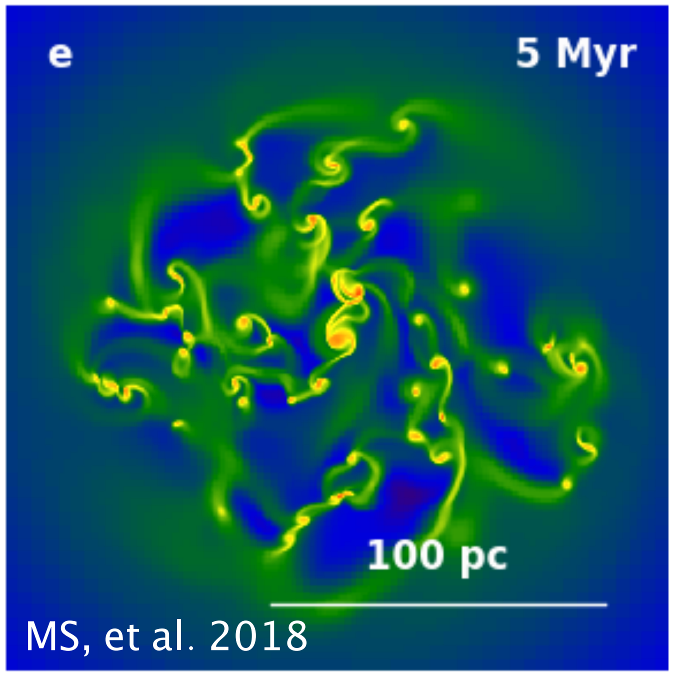
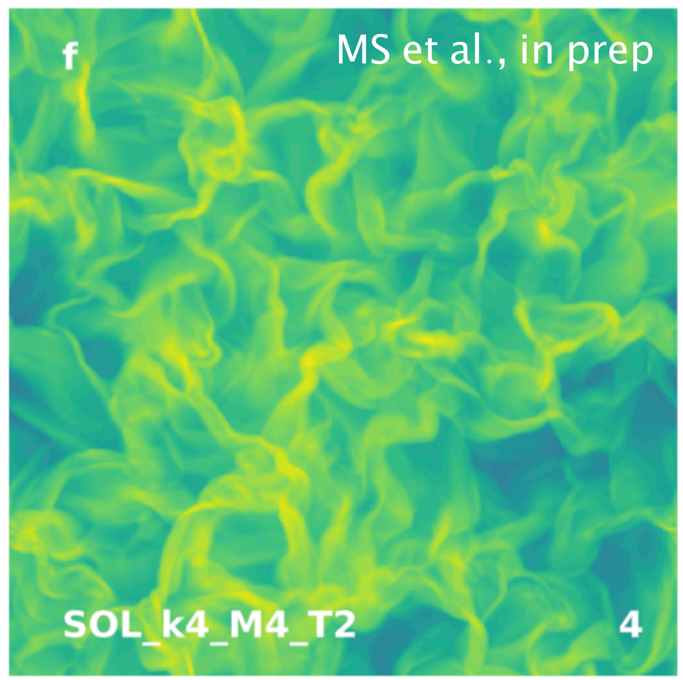
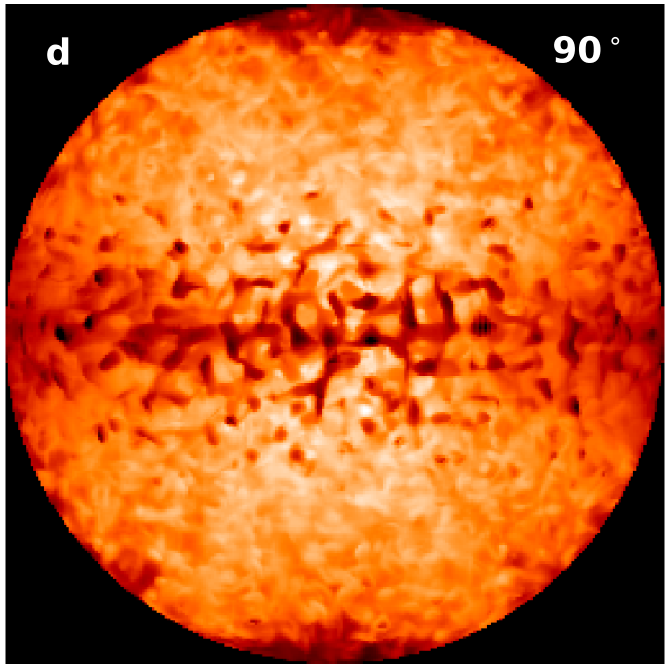
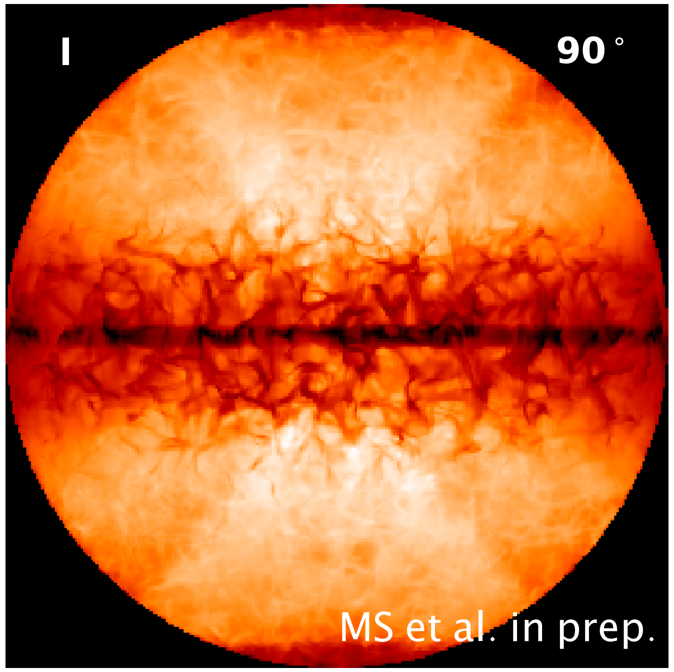
The effect of circum-nuclear discs on the central gas and dust distribution









Marc Schartmann

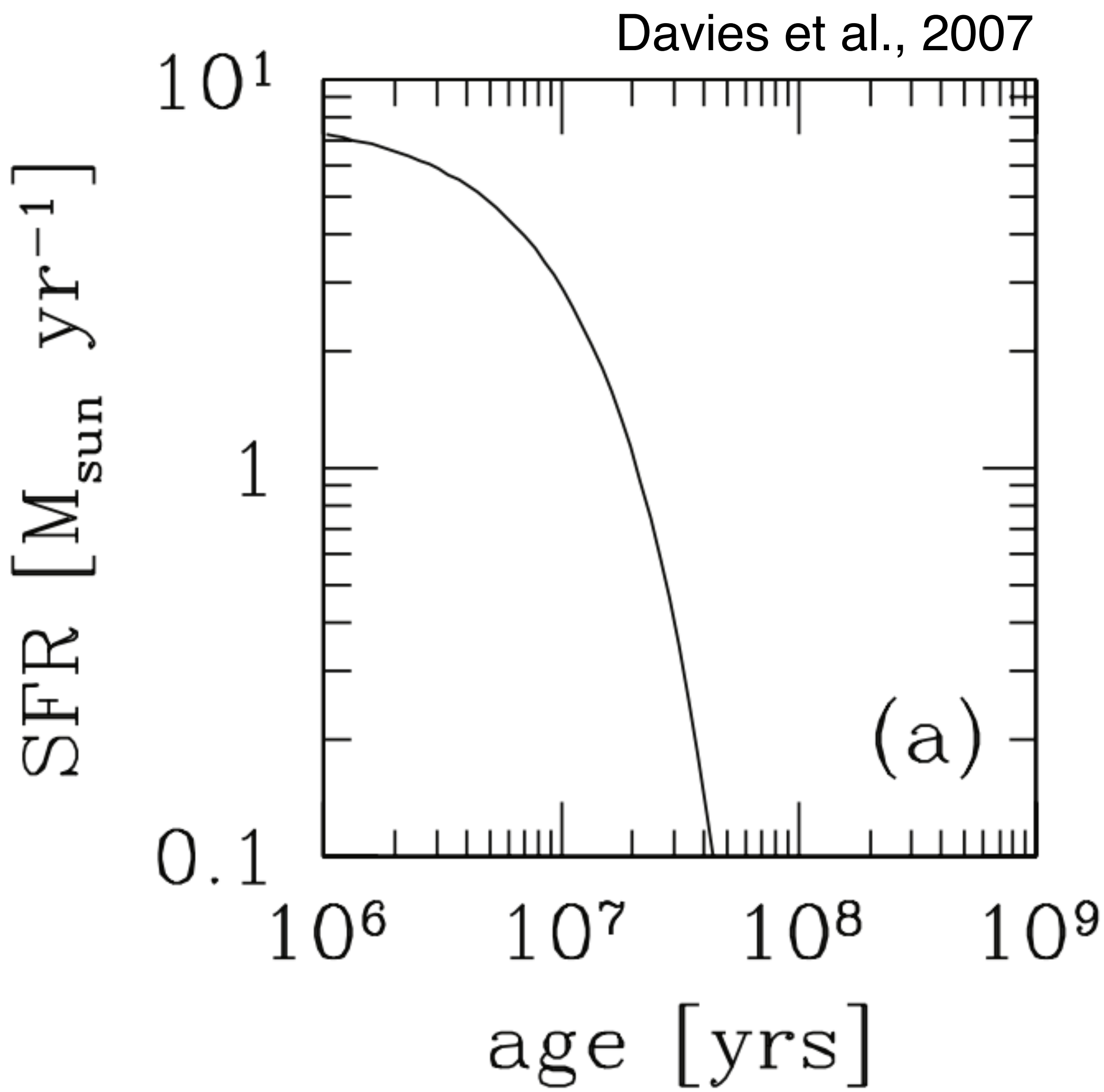
with M. Behrendt, A. Burkert, L. Burtscher, R.I.Davies, M. Durré, H. Jud, J. Mould, A. Prieto, K. Tristram, B. Vollmer, K. Wada

CAST Computational Astrophysics Group Munich University Observatory

MPE

SWINBURNE UNIVERSITY OF TECHNOLOGY

Circumnuclear disc setup

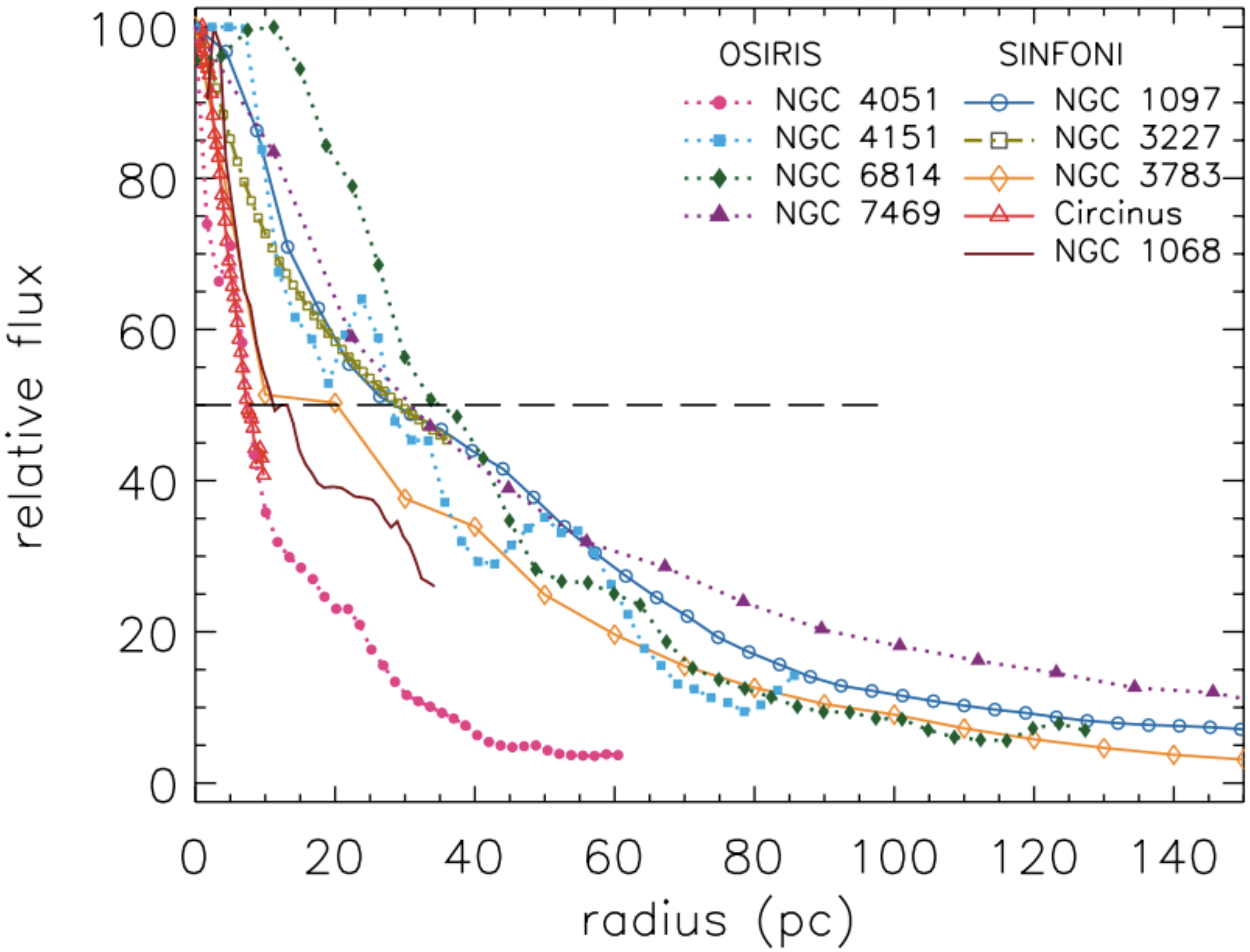


short duration star burst

population synthesis modelling of
SINFONI observations of nearby Seyferts

Circumnuclear disc setup

Hicks+ 2009



azimuthal averages of the H_2 flux distributions in the central parsecs of nearby Seyferts

