LIQUID-FILLED CANYONS ON TITAN

POGGIALI V. (1), MASTROGIUSEPPE M. (2), HAYES A. (2), SEU R. (1), BIRCH S. (2), LORENZ R. (3), GRIMA C. (4), HOFGARTNER J. (5) (1) DIET, SAPIENZA UNIVERSITÀ DI ROMA, ROMA, ITALY; (2) DEPARTMENT OF ASTRONOMY, CORNELL UNIVERSITY, ITHACA (NY), UNITED STATES; (3) APPLIED PHYSICS LABORATORY, JOHNS HOPKINS UNIVERSITY, LAUREL (MD), UNITED STATES; (4) INSTITUTE FOR GEOPHYSICS, UNIVERSITY OF TEXAS, AUSTIN (TX), UNITED STATES; (5) JET PROPULSION LABORA-

INTRODUCTION

SATURN'S LARGEST MOON. TITAN, HAS AN ACTIVE METHANE-BASED HYDROLOGIC CYCLE THAT DRIVES THE FORMA-TION AND EVOLUTION OF MORPHOLOGIC FEATURES AND PROCESSES WITH STRIKING SIMILARITIES TO THOSE FOUND ON EARTH. TITAN HAS NETWORKS OF FLUVIAL VALLEYS AND CHANNELS THAT EXTEND FOR HUNDREDS OF KILOMETERS ACROSS THE SURFACE AT ALL LATITUDES. HEREIN. WE REPORT AN ANALYSIS OF ALTIMETRY ECHOES AC QUIRED FROM VID FLUMINA, A NETWORK OF CHANNELS THAT DRAIN INTO LIGEIA MARE. EVEN THOUGH SAR IMAGES REVEAL THE PRESENCE OF SINUOUS RADAR-DARK FEATURES INTERPRETED AS FLUVIAL VALLEYS. THEY DO NOT DIRECTLY PROVE THE PHYSICAL EXTENT AND/OR PRESENCE OF LIQUID FILLING THEM. HEREIN, WE USE CASSINI KU-BAND ($\lambda = 2.17$ CM) radar altimeter nadir observations to directly detect the presence of liquid in TITAN'S NORTH POLAR CHANNELS AND CHARACTERIZE THEIR WIDTH AND GEOMORPHOLOGIC CONTEXT. ALTIME-TER RETURNS FROM THE VID FLUMINA CHANNELS ARE HIGHLY SPECULAR AND THE MEASURED STEEP INCREASES IN BACKSCATTER WITH RESPECT TO THE SURROUNDINGS REQUIRE SURFACES ROUGHNESS ON THE MILLIMETER SCALE OVER THE ~250 M DIAMETER OF THE FRESNEL ZONE. FURTHERMORE. IN ORDER TO SHOW THE LIQUID NATURE OF THE VID FLUMINA CHANNELS WE COMPARE THE BACKSCATTERING VALUES (σ0) OBTAINED BY THE CASSINI RADAR AL TIMETER FOR THE T91 FLYBY WITH THOSE PERTAINING TO ALL SOLID SURFACES OF TITAN. AS A RESULT. VID FLUMINA CHANNELS ARE CHARACTERIZED BY σ0 VALUES (~30 DB) THAT NO SOLID SURFACE OF TITAN, OBSERVED TO DATE BY THE ALTIMETER. HAS BEEN CAPABLE TO PRODUCE.

TORY/CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CA 91109, UNITED STATES.

METHOD AND RESULTS

WE SELECTED EIGHT BURSTS ALONG THE T91 ALTIMETRIC TRACK, TWO NORTH OF LIGEIA MARE AND SIX TO THE SOUTH, THAT ARE MARKED FROM "A" TO "H". MEAN SURFACE HEIGHT ESTIMATIONS USEFUL FOR OUTLINING THE TO-POGRAPHIC PROFILE ARE OBTAINED BY TRACKING THE CENTROID OF THE OBSERVED POWER DISTRIBUTION, AS DESCRIBED BY THE FIRST MOMENT OF THE ALTIMETRY ECHO WITH RESPECT TO TIME. THE RESULTING ELEVATION PROFILE OF THE REGIONS COMPRISING THESE SPECULAR REFLECTIONS SHOWS THE PRESENCE OF SHALLOW AND TIGHT VALLEYS THAT ARE HUNDREDS METERS DEEP RESPECT TO THE SURROUNDING TERRAIN AND LESS THAN A KM IN LATERAL EXTENT.

