Planetary nebulae as probes of the Galactic metallicity structure

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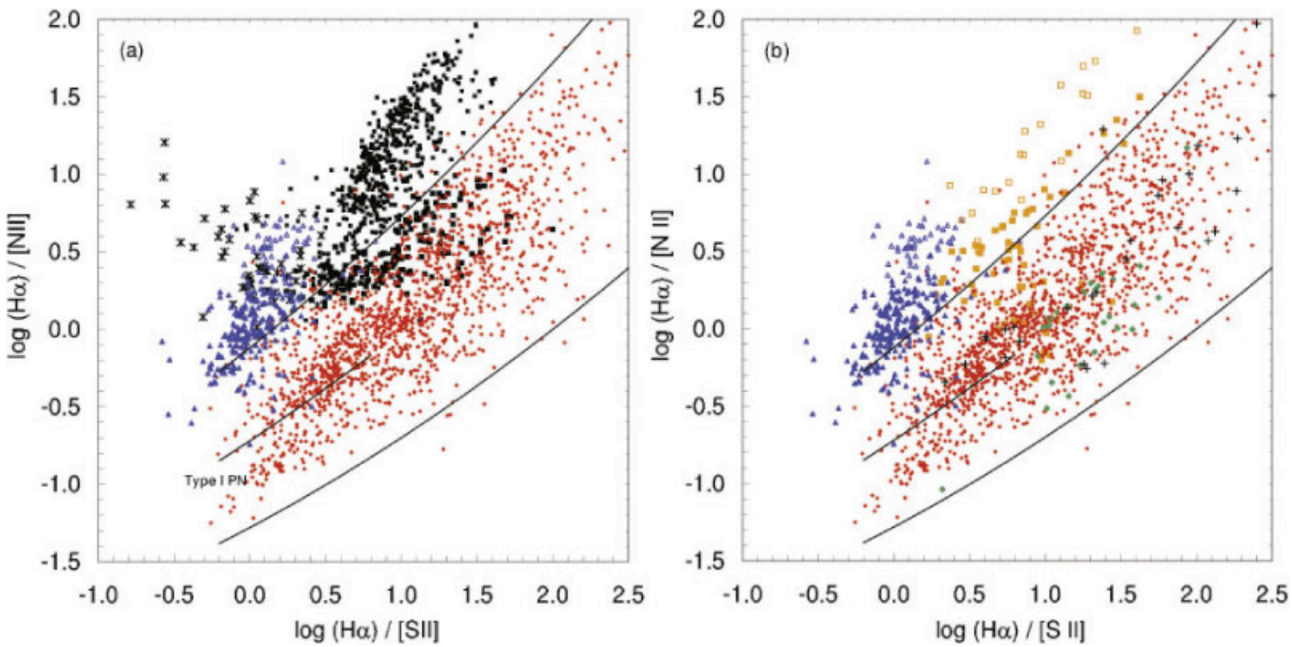
Outline

- The population of Galactic planetary nebulae and its components, defined by abundances, distances, and velocities
- Importance of a pure disk population
- Radial metallicity gradients
- Metallicity gradient evolution according to time-tagging the populations
- Transversal gradients, and the thin-thick disks
- Comparison with other Galactic stellar populations

Galactic PN

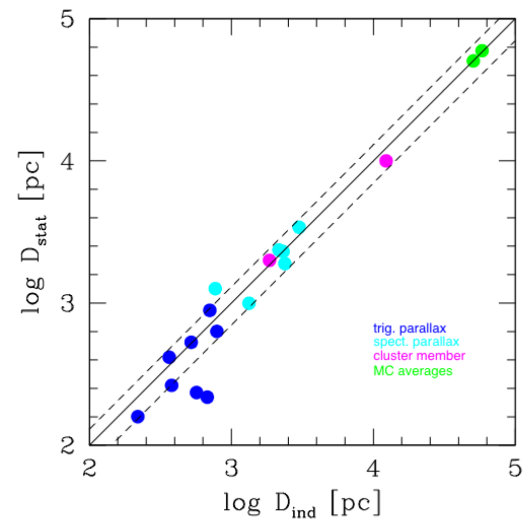
~3000 Galactic PN detected, ~1500 Galactic PN confirmed spectroscopically, (Acker 1982; Frew & Parker 2010) ; 200 spatially unresolved (from ground)



