DRAGONFLY

# "Lightning Talk" – *KISS Nebulae Workshop, August 2019*


**Dmitriy Bekker[1] (APL), Morgan Cable[2] (JPL), Alice Cocoros[1] (APL)**

[1] Mobility System Team
[2] Science Team



SOURCES:

I. R. Witte, D. L. Bekker, M. H. Chen, T. B. Criss, S. N. Jenkins, N. L. Mehta, C. A. Sawyer, J. A. Stipes, J. R. Thomas, "No GPS? No Problem! Exploring the Dunes of Titan with Dragonfly Using Visual Odometry," AIAA Scitech Forum, January 2019.

R. D. Lorenz et. al, Dragonfly: A Rotorcraft Lander Concept for Scientific Exploration at Titan, APL Tech Digest, 2018.

Hibbard, K. E., Adams, D. S., Cocoros, A. A., Mehta, N. L., Sawyer, C. A., and Villac, B. F., "Dragonfly: In Situ Terrain-Relative Navigation for Titan Surface Exploration," 16th International Planetary Probe Workshop (IPPW-16), July 8-12, 2019, Oxford, UK.



APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

# Titan

- Titan is fascinating
  - The largest moon of Saturn, larger than the planet Mercury
  - An ocean world with two solvents (water, hydrocarbons)
  - The only moon in our solar system with a dense atmosphere, mostly nitrogen

- Titan supports an Earth-like hydrological cycle
  - Rivers, lakes, seas, rain, sand dunes
  - Similar processes, just different materials
    - Water on Earth ~ Methane on Titan
    - Rock on Earth ~ Water-ice on Titan

- Abundant complex organic material on surface
  - Ideal destination for studying the kinds of chemical interactions that occurred before life developed on Earth, and to investigate how far prebiotic chemistry has progressed on Titan