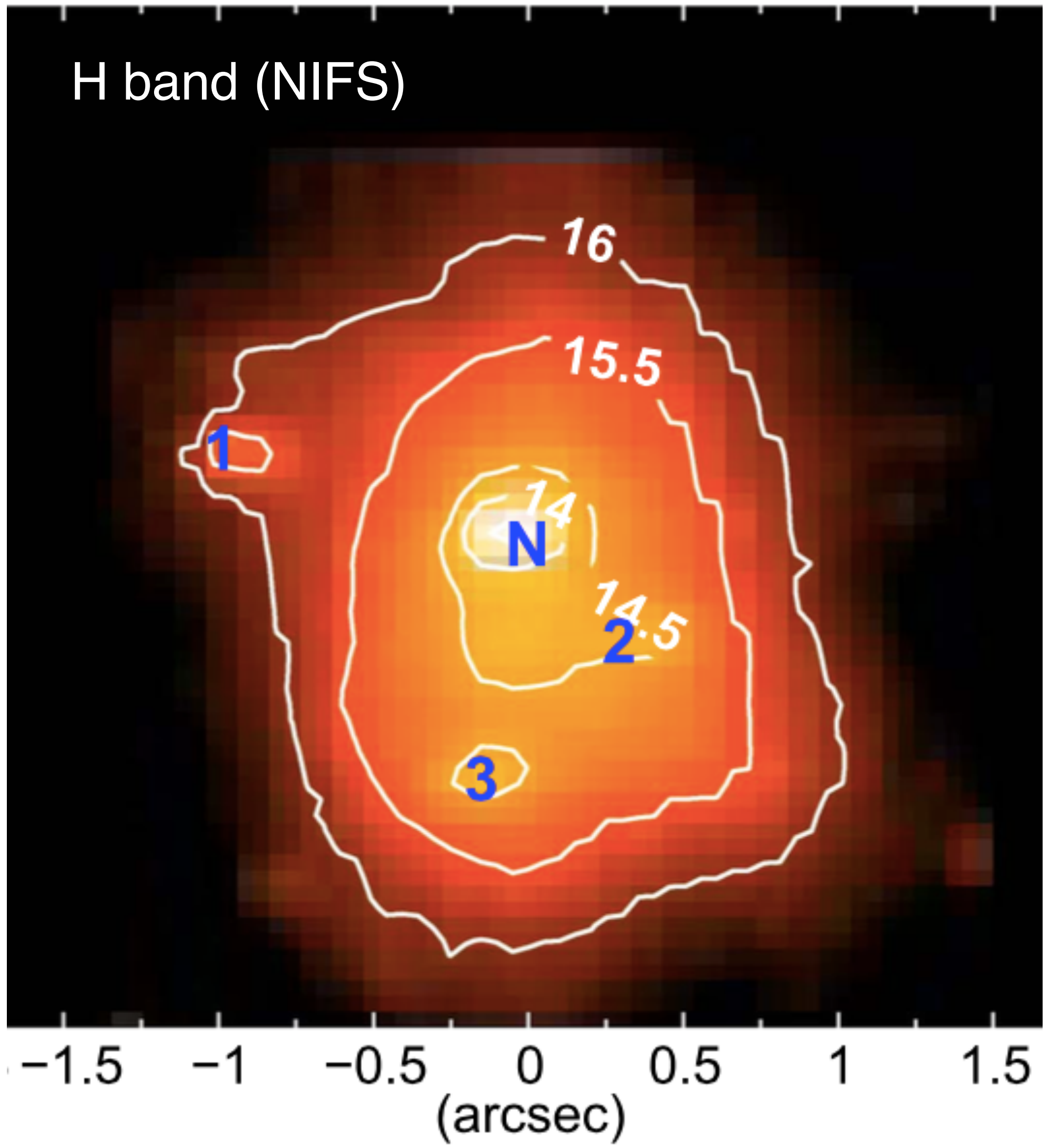
short duration star burst

+

(exponential) gas discs with $\sim 10^7\ M_\odot$ within 30 pc

Circumnuclear disc setup

Durré, Mould, MS et al. (2017)



short duration star burst

+

(exponential) gas discs with
~ 10^7 $M_\odot$ within 30 pc

+

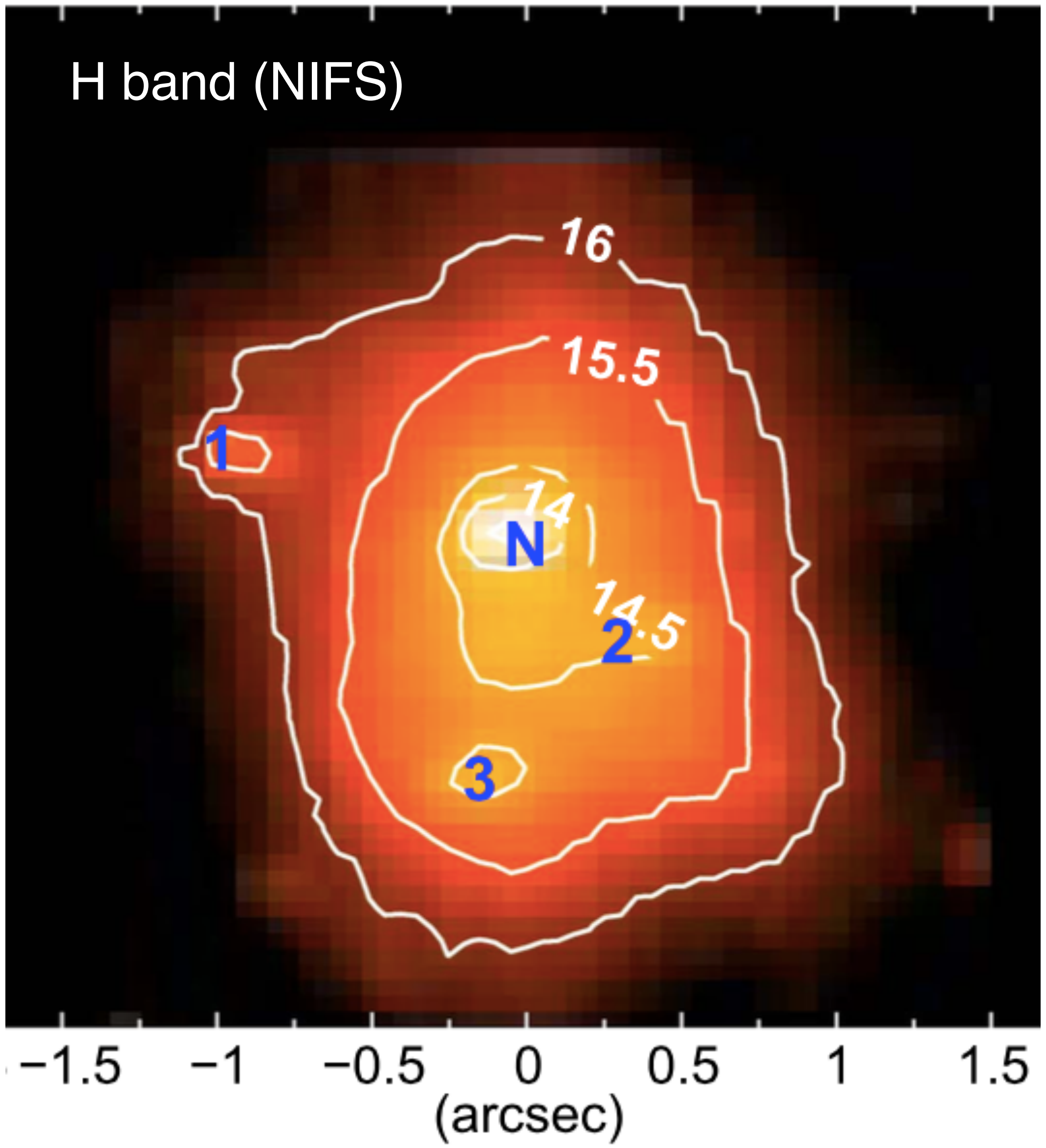
SF is dominated by a small no. of clusters in many sources

IC 630:

intense burst of recent star formation (~6 Myr old)
SFR ~ 1-2 $M_\odot$ / yr, concentrated in 4 clusters
outflow: 0.18 $M_\odot$ / yr, driven by SF

Circumnuclear disc setup

Durré, Mould, MS et al. (2017)



short duration star burst

+

(exponential) gas discs with $\sim 10^7\ M_\odot$ within 30 pc

+

SF is dominated by a small no. of clusters in many sources

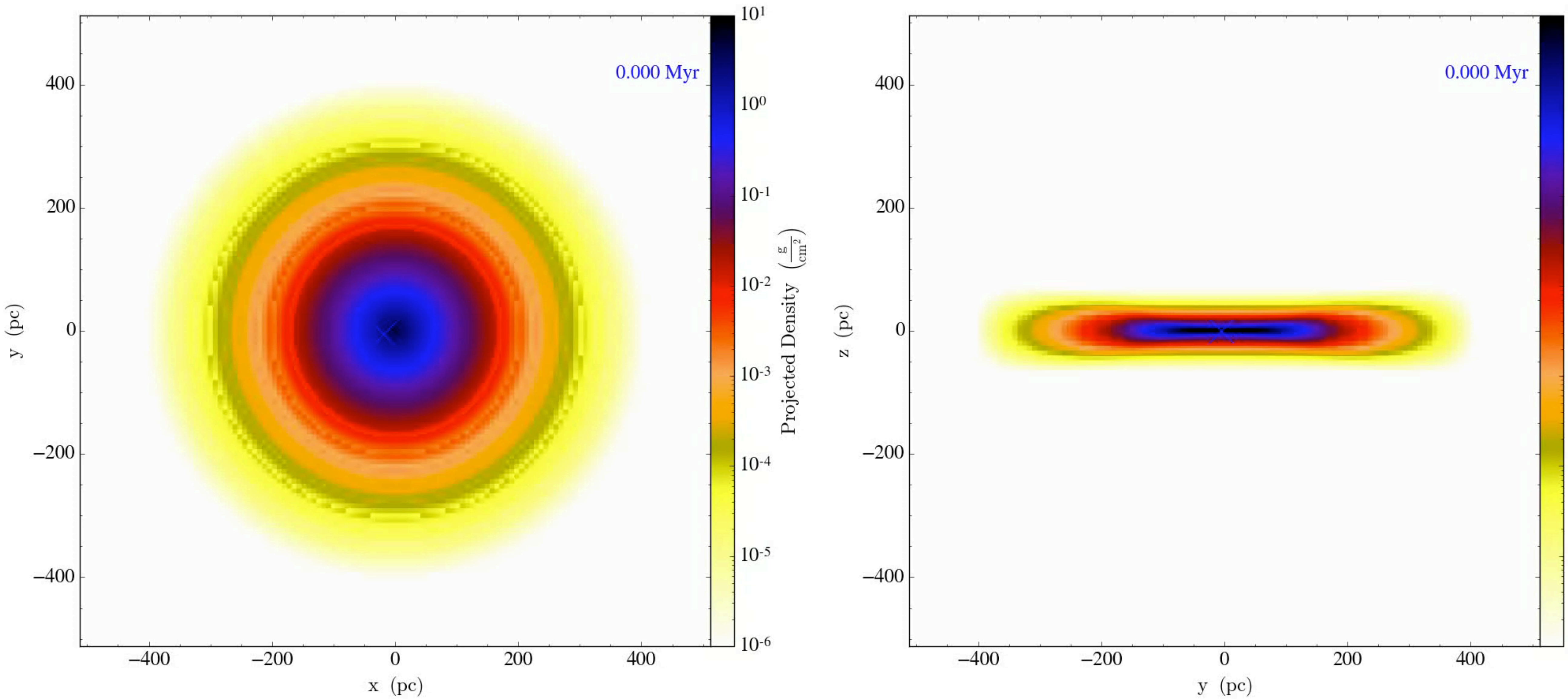
Simulation strategy

- gravitational instabilities in self-gravitating circum-nuclear discs
- include star formation and stellar feedback self-consistently

What are the implications for the formation of parsec-scale gas distributions?

