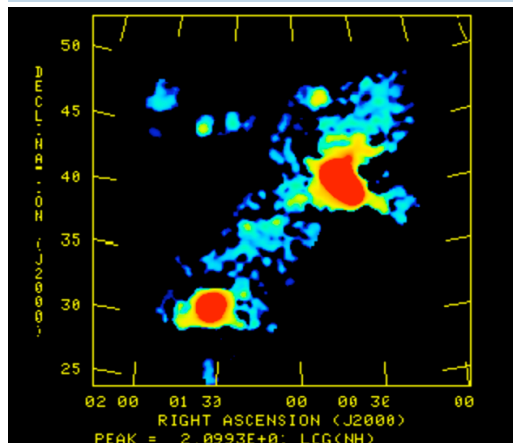


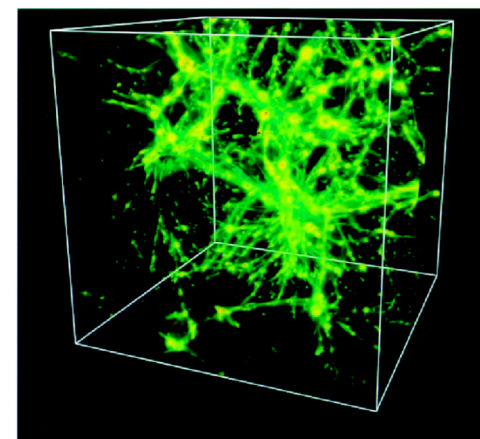
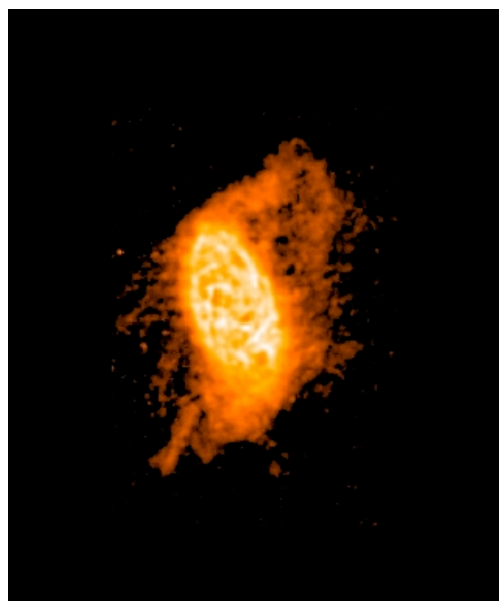
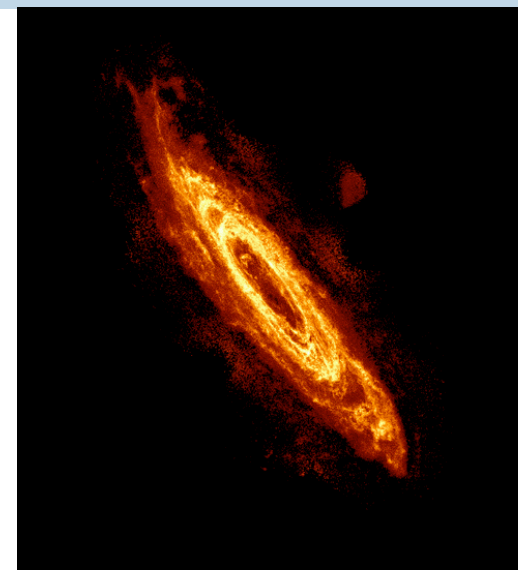
HI in the M31 Sub-group

Robert Braun

Outline



- Opaque filaments
- Feeding warps
- Ancient interactions



Opaque HI Filaments in M31

HI mosaic of M31

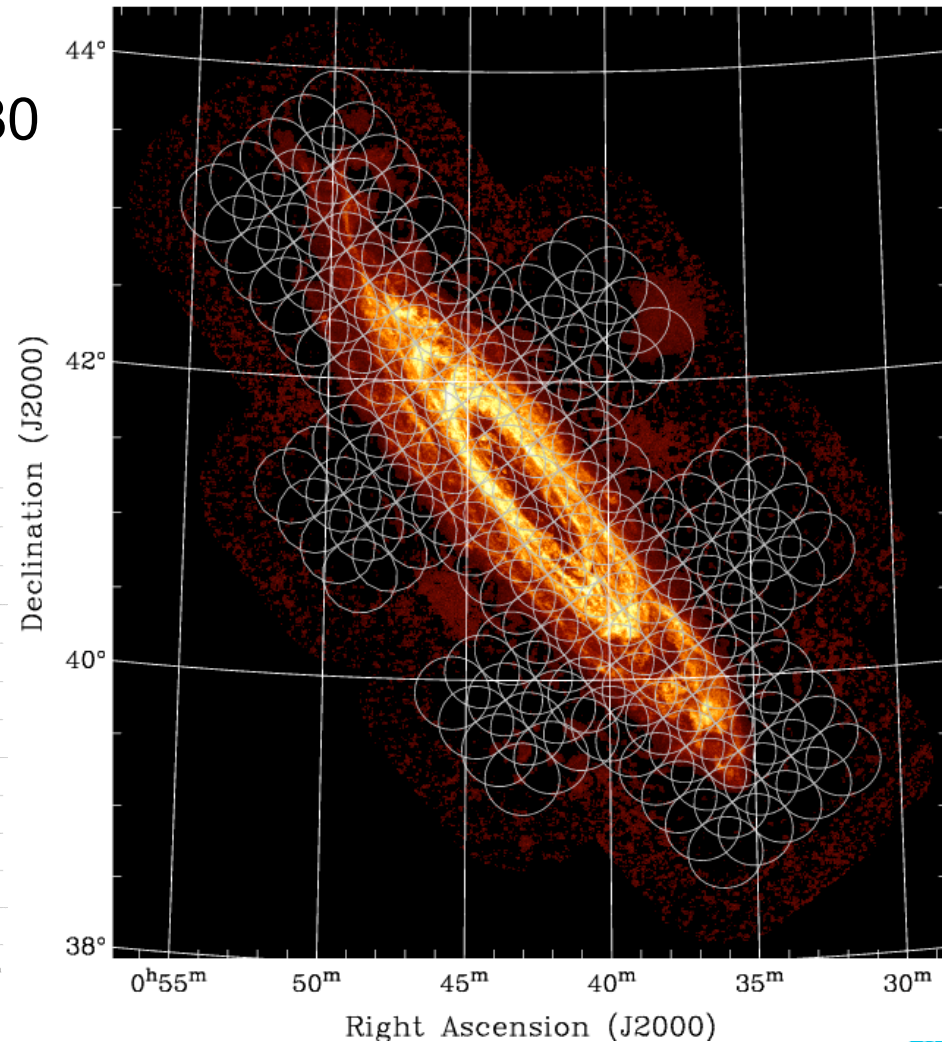
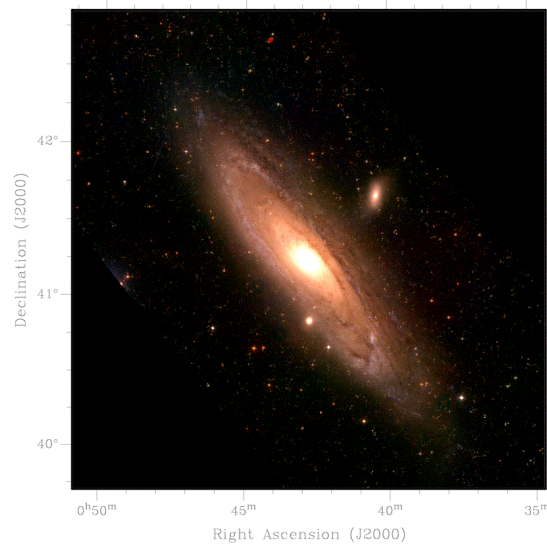
Braun, Corbelli, Thilker & Walterbos 2002 & 2007

- 163 pointings on 15 arcmin Nyquist-sampled grid
- 6 OTF passes with GBT of 7 x 7 deg.
- 50 pc x 2 km/s res. over the 80 kpc disk
- $\sigma = 1.4$ mJy/Beam (at $\Delta V = 2$ km/s)
- $\Delta N_{\text{HI}} = 1.0, 3.5, 11$ and $24 \times 10^{18} \text{cm}^{-2}$
@ 120, 60, 30 and 20" ($\Delta V=20$ km/s)
 - extended rotation curve / warping
 - outer HI edge / UV radiation field
 - CNM / WNM in disk
 - circum-galactic HI clouds and streams

