Identification of SDSS J141324.27+530527.0 as a New “Changing-look” Quasar with a “Turn-on” Transition

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Abstract

We report an identification of SDSS J141324+530527.0 (SBS 1411+533) at \(z = 0.456344\) as a new “changing-look” quasar with a “turn-on” spectral type transition from Type-1.9/2 to Type-1 within a rest-frame timescale of \(1–10\) yr by a comparison of our new spectroscopic observation and the Sloan Digital Sky Survey (SDSS) archive database. The SDSS DR7 spectrum taken in 2003 is dominated by a starlight emission from host galaxy redward of the Balmer limit, and has a non-detectable broad \(\text{H}\beta\) line. The new spectrum taken by us on 2017 June 1 and the SDSS DR14 spectrum taken on 2017 May 29 indicate that the object has a typical quasar spectrum with a blue continuum and strong Balmer broad emission lines. In addition, an intermediate spectral type can be identified in the SDSS DR13 spectrum taken in 2015. The invariability of the line wing of Mg\(\text{II}\) emission and timescale argument (the invariability of \([\text{O III}]\lambda5007\) line blue asymmetry) suggests that a variation of obscuration (an accelerating outflow) is not a favorable scenario. The timescale argument allows us to believe the type transition is possibly caused by either a viscous radial inflow or a disk instability around a \(\sim(5–9) \times 10^7\) \(M_\odot\) black hole.

Key words: galaxies: active – galaxies: nuclei – quasars: emission lines – quasars: individual (SDSS J141324+530527)

Supporting material: data behind figure

1. Introduction

Based on their observational properties, active galactic nuclei (AGNs) are classified into various types. These types can be traditionally understood by the widely accepted unified model due to either the orientation effect of the dust torus (see Antonucci 1993 for a review), or the viewing angle of the jet with respect to the line of sight of an observer (Urry & Padovani 1995). The so-called Type-1 AGNs whose spectra show both broad (FWHM > 1000 km s\(^{-1}\)) and narrow (FWHM \(\sim 10^2\) km s\(^{-1}\)) Balmer emission lines are the objects associated with an almost face-on dust torus, while Type-2 AGNs with only narrow Balmer emission lines are the objects with an almost edge-on torus. In addition to Type-1 and 2 AGNs, there are intermediate AGN types, i.e., Type-1.5, 1.8 and 1.9 AGNs. In Type-1.5 AGNs, the broad \(\text{H}\beta\) emission line is strong and there is an evident reflection in the \(\text{H}\beta\) line profile. The objects with weak and absent broad \(\text{H}\beta\) lines are classified as Type-1.8 and 1.9 AGNs, respectively (e.g., Osterbrock & Ferland 2006). In the context of the unified model, the intermediate type AGNs are explained by either partial obscuration (e.g., Stern & Laor 2012) or light scattering of the emission from the central engine (e.g., Antonucci & Miller 1985). Besides the unified model, some previous studies argued that the Type-1 and 2 AGNs are caused by an evolution of central supermassive black holes (SMBHs, e.g., Penston & Perez 1984; Wang & Zhang 2007; Elitzur et al. 2014).

With repeat spectroscopic observations, a few AGNs have been found to change their spectral types on a timescale of the order of years; these are the so-called “changing-look” AGNs (CL AGNs). Both “turn-on” and “turn-off” type transitions have been identified in previous studies. Some identified CL AGNs include: Mark 1018, Mark 590, 3C 390.3, NGC 2617, NGC 4151, SDSS J015957.64+003310.5, SDSS J101152.98+544206.4, and SDSS J155440.25+362952.0 (e.g., Shapovalova et al. 2010; Shappee et al. 2014; LaMassa et al. 2015; McLlroy et al. 2016; Runnoe et al. 2016; Gezari et al. 2017). Yang et al. (2017) recently identified 21 new CL AGNs within a redshift range from 0.08 to 0.58 from either repeat spectroscopic observations of both Sloan Digital Sky Survey (SDSS) and Large Sky Area Multi-Object Fiber Spectroscopic Telescope, or photometric variations followed by new spectroscopic observations. Additionally, 2 and 10 new CL quasars have been identified by Ruan et al. (2016) and MacLeod et al. (2016), respectively, through similar methods.

