ASTRON

Netherlands Institute for Radio Astronomy

Low N_{HI} science & HALOGAS

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PHISCC
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Outline

- Context & survey design
- Hard parts: data reduction & cube modeling
- Typical disk results
- Results & work in progress
  - Occurrence of thick HI disks in galaxies
  - Prevalence of HI clouds
  - Serendipitous discoveries
- The future

HALOGAS team members

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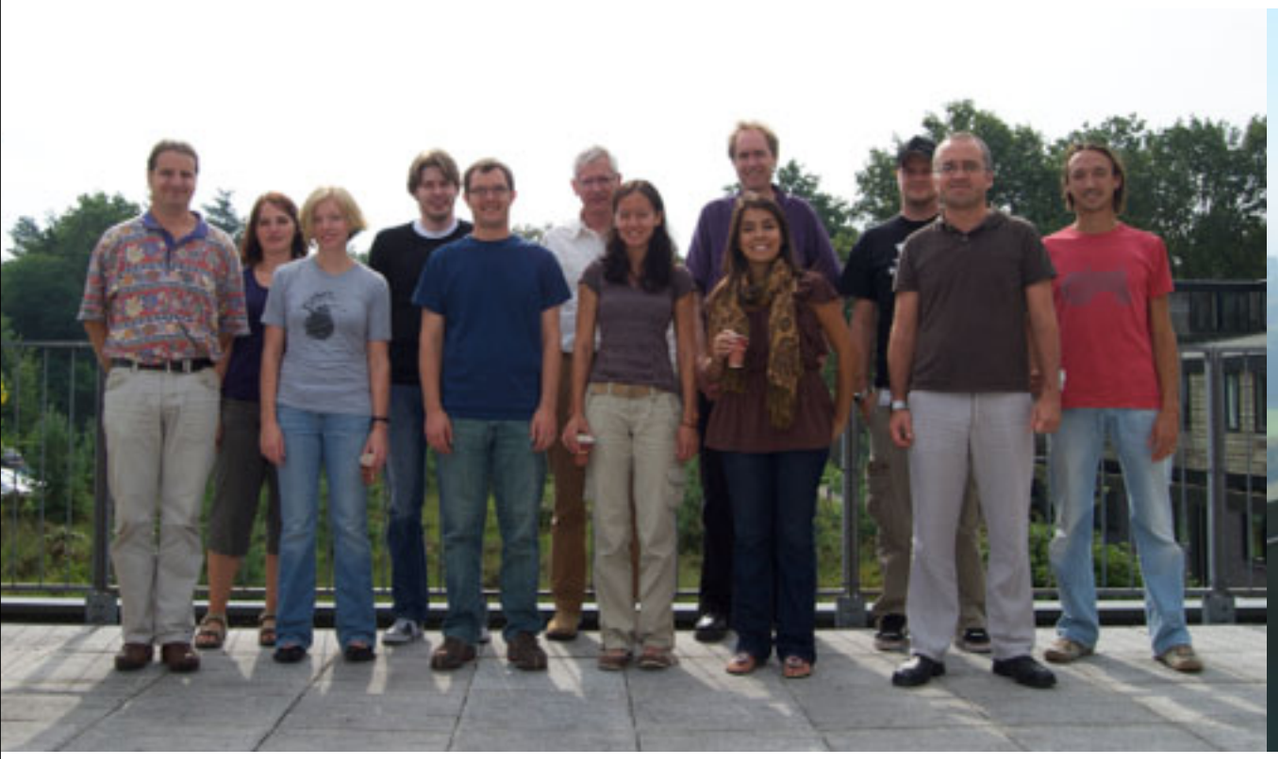
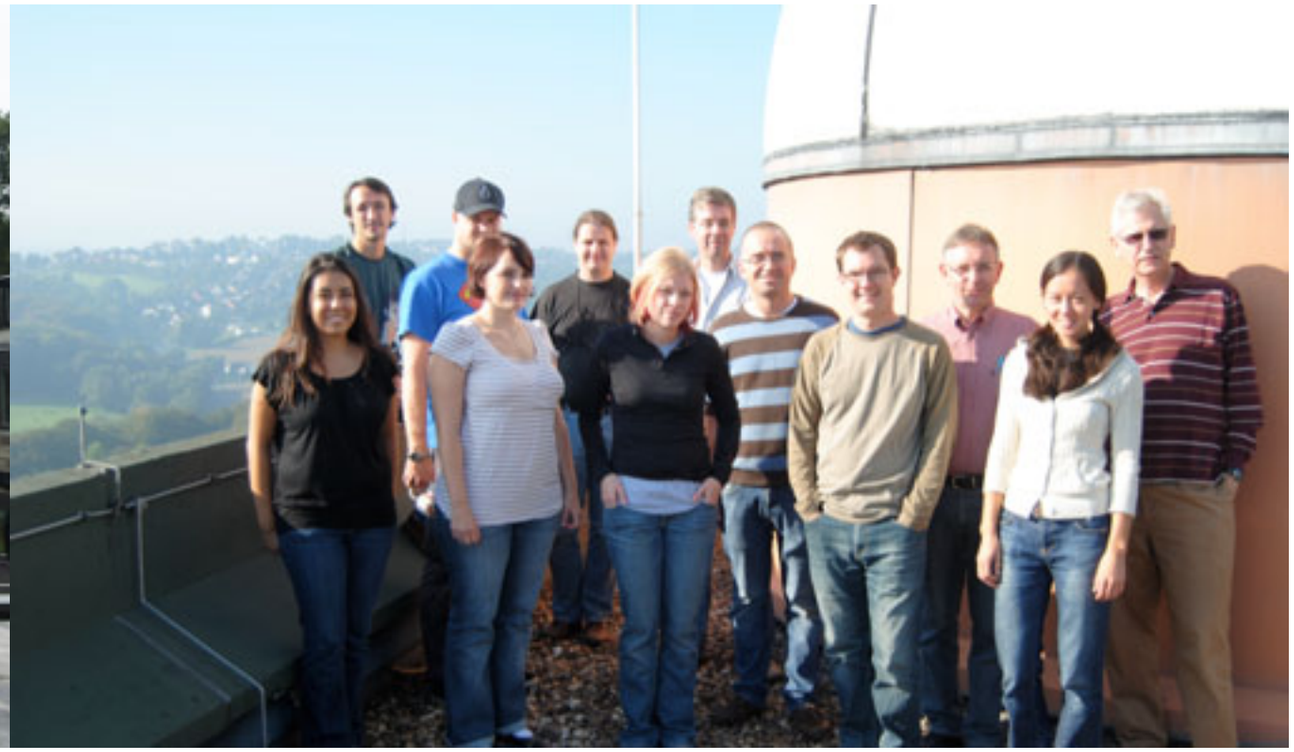
Filippo Fraternali (Bologna University) — Gianfranco Gentile (Ghent University)
Mark Gorski (University of New Mexico) — Gyula Jozsa (ASTRON) — Eva Jütte (Ruhr-Universität Bochum)
Peter Kamphuis (ATNF) — Tom Oosterloo (ASTRON) — Maria Patterson (New Mexico State University)
Rich Rand (University of New Mexico) — Renzo Sancisi (Osservatorio Astronomico di Bologna)
Paolo Serra (ATNF) — Carlos Vargas (New Mexico State University)
Rene Walterbos (New Mexico State University) — Benjamin Winkel (MPIfR)
Cat Wu (New Mexico State University) — Laura Zschaechner (MPA)

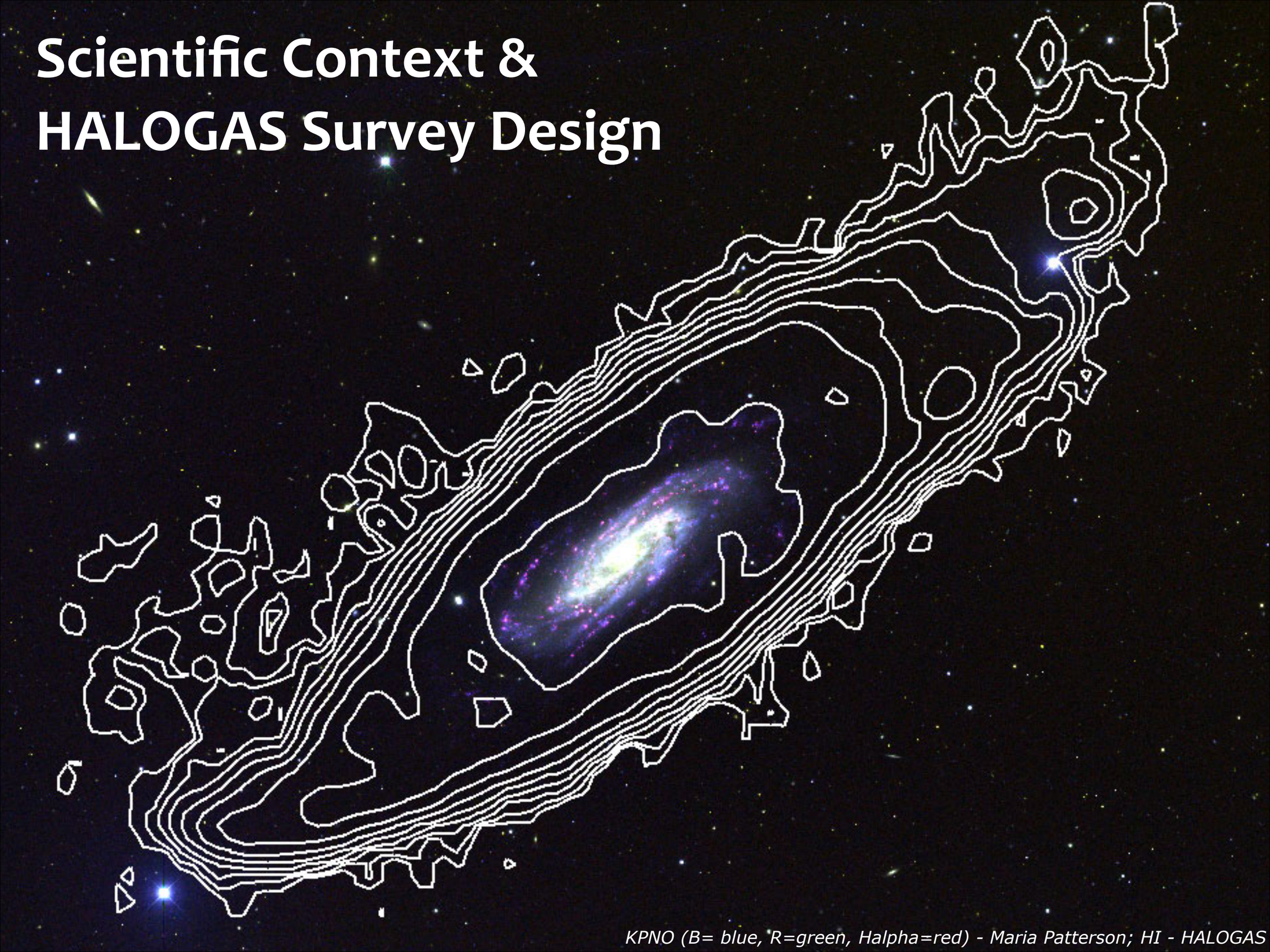


HALOGAS Meeting: Dwingeloo, August 2010



HALOGAS Meeting: Bochum, September 2011

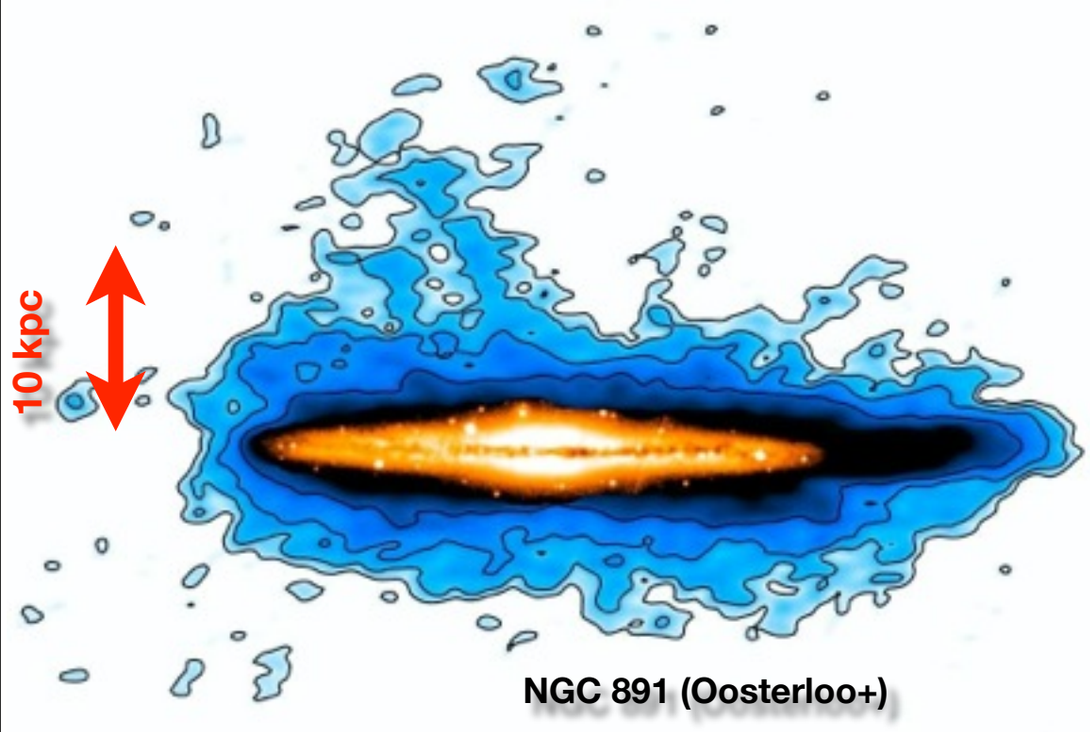
Scientific Context & HALOGAS Survey Design

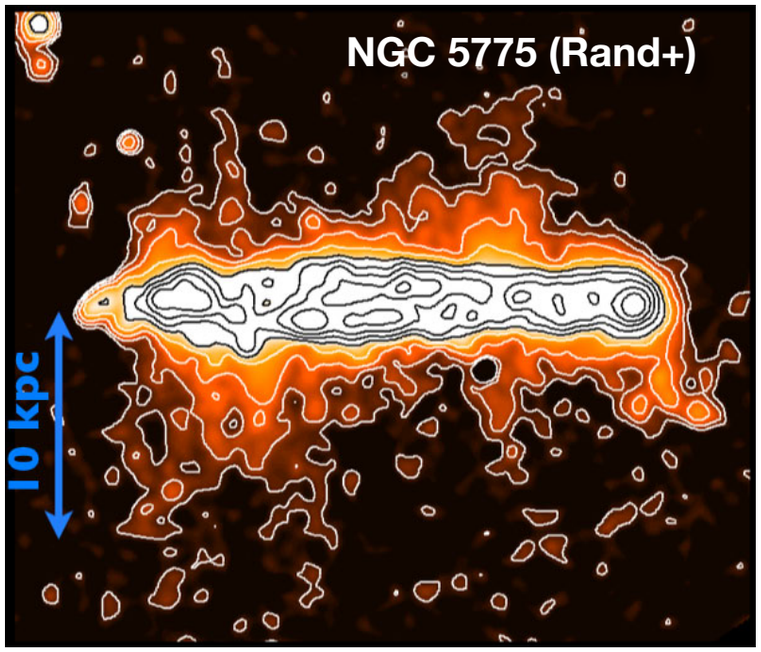


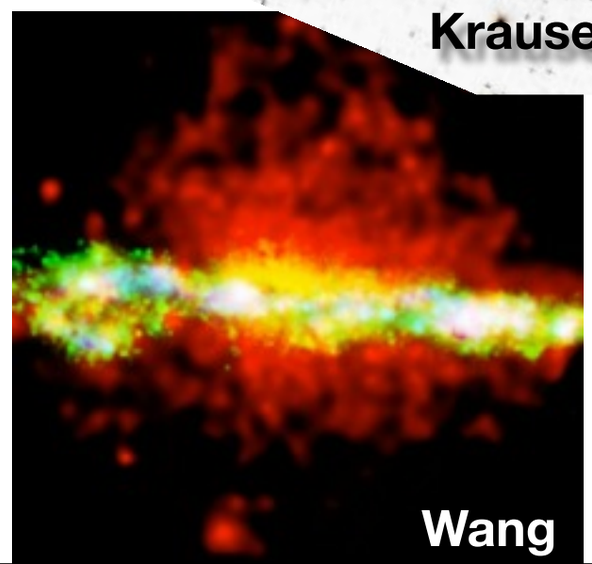
KPNO (B= blue, R=green, Halpha=red) - Maria Patterson; HI - HALOGAS

Multiphase extraplanar regions

- Deep observations of (edge-on) spirals show thick, vertically extended, multi-phase layers of gas, dust, and magnetic fields

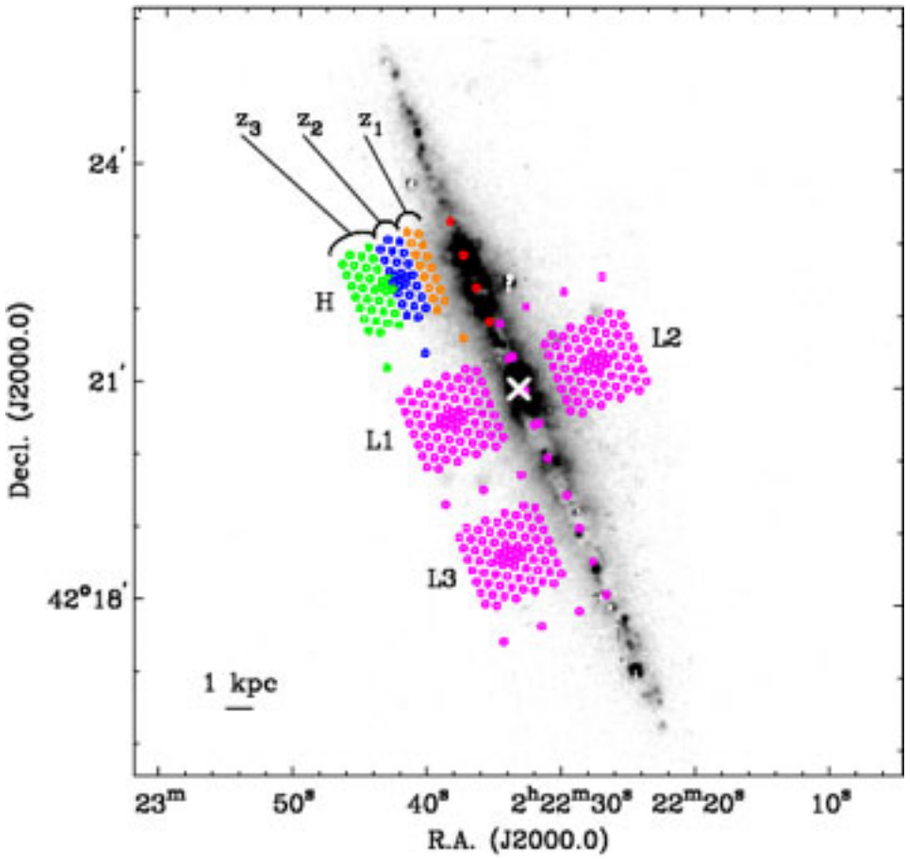


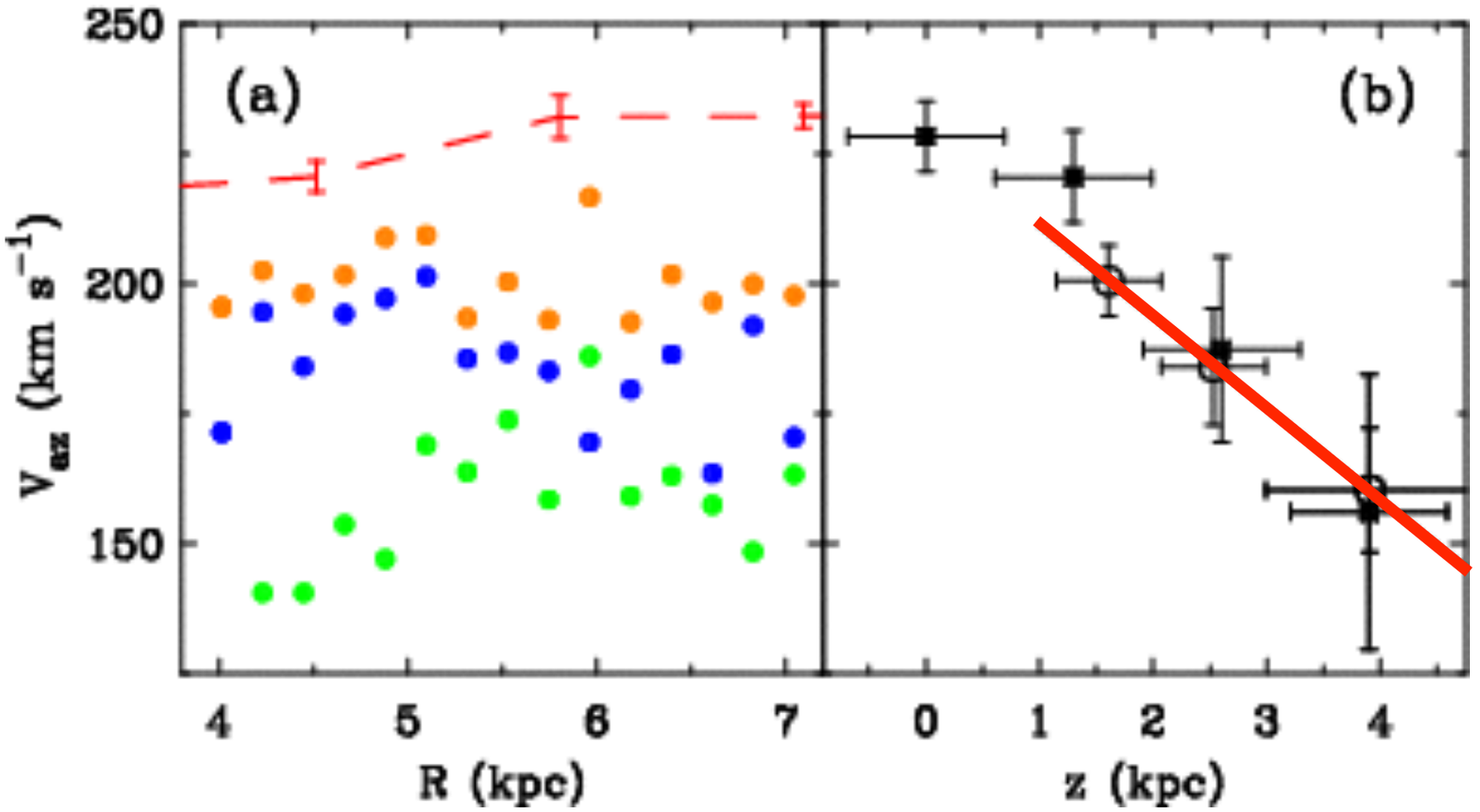




Extraplanar kinematics

- Extraplanar kinematics "lag" the disk rotation curve
  - This means that thick disks can be identified *kinematically* in inclined galaxies



