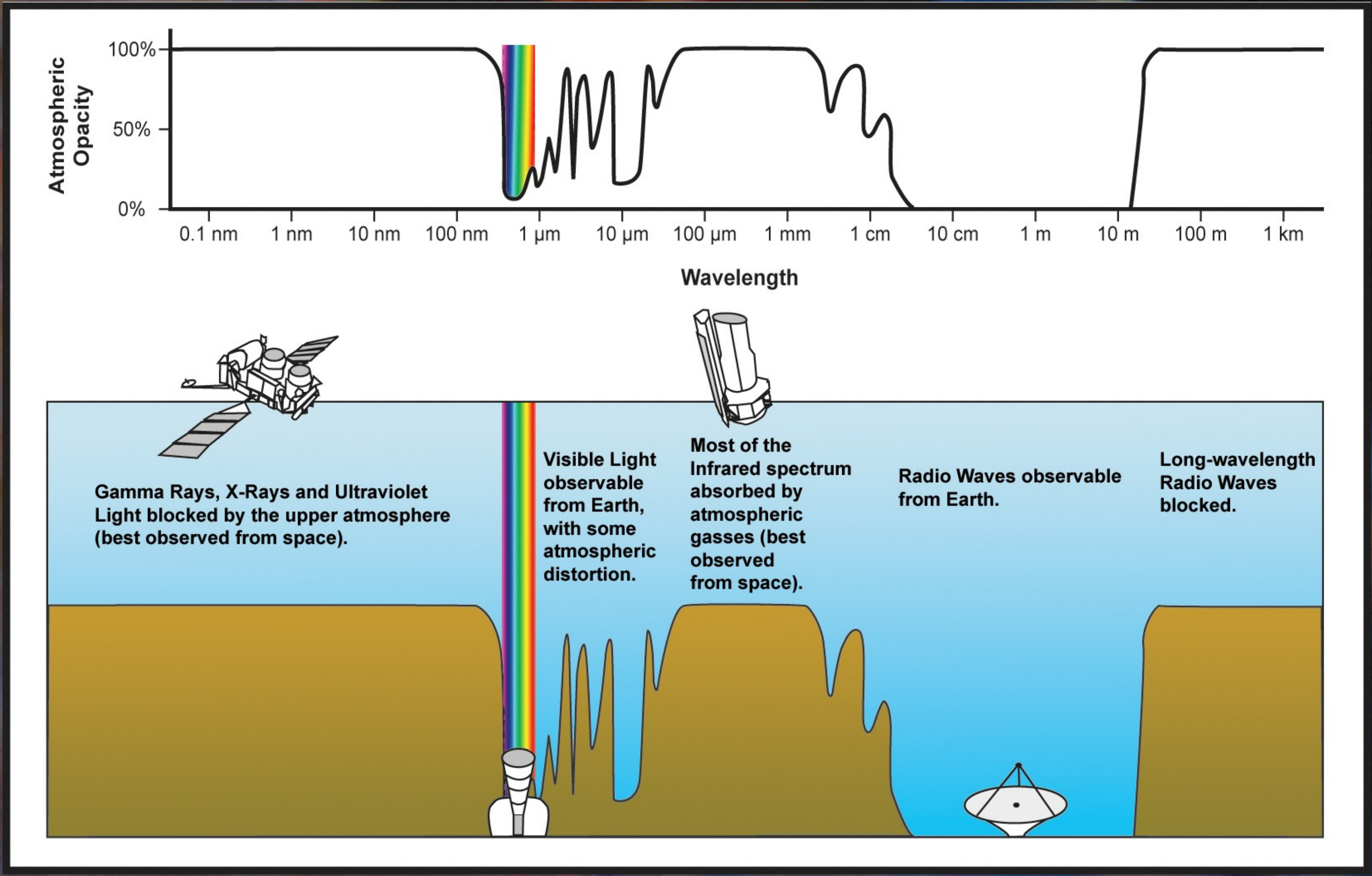
Overview of submm Single Dish: From Observations to Useful Data

Thomas Stanke (ESO)

