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Direct Observations of Fast Inflow Directly Feeding Quasar Accretion Disks

by $H I^*$ & $He I^*$

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Outline

1. what/why black holes?
2. why massive black hole inflow?
3. how to track accretion flows?
 - a: **HI*** & **HeI*** absorption lines
4. a case study (J1035+1422): disk-feeding-inflow
5. **analogues**: head and end of disk-feeding-inflow
6. what next (jet vs. outflow)?

GRAVITATIONAL COLLAPSE AND SPACE-TIME SINGULARITIES

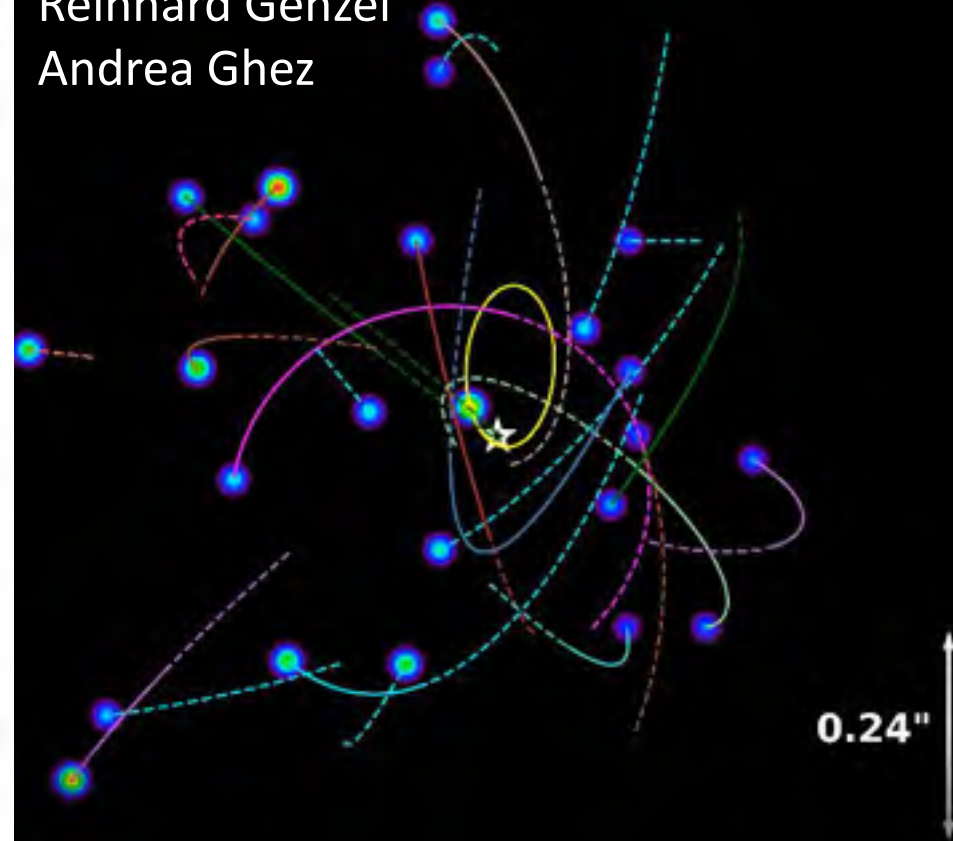
Roger Penrose

Department of Mathematics, Birkbeck College, London, England

(Received 18 December 1964)

The discovery of the quasistellar radio sources has stimulated renewed interest in the question of gravitational collapse. It has been suggested by some authors¹ that the enormous amounts of energy that these objects apparently emit may result from the collapse of a mass of the order of $(10^6-10^8)M_{\odot}$ to the neighborhood of its Schwarzschild radius, accompanied by a violent release of energy, possibly in the form of gravitational radiation. The detailed mathematical discussion of such situations is difficult since the full complexity of general relativity is required. Consequently, most exact calculations concerned with the implications of gravitational collapse have employed the simplifying assumption of spherical symmetry. Unfortunately, this precludes any detailed discussion of gravitational radiation - which requires at least a quadrupole structure.

Reinhard Genzel
Andrea Ghez



1. what/why black holes?

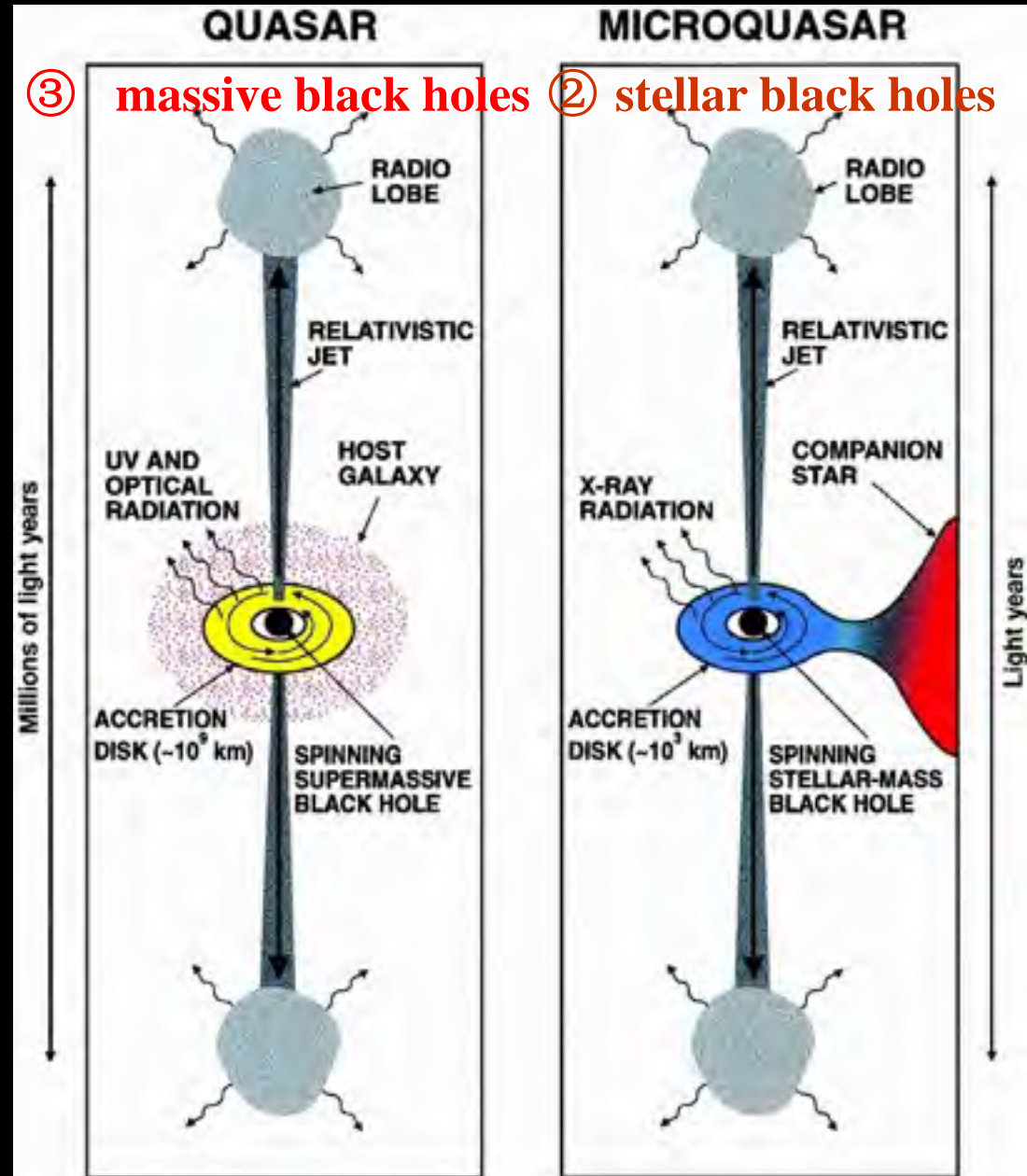
(1) primeval; (2) stellar, (3) (super-)massive black holes

1. What are black holes?

- 尸佼：“四方上下曰宇，往古来曰宙”
- Einstein: geometrodynamics
physical para. & law

- events: “points” in space-time
- Riemannian geometry
- Einstein’s Eq.
- Hawking-Penrose’s singularity theorems:
- black holes and the big bang

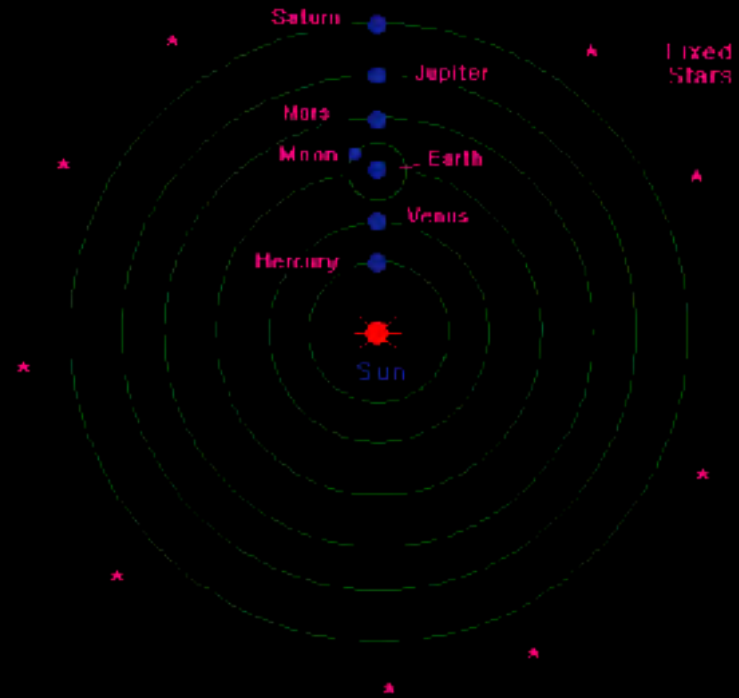
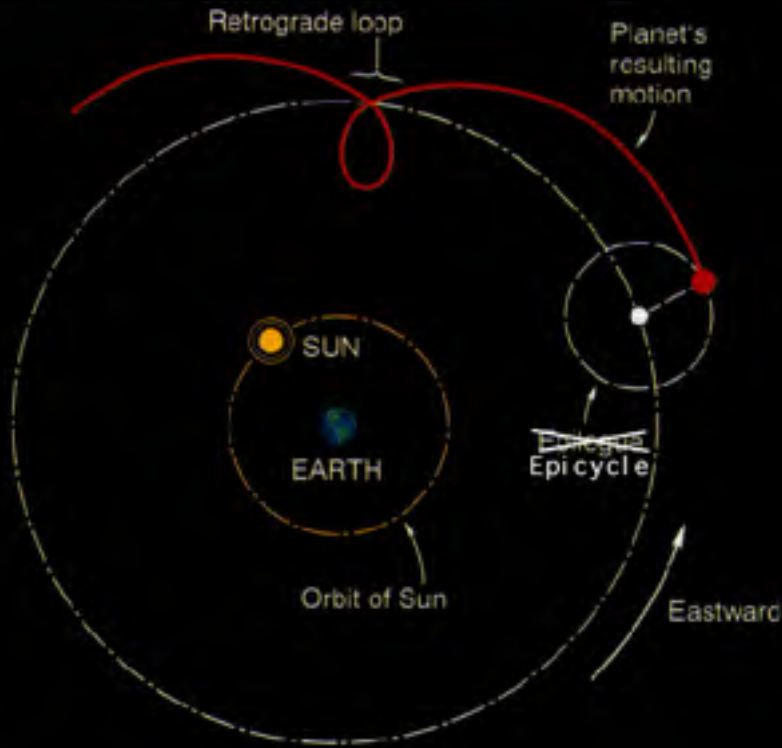
① primeval black holes?



1. What are black holes?

prehistoric astronomy: “天似穹庐，笼盖四野”

astronomical models of the “universe”



Pythagoras (582 - 500 BC)

Plato (428 - 347 BC)

Aristotle (384 - 322 BC):

“physics”

Hipparchus (190 - 120 BC); Copernicus (1473-1543)

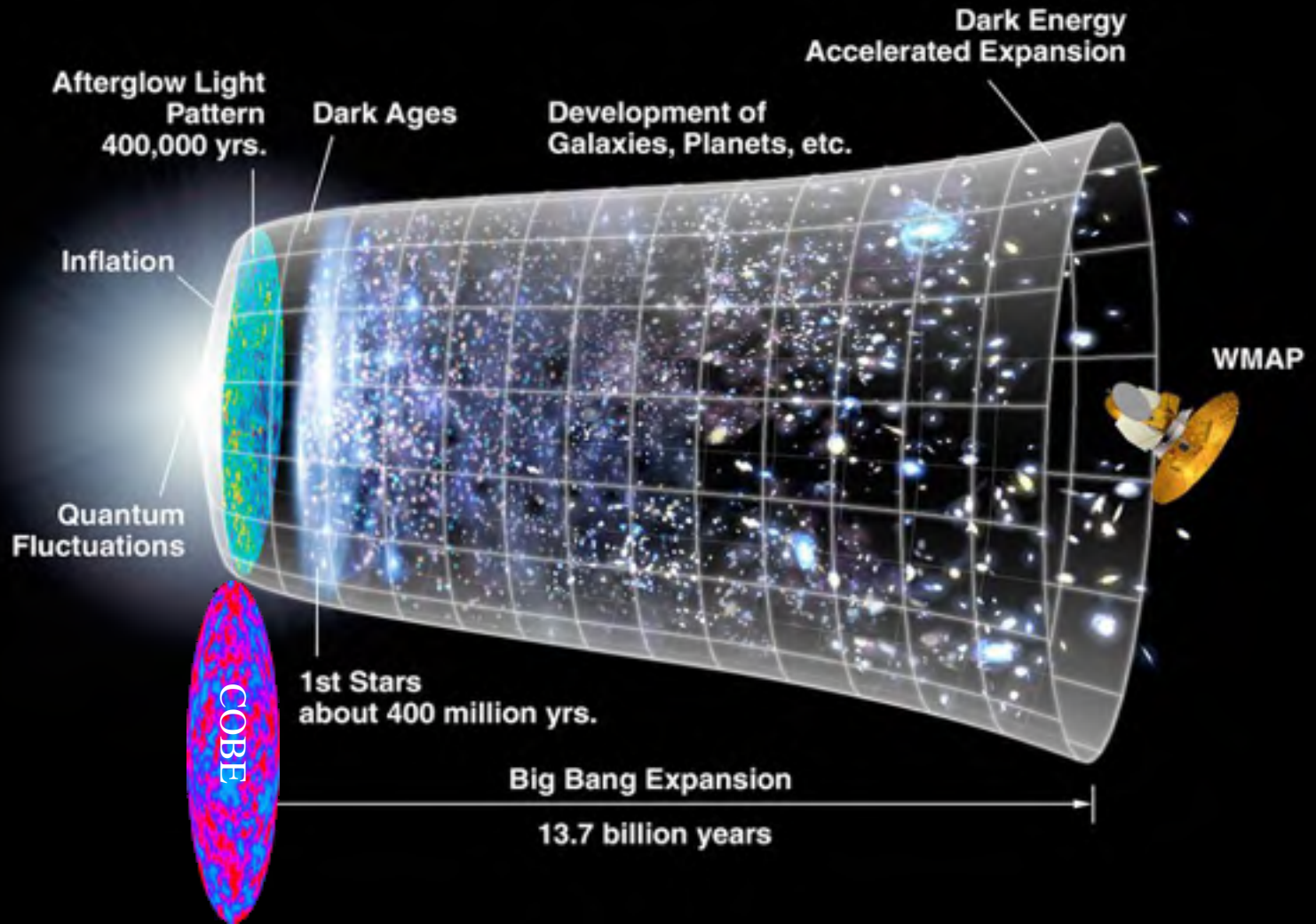
Tycho (1546-1601), Kepler (1571-1630)

Newton (1642-1727):

“Philosophiae Naturalis Principia Mathematica”

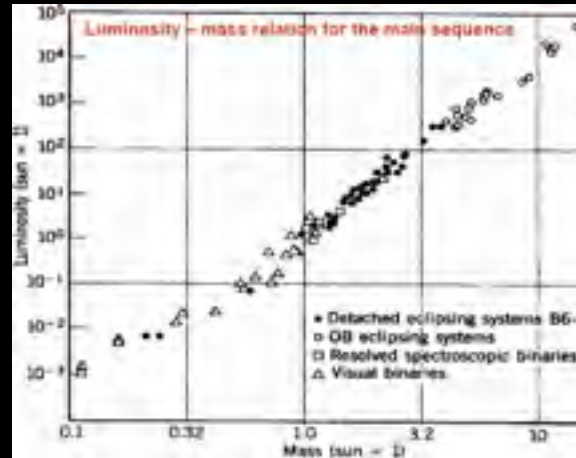
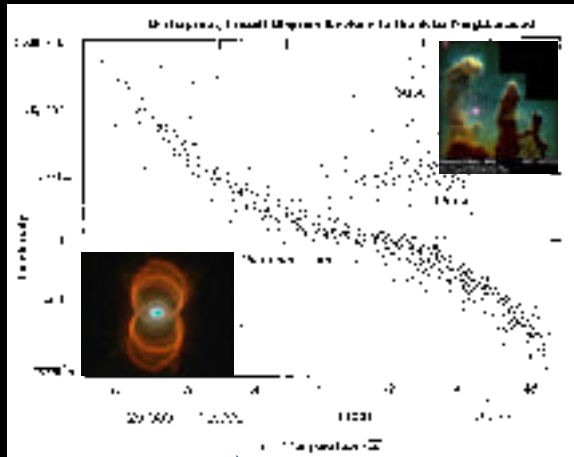
Euclid (330 – 275 BC): “elements of geometry”: the 1st physics theory (R. Penrose)

cosmology today: “physics of astrophysics”



stars → galaxies ← universe; 2. Why BH inflows?

stellar **structure**: simple observational facts →
HR diagram → **Vogt-Rusell conjecture**



$$\begin{cases} p = p(\rho, T, Z), \\ \kappa = \kappa(\rho, T, Z), \\ \epsilon = \epsilon(\rho, T, Z); \end{cases}$$

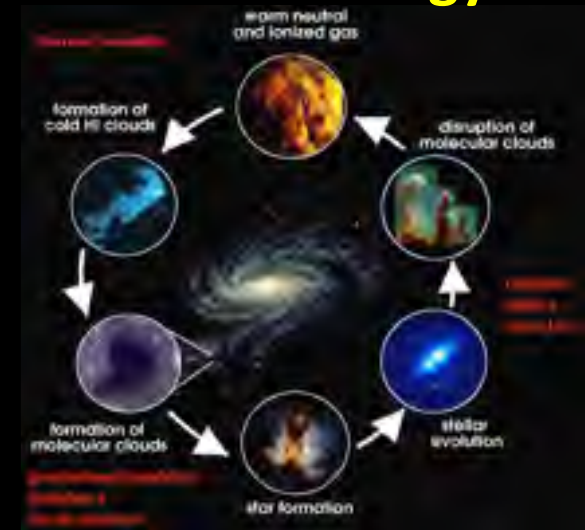
$$\begin{cases} \frac{dp(r)}{dr} = -\frac{GM(r)\rho(r)}{r^2}, \\ \frac{dM(r)}{dr} = 4\pi r^2 \rho(r), \\ \frac{dT(r)}{dr} = -\frac{3L(r)\kappa(r)\rho(r)}{4\pi r^2 \cdot 4acT^3(r)}, \\ \frac{dL(r)}{dr} = 4\pi r^2 \rho(r)\epsilon(r). \end{cases}$$

galaxies ← **stellar evolution** ← **cosmic ecology**

nonlinear regime ← linear regime
 big bang cosmology ← geometric cosmology

$$\leftarrow \text{Einstein: } R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

**Almost all galaxies have experienced/
 are going through AGN episodes !**



1. Anatomy of the AGN in NGC 5548

I. A global model for the broadband spectral energy distribution (Mehdipour, M. et al. 2015)

2. Anatomy of the AGN in NGC 5548. II. The spatial, temporal, and physical nature of the outflow from HST/COS Observations (Arav, N. et al. 2015)

3. Anatomy of the AGN in NGC 5548. III. The high-energy view with NuSTAR and INTEGRAL (Ursini, F. et al. 2015)

4. Anatomy of the AGN in NGC 5548. IV. The short-term variability of the outflows (Di Gesu, L. et al. 2015)

5. Anatomy of the AGN in NGC 5548. V. A clear view of the X-ray narrow emission lines (Whewell, M. et al. 2015)

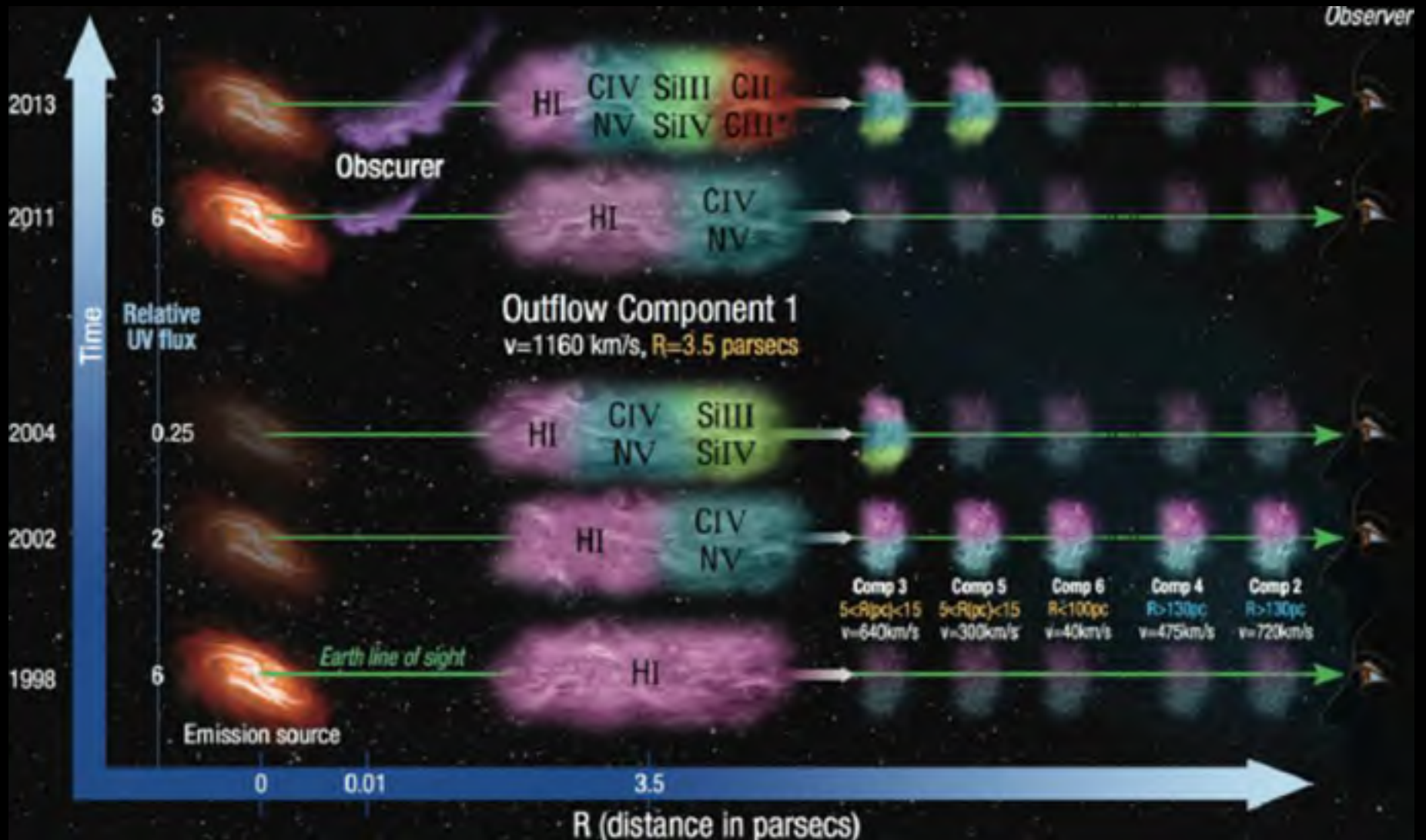
6. Anatomy of the AGN in NGC 5548. VI. Long-term variability of the warm absorber (Ebrero, J. et al. 2016)

