New Synthesis Imaging Tool for ALMA based on the Sparse Modeling

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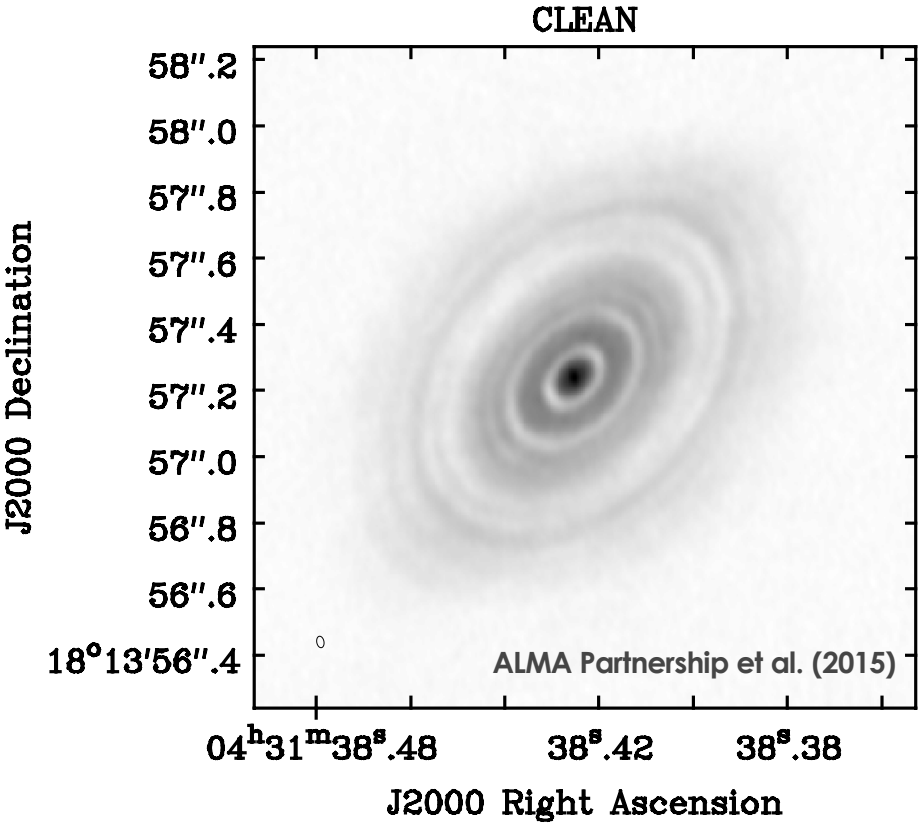
