

K-Band Science Using the Green Bank Telescope



19th – 21st September 2022, Green Bank, WV

Meeting Report and Summary

Summary

From the 19th to the 21st of September, 2022, Green Bank Observatory held a workshop with the goals of 1) celebrating the success of prior observing campaigns¹ and the K-band Focal Plane Array (KFPA), while encouraging use of the available archival data; 2) Poll the community on the science being done or proposed at K-band to establish if the GBT is able to meet those needs and 3) Seek community input on the future direction of K-band science and instrumentation at Green Bank.

The meeting was run as a hybrid event, with eight speakers presenting in a virtual format and six speakers presenting in person. Each of the three days included a panel discussion which were also run in a hybrid format, with panel and audience members contributing in both a virtual and in-person manner.

In all there were 43 attendees, 13 of these were GBO staff, 20 attended via Zoom only and 10 were present in-person. No record was kept of how long individuals stayed logged in, which country virtual attendees were calling from, etc.

All presentations were recorded and are viewable at <https://greenbankobservatory.org/science/meetings-and-workshops/current-future-k-band-workshop/>

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¹ Mainly, but not confined to, the GBT Ammonia Survey (GAS), the KFPA Examinations of Young Stellar Object Natal Environments (KEYSTONE) and the Radio Ammonia Mid-Plane Survey (RAMPS), ; Friesen et al, 2017; Keown et al, 2019 & Hogge et al, 2018, respectively

Meeting Outcomes

- GBO intends to host archives of the data from the three large ammonia surveys (GAS, RAMPS and KEYSTONE). It was suggested that this effort should incorporate more and/or better archive access tools, potentially as part of proposal tools.
- In terms of follow-up studies to the large surveys of the past, interest was expressed both in a full Galactic Plane survey as well as deeper surveys of existing mapped regions, with the priorities being different for different individuals.
- There was notable discussion regarding ways in which GBO can develop current practices, i.e. There were statements that more substantial support for students, as well as the provision of data reduction pipeline tools and operator-run observations would improve data publication rates. Further, there was substantial support for science-ready data products (SRDP), although there was not consensus on whether this should be introduced as a single option among others (i.e. allowing for a choice between constrained SRDP configurations or an 'expert' mode) or as a sweeping change.
- The main representations of K-band science were in the broad areas of star formation and astrochemistry. There did not seem to be compelling (large) science cases for K-band in the areas of extragalactic observations, VLBI, transients, polarisation or continuum
- A discussion of solar system/planetary science generated some interesting ideas but these do not seem to be being currently pursued
- There was some discussion on how to improve current instrumentation/technology, with suggestions that the 140' telescope might be refurbished, and current facilities might be improved, e.g. effects of wind on observing efficiency might be mitigated via beam-steering or simple motion tracking, also, current calibration accuracy could be improved.

Presentations

Scientific talks were presented as follows

Monday

Welcome (**Jim Jackson**)

Results of the GBT Ammonia Survey (**Jaime Pineda**)

The Radio Ammonia Mid-Plane Survey (RAMPS) (**Jim Jackson**)

Bayesian Multiple Velocity Component Fitting to the KEYSTONE Survey (**Brian Svoboda**)

The GOTHAM Project: A Showcase of the KFPA for Astrochemistry (**Brett McGuire**)

Current Progress and Future Plans for GLUCOSE: The GBT L1544 Unbiased Complex

Organics SurvEy (**Samantha Scibelli**)

Early Results from the KEYSTONE Survey (**Helen Kirk**)

The ngVLA at K-Band (**Erik Rosolowsky**)

Tuesday

K-Band Instrumentation (**Kevin Bandura**)

Technology Development for a K Band Wide Field Imaging Array (**Karl Warnick**)

Extragalactic Observations using the KFPA (**Jim Braatz**)

Wednesday

The Hunt for Lost Interstellar Rings and Chains: GOTHAM and the formation of aromatic molecules (**Andrew Burkhardt**)

Magnetic Field Strength in Molecular Clouds of the Gould Belt (**Jordan Guerra Aguilera**)

Detection of Dense Gas in the Galactic Bar Dust Lanes using the GBT (**Natalie Butterfield**)

Probing molecular cloud surfaces at K-band (**Pedro Salas**)

Discussions

Monday - The Green Bank Ammonia Surveys, What Now?