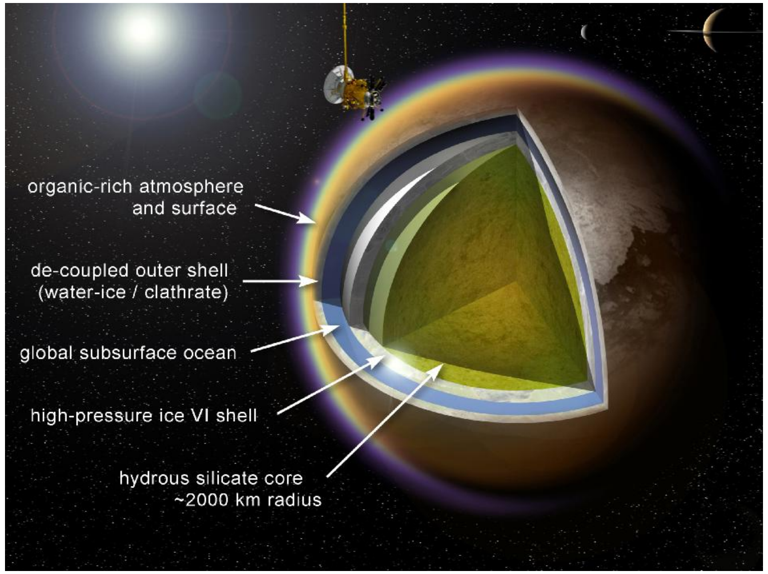


Image Credit: A. D. Fortes/UCL/STFC

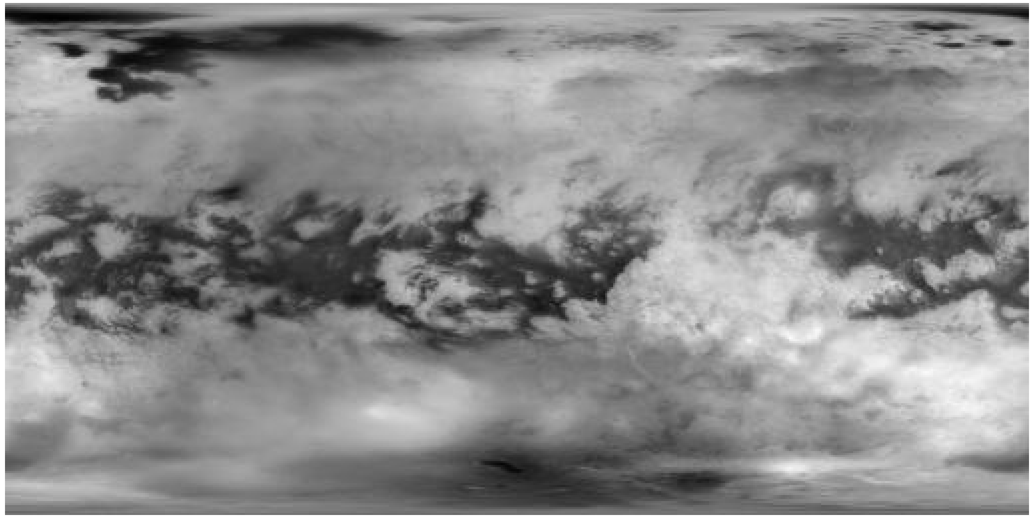
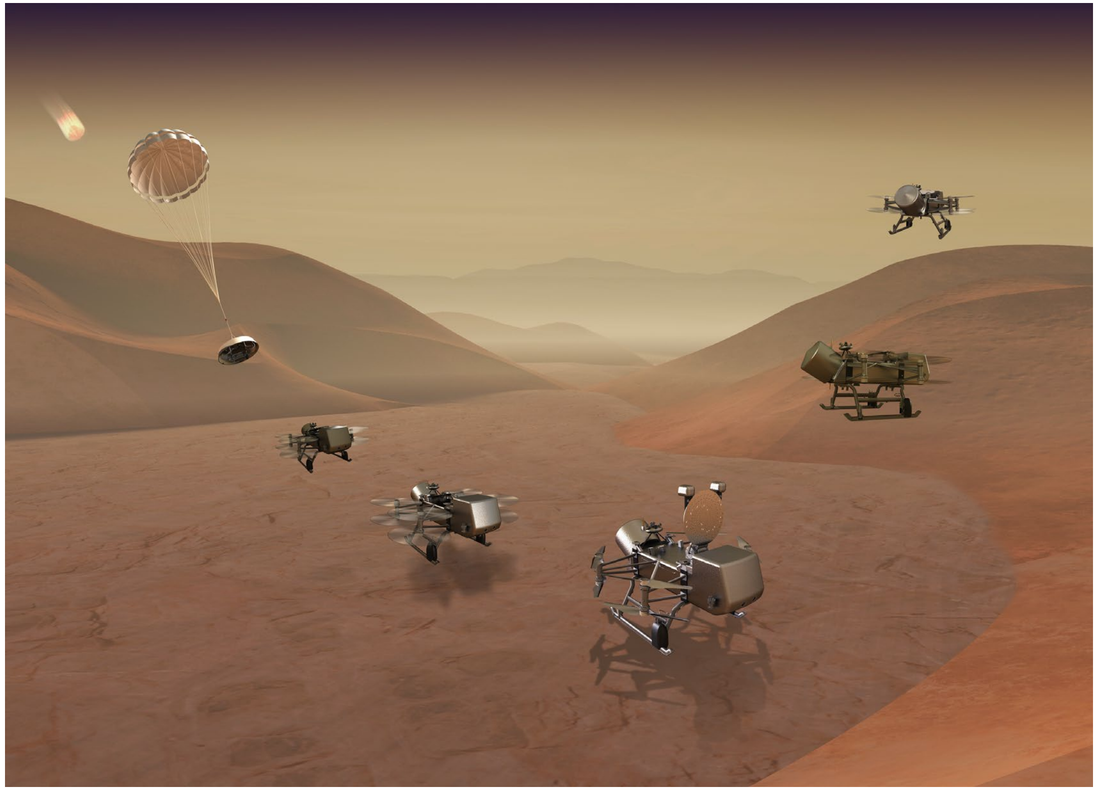


