CloudSat
EESS (active) + RAS (passive)

http://www.iucaf.org/CloudSat

Harvey S. Liszt

NRAO, CHARLOTTESVILLE

Outline of the talk

- The current CloudSat mission on-orbit (1)
- Regulatory background 1995 – present (2)
- Lessons for coordination (3)
- Moving forward (4)
- What's next (5)
  - W-band radar closer to home
  - More accidental discoveries
- How IRAM saw CloudSat (6)

CloudSat Mission

http://cloudsat.atmos.colostate.edu/

- Also http://www.iucaf.org/CloudSat/
- CloudSat is a 94.05 GHz, 1.8 kW radar
  - downward-looking, pulsed, narrow-band
  - Spot size on earth 1.5 km (2m dish)
- Near-polar (81°) 705 km orbit, 99m period
  - Nominally repeats exactly every 16 days
  - Atmospheric drag induces +/-10 km error
    - Requires very precise and current orbit elements

CloudSat Mission

- In formation near other A-train members
- Launch scheduled Summer 2005 or later
- Putting two + two together:

Global mapping experiment (2) +

Downward pointing 1.5 km spot (2) =

Direct overflight of ~ every spot (4)

CloudSat Orbit

- 0.2s for the spot to move its own extent
  - Orbital velocity is 7.5 km/s
- Most apparitions only graze the horizon
  - Typical duration 14 minutes, 3000 km distance
- Typical site has few apparitions/day
  - More at higher latitudes, ~4h/day at Pole
  - Typically CloudSat visible 1h/day
    - JPL initially suggested ~1 apparition/16 days

24h of the ATrain orbit

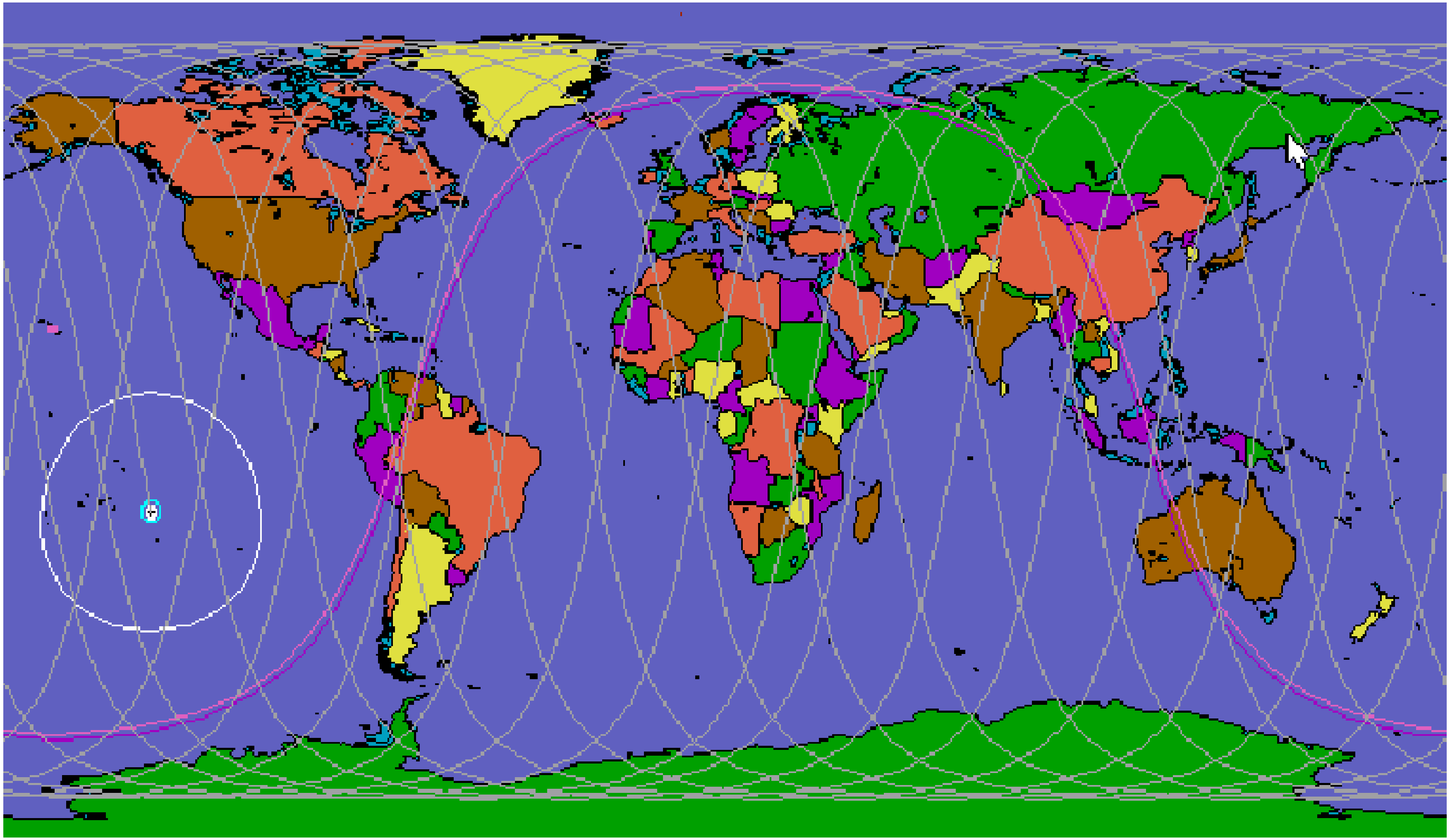


Figure 1: Aqua tracks over 24 hours. Note the light circle delineating the extent of the terrestrial horizon visible from Aqua at a certain instant in its orbit.

