Large Format Heterodyne Arrays

Challenges in the submm and THz spectral regime

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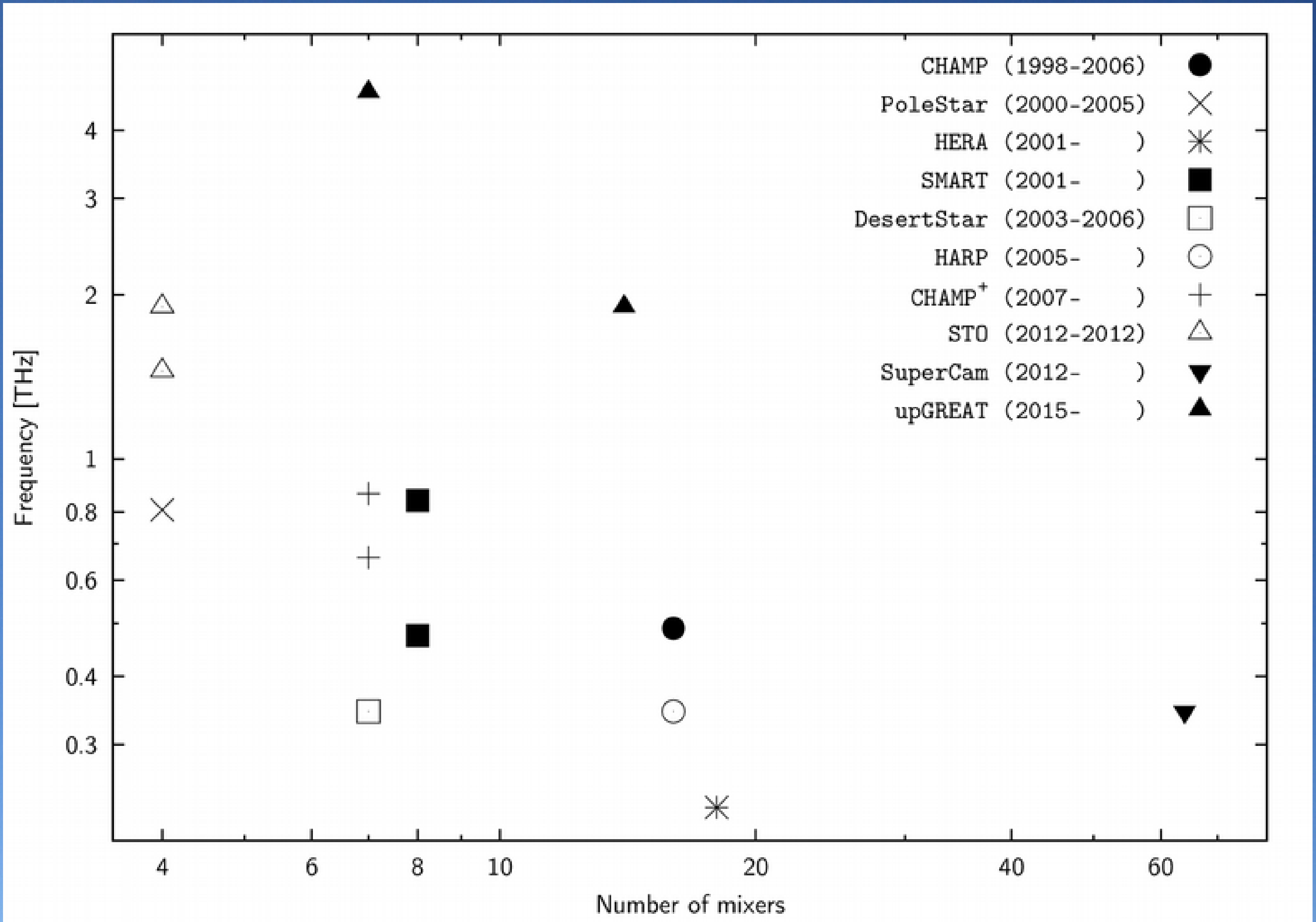
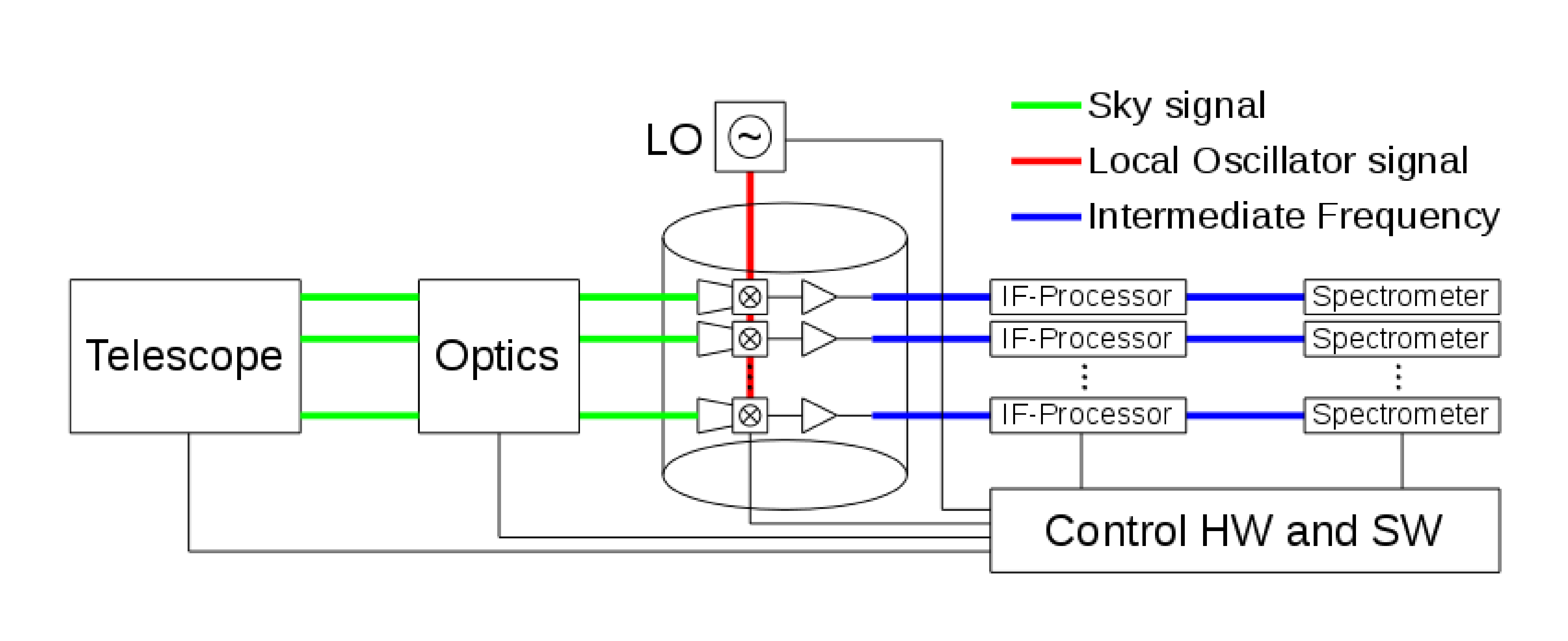
Talk Overview