Image Credit: NASA/JPL-Caltech/Univ. Arizona

# The *Dragonfly* Mission

- Titan's atmosphere is 4 times denser than Earth's, with a gravity about 1/7th of Earth's
  - Flying is an ideal way to travel on Titan
- *Dragonfly,* the next NASA New Frontiers mission, is a mission that will explore Titan with a nuclear-powered octocopter
- A versatile aerial vehicle allows exploration of multiple sites, investigating the spatial variability of the surface with a mobile sensor suite
  - Ability to travel 10s of kilometers in a single flight, and several hundred kilometers during the planned mission
  - Farther than any planetary rovers have traveled



I. R. Witte, D. L. Bekker, M. H. Chen, T. B. Criss, S. N. Jenkins, N. L. Mehta, C. A. Sawyer, J. A. Stipes, J. R. Thomas, "No GPS? No Problem! Exploring the Dunes of Titan with Dragonfly Using Visual Odometry," AIAA Scitech Forum, January 2019.

# Instruments

- DraMS—Dragonfly Mass Spectrometer (Goddard Space Flight Center)
  - Analysis of simple and complex organics
  - Chiral discrimination of amino acids

- DraGNS—Dragonfly Gamma-Ray and Neutron Spectrometer (APL/Goddard Space Flight Center)
  - Bulk composition of the surface

- DraGMet—Dragonfly Geophysics and Meteorology Package (APL)
  - Temperaure, pressure, wind speed and direction
  - ‘Relative humidity’ of methane

- DragonCam—Dragonfly Camera Suite (Malin Space Science Systems)
  - Geologic context
  - Micro-scale images for constraining grain size
  - UV fluorescence of organics

