The KIAA-Cambridge Joint Workshop on Near-Field Cosmology and Galactic Archeology
KIAA, Peking University, Beijing, 2008 Dec. 1 – 5

Planetary nebulae and H II of the local group of galaxies

Liu Xiaowei
Department of Astronomy
Kavli Institute for Astronomy and Astrophysics
Peking University

Topics

1. Deep spectroscopy of bright planetary nebulae and H II regions

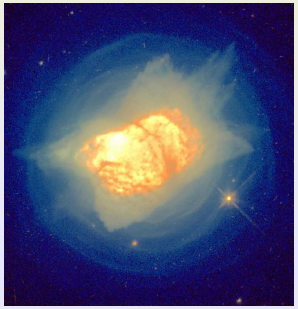
Liu X.-W., Probing the dark secrets of PNe with ORLs, in IAU Symp. #209, Planetary Nebulae: Their Evolution and Role in the Universe, eds. S. Kwok, M. Dopita and R. Sutherland, pp.339-346 (2003)

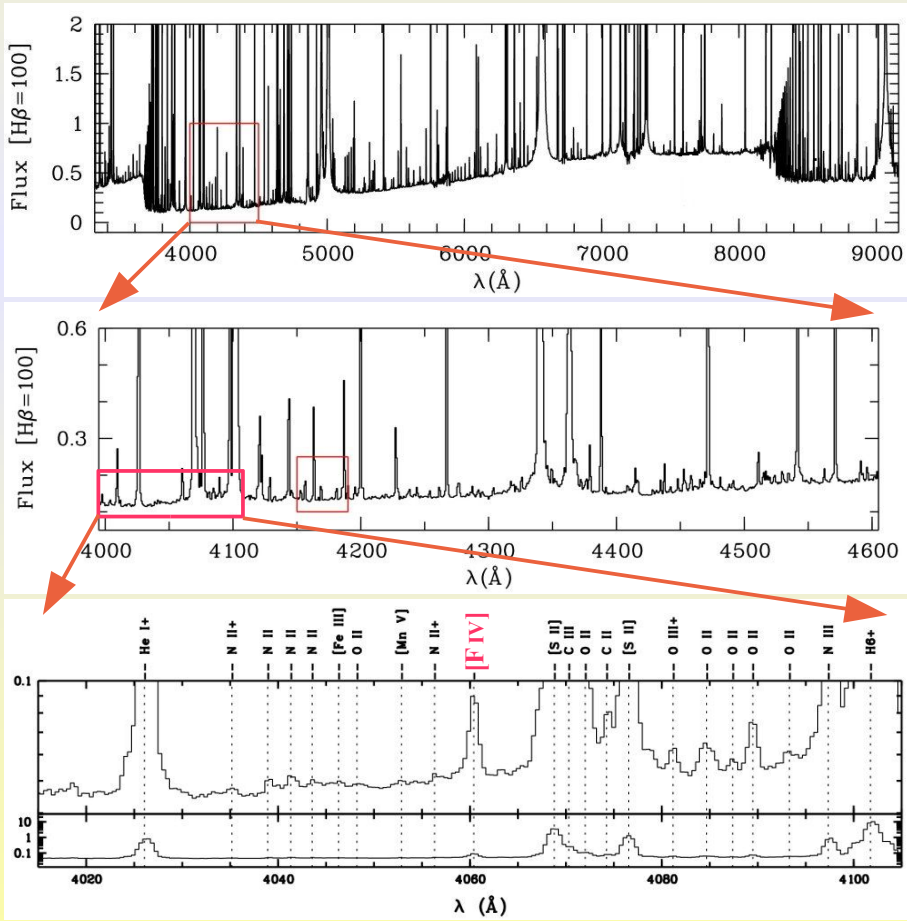
Liu X.-W., Optical recombination lines as probes of conditions in planetary nebulae, in IAU Symp. #234, Planetary Nebulae in our Galaxy and Beyond, eds. M. J. Barlow and R. H. Mendez, pp.219-226 (2006)

2. A LAMOST survey of M 31

Deep spectroscopy of emission line nebulae

- Measurements and analyses of lines as faint as $10^{-6} \times H\beta$ in bright nebulae (CNONe ORLs; CELs from rare elements, e.g. fluorine and s- and r-process elements)
- Mathis & Liu (1999), by comparing the observed [O III] λ5007/λ4959 and λ4931/λ4959 intensity ratios with theoretical predictions, demonstrate that accurate flux measurements can be achieved over a dynamic range of 10,000
- Progress in observational technology has enabled us to address some of the long-standing problems in nebular astrophysics as well as opened up new windows of opportunities.

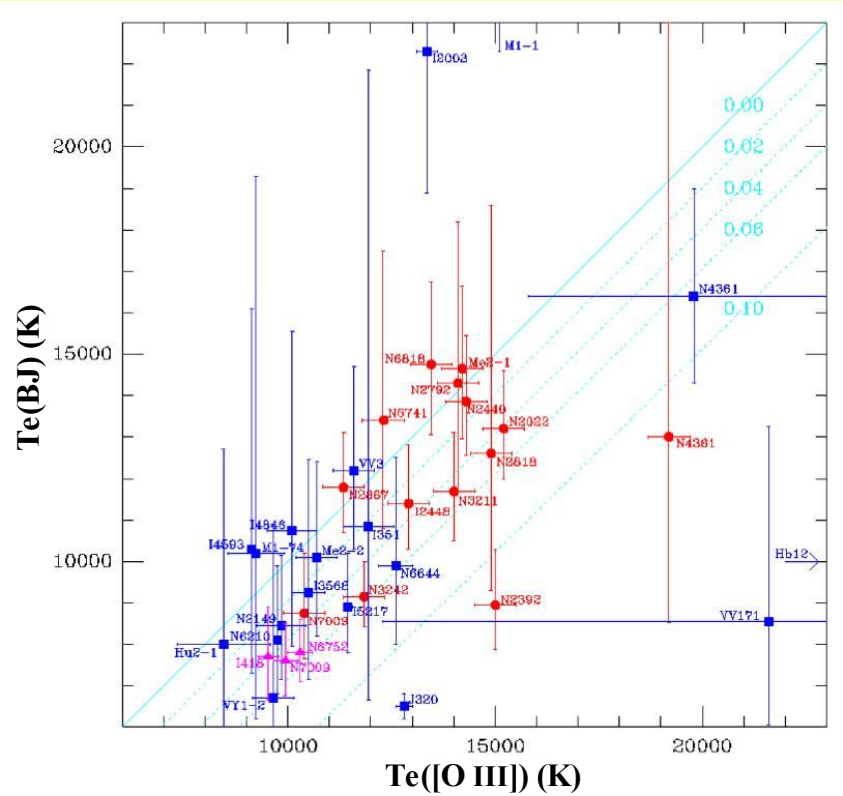




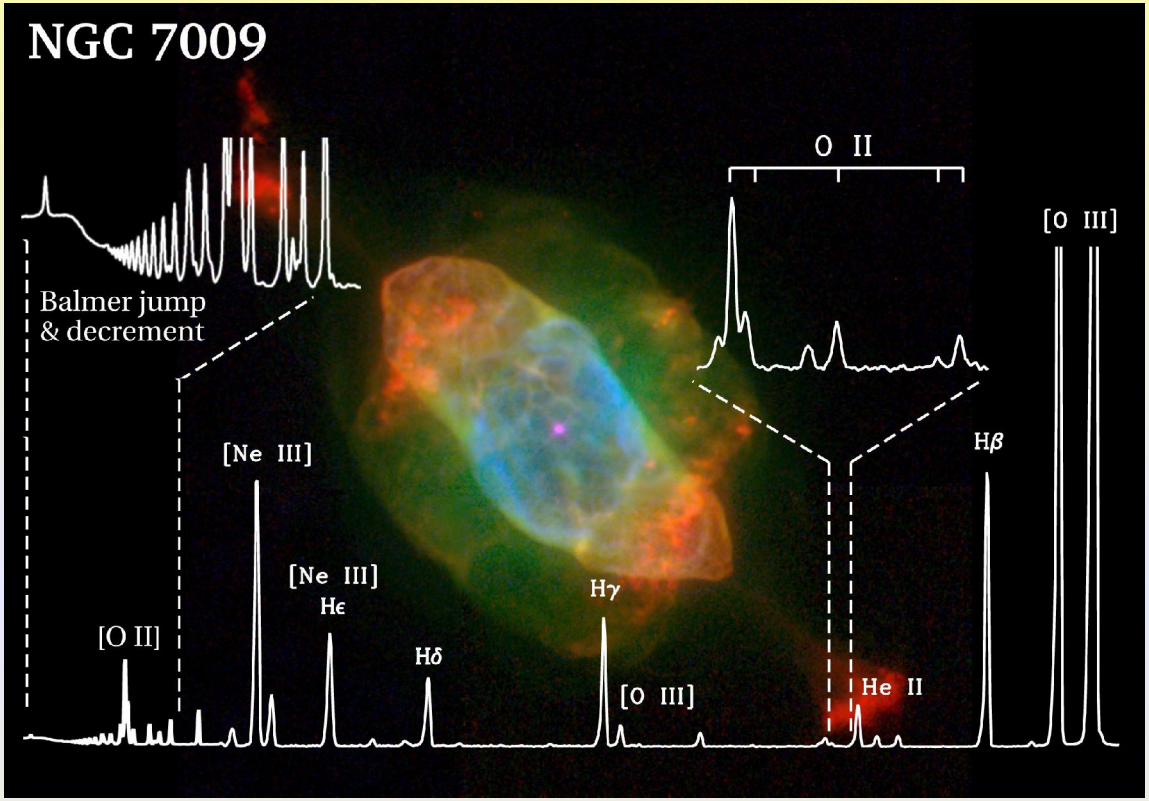
WHT optical spectrum of NGC 7027
(Zhang et al. 2005, A&A, 442, 249)

