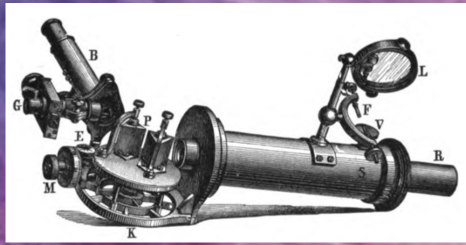
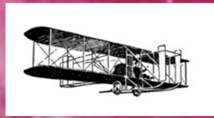
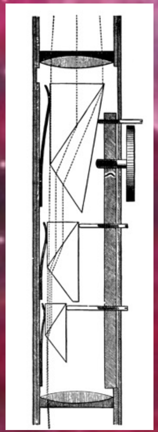
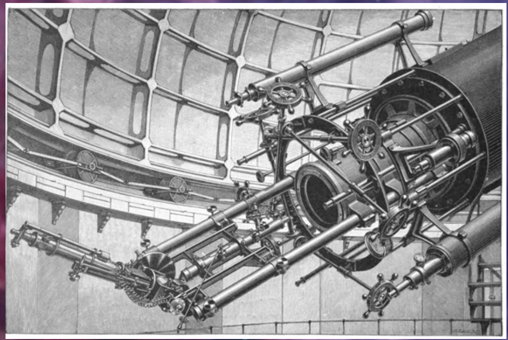
German/European Instrumentation Effort

04-Mar-2022









Bernhard Schulz

Deputy Director SOFIA Science Mission Operations, NASA Ames

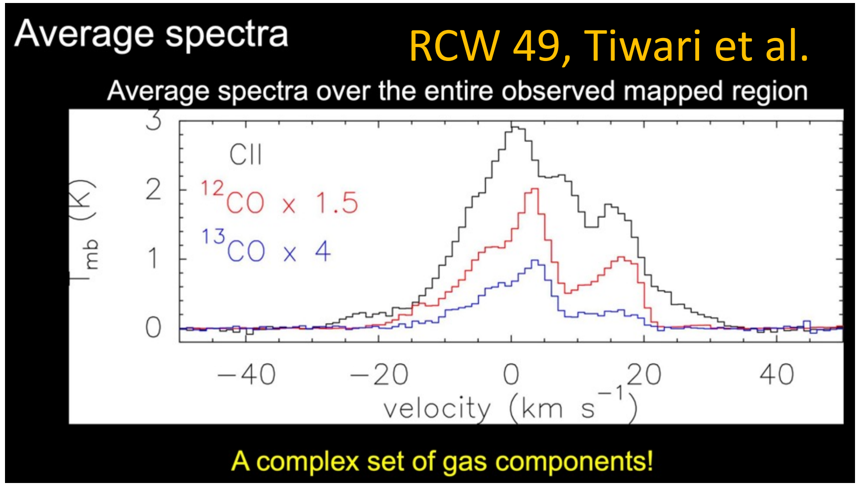
Deutsches SOFIA Institut, Univ. Stuttgart

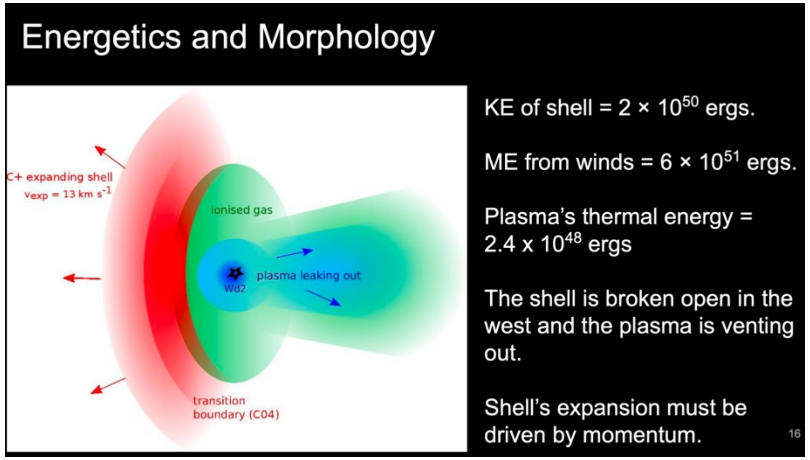
Science Requirements

Workshop 26-28 Jul 2021

- 231 registered participants;
- 3 days @ ~4.5h per day
- 56 Presenters
- Main Themes: ISM, PDRs, shocks, star formation, astrochemistry
- 1/3 of presentations extragalactic
  - **High resolution spectroscopy MIR and FIR**