- existing and planned instruments
- array subsystems
  - optics
  - detectors
  - local oscillators
  - IF-processing and backends
- system aspects

Existing (sub-)THz Arrays

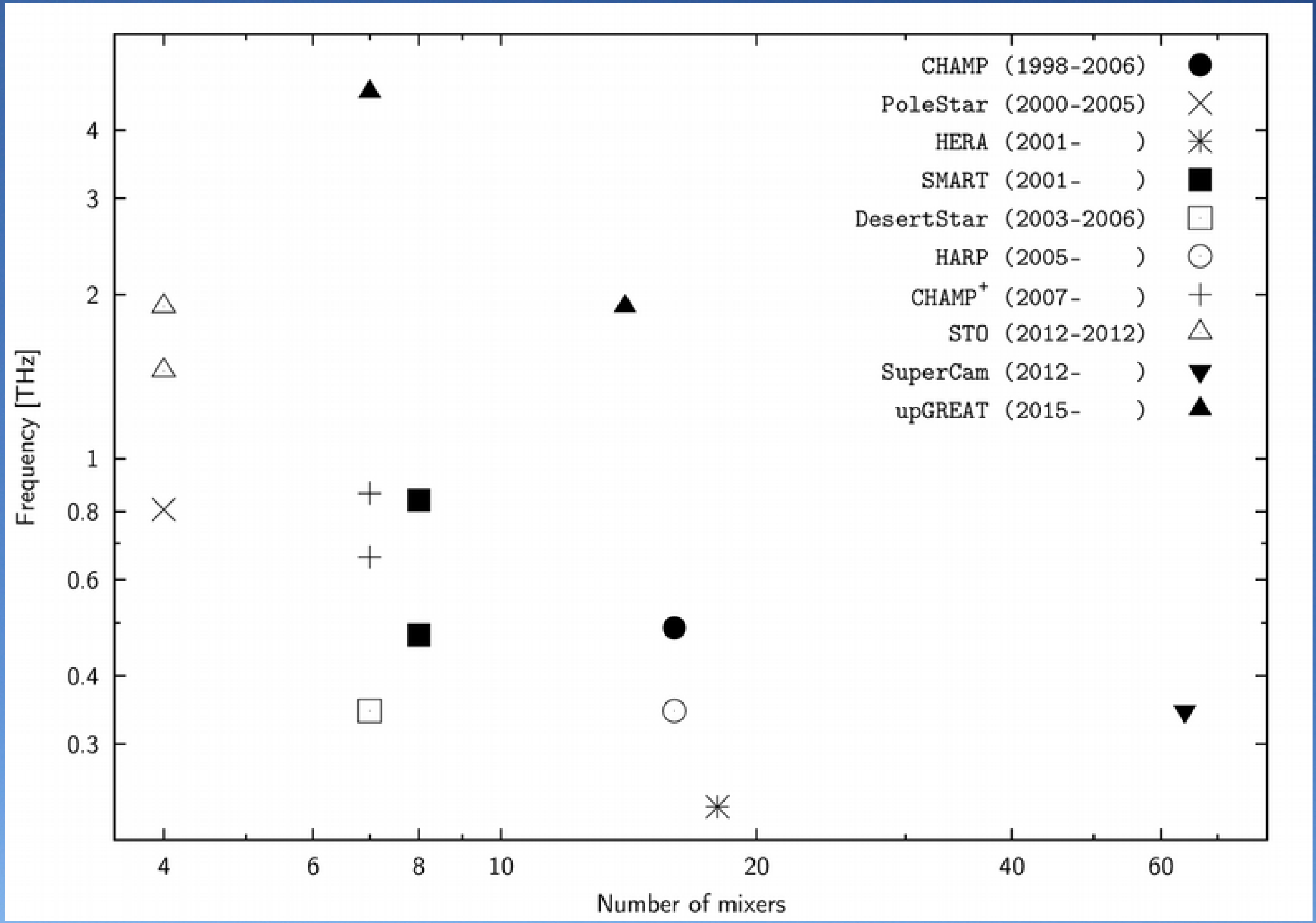


Heterodyne Array Receiver

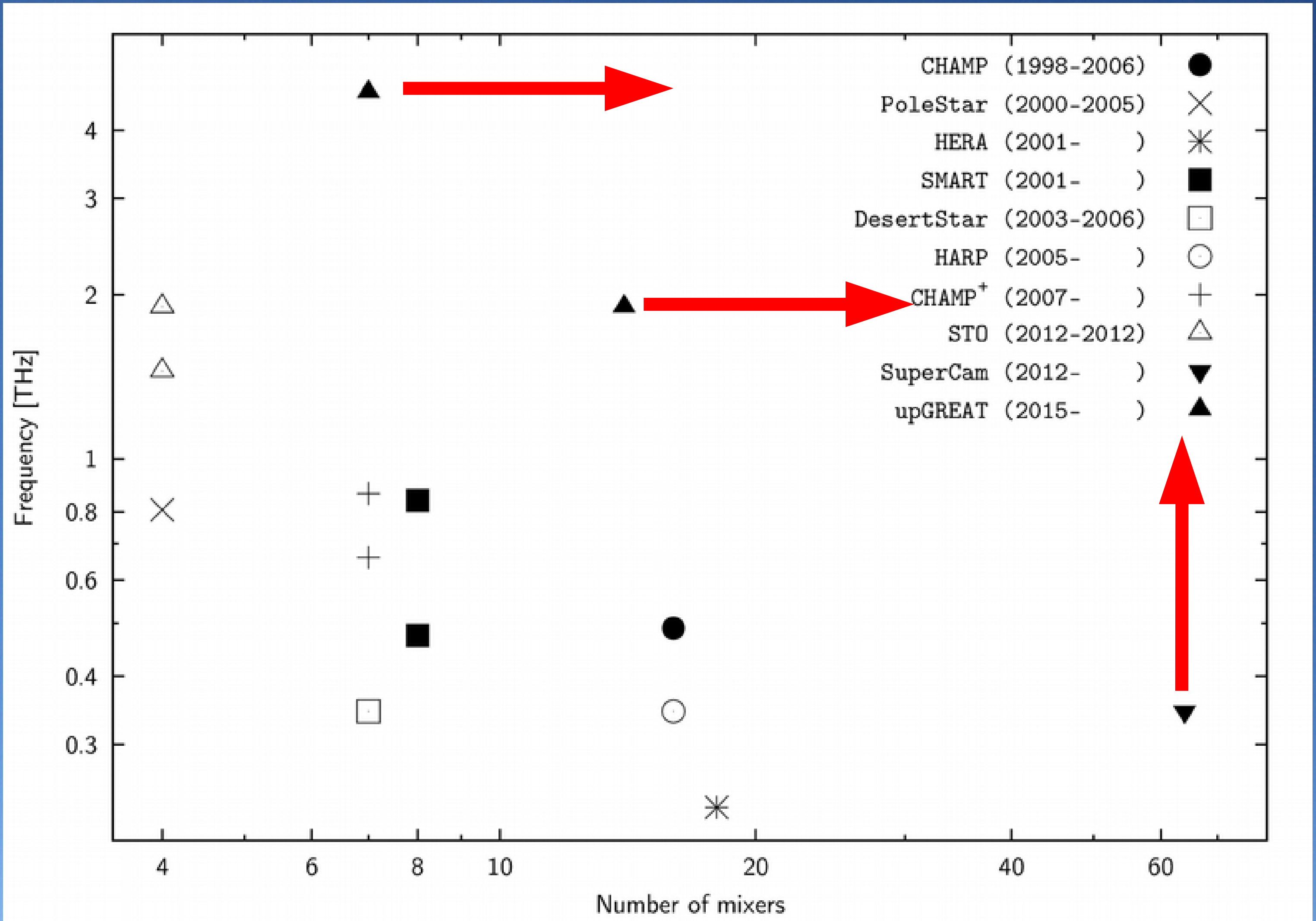