Synthesis of fluorine in AGBs:
Liu 1998, MNRAS, 295, 699
Zhang & Liu, 2005, ApJ, 631, L61

The dichotomy of CELs versus ORLs/Continua



Liu & Danziger 1993, MN, 263, 256



Liu et al. 1995, MN, 272, 369

T_e(BJ) = 7,200 K

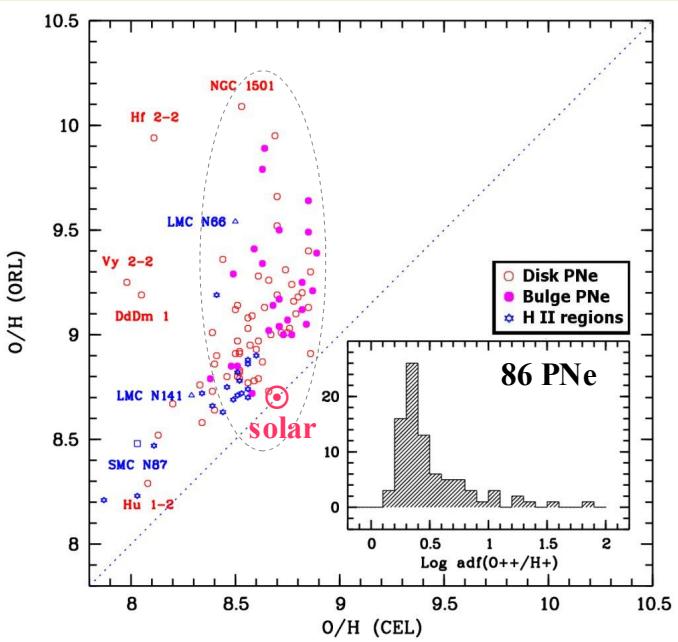
T_e([O III]) = 10,000 K

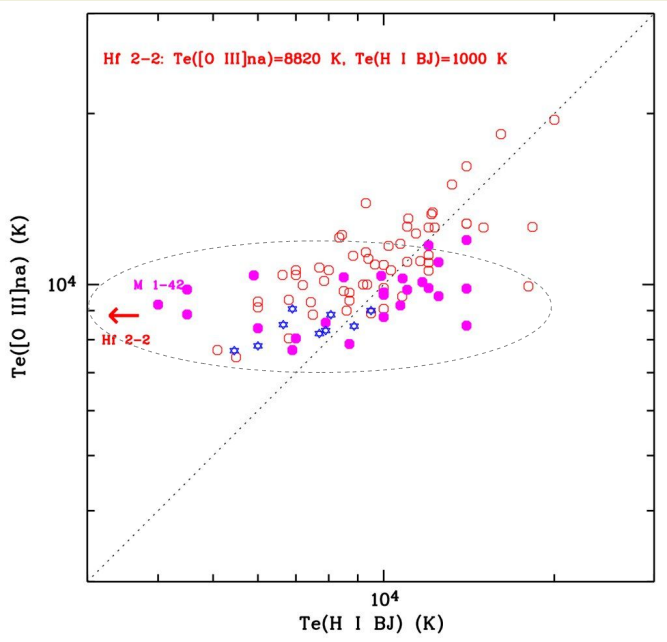
adf(O^{++}/H^{+}) = 4.7

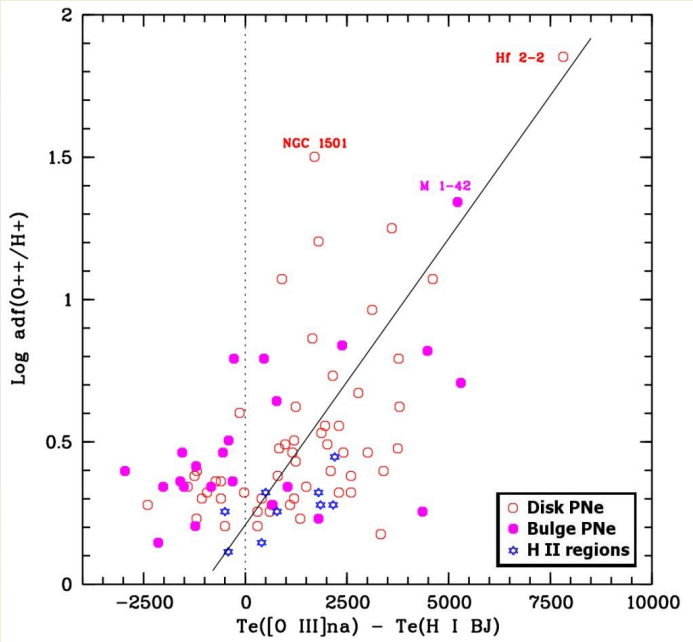
Dichotomy of CELs versus ORLs/Continua

The discrepancies between elelctron temperatures and ionic abundances deduced from ORLs/continua and from CELs are found to be ubiquitous amongst PNe and H II regions. The effects are bigger for larger, older PNe. For a given PN, the discrepancy increases towards the nebular center.

- **If the higher ORL abundances are correct, then we don't understand the nebular thermal structure.**
- **If the ORL abundances are wrong, we don't even understand the recombinations of hydrogenic ions!**



