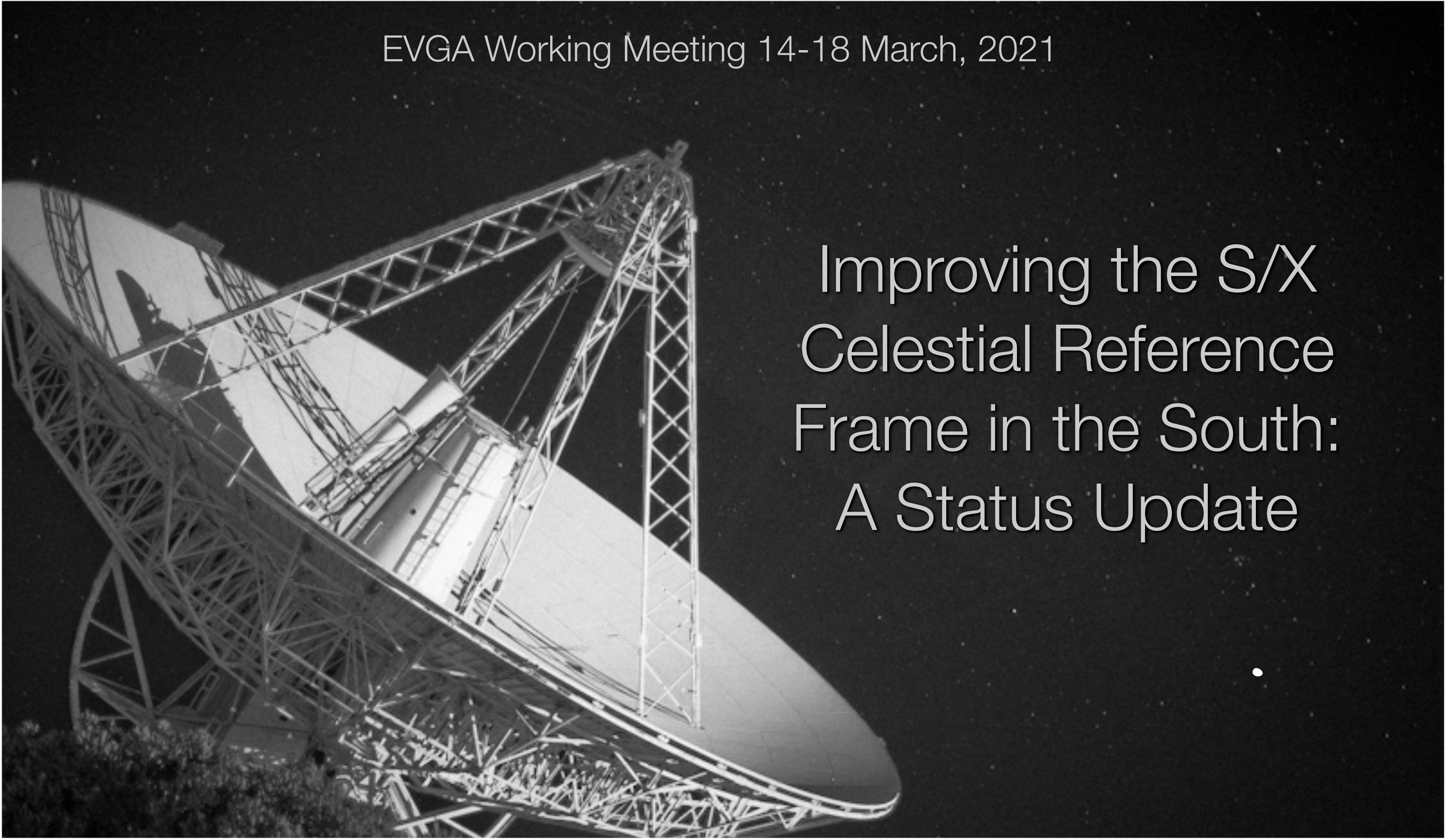
EVGA Working Meeting 14-18 March, 2021

Improving the S/X Celestial Reference Frame in the South: A Status Update



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Overview: Improving the SX-band CRF

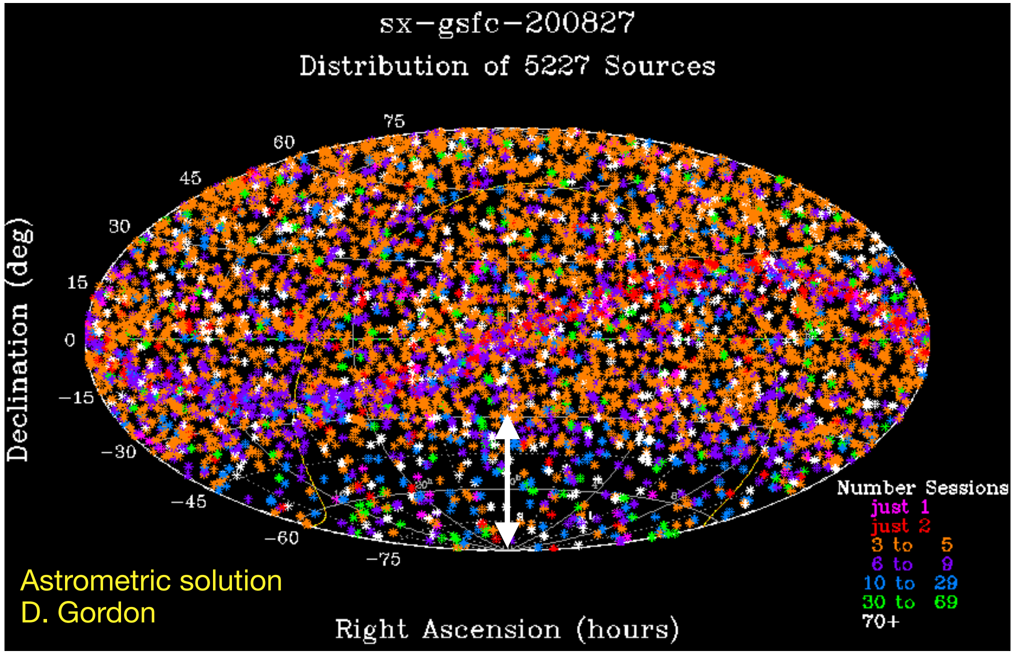
Update of "Improving the S/X Celestial Reference Frame" - IVS GM, Svalbard, 2018
"The Southern VLBI Operations Centre" - EVGA, Gran Canaria, 2019

- **History:** Catalogs of compact radio sources (incl. ICRF-3) are generally weaker in the south by factors of 2 or more in both density and precision.
  - ➡ The ICRF-3 has deficiencies by factors of 2-3 in the south.
  - ➡ Declination precision consistently worse than RA even at equator. (e.g. Charlot et al., ICRF-3, 2021)

