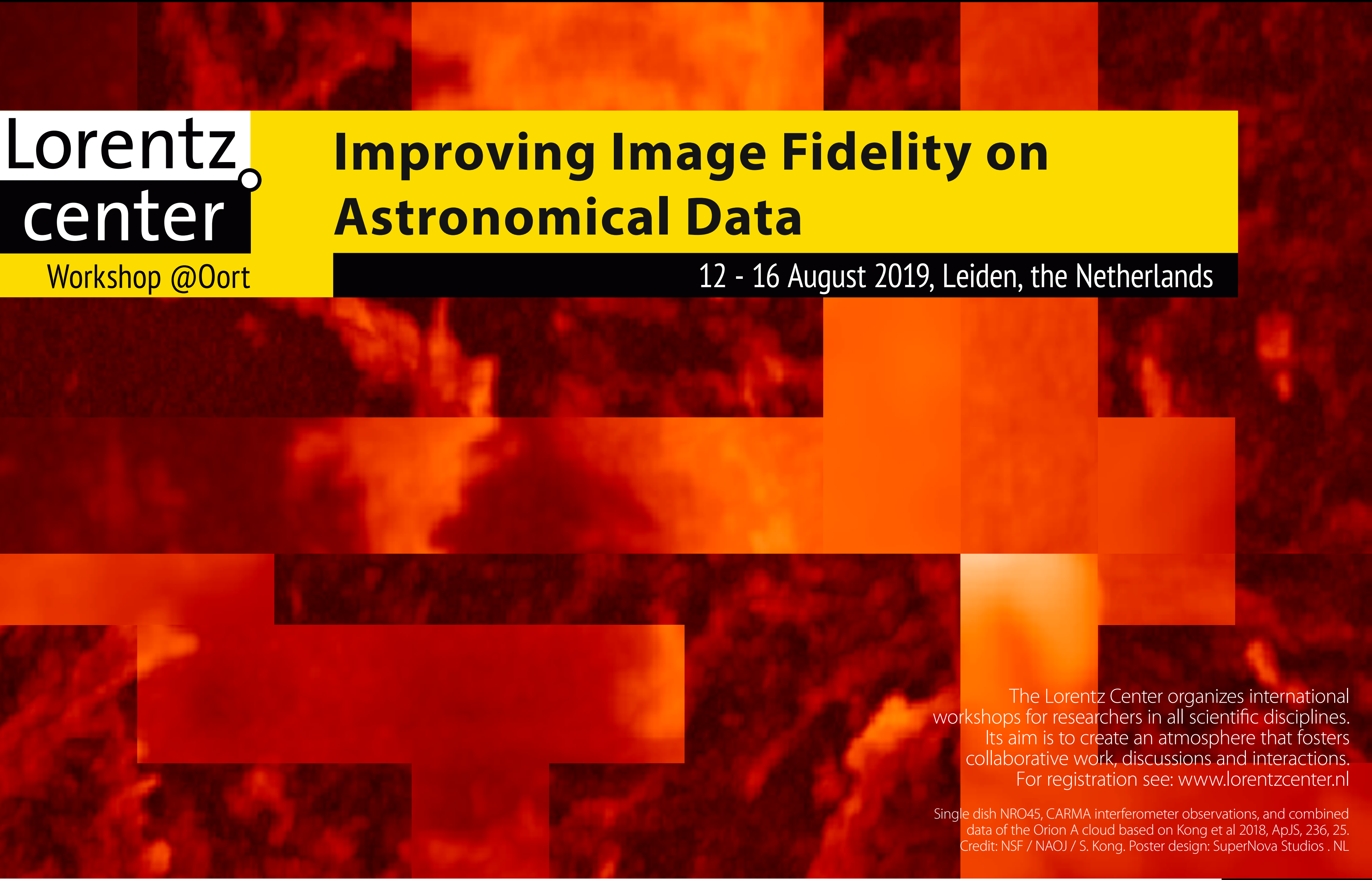

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Workshop @Oort

Improving Image Fidelity on Astronomical Data

12 - 16 August 2019, Leiden, the Netherlands

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Single dish NRO45, CARMA interferometer observations, and combined data of the Orion A cloud based on Kong et al 2018, ApJS, 236, 25. Credit: NSF / NAOJ / S. Kong. Poster design: SuperNova Studios . NL

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w w w . l o r e n t z c e n t e r . n l

On behalf of the scientific organizers:

Yanett Contreras	Leiden University, *Netherlands*
Hauyu (Baobab) Liu	Academia Sinica, *Taiwan*
Adele Plunkett	NRAO Charlottesville, *USA*
Álvaro Sánchez-Monge	University of Cologne, *Germany*

THANK YOU to:

Lizette Guzmán	Leiden University, *Netherlands*
Michelle Jonkers	Lorentz Center, *Netherlands*
Tara Seeger	Lorentz Center, *Netherlands*
Ed Fomalont	NRAO, *USA / Chile*
Dirk Petry	ESO, *Germany*
Nickolas Pingel	Australian National University, *Australia*
Thomas Stanke	ESO, *Germany*
Peter Teuben	University of Maryland, *USA*

… and thanks to all the **speakers** and **participants**!

https://www.lorentzcenter.nl/lc/web/2019/1179/participants.php3?wsid=1179&venue=Oort

Program

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>09:00 – 09:45</td><td>Registration</td><td>Feather</td><td>Low freqs.</td><td>Science I</td><td rowspan="3">Groups</td></tr>
<tr><td>09:45 – 10:15</td><td>Welcome</td><td>BREAK</td><td>BREAK</td><td>BREAK</td></tr>
<tr><td>10:15 – 11:00</td><td rowspan="3">Goals of the workshop</td><td>Joint</td><td>Extragalactic</td><td>Science II</td></tr>
<tr><td>11:00 – 11:45</td><td>Model</td><td>More tools</td><td>Discussion</td><td rowspan="2">Present Memos</td></tr>
<tr><td>11:45 – 12:30</td><td>QAC</td><td>Groups</td><td>Groups</td></tr>
<tr><td>12:30 – 13:15</td><td rowspan="2">LUNCH</td><td rowspan="2">LUNCH</td><td rowspan="2">LUNCH</td><td rowspan="2">LUNCH</td><td rowspan="2">LUNCH</td></tr>
<tr><td>13:15 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>Overview I</td><td rowspan="4">Groups</td><td rowspan="2">Groups</td><td>SDInt</td><td>Final notes</td></tr>
<tr><td>15:00 – 15:30</td><td>BREAK</td><td rowspan="3">Groups</td><td rowspan="5"></td></tr>
<tr><td>15:30 – 16:30</td><td>Overview II</td><td>Discussion</td></tr>
<tr><td>16:30 – 17:00</td><td>Discussion</td><td>BREAK</td></tr>
<tr><td>17:00 – 17:30</td><td rowspan="2">PARTY</td><td>Discussion</td><td rowspan="2">BOAT</td><td>Discussion</td></tr>
<tr><td>17:30 – 21:30</td><td></td><td></td></tr>
</table>

https://www.lorentzcenter.nl/lc/web/2019/1179/program.php3?wsid=1179&venue=Oort

Organizational information

We collect the documentation and relevant information at:

https://github.com/teuben/dc2019

*** Continues to be available after the workshop!*

contrib	Install scripts, makefiles, …
data	README with URL links to data
papers	Relevant references about data combination
scripts	Scripts, examples, …
talks	All the smart things people showed Recordings to come…

Communication via slack:

DataComb2019

GitHub
teuben/dc2019
Improving Image Fidelity on Astronomical Data: Radio Interferometer and Single-Dish Data Combination (workshop material) - teuben/dc2019

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Presentations

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Overview of Different Data Combination Methods [+Gaussian Simulation]

by Ed Fomalont

Real Data versus Simulations

Most of this workshop will deal with real ALMA mosaic+tp observations of interesting fields.

Alternative: Take some mosaic experiments, remove the observed data and replace with **known sky model**

Introduce TP image of this model data.

Test combination (feather vs tpvis vs other) results for these combined data sets.

Can also introduce most synthesis errors to determine their affects on the results.

What follows is a simple simulation result so far.

Outcome: Let's provide a library of known sky models for common structures, so users can test imaging when preparing and analyzing observations.

