Detection of extremely weak signals at room temperature for radioastronomy and Earth observation applications

MILLIMETER AND SUBMILLIMETER TEAM

Luis Enrique García Muñoz

Full Professor
Universidad Carlos III de Madrid

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MILLIMETER AND SUBMILLIMETER TEAM

Consideraciones previas

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* Exactamente: 299.792,458 km/s.

Consideraciones previas

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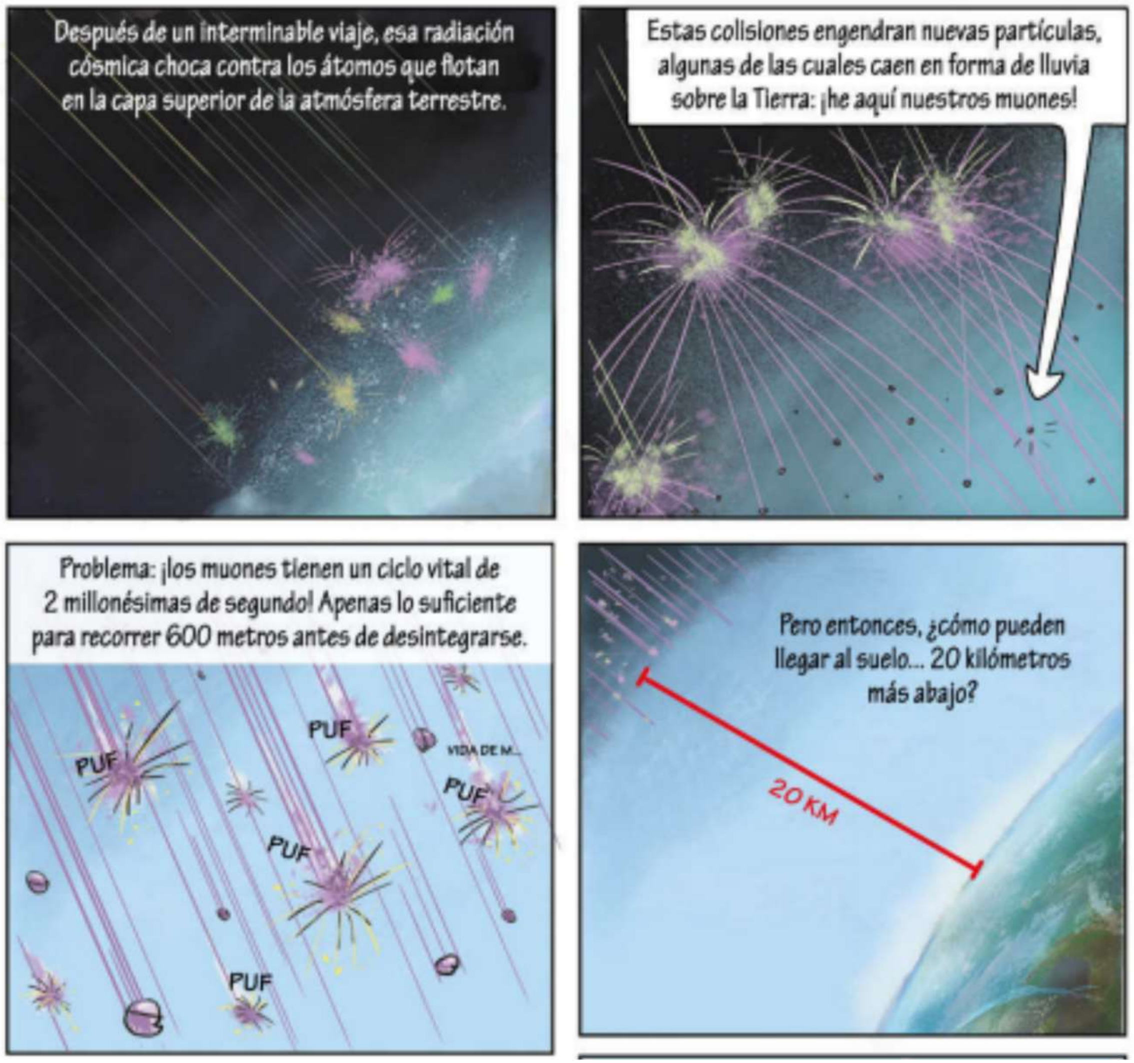

Consideraciones previas

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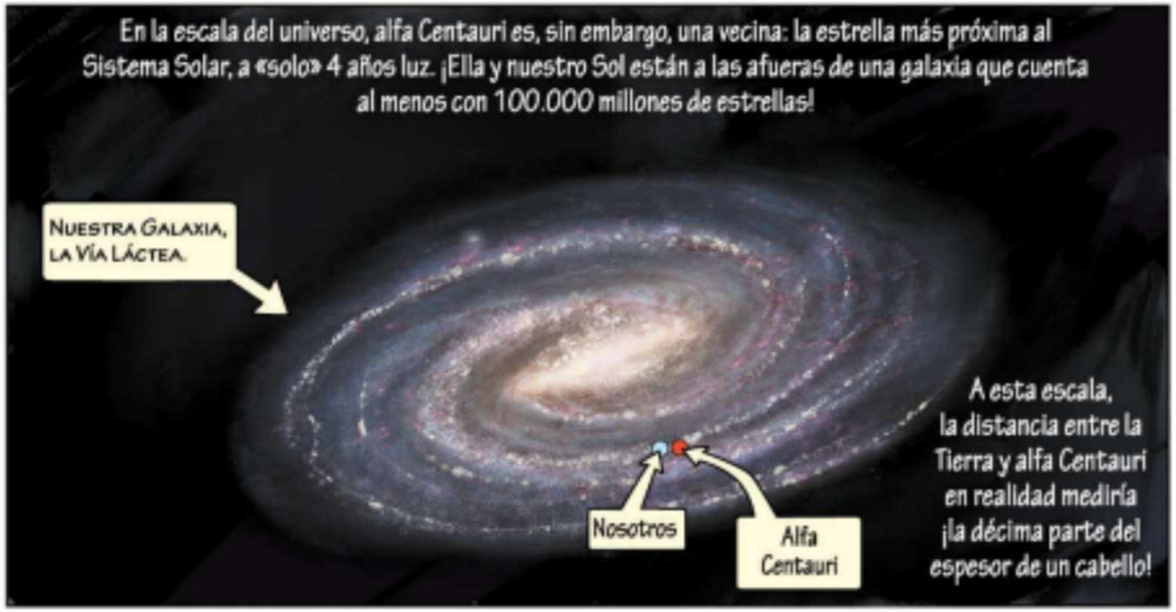

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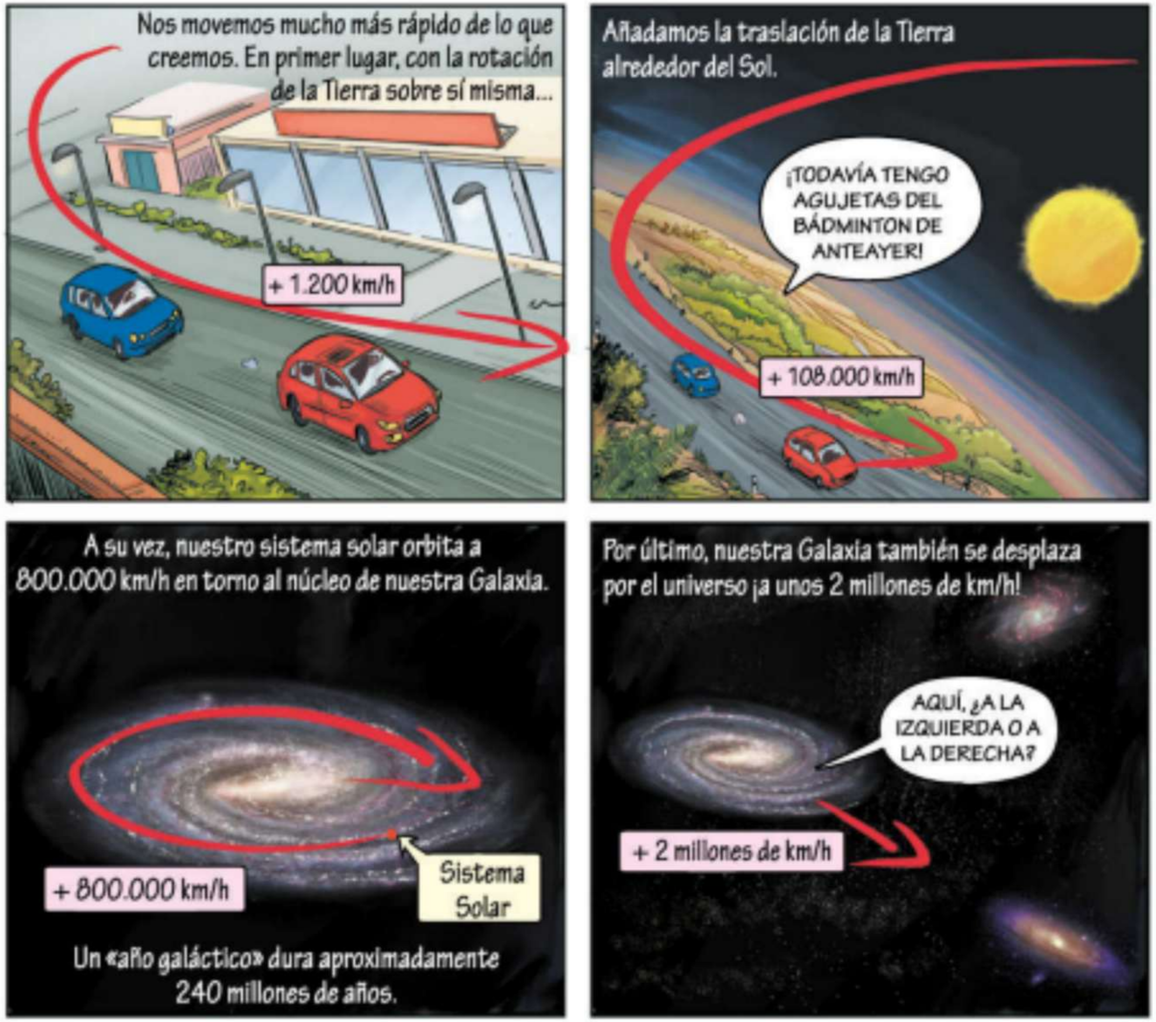

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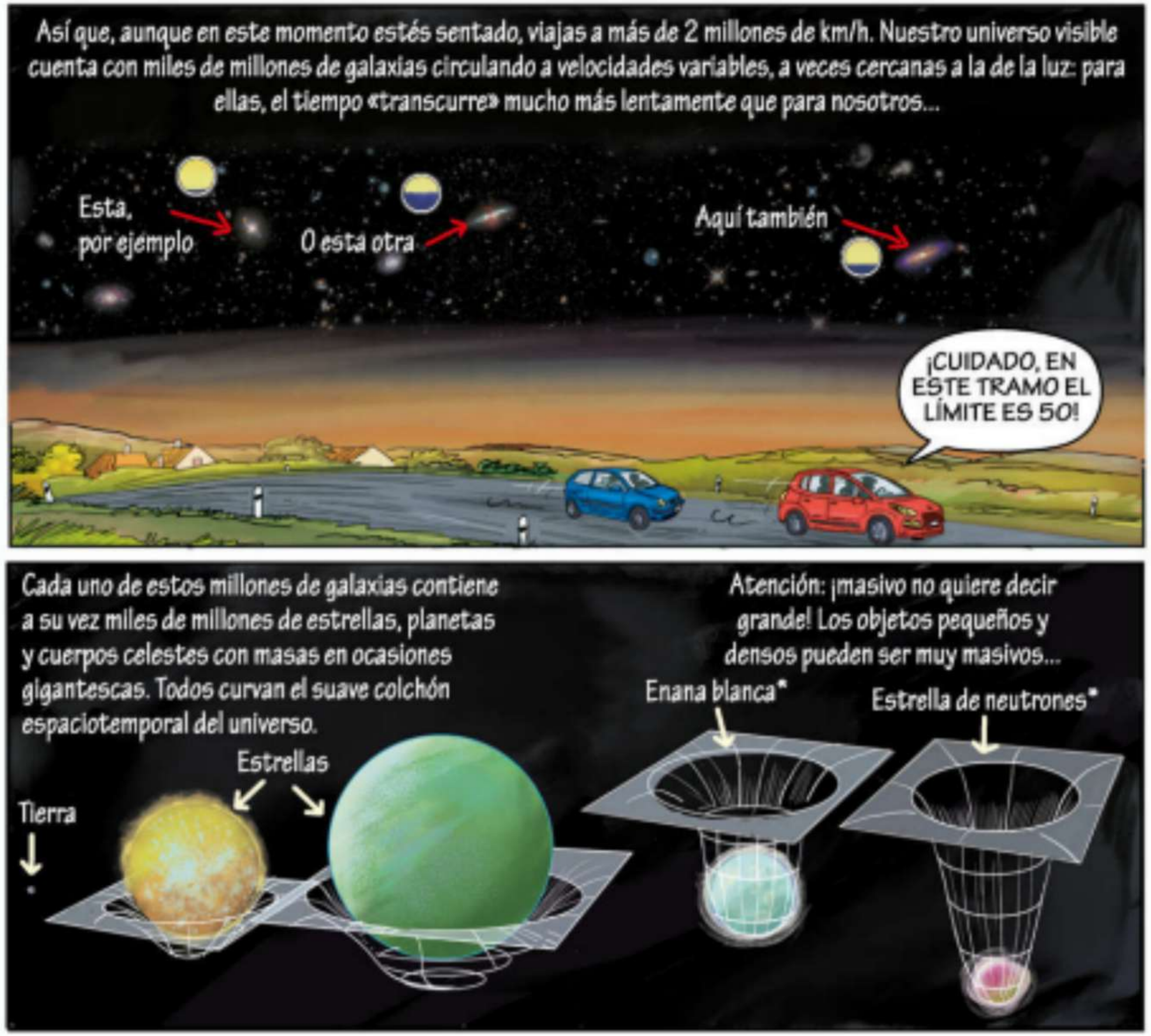

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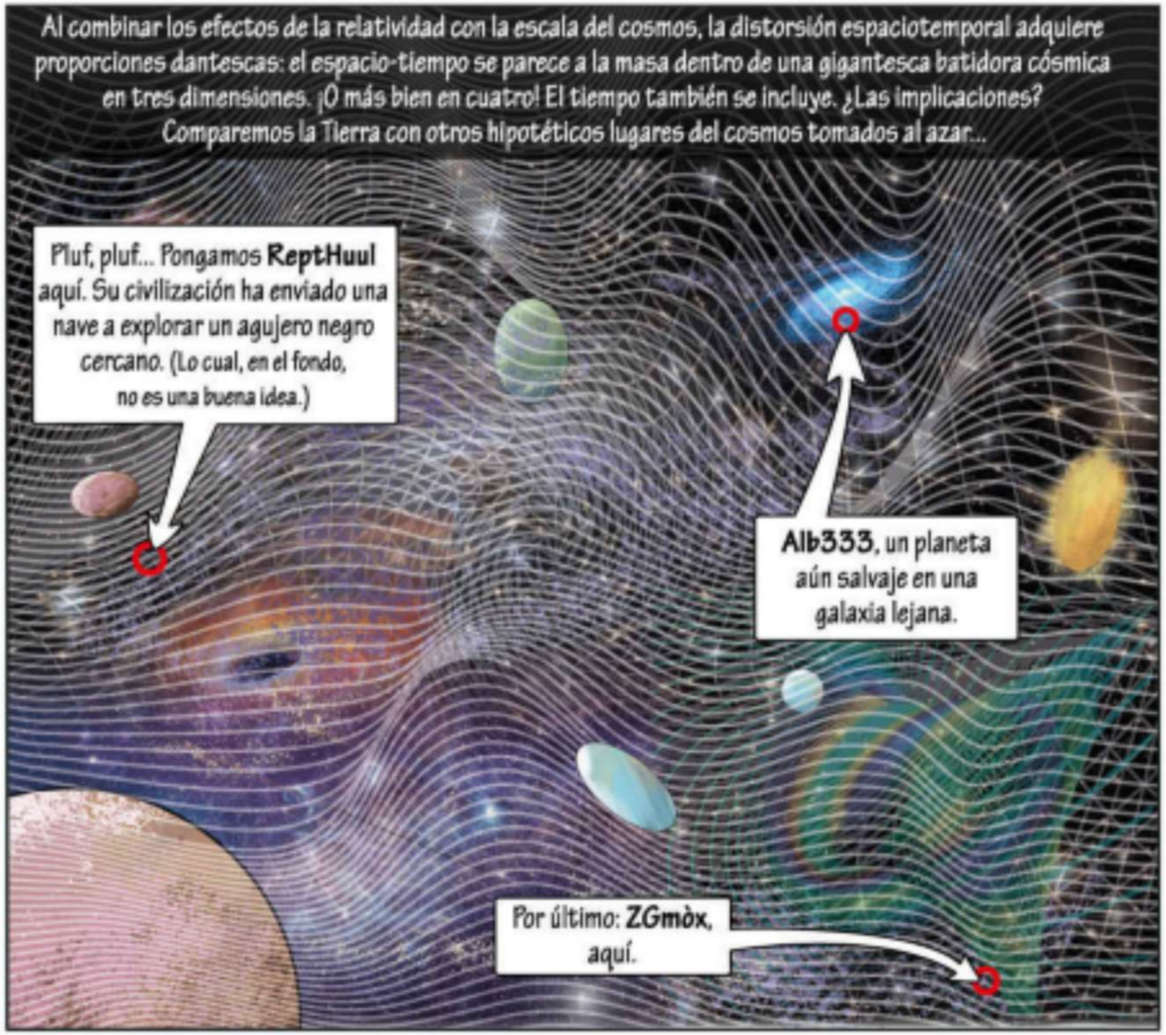

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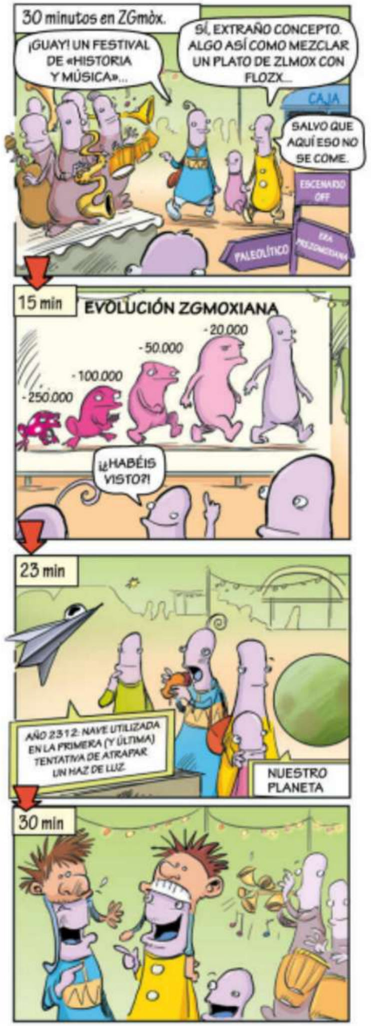

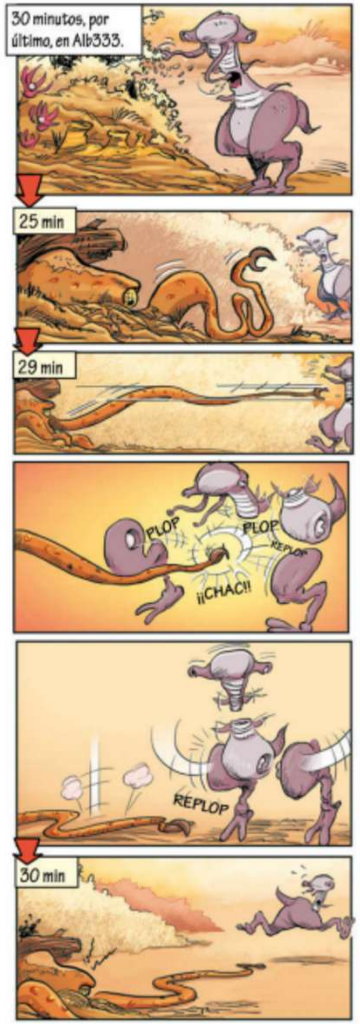

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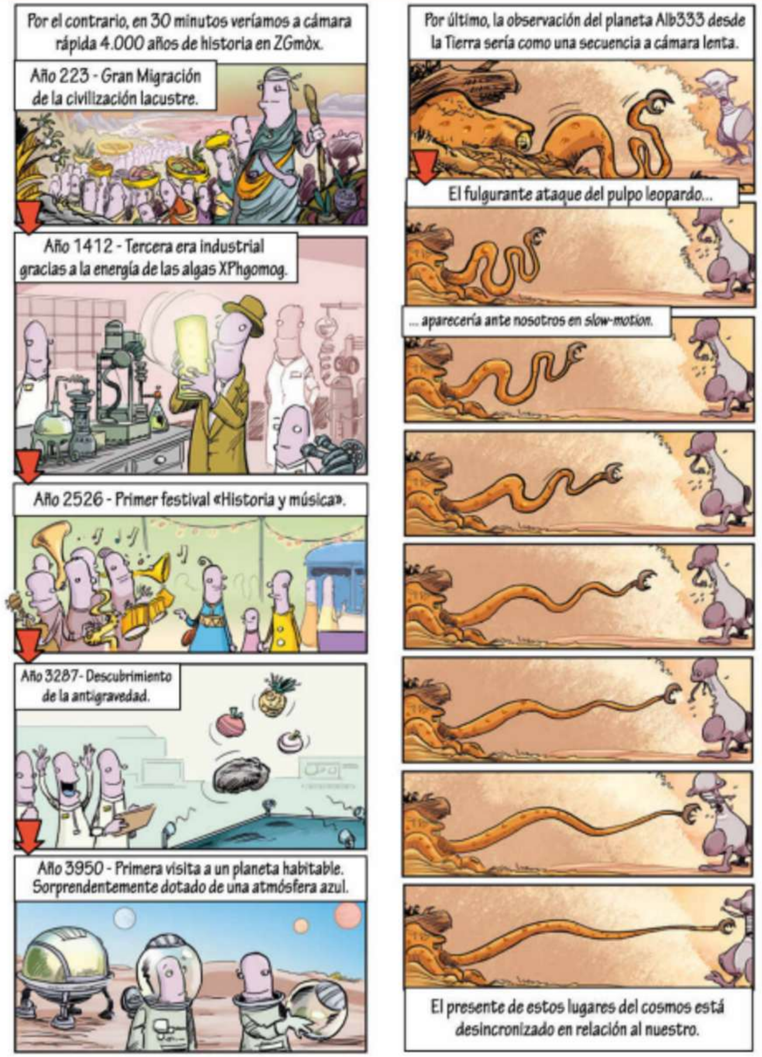

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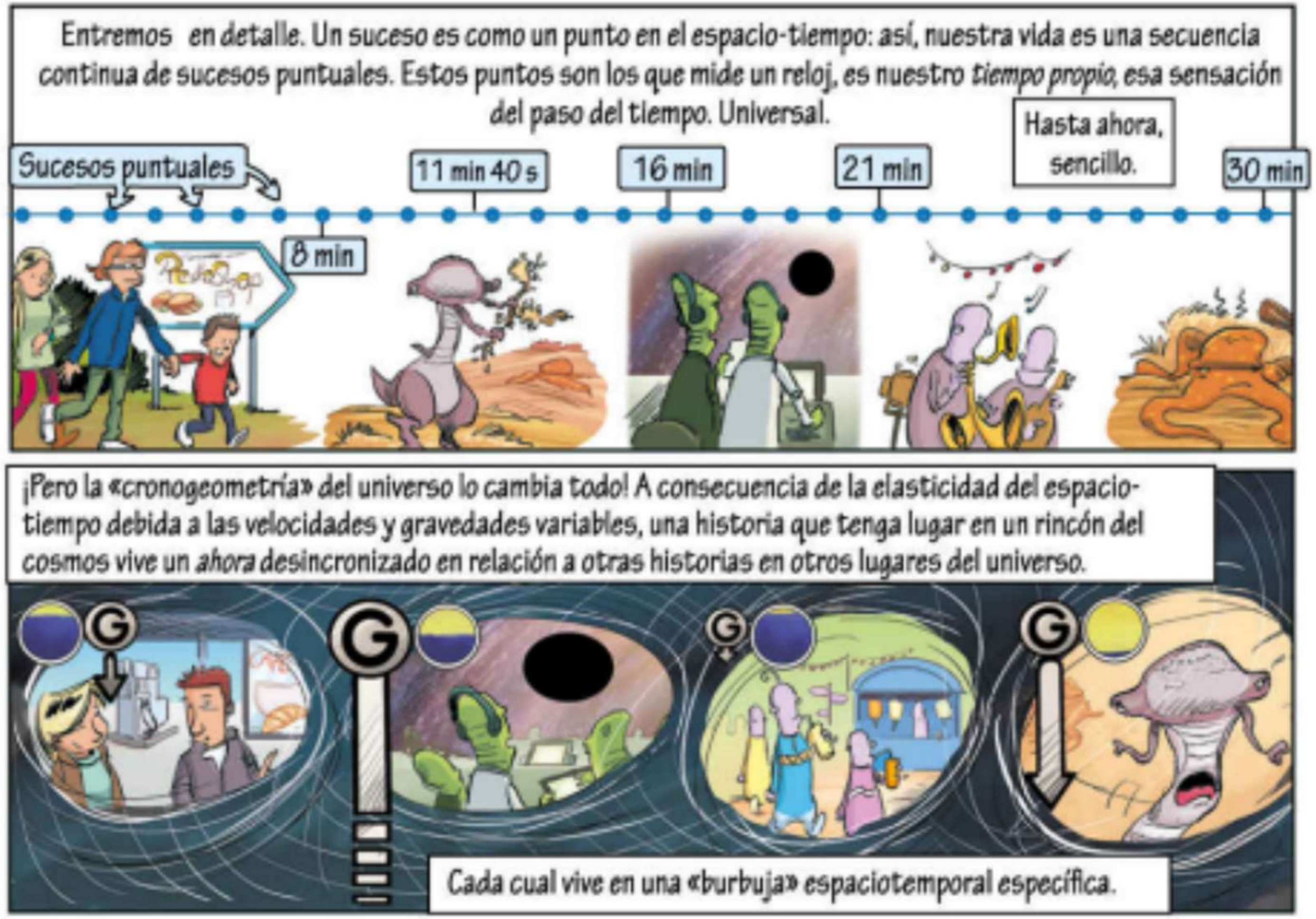

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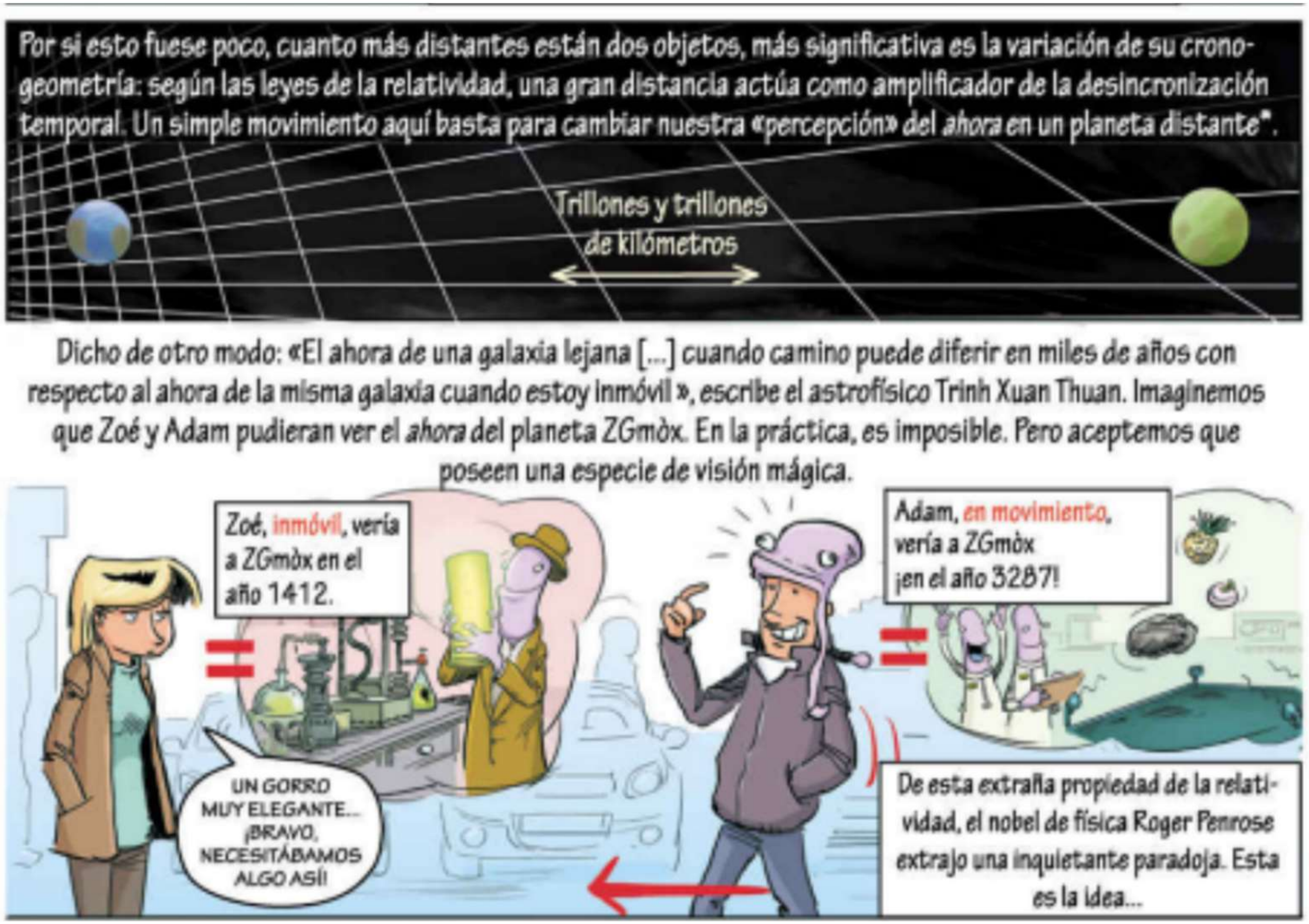

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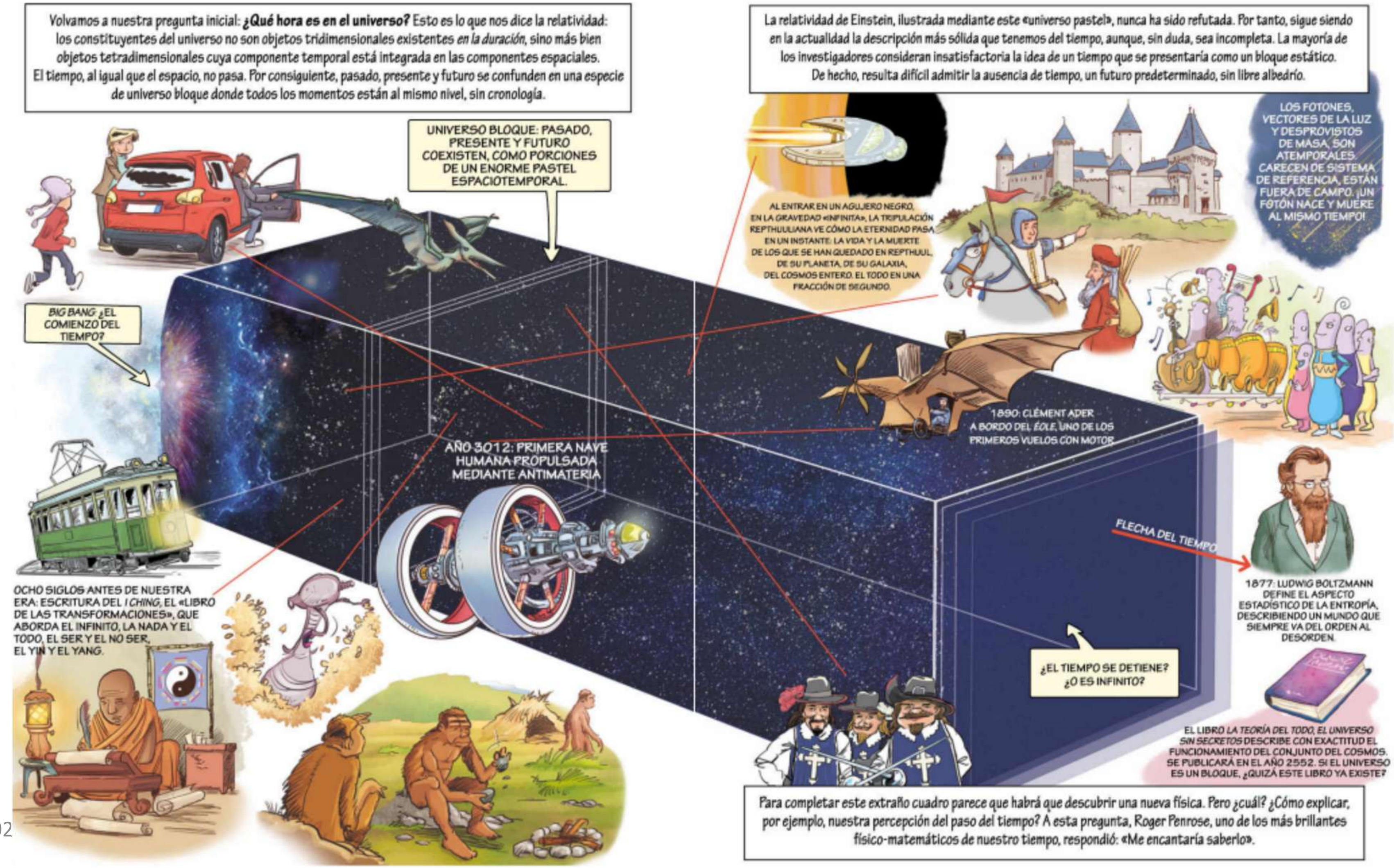

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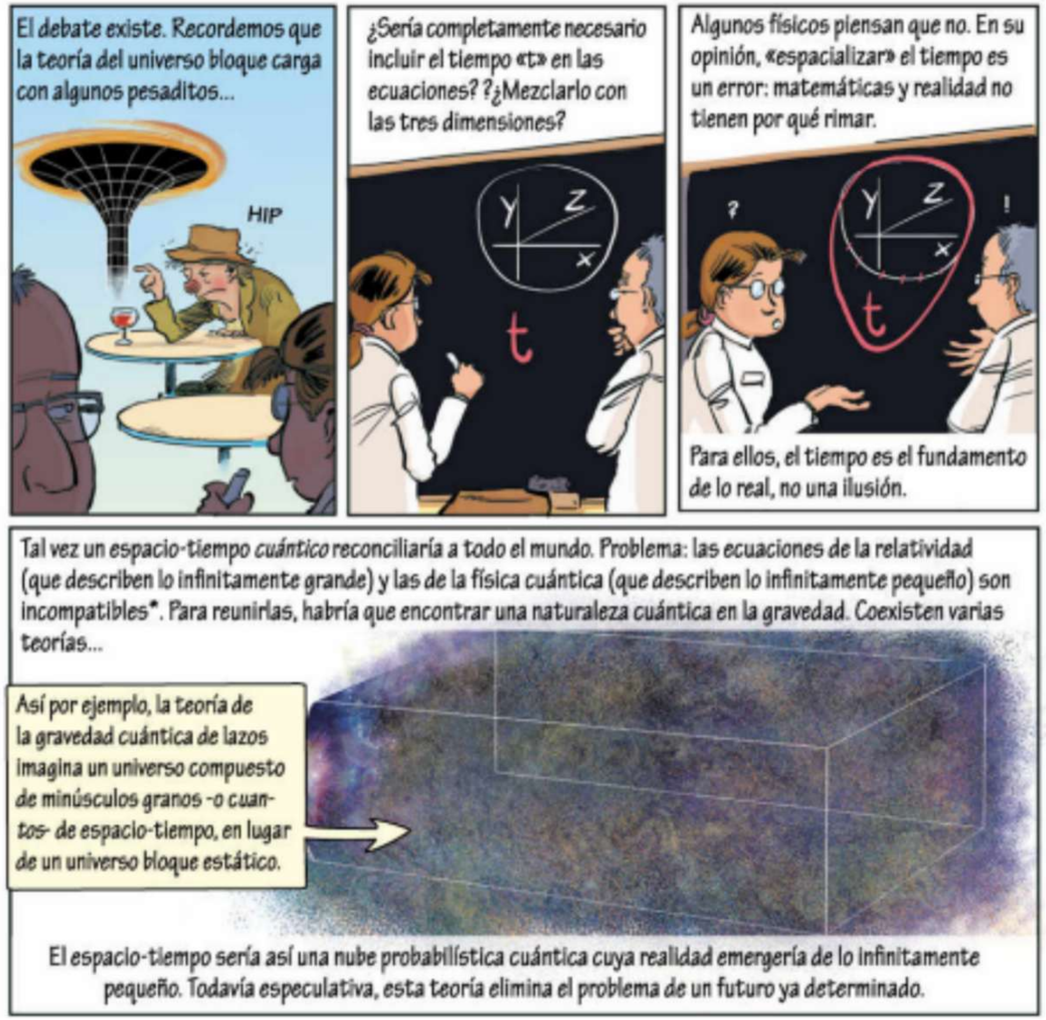