Overview of submm Single Dish: From Observations to Useful Data

- Submm challenge 1: The atmosphere
- Overview of the submm landscape: telescopes (present, future), instrumentation, observation types
- Submm challenge 2: The atmosphere
- Basic Data reduction tasks
- Calibration concepts (Heterodyne, Continuum)
- Things to keep in mind: the “other” sideband

Submm Challenge 1: The Atmosphere



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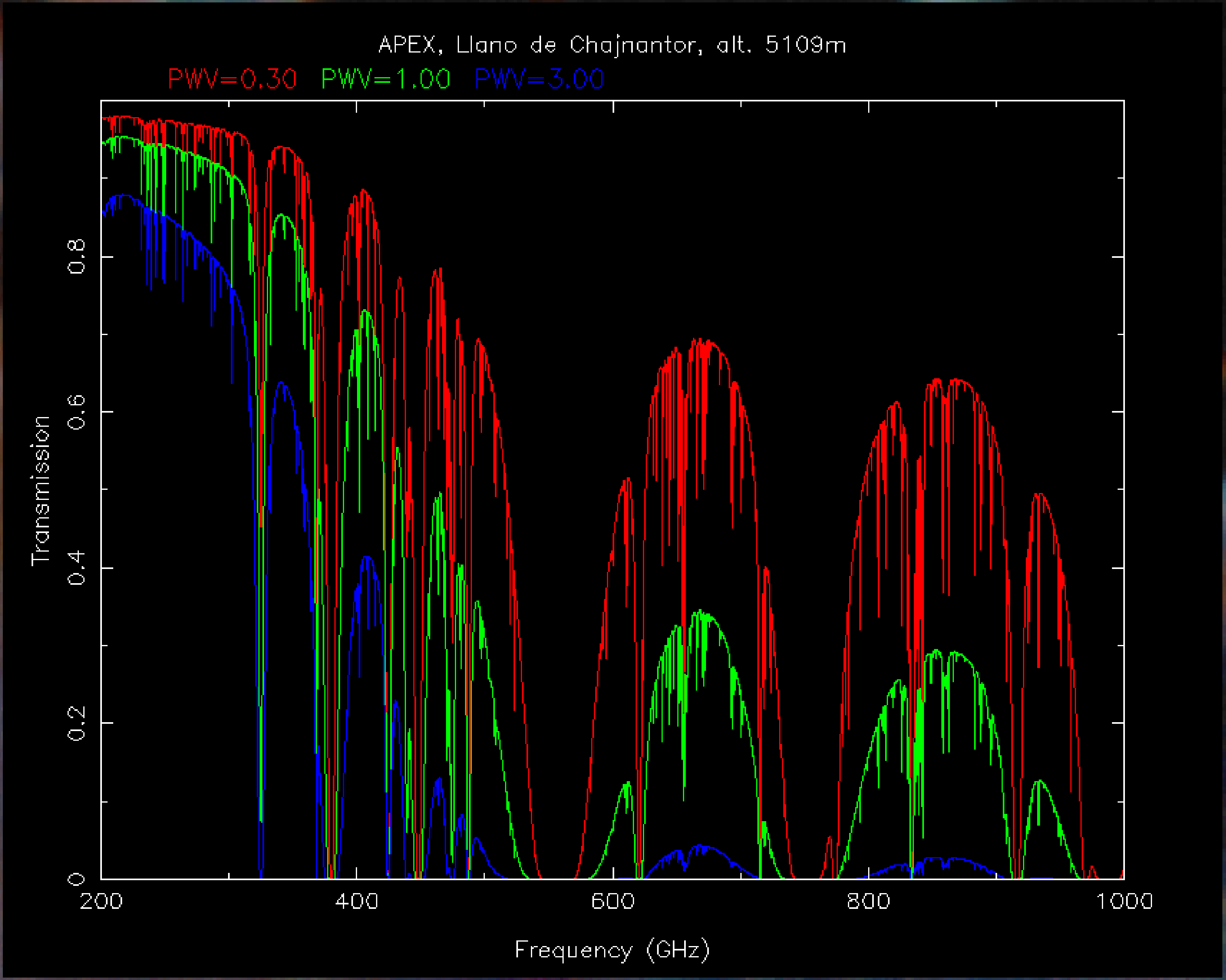

Submm Challenge 1:
The Atmosphere

Decent transmission only in atmospheric windows

Transmission limited (to large extent) by Water vapour

→ High and dry site!

