

IX

CONFERENCE SUMMARY



Mike Disney giving his congratulations speech to Piet van der Kruit at the barbecue held in the beach restaurant “De Branding”.

ISLAND UNIVERSES

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1. In the footsteps of Kapteyn

This has been an exciting conference covering a large range of topics on the properties of disk galaxies, much of it related to pioneering work done by Piet van der Kruit, the Jacobus C. Kapteyn Distinguished Professor of Astronomy at the University of Groningen. Let me therefore first say a few words about Piet, and then highlight some of the main results presented here this week.

Piet received his PhD degree with Jan Oort in Leiden in 1971, at the time when the Westerbork Synthesis Radio Telescope came on line. He was one of the first to publish data obtained with it, and rapidly established himself as an authority in radio studies of nearby galaxies. In the late seventies, Piet shifted his attention to optical studies of disk galaxies. Together with Leonard Searle, he wrote an influential set of papers which established that stellar disks are truncated at about four exponential scale-lengths, and that the vertical scale-height of disks is constant with radius. He obtained early stellar kinematic measurements of disks with Ken Freeman, and was quick to use new instrumental approaches. An example is his realization that the imager on the Pioneer 10 interplanetary probe could be used to measure the surface brightness distribution and scale-length of the Milky Way. Piet supervised the production of about a dozen high-quality PhD theses, and he continues to be active in research. This is a remarkable achievement considering his major management and science policy activities in the past two decades. These included a stint as dean of the Faculty of Science in Groningen, directing the Kapteyn Institute for a decade, chairing the boards of ASTRON and NOVA, and many advisory and oversight functions on the international level, most recently as President of the ESO Council and Chair of the ALMA Board.

It is appropriate to record that Piet also made some remarkable discoveries in statistics. The legendary papers with Leonard Searle have Piet as first author on all of them due to the use of the *van der Kruit guild*. The discovery paper is reproduced in Figure 1, and exemplifies Piet's style: concise and to the point.

