Jet Propulsion Laboratory
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Low SWaP, High performance, 94GHz RF-photonic Radar for Cloud and Precipitation Measurements

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Technology: A resonant photonic receiver to efficiently upconvert a weak microwave signal to the optical domain and directly downconvert to IF for digitization. This process is far less demanding in terms of the instrument SWaP. This RF-photonic receiver facilitates an amplification of the signal power with ultra low noise temperature. Additionally a very high quality photonic 93GHz LO further reduces SWaP and improves performance. This technology will enable a new generation of ultra-compact radars suitable for missions with limited resources.

Advantages: Most modern radar electronics consist of RF components such as low noise amplifiers (LNA), mixers, filters etc., usually in a heterodyne configuration to amplify, filter and down-convert the received RF signal. The sensitivity of a radar is determined primarily by its effective system temperature and LO phase noise. As radars scale in frequency to W- band (95GHz) and beyond, typical noise temperature of 1200K or higher and high oscillator phase noise result in poor overall sensitivity and thus low quality science. High Q Whispering Gallery Mode (WGM) based RF-photonic architectures offer an attractive alternative to typical RF radar front ends and LOs with realistically achievable effective system temperature, less than 300K possibly even better and phase noise as low as -110dBc/Hz at 10kHz far outperforming standard RF-electronics approaches.

Applicability to NASA mission concepts:

The small form factor W-band radar could address **"NEW FRONTIERS TITAN ORBITER"** addressing radar altimeter and atmospheric measurement needs, the **Titan Orbiter's** need for cloud distribution measurements. It can be part of the atmospheric structure instrument as a rideshare on a "**Small Mission to the Outer Solar System**". It can address **Small Next-Generation Atmospheric Probe (SNAP) For Ice Giant Missions** needs for measurements of vertical distribution of cloud-forming molecules, and **Uranus Orbiter and Probe (UOP)** addressing orbiting measurements of Uranus' atmosphere and **Enceladus Orbilander** addressing characterization of plume structure via W-band measurements and a W-band altimeter.

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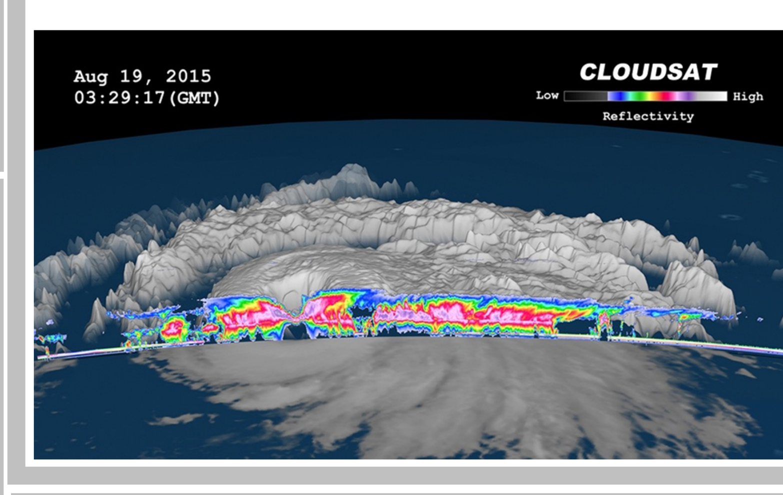
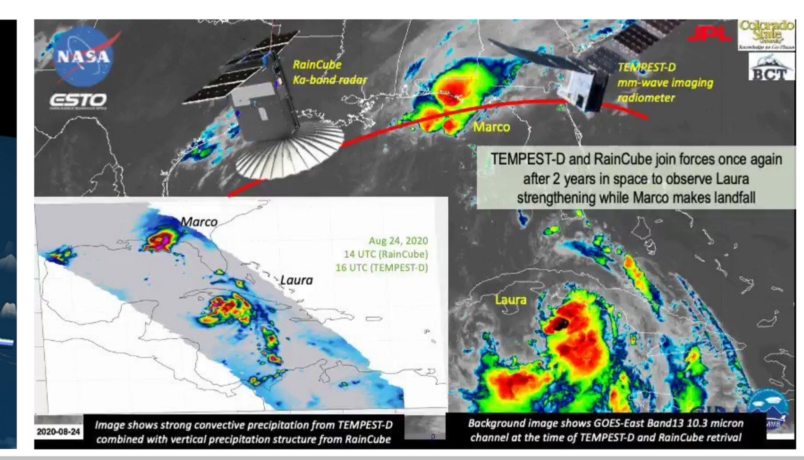
Cloud And Precipitation Radars

