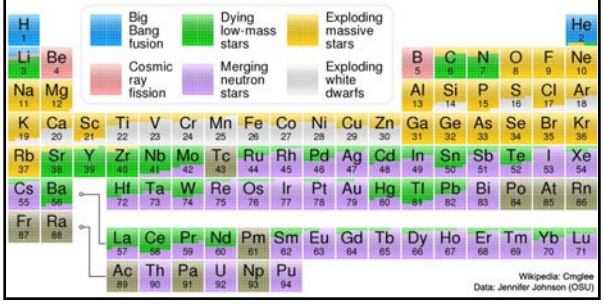
Physics & Spectra of Interstellar Matter

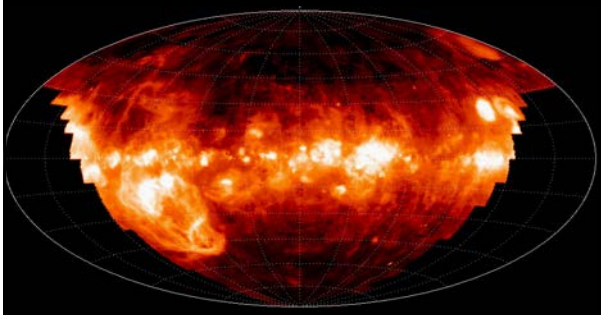
- How to measure this across the Universe?



1

Physics & Spectra of Interstellar Matter

- What is going on out there?



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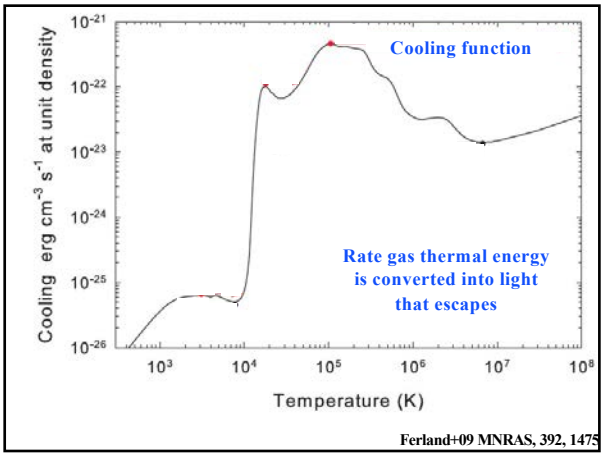

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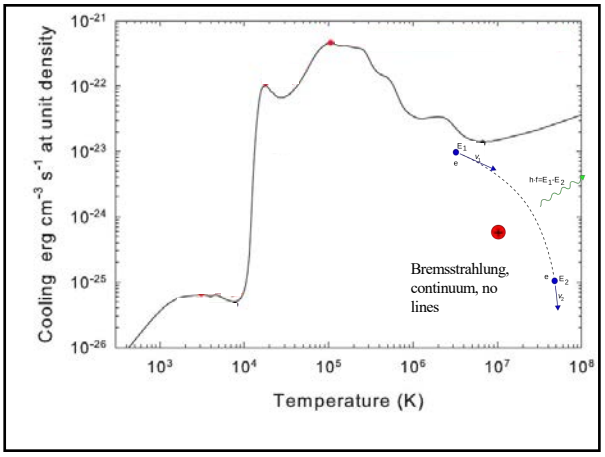

