Large High Resolution Array Development

Urs U. Graf

for the KOSMA Detector and Receiver Groups

People

- **Detector development:**
  - **Netty Honingh**
  - **Karl Jacobs**
  - **Patrick Pütz**
  - **students and engineers**
- **Receiver development:**
  - **Urs Graf**
  - **Matthias Justen**
  - **students and engineers**
- **Precision machining workshop**

KOSMA's Array Receivers

- **Single pixel, dual color heterodyne receivers:**
  - 345/660 GHz on KOSMA (1990s)
  - 490/810 GHz on NANTEN2 (2006)
  - 1.4/1.9 THz: GREAT on SOFIA (with MPIfR, 2011)
- **Multipixel, dual color heterodyne arrays:**
  - SMART (8px, 490/810 GHz) on KOSMA (2001) and NANTEN2 (2008)
  - STO (4px, 1.4/1.9 THz, with UofAz et al. 2011)
  - (2x)9px 1.1 THz for APEX (2012)
  - 7px 2 THz up-GREAT for SOFIA (with MPIfR, 2013)

What's on the Market?

- 10-20 pixel (sub)millimeter arrays (HERA, SMART, CHAMP+, HARP)
- 64 pixels under development (SuperCam)

Assembled as collection of single pixel receivers with common optics and LOs.

Pixel number limited by complexity of individual pixels (but: each spatial pixel corresponds to >1000 spectral pixels)

We need to do better!

Ingredients of Large Format Heterodyne Arrays

- State of the art mixers and LNAs
- Powerful LOs with efficient coupling
- High quality optics (focal plane unit, LO coupling)
- Backends and IF (total IF bandwidth >1 THz!)
- Intelligent control electronics (Autotuning!)

System level requirements:

- Minimize Complexity!
- Maximize Modularity (limited λ coverage)!

Ongoing Developments in Cologne

- **Mixers:**

  Balanced → 2SB → balanced 2SB

- **LO distribution systems:**

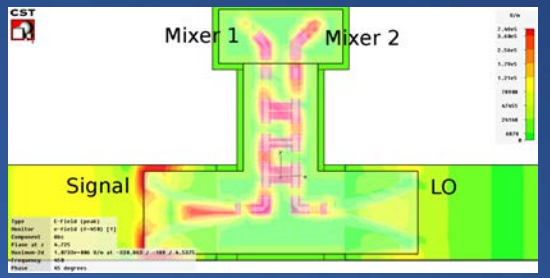
  Quasioptical, waveguide

- **Optics:**

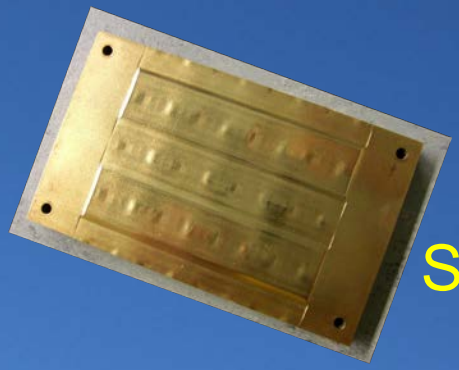
  Monolithic optics (FPU etc.)

