Dynamics of Galaxy Disks

from HI and IFU observations

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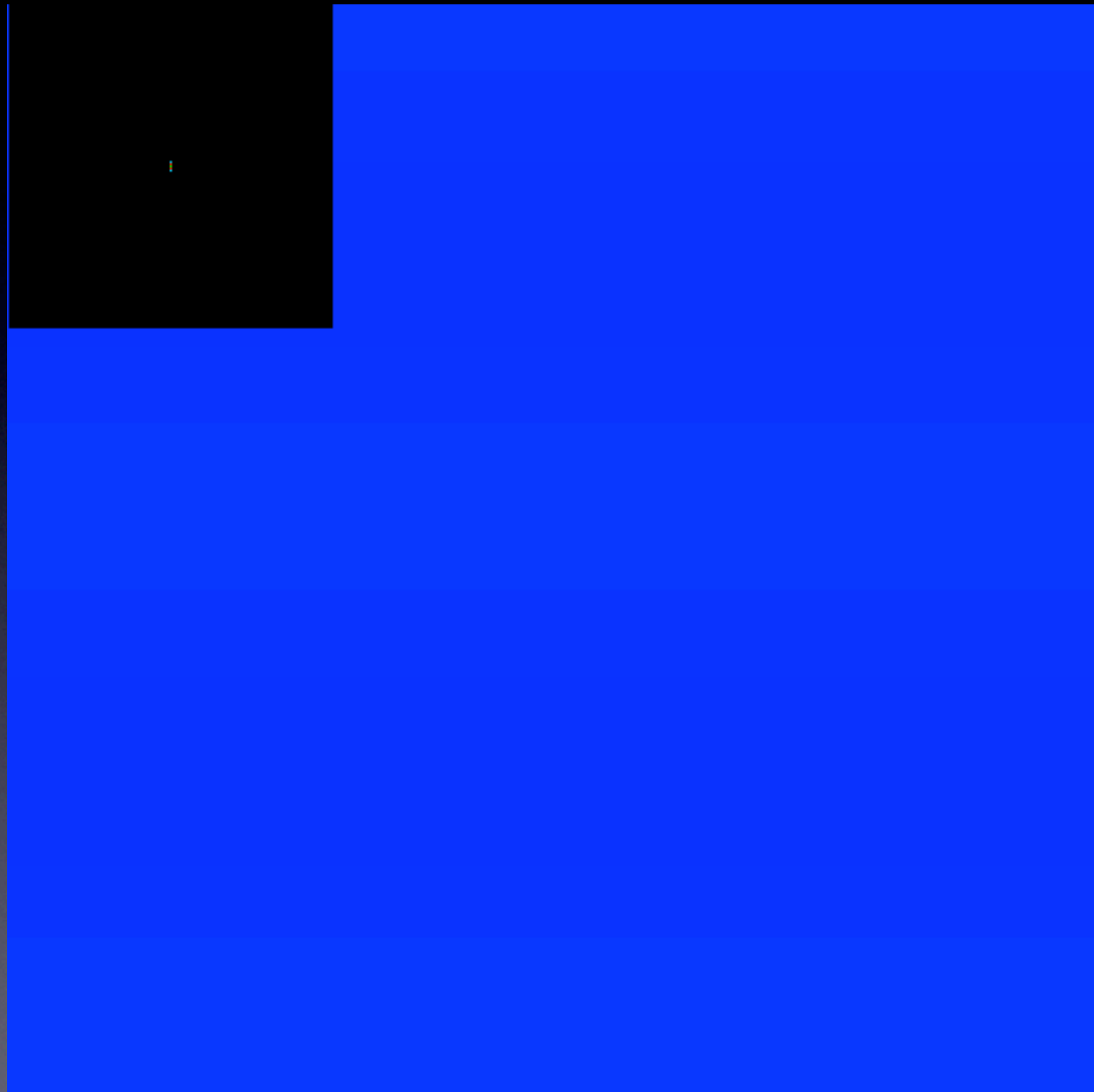
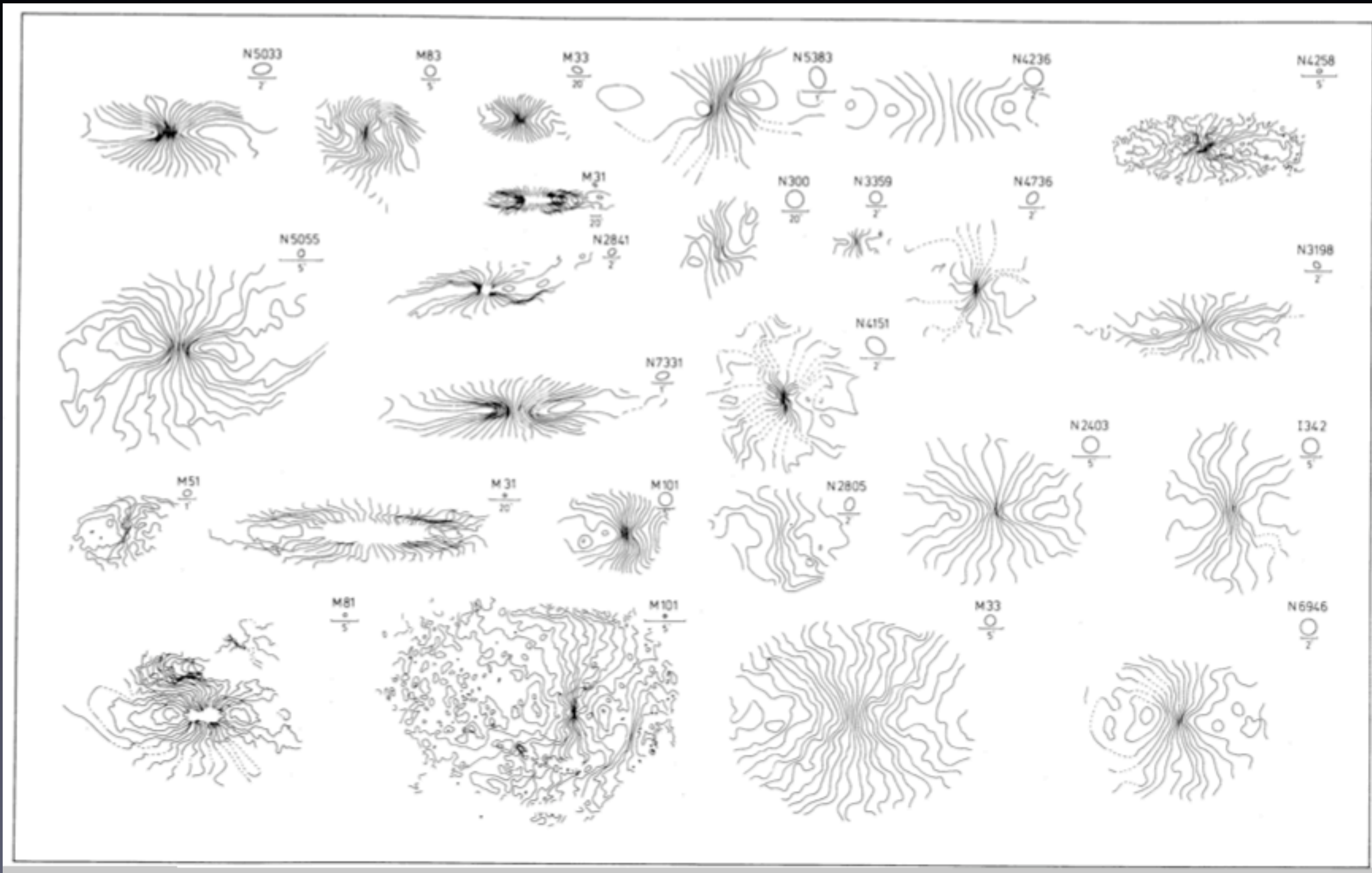
UGC 8490



outline

- Interpreting and modelling HI 21cm data cubes (signatures of bars, warps, streaming motions, lopsidedness)
- benefits & limitations of optical & near-IR Integral Field Units
- complementarity of HI and optical IFU data (2 examples)

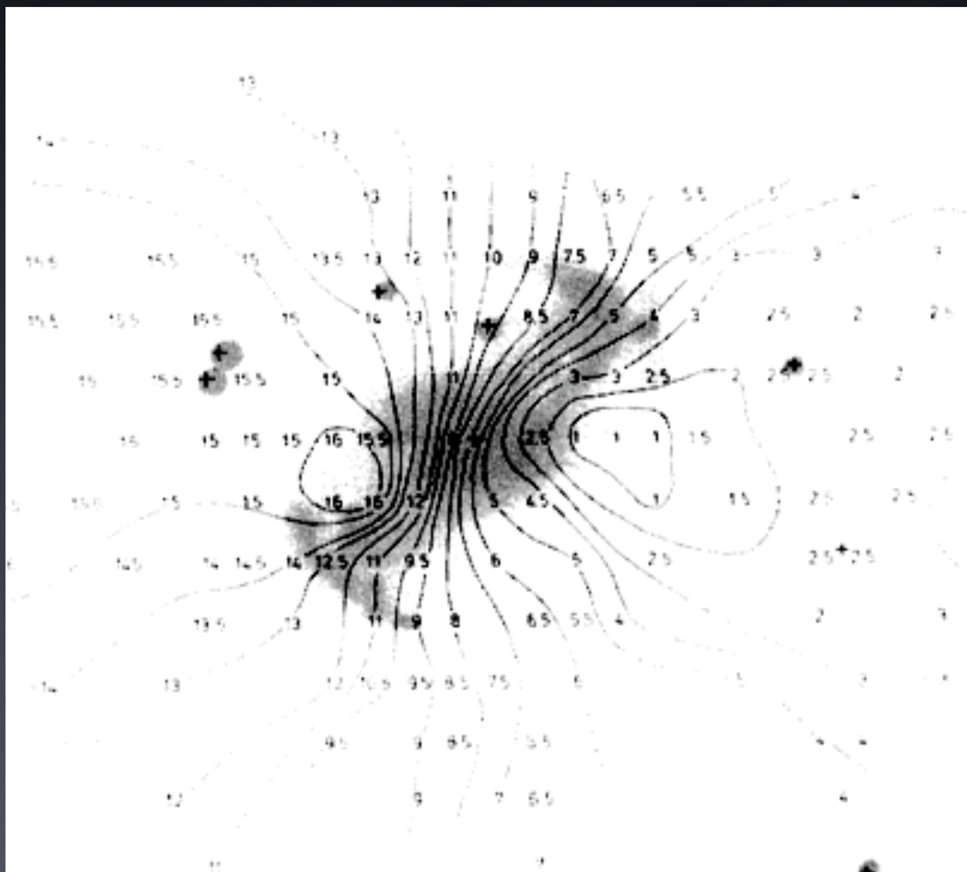
Interpreting HI velocity fields



Bosma (1981)

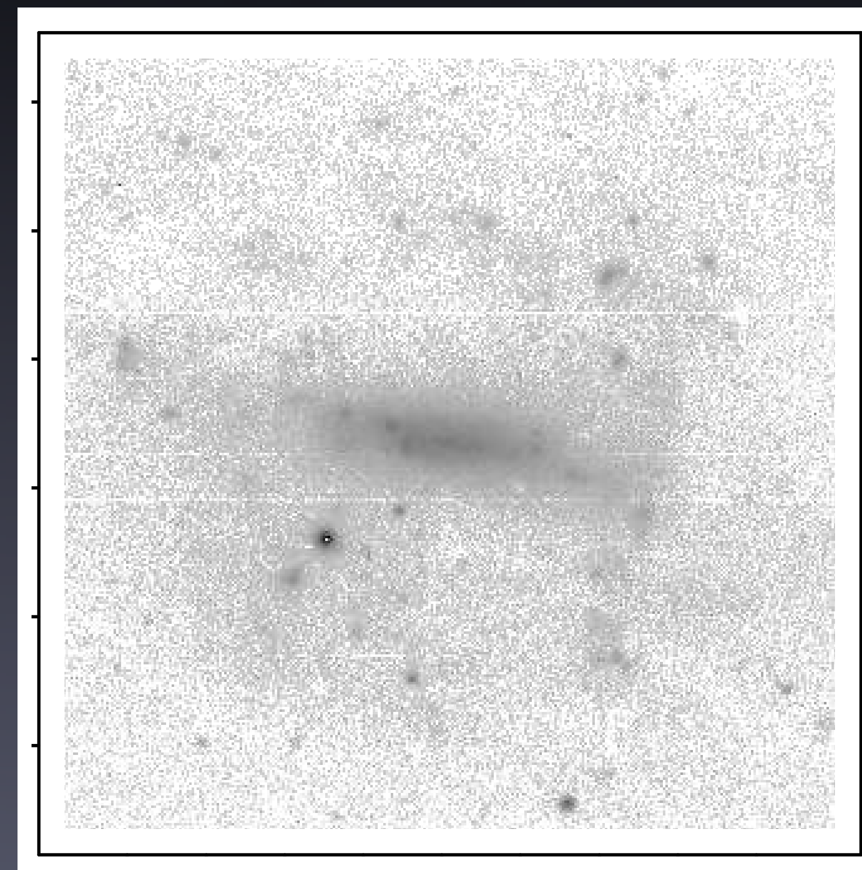
kinematic effect of bars

NGC 5383



Sancisi et al (1979)

UGC 6840



Verheijen & Sancisi (2001)

- streaming motions can mimic solid body rotation
- rotation curves based on velocity fields are meaningless inside bar region

kinematic effect of bars

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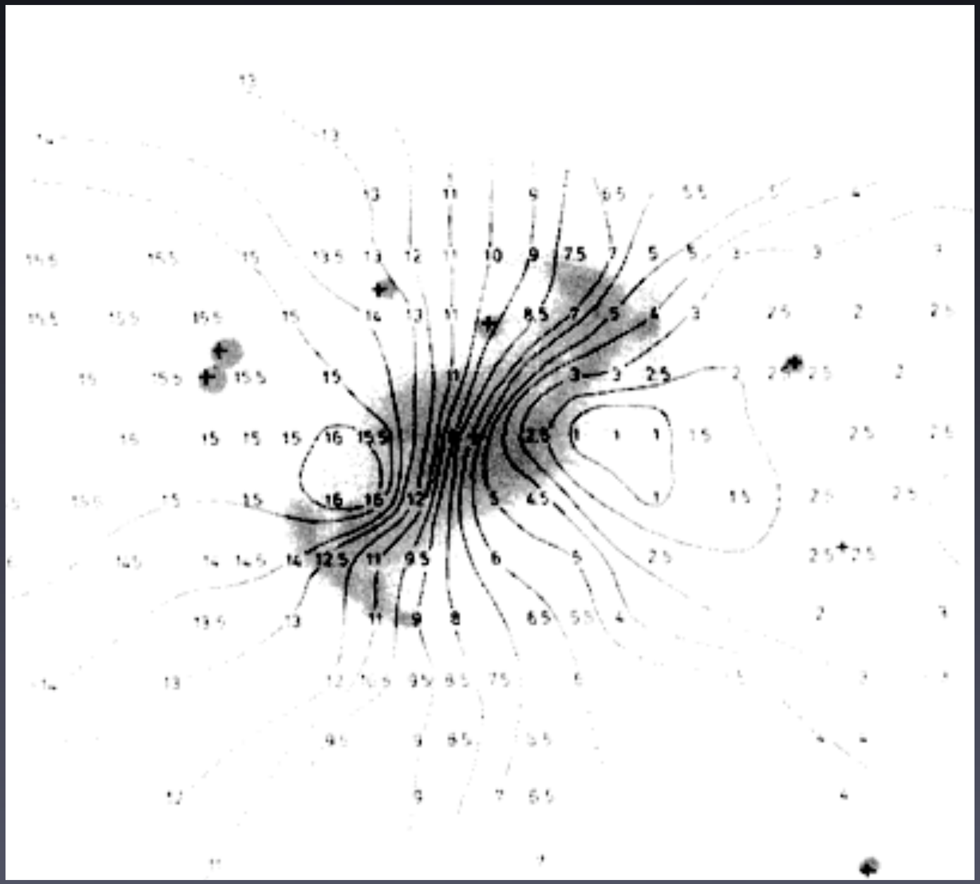

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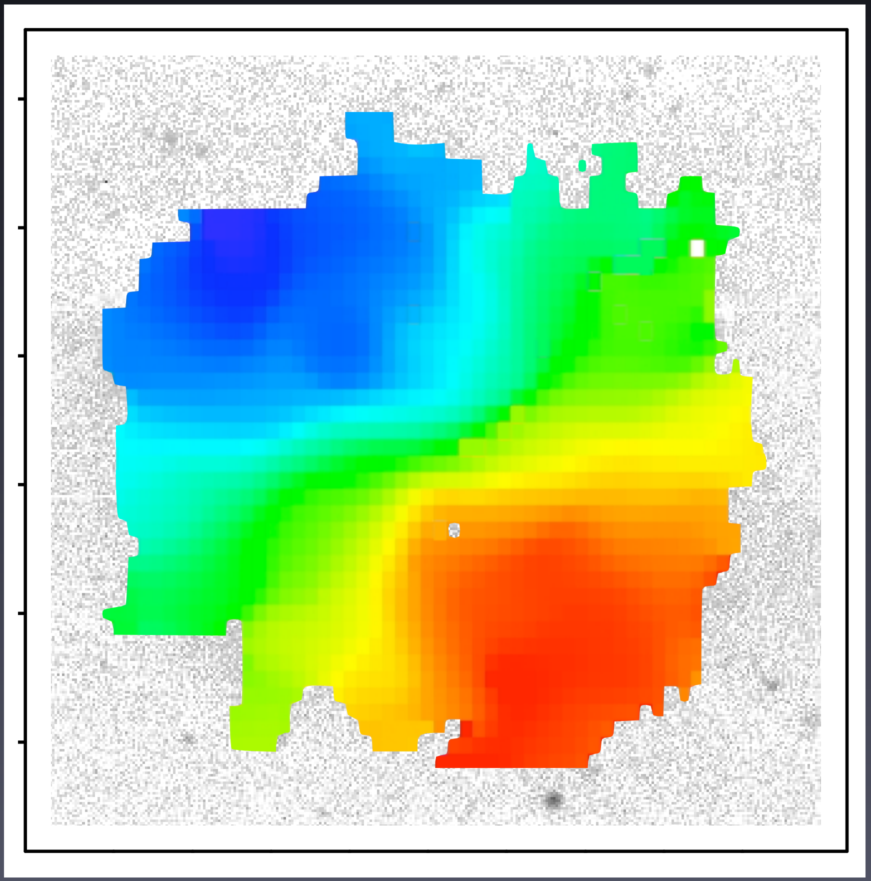

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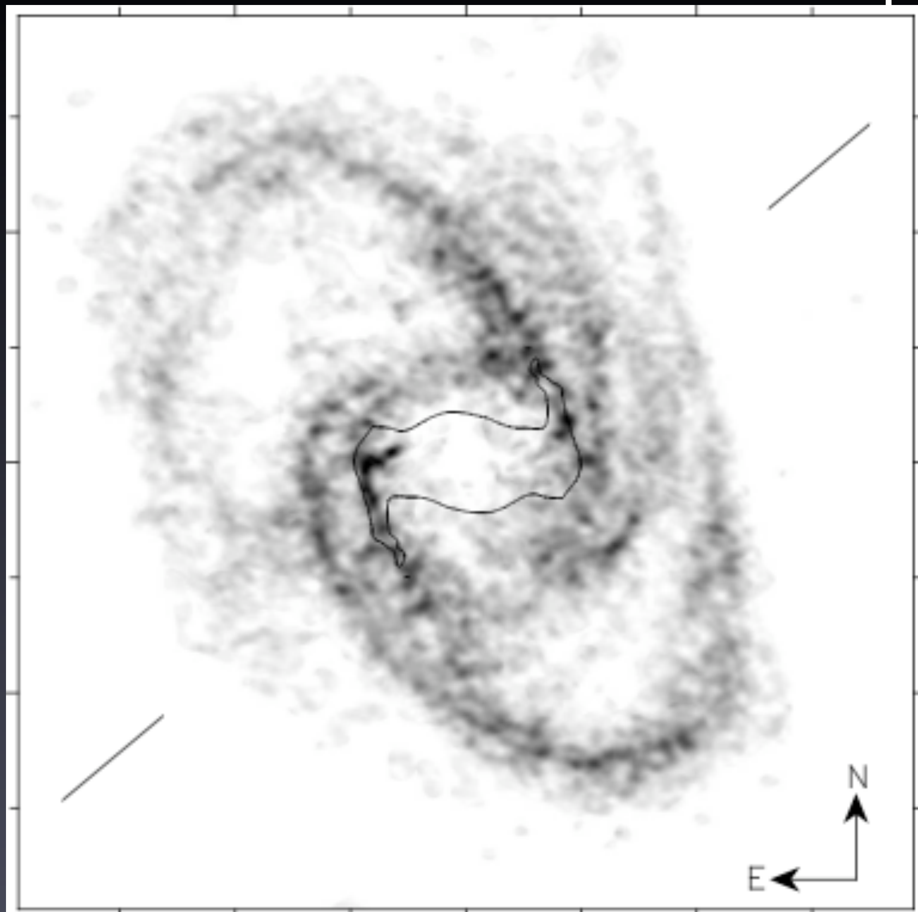
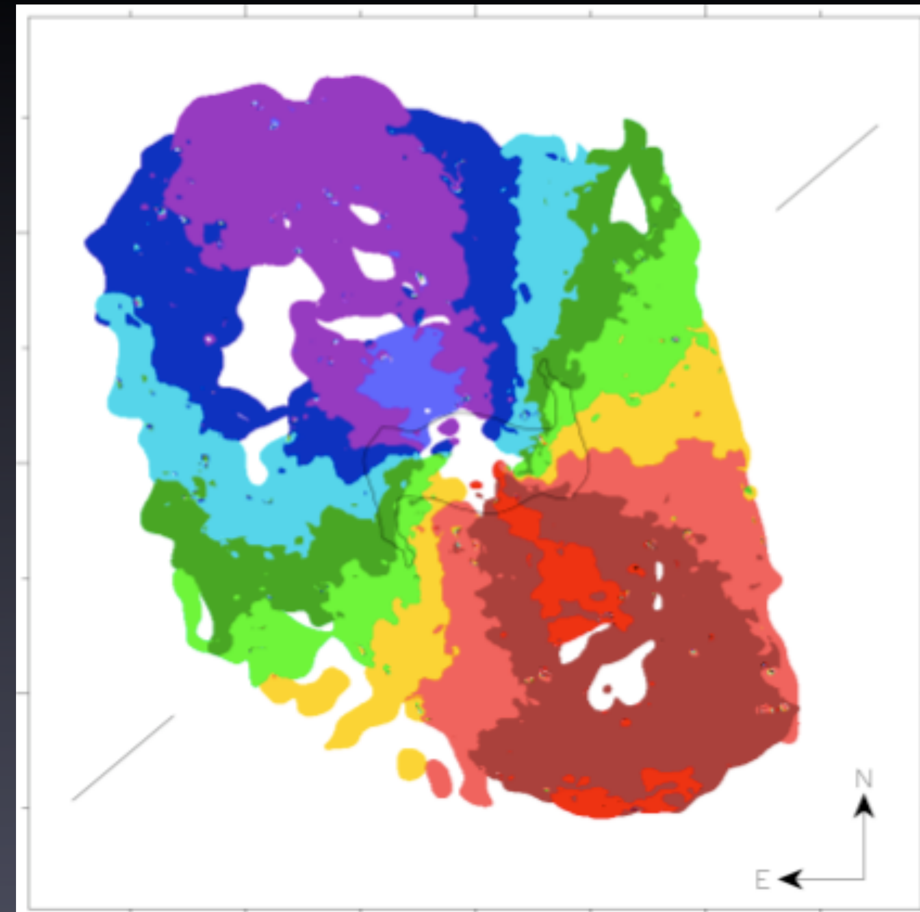
- rotation curves based on velocity fields are meaningless inside bar region

