Molecular gas in early-type galaxies: Fuel for residual star formation

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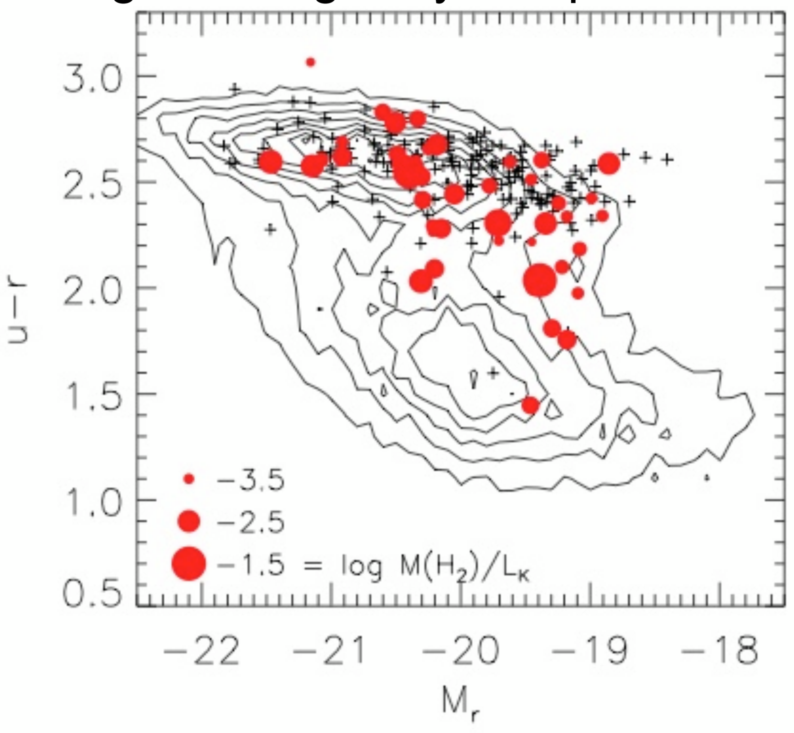
Abstract:

Over the past few years, early-type galaxies have shed their "red and dead" moniker, thanks to the discovery that many host low-level residual star formation. As part of the ATLAS^{3D} project we are conducting a complete, volume-limited survey of the molecular gas in 260 local early-type galaxies with the IRAM 30m telescope. We follow-up all detections with the CARMA interferometer, in an attempt to understand the fuel powering this star formation. We find that ≈23% of early-type galaxies in the local volume host significant molecular gas reservoirs, with molecular central discs, polar structures and rings being common. Galaxies in clusters always have aligned molecular gas, consistent with material cooling from recycled stellar mass loss. In the field however, kinematic misalignments between the stellar and gaseous components imply that the molecular gas is often supplied by external sources (mergers/accretion). These results have important implications for both observational and computational attempts to understand star formation processes within the red sequence and migration from the blue cloud.

1. The ATLAS^{3D} Survey

The ATLAS^{3D} project is a complete, morphologically selected, volume limited survey of northern early-type galaxies within 40 Mpc. It is a direct follow-up to the SAURON project (de Zeeuw et al., 02). The main aim is to determine how (major and minor) mergers, gas, star formation and feedback affect the transformation of galaxies, on a large, statistically significant galaxy sample at z=0.



For all 260 galaxies we have:
- Optical Integral-field data (SAURON)
  - → Stellar kinematics
  - → Ionised gas kinematics (H_β,[OIII],[NI])
  - → Linestrengths (H_β, Mgb, Fe5015)
  - → Stellar populations (age, Z, α/Fe)
- Optical Photometry (from SDSS/INT)
- CO(1-0) and (2-1) spectra (IRAM 30m telescope)
- HI datacubes (WSRT; DEC > 10°)

Figure 1: Detections (red circles, scaled by H_2 mass fraction) and non-detections (crosses) on a colour-magnitude diagram. Contours are for a large sample of local galaxies from SDSS

CO single-dish survey major results:
- **≈23% of early-type galaxies have significant molecular gas reservoirs**
- **Detection rate independent of luminosity**
- **Detection rate independent of environment**
- **Slow rotators have no molecular gas**

3. Kinematic Misalignments

By combining interferometric molecular gas observations with optical integral-field stellar and ionised gas kinematics it is possible to calculate the kinematic misalignment of the molecular gas with respect to the other galactic components.