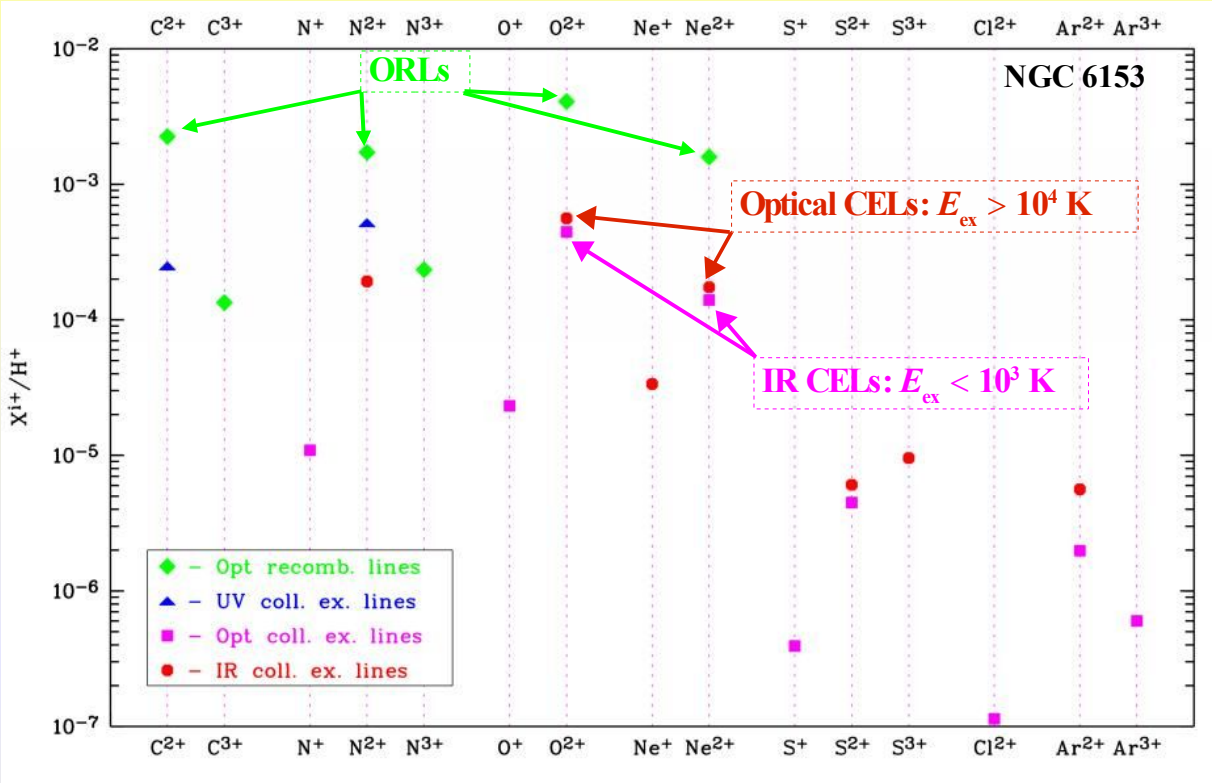


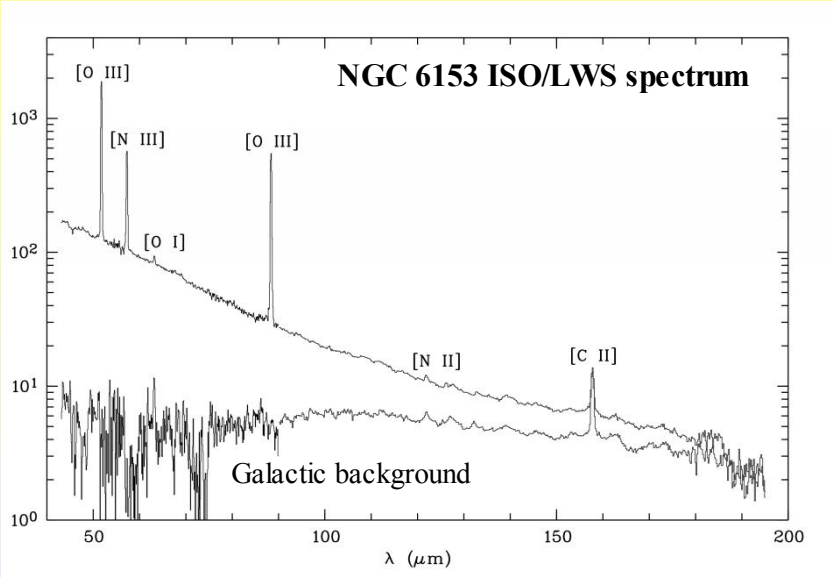


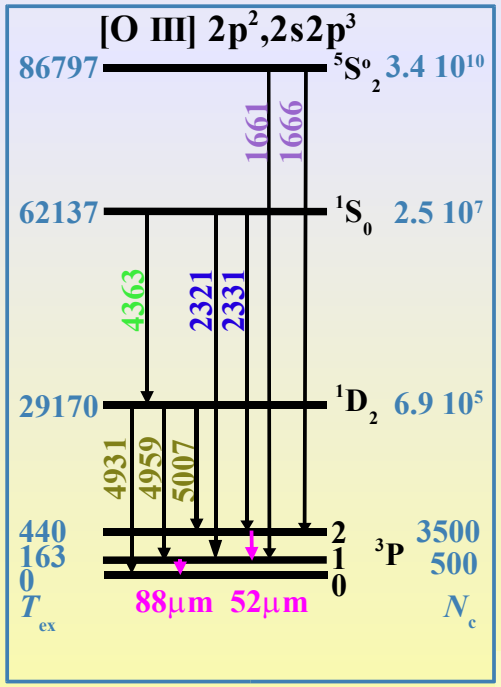
$$1)\ T_e(\text{ORLs/Cont.}) < T_e(\text{CELs}) \qquad 2)\ \frac{X^{i+}}{H^+}(\text{ORLs}) > \frac{X^{i+}}{H^+}(\text{CELs})$$

Are the discrepancies caused by temperature fluctuations postulated by Peimbert?

Evidence of a new component of cold, metal-rich plasma







Liu et al. 2000, MN, 312, 585

- X/H(CELs) derived from UV, optical or IR lines agree well
- X/H(ORLs) ≈ 10 × X/H(CELs)

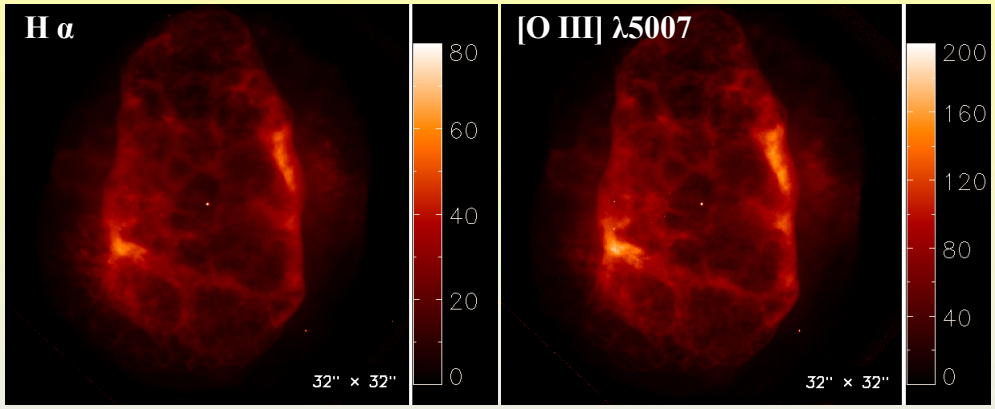
The nebula contains another presviously unknown component of cold, high-metallcity gas, which is too cool to excite any significant opt/UV CELs and is thus invisible via such lines.

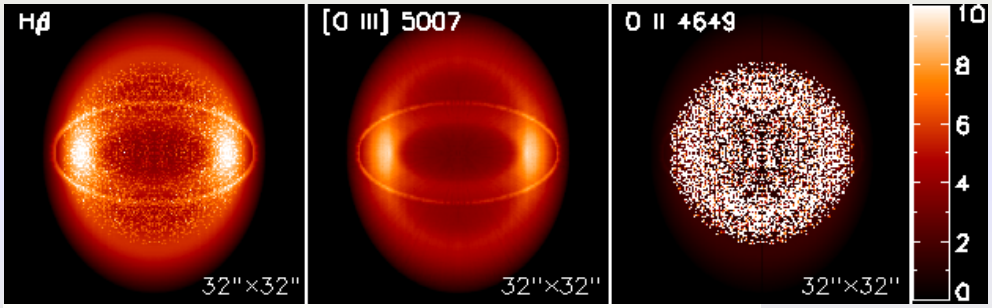
In this model, heavy element ORLs arise mainly from the cold (< 1000 K) plasma.