NGC 1365

HI map



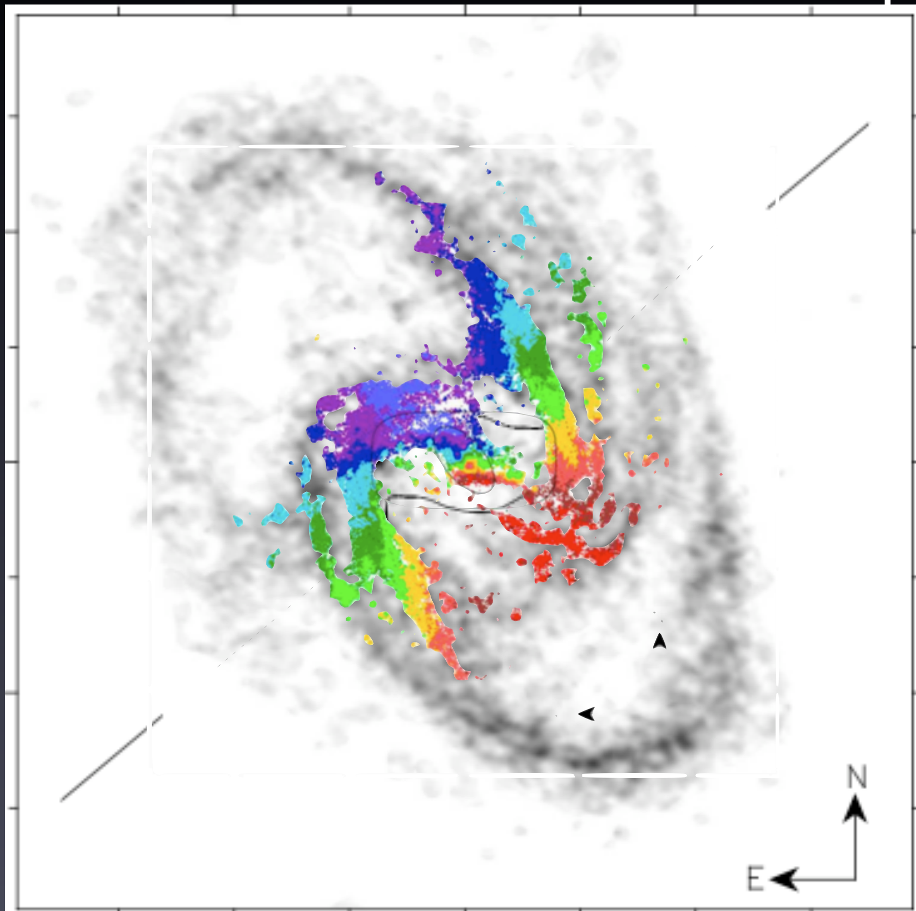
HI velocity field



Zánmar-Sánchez et al (2007)

NGC 1365

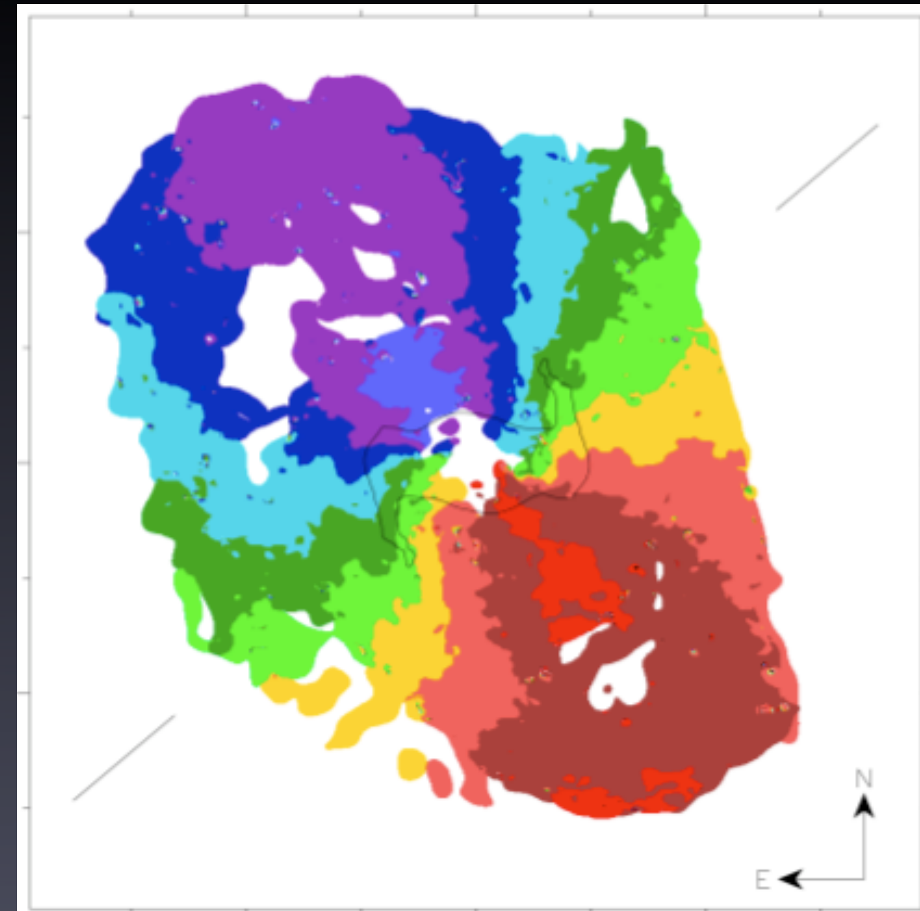
HI map



Zánmar-Sánchez et al (2007)

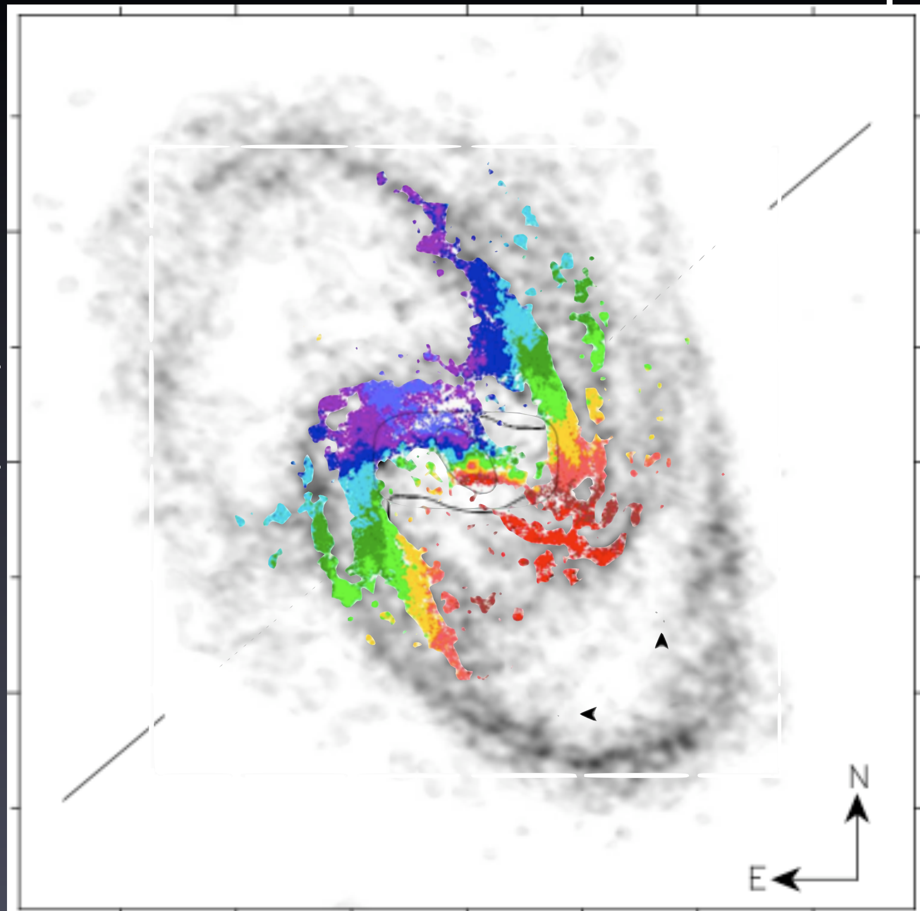
Hα velocity field (Fabry-Perot)

HI velocity field

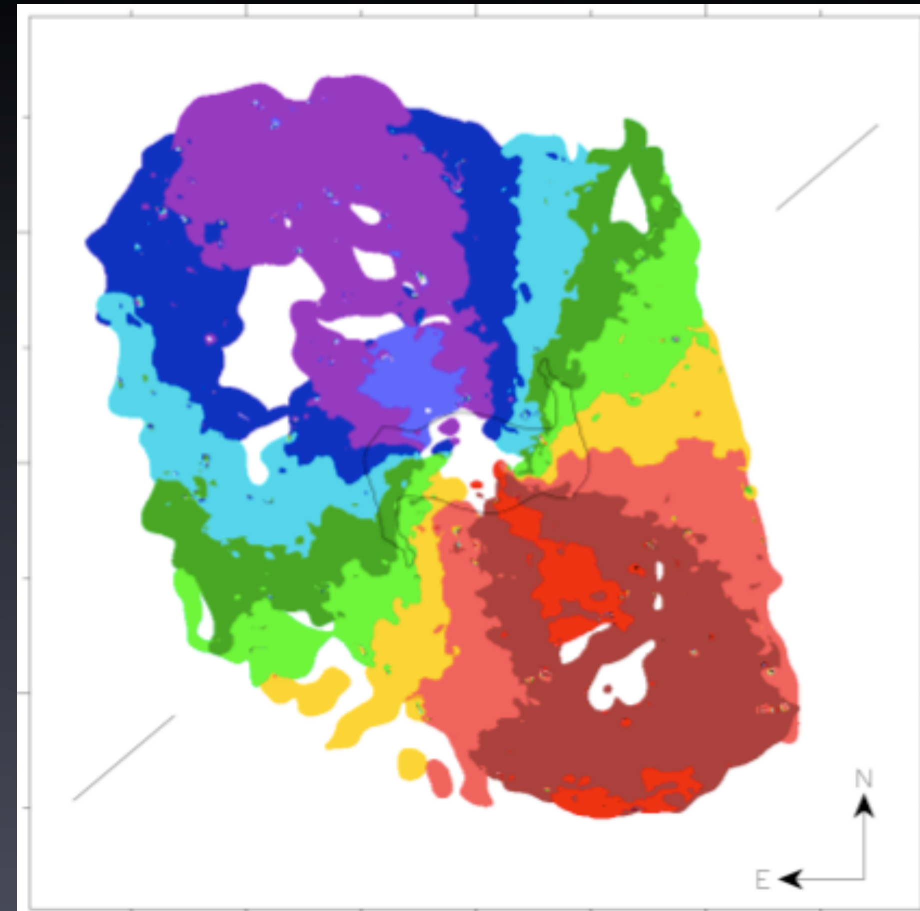


NGC 1365

HI map



HI velocity field



Zánmar-Sánchez et al (2007)

Hα velocity field (Fabry-Perot)

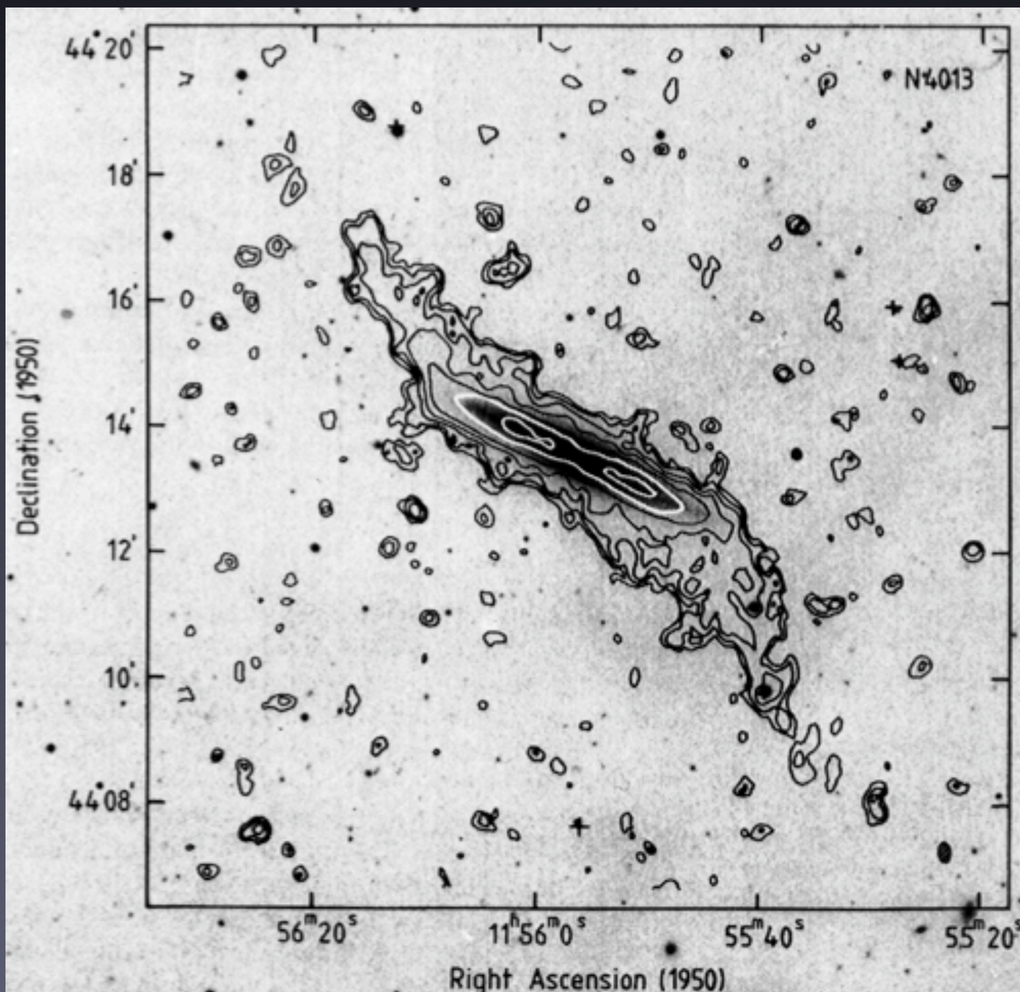
Kinematic modelling yields bar pattern speed, corotation radius and M/L.

In this case: a fast bar, $R_{cr} = 1.2\ R_{bar}$, $M/L_I = 2.0 \pm 1.0$, nearly maximum disk.

signature of warps

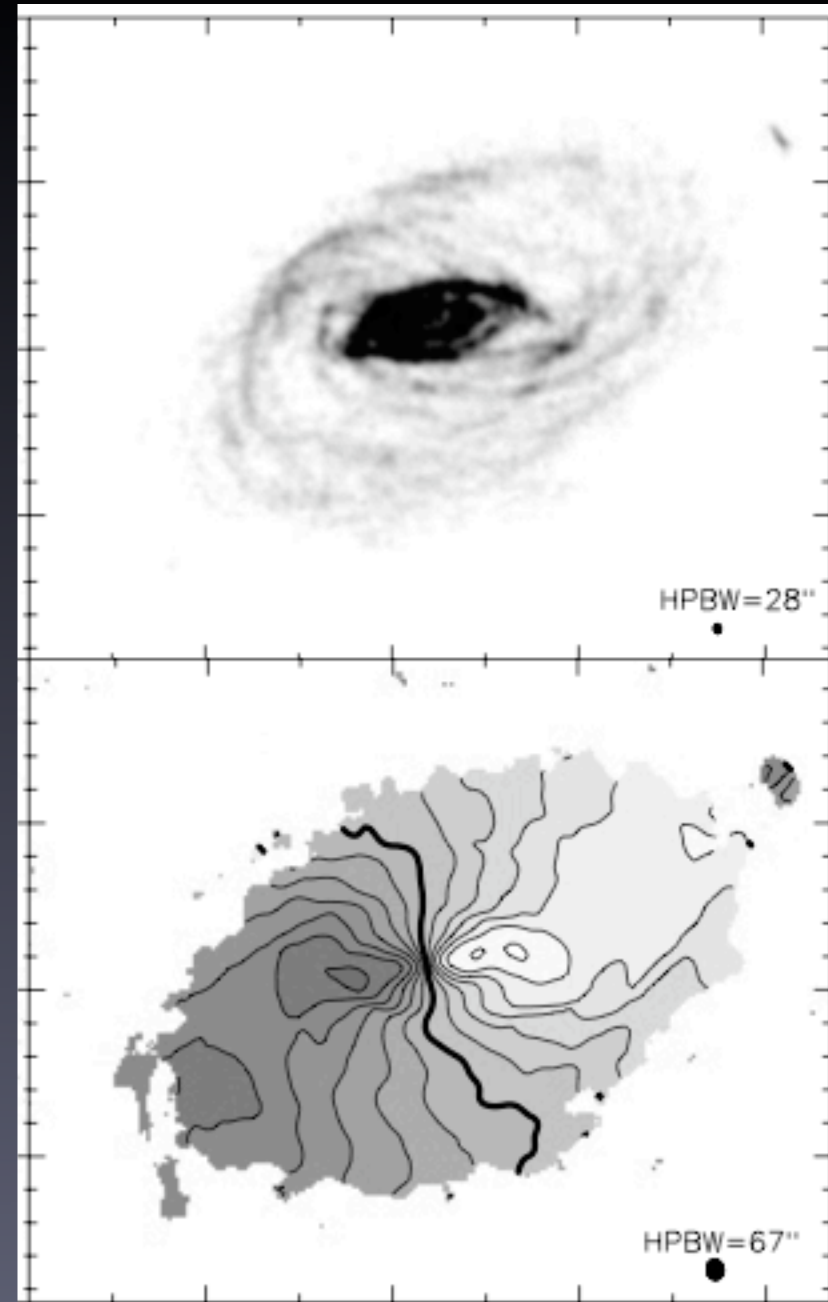
tidally excited? non-coplanar accretion?
lifetime? structural properties of DM halo?

NGC 4013



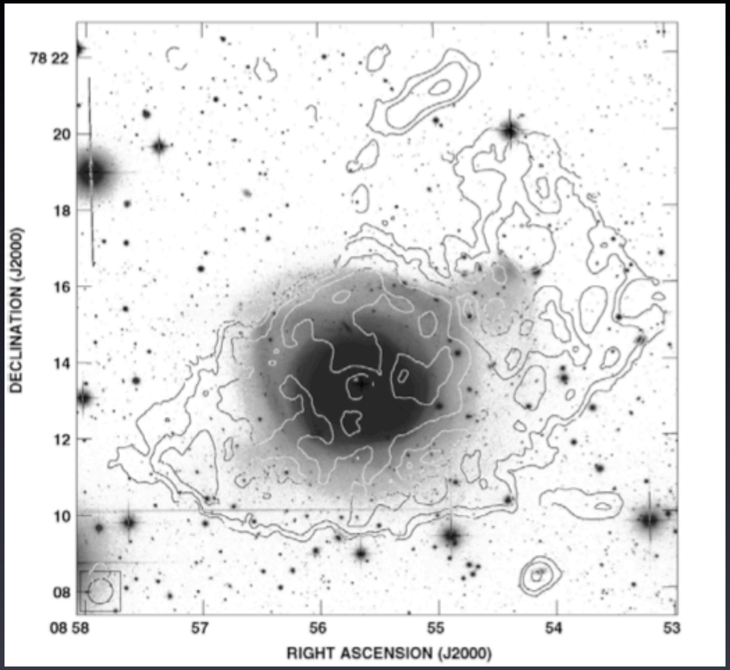
Bottema (1995)

NGC 5055

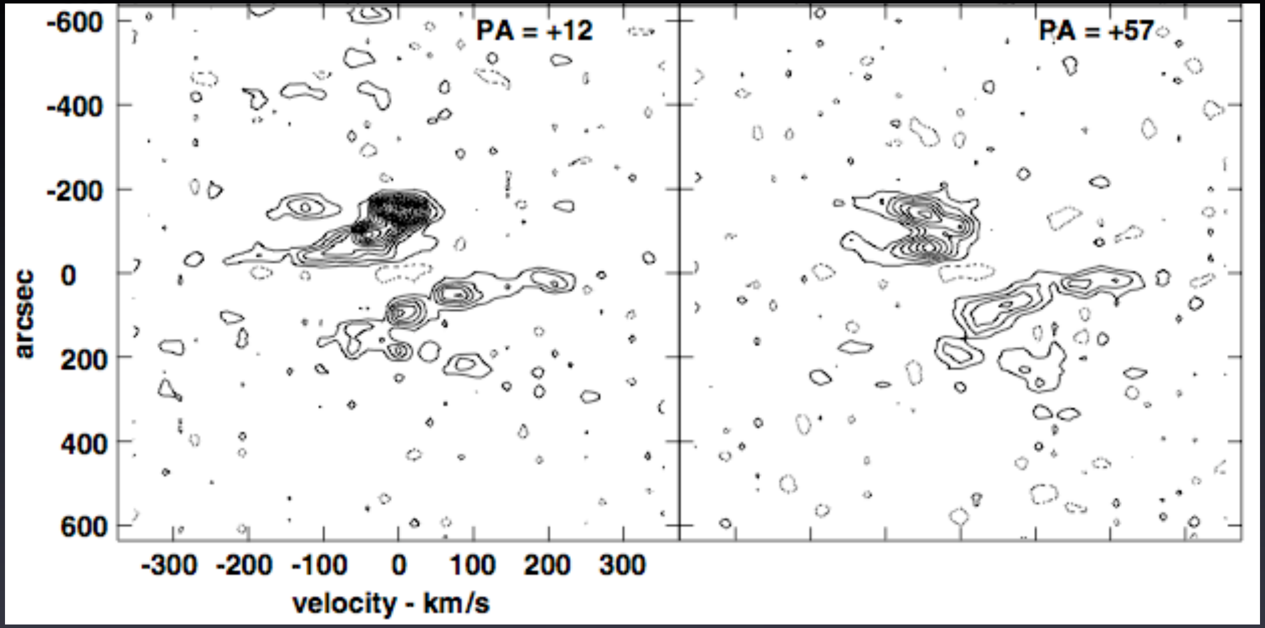


Bataglia et al (2006)

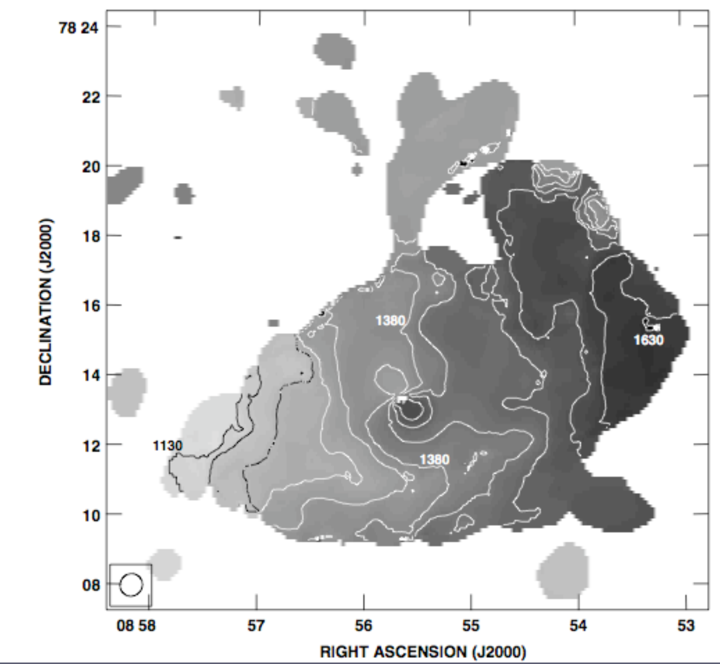
NGC 2656



position-velocity diagrams

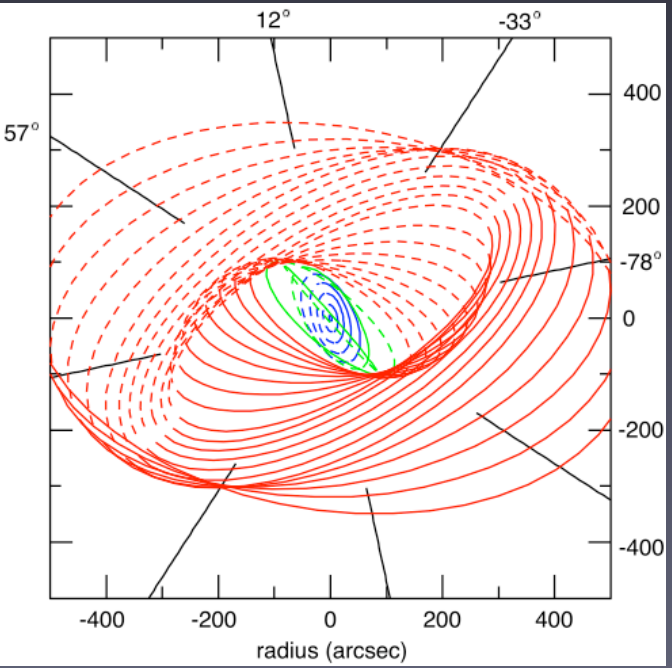


Sparke et al (2008)



Line-of-sight may cross gas disk multiple times: velocity field may be meaningless!