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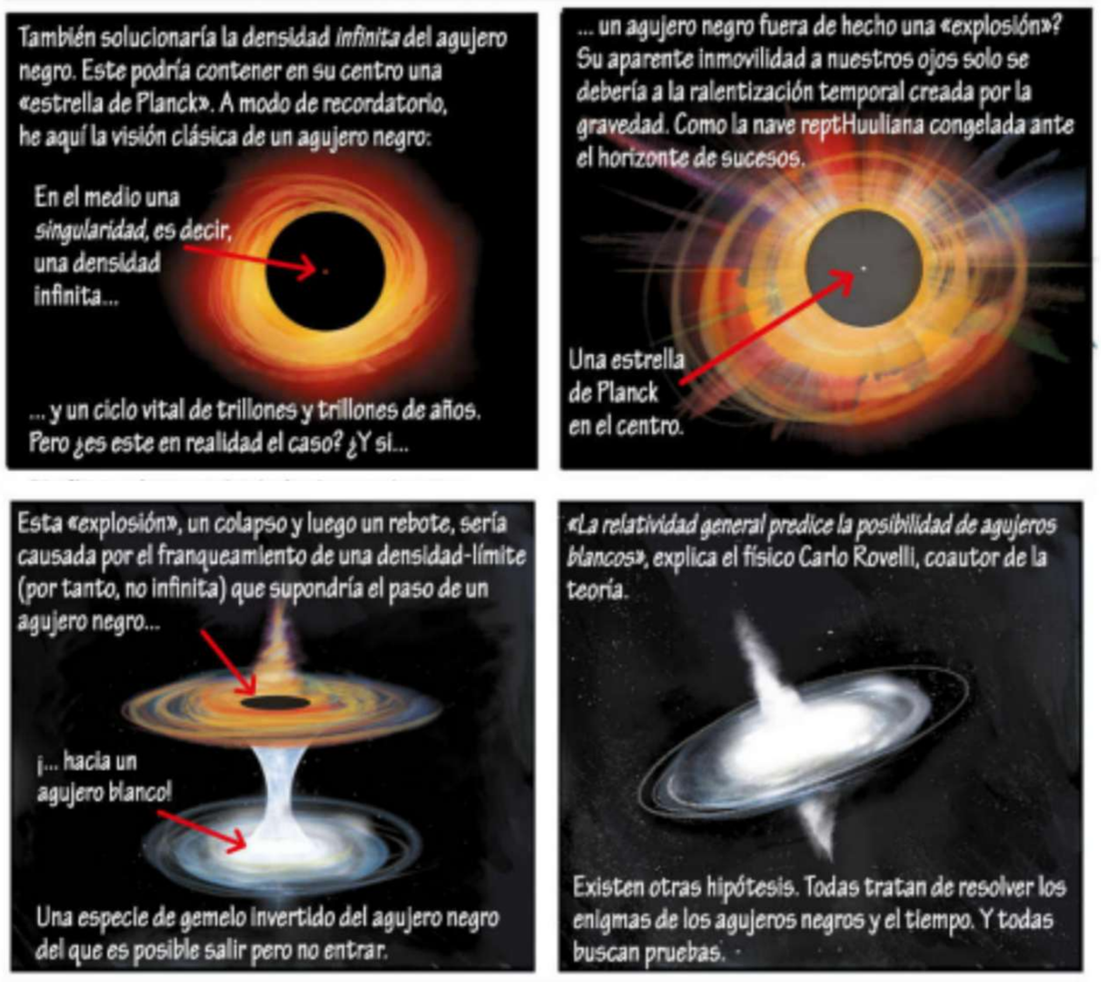

Consideraciones previas

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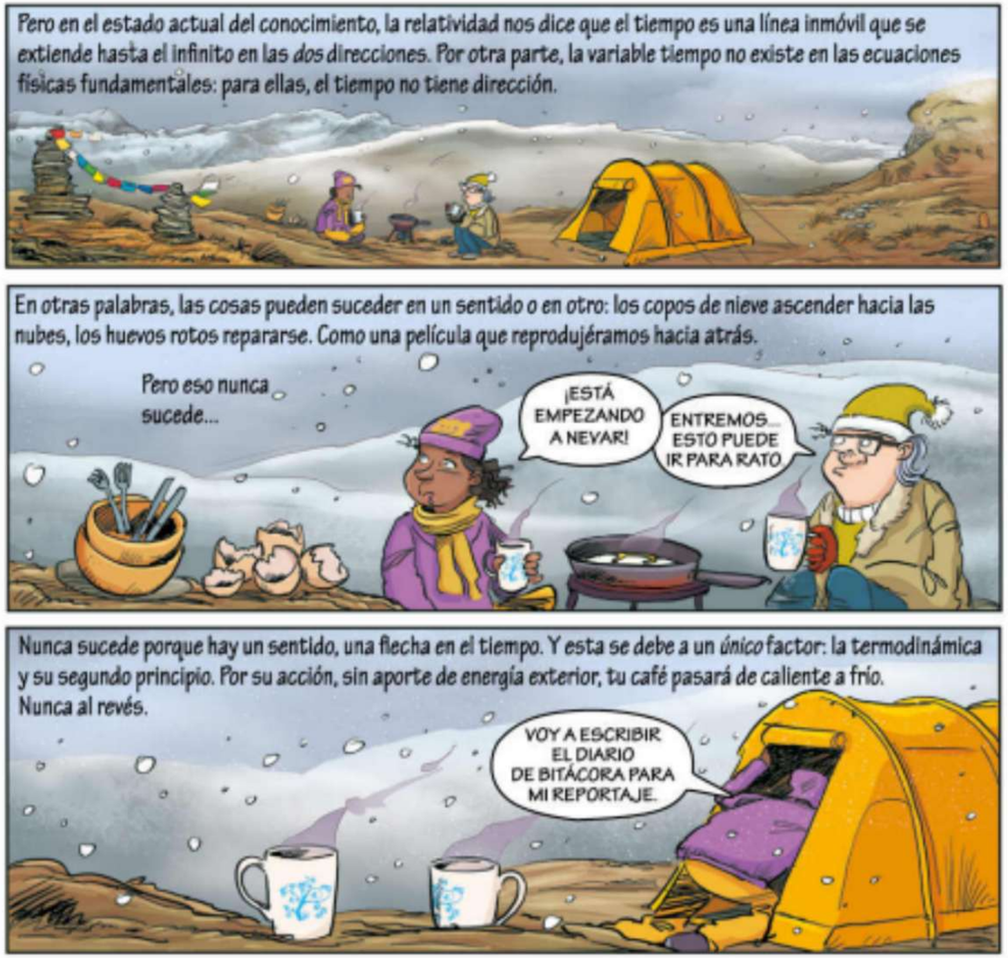

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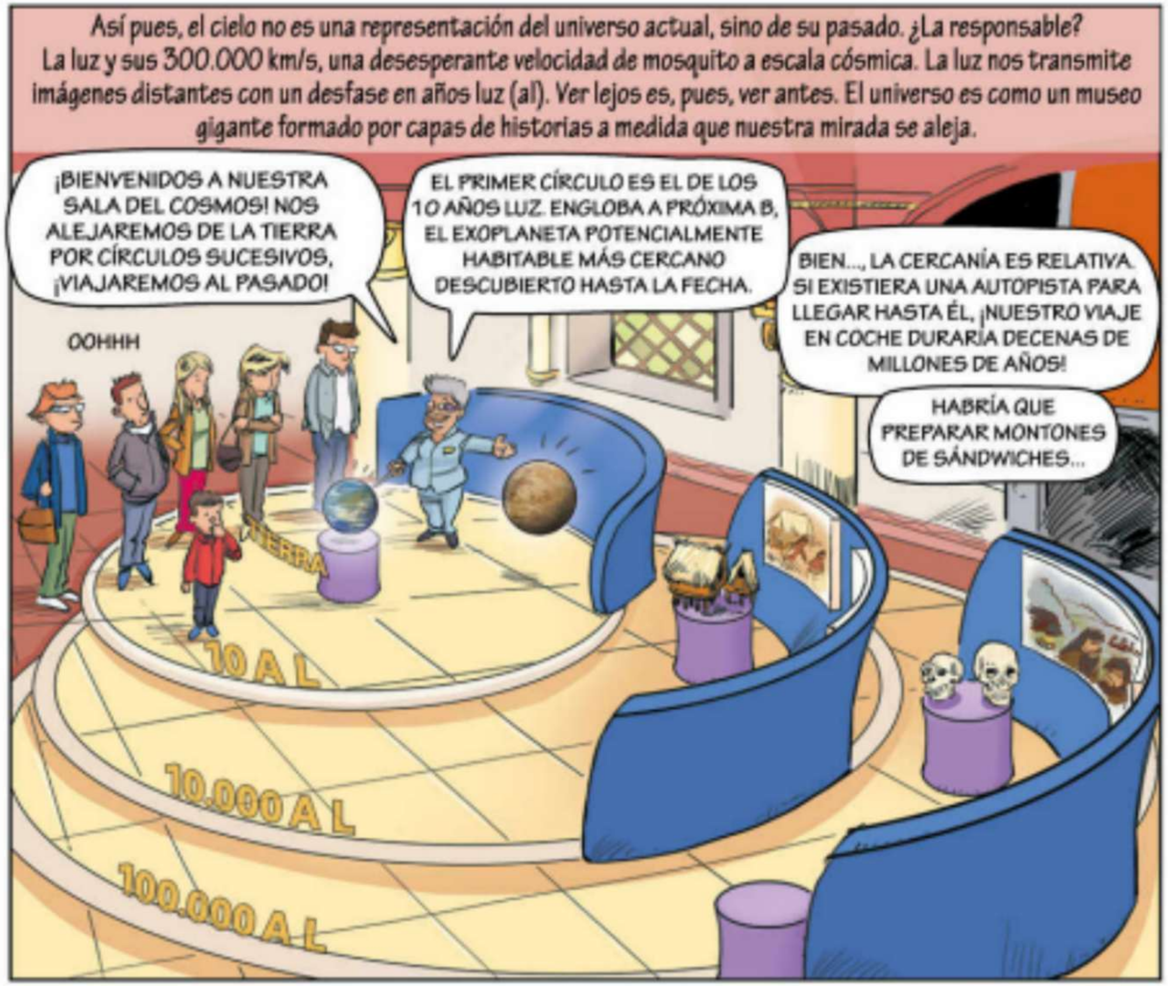

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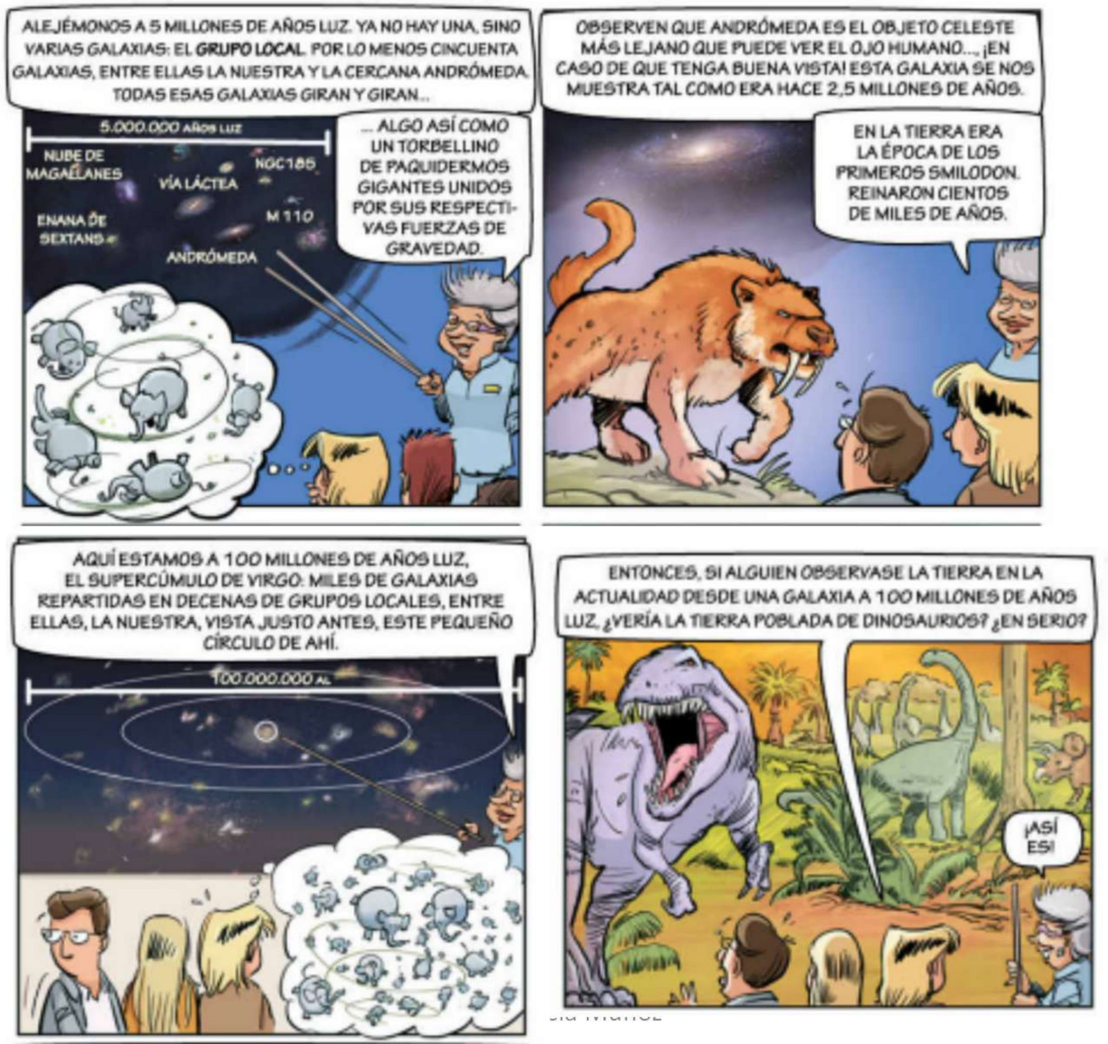

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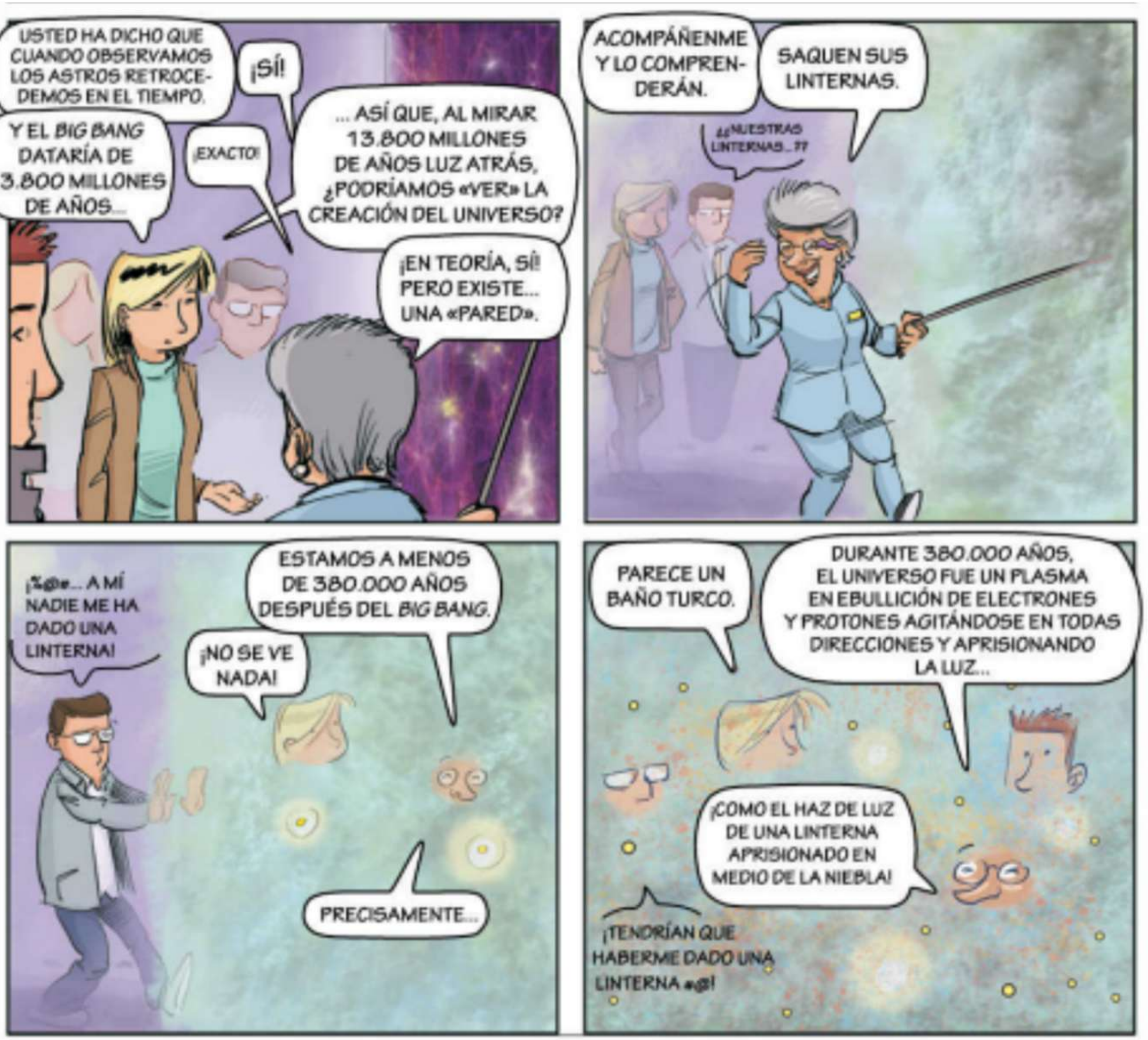

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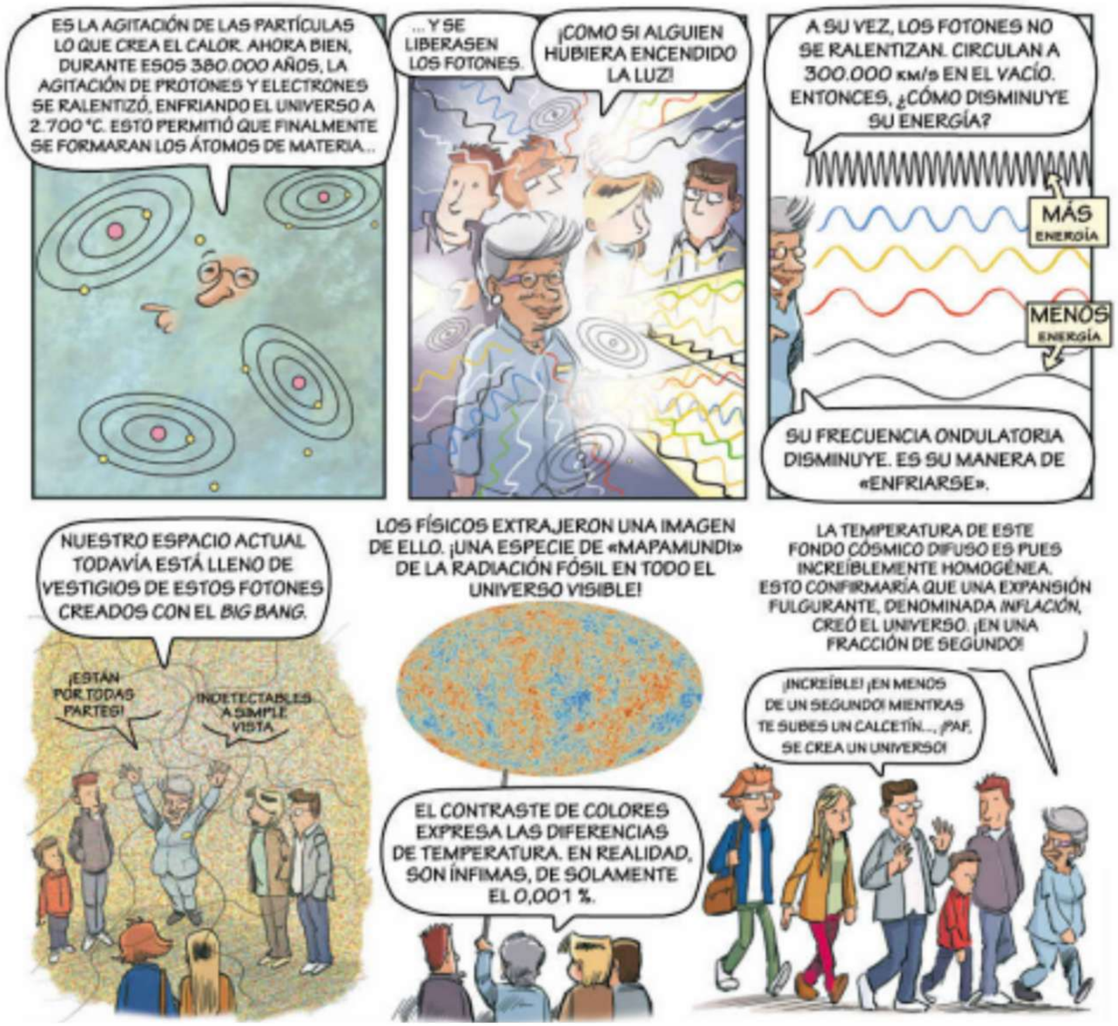

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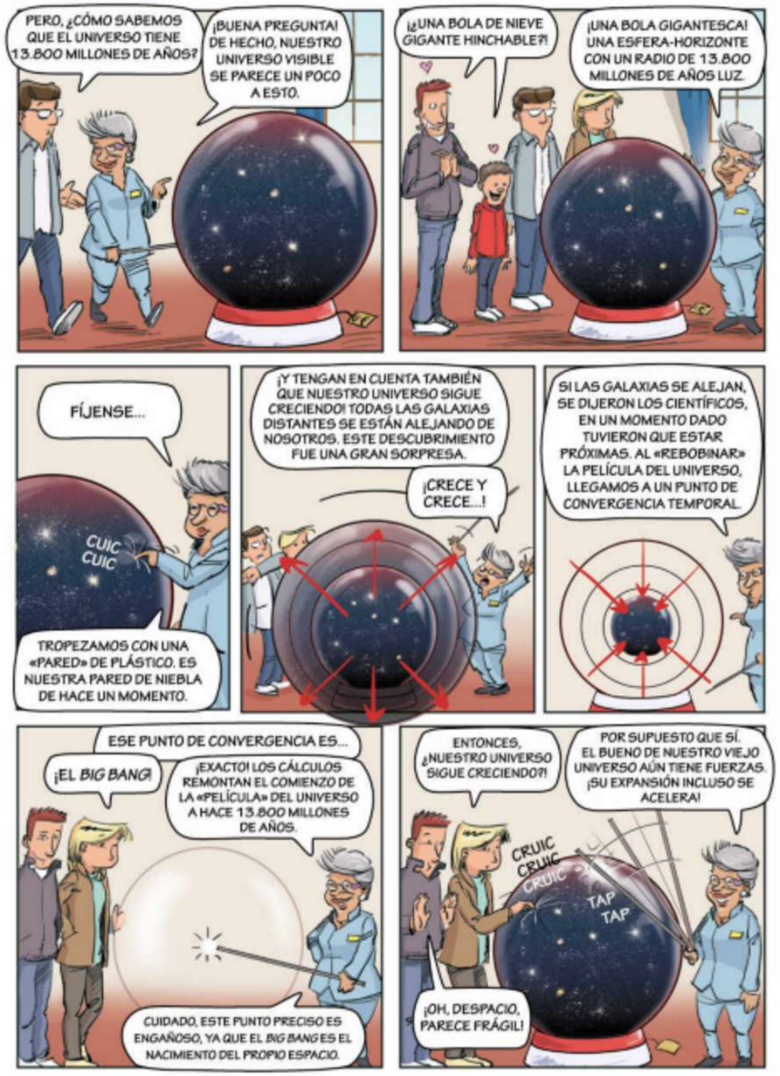

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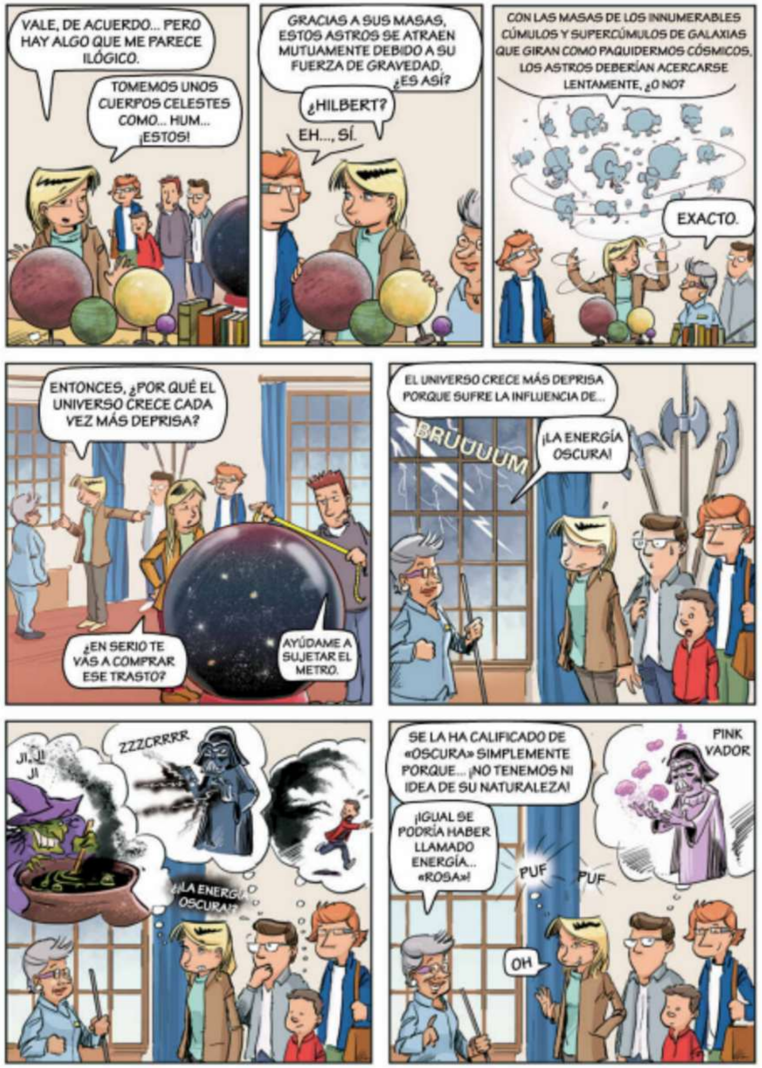

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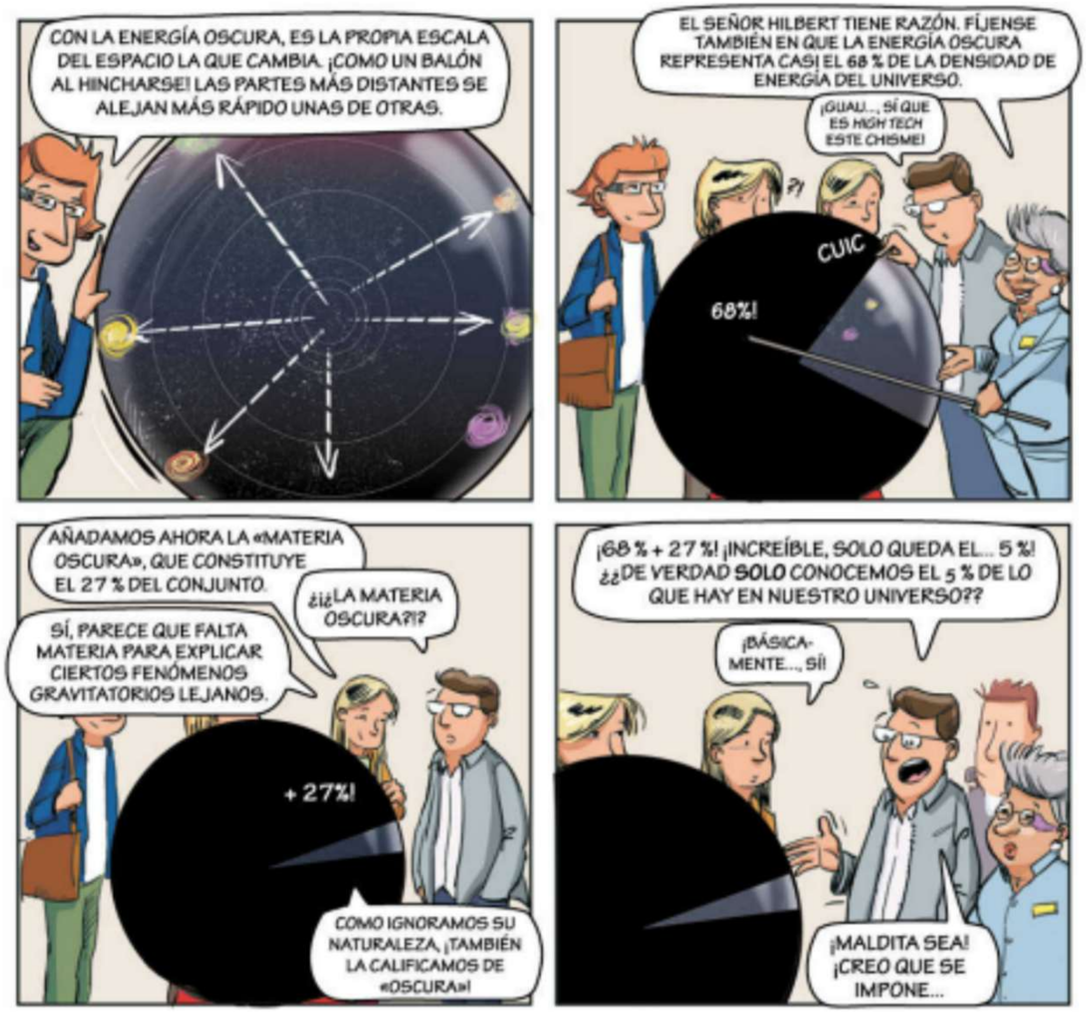

Consideraciones previas

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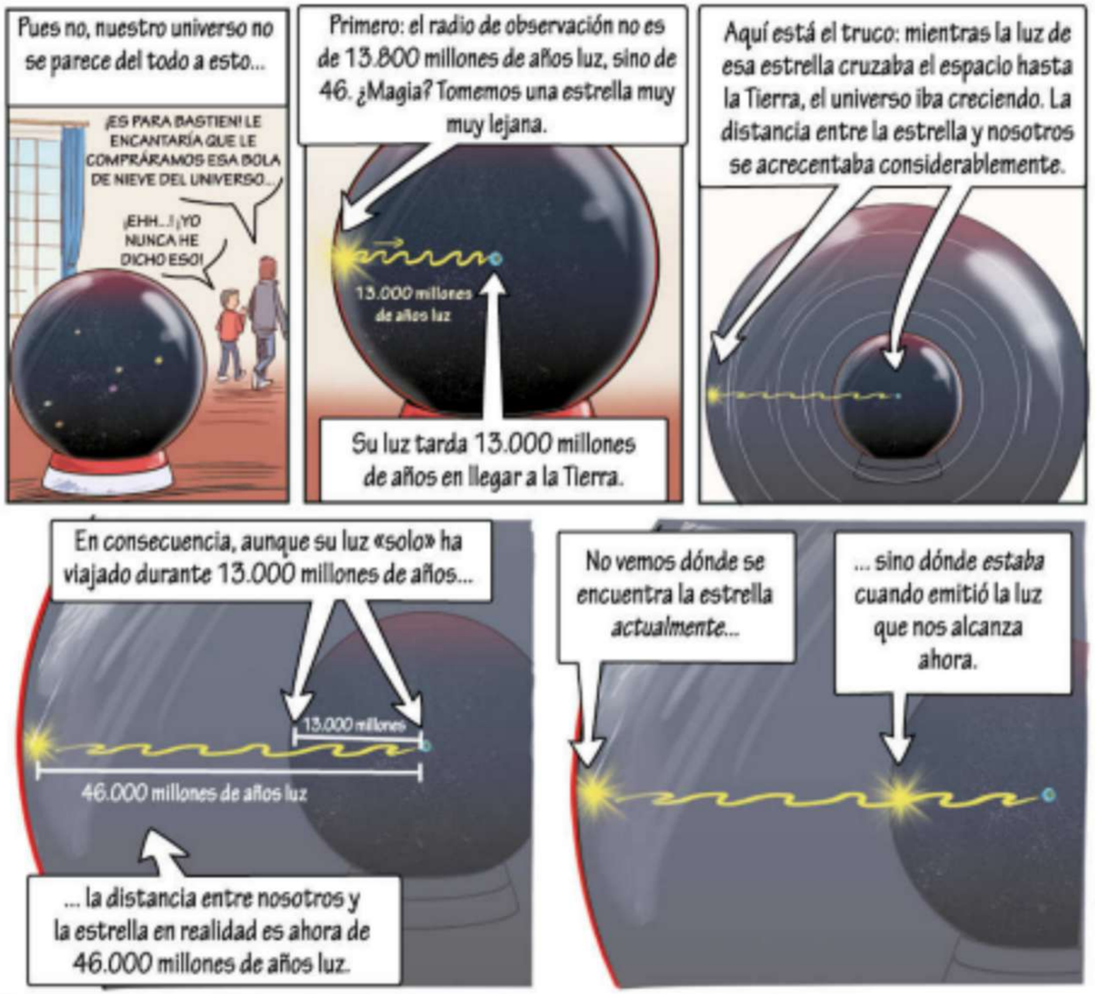

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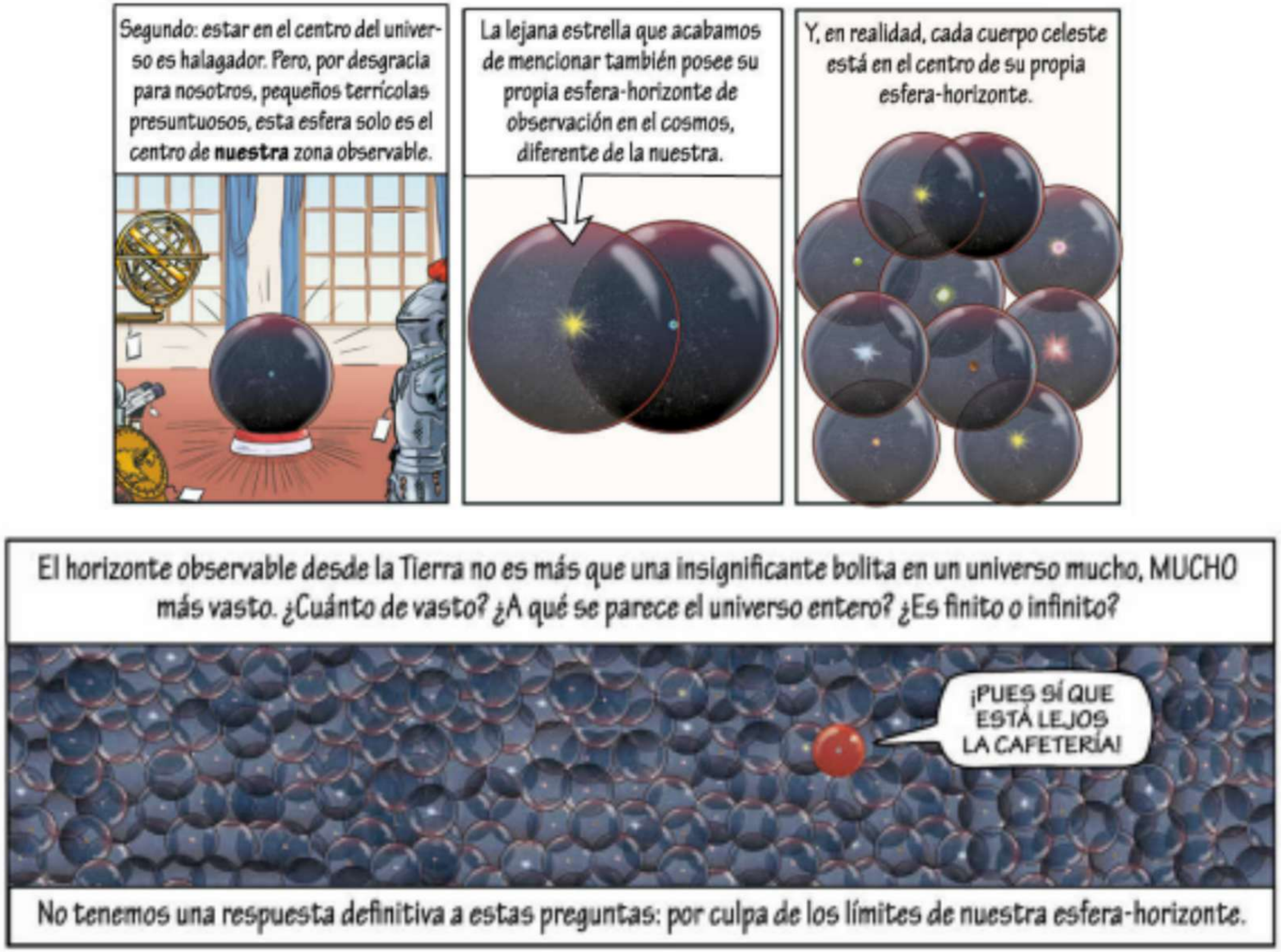

