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Automated Radio Astronomy Observations  
with the Deep Space Network

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# DSAO

DSN Science Automated Observatory

A status report on

## Automated Radio Astronomy Observations with the Deep Space Network

Tom Kuiper

Testing

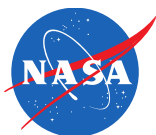
Shinji Horiuchi  
Cristina Garcia Miro

Architecture and Software

Tom Kuiper  
Chuck Naudet (PI)

System Admin and Web

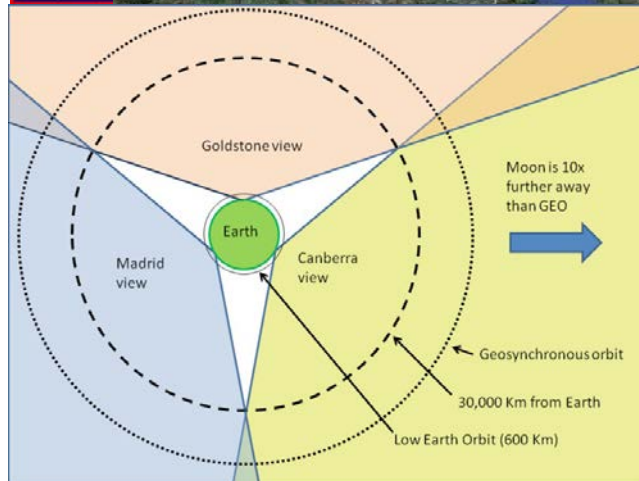
Steve Levoe  
Danny Luong  
George Wang



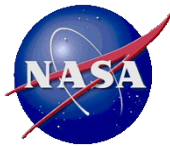
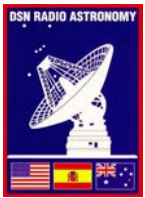
**Jet Propulsion Laboratory**  
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# Automated Radio Astronomy Observations with the Deep Space Network



- Changes of spacecraft positions with Earth's orbital motion cause gaps in the telecom schedule.
- The Canberra and Madrid stations are available for radio astronomy by treaty and Goldstone by NASA and JPL policy.