# Initial Descent

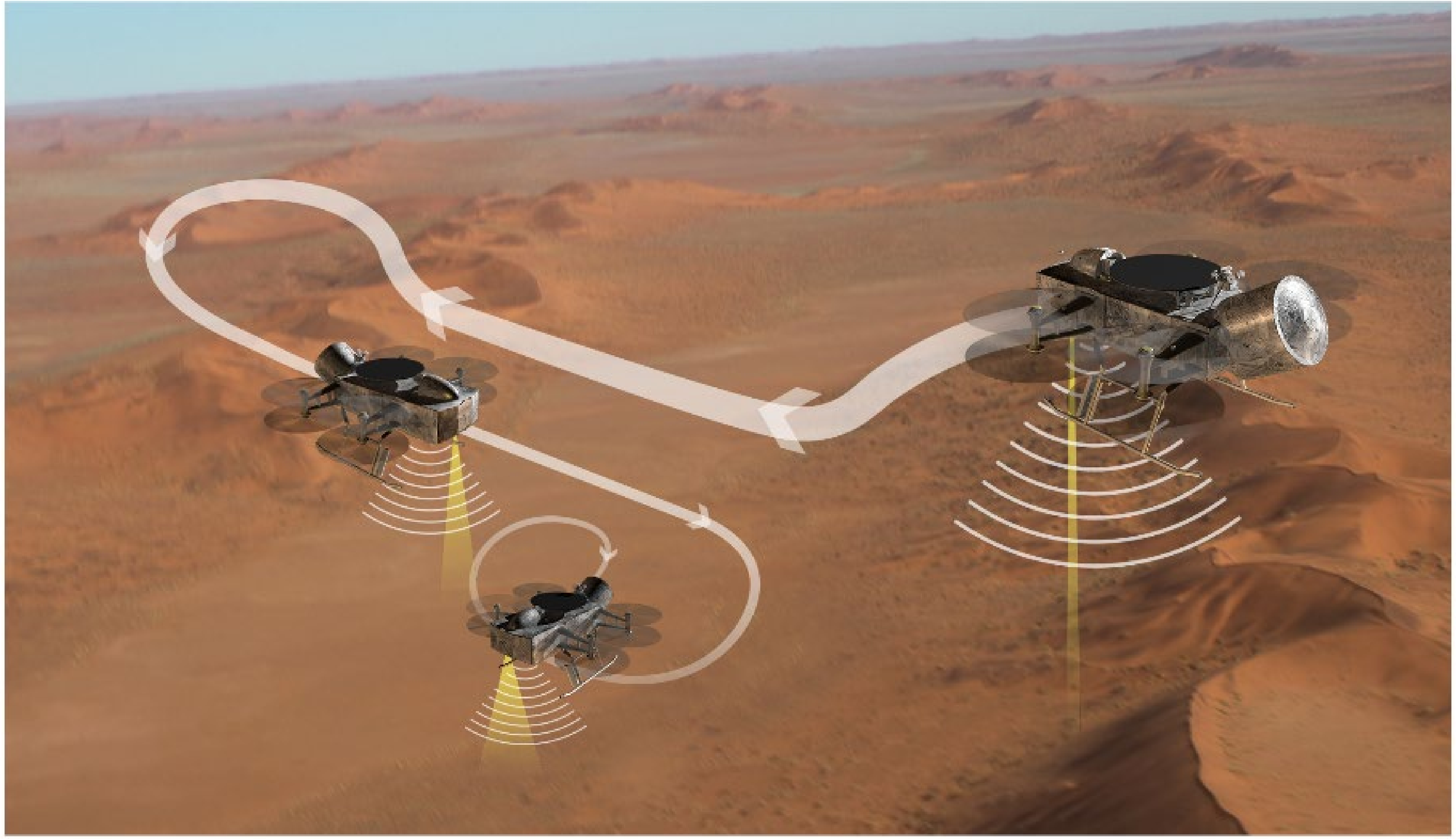


Image Credit: R. Lorenz et al., APL Tech Digest, 2018

- Flash lidar data allows Dragonfly to safely land
  - Lidar data collected during horizontal flight
  - Elevation map generated in realtime
  - Map processed to identify hazardous slopes and deviations (ie rocks, pits), using established numerical methods and conservative thresholds
  - Safe landing zones identified by calculating distance to nearest hazard
  - Potential safe landing sites identified and ranked