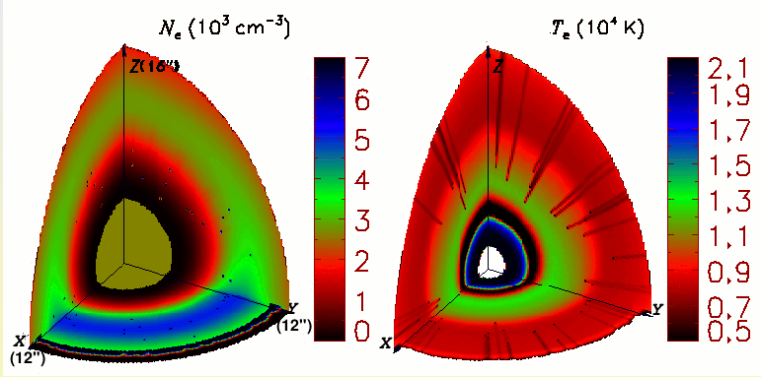
Photoionization models of NGC 6153

Yuan et al. 2008, in preparation

HST/WFPC2 images



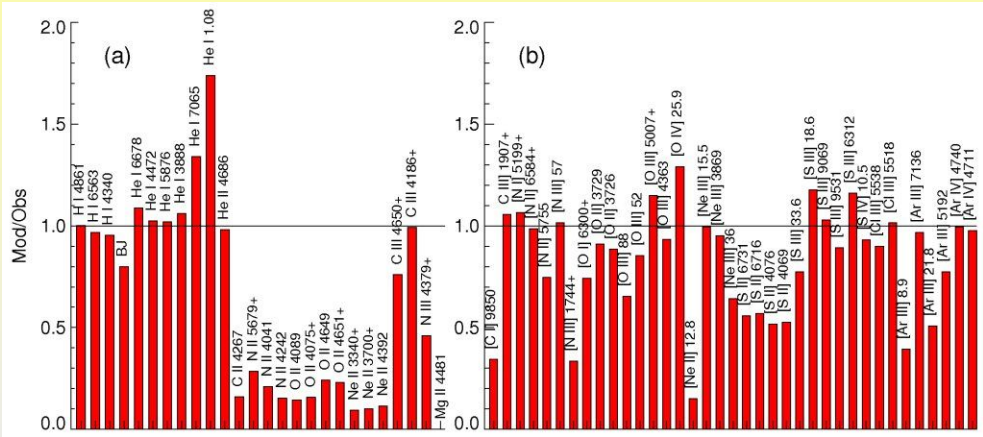




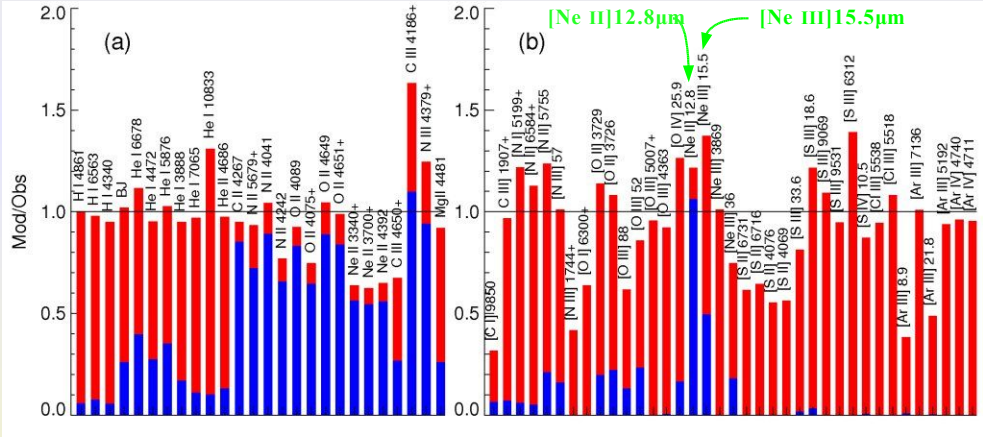
T_e = 9007 K
N_H = 1840 cm^{-3}
ff = 0.998
M = 0.243 M_{sun}

T_e = 815 K
N_H = 4000 cm^{-3}
ff = 0.002
M = 0.0031 M_{sun}

Chemically homogeneous model



Model with H-deficient inclusions (0.125″×0.167″)



Normal component	H-deficient component
H: 10000 He: 1000 C: 3.20	H: 10000 He: 5000 C: 177
N: 3.80 O: 5.53 Ne: 1.76	N: 150 O: 440 Ne: 177

H-deficient knots are cooled by infrared fine-structure lines: [O III] 52μm, [Ne II] 12.8μm and [Ne III] 16μm

The model predicts:

T_e([O III]) = 8800 K >> T_e(H I BJ) = 6080 K >> T_e(He I J3421) = 3300 K >> T_e(O II ORLs) = 800 K

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Department of Astronomy, Peking University

Comparison of plasma diagnostic results

	adf	T_e([O III]) (K)	N_e(CELs) (cm^{-3})	T_e(BJ) (K)	N_e(BD) (cm^{-3})	T_e(He I) (K)	T_e(O II) (K)	N_e(O II) (cm^{-3})
NGC 7009	4.7	9980	4260	7200	6300	5040	420	9000
NGC 6153	9.2	9120	3400	6000	6300	3350	350	9000
M 1-42	22	9220	1200	4000	5000	2260	<288	6000
Hf 2-2	71	8820	1000	1000	400	940	630	4800

O II ORLs arise from ~500 K plasma!

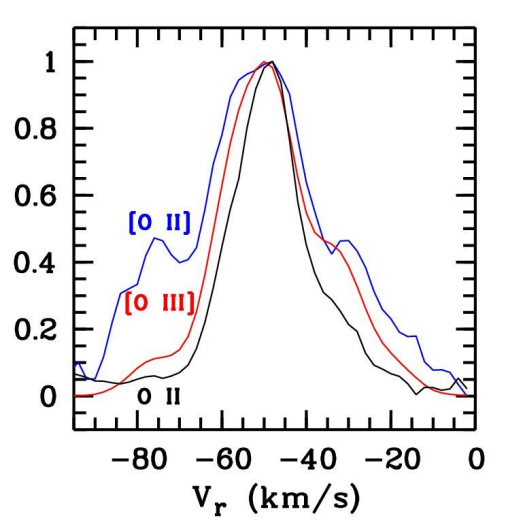
And as predicted, in general, T_e(O II) < T_e(He I) < T_e(BJ) < T_e ([O III])

(Liu 2003, in IAU Symp. 209; Liu et al. 2006, MN, 368, 1959)

	NGC 6153	Hf 2-2
Oxygen in "cold" component M_{ORL}(O) $M_\odot$	4.9×10^{-4} $M_\odot$	7.4×10^{-5}
Oxygen in "warm" component M_{CEL}(O)	1.5×10^{-3} $M_\odot$	4.6×10^{-5} $M_\odot$

Comparison of emission line widths of ORLs and

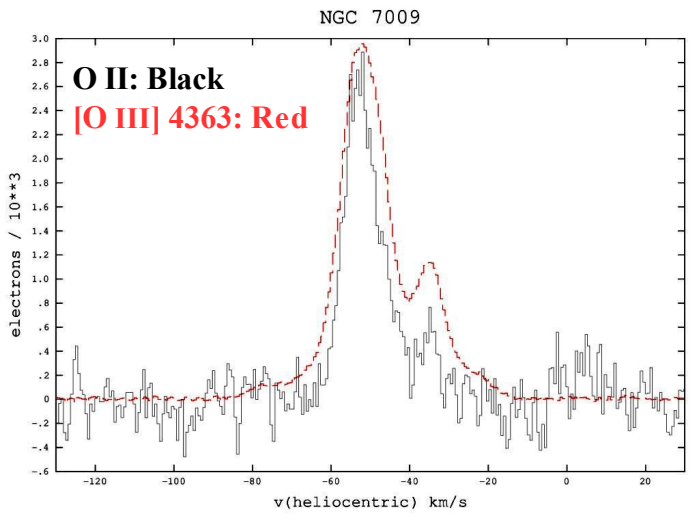
NGC 7009 (adf ~ 5)



ESO 1.52m FEROS
R **= 6 km/s**

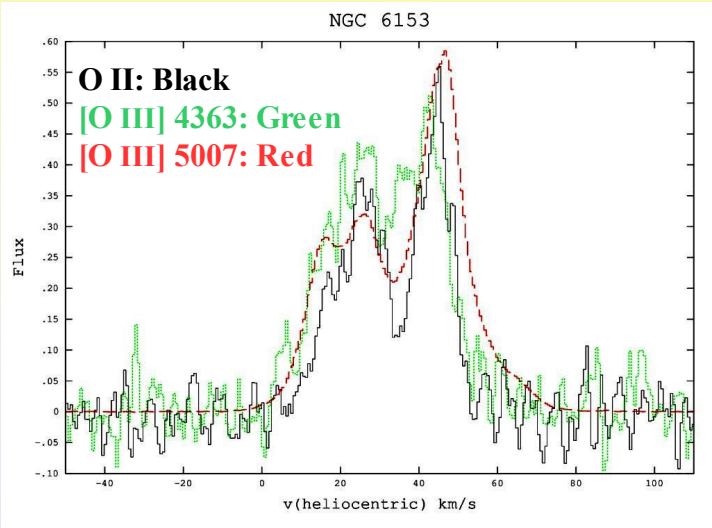
Liu 2006, in PNe beyond the Milky Way, eds. Walsh et al., p.169

NGC 7009 (adf ~ 5)



Gemini/South gHROS
R **= 2 km/s**

NGC 6153 (adf ~ 10)



Gemini/South gHROS
R **= 2 km/s**

Barlow et al. 2006, PNe in our Galaxy and beyond, eds. Barlow M. J. and Mendez R. H., p.367