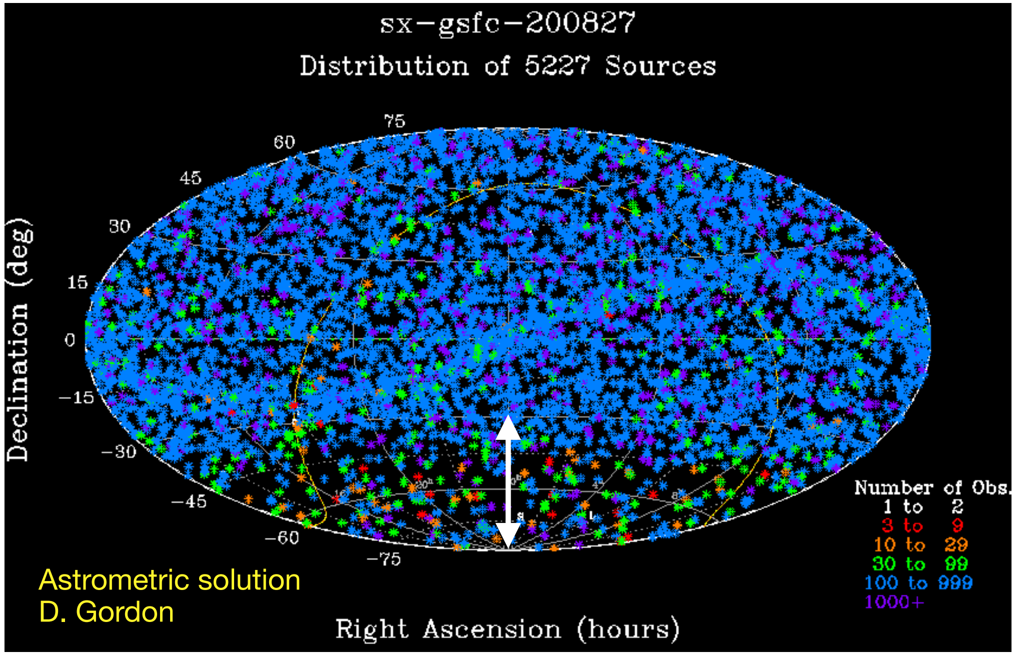
- **There are various efforts underway to correct this:**
  - Increase data rate by factor of 4 or more, from 256 Mbps to 1 - 2 Gbps
  - Revise frequency setup to avoid RFI
  - Scheduling optimised for astrometry (and imaging) instead of geodesy
  - Mapping & monitoring of source structure
  - Improve precision by a factor of 2.5
  - Expand source list in south by a factor of 2, improve spatial coverage
  - Network changes to include more southern and north-south baselines

Current status: The S/X-band CRF

Number of Sessions



Number of Observations

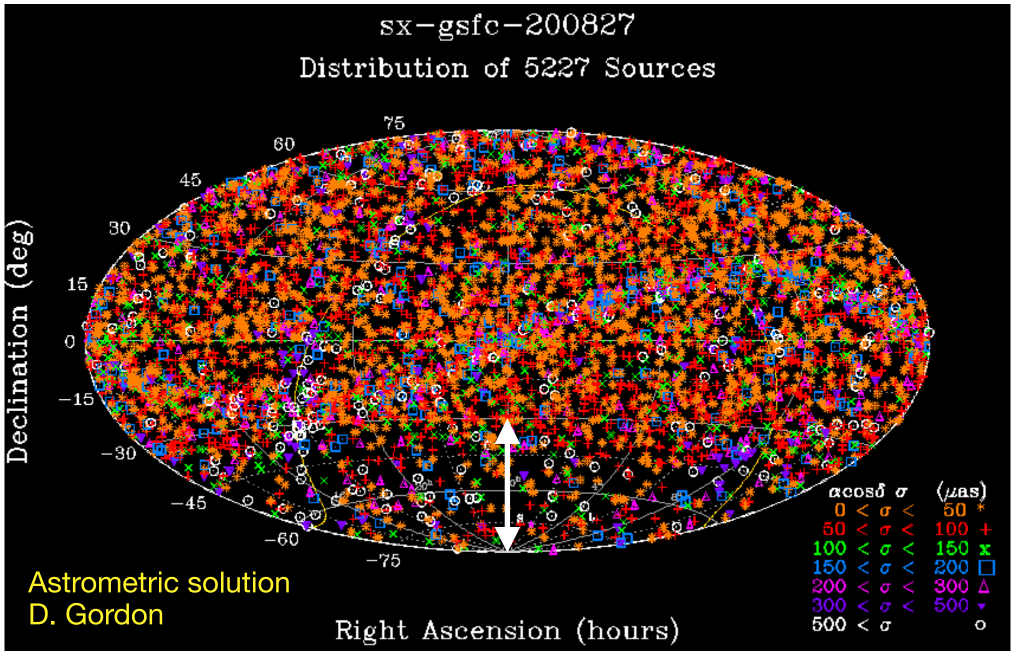


- ➡ Number of sources factor of 2 less in far-south (<-30°) vs. far-north (>+30°)
- ➡ Average number of sessions per source are the roughly the same
- ➡ Average number of observations per source is factor of 2 less in far-south

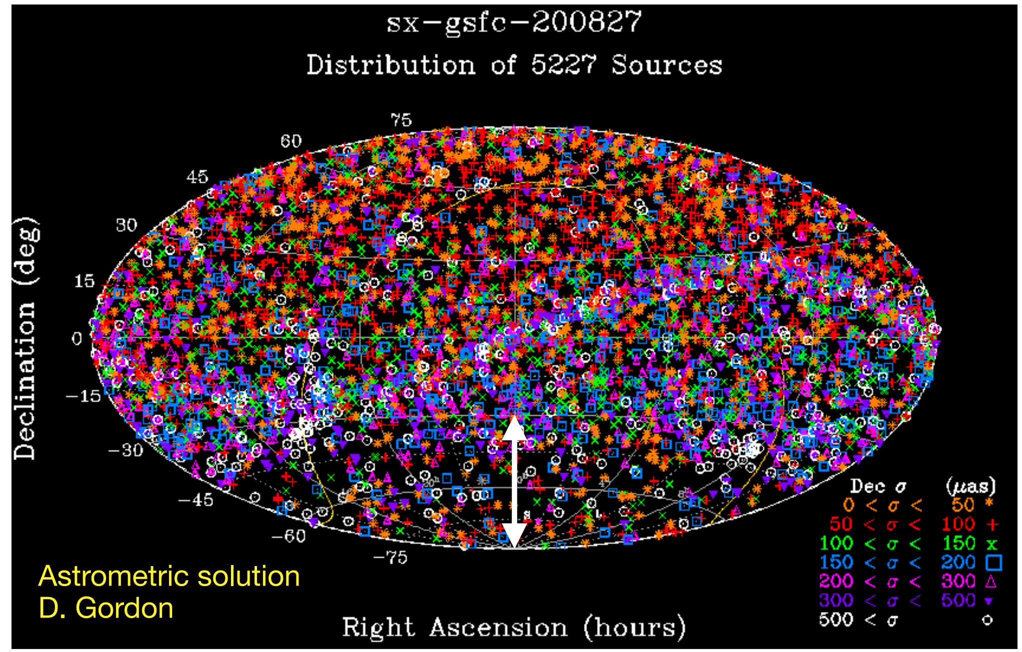
- We need more sources in the South (< -30°)
- We need to improve the spatial coverage in the South

Current status: The S/X-band CRF

RA* precision



Dec precision



➡ Median σ-RA factor of 1.49 weaker in far-south (<-30°) vs. far-north (>+30°)

➡ Median σ-Dec factor of 2.53 weaker in far-south

- Need more southern baselines
- Declinations are consistently worse than RA even at equator
- Need more north-south baselines

CRDS Sessions: Overview and Timeline

- **Imaging campaign started in 2013 (CRDS-63, Jan 2013)**
  Imaging completed for 9 CRDS-sessions (63, 66, 68, 94-97, 100-102)
  Analyse source structure and variability, update flux catalogues

- **Data rate increased from 256 to 512 MHz (CRDS-68, Nov 2013)**

- **Data rate increased to 1024 MHz (CRDS-93, Jan 2018)**
  Increased the sensitivity by a factor of 2
  Can detect weaker sources (down to ~350 Jy)
  Scheduling becomes more efficient (more sources and scans per source)
  Optimized the frequency sequence for S-band to accommodate RFI

