Science Operations for the VLA and VLBA; Application to SKA

Bryan Butler
VLA/VLBA Science Support Division Head
Claire Chandler
Deputy Assistant Director for Operations
National Radio Astronomy Observatory

Very Long Baseline Array
Karl G. Jansky Very Large Array
Atacama Large Millimeter/submillimeter Array

What is science operations?

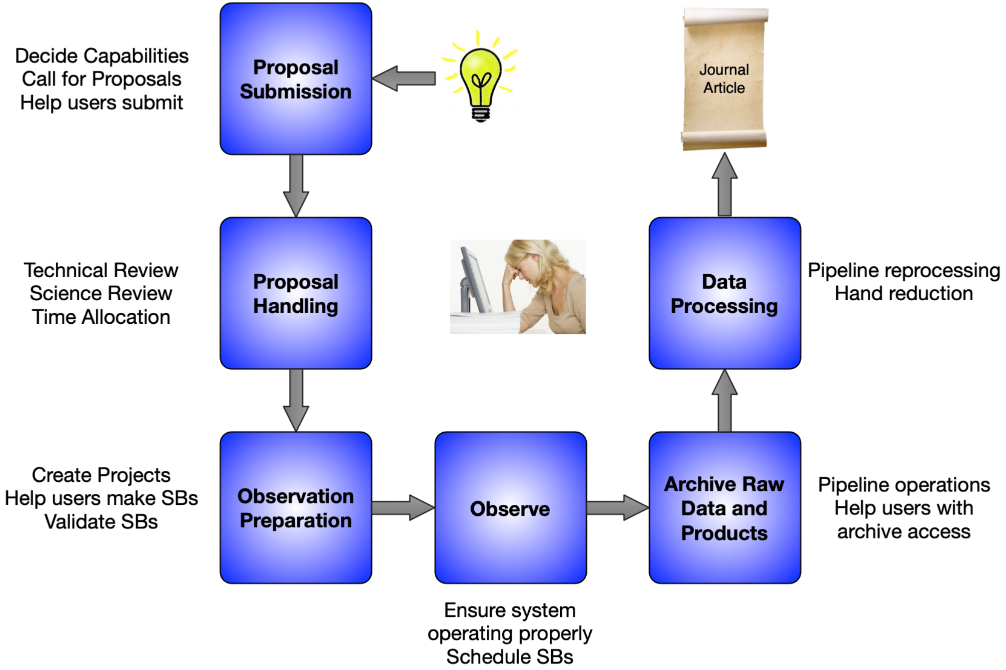
Encompasses all areas required to deliver science data to users, from proposal call to data products. Science operations is comprised of three main areas:

- **Telescope Time Allocation and Scheduling (TTAS)**
  - Proposals; call, submission, handling, and time allocation
  - Scheduling the telescope
- **“Telescope” Support (TS)**
  - Monitoring telescope, electronics (including correlator), and software performance
  - Commissioning new instrumentation and observing modes
- **User Support (US)**
  - Help users with software issues
  - Help users implement best practices
  - User training

Science operations workflow

This is the familiar "from scientists idea to published paper" workflow.

This does not describe the entirety of what science operations is concerned with (user training, for instance), but covers the bulk of it.



