Resolving the Cassini/Huygens Relay Radio Anomaly

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Resolving the Cassini/Huygens Relay Radio Anomaly

Background

- The Huygens probe carried by Cassini is to be released to Titan from orbit about Saturn
- Huygens will descend into Titan's atmosphere as Cassini flies overhead
- Images, physical measurements, and radio science will be gathered during the descent into the atmosphere
- If Huygens survives on the surface, science will be performed until Cassini passes Titan
- Cassini/Huygens is a joint NASA/ESA mission
- ESA built the Huygens spacecraft and both ends of the relay radio for the one-way telemetry link
- This link was tested on the ground before launch – but the kinds of signal dynamics expected in the real mission could not be realistically reproduced
- It was discovered in a DSN/Cassini test in 2000 that the link fails under dynamic conditions typical of the expected mission

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Huygens Telecommunications System

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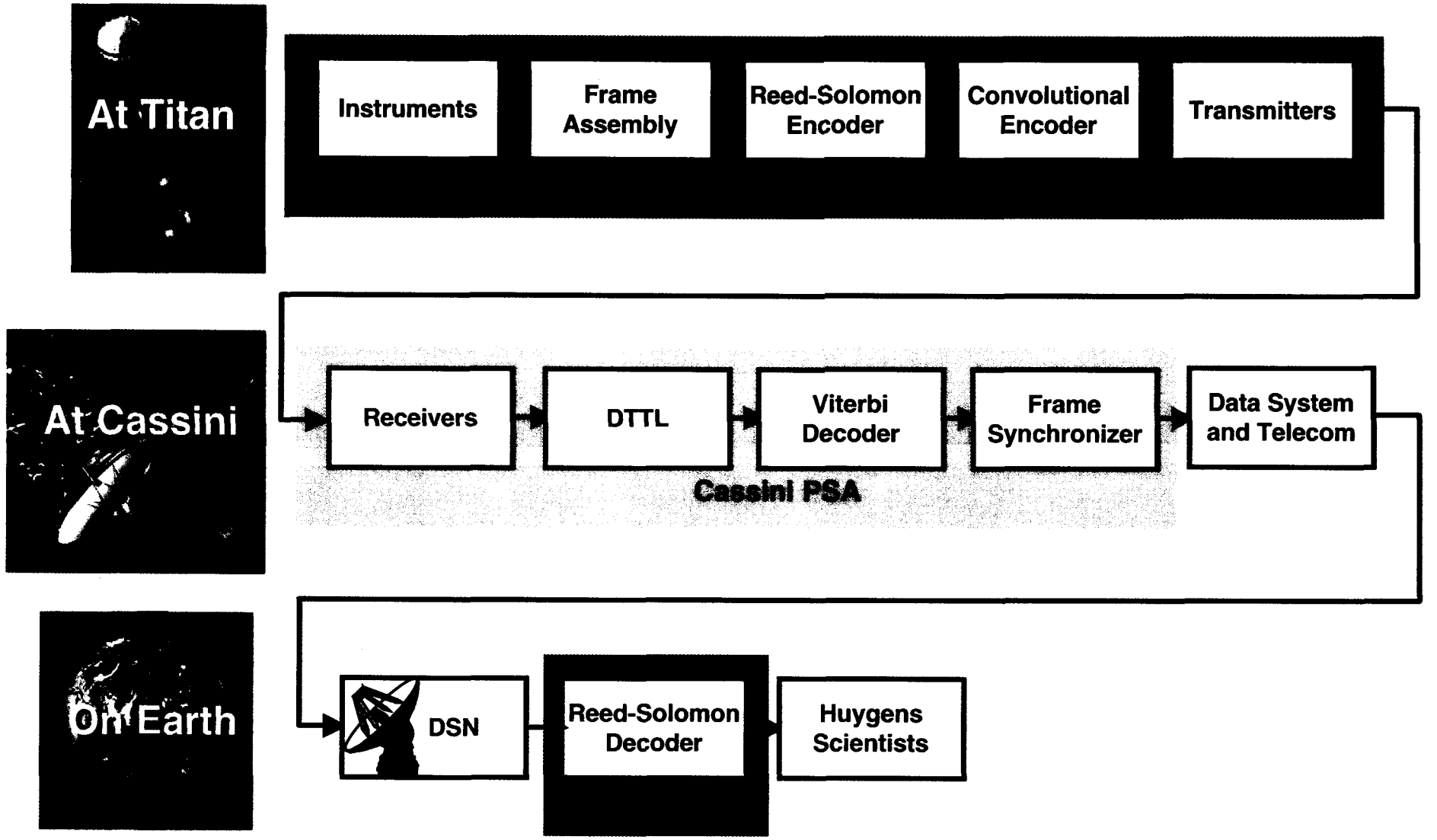

