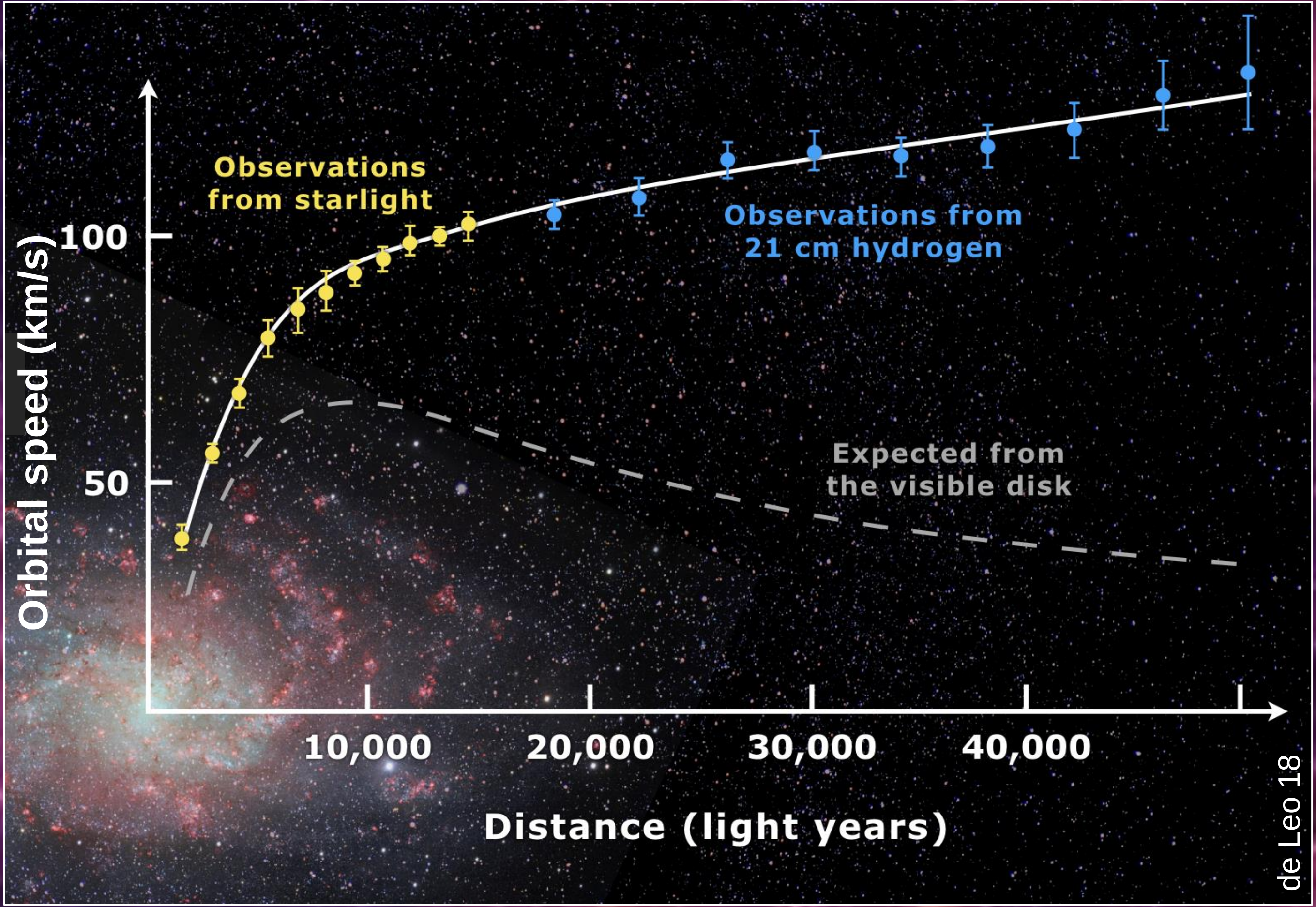
Cusps, Cores, and Kinematics:

Modelling gas in galaxies to measure dark matter



Kristine Spekkens

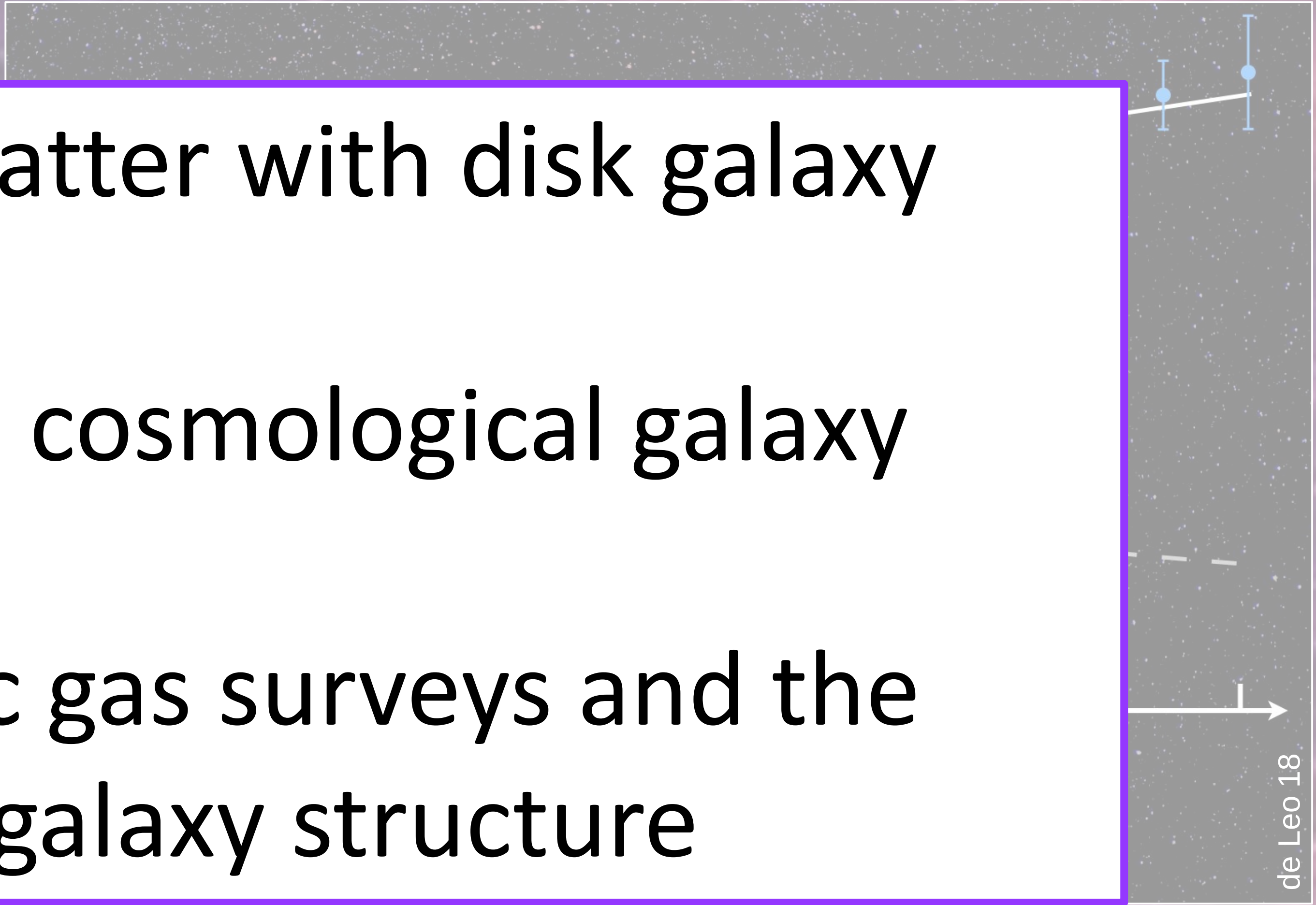
Royal Military College of Canada
Queen's University at Kingston

Springel et al. 2005

Cusps, Cores, and Kinematics:

Mod
galax
dark

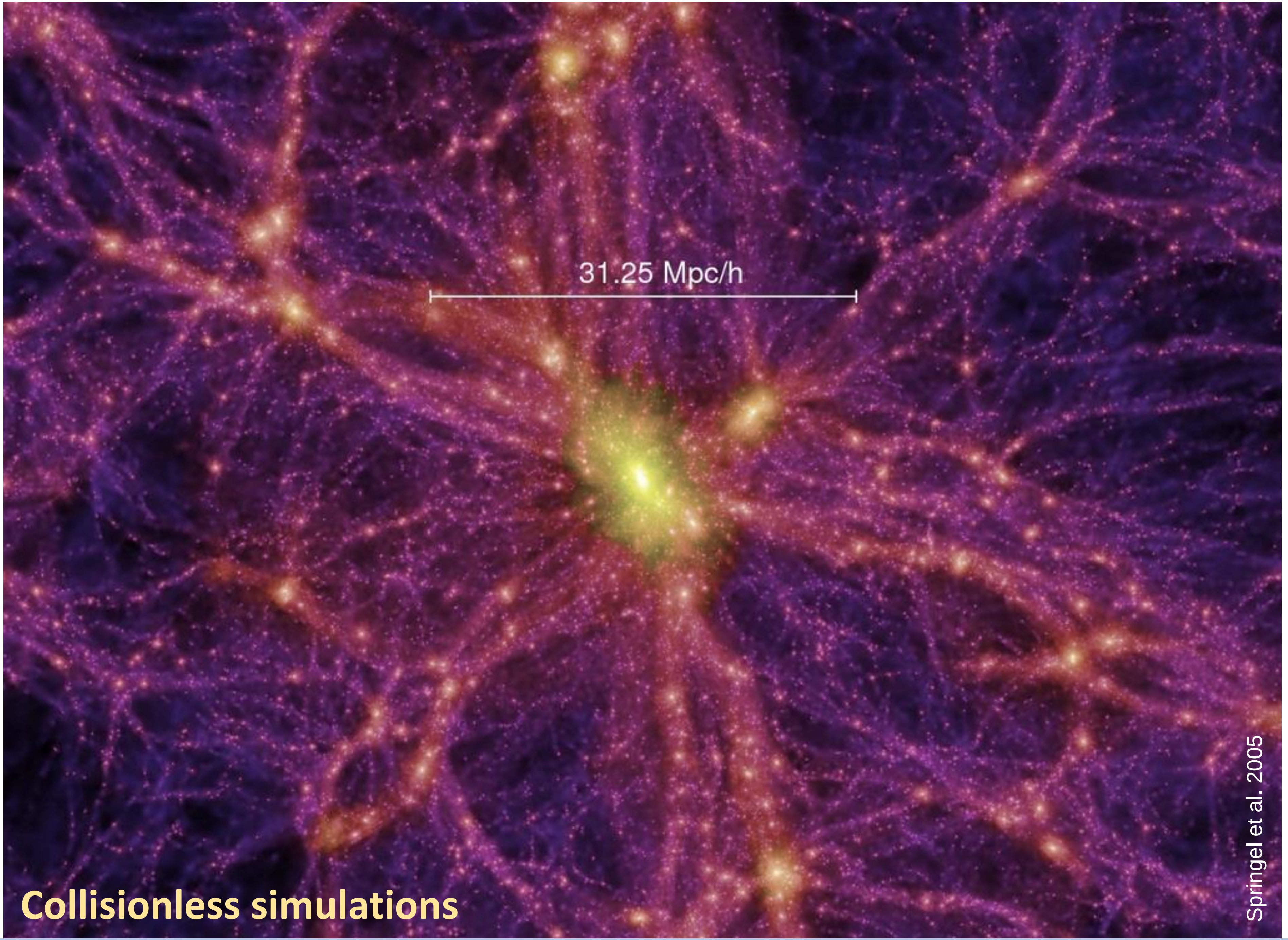
- Mapping dark matter with disk galaxy kinematics
- Cusps, cores and cosmological galaxy formation
- Widefield atomic gas surveys and the statistics of disk galaxy structure



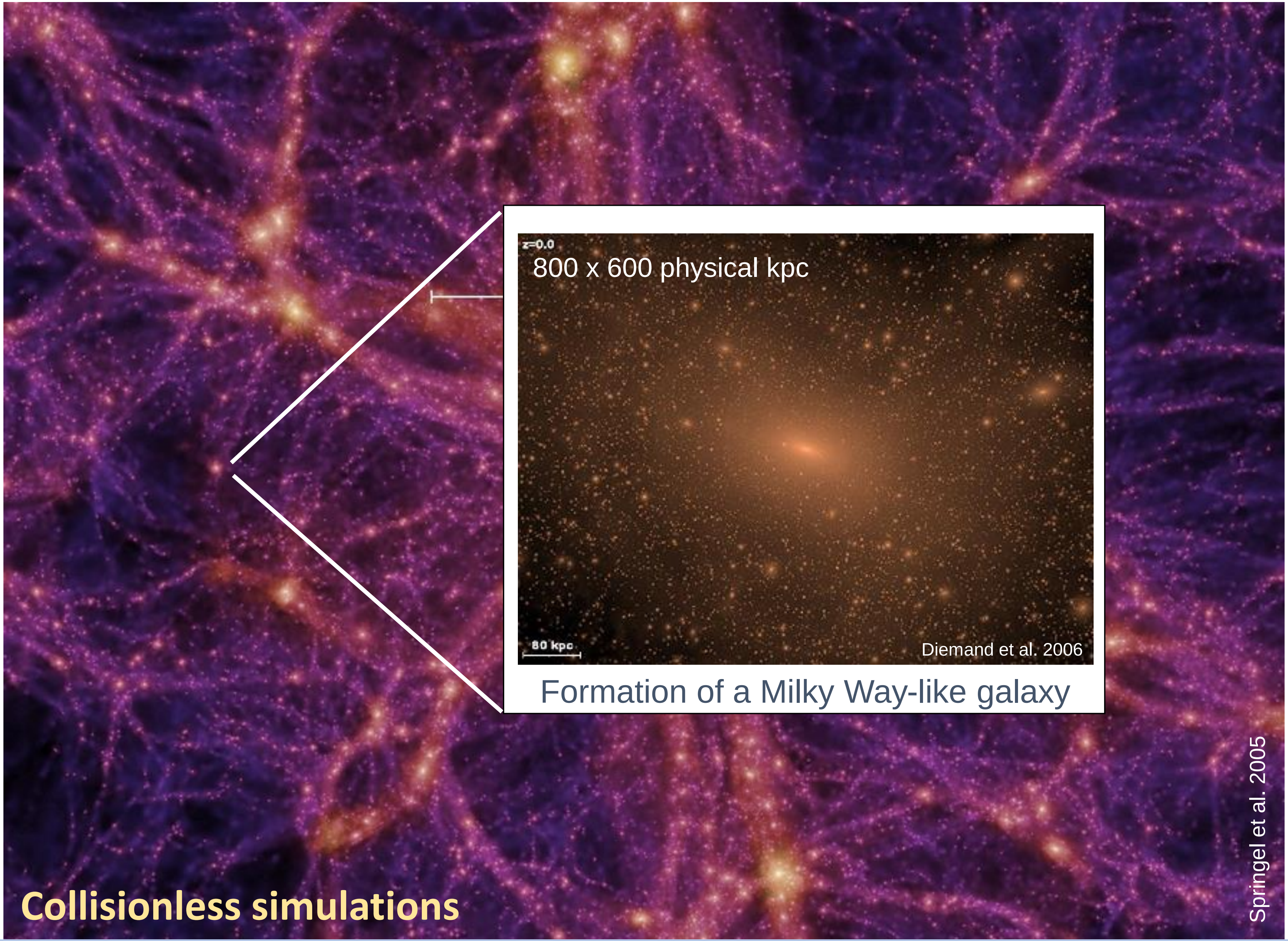
Kris
Spe
Royal Military College of Canada
Queen's University at Kingston

