Solar Observations with ALMA

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EUROPEAN ARC
ALMA Regional Centre || Czech

Astronomical Institute
of the Czech Academy of Sciences

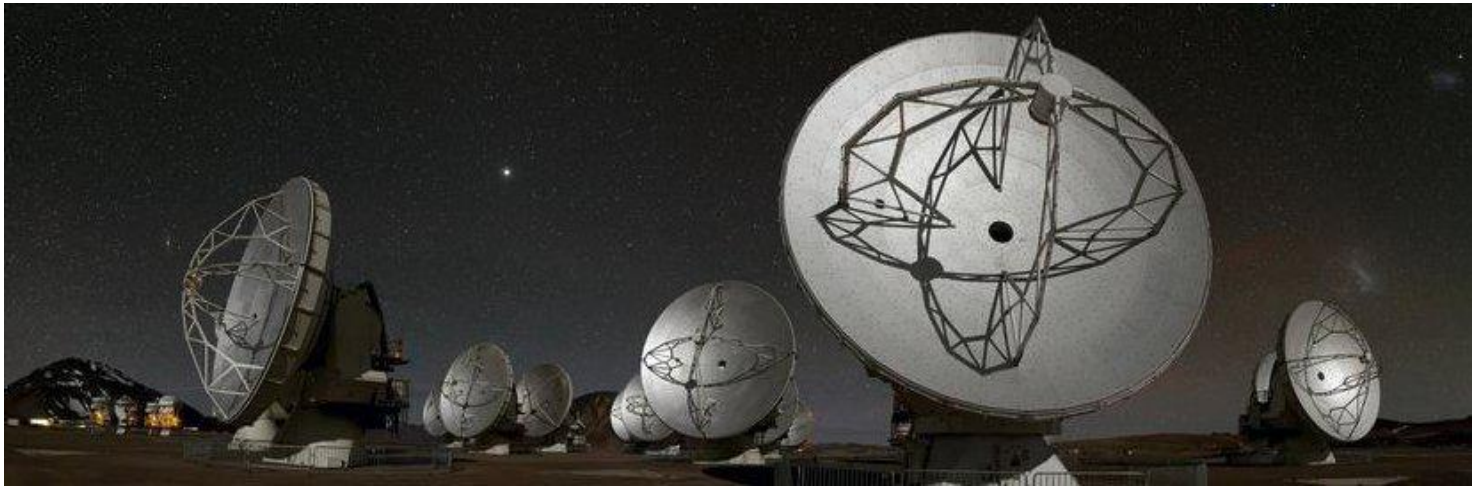
Outline

- Brief ALMA intro
  - What is ALMA?
  - How does ALMA work?
- Your ALMA project: SW and data flow
- Solar research with ALMA
  - Typical use cases
  - ‚Peculiarities' of solar observations
  - Solutions for project preparation, observation, and post-processing
- ARCs and EU ARC nodes – ALMA user support infrastructure
  - Role of ARC (nodes) – How can they help you?
  - EOC programme: Adding new ALMA capabilities
  - Commissioning of special solar observing mode
  - Test observing campaign
- Solar mode capabilities in Cycle 4 and beyond
- Summary

Acknowledgements for the Team: I. Skokic, R. Brajsa, R. Laing, M. Shimojo, T. Bastian, S. White, S. Kameno, A. Hirota, S. Kazamusa, T. Remijan, A. Hales, S. Wedemeyer-Boehm, … + European ARC network

What is ALMA?

- ALMA = **A**tacama **L**arge **M**illimeter/submillimeter **A**rray The largest project of contemporary ground-based observational facility in astronomy built in a world-wide international cooperation in Chile
- The key partners are **ESO**, NRAO and NAOJ
- System of fifty 12m high-precision antennas + twelve 7m (ACA) phased as an interferometer, + four 12m single-dish (TP)

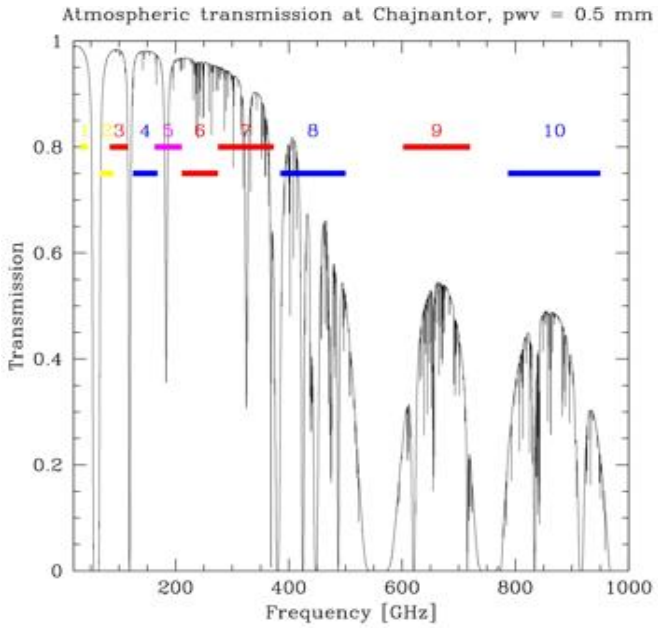


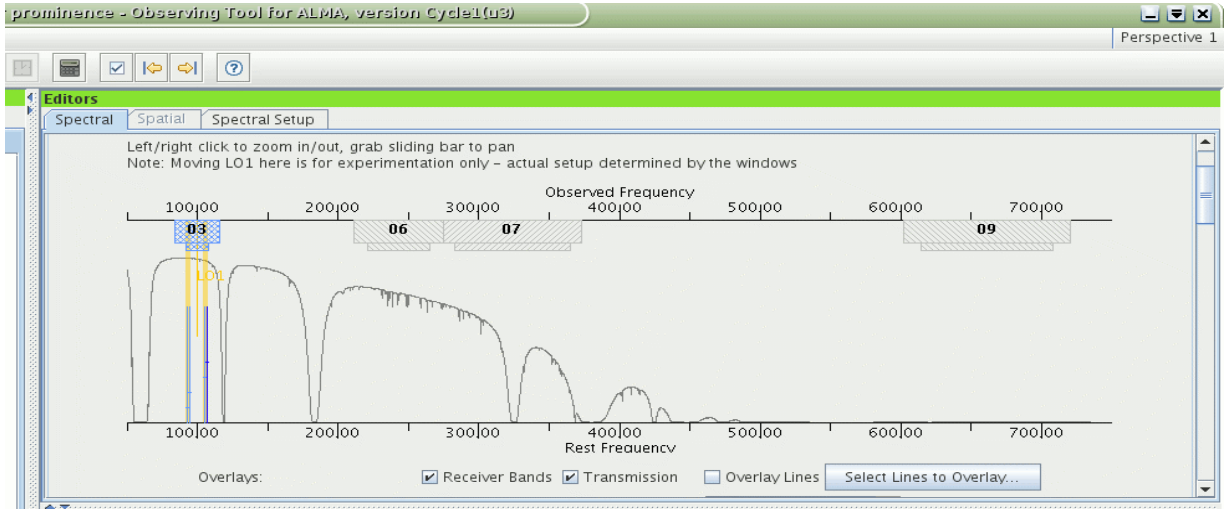
What is ALMA?

For the first time we (will) have

- Very high spatial resolution (up to 0.005“ in extended configuration @ 1THz)
- Extremely high spectral resolution – up to 30kHz
- Temporal resolution for very bright sources (e.g. the Sun) ~ 1s
- Very high sensitivity

at the same moment in a broad range of frequencies from 30GHz up to more than 1 THz

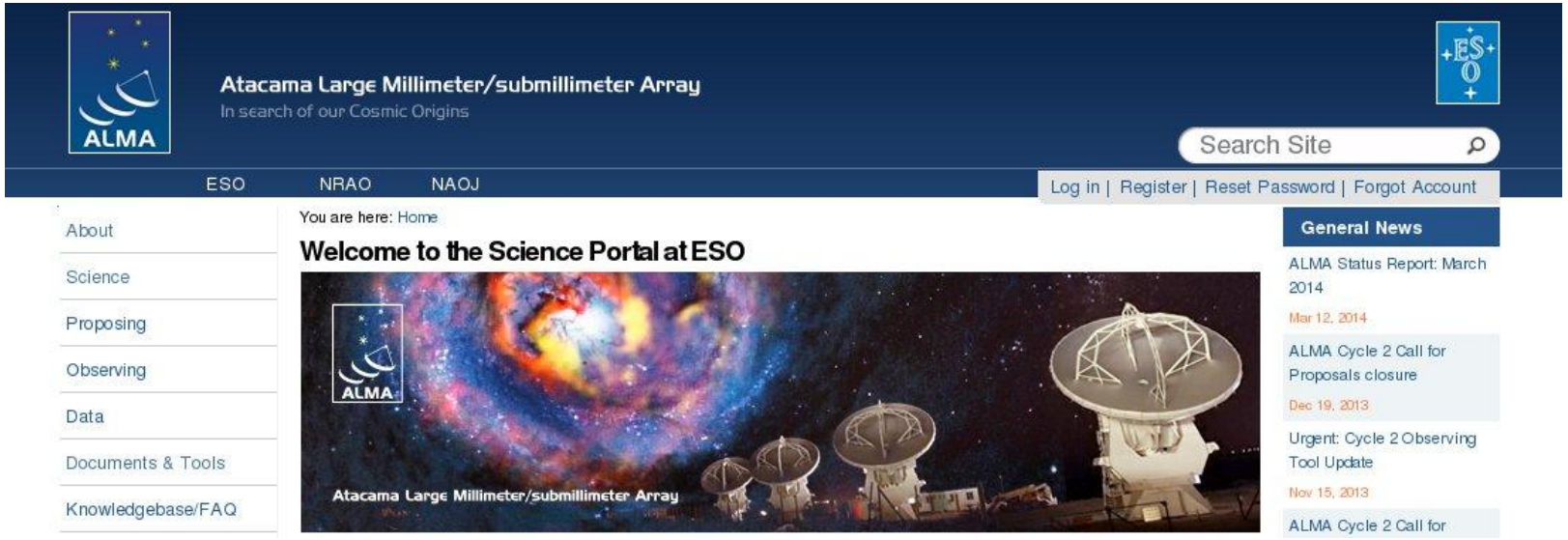




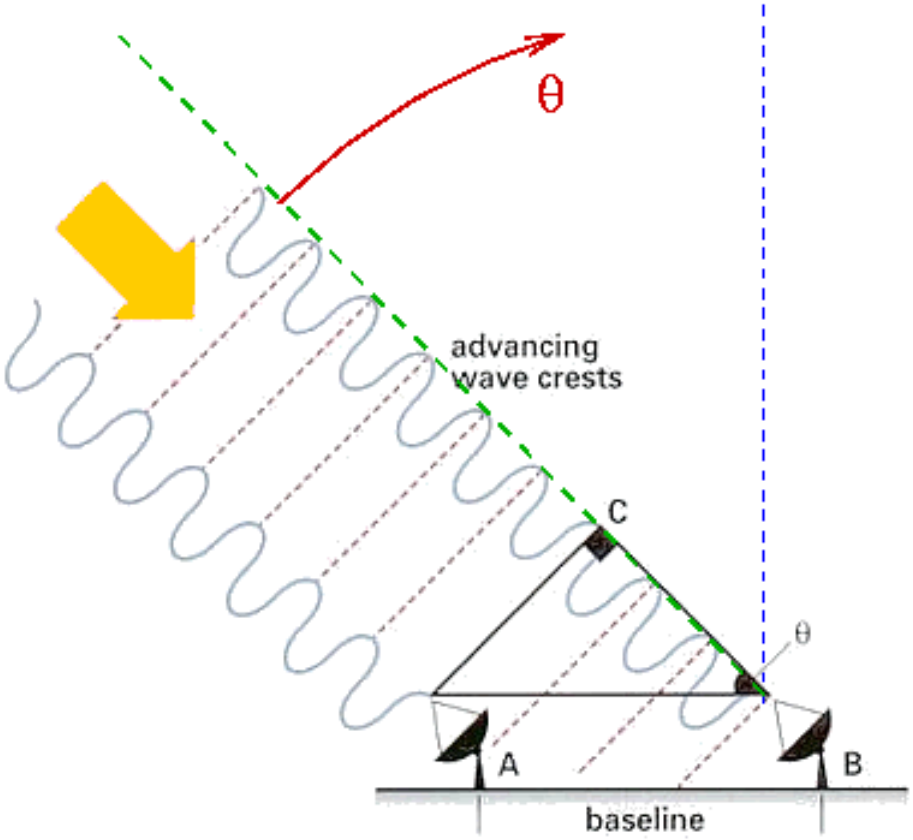
Science with ALMA

1. Cosmology and the high redshift universe
2. Galaxies and galactic nuclei
3. ISM, star formation and astrochemistry
4. Circumstellar disks, exoplanets and the solar system
5. Stellar evolution and the Sun

http://almascience.eso.org



How does ALMA work?