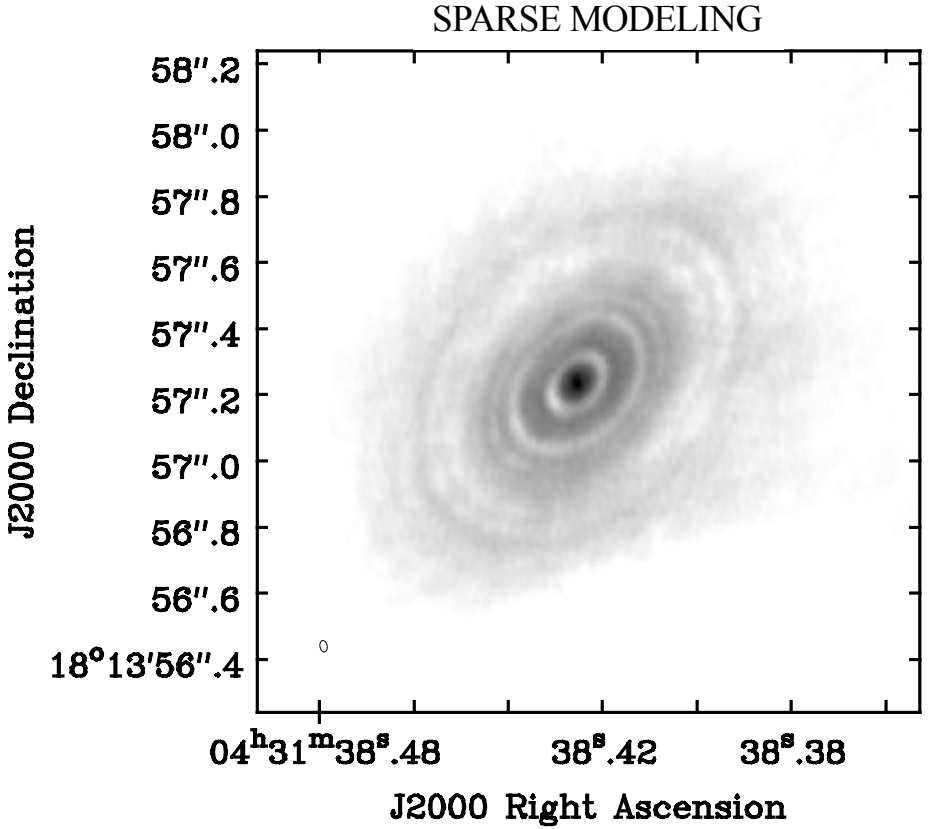
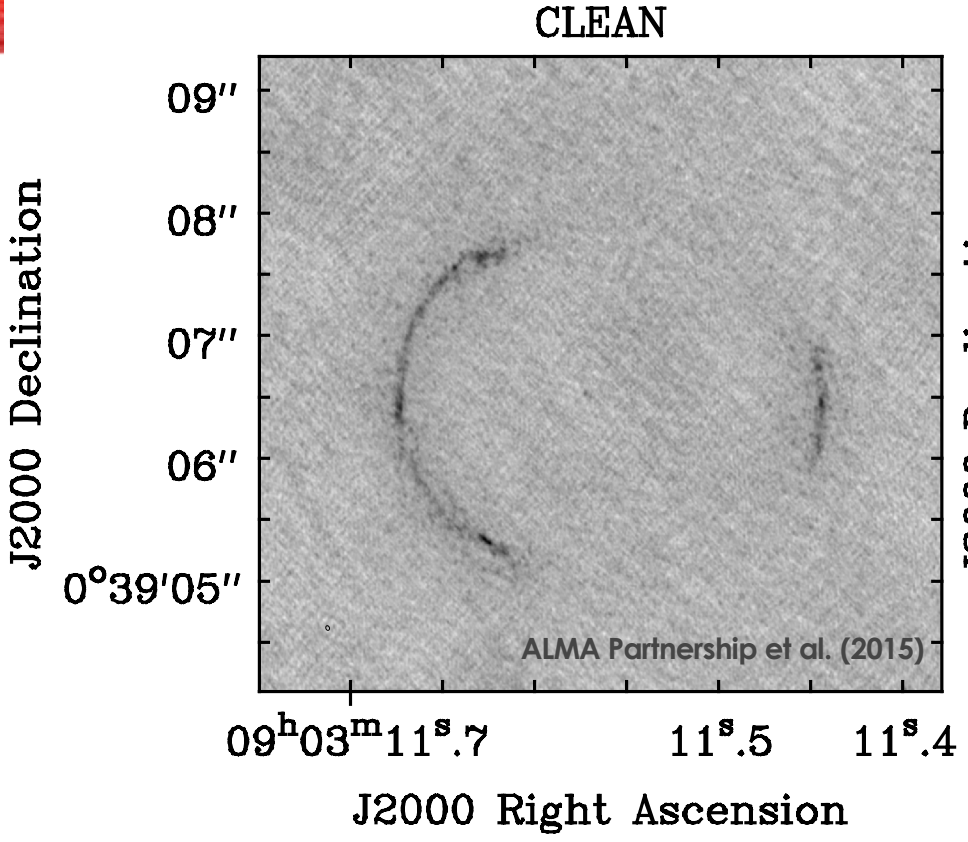
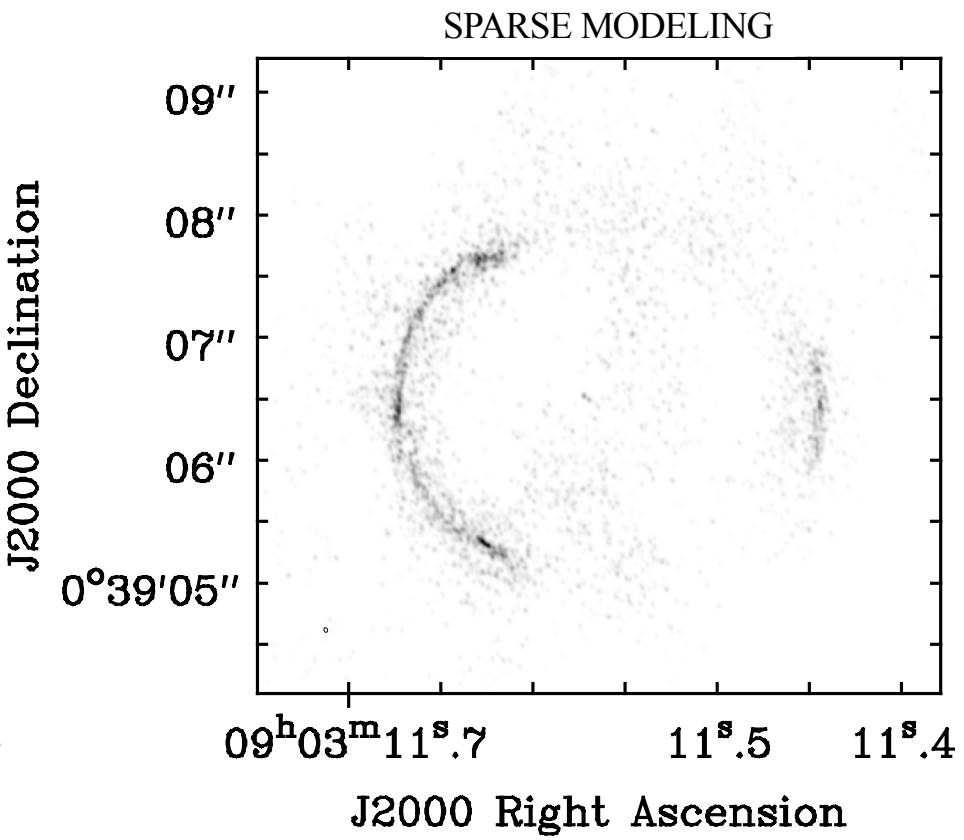
ALMA Long Baseline Campaign 2014: Protoplanetary Disk HL Tau





