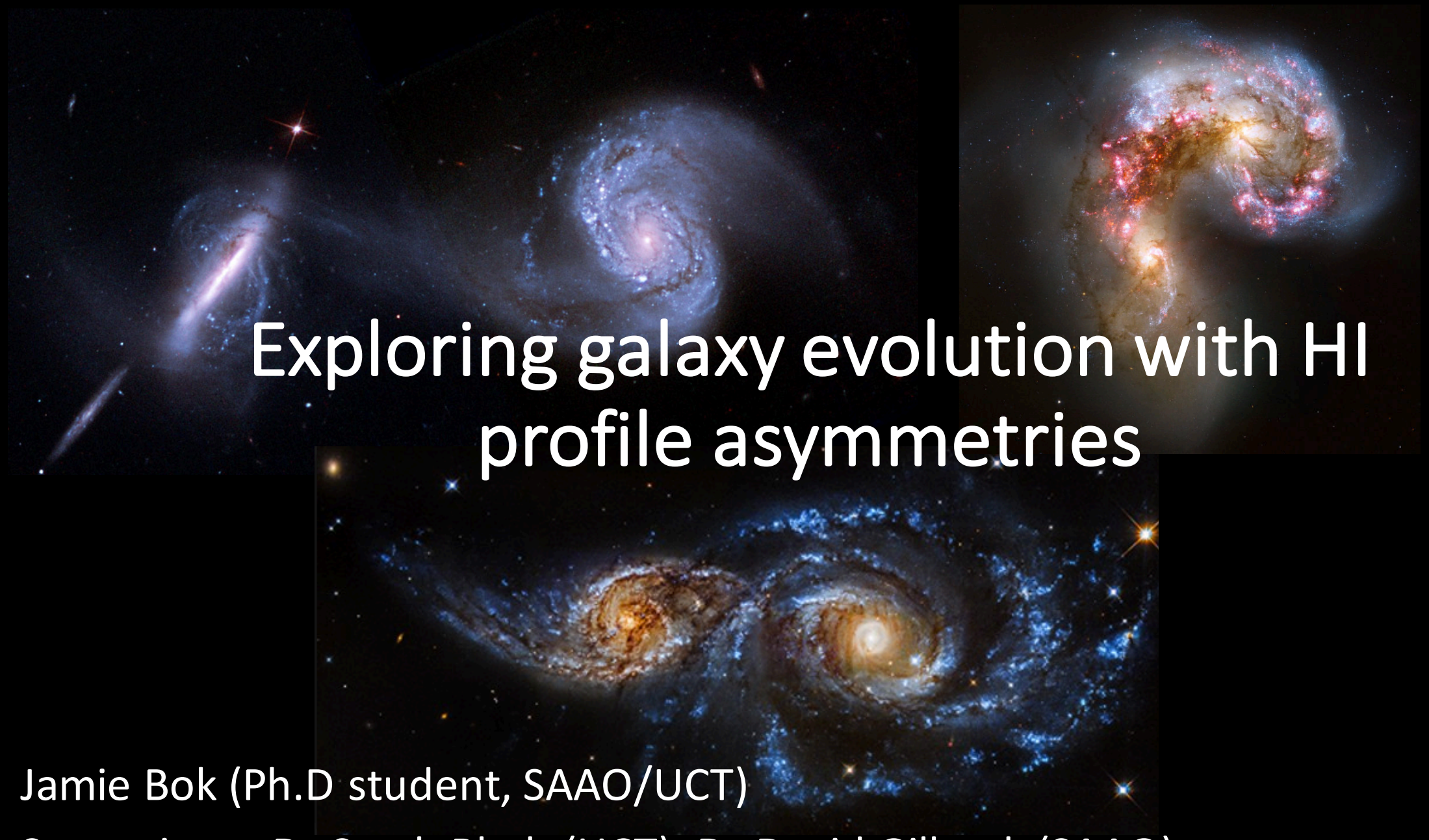


Exploring galaxy evolution with HI profile asymmetries

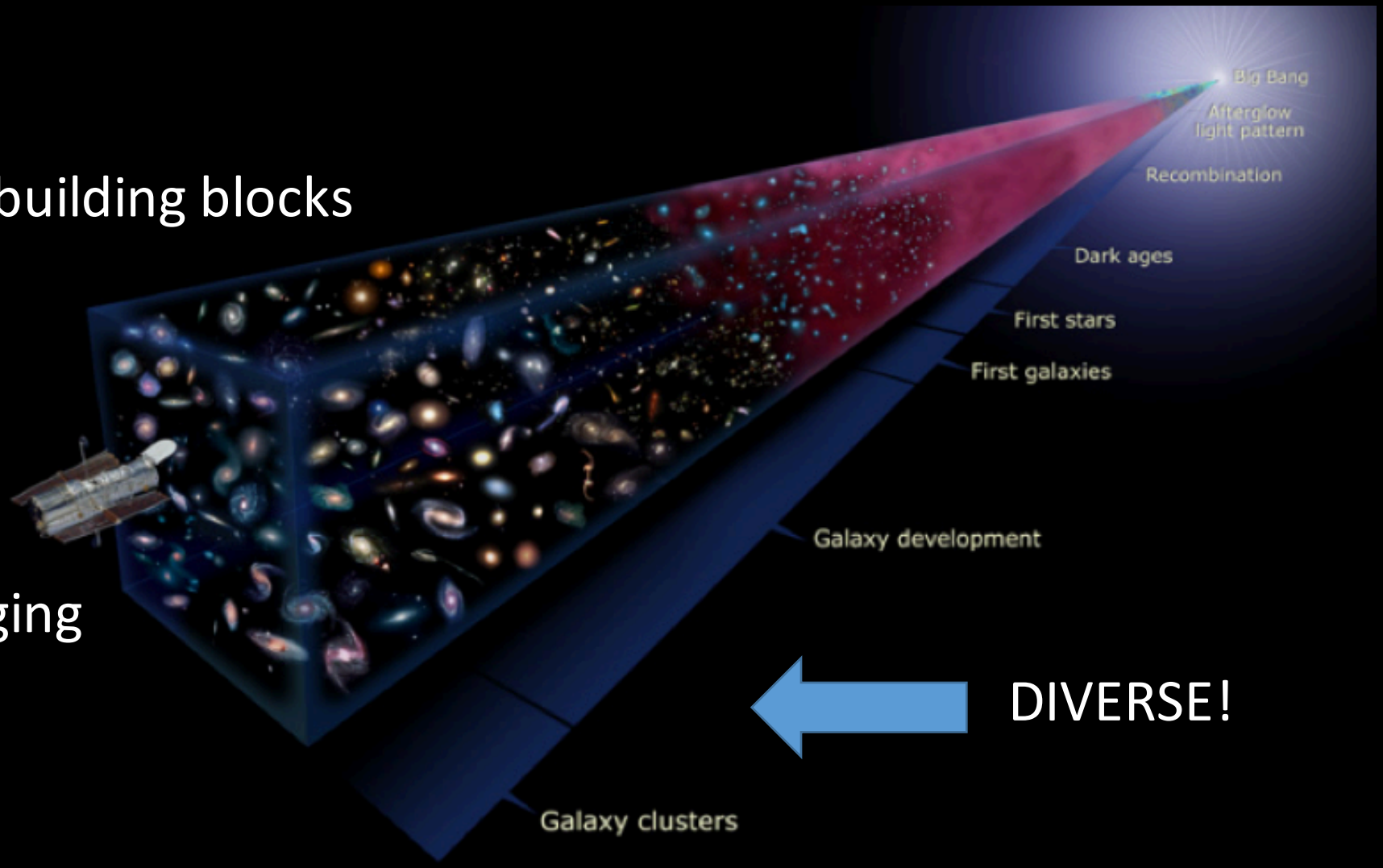
Jamie Bok (Ph.D student, SAAO/UCT)

Supervisors: Dr Sarah Blyth (UCT), Dr David Gilbank (SAAO)

The BIG picture

- Galaxies are the building blocks of the Universe

- Lambda-CDM: hierarchical merging



DIVERSE!

Picture credit: STScI http://hubblesite.org/newscenter/archive/releases/2006/2006/12/

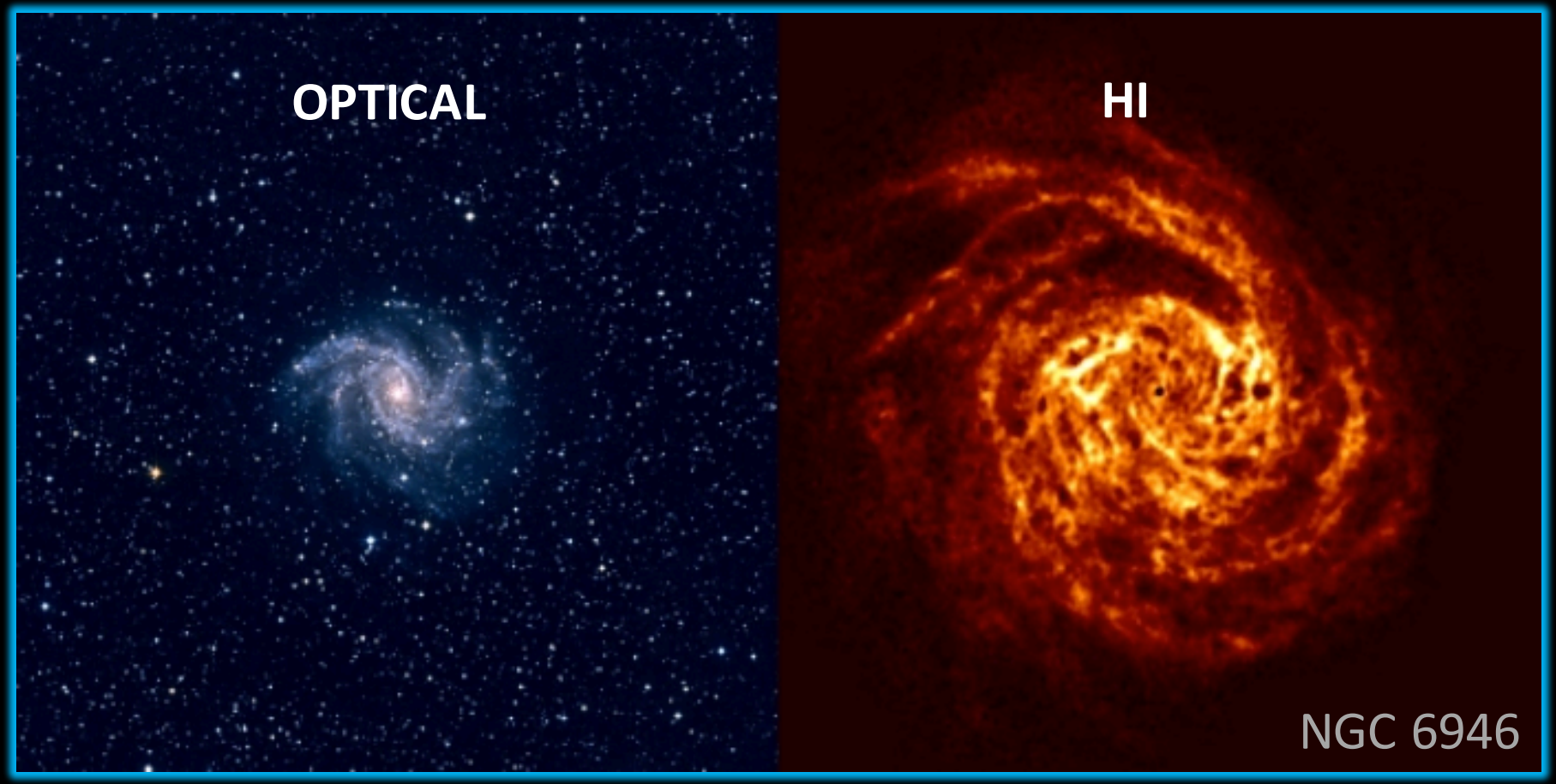
Evidence of mergers?

- Disturbed morphologies (post mergers)
- Tidal features (during mergers)
- Close pairs (about to merge)

Merger activity causes asymmetries

Tracing asymmetry: Optical vs HI

- Asymmetry more frequent in HI than in stars, & amplitude of asymmetry increases with galaxy radius (Rix & Zaritsky, 1998)



HI is a very sensitive probe of galaxy-galaxy interactions

Credit: Benne Holwerda, ESA-ESTE

Can we probe mergers using HI asymmetries?

- ‘Quantified HI Morphology II : Lopsidedness and Interaction in WHISP Column Density Maps’ (Holwerda et al. 2013)

→ Disturbed morphologies/asymmetries are good indicators of recent merger interaction

- Most HI surveys are single dish (galaxies are unresolved!)

- But we do have lots of HI profiles…

Image credit: VLA THINGS, Walter et al. 2008

Can we probe mergers using HI asymmetries?

- ‘Quantified HI Morphology II : Lopsidedness and Interaction in WHISP Column Density Maps’ (Holwerda et al. 2013)

→ Disturbed morphologies/asymmetries are good indicators of recent merger interaction

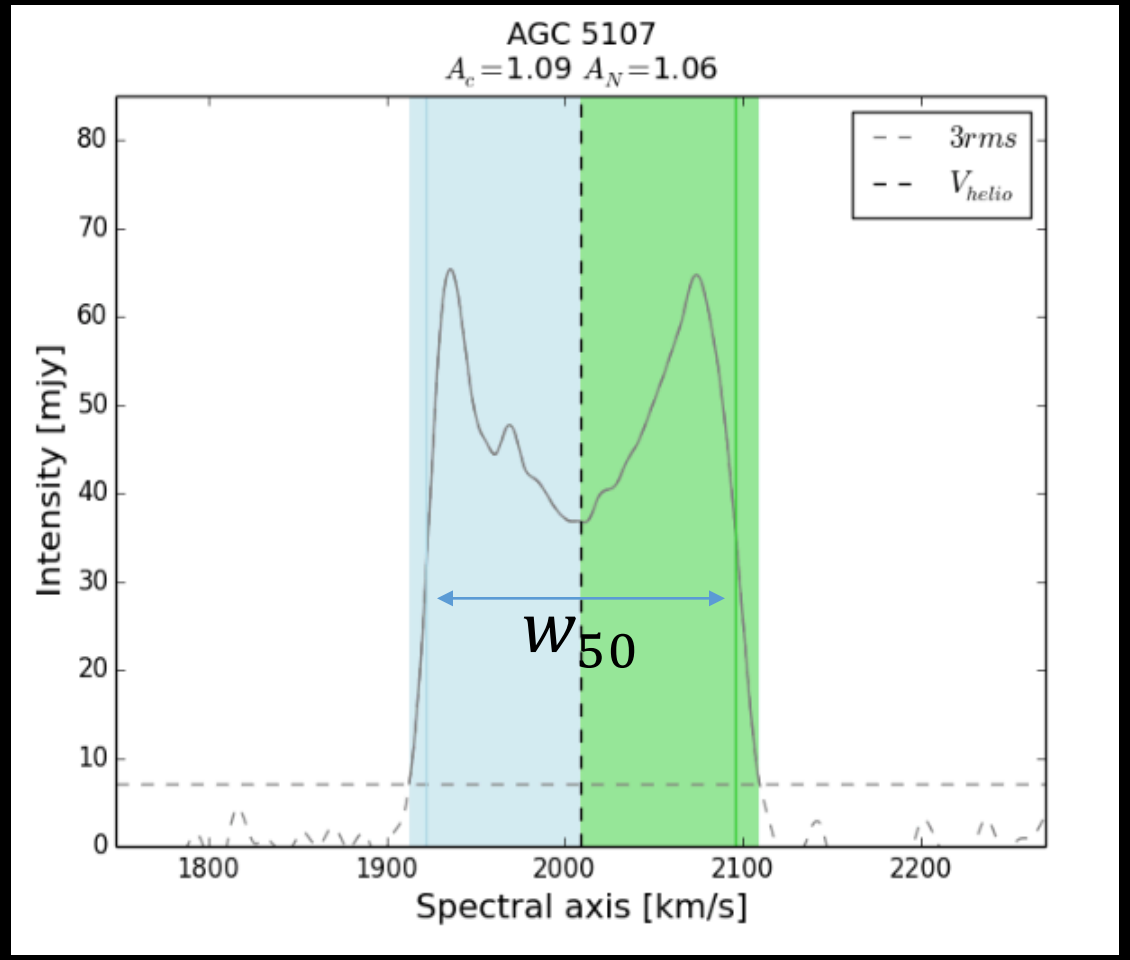
- Most HI surveys are single dish (galaxies are unresolved!)