Decide Capabilities
Call for Proposals
Help users submit

Proposal Submission

Technical Review
Science Review
Time Allocation

Proposal Handling

Create Projects
Help users make SBs
Validate SBs

Observation Preparation

Observe

Ensure system operating properly
Schedule SBs

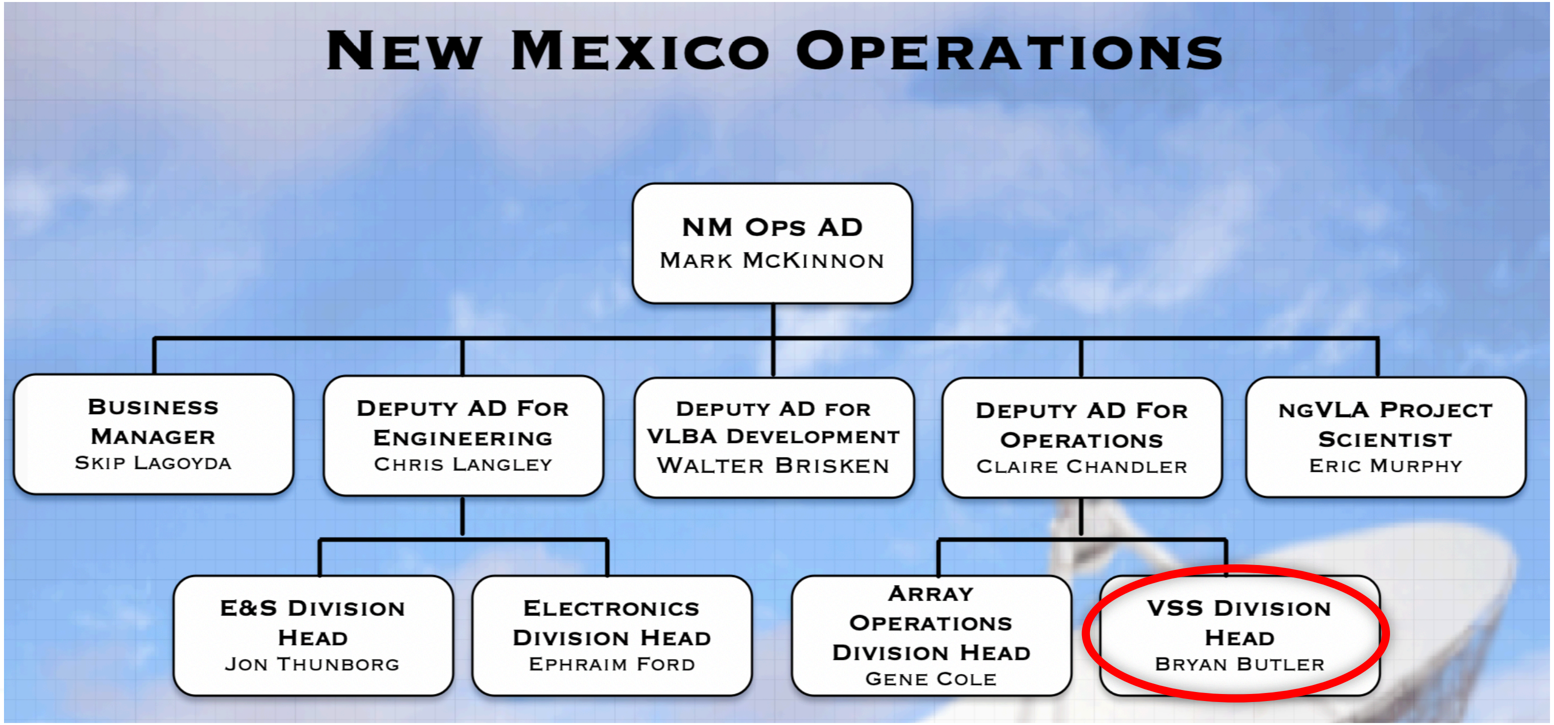
Archive Raw Data and Products

Pipeline operations
Help users with archive access

Data Processing

Pipeline reprocessing
Hand reduction

Organizational structure – NM Ops divisions



NEW MEXICO OPERATIONS

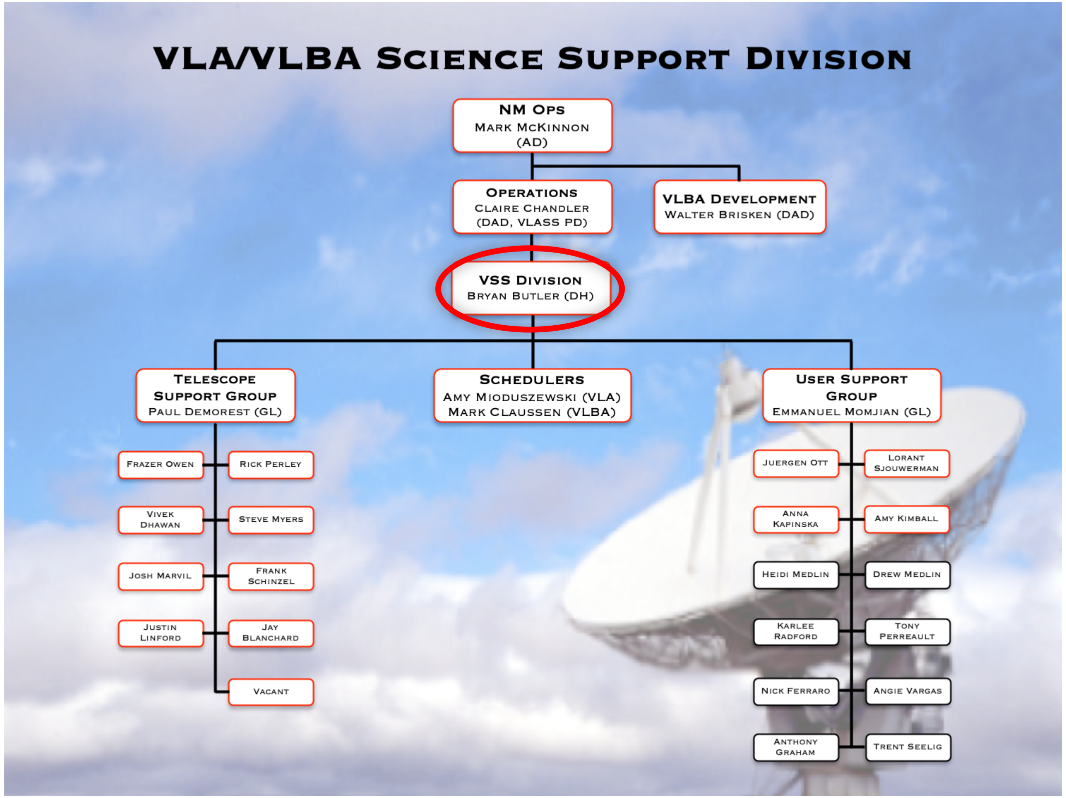
- **NM OPS AD** MARK MCKINNON
  - **BUSINESS MANAGER** SKIP LAGOYDA
  - **DEPUTY AD FOR ENGINEERING** CHRIS LANGLEY
    - **E&S DIVISION HEAD** JON THUNBORG
    - **ELECTRONICS DIVISION HEAD** EPHRAIM FORD
  - **DEPUTY AD FOR VLBA DEVELOPMENT** WALTER BRISKEN
  - **DEPUTY AD FOR OPERATIONS** CLAIRE CHANDLER
    - **ARRAY OPERATIONS DIVISION HEAD** GENE COLE
    - **VSS DIVISION HEAD** BRYAN BUTLER
  - **NGVLA PROJECT SCIENTIST** ERIC MURPHY

Organizational structure – Science Support Division

Members of the VSSD are about 2/3 "scientific staff" (with a Ph.D. in astronomy, astrophysics, etc.), and 1/3 Data Analysts (DAs; typically with a B.S. in astronomy, astrophysics, physics, etc...).

Most scientific staff have functional responsibilities in both the TS and US groups (matrix management).

All VLA DAs are in the User Support Group.



VLA/VLBA Science Support Division

NM Ops
Mark McKinnon
(AD)

Operations
Claire Chandler
(DAD, VLASS PD)

VLBA Development
Walter Brisken (DAD)

VSS Division
Bryan Butler (DH)

Telescope Support Group
Paul Demorest (GL)

- Frazer Owen
- Rick Perley
- Vivek Dhawan
- Steve Myers
- Josh Marvil
- Frank Schinzel
- Justin Linford
- Jay Blanchard
- Vacant

Schedulers
Amy Mioduszewski (VLA)
Mark Claussen (VLBA)

User Support Group
Emmanuel Momjian (GL)

- Juergen Ott
- Lorant Sjouwerman
- Anna Kapinska
- Amy Kimball
- Heidi Medlin
- Drew Medlin
- Karlee Radford
- Tony Perreault
- Nick Ferraro
- Angie Vargas
- Anthony Graham
- Trent Seelig

What is *not* science operations?

While the purview of science operations is broad, there are of course many aspects of operating the telescope that it is not directly tasked with ownership of, including:

- Software itself (this is the Data Management and Software Department's responsibility); though we do have functional ("dotted-line") management to the software group that maintains the telescope control software, and a number of our scientific staff develop software for particular uses.
- Electronics and Engineering Services (as noted in Peggy's talk).
- Operating the array (this is the Array Operations Division).

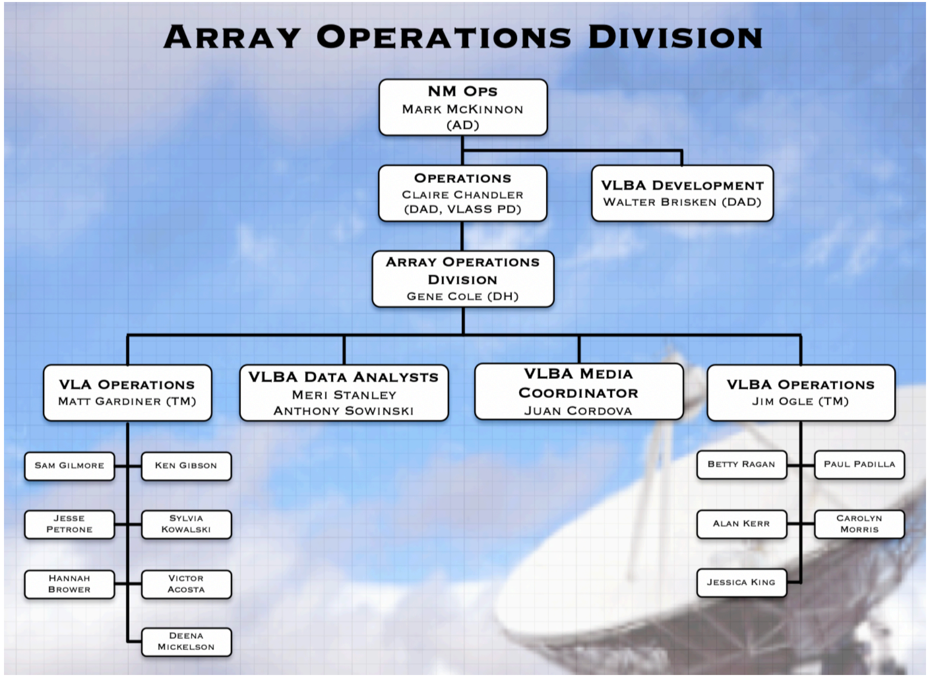
But science operations interacts closely with all of those, so good communication is critical. We do this through meetings, emails, JIRA, phone calls, etc. Some of those are regularly scheduled or recurring, some are as-needed.