Springel et al. 2005

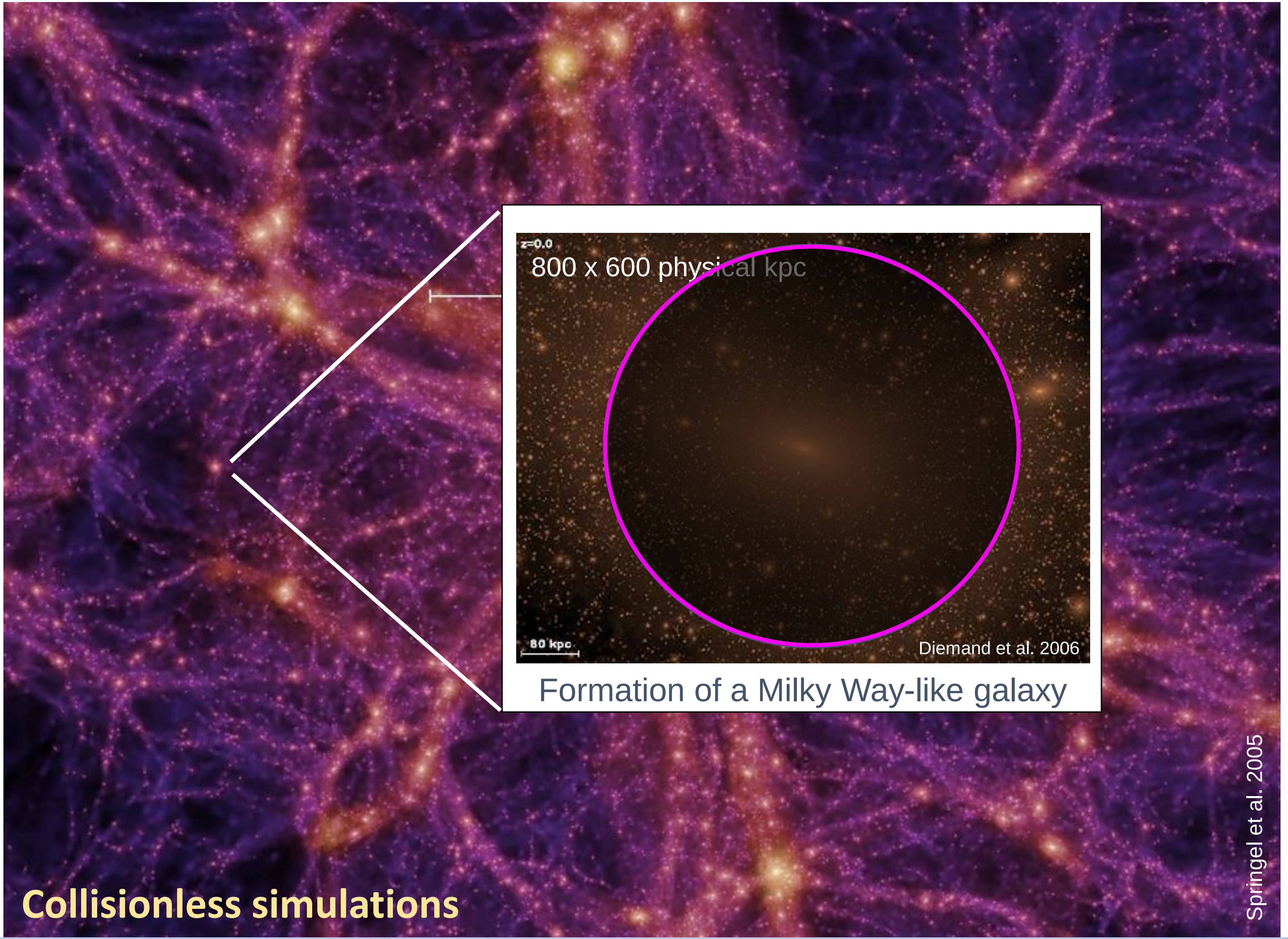
Cosmological galaxy formation



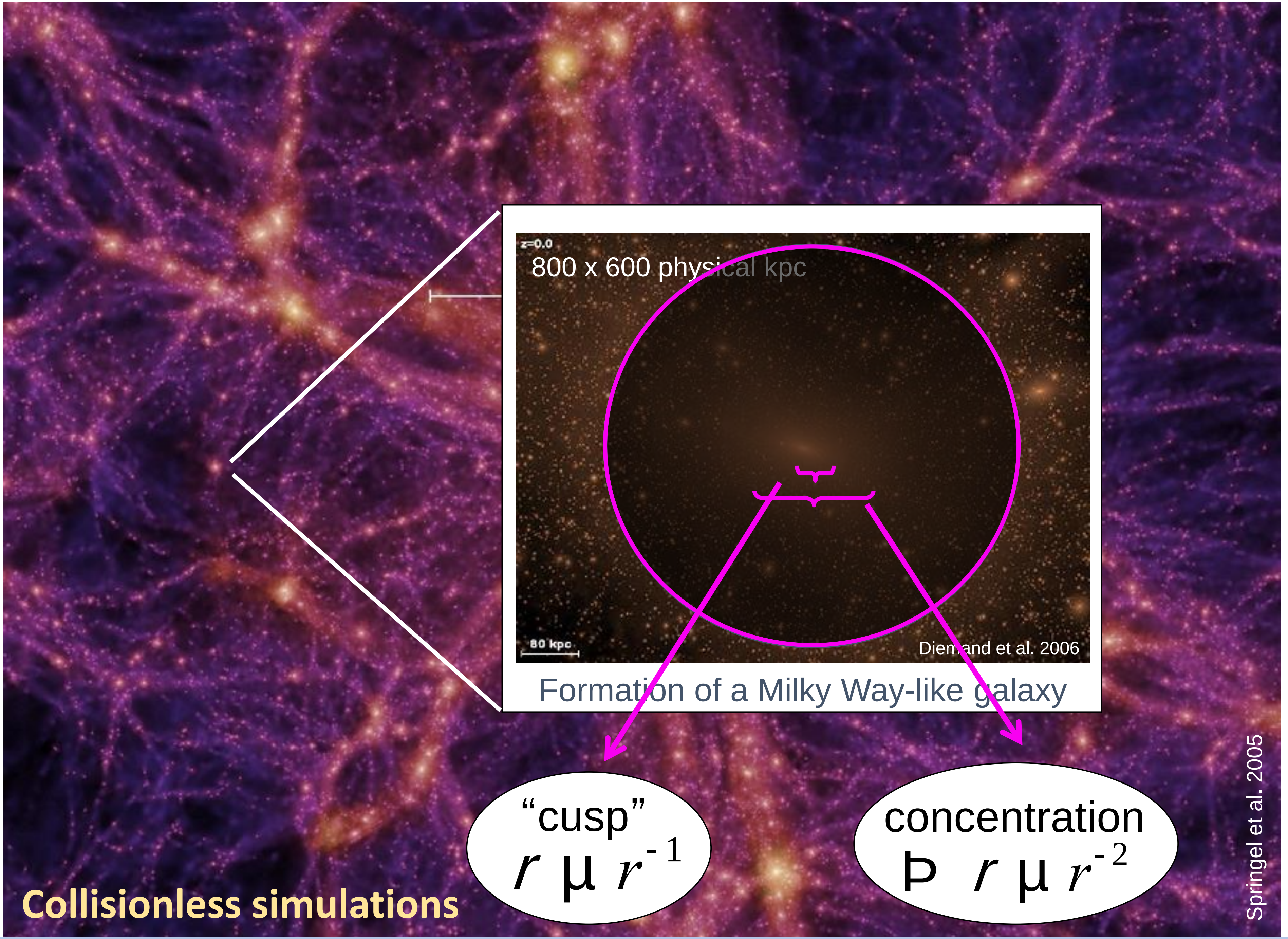
Cosmological galaxy formation



Cosmological galaxy formation

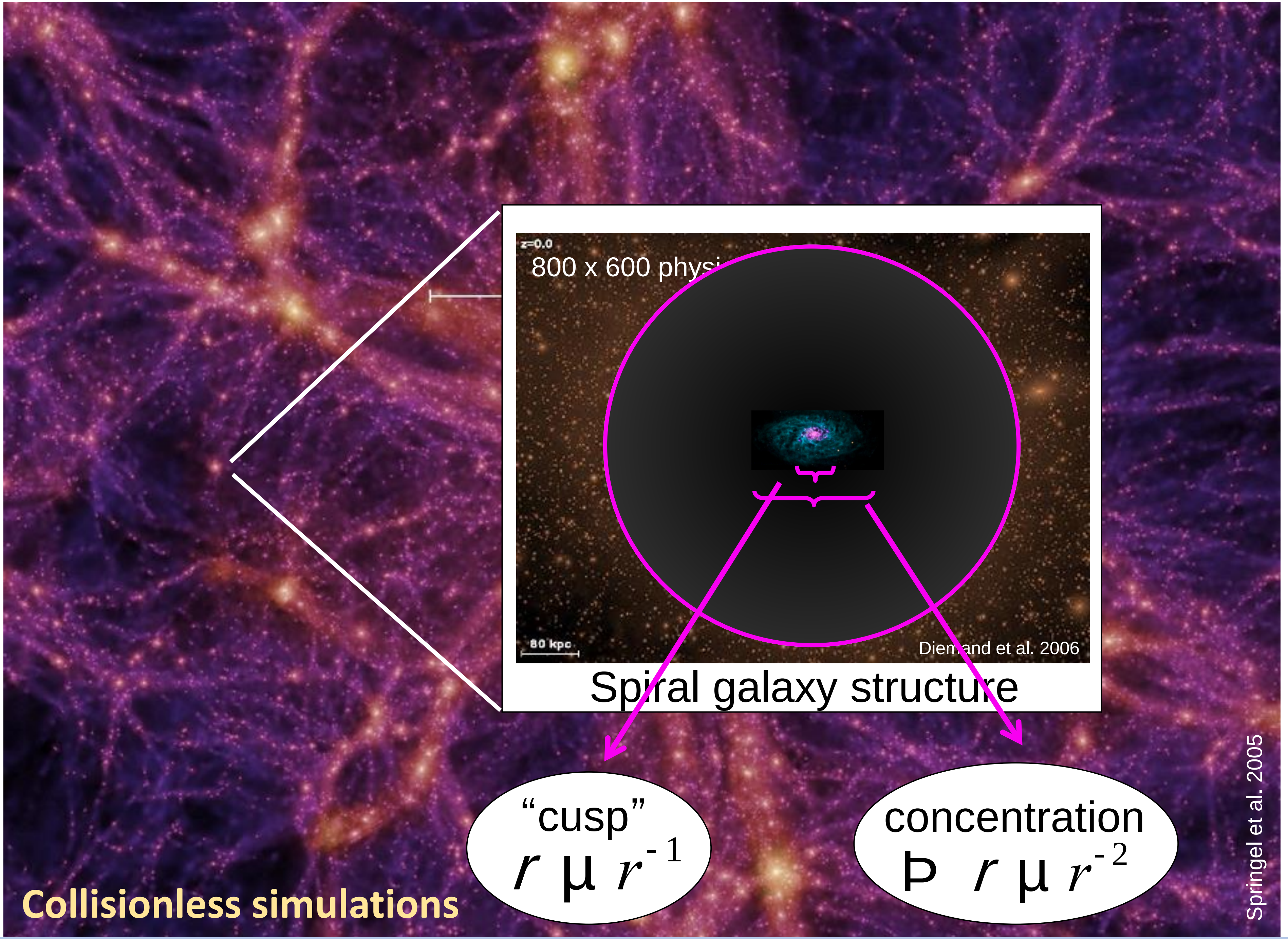


Cosmological galaxy formation



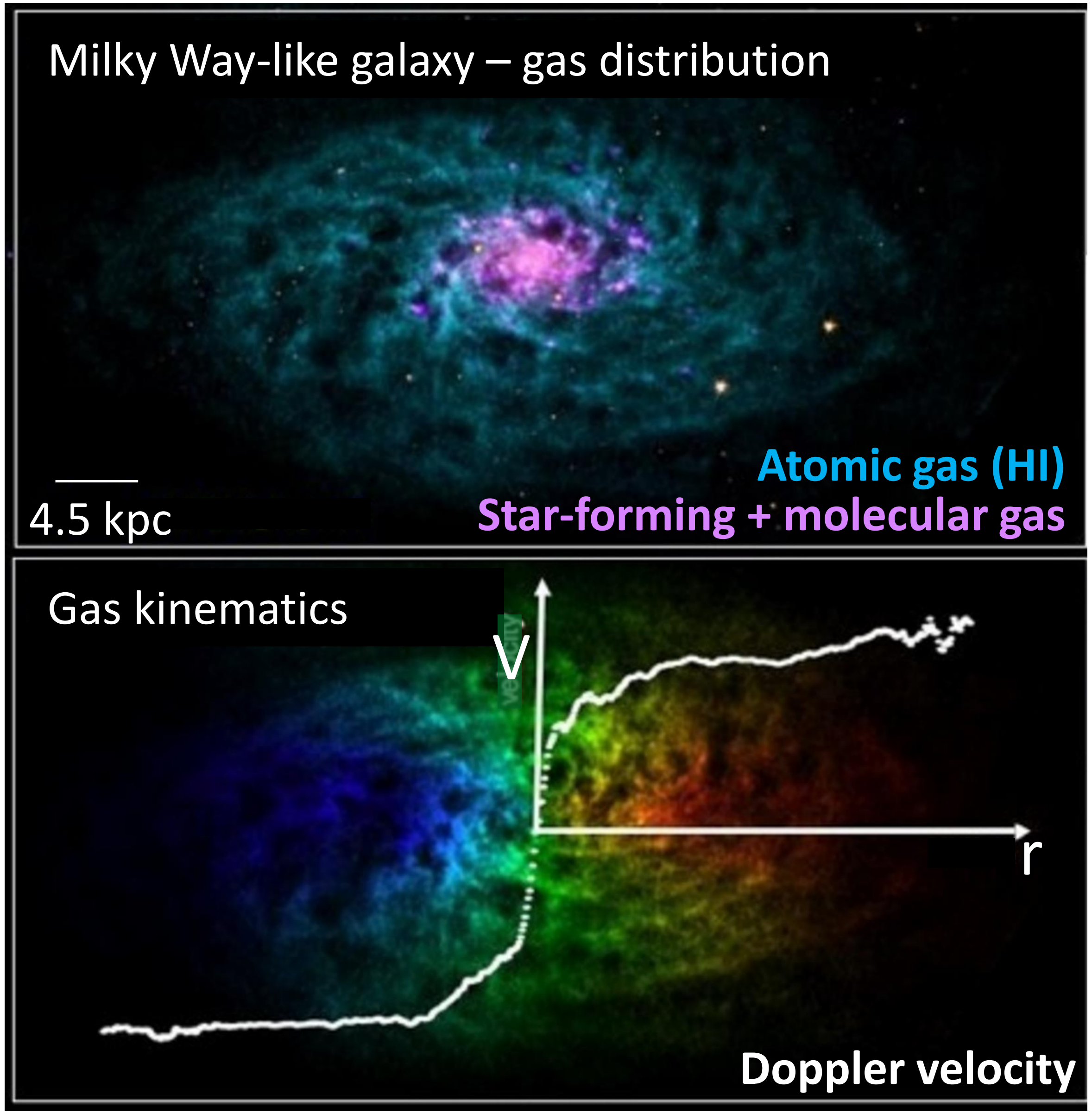
Cosmological galaxy formation

Disk galaxies: dissipative baryon collapse, conserving specific angular momentum



Measuring disk galaxy masses

Doppler-shift velocities from the spectral lines of gas disks in galaxies allow rotation curves – and therefore (dark matter) mass distributions – to be inferred.



THINGS, Walter+ 08

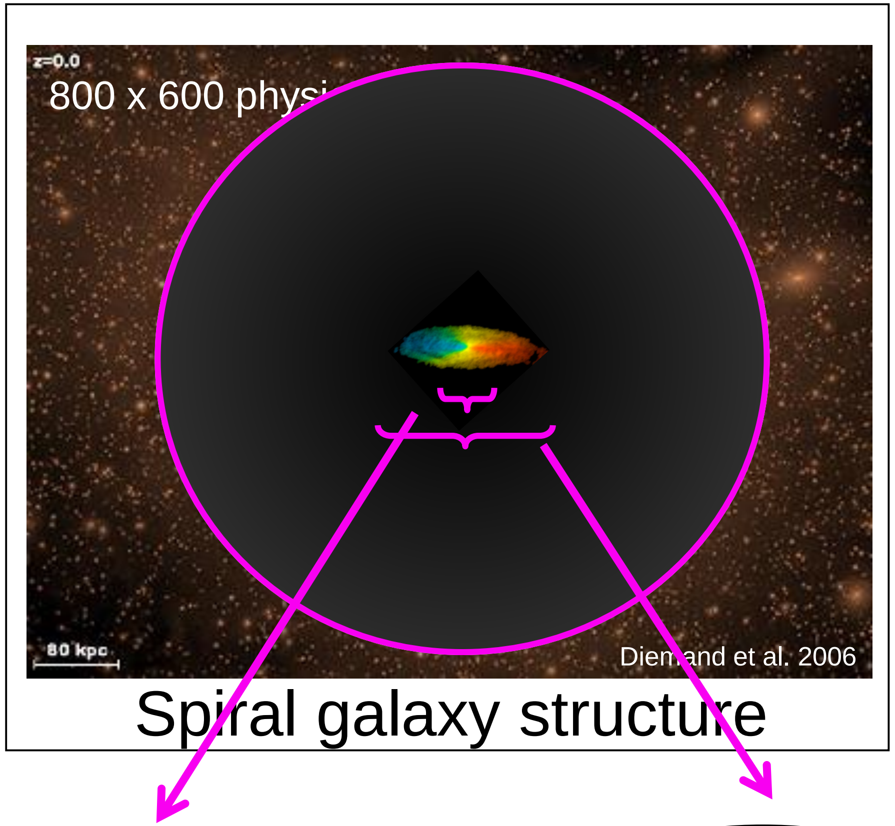
$$V_{obs}(r,\theta) \sim V_{rot}(r) \sin i \cos\theta$$

The cusp/core problem

If: Disk galaxy kinematics probe their mass distributions

And: There exists a (disk) galaxy population that formed without altering their parent halos

Then: The inner disk kinematics of those galaxies should imply cusps



Spiral galaxy structure

"cusp" $\rho \propto r^{-1}$

concentration $\Rightarrow \rho \propto r^{-2}$

The cusp/core problem

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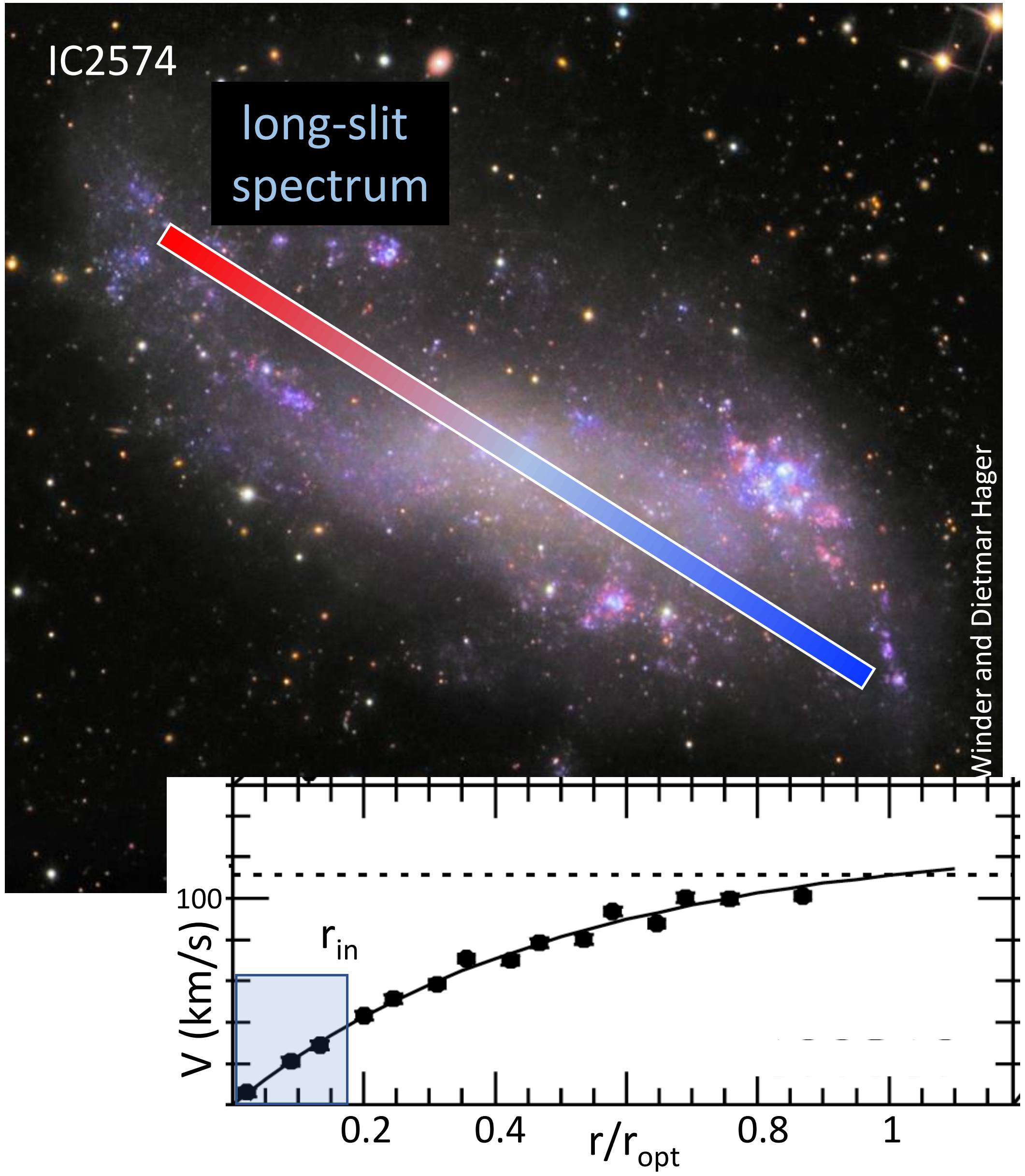
Dwarfs
LSBs



