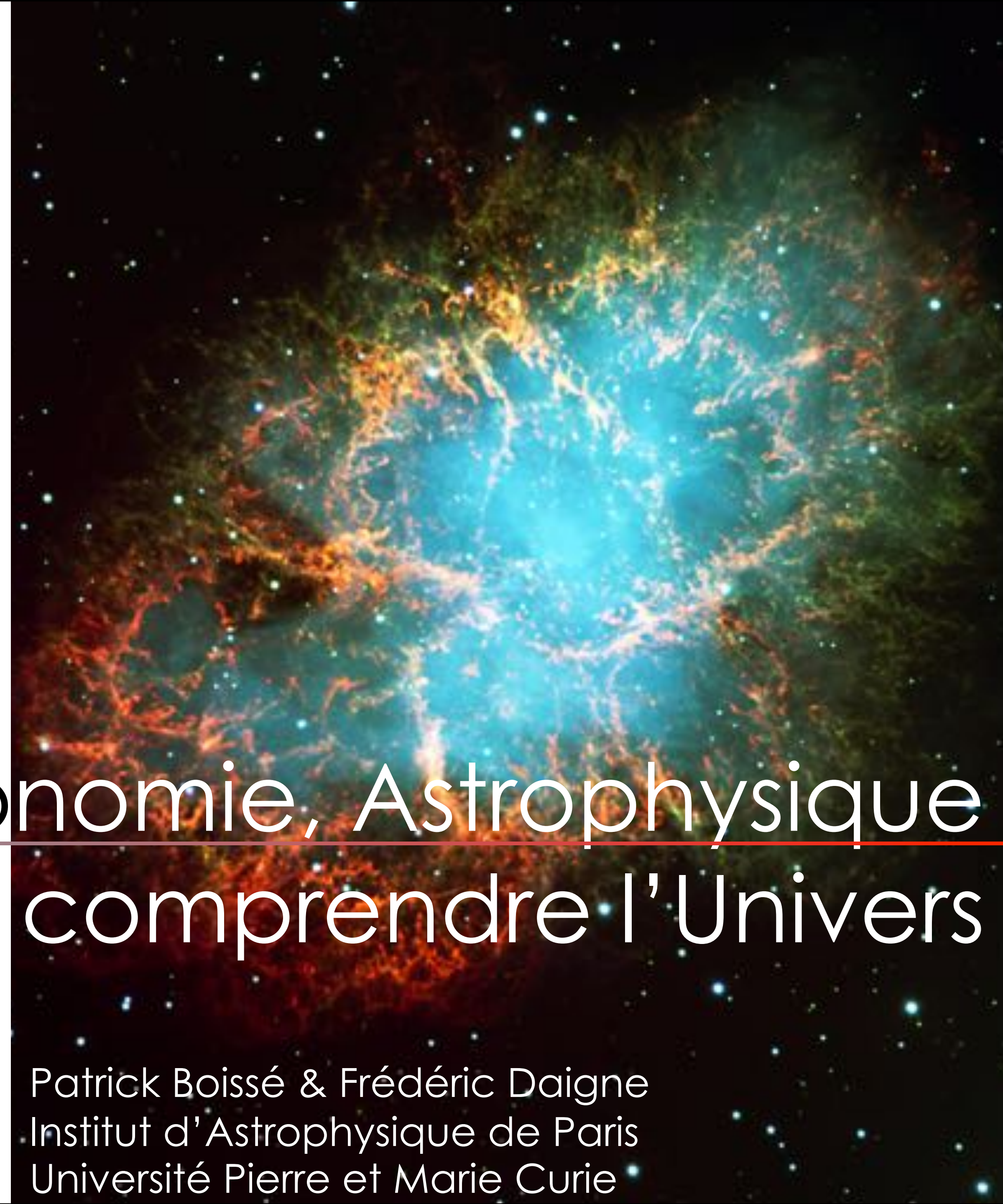


Astronomie, Astrophysique
Observer et comprendre l'Univers

Université inter-âges
Paris-Sorbonne

Patrick Boissé & Frédéric Daigne
Institut d'Astrophysique de Paris
Université Pierre et Marie Curie

Lundi 6 février 2012

12.Conclusion:
les défis pour l'astrophysique contemporaine

Les succès de l'astrophysique contemporaine

Quelle est aujourd'hui notre vision de l'Univers ? Quelle est sa composition aux différentes échelles : planètes, étoiles, galaxies, grandes structures, etc. Comment évolue-t-il ?

- Au début du XXème siècle, ces questions n'ont pas de réponses. Certaines ne sont même pas encore posées (par exemple, on ignore qu'il y a d'autres galaxies ou que l'Univers a une histoire).
- En quelques décennies, des progrès énormes ont été réalisés : les 11 cours que nous vous avons proposés vous ont présenté les réponses que les astrophysiciens peuvent apporter aujourd'hui à ces questions.
- Cette révolution dans notre compréhension de l'Univers est due à des observations nouvelles et fondamentales, souvent rendues possibles grâce à des progrès instrumentaux importants, et est due également à de nombreux progrès théoriques : *observer et comprendre l'Univers*.

Le moteur de la recherche : des questions

- Quelle est la source d'énergie des étoiles ?
- Comment les étoiles se forment ?
- Toutes les étoiles ont elles des planètes telluriques ?
- Comment les étoiles explosent ?
- Comment les systèmes avec un trou noir accrétant peuvent-ils éjecter de la matière à des vitesses proches de celle de la lumière ?
- Peut-on comprendre comment la Voie Lactée s'est formée ?
- Quand sont apparues les premières étoiles dans l'Univers ?
- Quelle est l'origine des petites fluctuations de densité qui ont donné naissance aux structures de l'Univers actuel ?
- Quelle est la nature de la matière noire ? De l'énergie noire ?

etc.

Certaines de ces questions ont déjà des réponses…

D'autres questions ont des réponses incomplètes ou pas de réponse du tout.

En cherchant la réponse à une question, on est souvent amené à en poser de nouvelles.

Bachelard : « l'essence même de la réflexion, c'est de comprendre qu'on avait pas compris »

La recherche au quotidien

Deux témoignages :

- Patrick Boissé : étude de la structure d'un nuage interstellaire
- Frédéric Daigne : les sursauts gamma

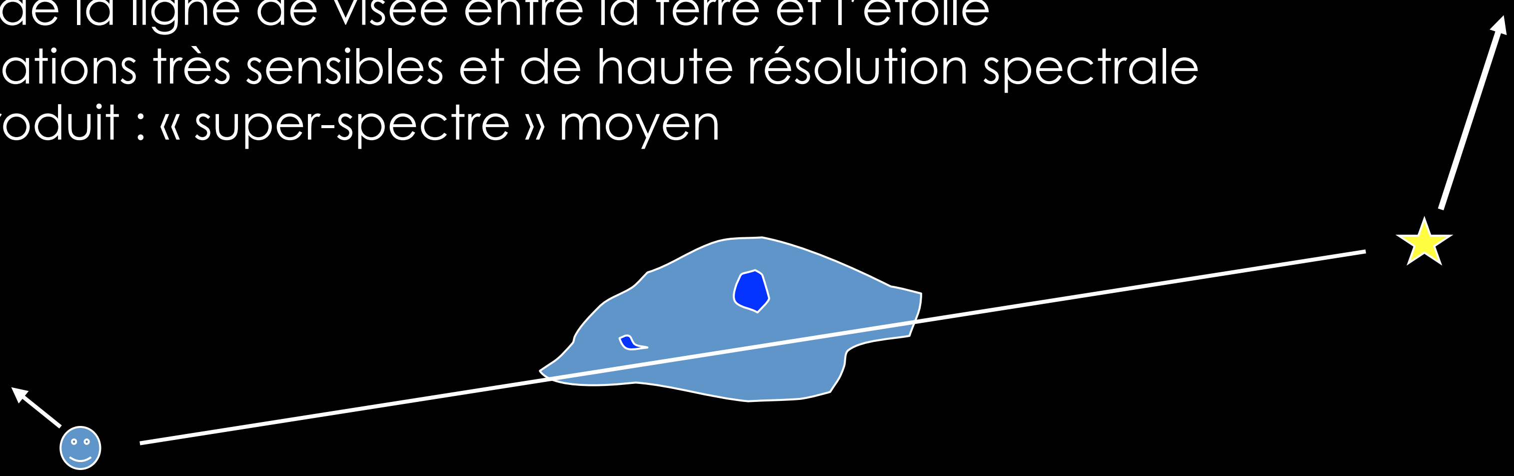
Travail en cours:
Etude de la structure d'un nuage

Pourquoi étudier cette question ?

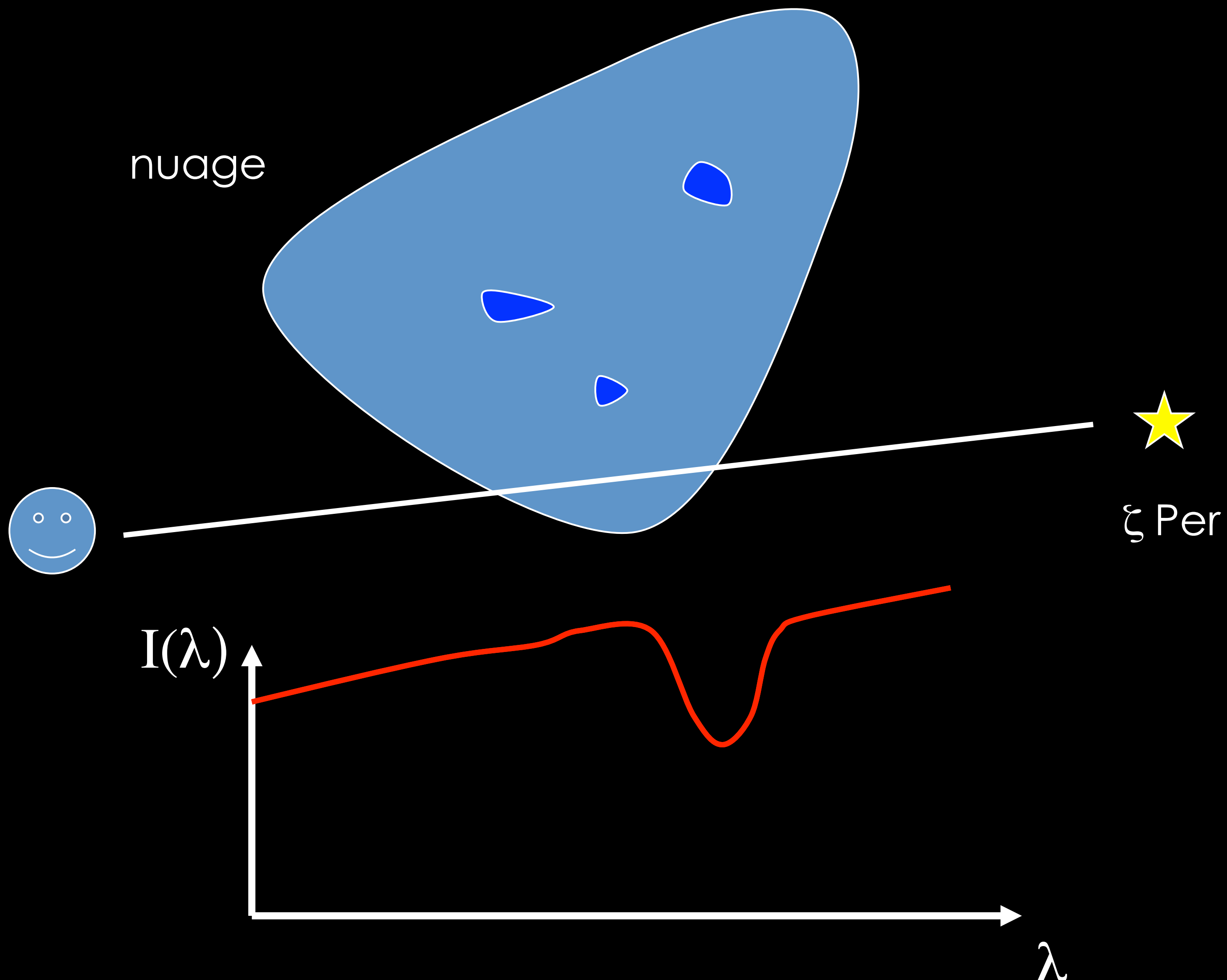
- Evolution très différente si non homogène
  refroidissement, interaction avec le rayonnement
- Origine non comprise de certaines molécules
  CH^+ : chocs, tourbillons ?

Méthode : suivi temporel de raies de « traceurs » dans le spectre d'une étoile

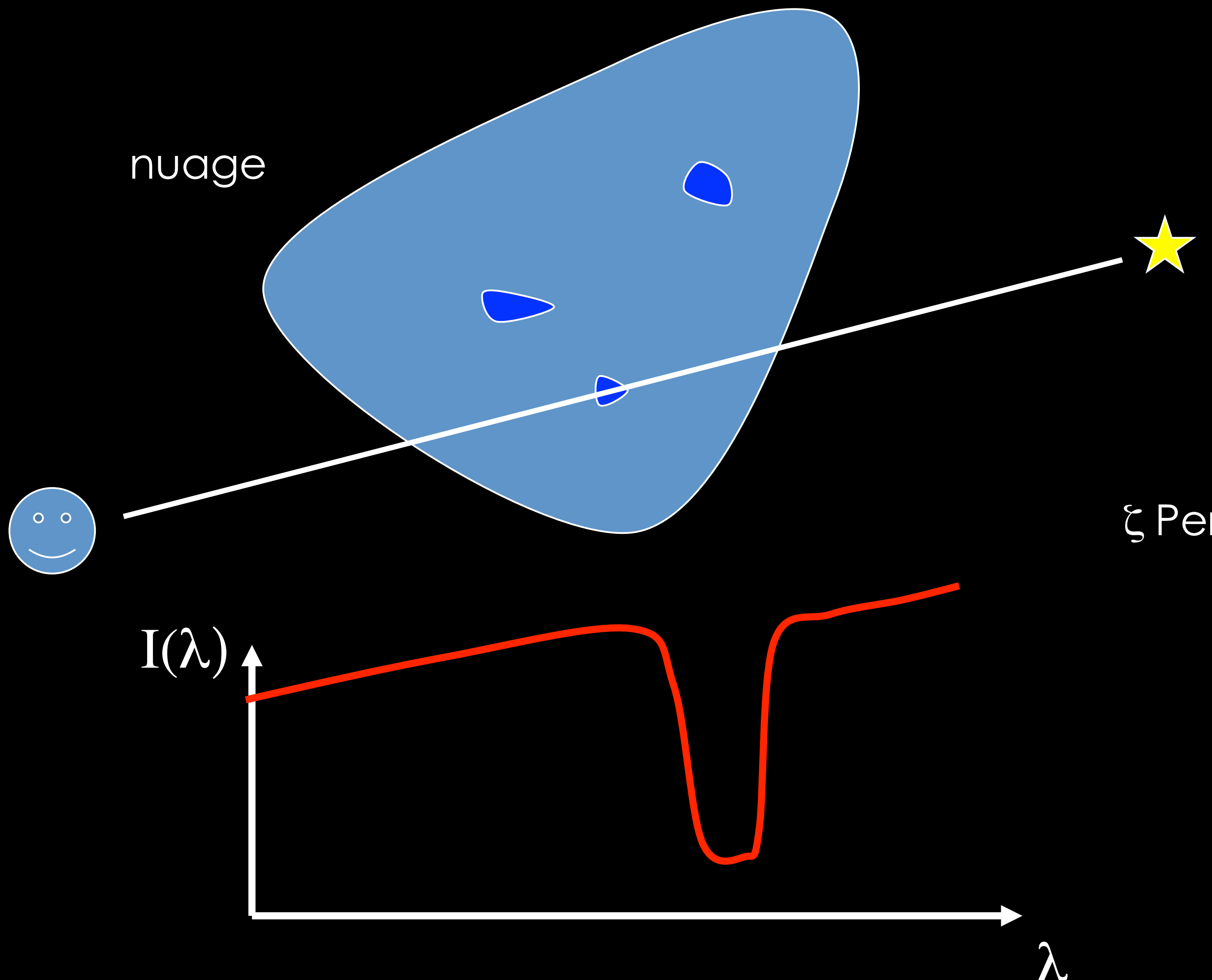
- Dérive de la ligne de visée entre la terre et l'étoile
- Observations très sensibles et de haute résolution spectrale
- Sous-produit : « super-spectre » moyen



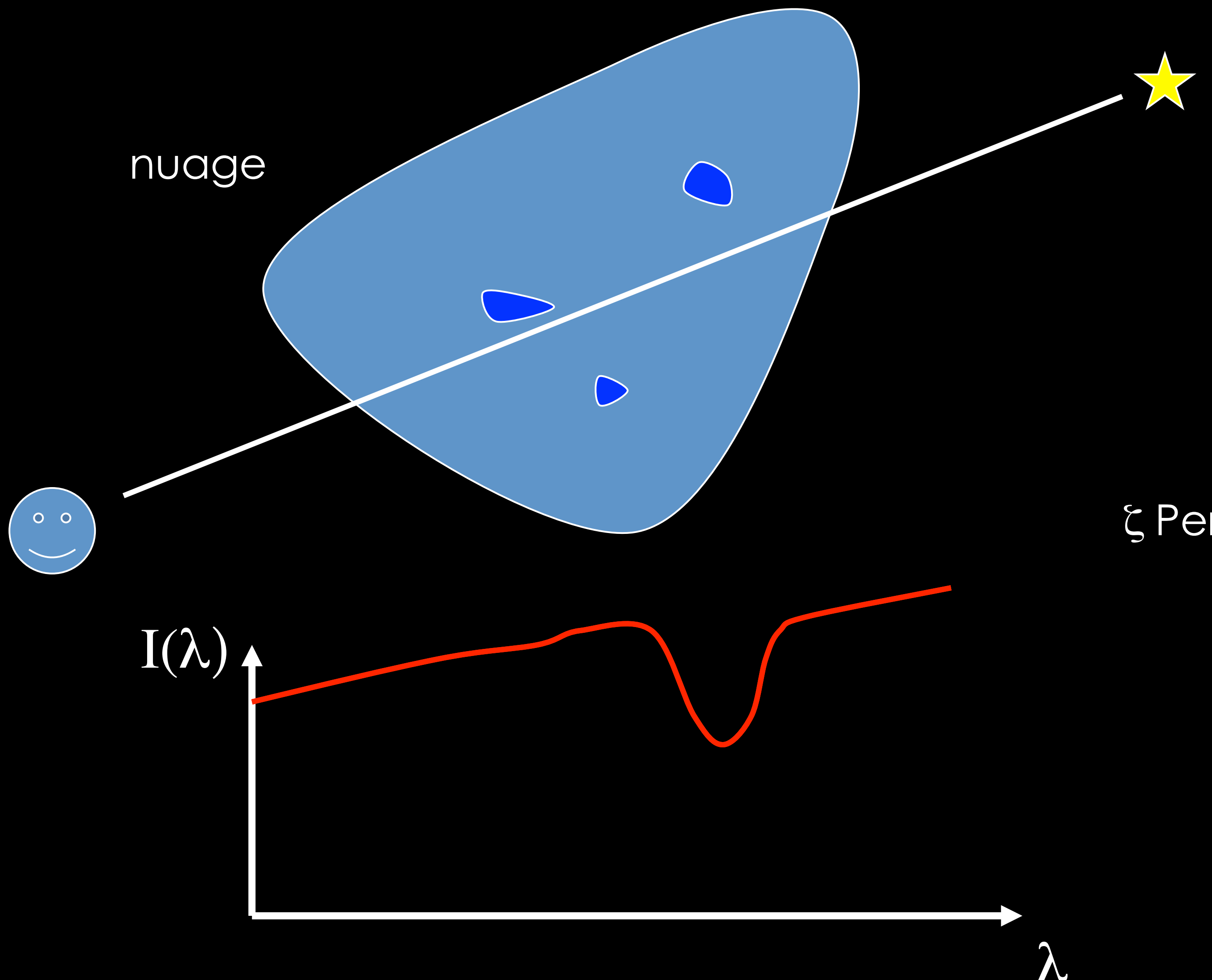
Structure d'un nuage interstellaire: méthode