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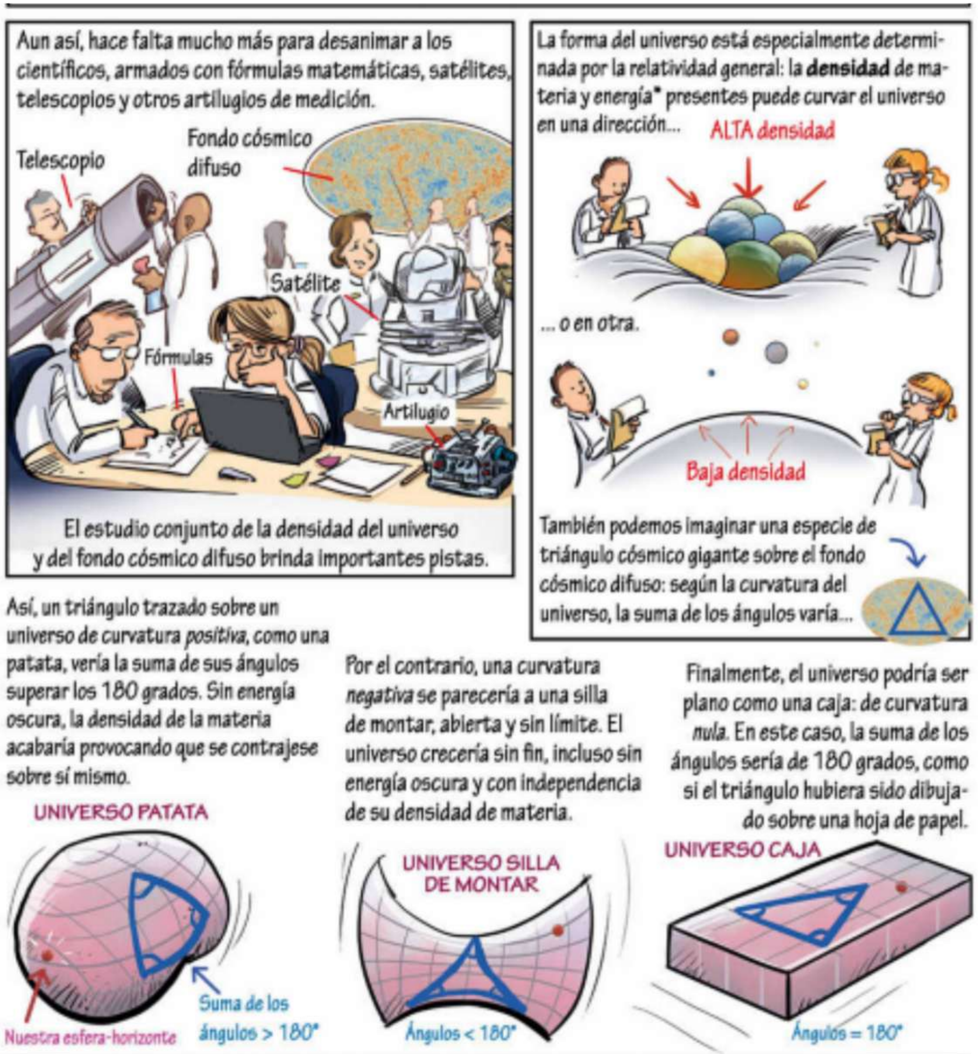

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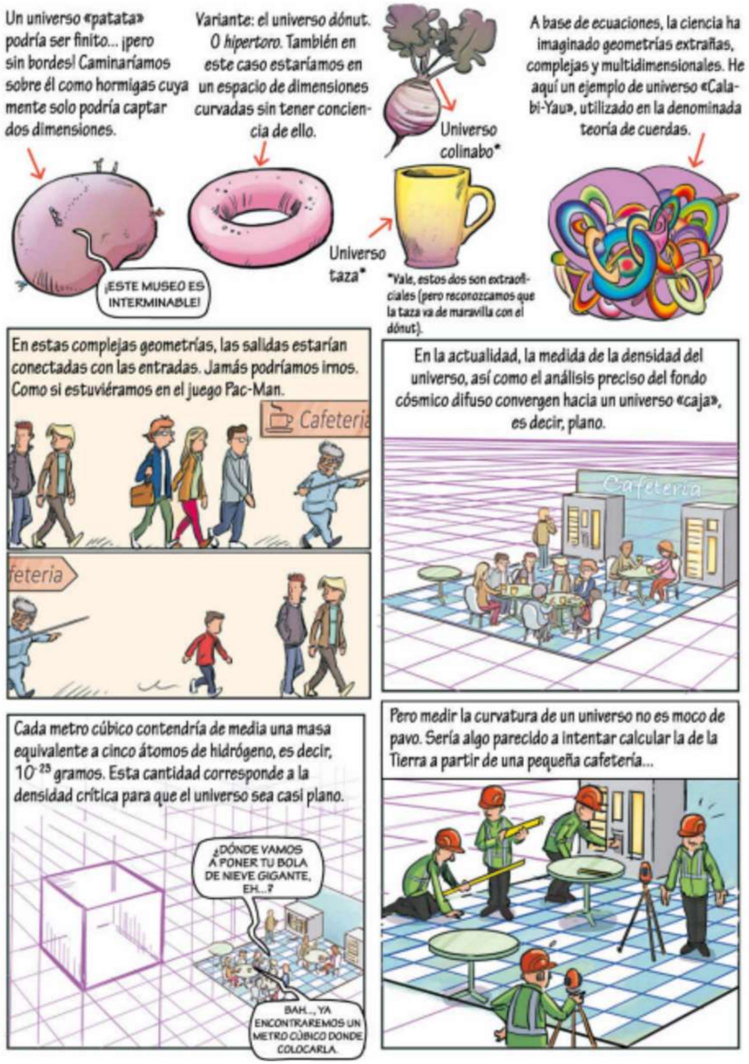

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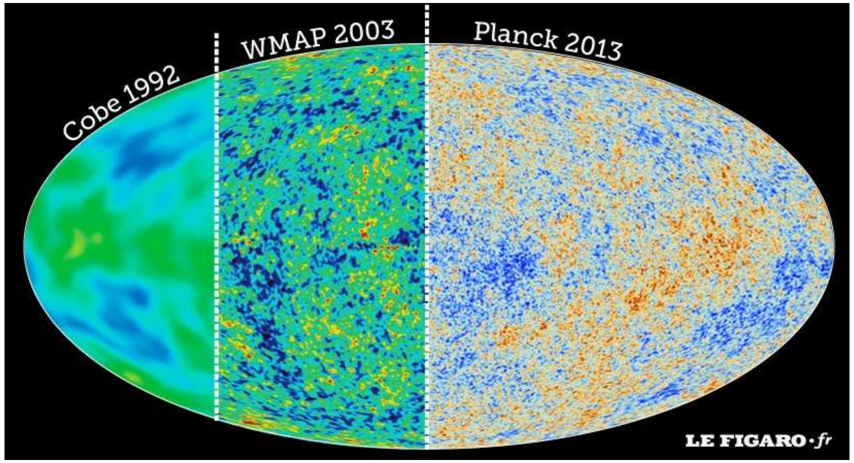
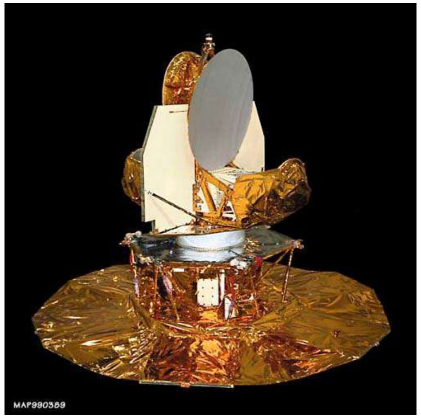
Motivación: radioastronomía y predicción climática

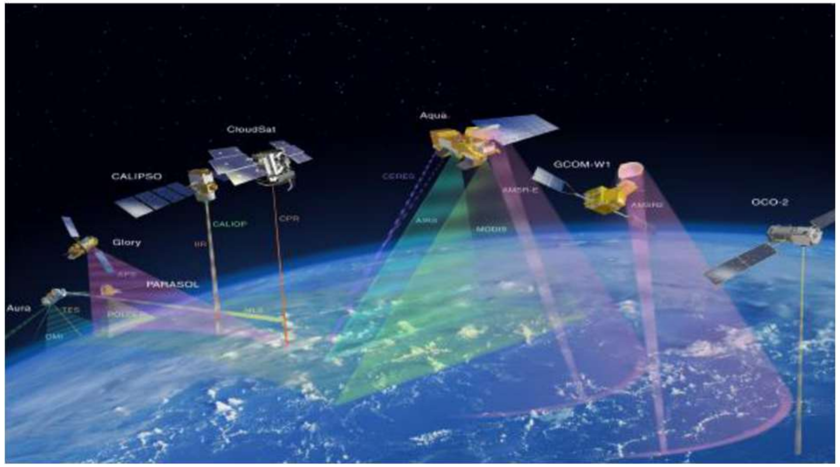


Ultra-low noise instrumentation

Radio astronomy, Earth observation, planetary missions, …

Source: WMAP website





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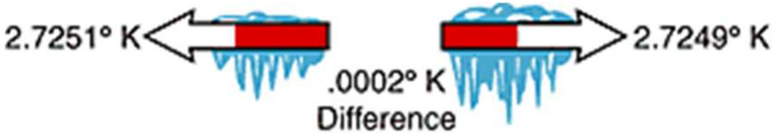
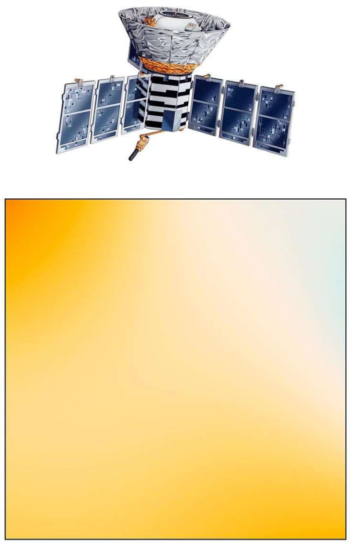
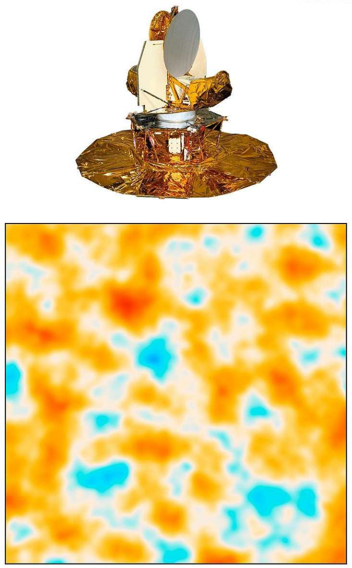
Motivación de las bandas milimétricas en radioastronomía

WMAP goal: map the relative CMB temperature over the full sky with a sensitivity of 20 μK per 0.3° square pixel.

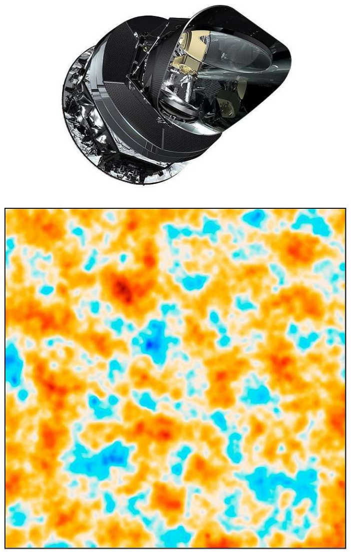




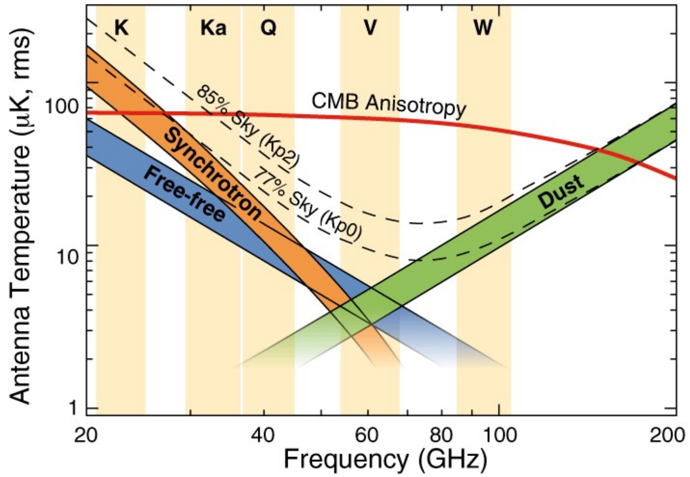
COBE



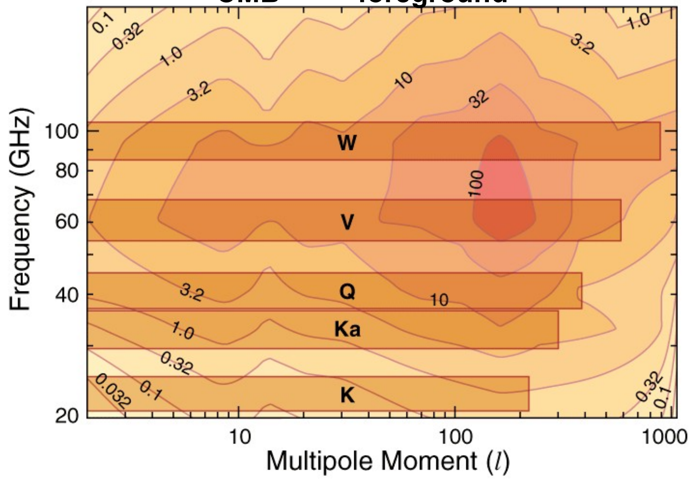
WMAP



Planck



$\Delta T_{CMB}/\,\Delta T_{foreground}$



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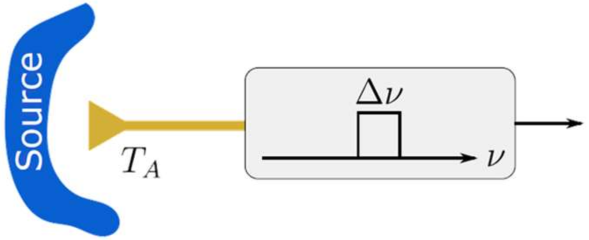
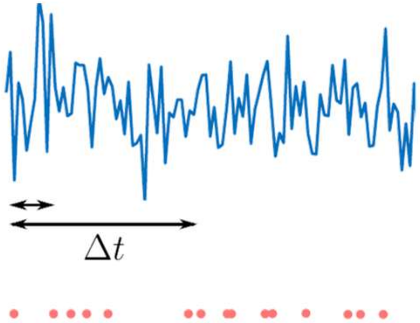
MILLIMETER AND SUBMILLIMETER TEAM

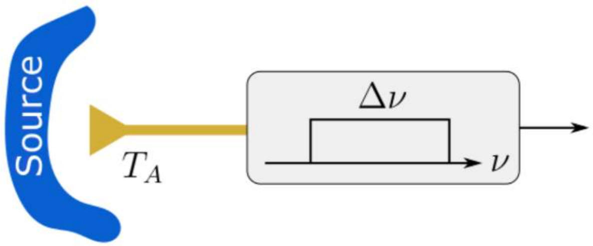
- **Motivación**
  - **Radioastronomía y predicción climática**
  - **Bandas milimétricas en radioastronomía**
  - **Ruido cuántico**
  - **Tecnologías en bandas mm y sub-mm**
- **Electro optic up-converter**
- **Experiment**
- **Sensitivity as radiometer**
- **Conclusions**

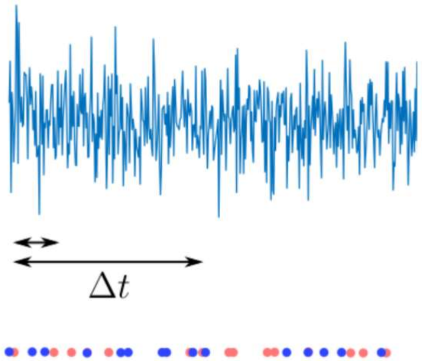
Motivación: ruido cuántico

“Ideal” radiometer: No noise added, and 100% of photons detected









Mandel’s formula

$$\Delta n = \sqrt{\underbrace{\bar{n}}_{\text{Shot noise}} + \underbrace{\frac{(\bar{n})^2}{\Delta\nu\Delta t}}_{\text{Thermal noise}}}$$

$$\Delta t \gg 1/\Delta\nu$$

Planck’s formula

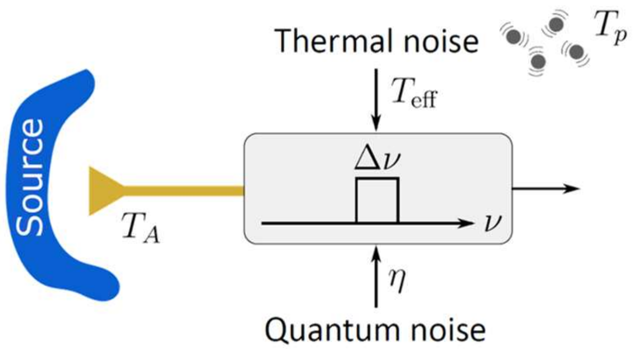
$$\Delta n \Rightarrow \Delta T$$

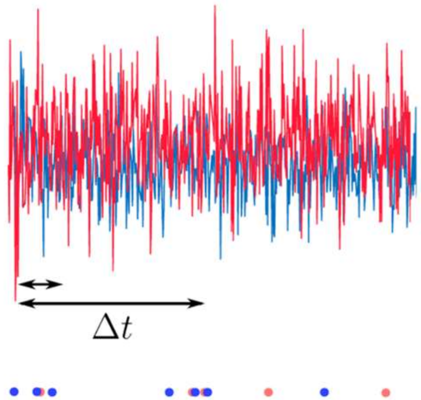
Radiometer equation

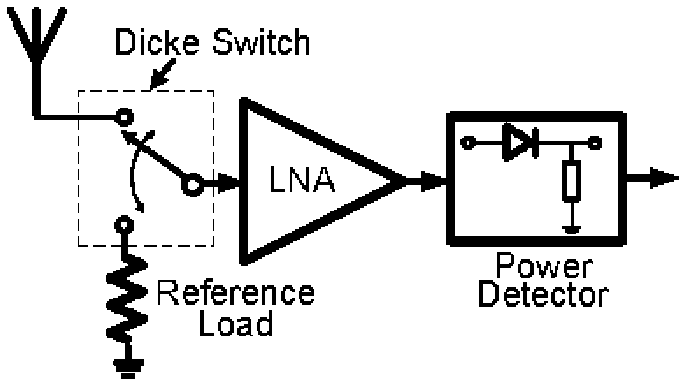
$$\Delta T = \underbrace{\frac{T_A}{\sqrt{\Delta t \Delta\nu}}}_{\text{classical}} \underbrace{\sqrt{\frac{h\nu}{k_B T_A} + 1}}_{\text{quantum}}$$

Motivación: ruido cuántico

“Actual” radiometer: Thermal noise added and η < 100%, some photons are lost.

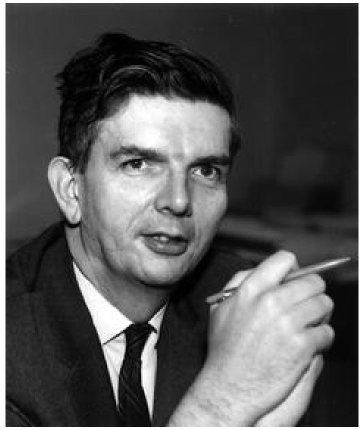


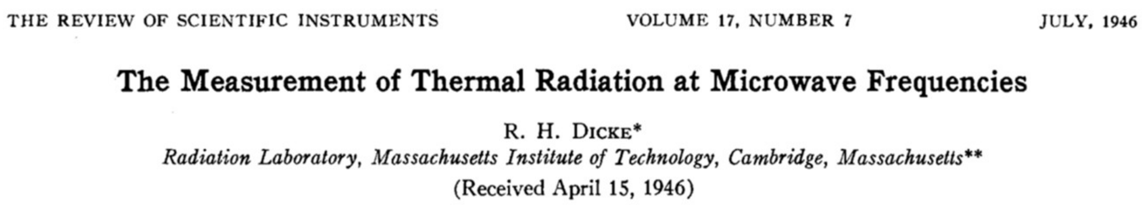




Some integration techniques

Dicke switching





THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 17, NUMBER 7 JULY, 1946

The Measurement of Thermal Radiation at Microwave Frequencies

R. H. DICKE*

*Radiation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts***

(Received April 15, 1946)

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MILLIMETER AND SUBMILLIMETER TEAM

Motivación: teconologías de detección en bandas mm y sub-mm

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- **Bolometric detectors (HEB, TES, …)**
- **Superconductor-Insulator-Superconductor (SIS)**
- **Kinetic Inductance Detectors (KIDs)**
- **High-electron-mobility transistors (HEMTs)**

	Type	Temp	Phase	NEP
Golay	thermal	300K	no	$150\ \mathrm{pW}/\sqrt{\mathrm{Hz}}$
Pyroelectric	thermal	300K	no	$150\ \mathrm{pW}/\sqrt{\mathrm{Hz}}$
HEB	thermal	mK	no	$10^{-19}\mathrm{W}/\sqrt{\mathrm{Hz}}$
TES	thermal	mK	no	$10^{-21}\mathrm{W}/\sqrt{\mathrm{Hz}}$
Schottky	field rectifying	300K	yes	$\mathrm{pW}/\sqrt{\mathrm{Hz}}$
CMOS	FET	300K	yes	$\mathrm{pW}/\sqrt{\mathrm{Hz}}$

Photon-counting detectors require sub-Kelvin cryogenic operation

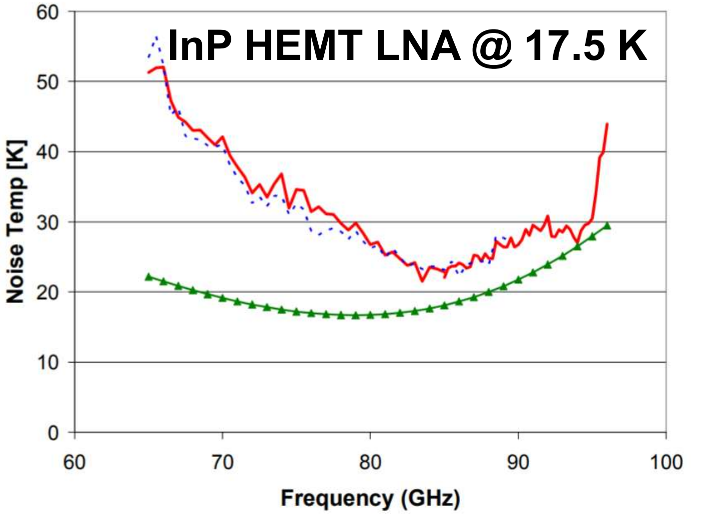
Cryogenic operation

A W-Band Low-Noise Amplifier with 22K Noise Temperature

Eric W. Bryerton[1], Xiaobing Mei[2], Young-Min Kim[2], William Deal[2], Wayne Yoshida[2], Mike Lange[2], Jansen Uyeda[2], Matthew Morgan[1], and Richard Lai[2]

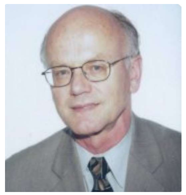
Extremely Low-Noise Cryogenic Amplifiers for Radio Astronomy: Past, Present and Future

Marian W. Pospieszalski



"I hope, after reading the paper, you will be convinced that there is a limit on the minimum noise temperature of FETs in general (based on their principle of operation) and for InP cryogenic HEMTs that limit is about 4-4.5 time quantum noise. We have practically reached it."

University of Colorado Boulder



National Radio Astronomy Observatory
Enabling forefront research into the Universe at radio wavelengths
NRAO

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Motivación

Electro optic up-converter

- Concepto
- Retos
- Aumentar η
- Disminuir ruido térmico
- Phase matching
- Aumentar BW

Experiment

Sensitivity as radiometer

Conclusions

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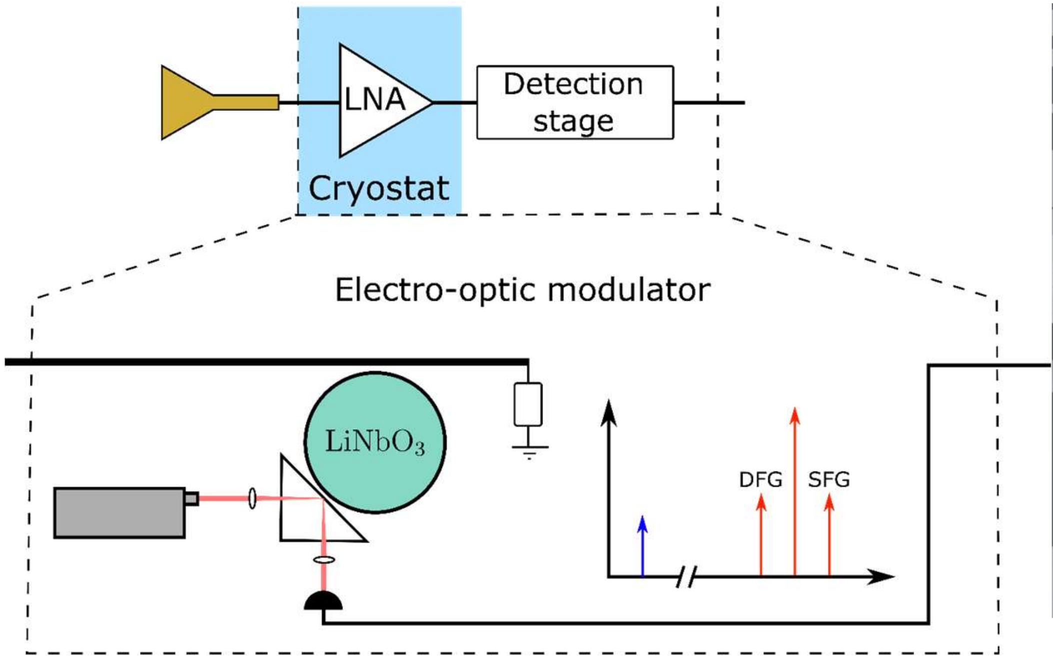
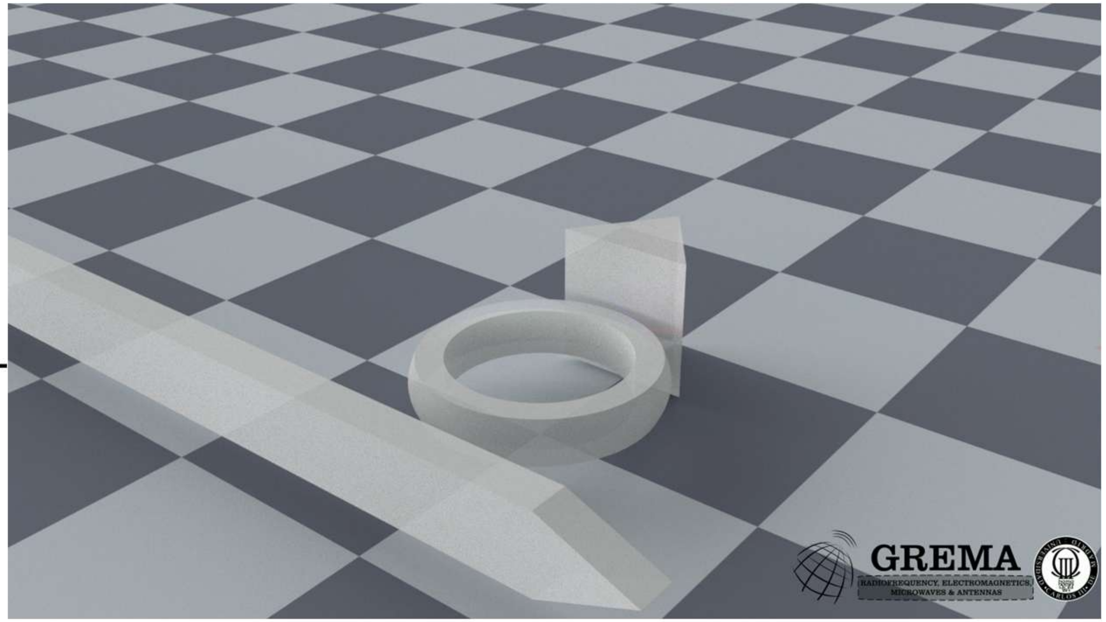
MILLIMETER AND SUBMILLIMETER TEAM

Electro-optic up-converter: concepto

MILLIMETER AND SUBMILLIMETER TEAM

Good candidate for low-noise detection with less strict cooling requirements





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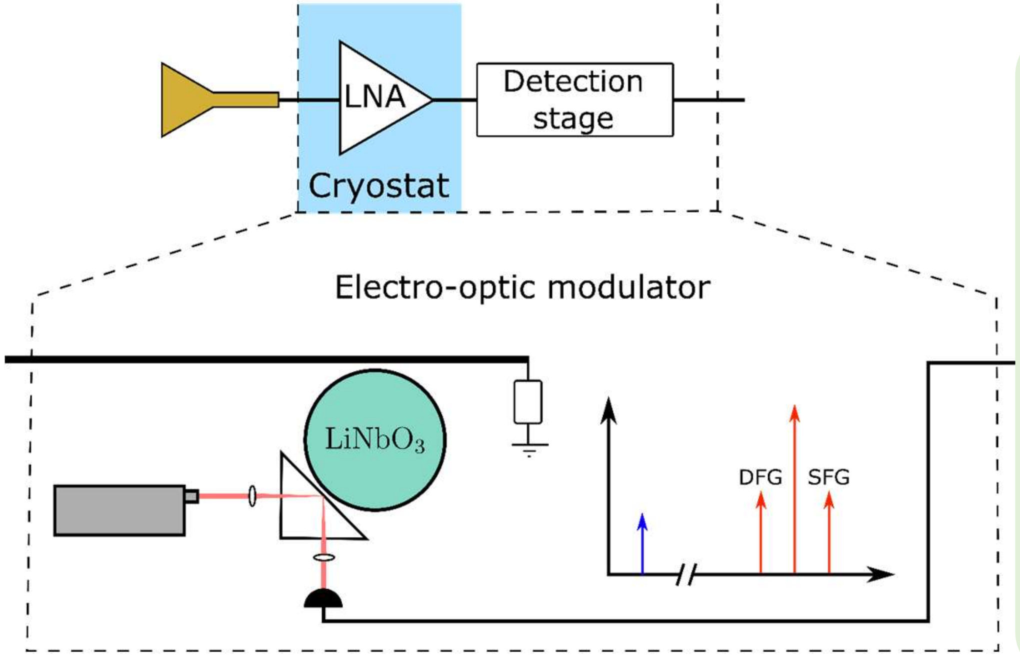
- Electro optic up-converter
  - Concepto
  - Retos
  - Aumentar η
  - Disminuir ruido térmico
  - Phase matching
  - Aumentar BW
- Experiment
- Sensitivity as radiometer
- Conclusions

Electro-optic up-converter: challenges



Challenges:

1. High conversion efficiency:

$$\eta = \frac{\#\text{ of upconverted photons}}{\#\text{ of input microwave photons}}$$

2. Avoid thermal noise being upconverted

3. Phase matching

4. High upconversion bandwidth

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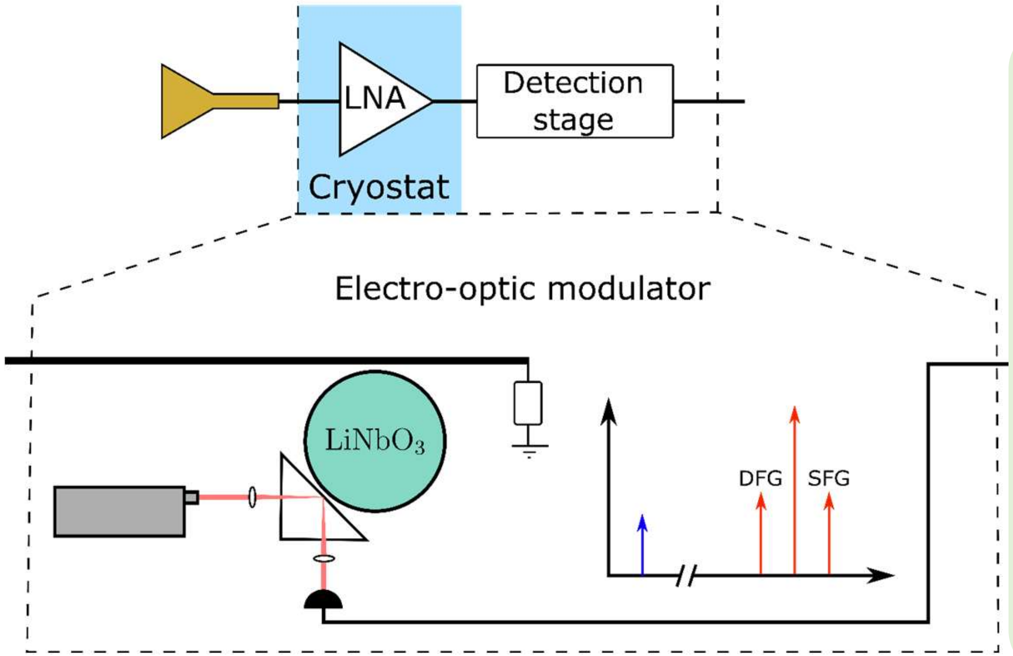
Electro-optic up-converter: challenges



Challenges:

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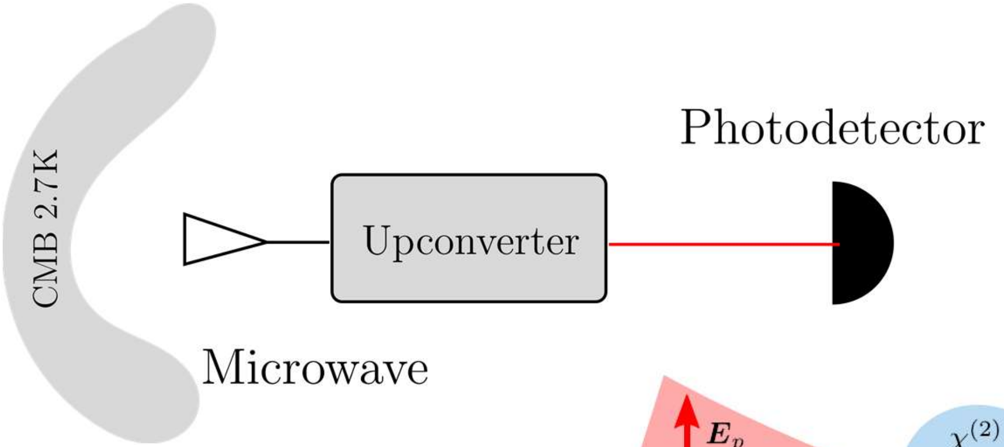
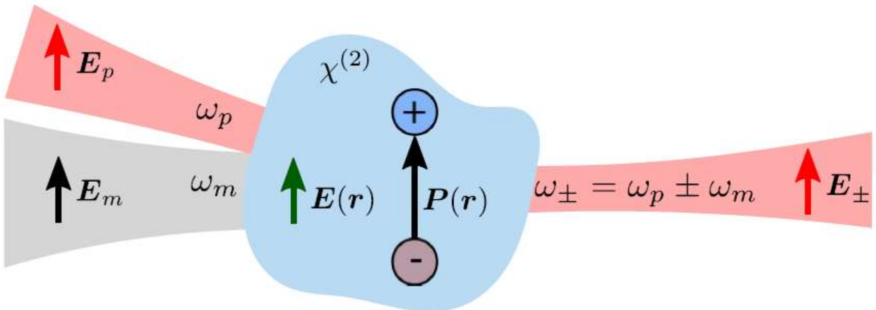
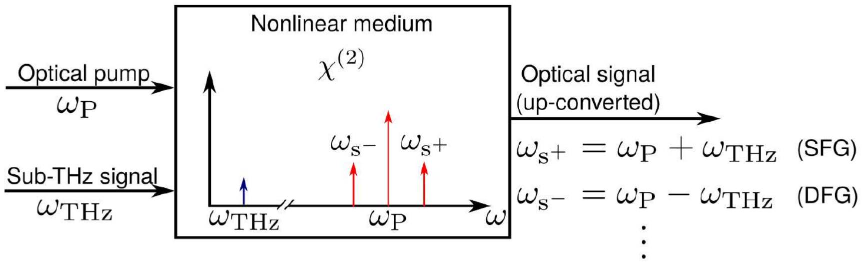
2. Avoid thermal noise being upconverted
3. Phase matching
4. High upconversion bandwidth

Electro-optic up-converter

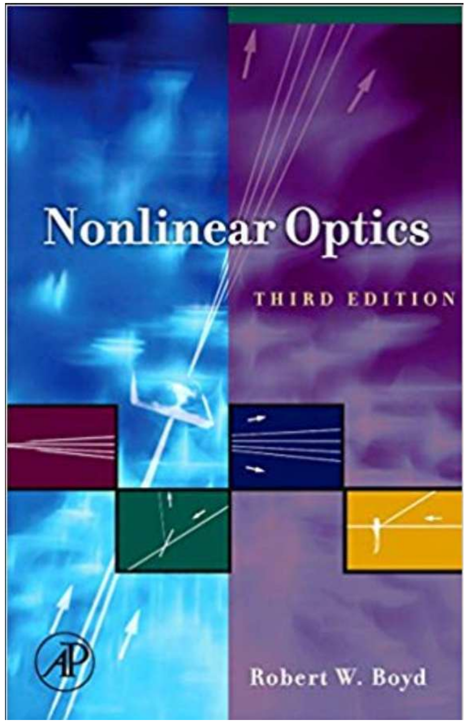


The signal is up-converted into the optical domain where it is easier to detect with available high-sensitivity optical receivers.





$$P(r) = \varepsilon_0 E(r) + \varepsilon_0 \chi^{(2)} E^2(r)$$



Electro-optic up-converter: theory and WGM resonators

Quantum Electronics **32** (5) 377 – 400 (2002) ©2002 Kvantovaya Elektronika and Turpion Ltd

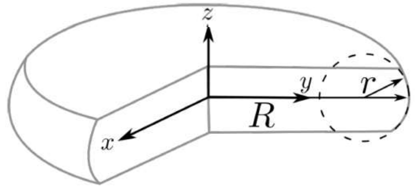
REVIEW

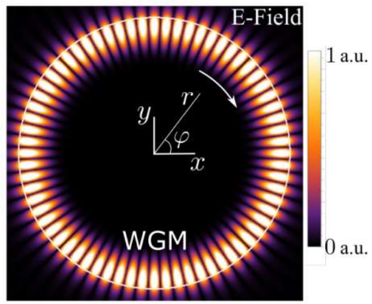
PACS numbers: 42.25.Bs; 42.25.Gy
DOI: 10.1070/QE2001v031n05ABEH002205