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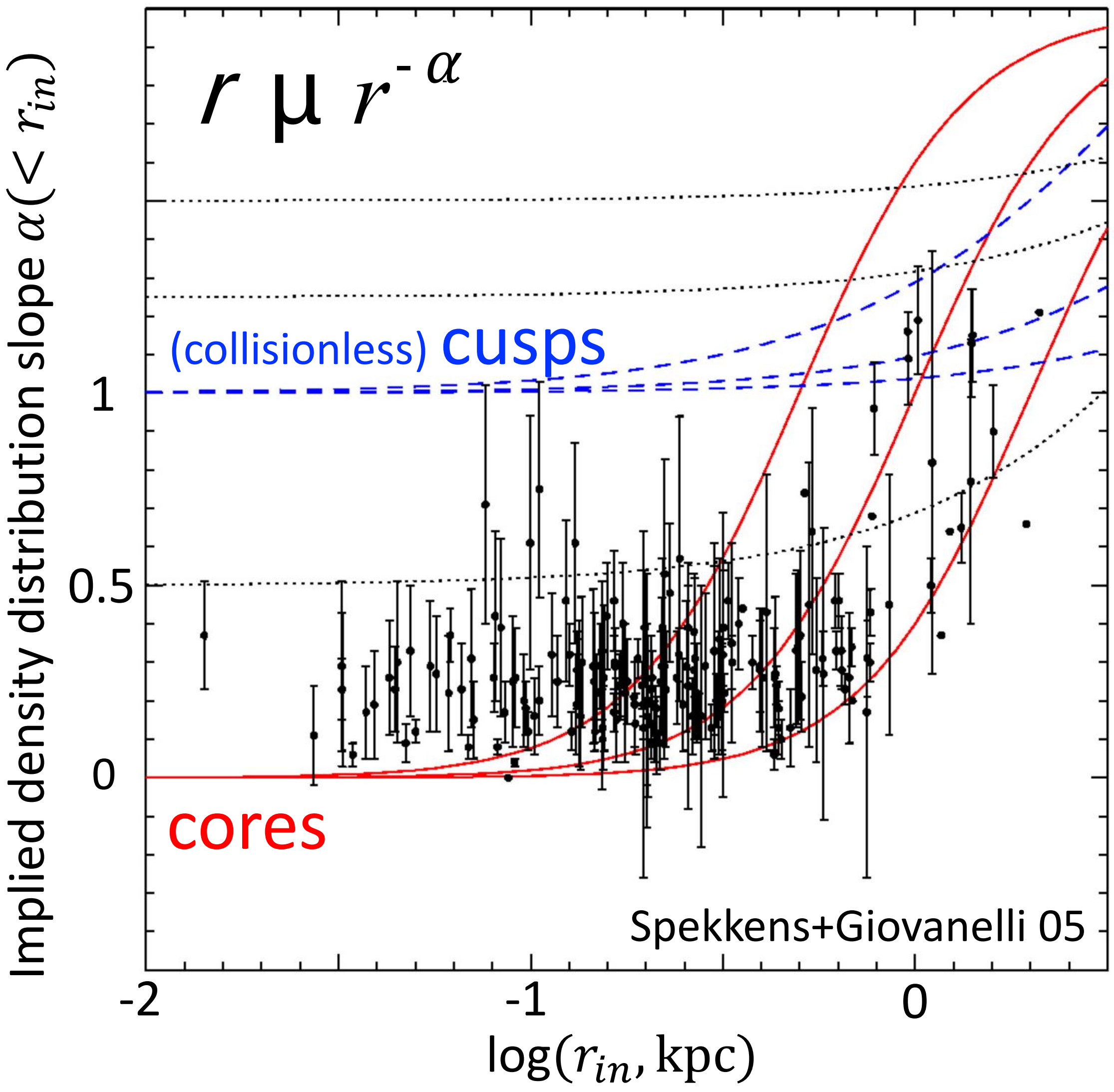
(de Blok+ 01, de Blok+Bosma 02, Swaters+ 03 and others)



→ cusp/core problem

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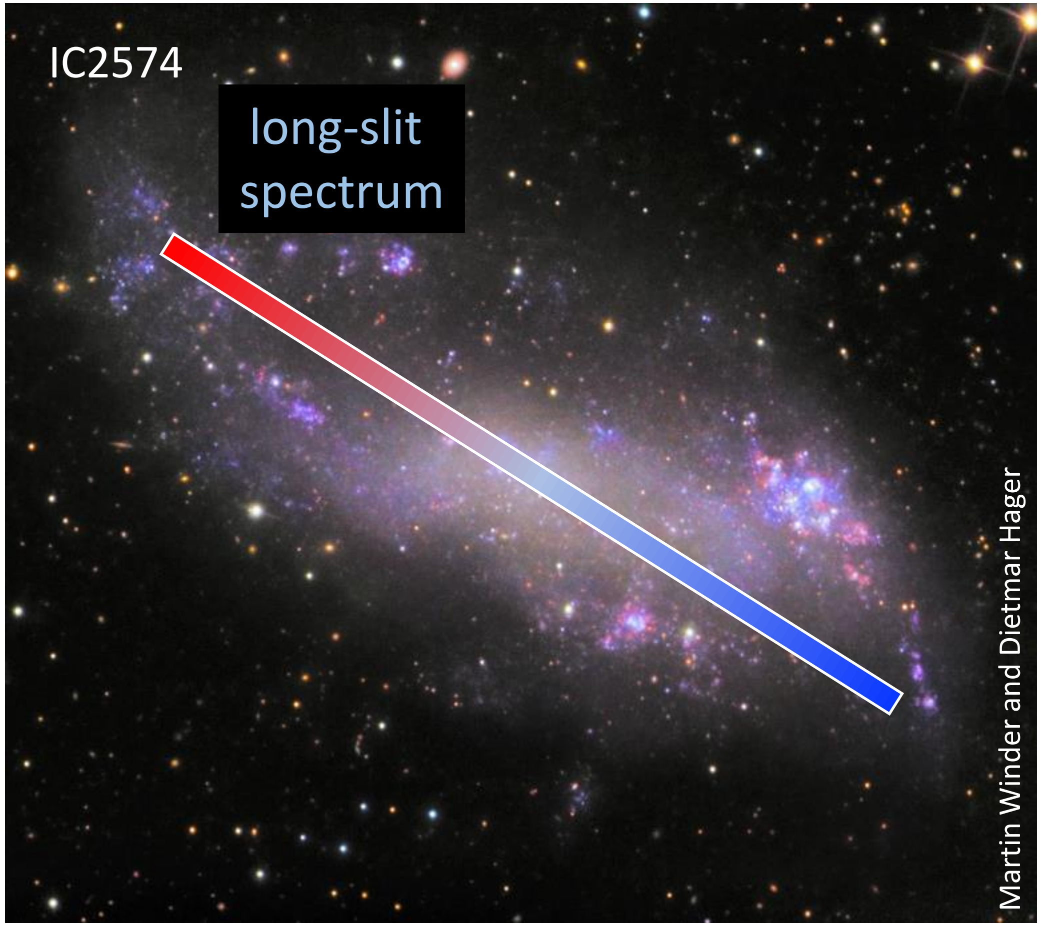

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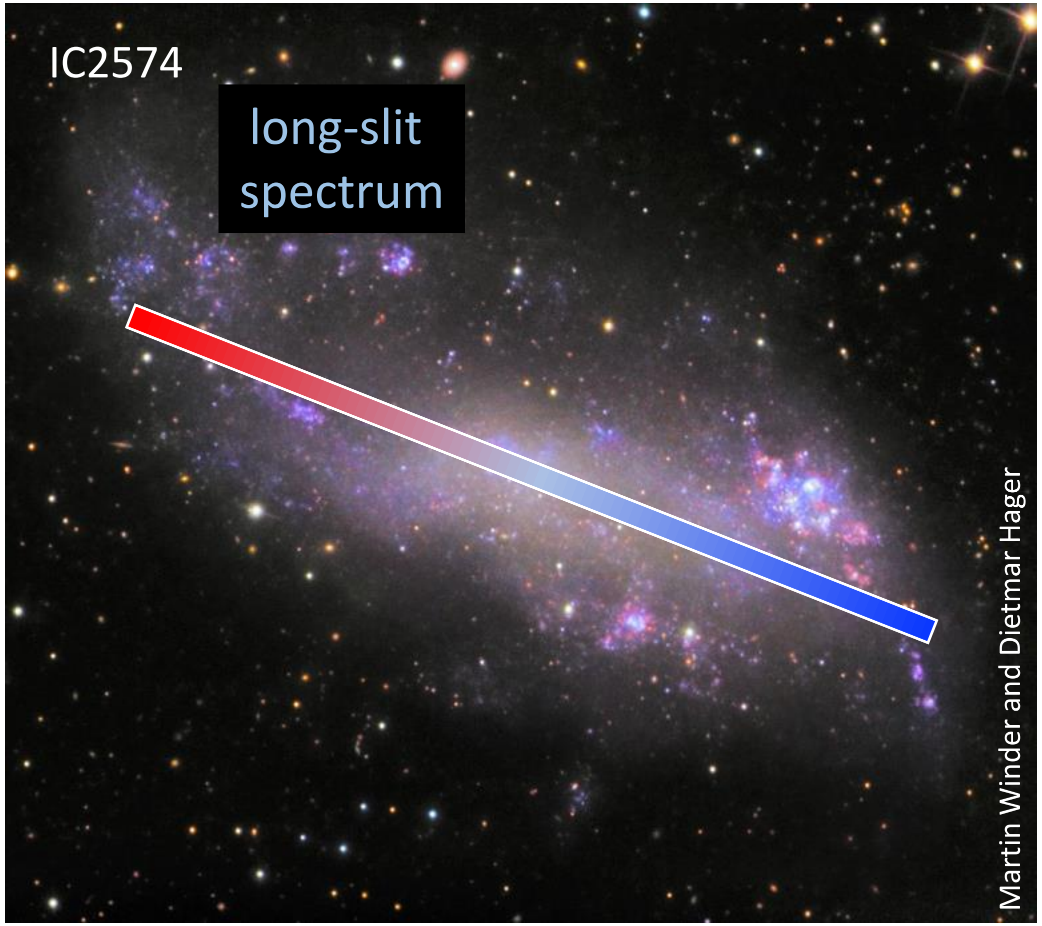

Slit width and galaxy major axis offsets systematically lower inferred α…

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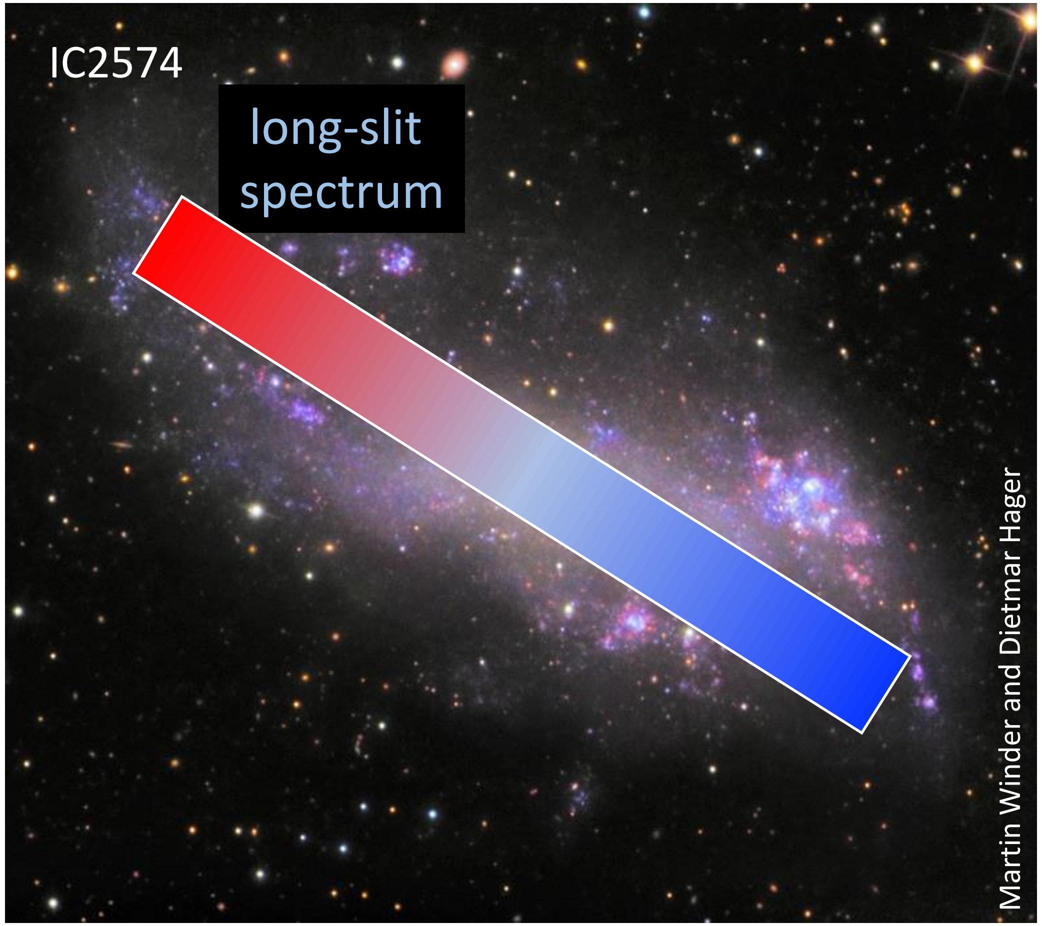
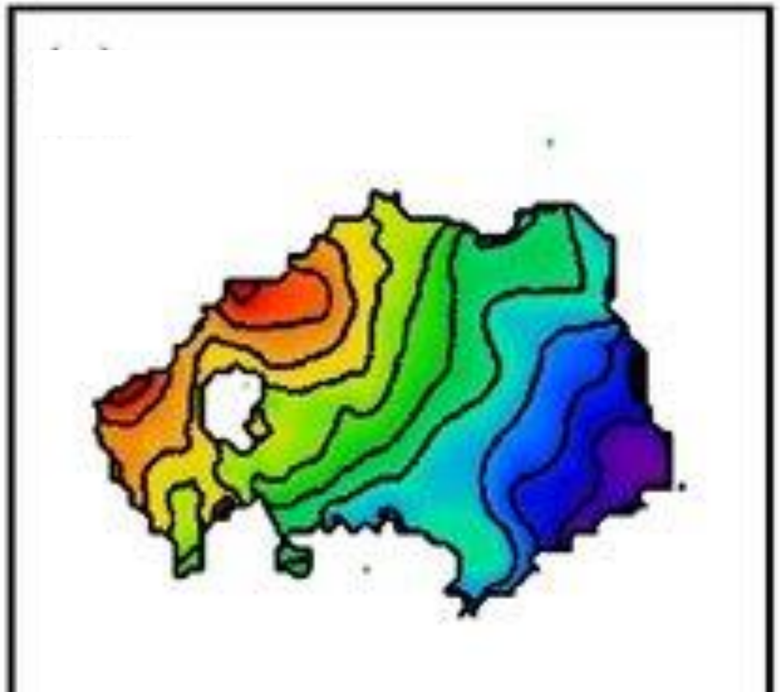


Slit width and galaxy major axis offsets systematically lower inferred α…

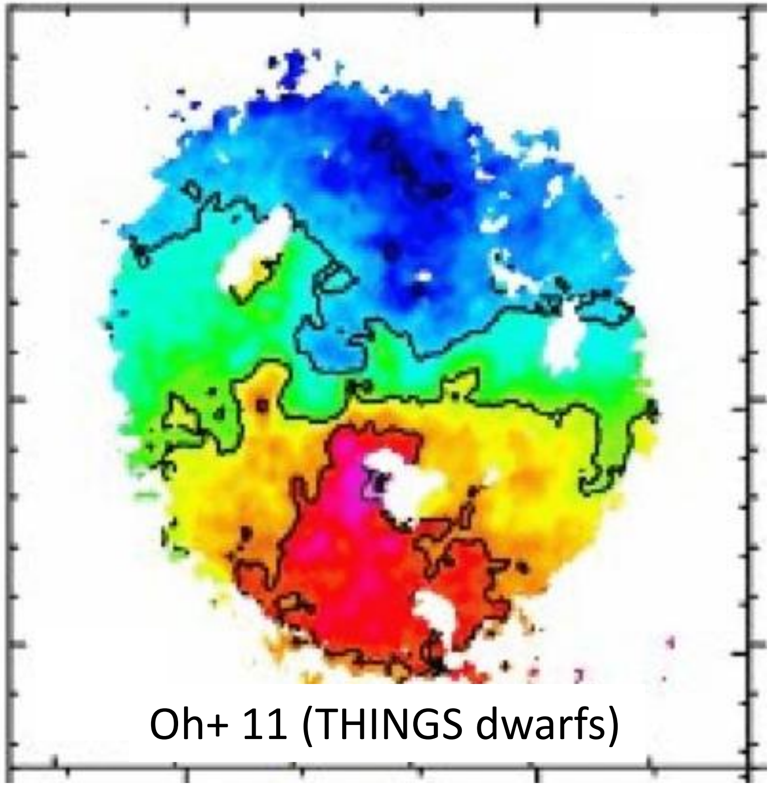
The cusp/core problem

If: Disk galaxy kinematics probe their mass distributions ?

