Systems Engineering Challenges at NASA's Jet Propulsion Laboratory

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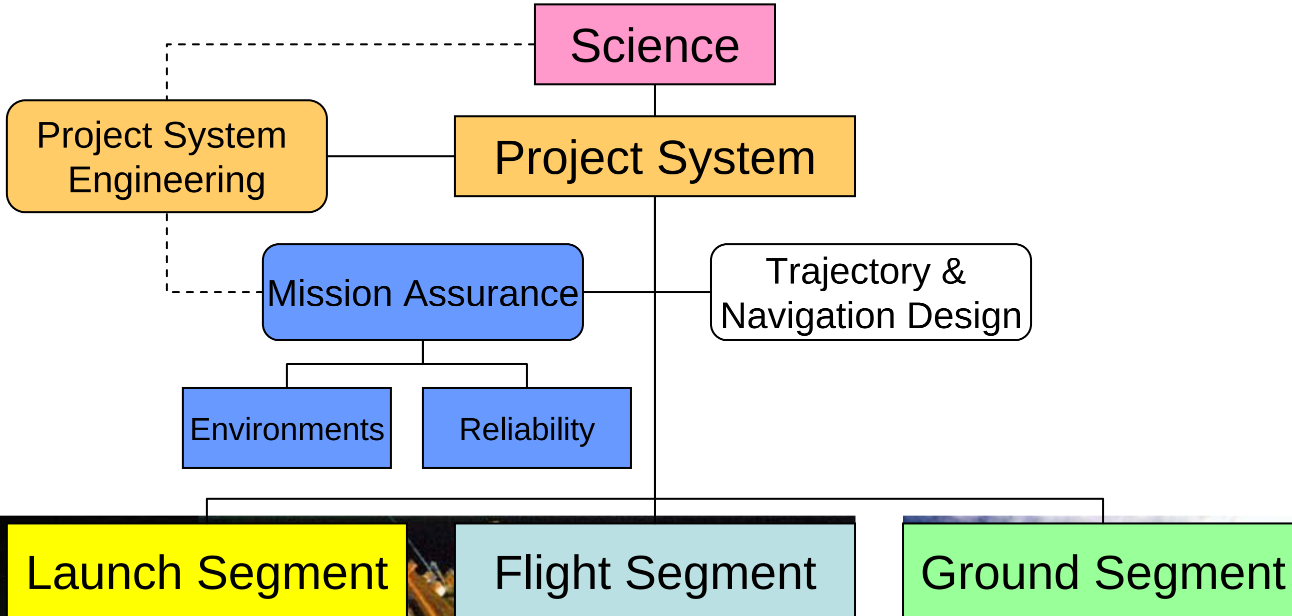
Outline

- Scope
  - JPL overview
  - What we System Engineer
- Challenges with deep-space exploration
  - Getting There
  - The Measurement Itself
- Systems Engineering
  - Issues
  - Upgrade initiative


BUCK ROGERS
IN THE 25TH CENTURY
XP-59A

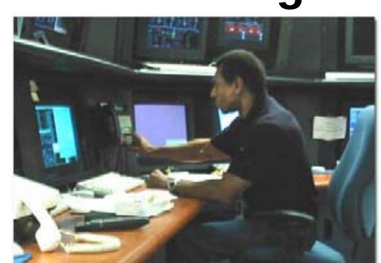
Typical Mission Elements



Launch Ve

Flight Segment

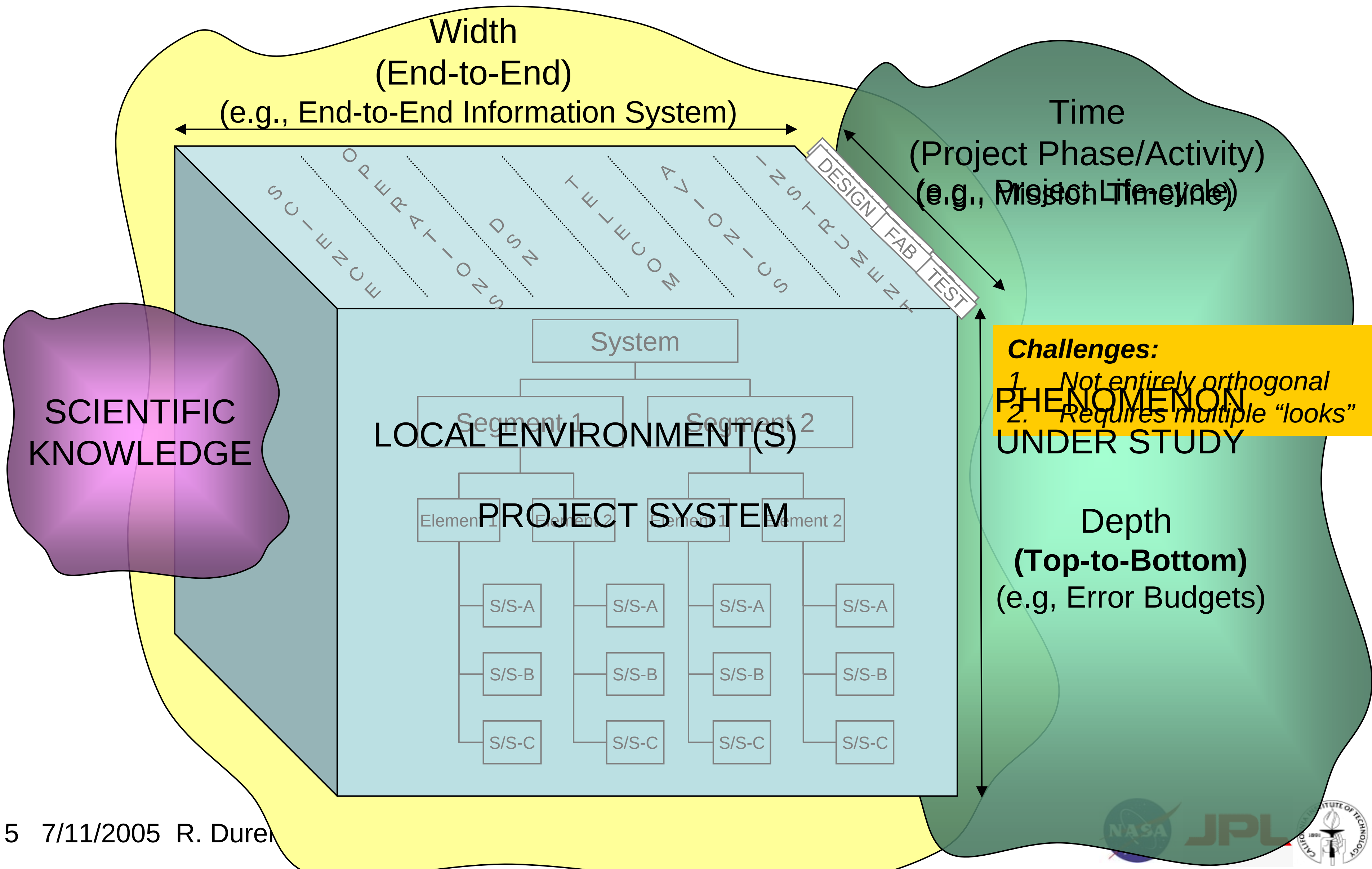
Ground Segment



Includes People, Processes,
& Procedures – not just H/W & S/W

Getting it right

The "Glue Function"