An example from the talk by Maytraiyee Tiwari





Science Requirements

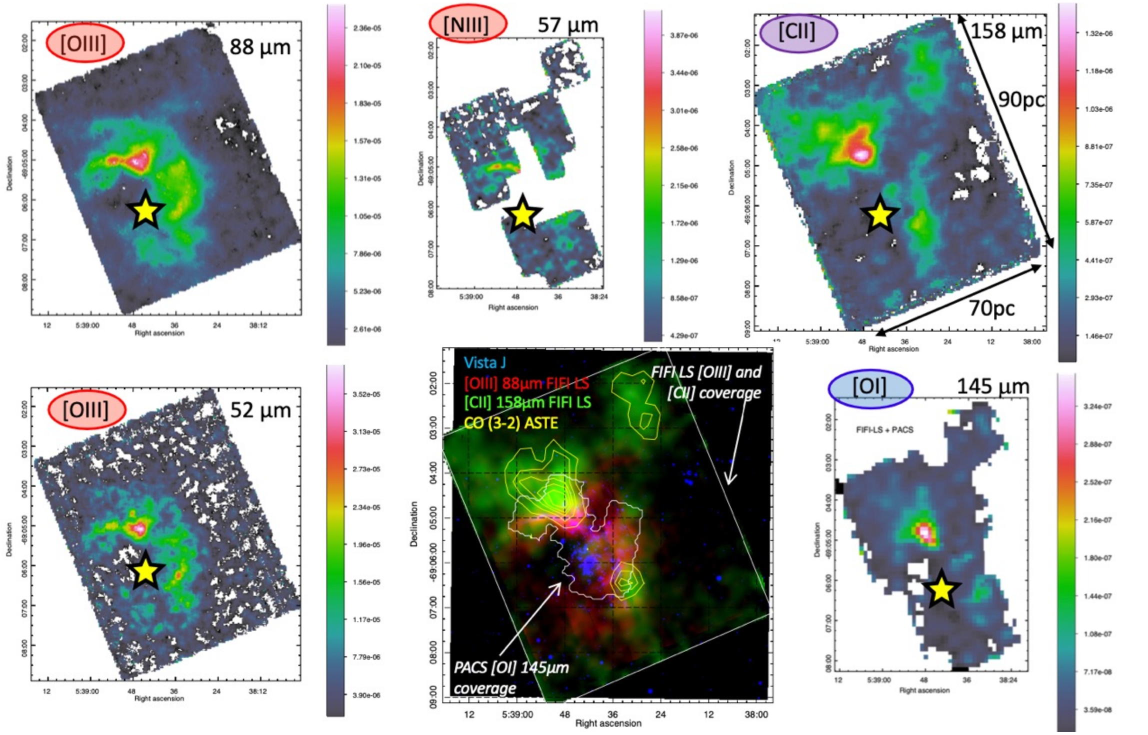
Workshop 26-28 Jul 2021

- 231 registered participants;
- 3 days @ ~4.5h per day
- 56 Presenters
- Main Themes: ISM, PDRs, shocks, star formation, astrochemistry
- 1/3 of presentations extragalactic
  - High resolution spectroscopy MIR and FIR
  - Trade spectral resolution for sensitivity

An example from the talk by Melanie Chevance

30Dor: SOFIA/FIFI-LS data

Chevance et al. 2020b



Science Requirements

Workshop 26-28 Jul 2021

- 231 registered participants;
- 3 days @ ~4.5h per day
- 56 Presenters
- Main Themes: ISM, PDRs, shocks, star formation, astrochemistry
- 1/3 of presentations extragalactic
  - High resolution spectroscopy MIR and FIR
  - Trade spectral resolution for sensitivity
  - Polarimetry in FIR
  - MIR/FIR broadband photometry
  - Specific lines
  - Time sampling
- Specific requests:
  - Fine structure lines, HD, CO ladder, oxygen compounds
  - large scale mapping of [NII] 122μm / 205μm
  - 350μm filter
  - NIR capabilities for occultation obs