high per pixel complexity:
need *N* mixers, LNAs, IF-processors, spectrometers

Existing (sub-)THz Arrays



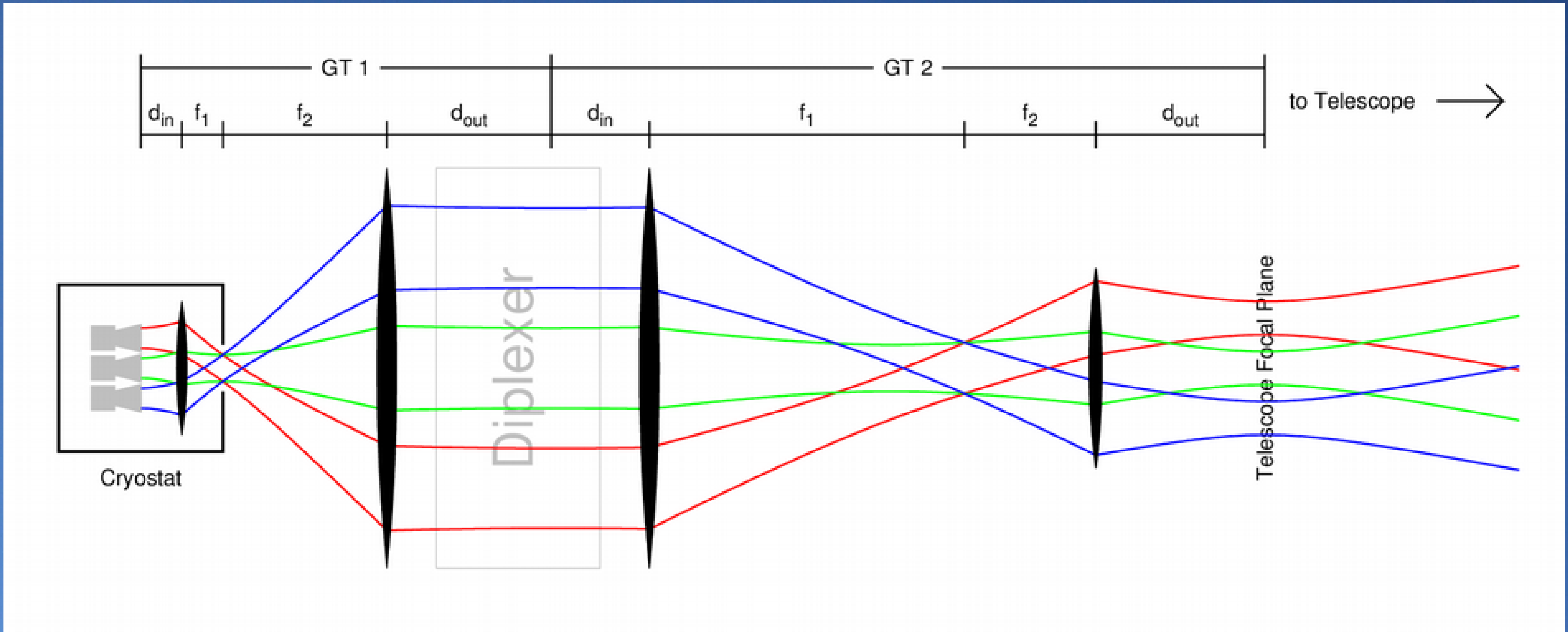
Where we want to go



Emerging Arrays

- KAPPa
- LASMA
- GUSSTO
- large format array for SOFIA?
- (large format?) array for OST?