# Surface Mobility & Ops

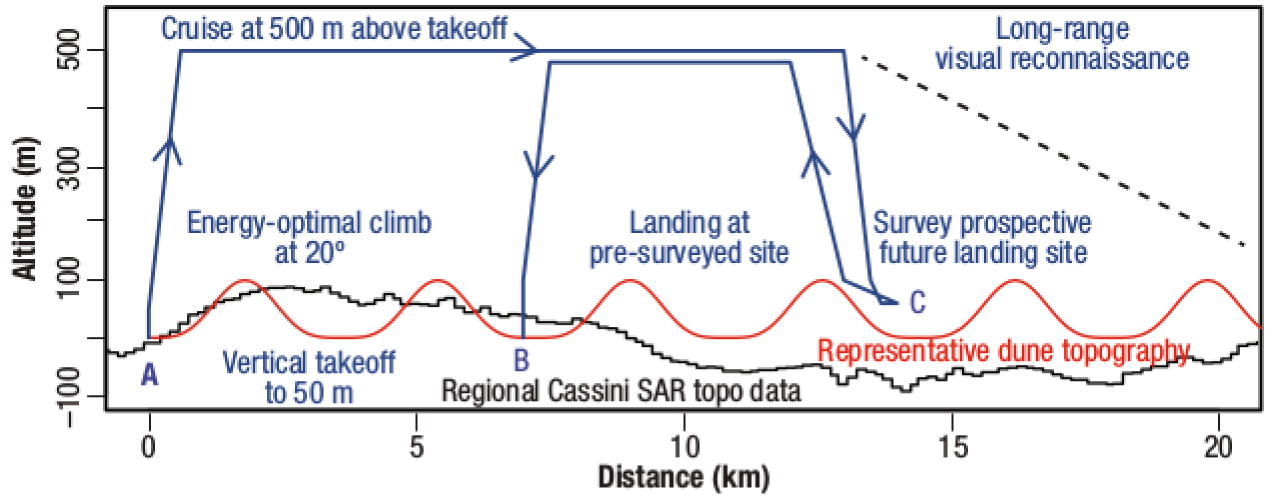



**Figure 6.** "Leapfrog" reconnaissance and survey strategy enables potential landing sites to be fully validated with sensor data and ground analysis before being committed to. Distance shown is example only—actual performance may be much better.

