Millimetre and Submillimetre Wave Astronomy

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Outline

- Mm & submm wave astronomy: why, what
- Specifics of mm/submm wave astronomy wrt protection
- Sensitivity levels & current regulations
- Spectrum usage at the Pico Veleta 30m telescope
- A case study: Cloud Radar(s)
- Other possible threats

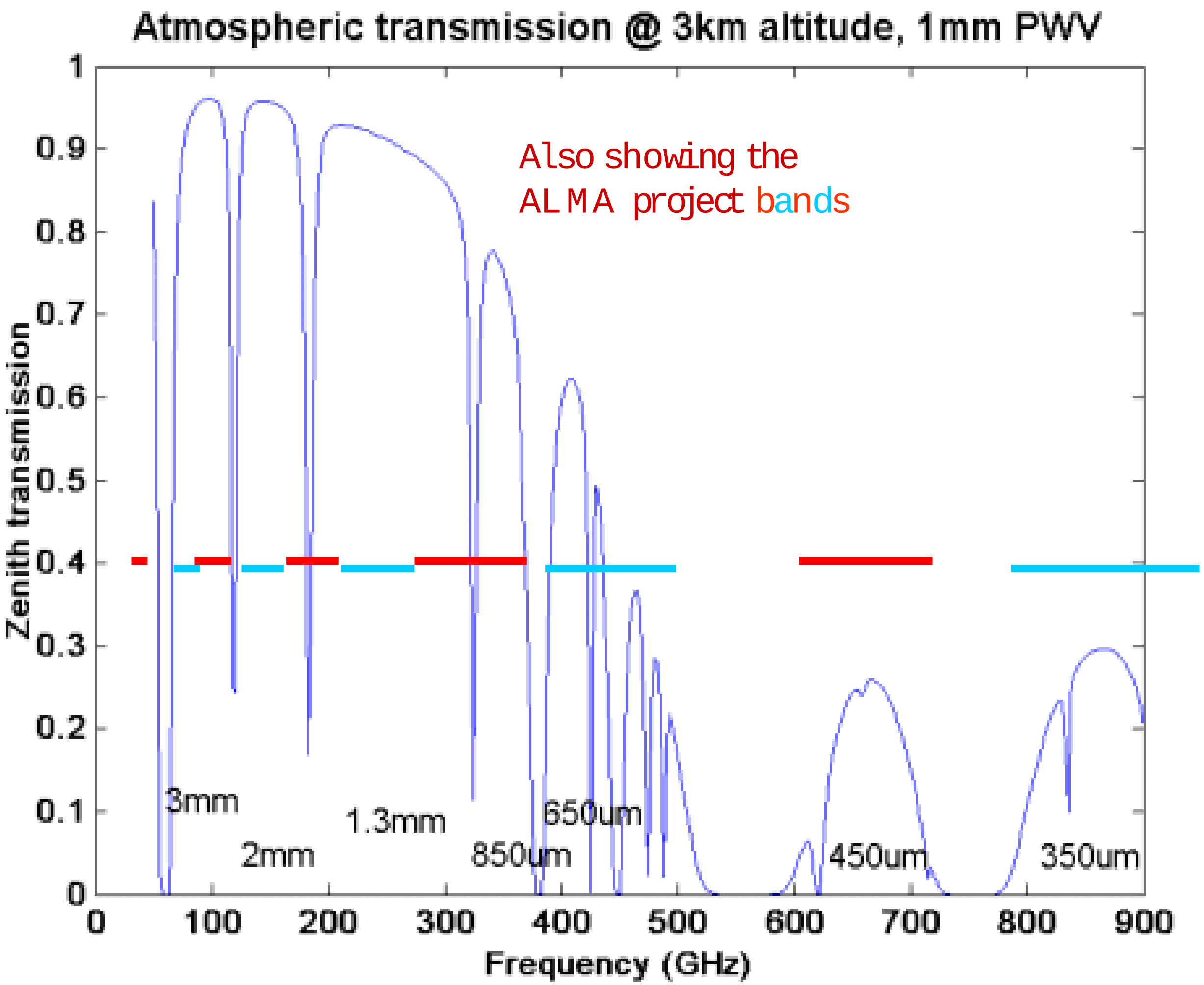
Mm/submm Astronomy: Scientific Themes

- Solar System
  - Comets, primordial solar nebula
  - Planetary atmospheres
- Interstellar medium & galactic structure
  - Kinematics
  - Chemistry (100's of molecules identified)
- Star formation
  - Pre-stellar gas collapse
  - Early evolution and protoplanetary disks
- Cosmology
  - The first stars and galaxies in the early Universe