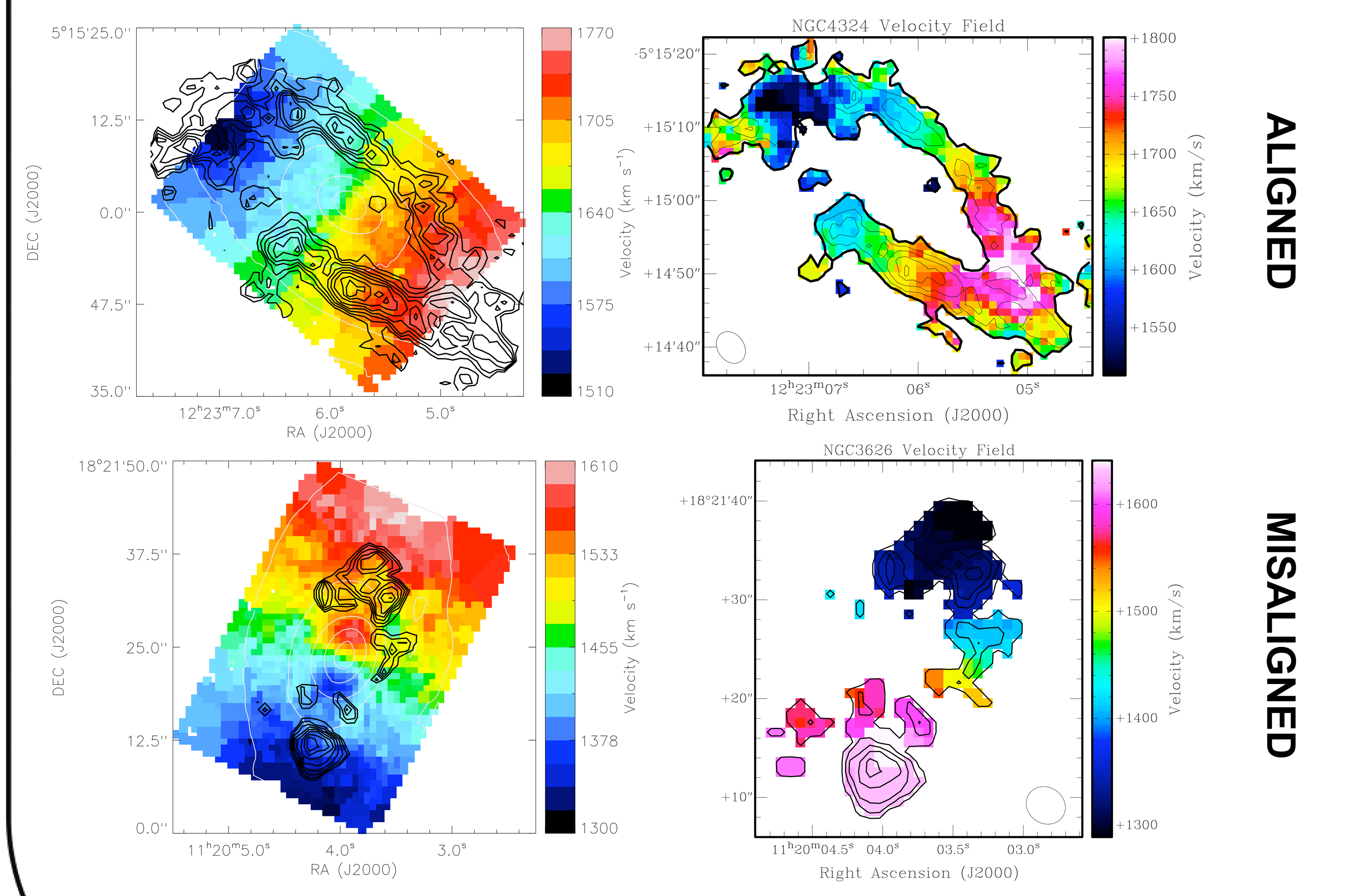
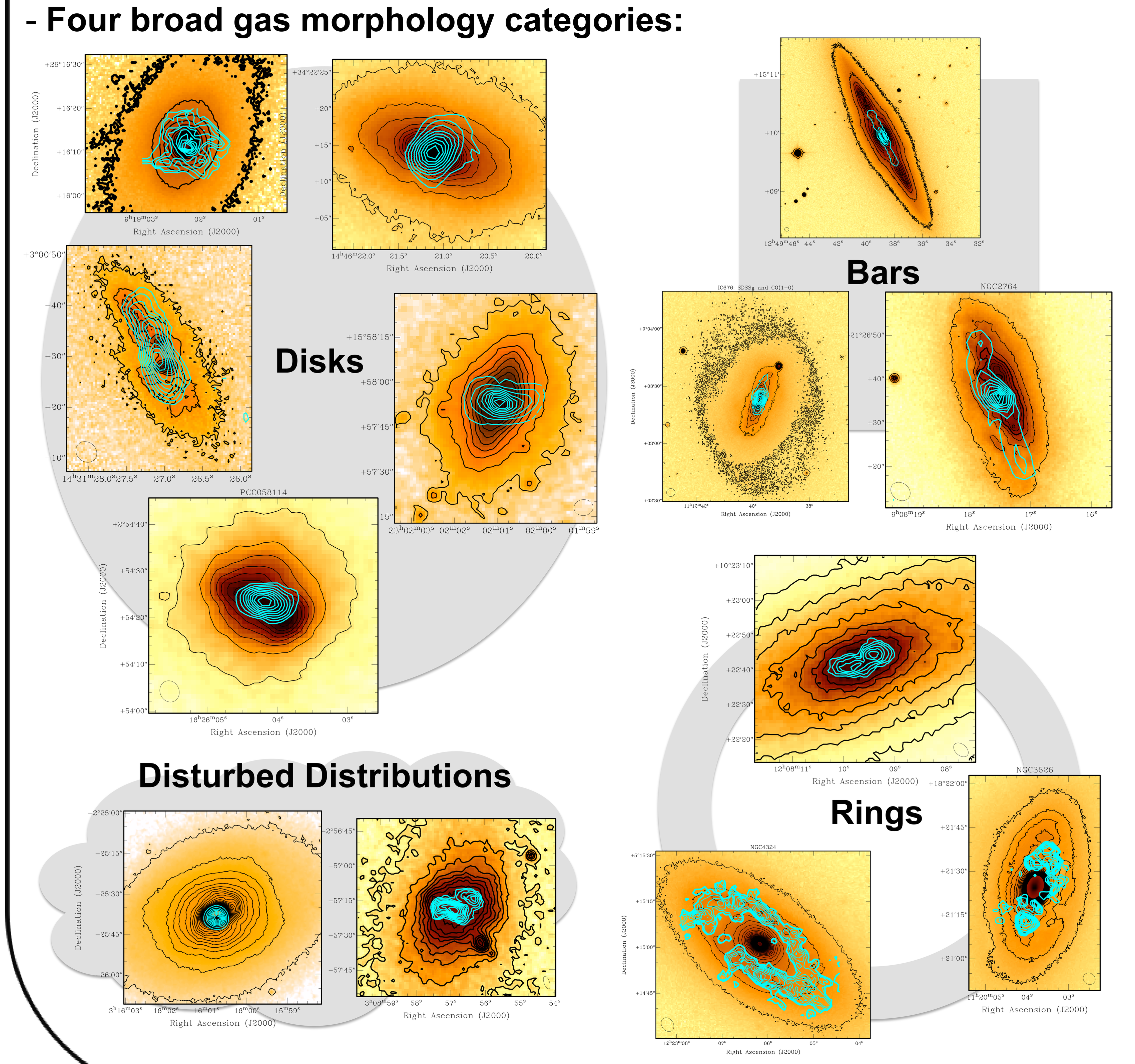


