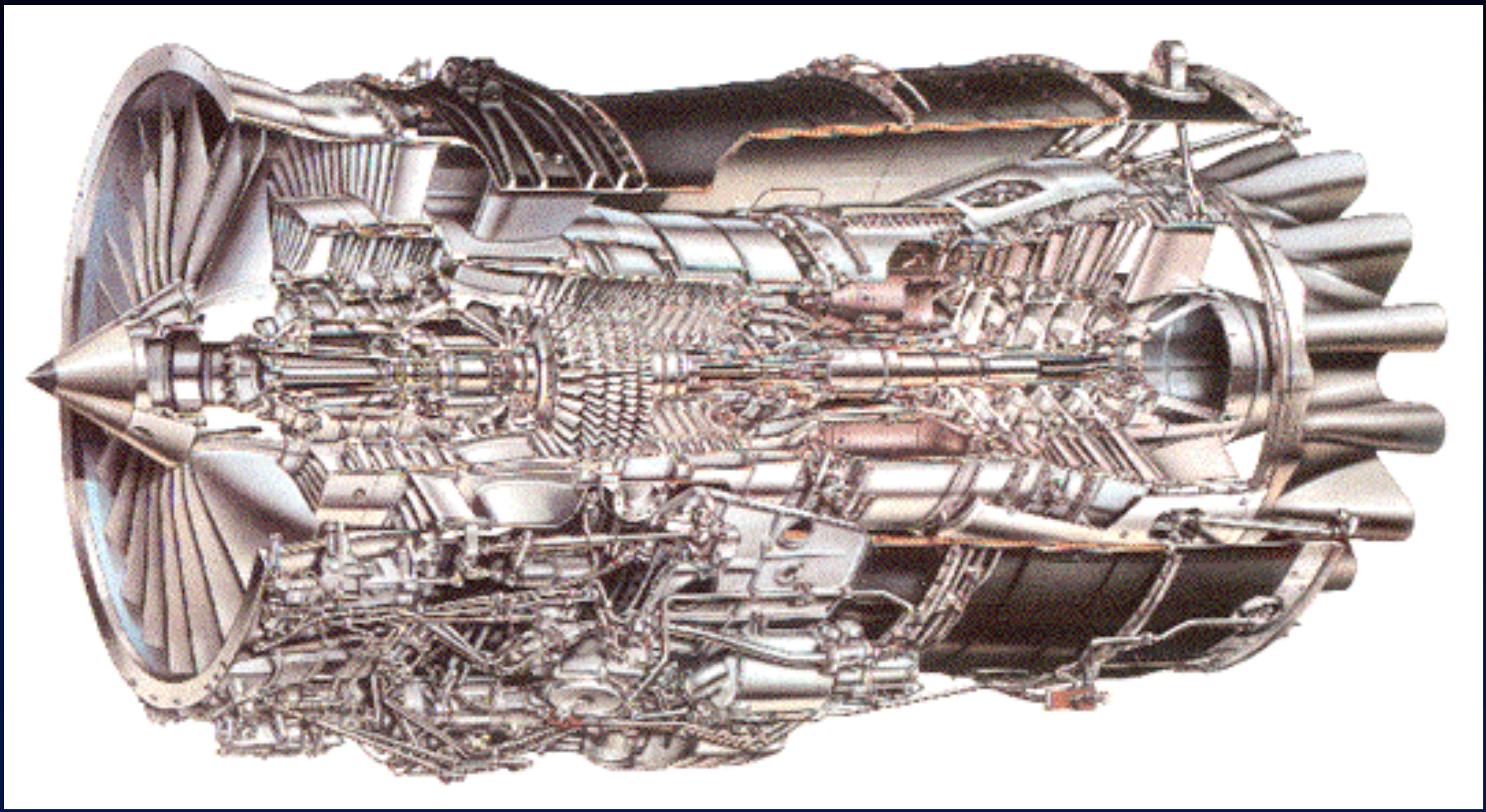
Second question:

Technologies also become more complex as they improve. Why?

Whittle engine



Modern powerplant--A Rolls Royce turbofan



The second improvement mechanism:

- Systems are added as workarounds for some limitation. I call this *structural deepening*
- E.g. At very high temperatures turbine blades melt, therefore add a cooling system

Why add subsystems to a technology?

- (a) to enhance its basic performance
- (b) to allow it to react to changed circumstances
- (c) to adapt it to a wider range of tasks
- (d) to enhance safety and reliability

