Dynamics of Galaxy Disks
from HI and IFU observations

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UGC 8490

UV-plane

WSRT
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

UGC 6840

Sancisi et al (1979)

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

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 modelling yields bar pattern speed, corotation radius and $\text{M}/\text{L}$.

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

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

NGC 4013

Bottema (1995)

NGC 5055

NGC 2656

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

asymmetric:

symmetric:

peculiar:

>50% is asymmetric

Richter & Sancisi (1994)

single-dish profiles
kinematic lopsidedness
inflow/outflow

Wong, Blitz & Bosma (2004)

harmonic expansion of VF:

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

(based on Schoenmakers et al 1997)

\[ s_1/c_1 \approx 0.35 , \; ds_3/ds_1 \approx -0.05 \]

\[ \rightarrow 60 \text{ km/s radial outflow} \]

but: elliptical streaming due to strong bar?
Anomalous gas in NGC 2403
• 20-50 km/s slower rotation
• 10-20 km/s radial inflow
A thick HI disk: inclined, warped, flared or slowly rotating?

Swaters et al (1997)
A thick HI disk: inclined, warped, flared or slowly rotating?

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
Integral Field Unit spectroscopy

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• probing all scales, from seeing/spaxel/diffraction limit up to FoV

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
DDO 39 - Quest for the Holy Cusp

Swaters et al. (2003)

HI WSRT  H\(\alpha\) (10")  H\(\alpha\) (5.5")

tilted-rings fit  combined  H\(\alpha\) + HI rotation curve
DDO 39 - Quest for the Holy Cusp

HI WSRT  Hα (10")  Hα (5.5")

tilted-rings fit  combined Hα + HI rotation curve
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 $\sigma_z$
Fiber bundles for the Disk-Mass Survey

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maximum disk  maximum halo

UGC 128 (LSB) - Hernquist halo
Fiber bundles for the Disk-Mass Survey
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$\rightarrow R \approx 10,000$ spectroscopy of $\sim 40$ 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  
UW - Madison

3.5m WIYN, Kitt Peak  
71"x72" field of view  
82 fibers (4.7" Ø)  
75 science, 7 sky  
R≈10,000 (Hα, MgIb, CaII)

P-Pak  
AIP - Potsdam

3.5m CAHA, Calar Alto  
64"x74" field of view  
382 fibers (2.7" Ø)  
331 science, 36 sky, 15 calib.  
R≈8,000 (MgIb, Hα/Hβ/Hγ)

Gas & Stars in Galaxies - Garching, 10-13 June 2008
azimuthal averaging to gain S/N

NGC 3982

\[
\begin{align*}
D &= 18.6 \text{ Mpc} \\
M_{K'} &= -22.8 \text{ mag} \\
V_{\text{max}} &= 195 \text{ km/s} \\
h_{\text{disk}} &= 0.96 \text{ kpc} \\
\mu_{0(B)} &= 19.27 \text{ mag/mm}^2 \\
\text{incl} &= 26\pm2 \text{ deg}
\end{align*}
\]
NGC 3982

azimuthal averaging to gain S/N

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

μ (mag/"

B-R

HST/WFPC-2
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
- $\mu_{0(B)} = 19.27$ mag/"^2
- incl = 26±2 deg

**Graph:**

- **B-R** vs Radius (")
- **$K'$** vs Radius (")
- **I** vs Radius ("")
- **R** vs Radius (""")

**Legend:**

- HST/WFPC-2
azimuthal averaging to gain S/N

NGC 3982

\[ D = 18.6 \text{ Mpc} \]
\[ M_{K'} = -22.8 \text{ mag} \]
\[ V_{\text{max}} = 195 \text{ km/s} \]
\[ h_{\text{disk}} = 0.96 \text{ kpc} \]
\[ \mu_{0(B)} = 19.27 \text{ mag}/"^2 \]
\[ \text{incl} = 26\pm2 \text{ deg} \]
azimuthal averaging to gain S/N

NGC 3982

D = 18.6 Mpc
M_V = -22.8 mag
V_{max} = 195 km/s
h_{disk} = 0.96 kpc
\mu_{0(B)} = 19.27 mag/"
incl = 26\pm2 deg

HST/WFPC-2
NGC 3982

azimuthal averaging to gain S/N

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/''
incl = 26\pm2 deg

HST/WFPC-2

B-R

K'

I

R

K

\mu (mag/''^2)

B-R

Radius ('')

0 30 60 90
azimuthal averaging to gain S/N

NGC 3982

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>18.6 Mpc</td>
</tr>
<tr>
<td>M&lt;sub&gt;K'&lt;/sub&gt;</td>
<td>-22.8 mag</td>
</tr>
<tr>
<td>V&lt;sub&gt;max&lt;/sub&gt;</td>
<td>195 km/s</td>
</tr>
<tr>
<td>h&lt;sub&gt;disk&lt;/sub&gt;</td>
<td>0.96 kpc</td>
</tr>
<tr>
<td>μ&lt;sub&gt;0(B)&lt;/sub&gt;</td>
<td>19.27 mag/″&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>incl</td>
<td>26±2 deg</td>
</tr>
</tbody>
</table>

B-R

Radius (″)

HST/WFPC-2
Detection of asymmetric drift → constrains $\sigma_{\text{stars}}$

SparsePak data

18 fiber azimuthal average at $\mu(B)=23.0$ and $R = 3.5 \, h_{\text{disk}}$

NGC 3982

Gas (H\alpha)
Stars (Call)

Deprojected offset from center (arcsec)

Velocity (km/s)
Galaxy spectra in radial bins

HD 107328
(K0.5 III)

NGC 3982

$M_{\text{gIB}}$  
$N_{\text{fib}}$ : 1, 6, 8, 12, 18, 18

Nucleus  
1.0 $h_{\text{disk}}$  
1.7 $h_{\text{disk}}$  
2.0 $h_{\text{disk}}$  
2.6 $h_{\text{disk}}$  
3.5 $h_{\text{disk}}$
\[ \Sigma = \frac{\sigma_z^2}{\pi G z_0} \]

\[ (M/L) = \frac{\sigma_z^2}{\pi G \mu z_0} \]
From $\sigma_z$ to M/L

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