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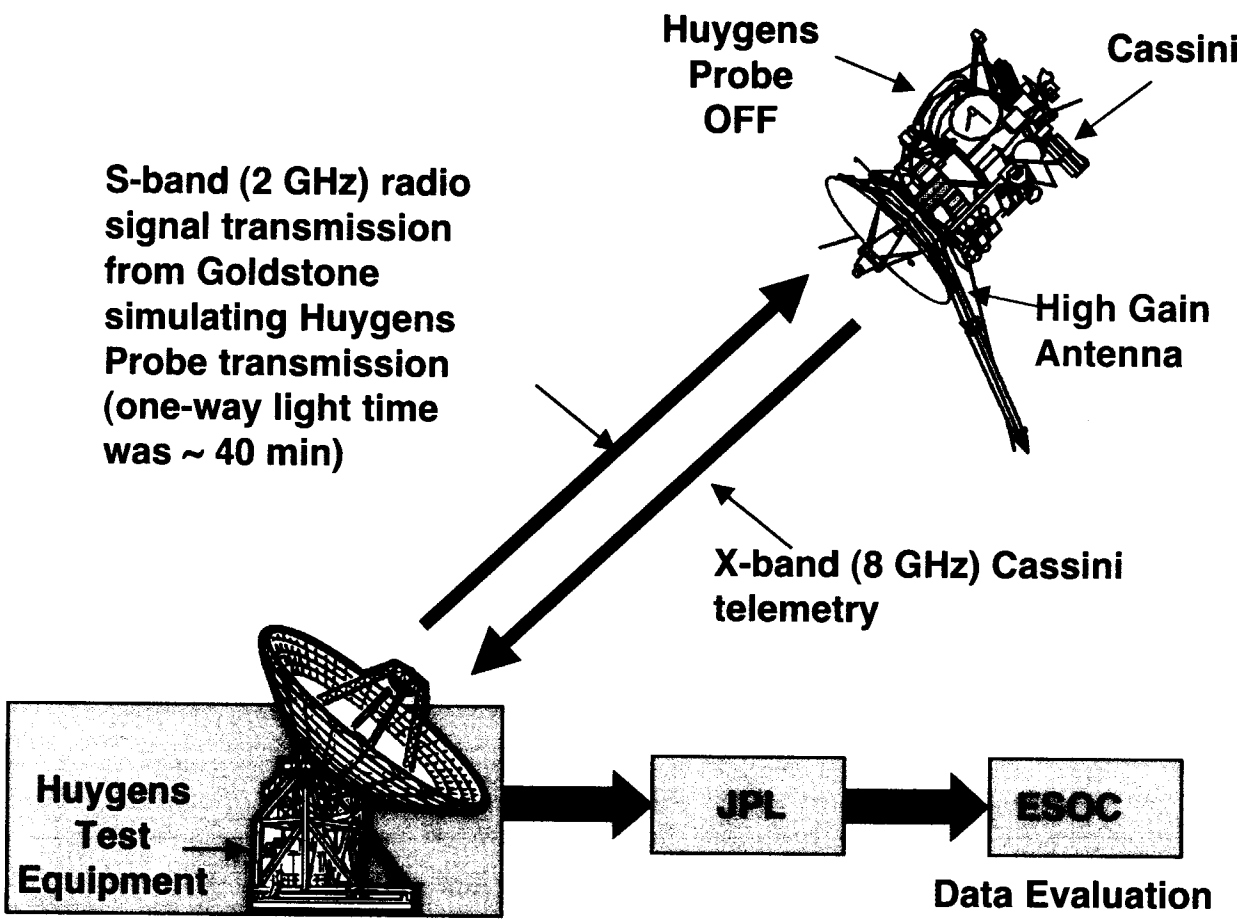
Probe Relay Test - Discovering the Problem



DSS 24
Deep Space
Network Antenna

Data Evaluation

Data arrive at ESOC 80 min after transmission From Goldstone!

DSS 24

Boris Smeds and Test Equipment

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Test Results

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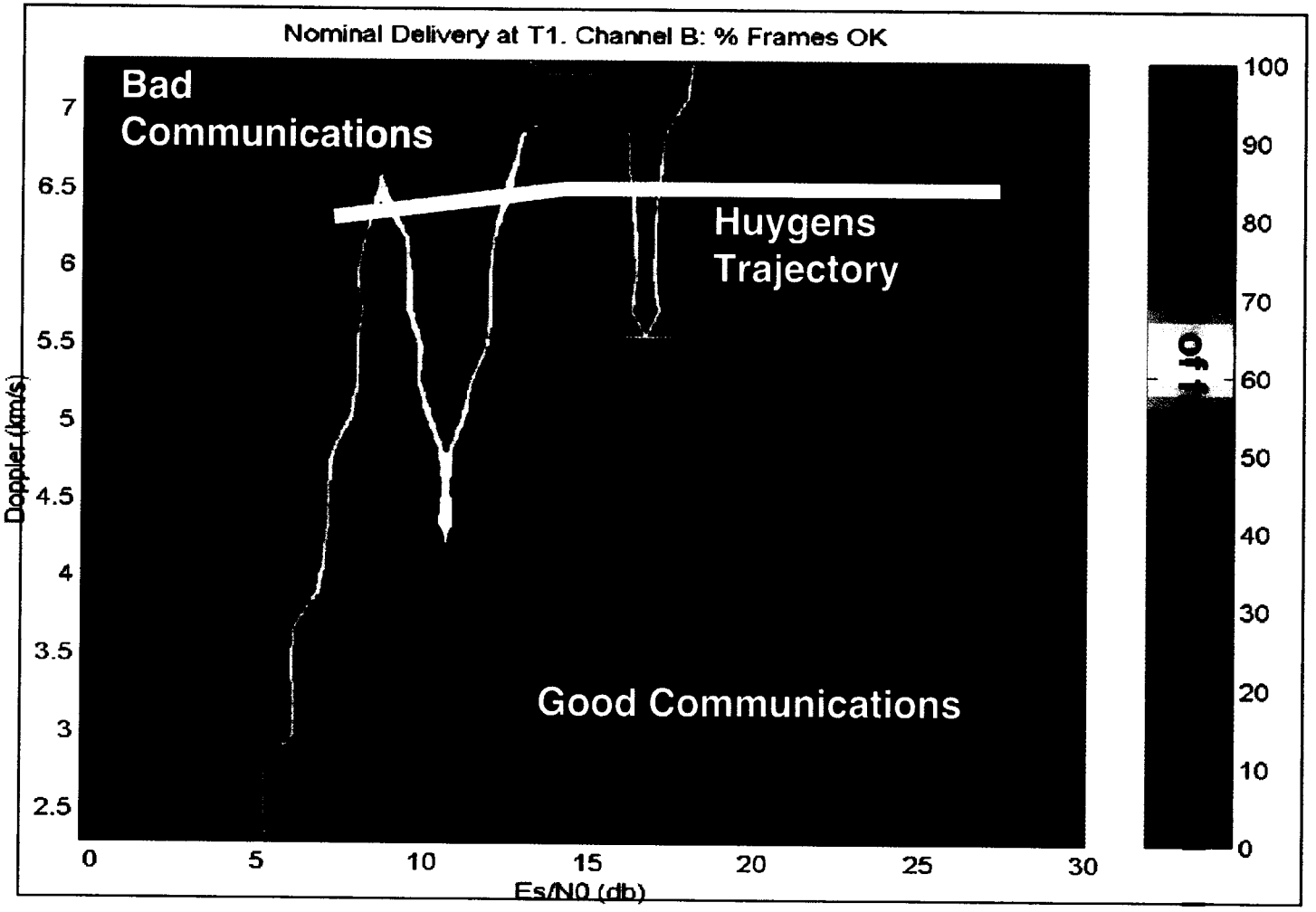