- "How can GBO help to disseminate your data?" - **Chair**
 - There was a suggestion that Green Bank Observatory (GBO) is prepared to host the data of all three large ammonia surveys (GAS, KEYSTONE and RAMPS), whether this be simply by linking to existing databases or through actually hosting the data in our archive. It was not discussed what the archival access tools might be in this case, or who would be responsible for developing and/or maintaining them.

There was general assent to the idea from the representatives of the surveys (**Jaime Pineda**, **Helen Kirk** and **Jim Jackson**). **Jim Jackson** - keen to get archives going so that non-team members and non-experts can have access to data.

Jaime Pineda suggested that it would be helpful if there were archive and/or proposal tools which made suggestions for related data, i.e. if one were proposing for Argus observations, the tool should point out if there are ammonia data of that source in the archive. - **Brett.McGuire** expanded on this, asking if TTAC tools incorporate feature that would tell you if data on your source already exist.
 - **Jim Jackson** - Do (the other survey teams) get many hits on Dataverse?
 - **Jaime Pineda** - yes, quite a few outside of the survey team
 - **Helen Kirk** - James DiFrancesco has been keeping note of these but can't really comment personally
- "Do we have enough ammonia data?"- **Chair**
 - **Jim Jackson** - we don't double the science by doubling the area but we do increase it. The current surveys could provide the basis for future targeting of new surveys
 - **Jaime Pineda** - GAS was as shallow as we could make it - it makes sense to do targeted follow-ups, even at non-detections, was GAS *too* shallow?
- "Should you go back and look again at blank areas in RAMPS?"- **Chair**
 - **Jim Jackson** - no, we know where ammonia is going to be
 - if you're going to map, it's more efficient to do large areas
 - **Helen Kirk** - KEYSTONE had more diffuse emission than expected so could go deeper
- "What about the lines other than ammonia that were surveyed?"- **Chair**
 - **Helen Kirk** - not much seen, higher transitions of ammonia are in absorption
 - **Jaime Pineda** - missed a lot of emission (meaning?) - carbon-chain molecules in relation to ammonia could tell you about evolution.
 - **Jim Jackson** - RAMPS went too fast to see other lines - saw 790 H₂O masers
- "What would you do with 100-pixel array?" - **Brett McGuire**
 - **Jim Jackson** (?) decade-long project to map Galactic Plane
 - **Jaime Pineda** - build up sensitivity in certain regions
- "Are your data reduction tools public? Would I be able to use your pipelines?" - **Pedro Salas**
 - **Jaime Pineda** - with the observing log, you can run these (so long as you have the same observing setup), this is on github and the main concern would be calibration consistency.
 - **Jim Jackson** - Taylor Hogge wrote his own tools and wrappers for PySpecKit
 - **Helen Kirk** - 'shamelessly' used the GAS tools

- **Tony Remijan** - Carta is great for extracting subsets of data/visualisation, etc.
- *"It seems like KEYSTONE has a lot of follow-up projects going on, what enabled this? Or is there stuff going on using GAS and RAMPS that we're just not aware of?"* - **Chair**
 - **Jim Jackson** - KEYSTONE had lots of enthusiastic manpower
 - **Helen Kirk** - James DiFrancesco (PI of KEYSTONE) pushed people consistently
 - **Jaime Pineda** - KEYSTONE took a pre-existing pipeline so got data more quickly. By the time GAS had data ready to go, everyone was exhausted (paraphrasing)
 - *Followup* - *"Getting data out is a large chunk of work, survey team members move on, what do we do?"* - **Chair**
 - **Tony Remijan** - GBO would increase output if we provided more student (financial) support. ALMA has support for students pursuing archival data projects.
 - **Tony Remijan** - NRAO can support results with press releases, etc. especially at AAS
- Comment (by ?) *"If the community want pipelines then maybe that means constraining setups?"*
 - **Jim Braatz** - there was a pipeline for the KFPA but need to make sure you know what the community wants (the implication being that the pipeline was a failure)
 - **Larry Morgan** (to the room) - *"Are you happy to accept constrained observations, if that means being given SRDPs?"*
 - **Brett McGuire** and **Andrew Burkhardt** say yes
 - **Jaime Pineda** says no because then there are data that only expert users can access. (That is, either everything should be SRDP, or nothing should be).
- *"If we can lower barrier to proposing, i.e. for optical + radio, then people from both ends will benefit"* - **Brett McGuire**
 - **Jim Jackson** - good example provided by Helen Kirk's talk ('Early Results from the KEYSTONE Survey') that external groups want ammonia data (This might include the HOBYS group, a study of DR21 (L.Bonne) and/or Polarisation measurements - V.Konyves (UK) and J.Hwang (KASI, Korea))
 - **Samantha Scibelli** - GBO Quick Guides - it would be good to send these out with proposal calls and reference them in the Proposers Guide
 - **Samantha Scibelli** - Joint proposals are helpful, GBT+SOFIA was good.