Circumnuclear disc evolution

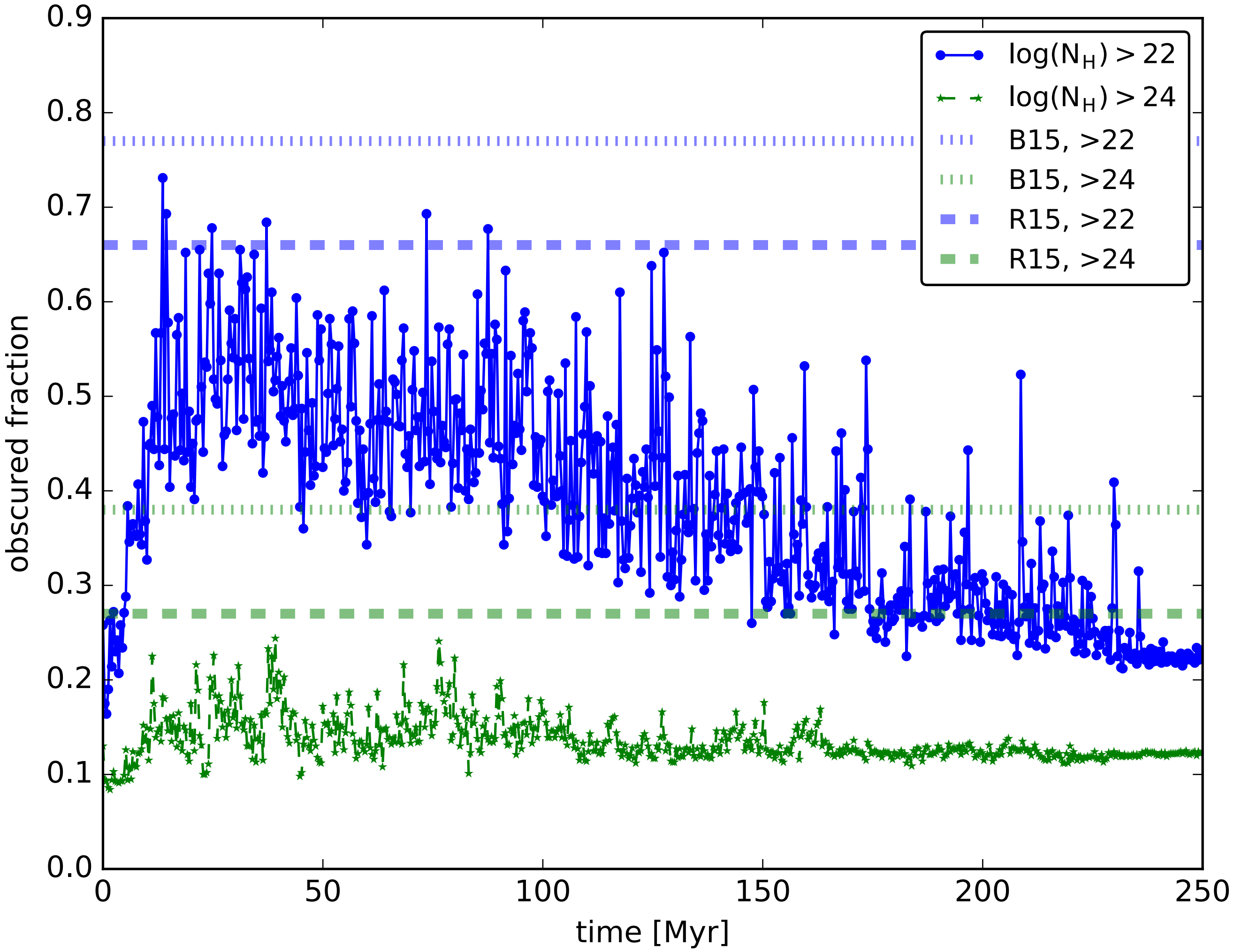
- use observed properties of circum nuclear discs in nearby Seyfert galaxies



- Toomre unstable gas disc: rings / spirals, clumps within ~150 pc
- clump merging, star formation in clumps
- SF, SN feedback slowly disrupts clumps, counterbalanced by clump merging
- high density fountain flow and tenuous, hot, high velocity (few 100 km/s) outflow
- turns into Toomre-stable smooth disc after ~ 150 Myr

MS, et al. 2018

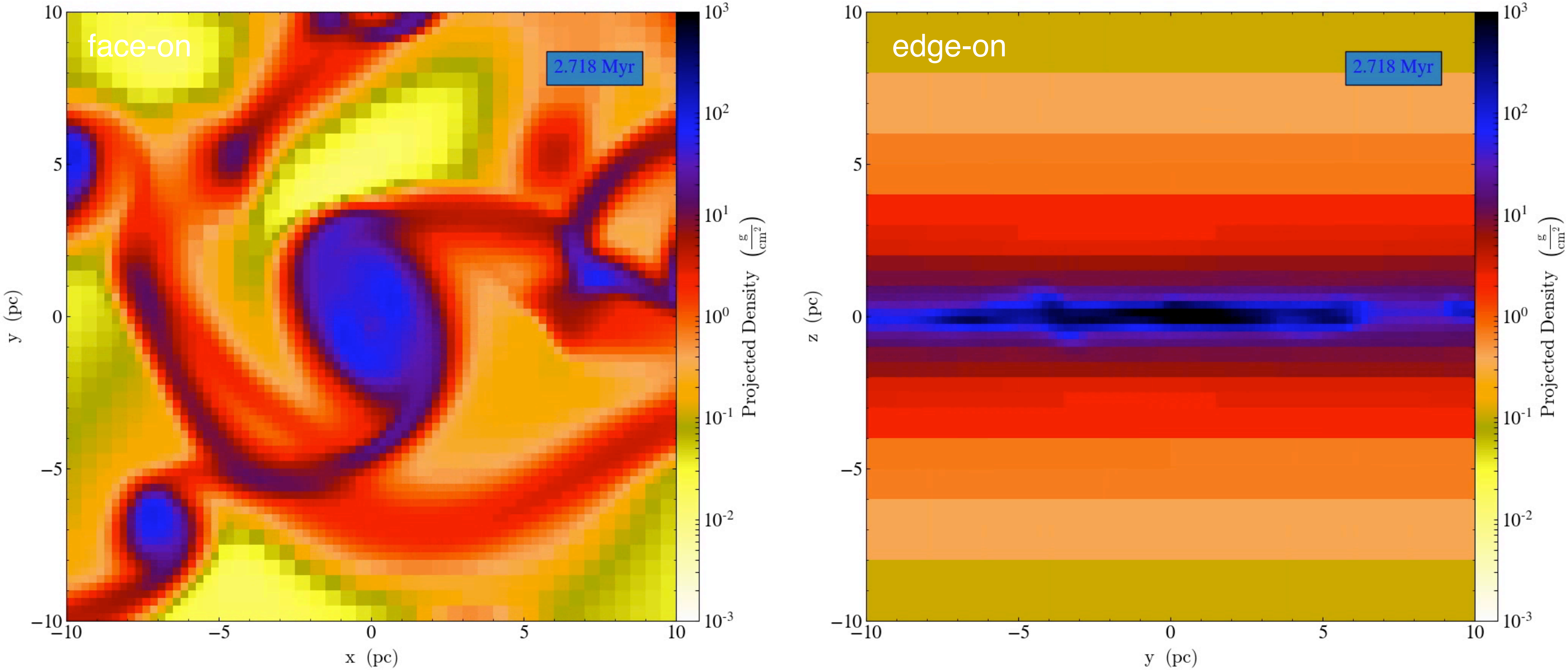
I. Obscuration on tens of pc scale



- central 5pc cut out
- increase in obscured fraction during starburst due to high density fountain like flow

MS, et al. 2018

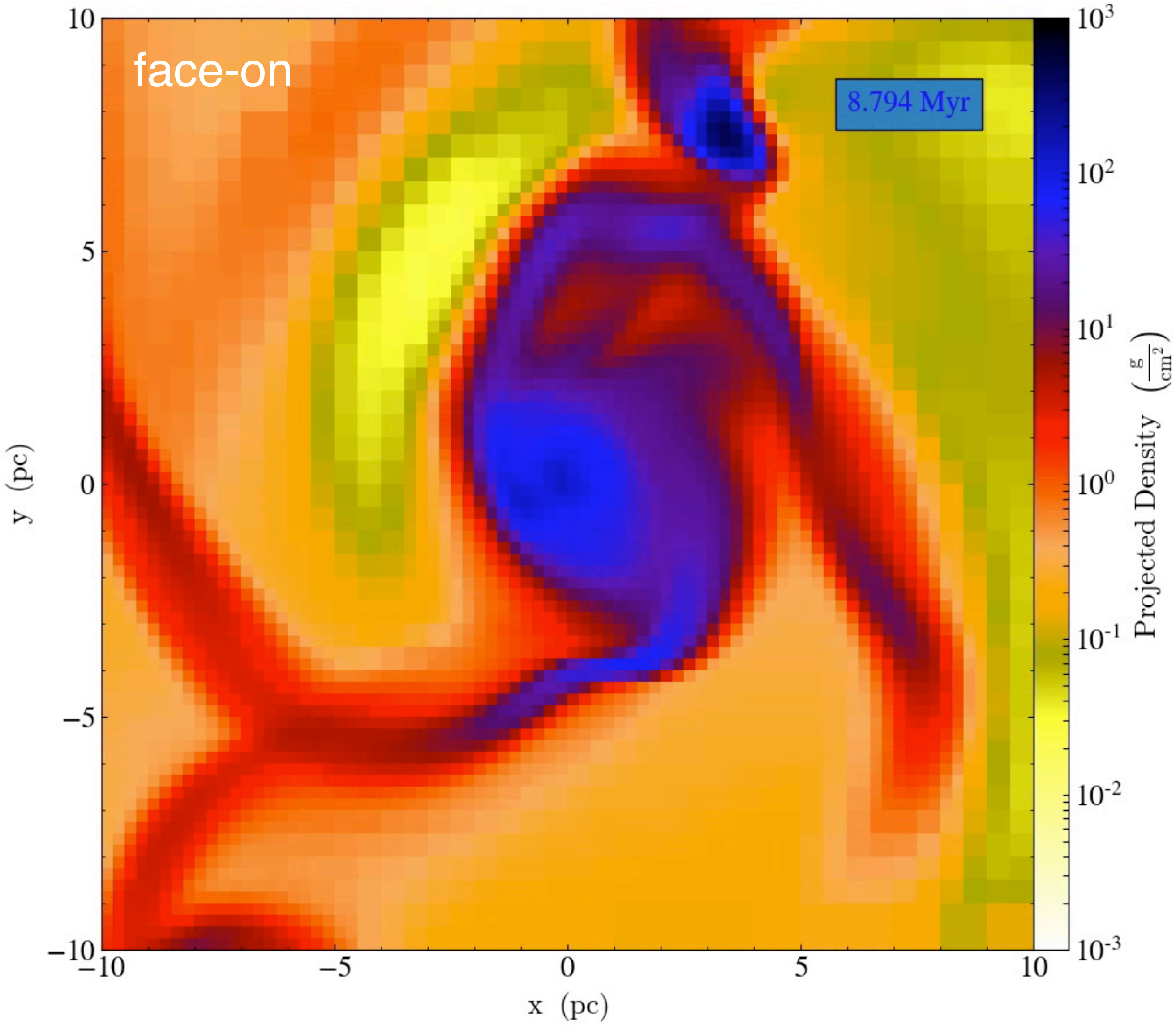
II. Forming and feeding tori via disc instability in circumnuclear discs

