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Multiwavelength search for the first blazars

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Abstract: High redshift massive protogalaxies, the sites of early star formation in the Universe, provided a suitable environment for the formation of the first supermassive black holes. Mass accretion causes the black hole to grow and become a gamma-ray blazar for those observers privileged by a line of sight parallel to the jet. Possible evolutionary sequences are explored in terms of their visibility in the millimeter, optical and gamma-ray regimes.

The epoch of galaxy formation

Over ten years ago we learned that most of the star formation in the Universe took place at redshifts $z \lesssim 2$ [16]. Newer evidence now shows that massive systems were already assembled and in vigorous stages of star formation beyond $z = 6$, as evidenced by *Spitzer* [18] and submillimeter surveys [20]. Mid infrared and sub-millimeter surveys sample star formation in the high redshift Universe benefiting from the stellar and dust emissions entering the respective spectral bands. So while the *Spitzer* data evidences the existence of stellar populations at high redshifts [18], in particular a burst having produced $6 \times 10^{11}\,\mathrm{M}_\odot$ within 1 Gyr, millimeter and sub-millimeter surveys have proven the existence of large amounts of dust when the Universe was younger than 1 Gyr [20]. New instruments, like the Large Millimeter Telescope (Gran Telescopio Milimétrico, LMT/GTM) have the potential of peering beyond $z \gtrsim 10$ into the first stages of star formation history [12, 21].

Analysis of the angular scales of mid infrared background fluctuations in the HST Deep Field North as observed by *Spitzer* suggests that primordial overdensities could have grown in the first 100 Myrs of cosmic time ($z \gtrsim 25$), with stellar burning getting widespread when the Universe was as young as 200 Myr ($z \sim 18$) [14, 15]. The classical "Madau plot" suggested that the peak of star formation occurred at $z \sim 2$, when the Universe was about 3 Gyr old [16]. This scenario has been revised considering sub-millimeter observations and the effects of extinction in the optical and infrared, leading to a more sustained star formation rate as a function of redshift [7], consistent with the finding of the massive starburst by *Spitzer* at $z \gtrsim 6.5$, when the Universe was some 800 Myr old. The mass assembly rate of this particular object was at least 750 $\mathrm{M}_\odot \mathrm{yr}^{-1}$, and maybe as high as 1200 $\mathrm{M}_\odot \mathrm{yr}^{-1}$ if one takes into consideration the $z > 9$ redshift of the best fit population synthesis models in [18].

The early Universe must have experienced an extremely rapid phase of turn-on of star formation, as pictured in figure 1. The actual date of onset and duration are likely to have depended on the local overdensity, say as $t \propto \delta\rho^{-1/2}$, with the largest density fluctuations growing at rates $> 1000\,\mathrm{M}_\odot \mathrm{yr}^{-1}$ during the first Gyr and most of the activity ongoing for the next 2 Gyr.

The epoch of black hole formation

A close relationship exists between star formation and nuclear activity, as it was established almost a decade ago [5]. Star formation produces stellar mass black holes and stimulates their growth by stirring the interstellar medium, stimulating the accretion process. The first natural hypothesis is that things occur in a similar manner at the largest redshifts and that the galaxy formation process includes somehow the creation of a black hole and

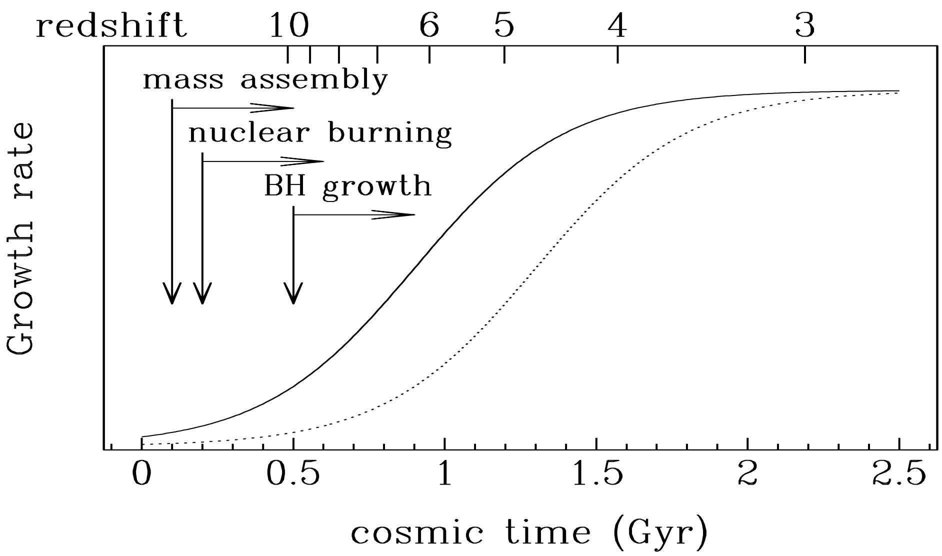

Figure 1: A fictitious galaxy and black hole formation scenario consistent with observational evidence. Half of star formation in galaxies occurs when the Universe is 0.9 Gyrs old, with a characteristic growth time of 0.5 Gyrs. Black hole formation follows the same pattern with a delay of 0.4 Gyrs.

an active nuclei. The link must be rather generic as pointed by the evidence of central black holes (BH) in most present day galaxies. The first generation of stars, the so-called population III, were able to produce black holes with masses in the range or in excess of 100 $M_{\odot}$ which acted as seeds for future supermassive black holes (SMBHs) [22].