- **Control electronics:**

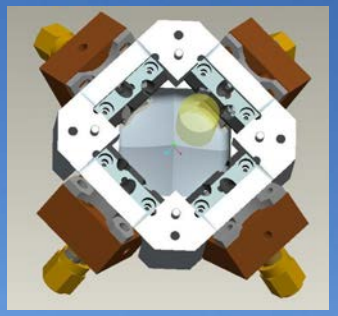
  reduce hardware complexity



IBAMI



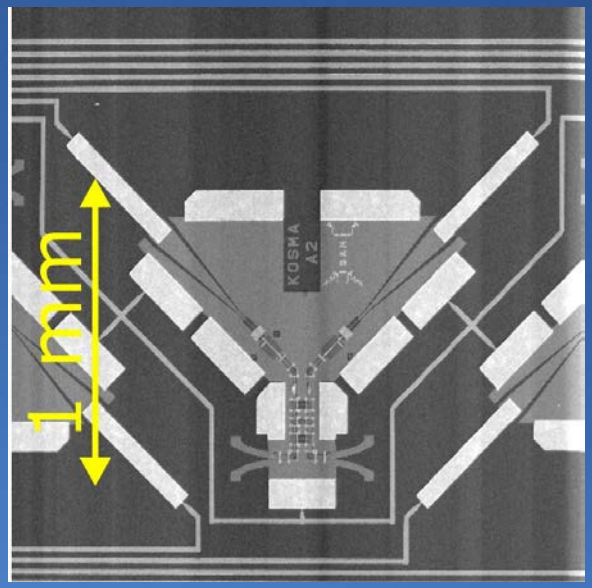
SMART

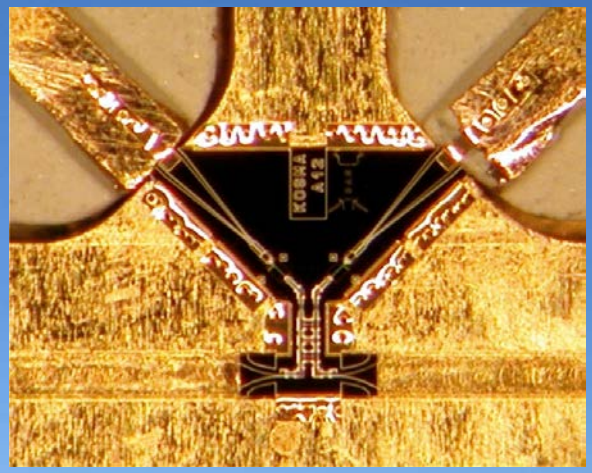


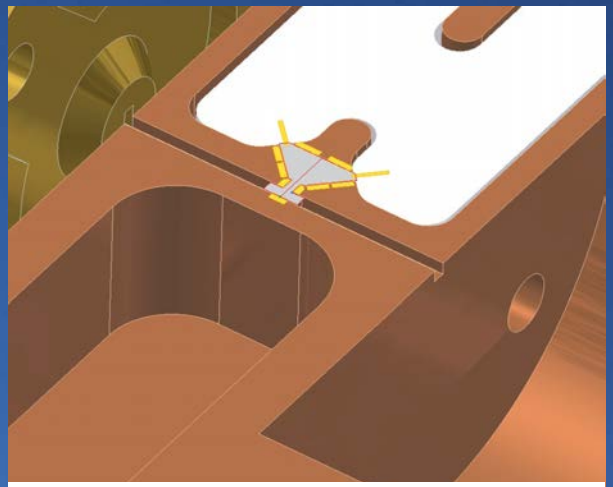
STO

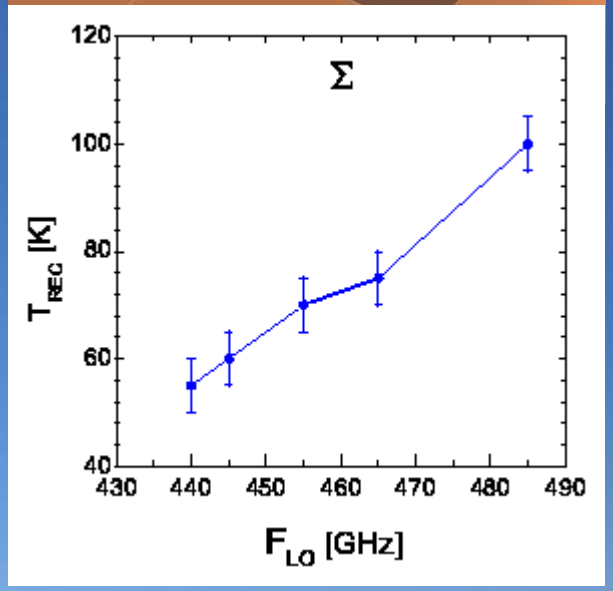
IBAMI: balanced SIS mixer

- Integrated balanced mixer design
- "Ideal diplexer":
  - Broad band
  - LO-noise rejection
  - Separate LO input port
  - Suitable for waveguide LO coupling
- Beam lead mounted