Structure d'un nuage interstellaire: méthode



Structure d'un nuage interstellaire: méthode



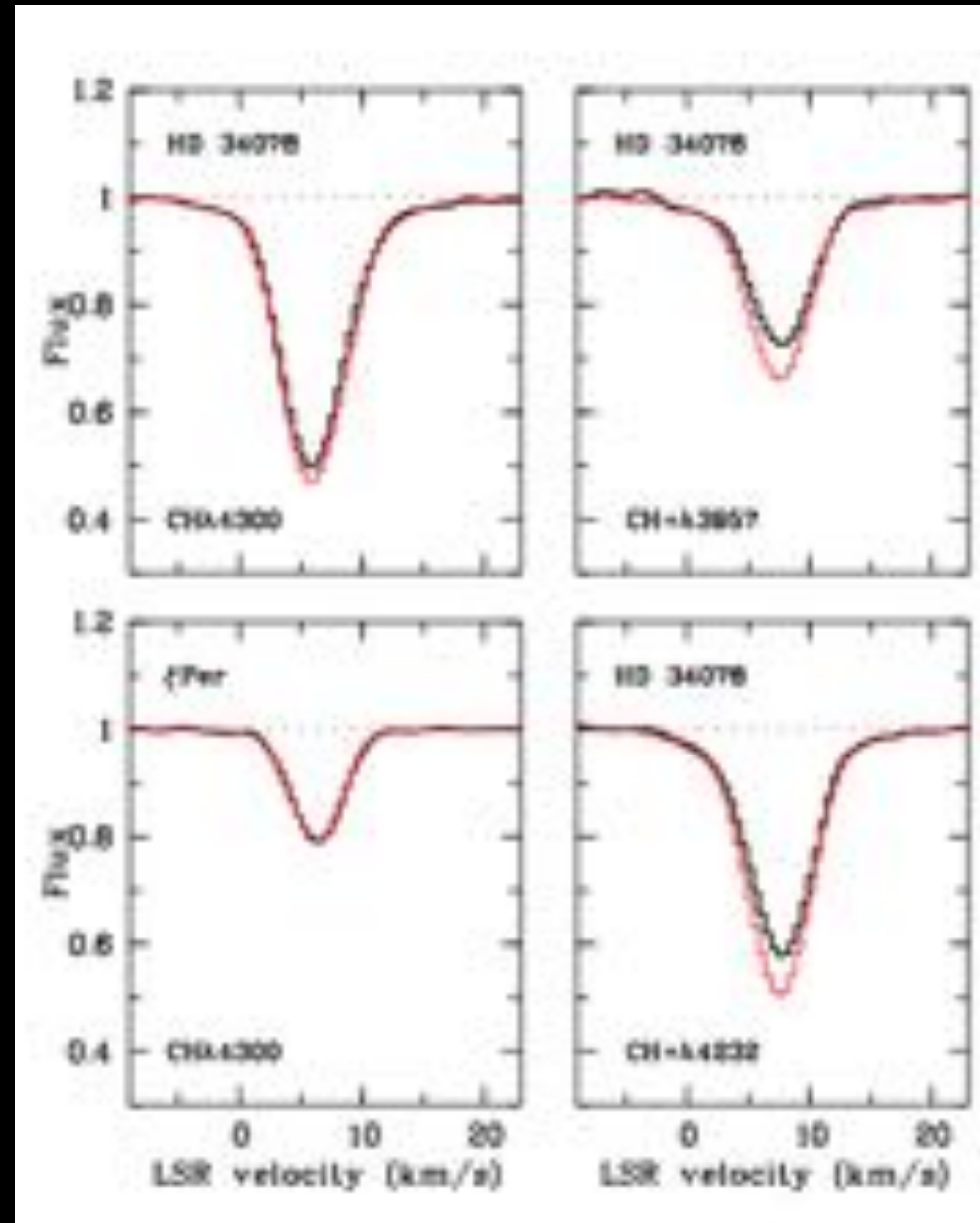
Structure d'un nuage interstellaire: résultats

Observations :
- McDonald (Texas), 2,7m
- OHP, 1,93m

Résultats :
- pas de variation pour CH
- variations pour CH+ de
    - profondeur
    - largeur

Comparaison aux prédictions :
- modèles de chocs
- modèles de turbulence
- autre ?

Confirmation ?
- Observations d'autres nuages
- Prédictions pour d'autres molécules



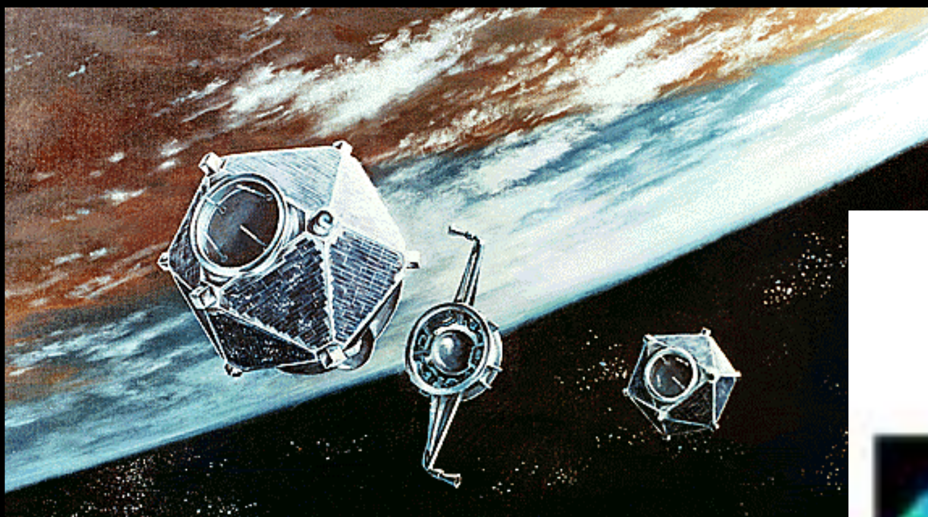
Mener un projet d'observation

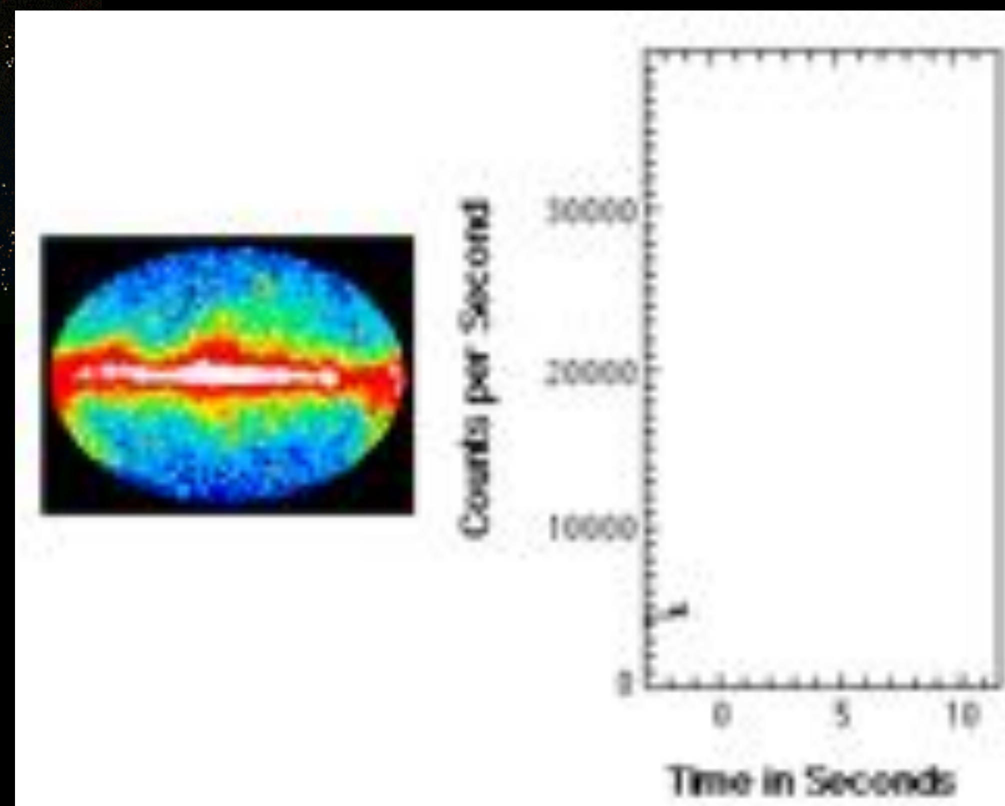
- **Demande de temps de télescope :**
  - question astrophysique importante, bien posée
  - pas de données adéquates déjà disponibles dans les bases
  - les observations proposées permettront-elles de répondre ?
  - choix de la source à observer (position, flux …)
  - justifier le temps de pose (signal/bruit, utilisation d'un E T C)
  - spécifications requises (qualité d'image …)
  - observations en mode visiteur ou de service ?
  - proposants qualifiés pour observation/analyse/interprétation ?
  - données antérieures exploitées et publiées ?
- **Examen par un comité d'attribution** (« pression » de ≈ 1 -> 5 à 10)
- **Projet accepté:** analyse, interprétation, publication, conférences
- **Projet refusé:** améliorer et resoumettre ou … autre projet

Les sursauts gamma

Les sursauts gamma sont des phénomènes très énergétiques, sans doute associés à la naissance d'un trou noir par l'effondrement gravitationnel d'une étoile très massive.

- Découverte fortuite à la fin des années 60 par les satellites militaires US Vela





Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water
Signed by the Original Parties, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America at Moscow: 5 August 1963

The Governments of the United States of America, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics, hereinafter referred to as the "Original Parties,"

Proclaiming as their principal aim the speediest possible achievement of an agreement on general and complete disarmament under strict international control in accordance with the objectives of the United Nations which would put an end to the armaments race and eliminate the incentive to the production and testing of all kinds of weapons, including nuclear weapons,

Seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time, determined to continue negotiations to this end, and desiring to put an end to the contamination of man's environment by radioactive substances,

Have agreed as follows:

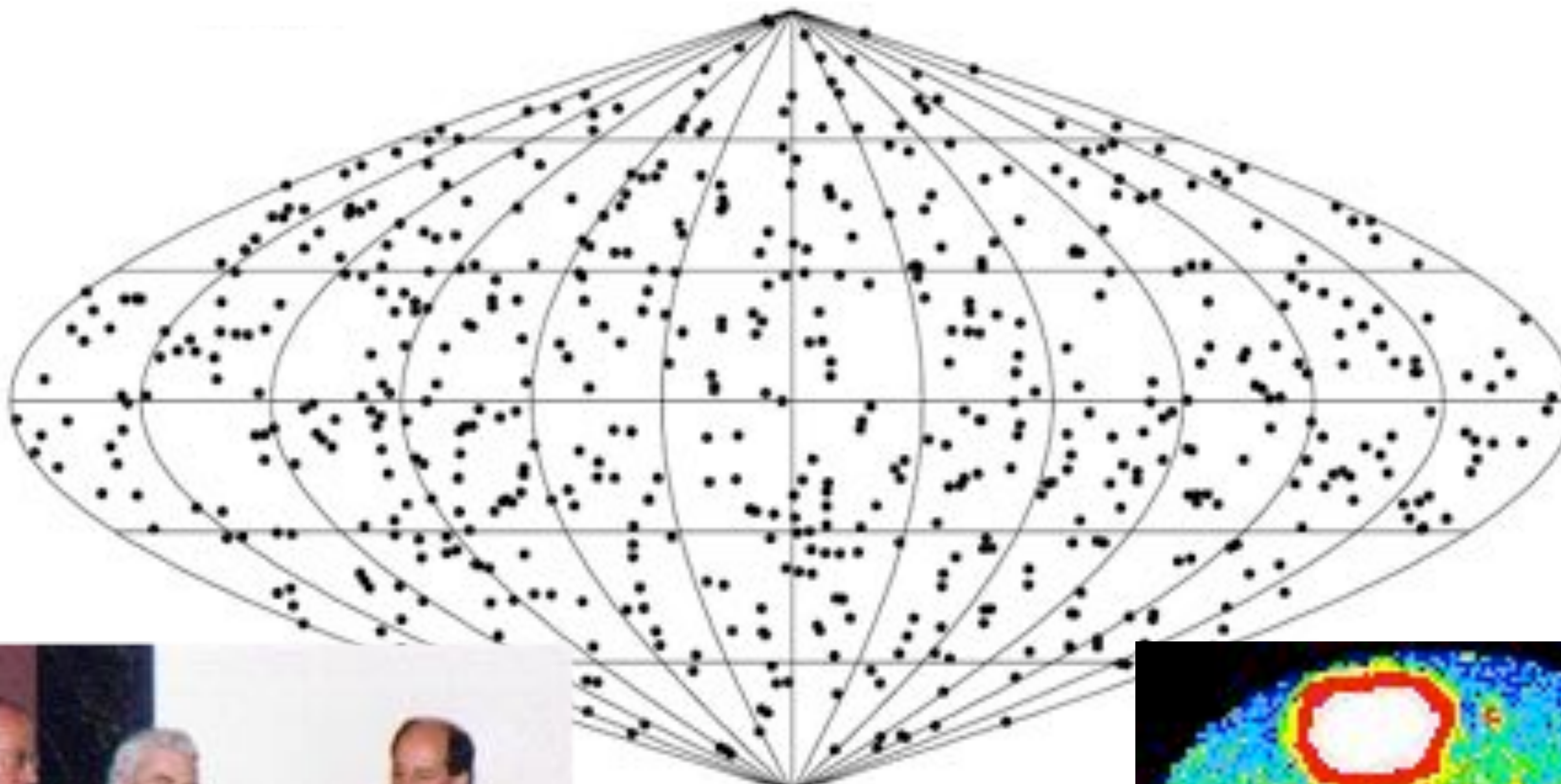
Article I

1. Each of the Parties to this Treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control:

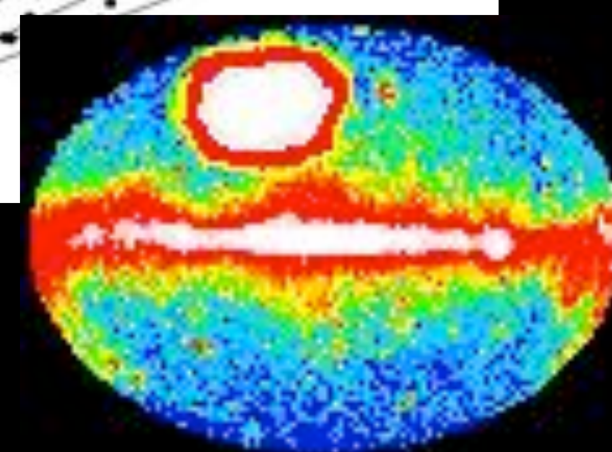
(a) in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas; or

Galactique ou extra-galactique ?

Carte des sursauts gamma (BATSE, 1994)

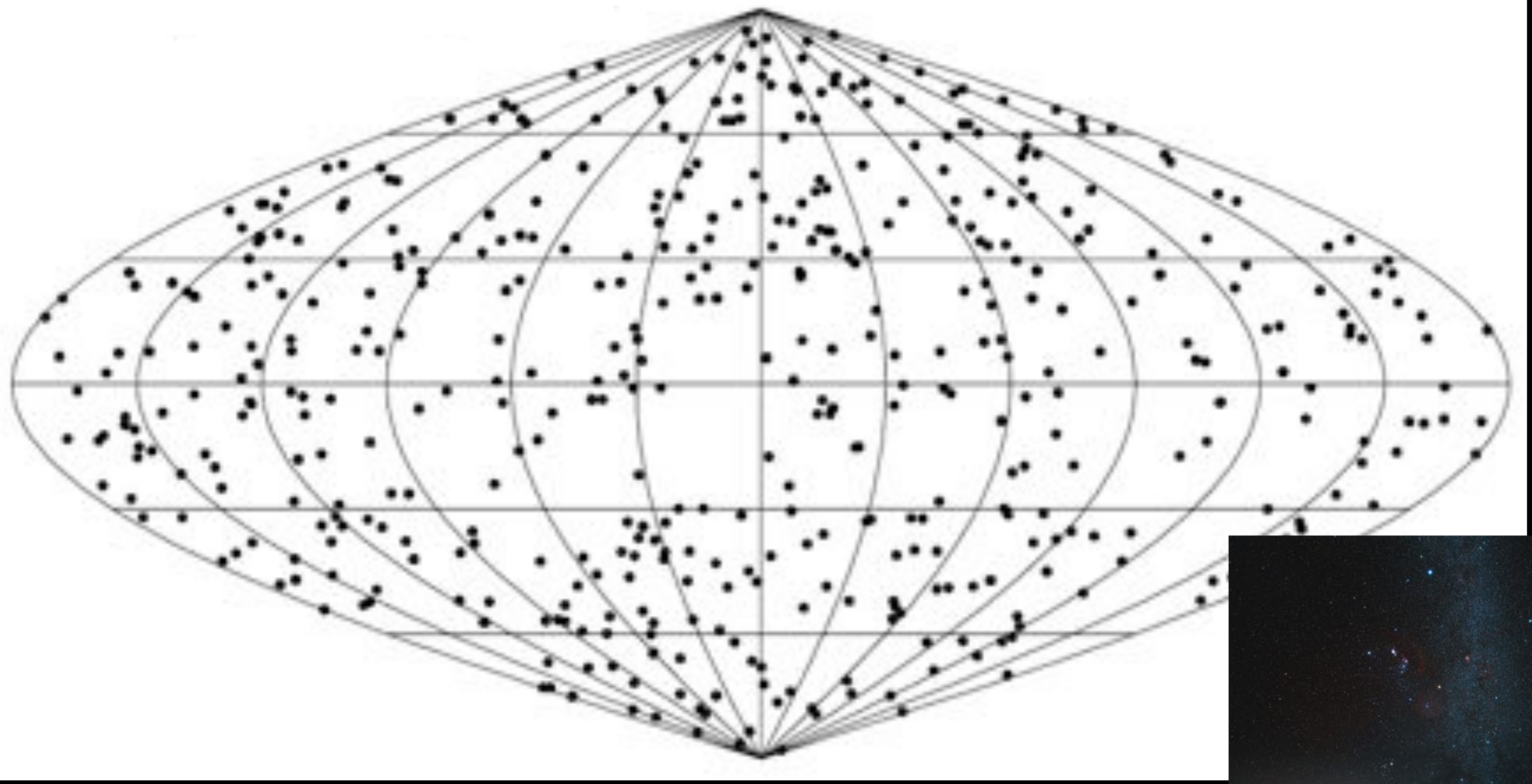


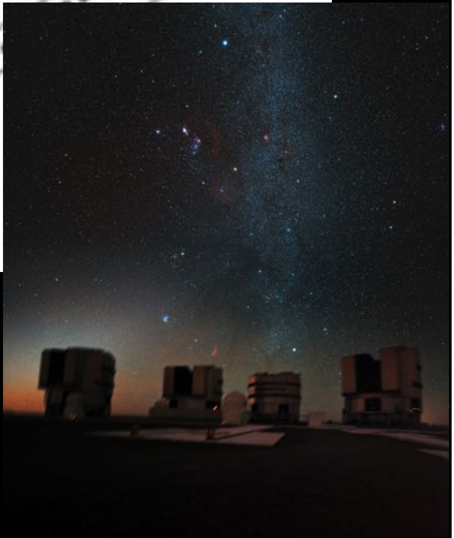
Paczynski, Rees & Lamb, 1994



Galactique ou extra-galactique ?