- But we do have lots of HI profiles…

Image credit: HST

[several 100 (spatially resolved) vs 10^4 (spectrally resolved)]

HI profiles



- Symmetric double-horn shape for an unperturbed disk
- non- circular motions (potentially caused by merger activity) → asymmetry (Haynes et al. 1998)

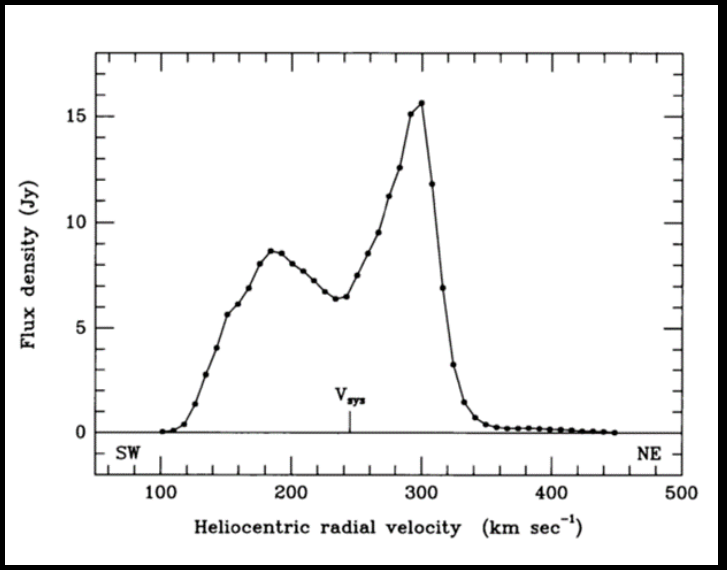
Asymmetric HI profiles

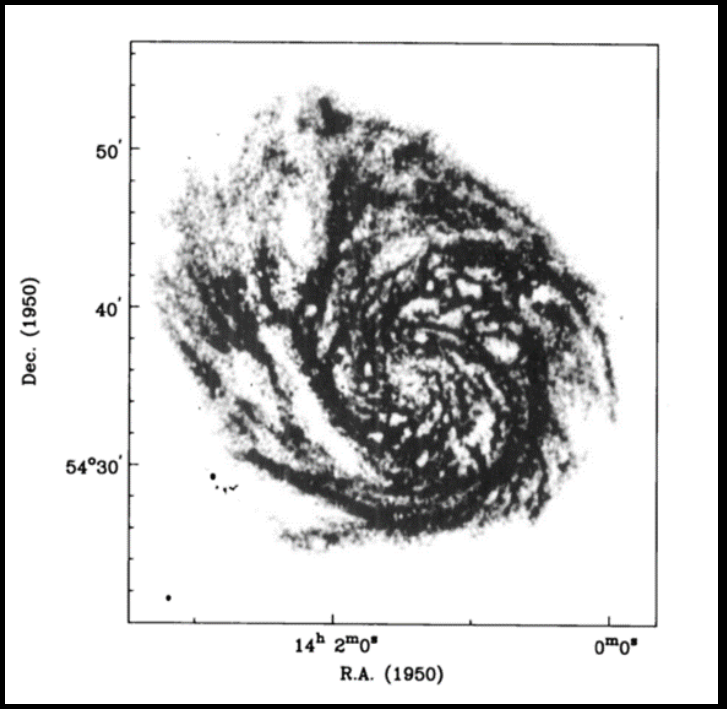
- ± 50% HI profiles are asymmetric (Richter & Sancisi 1994, Haynes 1998)

- Link between asymmetric HI profiles and lopsided HI distributions (Richter & Sancisi, 1994)

→ *Global velocity profile asymmetries are good tracers of the disk mass asymmetry*

→ So maybe we can use HI profiles to trace asymmetries associated with merger activity, and thereby trace mergers!





My project

KEY QUESTION: Can HI profile asymmetries tell us about mergers?

APPROACH: Investigate HI profile asymmetries of galaxies within close pairs

- Define a sample of close pairs
- Quantitatively describe asymmetry
- Compare with isolated galaxies (are mergers a likely candidate for causing HI profile asymmetries?)

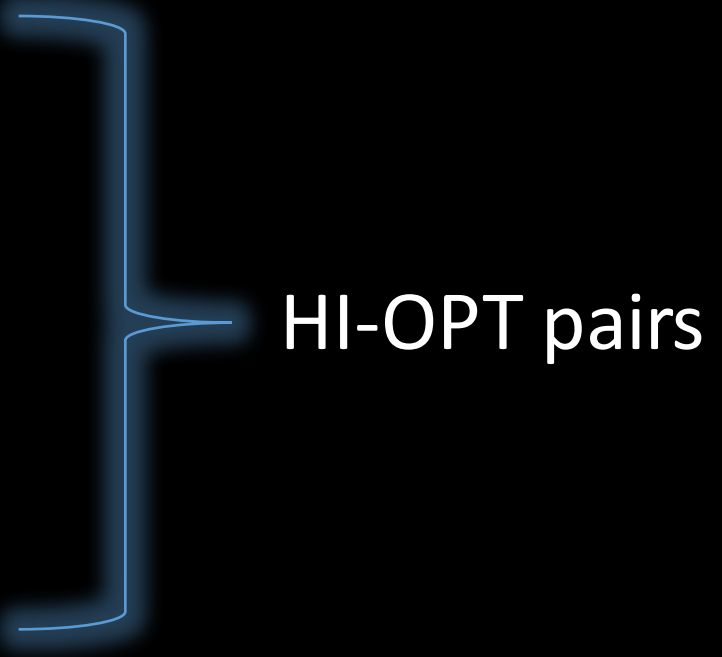
Data

- HI: ALFALFA α40 catalogue (Haynes et al., 2011)

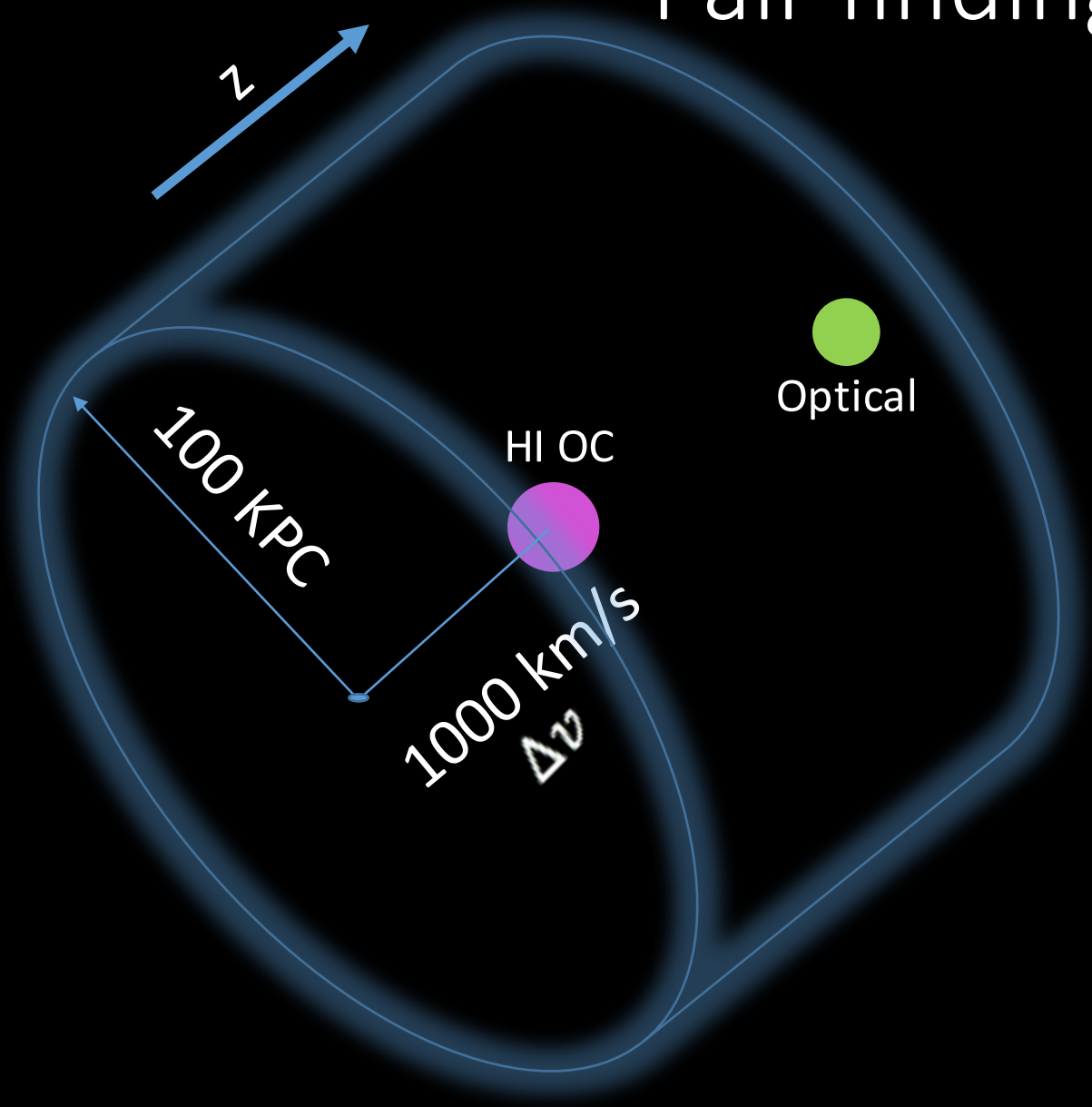
  (code 1's with spectroscopic OCs in SDSS -6768 galaxies)

- Optical: Sloan Digital Sky Survey DR7

  (spectroscopic)