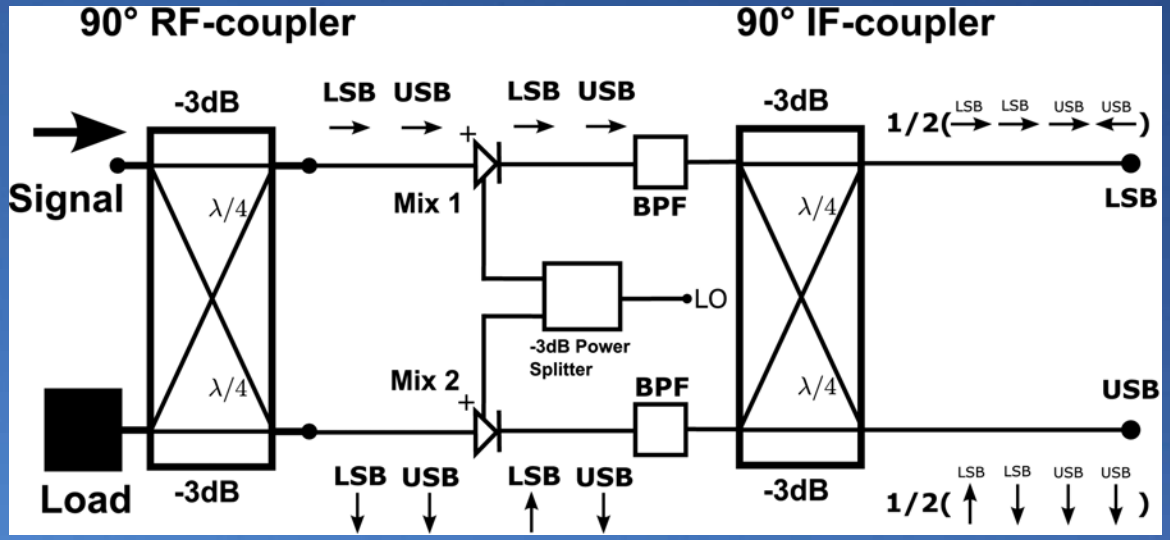




Westig et al. 2011

Balanced / 2SB

- **Further development:**
  - 2SB mixers
  - Balanced 2SB
  - IF band: 4-12 GHz
  - Array mixers



- **Assemble large arrays by dropping many (~100) "self aligned" mixer chips in a common multi-pixel mixer block, possibly with integrated feed horns**

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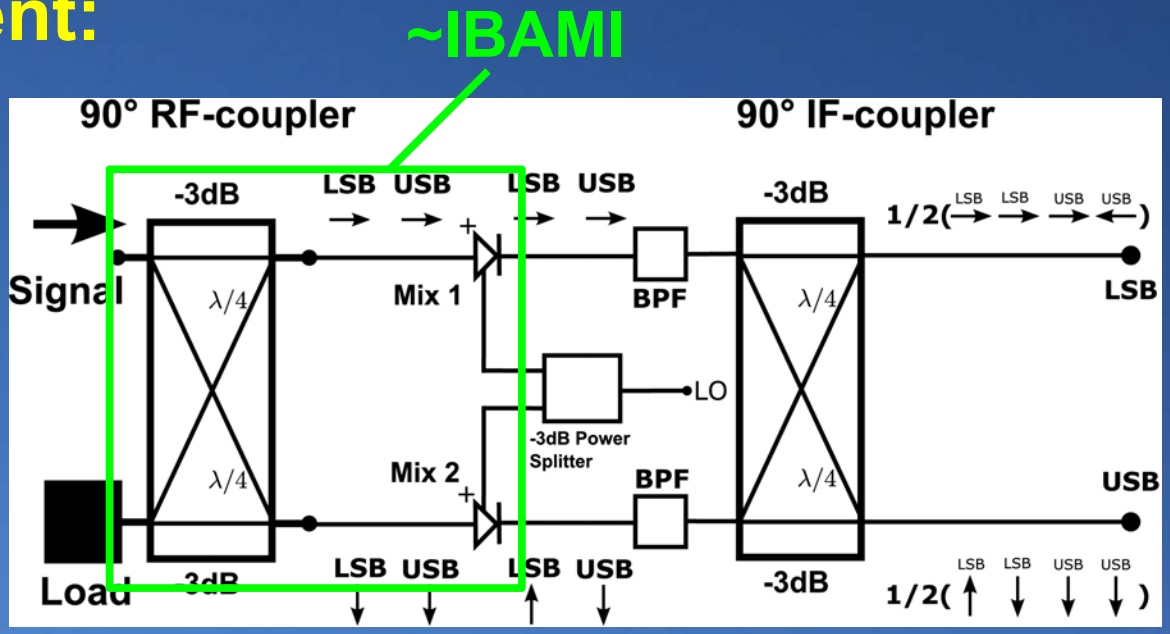