$$I_{AB} = 1 + \cos\frac{2\pi D}{\lambda}\theta$$

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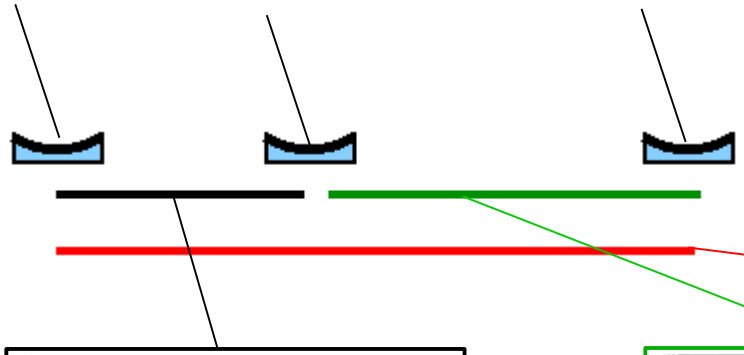
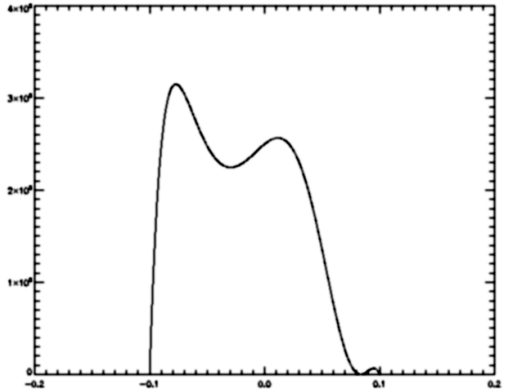
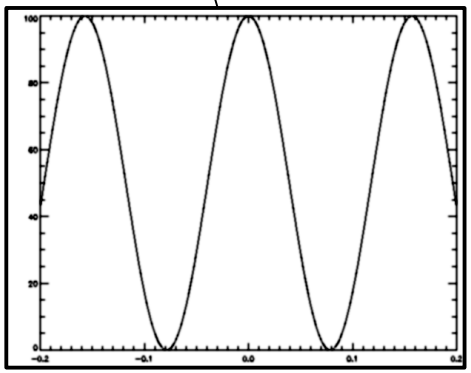
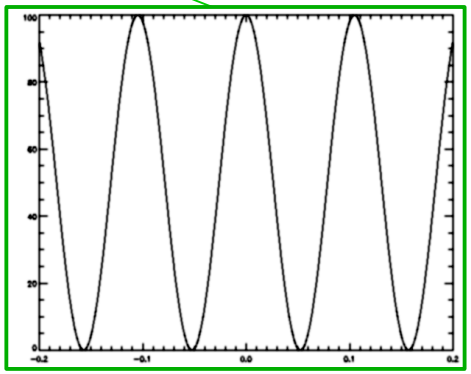
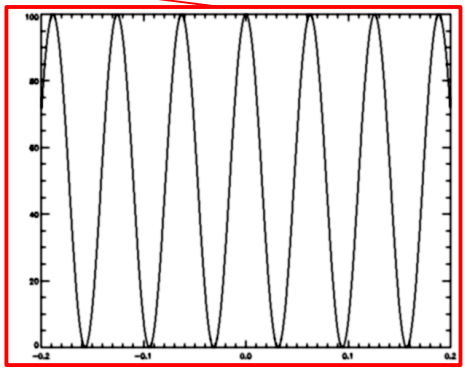
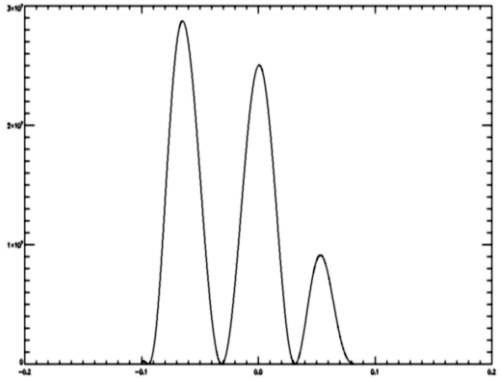






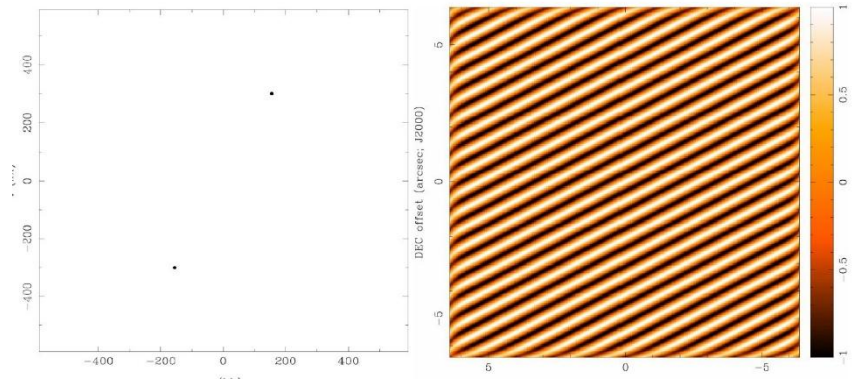




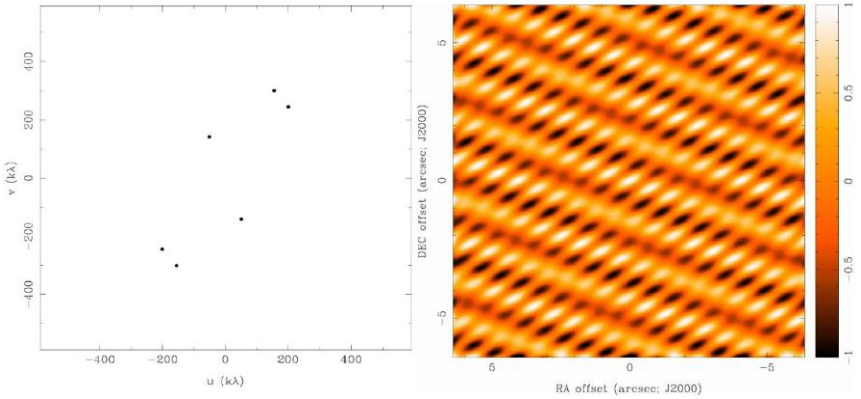


***Aperture Synthesis* – decomposition of image to harmonics = Fourier transform**

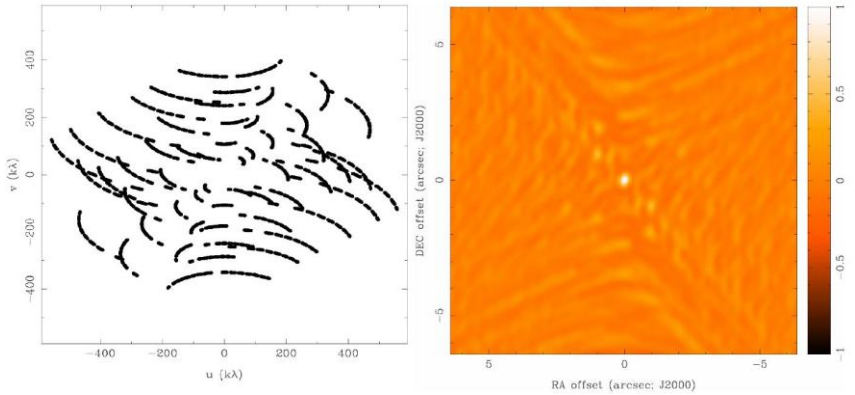
How does ALMA work?



2 antennas

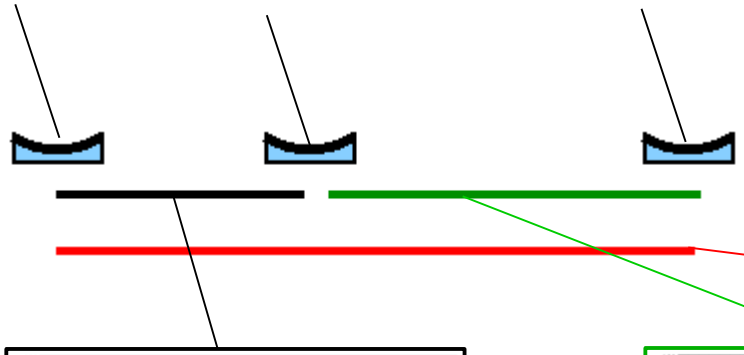


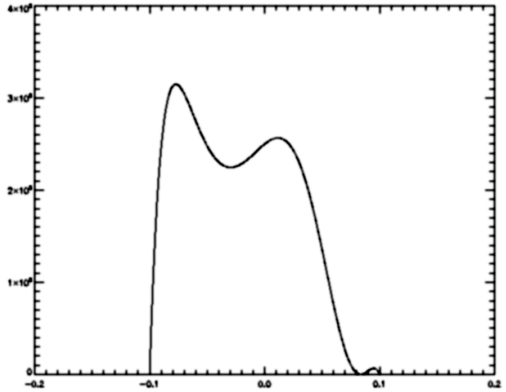
3 antennas

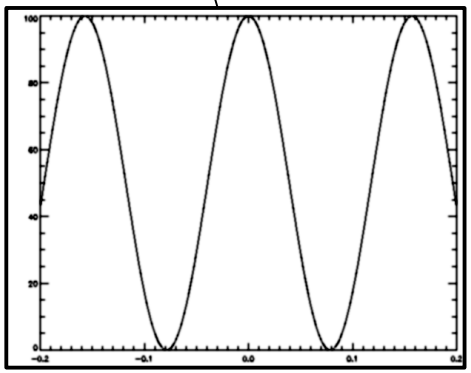


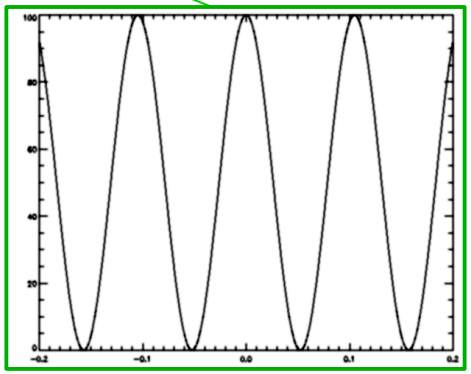
8 antennas x 240 samples

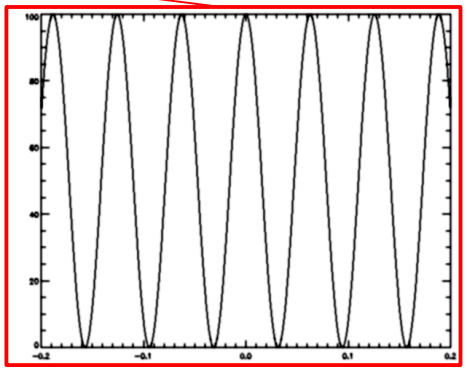
How does ALMA work?

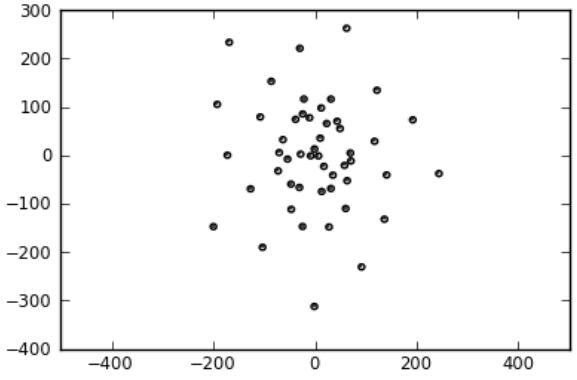


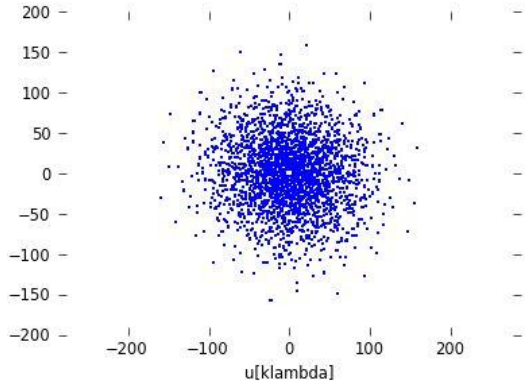


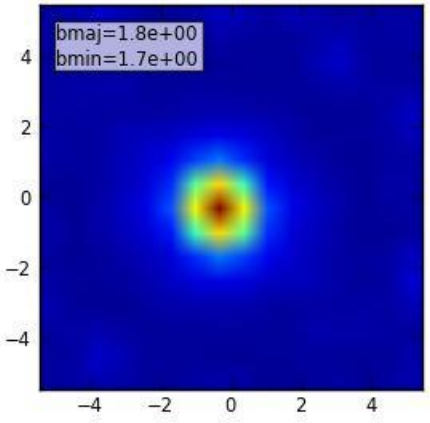






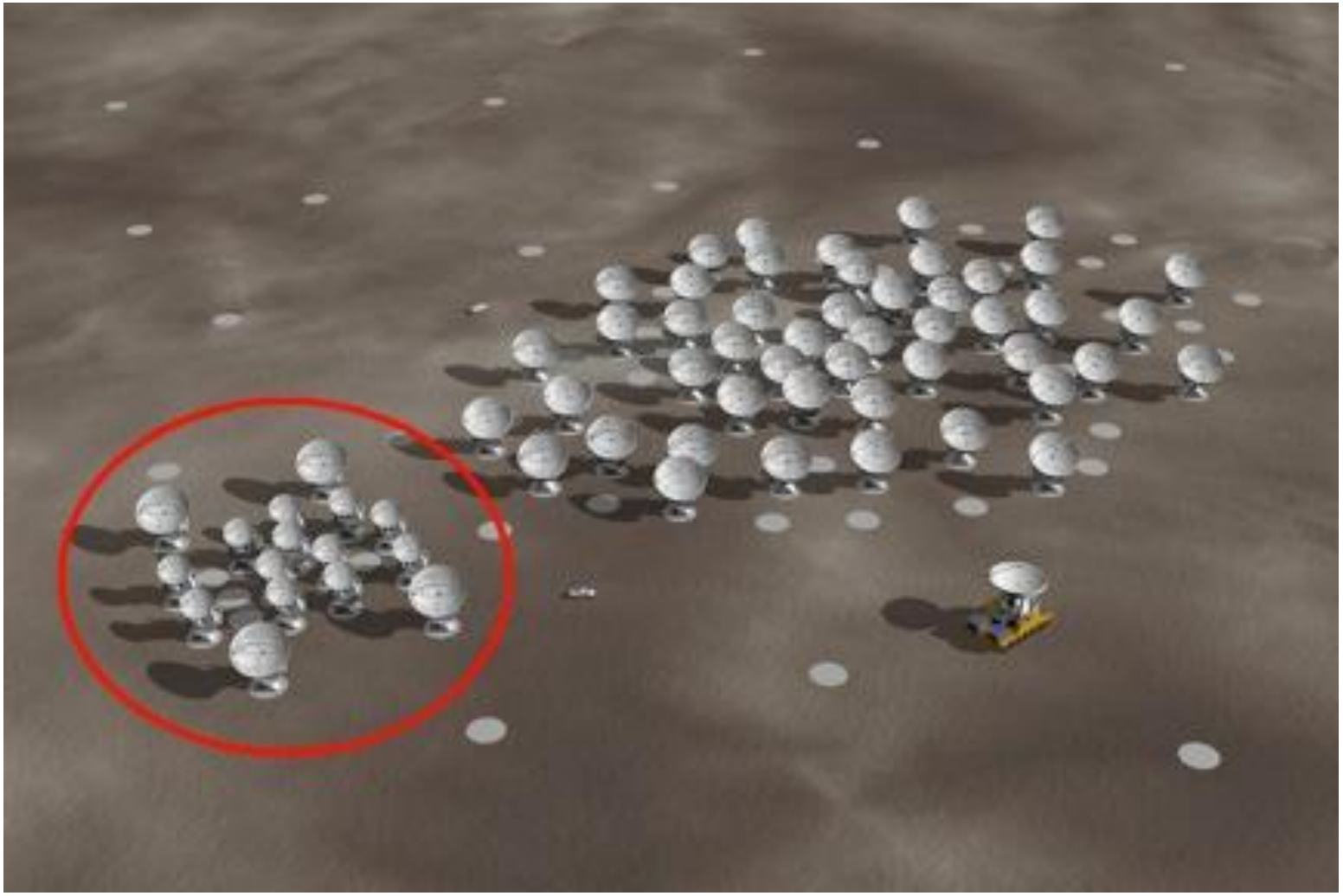






How does ALMA work?