## Goal

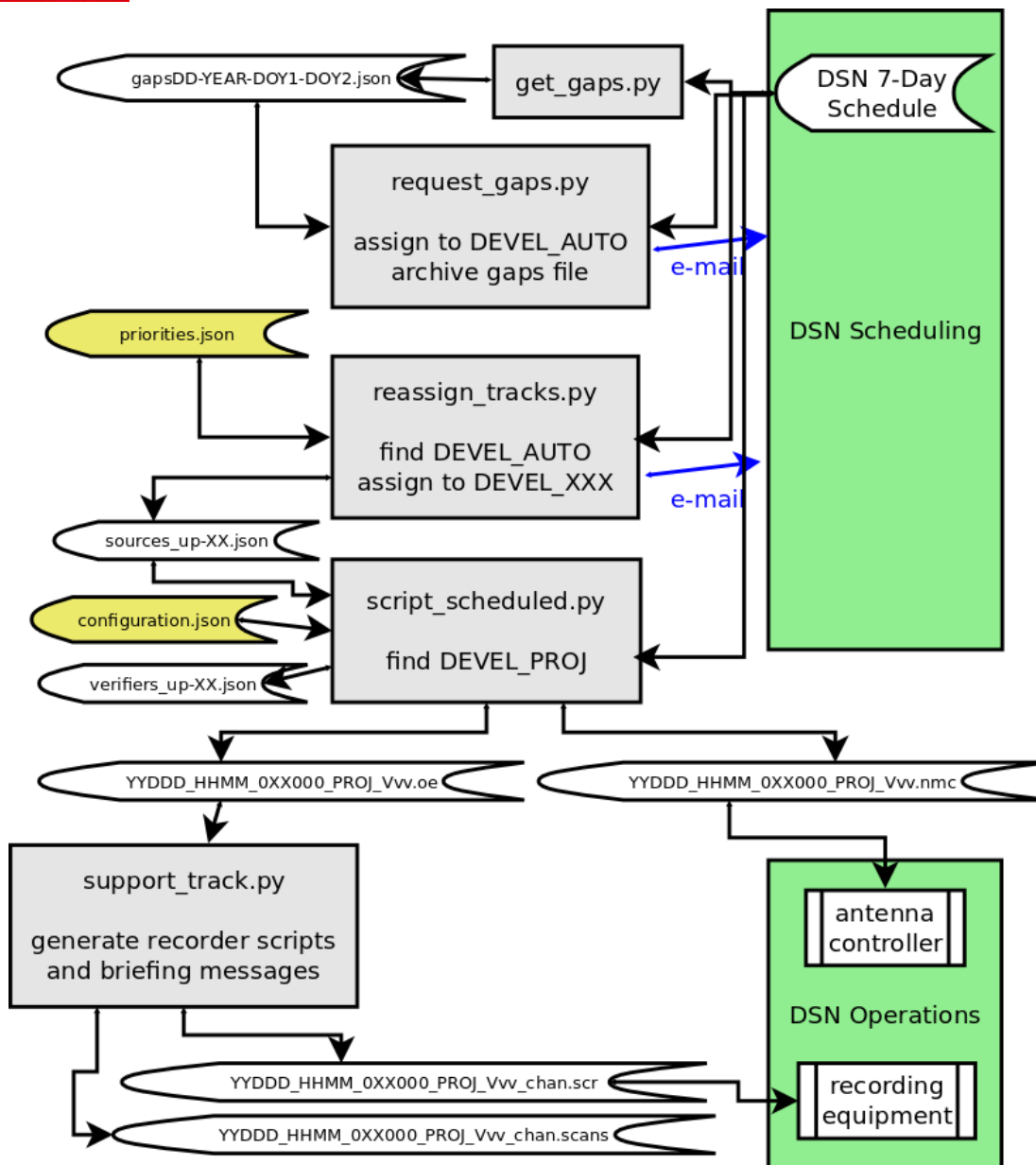
Completely autonomous scheduling, execution and first level processing of radio astronomy observations in telecom schedule gaps.

## Summary of Automated Science Operations

- Searches DSN tracking schedule for useful gaps
- Requests useful gaps to DSN science
- Selects research project to be supported
- Assigns suitable available recorder(s)
- Generates scripts for antenna and recorders
- Transfers data from recorder to DSN science HPC
- Starts initial post-processing
- Notifies project team



# Automated Radio Astronomy Observations with the Deep Space Network



## Scheduling Pipeline

- Checks DSN 7-Day Schedule daily for 2-hr+ gaps.
- E-mail\* request to DSN Scheduling office to re-assign gaps to Science.
- Checks DSN Schedule daily for new Science tracks.
- Selects science activity (project) to be supported
  - Project priority
  - Radio source availability
- E-mail\* request to DSN Scheduling to re-allocate track to science activity.
- Checks DSN Schedule daily for new Science activity tracks.
- Generates observing sequences for antenna and Operations personnel.

\* E-mails are placeholders for ReST (Representational State Transfer) messaging being implemented by DSN Scheduling