***Could a Deep Space computing node help here, by processing the data remotely while the rotorcraft is recharging?***

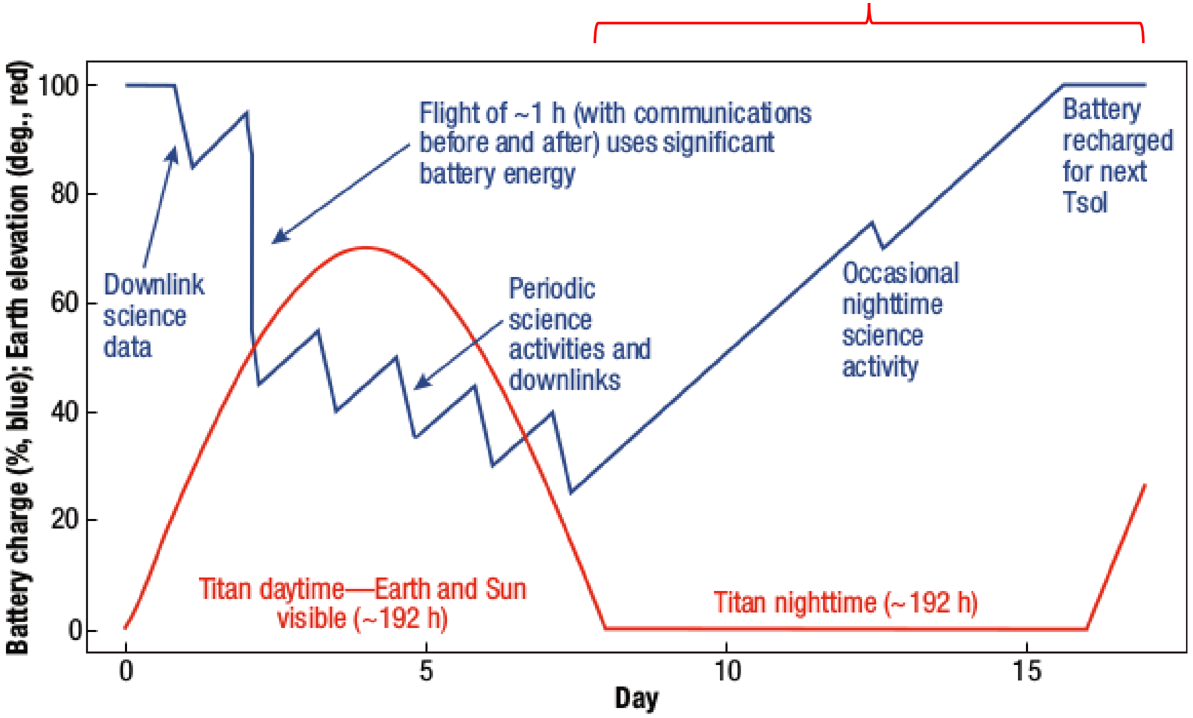


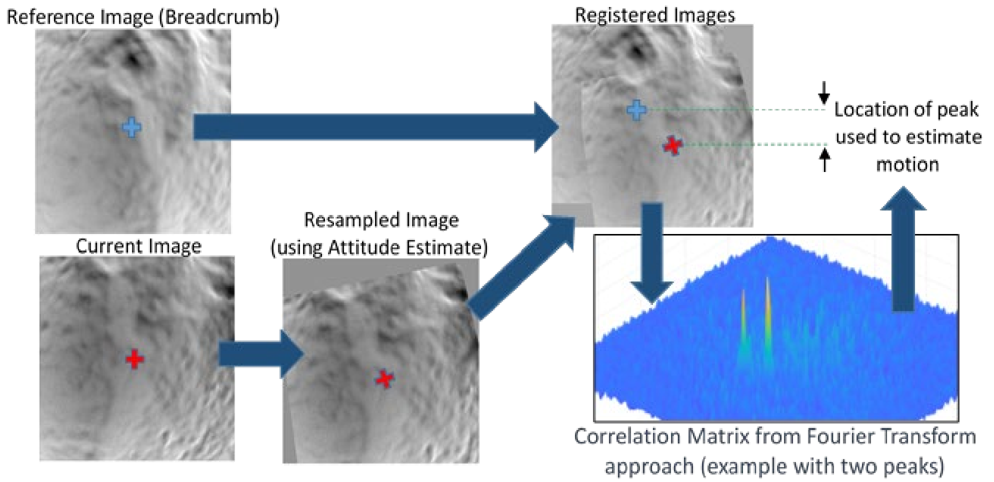

**Figure 7.** Energy management and communication concept of operations. MMRTG continuously recharges the battery, but downlink and especially flight demand significant energy. Activities can be paced to match MMRTG *in situ* capability while maintaining healthy margins on the battery state of charge.

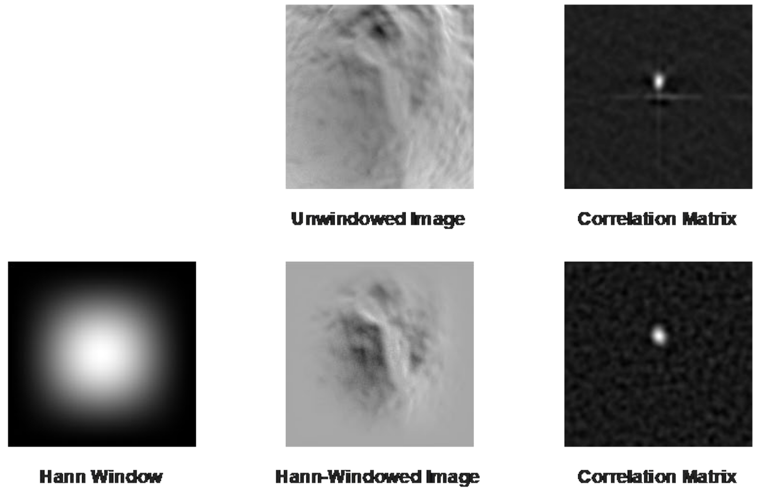
# Algorithm: Image-to-Image

- Due to the possibility of a lack of optical features on the Titan surface, APL has developed a correlation based TRN algorithm that continuously estimates the relative lateral position change of the craft

- The algorithm's inputs are two images, along with their corresponding states and parameters
  - Using the states, a homography warping matrix is calculated to warp one image from its reference frame into the perspective of the second image's reference frame
  - Now in the same frame, the two images are windowed using a user-defined windowing method

- After the images have been normalized and windowed, a phase-only DFT correlation method is applied to calculate a delta between the two images in pixel space
  - Then converted to a difference in lateral position