Deep-Space Missions: Challenges

- All are DISTANCE-challenged
  - Round-trip light-time→ Significant Onboard Autonomy
  - Energy constraints→ Clever Sequencing & Exotic Power Sources
  - Propulsion constraints → Ballistic Trajectories
    - → Precision Navigation
    - → Limited opportunities for Launch, Orbit Insertion, etc

- Most are uniquely challenging due to UNKNOWNS – either:
  - GETTING THERE is exceedingly difficult
    - → EXTREME &/OR POORLY-CHARACTERIZED ENVIRONMENTS
    - → Drives Functional Robustness and Operability
  - MEASUREMENT itself is exceedingly difficult
    - → SMALL FORCES – NEW PHYSICAL REGIMES
    - → Drives Tight Coupling and Physically Large/Distributed Systems

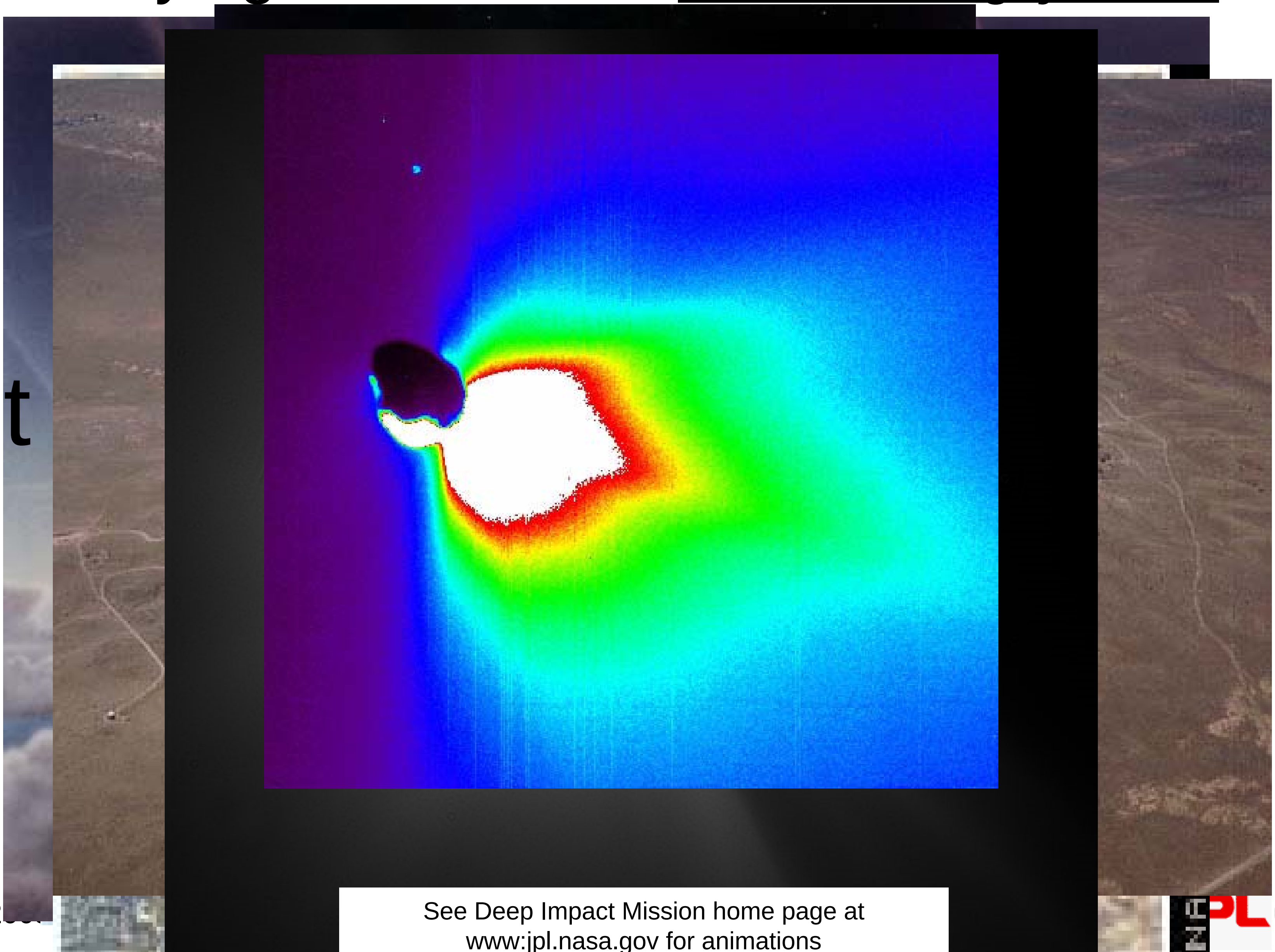
For the past 4.5 billion years,

Comets & Asteroids have been clobbering the Earth…

Deep Impact

Studying Comets with *Extreme Prejudice*

But



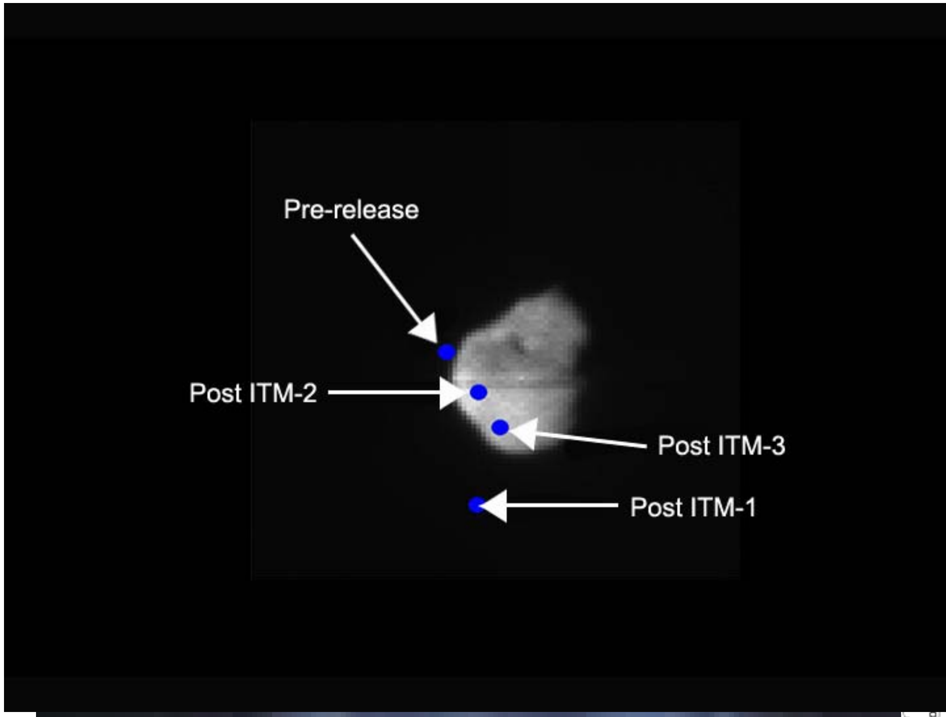
See Deep Impact Mission home page at
www:jpl.nasa.gov for animations

Landing on (or impacting) comets is tricky!