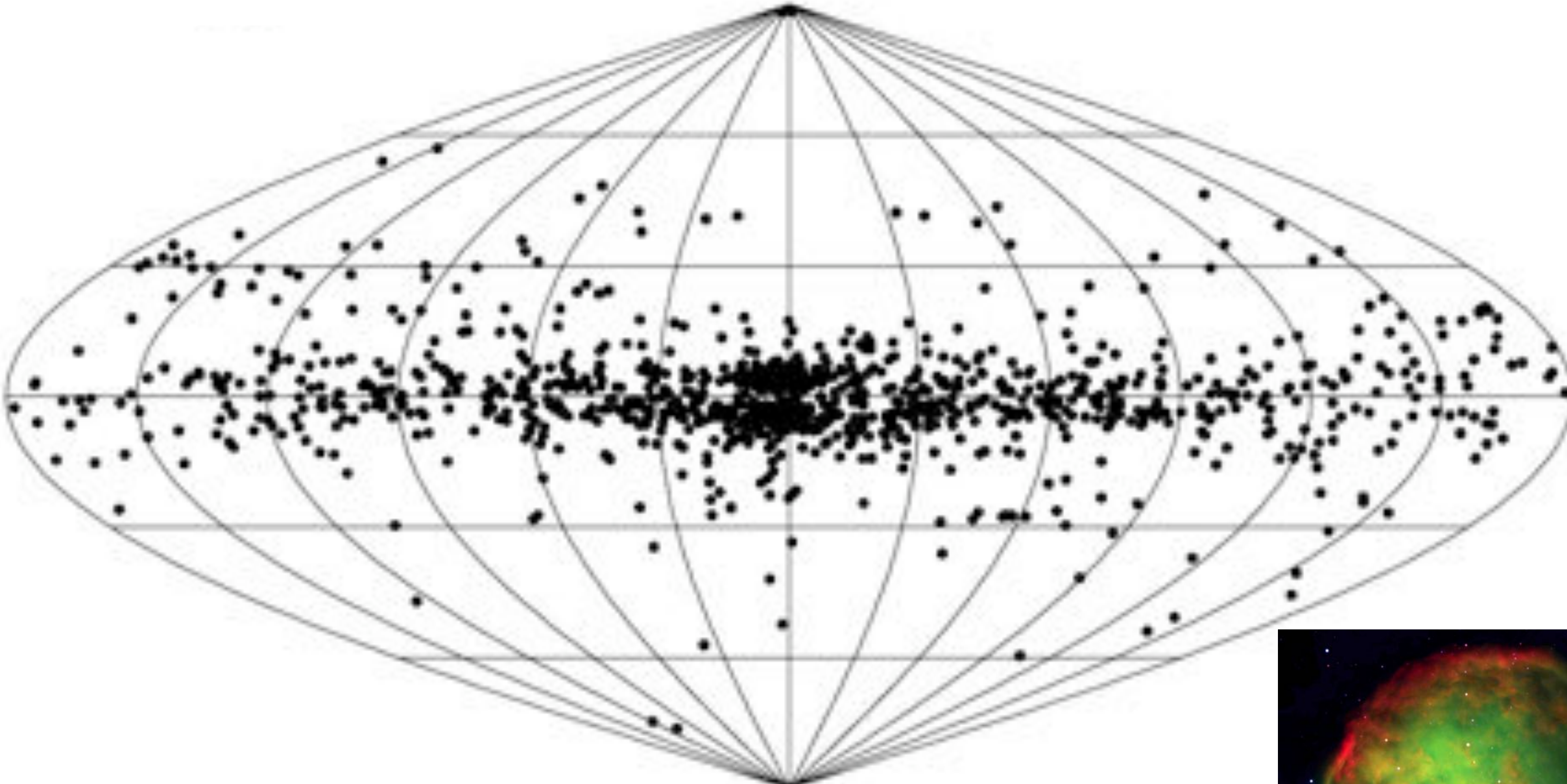
Carte des étoiles proches : isotropie & mouvement apparent





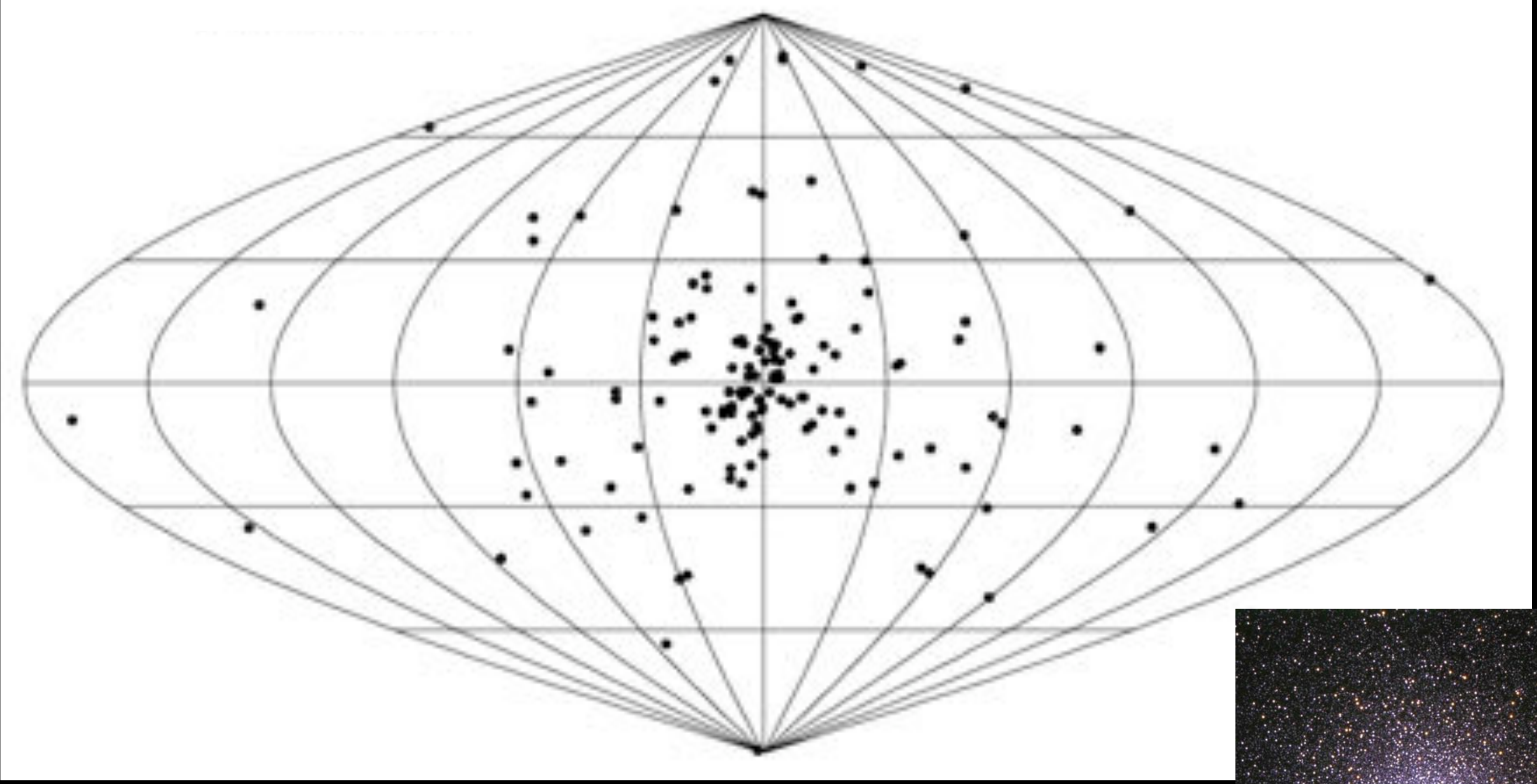
Galactique ou extra-galactique ?

Carte des nébuleuses planétaires : on voit le disque de la Galaxie



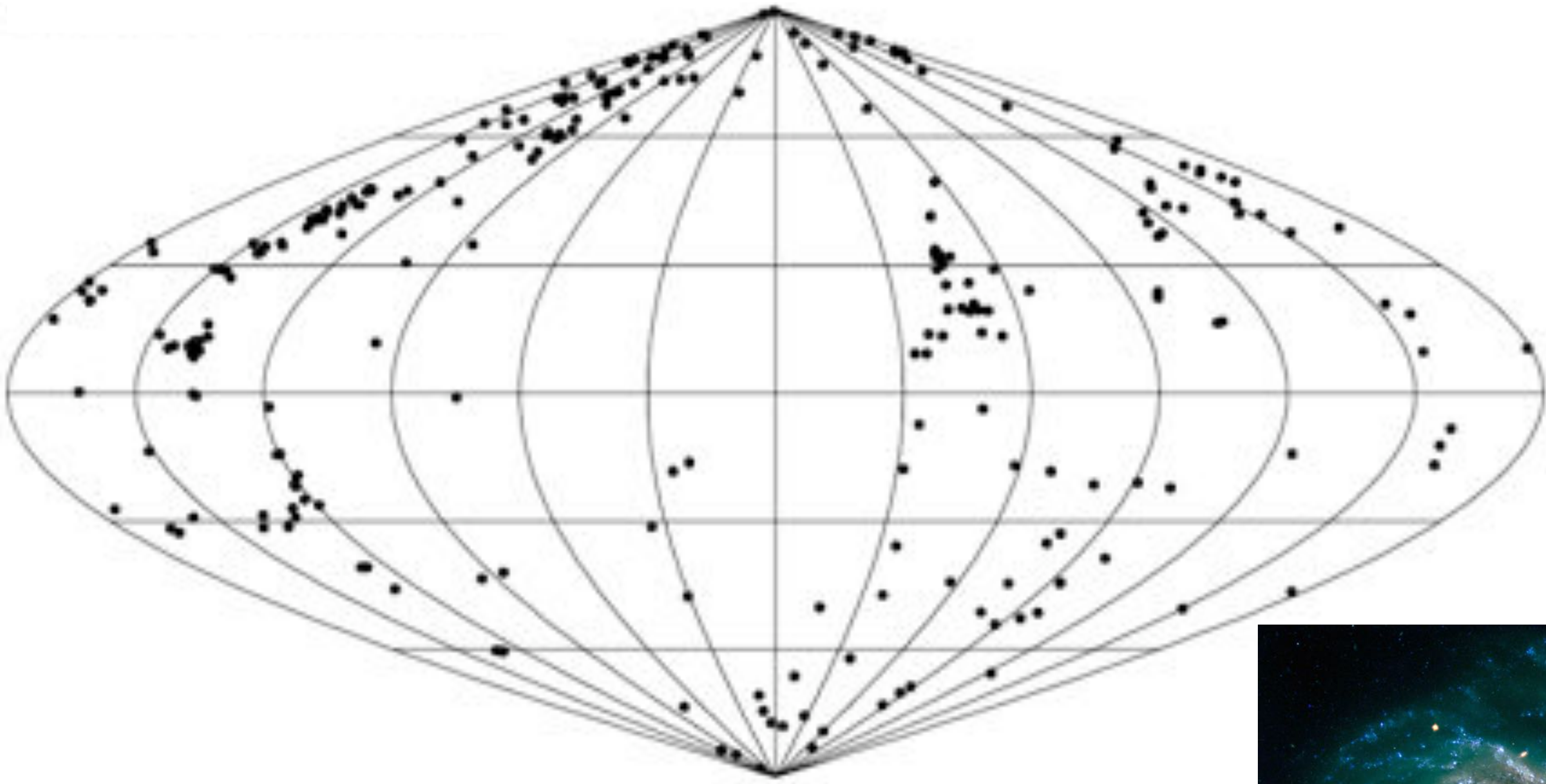
Galactique ou extra-galactique ?

Carte des amas globulaires : le Soleil n'est pas au centre de la Galaxie



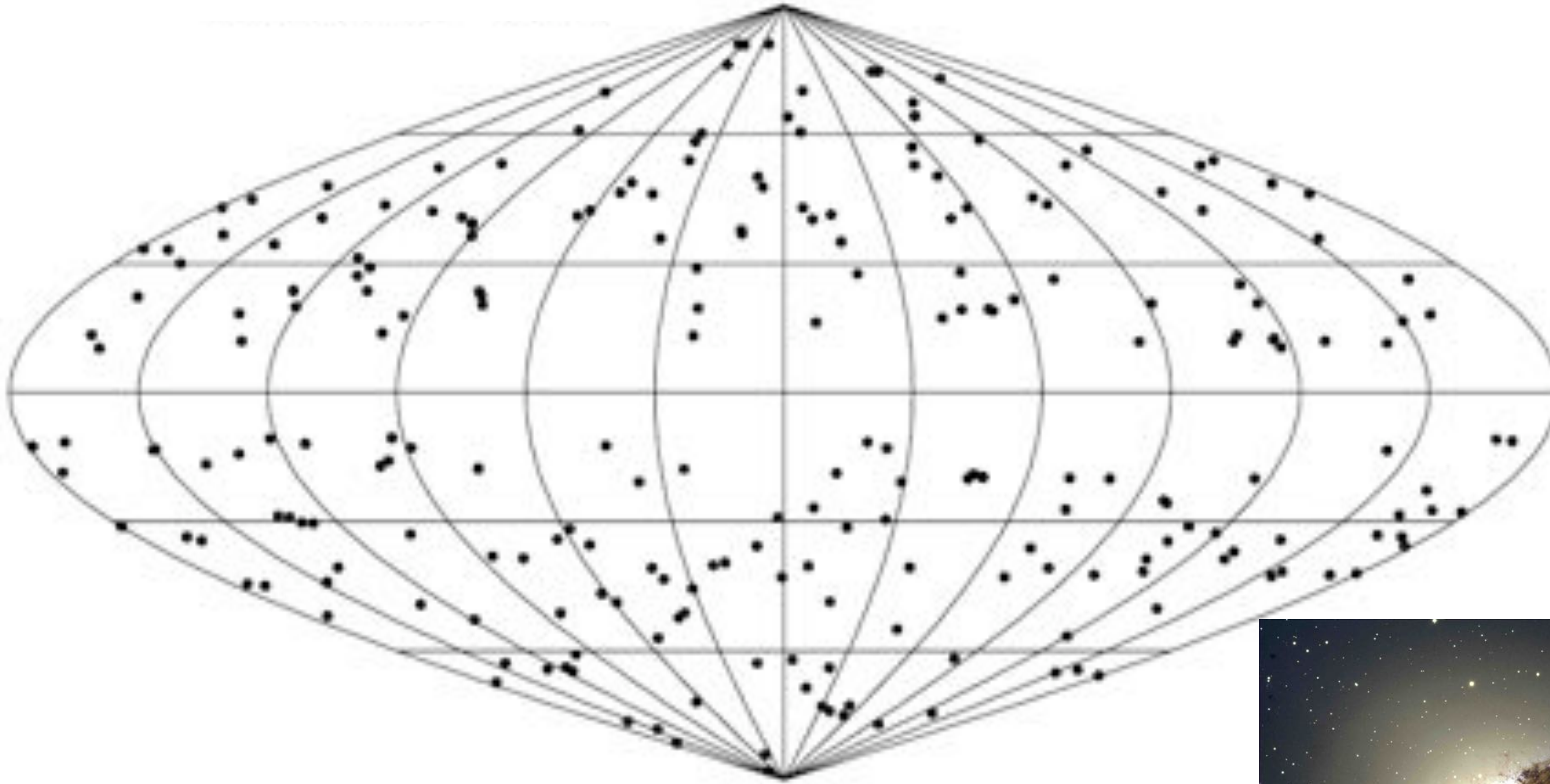
Galactique ou extra-galactique ?

Carte des galaxies proches : on voit des structures (groupes, amas).

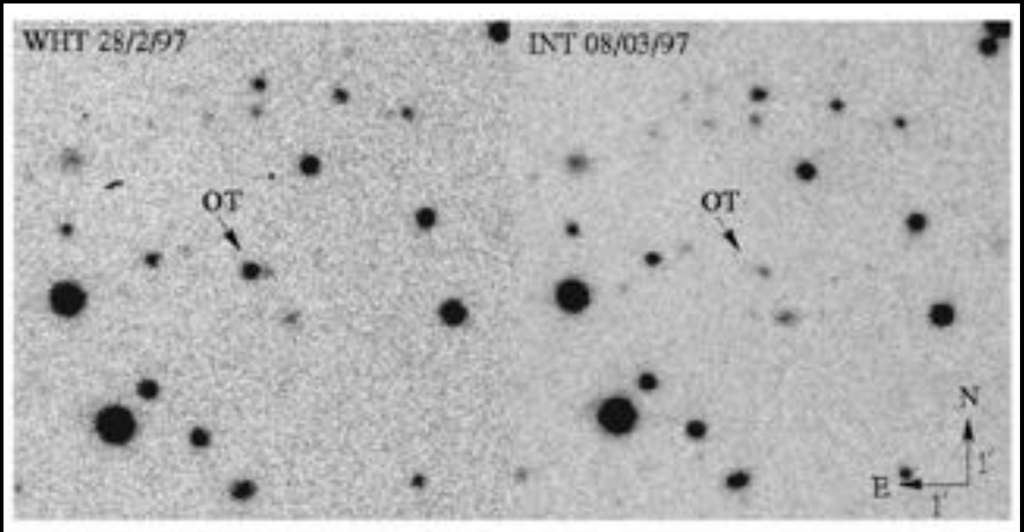


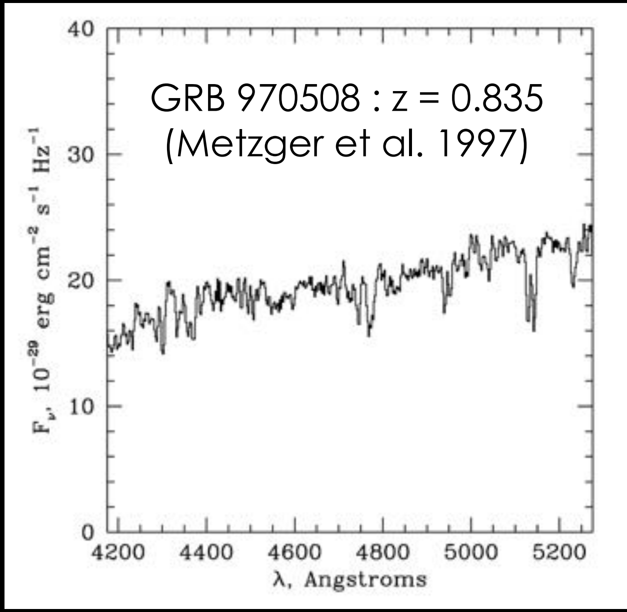
Galactique ou extra-galactique ?