Galaxy Zoo has a nice flow chart of this for morphology classifications of galaxies. (See Willett et al. 2013)

Overview and state of the art of different data combination methods II *by Urvashi Rau*

- Really nice (mathematical) presentation of the methods
- Comparison of some combination methods in different reduction packages
- SDInt to be implemented in CASA (with follow-up tutorial from Tim)

AIPS : IMERG $I^{sdint} = F^{-1}\left[F[I^{interf}]_{high\,uv} + F[I^{sd(mod)}]_{low\,uv} + f\left(F[I^{interf}], F[I^{sd(mod)}]\right)_{overlap}\right]$

$$I^{sd(mod)} = I^{sd} \rightarrow Deconvolve(B_{sd}) \rightarrow Convolve(B_{interf})$$

MIRIAD : IMMERGE

CASA : Feather

$$I^{sdint} = F^{-1}\left[\left(1 - F[B_{sd}]\right) F[I^{interf}] + \frac{A_{interf}}{A_{sd}} \cdot F[I^{sd}]\right]$$

NOD3 : Immerge

$$I^{sdint} = I^{interf} + \frac{A_{interf}}{A_{sd}}\left(I^{sd} - I^{interf}\right)$$

+ others

Summary of Data Combination Methods

- **Image Combination :** When INT and SD images are both well-behaved
  - Effective and simple
  - Errors arise from trade-offs between flux accuracy and error control.
- **Start Model :** When INT and SD data overlap well in UV-space
  - Easy to use with existing image reconstruction solvers
- **Joint Reconstructions :** When deconvolution just needs more constraints from the data
  - SD+INT, joint mosaics, multi-frequency-synthesis before reconstruction.
  - More robust to relative weighting schemes than a single-step approach
  - Faster convergence, less divergence, less need for masks, more accurate model
  - Instability can occur when the data do not match a uniform instrument model

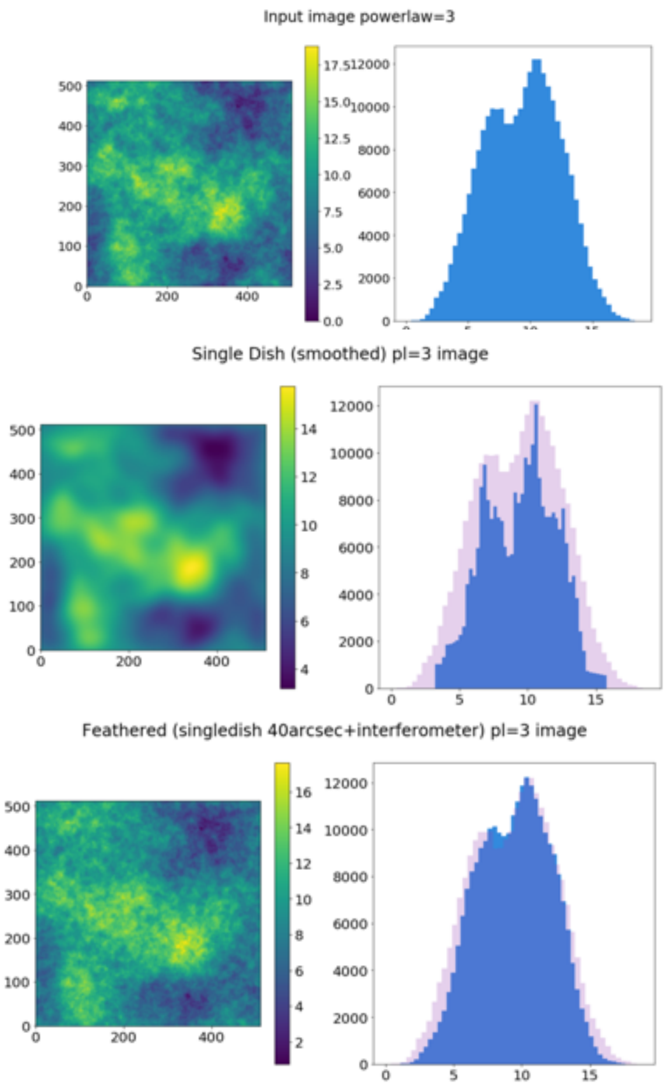
[[Roadmap for the user…]]

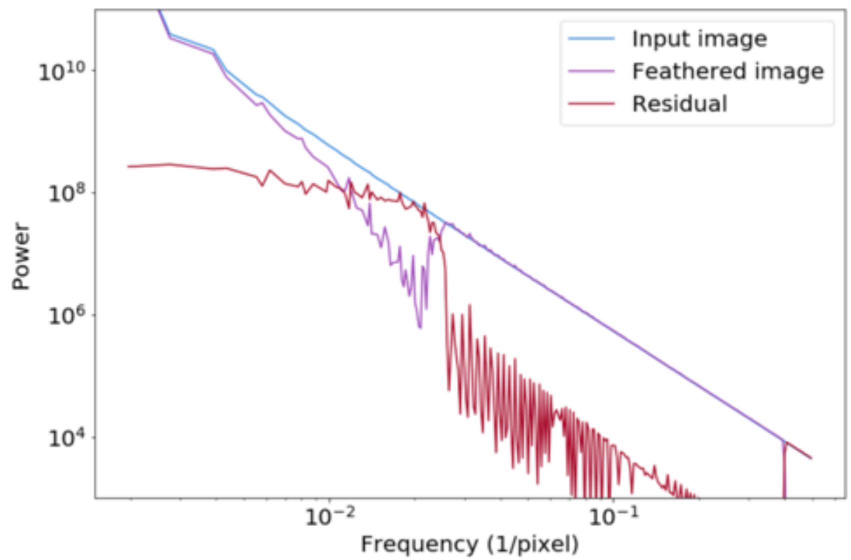
“The feathering technique”

by Adam Ginsburg

Input Image Visualization

This is the input image along with its histogram.



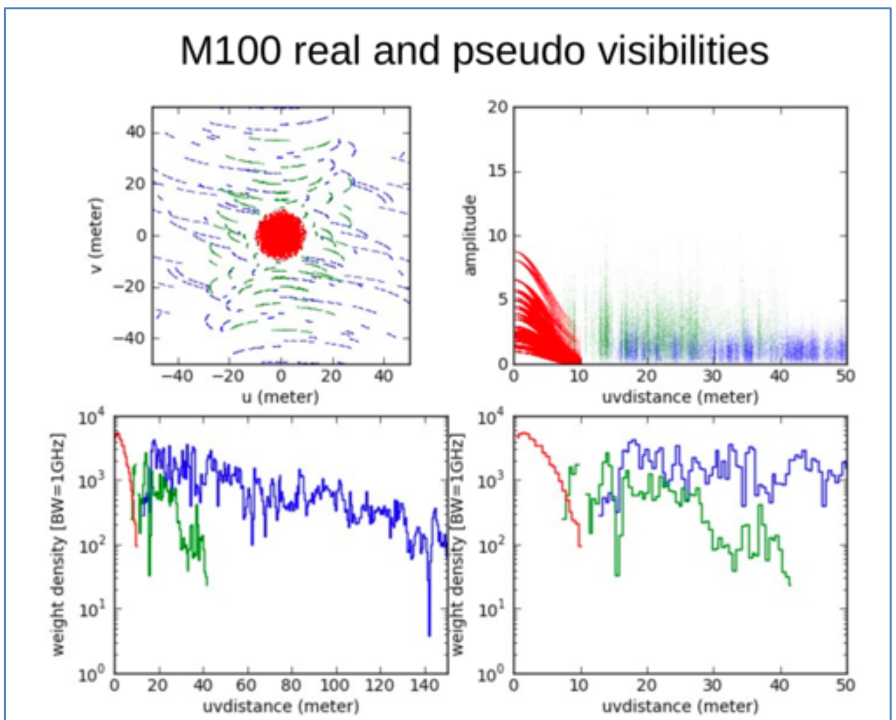


Outcome: (1) Be aware of which scales you are recovering.
(2) Test against simulated data so you know the “right” answer.

TP2VIS: Total Power to Visibilities Joint Deconvolution of ALMA 12m, 7m and TP in CASA

by Peter Teuben

- See Koda et al. (2019)
- tp2vis public release (v1.0) https://github.com/tp2vis/distribute



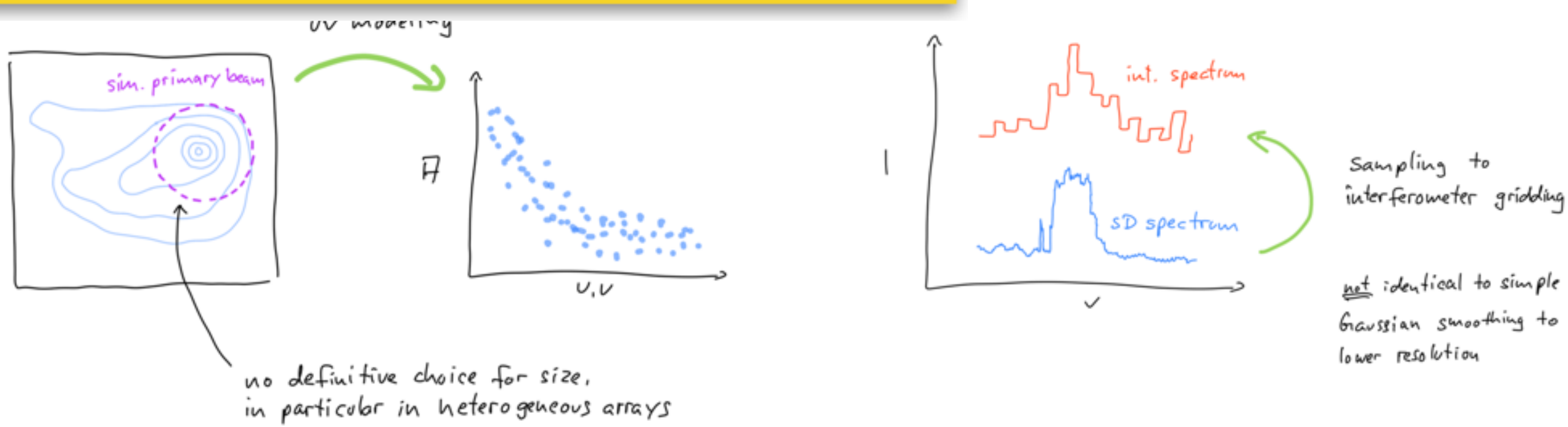
Outcome: We should be assessing the data we input in order to make the best possible combined image. Tp2vis has a really nice tp2vispl command for this.