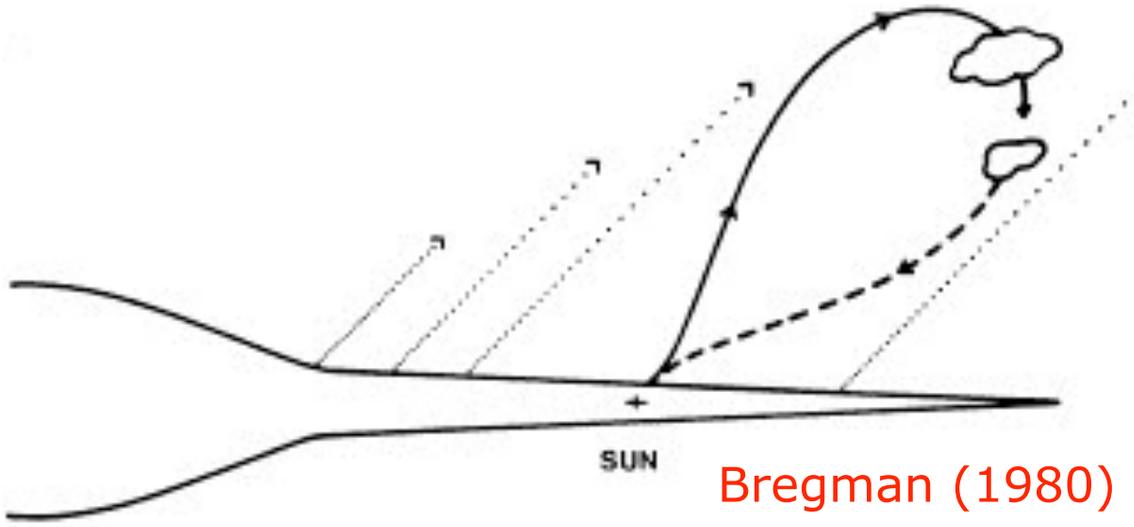


Heald et al. (2007)

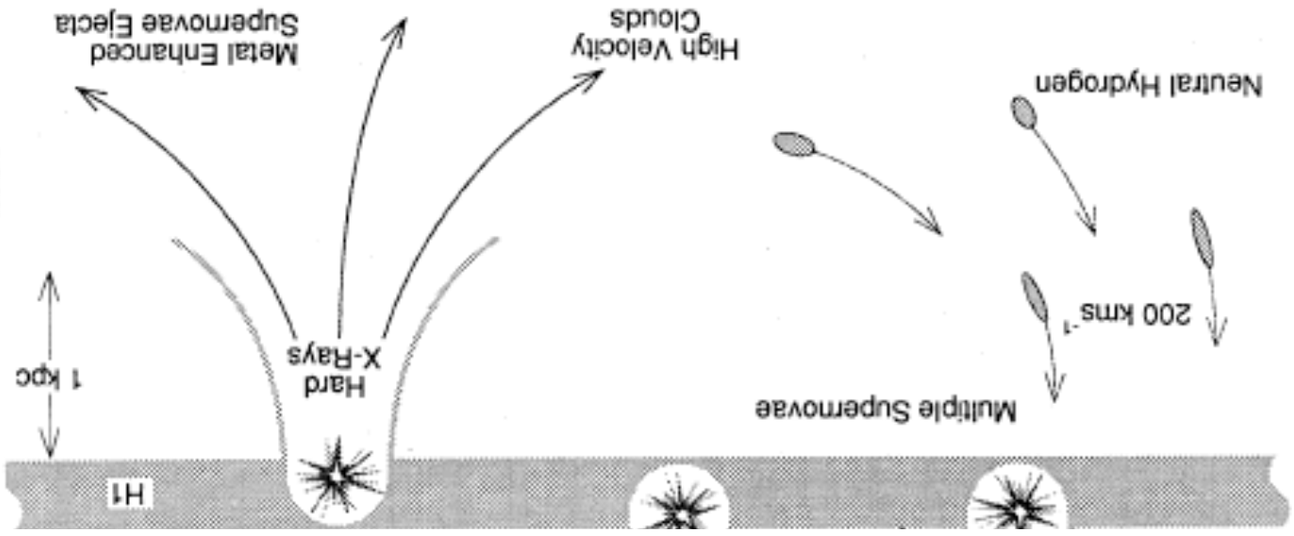
Ionized gas kinematics match HI kinematics from Fraternali et al. (2005)

Understanding extraplanar gas

- Origin thought to be a mixture of galactic fountain / chimney



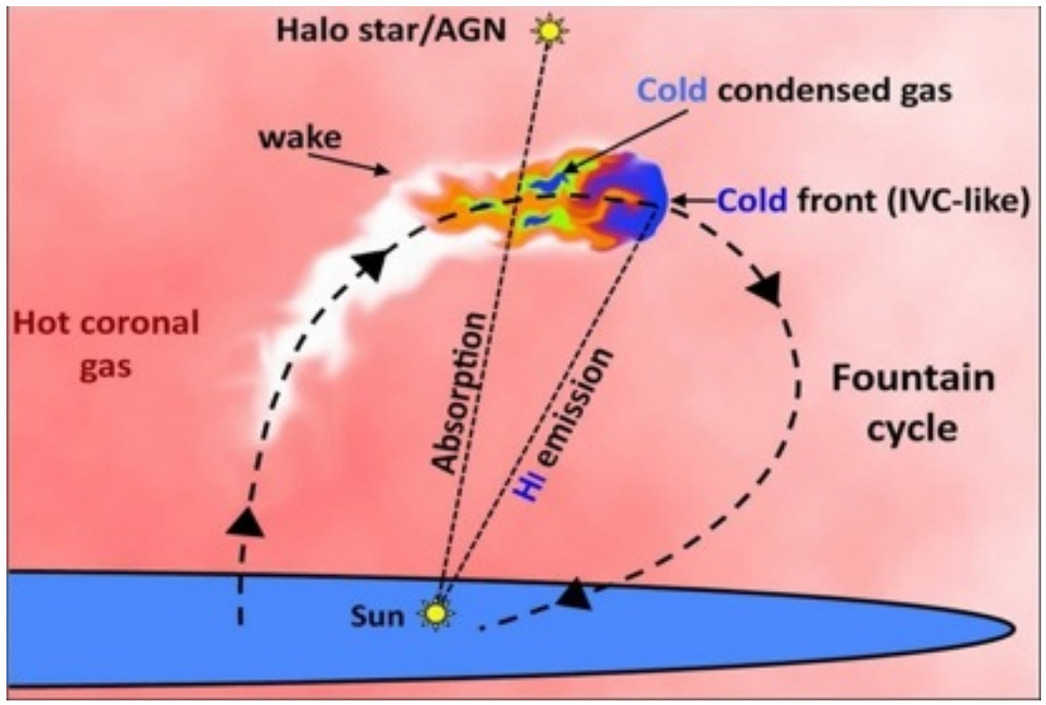
Bregman (1980)



Norman & Ikeuchi (1989)

and swept-up coronal gas

This combination can explain the kinematics, and appears to imply a reasonable accretion rate

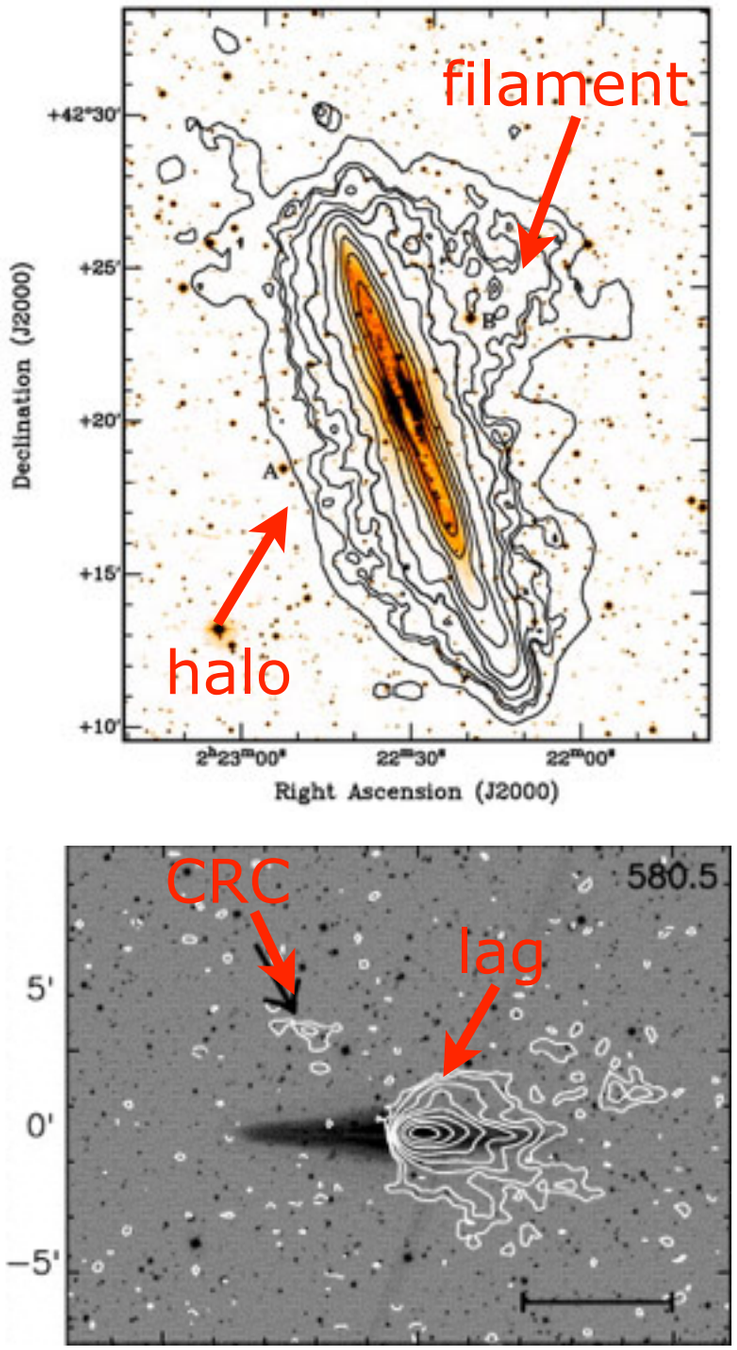


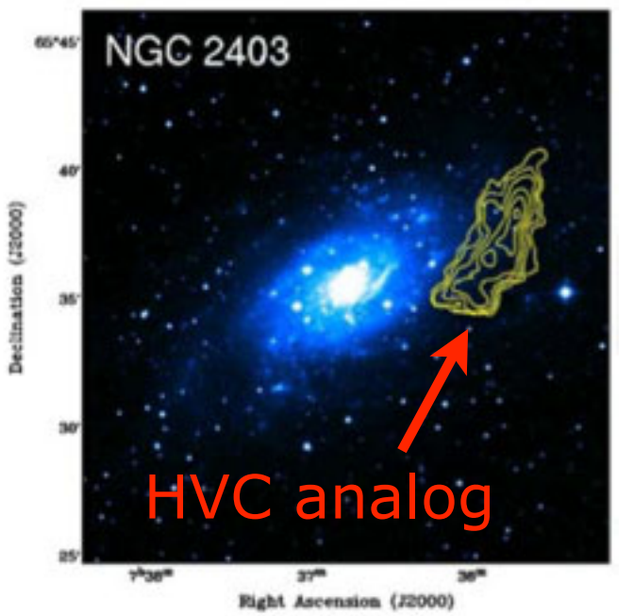
Fraternali et al (2013)

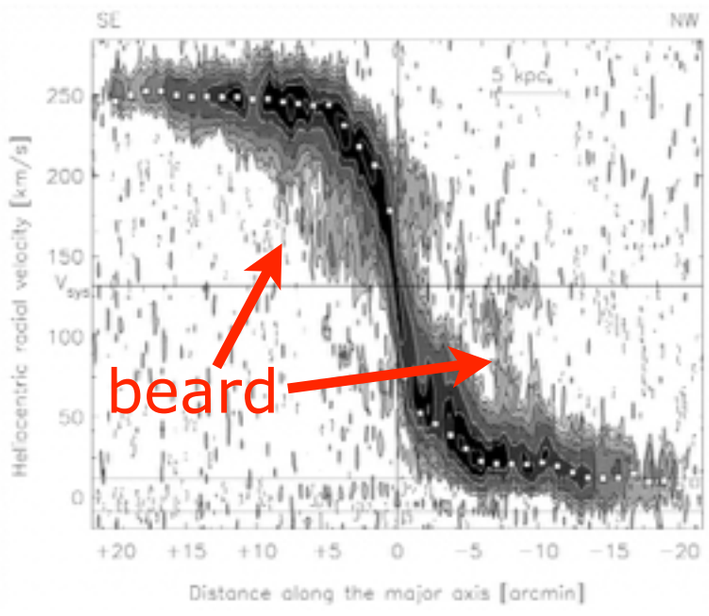
HALOGAS: Scientific motivation

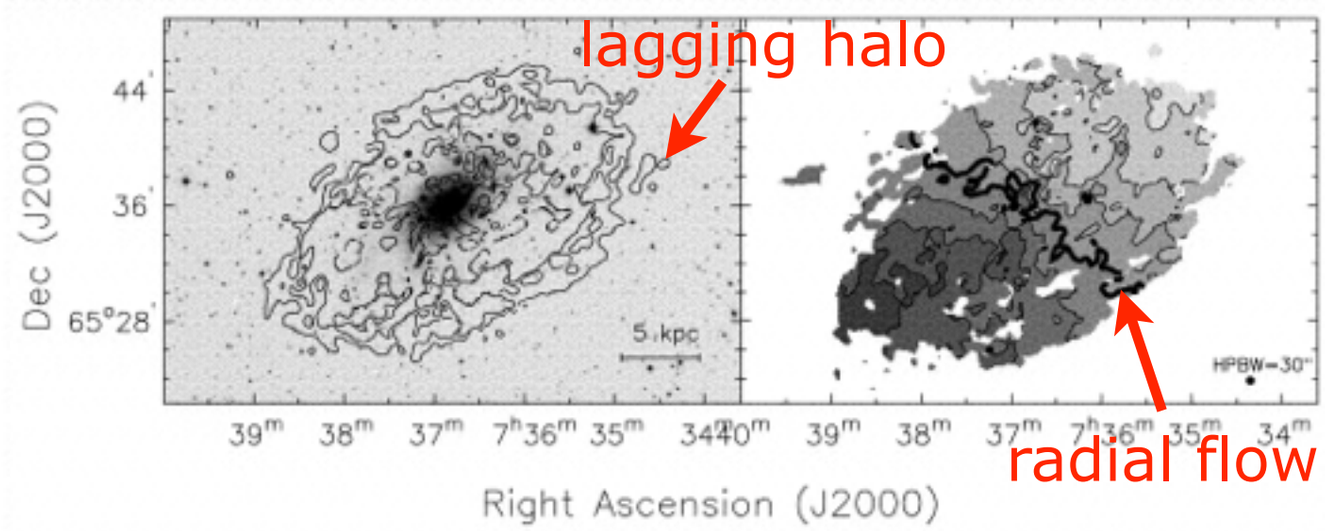
- How many nearby spiral galaxies show features like these?

Oosterloo et al. (2007)





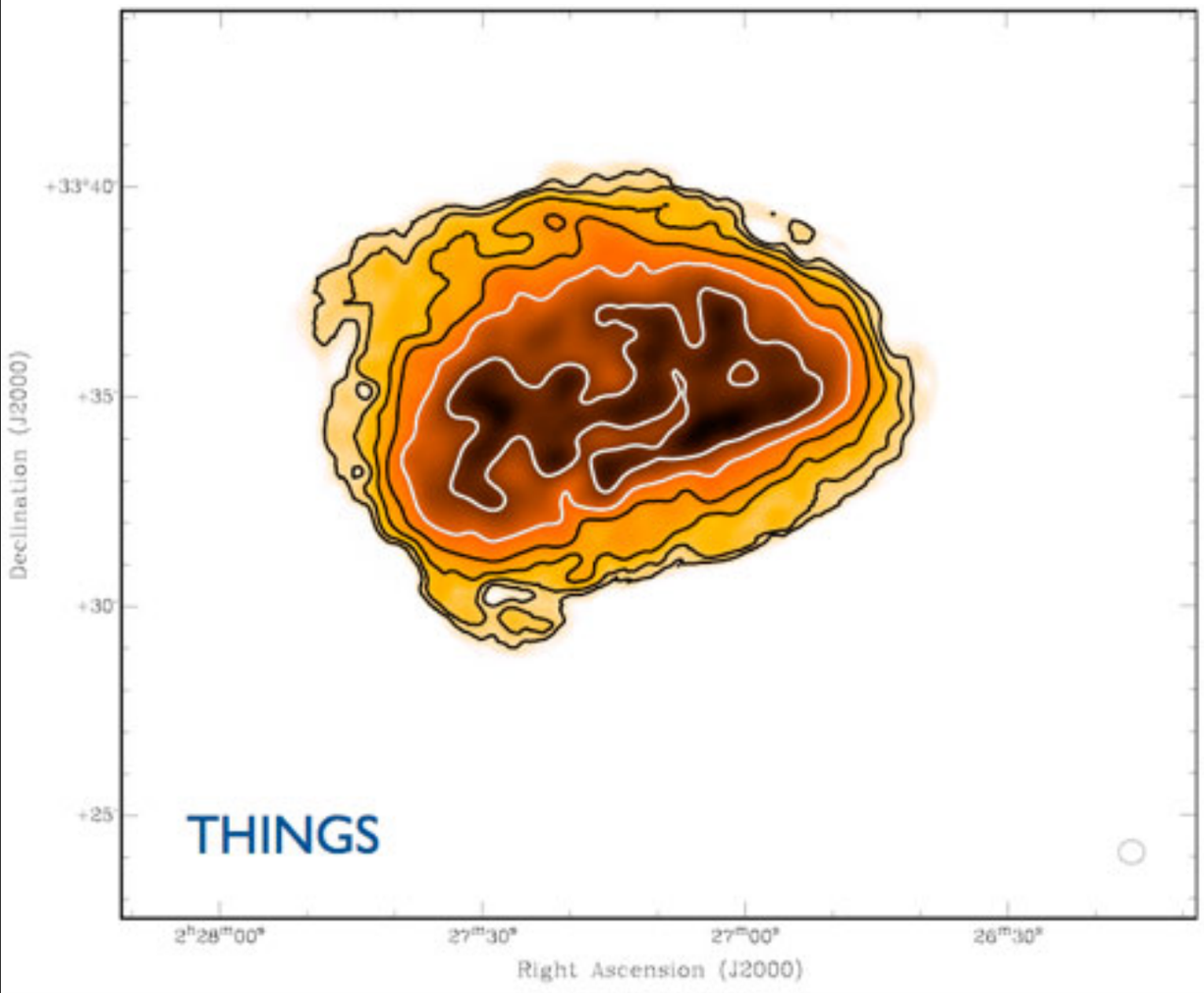


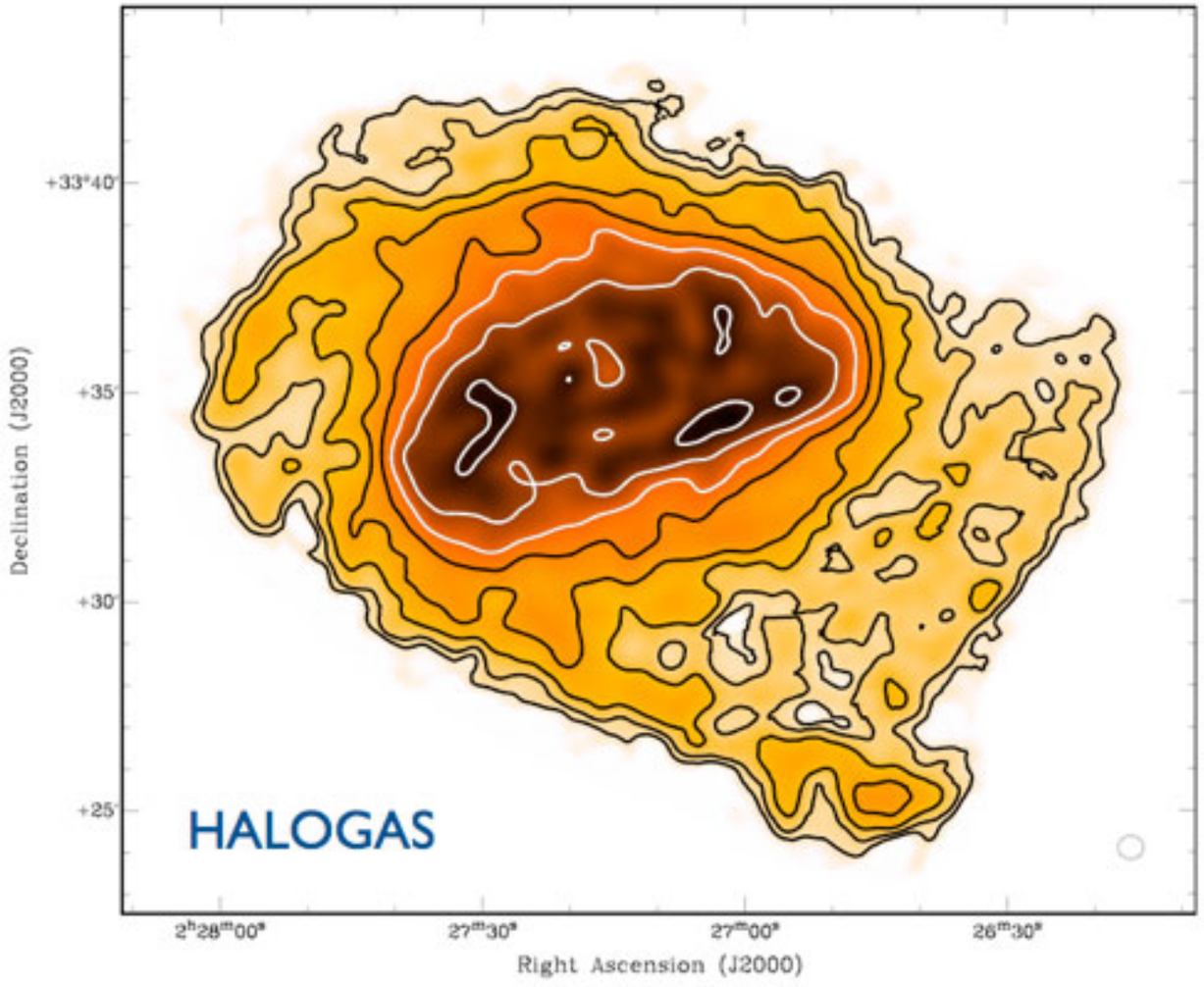


Fraternali et al. (2002)

HALOGAS: WSRT observations

- 10x12 hr per target, to reach typical column density sensitivity of N_{HI} = 1x10^{19} cm^{-2} (3σ) at 30” resolution (cf. THINGS: 5x10^{19} cm^{-2})
- Survey sample = 24 galaxies (including NGC 891 & NGC 2403)
- WSRT observations are complete as of early 2013.
- Advantage of deep WSRT observations seen at start of survey:





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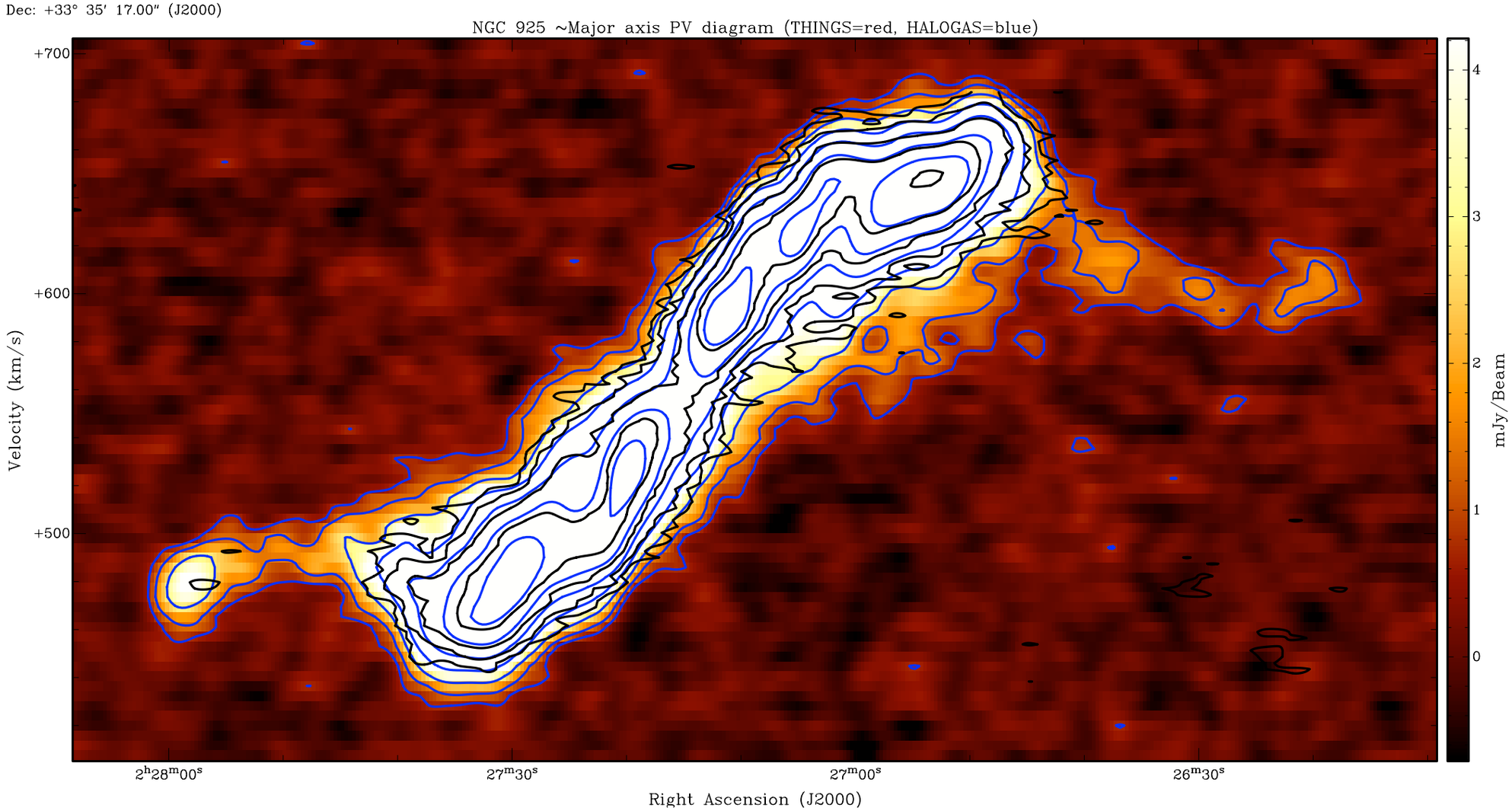
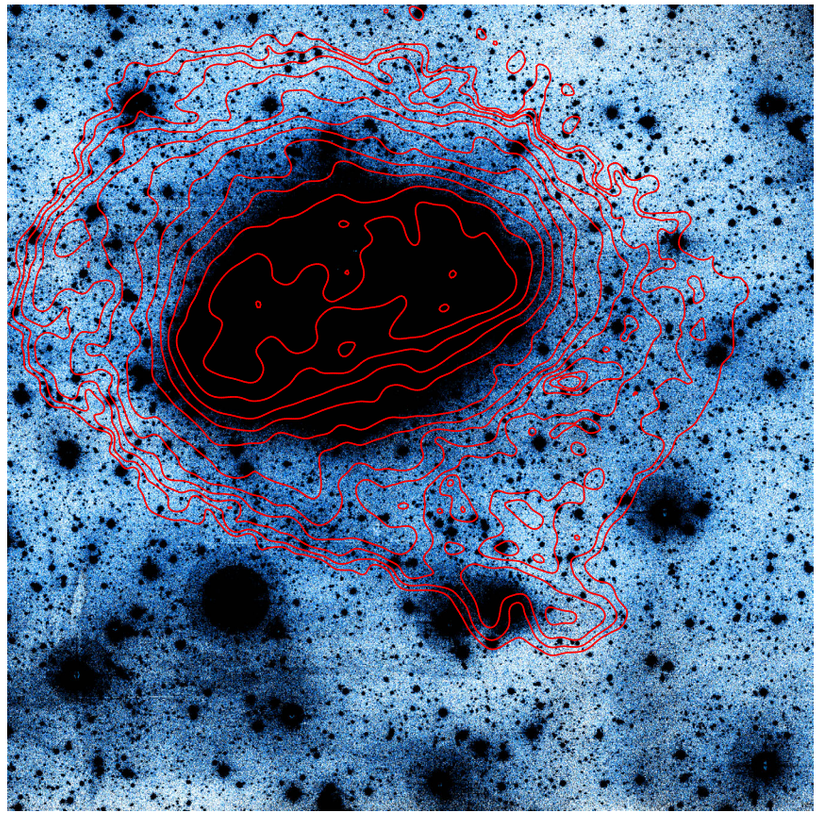


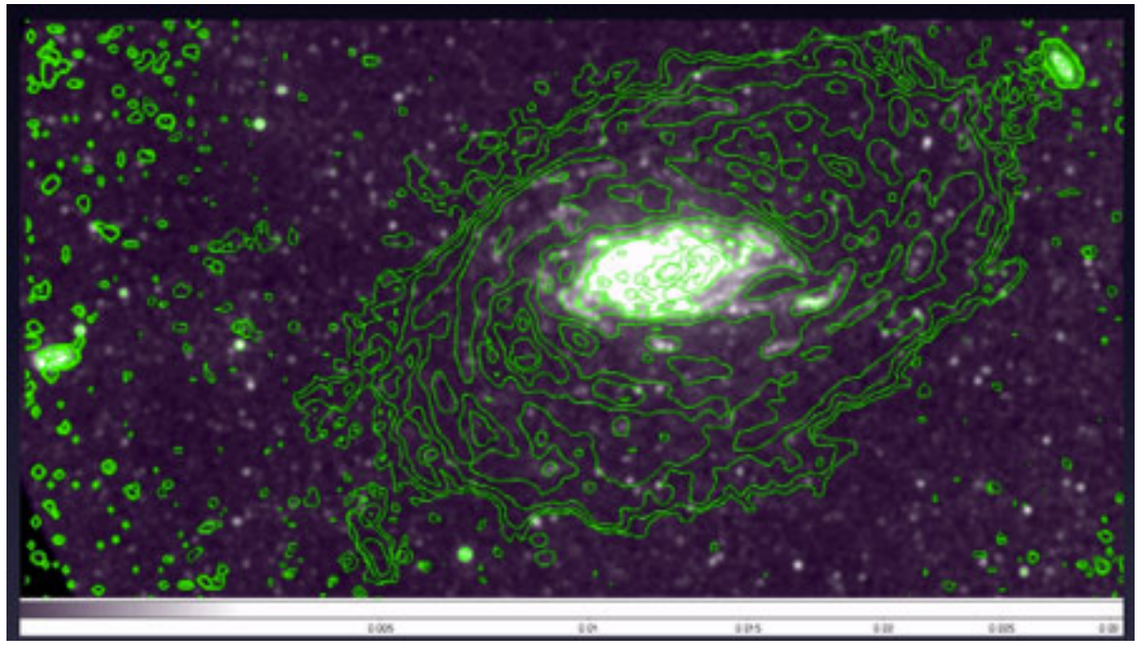
Ancillary HALOGAS observations



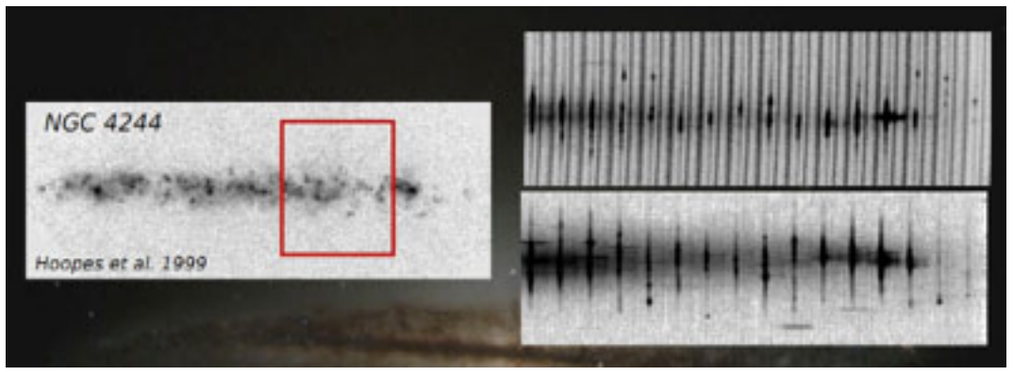
HALOSTARS
Deep R-band optical imaging at INT

Seach for stellar streams and counterparts to HI features detected in HALOGAS main survey

GALEX
Deep NUV observations of HALOGAS targets to fill gaps in deep galaxy survey



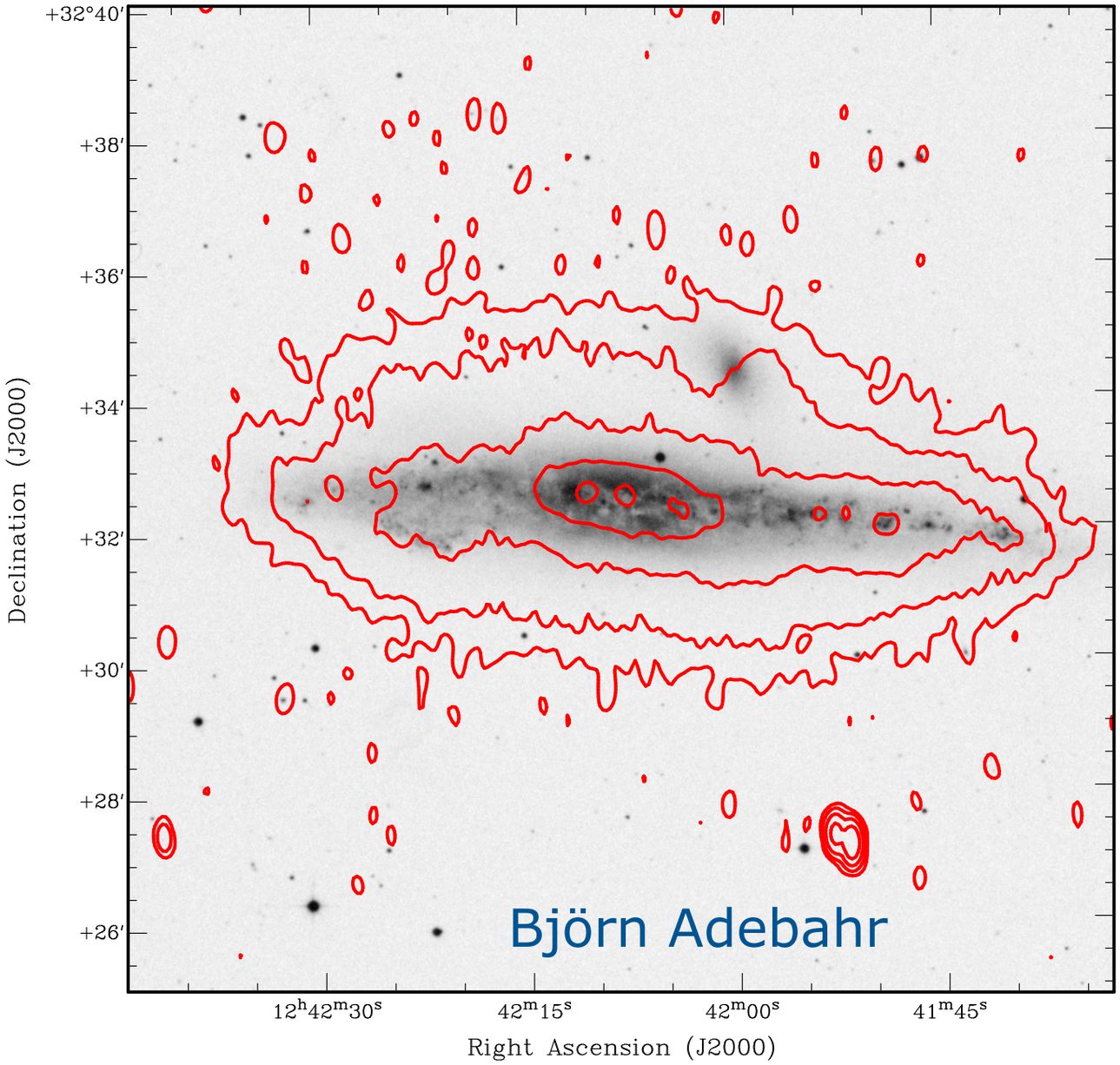
Main goals:
Detect outer disk star formation like in NGC 5055
Detect UV emission reflected from halo dust grains

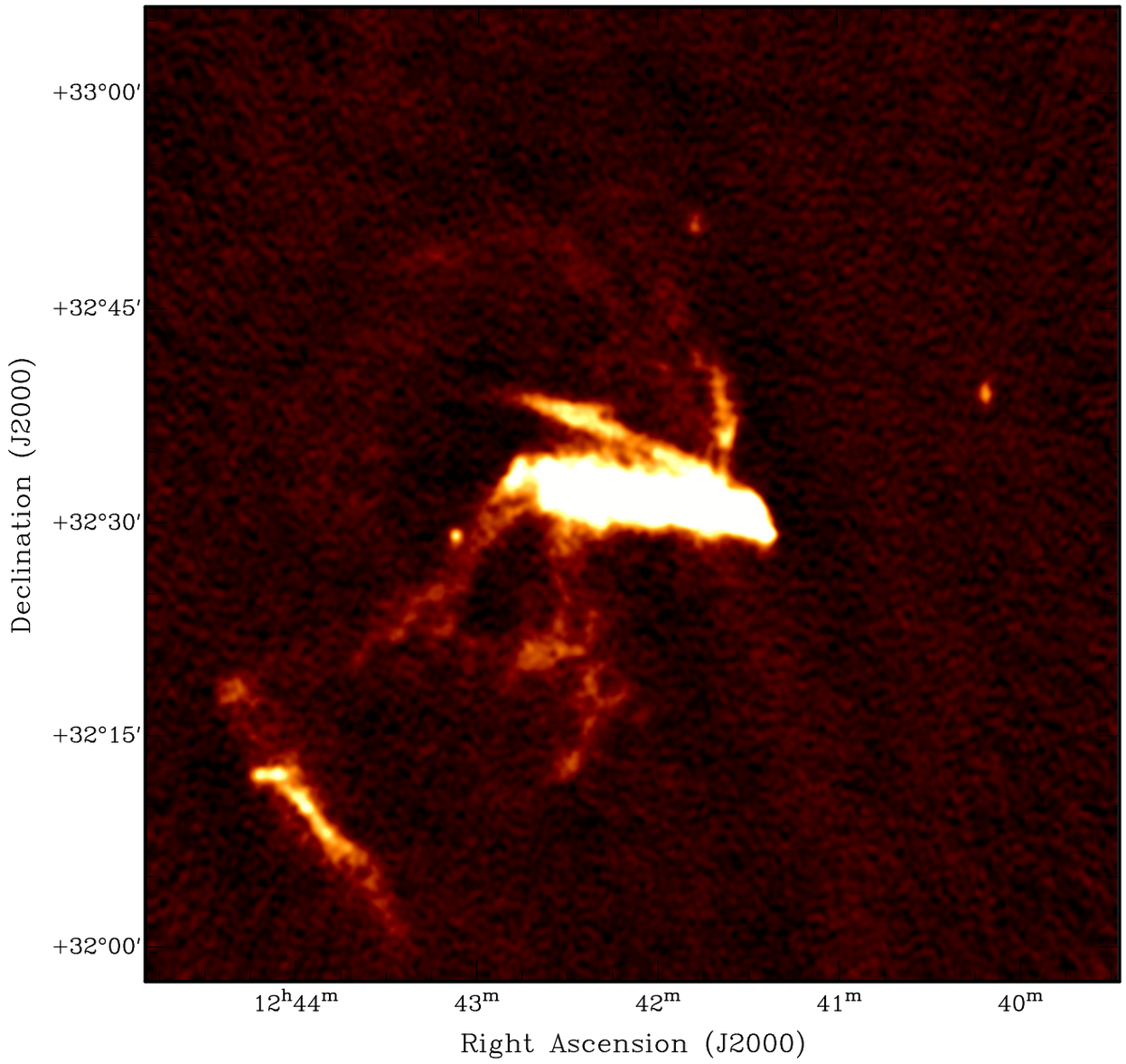


APO Multi-longslit spectroscopy: Build up 2D optical spectra of HALOGAS edge-ons; compare with HI observations made with WSRT program

Data reduction

- Half of the sample observed with simultaneous 4x20 MHz full-Stokes continuum bands … allowing commensal polarization work AND improved identification of Solar interference





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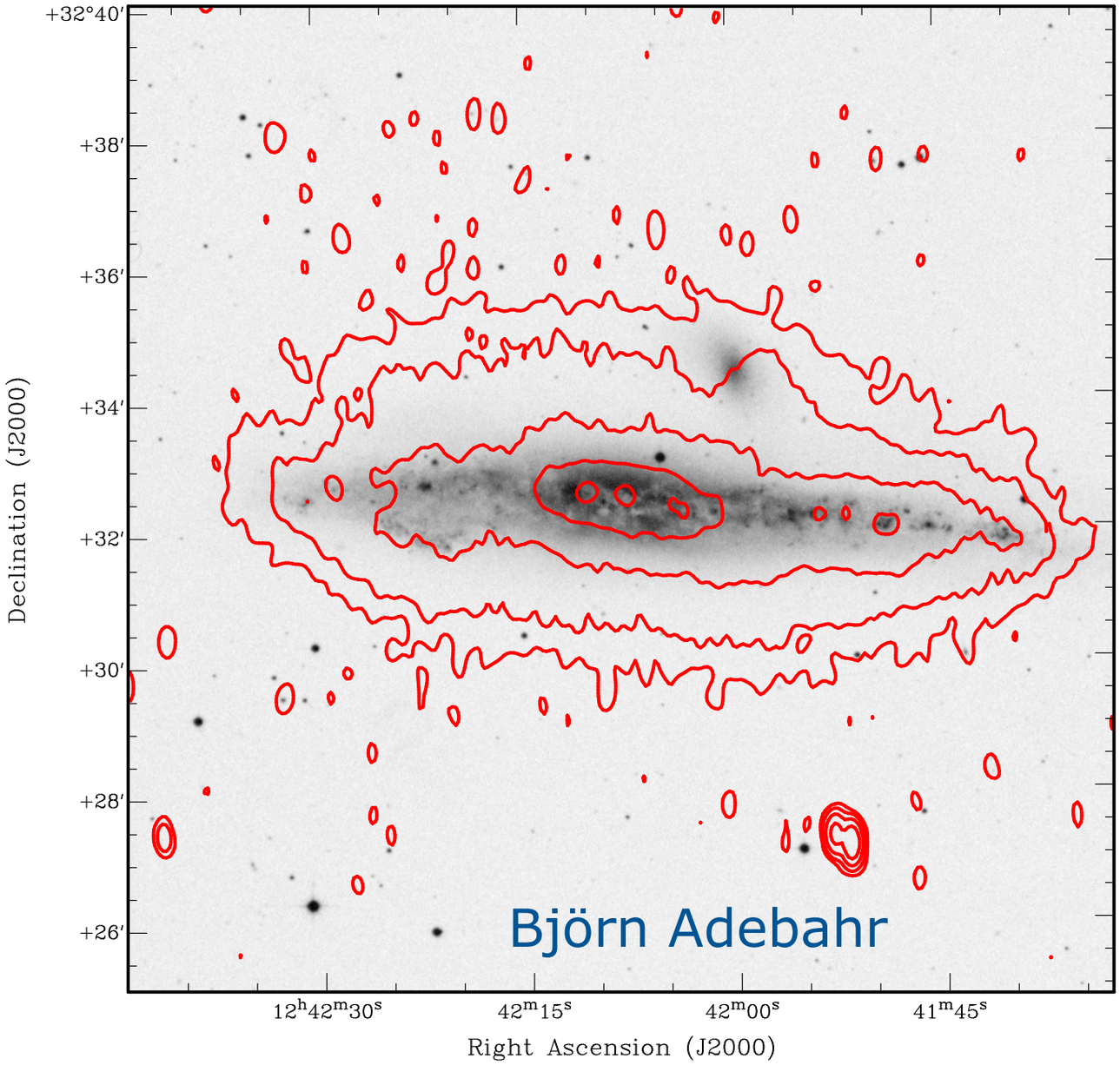