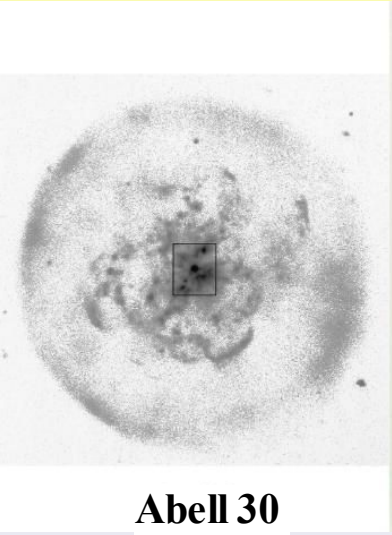
O II < [O III] < [O II]

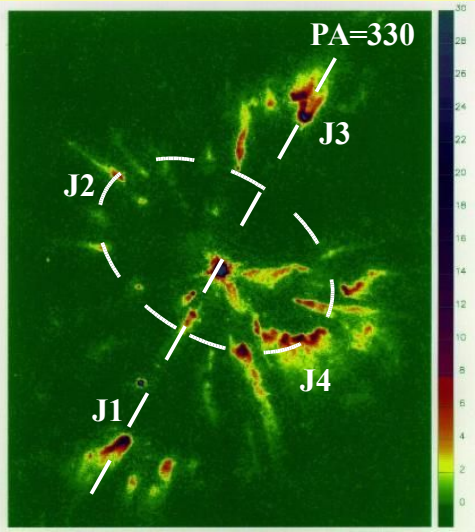
O II ORLs arise from either

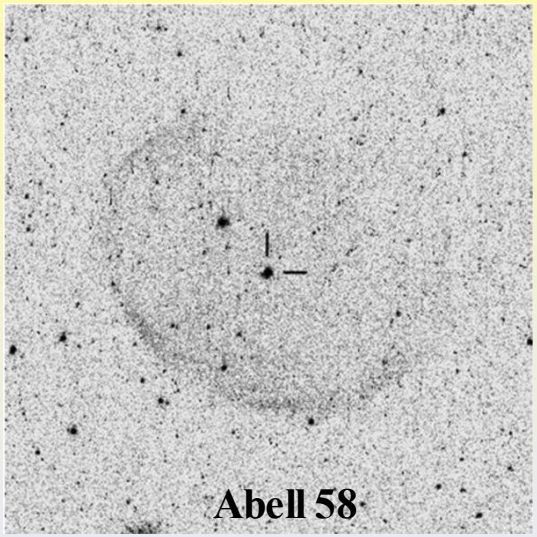
- **colder ionized regions or**
- **different spatial regions than those emitting [O III] and [O II] CELs**

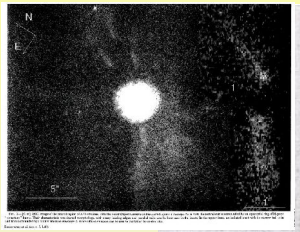
The observed different line widths can be explained by the H-deficient inclusion model, but not by a chemically homogeneous nebula (Zhang, 2008arXiv0805.2198Z)

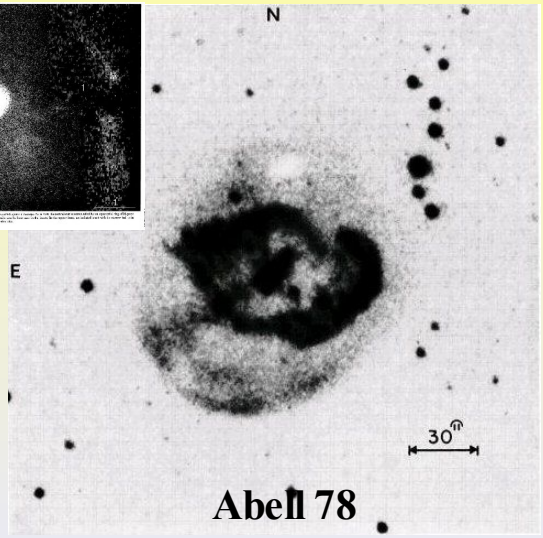
H-deficient knots in “born-again” PNe











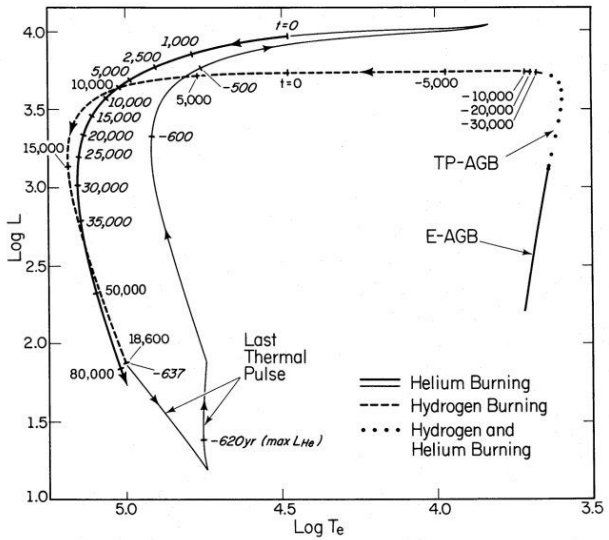


FIG. 1.—Post–horizontal-branch evolutionary track in the H-R diagram for a model star of mass $M = 0.6\ M_{\odot}$. The locations of the early (nonthermally pulsing) AGB phase and of the thermally pulsing AGB phase are represented, respectively, by the solid line and the heavy dots at low surface temperature. Along the dashed curve, the model burns hydrogen quiescently, and times to reach points on this track beyond the point where $T_e = 30{,}000$ K are denoted in years by unslanted numbers. Along the thin solid track which departs from the dashed track at $t = 18{,}600$ yr the model experiences a thermal pulse. Along the heavy solid track following the thin solid track the model burns helium quiescently. Times to evolve to points along this track from the point where $T_e = 30{,}000$ K are given in years by slanted numbers.

H-deficient PNe, only five known:

Abell 30, Abell 58, Abell 78,
IRAS 15154-5258,
IRAS 18333-2357 (in GC M22)

Iben I., Kaler J. B., Truran J. W., Renzini A., 1983, ApJ, 264, 605

WHT/ISIS spectral analyses of knots J3 and J1 in Abell 30

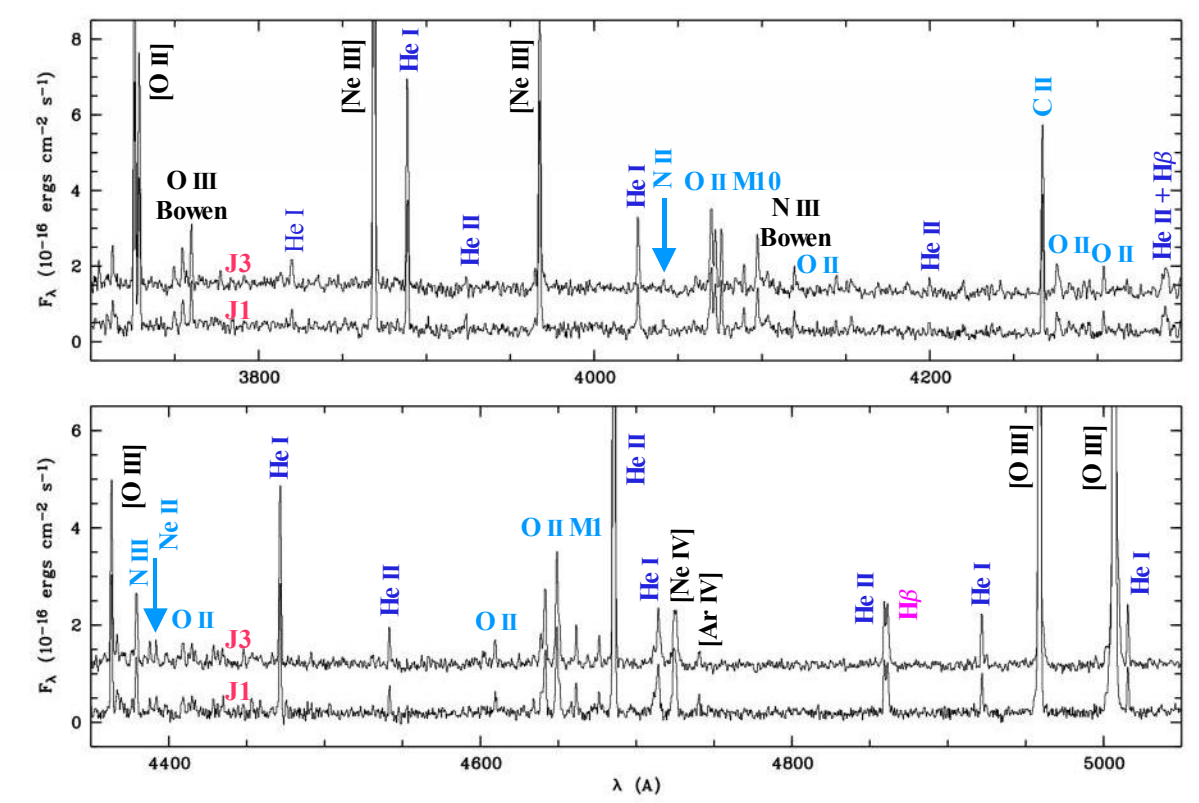


Table 15. Elemental abundances in units such that log N(H) = 12.0.