Optics: Typical Setup



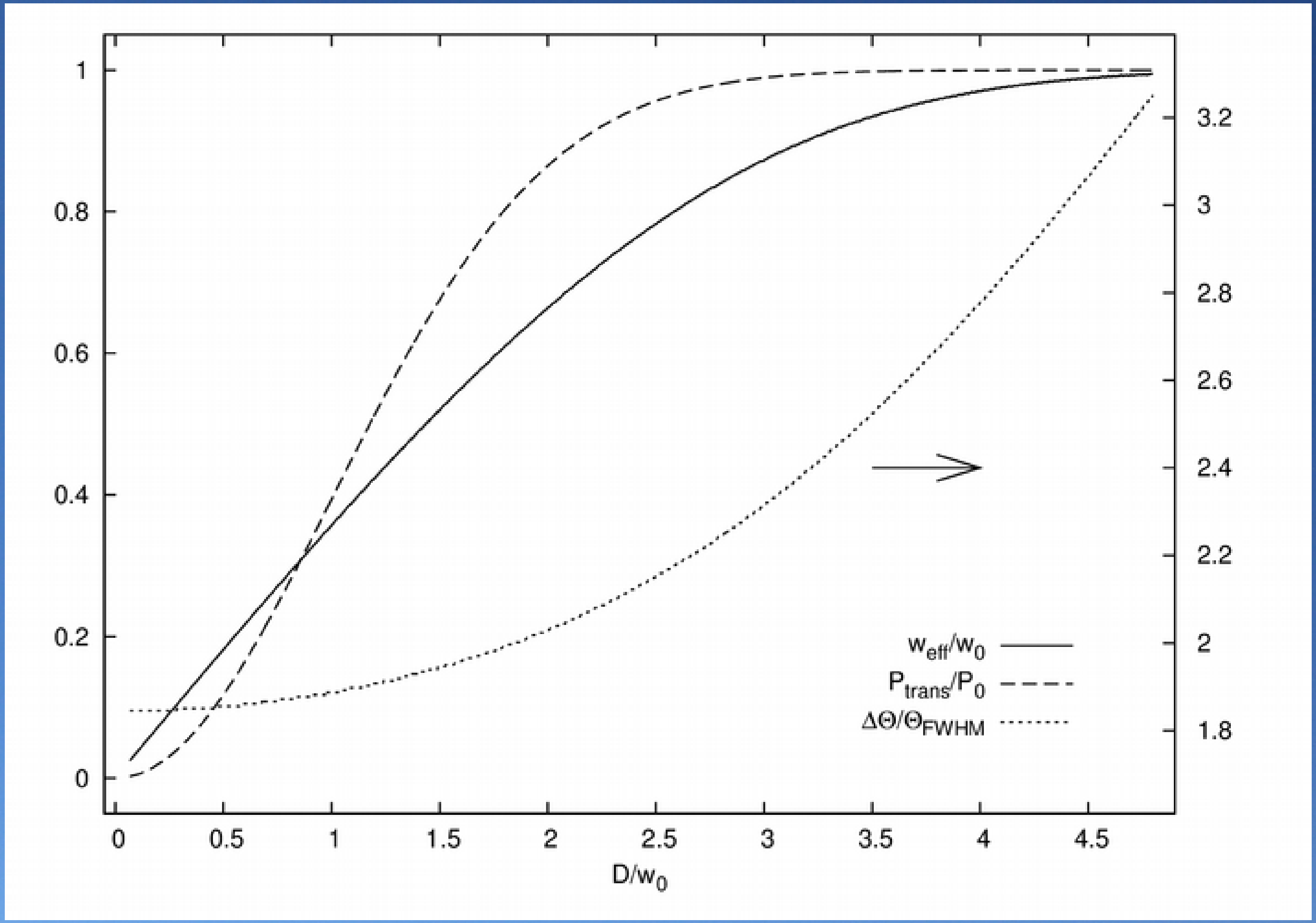
- **1-2 Gaussian Telescopes to match mixer FP to telescope FP**
- **mixer FP layout crucial – sets sky beam spacing**

Optics Constraints

ratio of beam spacing to beam waist is constant in every FP

$\Delta\Theta \,/\, \Theta_{FWHM} = 2/3 \times s_{FP} \,/\, w_{FP}$

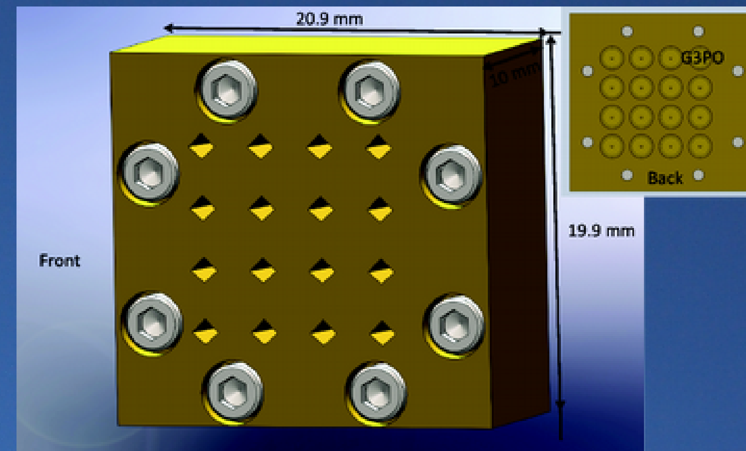
need to have $D/w_0 \approx 3$ in mixer FP



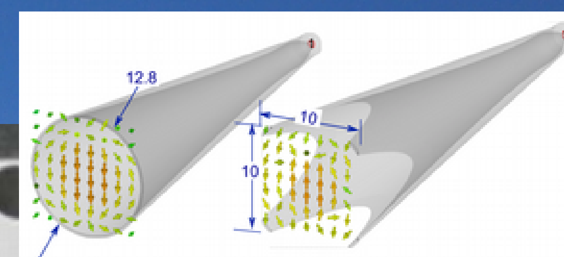
Graf+ 2015

How to achieve $D/w_0 \approx 3$

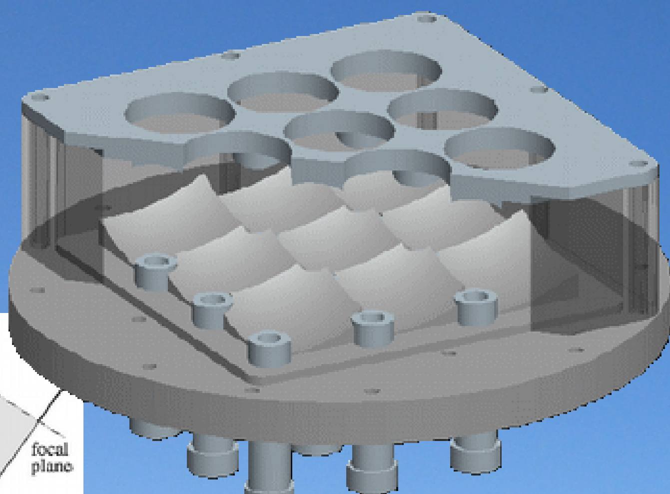
- **Densly packed feed horns**
  - **Design? Manufacturing?**
- **Lens array (HERA, CHAMP+)**
- **Mirror array (SMART, upGREAT)**

