

Experimental Effervescence Measurements of Nitrogen in Liquid Methane–Ethane Mixtures to Support an Extraterrestrial Submarine for Titan

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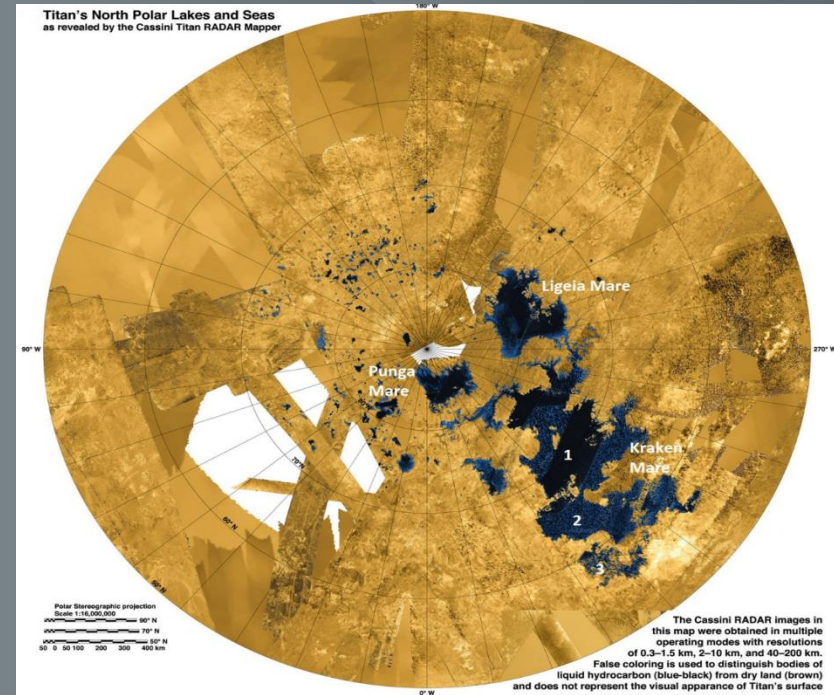
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Titan's Cryogenic Environment

1. Titan is the only known body (other than Earth) within the Solar System with stable seas

- Stable hydrocarbon seas similar in size/depth as Great Lakes on Earth
- Liquid surface temperature 90-96 K; near freezing point of ethane and methane
- Seas ~96% Liquid (ethane or methane), 4% GN_2
- Density variations of 30%



