Data Combination in PHANGS-ALMA Studies

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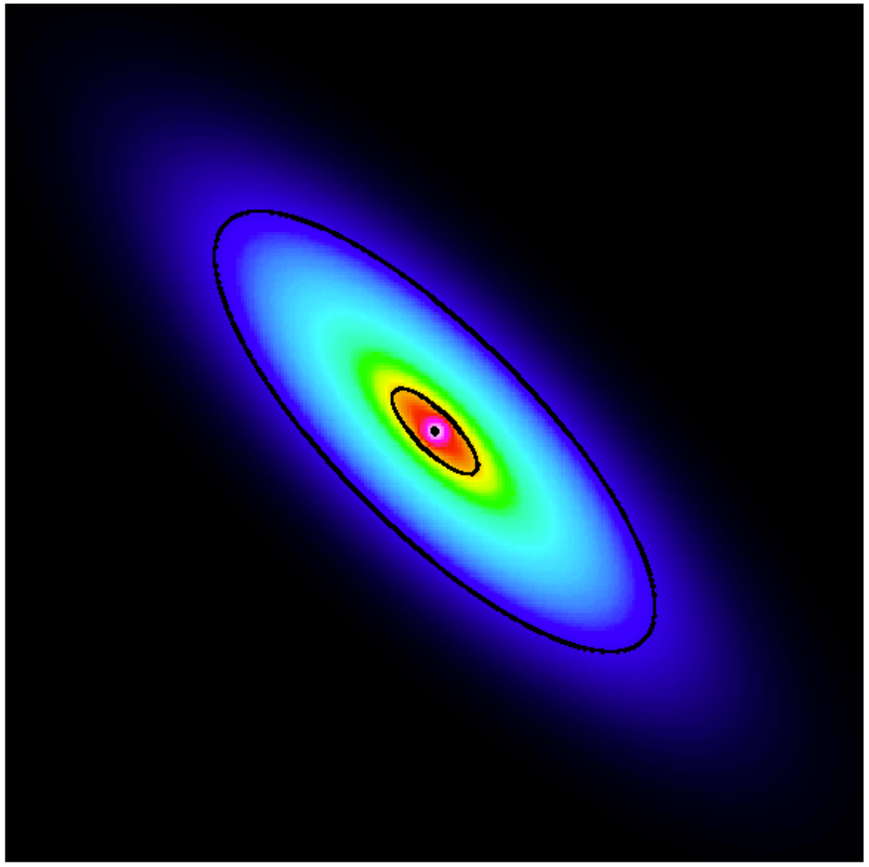
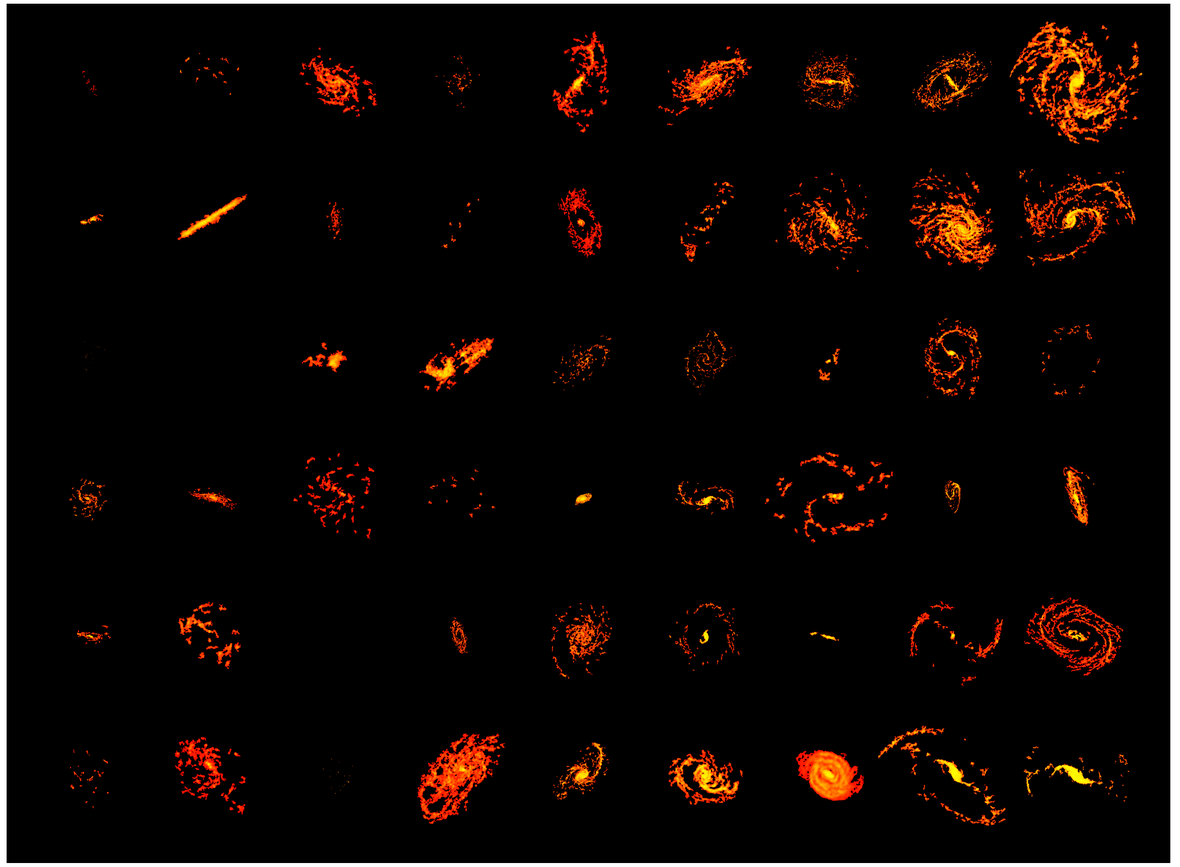
and special thanks to H. Beuther (THOR survey) and J. Koda (tp2vis)

This Talk

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.





Introduction to PHANGS-ALMA Survey

PHANGS science requires short-spacing data

Understanding the interplay between the small-scale physics of gas and star formation with galactic structure and galaxy evolution

How do local ISM conditions depend on galactic environment?

How do cloud-scale conditions in the gas affect the ability of gas to form stars and clusters?

What are the timescale and efficiencies for evolution of the molecular ISM?

Short-spacing correction is crucial for the PHANGS science!

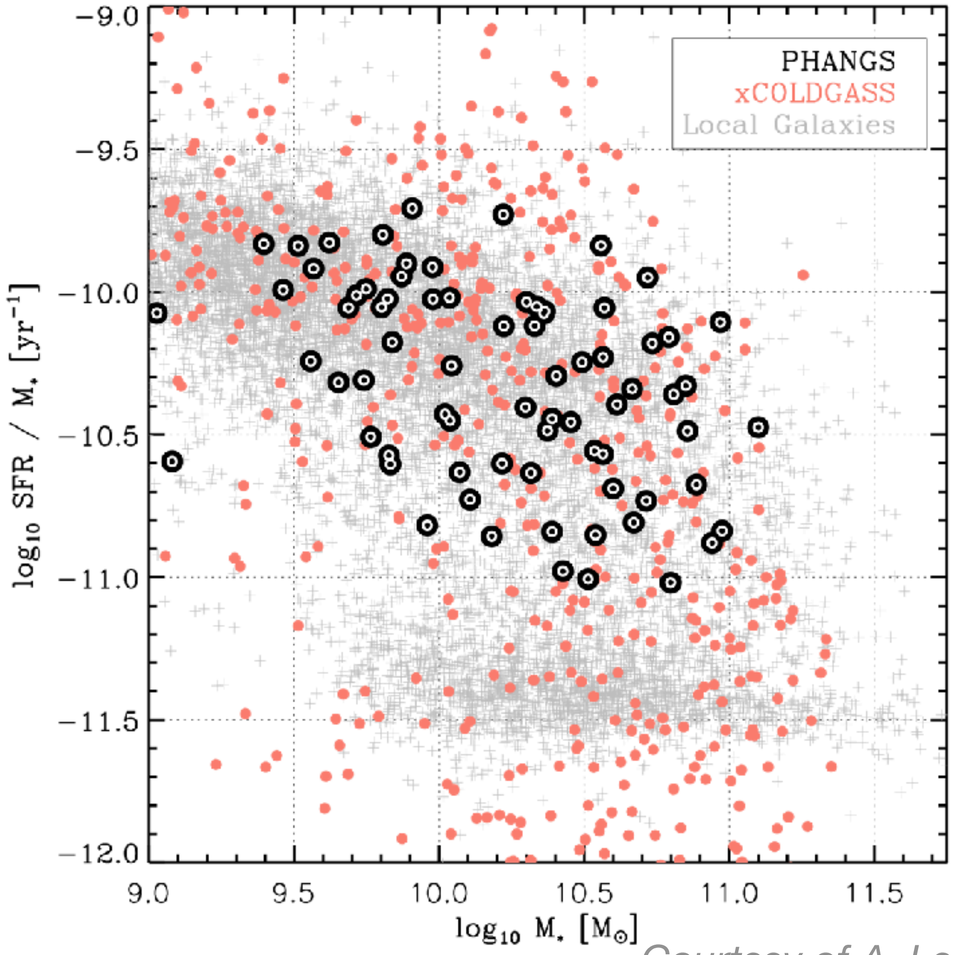
(see talk by Cinthya Herrera tomorrow)

100,000 GMCs in 74 main-sequence galaxies

PHANGS-ALMA is using ALMA's arcsecond CO 2-1 mapping capability to make the first complete 1" atlas of molecular gas in galaxies. By targeting nearby systems, we access our key goals - physical state of gas and time evolution.

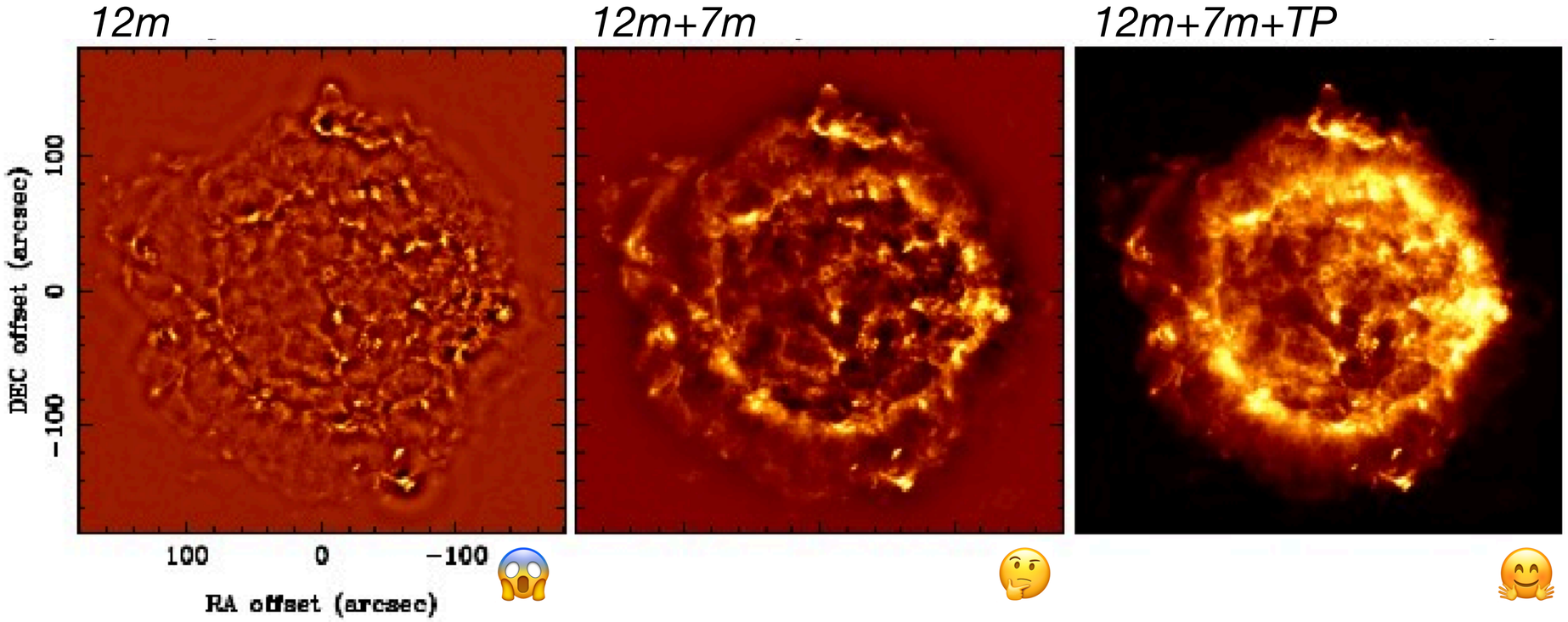
PHANGS ALMA Selection

1. Declination < 25°
2. Distance < 17 Mpc (1" < 100 pc)
3. Inclination < 75°
4. $9.5 < \log(M_\star) < 11.5$
5. $\log(SFR/M_\star) > -11$ (main-sequence)



Courtesy of A. Leroy; Leroy et al. in prep.