ACA = Atacama Compact Array – twelve 7-m antennas



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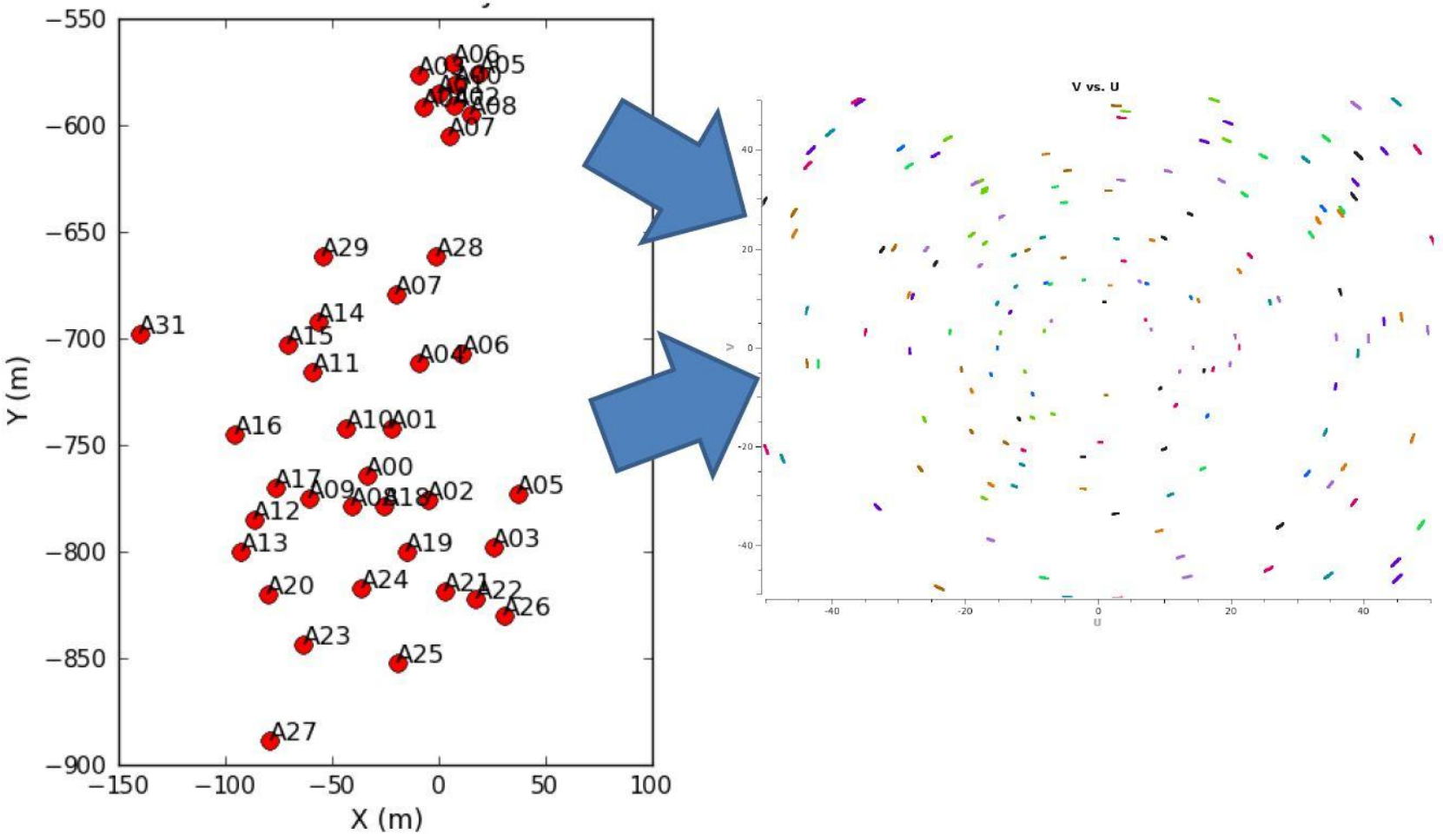
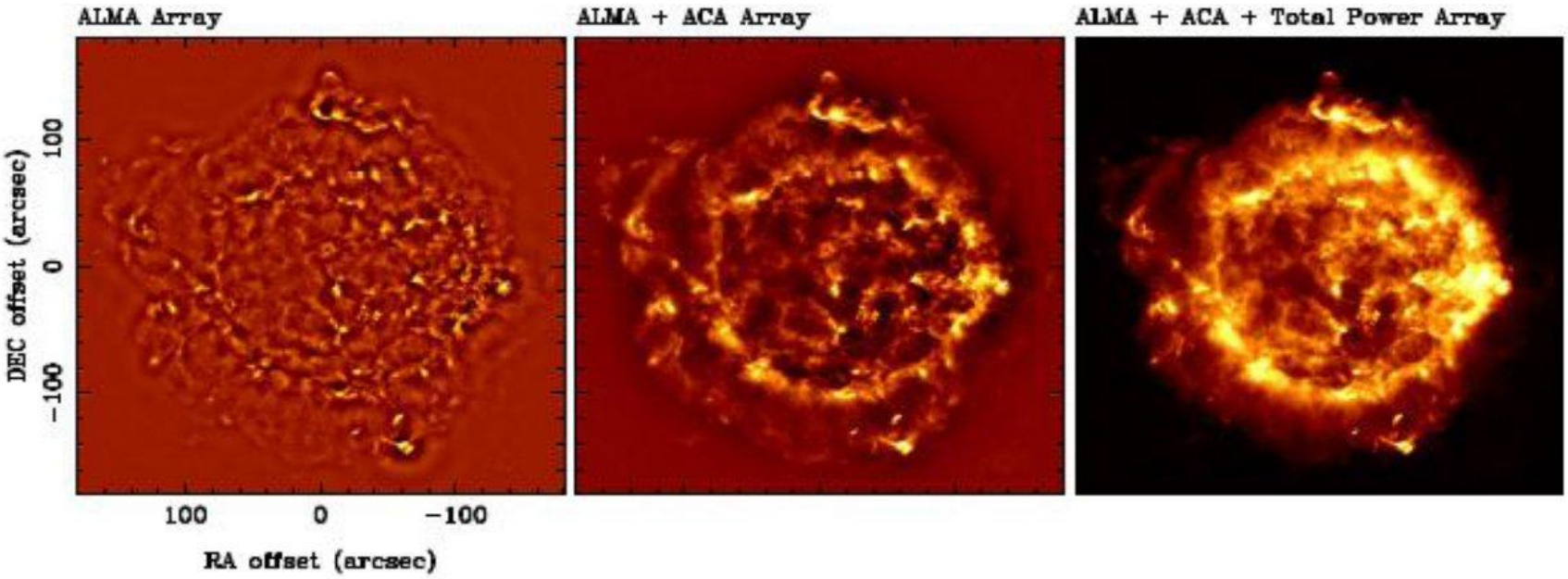


How does ALMA work?

Single dish / Total Power (TP) scanning

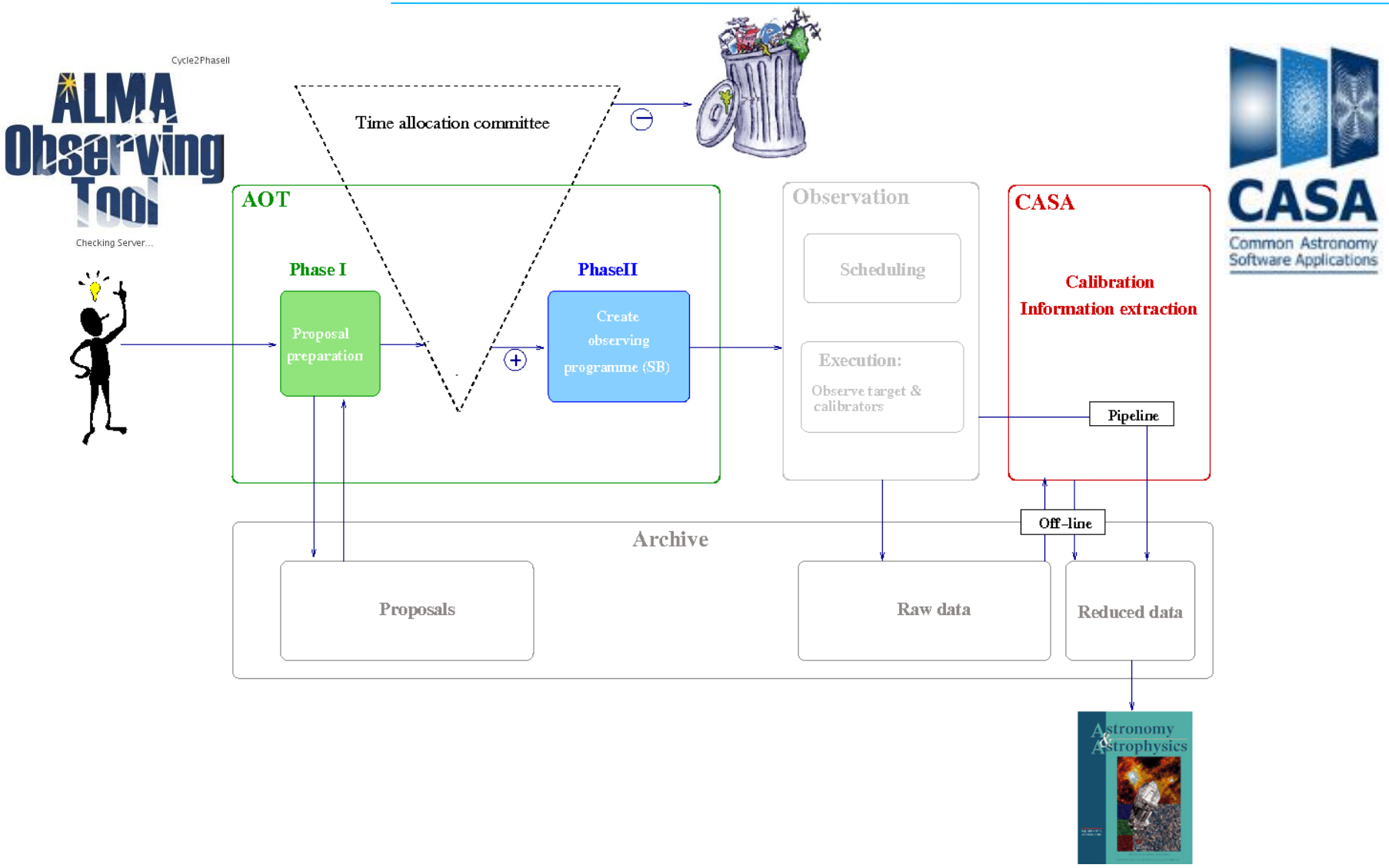
How does ALMA work?