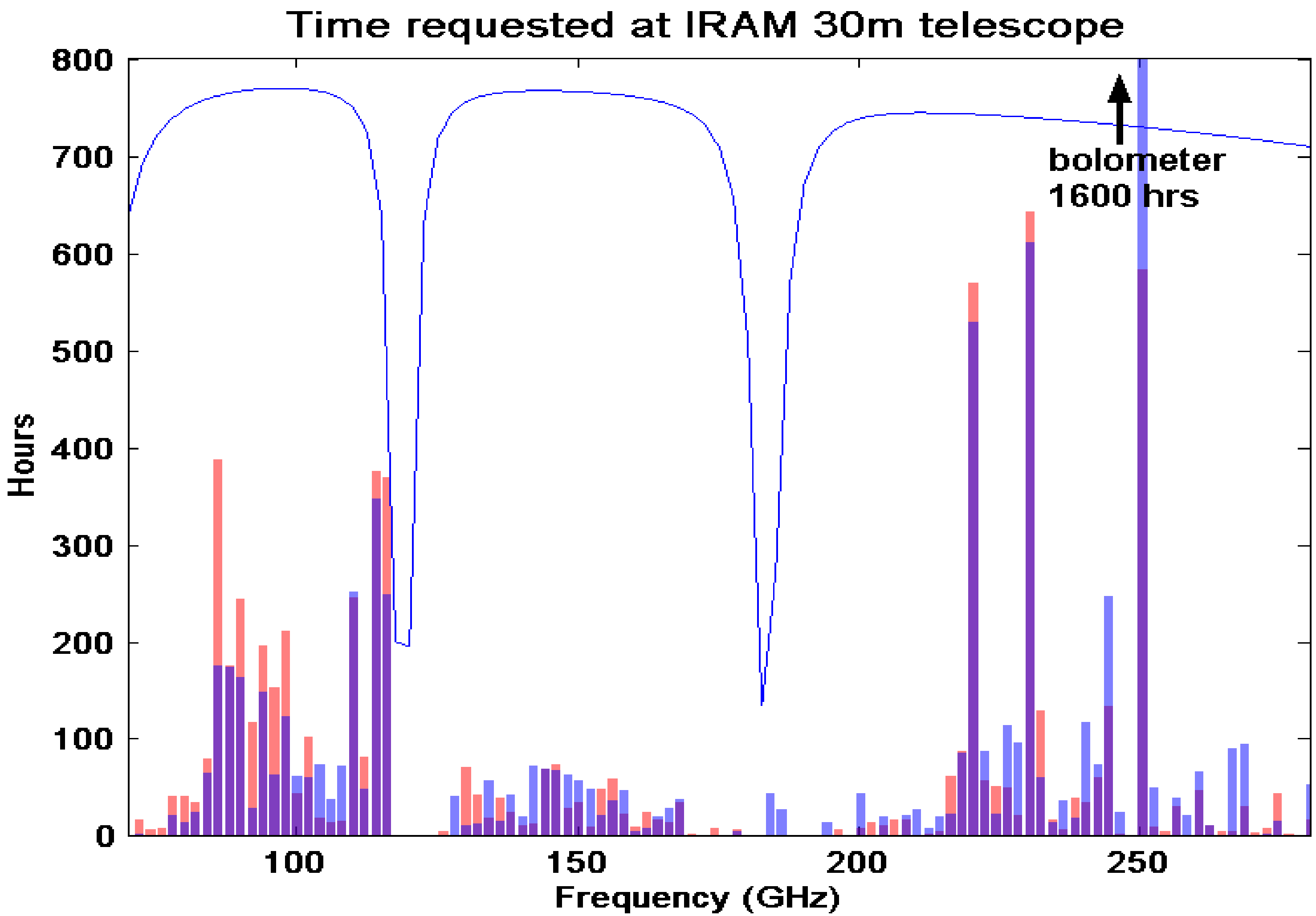
Mm/submm Astronomy: Emission mechanisms

- Thermal: interstellar matter (mostly cold)
  - Typical $T \approx 5 - 20K \Rightarrow \nu \approx kT/h \approx 100 - 400$ GHz
  - Most simple molecules emit line radiation
    @ $\nu = n \times \nu_0$, with $\nu_0 \approx 80 - 115$ GHz
  - Dust thermal continuum typically peaking @ $\nu \geq 300$ GHz
- Mm/submm is the prime frequency domain for the study of the interstellar matter
- Non-thermal
  - Synchrotron: quasars
    Mm VLBI accesses the "core engine"
  - Pulsars