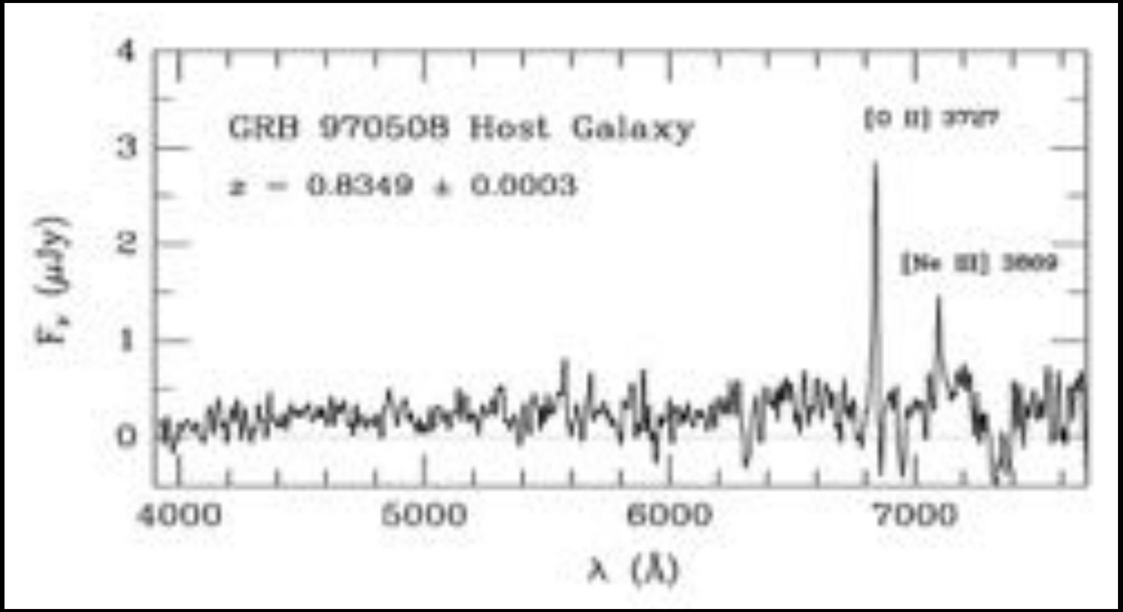
Carte des radio-galaxies galaxies à noyau actif, détectables à très grande distance) : distribution isotrope.



1997 : la réponse







Ce sursaut a été émis lorsque l'Univers n'était âgé que de 6,5 milliards d'années ! (rappel : âge actuel = 13,7 milliards d'années)

Les sursauts gamma

Les sursauts gamma sont des phénomènes très énergétiques, sans doute associés à la naissance d'un trou noir par l'effondrement gravitationnel d'une étoile très massive.

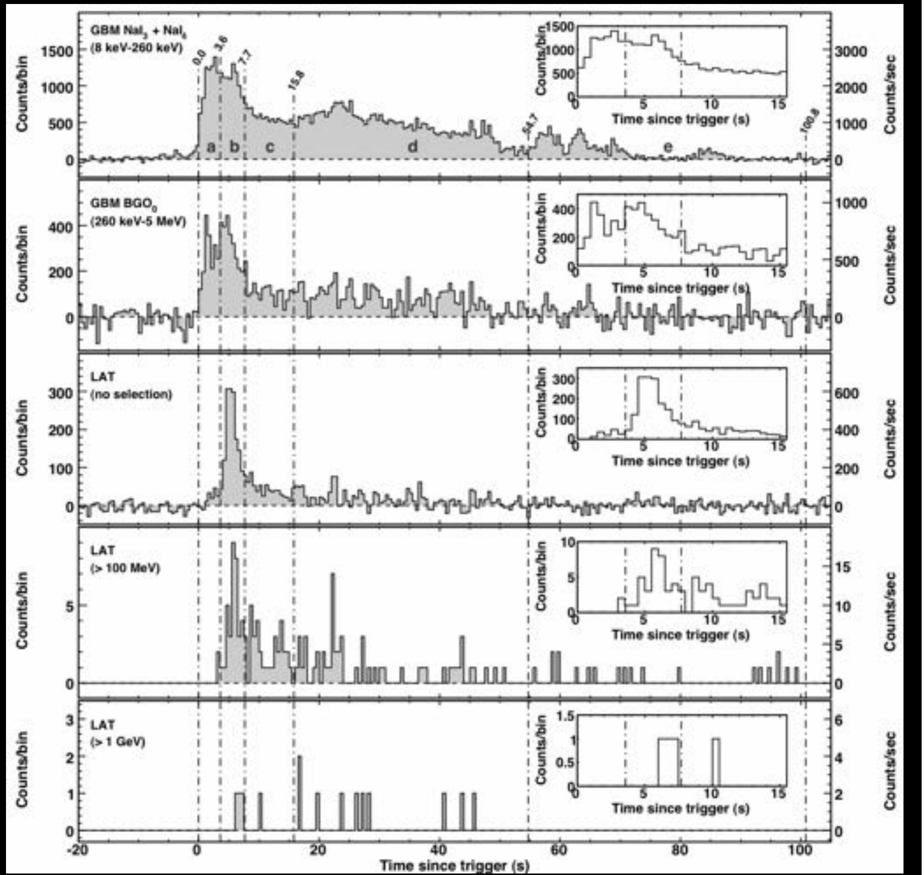
- L'extrême variabilité (quelques ms) indique une source de très petite taille
- L'énergie libérée est plus importante que pour une supernova normale
- On peut montrer que de la matière est éjectée à des vitesses très proches de celle de la lumière

- Les sursauts gamma sont de bons exemples de laboratoire de physique naturels.

  Exemple : tester l'invariance de la vitesse de la lumière

- Les sursauts gamma sont de bonnes sondes de l'Univers lointain

  Remonter jusqu'à la première génération d'étoiles ?



Les sursauts gamma

Mon activité de recherche principale (F.D.) : comprendre les mécanismes physiques à l'origine des sursauts gamma.

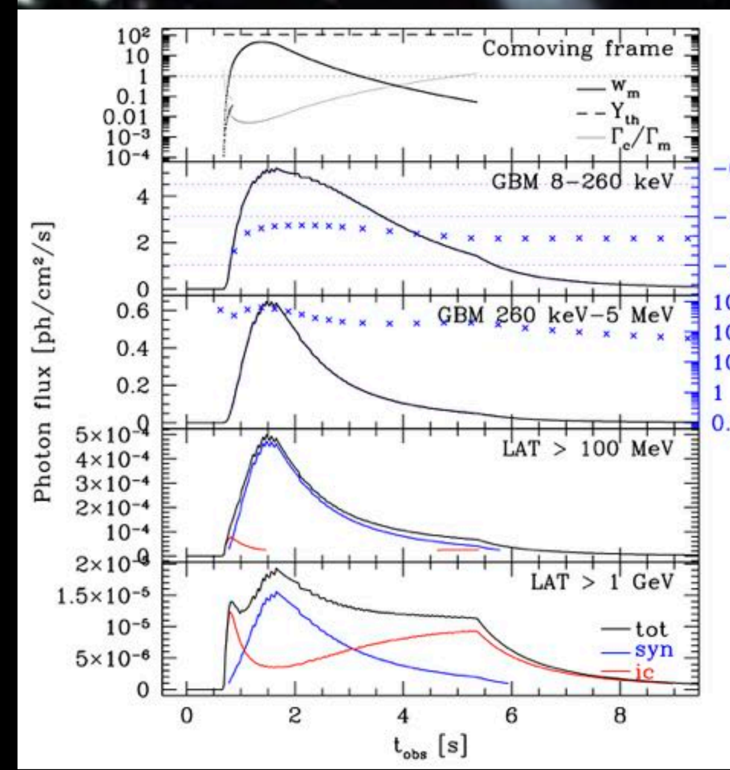
La physique mise en jeu :

- Relativité restreinte et générale
- Mécanique des fluides
- Physique du champ magnétique
- Physique de la matière dense
- Physique des particules
- Processus de rayonnement

etc.

Les outils :

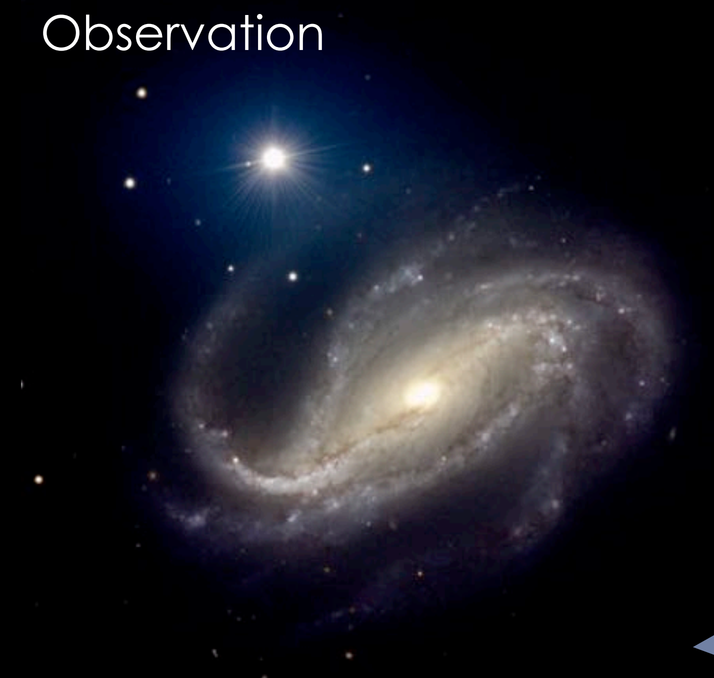
- Du calcul analytique au numérique léger
- Des simulations numériques plus lourdes
- Les bases de données sur les observations des sursauts gamma
- Beaucoup de discussions avec d'autres théoriciens, les observateurs, etc.



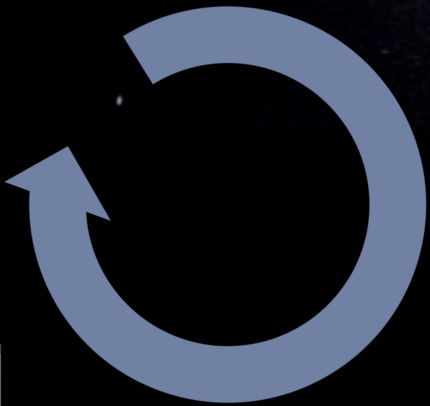
Daigne et al. 2011

La recherche en astrophysique

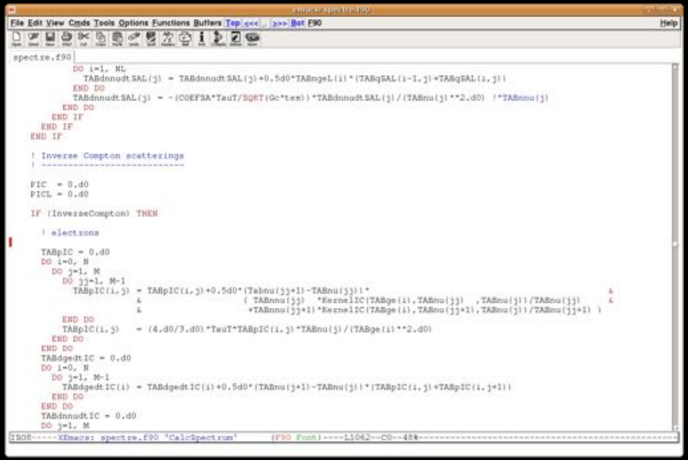
Observation

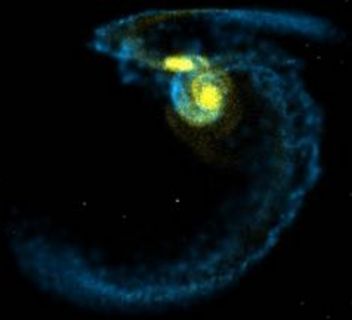


Instrumentation



Modélisation physique





$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu$$

$$\frac{\ddot{I}}{2} = 2E_c + E_{grav}$$

$$^1_1H +^1_1 H \rightarrow^2_1 D + \nu_e + e^+$$

La recherche en astrophysique

La recherche en astrophysique :

- beaucoup de métiers différents
  - Chercheurs : permanents, non-permanents
  - Techniciens & Ingénieurs
  - Administratifs
- un lien direct avec l'industrie
- un coût élevé mais
  - Transfert de technologie
  - 60 à 80% du coût des projets = contrats industriels

En France et en Europe :

- l'essentiel du financement est public
- la plus grande fraction va à l'industrie
- la motivation principale est la quête de nouvelles connaissances

Le futur ELT/ESO

La finalité de la recherche en astrophysique

La recherche fondamentale : étendre le champ des connaissances humaines

- Universalité
- Une communauté internationale (qui parle anglais !)

- Publications dans des revues spécialisées « à comité de lecture »
- Présentations dans des conférences internationales
- Principe de « l'évaluation par les pairs »

Les conférences scientifiques

Talk Invitation: Gamma-ray Bursts 2010 conference, Annapolis MD. — Congres : Annapolis GRB 2010

De : Julie McEnery
Objet : **Talk Invitation: Gamma-ray Bursts 2010 conference, Annapolis MD.**
Date : 7 août 2010 23:56:14 HAEC
À : Frédéric Daigne
Cc : Mcenery Julie <julie.e.mcenery@gsfc.nasa.gov> ,
Gehrels, Cornelis A. (Neil)(GSFC-661.0) <cornelis.a.gehrels@nasa.gov>

Dear Fred,

On behalf of the international organizing commitee, we are happy to invite you to give a talk at the Gamma-ray Bursts 2010 Conference in Annapolis MD, 1-4 November 2009. Information about the conference can be found at http://fermi.gsfc.nasa.gov/science/grb2010/index.html.

The invited talks will be 20 minutes plus 10 minutes for questions and discussion. We would like you to talk about theory and models of prompt emission from GRB.

Please let us know if you have any questions or would like to discuss any aspect of your talk or the conference. We hope you will be able to accept this invitation, and we look forward to hearing from you soon.

Best regards,
Julie McEnery
Neil Gehrels

Gamma Ray Bursts 2010 Conference

Nov 1-4, 2010, Annapolis, MD

Topics:

- Central Engines
- Prompt Emission
- Jet Physics
- Circumstellar Medium & Afterglow
- Supernova Connections
- Cosmological Tools
- Present and Future Missions

Scientific Organizing Committee:

Julie McEnery, Neil Gehrels, David Burrows, Valerie Connaughton, Derek Fox, Dieter Hartmann, Jens Hjorth, Nobuyuki Kawai, Chryssa Kouveliotou, Nicola Omodei, Bill Paciesas, Luigi Piro, Fred Piron, Soebur Razzaque, Ralph Wijers

Local Organizing Committee:

Judith Racusin, Takanori Sakamoto, Eleonora Troja, Vlasios Vasileiou

Swift — Fermi Gamma-ray Space Telescope

Website:

http://fermi.gsfc.nasa.gov/science/grb2010/

Early Registration Deadline: Sep 1, 2010
Abstract Deadline: Sep 15, 2010

Preliminary Program - SUBJECT TO CHANGE

	Presenter/Institution	Title	Presentation Type
Monday, November 1			
Breakfast 8:00 - 9:00 am			
	Neil Gehrels/Julie McEnery	Welcome	
Session 1: Prompt Observations I 9:00 - 10:35 am	**Takanori Sakamoto** GSFC/UMBC	Prompt Emission Properties of Swift GRBs	Invited Oral
	Michael Briggs	GBM	Invited Oral
	Veronique Pelassa LPTA, CNRS/IN2P3 - Universite Montpellier 2	LAT observations of Gamma-Ray Bursts	Invited Oral
Coffee Break 10:35 - 11:00 am			
Session 2: Prompt Observations II 11:00 am - 12:30 pm	**Frederic Piron** CNRS/IN2P3/LPTA	Fermi LAT observations of long-lasting high-energy emission from GRB 090323 and GRB 090328	Oral
	Vlasios Vasileiou NASA GSFC/UMBC	Towards the First Fermi-LAT GRB Catalog	Oral
	Binbin Zhang University of Nevada Las Vegas	The Three Spectral Components of Fermi/LAT GRBs	Oral
	Elisabetta Bissaldi Institute of Astro- and Particle Physics University Innsbruck	The 50 Brightest and Hardest GRBs detected with the Gamma ray Burst Monitor (GBM) on Fermi	Oral
	Antonio Martin-Carrillo UCD School of Physics	Spectral and temporal properties of long GRBs detected by INTEGRAL from 3 keV to 8 MeV	Oral

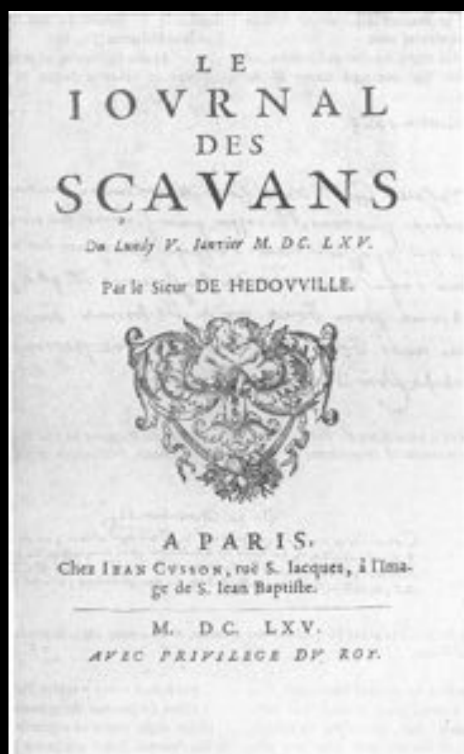
Preliminary Program - SUBJECT TO CHANGE

	Presenter/Institution	Title	Presentation Type
	TBD	*Late Breaking Topic*	Oral
Lunch 12:30 - 2:00 pm			
Session 3: Prompt Theory I 2:00 - 3:30 pm	**Frederic Daigne** Institut d'Astrophysique de Paris - Universite Pierre et Marie Curie-Paris 6	Modelling the prompt emission from GRBs	Invited Oral
	Bing Zhang University of Nevada Las Vegas	The Internal Collision-induced MAgnetic Reconnection and Turbulence (ICMART) model of GRBs	Oral
	Asaf Pe'er Space Telescope Science Institute	The Connection Between Thermal and Non-Thermal Emission in Gamma-ray Bursts: General considerations and GRB090902B as a Case Study	Oral
	Kenji Toma Pennsylvania State University	A Photosphere-Internal Shock Model of GRBs: Implications for the Fermi/LAT Results	Oral
	Andrei Beloborodov Columbia University	Collisional mechanism for the prompt GRB emission	Oral
Coffee Break 3:30 - 4:00 pm			
Session 4: Prompt Theory II 4:00 - 5:30 pm	**Robert Nemiroff** Michigan Technological University	A Simple Energy-Dependent Model for GRB Pulses with Interesting Physical Implications	Oral
	Kunihito Ioka KEK Theory Center	High Lorentz Factor Fireballs for High-Energy GRB Emission	Oral

La tradition des revues savantes

-Le *Journal des Sçavans*, fondé à Paris en 1665

-*The Philosophical Transactions of the Royal Society*, fondé à Londres en 1665



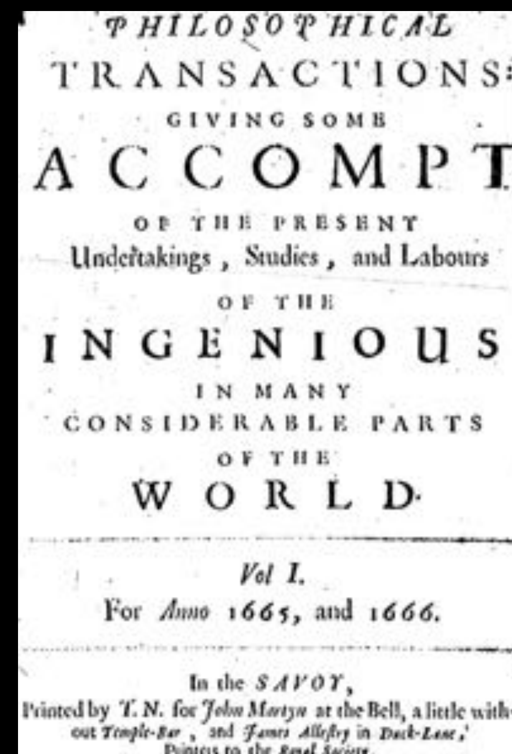
LE
IOVRNAL
DES
SÇAVANS

Du Lundy V. Ianvier M. DC. LXV.