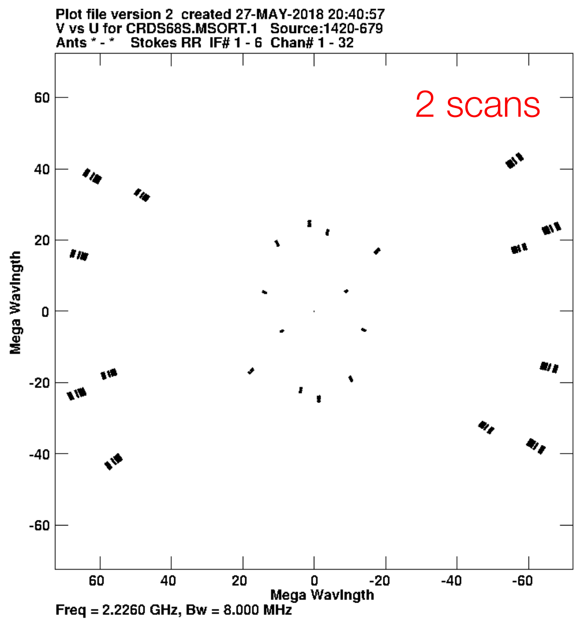
- **Expanded the source list (CRDS-93, Jan 2018)**
  Before CRDS-93 only ICRF-2 defining sources were scheduled
  Included 216 sources observed in less than 10 sessions with flux density > 350 mJy
  Focus on 124 sources in far-south with NO VLBI images
  CRDS-94 was used to image and analyse potential defining sources for the ICRF-3

- **Scheduling optimised for astrometry & imaging (CRDS-93, Jan 2018)**
  Use full network when possible for every scan
  Around 3-8 scans/source spread evenly over HA range
  Include tropospheric calibrators, also used as ties and for amplitude calibration
  New optimised schedules first done in SCHED and now VieSched++ (CRD-102, Jun 2019)

CRDS Sessions: Imaging Campaign

- Imaging of older sessions (before CRDS-93) were challenging
  - poor uv-coverage, few scans per source, low sensitivity, no fits files for import in AIPS
- Information for amplitude calibration not available for all of the stations
- No imaging done for CRDS-93 and CRDS-97 (only 4 stations), and CRDS-98 (only 3 stations)

