# Welcome and Introduction

**Ninth International Symposium on Space Terahertz Technology**

**Carl Kukkonen**

**Director, Center for Space Microelectronics Technology**

JPL

**March 17-19, 1998**

# SUBMILLIMETER AND THz DRIVERS

- **ASTROPHYSICS**

  **Long awaited major observation platforms, SOFIA, and FIRST now close to reality.**

- **EARTH ATMOSPHERIC CHEMISTRY**

  **EOS-MLS now in Phase C/D**

- **PLANETARY AND COMETARY SCIENCE**

- **LABORATORY SPECTROSCOPY**

# Terahertz Astrophysics Observing Platforms

- **Far Infrared Submillimeter Telescope (FIRST) - ESA Mission**

  **Proposal submitted for heterodyne instrument, February 15, 1998**
  **Joint European / US Instrument Team**

  **<u>Baseline Capabilities</u>**

  - **Passively cooled 3.8 m telescope**
  - **480-1250 GHz SIS mixers**
  - **1.4-1.9 THz and 2.4-2.7 THz HEB mixers**
  - **High resolution spectroscopy 85-600 $\mu$m, photoconductor and bolometer arrays**
  - **Broad band photometry 85-900 $\mu$m bolometer arrays**

  **<u>NASA Contributions</u>**

  - **Orbit: Increase observing time and sensitivity**
  - **3.8 m telescope**
  - **3 receiver bands: SIS 1.0-1.2 THz; HEB 1.4-1.9 THz, & 2.4-2.7 THz**
  - **MMIC Power amps for LO system**
  - **InP HEMT's for IF system**

# Terahertz Astrophysics Observing Platforms

## The Stratospheric Observatory for Infrared Astronomy (SOFIA)

- Joint US / German Project
- 2.5 m aperture airborne telescope for wavelengths between 0.3 $\mu$m and 1.6 mm, with emphasis on submillimeter and far-IR
- First round of instruments selected and under construction
  (A Submillimeter and Far-Infrared Heterodyne Receiver)
- First flights in 2001
- 20 year lifetime
- USRA, Raytheon E-Systems, United Airlines

# Terahertz Astrophysics Observing Platforms

- **Submillimeter Wave Astronomy Satellite (SWAS)**
  - Small Explorer Mission
  - Heterodyne receivers near 480 and 560 GHz
  - Observe interstellar water, oxygen, and carbon
  - Launch date 1998
- **Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)**
  - South Pole Observatory operational this year funded by NSF
  - 1.7 m aperture for 0.5 mm wavelengths
  - Built, running and taking data
- **Heinrich Hertz / Submillimeter Telescope Observatory (HHT/ SMTO)**
  - Located on Emerald Peak of Mt. Graham, approximately 75 miles north-east of Tucson, Arizona
  - 10 m aperture for wavelengths between 1.3 mm and 350 microns
  - Joint University of Arizona / Max-Planck Institut fur Radioastronomie project
  - Operational and taking data

# Terahertz Astrophysics Observing Platforms

- **NRAO - Millimeter Array in Chile**
  - 32 Telescopes (64 with European collaboration)
  - 10 m diameter (12 m with European collaboration)
  - Construction start 2001
  - Operational 2007
  - Frequency: 30 -950 GHz

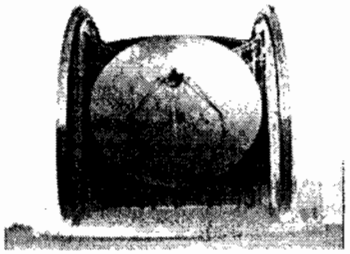
- **South Pole 10 m Telescope**
  - Operational 2003
  - AST/RO - NSF Funded Program
  - SIS & Bolometers up to 1.5 THz

# Terahertz Astrophysics Observing Platforms

- **Microwave Instrument for the Rosetta Orbiter (MIRO)**
  - Approved for the Rosetta Orbiter - Launch 2003
  - Currently in Phase B: Proto-flight models under development
  - Two channel continuum and spectroscopic heterodyne receiver system
    - Submillimeter Wave Receiver - Frequency: 540 GHz
    - Millimeter Wave Receiver - Frequency: 190 GHz
  - RFP for flight subsystems in 1998

- **Submillimeter Array (SMA)**
  - Harvard Smithsonian Center for Astrophysics
  - 6 telescopes, upgrade to 8
  - 6 m diameter
  - On Mauna Kea, Hawaii
  - Operational 2000
  - Operational frequency range: 200 - 800 GHz

# Terahertz Astrophysics Observing Platforms



- **Caltech Submillimeter Observatory**
  - **A cutting-edge facility for astronomical research and instrumentation development**
  - **Located on "submillimeter ridge" near the summit of Mauna Kea, Hawaii**
  - **10 m Telescope**
  - **Frequencies: 230 - 950 GHz**

- **Owens Valley Radio Observatory**
  - **Largest university-operated radio observatory in the world**
  - **Located five hours north of Pasadena, near the Sierra Nevada range**
  - **Six 10m telescopes**
    - **Frequency ranges 80-116 GHz and 210-270 GHz**
  - **40m Telescope**
  - **5m Telescope**
  - **Two 27m Telescopes**

# Status of NASA Submillimeter Sensors Astrophysics Program

- **Superconducting Mixers**
  - **Nb SIS Mixers meet needs of FIRST for frequencies up to 1 THz**
  - **Challenge is to improve performance to 1250 GHz**
    - **Approach: NbTiN SIS mixers**
  - **Above 1.4 THz: Use Hot Electron Bolometer Mixers**
    - **Approach: Diffusion Cooled (Nb, Al)**