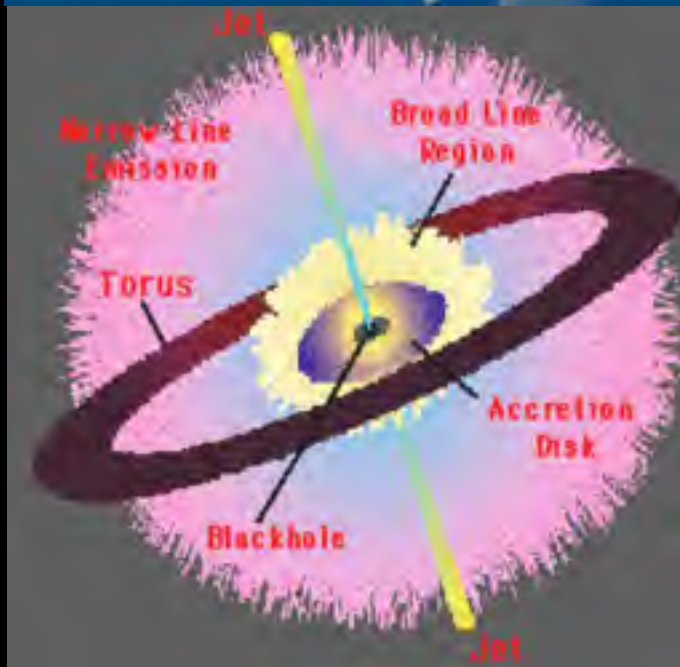
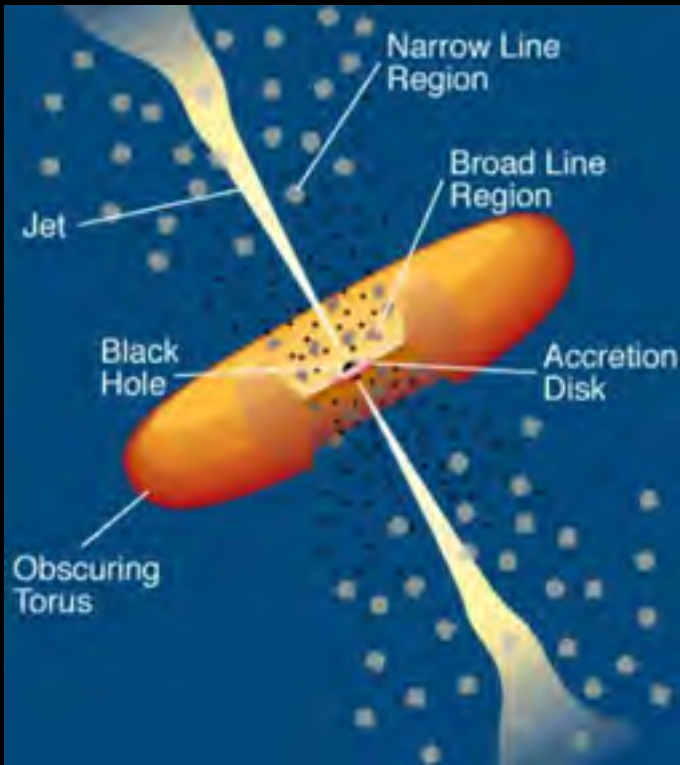
7. Anatomy of the AGN in NGC 5548. VII. Swift study of obscuration and broadband continuum variability (Mehdipour, M. et al. 2016)

8. Anatomy of the AGN in NGC 5548. VIII. XMM-Newton's EPIC detailed view of an unexpected variable multilayer absorber (Cappi, M. et al. 2015)

9. Anatomy of the AGN in NGC 5548.

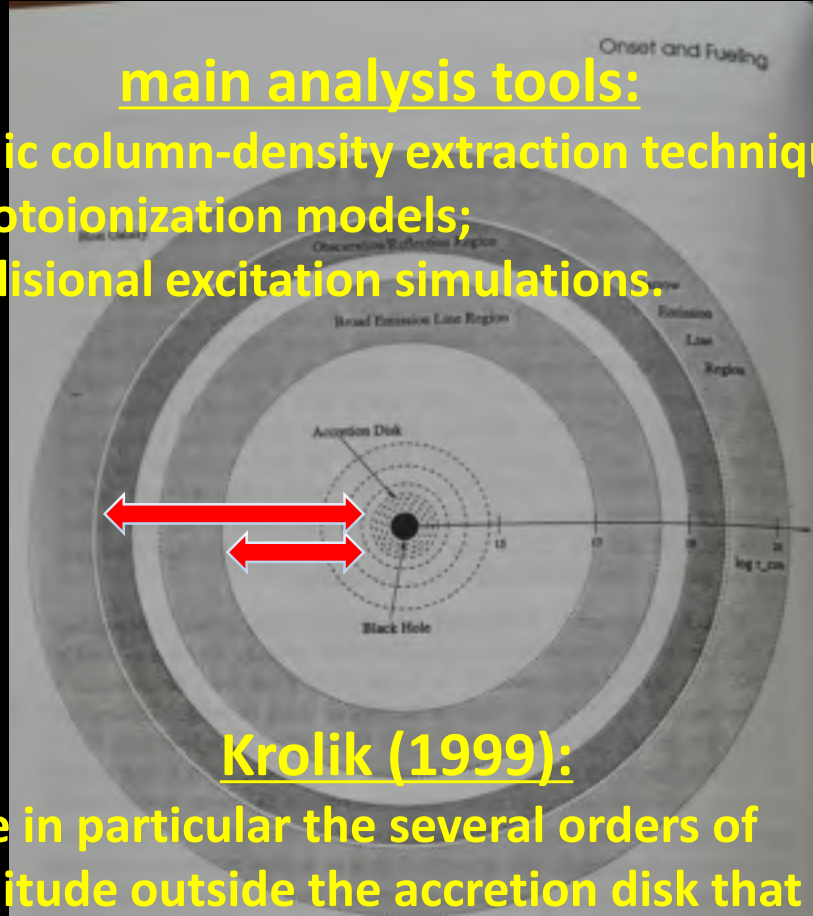
IX. Photoionized emission features in the soft X-ray spectra (Mao, Junjie et al. 2018)





main analysis tools:

- ionic column-density extraction techniques;
- photoionization models;
- collisional excitation simulations.



Krolik (1999):

“Note in particular the several orders of magnitude outside the accretion disk that are unlabeled. Because we have yet to identify any photons as coming from this range of radii, there is very little we can say about it.”

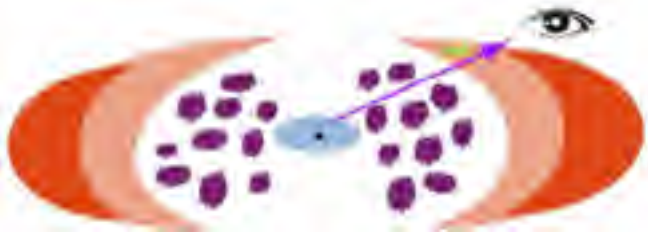
Fig. 14.1 The “onion-skin” model of AGNs. The distances are scaled logarithmically, not linearly, but should not in any event be taken as more than indicative. Many are rough estimates, and almost all scale with the luminosity of the AGN. Note in particular the several orders of magnitude outside the accretion disk that are unlabeled. Because we have yet to identify any photons as coming from this range of radii, there is very little we can say about it.

accretion flows in quasars

- ISM inflows → galactic nuclear region (headstream✓)
- disk feeding inflows (DFI?)
- disk inflows (end✓)



3. how to track black hole accretion flows?

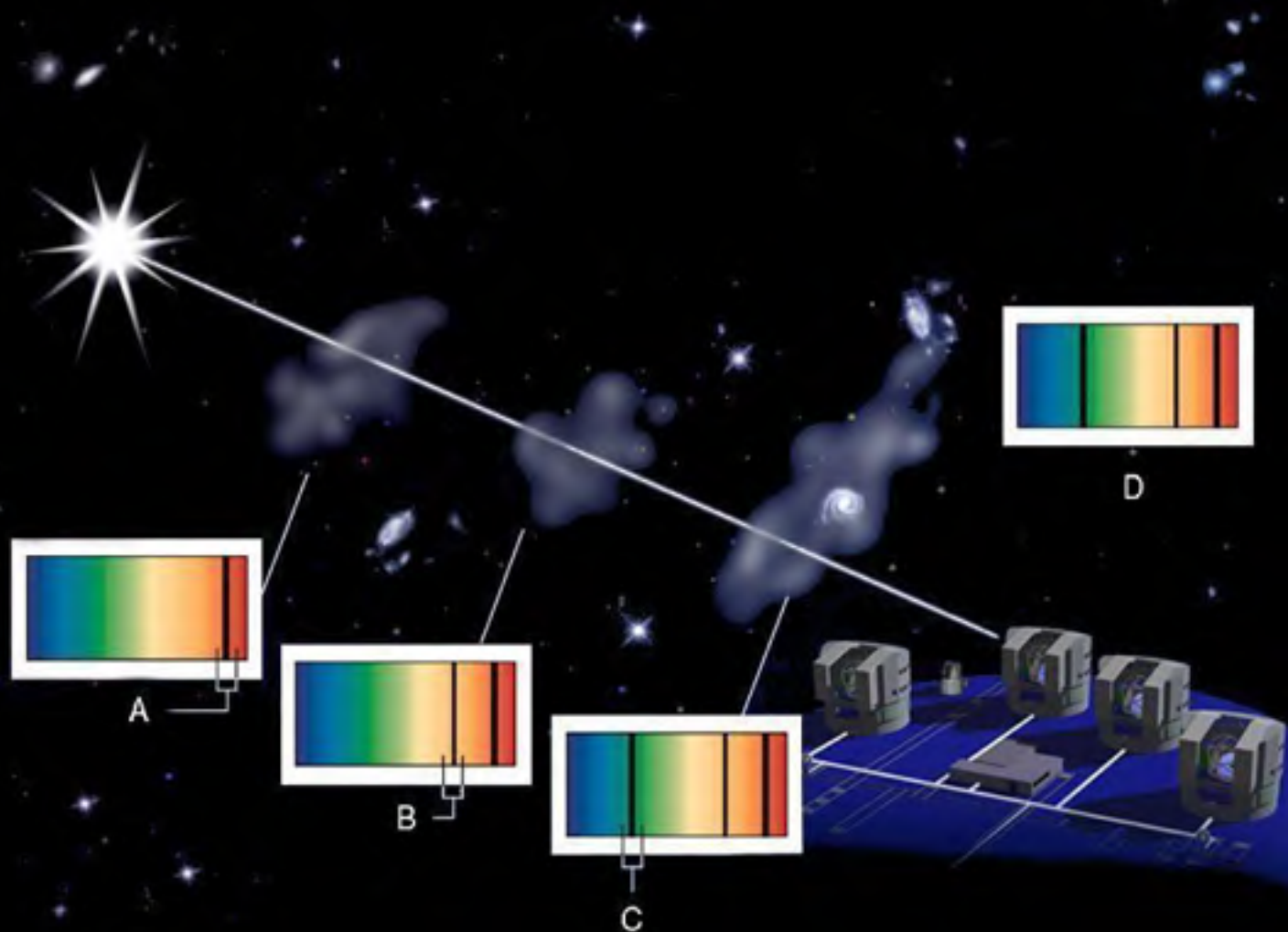


- (1). **EM** or other(s)?
- (2). **lines** or continuum?
- (3). **absorption** or emission lines?

Bulian donkey effect ?



(3). **absorption** or emission lines?



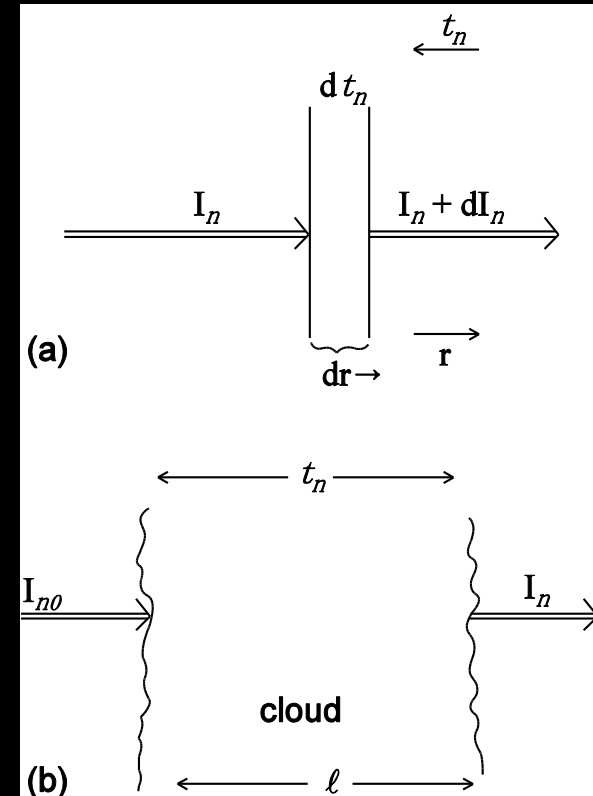
Radiative Transfer and Absorption Lines

Consider an incoming signal of a specific intensity, $I(\nu)$, passing through a gaseous slab, the intensity equals to photons gained and photons removed:

$$dI = dI_{loss} + dI_{gain} \equiv -\alpha I dl + j dl.$$

Define the absorption coefficient $\alpha \equiv \frac{d\tau}{dl}$, and consider only absorption, we have $dI = -I d\tau$.

Here τ is **optical depth**, which means the fraction of photons lost when the light passes a distance l . Solving the radiative transfer equation, $dI = -I d\tau$, we obtain $\int_{I_0}^I \frac{dI}{I} = \int_0^\tau d\tau$, i.e., $I = I_0 e^{-\tau}$. For a homogeneous medium, $\tau \propto l \propto N_H$, where N_H is the slab “thickness” parameterized as the total hydrogen ($H \equiv HI + HII$) column density. $I \propto F$, for parallel light.



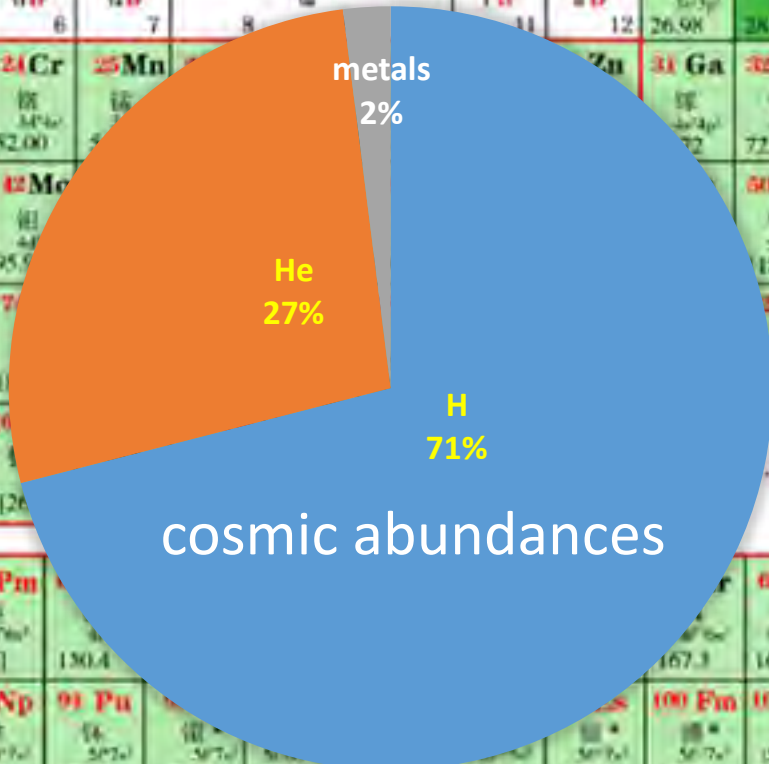
Assuming that the absorber is unsaturated and covers 100% of the emission region, we may calculate the column density of any ions by integration across the absorption-line profile (Savage & Sembach 1991):

$$N_X = \frac{m_e c}{\pi e^2 f_{ik} \lambda_0} \int \tau(\nu) d\nu = \frac{3.77 \times 10^{14} \text{ cm}^{-2}}{\lambda_0 f_{ik}} \int \tau(\nu) d\nu.$$

(4). H/He or metal absorption lines?