crds68
27 Nov 2013

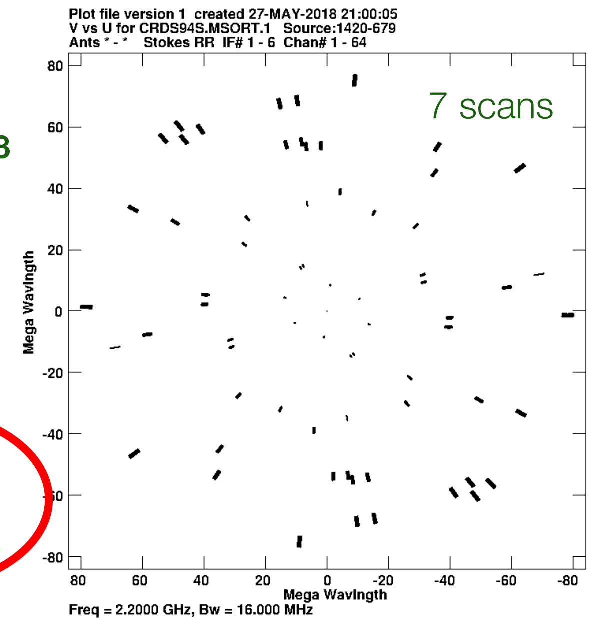


Hh
Ho
Hb
Yg
Ke
~~**Ww**~~

Total:
144 scans
38 sources

Data rate: 256 MHz

crds94
21 Mar 2018



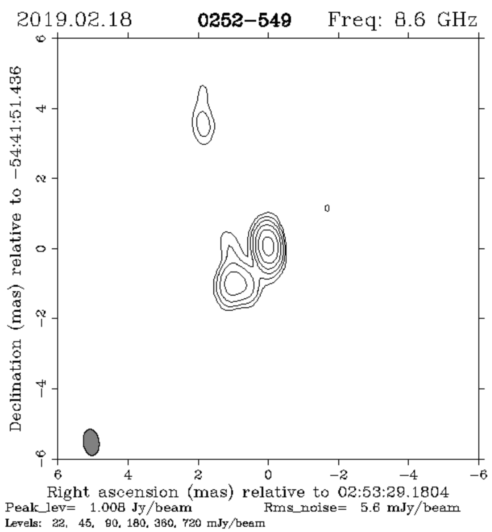
Hh
Ht
~~**Ho**~~
Yg
Ke
Ww

Total:
304 scans
51 sources

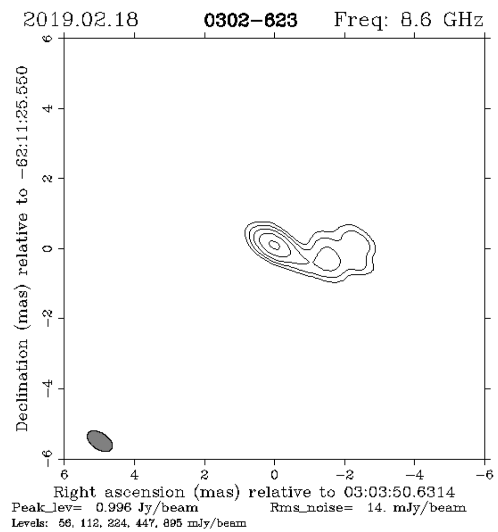
Data rate: 1024 MHz

CRDS Sessions: Sources Maps

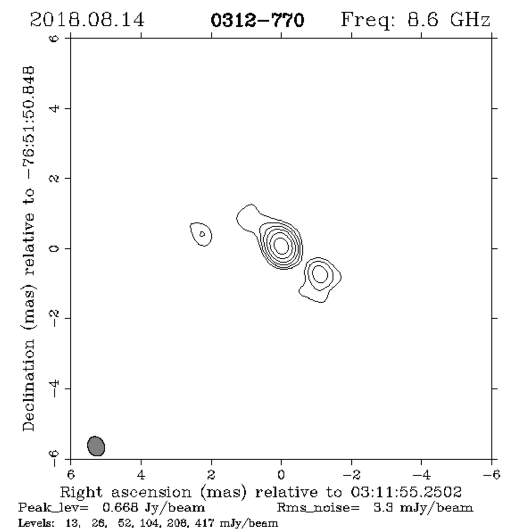
0252-549: SI = 3.6



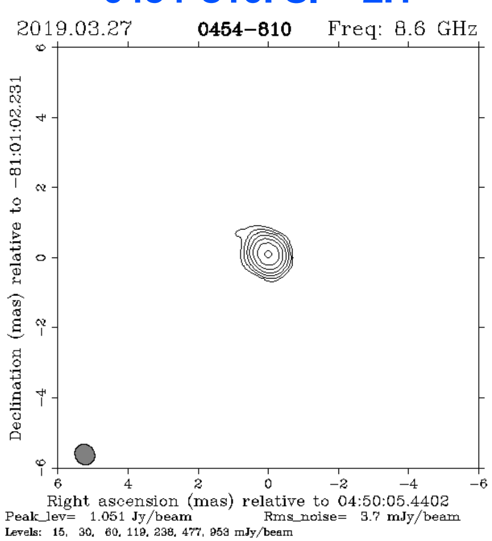
0302-623: SI = 3.5



0312-770: SI = 2.6

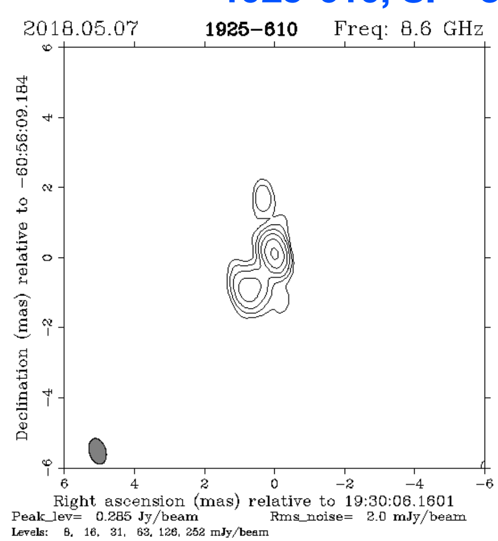


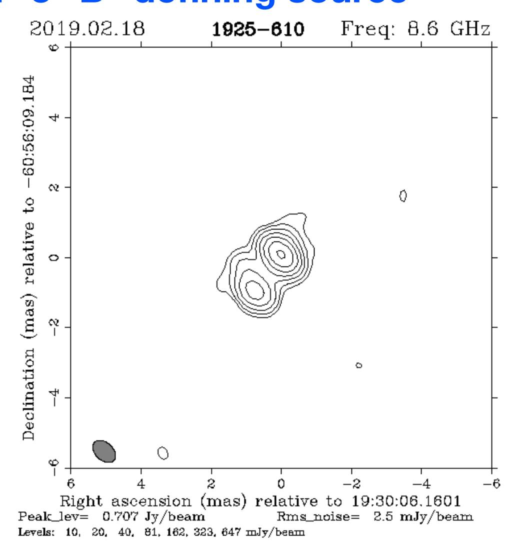
0454-810: SI = 2.1



ICRF-3 “A” defining source

1925-610, SI = 3.1, ICRF-3 “B” defining source

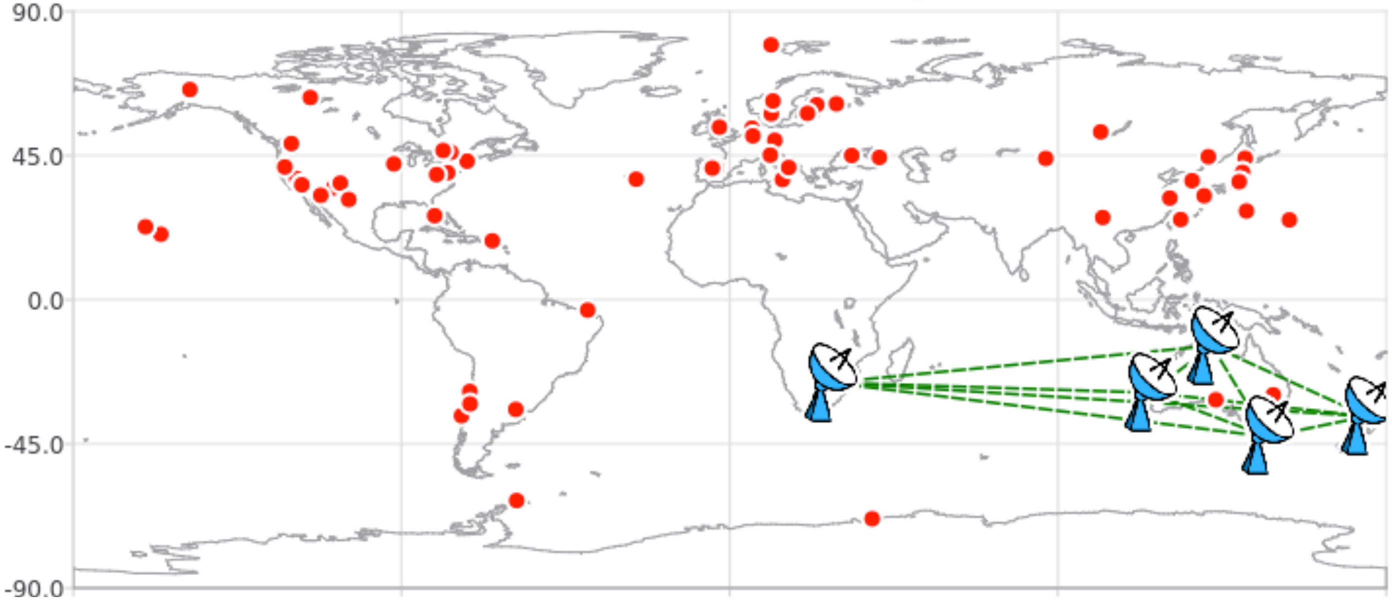




(see also poster by Basu et al.)

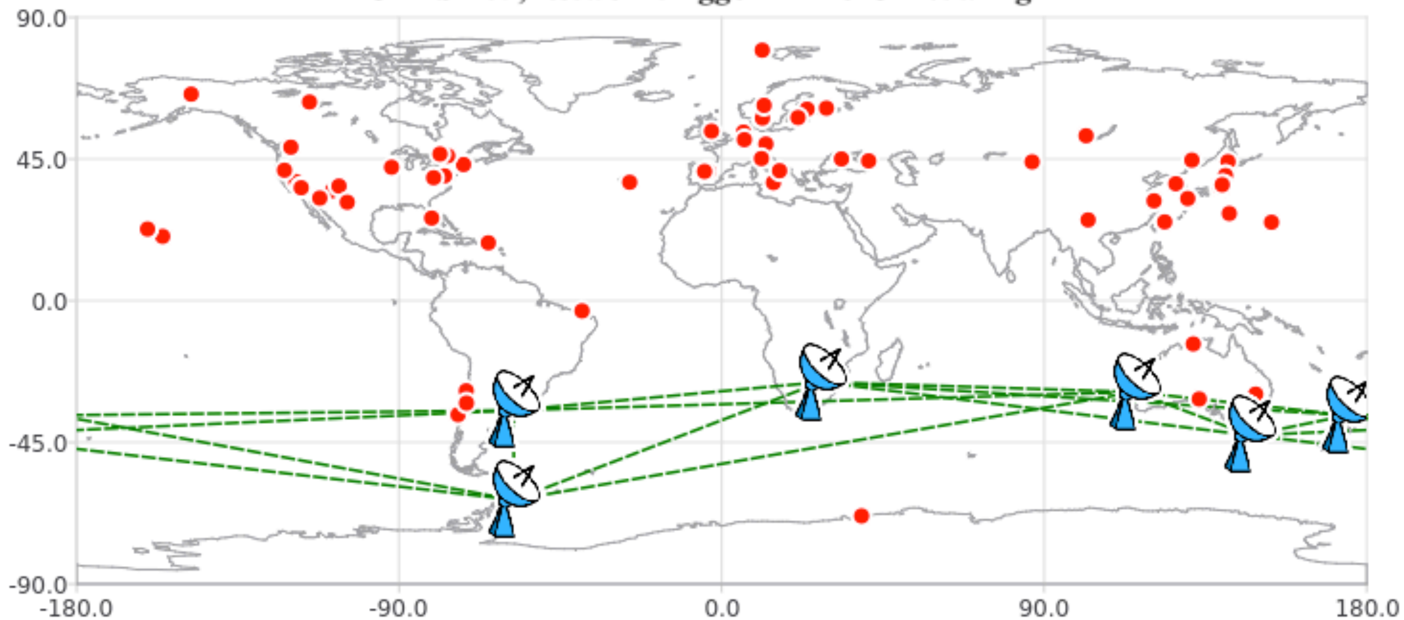
CRDS Sessions: Observing Network

CRDS-94, Network: Hh-Ho-Ke-Yg-Ww



5 antenna network

CRDS-105, Network: Aggo-Hh-Ho-Oh-Ww-Yg



6 antenna network
(from CRD-102 onward)