Opaque HI Filaments in M31

HI mosaic of M31

- 50 pc x 2 km/s res. over the 80 kpc disk
- most detailed ISM cube yet made

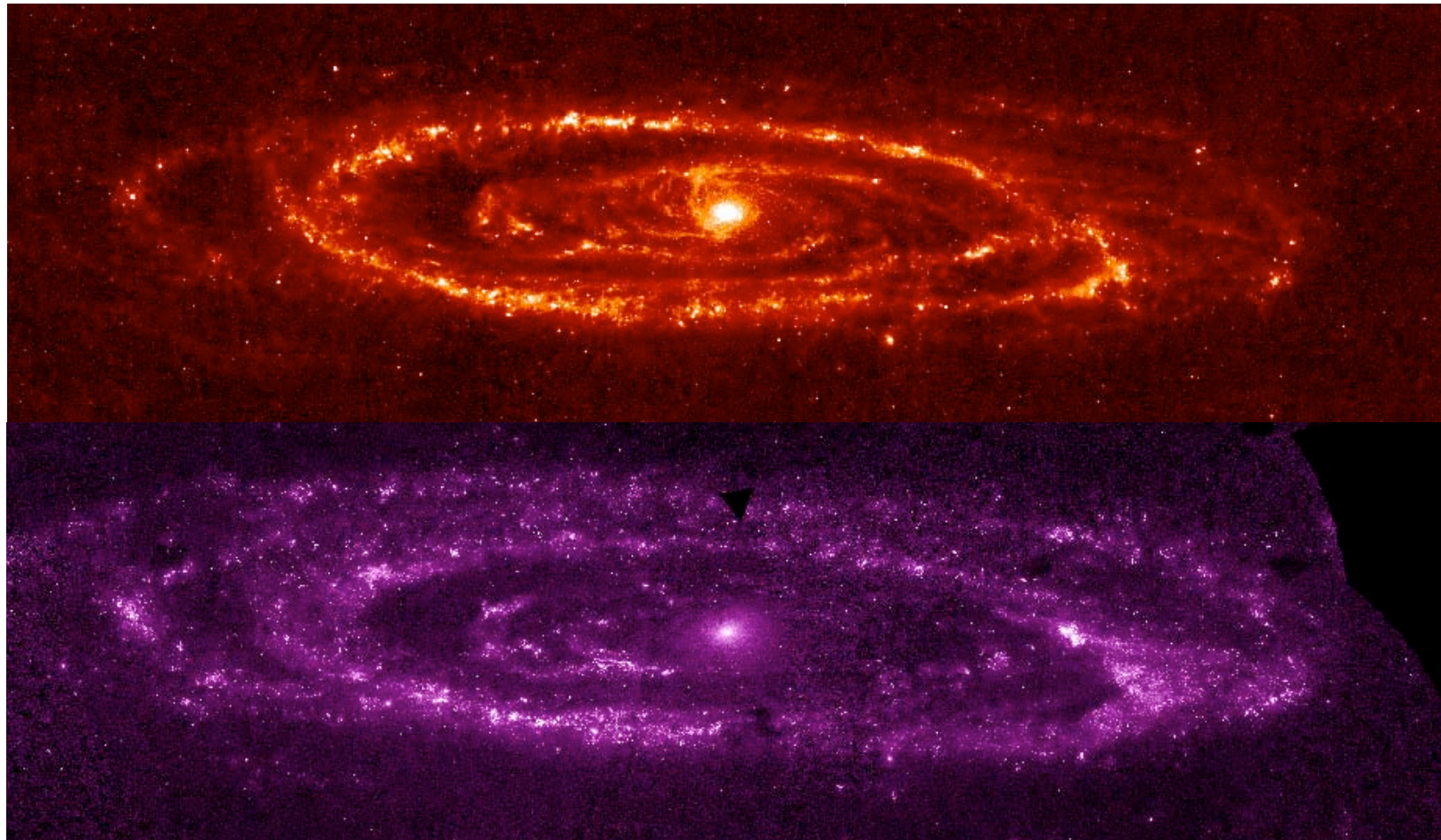


Braun et al. 2002, 2007

Opaque HI Filaments in M31

- multi- λ data-base, SST IR, GALEX FUV, WSRT HI, IRAM CO

with Karl Gordon, Dave Thilker and SINGS/GALEX teams, 2006, 2007



SST 24 μ m

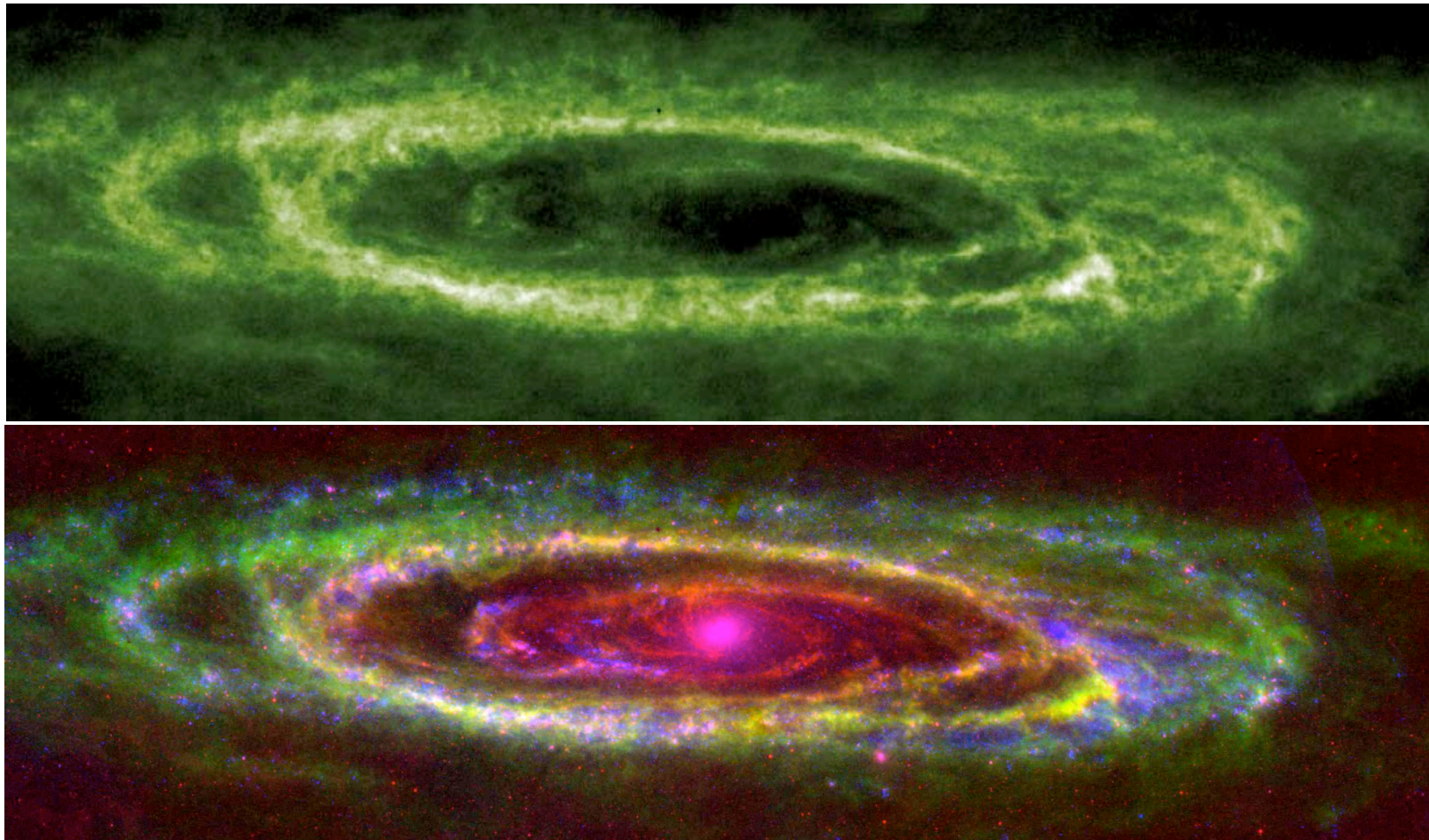
GALEX FUV



Opaque HI Filaments in M31

- multi- λ data-base, SST IR, GALEX FUV, WSRT HI, IRAM CO

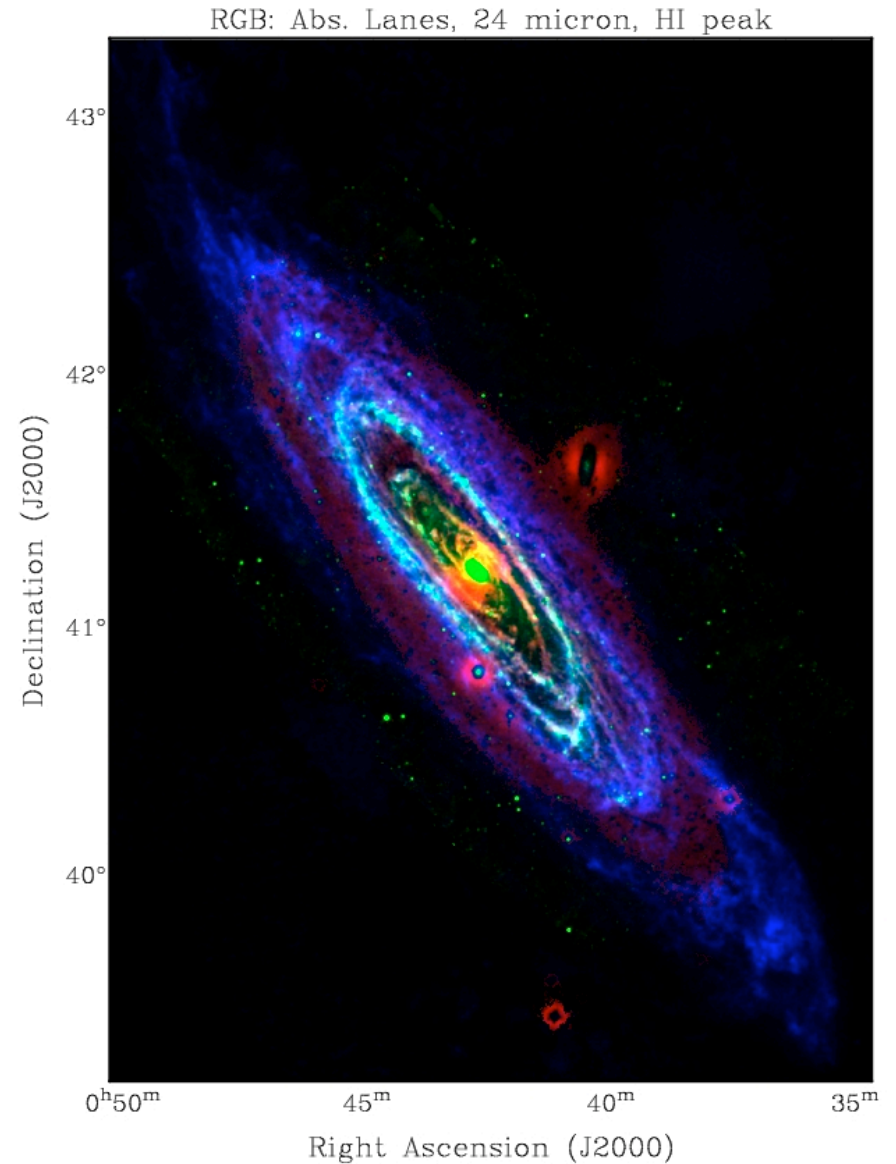
with Karl Gordon, Dave Thilker and SINGS/GALEX teams, 2006, 2007



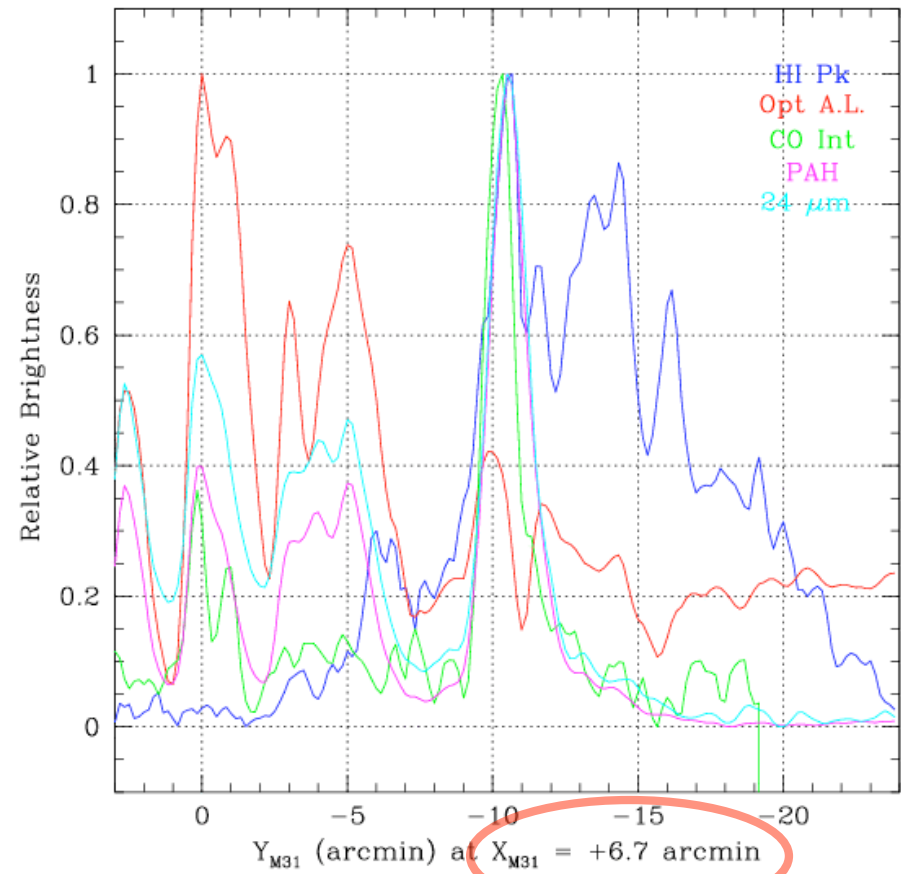
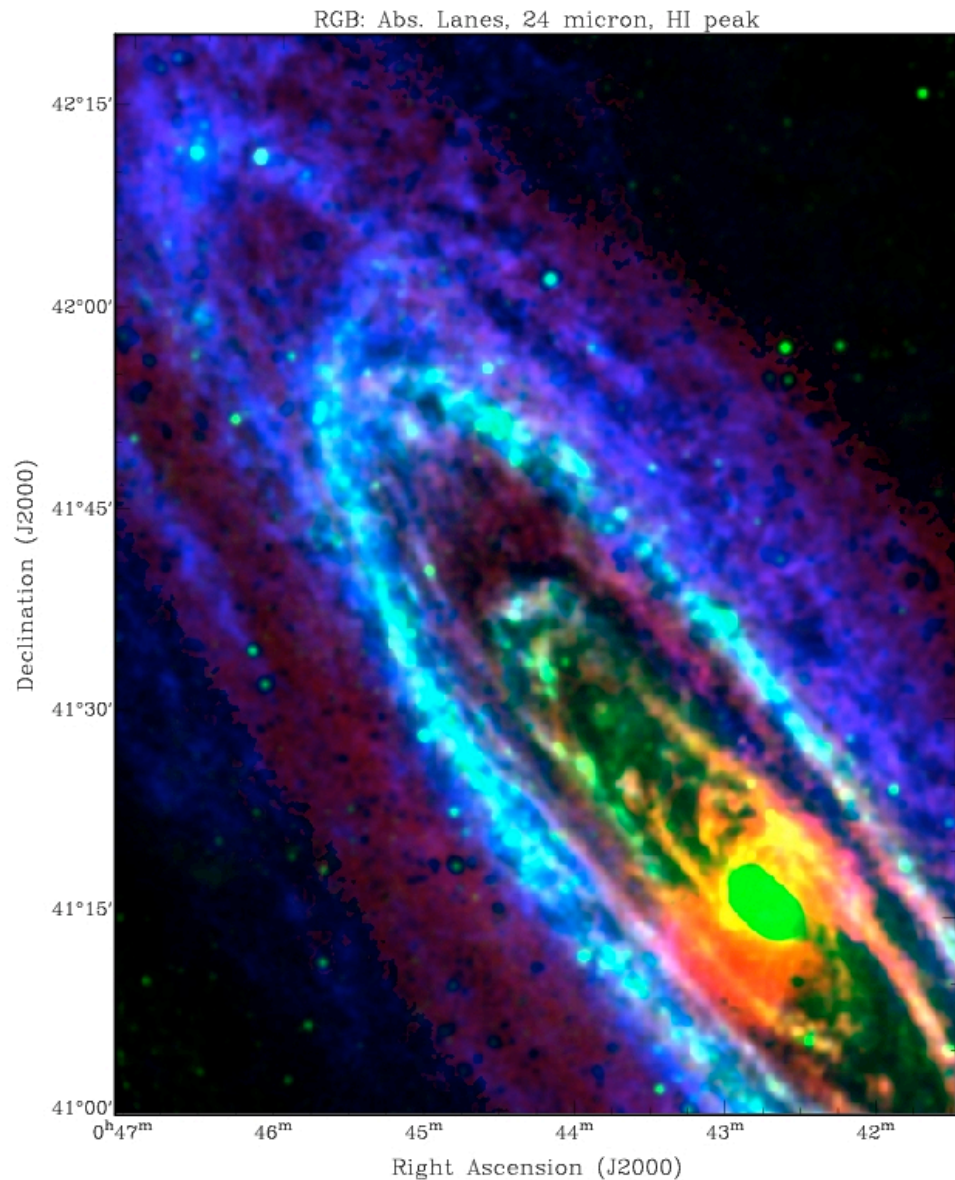
RGB = SST 24mm, WSRT HI, GALEX FUV

Opaque HI Filaments in M31

- How are the dust and gas correlated on the smallest accessible scales ?