Precision rotation curves require velocity field (or data cube) models



Kuzio de Naray+ 06 (LSBs)



Oh+ 11 (THINGS dwarfs)

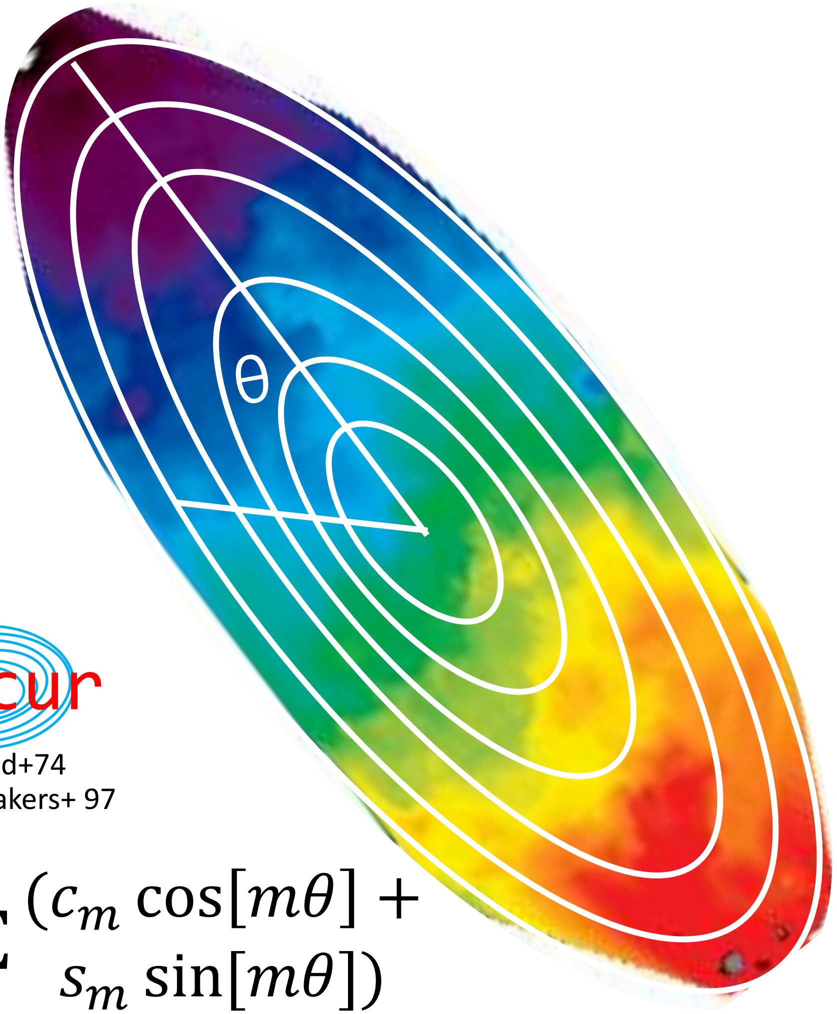
Titled rings and non-circular flows

KS+ Sellwod 07;Valenzuela+07, Sellwood+KS 15; Oman+19, Sellwood, KS+ 21

"Tilted Rings":

Rotcur

Rogstad+74
Schoenmakers+ 97

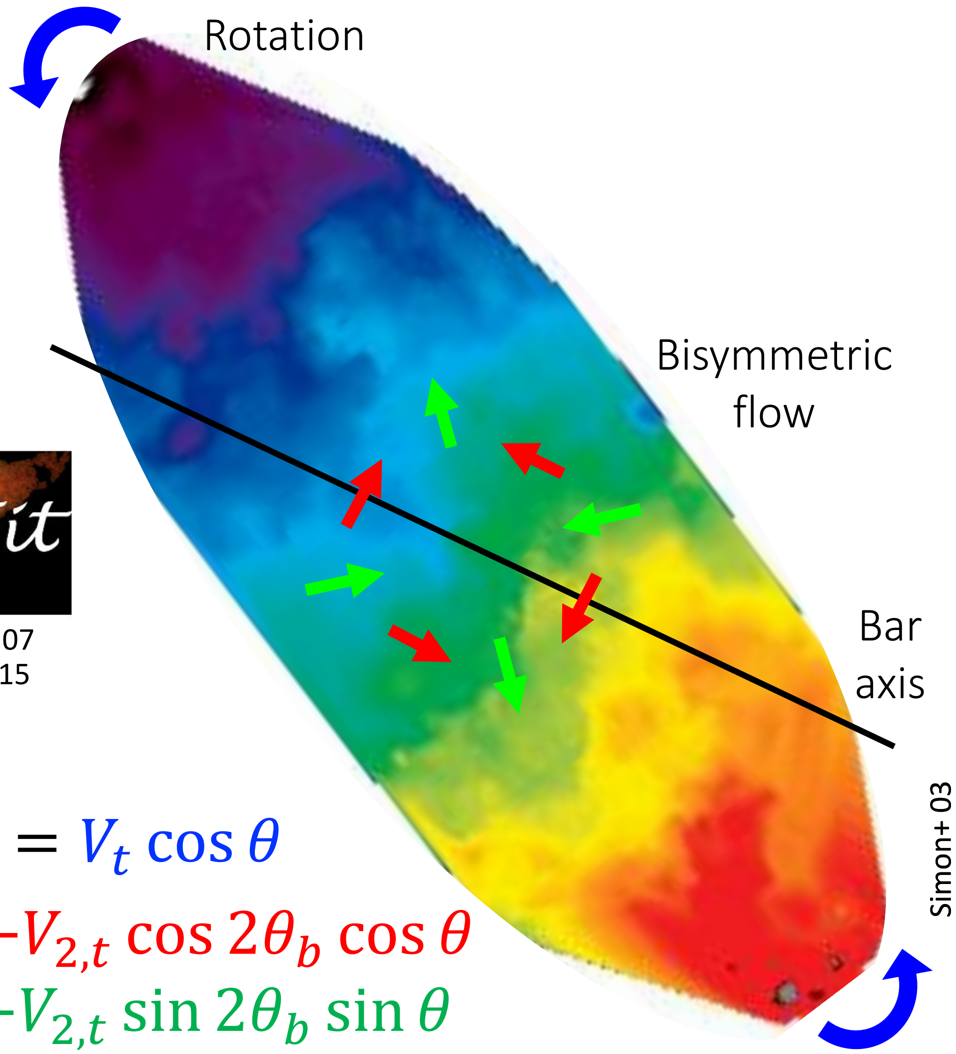


Simon+ 03

$$\frac{V-V_{sys}}{\sin i} = \sum (c_m \cos[m\theta] + s_m \sin[m\theta])$$

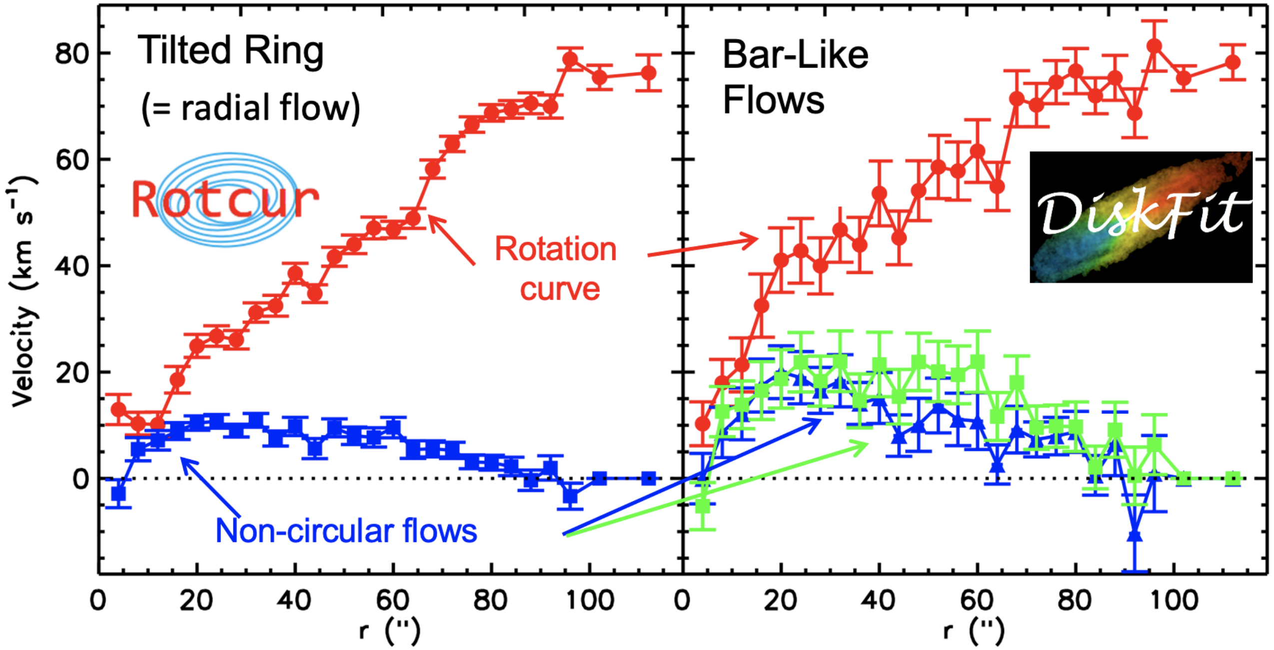
Titled rings and non-circular flows

KS+ Sellwod 07;Valenzuela+07, Sellwood+KS 15; Oman+19, Sellwood, KS+ 21



KS+ Sellwood 07
Sellwood+KS 15

$$\frac{V - V_{sys}}{\sin i} = V_t \cos\theta - V_{2,t}\cos 2\theta_b \cos\theta - V_{2,t}\sin 2\theta_b \sin\theta$$



How asymmetries are modelled impacts rotation curve shapes at a level that is relevant to cusp vs. core.

The cusp/core problem

If: **Disk galaxy kinematics probe their mass distributions ?**

And: There exists a (disk) galaxy population that formed without altering their parent halos

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The cusp/core problem

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(Velocity fields of well-behaved equilibrium disks combined with careful modelling)

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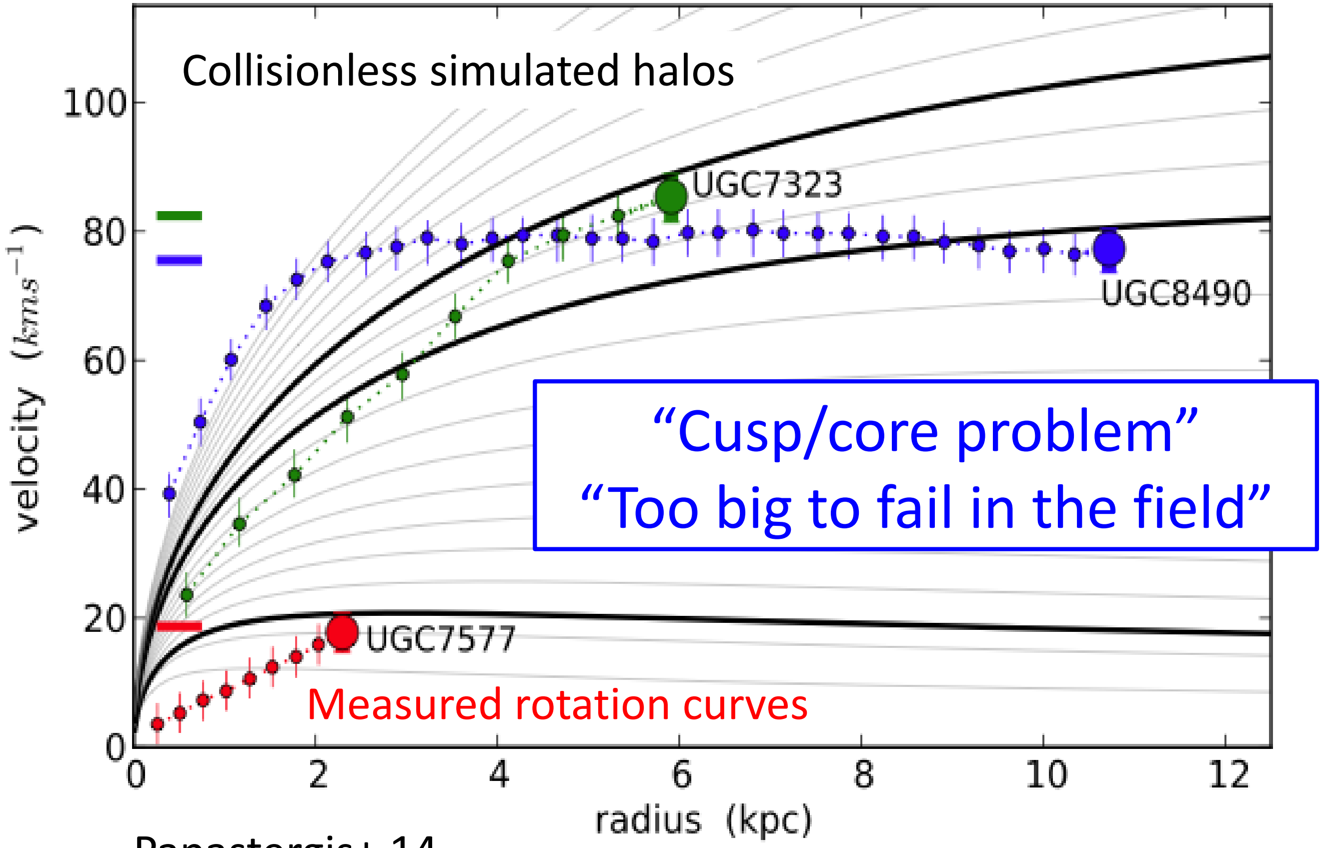
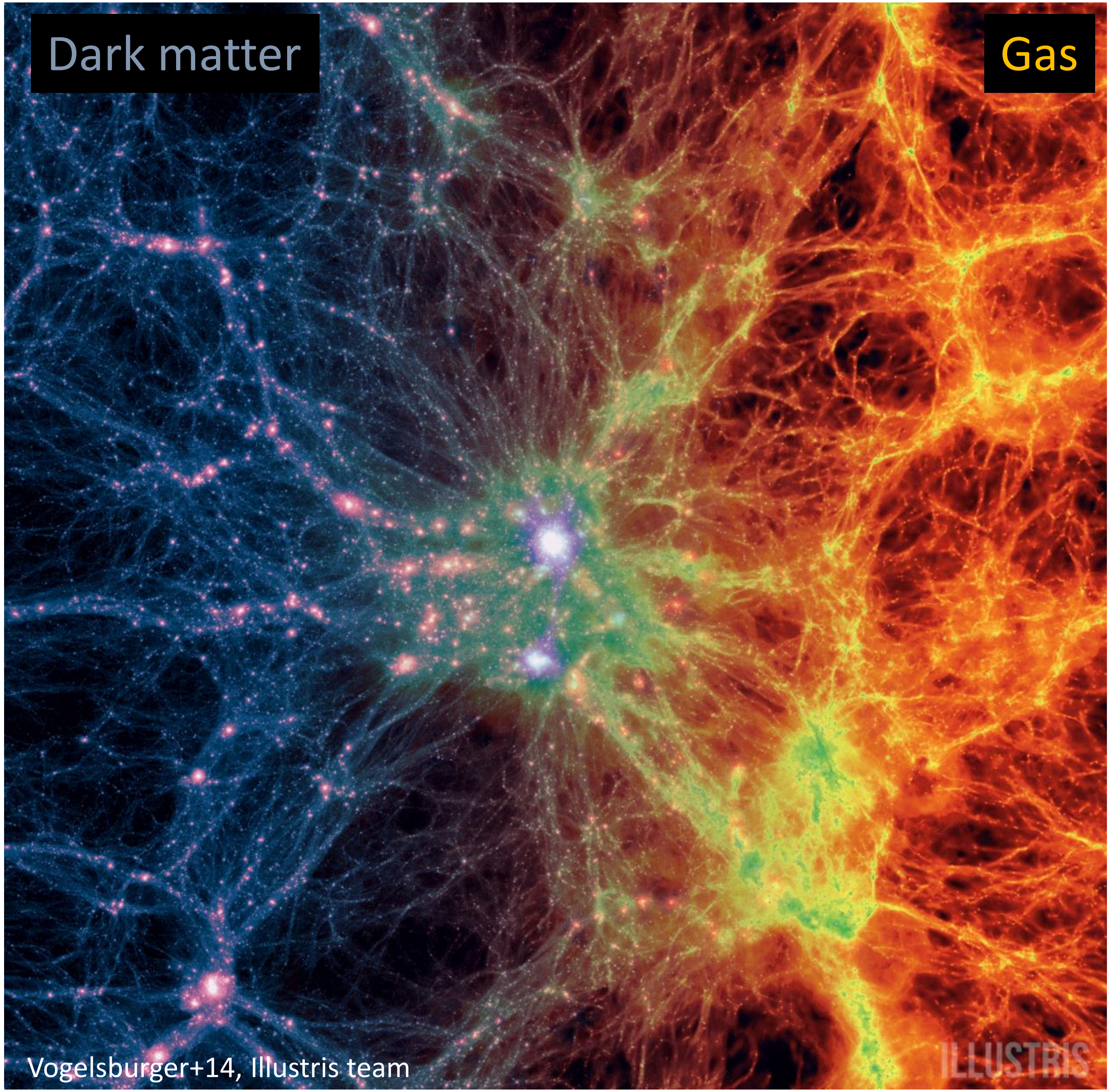


Papastergis+ 14

Modelling baryons

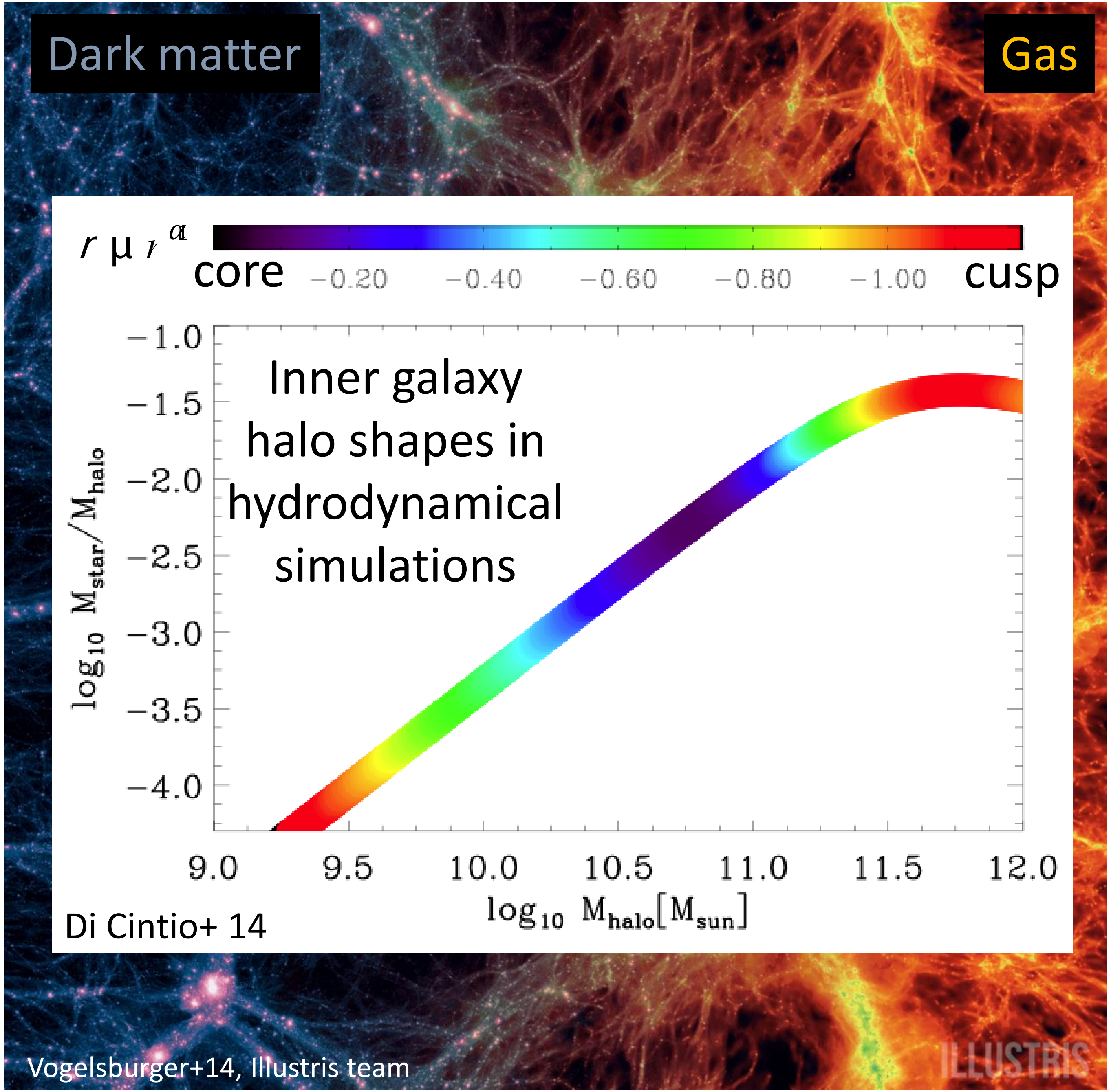


And: There exists a (disk) galaxy population that formed without altering their parent halos ?