RED: PN; black: HII regions; blue: SNR; symbiotic stars and other object: other

Distances to Galactic PN

- ~1500 spectroscopically confirmed Galactic PN, ~20-30 have acceptable individual distances (methods: reddening, companions, parallax, cluster membership)
- Statistical distances based on physical correlations of nebular parameters (e.g. ionized mass vs. surface brightness), calibrated on *known* distances
- Galactic PN distance scale has been calibrated with the Magellanic Cloud PN observed now wit HST, a sample of more than 100 calibrators with very well known distances (Stanghellini et al. 2008)
- results checked against relatively new trigonometric and spectroscopic parallaxes (Ciardullo et al 1999, Harris et al. 2007), and cluster distances (Alves et al. 2000)



dD/D~10% for most PNe, <26% for the whole calibration

PN types

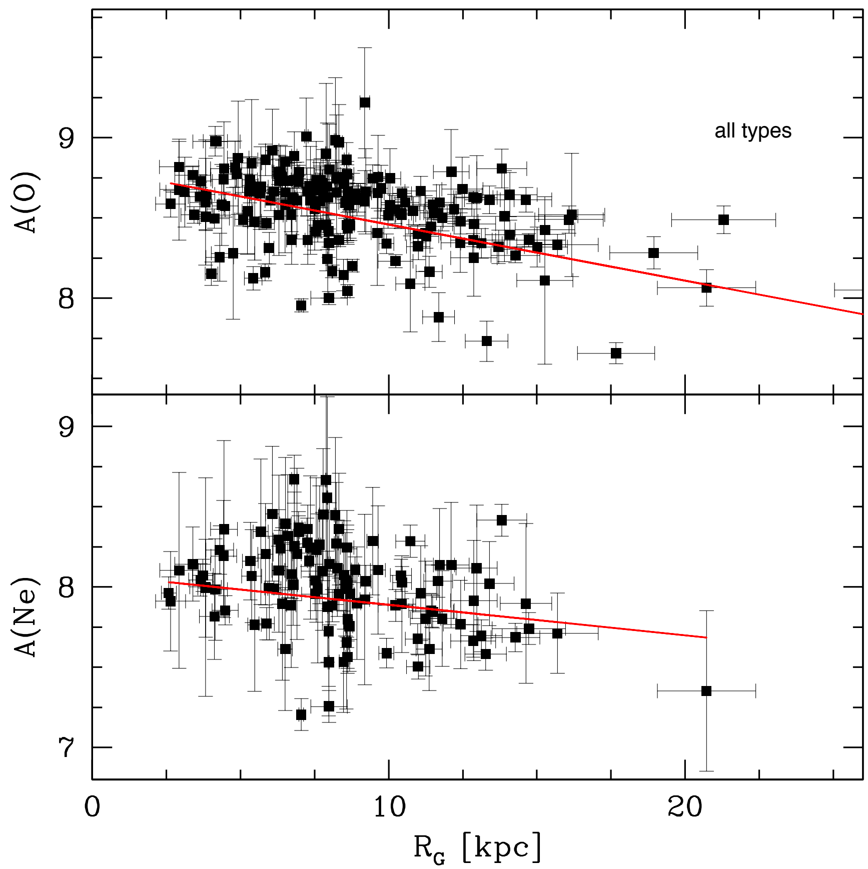
- PN types based on abundances and peculiar radial velocities (Peimbert 1978; Perinotto et al. 2004)
- Type I: log (N/O) > −0.3 and He/H 0.125 (from AGB evolution, it turns out Type I PN are those with massive progenitors, M>2-4 $M_{\odot}$ depending on metallicity); most Type I are bipolar in shape, and have low |z|
- Type II: non-Type I PN with peculiar radial velocity $V_p < 60$ km/s
- Type III: non-Type I PN with peculiar radial velocity $V_p \geq 60$ km/s

We have selected a “pure disk” population by doing our best in excluding bulge (within 10° of Galactic Center, $\theta \leq 10$ ”, $F_{5GHz} \leq 0.1$ Jy) and halo (Type III PN with |z|≥ alt_halo (usually between 600-800 pc) PN; note that this population might still have some stragglers, since distances are uncertain

- Stanghellini & Haywood (2010) studied the Galactic metallicity gradients by using all PN with published abundance and radial velocity, calculated distances, and built an homogeneous sample
- Sample is kept up to date (Stanghellini & Haywood 2012 in prep.) as new spectroscopy (i.e., abundances) and HST imaging (i.e., diameters and distances for unresolved PN) becomes available; updated data set includes anticenter PN from Henry et al. 2010