Some General Comments

- "Total time requests on the KFPA went from 2200 hours in 2014 to 240 hours in 2022" - **Toney Minter**
- "AUI/NSF say that SRDP should be in GBO's future" - **Jim Jackson**
- "A focal plane array isn't what is needed here (for most suggestions of proposed large projects) - can't go above ~60 elements, (these projects) need a phased array feed." - **Steve White**

Key Takeaways

- GBO is keen to get archives of the data from the three large ammonia surveys up and running so that non-team members and non-experts can have access to data (although these data are accessible elsewhere). There was general assent from the representatives of the three large ammonia surveys.

There is community desire for more and/or better archive access tools, including as part of the proposal tool, such as being able to identify sources of interest at or near supplied coordinates across multiple wavelengths.

- When asked what the survey leads would most like to see as follow-up to the surveys, there was desire expressed both for a full Galactic Plane survey as well as deeper surveys of existing mapped regions, with the priorities being different for different individuals.
- In terms of improving survey 'turn-around' time, the consensus seemed to be that the size of the team, plus enthusiasm was key. There were statements that more substantial support for students, as well as the provision of data reduction pipeline tools and operator-run observations would improve data publication rates.
- There was substantial support for science-ready data products (SRDP), although there was not consensus on whether this should be introduced as a single option among others (i.e. allowing for a choice between constrained SRDP configurations or an 'expert' mode) or as a sweeping change.

Tuesday - What is the Future of K-Band Science with the GBT?

- "What is the primary extragalactic science at K-band now?" - ? (chair?)
 - **Dave Frayer** - not much high-Z CO, not enough baseline stability, this has jumped to the VLA, also ALMA gets two lines at the same time
 - **J.Braatz** - there are multiple uses for Hubble constant stuff, although lots of work would be needed to improve on the 4% error. There is a need to re-do some sources in the Megamaser Cosmology Project (MCP)
- "How many VLBI projects are GBO doing at K-band?" - **Ron Maddalena** & "How much of VLBI is at K-band?" - **D.Frayer**
 - **Toney Minter** - not much, it varies a lot
- "Are extragalactic observations dead at K-band?" - **Tony Remijan**
 - **Dave Frayer** - no but it's not a major driver for a new instrument
 - **Brett McGuire** - any extragalactic chemistry? - **Jim Braatz** - a little, NGC 253 would be good
- "From the original science case for the GBT, how many goals are still being pursued?" - **Tony Remijan** (Don't think anyone had an answer for this)
- "What about demonstration science projects?" - **Tony Remijan**
 - **Jim Jackson** - There are diminishing returns - low numbers of sources but sure (my interpretation was that he meant - go ahead and propose).
 - **Tony Remijan** - ALMA-driven projects were a failure (because of lack of community involvement). VLASS, NVSS, FIRST were good but had outside support.
 - **Dave Frayer** - we would prefer external groups because then you have community buy-in
 - **Jim Jackson** - NSF wouldn't fund these
 - **Brett McGuire** - How was VLASS funded? - **Tony Remijan** - 'it was just done' (i.e. operational funding)
 - **Jim Jackson** - Surveys are manpower-intensive but could be done - what is the compelling science case?
- "What about transients?" - **Tony Remijan**
 - **Jim Jackson** - I'm not sure what GBT can do for transients - variability and monitoring are worthwhile but hard to get through TACs.