Model Based Deconvolution

by Jens Kauffman

- http://tinyurl.com/zero-spacing for details

Other Lessons



* remain vigilant
* check intermediate products

Data combination at low frequencies

by Pedro Salas

The problem is the same:

$$\hat{F}(0,0) = \int\int F(l,m)dldm$$

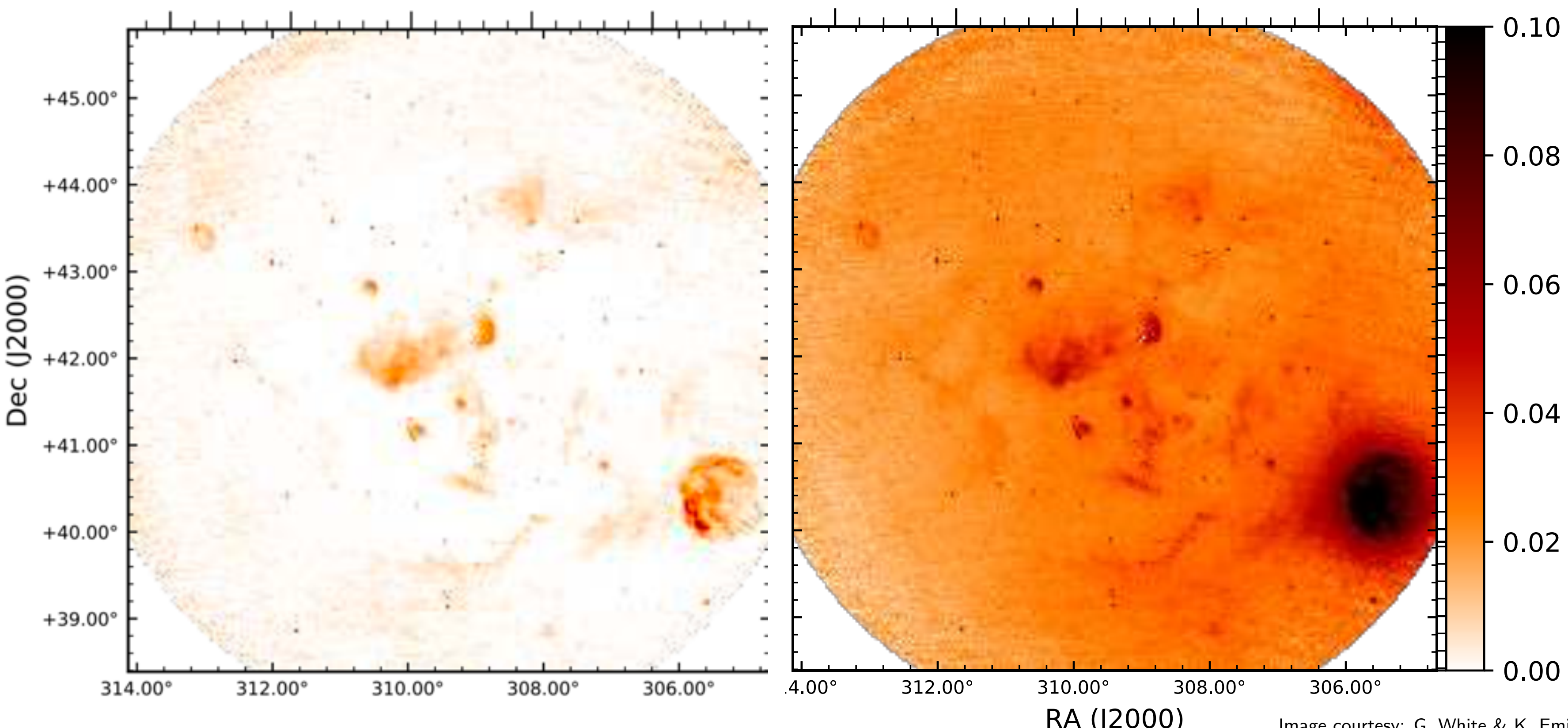


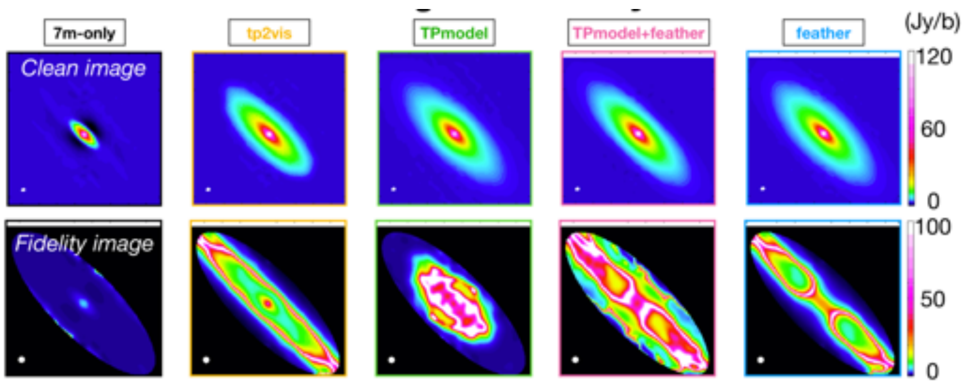
Image courtesy: G. White & K. Emig

Outcome: Let's bridge the communities.

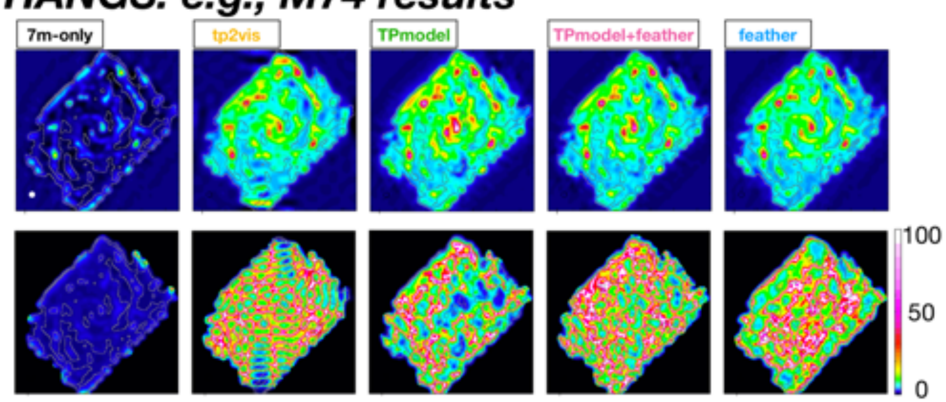
Data combination in PHANGS-ALMA Studies

by Toshiki Saito

Try to quantitatively evaluate the impact of short-spacing correction methods (SSCs) on extragalactic data by (1) using a simple model and (2) taking advantage of the sample size of PHANGS-ALMA.



PHANGS: e.g., M74 results



- We found all tested SSC methods are consistent within ~10% in terms of total flux and peak flux.
- Target galaxy size and flux do not affect the image fidelity.

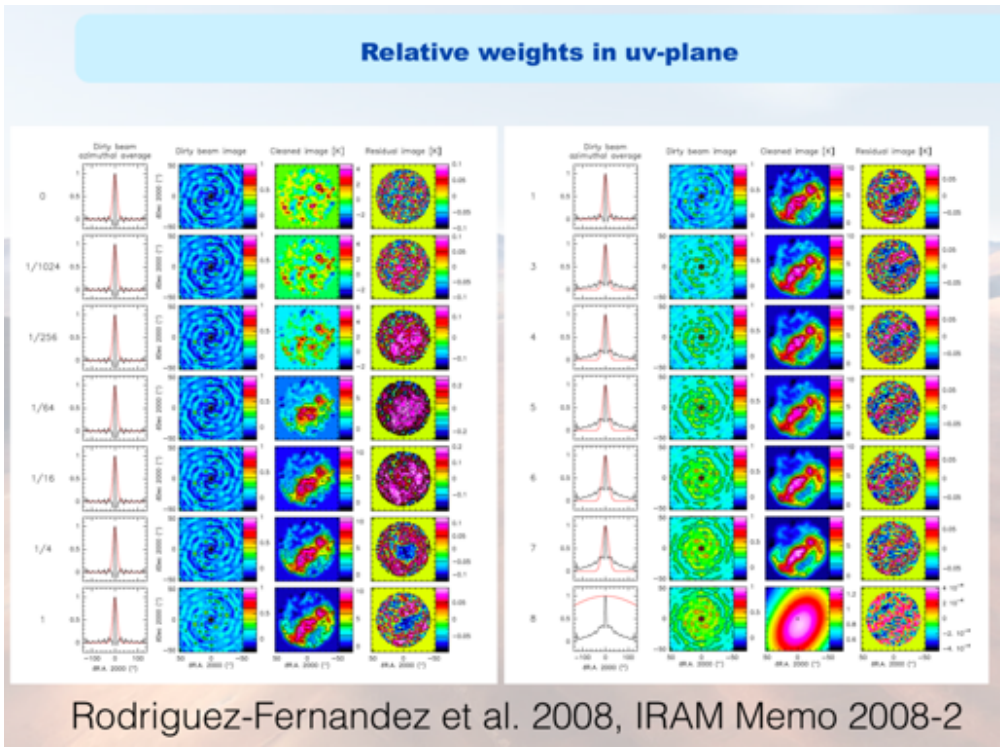
Caveats

- Improve TPmodel SSC according to Jens' talk
- uv fidelity instead of image fidelity (e.g., ALMA memo 488)
- 3D datacube (i.e., velocity structure)
- Multi-scale clean
- Flux calibration error
- Simulating 12m data
- Role of thermal noise/phase noise
- How to evaluate

Outcome: We should all become modelers like Toshiki!