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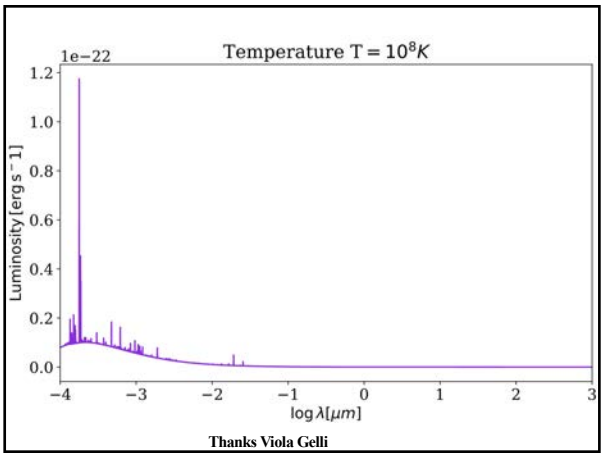
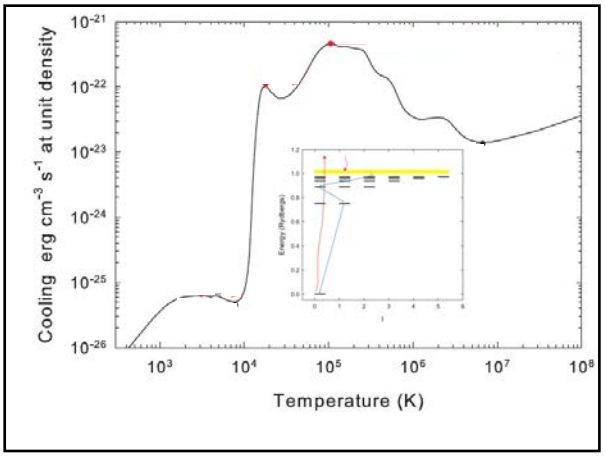


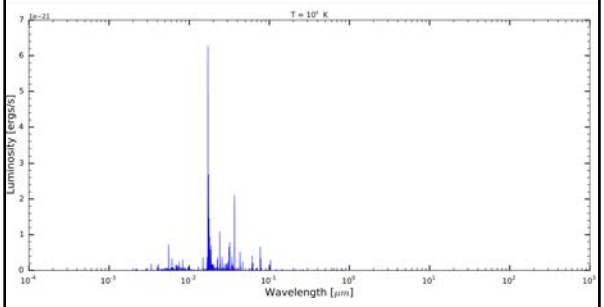
Thanks Viola Gelli

5



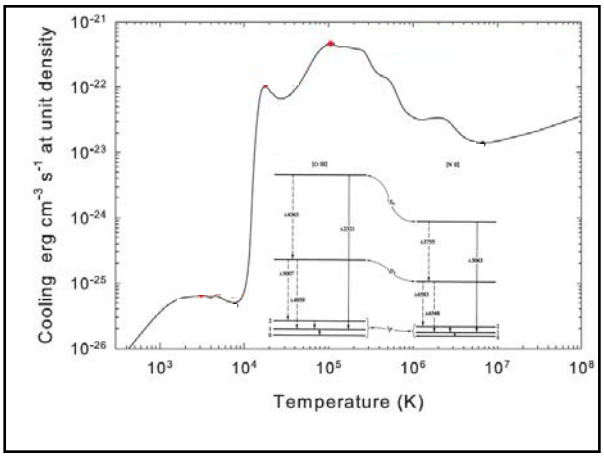
6

$T=10^6$ K



Thanks Susmita Barman

7



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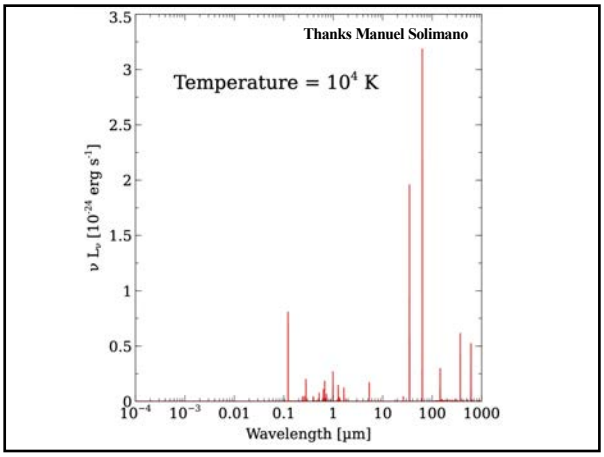