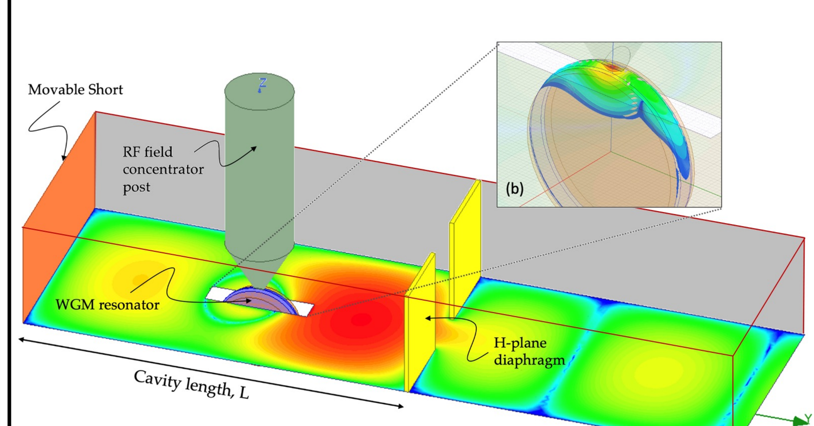
- TRMM, GPM, CloudSat have proven utility of spaceborne radars for measuring clouds and precipitation on Earth
  - TRMM/GPM/CloudSat (Volume > 10m^3, Weight > 100Kg, Power > 500W)
  - RainCube (6U, 5.5Kg, 22W) demonstrated feasibility of compact, affordable radars
- It is a significant engineering challenge to have highly sensitive radars with low Size Weight Power
- **We are developing an RF-photonics receiver that reduces SWaP while improving performance**