How to apply the different methods, and what is missing

by Sandra Burkutean



Rodriguez-Fernandez et al. 2008, IRAM Memo 2008-2

What about wavelets ?

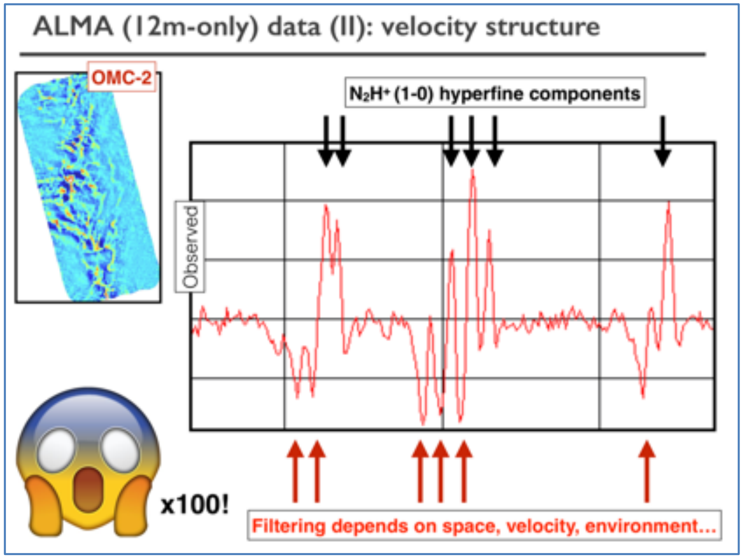
It would be worth looking
into INTF+SD MEM combination methods !

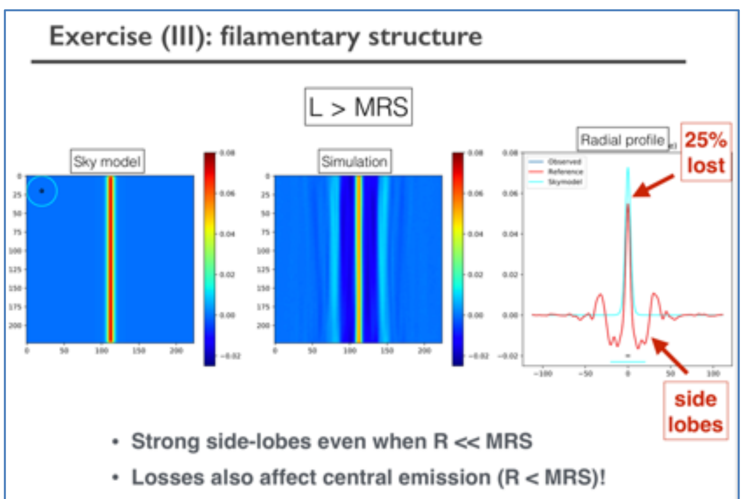
What about Bayesian approaches ?

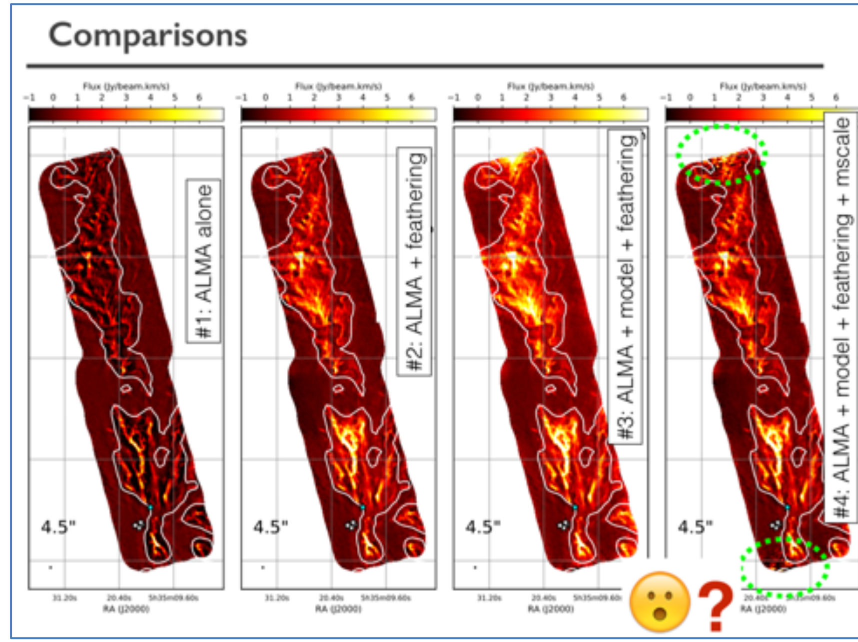
Outcome: (1) Thank you for adapting your talk to the emerging questions.
(2) We should consider how Machine Learning can drive these techniques.

Galactic studies, and the need of combining data

by Alvaro Hacar







Outcome: (1) Extended emission affects everything;
(2) Can we improve upon this table?
The reality is more complex.

Maximum Recoverable Scale (MRS) (I)

$$\boxed{\theta_{MRS} \approx 0.6\lambda/L_{min}}$$

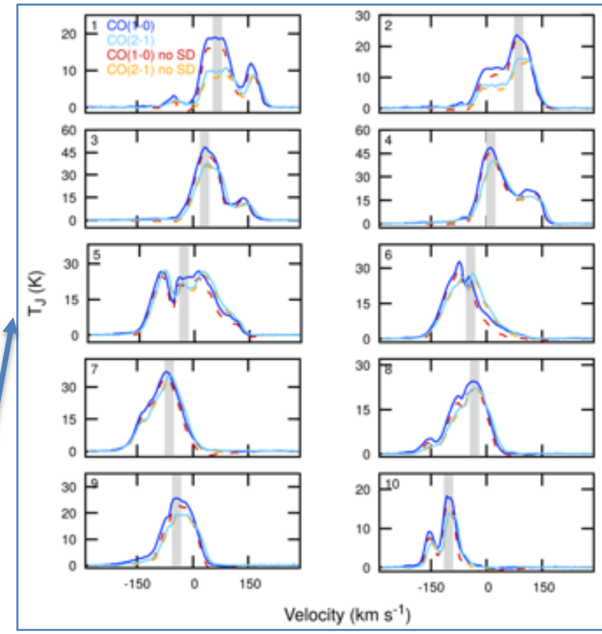
	Band	3	4	5	6
	Frequency (GHz)	100	150	185	230
Configuration					
7-m	θ_{res} (arcsec)	12.5	8.35	6.77	5.45
	θ_{MRS} (arcsec)	66.7	44.5	36.1	29.0
C43-1	θ_{res} (arcsec)	3.38	2.25	1.83	1.47
	θ_{MRS} (arcsec)	28.5	19.0	15.4	12.4
C43-2	θ_{res} (arcsec)	2.3	1.53	1.24	0.999
	θ_{MRS} (arcsec)	22.6	15.0	12.2	9.81
C43-3	θ_{res} (arcsec)	1.42	0.943	0.765	0.615
	θ_{MRS} (arcsec)	16.2	10.8	8.73	7.02
C43-4	θ_{res} (arcsec)	0.918	0.612	0.496	0.399
	θ_{MRS} (arcsec)	11.2	7.5	6.08	4.89

ALMA Handbook

MRS ~30" @ 1kpc < 0.15 pc
MRS ~30" @ 140pc < 0.02 pc

Most of the ISM emission filtered out by ALMA!!

“Extragalactic studies, and the need of combining data” *by Cynthia Herrera*



- NUGA (Krips +2005)
- PAWS (Schinnerer+2013)
- NGC253 (Bolatto+2013)

  Zschaechner + 2018: impact of including SD, up to 50%
- ALMA- PHANGS (PI: Schinnerer)

Outcome: Gildas/Mapping, comparison with CASA? Other comparisons would be informative, especially looking into the maths behind the tools.

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Summary of working groups

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Working groups

Datasets for the hands-on working sessions (groups):

1. **M100** (ALMA 12m + 7m + TP) #m100
2. **NGC346 in the SMC** (ALMA 7m + TP) #ngc346
3. **GMC fractal/powerspectrum model** (synthetic observations) #skymodel
4. **Gaussians model** (synthetic observations) #wg_simulations-sky_is_gaussian
5. **Protostellar outflows** (ALMA 12m + 7m + TP) #lupusoutflow_workgroup
6. **HI observations** (GBT + WSRT / LOFAR) #hi_working_group

Working groups

Combination techniques:

Feathering
This method uses to individually created images and combines them in the Fourier transform plane.