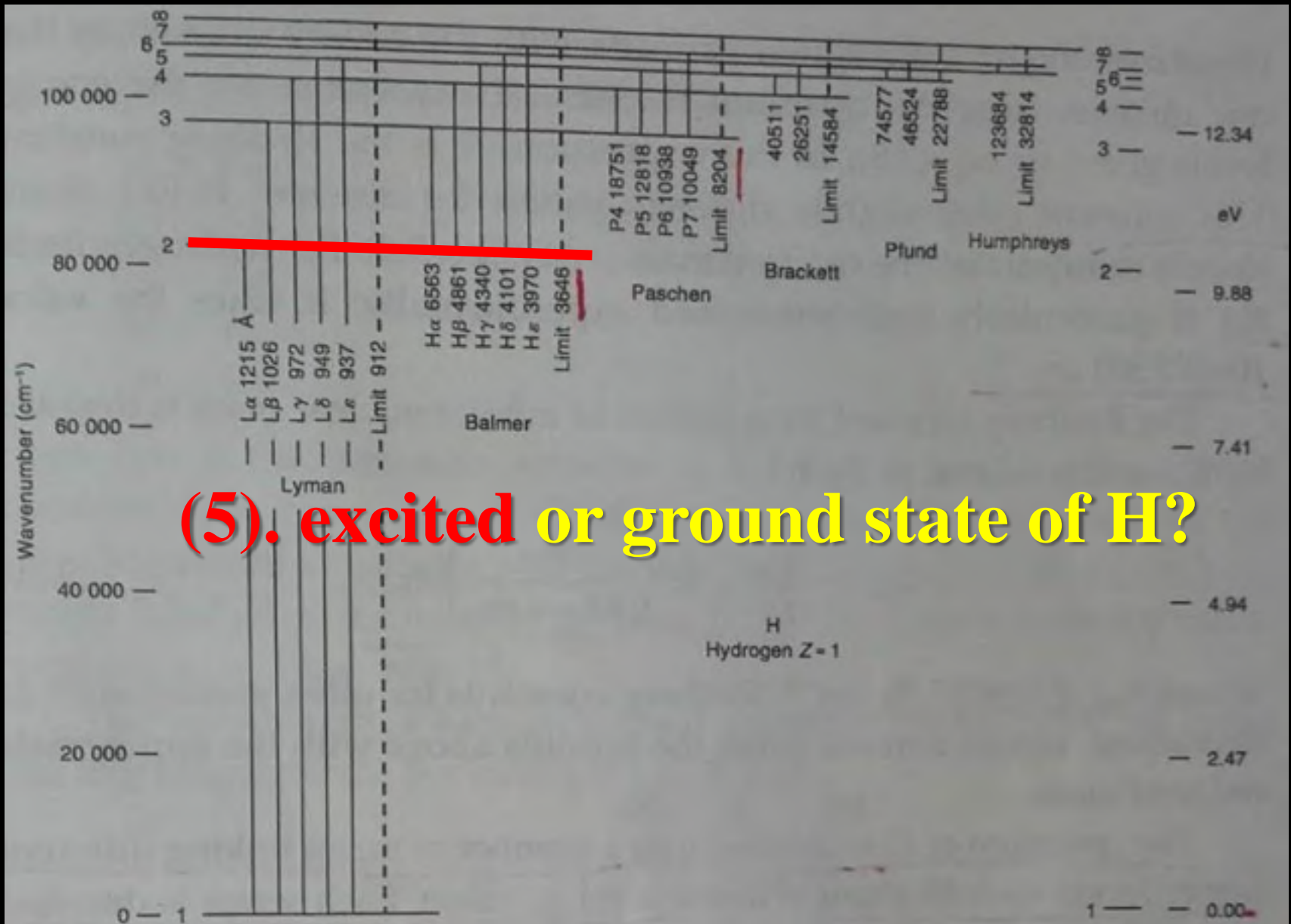
元素周期表

1	1A 1 H 1.008	2A	<p>原子序数 元素符号、颜色 放射性元素</p> <p>元素名称 拉丁文 人造元素</p> <p>外部电子层排布、族号 可能的电子层排布 相对原子质量 (加括号的数据为放射性元素半衰期最长时间求的近似数)</p> <p>非金属 金属</p> <p>过渡元素</p>										0 2 He 4.003	电子层 K	原子数 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
2	3A 3 Li 6.941	4A 4 Be 9.012	5A	6A	7A	8A	9A	10A	11A	12A	13A 13 B 10.81	14A 14 C 12.01	15A 15 N 14.01	16A 16 O 16.00	17A 17 F 19.00	18A 18 Ne 20.18	L K	3 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
3	11A 11 Na 22.99	12A 12 Mg 24.31	3B	4B	5B	6B	7B	8	9	10	11B 11 B 10.81	12B 12 Si 28.09	13B 13 P 30.97	14B 14 S 32.06	15B 15 Cl 35.45	16B 16 Ar 39.95	M L K	3 8 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
4	19A 19 K 39.10	20A 20 Ca 40.08	21A 21 Sc 44.96	22A 22 Ti 47.87	23A 23 V 50.94	24A 24 Cr 52.00	25A 25 Mn 54.94	26A	27A	28A	29A 29 Cu 63.55	30A 30 Zn 65.38	31A 31 Ga 69.72	32A 32 Ge 72.64	33A 33 As 74.92	34A 34 Se 78.96	35A 35 Br 79.90	36A 36 Kr 83.80	N M L K	4 8 8 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
5	37A 37 Rb 85.47	38A 38 Sr 87.62	39A	40A 40 Zr 91.22	41A 41 Nb 92.91	42A 42 Mo 95.94	43A	44A	45A	46A	47A	48A	49A	50A 50 Sn 118.7	51A 51 Sb 121.8	52A 52 Te 127.6	53A 53 I 126.9	54A 54 Xe 131.3	O N M L K	5 18 18 8 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
6	55A 55 Cs 132.9	56A 56 Ba 137.3	57-71 La-Lu 镧系	72A 72 Hf 178.5	73A 73 Ta 180.9	74A	75A	76A	77A	78A	79A	80A	81A	82A 82 Pb 207.2	83A 83 Bi 209.0	84A 84 Po [209]	85A 85 At [210]	86A 86 Rn [222]	P O N M L K	6 18 32 18 8 2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
7	87A 87 Fr [223]	88A 88 Ra [226]	89-103 Ac-Lr 锕系	104A 104 Rf [261]	105A 105 Db [262]	106A	107A	108A	109A	110A	111A	112A	113A	114A	115A	116A	117A	118A	119A	120A	121A	122A	123A	124A	125A	126A	127A	128A	129A	130A	131A	132A	133A	134A	135A	136A	137A	138A	139A	140A	141A	142A	143A	144A	145A	146A	147A	148A	149A	150A	151A	152A	153A	154A	155A	156A	157A	158A	159A	160A	161A	162A	163A	164A	165A	166A	167A	168A	169A	170A	171A	172A	173A	174A	175A	176A	177A	178A	179A	180A	181A	182A	183A	184A	185A	186A	187A	188A	189A	190A	191A	192A	193A	194A	195A	196A	197A	198A	199A	200A	201A	202A	203A	204A	205A	206A	207A	208A	209A	210A	211A	212A	213A	214A	215A	216A	217A	218A	219A	220A	221A	222A	223A	224A	225A	226A	227A	228A	229A	230A	231A	232A	233A	234A	235A	236A	237A	238A	239A	240A	241A	242A	243A	244A	245A	246A	247A	248A	249A	250A	251A	252A	253A	254A	255A	256A	257A	258A	259A	260A	261A	262A	263A	264A	265A	266A	267A	268A	269A	270A	271A	272A	273A	274A	275A	276A	277A	278A	279A	280A	281A	282A	283A	284A	285A	286A	287A	288A	289A	290A	291A	292A	293A	294A	295A	296A	297A	298A	299A	300A	301A	302A	303A	304A	305A	306A	307A	308A	309A	310A	311A	312A	313A	314A	315A	316A	317A	318A	319A	320A	321A	322A	323A	324A	325A	326A	327A	328A	329A	330A	331A	332A	333A	334A	335A	336A	337A	338A	339A	340A	341A	342A	343A	344A	345A	346A	347A	348A	349A	350A	351A	352A	353A	354A	355A	356A	357A	358A	359A	360A	361A	362A	363A	364A	365A	366A	367A	368A	369A	370A	371A	372A	373A	374A	375A	376A	377A	378A	379A	380A	381A	382A	383A	384A	385A	386A	387A	388A	389A	390A	391A	392A	393A	394A	395A	396A	397A	398A	399A	400A	401A	402A	403A	404A	405A	406A	407A	408A	409A	410A	411A	412A	413A	414A	415A	416A	417A	418A	419A	420A	421A	422A	423A	424A	425A	426A	427A	428A	429A	430A	431A	432A	433A	434A	435A	436A	437A	438A	439A	440A	441A	442A	443A	444A	445A	446A	447A	448A	449A	450A	451A	452A	453A	454A	455A	456A	457A	458A	459A	460A	461A	462A	463A	464A	465A	466A	467A	468A	469A	470A	471A	472A	473A	474A	475A	476A	477A	478A	479A	480A	481A	482A	483A	484A	485A	486A	487A	488A	489A	490A	491A	492A	493A	494A	495A	496A	497A	498A	499A	500A	501A	502A	503A	504A	505A	506A	507A	508A	509A	510A	511A	512A	513A	514A	515A	516A	517A	518A	519A	520A	521A	522A	523A	524A	525A	526A	527A	528A	529A	530A	531A	532A	533A	534A	535A	536A	537A	538A	539A	540A	541A	542A	543A	544A	545A	546A	547A	548A	549A	550A	551A	552A	553A	554A	555A	556A	557A	558A	559A	560A	561A	562A	563A	564A	565A	566A	567A	568A	569A	570A	571A	572A	573A	574A	575A	576A	577A	578A	579A	580A	581A	582A	583A	584A	585A	586A	587A	588A	589A	590A	591A	592A	593A	594A	595A	596A	597A	598A	599A	600A	601A	602A	603A	604A	605A	606A	607A	608A	609A	610A	611A	612A	613A	614A	615A	616A	617A	618A	619A	620A	621A	622A	623A	624A	625A	626A	627A	628A	629A	630A	631A	632A	633A	634A	635A	636A	637A	638A	639A	640A	641A	642A	643A	644A	645A	646A	647A	648A	649A	650A	651A	652A	653A	654A	655A	656A	657A	658A	659A	660A	661A	662A	663A	664A	665A	666A	667A	668A	669A	670A	671A	672A	673A	674A	675A	676A	677A	678A	679A	680A	681A	682A	683A	684A	685A	686A	687A	688A	689A	690A	691A	692A	693A	694A	695A	696A	697A	698A	699A	700A	701A	702A	703A	704A	705A	706A	707A	708A	709A	710A	711A	712A	713A	714A	715A	716A	717A	718A	719A	720A	721A	722A	723A	724A	725A	726A	727A	728A	729A	730A	731A	732A	733A	734A	735A	736A	737A	738A	739A	740A	741A	742A	743A	744A	745A	746A	747A	748A	749A	750A	751A	752A	753A	754A	755A	756A	757A	758A	759A	760A	761A	762A	763A	764A	765A	766A	767A	768A	769A	770A	771A	772A	773A	774A	775A	776A	777A	778A	779A	780A	781A	782A	783A	784A	785A	786A	787A	788A	789A	790A	791A	792A	793A	794A	795A	796A	797A	798A	799A	800A	801A	802A	803A	804A	805A	806A	807A	808A	809A	810A	811A	812A	813A	814A	815A	816A	817A	818A	819A	820A	821A	822A	823A	824A	825A	826A	827A	828A	829A	830A	831A	832A	833A	834A	835A	836A	837A	838A	839A	840A	841A	842A	843A	844A	845A	846A	847A	848A	849A	850A	851A	852A	853A	854A	855A	856A	857A	858A	859A	860A	861A	862A	863A	864A	865A	866A	867A	868A	869A	870A	871A	872A	873A	874A	875A	876A	877A	878A	879A	880A	881A	882A	883A	884A	885A	886A	887A	888A	889A	890A	891A	892A	893A	894A	895A	896A	897A	898A	899A	900A	901A	902A	903A	904A	905A	906A	907A	908A	909A	910A	911A	912A	913A	914A	915A	916A	917A	918A	919A	920A	921A	922A	923A	924A	925A	926A	927A	928A	929A	930A	931A	932A	933A	934A	935A	936A	937A	938A	939A	940A	941A	942A	943A	944A	945A	946A	947A	948A	949A	950A	951A	952A	953A	954A	955A	956A	957A	958A	959A	960A	961A	962A	963A	964A	965A	966A	967A	968A	969A	970A	971A	972A	973A	974A	975A	976A	977A	978A	979A	980A	981A	982A	983A	984A	985A	986A	987A	988A	989A	990A	991A	992A	993A	994A	995A	996A	997A	998A	999A	1000A



57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Tm	70 Yb	71 Lu
镧	铈	镨	钕	钷	钐	铕	钆	铽	镝	铈	铥	镱	镱
138.9	140.1	140.9	144.2	[145]	150.4	151.96	157.25	162.50	164.93	167.26	168.93	173.05	175.07
80 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Fm	101 Md	102 No	103 Lr
锕	钍	镤	铀	镎	钚	镅	锔	锇	锿	镄	镆	镎	镌
[227]	232.0	231.0	238.0	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[258]	[259]	[262]

schematic energy levels of a hydrogen atom



(5). excited or ground state of H?

home works (introduction for astrophysics)

1. For a uniform cloud of pure hydrogen with temperature T and density n_H , determine the fraction of hydrogen atoms in the 1st excited state $\frac{n_{HI(n=2)}}{n_{HI}}$ as a function of temperature T and plot this function.
2. For the same cloud, determine the fraction of all hydrogen atoms that are ionized $\frac{n_{HII}}{n_{HI+HII}}$ as a function of T and $n_H \equiv n_{HI+HII}$, and plot this function for $n_H = 10^2$ and 10^{10} cm^{-3} .
3. For $n_H = 10^6 - 10^{12} \text{ cm}^{-3}$, determine and plot $\frac{n_{HI(n=2)}}{n_H}$ as a function of T .

Solution:

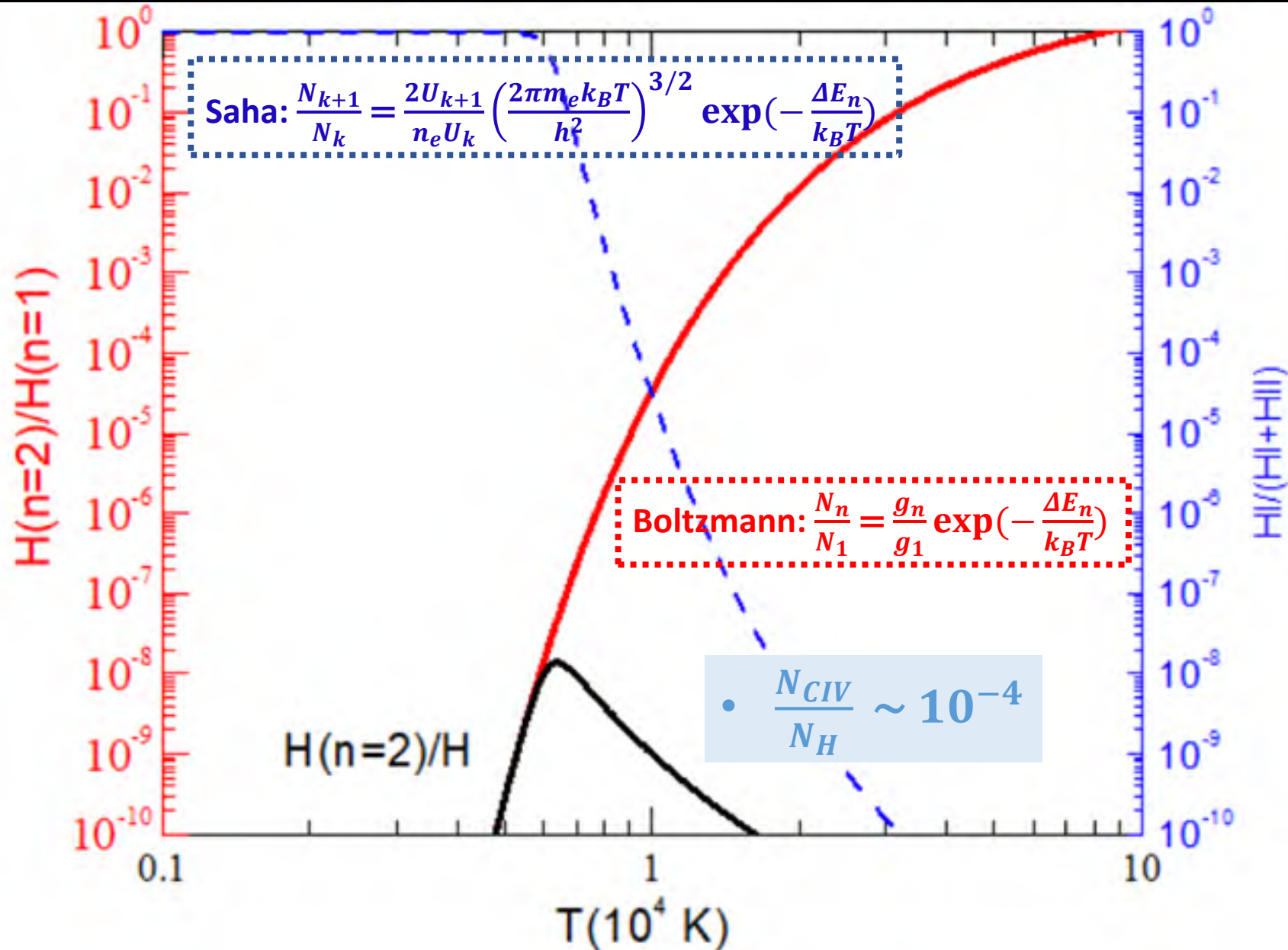
1. The ratio is determined by the Boltzmann equation, if LTE holds, i.e.,

$$\frac{n_{HI(n=2)}}{n_{HI}} = \frac{g_2}{g_1} \exp\left[-\frac{\Delta E(n=1 \leftrightarrow n=2)}{k_B T}\right] = \frac{2 \cdot 2^2}{2 \cdot 1^2} \exp\left[-\frac{(1-1/2^2)13.6 \text{ eV}}{8.62 \times 10^{-5} \text{ eV K}^{-1} T}\right] = 4 \exp\left[-\frac{11.83}{T/10^4 \text{ K}}\right]$$

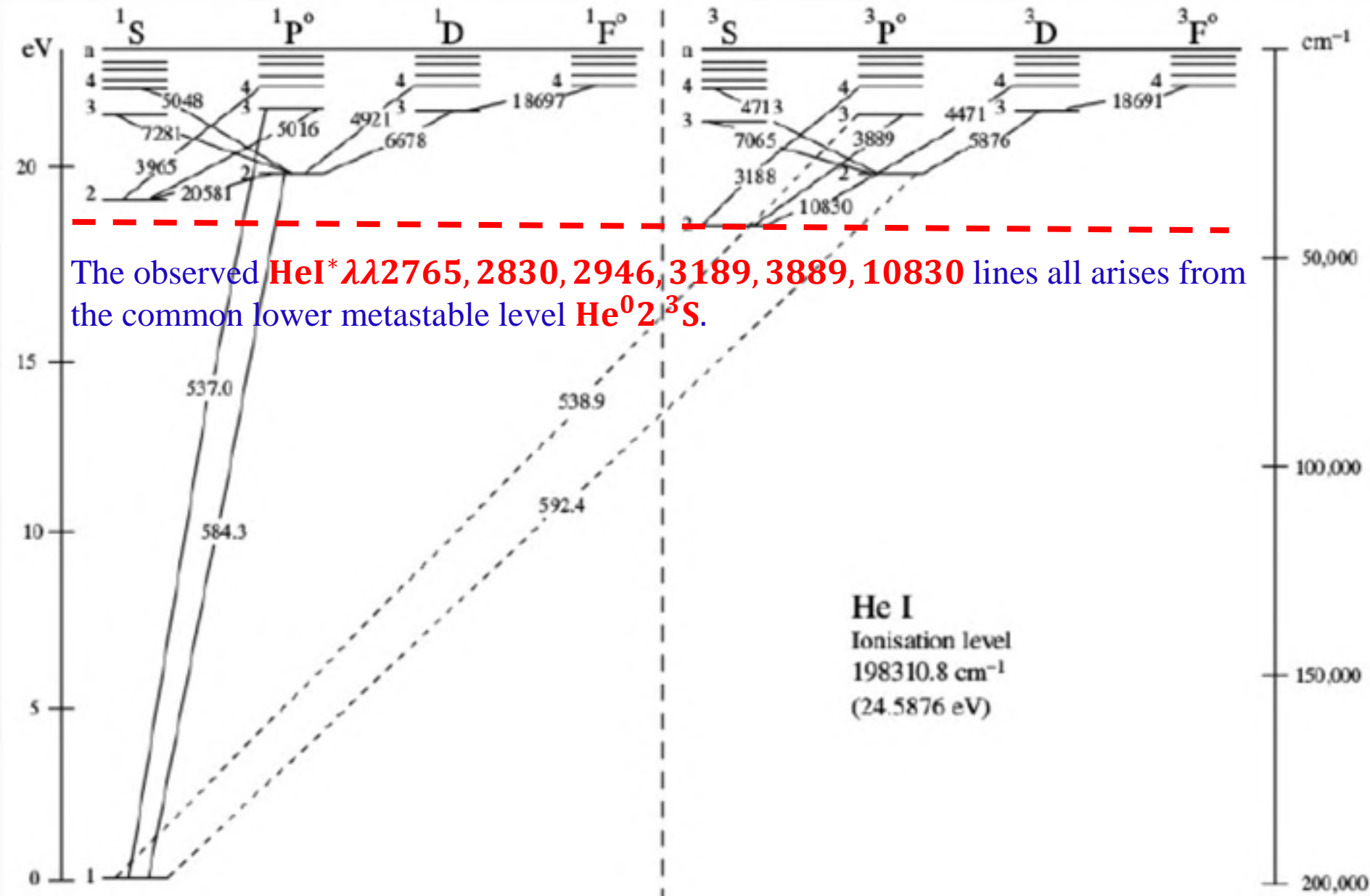
2. According to the Saha equation, $\frac{n_{HII}}{n_{HI+HII}} = \frac{2U_{1+1}}{n_e U_1} \left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} \exp\left(-\frac{\Delta E_1}{k_B T}\right) = 2.41 \times 10^{11} \frac{(T/10^4 \text{ K})^{3/2}}{(n_e/10^{10} \text{ cm}^{-2})} \exp\left[-\frac{15.77}{T/10^4 \text{ K}}\right]$.

3. $\frac{n_{HI(n=2)}}{n_H} = \frac{n_{HI(n=2)}}{n_{HI}} \times \frac{n_{HI}}{n_{HI+HII}}$.

the 1st excited state of HI



Grotrian diagram for a helium atom



Physics of HeI* absorption line multiplets

In equilibrium, the population of the 2^3S is determined by the balance of arrivals from recombination to all triplet levels versus departures mainly due to collisional transition to other levels. Under most conditions all recombinations to the triplet levels end up in the 2^3S level, the total recombination coefficient is $\alpha_T \approx \alpha(\text{He}^0 2^3S) + \alpha(\text{He}^0 2^3P^o)$; and

$$n_{\text{He}^+} \cdot n_e \cdot \alpha_T = n_{2^3S} \left[A_{21} + n_e (q_{ct} + q_{ci}) + \int_{\nu_0}^{\infty} \frac{\alpha_\nu L_\nu}{4\pi r^2 h\nu} d\nu \right],$$

where n_{He^+} is the number density of He^+ ions, n_e is the electron number density, α_T is the total recombination coefficient to all triplet levels, n_{2^3S} is the number density of neutral helium in the 2^3S level, A_{21} is the Einstein A-coefficient for the forbidden transition (625 Å) from the 2^3S level to the ground level (1^1S), q_{ct} is the rate of collisional transfer to all singlet level (which is dominated by collisions to the 2^1S and 2^1P levels), q_{ci} is the collisional ionization rate which becomes important above 20,000 K (Clegg 1987), α_ν is the photoionization cross section for 2^3S , L_ν is the spectral luminosity and r is the distance to the emitting source, h is Planck's constant, and ν_0 is the threshold frequency for ionizing the 2^3S level (4.77 eV or 2600 Å).

Including radiative transition to the ground level but neglecting photoionization, we may have a good approximation of (for $8 \times 10^3 < T < 2 \times 10^4$; Clegg 1987):

$$\frac{n_{2^3S}}{n_{\text{He}^+}} = \frac{5.8 \times 10^{-6} T_4^{-1.19}}{1 + 3.11 \times 10^3 T_4^{-0.51} n_e^{-1}}, \text{ where } T_4 \text{ is the temperature in units of } 10^4 \text{ K.}$$

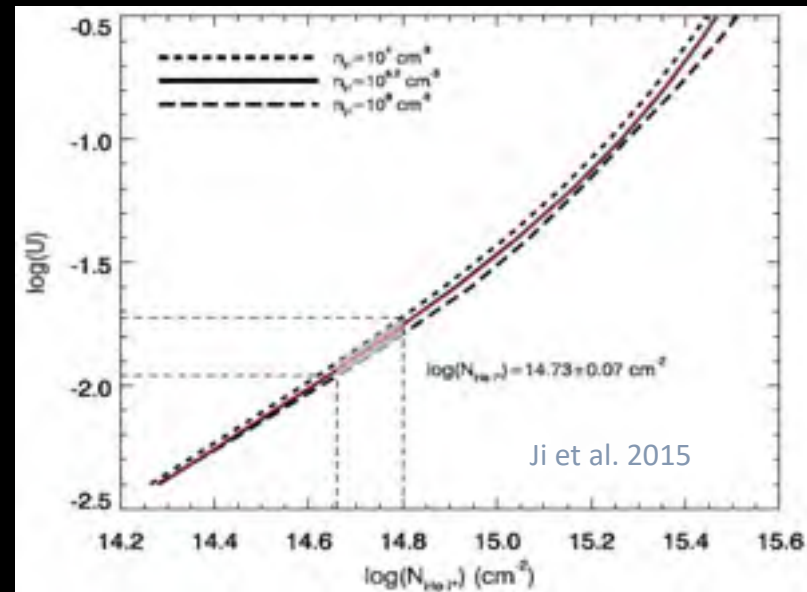
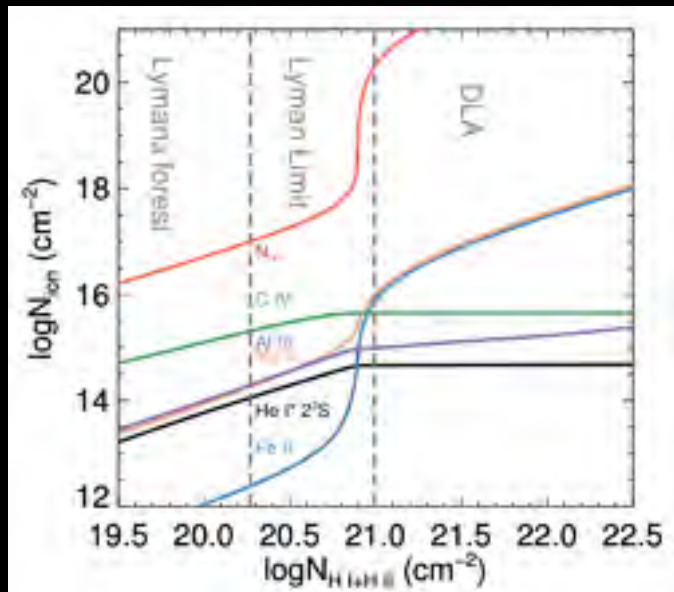
Physics of HeI* absorption line multiplets

If $n_e > 3 \times 10^3 \text{ cm}^{-3}$ (the critical density), the effects of photoionization, collisional ionization and radiative transition to the ground level, can be neglected, we only need to consider recombination and the collisional transfer to the singlet level, and thus can further simplify the ratio as