CloudSat + SiS: Tap on wrist or Toast?

- Main-beam to Main-beam: SiS devices fry
  - Could destroy 100 ALMA devices in an instant
  - Even more devices in focal plane arrays
- Main-beam to 0 dBi side-lobe (either way)
  - SiS detector saturates
    - during overflight **or** if CloudSat is in main beam
- Known at ITU-R WP7C & WP7D in 1996
  - But not at NRAO or JPL in June, 2004

(2)
History: As of WRC95

- In 1995 EESS (active) had 77-78 GHz allocation for cloud profiling radar
  - Based on Rayleigh backscatter
    - Cross-section ~ $(\text{particle size})^2 * (\text{size/lambda})^4$
- Not useful, no transmitter existed at 77 GHz
- Lower-frequency work much less sensitive
- Res 712 (WRC95) identified this dilemma

The 1996-1997 ITU Cycle

- US Star Wars had developed 94 GHz radar
- EESS calculated sensitivity with 2kW EIA
  - Argued nothing less (in frequency) would do
- Issue was progressed within WP7C,D & 7-8
  - FSS wasn’t using 92-95 GHz but sharing not feasible
  - RAS didn’t have its mm-wave allocation yet

The 1996-1997 ITU Cycle

- Orbit properties not exactly known
  - 420 km altitude *vs*. 705 km final
  - Inclination not settled
- RAS-EESS encounters detailed **7C**/91-E
  - Main beam/MB would kill RAS' SiS receiver
  - Main beam/side-lobe would saturate SiS rcvr
  - Not feasible for RAS to filter EESS signal
  - Extent of data loss uncertain, depend on orbit

WRC97

- WRC97 granted primary use to EESS(active) 94-94.1GHz
  - Developed Rec. SA [] re: sharing RAS never really aware uh?

5.562A

In the bands 94-94.1 GHz and 130-134 GHz, transmissions from space stations of the Earth exploration-satellite service (active) that are directed into the main beam of a radio astronomy antenna have the potential to damage some radio astronomy receivers. *Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible.*

Dialogue
WRC97 to 2004

- 1997
- 1998
- 1999
- 2000
- 2001 Jan-Feb & June JPL: ‘we’ll get back to you’
- 2002
- 2003
- 2004 June, JPL calls at RAS’ door

Mid-2004

- JPL expresses desire to learn about RAS
- I inform US RAS, IUCAF, CRAF, *etc*.
- NRAO and JPL discuss details while CloudSat documentation clears ITAR
  - Both sides have no historical context
    - JPL divorced from NASA spectrum managers
    - No-one provides ITU historical record to NRAO
      - Dick Thompson had John Ponsonby notes

2004, 2005

2004

- JPL unaware of
  - Effects on RAS receivers
  - Frequency of overflights
- ALMA memo 504 (Darrel)
- IUCAF-SFCG agreement
  - *"Operational schedule"*
- IUCAF web site created
- NRAO Newsletter article

2004, 2005

2004

- JPL unaware of
  - Effects on RAS receivers
  - Frequency of overflights
- ALMA memo 504 (Darrel)
- IUCAF-SFCG agreement
  - *“Operational schedule”*
- IUCAF web site created
- NRAO Newsletter appears

2005

- US government threatens to classify all orbit info
  - Restricts but does not deny access
- CloudSat launch delayed
- JPL orbit tracking tool awaited
- New ITU-R Rec prepared, touching also on *design*
- *Still no regularly scheduled JPL/RAS contact*

Complementary Arrangements

- SFCG-24 for *operational coordination*
- ITU-R Rec RA. 1750 discusses *design* & operations (incorporates ALMA 504)
  - *But neither discusses other bands beyond 94 & 130 GHz*
  - *The same considerations for RA operate at cm-waves, our amplifiers can be fried in 100m antennas (depending on satellite spot size)*

The SFCG-IUCAF agreement

The SFCG CONSIDERING

- that there is a large scientific interest for using active sensors to map cloud profiles in the band 94 – 94.1 GHz, as well as for astronomical observations of cosmic radio sources in this band and in adjacent bands;
- that, in order to address this need, the Earth exploration-satellite (active) and space research (active) services have a primary allocation in the band 94 – 94.1 GHz, the use of which has been limited to spaceborne cloud radars per RR 5.562;
- that, in order to address this need, the radio astronomy service has a secondary allocation in the band 94 – 94.1 GHz, and primary allocations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz;
- that transmissions in the band 94 – 94.1 GHz from space stations of the EESS (active) that are directed into the main beam of a radio astronomy antenna have the potential to severely damage some radio astronomy receivers;
- that, in order to protect the radio astronomy service operations in the band 94 – 94.1 GHz, RR 5.562A states that “Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible.”;
- that there is a potential for detrimental interference from transmissions in the band 94 – 94.1 GHz from space stations of the EESS (active) to radio astronomy observations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz;
- that, in order to protect the radio astronomy service operations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz, RR 5.149 urges administrations “to take all practicable steps to protect the radio astronomy service from harmful interference”;