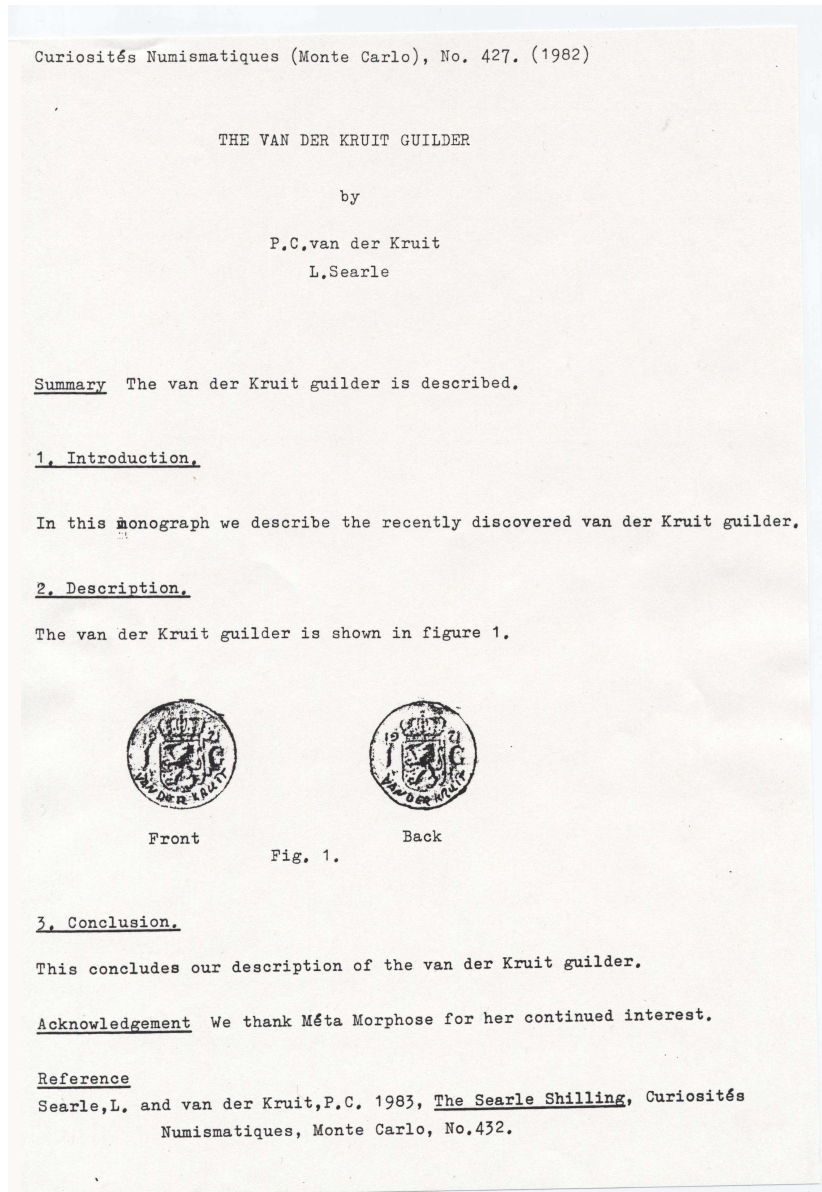


Figure 1. The paper on the van der Kruit guilder cited in the influential series of papers on *Surface-photometry of edge-on spiral galaxies* by van der Kruit & Searle (1981a, b, 1982a, b). It was not needed in Paper V of the series, in which Piet used Pioneer 10 data to measure the scalelength of the Milky Way (van der Kruit 1986).

2. Structure and Evolution of Disk Galaxies

This conference saw many new (and some old) results on disk galaxies. The talks and poster contributions demonstrated clearly that these systems are quite complex *Island Universes*, and that their properties pose a considerable challenge to the theory of galaxy formation (as reviewed by Freeman and Silk). In these concluding remarks, I draw attention to some results on the various components of these galaxies, briefly comment on new insights provided by ongoing panchromatic surveys, and close with a glimpse into the future.

Stellar Disks

The basic properties of the surface brightness distribution of stellar disks were established by Freeman (1970) and van der Kruit & Searle (1981a, b, 1982a, b), based on photographic photometry. Various speakers addressed recent work in this area. Three types of surface brightness profiles are seen, namely the pure exponential profile (corresponding to the canonical Freeman disk) extending out to as much as nine scalelengths (Pohlen). Many galaxies instead have a double exponential profile, with the outer slope steeper than the inner slope; these are essentially the truncated profiles discovered by van der Kruit & Searle, and reminiscent of Freeman's 'Type II' curves. A third class of galaxies also displays double exponential profiles, but these have an outer slope that is shallower than the inner slope. Pérez reported evidence that the ratio of inner to outer scalelengths is fairly constant out to a redshift of about one.

At least during this conference, there appeared to be some confusion on whether studies of face-on objects and those of edge-on systems (where the effect of the line-of-sight integration is different) agree. There is also some uncertainty about the relative numbers in each of the three classes of galaxies. We heard initial reports on automated measurements of the structural properties of disks in very large samples, including the Sloan Digital Sky Survey and the Millennium Galaxy Catalogue (Allen). This should resolve the inclination issues and establish the relative importance of the three classes.

A fascinating new development in this area is provided by detailed studies of the nearest galaxies, based on star counts. This allows disks to be traced to very faint (integrated) magnitudes. Heroic counts in M31 by Ferguson's team, based on the wide-field mosaic obtained with the Isaac Newton Telescope on La Palma, and related work by Guhathakurta and colleagues, not only traces various streams of stars in the halo of the nearest large spiral galaxy, but also revealed tantalizing evidence for a giant extended structure perhaps as large as 100 kpc. It is not yet clear whether this is a giant disk or a metal-poor halo, or how it formed, but spectroscopy obtained at 8-10m class telescopes provides kinematics and [Fe/H] measurements, and should clarify this soon.

Some disk galaxies display UV and $H\alpha$ emission which extends well beyond the Holmberg radius, suggesting recent star formation in the ‘Outer Banks’ (Zaritsky). It is not clear whether the presence of these stars is in harmony with the canonical threshold for star formation (Kennicutt 1998), or whether there is a link with the presence of a flaring or warped HI disk.

Thick disks

In addition to the standard stellar disk, most spirals contain a thick disk of modest mass. The mass fraction appears to increase in galaxies with a circular velocity below about 120 km/s, and spectroscopic observations with Gemini show that some thick disks counter-rotate relative to the main disk of the galaxy (Dalcanton). This strongly suggests an external origin, and resembles the situation in S0 galaxies, where a number of cases are known of counter-rotating disks with different scaleheights.

The run of $[\alpha/\text{Fe}]$ versus $[\text{Fe}/\text{H}]$ indicates that the thick disk of the Milky Way cannot have formed by accretion of small stellar lumps (Venn). The inference is that all these structures formed via *wet* accretion, i.e., an accretion of perhaps a small satellite, but involving gas. The theorists, of course, reminded us that they thought this all along, but it is gratifying to see that high-resolution simulations are now being carried out to compare this scenario in detail with observed galaxies (Bullock, Brook, Governato, Sommer-Larsen).

Bars

Nearly 70% of disk galaxies contain a large-scale stellar bar (Knapen). This influences the dynamics in the disks, allows efficient redistribution of angular momentum, and can drive gas to the center (as do interactions) which can trigger a starburst, sometimes in a spectacular ring (Falcon-Barroso, Allard). The bars themselves slow down and change shape due to friction by the halo. Determining the rate of slowing down has been a long-standing problem, but recent work by Sellwood and Athanassoula appears to have sorted this out—at last. However, it is not yet clear whether this result is consistent with the constant bar fraction observed in galaxies since redshift one (Bell).