## Observing Pipeline

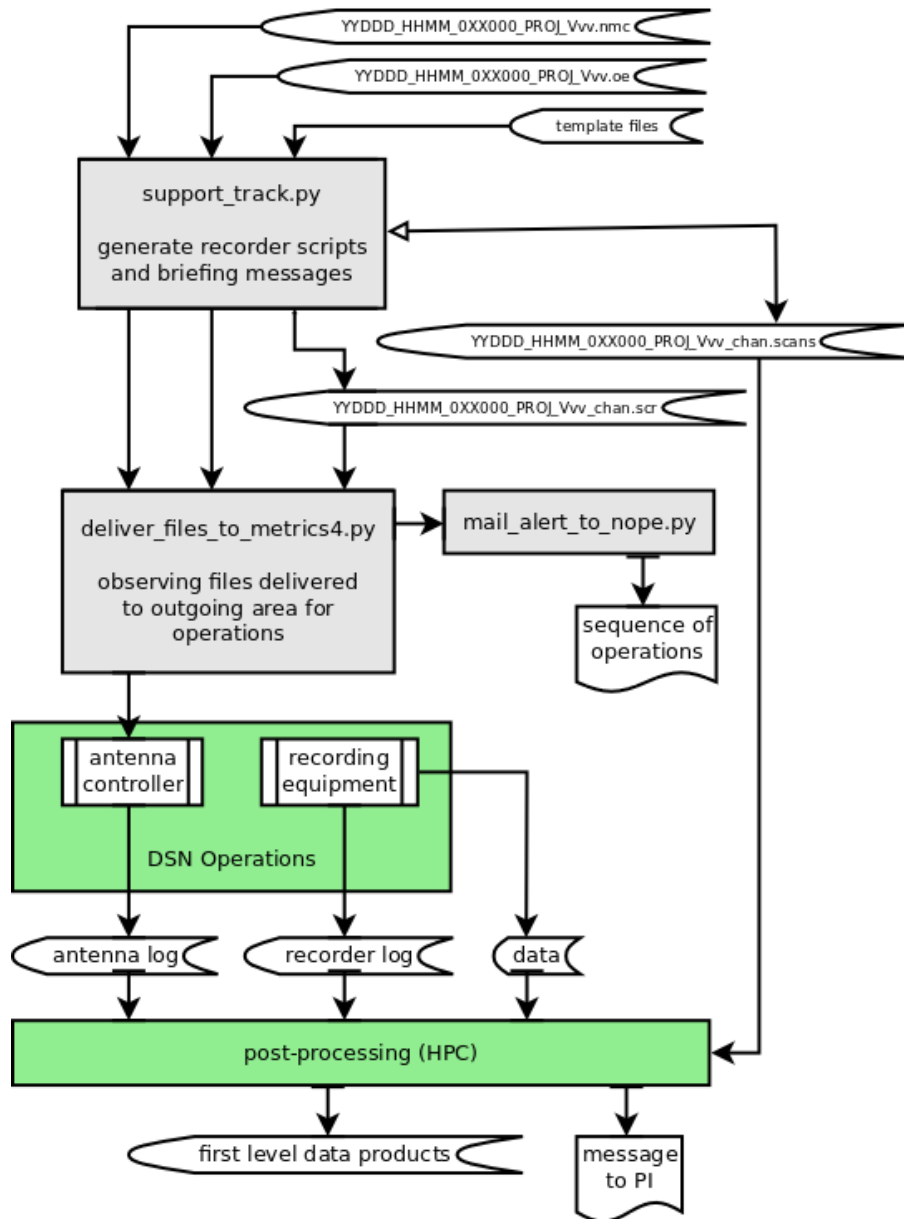
### Before Observations

- Observing sequence converted to recorder script, briefing message and instructions for post-processing.
- Files for Operations are placed in a delivery area.
- Network Operations Engineer (NOPE) notified that files are ready.
- Files for antenna and recorder are moved manually\* by the NOPE to respective controllers.

### After Observations

- Antenna log, recorder log and data files moved manually\* to high performance Science workstation.
- Routine post-processed done and PI notified.

\* See Current Focus slide.