Titan's Cryogenic Environment

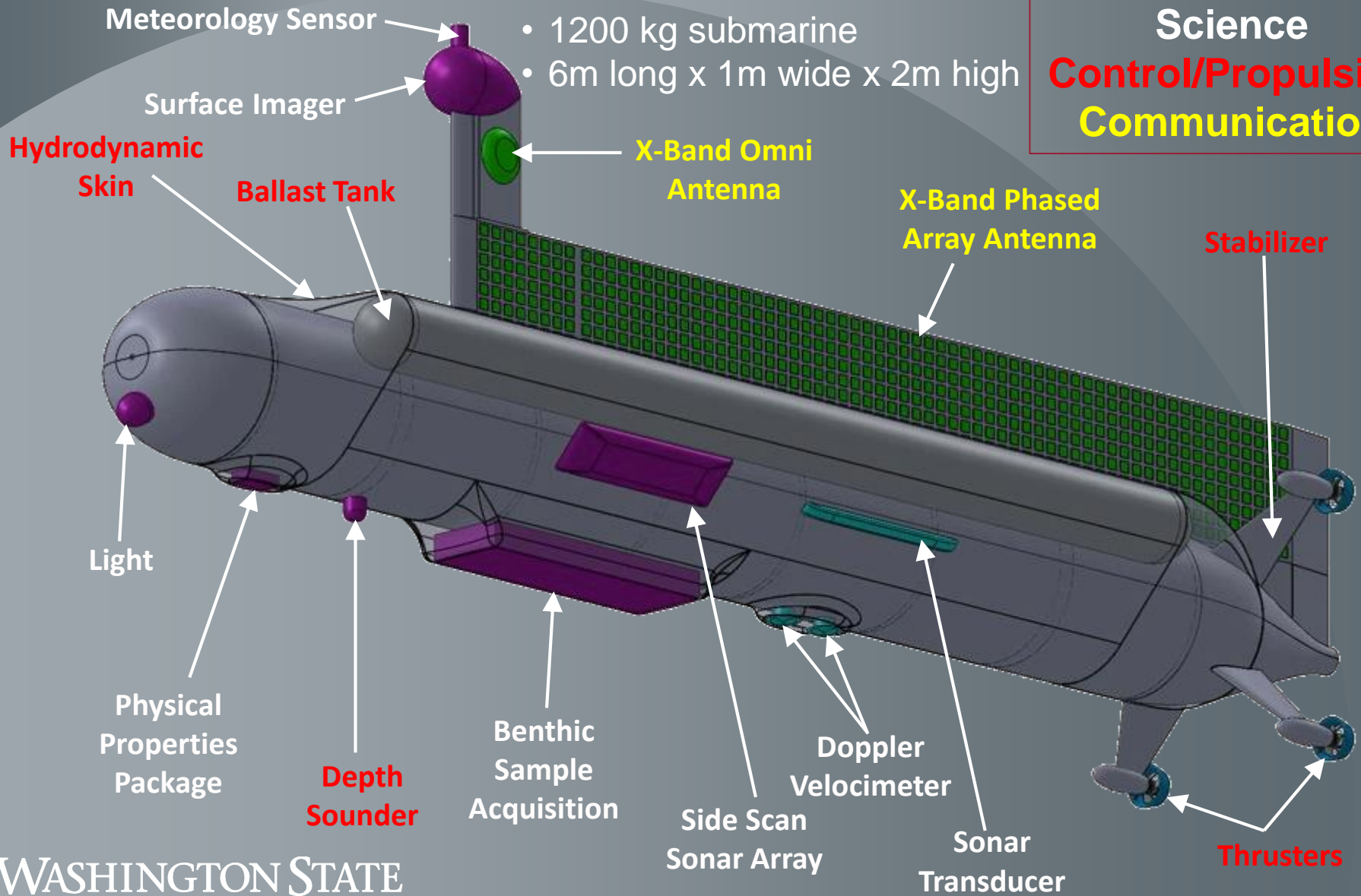
2. Only known moon with significant atmosphere
 - Organic compounds accumulate to form thick haze, clouds
 - 1.5 atm, 95% GN_2 , 5% GCH_4
 - 5x density of Earth
 - 14% of Earth's gravity

3. GN_2 solubility increases with increasing pressure, decreasing temperature and increasing mole fraction of methane

4. At Titan's surface (95 K, 22 psia)
 - 15% dissolved GN_2 in pure liquid methane
 - 3% dissolved GN_2 in pure liquid ethane

Titan Submarine

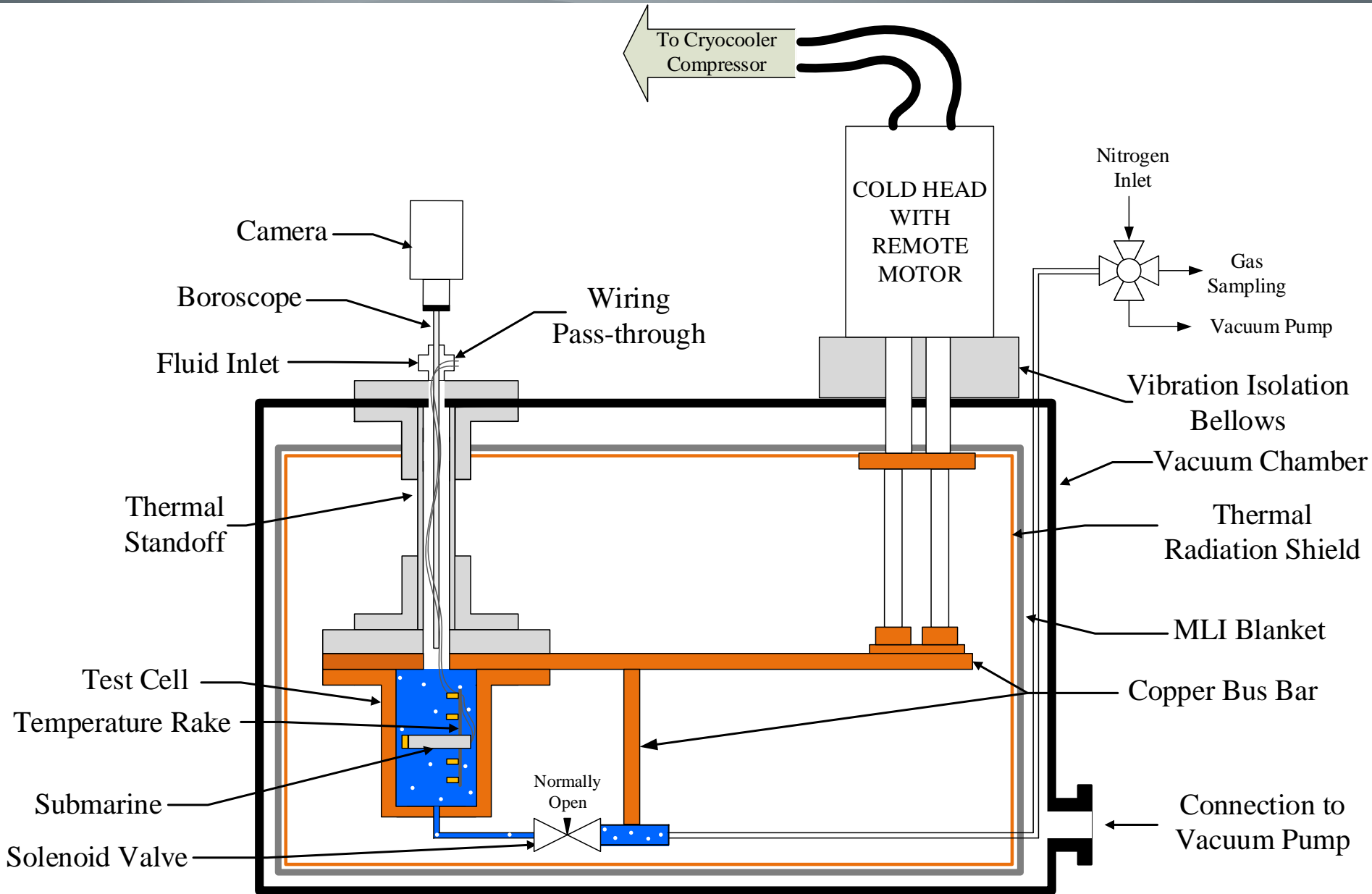
Science
Control/Propulsion
Communication