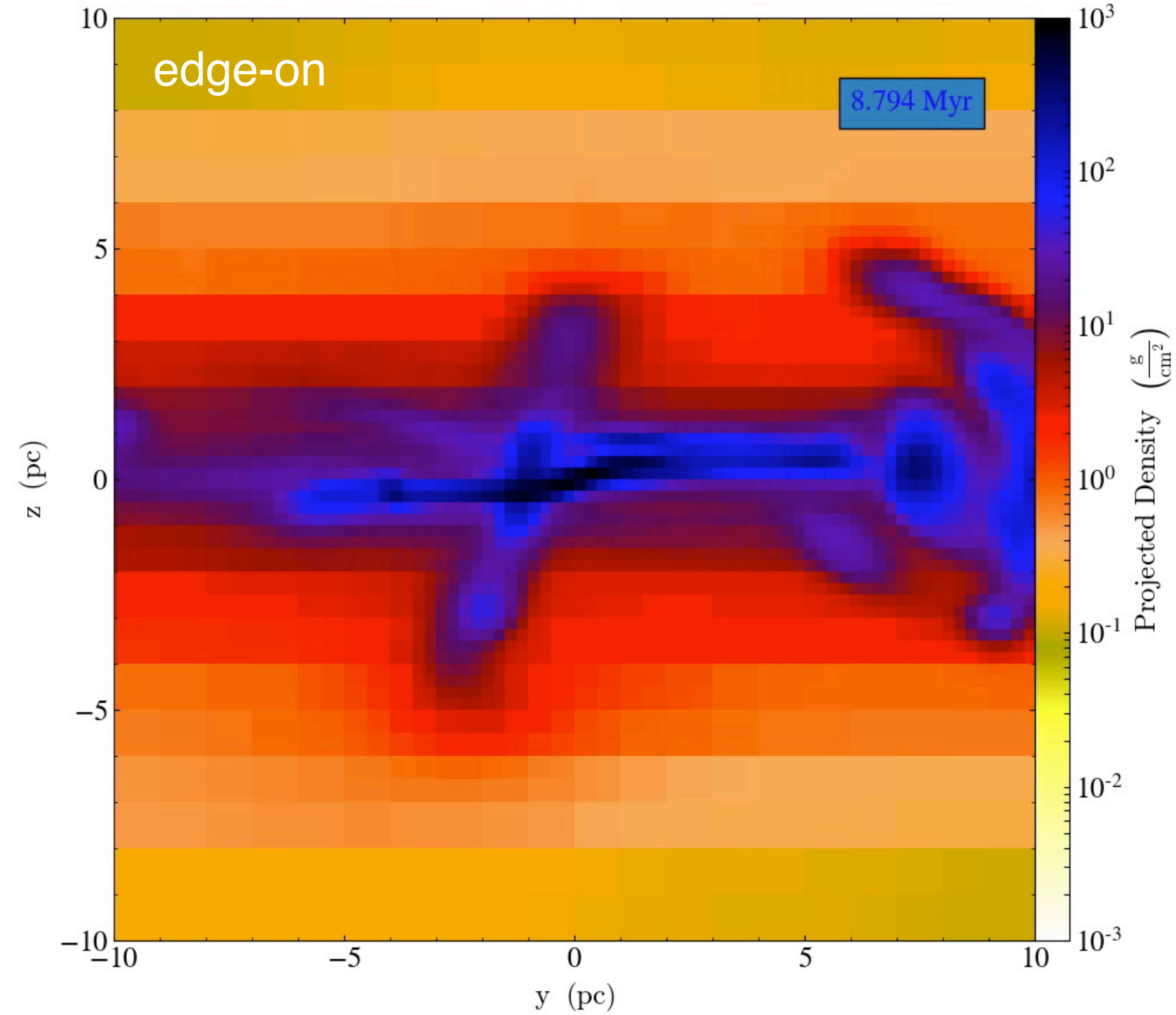


- combination of clump merging and dynamical friction leads to clump migration towards the centre
- build-up of a central disc / torus on a few parsec scale

MS, et al. 2018

II. Forming and feeding tori via disc instability in circumnuclear discs





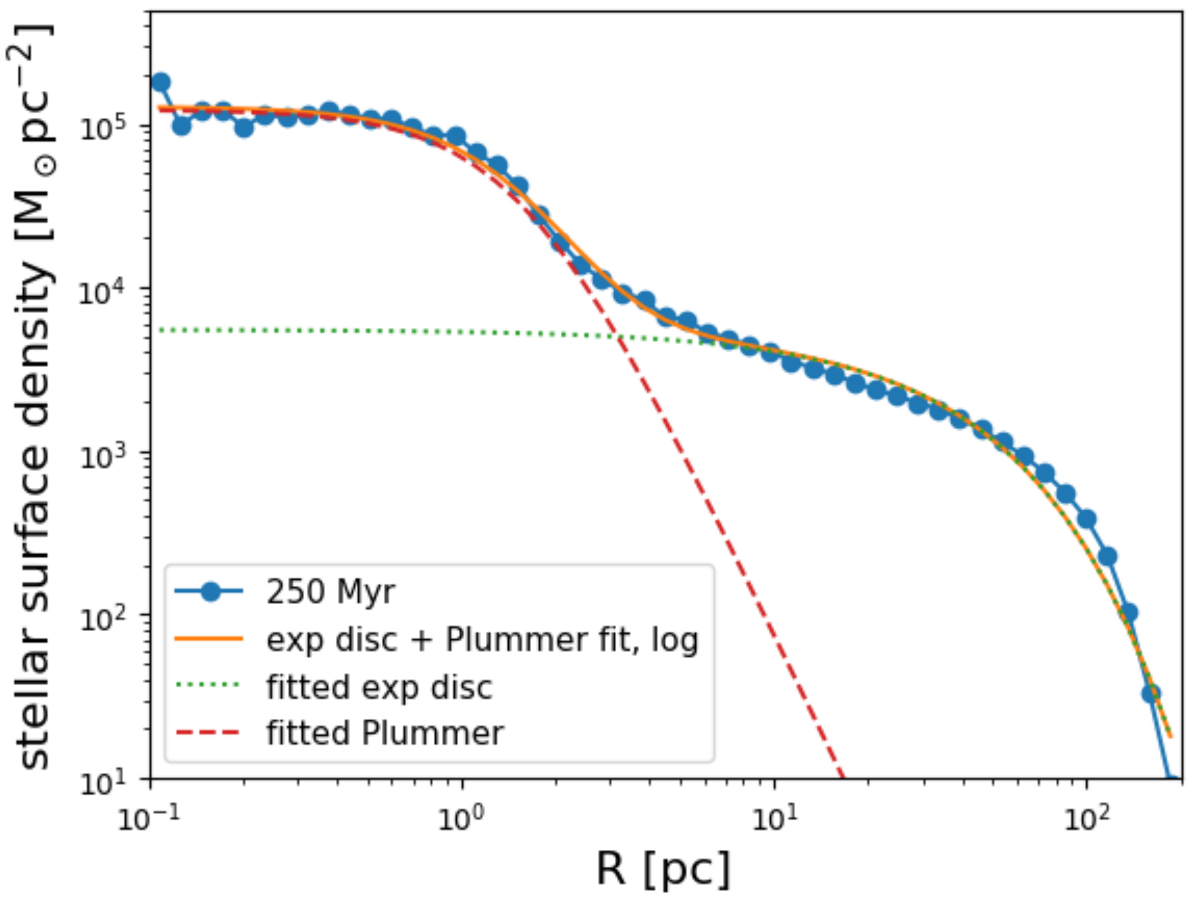
- combination of clump merging and dynamical friction leads to clump migration towards the centre
- build-up of a central disc / torus on a few parsec scale

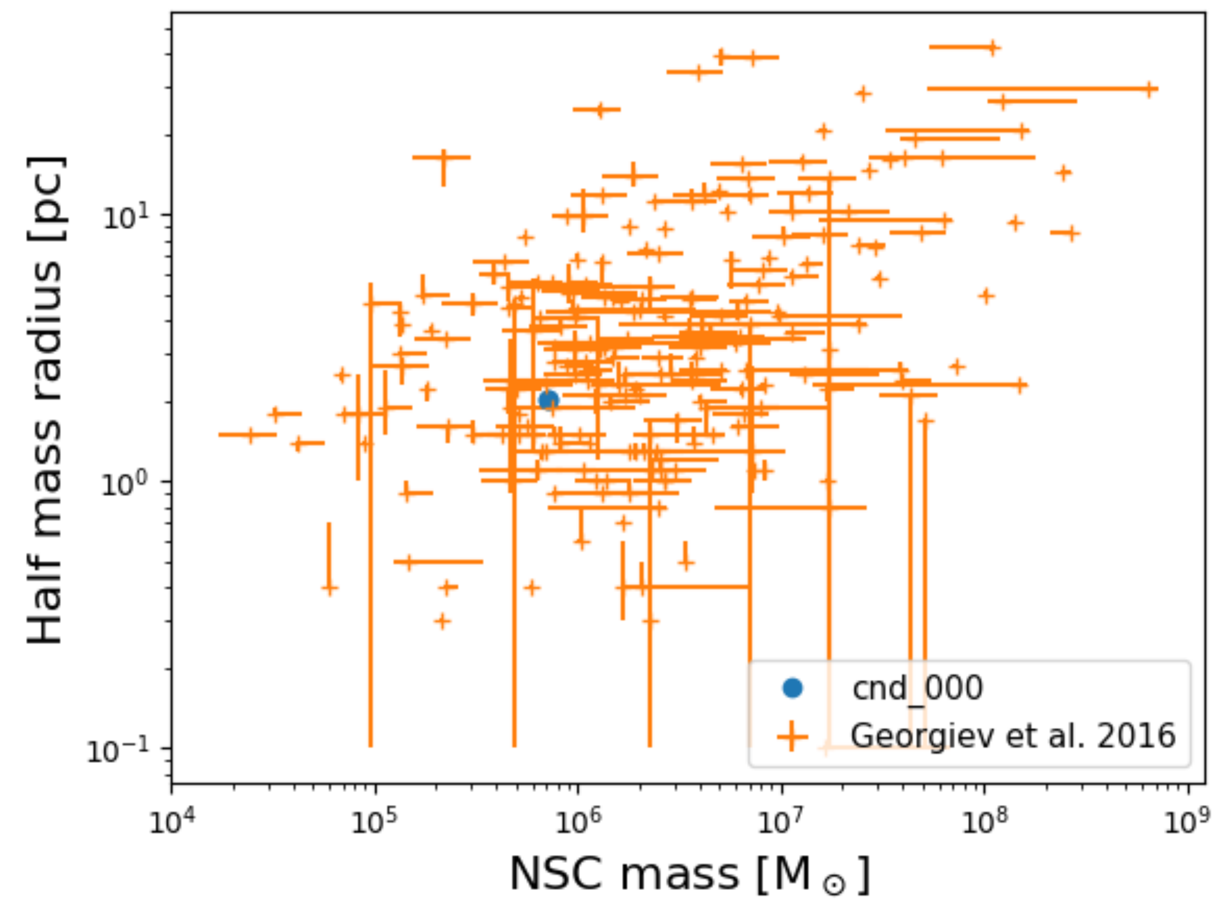
clump accretion drives random motions / turbulence in the central few parsec region

How does turbulent substructure affect observable quantities?

MS, et al. 2018

II. Forming and feeding tori via disc instability in circumnuclear discs





- combination of clump merging and dynamical friction leads to clump migration towards the centre
- build-up of a central disc / torus on a few parsec scale

➡ clump accretion drives random motions / turbulence in the central few parsec region

➡ How does turbulent substructure affect observable quantities?