Session	Talks	Posters
Solar System	5	
Star & Planet Formation	6	
Interstellar Medium	15	8
Late Stellar Evolution	2	
Nearby Galaxies	8	3
High-Redshift Galaxies	3	4

Instrumental Requirements

Spectrometer	46	73%
Photometer	15	24%
Heterodyn	32	51%
R=5000 FIFI	13	21%
FIFI-LS	19	30%
EXES	4	6%
FIR camera	12	19%
MIR camera	2	3%
NIR camera	3	5%
Pol.	7	11%
Time sampling	5	8%
balloon	6	10%
single pointing	21	33%
maps	37	59%
Total Science Cases	63	100%

Version: 14-Oct-2021

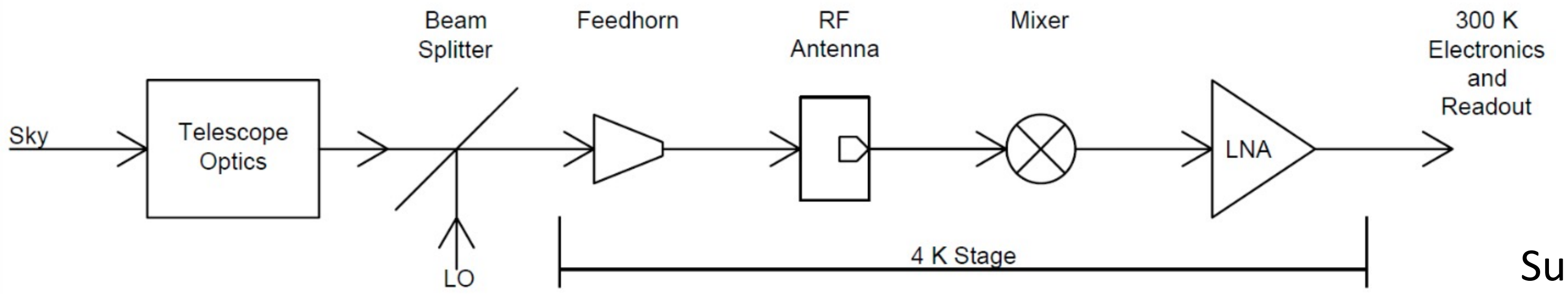
Second Workshop

Workshop 17-19 Nov 2021

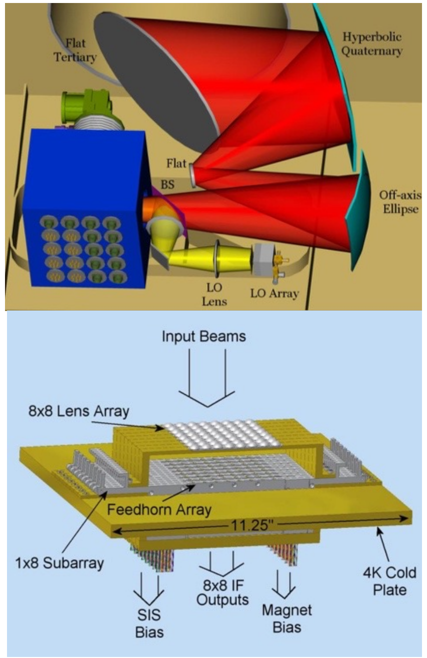
- 156 registered participants;
- 3 days @ ~4.5h per day
- 31 Presenters
- Main Themes:
  - Airborne platforms
  - Heterodyne devices/systems
  - Direct detection devices/systems
  - Instruments and funding

Heterodyne Technology

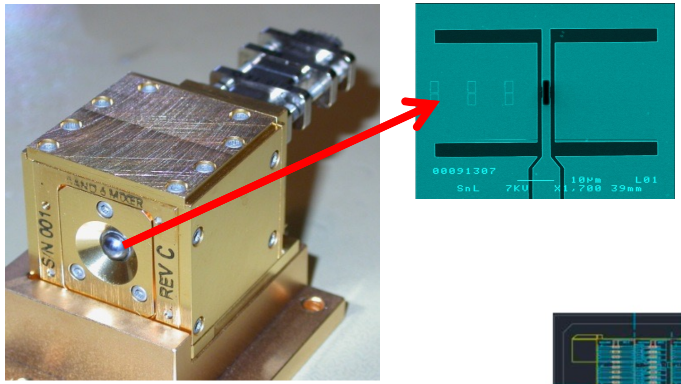
Typical SIS Receiver Architecture



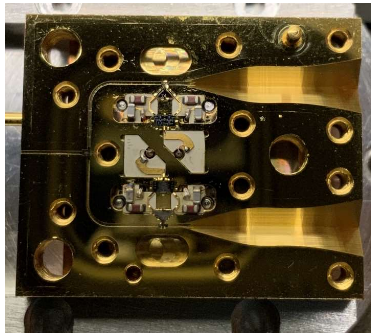
SuperCam 64 Pixel (Guest on APEX)