Whispering-gallery waves

A.N. Oraevsky

- Travelling-wave resonator
- The circulating power can result significantly higher than the incoming power
- The effective path of the interaction is increased in the WGM resonator
- Three WGMs are excited (optical pump, sub-THz signal, up-converted signal)



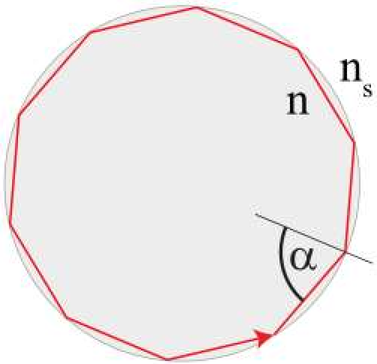


Electro-optic up-converter: WGM resonators

Q factors are only limited by host material

strong confinement of the light

→ great for nonlinear frequency mixing



resonance condition:

$$2\pi R n \approx m\lambda$$

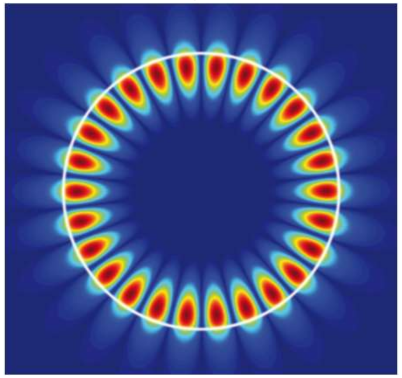
total internal reflection:

$$\sin\alpha \geq \frac{n_s}{n} \Rightarrow n > n_s$$

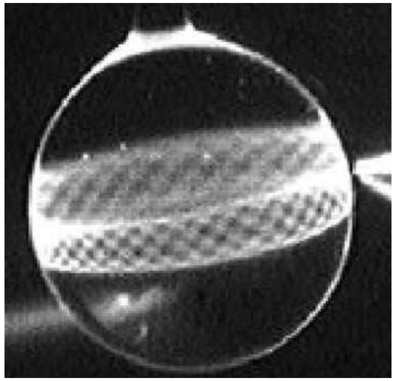
evanescent field

→ interaction with the environment

wave picture



actual picture

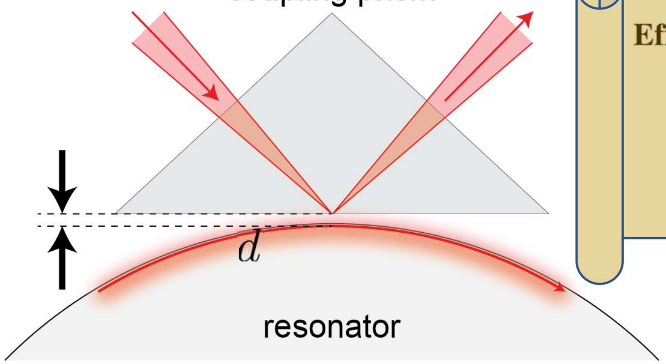


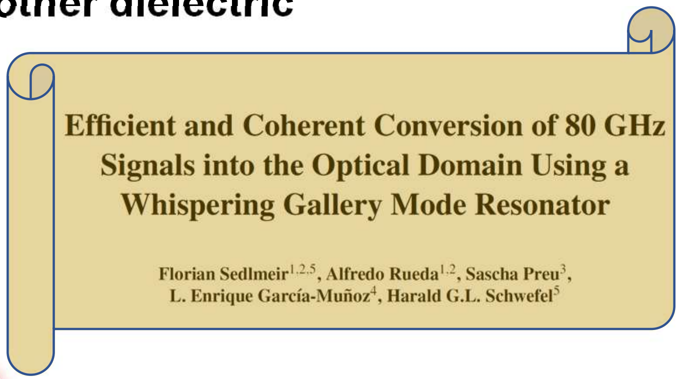
Gorodetsky et al,
Opt. Comm. 113, 133-143 (1994)

Electro-optic up-converter: how to couple light in a WGM resonator

MILLIMETER AND SUBMILLIMETER TEAM

Frustrating the TIR by another dielectric




Efficient and Coherent Conversion of 80 GHz Signals into the Optical Domain Using a Whispering Gallery Mode Resonator

Florian Sedlmeir[1,2,5], Alfredo Rueda[1,2], Sascha Preu[3], L. Enrique García-Muñoz[4], Harald G.L. Schwefel[5]

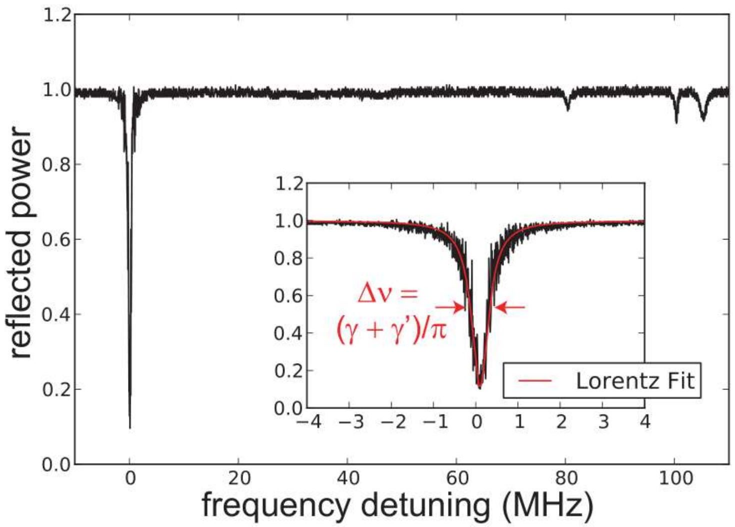
<u>coupling condition</u>

$$n_{\text{prism}} > n_{\text{resonator}}$$

tunable coupling rate: $\gamma \propto e^{-\kappa d}$

→ tunable bandwidth
→ optimize nonlinear experiments

Spectrum in reflection

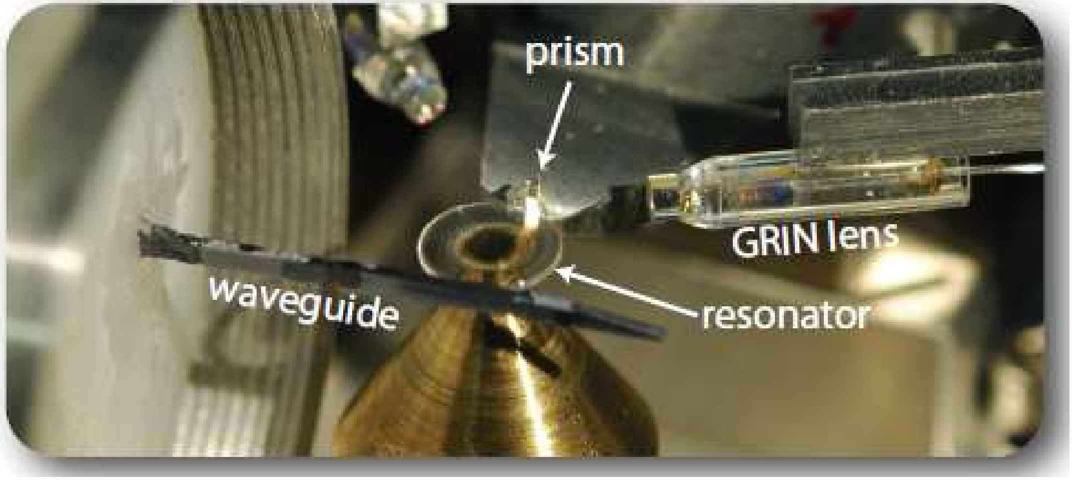


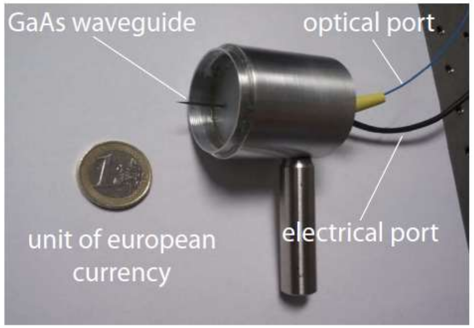
$$Q = \frac{\nu}{\Delta\nu}$$

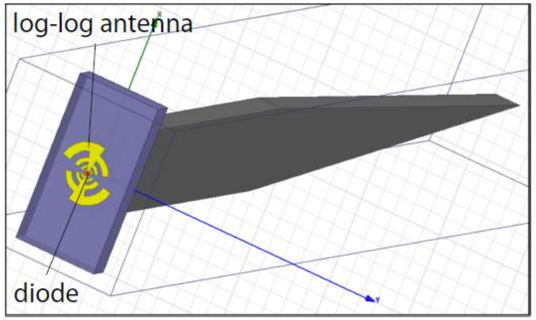
typical values:

$$Q \approx 10^7..10^9$$

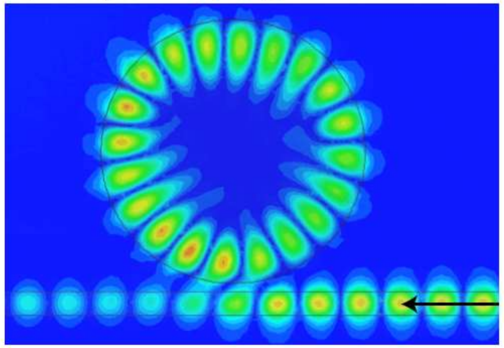
Electro-optic up-converter: how to couple mm-waves in a WGM resonator



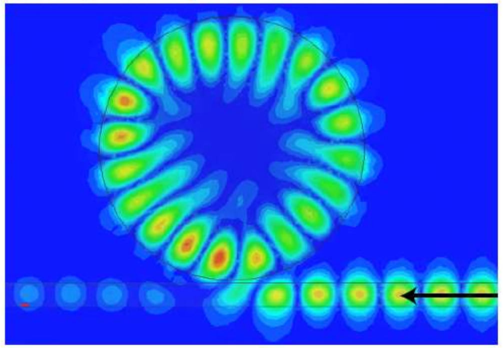




a) 200µm coupling distance



b) 20µm coupling distance

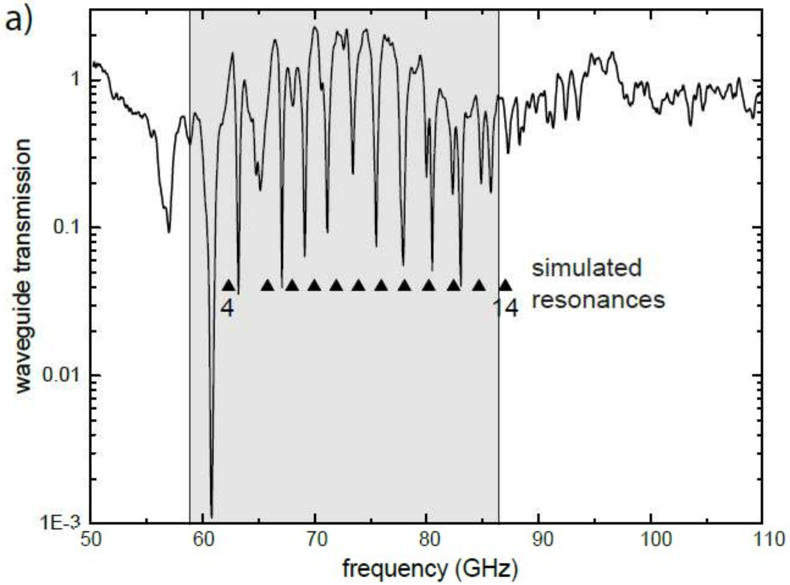


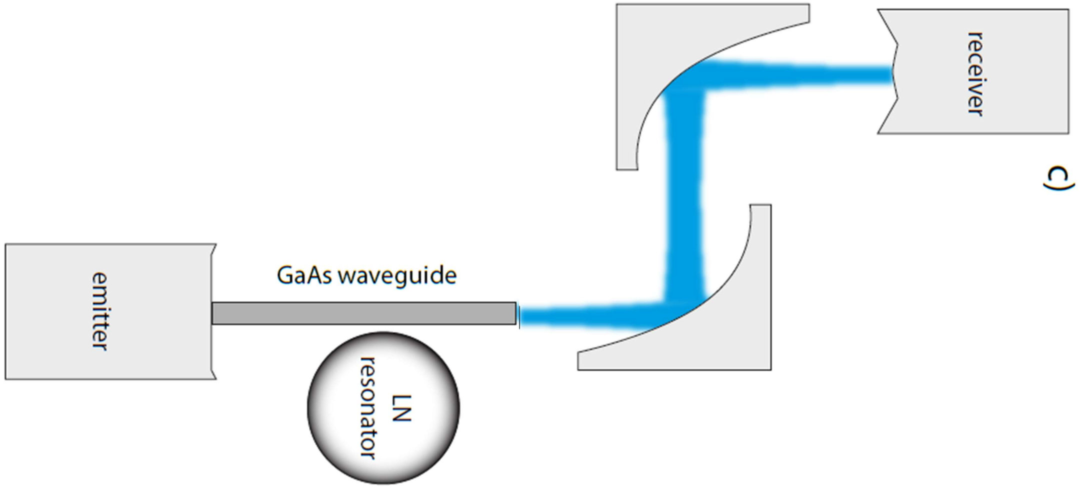
882 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 63, NO. 3, MARCH 2015

Dielectric Rod Waveguide Antenna as THz Emitter for Photomixing Devices

Alejandro Rivera-Lavado, Sascha Preu, Luis Enrique García-Muñoz, Andrey Generalov, Javier Montero-de-Paz, Gottfried Döhler, Dmitri Lioubtchenko, Mario Méndez-Aller, Florian Sedlmeir, Martin Schneidereit, Harald G. L. Schwefel, Stefan Malzer, Daniel Segovia-Vargas, and Antti V. Räisänen

Electro-optic up-converter: how to couple mm-waves in a WGM resonator



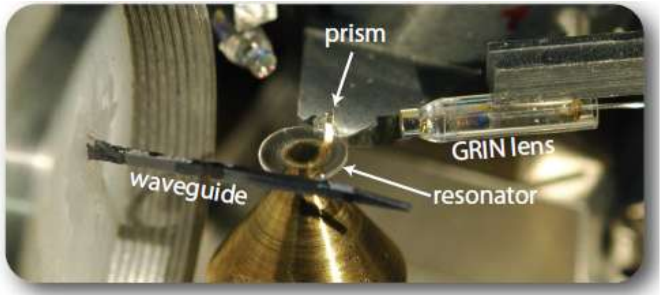


532 IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 3, NO. 5, SEPTEMBER 2013

From Arrays of THz Antennas to Large-Area Emitters

Gottfried H. Döhler, Luis Enrique Garcia-Muñoz, Sascha Preu, Stefan Malzer, Sebastian Bauerschmidt, Javier Montero-de-Paz, Eduardo Ugarte-Muñoz, Alejandro Rivera-Lavado, Vicente Gonzalez-Posadas, and Daniel Segovia-Vargas, *Member, IEEE*

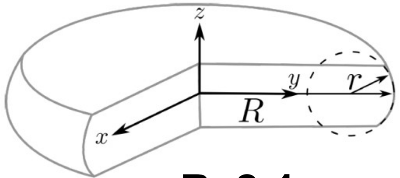
Electro-optic up-converter: experimento



n_{prism}=2,42

n_{laser}=2,14

n_{mw}=5



Q_{laser}=5x10^6 Finesse=300

Q_{mw}=100   BW=150 MHz

R=2,4 mm   r=150 µm

1550 nm laser power = 2…5 mW

Optical output efficiency = 10 dB

FSR=9,155GHz

Efficient and Coherent Conversion of 80 GHz Signals into the Optical Domain Using a Whispering Gallery Mode Resonator

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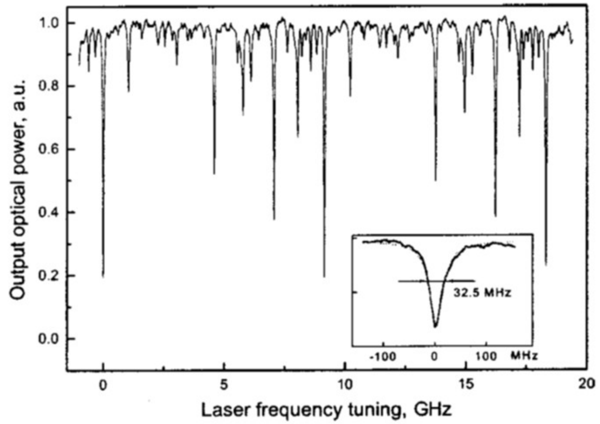
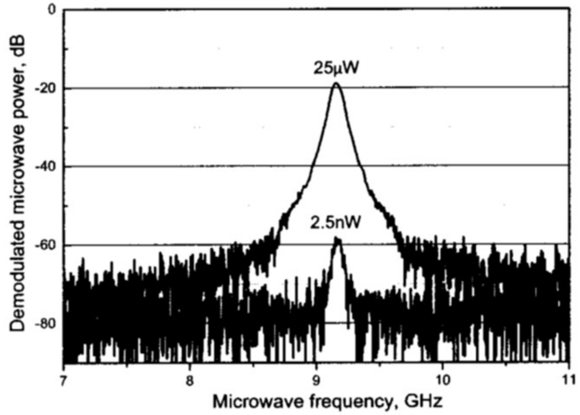
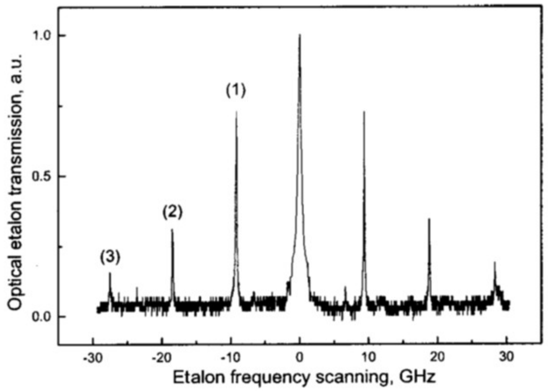
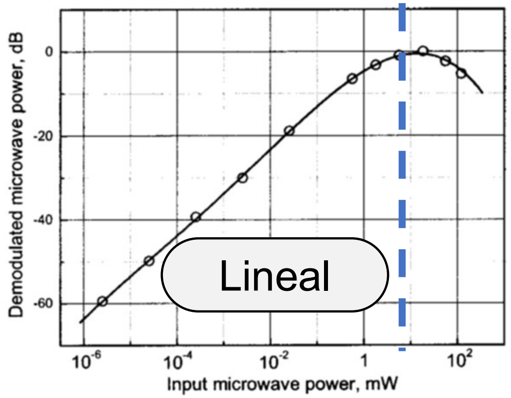


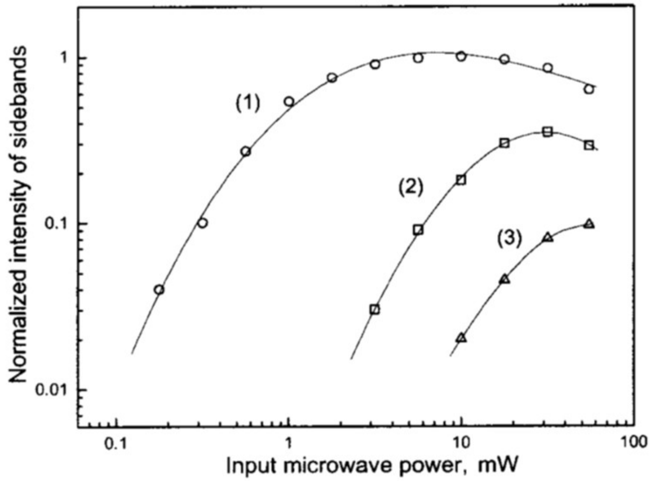


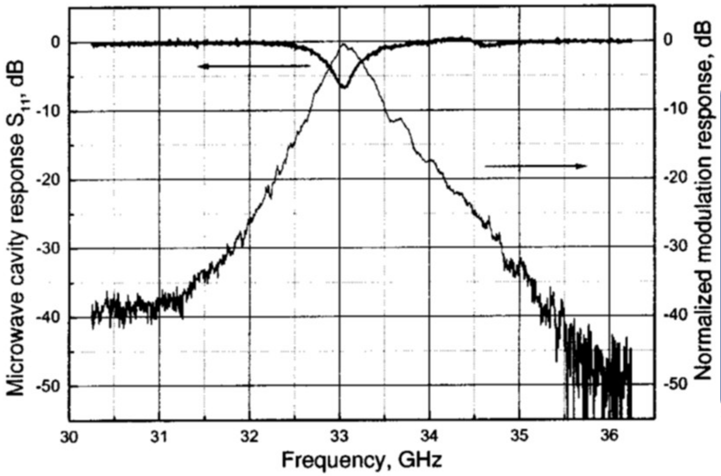
P_{mw}minimum = 1nW





Electro-optic up-converter: experimento





Efficient and Coherent Conversion of 80 GHz Signals into the Optical Domain Using a Whispering Gallery Mode Resonator

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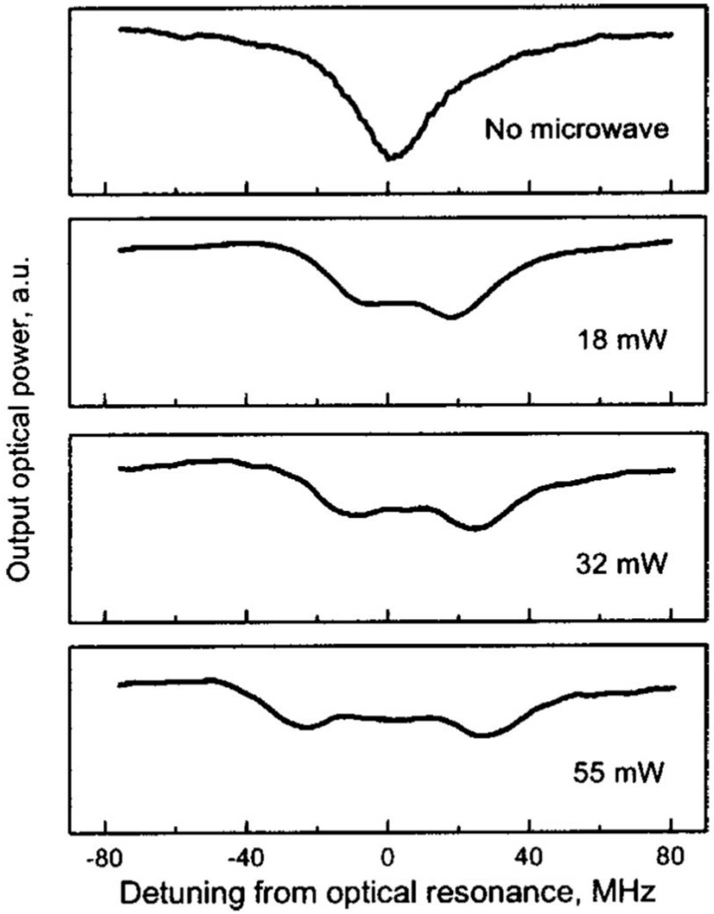
Research Article Vol. 24, No. 23 | 14 Nov 2016 | OPTICS EXPRESS 26503
Optics EXPRESS

Maximization of the optical intra-cavity power of whispering-gallery mode resonators via coupling prism

G. A. Santamaría-Botello,[1] L. E. García Muñoz,[1,*] F. Sedlmeir,[2] S. Preu,[3] D. Segovia-Vargas,[1] K. Atia Abdalmalak,[1] S. Llorente Romano,[1] A. García Lampérez,[1] S. Malzer,[4] G. H. Döhler,[4] H. G. L. Schwefel,[2] and H. B. Weber[4]



Electro-optic up-converter: aumentar la eficiencia

MILLIMETER AND SUBMILLIMETER TEAM

$$\eta_{ph} = \frac{2P_p}{\varepsilon_0\omega_\pm}\,\frac{{\chi^{(2)}}^2 Q_p^2 Q_m}{n_p^4 n_m^2}\,\frac{E_m'^2(\boldsymbol{r}_p)}{V_m}\,\left(\mathbf{1} - \boldsymbol{S}_{11}^2 - \boldsymbol{S}_{21}^2\right)$$

Research Article Vol. 24, No. 23 | 14 Nov 2016 | OPTICS EXPRESS 26503
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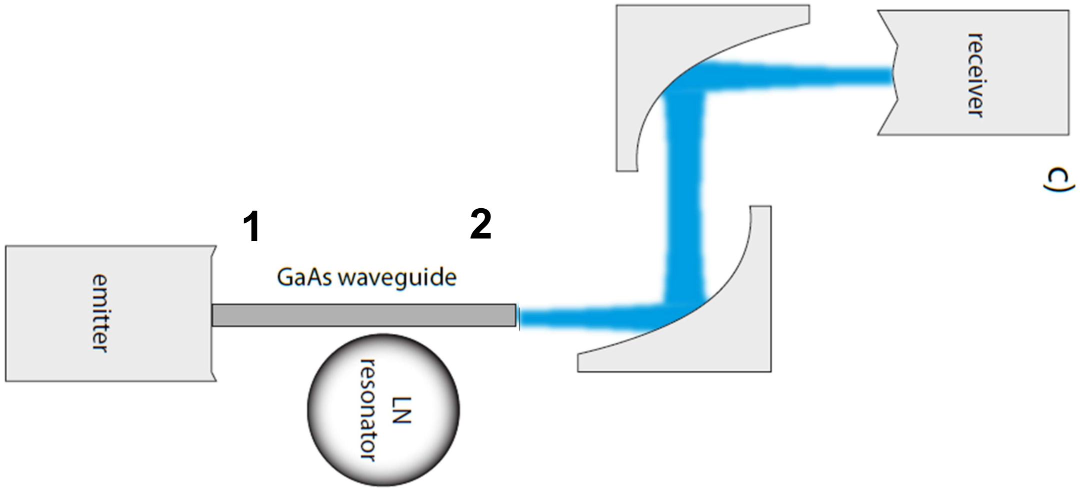
Topical Review

Nonlinear and Quantum Optics with Whispering Gallery Resonators

Dmitry V Strekalov[1,2], Christoph Marquardt[2,3], Andrey B Matsko[4], Harald G L Schwefel[2,3,5] and Gerd Leuchs[2,3]



Electro-optic up-converter: aumentar la eficiencia

MILLIMETER AND SUBMILLIMETER TEAM

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1

Limited to:

The <u>application (frequency)</u>

The <u>maximum optical power</u> that the resonator can handle

Electro-optic up-converter: aumentar la eficiencia

MILLIMETER AND SUBMILLIMETER TEAM

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2

Depends on the selection of the <u>material</u> of the WGM resonator

Electro-optic up-converter: aumentar la eficiencia

MILLIMETER AND SUBMILLIMETER TEAM

Material	$\chi^{(2)}$(pm/V)	n_p	n_m	Q_p	Q_m	$\frac{{\chi^{(2)}}^2 Q_p^2 Q_m}{n_p^4 n_m^2}$
Lithium tantalate ($LiTaO_3$)	155	2.116	6.29	5.7×10^8	150	1.5×10^{-3}
Lithium Niobate ($LiNbO_3$)	151	2.138	4.95	1×10^8	200	8.9×10^{-5}
Quartz (SiO_2)	0.4	1.536	2.11	5×10^7	5000	8.1×10^{-8}
Aluminium nitride (AlN)	5	2.16	2.88	6×10^5	2000	1.0×10^{-10}
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Electro-optic up-converter: aumentar la eficiencia

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Electro-optic up-converter: aumentar la eficiencia

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Electro-optic up-converter: aumentar la eficiencia

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3

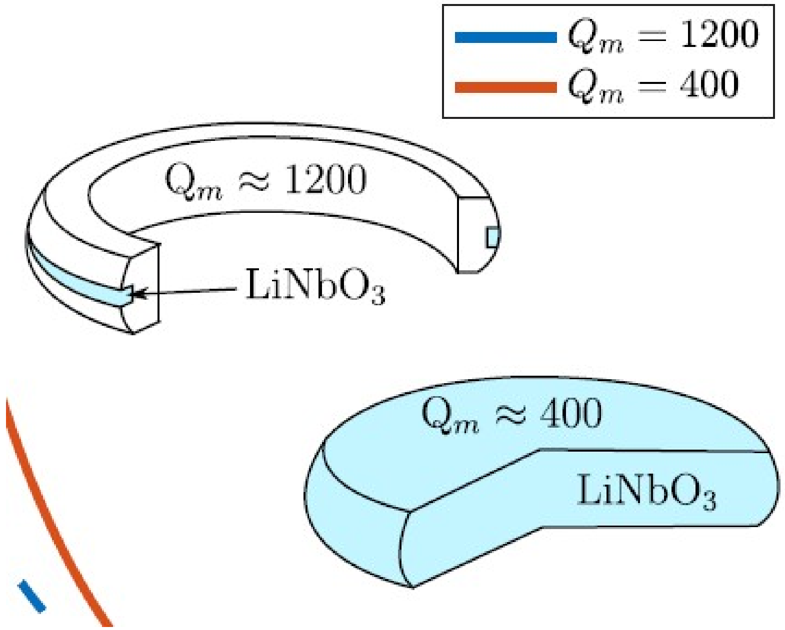
Depends on the <u>geometry of the resonator</u>, the overlap between both input signals needs to be maximized by:

Pushing the microwave mode's maximum intensity towards the rim of the resonator

Decreasing the mode volume of the microwave signal

Electro-optic up-converter: aumentar la eficiencia

$$\eta_{ph} = \frac{2P_p}{\varepsilon_0 \omega_\pm} \frac{{\chi^{(2)}}^2 Q_p^2 Q_m}{n_p^4 n_m^2} \frac{E_m'^2(\boldsymbol{r}_p)}{V_m} \left(\boldsymbol{1} - \boldsymbol{S}_{\boldsymbol{11}}^{\boldsymbol{2}} - \boldsymbol{S}_{\boldsymbol{21}}^{\boldsymbol{2}}\right)$$



Electro-optic up-converter: aumentar la eficiencia

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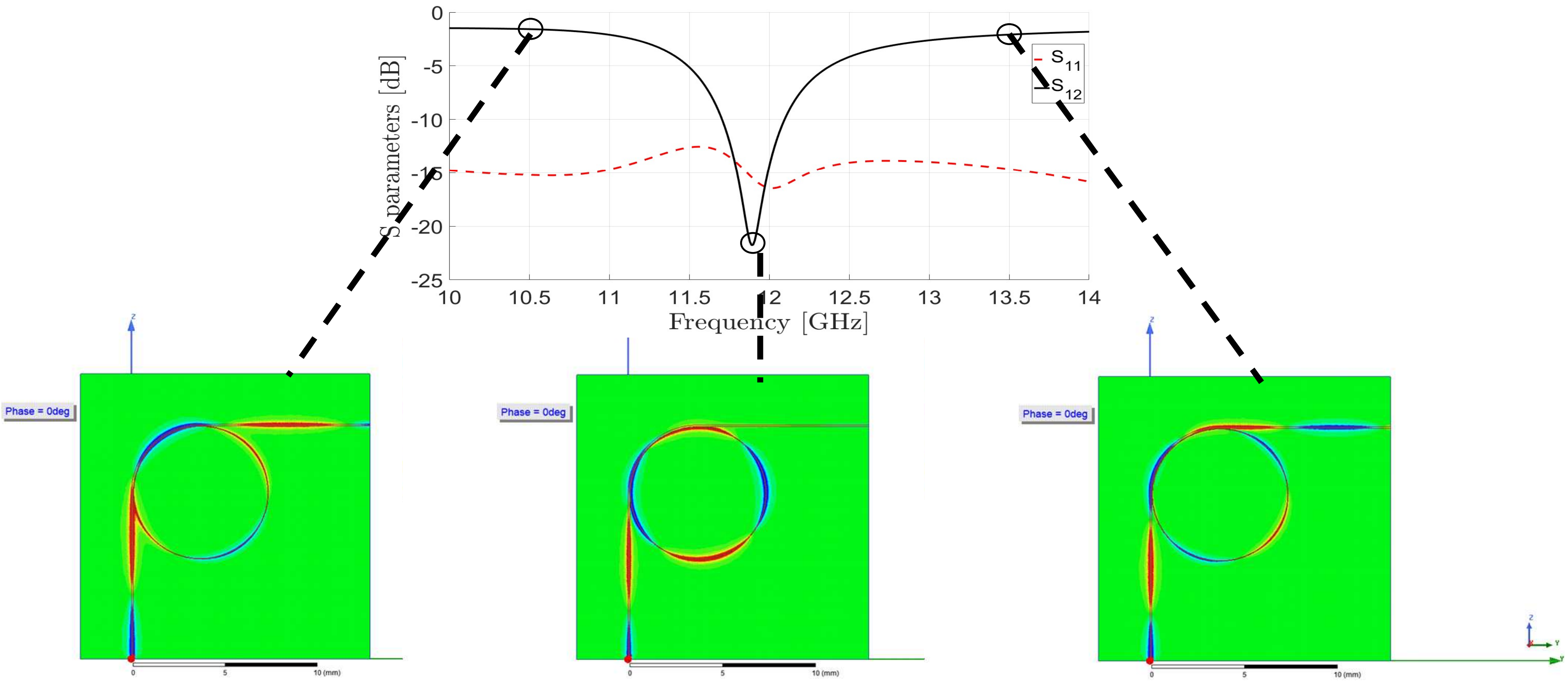
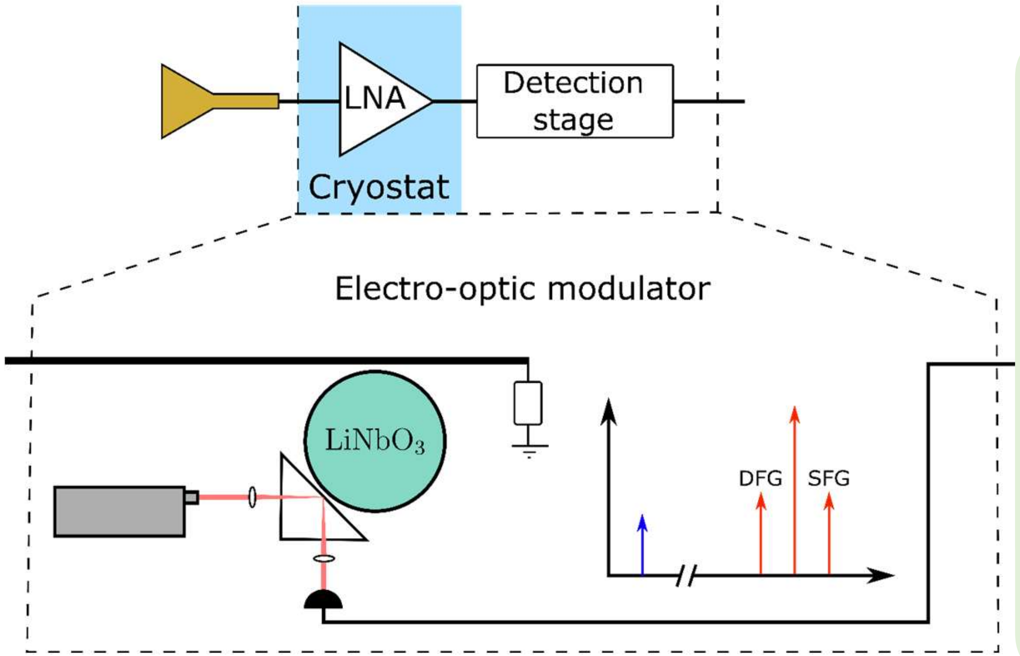


Índice

MILLIMETER AND SUBMILLIMETER TEAM

Electro-optic up-converter: challenges



Challenges:

1. High conversion efficiency:

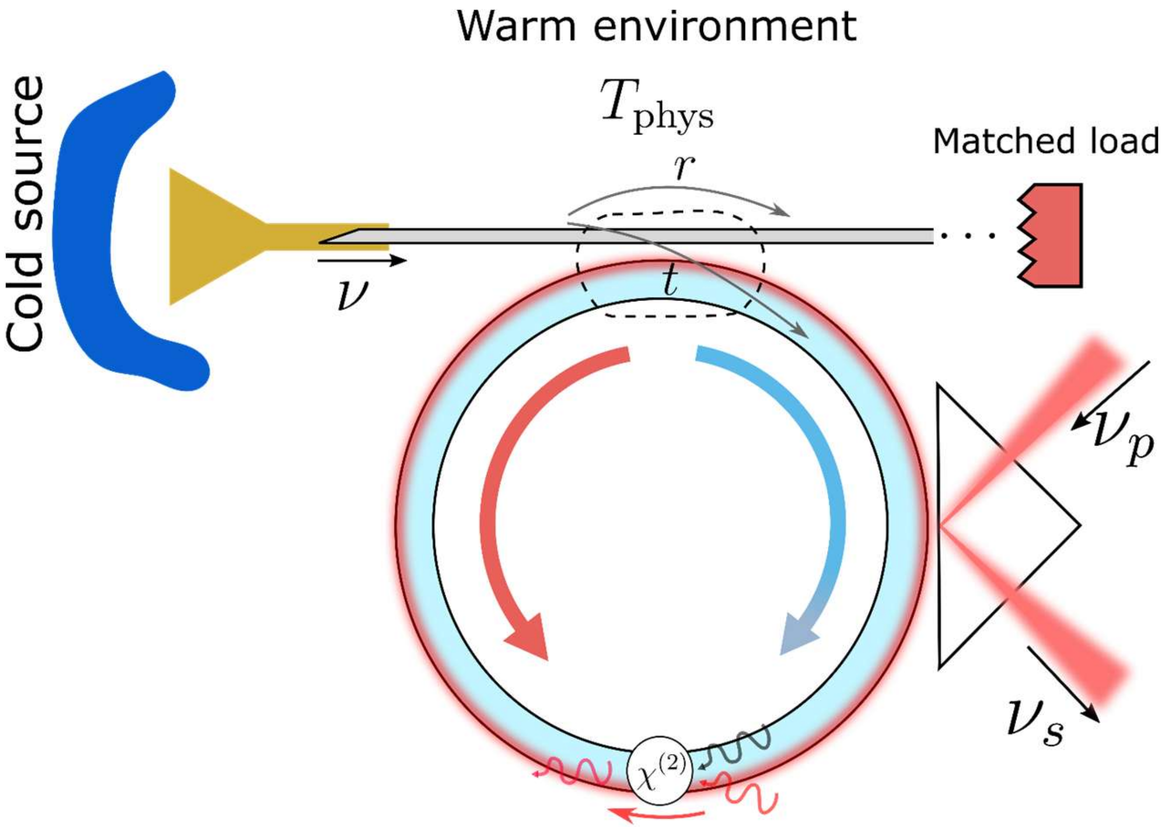
$$\eta = \frac{\#\text{ of upconverted photons}}{\#\text{ of input microwave photons}}$$