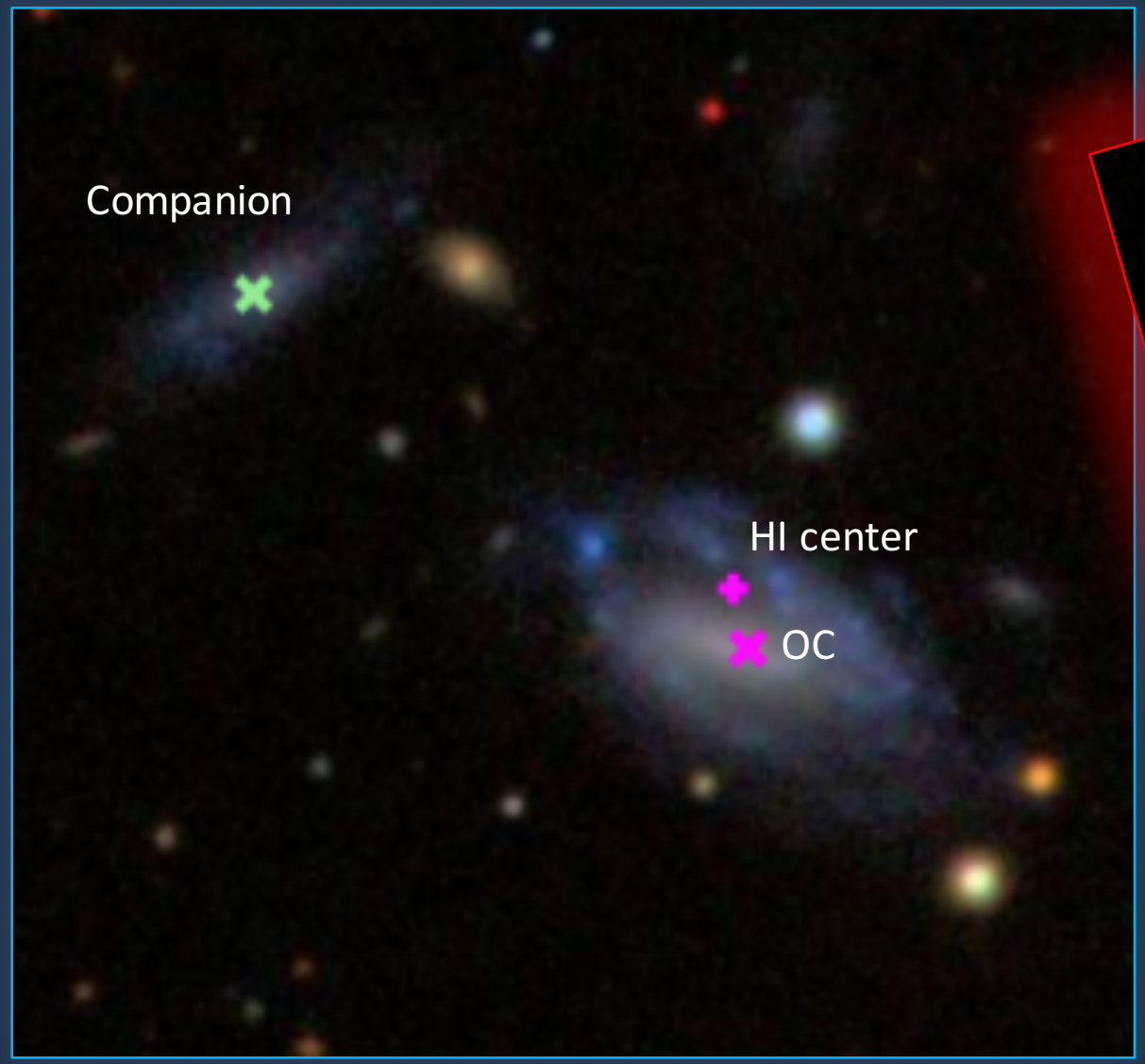


Pair finding method



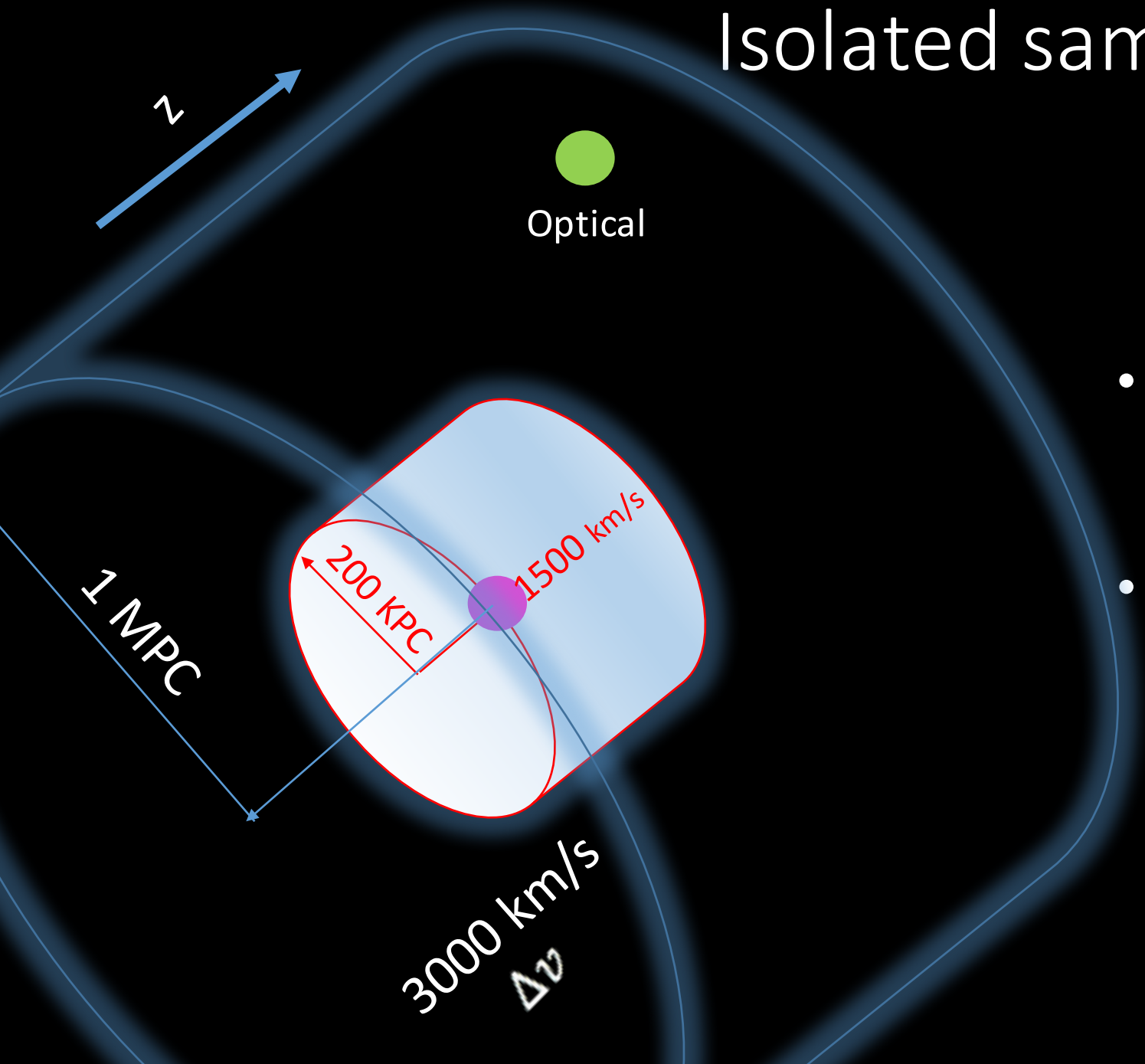
- Distance cut (r < 100 kpc)
- Velocity cut ($|\Delta v|$ < 1000 km/s)
- Self-match check
- HI isolation check
- Visual inspection

329 pairs



238 ‘pure’ pairs

Isolated sample



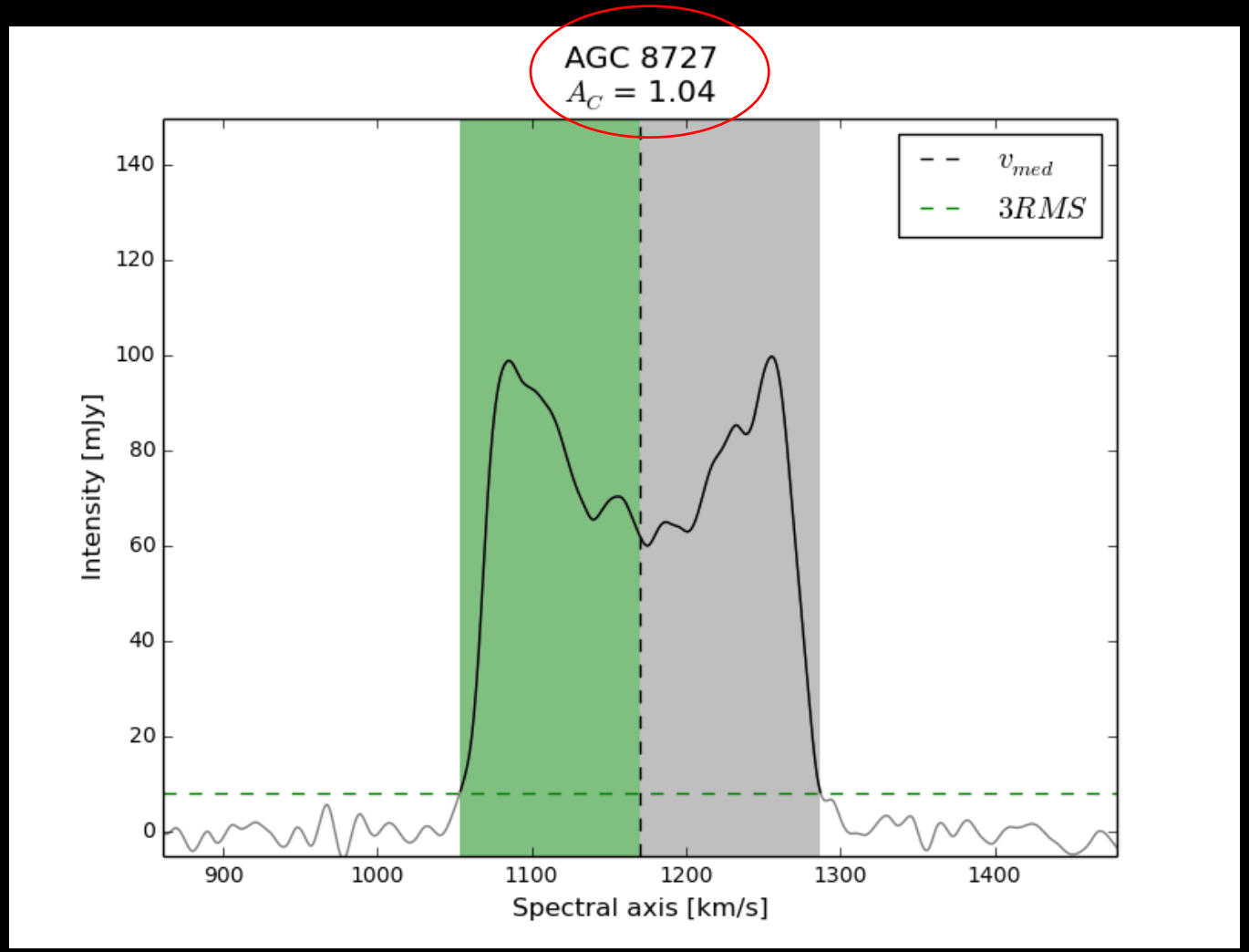
- 1 companion within 1 MPC & 3000 km/s
- Closest neighbour:

r > 200 kpc and
$|\Delta v|$ > 1500 km/s

305 isolated

Measuring profile asymmetry

$$A_c = \frac{Area_{big}}{Area_{small}} = \frac{\int_{v_{low}}^{v_{med}} I}{\int_{v_{med}}^{v_{high}} I}$$



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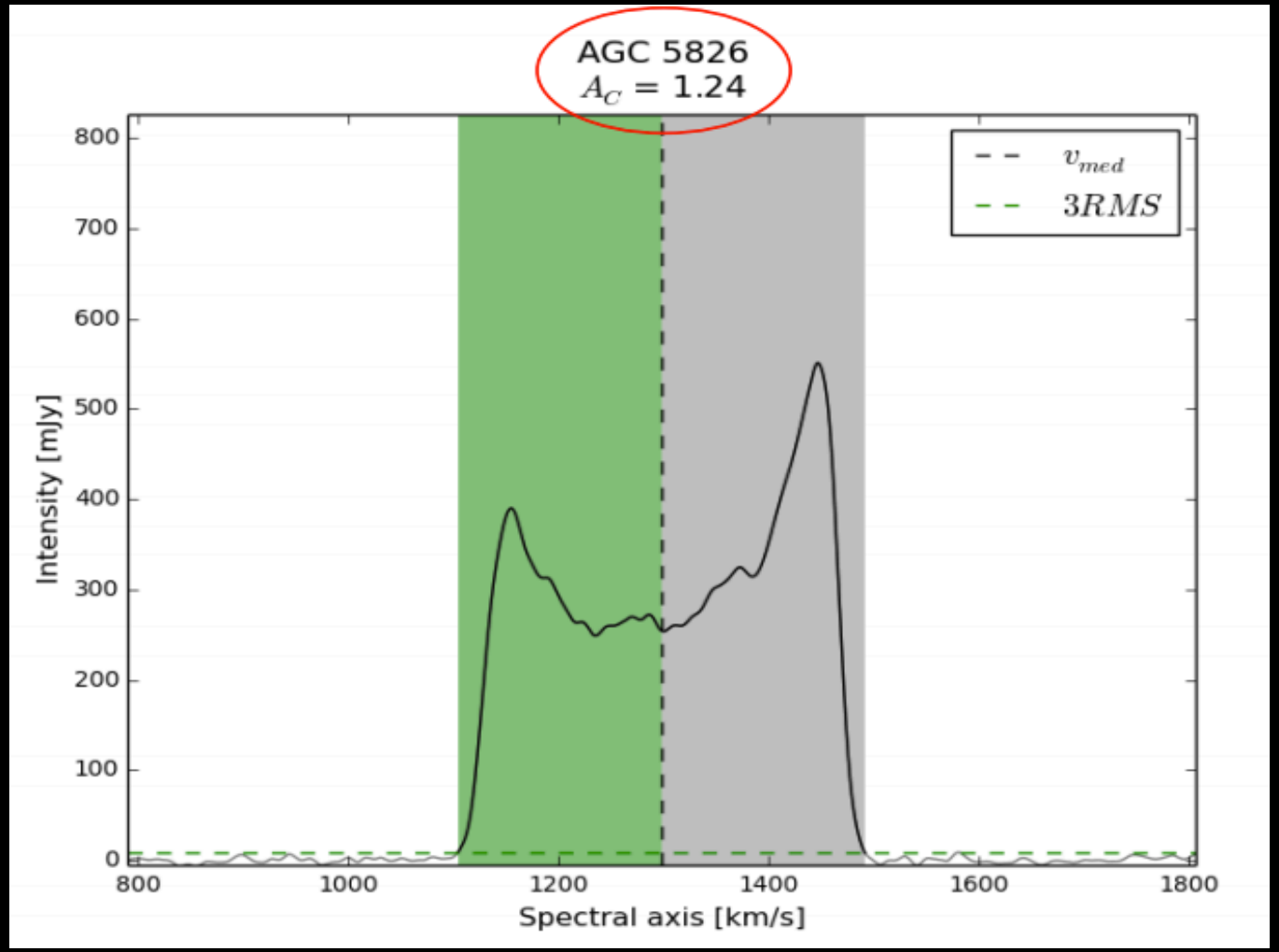