Herschel HIFI

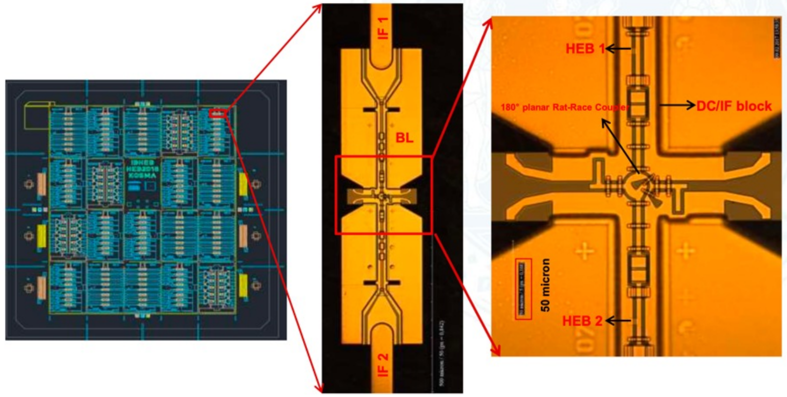


Balanced Mixer fort CHAI



460 GHz

Balanced Mixer at 1.9 THz



Heterodyne Technology

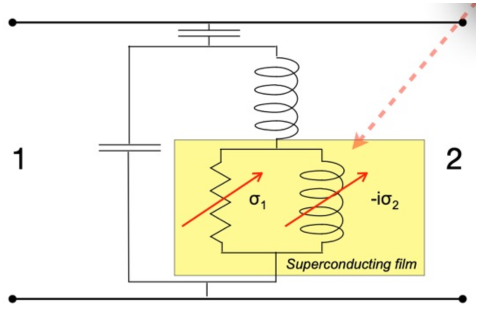
- Highest spectral resolution ($R \sim 10^6$)
- Well understood technology

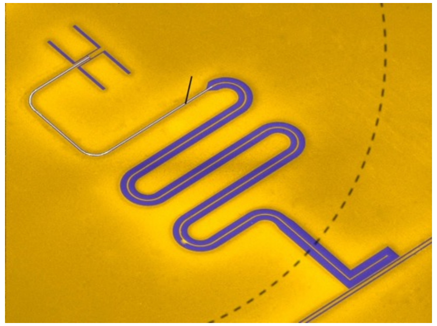
- Feedhorns
- Mixer:
  - ν>1 THz: HEB (Hot electron bolometers)
  - ν<1THz: SIS (Superconductor-Insulator-Superconductor)
  - IF Bandwith <5GHz, with new materials ~9 GHz possible
- Local Oscillator (LO):
  - ν<2THz: Frequency multiplied types
  - ν>2THz: Quantum cascade lasers (QCL)

- Backend Spectrometer
  - Much electronics that requires power
- 100 Pixels challenging
- Challenges:
  - Micromachining and handling
  - Miniaturization
  - LO coupling and power
  - Mixer cooling
  - Low power spectrometer electronics (CMOS?)
- Modular approach? 35 pixels?
- Single frequency exchangeable front end