RECOGNIZING

- that avoidance of transmissions by EESS (active) missions in the band 94 – 94.1 GHz in case of main-beam to main-beam coupling with radio astronomy stations observing in the band 94-94.1 GHz may be necessary to avoid damage to radio astronomy receivers;
- that not all currently planned EESS (active) missions in the band 94 – 94.1 GHz will be able to switch off their transmissions;
- that avoidance of radio astronomy observations in the band 94 – 94.1 GHz in case of main-to-main beam coupling with an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid damage to radio astronomy receivers;
- that avoidance of radio astronomy observations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz when in line of sight of an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid detrimental interference to radio astronomy observations;
- that the free and open availability of advanced operational schedule information on each and every EESS (active) mission in the band 94 – 94.1 GHz would facilitate the protection of the radio astronomy service;
- that more than 30 radio astronomy telescopes worldwide (see Annex 2 for a non-exclusive list) will be potentially involved in observations in these bands, which are generally planned long (weeks to months) in advance;

RESOLVES

- that the SFCG will provide the free and open means for member agencies to make advanced operational schedule information available and up-to-date, via the official SFCG Web Site;
- that member agencies submit such operational schedule information on intended spaceborne active sensing missions that will use the primary allocation in the 94-94.1 GHz band to the SFCG Web Coordinator;
- that member agencies with active missions keep such operational schedule information up-to-date;
- that member agencies and IUCAF use the mutual planning procedure given in Annex 1 to ensure the protection of radio astronomy service operations in the band 94-94.1 GHz.

- ANNEX 1
- **Mutual planning procedure for EESS (active) cloud radar operations with radio astronomy service observations in the band 94 – 94.1 GHz**
- This mutual planning activity shall be carried out as follows:
- The Space agency responsible for the operation of the EESS (active) sensor (EESS Agency) shall provide all relevant information via the SFCG WebSite (http://www.sfcgonline.org) sufficiently in advance of the launch of the satellite. This information will include all the orbital elements that are necessary to allow the avoidance of radio astronomy observations during line-of-sight transmissions from the EESS (active) sensor and the identification of the designated contact person.
- Before the launch or during any time of the operation of EESS active sensor, if there is any change in the planned operation of EESS active sensor (in terms of time and duration of operation and area of operation), the EESS Agency shall provide this information.
- IUCAF will inform the radio observatories that are potentially concerned of planned EESS missions and provide them with instructions on the use of the information available on the SFCG Website that will allow the planning of observations avoiding line-of-sight transmissions from the EESS (active) sensor.
- During any stage of this mutual planning procedure, the EESS Agency and IUCAF shall ensure the availability of their designated contact persons..

ITU-R Rec. RA. 1750

RA.1750	03-2006	Mutual planning between the Earth exploration-satellite service (active) and the radio astronomy service in the 94 GHz and 130 GHz bands	In force

Considering

- a) that current and future satellite-borne cloud radar mapping experiments of the EESS (active) in the 94 and 130 GHz bands shared with RAS may be expected to return important scientific results on global climate;
- b) that the RAS may be expected to continue studying important scientific questions in the 94 and 130 GHz bands shared with EESS (active);
- c) that at mm wavelengths, the directive antenna gain available both on a satellite and at RAS ground stations is very high, creating the possibility of very strong main beam to main beam coupling between a satellite transmitter antenna and an RAS antenna;
- d) that in order to obtain adequate radar echoes from atmospheric phenomena, orbiting radars of the EESS (active) require very high EIRP possibly with sufficient power being coupled to the sensitive RAS receiver to cause physical damage;
- e) that individual RAS instruments may consist of dozens or even hundreds of co-directed antennas, all or part of which may be co-located within the main beam of an EESS (active) satellite on an instantaneous basis, greatly multiplying the consequences of a main beam to main beam encounter;
- f) that at mm wavelengths, current technology does not permit the construction of high performance stop band filters with sufficiently low insertion loss within the wanted passband;

- g) that receivers used by the RAS at mm wavelengths must employ state-of-the-art technology in order to be sufficiently sensitive to carry out original astronomical research and that such technology currently allows very limited dynamic range with a relatively low saturation threshold;
- h) that because of the high EIRP, main beam to sidelobe coupling between the satellite transmitter and the RAS station may cause saturation of the RAS receiver, potentially preventing observations at an RAS station for a significant fraction of the time that the active radar satellite is above the local horizon;
- i) that current technology now permits RAS stations to be outfitted with multi-element focal plane array receiver systems having full main beam sensitivity subtending 1000 times the angular area of a single pixel receiver.