Par le Sieur DE HEDOVVILLE.

A PARIS,
Chez IEAN CVSSON, ruë S. Iacques, à l'Image de S. Iean Baptiste.

M. DC. LXV.
AVEC PRIVILEGE DV ROY.



PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.

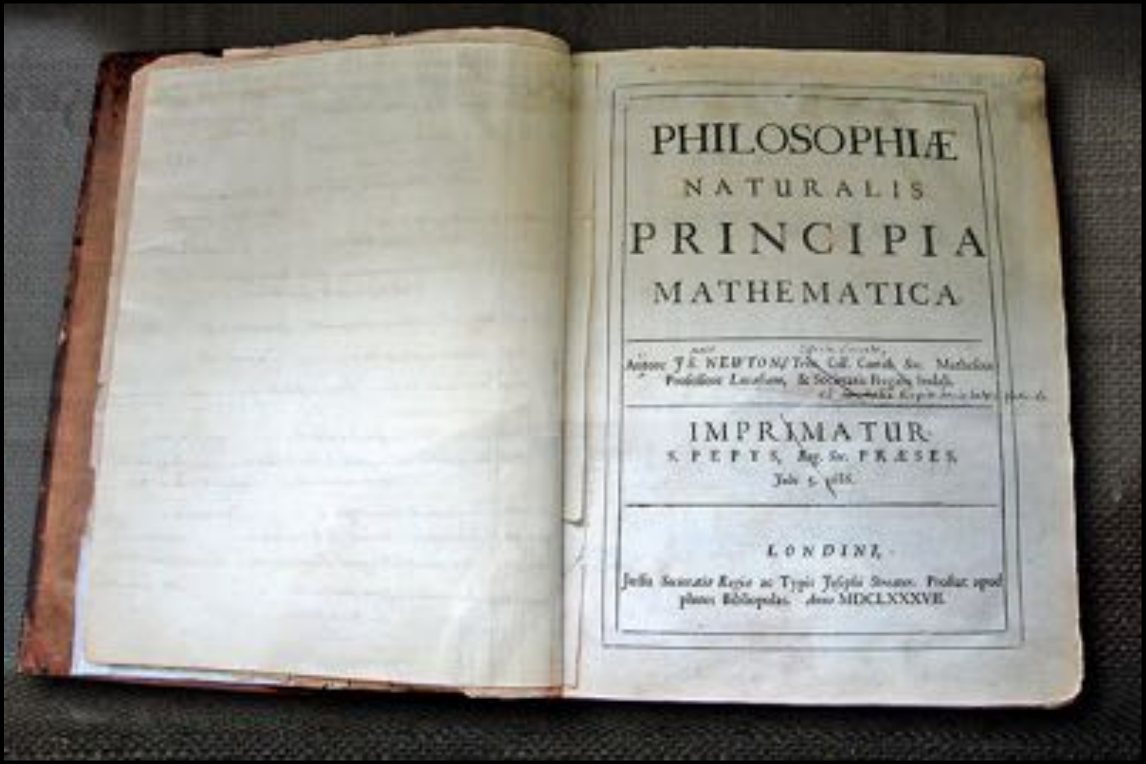
Vol I.
For *Anno* 1665, and 1666.

In the *SAVOY*,
Printed by *T. N.* for *John Martyn* at the Bell, a little without *Temple-Bar*, and *James Allestry* in *Duck-Lane*,
Printers to the *Royal Society*.

La science n'a pas de frontières

Un exemple : traduction du latin au français par Emilie du Chatelet (1756) de l'ouvrage de Newton *Philosophiæ Naturalis Principia Mathematica* (1686).

« Le français qui est la langue courante de l'Europe, et qui s'est enrichi de toutes ces expressions nouvelles et nécessaires, est beaucoup plus propre que le latin à répandre dans le monde toutes ces connaissances nouvelles »
(préface de Voltaire à la traduction de Mme du Chatelet)



Les trois principales revues spécialisées en astrophysique

- *The Monthly Notices of the Royal Astronomical Society* (UK) : fondé en 1827
- *The Astrophysical Journal* (USA) : fondé en 1895
- *Astronomy & Astrophysics* (Europe) : fondé en 1969 à partir de la fusion de 6 revues européennes (France, Suède, Pays-Bas, Allemagne).

Un exemple d'article scientifique

Mon. Not. R. Astron. Soc. 285, L15–L19 (1997)

Gamma-ray bursts and the runaway instability of thick discs around black holes

F. Daigne and R. Mochkovitch

Institut d'Astrophysique de Paris, CNRS, 98 bis, Boulevard Arago, 75014 Paris, France

Accepted 1997 January 3. Received 1996 November 12

ABSTRACT

In the context of cosmological models for gamma-ray bursts where the energy is extracted from a thick disc orbiting a stellar-mass black hole we discuss the stability of accretion when the specific angular momentum is increasing outwards in the disc. Discs with constant angular momentum are known to lead to a runaway instability, with catastrophic accretion taking place on a dynamical time-scale. We find that even a slight increase of the specific angular momentum outwards has a strong stabilizing effect on the accretion process. We finally comment on the limitations of our results, which are obtained with classical physics and neglecting the disc self-gravity.

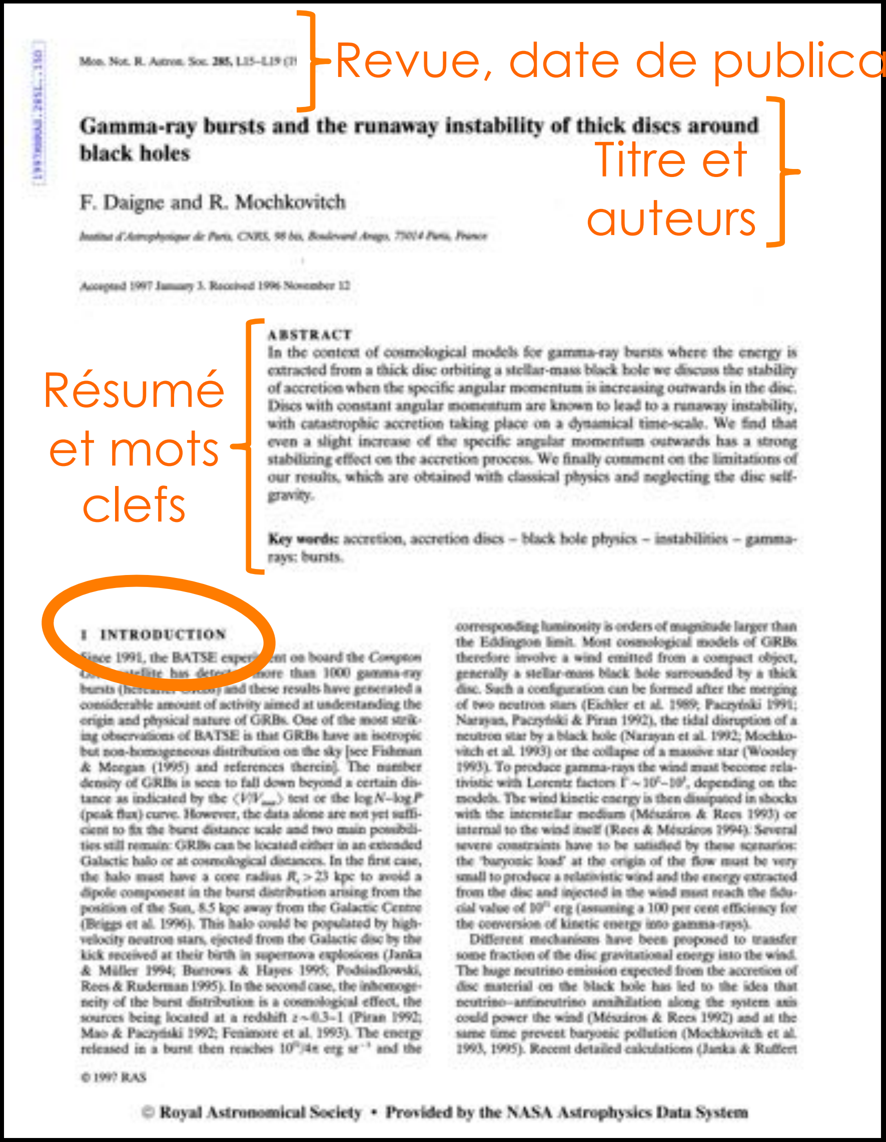
Key words: accretion, accretion discs – black hole physics – instabilities – gamma-rays: bursts.

1 INTRODUCTION

Since 1991, the BATSE experiment on board the *Compton GRO* satellite has detected more than 1000 gamma-ray bursts (hereafter GRBs) and these results have generated a considerable amount of activity aimed at understanding the origin and physical nature of GRBs. One of the most striking observations of BATSE is that GRBs have an isotropic but non-homogeneous distribution on the sky [see Fishman & Morgan (1995) and references therein]. The number density of GRBs is seen to fall down beyond a certain distance as indicated by the $\langle V/V_{max} \rangle$ test or the $\log N$–$\log P$ (peak flux) curve. However, the data alone are not yet sufficient to fix the burst distance scale and two main possibilities still remain: GRBs can be located either in an extended Galactic halo or at cosmological distances. In the first case, the halo must have a core radius $R_c > 23$ kpc to avoid a dipole component in the burst distribution arising from the position of the Sun, 8.5 kpc away from the Galactic Centre (Briggs et al. 1996). This halo could be populated by high-velocity neutron stars, ejected from the Galactic disc by the kick received at their birth in supernova explosions (Janka & Müller 1994; Burrows & Hayes 1995; Podsiadlowski, Rees & Ruderman 1995). In the second case, the inhomogeneity of the burst distribution is a cosmological effect, the sources being located at a redshift $z \sim 0.3$–1 (Piran 1992; Mao & Paczyński 1992; Fenimore et al. 1993). The energy released in a burst then reaches $10^{51}/4\pi$ erg sr^{-1} and the corresponding luminosity is orders of magnitude larger than the Eddington limit. Most cosmological models of GRBs therefore involve a wind emitted from a compact object, generally a stellar-mass black hole surrounded by a thick disc. Such a configuration can be formed after the merging of two neutron stars (Eichler et al. 1989; Paczyński 1991; Narayan, Paczyński & Piran 1992), the tidal disruption of a neutron star by a black hole (Narayan et al. 1992; Mochkovitch et al. 1993) or the collapse of a massive star (Woosley 1993). To produce gamma-rays the wind must become relativistic with Lorentz factors $\Gamma \sim 10^2$–10^3, depending on the models. The wind kinetic energy is then dissipated in shocks with the interstellar medium (Mészáros & Rees 1993) or internal to the wind itself (Rees & Mészáros 1994). Several severe constraints have to be satisfied by these scenarios: the 'baryonic load' at the origin of the flow must be very small to produce a relativistic wind and the energy extracted from the disc and injected in the wind must reach the fiducial value of 10^{51} erg (assuming a 100 per cent efficiency for the conversion of kinetic energy into gamma-rays).

Different mechanisms have been proposed to transfer some fraction of the disc gravitational energy into the wind. The huge neutrino emission expected from the accretion of disc material on the black hole has led to the idea that neutrino–antineutrino annihilation along the system axis could power the wind (Mészáros & Rees 1992) and at the same time prevent baryonic pollution (Mochkovitch et al. 1993, 1995). Recent detailed calculations (Janka & Ruffert

Un exemple d'article scientifique



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Gamma-ray bursts and the runaway instability of thick discs around black holes

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ABSTRACT

In the context of cosmological models for gamma-ray bursts where the energy is extracted from a thick disc orbiting a stellar-mass black hole we discuss the stability of accretion when the specific angular momentum is increasing outwards in the disc. Discs with constant angular momentum are known to lead to a runaway instability, with catastrophic accretion taking place on a dynamical time-scale. We find that even a slight increase of the specific angular momentum outwards has a strong stabilizing effect on the accretion process. We finally comment on the limitations of our results, which are obtained with classical physics and neglecting the disc self-gravity.

Key words: accretion, accretion discs – black hole physics – instabilities – gamma-rays: bursts.

1 INTRODUCTION

Since 1991, the BATSE experi[illegible]ent on board the *Compton* [illegible] satellite has detect[illegible] more than 1000 gamma-ray bursts (he[illegible]) and these results have generated a considerable amount of activity aimed at understanding the origin and physical nature of GRBs. One of the most striking observations of BATSE is that GRBs have an isotropic but non-homogeneous distribution on the sky [see Fishman & Morgan (1995) and references therein]. The number density of GRBs is seen to fall down beyond a certain distance as indicated by the $\langle V/V_{max} \rangle$ test or the $\log N$–$\log P$ (peak flux) curve. However, the data alone are not yet sufficient to fix the burst distance scale and two main possibilities still remain: GRBs can be located either in an extended Galactic halo or at cosmological distances. In the first case, the halo must have a core radius $R_c > 23$ kpc to avoid a dipole component in the burst distribution arising from the position of the Sun, 8.5 kpc away from the Galactic Centre (Briggs et al. 1996). This halo could be populated by high-velocity neutron stars, ejected from the Galactic disc by the kick received at their birth in supernova explosions (Janka & Müller 1994; Burrows & Hayes 1995; Podsiadlowski, Rees & Ruderman 1995). In the second case, the inhomogeneity of the burst distribution is a cosmological effect, the sources being located at a redshift $z \sim 0.3$–1 (Piran 1992; Mao & Paczyński 1992; Fenimore et al. 1993). The energy released in a burst then reaches $10^{51}/4\pi$ erg sr^{-1} and the corresponding luminosity is orders of magnitude larger than the Eddington limit. Most cosmological models of GRBs therefore involve a wind emitted from a compact object, generally a stellar-mass black hole surrounded by a thick disc. Such a configuration can be formed after the merging of two neutron stars (Eichler et al. 1989; Paczyński 1991; Narayan, Paczyński & Piran 1992), the tidal disruption of a neutron star by a black hole (Narayan et al. 1992; Mochkovitch et al. 1993) or the collapse of a massive star (Woosley 1993). To produce gamma-rays the wind must become relativistic with Lorentz factors $\Gamma \sim 10^2$–10^3, depending on the models. The wind kinetic energy is then dissipated in shocks with the interstellar medium (Mészáros & Rees 1993) or internal to the wind itself (Rees & Mészáros 1994). Several severe constraints have to be satisfied by these scenarios: the 'baryonic load' at the origin of the flow must be very small to produce a relativistic wind and the energy extracted from the disc and injected in the wind must reach the fiducial value of 10^{51} erg (assuming a 100 per cent efficiency for the conversion of kinetic energy into gamma-rays).

Different mechanisms have been proposed to transfer some fraction of the disc gravitational energy into the wind. The huge neutrino emission expected from the accretion of disc material on the black hole has led to the idea that neutrino–antineutrino annihilation along the system axis could power the wind (Mészáros & Rees 1992) and at the same time prevent baryonic pollution (Mochkovitch et al. 1993, 1995). Recent detailed calculations (Janka & Ruffert

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1996) have shown however that $\nu\bar{\nu}$ annihilation does not provide enough energy for cosmological GRBs, except maybe for very massive discs and if the efficiency for the production of gamma-rays is close to unity. Other models therefore rely on the Poynting flux emitted from the disc where the magnetic field is supposed to have reached equipartition values of 10^{14}–10^{15} G (Mészáros, Laguna & Rees 1993). In any case, these scenarios all make the initial assumption that the disc is a sufficiently long-lived structure, so that some mechanisms for the transfer of energy into the wind can operate. This supposes that accretion from the disc to the hole is a stable process, its time-scale being controlled by the mechanism responsible for the transport of angular momentum. However, a different possibility would be that accretion leads to a runaway instability, the disc falling into the black hole on a dynamical time-scale of a few milliseconds.

Most models of cosmological GRBs then critically depend on the possibility of forming a stable disc. The stability of mass transfer was first discussed in the context of AGN models by Abramowicz, Calvani & Nobili (1983) who used the pseudo-potential $\Phi = -GM_{BH}/(r - r_g)$ to represent the black hole (of mass M_{BH} and gravitational radius r_g) and made their calculations with classical physics. They assumed a constant specific angular momentum in the disc and found that it is unstable for disc-to-hole mass ratios larger than a few per cent, the effect of self-gravity being included or not. Wilson (1984) performed his analysis in general relativity but neglected self-gravity. He obtained a stable disc, again assuming a constant specific angular momentum. In order to get a fully reliable result, Nishida et al. (1996) recently repeated the calculation now taking into account both self-gravity and general relativity. In the whole range of disc-to-hole mass ratios explored they found a runaway instability, therefore casting some doubt on the possibility of powering a cosmological GRB by mass transfer from a thick disc to a stellar-mass black hole.

The result of Nishida et al. (1996) was, however, limited to a disc with a constant specific angular momentum which may not apply to neutron star mergers or massive star collapse. In the first case the outcome of numerical simulations (Rasio & Shapiro 1992; Davies et al. 1994; Ruffert, Janka & Schaefer 1996) using Newtonian gravity consists of a massive (~ 2–$2.5\ M_\odot$) core in uniform rotation (which would probably collapse and form a black hole in a relativistic calculation) surrounded by a thick disc (0.3–0.5 $M_\odot$) in differential rotation with a specific angular momentum $j(\varpi) \propto \varpi^{0.2}$ (ϖ being the distance to the rotation axis).

The collapse of a massive star to a black hole has been studied less and the distribution of angular momentum in the disc is not known. However, the simple constraint given by the Rayleigh criterion imposes $dj/d\varpi \geq 0$ both in the star before collapse and in the resulting disc. A constant angular momentum then represents a limiting case, which we believe to be rather improbable.