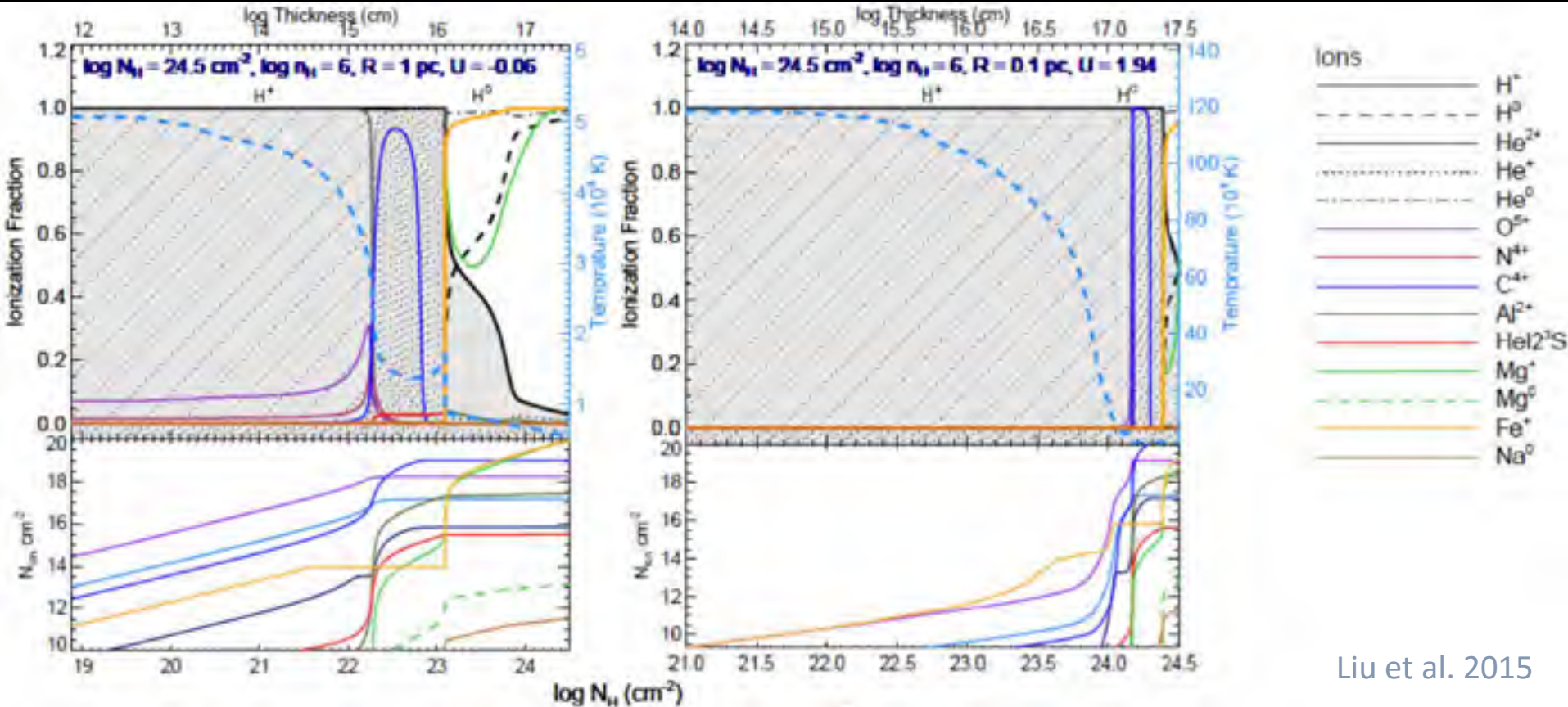
$$\frac{n_{2^3S}}{n_{\text{He}^+}} = \frac{q_{ct}}{\alpha_T} = 6 \times 10^{-6}$$

Typically, $N_{\text{He}^0 2^3S} = \frac{3.77 \times 10^{14} \text{ cm}^{-2}}{\lambda_{\text{of ik}}} \int \tau(\nu) d\nu \sim \frac{3.77 \times 10^{14} \text{ cm}^{-2}}{3889.74 \cdot 0.064} \cdot 10^{3-4} \sim 10^{15-16} \text{ cm}^{-2}$,

$N_{\text{He}^+} \sim 2 \times 10^{20-21} \text{ cm}^{-2}$. Assuming solar abundances this estimate yields a minimal H II column density of $N_{\text{H}^+} > 2 \times 10^{21-22} \text{ cm}^{-2}$. Higher order HeI* absorption lines can probe $\sim 2 - 3$ orders of magnitude higher column densities (up to **Compton thick**).



ionization structure of quasar intrinsic absorbers



Liu et al. 2015

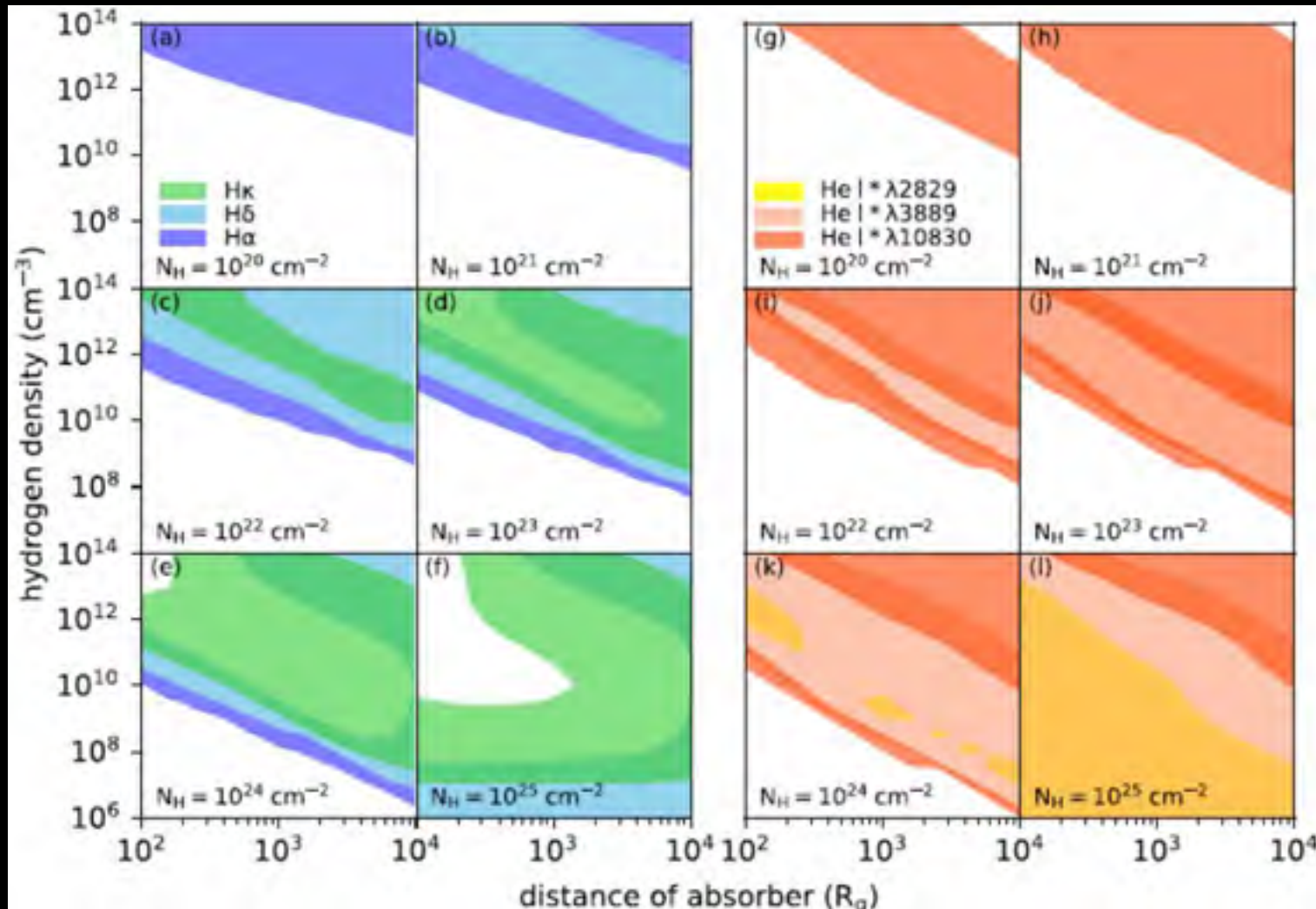
- $\frac{N_{\text{HeI}^*}}{N_{\text{H}}} \sim 6 \times 10^{-7}$
- $\frac{N_{\text{HeI}^*(n=2)}}{N_{\text{H}}} \sim 10^{-7}$

- $\frac{N_{\text{CIV}}}{N_{\text{H}}} \sim 10^{-4}$
- $\frac{N_{\text{MgII}}}{N_{\text{H}}} \sim 10^{-5}$

diagnosability of H Balmer and HeI* absorption lines

$$1 - 10 M_{\odot} \text{yr}^{-1} \sim \dot{M} = 4\pi r \cdot \Omega \cdot \mu \cdot m_p \cdot N_H \cdot v \rightarrow N_H \sim 10^{23-25} \text{cm}^{-1}$$

(for **in/outflows** with $\Omega \sim 10\%$, $v \sim 3,000 \text{ km s}^{-1}$; $r \sim 0.1-1 \text{ pc}$)



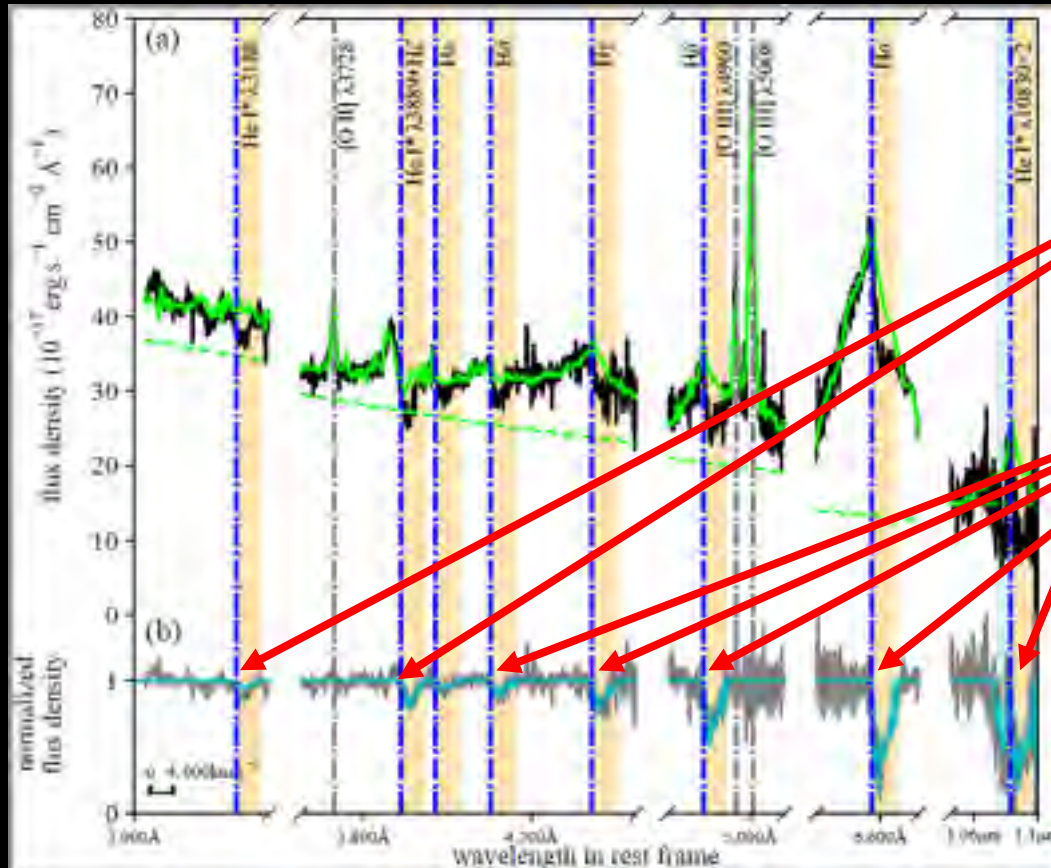
prep. works

1. Zhang et al. 2010, Low-z **Mg II** Broad Absorption-line Quasars from SDSS
2. Ji et al. 2012, Discovery of **Balmer** broad absorption lines in the quasar LBQS 1206+1052
3. Ji et al. 2013, **Balmer** Absorption Line Spectrum of Quasar SDSS J2220+0109
4. Liu et al. 2015, Prevalence of **HeI*** Absorption Line Multiplets in **Mg II** Low-ionization Objects
5. Zhang et al. 2015, Discovery of Extremely Broad **Balmer** Absorption Lines in SDSS J1523+3914
6. Shi et al. 2016, Broad **Balmer** Absorption Line Variability
7. Jiang et al. 2016, Strong **Ly α Emission** in the **Proximate Damped Ly α Absorption** Trough
- 8. Shi et al. 2016, Redshifted Hydrogen Balmer and Metastable HeI* Absorption Line System**
9. Pan et al. 2017, Intrinsic Dusty Absorber with a Metal-rich **Damped Ly α** Absorption Line System
10. Sun et al. 2017, Variability in **Balmer Absorption Line** Quasar
11. Shi et al. 2017, Variable **Hydrogen Balmer Absorption Lines with Inverse Decrement**
12. Zhang et al. 2018, **Ultra-dense Broad-line Region Scale Outflow**
13. Pan et al. 2018, Scattered Continuum in the **Lyman Limit Absorption Edge**
- ...
- Tian et al. 2019, **Galactic-scale** Broad Absorption Line Outflow
- Pan et al. 2019, Metastable **He I* λ 10830** Absorption and Very Narrow **Paschen α** Emission Lines
- Li et al. 2020, **Ultradense Gas at the Dusty Torus Scale** in a Partially Obscured Quasar
- ...

France Bacon: "the cripple but not lost can surpass the people who walk fast but in a wrong road."

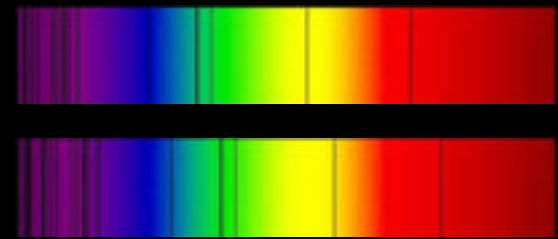
4. a case study of J1035+1422

刘万东：“氢氦红移流速定”



meta-stable HeI*

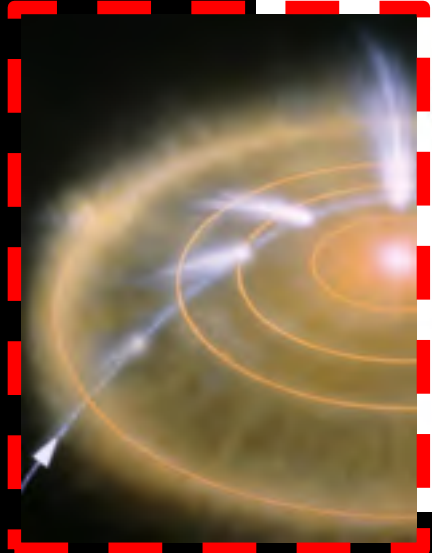
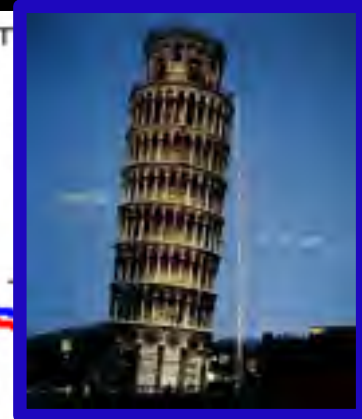
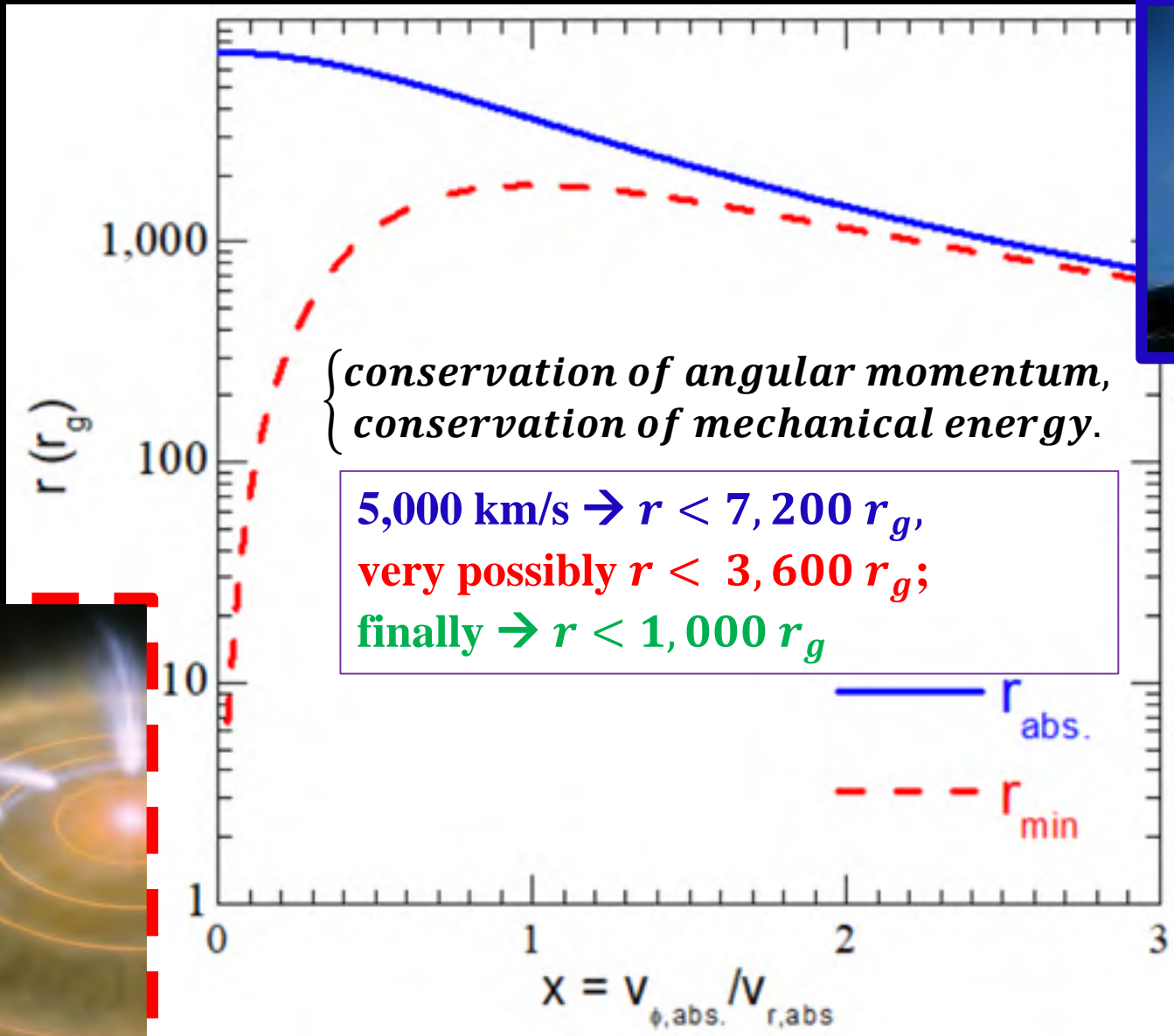
HI* Balmer



多普勒红移

Doppler redshift up to 5,000 km/s $\rightarrow r < 7,200 r_g$

inflow distance constrained by the simple physics of gravity



J1035+1422: isolated BALs in velocity space

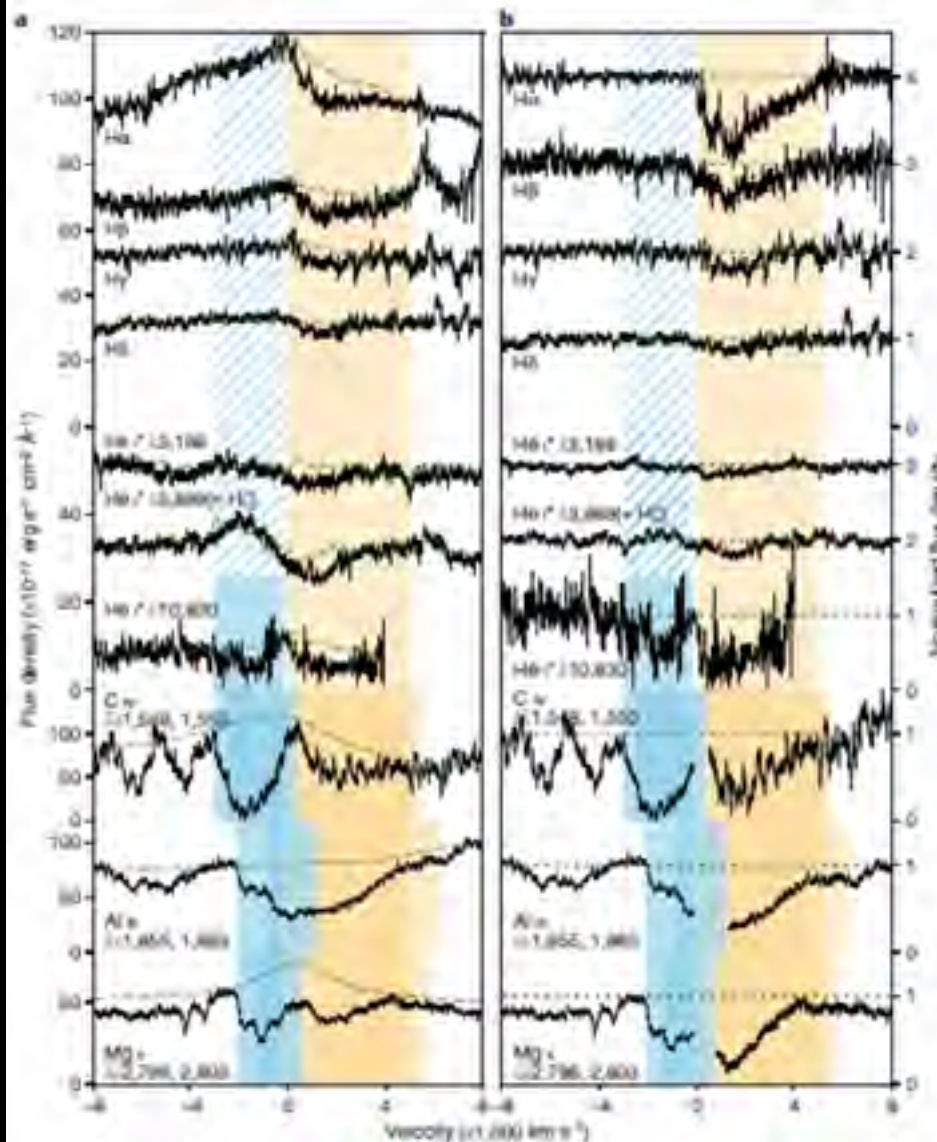
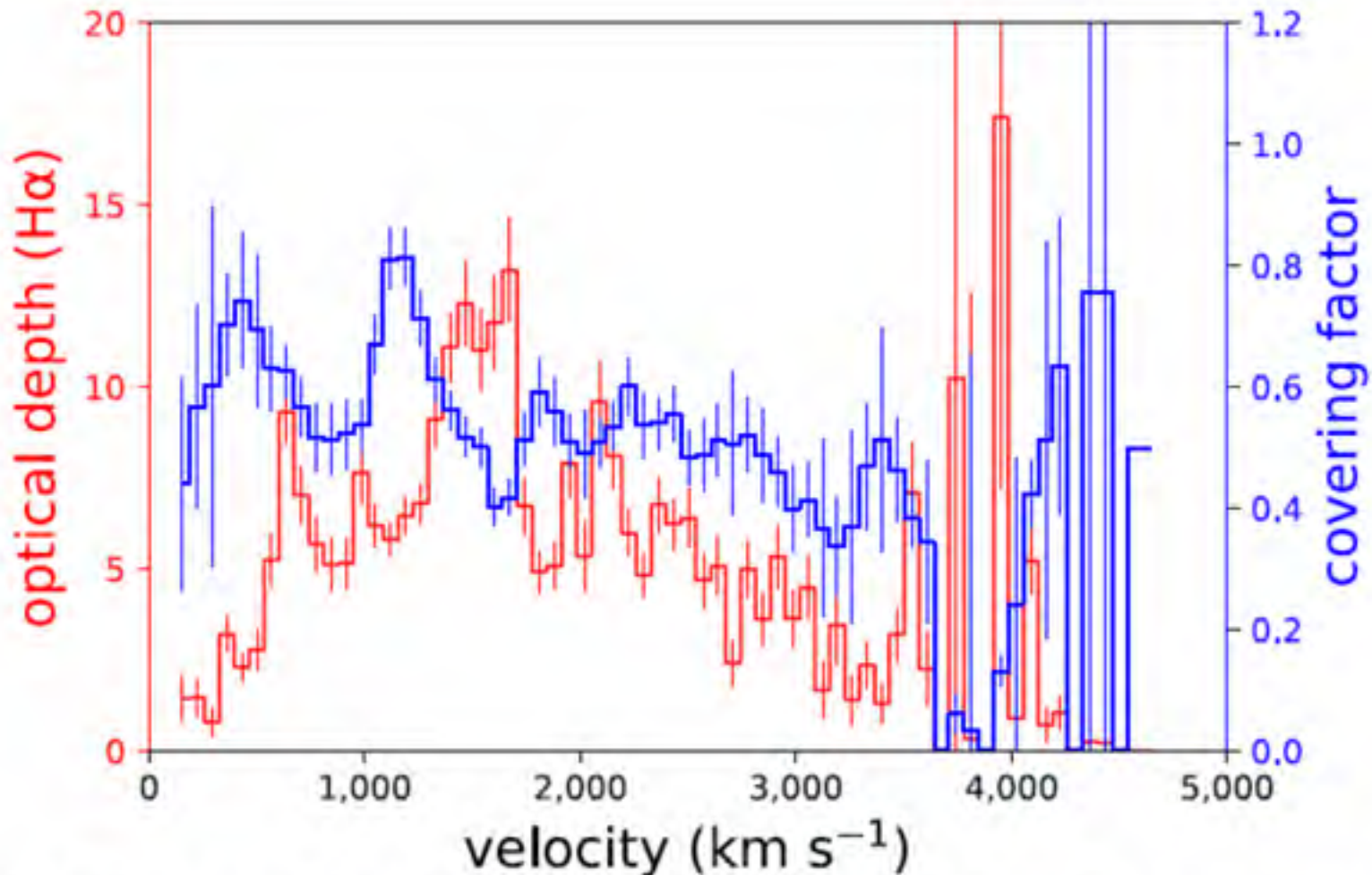