Ke -> broadband
Aggo + Oh -> added

CRDS Sessions: Performance

	#scans	(4+ sta)	#obs	used		fit [ps]	#src	(4+ scans)	#sta	network
crds93	226	(100%)	1716				42	(60%)	5	HoHhKeYgWw
crds94	304	(100%)	3885	SCHED			51	(92%)	6	HoHhHtKeYgWw
crds95	182	(100%)	1644				40	(75%)	5	HoHhKeYgWw
crds96	232	(100%)	1756	914	(52%)	31	44	(75%)	5	HhHoKeWwYg
crds97	233	(100%)	1779	713	(40%)	34	52	(75%)	5	HhHoKeWwYg
crds98	214	(100%)	2140	1299	(61%)	42	54	(54%)	5	HhHoKeWwYg
crds99	231	(100%)	1386	361	(26%)	44	52	(81%)	4	HhKeWwYg
crd100	212	(100%)	1640				50	(70%)	5	HhHoKeYgWw
crd101	213	(100%)	1711	1186	(69%)	40	53	(62%)	5	HhHoKeWwYg
crd102	203	(100%)	2322	1422	(61%)	34	36	(97%)	6	HhHoKeOhWwYg
crd103	205	(100%)	2386	849	(36%)	47	37	(100%)	6	HhHoKeOhWwYg
crd104	218	(100%)	2356	719	(31%)	35	40	(90%)	6	HhHoKeOhWwYg
crd105	186	(100%)	2480	477	(19%)	36	31	(94%)	6	AgHhHoOhWwYg
crd106	200	(100%)	2698				32	(97%)	6	AgHhHoOhWwYg
crd107	199	(100%)	2585				33	(94%)	6	AgHhHoOhWwYg
crd108	198	(100%)	2798	VieSched++			32	(94%)	6	AgHhHoOhWwYg
crd109	206	(100%)	2259				36	(94%)	6	AgHhHoOhWwYg
crd110	211	(100%)	2340				36	(97%)	6	AgHhHoOhWwYg

hard scheduling constraints

** **7 sources not detected** (not all analysis reports available)

Notes:
Achieving 4+ scans for every source is very hard scheduling constraint

Open Problems:
Only a small % of observations are used for analysis
(long baselines to smaller antennas)

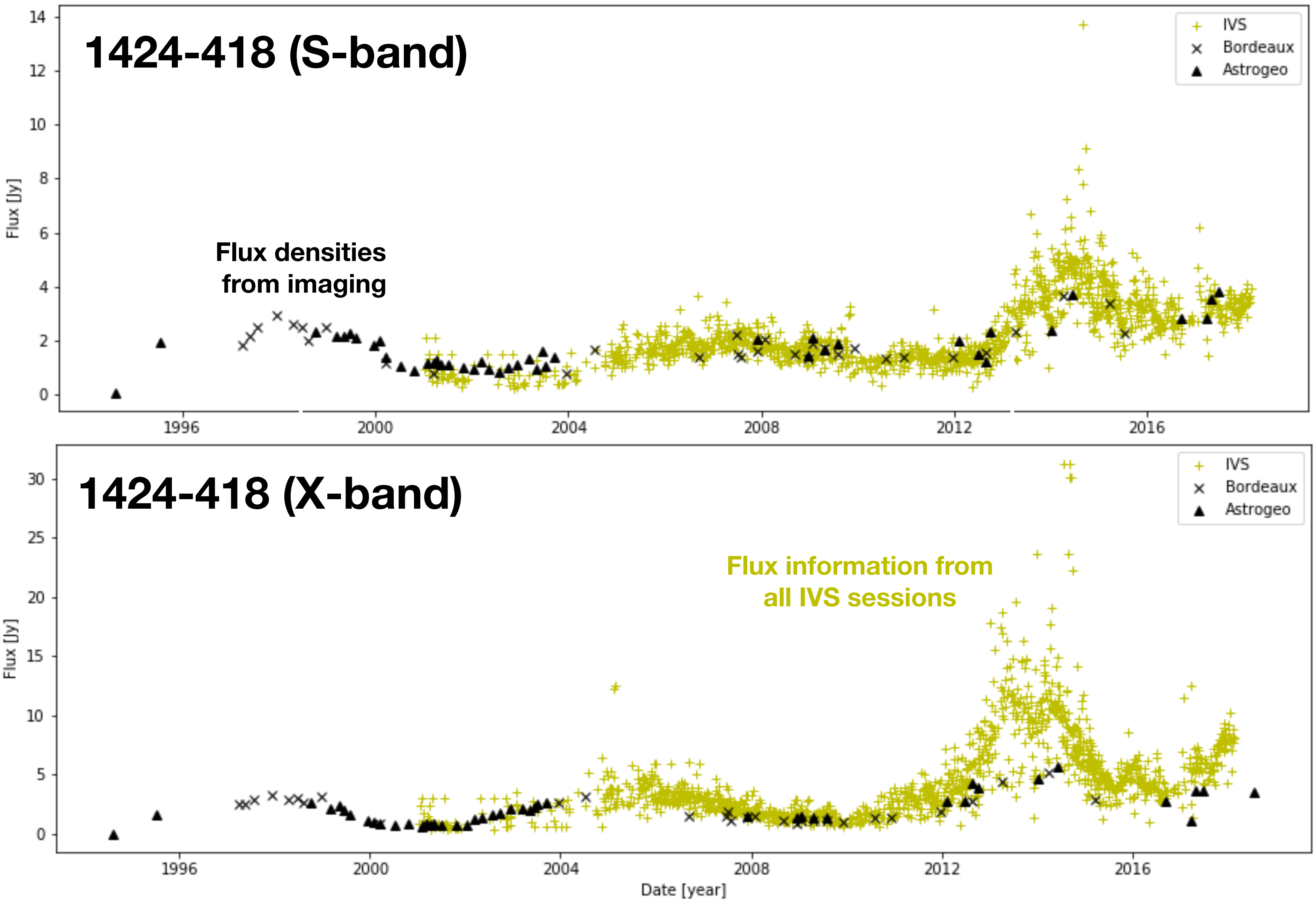
Solutions:
Increase scan length for weak sources (~300 sec from CRDS-114)

Move to SNR based scheduling? (if correct flux information available)