Overview of the submm (Single Dish) landscape

Ground based:
JCMT (15m Hawaii), APEX (12m Chajnantor)
ASTE (10m), Nanten (4m) (Chajnantor)
ALMA ACA TP (4x12m, Chajnantor)
(Kitt Peak 12m (?)), SMT (10m, US),
(LMT (Mexico), IRAM 30m (Spain))
SPT (South Pole), ACT (Chajnantor), balloons

Air/Space based:
SOFIA (2.7m)
(Herschel)

Overview of the submm (Single Dish) landscape: Future

Ground based:

CCAT-prime (6m, Cerro Chajnantor, mid 2021)

Greenland Telescope (12m)

CSO? (10.4m, Chajnantor?)

LST (Japan, 50m, Chajnantor)

CSST (Caltech, 30m, Chajnantor)

AtLAST (40m? Chajnantor)

Air/Space based:

SPICA (Japan, 2.5m, L2)

Overview of the submm (Single Dish) landscape: Instrumentation (types)

Spectroscopy:
Heterodyne receivers:
- spectral resolution: up to (few) 10m/s
- frequency coverage: multi-GHz
- single pixel, arrays (10s of pixels)

Bolometer based low spectral resolution spectrometers

Continuum:
Multipixel (Many thousand) Bolometer Cameras
(Heterodyne receivers)

Overview of the submm (Single Dish) landscape: Basic observation types

Spectroscopy:
Spectroscopy of single objects/positions
Spectral line mapping: raster, On The Fly (OTF)

Continuum:
Photometry of single objects (e.g., using wobbler)
(OTF) maps

Polarimetry

Submm Challenge 2:
The Atmosphere

Atmosphere absorbs → Atmosphere emits!

→ (highly variable) bright sky emission
→ needs to be removed

- position switching
(wobbling secondary, telescope offsets → reference/OFF position, map edges)
- Frequency switching
- For array receivers: use off-source pixels

Basic data reduction tasks

Heterodyne/Spectroscopy **Continuum/Bolometers**

Convert instrumental units to meaningful brightness scale

Submm challenge 3:
correction for atmospheric extinction

Remove “bad” data

Remove sky emission

Account for atmospheric and instrumental instability

Remove spectral baseline | Remove temporal baseline and “sky noise”

Sum up and/or map data

Calibration Concepts (Heterodyne)

Radio Astronomers like to express intensities in (brightness) temperatures...

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT} - 1}$$

In the Rayleigh-Jeans limit (hν « kT, ν(GHz) « 20.84 T(K)):

$$B_{\rm RJ}(\nu, T) = \frac{2\nu^2}{c^2}kT$$

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- measurement of sky brightness → atmospheric optical depth
  (taking into account spillover, the “other” sideband, ...)

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Applying the factor results in T_A^* (atmosphere corrected Antenna temperature).