Survey design



1. **<u>ACA and TP array recover all spatial scales.</u>**

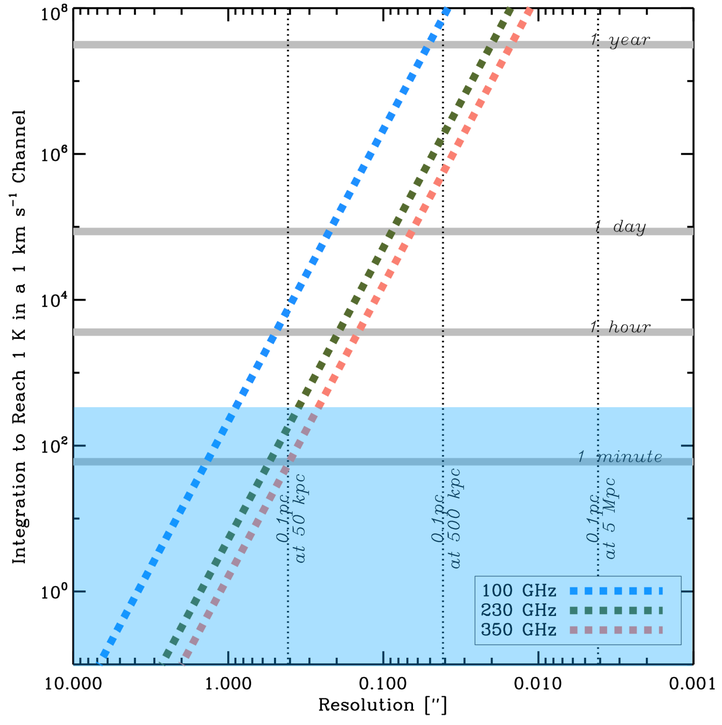
   => allow us to observe big, complex structures like nearby spirals.

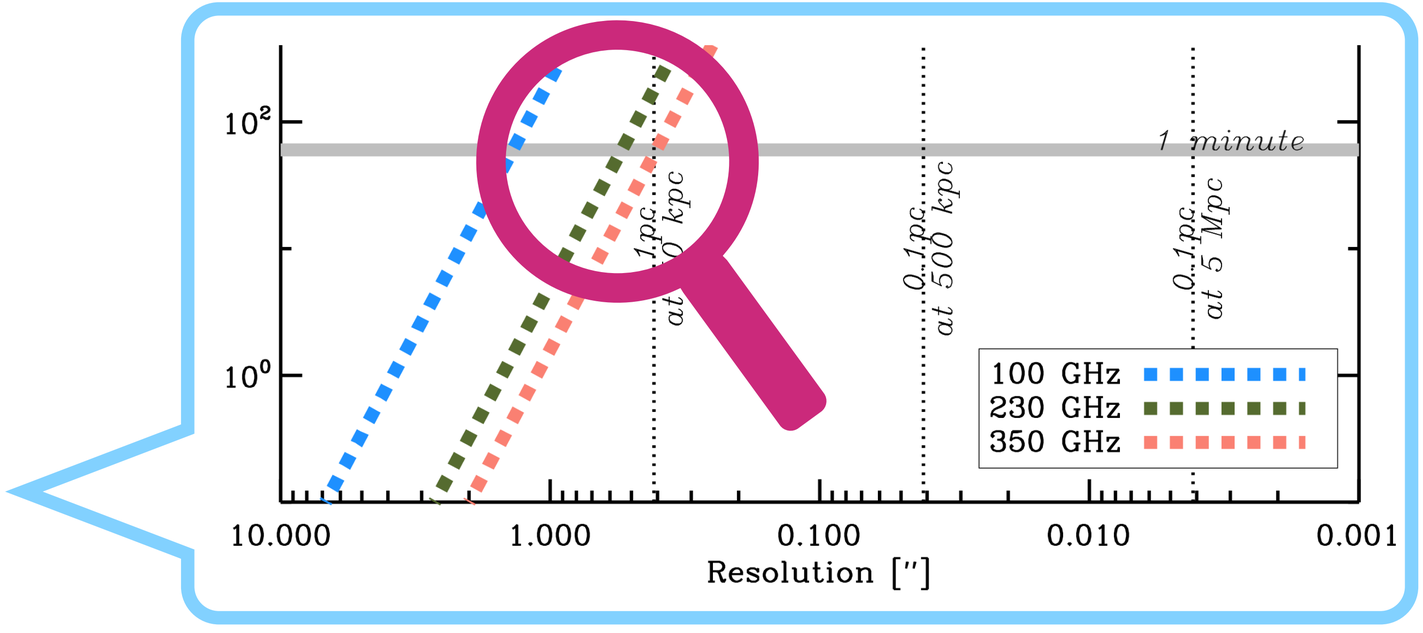
2. **<u>Unfair trade-off between angular resolution and sensitivity ($t \sim \theta^{-4}$).</u>**

   => 1 K@1 km/s can be achieved by ~1”.0 with 1 minute integration.

Simulations by T. Kurono

Survey design





1. **ACA and TP array recover all spatial scales.**

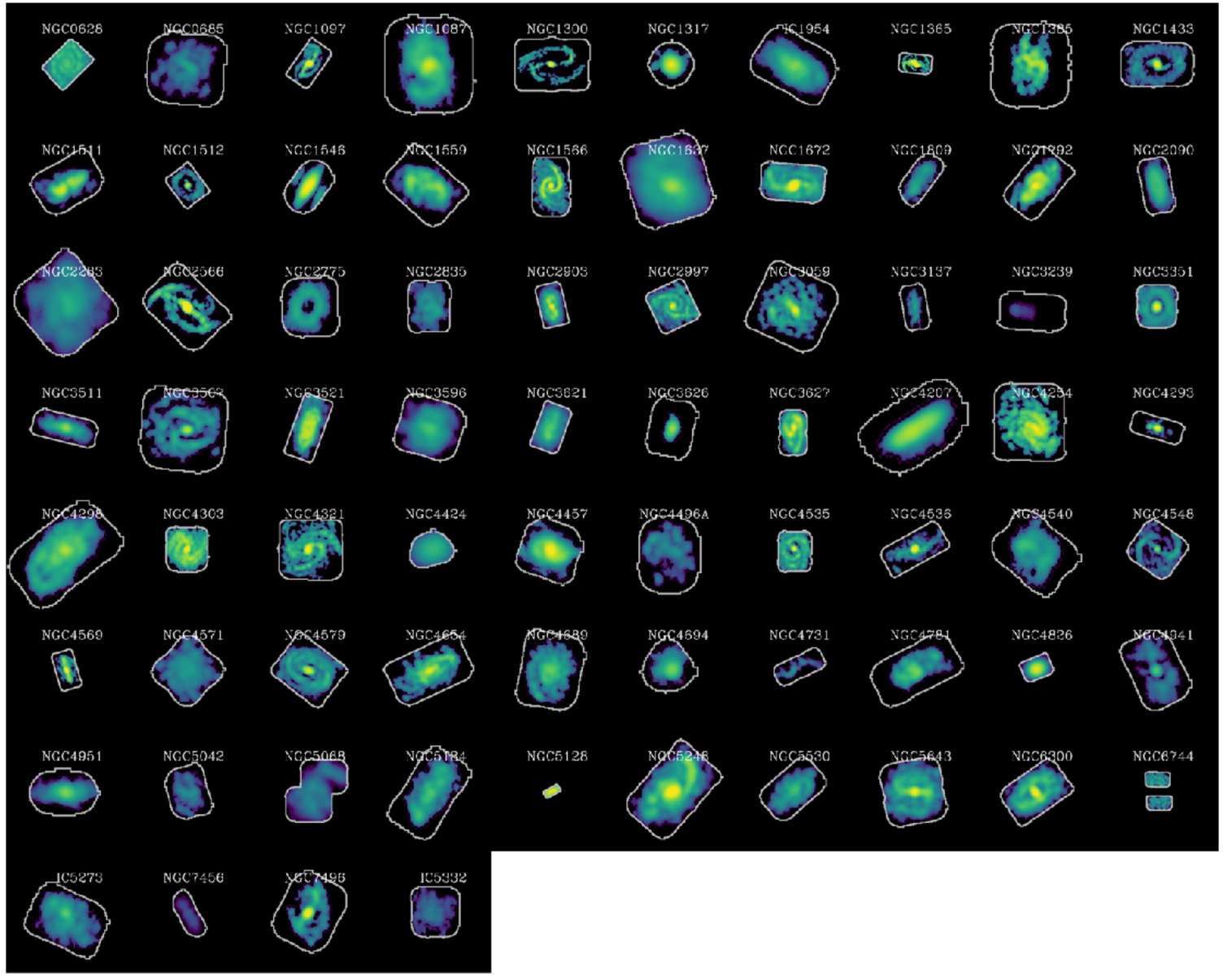
   => allow us to observe big, complex structures like nearby spirals.

2. **Unfair trade-off between angular resolution and sensitivity ($t \sim \theta^{-4}$).**

   => 1 K@1 km/s can be achieved by ~1”.0 with 1 minute integration.

Leroy et al. in prep.

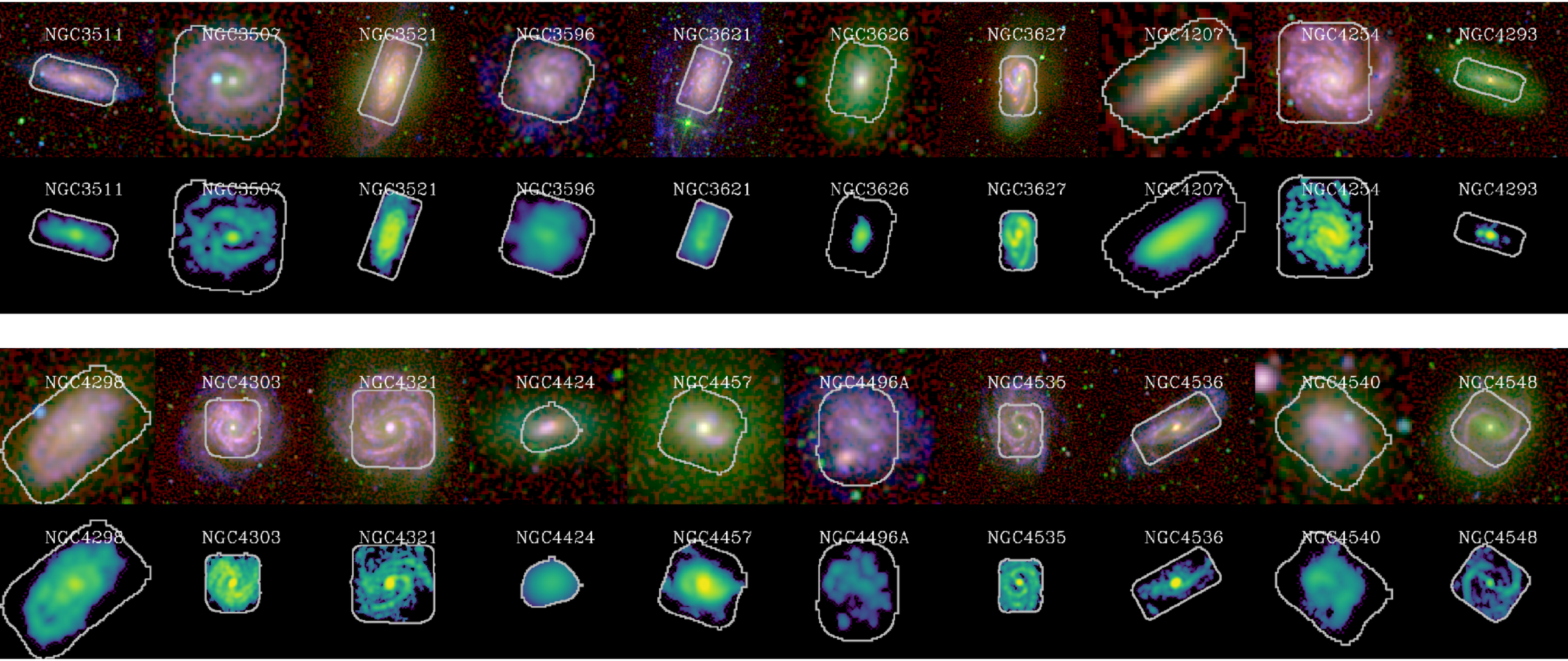
PHANGS “feathered” 7m+TP CO(2-1)



Leroy et al. in prep.