- Controlled landings are problematic since we don't understand comets
- Are they Dirty Snowballs? or Frozen Mudballs? or none of the above?
- It makes a big difference on how you design the lander
- On Champollion, we tried to cover both cases.

- Striking them in a ballistic fashion is "easier" – relatively speaking!
- Like hitting a specific spot on a bullet with another bullet – while watching from a 3rd bullet
  - Except the bullets are moving 10x faster than normal
  - And are 84 million miles from earth when they collide
  - And the target bullet is tumbling….and spewing debris

See Deep Impact Mission home page at www:jpl.nasa.gov for animations



The Mars Atmosphere is a Harsh Mistress

- Too much atmosphere to land like we do on the Moon
  - Supersonic propulsive deceleration is not impossible, just real hard.
    - How do you keep a rocket stable while flying backwards?
  - Still need to worry about severe heating at super and hypersonic speeds.

- Too little atmosphere to land like we do at Earth
  - With 1% of Earth, imagine landing the Shuttle at 100,000 ft!
  - Even w/ huge parachutes, our landers still fall at hundreds of miles per hour!
    - Scaling results in unrealizable Rose-bowl size (100 m) parachutes.
  - For big landers we still need rockets near the ground.

Mars Exploration Rover (MER)

Current generation of Martian landers

See Mars Exploration Rovers home page at www.jpl.nasa.gov for animations

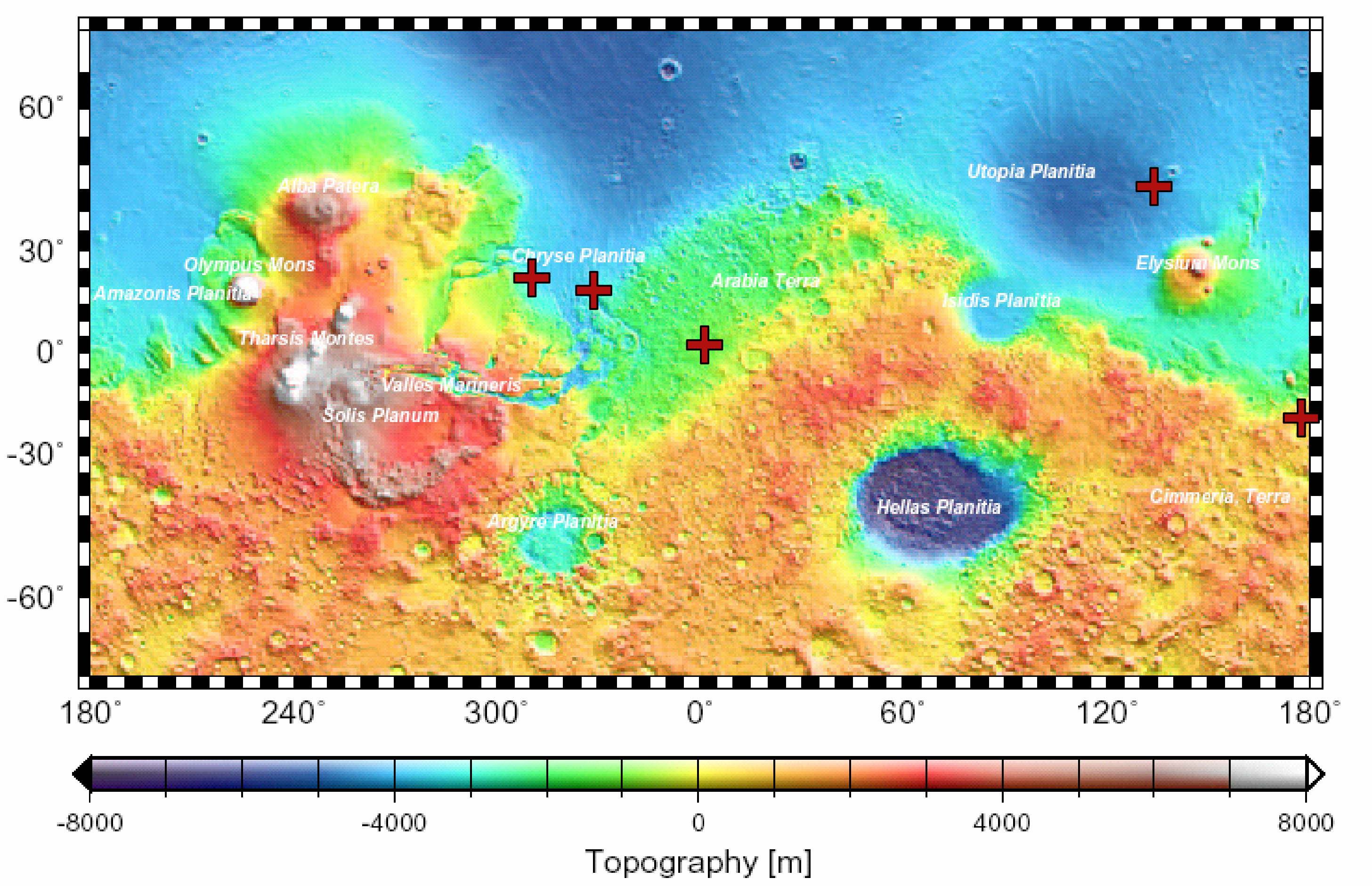
MER Descent Image Motion Estimation System (DIMES)
Mars really is full of surprises

Search the web for "MER Descent Image Motion Estimation System"