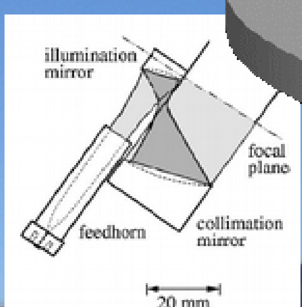


Kloosterman+ 2015



Cortes 2014



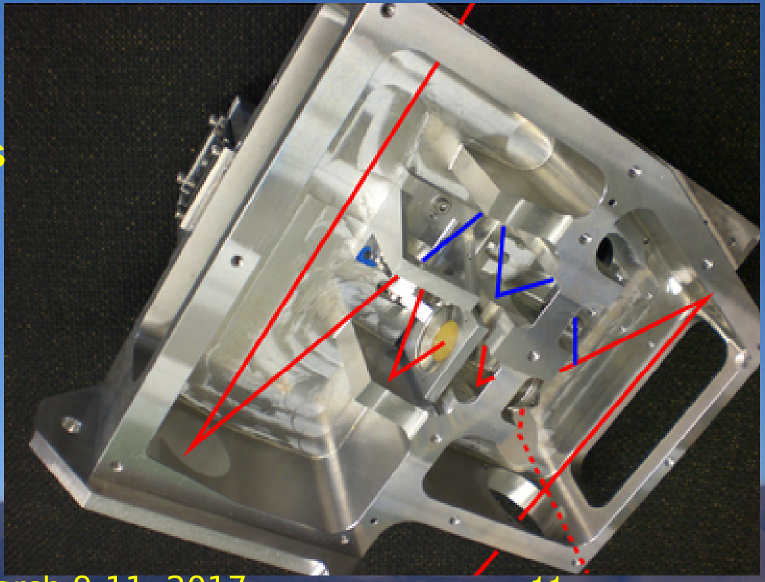


Lüthi+ 2006

Leech+ 2012

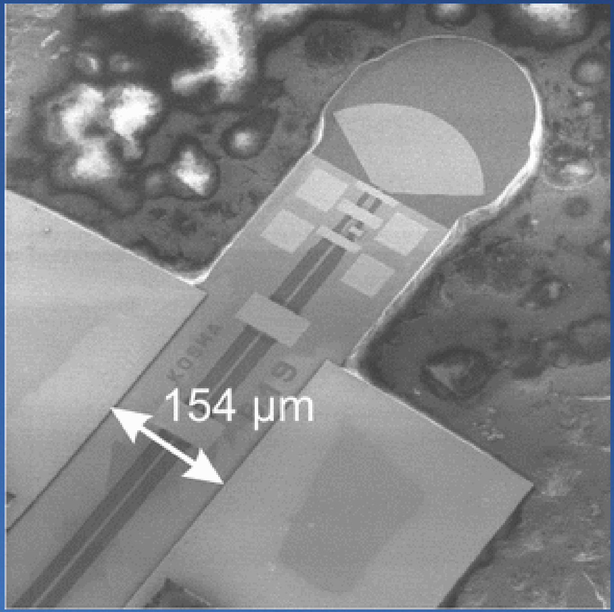
Optics: Refractive / Reflective

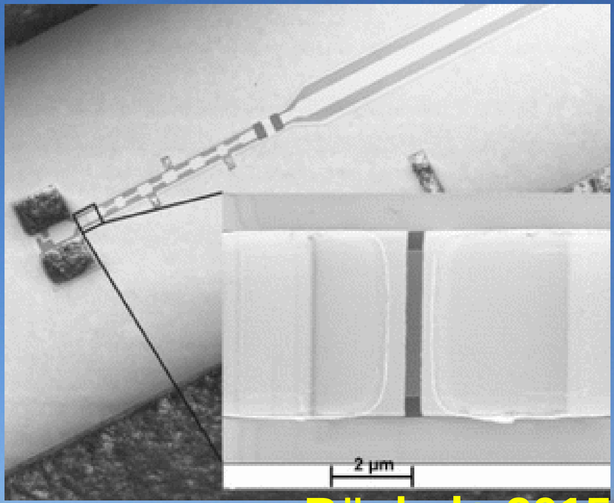
- **Refractive Optics**
  - compact
  - lossy (reflection and transmission)
    - thin lenses, AR coating / grooving
- **Reflective Optics**
  - very low loss
  - monolithic option
  - bulky
  - aberrations
    - long focal length mirrors, small reflection angles
- **Best: no Optics!**
- **Minimal optics: cryostat window**
- **Image rotator?**



Detectors for THz Arrays

- **SIS**
  - **near quantum limited noise performance**
  - **large IF-bandwidth**
  - **RF frequency limited to ~1.5 THz**
  - **high LO power required**
  - **new materials?**
- **HEB**
  - **slightly less sensitive**
  - **limited IF bandwidth (few GHz) – bad at THz!**
  - **no known RF frequency limit**
  - **low LO power requirement**
  - **new materials?**
- **Manufacturing challenge: device uniformity**

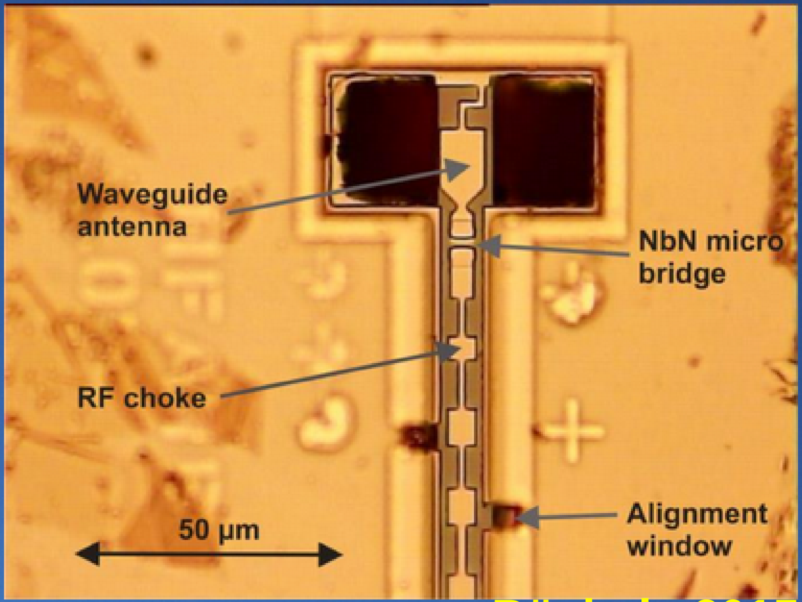




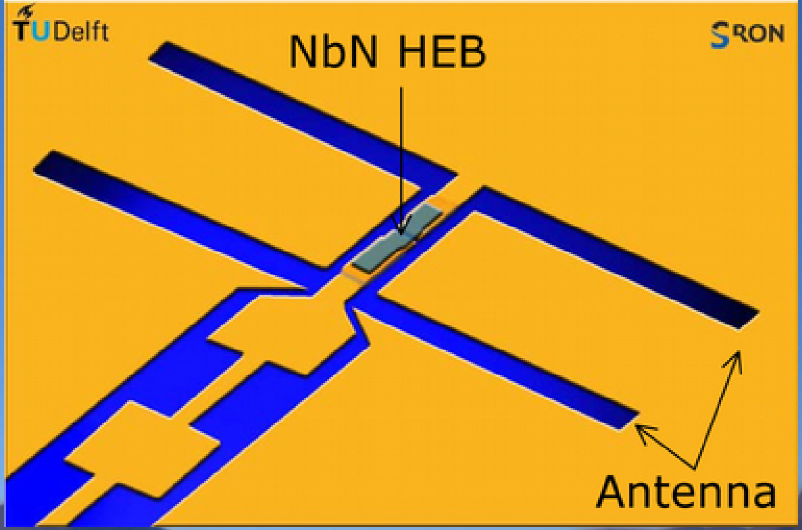
Büchel+ 2015

Waveguide or Open Structure?