	J1		J3	
Ion	ORLs	CELs	ORLs	CELs
He	13.03		13.07	
C	11.65		11.66	9.22
N	11.49	8.88	11.43	8.90
O	12.15	9.26	12.10	9.32
Ne	11.51	9.70	11.99	9.78
Ar		7.45		7.22

Abell 30: Wesson et al. 2003, MN, 340, 253;
Abell 58: Wesson et al. 2008, MN, 383, 1639

ORLs from C, N, O & Ne ions and their relative strengths remarkably similar to those observed in other PNe such as Hf 2-2, M 1-42 and NGC 6153

Properties of the H-deficient knots in Abell 30 and 58

- **O II ORLs arise from ~ 500 K plasma**
- **C/O = 0.32 – 0.36 (Abell 30 J1 and J3), 0.085 (Abell 58)**

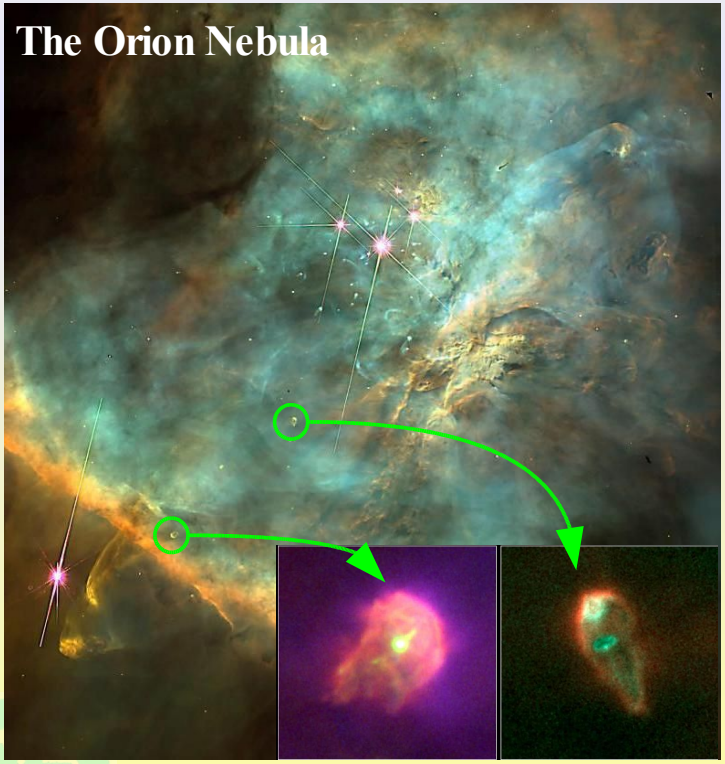
Problems with the "born-again" scenario

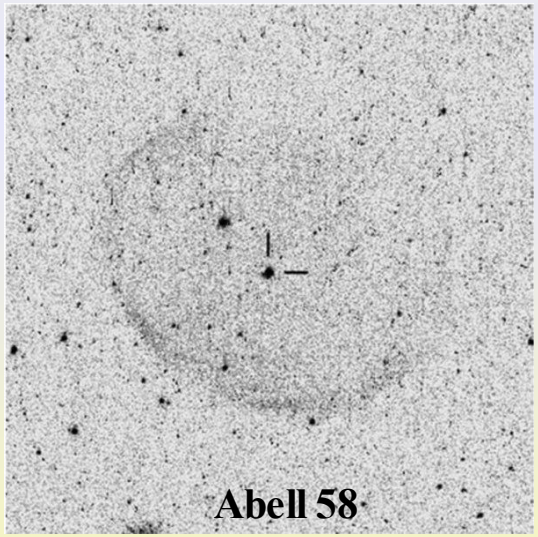
- **In Abell 30, H contributes only 1% of the mass of the knots, whereas for the postulated H-deficient inclusions in NGC6153, H contributes 22% by mass (H:He:O = 1:2:0.7). But the difference could be caused by mixing of H-deficient material with "normal" gas in NGC 6153**
- **It is unclear by what mechanism and by how much the He- and C-rich stellar surface material is ejected?**
- **Observations show that the knots are O-rich (C/O < 1), contradictory to the "born-again" scenario**

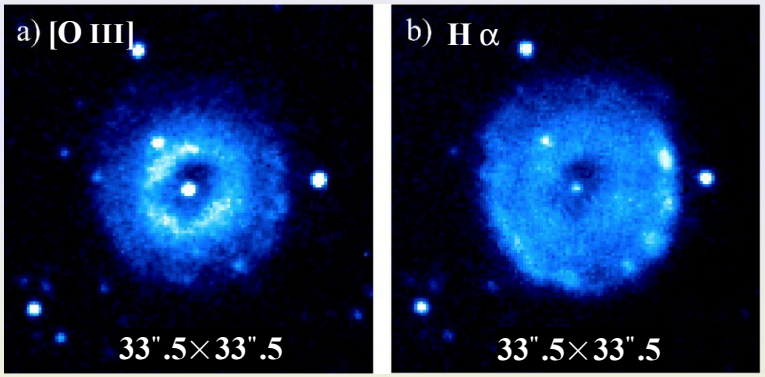
Origins of cold, metal-rich plasmas – evaporating planetesimals or nova ejecta?

- What happen to the orbiting planetary system when the Sun turns a WD and its envelope a PN?
- In the Orion Nebula, propleds (proto-planetary disks) are being evaporated by the strong UV radiation fields from the θ^1 C
- Difficult to explain the high ORL abundance of inert gas such as Ne

- The central H-deficient knot in Abell 58 (V605 Aql) is assumed to have formed in a nova-like outburst which peaked in 1919 (Clayton G. C., et al. 2006, ApJ, 646, 69)
- The central star of Hf 2-2 is known to be a close binary with a period of 0.4 days (Lutz, et al., 1998, BAAS, 30, 894)



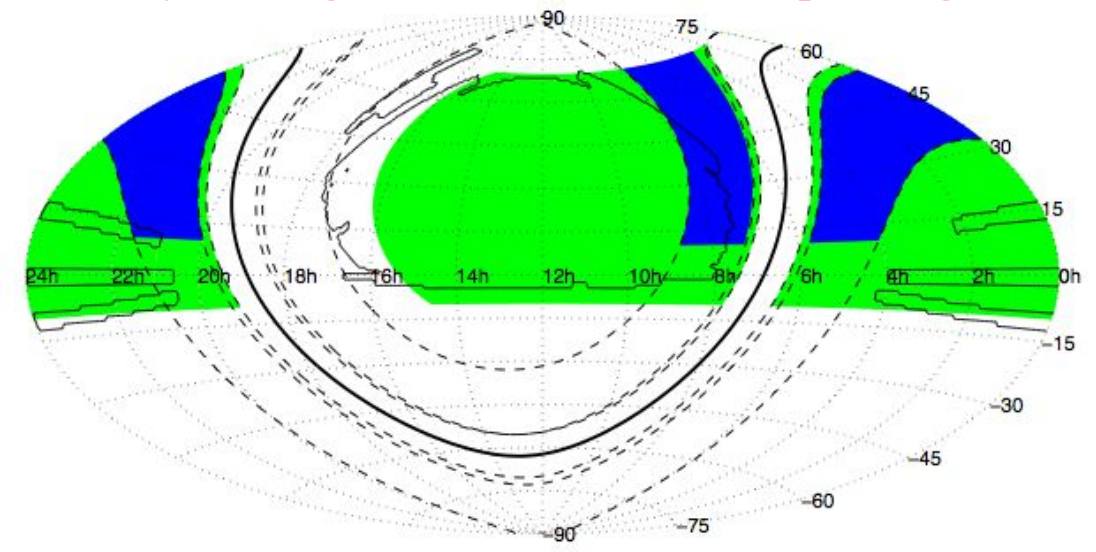




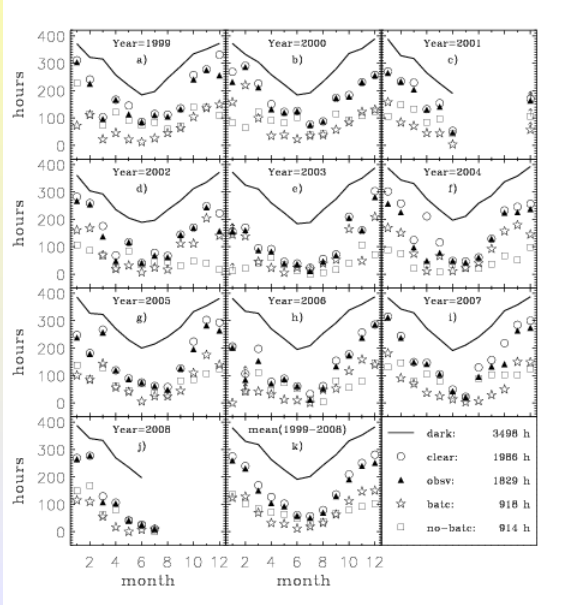
Hf 2-2

LAMOST surveys – site conditions

Not many clear nights for the north Galactic polar region!