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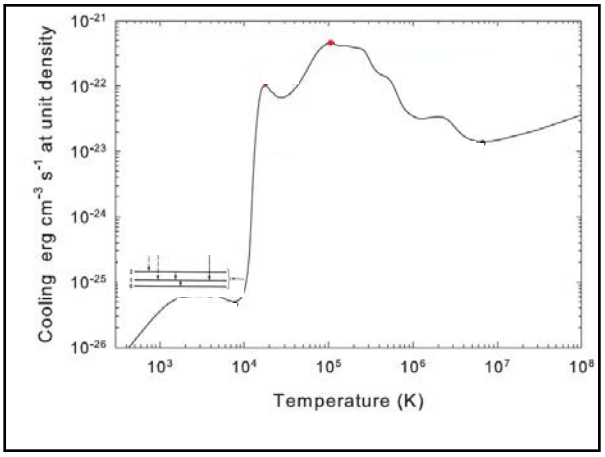

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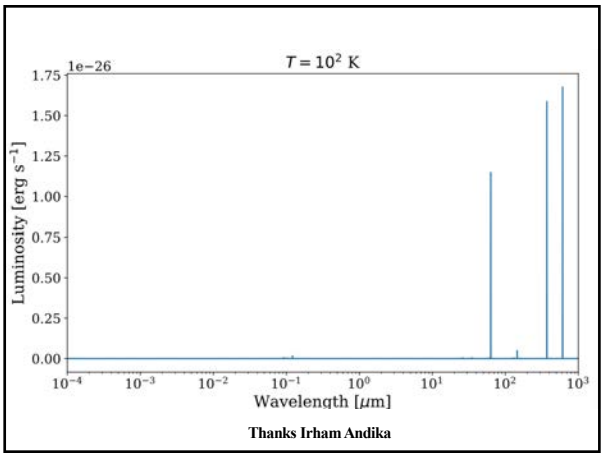
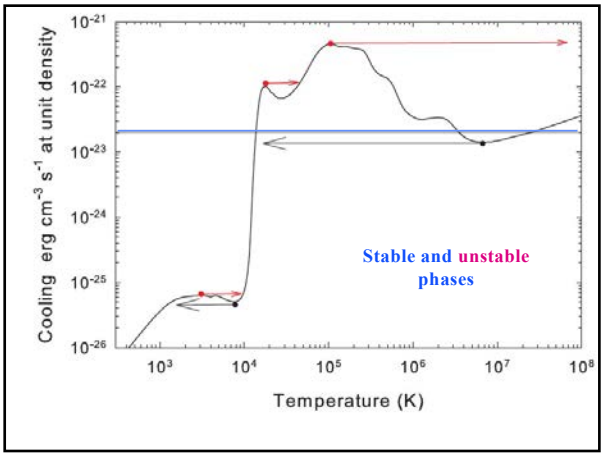