The origin of CL AGNs is still under debate. There are several possible explanations: (1) a variation of the obscuration if the torus has a patchy configuration (e.g., Elitzur 2012); (2) a variation of SMBH accretion rate that resulted from the secular evolution or instability (e.g., Elitzur et al. 2014; Gezari et al. 2017; Sheng et al. 2017; Yang et al. 2017); (3) an accelerating outflow launched from the central SMBH, adopted to understand the type transition that occurred in NGC 4151 (e.g., Shapovalova et al. 2010); and (4) a tidal disruption event (TDE) caused by an accretion of the material of a star disrupted by the gravity of a central SMBH (e.g., Merloni et al. 2015; Blanchard et al. 2017).

The study of type transition phenomena in AGNs is of particular importance. At first, in addition to being a challenge to the widely accepted unified AGN model, the “turn-on” phenomenon enables us to study the accretion physics around central SMBHs. Second, both “turn-off” and “turn-on” phenomena provide us with an ideal case for studying the host galaxy of a luminous AGN whose light from the host galaxy is overwhelmed by the luminous radiation emitted from the central accretion disk, which is necessary for studying the coevolution of the SMBH and its host galaxy, especially at...
high redshift (see a recent review in Heckman & Best 2014). Finally, the frequency of the “turn-off” phenomenon has been suggested to restrict the lifetimes of AGNs (Martini & Schneider 2003).

In this paper, we report SDSS J141324.27+530527.0 (SBS 1411+533) as a new CL quasar with a “turn-on” type transition on a rest-frame timescale of \(\sim 1\)–10 yr. The paper is organized as follows. Section 2 describes our new spectroscopic observation and identification of the type transition phenomenon. A spectral analysis is presented in Section 3. A discussion and conclusions are given in the last section. A \(\Lambda\)CDM cosmology with parameters \(H_0 = 70\) km s\(^{-1}\) Mpc\(^{-1}\), \(\Omega_m = 0.3\), and \(\Omega_\Lambda = 0.7\) (Spergel et al. 2003) is adopted throughout the paper.

## 2. Observation and Identification

The “turn-on” type transition of SDSS J141324.27+530527.0 (with a brightness of \(r' = 19.87\) at \(z = 0.456344\)) was serendipitously discovered when we performed a spectroscopic re-observation on a sample of quasars at \(z \sim 0.5\) with hybrid spectroscopic properties selected from SDSS Data Release 6 (Wang & Wei 2009 and references therein) to study the coevolution issue of SMBHs and their host galaxies. The spectra of these hybrid quasars taken by SDSS DR6/7 are dominated by a starlight emission from host galaxies redward of the Balmer limit and by an evident Mg\(\text{II}\) \(\lambda2800\) emission at the blue end.

### 2.1. New P200 Spectroscopic Observation

The new spectroscopic observation was carried out with Palomar observatory Hale 5 m (P200) telescope on 2017 June 1st. Both the blue and red cameras of the DoubleSpec spectrograph were used in our observation. A grating with 600 line mm\(^{-1}\), along with a slit of 1” oriented in the south–north direction, was adopted for both cameras, which provided us with a spectral resolution \(\sim 3\) Å, as measured from the telluric emission lines and comparison arcs. This spectral resolution is comparable with the previous observations taken by SDSS. In order to cover both the Mg\(\text{II}\)\(\lambda2800\) emission line and the 4000 Å break for the objects listed in our sample, the blazed wavelength was fixed at 5000 Å for the blue camera. The blazed wavelength was fixed at 8500 Å for the red one to cover the H\(_\alpha\) emission line. In order to enhance the signal-to-noise ratio and to easily eliminate the contamination of cosmic rays, the object was observed with 7 frames, with an exposure time of 1200 s for each frame. The average airmass and seeing are 1.2 and 1″0, respectively, during the observation. The wavelength calibration was carried out by the iron–argon comparison arc for the blue camera and by the helium–neon–argon comparison arc for the red one. The observed flux was calibrated by the Kitt Peak National Observatory standard stars BD 284211 and Feige 34 (Massey et al. 1988).