# Automated Radio Astronomy Observations with the Deep Space Network

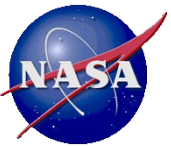
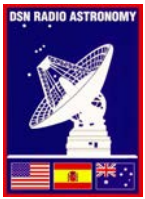


## Example Schedule

Selected Tracks at Mon Nov 7 06:00:26 2016 UT

	Year	DOY	Station	Mission	Project	Start	End	Month/Day	LST
assigned	2016	311	DSS-14	GBRA	DEVEL-UVC 0311 1946	2016-311T02:30	2016-311T11:35	11/06	22.5 - 6.4
	2016	312	DSS-14	GBRA	DEVEL-PSR 0312 1946	2016-312T03:45	2016-312T11:30	11/07	23.8 - 6.3
	2016	313	DSS-14	GBRA	DEVEL-PSR 0313 1946	2016-313T03:40	2016-313T11:30	11/08	23.8 - 6.4
	2016	314	DSS-14	GBRA	DEVEL-PSR 0314 1946	2016-314T05:00	2016-314T15:35	11/09	1.2 - 10.6
	2016	316	DSS-14	GBRA	DEVEL-RRL 0316 0918	2016-316T04:50	2016-316T07:05	11/11	1.2 - 2.2
	2016	316	DSS-14	GBRA	DEVEL-EGG 0316 0918	2016-316T13:50	2016-316T16:00	11/11	10.2 - 11.1
	2016	317	DSS-14	GBRA	DEVEL-PSR 0317 1946	2016-317T04:30	2016-317T07:20	11/12	0.9 - 2.5
	2016	317	DSS-14	GBRA	DEVEL-RRL 0317 0918	2016-317T12:15	2016-317T15:55	11/12	8.7 - 11.1
	2016	318	DSS-14	GBRA	DEVEL-EGG 0318 0918	2016-318T03:20	2016-318T06:50	11/13	23.8 - 2.1
	2016	319	DSS-14	GBRA	DEVEL-PSR 0319 1946	2016-319T03:15	2016-319T08:20	11/14	23.8 - 3.6
	2016	319	DSS-14	GBRA	DEVEL-RRL 0319 0918	2016-319T12:20	2016-319T14:55	11/14	8.9 - 10.2
	2016	320	DSS-14	GBRA	DEVEL-EGG 0320 0918	2016-320T03:20	2016-320T05:50	11/15	23.9 - 1.2
	2016	325	DSS-14	GBRA	DEVEL-UVC 0325 1946	2016-325T03:00	2016-325T10:50	11/20	23.9 - 6.5
pending	2016	328	DSS-14	GBRA	DEVELOP-SD 0328	2016-328T08:50	2016-328T16:00	11/23	5.2 - 12.4
	2016	334	DSS-14	ATOT	DEVELOPMENT 0334	2016-334T02:30	2016-334T10:10	11/29	0.0 - 6.5
	2016	335	DSS-14	GBRA	DEVELOP-AUTO 0335	2016-335T04:50	2016-335T10:20	11/30	2.4 - 6.7
	2016	336	DSS-14	GBRA	DEVELOP-AUTO 0336	2016-336T04:50	2016-336T10:20	12/01	2.5 - 6.8
	2016	338	DSS-14	GBRA	DEVELOP-AUTO 0338	2016-338T04:40	2016-338T09:50	12/03	2.5 - 6.4
2016	339	DSS-14	GBRA	DEVELOP-AUTO 0339	2016-339T03:50	2016-339T10:10	12/04	1.7 - 6.8	