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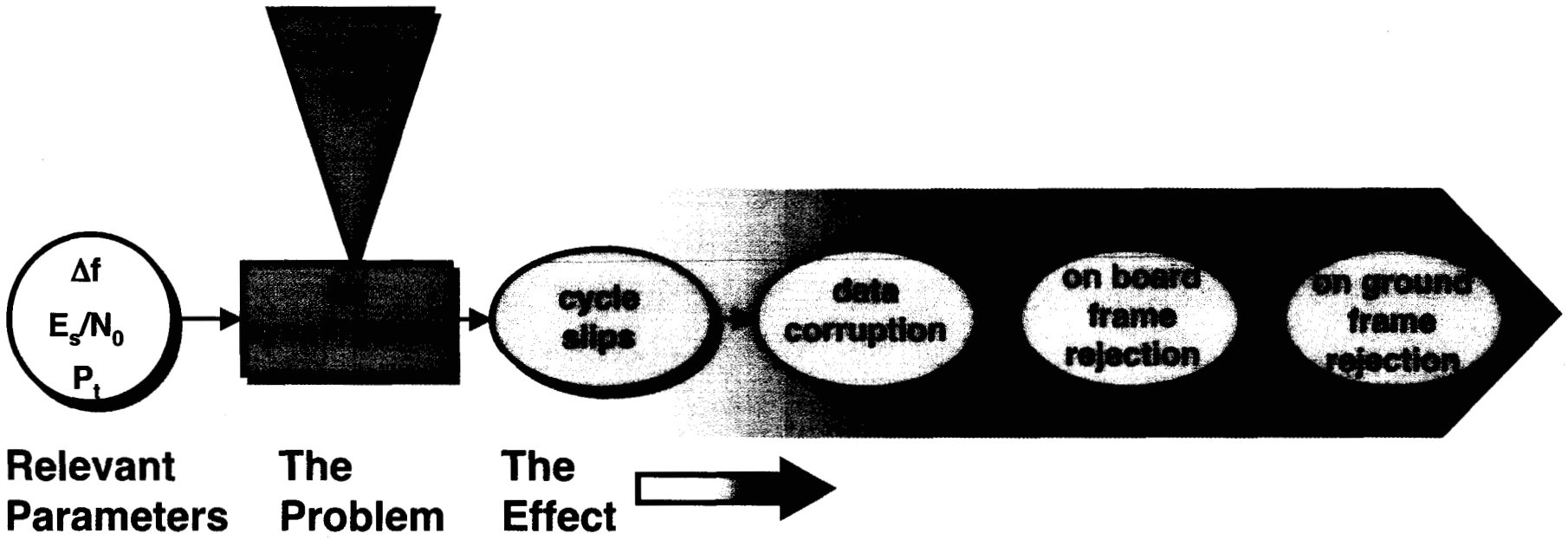
Hypothesized Failure Mechanism



- Because of a design flaw, the bit synchronizer in the Probe Support Avionics (PSA) of Cassini slips cycles under certain combinations of Doppler, signal-to-noise ratio, and bit transition density in the data stream
- This results in poor frame synchronization resulting in
  - Some corrupted frames sent to Earth
  - Some frames discarded in the PSA completely ("dump frames")
- Existing ground equipment cannot recover many of the corrupted frames