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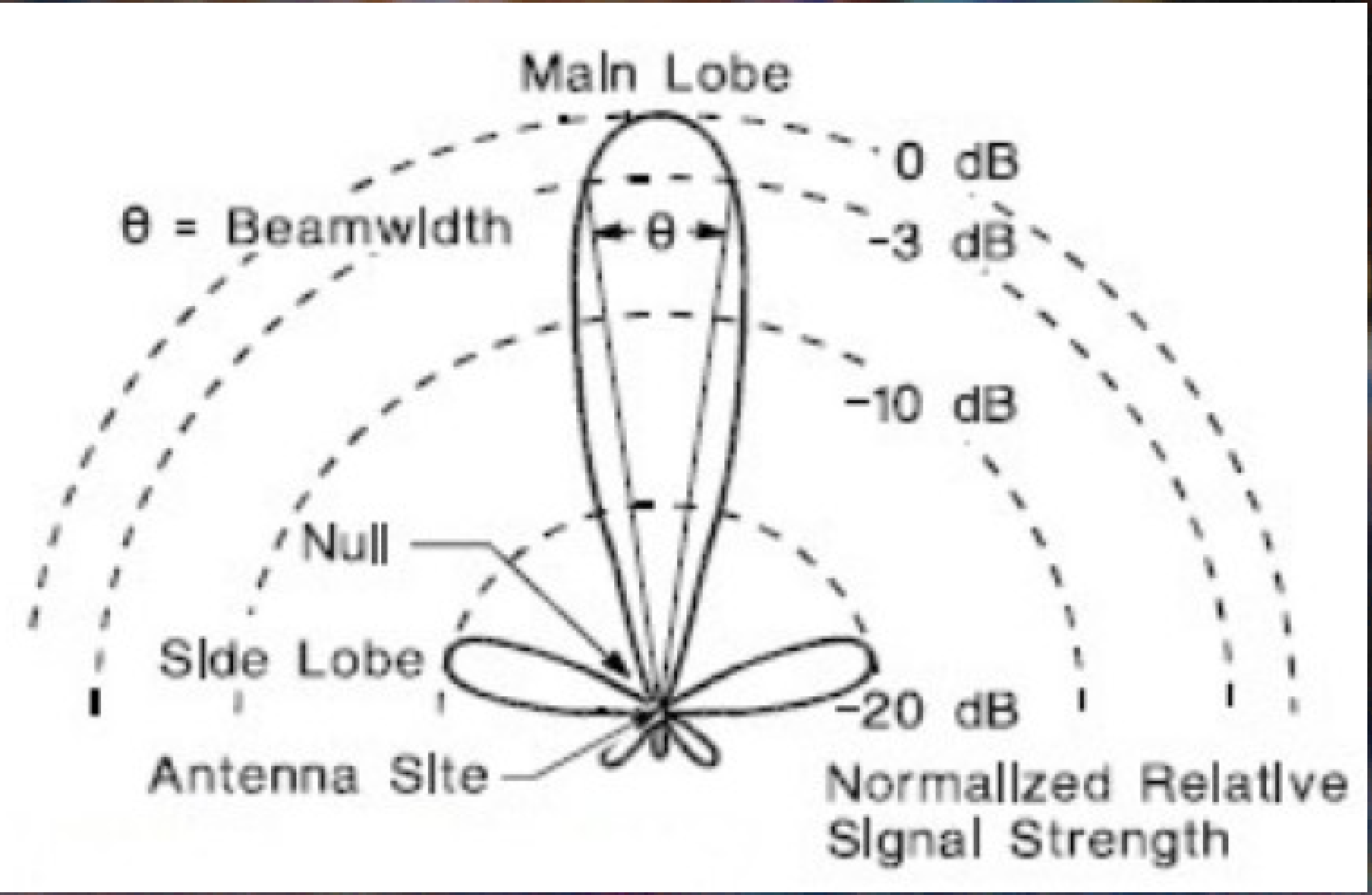
…. but you are not done yet ...

Calibration Concepts (Heterodyne)

Any antenna will have a certain point spread function or beam pattern: main beam, side lobes, error beam