Organizational structure – Array Operations Division

Two main groups: VLA operators and VLBA operators. These groups make sure the arrays are running smoothly.

VLBA DAs help with observation preparation and do data QA after correlation, among other duties.

VLBA Technical Manager and DAs help the VLBA Scheduler with daily dynamic scheduling.



ARRAY OPERATIONS DIVISION

- **NM OPS** Mark McKinnon (AD)
  - **OPERATIONS** Claire Chandler (DAD, VLASS PD)
    - **ARRAY OPERATIONS DIVISION** Gene Cole (DH)
      - **VLA OPERATIONS** Matt Gardiner (TM)
        - Sam Gilmore
        - Ken Gibson
        - Jesse Petrone
        - Sylvia Kowalski
        - Hannah Brower
        - Victor Acosta
        - Deena Mickelson
      - **VLBA DATA ANALYSTS** Meri Stanley, Anthony Sowinski
      - **VLBA MEDIA COORDINATOR** Juan Cordova
      - **VLBA OPERATIONS** Jim Ogle (TM)
        - Betty Ragan
        - Paul Padilla
        - Alan Kerr
        - Carolyn Morris
        - Jessica King
  - **VLBA DEVELOPMENT** Walter Brisken (DAD)

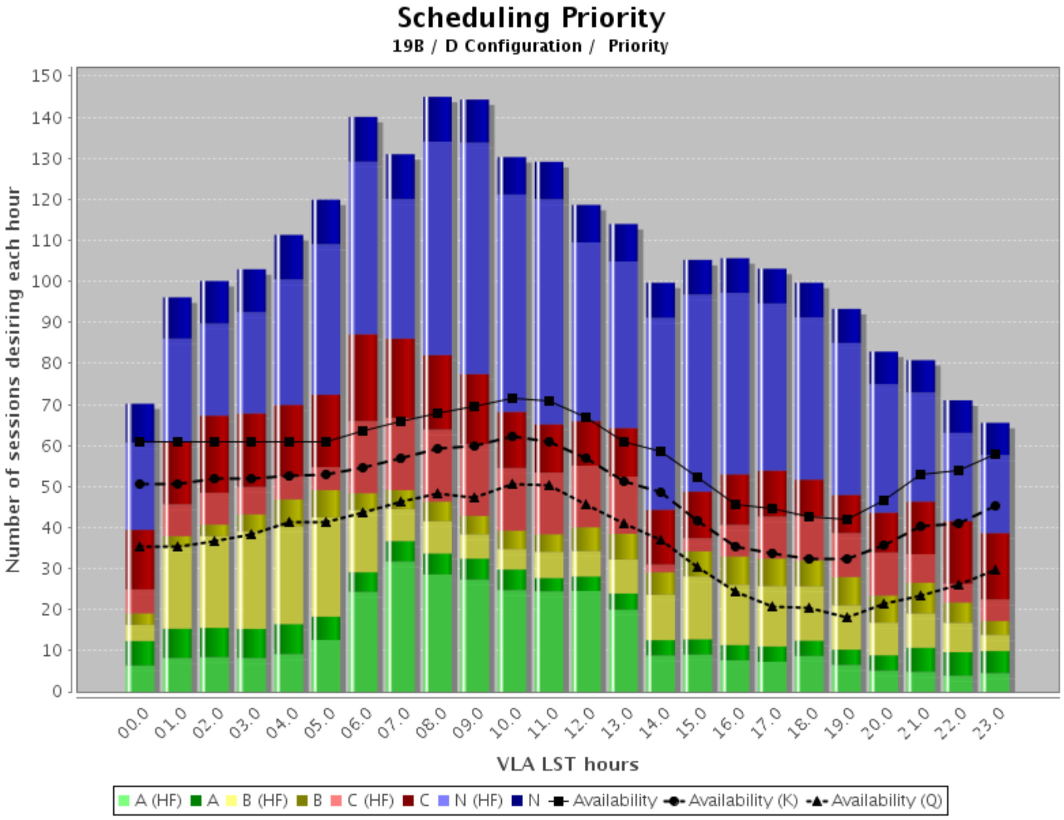
TTAS – Proposals

- Everything starts with a Call for Proposals (CfP). NRAO has two CfPs per year (one per semester), which includes all three of VLA, VLBA, and GBT, which go out around January 1 (for a February 1 deadline) and July 1 (for an August 1 deadline).
- ~4 months before the CfP, all *capabilities* (observing modes) must be decided, and approved with the responsible software group; we make this decision after a meeting with the scientific and technical staff.
- Scientific staff and DAs help users with questions about proposal submission, which is done electronically with our Proposal Submission Tool (PST).
- After the deadline we must organize technical and scientific reviews of the proposals, which are also done in the PST. Note that proposals for all telescopes are reviewed together scientifically.
- We then have software (the Proposal Handling Tool, or PHT) that assigns preliminary scheduling priorities to all "sessions" (which are essentially Scheduling Blocks, the atomic unit of observing on the VLA and VLBA)
- The NRAO Time Allocation Committee then meets, along with NRAO staff, to specifically discuss every proposal and decide whether the PHT has made the proper priority assignment.

TTAS – Proposals

We end up with an approved science program for both VLA and VLBA, which is made up of projects, each of which has a number of Scheduling Blocks to be observed.

SBs each have a scheduling priority: A, B, or C.



An aside – observation preparation

- Proposers are contacted with the results of the TAC deliberations.
- As the semester (VLBA) or configuration (VLA) approaches, users are contacted again, and encouraged to submit their Scheduling Blocks (really, “sessions” for VLBA, but they are equivalent)
- For VLBA this is done with SCHED software; for VLA with the Observation Preparation Tool (OPT).
- DAs and staff scientists (but mostly DAs) provide help with SCHED or the OPT when needed, and must validate all SBs.
- After validation, the SB ends up in the pool of schedulable SBs.