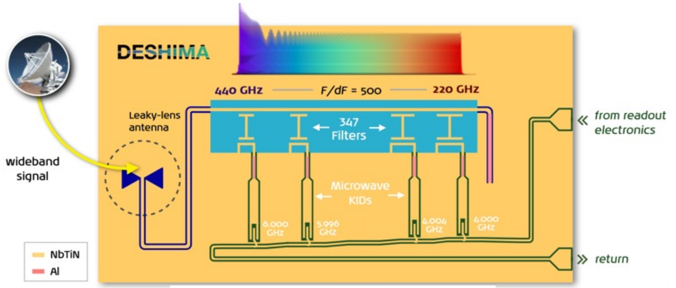
Direct Detection Technology

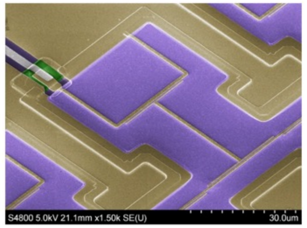
MKIDs



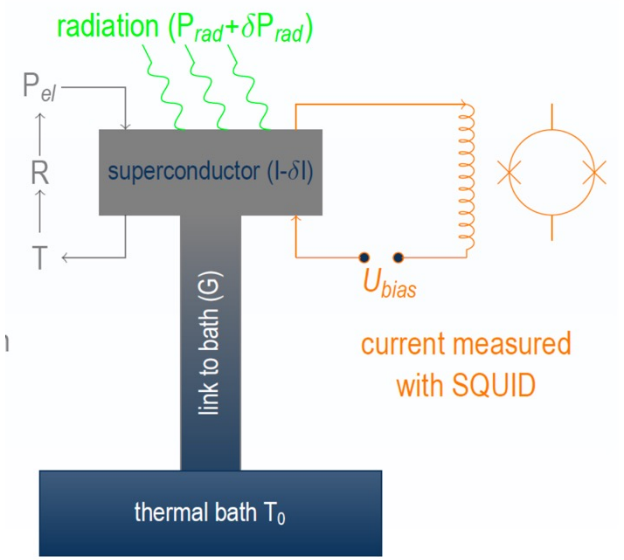


Integral Field Unit (IFU)

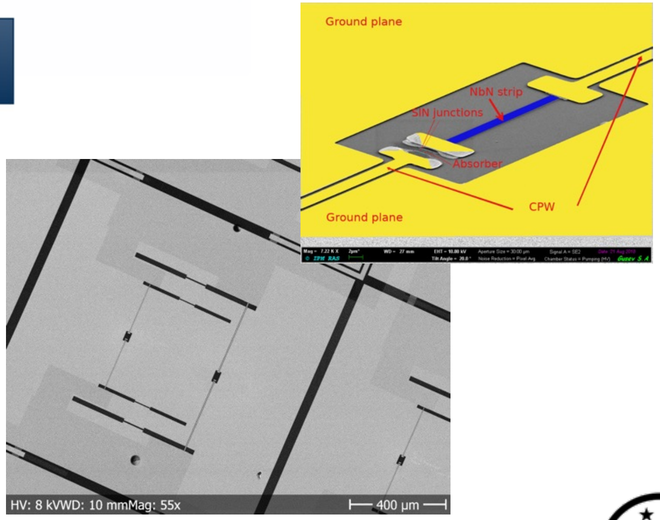




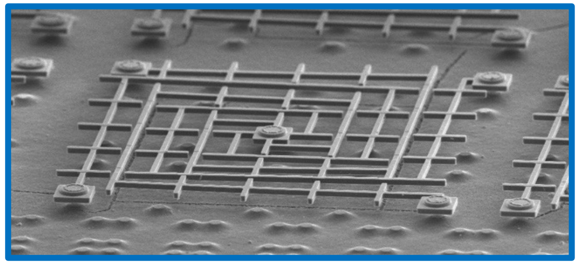
TES Detectors

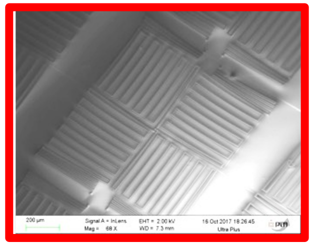


Cold Electron Bolometers



Si Polarimetric Bolometers





Direct Detection Technology

- large pixel counts
- No quantum noise penalty
- Maximum R~10^5

- Kinetic Inductance Detectors (KIDs)
  - Lumped element KIDs (CNRS Grenoble)
    - NEP~10^{-19} W/√Hz
  - Antenna Coupled KIDs (SRON,TU-Delft)
  - Integrated Field Unit (IFU) (TU-Delft)
    - Spectrally resolved pixels with KIDs
    - 350 µm spectral mapping at R ~10 (“filter”) or R = 100-2000?
  - FIFI+LS Upgrade (Illinois, DSI, JPL, UdEC, USRA)
    - Use JPL Starfire KID development
    - Increase spaxels to 9x7 and FOV by 1.75
    - Extend range to 42µm and 206µm