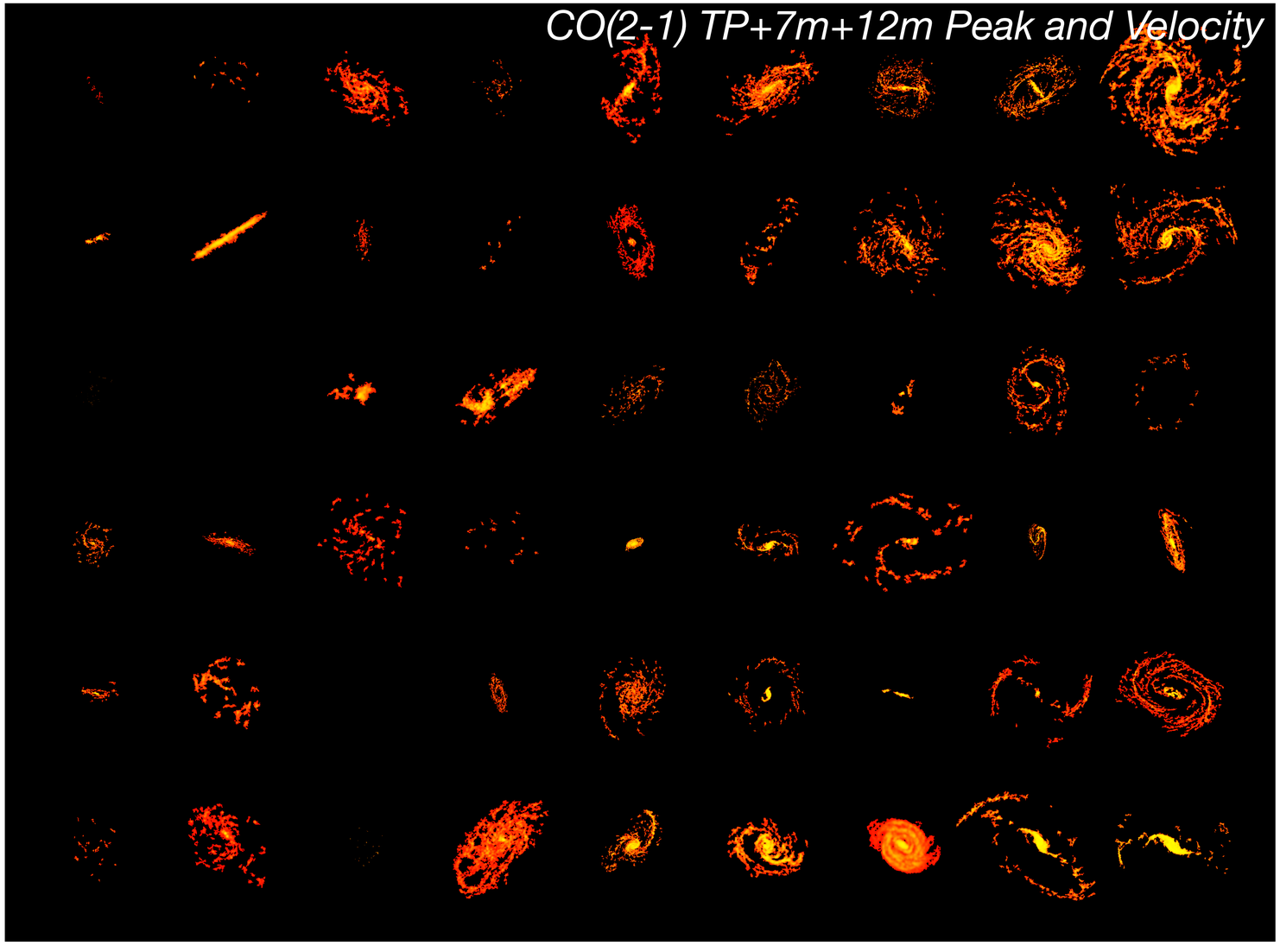
PHANGS “feathered” 7m+TP CO(2-1)

NUV+WISE1+WISE3 CO(2-1) TP+7m Peak Intensity



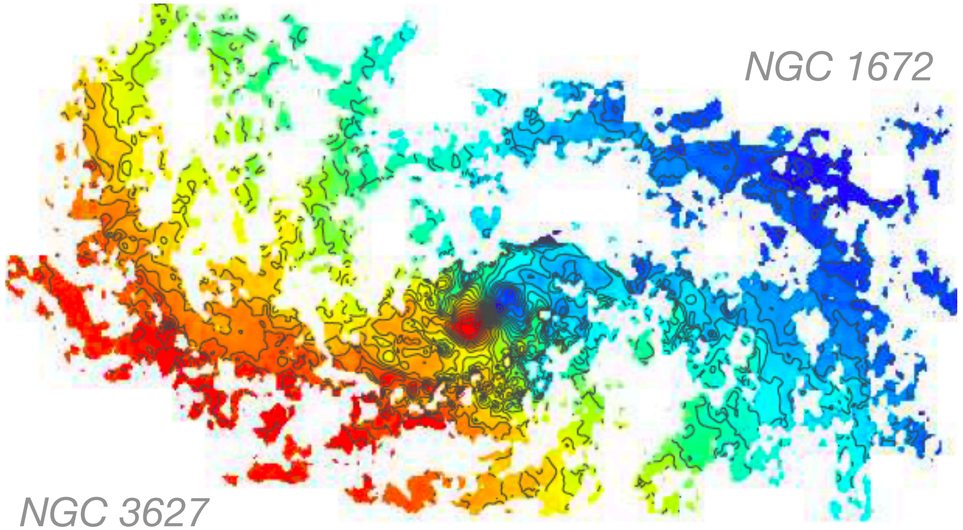
Leroy et al. in prep.

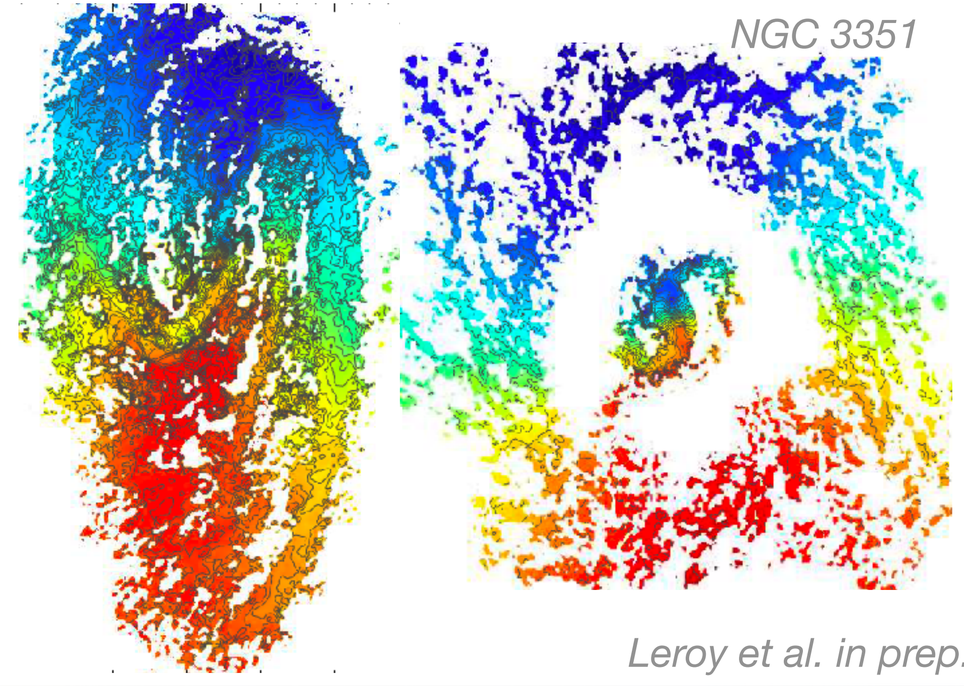
PHANGS “feathered” 12m+7m+TP CO(2-1)



Low mass

High mass



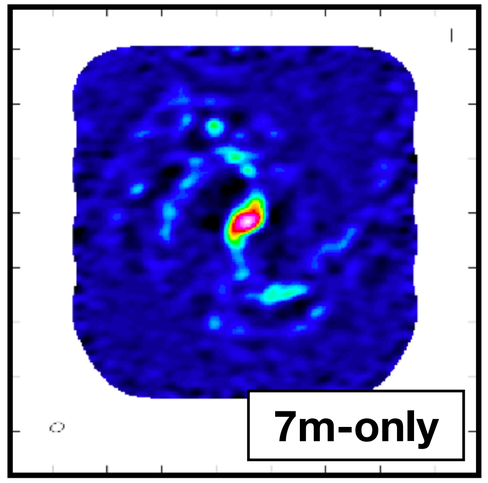


Leroy et al. in prep.

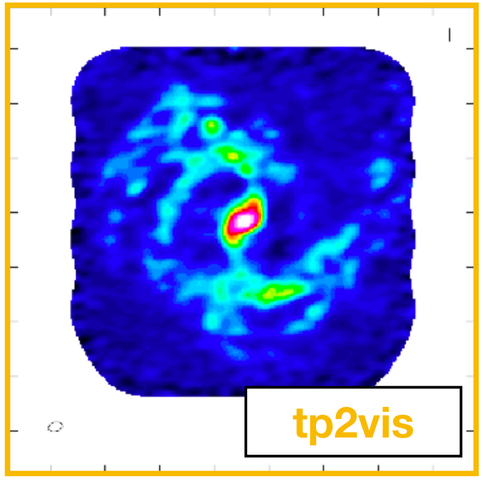
Short-spacing Correction Test

Short Spacing Correction Test for 7m and TP data

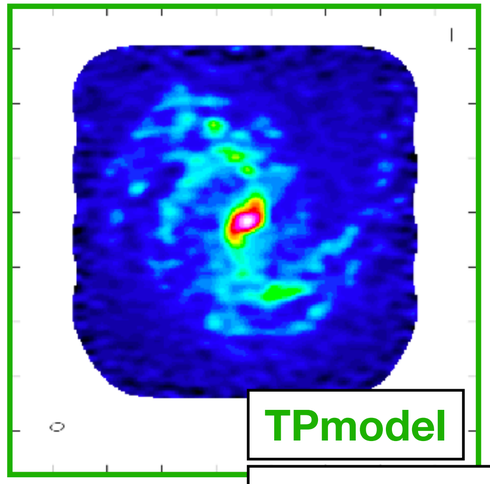
No Combine



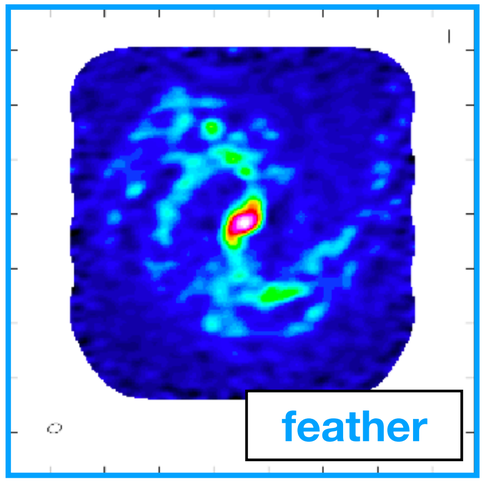
Combine ***before*** Deconvolution

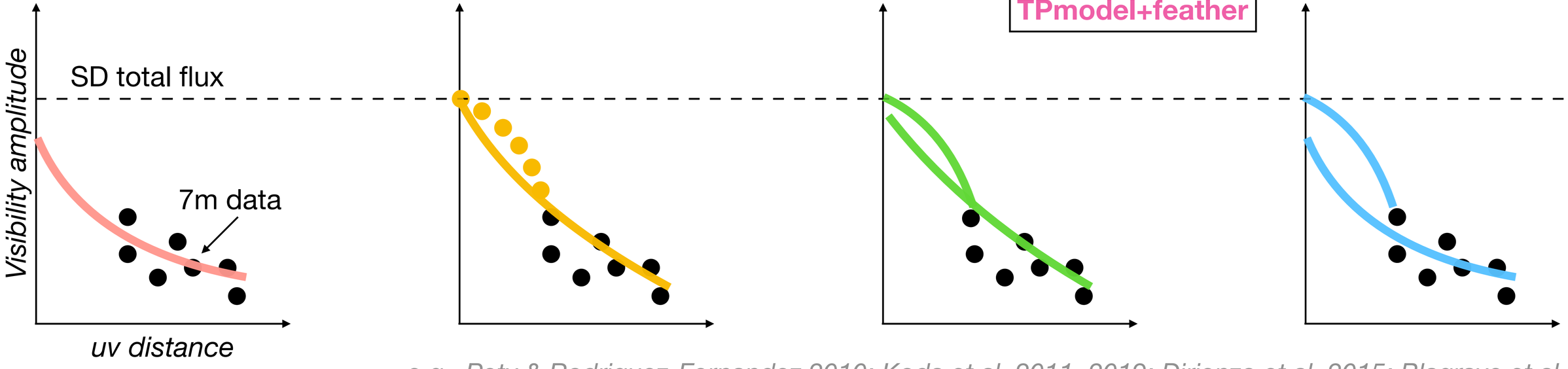


Combine ***during*** Deconvolution



Combine ***after*** Deconvolution

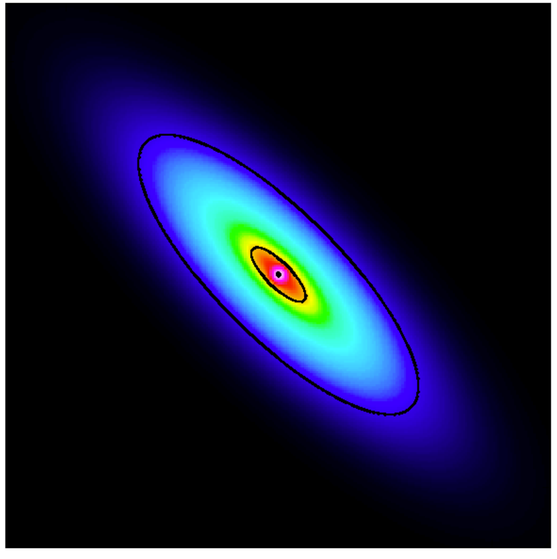




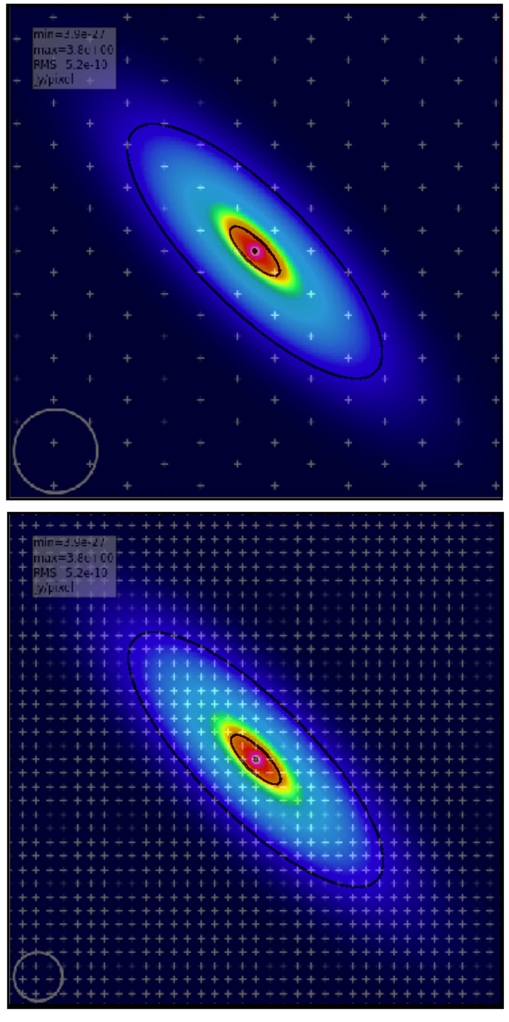
e.g., Pety & Rodriguez-Fernandez 2010; Koda et al. 2011, 2019; Dirienzo et al. 2015; Blagrave et al. 2017