Atmospheric Windows



Spectrum Usage at IRAM 30m Telescope



Specifics of mm/submm Telescopes

- Receiver noise improving towards quantum limit:
  - e.g. ALMA Band 7 (IRAM):
    Spec: 67K DSB (4 photons)
    Best achieved: 30K DSB (2 photons)
- Very high gain antennas, e.g. IRAM 30m telescope:
  - ε = 50μm rms , D = 30m
    @ λ 1.3mm, $A_{eff} = A_{geom}\,\varepsilon_{sp}\,\varepsilon_{ill}\,\varepsilon_{ruze} \approx 420\,m^2$ $\quad G_i = 95\,dB$
- High altitude observatories $\Rightarrow$ distant horizon
  - Pico Veleta, h = 3000m, D = 190km (but atm. atten.)
- Millivolt-level bias electronics easily jammed by "low" frequency radiation
- WVR monitor for phase correction

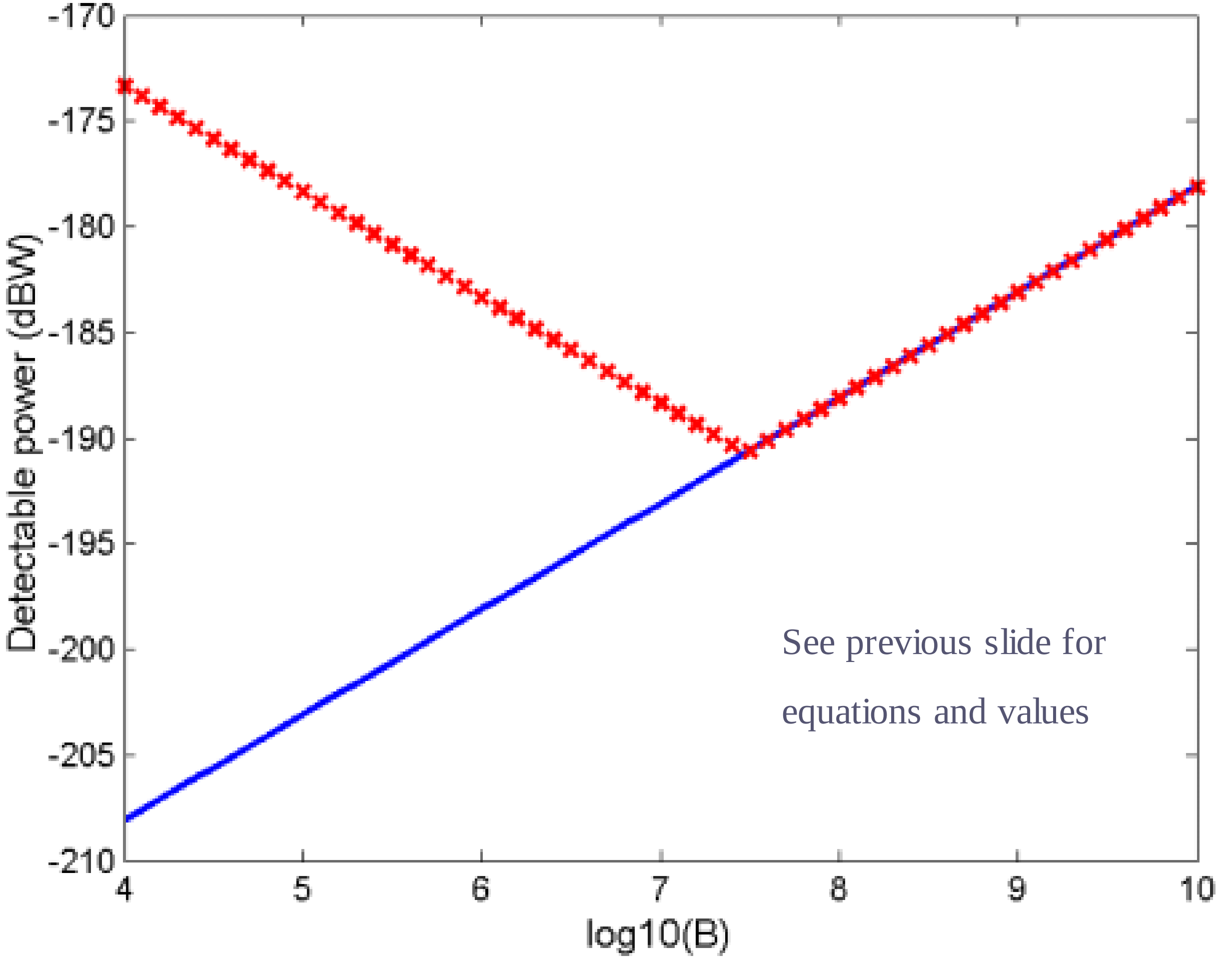
Threshold interference levels (at receiver input)