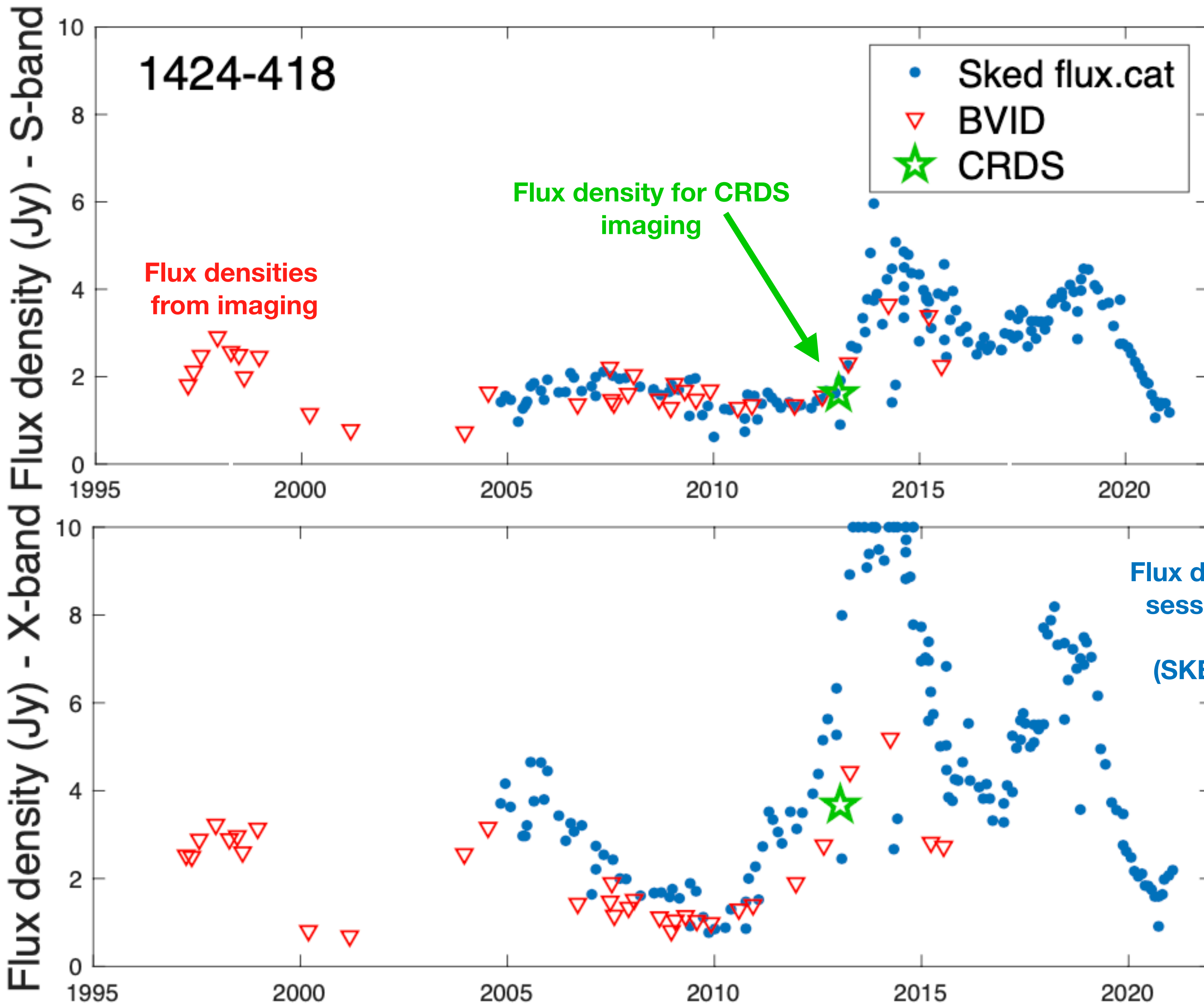
Increase data rate to 2 Gbps?

Add large, sensitive antennas?
(~e.g. Tidbinbilla antennas)

CRDS Sessions: Flux Catalogues



CRDS Sessions: Flux Catalogues



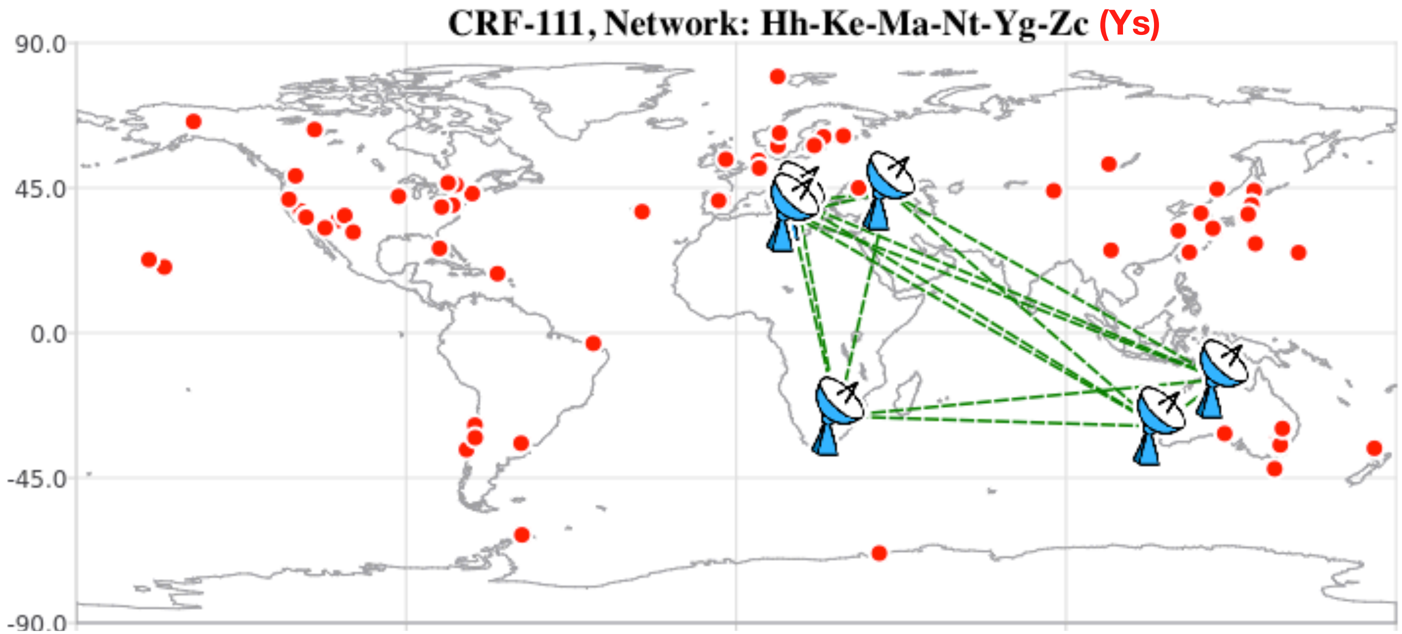
Flux data from all IVS sessions averaged over time (SKED catalogue)