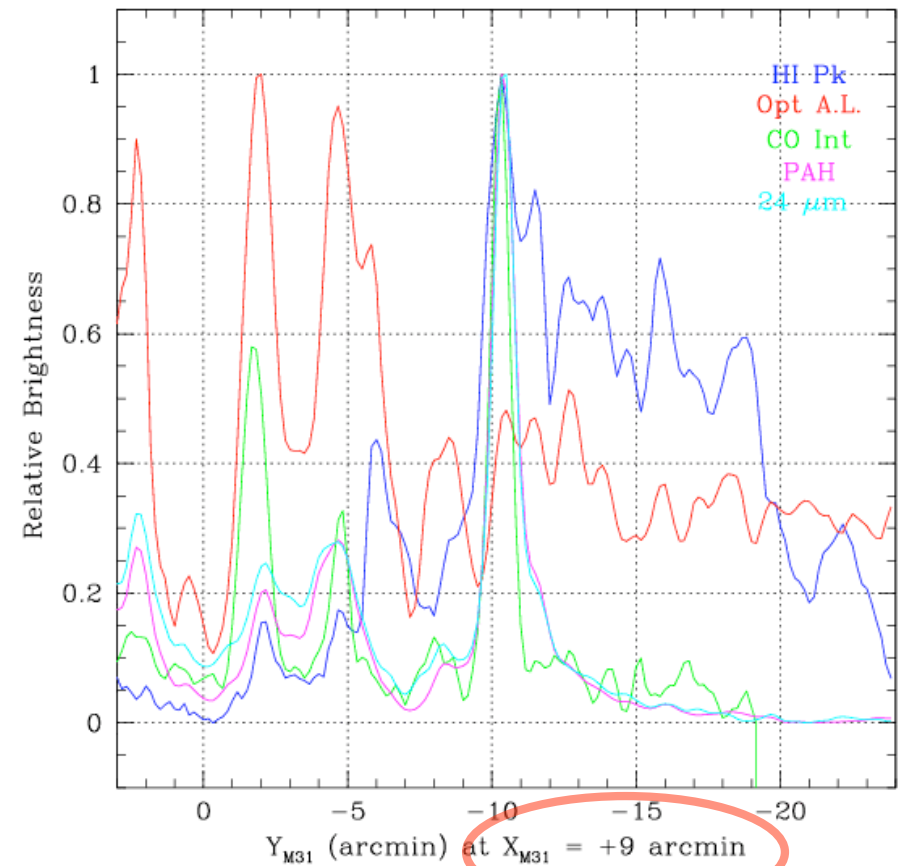
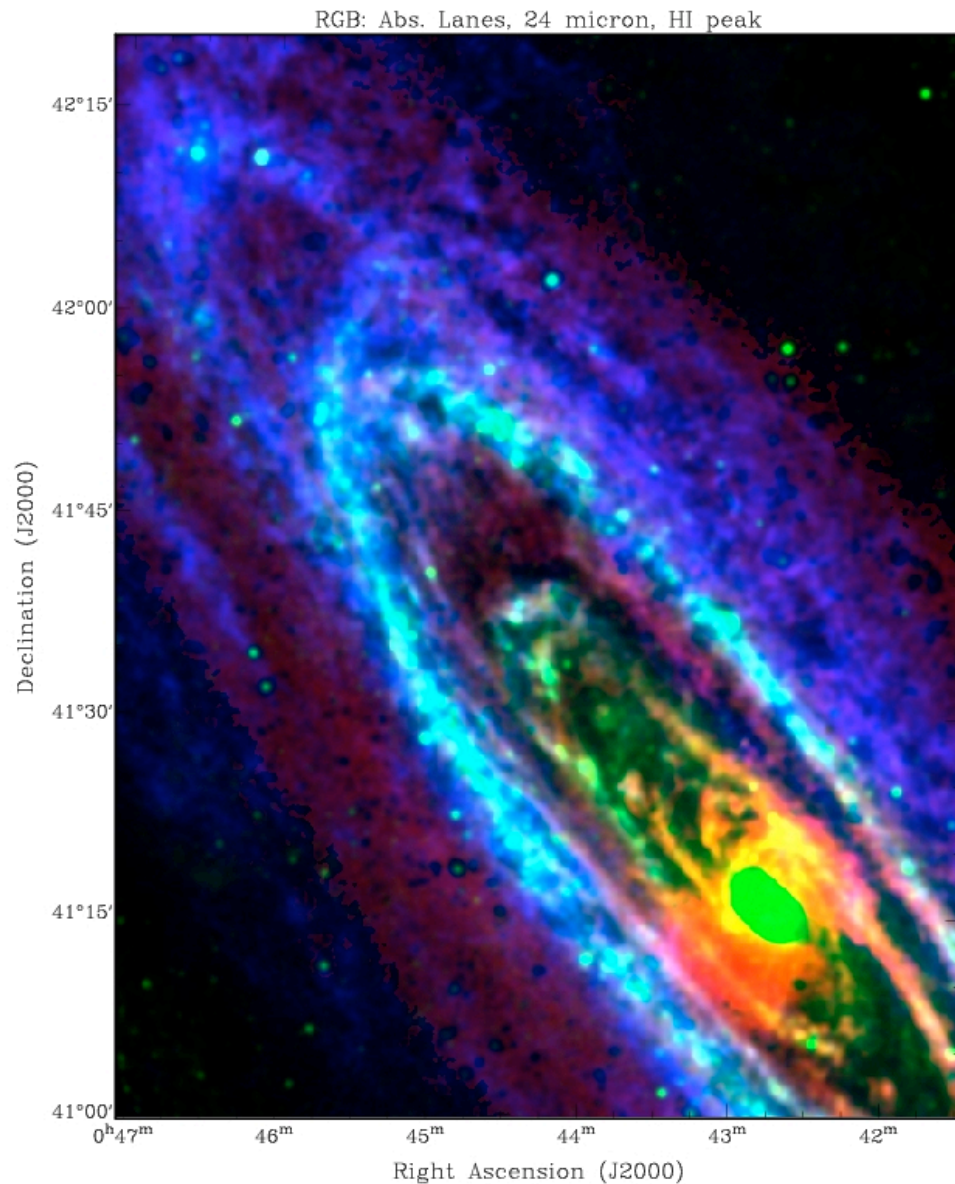


Opaque HI Filaments in M31



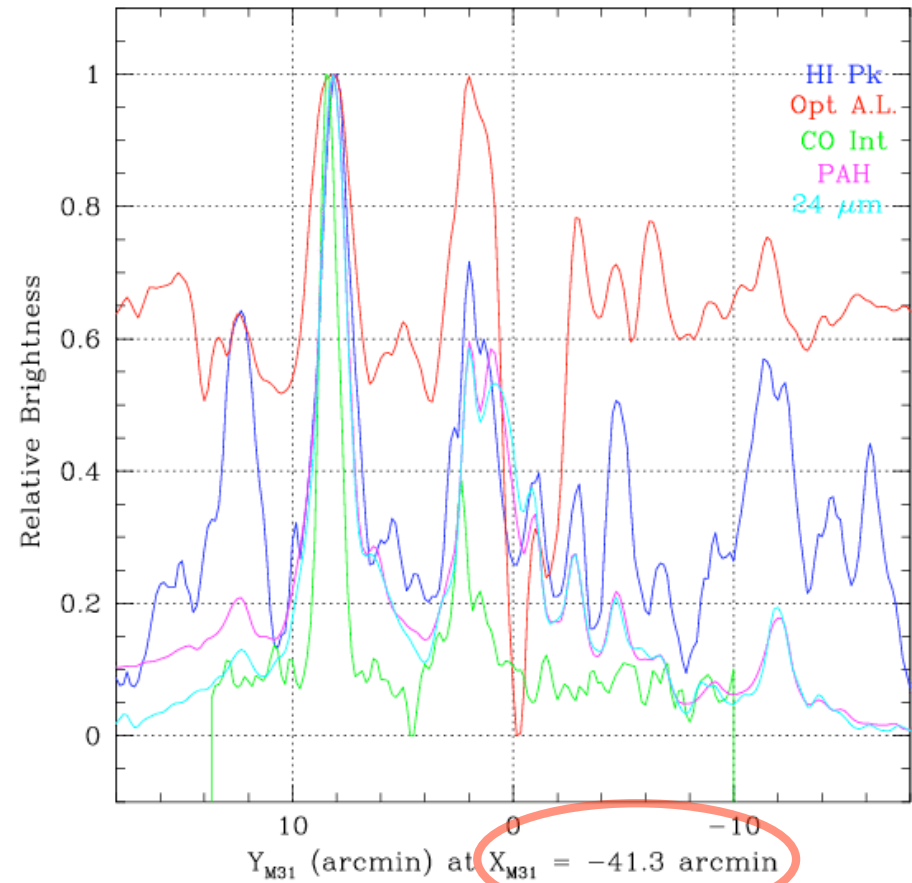
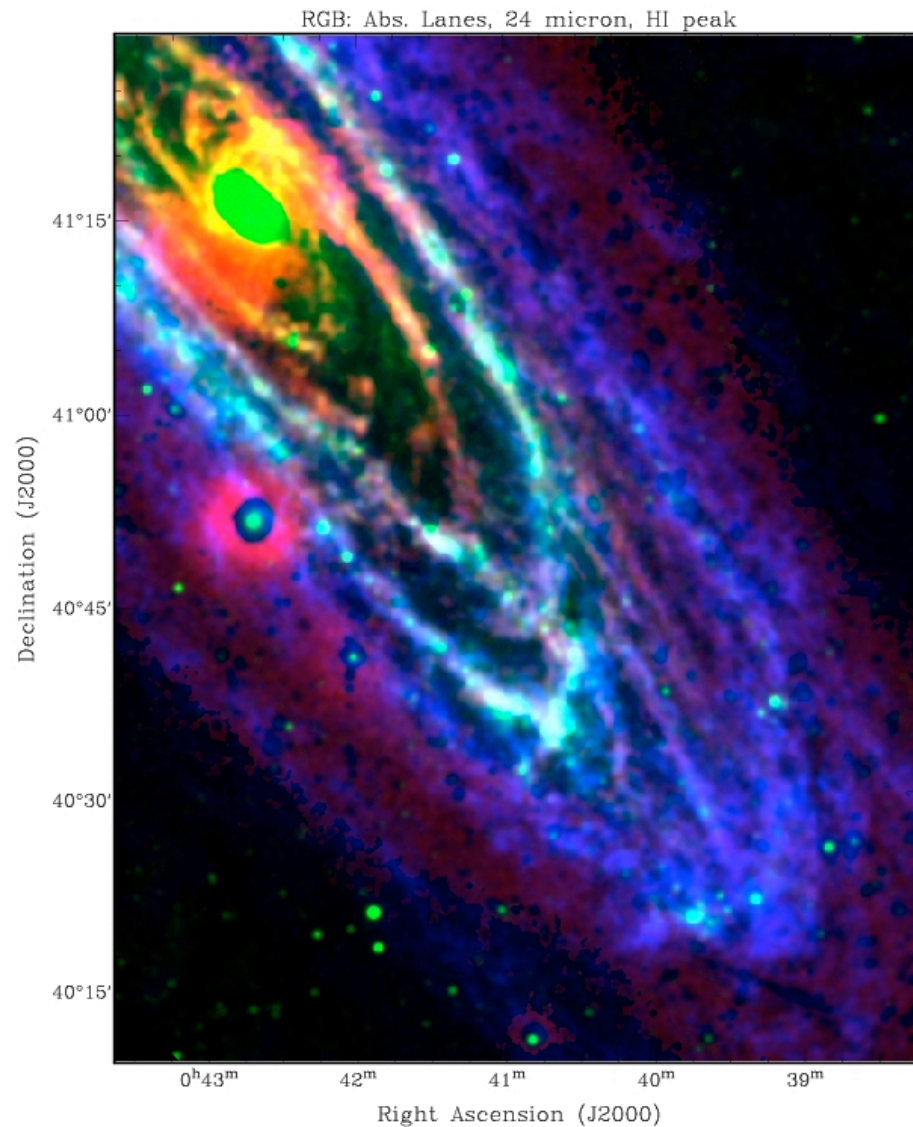
- spotty correspondence
- variation with radius