SSC Test Procedure

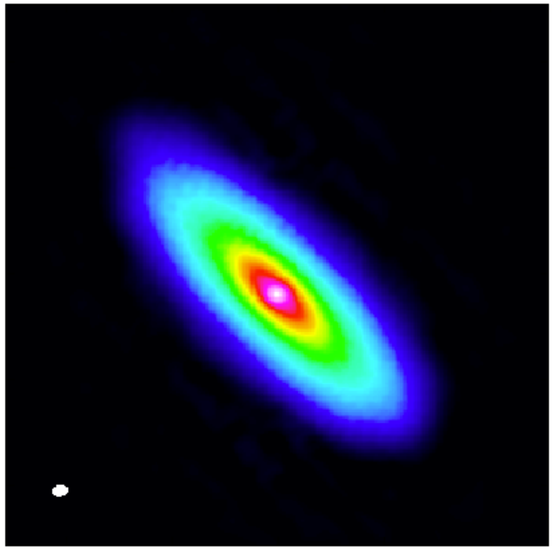
(1) Model image



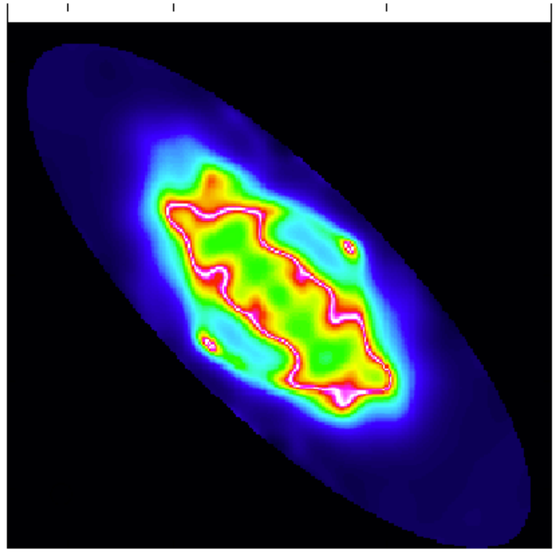
(2) simobserve



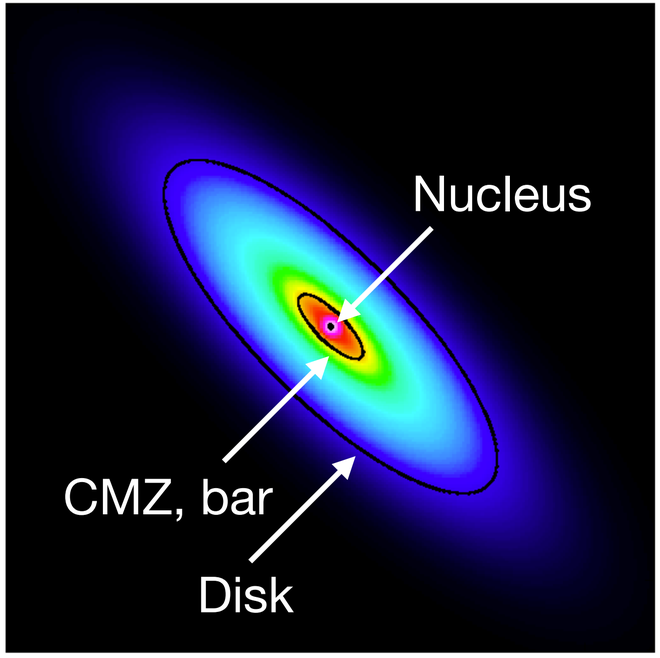
(3) tclean + SSC

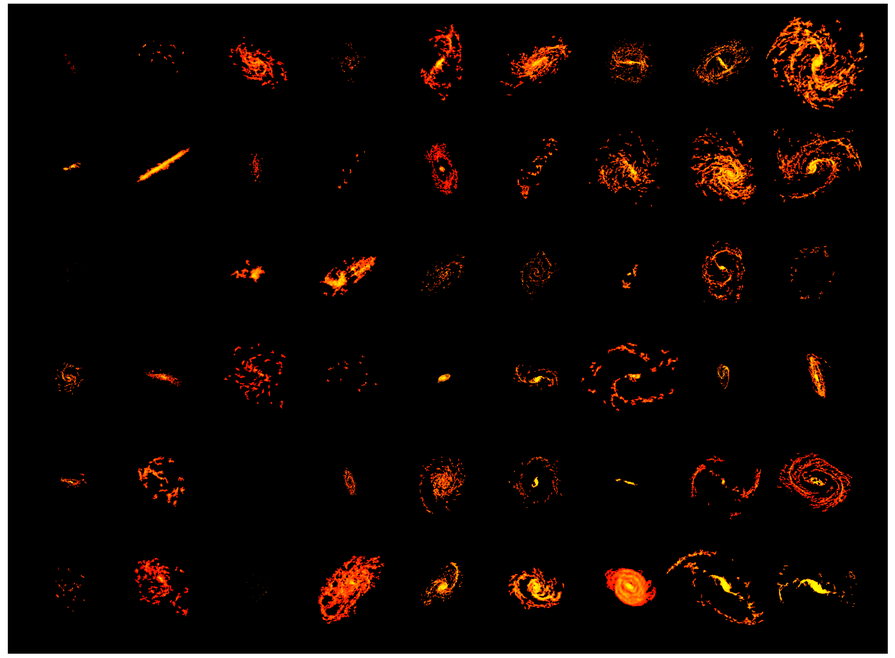


(4) Evaluate fidelity



SSC (1): Model Input



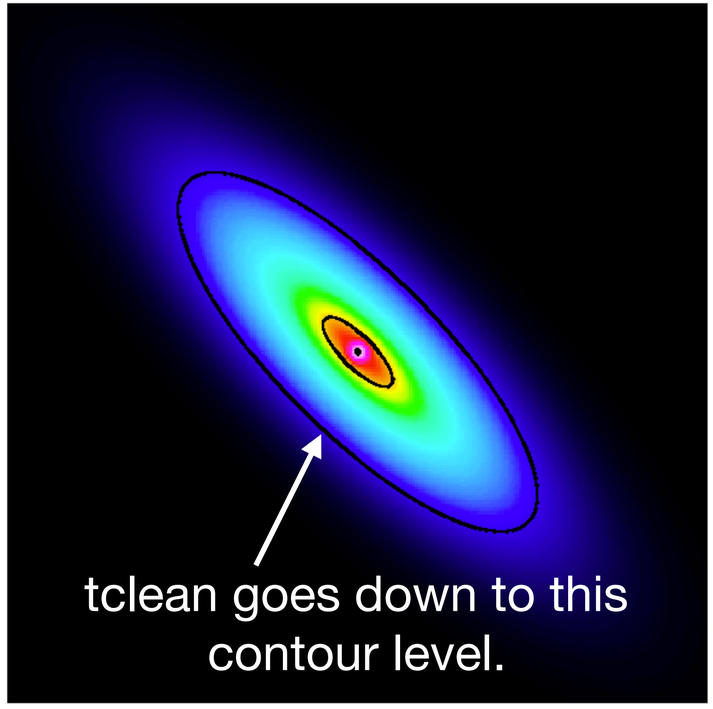


- **Three Gaussians** (Total flux = 3032 Jy)
- Gauss 1 = 98 Jy, 5” x 5” (round)
- Gauss 2 = 489 Jy, 30” x 10” (ellipse)
- Gauss 3 = 2445 Jy, 120” x 40” (ellipse)
- Flux ratio = 1 : 5 : 25

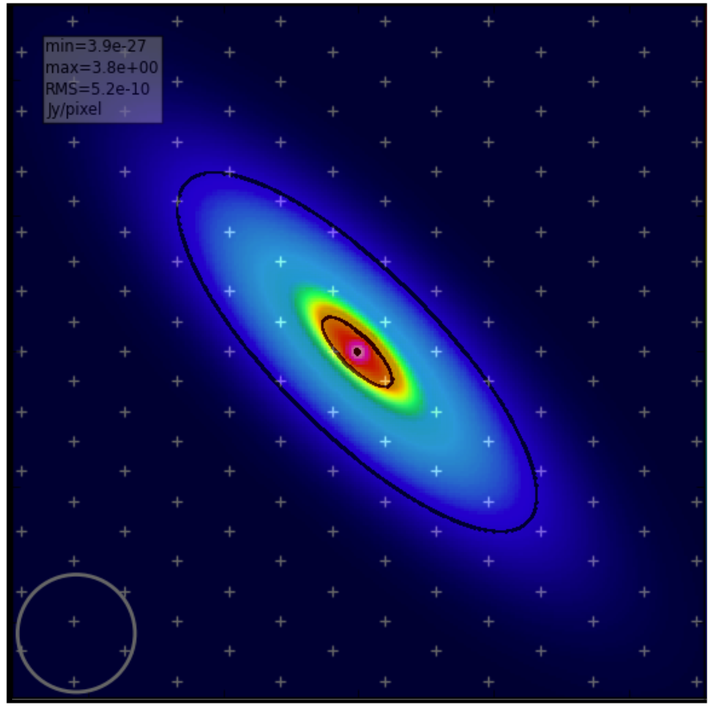
- **PHANGS CO(2-1)** 12m+7m+TP T_{peak}
- Datacubes combined by feathering
- CO size diameter = 10” ~ 300”
- CO total flux < 1000 Jy
- 63 main-sequence galaxies available