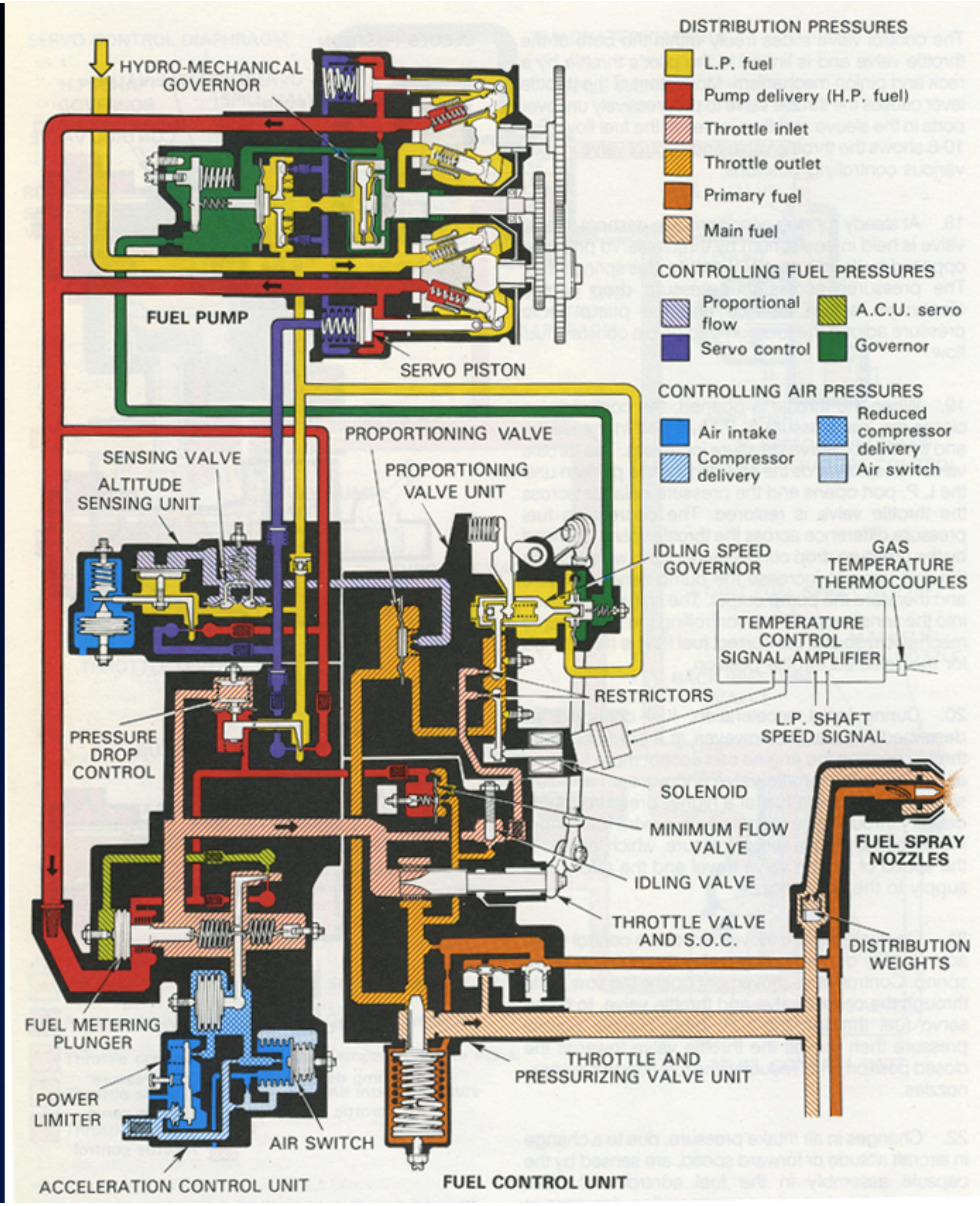
- But (a) to (d) apply to any part in the technology, so sub-sub-systems add to sub-systems, etc.

How one system elaborated

- Move from 2 or 3 axial compressors to assembly of these
- But compression system needs to operate in different conditions. Add a guide-vane system to regulate the air admitted
- Guide-vane system requires a control assembly to sense ambient conditions and adjust vanes accordingly
- Now the high-pressure compressed air could blow backwards through the compressor in unexpected pressure surges. Add anti-surge bleed-valve subsystem
- Anti-surge system now requires a sensing and control system

Other elaborations

- After-burner assemblies, fire-detection systems, de-icing assemblies
- Specialized fuel systems, lubrication systems, variable exhaust-nozzle systems, engine-starting systems …
  - All these require control, sensor, and instrumentation systems



The high-level functions of the control system include starting and shutdown control, thrust management, acceleration and deceleration control, protection from exceeding engine operating limits, and communications with aircraft systems including cockpit displays and pilot commands.

Result: a growing tree (or bush) of complexity

- Yields a system that consists of systems, that adds systems hung off these, adds further ones hung off these, ad finitum
- Modern aircraft powerplants: 40 to 50 times more powerful than Whittle's original, but considerably more complicated. Whittle's prototype of 1936 had a few hundred parts; modern equivalent has upwards of 22,000 parts

Often we see a cycle (Cf. Kuhn, Dosi)

- A technology develops, is pushed, reaches limits
- Adaptive stretch happens
  - adds systems and sub-systems
- Technology becomes encrusted, reaches dim. returns
- A new principle arrives

Some remarks on learning curves

- Curves we saw yesterday are remarkable
- But underlying replacement and structural deepening mechanisms aren't predictable

Further …

- A technology has to be viable within an ecology of technologies. Context matters.
  - This will determine the effort put in to improve it

Non-quantitative consequences of techs improving

- A tech adds to knowledge base
  - of company, region, country, etc. (Cf. Mokyr)
- Provides potential building block for subsequent use
  - laser, computer, machine tools, PCR, etc.

These payoffs are imponderable

Q. "What was the return on investment for computation?"

Andy Grove: "What was Columbus's return on investment when he discovered America?"

Summary

1. Technologies are “pushed” and reach limitations

2. Better parts are swapped in. Not predictably
   - The dominant places of limitation keep shifting

4. Technologies also improve by structural deepening. This is recursive, and causes large increases in complexity
   - and a cycle

5. Learning curves are remarkably consistent, but payoffs are not determinate