- Transition Edge Detectors (TES)
  - Wide range all IR/submm, very adaptable
  - TES application for security scanner (Leibnitz Inst.)
- Semiconductor Bolometers
  - Silicon Polarimetric Detector Arrays (CEA, MPE)
    - On chip polarimetry
    - Add spectroscopy with Etalon, Fabry-Perot Scanner, Moving Backshort
- Cold Electron Bolometers
  - Multichroic receivers with Cold-Electron Bolometers (Chalmers, Nizni Novgorod TU…)
  - Wide wavelength range and very small detector element
  - Self cooling

Airborne Platforms

- SOFIA (NASA, DLR)
  - Airplane 2.7m telescope,~150 flights per year to the stratosphere 4 flights/week @ 10h
  - Crewed mission
  - Fully functional observatory with 20 year operational lifetime
  - Payload mass <600kg, <6500 Watts (instrument only)
  - LHe cryocoolers
- COPILOT (CNES,IRAp,IAS,CEA,Cardiff, Rome)
  - Balloon missions, 1 m telescope
  - wide field broad band photometry of C+
- Blast Observatory (NASA and Italian space agency)
  - Balloon mission, 1.8 m Gregorian telescope
  - 175 µm 250 µm, 350 µm MKIDs (~8000 det), 30 days, ~500 W power by solar cells (up to 1980W)
  - Payload 1225kg (includes telescope)
- ASTHROS (NASA-JPL)
  - Balloon mission, 2.5m telescope, 2 year cadence
  - [NII] 122µm (2.675 THz) and 205µm (1.461 THz), 4 pixels, 4K cryocooler, 20 days
  - 15 days around Antarctica
  - payload 2700 kg, 900kg, 450kg (balloon type)
  - 900 W of power
- Sunrise Mission (MPS Göttingen)
  - 1 m telescope, UV and visible
  - Altitudes are 35km-43km
  - durations are 5-6 days arctic, <43 days antarctic

Airborne Platforms as Observatories

- Airplane and balloons have each their individual strengths
- SOFIA
  - regular observations 4 days a week
  - Safe landings
  - Good calibration
    - long instrument lifetime
  - Observatory operation serves many communities
  - Accommodating power and mass limits
  - Moveable observatory
    - “Rapid” response within reason is possible
  - Overflight restrictions only minor problem
- Balloons
  - Higher altitude
  - Long observing time, especially with high pressure balloons
  - Relatively cheap
  - Safe landing considered biggest issue
    - Gondola protection for payload
  - Probability for total loss high
  - Overflight restrictions an issue in the north
  - Very different schedule considerations
    - Typically plan for 1 flight, next one ~2 years later
    - Waiting for the right weather conditions
  - Stringent mass and power limitations
    - Long duration balloons less lift
  - Good for focused longer duration missions

Heterodyne Instrument

- Terahertz Mapper
  - Relatively clear idea how it will look
  - Specific frequencies important (science feedback needed)
- 100 Pixels considered a challenge
  - Needs simple reproducible design
  - Multiple suggestions of building modular and upgradeable
    - (GREAT example)
  - LOs for >1 THz will be QCLs that are harder to tune
  - Exchangeable front ends for single frequency
- Expertise is still there. Funding needed.

Direct Detection Instrument Ideas

- FIFI+LS: FIFI-LS Upgrade to more pixels and better detectors
  - Est. cost is ~$4M ($2.5M is for detectors), . 2.5 years (1.5 years downtime)
- HIRMES-2: Solve detector issues, reduce complexity and finish
- HIRMES pHD: HD specialized spectrometer based on HIRMES
  - Could be modular approach to HIRMES-2
- Near-infrared channel for SOFIA's Focal Plane Imager FPI+
  - NIR channel ~$350k, new M3 ~940k
- B-BOP derivative for Co-PILOT (or SOFIA)
- 350 µm Spectral Mapper based on IFU technology

- Many options: Loop back with science needed

Airborne Platforms

- Balloons are great for focused high altitude missions
  - It is still a long way to a regular observatory operation
  - Main obstacles are
    - Considerable risk during landing
    - Strong weather dependence of launch
- New airborne observatories need safe landing and mobility
  - Study steerable glider landing and propulsion systems
  - Study by Keck Institute of airships reaching 65000 ft.
  - Considering development time, this would be a good SOFIA successor
- SOFIA is a working and well performing observatory
  - There are still 11 years of the 20 year operational lifetime left
  - New instrumentation can be built but needs project stability

Conclusion

- European technology is there to substantially upgrade SOFIA abilities and science.
- Another iteration with scientists is needed
- Any European funding will require project stability for the projected development time, i.e. >= 5 years
- Balloons are good for specific tasks but are not the Far-IR observatory solution for the next 10-15 years due to lack of safe landing capability and strong weather dependence

Keep SOFIA flying!