Thanks Irham Andika

11



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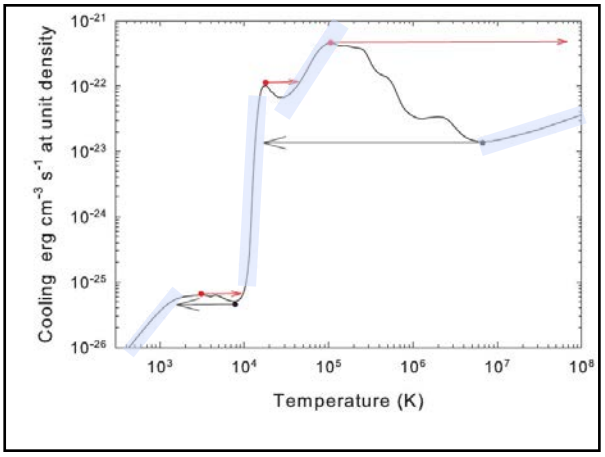
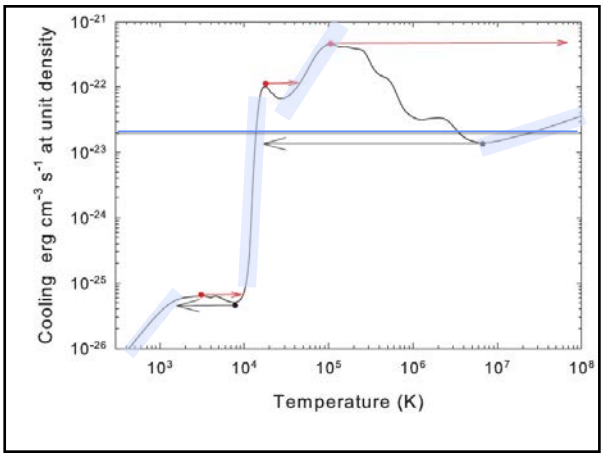
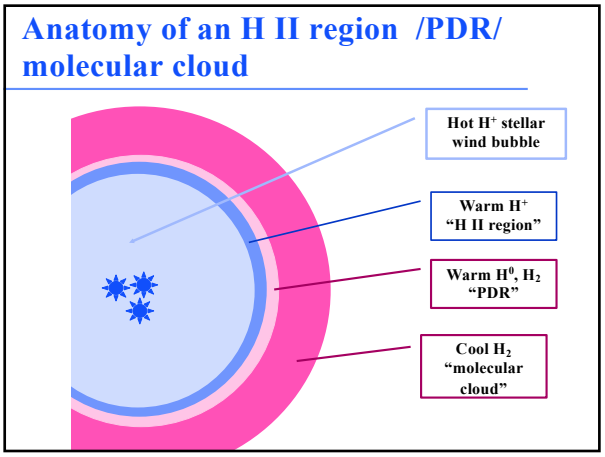

Cooling erg cm^{-3} s^{-1} at unit density
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
Temperature (K)

13


Cooling erg cm^{-3} s^{-1} at unit density
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
Temperature (K)

14


Anatomy of an H II region /PDR/ molecular cloud
Hot H$^+$ stellar wind bubble
Warm H$^+$ "H II region"
Warm H^0, H$_2$ "PDR"
Cool H$_2$ "molecular cloud"

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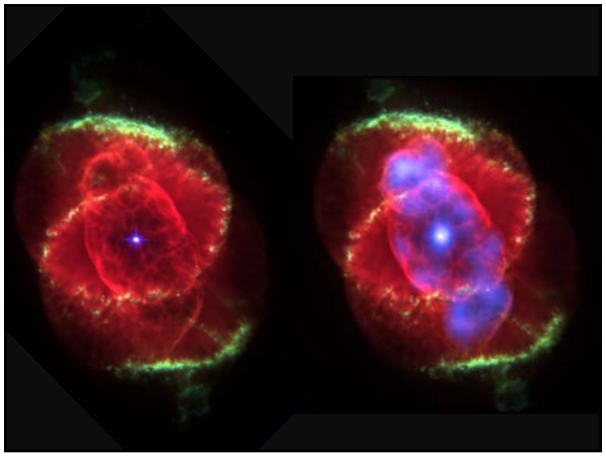

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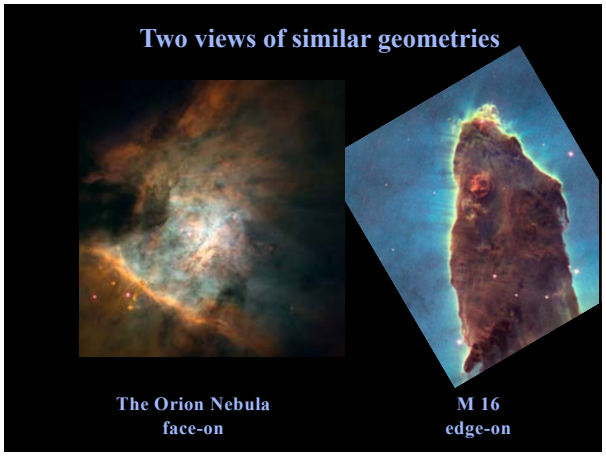
Two views of similar geometries
The Orion Nebula
face-on
M 16
edge-on