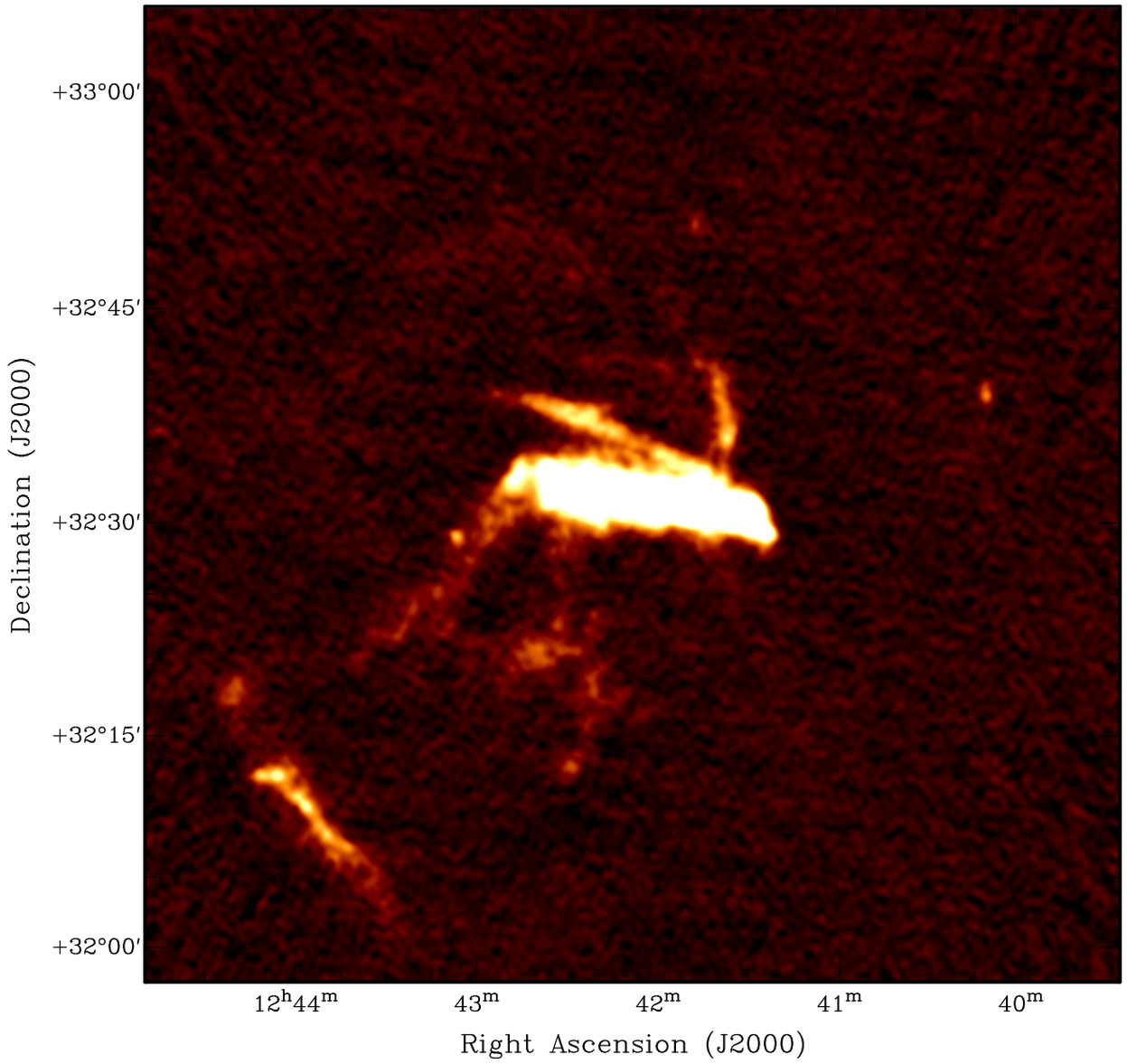

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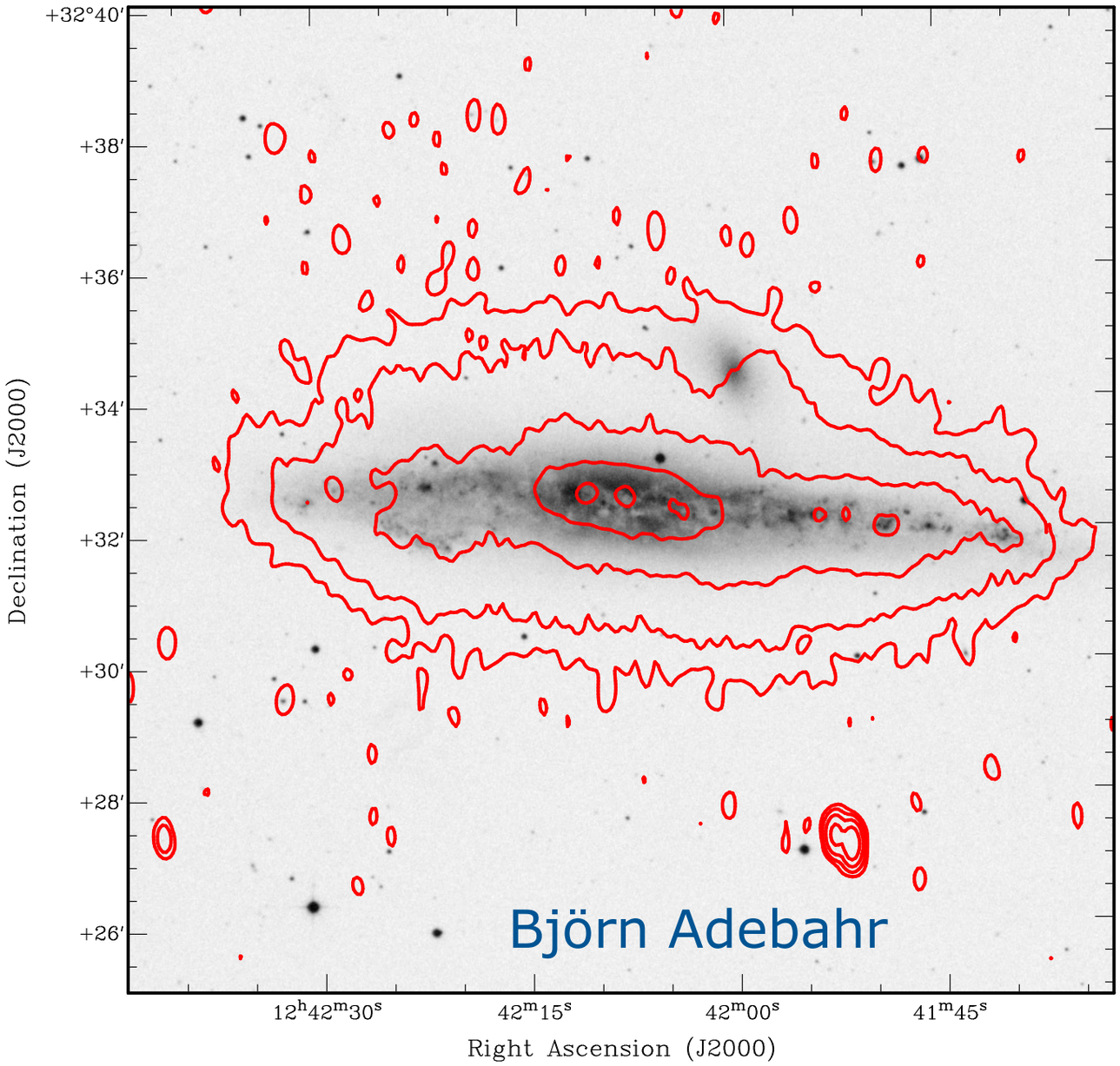
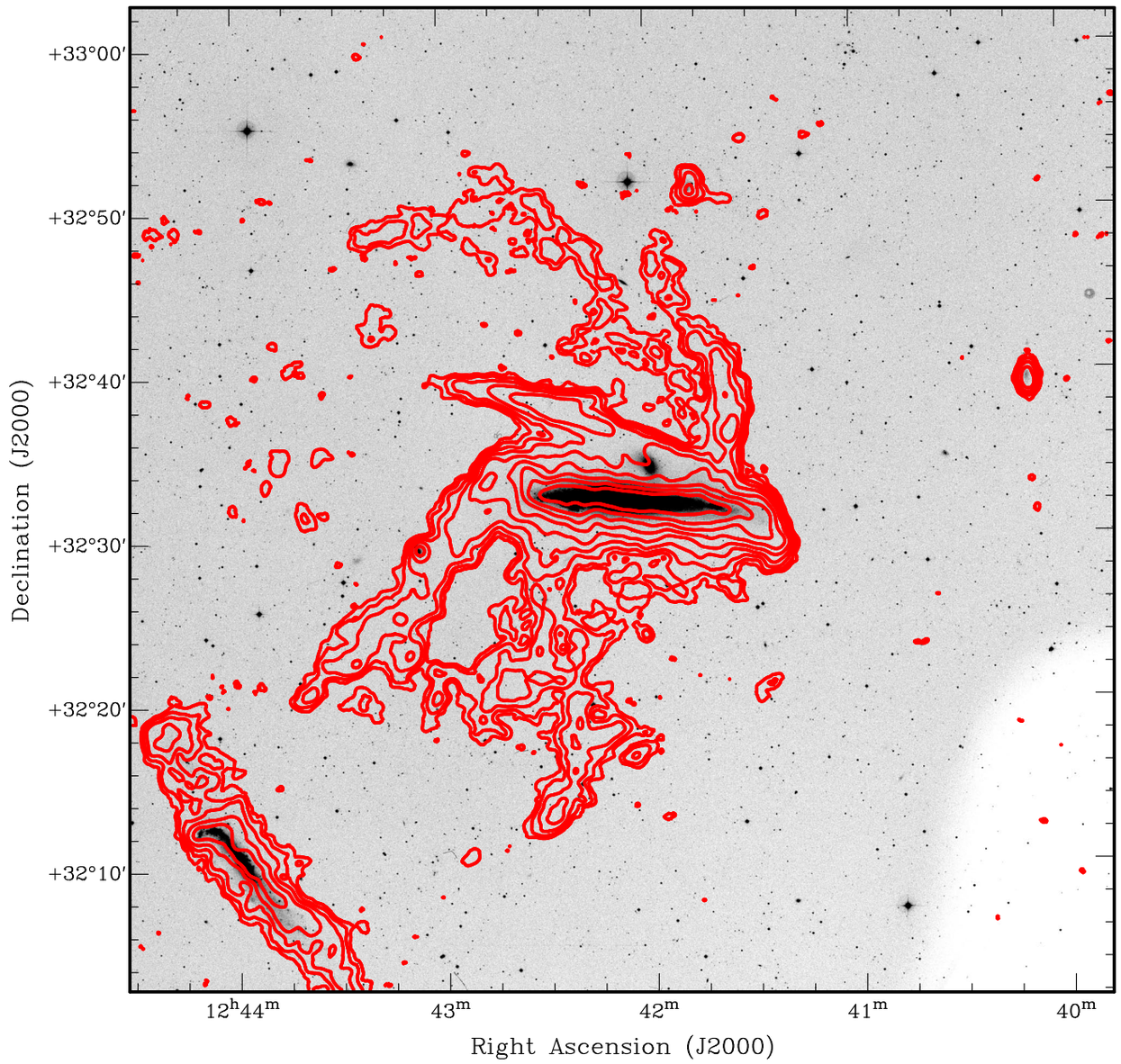
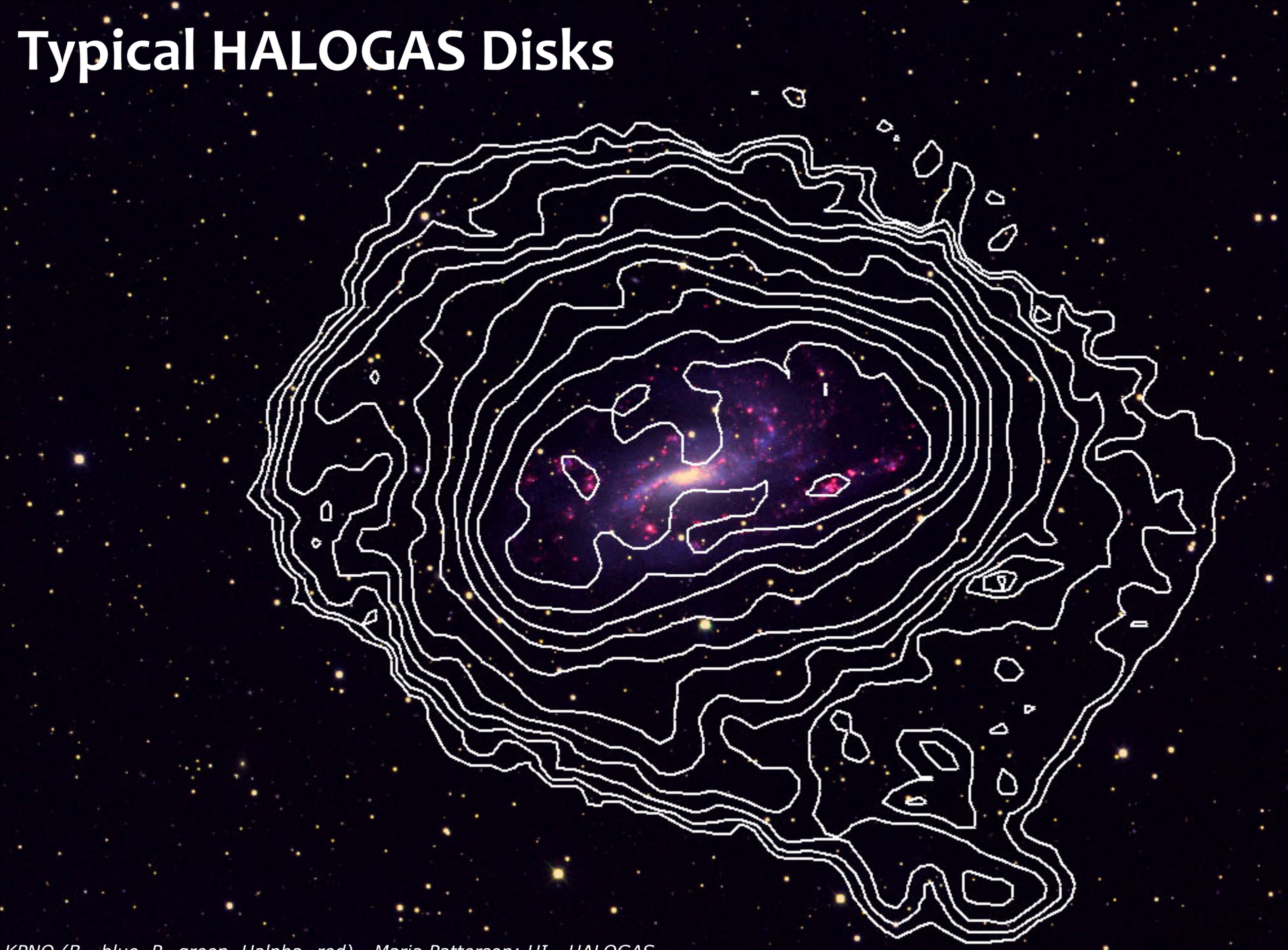




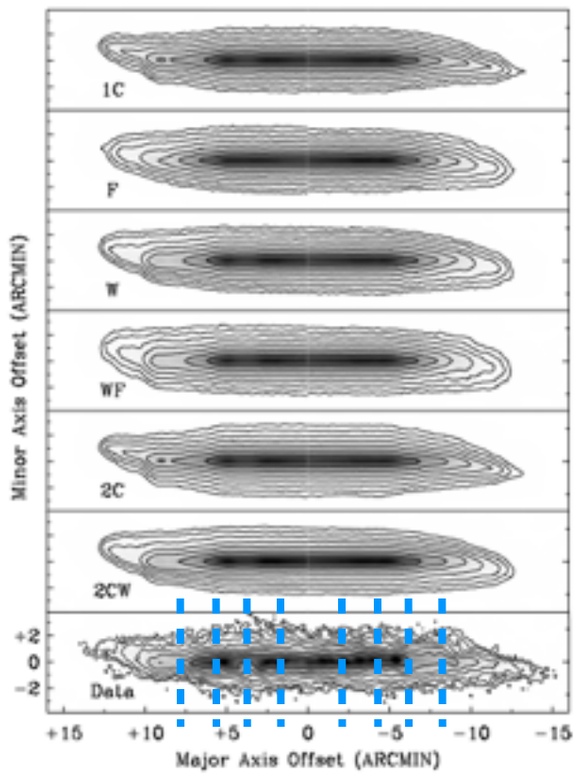
Typical HALOGAS Disks

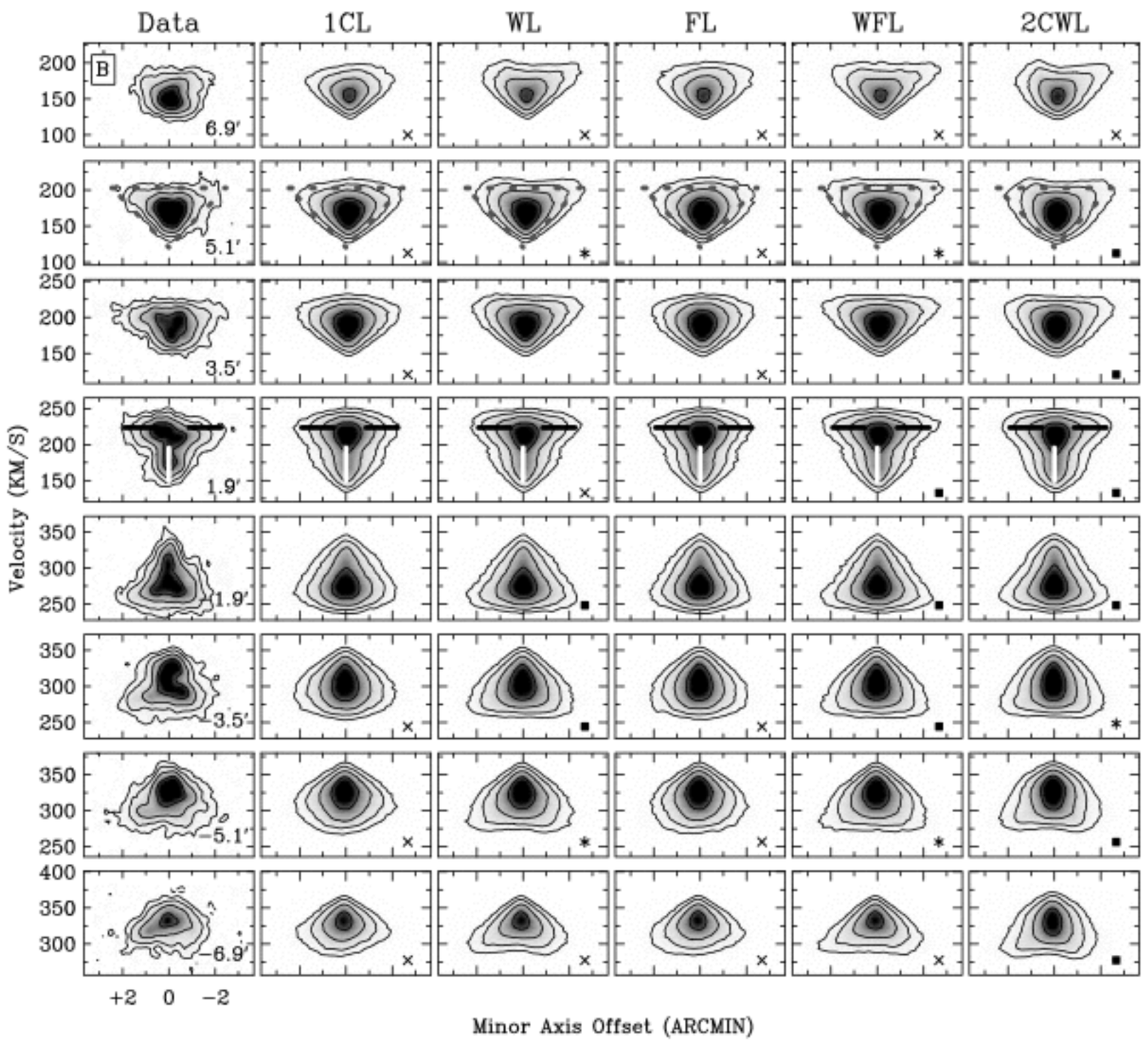


KPNO (B= blue, R=green, Halpha=red) - Maria Patterson; HI - HALOGAS

NGC 4244 (Zschaechner+ 2011)

- Key results:
  - no halo - *surprisingly thin*
  - radially varying rotational lag ~9 km/s/kpc

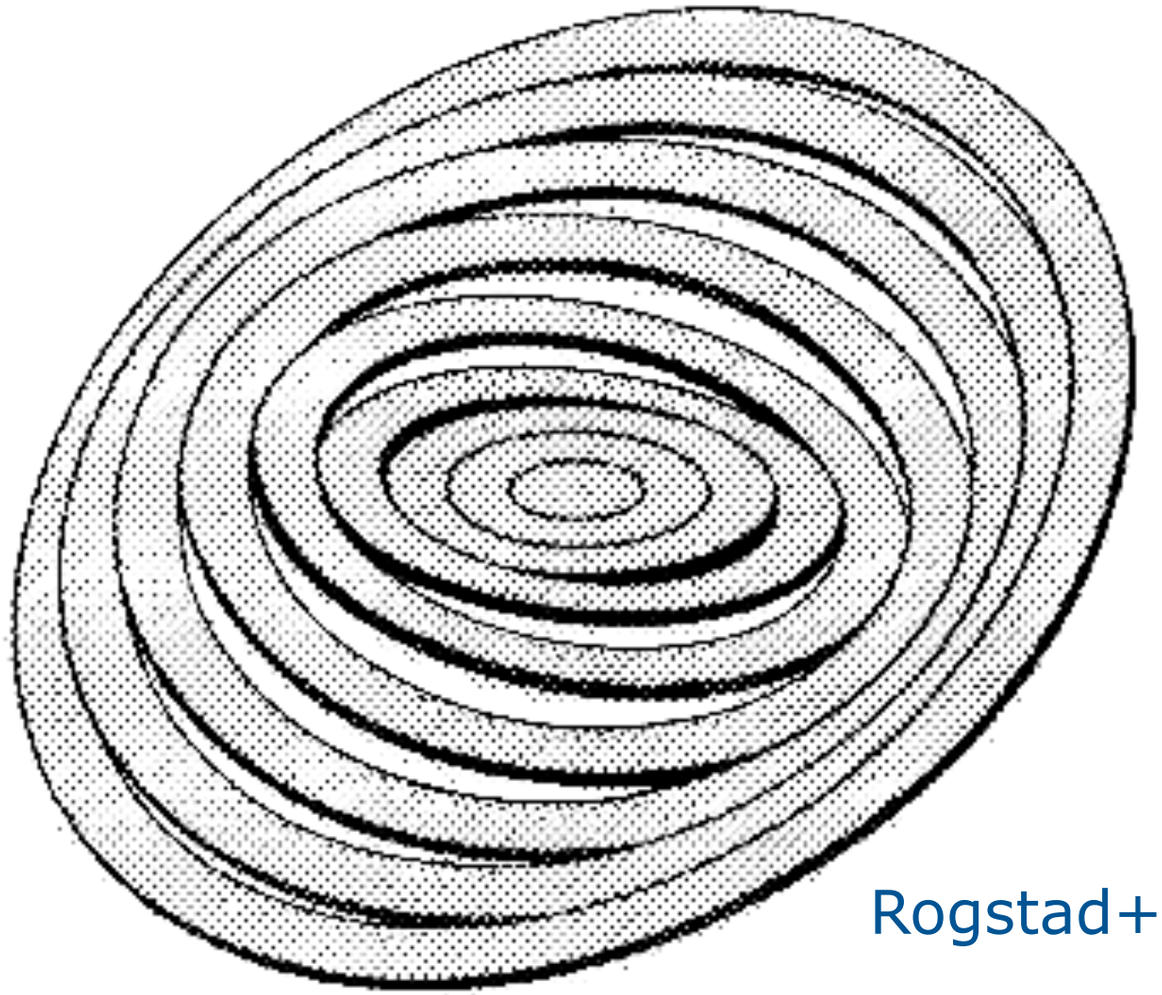




TiRiFiC (Jozsa et al 2007)

- Tilted Ring Fitting Code

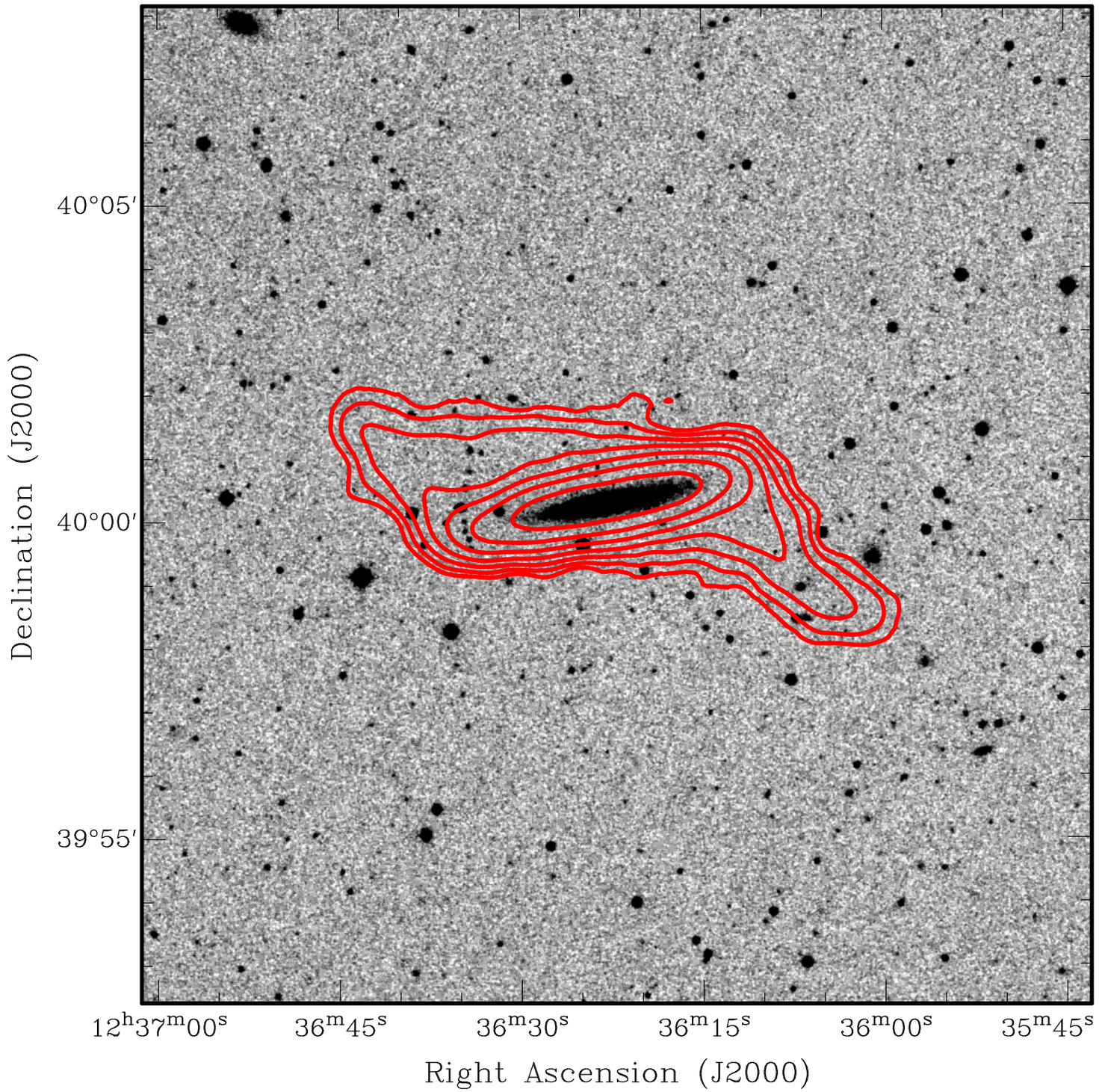
- Used to model in 3D: warps, flares, thick disks, spiral arms, ...
  Extraordinary ability to assess the effect of various features