Very high redshift quasars, up to $z \gtrsim 6$, have been found as a result of the Sloan Digital Survey [9], with most of these quasars showing evidence for the presence of heated dust [13]. We currently believe that most of the initial star formation in the Universe took place in systems highly obscured by dust, the now called submillimeter massive galaxies (SMGs). There is observational evidence for the formation of active nuclei inside these systems [2]. Feeding the seed BHs in these systems is complicated by the need of efficiently removing the angular momentum of the mass been accreted and the details of the process remain unclear. One efficient way to remove angular momentum is through the formation of a jet, with the mass ejecta acquiring the angular momentum of the matter falling into the black hole [3].

The observed mass ratio between the most massive protogalaxies and the most massive SMBHs is of the order of 1/1000, leading us to consider a scenario in which a similar fraction of the mass assembled is channelled to the seed black hole, of the order of 1 $M_{\odot}$/yr. If protogalaxy mass assembly started *before* the creation of the first BHs, these been the product of the initial phases of nuclear burning, we can introduce a delay of $\gtrsim 100$ Myrs between the beginning of the growth of the protogalaxies and the beginning of the growth of the SMBH, as expressed in figure 1. The growth of the BH requires capturing material from the interstellar medium, material ejected by subsequent generation of stars, with the channelling of this material to the BH resulting in a further delay in the BH growth. Still, the observational evidence for AGNs with $z > 6$, like in the Sloan Digital Survey, indicates that this delay cannot be higher than some 500 Myr [9, 8]. The tightness of this timing has recently prompted models where black hole formation proceeds *before* the onset of star formation through the direct collapse of protohaloes [1]. We infer the delayed growth of BHs in SMGs and the existence of high redshit blazars, defined as the subset of these active galaxies whose relativistic jet is pointed parallel to our line of sight.

Blazars became a major topic in high energy astrophysics with the discovery by EGRET on board *CGRO* of $E > 100$ MeV photons from more than 50 active galactic nuclei reaching up to $z \gtrsim 2$. These were more precisely identified with radio loud flat spectrum quasars[17], often with supraluminical motions denouncing a relativistic jet pointed towards the observers - us. The multiwavelength data and its fitting through leptonic and hadronic models led several authors to identify a blazar sequence. In particular Fossati et al. [10] proposed a sequence going from typical Flat Spectrum Radio Quasars (FSRQs) to radio and x-ray BL Lac objects. This sequence has been proposed to follow the reduction of accretion rate onto the SMBH with time [4], systematic changes in accretion rates [6] or a combination of orientation and intrinsic luminosity [11].

Searching the first blazars with LMT and *GLAST*

The Large Millimeter Telescope is a 50 meter antenna devoted to millimeter wave astronomy and located at the top of Sierra Negra, Mexico, its 4600m site [21]. Inaugurated by Mexican President Fox in November 2006, LMT is expected to see its first 3mm light in 2008 in order to start the exploration of the 80-345 GHz window. Because of its unprecedentedly large collecting area, LMT instruments will achieve sub-mJy fluxes in very short exposures - reaching the confusion limit of the telescope. The real strength of the telescope resides in the combination of sensitivity with large format heterodyne and continuum cameras, like SEQUOIA and AzTEC, which will make LMT the most powerful telescope for mapping the millimeter sky. One of the prime scientific goals of LMT is tracing the star formation history of the Universe.

SMGs show a dust-like ‘gray-body’ spectrum, which in the Rayleigh-Jeans regime follows a $F \propto \nu^{2+\beta}$ power law. This behavior becomes a powerful tool to search for high redshift galaxies, since it leads to a negative K-correction which maintains almost the same flux from a galaxy redshifted from $z = 2$ to a redshift up to $z \sim 10$, for dust with a temperature of 30–60 K. LMT will be able to detect thousands of protogalaxies per square degree, down to its confusion limits.

Identifying quasars inside these systems requires either hard to obtain spectra, not always unambiguous, or indirect evidence. In this respect finding a γ-ray source coincident with a dusty system would be unmistakable evidence in favor of BH formation in star forming dust obscured systems. In blazar systems the emission is restricted to a solid angle of $4\pi\ \eta$, with $\eta \sim 10^{-3}$ typically. This means on one hand that these systems are rare, but on the other hand finding one system implies the existence of many with different viewing angle and their emission is easier to find at larger distances due to the beaming.