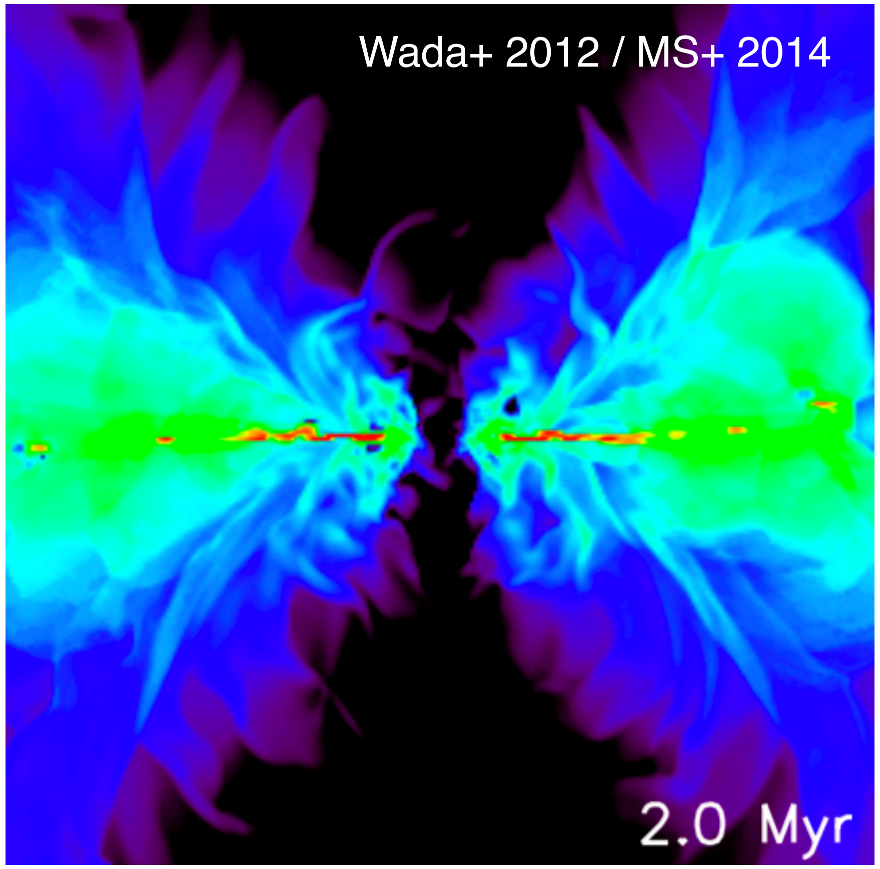
- SN: nuclear star cluster forms via wet-migration scenario (Guillard et al 2016)

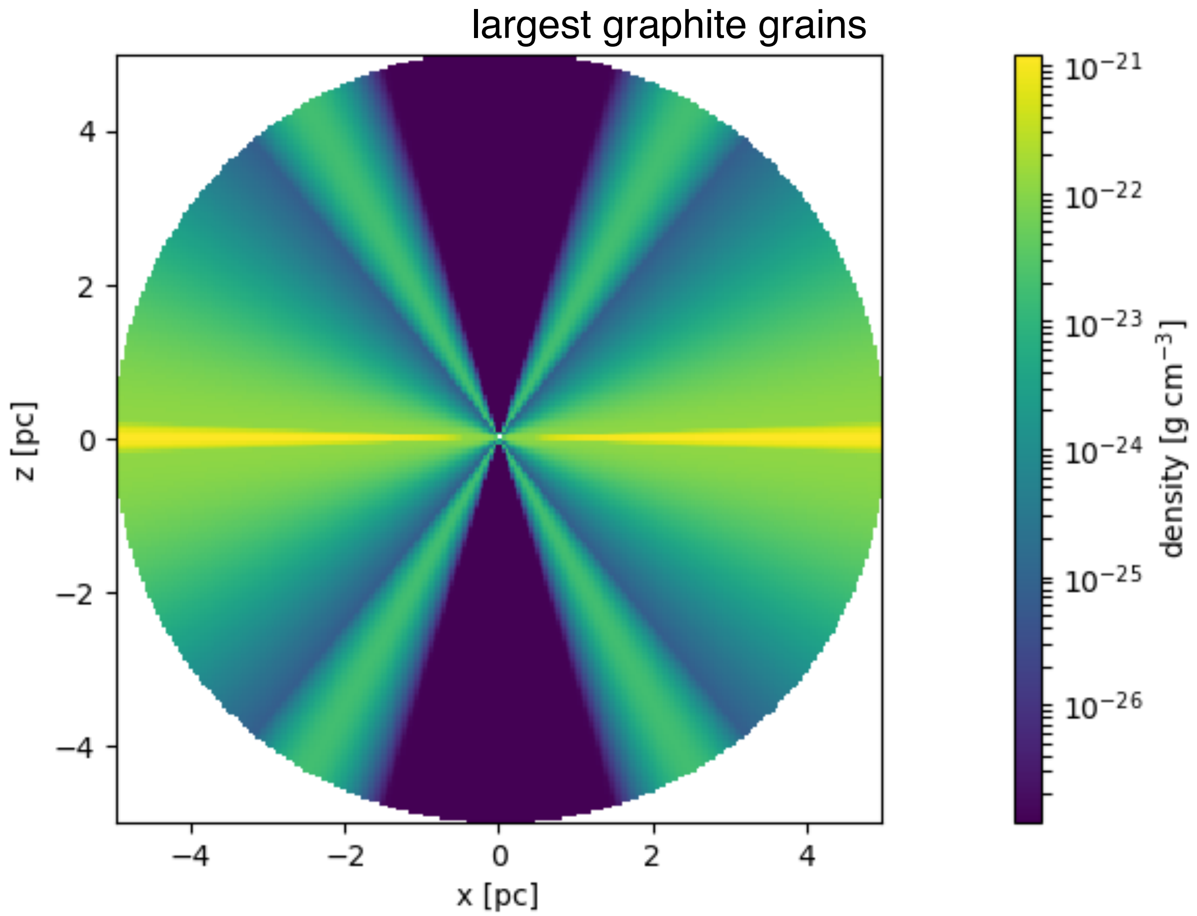
MS, et al. 2018

Turbulent tori - the detectability of substructure

work in progress

- (some) torus models and observations seem to favour a multi-component structure: thin disc, thick disc / torus, outflow





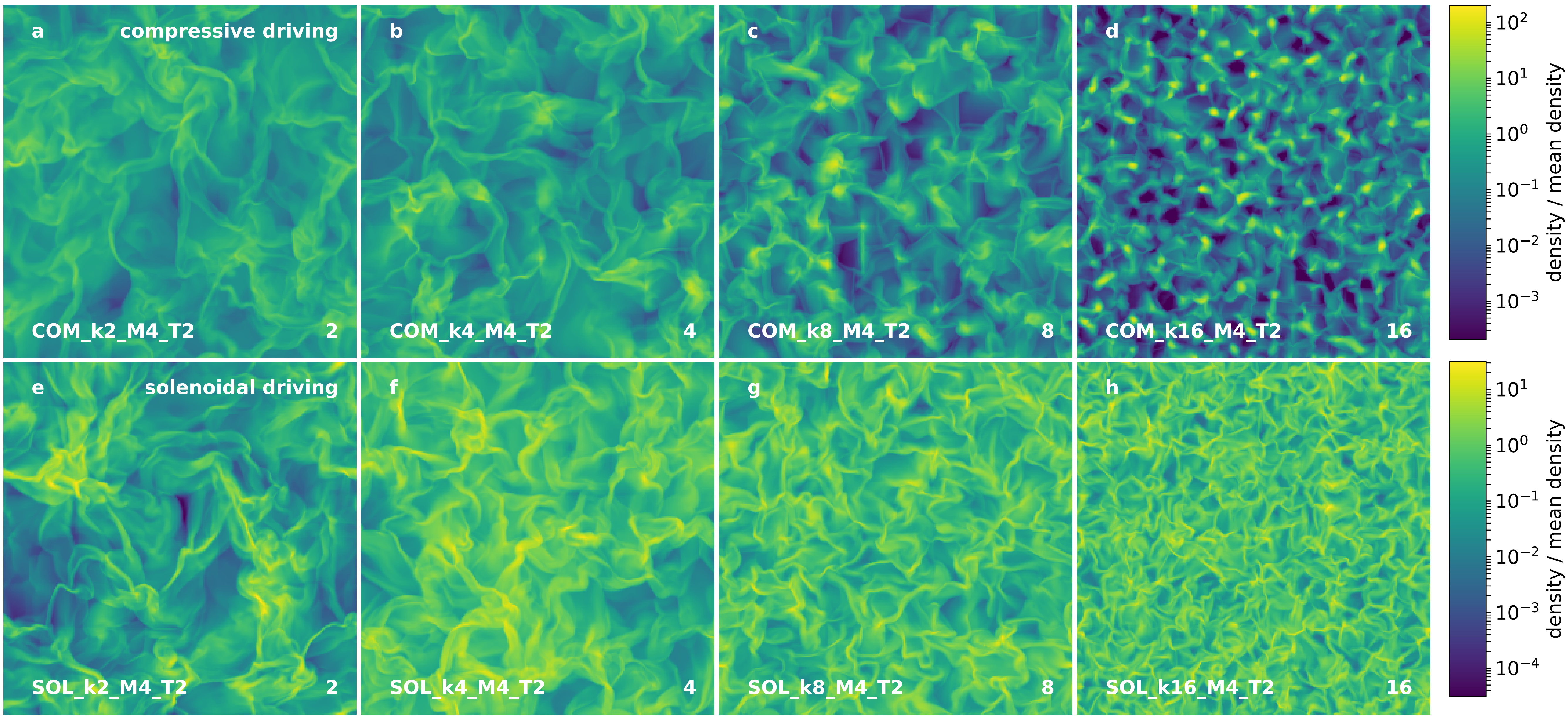
Idea:
- use such a structure (that describes SEDs, etc. nicely)
- change the substructure (graininess) by using turbulent boxes
- investigate the influence on observables with RT sims

Questions / (Final) Goals:

- can the new instruments (Matisse/Gravity) tell us something about the substructure of the density distribution?
- can we learn something about the physics of the turbulent medium in AGN tori?

STEP 1: Hydro simulations of driven turbulence

Setup:
- constant density, zero velocity IC
- isothermal EOS
- turbulence driven via Ornstein / Uhlenbeck stochastic process following Federrath et al., 2008, 2010, …
- driven until equilibrium is reached (min/max density, Mach no.) using the PLUTO code (Mignone et al. 2012)
- torus model fixed, vary substructure only (excited wave numbers, Mach number, etc.)



STEP 2: RT simulation

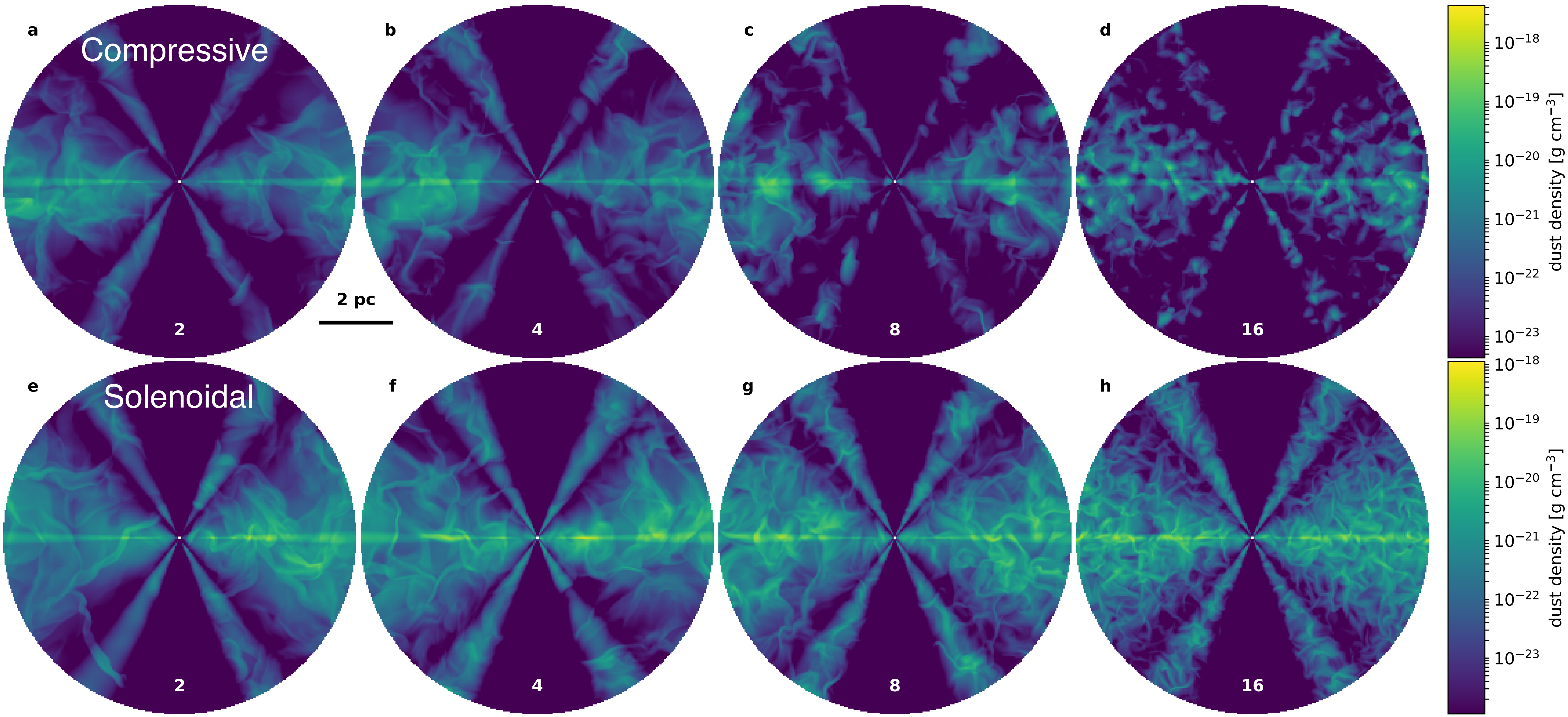
Dust distribution:

- constant gas-to-dust ratio of 150
- use weighting function to “carve-out” toroidal structure: thin disc + thick disc + bi-cone
- split into 5 dust grain sizes for 3 dust ingredients (silicate, graph perp/para)
- density normalisation to reach mean optical depth in mid plane of 10^4 at 0.55 micron
- RT with RADMC-3D: dust sublimation + full MC run + images, SEDs

Structure size decreases

Density contrast increases

“clumpy torus model”