further considering

- k) that a given orbiting cloud radar has the potential of directing its main beam to any spot on the surface of the earth even if it is pointed only toward the nadir, but could in principle be directed arbitrarily;
- l) that of necessity, mm-wave RAS observatories operate at the frequencies shared with EESS (active) only under dry clear conditions so that atmospheric attenuation gives no protection to the RAS station from the satellite radar;

therefore noting

- m) that coordination between the EESS (active) and RAS is essential in order to avoid damage to the RAS instrumentation, and in order to maintain the integrity both the RAS and the EESS (active) data to the maximum extent possible;

Recommends

- ***1.*** *that as early as possible in the design cycle of such an EESS (active) system, contact be established with the RAS – the international organization IUCAF may provide the initial link between the EESS and potentially affected RAS observatories;*
- ***2.*** *that close contact between the RAS and the EESS (active) be maintained throughout the design and operational life-cycles of all systems which are subject to sharing in the 94 and 130 GHz bands such that each service is apprised of pertinent developments within the other.*
- ***3.*** *that the design and operation of systems of each service be performed so as to account for sharing to the greatest practicable extent*
- ***4****. that examples of considerations relevant to sharing which could be taken into account in the design and operations of such systems are given in Annex*

Further recommends

- ***5.*** *That the example provided in Annex 2 of the impact upon one instrument of the RAS from one station of the EESS (active) be considered in the design and operation of stations of both services.*

Annex I

Considerations relevant to the *design* and operation of systems intended for sharing between EESS (active) and RAS in the 94 GHz and 130 GHz bands

For the EESS (active):

- **1.** An active radar system should be *design*ed according to best engineering practices to minimize OOB emission, and to minimize off-axis emission from the radar antenna into sidelobes;
- **2.** An EESS (active) system should be *design*ed and operated in such a way as to avoid transmitting through its main beam directly at stations of the RAS, either by suppressing all transmissions when directed toward an RAS station or by arranging the satellite main beam to be forever directed away from RAS stations;
- **3.** Operators of an EESS (active) system should provide that all operational help possible be given to RAS stations, such as providing timely orbital details of the satellite radar;

For the RAS:

- **4.** RAS stations should be designed to as to prevent their antennas from pointing directly at the orbiting radar, by flexible dynamic scheduling of observations or other means;
- **5.** RAS stations should provide the means to protect their receivers from physical damage if complete avoidance of main beam encounters is impracticable.
- **6.** To the extent reasonably possible, without compromising the capability of the RAS station, RAS receiver systems should be designed to have a high tolerance for damage from received high power transmissions, and to possess as high a dynamic range as is feasible, with low RAS antenna sidelobes, so as to permit observations to continue while the satellite radar is above the local horizon, although not directing its radar towards the RAS station.
- **7**. RAS antennas should be designed with the lowest practicable sidelobe levels so as to permit observations to continue while the satellite radar is above the local horizon, although not directing its radar towards the RAS station.
- **8.** RAS data acquisition systems should be designed to log or flag instances of potential interference from the orbiting radar, based on known RAS and satellite operational parameters;
- **9.** RAS should continue to devote resources to extending the possibilities of real time or post-observation RFI mitigation techniques

(3) Aftermath :: Why was CloudSat a surprise?

- Spectrum managers didn’t alert their clients
- Spectrum managers didn’t talk to each other
- RAS spectrum managers didn’t convey a record to their successors
- Why have interdisciplinary committees like CORF and IUCAF?
- Why have 7C and 7D meet together?

Aftermath ::
Lost Opportunities

- Might ALMA have decided not to use SiS at 94 GHz? VLBA used HEMT.
- Might RAS have begun to work on filters?
- Might CloudSat have considered turning off over RAS sites?
  - ESA's spectrum manager is advocating this for CloudSat's successor

Battle fatigue

- World-wide only two full-time spectrum managers for RAS, Gergely & Laurentiu
- Effort organized on heroic (best-effort) basis otherwise
- Overall organization necessarily loose
- Matters are dropped asap
  - Participants are worn out and must move on
  - True in general, not just for radioastronomy

(4) Moving Forward

- Is better organization/coordination possible?
- Can our history and legacy be better preserved?
- Can we identify and track important issues?
  - Assign portfolios to responsible parties?
- Can we effectively reach out and across
  - To our community?
  - To the other community & spectrum managers

(4)
Moving Forward

- Is better organization/coordination possible?
- No, actually, at least not world-wide
  - The preceding suggestions presented at the 2005 IUCAF SM Summer School produced NO noticeable effect
- Inside the US there is good coordination but the institutional memory is fragile