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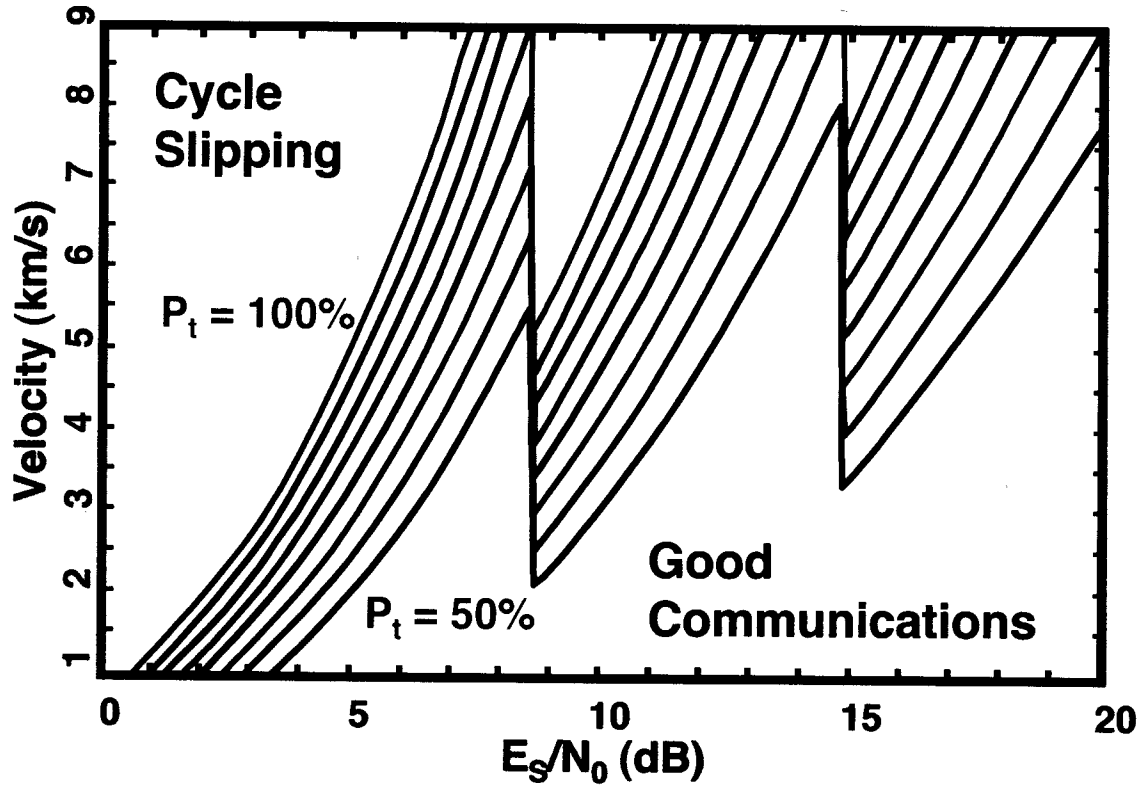
Modeling the Failure Mechanism

- A complete model of the relay system was developed including
  - DTTL dynamics as a function of bit transition probability
  - Convolutional decoding
  - Frame synchronization
  - Reed-Solomon decoding
- Symbol cycle slips are generated with a period that is a function of E_b/N_0, Δf, and P_t
- Fingers are caused by AGC function
- Analysis shows the anomaly was caused by improper bandwidths chosen for the symbol loop
- Unfortunately, all PSA parameters are hard-coded and cannot be changed in flight



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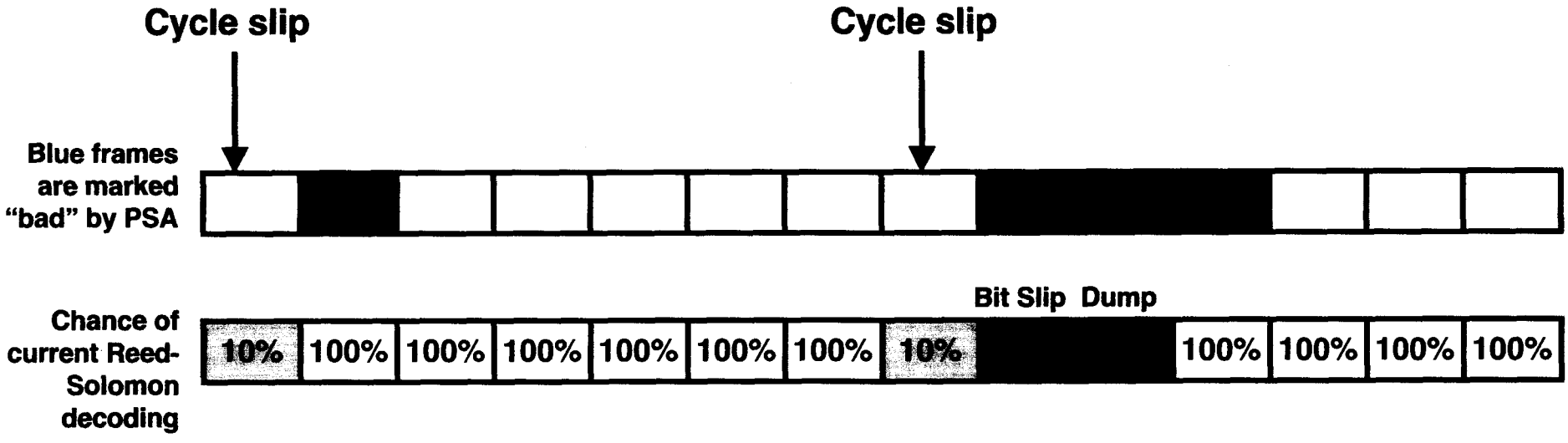
What Actually Happens to the Frames?

- This corruption model helps us predict which frames will be returned to Earth and which of those will be recoverable
  - The PSA does not return some frames it believes are corrupt!
- Consider the following example