ALMA Long Baseline Campaign 2014: Lensed Galaxy SDP.81





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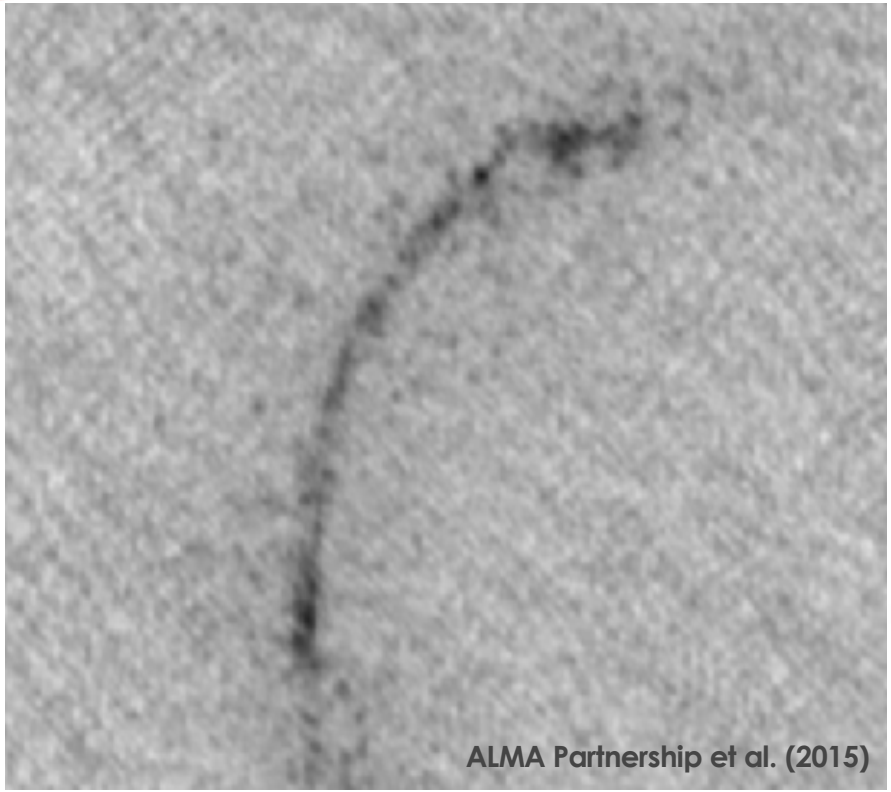