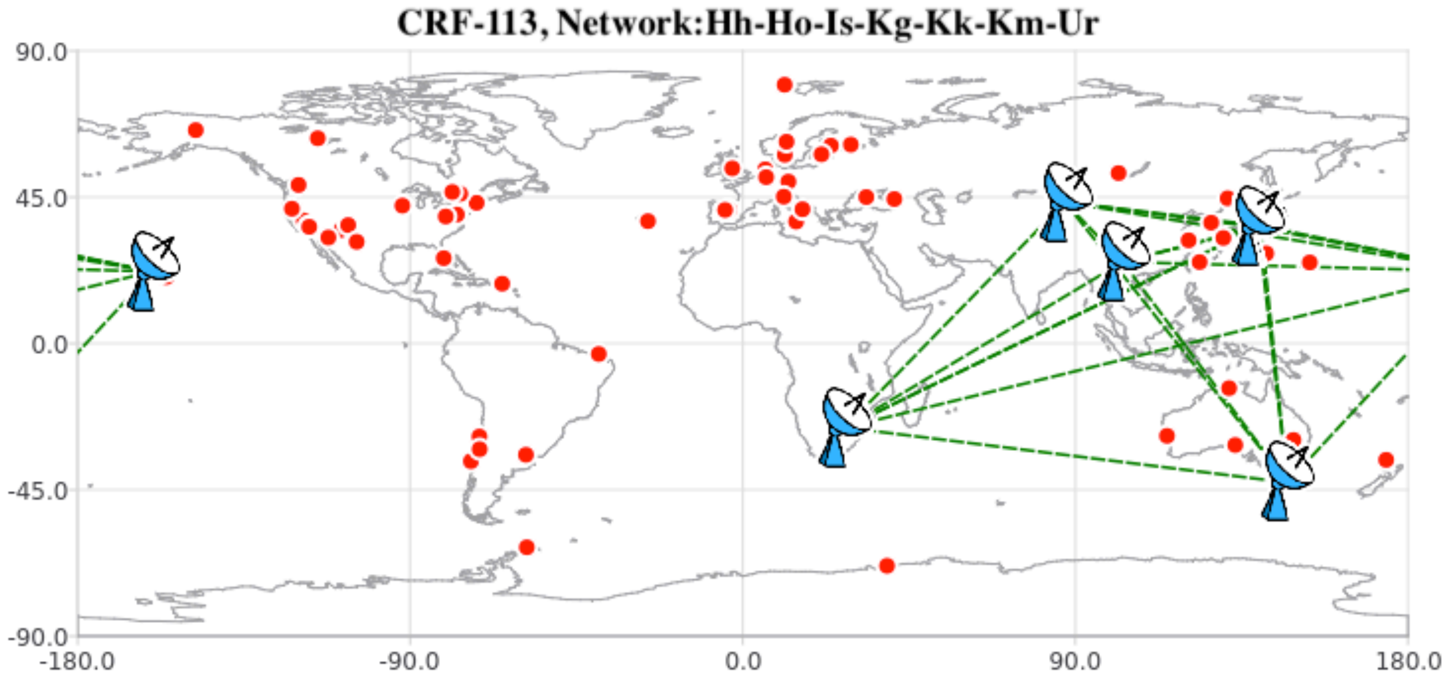
CRF Sessions: Overview and Timeline

- **Data rate increased from 128 to 1024 MHz + network changes (CRF-110, April 2019)**
  Increased the sensitivity by a factor of 2
  New + more sensitive stations added to allow for more N-S baselines and possible imaging

- **Scheduling optimised for imaging and astrometry (from CRF-114, Nov 2019)**
  Four scans per source and only 4-station scans allowed
  Reduced idle time, increased observing time, increased number of observations
  New optimised scheduling done in VieSched++ (CRF-110, April 2019)

CRF Sessions: Observing Network





Network 1 (7 antennas)

Sessions alternate between network 1 and network 2

Network 2 (7 antennas)

CRF Sessions: Performance

	#scans (4+ sta)	#obs	used	fit [ps]	t_{obs}	t_{idle}	#src (4+ scans)	#sta	network
crf104	257 (74%)	2630	1595 (61%)	35	64%	26%	43 (100%)	8	HtHoK1KeKkKmNtYg
crf105	267 (57%)	1654			69%	19%	43 (84%)	7	HtHoK1KeKkNtYg
crf106	185 (84%)	1307	865 (66%)	61	54%	40%	43 (81%)	7	HtHoK1KeKkNtYg
crf107	185 (24%)	653	185 (28%)	58	41%	45%	43 (74%)	5	FtHhHoKgNt
crf108	290 (13%)	753	355 (47%)	106	55%	24%	43 (91%)	5	FtHhHoKgNt
crf109	548 (0%)	720	292 (41%)	78	35%	27%	43 (100%)	4	FtHhHoKg
crf110	321 (56%)	1318	660 (50%)	26	73%	5%	65 (60%)	4	HhKeYgZc
crf111	538 (44%)	4092	1105 (27%)	47	68%	8%	62 (92%)	7	HhKeMaNtYgYsZc
crf112	330 (71%)	3187	726 (23%)	41	78%	5%	56 (95%)	6	HhHoIsKbKgUr
crf113	309 (81%)	3475	1076 (31%)	20	68%	14%	52 (92%)	7	HhHoIsKgKkKmUr
crf114	249 (100%)	2490	1349 (54%)	27	76%	1%	59 (53%)	5	HhMaMcYsZc
crf115	220 (100%)	1968	642 (33%)	35	66%	16%	47 (62%)	6	HhHoKgKkKmUr
crf116	220 (100%)	3288	1033 (31%)	21	82%	1%	41 (80%)	6	BdHhKmMaYgZc
crf117	234 (100%)	3510	1309 (37%)	20	80%	1%	38 (97%)	6	BdHhKmMaYgZc
crf118	231 (100%)	3465	832 (24%)	24	84%	1%	40 (95%)	6	HhHoIsKmUrYg
crf119	237 (100%)	2366	1040 (44%)	34	79%	1%	37 (97%)	5	HhHoKmUrYg
crf120	221 (100%)	3315	268 (8%)	13	82%	1%	40 (100%)	6	HhKmMaNtYgZc
crf121	221 (100%)	2210	464 (21%)	52	83%	0%	38 (97%)	5	HhHoKmUrYg

SKED (crf104–crf109)

VieSched++ (crf110–crf121)

hard scheduling constraints

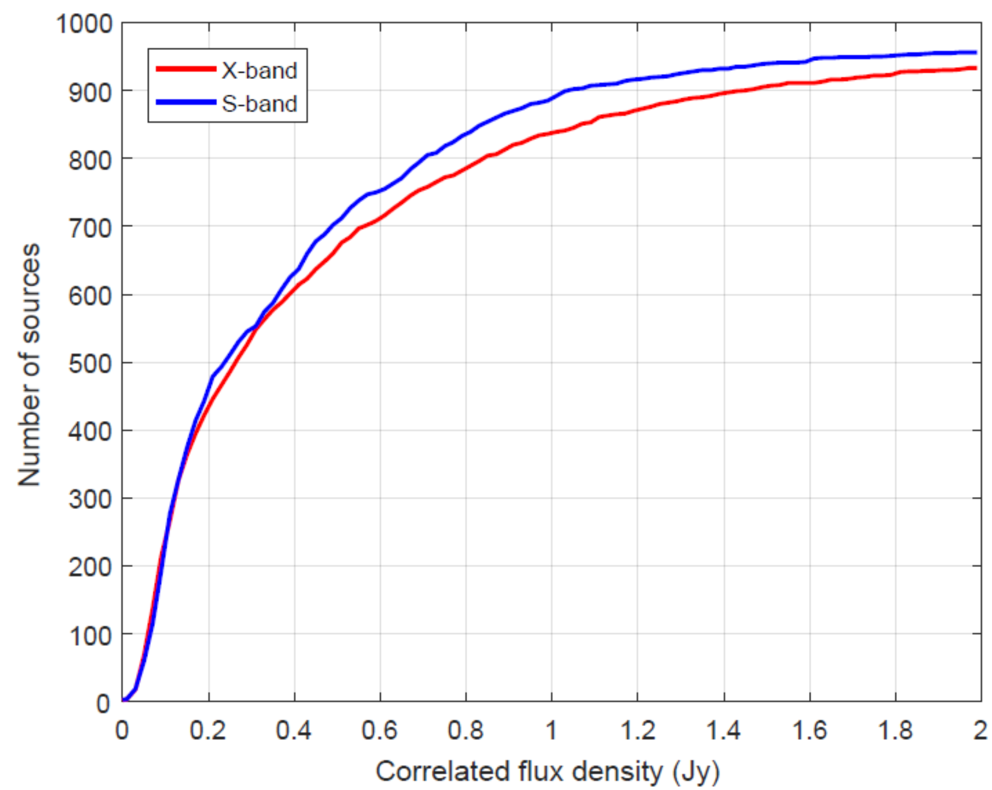
Notes:

- Starting CRF114: VieSched++, Only 4+ station scans
- Starting CRF117: min 4 scans per source
- Reduced idle time, Increased observing time, Increased #obs

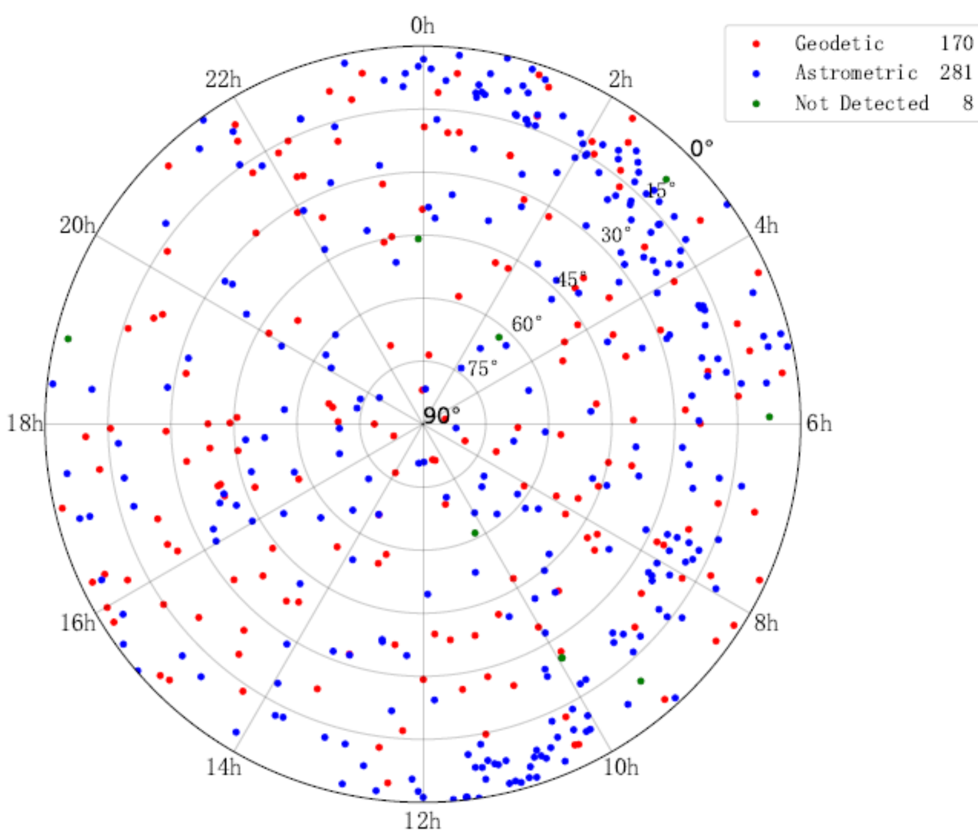
Open Problems:
Only a small % of observations are used for analysis

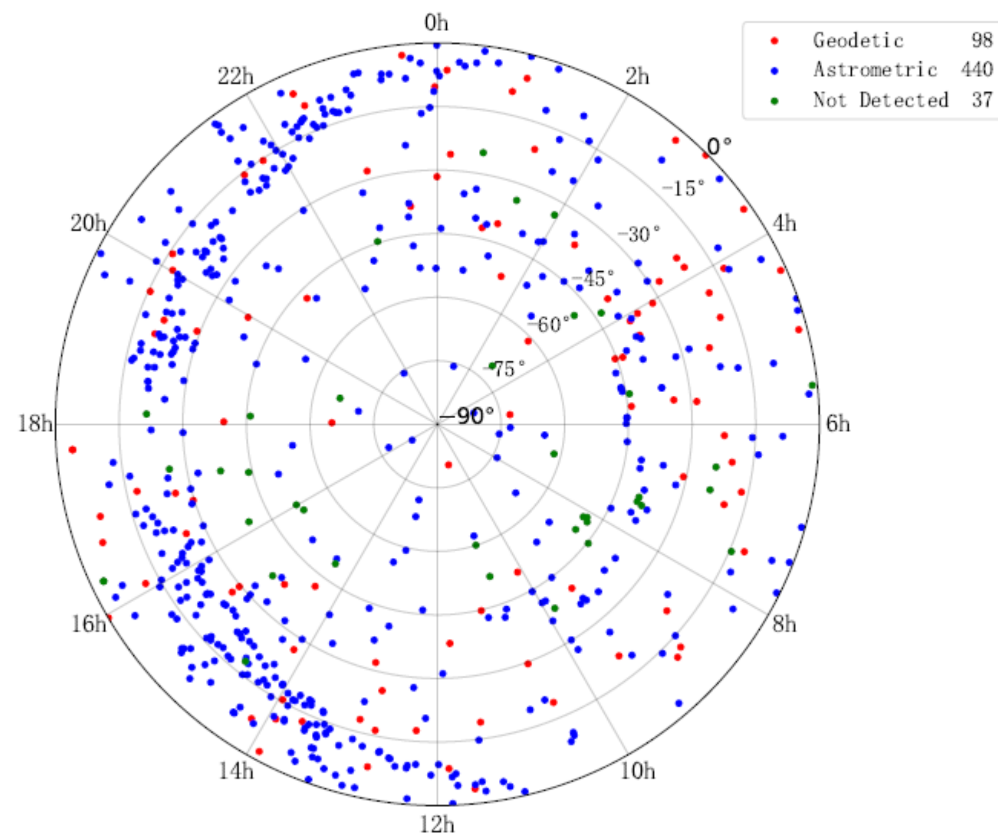
AOV Sessions: Overview and Source List

- AOV observing program was launched in 2015
- One goal is astrometry of weak sources, with emphasis on ecliptic plane and southern hemisphere
- All astrometric sessions were observed at 1 Gbps rate
- 1034 targets have been observed, including 861 ICRF3 sources and a few radio stars.
- 989 sources were detected at S/X dual band. The median values of flux densities are 0.26Jy at X-band and 0.24Jy at S-band.



AOV Sessions: Observed Targets





Geodetic good sources listed in the sked catalog, astrometric targets as well as undetected sources are shown

Summary and Future Plans

- **Goal:** To improve the S/X-band frame in the south, by at least a factor of 2 in density and 2.5 in precision, to be about as good as the north.

- **Roadmap:**
  - Increase data rate of southern IVS sessions to 2 Gbps.
  - Optimise the scheduling of these sessions for astrometry & imaging vs. geodesy.
  - Increase the number of south-south but also north-south baseline observations.
  - Image sources to quantify non-pointlike structure and measure jet directions.
  - Expand the southern source list and improve spatial coverage
    - follow recommendations in ICRF-3 paper
  - Get the far south precision about as good as the north.
  - Add more sensitive antennas in the south and address RFI issues
    - e.g. adding Tidbinbilla antennas and VLBA-Saint Croix and Mauna Kea
    - adding Warkworth 30m in single-frequency mode (use external ionosphere data)
    - single-frequency mode may be also applied for the Hobart 26m (severe RFI issues)

- **Coordinating Efforts:** The newly established IVS-CRF Committee will coordinate efforts to improve the celestial reference frame in the South

Thank You

Contact Details

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Image credit: Ani Vermeulen, NASSP student 2014