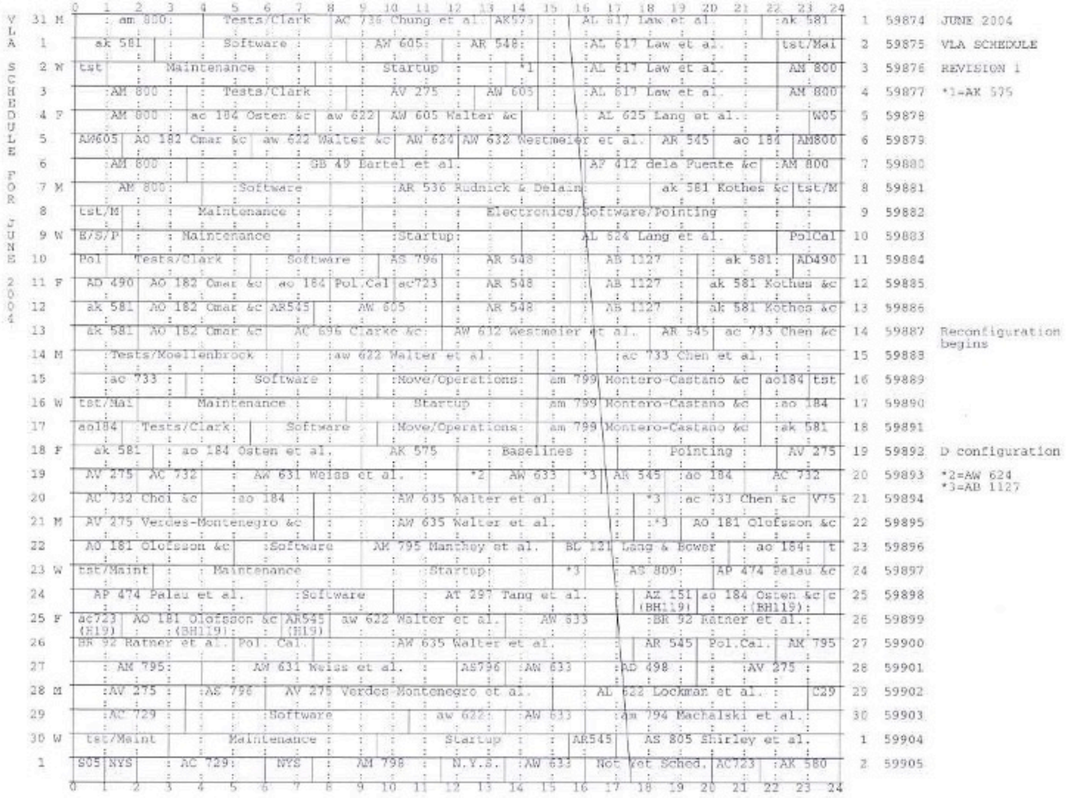
TTAS – Scheduling

- Once we have an approved science program for a semester, and users have submitted their SBs, we must be sure that those actually get observed (to the level of their scheduling priority).
- The VLA and VLBA are **dynamically scheduled**, for the most part, though details (and software) differ.
- The VLBA schedule is typically made daily (or for the weekend on Friday); sometimes tweaked mid-day when needed, using a software tool called scenario.
- The VLA is typically scheduled in real-time, as each SB concludes its execution, using a software tool called the Observation Scheduling Tool (OST).

TTAS – VLA scheduling (historical)

Barry Clark made a monthly schedule which was typically completed about a week before the month started. He had software to help, but then adjusted by hand.

It was time-consuming, and resulted in observations happening under inappropriate conditions.



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V L A   S C H E D U L E   F O R   J U N E   2 0 0 4