Modelling baryons

And: There exists a (disk) galaxy population that formed without altering their parent halos ?

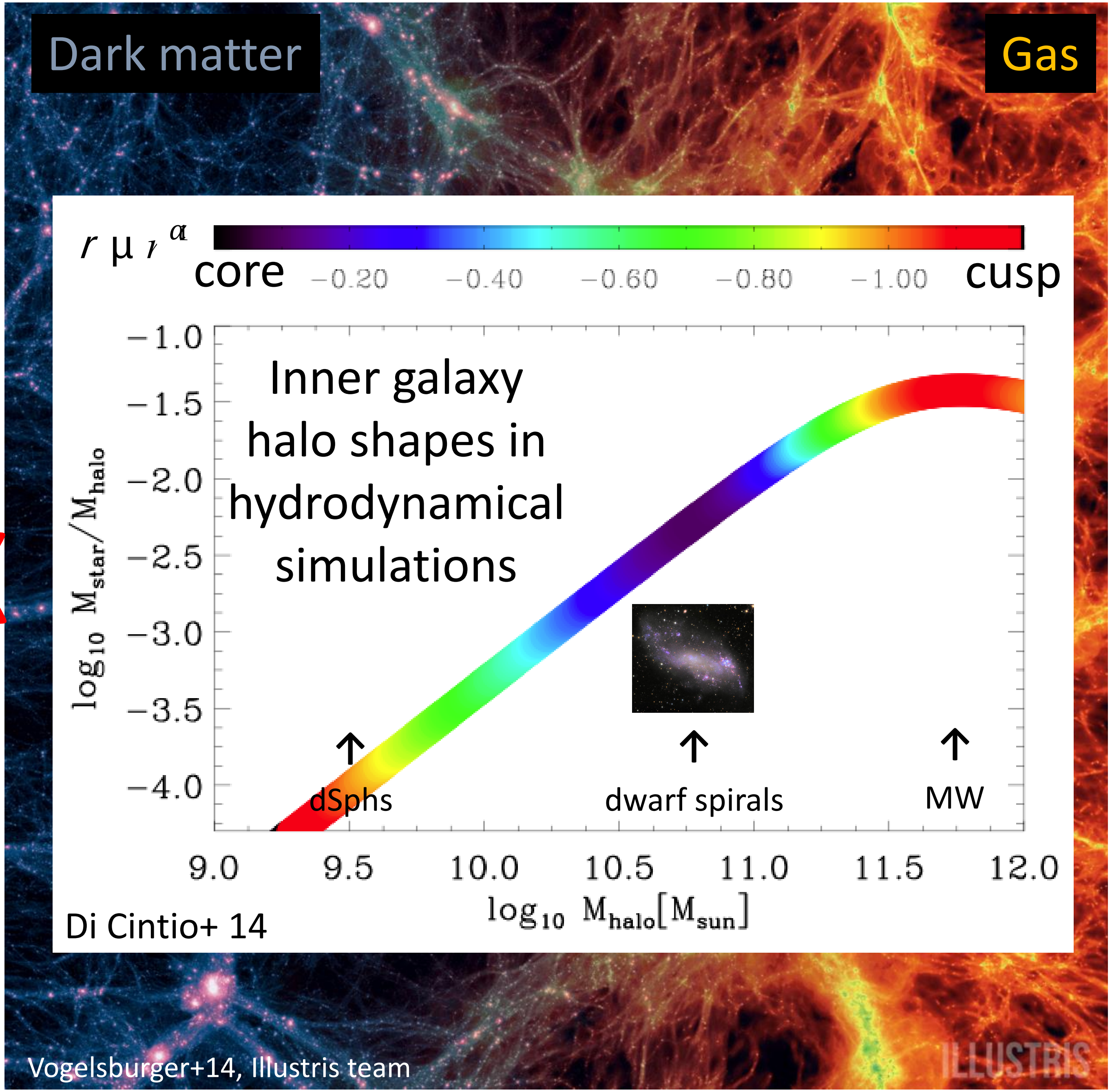
Star formation and feedback can alter dark matter halos



Modelling baryons

And: There exists a (disk) galaxy population that formed without altering their parent halos ✗

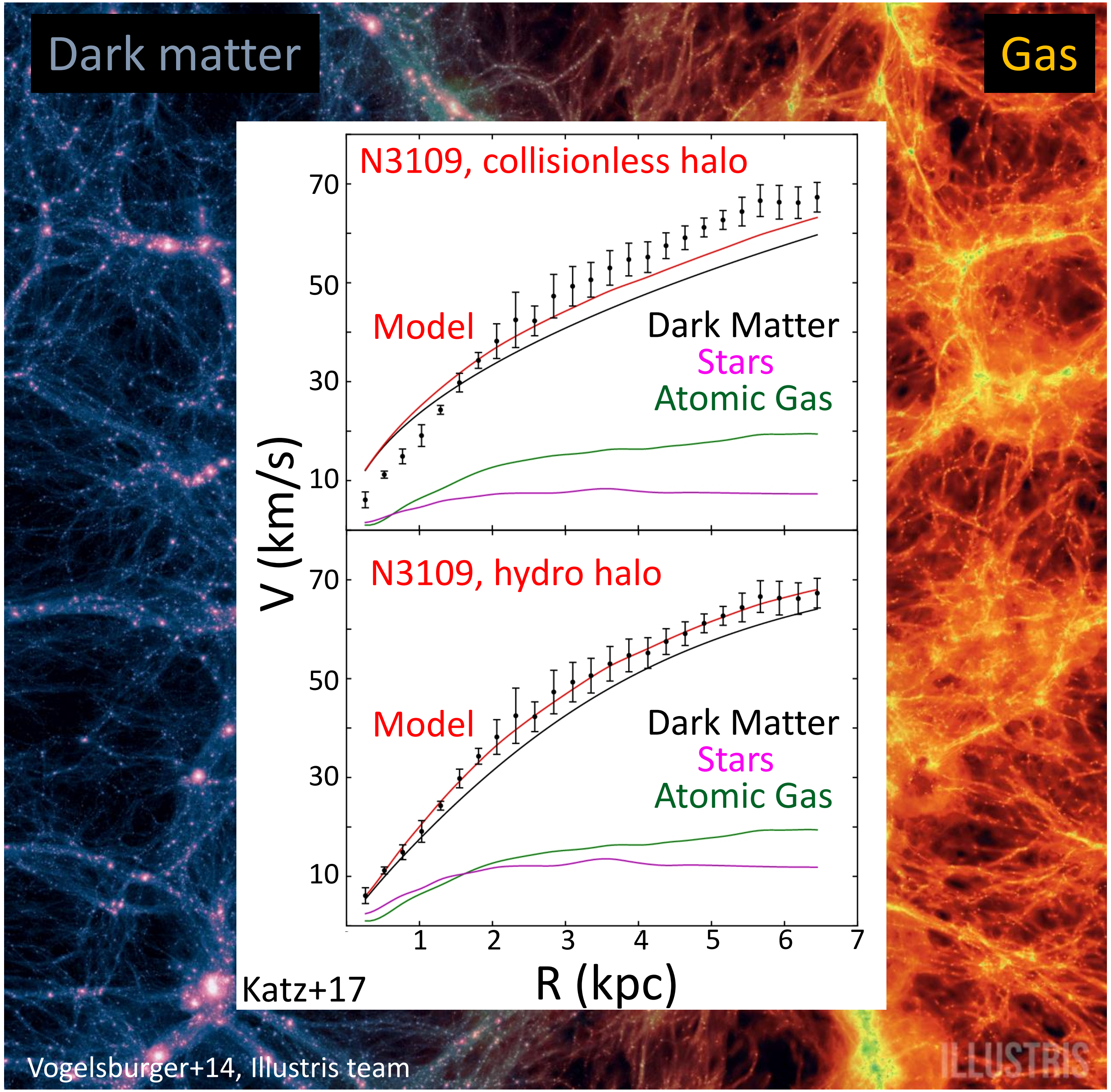
Star formation and feedback can alter dark matter halos



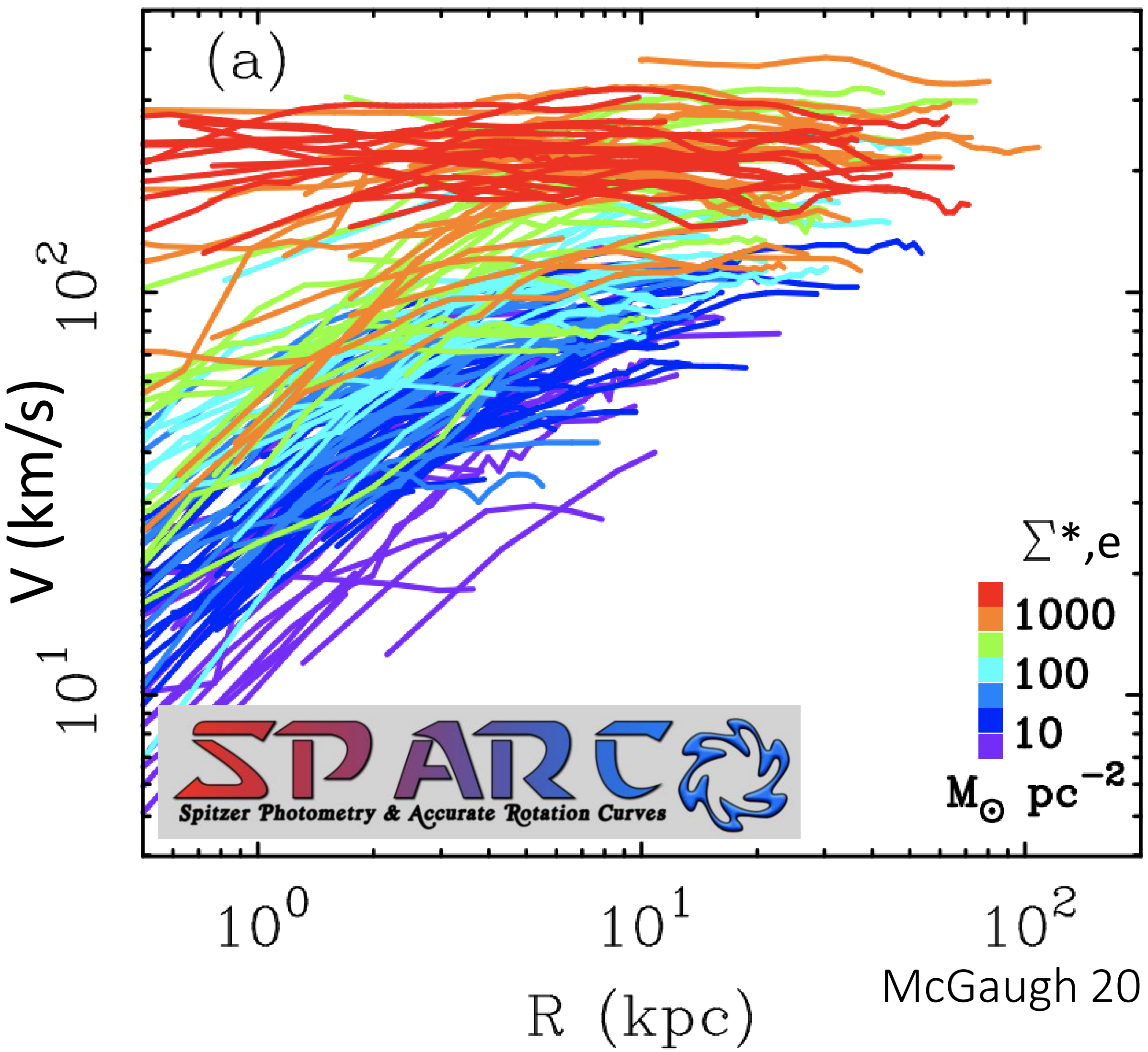
Modelling baryons

Star formation and feedback can alter dark matter halos + inner rotation curve shapes depend on kinematic model assumptions...

Small, curated samples of high-resolution galaxy maps are unlikely to constrain dark matter models; there are no "smoking guns".