### 2.2. Data Reduction

The two-dimensional spectra in both cameras were reduced by standard procedures through the IRAF package,\(^3\) including bias subtraction, flat-field correction, and image combination, along with cosmic-ray removal before the extraction of the one-dimensional spectra. The extracted spectra in both cameras were then calibrated in wavelength and flux by the corresponding comparison arc and standards. The A-band telluric feature around \(\lambda\lambda7600-7630\) due to O\(_2\) molecules was removed from the observed spectrum by the standard. The Galactic extinction was corrected by the extinction magnitude of \(A_V = 0.023\) (Schlafly & Finkbeiner 2011) taken from the NASA/IPAC Extragalactic Database (NED), assuming the \(R_V = 3.1\) extinction law of our Galaxy (Cardelli et al. 1989). The spectrum was then transformed to the rest-frame, along with the correction of the relativity effect on the flux, according to its redshift.

\(^3\) IRAF is distributed by the National Optical Astronomical Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
2.3. Identification of a “Turn-on” Type Transition

Figure 1 shows the rest-frame P200 spectrum of the object, along with the three previous spectra taken by SDSS at different epochs. As an additional illustration, Figure 2 compares the four spectra for the H\textalpha, H\beta, and H\gamma emission lines, after the AGN’s continuum and underlying starlight emission are removed (see Section 3.1 for details). One can see from the comparison in both figures that the P200 spectrum is highly consistent with the SDSS DR14 spectrum taken on 2017 May 29. Both spectra show that the object can be classified as a typical Type-1 AGN (e.g., Vanden Berk et al. 2001), with the dominant AGN’s continuum at the blue end and evident broad Balmer emission lines, especially the H\beta and H\gamma broad lines. In contrast to the two spectra taken in 2017, the spectrum taken by SDSS DR6/7 on 2003 May 2 shows not only a quite weak AGN continuum, but also an absence of H\beta and H\gamma broad emission lines, which strongly suggests that the object has either a Seyfert 2 or 1.9-like spectrum. In addition, compared with the 2017 and 2003 spectra, an intermediate spectral type can be identified for the SDSS DR13 spectrum taken on 2015 October 08. In the 2015 spectrum, the 4000 Å features are clearly diluted by the increased AGN’s continuum, and there is, if any, a considerably weak H\beta broad emission line.

In summary, with the four spectra taken at different epochs, we clearly see a “turn-on” type transition occurring in SDSS J141324+530527, in which its spectral type changes from Type-2/1.9 to Type-1 within a rest-frame timescale of 1–10 yr.

3. Spectral Analysis

In this section, we perform a spectral analysis on the spectra taken at the four different epochs to shed a light on the “turn-on” transition occurring in the object.
modeling because of its weakness in all the spectra. The theoretical template (Bruhweiler & Verner 2008) of the ultraviolet Fe II complex giving the best fit to the observed I Zw1 spectrum is used in our continuum modeling. The line width of the template is fixed in advance to be that of the broad component of Hβ, which is determined by our line profile modeling (see below).

The template of the Balmer continuum $f_{BC}$ is built from the emission from a partially optically thick cloud with an electron temperature of $T_e = 1 \times 10^4$ K by following Dietrich et al. (2002, see also in Grandi 1982 and Malkan & Sargent 1982):

$$f_{\lambda}^{BC} = f_{\lambda}^{BE} B_{\lambda}(T_e)(1 - e^{-\tau}) \lambda \leq \lambda_{BE}$$  \hspace{1cm} (1)

where $f_{\lambda}^{BE}$ is the continuum flux at the Balmer edge $\lambda_{BE} = 3646$ Å and $B_{\lambda}(T)$ is the Planck function. $\tau_{\lambda}$ is the optical depth at wavelength $\lambda$, which is related to the one at the Balmer edge $\tau_{BE}$ as $\tau_{\lambda} = \tau_{BE}(\lambda/\lambda_{BE})^3$. A typical value of $\tau_{BE} = 0.5$ is adopted in the current modeling.

The high-order Balmer lines (i.e., H7-H50) are modeled by the case B recombination model with an electron temperature of $T_e = 1.5 \times 10^4$ K and an electron density of $n_e = 10^{8-10}$ cm$^{-3}$ (Storey & Hummer 1995). The widths of these high-order Balmer lines are, again, determined from the line profile modeling of the Hβ broad emission (see below).