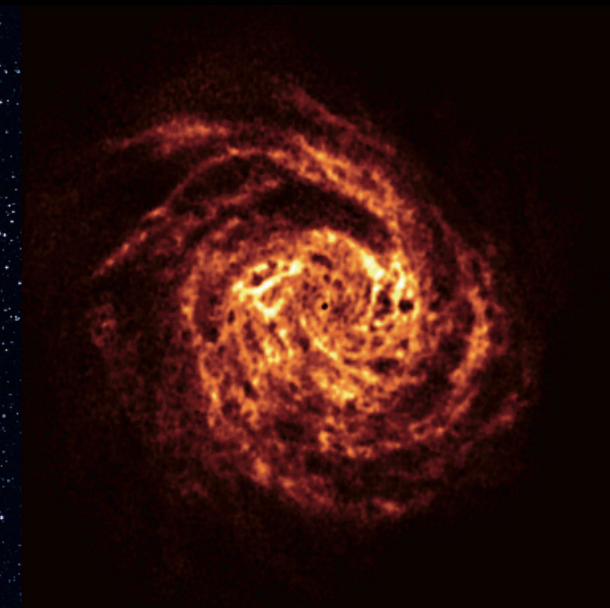
Full 3D modelling required to account for double profiles and velocity crowding.



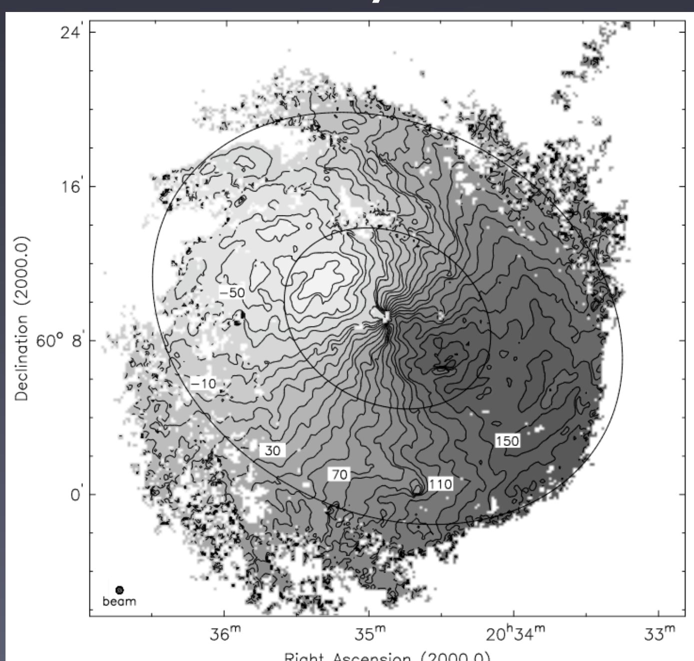
streaming motions

Up to 80 km/s in
outer plane of disk!

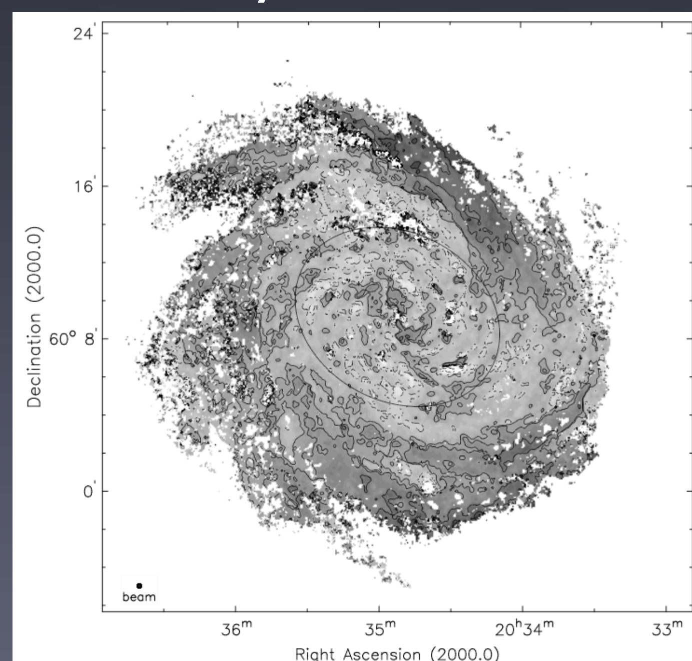
Boomsma (2007)

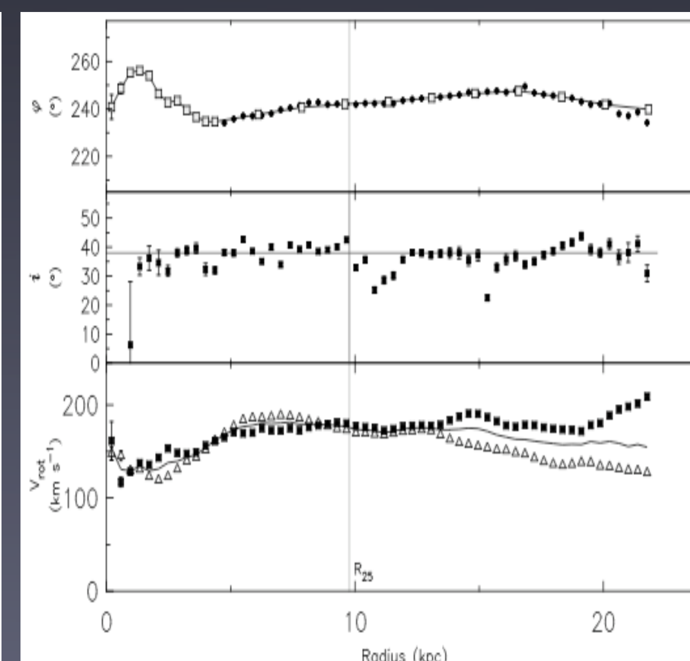


velocity field



velocity field residual

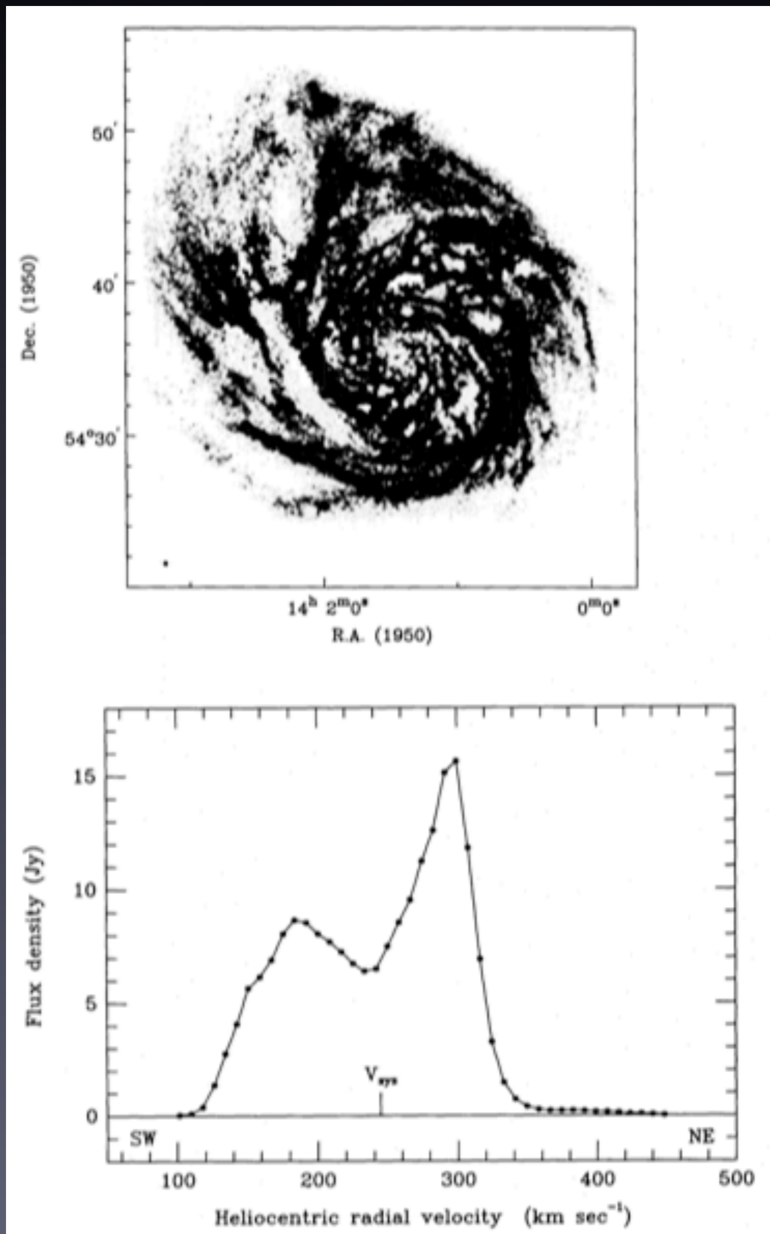




wiggles in rotation curve

lopsided galaxies

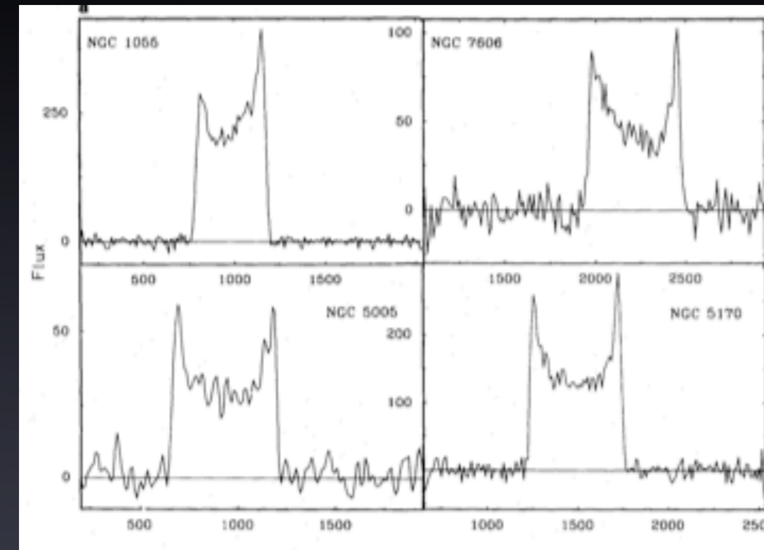
M101



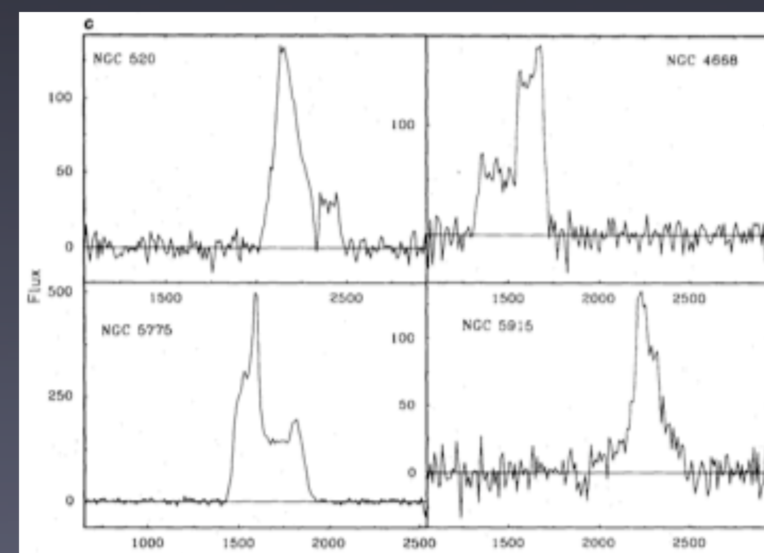
single-dish profiles

asymmetric :

symmetric :



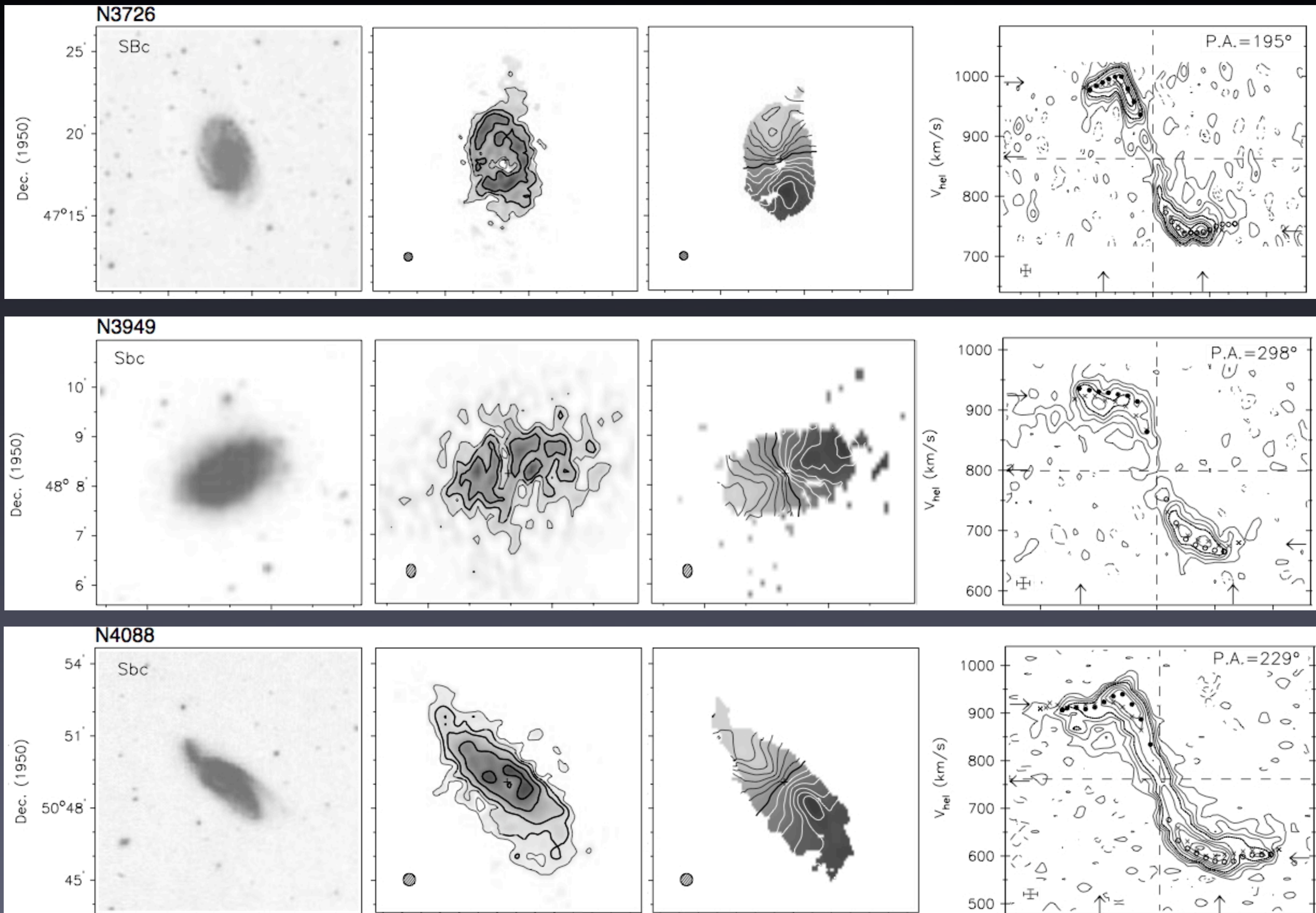
peculiar :



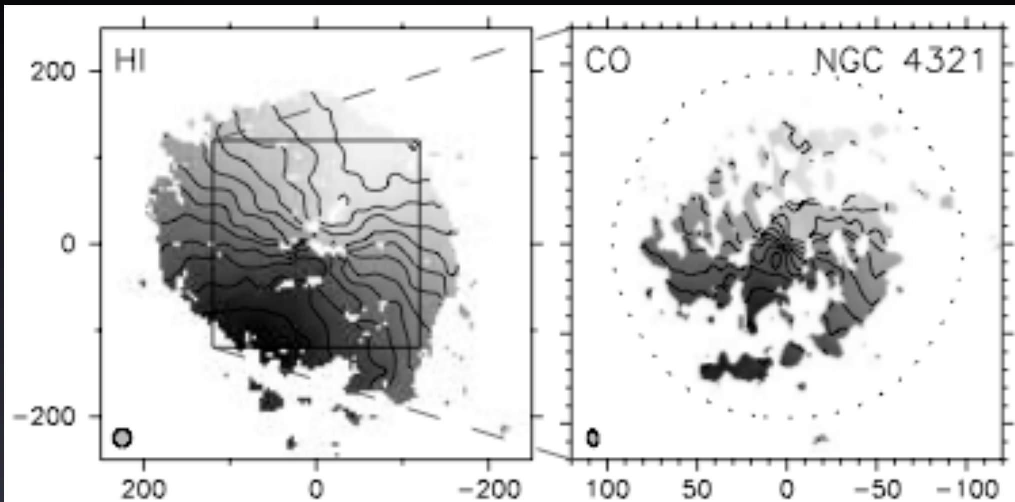
Richter & Sancisi (1994)

>50% is asymmetric

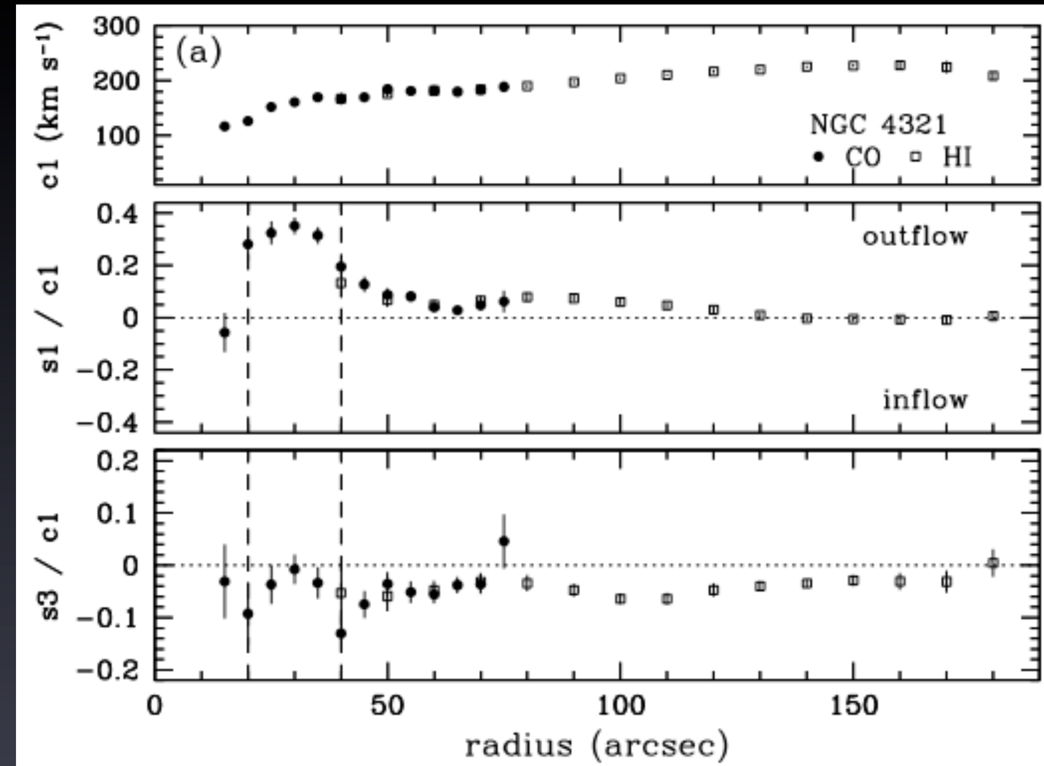
kinematic lopsidedness



inflow/outflow



Wong, Blitz & Bosma (2004)



harmonic expansion of VF:

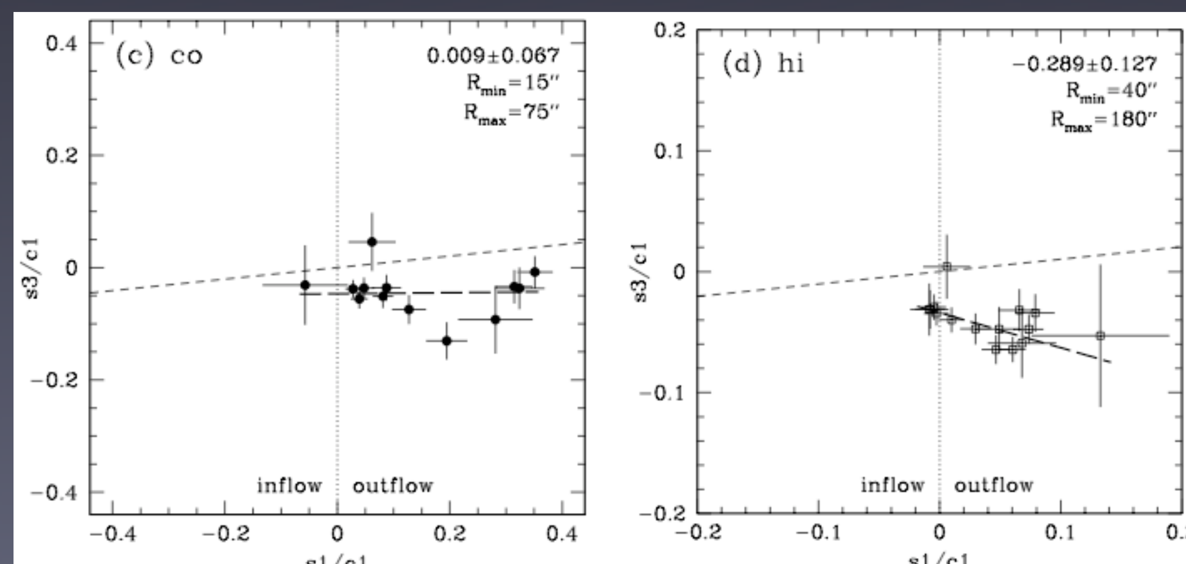
$$V_{\rm los} = c_0 + \sum_{j=1}^{n} \left[c_j \cos\left(j\psi\right) + s_j \sin\left(j\psi\right) \right]$$

(based on Schoenmakers et al 1997)

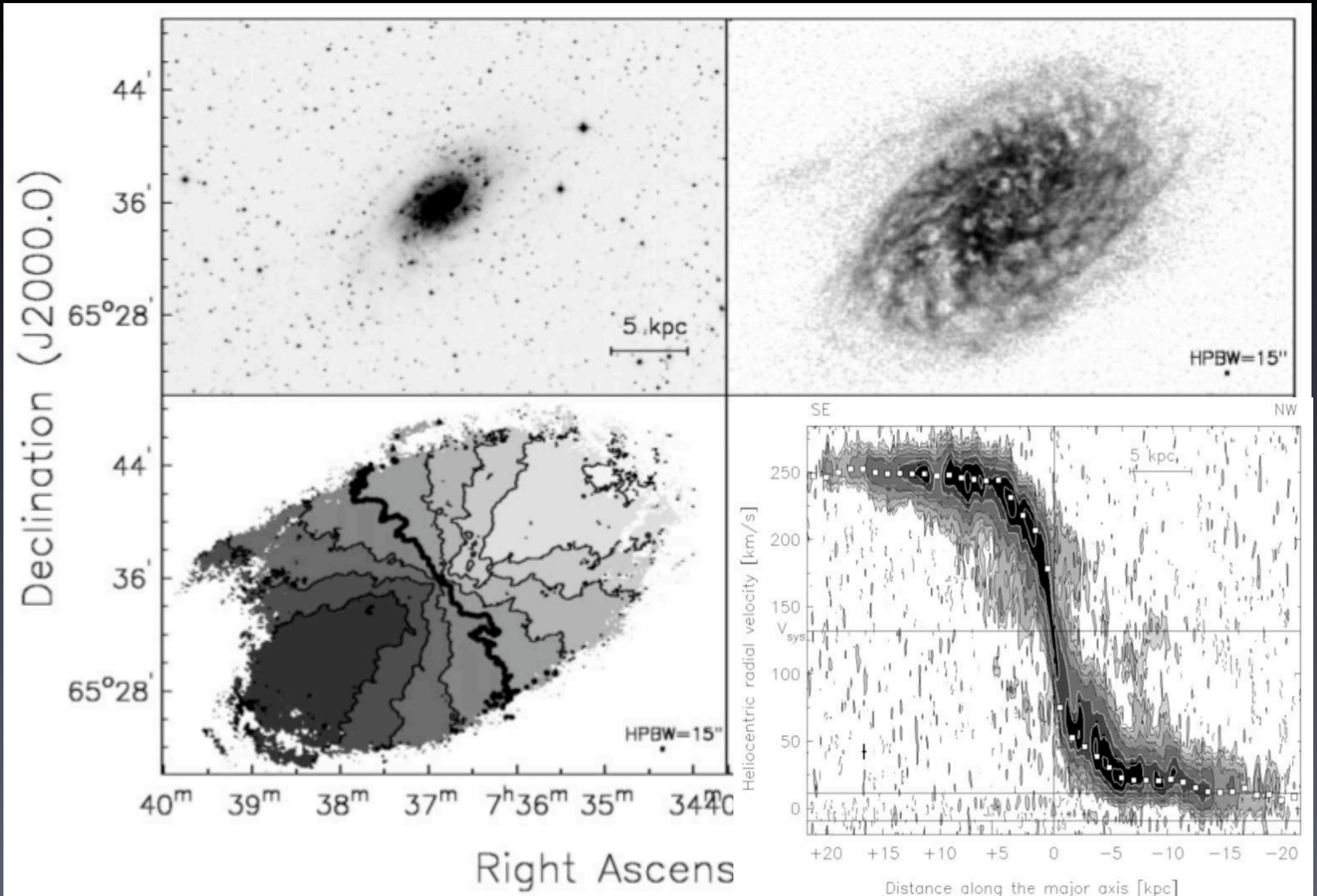
$s1/c1 \approx 0.35$, $ds3/ds1 \approx -0.05$

→ 60 km/s radial outflow

but: elliptical streaming
due to strong bar?