THE ASSOCIATED SPECULAR REFLECTIONS, AS WE HAVE SEEN, SUGGEST THAT THE BOTTOM OF THESE CANYON-LIKE FEATURES ARE VERY SMOOTH WITH RESPECT TO THE CASSINI RADAR INCIDENT WAVELENGTH, A TYPICAL CHARACTERISTIC OF ALTIMETER RETURNS FROM TITAN'S LIQUID BODIES.

We find that, to within a ~ 0.7 m precision (2σ), all the echoes received from Vid Flumina's main trunk and tributary branches (inparticular "e", "f" and "G") are found to be at the same level as the sea surface, even though they are located in a wide range of horizontal distances from Ligeia mare

THE MEASUREMENT OF THE TIME INTERVAL BETWEEN THE FIRST TWO ECHOES IS A DIRECT MEASURE OF THE DEPTH OF THE CANYONS. IN PARTICULAR, WE MEASURE THE TIME DELAY FROM THE LEADING EDGE OF THE FIRST ECHO (-6 DB FROM THE PEAK) TO THE PEAK OF THE SECOND ECHO ASSOCIATED TO THE LIQUID. IN THIS WAY, WE OBTAIN AN ESTIMATE OF THE MEAN LEVEL OF THE AREA ILLUMINATED BY THE ALTIMETRIC FOOTPRINT. THE PRECISION OF THE DEPTH MEASUREMENTS OF THESE CANYONS IS MAINLY DEPENDENT ON THE SIGNAL TO NOISE RATIO (\$NR) OF THE SIGNAL REFLECTED FROM THE SURFACE AT THE CLIFF'S EDGE AND ON THE LARGE-SCALE VERTICAL ROUGHNESS OF THIS SURFACE ITSELF. THUS, IT CAN BE INFERRED TO BE IN THE SAME ORDER OF THE RADAR RANGE RESOLUTION (35 M).