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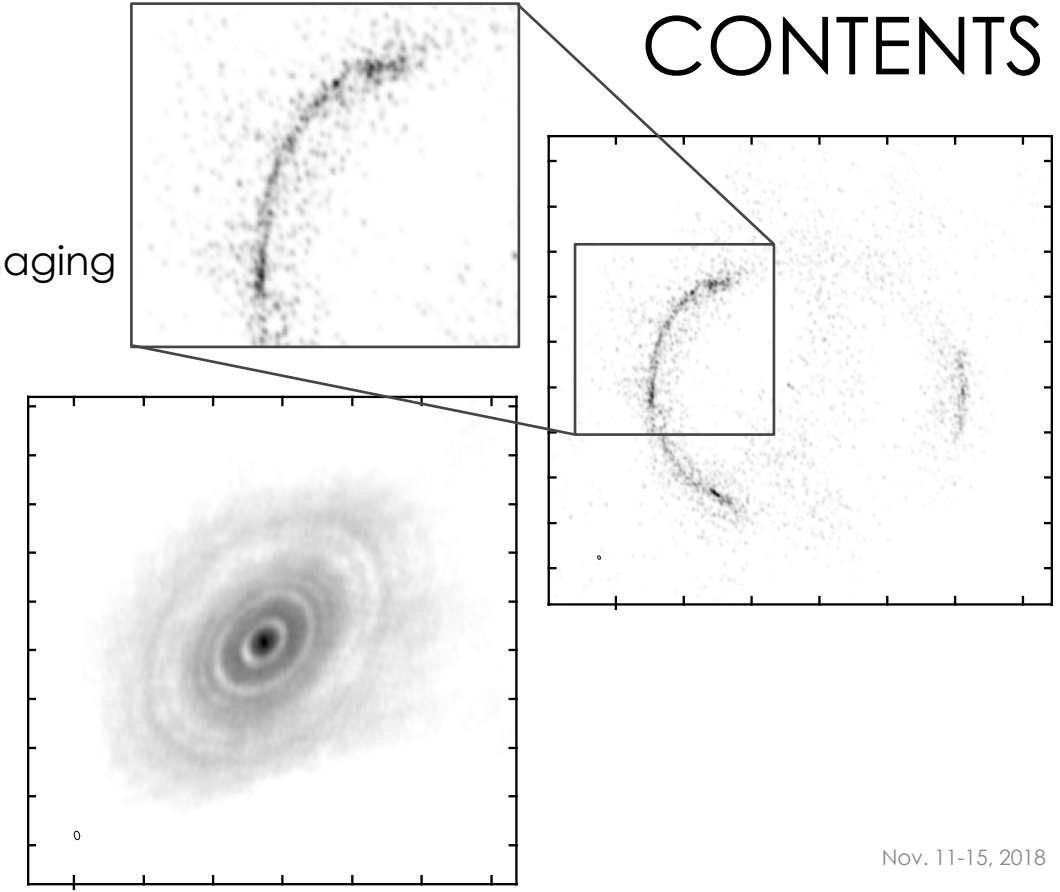


- Sparse Modeling
  - Application to Synthesis Imaging
  - Formulation
  - Cross-Validation
- PRIISM
  - What is PRIISM
  - Usage
  - Future Improvements
- Summary

SPARSE MODELING: APPLICATION TO SYNTHESIS IMAGING

- Based on recent results in statistics and information theory
  - Different from Maximum Entropy Method (MEM)
- Solve the problem under the constraint that the solution is **"sparse"**
- Useful for underdetermined problem (e.g. visibility sampling is incomplete)
- Originally designed for VLBI (Honma et al. 2014; Akiyama et al. 2017)
- We have developed the method for ALMA
  - can be imported into Common Astronomy Software Applications (CASA)
  - interact with MeasurementSet and produce FITS image
  - visibility gridding to handle enormous number of visibility data