- Threshold power for interfering signal according to value of interference bandwidth B_{int} and pre-detection bandwidth B

$$P_{\text{int}} = \begin{cases} 2\,k\,T_{sys}\,B^{1/2}\,\tau^{-1/2} & \text{for } B \geq B_{\text{int}} \\ 2\,k\,Tsys\,B_{\text{int}}\,B^{-1/2}\,\tau^{-1/2} & \text{for } B < B_{\text{int}} \end{cases}$$

- Assume Tsys 50K, B_{int} = 30MHz, τ = 2000s

Threshold power level for a 30 MHz wide interference



Threshold power flux densities

- Bore sight (IRAM 30m, λ 1.3mm, $A_{eff} = 420m^2$)
  - F_H = -216 dB(W/m^2)
- Isotropic G_i = 0dB
  - F_I = -121 dB(W/m^2)
- ITU-R RA.796-1
  - F_{ITU} = -114 dB(W/m^2)
- Susceptibility to interference strongly dependent on angle from bore sight

A Case Study: Cloud Radars

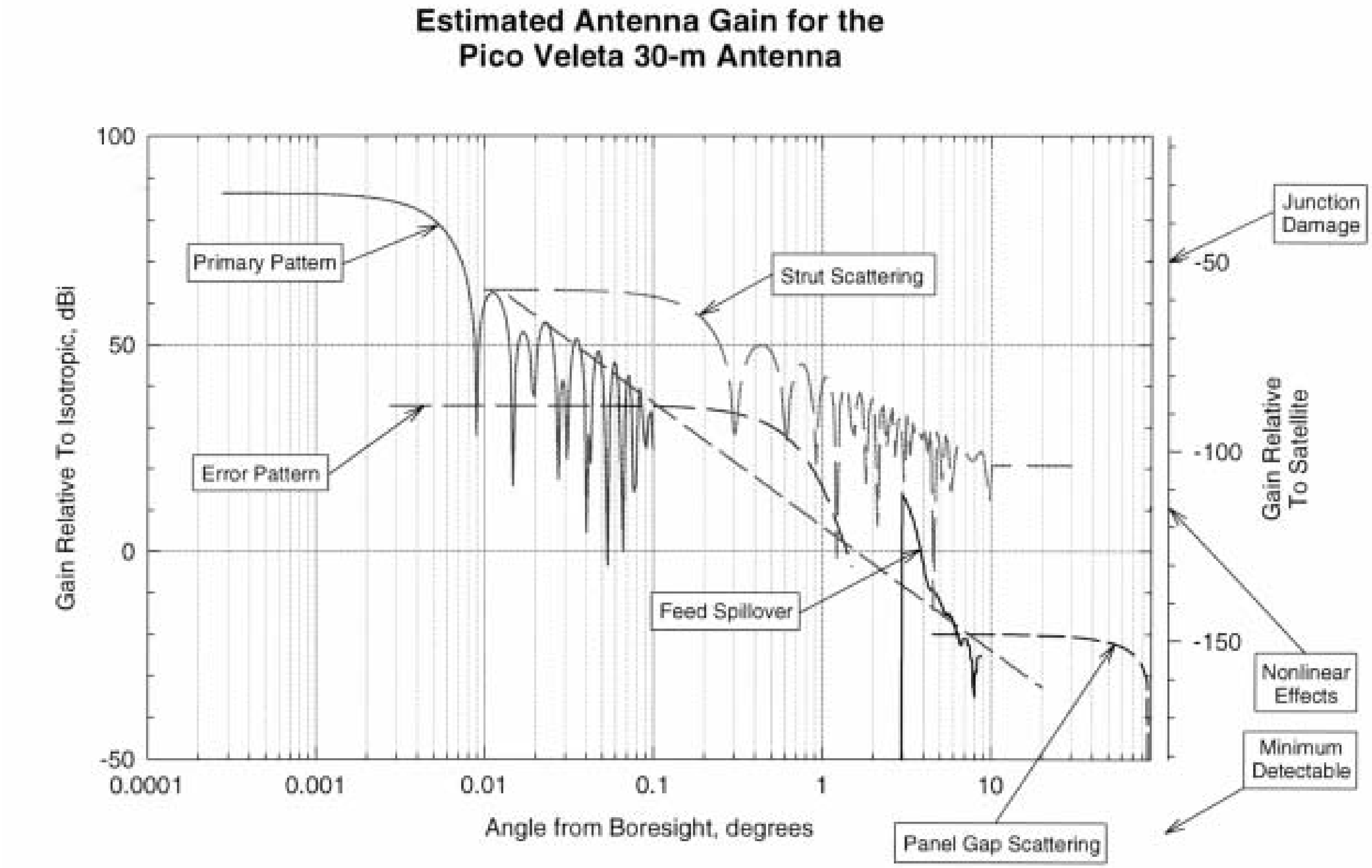
- Nadir-pointing radars for the study of vertical cloud distribution
- Two projects:
  - CloudSat (Earth System Science Pathfinder, NASA)
  - MACSIM / ACRI (Earth Radiation Mission, ESA)
- Very similar technical specs