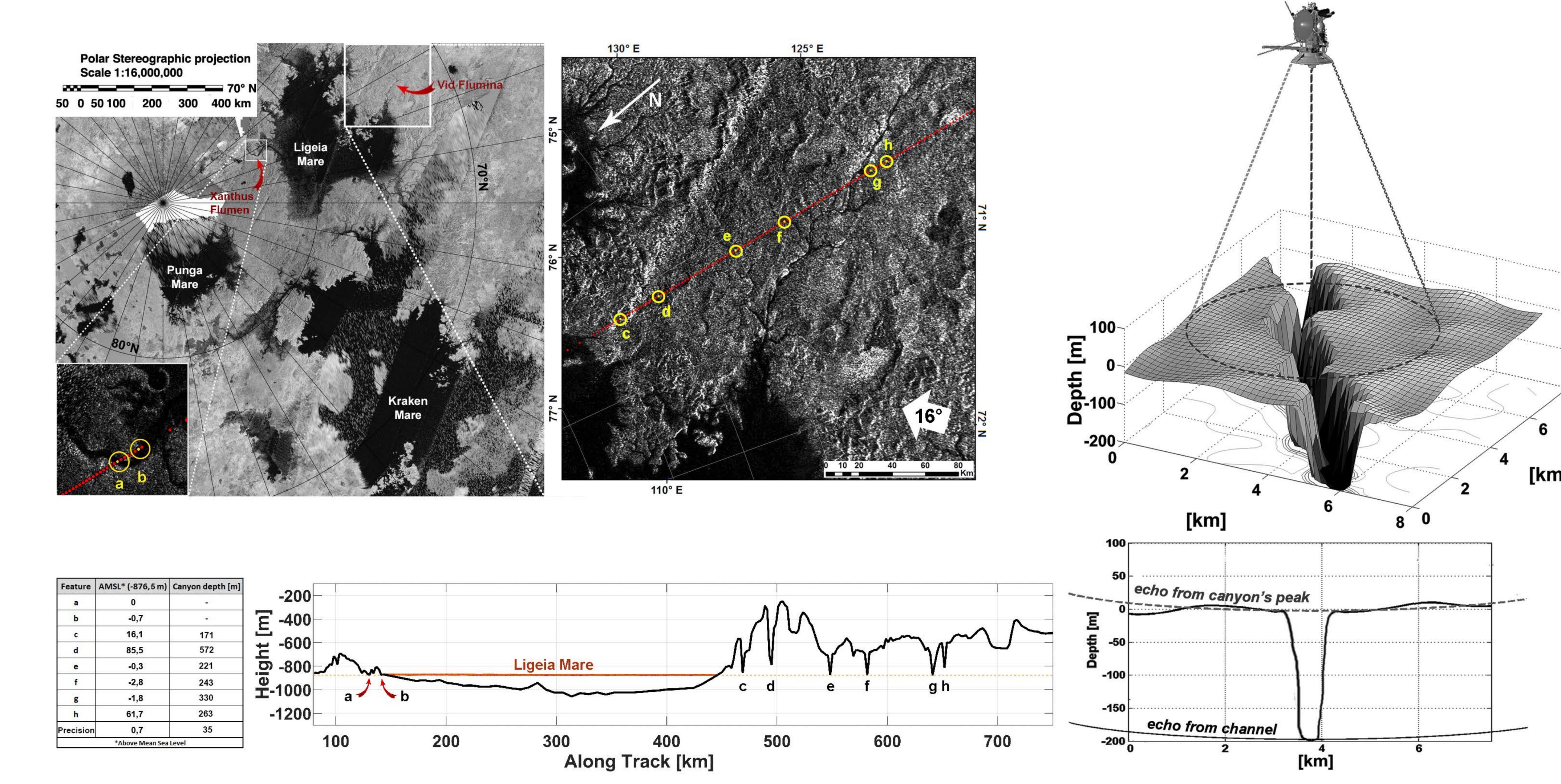
Using T28 flyby SAR images, we have been able to measure the width of the two sections of Vid Flumina comprising features "f" (a first order tributary) and "g" (main trunk).

GIVEN THE MEASURED CANYON'S DEPTHS RESPECTIVELY OF ABOUT 240 AND 330 M FOR FEATURES "F" AND "G" WE CAN INFER MEAN SLOPES >40 DEG FOR THEIR WALLS.

FOR OBSERVATIONS "C", "D" AND "H" THE LEVELS OF LIQUID ARE SOMEHOW HIGHER IN ELEVATION WITH RESPECT

TO THE SEA. IN THIS CASE SAR IMAGES SHOW THAT THE PRESENCE OF A SINGLE
LIQUID BODY WITH DIMENSIONS OF SEVERAL HUNDREDS OF METERS IS NOT LIKELY, BUT THE PRESENCE OF

HIGHER ORDER TRIBUTARIES OCCURRING SEVERAL TENS OF METERS ABOVE THE LEVEL OF LIGEIA MARE COULD BE CONSISTENT WITH DRAINAGE FEEDING INTO THE VID MAIN CHANNEL SYSTEM.