Stopping now is like stopping Herschel after 2 years!

Agree on a remaining lifetime and provide stability

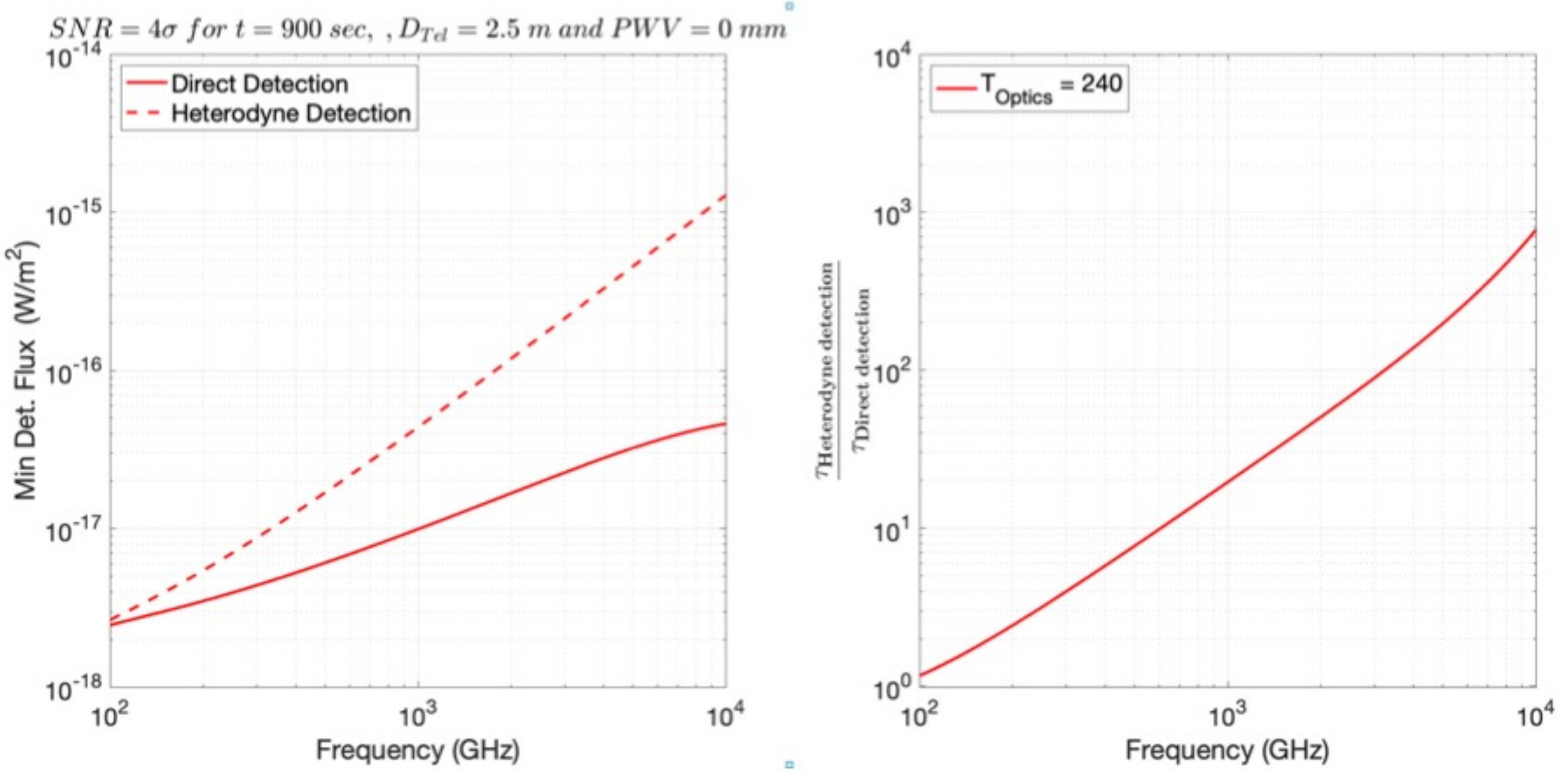
Spend a moderate budget per year on upgrades