2. **Avoid thermal noise being upconverted**

3. Phase matching

4. High upconversion bandwidth

Electro-optic up-converter: ocupación térmica



Hot matched load

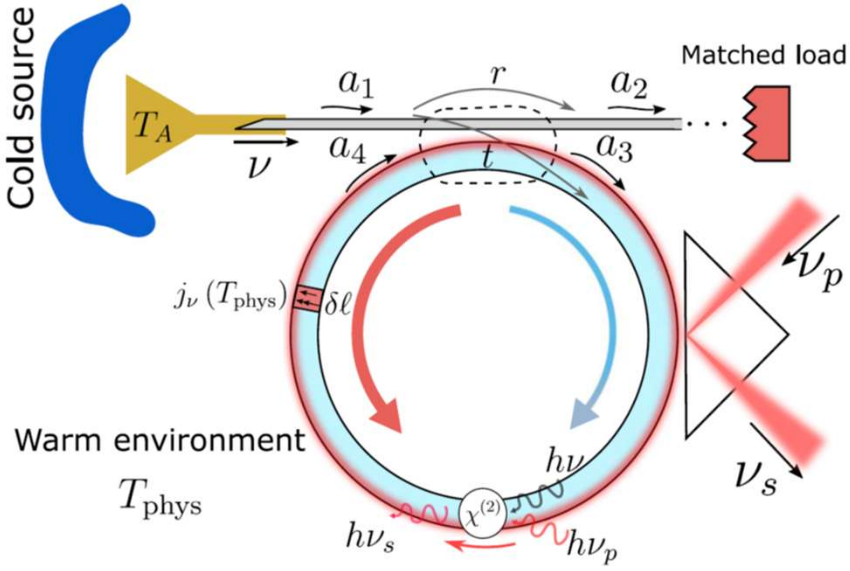
Thermal noise from thermic bath

Thermal noise from horn+waveguide

Thermal noise from the resonator

Electro-optic up-converter: ruido inherente al resonador

MILLIMETER AND SUBMILLIMETER TEAM



Thermal equilibrium

$$|j_\nu(T_{\rm phys})|^2 = h\nu(1-\underbrace{\exp(-2\alpha\delta\ell)}_{a^2})\Theta_\nu(T_{\rm phys}).$$

$$\Theta_\nu(T) = [\exp(h\nu/(k_B T)) - 1]^{-1}$$

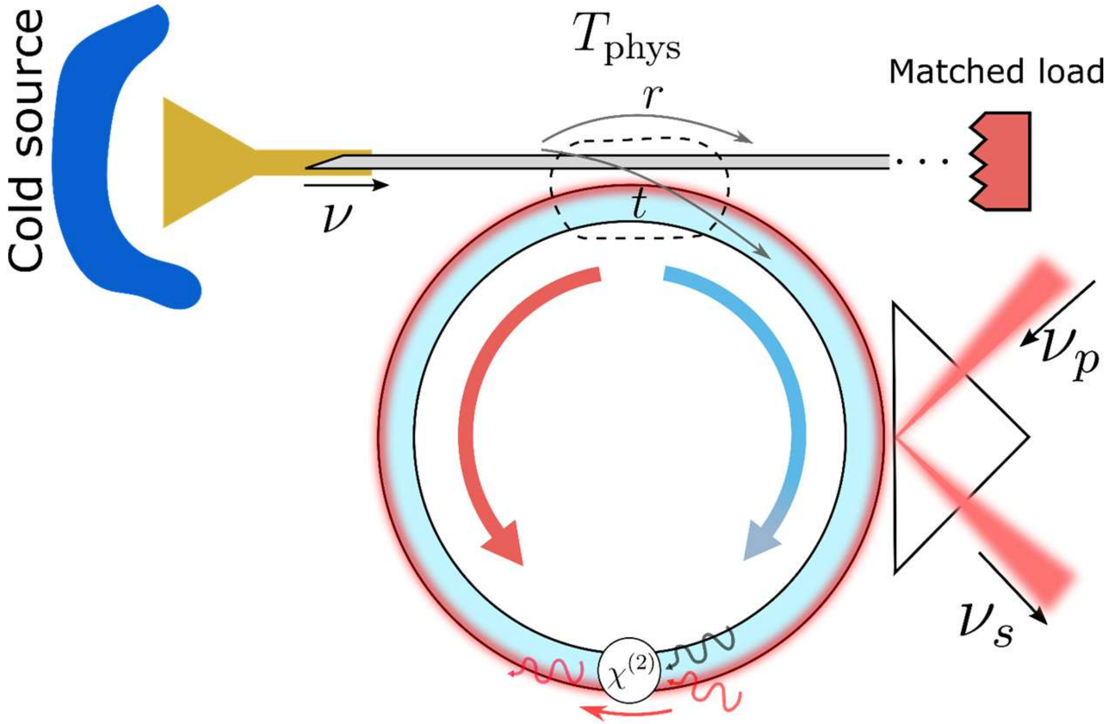
$$|s_T(\nu,\ell_2)|^2 = \underbrace{\frac{a^{2\ell_2/L}(1-|r|^2)}{|1-a|r|\exp(i2\pi\tau\delta\nu)|^2}h\nu\Theta_\nu(T_A)}_{\text{Antenna contribution}} + \underbrace{\frac{1-|r|^2a^2-(1-|r|^2)a^{2\ell_2/L}}{|1-a|r|\exp(i2\pi\tau\delta\nu)|^2}h\nu\Theta_\nu(T_{\rm phys})}_{\text{``Hot'' resonator contribution}}$$

$$P_s \propto \frac{(1-a^2)(1-|r|^2)}{\ln(a^{-2})}h\nu[\Theta_\nu(T_A)+\Theta_\nu(T_{\rm eff})].$$

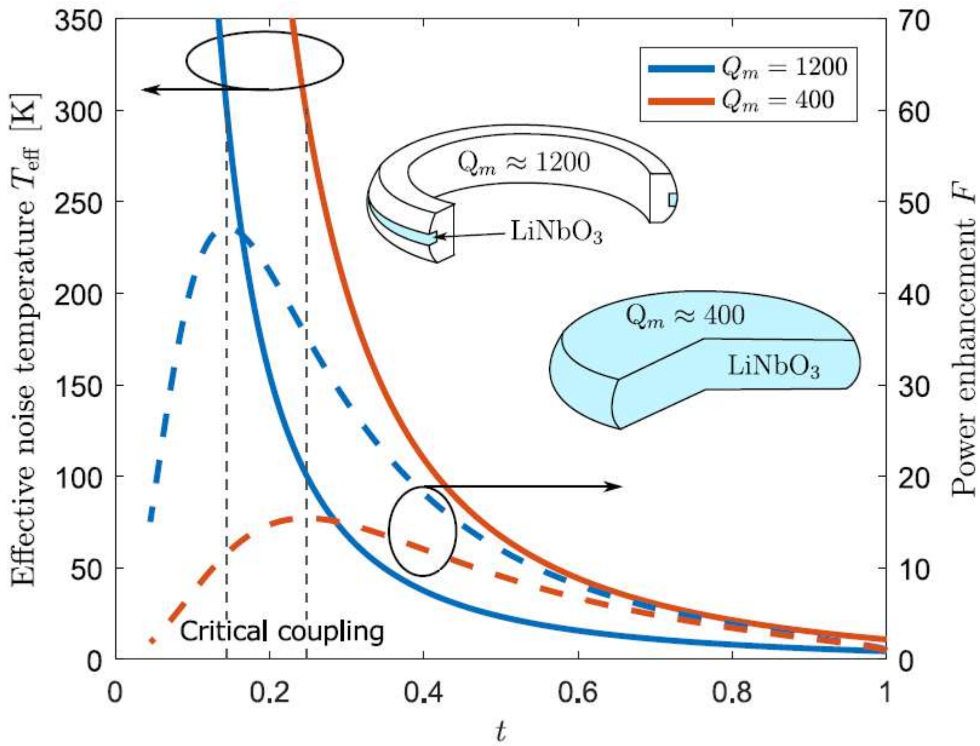
$$\Theta_\nu(T_{\rm eff}) = \left[\frac{(1-a^2|r|^2)\ln(a^{-2})}{(1-a^2)(1-|r|^2)} - 1\right]\Theta_\nu(T_{\rm phys}).$$

$$T_{\rm eff} = \left[\frac{(1-a^2|r|^2)\ln(a^{-2})}{(1-a^2)(1-|r|^2)} - 1\right]T_{\rm phys}.$$

Electro-optic up-converter: ruido inherente al resonador



$$T_{\text{eff}} = \left[\frac{(1 - a^2|r|^2)\ln(a^{-2})}{(1 - a^2)(1 - |r|^2)} - 1\right] T_{\text{phys}}.$$



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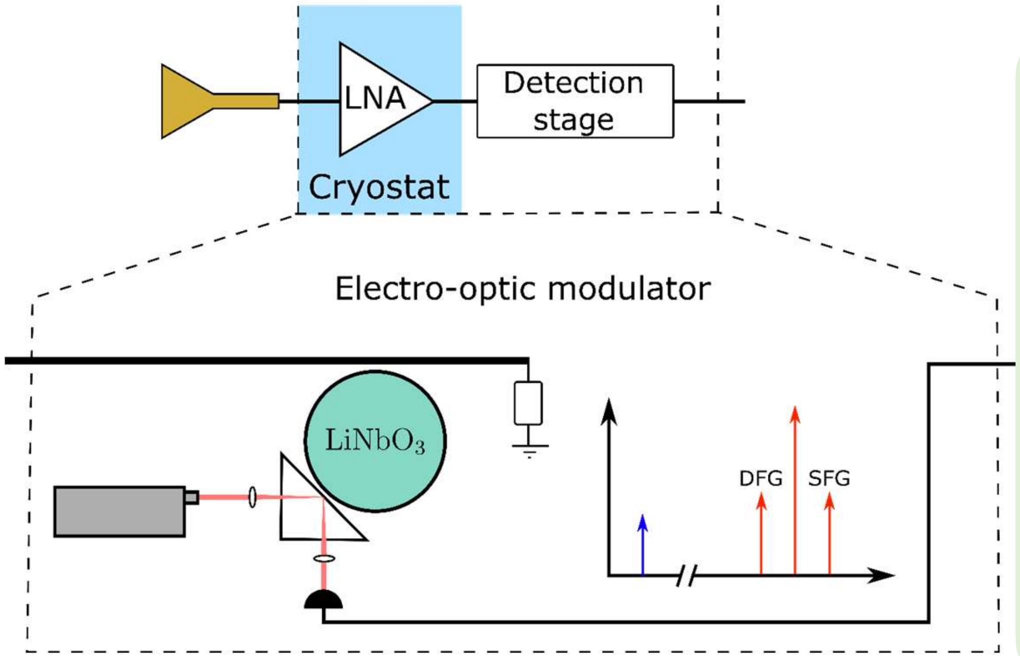
MILLIMETER AND SUBMILLIMETER TEAM

Electro-optic up-converter: challenges



Challenges:

1. High conversion efficiency:

$$\eta = \frac{\#\text{ of upconverted photons}}{\#\text{ of input microwave photons}}$$

2. Avoid thermal noise being upconverted

3. **Phase matching**

4. High upconversion bandwidth

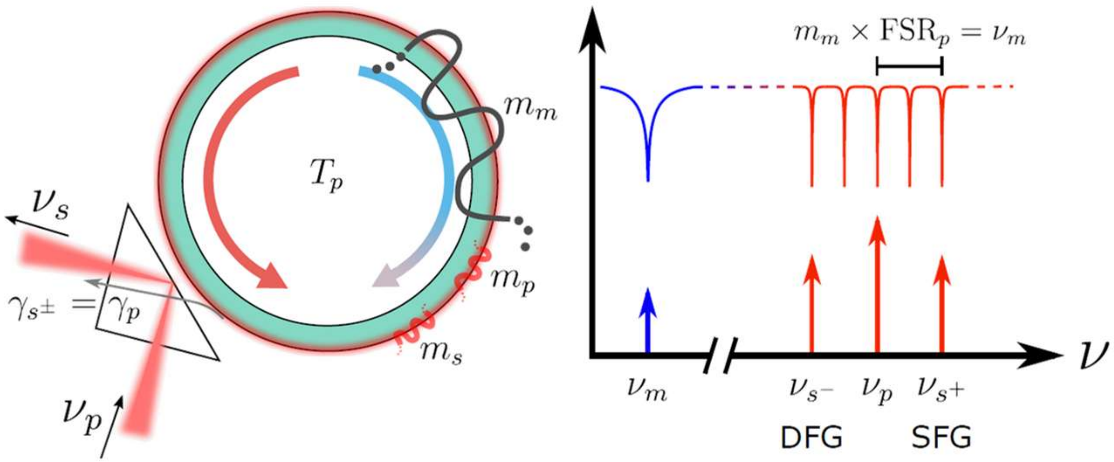
Electro-optic up-converter: realizing phase matching

==Momentum conservation== constrains mode azimuthal numbers to fullfill the relation:

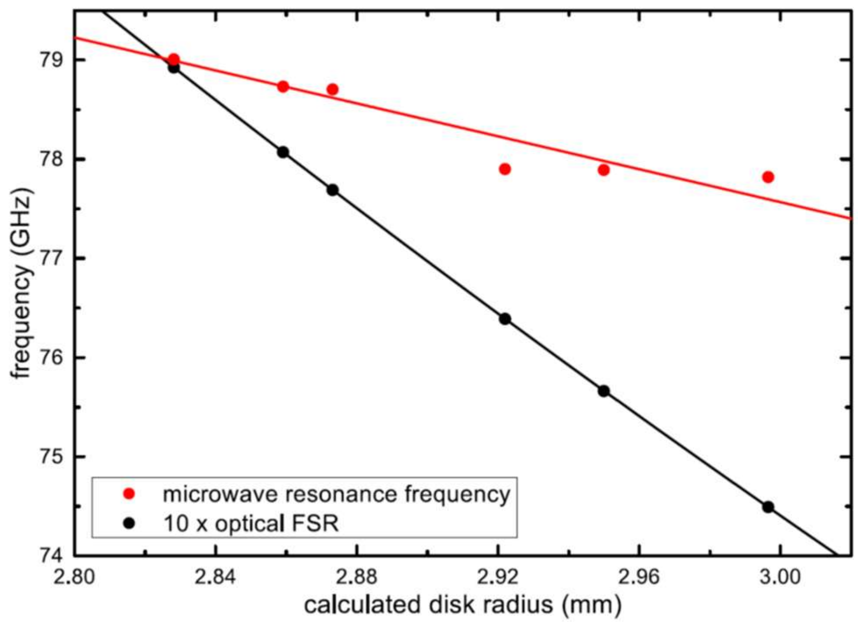
$$m_s = m_p \pm m_m$$

==Energy conservation== constrains the frequency to fullfill the relation

$$f_s = f_p \pm f_m$$

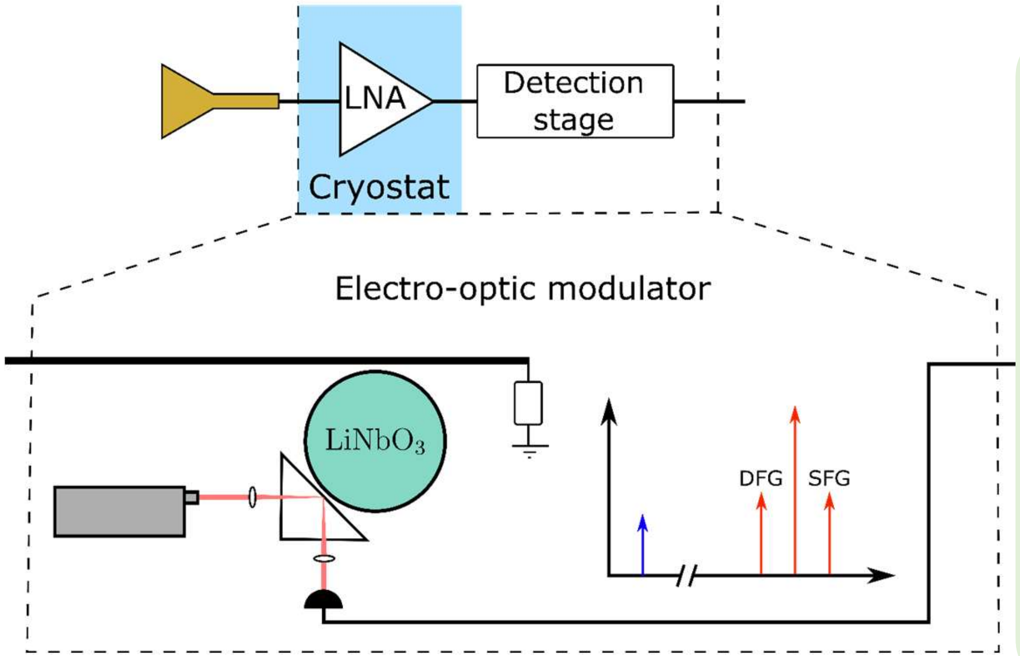


Since the prism couples both optical modes with the same rate, the sideband must also be resonant. Narrowband up-conversion! ≈ 2 MHz for 1550 nm light and $Q \approx 10^8$ cavity



Índice

Electro-optic up-converter: challenges



Challenges:

1. High conversion efficiency:

$$\eta = \frac{\#\text{ of upconverted photons}}{\#\text{ of input microwave photons}}$$

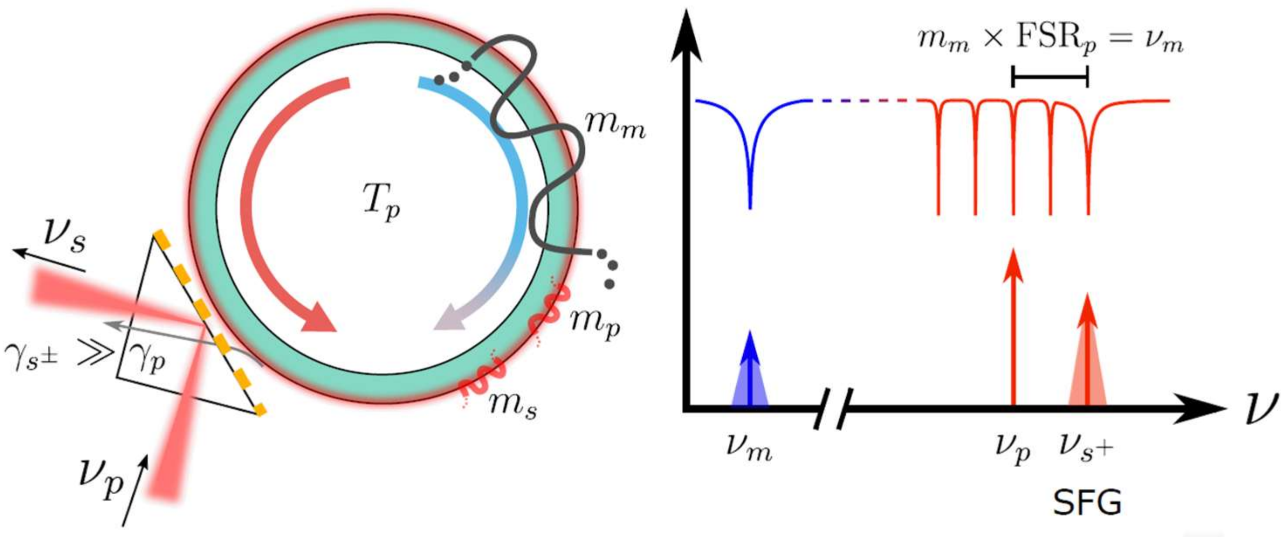
2. Avoid thermal noise being upconverted

3. Phase matching

4. **High upconversion bandwidth**

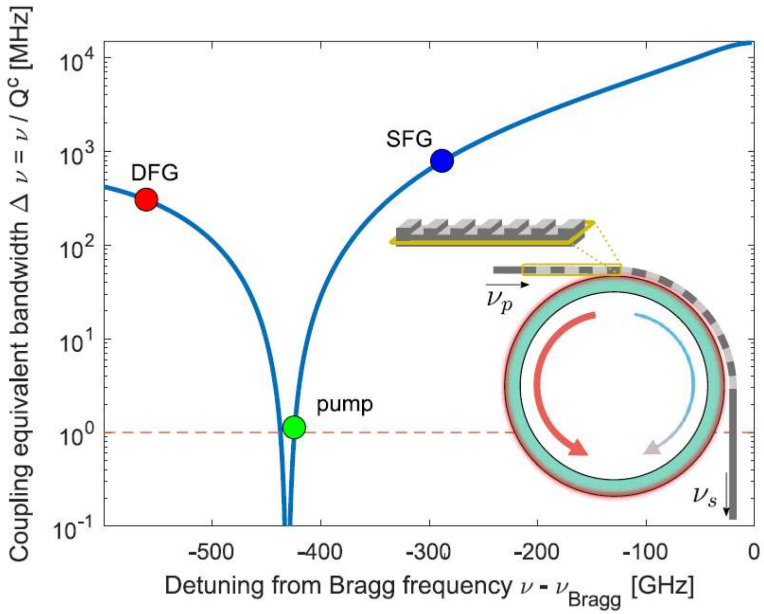
Electro-optic up-converter: increasing bandwidth

Finding a strong mode selective coupler

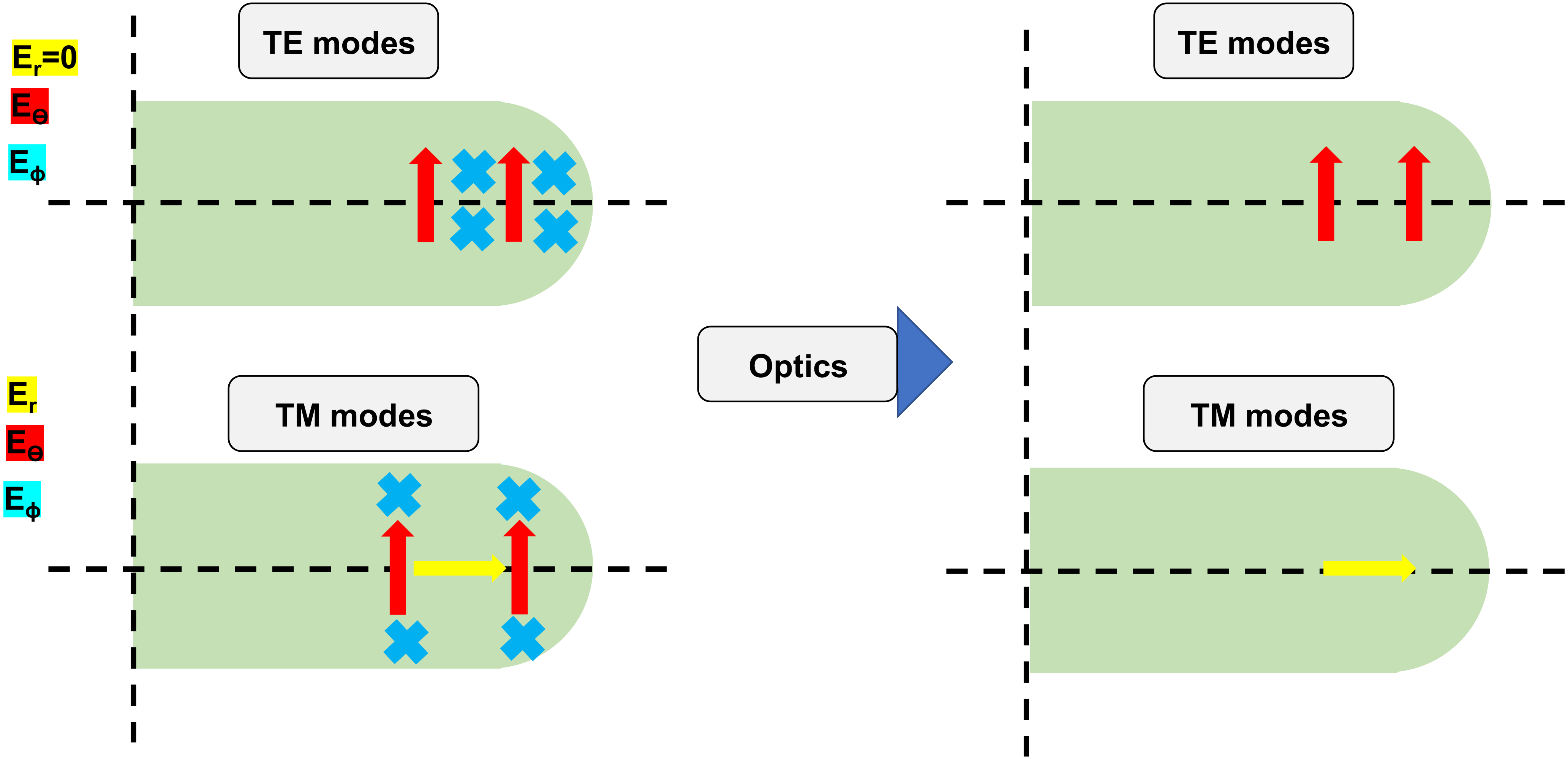


Grating etched in optical silicon coupling waveguide.

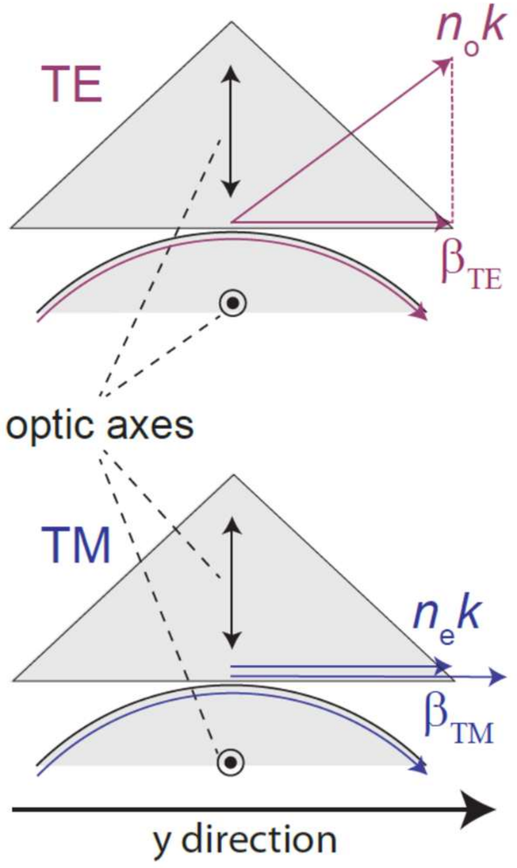
Preliminary theoretical study with coupled-mode theory shows 800 MHz upconversion bandwidth of 130 GHz signals.



Electro-optic up-converter: increasing bandwidth



Electro-optic up-converter: increasing bandwidth

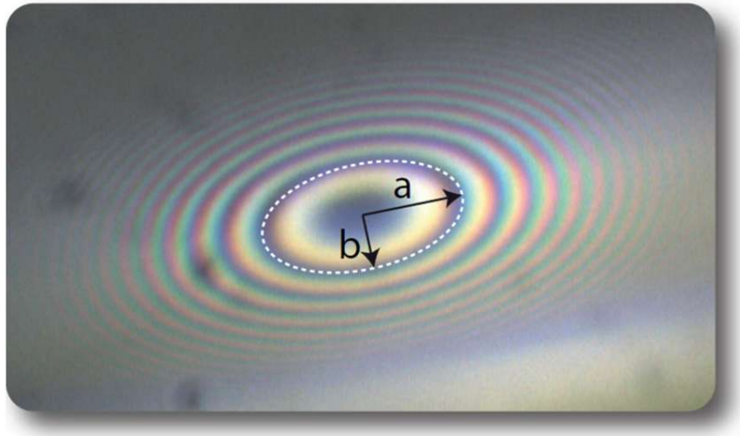


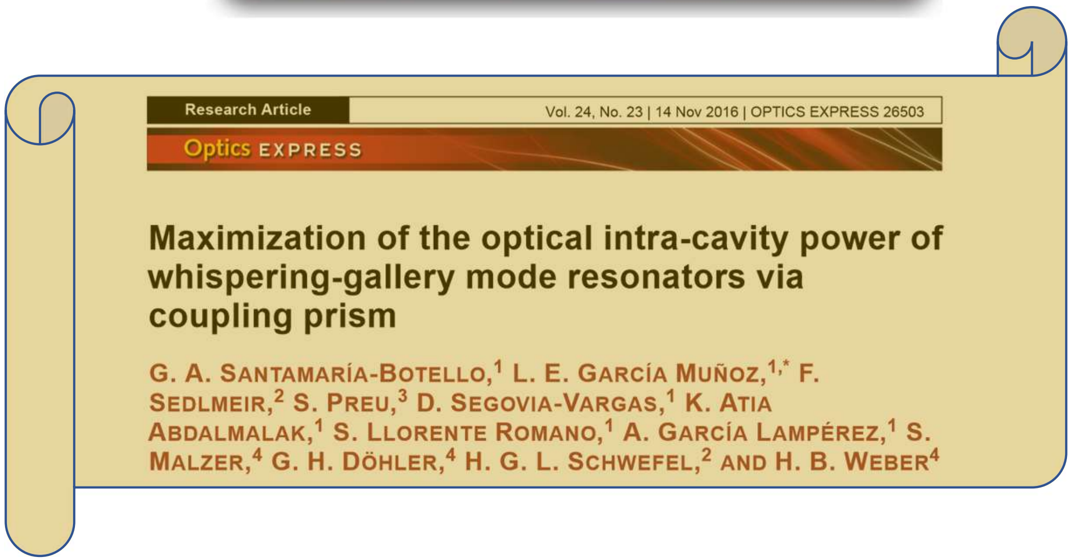
$n_{o\_prism} > n_{e\_res}$

Coupling

$n_{e\_prism} < n_{o\_res}$

No coupling



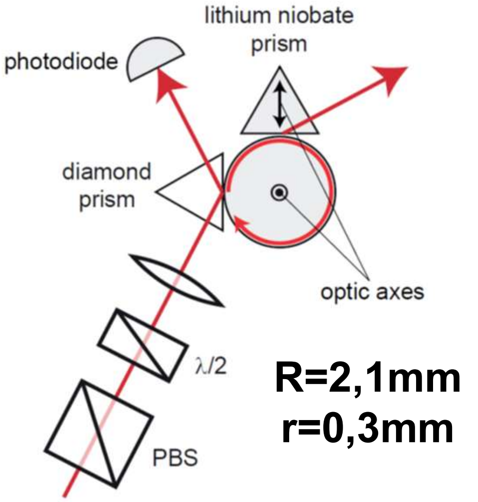


Research Article
Vol. 24, No. 23 | 14 Nov 2016 | OPTICS EXPRESS 26503
Optics EXPRESS

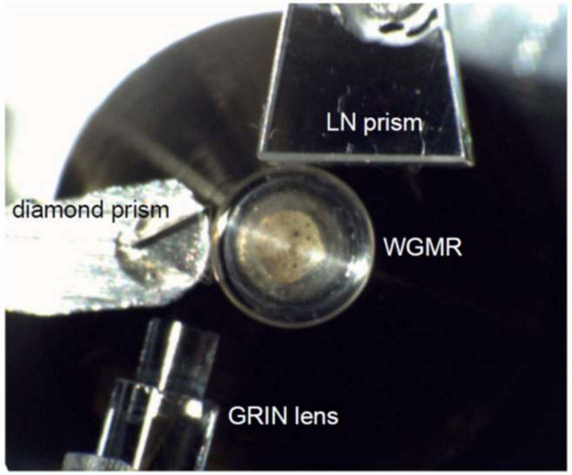
Maximization of the optical intra-cavity power of whispering-gallery mode resonators via coupling prism

G. A. SANTAMARÍA-BOTELLO,[1] L. E. GARCÍA MUÑOZ,[1,*] F. SEDLMEIR,[2] S. PREU,[3] D. SEGOVIA-VARGAS,[1] K. ATIA ABDALMALAK,[1] S. LLORENTE ROMANO,[1] A. GARCÍA LAMPÉREZ,[1] S. MALZER,[4] G. H. DÖHLER,[4] H. G. L. SCHWEFEL,[2] AND H. B. WEBER[4]