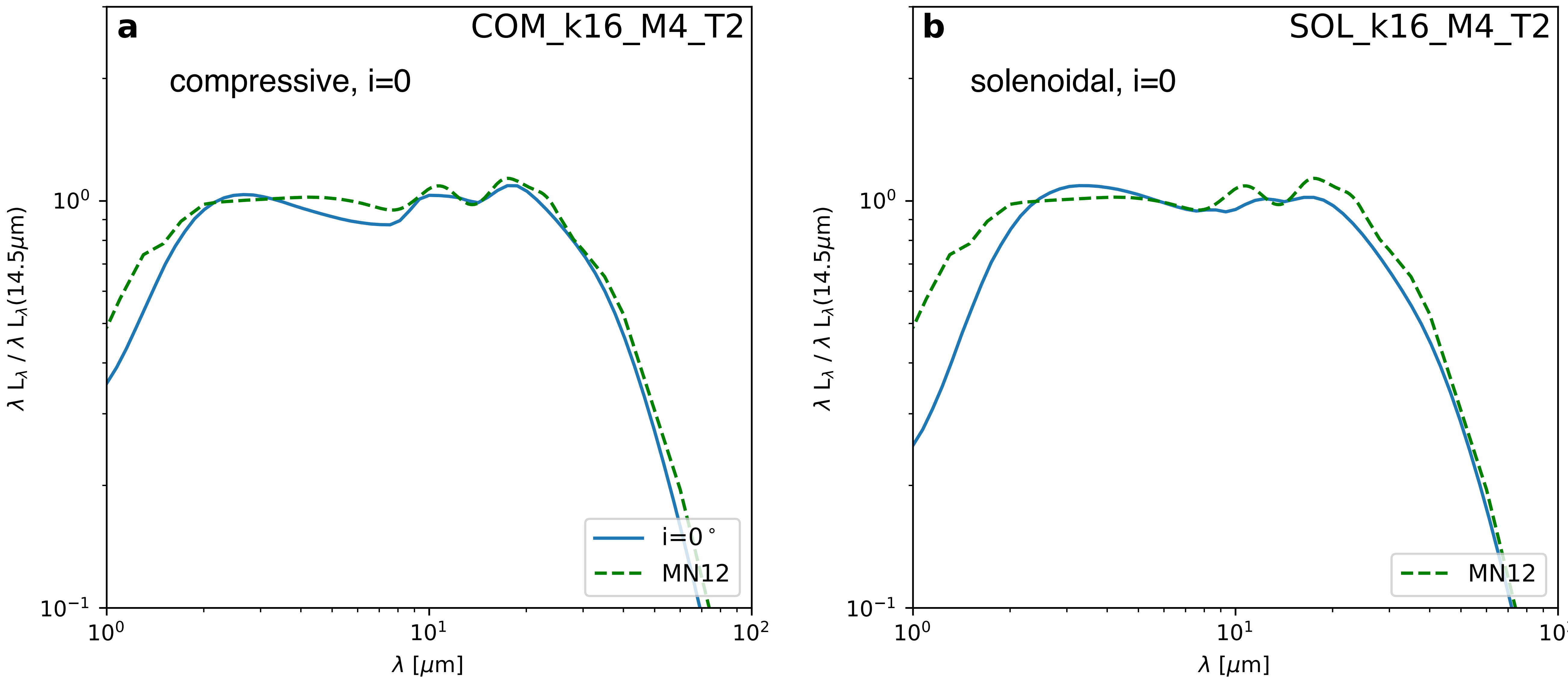


Solenoidal driving:

- more filamentary than clumpy structure
- lower density contrast

STEP 2: RT simulation - SEDs

normalised at 14.5 micron



- parameters of weighting function chosen to match observed mean SEDs of Seyferts and quasars
- face-on matches Mor & Netzer 2012 and Elvis 1994 fairly well

STEP 2: RT simulation - SEDs

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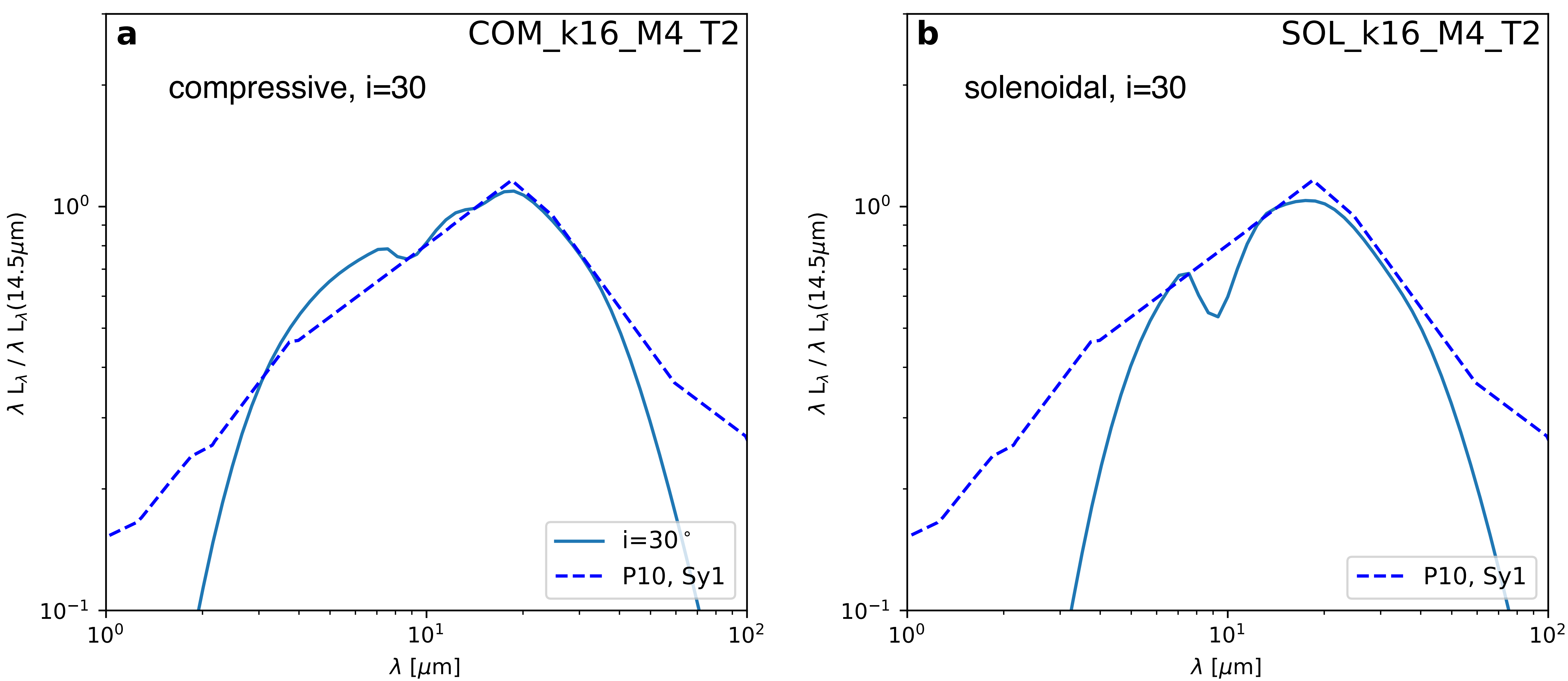

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- 30 degrees in good agreement with Prieto 2010 Sy 1

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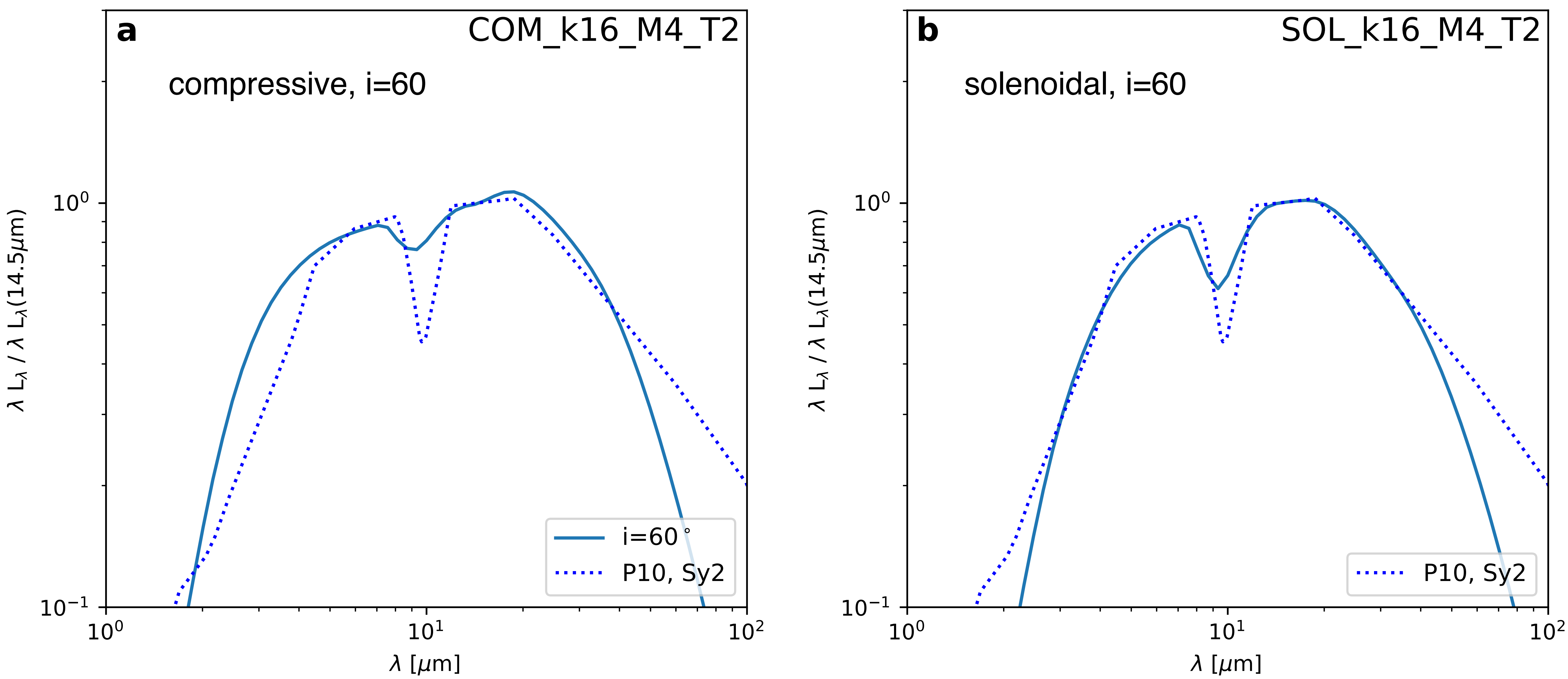

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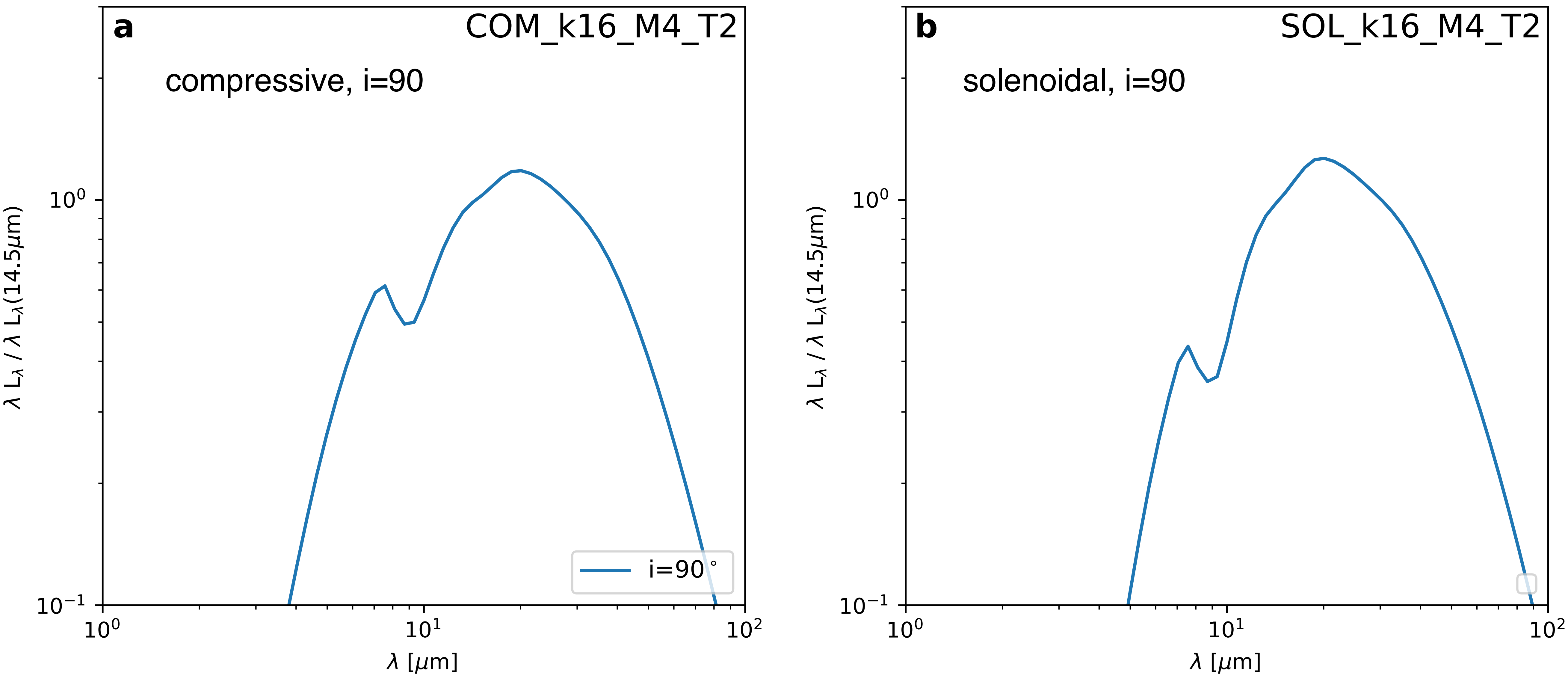