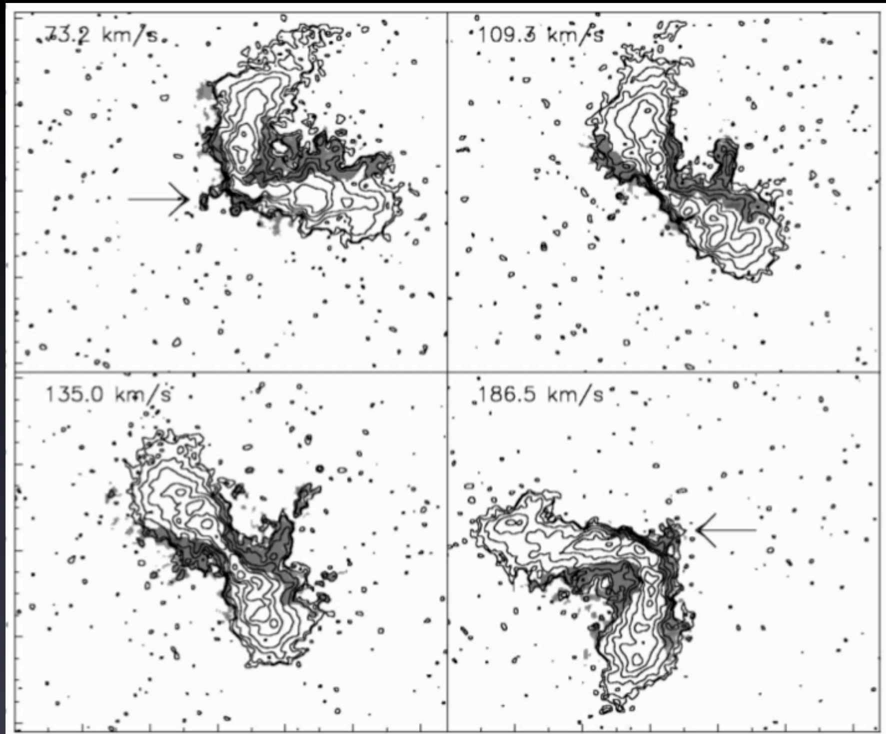


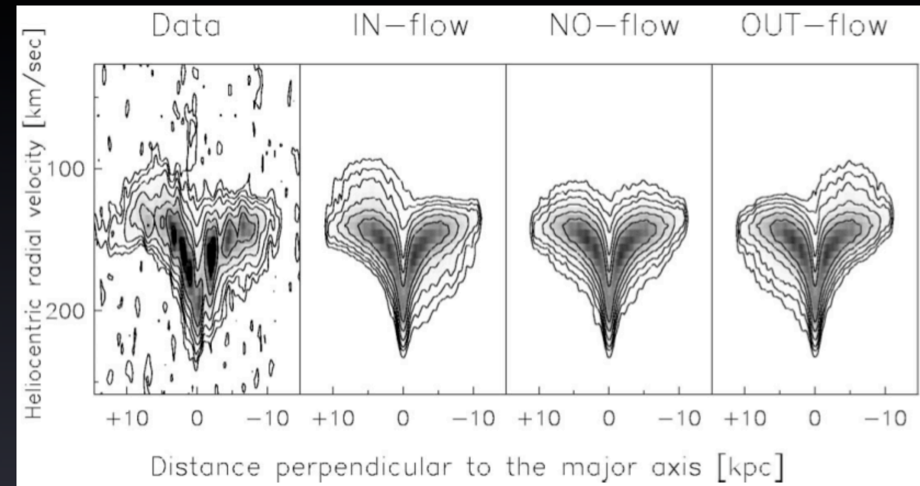
Anomalous gas in NGC 2403



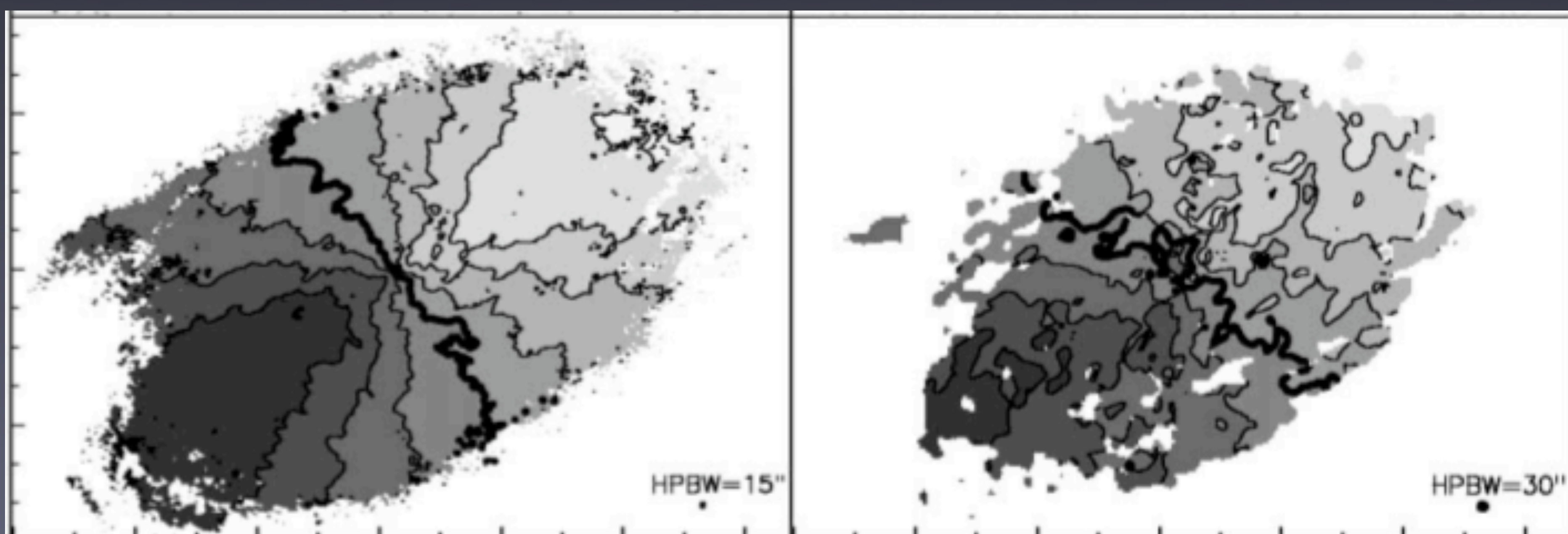
Fraternali et al (2001)

3D modelling



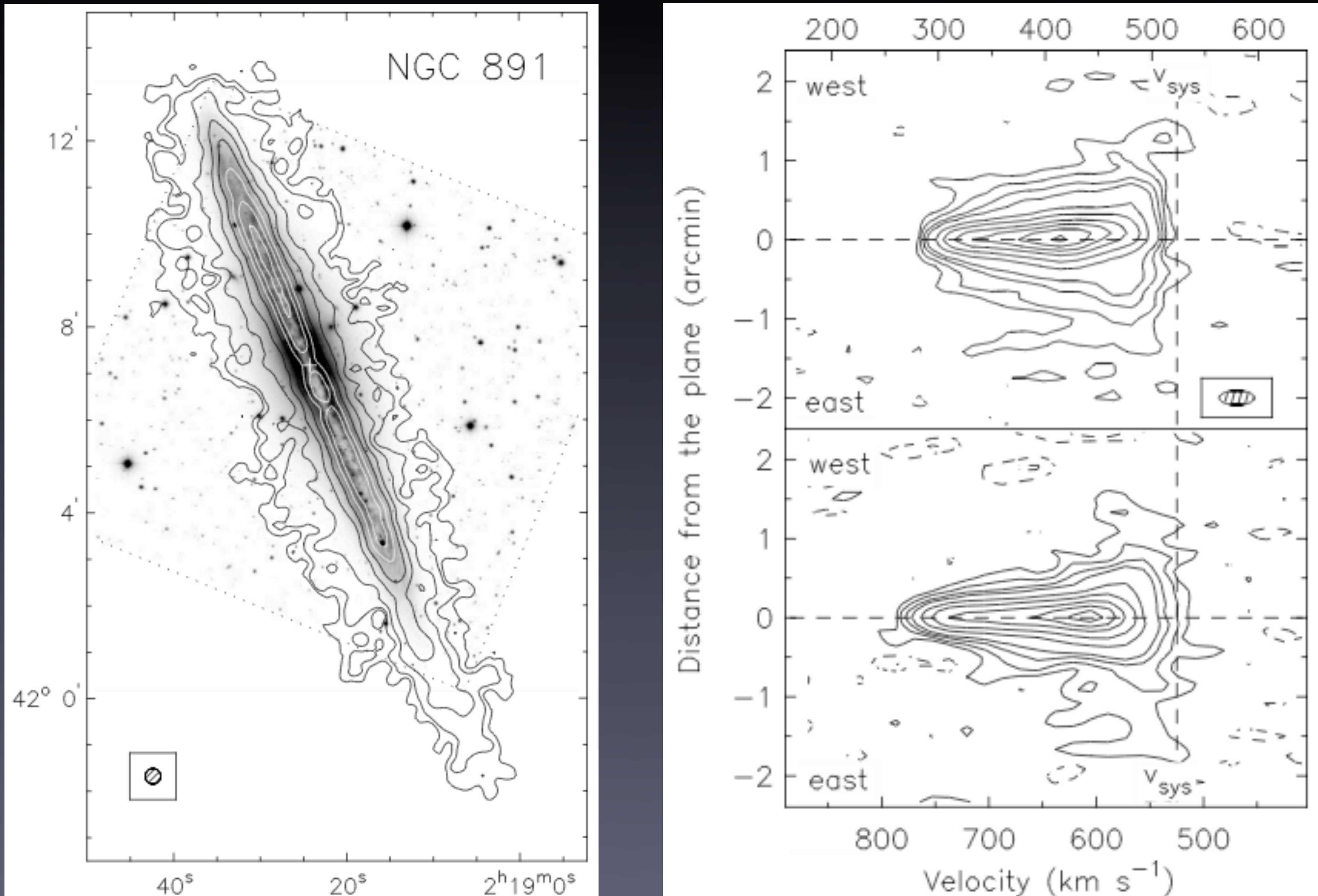


- 20-50 km/s slower rotation
- 10-20 km/s radial inflow



Fraternali et al (2001)

A thick HI disk: inclined, warped, flared or slowly rotating?



Swaters et al (1997)

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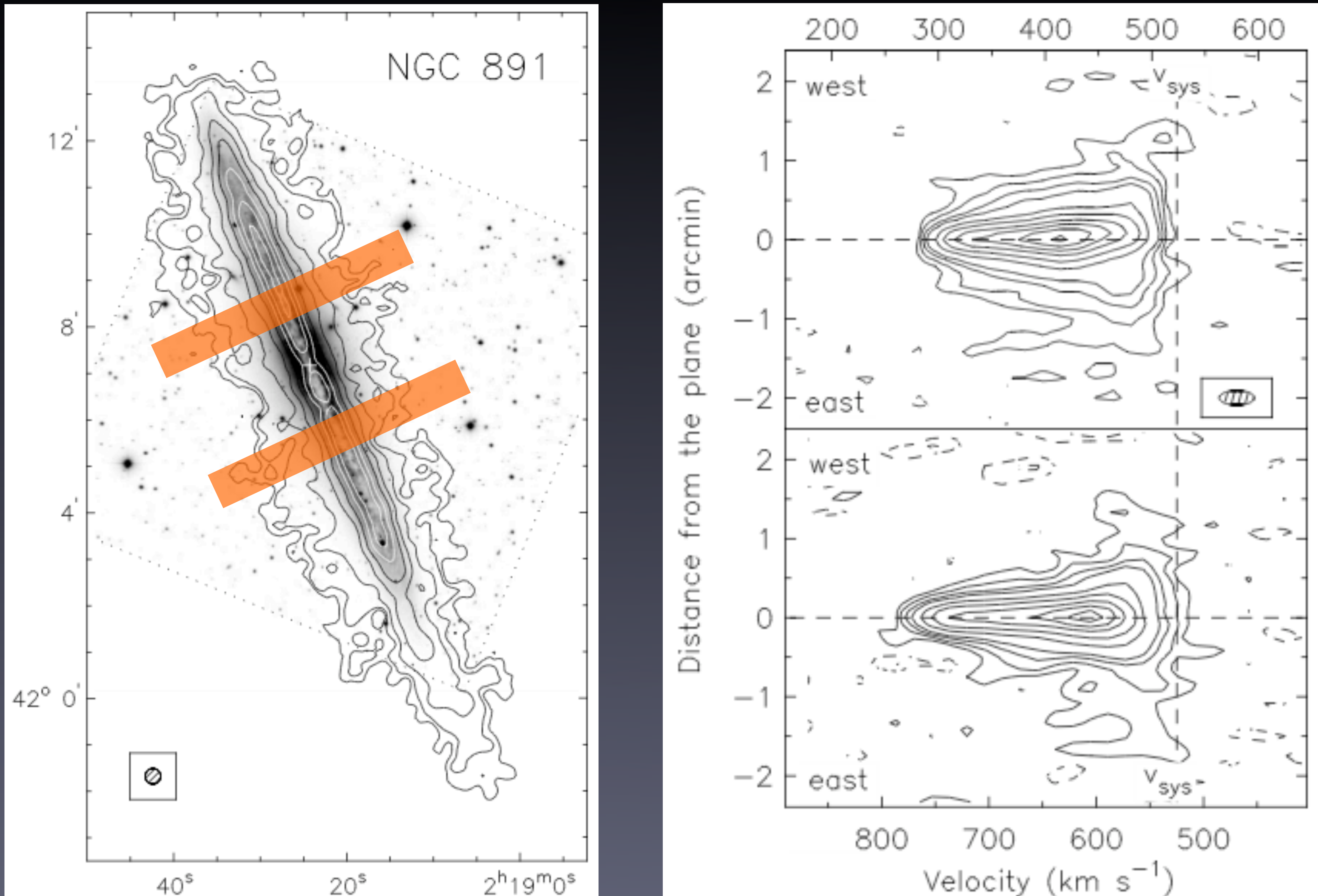

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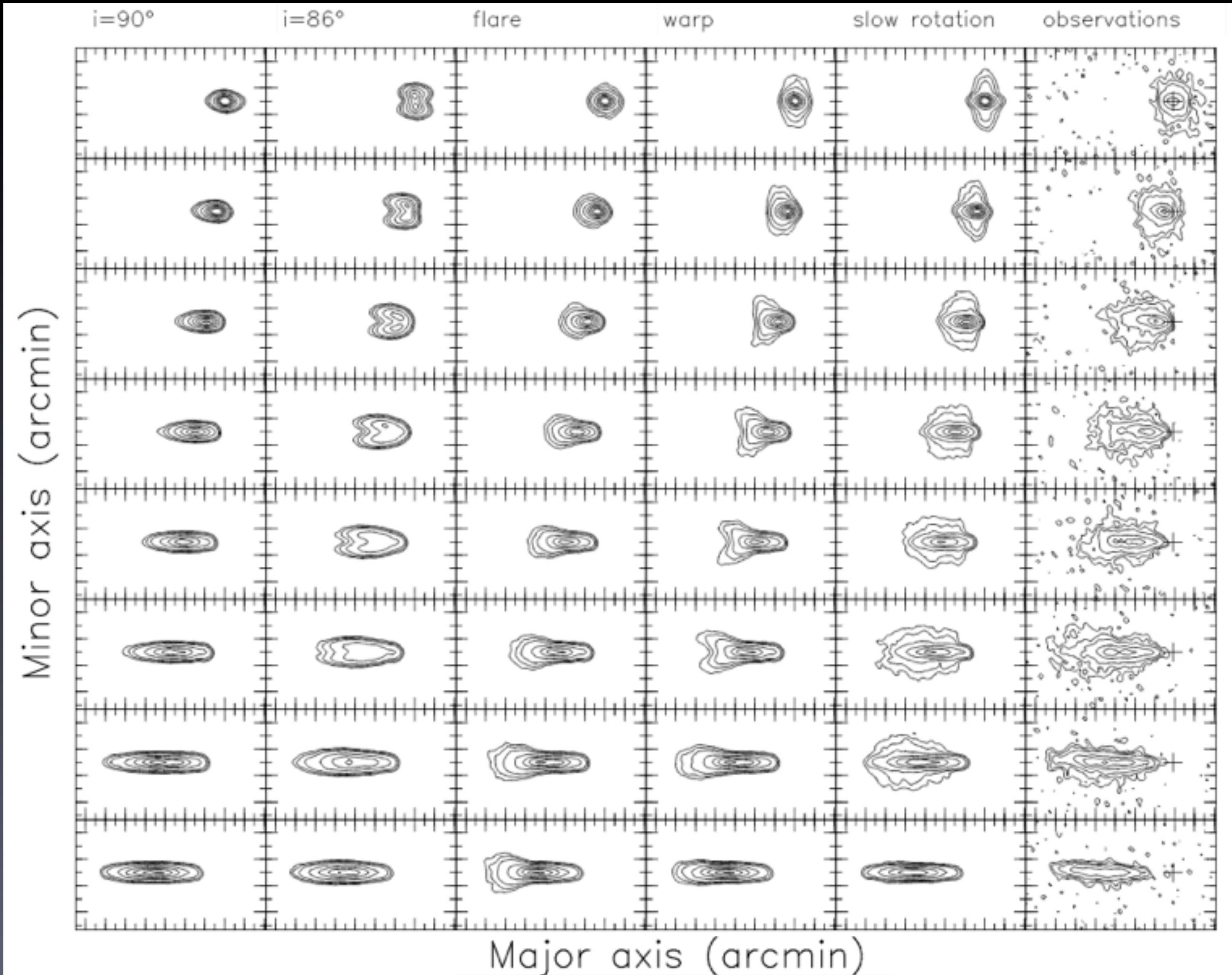

Swaters et al (1997)

Slow rotation is the better model.

limitations of HI 21cm radio data

- relatively poor spatial resolutions
- often no HI in central regions
- limited to nearby universe
- only gas kinematics
- expensive to obtain with few telescopes
- steep learning curve (think in Fourier space)

Integral Field Unit spectroscopy

Advantages:

- multiple emission lines at once
- access to stellar kinematics
- probing all scales,
  from seeing/spaxel/diffraction limit up to FoV

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But:

- small field-of-view compared to radio telescopes
- limited spectral resolution
- limited filling factor may require dithering
- night-time & good weather required
- cumbersome data handling (eg Fabry-Perot)

no DM halo cusps in LSB galaxies?

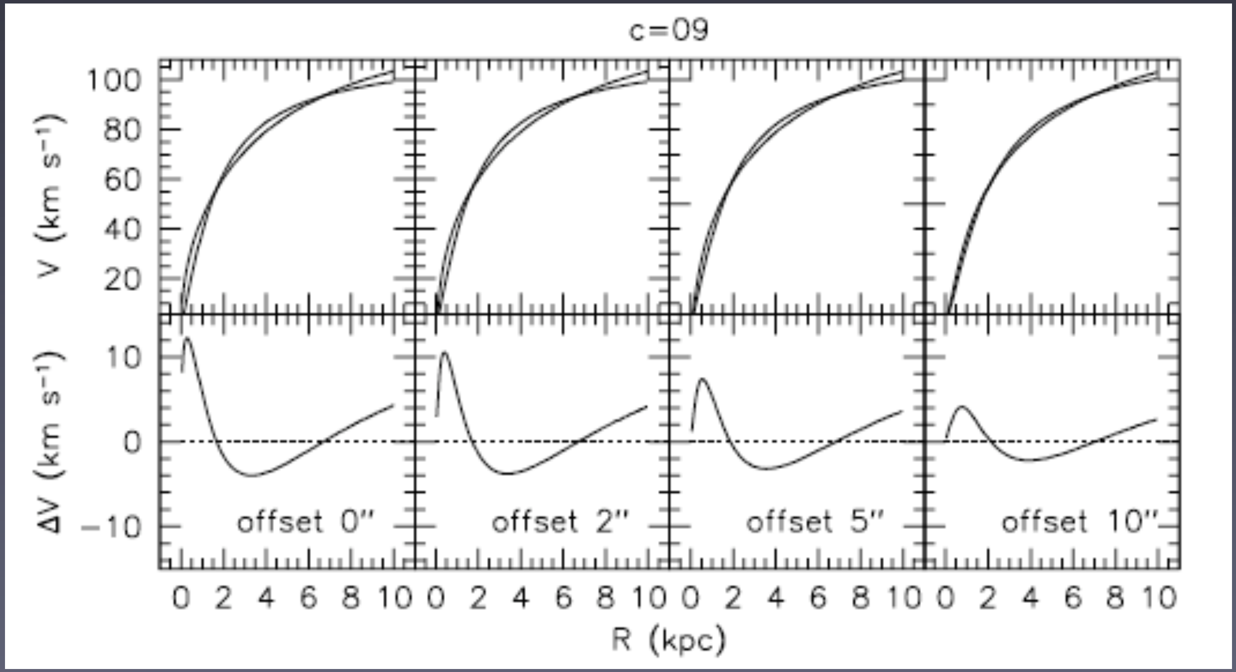
LSB galaxies are assumed to be dark matter dominated at all radii but a central cusp in the rotation curve is not observed.

arguments brought forward include:

- beam-smearing
- long-slit misalignment
- bars and non-axisymmetry
- 'baryon physics'
- ...

cusps are seemingly impossible to detect

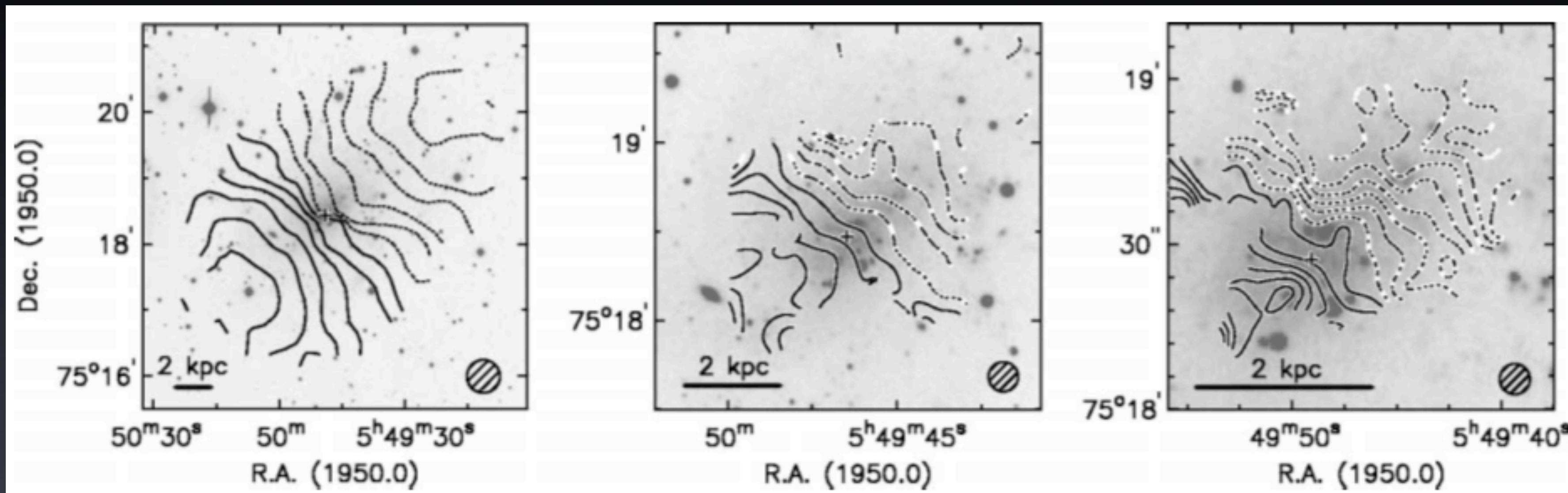
de Blok & Bosma (2002)