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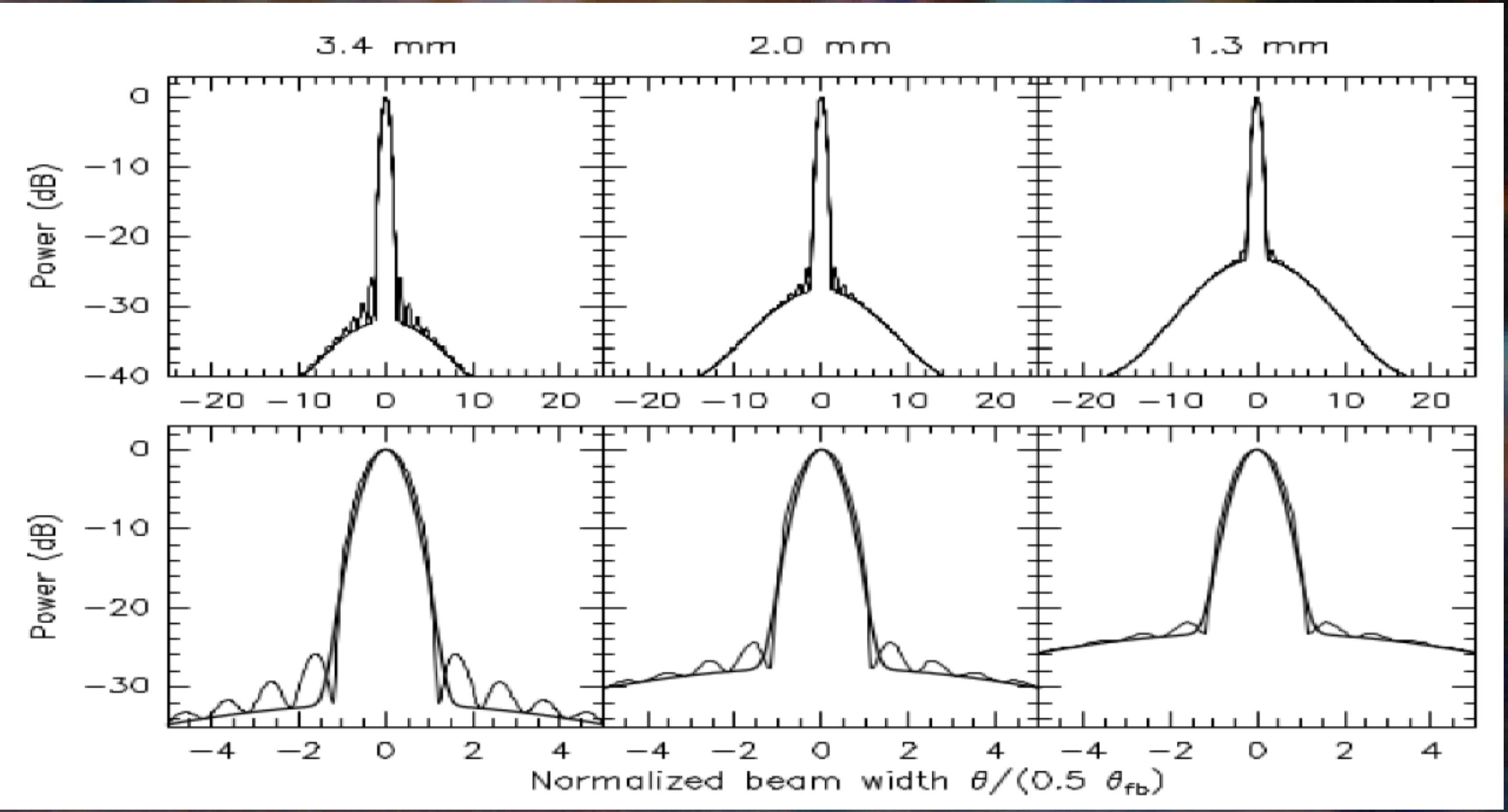

IRAM beam patterns (Greve et al 1998)

Calibration Concepts (Heterodyne)

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Only a certain fraction of the target emission will arrive at (and "heat") the receiver, given by the ratio of the Main Beam solid angle Ω_{MB} and the full beam solid angle Ω:

Normalized power pattern: $P_{\mathrm{n}}(\vartheta,\varphi) = \frac{1}{P_{\max}} P(\vartheta,\varphi)$

Beam solid angle:

$$\Omega_{\mathrm{A}} = \iint_{4\pi} P_{\mathrm{n}}(\vartheta,\varphi)\ \mathrm{d}\Omega$$

Main beam solid angle:

$$\Omega_{\mathrm{MB}} = \iint_{\substack{\text{main}\\ \text{lobe}}} P_{\mathrm{n}}(\vartheta,\varphi)\ \mathrm{d}\Omega$$