- **all existing arrays use waveguide with feedhorn**
  - **well defined optical beam**
  - **manufacturing increasingly difficult at THz frequencies**
- **open structure used in single pixel applications**
  - **manufacturing much easier at high frequencies, but**
  - **optical performance in array not demonstrated yet**

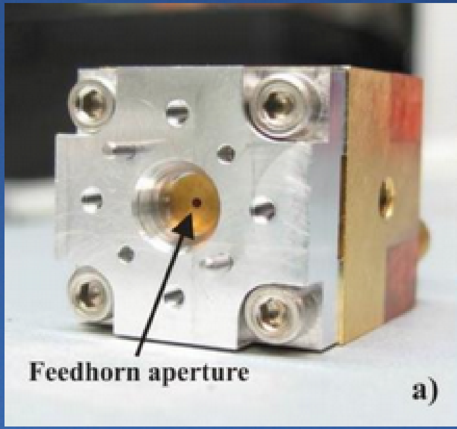


Büchel+ 2015

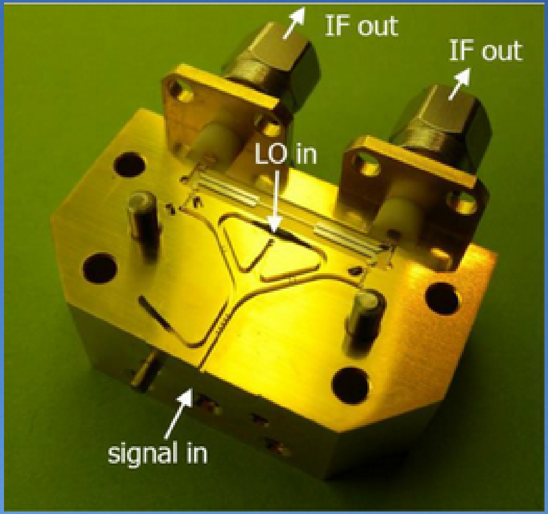


DSB, SSB, 2SB, balanced?

- **Double Side Band:**
  - simplest
- **Single Side Band:**
  - atmospheric noise rejection
- **Two Side Bands:**
  - increased bandwidth
- **balanced mixers:**
  - efficient LO coupling
  - LO noise rejection
- **Array requires integrated design**

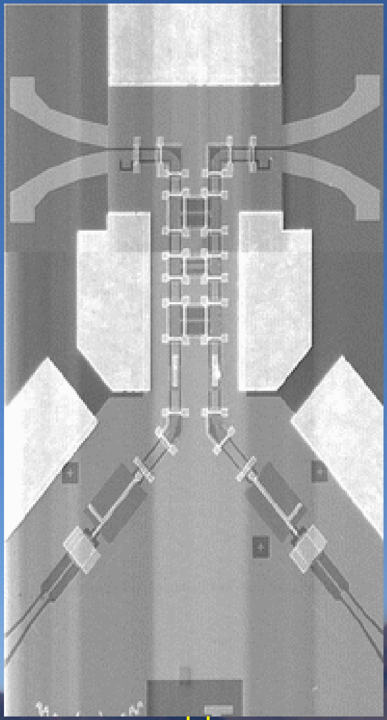


Büchel+ 2015



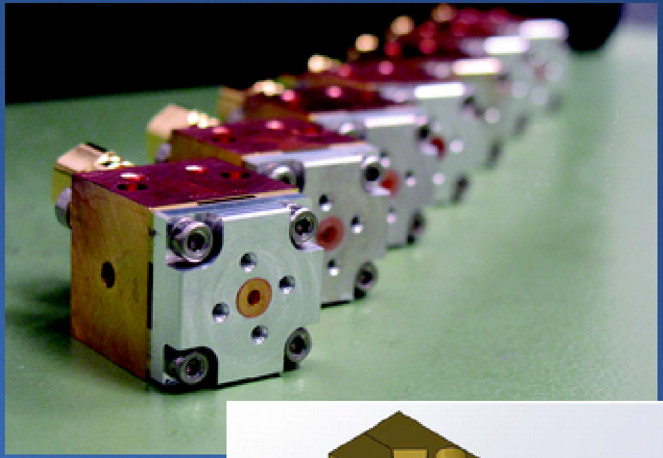
Maier+ 2016

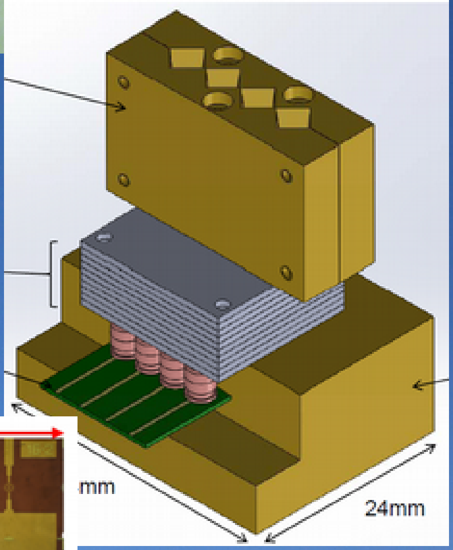
Westig+ 2011



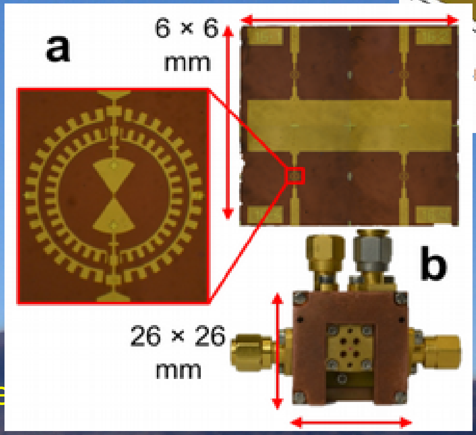
Individual Mixers or Integrated Array?