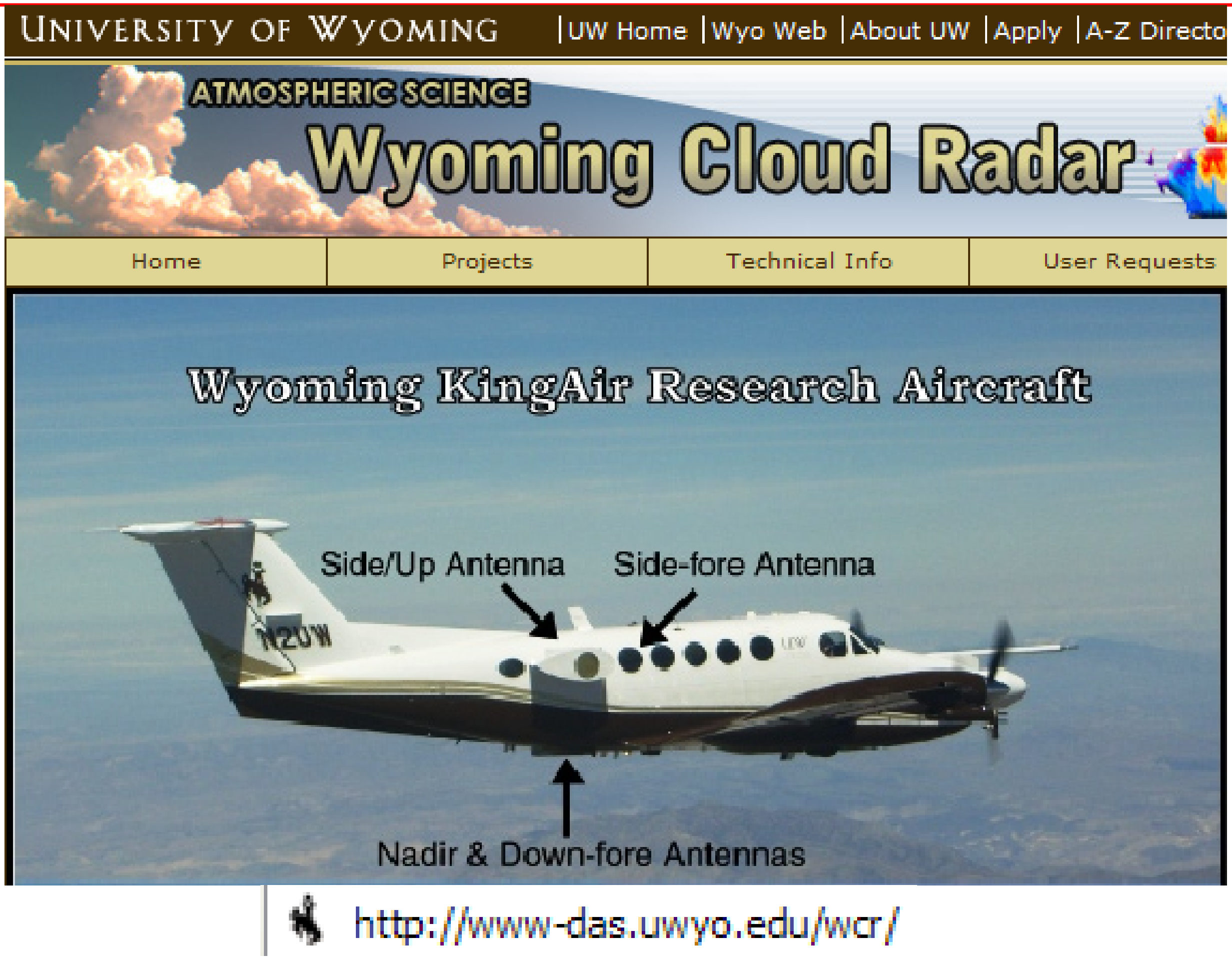
Combating Isolation

- ITU information privileged, expensive
  - Background info goes out of scope quickly
  - Recs, Regs *etc.* should be public *ha ha*
- Information localized + trapped
  - Separately inside ITU, other organizations

(5)
What's next ?

- Other EESS (active) allocations, missions
  - 130-134 GHz, 238 GHz in the future
  - 1.25, 3.2, 5.3, 8.6, *9.6* 13.4, 17.2, 24, 36 GHz
  - MPIfR calculates *9.6* GHz HEMT fries in a main-beam encounter, even if off during illumination
- Other interactions, at closer hand even

W-band radar closer to home
In the air



W-band radar closer to home

In the air

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Mobile Laboratory (MARSF). Operating at 95 GHz (3 mm wavelength), the radar provides high-resolution measurements of reflectivity, velocity and polarization fields. Depending on the antenna configuration used (see **Modes** section), the scanned plane from the KingAir can be vertical or horizontal, and with two antennas, dual-Doppler analysis is possible. Coupled with the in

The sponsors of the new WCR2 are **The University of Wyoming**, **NSF**, and **NASA.**

http://www-das.uwyo.edu/wcr/

Et tu, Washington?

The NSF C-130 aircraft instrument payload for VOCALS-REx is given in Table 1. A total of 90 hours research time is requested for the C-130 to make approximately 10 flights of 9 hours duration. Preliminary costs estimates have been provided by NCAR Earth Observing Laboratory (EOL). The C-130 will be based either in Arica (18°S, 70°W) or Iquique (20°S, 70°W).
The C-130 will be equipped with the full range of *in-situ* meteorological, turbulence, and microphysical probes, and a dropsonde system will be used to give the large-scale meteorological context. A scanning backscatter lidar (SABL) will be used in vertically-pointing mode (both up and down) to detect cloud boundaries. The 95 GHz (W-band) Doppler polarization Wyoming Cloud Radar (WCR) will be used above cloud as depicted in Fig. 3 to detect the structural and kinematic structure of drizzle within and below stratocumulus clouds using dual antennas to carry out dual doppler analysis and obtain horizontal wind components along the flight direction. This configuration was employed successfully in the Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) campaign in 2001.