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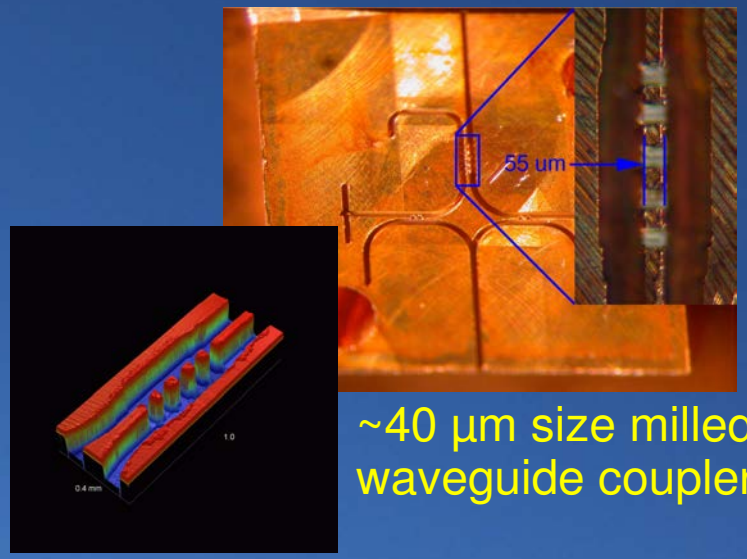
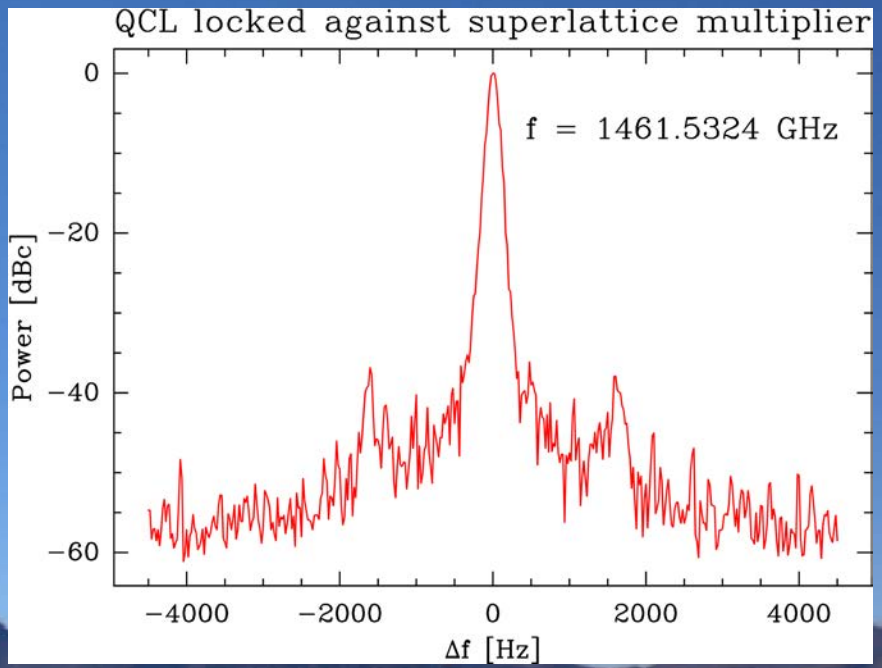
Local Oscillators