Main beam efficiency: $\eta_{\mathrm{B}} = \frac{\Omega_{\mathrm{MB}}}{\Omega_{\mathrm{A}}}$

Calibration Concepts (Heterodyne)

Any antenna will have a certain point spread function or beam pattern: main beam, side lobes, error beam

→ atmospheric extinction corrected antenna temperature T_A* has to be corrected for the main beam efficiency η_{MB} to get the final “Main Beam Brightness temperature” T_{MB}

$$T_{MB} = \frac{(\eta_F)}{\eta_{MB}} \times T_A^{star}$$

Calibration Concepts (Heterodyne)

Radio Astronomers like to express intensities in brightness temperatures...

In the Rayleigh-Jeans limit (hν « kT, ν(GHz) « 20.84 T(K)):

$$S_\nu = I_\nu \cdot \Omega_{MB} = B_\nu \cdot \Omega_{MB} \approx \frac{2 h \nu^2 k}{c^2} \cdot \Omega_{MB} \cdot T_{MB}$$

To get to useful units, insert T_{MB} into this formula (assuming you know the main beam solid angle), or go get a K to Jy conversion factor somehow (e.g., evaluate calibrator measurement, find something useful in the observatory documentation)

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Making use of the relation between (effective) Antenna diameter and the achieved beam size, this relation can be transformed to:

$$S_\nu \cdot A_{Eff} = 2 k T_{MB}$$

A_{eff}: effective antenna surface, related to the “real” surface $A_D = \pi/4 D^2$ via the aperture efficiency $\eta_A = A_{eff}/A_D$. η_A is usually available from the telescope documentation.

Calibration Concepts (Continuum)

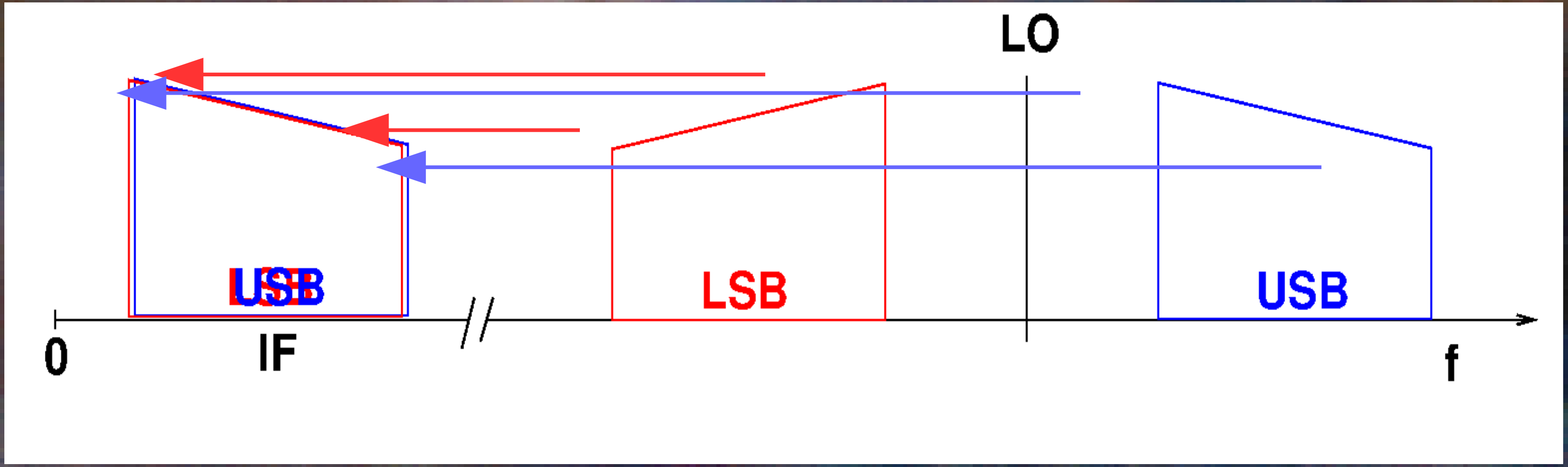
Correction for atmospheric extinction: Skydips
Absolute flux calibration: comparison with calibrator sources with known fluxes (planets, secondary calibrators)

Things to keep in mind: the “other” Sideband

Heterodyne receivers mix a Local Oscillator (LO) signal with the incoming signal, in order to downconvert the high-frequency signal into something more easily manageable (intermediate Frequency – IF).