VOCALS at the University of Washington -

W http://www.atmos.washington.edu/~robwood/VOCALS/vocals_uw.html

Rob Wood Home

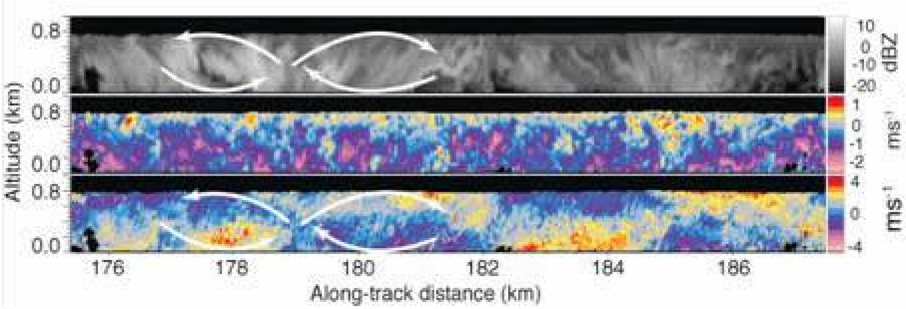

Figure 3: Proposed WCR configuration on the C-130 during VOCALS-REx. Three derived fields are shown

(5) *bis*
Guess What?

- Radio astronomy discovered these largely by accident *after* they operated in the vicinity of our telescopes, were mentioned as operating under CloudSat in CloudSat operational reports, *usw*.

Guess What?

- The 94 GHz Wyoming Cloud Radar is

UNLICENSED

"What, we need a license?"

May have applied, maybe not

The dark side

DEFENSETECH.ORG

the future of the military, law enforcement, and national security

« STRYKER FIGHT RAGES | Main | SPOOKS BATTLE NEW BOSS »

PAIN RAY GOING AIRBORNE

It was only a matter of time, I guess. First, the Air Force builds a real-life, microwave-like pain ray. Then, it gets a company to strap that real-life, microwave-like pain ray to the back of a jet.

For years, the Air Force Research Laboratory (AFRL) has been working on a millimeter-wave beam that penetrates a 64th of an inch beneath the skin. That causes the water molecules there to bubble. And that hurts like hell; people tend to run -- fast -- in the other direction. Small wonder, then, that non-lethal weapons experts call this "Active Denial System" the "holy grail of crowd control."

Active Denial been tested on people a bunch of times. A Humvee-mounted prototype is about to start undergoing trials. And now, Active Denial is going airborne.

http://www.defensetech.org/archives/001219.html

The dark side

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(6) Putting it to the test: Did IRAM see Cloudsat?

TEST OBSERVATIONS OF CLOUDSAT

D.Morris, G.Butin, N.Marcelino *
IRAM, 38406 St. Martin d'Heres,
France.,

June 1, 2007

Abstract

Interference from Cloudsat emissions is unlikely to occur in routine observations. If observations are attempted near or within the 300 KHz band containing the Cloudsat signal at 94.05 GHz, then interference is possible for a few seconds during short integrations made at high elevations $\geq$ 80 degrees and with telescope pointing offsets from the satellite of $\leq$ 1 degree (alternative combinations are for example $\geq$ 85 degrees and $\leq$ 10 degrees). Even then neither receiver damage nor saturation is likely.

Putting it to the test: Did IRAM see Cloudsat?