SSC (2): CASA simobserve at 230 GHz

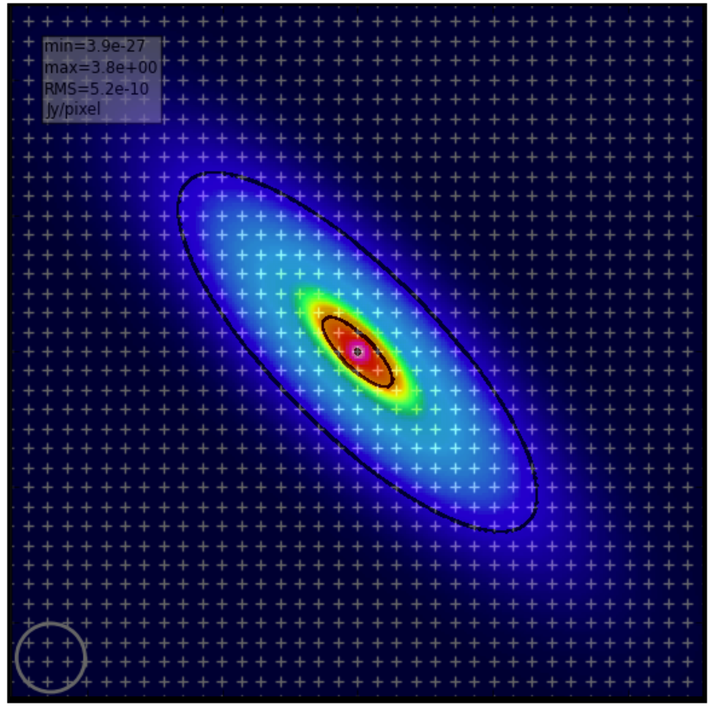
Model image



Model with 7m array grid



Model with TP array grid

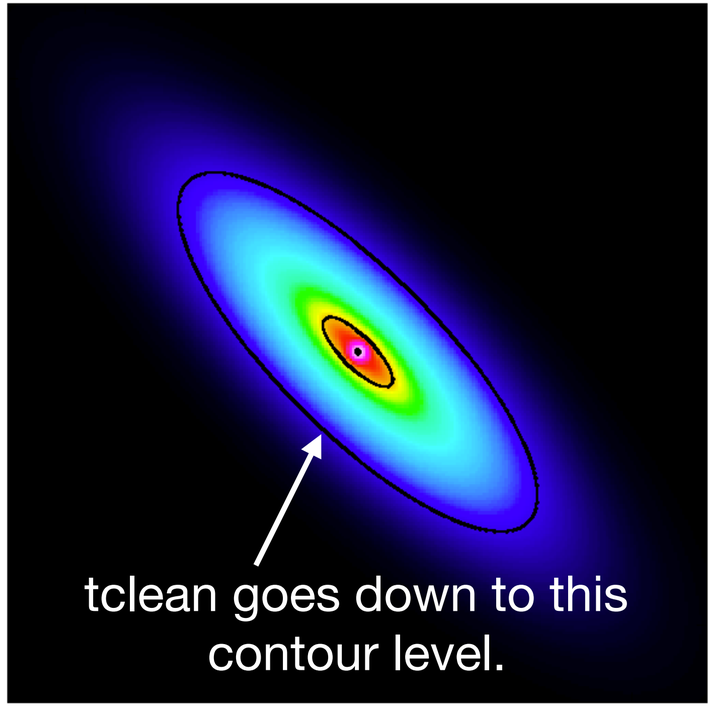


Simulation setup

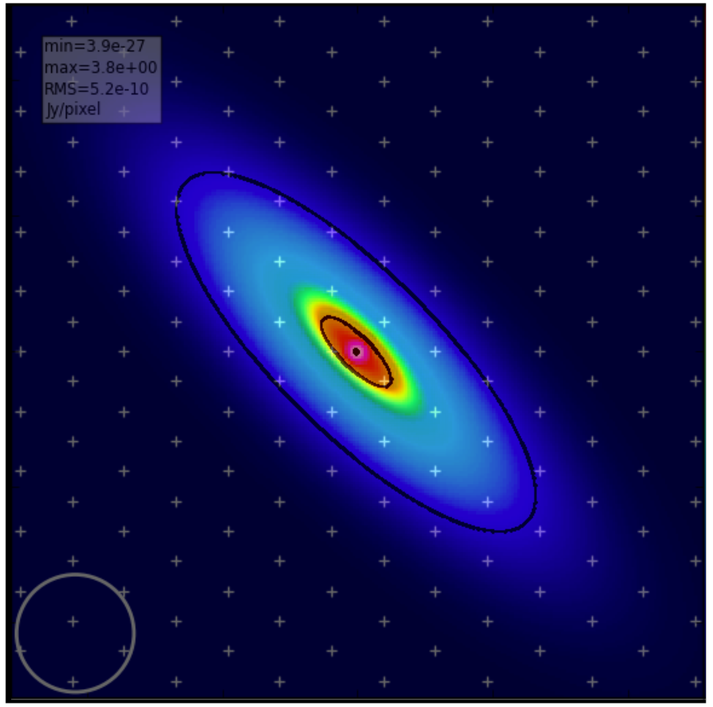
- No thermal noise and no phase noise
- cycle 5 ACA and TP configurations
- 10sec integration for each uv datum
- Mosaic the entire image (standard sampling)
- 7m on-source = 4 hrs in total
- TP on-source = 8 hrs in total

SSC (2): CASA simobserve at 230 GHz

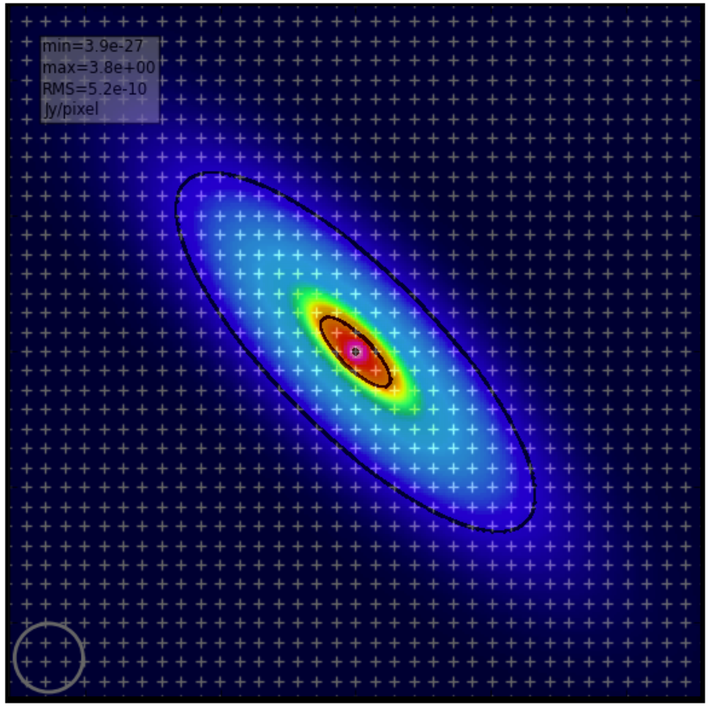
Model image



Model with 7m array grid



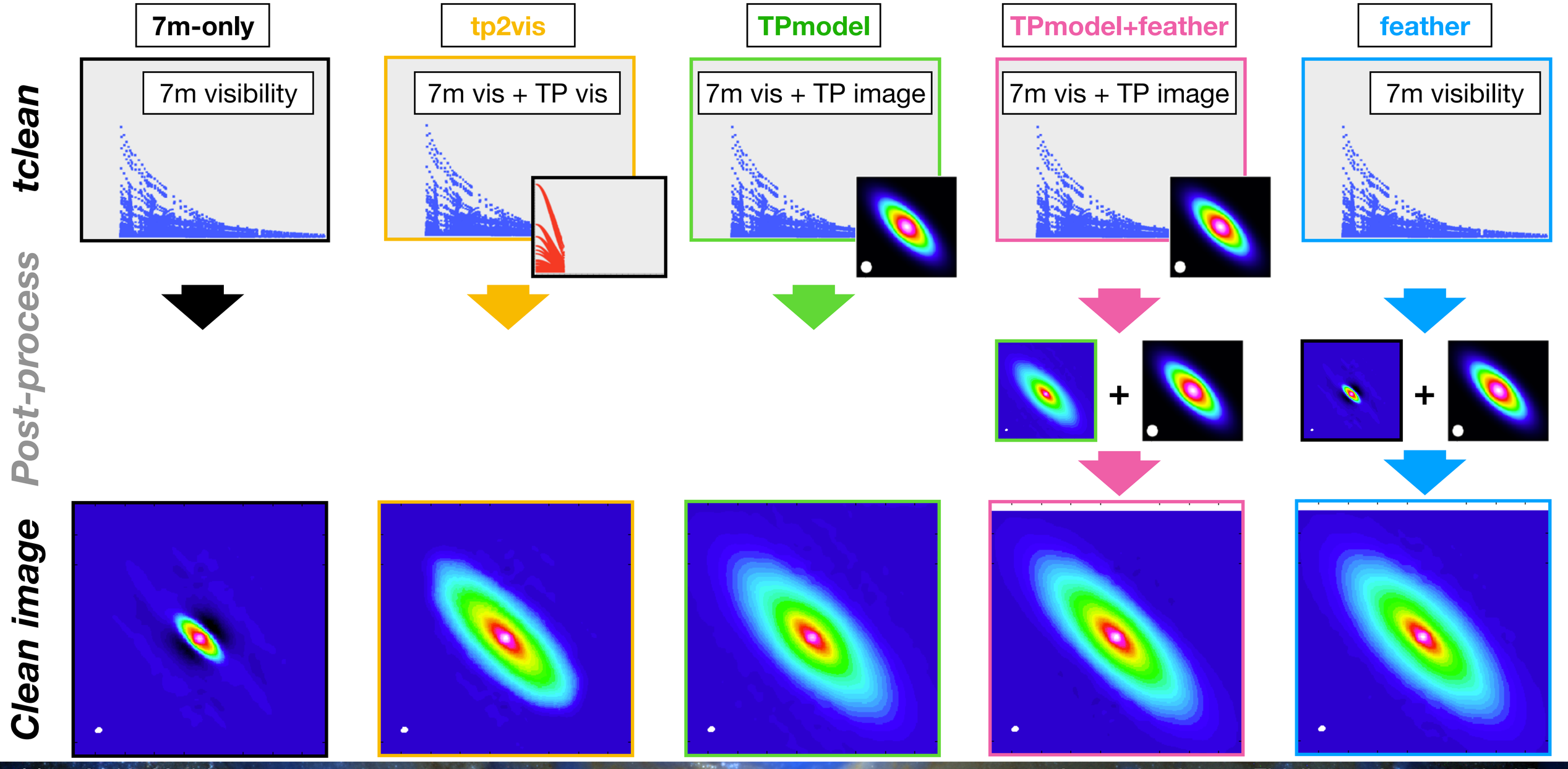
Model with TP array grid



tclean setup

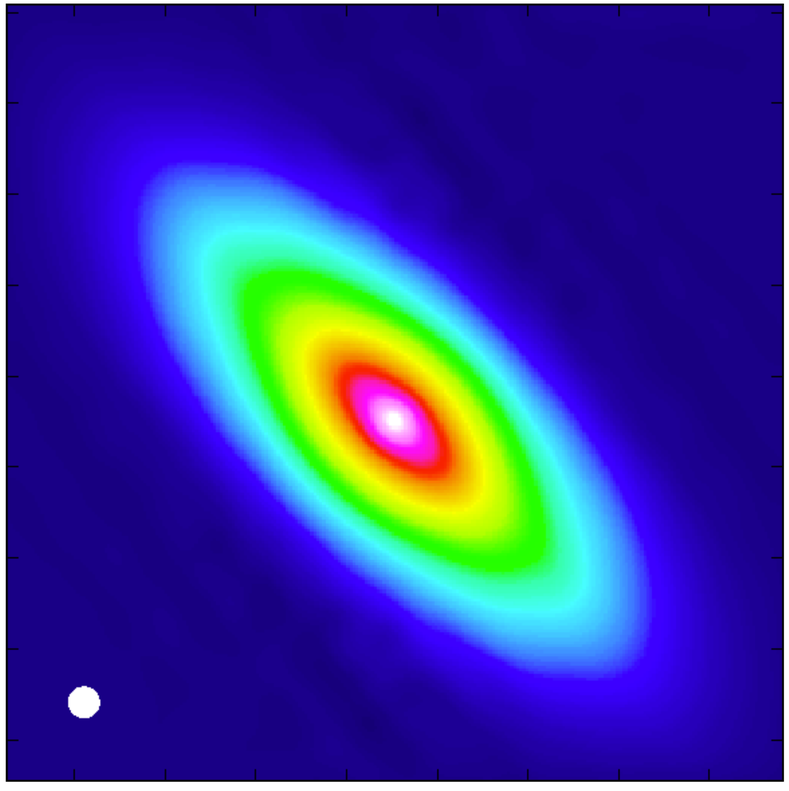
- single-scale clean
- Robust = 0.5
- Rough masking using convolved model
- Pixel = 1.0 arcsec (7m beam > 5.0 arcsec)
- Clean threshold down to 0.3 Jy/pixel