- **Solid State Local Oscillator Sources**
  - **Multiplier chains meet power requirements of FIRST for frequencies up to about 1.2 THz**
  - **Challenge is to provide**
    - **Wide bandwidth with fixed tuning**
    - **Reliability**
  - **Higher Power and Stable Photomixer L.O. (1-3 THz)**

# NASA Terahertz Space Missions for Earth Observations

- **Earth Observing Satellite Microwave Limb Sounder**
  - **Study of chemistry of stratospheric ozone on a global scale**
  - **118 GHz**
    - **Temperature and Pressure**
  - **190 GHz**
    - **Continuity with UARS MLS for $O_3$, ClO, and $H_2O$**
  - **240 GHz**
    - **$O_3$, CO - Temperature and Pressure**
  - **640 GHz**
    - **Ozone chemistry ($O_3$, HCl, ClO, $NO_2$ and others)**
  - **2.5 THz**
    - **Ozone chemistry (OH), Temperature and Pressure**
- **Approved mission, Phase C/D began January 1998; instrument engineering model build in 1998**
- **Launch date 2002**

# Status of NASA Submillimeter Sensors Earth Remote Sensing Program

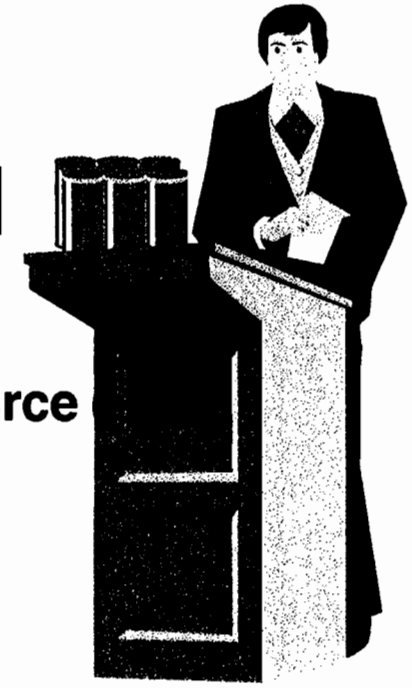
- **EOS Microwave Limb Sounder is beginning Phase C/D Receiver Engineering Models to be delivered 1998.**

- **Major development thrust areas include:**
  - **Planar Schottky diode waveguide harmonic mixers up to 640 GHz**
  - **Planar Schottky diodes & integrated mixer circuitry for 2.5 THz**
  - **Planar varactor diode waveguide multipliers up to 320 GHz**
  - **Superconducting high-$T_c$ diffusion cooled bolometer mixers**
  - **Laser diode pumped photomixers for THz LO generation**
  - **$CO_2$ pumped gas lasers for high power THz LO generation**
  - **High frequency GUNN oscillators**
  - **Low power digital autocorrelators**
  - **1-20 GHz ultra low noise HEMT amplifiers**
  - **MMIC power amplifiers**

# Kukkonen Challenge 1993

- First SIS mixer with
  - Frequency > 1 THz
  - $T_{sys}$ < 1000 K DSB

Awarded 1995



- First Solid State Local Oscillator Source
  - Frequency > 1 THz
  - Output power > 100 microwatts (100 GHz Bandwidth) Unclaimed

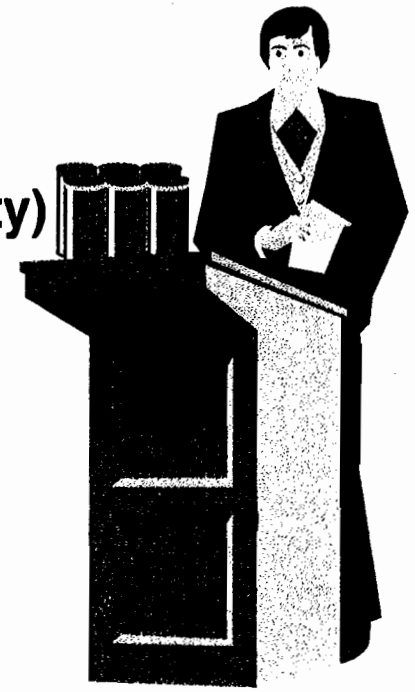
# 1997
# Kukkonen Challenge

**Local Oscillator**

**Frequency: 1-3 THz (500 GHz Tunability)**

**Power: 10-50 $\mu$watts**

**Unclaimed**



# SOFIA -- A Versatile Facility for Infrared and Submillimeter Astronomy in the New Millenium

Mark Morris

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SOFIA, The Stratospheric Observatory for Infrared Astronomy, is a joint US and German project to develop and operate a 2.5-meter infrared telescope in an airborne platform, a Boeing 747-SP. NASA has contracted with the Universities Space Research Association (USRA), teamed with Raytheon E-Systems and United Airlines, to build and operate the observatory. The telescope assembly is being provided by a consortium of German companies led by MAN-GHH. Work has been under way for over a year on both the telescope and the aircraft, and first science flights are expected to begin in 2001. Observations and instrument development will proceed through the 20-year lifetime of the observatory, with 20% of the observing time (and a similar fraction of the instrument development) being assigned to German investigators. SOFIA will be used for observations from the UV to submillimeter wavelengths (0.3 microns to 1.6mm), with particular emphasis on mid and far-infrared, and submillimeter. The initial complement of instruments has been selected, and will be discussed, as will the broad scientific themes which SOFIA will be used to address. The prospects for THz astronomy are particularly exciting, and will be featured. Unlike its predecessor, the Kuiper Airborne Observatory, SOFIA will have facility instrumentation in addition to more specialized instruments built by selected principal investigator teams.