Rogstad+ (1974)

UGC 7774

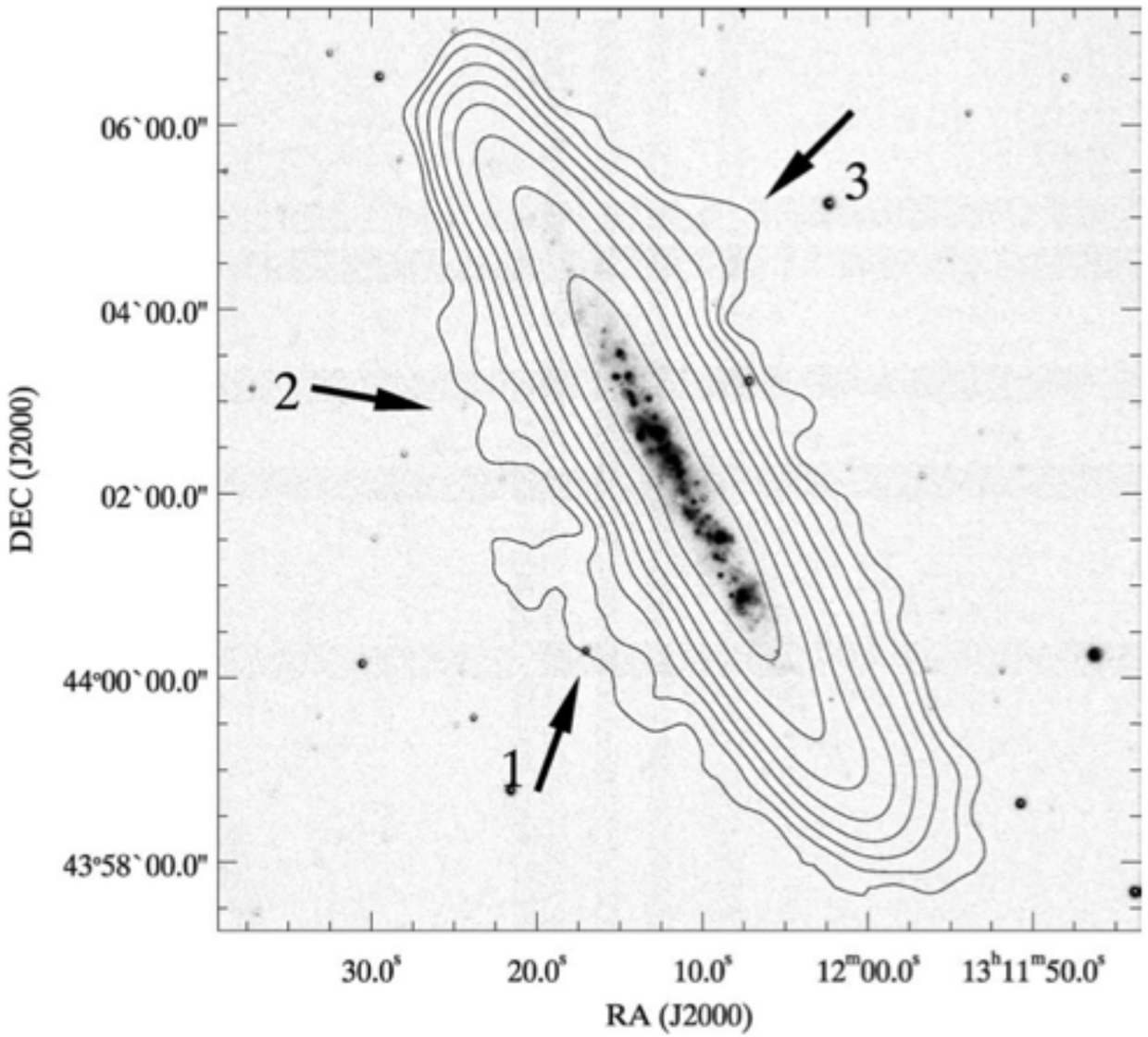
- Strongly warped! but no sign of extraplanar HI...



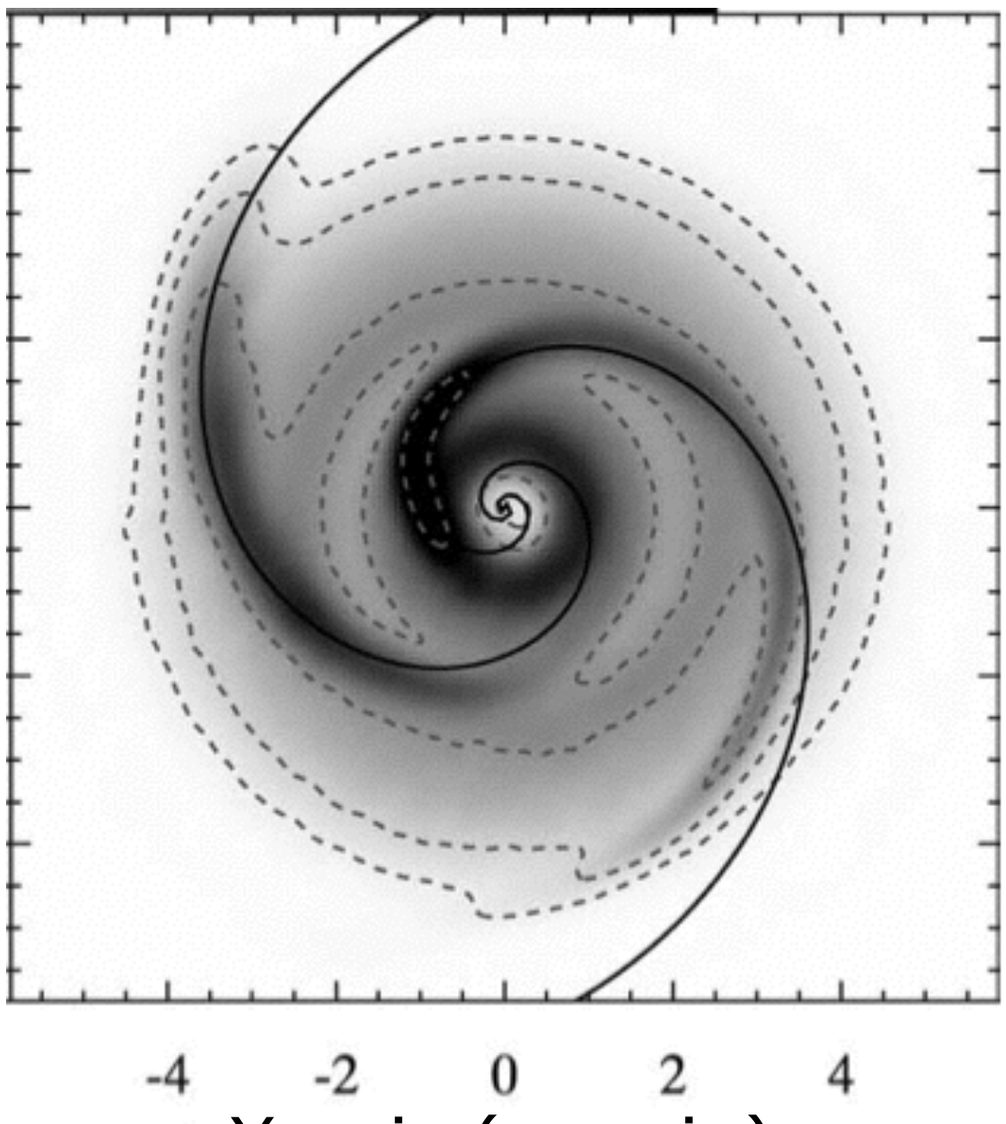
NGC 5023 (Kamphuis+ 2013)

- Need to model spiral structure in an edge-on galaxy....
  - Reduces (but does not eliminate) lagging thick disk, removes model asymmetries, lag does not radially vary, disk thins

Edge-on (sky) view

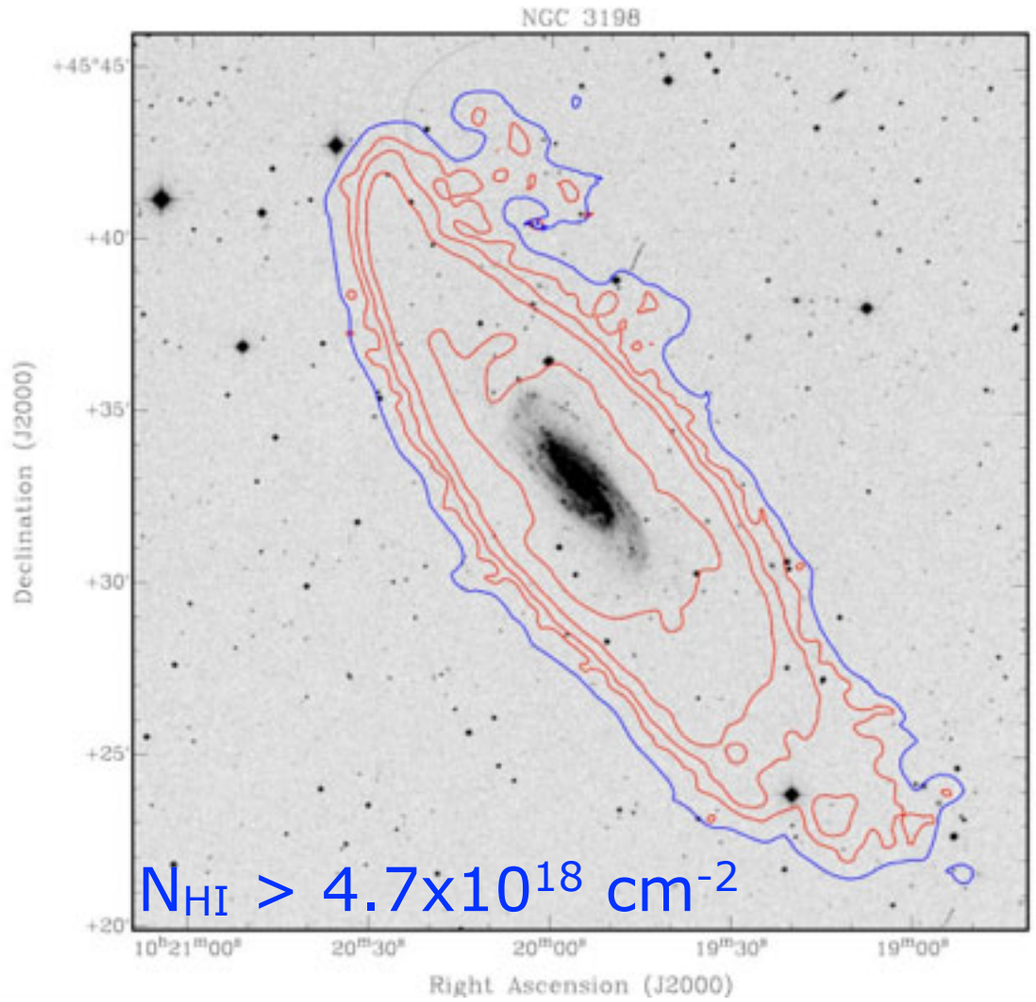


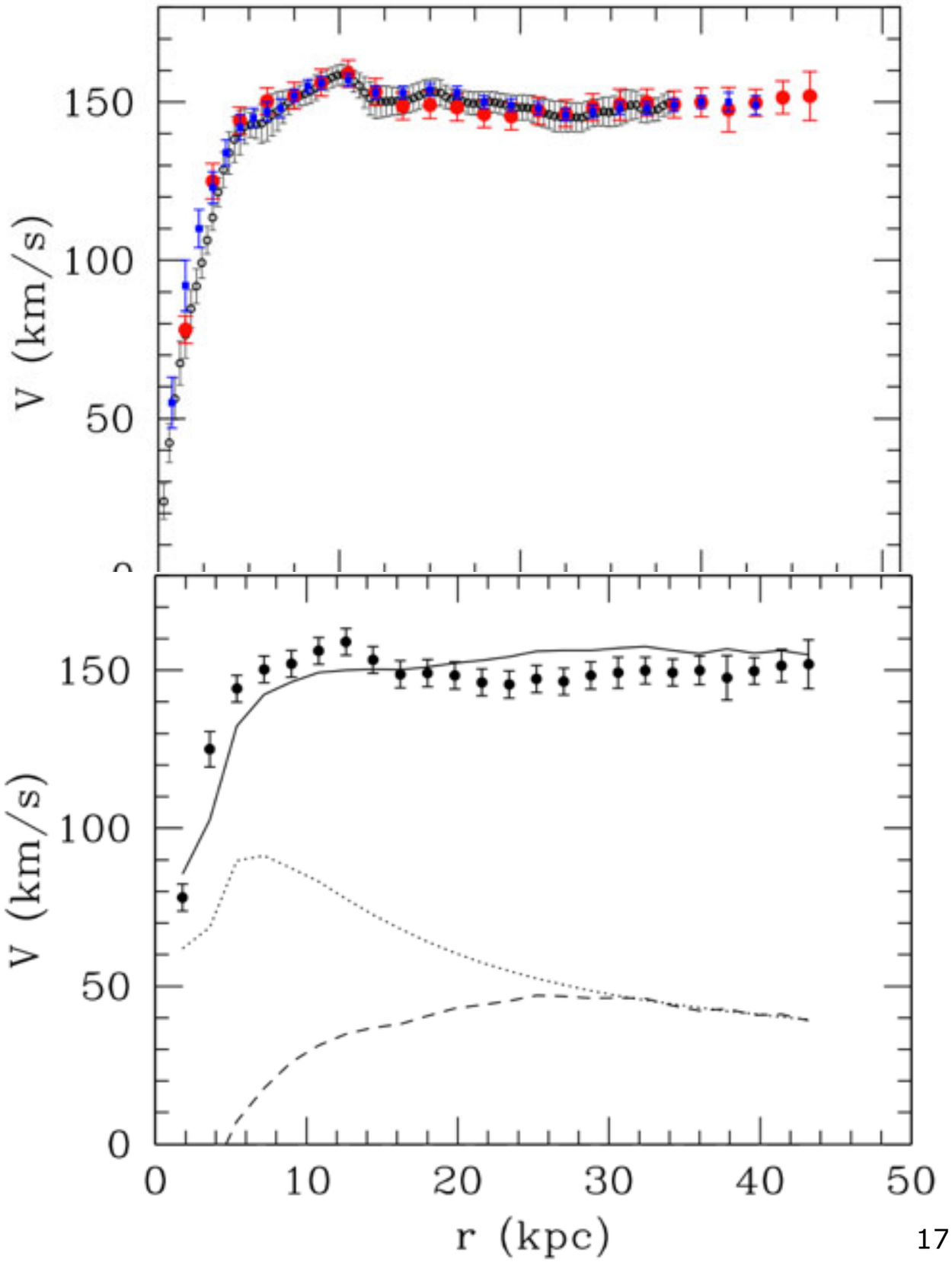
Face-on (model) view



NGC 3198 (Gentile+ 2013)

- Key result: lagging thick disk (~7-15 km/s/kpc) containing estimated ~15% of HI mass from disk-halo separation





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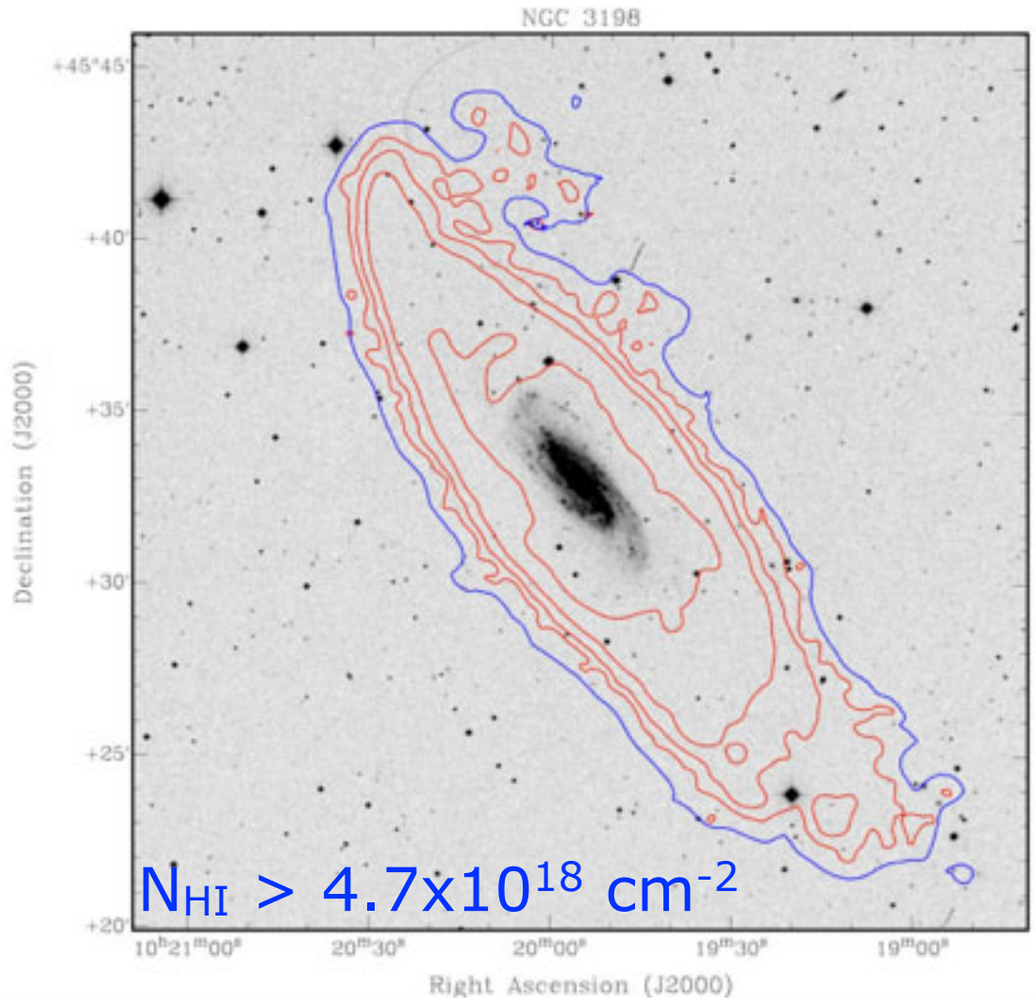
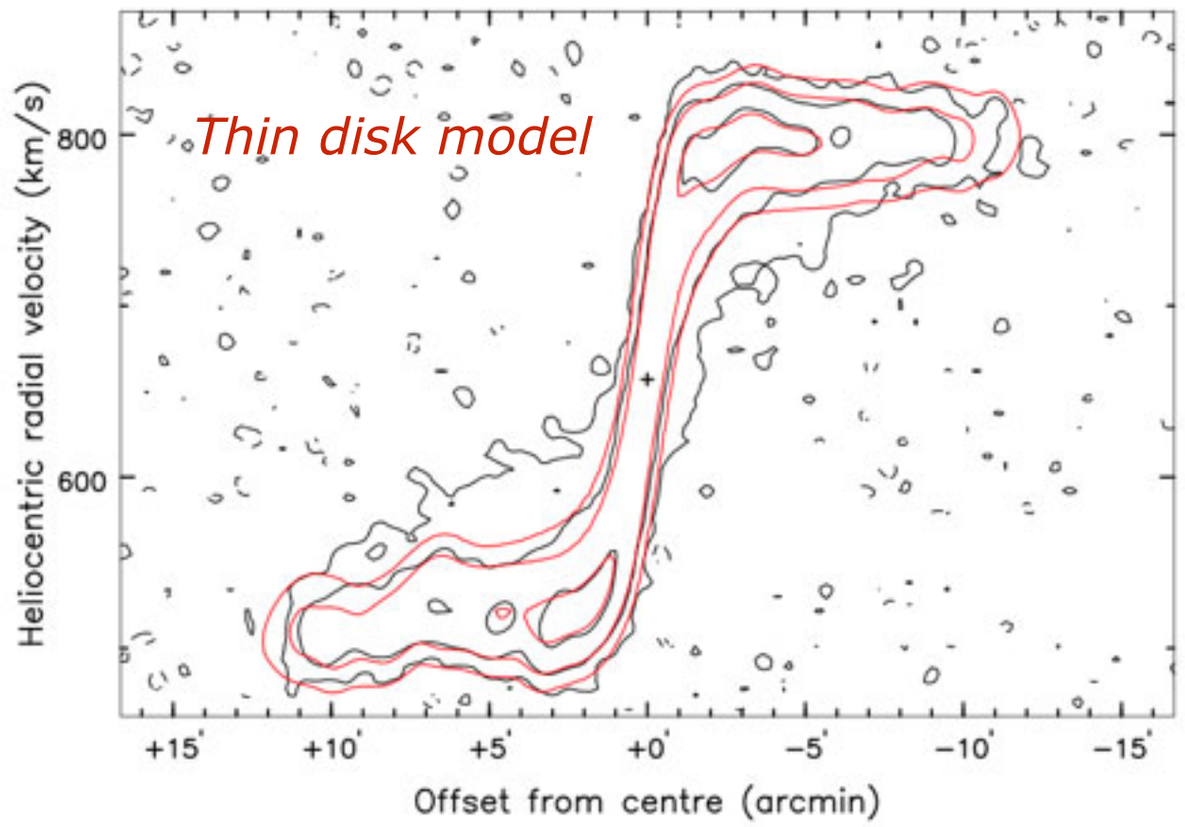
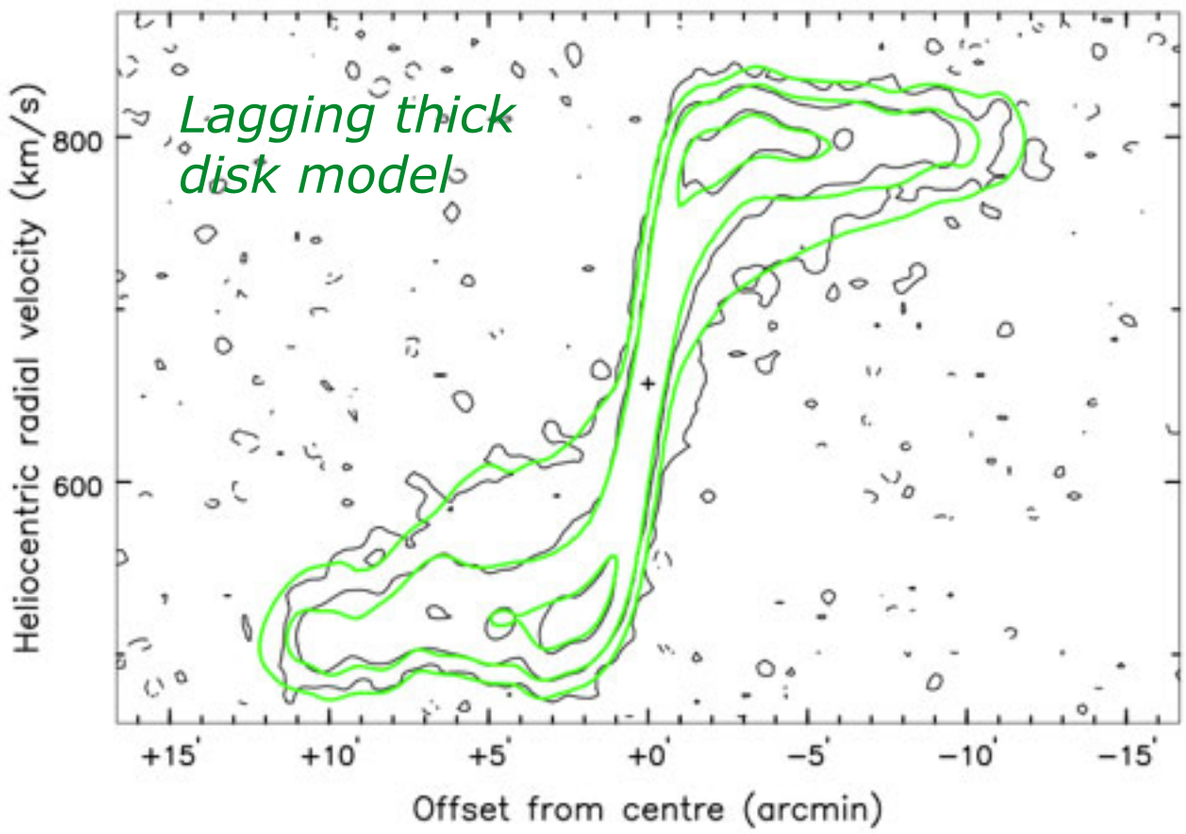
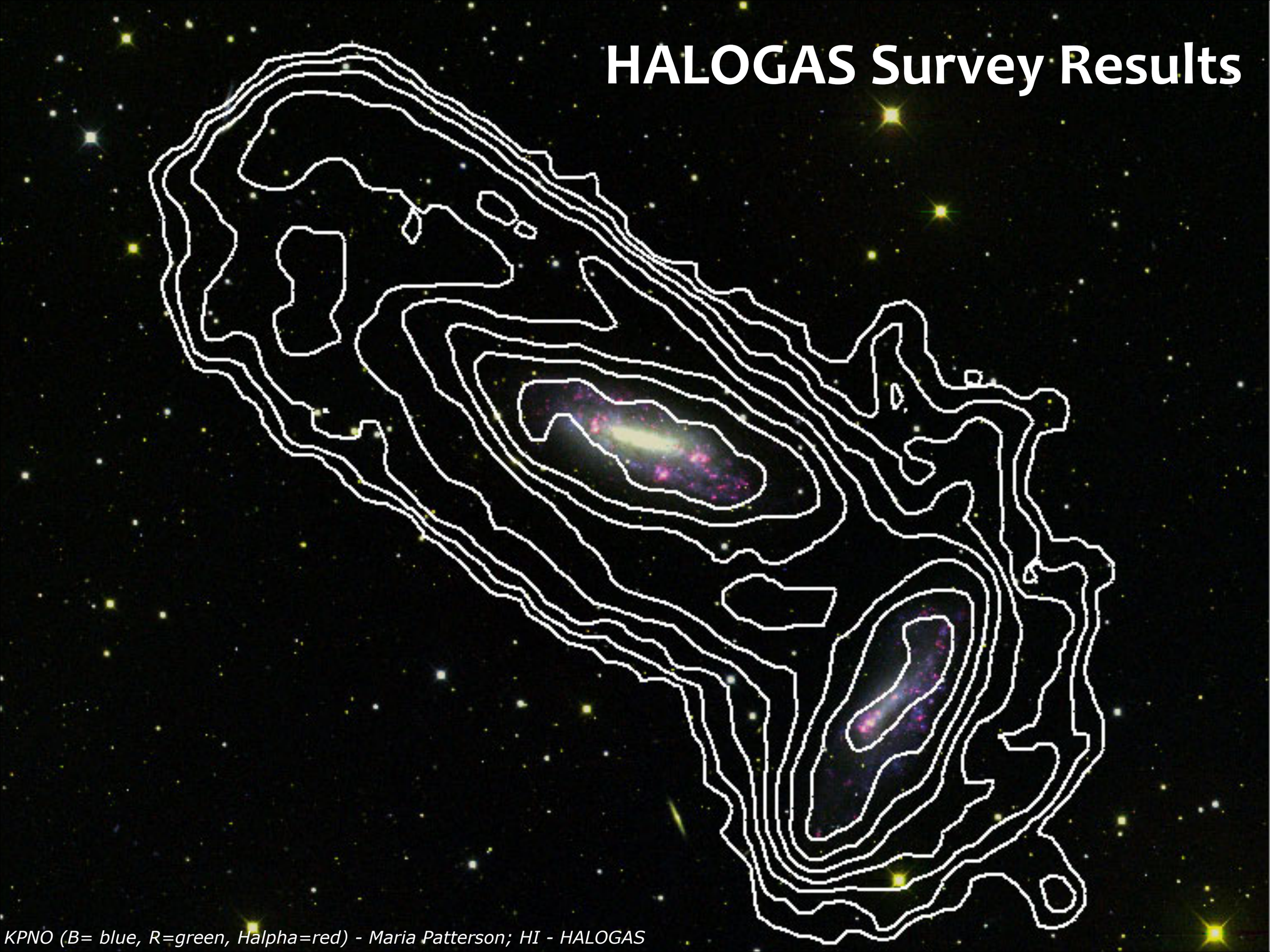