- Large arrays need lots of LO power
- Problem gets worse with increasing frequency
- Waveguide LO distribution introduces losses (active phase gratings?)
- Options:
  - (Several) multiplier chains
  - Photonic LOs
  - Quantum Cascade Lasers



~40 µm size milled waveguide couplers



Rabanus et al. 2010

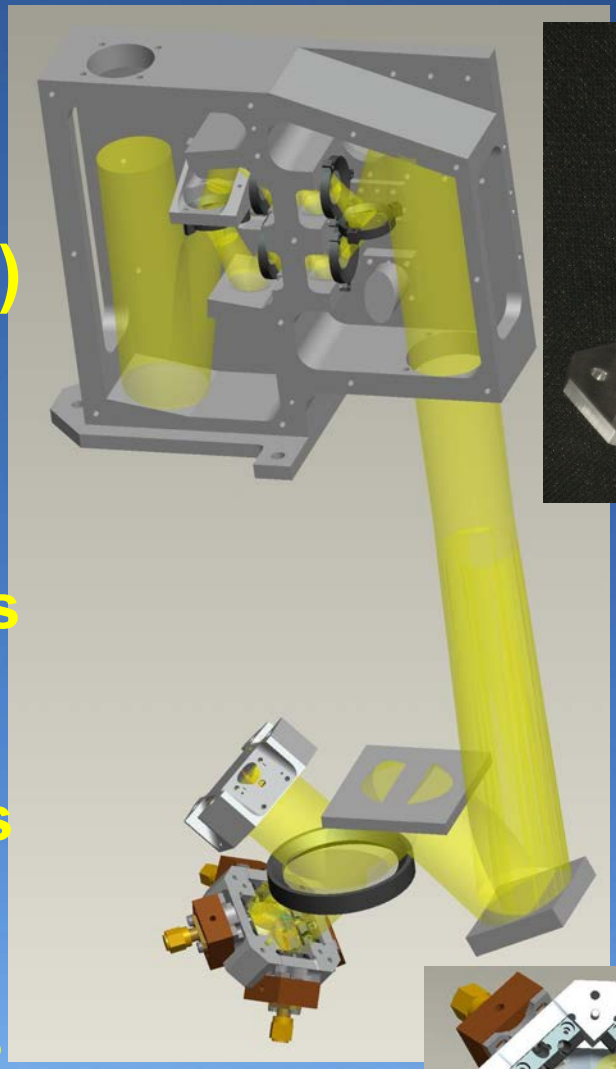
Monolithic Optics

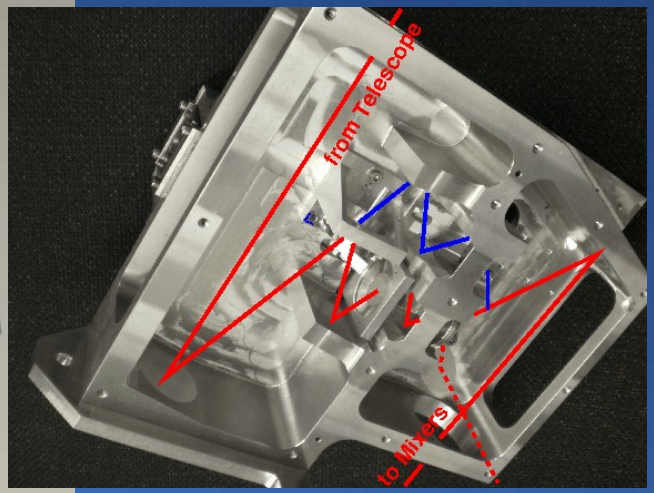
- **Machine complex optical structures monolithically from a single block**
  - **Essentially no alignment required**
  - **Only way to produce high quality, easy to use optics**
  - **Ideal for large format array receivers**
- **Requires advanced CAD/CAM techniques and high precision 5-axis milling capablity**