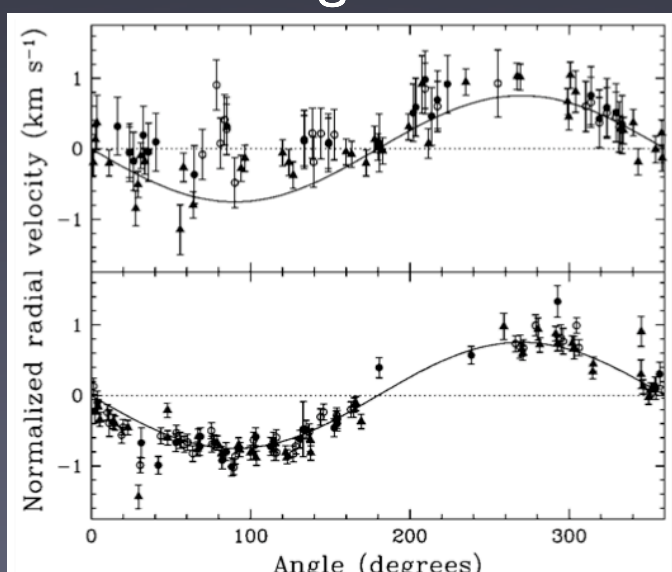
DDO 39 - Quest for the Holy Cusp

HI WSRT | Hα (10”) | Hα (5.5”)

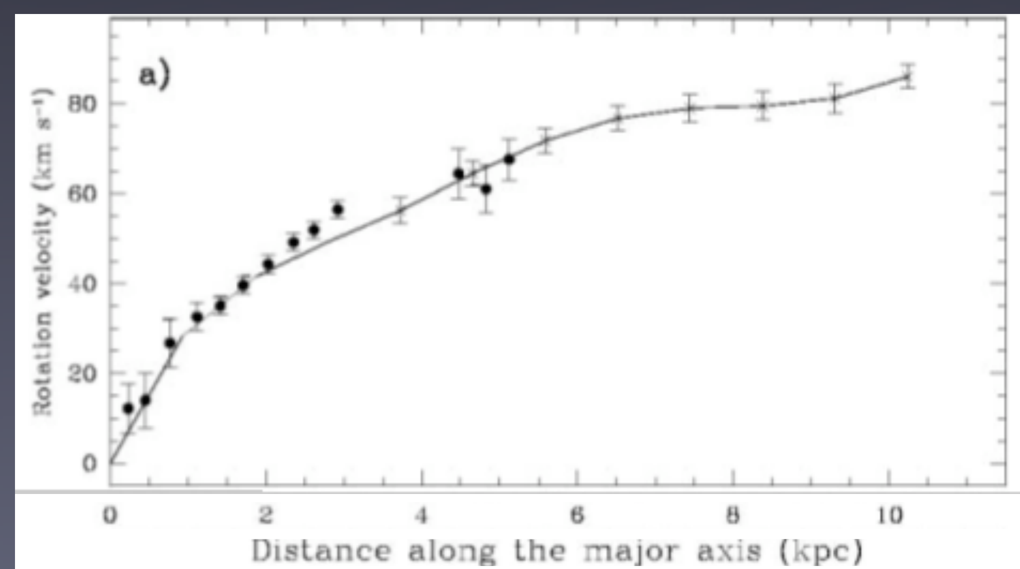
Swaters et al (2003)



tilted-rings fit



combined Hα + HI rotation curve



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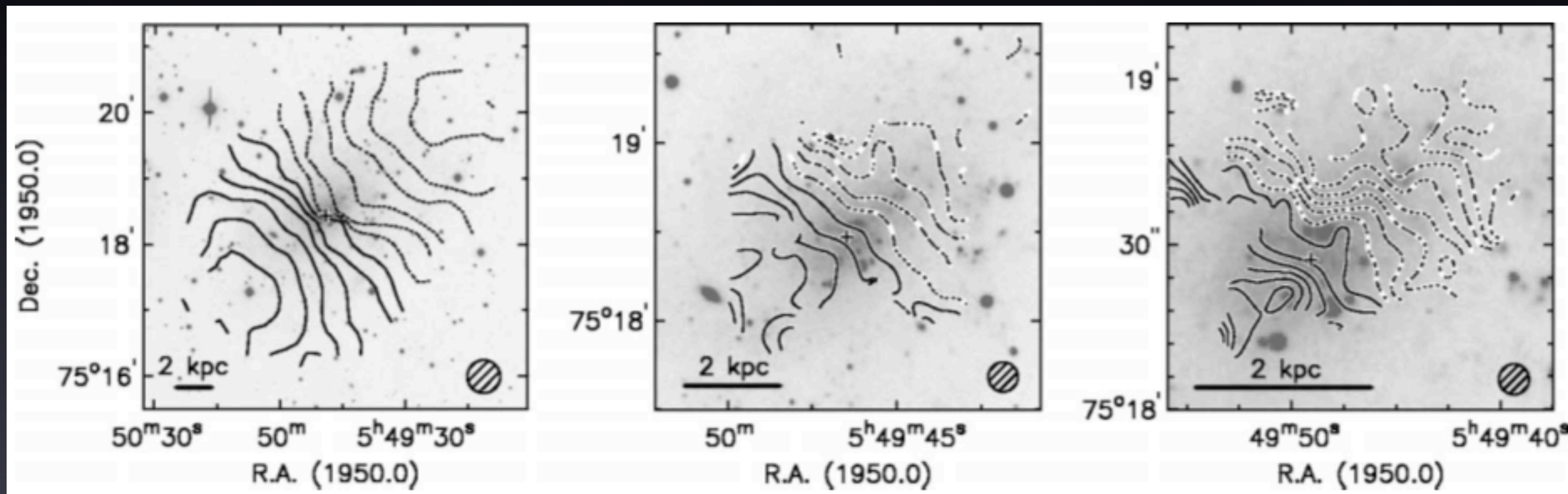

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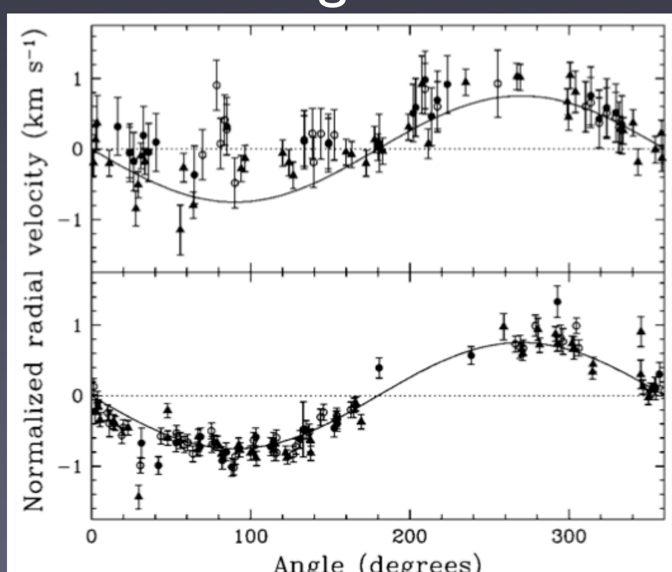

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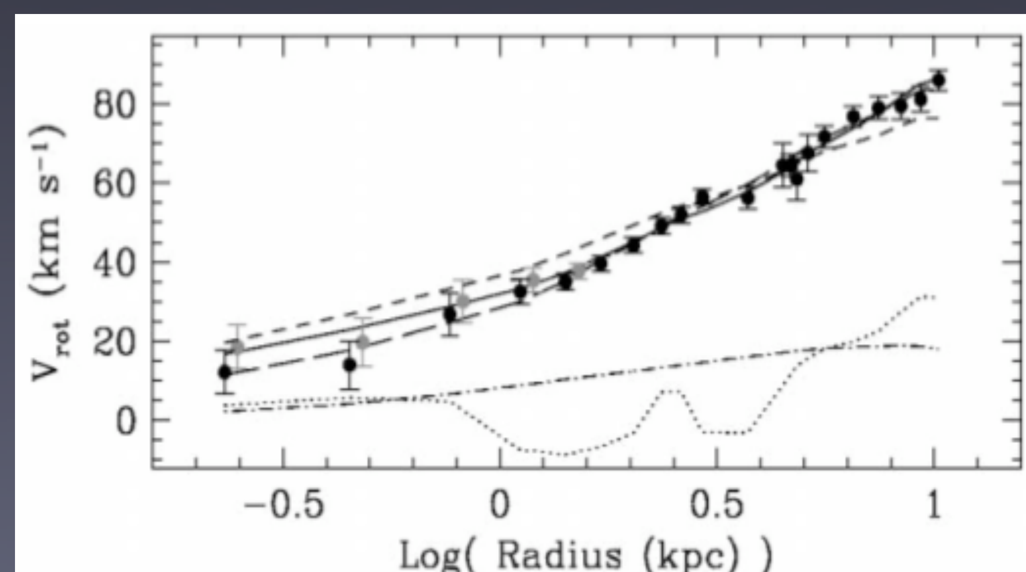
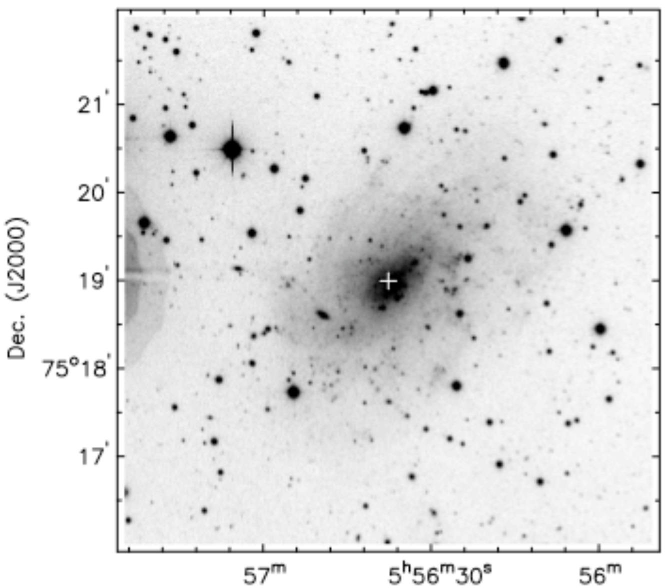
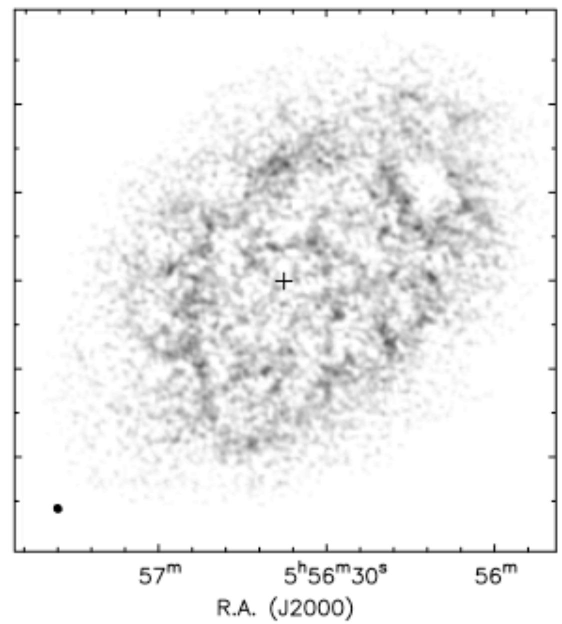


improved VLA-B HI observations

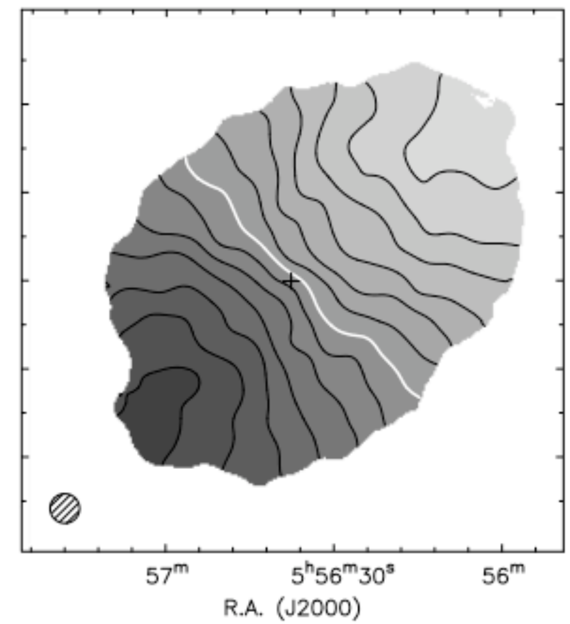
R-band image



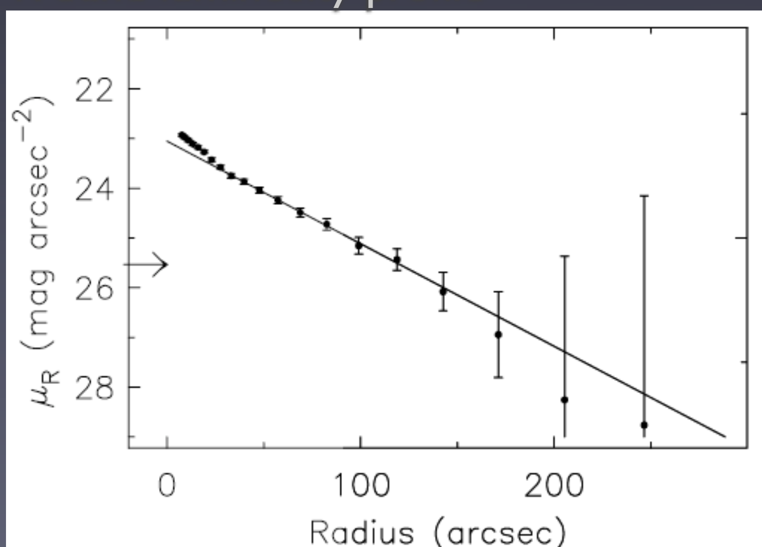
HI density map



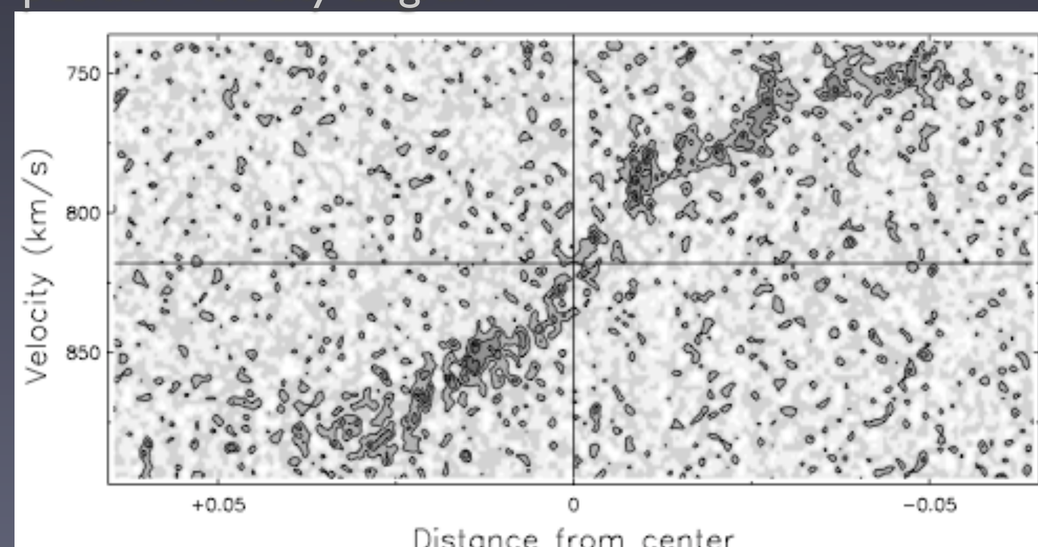
HI velocity field



R-band luminosity profile



position-velocity diagram



Fiber bundles for the Disk-Mass Survey

Bershady Verheijen Westfall Martinsson Swaters Andersen

goal : obtain a direct kinematic measure of mass surface density
of the stellar disks via vertical stellar velocity dispersion σ_z

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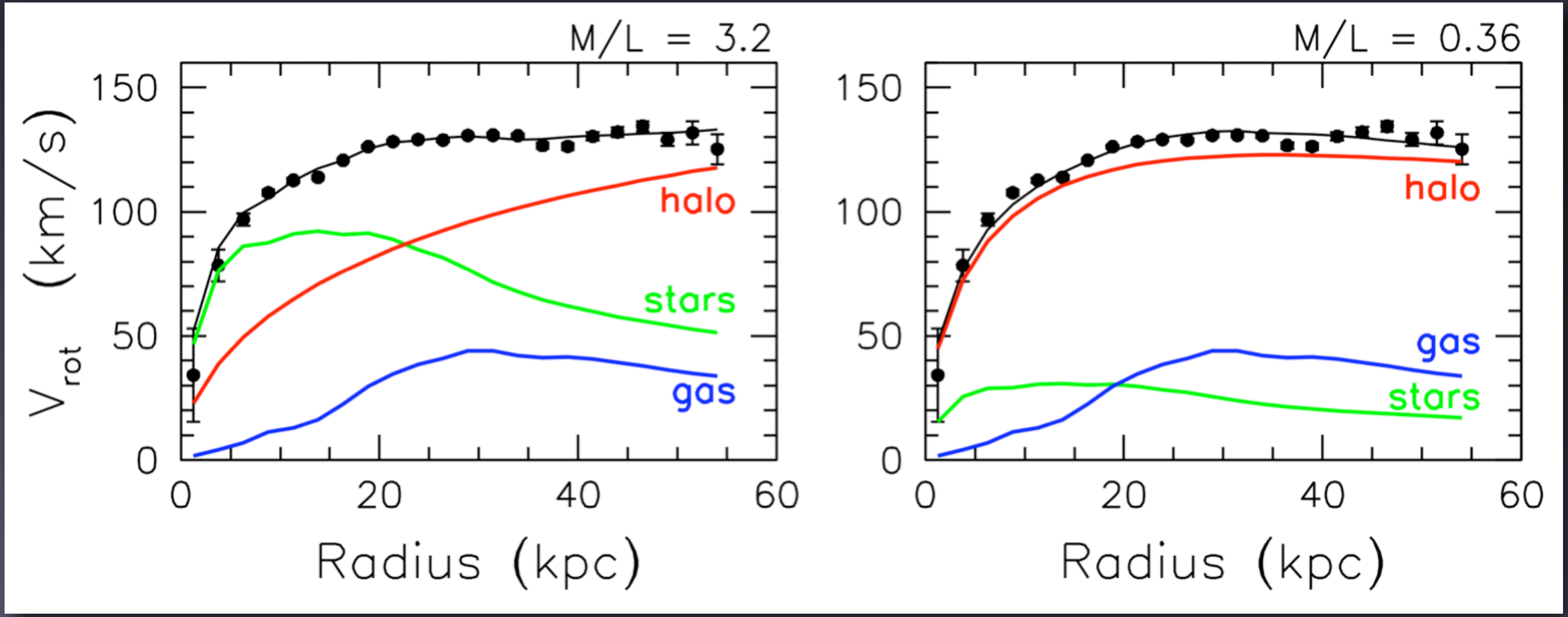
maximum disk maximum halo



UGC 128 (LSB) - Hernquist halo

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→ R≈10.000 spectroscopy of ~40 nearly face-on (incl=25°-35°) spirals at 3 disk scale lengths, or $\mu(B)=24.5$ mag/arcsec^2.

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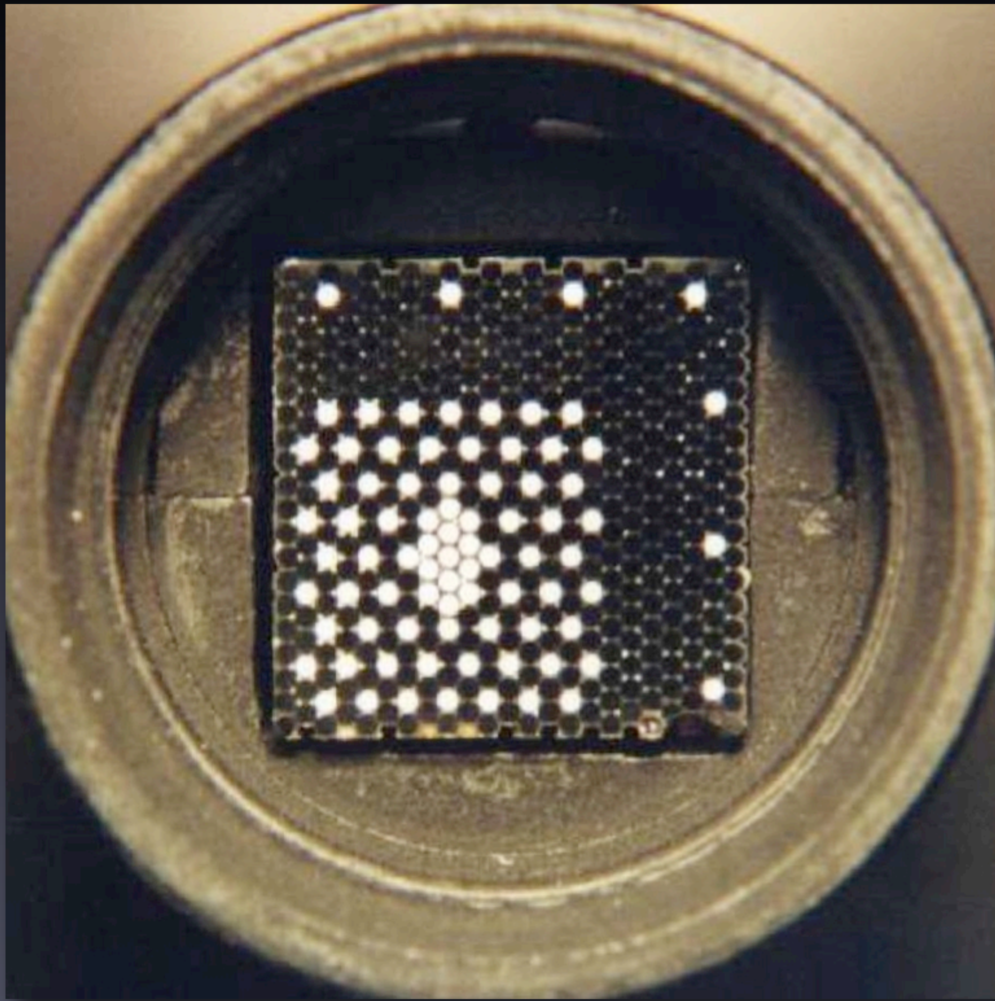
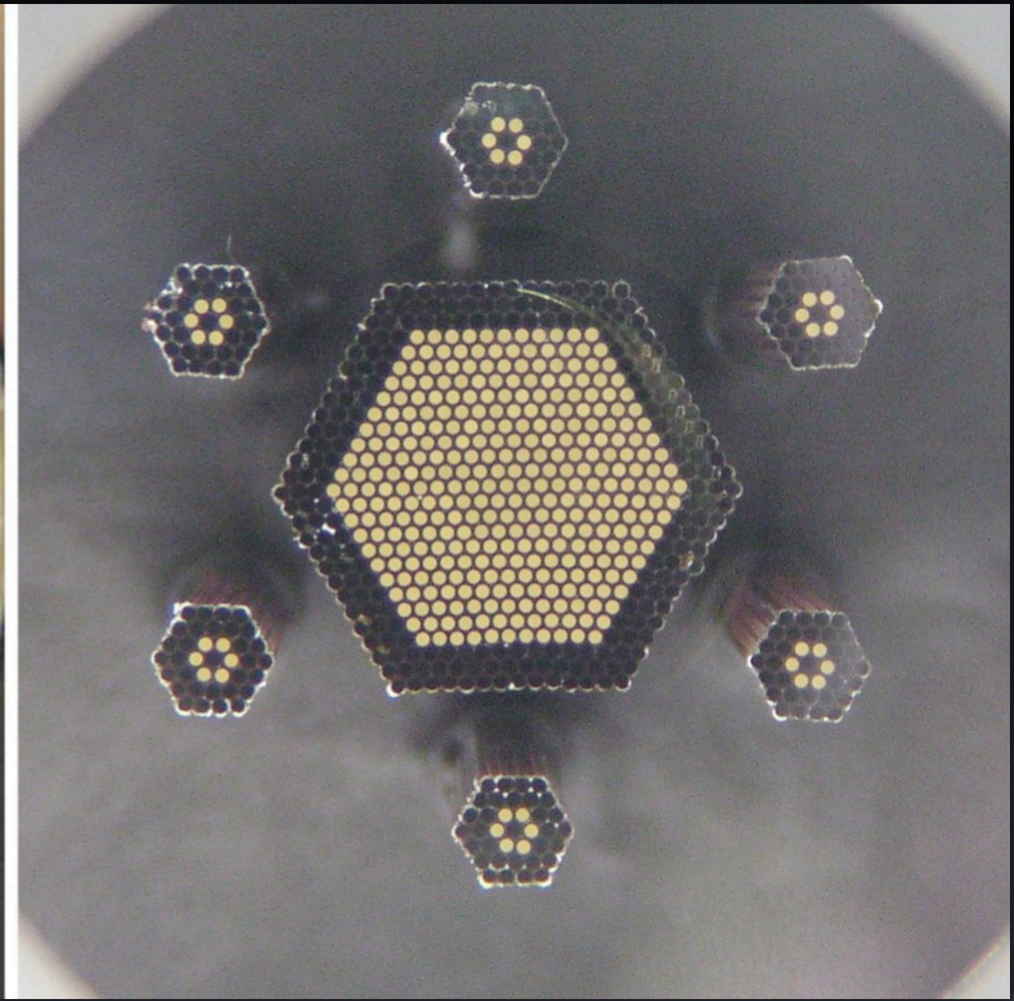
3D data products:

- Hα velocity fields for pre-selection and high-resolution gas kinematics
- stellar MgIb and CaII velocity fields and radial velocity dispersion profiles
- HI velocity fields for extended rotation curves (VLA, WSRT, GMRT)
- low resolution IFU spectroscopy to characterize stellar populations and the ISM (future)

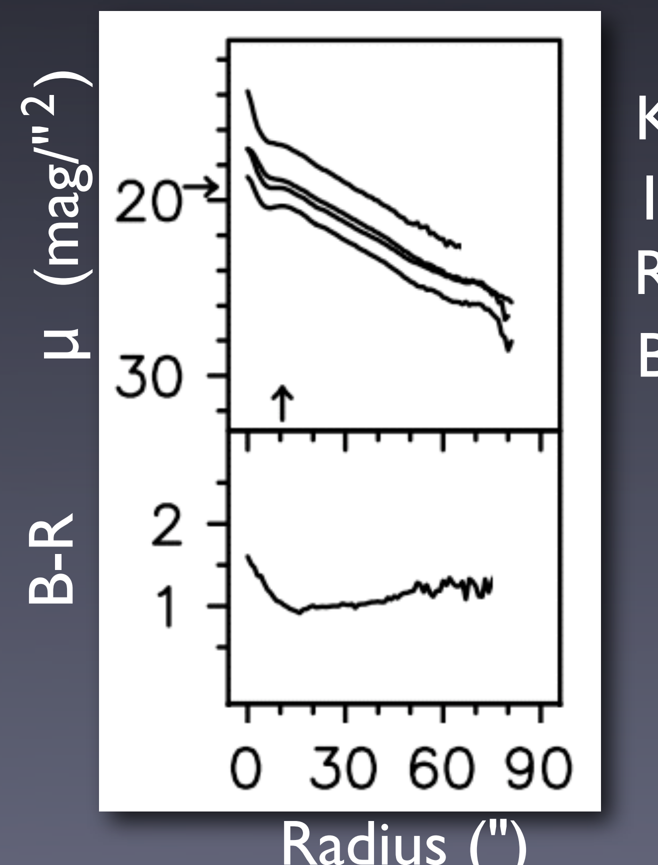
SparsePak	P-Pak
UW - Madison	AIP - Potsdam
	
3.5m WIYN, Kitt Peak	3.5m CAHA, Calar Alto
71"x72" field of view	64"x74" field of view
82 fibers (4.7" ∅)	382 fibers (2.7" ∅)
75 science, 7 sky	331 science, 36 sky, 15 calib.
R≈10.000 (Hα, MgIb, CaII)	R≈8.000 (MgIb, Hα/Hβ/Hγ)

azimuthal averaging to gain S/N

NGC 3982

HST/WFPC-2

D	=	18.6	Mpc
$M_{K'}$	=	-22.8	mag
V_{max}	=	195	km/s
h_{disk}	=	0.96	kpc
$\mu_0(B)$	=	19.27	mag/"2
incl	=	26±2	deg



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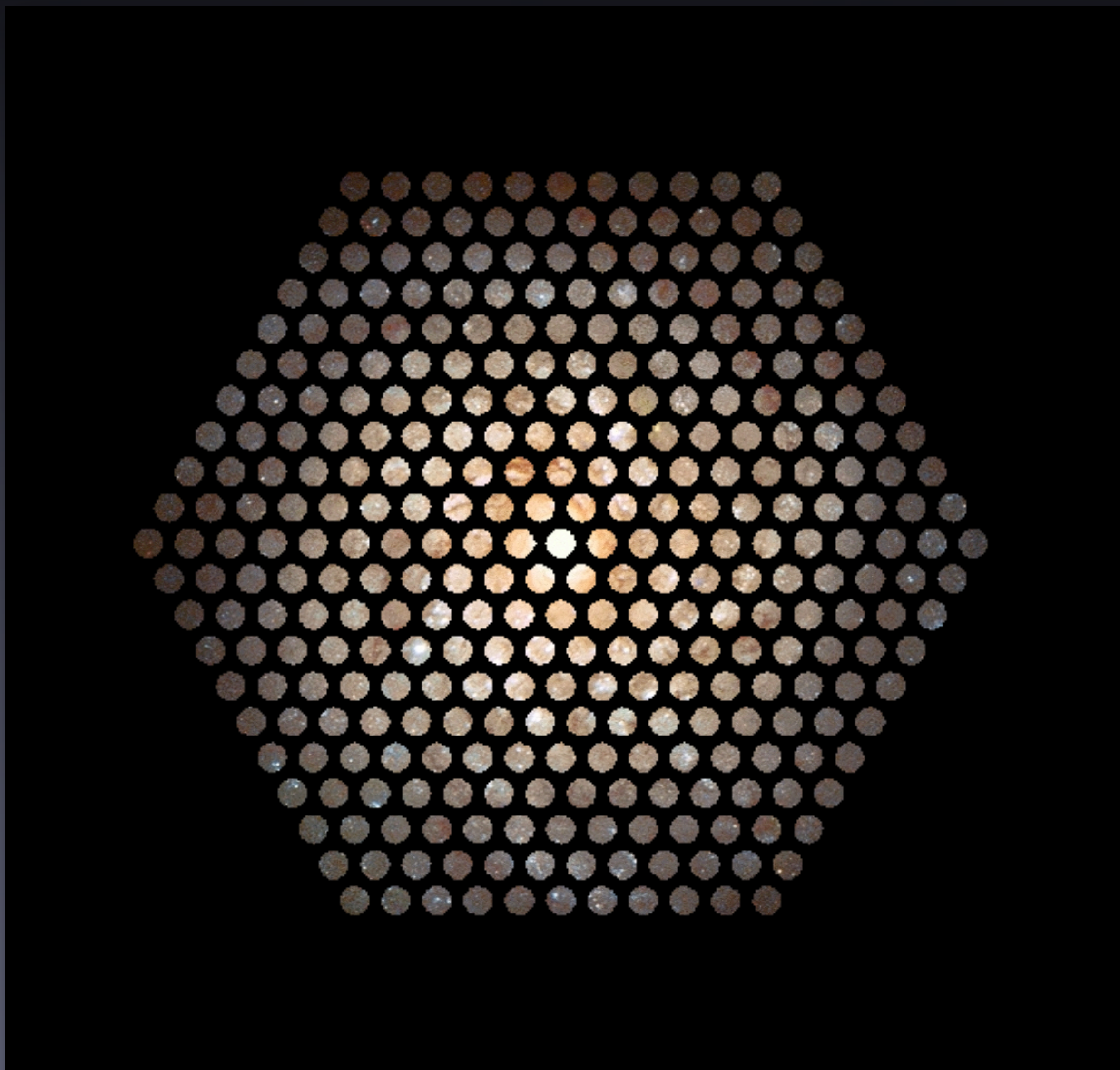

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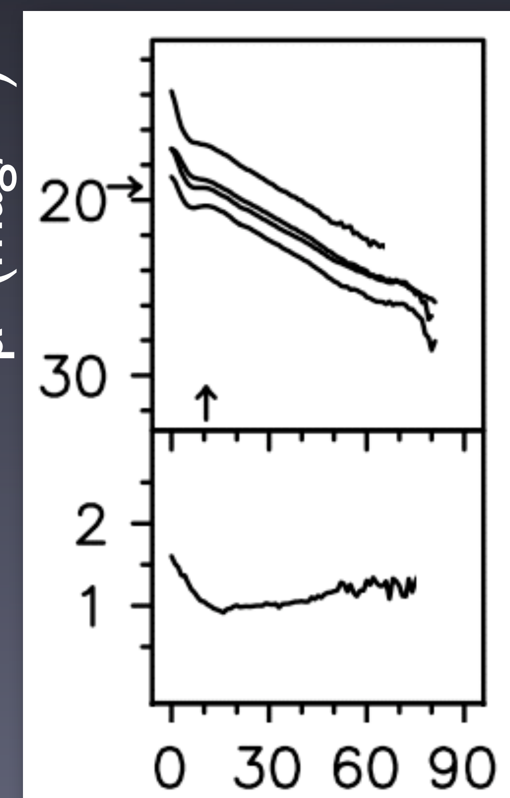

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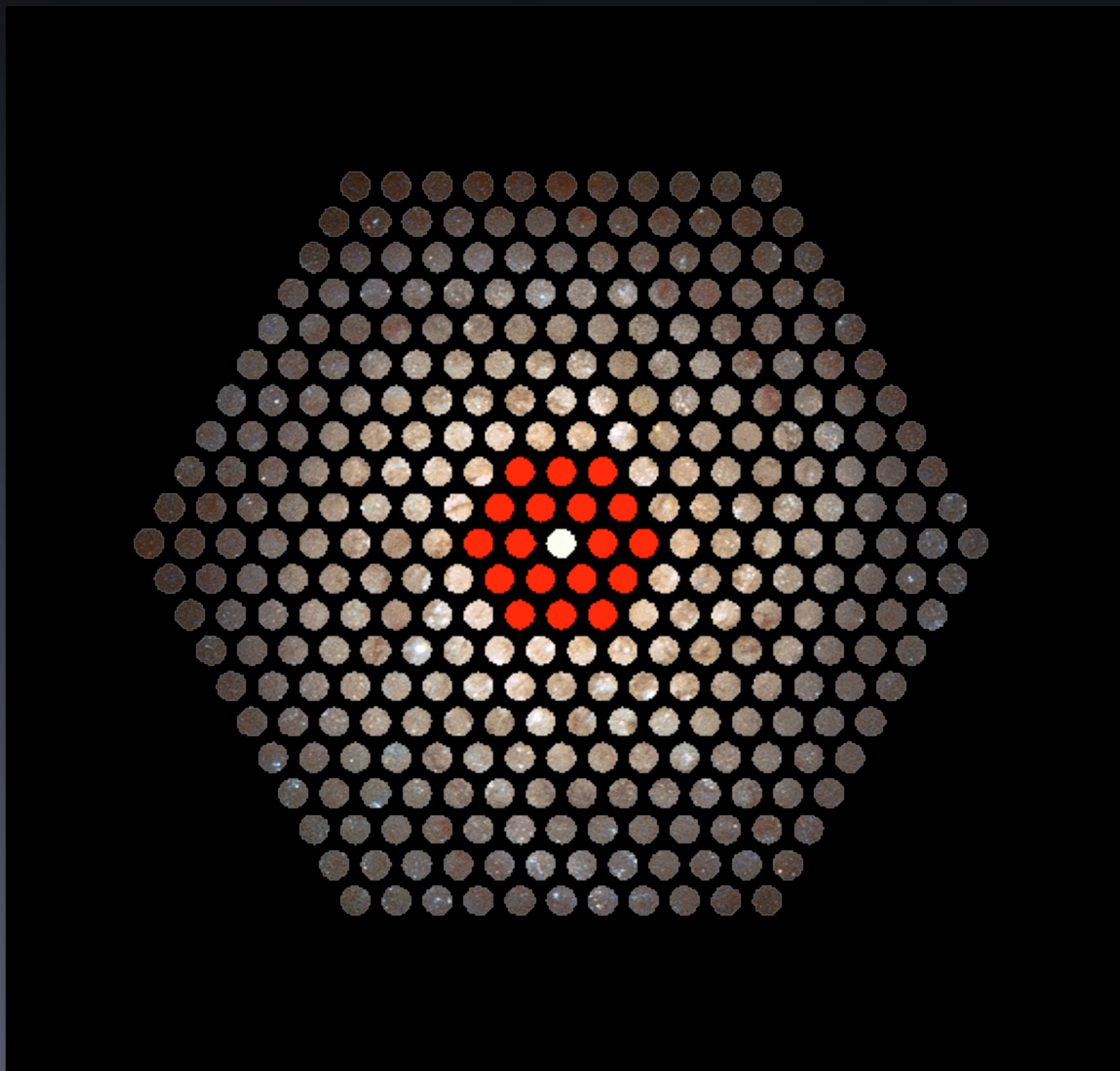

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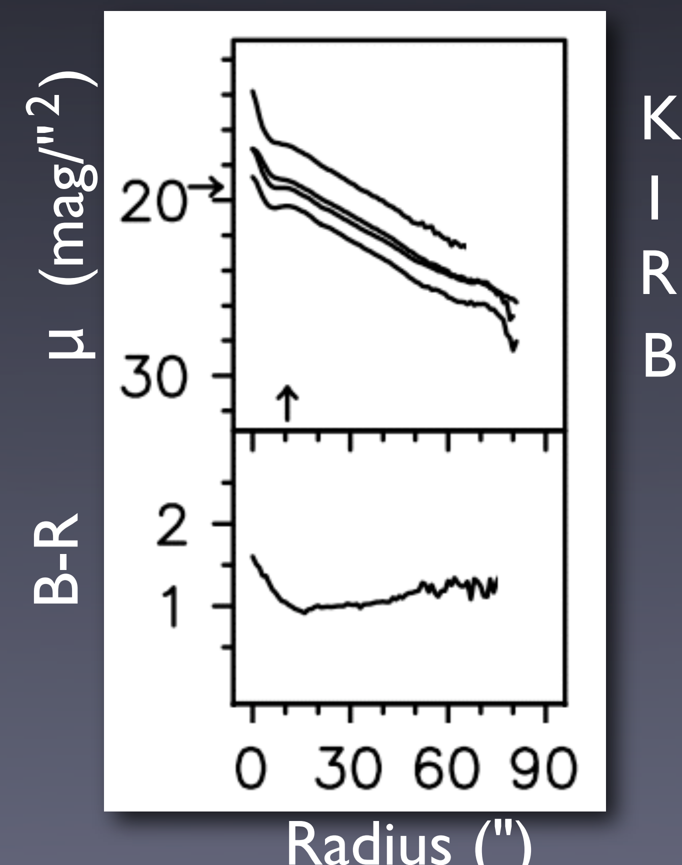
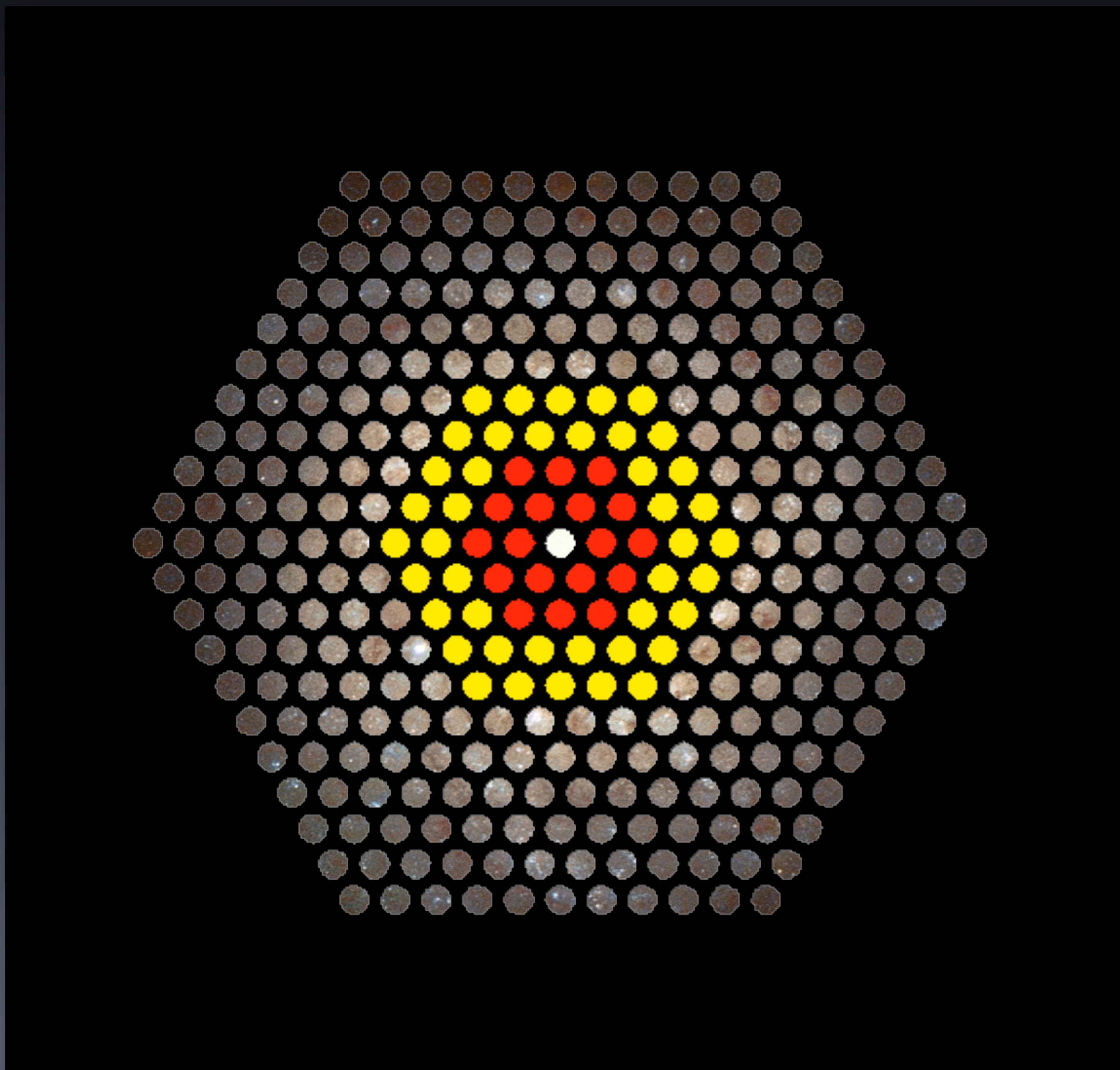
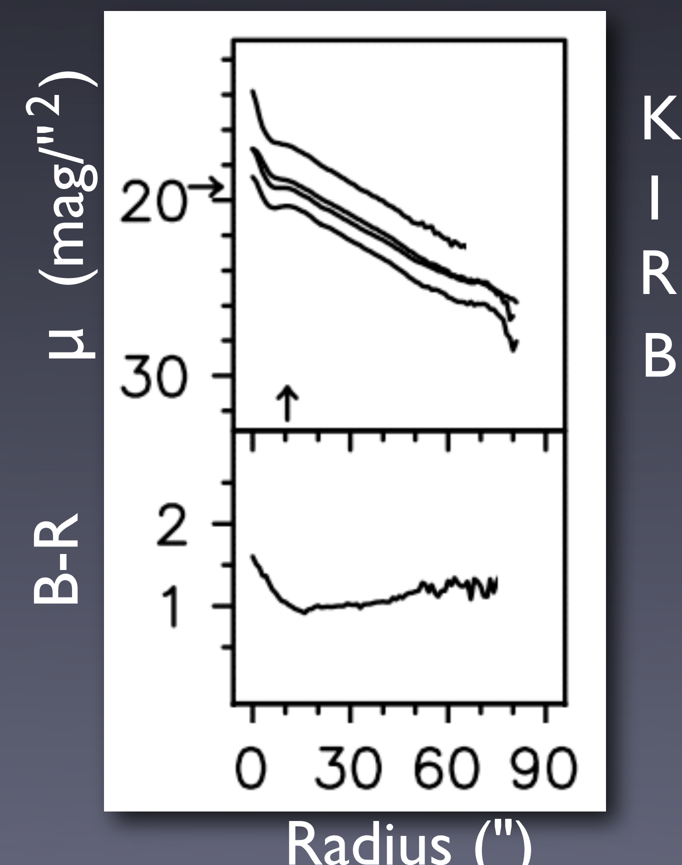


azimuthal averaging to gain S/N

NGC 3982

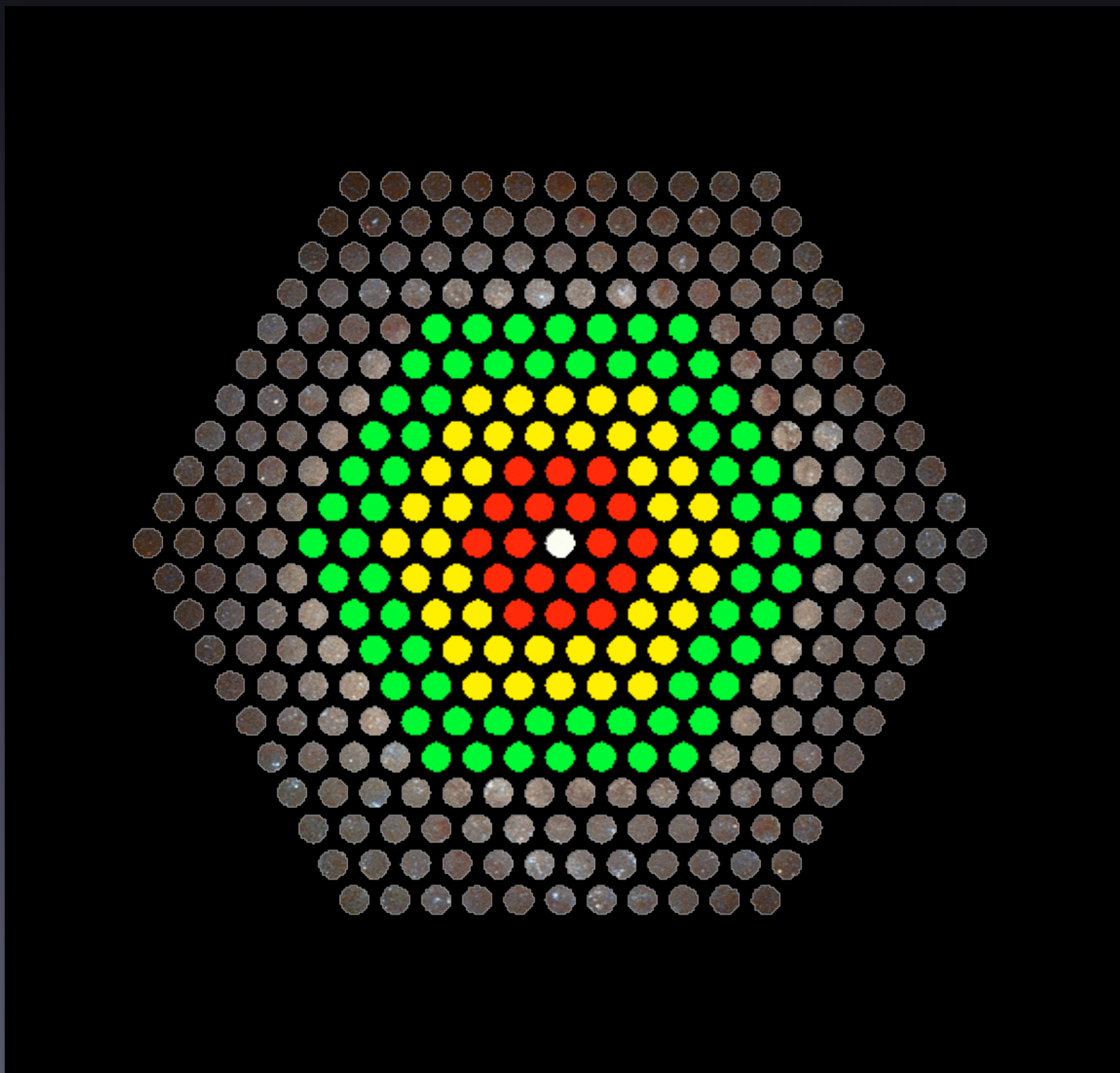


D	=	18.6	Mpc
$M_{K'}$	=	-22.8	mag
V_{max}	=	195	km/s
h_{disk}	=	0.96	kpc
μ_0(B)	=	19.27	mag/"^{2}
incl	=	26±2	deg