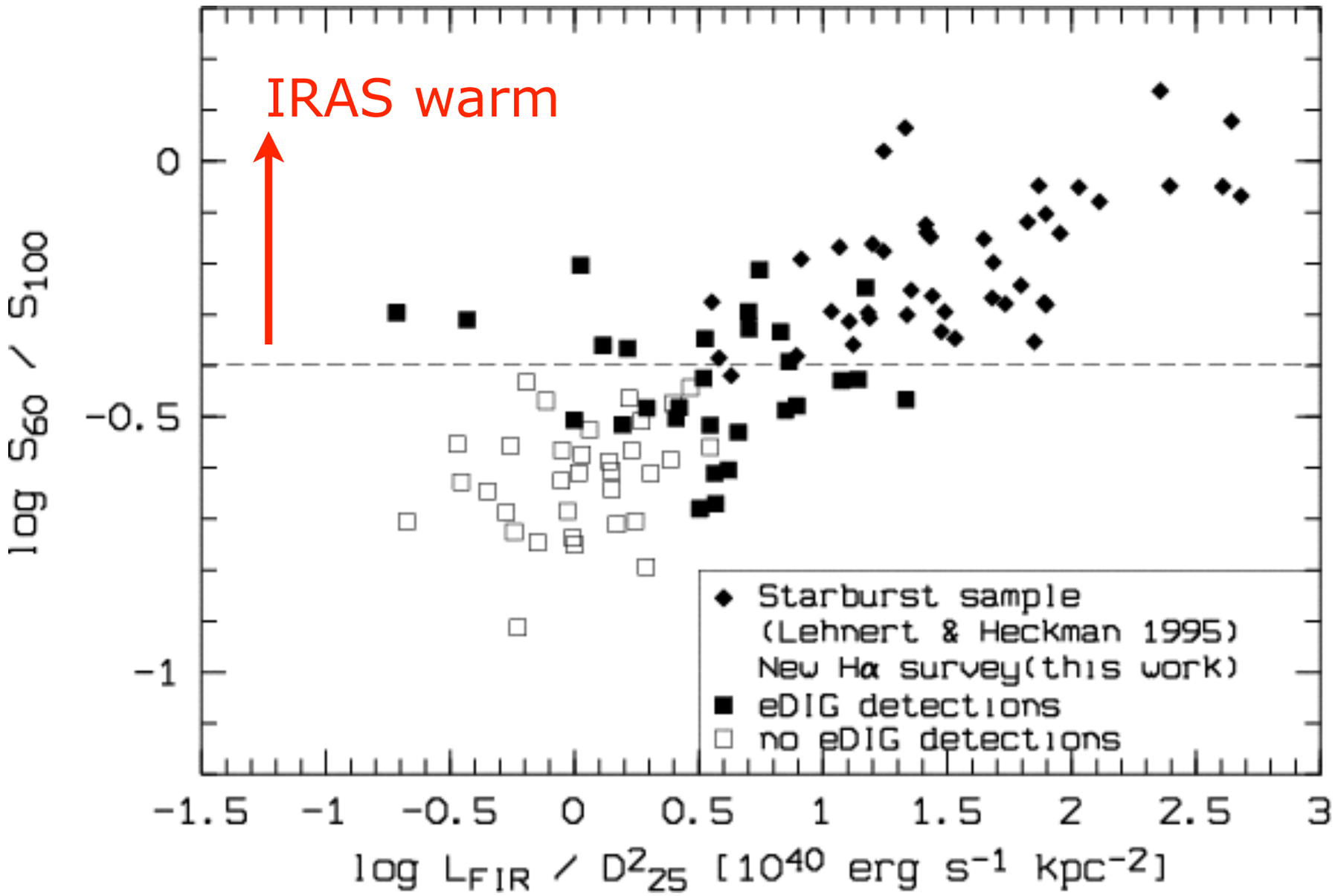
HALOGAS Survey Results



KPNO (B= blue, R=green, Halpha=red) - Maria Patterson; HI - HALOGAS

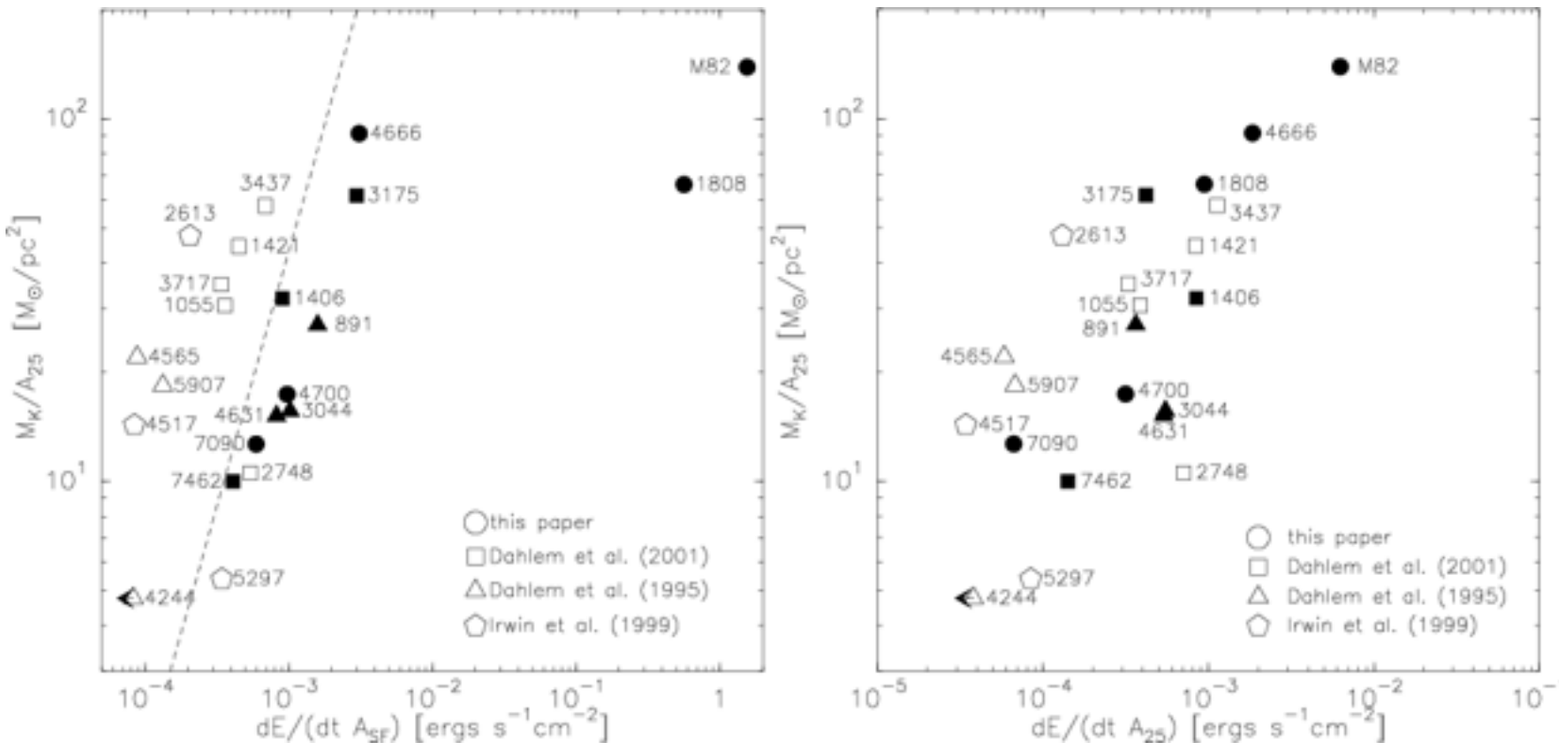
Multiphase thick disks: correlations

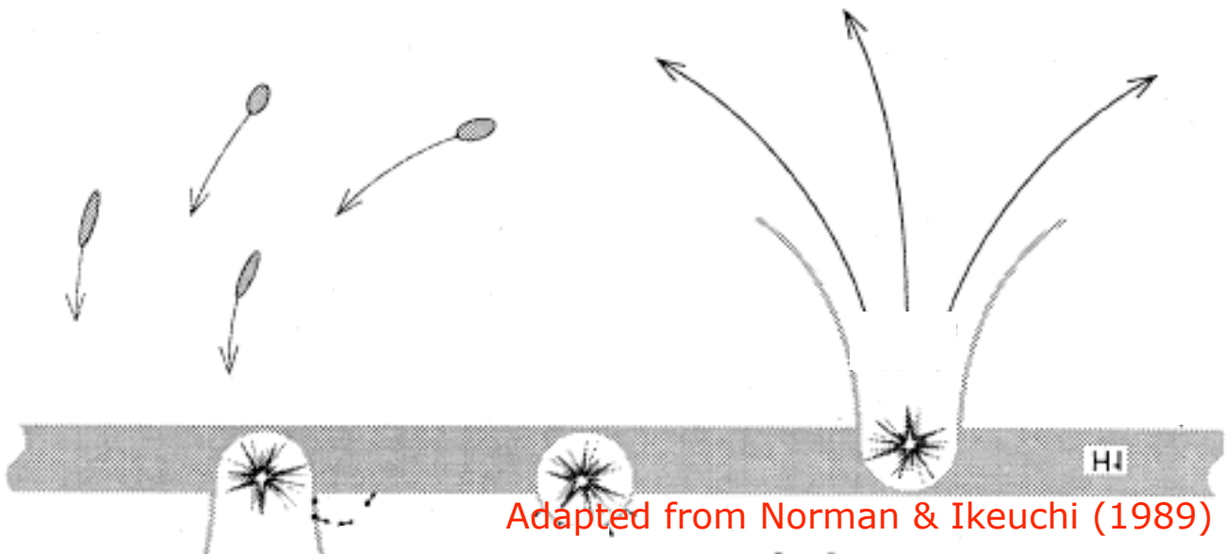
- Rossa & Dettmar (2003): Connection between energy input (from star formation) and presence of EDIG halos



Multiphase thick disks: correlations

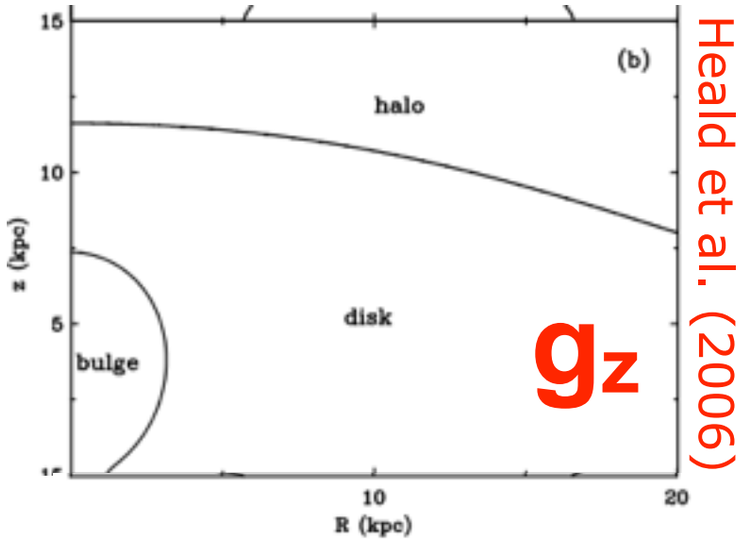
- Dahlem et al. (2006): radio continuum halos linked to energy input by star formation on the one hand, and disk gravity (traced by K-band emission ↔ old stellar population) on the other hand





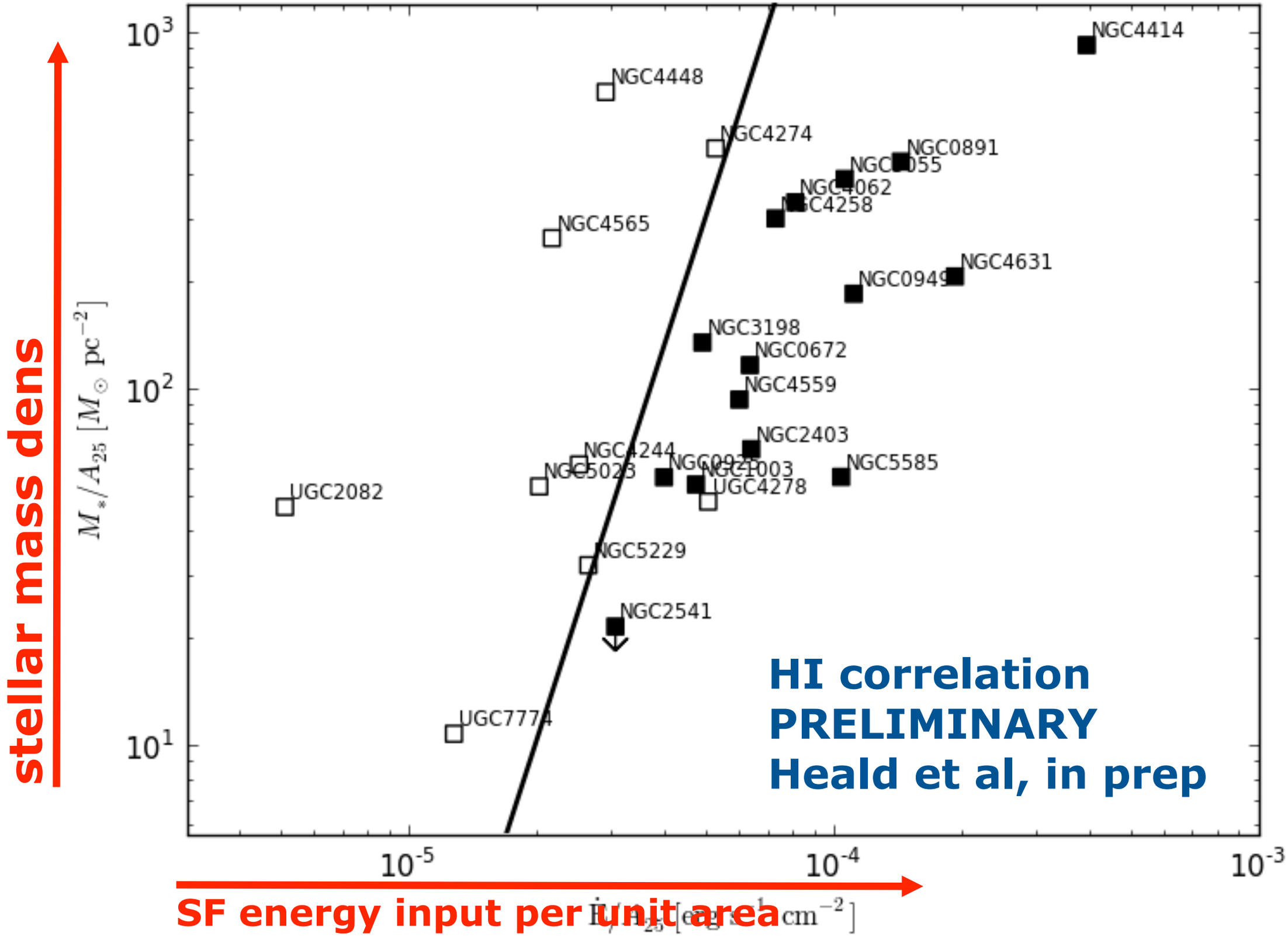
Adapted from Norman & Ikeuchi (1989)

$\dot{E}_A$ g_z



Heald et al. (2006)