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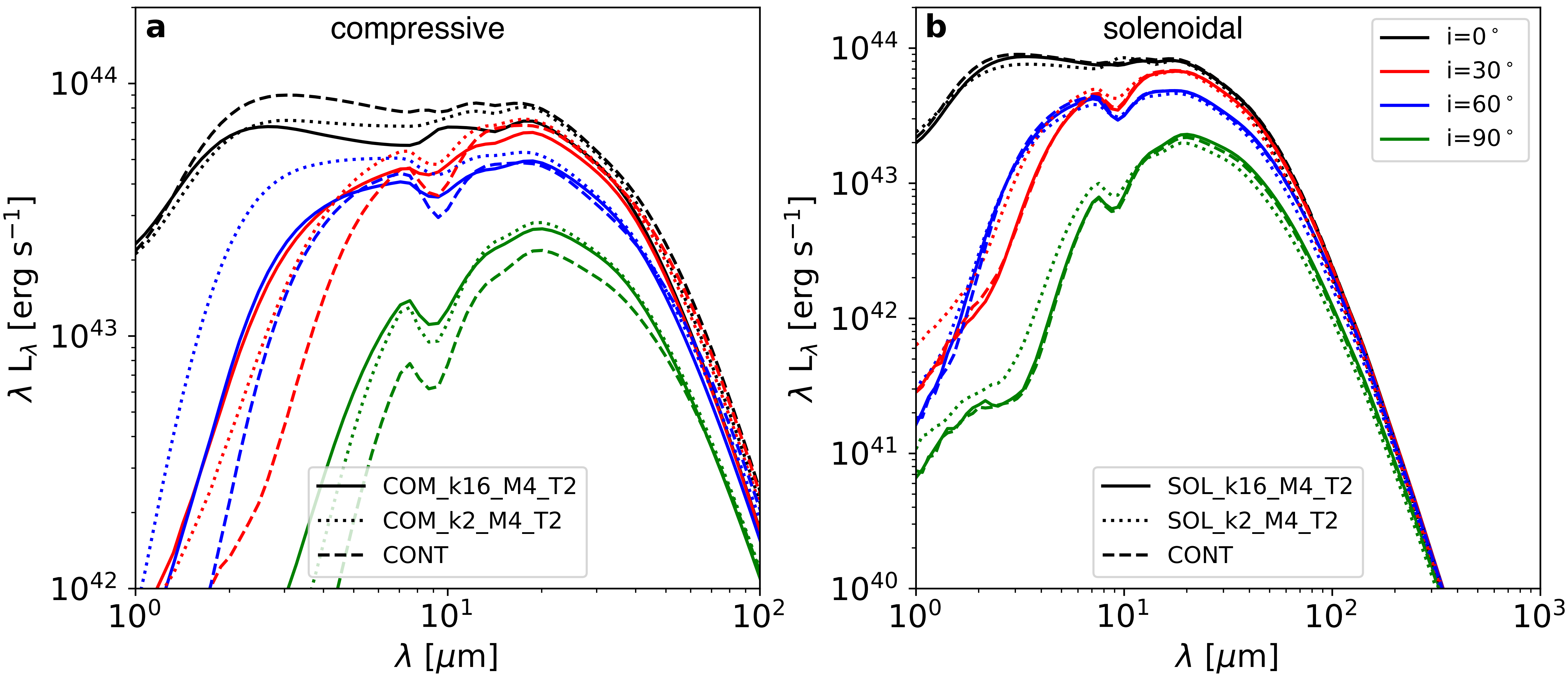
- face-on matches Mor & Netzer 2012 and Elvis 1994 fairly well
- 30 degrees in good agreement with Prieto 2010 Sy 1
- 60 degrees matches roughly Sy 2 (Prieto 2010), less deep silicate absorption feature related to silicates in outflow
- edge-on case similar to heavily obscured sources (e.g. Circinus)

SEDs at various inclination angles: changing the wavenumber

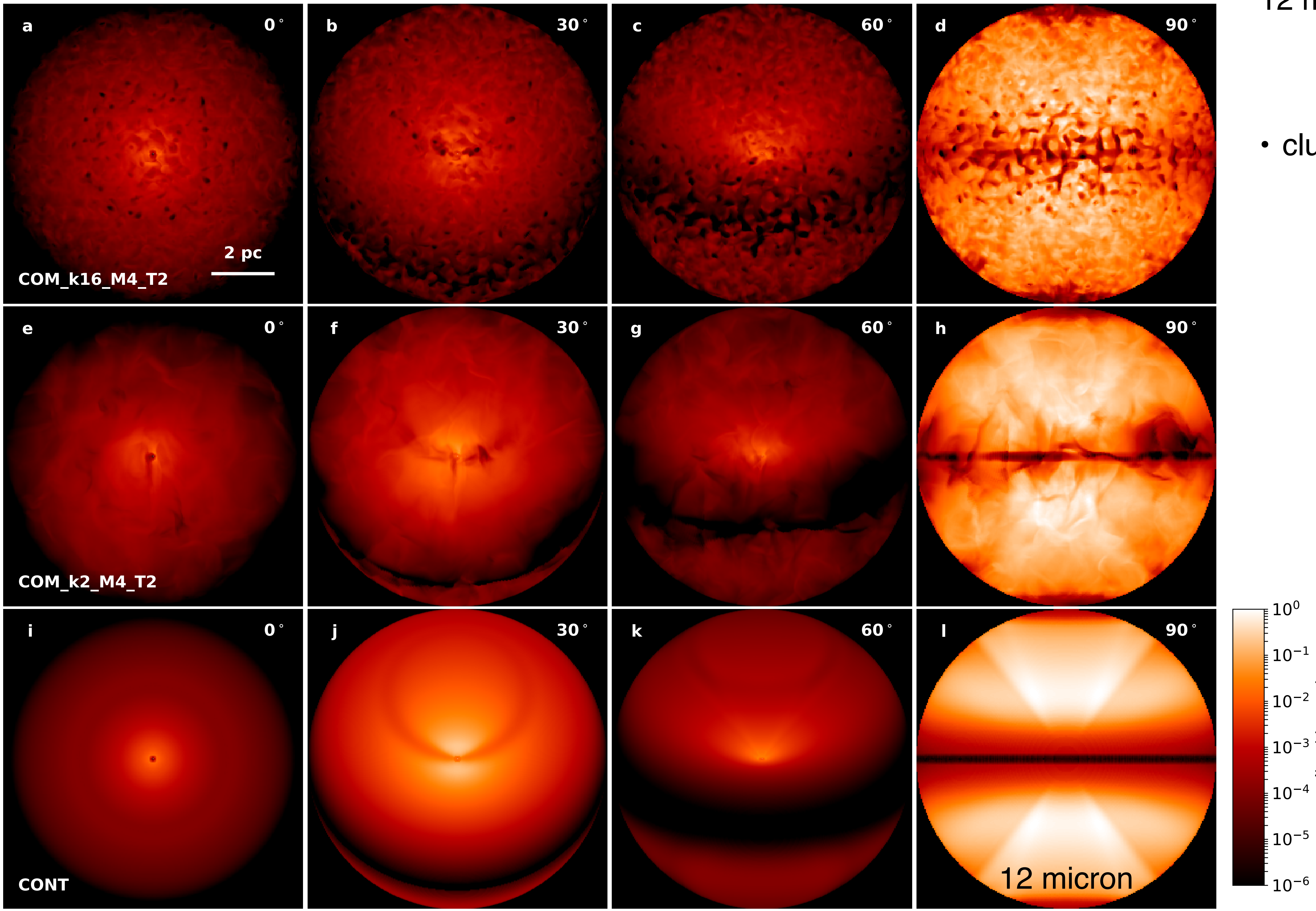


- continuous model shows more flux face-on, less edge-on due to missing "holes"
- larger sub-scales result in stronger variations in viewing angle (and time)

- almost identical, due to lower density contrast

overall, sub-structure leads to minor change in the IR SEDs

Images at various inclination angles: changing the wavenumber



12 micron

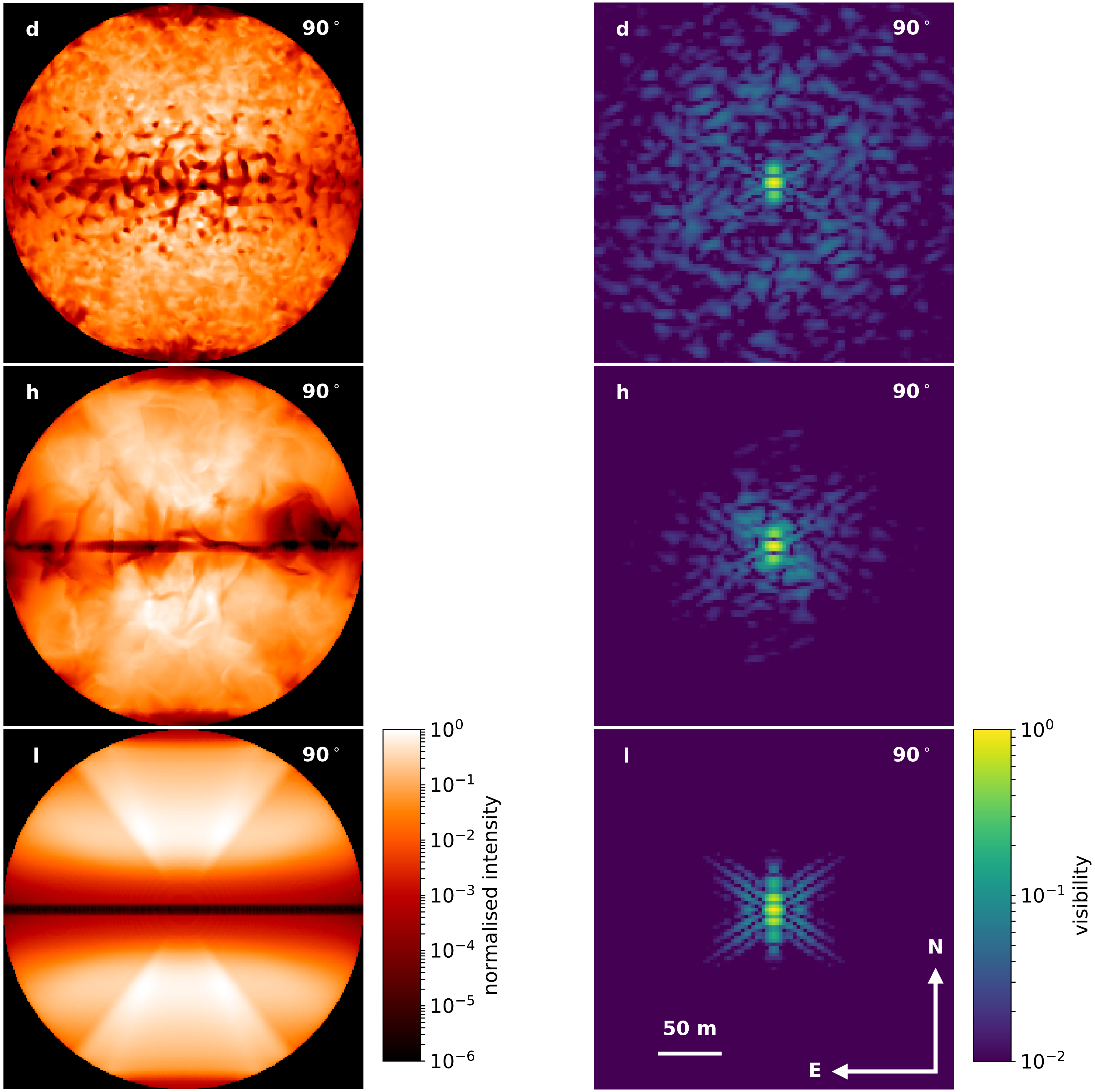
- clumpy structure

- extinction band due to dense discs
- thin disc
- outflow cone

- Dark ring = where the hollow outflow cone gets optically thick or cold enough to be visible in absorption against the body of the "torus"