      0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
31 M | : am 800: | Tests/Clark | AC 736 Chung et al. | AK575 | : | AL 617 Law et al. : | :ak 581 |  1  59874  JUNE 2004
 1   | ak 581 | : : Software : | : AW 605: | : AR 548: | : | :AL 617 Law et al. : | tst/Mai |  2  59875  VLA SCHEDULE
 2 W | tst | : Maintenance : | : | : Startup : : | *1 | : | :AL 617 Law et al. : | AM 800 |  3  59876  REVISION 1
 3   | :AM 800 : | : Tests/Clark | : AV 275 : | AW 605 | : | :AL 617 Law et al. : | AM 800 |  4  59877  *1=AK 575
 4 F | :AM 800 : | ac 184 Osten &c | aw 622 | AW 605 Walter &c | : | : AL 625 Lang et al.: : | W05 |  5  59878
 5   | AW605 | AO 182 Omar &c | aw 622 Walter &c | AW 634 | AW 632 Westmeier et al. | AR 545 | ao 184 | AM800 |  6  59879
 6   | :AM 800 : | : : : : GB 49 Bartel et al. : : : | AP 412 dela Puente &c | :AM 800 |  7  59880
 7 M | AM 800: | :Software | : :AR 536 Rudnick & Delain: : | ak 581 Kothes &c | tst/M |  8  59881
 8   | tst/M | : : Maintenance : | : | : : : Electronics/Software/Pointing : : : |  9  59882
 9 W | E/S/P | : : Maintenance : | : :Startup: | : | AL 624 Lang et al. : | PolCal | 10  59883
10   | Pol | Tests/Clark : | : Software : | AS 796 | : AR 548 : | : AB 1127 : | : ak 581: | AD490 | 11  59884
11 F | AD 490 | AO 182 Omar &c | ao 184 | Pol.Cal | ac723 | : AR 548 : | : AB 1127 : | ak 581 Kothes &c | 12  59885
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13   | ak 581 | AO 182 Omar &c | AC 696 Clarke &c: | AW 612 Westmeier et al. | AR 545 | ac 733 Chen &c | 14  59887  Reconfiguration
                                                                                                          begins
14 M | :Tests/Koellenbrock : | : :aw 622 Walter et al. : | : : | :ac 733 Chen et al. : : | 15  59888
15   | :ac 733 : | : : Software : | : :Move/Operations: | am 799 | Montero-Castano &c | ao184 | tst | 16  59889
16 W | tst/Mai | : Maintenance : | : | : : Startup : : | am 799 | Montero-Castano &c | :ao 184 | 17  59890
17   | ao184 | Tests/Clark: | : Software : | :Move/Operations: | am 799 | Montero-Castano &c | :ak 581 | 18  59891
18 F | ak 581 | : ao 184 Osten et al. | AK 575 | : Baselines : | : Pointing : | AV 275 | 19  59892  D configuration
19   | AV 275 | AC 732 | : AW 631 Weiss et al. : | *2 | AW 633 | *3 | AR 545 | :ao 184 | AC 732 | 20  59893  *2=AW 624
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20   | AC 732 Choi &c | :ao 184 : | : : :AW 635 Walter et al. : : | *3 | :ac 733 Chen &c | V75 | 21  59894
21 M | AV 275 Verdes-Montenegro &c | : : :AW 635 Walter et al. : | : | :*3 | AO 181 Olofsson &c | 22  59895
22   | AO 181 Olofsson &c | :Software | AK 795 Manthey et al. | BL 121 Lang & Bower | : ao 184: | t | 23  59896
23 W | tst/Maint | : : Maintenance : | : : :Startup: : | *3 | : AS 809: | AP 474 Palau &c | 24  59897
24   | AP 474 Palau et al. | :Software | : AT 297 Tang et al. : | AZ 151 | ao 184 Osten &c | c | 25  59898
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26   | BR 92 Ratner et al. | Pol. Cal. | : : :AW 635 Walter et al. : : | AR 545 | Pol.Cal. | AK 795 | 27  59900
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28 M | :AV 275 : | :AS 798 | AV 275 Verdes-Montenegro et al. | : AL 622 Lockman et al. : | C29 | 29  59902
29   | :AC 729 : | : : :Software : : | : aw 622: | :AW 633 | :am 794 Machalski et al.: | 30  59903
30 W | tst/Maint | : Maintenance : : | : : : Startup : : | AR545 | AS 805 Shirley et al. |  1  59904
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      0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
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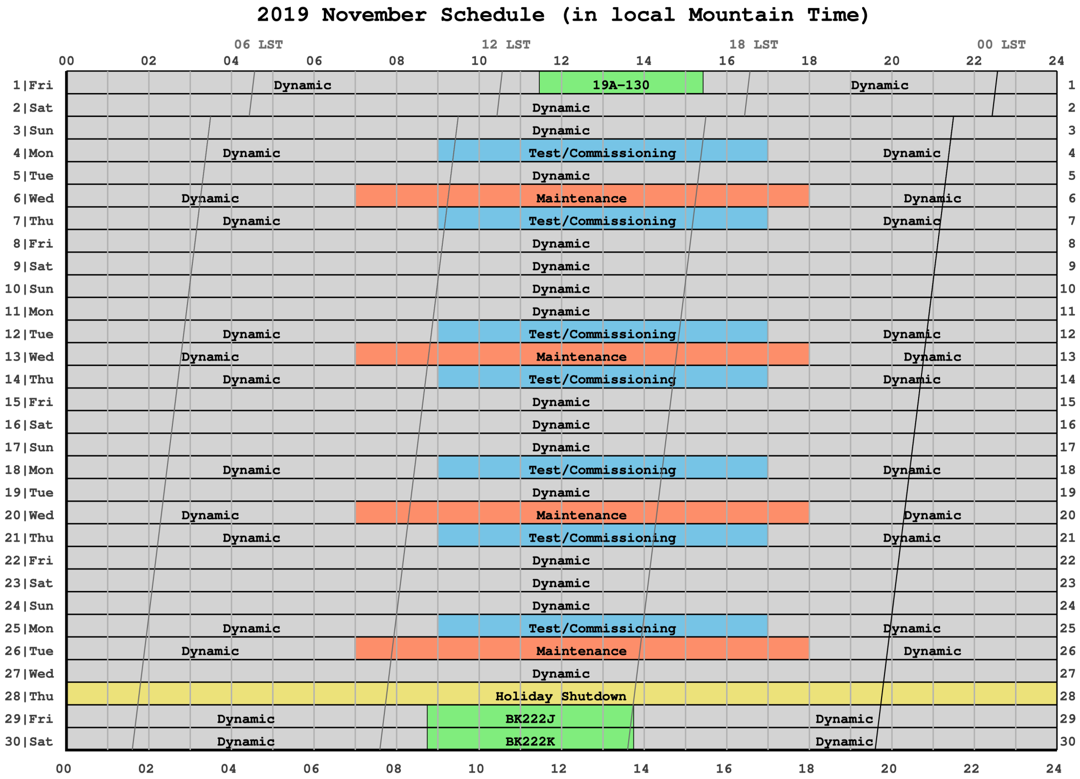
TTAS – VLA scheduling (now)

The VLA is now (since ~2008) mostly **dynamically scheduled**. The gray areas in the monthly schedule to the right are all dynamically scheduled time. Red is weekly preventive maintenance time; blue is test/commissioning time. The green are "fixed-date" observations, which are not dynamic.