- **Jim Braatz** - Megamaser Cosmology Project looks for this so that we can jump on it with VLBI.
- **Ellie White** - Ruben follow-ups - we have reached out to coordinator and we are looking at other instruments on site. - **Brett McGuire** - 140' would be great - **Ron Maddalena** - used to have a dichroic splitter on the 140' - **Jim Jackson** - this is quite lossy
- **Larry Morgan** - can you go to 30 GHz on the 140'? - **Ron Maddalena** - used to be able to but machinery is decrepit.
- "*There are competing arguments for different K-band instruments, can we have both?*" - **Jim Braatz**
 - Steve White - you can combine Ka and K if you only want two pixels.
 - **Tony Remijan** - Astrochemists just want bandwidth (though there was later discussion in which Tony said that there is an equal (?) argument that other astrochemists wish to map distribution of various molecular species).
- "*Should we be combining VLA+GBT more?*" - **Chair**
 - **Ci Xue** - our group is doing this with benzonitrile
 - **Jaime Pineda** - It's very exciting to do this, we have many datasets to do this (as examples, or as work to be done?) - **Larry Morgan** - not many people do this, can you give any advice? **Jaime Pineda** - use the GBT data as the model for VLA data
 - **Rachel Friesen** - One of the reasons more people haven't done this is that it takes a long time to do with the VLA, the VLA is not efficient at mapping large areas.
 - **Toney Minter** - A lot of data exist for RAMPS, GAS, etc so there is little need for more observations.
- "*Can we find ways to increase time spent observing at K-band?*" - **Chair**
 - **Ron Maddalena** - what are you willing to accept in terms of Tsys?
 - **Brett McGuire** - would like a way to propose and say that you are willing to accept worse weather as filler time - **Andrew Burkhardt** - This would be good for exploratory obs - **Ron Maddalena** - Why not propose using the RMS as the defining metric?
 - **Toney Minter** - wind limits may be more constraining than atmospheric opacity (paraphrasing). - **Jim Braatz** - any spectrum from the GBT is valuable, unless it's windy. Monitoring needs the best weather.
 - **Ellie White** - there have been suggestions for an accelerometer in the receiver cabin - The MUSTANG team use the quadrant detector to monitor this (the motion of the feed arm due to the wind)
 - **Ron Maddalena** - we can technically move the subreflector fast enough to steer the beam in wind
- "*What other science can be done at K-band that hasn't been discussed?*" - **Chair**
 - *Continuum at K-band?* - **Ron Maddalena** - just use Ka, it's so much better!
 - **Toney Minter** - Galactic centre is highly oversubscribed
 - **Ron Maddalena** - mapping other chemicals? **Tony Remijan** - cyclic C₃H₂ is very strong but what is the science case?
 - *Polarisation?* No Zeeman split lines, or not many, not a strong science case (need single diode for all beams?)
 - **Tony Remijan** - basically all lines at low freqs are masing, at least in Sgr B2
 - **Ron Maddalena** - Any planetary obs?

- Triton, Titan, should look for CO on Mars?
- Could look for absorption as a satellite passes in front of Jupiter

Key Takeaways

- There did not seem to be compelling (large) science cases for K-band in the areas of extragalactic observations, VLBI, transients, polarisation or continuum
- A discussion of solar system/planetary science generated some interesting ideas but these do not seem to be being currently pursued
- There was a suggestion that a large demonstration project could be undertaken but little suggestion of what the science case might be here.
- It was asked how many of the original science case for the GBT was still being pursued, although no-one present was able to answer off-the-cuff
- There was some discussion on how to improve current instrumentation/technology
 - The idea to refurbish the 140' generated some interest, particularly with astrochemists (Brett McGuire)
 - There was discussion of how to mitigate effects of wind via beam-steering or just motion tracking

Wednesday - What is the Next Step for Scientific Instrumentation at K-Band with the GBT?