Electro-optic up-converter: experiment for increasing bandwidth



R=2,1mm
r=0,3mm

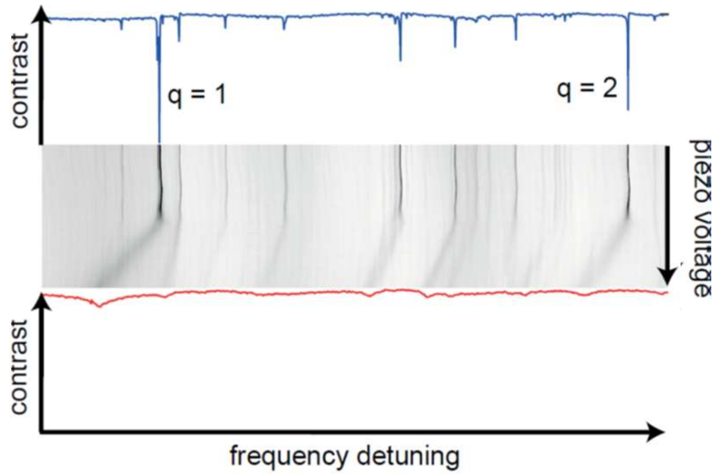


Coupling to the LN prism

TE modes { n_{e_res}, n_{o_prism}

Q=8,8x10⁷

Δv_{TE}=2,2 MHz

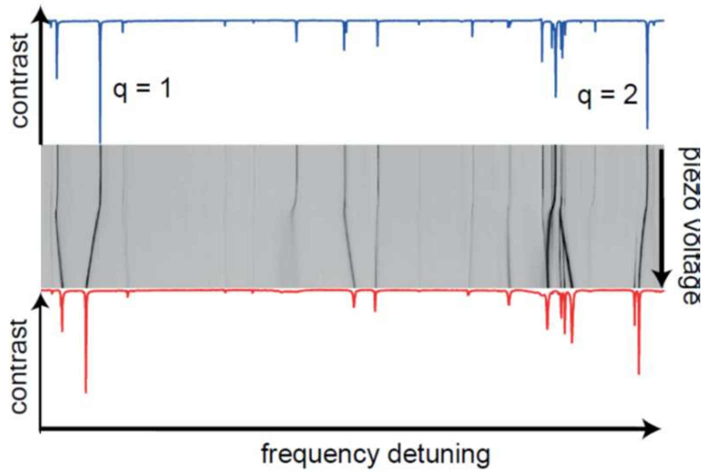


No coupling to the LN prism

TM modes { n_{o_res}, n_{e_prism}

Q=1,9x10⁸

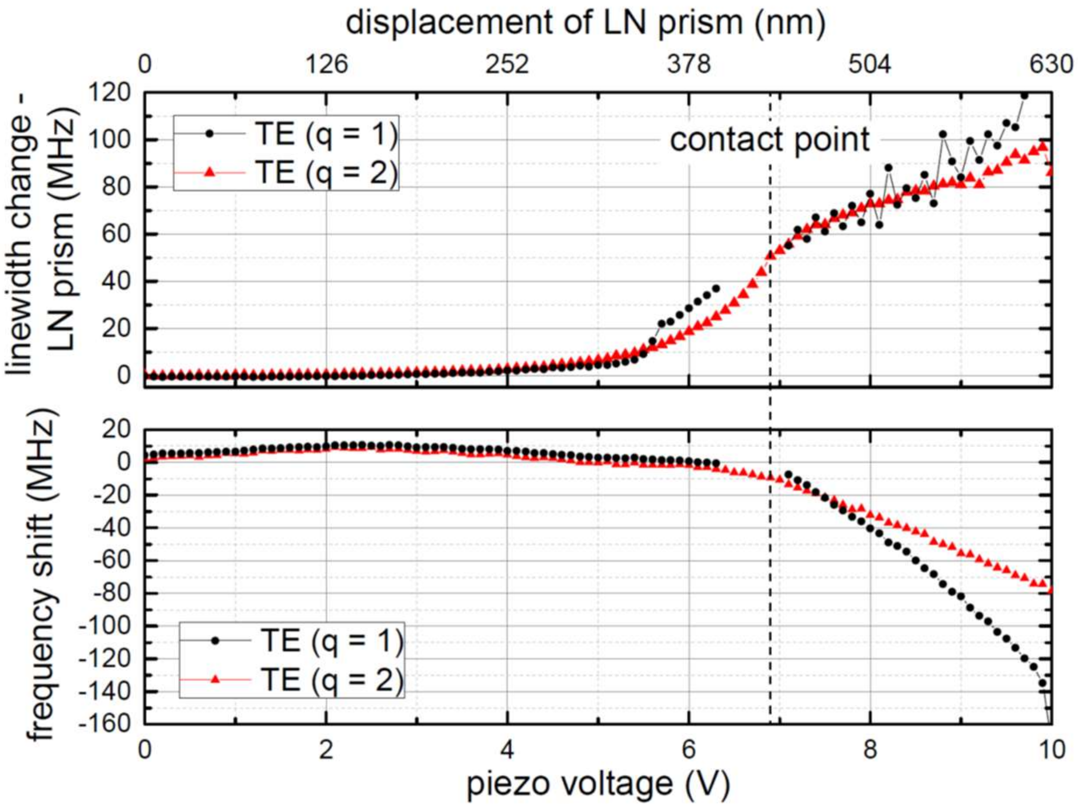
Δv_{TE}=1 MHz

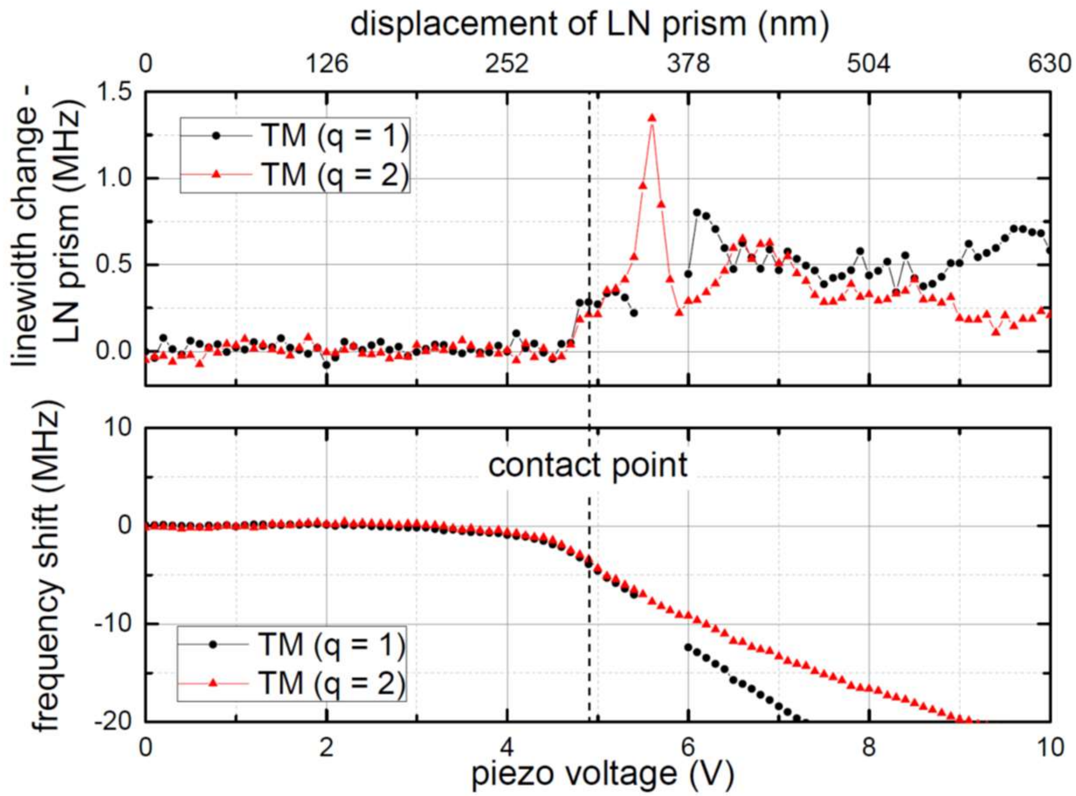


Electro-optic up-converter: experiment for increasing bandwidth

MILLIMETER AND SUBMILLIMETER TEAM

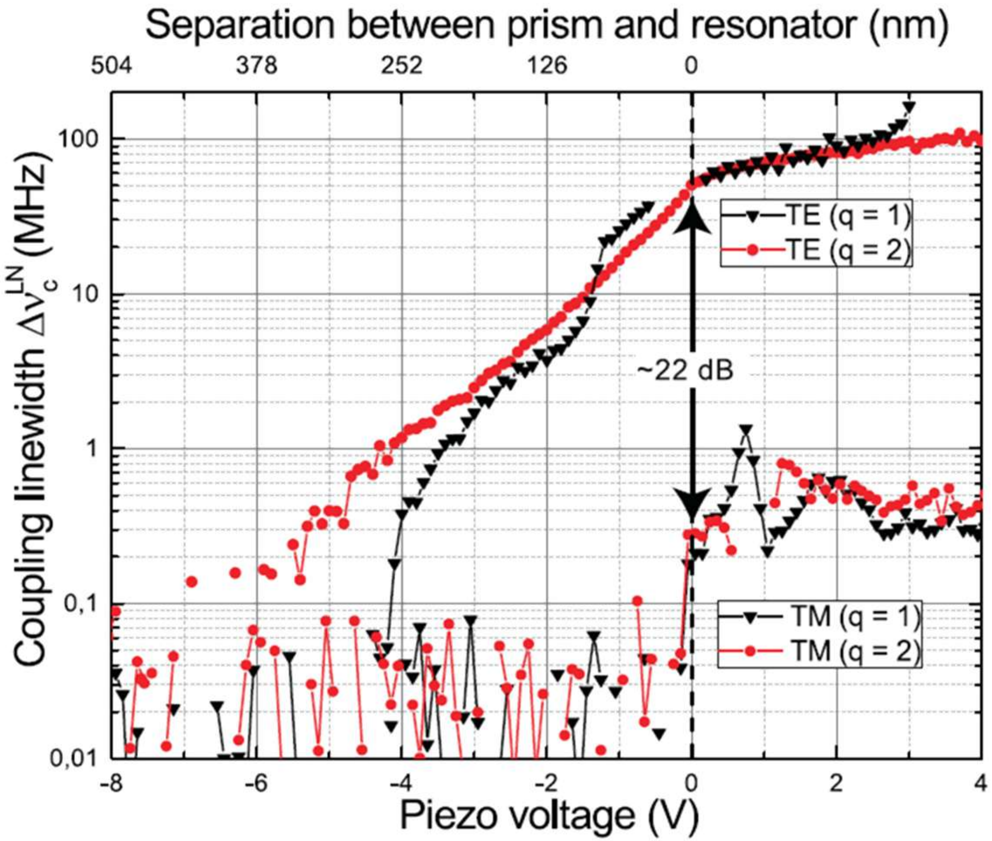
Piezo 0,1V=6,3nm



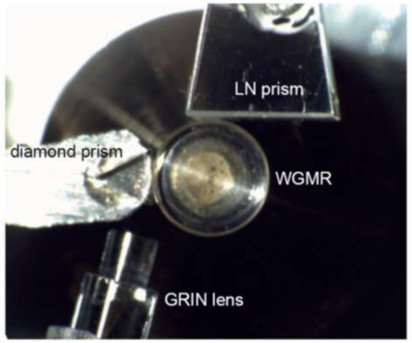


Electro-optic up-converter: experiment for increasing bandwidth

MILLIMETER AND SUBMILLIMETER TEAM



Up to 100 MHz coupling bandwidth difference between TE and TM modes



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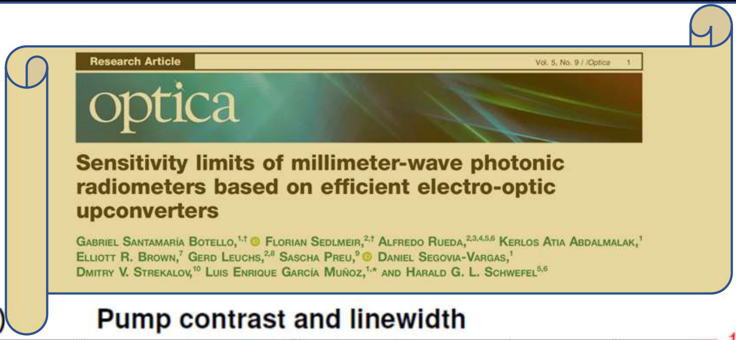
Electro-optic up-converter: increasing bandwidth, SHG experiment


Research Article

Vol. 5, No. 9 / Optica 1

optica

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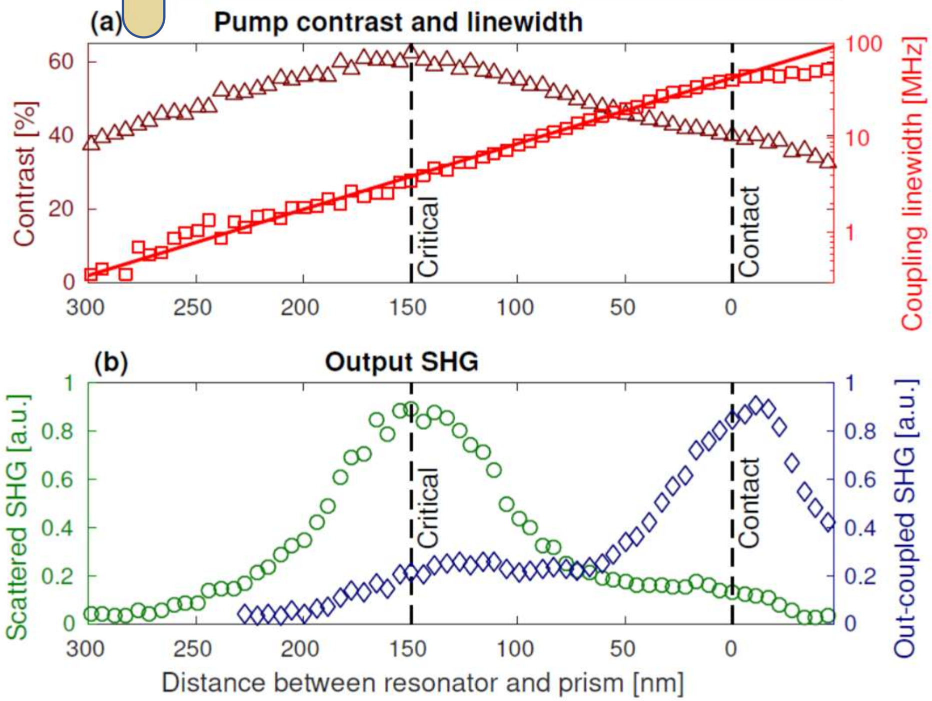
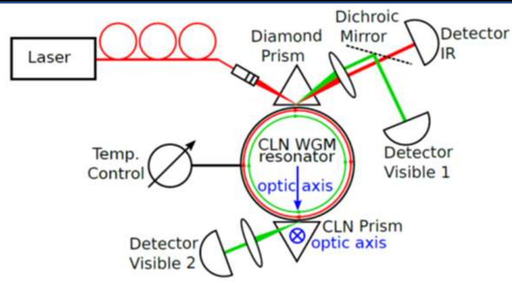
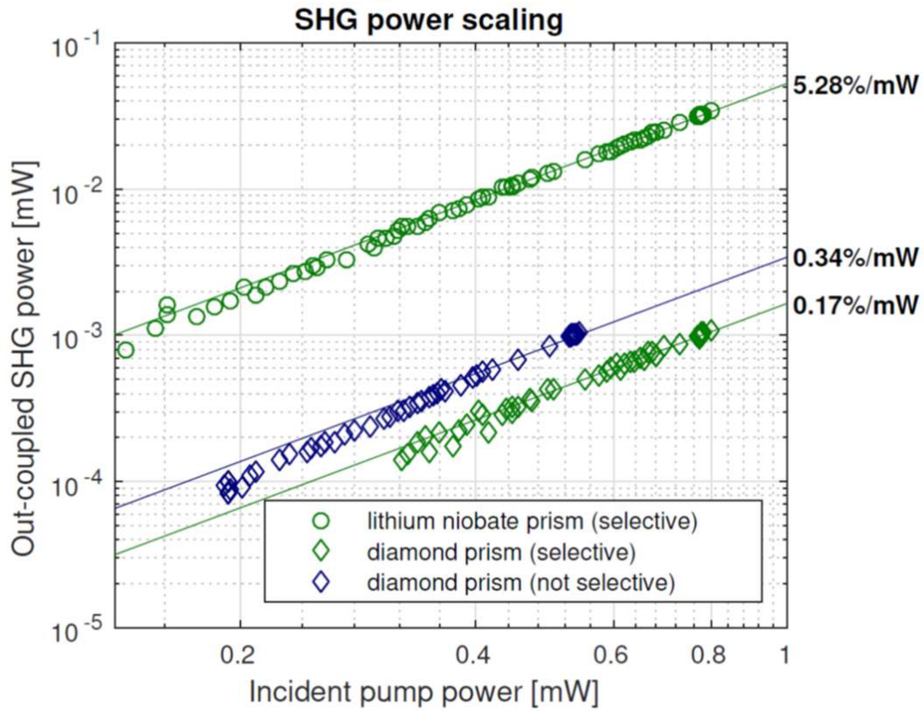


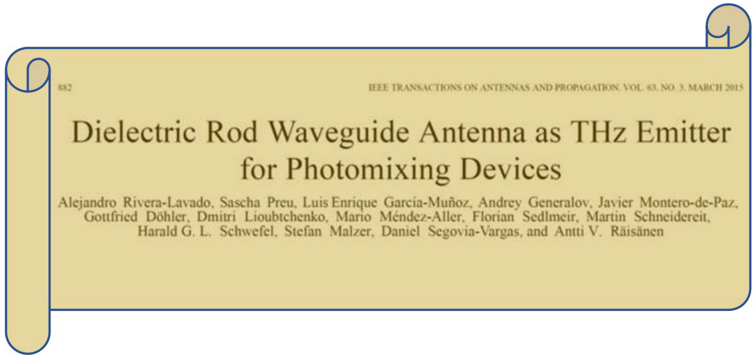




Índice

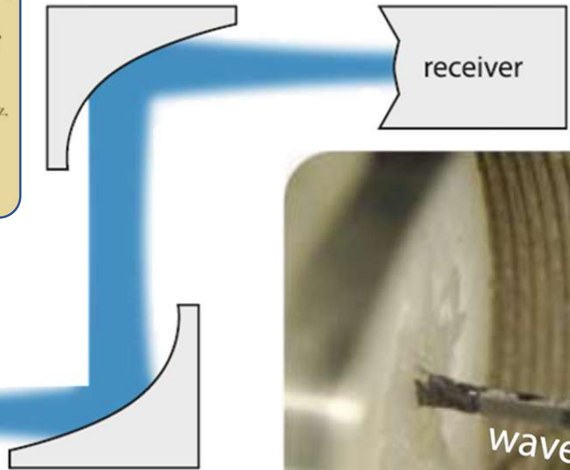
Electro-optic up-converter: Experimental proof of concept

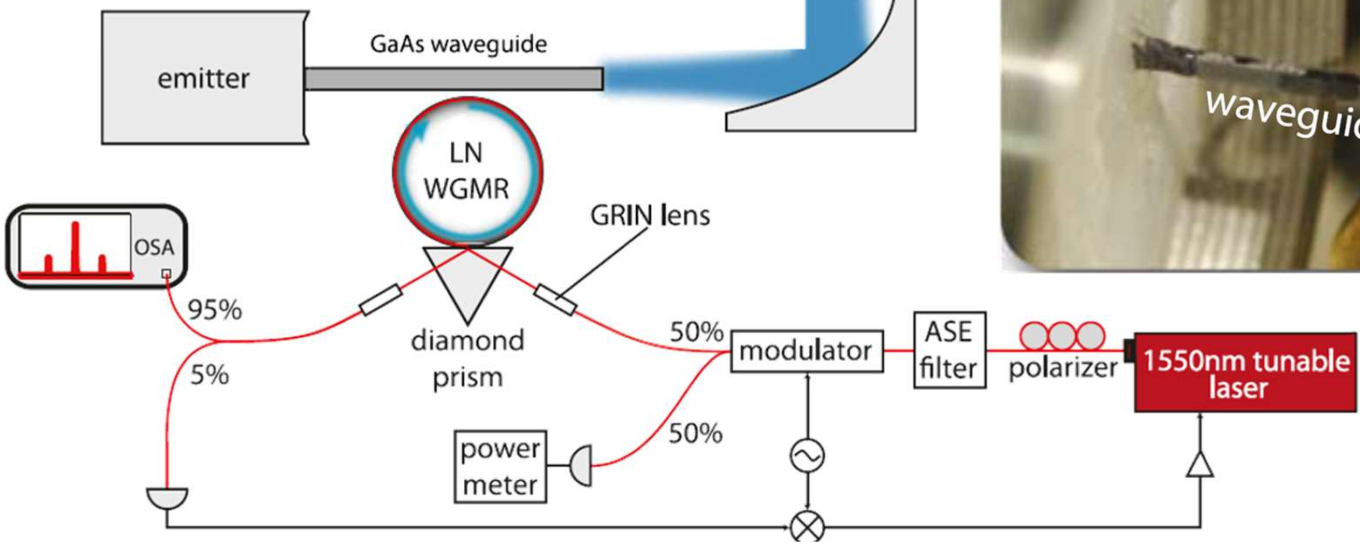
MILLIMETER AND SUBMILLIMETER TEAM

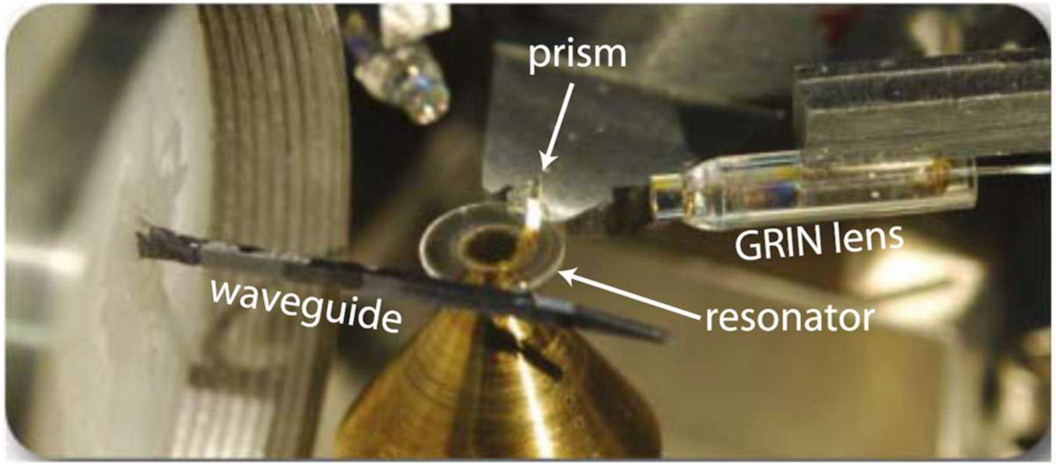

882 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 63, NO. 3, MARCH 2015

Dielectric Rod Waveguide Antenna as THz Emitter for Photomixing Devices

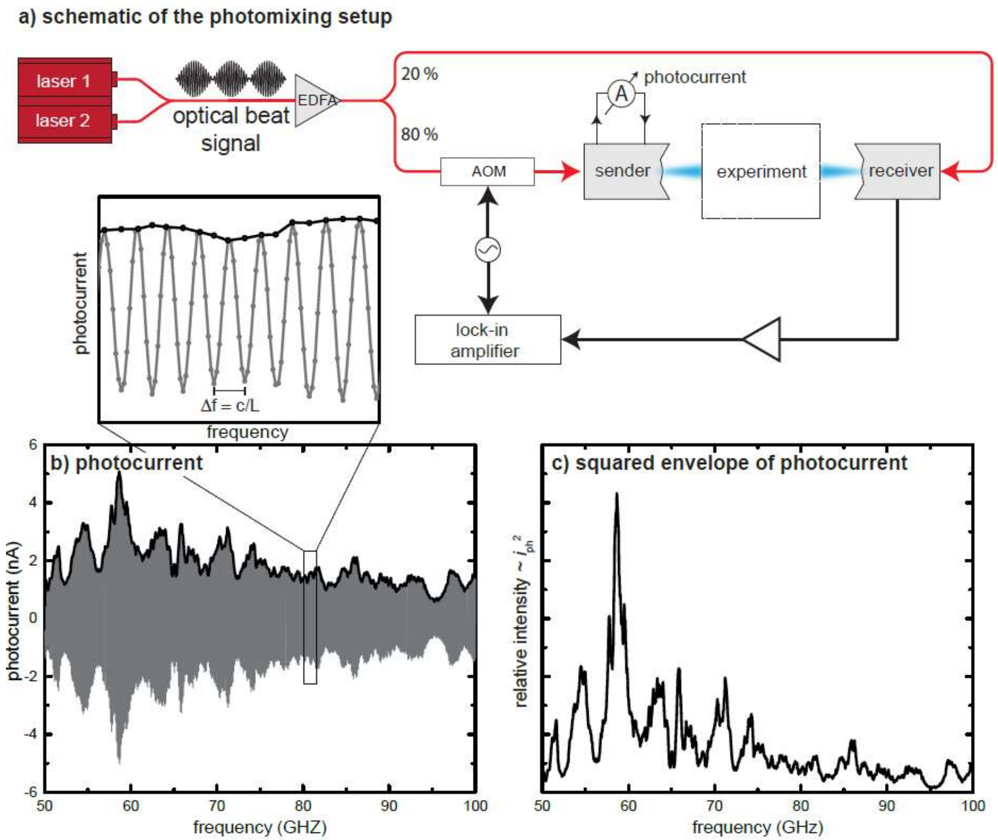
Alejandro Rivera-Lavado, Sascha Preu, Luis Enrique García-Muñoz, Andrey Generalov, Javier Montero-de-Paz, Gottfried Döhler, Dmitri Lioubtchenko, Mario Méndez-Aller, Florian Sedlmeir, Martin Schneidereit, Harald G. L. Schwefel, Stefan Malzer, Daniel Segovia-Vargas, and Antti V. Räisänen

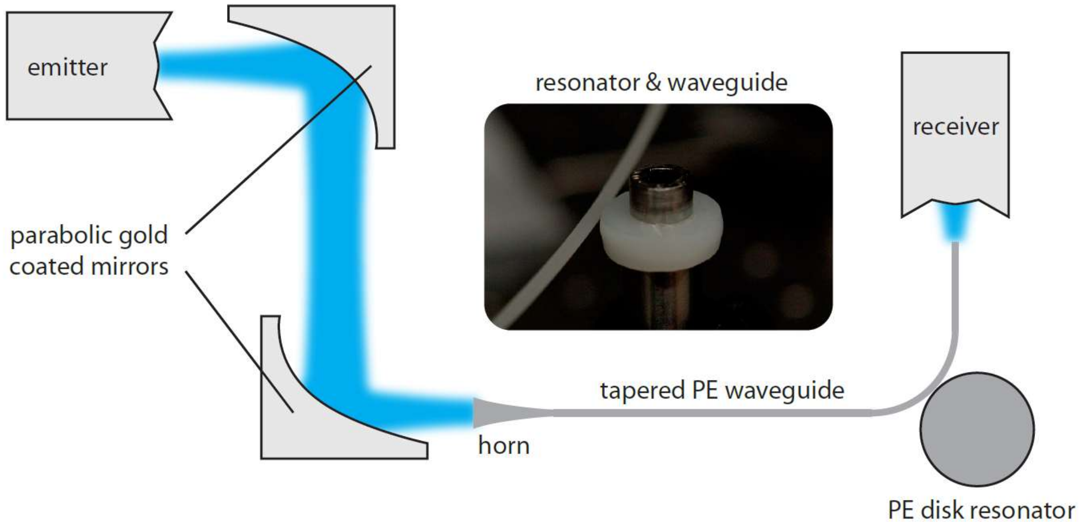






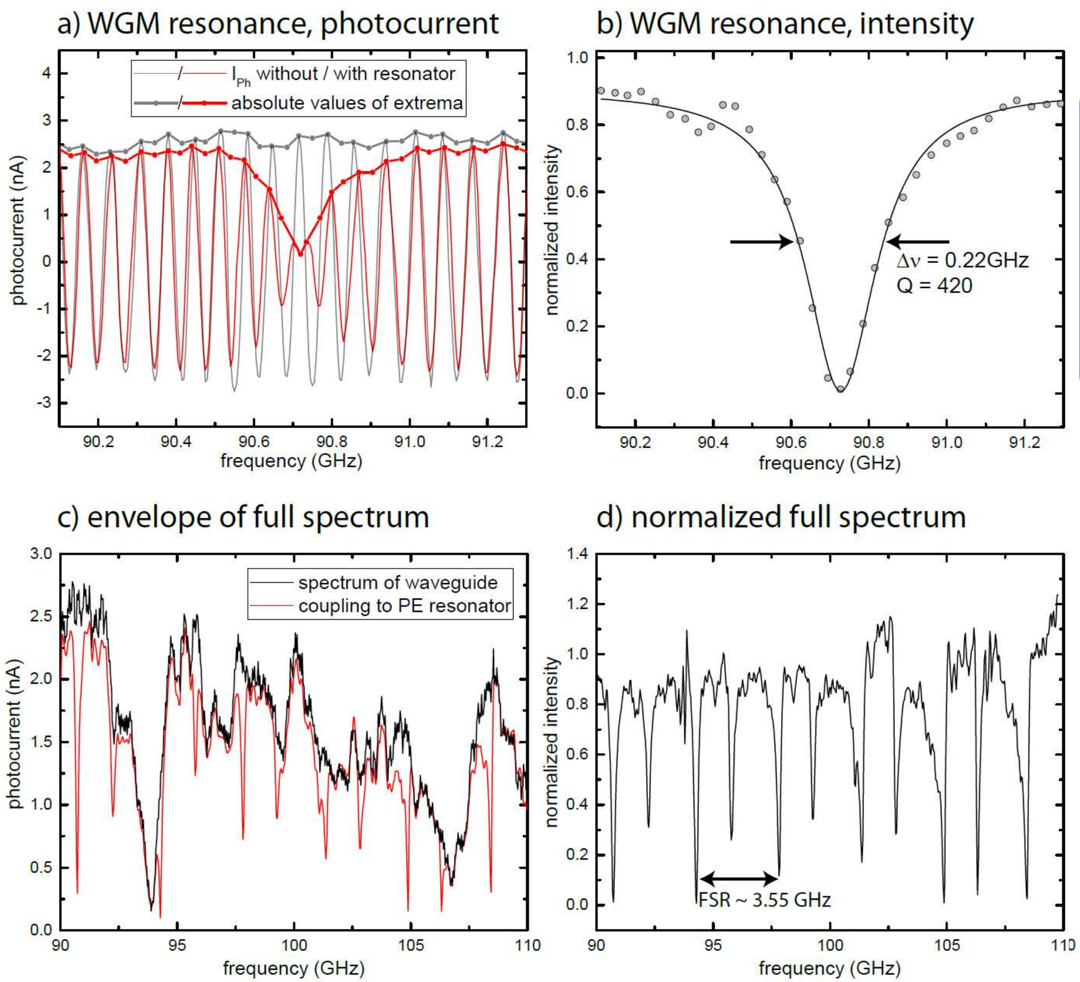
Electro-optic up-converter: Experimental proof of concept

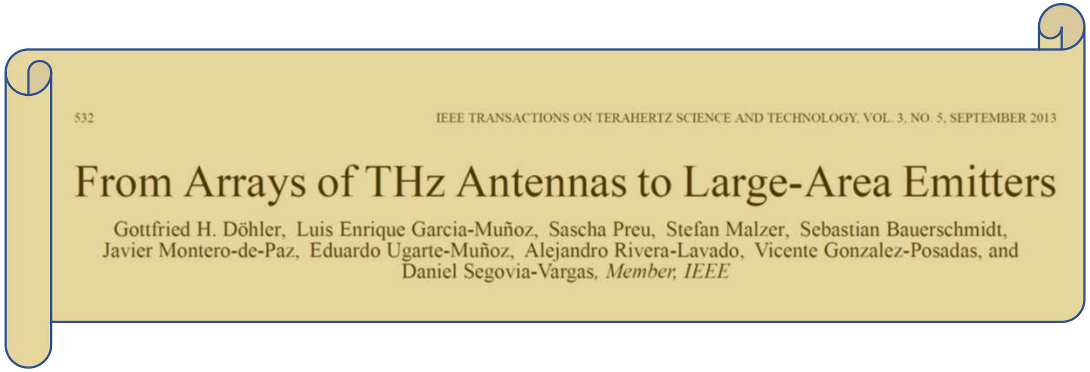




This schematic shows the setup used to couple to a PE resonator (R = 10 mm): The microwave from a photomixer emitting to free space is collimated and refocused with two parabolic mirrors into a tapered PE waveguide. The waveguide is bent to improve coupling to the resonator.

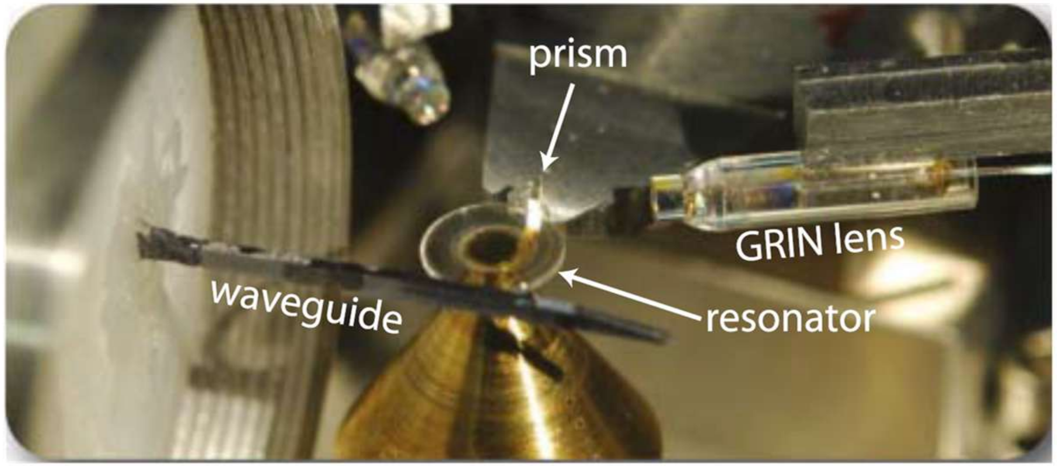
Electro-optic up-converter: Experimental proof of concept



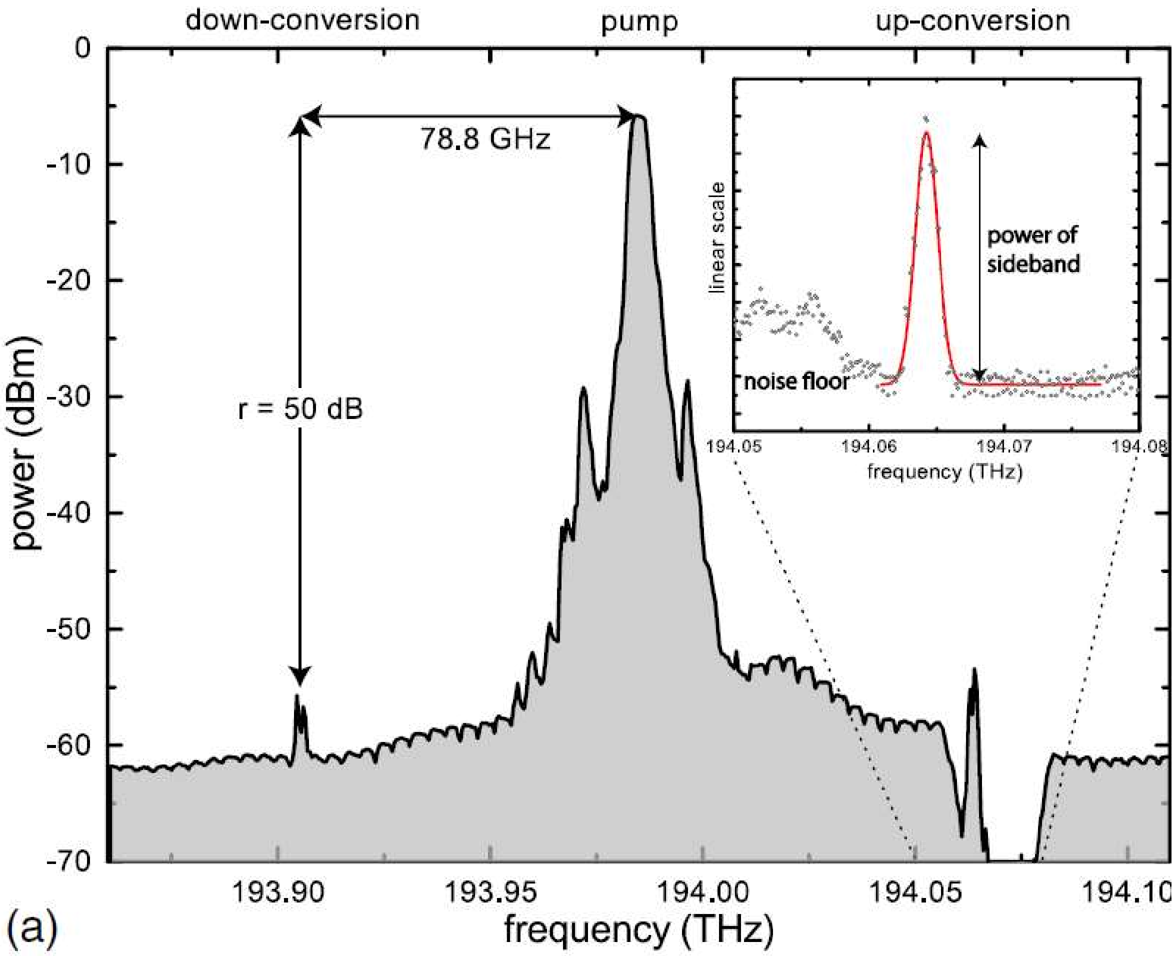

532 IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 3, NO. 5, SEPTEMBER 2013

From Arrays of THz Antennas to Large-Area Emitters

Gottfried H. Döhler, Luis Enrique Garcia-Muñoz, Sascha Preu, Stefan Malzer, Sebastian Bauerschmidt, Javier Montero-de-Paz, Eduardo Ugarte-Muñoz, Alejandro Rivera-Lavado, Vicente Gonzalez-Posadas, and Daniel Segovia-Vargas, *Member, IEEE*

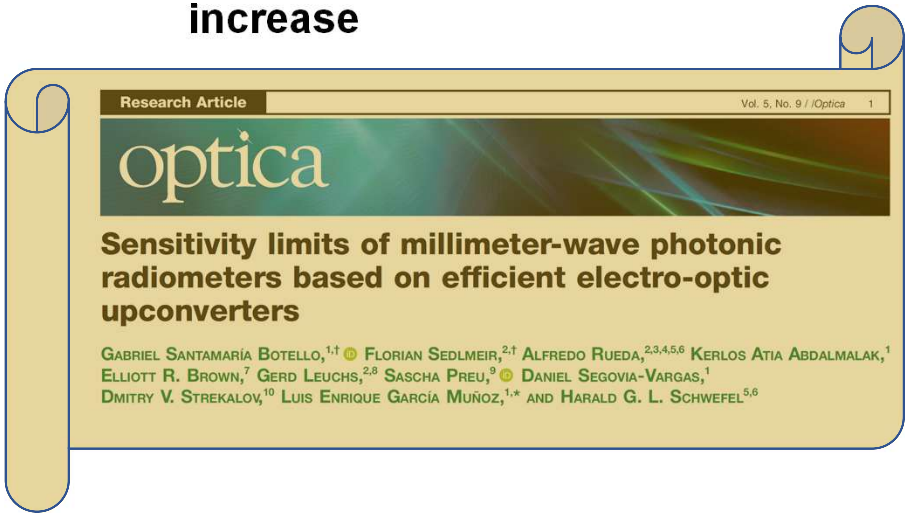


Electro-optic up-converter: Experimental proof of concept



Record conversion efficiency $\boldsymbol{\eta = 2.5 \times 10^{-5}}$ per mW pump power

Geometry optimizations from full-wave simulations show about 2 orders of magnitude efficiency increase


Research Article

Vol. 5, No. 9 / Optica 1

optica

Sensitivity limits of millimeter-wave photonic radiometers based on efficient electro-optic upconverters

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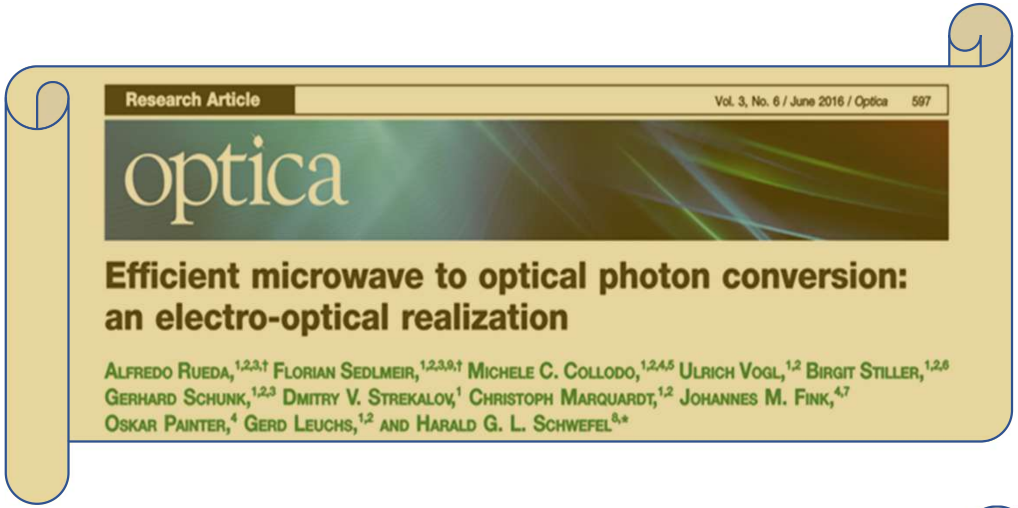
Electro-optic up-converter: Experimental proof of concept