SPARSE MODELING: FORMULATION

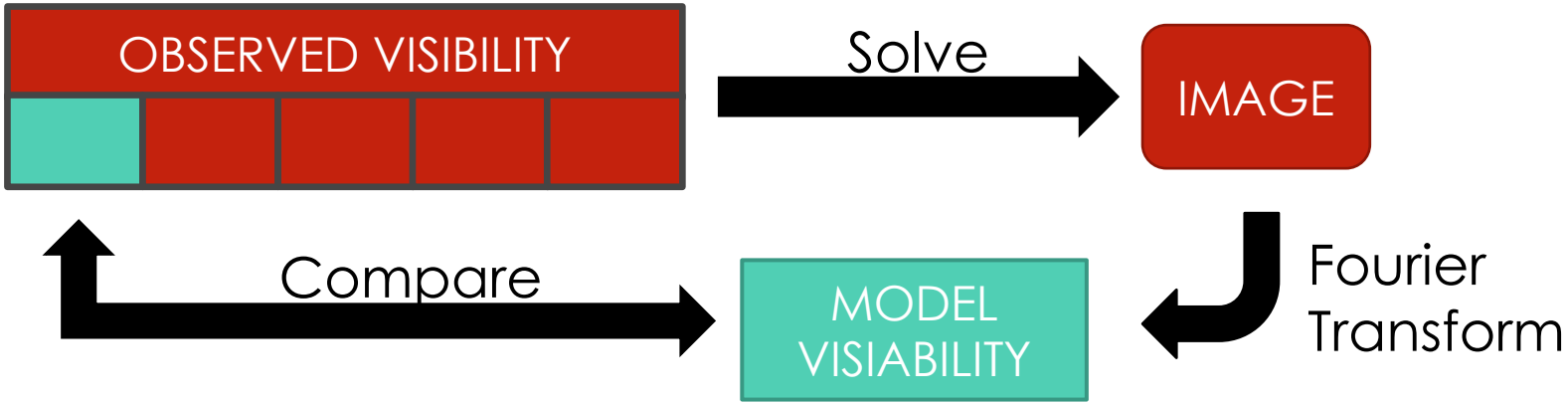
- It can be formulated as a least-square problem with constraints
- We minimize,

$$\frac{1}{2}|v - F(x)|^2 + \lambda_1|x| + \lambda_{\mathrm{TSV}}\mathrm{TSV}(x),$$

- Another constraint: Total Squared Variation (TSV) term
- TSV term is an indicator of the **"smoothness"** of the solution (Kuramochi et al. 2018)
- Given λ_1 and λ_{TSV}, we obtain the image x from the observed visibility v

SPARSE MODELING: CROSS-VALIDATION

- Both λ_1 and λ_{TSV} are free parameters and they must be optimized
- Optimal value depends on the property of the image to be reconstructed
- We introduced the **cross-validation** for this purpose



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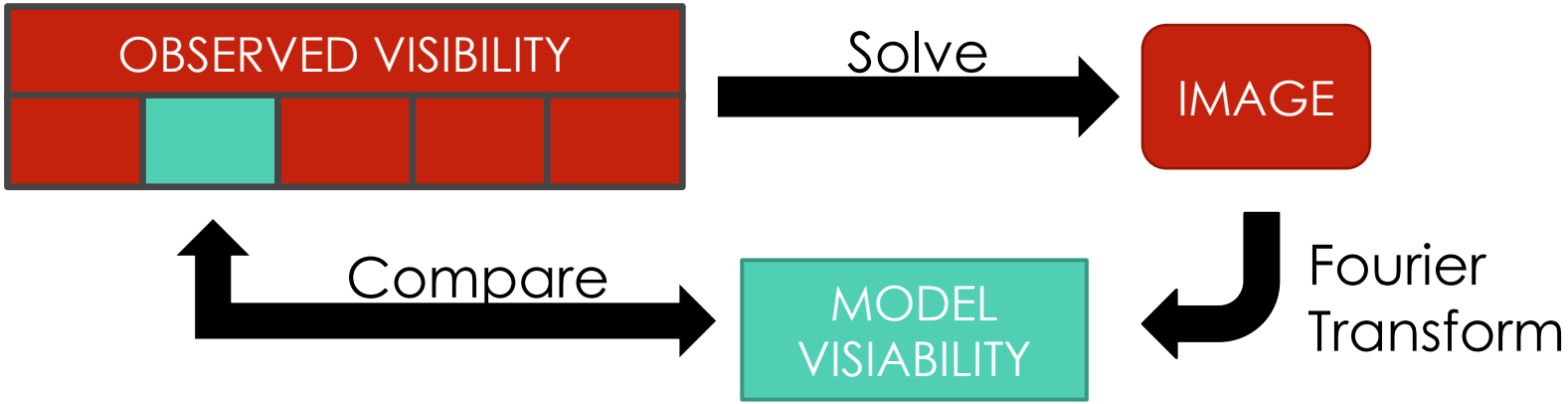