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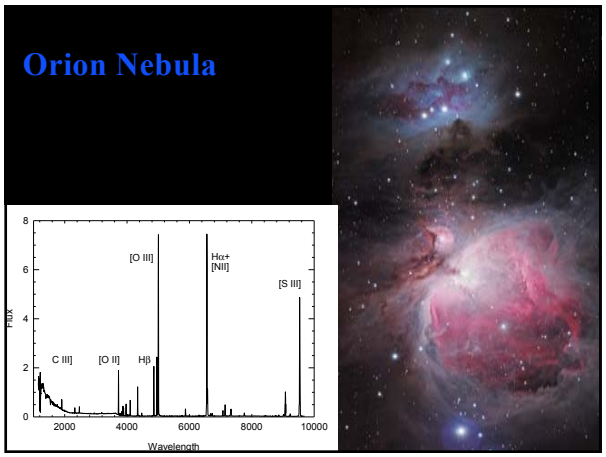
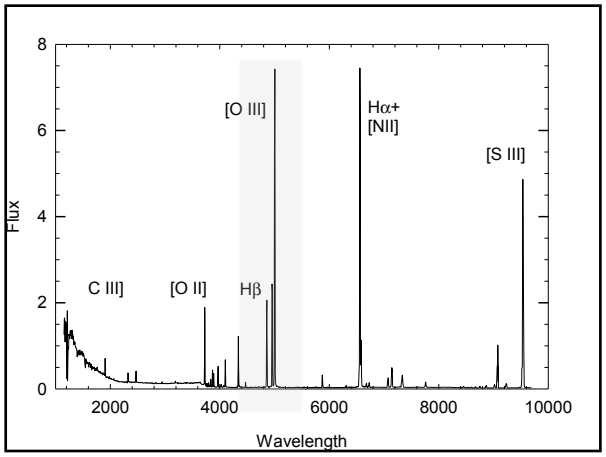
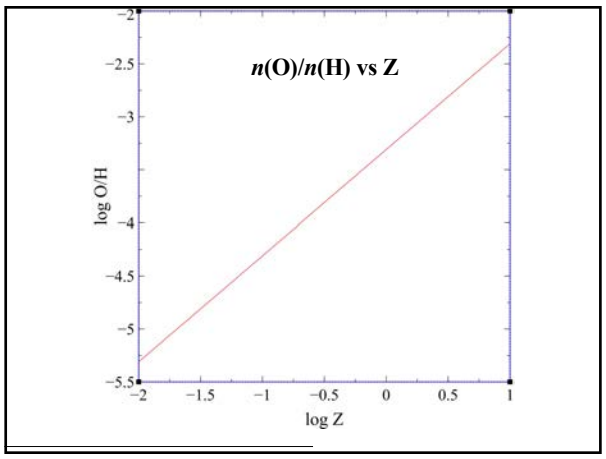