PN α-element gradients in the Galactic disk

- bulge PN excluded (see Chiappini et al. 2006; Stanghellini & Haywood 2010)
- halo PN tentatively eliminated (high peculiar velocity and |z|>600 pc)
- $\Delta d_{\odot}$=0.26% (from Stanghellini et al. 2008)



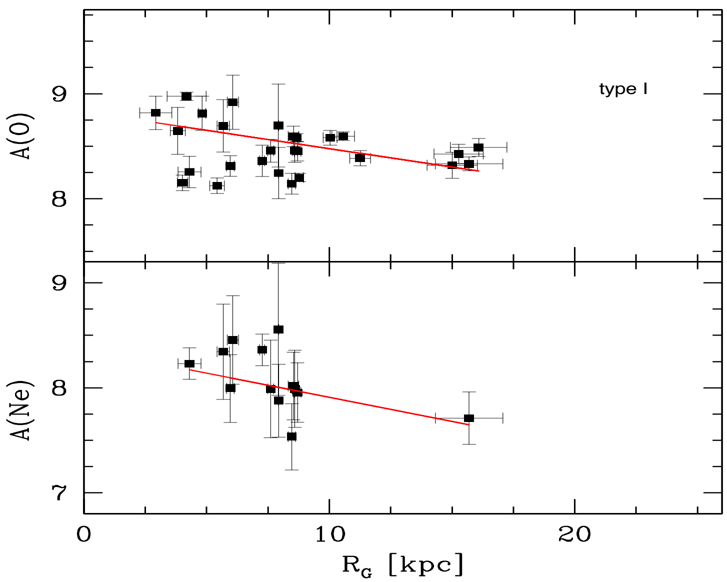
Metallicity gradients are negative, shallow, and one slope through galaxy

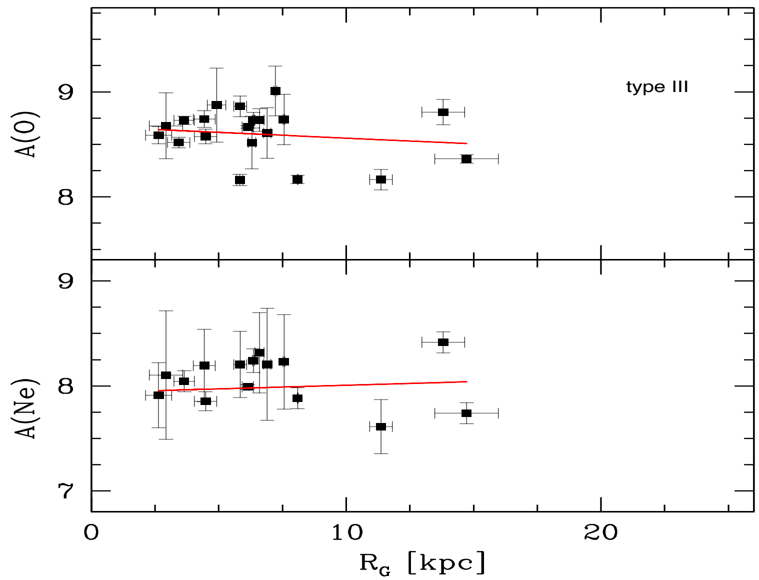
Gradients by PN type

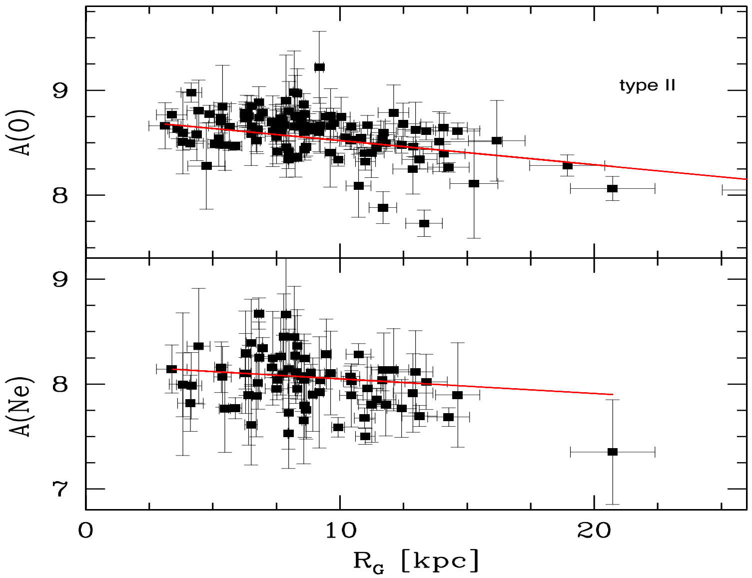
- It is essential to describe the population of PN selected when giving gradient slopes, since they change considerably by population
  - Type I PN mostly have bipolar shapes, thus their radii/ distances uncertainties are always underestimated
  - Type III PNe may belong to the Galactic halo
    - by looking at Type III PN we determine that they belong to the halo for $|z|>600$-800 pc
  - It is important to do one's best to eliminate bulge PN
    - Gradients that include bulge PN are always steeper!