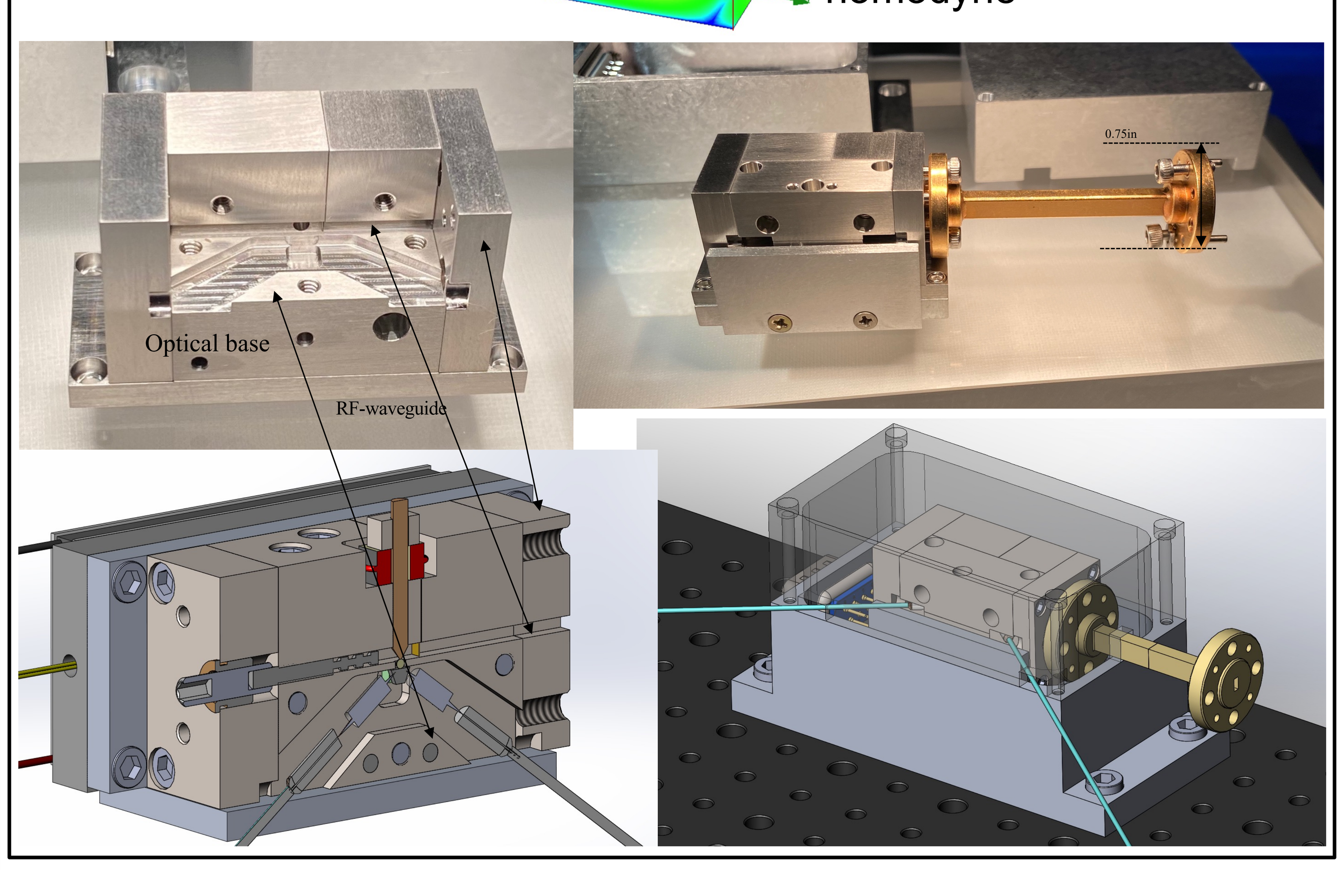


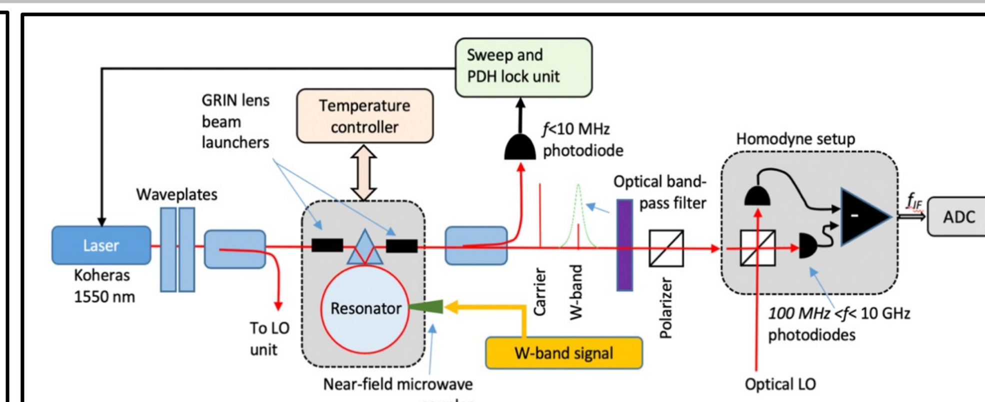
Sensitivity	Science	Missions
+15dBZ	Moderate to light rain	TRMM, GPM, RainCube
0dBZ	Most light rain, snowfall	
-15dBZ	99% of all precipitation	
-25dBZ	Most clouds associated with precipitation	ACCP, CloudCube (IIP 19)
-30dBZ	Large fraction of non-precipitating clouds	CloudSat
-35dBZ	Majority of clouds impacting radiation budget	EarthCare

RF-Photonics Receiver and LO Subsystems

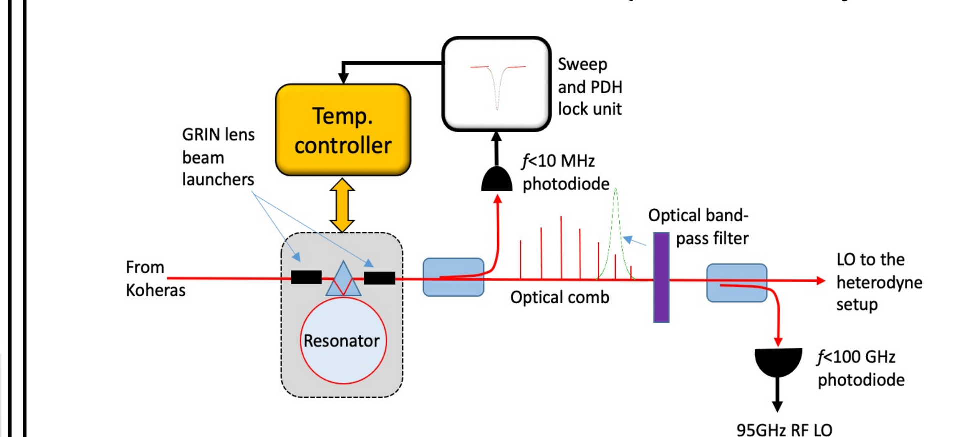


The front-end focuses RF-energy from the antenna to the WGM resonator via an RF cavity and a concentrator. This modulates the pump laser that is detected via a homodyne