Extended sources with fine structures: Combined approach

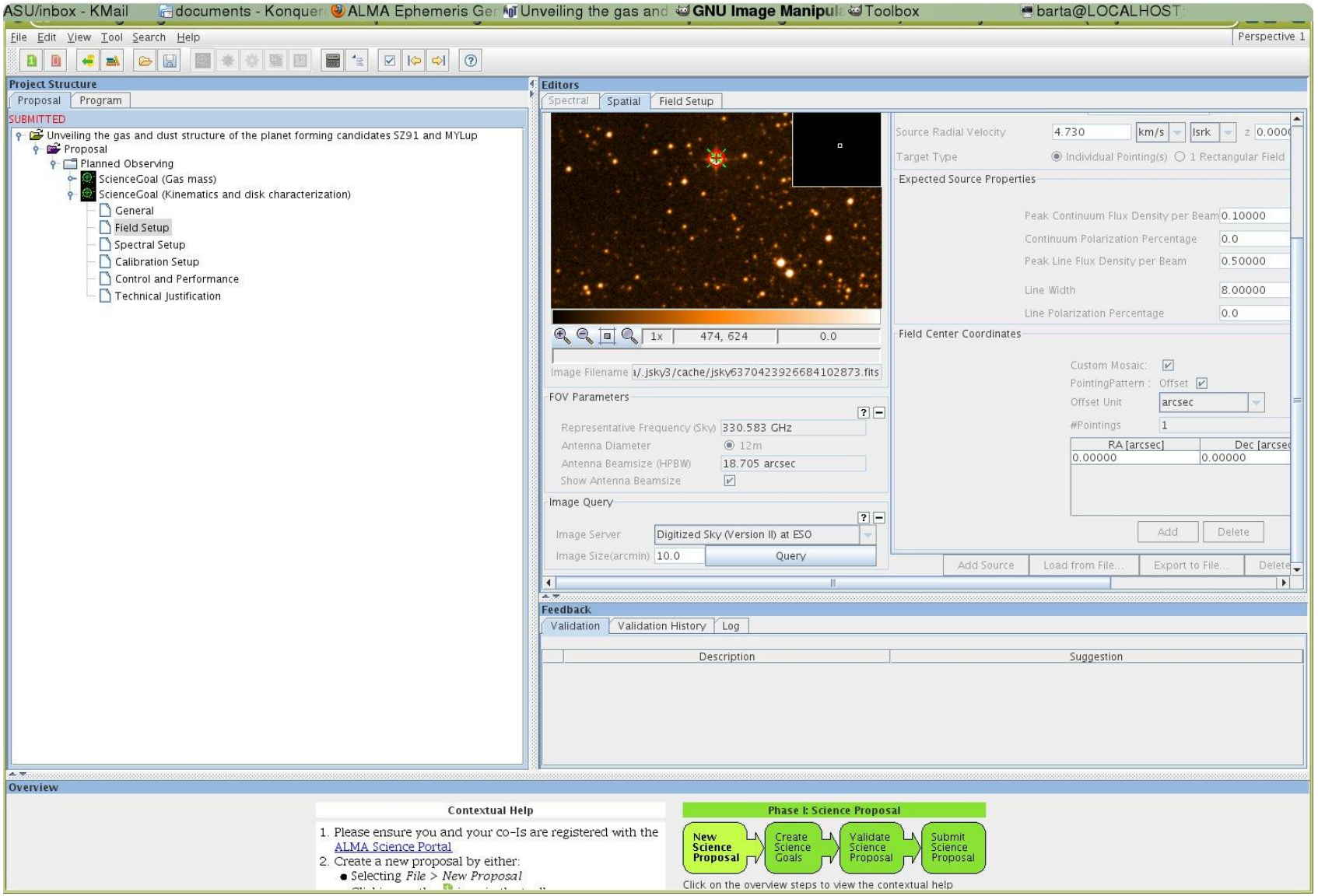


simple simulation of ALMA observation by Y.Kurono

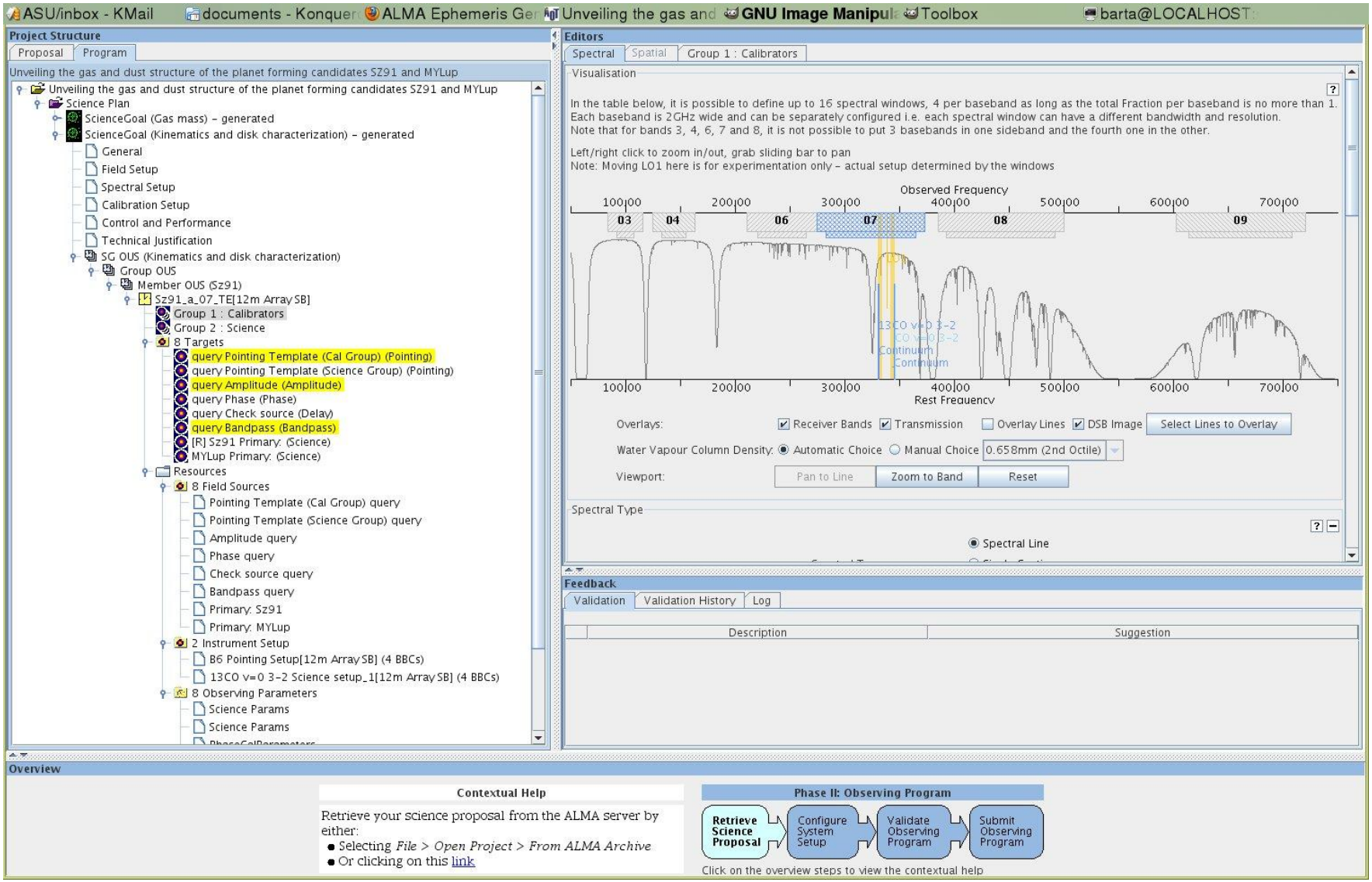
Your ALMA project: Data flow, infrastructure & SW



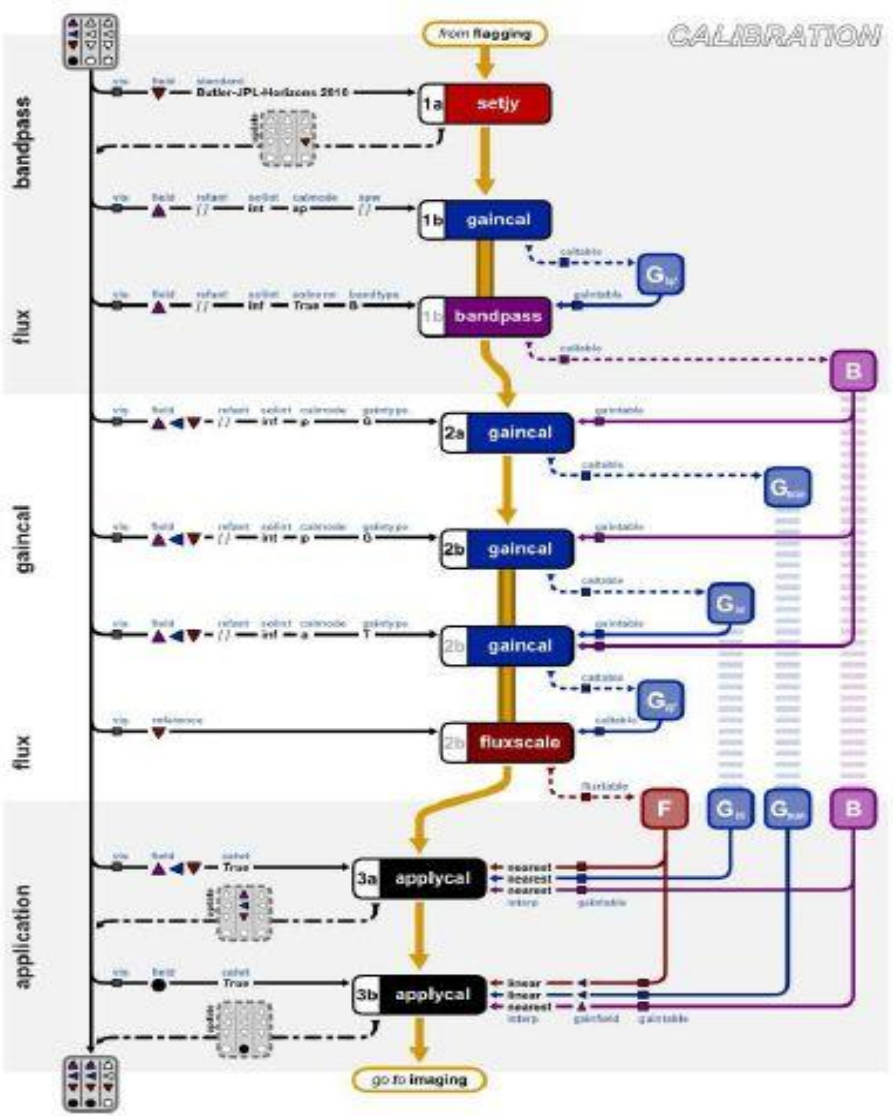
Preparing your project – ALMA OT

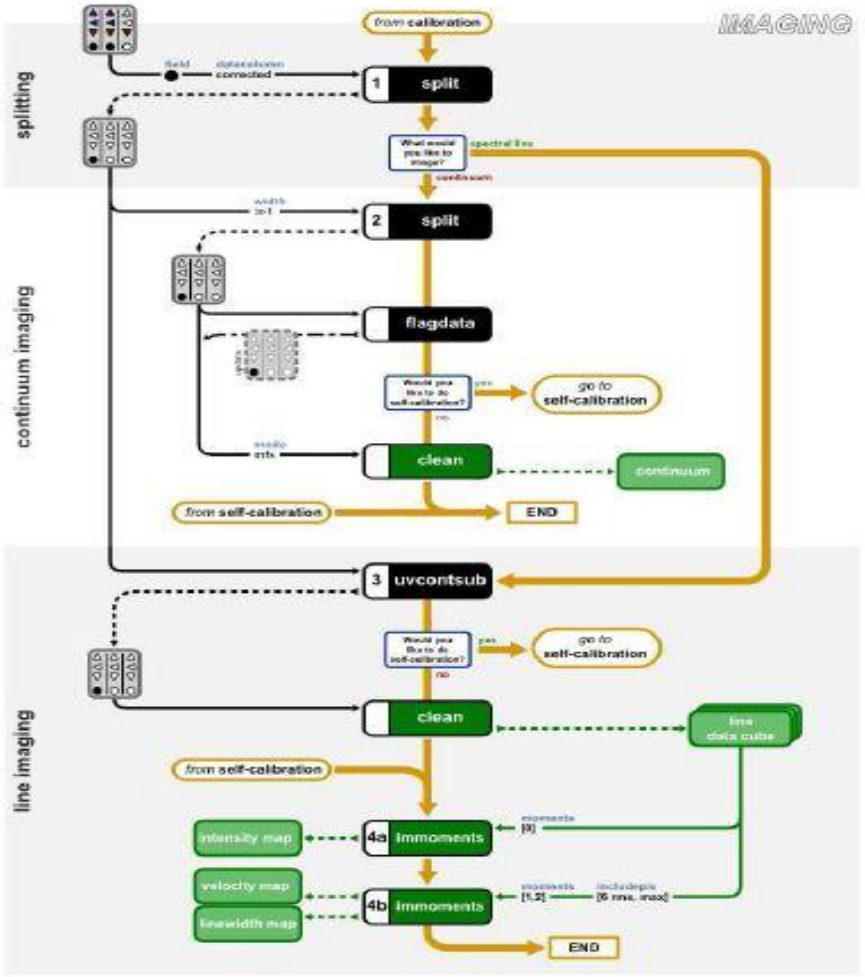


Project execution – typical *Scheduling Block*



Postprocessing – calibration and imaging in CASA





Specifics of solar ALMA observations

Why to observe the Sun with ALMA?

- A lot of key science questions in solar physics can be addressed with ALMA – reflected in many documents (*Science with ALMA, Skokic: EOC T1 Report 2015, Karlicky et al. 2012, Wedemeyer et al. 2015)*
- Meaningful use of the day time (not so sensitive to bad weather) → increase of the ALMA scientific return/efficiency

Solar peculiarities: Why the solar observations need special treatment?

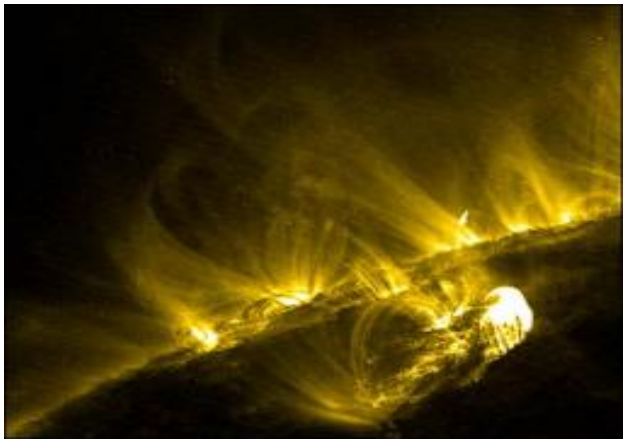
- The Sun is **far brighter** in mm/sub-mm than other sources (+ obvious thermal radiation)
  - Issue of dynamic range/saturation (e.g., in comparison with **calibrators**)
- **Variability** on short timescales (down to <1s in solar flares) → just **instantaneous** *uv* **coverage**. The product will be a **movie** – a new standard required for **Archive.**
- In addition to apparent celestial motion of the Sun‘s center also (differential) solar rotation → **complicated pointings** / **specific ephemeris**
- **Specific coordinate systems** used in solar physics
- **Extended sources** – TP mapping needed in a fast-scanning mode

  - **Solar mode still under commissioning** – SciObs likely since Cycle 4

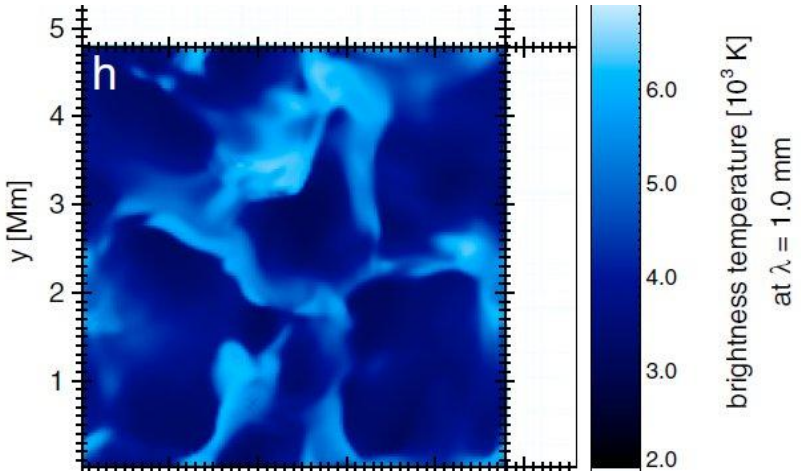
What can ALMA tell us about the Sun? Typical science uses cases (WP1)

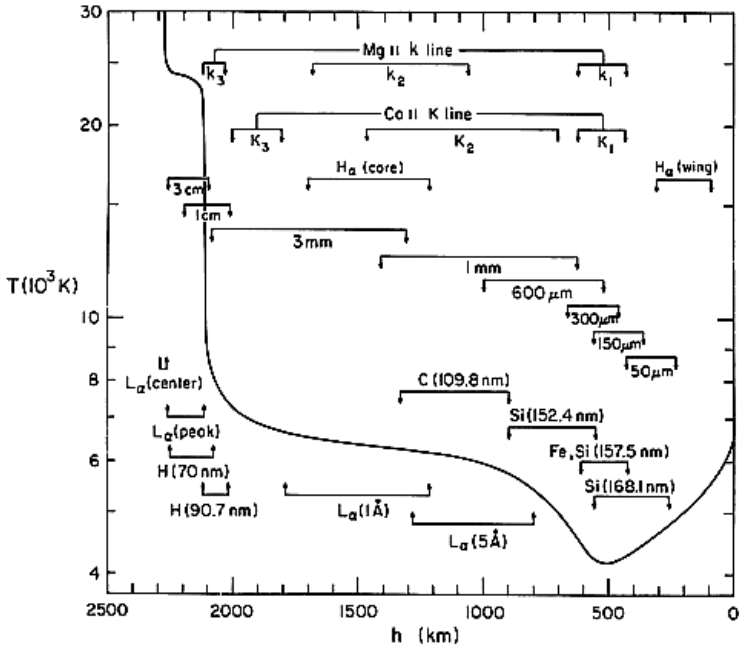
(I. Skokic, R. Brajsa, S. Wedemeyer-Boehm + S-SALMON)

- **Particle acceleration in solar flares**
  Ultra energetic electrons can produce synchrotron radiation in mm range. With ALMA we would reach unprecedented spatial imaging of energetic particles.