Metallicity gradients by PN Type

exclude Type III with|z|>600 pc, and bulge PN







Gradient get slightly shallower from Type I to Type III PN

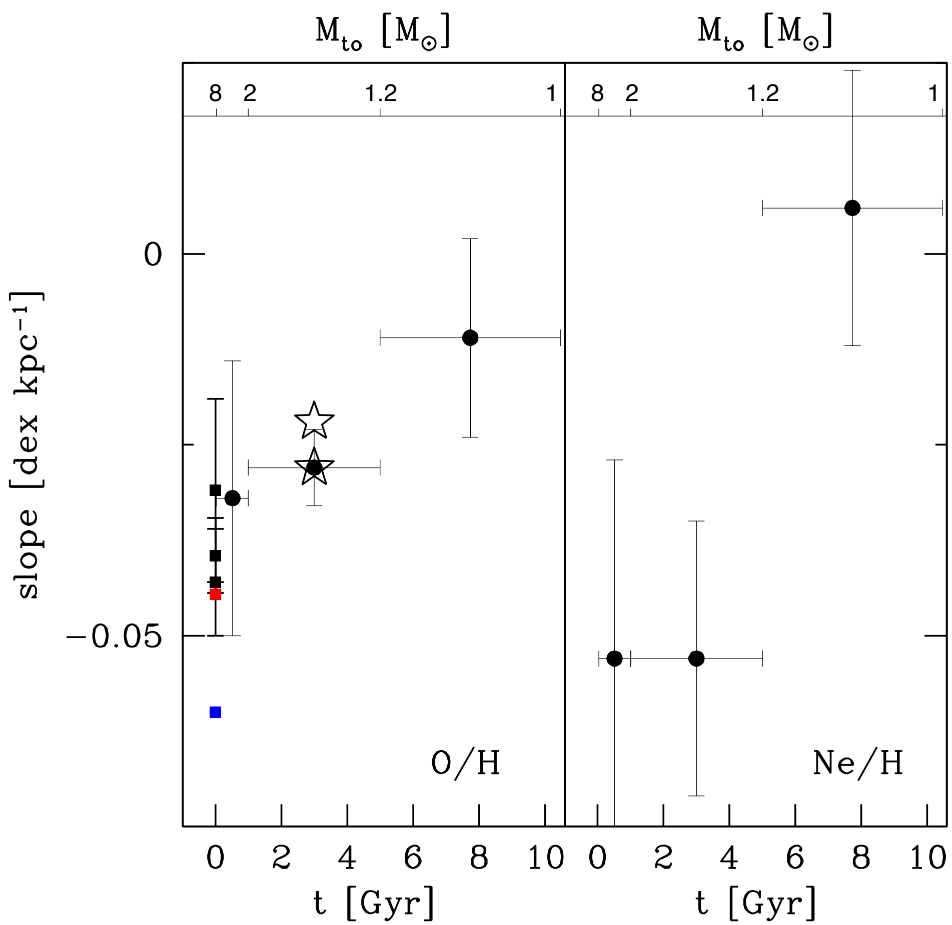
New samples: smaller dispersion, larger data sets