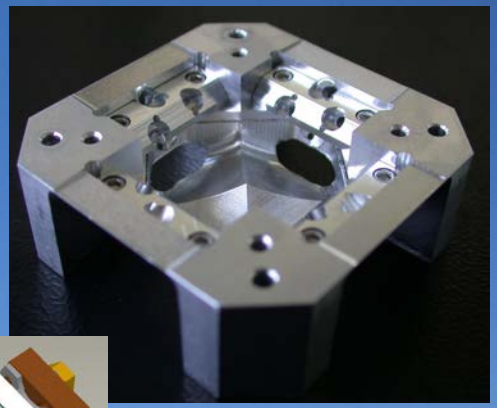
KERN ultra precision milling machine

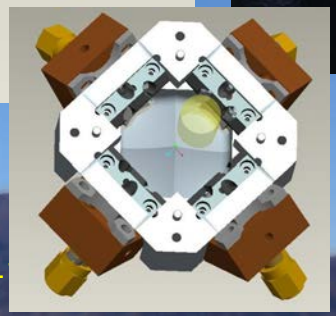
Monolithic Optics: STO

- Integrated optics for 4 dual-color pixels (1.4/1.9 THz)
- One monolithic block containing:
  - 12 imaging mirrors
  - 2 diplexers
  - 6 wire grid mounts
  - No internal DOFs
- 2 monolithic FPUs



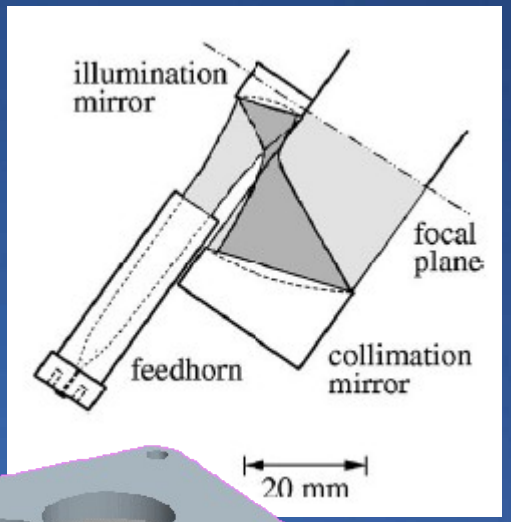


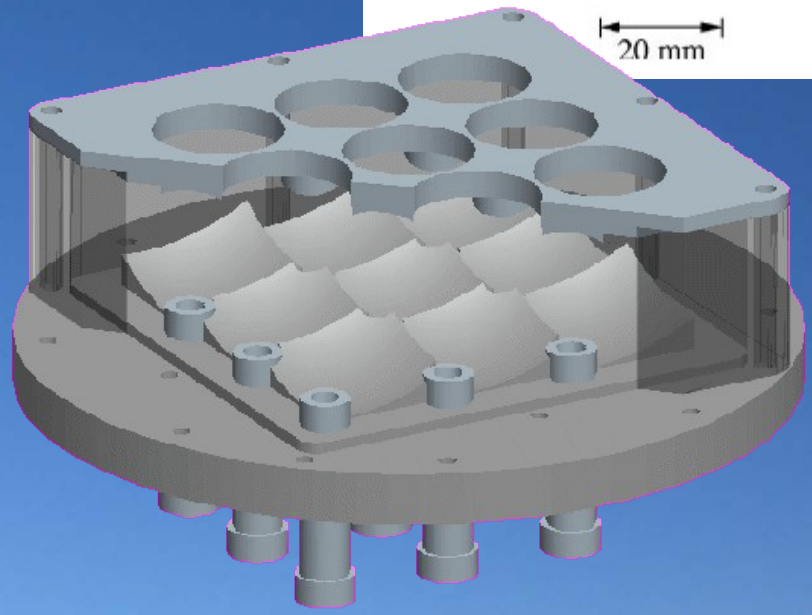




CHARM

- Each pixel is collimated by a small off-axis Cassegrain telescope
- Integrated optics → simple alignment
- scalable both in frequency and pixel-#
- 1.1 THz array under development