Opaque HI Filaments in M31



- spotty correspondence
- variation with radius

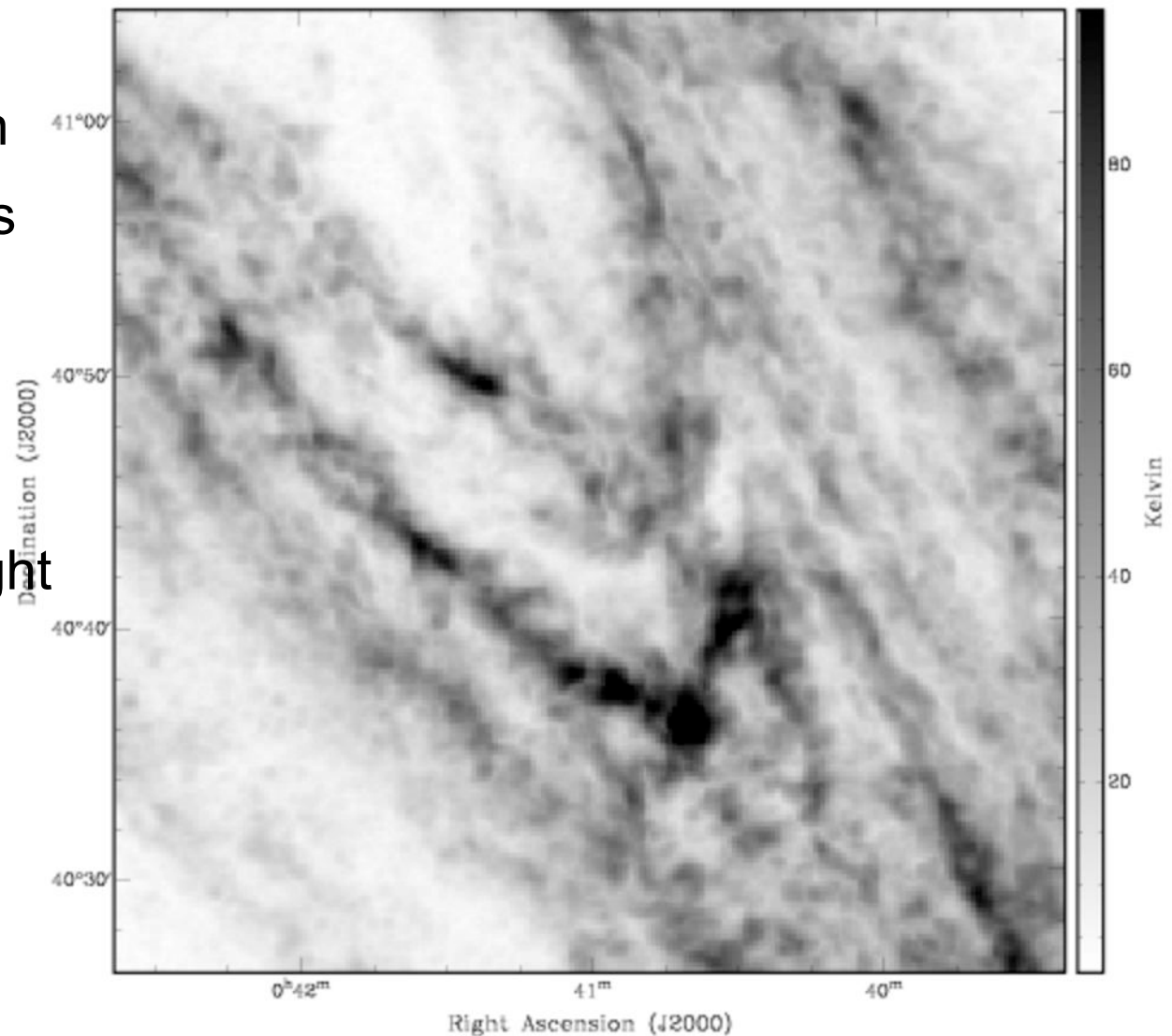
Opaque HI Filaments in M31



- spotty correspondence
- variation with radius

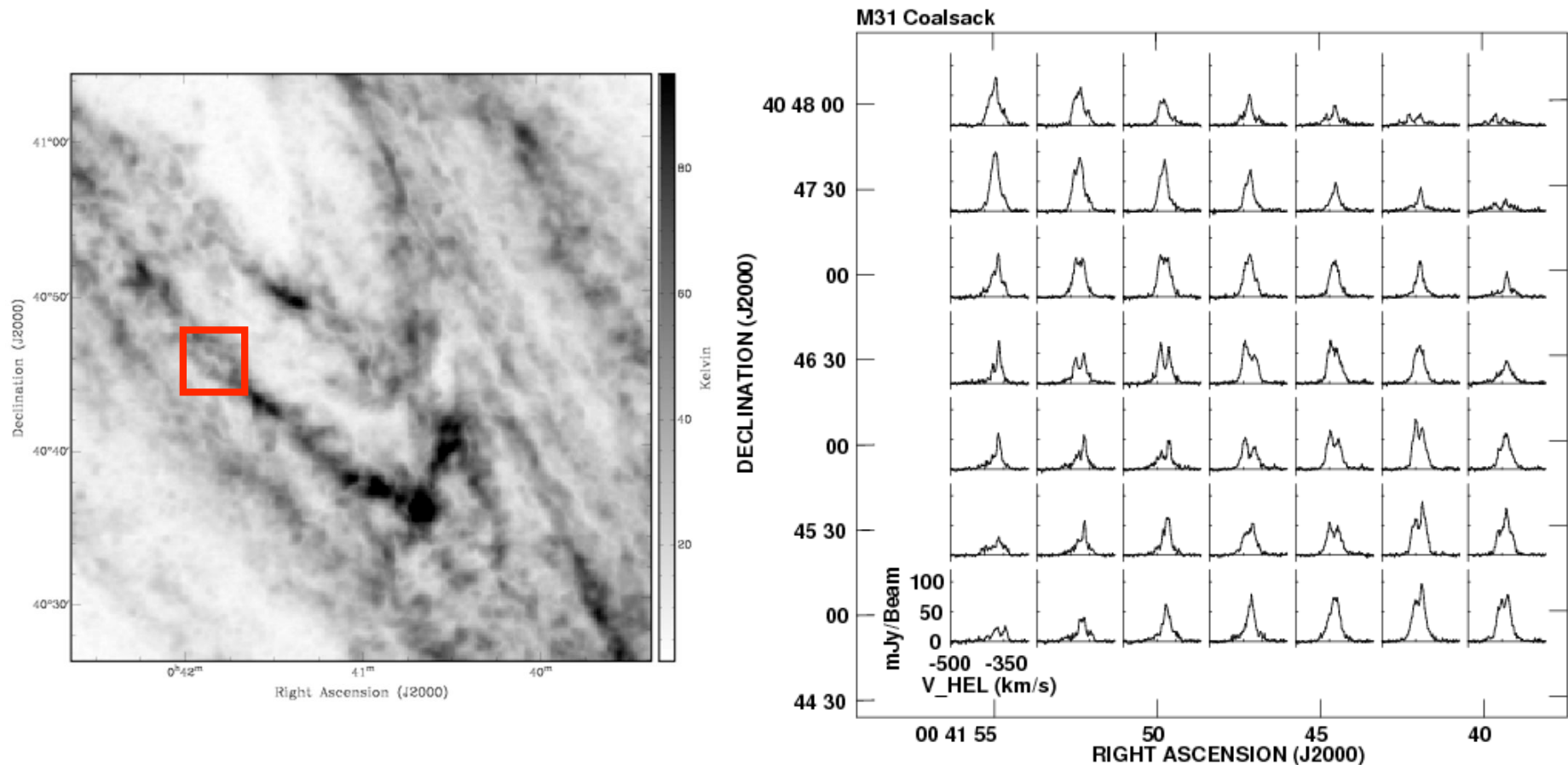
Opaque HI Filaments in M31

- Careful examination of peak HI T_B shows wealth of “negative” as well as positive features
- The absence of bright emission is also organized into structures !



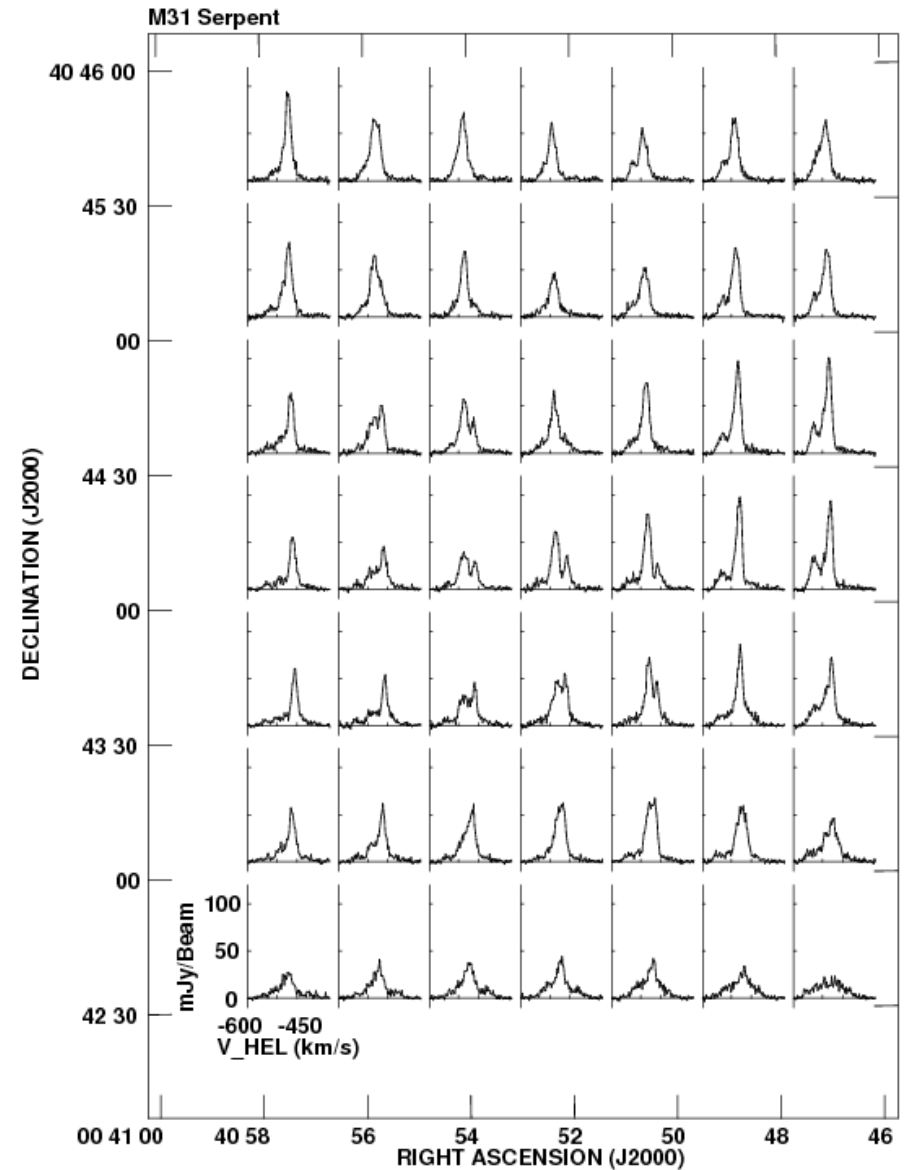
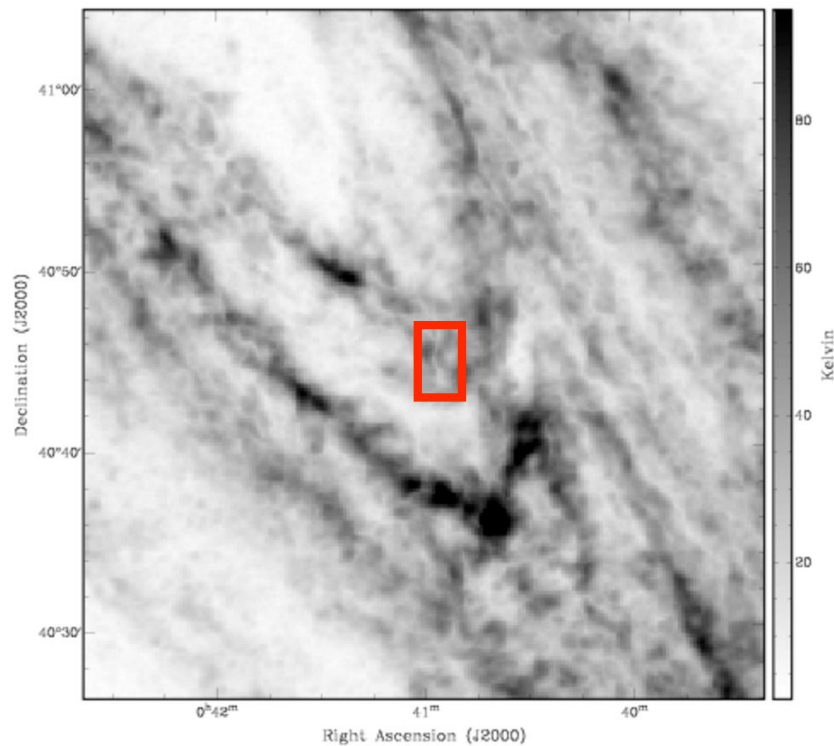
Opaque HI Filaments in M31

- “negative” features are accompanied by self-absorbed spectra
- deepest absorbers are very cold (for HI), ~ 20 K



Opaque HI Filaments in M31

- self-absorbed spectra are very common



Opaque HI Filaments in M31

- Cold HI clouds are apparently a common phenomena
- Opaque filaments are extended over 100 -1000 pc
- No obvious correspondence with other ISM tracers so far: in particular not CO or FIR
- Need to calculate apparent (hidden) mass in this phase
- Pre-cursor to GMC's or what?
- Only Local Group is currently accessible (combination of sensitivity and physical resolution) to such ISM study
- SKA will reach beyond the Virgo cluster distance

Feeding the warp of M33

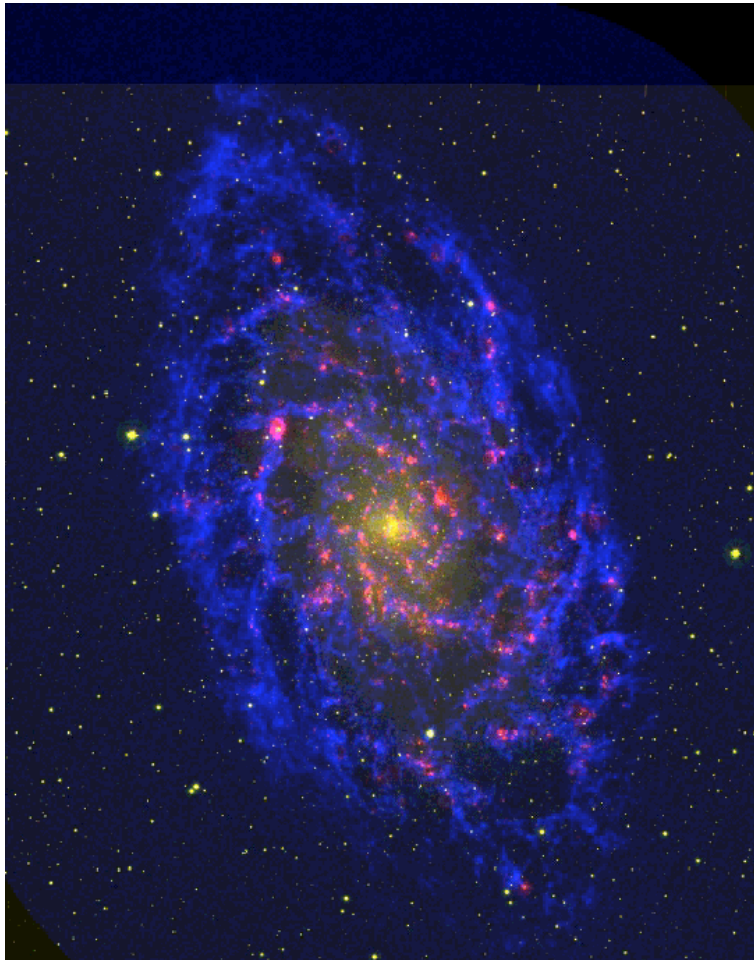
VLA HI mosiac of M33

Thilker, Braun & Corbelli 2002 & 2007

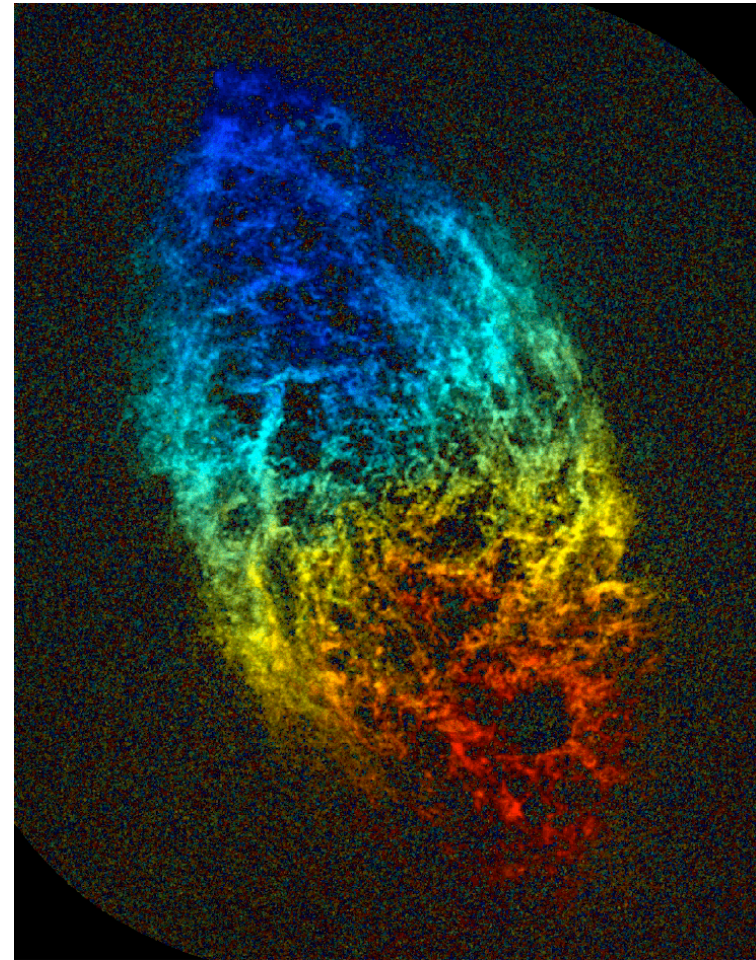
- 6 pointings in VLA B, C and D configs.
 - 100 D-config. ptgs on 15' Nyquist-sampled grid
 - 6 OTF passes with GBT of 5 x 5 deg.
 - 20 pc x 2 km/s res. over the 25 kpc disk
 - $\sigma = 0.7$ mJy/Beam (at $\Delta V = 2$ km/s)
 - $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27, \text{ and } 110 \times 10^{18} \text{cm}^{-2}$
@ 130, 60, 20, 10 and 5" ($\Delta V=20$ km/s)
-
- extended rotation curve / warping
 - outer HI edge / UV radiation field
 - CNM / WNM in disk
 - circum-galactic HI clouds and streams