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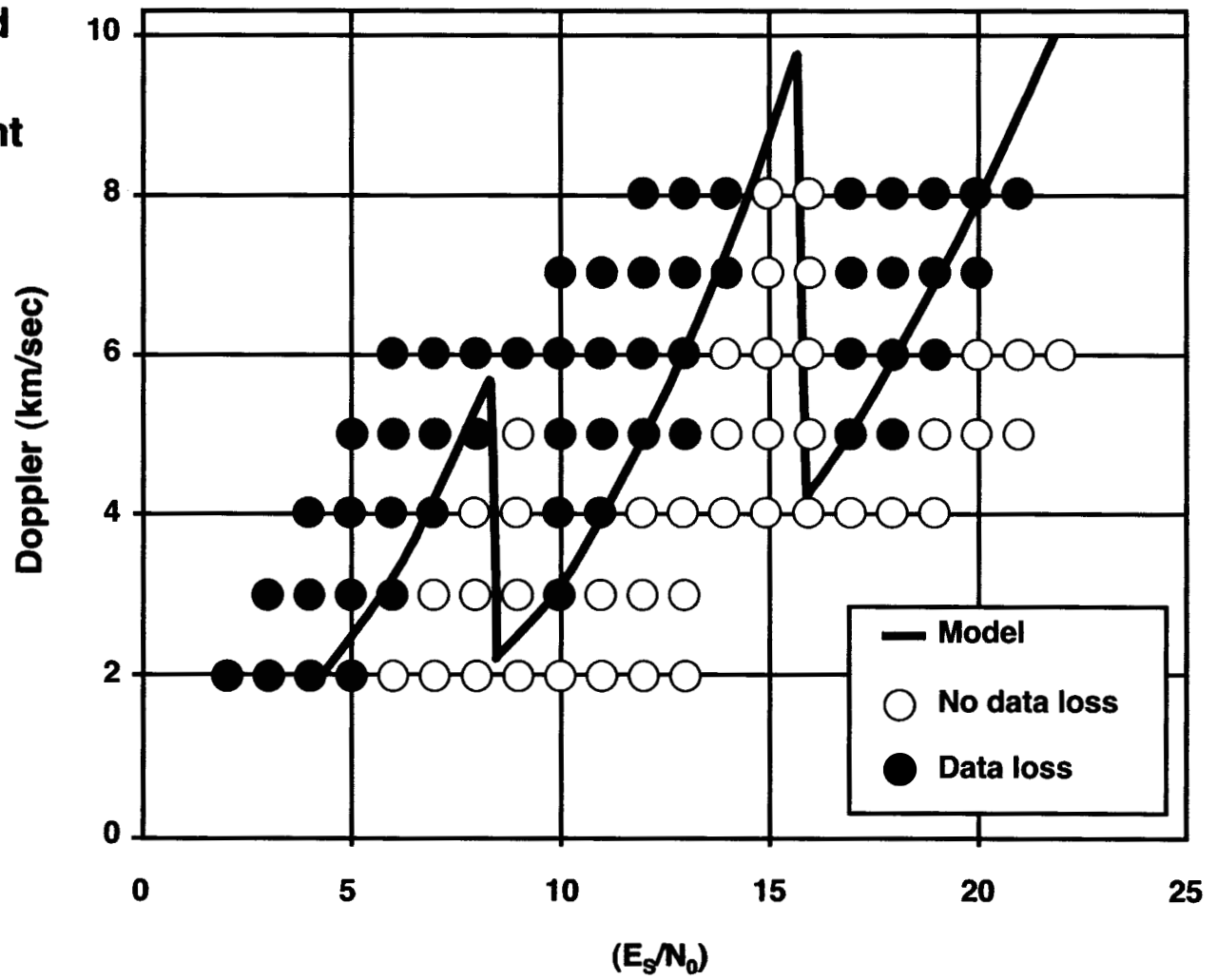
Verifying the Model

- Two additional DSN tests were run to verify and calibrate the model
- Results were excellent



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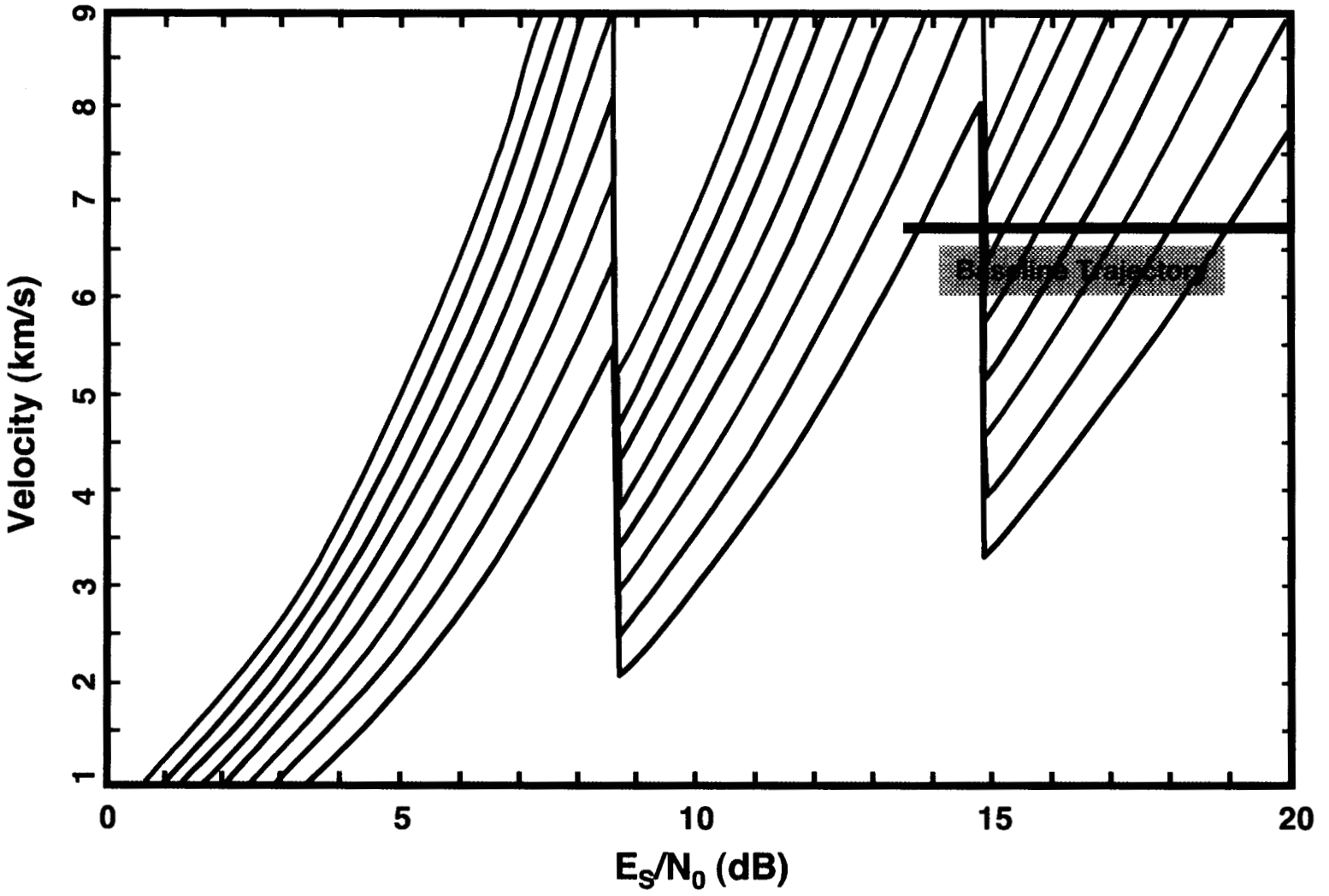
How Well Would Huygens Do?