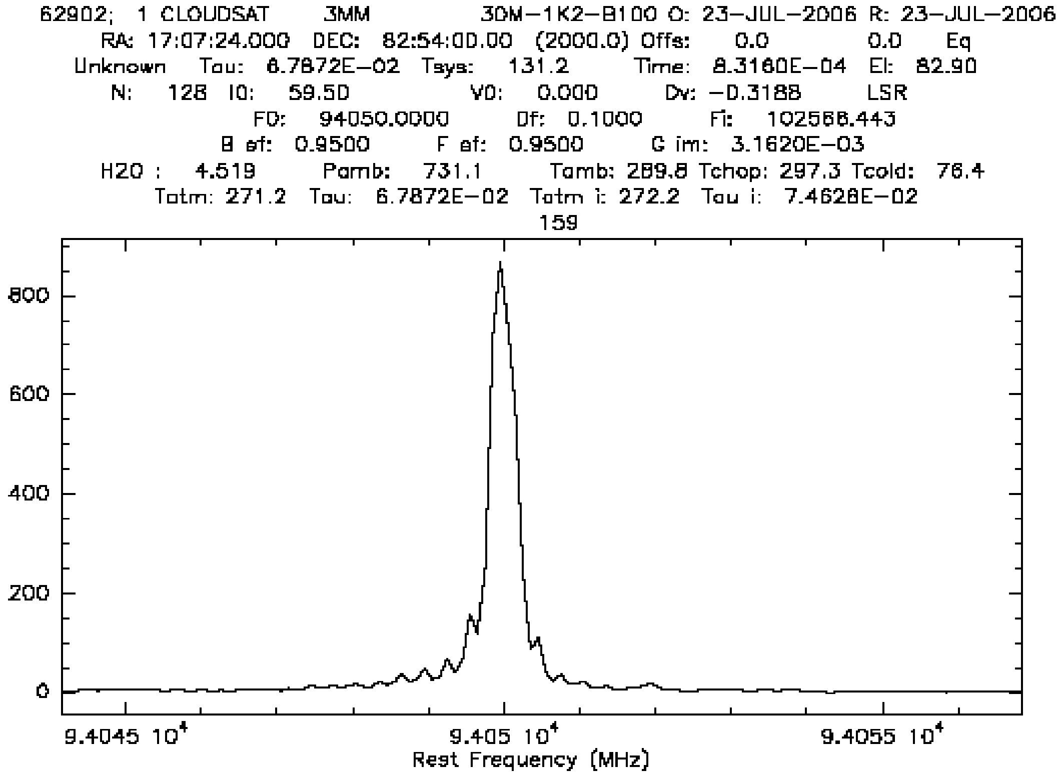

Figure 26: Scan 159 23 July 2006, receiver B100. Ordinate - antenna temperature (K), elevation 82.9 degrees. Tel.-NASA=-0.02, Tel.-clsat=-0.10.

Putting it to the test: Did IRAM see Cloudsat?

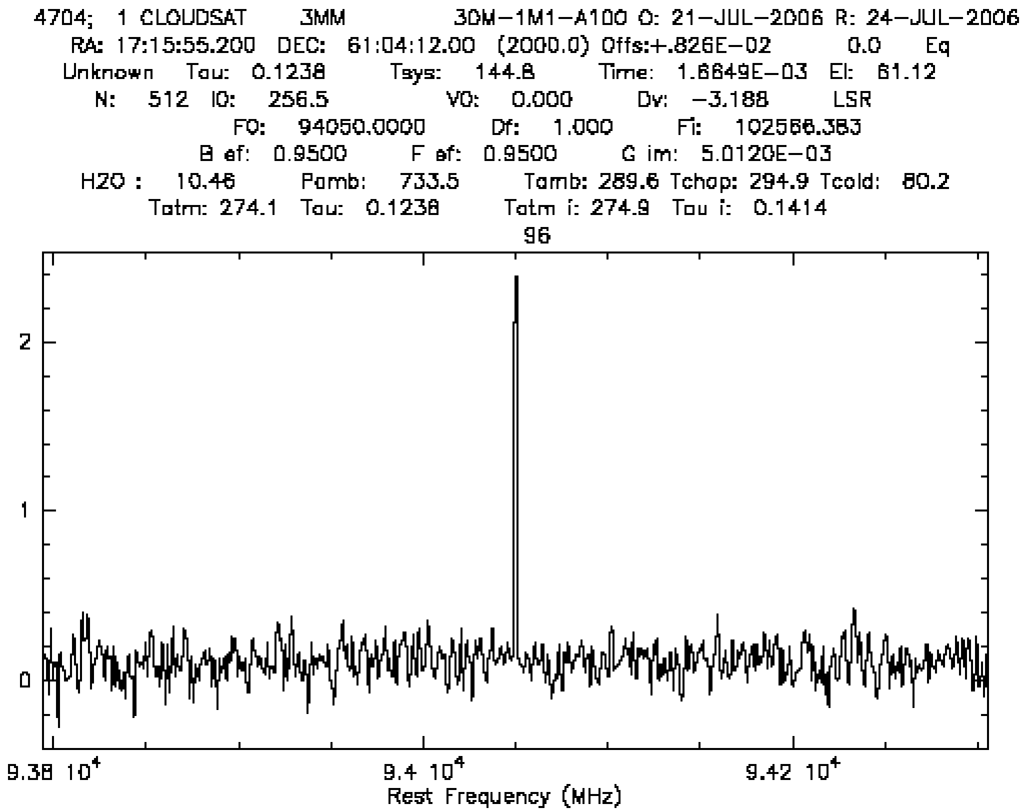

Figure 24: Scan 96, 21 July 2006, receiver A100. Ordinate - antenna temperature (K), elevation 61.0 degrees. Tel.-NASA=-0.09, Tel.-clstat=0.05.

Putting it to the test: Did IRAM see Cloudsat?