Feeding the warp of M33

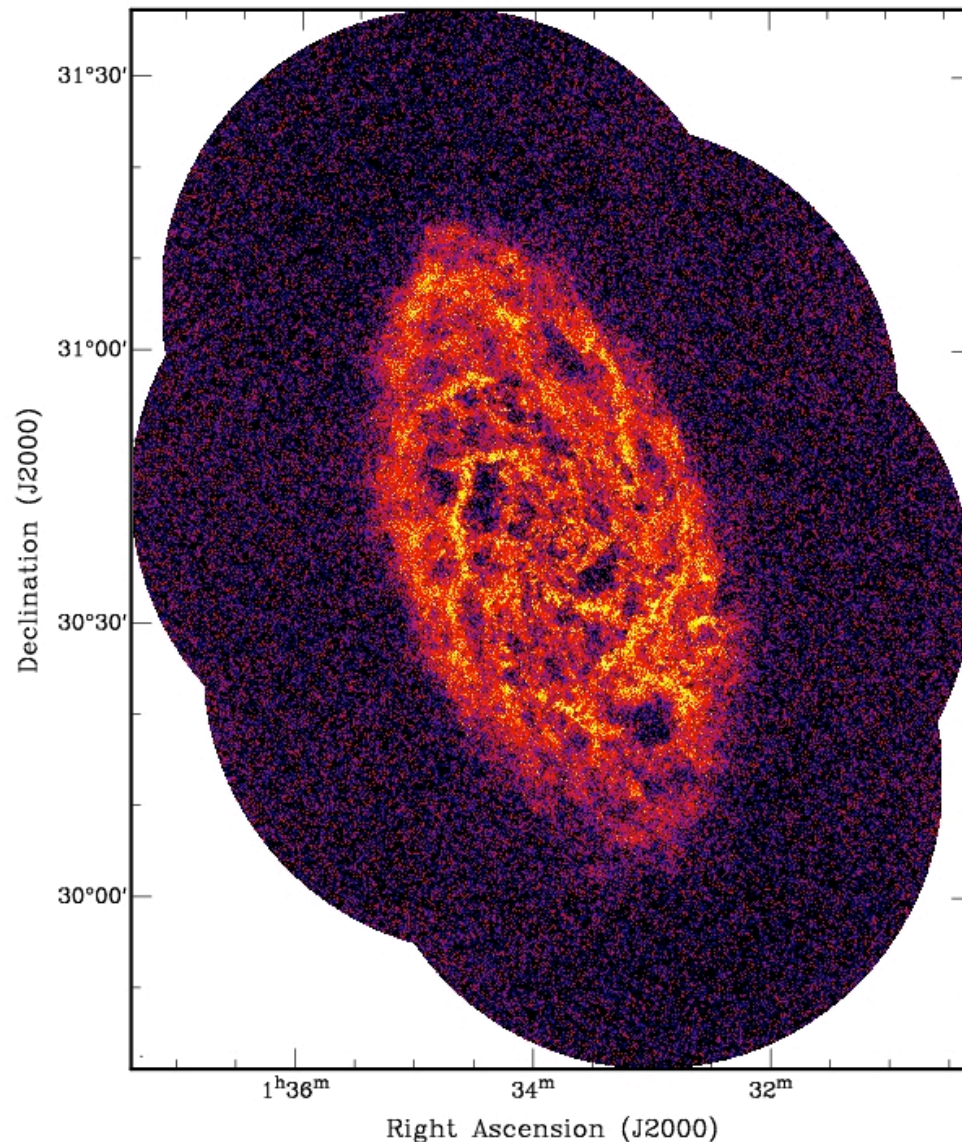
VLA+GBT HI mosiac of M33, 20 pc x 2 km/s res. covering the 25 kpc disk



Thiilker & Braun 2002, 2007

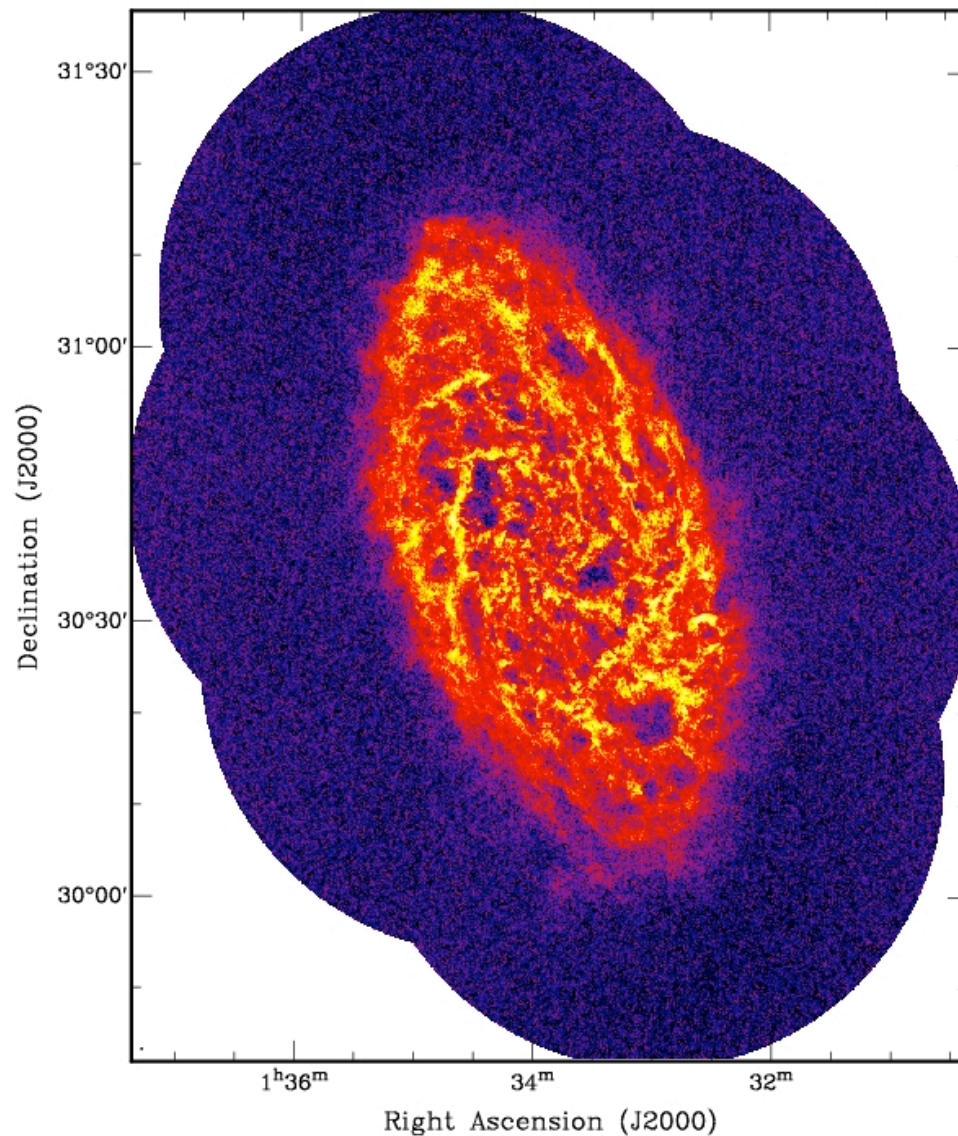


Feeding the warp of M33



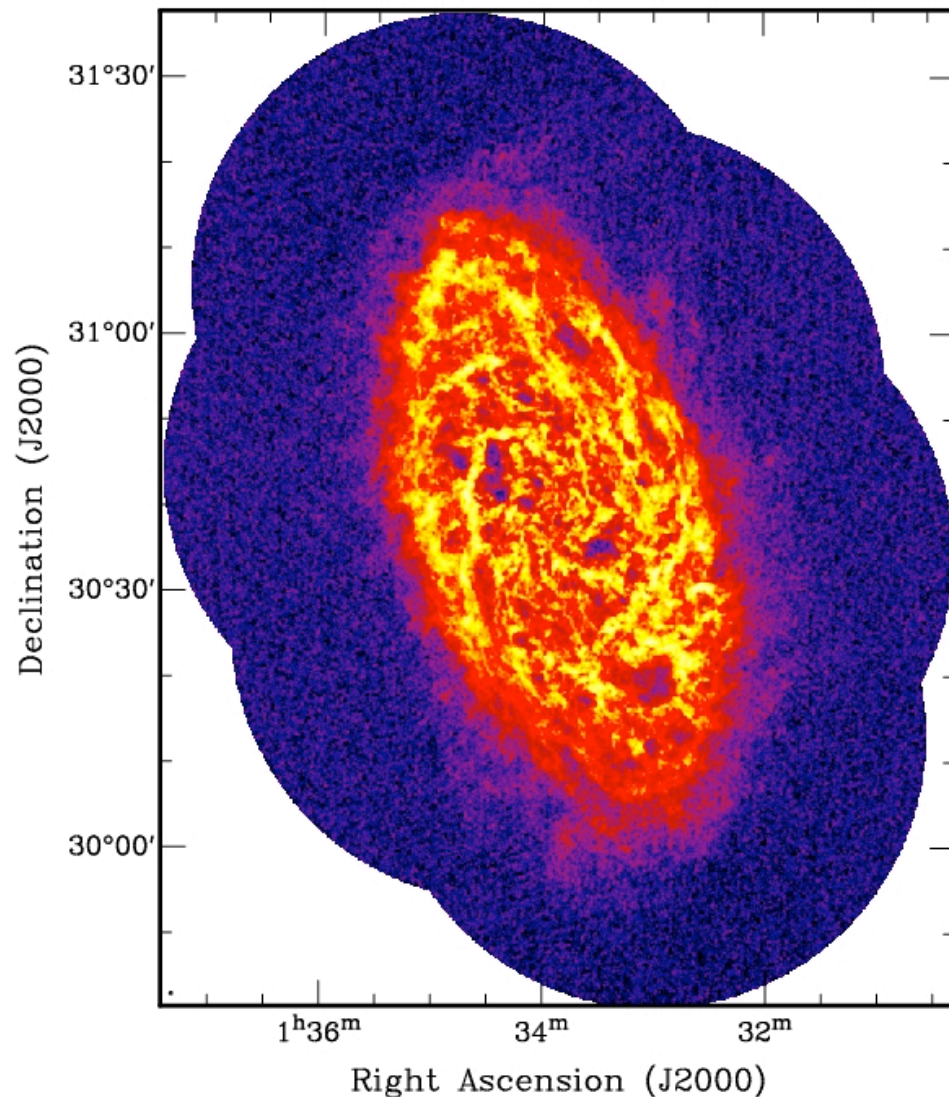
- Resolution vs. Sensitivity
- $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27,$
and **110** $\times 10^{18} \text{cm}^{-2}$
- @ 130, 60, 20, 10 and **5''**
($\Delta V = 20 \text{ km/s}$)

Feeding the warp of M33



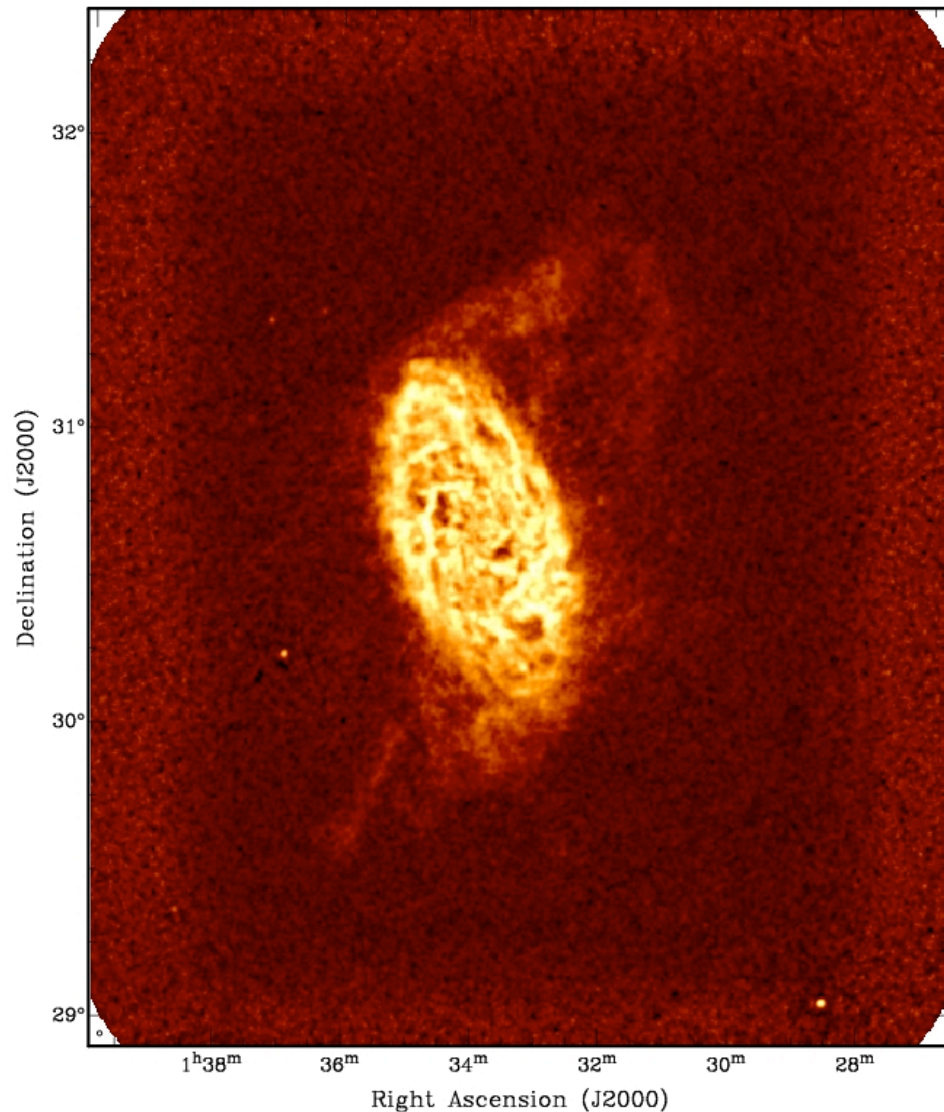
- Resolution vs. Sensitivity
- $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27,$
and $110 \times 10^{18} \text{cm}^{-2}$
- @ 130, 60, 20, 10 and 5''
($\Delta V = 20 \text{ km/s}$)