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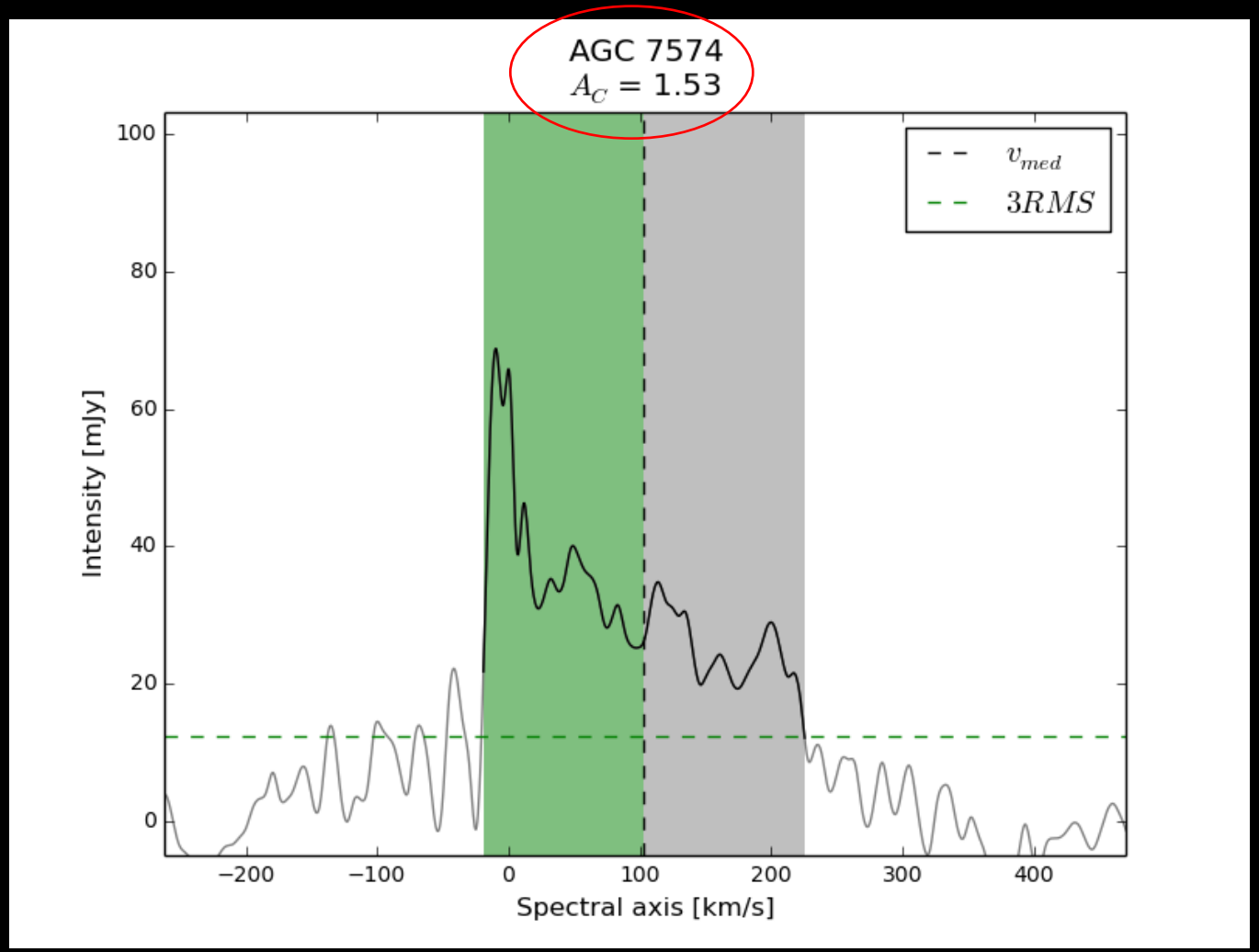
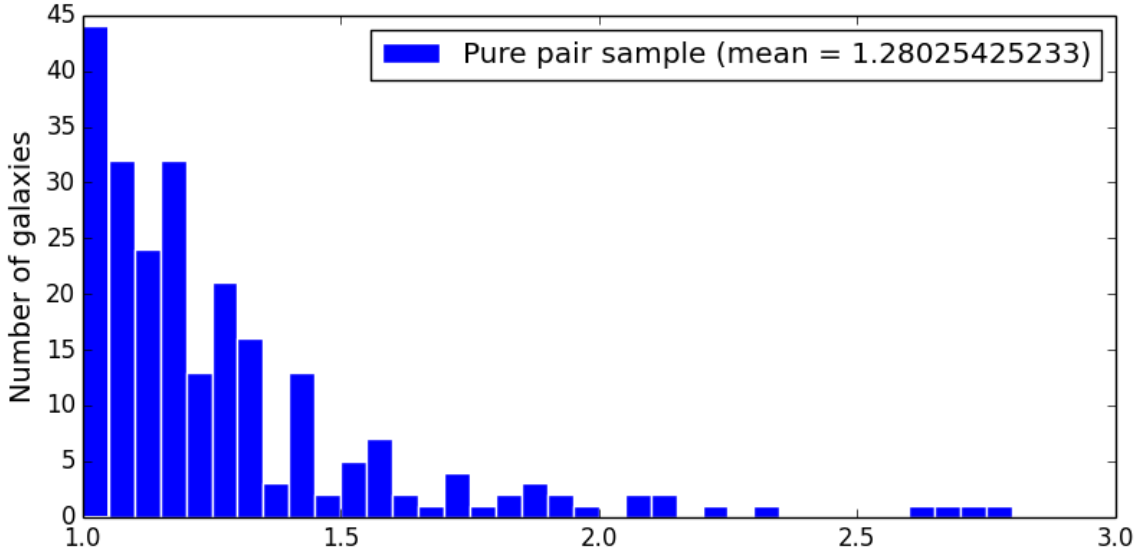
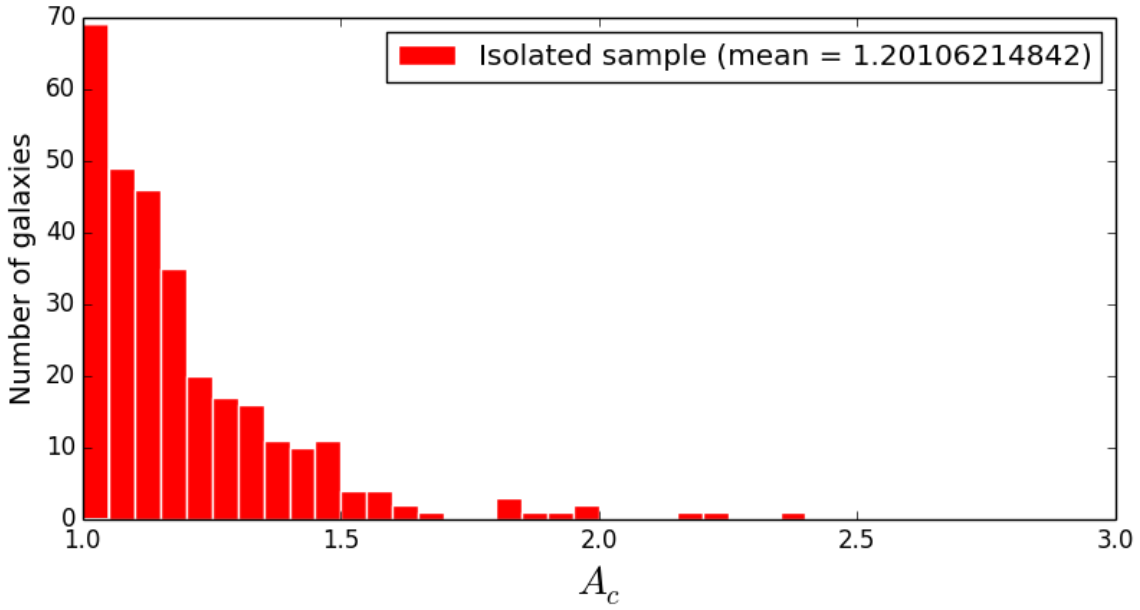




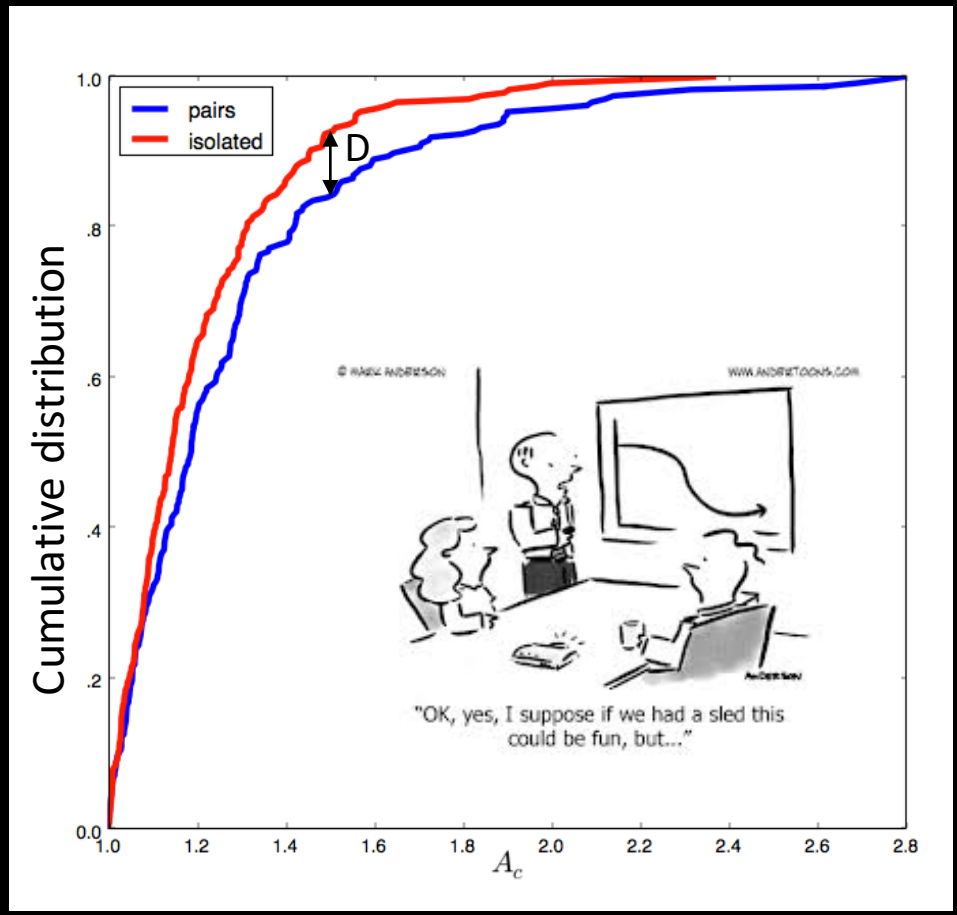


- Pure pair sample (238)
- Isolated sample (305)

Preliminary results!

Pairs vs Isolated

- Kolomorogov-Smirnov test
- KS statistic:
  D = 0.125
  (p-value = 0.012)

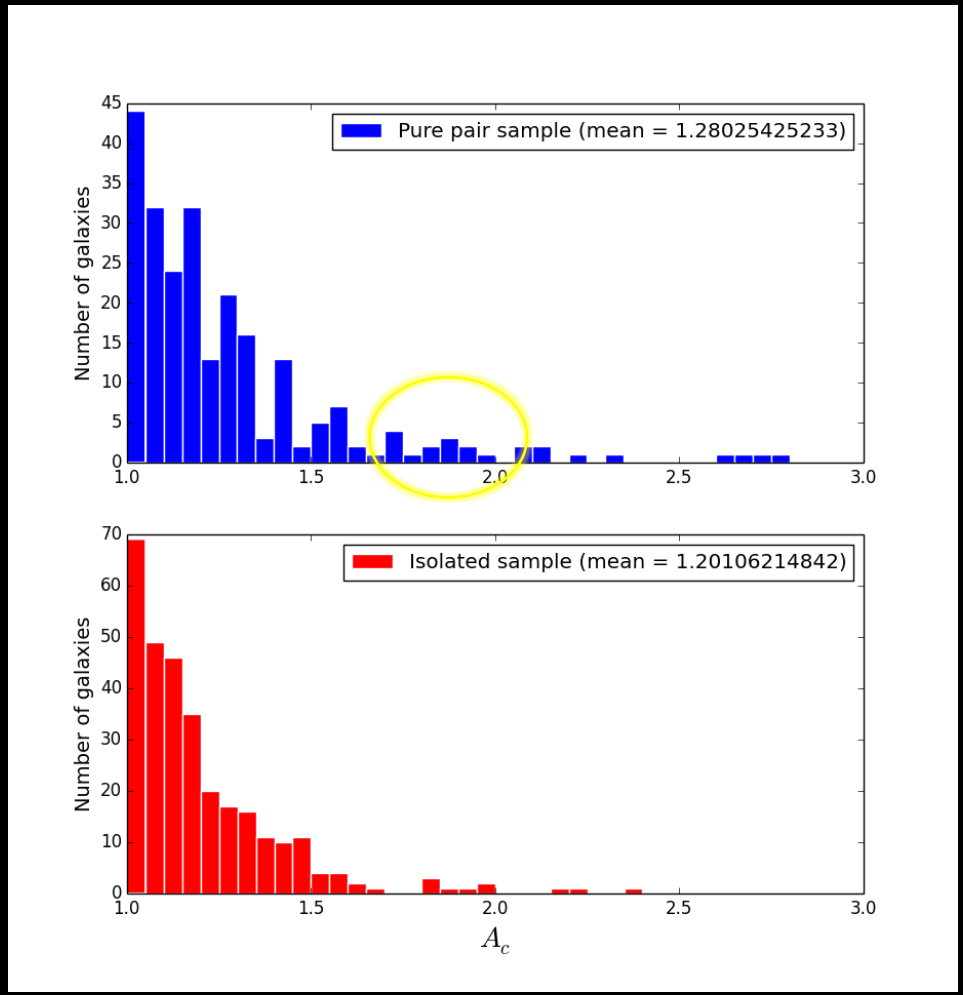


Preliminary results!

Next steps:

- Statistical tests
- Confusion correction

} PAPER 1



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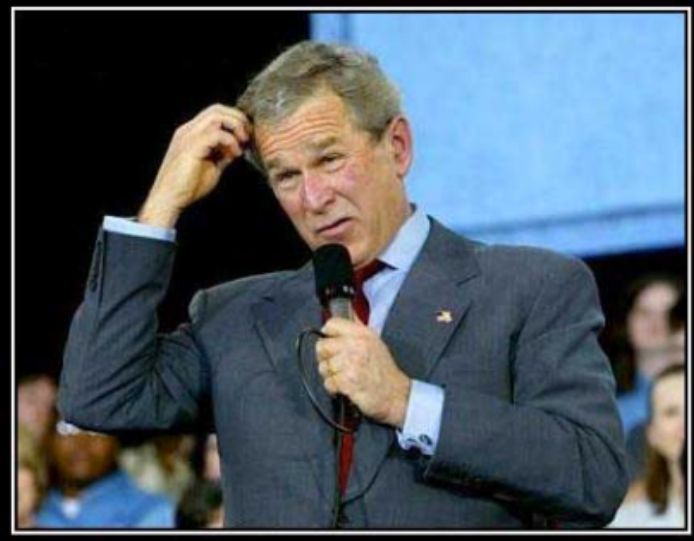
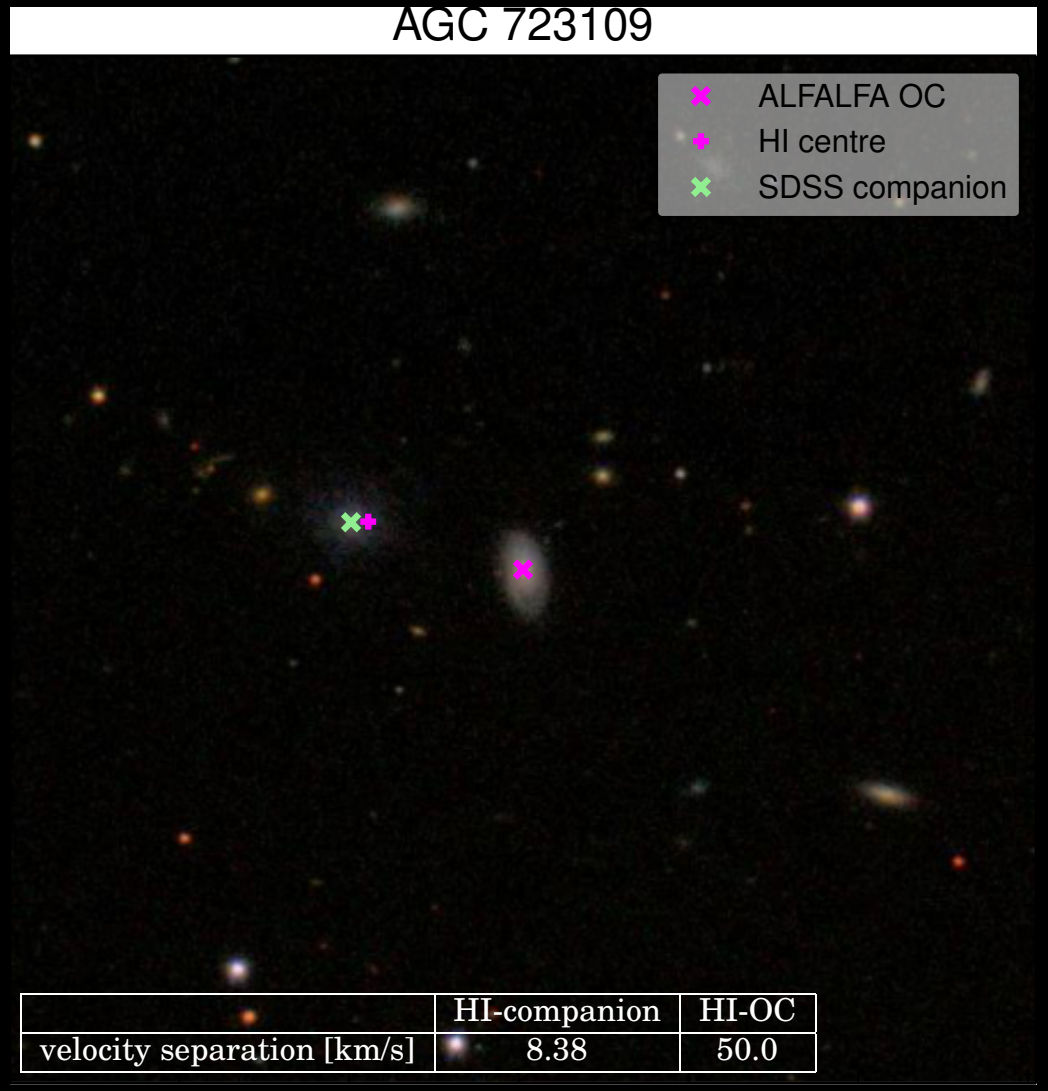
} PAPER 1