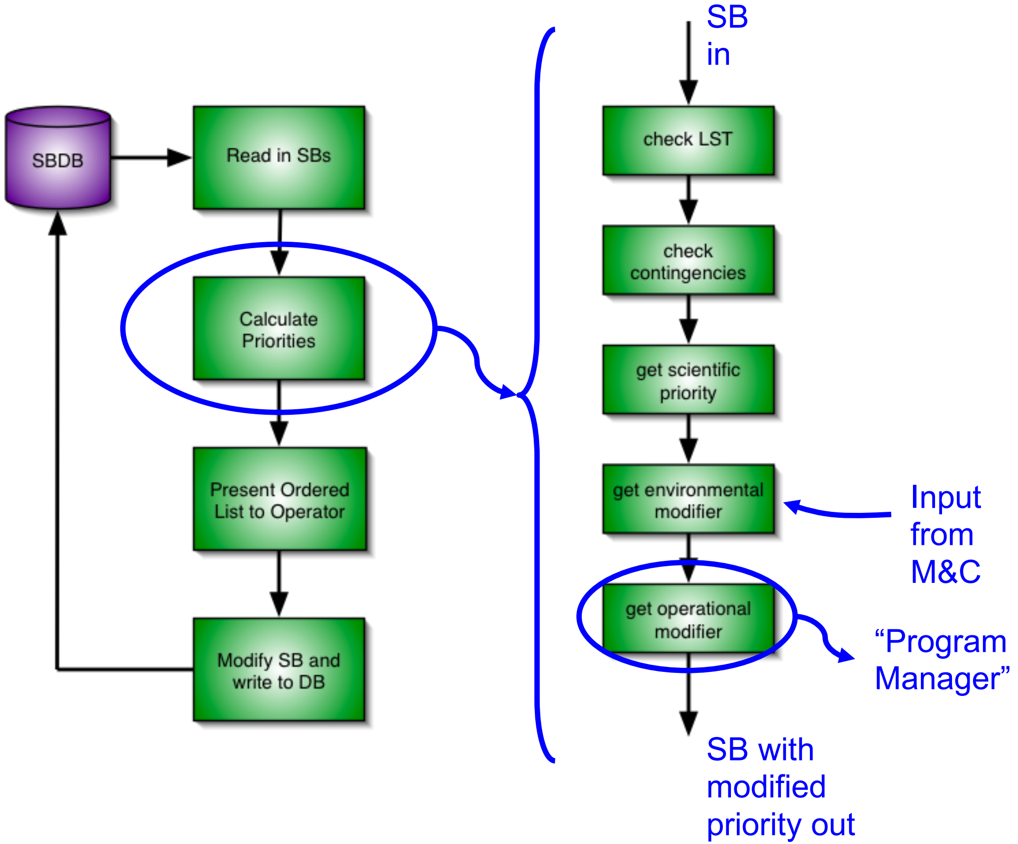


2019 November Schedule (in local Mountain Time)

1|Fri	Dynamic	19A-130	Dynamic	1
2|Sat	Dynamic			2
3|Sun	Dynamic			3
4|Mon	Dynamic	Test/Commissioning	Dynamic	4
5|Tue	Dynamic			5
6|Wed	Dynamic	Maintenance	Dynamic	6
7|Thu	Dynamic	Test/Commissioning	Dynamic	7
8|Fri	Dynamic			8
9|Sat	Dynamic			9
10|Sun	Dynamic			10
11|Mon	Dynamic			11
12|Tue	Dynamic	Test/Commissioning	Dynamic	12
13|Wed	Dynamic	Maintenance	Dynamic	13
14|Thu	Dynamic	Test/Commissioning	Dynamic	14
15|Fri	Dynamic			15
16|Sat	Dynamic			16
17|Sun	Dynamic			17
18|Mon	Dynamic	Test/Commissioning	Dynamic	18
19|Tue	Dynamic			19
20|Wed	Dynamic	Maintenance	Dynamic	20
21|Thu	Dynamic	Test/Commissioning	Dynamic	21
22|Fri	Dynamic			22
23|Sat	Dynamic			23
24|Sun	Dynamic			24
25|Mon	Dynamic	Test/Commissioning	Dynamic	25
26|Tue	Dynamic	Maintenance	Dynamic	26
27|Wed	Dynamic			27
28|Thu	Holiday Shutdown			28
29|Fri	Dynamic	BK222J	Dynamic	29
30|Sat	Dynamic	BK222K	Dynamic	30

TTAS – Observation Scheduling Tool (OST)

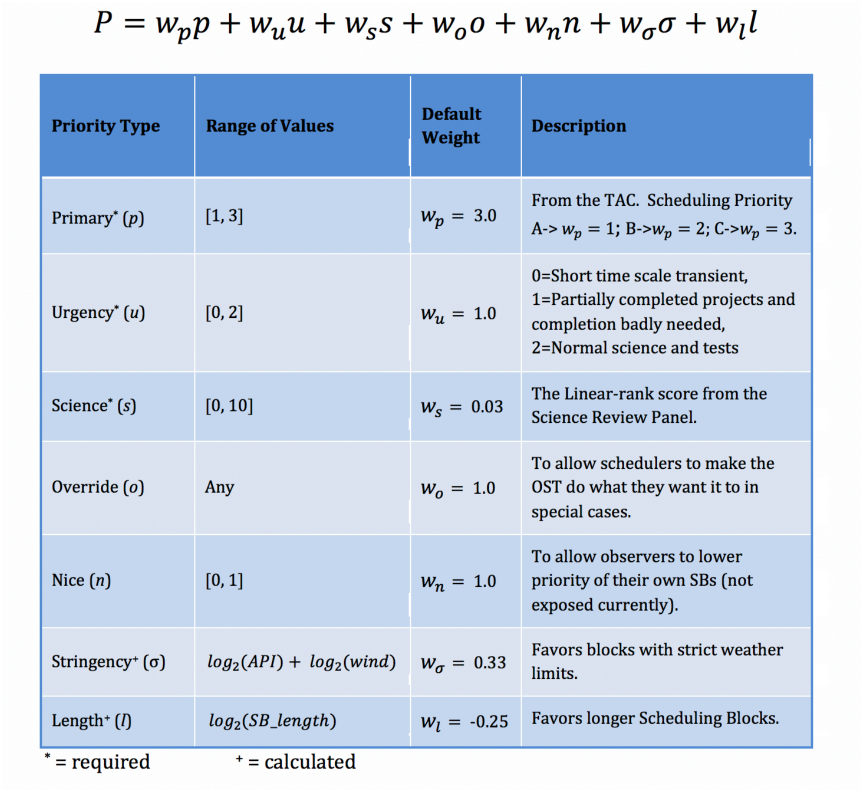
The OST checks the pool of schedulable SBs, filters by time, filters based on observing conditions (wind speed and atmospheric phase stability), and presents an ordered list by priority to the operator, who then queues the next SB to be observed.



TTAS – Calculating priority (details)

In detail, once an SB makes it through the filters, there are many terms which go into the observing priority.

One thing we have learned is that “difficult” observations (requiring strict observing conditions, for instance) must be observed when they can. Given the fixed-length configurations of the VLA, this can present problems.



$$P = w_p p + w_u u + w_s s + w_o o + w_n n + w_\sigma \sigma + w_l l$$

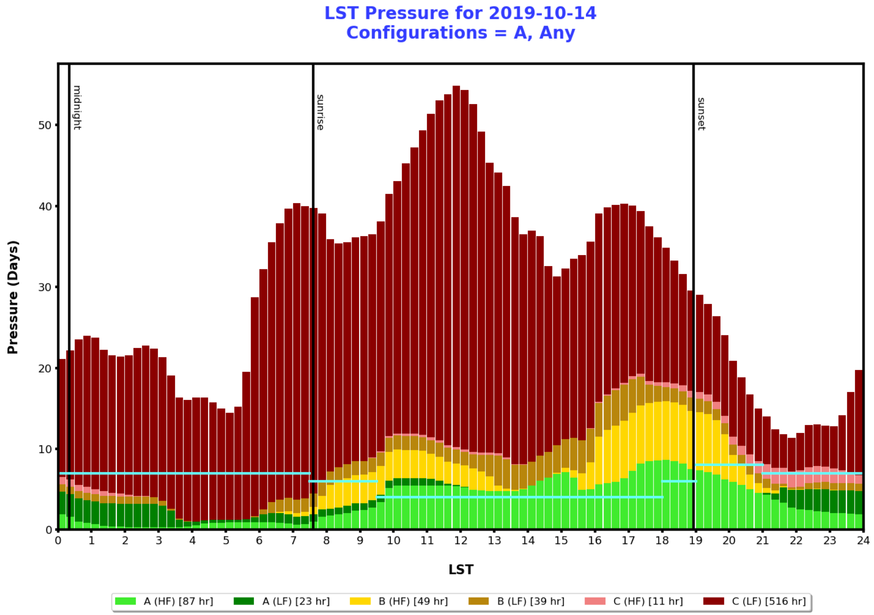
Priority Type	**Range of Values**	**Default Weight**	**Description**
Primary* (p)	[1, 3]	$w_p = 3.0$	From the TAC. Scheduling Priority A-> $w_p = 1$; B->$w_p = 2$; C->$w_p = 3$.
Urgency* (u)	[0, 2]	$w_u = 1.0$	0=Short time scale transient, 1=Partially completed projects and completion badly needed, 2=Normal science and tests
Science* (s)	[0, 10]	$w_s = 0.03$	The Linear-rank score from the Science Review Panel.
Override (o)	Any	$w_o = 1.0$	To allow schedulers to make the OST do what they want it to in special cases.
Nice (n)	[0, 1]	$w_n = 1.0$	To allow observers to lower priority of their own SBs (not exposed currently).
Stringency+ (σ)	$log_2(API) + log_2(wind)$	$w_\sigma = 0.33$	Favors blocks with strict weather limits.
Length+ (l)	$log_2(SB\_length)$	$w_l = $ -0.25	Favors longer Scheduling Blocks.