It is suspected on very simple grounds that an angular momentum increasing outwards should have a stabilizing effect on the disc. Assuming that catastrophic accretion takes place on a time-scale sufficiently short to neglect the transport of angular momentum, it would bring to the hole material with more and more angular momentum and therefore larger centrifugal support at a given radius. We then believe it is reasonable to consider again the stability problem, to see whether a non-constant angular momentum could prevent catastrophic accretion.

2 METHOD OF CALCULATION

We have adopted a very simplified approach using classical physics and the pseudo-potential

$$\Phi(\varpi, z) = -\frac{GM_{BH}}{\sqrt{\varpi^2 + z^2} - r_g}, \qquad (1)$$

to represent the black hole as in Abramowicz et al. (1983). Moreover, we also neglect the disc self-gravity and all these limitations clearly give to our study an exploratory character only. We nevertheless believe that it can still provide some insight about the effect of a non-constant distribution of angular momentum.

To construct an initial disc model we use the results of the smoothed particle hydrodynamics (SPH) simulation by Davies et al. (1994). The total mass of the system is $M_T = 2.8\ M_\odot$. The final SPH configuration consists of a core in uniform rotation of mass 2.44 $M_\odot$ surrounded by a thick disc with $M_D = 0.36\ M_\odot$. In a relativistic calculation it is expected that the core would become a black hole. The distribution of angular momentum in the disc is close to a power law of index 0.2. In our model we therefore adopt $M_{BH} = 2.44\ M_\odot$, $M_D = 0.36\ M_\odot$ and

$$j(\varpi) = j(\varpi_{in}) \left(\frac{\varpi}{\varpi_{in}}\right)^{0.2}, \qquad (2)$$

where ϖ_{in} is the inner disc radius. The value of $j(\varpi_{in})$ is obtained by the condition that the disc just fills its Roche lobe, i.e. $j(\varpi_{in}) = j_K(\varpi_{in})$ where $j_K(\varpi)$ is the Keplerian value of the angular momentum at a distance ϖ

$$j_K(\varpi) = \left[\frac{GM_{BH}\varpi^3}{(r - r_g)^2}\right]^{1/2}. \qquad (3)$$

The equation of state in the disc is dominated by the contribution of degenerate relativistic electrons (the typical disc density is $\rho \sim 10^{11}$ g cm^{-3}) so that the pressure is given by

$$P = K(\rho Y_e)^{4/3} = \kappa\rho^{4/3}, \qquad (4)$$

with $K \simeq 1.2 \times 10^{15}$ c.g.s. and where Y_e is the number of electrons per nucleon. We have taken $Y_e = 0.5$ even if a somewhat smaller value can be expected in a material coming from the decompression of neutron star matter. The disc structure can be obtained from the equilibrium condition

$$4\kappa\rho^{1/3} = \Phi(\varpi_{in}, 0) - \Phi(\varpi, z) + \int_{\varpi_{in}}^{\varpi} \frac{j^2}{\varpi^3}\, d\varpi. \qquad (5)$$

The position of the inner radius ϖ_{in} is adjusted so that the total disc mass is equal to M_D. The total angular momentum J_D of this initial configuration is then computed together with the mass distribution $m(\varpi)$, where $m(\varpi)$ is the mass within an axial cylinder of radius ϖ, normalized to the total disc mass M_D. We need $m(\varpi)$ to compute the disc structure after a transfer of mass to the black hole because instead of (2) the angular momentum must be known in this case as a

function of the Lagrangian coordinate m. We write

$$j(m) = j[m(\varpi)] = \frac{J_D}{M_D}\, \mathcal{J}(m), \qquad (6)$$

with

$$\int_0^1 \mathcal{J}(m)\, dm = 1. \qquad (7)$$

We assume that a mass ΔM_D (located between ϖ_{in} and $\varpi_{in} + \Delta\varpi$) is transferred to the black hole while the remaining disc material keeps its original angular momentum. The amount of angular momentum carried by ΔM_D is

$$\Delta J_D = J_D \int_0^{\Delta M_D/M_D} \mathcal{J}(m)\, dm, \qquad (8)$$

and the change from M_D, J_D to $M_D - \Delta M_D$, $J_D - \Delta M_D$ leads to a new distribution of specific angular momentum after mass transfer

$$j'(m') = \frac{J_D - \Delta J_D}{M_D - \Delta M_D}\, \mathcal{J}'(m'), \qquad (9)$$

where $\mathcal{J}'(m')$ is given by

$$\mathcal{J}'(m') = \frac{1 - \Delta M_D/M_D}{1 - \Delta J_D/J_D}\, \mathcal{J}\left[\left(1 - \frac{\Delta M_D}{M_D}\right) m' + \frac{\Delta M_D}{M_D}\right]. \qquad (10)$$

After mass transfer, the location of the Roche lobe changes as well as the position of the inner radius of the disc. Two cases are then possible: either (i) the new disc overflows its Roche lobe, no equilibrium configuration can be constructed and the runaway instability takes place or (ii) the new disc is inside its Roche lobe. Accretion is stable and occurs on a time-scale controlled by the transport of angular momentum [for a more detailed description of the mechanism of the runaway instability, see Nishida et al. (1996)].

To test the stability of the accretion process we therefore try to construct a disc of total mass $M_D - \Delta M_D$, total angular momentum $J_D - \Delta J_D$ and with a profile of specific angular momentum given by (9). We use for that purpose an iterative procedure which works in the following way: for a given value of the inner radius ϖ_{in} we make a first guess of the density distribution in the disc. From this distribution we compute the mass distribution $m'(\varpi')$ and we use (5) to obtain a new estimate of the density distribution. We iterate the process until the maximum relative difference between the density profiles of two successive configurations becomes less than 10^{-5}. A reasonably fast convergence is obtained if, for the first guess of the density distribution, we take the result given by (5) when the wrong profile of specific angular momentum

$$j'(\varpi') = \frac{J_D}{M_D}\, \mathcal{J}\left(\frac{\Delta M_D}{M_D}\right)\left(\frac{\varpi'}{\varpi'_{in}}\right)^{0.2}, \qquad (11)$$

is used instead of (9). We finally try to adjust ϖ'_{in} so that the mass of the disc built by this procedure is $M'_D = M_D - \Delta M_D$. In this case, the angular momentum automatically has the correct value $J'_D = J_D - \Delta J_D$.

If a disc with the right mass can be constructed, accretion is stable: the new disc lies inside its Roche lobe and the continuation of mass transfer requires the transport of angular momentum outwards. Conversely, if the disc mass is always smaller than $M_D - \Delta M_D$ (even with the disc filling its Roche lobe) the runaway instability occurs.

3 RESULTS

The method described in Section 2 has been used to test the stability of discs with distributions of specific angular momentum given by $j(\varpi) \propto \varpi^{\alpha}$. We first considerd $\alpha = 0$ (constant angular momentum) to check that we indeed obtain a runaway instability in this case. The results are shown in Fig. 1 for $\Delta M_D/M_D = 0.01$. Before mass transfer, the disc fills its Roche lobe and its inner radius is located at $\varpi_{in} = 2.105 r_g$. After mass transfer the equipotentials cross themselves at the 'Lagrange point' $\varpi'_L = 2.113 r_g$ and the maximum disc mass $M_D'^{max} = 0.284\ M_\odot$, corresponding to $\varpi'_{in} = \varpi'_L$, falls well below the required value, $M'_D = 0.356\ M_\odot$. Accretion is therefore unstable, in agreement with the previous calculations of Abramowicz et al. (1983).

For $\alpha = 0.2$, Fig. 2 shows the distribution of specific angular momentum as a function of the mass coordinate m in the initial configuration and after the transfer of 1 per cent of the disc mass. In the initial configuration, which just overfills its Roche lobe, $j(m)$ starts with a vertical derivative at $m = 0$ because $dm/d\varpi|_{\varpi_{in}} = 0$ [more precisely for $\varpi \gtrsim \varpi_{in}$, $dm/d\varpi$ behaves as $(\varpi - \varpi_{in})^4$]. The consequence of this rapid increase of j with m is to keep the inner radius of the disc inside the Roche lobe after mass transfer as shown in Fig. 3. In the initial model, the cusp is located at $\varpi_L = 2.80 r_g$ while the inner radius has moved to $\varpi'_{in} = 4.07 r_g$ for $\Delta M_D/M_D = 0.01$.

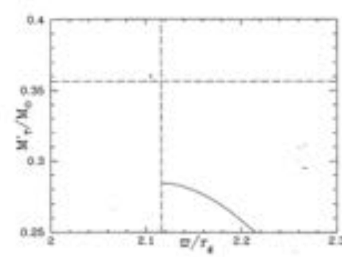
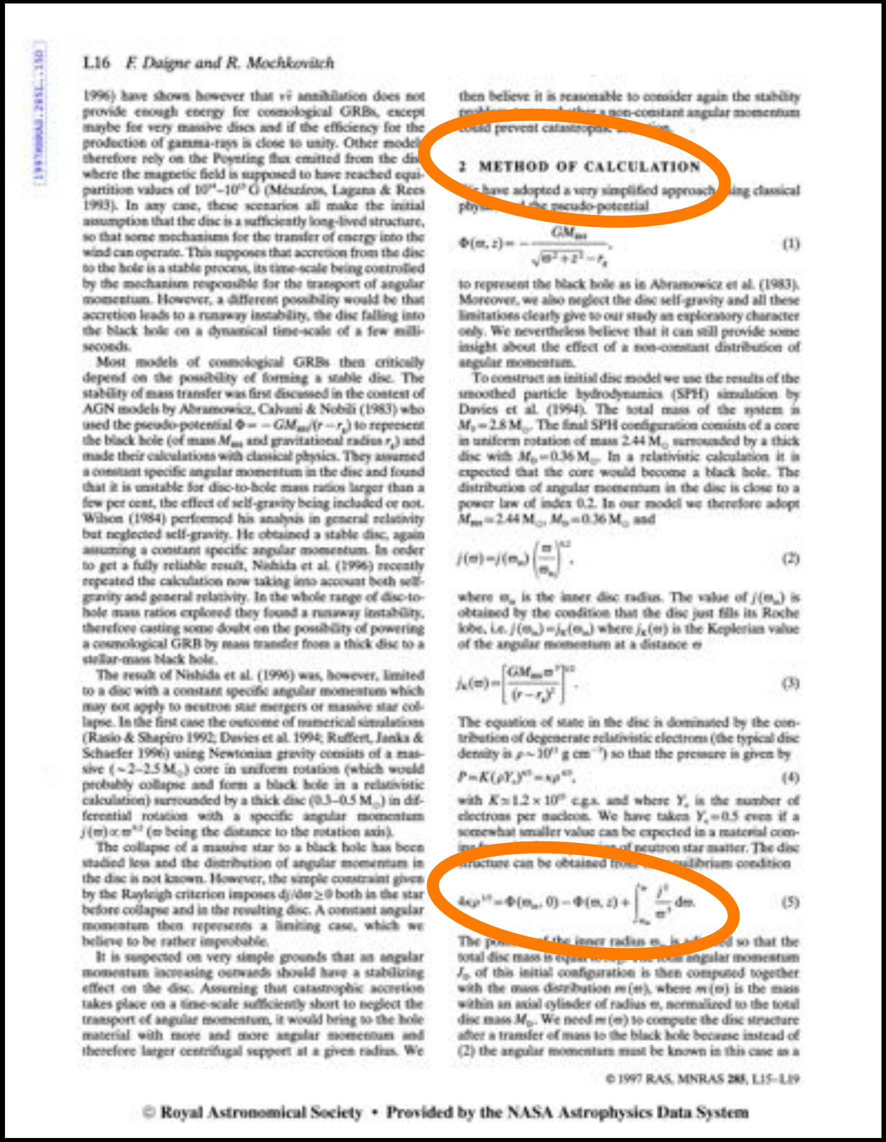


Figure 1. Mass of the disc as a function of the position of its inner radius (in units of the black hole gravitational radius) for a constant specific angular momentum and an increase of the black hole mass corresponding to a transfer of 1 per cent of the disc mass. The dot represents the initial model. The horizontal and vertical dashed lines indicate the new disc mass and the new position of the 'Lagrange point' after mass transfer. Even when the disc fills its Roche lobe its mass remains below the required value.

Un exemple d'article scientifique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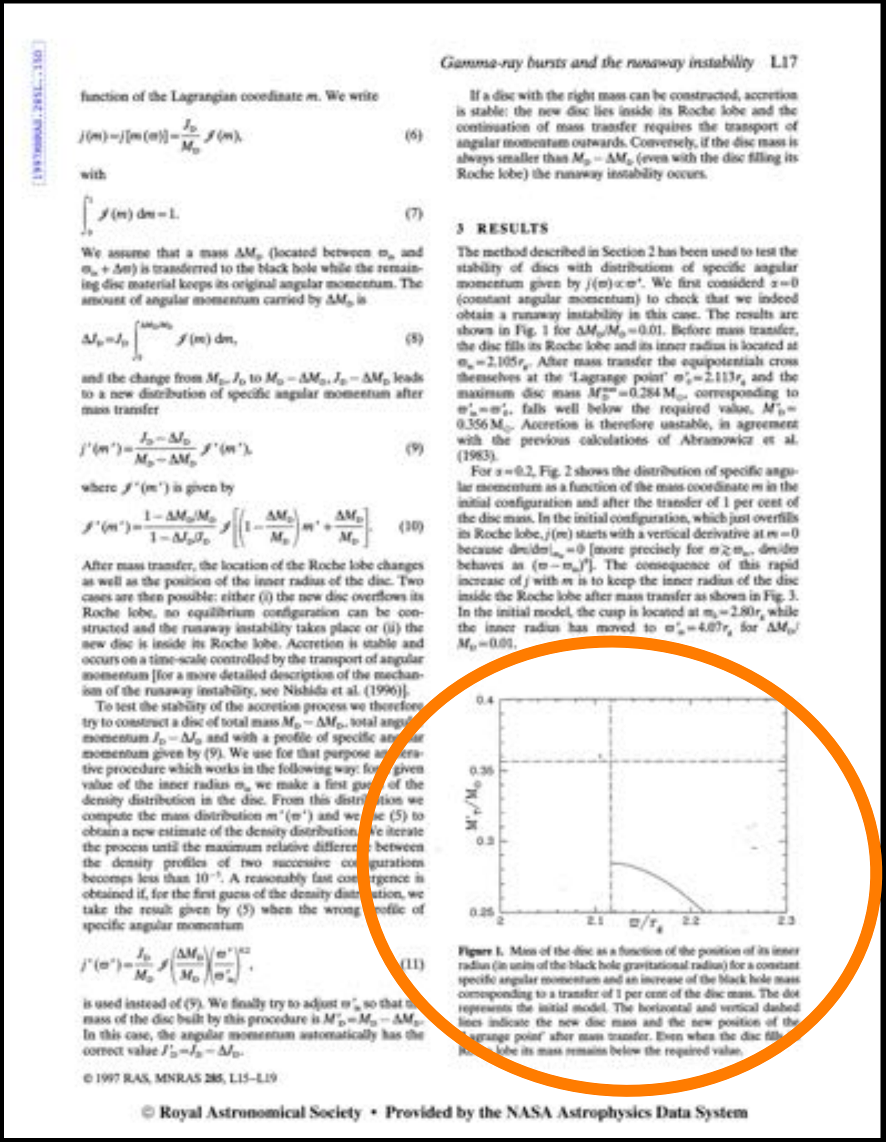
Gamma-ray bursts and the runaway instability L17

3 RESULTS

Figure 1. Mass of the disc as a function of the position of its inner radius (in units of the black hole gravitational radius) for a constant specific angular momentum and an increase of the black hole mass corresponding to a transfer of 1 per cent of the disc mass. …

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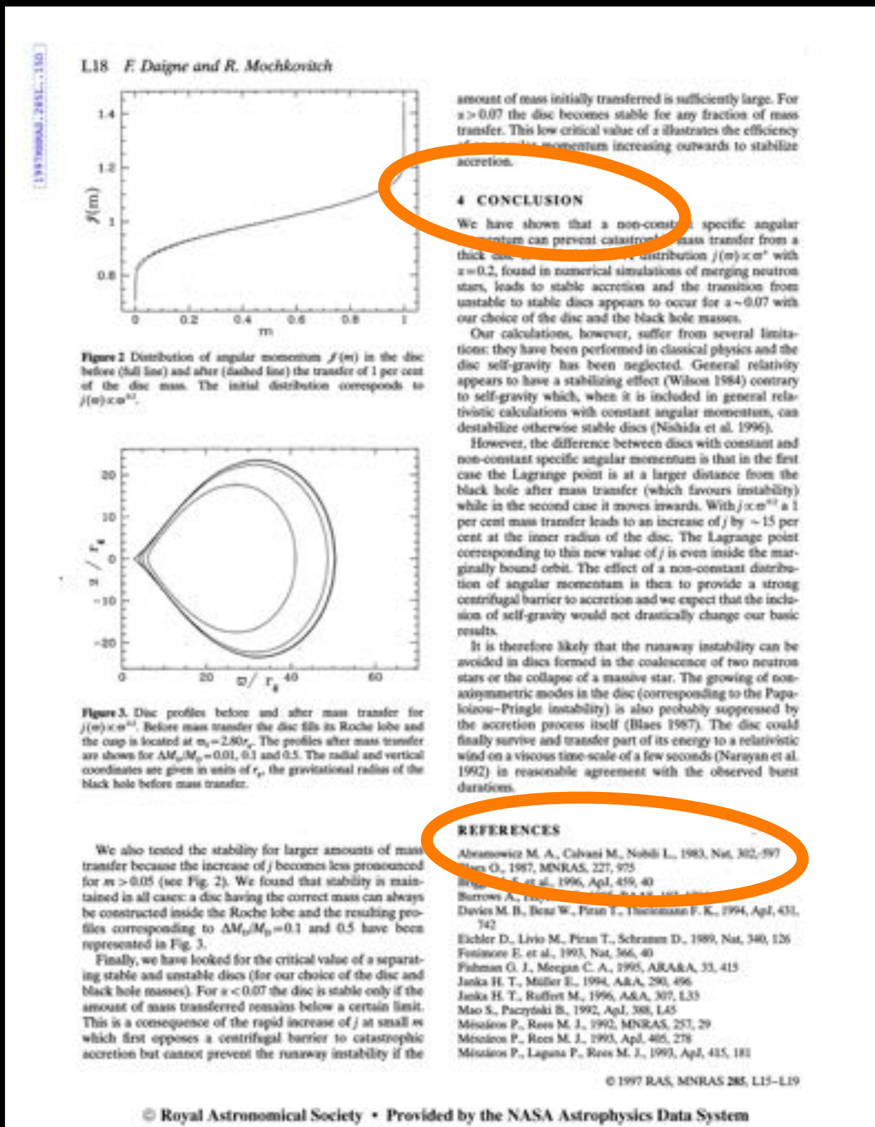

Figure 2. Distribution of angular momentum $j(m)$ in the disc before (full line) and after (dashed line) the transfer of 1 per cent of the disc mass. The initial distribution corresponds to $j(m) \propto m^{a/2}$.

Figure 3. Disc profiles before and after mass transfer for $j(m) \propto m^{a/2}$. Before mass transfer the disc fills its Roche lobe and the cusp is located at $\varpi_L = 2.80 r_g$. The profiles after mass transfer are shown for $\Delta M_D/M_D = 0.01$, 0.1 and 0.5. The radial and vertical coordinates are given in units of r_g, the gravitational radius of the black hole before mass transfer.