Multiphase thick disks: correlations



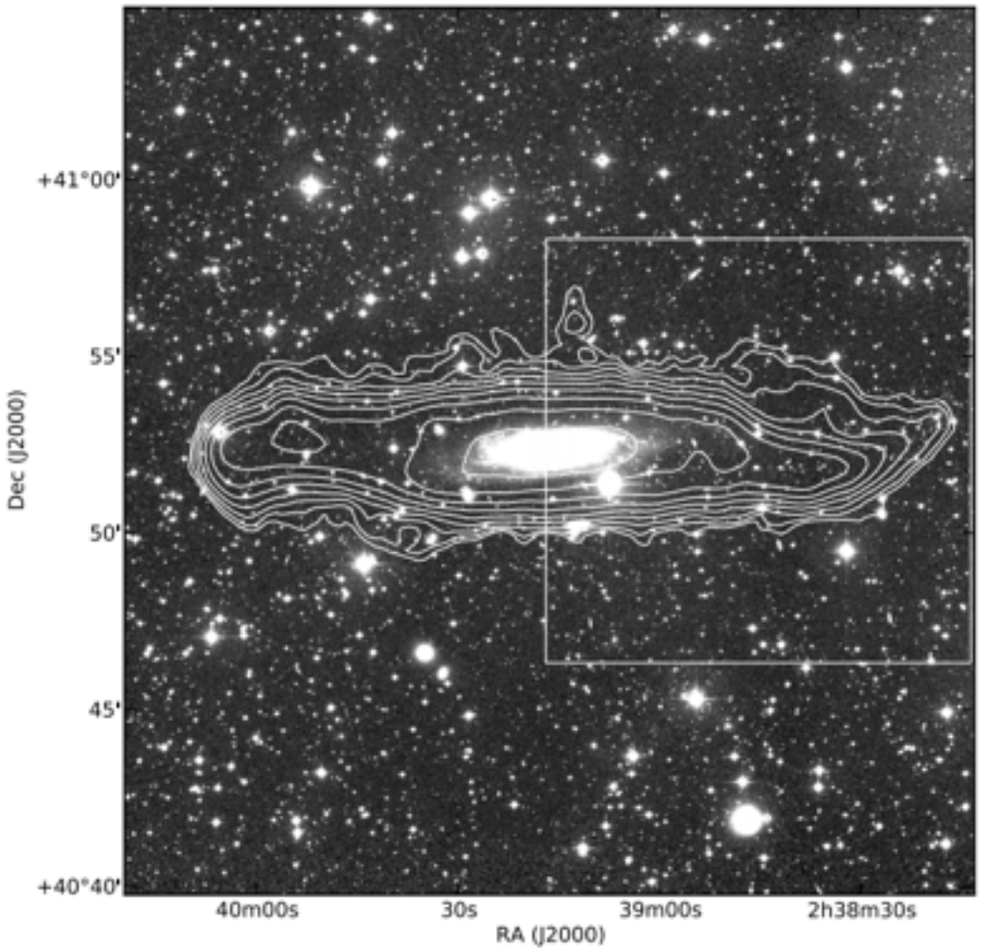
HALOGAS Accretion Catalog

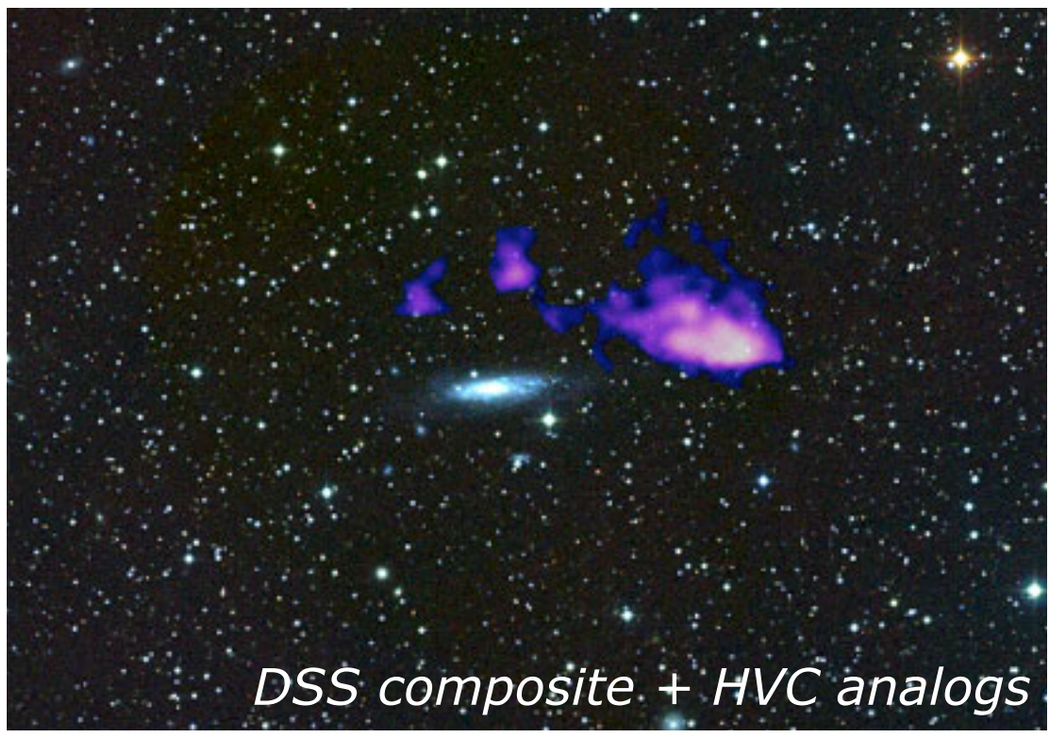
- Effort underway to collect full list of all clouds and streams in HALOGAS target fields
  - formation of master catalog
  - How many galaxies show signs of accretion? How much (and at what rate)? Clouds or diffuse? Corotating with the galaxy? Associated with star formation? …

- Preliminary result already clear: some features attributable to cold accretion (in the form of HI), but insufficient to fully balance SFR in a typical galaxy

NGC 1003

- Key results:
  - HVC analogs detected at 11 Mpc distance
  - Contributing ~4x10^6 $M_\odot$ of the HI in the system
  - over a dynamical time, these features contribute only ~2% SFR



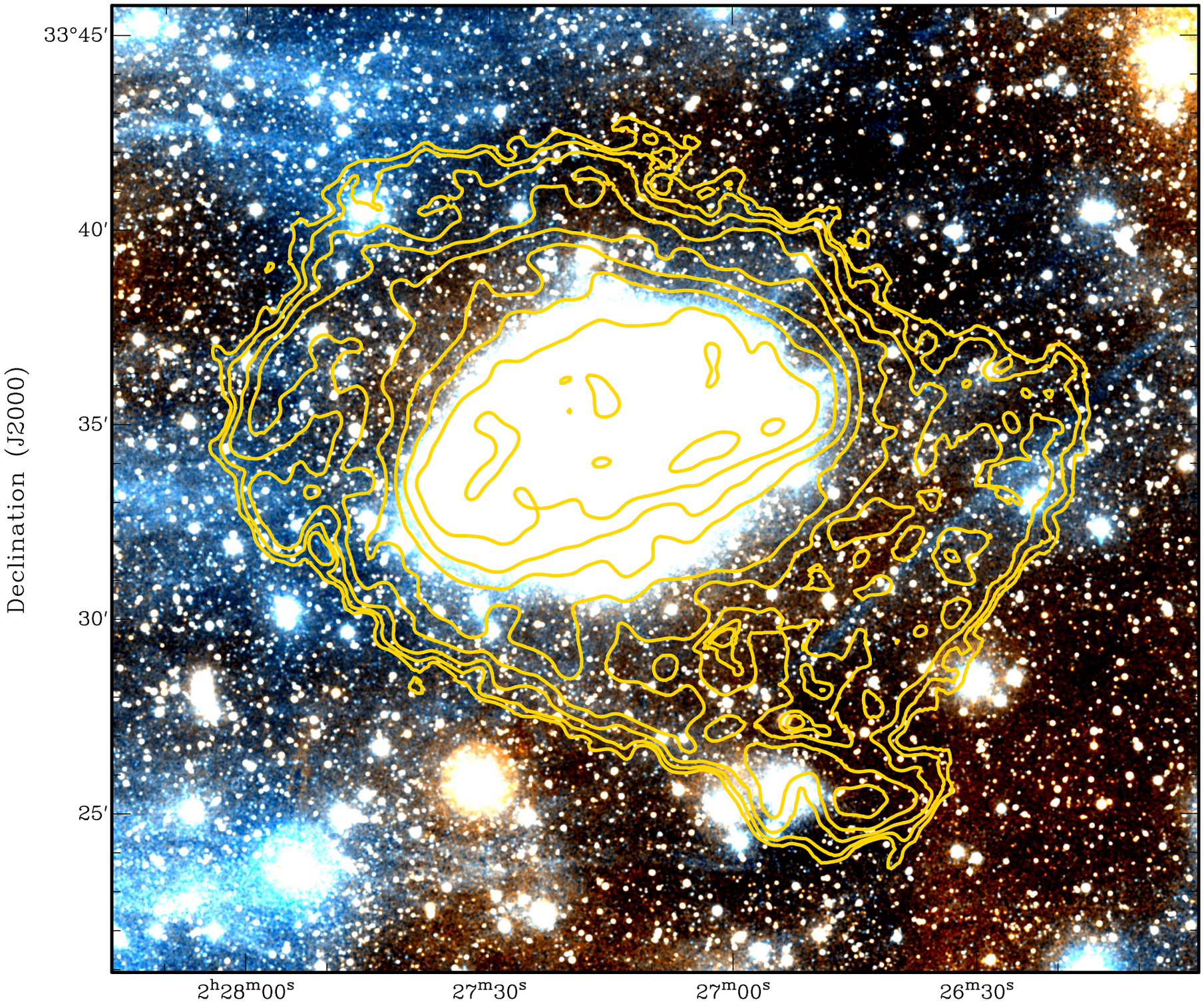


Heald et al. (in prep) *HALOGAS + HALOSTARS*

Cloud	Mass	Height
1	2 x 10	10 kpc
2	3.3 x 10	10 kpc
3	3 x 10	5 kpc
AC (excl #3)	2.9 x 10	-

NGC 925

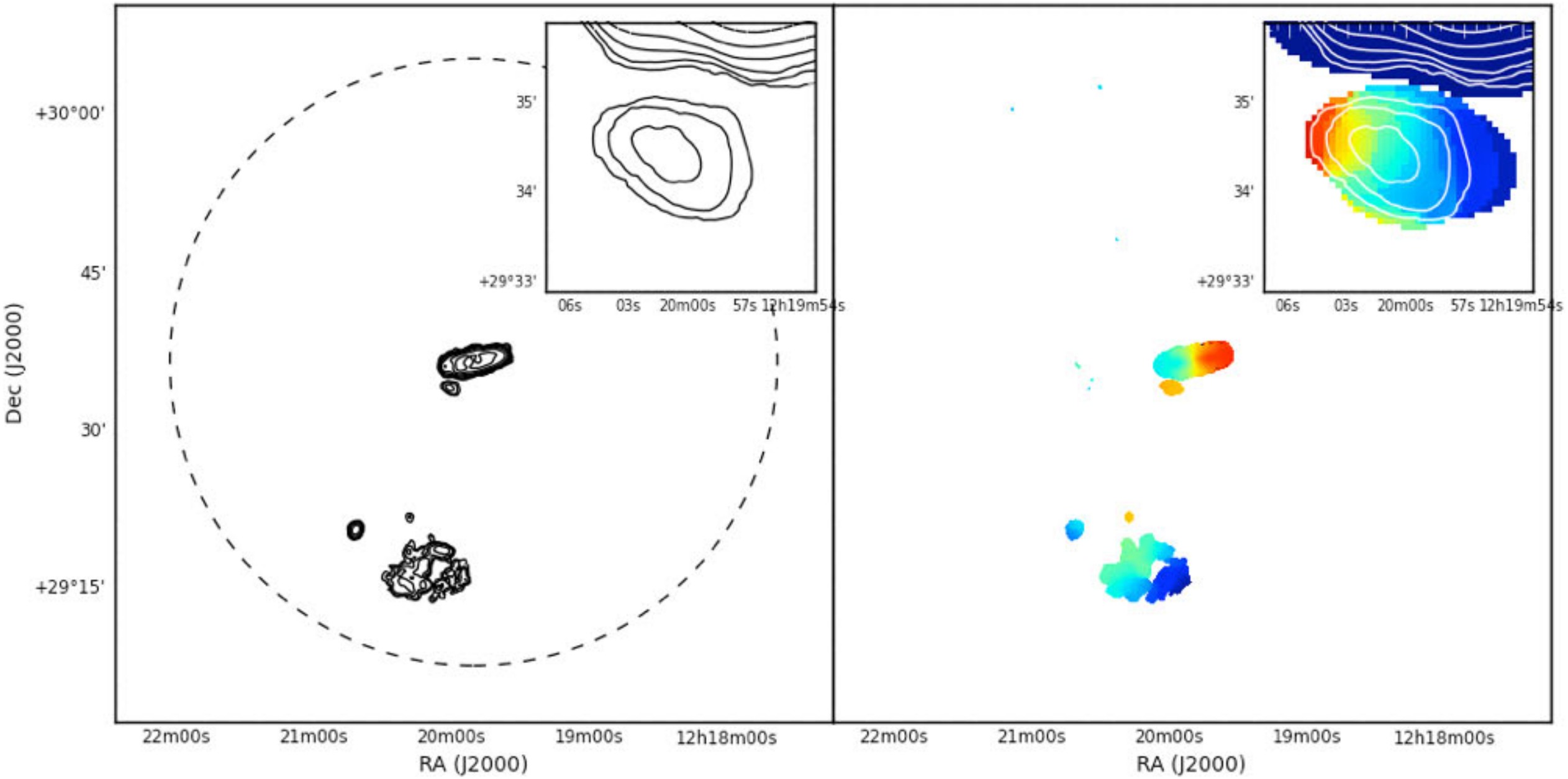
- Powerful combination of deep optical and HI reveals tidal remnants



Heald, Patterson et al.

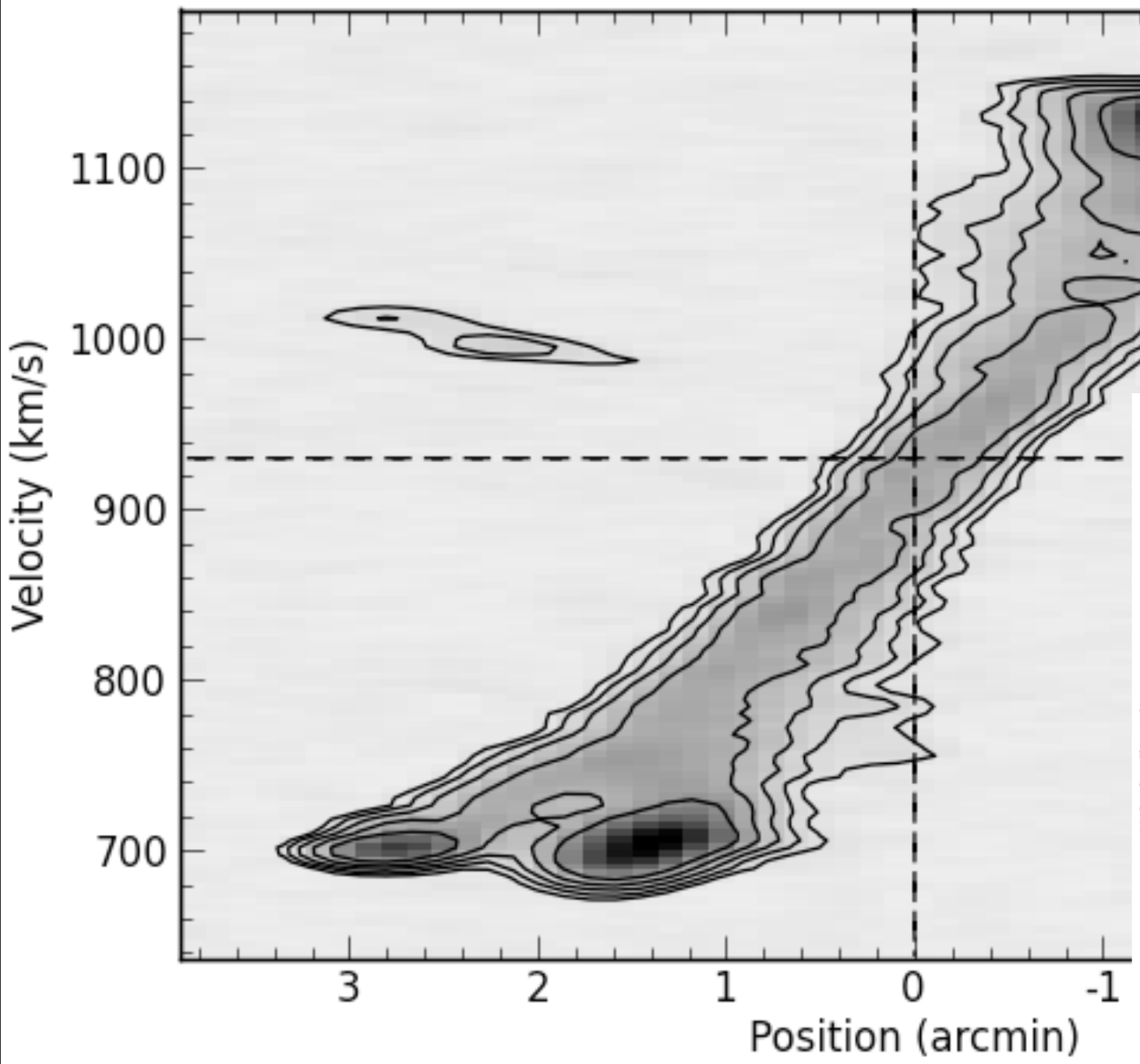
HALOGAS Cloud of Interest

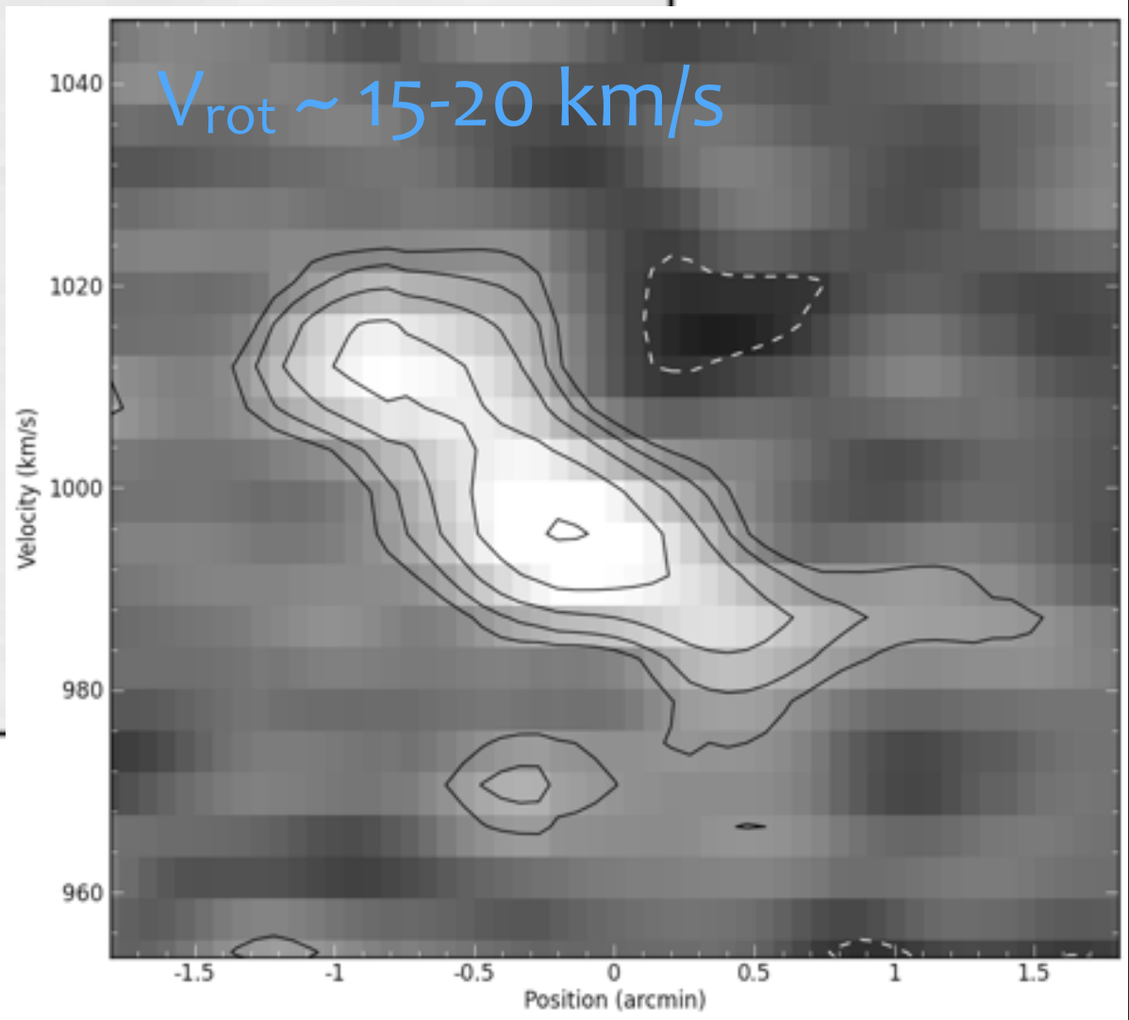
- Dark HI cloud near NGC 4274: HVC? LSB dwarf? *Dark galaxy?*



HALOGAS Cloud of Interest

- Dark HI cloud near NGC 4274: HVC? LSB dwarf? *Dark galaxy?*

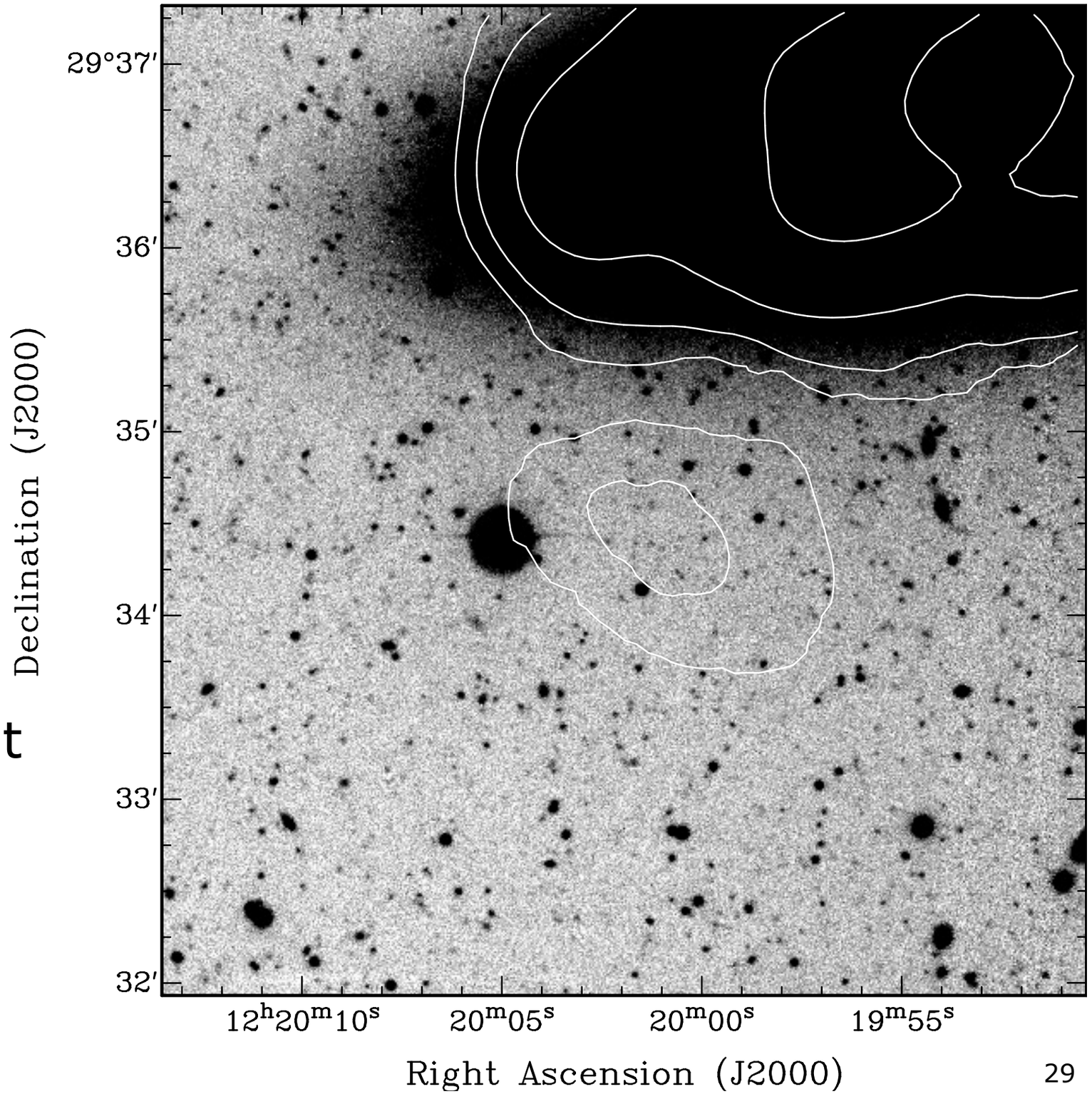




Soon: new GMRT hi-res HI cube!