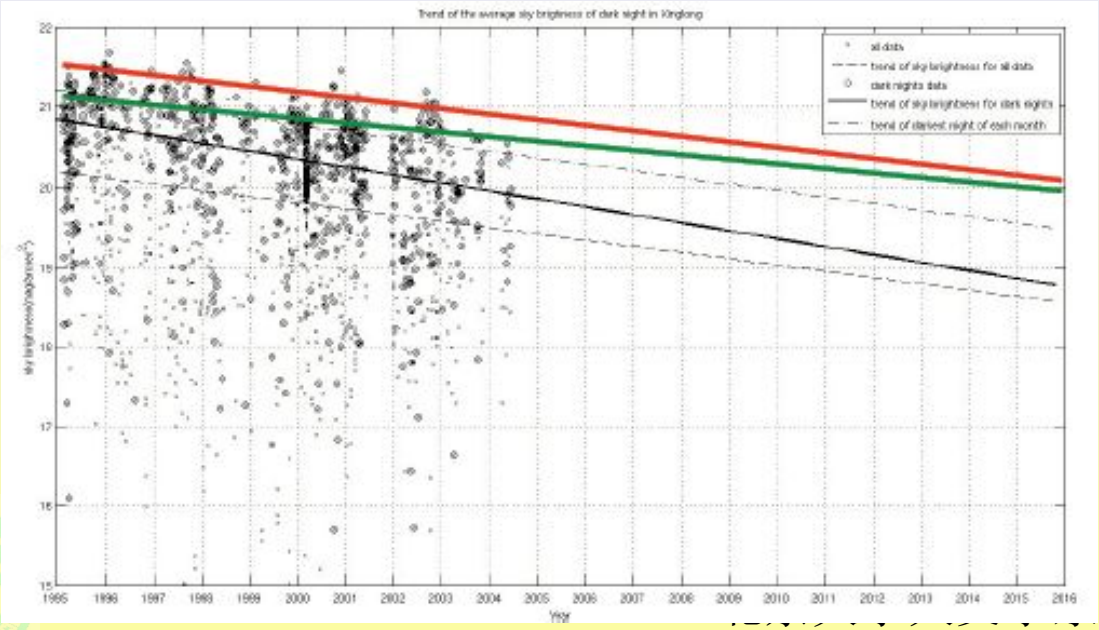


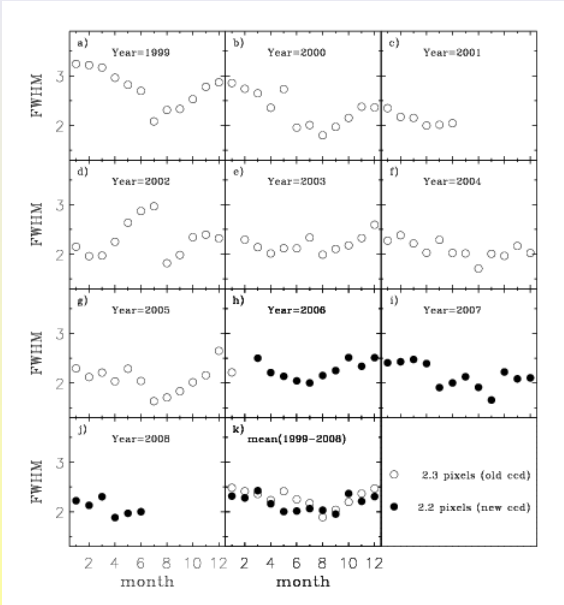
Newberg, Deng et al., 2007, AAS, 211, 1428



Zhang W., et al. 2008, in preparation

Sky background brightens steadly over the years!





The kinematics and elemental abundance distribution of M 31 – a science commissioning program for LAMOST

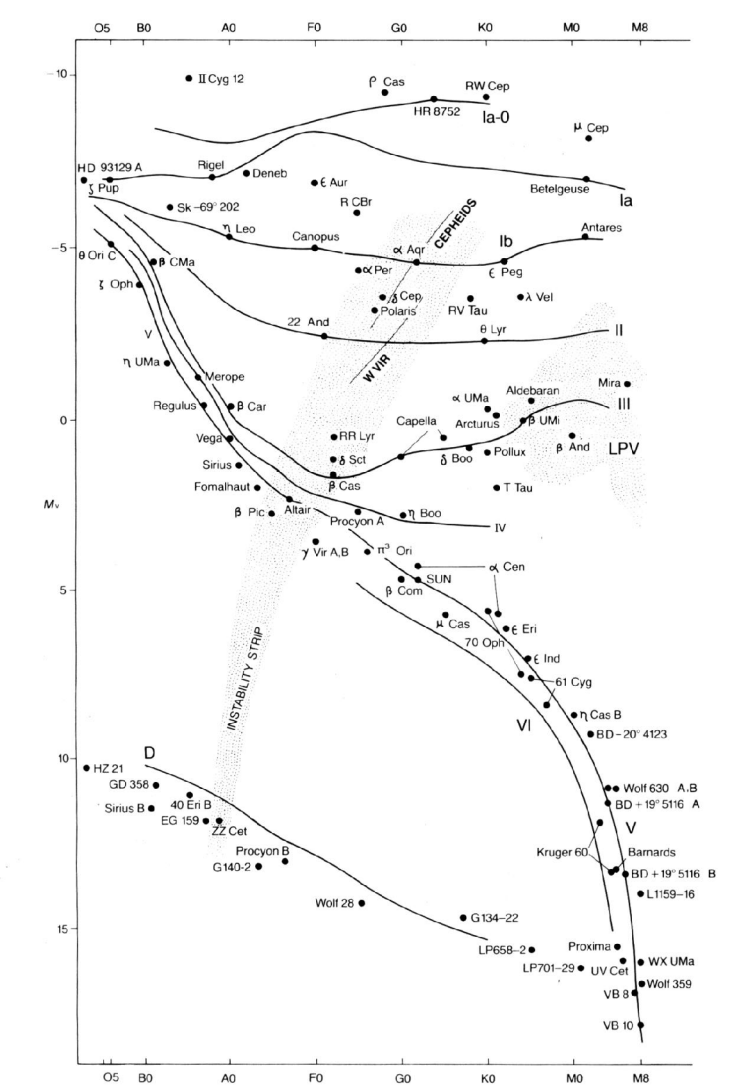
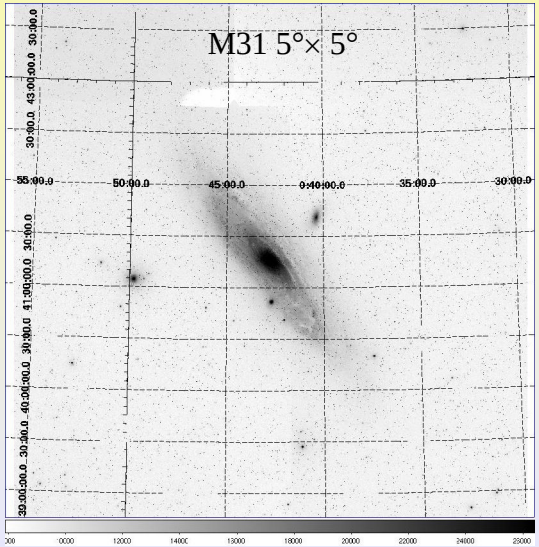
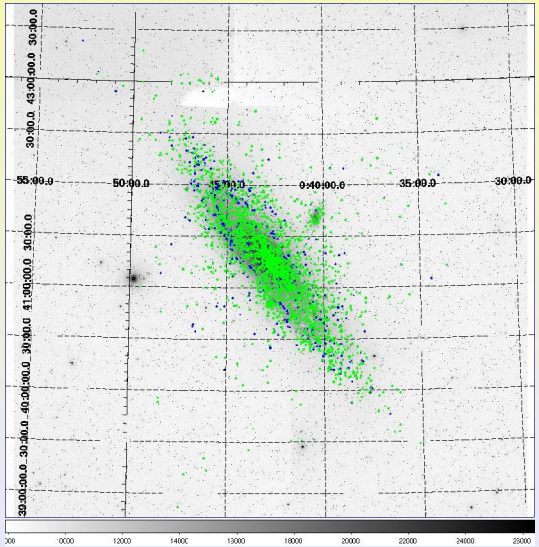
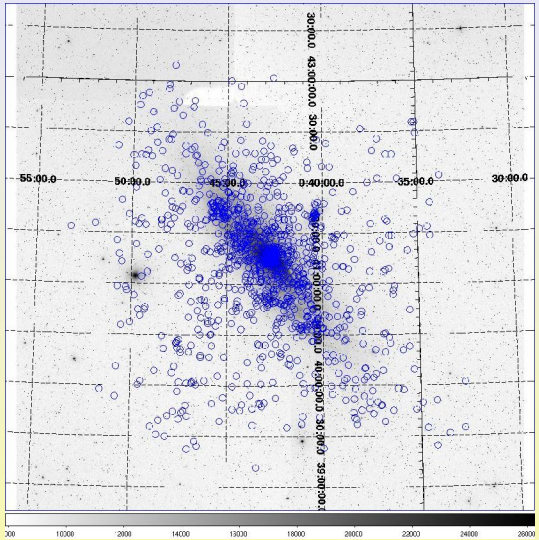