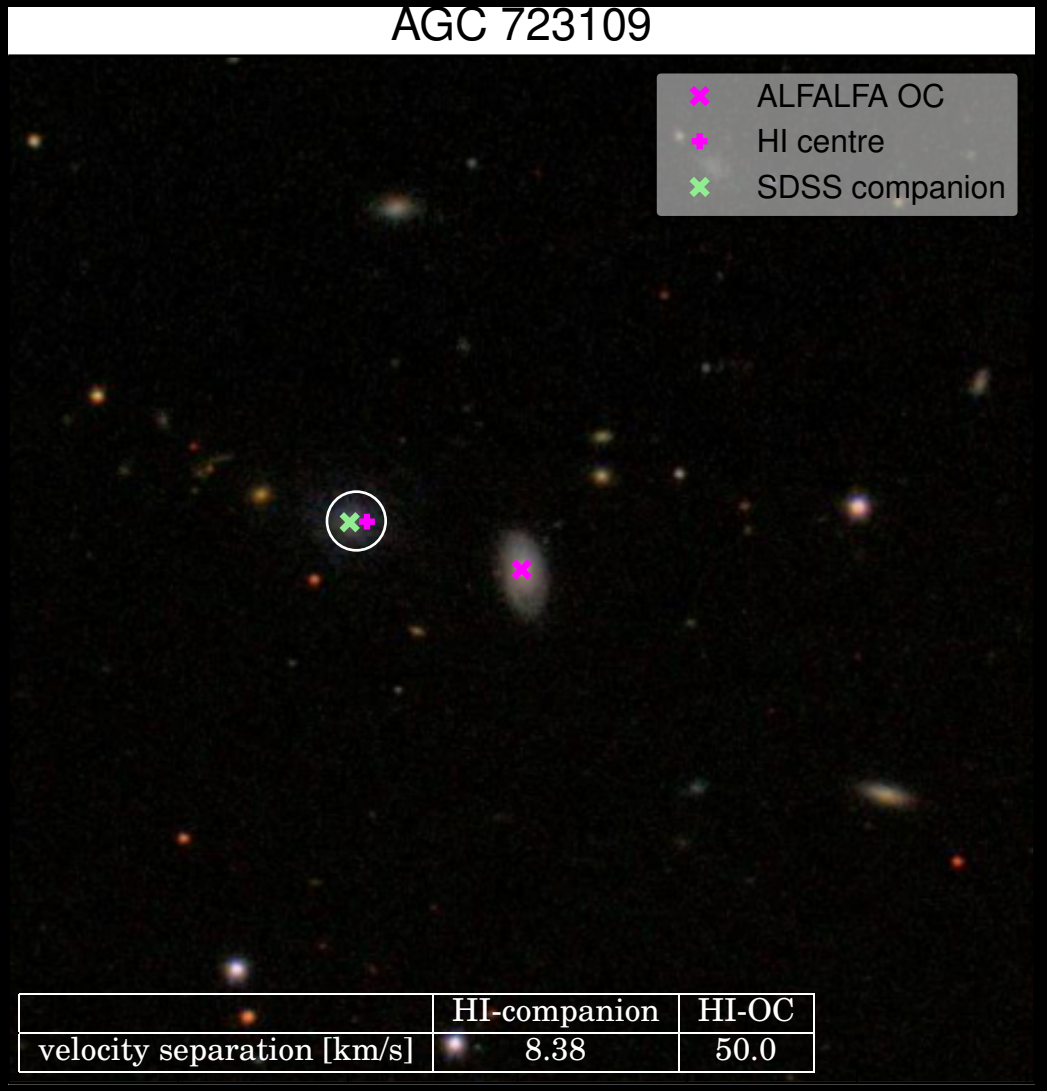


Future work

- Investigate/compare alternative techniques for quantitatively describing asymmetry
- Compare with optical properties for the sample galaxies (SDSS data); deeper optical images…
- High resolution radio follow up… (MeerKat is coming!!!)



	HI-companion	HI-OC
velocity separation [km/s]	8.38	50.0



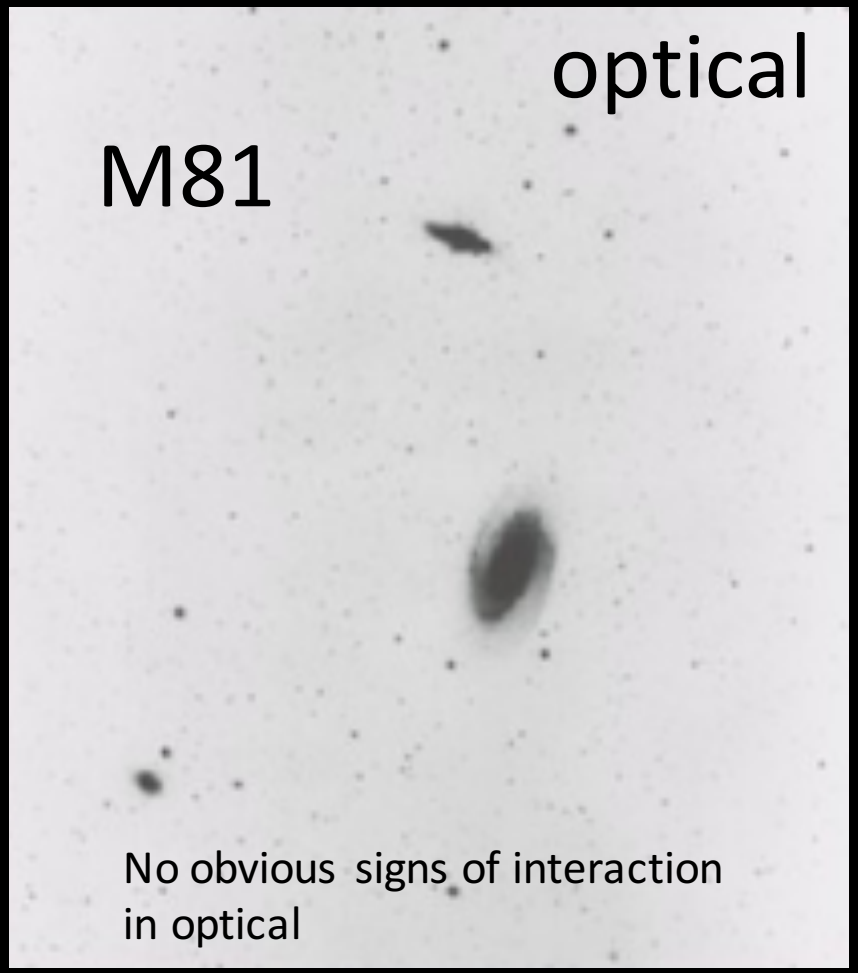
	HI-companion	HI-OC
velocity separation [km/s]	8.38	50.0

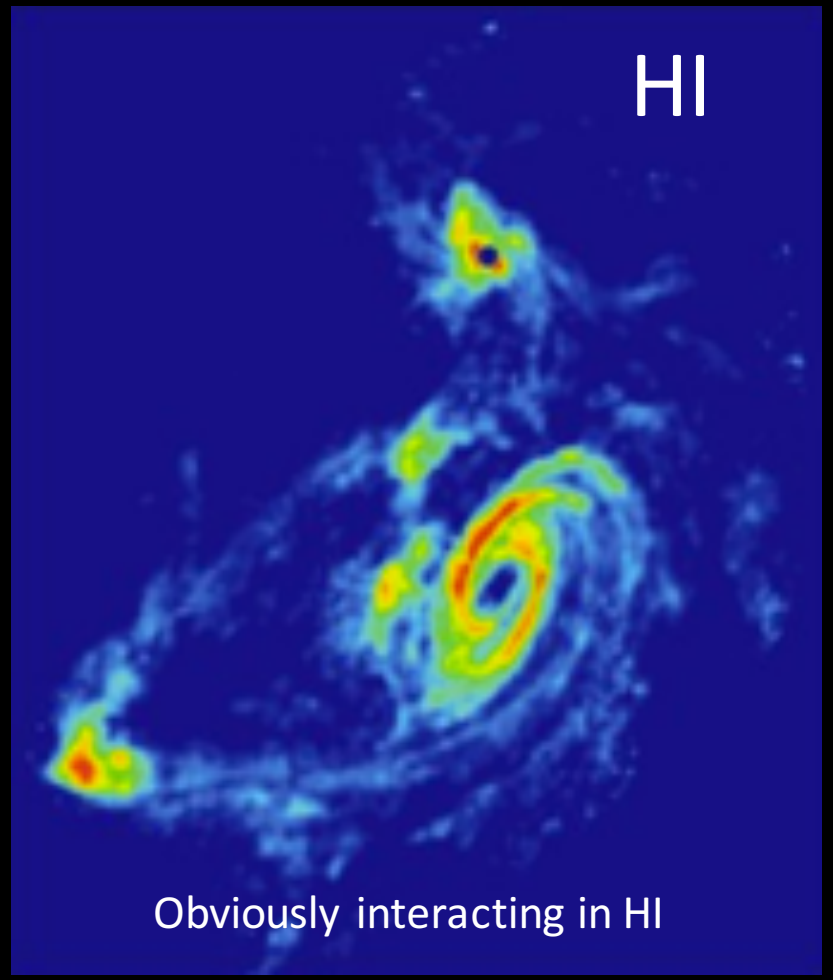
Interferometric radio data: 3.5’ res. for ALFALFA vs ~ 10’’ res. for MeerKAT

Thank you!

Questions ?

Tracing asymmetry: Optical versus HI



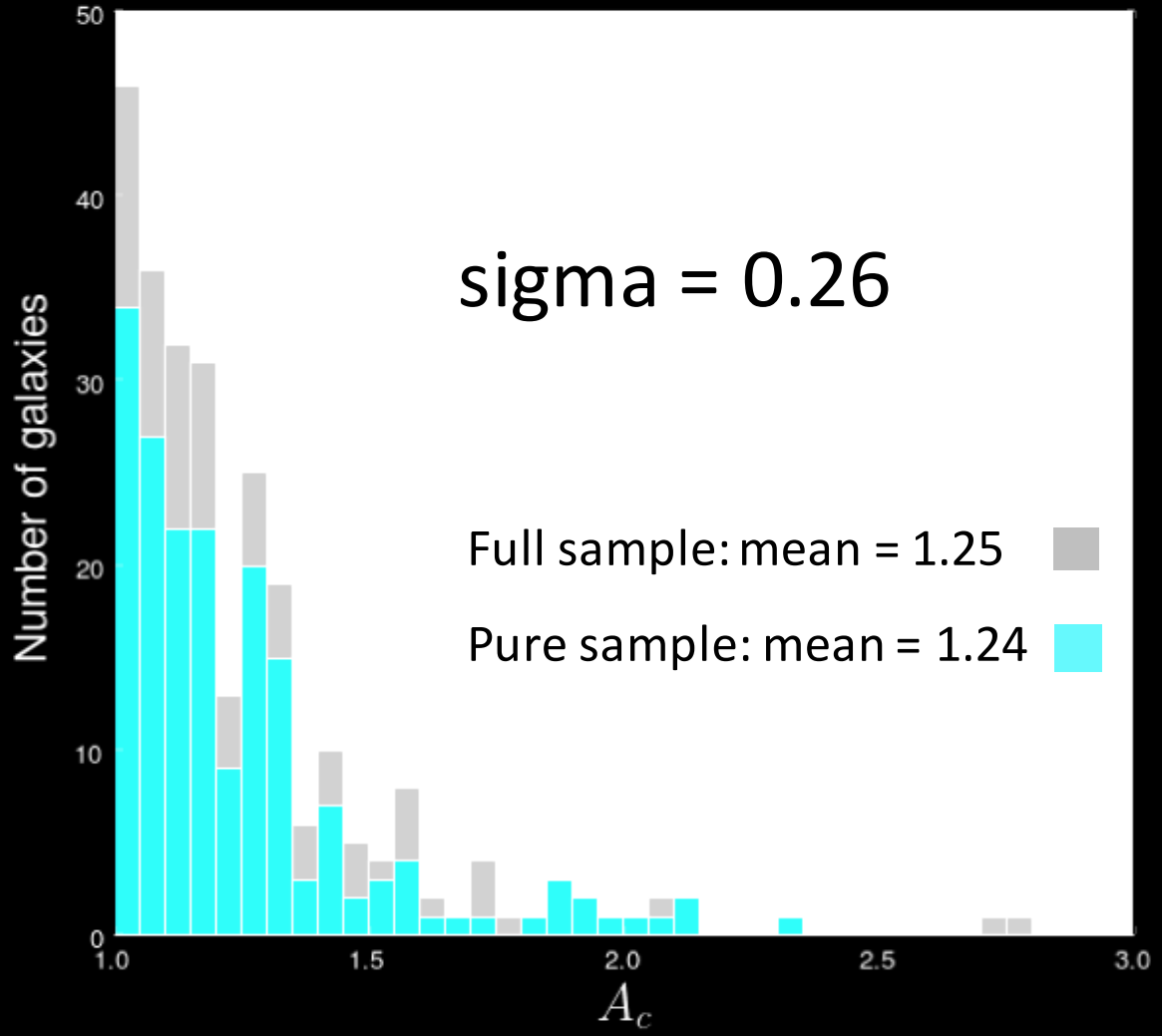


The gas asymmetry tells us about interactions on a different time-scale to the stars