Figure 2: Left – Integrated CO map overlaid on SAURON stellar velocity field. Right– CO velocity field.

2. The ATLAS^{3D} CARMA Survey

We are following-up the molecular gas detections with the CARMA interferometer. 25 galaxies have been imaged to date, with ≈10 available in the literature.
Examples are shown below (CO overlaid on optical image).

- **The molecular gas is often centrally concentrated**
- **The gas is always coincident with dust features**
- **The molecular gas is a good tracer of the circular velocity**
- **Four broad gas morphology categories:**



4. Origin of the molecular gas

The Ionised and molecular gas are always appear to be aligned in early-type galaxies
→ Share a common origin

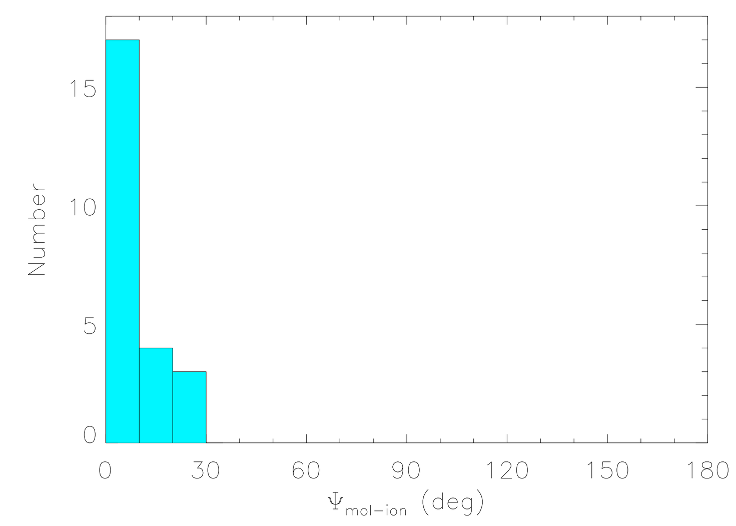


Figure 3: Kinematic misalignment between the ionised gas and the molecular gas.