Joint deconvolution
Combines the interferometer and single-dish data in the uv plane, and images the combined set of visibilities.

[[Model-assisted cleaning]]
Uses the single-dish image as a model to clean the interferometer data, and then finishes the process feathering the images.

SDInt
Joint deconvolution of wideband single-dish and interferometer data

… (+ others)

Assessment…

	Feathering	TP2VIS	SDInt	Other?
#m100				
#ngc346				
#skymodel				
#wg_simulations-sky_is_gaussian				
#lupusoutflow_workgroup				
#hi_working_group				

Luke Maud 6:39 AM
Can we all list what we got succesffully?

Luke: feather - OK, tp2vis: NO, SDint: NO

Veena V S 7:57 AM
Veena: Feather - OK; TP2VIS - NO; SDINT - OK

1. **M100** (ALMA 12m + 7m + TP)

Adjust parameters:

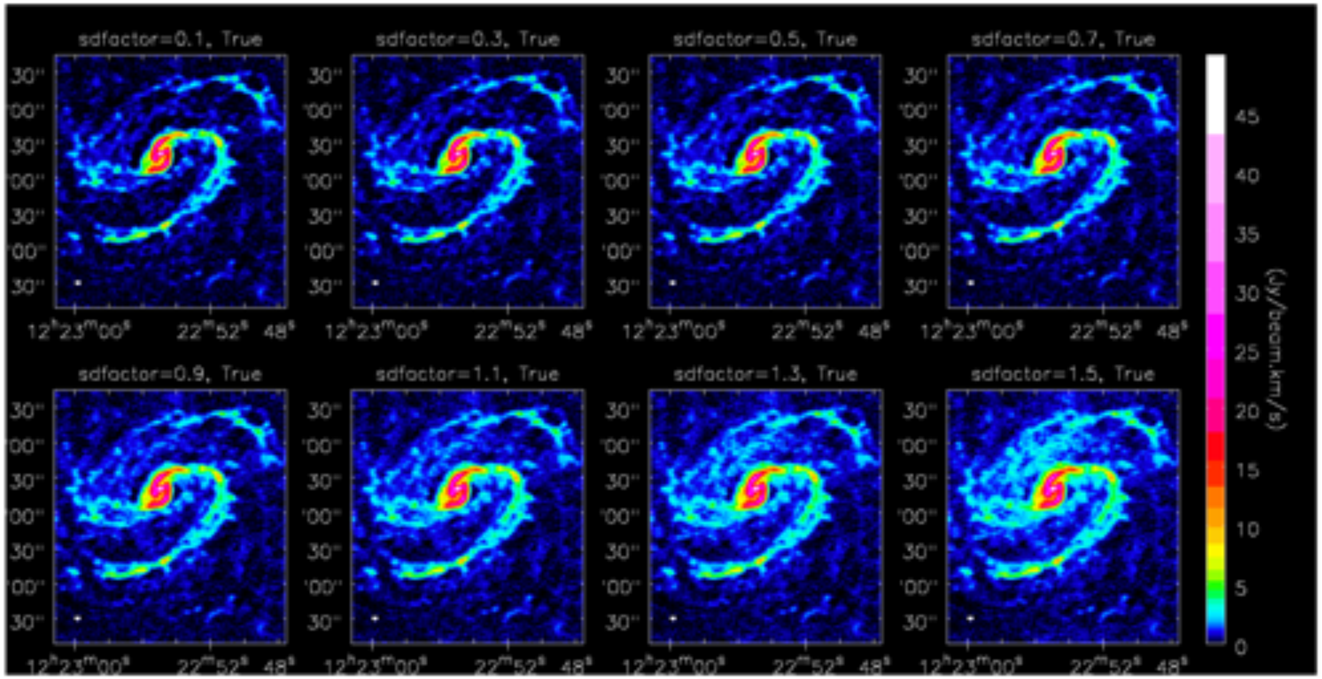


Figure 6: Feathered 12m+7m+TP Moment-0 maps for M100 with varying `sdfactor` from 0.1 to 1.5 (step 0.2).

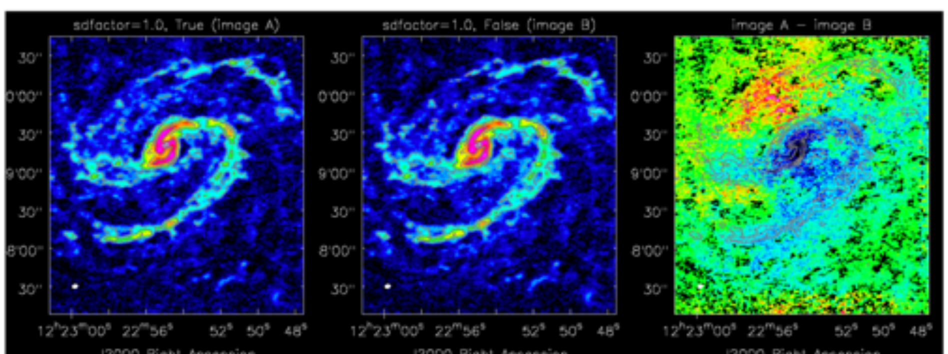
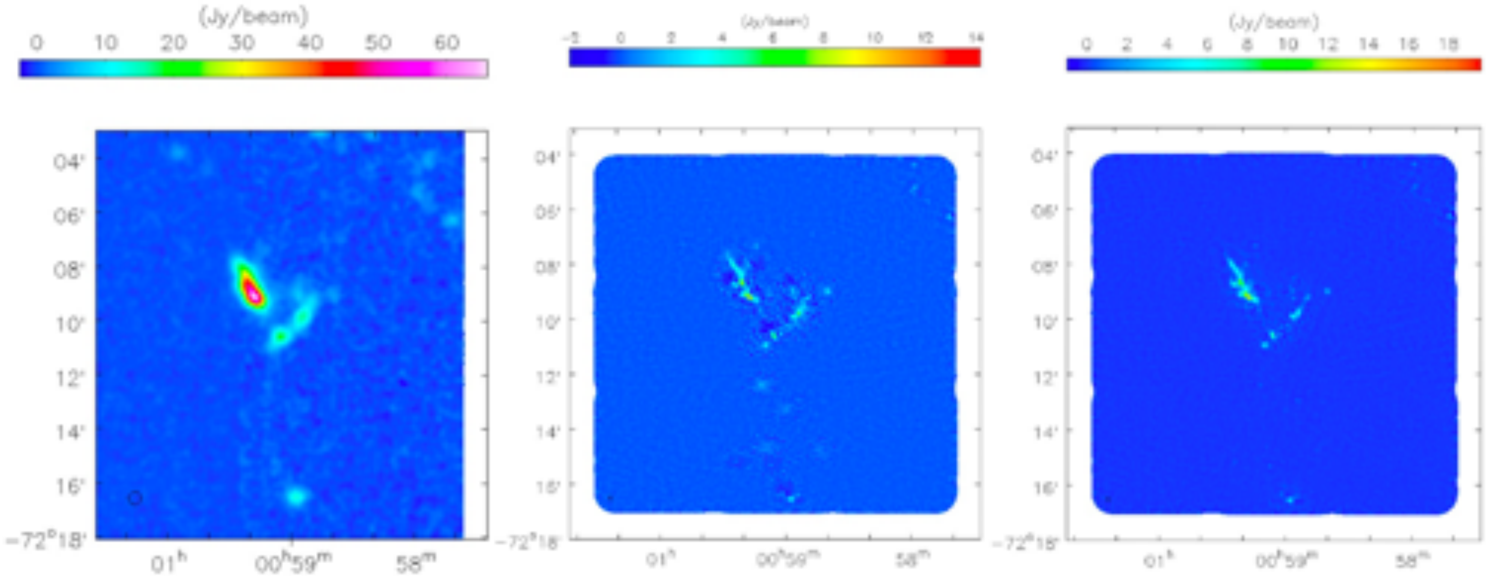


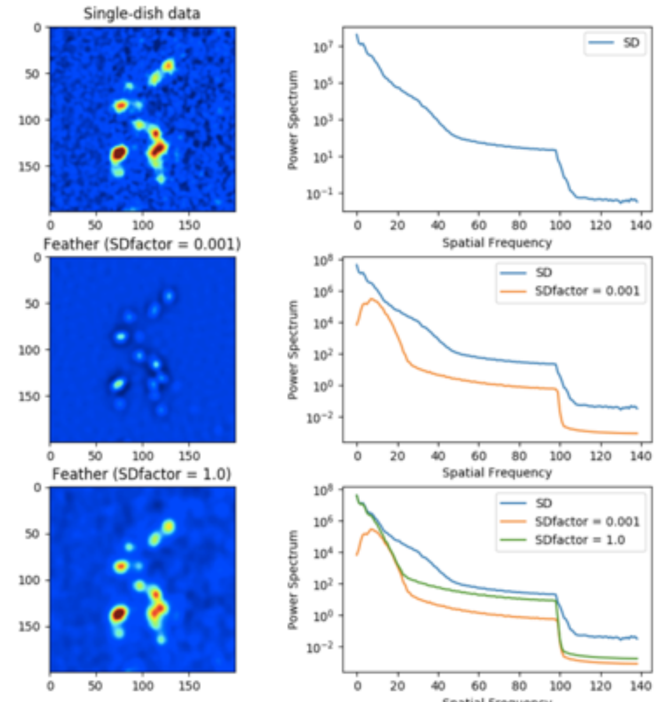
Figure 7: Feathered 12m+7m+TP Moment-0 maps for M100 with lowpassfiltersd=True (left) and lowpassfiltersd=False. The sdfactor is 1.0. The difference between them is shown in the right plot. The