Impostor Bulges

It has become clear in the past decade that the bulges of disk galaxies comprise a mix of structures, with subclassifications into classical and ‘pseudo’ bulges, bars and ‘peanuts’. The nomenclature is colorful but the nature of the central regions remains a subject of confusion. Perhaps as many as half of all disk galaxies have ‘classical’ bulges with a de Vaucouleurs’ $R^{1/4}$ surface brightness profile and substantial rotation. These appear quite similar to small E/S0 galaxies. High-resolution imaging with the Hubble Space Tele-

scope (HST) revealed that the remaining ‘bulges’ have approximately exponential light profiles, and may in fact be small disks with a central star cluster (Carollo 1999). These structures are sometimes referred to as pseudo-bulges (Kormendy & Kennicutt 2004), but their definition may need further clarification, as the label is often connected to preconceived notions on formation. Perhaps a new name is useful, as emphatic statements made during this conference that the speaker believes that such-and-such a galaxy has ‘a real pseudo bulge’ are not very illuminating to the uninitiated.

Elmegreen argued that bars do not transform into bulges today, as some scenarios have it, while Bureau reminded us that ‘an end-on peanut looks like a bulge’, so that a central bar may in some cases *be* the bulge.

A related topic which, however, was not discussed during this conference is the presence/absence of supermassive black holes in the nuclei of disk galaxies, and the relation with the nature of the central regions.

Extraplanar Gas and Warps

Extended extraplanar gas is seen in nearby edge-on galaxies in HI (Fraternali/Sancisi) and in $H\alpha$ and X-rays (Dettmar). The properties appear consistent with the theory of galactic fountains and winds, and it is not evident that in-situ star formation is needed in the halo, as has been suggested. It will be interesting to investigate the effect of the odd run-away O/B star that escapes from the disk population at high speed, and finds itself in the halo before expiring in a supernova explosion.

Binney reviewed the origin of warps, in a talk which was interrupted by one of the more spectacular rainstorms seen in the Low Countries in the past decade, and saw more than half the audience run to their rooms to close the windows. After a simple “my goodness” Binney continued unfazed by this behavior, and demonstrated that warps are most likely caused by the torques on the dark halo related to the local cosmic inflow pattern. This may provide a way to read more of the fossil record of the formation of, e.g., the Local Group, and, in any case, is clear evidence that disk galaxies are, in fact, not isolated island universes.

Dark Halos

Studies of dark halos based on HI rotation curves are now mature (de Blok). It seemed to me, at least, that the field needs to move beyond the ‘cusp wars’ regarding the central structure of dwarf and low-surface-brightness galaxies, and the arguments whether it is the observers who do their measurements wrong, or the theorists who are missing key ingredients in their N-body simulations. I was impressed to see recent progress in this area using an approach pioneered by Piet and developed further by his student Bottema, namely the measure-

ment of the stellar M/L_* of the disk (e.g., Bottema 1993). This requires measuring the vertical velocity dispersion, which breaks the degeneracy between the contributions of the stellar and halo mass to the observed rotation curve. Comparison of the resulting dynamical M/L_* with the value inferred from the colors and line-strengths sets important limits on the IMF (de Jong), and on the specific angular momentum content of the halo (Kassin). Multi-slit, or, even better, integral-field spectroscopy is the next step, as it simultaneously constrains the shape of the velocity ellipsoid and the value of M/L_* . We were treated to a preview on this by Verheijen and Bershady.

The Milky Way

Kapteyn's own Island Universe received relatively little attention at this conference. Binney discussed the kinematics of disk stars in the Milky Way, and Venn showed evidence that the stellar halo cannot have formed by dissolving present-day dwarf spheroidals, dIrr or LMC clones. But a detailed comparison of Milky Way properties with simulations of galaxy formation constitute a key test of the entire formation paradigm (Bullock, Sommer-Larsen, Governato). There is much room for further work here.

3. Panchromatic Surveys

The recent launch of the GALEX and Spitzer space telescopes has enabled high-quality imaging of galaxies from the UV via the optical and the infrared to CO/HI in the millimeter and radio regime (Kennicutt, Regan, Murphy, Matthews, Braun). The near and mid-infrared maps allow separation of stars and dust, and provide a test of the dust extinction derived from groundbased NIR data (Alves) and other methods (Holwerda). The panchromatic maps obtained as part of surveys such as the SINGS Legacy Program in principle provide good estimates of the spectral energy distribution as function of position, of star formation rates, constrain the lifetime of embedded phases of massive star formation, and delineate the cosmic-ray structure, all as a function of Hubble type. The challenge is to model all this in detail, and Dopita showed us the way forward here, in a comprehensive presentation with impressive graphics.