* = required   + = calculated

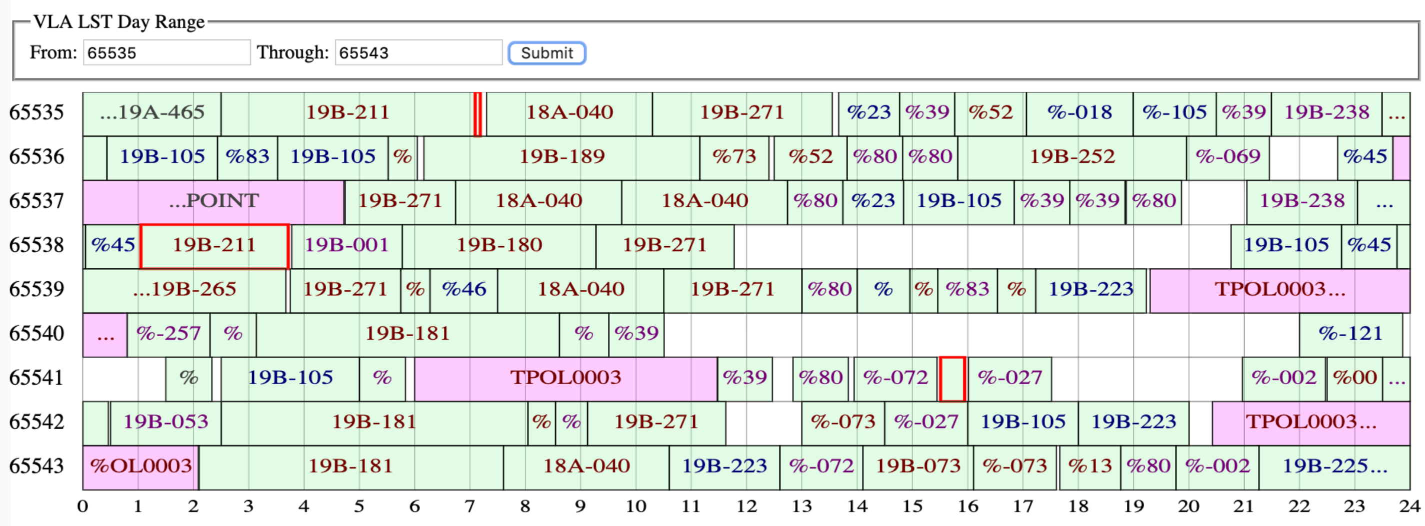
TTAS – tracking how we are doing

To track how we are doing with observing SBs for a configuration, we make a “pressure plot” twice per week (Monday and Friday) for discussion at a meeting. This shows the SBs that are available to the OST (the current queue of schedulable SBs) as a function of LST.

The cyan line is the number of SBs which can be observed at a given LST in the configuration.



TTAS – tracking how we are doing



VLA LST Day Range

From: 65535 Through: 65543 Submit

65535 ...19A-465 | 19B-211 | 18A-040 | 19B-271 | %23 | %39 | %52 | %-018 | %-105 | %39 | 19B-238 | ...
65536 19B-105 | %83 | 19B-105 | % | 19B-189 | %73 | %52 | %80 | %80 | 19B-252 | %-069 | %45
65537 ...POINT | 19B-271 | 18A-040 | 18A-040 | %80 | %23 | 19B-105 | %39 | %39 | %80 | 19B-238 | ...
65538 %45 | 19B-211 | 19B-001 | 19B-180 | 19B-271 | 19B-105 | %45
65539 ...19B-265 | 19B-271 | % | %46 | 18A-040 | 19B-271 | %80 | % | % | %83 | % | 19B-223 | TPOL0003...
65540 ... | %-257 | % | 19B-181 | % | %39 | %-121
65541 % | 19B-105 | % | TPOL0003 | %39 | %80 | %-072 | %-027 | %-002 | %00 | ...
65542 19B-053 | 19B-181 | % | % | 19B-271 | %-073 | %-027 | 19B-105 | 19B-223 | TPOL0003...
65543 %OL0003 | 19B-181 | 18A-040 | 19B-223 | %-072 | 19B-073 | %-073 | %13 | %80 | %-002 | 19B-225...

We can also retrieve a detailed graphic of what was observed in any given period on the VLA. We also use this at those Monday and Friday morning meeting discussions, to assess what has happened and what is coming up for the VLA. The VLBA is tracked differently, and a weekly email sent out summarizing observing statistics.

TS – monitoring “telescope” performance

- We must make sure that the “telescopes” are running well. This includes the physical telescopes themselves, the electronics, and the software.
- We measure and maintain the system on a number of timescales:
  - Over years, we measure the gains of the antennas, and on rare occasion adjust panels using holography. Gain curve coefficients are provided to post-processing packages for application to data.
  - At VLA configuration changes (~every four months), must determine delays and antenna positions (“baselines”); pointing comes along with this. This is also done as an antenna comes out of preventive maintenance (one every ~two months).
  - Roughly weekly – delays, pointing, baselines are checked. We run two stress tests each week, which measure T_{sys}, antenna gains, sampler performance, and all other parts of the system. Issues that result from this, or from our regular calibration pipeline QA, are diagnosed (JIRA tickets are used to track these). One thing we could do a much better job of in both software and process is automatic fault detection (and fault tree analysis), and tracking of failures.
  - Software is continually checked; as problems arise they are diagnosed.

TS – commissioning new modes

- New observing modes are either pushed by us (pulsar observing, for instance), or by users who put in "RSRO" (Resident Shared Risk Observing) proposals (triggered observing, for instance).
- We advertise things we are working on, and things that we are encouraging observers to work on, in the CfP.
- New modes (at the RSRO stage) start by implementation at a low level in software – they may involve direct correlator manipulation by GUIs, or hand-crafted jython control scripts, or other non-standard uses of the software.
- The Telescope Support Group works closely with software groups to get RSRO modes into standard software. Once an observation can be set up in the software, it is moved from RSRO to SRO.
- When we are confident that the mode works properly, it is shifted from SRO to GO.
- Observing modes that are SRO and GO are noted as such in the CfP.

US – software support

I've mentioned previously areas where we provide support to our users for our various software packages. This incudes all stages of the workflow:

- NRAO User Accounts (including "visitor" accounts on our post-processing cluster)
- PST
- OPT and SCHED
- Archive search and retrieval (the Archive Access Tool, or AAT)
- Data post-processing (CASA and AIPS), including pipelines

For direct user contact, we use a Kayako helpdesk, with various departments (this system is also used by ALMA). The DAs are typically the front-line for this; if there is a problem they cannot handle, they send it on to scientific staff.