Orion Nebula
[O III]
Hα+
[NII]
[S III]
C III]
[O II]
Hβ
Flux
Wavelength

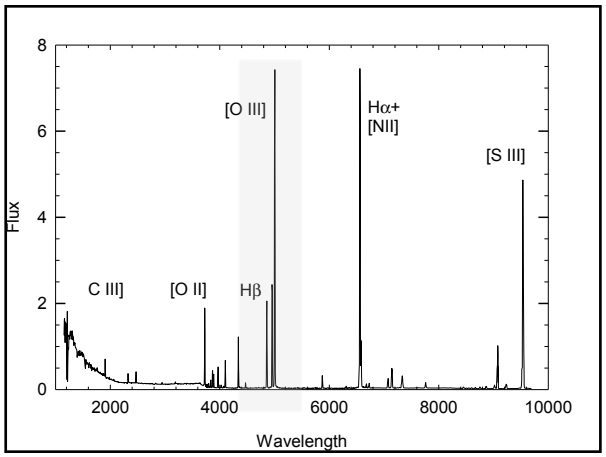
20


[O III]
Hα+
[NII]
[S III]
C III]
[O II]
Hβ
Flux
Wavelength

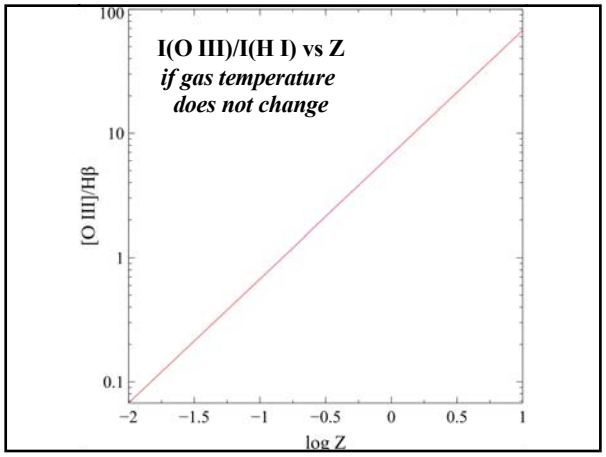
21


n(O)/n(H) vs Z
log O/H
log Z
−2
−2.5
−3
−4
−4.5
−5
−5.5
−2
−1.5
−1
−0.5
0
0.5
1

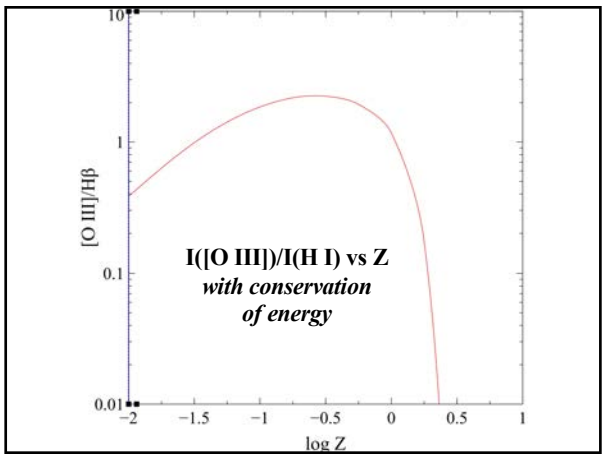
22


Flux
Wavelength
C III]
[O II]
Hβ
[O III]
Hα+
[NII]
[S III]
0
2
4
6
8
2000
4000
6000
8000
10000

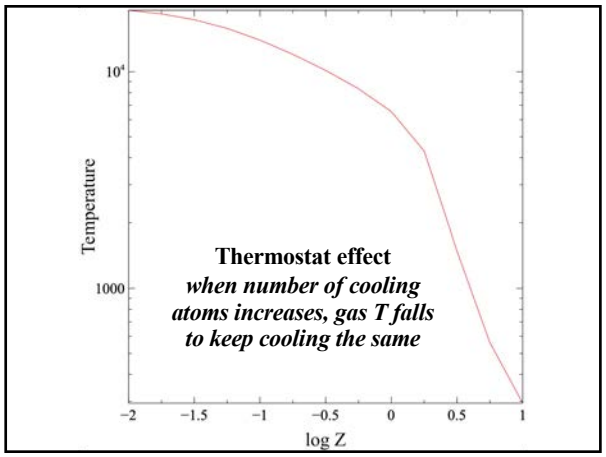
23


I(O III)/I(H I) vs Z
if gas temperature
does not change
[O III]/Hβ
log Z
100
10
1
0.1
−2
−1.5
−1
−0.5
0
0.5
1

24


10
1
0.1
0.01
[O III]/Hβ
I([O III])/I(H I) vs Z
with conservation
of energy
−2
−1.5
−1
−0.5
0
0.5
1
log Z

25


10⁴
1000
Temperature
Thermostat effect
when number of cooling
atoms increases, gas T falls
to keep cooling the same
−2
−1.5
−1
−0.5
0
0.5
1
log Z