Gradients different for the 3 pops

Element	PN Type	M_{to} [$M_\odot$]	Age [Gyr]	N_{PN}	Slope [dex kpc^{-1}]
O/H	Type I	$M \geq 2$	$t \leq 1$	27	-0.032 ± 0.018
Ne/H		(Peimbert & Serrano 1980, Kaler et al. 1990)		13	-0.053 ± 0.026
O/H	Type II	$1.2 \leq M < 2$	$1 < t \leq 5$	110	-0.028 ± 0.005
Ne/H		(Perinotto et al. 04)		71	-0.053 ± 0.018
O/H	Type III	$M < 1.2$	$t > 5$	20	-0.011 ± 0.013*
Ne/H		(Perinotto et al. 04)		15	0.006 ± 0.018
			(Ages: Maraston 1998)		
O/H	All Types			177	-0.035 ± 0.006

* Not converging with fitexy, used lsq

Metallicity gradient evolution



- PN
  (Stanghellini & Haywood 2012 in prep.)
- ☆ Open clusters
  (Stanghellini & Haywood 2010)
- ■ Young stars and HII regions
  (Daflon & Cunha 2003; Rood et al 2007)
- ■ HII regions
  (Balser et al. 2011)
- ■ Cepheids
  (Luck et al. 2011)

The updates PN sample still shows some flattening of metallicity gradient with time, mostly Between the Type I and II versus the Type III PN. In the best sample (O/H) the differences are Within the errors (which in turn are uncertain, due to distance scale). → Issue still open! We can conclude that gradients in MW are shallow for all pops, flat for old pops.

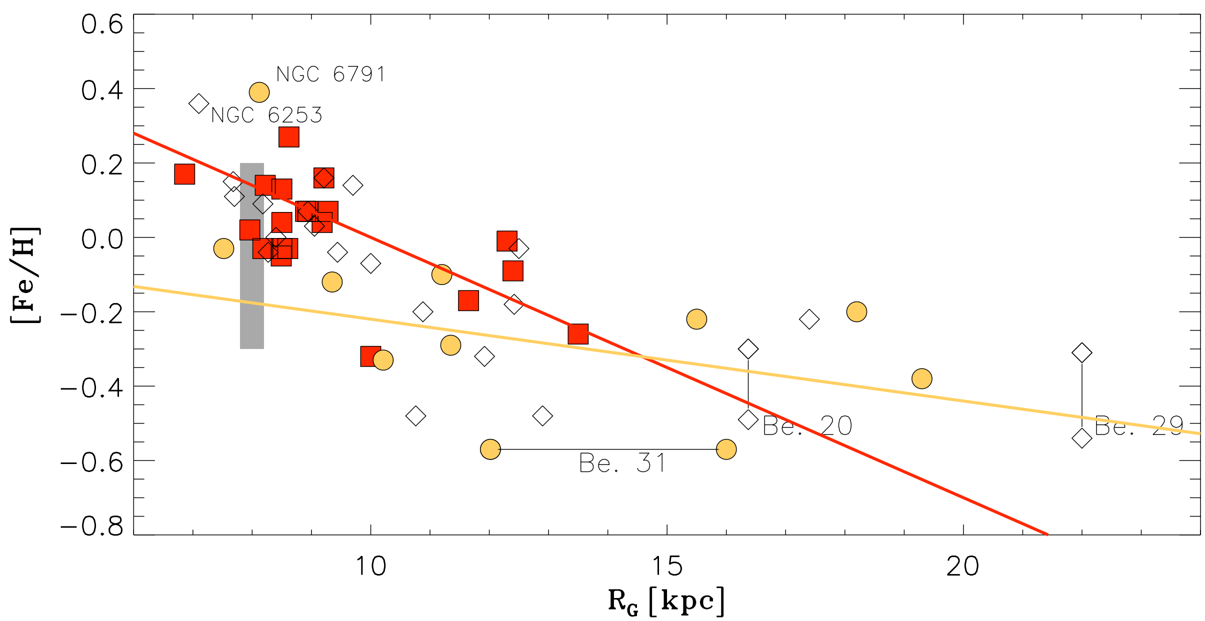
Steepening with time

- Gradient may flatten toward the older populations, i.e., they may be steepening with the time since Galaxy formation
- Young stars, HII regions, and intermediate age open cluster (oxygen) gradients agree with this scenario
- Is this compatible with other observables?
  - Local stellar population
  - Clusters, iron abundance
- Why is the gradient steepening with time?
- Is this the same for all spiral galaxies? [L. Magrini talk]