azimuthal averaging to gain S/N

NGC 3982



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V_{max} = 195 km/s
h_{disk} = 0.96 kpc
$\mu_0(B)$ = 19.27 mag/"^{2}
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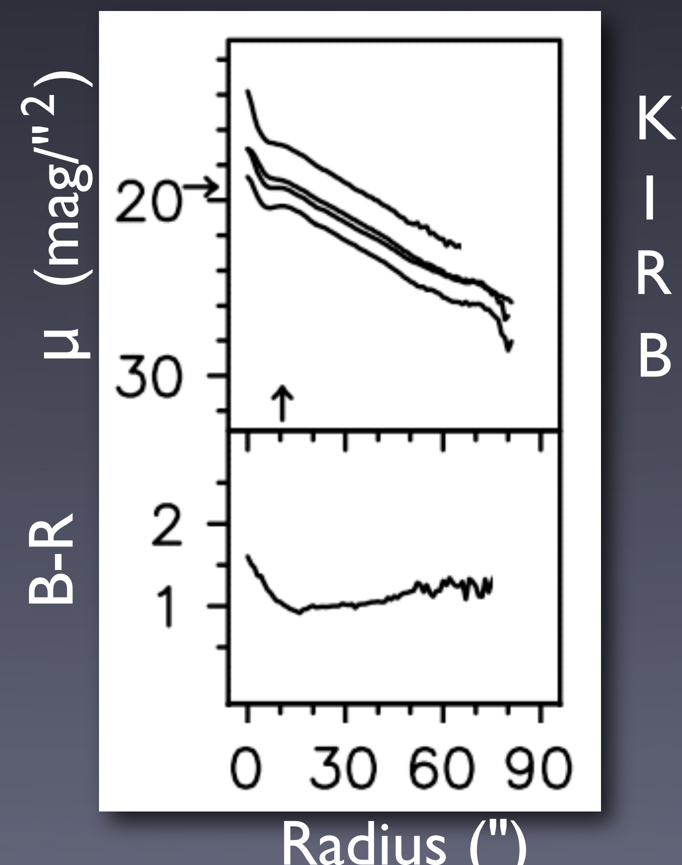

azimuthal averaging to gain S/N

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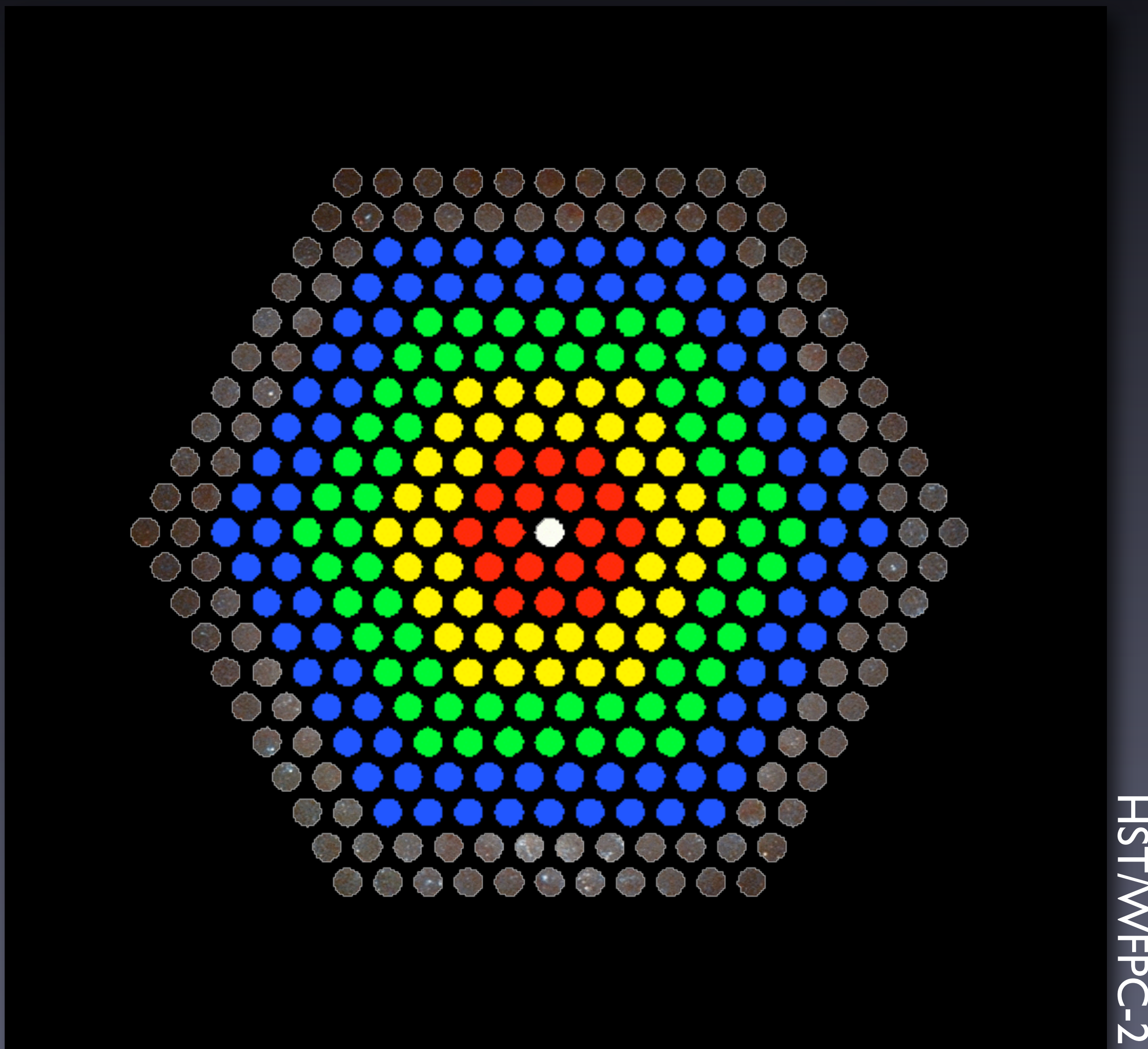
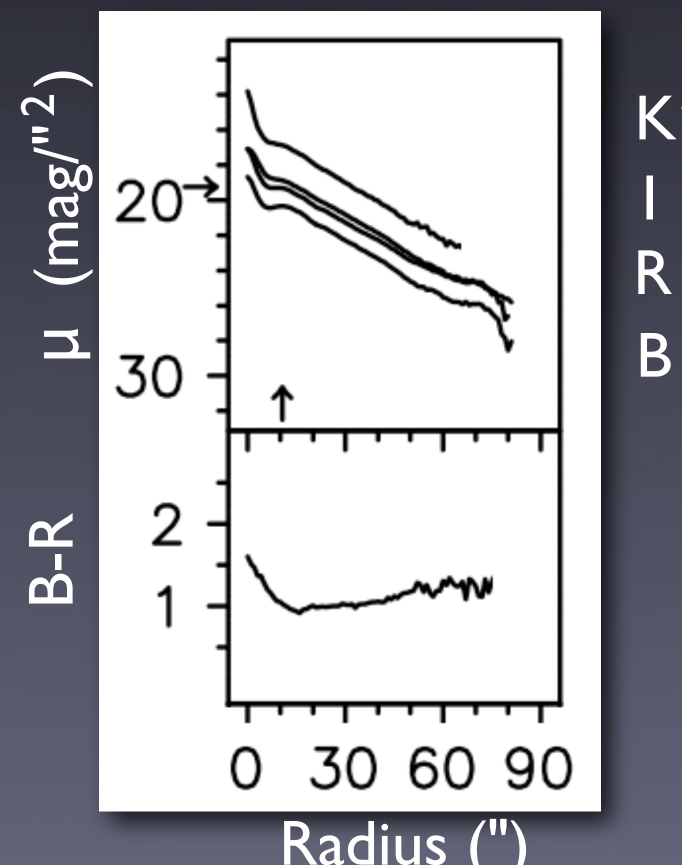
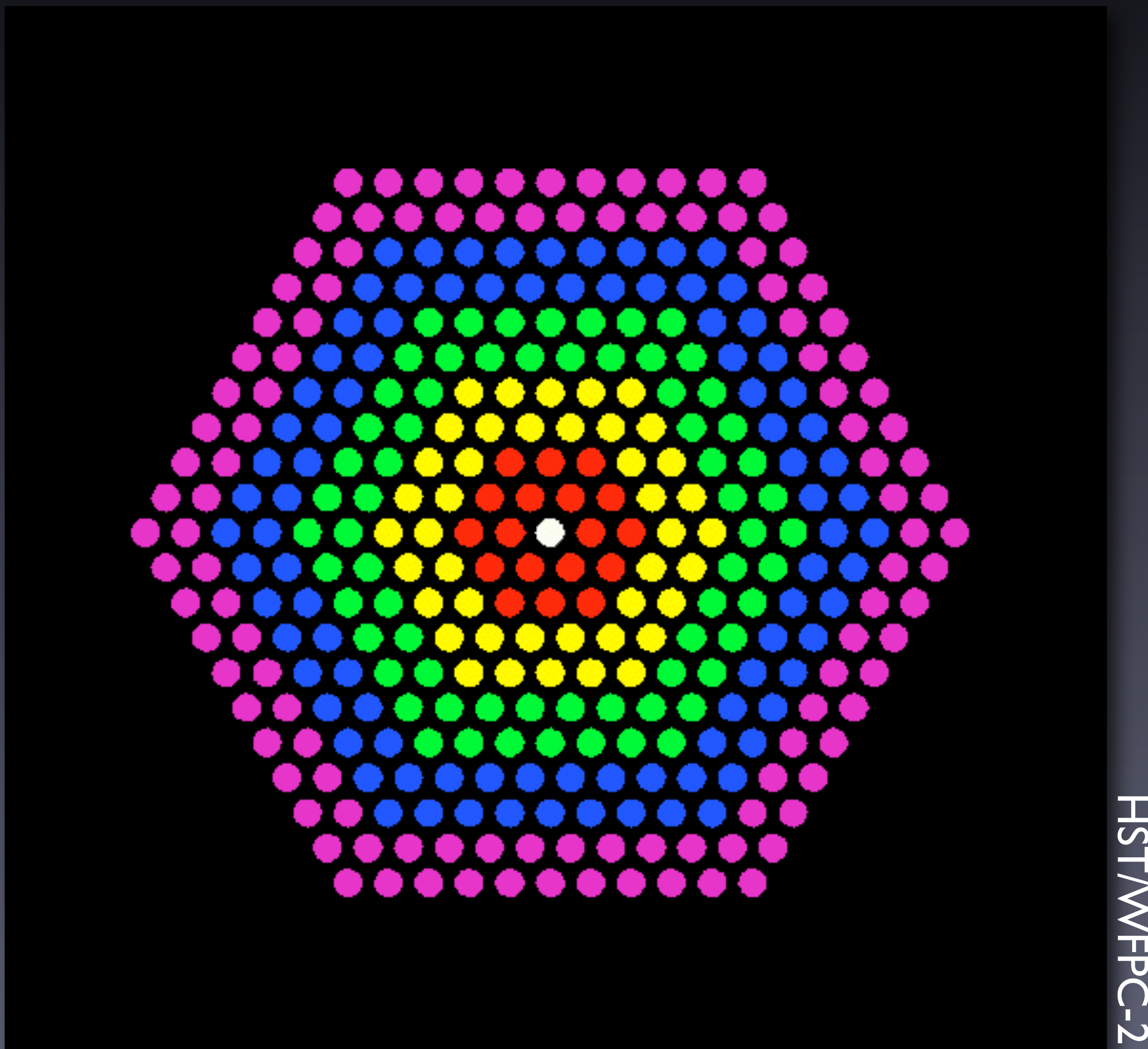
NGC 3982





azimuthal averaging to gain S/N

NGC 3982



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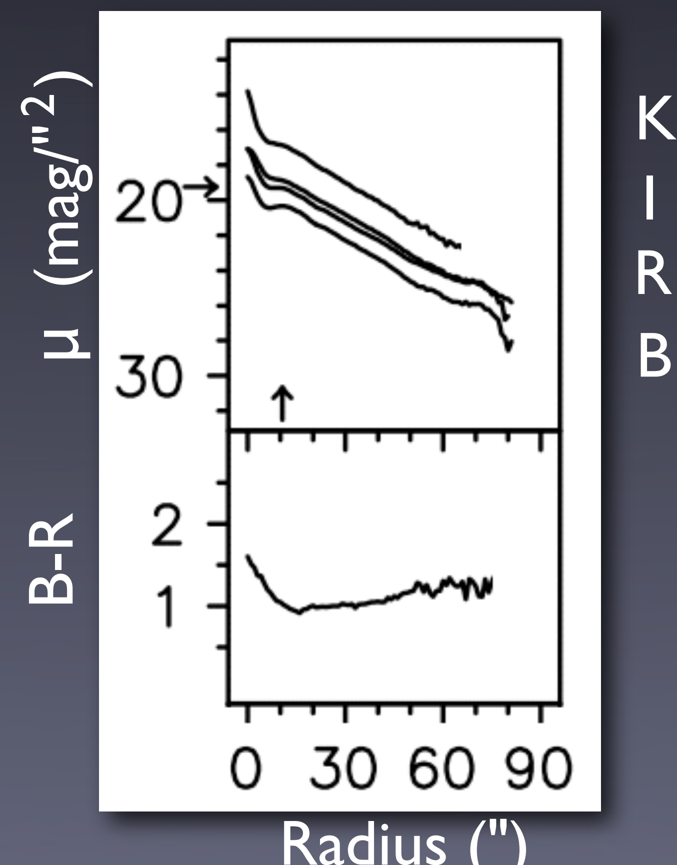
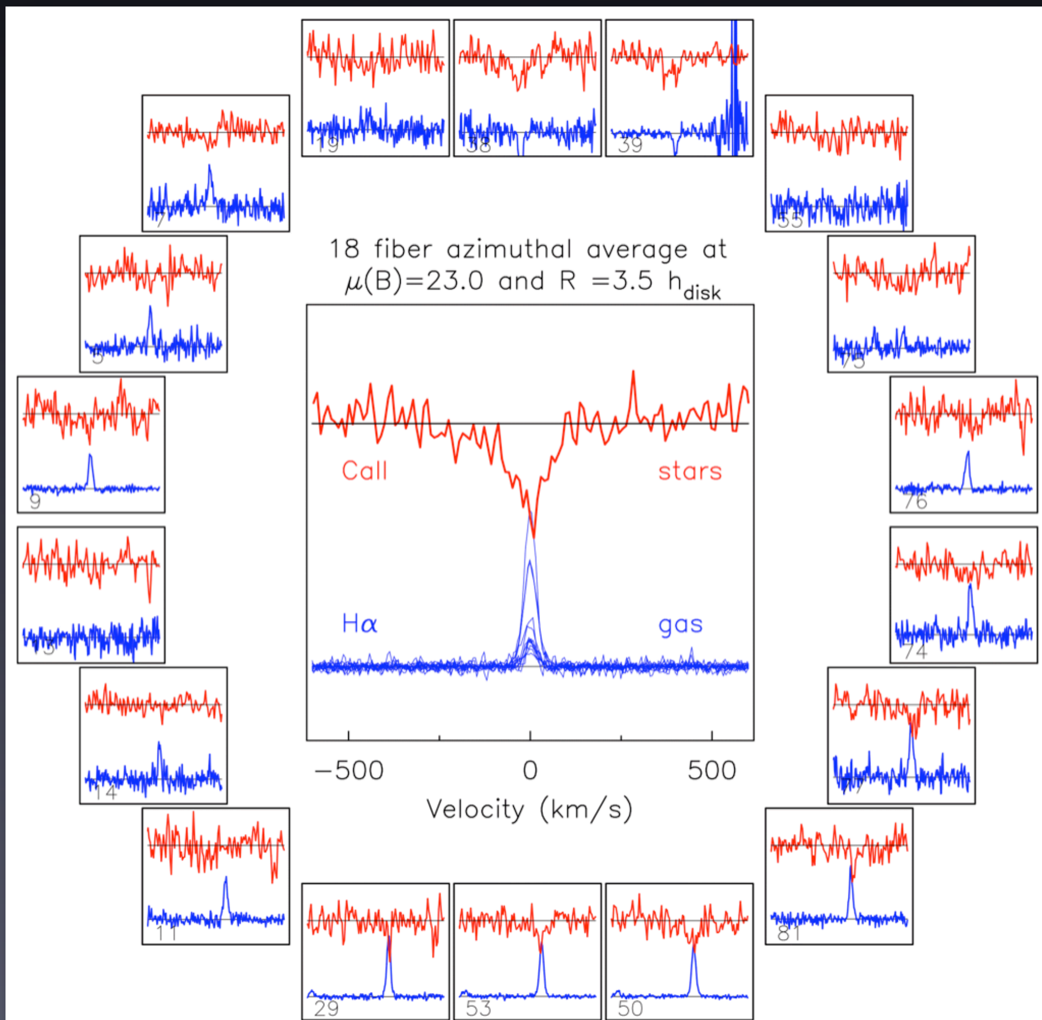
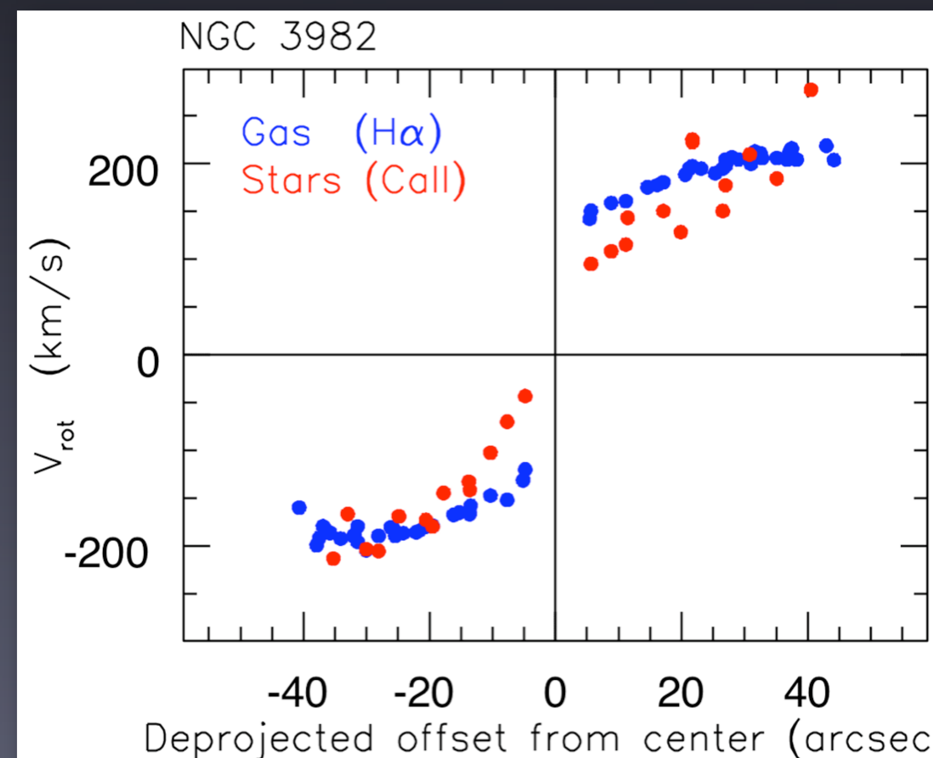