Pütz+ 2015





Chattopadhyay+

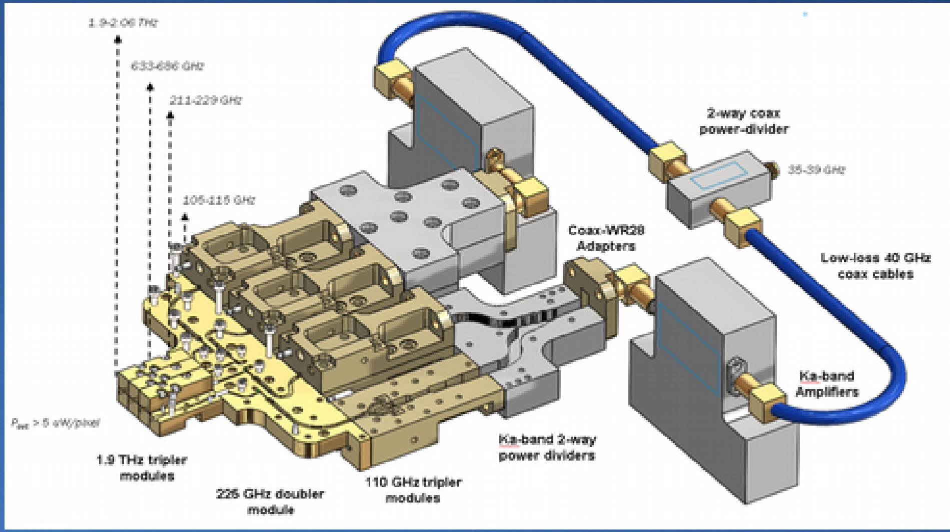


Trifonov+ 2017

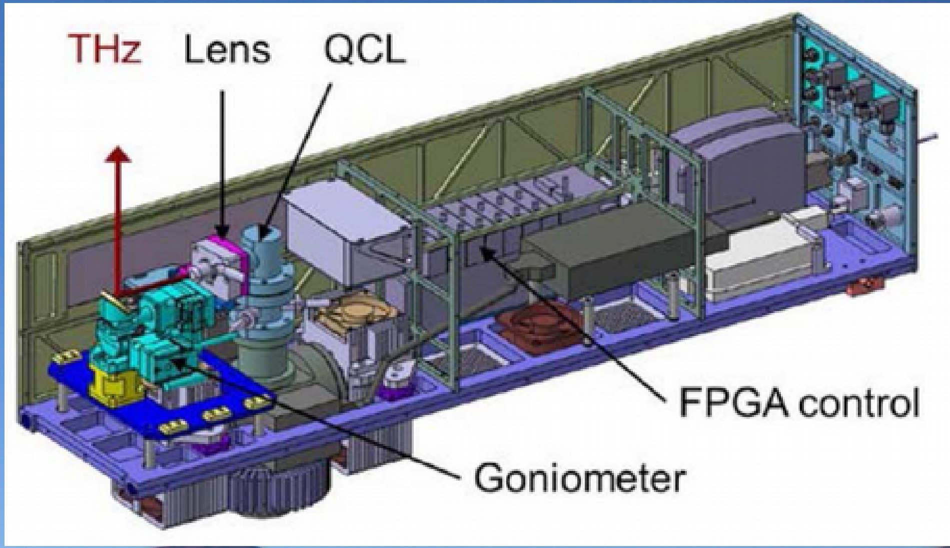
- all existing arrays use individual chips embedded in machined metal mixer blocks
  - mixers can be individually tested and selected
  - broken mixers can be exchanged
  - high machining and assembly effort
- on-chip array development ongoing
  - promise of low assembly effort
  - dead pixels are dead
  - requires high wafer yield and uniformity

Local Oscillators

- **Multiplied Sources (up to ~2 THz)**
  - easy to use
  - low power at highest frequencies
  - pay attention to LO noise
- **Quantum Cascade Lasers (above ~2 THz)**
  - high power
  - more complex
  - tunability / frequency control difficult
- **other options (e.g. photonics)**