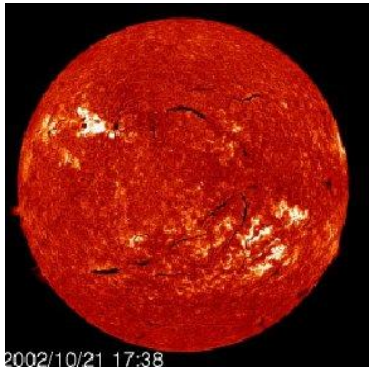
- **Structure and dynamics of solar chromosphere**
  Temperature structure remains unclear. What is the role and nature of oscillations and waves? Thermal emission in ALMA range can provide an answer.

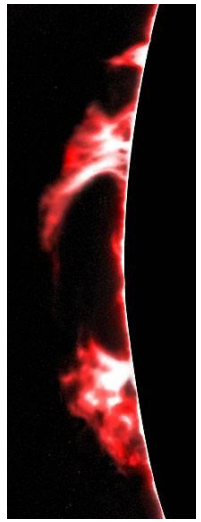




What can ALMA tell us about the Sun? Typical science use cases

- **Structure of solar prominences**
  Internal structure of prominences and filaments remain unclear. ALMA can look through with very high resolution.





- **Study of recombination lines in solar atmosphere**
  It still unclear whether these can be observed in the mm wavelength range. If yes, an important diagnostic tool for measurement of magnetic field in the part of the solar atmosphere where it is otherwise difficult would emerge.

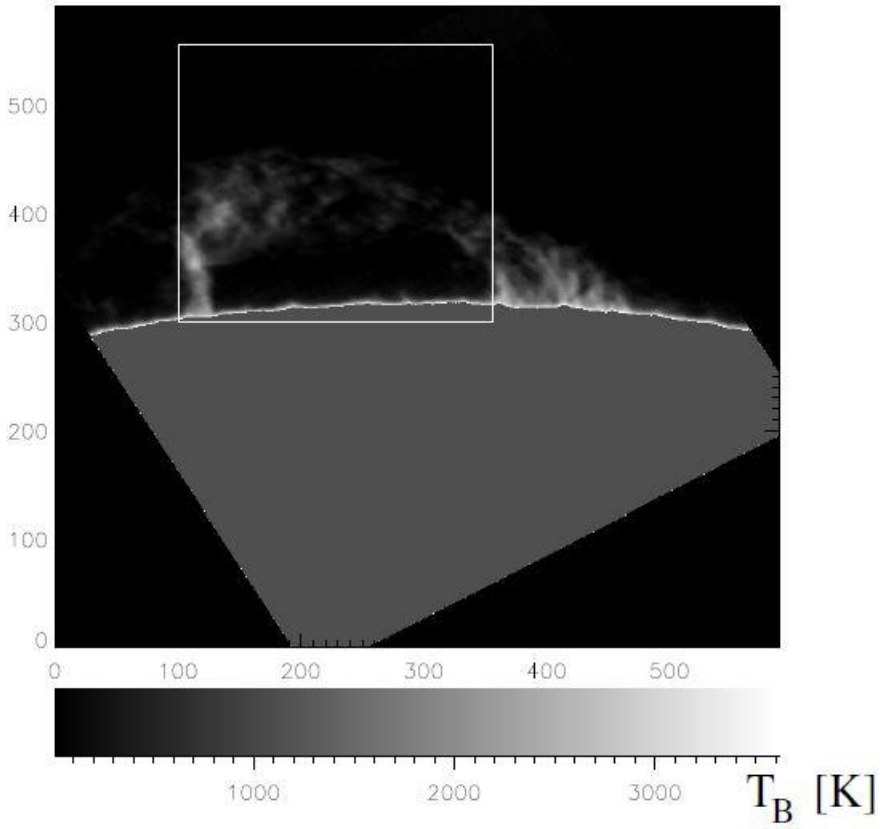
- **Many more open issues...** We are collecting inputs from the solar-physics community. Numerical modelling combined with *CASA simulation toolkit* represent a way how to find out optimum parameter ranges

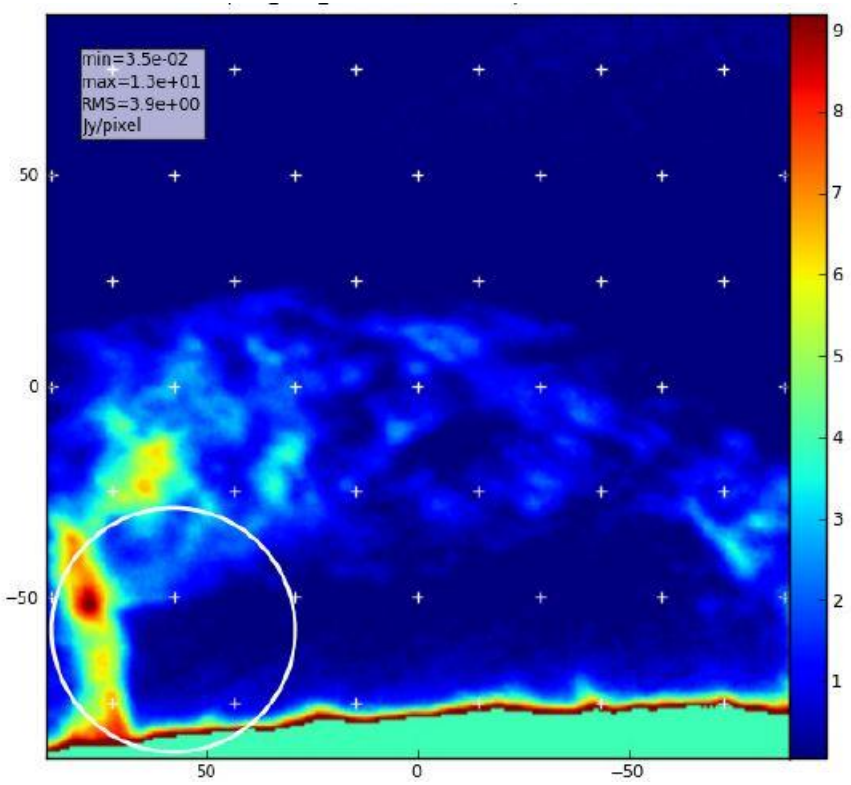
Research summary published in:
EOC T1 Report for ESO + recent review at http://arxiv.org/abs/1504.06887 (to appear in SSR)

What can ALMA tell us about the Sun? Typical science use case

(M. Barta, P. Heinzel)

Prominences: Simulation using CASA::simobserve(), imaging using CASA::clean(), Heinzel et al. 2015





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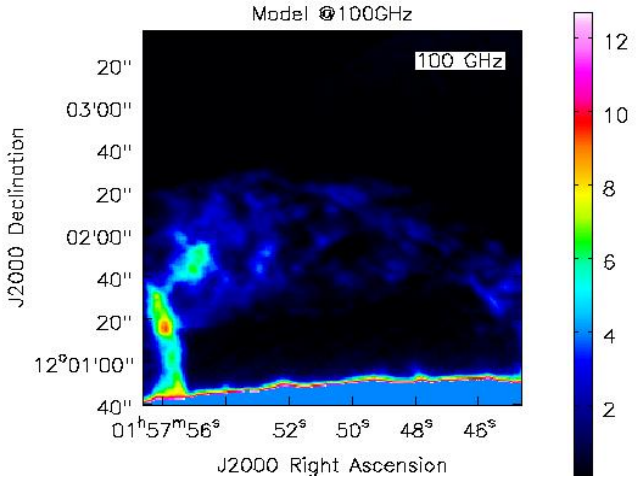
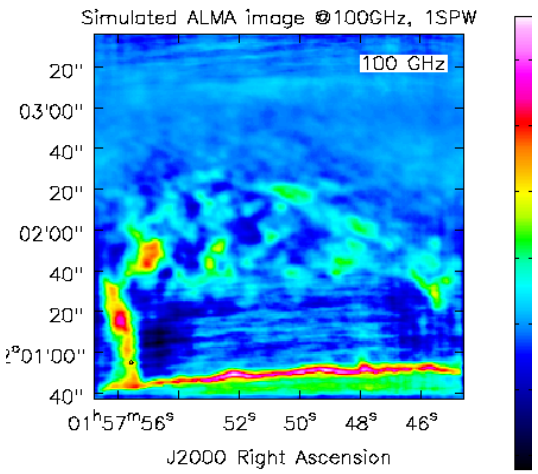
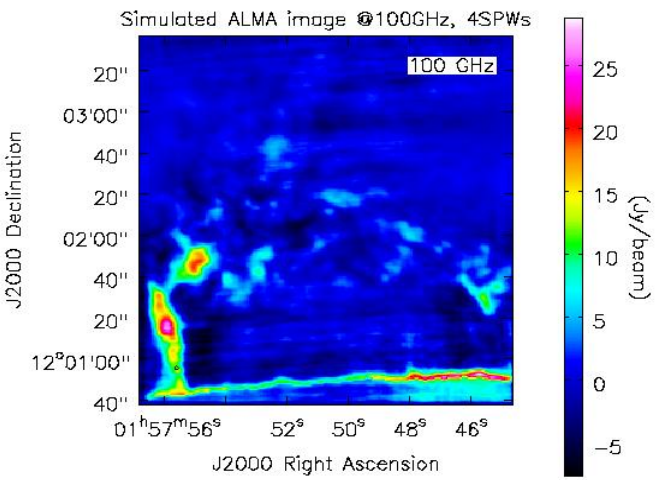


Model data



Single continuum:1 SPW



Single continuum: 4 SPWs

Result: MFS improves *uv* Coverage and reconstructed image fidelity even for continuum images

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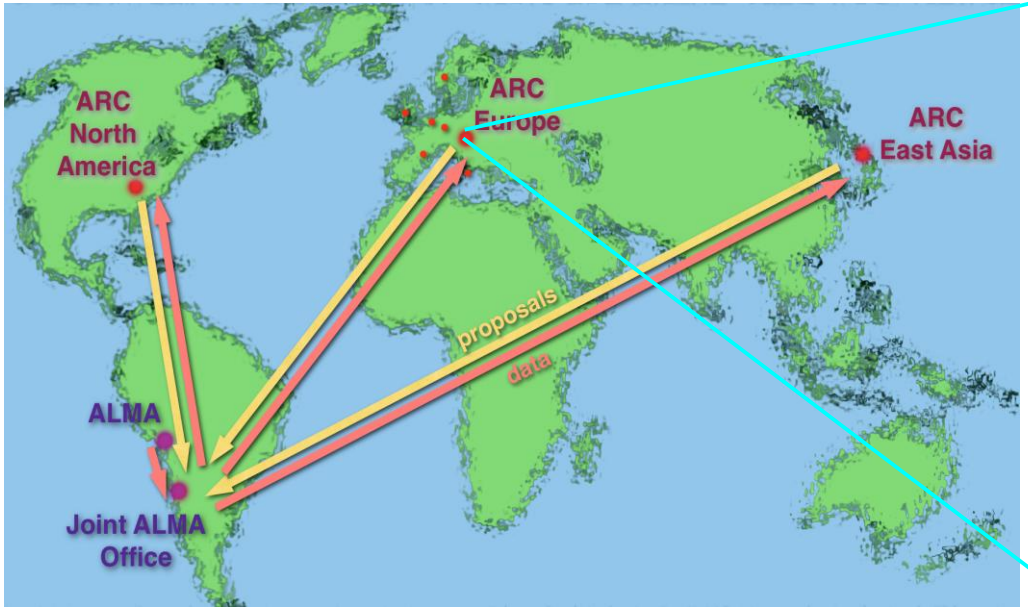
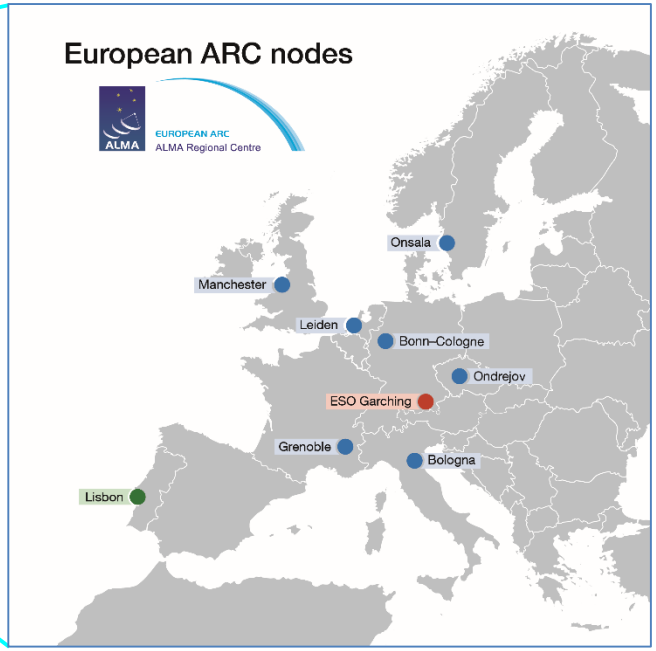
- **Specific coordinate systems** used in solar physics
- (usually) **Extended sources** – TP mapping needed in a fast-scanning mode
  - **Solar mode still under commissioning** – Early Science since Cycle 4

ALMA Regional Centers / ARCs and the ARC nodes





ALMA Regional Centers – ARCs:
Supporting infrastructure – interface between ALMA observatory and user community

Structure of the European ARC:

- Head in ESO Garching
- Seven nodes across Europe
  - **<u>One in Ondřejov</u>**

EUROPEAN ARC
ALMA Regional Centre

EU ARC – Czech node

EUROPEAN ARC
ALMA Regional Centre || Czech

Status

- Hosted by the Astronomical Institute ASCR
- Negotiations with ESO started in 2007, node accepted into EU ARC network in 2009
- Since 2015 ***Research Infrastructure*** (support till 2022, listed in CZ *Roadmap*, one of the 42 in CR)
- Expertise areas: Galactic & extragalactic physics, stars & ISM, solar physics, laboratory mw spectroscopy

Mission

- User support, community building & training, help with ALMA development
- Serves the community in CR and entire CE Europe in all its expertise areas
- In solar physics it supports community on the European-wide scale

Role of the ARC nodes

Towards user community:

- Face-to-face (F2F) support of users in all stages of their ALMA-oriented projects.
- ALMA-system knowledge dissemination
- Spreading awareness of ALMA among scientific community

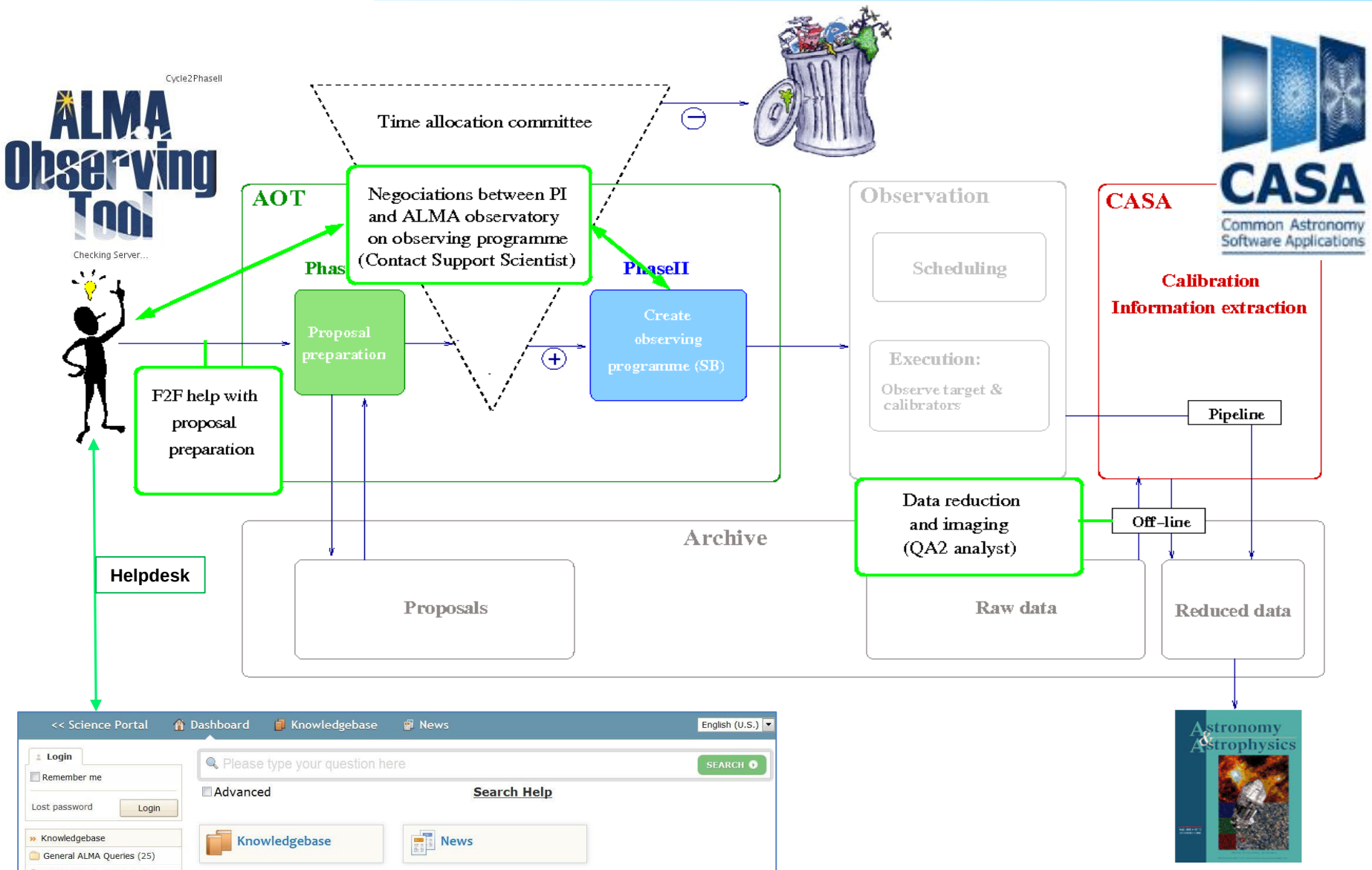
Towards ALMA observatory and ALMA-system developers:

- Help to the developers of ALMA user software:
- testing of CASA, ALMA OT, ALMA Helpdesk system,
- suggestions for improvement

Connecting users ↔ ALMA developers:

- Definition of new modes of observation – based on scientific community requests:
  → use-case studies, simulations, test observations (CSV/**EOC**),
  assembling requirements for system update => suggestions
  to ALMA observatory and developers.

User support



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The ARC node in Ondrejov is developping the solar ALMA observing mode for entire Europe – mandated by ESO: **EOC Project *Solar Research with ALMA***

EOC project *Solar Research with ALMA*: Commissioning of new ObsMode

Project strategy translated into *Working Packages*

- WP1: Science use-cases for solar research with ALMA
  - Develop and investigate a set of detailed use cases for solar observing with ALMA
    - Request input from the community
    - Define requirements for spatial/spectral/temporal resolution, FOV, polarisation, …
    - Use CASA simulation package for TA
- WP2: Solar Observing Modes and Calibration
  - Research in possible new solar observing modes and analyse calibration requirements
    - Solar attenuators („filters“)
    - MD1/MD2 w/wo attenuation
    - SD/TP fast-scanning observations
- WP3: Software Requirements
  - Produce requirements for observing preparation, execution and post-processing

Project team

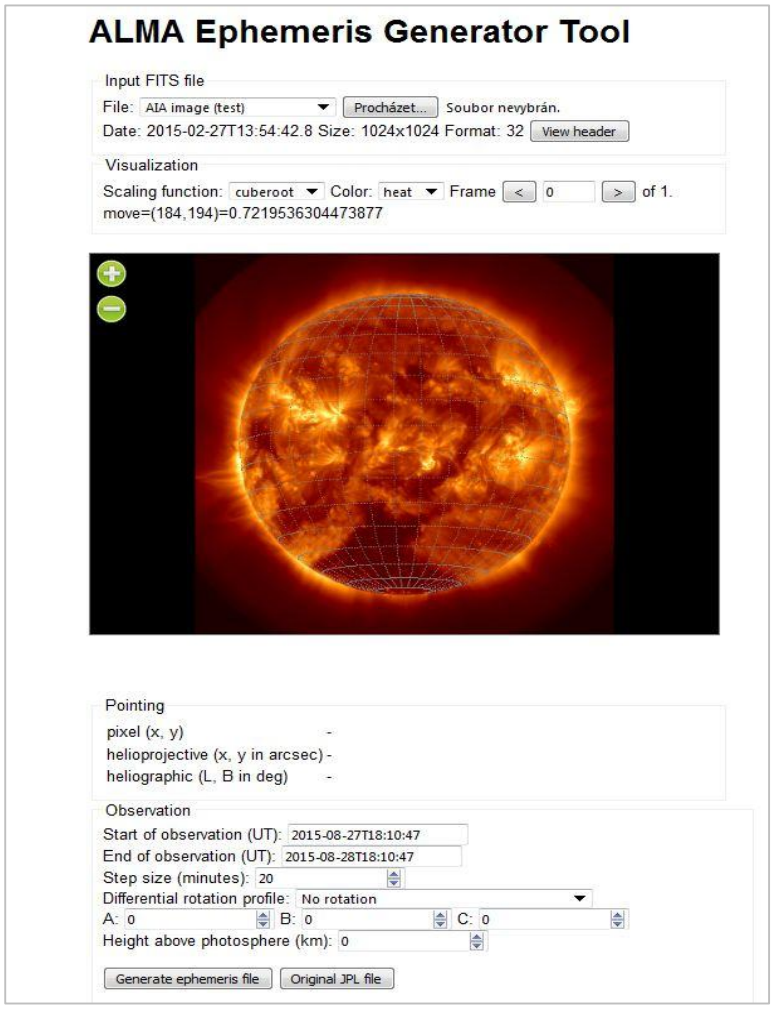
- Core: M. Bárta (PM), R. Brajša (PI), **I. Skokič**, M. Karlický, P. Heinzel
- ESO Coordinator: R. Laing
- External collaborators (ESO): A. Hanslmeier, M. Temmer (Uni Graz, AT), A. Benz (FNHW Windisch, CH), E. Kontar (Uni Glasgow, UK), S. Wedemayer-Boehm (Uni Oslo, NO), R. Hills (Cambridge, UK)
- Cooperation with similar activity at NA and EA ARCS: S. White (US Air Force Research Lab, Albuquerque, US), T. Bastian (NRAO, Charlottesville, US), M. Shimojo (NAOJ, JP), A. Kazamusa (NAOJ/Nobeyama)

Specifics of solar ALMA observations: Solutions for project preparation

(I. Skokic)

Proper motion of solar sources: Ephemeris/pointings

ALMA OT + *Ephemeris Generator Tool* http://celestialscenes.com/alma/coords/CoordTool.html



Author: Ivica Skokic
Test version (beta), use with care!

Solar proposal preparation using ALMA OT and ALMA Ephemeris Generator Tool:

Our task for afternoon hands-on session

Specifics of solar ALMA observations: Solutions for project execution

(P. Yagoubov, M. Shimojo)

Interferometric observations: The Sun is far brighter in mm/sub-mm than other sources

–Issue of dynamic range - e.g., in comparison with phase calibrators

Two suggested solutions:

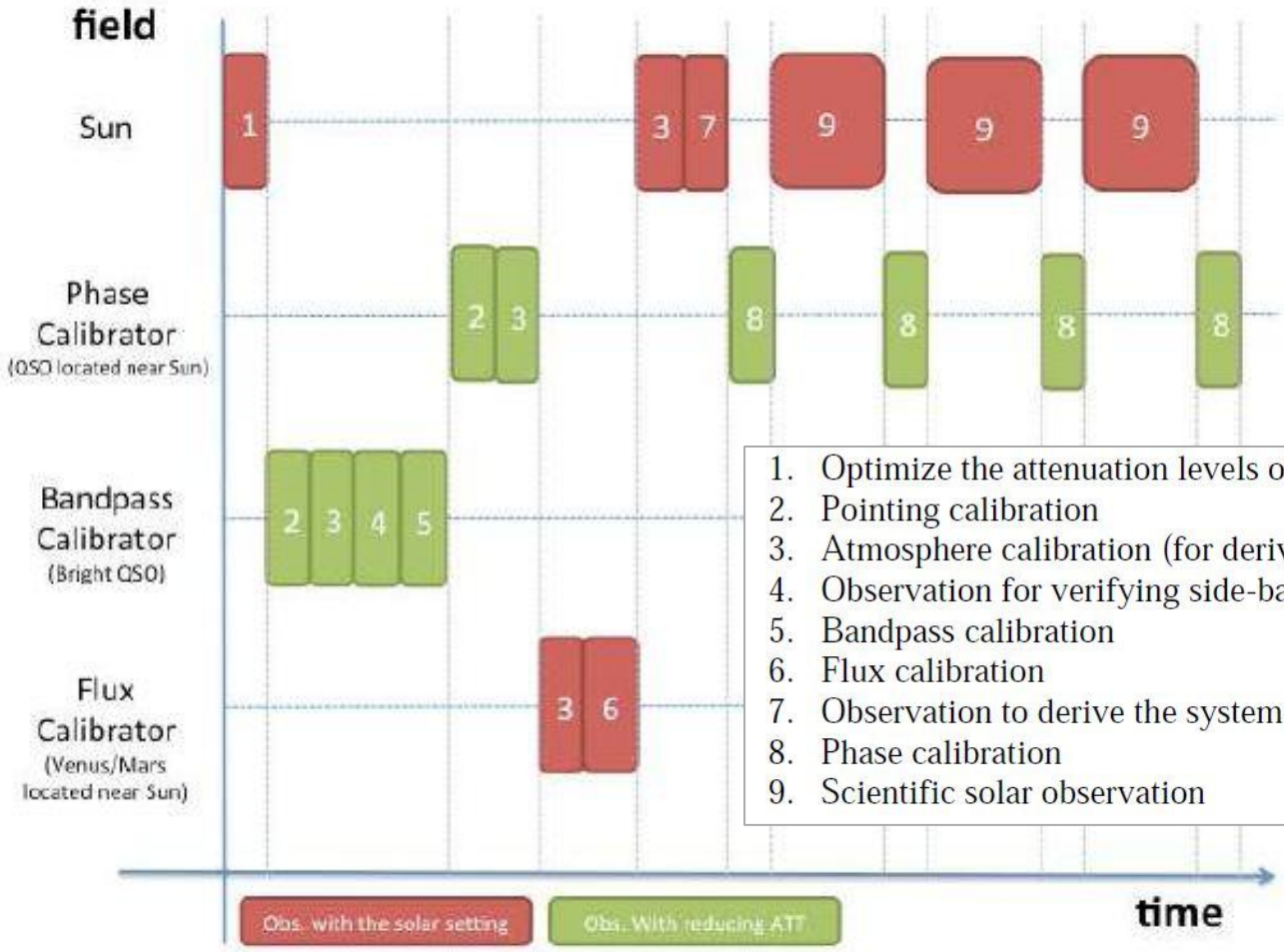
- Solar attenuators (“filters”)
  - Put them in the optical path for solar target, remove for P-cal (mechanicaly, carousel/robotic arm)
  - Large time overhead
  - Phase delays in filters depending on too many parameters, measurements of phase delays practically unreproducible
  - **Now mostly deprecated**

- Mixer detuning (+electronic attenuation)
  - **A new and hopefully working approach!**

Specifics of solar ALMA observations: Solutions for project execution

(M. Shimojo, I. Skokic)