### 3.2. Line Profile Modeling

After removing the underlying continuum, the emission line profiles are modeled on each emission-line-isolated spectrum for both Hα and Hβ regions by the SPECFIT task (Kriss 1994) in the IRAF package. The profile modeling of the Hα region is
abandoned for the P200 spectrum because of its poor S/N at the red end. The flux of \([\text{O III}]\lambda5007\) emission line of the SDSS DR7 spectrum is obtained from a direct integration. In the profile modeling, each \([\text{O III}]\lambda5007\) line profile is modeled by a sum of two Gaussian functions. In addition to the narrow component with a width of several hundreds of \(\text{km s}^{-1}\), a broad and blueshifted component is usually required to reproduce the observed \([\text{O III}]\) line profile in AGNs (e.g., Boroson 2005; Wang et al. 2011, 2016, 2018, Zhang et al. 2013; Harrison et al. 2014; Woo et al. 2017 and references therein). The line flux ratios of the \([\text{O III}]\lambda4959, 5007\) and \([\text{N II}]\lambda6548, 6583\) doublets are fixed to their theoretical values. Two Gaussian profiles, a broad and a narrow component, are required to adequately reproduce the \(\text{H}\alpha\) line profiles in the two SDSS spectra taken in 2015 and 2017. One broad component is sufficient to reproduce the observed \(\text{H}\beta\) line profiles adequately in both spectra taken in 2017. The line modeling are presented in the left and right panels of Figure 4 for the \(\text{H}\beta\) and \(\text{H}\alpha\) regions, respectively. The results of the spectral modeling are listed in Table 1. No intrinsic extinction correction is applied to all the derived line fluxes, both because the traditionally used method based on the Balmer decrement of narrow emission lines is unavailable for the current spectra and because the Balmer decrement obtained from the broad emission lines is \(\text{H}\alpha/\text{H}\beta = 2.46 \pm 0.26\), which is close to the standard case B recombination (e.g., Dong et al. 2008). All the errors reported in the table correspond to the \(1\sigma\) significance level after taking into account the proper error propagation.

3.3. \([\text{O III}]\lambda5007\) and \(\text{Mg}\ ii\lambda2800\) Emission Line Profiles

The left panel in Figure 5 compares the \([\text{O III}]\lambda5007\) emission line profiles taken at four different epochs. In the comparison, the rest-frame line profile taken by P200 is convolved with a Gaussian function with a width of \(\sigma = \sqrt{\sigma_{\text{SDSS}}^2 - \sigma_{\text{P200}}^2}/(1 + z)\) to match the instrumental resolution of the P200 spectrum to that of the SDSS spectra, where \(\sigma_{\text{SDSS}}\) and \(\sigma_{\text{P200}}\) are the instrumental resolution at the observer frame, respectively, and \(z\) is the redshift of the object. The comparison clearly indicates that there is no detectable variation of the \([\text{O III}]\) line profile with a timescale of a dozen years. In fact, an extremely high consistence for the \([\text{O III}]\) line profile can be found for the SDSS 2015 and 2017 spectra in which the object changes its spectral type from type 1.8/1.9 to type 1.

In contrast to a lack of strong variation of \(\text{Mg}\ ii\lambda2800\) line emission for some CL AGNs (Gezari et al. 2017), a dramatic line profile variation can be identified for the \(\text{Mg}\ ii\) emission line in the right panel of Figure 5. When the spectral type changes from 1.8/1.9 to 1.0, the \(\text{Mg}\ ii\) line core emission increases significantly, although its high-velocity wings are still invariable.

3.4. Analysis

With the line profile modeling, we estimate both SMBH mass \(M_{\text{BH}}\) and Eddington ratio \(L/L_{\text{Edd}}\) (where \(L_{\text{Edd}} = 1.26 \times 10^{38}M_{\odot}/L_{\odot}\)) is the Eddington luminosity); these are critical parameters that describe AGN phenomena (e.g., Shen & Ho 2014 and references therein) using several calibrated relationships. These calibrations enable us to estimate \(M_{\text{BH}}\) and \(L/L_{\text{Edd}}\) from different broad emission lines in single-epoch spectroscopy (e.g., Wu et al. 2004), thanks to the great progress made in the reverberation mapping technique (e.g., Kaspi et al. 2000, 2005; Peterson & Bentz 2006; Marziani & Sulentic 2012; Du et al. 2014, 2015; Peterson 2014; Wang et al. 2014).