Roughly 50% of early-type galaxies have misalignments between the stellar and molecular gas kinematics
→ Molecular (and ionised) gas has an external origin in at least half the objects

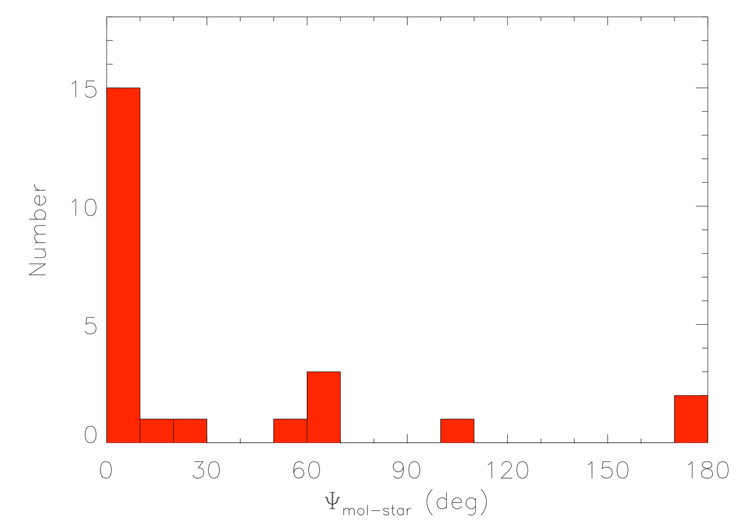


Figure 4: Kinematic misalignment between the stars and the molecular gas.

The molecular gas is always aligned in the cluster (Virgo), while many galaxies are misaligned in the field

→ In the field molecular gas is often supplied by mergers/accretion, whereas in Virgo the gas is likely to have a purely internal origin.

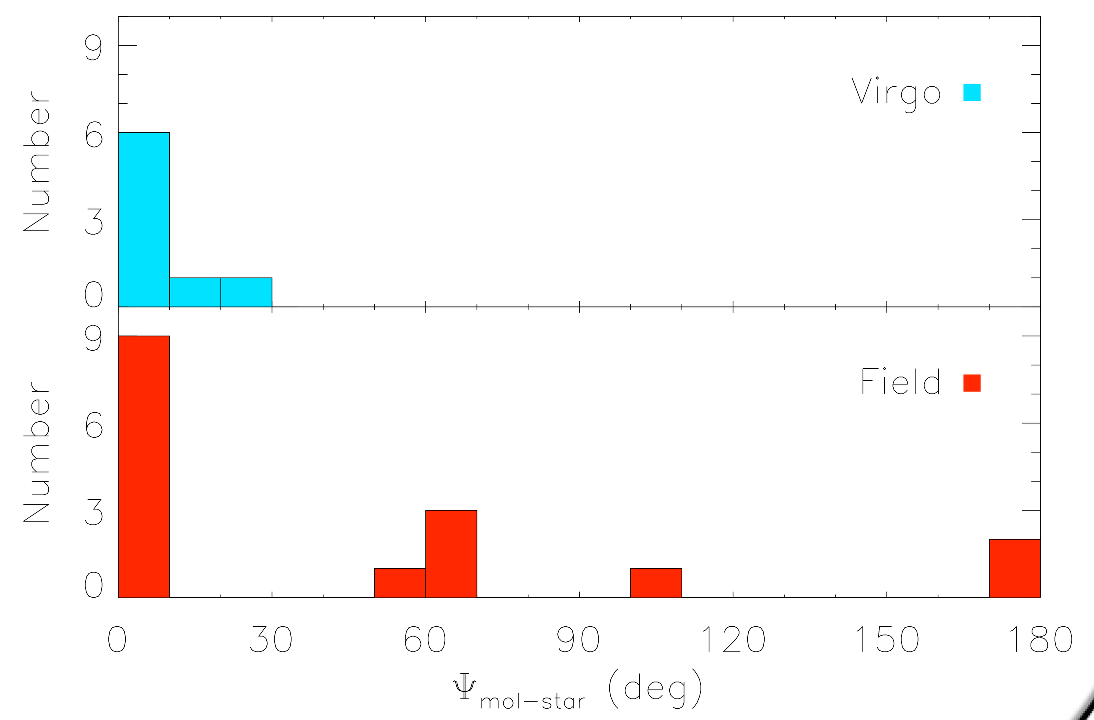


Figure 5: Kinematic misalignment between the stars and the molecular gas split by environment. Galaxies in the Virgo cluster and in blue, and field galaxies are red.