SSC (3): CASA tclean and SSC

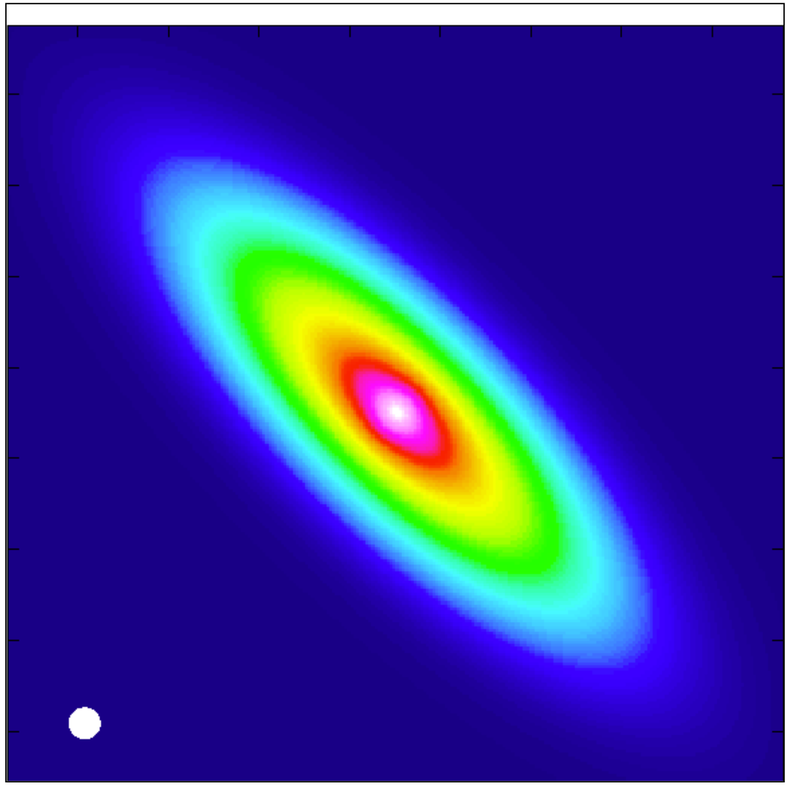


SSC (4): convolve to 10 arcsec, then fidelity

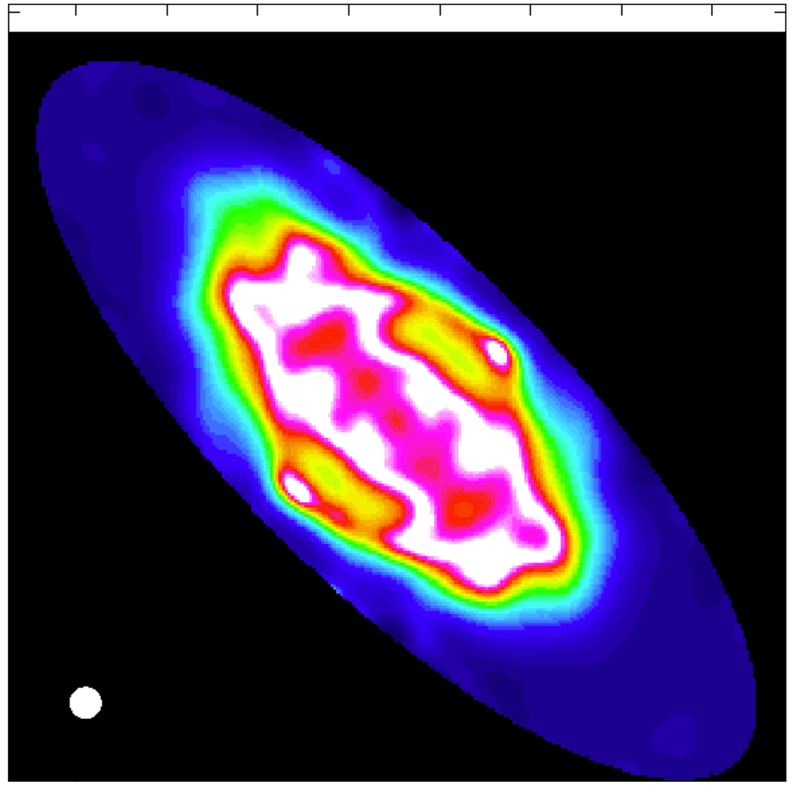
Smoothed clean image



Smoothed model image

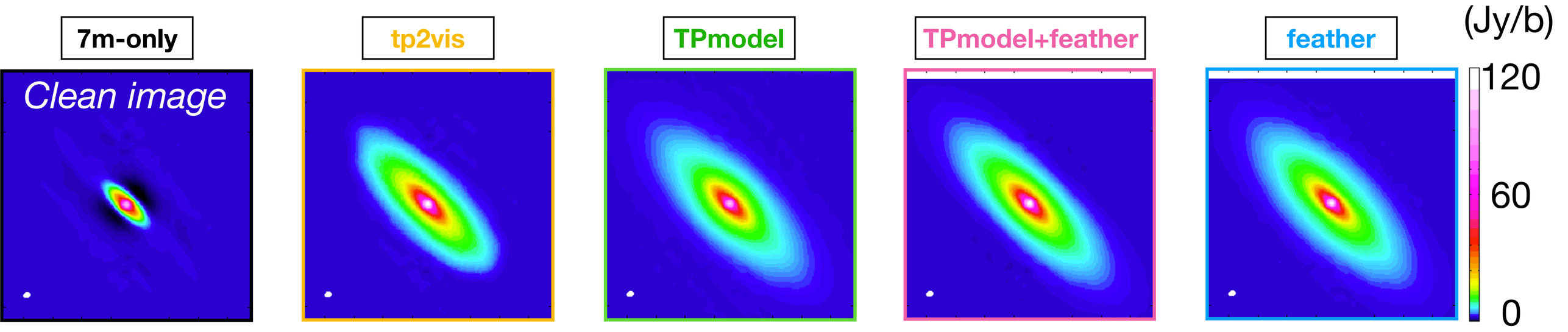


Fidelity image



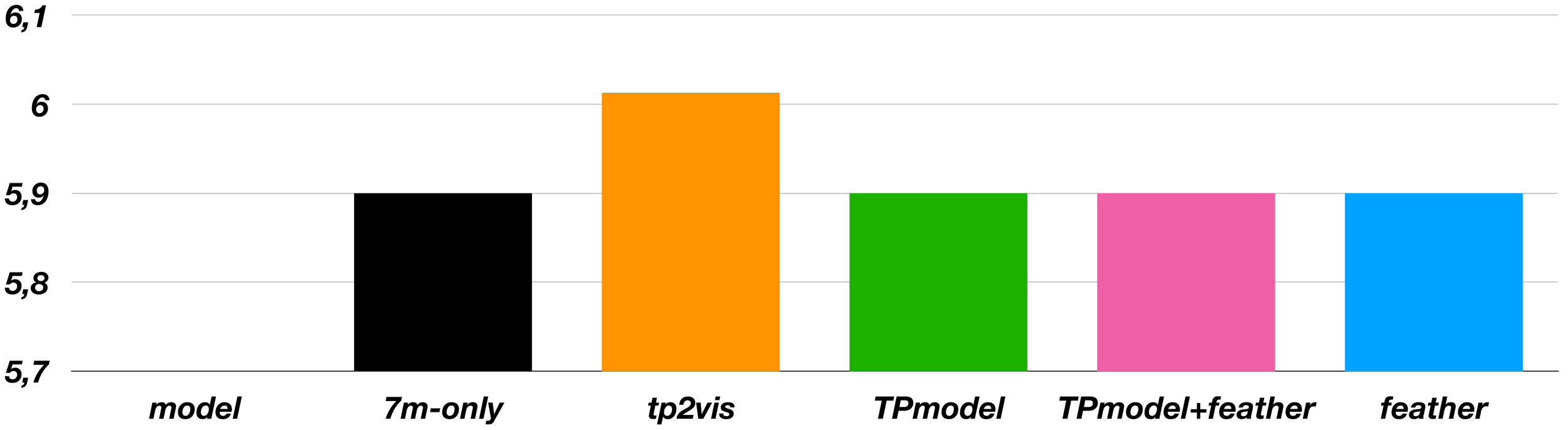
- Fidelity = abs(model) / abs(image - model); higher fidelity is better.
- Cut the outer part of the fidelity image

Gaussians: clean image



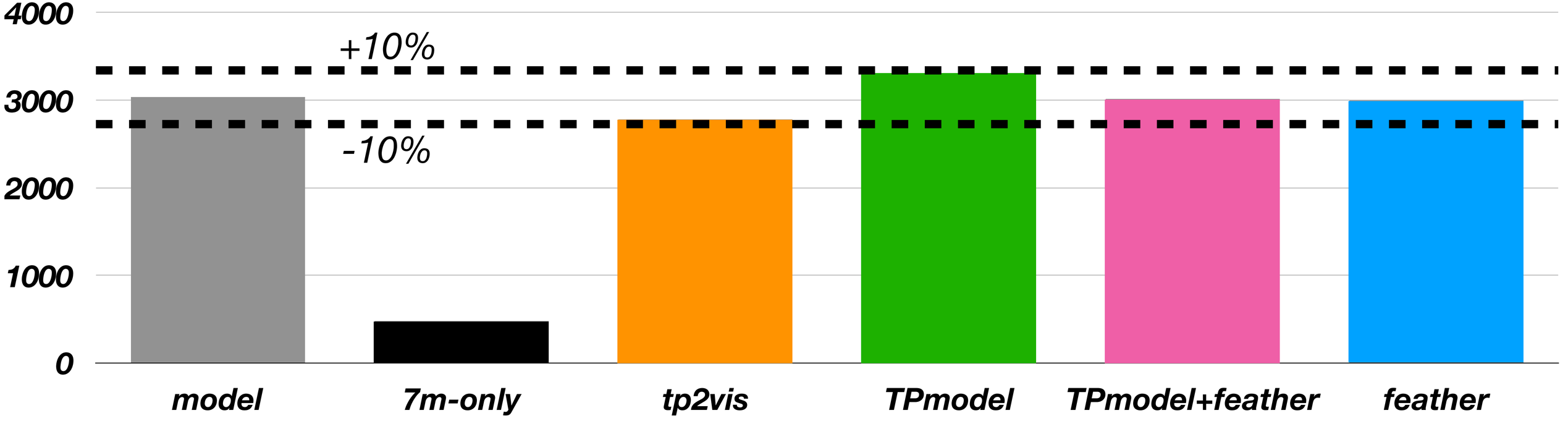
- All SSC methods well recover three Gaussian components.

Gaussians: Beam size geometrical mean (arcsec)



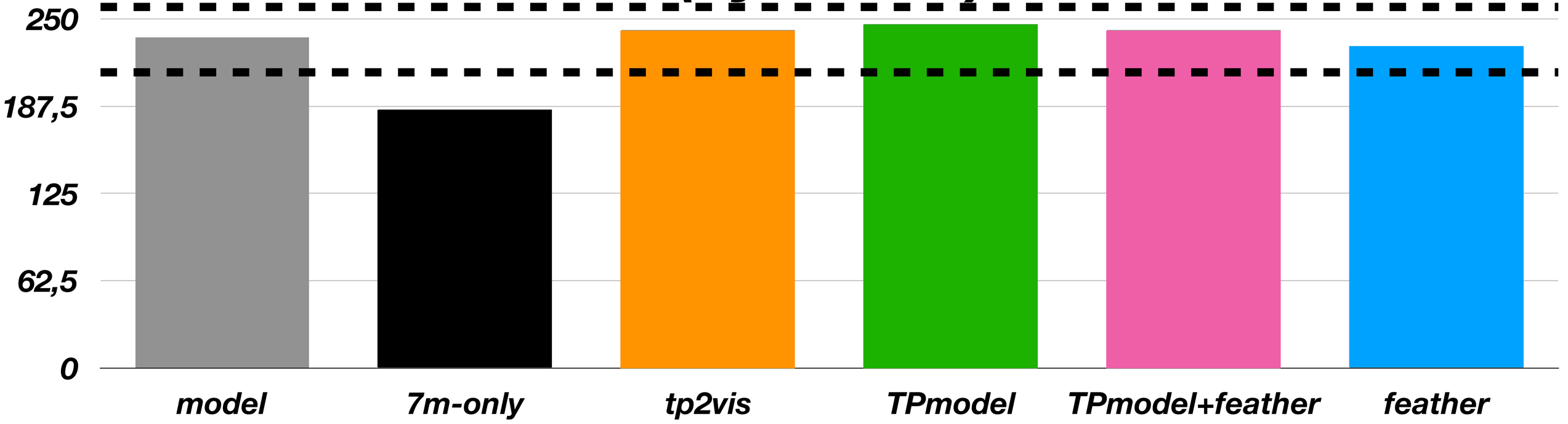
- **tp2vis** shows slightly larger beam size than other methods, because tp2vis put data points at the inner part of the uv coverage.

Gaussians: Total flux (Jy)



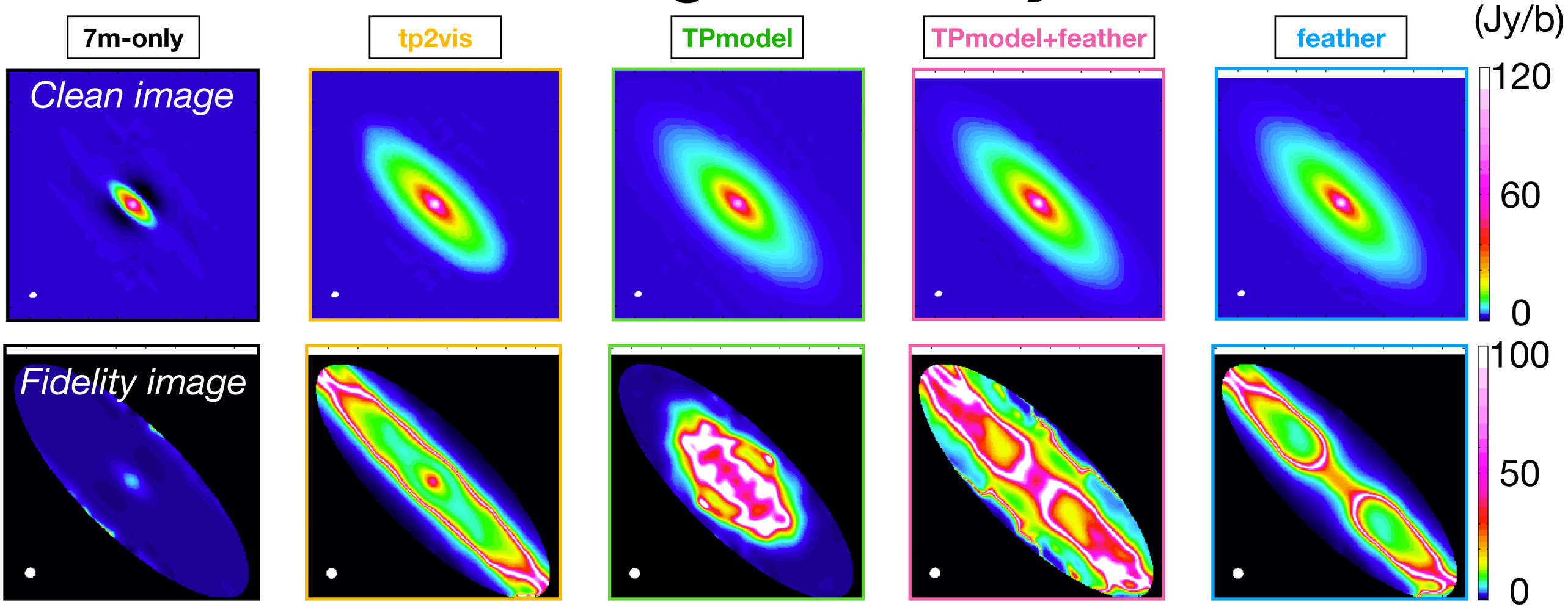
- **tp2vis** tends to underestimate, **TPmodel** overestimates, within 10% from the model input. (due to under/overestimate of extended structures)
- **feather** forces to set accurate <u>total</u> flux. (but depending on TP data quality of course.)