Fig. 2 | Close-up of the absorption spectrum of J1035 + 1422 in selective hydrogen, helium and metal lines. a, Observed flux density, b, Normalized flux density. The velocity ranges for the redshifted and blueshifted broad absorption-line systems (regions coloured in orange and blue, respectively) are determined according to the normalized $\text{H}\alpha$ and $\text{He I}^* \lambda 10,830$ broad absorption-line spectra. The seeming velocity differences between the H I^* , He I^* and metal lines are mostly due to the fact that all of the metal lines are actually doublets, with velocity offsets of 500 km s^{-1} , $1,300 \text{ km s}^{-1}$ and 770 km s^{-1} between the two member lines of C iv, Al iii and Mg ii, respectively. The best-fit quasar composite spectrum is shown by the green dashed lines. It is obvious that the redshifted C iv trough is shallower than the blueshifted C iv trough and than the redshifted Mg ii and H α troughs. The $\text{He I}^* \lambda 10,830$ line is severely blended with $\text{He I } \lambda 10,890$, with a measured optical depth ratio of 0.7/0.3. Note that all of the H I^* and He I^* lines show solely redshifted absorption troughs except for $\text{He I}^* \lambda 10,830$, which is the strongest of the multiplets¹⁰. This implies a drastically distinctive physical condition of the redshifted broad-absorption-line gas from that of the blueshifted one. Unlike emission lines, which may be complicated by various effects, such as obscuration and projection, redshifted absorption lines are clean in kinematics and are a robust indication of inward motion of the absorbing gas along the line of sight⁹.

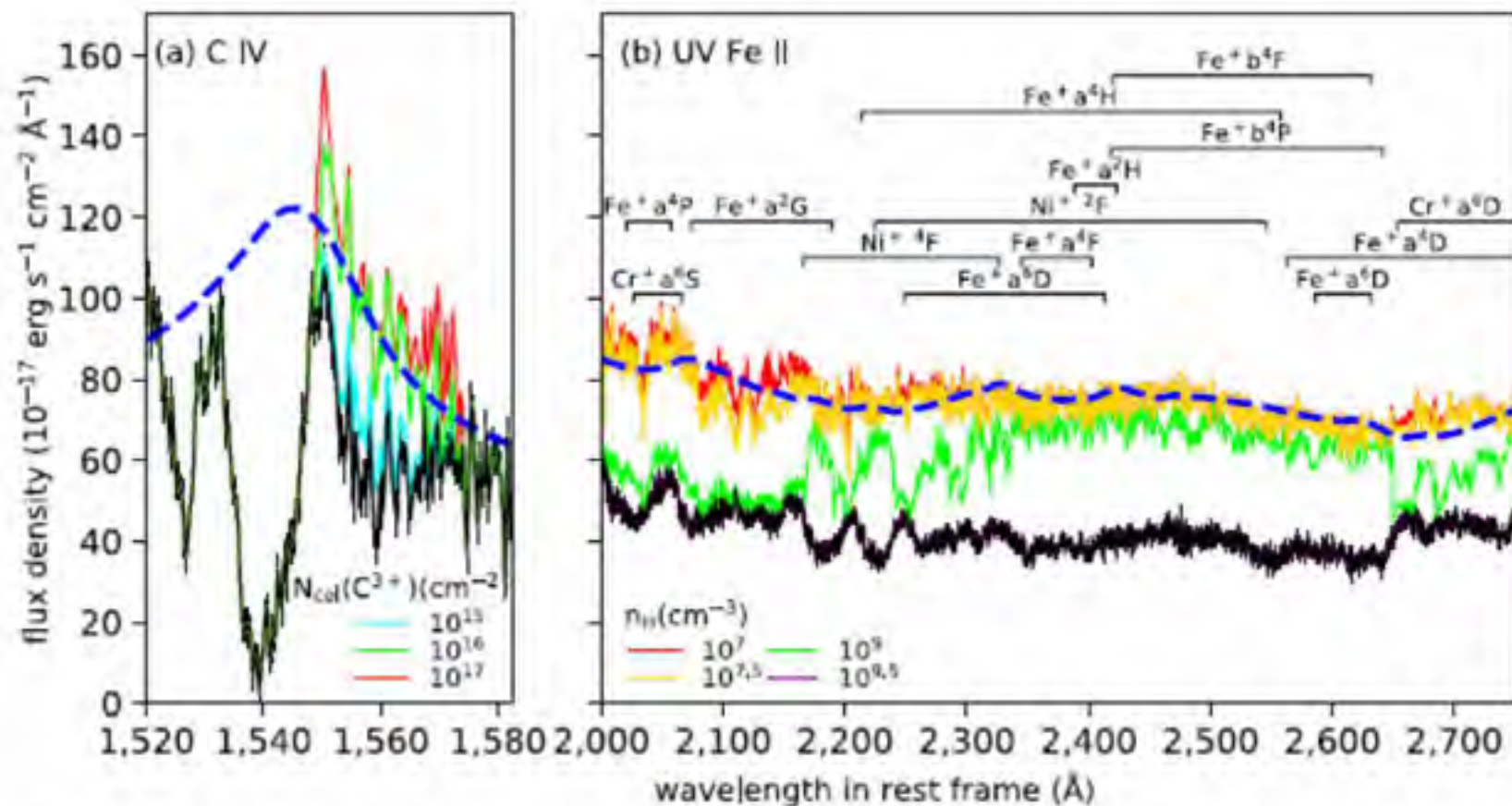
H α optical depth and covering fraction



Extended Data Fig. 4 | Velocity structure of the redshifted H α broad absorption line of J1035 + 1422. The optical depth (red) and local covering factor (blue) of the line, derived from the continuum-

normalized spectrum, are shown as a function of velocity shift with respect to the quasar's rest frame. The error bars represent 1σ uncertainties.

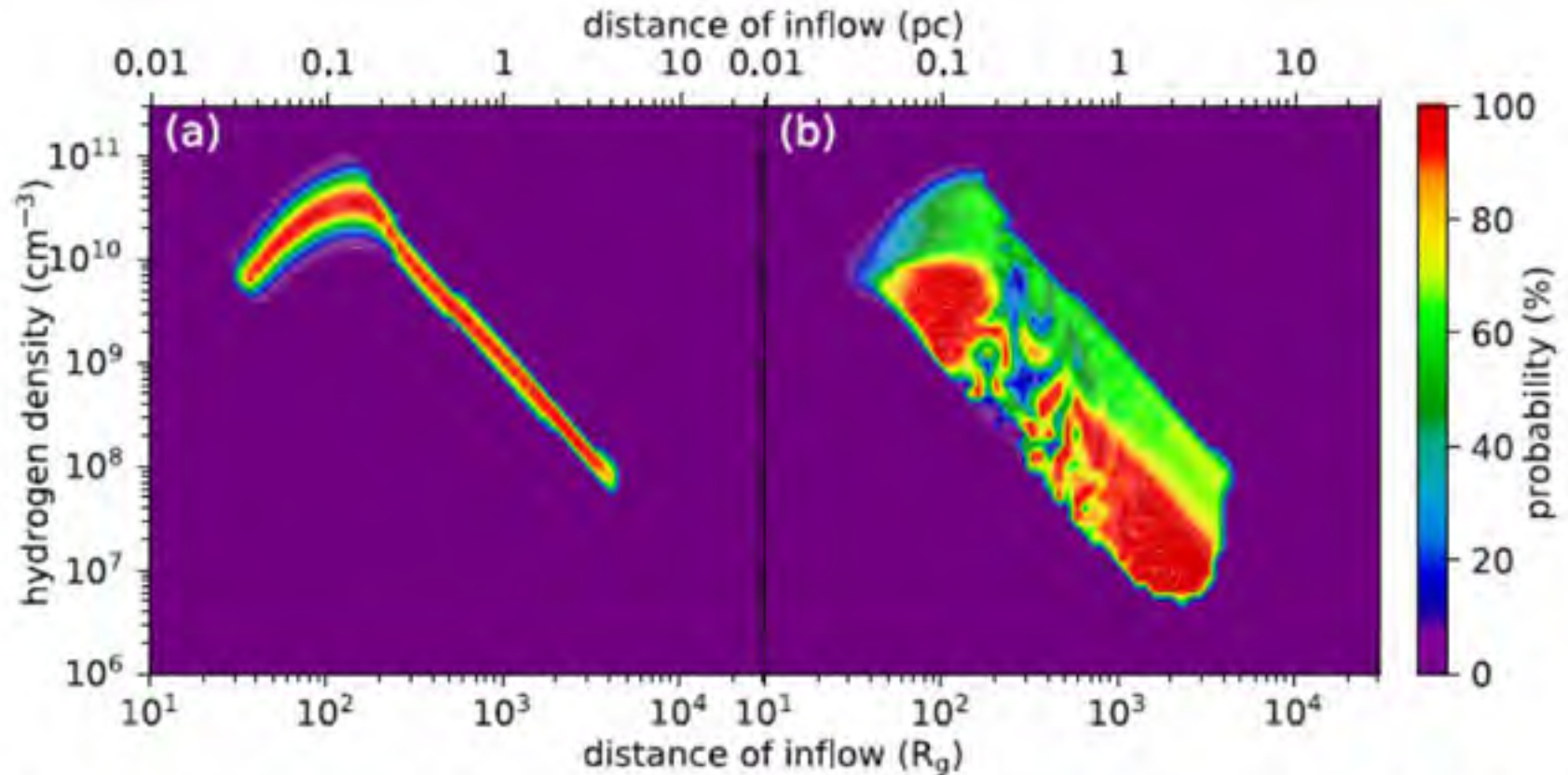
anomalous metal absorption lines



Extended Data Fig. 6 | Comparison between observation and model calculations for selected metal absorption lines. **a.** Recovered spectra of C IV, corrected for redshifted absorption, assuming C^{2+} ion column densities of $N_{\text{col}}(\text{C}^{2+}_{\text{ground}}) = 10^{15}$, 10^{16} and 10^{17} cm $^{-2}$ in the quasar's rest frame. The error bars on the observed flux denote 1σ uncertainty. Compared with the best-fit SDSS composite spectrum (blue dashed line), the recovered flux is much too weak for the absorption when $N_{\text{col}}(\text{C}^{2+}_{\text{ground}}) = 10^{15}$ cm $^{-2}$, while it is too high (showing two extra deceptive peaks at around 1,550 and 1,570 Å) for the absorption when $N_{\text{col}}(\text{C}^{2+}_{\text{ground}}) = 10^{17}$ cm $^{-2}$. The absorption

model with $N_{\text{col}}(\text{C}^{2+}_{\text{ground}}) \approx 10^{16}$ cm $^{-2}$ predicts unabsorbed flux that is reasonably consistent with the composite spectrum, and is thus adopted. **b.** Absorption-corrected UV Fe II spectra between 2,000 and 2,750 Å for the post- C^{2+} inflow models with $n_{\text{H}} = 10^7$ cm $^{-3}$ (red), $10^{7.5}$ cm $^{-3}$ (yellow), 10^9 cm $^{-3}$ (green), and $10^{9.5}$ cm $^{-3}$ (violet) in the high 'probability' zone of Extended Data Fig. 5b. The error bars on observed flux are 1σ uncertainties. Compared with the best-fit composite (blue dashed line), the models with higher densities can be clearly ruled out.

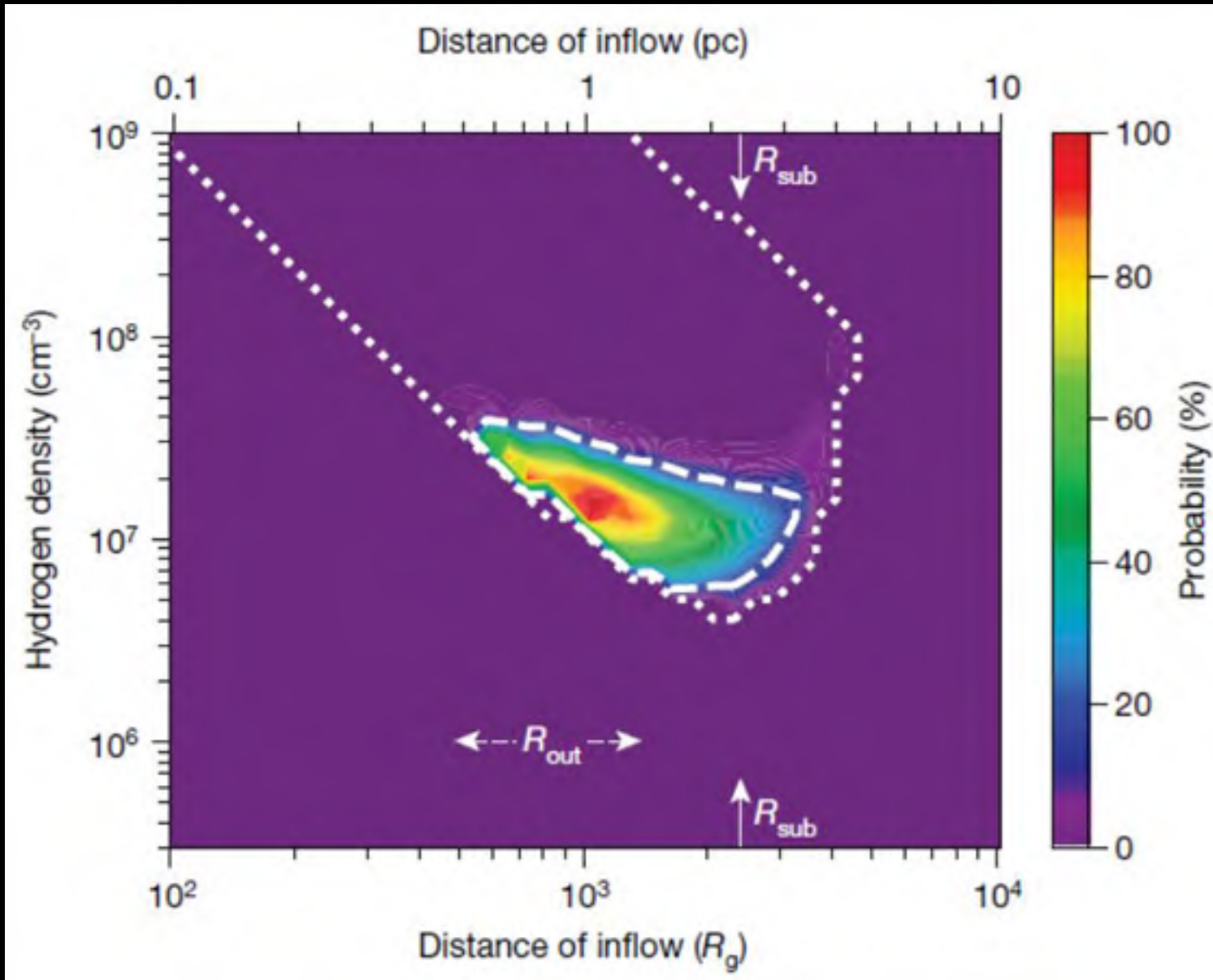
distance constrained by photoionization models of HI^* and HeI^*



Extended Data Fig. 5 | Probability density distribution in the parameter space of the total hydrogen density (n_{H}) and distance from the central engine (d_{inflow}) for different inflow models. a. The simplest primordial models are applied, and the redshifted H I^* and He I^* broad absorption lines are used to evaluate the probability density. However, the highly probable models predict much higher column densities of C^{3+} ions ($N_{\text{col}}(\text{C}^{3+}_{\text{ground}})$) than that estimated from the redshifted C IV broad-

absorption-line trough. **b.** To resolve this problem, only the region beyond the C^{3+} region (the 'post- C^{3+} region') in the primordial models is used to describe the inflow gas, and probability density is recalculated by including C IV . The results of these refined model calculations are shown here. The probability density shows two peaks around $n_{\text{H}} \approx 10^7 \text{ cm}^{-3}$ and $d_{\text{inflow}} \approx 2,000 R_g$, and $n_{\text{H}} \approx 10^{10.5} \text{ cm}^{-3}$ and $d_{\text{inflow}} \approx 100 R_g$ (see also Fig. 3).