Figure 12.7. The completed HR diagram. Stellar data were taken from *The Bright Star Catalogue*, 4th rev. edn., by D. Hoffleit with the collaboration of C. Jaschek, Yale University Observatory, 1982, and from *Astrophysical Quantities*, 3rd edn., by R. H. Allen, Athlone Press, London, 1973. See Figure 3.8 for further credits.

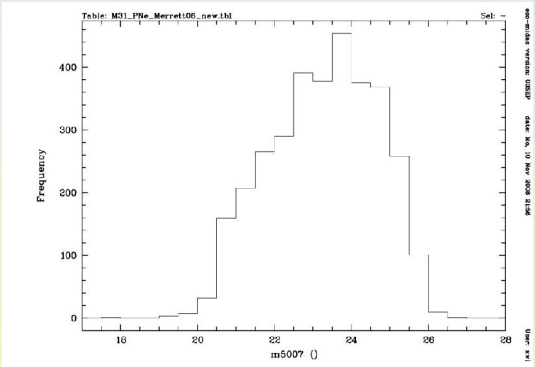




3300 emission line nebulae
(2769 PN candidates)



1700 GC candidates



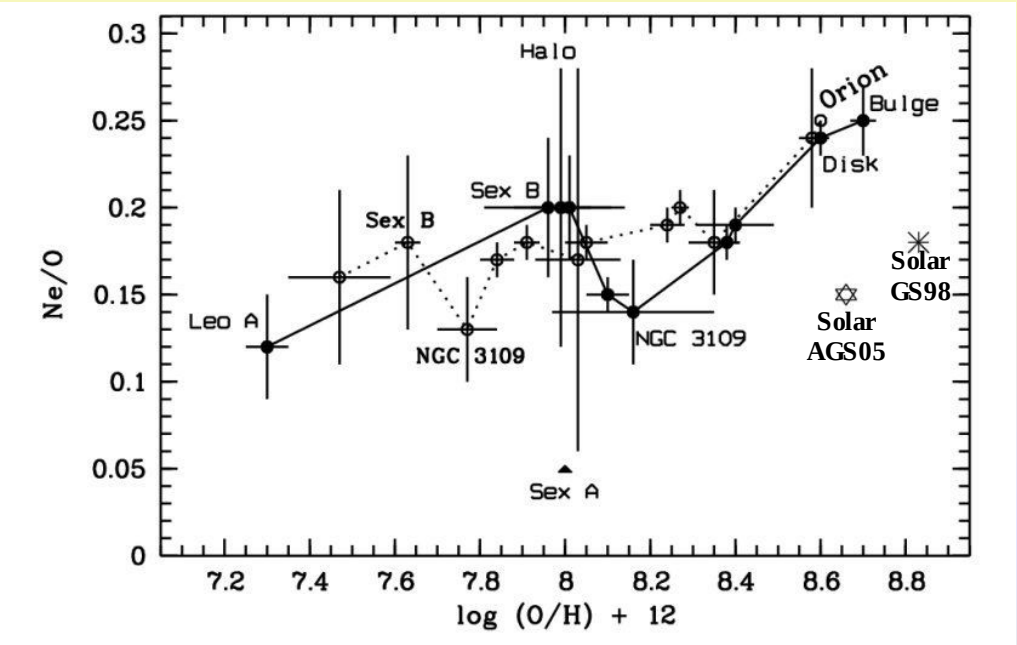
$m_{5007} = -2.5 \log F_{5007} - 13.74$ (in cgs units)

北京大学天文学系
Department of Astronomy, Peking University

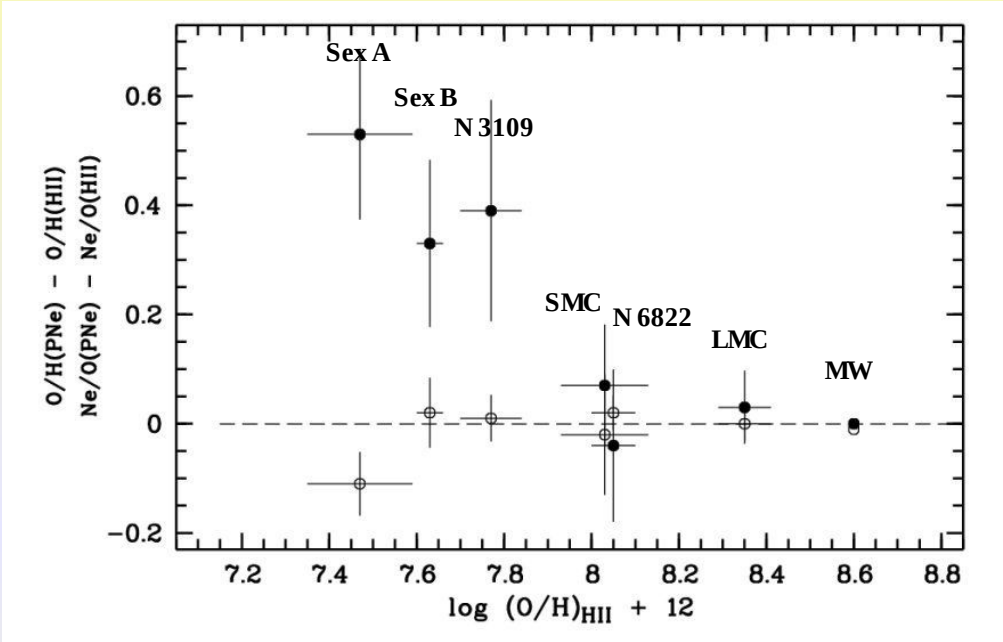
Are oxygen and neon enriched in PNe and is the current solar Ne/O abundance ratio underestimated?

Ne/O versus O/H

● Planetary nebulae
○ H II regions



● O/H(PNe) – O/H(H II)
○ Ne/O(PNe) – Ne/O(H II)



Wang & Liu 2008, MNRAS (Lett.), in press

- Ne/H and Ne/O increase with increasing O/H in both PNe and H II regions
- The enrichment of neon in the ISM lags behind oxygen. The variations of Ne/O versus O/H agree well with the theoretical calculations of Kobayashi et al. (2006)
- Both oxygen and neon are significantly enriched in LIMS at low metallicity but not at metallicity higher than the SMC.
- That Ne/O(PNe) ~ Ne/O(H II), regardless of metallicity, suggests a very similar production mechanism of neon and oxygen in LIMS of low initial metallicity and in more massive stars.
- The solar Ne abundance and Ne/O ratio should be revised upwards by ~ 0.22 dex from the Asplund et al. (2005) values or by ~ 0.14 dex from the Grevesse & Sauval (1998) ones.