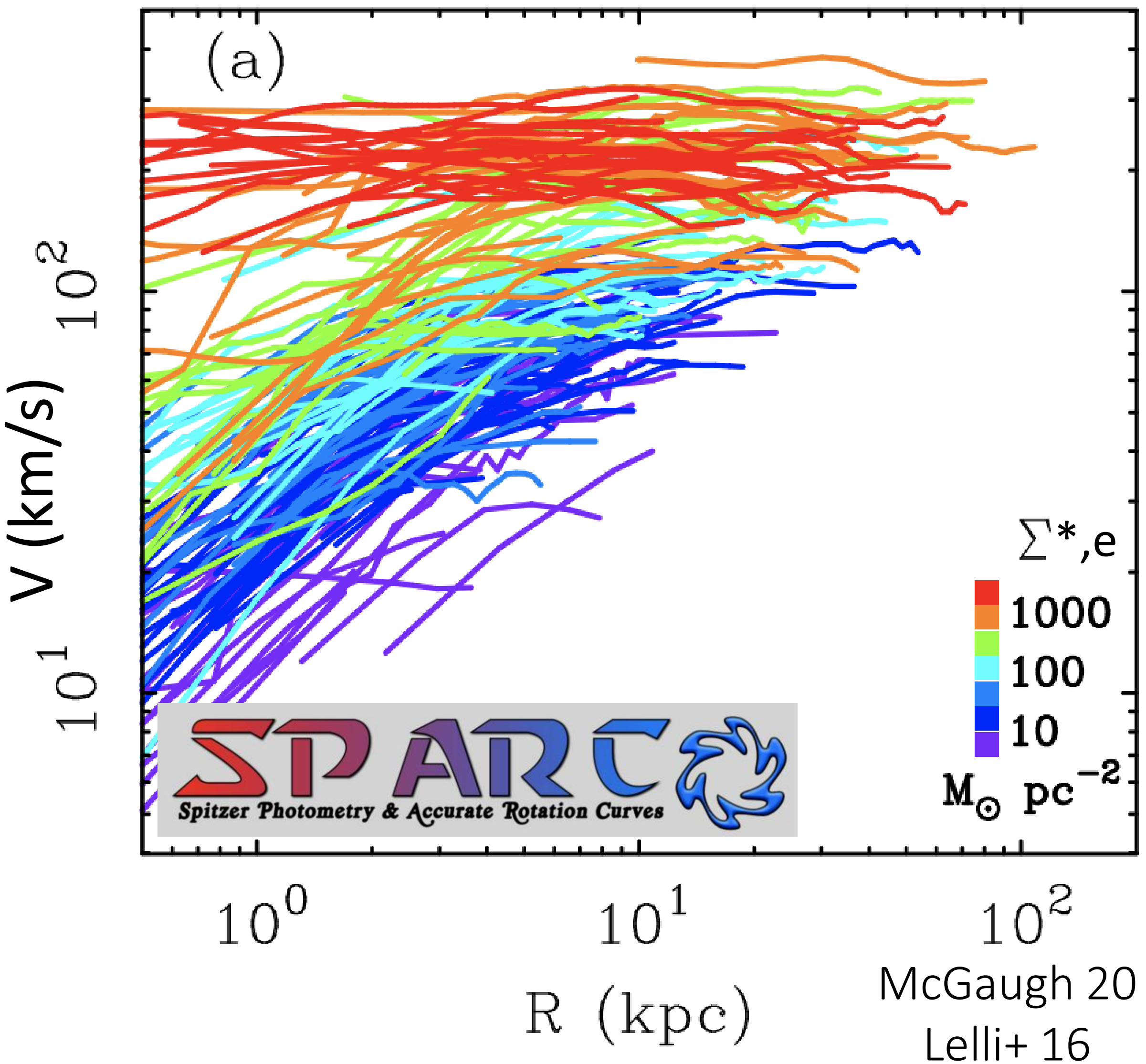


Populations: RC diversity

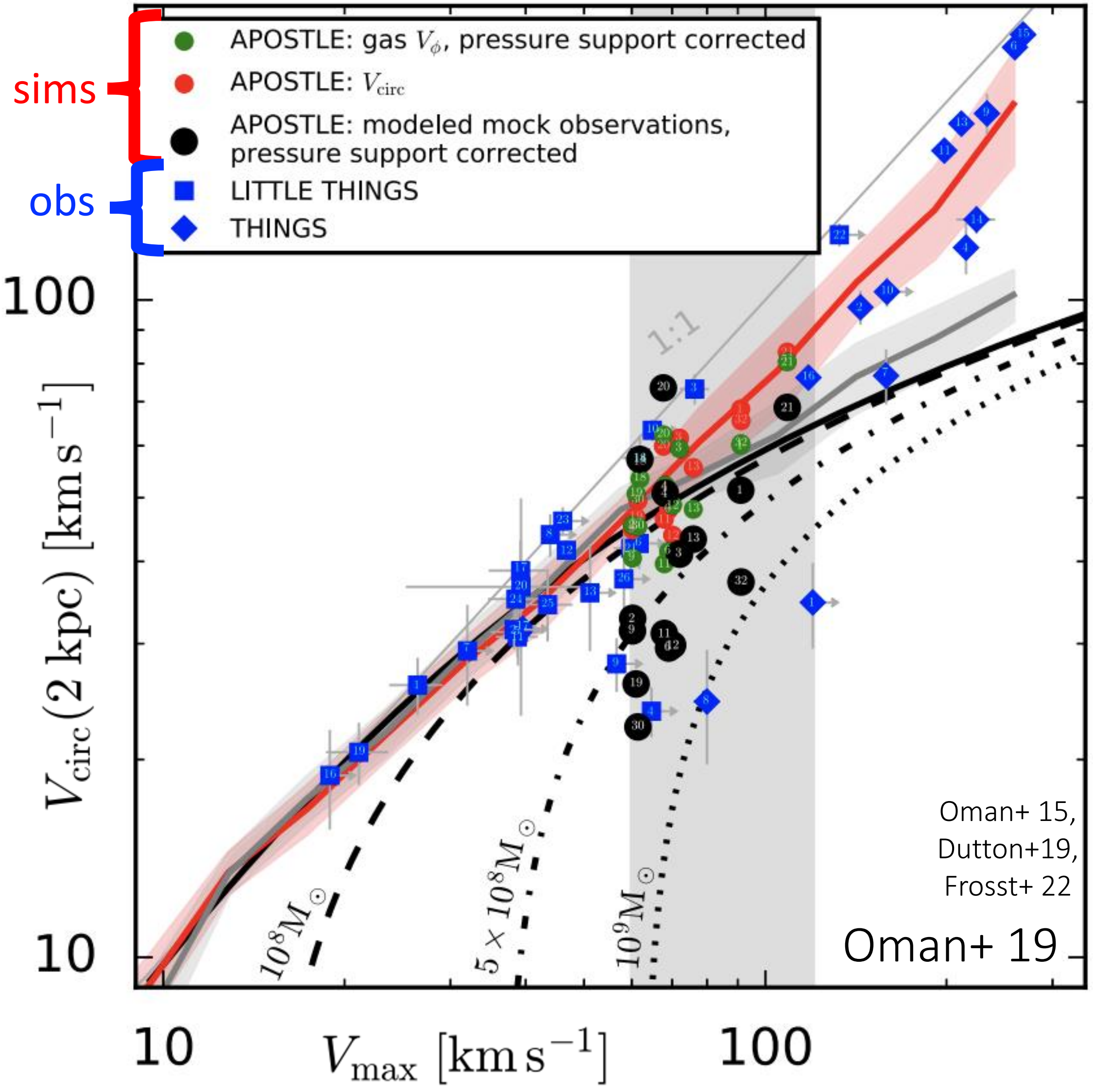


McGaugh 20

Populations: RC diversity



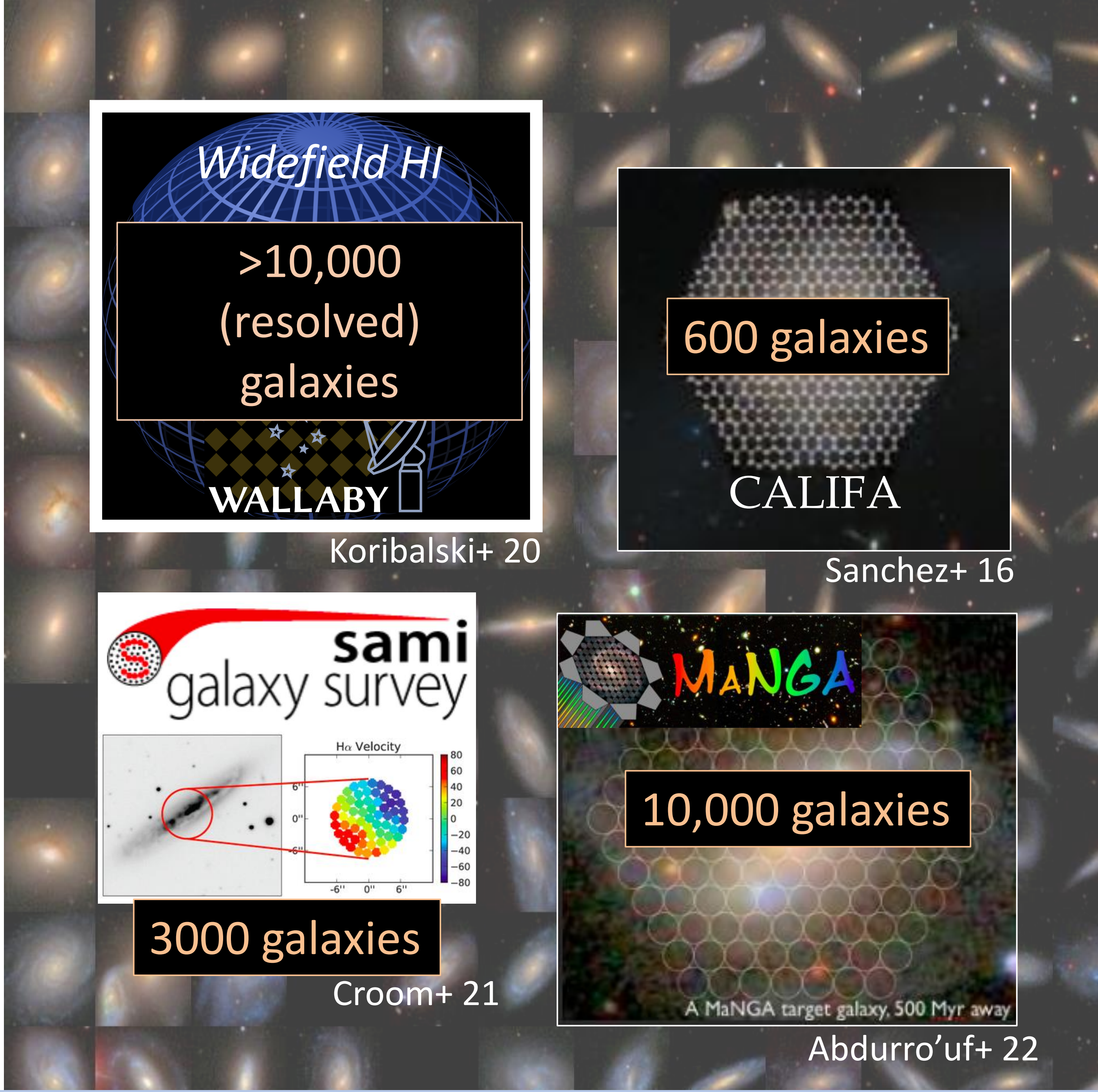
McGaugh 20
Lelli+ 16



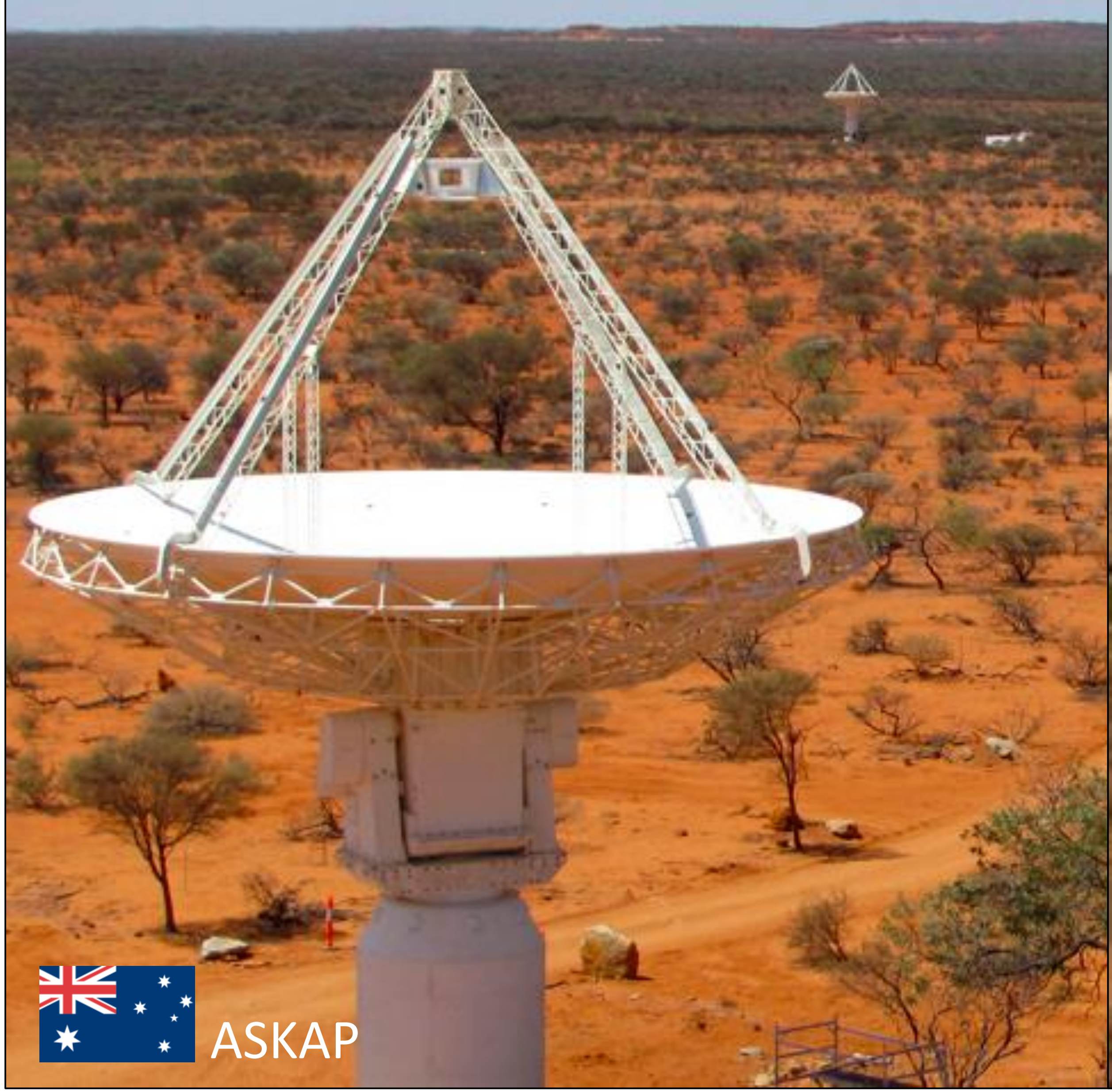
Why are rotation curve shapes in real galaxies more varied than in cosmological simulations?

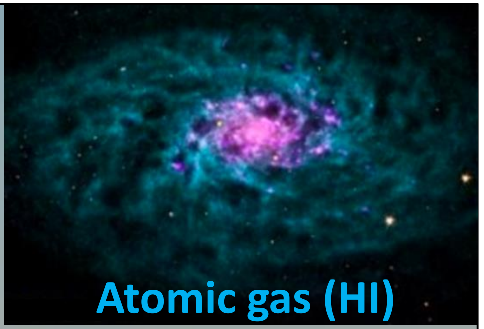
Population studies

What are the statistics of disk galaxy structure, and how do they compare with cosmological predictions?