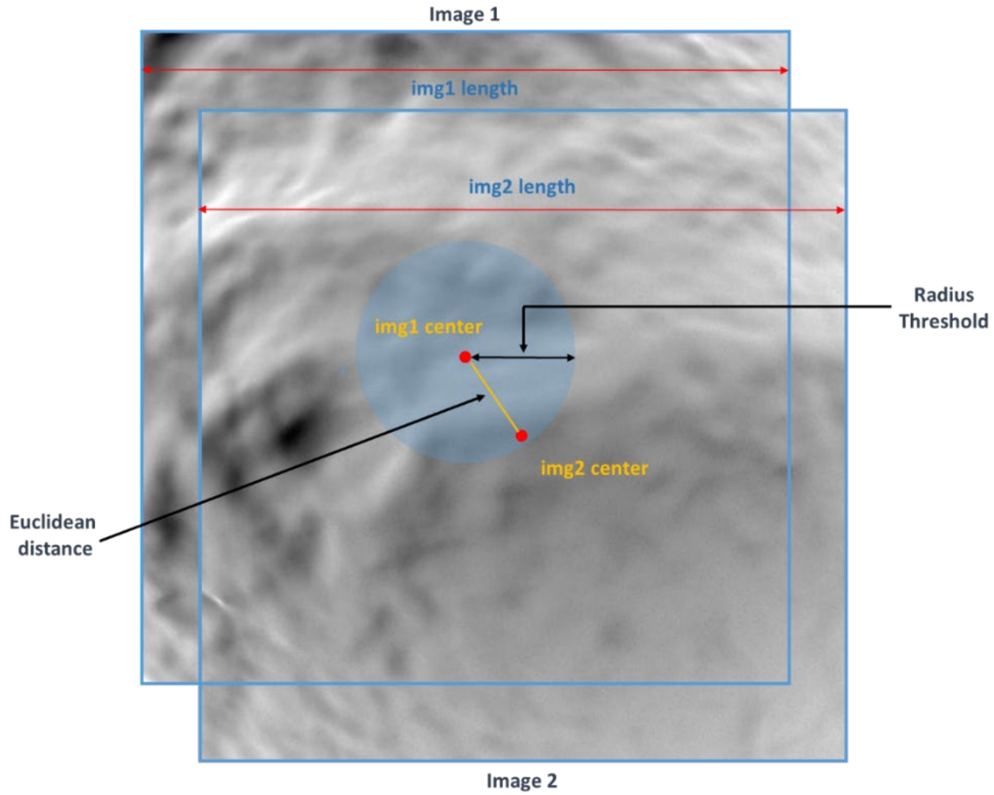


# Algorithm: Breadcrumbs

- An approach of “breadcrumbs” was developed, which enables re-alignment of drift error when reaching an area that has previously been visited
  - Even with TRN, the drift error can accumulate
  - Beneficial to recognize when the rotorcraft is revisiting an area and to localize to a previously captured image, or “breadcumb”