Feeding the warp of M33



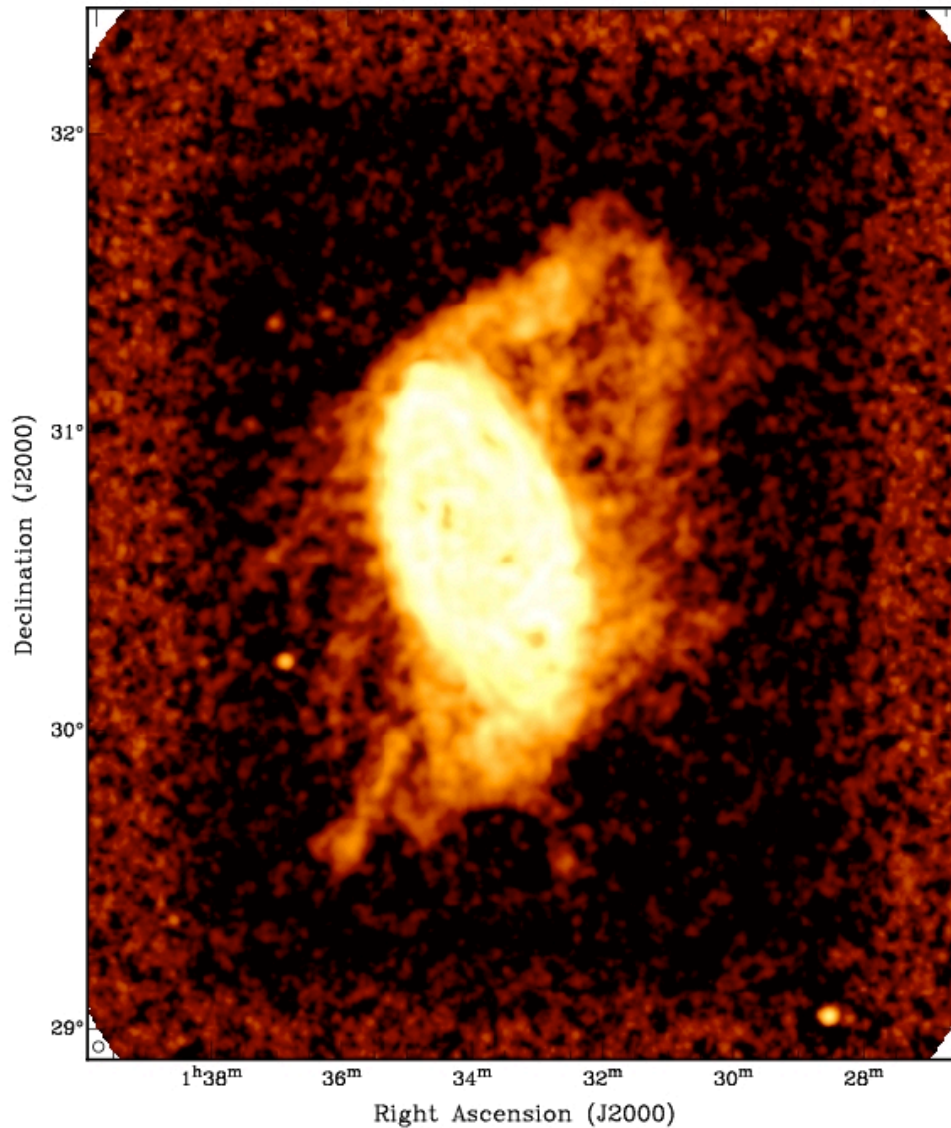
- Resolution vs. Sensitivity
- $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27,$
and $110 \times 10^{18} \text{cm}^{-2}$
- @ 130, 60, 20, 10 and 5" ($\Delta V = 20 \text{ km/s}$)

Feeding the warp of M33



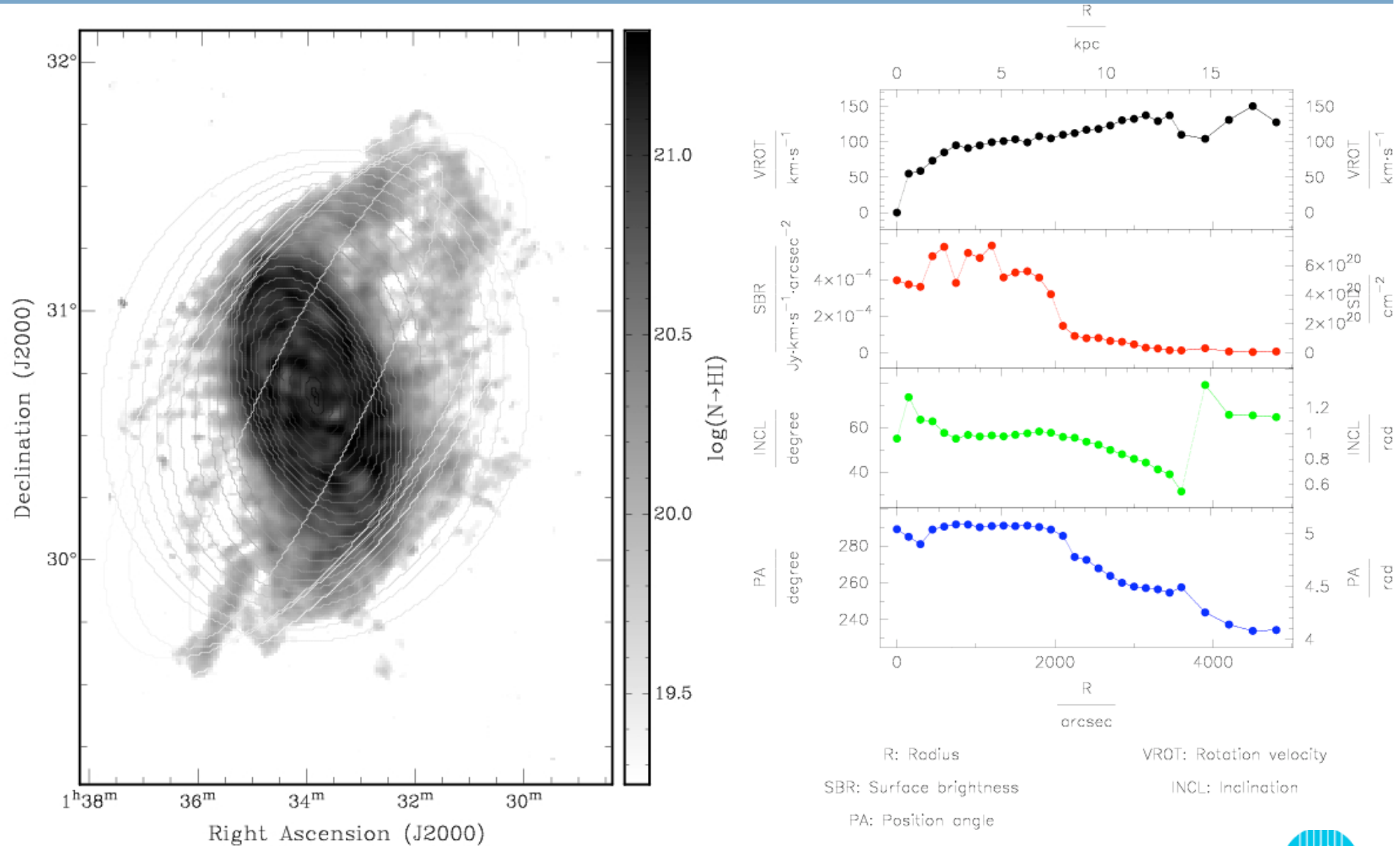
- Resolution vs. Sensitivity
- $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27,$
and $110 \times 10^{18} \text{cm}^{-2}$
- @ 130, 60, 20, 10 and 5''
($\Delta V = 20 \text{ km/s}$)

Feeding the warp of M33



- Resolution vs. Sensitivity
- $\Delta N_{\text{HI}} = 0.6, 2.5, 17, 27,$
and $110 \times 10^{18} \text{cm}^{-2}$
- @ 130, 60, 20, 10 and 5''
($\Delta V = 20 \text{ km/s}$)

Feeding the warp of M33

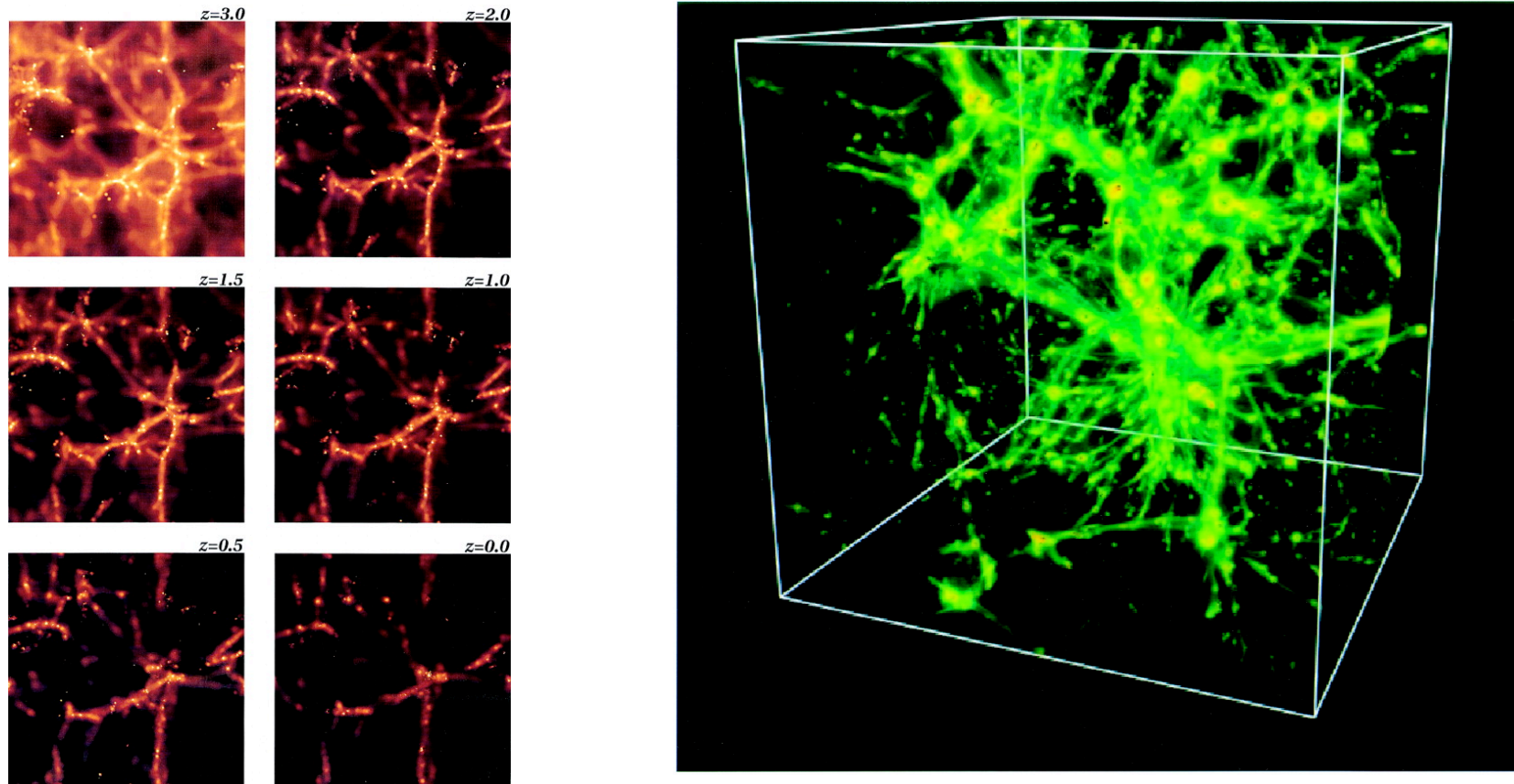


- preliminary model still far from perfect

Feeding the warp of M33

- 3D model of HI brightness, kinematics and potential is now being developed
- various approaches being explored in parallel:
 - sequential optimization (Gyula Josza's Tirific)
 - simultaneous, constrained optimization (being done by Edvige Corbelli)
- preliminary model still far from perfect
- Problems:
 - major asymmetries in morphology and kinematics
 - tidal effects, infall: => non-equilibrium kinematics
 - computationally very demanding !!
- Stay tuned ...