Image credit: NRAO

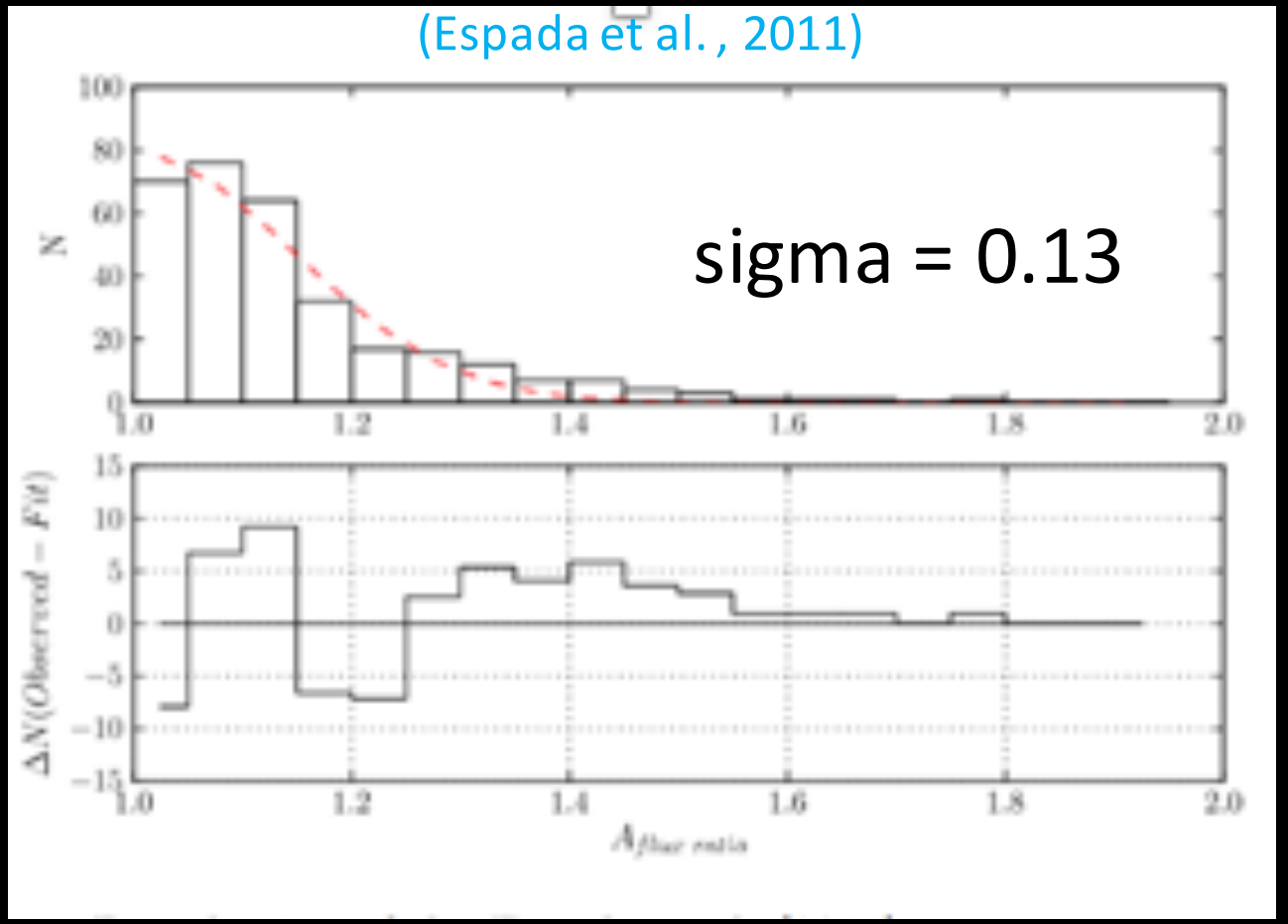
Preliminary results

Pair sample

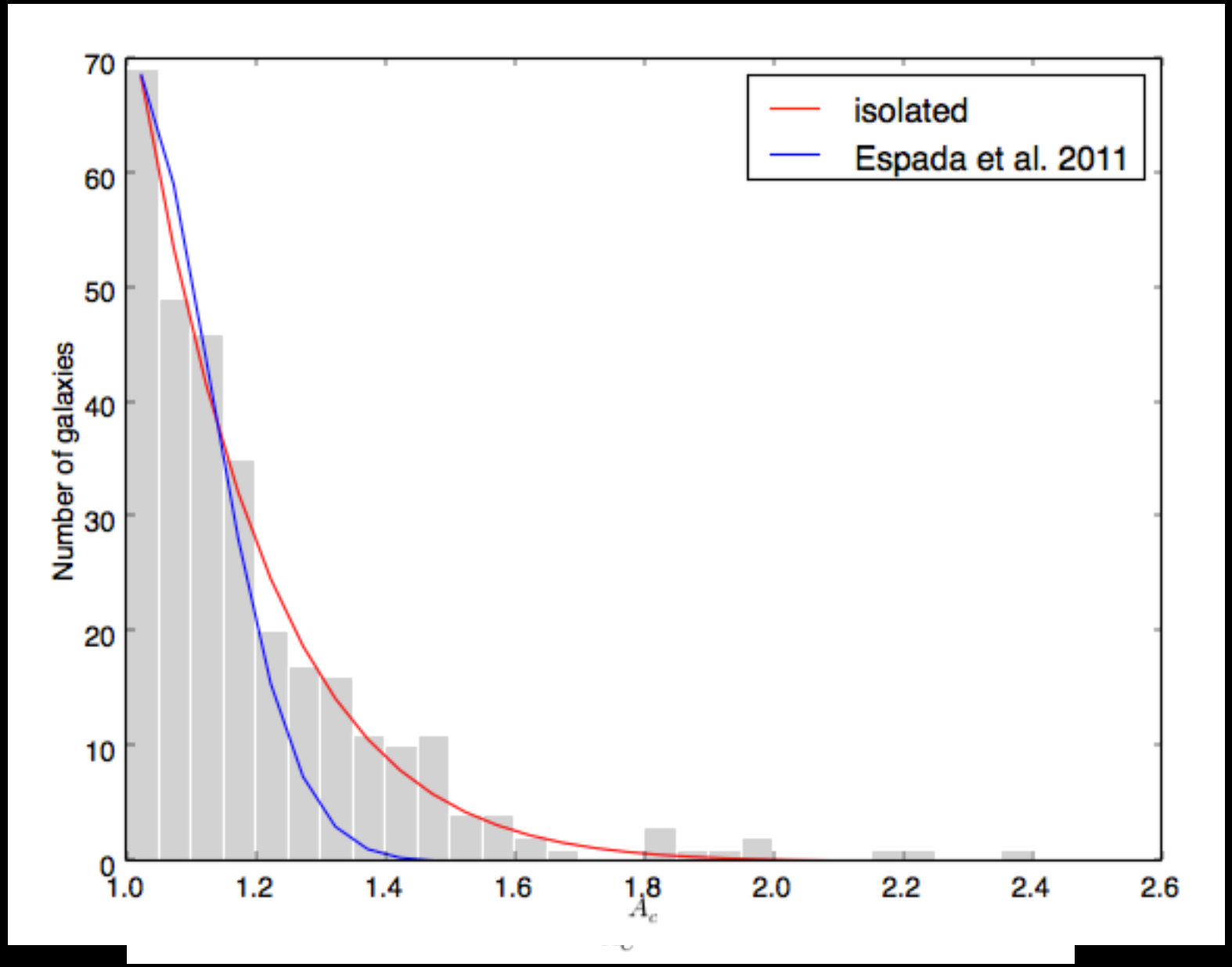


AMIGA isolated sample

(Espada et al. , 2011)

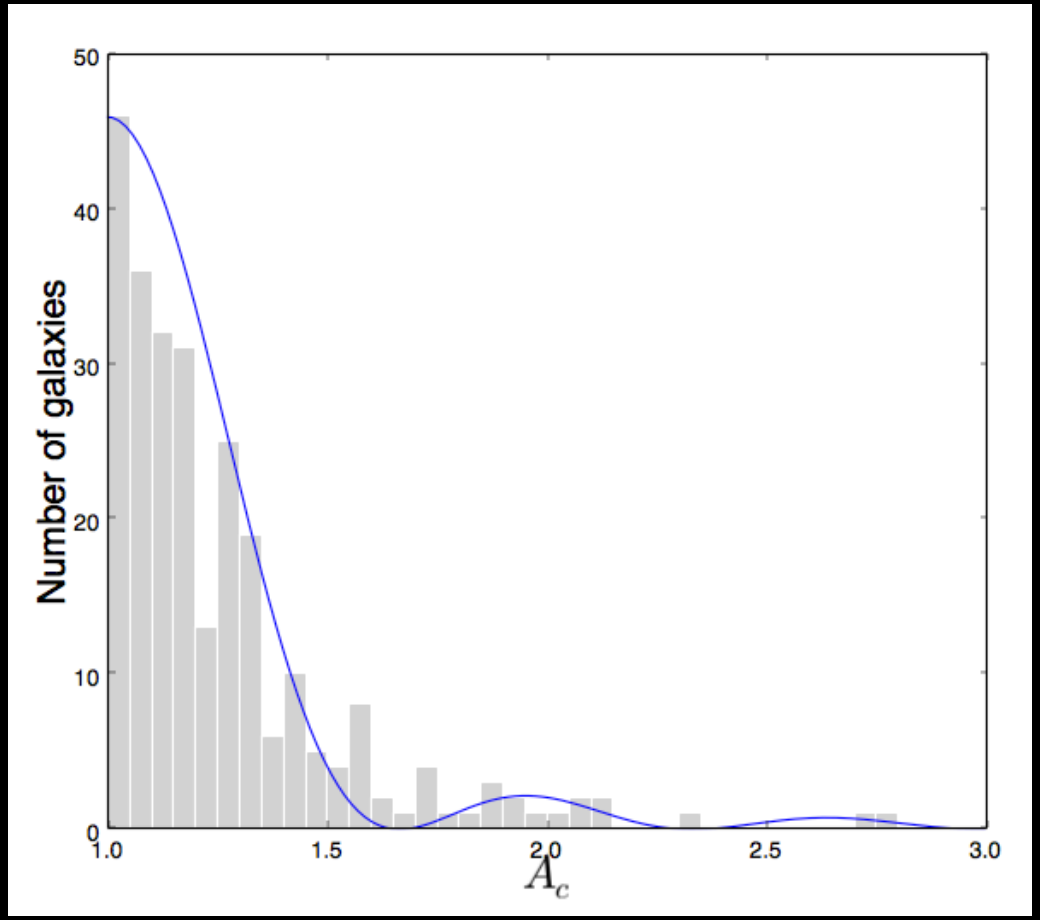


Prelim



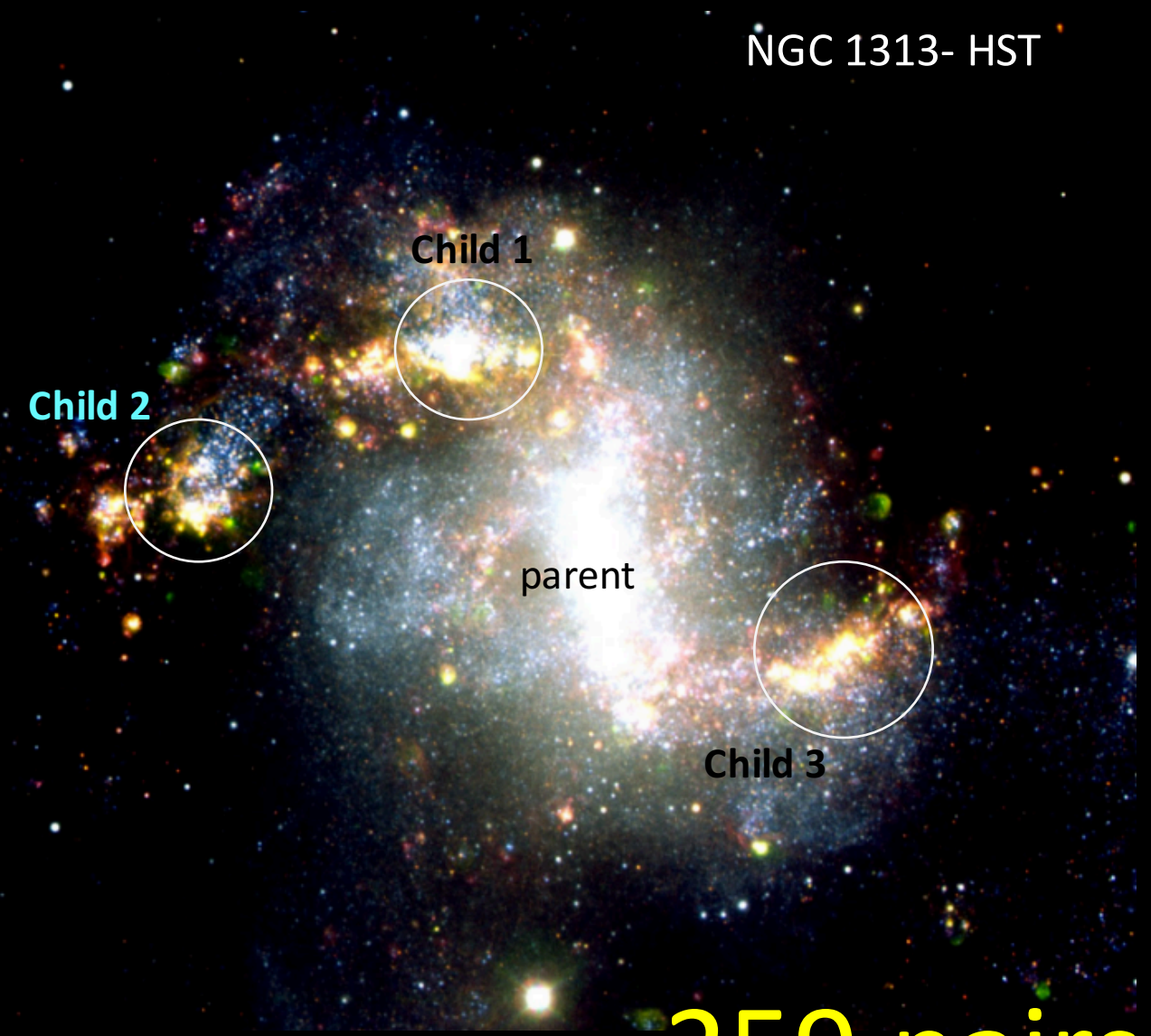
(P-value=2.03e-06)

Extra slides



Pair finding method

- Distance cut (100 kpc)
  (Robotham et al. 2012)
- Velocity cut (1000 km/s)
- Self-match check
- Unique pair check
  (exclude triples/groups)
- HI isolation check



259 pairs

And then?