The resulting frequency is the difference between the LO and incoming signal frequency.

This works on BOTH sides of the LO frequency!
→ “Upper” and “Lower” Sideband (USB, LSB)



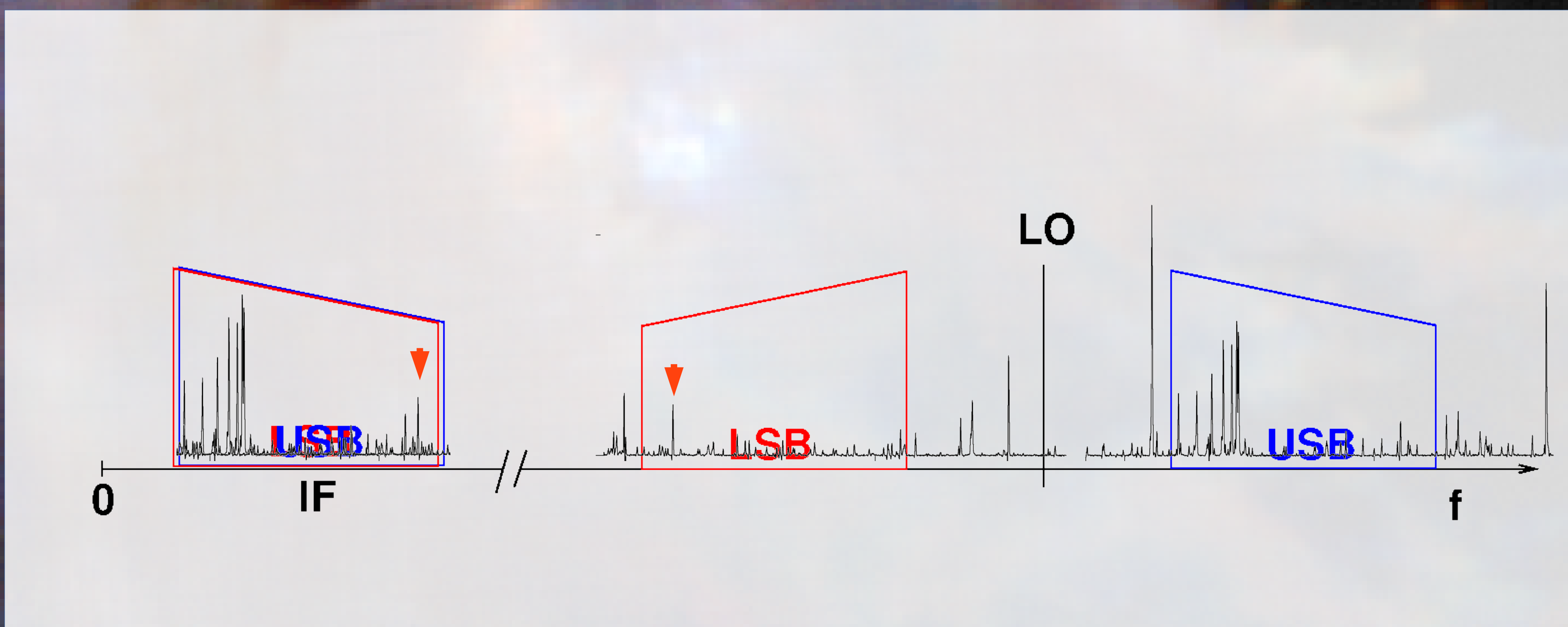
Things to keep in mind:
the “other” Sideband

Heterodyne receivers may come in different flavors:

- “Double Sideband” (DSB): both sidebands end up in the same spectrum
- “Single Sideband” (SSB): one sideband (“signal sideband” is provided as spectrum, the other one (“image sideband”) is suppressed
- “Dual Sideband (2SB)”: sidebands are separated, both are delivered as spectrum