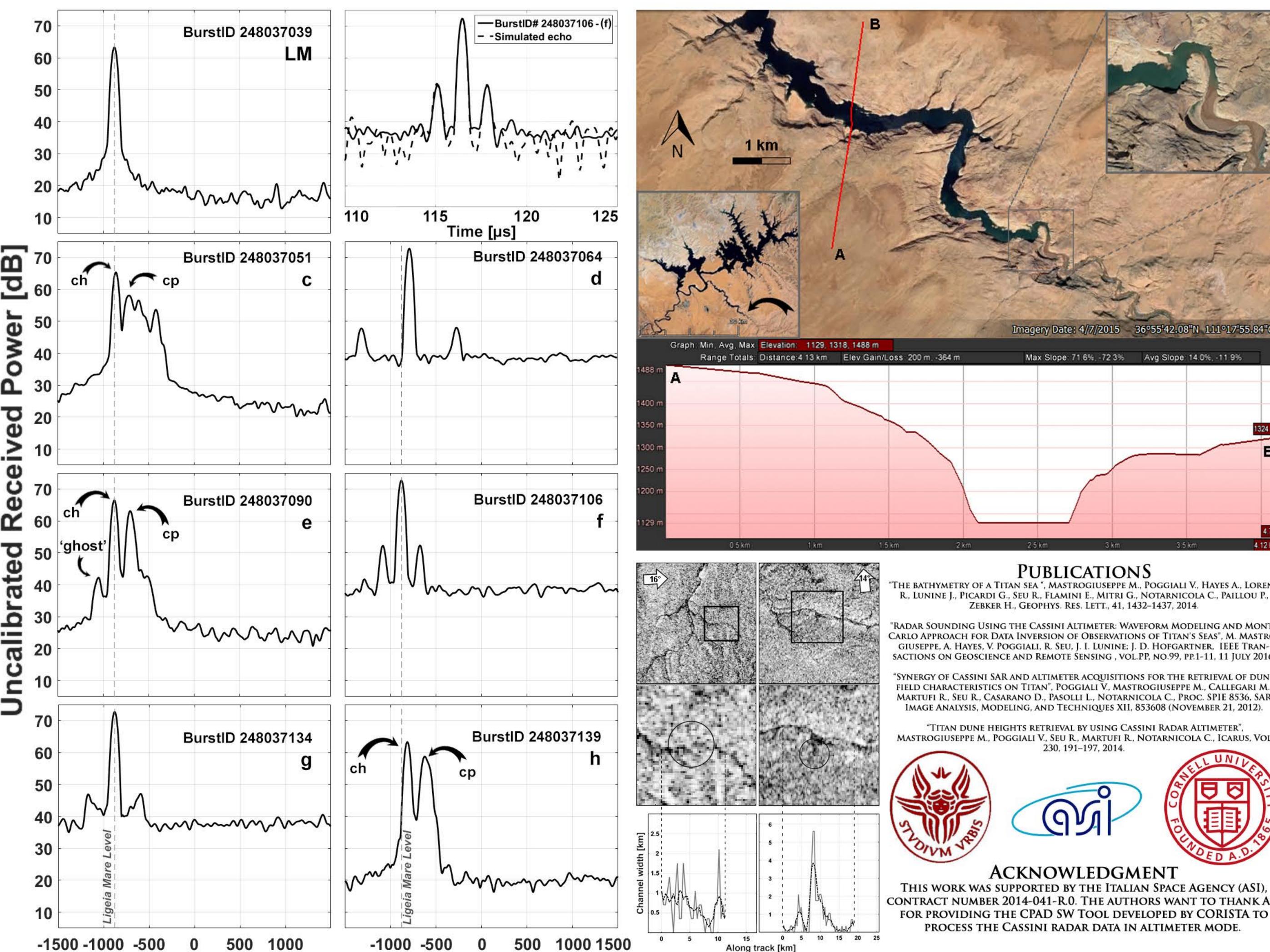
ABSTRACT

In May 2013 the Cassini RADAR altimeter observed channels in Vid Flumina, a drainage network connected to Titan's second largest hydrocarbon sea, Ligeia Mare. Analysis of these altimeter echoes shows that the channels are located in deep (up to ~570 m), steep-sided, canyons and have strong specular surface reflections that indicate they are currently liquid-filled. Elevations of the liquid in these channels are at the same level as Ligeia Mare to within a vertical precision of about 0.7 m, consistent with the interpretation of drowned river valleys. Specular reflections are also observed in lower order tributaries elevated above the level of Ligeia Mare, consistent with drainage feeding into the main channel system.