For \(\text{H}\beta\) broad emission line, we use the calibration in Vestergaard & Peterson (2006),

\[
M_{\text{BH}} = 10^{6.67} \left( \frac{L_{\text{H}\beta}}{10^{42} \text{ erg s}^{-1}} \right)^{0.63} \left( \frac{\text{FWHM}(\text{H}\beta)}{1000 \text{ km s}^{-1}} \right)^{-2} M_{\odot},
\]

(2)

to obtain an estimation of \(M_{\text{BH}}\). The bolometric luminosity \(L_{\text{bol}}\) is then estimated from the standard bolometric correction \(L_{\text{bol}} = 9L_{\lambda}(5100 \text{ Å})\) (Kaspi et al. 2000), where \(L_{\lambda}(5100 \text{ Å})\) is the AGN’s specific continuum luminosity at 5100 Å, which can be inferred from \(\text{H}\beta\) broad-line luminosity through the calibration given in Greene & Ho (2005)

\[
L_{\lambda}(5100 \text{ Å}) = 7.31 \times 10^{41} \left( \frac{L_{\text{H}\beta}}{10^{42} \text{ erg s}^{-1}} \right)^{0.883} \text{ erg s}^{-1}.
\]

(3)

In the case of the \(\text{H}\alpha\) broad emission line, \(M_{\text{BH}}\) is estimated from the calibration provided in Greene & Ho (2007),

\[
M_{\text{BH}} = 3.0 \times 10^{6} \left( \frac{L_{\text{H}\alpha}}{10^{42} \text{ erg s}^{-1}} \right)^{0.45} \left( \frac{\text{FWHM}(\text{H}\alpha)}{1000 \text{ km s}^{-1}} \right)^{-2.06} M_{\odot},
\]

(4)

and the luminosity at 5100 Å is estimated from the \(L_{\lambda}(5100)\)–\(L_{\text{H}\alpha}\) relationship in Greene & Ho (2005),

\[
L_{\lambda}(5100 \text{ Å}) = 2.4 \times 10^{43} \left( \frac{L_{\text{H}\alpha}}{10^{42} \text{ erg s}^{-1}} \right)^{0.86} \text{ erg s}^{-1}.
\]

(5)

The estimated \(M_{\text{BH}}\), bolometric luminosity \(L_{\text{bol}}\), and \(L/L_{\text{Edd}}\) are tabulated in Table 1. In the estimation, the used \(\text{H}\alpha\) and \(\text{H}\beta\) line fluxes are calibrated by a constant total flux of \([\text{O III}]\lambda5007\) of the SDSS DR14 spectrum, because of the invariability of the \([\text{O III}]\) line profile shown in Section 3.2. The resulted \(L_{\text{bol}}\) \((>10^{44} \text{ erg s}^{-1})\) enables us to classify SDSS J141324+530527 as a quasar with an \(M_{\text{BH}}\) of \((5–9) \times 10^{7} M_{\odot}\) at a moderate \(L/L_{\text{Edd}} \sim 0.1\).

4. Conclusion and Discussion

By comparing the new optical spectrum taken by the P200 telescope on 2017 June 1 and three previous spectra taken by SDSS, we report SDSS J141324+530527 as a new CL quasar (\(z = 0.456344\) and \(M_{\text{BH}} \sim (5–9) \times 10^{7} M_{\odot}\)) with a “turn-on” type transition from Type-2/1.9 to Type-1 within a rest-frame timescale of \(1–10\) yr.