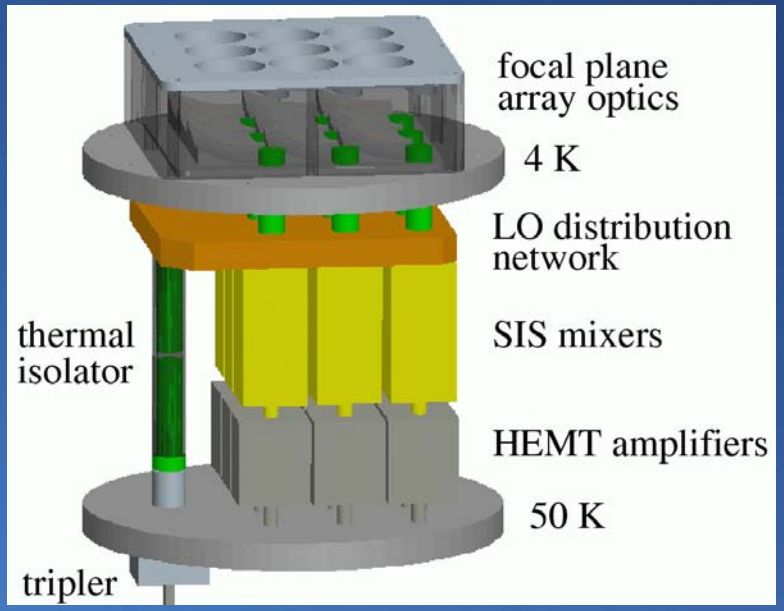


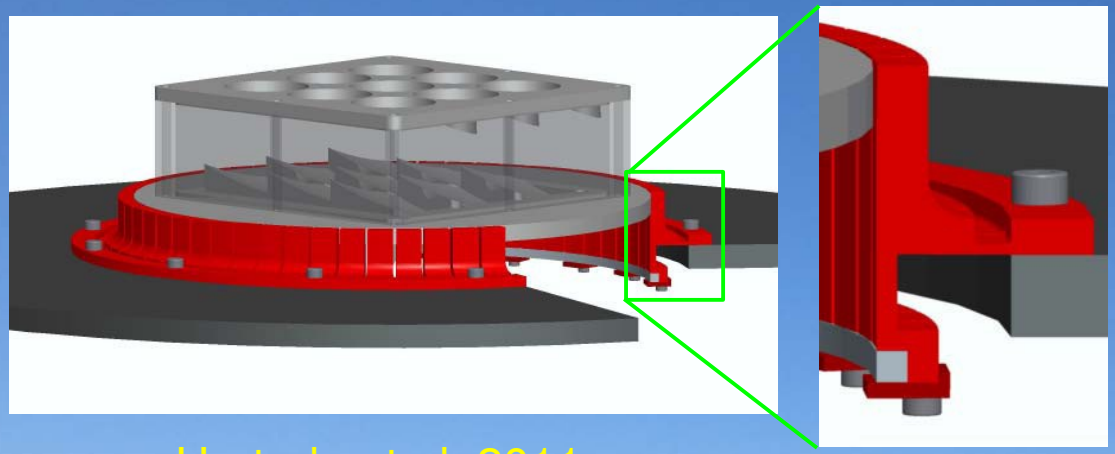


Lüthi et al. 2005, 2006

Modularity

- **Assemble receiver in cartridges (e.g. ALMA) to maximize serviceability, exchangeability...**
- **Automatic thermal links simplify cartridge mounting**





Hurtado et al. 2011

Heterodyne Receiver Concept for CCAT

- Generic heterodyne cryostat with easily exchangeable receiver modules/cartridges
  - Use common optics to provide
    - polarization splitting
    - image (de-)rotation etc.
  - Use common backends and maybe control electronics
- Start with, say, 2 (array-)receiver cartridges, e.g. 350 µm and 450 µm bands, ~100 2SB pixels, each (32 Mpx @ 100 kHz)
- Add more cartridges as technology and funds become available


Thank you