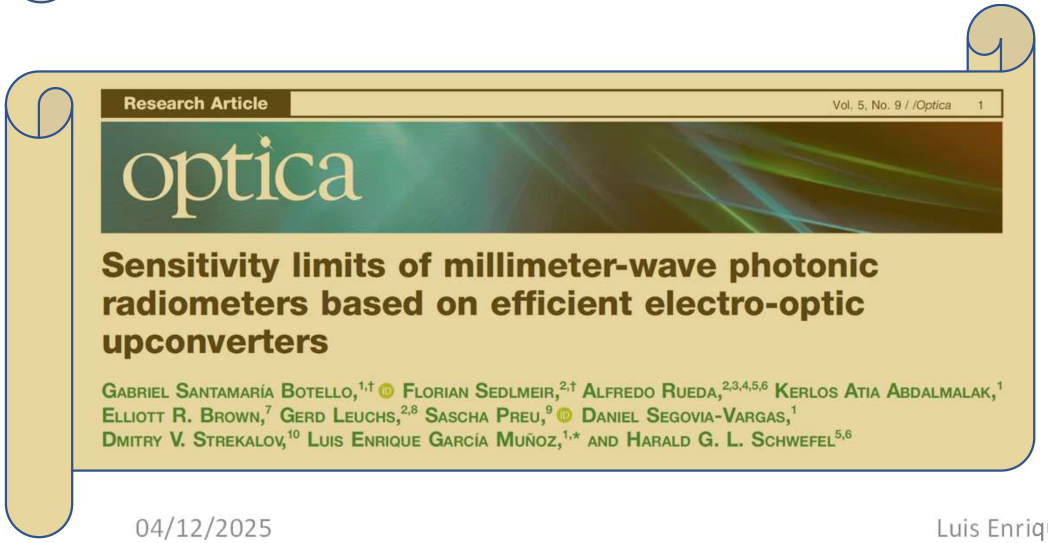
MILLIMETER AND SUBMILLIMETER TEAM


Research Article Vol. 3, No. 6 / June 2016 / Optica 597

optica

Efficient microwave to optical photon conversion: an electro-optical realization

Alfredo Rueda,[1,2,3,†] Florian Sedlmeir,[1,2,3,9,†] Michele C. Collodo,[1,2,4,5] Ulrich Vogl,[1,2] Birgit Stiller,[1,2,6] Gerhard Schunk,[1,2,3] Dmitry V. Strekalov,[1] Christoph Marquardt,[1,2] Johannes M. Fink,[4,7] Oskar Painter,[4] Gerd Leuchs,[1,2] and Harald G. L. Schwefel[8,*]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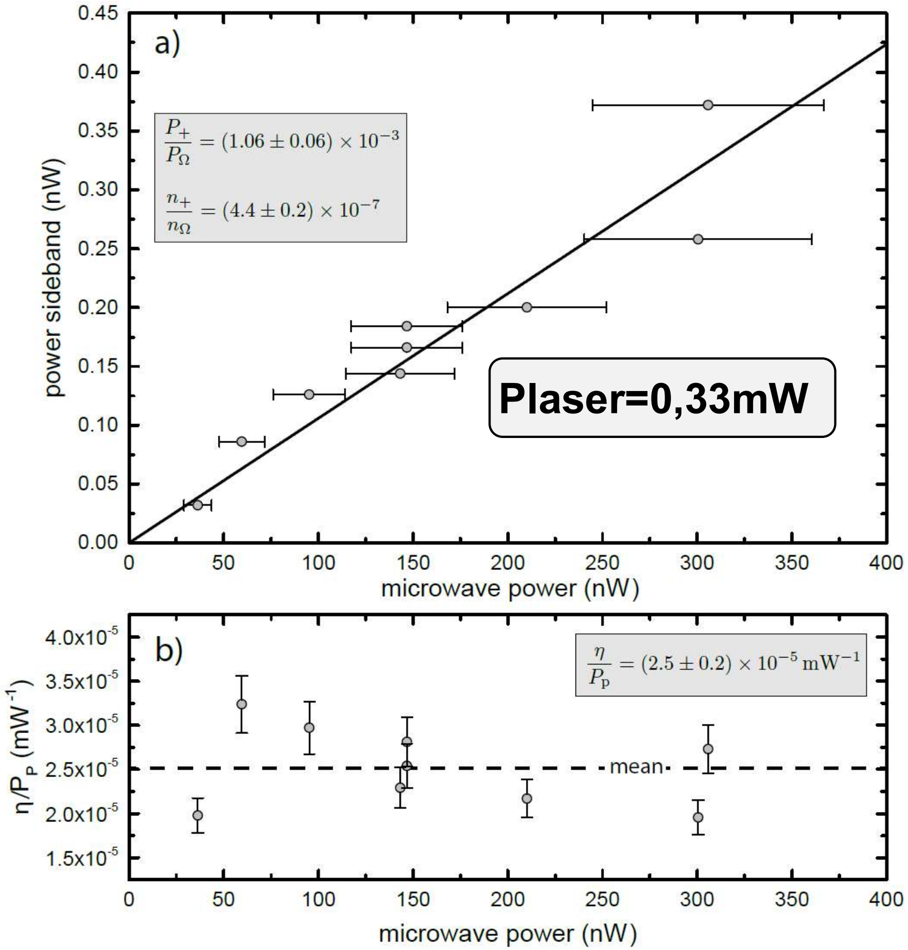
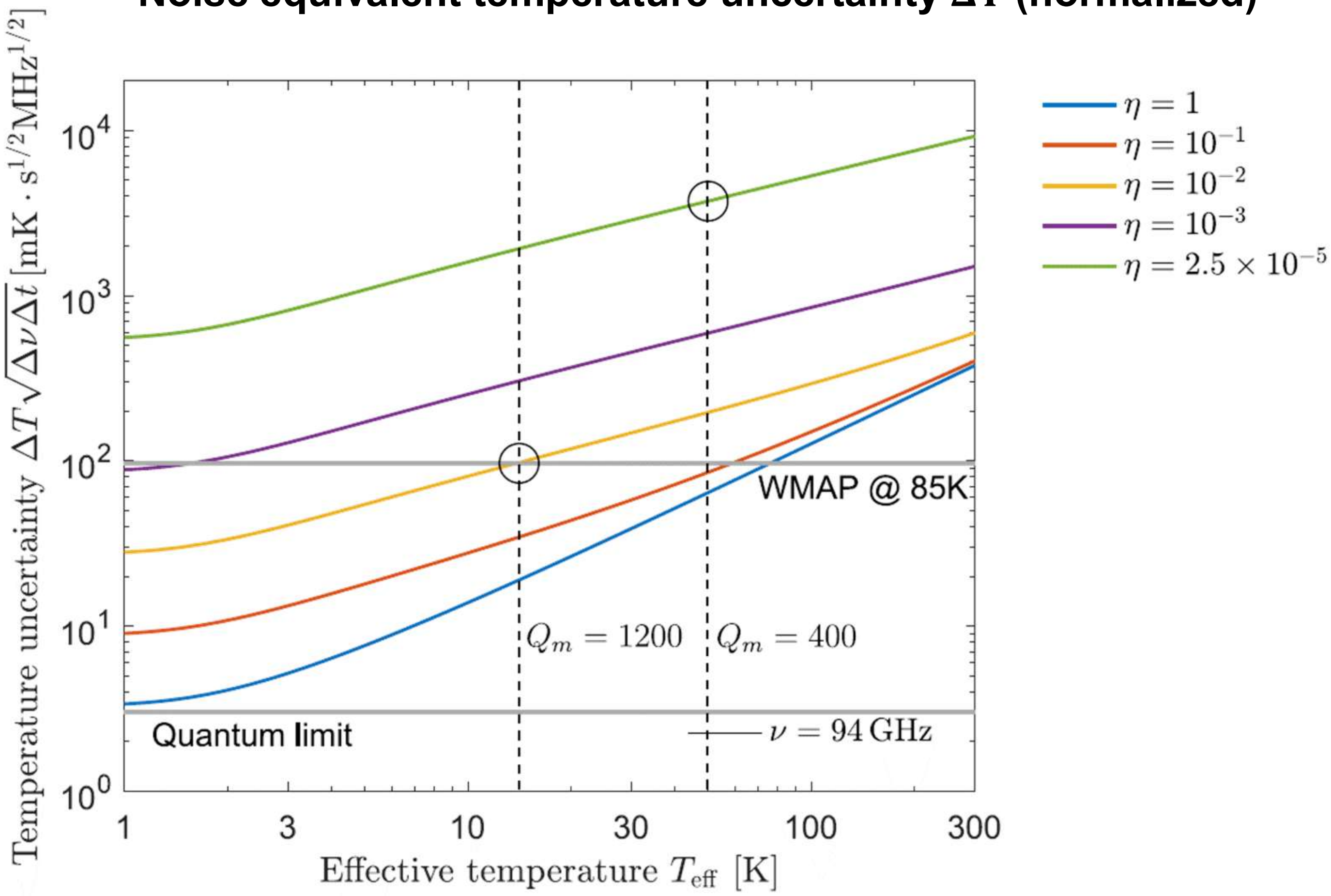


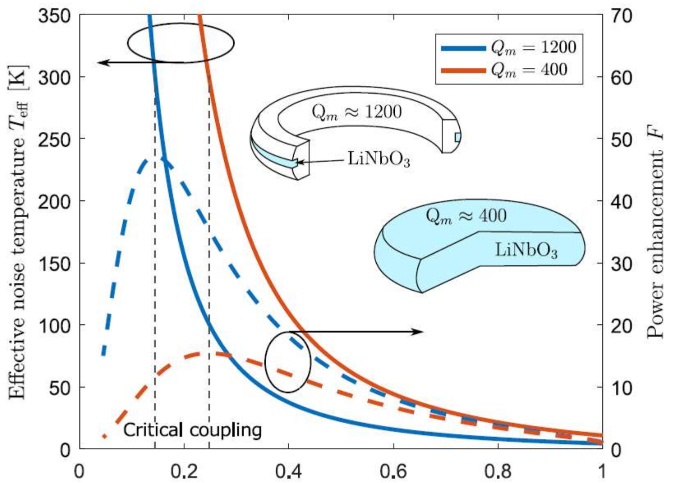
Índice

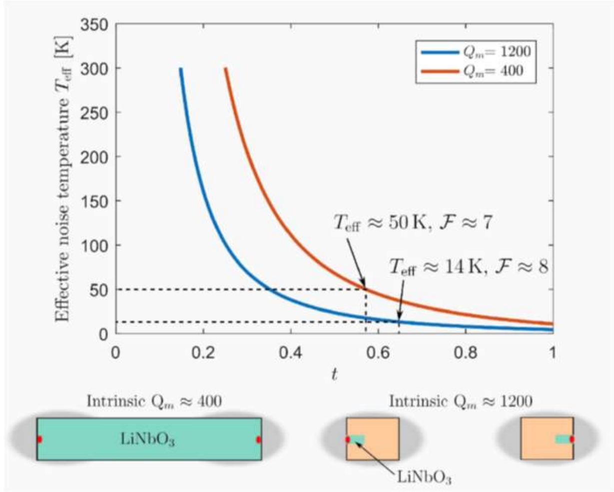
MILLIMETER AND SUBMILLIMETER TEAM

Sensitivity as a radiometer

Noise equivalent temperature uncertainty ΔT (normalized)







Sensitivity as a radiometer

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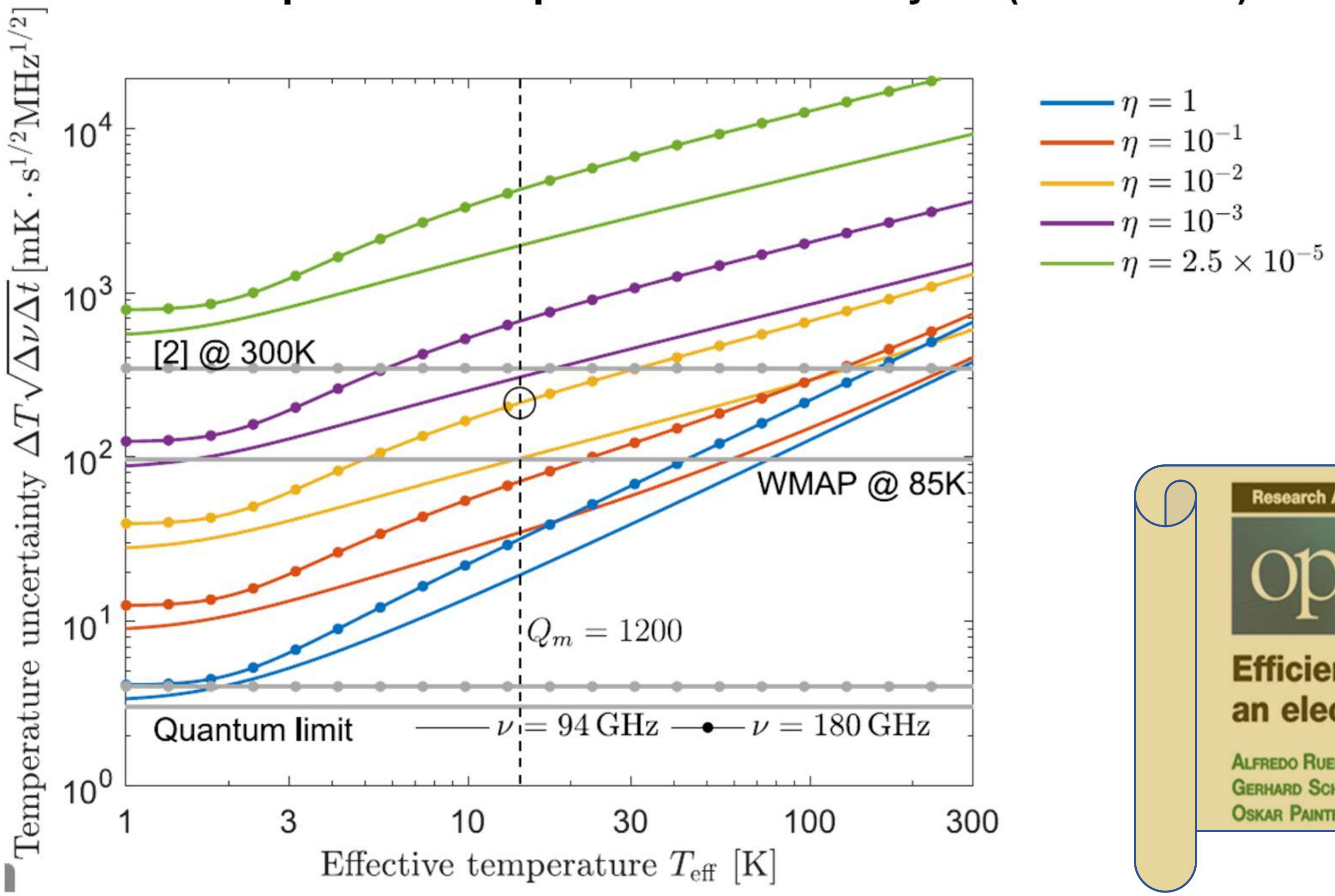

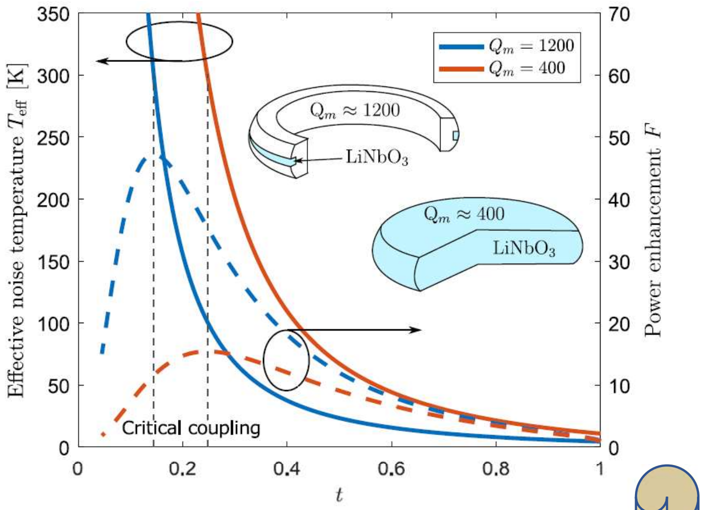

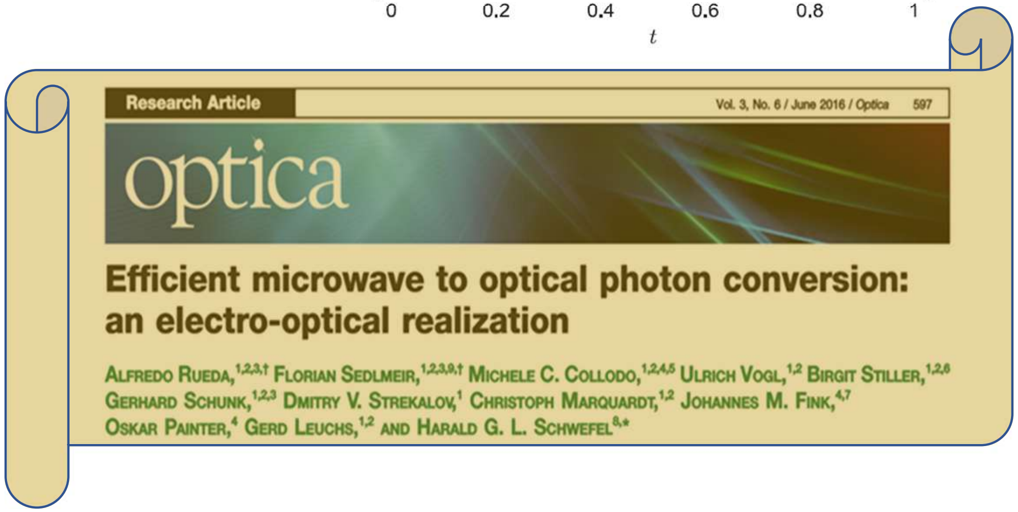
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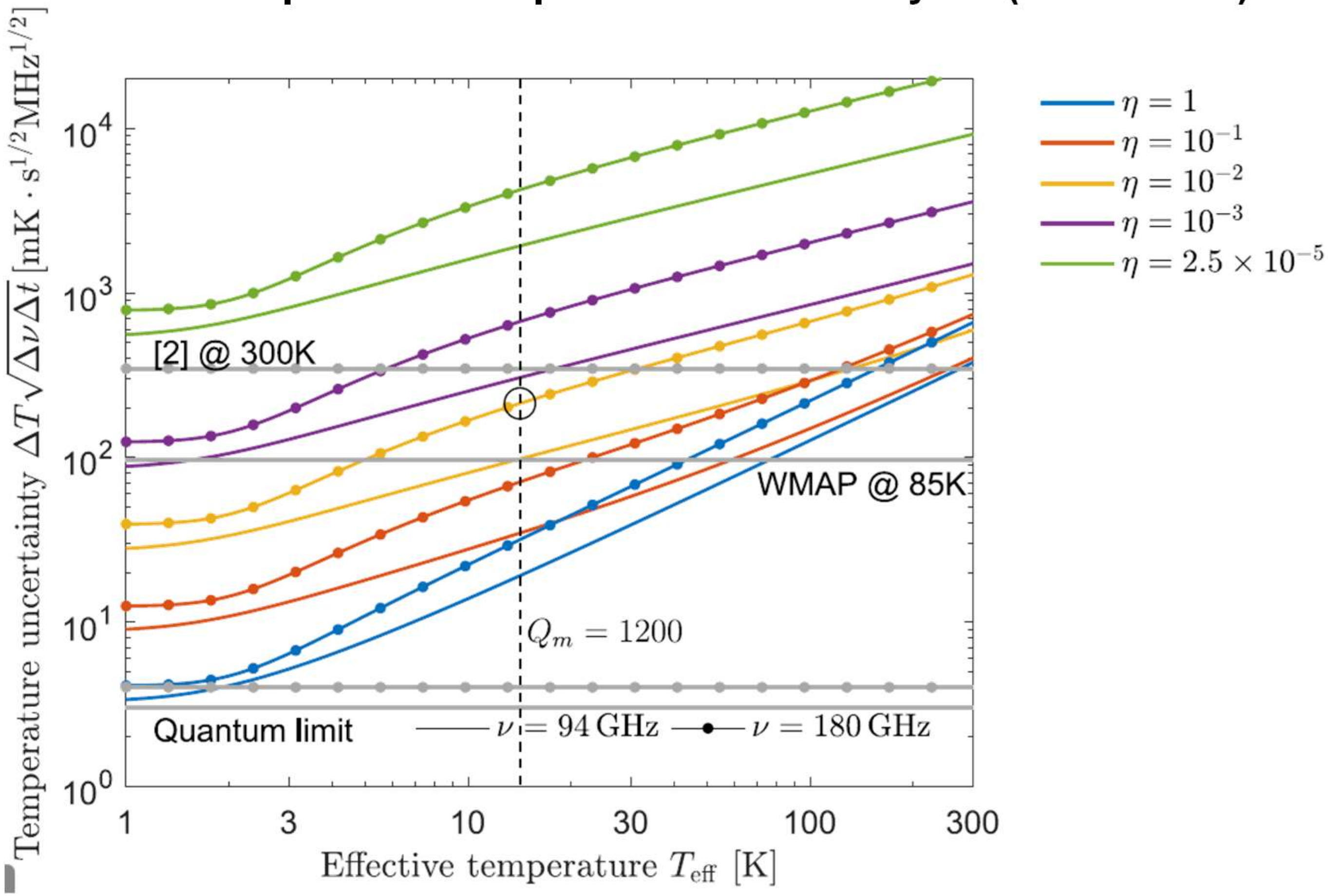
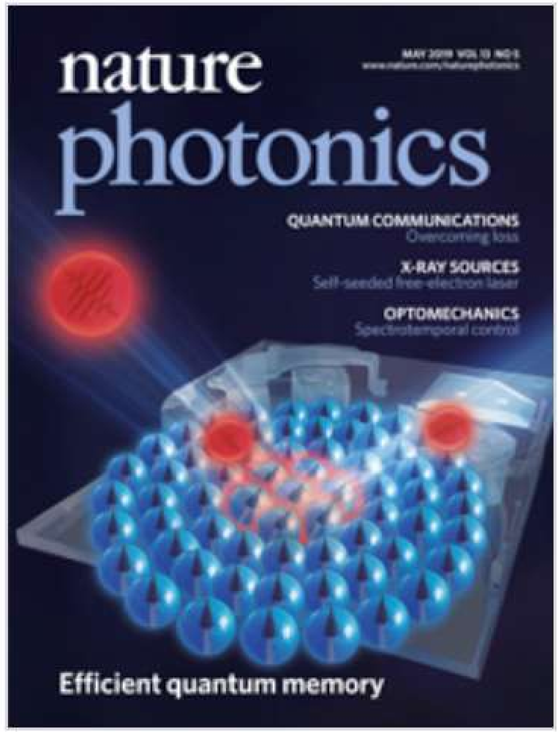
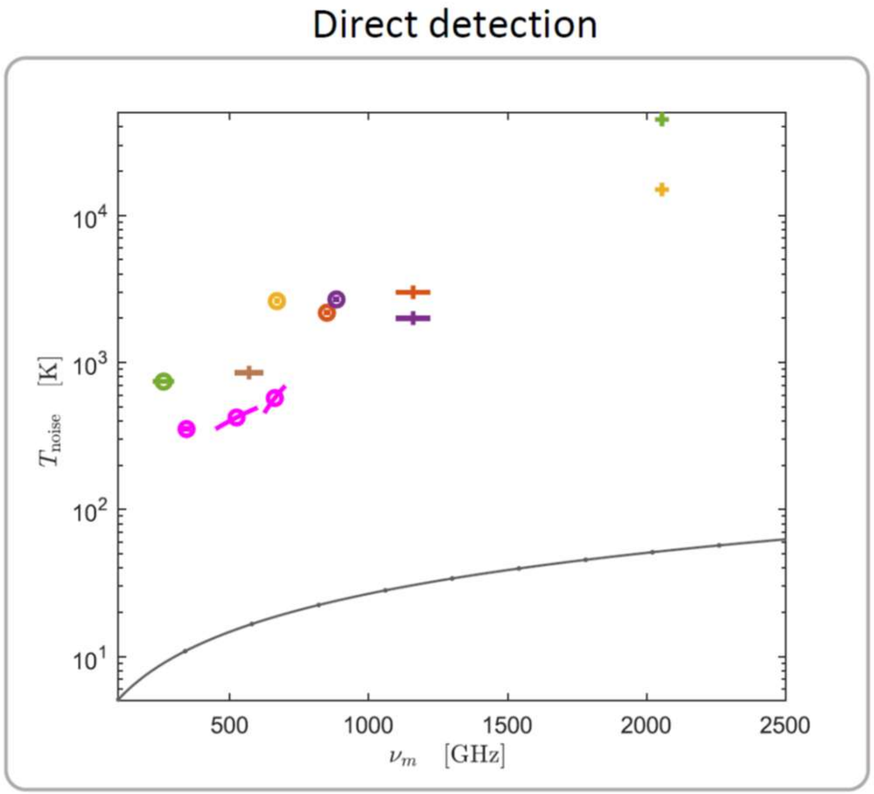
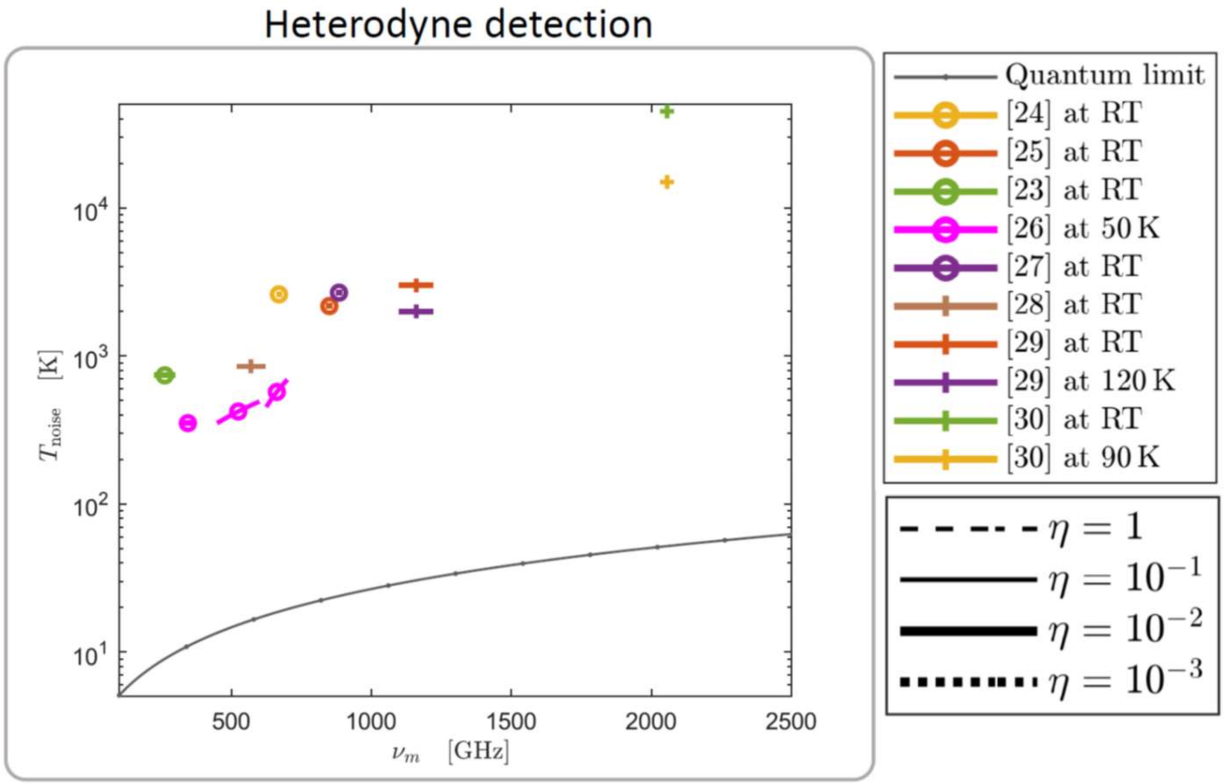




Sensitivity as a radiometer





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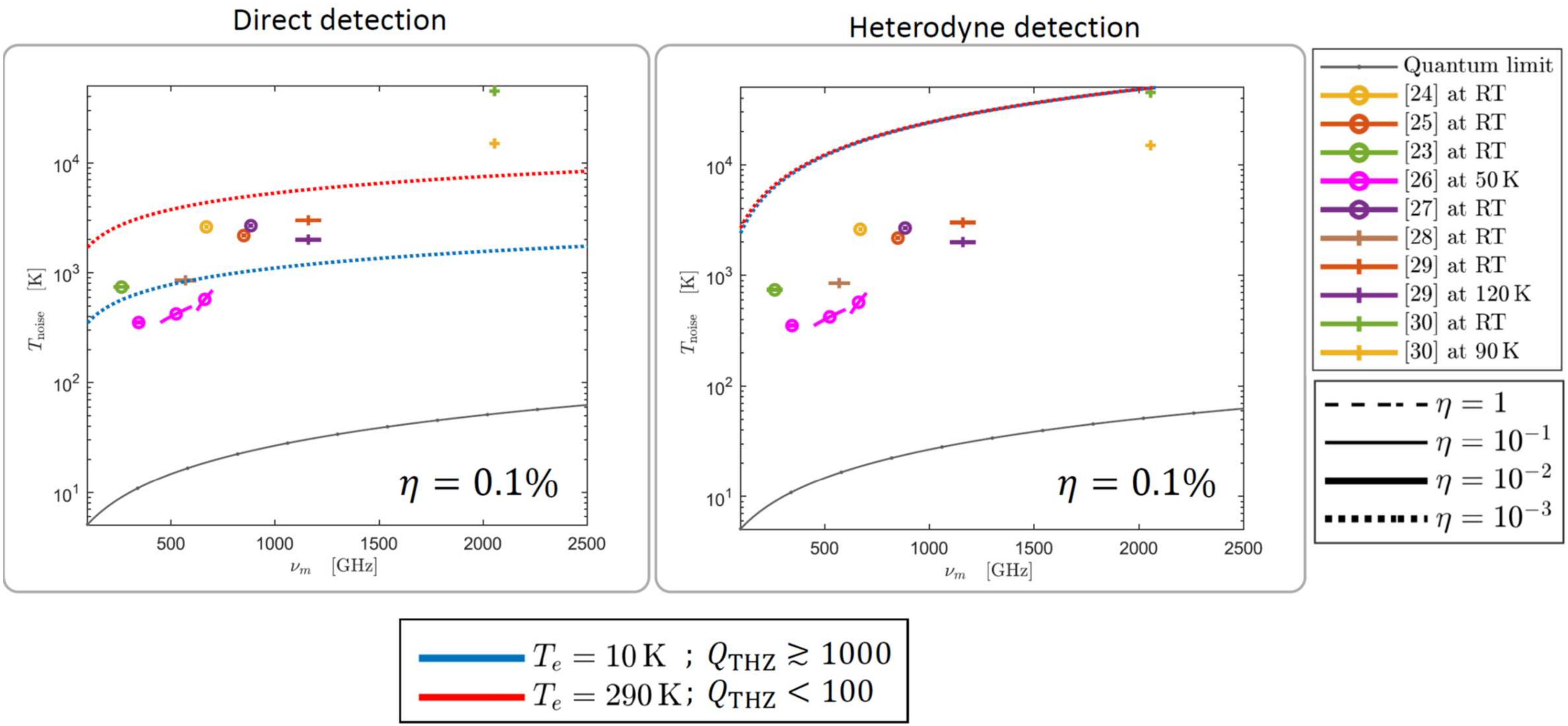

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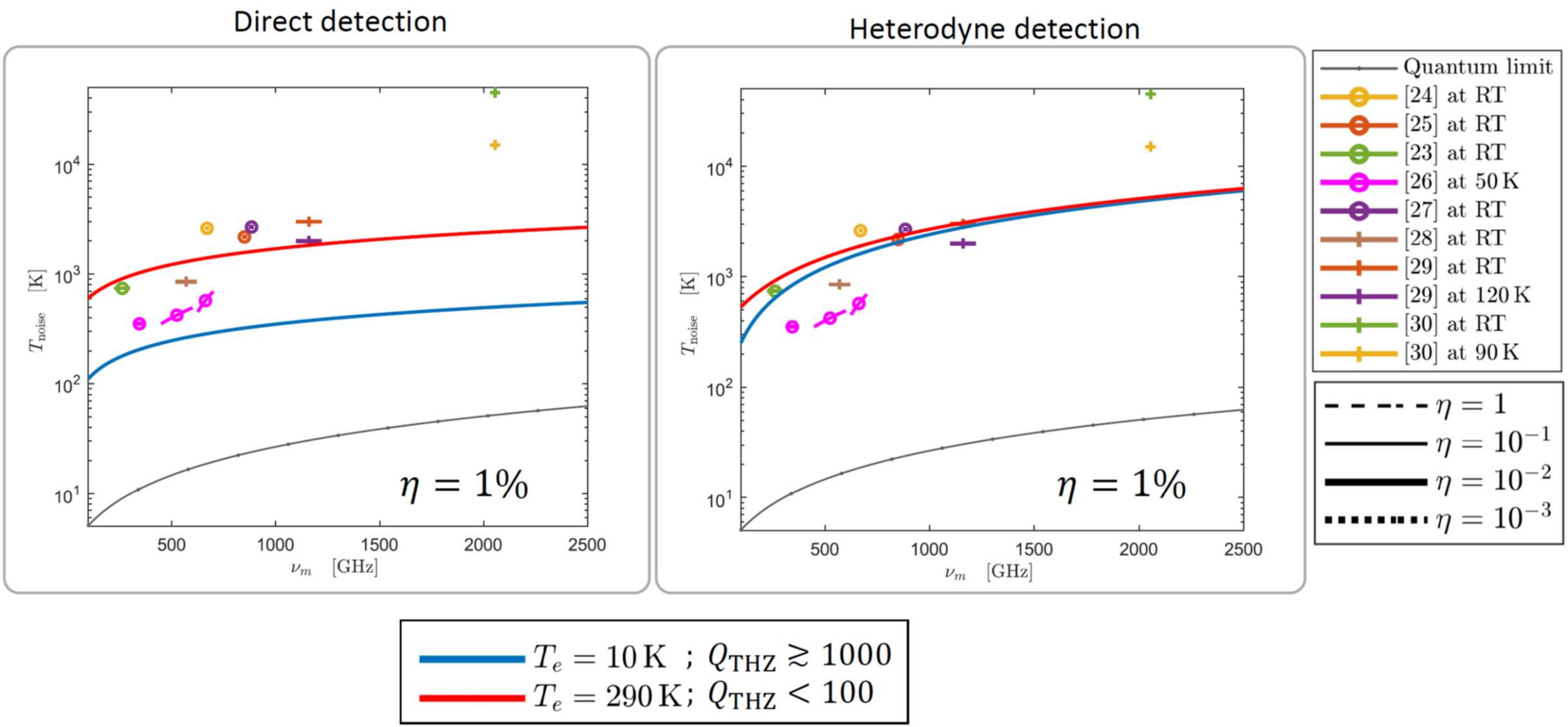
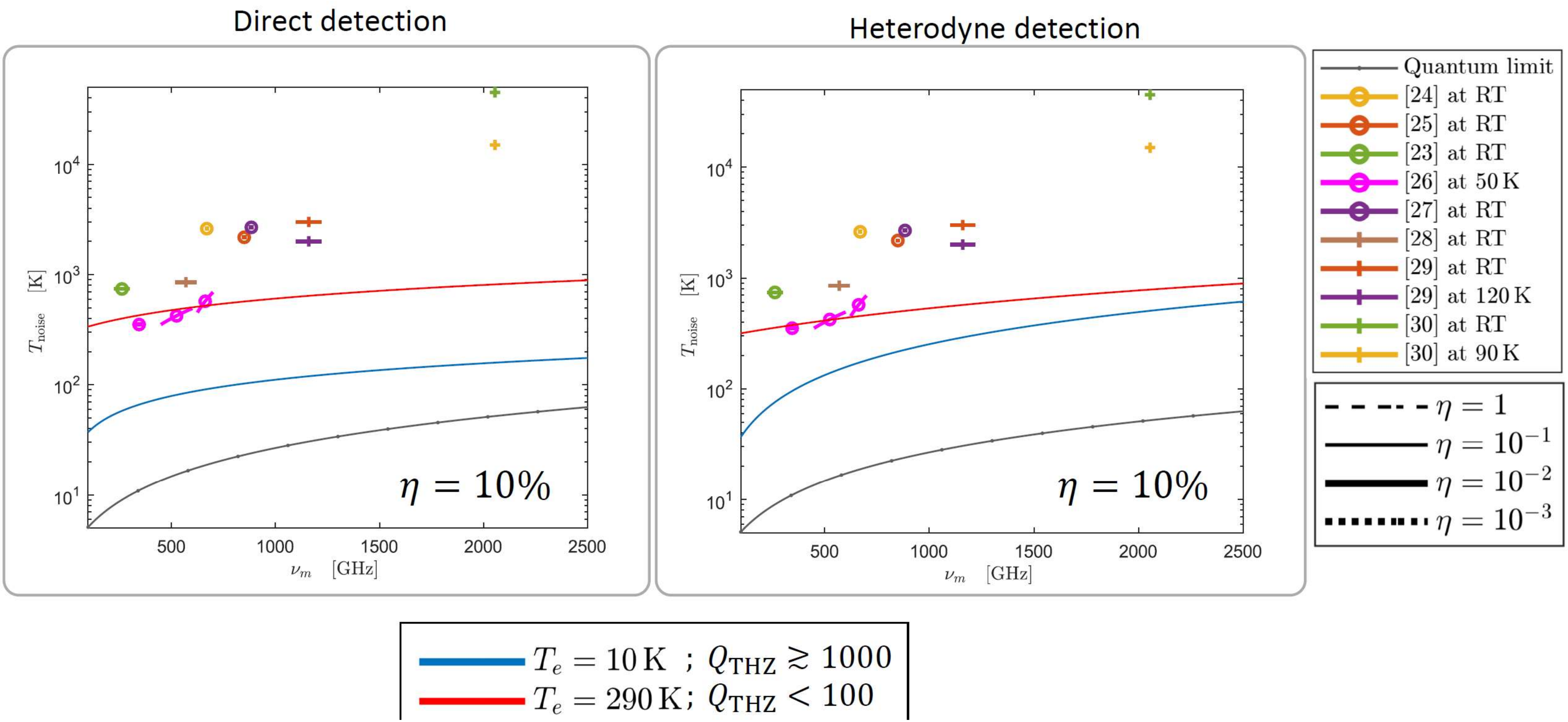
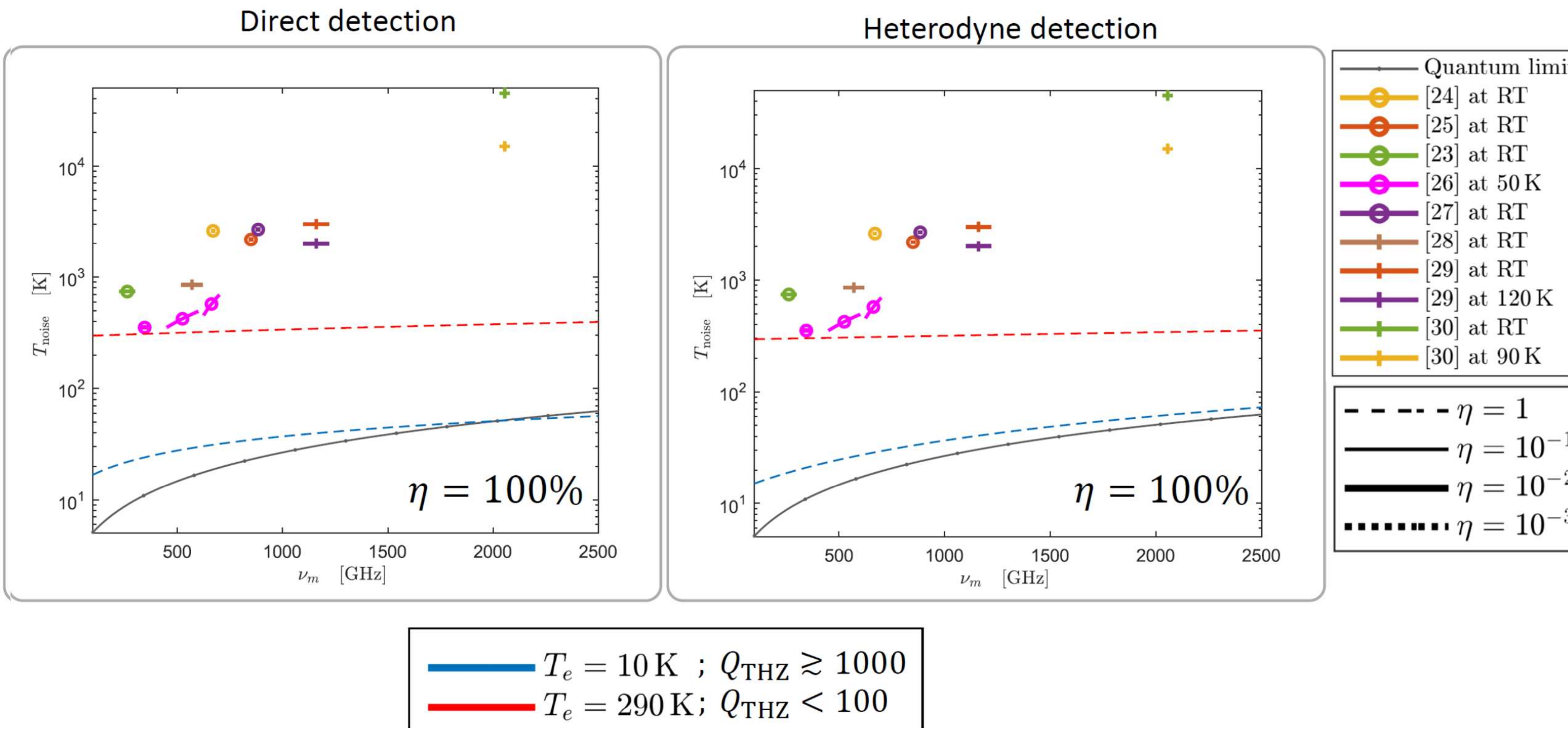