Ancient Galaxy Interactions

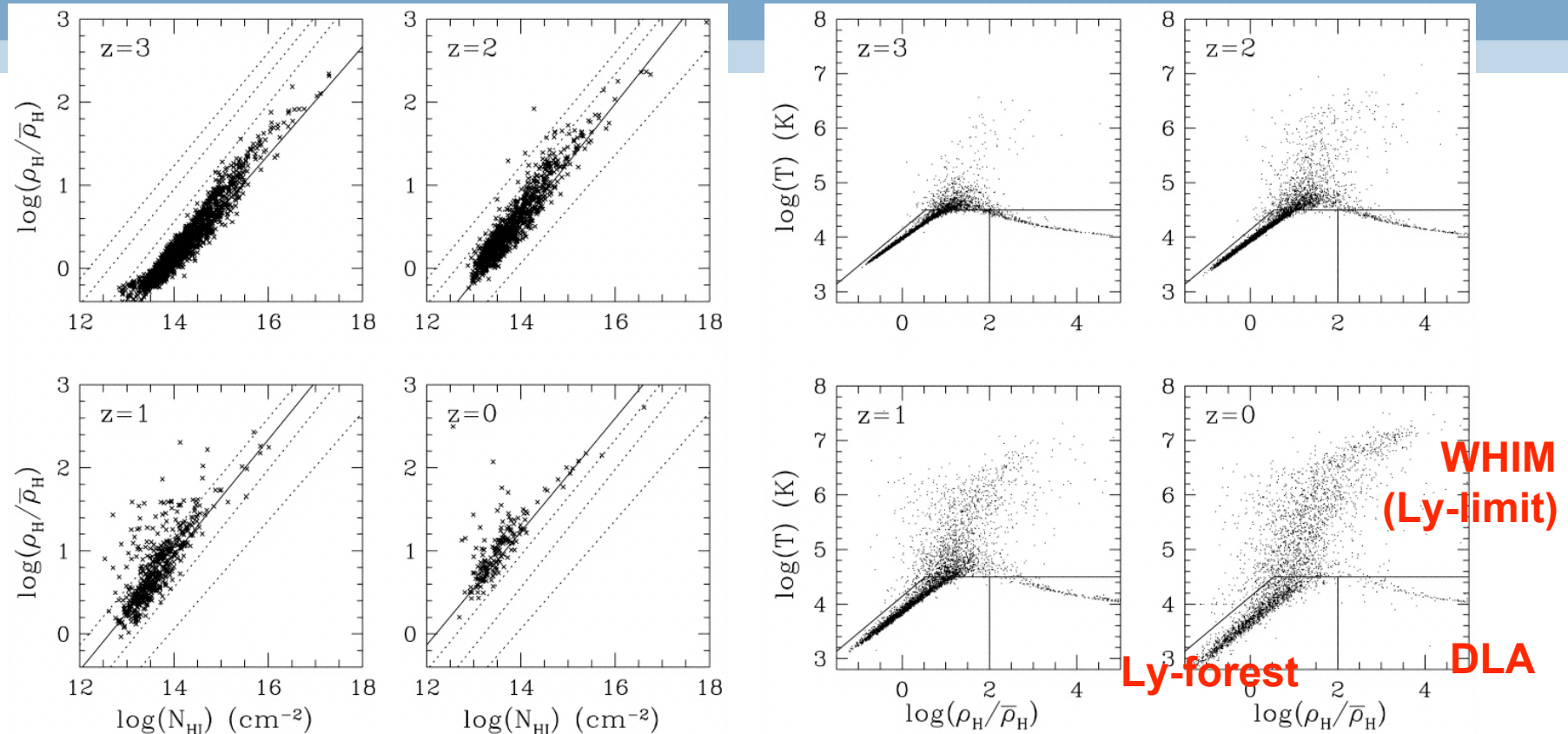


Dave et al. 1999, ApJ 511, 521, 2001, ApJ 552, 473

- high res. num. sim. predict cosmic web of filaments between galaxies
- apparent correspondence with QSO absorbers

Ancient Galaxy Interactions

Dave et al. 1999, ApJ 511, 521

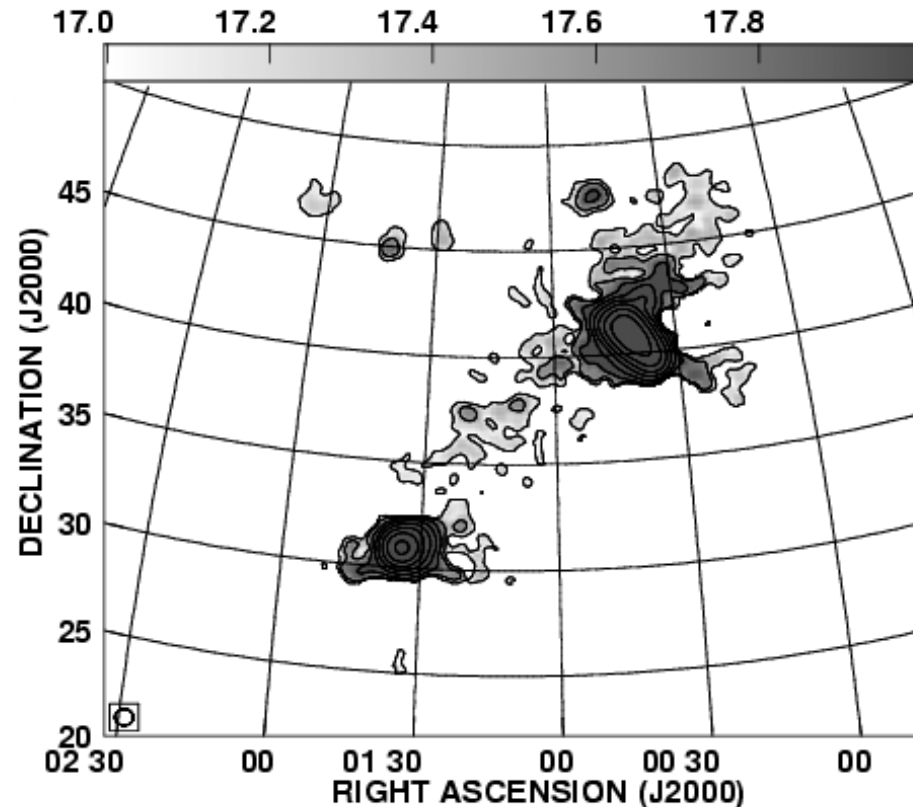


- strong (density-dependent) evolution predicted with cosmic epoch
- DLA's down by orders of magnitude, LLS's up ($z=0$)
- The aftermath of the gravity era and signature of dark energy domination!

Ancient Galaxy Interactions

The M31 Filament

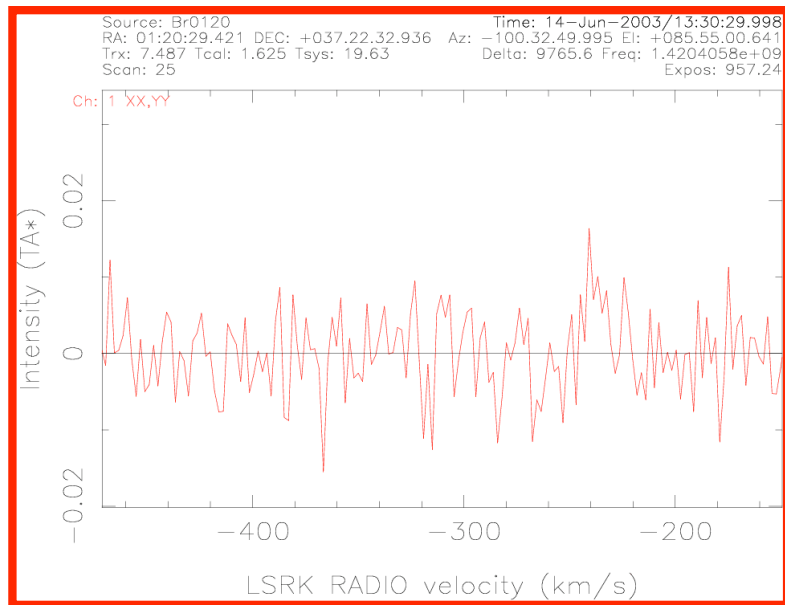
- connects V_{SYS} of M31 and M33
- continues in anti-M33 direction (300 kpc total extent)
- filamentary structure within 30 kpc
- connects to ongoing fueling of both M31 and M33



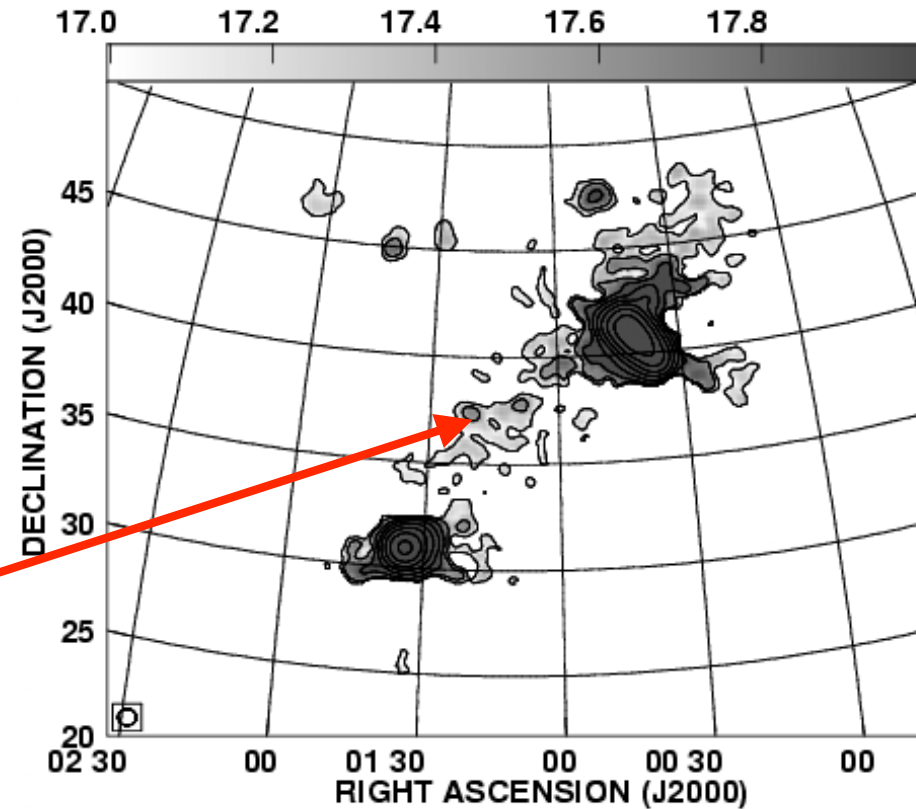
wide-field WSRT data

Ancient Galaxy Interactions

- extremely diffuse in bridge region (same low N_{HI} in GBT and WSRT TP beams)



GBT confirmation (30 min ON/OFF)



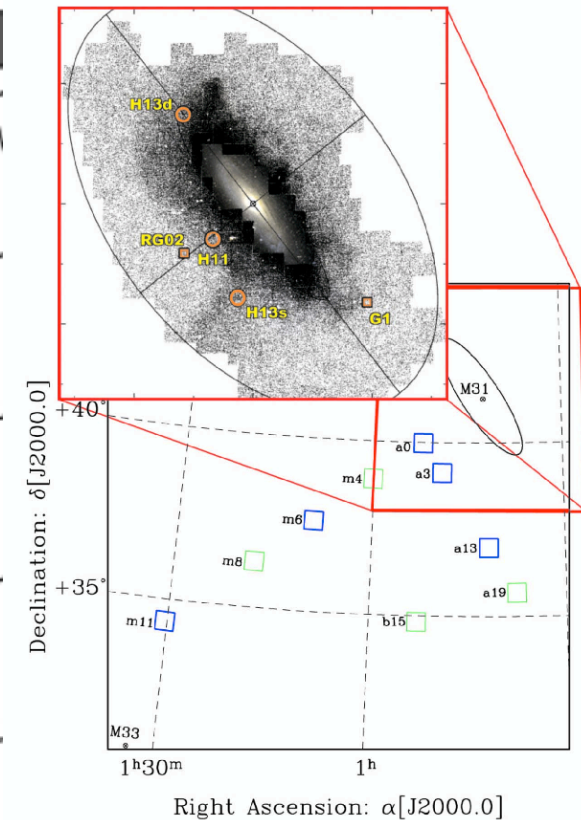
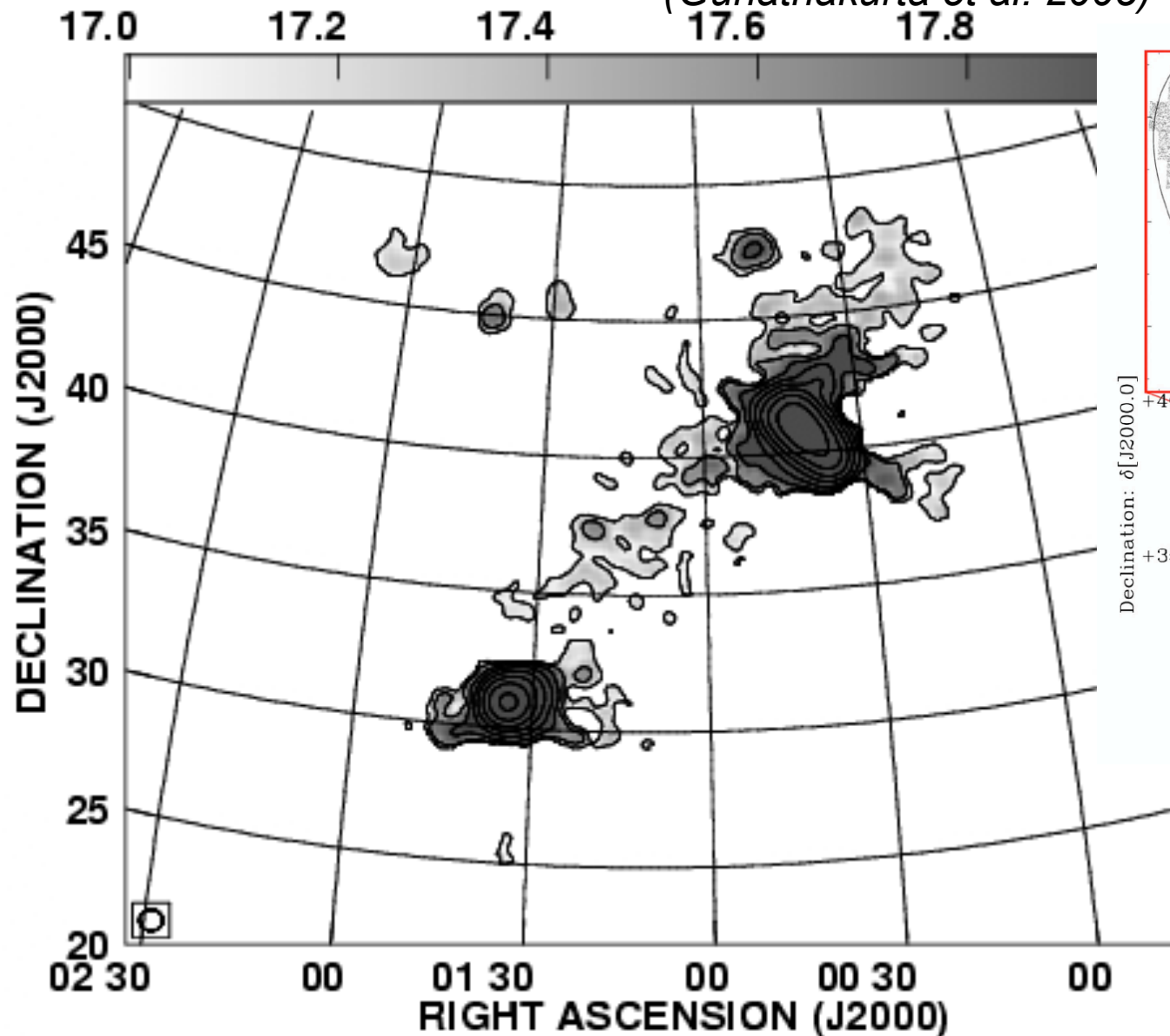
wide-field WSRT data