- MeerKAT is coming, we'll be seeing deeper than ever before, and getting HI profiles for galaxies over 2/3 the age of the universe
- Use methods developed in this work to extend studies to higher redshift samples to learn more about galaxy evolution over cosmic time

Preliminary results

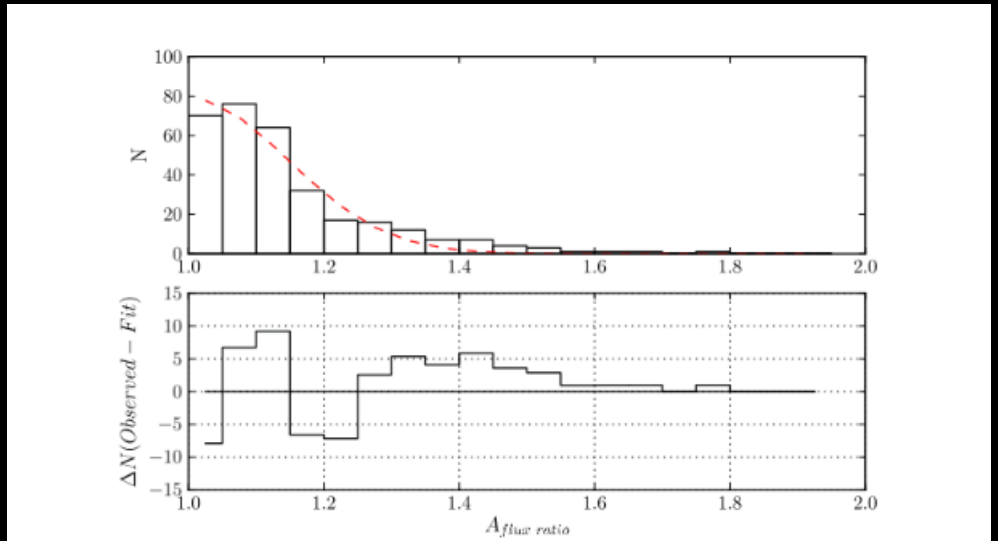


Figure 4: Distribution of the Espada et al. (2011) asymmetry parameter.

- Isolated: sigma = 0.13
- Pairs: sigma = 0.26

Next steps:

- **Verify optical counterpart matching**
- Confusion correction
- Part 2: Quantify optical morphologies of HI galaxies in close pairs
- Part 3: Multi-wavelength follow up (MeerKAT/VLA, KMTnet)

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- Part 2: Quantify optical morphologies of HI galaxies in close pairs
- **Part 3: Multi-wavelength follow up (MeerKAT/VLA, KMTnet)**

"So our project has been greenlit. But since we're dogs I don't know what that means."

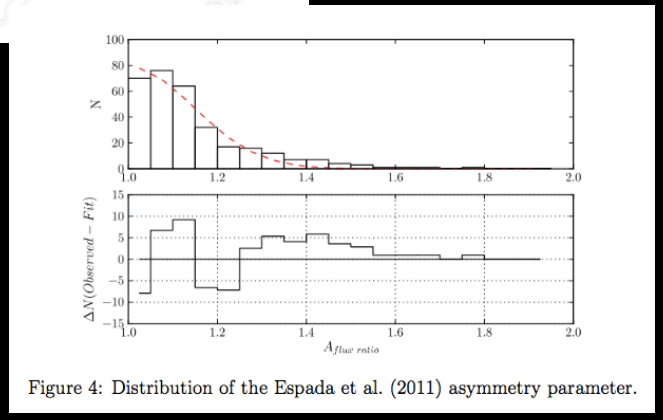
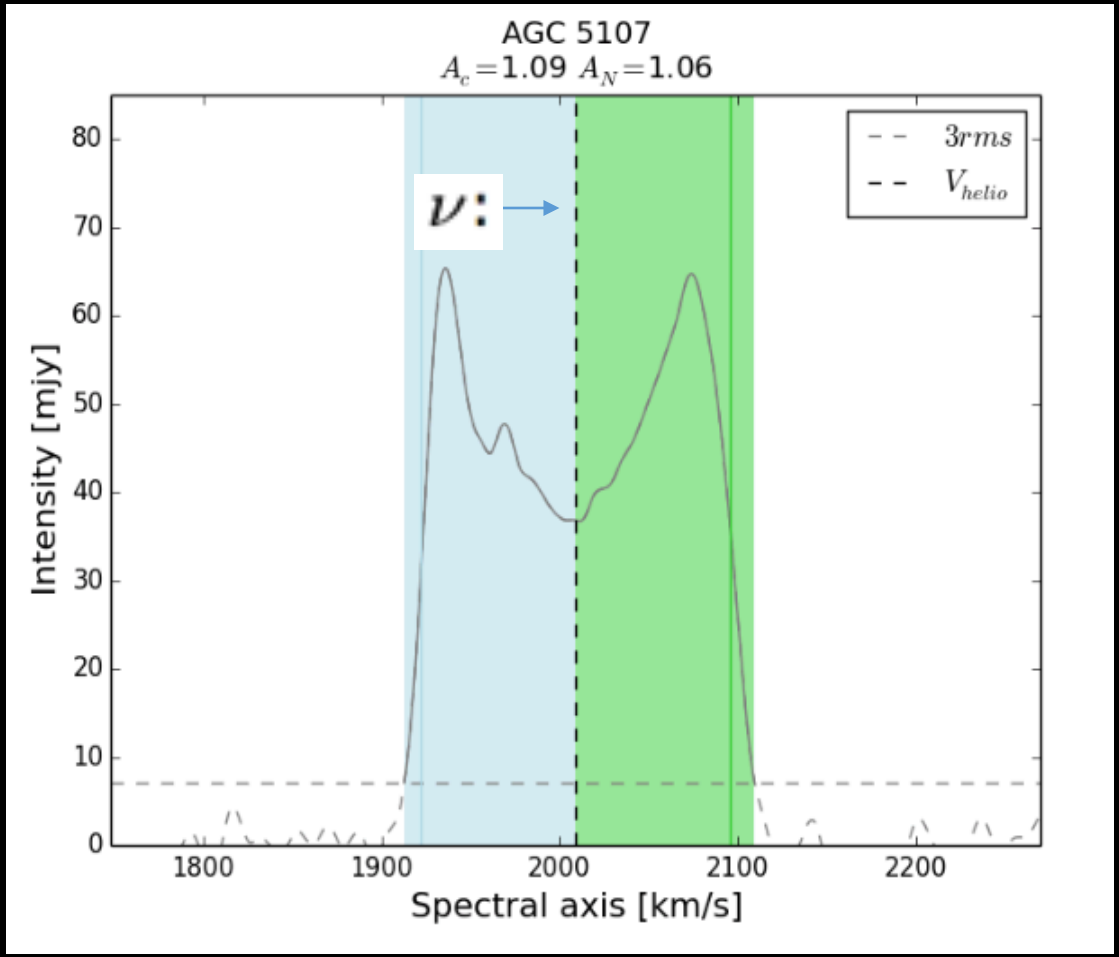


Figure 4: Distribution of the Espada et al. (2011) asymmetry parameter.

Deeper optical images:

- Previously unobserved tidal features
- Improve OC matching- Dark galaxies ? (Disney et al. 2016)
- Why are a significant portion of Espada et al's. isolated galaxies asymmetric? (post mergers? KDCs… Krajnovic 2015)

HI profiles



- Hubble distance:

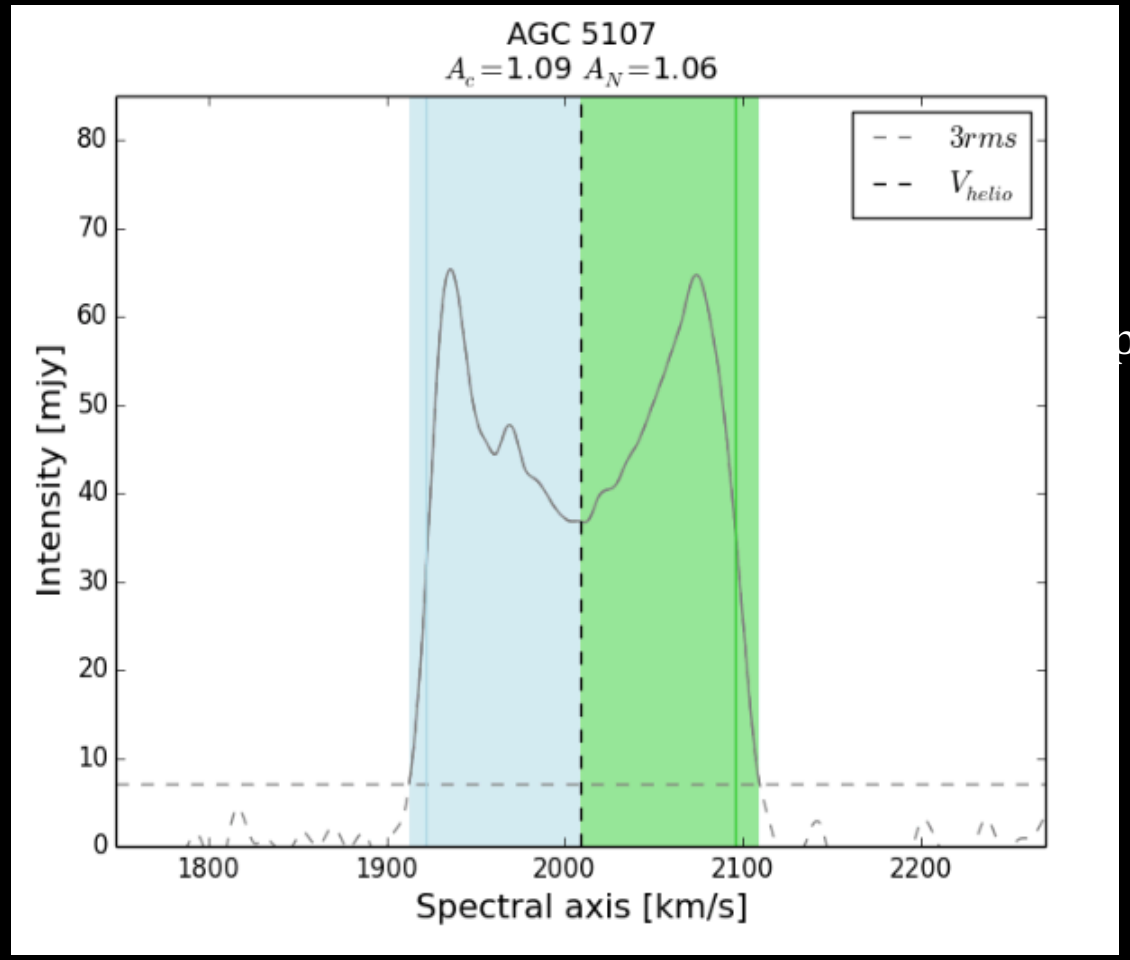
$$D \approx v_r / H_0 \qquad \frac{v_r}{c} \approx \frac{\nu_0 - \nu}{\nu_0}$$

$\nu_0 \approx 1420.4$ MHz

$H_0 \approx 72$ km s^{-1} Mpc^{-1}

ν: observed line frequency

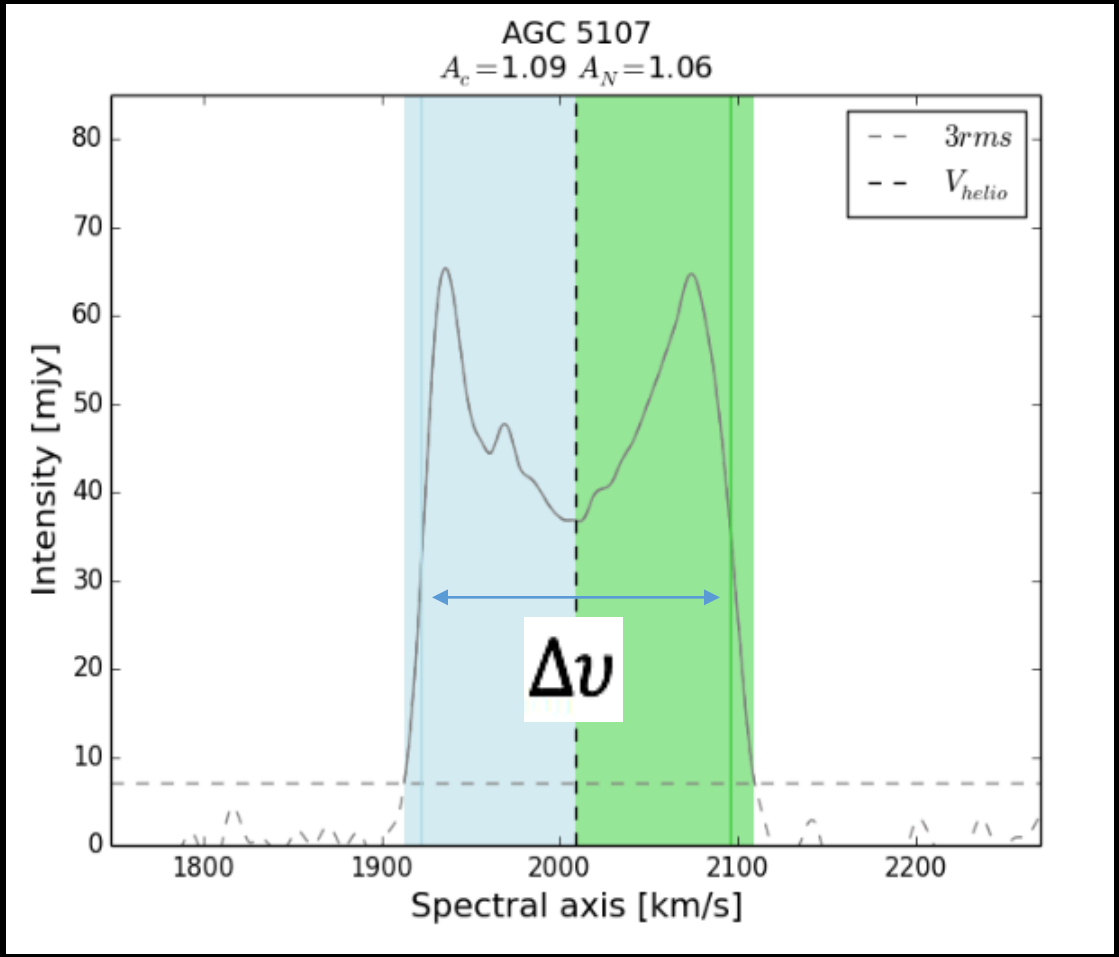
HI profiles



- HI mass:

$$\left(\frac{M_{\mathrm{H}}}{M_{\odot}}\right) \approx 2.36 \times 10^{5} \left(\frac{D}{\mathrm{Mpc}}\right)^{2} \int \left[\frac{S(v)}{\mathrm{Jy}}\right] \left(\frac{dv}{\mathrm{km\ s^{-1}}}\right)$$

