Kinematics of Multiphase Extraplanar Gas in Spiral Galaxies

George Heald
ASTRON
3D2008
Garching
10 June 2008

In collaboration with:
R. Rand, B. Benjamin, M. Bershady,
J. Collins, J. Bland-Hawthorn
Extraplanar gas in spiral galaxies: morphology, kinematics

Fabry-Perot imaging spectroscopy: NGC 5775

SparsePak IFU spectroscopy: NGC 891, NGC 4302

WSRT HI observations: NGC 4395

Conclusions
Extraplanar gas in spiral galaxies

- Deep observations of (edge-on) spirals show thick, vertically extended, *multi-phase* gas layers.

NGC 891 (Oosterloo+)

NGC 5775 (Rand+)

Howk

Wang

WHAM

George Heald

ASTRON

NWO

3D2008

10 June 2008
Extraplanar gas: kinematics

- What is the origin of these extraplanar gas layers?
  - Galactic fountain?

- Accretion? Cold mode expected to be important even at $z=0$
- Both? *Kinematics can help determine importance of SF/accretion.*

Bregman (1980)
Extraplanar gas: kinematics

- What is the origin of these extraplanar gas layers?
  - Galactic fountain?

- Accretion? Cold mode expected to be important even at z=0
- Both? *Kinematics can help determine importance of SF/accretion.*
Extraplanar gas: kinematics

- What is the origin of these extraplanar gas layers?
  - Galactic fountain?

- Accretion? Cold mode expected to be important even at z=0

Bregman (1980)

Dahlem et al. (2006)

Rossa & Dettmar (2003)
Extraplanar gas: kinematics

- What is the origin of these extraplanar gas layers?
  - Galactic fountain?

- Accretion? Cold mode expected to be important even at z=0

- Both? Kinematics can help determine importance of SF/accretion.

George Heald

Bregman (1980)

Dahlem et al. (2006)

Rossa & Dettmar (2003)
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

- Radial gas distribution (for rotation curve): 1D
- Vertical gas distribution (for halo kinematics): 2D
- The velocity axis itself: 3D
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

- Radial gas distribution (for rotation curve): 1D
- Vertical gas distribution (for halo kinematics): 2D
- The velocity axis itself: 3D
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

  - Radial gas distribution (for rotation curve): 1D
  - Vertical gas distribution (for halo kinematics): 2D
  - The velocity axis itself: 3D
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

- Radial gas distribution (for rotation curve): 1D
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

  - Radial gas distribution (for rotation curve): 1D
  - Vertical gas distribution (for halo kinematics): 2D
Why 3D?

- In edge-on galaxies, it is essential to understand velocity projections!

- Radial gas distribution (for rotation curve): 1D
- Vertical gas distribution (for halo kinematics): 2D
- The velocity axis itself: 3D
Fabry-Perot imaging spectroscopy

- TAURUS-II (AAT)
Fabry-Perot imaging spectroscopy

- TAURUS-II (AAT)

Raw frames:
- telescope pointing errors
- wavelength solution?
- cosmic rays hits
- sky line rings
- stellar continuum
- Halpha emission
Fabry-Perot imaging spectroscopy

- TAURUS-II (AAT)

Raw frames:
- telescope pointing errors
- wavelength solution?
- cosmic rays hits
- sky line rings
- stellar continuum
- Halpha emission
Fabry-Perot imaging spectroscopy

- TAURUS-II (AAT)

Processed frames:
- Halpha emission
- constant wavelength per frame
Fabry-Perot imaging spectroscopy

- TAURUS-II (AAT)

Processed frames:
- Halpha emission
- constant wavelength per frame
Fabry-Perot imaging spectroscopy

- Halo kinematics determined by performing geometric modeling and comparing simulated data with the real data

SparsePak IFU spectroscopy

- SparsePak (WIYN) = 82 fiber IFU spectrograph

SparsePak IFU spectroscopy

- SparsePak (WIYN) = 82 fiber IFU spectrograph

SparsePak IFU spectroscopy

- SparsePak (WIYN) = 82 fiber IFU spectrograph

SparsePak IFU spectroscopy

- SparsePak (WIYN) = 82 fiber IFU spectrograph

SparsePak IFU spectroscopy

- SparsePak (WIYN) = 82 fiber IFU spectrograph

$dV_\phi/dz \approx -15 \text{ km s}^{-1} \text{ kpc}^{-1}$

Results of optical observations

NGC 5775

NGC 891

NGC 4302

Major axis length (kpc)