We argue that the variation of obscuration is a disfavored explanation for the type transition observed in the object, based on the timescale argument. A crossing time can be estimated from Equation (4) in LaMassa et al. (2015) for the obscuration material orbiting outside the BLR on a circular, Keplerian orbit as

\[
t_{\text{cross}} = 0.07 \left( \frac{r_{\text{orb}}}{11d} \right)^{3/2} \sin^{-1} \left( \frac{r_{\text{src}}}{r_{\text{orb}}} \right) \left( \frac{M_{\text{BH}}}{10^{7} M_{\odot}} \right)^{-1/2},
\]

(6)

where \(r_{\text{orb}}\) and \(r_{\text{src}}\) are the orbital radius of the obscuration material and the true size of the BLR, respectively. The characteristic radius of BLR, \(R_{\text{BLR}}\), is estimated to be \(
\sim 47\) days from the \(\text{H}\beta\) line luminosity through a combination of Equation (2) and
the radius–luminosity relationship \( \log(\frac{R_{\text{BLR}}}{1 \text{d}}) = 1.559 + 0.549 \log(\lambda L_{\lambda}(5100 \, \text{Å})/10^{44} \text{ erg s}^{-1}) \) given in Bentz et al. (2013), which yields a \( t_{\text{cross}} > 42 \, \text{yr} \) when \( M_{\text{BH}} = 7 \times 10^8 M_\odot \) and \( r_{\text{orb}} = R_{\text{BLR}} \) are adopted. This crossing timescale is obviously larger than the type transition time observed in the object. The disapproval of the obscuration scenario is further supported by the observed line profile variation of the Mg II \( \lambda 2800 \) emission line profile. For BLR gas in a circular, Keplerian orbit around the central SMBH, the line wings are produced by the emission from the high-velocity gas at the inner part of the BLR, and the line core of the low-velocity gas at the outer part. This configuration suggests that the strengths of line wings are more sensitive to the obscuration than the line core, which is, however, in contradiction with the observed line profile variation.

The scenario of an accelerating outflow also seems to be disfavored, because of the invariability of the blue asymmetry of the \([\text{O III}] \lambda 5007 \) line profile, which is usually used as an assessment of the strength of the outflow in AGNs (e.g., Wang et al. 2018 and references therein).

Another considered mechanism of AGN’s spectral type transition is the TDE in which a star close enough to the SMBH is disrupted and about half of the material of the star is accreted by the SMBH to rapidly increase accretion rate (e.g., Rees 1988). However, both 2017 spectroscopic observations taken at the “turn-on” phase suggest that the spectra of the
Follow-up observations, especially the photometry observations, are useful for determining the truth about TDE in the object. The brightness of the TDE typically follows a $t^{-5/3}$ power-law decay with a timescale...

Table 1

| Property          | SDSS DR7 | SDSS DR13 | SDSS DR14 | P200  |
|-------------------|----------|-----------|-----------|-------|
| epoch             | 2003 May 02 | 2015 Oct 08 | 2017 May 29 | 2017 Jun 01 |
| AGN type          | 1.9/2.0 | 1.8/1.9 | 1.0       | 1.0   |
| F([O III]λ5007)   | $0.90 \pm 0.07$ | $1.22 \pm 0.05$ | $1.34 \pm 0.04$ | $0.93 \pm 0.20$ |
| $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ | ... | ... | ... | ... |
| F(H$\beta$)       | ... | $0.39 \pm 0.04$ | $3.05 \pm 0.14$ | $2.00 \pm 0.18$ |
| FWHM(H$\beta$)    | ... | $2780 \pm 220$ | $2900 \pm 160$ | $2900 \pm 60$ |
| F([H$\alpha$])    | ... | $3.64 \pm 0.19$ | $7.49 \pm 0.70$ | ... |
| $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ | ... | ... | ... | ... |
| FWHM([H$\alpha$]) | ... | $3610 \pm 230$ | $3640 \pm 220$ | ... |
| $M_{\text{BH}}/M_{\odot}$ | ... | $6.8 \times 10^7$ | $6.1 \times 10^7$ | ... |
| $L_{\text{bol}}$ | ... | $7.0 \times 10^7$ | $9.5 \times 10^7$ | ... |
| $L_{\text{bol}}/L_{\text{Edd}}$ | ... | ... | $1.4 \times 10^{45}$ | $1.2 \times 10^{45}$ |
| $L_{\text{bol}}/L_{\text{edd}}$ | ... | ... | 0.16 | 0.16 |

Note.

* For each property, the first line is based on the measurements of H$\beta$ broad emission lines, and the second line is based on the measurements of H$\alpha$ emission lines.

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Facility: Palomar Hale 5 m Telescope.

Software: IRAF (Tody 1986, 1993).

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