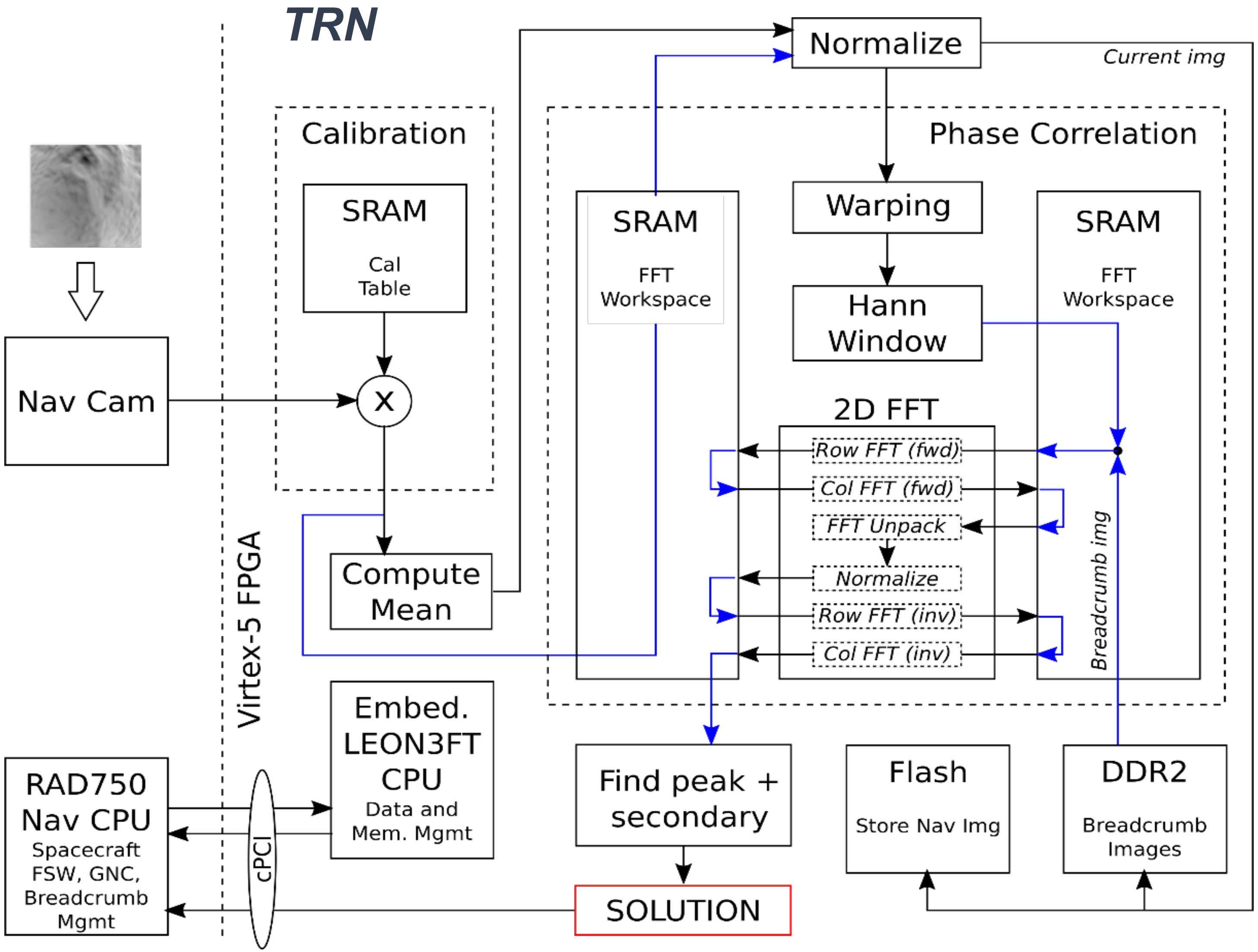
- To choose which breadcrumb to use, the Ground Radius Estimation for Timed Image Localizer (GRETIL) is used to select the oldest viable image
  - Oldest image is selected because the associated drift error is typically smaller
  - GRETIL estimates the two image “footprints” on the ground, and estimates the amount of overlap between the two footprints in order to determine if the image is viable




I. R. Witte, D. L. Bekker, M. H. Chen, T. B. Criss, S. N. Jenkins, N. L. Mehta, C. A. Sawyer, J. A. Stipes, J. R. Thomas, “No GPS? No Problem! Exploring the Dunes of Titan with Dragonfly Using Visual Odometry,” AIAA Scitech Forum, January 2019.

# Concept Flight Implementation

- In order to generate position estimates at a rate needed for *Dragonfly*, portions of TRN were designed to be executed on a field-programmable gate array (FPGA) that excels in computer vision applications
- Hazard detection processing also assisted by FPGA
- Entire vision-processing chain inside the FPGA is estimated to consume ~60% of the FPGA resources:
  - Phase Correlation Rate: ~5 Hz (est max)
  - Lidar Processing Rate: ~2 Hz (est max)




I. R. Witte, D. L. Bekker, M. H. Chen, T. B. Criss, S. N. Jenkins, N. L. Mehta, C. A. Sawyer, J. A. Stipes, J. R. Thomas, “No GPS? No Problem! Exploring the Dunes of Titan with Dragonfly Using Visual Odometry,” AIAA Scitech Forum, January 2019.

DRAGONFLY