Gaussians: Peak flux (Jy/beam)



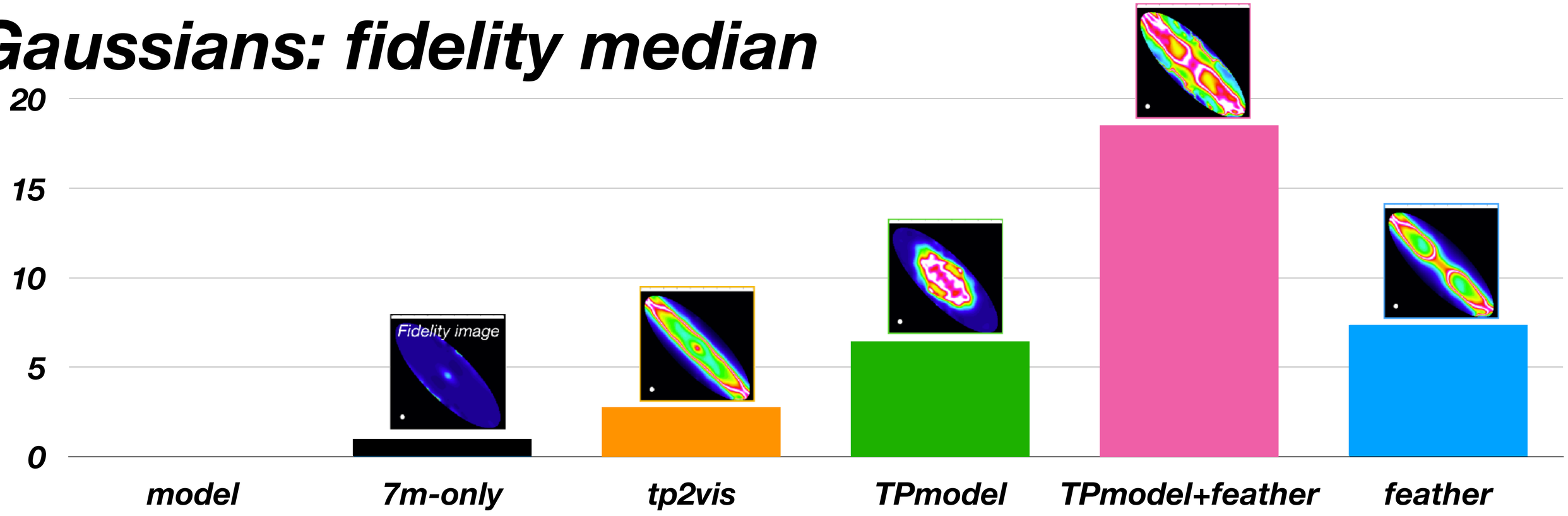
- This value corresponds to the pixel value at the image center.
- Differences from the model peak flux are <5%, except for **7m-only**.
- The **7m-only data** is missing more than 10% flux at the peak pixel, due to missing underlying extended structures.

Gaussians: clean image vs fidelity



- All SSC methods well recover three concentric Gaussian components.
- **TPmodel** shows higher fidelity around the centre of the image.

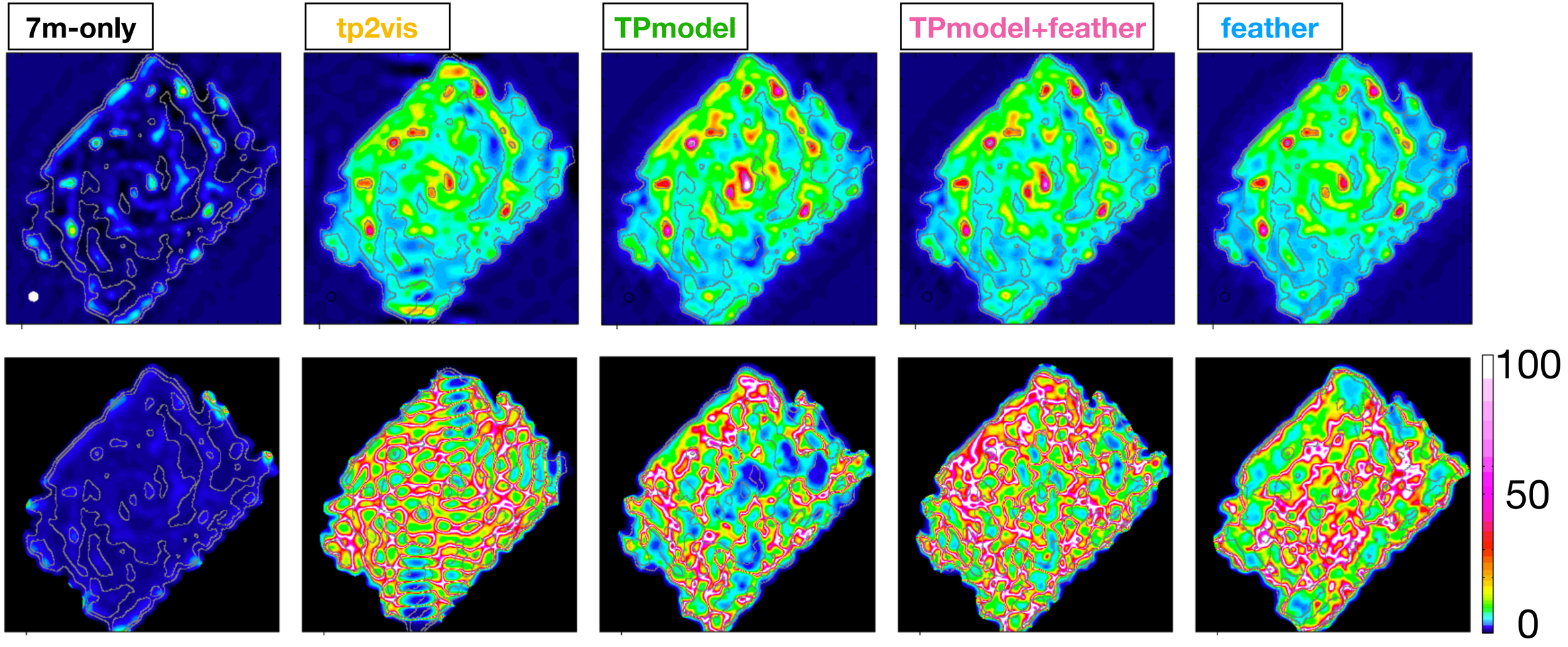
Gaussians: fidelity median



- This value depends on the masked area (e.g., smaller mask tends to give a larger fidelity median for **tp2vis**, **TPmodel**, and **feather**).
- **TPmodel+feather** provides the most accurate flux for the largest Gaussian component.

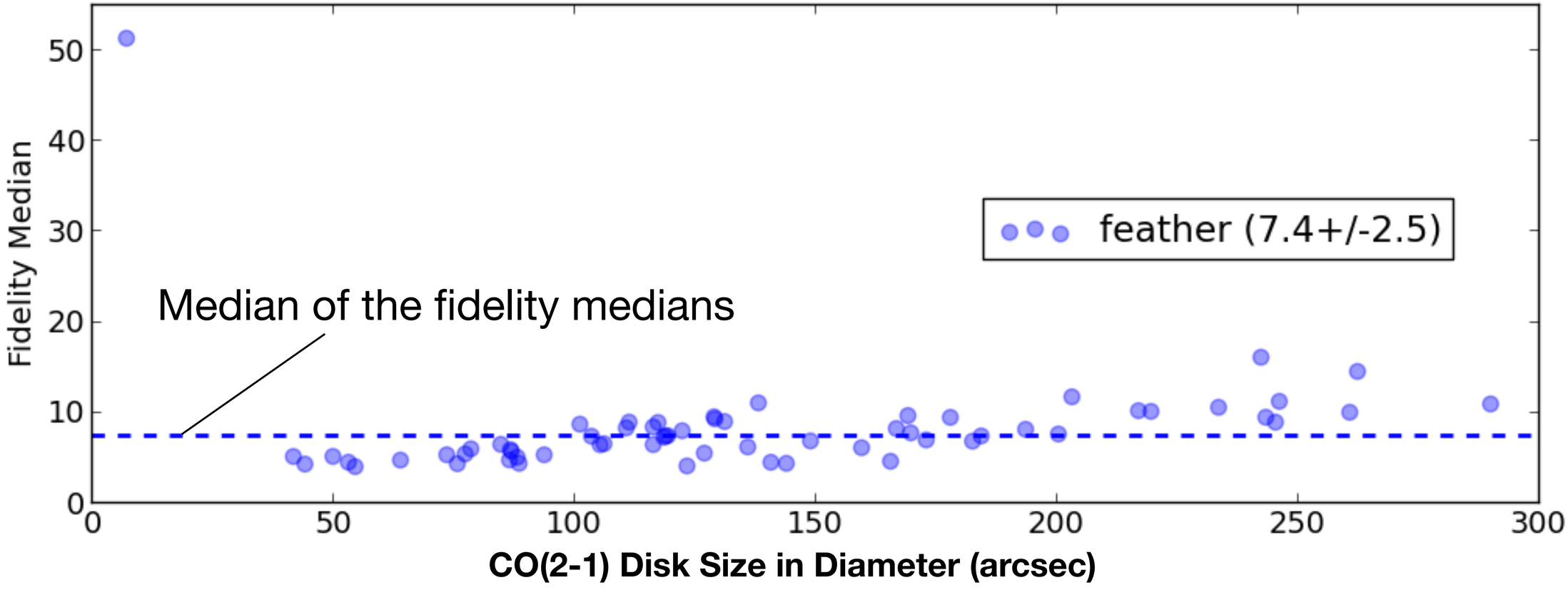
Short-spacing Correction for PHANGS

PHANGS: e.g., M74 results



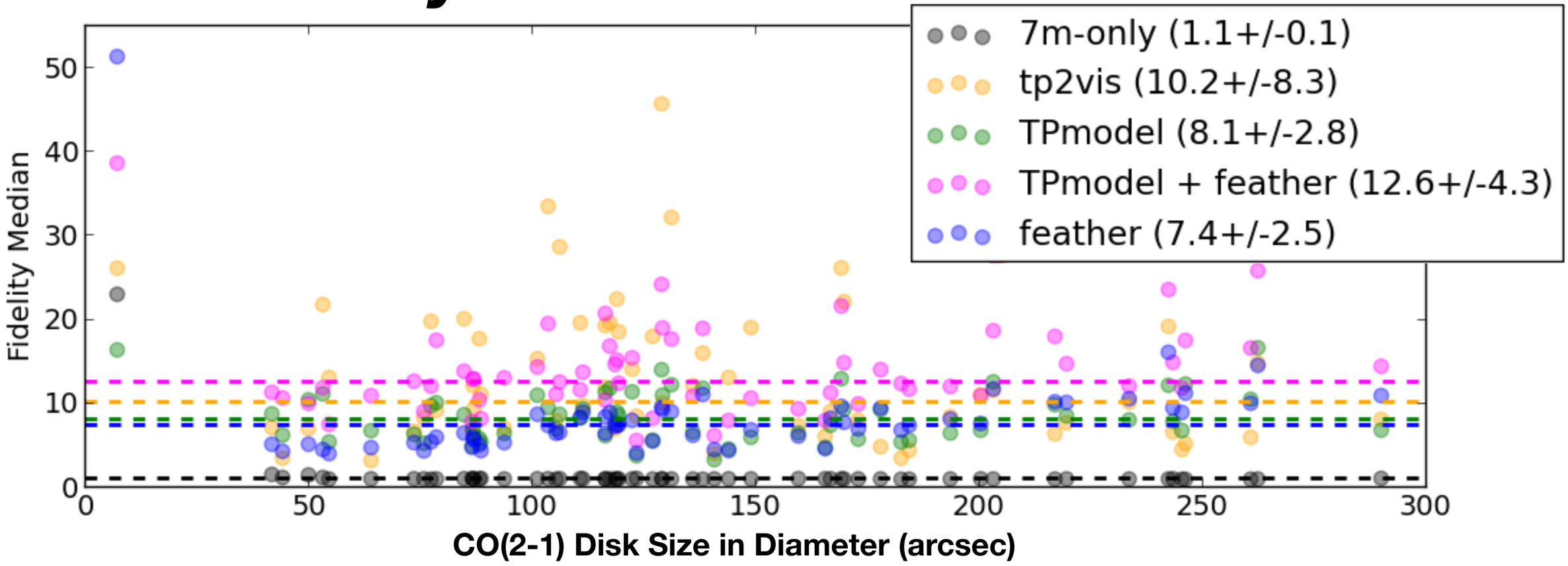
- **TPmodel** shows low fidelity around the image center due to flux overestimate. (c.f., **Jens' talk yesterday**)