2. NGC346 in the SMC (ALMA 7m + TP)

Maps:

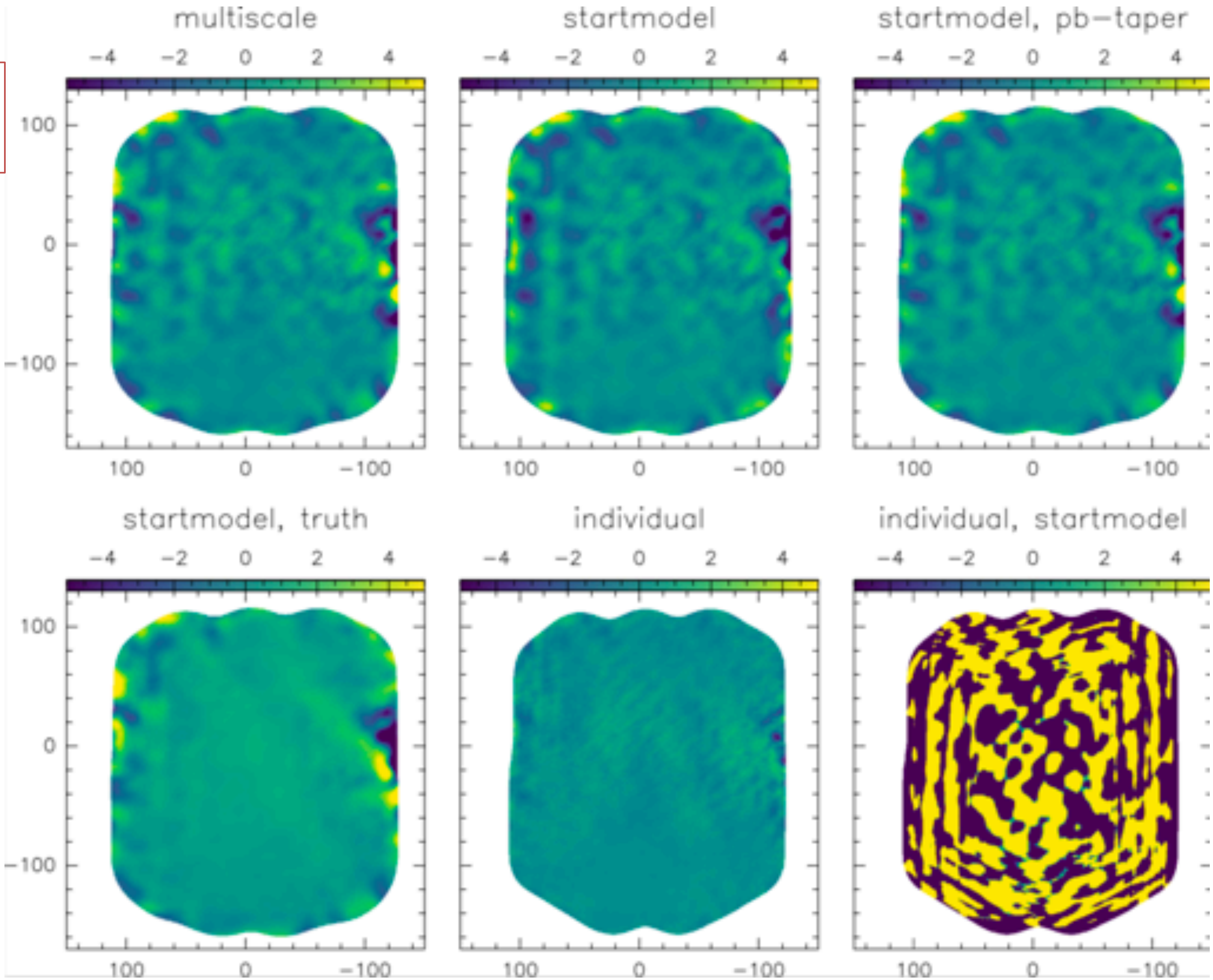


Evaluate:



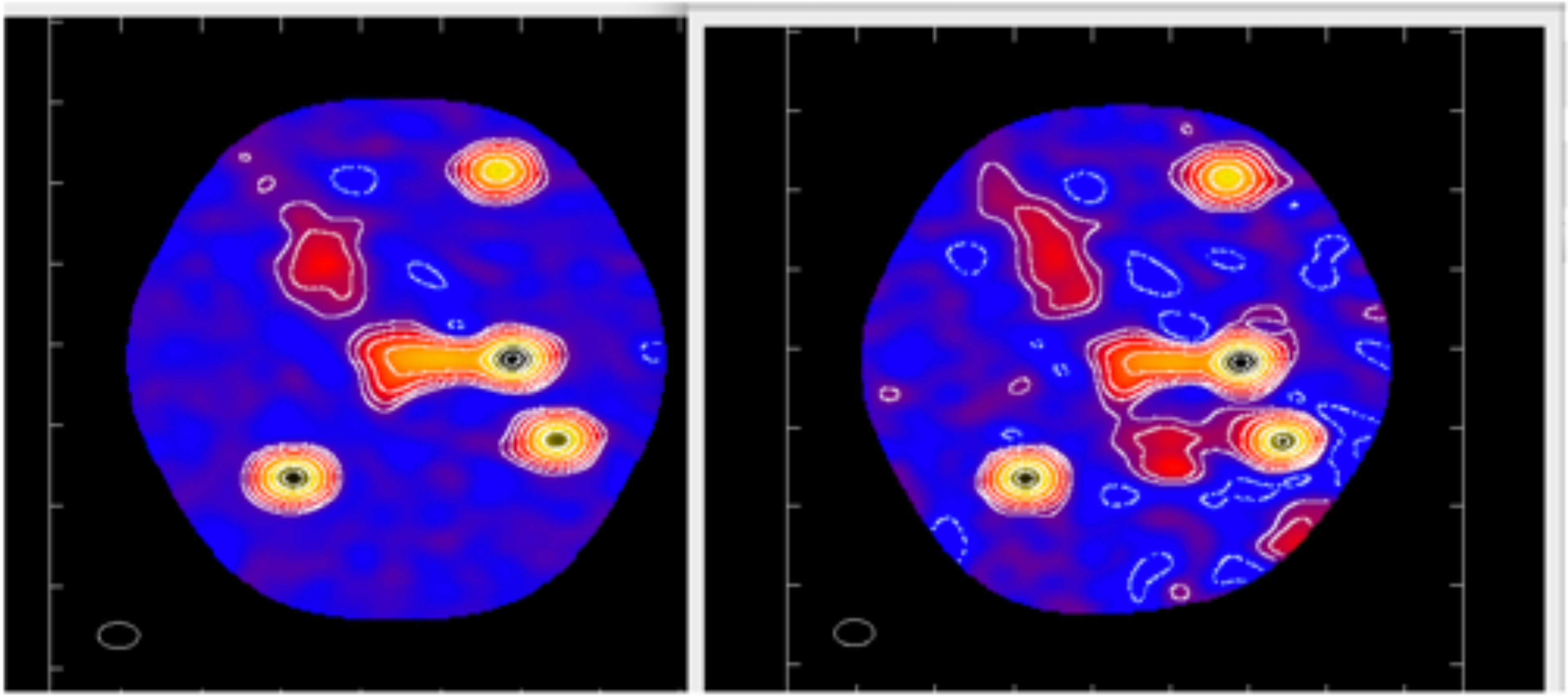
3. GMC fractal / powerspectrum model

Evaluate spatially:



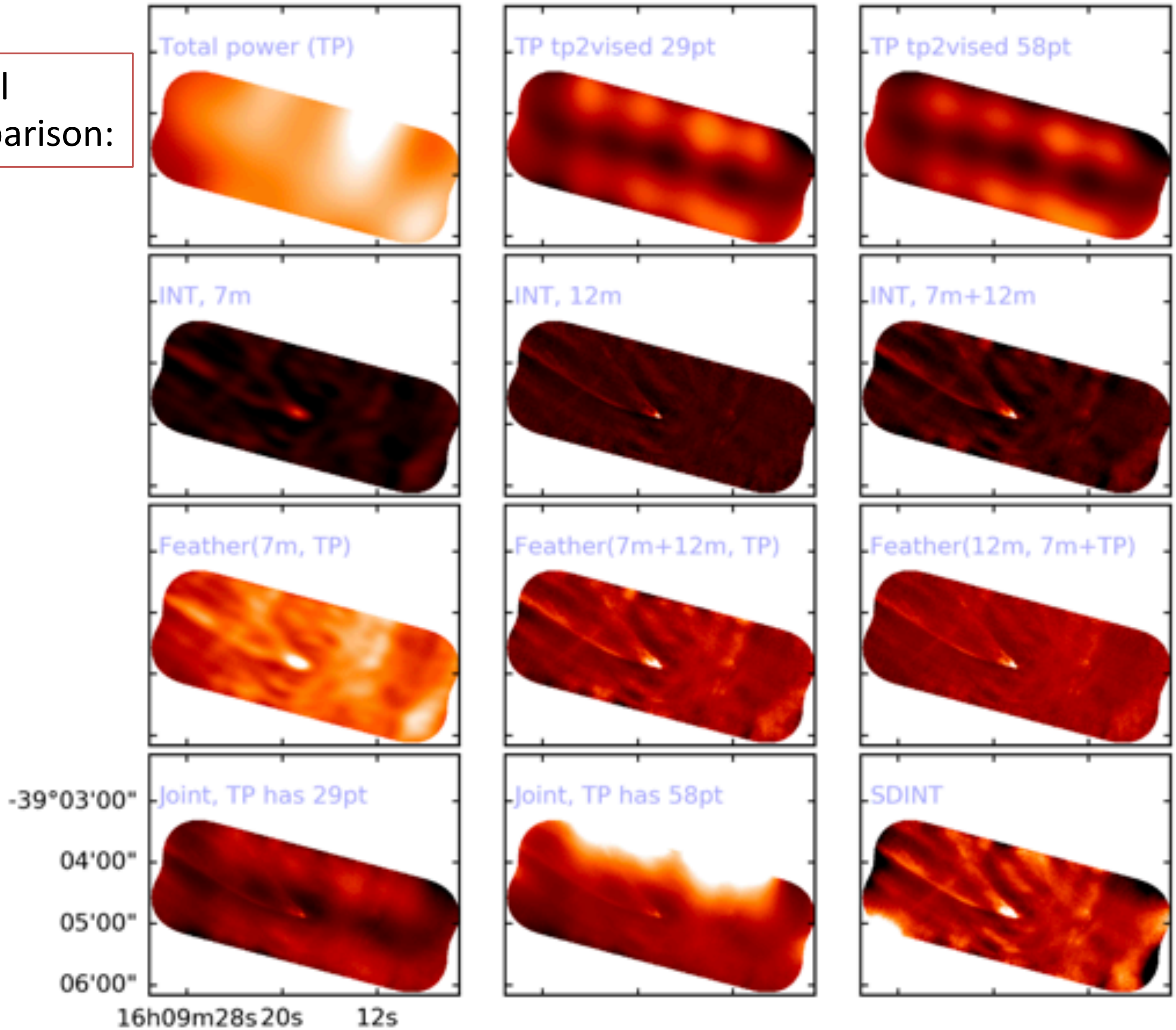
4. **Gaussians model** (synthetic observations)

Advances to make the models more “realistic”:



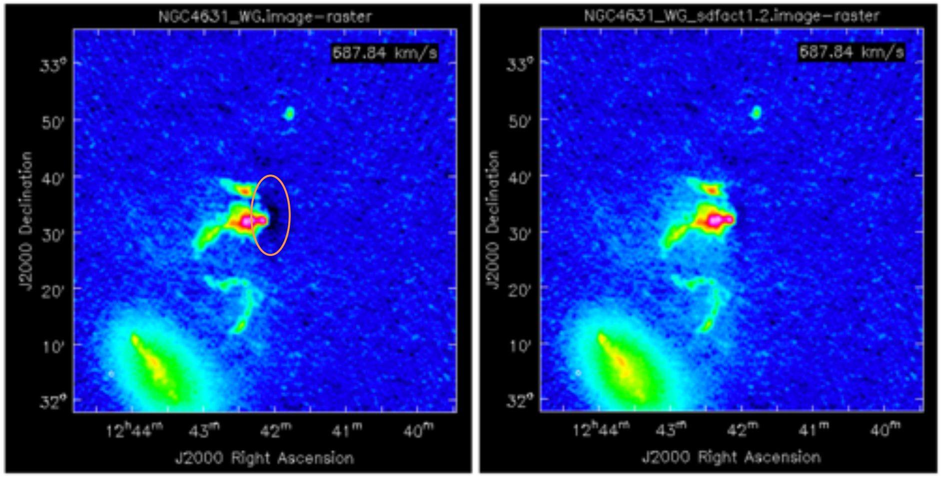
Protostellar outflows (ALMA 12m + 7m + TP)

Visual comparison:

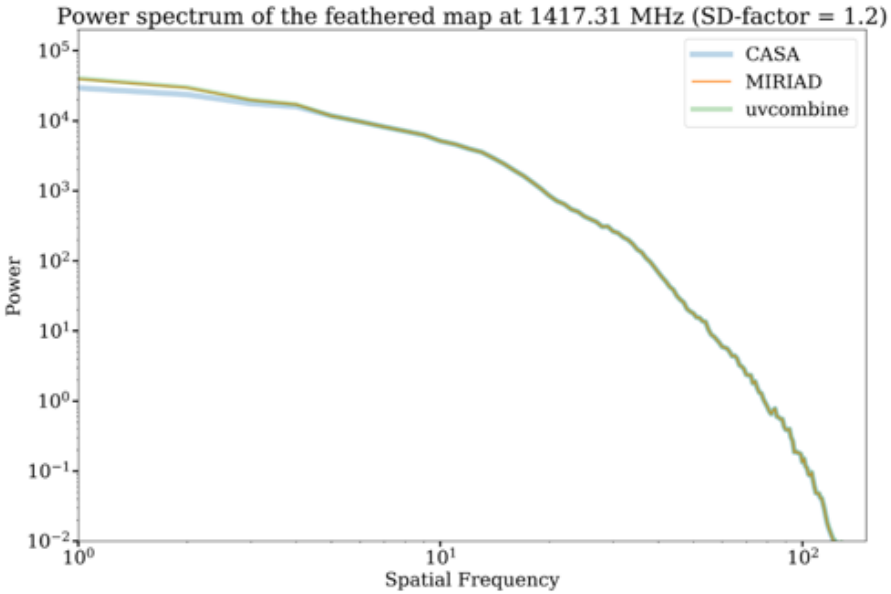


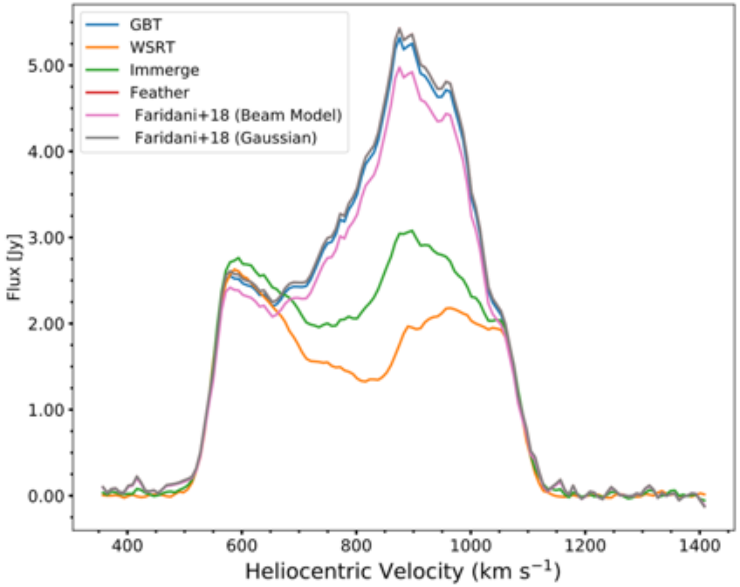
6. **HI observations** (GBT + WSRT)

Challenges in the data:

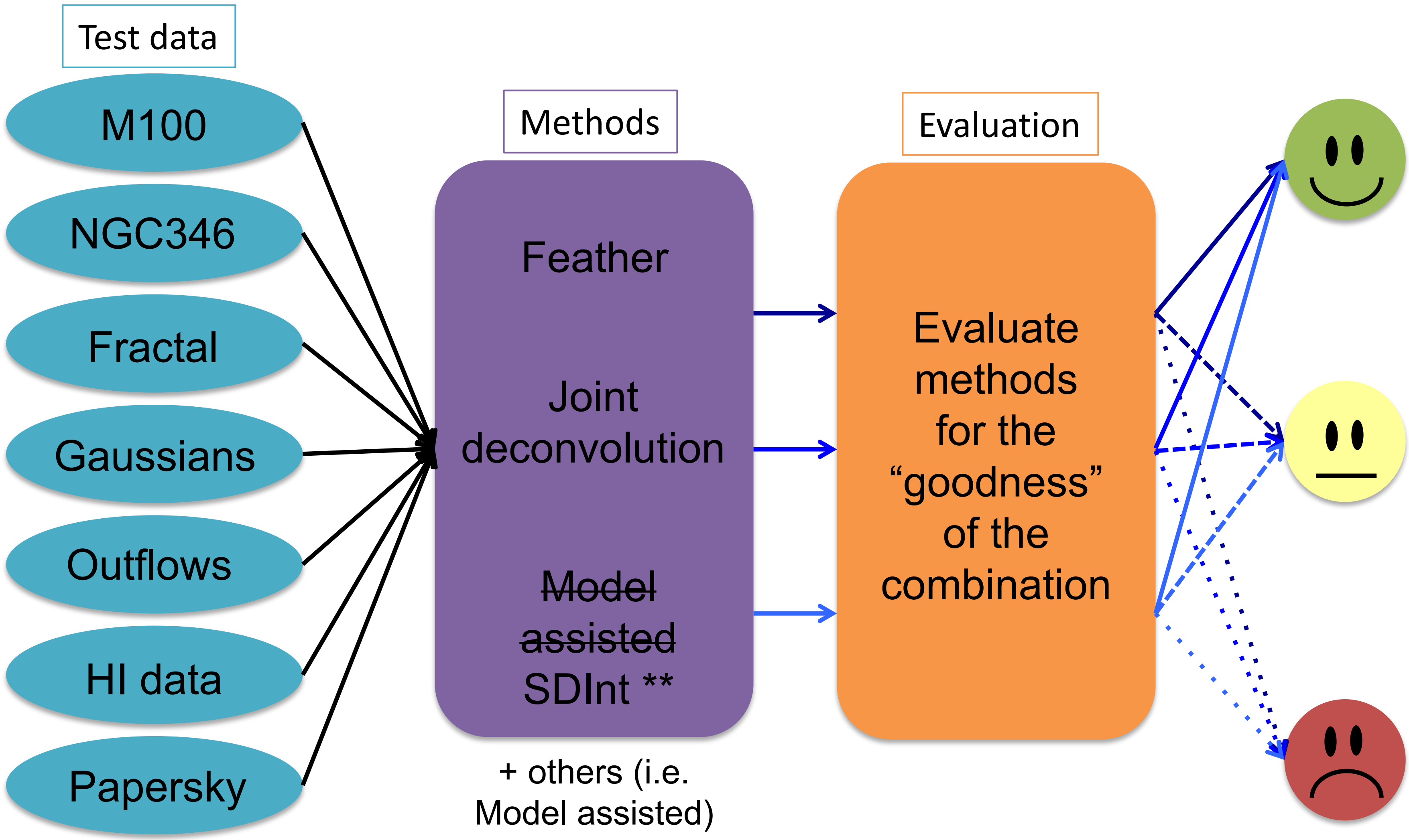


Evaluate methods:



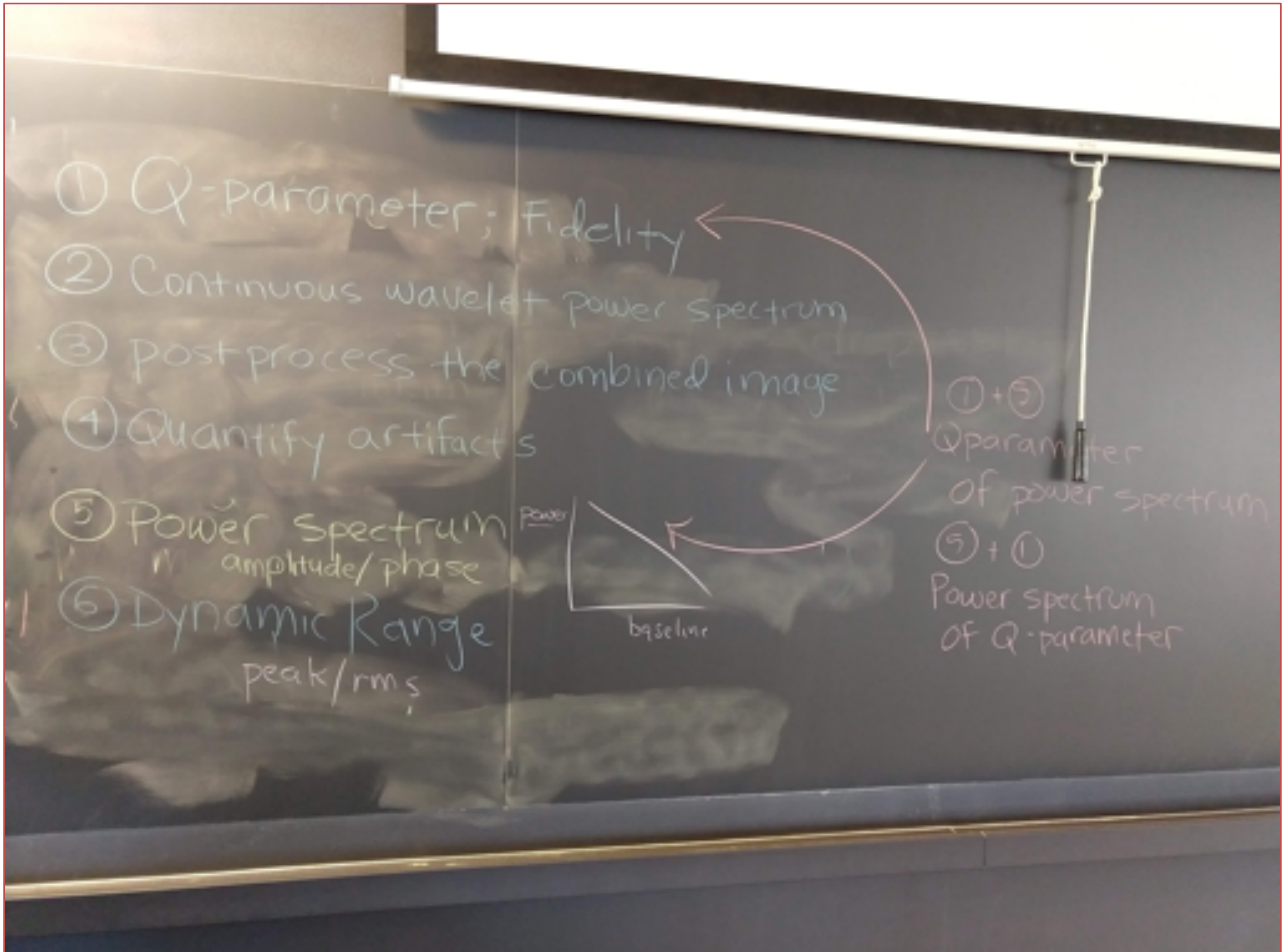


Working groups – strategy



*** We shifted our strategy, and chose to test SDInt because it is actively being developed in CASA (see talk by Urvashi).*

Evaluation of methods



Evaluation of methods (typed, annotated)

1. Q-parameter; fidelity
2. Continuous wavelet power spectrum
3. Post-process the combined image
4. Quantify artifacts (how?)
5. Power spectrum (on amplitude; phase?)
6. Dynamic range (peak/rms, general assessment of image quality)

Then some creative combinations, hopefully to give some statistical and spatial information:

1+5 Q-parameter of power spectrum

5+1 Power spectrum of Q-parameter

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Proceedings, and beyond

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Proceedings, our legacy!

- Update memos until Friday August 30
- Proceedings will be by “opt-in” method
- All participants will be noted as contributing
- Exact publication scheme to be determined…
- Thank you!!!

- *For those of you reviewing this summary *after* the workshop, these proceedings will provide a much better, more formal explanation of this workshop. Please stay tuned!*

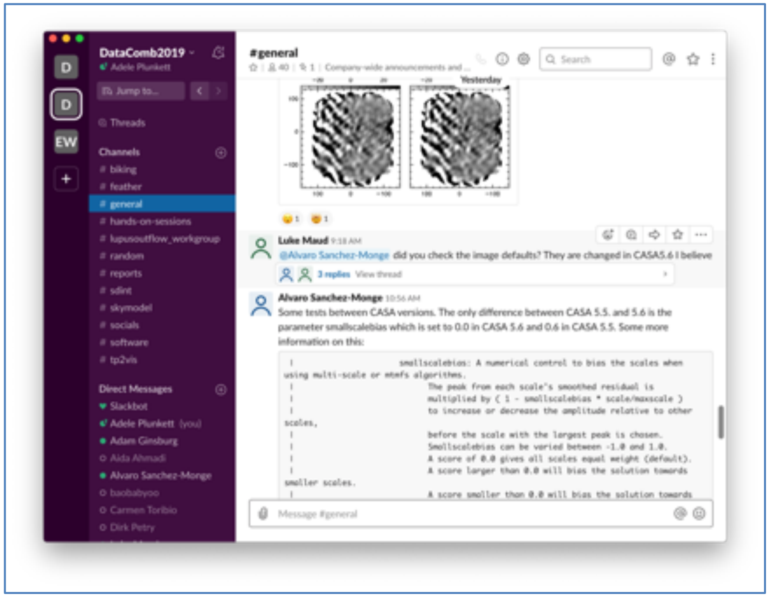
Towards the future…

- After completing your memo:
  - Use your scripts (and info from other reports) to combine the data used by the other groups
  - Share your scripts; report errors
  - Evaluate in more detail the "goodness" of the combination
  - Development of new techniques to determine the "goodness" of the combination
  - …

A few more reflections on this workshop

- Keep an open mind:
  “Feathering is not dead”

- Our Slack strategy worked, thanks for playing along.



- Amazing experience at the Lorentz center!!

An additional note after the workshop

- If you have any questions about these slides, **please contact Adele Plunkett at aplunket@nrao.edu.** I'll be happy to discuss the outcomes of this workshop.

- The content of these slides are the ideas and opinions of Adele and Alvaro S-M, not necessarily the main idea of any presentation; working group; or discussion.

- Please use the material from this workshop, including slides in this summary, in order to promote data combination techniques among the astronomy community.