„Extended“ Scheduling Block



1. Optimize the attenuation levels of the receiver
2. Pointing calibration
3. Atmosphere calibration (for deriving the system temperature on the sky)
4. Observation for verifying side-band separation
5. Bandpass calibration
6. Flux calibration
7. Observation to derive the system temperature on the target region
8. Phase calibration
9. Scientific solar observation

Specifics of solar ALMA observations: Solutions for post-processing

(M. Shimojo, A. Hales)

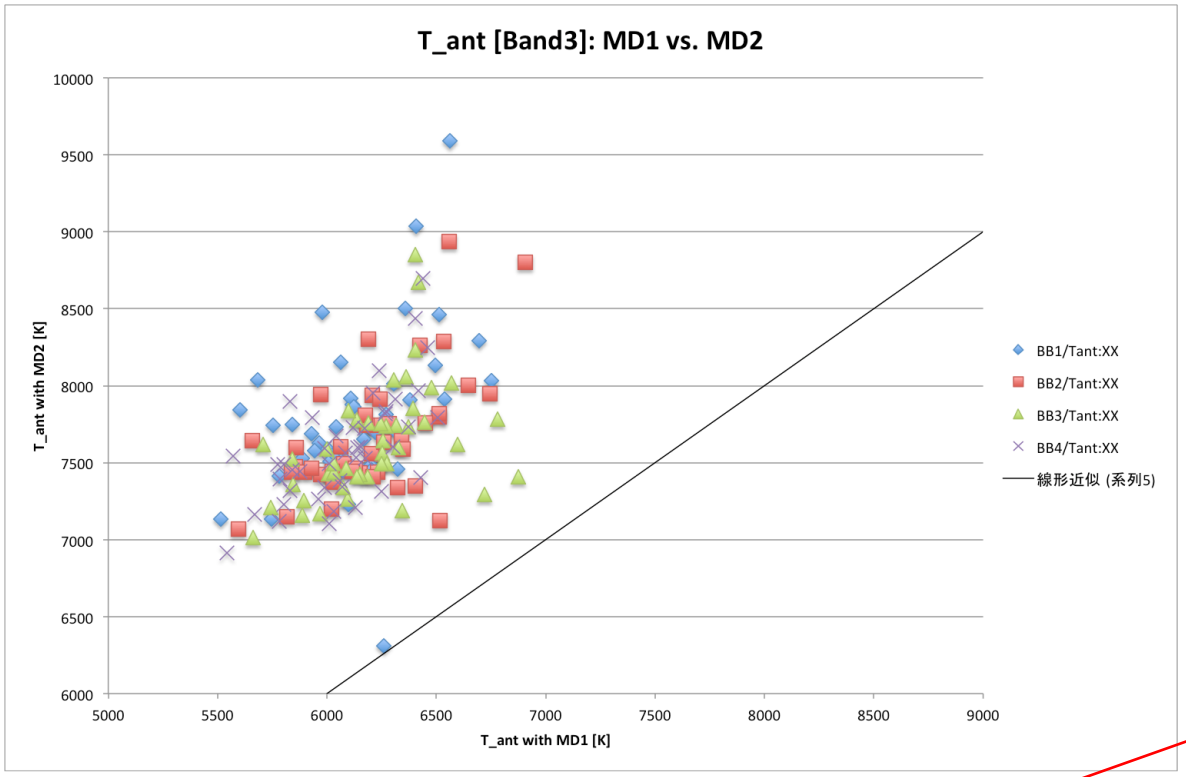
Mixer detunig approach – calibration issues

- Two modes for low/high dynamic range: MD1, MD2
- T_sys := T_sys + T_ant for solar observations (independent of MD mode). Need to calculate antena temperature
- MD may introduce instrumental phase delays – need to be corrected by additional calibration step?
- Signal saturation: Correction can be done via TP (single dish) observation

```
# CALIBRATE_ATMOSPHERE: Sun(Active Region w/Sunspot) J1058+0133 J0522-3627 J0854+2006
# CALIBRATE_BANDPASS: J1058+0133
# CALIBRATE_FLUX: J0522-3627
# CALIBRATE_PHASE: J0854+2006
# CALIBRATE_POINTING: J1058+0133 J0522-3627 J0854+2006
# OBSERVE_TARGET: Sun(Active Region w/Sunspot)

# Using reference antenna = PM03

# Import of the ASDM
mystep = 0
if(mystep in thesteps):
  casalog.post('Step '+str(mystep)+' '+step_title[mystep],'INFO')
  print 'Step ', mystep, step_title[mystep]

#=================================================
  if os.path.exists(mso) == False:
    importasdm(asdm = asdm, vis = mso,
               asis='Antenna Station Receiver Source CalAtmosphere CalWVR CorrelatorMode SBSummary CalDevice ')
#================================================= (added CalDevice to asis)
```

Specifics of solar ALMA observations: Solutions for data post-processing

(M. Shimojo, A. Hales)



Saturation correction factor – to be determined from TP obs

$$T_a = \left(\alpha P_{sun} - P_{off}\right) \frac{\left(P_{sky} - P_{zero}\right)}{\left(P_{off} - P_{zero}\right)\left(P_{hot} - P_{cold}\right)} \left(T_{hot} - T_{cold}\right)$$

Imaging Issues

- Multi-scale and diffuse data: Advanced clean methods to be used (MEM, multi-scale clean,…)

Testing of suggested solutions: Solar CSV campaign, Dec. 2014

Goals

Interferometric observations

- Verify use of mixer-detuning for attenuation of the solar signal
- Measure the differential phase delays for tuned (P-cal)/detuned (solar target) mode in Bands 3 and 6
  - Do this for different levels of attenuation (mode MD1/MD2)
- Try this strategy for various solar targets (quiet Sun, AR, prominence, filament,…)

Single dish observations

- Special scanning patterns for TP antennas: Fast scanning mode (more general applicability – not solar specific)

Testing of suggested solutions: Solar CSV campaign, Dec. 2014

Team

- EU ARC: M. Bárta (CZ node, Ondrejov), R. Brajša (CZ node, Zagreb)
- NA ARC: T. Bastian (NRAO), S. White (US Air Force Research Lab)
- EA ARC: M. Shimojo (NAOJ), S. Kazamusa (NAOJ/Nobeyama)
  + strong JAO support (T. Remijan, A. Hales, A. Hirota,…)

Testing of suggested solutions: Solar CSV campaign, Dec. 2014

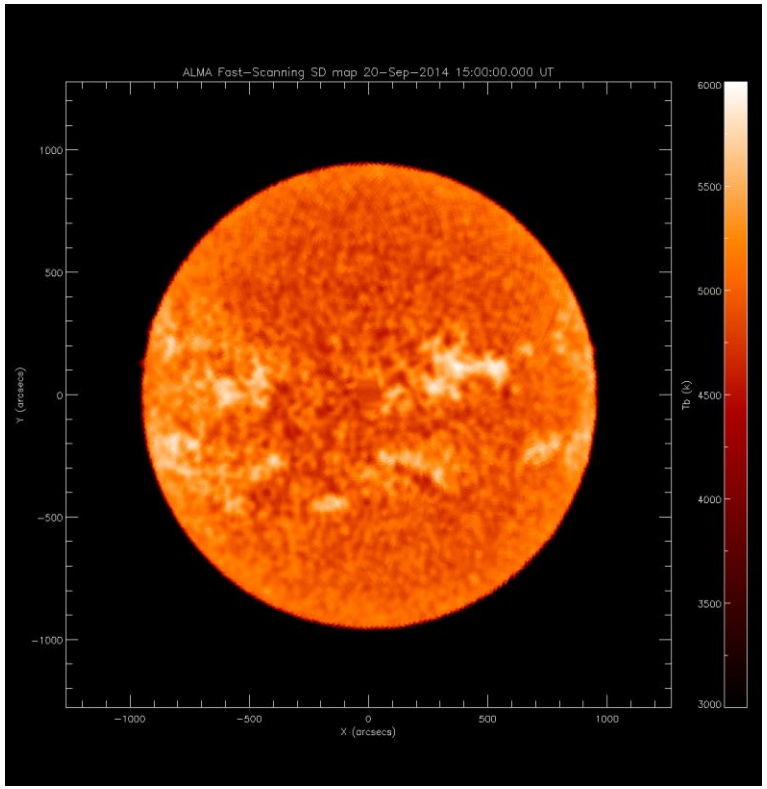
Results

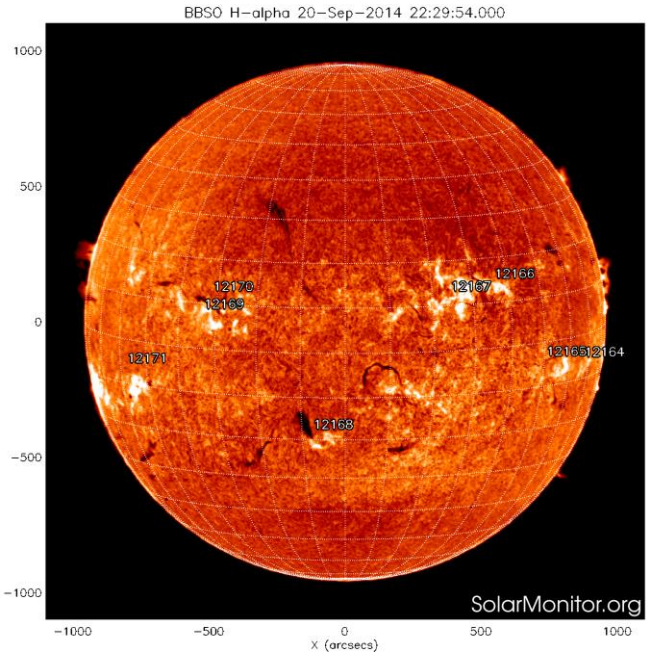
- MD1/MD2 modes work well in Bands 3 and 6. The instrumental phase delays introduced by MD is negligible.
- Obtained sensible preliminary images – more detailed calibration and analysis is required, in particular TP-based correction for flux calibration. Poor *uv* coverage with just ~10 antennas used.
- Fast scanning TP patterns give good images with tailored (non-CASA) SW. CASA SD imaging works well since version 4.3.

Testing of suggested solutions: Solar CSV campaign, Dec. 2014

Results

Whole-disc SD scan, continuum @230GHz (Band 6) – proprietary (R. Hills) SW for imaging

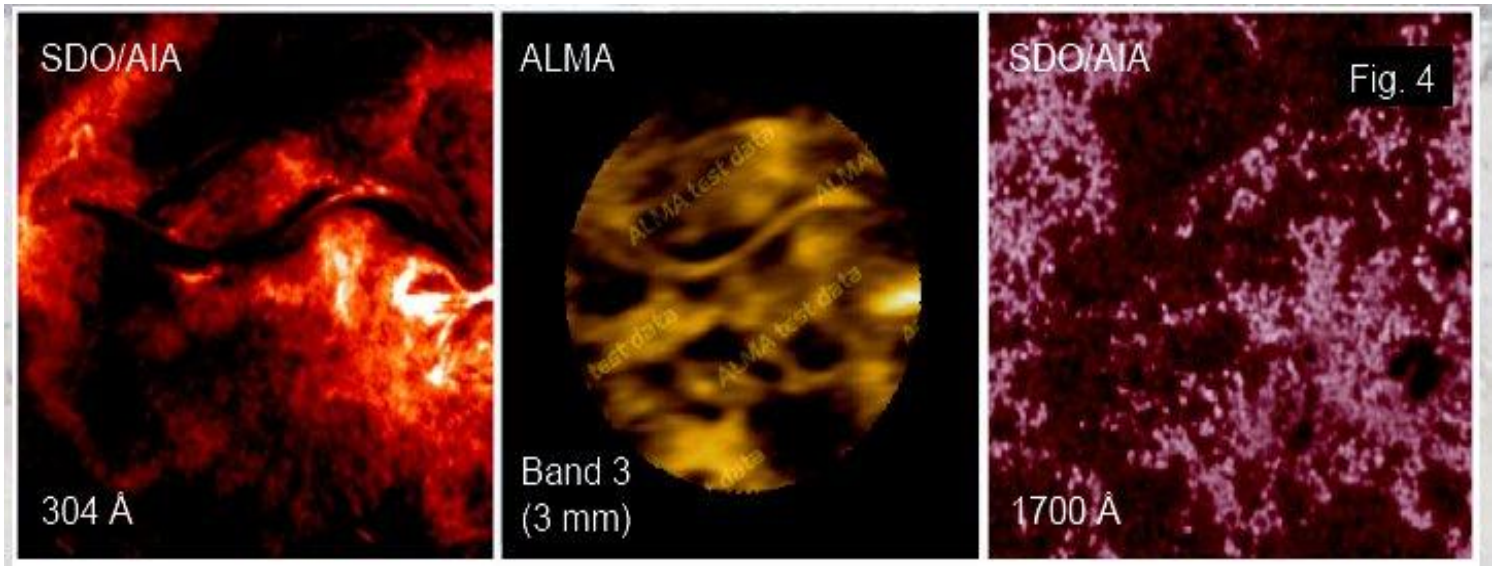




Testing of suggested solutions: Solar CSV campaign, Dec. 2014

Results

Continuum @100GHz (Band 3) Carefully calibrated in CASA, detuning delays and flux corrections incorp.