We also tested the stability for larger amounts of mass transfer because the increase of j becomes less pronounced for $m > 0.05$ (see Fig. 2). We found that stability is maintained in all cases: a disc having the correct mass can always be constructed inside the Roche lobe and the resulting profiles corresponding to $\Delta M_D/M_D = 0.1$ and 0.5 have been represented in Fig. 3.

Finally, we have looked for the critical value of a separating stable and unstable discs (for our choice of the disc and black hole masses). For $a < 0.07$ the disc is stable only if the amount of mass transferred remains below a certain limit. This is a consequence of the rapid increase of j at small m which first opposes a centrifugal barrier to catastrophic accretion but cannot prevent the runaway instability if the amount of mass initially transferred is sufficiently large. For $a > 0.07$ the disc becomes stable for any fraction of mass transfer. This low critical value of a illustrates the efficiency of angular momentum increasing outwards to stabilize accretion.

4 CONCLUSION

We have shown that a non-constant specific angular momentum can prevent catastrophic mass transfer from a thick disc. The distribution $j(m) \propto m^a$ with $a = 0.2$, found in numerical simulations of merging neutron stars, leads to stable accretion and the transition from unstable to stable discs appears to occur for $a \sim 0.07$ with our choice of the disc and the black hole masses.

Our calculations, however, suffer from several limitations: they have been performed in classical physics and the disc self-gravity has been neglected. General relativity appears to have a stabilizing effect (Wilson 1984) contrary to self-gravity which, when it is included in general relativistic calculations with constant angular momentum, can destabilize otherwise stable discs (Nishida et al. 1996).

However, the difference between discs with constant and non-constant specific angular momentum is that in the first case the Lagrange point is at a larger distance from the black hole after mass transfer (which favours instability) while in the second case it moves inwards. With $j \propto m^{a/2}$ a 1 per cent mass transfer leads to an increase of j by ~ 15 per cent at the inner radius of the disc. The Lagrange point corresponding to this new value of j is even inside the marginally bound orbit. The effect of a non-constant distribution of angular momentum is then to provide a strong centrifugal barrier to accretion and we expect that the inclusion of self-gravity would not drastically change our basic results.

It is therefore likely that the runaway instability can be avoided in discs formed in the coalescence of two neutron stars or the collapse of a massive star. The growing of non-axisymmetric modes in the disc (corresponding to the Papaloizou–Pringle instability) is also probably suppressed by the accretion process itself (Blaes 1987). The disc could finally survive and transfer part of its energy to a relativistic wind on a viscous time-scale of a few seconds (Narayan et al. 1992) in reasonable agreement with the observed burst durations.

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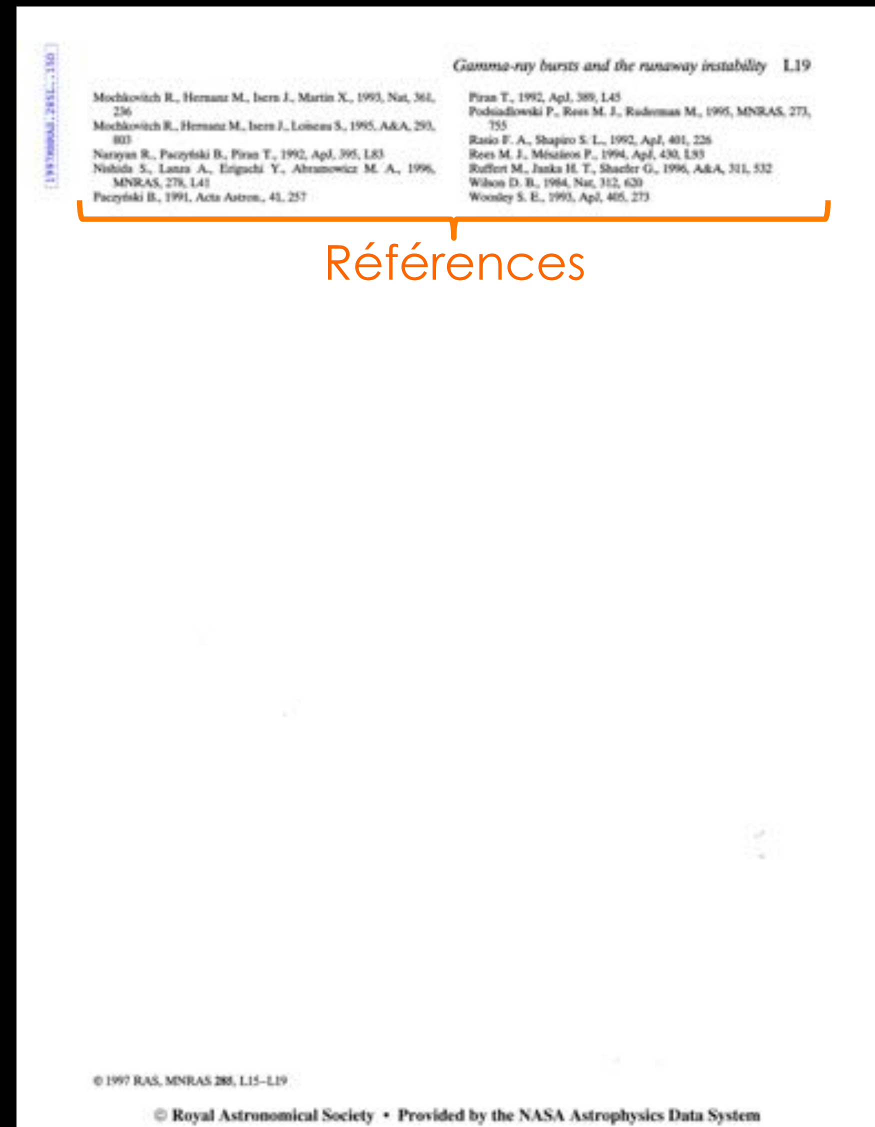

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Références

Un exemple d'article scientifique

Dans cet exemple, l'article est plutôt « théorique » et cherche à répondre à la question : *« la source centrale des sursauts gamma est supposé être un trou noir qui accrète la matière depuis un disque épais qui l'entoure. Cette configuration est-elle stable assez longtemps pour effectivement permettre de produire un sursaut gamma ? »*

-Un article précédent d'Abramowicz et collaborateurs (1992) : *« le disque tombe rapidement dans le trou noir »*

-Notre article (1997) : *« le disque ne tombe pas rapidement dans le trou noir car il tourne vite et la force centrifuge ralentit la chute »*

-D'autres articles ont suivi pour approfondir l'étude, comprendre ses implications pour différents astres, etc.

Un exemple d'article scientifique

Astron. Astrophys. 331, 1143–1146 (1998)

ASTRONOMY AND ASTROPHYSICS

Research Note

On the runaway instability of relativistic tori*

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Abstract. We further investigate the runaway instability of relativistic tori around black holes assuming a power law distribution of the specific angular momentum. We neglect the self-gravity of the torus; thus the gravitational field of the system is determined by the central rotating black hole alone (the Kerr geometry). We find that for any positive (*i.e.* consistent with the local Rayleigh stability condition) power law index of the angular momentum distribution, the tori are always runaway stable for a sufficiently large spin of the black hole. However, before concluding that some (astrophysically realistic) tori could indeed be runaway stable, one should include, in full general relativity, the destabilizing effect of self-gravity.

Key words: accretion: accretion-discs – black hole physics – instabilities

1. Introduction

Toroidal fluid configurations around black holes, known as thick accretion disks, have been suggested as models of quasars, other active galactic nuclei, and some X-ray binaries. Recently they have also assumed an important role in cosmological models of γ-ray bursts based on the merging of two neutron stars. A rather simple mathematical class of such configurations has been introduced by Fishbone & Moncrief (1976), Fishbone (1977), and fully described analytically by the Warsaw group: Abramowicz, Jaroszyński & Sikora (1978), Kozłowski, Jaroszyński & Abramowicz (1978), Jaroszyński, Abramowicz & Paczyński (1980), and Paczyński & Wiita (1980). In the last paper, a very practical and accurate Newtonian model for the gravitational field of a non-rotating black hole, known as the Paczyński-Wiita potential, was introduced.

The question of stability of such configurations attracted considerable attention, because it was recognized that some types of instability could have very direct, and quite interesting, astrophysical consequences. Obviously, for the same reason as in the Newton theory, the essentially *local* Rayleigh criterion for dynamical stability with respect to axially symmetric local perturbations demands that the specific angular momentum l should increase with the distance R from the axis of rotation (Seguin 1975). Even the Rayleigh-stable tori with $dl/dR > 0$ are dynamically unstable in the presence of a weak magnetic field (Balbus & Hawley 1991). The Balbus-Hawley instability does not destroy the large scale structure of tori, but instead drives a local turbulence which induces viscosity that is needed for accretion to occur. Much more threatening for the global structure was the important discovery by Papaloizou & Pringle (1987) that all *non-accreting* tori are unstable to global non-axisymmetric perturbations. The consequences of this brilliant work have been studied by numerous authors, and the present view is that even a very modest mass loss due to accretion may be sufficient to stabilize the Papaloizou-Pringle modes (Blaes 1988). Also, it has been shown that the self-gravity of the disk has a stabilizing effect (Goodman & Narayan 1988).

2. The runaway instability

A general feature of fluid distribution around a black hole, is the existence of a self-crossing equipotential surface, similar to the Roche lobe in binary systems. The circle at which it crosses itself is called the cusp. The material inside the Roche lobe is gravitationally bound and only in such a case is equilibrium

Send offprint requests to: V. Karas

* Work prepared during The Annual Nordic-Trieste Astrophysics Workshop (ICTP, Trieste 1997)

Un exemple d'article scientifique

Astron. Astrophys. 331, 1143–1146 (1998)

ASTRONOMY
AND
ASTROPHYSICS

Research Note

On the runaway instability of relativistic tori*

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Abstract. We further investigate the runaway instability of relativistic tori around black holes assuming a power law distribution of the specific angular momentum. We neglect the self-gravity of the torus; thus the gravitational field of the system is determined by the central rotating black hole alone (the Kerr geometry). We find that for any positive (*i.e.* consistent with the local Rayleigh stability condition) power law index of the angular momentum distribution, the tori are always runaway stable for a sufficiently large spin of the black hole. However, before concluding that some (astrophysically realistic) tori could indeed be runaway stable, one should include, in full general relativity, the destabilizing effect of self-gravity.

Key words: accretion: accretion-discs – black hole physics – instabilities

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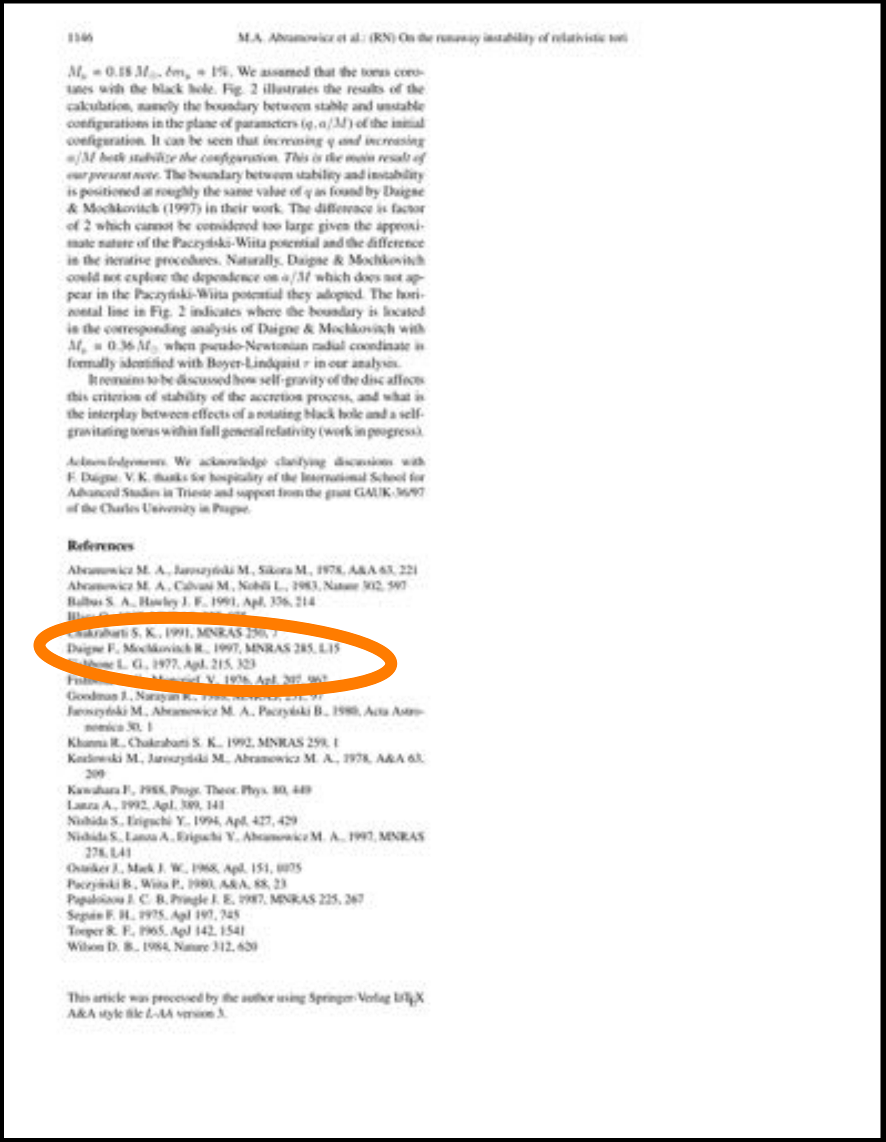
Un exemple d'article scientifique

Most recently, however, Daigne & Mochkovitch (1997) made an important discovery that a non-zero gradient of the angular momentum distribution inside the torus has a strong stabilizing effect. They used models of non self-gravitating tori and the Paczyński-Wiita potential to describe the black hole. In this case, after the mass transfer, the angular momentum content in the innermost part of the resulting configuration is higher



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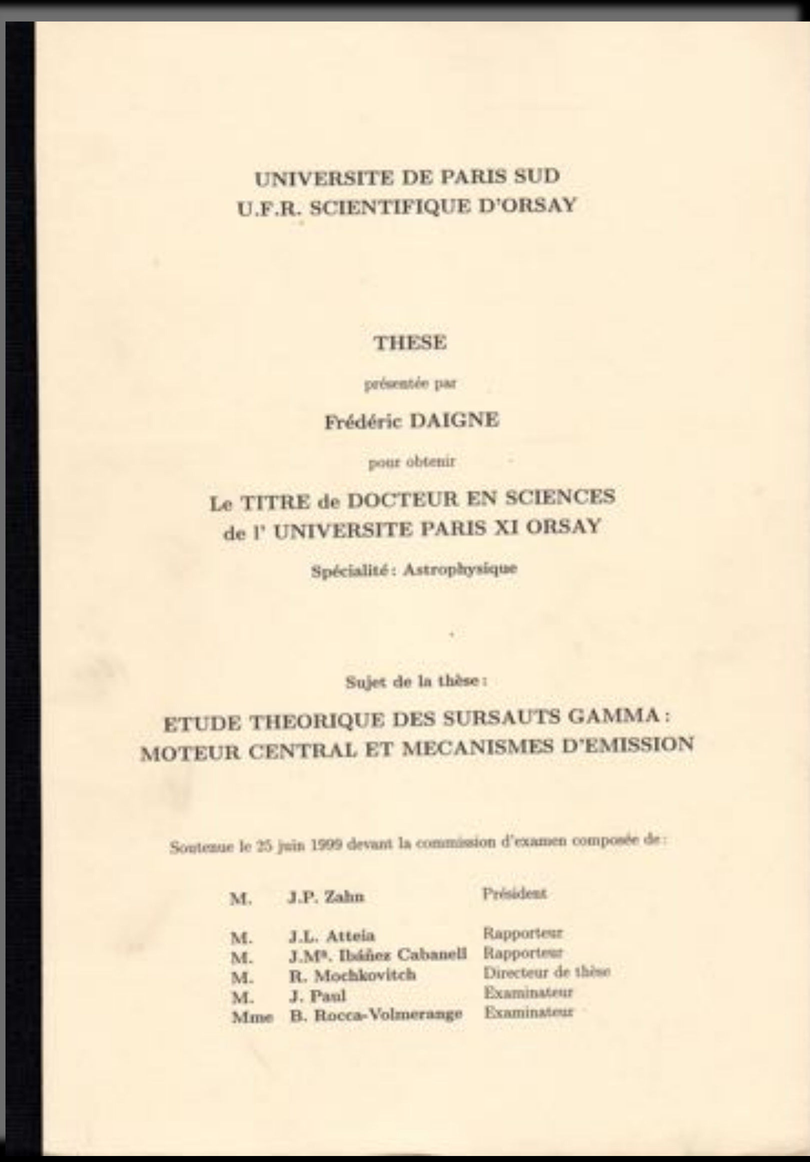
Comment devient-on chercheur ?

Thèse de doctorat, donnant le droit au titre de *docteur*, c'est à dire *savant*. Mais attention, les *savants* d'aujourd'hui ne sont plus universels : leur savoir est le plus souvent extrêmement spécialisé.

La thèse est l'aboutissement d'un premier travail de recherche original, suivi de la rédaction d'une thèse et de sa soutenance devant un jury académique.

Comment devient-on chercheur ?



UNIVERSITE DE PARIS SUD
U.F.R. SCIENTIFIQUE D'ORSAY

THESE

présentée par

Frédéric DAIGNE

pour obtenir

Le TITRE de DOCTEUR EN SCIENCES
de l' UNIVERSITE PARIS XI ORSAY

Spécialité : Astrophysique

Sujet de la thèse :

ETUDE THEORIQUE DES SURSAUTS GAMMA :
MOTEUR CENTRAL ET MECANISMES D'EMISSION

Soutenue le 25 juin 1999 devant la commission d'examen composée de :

M.	J.P. Zahn	Président
M.	J.L. Atteia	Rapporteur
M.	J.Ma. Ibáñez Cabanell	Rapporteur
M.	R. Mochkovitch	Directeur de thèse
M.	J. Paul	Examinateur
Mme	B. Rocca-Volmerange	Examinateur

N°d'ordre 5787

U.F.R SCIENTIFIQUE D'ORSAY

DOCTORAT

(arrêté du 30 Mars 1992)

RAPPORT DE SOUTENANCE

établi par le Président du Jury

Thèse de Doctorat : Spécialité : ASTROPHYSIQUE

de Monsieur DAIGNE Frédéric

Sujet : " ETUDE THEORIQUE DES SURSAUTS GAMMA :

MOTEUR CENTRAL ET MECANISMES D'EMISSION. "

Date de soutenance : Le 25 juin 19 99

Date et signature des membres du Jury :

le 25 Juin 1999

UNIVERSITE DE PARIS-SUD (XI) — ETUDES DOCTORALES — UFR SCIENTIFIQUE D'ORSAY

CERTIFIE CONFORME A L'ORIGINAL

sincères félicitations.

CERTIFIE CONFORME A L'ORIGINAL

UNIVERSITE DE PARIS-SUD (XI) — ETUDES DOCTORALES — UFR SCIENTIFIQUE D'ORSAY

Après la thèse : le « post-doc »

La thèse : capacité à mener des activités de recherche

L'après-thèse : capacité à le faire de manière autonome

La plupart du temps, le « post-doc » est l'occasion de changer de laboratoire, et même de pays, pour découvrir d'autres façons de travailler et pouvoir nouer de nouvelles collaborations.