Sensitivity as a radiometer

MILLIMETER AND SUBMILLIMETER TEAM



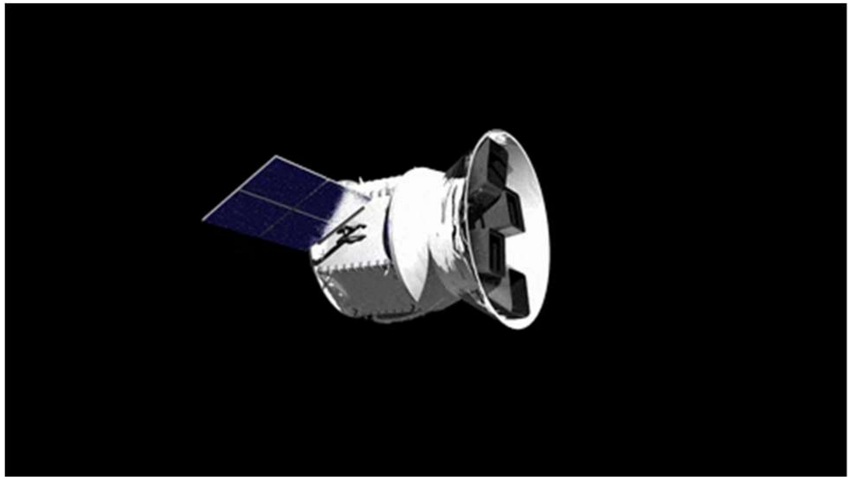
Sensitivity as a radiometer

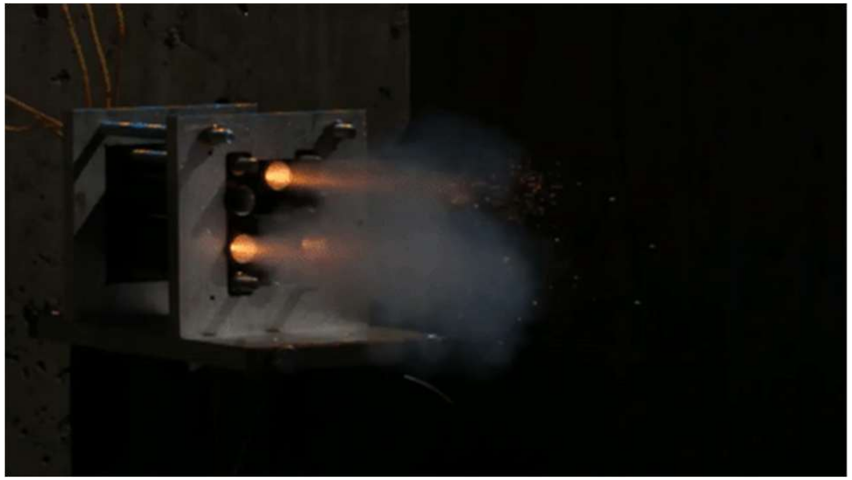


MARTINLARA CUBESAT

MILLIMETER AND SUBMILLIMETER TEAM

Millimeter wave **A**rray at **R**oom **T**emperature for **IN**struments in **L**EO **A**ltitude **R**adio **A**stronomy (MARTINLARA) desarrolla una misión espacial de demostración en órbita integrando en un nanosatélite tecnologías de uso espacial en radioastronomía, observación de la Tierra, fotónica espacial, y propulsión espacial eléctrica.

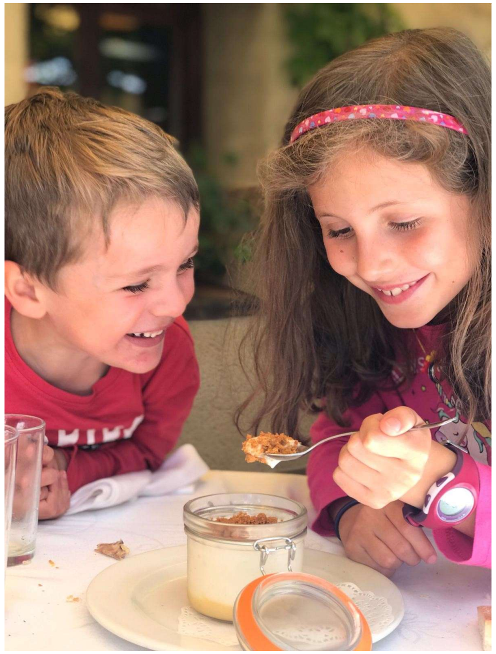




MARTINLARA

MARTINLARA CUBESAT

Millimeter wave **A**rray at **R**oom **T**emperature for **IN**struments in **L**EO **A**ltitude **R**adio **A**stronomy (MARTINLARA)



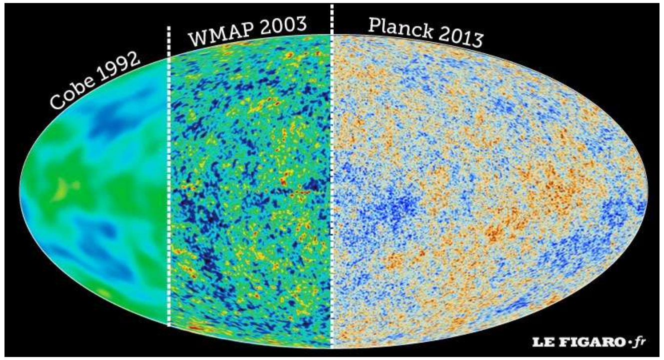
MARTINLARA

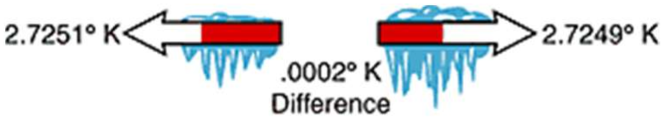
MARTINLARA CUBESAT

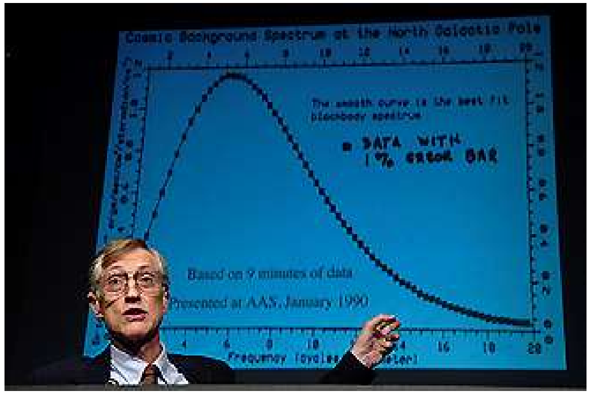
MILLIMETER AND SUBMILLIMETER TEAM

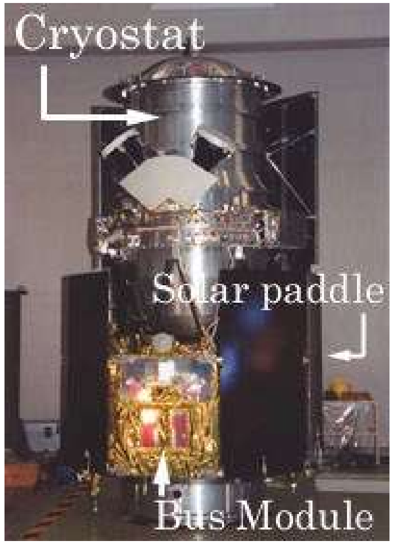
Anisotropías de CMB

CMB a 180, 200 y 250 GHz

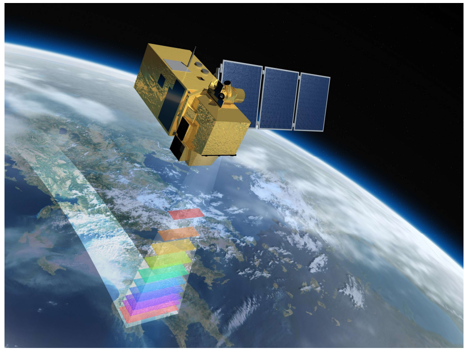


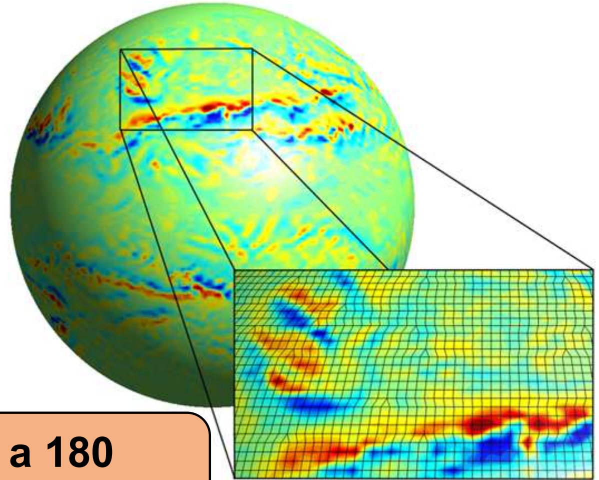






"Numerical Weather Prediction"





Vapor de agua a 180 GHz

Antenas

MARTINLARA

Anisotropías de CMB

CMB a 150, 200 y 250 GHz

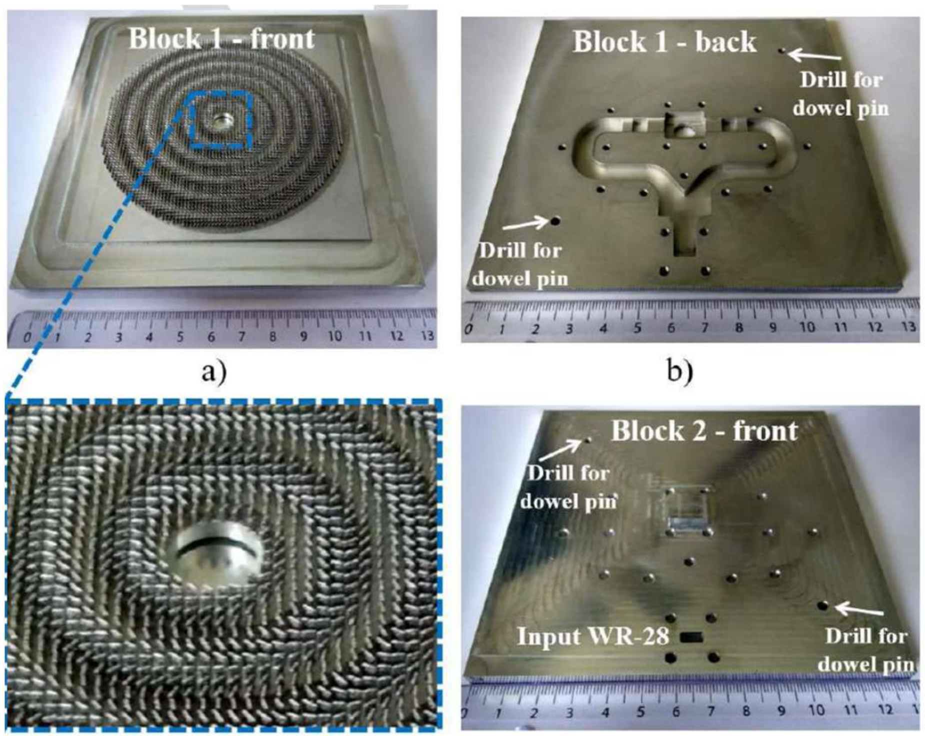
"Numerical Weather Prediction"

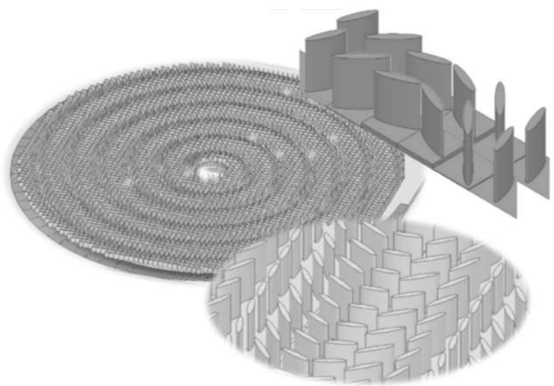
NWP a 150, 200 y 250 GHz

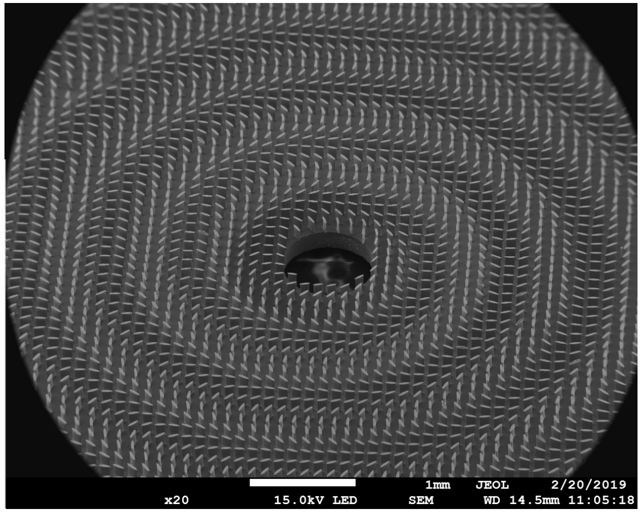
Eficiencia de apertura = 40%
Órbita = 800 km
Directividad = 38 dB
Apertura = 20*lambda
Cielo → 10º (3x3º)
Tierra → 10º (40x40 km de spot)

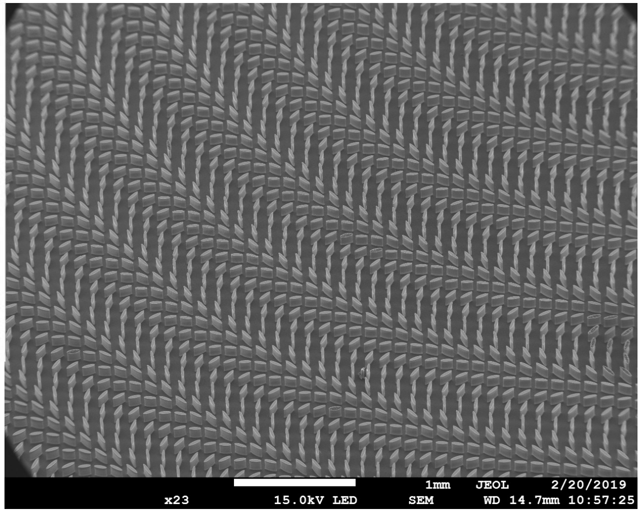
$\text{Diámetro}_{150\ GHz}$ = 8 cm
$\text{Diámetro}_{200\ GHz}$ = 6 cm
$\text{Diámetro}_{250\ GHz}$ = 4,8 cm

Antenas

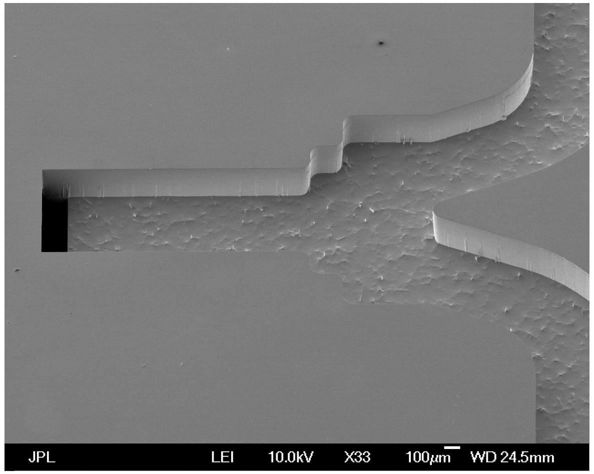

Block 1 - front
Block 1 - back
Drill for dowel pin
Drill for dowel pin
a)
b)
Block 2 - front
Drill for dowel pin
Input WR-28
Drill for dowel pin

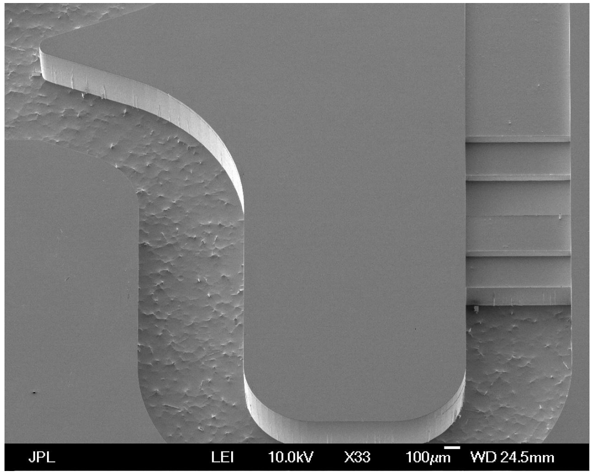


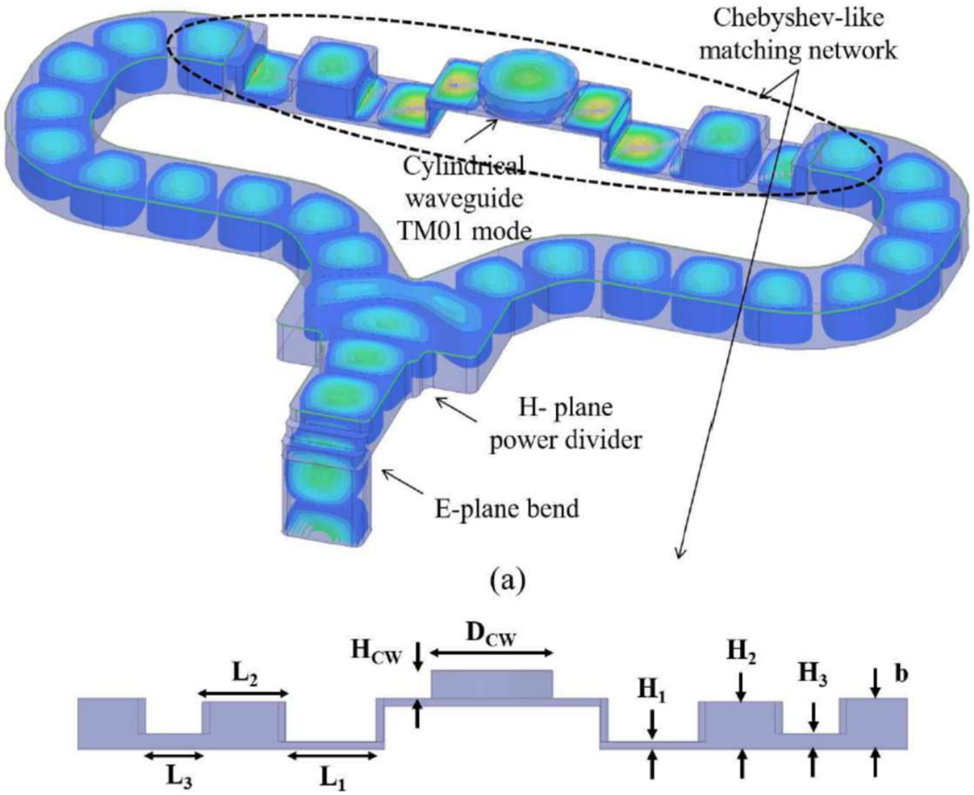

1mm JEOL 2/20/2019
x20 15.0kV LED SEM WD 14.5mm 11:05:18


1mm JEOL 2/20/2019
x23 15.0kV LED SEM WD 14.7mm 10:57:25

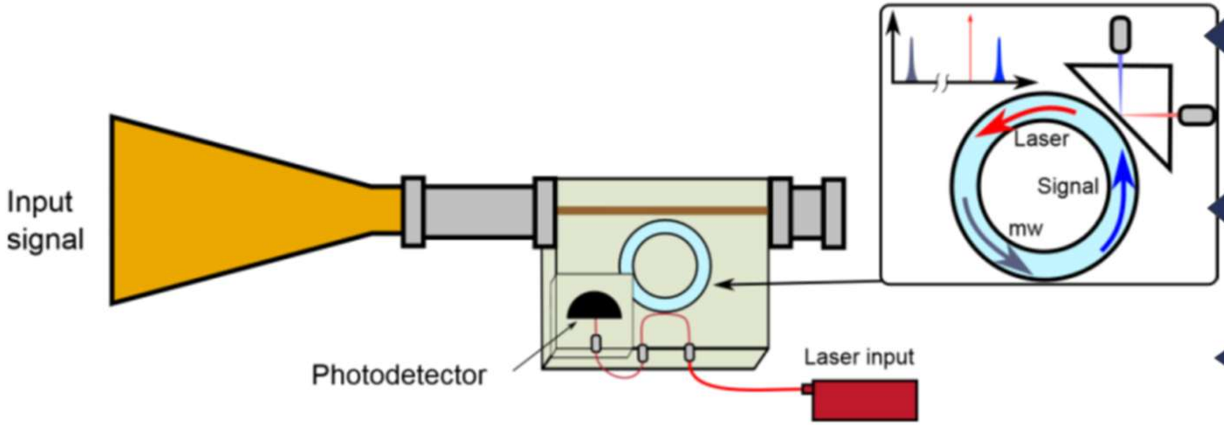
Antenas


JPL LEI 10.0kV X33 100μm WD 24.5mm


JPL LEI 10.0kV X33 100μm WD 24.5mm


Chebyshev-like
matching network
Cylindrical
waveguide
TM01 mode
H- plane
power divider
E-plane bend
(a)
H_{CW}
D_{CW}
L_2
L_3
L_1
H_1
H_2
H_3
b

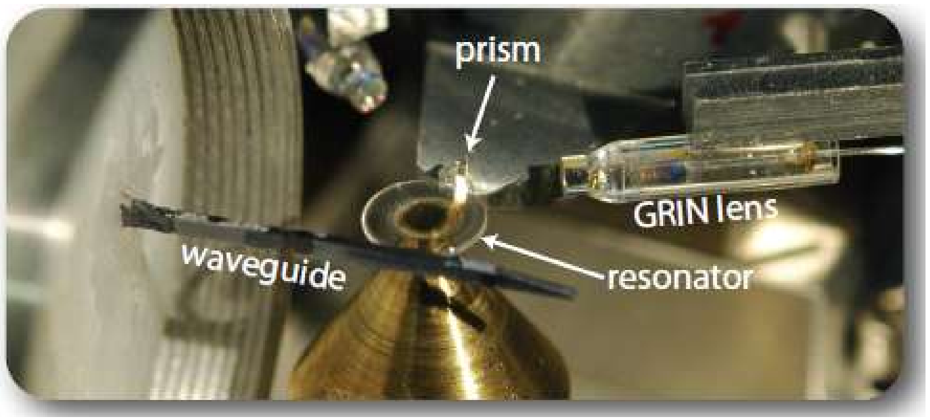
Radiómetros



CONCEPT
Low-cost array of sensors working at room temperature for high performance hyperspectral imaging systems, based on a novel miniaturised radiometer concept scalable to fulfil a wide range of institutional and commercial applications.

SCOPE
- Technical feasibility study
- Assessment of the user need requirements
- Proof of concept demonstration and compact sensor demonstration (TRL rising)
- Exploitation plan and use cases

CHALLENGES
Provide high resolution measurements and wide frequency coverage at an affordable cost



Radiómetros

MARTINLARA

Cada radiómetro (sin guía de onda ni antena):

Caja de aluminio de 3 mm de espesor
Peso: 500 g
Volumen: 150 x 80 x 30 mm
Consumo: 10 W

Índice

MILLIMETER AND SUBMILLIMETER TEAM

Conclusiones

Currently the experiment is limited by shot noise.

Optimized geometries and structures have to be designed to reduce thermal noise and increase efficiency.

For intrinsic (unloaded) microwave $Q \approx 1500$ and $\eta \approx 10\%$, the sensitivity would be 10 times above the quantum limit at room temperature.

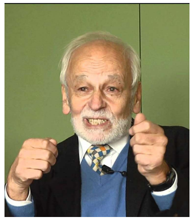
The same concept can be extended to the sub-millimeter range by just scaling the resonator's geometry.

The conversion bandwidth is not fundamentally limited. We are seeking for other ideas and approaches to achieve broadband up-conversion.

Conclusiones: el equipo de trabajo

MILLIMETER AND SUBMILLIMETER TEAM

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

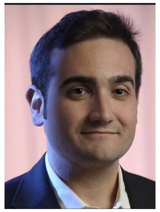



WRIGHT STATE UNIVERSITY

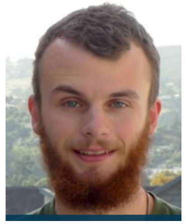
INSTITUTO D ASTROFISICA D CANARIAS · IAC ·

TECHNISCHE UNIVERSITÄT DARMSTADT

IETR



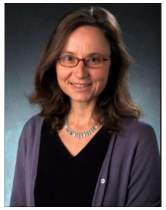
UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

MAX PLANCK INSTITUTE for the science of light



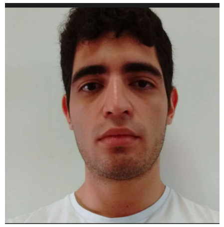
University of Colorado Boulder



NASA JPL

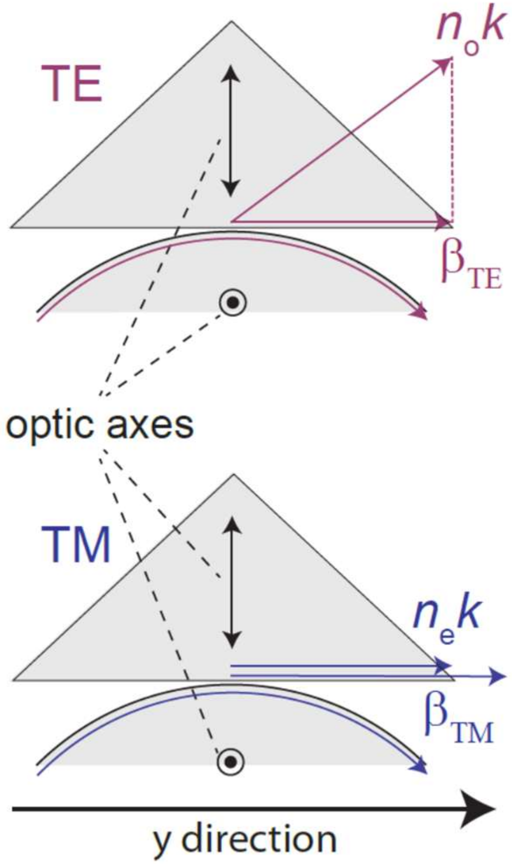
Maynooth University
National University of Ireland Maynooth

uc3m Universidad Carlos III de Madrid

Electro-optic up-converter: increasing bandwidth

MILLIMETER AND SUBMILLIMETER TEAM

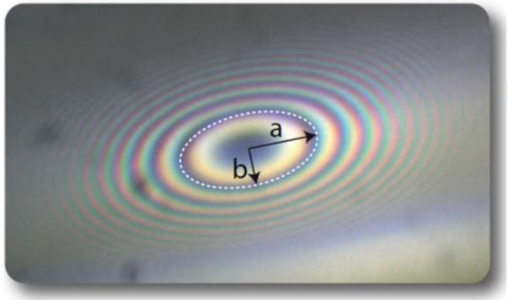


$n_{o\_prism} > n_{e\_res}$

Coupling

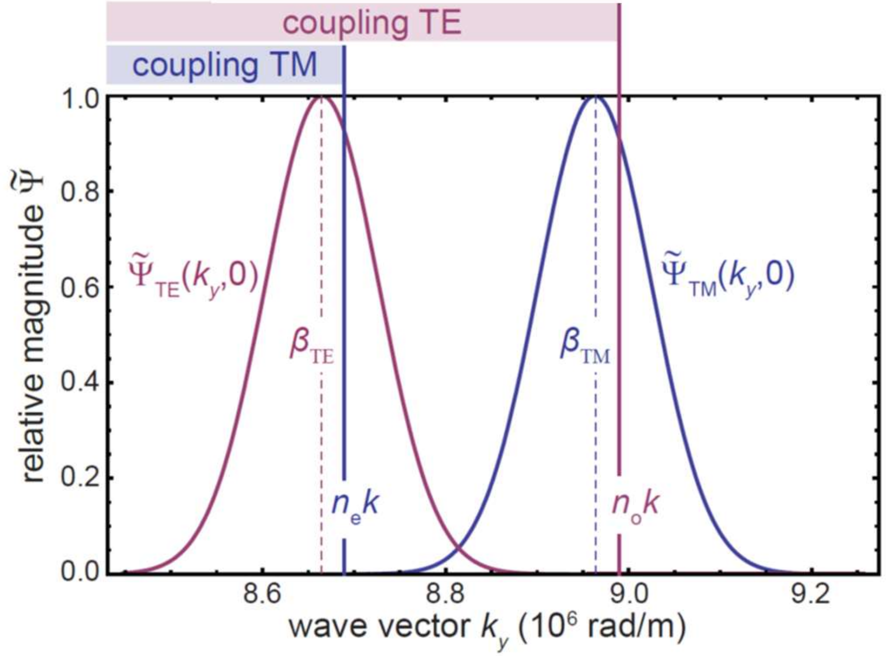
$n_{e\_prism} < n_{o\_res}$

No coupling

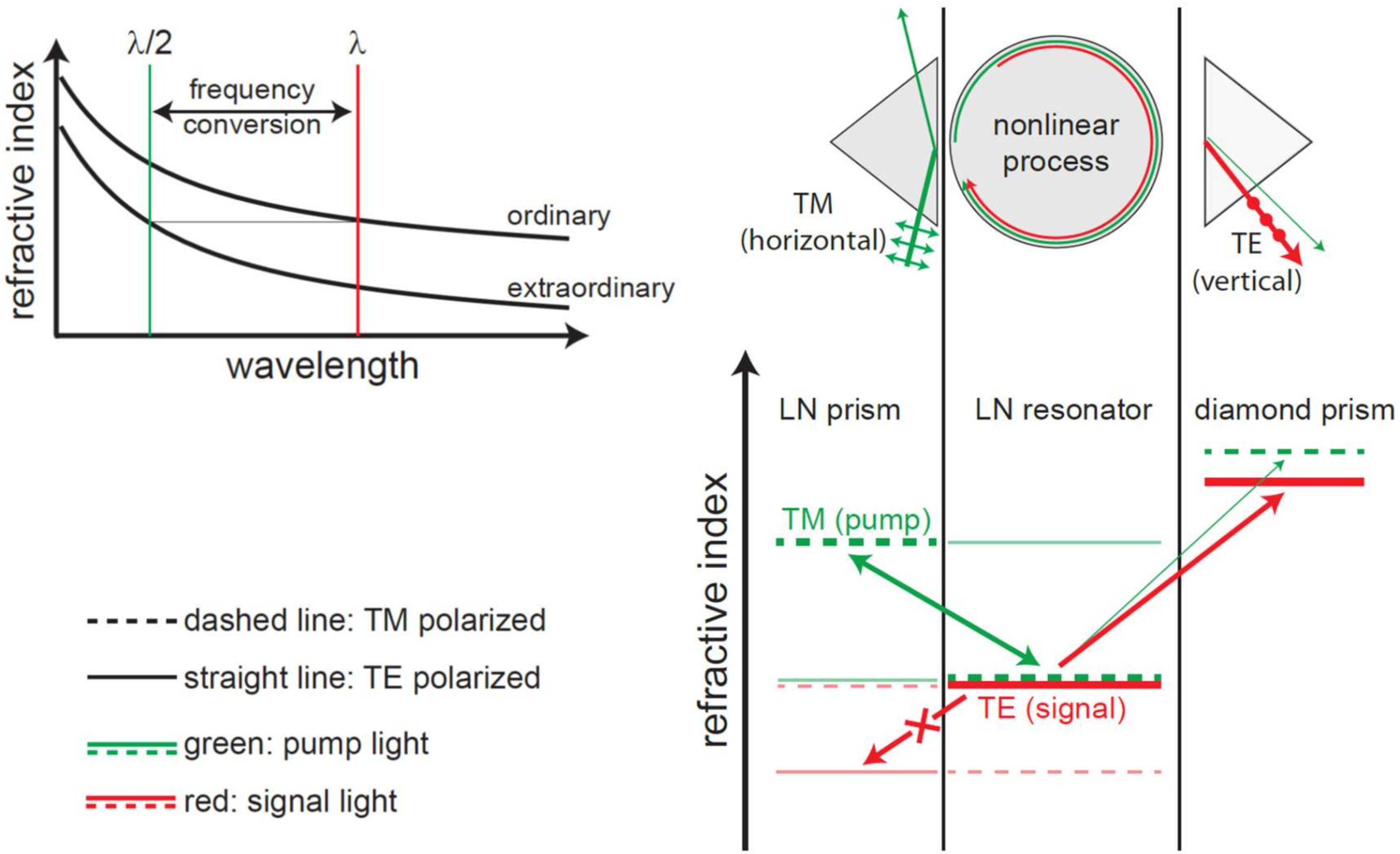


$$\Psi^{p}(x_{p}, y, z) \propto \Psi^{r}(x, y, z)\Big|_{\rho=r} \times \exp\left[-\kappa\left(d + \frac{z^2}{2r} + \frac{y^2}{2R}\right)\right]$$

$$|\widetilde{\Psi}^{p}(k_y, k_z)|^2 \propto \exp\left[-\Delta y^2 \left(k_y - \beta\right)^2 - \Delta z^2 k_z^2\right]$$



Electro-optic up-converter: increasing bandwidth



Second harmonic generation (SHG)