Start preparing for a successor now

Backups

Sensitivity Limits Direct Detection vs. Coherent Detection

Talk by Baselmans



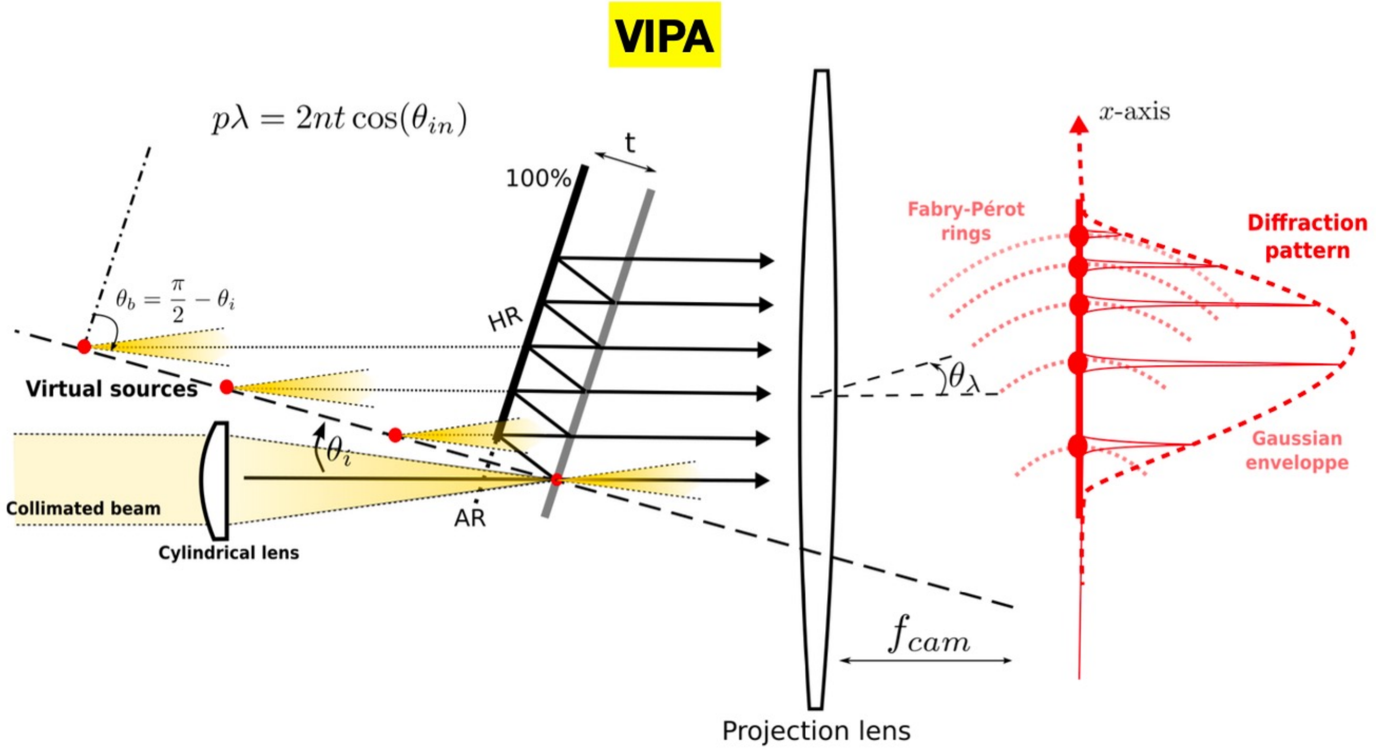
VIPA Spectroscopy

Talk by Baselmans

High resolution spectroscopy using direct detectors

On needs a folded mechanism to beat the long path length differences:

- disambiguation distance: $\Delta d = \frac{1}{2}\lambda \cdot R, \quad R = \frac{\lambda}{\delta\lambda}$
- Resonant cavities, such as VIPA's, are more compact



Bourdarot, G. Et al.,(2018). Experimental test of a 40 cm-long R=100 000 spectrometer for exoplanet characterisation. https://doi.org/10.1117/12.2311696