- With the planned mission, there would be more than 50% data loss



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Ways to Improve Data Return

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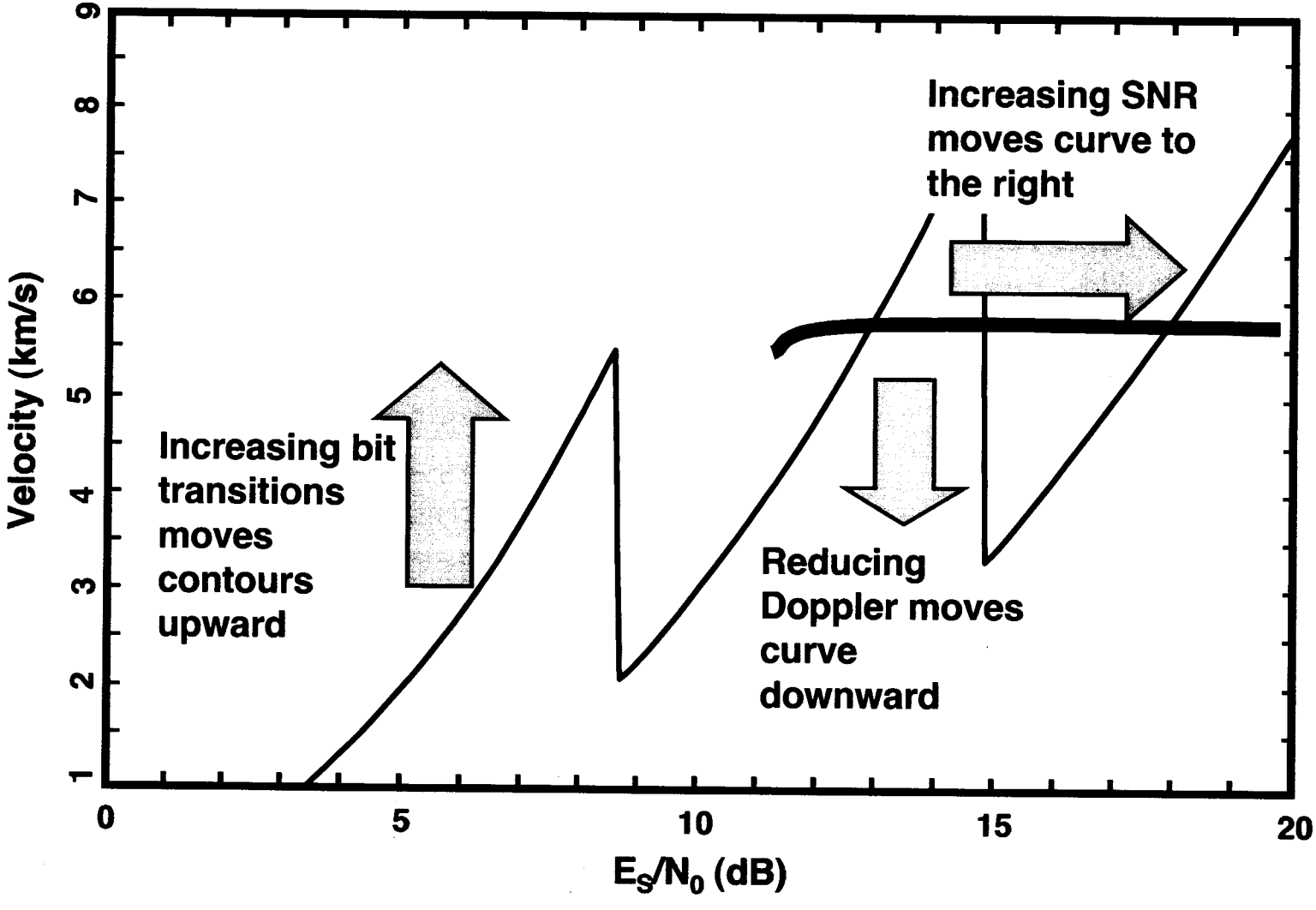
Varying the critical parameters "moves" the probe curve with respect to the contours - resulting in more good data returned to Earth



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Possibilities

- Increase P_t
  - Precode data to have more transitions – wastes data bandwidth
  - Insert zero packets periodically – wastes data bandwidth
- Increase E_b/N_0
  - Implement closed loop antenna pointing on Cassini – expensive
  - Decrease "Orbiter Delay Time" – reduces on-surface mission
- Decrease Δf
  - Fly Cassini further from Titan – reduces E_b/N_0, uses propellant
  - Pre-heat Huygens oscillator – eats into battery margin
- Recover more bad frames on the ground
  - Recognize frames that are bit-slipped
  - Use erasure capability of Reed-Solomon codes
  - Use known structure of frames
  - Use stack decoding – expensive to use on all frames