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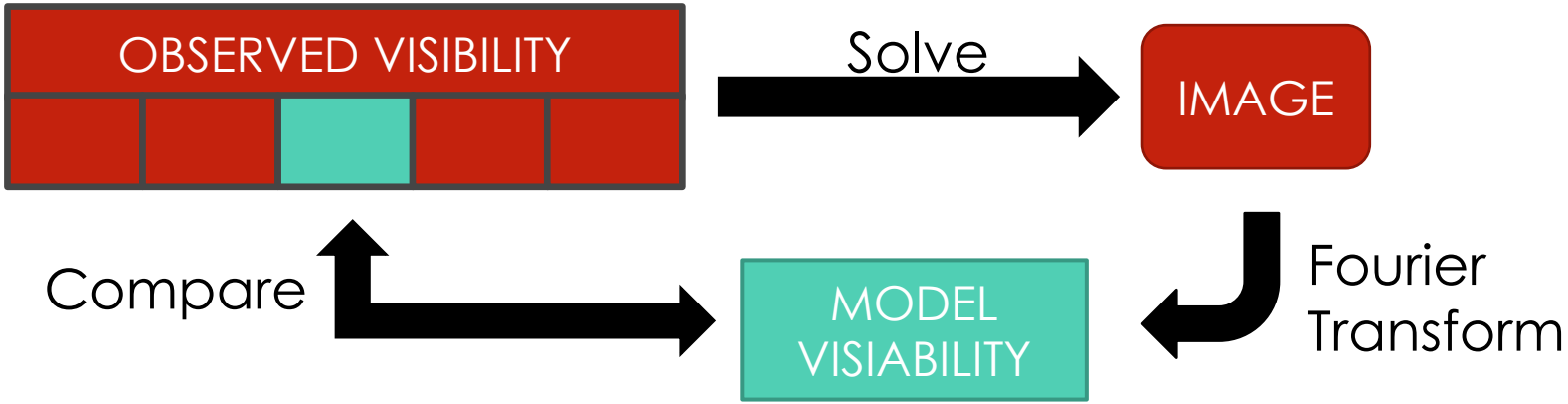

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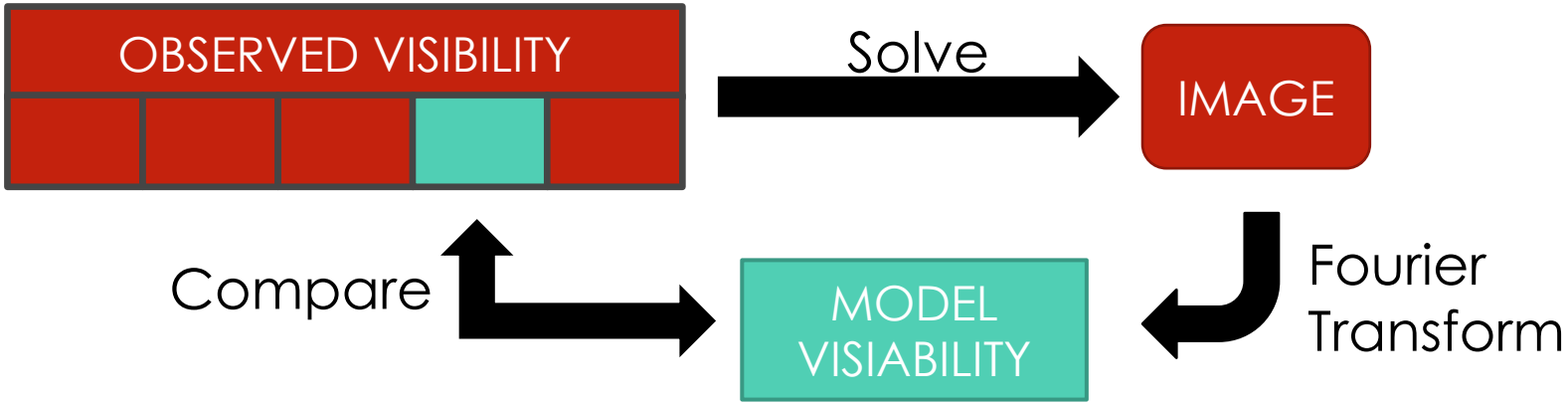