DEVEL track errors do not trigger Discrepancy Reports to Operations management

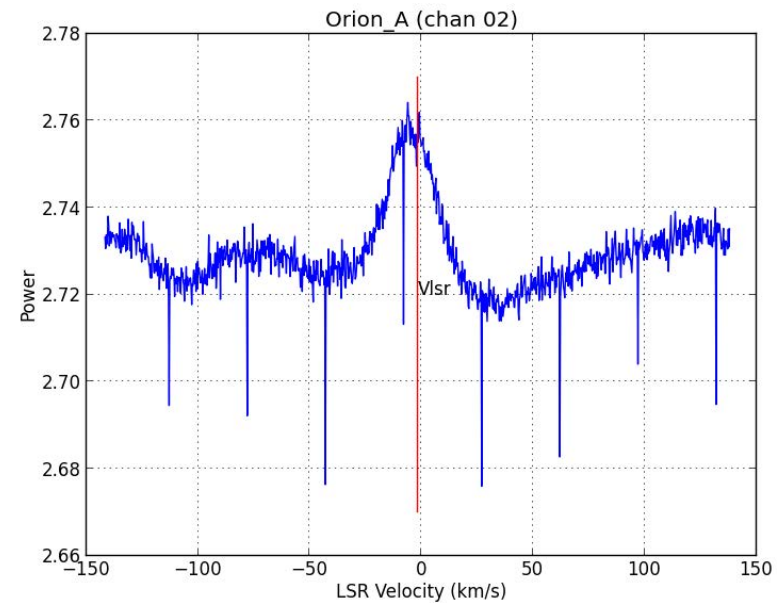
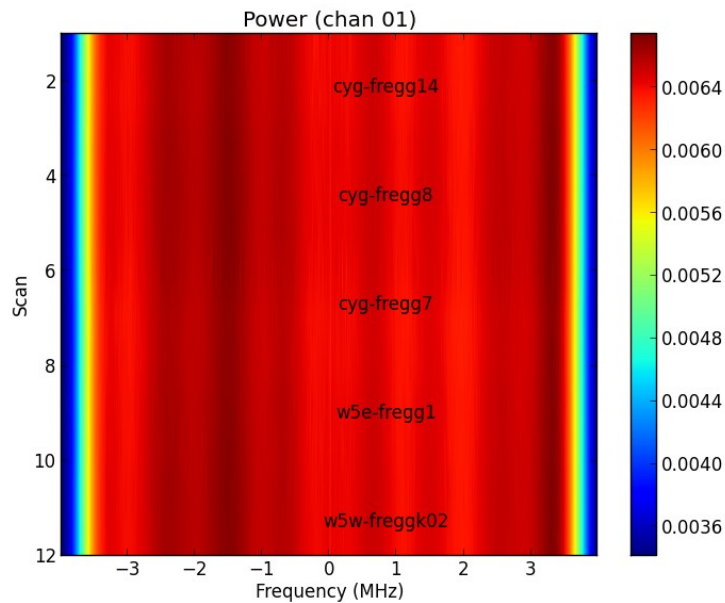


## Science Projects for Testing

- **EGG**: Radio recombination lines from free floating evaporating gaseous globule (Sahai)
- **RRL**: r.r.lines along selected lines of sight through the Galaxy and the Magellanic Clouds (Pineda)
- **UVC**: Radio emission from UV Ceti (Villadsen)
- **PSR**: FERMI giant radio pulses (Majid)

All observations are currently treated as DSAO tests, with top priority given to validating procedures and software

## Post-Processing Quality Check



Standard check (all projects) for RFI  
and recorder problems

Activity-specific check for data quality.  
1-MHz tones used for testing (like VLBI).