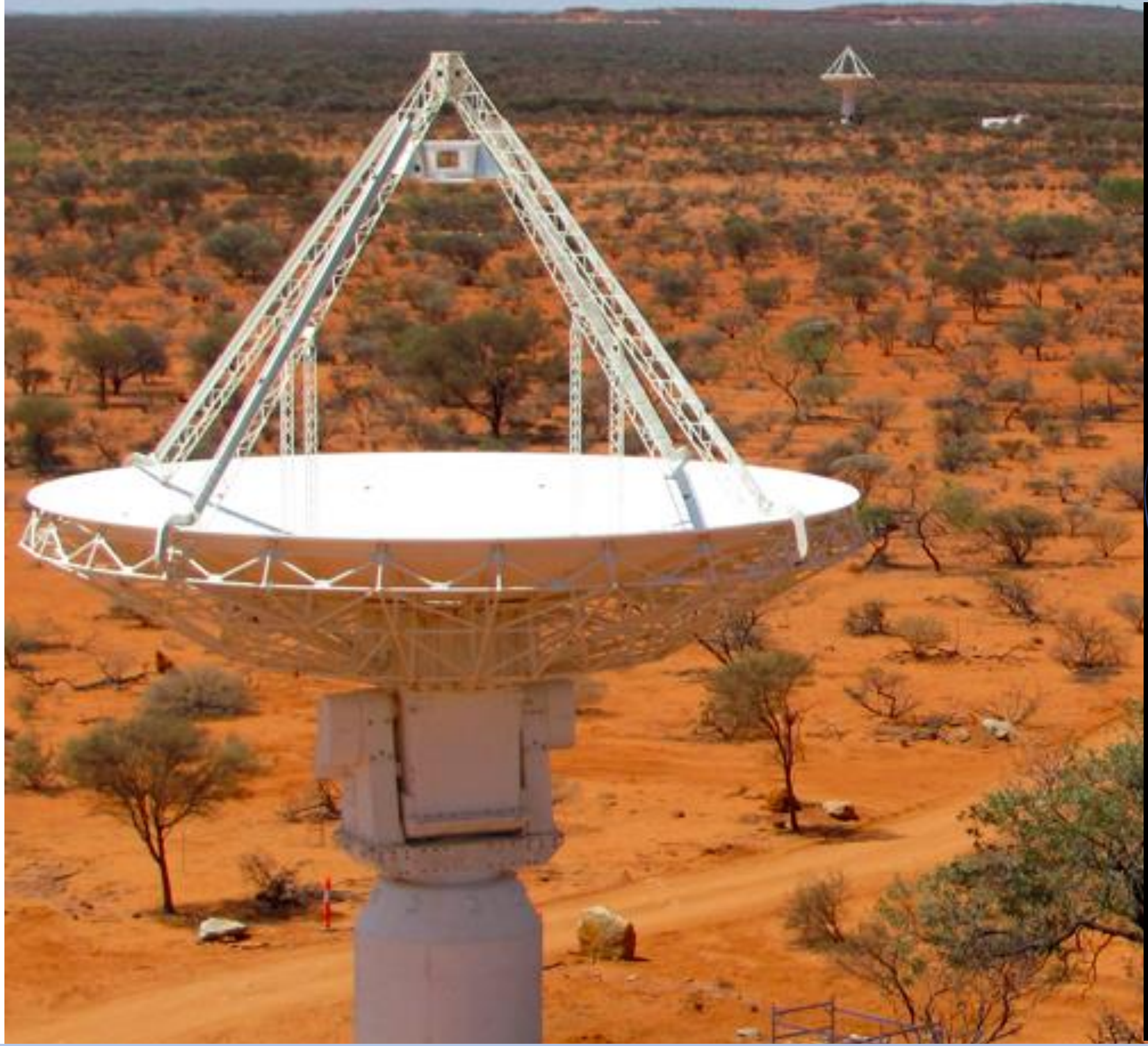


Next-generation radio facilities: ASKAP + MeerKAT

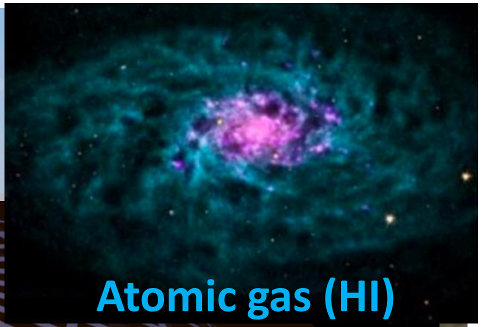




Resolving HI disks with WALLABY on ASKAP



Southern hemisphere HI survey,
30” + 5km/s resolution



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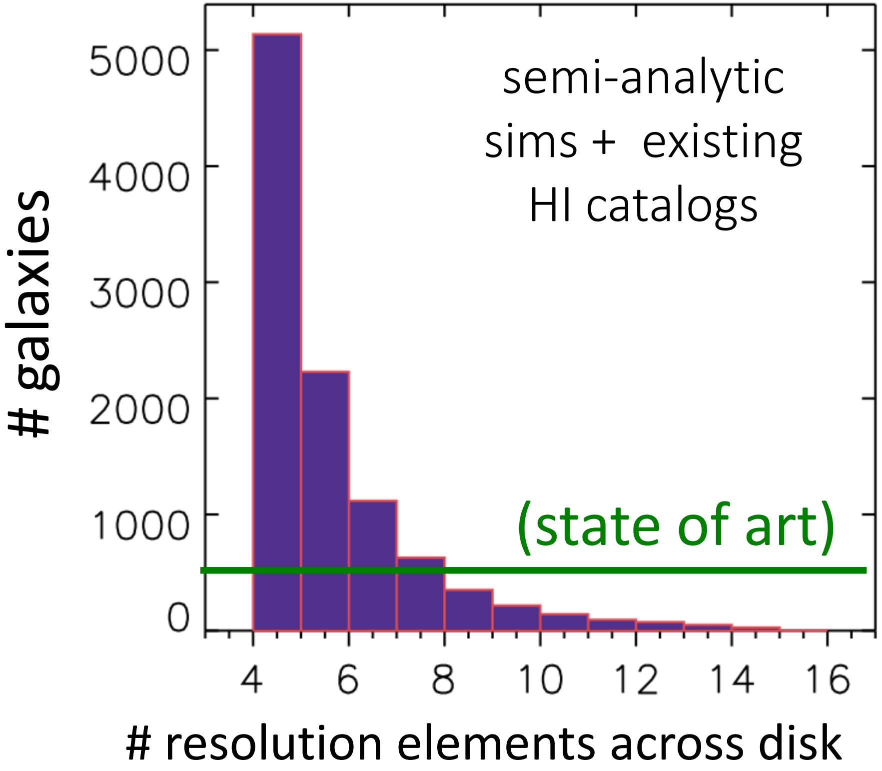
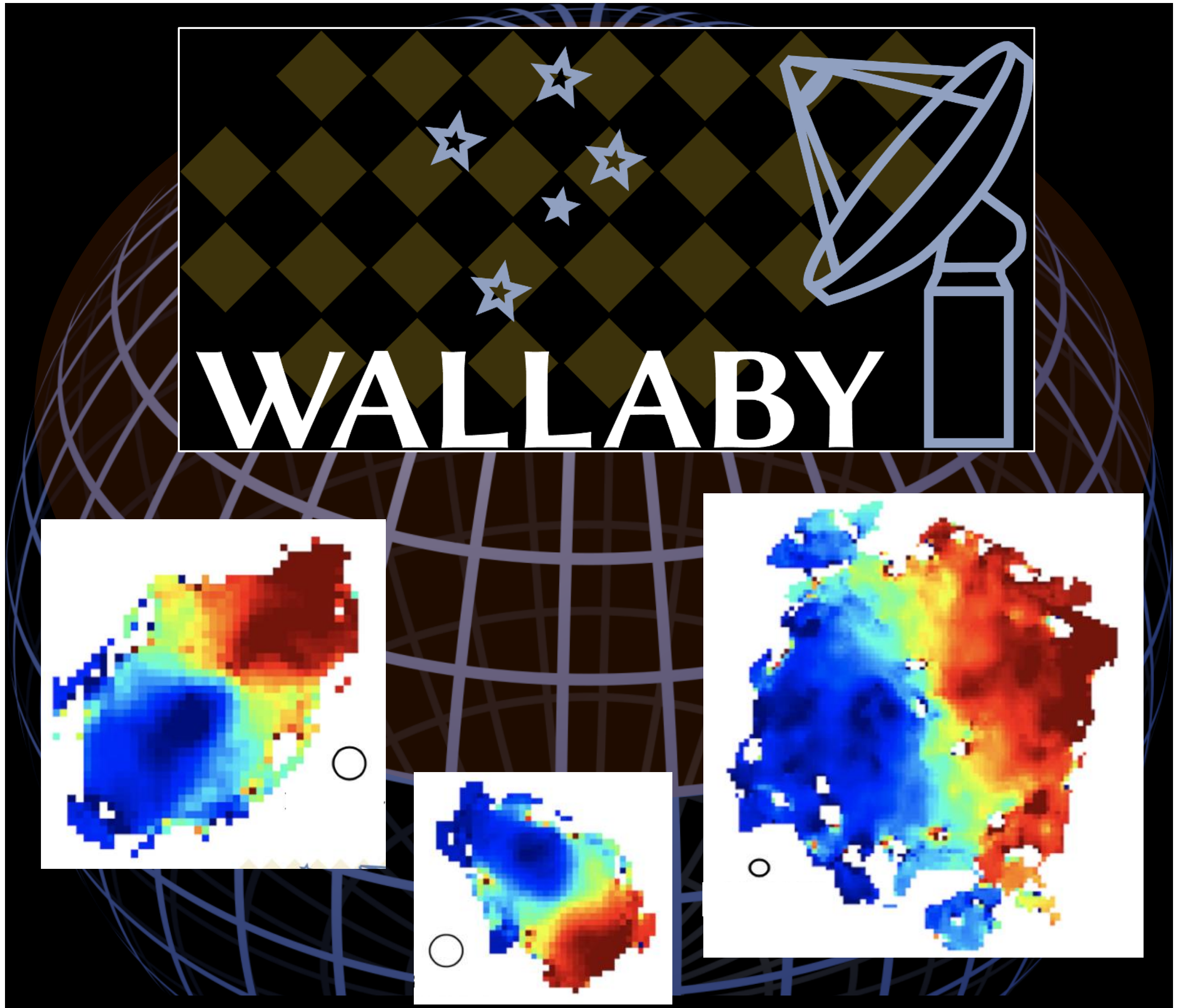


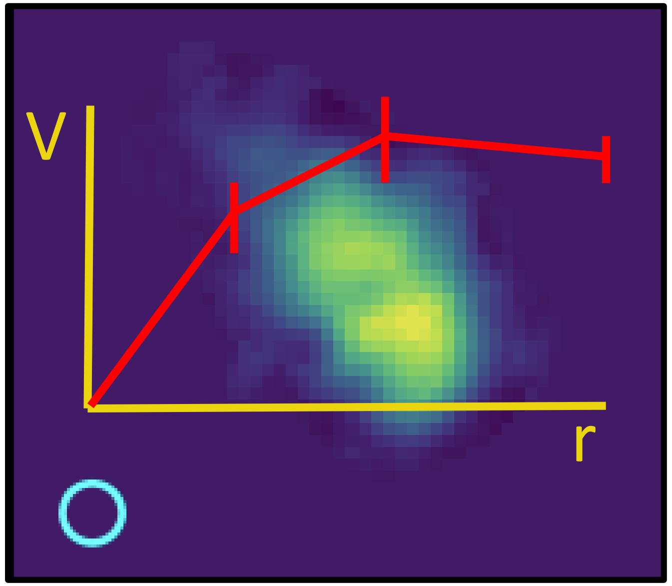
Wallaby will spatially resolve >10,000 HI disks.

Statistics! Selection function!



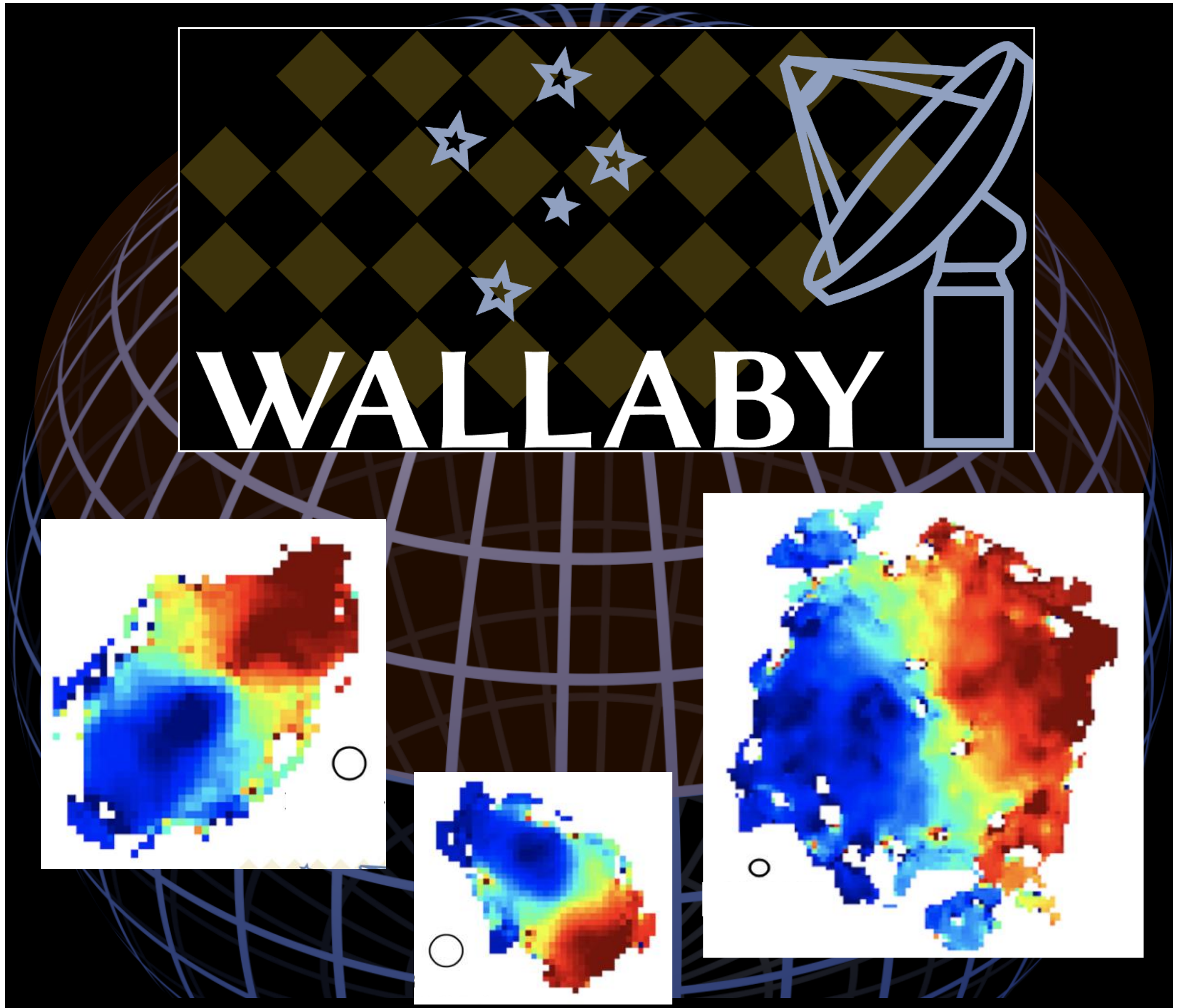
Pilot surveys nearing completion and producing beautiful data!

Resolving HI disks with WALLABY on ASKAP



3D models are required to extract physical structure such as rotation curve and disk geometry.

Rogstad 74; Bosma 78; Begeman 87; Sicking 97; Jozsa+ 07; Spekkens+Sellwood 07; Kamphuis+ 15, Bekiaris+ 16; di Teodoro+Fraternali 15; Davies+ 17; Oh+ 19; Varidel+19; Deg+22

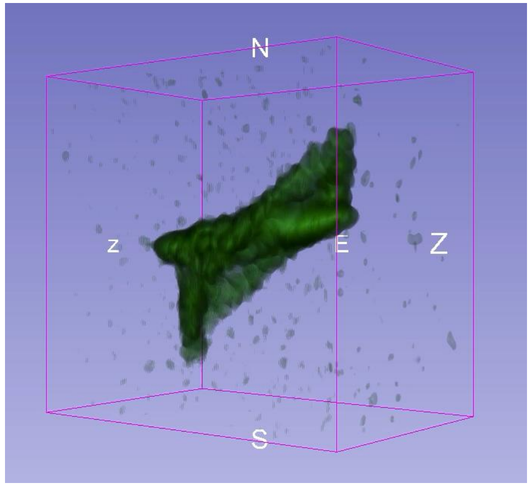


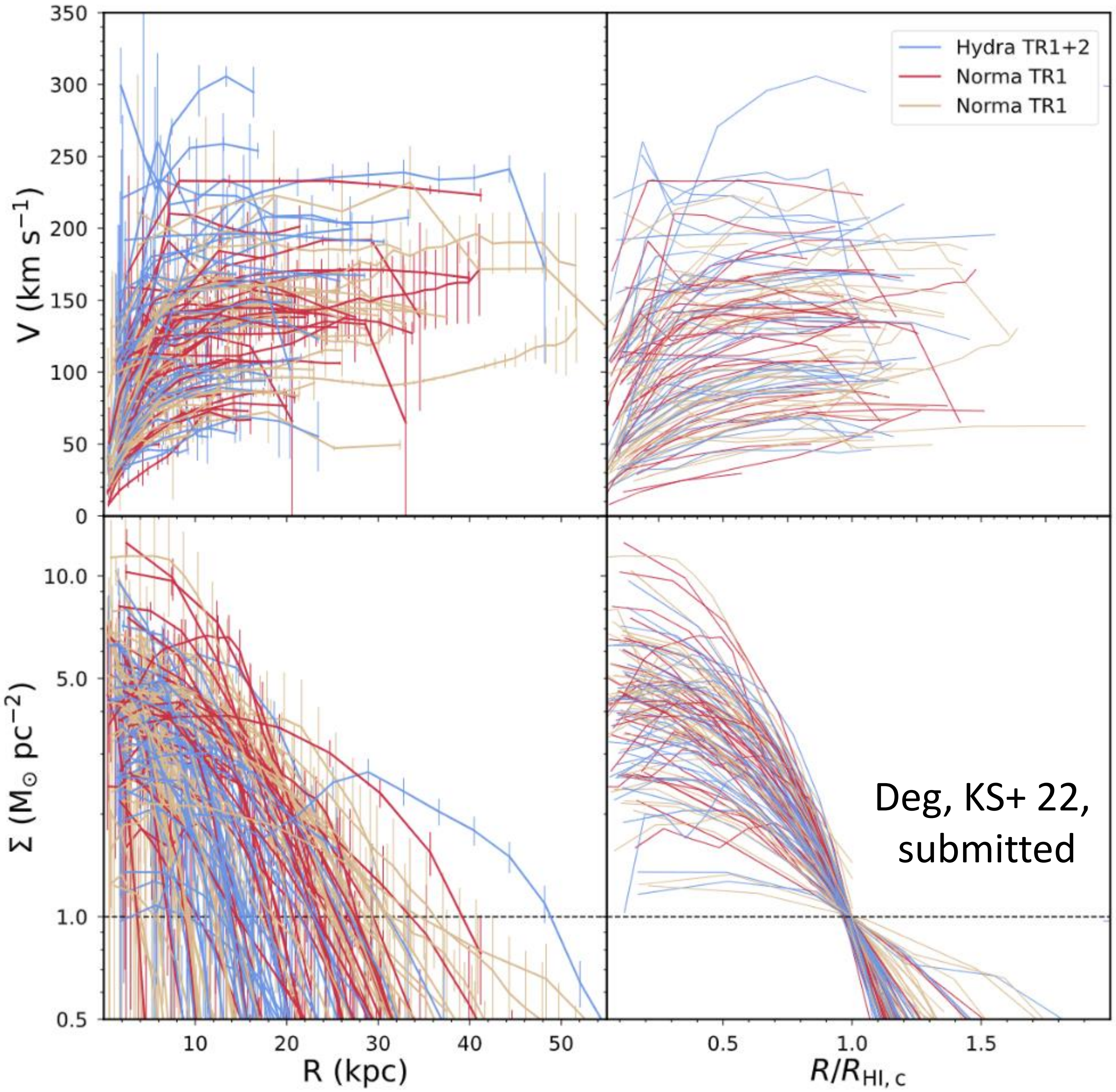
Pilot surveys nearing completion and producing beautiful data!

Towards populations of resolved disks

~100 homogeneously-modelled, blindly-detected objects...