Visibilities for various substructures

work in progress
assumed distance: 4.2 Mpc (Circinus galaxy)



- binary signal remains
- "bug"-like appearance weakens
- higher visibilities at larger baselines / smaller scale in a ring at BL~100m

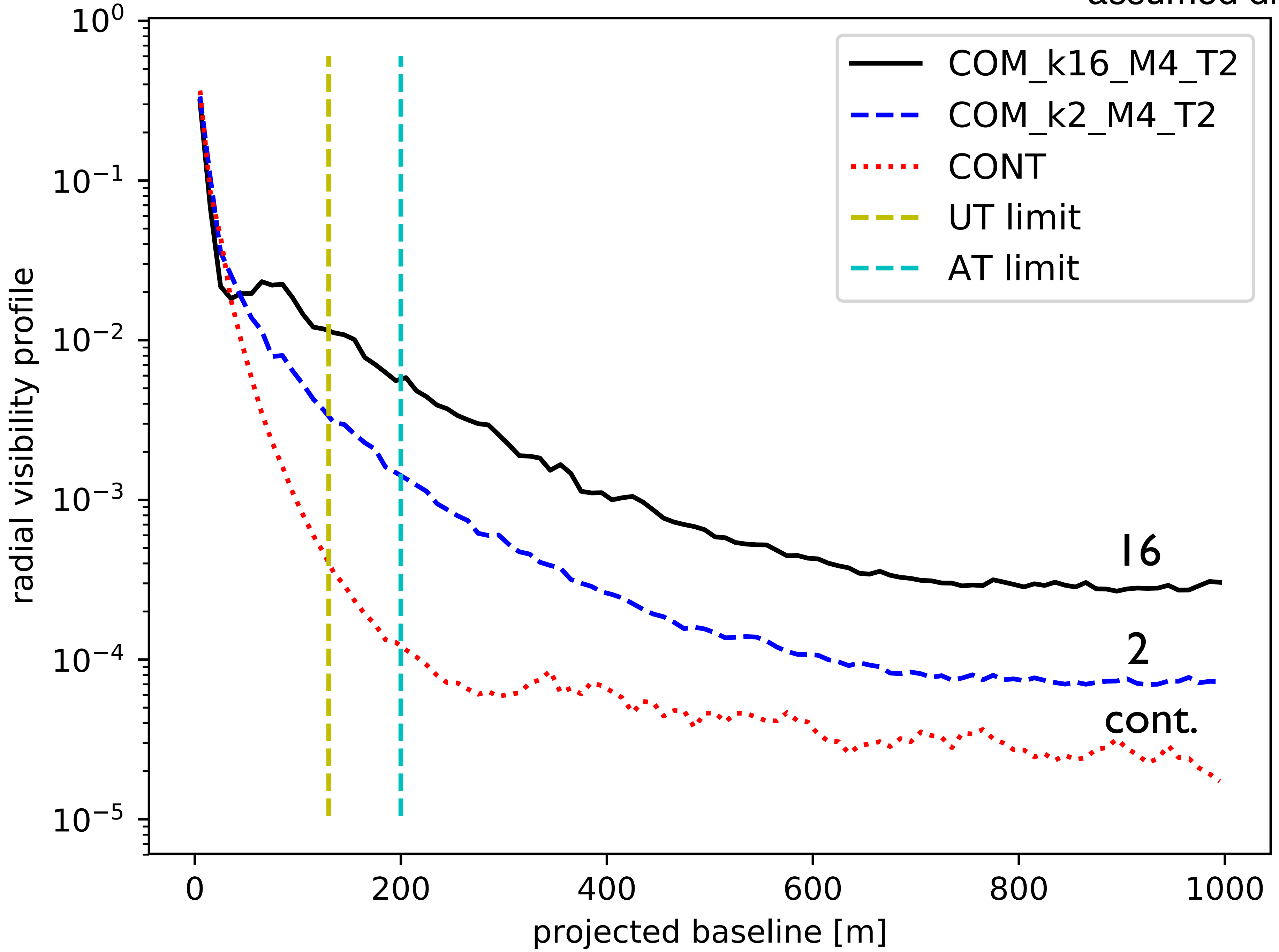
- binary signal remains
- "bug"-like appearance weakens
- higher visibilities at larger baselines / smaller scale

- "bug"-like appearance
- binary signal along PA=0
- both given by largest scales and visible "edges"

Azimuthal averages of the visibilities in the UV plane for i=90

work in progress

assumed distance: 4.2 Mpc (Circinus galaxy)



- the more sub structure, the higher visibilities at longer projected base lines
- clear bump at around BL~100m for COM_k16_M4_T2
- position depends on graininess (separation) of sub structure and assumed distance of object, bump could be hidden in steep inner part

Summary and Conclusions

- observations of radial gas surface density distributions of nearby Seyfert nuclei, as well as short duration star bursts and the concentration of SF in clumps might point towards the importance of gravitational instability in the evolution of circum-nuclear gas discs
- we employ RAMSES simulations to follow the star formation and stellar feedback self-consistently
- gravitational instability forms a clumpy, high density disc

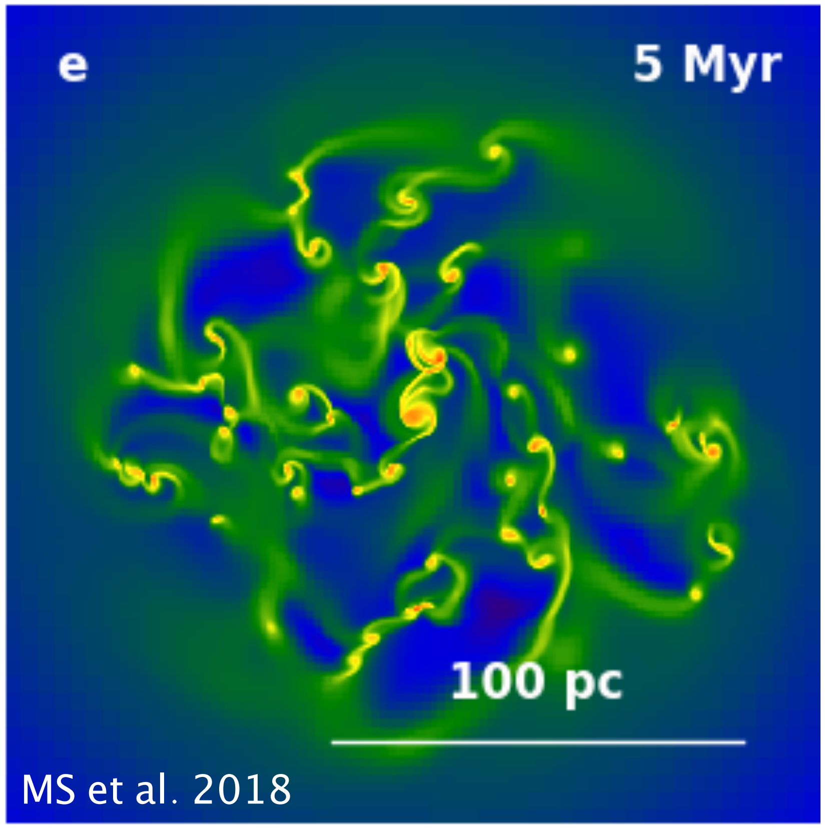
Feeding from circumnuclear discs

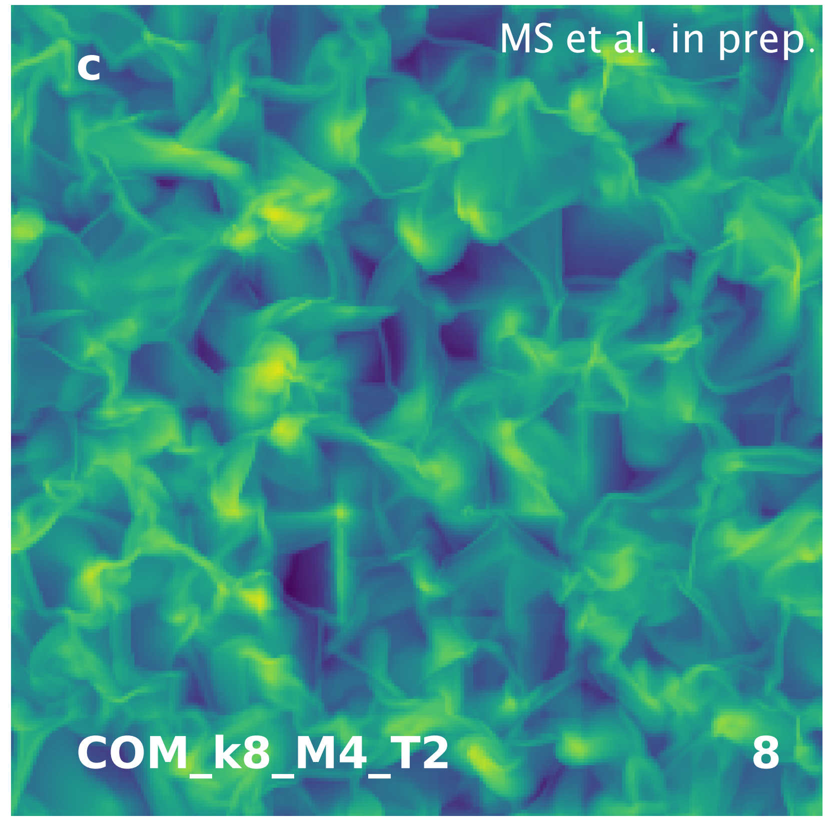
- clump migration by interaction / dynamical friction feeds the central parsec region, drives random motions

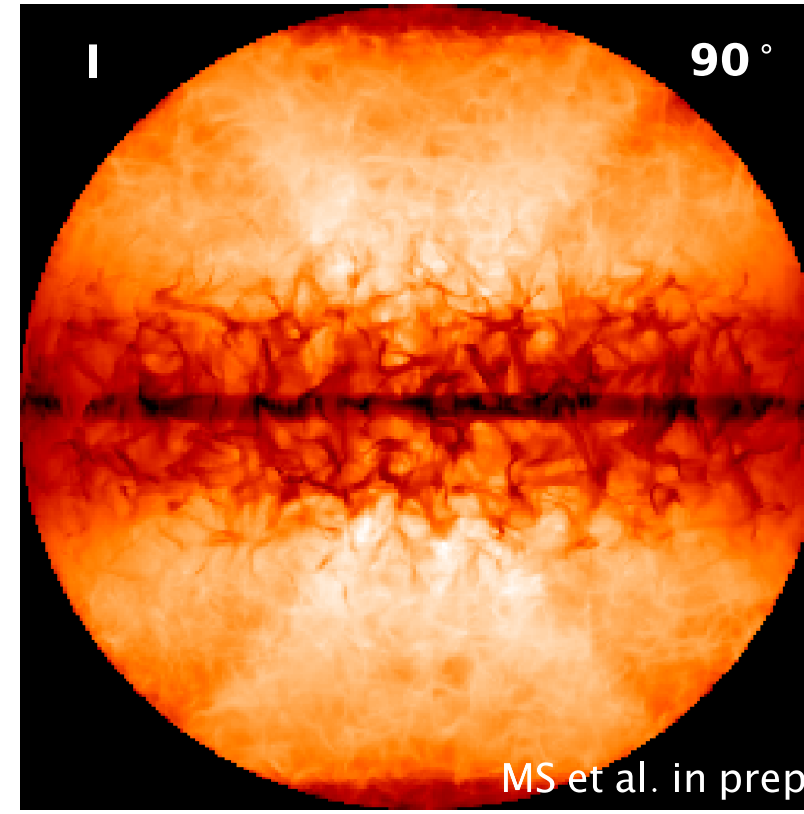
Substructure in AGN tori

- leads to small changes in the SED, visible differences in images and visibilities
- shows up as distinct bump in radial visibility plots
- high contrast needed, best reached in close to edge-on inclinations and / or if central point source is hidden behind optical thick layer of dust
- not enough information / not unambiguous enough to conclude on the nature of turbulence in AGN tori from observations

Thanks for your attention!







and to:

- R. Teyssier & team (RAMSES)
- A. Mignone & team (PLUTO)
- K. Dullemond & team (RADMC-3D)
- M. Turk & team (yt)
- many open source tool developers (python, matplotlib, NumPy, SciPy, etc.)

and to:

DFG Deutsche Forschungsgemeinschaft

DFG Priority Program 1573 ISM-SPP Interstellar Medium