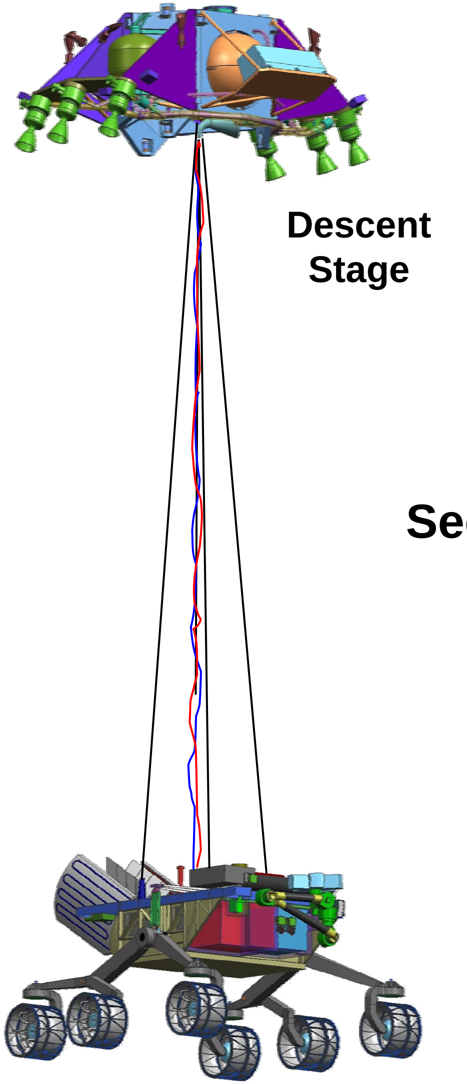
for literature on this system – and the problem it was designed to solve

We still have a long way to go

- There have only been five successful landings on Mars
  - 2 Viking landing in ‘76, 1 Mars Pathfinder in ‘97, 2 MER in ‘04
  - There have been at least as many failures
- These systems had touchdown masses < 0.6 MT



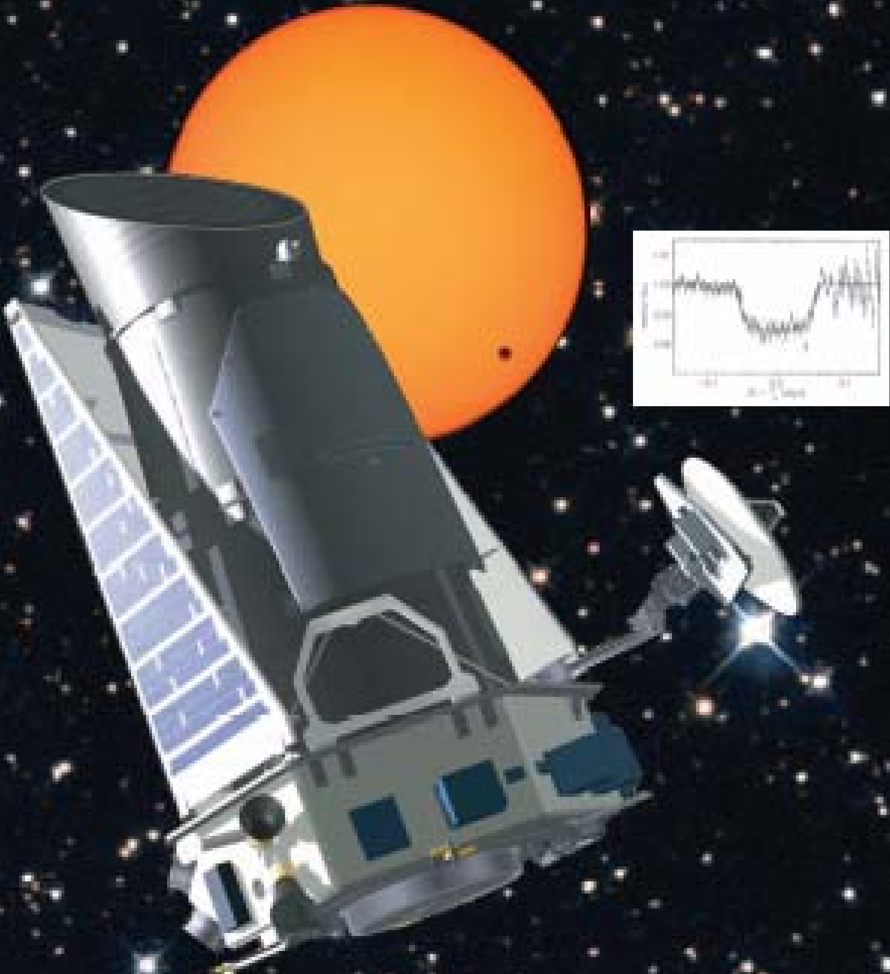
Mars Science Laboratory:
The Next Big Thing



See Mars Science Laboratory mission home page at

www.jpl.nasa.gov for latest information

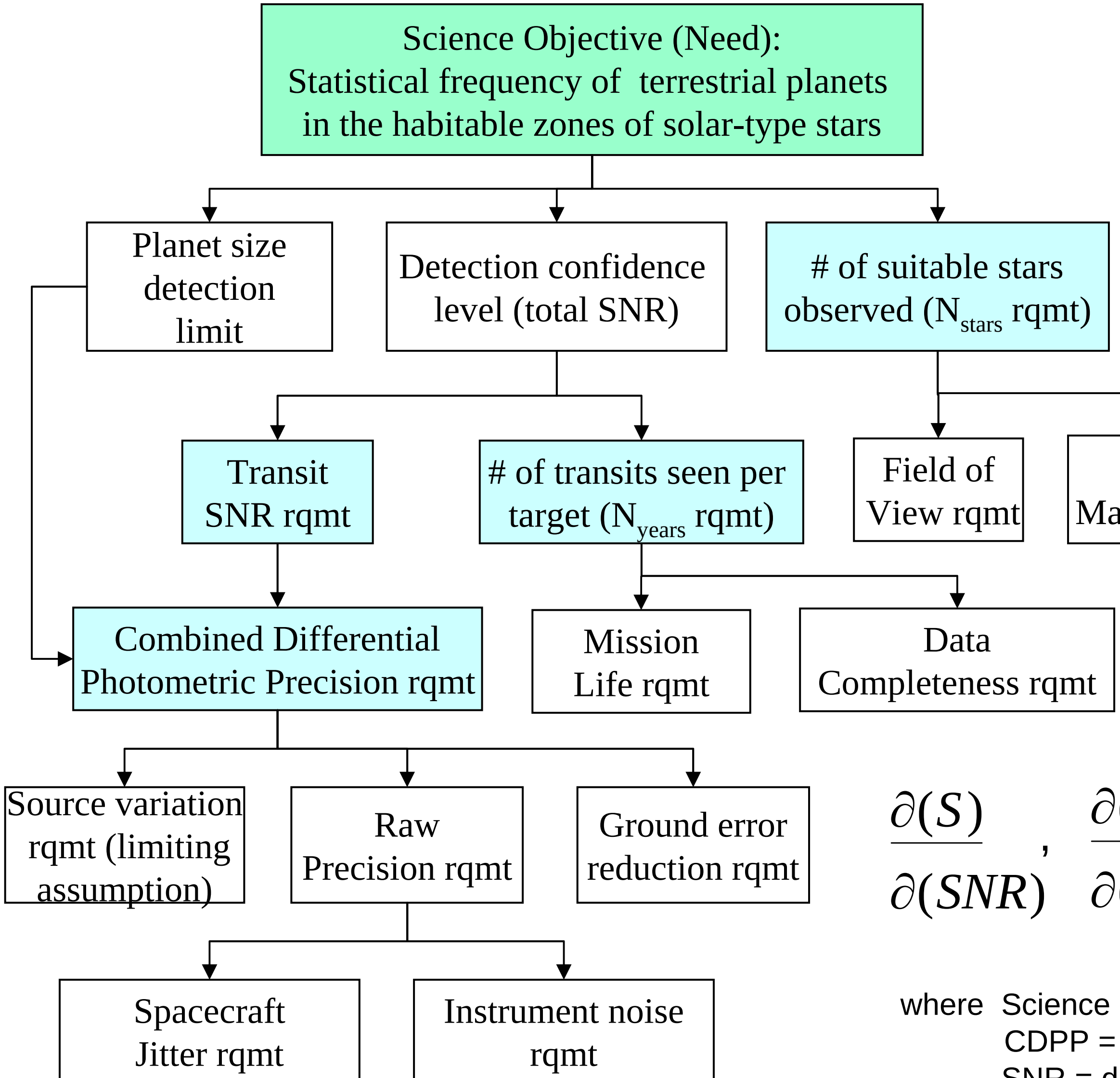
KEPLER *the Search for Extra-solar Planets*