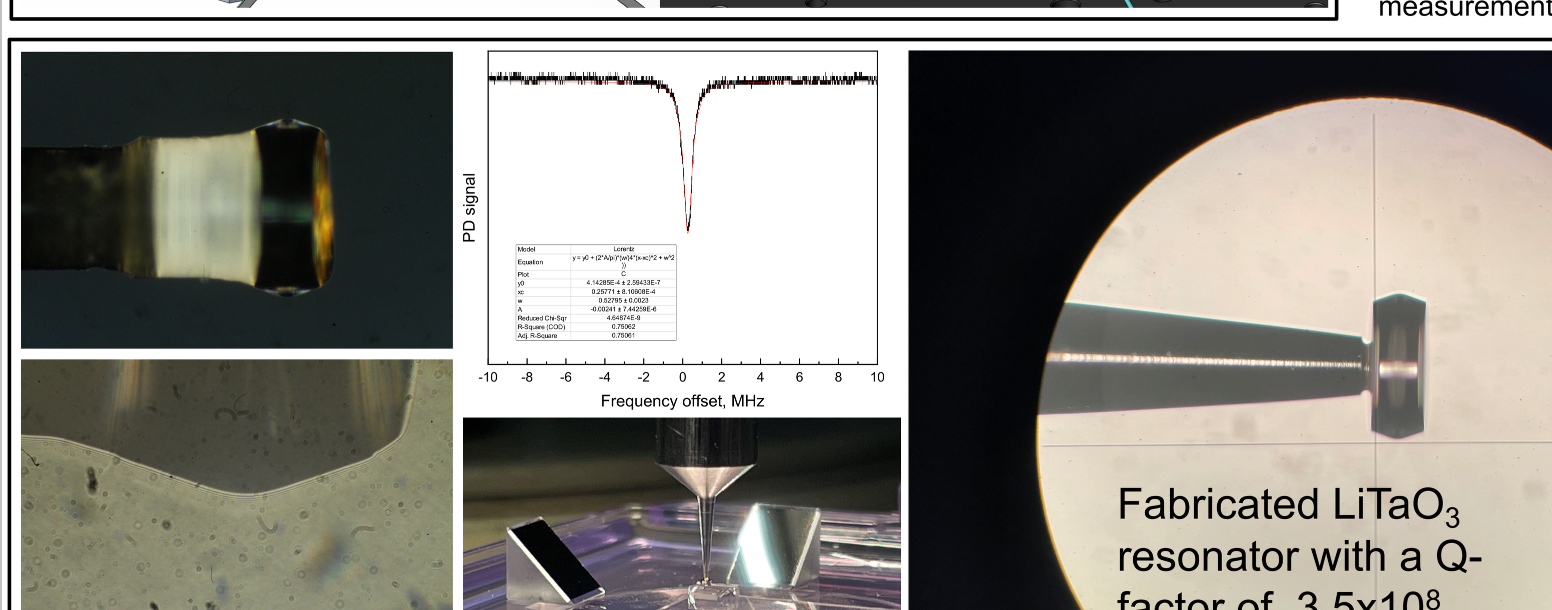
The RF-photonics receiver front-end with High-Q $LiTaO_3$ WGM resonator uses the electro-optic effect to upconvert 94GHz signal to the optical domain which is then downconverted to 1GHz IF via an optical homodyne



The LO-subsystem uses an MgF_2 WGM resonator to generate a Kerr-comb that is used to produce an ultra high quality 93GHz tone

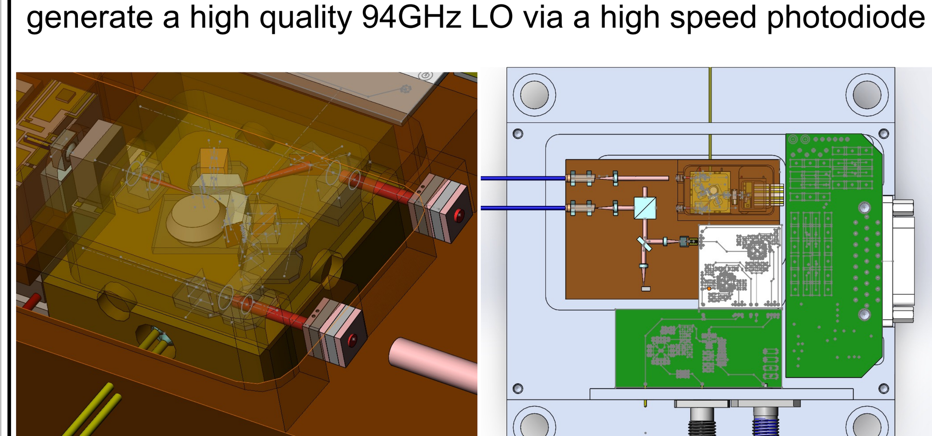
Receiver Parameters based on models and measurements