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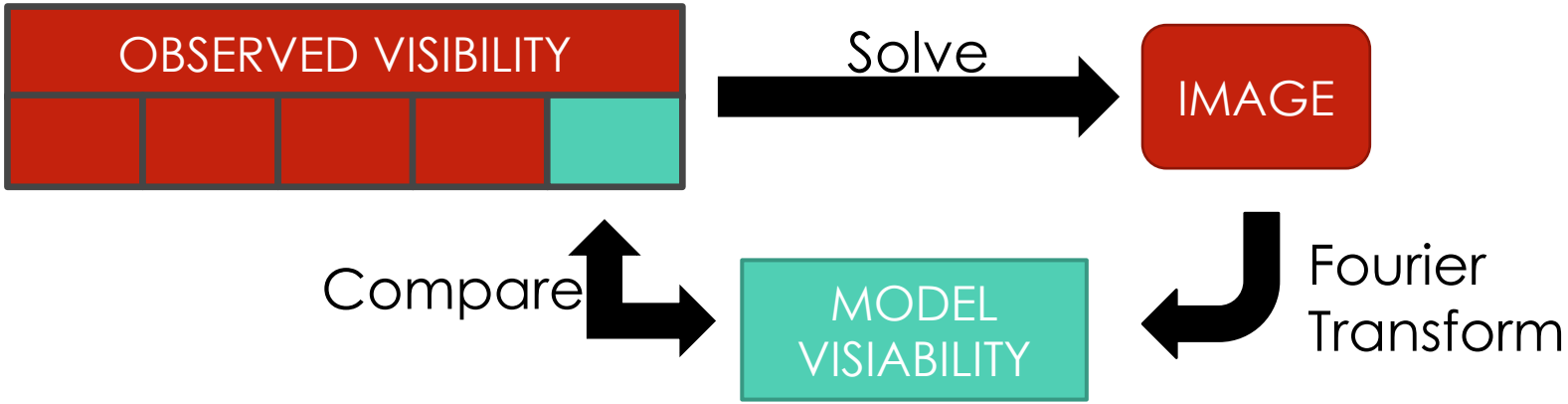