	CloudSat	MACSIM
Frequency (GHz)	94.05	94.05
Peak power (kW)	1.8	1.7
Antenna gain (dBi)	63.3	66.2
Footprint (km)	1.4	0.8
EIRP (dBW)	95.8	96.2
Power flux density dB(W/m2)	-29.3	-24.71

A Case Study: Cloud Radars

- Power collected by IRAM's Pico Veleta Dish (boresight-boresight):
  - CloudSat 0.8 W
  - MACSIM 2.4 W
- Three levels of interference identified:
  - Destruction of SIS junctions
    (assume 2-jcn array, 4μm^2 each)
    Estimate by A.R.Kerr (NRAO): 8 mW (peak)
  - Frontend saturation
    Assume @ 10% of LO power 2 nW (avg)
  - Detectable in observation 10^{-19}W (avg)

IRAM 30m susceptibility vs angle (Study by J.Lamb, IRAM, 1996)



Cloud Radar Mitigation Actions

- RATEP study by Oerlikon under ESTC contract (1996)
  Various bandstop devices designed/prototyped, intended for radioastronomy receivers
  - Stop band wider than necessary (>2GHz)
  - Out-of-band attenuation 0.5...1.6 dB, causes significant performance degradation
- Avoidance by RA telescope
  - Requires accurate satellite ephemeris
  - Why should we bear the load of risk avoidance?
- Short interruption of radar transmitter when passing over mm-wave observatories. Preferred solution.
- Recent (Aug2004) study by ALMA North American Technical Advisory Committee

Water Vapour Radiometers

- Used by mm-wave interferometers to correct atmospheric phase; significant improvement of mapping quality
- Two water lines used:
  - 22 GHz: IRAM PdBI, Caltech OVRO
  - 183 GHz: CFA SMA, ALMA (under construction)
- Frequency bands used by IRAM PdBI WVR:
  - Ch1: 18.67 – 19.67 GHz
  - Ch2: 21.46 – 22.46 GHz
  - Ch3: 24.67 – 25.67 GHz
- Potential interference by ground microwave links

Other potential threats

- Cloud radar 35 GHz
- Space to earth (fixed) downlinks (what is footprint?)
- Anticollision car radars 94/76 GHz. Means to enforce quiet zones?