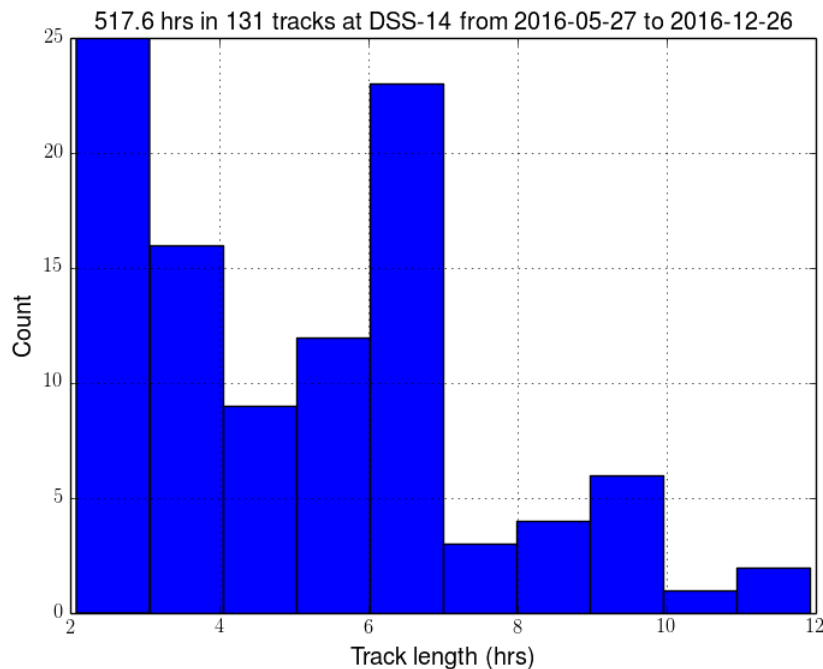




## Performance Assessment

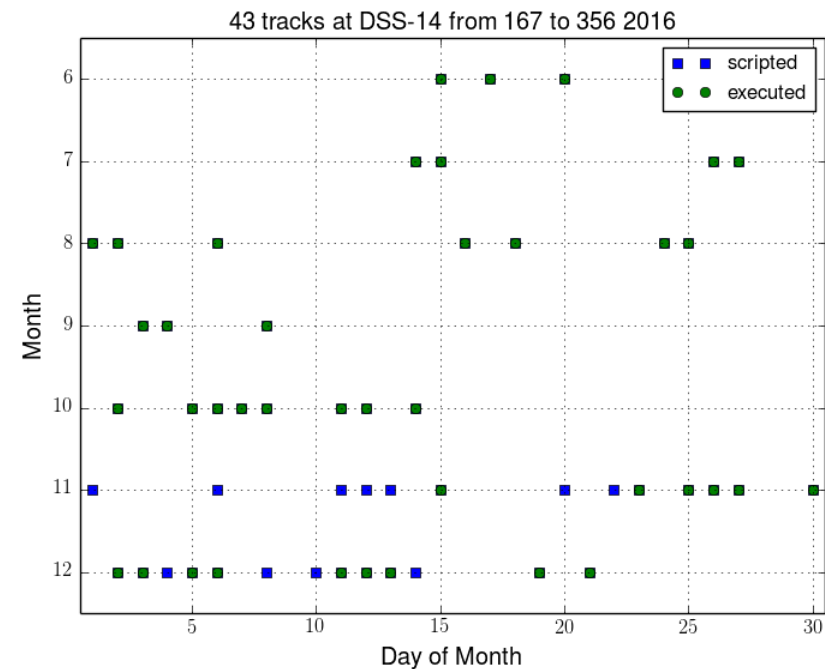
15 months into a 36 month project

### Schedule Gaps Recovered



Gap size and view periods vary as Earth moves around the Sun.

### Re-scheduled Gaps Used



87 hrs of data processed: EGG: 43.7 hrs, RRL: 32.7 hrs, UVC: 11 hrs.

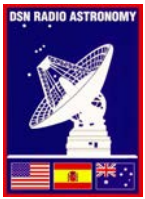


## Status: Current Focus

- People in the process
  - Pending implementation of ReST protocol by DSN Scheduling development team
- File transfer restrictions
  - DSN Configuration Control for mission reliability
  - IT security concerns

## Status: Future Development

- More sophisticated automated activity assignment algorithm based on
  - weighting of peer review based priority
  - equipment status
  - degree of completion
- RA controller using IPC with hardware controllers and DSN Operations controllers instead of scripts
- Non-DSN (*i.e.* research) recorders
- Short-term weather-based activity reprogramming



## Backup

# Modified TSP for Source Sequencing

- Add virtual targets to list of objects visible during track:
  - RA, dec of stow position at start
  - RA, dec of stow position at end
  - Intermediate position with zero distance to start and end
- Use Traveling Salesman Problem algorithm to minimize path
- Compute first and last slew times (from and to stow position)
- Remove virtual sources
- Compute slew times between sources
- Assign integration time in source order:
  - If source visible < specified minimum, discard source
  - Set integration to specified maximum or source set time
  - Add slew time to get start of next source
- Add verifiers (*e.g.* calibrators) according to project requirements (at beginning, during, at end)