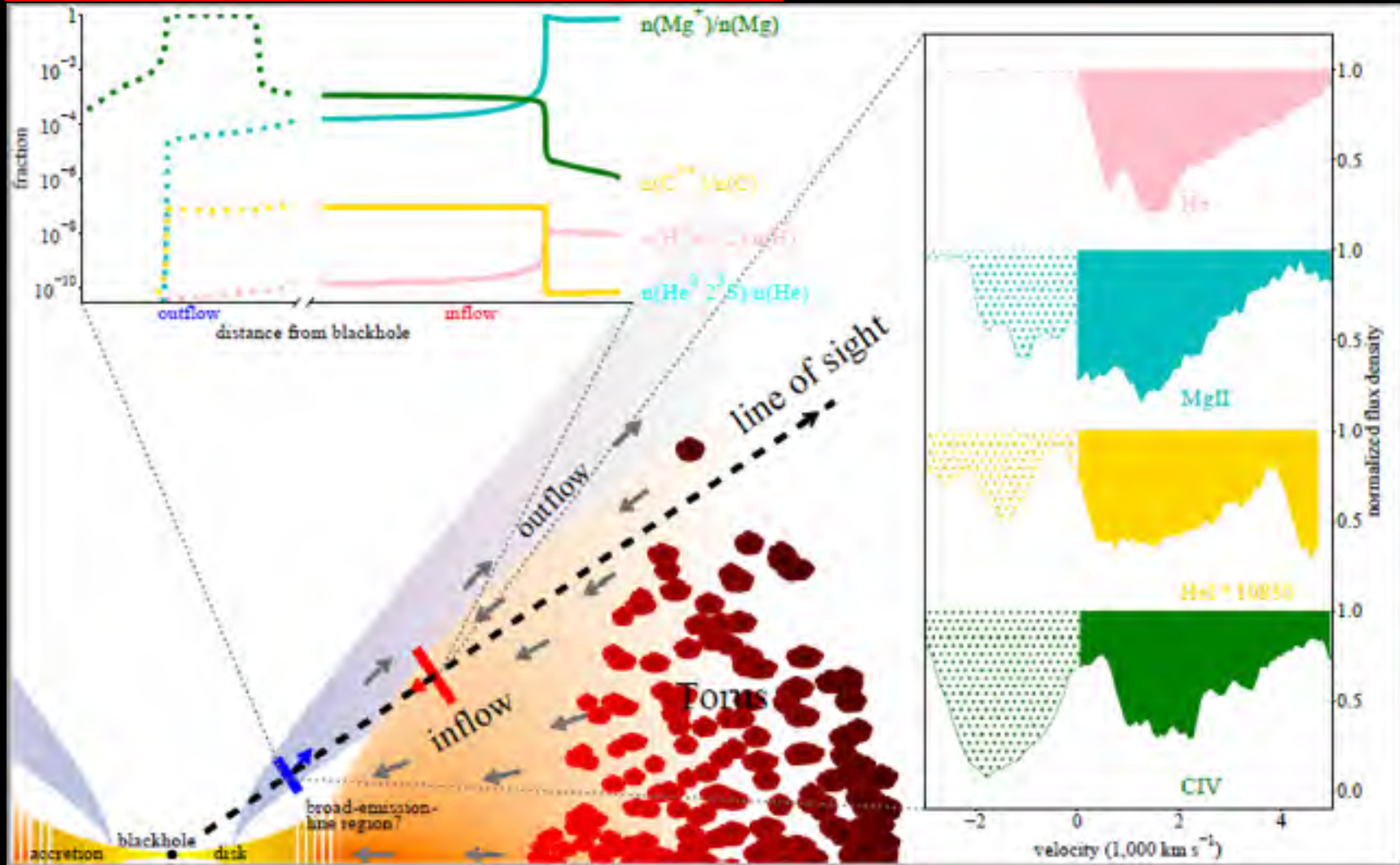
distance by HI, HeI* and metal BALs



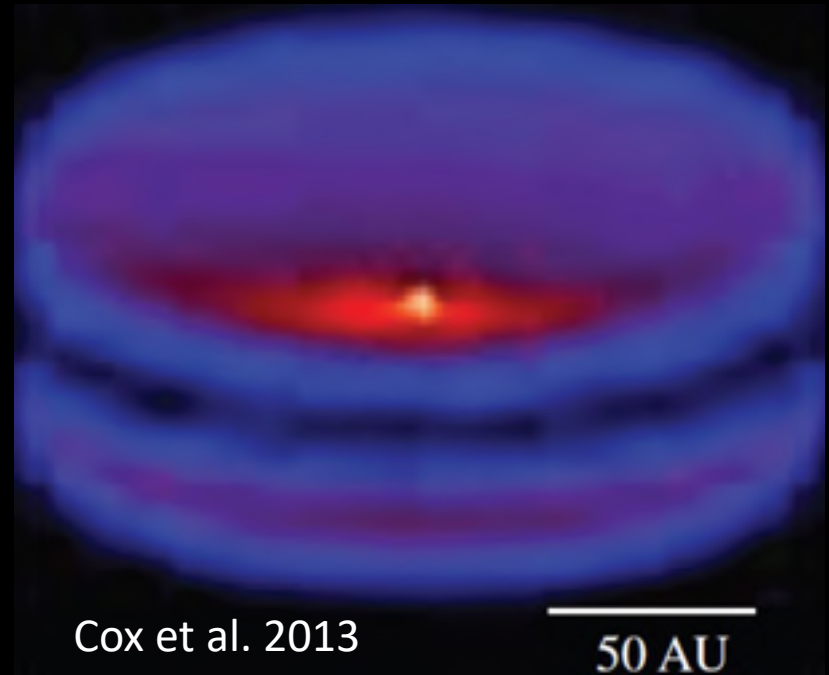
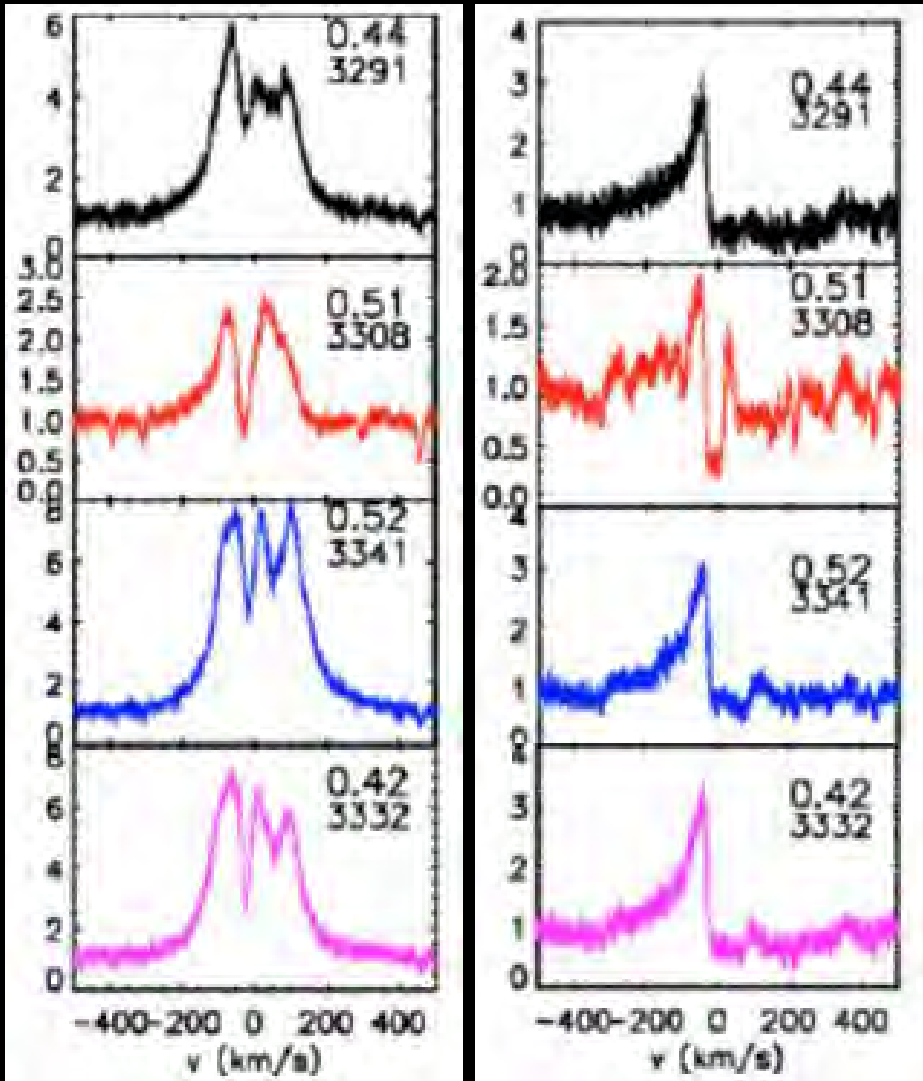
Fast inflows as the adjacent fuel of supermassive black hole accretion disks in quasars

Houyuan Zou^{1,2,3,4}, Xihou Wu^{1,2,3,4}, Weiyang Yuan^{1,2,3,4}, Lixi Han^{1,2,3,4}, Xiangping Chen^{1,2,3,4}, Jun Gu^{1,2,3,4}, Tian Li^{1,2,3,4}, Peng Jiang^{1,2,3,4}, Guohua Li^{1,2,3,4}, Jiahua Liu^{1,2,3,4}, Weizhan Liu^{1,2,3,4}, Donghai Lu^{1,2,3,4}, Xiang Pan^{1,2,3,4}, Jiantai Shen^{1,2,3,4}, Xinyu Shen^{1,2,3,4}, Liyong Sun^{1,2,3,4}, Qiyun Sun^{1,2,3,4}, Huiyuan Wang^{1,2,3,4}, Donghai Wang^{1,2,3,4}, Shengnan Wu^{1,2,3,4}, Chensu Yang^{1,2,3,4}, Shuchan Zhou^{1,2,3,4} & Zhenhao Zhou^{1,2,3,4}

“the last piece of the puzzle falls in place”

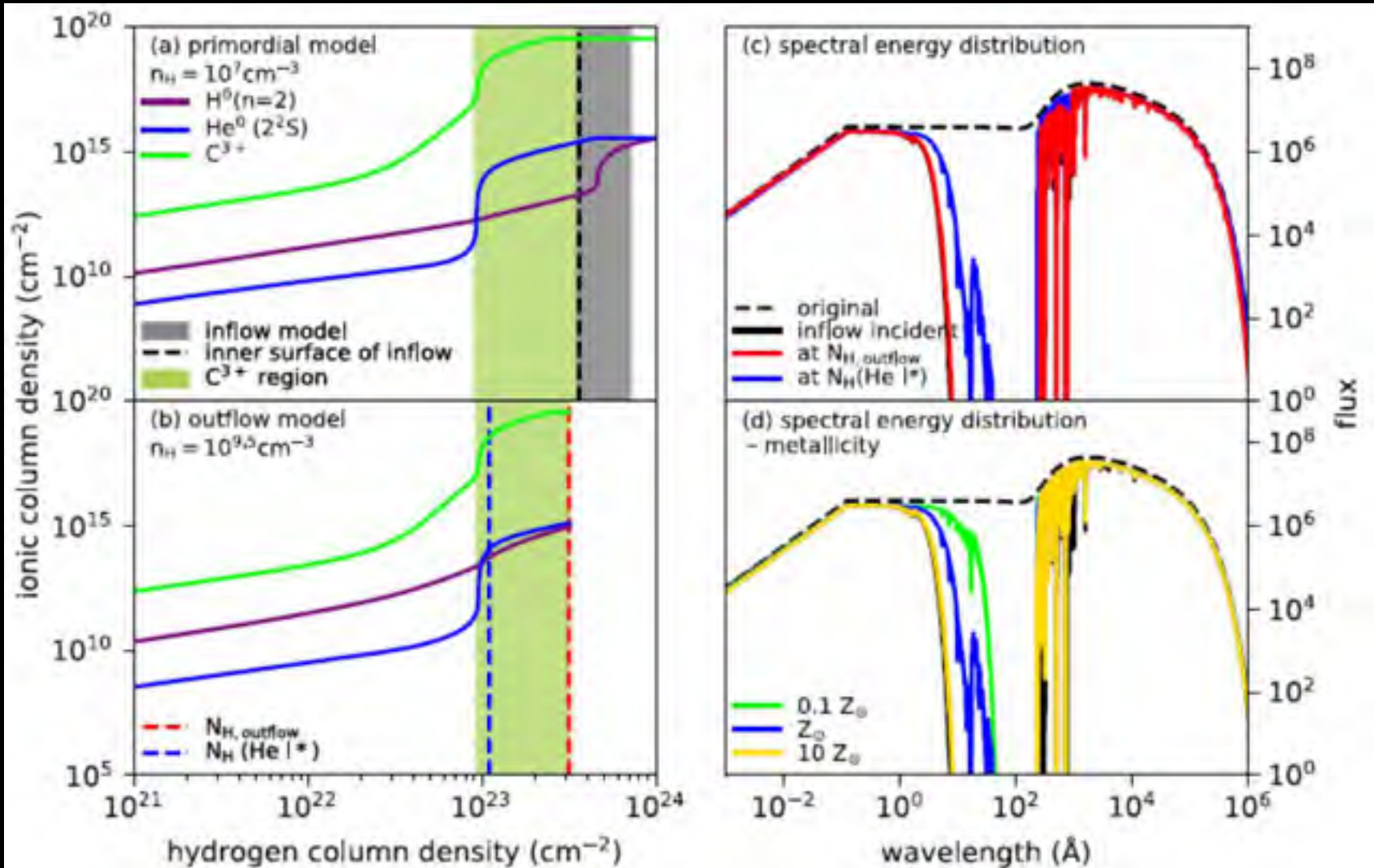


AA Tauri (“金牛”, $V = 0^m.8$)

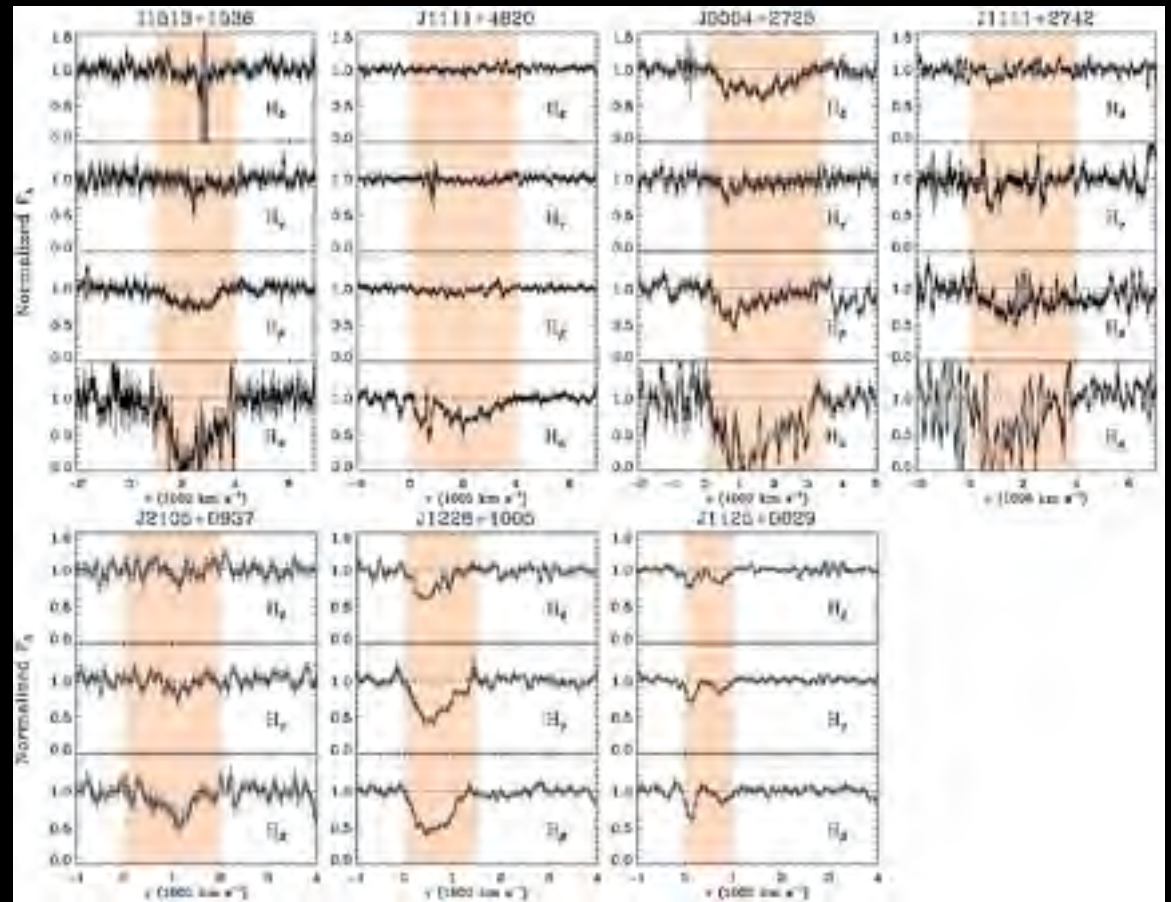
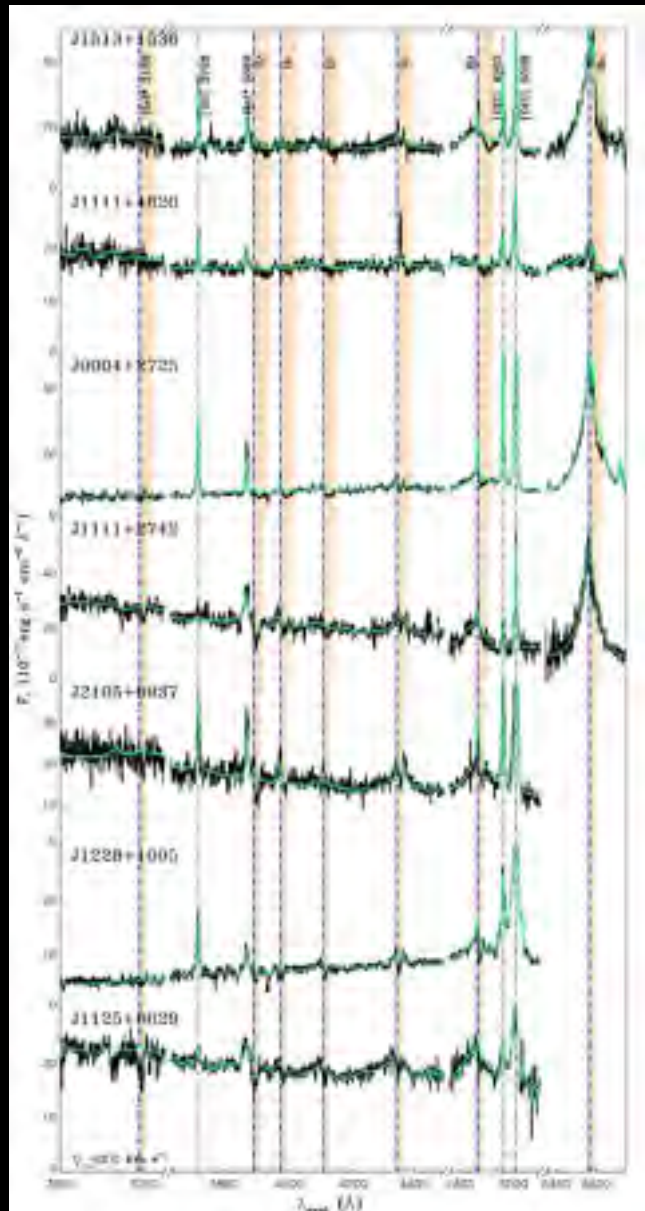


accretion from the circumstellar disk (or occultation of the star by material in the disk) revealed by **redshifted H α and H β** absorption lines.

ionization structure and metallicities



5. J1035+1422's analogues



5. the last piece of the puzzle?

- *ISM inflows* → *galactic nuclear region* (headstream ✓ ?)
- **disk feeding inflows (DFI ✓)**
- *disk inflows* (end ✓ ?)



? HI, OH, CO, HCN ...

(HI* & HeI*)



? OVII, FeXXVI ...

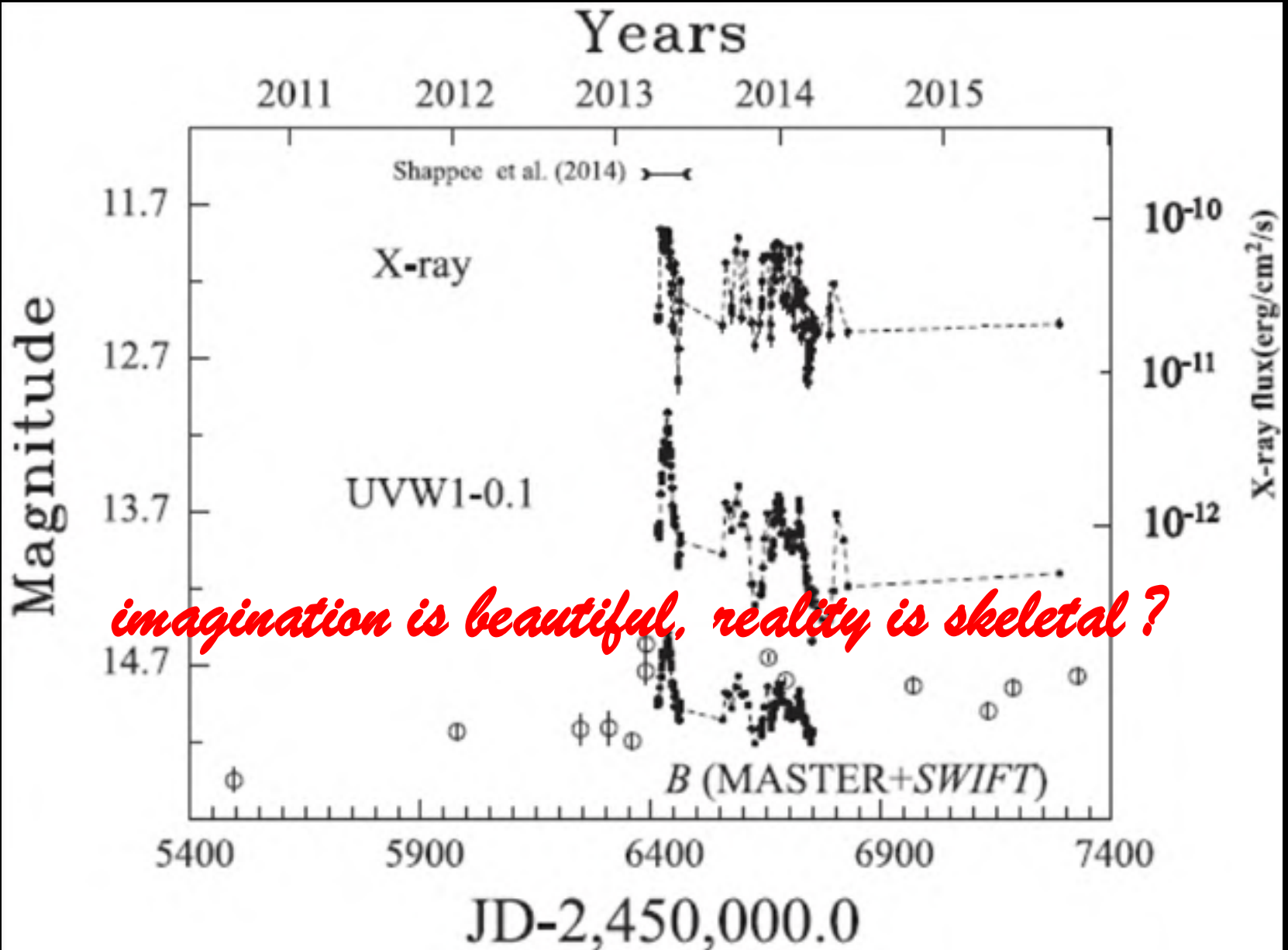
black hole accretion disks:

imagination is beautiful, reality is skeletal?



Credit: NASA, [Jeremy Schnittman](#)

curtain remains open: NGC 2617



Probing the Accretion Disk-Feeding Inflow for a Unique Redshift-BAL AGN Sample

PI: C. Jin, CoI: H. Zhou, W. Yuan, P. Jiang, X. Pan, X. Shi

1. Abstract

A fundamental question remains unanswered about AGN is how the accretion disc is fed with external gas. Recently, Zhou et al. (2019) present the first compelling evidence for the long-sought inflow directly feeding the disc, and propose a global scenario including both inflow and outflow. However, there is still a lack of crucial knowledges from the X-ray band. Here we propose 6 carefully selected sources from Zhou et al.'s redshift-BAL AGN sample for *XMM-Newton* observations, including a superb archetypal source for a deep exposure. This program will provide valuable X-ray data for investigating various X-ray absorption features in these AGN, verifying their disc-feeding inflow scenario, and exploring detailed properties of the inflow and outflow materials, thereby allowing us to better understand the AGN fuelling mechanism.

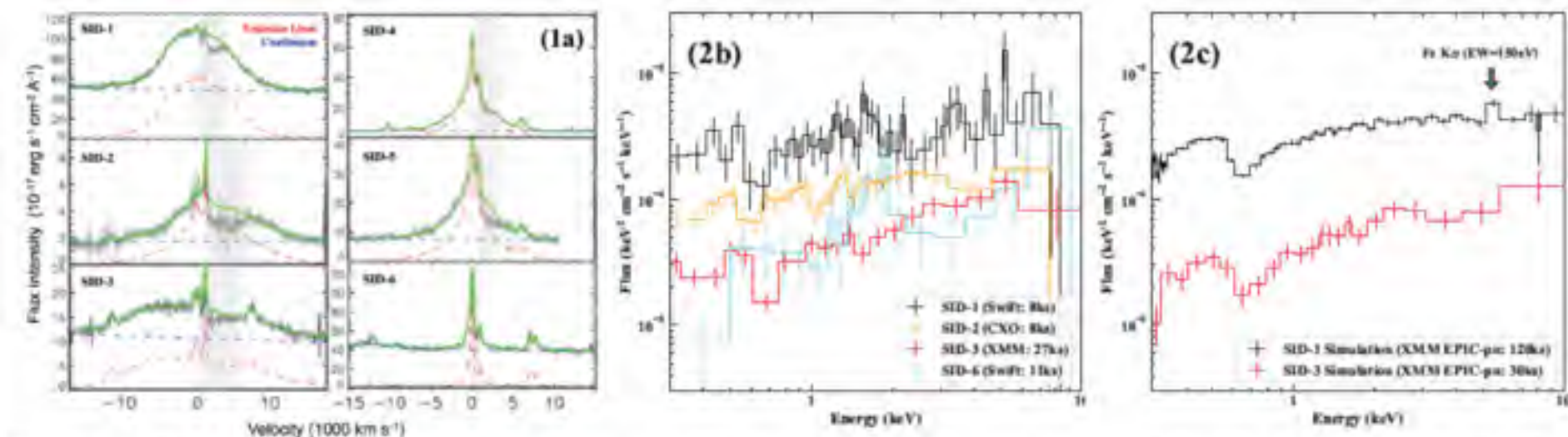
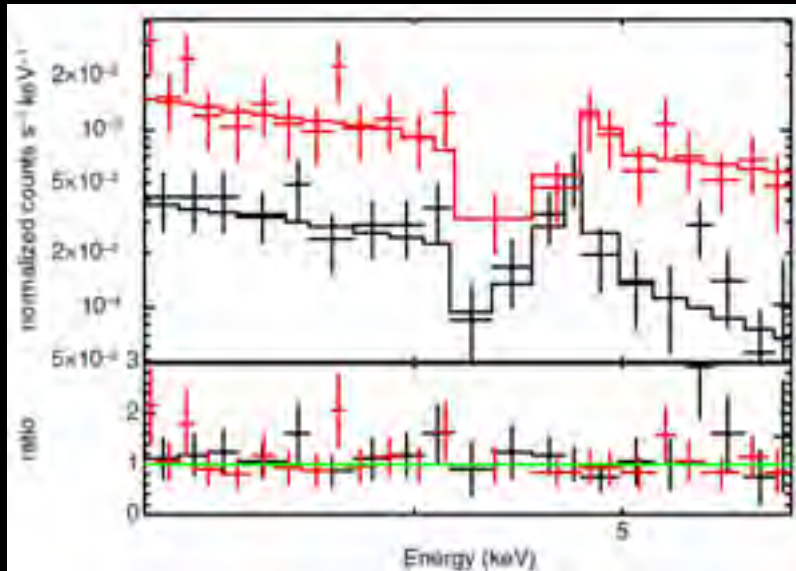


Figure 2: Panel-a: fitting the optical spectrum around H α line for all the 6 sources. A redshifted H α -BAL is clearly identified in every sources as indicated the gray region. Panel-b: the X-ray spectra of 4 sources from archival observations, where the signature of OVII K absorption edge can be seen at ~ 0.6 keV (AGN rest-frame). Panel-c: the simulated *XMM-Newton* EPIC-pn spectra for 120 ks of SID-1 and 30 ks of SID-3 to demonstrate the spectral quality that is required by our research objectives.