Other populations-Open clusters and local pops

- Open clusters
  - We use Magrini et al. (2009)'s working list plus additional clusters in the lit. Only intermediate age cluster sample is statistically significant in the radial range considered
  - Even if not enough data to meaningfully derive a gradient, young (t<1 Gyr) and old (t>5 Gyr) open cluster A(O) vs. R_G encompass PN data
  - Qualitative agreement between iron gradients of young and old open clusters and young and old PN
- Local stellar populations
  - Metallicity spread of thin disk at solar radii due to non-evolutionary effects, rather to stars migrating across the disk (Haywood 2008)
  - Solar neighbor stars fully compatible with Type II PN gradient, taking into account local stellar metallicity, and stellar migration (-0.05 dex kpc^{-1} for [Fe/H])

Open clusters, iron gradients
Red squares: t< 1 Gyr; yellow circles: t> 5 Gyr
Lines: type I and Type III PN oxygen gradients (O/H=0.5 Fe/H]
(Stanghellini & Haywood 2010)



why are gradients steepening?

- Inner and outer parts of MW have evolved at different rates
  - Disk evolutionary rate depends on distance from center (Schonrich & Binney 2009)
- The inner disk had more time to produce metals (outer disk younger than inner disk)
  - this scenario will be tested with Gaia, but there are suggestions from the local stellar pops that this is not the case

- >currently, there is no supporting evidence that PN oxygen gradients in the Galaxy flatten with time (but other spirals might behave differently, stay tuned…)

Is there a thick disk?

Astrophys. J., in press
Preprint typeset using LaTeX style emulateapj v. 5/2/11

THE MILKY WAY HAS NO THICK DISK

Jo Bovy[1,2,3], Hans-Walter Rix[4], & David W. Hogg[4,5]

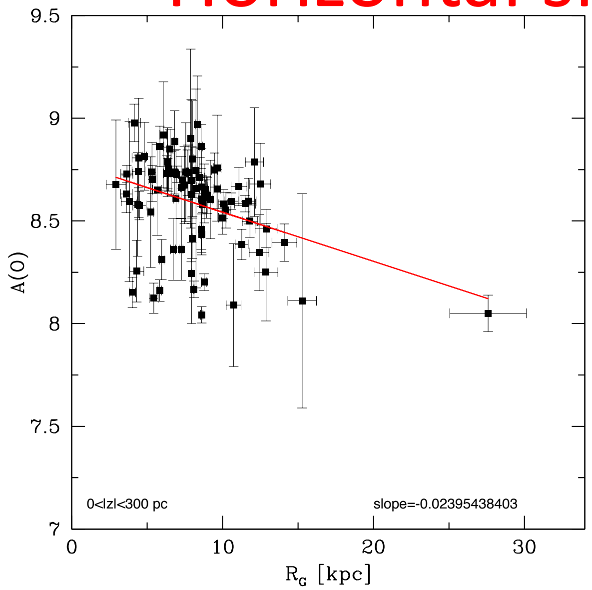
Astrophys. J., in press

ABSTRACT

Different stellar sub-populations of the Milky Way's stellar disk are known to have different vertical scale heights, their thickness increasing with age. Using *SEGUE* spectroscopic survey data, we have recently shown that mono-abundance sub-populations, defined in the [α/Fe]-[Fe/H] space, are well described by single exponential spatial-density profiles in both the radial and the vertical direction; therefore any star of a given abundance is clearly associated with a sub-population of scale height h_z. Here, we work out how to determine the stellar surface-mass density contributions at the solar radius R_0 of each such sub-population, accounting for the survey selection function, and for the fraction of the stellar population mass that is reflected in the spectroscopic target stars given populations of different abundances and their presumed age distributions. Taken together, this enables us to derive $\Sigma_{R_0}(h_z)$, the surface-mass contributions of stellar populations with scale height h_z. Surprisingly, we find no hint of a thin-thick disk bi-modality in this mass-weighted scale-height distribution, but a smoothly decreasing function, approximately $\Sigma_{R_0}(h_z) \propto \exp(-h_z)$, from $h_z \approx 200$ pc to $h_z \approx 1$ kpc. As h_z is ultimately the structurally defining property of a thin or thick disk, this shows clearly that the Milky Way has a continuous and monotonic distribution of disk thicknesses: there is no 'thick disk' sensibly characterized as a distinct component. We discuss how our result is consistent with evidence for seeming bi-modality in purely geometric disk decompositions, or chemical abundances analyses. We constrain the total visible stellar surface-mass density at the Solar radius to be $\Sigma^*_{R_0} = 30 \pm 1\ M_\odot$ pc^{-2}.