US – user community training

We have a significant program for training of our user community (and those who want to become part of our user community). This includes:

- Community Day Events (CDEs). For a CDE, we send several staff to a remote institution where we give presentations on the various aspects of using our telescopes. These are often done in conjunction with ALMA. They are requested by the remote institution and typically involve ~30 attendees from several institutions. We typically do two of these per year, but it is driven by requests so varies.
- Once every two years we host the NRAO Synthesis Imaging Workshop, which is a two week intensive course on radio interferometry meant for those not familiar with the concepts and practices (novices).
- Once every eighteen months, we host a Data Reduction Workshop (DRW) in Socorro, where users come for two weeks for an in-depth set of presentations on data reduction, and then reduce one of their own datasets. This is not meant for novices.

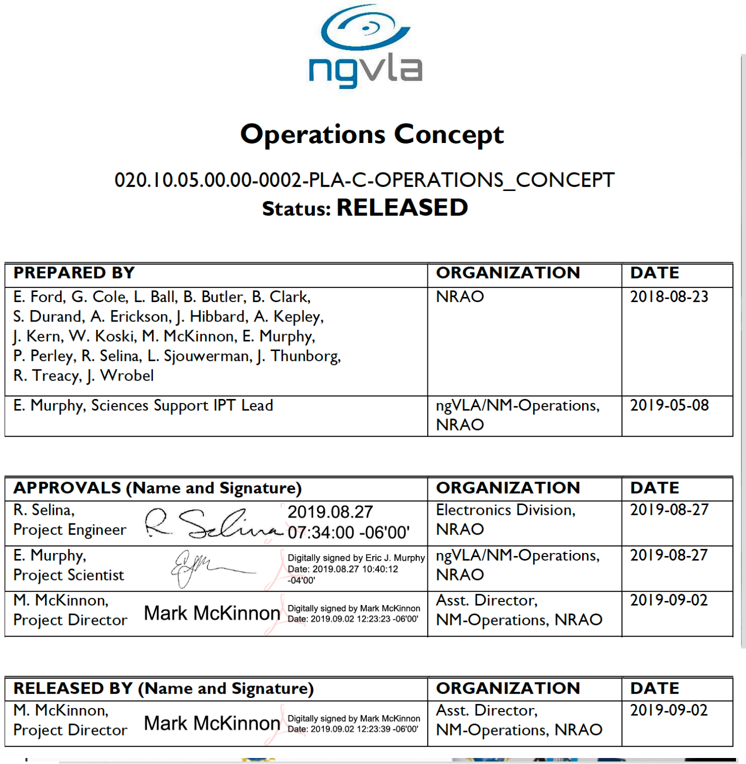
A lesson – "one observatory"

- On Monday and today, we heard many times the phrase "one observatory" for SKA. In the mid-2000s we had exactly that phrase for NRAO and its three operating telescopes at the time (VLA, VLBA, and GBT), and in anticipation of adding ALMA to the effort (the NAASC anyway).
- Our user support groups were actually re-organized to support this, with a changed management structure, and cross-training so that scientists and DAs could potentially support multiple telescopes.
- There is one area where this was incredibly successful – the TTA effort. Prior to this, each telescope had its own process for handling and determining the disposition of proposals. Going to a unified system was a vast improvement.
- However, the broad goal of having one user support group, and the same software for all telescopes, was not successful. It turned out to be too difficult for staff to become expert enough with multiple telescopes to provide proper user support.
- Ten years later, we are still stuck with some of the vestiges of the re-organization (because organizational restructuring can be difficult when it cuts across groups and telescopes).
- So, "one observatory" can be great for some things, but don't take it too far!

The future – ngVLA

The ngVLA is a proposed expansion of the VLA and VLBA, covering 1.2-116 GHz with 10 X VLA (and ALMA) sensitivity, baselines to 1000 km (and also VLBA scales), and a dense core for low brightness imaging.

An 850+ page science book has been written, along with a reference design document (3 volumes, ~1500 pages), which includes an Operations Concept document (with a section for Science Operations) . We have used the lessons learned from operating VLA, VLBA, and ALMA in writing this operations document.



ngvla

Operations Concept

020.10.05.00.00-0002-PLA-C-OPERATIONS_CONCEPT
Status: **RELEASED**

PREPARED BY	ORGANIZATION	DATE
E. Ford, G. Cole, L. Ball, B. Butler, B. Clark, S. Durand, A. Erickson, J. Hibbard, A. Kepley, J. Kern, W. Koski, M. McKinnon, E. Murphy, P. Perley, R. Selina, L. Sjouwerman, J. Thunborg, R. Treacy, J. Wrobel	NRAO	2018-08-23
E. Murphy, Sciences Support IPT Lead	ngVLA/NM-Operations, NRAO	2019-05-08

APPROVALS (Name and Signature)	ORGANIZATION	DATE
R. Selina, Project Engineer R. Selina 2019.08.27 07:34:00 -06'00'	Electronics Division, NRAO	2019-08-27
E. Murphy, Project Scientist Digitally signed by Eric J. Murphy Date: 2019.08.27 10:40:12 -04'00'	ngVLA/NM-Operations, NRAO	2019-08-27
M. McKinnon, Project Director Mark McKinnon Digitally signed by Mark McKinnon Date: 2019.09.02 12:23:23 -06'00'	Asst. Director, NM-Operations, NRAO	2019-09-02

RELEASED BY (Name and Signature)	ORGANIZATION	DATE
M. McKinnon, Project Director Mark McKinnon Digitally signed by Mark McKinnon Date: 2019.09.02 12:23:39 -06'00'	Asst. Director, NM-Operations, NRAO	2019-09-02

Summary (part 1)

- Science operations is an important part of running telescopes efficiently.
- Science operations touches nearly all aspects of running telescopes.
- A good blend of people is important – having different skill sets and different levels of ability to support complex support issues (this includes science, software, hardware, people skills, etc.).
- Let folks do what they can at their level; for instance, let DAs do as much as they can, so scientists can focus on potentially more difficult problems.
- Give scientists as much freedom as you can, they are smart folks and will do good things (mostly).
- Think early about what internal software you will need for science operations, and get requirements to the software group(s). This is often an afterthought.

Summary (part 2)

- Automate as much as you can (fault tree diagnosis software; make modules smart at as low a level possible); capture "Defined Failure Modes" and have software to take advantage of that – we haven't done this and should have. BUT, recognize you can't automate everything; scientific and engineering expertise is critical.
- Communication is key – keep folks informed and include them before decisions are finalized; regular meetings with cross-group attendance are important at all levels (senior management; division heads; group leads; scientists and DAs with software and hardware engineers; etc.).
- Don't expect your users to read your documentation!
- Remain as flexible as possible.

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