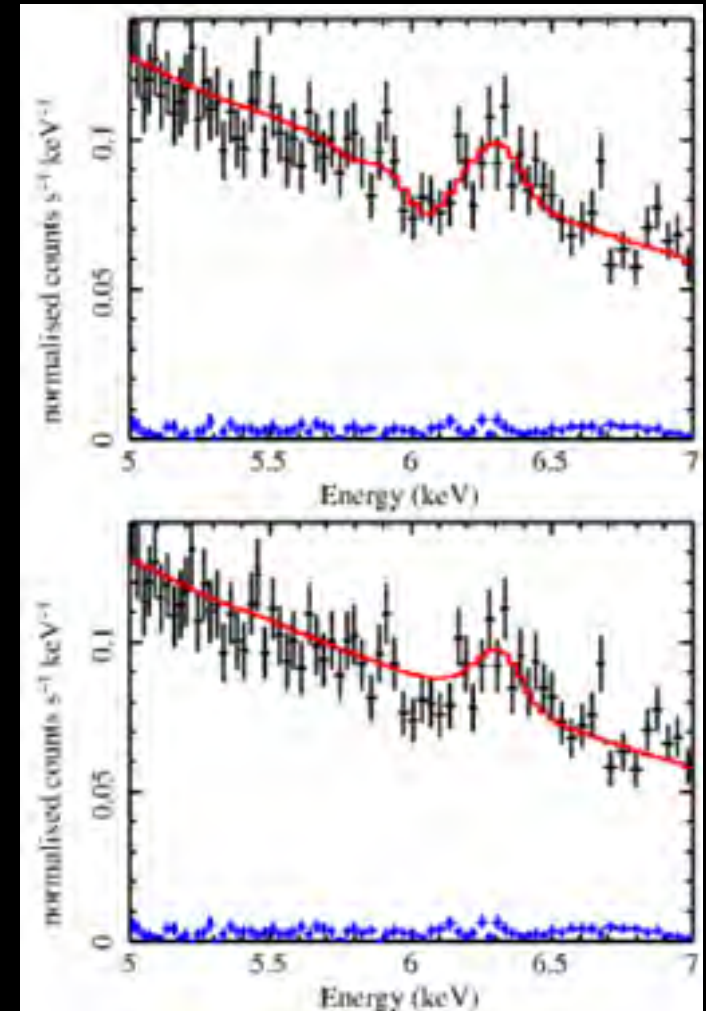
previous detections in the X-rays

CXOC J100043.1+020637 (Civano et al. 2010).

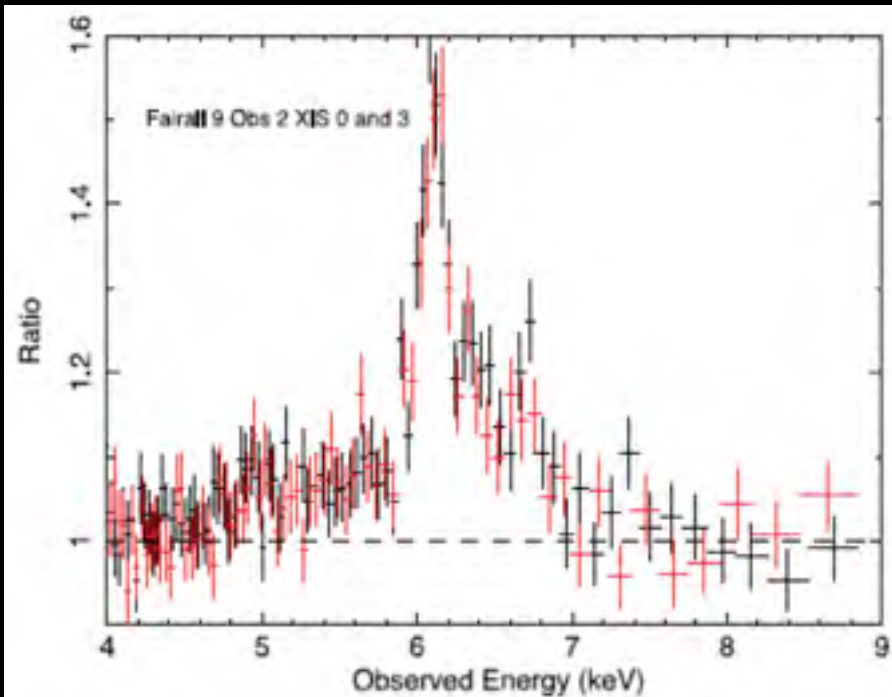
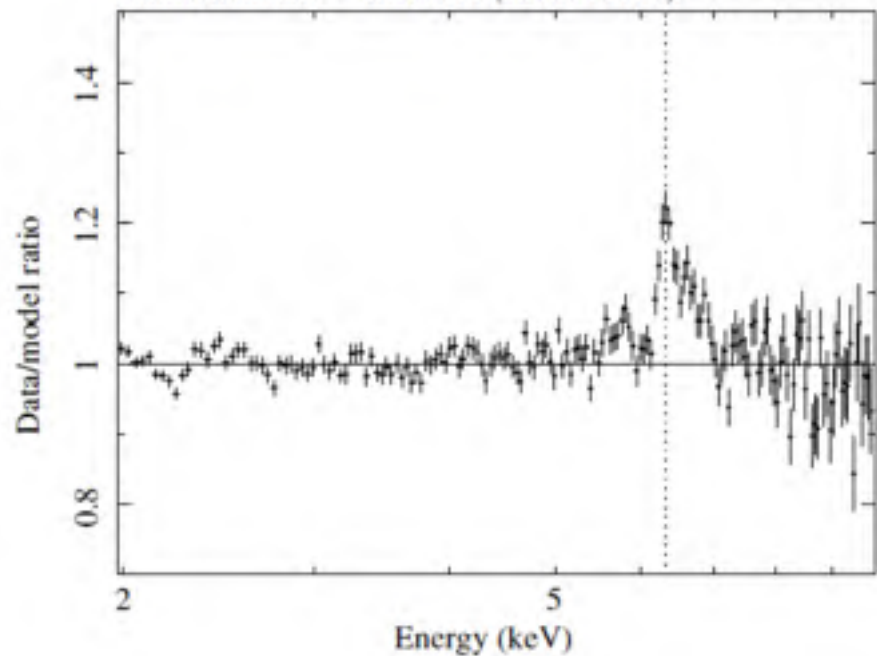


The redshifted absorber can be ascribed to a **failed wind/aborted jets component**, to **gravitational redshift** effects, and/or to **matter directly falling towards the central supermassive black hole**.

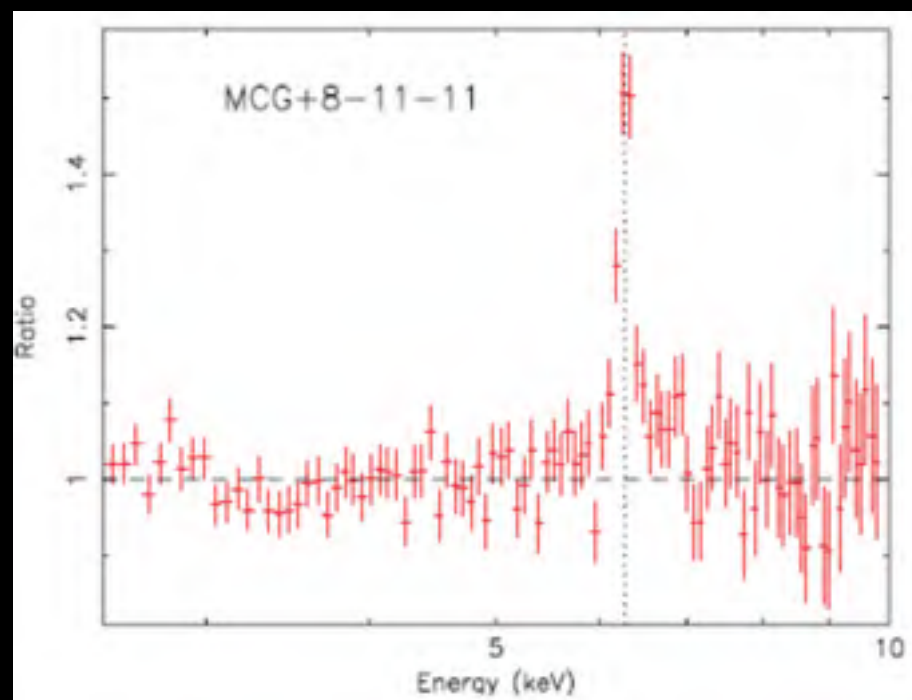
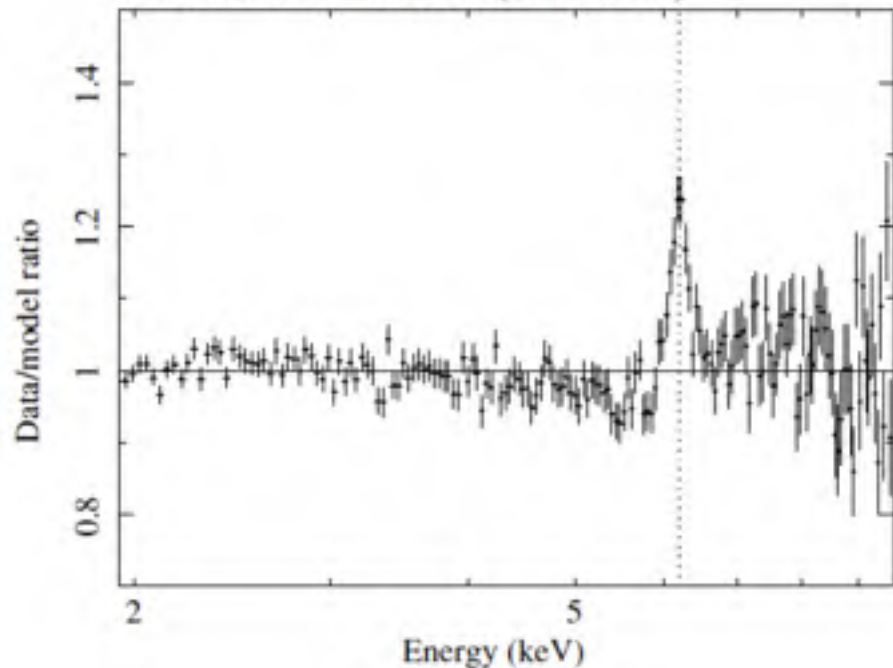
NGC 2617 (Giustini et al. 2018)



Full Relativistic - MRK766 (0000000019)



Full Relativistic - ARK120 (0147190101)



the **end** of BH accretion flows (EP)



headstream (✓?) of accretion flows in the radio

A hyperfine transition exists for hydrogen atoms in the ground state $1^2S_{1/2}$: Depending on the relative spins of the proton and the electron, there is a very small difference in the energy of the ground state $\Delta E = 5.87 \mu\text{eV} \sim 1.4 \text{ GHz} \sim \mathbf{21 \text{ cm}}$.

$$\frac{n_u}{n_l} = \frac{g_u}{g_l} \exp\left(-\frac{h\nu}{k_B T_S}\right) \approx \frac{3}{1};$$

$$T_B(\nu) = C_f T_C e^{-\tau(\nu)} + [1 - C_f] T_C + [1 - e^{-\tau(\nu)}];$$

$$\Delta T(\nu) = T_B(\nu) - T_C = [T_S - C_f T_C][1 - e^{-\tau(\nu)}].$$

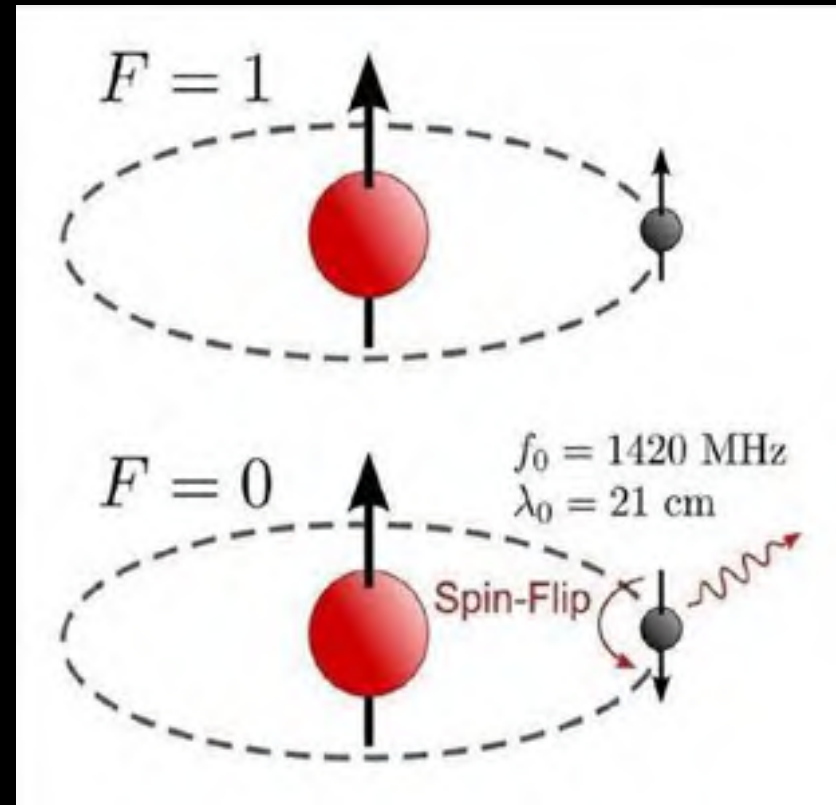
Line emission ($T_S - C_f T_C > 0$):

$$T_B(\nu) \approx \tau(\nu) T_S \propto \frac{N_{\text{HI}}}{T_S} T_S;$$

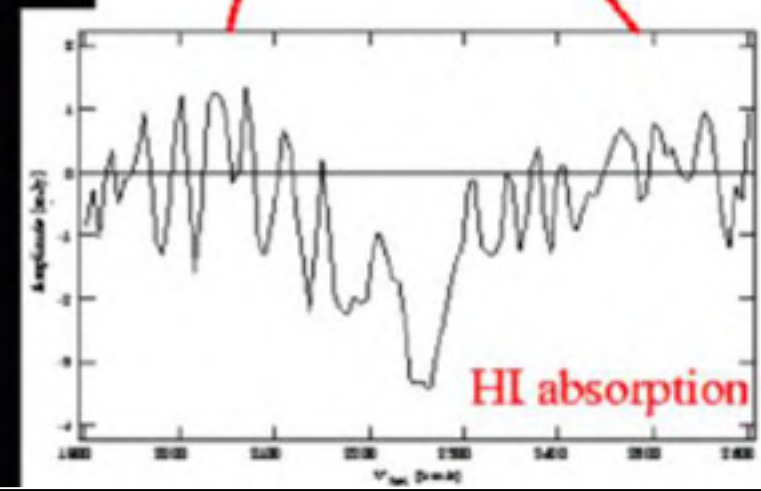
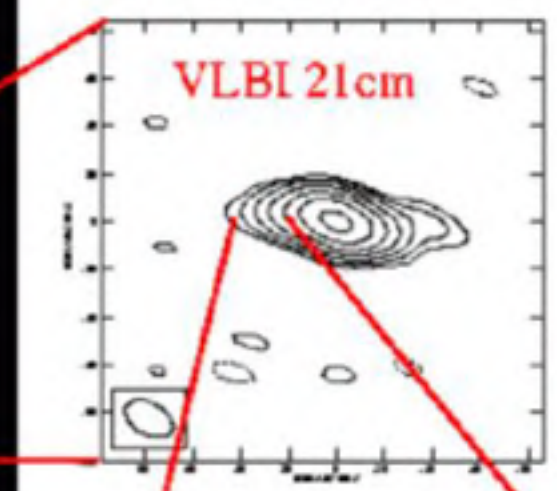
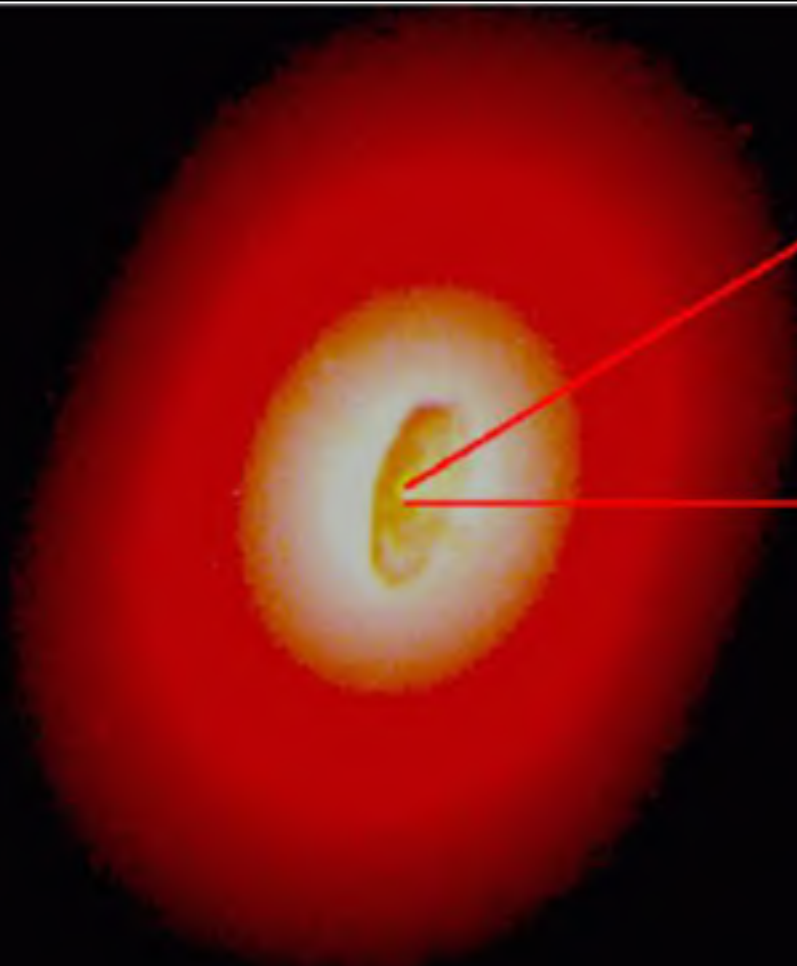
$$N_{\text{HI}} = 1.82 \times 10^{18} [\text{cm}^{-2}] \int T_B(V) [\text{K}] dV [\text{km} \cdot \text{s}^{-1}].$$

Line absorption ($T_S - C_f T_C < 0, \tau \ll 1$):

$$N_{\text{HI}} = 1.82 \times 10^{18} [\text{cm}^{-2}] \frac{T_S}{C_f T_C} \int \Delta T(V) [\text{K}] dV [\text{km} \cdot \text{s}^{-1}] \text{ (for } \tau \ll 1 \text{)}.$$

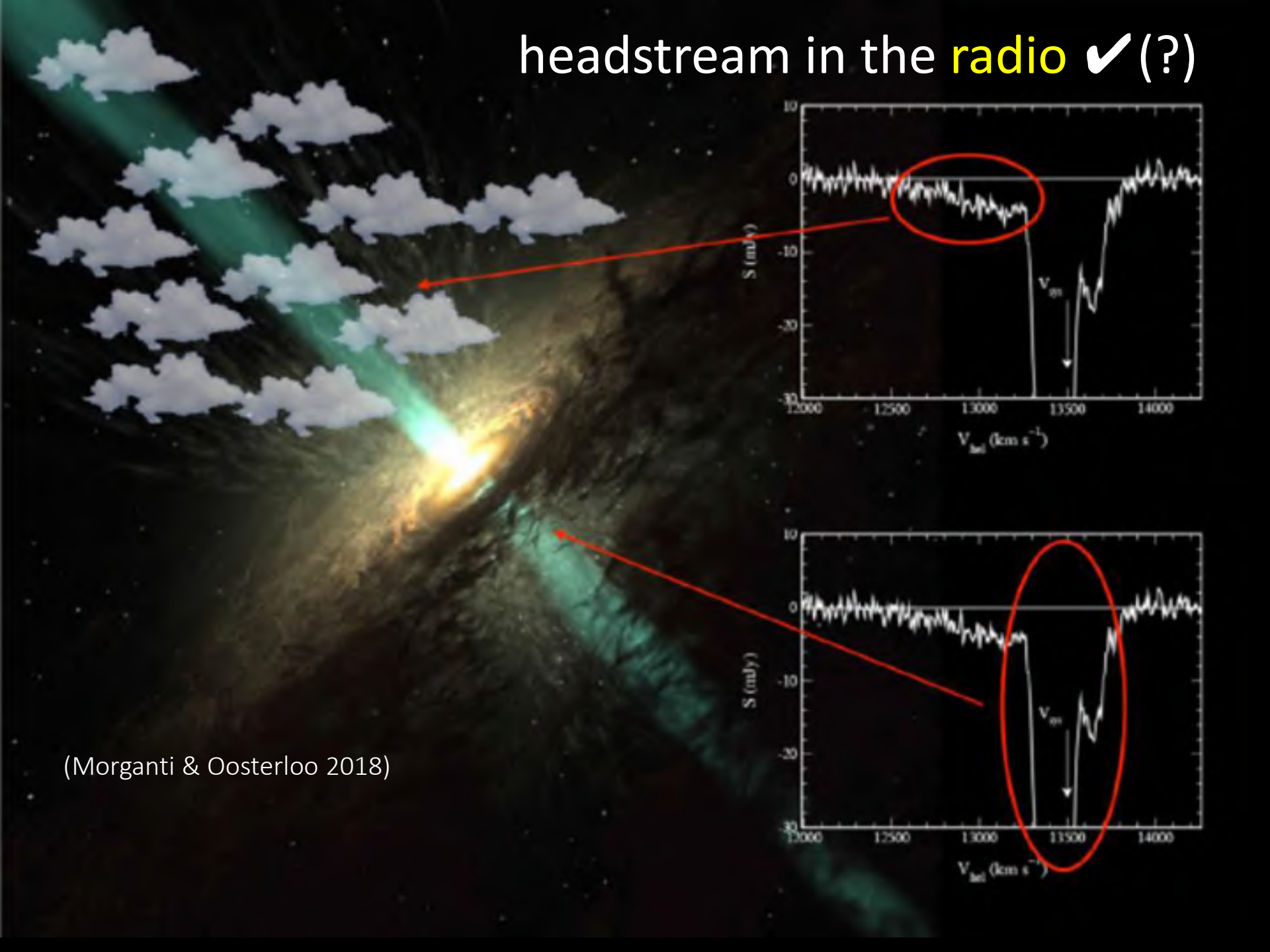


headstream in the radio ✓ (?)