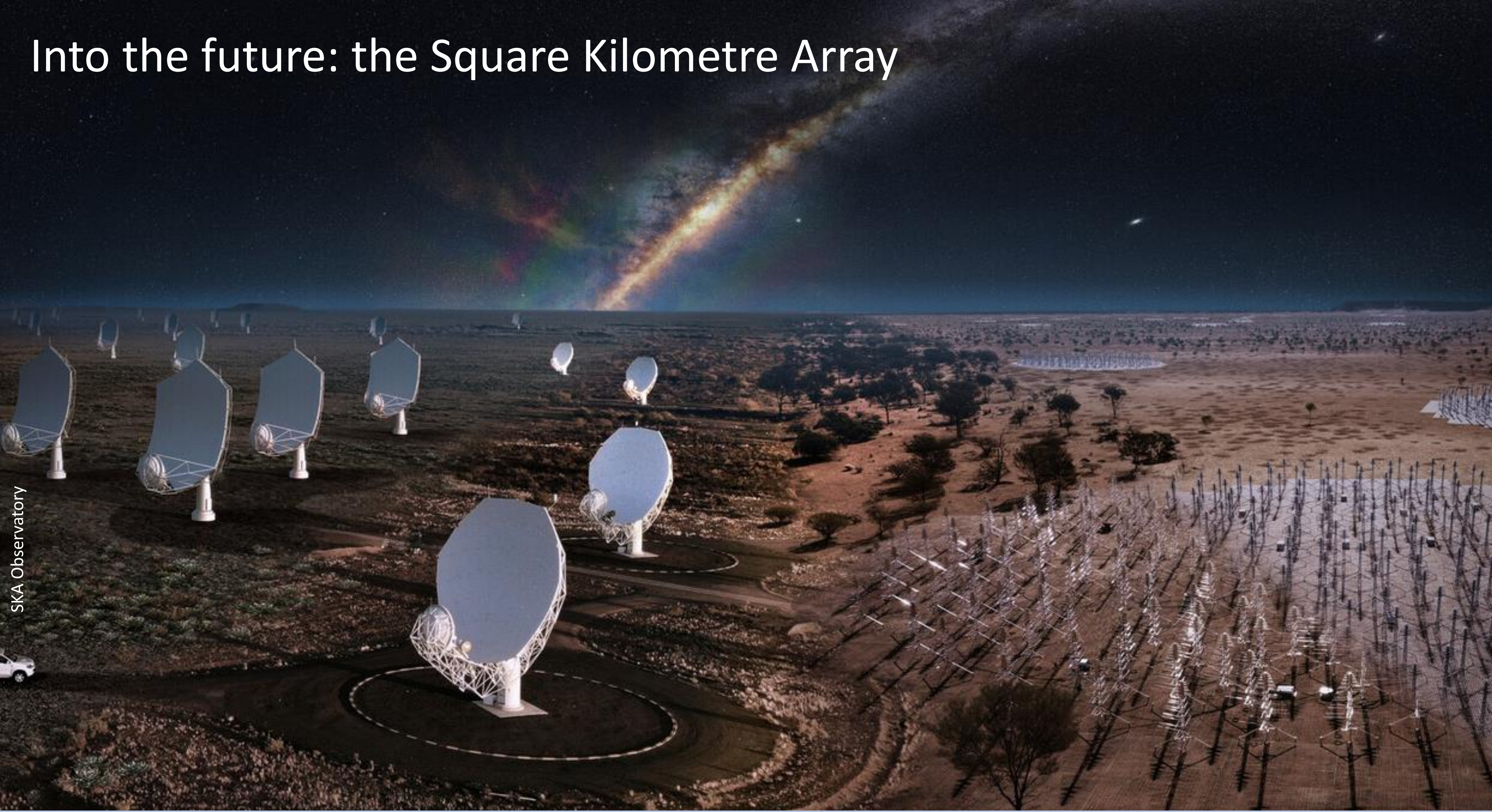
...and some interesting failures





Deg, KS+ 22, submitted

Into the future: the Square Kilometre Array

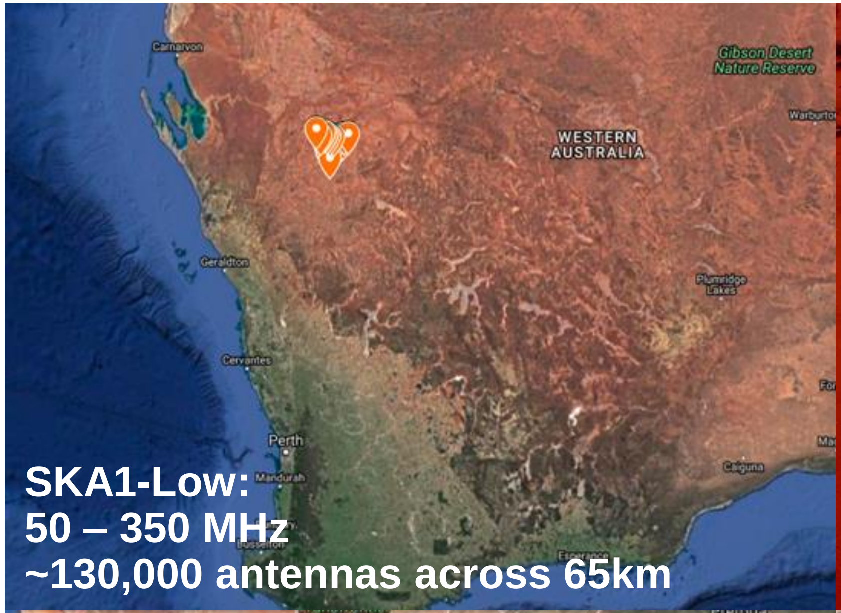


SKA Observatory

The SKA

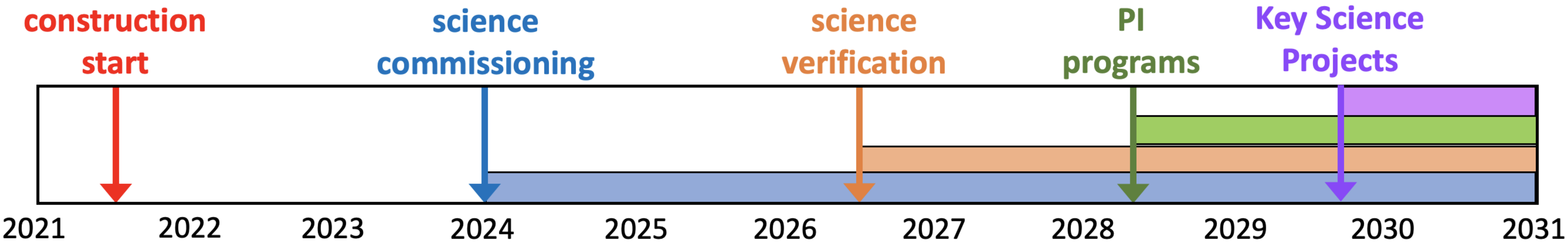
- SKA-Mid in South Africa
- SKA-Low in Australia
- Headquarters in the UK

16 partner countries in the SKA Observatory (*=Member States):



world's largest radio telescope

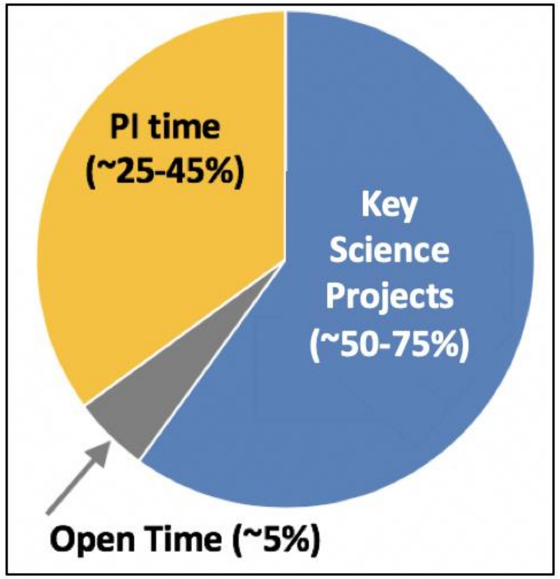
SKA timeline



SKA construction is underway.

First data in 2024.

Scientifically-competitive facilities by 2026.



Exploring the Universe with the world's largest radio telescope

https://www.skatelescope.org/news/skao-publishes-construction-proposal/

Broader impacts from the SKA

The broader impacts expected from the SKA are structured around the UN Sustainable Development Goals.

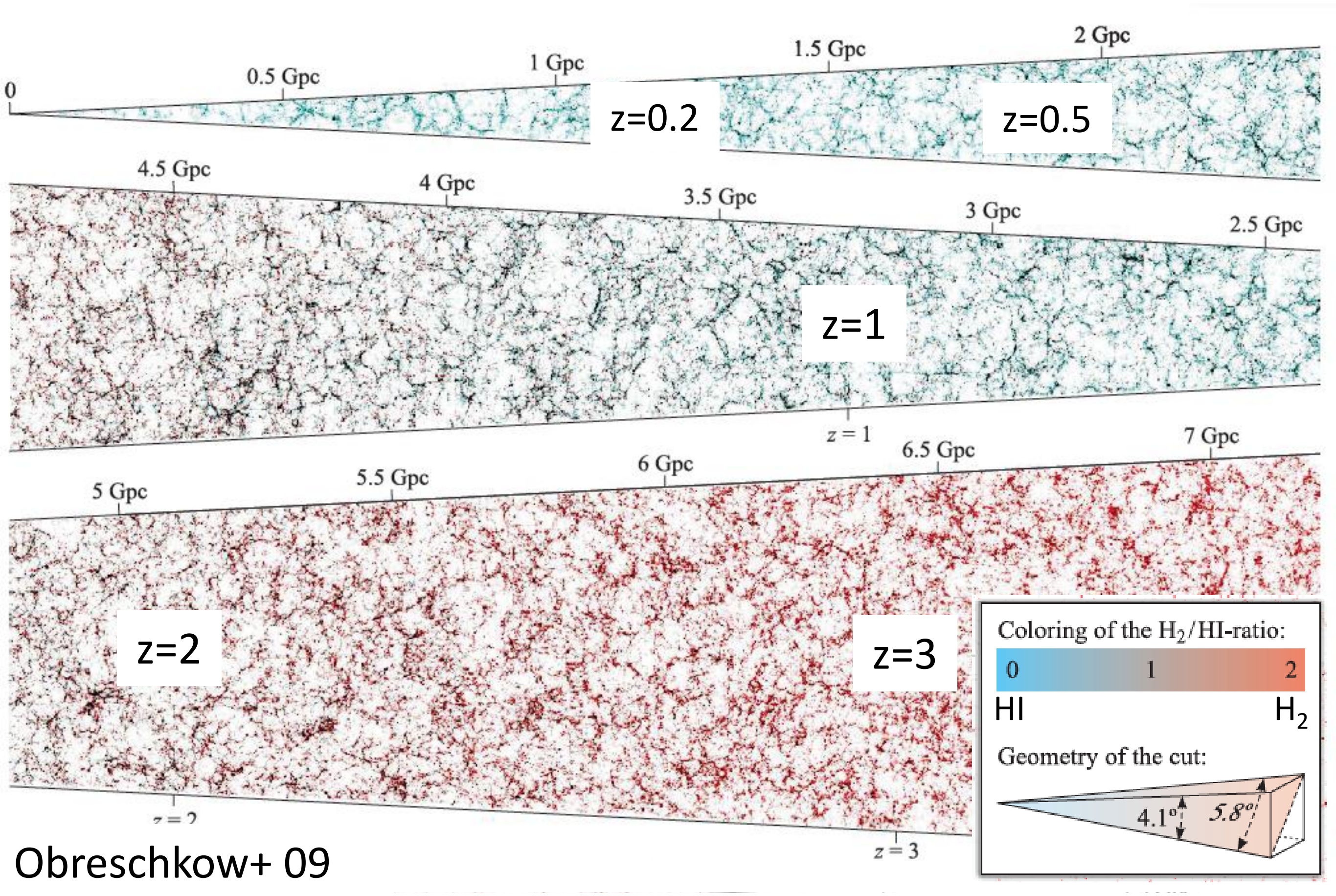
Our vision

"The SKAO is one observatory, with two telescopes, on three continents; a 21st century observatory and an inter-governmental organisation with sustainability and respect to all our communities at its heart, driven by a commitment to fundamental science and technology."

https://www.skatelescope.org/news/skao-publishes-construction-proposal/

Exploring the Universe with the world's largest radio telescope

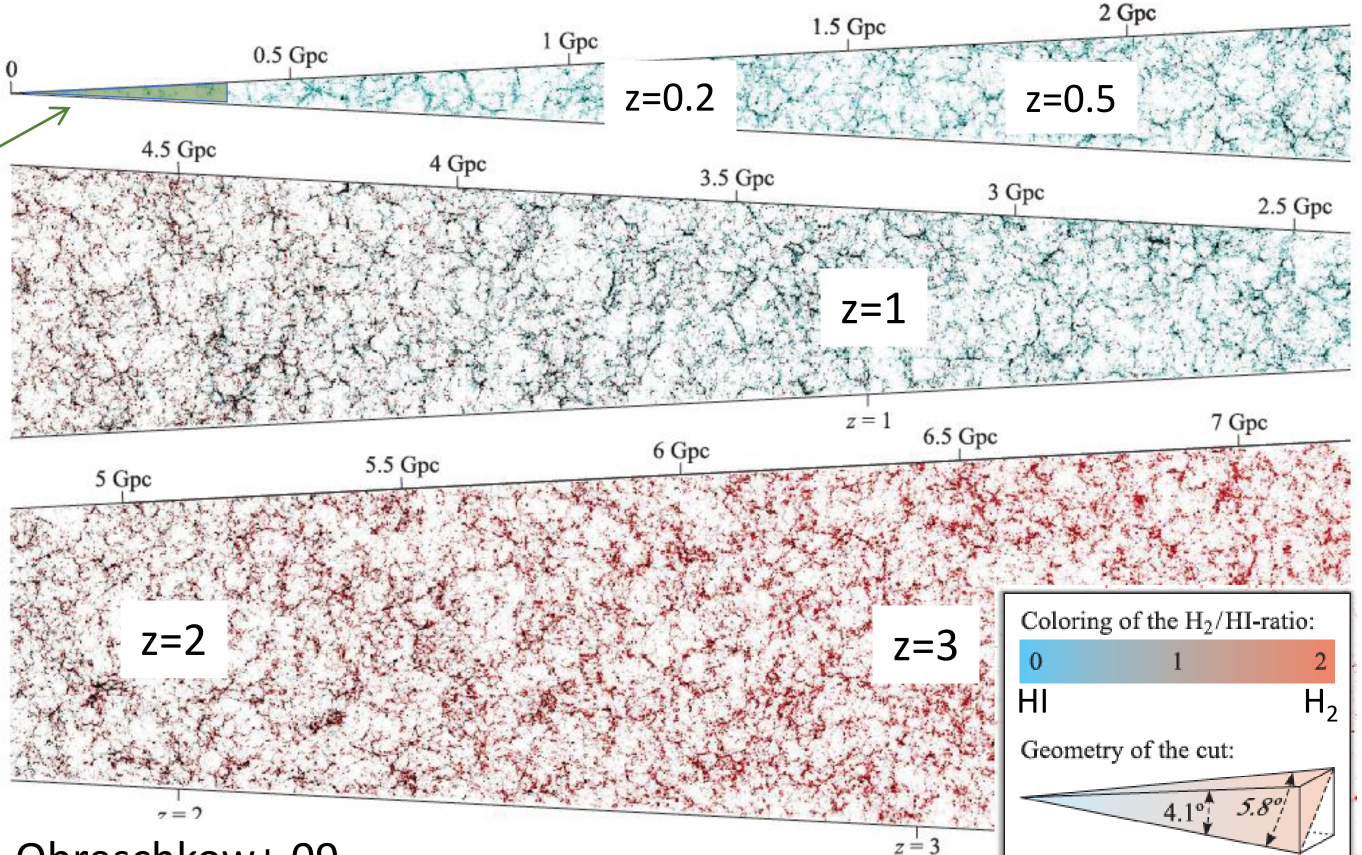
Into the future: resolving galaxies with the SKA



Obreschkow+ 09

Into the future: resolving galaxies with the SKA

State of the art + SKA pathfinders, spatially **resolved** individual detections



Obreschkow+ 09

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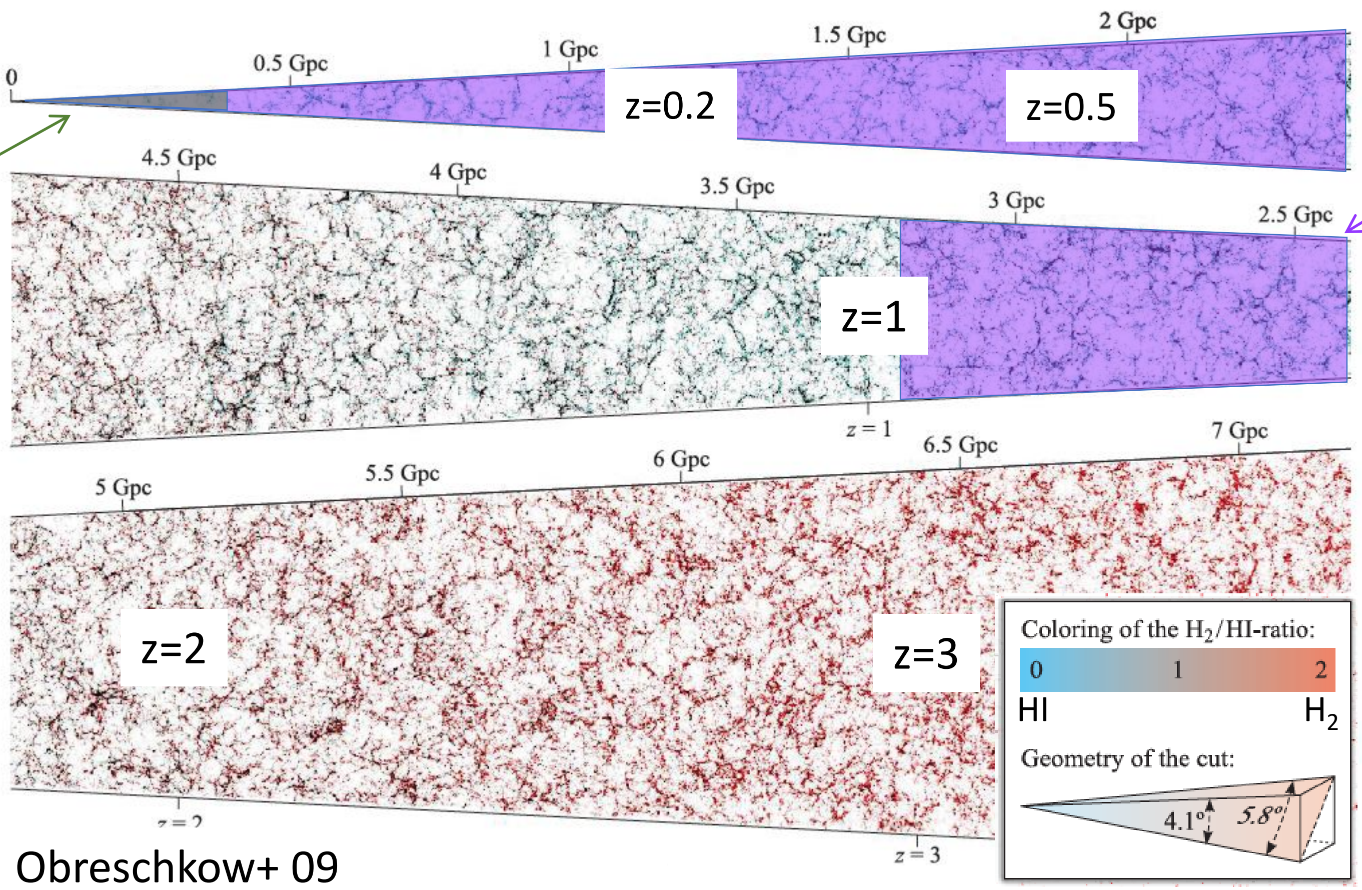
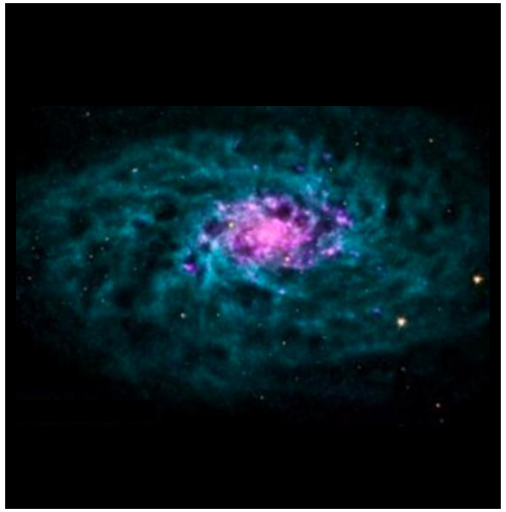


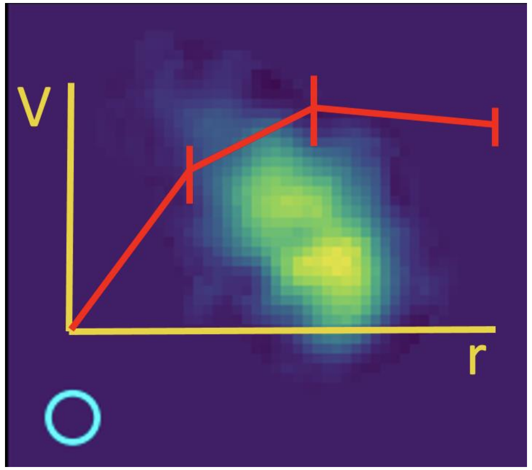
Obreschkow+ 09

SKA HI, spatially **resolved** individual detections

Key Science: buildup of galaxy mass/angular momentum across cosmic time

The kinematics of nearby disk galaxies can measure inner dark matter halo structure. The state of the art is population-wide studies.





WALLABY on ASKAP (along with other widefield surveys) is producing the first statistical samples of rotation curves to compare with simulations.

When complete in late 2028, the SKA will map nearby galaxies with detail and depth, probing both deeper into the halo and across cosmic time.