Design Challenges

1. When will effervescence occur?
2. How will the nitrogen bubbles behave?
3. What affects will nitrogen bubbles have on the ballast systems, scientific instruments, and propellers?

Experimental Apparatus



Effervescence Results

Data Point	CH ₄ [mol %]	C ₂ H ₆ [mol %]	N ₂ [mol %]	Pressure [bar]	Sea Temp. [K]	Heater Surface Temp. [K]	Heat Flux at Bubble Incipience [W/m ²]
1	87.1	0.0	12.9	1.546	96.2	101.4	10830
2	87.7	0.0	12.3	1.65	93.5	100.2	13029
3	82.5	0.0	17.5	1.782	95.9	99.6	3257
4	72.3	0.0	27.7	4.53	97.0	104.1	17915
5	0.0	97.3	2.7	1.73	103.6	118.7	28810
6	0.0	94.6	5.4	4.41	92.5	107.2	24559
7	50.6	44.2	5.2	1.85	97.8	108.7	18729
8	57.5	37.2	5.3	1.561	92.7	107.8	26448
9	47.6	30.9	21.5	3.21	91.9	97.8	11074
10	24.9	48.3	26.8	3.44	91.9	94.2	2475
11	27.0	61.4	11.6	3.85	91.8	98.8	10244
12	30.2	63.9	5.9	2.133	93.6	111.6	31758

- Likelihood of effervescence increases with increased nitrogen content.

Freezing Point Depression Measurements

- Freezing point measurements showed 16 K subcooling below the triple point temperature of methane (90.7 K) and ethane (90.4 K)

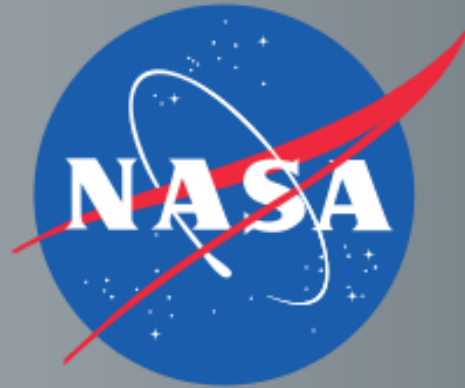
Data Point	Methane [mol %]	Ethane [mol %]	Nitrogen [mol %]	Pressure [bar]	Sea Temp. [K]
F1	61.0	25.6	13.4	0.290	71.5
F2	46.9	45.3	7.9	0.517	74.0

Measurement Video

Video available at: <http://hdl.handle.net/2376/12183>



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THANK
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