- Discovery Mission
- Habitable Zone Planet Finder
- Heliocentric Earth –Trailing Orbit
- Science Instrument:
  - – Photometer
  - – 95 cm aperture, 42 CCD's
- Launch Date: 2008
- Mission Duration: 4 years

Provide Statistics on the Distribution of Planet Sizes

Understanding Performance Sensitivities: the *Kepler* "Merit Function"

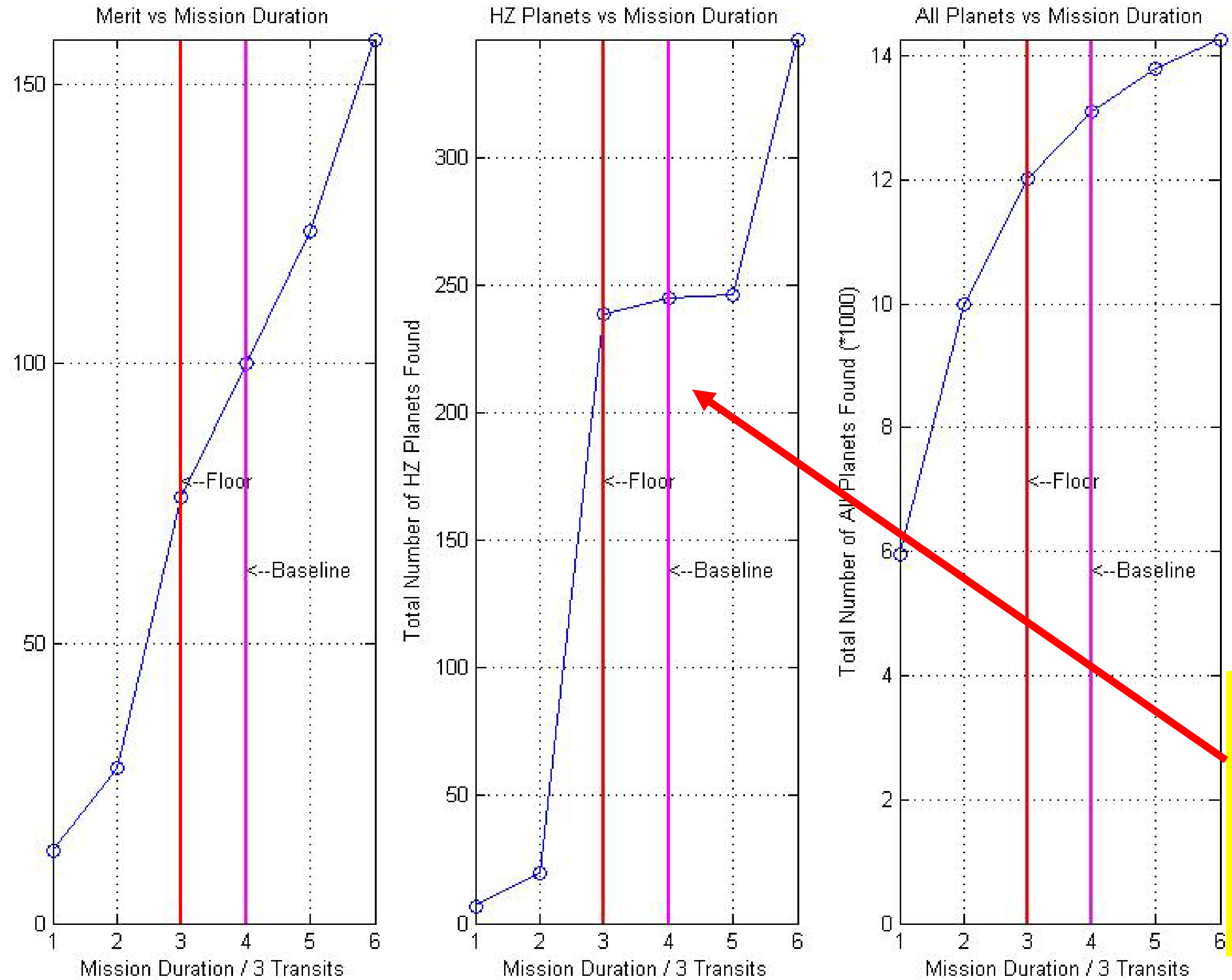


$$\frac{\partial(S)}{\partial(SNR)}, \quad \frac{\partial(S)}{\partial(CDPP)}, \quad \frac{\partial(S)}{\partial(N_{stars})}, \quad \frac{\partial(S)}{\partial(N_{years})}$$

where Science goodness S = f(CDPP, SNR, Nstars, Nyears)
CDPP = combined differential photometric precision
SNR = detection signal-to-noise ratio
Nstars = number of stars observed
Nyears = number of years observed