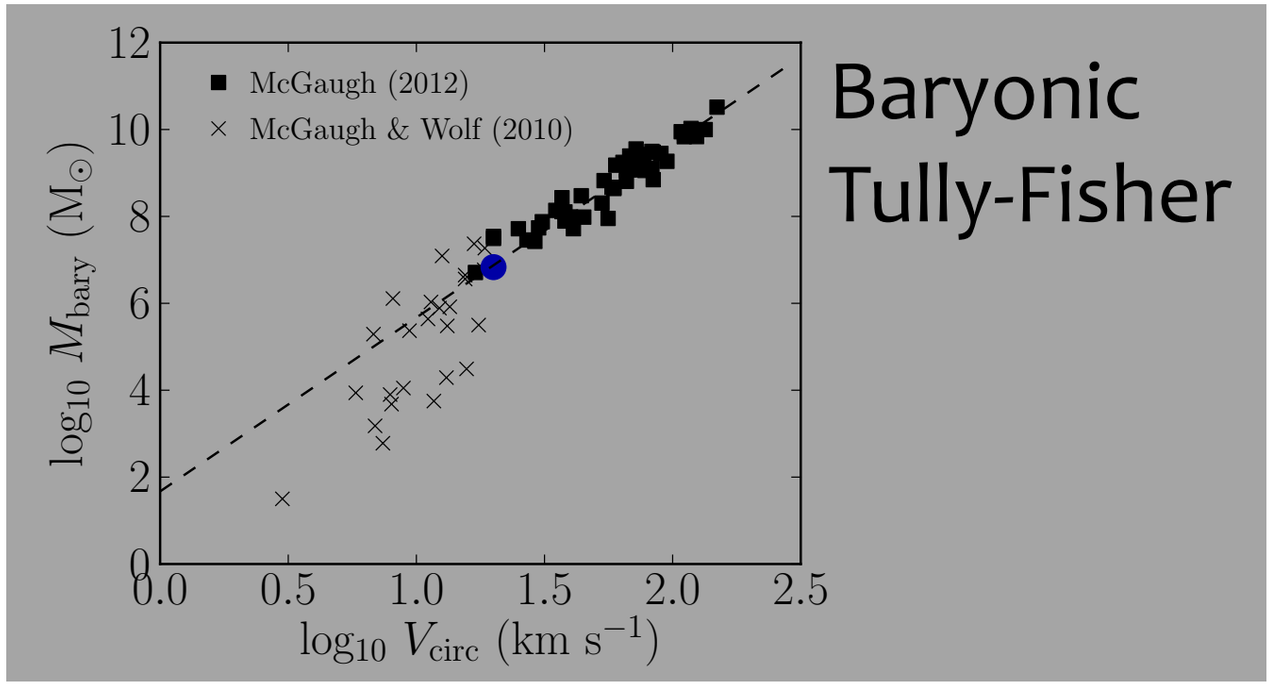
HALOGAS Cloud of Interest

- Dark HI cloud near NGC 4274: HVC? LSB dwarf? *Dark galaxy?*
- Background image:
  CFHT MegaCam *g*-band
  ~28.5 mag arcsec^{-2}
  THANKS TO ATLAS3D!
- Several other deep images available (KPNO, INT, GALEX) but nothing seen
- Leads to mass/light limit
  $M_{HI}/L_V \geq 11$

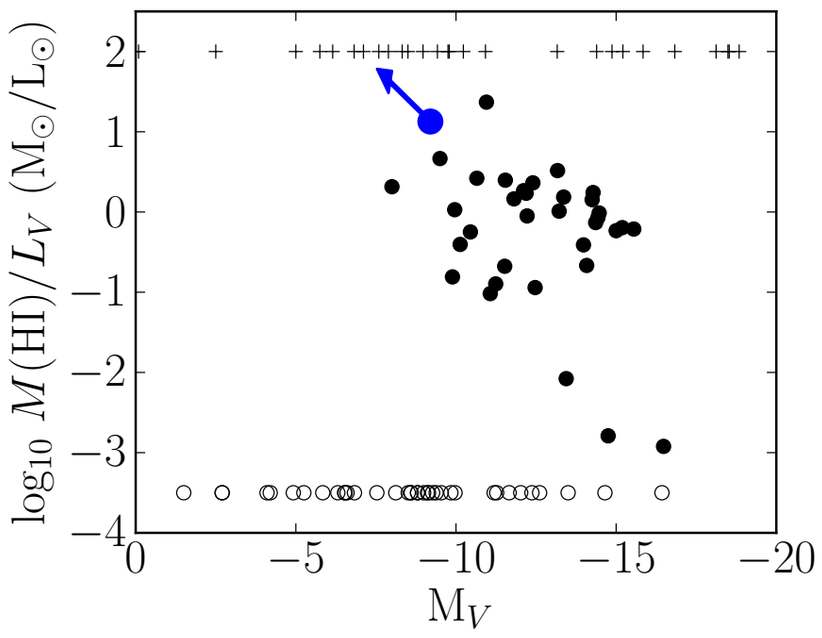


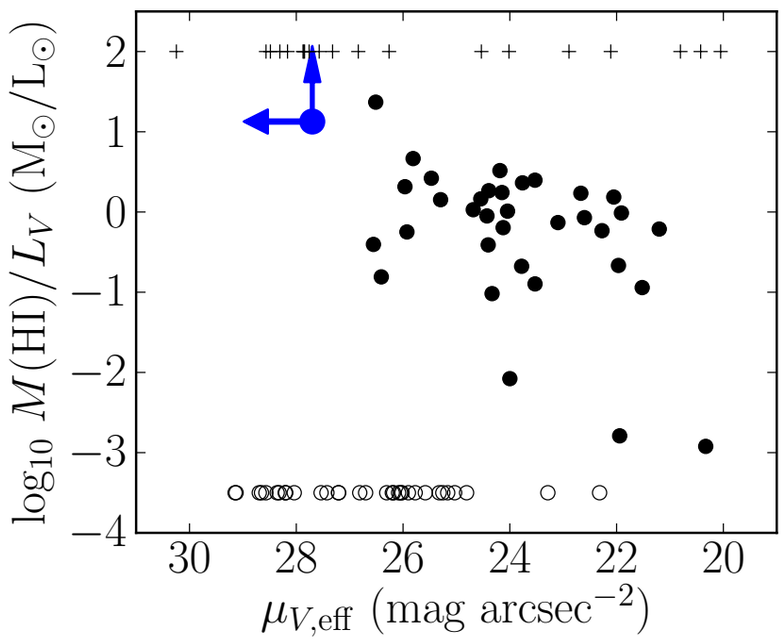
HALOGAS Cloud of Interest

- Dark HI cloud near NGC 4274: HVC? LSB dwarf? *Dark galaxy?*
- Would be very faint, but dark?
- NB: HI surface mass density (assuming distance of N4274) is only 0.1 $M_\odot$ pc^{-2}!



LG dwarfs from McConnachie (2012)





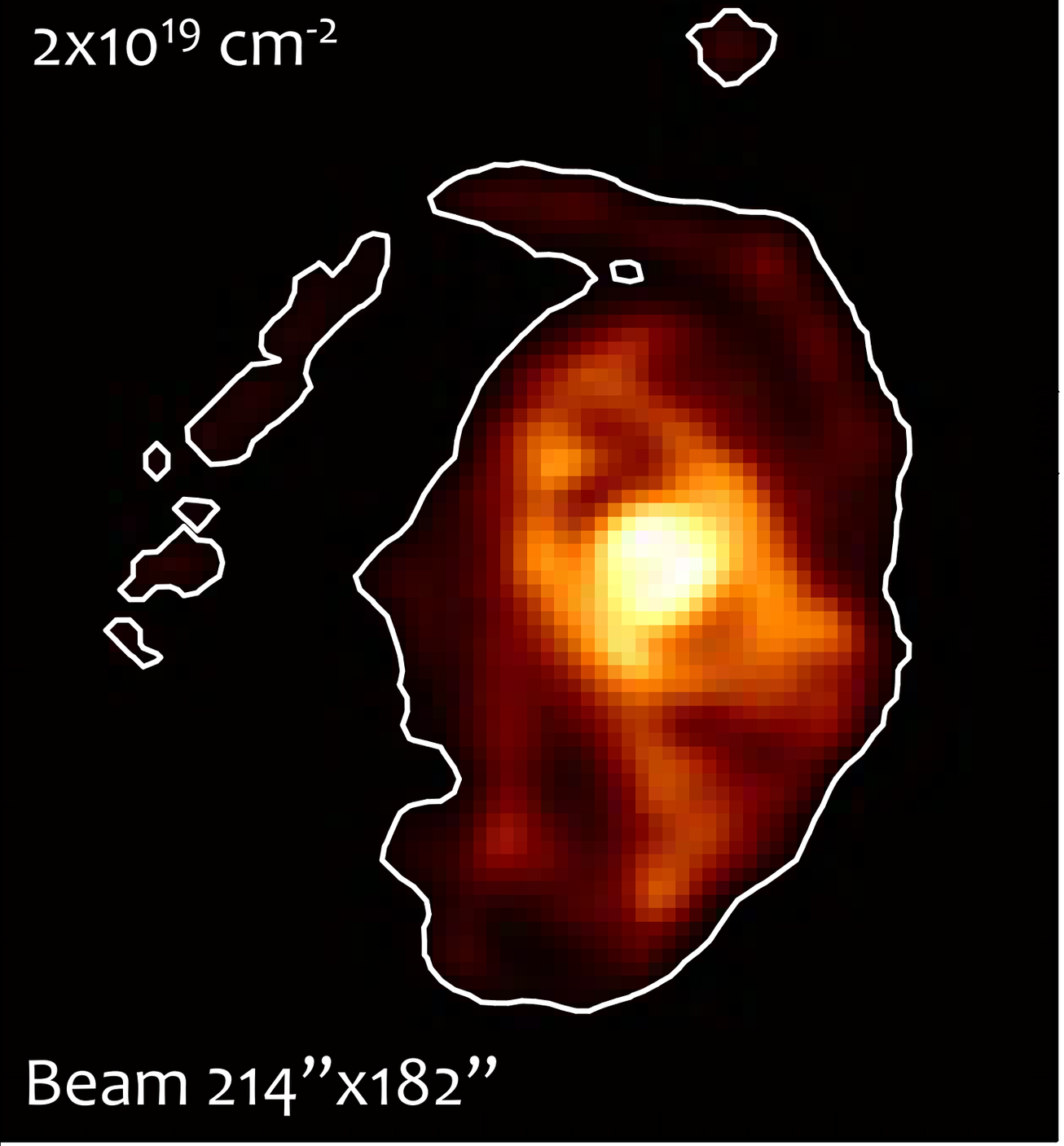
Looking to the future

Preparation for MHONGOOSE

- MHONGOOSE (de Blok et al)
  MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters
- Deep HI observations of nearby galaxies, with commensal polarized continuum to investigate magnetic fields
- First look at M83 with KAT-7 in 2013
  - Initially in full-Stokes continuum mode
    Produced intriguing HI map despite poor velocity resolution
  - Recent reobservation (THANKS DANIELLE!) in line mode
    - 6/7 antennas operational
    - 3 pointing mosaic, in total ~10.5h on source
    - Data reduced in miriad using standard bandpass and interleaved gain (phase) calibrators

KAT-6 view of M83

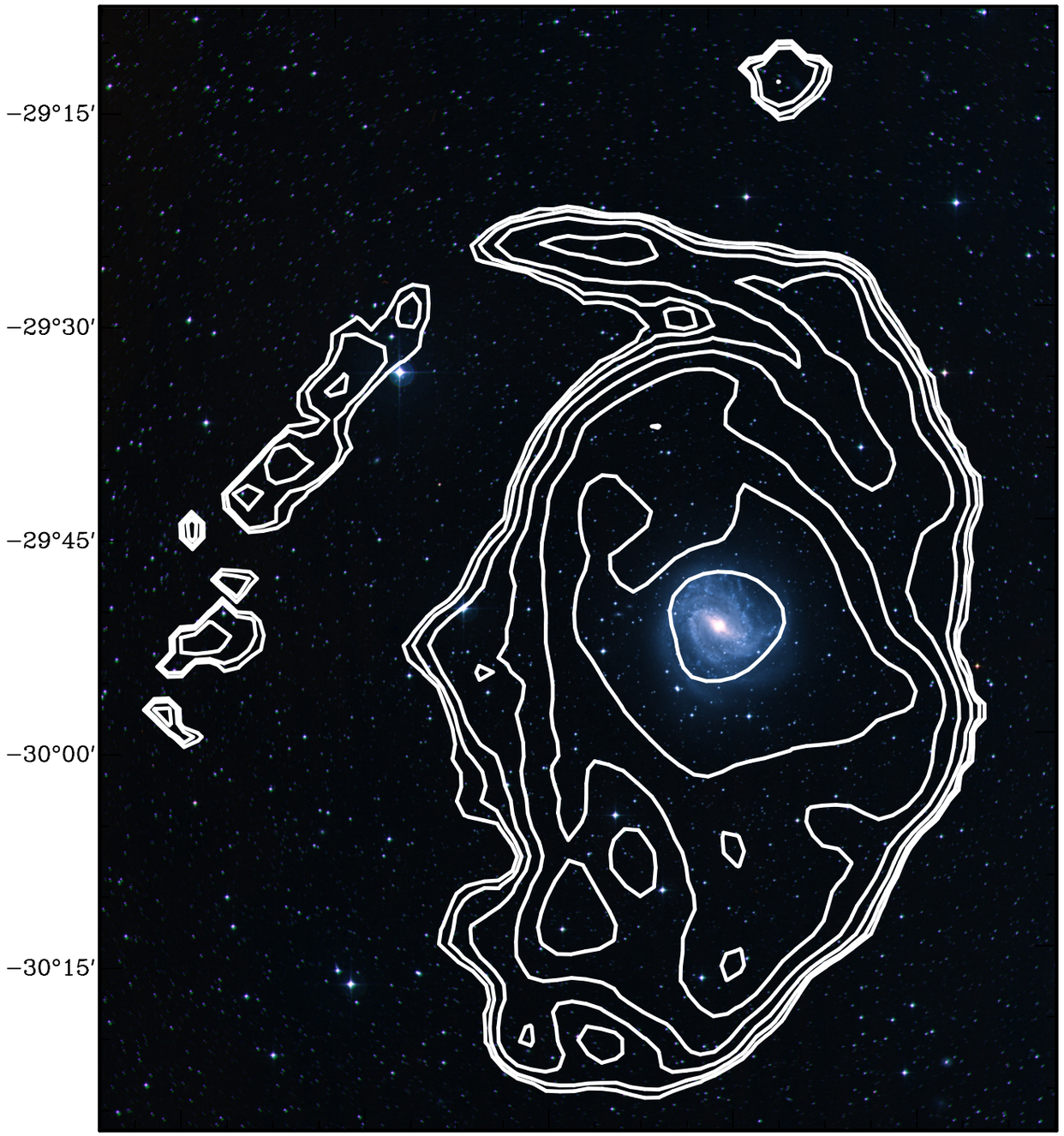
Column density limit
$2x10^{19}$ cm^{-2}



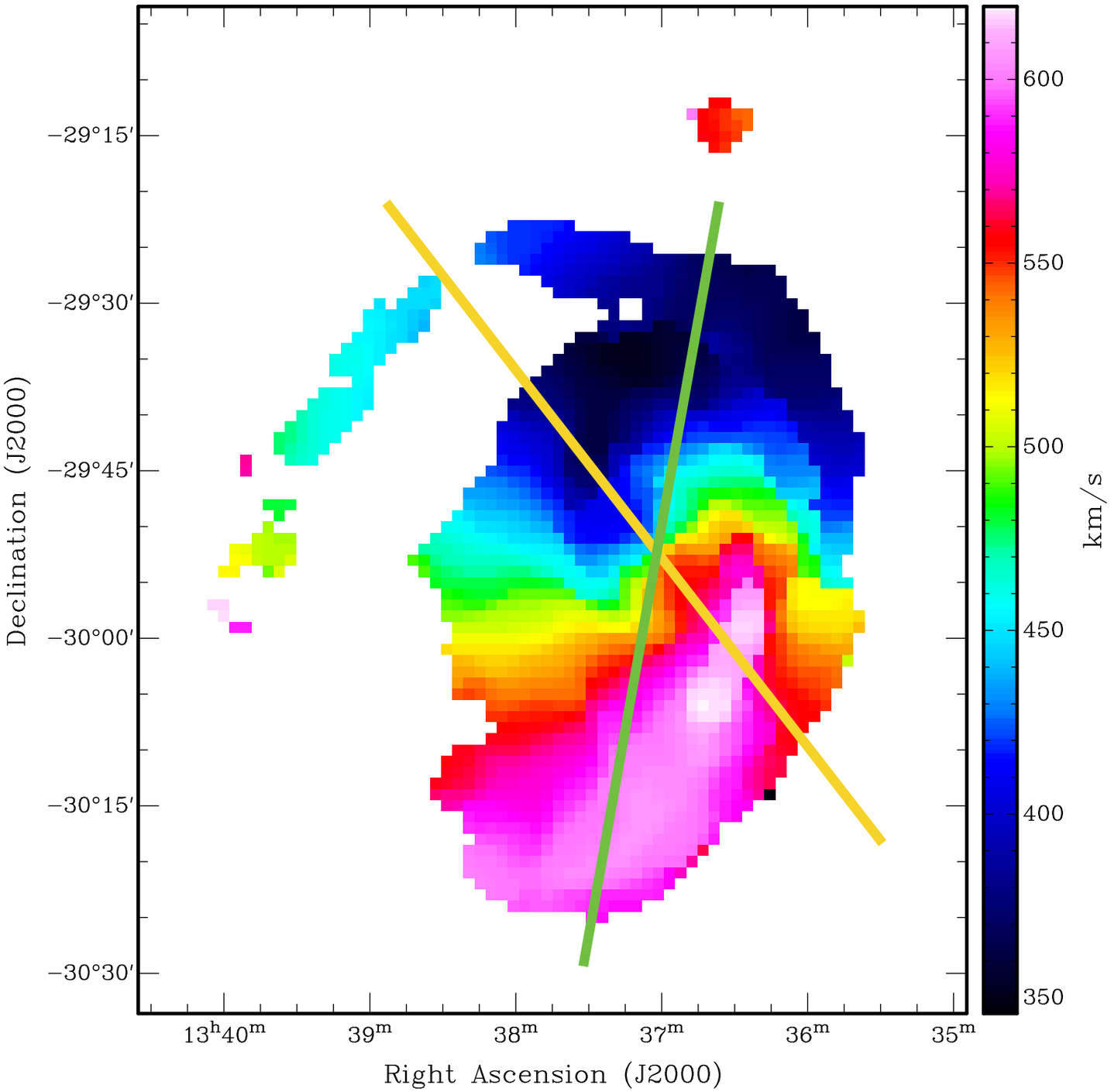
Beam 214”x182”

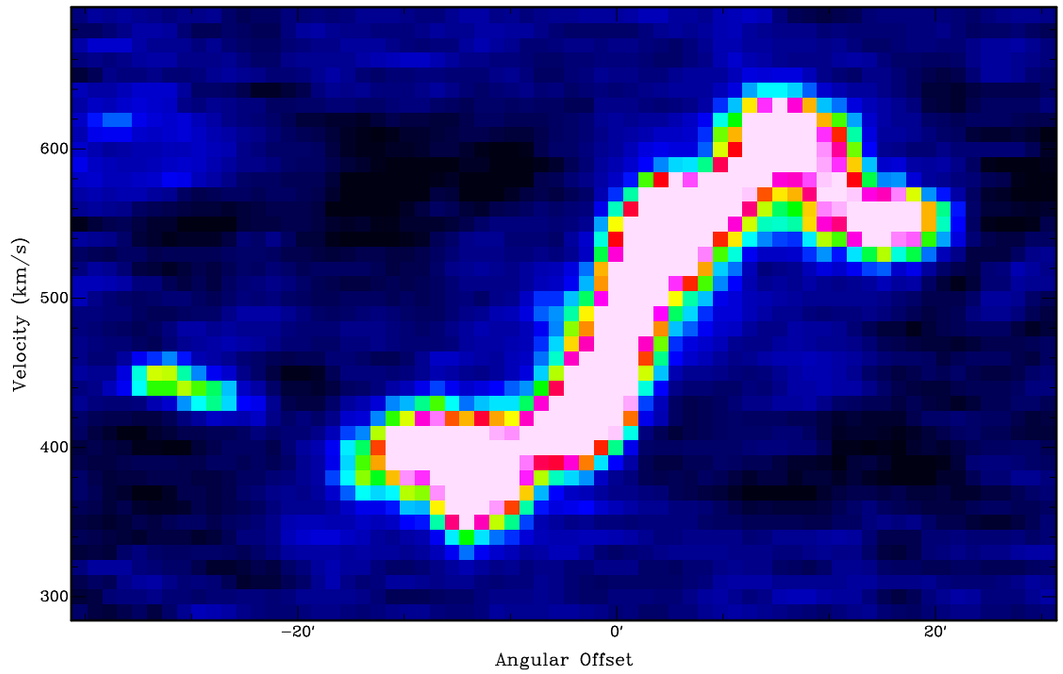
13^h40^m 39^m 38^m 37^m 36^m 35^m

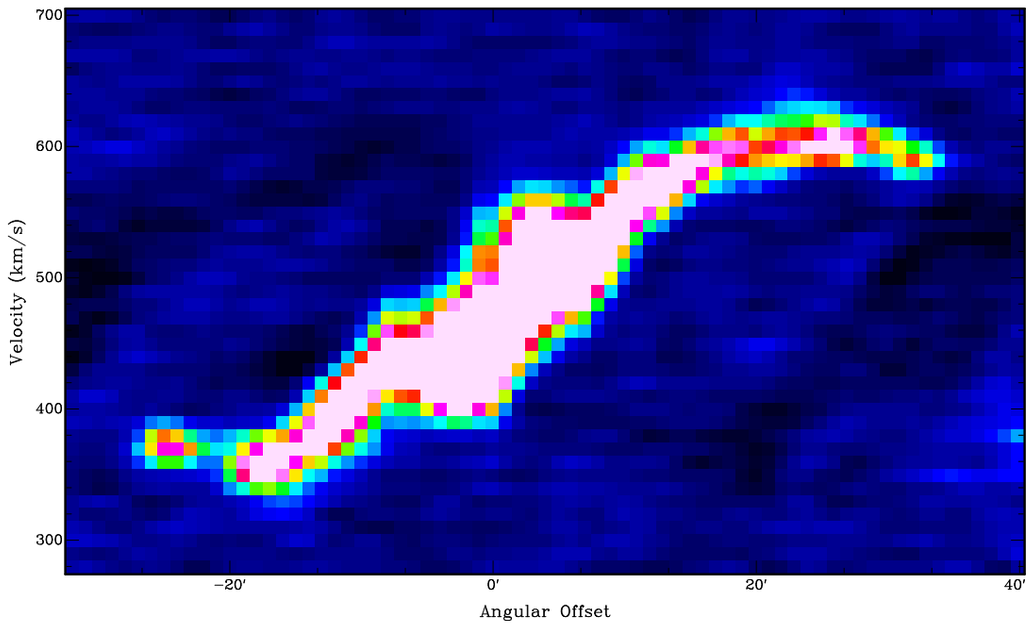
Right Ascension (J2000)



KAT-6 view of M83







Summary

- HALOGAS: Observations (of the full sample!) now complete
  - Providing access to a broad range of extraplanar characteristics (including *important* non-detections...)
  - Ancillary data brings extra value to the survey
  - Stay tuned for forthcoming HALOGAS papers and data releases

- Near-term prospects for extending lessons from HALOGAS
  - APERTIF Medium-deep survey
  - MeerKAT/MHONGOOSE
  - Preliminary work with KAT-7 is already providing new access to low column density (diffuse) HI!