The inminent launch of the *Gamma-ray Large Area Space Telescope (GLAST)* conveys the opportunity of seeking for high redshift blazars. *GLAST* will be over an order of magnitude more sensitive that EGRET, been able to reach photon fluxes down to $10^{-9}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $E > 100\,\mathrm{MeV}$. The extrapolation of the observed flux distribution from the sensitivity limit of EGRET to that of *GLAST* translates in the expectation of finding at least 2000 blazars - if there enough of these systems at high redshifts! How far will *GLAST* be able to reach? An AGN accreting 2 $M_\odot yr^{-1}$ and converting 1% of this into γ-rays emitted in a solid angle of $4\pi\ 10^{-2}$ sr can be detected by *GLAST* up to $z \approx 7.5$. Surveys from *GLAST* blazar candidates have already produced a promising 5.48 blazar candidate, now awaiting the γ-ray data to be acquired and tested [23, 19]. If a similar amount of power arises from star formation as reprocessed isotropic thermal emission, the corresponding flux in the millimeter band is of the order of tens of mJy, one order of magnitud above the 1σ flux sensitivity of LMT in *one second*. LMT will perform both deep and shallow surveys in search for high-redshift protogalaxies. The most interesting systems for searches in the *GLAST* data will be those with fluxes above tens of mJy found in the most extended surveys. LMT will have the possibility of searching for redshifts directly from the mm-wave data, making the redshift assesment unmistakable.

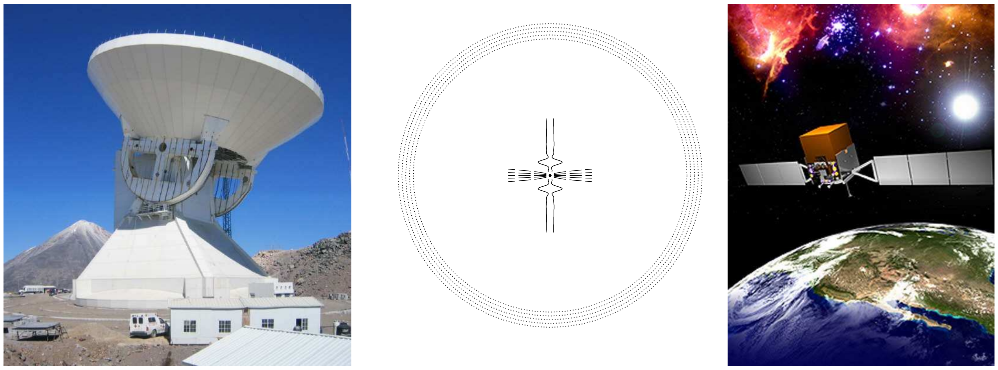

Figure 2: A blazar inside a dust enshrouded star forming galaxy observed by *GLAST* and LMT.

References

[1] M.C. Begelman, M. Volonteri, and M.J. Rees. . *MNRAS*, 370:289, 2006.

[2] A.W. Blain, A. Jameson, I. Smail, M.S. Longair, J.P. Kneib, and R.J. Ivison. . *MNRAS*, 309:715, 1999.

[3] R.D. Blandford and D.G. Payne. . *MNRAS*, 199:883, 1982.

[4] M. Böttcher and C. D. Dermer. An evolutionary scenario for blazar unification. *Astrophysical Journal*, 564:86–91, 2002.

[5] B.J. Boyle and R.J. Televich. . *MNRAS*, 293:49, 1998.

[6] A. Cavaliere and V. D'Elia. The blazar main sequence. *Astrophysical Journal*, 571:226–233, 2002.

[7] S.C. Chapman, A.W. Blain, I. Smail, and R.J. Ivison. . *ApJ*, 622:772, 2005.

[8] R.J. Cool et al. . *ApJ*, 132:823, 2006.

[9] X. Fan et al. . *AJ*, 125:1649, 2003.

[10] A. M. Fossati, L. Maraschi, A. Celotti, A. Comastri, and G. Ghisellini. A unifying view of the spectral energy distributions of blazars. *Mon. Not. R. Astron. Soc.*, 299:433–448, 1998.

[11] M. Georganopoulos. Blue quasars and blazar unification schemes. *Astrophysical Journal*, 543:L15–L18, 2000.

[12] D. Hughes and I. Aretxaga. . *RMAASC*, 24:144, 2005.

[13] L. Jiang et al. . *AJ*, 132:2127, 2006.

[14] A. Kashlinsky, R.G. Arendt, J. Mather, and S. Moseley. . *ApJ*, 654:L1, 2007.

[15] A. Kashlinsky, R.G. Arendt, J. Mather, and S.H. Moseley. . *ApJ*, 654:L5, 2007.

[16] P. Madau et al. . *MNRAS*, 283:1388, 1996.

[17] J.R. Mattox, R.C. Hartman, and O. Reimer. . *ApJS*, 135:155, 2001.

[18] X. Mobasher et al. . *ApJ*, 635:832, 2005.

[19] R. Romani. . *AJ*, 132:1959, 2006.

[20] D. Scott et al. . *AAS*, 209:125.04, 2006.

[21] A. Serrano Pérez-Grovas, F.P. Schloerb, D. Hughes, and M. Yun. . *SPIE*, 6267:1, 2006.

[22] S. Shapiro. . *ApJ*, 620:59, 2005.

[23] D. Sowards-Emmerd et al. . *ApJ*, 626:95, 2005.