Kepler Merit Function

science vs mission-duration curves



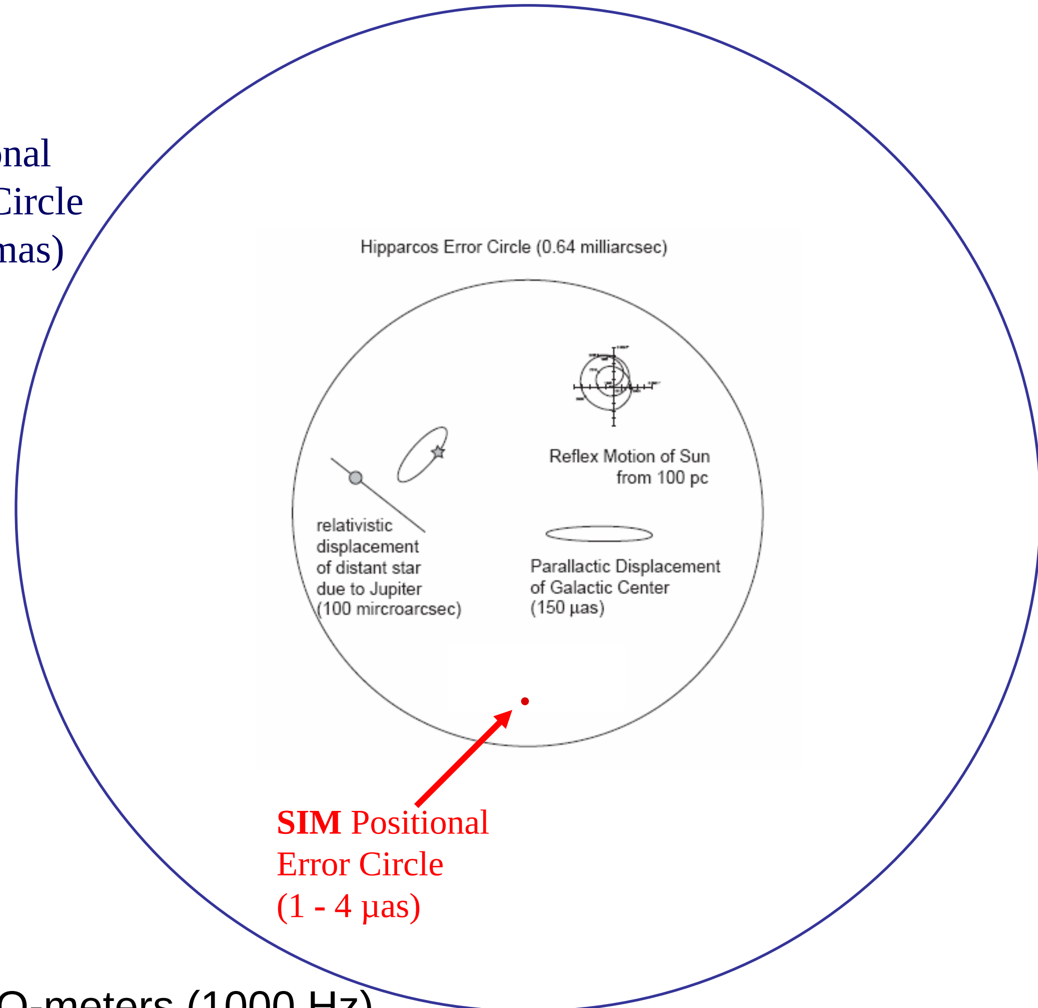
Tells us we're not on a cliff - AND with other curves, how to optimize performance

Courtesy NASA ARC & SETI Institute (William Borucki & Jeff Garside)

Space Interferometry Mission (SIM)

Measuring the motion of stars to find planets

Astrometric Stellar Interferometer



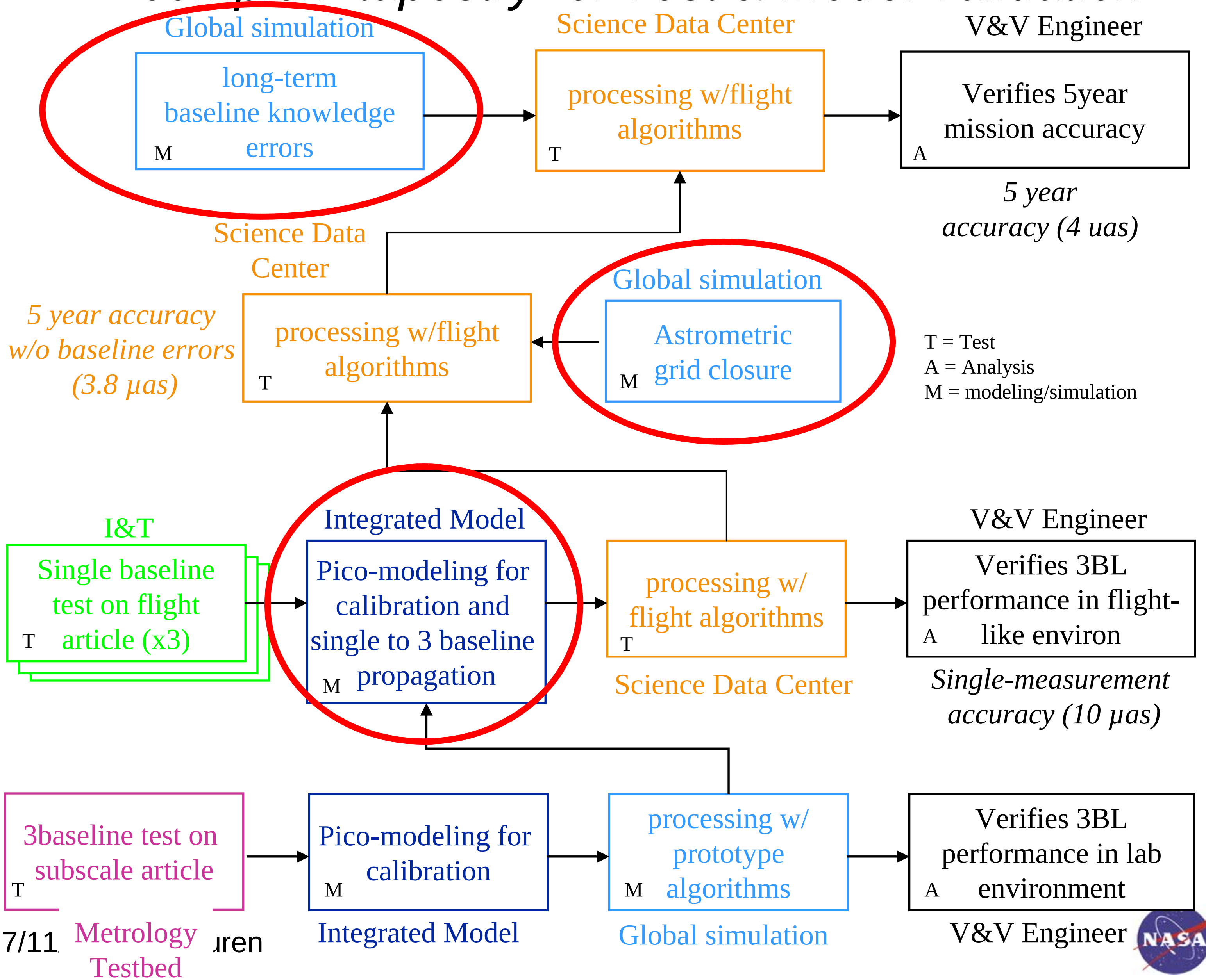
Interferometry & Astrometry require that we:

1. CONTROL optical pathlengths to 10 NANO-meters (1000 Hz)
2. MEASURE changes in component positions to 50 PICO-meters

That's half the diameter of a Hydrogen atom!