- first detection of the “cosmic web”/ WHIM in HI emission

Ancient Galaxy Interactions

- close correspondence with observed minor axis red giant fields

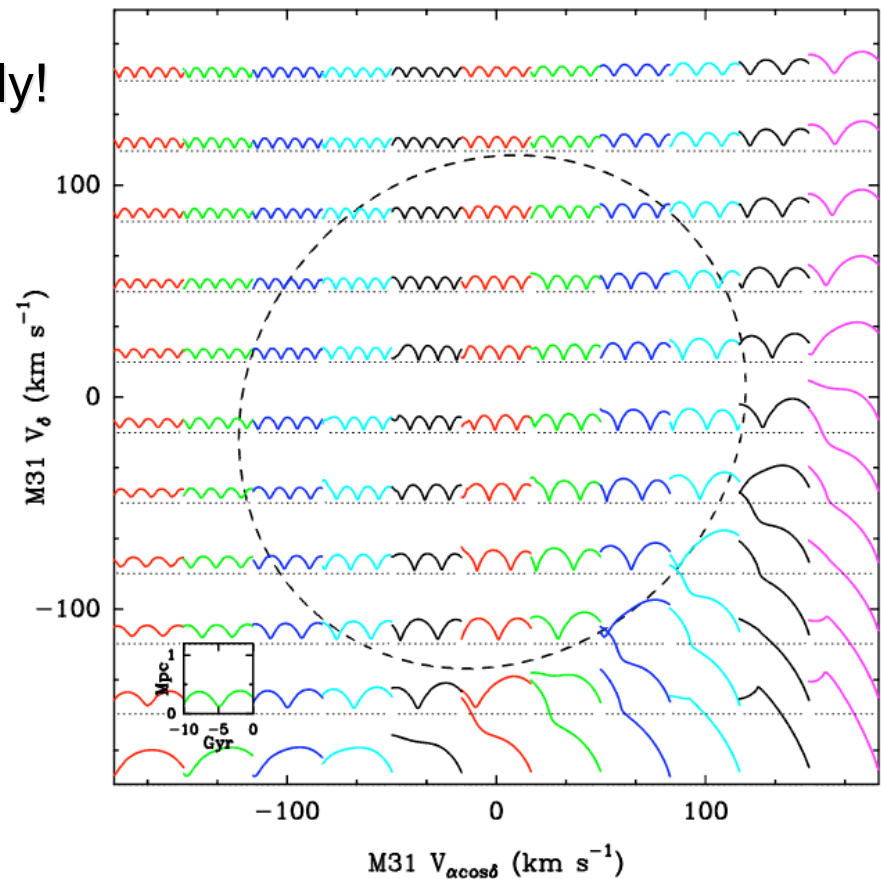
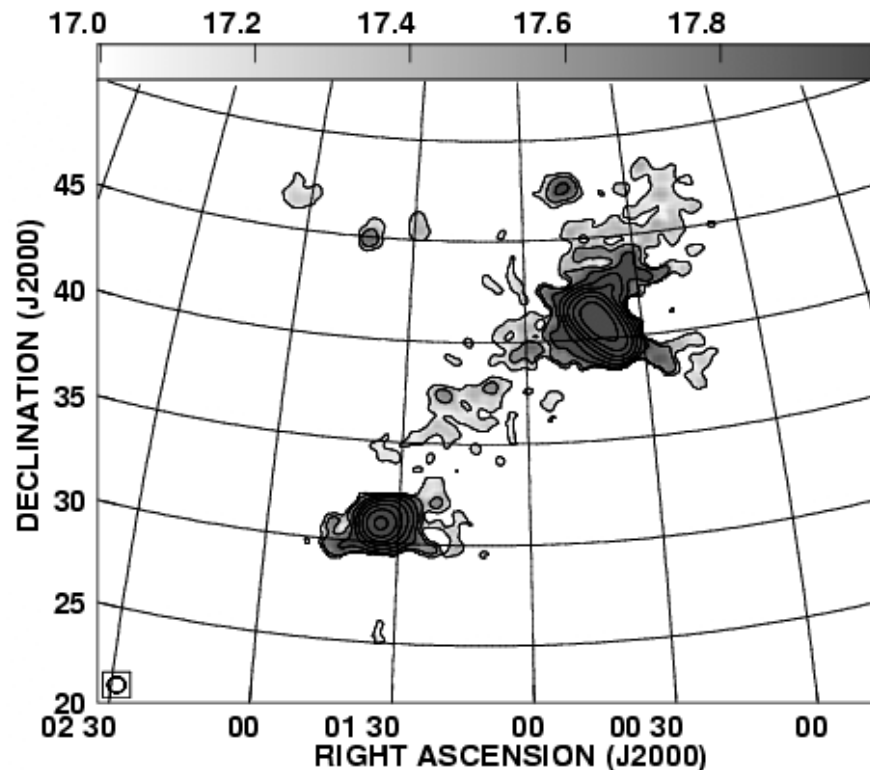
(Guhathakurta et al. 2005)



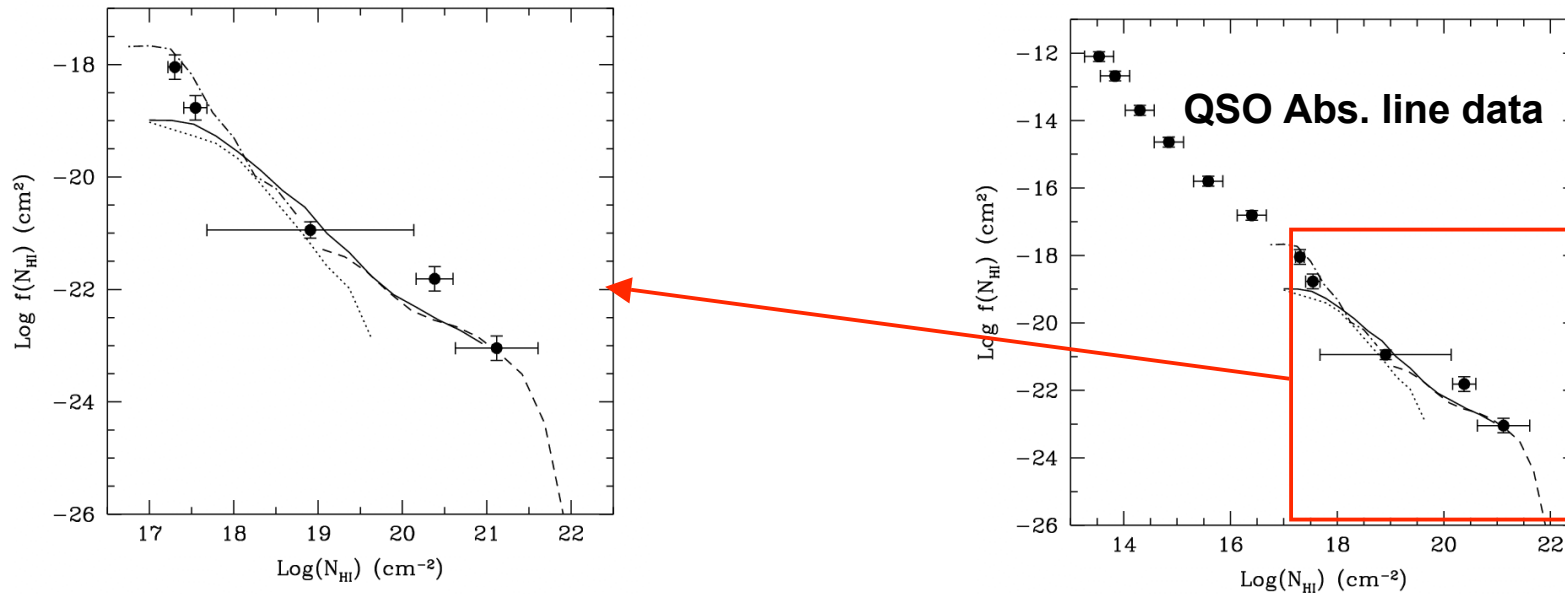
Ancient Galaxy Interactions

Is it primordial or is it tidal ?

- M33 stellar disk is both very extended and seemingly very undisturbed (*Ferguson et al. 2005*): “perfect” exponential to 40’
- Given M33 space velocity (*Brunthaler et al. 2005*) can consider interaction history as function of M31 space velocity (*Loeb et al. 2005*)
- Previous interaction (>3 Gyr) very likely!

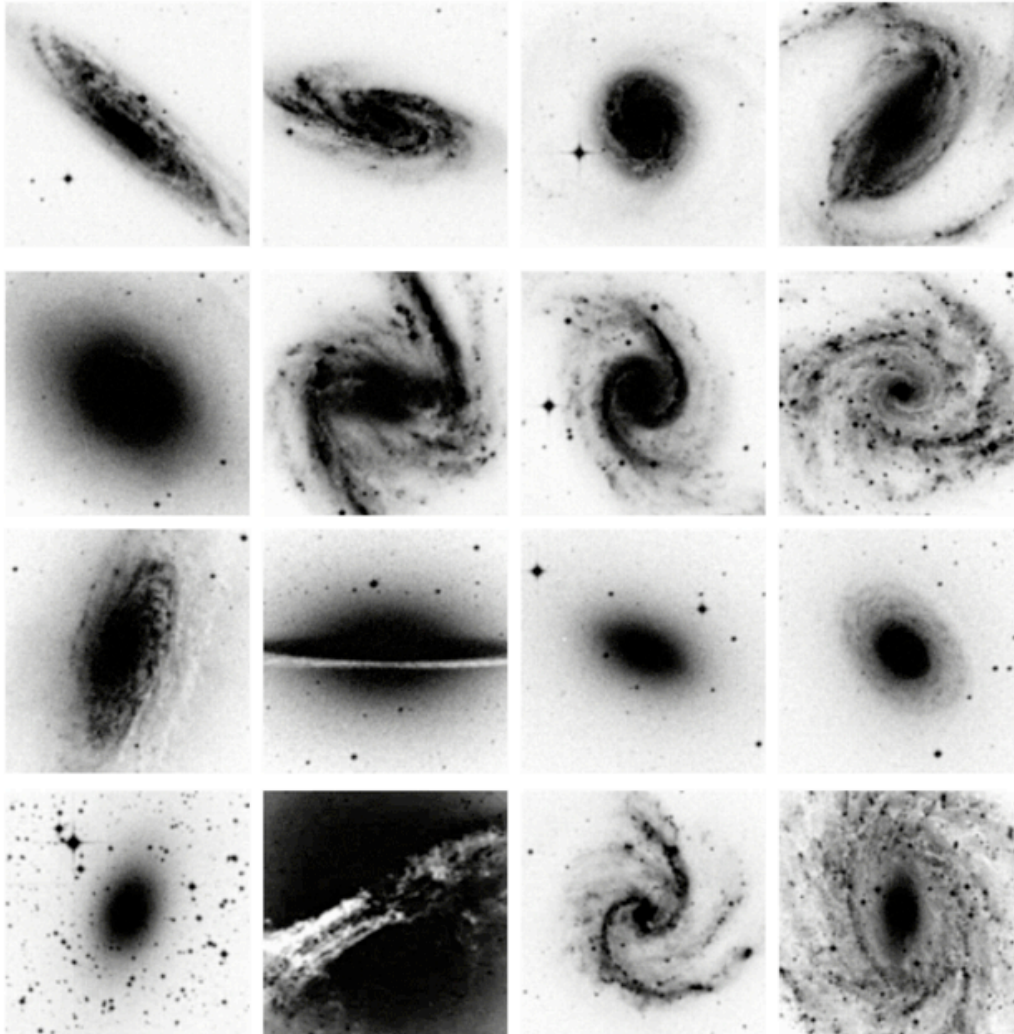


Ancient Galaxy Interactions



- composite N_{HI} distribution from WSRT mosaic, GBT, wide-field WSRT
- normalization from HIPASS BGC (Zwaan et al. 2003)
- good agreement with QSO absorption line data
- confirmation of 30-fold increase in covering factor $10^{19} - 10^{17} \text{ cm}^{-2}$
- the first image of a Lyman Limit absorption System
- chance to visualize \sim Hubble-time of interaction and accretion history

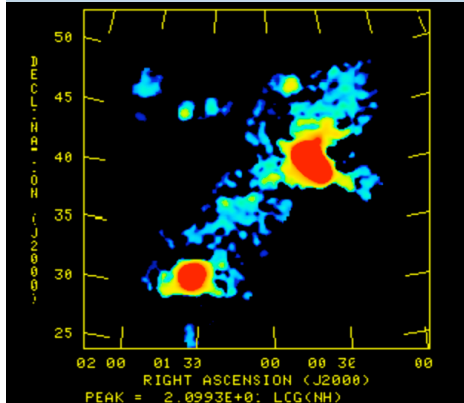
Galaxy Accretion and Feed-back @ Red-shift Zero



GAF@RZ

- Braun, Popping, Webster, Sadler, Koribalski, Hawthorn, Barnes, Westmeier, Lopez-Sanchez
- Parkes Multi-Beam Survey (~5000 hr proposed)
- Probe extended environment ($>1 \times 1$ Mpc) of the most massive galaxies ($M_B < -21$) and AGN (Cen A, Fornax A) within ~ 20 Mpc ($\delta < 0$)
- Reach 10^{17} cm^{-2} @ 20 km/s at 3σ in ~ 60 kpc beam

HI in the M31 Sub-group



Plenty of unsolved mysteries in our own backyard

- opaque filaments: how much atomic gas mass is hidden ?
- feeding warps: is infall from ancient interactions the prime driver ?
- ancient interactions: a Hubble-time of interaction and accretion history is waiting to be imaged !