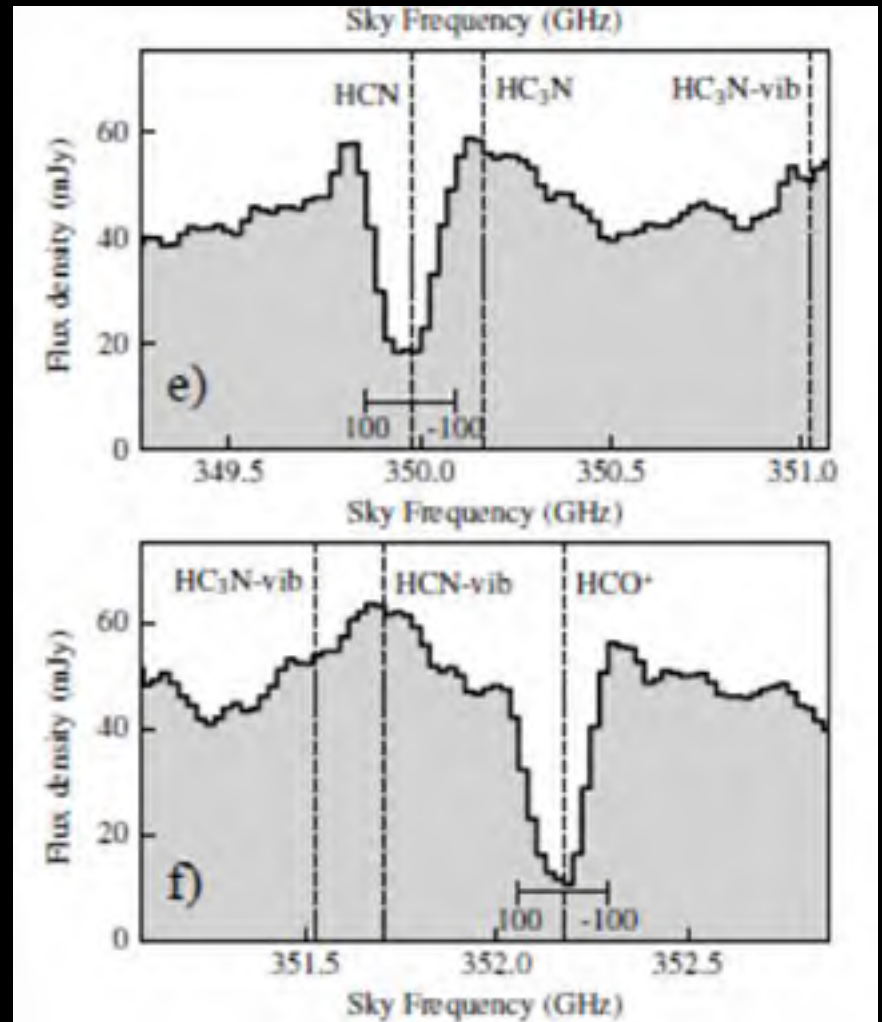
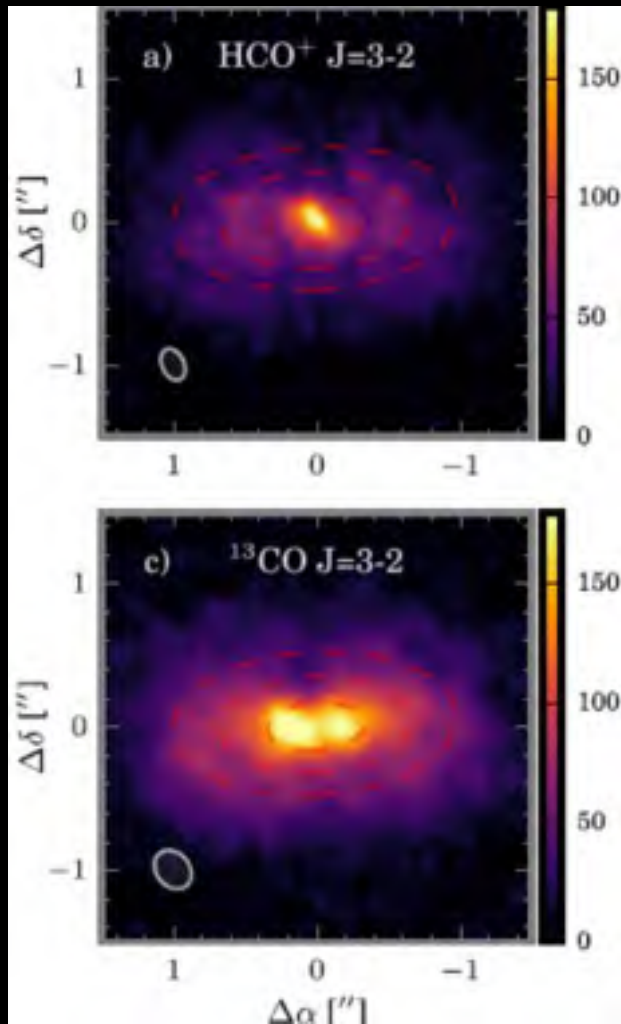
HST and VLBI image of NGC 4261 (Langevelde et al. 2000)

headstream in the **radio** ✓ (?)



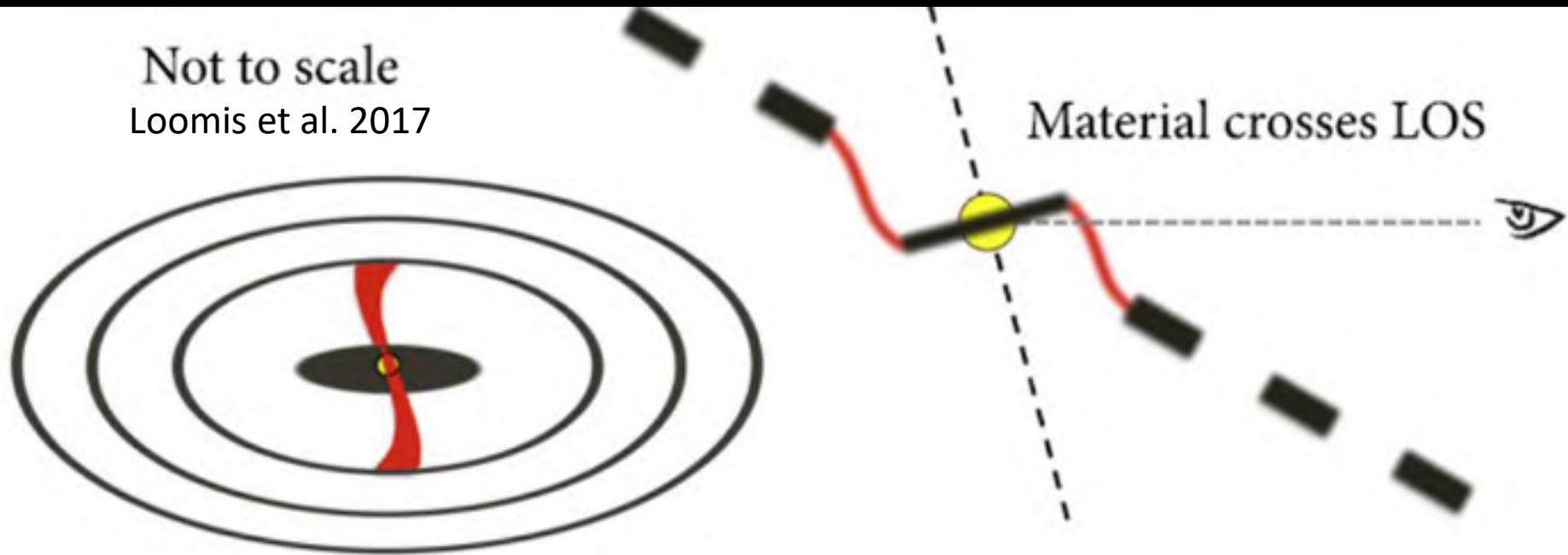
(Morganti & Oosterloo 2018)

headstream in the infrared ✓(?)

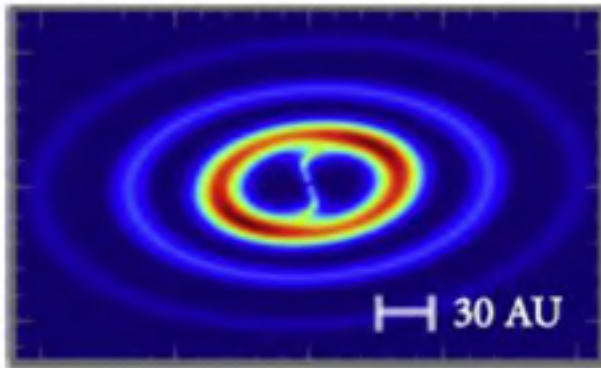


model & observation of stellar mass black holes

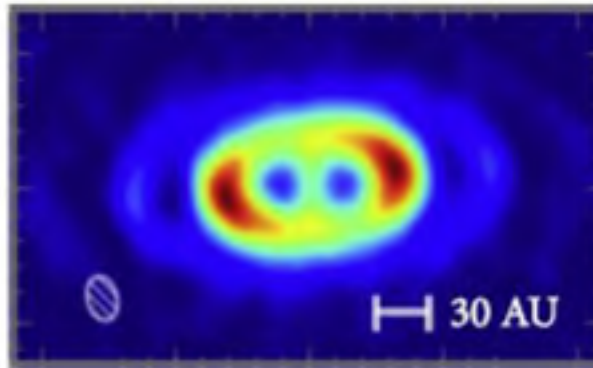
Not to scale
Loomis et al. 2017



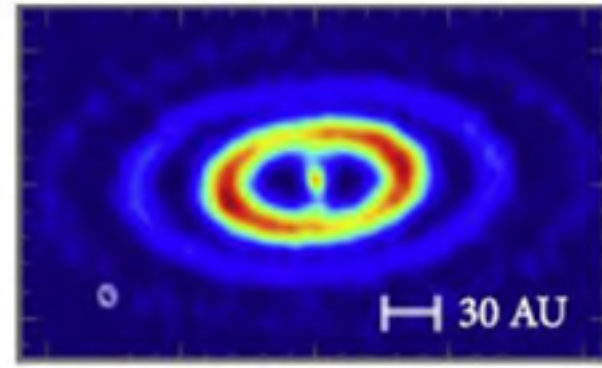
Modeled streamers



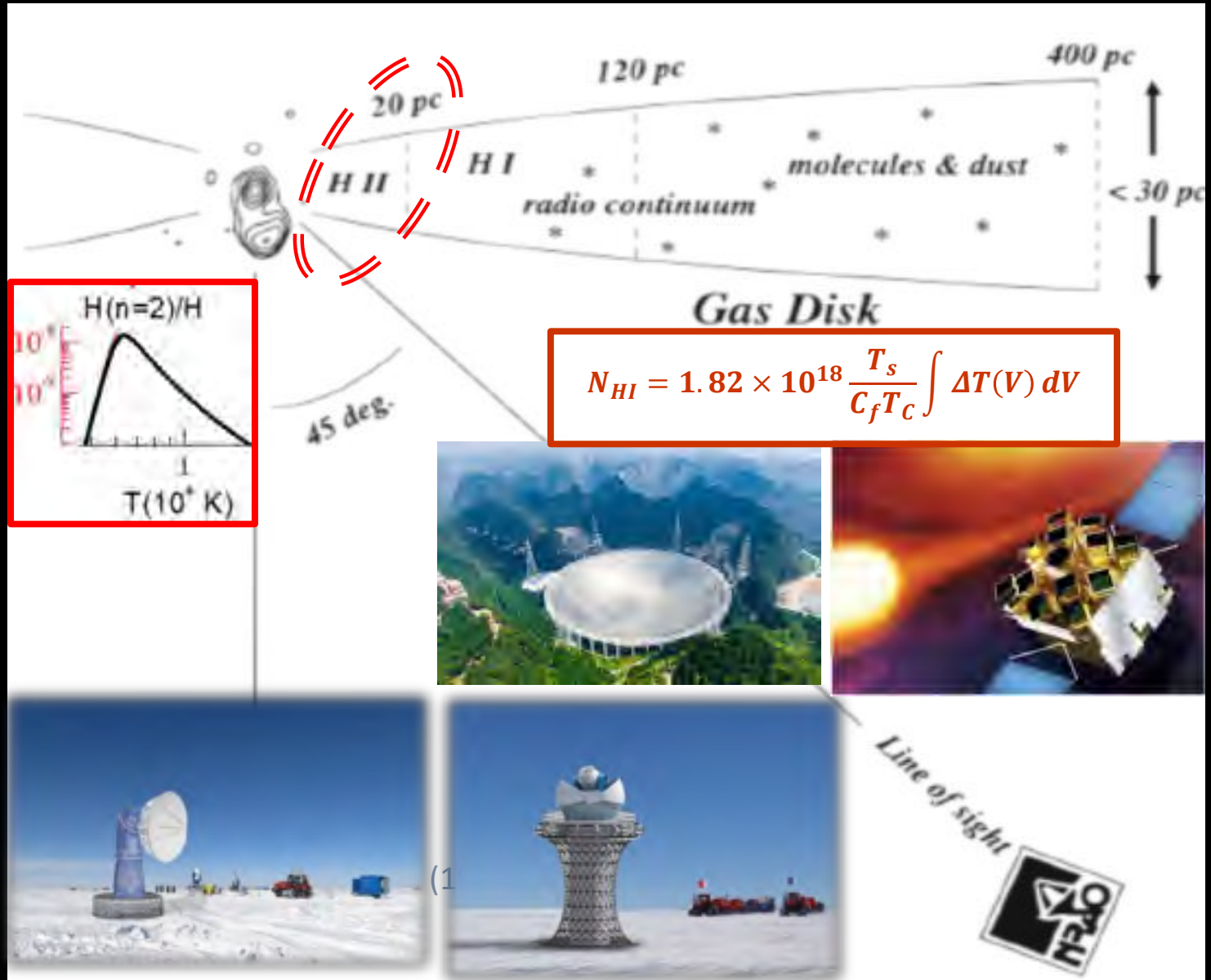
Sim. Obs.



High Res. Obs.



theories & observations of accretion flows



叶叔华院士寄语

2020年6月29日

我觉得南极天文台，不但是国家的一个重要基地，而且是各方面应用都可以使用的，而且它已经有很多年的基础，可以自动控制、自动传输，经验还是很丰富的。飞过两极的卫星非常多，其中有很多都是侦察卫星、军用卫星。除此之外，这个地点还可以作为以后的远程测控的一个基地。比方，我们飞到以后的深空探测，如果需要的话，这是唯一可用的一个最南端的观测点。所以我非常希望保留这个观测点，并且随着国家的应用加以发挥。















29° CHINARE
1223新选站址









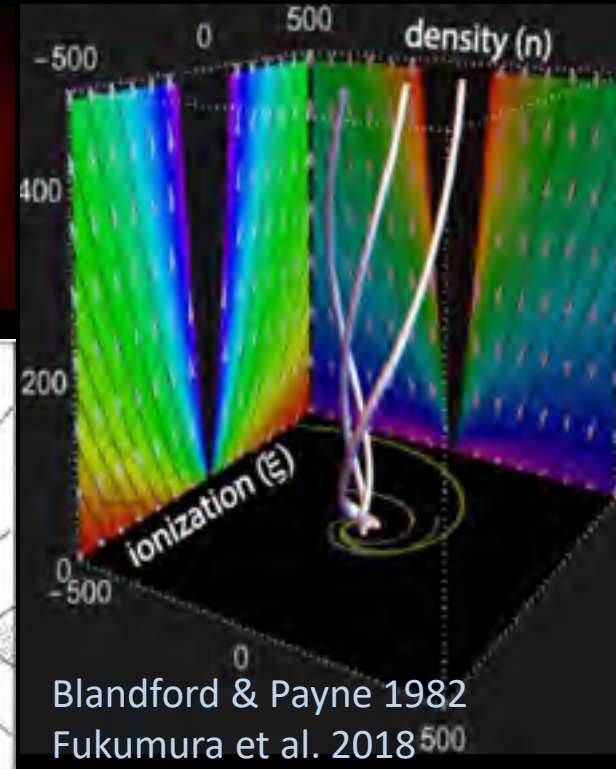
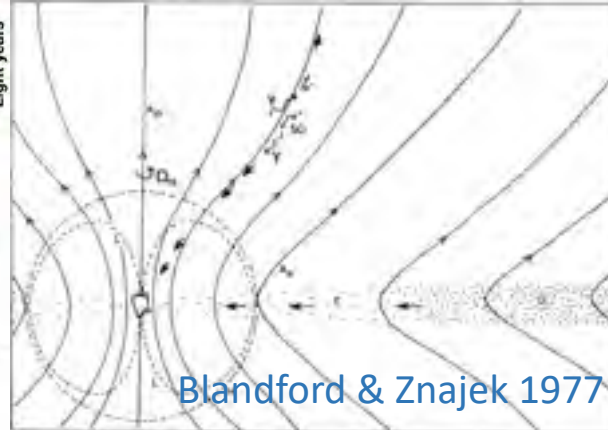
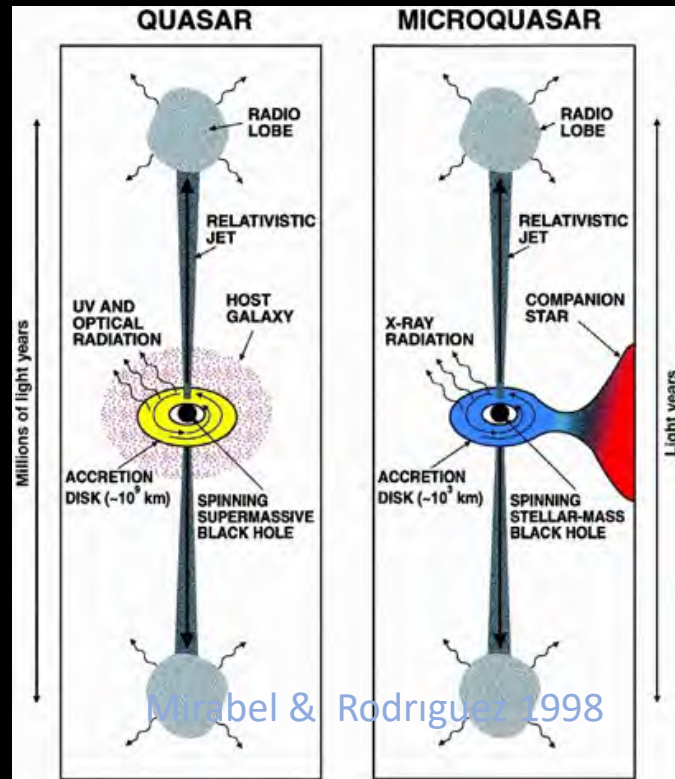






海上升明月，天涯共此时

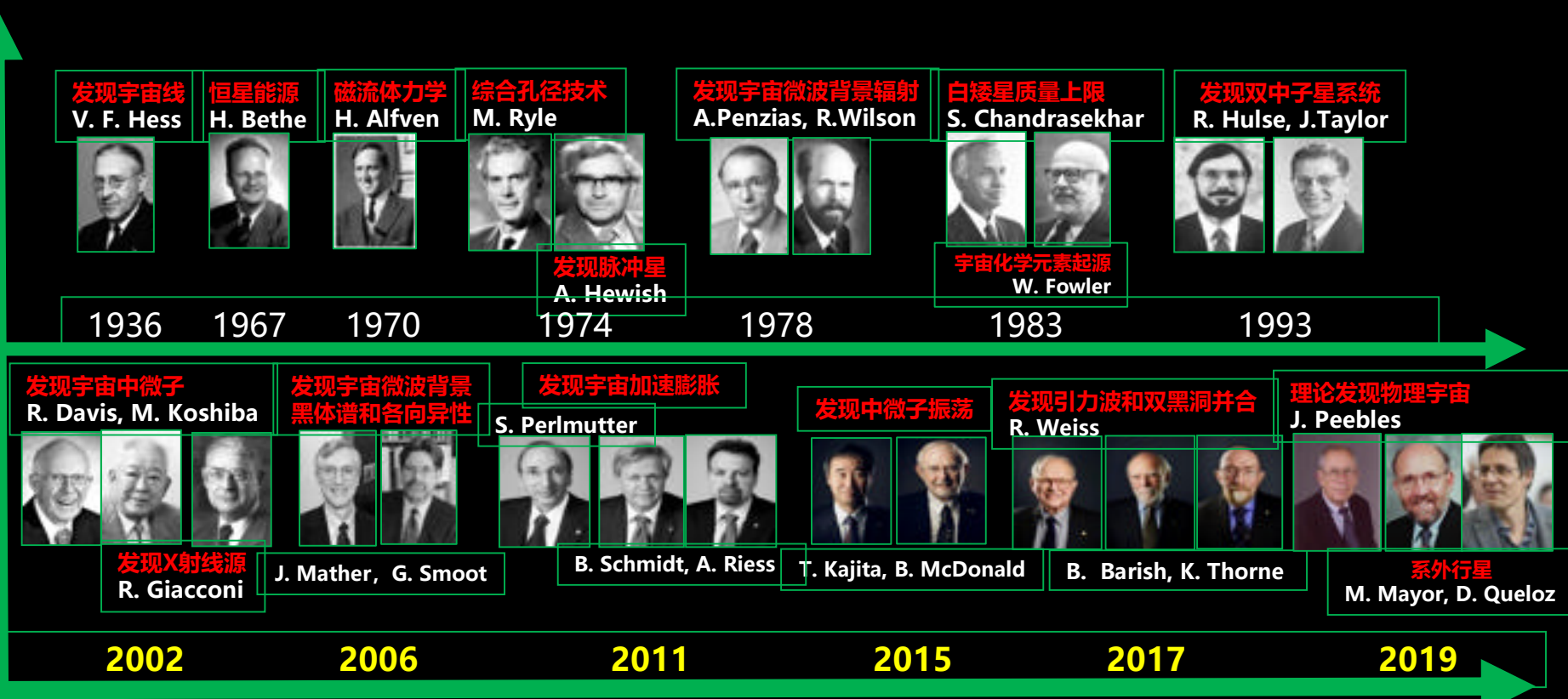
6. What next



天文学重大突破正在加速

1960-2010, 每5-10年获得1次诺贝尔物理学奖

2011-2019, 每2-3年获得1次诺贝尔物理学奖



- 习近平(2012): “空间天文和南极天文等重要前沿研究领域取得重要进展”

thanks!