Things to keep in mind: the “other” Sideband

“Double Sideband” (DSB): both sidebands end up in the same spectrum → lines (and atmosphere) from BOTH sidebands fully show up



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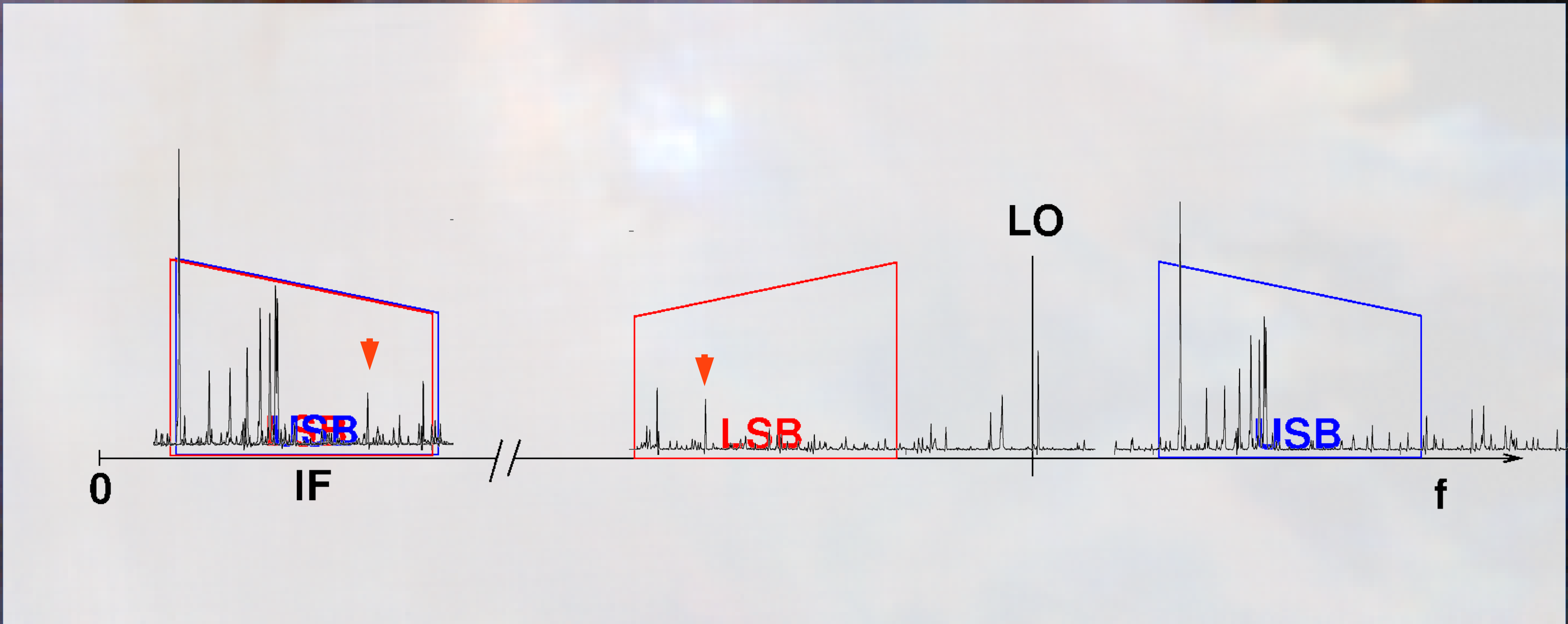

Things to keep in mind:
the “other” Sideband

“Single Sideband” (SSB), “Dual Sideband (2SB)”: Sidebands are separated, both are delivered as Spectrum → Atmosphere (and bright lines) from “other” sideband will spill over into spectrum, attenuated by the “Sideband rejection ratio”

Basic data reduction tasks

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Further reading...

Tools of Radio Astronomie (T. Wilson/ K. Rohlfs/S. Hüttemeister)
Terahertz Astronomie (C. Walker)
IRAM 30m Summer school talks, lecture notes