HI profiles



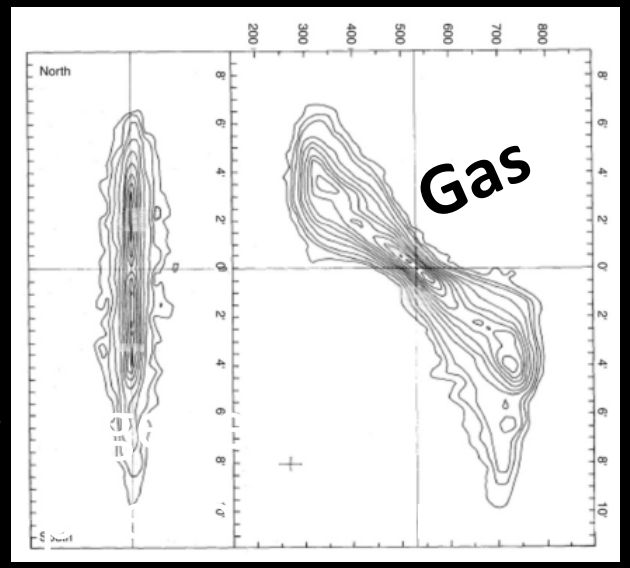
- Doppler broadening:

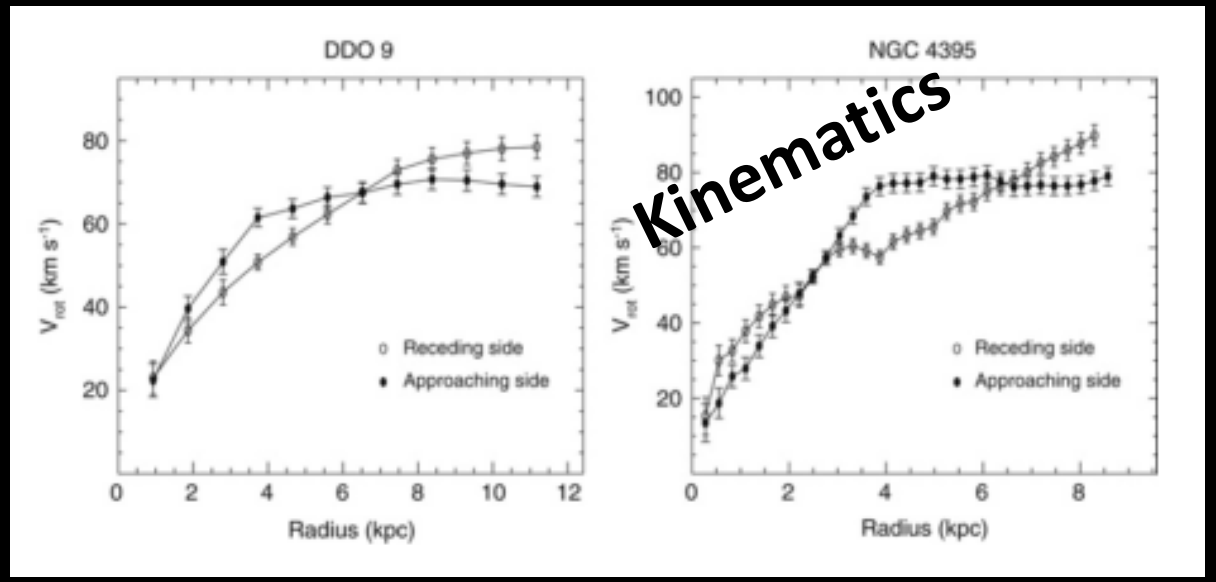
$width$: Δv $[kms^{-1}]$

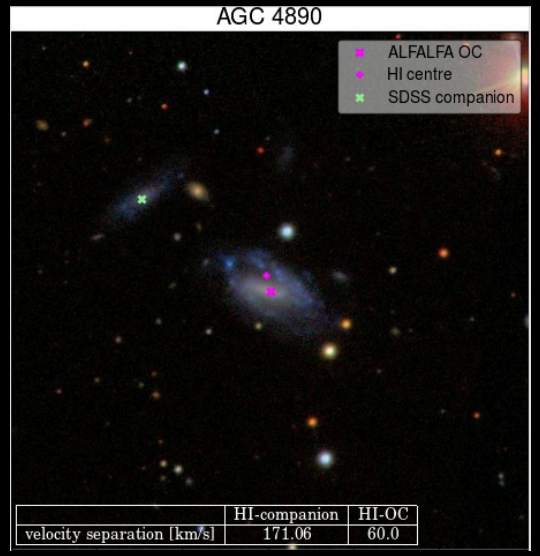
→ galaxy rotation

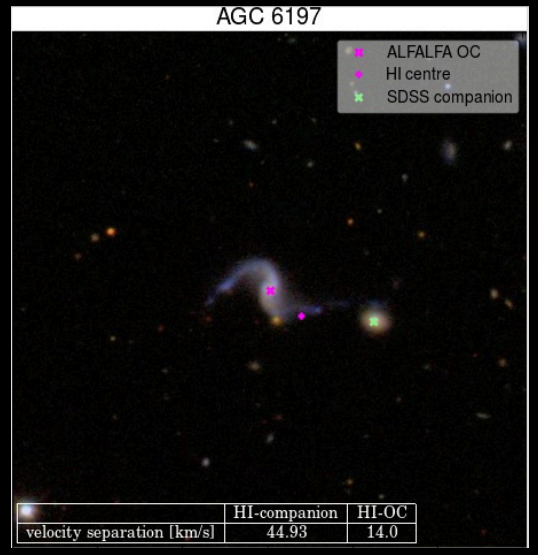
Asymmetry

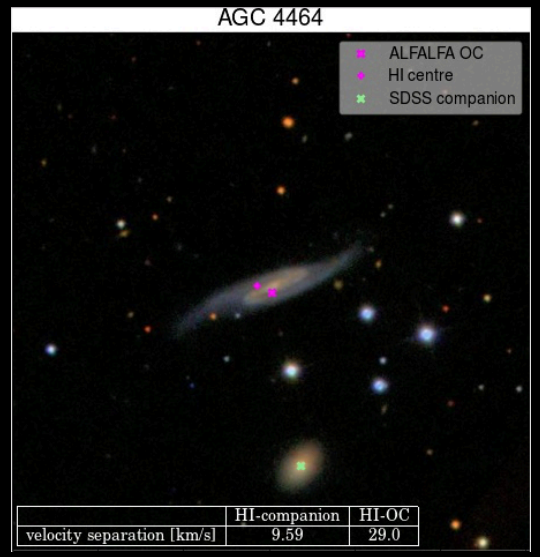
- "Lopsidedness is ubiquitous and occurs in a variety of settings and tracers."- Jog & Combes, 2009
- Caused by mergers and tidal interactions, possibly also asymmetric accretion of gas from the cosmic web…

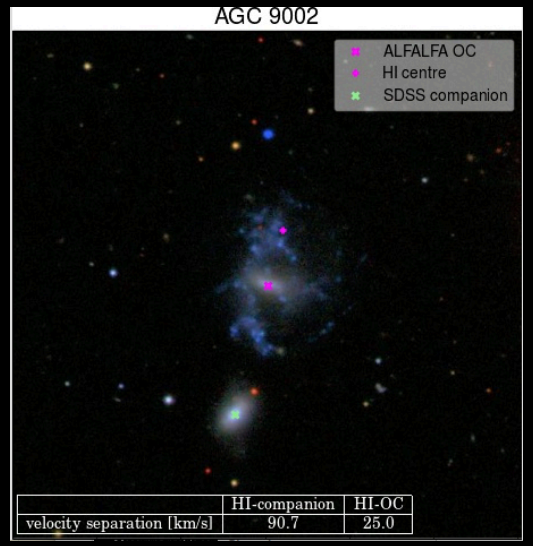


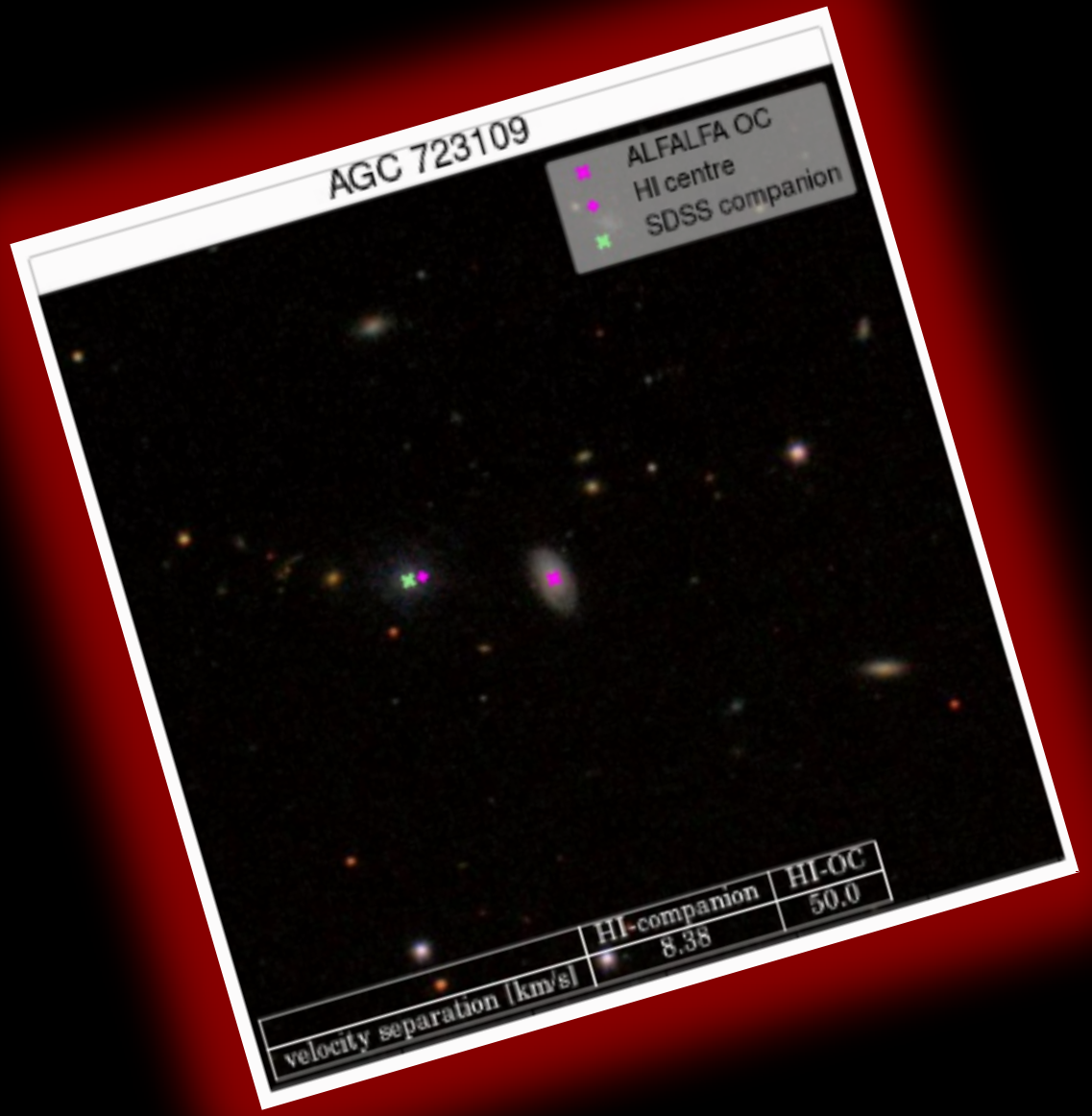






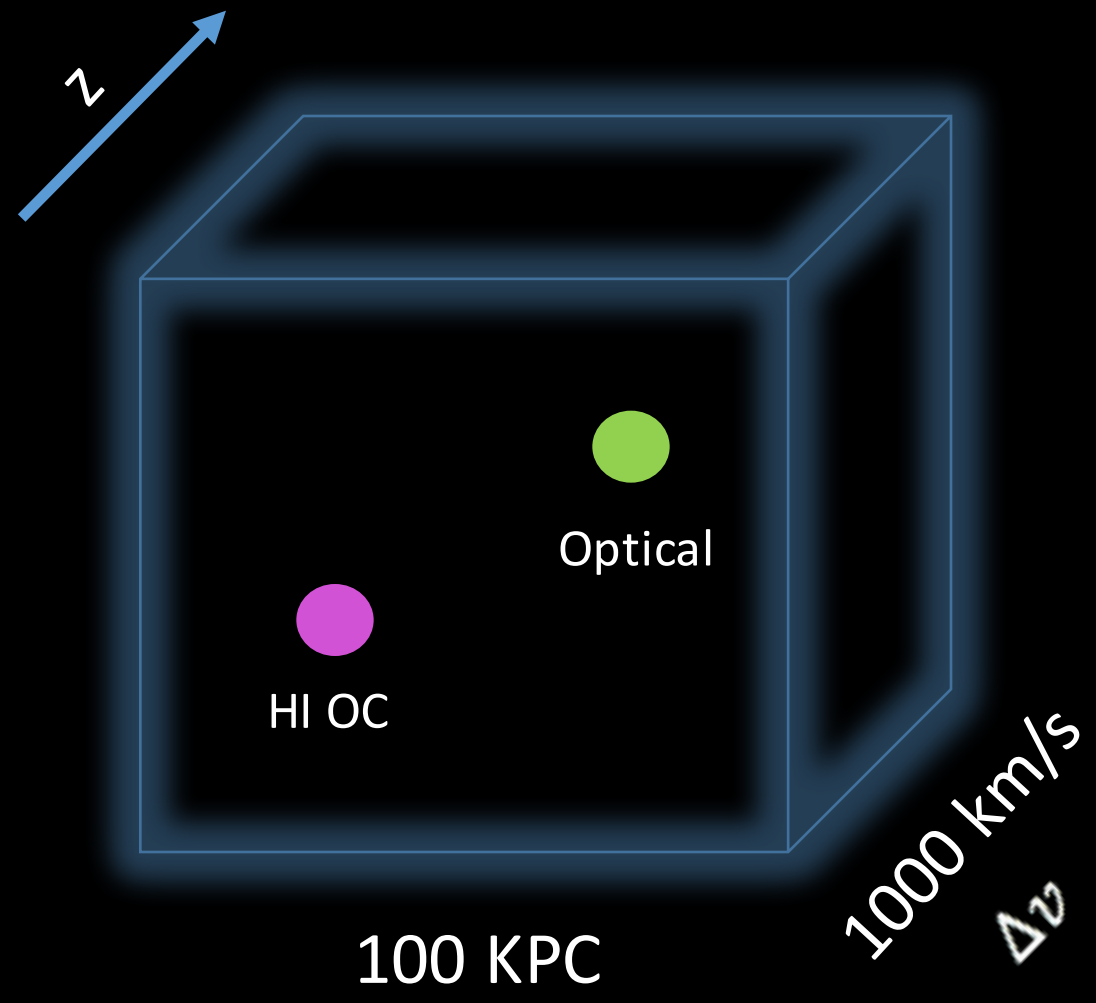






238 ‘pure’ pairs

Pair finding method



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329 pairs