Minor axis length (kpc)
Results of optical observations

<table>
<thead>
<tr>
<th>NGC 5775</th>
<th>NGC 891</th>
<th>NGC 4302</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 km/s/kpc</td>
<td>15 km/s/kpc</td>
<td>30 km/s/kpc</td>
</tr>
</tbody>
</table>
Models & Interpretation

- Rotation speed decreases as gas is higher in halo -- this seems to be a *general trend*.

Rotation speed decreases as gas is higher in halo -- this seems to be a general trend.

This should be the case (assuming galactic fountain) from conservation of angular momentum.

Models & Interpretation

- Rotation speed decreases as gas is higher in halo -- this seems to be a general trend.
- This should be the case (assuming galactic fountain) from conservation of angular momentum
- Predictions of ballistic model do not match observations

Models & Interpretation

- Rotation speed decreases as gas is higher in halo -- this seems to be a general trend.
- This should be the case (assuming galactic fountain) from conservation of angular momentum.
- Predictions of ballistic model do not match observations.
- Interpretation:
  - More SF = more fountain = less gradient
  - Less SF = less fountain = more gradient
  - See talk by Fraternali.

Models & Interpretation

- Rotation speed decreases as gas is higher in halo -- this seems to be a **general trend**.
- This should be the case (assuming galactic fountain) from conservation of angular momentum.
- Predictions of ballistic model **do not match** observations.
- Interpretation:
  - More SF = more fountain = less gradient
  - Less SF = less fountain = more gradient
  - See talk by Fraternali

Models & Interpretation

- Rotation speed decreases as gas is higher in halo -- this seems to be a **general trend**.
- This should be the case (assuming galactic fountain) from conservation of angular momentum.
- Predictions of ballistic model **do not match** observations.
- Interpretation:
  - More SF = more fountain = less gradient
  - Less SF = less fountain = more gradient
  - See talk by Fraternali
- Need face-on galaxies to compare w/ SFR

Kinematics in not-edge-on galaxies

- In more face-on galaxies, halo gas can be distinguished by its kinematics (and again, 3D data is crucial)
Kinematics in not-edge-on galaxies

- In more face-on galaxies, halo gas can be distinguished by its kinematics (and again, 3D data is crucial)

NGC 2403 (Fraternali+ 2001)
Kinematics in not-edge-on galaxies

- In more face-on galaxies, halo gas can be distinguished by its kinematics (and again, 3D data is crucial)

NGC 2403 (Fraternali+ 2001)
WSRT HI data: NGC 4395

- NGC 4395 (~face-on spiral w/ low SFR) observed 8x12hr with WSRT
WSRT HI data: NGC 4395

- NGC 4395 (~face-on spiral w/ low SFR) observed 8x12hr with WSRT
- (Lopsided!) rotation curve determined
WSRT HI data: NGC 4395

- NGC 4395 (~face-on spiral w/ low SFR) observed 8x12hr with WSRT
- (Lopsided!) rotation curve determined
- “Shuffled” the data cube
- Extracted emission with more than 30 km/s deviation from rotation
Most “anomalous” gas corresponds to locations of star formation.

Large cloud complex \((\sim 10^7 \, M_\odot)\) unassociated with SF, may be accreting.

Heald & Oosterloo (2008)
Gaseous halos of spiral galaxies have \textit{slower rotation} than the disk.
Summary

- Gaseous halos of spiral galaxies have *slower rotation* than the disk.
- This “rotational lag” seems to be stronger in galaxies with lower star formation rates.
Summary

- Gaseous halos of spiral galaxies have *slower rotation* than the disk.
- This “rotational lag” seems to be stronger in galaxies with lower star formation rates.
- Physical mechanism needed to remove angular momentum from the halo gas --- accretion is a likely suspect.
Summary

- Gaseous halos of spiral galaxies have **slower rotation** than the disk.
- This “rotational lag” seems to be stronger in galaxies with lower star formation rates.
- Physical mechanism needed to remove angular momentum from the halo gas --- accretion is a likely suspect.
- 3D data analysis techniques essential for this type of study!