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Constraints

- Change as little of the Saturn tour as possible
  - Replanning would take more time and funding than is available
- Perform early in Saturn tour
- Use as little propellant as possible
  - Maintain margin for other possible anomalies, science opportunities, and a possible extended mission
- Maintain power margin for Huygens mission
- Maintain sun illumination for Huygens instruments
- Maintain favorable geometry for Huygens radio science
- Do nothing to endanger other Cassini instruments or science observations
- Minimize any effect on radio occultations of Saturn
- Avoid, as much as possible, major rewrites of Huygens instrument software
- Provide a solution that balances Huygens science goals

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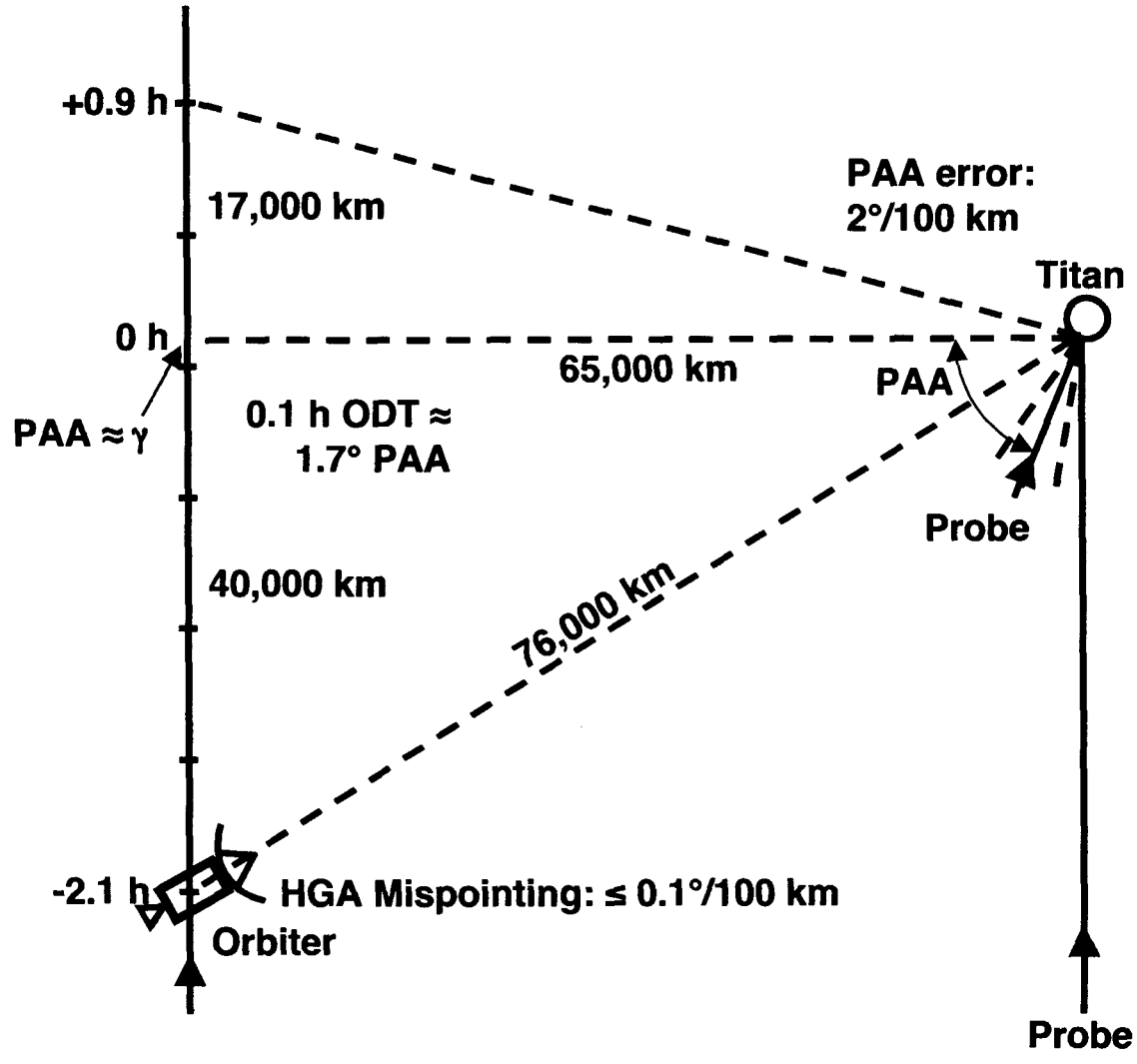
A New Retrograde Flyby Saves the Day

- The trick now was to find a high altitude flyby that uses minimal fuel (~150 m/s for simple altitude increase)
- JPL navigators came up with the idea of flying by the opposite side (retrograde) of Titan
- This uses Titan's gravity to help more with Cassini maneuvers
- New trajector may use as little as 80 m/s of propellant
- There is actually a class of these trajectories with one to be chosen by the Project