Obtenir un poste de chercheur permanent en France

La recherche en astrophysique est de l'ordre de la *recherche fondamentale*. Elle est donc menée dans des organismes publics. Il y a trois principaux statuts de chercheurs en astrophysique :

- Chercheur au C.N.R.S
  (Chargé de recherche ou Directeur de Recherche)
- Enseignant-Chercheur à l'Université
  (Maître de Conférences ou Professeur d'Université)
- Astronome dans un Observatoire
  (Astronome adjoint ou Astronome)
- Le C.E.A. a également un Service d'Astrophysique

Tous ces postes donnent un statut de fonctionnaire ou assimilé.
L'obtention d'un poste se fait sur concours (dossier et audition).

Il y a environ 100 thèses soutenues en astrophysique par an (en France).

En 2010, le nombre de postes ouverts au concours était de

- 11 postes au C.N.R.S
- 8 postes de maîtres de conférences
- 7 postes d'astronomes adjoints

La pression est donc très forte…

L'enseignement supérieur : une motivation supplémentaire

Un enseignant chercheur partage son temps entre l'enseignement à l'université (192 heures de cours/TD/TP par an) et la recherche dans un laboratoire.

L'enseignement est une mission fondamentale, complémentaire de la recherche : transmettre le savoir accumulé par l'humanité d'une génération à l'autre.

Le savoir est cumulatif

« Nous sommes comme des nains juchés sur des épaules de géants, de telle sorte que nous puissions voir plus de choses et de plus éloignées que n'en voyaient ces derniers. Et cela, non point parce que notre vue serait puissante ou notre taille avantageuse, mais parce que nous sommes portés et exhaussés par la haute stature des géants. »

(Bernard de Chartres, XII° siècle)


L'UNIVERSITÉ AU MOYEN AGE
(La Logique - La Réthorique).
(Manuscrit français 574. F° 27 V°).

Obtenir les moyens de faire de la recherche ?

Les chercheurs doivent en permanence faire des demandes motivées pour effectuer leur recherche :

- Demandes de moyens (voyage, matériel informatique, instrumentation, …)
  [le « soutien de base » des laboratoires ne couvrent que les besoins élémentaires : bâtiment, électricité, chauffage, … Tout le reste s'obtient par appel à projet]
- Demandes de temps d'observation sur les instruments existants

Toutes les demandes ne sont pas acceptées. La sélection se fait

- En fonction de la qualité des travaux de recherches qui sont menés (évaluée par d'autres chercheurs)
- De priorités scientifiques décidées à l'avance
- De la faisabilité à court ou moyen terme,

Etc.

Les chercheurs sont évalués en permanence !

Le quotidien de l'astrophysicien : recherche et enseignement ?

Recherche et enseignement sont les deux activités essentielles, mais il y a d'autres activités qui s'ajoutent :

- encadrement des futurs chercheurs (étudiants en thèse)
- diffusion des connaissances
- demande de financement sur projet

- recrutement des chercheurs, évaluation des chercheurs et des laboratoires
- politique scientifique

etc.

Un aspect important consiste à participer à l'élaboration d'une politique scientifique commune à l'échelle nationale ou internationale.

L'organisation de la recherche en astrophysique

Les moyens d'observation nécessaires à l'astrophysique moderne nécessitent une coordination à l'échelle nationale et internationale.

Exemples :

- L'INSU est le département du CNRS qui gère les « Sciences de l'Univers ».
- L'ESO (*European Southern Observatory*) : une association de pays européens pour construire de grands télescopes au sol (exemple: le VLT).
- L'ESA (*European Space Agency*) : l'agence spatiale européenne
- Le *Hubble Space Telescope* ou la mission *Cassini-Huygens* sont des projets menés en collaboration entre l'ESA et la NASA (agence spatiale américaine).

  etc.

On ne peut pas entreprendre tous les projets instrumentaux dont on rêve à un instant donné… Pour choisir :

- Des contraintes politiques et budgétaires
- L'établissement de priorités scientifiques, de manière collégiale

  (exemple: prospective INSU; feuille de route AstroNet ; decadal survey de la NASA ; etc.)

Ce qui guide les grands projets

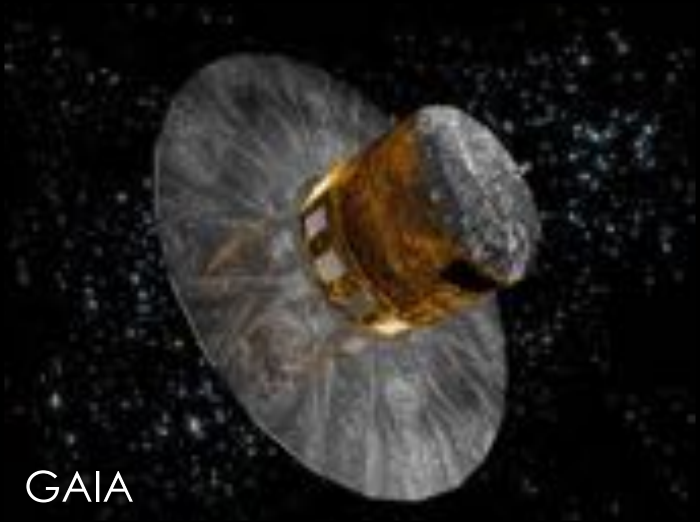
Les questions scientifiques et les progrès technologiques sont les déclencheurs de nouveaux projets instrumentaux.

Un peu comme aux jeux olympiques, il s'agit d'aller

- Plus vite : pour observer fréquemment de grandes régions du ciel
  - Approche statistique
  - Variabilité à courte échelle de temps

  Exemple : l'astronomie X (1ère source en 1960 ; 160 sources en 1974 ; 8000 sources en 1990 ; plus de 1 000 000 sources aujourd'hui).

  Exemple de projet dans cette approche : GAIA = caractériser un très grand nombre d'étoiles de la galaxie (cf. cours n°5 et n°6)



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Les questions scientifiques et les progrès technologiques sont les déclencheurs de nouveaux projets instrumentaux.

Un peu comme aux jeux olympiques, il s'agit d'aller

- Plus vite
- Plus haut :
  - en haute montagne ou dans l'espace
  - pour développer l'observation à toutes les longueurs d'onde

Exemples de projets : JWST ; ALMA

JWST : le successeur du HST

ALMA : un interféromètre radio dans le désert chilien de l'Atacama

Ce qui guide les grands projets

Les questions scientifiques et les progrès technologiques sont les déclencheurs de nouveaux projets instrumentaux.

Un peu comme aux jeux olympiques, il s'agit d'aller

- Plus vite
- Plus haut
- Plus fort : c'est à dire plus sensible, donc plus grand
  - Dans le visible : en 4 siècles, la surface collectrice des instruments est passée de 5 mm de diamètre (œil nu) à environ 10 m (VLT, …)
  - Aux autres longueurs d'onde, l'enjeu est le même

Exemples de projets gigantesques : l'ELT ou SKA

L'ELT, un télescope de 40 m de diamètre


SKA, un radiotélescope de 1 km^2

Quelques grands projets : E-ELT
(European Extremely Large Telescope)

- Objectifs :

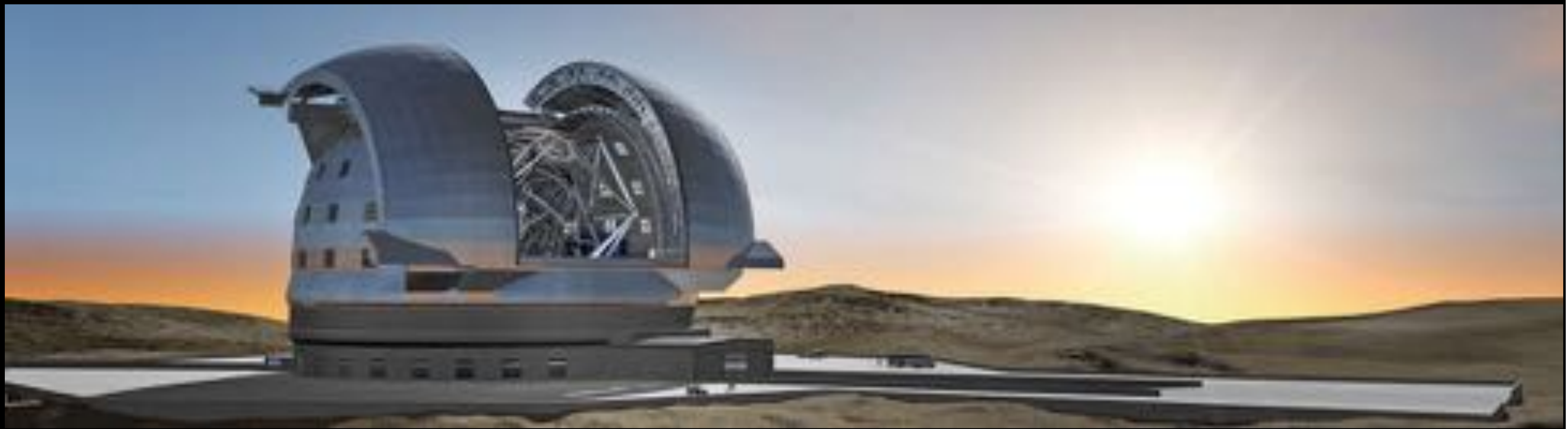
  - détection et observation d'exoplanètes et de leur atmosphère
  - détection des premières sources de lumière (étoiles, galaxies ?)
  - mesure directe de l'accélération de l'expansion

- Concept :

  - télescope de diamètre : 39m, 1000 éléments, secondaire : 4,2m
  - optique adaptive (6000 actuateurs, 1000 Hz), optique -> IR moyen

- Situation du projet :

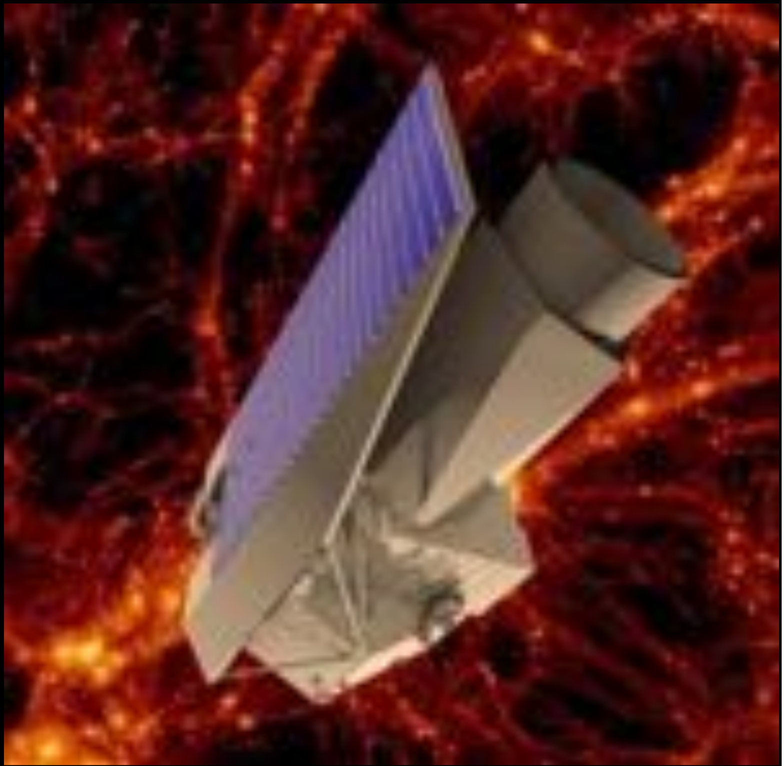
  - décision : mi-2012 (participation Brésil ?)
  - coût: ≈ 1 milliard d'euros



Quelques grands projets : EUCLID

- Objectifs :
  - Comprendre l'origine de l'accélération de l'expansion de l'Univers
  - Moyen : observation des grandes structures cosmiques et des lentilles gravitationelles
- Concept :
  - télescope spatial de diamètre : 1,2m
  - caméra géante dans le visible : haute précision des images (lentilles grav.)
  - caméra géante dans l'infrarouge : imagerie et spectroscopie des galaxies
  - 6 ans d'observation
- Situation du projet :
  - sélection par l'ESA comme mission M2
  - approbation finale : mi 2012
  - coût ESA : ~ 500 M€

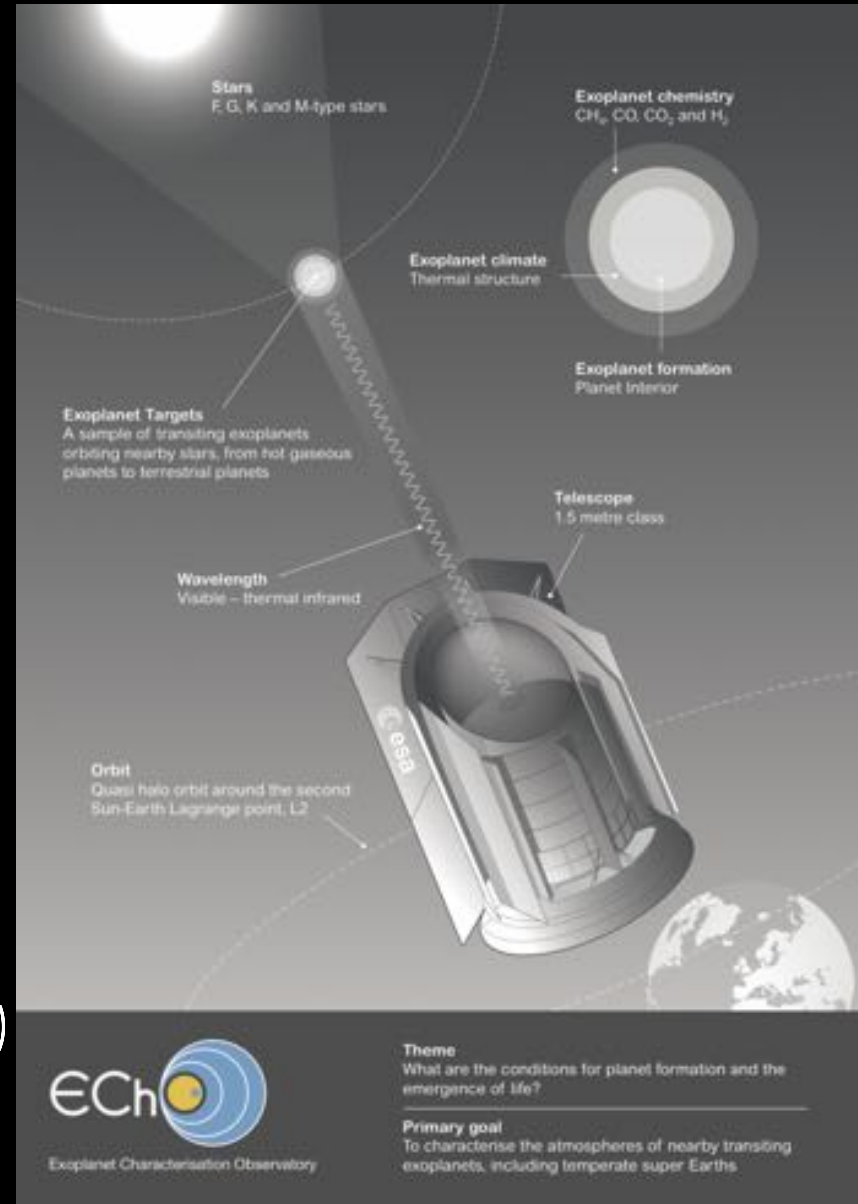
  (Programme ESA :
  missions L à ~ 1 000 M€
  missions M à ~ 500 M€)



Quelques grands projets : EChO

Exoplanet Charaterization Observatory

- Objectifs :
  - conditions pour la formation de planètes et apparition de la vie
  - les systèmes planétaire analogues au système solaire sont-ils rares ?
- Méthode :
  - observation de l'atmosphère d'exoplanètes en transit
  - observation de leur émission IR
- Concept :
  - télescope de 1,5m au point L2 (5 ans)
  - spectre simultané de 0,4 µm à ≈ 16 µm
- Situation du projet:
  - En compétition comme mission M3 de l'ESA (avec LOFT, Marco Polo-R, STE-QUEST)
  - décisions en 2013, puis 2015; lancement M3 en 2022



Un coût raisonnable ?

Coût de quelques projets de la communauté astronomique :

- LSST : 500 M$
- EUCLID : 550 M€ (ESA) + 30 % états membres
- GAIA : 550 M€ (ESA) + 20 % états membres
- ALMA : 1 000 M€ dont 450 M€ coût ESO
- E-ELT : 1 083 M€ coût ESO
- SKA : 1 500 M€ (objectif : « target cost »)
- JWST : 8 700 M$
- Un lancement de navette : 500 M$ (total 1 500 M$ pour l'entretien du HST)
- Herschel + Planck : 1 400 M€

Pour comparer

- A 380 : 250 M€
- Rafale : 300 M€
- Porte avion : 3 000 M€
- 100 km d'autoroute : 600 M€
- Centrale EPR : 5 000 M€
- ITER : 16 000 M€
- International Space Station (ISS) : 115 000 M$ (construction et opération)

Rappel important : les projets en recherche fondamentale ne sont pas évalués en fonction d'un retour financier sur investissement. Ce qui compte, c'est la quête de nouvelles connaissances…

Pour conclure

L'un des projets « pierres angulaires » de l'Année Mondiale de l'Astronomie en 2009 (UAI/UNESCO) était « *Astronomy and World Heritage: universal treasures* », qui mettait en avant le ciel comme patrimoine commun à toute l'humanité, aujourd'hui mais aussi à travers les âges. Un sujet de méditation pour conclure ce cycle de conférences…

Pour conclure

Nuit étoilée sur le Rhône
Vincent Van Gogh - 1888

« Deux choses me remplissent le cœur d'une admiration et d'une vénération, toujours nouvelles et toujours croissantes, à mesure que la réflexion s'y attache et s'y applique : le ciel étoilé au-dessus de moi et la loi morale en moi. […] Le premier spectacle, d'une multitude innombrable de mondes, anéantit pour ainsi dire mon importance, en tant que je suis une créature animale qui doit rendre la matière dont elle est formée à la planète (à un simple point dans l'Univers), après avoir été pendant un court espace de temps (on ne sait comment) douée de la force vitale. Le second, au contraire, élève infiniment ma valeur, comme celle d'une intelligence, par ma personnalité dans laquelle la loi morale me manifeste une vie indépendante de l'animalité et même de tout le monde sensible. »

(E. Kant, Critique de la raison pratique, 1788)

Astronomie, Astrophysique
Observer et comprendre l'Univers

1. Introduction: qu'est ce que l'astrophysique
2. Notre étoile, le Soleil
3. De la lunette de Galilée
   aux télescopes spatiaux :
   l'observation en astronomie
4. Panorama du système solaire
5. A la recherche d'autres mondes,
   les exoplanètes
6. Vie et mort des étoiles
7. Explosions et monstres cosmiques :
   supernovae, étoiles à neutrons, trous noirs
8. Les nuages interstellaires
   et la formation des étoiles
9. La Voie Lactée et les galaxies proches
10. L'Univers lointain
11. La cosmologie moderne :
    un Univers en évolution
12. Conclusion :
    les défis pour l'astrophysique contemporaine

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