SIM Validation & Verification

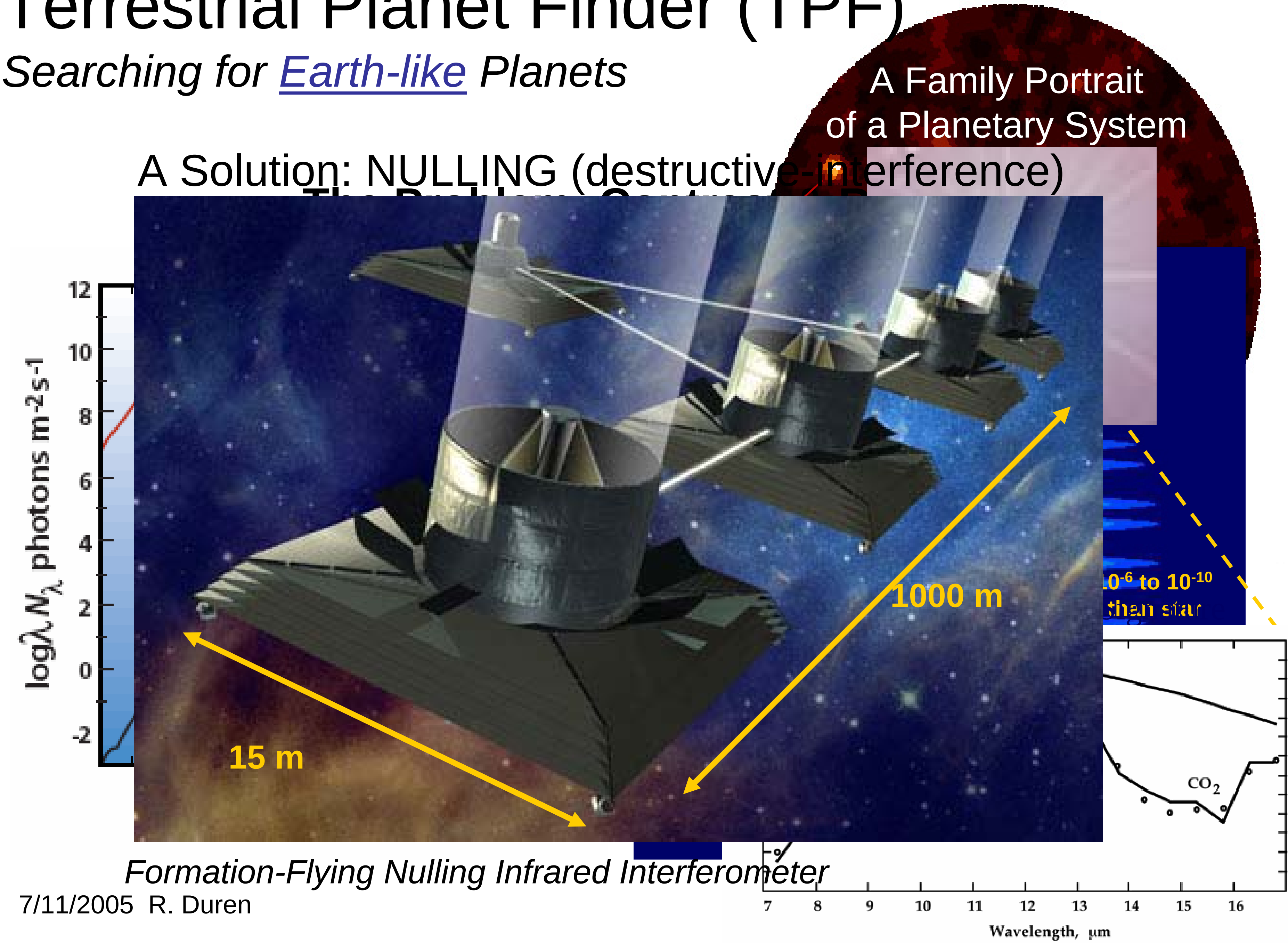
complex "tapestry" of Test & Model-validation



Terrestrial Planet Finder (TPF)

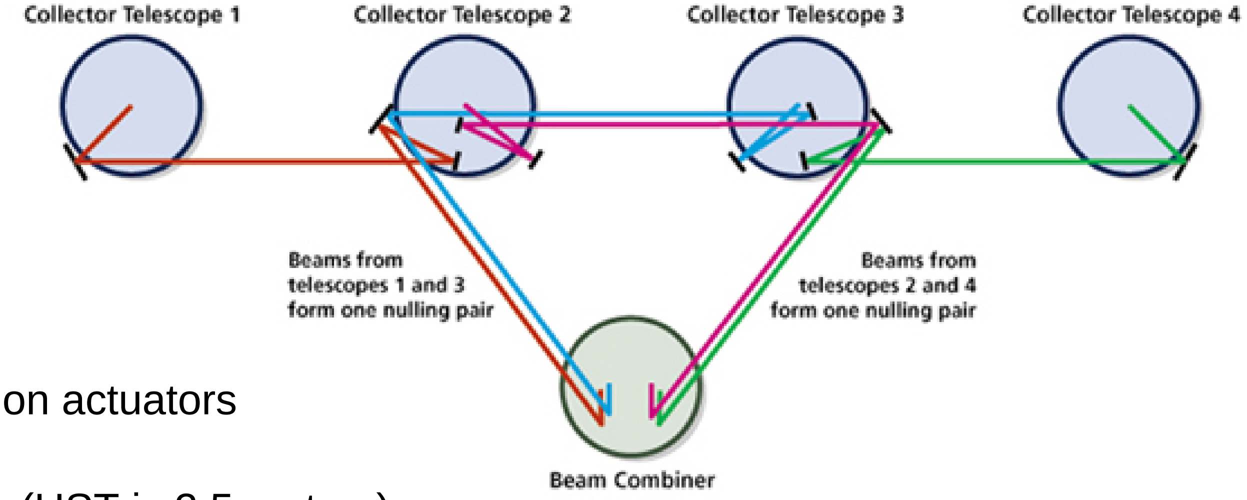
Searching for Earth-like Planets

A Solution: NULLING (destructive interference)



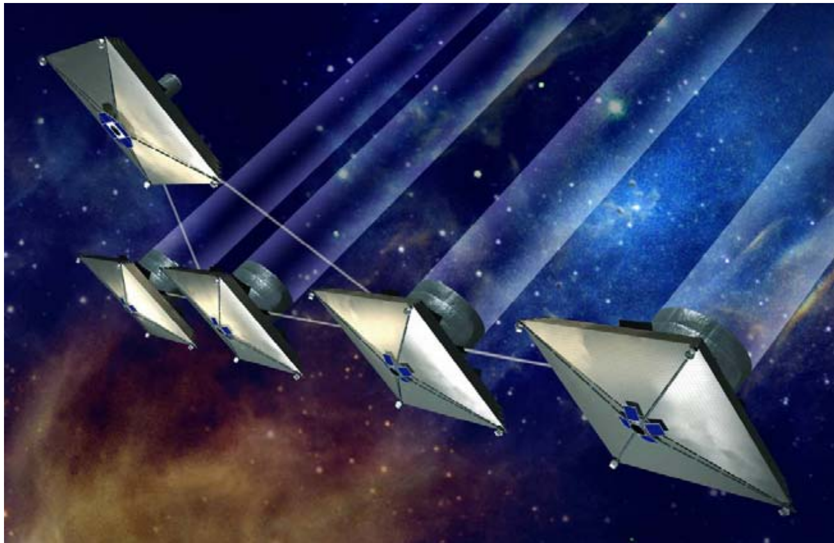
Formation-Flying Nulling Infrared Interferometer

TPF complexity
(SIM is starting to look "easy"!)