The next step is to obtain similar panoramic information for nearby galaxies at much higher spectral resolution. This has been available at radio wavelengths for over three decades, and the deployment of integral-field spectrographs allows the optical community to finally catch up. Examples of the value of such studies were presented by Falcon-Barroso, Ganda, and Verheijen. Despite Kennicutt's suggestion that the SINGS/HUGS community is the team to join, even he agreed that the darker forces employing all-seeing eyes such as SAURON should be watched with interest, if not trepidation.

Much ongoing work addresses properties of galaxies to high redshift, and we were treated to a whirlwind overview on the last day of the conference. These studies observe galaxy evolution over much of the history of the Universe, but at the expense of limited spatial resolution. Most objects found to date are the progenitors of present-day spheroids (Pettini), although disks have been detected to a redshift of about two (Abraham/Kassin) and the Damped-Lyman- α (DLA) systems seen in the spectra of distant quasars resemble local galaxies with HI (Zwaan). There is substantial evidence for inside-out formation (Bell/Trujillo), but proper correction for selection bias is critical (Vogt) and one should keep in mind that the evolution of a population is not the same as the evolution of the individual objects (Bell). I was impressed by the recent progress on determining metallicities in disks to redshifts as large as three, reported by Kewley, and by similar studies for the intergalactic medium summarized by Fall. Both speakers made it clear that the samples are not as large as one would want, and that selection effects are important.

4. The Future

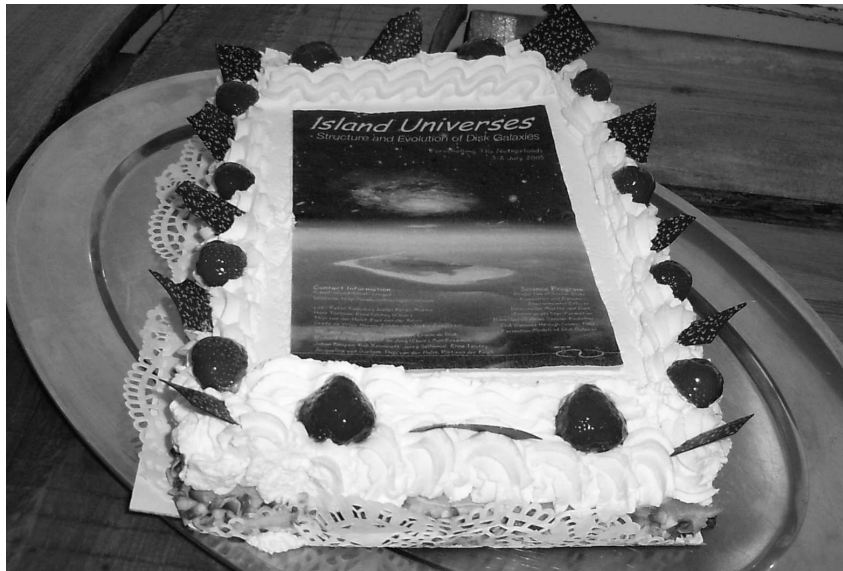
Ongoing and planned spectroscopic studies of the resolved stellar populations in the Milky Way and Local Group galaxies will teach us much. Panchromatic surveys of nearby galaxies complemented by integral-field spectroscopic studies in the optical and near-infrared are now possible, and the new adaptive-optics assisted instruments SINFONI, NIFS and OSIRIS on 8-10m class telescopes will allow extension of spatially resolved studies of the integrated light of galaxies to substantial redshifts. Theoretical models and simulations need to fit the observations in detail, and this appears within reach, not only for accretion of individual satellites in the early history of Local Group galaxies, but also for the evolution of populations of cluster and field objects.

The Herschel Space Observatory will be launched in a few years, followed in about 2013 by the James Webb Space Telescope. Both will be complemented by ALMA. This will provide a major jump in sensitivity and resolution at infrared and submillimeter wavelengths, further enabling studies of galaxy evolution to high redshift. The launch of GAIA in 2011 will result in a three-dimensional stereoscopic survey of the entire Milky Way and its halo, which will reveal the fossil record of formation of our own galaxy with unprecedented precision. All this bodes well for the future, and there clearly is much scope for further pioneering work by Piet.

Acknowledgements It is a pleasure to congratulate Roelof de Jong with organizing such a stimulating conference, to thank Jesus Falcon-Barroso, Leonie Snijders and Remco van den Bosch for assistance with the manuscript, and to thank Piet and Corry for a longstanding and warm friendship.

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Dessert after the barbecue: Island Universes cake!