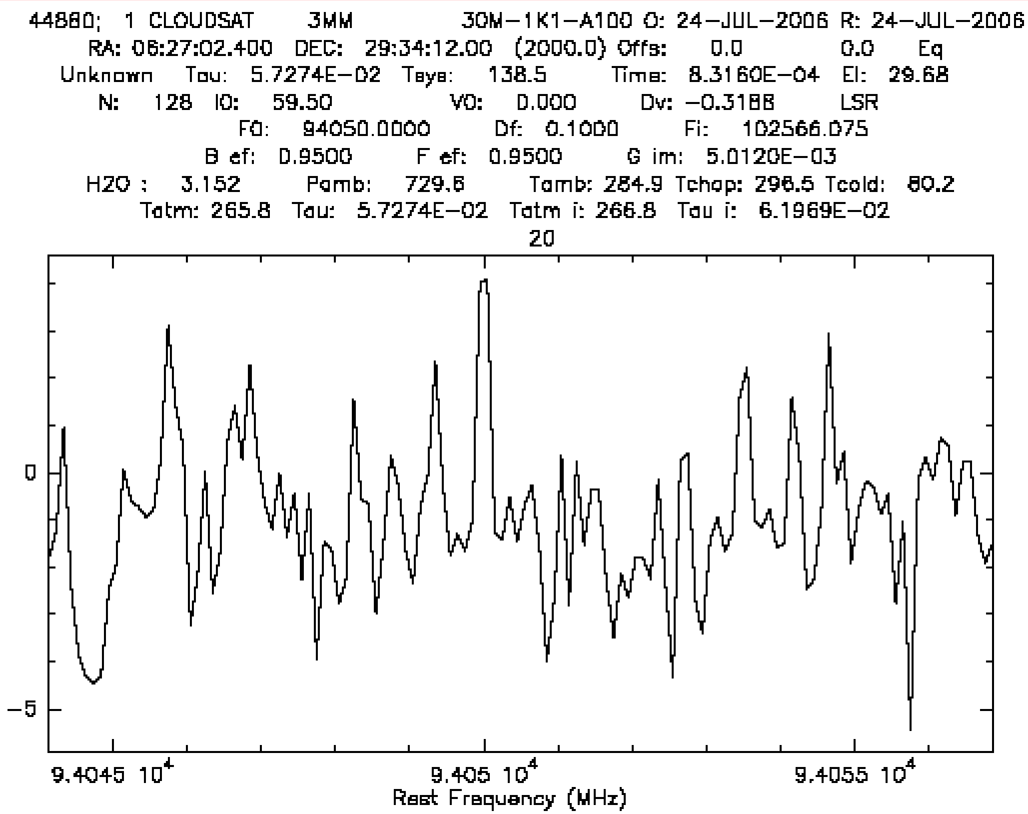

Figure 27: Scan 20, 24 July 2006, receiver A100. Ordinate - antenna temperature (K), elevation 29.6 degrees. This is the weakest signal detected.

Putting it to the test: Did IRAM see Cloudsat?

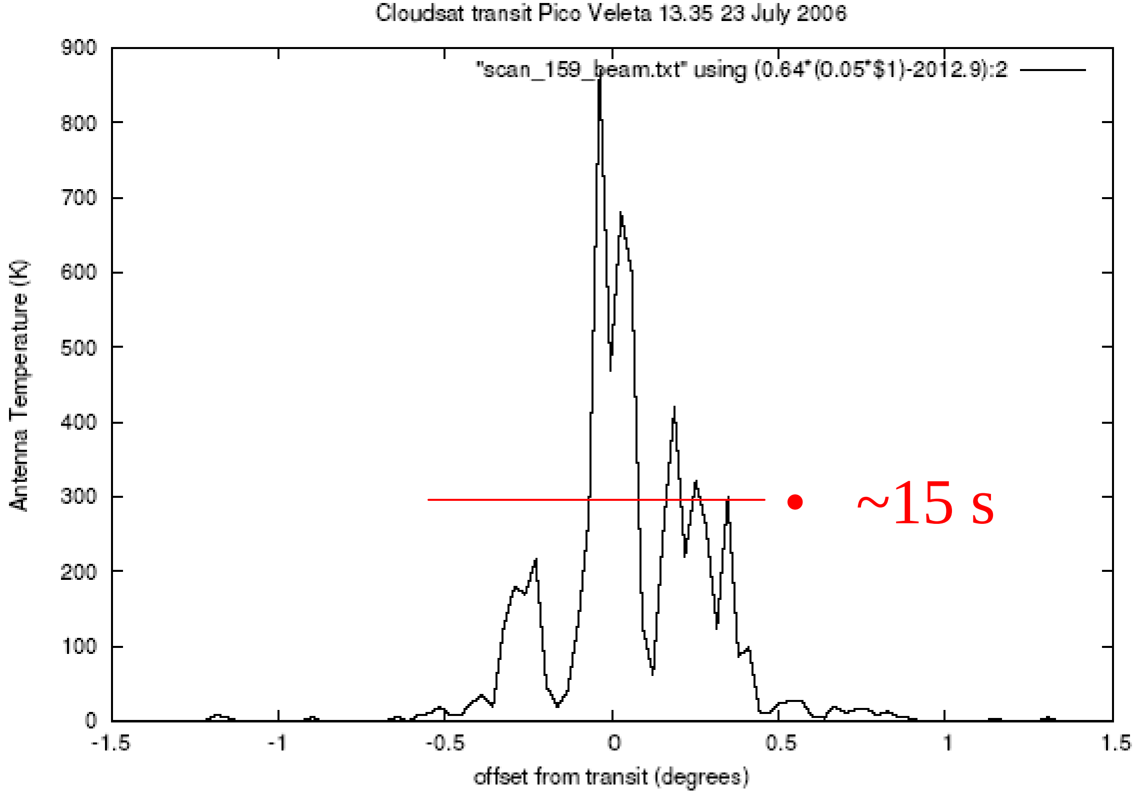

Figure 14: Observed power at 94.05 GHz versus time, Scan 159, 23 July 2006. Abscissa labelled in azimuth offset from boresight. Sample time 0.05 second. No fit has been found to explain this observation.