Testing of suggested solutions: Solar CSV campaign, Dec. 2014

Follow-ups

- Analysis of the acquired data (1st half of 2015)
- Extension/update of the ALMA OT (1st meeting in ESO Garching Jan 27, 2015)
  - Solar mode in general (a lot of tasks leaved for Phase II)
  - Timing/sensitivity calculator
  - MD modes
  - Ephemeris - external *Ephemeris Generator Tool* at least for Cycle 4)
- Based on analysis of the result a next solar CSV campaign is planned for **December 2015** (combined BL + ACA correlations, MD1 vs. MD2 – nonlinear flux calibration curve, mosaics, subarrays…)

Solar observations with ALMA: Cycle 4 and beyond

Cycle 4

Call for proposals: Spring 2016
Observations: Since Autumn 2016

Expected ALMA capabilities in solar mode:

- Band 3 and 6 (100GHz and 240 GHz)
- Single continuum only
- Small mosaics
- Time resolution 2s
- Compact configurations only (max. BL ~100m)
- ACA & TP support

***ALMA Community Days* for researchers in solar physics: Feb/March 2015 (to be announced soon), CZ ARC node, Prague**

Cycle 5 and beyond

New capabilities consecutivelly added: Other frequency bands, large mosaics, polarization, spectral lines (recombination, TiO, …), sub-arrays (multiple frequency bands), more extended configurations +ACA +TP

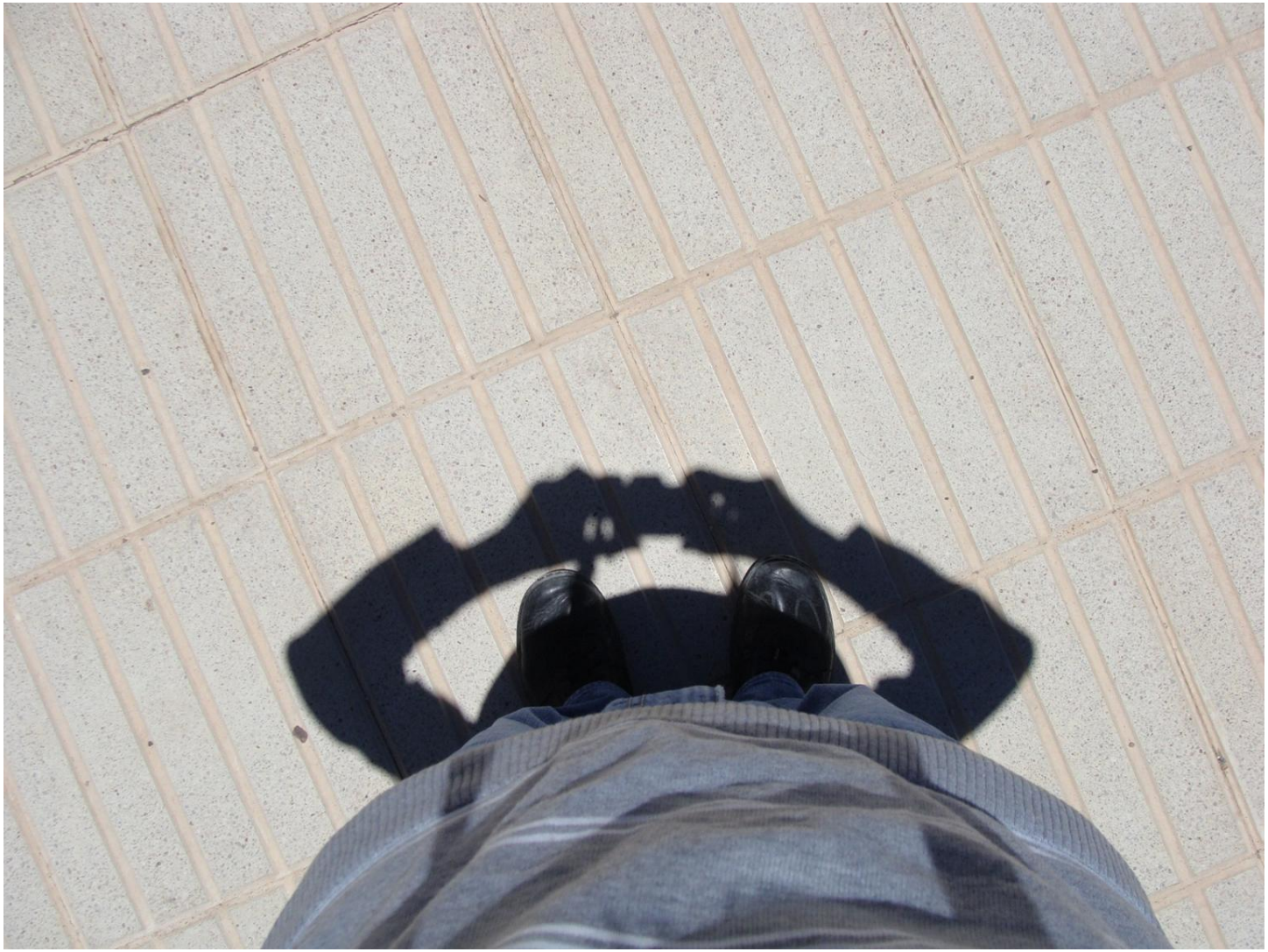
Summary

- ALMA is the largest ground-based observing facility of nowadays astronomy
- In spite it have not reached all its planned capabilities yet, it already brings break-through reveals in many branches of astrophysics
- We can expect revolutionary results in the solar physics soon, too. But before that a special observing mode has to be developer/commissioned
- ALMA is a cutting-edge facility but too technically complicated for many users with even bright ideas in astrophysics. Therefore, the user support infrastructure – three ARCs – has been formed in order to serve the researchers at all stages of their ALMA projects.
- The EU ARC is formed as a distributed coordinated network of seven nodes centered around the head at ESO in Garching bei Muenchen. One of the node has been formed at AI in Ondrejov. It has a unique role in the branch of solar research with ALMA among all the EU nodes: Now it develops (together with partners form NA and EA ARCs) the solar observing mode, later it shall serve as a support infrastructure for entire European solar physics community.

Links

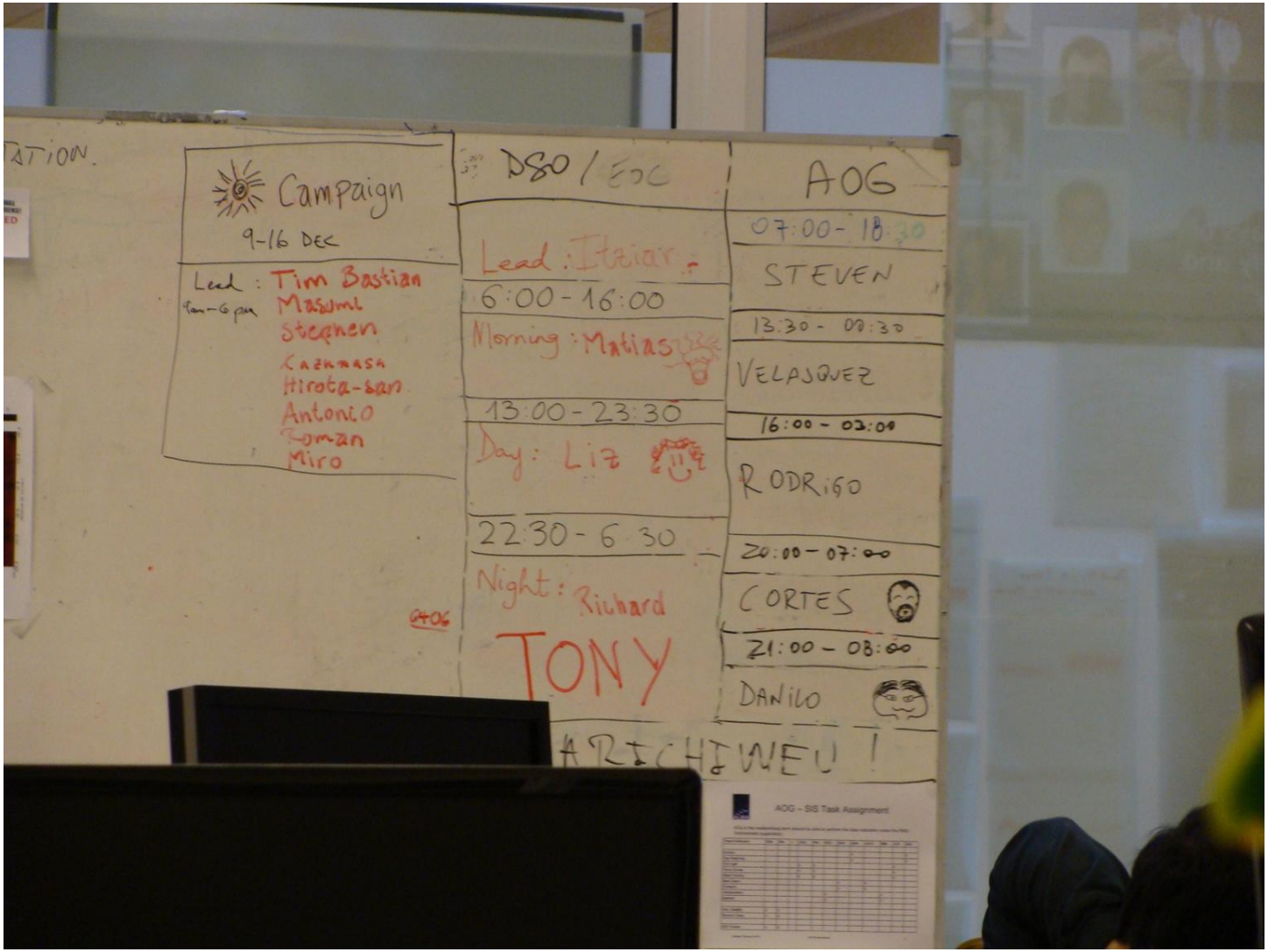
http://www.almaobservatory.org – ALMA observatory
http://www.almascience.org – User ALMA portal – hub to ARCs
https://www.eso.org/sci/facilities/alma/arc.html - European ARC @ ESO
http://www.asu.cas.cz/alma - EU ARC - Czech node


EXTREMO
PELIGROSO
ALTO
MEDIO
BAJO
SOLMAFORO
UV Rays Indicator
Alert
Maximum time of exposure (Minutes)
White tone skin
Matte tone Skin
Suggestion
Extreme 11 - 22 20 - 33 Avoid the sun, use protection
Dangerous 15 - 30 27 - 45 Seek the shade, wear long sleeve clothing and a hat
High 21 - 40 38 - 60 Put on sun block and wear a hat
Medium 30 - 80 54 - 120 You might stay outside with precaution
Low 75 - 240 135 - 360 You might safely stay outdoors with minimal protection
SOLMAFORO
INDICADOR DE RAYOS ULTRAVIOLETA
Alerta
Tiempo máximo de exposición (minutos)
Piel Blanca
Piel Mate
Sugerencia
EXTREMO 11 - 22 20 - 33 Evite el sol, use protección
PELIGROSO 15 - 30 27 - 45 Busque sombra, use manga larga y gorro
ALTO 21 - 40 38 - 60 Use bloqueador y gorro
MEDIO 30 - 80 54 - 120 Puede tomar sol con precaución
BAJO 75 - 240 135 - 360 Puede tomar sol sin peligro

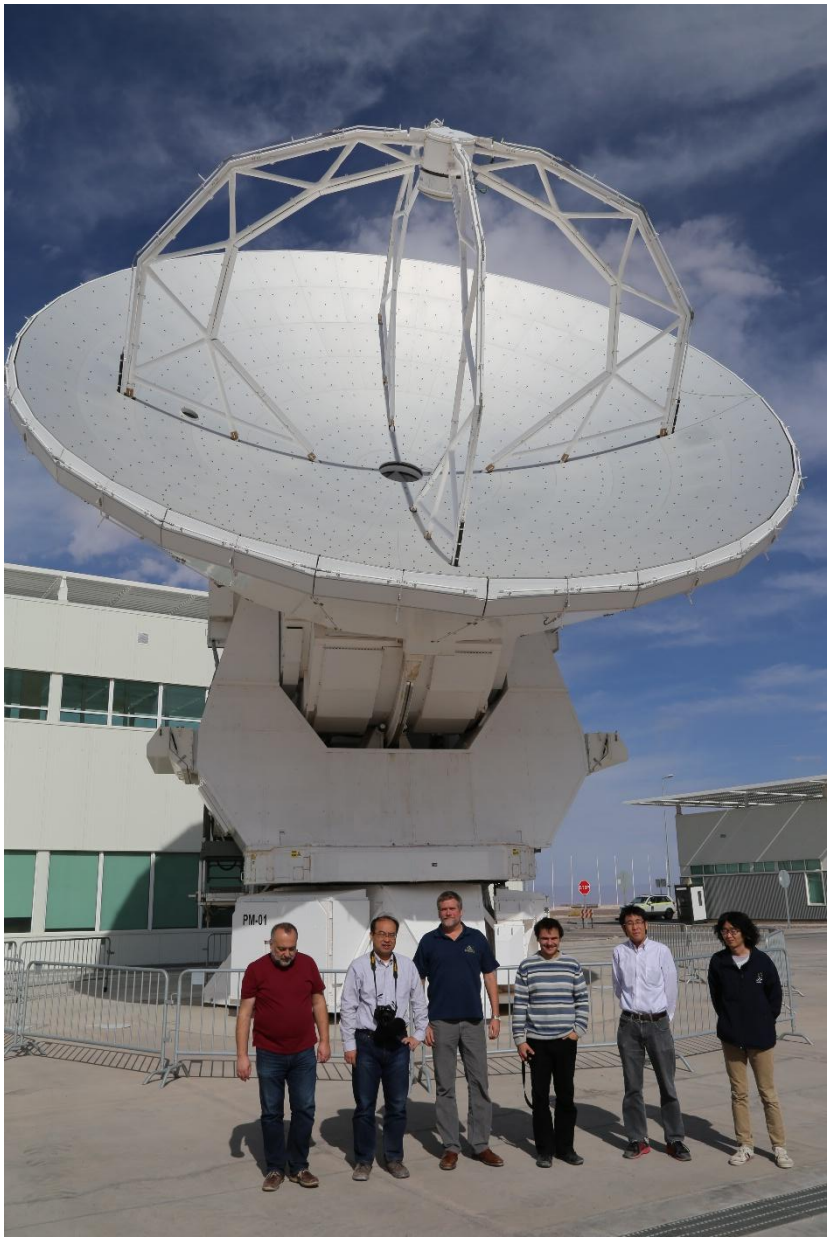



100
OXIGENO
MEDICINAL
INDURA
100
OXIGENO
MEDICINAL
OXIGENO MEDICINAL COMPRIMIDO
Una de las funciones fundamentales para
respirar, cuyo objetivo es simplemente lograr
oxígeno del aire sea atrapado en los pulmones
ser transportado a todas las células del cuerpo
lo necesitan para su metabolismo y vida.
Cuando no hay suficiente oxígeno disponible
funciones corporales se resienten y pueden
En estas circunstancias es vital contar con
INDURA S.A.
Las Américas 585
Cerrillos – Santiago


DV-02


Campaign
9-16 DEC
Lead : Tim Bastian
Masumi
Stephen
Kazunasa
Hirota-san
Antonio
Roman
Miro
DSO / EOC
Lead : Itziar
6:00 - 16:00
Morning : Matias
13:00 - 23:30
Day : Liz
22:30 - 6:30
Night : Richard
TONY
AOG
07:00 - 18:30
STEVEN
13:30 - 00:30
VELASQUEZ
16:00 - 02:00
RODRIGO
20:00 - 07:00
CORTES
21:00 - 08:00
DANILO
ARCHIVE !
AOG - SIS Task Assignment


SCHEUERLE
Otto


PM-01