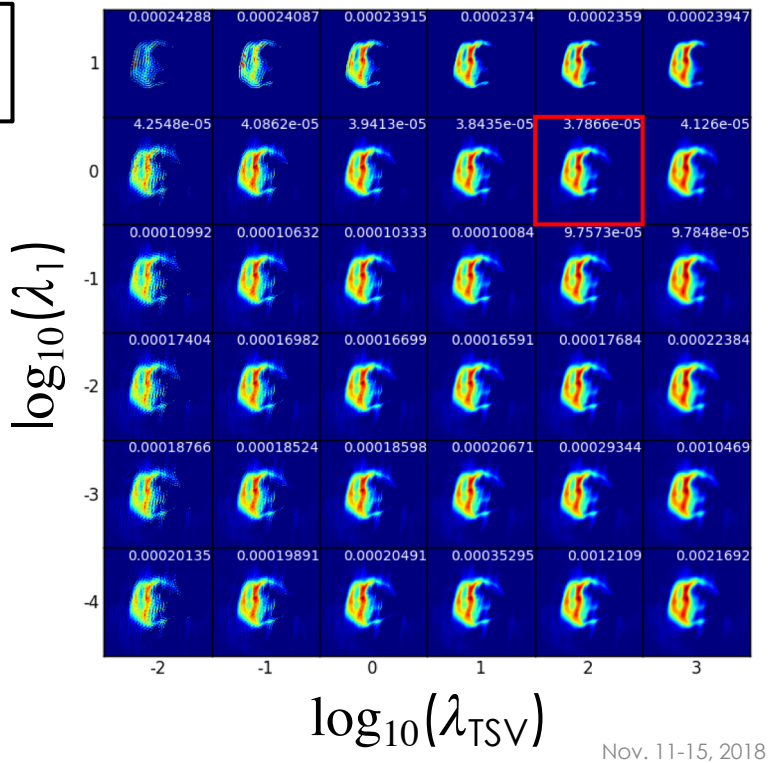
PRIISM: WHAT IS PRIISM

- **P**ython Module for **R**adio **I**nterferometry **I**maging with **S**parse **M**odeling
- Python module: `priism`
- `priism.core` – API for Python (2.7.x/3.x)
  - generic but primitive
- **`priism.alma`** – API for CASA
  - specific for ALMA
  - accepts MeasurementSet and produces FITS image
  - visibility data are gridded for FFT

PRIISM: USAGE

- **EASY:** only three steps
  1. configuration
  2. gridding
  3. cross-validation
- Template script
  - less than 60 lines incl. spaces and comments for readability
- **AUTOMATIC**
  - just `execfile`
  - might need multiple run to refine solution

Visualization of cross-validation result



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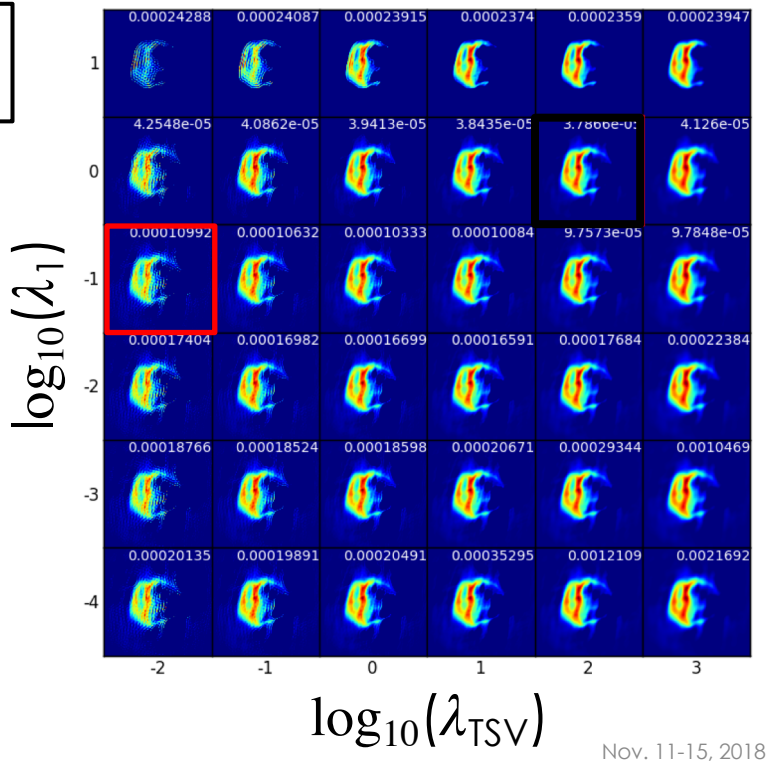

PRIISM: FUTURE IMPROVEMENTS

	CURRENT	FUTURE
Spectral Axis	Continuum Imaging	add Spectral Imaging capability
Stokes Axis	Stokes I	full Stokes (IQUV) support
Phase Center	fixed phase center	support of arbitrary phase center
Performance	bit time-consuming	better performance

SUMMARY

- PRIISM: Python implementation of sparse modeling for synthesis imaging
  - **EASY-TO-USE**
  - **AUTOMATIC:** no sophisticated setting (although time-consuming so far)
  - **ONGOING PROJECT:** continued effort for improvement
- Demo
  - HL Tau and SDP.81 from ALMA Science Verification Data
- Future Improvements
  - More functionality: spectral line image, full Stokes image
  - Performance
  - Super-resolution imaging

Thank you for your attention

Please contact takeshi.nakazato@nao.ac.jp if you are interested in PRIISM

P12.9 Kosugi et al.
"Qualification of Sparse Modeling Technique for radio interferometric imaging of ALMA"

P13.22 Yamaguchi et al.
"Super-resolution Imaging of the Protoplanetary Disk HD 142527 using Sparse Modeling"

This paper makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.00015.SV and ADS/JAO.ALMA#2011.0.00016.SV. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.