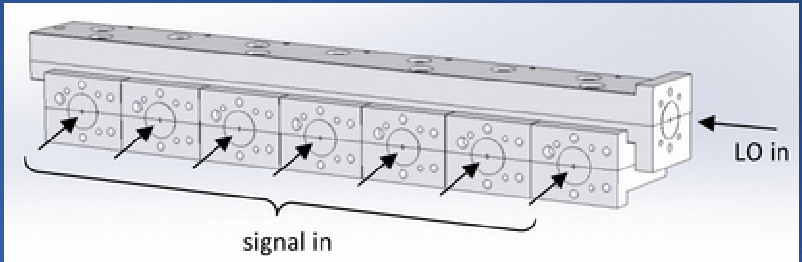


Siles+ 2014



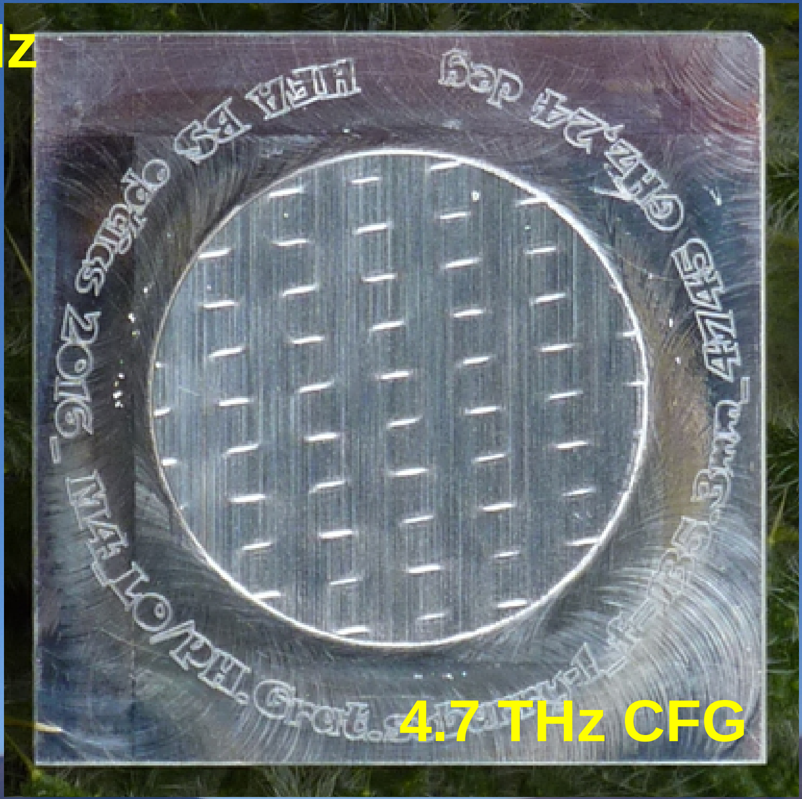
Richter+ 2015

LO Splitting



Maier+ 2016

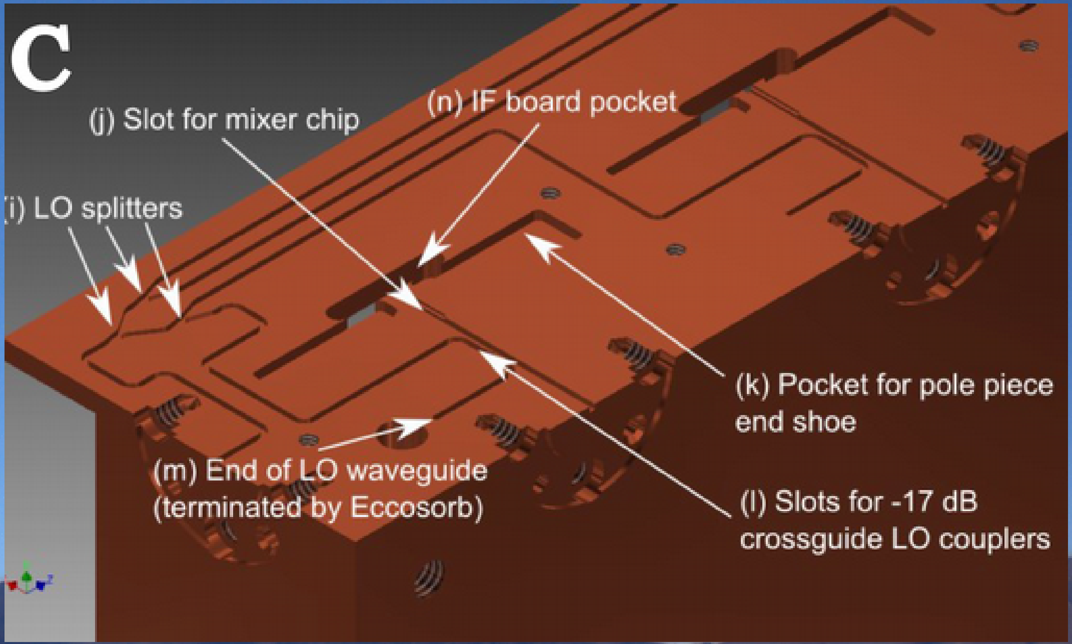
- **None: one LO chain per mixer**
  - **expensive, complex**
- **Waveguide couplers (HERA, Supercam)**
  - **very attractive, but difficult at THz**
- **Optical couplers (HARP)**
  - **not practical for large arrays**
- **Collimating Fourier gratings (SMART, CHAMP+, upGREAT)**
  - **requires optical coupling, difficult for large arrays**



LO coupling

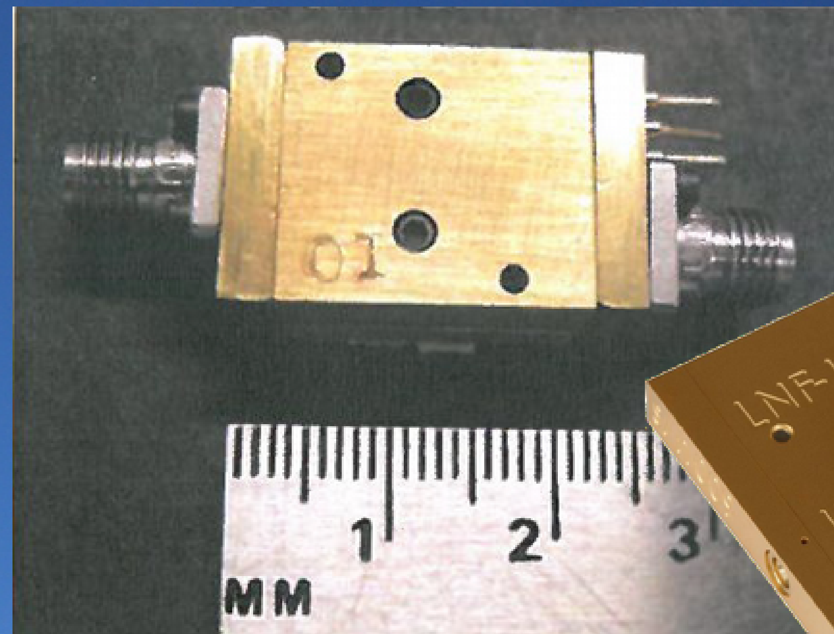
- **Beamsplitter (e.g. SuperCam, upGREAT)**
  - simplest
  - poor LO power utilization
- **Interferometric diplexer (e.g. SMART, CHAMP+)**
  - high coupling efficiency
  - LO noise suppression
  - not practical for large arrays (alignment, space)
- **Waveguide coupling (e.g. HERA)**
  - high coupling efficiency
  - compact
  - difficult to manufacture
- **Balanced mixer**
  - high coupling efficieny
  - LO noise suppression

Leech+ 2015

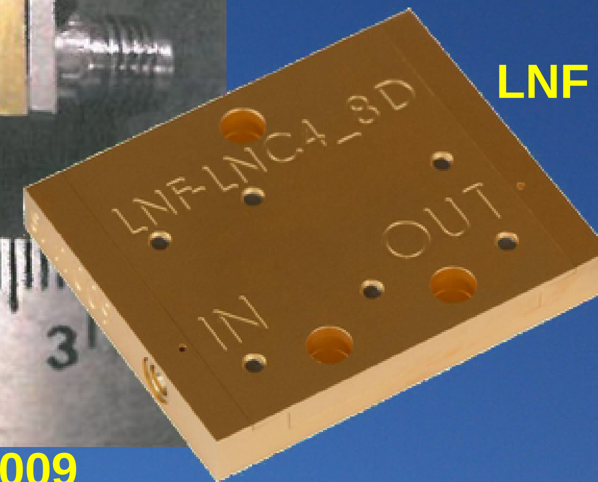


IF-processing & Backends

- **cold LNA**
  - small footprint
  - low dissipation
- **warm IF-processor**
  - avoid complexity
  - total power signal?
- **digital (FFT) spectrometers**
  - high bandwidth, channel count
  - compact
  - significant power dissipation



Weinreb+ 2009



LNF

Klein+

System Aspects for Large Arrays

- **Priority for large arrays: reduce complexity**
  - **Cryostat design:**
    - **ease of integration**
    - **cable type / connectors (e.g. GxPO, flex PC)**
    - **cable count**
      - **common bias lines for mixers or LNAs**
      - **permanent magnets for SIS mixers**
  - **Electronics**
  - **Software**
    - **need efficient (i.e. automatic) tuning**
- **Thermal design (e.g. mixer heating by LNAs)**


Thank you