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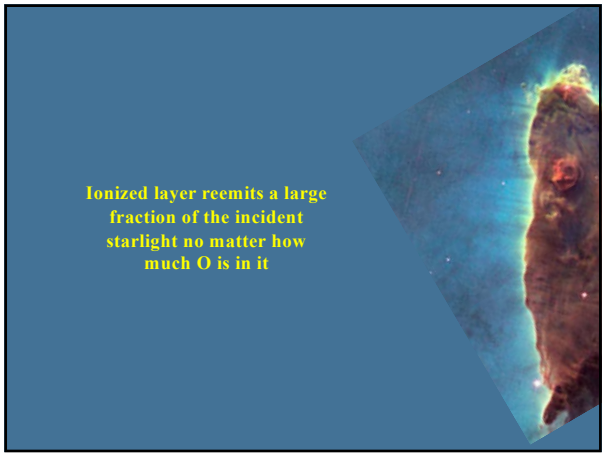
Ionized layer reemits a large
fraction of the incident
starlight no matter how
much O is in it

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Thermostat effect

- Strong optical forbidden lines are the main cooling
- Their intensity is set by the heating (the star) rather than the abundance
- Lower abundances require higher temperature to keep cooling the same
  - Osterbrock & Ferland Sec 9.5
- To know the abundance, you need to know the temperature

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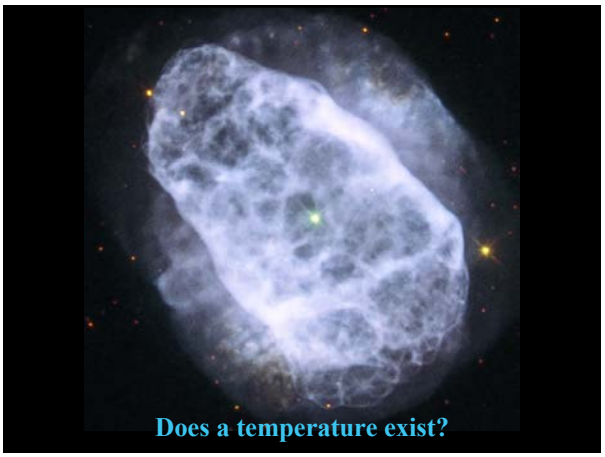

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Does a temperature exist? Pt 1; t^2

- Density inhomogeneities are present, are temperature inhomogeneities (t^2) too?
  - Peimbert 1967ApJ...150..825P (600+ citations!)
- Theoretically, the form of the cooling function makes it difficult for T to change much
- Observationally, a challenging measurement
- The largest unsolved puzzle in nebular astrophysics

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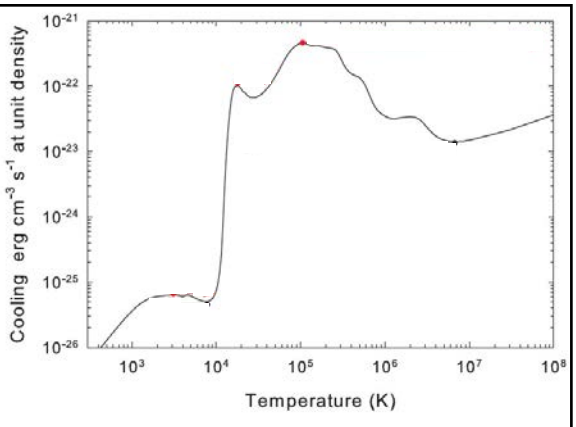

Ferland+09 MNRAS, 392, 1475

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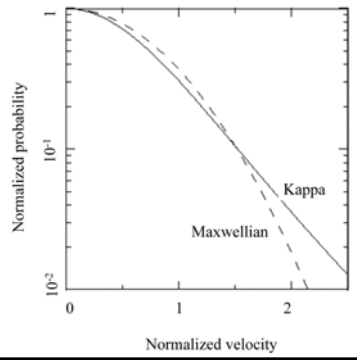
Does a temperature exist? Pt 2; Kappa electron velocity distributions



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Does a temperature exist Pt 2; kappa

- Non-thermal kinetics can occur over *small* regions where gas with very different properties interact
- Foundational work by Bohm & Aller 1947, and numerous Spitzer papers and books (1948-1978), showed electrons are Maxwellian in nebulae, kappa should not occur
- Recent work confirms this
  - Ferland, Heney, O'Dell, & Peimbert 2016RMxAA..52..261F
  - Draine & Kreisch 2018ApJ...862...30D

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