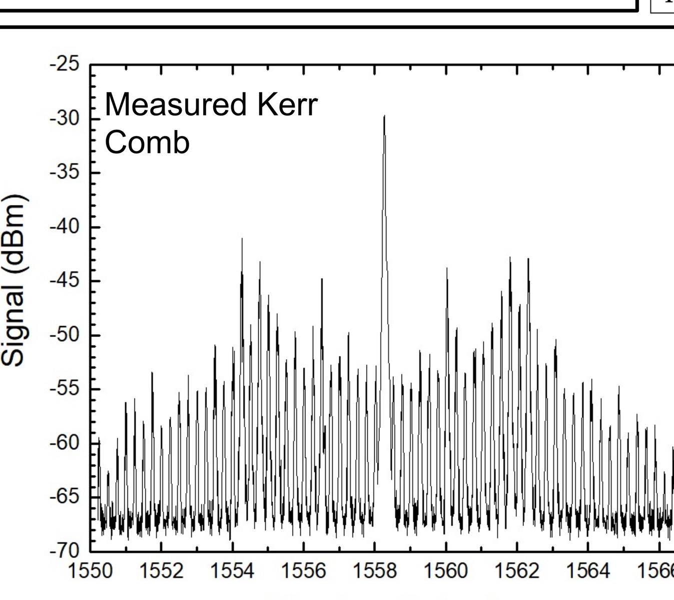
Parameter	Symbol	Value	Units
Optical wavelength	λ	1558.6	nm
Resonator radius	R	490	μm
Rim radius	r	104	μm
Ordinary refractive index	n_o	2.1189	
Extraordinary refractive index	n_e	2.1231	
Electro-optic coefficient	r_{51}	20	pm/V
TM coupling rate	γ_{TM}	2×10^7	rad/s
TE coupling rate	γ_{TE}	4×10^8	rad/s
Pump power	P_0	10	mW
LO power	P_{LO}	2	mW
RF impedance	ρ	50	Ω
Photodiode responsivity	$\mathcal{R}$	0.9	A/W
Differential mode number	Δm	7	
Predicted Performance	**Symbol**	**Value**	**Units**
Peak field value	E_0	1800	kV/m
RF coefficient	α_W	3.1×10^{-13}	W(m/V)^2
Coupling rate	g	3.91×10^9	1/s
Normalized coupling rate	g_0	2200	m/(V s)
Photonic gain	G	6.3	
Shot noise		$0.19 \times k_B T_{rec}$	W/Hz
Receiver sensitivity		$0.35 \times k_B T_{rec}$	W/Hz

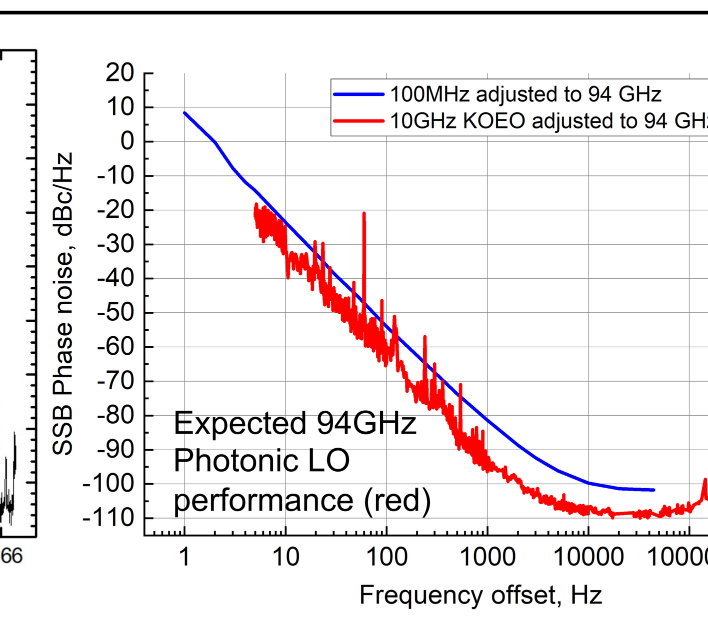


Fabricated $LiTaO_3$ resonator with a Q-factor of 3.5×10^8

The integrated oscillator subsystem generates a photonic Kerr-comb using the same pump laser as the receiver. Part of this comb is used to demodulate the W-band signal and other to generate a high quality 94GHz LO via a high speed photodiode







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