<u>Challenges:</u>

- COLD
  - 7-40 Kelvin
  - Including lots of precision actuators
- BIG
  - Four 4 meter apertures (HST is 2.5 meters)
  - 15 meter deployable thermal shields
  - 75 – 1000 meter baselines
- DISTRIBUTED
  - Precision Formation-Flying
  - Constellation Fault-Protection
  - Time synchronization
- TIGHT TOLERANCES
  - Inter-spacecraft pathlength control
  - Inter-spacecraft straylight
  - Intensity (amplitude) matching



So how's it going?

- Some great successes – but still some notable failures
- Common theme from Mishap Reports
  - "Systems Engineering should have caught that"
- NASA's Deep-Space exploration program has undergone a profound "paradigm shift" over the past 10 years
  - Faster-Better-Cheaper pressures
    - Faster = more missions, less time → # of experienced SEs
    - Better = more complex → capabilities of tools & processes
    - Cheaper = fewer resources & <u>fixed price</u> → need for fine-tuned design
- We want (& need) to do better…

Systems Engineering @ JPL
(our self-assessment)

1. Chronic shortage of "good" system engineers
   - Many concurrent missions vs few large missions

2. Systems engineering is implemented ad hoc based upon the "personalities of the moment"
   - e.g., Verification and Validation & Model-based Engineering

3. Mission complexity is overwhelming traditional methods
   - Highly autonomous
   - Large & Physically Distributed
   - New performance regimes
   - Tight Coupling

Systems Engineering Advancement initiative

Personal Attributes

- Intellectual Curiosity
- Big Picture View
- Seek Out & Understand Connections
- Comfortable with Change
- Comfortable with Uncertainty
- Proper Paranoia
- "Head for" Resources & Margins
- Communication Skills
- Self-Confidence & Energy
- Appreciation for Process

- Research (psycho-social)
- Recruiting

Processes & Tools

- Deep knowledge of sub-field(s)
- Formal Education (school & continuing)
- Understanding of total life-cycle
- Hands-on Experience

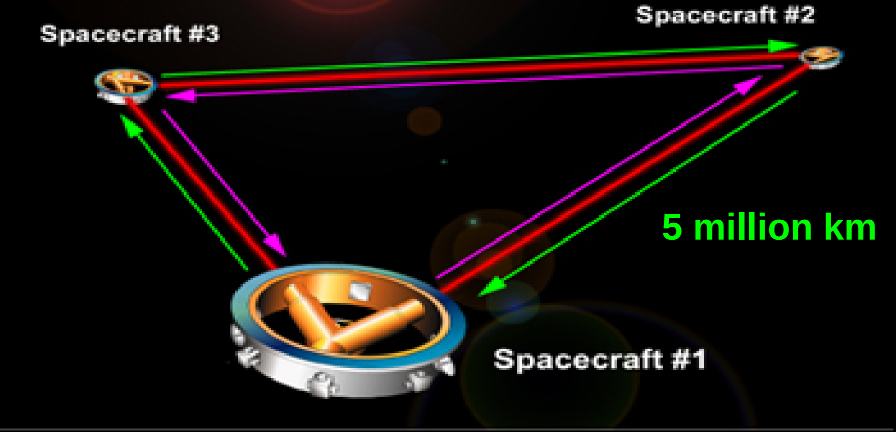
Detailed Knowledge

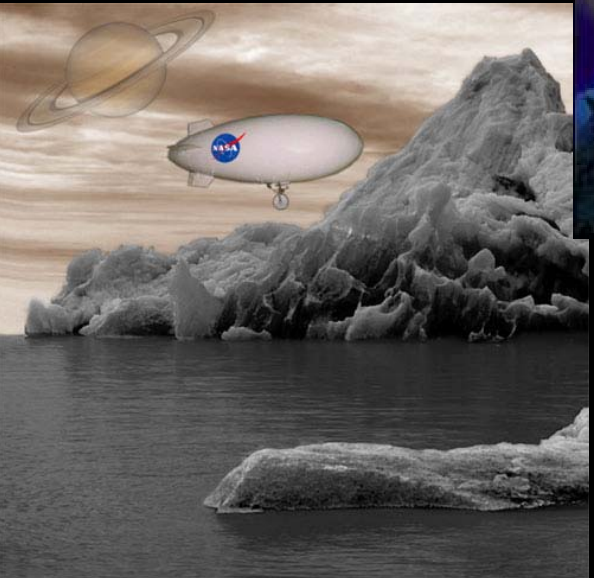
- Systems Engineering Processes
  - develop system architecture
  - develop requirements
  - develop interfaces
  - manage technical resources
  - analyze alternatives and trade design
  - verify and validate
  - manage risk
  - conduct reviews
  - manage & control the design

- Modeling/Simulation Tools
  - Merit Functions
  - End-to-End Simulations
  - State Analysis
  - Error Analysis
  - Probabilistic Risk Assessment

- Establish & Communicate Processes
- Modeling Tool Development
- Training Program (3 year curriculum)

Zany ideas of the Future?
We've just scratched the surface….





Wrap Up

- **Future Deep-Space Missions pose significant new challenges to Systems Engineering – due to growing complexity associated with:**
  - **Getting There**
  - **Measurement Itself**

- **Systems Engineering is the project "glue function" – getting it right requires deep, multi-dimensional awareness of key relationships**

- **Initiatives are underway at JPL/NASA to improve our Systems Engineering infrastructure (including the Engineers):**
  - **Personal Attributes**
  - **Processes & Tools (particularly V&V and Model-based Engineering)**
  - **Detailed Knowledge & Experience**

- **For more discussion,**
  - **stick around for the Academic Panel Session**
  - **stop by the JPL booth**
  - **Contact: Riley Duren (Riley.M.Duren@jpl.nasa.gov), Ross Jones (Ross.M.Jones@jpl.nasa.gov)**

- **Also see Matthew Bennett's upcoming talk on "State Analysis…."**

Links to animations in version presented at INCOSE

- http://deepimpact.jpl.nasa.gov/gallery/animation.html
- http://marsrovers.jpl.nasa.gov/gallery/video/animation.html
- http://mars.tv/video/02.06.04.rover.spin.html

(note: last site which hosts the “Mars rover arm spin” spoof video is not a NASA site and may change but is widely available on the internet)