PHANGS: fidelity median vs CO size



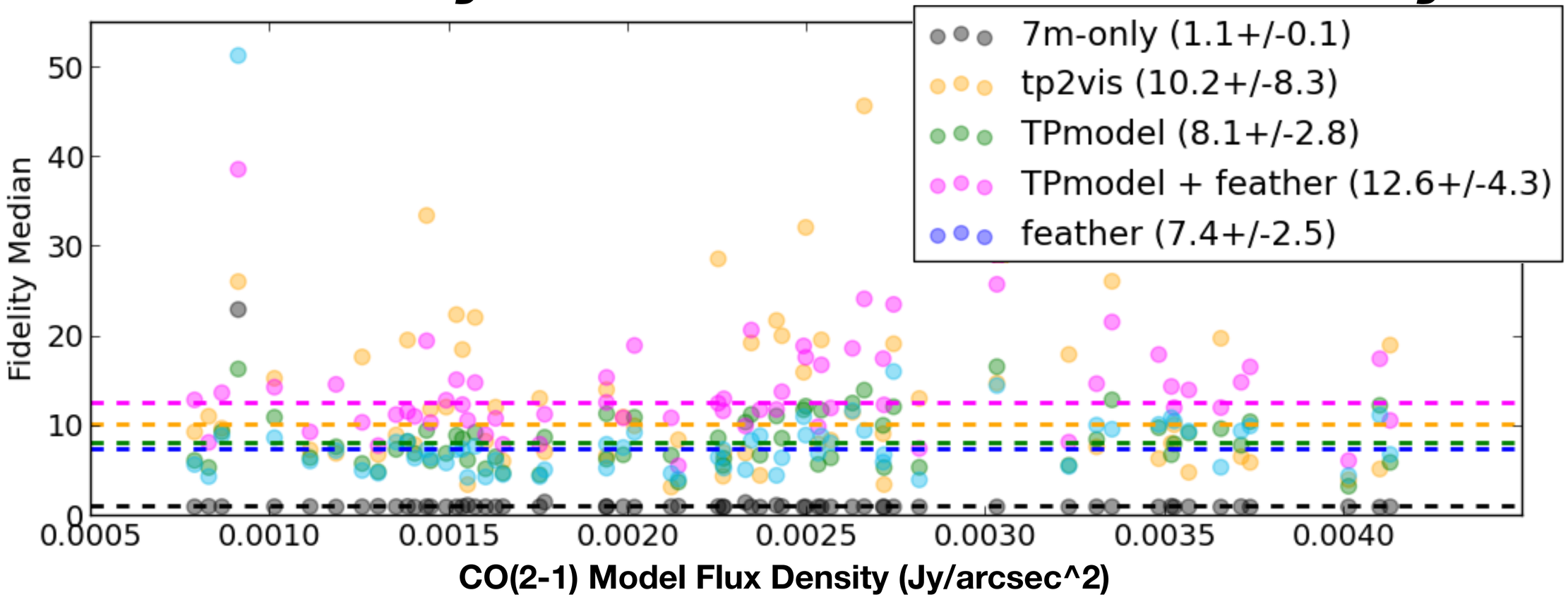
- Fidelity median very slightly increases as the CO size becomes larger.

PHANGS: fidelity median vs CO disk size



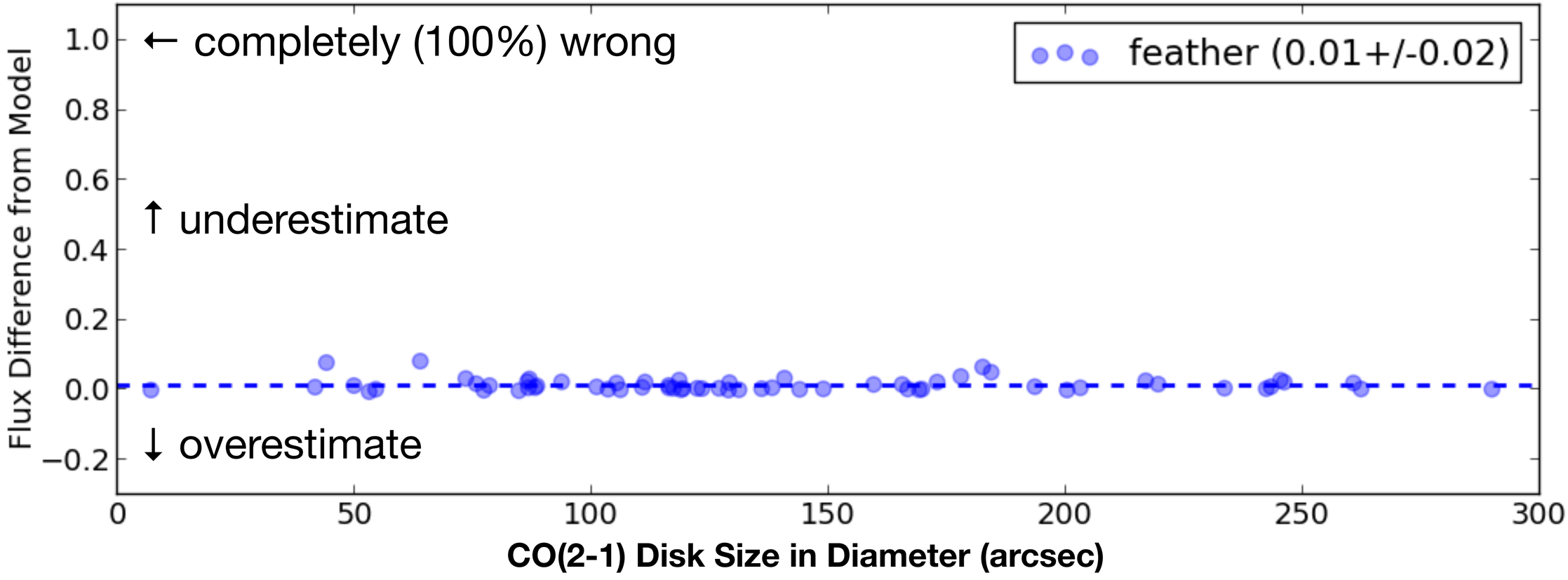
- **tp2vis** shows larger scatter.
- **TPmodel+feather** and **tp2vis** show higher fidelity median.
- CO disk size seems not to affect image quality.

PHANGS: fidelity median vs CO flux density

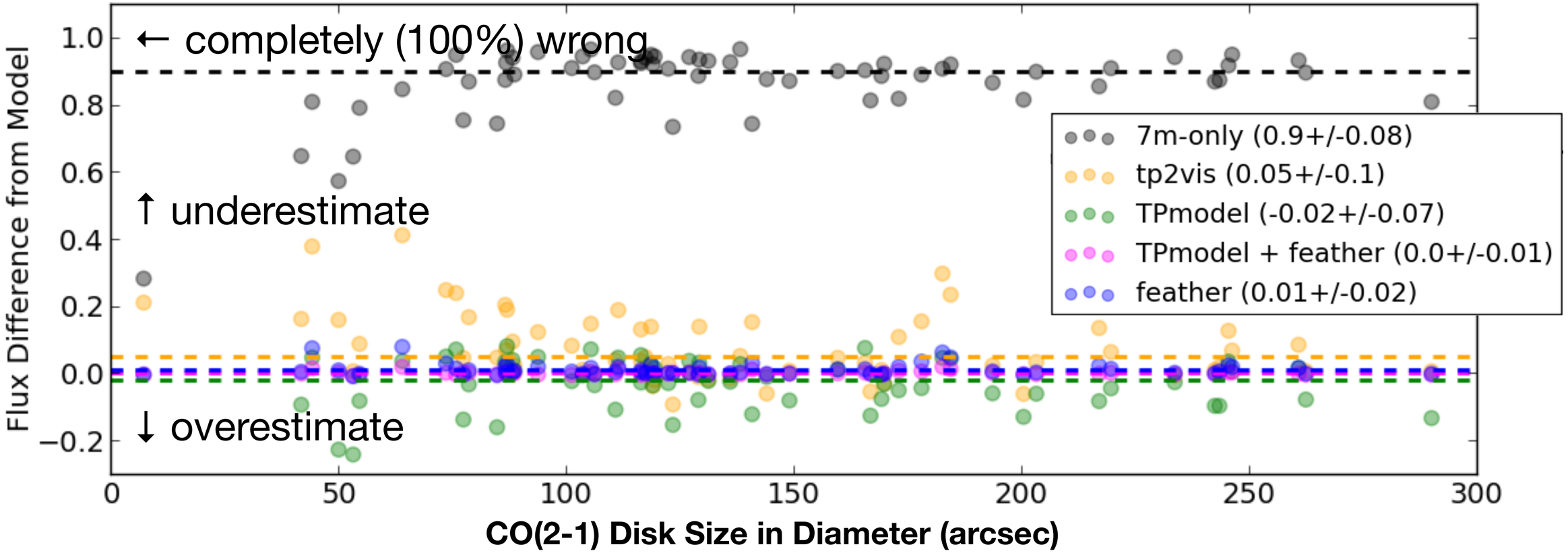


- **tp2vis** shows larger scatter.
- **TPmodel+feather** and **tp2vis** show higher fidelity median.
- CO total flux seems not to affect image quality too.

PHANGS: Total flux difference vs CO disk size

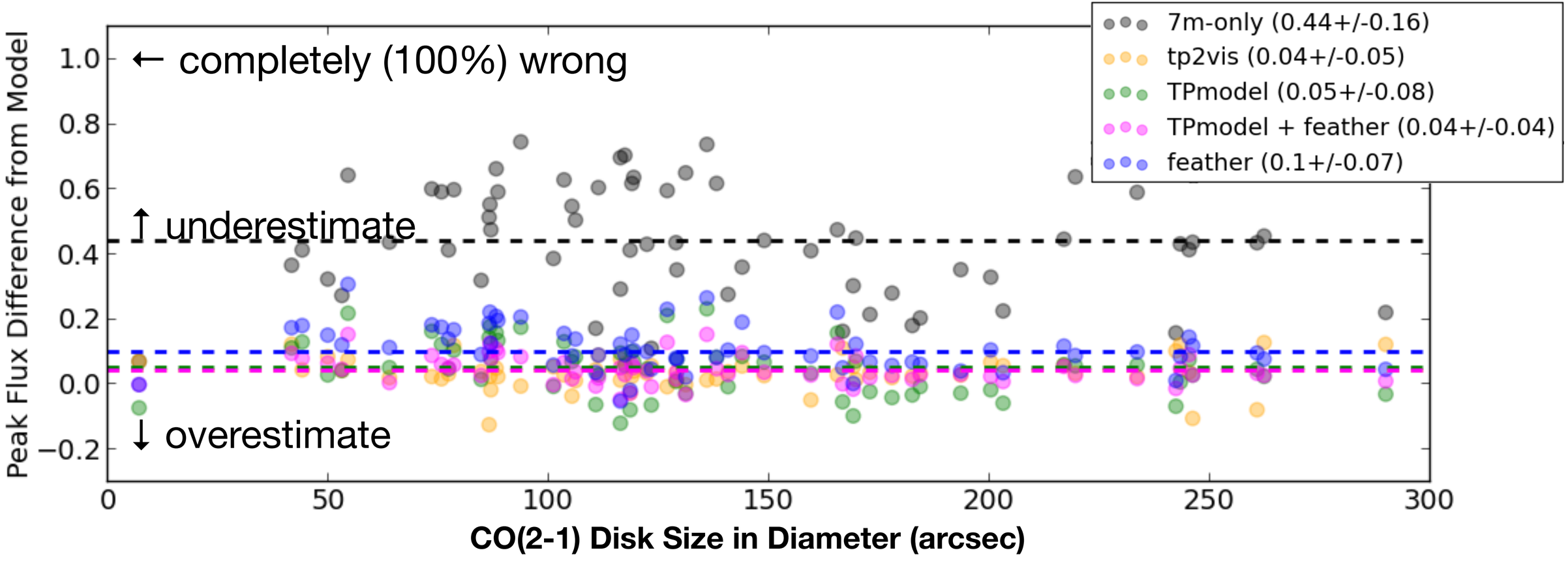


PHANGS: Total flux difference vs CO disk size



- **TPmodel** and **tp2vis** show larger scatter.
- **TPmodel** overestimates total flux (Jens' talk). **tp2vis** tends to underestimates.
- All SSC methods are consistent within ~10% with some outliers.

PHANGS: Peak flux difference vs CO disk size



- All SSC methods are consistent within ~10%.
- **7m-only** underestimates the peak flux independently of CO size, indicating the importance of TP data for nuclear region studies.

Summary

- We tested different short-spacing-correction methods, including tp2vis, TPmodel, feather, and TPmodel+feather (and 7m-only) using multi-Gaussian model and PHANGS CO(2-1) T_{peak} images.
- We found all tested SSC methods are consistent within ~10% in terms of total flux and peak flux.
- TPmodel overestimates flux, tp2vis tends to underestimate.
- CASA feather sets accurate total flux (tp2vis+feather works?).
- TPmodel+feather gives the most accurate flux for the extended structures.
- Target galaxy size and flux do not affect the image fidelity.
- Adding TP data is important for nuclear region studies.

Thank you!

http://www.phangs.org

NRAO/AUI/NSF, B. Saxton: ALMA (ESO/NAOJ/NRAO); NASA/Hubble

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