DISCUSSION

WHILE TOPOGRAPHIC PROFILES OF THE OBSERVED FLUVIAL VALLEYS ARE COMPARABLE TO GLACIALLY ERODED FJORDS ON EARTH, WE RULE OUT ANY GLACIAL FORMATION MECHANISMS. THIS IS BECAUSE THE PRESENCE OF ANY LARGE-SCALE ICES, SUCH ARE ALPINE GLACIERS. ON THE SURFACE ARE THERMODYNAMICAL LY IMPROBABLE ON TITAN. THE PRESENCE OF DEEPLY ENTRENCHED CHANNELS INDICATES PERIODS OF PROLONGED INCISION INTO AN EROSIONALLY-WEAK MATERIAL. THE DEGREE OF EROSIONAL INCISION SUGGESTS A PROTRACTED PERIOD OF EROSION. ALTHOUGH EROSION RATES AND HENCE DURATION REMAIN TO BE CONSTRAINED. IN ORDER TO DRIVE THE INCISION VERTICALLY INTO THE TERRAIN, LIQUID ELEVATIONS OF THE SEAS MUST HAVE BEEN LOWER IN THE GEOLOGIC PAST TO DRIVE THE POTENTIAL FOR FLOW AND TRANSPORT OF SEDIMENT. ALTERNATIVELY, IF SEA LEVEL REMAINED CONSTANT, TECTONIC UPLIFT OF THE SURROUNDING TERRAINS WOULD CAUSE THE RIVER TO INCISE VERTICALLY. FORMING A MORPHOLOGICALLY SIMILAR TERRAIN. IF FORMED PRIMARILY BY SEA LEVEL VARIATIONS. THEN THERE MUST HAVE STILL BEEN SUFFICIENT PRECIPITATION AND CHANNELIZED FLOW THROUGHOUT THE PERIODS OF LOWER BA-SELEVELS IN ORDER TO DRIVE LANDSCAPE EVOLUTION AND CANYON FORMATION. SUBSEQUENT BASELEVEL RISE WITHIN THE NORTH POLAR REGIONS WOULD THEN RESULT IN A BACKWATER EFFECT OF THE MAIN BRANCHES OF THE VID FLUMINA DRAINAGE NETWORK, AND RESULT IN LIQUID ELEVATIONS EQUIVALENT TO THOSE OF LIGEIA MARE. THE SURROUNDING TRIBUTARIES WOULD NOT BE AFFECTED BY THE BACKWATER. RESULTING IN THEM HAVING THE HIGHER LIQUID ELEVATIONS THAT WE OBSERVE. IF THEY ARE HYDRAULICALLY CONNECTED, THEN THIS WOULD BE DIRECT EVIDENCE OF ACTIVE FLOW IN TITAN RIVERS. WHILE A CONTRIBUTION FROM TECTONIC UPLIFT CAN NOT BE NEGLECTED ON TITAN, WE FAVOR A MODEL WHERE THE VARIATION IN THE SURFACE ELEVATION OF LIQUIDS HAS DRIVEN THE FORMATION OF THE CANYONS. THIS IS SUPPORTED BY PREVIOUS OBSERVATIONS OF DROWNED RIVER VALLEYS AT CHANNEL TER-MINI IN THE NORTH. LIKELY, HOWEVER, BOTH TECTONICS AND SEA LEVEL VARIATIONS CONTRIBUTE TO THE FORMATION OF THE TOPOGRAPHIC FEATURES THAT WE OBSERVE. THOUGH TO WHAT DEGREE REMAINS UNCONSTRAINED. THE CASE OF VARIABLE SEA ELEVATIONS DRIVING CANYON FORMATION. FOLLOWED BY A RESURGENT. OR RISING. SEA LEVEL HAS NUMEROUS COUNTERPARTS ON EARTH. EXAMPLES INCLUDE LAKE POWELL, A RESERVOIR ON THE COLORADO RIVER THAT WAS CREATED BY THE GLEN CANYON DAM (SEE FIGURE); THE GEORGES RIVER IN NEW SOUTH WALES, AUSTRALIA; AND THE NILE RIVER GORGE, WHICH FORMED AS THE MEDITERRANEAN SEA DRIED UP DURING THE LATE MIOCENE. RISING LIQUID LEVELS IN THE GEOLOGICALLY RECENT PAST LED TO THE FLOO-DING OF THESE VALLEYS. WITH MORPHOLOGIES SIMILAR TO THOSE OBSERVED AT VID FLUMINA.

Our study reports the first direct detection and characterization of liquid-filled canyons on Titan. Understanding the processes that led to the formation of such hydrological features will be crucial in understanding the evolution and the present state of Titan's Geomorphology. Regardless, any model of polar landscape evolution on Titan needs to explain the generation of such greatly incised, hundred-meter deep canyons that drain into the Mare.



Height [m]