SparsePak data



Detection of asymmetric drift

→ constrains σ_{stars}

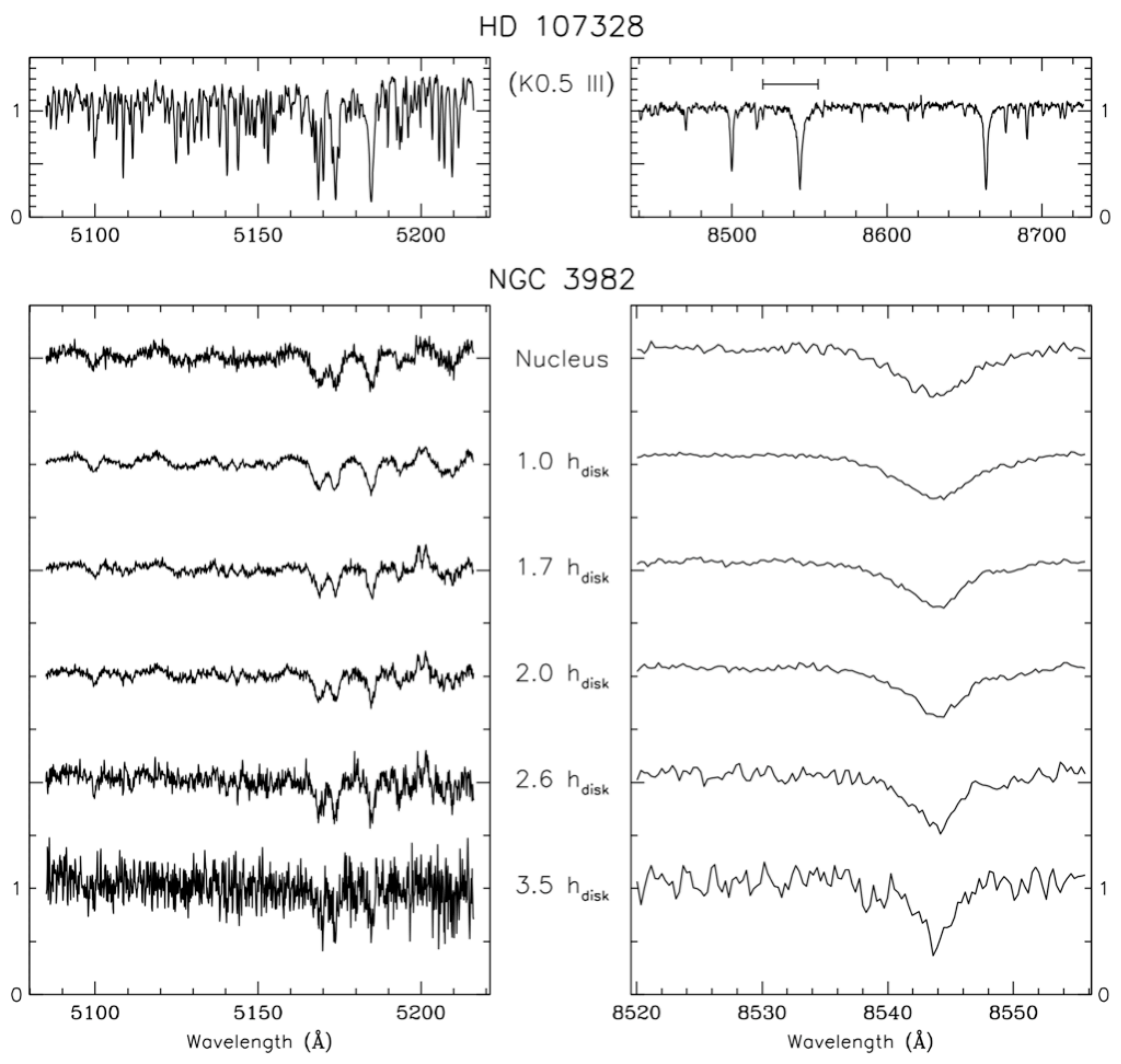


Galaxy spectra in radial bins

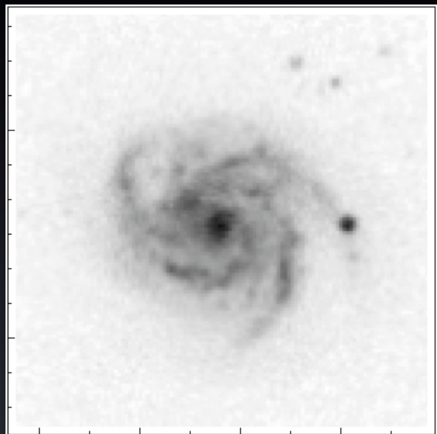
MgIb

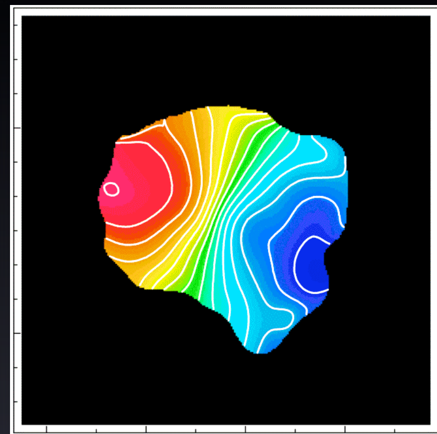
CaII

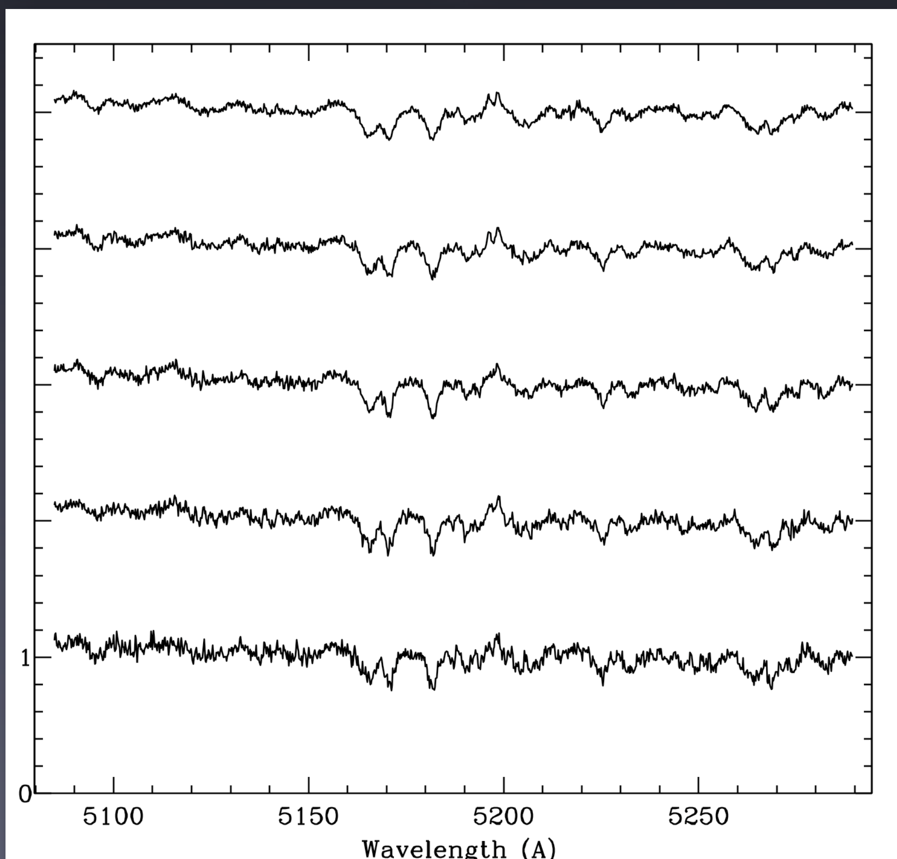
N_{fib}: 1, 6, 8, 12, 18, 18



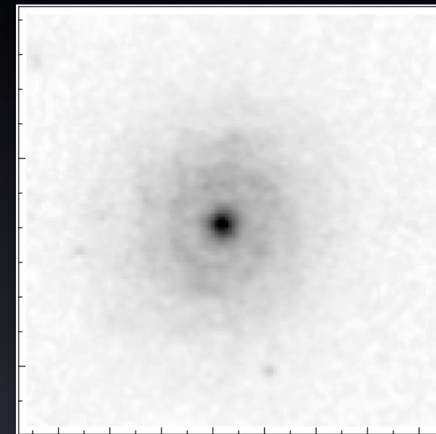
UGC 463

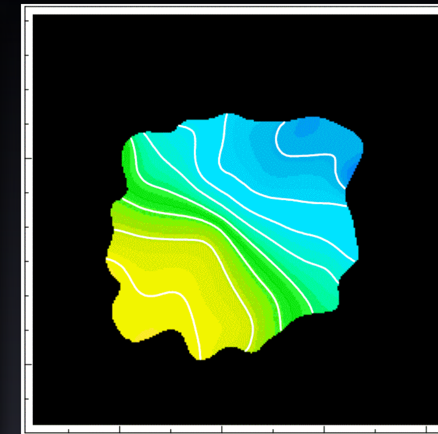


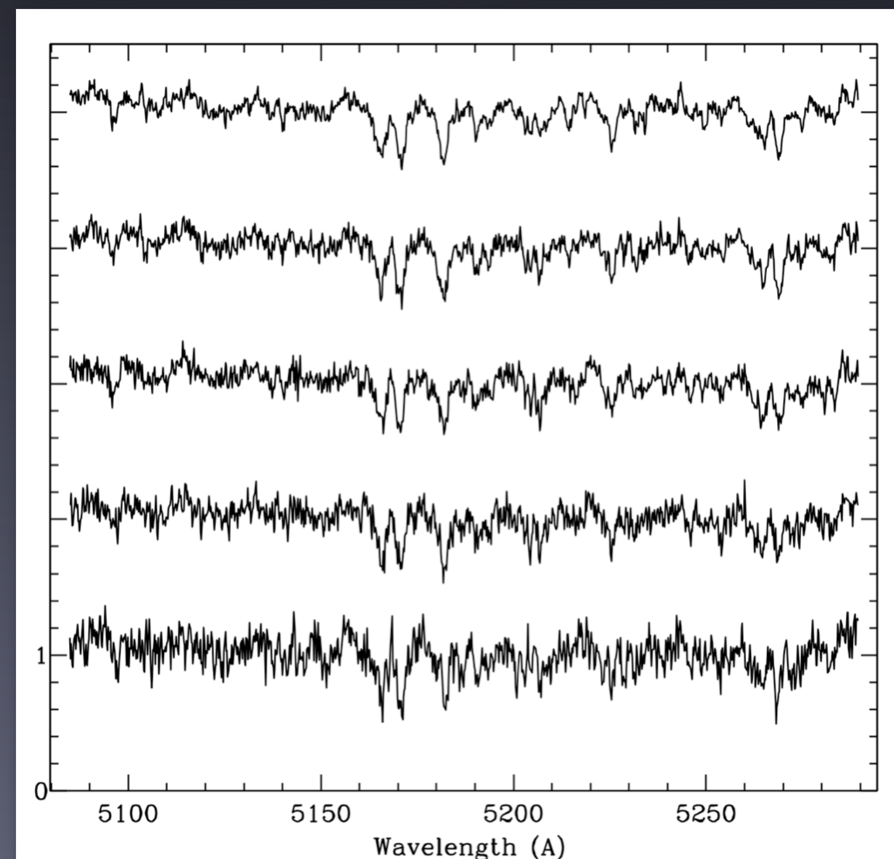




UGC 1635

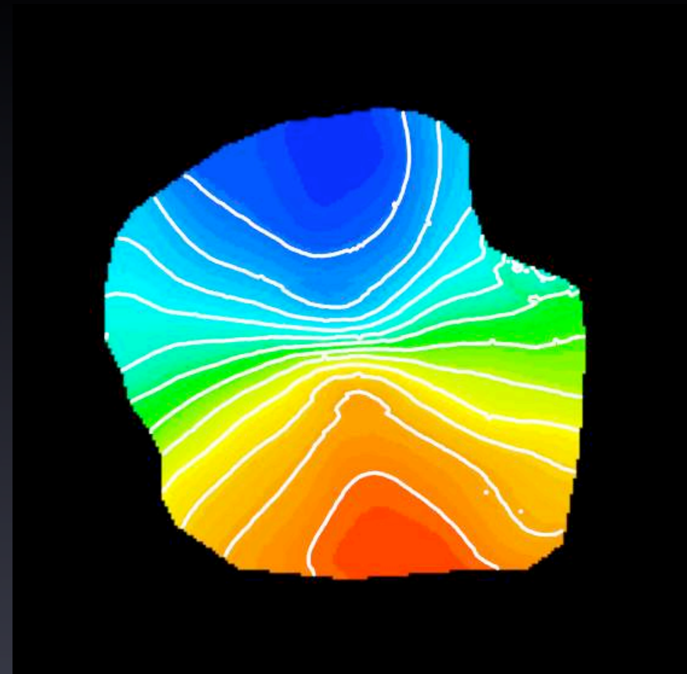




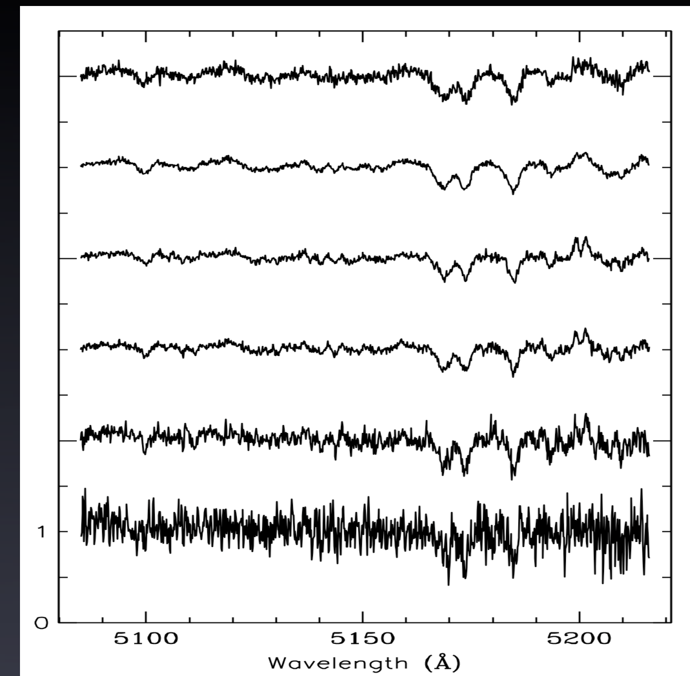


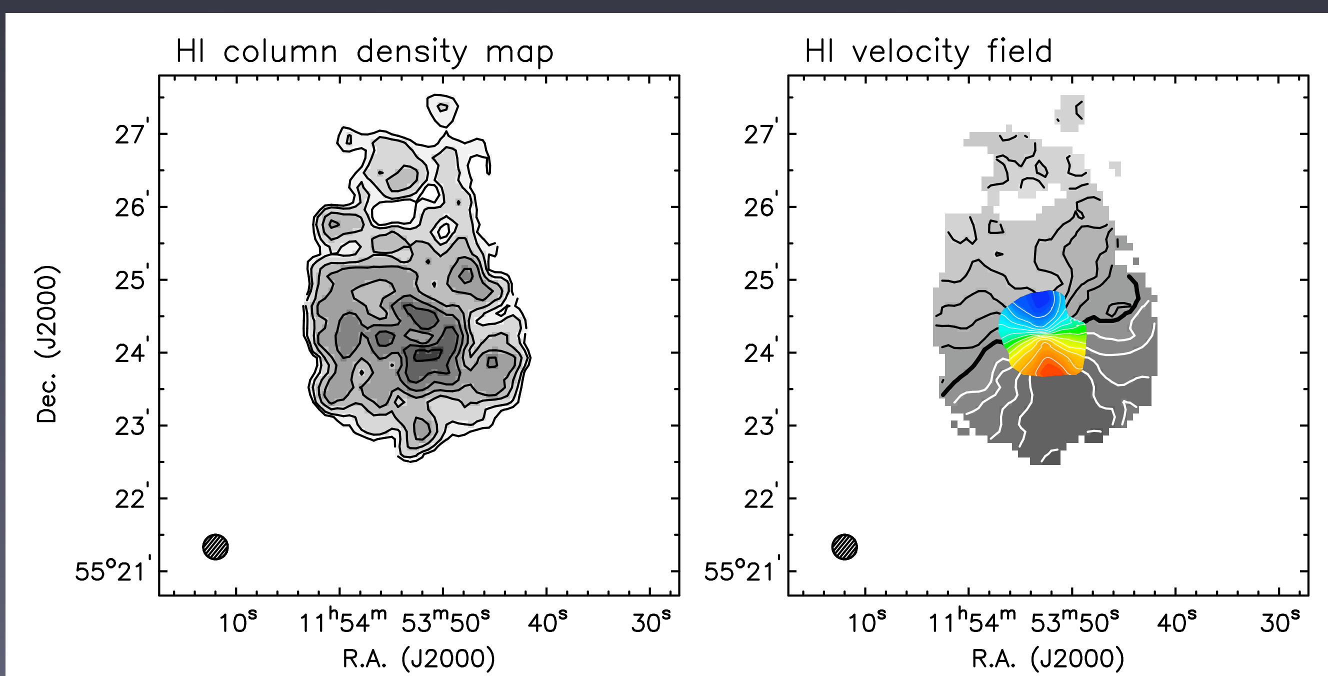
photometry

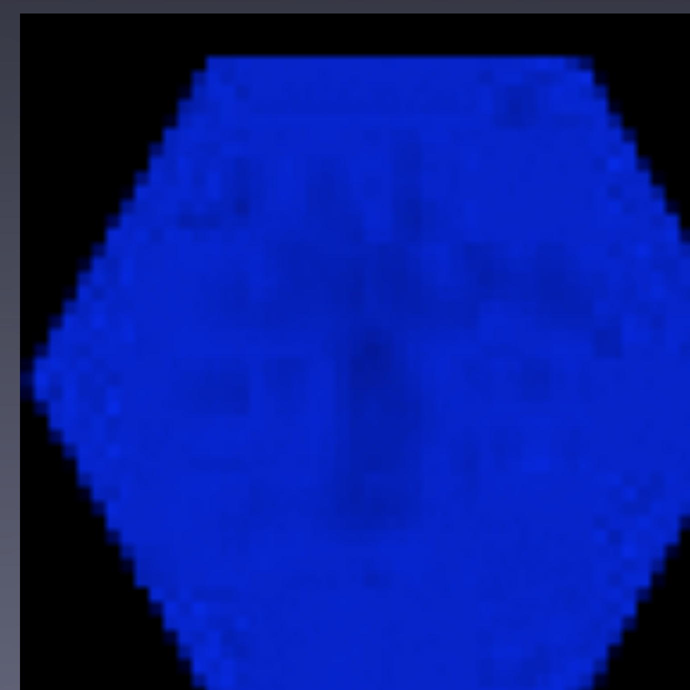
Hα velocity field

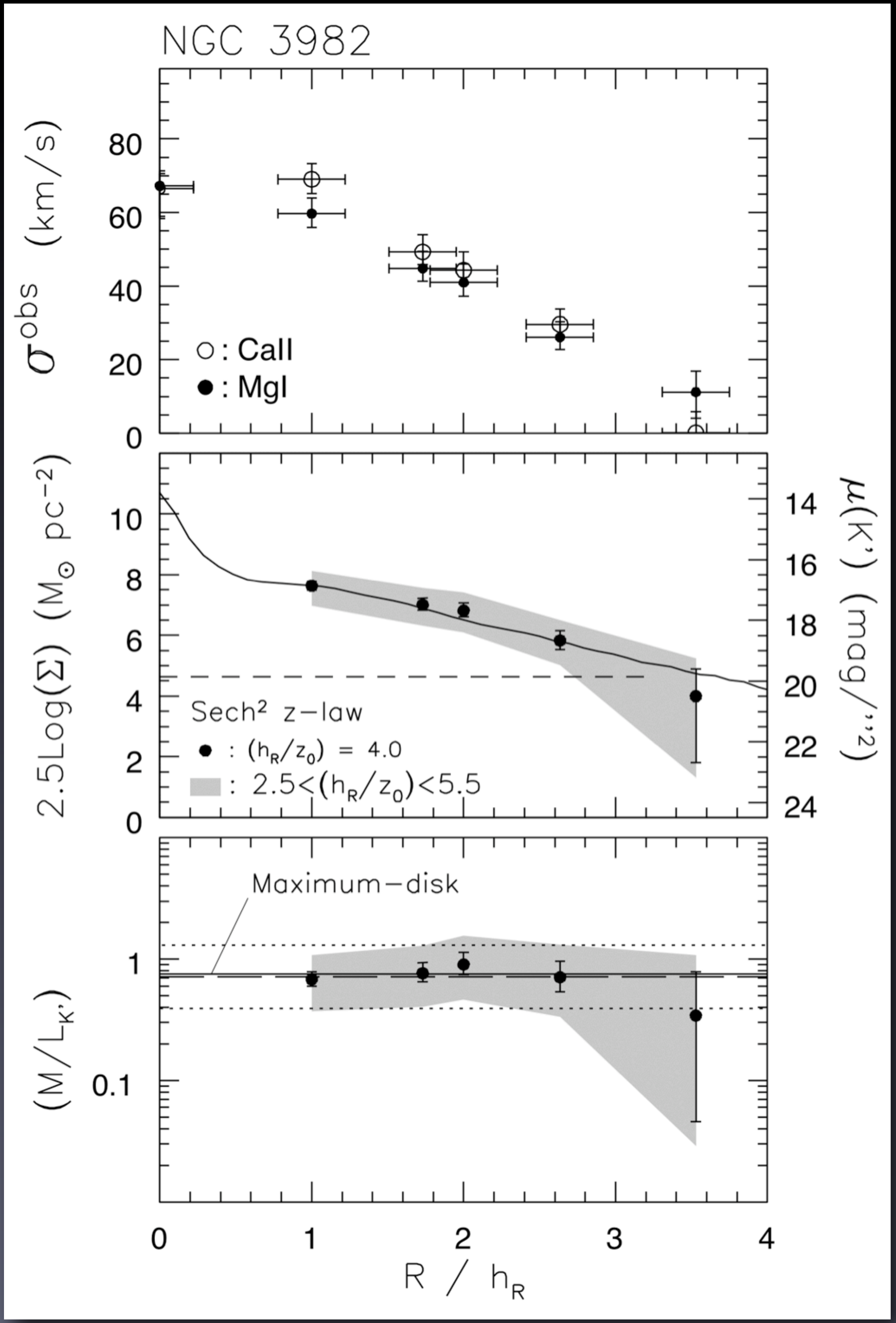


stellar VF & LOSVD



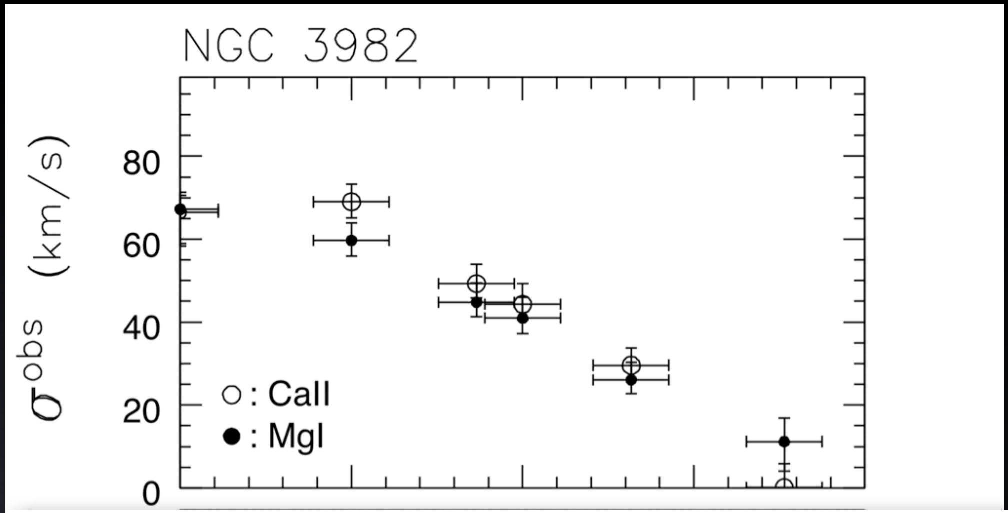






From σ_z to M/L

$$\Sigma = \frac{\sigma_z^2}{\pi \, G \, z_0} \qquad (M/L) = \frac{\sigma_z^2}{\pi \, G \, \mu \, z_0}$$



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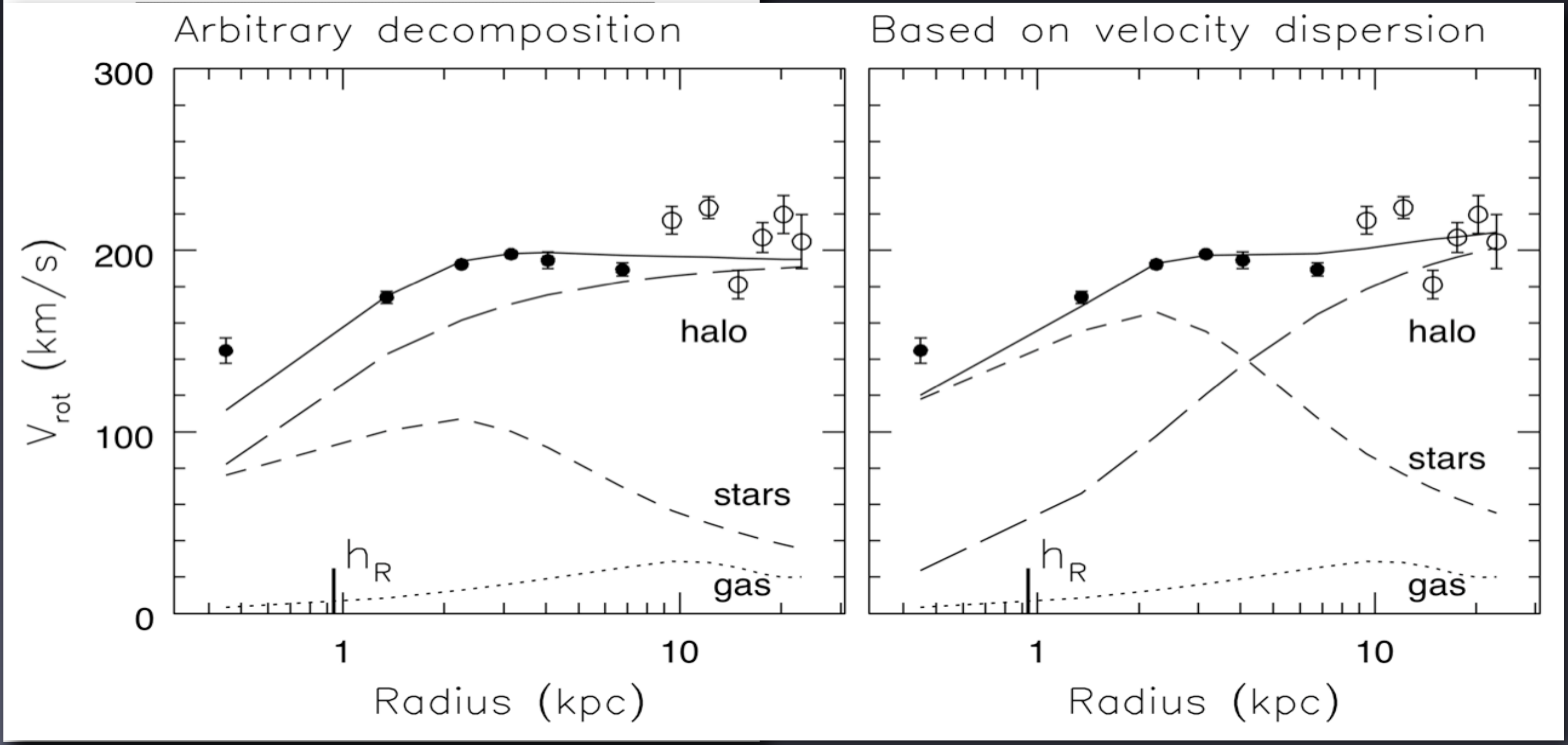

university of groningen
Kapteyn Astronomical Institute

Summary

Decades of spectral line aperture synthesis imaging provides a strong basis for modelling and interpreting IFU data.

Combining 3D data from radio, mm, NIR and optical can be scientifically highly rewarding given their complementarity.