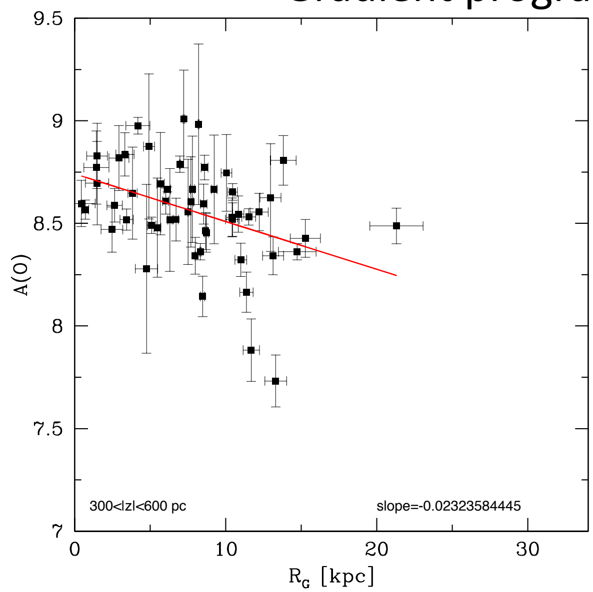
Subject headings: Galaxy: abundances — Galaxy: disk — Galaxy: evolution — Galaxy: formation — Galaxy: fundamental parameters — Galaxy: structure

Horizontal slices of MW and radial metallicity gradients

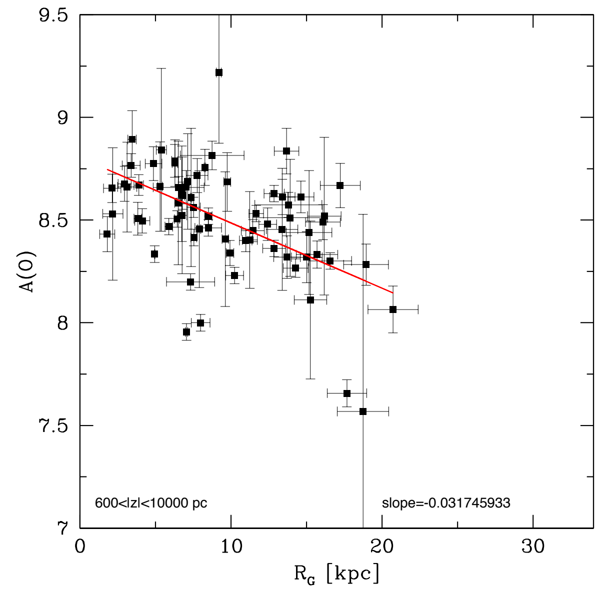


<O/H>=(4.44±2.10) 10^{-4}

We have sliced the MW horizontally and run the Gradient program for the individual slices



<O/H>=(4.02±2.20) 10^{-4}



<O/H>=(3.80±2.20) 10^{-4}

<O/H> $|v_{pr}|<60$ km s^{-1} =(4.20±2.20) 10^{-4}
<O/H> $|v_{pr}|>60$ km s^{-1} =(3.80±2.20) 10^{-4}
No clear sign of a thin/thick disk discontinuity based on PN abundances; rather, some halo contamination

Gradients - summary

- Thorough study of Galactic disk PN allowed determination of metallicity gradients of $\Delta\log(O/H)/\Delta\log R_G$~-0.02 to -0.03 dex kpc^{-1}
- Gradients of Type I, II, and III PN show that metallicity gradients may be <u>steepening with time since galaxy formation</u> although evidence is not conclusive
- PN gradients <u>agree with local disk population, young stars, HII regions, open clusters</u>
- There is not clear sign of a vertical gradient not thick/thin disk discontinuity from PN abundances

Future endeavors

- Abundances of ~150 compact Galactic PN are derived from IRS/Spitzer and ground-based spectroscopy (IRS data: Stanghellini et al. ApJ. In press; abundances: Lee et al. in preparation); IR +optical data will allow disregard of ICF and greatly reduce abundance error bars
- Distances to Galactic PN with GAIA will greatly reduce the systematic uncertainty that debilitate Galactic PN gradients
- (eq. V mag=15 PN located at 1, 5 or 10 kpc with an accuracy of 3%, 13% and 26% respectively [Manteiga et al. 2012])
- The improved metallicity gradients from PN and HII regions in external spiral galaxies will allow comparison and study across galaxy type/mass/ environment