- *"Do we need to build anything at all?"* - **Chair**
 - **Steve White** - note that any focal plane array would be limited to 60 feeds at most.
 - **Erik Rosolowsky** - Line polarimetry? There's not a strong case for circularly polarised obs but maybe linear? - **Jaime Pineda** - 3D model of Galactic magnetic field would be good. (Doable with CCS? Argus?)
- *"Is there a case for building an array at Green Bank?"* - **Glen Langston**
 - Could have ngVLA total power array here - 3 antennas - 3" resolution - expensive, would need correlator here
- *"An instrument with good continuum at K-band would be the only instrument in the world"* - **Tony Remijan**
 - AME could be problematic
 - What is the science case?
 - Requirements for spectral line and continuum instruments are not necessarily exclusive but spectral line observations would be worse if the instrument is optimised for continuum
 - **Erik Rosolowsky** - not really sure of science case for k-band continuum as no-one does it. However, CMB people would be excited.
- *"Would anyone present actually propose for a full Galactic plane survey in ammonia?"* - **Chair**
 - **Jim Jackson** - yes
 - **Jaime Pineda** - would rather go deeper on existing diffuse areas
- *"Can we vote on who would most highly prioritise a) a bigger/better spectrometer, b) a KPAF or KPFA with more beams or c) improved pipelines/software?"* - **Chair**
 - Votes were pretty evenly split, with 5 - 6 votes for each option
 - For larger bandwidth - the IF chain would need an upgrade, the current down converters are limited to 1.8 GHz, VEGAS is expandable
 - **Tony Remijan** - There is little point in getting much better capabilities if there's still a large potential barrier to using it. Get calibration issues, etc sorted first, and you will

develop an experienced community who want to use the capabilities (and give better advice on what should be built).

- **Erik Rosolowsky** - Need a cost/benefit analysis to make the decision.

Key Takeaways

- There is a divergence of opinions on whether the next step for a large ammonia survey would be to map more of the Galaxy, or to go deeper on existing known regions (or both).
- There was a recommendation that GBO improve current facilities (e.g. increase calibration accuracy) before building more instrumentation
- There was a suggestion that some form of cost/benefit analysis would make it clearer whether GBO should take the option of a) a bigger/better spectrometer, b) a KPAF or KFPA with more beams or c) improved pipelines/software.

List of Participants

Speakers and/or In-person

Kevin Bandura (WVU)

Jim Braatz (NRAO)

Andrew Burkhardt (Worcester State University)

Natalie Butterfield (NRAO)

Alex Byrne (MIT)

Dave Frayer (GBO)

Zach Fried (MIT)

Rachel Friesen (University of Toronto)

Jordan Guerra Aguilera (Villanova University)

Jim Jackson (GBO)

Helen Kirk (Herzberg Astronomy & Astrophysics Research Centre)

Glen Langston (GBO)

Jay Lockman (GBO)

Ron Maddalena (GBO)

Brett McGuire (MIT)

Toney Minter (GBO)

Larry Morgan (GBO)

Jaime Pineda (Max-Planck-Institut für extraterrestrische Physik)

Tony Remijan (NRAO)

Erik Rosolowsky (University of Alberta)

Pedro Salas (GBO)

Anika Schmiedeke (GBO)

Samantha Scibelli (University of Arizona)

Bob Simon (GBO)

Brian Svoboda (NRAO)

Hannah Toru (Shay) (MIT)

Karl Warnick (BYU)

Ellie White (GBO)

Steve White (GBO)

Ci Xue (MIT)

Remote

Mitch Burnett (BYU)

Tierra Candeleria (NMT)

Hamid Hassani (University of Alberta)

Juan Li (Shanghai Astronomical Observatory)

Xing Lu (Shanghai Astronomical Observatory)

Brian Kent (NRAO)

Yvonne Pendleton (NASA Ames)

Maria Pettyjohn (UNSW)

Yancy Shirley (University of Arizona)

Rey Squillace (University of Arizona)

Glenn White (Rutherford Lab UK & Open University, UK)

Jinjin Xie (Shanghai Astronomical Observatory)

Katarina Yocum (NASA-Goddard)