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Recommended Solution

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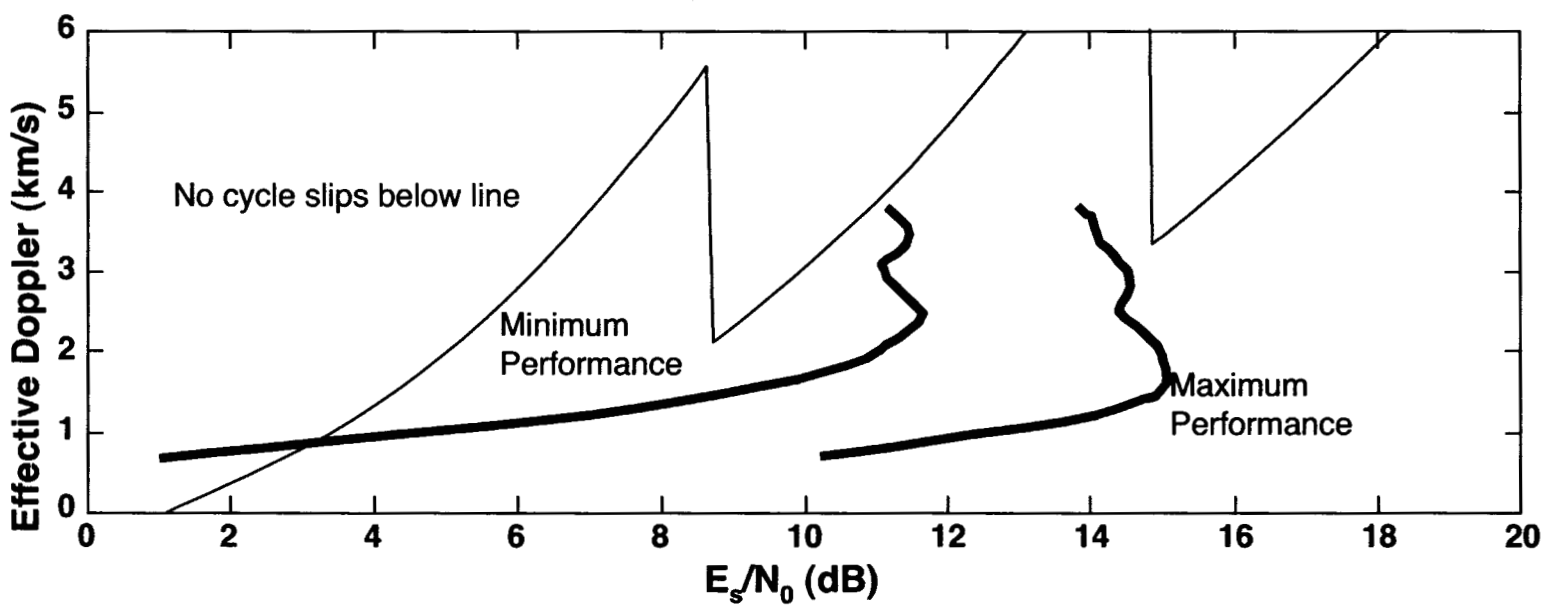
- The team developed several point designs that show possible solutions to the anomaly
  - Each of these returns close to 100% of the data with margin
- Here is an example design, Case 1:
  - Sun Zenith Angle ≈ 30° (good instrument illumniation)
  - Latitude of nominal landing point: -9°
  - 99% link up to 156 minutes after entry
  - 90% link up to 180 minutes after entry
  - PAA ≤ 82°



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Conclusions

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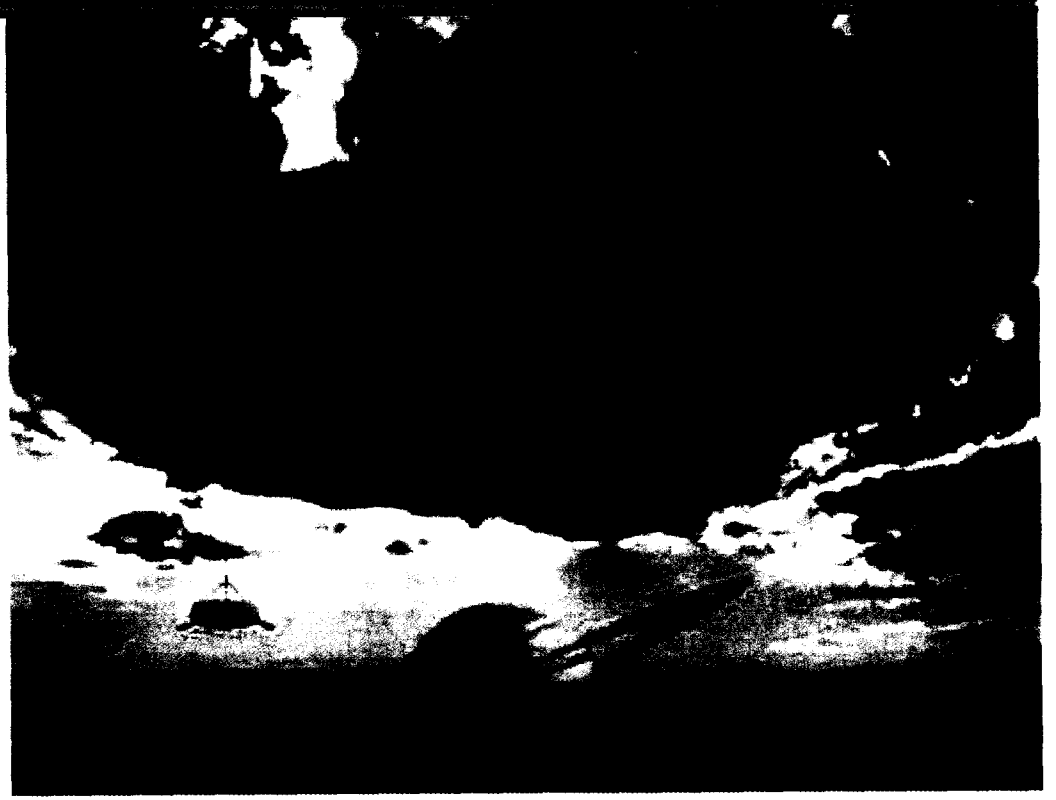

- Solutions exist for the Huygens radio relay anomaly
- The solution space must be searched by the implementation project to minimize propellant use
  - Leave as much propellant for other unforeseen problems as possible
  - Keep high probability of extended Cassini mission
- Learn from the mistakes that caused this problem (and problems in solving the problem!)
  - Spacecraft systems must be tested to all of their requirements before launch
  - Keep engineering model and flight spares operational throughout the mission
  - Maintain documentation of spacecraft hardware and testing
  - Never intentionally throw away data in a deep space mission
  - Spacecraft systems need to have an appropriate level of reconfigurability in flight